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Introduction

Physical geography is one of the two major subfields of geography. Physical geography is that branch of natural science which deals with the study of processes and patterns in the natural environment like atmosphere, biosphere and geosphere, as opposed to the cultural or built environment, the domain of human geography.

Within the body of physical geography, the Earth is often split either into several spheres or environments, the main spheres being the atmosphere, biosphere, cryosphere, geosphere, hydrosphere, lithosphere and pedosphere. Research in physical geography is often interdisciplinary and uses the systems approach.

Fields of Physical Geography

Geomorphology is the science concerned with understanding the surface of the Earth and the processes by which it is shaped, both at the present as well as in the past. Geomorphology as a field has several sub-fields that deal with the specific landforms of various environments e.g. desert geomorphology and fluvial geomorphology, however, these sub-fields are united by the core processes which cause them; mainly tectonic or climatic processes. Geomorphology seeks to understand landform history and dynamics, and predict future changes through a combination of field observation, physical experiment, and numerical modelling. (Geomorphometry). Early studies in geomorphology are the foundation for pedology, one of two main branches of soil science:

- Hydrology is predominantly concerned with the amounts and quality of water moving and accumulating on the land surface and in the soils and rocks near the surface and is typified by the hydrological cycle. Thus the field encompasses water in rivers, lakes, aquifers and to an extent glaciers, in which the field examines the process and dynamics involved in these bodies of water. Hydrology has historically had an important connection with engineering and has thus developed a largely quantitative method in its research; however, it does have an earth science side that embraces the systems approach. Similar to most fields of physical geography it has sub-fields that examine the specific bodies of water or their interaction with other spheres e.g. limnology and ecohydrology.
- Glaciology is the study of glaciers and ice sheets, or more commonly the cryosphere or ice and phenomena that involve ice. Glaciology groups the latter (ice sheets) as continental glaciers and the former (glaciers) as alpine glaciers. Although, research in the areas are similar with research undertaken into both the dynamics of ice sheets and glaciers the former tends to be concerned with the interaction of ice sheets with the present climate and the latter with the impact of glaciers on the landscape. Glaciology also has a vast array of sub-fields examining the factors and processes involved in ice sheets and glaciers e.g. snow hydrology and glacial geology.
- Biogeography is the science which deals with geographic patterns of species distribution and the processes that result in these patterns. Biogeography emerged as a field of study as a result of the work of Alfred Russel Wallace, although the field prior to the late twentieth century had largely been viewed as historic in its outlook and descriptive in its approach. The main stimulus for the field since its founding has been that of evolution, plate tectonics and the theory of island biogeography. The field can largely be divided into five sub-fields: island biogeography, paleobiogeography, phylogeography, zoogeography and phytogeography.

- Climatology is the study of the climate, scientifically defined as weather conditions averaged over a long period of time. It differs from meteorology, which studies atmospheric processes over a shorter duration, which are then examined by climatologists to find trends and frequencies in weather patterns/phenomena. Climatology examines both the nature of micro (local) and macro (global) climates and the natural and anthropogenic influences on them. The field is also sub-divided largely into the climates of various regions and the study of specific phenomena or time periods e.g. tropical cyclone rainfall climatology and paleoclimatology.
- Pedology is the study of soils in their natural environment. It is one of two main branches of soil science, the other being edaphology. Pedology mainly deals with pedogenesis, soil morphology, soil classification. In physical geography pedology is largely studied due to the numerous interactions between climate (water, air, temperature), soil life (micro-organisms, plants, animals), the mineral materials within soils (biogeochemical cycles) and its position and effects on the landscape such as laterization.
- Palaeogeography is the study of the distribution of the continents through geologic time through examining the preserved material in the stratigraphic record. Palaeogeography is a cross-discipline, almost all the evidence for the positions of the continents comes from geology in the form of fossils or geophysics the use of this data has resulted in evidence for continental drift, plate tectonics and supercontinents this in turn has supported palaeogeographic theories such as the Wilson cycle.
- Coastal geography is the study of the dynamic interface between the ocean and the land, incorporating both the physical geography (i.e coastal geomorphology, geology and oceanography) and the human geography of the coast. It involves an understanding of coastal weathering processes, particularly wave action, sediment movement and weathering, and also the ways in which humans

interact with the coast. Coastal geography although predominantly geomorphological in its research is not just concerned with coastal landforms, but also the causes and influences of sea level change.

- Oceanography is the branch of physical geography that studies the Earth's oceans and seas. It covers a wide range of topics, including marine organisms and ecosystem dynamics (biological oceanography); ocean currents, waves, and geophysical fluid dynamics (physical oceanography); plate tectonics and the geology of the sea floor (geological oceanography); and fluxes of various chemical substances and physical properties within the ocean and across its boundaries (chemical oceanography). These diverse topics reflect multiple disciplines that oceanographers blend to further knowledge of the world ocean and understanding of processes within it.
- Quaternary science is an inter-disciplinary field of study focusing on the Quaternary period, which encompasses the last 2.6 million years. The field studies the last ice age and the recent interstadial the Holocene and uses proxy evidence to reconstruct the past environments during this period to infer the climatic and environmental changes that have occurred.
- Landscape ecology is a sub-discipline of ecology and geography that address how spatial variation in the landscape affects ecological processes such as the distribution and flow of energy, materials and individuals in the environment (which, in turn, may influence the distribution of landscape "elements" themselves such as hedgerows). The field was largely founded by the German geographer Carl Troll Landscape ecology typically deals with problems in an applied and holistic context. The main difference between biogeography and landscape ecology is that the latter is concerned with how flows or energy and material are changed and their impacts on the landscape whereas the former is concerned with the spatial patterns of species and chemical cycles.

- Geomatics is the field of gathering, storing, processing, and delivering of geographic information, or spatially referenced information. Geomatics includes geodesy (scientific discipline that deals with the measurement and representation of the earth, its gravitational field, and other geodynamic phenomena, such as crustal motion, oceanic tides, and polar motion) and G.I.S. (a system for capturing, storing, analyzing and managing data and associated attributes which are spatially referenced to the earth) and remote sensing (the short or large-scale acquisition of information of an object or phenomenon, by the use of either recording or real-time sensing devices that are not in physical or intimate contact with the object).
- Environmental geography is a branch of geography that analyzes the spatial aspects of interactions between humans and the natural world. The branch bridges the divide between human and physical geography and thus requires an understanding of the dynamics of geology, meteorology, hydrology, biogeography, and geomorphology, as well as the ways in which human societies conceptualize the environment. Although the branch was previously more visible in research than at present with theories such as environmental determinism linking society with the environment. It has largely become the domain of the study of environmental management or anthropogenic influences on the environment and vice a versa.

Physical Geography Literature

Physical geography and Earth Science journals communicate and document the results of research carried out in universities and various other research institutions. Most journals cover a specific field and publish the research within that field, however unlike human geographers, physical geographers tend to publish in inter-disciplinary journals rather than predominantly geography journal; the research is normally expressed in the form of a scientific paper. Additionally, textbooks, books, and magazines on geography communicate research to laypeople, although these tend to focus on environmental issues or cultural dilemmas.

Historic Evolution of Physical Geography

From the birth of geography as a science during the Greek classical period and until the late nineteenth century with the birth of anthropography or Human Geography, Geography was almost exclusively a natural science: the study of location and descriptive gazetteer of all places of the known world. Several works among the best known during this long period could be cited as an example, from Strabo (Geography), Eratosthenes (Geography) or Dionisio Periegetes (Periegesis Oiceumene) in the Ancient Age to the Alexander von Humboldt (Cosmos) in the century XIX, in which geography is regarded as a physical and natural science, of course, through the work Summa de Geografia of Martin Fernandez de Enciso from the early sixteenth century, which is indicated for the first time the New World.

During the eighteenth and nineteenth centuries, a controversy exported from Geology, between supporters of James Hutton (uniformitarianism Thesis) and Georges Cuvier (catastrophism) strongly influenced the field of geography, because geography at this time was a natural science since Human Geography or Antropogeography had just developed as a discipline in the late nineteenth century.

Two historical events during the nineteenth century had a great effect in the further development of physical geography. The first was the European colonial expansion in Asia, Africa, Australia and even America in search of raw materials required by industries during the Industrial Revolution. This fostered the creation of geography departments in the universities of the colonial powers and the birth and development of national geographical societies, thus giving rise to the process identified by Horacio Capel as the institutionalization of geography.

One of the most prolific empires in this regard was the Russian. A mid-eighteenth century many geographers are sent by the Russian altamirazgo different opportunities to perform geographical surveys in the area of Arctic Siberia. Among these is who is considered the patriarch of Russian geography: Mikhail Lomonosov who in the mid-1750s began working in the Department of Geography, Academy of Sciences to conduct research in Siberia, their contributions are notable in this regard, shows the soil organic origin, develops a comprehensive law on the movement of the ice that still governs the basics, thereby founding a new branch of Geography: Glaciology. In 1755 his initiative was founded Moscow University where he promotes the study of geography and the training of geographers. In 1758 he was appointed director of the Department of Geography, Academy of Sciences, a post from which would develop a working methodology for geographical survey guided by the most important long expeditions and geographical studies in Russia.

Thus followed the line of Lomonosov and the contributions of the Russian school became more frequent through his disciples, and in the nineteenth century we have great geographers as Vasily Dokuchaev who performed works of great importance as a “principle of comprehensive analysis of the territory” and “Russian Chernozem” latter being the most important where introduces the geographical concept of soil, as distinct from a simple geological strata, and thus founding a new geographic area of study: the Pedology. Climatology also receive a strong boost from the Russian school by Wladimir Koppen whose main contribution, climate classification, is still valid today. However, this great geographer also contributed to the Paleogeography through his work “The climates of the geological past” which is considered the father of Paleoclimatology. Russian geographers who made great contributions to the discipline in this period were: NM Sibirtsev, Pyotr Semyonov, K. D. Glinka, Neustrayev, among others.

The second important process is the theory of evolution by Darwin in mid-century (which decisively influenced the work of Ratzel, who had academic training as a zoologist and was a follower of Darwin’s ideas) which meant an important impetus in the development of Biogeography.

Another major event in the late nineteenth and early twentieth century will give a major boost to development of geography and will take place in United States. It is the work of the famous geographer William Morris Davis who not only made important contributions to the establishment of discipline in his country, but revolutionized the field to develop geographical cycle theory which he proposed as a paradigm for Geography in general, although in actually served as a paradigm for Physical Geography. His theory explained that mountains and other landforms are shaped by the influence of a number of factors that are manifested in the geographical cycle.

He explained that the cycle begins with the lifting of the relief by geological processes (faults, volcanism, tectonic upheaval, etc.).. Geographical factors such as rivers and runoff begins to create the V-shaped valleys between the mountains (the stage called “youth”). During this first stage, the terrain is steeper and more irregular. Over time, the currents can carve wider valleys (“maturity”) and then start to wind, towering hills only (“senescence”).

Finally, everything comes to what is a plain flat plain at the lowest elevation possible (called “baseline”) This plain was called by Davis’ “peneplain” meaning “almost plain” Then the rejuvenation occurs and there is another mountain lift and the cycle continues. Although Davis’s theory is not entirely accurate, it was absolutely revolutionary and unique in its time and helped to modernize and create Geography subfield of Geomorphology. Its implications prompted a myriad of research in various branches of Physical Geography. In the case of the Paleogeography this theory provided a model for understanding the evolution of the landscape.

For Hydrology, Glaciology and Climatology as a boost investigated as studying geographic factors shape the landscape and affect the cycle. The bulk of the work of William Morris Davis led to the development of a new branch of Physical Geography: Geomorphology whose contents until then did not differ from the rest of Geography. Shortly after this branch would present a major development. Some of his disciples made significant contributions to various branches of physical geography such as Curtis Marbut and his invaluable legacy for Pedology, Mark Jefferson, Isaiah Bowman, among others.

Geography and Arctic Lands

The Arctic is the region around the Earth’s North Pole, opposite the Antarctic region around the South Pole. The Arctic includes the Arctic Ocean (which overlies the North Pole) and parts of Canada, Greenland (a territory of Denmark), Russia, the United States (Alaska), Iceland, Norway, Sweden and Finland. The word Arctic comes from the Greek (*arktikos*), "near the Bear, arctic, northern" and that from the word *Uniao* (*arktos*), which means bear. The name refers either to the constellation Ursa Major, the "Great Bear", which is prominent in the northern portion of the celestial sphere, or to the constellation Ursa Minor, the "Little Bear", which contains Polaris, the Pole Star, also known as the North Star.

The Arctic region can be defined as the area north of the Arctic Circle (66° 33'N), which is the approximate limit of the midnight sun and the polar night. Alternatively, it can be defined as the region where the average temperature for the warmest month (July) is below 10 °C (50 °F); the northernmost tree line roughly follows the isotherm at the boundary of this region. Socially and politically, the Arctic region includes the northern territories of the eight Arctic states, although by natural science definitions much of this territory is considered subarctic. The Arctic region consists of a vast, ice-covered ocean (which is sometimes considered to be a northern arm of the Atlantic Ocean) surrounded by treeless permafrost. In recent years the extent of the sea ice has declined. Life in the Arctic includes organisms living in the ice, zooplankton and phytoplankton, fish and marine mammals, birds, land animals, plants, and human societies. The Arctic region is a unique area among Earth's ecosystems. The cultures in the region and the Arctic indigenous peoples have adapted to its cold and extreme conditions.

Due to the poleward migration of the planet's isotherms (about 35 miles per decade during the past 30 years as a consequence of global warming), the Arctic region (as defined by tree line and temperature) is currently shrinking. Perhaps the most spectacular result of Arctic shrinkage is sea ice loss. There is a large variance in predictions of Arctic sea ice loss, with models showing near-complete to complete loss in September from 2040 to some time well beyond 2100. About half of the analyzed models show near-complete to complete sea ice loss in September by the year 2100.

Nature

Climate

The Arctic's climate is characterized by cold winters and cool summers. Precipitation mostly comes in the form of snow. The Arctic's annual precipitation is low, with most of the area receiving less than 50 centimetres (20 in). High winds often stir up snow, creating the illusion of continuous snowfall.

Average winter temperatures can be as low as “40 °C (“40 °F), and the coldest recorded temperature is approximately “68 °C (“90 °F). Coastal Arctic climates are moderated by oceanic influences, having generally warmer temperatures and heavier snowfalls than the colder and drier interior areas. The Arctic is affected by current global warming, leading to Arctic shrinkage and Arctic methane release.

Plants

Arctic vegetation is composed of plants such as dwarf shrubs, graminoids, herbs, lichens and mosses, which all grow relatively close to the ground, forming tundra. As one moves northward, the amount of warmth available for plant growth decreases considerably. In the northernmost areas, plants are at their metabolic limits, and small differences in the total amount of summer warmth make large differences in the amount of energy available for maintenance, growth and reproduction. Colder summer temperatures cause the size, abundance, productivity and variety of plants to decrease. Trees cannot grow in the Arctic, but in its warmest parts, shrubs are common and can reach 2 m (6 ft 7 in) in height; sedges, mosses and lichens can form thick layers. In the coldest parts of the Arctic, much of the ground is bare; nonvascular plants such as lichens and mosses predominate, along with a few scattered grasses and forbs (like the arctic poppy).

Animals

Herbivores on the tundra include the Arctic hare, lemming, muskox, and caribou. They are preyed on by the Arctic fox and wolf. The polar bear is also a predator, though it prefers to hunt for marine life from the ice. There are also many birds and marine species endemic to the colder regions. Other land animals include wolverines, ermines, and arctic ground squirrels. Marine mammals include seals, walrus, and several species of cetacean—baleen whales and also narwhals, killer whales and belugas.

Natural Resources

The Arctic includes sizable natural resources (oil, gas, minerals, fresh water, forest—if the subarctic is included—and fish) to which modern technology and the economic opening up of Russia have given significant new opportunities. The interest of the tourism industry is also on the increase.

The Arctic is one of the last and most extensive continuous wilderness areas in the world, and its significance in preserving biodiversity and genotypes is considerable. The increasing presence of humans fragments vital habitats. The Arctic is particularly susceptible to the abrasion of ground cover and to the disturbance of the rare reproduction places of the animals that are characteristic to the region. The Arctic also holds 1/5 of the Earth's water supply.

Paleo-history

During the Cretaceous, the Arctic still had seasonal snows, though only a light dusting and not enough to permanently hinder plant growth. Animals such as *Chasmosaurus*, *Hypacrosaurus*, *Troodon*, and *Edmontosaurus* may have all migrated north to take advantage of the summer growing season, and migrated south to warmer climes when the winter came. A similar situation may also have been found amongst dinosaurs that lived in Antarctic regions, such as *Muttaburrasaurus* of Australia.

Indigenous Population

The earliest inhabitants of North America's central and eastern Arctic are referred to as the Arctic small tool tradition (AST) and existed circa 2500 BC. AST consisted of several subsets, including Independence culture and Pre-Dorset culture. The Dorset culture (Inuktitut: *Tuniit* or *Tunit*) refers to the next inhabitants of central and eastern Arctic.

The Dorset culture evolved because of technological and economic changes during the period of 1050-550 BC. With the exception of the Quebec/Labrador peninsula, the Dorset culture vanished around 1500 AD. Supported by genetic testing, evidence shows that Dorset culture survived in Aivilik, Southampton and Coats Islands, until the beginning of the 20th century.

Dorset/Thule culture transition dates around the 9th-10th centuries. Scientists theorize that there may have been cross-contact of the two cultures with sharing of technology, such as fashioning harpoon heads, or the Thule may have found Dorset remnants and adapted their ways with the predecessor culture. Others believe the Thule displaced the Dorset. By 1300, the Inuit, present-day Arctic inhabitants and descendants of Thule culture, had settled west Greenland, and moved into east Greenland over the following century. Over time, the Inuit have migrated throughout the Arctic regions of Canada, Greenland, Russia and the United States.

International Cooperation and Politics

The Arctic region is a focus of international political interest. International Arctic cooperation got underway on a broad scale well over ten years ago. The International Arctic Science Committee (IASC), hundreds of scientists and specialists of the Arctic Council, the Barents Euro-Arctic Council and its regional cooperation have compiled high quality information on the Arctic.

Territorial Claims

No country owns the geographic North Pole or the region of the Arctic Ocean surrounding it. The surrounding Arctic states that border the Arctic Ocean — Russia, Norway, the United States, Canada and Denmark (via Greenland)—are limited to a 370 kilometre (200 nautical mile) economic zone around their coasts.

Upon ratification of the United Nations Convention on the Law of the Sea, a country has ten years to make claims to extend its 200 mile zone. Due to this, Norway (which ratified the convention in 1996), Russia (ratified in 1997), Canada (ratified in 2003) and Denmark (ratified in 2004) launched projects to establish claims that certain Arctic sectors should belong to their territories.

On August 2, 2007, two Russian bathyscaphes, MIR-1 and MIR-2, for the first time in history descended to the Arctic seabed beneath the North Pole and placed there a Russian flag made of rust-proof titanium alloy. The mission was a scientific expedition, but the flag-placing raised concerns of a race for control of the Arctic's vast petroleum resources. Foreign ministers and other officials representing Canada, Denmark, Norway, Russia, and the United States met in Ilulissat, Greenland on May 28, 2008 at the Arctic Ocean Conference and announced the Ilulissat Declaration.

Scientific Exploration

Since 1937, the whole Arctic region has been extensively explored by Soviet and Russian manned drifting ice stations. Between 1937 and 1991, 88 polar crews established and occupied scientific settlements on the drift ice and were carried thousands of kilometres by the ice flow.

Pollution

The Arctic is comparatively clean, although there are certain ecologically difficult localized pollution problems that present a serious threat to people's health living around these pollution sources. Due to the prevailing worldwide sea and air currents, the Arctic area is the fallout region for long-range transport pollutants, and in some places the concentrations exceed the levels of densely populated urban areas. An example of this is the phenomenon of Arctic haze, which is commonly blamed on long-range pollutants. Another example is with the bioaccumulation of PCB's (polychlorinated biphenyls) in Arctic wildlife and people.

Climate Change

The Arctic is especially vulnerable to the effects of global warming, as has become apparent in the melting sea ice in recent years. Climate models predict much greater warming in the Arctic than the global average, resulting in significant international attention to the region. In particular, there are concerns that Arctic shrinkage, a consequence of melting glaciers and other ice in Greenland, could soon contribute to a substantial rise in sea levels worldwide. Climate models give a range of predictions of Arctic sea ice loss, showing near-complete to complete loss in September anywhere from 2040 to some time well beyond 2100. About half of the analyzed models show near-complete to complete sea ice loss in September by the year 2100. More recently, the Catlin Arctic Survey concluded that summer ice loss would occur around 2029.

In September 2008, the extent of the summer Arctic ice cap was at a near-record low, only 9.01 percent greater than the record low in 2007, and 33.6 percent below the average extent of sea ice from 1979 to 2000.

The current Arctic shrinkage is leading to fears of Arctic methane release. Release of methane stored in permafrost could cause abrupt and severe global warming, as methane is a potent greenhouse gas. On millennial time-scales, decomposition of methane hydrates in the Arctic seabed could also amplify global warming. Previous methane release events have been linked to the great dying, a mass extinction event at the boundary of the Permian and Triassic, and the Paleocene-Eocene thermal maximum, in which temperatures abruptly increased.

Apart from concerns regarding the detrimental effects of warming in the Arctic, some potential opportunities have gained attention as well. The melting of the ice is making the Northwest passage, the shipping routes through the northernmost latitudes, more navigable, raising the possibility that the Arctic region will become a prime trade route. In addition, it is believed that the Arctic seabed may contain substantial oil fields which may become accessible if the ice covering them melts. These factors have led to recent international debates as to which nations can claim sovereignty or ownership over the waters of the Arctic.

The National Oceanic and Atmospheric Administration's Arctic Report Card presents annually updated, peer-reviewed information on recent observations of environmental conditions in the Arctic relative to historical records. In 2008, there continues to be widespread and, in some cases, dramatic evidence of an overall warming of the Arctic system.

Ecosystems and Ecology

Although the Arctic is considered a single system, it is often convenient to identify specific ecosystems within that system. Such classifications are not meant to imply clear separations between these ecosystems. In fact, the transition zones between terrestrial, freshwater, and marine areas are often dynamic, sensitive, and biologically productive.

Nonetheless, much scientific research, and indeed subsequent chapters in this assessment, use these three basic categories.

Terrestrial Ecosystems

Species diversity appears to be low in the Arctic, and on land decreases markedly from the boreal forests to the polar deserts of the extreme north. Only about 3% (5,900 species) of the world's plant species occur in the Arctic north of the treeline. However, primitive plant species of mosses and lichens are relatively abundant. Arctic plant diversity appears to be sensitive to climate. The temperature gradient that has such a strong influence on species diversity occurs over much shorter distances in the Arctic than in other biomes. North of the treeline in Siberia, for example, mean July temperature decreases from 12 to 2 ºC over 900 km. In the boreal zone, a similar change in temperature occurs over 2000 km. From the southern boreal zone to the equator, the entire change is less than 10 ºC.

The diversity of arctic animals north of the treeline (about 6000 species) is similar to that of plants. As with plants, the arctic fauna account for about 3% of the global total, and evolutionarily primitive species are better represented than advanced species. In general, the decline in animal species with increasing latitude is more pronounced than that of plants. An important consequence of this is an increase in dominance. "Super-dominant" species, such as lemmings, occupy a wide range of habitats and generally have large effects on ecosystem processes.

Many of the adaptations of arctic species to their current environments limit their responses to climate warming and other environmental changes. Many adaptations have evolved to cope with the harsh climate, and these make arctic species more susceptible to biological invasions at their southern ranges while species at their northern range limit are particularly sensitive to warming. During environmental changes in the past, arctic species have changed their distributions rather than evolving significantly. In the future, changes in the conditions in arctic ecosystems may affect the release of greenhouse gases to the atmosphere, providing a possibly significant feedback to climate warming although both the direction and magnitude of the feedback are currently very uncertain. Furthermore, vegetation type profoundly influences the water and energy exchange of arctic ecosystems, and so future changes in vegetation driven by climate change could profoundly alter regional climates.

Freshwater Ecosystems

Arctic freshwater ecosystems are extremely numerous, occupying a substantial area of the arctic landmass. Even in areas of the Arctic that have low precipitation, freshwater ecosystems are common and the term "polar deserts" refers more to the impoverishment of vegetation cover than to a lack of groundwater. Arctic freshwater ecosystems include three main types: flowing water (rivers and streams), permanent standing water (lakes and ponds), and wetlands such as peatlands and bogs. All provide a multitude of goods and services to humans and the biota that use them.

Flowing water systems range from the large, north-flowing rivers that connect the interiors of continents with the Arctic Ocean, through steep mountain rivers, to slow-flowing tundra streams that may contain water during spring snow melt. The large rivers transport heat, water, nutrients, contaminants, sediment, and biota into the Arctic and together have a major effect on regional environments. The larger rivers flow throughout the year, but small rivers and streams freeze in winter. The biota of flowing waters are extremely variable: rivers fed mainly by glaciers are particularly low in nutrients and have low productivity. Spring-fed streams can provide stable, year-round habitats with a greater diversity of primary producers and insects.

Permanent standing waters vary from very large water bodies to small and shallow tundra ponds that freeze to the bottom in winter. By the time the ice melts in summer, the incoming solar radiation is already past its peak, so that the warming of lakes is limited. Primary production, by algae and aquatic mosses, decreases from the subarctic to the high Arctic. Zooplankton species are limited or even absent in arctic lakes because of low temperatures and low nutrient availability. Species abundance and diversity increase with the trophic status of the lake. Fish species are generally not diverse, ranging from 3 to 20 species, although species such as Arctic char (Salvelinus alpinus) and salmon (Salmo salar) are an important resource.

Wetlands are among the most abundant and productive aquatic ecosystems in the Arctic. They are ubiquitous and characteristic features throughout the Arctic and almost all are created by the retention of water above the permafrost. They are more extensive in the southern Arctic than the high Arctic, but overall, cover vast areas – up to 3.5 million km^2 or 11% of the land surface. Several types of wetlands are found in the Arctic, with specific characteristics related to productivity and climate. Bogs, for example, are nutrient poor and have low productivity but high carbon storage, whereas fens are nutrient rich and have high productivity. Arctic wetlands have greater biological diversity than other arctic freshwater ecosystems, primarily in the form of mosses and sedges. Together with lakes and ponds, arctic wetlands are summer home to hundreds of millions of migratory birds. Arctic freshwater ecosystems are particularly sensitive to climate change because the very nature of their habitats results from interactions between temperature, precipitation, and permafrost. Also, species limited by temperature and nutrient availability are likely to respond to temperature changes and effects of UV radiation on dead organic material in the water column.

Marine Ecosystems

Approximately two-thirds of the Arctic as defined by the ACIA comprises ocean, including the Arctic Ocean and its shelf seas plus the Nordic, Labrador, and Bering Seas. These areas are important components of the global climate system, primarily because of their contributions to deepwater formation that influences global ocean circulation. Arctic marine ecosystems are unique in having a very high proportion of shallow water and coastal shelves. In common with terrestrial and freshwater ecosystems in the Arctic, they experience strong seasonality in sunlight and low temperatures. They are also influenced by freshwaters delivered mainly by the large rivers of the Arctic. Ice cover is a particularly important physical characteristic, affecting heat exchange between water and atmosphere, light penetration to organisms in the water below, and providing a biological habitat above (for example, for seals and polar bears (Ursus maritimus)), within, and beneath the ice. The marginal ice zone, at the edge of the pack ice, is particularly important for plankton production and plankton-feeding fish.

Some of these factors are highly variable from year to year and, together with the relatively young age of arctic marine ecosystems, have imposed constraints on the development of ecosystems that parallel those of arctic lands and freshwaters. Thus, in general, arctic marine ecosystems are relatively simple, productivity and biodiversity are low, and species are long-lived and slow-growing.

Some arctic marine areas, however, have very high seasonal productivity and the sub-polar seas have the highest marine productivity in the world. The Bering and Chukchi Seas, for example, include nutrient-rich upwelling areas that support large concentrations of migratory seabirds as well as diverse communities of marine mammals. The Bering and Barents Seas support some of the world's richest fisheries.

The marine ecosystems of the Arctic provide a range of ecosystem services that are of fundamental importance for the sustenance of inhabitants of arctic coastal areas. Over 150 species of fish occur in arctic and subarctic waters, and nine of these are common, almost all of which are important fishery species such as cod. Arctic marine mammals escaped the mass extinctions of the ice ages that dramatically reduced the numbers of arctic terrestrial mammal species, but many are harvested. They include predators such as the toothed whales, seals, walrus, sea otters, and the Arctic's top predator, the polar bear. Over 60 species of migratory and resident seabirds occur in the Arctic and form some of the largest seabird populations in the world. At least one species, the great auk (Pinguinus impennis), is now extinct because of over exploitation.

The simplicity of arctic marine ecosystems, together with the specialization of many of its species, make them potentially sensitive to environmental changes such as climatic change, exposure to higher levels of UV radiation, and increased levels of contaminants. Concomitant with these pressures is potential over-exploitation of some marine resources.

Humans

Some two to four million people live in the Arctic today, although the precise number depends on where the boundary is drawn. These people include indigenous peoples and recent arrivals, herders and hunters living on the land, and city dwellers with desk jobs. Humans have occupied large parts of the Arctic since at least the last ice age. Archeological remains have been found in northern Fennoscandia, Russia, and Alaska dating back more than 12000 years. In the eastern European Arctic, Paleolithic settlements have been recorded from as early as 40000 years ago. In Eurasia and across the North Atlantic, groups of humans have moved northward over the past several centuries, colonizing new lands such as the Faroe Islands and Iceland, and encountering those already present in northern Fennoscandia and Russia and in western Greenland.

In the 20th century, immigration to the Arctic has increased dramatically, to the point where nonindigenous persons outnumber indigenous ones in many regions. The new immigrants have been drawn by the prospect of developing natural resources, from fishing to gold to oil, as well as by the search for new opportunities and escape from the perceived and real constraints of their home areas. Social, economic, and cultural conflicts have arisen as a consequence of competition for land and resources and the incompatibility of some aspects of traditional and modern ways of life. In North America, indigenous claims to land and resources have been addressed to some extent in land claim agreements, the creation of largely self-governed regions such as Nunavut and Greenland within nation states, and other political and economic actions. In Eurasia, by contrast, indigenous claims and rights have only recently begun to be addressed as matters of national policy.

Many aspects of demography are also changing. Over the past decade, total population has increased rapidly in only three areas: Alaska, Iceland, and the Faroe Islands. Rapid declines in population have occurred across most of northern Russia, with lesser declines or modest increases in other parts of the North.

Life expectancy has increased greatly across most of the Arctic in recent decades, but declined sharply in Russia in the

1990s. The prevalence of indigenous language use has decreased in most areas, with several languages in danger of disappearing from use. In some respects, the disparities between northern and southern communities in terms of living standards, income, and education are shrinking, although the gaps remain large in most cases.

Traditional economies based on local production, sharing, and barter, are giving way to mixed economies in which money plays a greater role.

Despite this assimilation on many levels, or perhaps in response to it, many indigenous peoples are reasserting their cultural identity. With this activism comes political calls for rights, recognition, and self-determination.

The response of arctic indigenous groups to the presence of long-range pollutants in their traditional foods is a useful illustration of their growing engagement with the world community. In Canada particularly, indigenous groups led the effort to establish a national program to study contaminants, there sults of which were used by those groups to advocate and negotiate international conventions to control persistent organic pollutants. The arguments were often framed in terms of the rights of these distinct peoples to live without interference from afar. The use of international fora to make this case emphasizes the degree to which the indigenous groups think of themselves as participants in global, in addition to national, affairs.

At the same time that indigenous peoples are reaching outward, traditional hunting, fishing, herding, and gathering practices remain highly important. Traditional foods have high nutritional value, particularly for those adapted to diets high in fat and protein rather than carbohydrates.

Sharing and other forms of distributing foods within and between communities are highly valued, and indeed create a highly resilient adaptation to uncertain food supplies while strengthening social bonds. The ability to perpetuate traditional practices is a visible and effective way for many indigenous people to exert control over the pace and extent of modernization, and to retain the powerful spiritual tie between people and their environment.

It is within this context of change and persistence in the Arctic today that climate change and increased UV radiation act as yet more external forces on the environment that arctic residents rely upon and know well. Depending on how these new forces interact with existing forces in each arctic society and each geographical region, the impacts and opportunities associated with climate change and UV radiation may be minimized or magnified.

The degree to which people are resilient or vulnerable to climate change depends in part on the cumulative stresses to which they are subject through social, political, and economic changes in other aspects of their lives. It also depends in part on the sensitivity of social systems and their capacity for adaptation. The human impacts of climate change should be interpreted not in sweeping generalizations about the entire region, but as another influence on the already shifting mosaic that comprises each arctic community.

Natural Resources and Economics

In economic terms, the Arctic is best known as a source of natural resources. This has been true since the first explorers discovered whales, seals, birds, and fish that could be sold in more southerly markets. In the 20th century, arctic minerals were also discovered and exploited, the size of some deposits of oil, gas, and metal ores more than compensating for the costs of operating in remote, cold regions. Military bases and other facilities were also constructed across much of the Arctic, providing employment but also affecting population distribution and local environments. In recent decades, tourism has added another sector to the economies of many communities and regions of the Arctic. The public sector, including government services and transfer payments, is also a major part of the economy in nearly all areas of the Arctic, responsible in some cases for over half the available jobs. In addition to the cash economy of the Arctic, the traditional subsistence and barter economies are major contributors to the overall well-being of the region, producing significant value that is not recorded in official statistics that reflect only cash transactions.

The three most important economic resources of the Arctic are oil and gas, fish, and minerals.

Oil and Gas

The Arctic has huge oil and gas reserves. Most are located in Russia: oil in the Pechora Basin, gas in the lower Ob Basin, and other potential oil and gas fields along the Siberian coast. Canadian oil and gas fields are concentrated in two main basins in the Mackenzie Delta/ Beaufort Sea region and in the Arctic Islands. In Alaska, Prudhoe Bay is the largest oil field in North America 16 Arctic Climate Impact Assessment and other fields have been discovered or remain to be discovered along the Beaufort Sea coast. Oil and gas fields also exist on Greenland's west coast and in Norway's arctic territories.

Fish

Arctic seas contain some of the world's oldest and richest commercial fishing grounds. In the Bering Sea and Aleutian Islands, Barents Sea, and Norwegian Sea annual fish harvests in the past have exceeded two million tonnes, although many of these fisheries have declined (in 2001 fish catches in the Bering Sea totaled 1.6 million tonnes). Important fisheries also exist around Iceland, Svalbard, Greenland, and Canada. Fisheries are important to many arctic countries, as well as to the world as a whole. For example, Norway is the world's biggest fish exporter with exports worth four billion US dollars in 2001.

Minerals

The Arctic has large mineral reserves, ranging from gemstones to fertilizers. Russia extracts the greatest quantities of these minerals, including nickel, copper, platinum, apatite, tin, diamonds, and gold, mostly on the Kola Peninsula but also in Siberia. Canadian mining in the Yukon and Northwest Territories and Nunavut is for lead, zinc, copper, diamonds, and gold. In Alaska lead and zinc deposits in the Red Dog Mine, which contains two-thirds of US zinc resources, are mined, and gold mining continues. The mining activities in the Arctic are an important contributor of raw materials to the world economy.

2

Topographic Landforms

Topography is the study of Earth's surface shape and features or those of planets, moons, and asteroids. It is also the description of such surface shapes and features (especially their depiction in maps).

The topography of an area can also mean the surface shape and features themselves.

In a broader sense, topography is concerned with local detail in general, including not only relief but also vegetative and human-made features, and even local history and culture. This meaning is less common in America, where topographic maps with elevation contours have made "topography" synonymous with relief. The older sense of topography as the study of place still has currency in Europe.

For the purposes of this article, topography specifically involves the recording of relief or terrain, the three-dimensional quality of the surface, and the identification of specific landforms. This is also known as geomorphometry. In modern usage, this involves generation of elevation data in electronic form. It is often considered to include the graphic representation of the landform on a map by a variety of techniques, including contour lines, Hypsometric tints, and relief shading.

Etymology

The term topography originated in ancient Greece and continued in ancient Rome, as the detailed description of a place. The word comes from the Greek words (*topos*, place) and (*graphia*, writing). In classical literature this refers to writing about a place or places, what is now largely called 'local history'. In Britain and in Europe in general, the word topography is still sometimes used in its original sense.

Detailed military surveys in Britain (beginning in the late eighteenth century) were called Ordnance Surveys, and this term was used into the 20th century as generic for topographic surveys and maps. The earliest scientific surveys in France were called the Cassini maps after the family who produced them over four generations.

The term "topographic surveys" appears to be American in origin. The earliest detailed surveys in the United States were made by the "Topographical Bureau of the Army," formed during the War of 1812. After the work of national mapping was assumed by the U.S. Geological Survey in 1878, the term topographical remained as a general term for detailed surveys and mapping programs, and has been adopted by most other nations as standard.

In the 20th century, the term topography started to be used to describe surface description in other fields where mapping in a broader sense is used, particularly in medical fields such as neurology.

Objectives

An objective of topography is to determine the position of any feature or more generally any point in terms of both a horizontal Coordinate system such as latitude and longitude, and altitude. Identifying (naming) features and recognizing typical landform patterns are also part of the field.

A topographic study may be made for a variety of reasons: military planning and geological exploration have been primary motivators to start survey programs, but detailed information about terrain and surface features is essential for the planning and construction of any major civil engineering, public works, or reclamation projects.

Techniques of Topography

There are a variety of approaches to studying topography. Which method(s) to use depend on the scale and size of the area under study, its accessibility, and the quality of existing surveys.

Direct Survey

Surveying helps determine accurately the terrestrial or three-dimensional space position of points and the distances and angles between them using levelling instruments such as theodolites, dumpy levels and clinometers.

Even though remote sensing has greatly speeded up the process of gathering information, and has allowed greater accuracy control over long distances, the direct survey still provides the basic control points and framework for all topographic work, whether manual or GIS-based.

In areas where there has been an extensive direct survey and mapping program (most of Europe and the Continental US, for example), the compiled data forms the basis of basic digital elevation datasets such as USGS DEM data. This data must often be "cleaned" to eliminate discrepancies between surveys, but it still forms a valuable set of information for large-scale analysis.

The original American topographic surveys (or the British "Ordnance" surveys) involved not only recording of relief, but identification of landmark features and vegetative land cover.

Remote Sensing

Remote sensing is a general term for geodata collection at a distance from the subject area.

Aerial and Satellite Imagery

Besides their role in photogrammetry, aerial and satellite imagery can be used to identify and delineate terrain features and more general land-cover features. Certainly they have become more and more a part of geovisualization, whether maps or GIS systems. False-colour and non-visible spectra imaging can also help determine the lie of the land by delineating vegetation and other land-use information more clearly. Images can be in visible colours and in other spectra.

Photogrammetry

Photogrammetry is a measurement technique for which the co-ordinates of the points in 3D of an object are determined by the measurements made in two photographic images (or more) taken starting from different positions, usually from different passes of an aerial photography flight. In this technique, the common points are identified on each image. A line of sight (or ray) can be built from the camera location to the point on the object. It is the intersection of its rays (triangulation) which determines the relative three-dimensional position of the point. Known control points can be used to give these relative positions absolute values. More sophisticated algorithms can exploit other information on the scene known a priori (for example, symmetries in certain cases allowing the rebuilding of three-dimensional co-ordinates starting from one only position of the camera).

Radar and Sonar

Satellite radar mapping is one of the major techniques of generating Digital Elevation Models. Similar techniques are applied in bathymetric surveys using sonar to determine the terrain of the ocean floor. In recent years, LIDAR (Light Detection and Ranging), a remote sensing technique using a laser instead of radio waves, has increasingly been employed for complex mapping needs such as charting canopies and monitoring glaciers.

Landform

In the earth sciences and geology sub-fields, a landform or physical feature comprises a geomorphological unit, and is largely defined by its surface form and location in the landscape, as part of the terrain, and as such, is typically an element of topography. Landform elements also include seascape and oceanic waterbody interface features such as bays, peninsulas, seas and so forth, including sub-aqueous terrain features such as submersed mountain ranges, volcanoes, and the great ocean basins.

Physical Characteristics

Landforms are categorised by characteristic physical attributes such as elevation, slope, orientation, stratification, rock exposure, and soil type.

Gross *physical features or landforms* include intuitive elements such as berms, mounds, hills, ridges, cliffs, valleys, rivers, peninsulas and numerous other structural and size-scaled (i.e. ponds vs. Lakes, Hills vs. Mountains) elements including various kinds of inland and oceanic waterbodies and sub-surface features.

Hierarchy of Classes

Oceans and continents exemplify the highest-order landforms. Landform elements are parts of a high-order landforms that can be further identified and systematically given a cohesive definition such as hill-tops, shoulders, saddles, foreslopes and backslopes.

Some generic landform elements including: pits, peaks, channels, ridges, passes, pools and plains, may be extracted from a digital elevation model using some automated techniques where the data has been gathered by modern satellites and stereoscopic aerial surveillance cameras. Until recently, compiling the data found in such data sets required time consuming and expensive techniques of many man-hours.

Terrain (or *relief*) is the third or vertical dimension of *land surface*. Topography is the study of terrain, although the word is often used as a synonym for relief itself. When relief is described underwater, the term bathymetry is used. In cartography, many different techniques are used to describe relief, including contour lines and TIN (Triangulated irregular network).

Elementary landforms (segments, facets, relief units) are the smallest homogeneous divisions of the land surface, at the given scale/resolution. These are areas with relatively homogenous morphometric properties, bounded by lines of discontinuity. A plateau or a hill can be observed at various scales ranging from few hundred meters to hundreds of kilometres. Hence, the spatial distribution of landforms is often scale-dependent as is the case for soils and geological strata.

A number of factors, ranging from plate tectonics to erosion and deposition, can generate and affect landforms. Biological factors can also influence landforms— for example, note the role of vegetation in the development of dune systems and salt marshes, and the work of corals and algae in the formation of coral reefs.

Landforms do not include man-made features, such as canals, ports and many harbours; and geographic features, such as deserts, forests, grasslands, and impact craters.

Many of the terms are not restricted to refer to features of the planet Earth, and can be used to describe surface features of other planets and similar objects in the Universe. Examples are mountains, polar caps, and valleys, which are found on all of the terrestrial planets.

Terrain

Terrain, or land relief, is the vertical dimension of land surface. When relief is described underwater, the term bathymetry is used. Topography has recently become an additional synonym, though in many parts of the world it retains its original more general meaning of description of place.

Terrain is used as a general term in physical geography, referring to the lie of the land. This is usually expressed in terms of the elevation, slope, and orientation of terrain features. Terrain affects surface water flow and distribution. Over a large area, it can affect weather and climate patterns.

Importance

The understanding of terrain is critical for many reasons:

- The terrain of a region largely determines its suitability for human settlement: flatter, alluvial plains tend to have better farming soils than steeper, rockier uplands.
- In terms of environmental quality, agriculture, and hydrology, understanding the terrain of an area enables the understanding of watershed boundaries, drainage characteristics, water movement, and impacts on water quality. Complex arrays of relief data are used as input parameters for hydrology transport models (such as the SWMM or DSSAM Models) to allow prediction of river water quality.
- Understanding terrain also supports on soil conservation, especially in agriculture. Contour plowing is an established practice enabling sustainable agriculture on sloping land; it is the practice of plowing

along lines of equal elevation instead of up and down a slope.

- Terrain is militarily critical because it determines the ability of armed forces to take and hold areas, and move troops and material into and through areas. An understanding of terrain is basic to both defensive and offensive strategy.
- Terrain is important in determining weather patterns. Two areas geographically close to each other may differ radically in precipitation levels or timing because of elevation differences or a “rain shadow” effect.
- Since terrain comes in vast varieties, certain features can be specific according to one type terrain, but also other features can be specific to multiple types of terrain. Basically, different terrains can both share the same features as well as have their own unique features.

Geomorphology

Geomorphology is in large part the study of the formation of terrain or topography. Terrain is formed by intersecting processes:

- Geological processes: migration of tectonic plates, faulting and folding, volcanic eruptions, rivers.
- Erosional processes: water and wind erosion, landslides.
- Extraterrestrial: meteorite impacts.

Tectonic processes such as orogenies cause land to be elevated, and erosional or weathering processes cause land to be worn away to lower elevations.

Land surface parameters are quantitative measures of various morphometric properties of a surface. The most common examples are used to derive slope or aspect of a terrain or curvatures at each location. These measures can also be used to derive hydrological parameters that reflect flow/erosion processes. Climatic parameters are based on the modelling of solar radiation or air flow.

Land surface objects, or landforms, are definite physical objects (lines, points, areas) that differ from the surrounding objects. The most typical examples arelines of watersheds, stream patterns, ridges, break-lines, pools or borders of specific landforms.

During the early 1900s, the study of regional-scale geomorphology was termed "physiography". Unfortunately, physiography later was considered to be a contraction of "*physi*cal" and "ge*ography*", and therefore synonymous with physical geography, and the concept became embroiled in controversy surrounding the appropriate concerns of that discipline. Some geomorphologists held to a geological basis for physiography and emphasized a concept of physiographic regions while a conflicting trend among geographers was to equate physiography with "pure morphology," separated from its geological heritage. In current usage, physiography still lends itself to confusion as to which meaning is meant, the more specialized "geomorphological" definition or the more encompassing "physical geography" definition. For the remainder of this article, emphasis will remain on the more "geomorphological" usage, which is based upon geological landforms, not on climate, vegetation, or other non-geological criteria.

For the purposes of physiographic mapping, landforms are classified according to both their geologic structures and histories. Distinctions based on geologic age also correspond to physiographic distinctions where the forms are so recent as to be in their first erosion cycle, as is generally the case with sheets of glacial drift. Generally, forms which result from similar histories are characterized by certain similar features, and differences in history result in corresponding differences of form, usually resulting in distinctive features which are obvious to the casual observer, but this is not always the case. A maturely dissected plateau may grade without a break from rugged mountains on the one hand to mildly rolling farm lands on the other. So also, forms which are not classified together may be superficially similar; for example, a young coastal plain and a peneplain. In a large number of cases, the boundary lines are also geologic lines, due to differences in the nature or structure of the underlying rocks.

History

The history of "physiography" itself is at best a complicated effort. Much of the complications arise from how the term has evolved over time, both as its own 'science' and as a synonym for other branches of science. In 1848, Mary Somerville published her book *Physical Geography* which gave detailed descriptions of the topography of each continent, along with the distribution of plant, animals and humans. This work gave impetus to further works along the field. In Germany, Oscar Peschel in 1870, proposed that geographers should study the morphology of the Earth's surface, having an interest in the study of landforms for the development of human beings. As the chair of geography (and a geologist by training) in Bonn, Germany, Ferdinand von Richtofen made the study of landforms the main research field for himself and his students. Elsewhere, Thomas Henry Huxley's *Physiography* was published in 1877 in Britain. Shortly after, the field of "physical geography" itself was renamed as "physiography". Afterwards, physiography became a very popular school subject in Britain, accounting for roughly 10% of all examination papers in both English and Welsh schools, and physiography was now regarded as an integral, if not the most important aspect of geography.

In conjunction with these 'advances' in physiography, physically and visually mapping these descriptive areas was underway as well. The early photographers and balloonists, Nadar and Triboulet, experimented with aerial photography and the view it provided of the landscape. In 1899, Albert Heim published his photographs and observations made during a balloon flight over the Alps; he is probably the first person to use aerial photography in geomorphological or physiographical research. The block diagrams of Feeneman, Raisz, Lobeck and many others were based in part upon both aerial photography and topographic maps, giving an oblique "birds-eye" view.

By 1901, there were clear differences in the definition of the term physiography. "In England, physiography is regarded as the introduction to physical science in general. It is made to include the elements of physics, chemistry, astronomy, physical geography, and geology, and sometimes even certain phases of botany and zoology. In America, the term has a somewhat different meaning. It is sometimes used as a synonym for physical geography, and is sometimes defined as the science which describes and explains the physical features of the earth's surface". By 1911, the definition of physiography in *Encyclopaedia Britannica* had evolved to be "In popular usage the words 'physical geography' have come to mean geography viewed from a particular standpoint rather than any special department of the subject. The popular Physical meaning is better conveyed by the word physiography, a geography term which appears to have been introduced by Linnaeus, and was reinvented as a substitute for the cosmography of the Middle Ages by Professor Huxley.

Although the term has since been limited by some writers to one particular part of the subject, it seems best to maintain the original and literal meaning. In the stricter sense, physical geography is that part of geography which involves the processes of contemporary change in the crust and the circulation of the fluid envelopes. It thus draws upon physics for the explanation of the phenomena with the space-relations of which it is specially concerned. Physical geography naturally falls into three divisions, dealing respectively with the surface of the lithosphere - geomorphology; the hydrosphere - oceanography; and the atmosphere - climatology. All these rest upon the facts of mathematical geography, and the three are so closely inter-related that they cannot be rigidly separated in any discussion".

The 1919 edition of *The Encyclopedia Americana: A Library of Universal Knowledge* further adjusted the definition to be "Physiography (geomorphology), now generally recognized as a science distinct from geology, deals with the origins and development of land forms, traces out the topographic expression of structure, and embodies a logical history of oceanic basins, and continental elevations; of mountains, plateaus and plains; of hills and valleys. Physical geography is used loosely as a synonym, but the term is more properly applied to the borderland between geography and physiography; dealing, as it does, largely with the human element as influenced by its physiographic surroundings".

Even in the 21 century, some confusion remains as to exactly what "physiography" is. One source states "Geomorphology includes quaternary geology, physiography and most of physical geography", treating physiography as a separate field, but subservient to geomorphology. Another source states “Geomorphology (or physiography) refers to the study of the surface features of the earth. It involves looking at the distribution of land, water, soil and rock material that forms the land surface. Land is closely linked to the geomorphology of a particular landscape”, regarding physiography as synonymous with geomorphology.

Yet another source states “Physiography may be viewed from two distinct angles, the one dynamic, the other passive”. The same source continues by stating “In a large fashion geodynamics is intimately associated with certain branches of geology, as sedimentation, while geomorphology connects physiography with geography. The dynamic interlude representing the active phase of physiography weaves the basic threads of geologic history.” The U.S. Geological Survey defines physiography as a study of “Features and attributes of earth’s land surface”, while geomorphology is defined separately as “Branch of geology dealing with surface land features and the processes that create and change them”.

Partly due to this confusion over what “physiography” actually means, some scientists have refrained from using the term physiography (and instead use the similar term geomorphology) because the definitions vary from the American Geological Institute’s “the study and classification of the surface features of Earth on the basis of similarities in geologic structure and the history of geologic changes” to descriptions that also include vegation and/or land use.

Major Lineaments of the Earth Surface

The Earth’s terrain varies greatly from place to place. About 70.8% of the surface is covered by water, with much of the continental shelf below sea level. The submerged surface has mountainous features, including a globe-spanning mid-ocean ridge system, as well as undersea volcanoes, oceanic trenches, submarine canyons, oceanic plateaus and abyssal plains. The remaining 29.2% not covered by water consists of mountains, deserts, plains, plateaus, and other geomorphologies.

The planetary surface undergoes reshaping over geological time periods because of tectonics and erosion. The surface features built up or deformed through plate tectonics are subject to steady weathering from precipitation, thermal cycles, and chemical effects. Glaciation, coastal erosion, the build-up of coral reefs, and large meteorite impacts also act to reshape the landscape.

The continental crust consists of lower density material such as the igneous rocks granite and andesite. Less common is basalt, a denser volcanic rock that is the primary constituent of the ocean floors. Sedimentary rock is formed from the accumulation of sediment that becomes compacted together. Nearly 75% of the continental surfaces are covered by sedimentary rocks, although they form only about 5% of the crust. The third form of rock material found on Earth is metamorphic rock, which is created from the transformation of pre-existing rock types through high pressures, high temperatures, or both. The most abundant silicate minerals on the Earth's surface include quartz, the feldspars, amphibole, mica, pyroxene and olivine. Common carbonate minerals include calcite (found in limestone), aragonite and dolomite.

The pedosphere is the outermost layer of the Earth that is composed of soil and subject to soil formation processes. It exists at the interface of the lithosphere, atmosphere, hydrosphere and biosphere. Currently the total arable land is 13.31% of the land surface, with only 4.71% supporting permanent crops. Close to 40% of the Earth's land surface is presently used for cropland and pasture, or an estimated 1.3×10^7 km^2 of cropland and 3.4×10^7 km^2 of pastureland.

The elevation of the land surface of the Earth varies from the low point of “418 m at the Dead Sea, to a 2005-estimated maximum altitude of 8,848 m at the top of Mount Everest. The mean height of land above sea level is 840 m.

Structure of the Atmosphere

Principal Layers

Earth's atmosphere can be divided into five main layers. These layers are mainly determined by whether temperature increases or decreases with altitude. From highest to lowest, these layers are:

Exosphere: The outermost layer of Earth's atmosphere extends from the exobase upward. Here the particles are so far apart that they can travel hundreds of kilometres without colliding with one another. Since the particles rarely collide, the atmosphere no longer behaves like a fluid. These free-moving particles follow ballistic trajectories and may migrate into and out of the magnetosphere or the solar wind. The exosphere is mainly composed of hydrogen and helium.

Thermosphere: Temperature increases with height in the thermosphere from the mesopause up to the thermopause, then is constant with height. The temperature of this layer can rise to 1,500 °C (2,730 °F), though the gas molecules are so far apart that temperature in the usual sense is not well defined. The International Space Station orbits in this layer, between 320 and 380 km (200 and 240 mi). The top of the thermosphere is the bottom of the exosphere, called the exobase. Its height varies with solar activity and ranges from about 350–800 km (220–500 mi; 1,100,000–2,600,000 ft).

Mesosphere: The mesosphere extends from the stratopause to 80–85 km (50–53 mi; 260,000–280,000 ft). It is the layer where most meteors burn up upon entering the atmosphere. Temperature decreases with height in the mesosphere. The mesopause, the temperature minimum that marks the top of the mesosphere, is the coldest place on Earth and has an average temperature around “85 °C (“121.0 °F; 188.1 K). Due to the cold temperature of the mesophere, water vapour is frozen, forming ice clouds (or Noctilucent clouds). A type of lightning referred to as either sprites or ELVES, form many miles above thunderclouds in the trophosphere.

Stratosphere: The stratosphere extends from the tropopause to about 51 km (32 mi; 170,000 ft). Temperature increases with height, which restricts turbulence and mixing. The stratopause, which is the boundary between the stratosphere and mesosphere, typically is at 50 to 55 km (31 to 34 mi; 160,000 to 180,000 ft). The pressure here is 1/1000th sea level.

Troposphere: The troposphere begins at the surface and extends to between 7 km (23,000 ft) at the poles and 17 km (56,000 ft) at the equator, with some variation due to weather. The troposphere is mostly heated by transfer of energy from the surface, so on average the lowest part of the troposphere is warmest and temperature decreases with altitude. This promotes vertical mixing (hence the origin of its name in the Greek word "τροπή", *trope*, meaning turn or overturn). The troposphere contains roughly 80% of the mass of the atmosphere. The tropopause is the boundary between the troposphere and stratosphere.

Other Layers

Within the five principal layers determined by temperature are several layers determined by other properties:

- The ozone layer is contained within the stratosphere. In this layer ozone concentrations are about 2 to 8 parts per million, which is much higher than in the lower atmosphere but still very small compared to the main components of the atmosphere. It is mainly located in the lower portion of the stratosphere from about 15–35 km (9.3–22 mi; 49,000–110,000 ft), though the thickness varies seasonally and geographically. About 90% of the ozone in our atmosphere is contained in the stratosphere.
- The ionosphere, the part of the atmosphere that is ionized by solar radiation, stretches from 50 to 1,000 km (31 to 620 mi; 160,000 to 3,300,000 ft) and typically overlaps both the exosphere and the thermosphere. It forms the inner edge of the magnetosphere. It has practical importance because it influences, for example, radio propagation on the Earth. It is responsible for auroras.
- The homosphere and heterosphere are defined by whether the atmospheric gases are well mixed. In the homosphere the chemical composition of the atmosphere does not depend on molecular weight because the gases are mixed by turbulence. The homosphere includes the troposphere, stratosphere, and mesosphere. Above the *turbopause* at about 100 km (62 mi; 330,000 ft) (essentially corresponding to the mesopause), the composition varies with altitude. This is because the distance that particles can move without colliding with one another is large compared with the size of motions that cause mixing. This allows the gases to stratify by

molecular weight, with the heavier ones such as oxygen and nitrogen present only near the bottom of the heterosphere. The upper part of the heterosphere is composed almost completely of hydrogen, the lightest element.

- The planetary boundary layer is the part of the troposphere that is nearest the Earth's surface and is directly affected by it, mainly through turbulent diffusion. During the day the planetary boundary layer usually is well-mixed, while at night it becomes stably stratified with weak or intermittent mixing. The depth of the planetary boundary layer ranges from as little as about 100 m on clear, calm nights to 3000 m or more during the afternoon in dry regions.

The average temperature of the atmosphere at the surface of Earth is 14 °C (57 °F; 287 K) or 15 °C (59 °F; 288 K), depending on the reference.

Atmospheric Pressure, Winds, Air Mosses and Storms

The atmosphere of Earth is a layer of gases surrounding the planet Earth that is retained by Earth's gravity. The atmosphere protects life on Earth by absorbing ultraviolet solar radiation, warming the surface through heat retention (greenhouse effect), and reducing temperature extremes between day and night.

Dry air contains roughly (by volume) 78.09% nitrogen, 20.95% oxygen, 0.93% argon, 0.039% carbon dioxide, and small amounts of other gases. Air also contains a variable amount of water vapour, on average around 1%.

The atmosphere has a mass of about 5×10^{18} kg, three quarters of which is within about 11 km (6.8 mi; 36,000 ft) of the surface. The atmosphere becomes thinner and thinner with increasing altitude, with no definite boundary between the atmosphere and outer space. An altitude of 120 km (75 mi) is where atmospheric effects become noticeable during atmospheric re-entry of spacecraft. The Karman line, at 100 km (62 mi), also is often regarded as the boundary between atmosphere and outer space.

Composition

Air is mainly composed of nitrogen, oxygen, and argon, which together constitute the major gases of the atmosphere. The remaining gases are often referred to as trace gases, among which are the greenhouse gases such as water vapour, carbon dioxide, methane, nitrous oxide, and ozone.

Filtered air includes trace amounts of many other chemical compounds.

Many natural substances may be present in tiny amounts in an unfiltered air sample, including dust, pollen and spores, sea spray, volcanic ash, and meteoroids. Various industrial pollutants also may be present, such as chlorine (elementary or in compounds), fluorine compounds, elemental mercury, and sulfur compounds such as sulfur dioxide [SO_2].

Composition of Dry Atmosphere, by Volume

ppmv: parts per million by volume (note: volume fraction is equal to mole fraction for ideal gas only, see Gas Volume)

Gas	Volume
Nitrogen (N_2)	780,840 ppmv (78.084%)
Oxygen (O_2)	209,460 ppmv (20.946%)
Argon (Ar)	9,340 ppmv (0.9340%)
Carbon dioxide (CO_2)	390 ppmv (0.0390%)
Neon (Ne)	18.18 ppmv (0.001818%)
Helium (He)	5.24 ppmv (0.000524%)
Methane (CH_4)	1.79 ppmv (0.000179%)
Krypton (Kr)	1.14 ppmv (0.000114%)
Hydrogen (H_2)	0.55 ppmv (0.000055%)
Nitrous oxide (N_2O)	0.3 ppmv (0.00003%)
Carbon monoxide (CO)	0.1 ppmv (0.00001%)
Xenon (Xe)	0.09 ppmv (9×10^{-6}%)
Ozone (O_3)	0.0 to 0.07 ppmv (0% to 7×10^{-6}%)
Nitrogen dioxide (NO_2)	0.02 ppmv (2×10^{-6}%)
Iodine (I)	0.01 ppmv (1×10^{-6}%)
Ammonia (NH_3)	trace
Not included in above dry atmosphere:	
Water vapour (H_2O)	~0.40% over full atmosphere, typically 1%-4% at surface

Physical Properties

Pressure and Thickness

The average atmospheric pressure at sea level is about 1 atmosphere (atm) = 101.3 kPa (kilopascals) = 14.7 psi (pounds per square inch) = 760 torr = 29.9 inches of mercury (symbol Hg). Total atmospheric mass is 5.1480×10^{18} kg (1.135×10^{19} lb), about 2.5% less than would be inferred naively from the average sea level pressure and the Earth's area of 51007.2 megahectares, this defect having been displaced by the Earth's mountainous terrain. Atmospheric pressure is the total weight of the air above unit area at the point where the pressure is measured. Thus air pressure varies with location and time, because the amount of air above the Earth's surface varies.

If atmospheric density were to remain constant with height the atmosphere would terminate abruptly at 8.50 km (27,900 ft). Instead, density decreases with height, dropping by 50% at an altitude of about 5.6 km (18,000 ft). As a result the pressure decrease is approximately exponential with height, so that pressure decreases by a factor of two approximately every 5.6 km (18,000 ft) and by a factor of e = 2.718… approximately every 7.64 km (25,100 ft), the latter being the average scale height of Earth's atmosphere below 70 km (43 mi; 230,000 ft). However, because of changes in temperature, average molecular weight, and gravity throughout the atmospheric column, the dependence of atmospheric pressure on altitude is modeled by separate equations for each of the layers listed above. Even in the exosphere, the atmosphere is still present. This can be seen by the effects of atmospheric drag on satellites.

In summary, the equations of pressure by altitude in the above references can be used directly to estimate atmospheric thickness. However, the following published data are given for reference:

- 50% of the atmosphere by mass is below an altitude of 5.6 km (18,000 ft).
- 90% of the atmosphere by mass is below an altitude of 16 km (52,000 ft). The common altitude of commercial airliners is about 10 km (33,000 ft) and Mt. Everest's summit is 8,848 m (29,029 ft) above sea level.

- 99.99997% of the atmosphere by mass is below 100 km (62 mi; 330,000 ft), although in the rarefied region above this there are auroras and other atmospheric effects. The highest X-15 plane flight in 1963 reached an altitude of 354,300 ft (108.0 km).

Density and Mass

The density of air at sea level is about 1.2 kg/m^3 (1.2 g/L). Density is not measured directly but is calculated from measurements of temperature, pressure and humidity using the equation of state for air (a form of the ideal gas law). Atmospheric density decreases as the altitude increases. This variation can be approximately modeled using the barometric formula. More sophisticated models are used to predict orbital decay of satellites.

The average mass of the atmosphere is about 5 quadrillion (5×10^{15}) tonnes or 1/1,200,000 the mass of Earth. According to the National Centre for Atmospheric Research, "The total mean mass of the atmosphere is 5.1480×10^{18} kg with an annual range due to water vapour of 1.2 or 1.5×10^{15} kg depending on whether surface pressure or water vapour data are used; somewhat smaller than the previous estimate. The mean mass of water vapour is estimated as 1.27×10^{16} kg and the dry air mass as $5.1352 \pm 0.0003 \times 10^{18}$ kg."

Optical Properties

Solar radiation (or sunlight) is the energy the Earth receives from the Sun. The Earth also emits radiation back into space, but at longer wavelengths that we cannot see. Part of the incoming and emitted radiation is absorbed or reflected by the atmosphere.

Scattering

When light passes through our atmosphere, photons interact with it through *scattering*. If the light does not interact with the atmosphere, it is called *direct radiation* and is what you see if you were to look directly at the Sun. *Indirect radiation* is light that has been scattered in the atmosphere. For example, on an overcast day when you cannot see your shadow there is no direct radiation reaching you, it has all been scattered. As another example, due to a phenomenon called Rayleigh scattering, shorter (blue) wavelengths scatter more easily than longer (red) wavelengths. This is why the sky looks blue, you are seeing scattered blue light. This is also why sunsets are red. Because the Sun is close to the horizon, the Sun's rays pass through more atmosphere than normal to reach your eye. Much of the blue light has been scattered out, leaving the red light in a sunset.

Absorption

Different molecules absorb different wavelengths of radiation. For example, O_2 and O_3 absorb almost all wavelengths shorter than 300 manometers. Water (H_2O) absorbs many wavelengths above 700 nm. When a molecule absorbs a photon, it increases the energy of the molecule. We can think of this as heating the atmosphere, but the atmosphere also cools by emitting radiation, as discussed below.

The combined absorption spectra of the gases in the atmosphere leave "windows" of low opacity, allowing the transmission of only certain bands of light. The optical window runs from around 300 nm (ultraviolet-C) up into the range humans can see, the visible spectrum (commonly called light), at roughly 400–700 nm and continues to the infrared to around 1100 nm. There are also infrared and radio windows that transmit some infrared and radio waves at longer wavelengths. For example, the radio window runs from about one centimetre to about eleven-meter waves.

Emission

Emission is the opposite of absorption, it is when an object emits radiation. Objects tend to emit amounts and wavelengths of radiation depending on their "black body" emission curves, therefore hotter objects tend to emit more radiation, with shorter wavelengths. Colder objects emit less radiation, with longer wavelengths. For example, the Sun is approximately 6,000 K (5,730 °C; 10,340 °F), its radiation peaks near 500 nm, and is visible to the human eye. The Earth is approximately 290 K (17 °C; 62 °F), so its radiation peaks near 10,000 nm, and is much too long to be visible to humans. Because of its temperature, the atmosphere emits infrared radiation. For example, on clear nights the Earth's surface cools down faster than on cloudy nights. This is because clouds (H_2O) are strong absorbers and emitters of infrared radiation. This is also why it becomes colder at night at higher elevations. The atmosphere acts as a "blanket" to limit the amount of radiation the Earth loses into space.

The *greenhouse effect* is directly related to this absorption and emission (or "blanket") effect. Some chemicals in the atmosphere absorb and emit infrared radiation, but do not interact with sunlight in the visible spectrum. Common examples of these chemicals are CO_2 and H_2O. If there are too much of these *greenhouse gases*, sunlight heats the Earth's surface, but the gases block the infrared radiation from exiting back to space. This imbalance causes the Earth to warm, and thus climate change.

Refractive Index

The refractive index of air is close to, but just greater than 1. Systematic variations in refractive index can lead to the bending of light rays over long optical paths. One example is that, under some circumstances, observers on board ships can see other vessels just over the horizon because light is refracted in the same direction as the curvature of the Earth's surface.

The refractive index of air depends on temperature, giving rise to refraction effects when the temperature gradient is large. An example of such effects is the mirage.

Circulation

Atmospheric circulation is the large-scale movement of air, and the means (with ocean circulation) by which heat is distributed around the Earth. The large-scale structure of the atmospheric circulation varies from year to year, but the basic structure remains fairly constant as it is determined by the Earth's rotation rate and the difference in solar radiation between the equator and poles.

Evolution of Earth's Atmosphere

Second Atmosphere

Water related sediments have been found dating from as early as 3.8 billion years ago. About 3.4 billion years ago, nitrogen was the major part of the then stable “second atmosphere.” An influence of life has to be taken into account rather soon in the history of the atmosphere, since hints of early life forms are to be found as early as 3.5 billion years ago. The fact that this is not perfectly in line with the - compared to today 30% lower - solar radiance of the early Sun has been described as the “Faint young Sun paradox”.

The geological record however shows a continually relatively warm surface during the complete early temperature record of the Earth with the exception of one cold glacial phase about 2.4 billion years ago. In the late Archaean era an oxygen-containing atmosphere began to develop, apparently from photosynthesizing algae which have been found as stromatolite fossils from 2.7 billion years ago. The early basic carbon isotopy (isotope ratio proportions) is very much in line with what is found today, suggesting that the fundamental features of the carbon cycle were established as early as 4 billion years ago.

The accretion of continents about 3.5 billion years ago added plate tectonics, constantly rearranging the continents and also shaping long-term climate evolution by allowing the transfer of carbon dioxide to large land-based carbonate storages. Free oxygen did not exist until about 1.7 billion years ago and this can be seen with the development of the red beds and the end of the banded iron formations. This signifies a shift from a reducing atmosphere to an oxidising atmosphere. O_2 showed major ups and downs until reaching a steady state of more than 15%. The following time span was the Phanerozoic era, during which oxygen-breathing metazoan life forms began to appear.

Currently, anthropogenic greenhouse gases are increasing in the atmosphere. According to the Intergovernmental Panel on Climate Change, this increase is the main cause of global warming.

Wind

Wind is the flow of gases on a large scale. On Earth, wind consists of the bulk movement of air. In outer space, solar wind is the movement of gases or charged particles from the sun through space, while planetary wind is the out gassing of light chemical elements from a planet’s atmosphere into space. Winds are commonly classified by their spatial scale, their speed, the types of forces that cause them, the regions in which they occur, and their effect. The strongest observed winds on a planet in our solar system occur on Neptune and Saturn.

In meteorology, winds are often referred to according to their strength, and the direction the wind is blowing *from*. Short bursts of high speed wind are termed gusts. Strong winds of intermediate duration (around one minute) are termed squalls. Long-duration winds have various names associated with their average strength, such as breeze, gale, storm, hurricane, and typhoon. Wind occurs on a range of scales, from thunderstorm flows lasting tens of minutes, to local breezes generated by heating of land surfaces and lasting a few hours, to global winds resulting from the difference in absorption of solar energy between the climate zones on Earth.

The two main causes of large scale atmospheric circulation are the differential heating between the equator and the poles, and the rotation of the planet (Coriolis effect). Within the tropics, thermal low circulations over terrain and high plateaus can drive monsoon circulations. In coastal areas the sea breeze/land breeze cycle can define local winds; in areas that have variable terrain, mountain and valley breezes can dominate local winds.

In human civilization, wind has inspired mythology, influenced the events of history, expanded the range of transport and warfare, and provided a power source for mechanical work, electricity, and recreation. Wind has powered the voyages of sailing ships across Earth's oceans. Hot air balloons use the wind to take short trips, and powered flight uses it to increase lift and reduce fuel consumption. Areas of wind shear caused by various weather phenomena can lead to dangerous situations for aircraft. When winds become strong, trees and man-made structures are damaged or destroyed.

Winds can shape landforms, via a variety of Aeolian processes such as the formation of fertile soils, such as loess, and by erosion. Dust from large deserts can be moved great distances from its source region by the prevailing winds; winds that are accelerated by rough topography and associated with dust outbreaks have been assigned regional names in various parts of the world because of their significant effects on those regions. Wind effects the spread of wildfires. Winds disperse seeds from various plants, enabling the survival and dispersal of those plant species, as well as flying insect populations. When combined with cold temperatures, wind has a negative impact on livestock. Wind affects animals' food stores, as well as their hunting and defensive strategies.

Cause

Wind is caused by differences in pressure. When a difference in pressure exists, the air is accelerated from higher to lower pressure. On a rotating planet the air will be deflected by the Coriolis effect, except exactly on the equator. Globally, the two major driving factors of large scale winds (the atmospheric circulation) are the differential heating between the equator and the poles (difference in absorption of solar energy leading to buoyancy forces) and the rotation of the planet.

Outside the tropics and aloft from frictional effects of the surface, the large-scale winds tend to approach geostrophic balance. Near the Earth's surface, friction causes the wind to be slower than it would be otherwise. Surface friction also causes winds to blow more inward into low pressure areas.

Winds defined by an equilibrium of physical forces are used in the decomposition and analysis of wind profiles. They are useful for simplifying the atmospheric equations of motion and for making qualitative arguments about the horizontal and vertical distribution of winds.

The geostrophic wind component is the result of the balance between Coriolis force and pressure gradient force. It flows parallel to isobars and approximates the flow above the atmospheric boundary layer in the midlatitudes. The thermal wind is the *difference* in the geostrophic wind between two levels in the atmosphere.

It exists only in an atmosphere with horizontal temperature gradients. The ageostrophic wind component is the difference between actual and geostrophic wind, which is responsible for air "filling up" cyclones over time. The gradient wind is similar to the geostrophic wind but also includes centrifugal force (or centripetal acceleration).

Measurement

Wind direction is reported by the direction from which it originates. For example, a *northerly* wind blows from the north to the south. Weather vanes pivot to indicate the direction of the wind. At airports, windsocks are primarily used to indicate wind direction, but can also be used to estimate wind speed by its angle of hang. Wind speed is measured by anemometers, most commonly using rotating cups or propellers. When a high measurement frequency is needed (such as in research applications), wind can be measured by the propagation speed of ultrasound signals or by the effect of ventilation on the resistance of a heated wire. Another type of anemometer uses pitot tubes that take advantage of the pressure differential between an inner tube and an outer tube that is exposed to the wind to determine the dynamic pressure, which is then used to compute the wind speed.

Sustained wind speeds are reported globally at a 10 meters (33 ft) height and are averaged over a 10 minute time frame. The United States reports winds over a 2 minute average, while India typically reports winds over a 3 minute average. Knowing the wind sampling average is important, as the value of a one-minute sustained wind is typically 14 percent greater than a ten-minute sustained wind. A short burst of high speed wind is termed a wind gust, one technical definition of a wind gust is: the maxima that exceed the lowest wind speed measured during a ten minute time interval by 10 knots (19 km/h). A squall is a doubling of the wind speed above a certain threshold, which lasts for a minute or more.

To determine winds aloft, rawinsondes determine wind speed by GPS, radio navigation, or radar tracking of the probe. Alternatively, movement of the parent weather balloon position can be tracked from the ground visually using theodolites. Remote sensing techniques for wind include SODAR, Doppler LIDARs and RADARs, which can measure the Doppler shift of electromagnetic radiation scattered or reflected off suspended aerosols or molecules, and radiometers and radars can be used to measure the surface roughness of the ocean from space or airplanes. Ocean roughness can be used to estimate wind velocity close to the sea surface over oceans. Geostationary satellite imagery can be used to estimate the winds throughout the atmosphere based upon how far clouds move from one image to the next. Wind Engineering describes the study of the effects of the wind on the built environment, including buildings, bridges and other man-made objects.

Wind Force Scale

Historically, the Beaufort wind force scale provides an empirical description of wind speed based on observed sea conditions. Originally it was a 13-level scale, but during the 1940s, the scale was expanded to 17 levels. There are general terms that differentiate winds of different average speeds such as a breeze, a gale, a storm, tornado, or a hurricane. Within the Beaufort scale, gale-force winds lie between 28 knots (52 km/h) and 55 knots (102 km/h) with preceding adjectives such as moderate, fresh, strong, and whole used to differentiate the wind's strength within the gale category. A storm has winds of 56 knots (104 km/h) to 63 knots (117 km/h). The terminology for tropical cyclones differs from one region to another globally. Most ocean basins use the average wind speed to determine the tropical cyclone's category. The station model plotted on surface weather maps uses a wind barb to show both wind direction and speed. The wind barb shows the speed using "flags" on the end:

- Each half of a flag depicts 5 knots (9.3 km/h) of wind.
- Each full flag depicts 10 knots (19 km/h) of wind.
- Each pennant (filled triangle) depicts 50 knots (93 km/h) of wind.

Winds are depicted as blowing from the direction the barb is facing. Therefore, a northeast wind will be depicted with a line extending from the cloud circle to the northeast, with flags indicating wind speed on the northeast end of this line. Once plotted on a map, an analysis of isotachs (lines of equal wind speeds) can be accomplished. Isotachs are particularly useful in diagnosing the location of the jet stream on upper level constant pressure charts, and are usually located at or above the 300 hPa level.

Global Climatology

Easterly winds, on average, dominate the flow pattern across the poles, westerly winds blow across the mid-latitudes of the earth, to the north of the subtropical ridge, while easterlies again dominate the tropics.

Directly under the subtropical ridge are the doldrums, or horse latitudes, where winds are lighter. Many of the Earth's deserts lie near the average latitude of the subtropical ridge, where descent reduces the relative humidity of the air mass. The strongest winds are in the mid-latitudes where cold Arctic air meets warm air from the tropics.

Tropics

The trade winds (also called trades) are the prevailing pattern of easterly surface winds found in the tropics towards the Earth's equator. The trade winds blow predominantly from the northeast in the Northern Hemisphere and from the southeast in the Southern Hemisphere. The trade winds act as the steering flow for tropical cyclones that form over world's oceans. Trade winds also steer African dust westward across the Atlantic Ocean into the Caribbean Sea, as well as portions of southeast North America.

A monsoon is a seasonal prevailing wind that lasts for several months within tropical regions. The term was first used in English in India, Bangladesh, Pakistan, and neighbouring countries to refer to the big seasonal winds blowing from the Indian Ocean and Arabian Sea in the southwest bringing heavy rainfall to the area. Its poleward progression is accelerated by the development off a heat low over the Asian, African, and North American continents during May through July, and over Australia in December.

Westerlies and their Impact

The Westerlies or the Prevailing Westerlies are the prevailing winds in the middle latitudes between 35 and 65 degrees latitude. These prevailing winds blow from the west to the east to the north of the subtropical ridge, and steer extratropical cyclones in this general manner. The winds are predominantly from the southwest in the Northern Hemisphere and from the northwest in the Southern Hemisphere. They are strongest in the winter when the pressure is lower over the poles, and weakest during the summer and when pressures are higher over the poles.

Together with the trade winds, the westerlies enabled a round-trip trade route for sailing ships crossing the Atlantic and Pacific Oceans, as the westerlies lead to the development of strong ocean currents on the western sides of oceans in both hemispheres through the process of western intensification. These western ocean currents transport warm, tropical water polewards toward the polar regions. The westerlies can be particularly strong, especially in the southern hemisphere, where there is less land in the middle latitudes to cause the flow pattern to amplify, which slows the winds down. The strongest westerly winds in the middle latitudes are within a band known as the Roaring Forties, between 40 and 50 degrees latitude south of the equator. The Westerlies play an important role in carrying the warm, equatorial waters and winds to the western coasts of continents, especially in the southern hemisphere because of its vast oceanic expanse.

Polar Easterlies

The polar easterlies, also known as Polar Hadley cells, are dry, cold prevailing winds that blow from the high-pressure areas of the polar highs at the north and south poles towards the low-pressure areas within the Westerlies at high latitudes. Unlike the Westerlies, these prevailing winds blow from the east to the west, and are often weak and irregular. Because of the low sun angle, cold air builds up and subsides at the pole creating surface high-pressure areas, forcing an equatorward outflow of air; that outflow is deflected eastward by the Coriolis effect.

Local Considerations

Sea and Land Breezes

In coastal regions, sea breezes and land breezes can be important factors in a location's prevailing winds. The sea is warmed by the sun more slowly because of water's greater specific heat compared to land. As the temperature of the surface of the land rises, the land heats the air above it by conduction. The warm air is less dense than the surrounding environment and so it rises. This causes a pressure gradient of about 2 millibars from the ocean to the land. The cooler air above the sea, now with higher sea level pressure, flows inland into the lower pressure, creating a cooler breeze near the coast. When large-scale winds are calm, the strength of the sea breeze is directly proportional to the temperature difference between the land mass and the sea. If an offshore wind of 8 knots (15 km/h) exists, the sea breeze is not likely to develop.

At night, the land cools off more quickly than the ocean because of differences in their specific heat values. This temperature change causes the daytime sea breeze to dissipate. When the temperature onshore cools below the temperature offshore, the pressure over the water will be lower than that of the land, establishing a land breeze, as long as an onshore wind is not strong enough to oppose it.

Near Mountains

Over elevated surfaces, heating of the ground exceeds the heating of the surrounding air at the same altitude above sea level, creating an associated thermal low over the terrain and enhancing any thermal lows that would have otherwise existed, and changing the wind circulation of the region. In areas where there is rugged topography that significantly interrupts the environmental wind flow, the wind circulation between mountains and valleys is the most important contributor to the prevailing winds. Hills and valleys substantially distort the airflow by increasing friction between the atmosphere and landmass by acting as a physical block to the flow, deflecting the wind parallel to the range just upstream of the topography, which is known as a barrier jet. This barrier jet can increase the low level wind by 45 percent. Wind direction also changes because of the contour of the land.

If there is a pass in the mountain range, winds will rush through the pass with considerable speed because of the Bernoulli principle that describes an inverse relationship between speed and pressure. The airflow can remain turbulent and erratic for some distance downwind into the flatter countryside. These conditions are dangerous to ascending and descending airplanes. Cool winds accelerating through mountain gaps have been given regional names. In Central America, examples include the Papagayo wind, the Panama wind, and the Tehuano wind. In Europe, similar winds are known as the Bora, Tramontane, and Mistral. When these winds blow over open waters, they increase mixing of the upper layers of the ocean that elevates cool, nutrient rich waters to the surface, which leads to increased marine life.

In mountainous areas, local distortion of the airflow becomes severe. Jagged terrain combines to produce unpredictable flow patterns and turbulence, such as rotors, which can be topped by lenticular clouds. Strong updrafts, downdrafts and eddies develop as the air flows over hills and down valleys. Orographic precipitation occurs on the windward side of mountains and is caused by the rising air motion of a large-scale flow of moist air across the mountain ridge, also known as upslope flow, resulting in adiabatic cooling and condensation.

In mountainous parts of the world subjected to relatively consistent winds (for example, the trade winds), a more moist climate usually prevails on the windward side of a mountain than on the leeward or downwind side. Moisture is removed by orographic lift, leaving drier air on the descending and generally warming, leeward side where a rain shadow is observed.

Winds that flow over mountains down into lower elevations are known as downslope winds. These winds are warm and dry. In Europe downwind of the Alps, they are known as foehn. In Poland, an example is the halny waiter. In Argentina, the local name for downsloped winds is zonda. In Java, the local name for such winds is koembang. In New Zealand, they are known as the Narrowest arch, and are accompanied by the cloud formation they are named after that has inspired artwork over the years. In the Great Plains of the United States, the winds are known as a chinook. In California, downsloped winds are funnelled through mountain passes, which intensify their effect, and examples into Santa Ana and sundowner winds. Wind speeds during downslope wind effect can exceed 160 kilometres per hour (99 mph).

Average Wind Speeds

As described earlier, prevailing and local winds are not spread evenly across the earth, which means that wind speeds also differ by region. In addition, the wind speed also increases with the altitude.

Wind Power Density

Nowadays, a yardstick used to determine the best locations for wind energy development is referred to as wind power density (WPD). It is a calculation relating to the effective force of the wind at a particular location, frequently expressed in terms of the elevation above ground level over a period of time. It takes into account wind velocity and mass. Colour coded maps are prepared for a particular area are described as, for example, “mean annual power density at 50 meters.” The results of the above calculation are included in an index developed by the National Renewable Energy Lab and referred to as “NREL CLASS.” The larger the WPD calculation, the higher it is rated by class. At the end of 2008, worldwide nameplate capacity of wind-powered generators was 120.8 gigawatts. Although wind produces only about 1.5 percent of worldwide electricity use, it is growing rapidly, having doubled in the three years between 2005 and 2008. In several countries it has achieved relatively high levels of penetration, accounting for approximately 19 percent of electricity production in Denmark, 10 percent in Spain and Portugal, and 7 percent in Germany and the Republic of Ireland in 2008. One study indicates that an entirely renewable energy supply based on 70 percent wind is attainable at today’s power prices by linking wind farms with an HVDC supergrid.

Shear

Wind shear, sometimes referred to as windshear or wind gradient, is a difference in wind speed and direction over a relatively short distance in the Earth’s atmosphere. Wind shear can be broken down into vertical and horizontal components, with horizontal wind shear seen across weather fronts and near the coast, and vertical shear typically near the surface, though also at higher levels in the atmosphere near upper level jets and frontal zones aloft.

Wind shear itself is a microscale meteorological phenomenon occurring over a very small distance, but it can be associated with mesoscale or synoptic scale weather features such as squall lines and cold fronts. It is commonly observed near microbursts and downbursts caused by thunderstorms, weather fronts, areas of locally higher low level winds referred to as low level jets, near mountains, radiation inversions that occur because of clear skies and calm winds, buildings, wind turbines, and sailboats. Wind shear has a significant effect during take-off and landing of aircraft because of their effects on control of the aircraft, and was a significant cause of aircraft accidents involving large loss of life within the United States.

Sound movement through the atmosphere is affected by wind shear, which can bend the wave front, causing sounds to be heard where they normally would not, or vice versa. Strong vertical wind shear within the troposphere also inhibits tropical cyclone development, but helps to organize individual thunderstorms into living longer life cycles that can then produce severe weather. The thermal wind concept explains how differences in wind speed with height are dependent on horizontal temperature differences, and explains the existence of the jet stream.

Usage of Wind

History

As a natural force, the wind was often personified as one or more wind gods or as an expression of the supernatural in many cultures. Vayu is the Hindu God of Wind. The Greek wind gods include Boreas, Notus, Eurus, and Zephyrus. Aeolus, in varying interpretations the ruler or keeper of the four winds, has also been described as Astraeus, the god of dusk who fathered the four winds with Eos, goddess of dawn. The Ancient Greeks also observed the seasonal change of the winds, as evidenced by the Tower of the Winds in Athens. Venti are the Roman gods of the winds.

Fujin, the Japanese wind god and is one of the eldest Shinto gods. According to legend, he was present at the creation of the world and first let the winds out of his bag to clear the world of mist. In Norse mythology, Njord is the god of the wind. There are also four dvargar (Norse dwarves), named Norori, Suri, Austri and Vestri, and probably the four stags of Yggdrasil, personify the four winds, and parallel the four Greek wind gods. Stribog is the name of the Slavic god of winds, sky and air. He is said to be the ancestor (grandfather) of the winds of the eight directions.

Kamikaze is a Japanese word, usually translated as divine wind, believed to be a gift from the gods. The term is first known to have been used as the name of a pair or series of typhoons that are said to have saved Japan from two Mongol fleets under Kublai Khan that attacked Japan in 1274 and again in 1281. Protestant Wind is a name for the storm that deterred the Spanish Armada from an invasion of England in 1588 where the wind played a pivotal role, or the favourable winds that enabled William of Orange to invade England in 1688. During Napoleon's Egyptian Campaign, the French soldiers had a hard time with the khamsin wind: when the storm appeared "as a blood-stint in the distant sky", the natives went to take cover, while the French "did not react until it was too late, then choked and fainted in the blinding, suffocating walls of dust." During the North African Campaign of the World War II, "allied and German troops were several times forced to halt in mid-battle because of sandstorms caused by khamsin.. Grains of sand whirled by the wind blinded the soldiers and created electrical disturbances that rendered compasses useless."

Transportation

There are many different forms of sailing ships, but they all have certain basic things in common. Except for rotor ships using the Magnus effect, every sailing ship has a hull, rigging and at least one mast to hold up the sails that use the wind to power the ship. Ocean journeys by sailing ship can take many months, and a common hazard is becoming becalmed because of lack of wind, or being blown off course by severe storms or winds that do not allow progress in the desired direction. A severe storm could lead to shipwreck, and the loss of all hands. Sailing ships can only carry a certain quantity of supplies in their hold, so they have to plan long voyages carefully to include appropriate provisions, including fresh water.

While aircraft usually travel under an internal power source, tail winds affect groundspeed, and in the case of hot air balloons and other lighter-than-air vehicles, wind may play a significant role in their movement and ground track. In addition, the direction of wind plays a role in the takeoff and landing of fixed-wing aircraft and airfield runways are usually aligned to take the direction of wind into account. Of all factors affecting the direction of flight operations at an airport, wind direction is considered the primary governing factor. While taking off with a tailwind may be permissible under certain circumstances, it is generally considered the least desirable choice because of performance and safety considerations, with a headwind the desirable choice.

A tailwind will increase takeoff distance and decrease climb gradient such that runway length and obstacle clearance may become limiting factors. An airship, or dirigible, is a lighter-than-air aircraft that can be steered and propelled through the air using rudders and propellers or other thrust. Unlike other aerodynamic aircraft such as fixed-wing aircraft and helicopters, which produce lift by moving a wing, or airfoil, through the air, aerostatic aircraft, such as airships and hot air balloons, stay aloft by filling a large cavity, such as a balloon, with a lifting gas. The main types of airship are non-rigid (or blimps), semi-rigid and rigid. Blimps are small airships without internal skeletons. Semi-rigid airships are slightly larger and have some form of internal support such as a fixed keel. Rigid airships with full skeletons, such as the massive Zeppelin transoceanic models, all but disappeared after several high-profile catastrophic accidents during the mid-20th century.

Power Source

Historically, the ancient Sinhalese of Anuradhapura and in other cities around Sri Lanka used the monsoon winds to power furnaces as early as 300 BCE. The furnaces were constructed on the path of the monsoon winds to exploit the wind power, to bring the temperatures inside up to 1,200 °C (2,190 °F). An early historical reference to a rudimentary windmill was used to power an organ in the first century CE. The first practical windmills were later built in Sistan, Afghanistan, from the 7th century CE. These were vertical-axle windmills, which had long vertical driveshafts with rectangle shaped blades. Made of six to twelve sails covered in reed matting or cloth material, these windmills were used to grind corn and draw up water, and were used in the gristmilling and sugarcane industries. Horizontal-axle windmills were later used extensively in Northwestern Europe to grind flour beginning in the 1180s, and many Dutch windmills still exist. High altitude wind power is the focus of over 30 companies worldwide using tethered technology rather than ground-hugging compressive-towers. Oil is being saved by using wind for powering cargo ships by use of the mechanical energy converted from the wind's kinetic energy using very large kites.

Recreation

Wind figures prominently in several popular sports, including recreational hang gliding, hot air ballooning, kite flying, snowkiting, kite landboarding, kite surfing, paragliding, sailing, and windsurfing. In gliding, wind gradients just above the surface affect the takeoff and landing phases of flight of a glider. Wind gradient can have a noticeable effect on ground launches, also known as winch launches or wire launches. If the wind gradient is significant or sudden, or both, and the pilot maintains the same pitch attitude, the indicated airspeed will increase, possibly exceeding the maximum ground launch tow speed.

The pilot must adjust the airspeed to deal with the effect of the gradient. When landing, wind shear is also a hazard, particularly when the winds are strong. As the glider descends through the wind gradient on final approach to landing, airspeed decreases while sink rate increases, and there is insufficient time to accelerate prior to ground contact. The pilot must anticipate the wind gradient and use a higher approach speed to compensate for it.

Role in the Natural World

In arid climates, the main source of erosion is wind. The general wind circulation moves small particulates such as dust across wide oceans thousands of kilometres downwind of their point of origin, which is known as deflation. Westerly winds in the mid-latitudes of the planet drive the movement of ocean currents from west to east across the world's oceans. Wind has a very important role in aiding plants and other immobile organisms in dispersal of seeds, spores, pollen, etc. Although wind is not the primary form of seed dispersal in plants, it provides dispersal for a large percentage of the biomass of land plants.

Erosion

Erosion can be the result of material movement by the wind. There are two main effects. First, wind causes small particles to be lifted and therefore moved to another region. This is called deflation. Second, these suspended particles may impact on solid objects causing erosion by abrasion (ecological succession). Wind erosion generally occurs in areas with little or no vegetation, often in areas where there is insufficient rainfall to support vegetation. An example is the formation of sand dunes, on a beach or in a desert. Loess is a homogeneous, typically nonstratified, porous, friable, slightly coherent, often calcareous, fine-grained, silty, pale yellow or buff, windblown (Aeolian) sediment. It generally occurs as a widespread blanket deposit that covers areas of hundreds of square kilometres and tens of meters thick. Loess often stands in either steep or vertical faces. Loess tends to develop into highly rich soils. Under appropriate climatic conditions, areas with loess are among the most agriculturally productive in the world. Loess deposits are geologically unstable by nature, and will erode very readily. Therefore, windbreaks (such as big trees and bushes) are often planted by farmers to reduce the wind erosion of loess.

Desert Dust Migration

During mid-summer (July), the westward-moving trade winds south of the northward-moving subtropical ridge expand northwestward from the Caribbean Sea into southeastern North America. When dust from the Sahara moving around the southern periphery of the ridge within the belt of trade winds moves over land, rainfall is suppressed and the sky changes from a blue to a white appearance, which leads to an increase in red sunsets. Its presence negatively impacts air quality by adding to the count of airborne particulates. Over 50 percent of the African dust that reaches the United States affects Florida. Since 1970, dust outbreaks have worsened because of periods of drought in Africa. There is a large variability in the dust transport to the Caribbean and Florida from year to year. Dust events have been linked to a decline in the health of coral reefs across the Caribbean and Florida, primarily since the 1970s. Similar dust plumes originate in the Gobi desert, which combined with pollutants, spread large distances downwind, or eastward, into North America.

There are local names for winds associated with sand and dust storms. The Calima carries dust on southeast winds into the Canary islands. The Harmattan carries dust during the winter into the Gulf of Guinea. The Sirocco brings dust from north Africa into southern Europe because of the movement of extratropical cyclones through the Mediterranean Sea. Spring storm systems moving across the eastern Mediterranean Sea cause dust to carry across Egypt and the Arabian peninsula, which are locally known as Khamsin. The Shamal is caused by cold fronts lifting dust into the atmosphere for days at a time across the Persian Gulf states.

Effect on Plants

Wind dispersal of seeds, or anemochory, is one of the more primitive means of dispersal: Wind dispersal can take on one of two primary forms: seeds can float on the breeze or alternatively, they can flutter to the ground. The classic examples of these dispersal mechanisms include dandelions (*Taraxacum* spp., Asteraceae), which have a feathery pappus attached to their seeds and can be dispersed long distances, and maples (*Acer (genus)* spp., Sapindaceae), which have winged seeds and flutter to the ground. An important constraint on wind dispersal is the need for abundant seed production to maximize the likelihood of a seed landing in a site suitable for germination. There are also strong evolutionary constraints on this dispersal mechanism.

For instance, species in the Asteraceae on islands tended to have reduced dispersal capabilities (i.e., larger seed mass and smaller pappus) relative to the same species on the mainland. Reliance upon wind dispersal is common among many weedy or ruderal species. Unusual mechanisms of wind dispersal include tumbleweeds. A related process to anemochory is anemophily, which is the process where pollen is distributed by wind. Large families of plants are pollinated in this manner, which is favoured when individuals of the dominant plant species are spaced closely together.

Wind also limits tree growth: On coasts and isolated mountains, the tree line is often much lower than in corresponding altitudes inland and in larger, more complex mountain systems, because strong winds reduce tree growth. High winds scour away thin soils through erosion, as well as damage limbs and twigs. When high winds knock down or uproot trees, the process is known as windthrow. This is most likely on windward slopes of mountains, with severe cases generally occurring to tree stands that are 75 years or older. Plant varieties near the coast, such as the Sitka spruce and sea grape, are pruned back by wind and salt spray near the coastline.

Wind can also cause plants damage through sand abrasion: Strong winds will pick up loose sand and topsoil and hurl it through the air at speeds ranging from 25-40 miles per hour. Such windblown sand causes extensive damage to plant seedlings because it ruptures plant cells, making them vulnerable to evaporation and drought. Using a mechanical sandblaster in a laboratory setting, scientists affiliated with the Agricultural Research Service studied the effects of windblown sand abrasion on cotton seedlings. The study showed that the seedlings responded to the damage created by the windblown sand abrasion by shifting energy from stem and root growth to the growth and repair of the damaged stems. After a period of four weeks the growth of the seedling once again became uniform throughout the plant, as it was before the windblown sand abrasion occurred.

Effect on Animals

Cattle and sheep are prone to wind chill caused by a combination of wind and cold temperatures, when winds exceed 40 kilometres per hour (25 mph) that renders their hair and wool coverings ineffective. Although penguins use both a layer of fat and feathers to help guard against coldness in both water and air, their flippers and feet are less immune to the cold. In the coldest climates such as Antarctica, emperor penguins use huddling behaviour to survive the wind and cold, continuously alternating the members on the outside of the assembled group, which reduces heat loss by 50%. Flying insects, a subset of arthropods, are swept along by the prevailing winds, while birds follow their own course taking advantage of wind conditions, in order to either fly or glide. As such, fine line patterns within weather radar imagery, associated with converging winds, are dominated by insect returns. Bird migration, which tends to occur overnight within the lowest 7,000 feet (2,100 m) of the Earth's atmosphere, contaminates wind profiles gathered by weather radar, particularly the WSR-88D, by increasing the environmental wind returns by 15 knots (28 km/h) to 30 knots (56 km/h).

Pikas use a wall of pebbles to store dry plants and grasses for the winter in order to protect the food from being blown away. Cockroaches use slight winds that precede the attacks of potential predators, such as toads, to survive their encounters. Their cerci are very sensitive to the wind, and help them survive half of their attacks. Elk has a keen sense of smell that can detect potential upwind predators at a distance of 0.5 miles (800 m). Increases in wind above 15 kilometres per hour (9.3 mph) signals glaucous gulls to increase their foraging and aerial attacks on thick-billed murres.

Related Damage

High winds are known to cause damage, depending upon their strength. Infrequent wind gusts can cause poorly designed suspension bridges to sway. When wind gusts are at a similar frequency to the swaying of the bridge, the bridge can be destroyed more easily, such as what occurred with the Tacoma Narrows Bridge in 1940. Wind speeds as low as 23 knots (43 km/h) can lead to power outages due to tree branches disrupting the flow of energy through power lines. While no species of tree is guaranteed to stand up to hurricane-force winds, those with shallow roots are more prone to uproot, and brittle trees such as eucalyptus, sea hibiscus, and avocado are more prone to damage.

Hurricane-force winds cause substantial damage to mobile homes, and begin to structurally damage homes with foundations. Winds of this strength due to downsloped winds off terrain have been known to shatter windows and sandblast paint from cars. Once winds exceed 135 knots (250 km/h), homes completely collapse, and significant damage is done to larger buildings. Total destruction to man-made structures occurs when winds reach 175 knots (324 km/h). The Saffir-Simpson scale and Enhanced Fujita scale were designed to help estimate wind speed from the damage caused by high winds related to tropical cyclones and tornadoes, and vice versa.

Australia's Barrow Island holds the record for the strongest wind gust, reaching 408 km/h (253 mph) during tropical cyclone Olivia on 10 April 1996, surpassing the previous record held by Mount Washington (New Hampshire) of 372 km/h (231 mph) on the afternoon of 12 April 1934.

Wildfire intensity increases during daytime hours. For example, burn rates of smoldering logs are up to five times greater during the day because of lower humidity, increased temperatures, and increased wind speeds. Sunlight warms the ground during the day and causes air currents to travel uphill, and downhill during the night as the land cools. Wildfires are fanned by these winds and often follow the air currents over hills and through valleys. United States wildfire operations revolve around a 24-hour *fire day* that begins at 10:00 a.m. because of the predictable increase in intensity resulting from the daytime warmth.

In Outer Space

The solar wind is quite different from a terrestrial wind, in that its origin is the sun, and it is composed of charged particles that have escaped the sun's atmosphere. Similar to the solar wind, the planetary wind is composed of light gases that escape planetary atmospheres. Over long periods of time, the planetary wind can radically change the composition of planetary atmospheres.

Planetary Wind

The hydrodynamic wind within the upper portion of a planet's atmosphere allows light chemical elements such as hydrogen to move up to the exobase, the lower limit of the exosphere, where the gases can then reach escape velocity, entering outer space without impacting other particles of gas. This type of gas loss from a planet into space is known as planetary wind. Such a process over geologic time causes water-rich planets such as the Earth to evolve into planets such as Venus over billions of years. Planets with hot lower atmospheres could result in humid upper atmospheres that accelerate the loss of hydrogen.

Solar Wind

Rather than air, the solar wind is a stream of charged particles—a plasma—ejected from the upper atmosphere of the sun at a rate of 400 kilometres per second (890,000 mph). It consists mostly of electrons and protons with energies of about 1 keV. The stream of particles varies in temperature and speed with the passage of time.

These particles are able to escape the sun's gravity, in part because of the high temperature of the corona, but also because of high kinetic energy that particles gain through a process that is not well-understood.

The solar wind creates the Heliosphere, a vast bubble in the interstellar medium surrounding the solar system. Planets require large magnetic fields in order to reduce the ionization of their upper atmosphere by the solar wind.

Other phenomena include geomagnetic storms that can knock out power grids on Earth, the aurorae such as the Northern Lights, and the plasma tails of comets that always point away from the sun.

On Other Planets

Strong 300 kilometres per hour (190 mph) winds at Venus's cloud tops circle the planet every four to five earth days. When the poles of Mars are exposed to sunlight after their winter, the frozen CO_2 sublimes, creating significant winds that sweep off the poles as fast as 400 kilometres per hour (250 mph), which subsequently transports large amounts of dust and water vapour over its landscape.

Other Martian winds have resulted in cleaning events and dust devils. On Jupiter, wind speeds of 100 meters per second (220 mph) are common in zonal jet streams. Saturn's winds are among the solar system's fastest.

Cassini–Huygens data indicated peak easterly winds of 375 meters per second (840 mph). On Uranus, northern hemisphere wind speeds reach as high as 240 meters per second (540 mph) near 50 degrees north latitude. At the cloud tops of Neptune, prevailing winds range in speed from 400 meters per second (890 mph) along the equator to 250 meters per second

(560 mph) at the poles. At 70° S latitude on Neptune, a high-speed jet stream travels at a speed of 300 meters per second (670 mph).

Storm

A storm is any disturbed state of an astronomical body's atmosphere, especially affecting its surface, and strongly implying severe weather. It may be marked by strong wind, thunder and lightning (a thunderstorm), heavy precipitation, such as ice (ice storm), or wind transporting some substance through the atmosphere (as in a dust storm, snowstorm, hailstorm, etc).

Formation

Storms are created when a centre of low pressure develops, with a system of high pressure surrounding it. This combination of opposing forces can create winds and result in the formation of storm clouds, such as the cumulonimbus. Small, localized areas of low pressure can form from hot air rising off hot ground, resulting in smaller disturbances such as dust devils and whirlwinds.

Types

There are many varieties and names for storms:

- Ice Storm - Ice storms are one of the most dangerous forms of winter weather. When surface temperatures are below freezing, but a thick layer of above freezing air remains aloft above ground level, rain can fall into the freezing layer and freeze upon impact into a "glaze". In general, 8 millimetres (1/4 in) of accumulation is all that is required, especially in combination with breezy conditions, to start downing power lines as well as tree limbs. Ice storms also make unheated road surfaces too slick to drive upon. Ice storms can vary in time range from hours to days and can cripple both small towns and large urban centres alike.
- Blizzard - There are varying definitions for blizzards, both over time and by location. In general, a blizzard is accompanied by gale-force winds, heavy snow (accumulating at a rate of at least 5 centimetres (2 in)

per hour), and very cold conditions (below approximately -10 degrees Celsius or 14 F). As of late, the temperature criterion has fallen out of the definition across the United States.

- Snowstorm - A heavy fall of snow accumulating at a rate of more than 5 centimetres (2 in) per hour that lasts several hours. Snow storms, especially ones with a high liquid equivalent and breezy conditions, can down tree limbs, cut off power, and paralyze travel over a large region.
- Ocean Storm - Storm conditions out at sea are defined as having sustained winds of 48 knots (55 mph or 90 km/h) or greater. Usually just referred to as a storm, these systems can sink vessels of all types and sizes.
- Firestorm - Firestorms are conflagrations which attain such intensity that they create and sustain their own wind systems. It is most commonly a natural phenomenon, created during some of the largest bushfires, forest fires, and wildfires. The Peshtigo Fire is one example of a firestorm. Firestorms can also be deliberate effects of targeted explosives such as occurred as a result of the aerial bombings of Dresden and Tokyo during World War II. Nuclear detonations almost invariably generate firestorms.
- Dust devil - a small, localized updraft of rising air.
- Windstorm - A storm marked by high wind with little or no precipitation. Windstorm damage often opens the door for massive amounts of water and debris to cause further damage to a structure. European windstorms and derechos are two type of windstorms.
- Squall - sudden onset of wind increase of at least 16 knots (30 km/h) or greater sustained for at least one minute.
- Gale - An extratropical storm with sustained winds between 34-48 knots (39-55 mph or 63–90 km/h).
- Thunderstorm - A thunderstorm is a type of storm that generates lightning and the attendant thunder. It is normally accompanied by heavy precipitation. Thunderstorms occur throughout the world, with the

highest frequency in tropical rainforest regions where there are conditions of high humidity and temperature along with atmospheric instability. These storms occur when high levels of condensation form in a volume of unstable air that generates deep, rapid, upward motion in the atmosphere. The heat energy creates powerful rising air currents that swirl upwards to the tropopause. Cool descending air currents produce strong downdraughts below the storm. After the storm has spent its energy, the rising currents die away and downdraughts break up the cloud. Individual storm clouds can measure 2–10 km across.

- Tropical Cyclone - A tropical cyclone is a storm system with a closed circulation around a centre of low pressure, fuelled by the heat released when moist air rises and condenses. The name underscores its origin in the tropics and their cyclonic nature. Tropical cyclones are distinguished from other cyclonic storms such as northeaster and polar lows by the heat mechanism that fuels them, which makes them "warm core" storm systems.

  Tropical cyclones form in the oceans if the conditions in the area are favorable, and depending on their strength and location, there are various terms by which they are called, such as *tropical depression*, *tropical storm*, *hurricane* and *typhoon*.

- Hailstorm - a type of storm that precipitates chunks of ice. Hailstorms usually occur during regular thunder storms. While most of the hail that precipitates from the clouds is fairly small and virtually harmless, there have been cases of hail greater than 2 inches diameter that caused much damage and injuries.
- Tornado - A tornado is a violent, destructive wind storm occurring on land. Usually its appearance is that of a dark, funnel-shaped cyclone. Often tornadoes are preceded by a thunderstorm and a wall cloud. They are often called the most destructive of storms, and while they form all over the world, the interior of the United States is the most prone area, especially throughout Tornado Alley.

Classification

A strict meteorological definition of a terrestrial storm is a wind measuring 10 or higher on the Beaufort scale, meaning a wind speed of 24.5 m/s (89 km/h, 55 mph) or more; however, popular usage is not so restrictive. Storms can last anywhere from 12 to 200 hours, depending on season and geography. The east and northeast storms are noted for the most frequent repeatability and duration, especially during the cold period. Big terrestrial storms alter the oceanographic conditions that in turn may affect food abundance and distribution: strong currents, strong tides, increased siltation, change in water temperatures, overturn in the water column, etc.

3

Plant Geography

A flora is the collection of all plant species in an area, or in a period of time, independent of their relative abundances and relationships to one another. The species can be grouped and regrouped into various kinds of floral elements based on some common feature. For example, a genetic element is a group of species with a common evolutionary origin; a migration element has a common route of entry into the territory; a historical element is distinct in terms of some past event; and an ecological element is related to an environmental preference. An endemic species is restricted to a particular area, which is usually small and of some special interest. The collection of all interacting individuals of a given species, in an area, is called a population.

An area is the entire region of distribution or occurrence of any species, element, or even an entire flora. The description of areas is the subject of areography, while chorology studies their development. The local distribution within the area as a whole, as that of a swamp shrub, is the topography of that area. Areas are of interest in regard to their general size and shape, the nature of their margin, whether they are continuous or disjunct, and their relationships to other areas. Closely related plants that are mutually exclusive are said to be vicarious (areas containing such plants are also called vicarious). A relict area is one surviving from an earlier and more extensive occurrence. On the basis of areas and their floristic relationships, the Earth's, surface is divided into floristic regions, each with a distinctive flora.

Floras and their distribution have been interpreted mainly in terms of their history and ecology. Historical factors, in addition to the evolution of the species themselves, include consideration of theories of shifting continental masses, changing sea levels, and orographic and climatic variations in geologic time, as well as theories of island biogeography, all of which have affected migration and perpetuation of floras. The main ecological factors include the immediate and contemporary roles played by climate, soil, animals, and humans.

Vegetation refers to the mosaic of plant life found on the landscape. The vegetation of a region has developed from the numerous elements of the local flora but is shaped also by nonfloristic physiological and environmental influences. Vegetation is an organized whole, at a higher level of integration than the separate species, composed of those species and their populations. Vegetation may possess emergent properties not necessarily found in the species themselves. Sometimes vegetation is very weakly integrated, as pioneer plants of an abandoned field. Sometimes it is highly integrated, as in an undisturbed tropical rainforest. Vegetation provides the main structural and functional framework of ecosystems.

Plant communities are an important part of vegetation. No definition has gained universal acceptance, in part because of the high degree of independence of the species themselves. Thus, the community is often only a relative social continuity in nature, bounded by a relative discontinuity, as judged by competent botanists.

In looking at vegetation patterns over larger areas, it is the basic physiognomic distinctions between grassland, forest, and desert, with such variants as woodland (open forest), savanna (scattered trees in grassland), and scrubland (dominantly shrubs), which are most often emphasized. These general classes of vegetation structure can be broken down further by reference to leaf types and seasonal habits (such as evergreen or deciduous). Geographic considerations may complete the names of the main vegetation formation types, also called biomes (such as tropical rainforest, boreal coniferous forest, or temperate grasslands). Such natural vegetation regions are most closely related to climatic patterns and secondarily to soil or other environmental factors.

Vegetational plant geography has emphasized the mapping of such vegetation regions and the interpretation of these in terms of environmental (ecological) influences. Distinction has been made between potential and actual vegetation, the latter becoming more important due to human influence.

Some plant geographers point to the effects of ancient human populations, natural disturbances, and the large-herbivore extinctions and climatic shifts of the Pleistocene on the species composition and dynamics of so-called virgin vegetation. On the other hand, it has been shown that the site occurrence and geographic distributions of plant and vegetation types can be predicted surprisingly well from general climatic and other environmental patterns. Unlike floristic botany, where evolution provides a single unifying principle for taxonomic classification, vegetation structure and dynamics have no single dominant influence.

Basic plant growth forms (such as broad-leaved trees, stem-succulents, or forbs) have long represented convenient groups of species based on obvious similarities. When these forms are interpreted as ecologically significant adaptations to environmental factors, they are generally called life forms and may be interpreted as basic ecological types.

In general, basic plant types may be seen as groups of plant taxa with similar form and ecological requirements, resulting from similar morphological responses to similar environmental conditions. When similar morphological or physiognomic responses occur in unrelated taxa in similar but widely separated environments, they may be called convergent characteristics.

As human populations alter or destroy more and more of the world's natural vegetation, problems of species preservation, substitute vegetation, and succession have increased in importance. This is especially true in the tropics, where deforestation is proceeding rapidly.

Probably over half the species in tropical rainforests have not yet even been identified. Because nutrients are quickly washed out of tropical rainforest soils, cleared areas can be used for only a few years before they must be abandoned to erosion and much degraded substitute vegetation. Perhaps the greatest current challenge in plant geography is to understand tropical vegetation and succession sufficiently well to design self-sustaining preserves of the great diversity of tropical vegetation.

Biogeography

Biogeography is the study of the distribution of biodiversity spatially and temporally. Over areal ecological changes, it is also tied to the concepts of species and their past, or present living 'refugium', their survival locales, or their interim living sites. It aims to reveal where organisms live, and at what abundance. As writer David Quammen put it, "...biogeography does more than ask *Which species?* and *Where*. It also asks *Why?* and, what is sometimes more crucial, *Why not?*." The patterns of species distribution across geographical areas can usually be explained through a combination of historical factors such as speciation, extinction, continental drift, glaciation (and associated variations in sea level, river routes, and so on), and river capture, in combination with the area and isolation of landmasses (geographic constraints) and available energy supplies.

Modern biogeography often employs the use of Geographic Information Systems (GIS), to understand the factors affecting organism distribution, and to predict future trends in organism distribution. Often mathematical models, and GIS are employed to solve ecological problems that have a spatial aspect to them.

History

The scientific theory of biogeography grows out of the work of Hewett Cottrell Watson (1804–1881), Alfred Russel Wallace (1823–1913) and other early evolutionary scientists. Wallace studied the distribution of flora and fauna in the Malay Archipelago in the 19th century. With the exception of Wallace and a few others, prior to the publication of *The Theory of Island Biogeography* by Robert MacArthur and E.O. Wilson in 1967 the field of biogeography was seen as a primarily historical one and as such the field was seen as a purely descriptive one.

MacArthur and Wilson changed this perception, and showed that the species richness of an area could be predicted in terms of such factors as habitat area, immigration rate and extinction rate. This gave rise to an interest in island biogeography. The application of island biogeography theory to habitat fragments spurred the development of the fields of conservation biology and landscape ecology.

Classic biogeography has been expanded by the development of molecular systematics, creating a new discipline known as phylogeography. This development allowed scientists to test theories about the origin and dispersal of populations, such as island endemics. For example, while classic biogeographers were able to speculate about the origins of species in the Hawaiian Islands, phylogeography allows them to test theories of relatedness between these populations and putative source populations in Asia and North America.

Paleobiogeography

Paleobiogeography goes one step further to include paleogeographic data and considerations of plate tectonics. Using molecular analyses and corroborated by fossils, it has been possible to demonstrate that perching birds evolved first in the region of Australia or the adjacent Antarctic (which at that time lay somewhat further north and had a temperate climate). From there, they spread to the other Gondwanan continents and Southeast Asia - the part of Laurasia then closest to their origin of dispersal - in the late Paleogene, before achieving a global distribution in the early Neogene. Not knowing the fact that at the time of dispersal, the Indian Ocean was much narrower than it is today, and that South America was closer to the Antarctic, one would be hard pressed to explain the presence of many “ancient” lineages of perching birds in Africa, as well as the mainly South American distribution of the suboscines.

Ecology

Ecology is the scientific study of the distributions, abundance and relations of organisms and their interactions with the environment. Ecology includes the study of plant and animal populations, plant and animal communities and ecosystems. Ecosystems describe the web or network of relations among organisms at different scales of organization. Since ecology refers to any form of biodiversity, ecologists research everything from tiny bacteria’s role in nutrient recycling to the effects of tropical rain forest on the Earth's atmosphere. The discipline of ecology emerged from the natural sciences in the late 19th century. Ecology is not synonymous with environment, environmentalism, or environmental science. Ecology is closely related to the disciplines of physiology, evolution, genetics and behaviour.

Like many of the natural sciences, a conceptual understanding of ecology is found in the broader details of study, including:

- Life processes explaining adaptations
- Distribution and abundance of organisms
- The movement of materials and energy through living communities
- The successional development of ecosystems
- The abundance and distribution of biodiversity in context of the environment

Ecology is distinguished from natural history, which deals primarily with the descriptive study of organisms. It is a sub-discipline of biology, which is the study of life.

There are many practical applications of ecology in conservation biology, wetland management, natural resource management (agriculture, forestry, fisheries), city planning (urban ecology), community health, economics, basic & applied science and it provides a conceptual framework for understanding and researching human social interaction (human ecology).

Scale and Complexity

The scale and dynamics of time and space must be carefully considered when describing ecological phenomena. In reference to time, it can take thousands of years for ecological processes to mature. The life-span of a tree, for example, can include different successional or seral stages leading to mature old-growth forests. The ecological process is extended even further through time as trees topple over, decay and provide critical habitat as nurse logs or coarse woody debris. In reference to space, the area of an ecosystem can vary greatly from tiny to vast. For example, a single tree is of smaller consequence to the classification of a forest ecosystem, but it is of larger consequence to smaller organisms. Several generations of an aphid population, for example, might exist on a single leaf. Inside each of those aphids exist diverse communities of bacteria. Tree growth is, in turn, related to local site variables, such as soil type, moisture content, slope of the land, and forest canopy closure. However, more complex global factors, such as climate, must be considered for the classification and understanding of processes leading to larger patterns spanning across a forested landscape.

Global patterns of biological diversity are complex. This biocomplexity stems from the interplay among ecological processes that operate and influence patterns that grade into each other, such as transitional areas or ecotones that stretch across different scales. “Complexity in ecology is of at least six distinct types: spatial, temporal, structural, process, behavioural, and geometric.” There are different views on what constitutes complexity. One perspective lumps things that we do not understand into this category by virtue of the computational effort it would require to piece together the numerous interacting parts.

Alternatively, complexity in life sciences can be viewed as emergent self-organized systems with multiple possible outcomes directed by random accidents of history. Small scale patterns do not necessarily explain large scale phenomena, otherwise captured in the expression ‘the sum is greater than the parts’. Ecologists have identified emergent and self-organizing phenomena that operate at different environmental scales of influence, ranging from molecular to planetary, and these require different sets of scientific explanation. Long-term ecological studies provide important track records to better understand the complexity of ecosystems over longer temporal and broader spatial scales. The International Long Term Ecological Network manages and exchanges scientific information among research sites. The longest experiment in existence is the Park Grass Experiment that was initiated in 1856. Another example includes the Hubbard Brook study in operation since 1960.

To structure the study of ecology into a manageable framework of understanding, the biological world is conceptually organized as a nested hierarchy of organization, ranging in scale from genes, to cells, to tissues, to organs, to organisms, to species and up to the level of the biosphere. Together these hierarchical scales of life form a panarchy. Ecosystems are primarily researched at (but not restricted to) three key levels of organization, including organisms, populations, and communities. Ecologists study ecosystems by sampling a certain number of individuals that are representative of a population. Ecosystems consist of communities interacting with each other and the environment. In ecology, communities are created by the interaction of the populations of different species in an area.

Biodiversity is an attribute of a site or area that consists of the variety within and among biotic communities, whether influenced by humans or not, at any spatial scale from microsites and habitat patches to the entire biosphere.

Biodiversity (portmanteau of the words biological diversity) describes all varieties of life from genes to ecosystems and spans every level of biological organization. There are many ways to index, measure, and represent biodiversity. Biodiversity includes species diversity, ecosystem diversity, genetic diversity and the complex processes operating at and among these respective levels.

Biodiversity plays an important role in ecological health as much as it does for human health. Preventing or prioritizing species extinctions is one way to preserve biodiversity, but populations, the genetic diversity within them and ecological processes, such as migration, are being threatened on global scales and disappearing rapidly as well. Conservation priorities and management techniques require different approaches and considerations to address the full ecological scope of biodiversity. Populations and species migration, for example, are more sensitive indicators of ecosystem services that sustain and contribute natural capital toward the well-being of humanity.

An understanding of biodiversity has practical application for ecosystem-based conservation planners as they make ecologically responsible decisions in management recommendations to consultant firms, governments and industry.

Ecological Niche and the Habitat

There are many definitions of the niche dating back to 1917, but George Evelyn Hutchinson made conceptual advances in 1957 and introduced the most widely accepted definition: "The niche is the set of biotic and abiotic conditions in which a species is able to persist and maintain stable population sizes." The ecological niche is a central concept in the ecology of organisms and is sub-divided into the *fundamental* and the *realized* niche. The fundamental niche is the set of environmental conditions under which a species is able to persist. The realized niche is the set of environmental plus ecological conditions under which a species persists.

The habitat of a species is a related but distinct concept that describes the environment over which a species is known to occur and the type of community that is formed as a result. More specifically, "habitats can be defined as regions in environmental space that are composed of multiple dimensions, each representing a biotic or abiotic environmental variable; that is, any component or characteristic of the environment related directly (e.g. forage biomass and quality) or indirectly (e.g. elevation) to the use of a location by the animal." For example, the habitat might refer to an aquatic or terrestrial environment that can be further categorized as montane or alpine ecosystems.

Biogeographical patterns and range distributions are explained or predicted through knowledge and understanding of a species traits and niche requirements. Species have functional traits that are uniquely adapted to the ecological niche. A trait is a measurable property of an organism that influences its performance. Traits of each species are suited ar uniquely adapted to their ecological niche. This means that resident species are at an advantage and able to competitively exclude other similarly adapted species from having an overlapping geographic range. This is called the competitive exclusion principle.

Organisms are subject to environmental pressures, but they are also modifiers of their habitats. The regulatory feedback between organisms and their environment can modify conditions from local (e.g., a pond) to global scales (e.g., Gaia), over time and even after death, such as decaying logs or silica skeleton deposits from marine organisms. The process and concept of ecosystem engineering has also been called niche construction. Ecosystem engineers are defined as: "...organisms that directly or indirectly modulate the availability of resources to other species, by causing physical state changes in biotic or abiotic materials. In so doing they modify, maintain and create habitats."

The ecosystem engineering concept has stimulated a new appreciation for the degree of influence that organisms have on the ecosystem and evolutionary process. The terms niche construction are more often used in reference to the under appreciated feedback mechanism of natural selection imparting forces on the abiotic niche. An example of natural selection through ecosystem engineering occurs in the nests of social insects, including ants, bees, wasps, and termites. There is an emergent homeostasis in the structure of the nest that regulates, maintains and defends the physiology of the entire colony.

Termite mounds, for example, maintain a constant internal temperature through the design of air-conditioning chimneys. The structure of the nests themselves are subject to the forces of natural selection. Moreover, the nest can survive over successive generations, which means that ancestors inherit both genetic material and a legacy niche that was constructed before their time. Diatoms in the Bay of Fundy, Canada, provide another example of an ecosystem engineer. Benthic diatoms living in estuarine sediments secrete carbohydrate exudates that bind the sand and stabilizes the environment. The diatoms cause a physical state change in the properties of the sand that allows other organisms to colonize the area. The concept of ecosystem engineering brings new conceptual implications for the discipline of conservation biology.

Population Ecology

The population is the unit of analysis in population ecology. A population consists of individuals of the same species that live, interact and migrate through the same niche and habitat. A primary law of population ecology is the Malthusian growth model. This law states that:

"A population will grow (or decline) exponentially as long as the environment experienced by all individuals in the population remains constant."

This Malthusian premise provides the basis for formulating predictive theories and tests that follow. Simplified population models usually start with four variables including death, birth, immigration, and emigration. Mathematical models are used to calculate changes in population demographics using a null model. A null model is used as a null hypothesis for statistical testing. The null hypothesis states that random processes create observed patterns. Alternatively the patterns differ significantly from the random model and require further explanation. Models can be mathematically complex where "...several competing hypotheses are simultaneously confronted with the data." An example of an introductory population model describes a closed population, such as on an island, where immigration and emigration does not take place. In these island models the per capita rates of change are described as:

$dN / dT = B$ “ $D = bN$ “ $dN = (b$ “ $d)N = rN$,

Where N is the total number of individuals in the population, B is the number of births, D is the number of deaths, b and d are the per capita rates of birth and death respectively, and r is the per capita rate of population change. This formula can be read out as the rate of change in the population (dN/dT) is equal to births minus deaths (B – D).

Using these modelling techniques, Malthus' population principle of growth was later transformed into a model known as the logistic equation:

$dN / dT = aN(1$ “ $N / K)$,

Where N is the number of individuals measured as biomass density, a is the maximum per-capita rate of change, and K is the carrying capacity of the population. The formula can be read as follows: the rate of change in the population (dN/dT) is equal to growth (aN) that is limited by carrying capacity $(1 – N/K)$. The discipline of population ecology builds upon these introductory models to further understand demographic processes in real study populations and conduct statistical tests. The field of population ecology often uses data on life history and matrix algebra to develop projection matrices on fecundity and survivorship. This information is used for managing wildlife stocks and setting harvest quotas.

Metapopulation Ecology

Populations are also studied and modeled according to the metapopulation concept. The metapopulation concept was introduced in 1969: "as a population of populations which go extinct locally and recolonize." Metapopulation ecology is another statistical approach that is often used in conservation research. Metapopulation research simplifies the landscape into patches of varying levels of quality.

Metapopulation models have been used to explain life-history evolution, such as the ecological stability of amphibian metamorphosis in small vernal ponds. Alternative ecological strategies have evolved. For example, some salamanders forgo metamorphosis and sexually mature as aquatic neotenes. The seasonal duration of wetlands and the migratory range of the species determines which ponds are connected and if they form a metapopulation. The duration of the life history stages of amphibians relative to the duration of the vernal pool before it dries up regulates the ecological development of metapopulations connecting aquatic patches to terrestrial patches.

In metapopulation terminology there are emigrants (individuals that leave a patch), immigrants (individuals that move into a patch) and sites are classed either as sources or sinks. A site is a generic term that refers to places where ecologists sample populations, such as ponds or defined sampling areas in a forest. Source patches are productive sites that generate a seasonal supply of juveniles that migrate to other patch locations. Sink patches are unproductive sites that only receive migrants and will go extinct unless rescued by an adjacent source patch or environmental conditions become more favorable. Metapopulation models examine patch dynamics over time to answer questions about spatial and demographic ecology. The ecology of metapopulations is a dynamic process of extinction and colonization. Small patches of lower quality (i.e., sinks) are maintained or rescued by a seasonal influx of new immigrants. A dynamic metapopulation structure evolves from year to year, where some patches are sinks in dry years and become sources when conditions are more favorable. Ecologists use a mixture of computer models and field studies to explain metapopulation structure.

Ecosystem Ecology

These ecosystems, as we may call them, are of the most various kinds and sizes. They form one category of the multitudinous physical systems of the universe, which range from the universe as a whole down to the atom.

The concept of the ecosystem was first introduced in 1935 to describe habitats within biomes that form an integrated whole and a dynamicaly responsive system having both physical and biological complexes. Within an ecosystem there are inseperable ties that link organisms to the physical and biological components of their environment to which they are adapted. Ecosystems are complex adaptive systems where the interaction of life processes form self-organizing patterns across different scales of time and space. This section introduces key areas of ecosystem ecology that are used to inquire, understand and explain observed patterns of biodiversity and ecosystem function across different scales of organization.

Community Ecology

Community ecology is a subdiscipline of ecology which studies the distribution, abundance, demography, and interactions between coexisting populations. An example of a study in community ecology might measure primary production in a wetland in relation to decomposition and consumption rates. This requires an understanding of the community connections between plants (i.e., primary producers) and the decomposers (e.g., fungi and bacteria). or the analysis of predator-prey dynamics affecting amphibian biomass. Food webs and trophic levels are two widely employed conceptual models used to explain the linkages among species.

Food Webs

A food web is the archetypal ecological network. They are a type of concept map that illustrate pathways of energy flows in an ecological community, usually starting with solar energy being used by plants during photosynthesis. As plants grow, they accumulate carbohydrates and are eaten by grazing herbivores. Step by step lines or relations are drawn until a web of life is illustrated.

There are different ecological dimensions that can be mapped to create more complicated food webs, including: species composition (type of species), richness (number of species), biomass (the dry weight of plants and animals), productivity (rates of conversion of energy and nutrients into growth), and stability (food webs over time). A food web diagram illustrating species composition shows how change in a single species can directly and indirectly influence many others. Microcosm studies are used to simplify food web research into semi-isolated units such as small springs, decaying logs, and laboratory experiments using organisms that reproduce quickly, such as daphnia feeding on algae grown under controlled environments in jars of water.

Principles gleaned from food web microcosm studies are used to extrapolate smaller dynamic concepts to larger systems. Food webs are limited because they are generally restricted to a specific habitat, such as a cave or a pond. The food web illustration (right) only shows a small part of the complexity connecting the aquatic system to the adjacent terrestrial land. Many of these species migrate into other habitats to distribute their effects on a larger scale. In other words, food webs are incomplete, but are nonetheless a valuable tool in understanding community ecosystems.

Food chain length is another way of describing food webs as a measure of the number of species encountered as energy or nutrients move from the plants to top predators. There are different ways of calculating food chain length depending on what parameters of the food web dynamic are being considered: connectance, energy, or interaction. In a simple predator-prey example, a deer is one step removed from the plants it eats (chain length = 1) and a wolf that eats the deer is two steps removed (chain length = 2). The relative amount or strength of influence that these parameters have on the food web address questions about:

- The identity or existence of a few dominant species (called strong interactors or keystone species)
- The total number of species and food-chain length (including many weak interactors)

- How community structure, function and stability is determined

Trophic Dynamics

The Greek root of the word *troph*, trophic, means food or feeding. Links in food-webs primarily connect feeding relations or trophism among species. Biodiversity within ecosystems can be organized into vertical and horizontal dimensions. The vertical dimension represents feeding relations that become further removed from the base of the food chain up toward top predators. The horizontal dimension represents the abundance or biomass at each level. When the relative abundance or biomass of each functional feeding group is stacked into their respective trophic levels they naturally sort into a 'pyramid of numbers'. Functional groups are broadly categorized as autotrophs (or primary producers), heterotrophs (or consumers), and detrivores (or decomposers). Heterotrophs can be further sub-divided into different functional groups, including: primary consumers (strict herbivores), secondary consumers (predators that feed exclusively on herbivores) and tertiary consumers (predators that feed on a mix of herbivores and predators). Omnivores do not fit neatly into a functional category because they eat both plant and animal tissues. It has been suggested, however, that omnivores have a greater functional influence as predators because relative to herbivores they are comparatively inefficient at grazing.

Ecologist collect data on trophic levels and food webs to statistically model and mathematically calculate parameters, such as those used in other kinds of network analysis (e.g., graph theory), to study emergent patterns and properties shared among ecosystems. The emergent pyramidal arrangement of trophic levels with amounts of energy transfer decreasing as species become further removed from the source of production is one of several patterns that is repeated amongst the planets ecosystems. The size of each level in the pyramid generally represents biomass, which can be measured as the dry weight of an organism. Autotrophs may have the highest global proportion of biomass, but they are closely rivalled or surpassed by microbes. The decomposition of dead organic matter, such as leaves falling on the forest floor, turns into soils that feed plant production. The total sum of the planet's soil ecosystems is called the pedosphere where a very large proportion of the Earth's biodiversity sorts into other trophic levels. Invertebrates that feed and shred larger leaves, for example, create smaller bits for smaller organisms in the feeding chain. Collectively, these are the detrivores that regulate soil formation. Tree roots, fungi, bacteria, worms, ants, beetles, centipedes, spiders, mammals, birds, reptiles, amphibians and other less familiar creatures all work to create the trophic web of life in soil ecosystems. As organisms feed and migrate through soils they physically displace materials, which is an important ecological process called bioturbation. Biomass of soil microorganisms are influenced by and feed back into the trophic dynamics of the exposed solar surface ecology. Paleoecological studies of soils places the origin for bioturbation to a time before the Cambrian period. Other events, such as the evolution of trees and amphibians moving into land in the Devonian period played a significant role in the development of soils and ecological trophism.

Functional trophic groups sort out hierarchically into pyramidic trophic levels because it requires specialized adaptations to become a photosynthesizer or a predator, so few organisms have the adaptations needed to combine both abilities. This explains why functional adaptations to trophism (feeding) organizes different species into emergent functional groups. Trophic levels are part of the holistic or complex systems view of ecosystems. Each trophic level contains unrelated species that grouped together because they share common ecological functions. Grouping functionally similar species into a trophic system gives a macroscopic image of the larger functional design.

Links in a food-web illustrate direct trophic relations among species, but there are also indirect effects that can alter the abundance, distribution, or biomass in the trophic levels. For example, predators eating herbivores indirectly influence the control and regulation of primary production in plants. Although the predators do not eat the plants directly, they regulate the population of herbibores that are directly linked to plant trophism. The net effect of direct and indirect relations is called trophic cascades. Trophic cascades are separated into species-level cascades, where only a subset of the food-web dynamic is impacted by a change in population numbers, and community-level cascades, where a change in population numbers has a dramatic effect on the entire food-web, such as the distribution of plant biomass.

Keystone Species

A keystone species is a species that is disproportionately connected to more species in the food-web. Keystone species have lower levels of biomass in the trophic pyramid relative to the importance of their role. The many connections that a keystone species holds means that it maintains the organization and structure of entire communities. The loss of a keystone species results in a range of dramatic cascading effects that alters trophic dynamics, other food-web connections and can cause the extinction of other species in the community.

Sea otters (*Enhydra lutris*) are commonly cited as an example of a keystone species because they limit the density of sea urchins that feed on kelp. If sea otters are removed from the system, the urchins graze until the kelp beds disappear and this has a dramatic effect on community structure. Hunting of sea otters, for example, is thought to have indirectly lead to the extinction of the Steller's Sea Cow (*Hydrodamalis gigas*). While the keystone species concept has been used extensively as a conservation tool, it has been criticized for being poorly defined from an operational stance. It is very difficult to experimentally determine in each different ecosystem what species may hold a keystone role. Furthermore, food-web theory suggests that keystone species may not be all that common. It is therefore unclear how generally the keystone species model can be applied.

The Biome

Ecological units of organization are defined through reference to any magnitude of space and time on the planet. Communities of organisms, for example, are somewhat arbitrarily defined, but the processes of life integrate at different levels and organize into more complex wholes. Biomes, for example, are a larger unit of organization that categorize regions of the Earth's ecosystems mainly according to the structure and composition of vegetation. Different researchers have applied different methods to define continental boundaries of biomes dominated by different functional types of vegetative communities that are limited in distribution by climate, precipitation, weather and other environmental variables. Examples of biome names include: tropical rainforest, temperate broadleaf and mixed forests, temperate deciduous forest, taiga, tundra, hot desert, and polar desert. Other researchers have recently started to categorize other types of biomes, such as the human and oceanic microbiomes. To a microbe, the human body is a habitat and a landscape. The microbiome has been largely discovered through advances in molecular genetics that have revealed a hidden richness of microbial diversity on the planet. The oceanic microbiome plays a significant role in the ecological biogeochemistry of the planet's oceans.

The Biosphere

Ecological theory has been used to explain self-emergent regulatory phenomena at the planetary scale. The largest scale of ecological organization is the biosphere: the total sum of ecosystems on the planet. Ecological relations regulate the flux of energy, nutrients, and climate all the way up to the planetary scale. For example, the dynamic history of the planetary CO_2 and O_2 composition of the atmosphere has been largely determined by the biogenic flux of gases coming from respiration and photosynthesis, with levels fluctuating over time and in relation to the ecology and evolution of plants and animals. When sub-component parts are organized into a whole there are oftentimes emergent properties that describe the nature of the system. This the Gaia hypothesis, and is an example of holism applied in ecological theory. The ecology of the planet acts as a single regulatory or holistic unit called Gaia. The Gaia hypothesis states that there is an emergent feedback loop generated by the metabolism of living organisms that maintains the temperature of the Earth and atmospheric conditions within a narrow self-regulating range of tolerance.

Relation to Evolution

Ecology and evolution are considered sister disciplines of the life sciences. Natural selection, life history, development, adaptation, populations, and inheritance are examples of concepts that thread equally into ecological and evolutionary theory. Morphological, behavioural and/or genetic traits, for example, can be mapped onto evolutionary trees to study the historical development of a species in relation to their functions and roles in different ecological circumstances. In this framework, the analytical tools of ecologists and evolutionists overlap as they organize, classify and investigate life through common systematic principals, such as phylogenetics or the Linnaean system of taxonomy.

The two disciplines often appear together, such as in the title of the journal *Trends in Ecology and Evolution*. There is no sharp boundary separating ecology from evolution and they differ more in their areas of applied focus. Both disciplines discover and explain emergent and unique properties and processes operating across different spatial or temporal scales of organization. While the boundary between ecology and evolution is not always clear, it is understood that ecologists study the abiotic and biotic factors that influence the evolutionary process.

Behavioural Ecology

All organisms are motile to some extent. Even plants express complex behaviour, including memory and communication. Behavioural ecology is the study of ethology and its ecological and evolutionary implications. Ethology is the study of observable movement or behaviour in nature. This could include investigations of motile sperm of plants, mobile phytoplankton, zooplankton swimming toward the female egg, the cultivation of fungi by weevils, the mating dance of a salamander, or social gatherings of amoeba.

Adaptation is the central unifying concept in behavioural ecology.□ Behaviours can be recorded as traits and inherited in much the same way that eye and hair colour can. Behaviours evolve and become adapted to the ecosystem because they are subject to the forces of natural selection. Hence, behaviours can be adaptive, meaning that they evolve functional utilities that increases reproductive success for the individuals that inherit such traits. This is also the technical definition for fitness in biology, which is a measure of reproductive success over successive generations. Predator-prey interactions are an introductory concept into food-web studies as well as behavioural ecology. Prey species can exhibit different kinds of behavioural adaptations to predators, such as avoid, flee or defend. Many prey species are faced with multiple predators that differ in the degree of danger posed. To be adapted to their environment and face predatory threats, organisms must balance their energy budgets as they invest in different aspects of their life history, such as growth, feeding, mating, socializing, or modifying their habitat. Hypotheses posited in behavioural ecology are generally based on adaptive principals of conservation, optimization or efficiency. For example;

> *"The threat-sensitive predator avoidance hypothesis predicts that prey should assess the degree of threat posed by different predators and match their behaviour according to current levels of risk."*

> *"The optimal flight initiation distance occurs where expected postencounter fitness is maximized, which depends on the prey's initial fitness, benefits obtainable by not fleeing, energetic escape costs, and expected fitness loss due to predation risk."*

The behaviour of long-toed salamanders (*Ambystoma macrodactylum*) presents an example in this context. When threatened, the long-toed salamander defends itself by waving its tail and secreting a white milky fluid. The excreted fluid is distasteful, toxic and adhesive, but it is also used for nutrient and energy storage during hibernation. Hence, salamanders subjected to frequent predatory attack will be energetically compromised as they use up their energy stores.

Ecological interactions can be divided into host and associate relationships. A host is any entity that harbours another that is called the associate. Host and associate relationships among species that are mutually or reciprocally beneficial are called mutualisms. If the host and associate are physically connected, the relationship is called symbiosis. Approximately 60% of all plants, for example, have a symbiotic relationship with arbuscular mycorrhizal fungi. Symbiotic plants and fungi exchange carbohydrates for mineral nutrients. Symbiosis differs from indirect mutualisms where the organisms live apart. For example, tropical rainforests regulate the Earth's atmosphere. Trees living in the equatorial regions of the planet supply oxygen into the atmosphere that sustains species living in distant polar regions of the planet. This relationship is called commensalism because many other host species receive the benefits of clean air at no cost or harm to the associate tree species supplying the oxygen. The host and associate relationship is called parasitism if one species benefits while the other suffers. Competition among species or among members of the same species is defined as reciprocal antagonism, such as grasses competing for growth space.

Popular ecological study systems for mutualism include, fungus-growing ants employing agricultural symbiosis, bacteria living in the guts of insects and other organisms, the fig wasp and yucca moth pollination complex, lichens with fungi and photosynthetic algae, and corals with photosynthetic algae.

Intraspecific behaviours are notable in the social insects, slime moulds, social spiders, human society, and naked mole rats where eusocialism has evolved. Social behaviours include reciprocally beneficial behaviours among kin and nest mates. Social behaviours evolve from kin and group selection. Kin selection explains altruism through genetic relationships, whereby an altruistic behaviour leading to death is rewarded by the survival of genetic copies distributed among surviving relatives. The social insects, including ants, bees and wasps are most famously studied for this type of relationship because the male drones are clones that share the same genetic make-up as every other male in the colony. In contrast, group selectionists find examples of altruism among non-genetic relatives and explain this through selection acting on the group, whereby it becomes selectively advantageous for groups if their members express altruistic behaviours to one another. Groups that are predominantely altruists beat groups that are predominantely selfish.

A often quoted behavioural ecology hypothesis is known as Lack's brood reduction hypothesis (named after David Lack). Lack's hypothesis posits an evolutionary and ecological explanation as to why birds lay a series of eggs with an asynchronous delay leading to nestlings of mixed age and weights. According to Lack, this brood behaviour is an ecological insurance that allows the larger birds to survive in poor years and all birds to survive when food is plentiful.

Elaborate sexual displays and posturing are encountered in the behavioural ecology of animals. The birds of paradise, for example, display elaborate ornaments and song during courtship. These displays serve a dual purpose of signalling healthy or well-adapted individuals and good genes. The elaborate displays are driven by sexual selection as an advertisement of quality of traits among male suitors.

Biogeography

The word *biogeography* is an amalgamation of *biology* and *geography*. Biogeography is the comparative study of the geographic distribution of organisms and the corresponding evolution of their traits in space and time. The Journal of Biogeography was established in 1974. Biogeography and ecology share many of their disciplinary roots. For example, the theory of island biogeography, published by the mathematician Robert MacArthur and ecologist Edward O. Wilson in 1967 is considered one of the fundamentals of ecological theory.

Biogeography has a long history in the natural sciences where questions arise concerning the spatial distribution of plants and animals. Ecology and evolution provide the explanatory context for biogeographical studies. Biogeographical patterns result from ecological processes that influence range distributions, such as migration and dispersal and from historical processes that split populations or species into different areas.

The biogeographic processes that result in the natural splitting of species explains much of the modern distribution of the Earth's biota. The splitting of lineages in a species is called vicariance biogeography and it is a sub-discipline of biogeography.

There are also practical applications in the field of biogeography concerning ecological systems and processes. For example, the range and distribution of biodiversity and invasive species responding to climate change is a serious concern and active area of research in context of global warming.

r/K-Selection Theory

Another concept that was introduced in MacArthur and Wilson's (1964) classical book, *The Theory of Island Biogeography* was r/K selection theory, which was one of the first predictive models in ecology that could be used to explain life-history evolution. The premise behind the r/K selection model is that the pressure of natural selection changes according to population densities. When an island is first colonized the density of individuals is low. The initial increase in population size is not limited by competition, which leaves an abundance of available resources for rapid population growth. These early phases of population growth experience density independent forces of natural selection, which is called *r*-selection. When the population becomes crowded, it reaches the island's carrying capacity, and individuals compete more heavily for fewer available resources. Under crowded conditions the population experiences density-dependent forces of natural selection, called *K*-selection.

In the *r/K*-selection model, the first variable *r* is the intrinsic rate of natural increase in population size and the second variable *K* is the carrying capacity of a population. Different species evolve different life-history strategies spanning a continuum between these two selective forces. An *r*-selected species is one that has high birth rates, low levels of parental investment, and high rates of mortality before individuals reach maturity. Evolution favours high rates of fecundity in *r*-selected species. Many kinds of insects and invasive species exhibit *r*-selected characteristics. In contrast, a *K*-selected species has low rates of fecundity, high levels of parental investment in the young, and low rates of mortality as individuals mature. Humans and elephants are examples of species exhibiting *K*-selected characteristics, including longevity and efficiency in the conversion of more resources into fewer offspring.

Molecular Ecology

The important relationship between ecology and genetic inheritance predates modern techniques for molecular analysis. Molecular ecological research became more feasible with the development of rapid and accessible genetic technologies, such as the polymerase chain reaction (PCR). The rise of molecular technologies and influx of research questions into this new ecological field resulted in the publication *Molecular Ecology* in 1992. Molecular ecology uses various analytical techniques to study genes in an evolutionary and ecological context. In 1994, professor John Avise also played a leading role in this area of science with the publication of his book, *Molecular Markers, Natural History and Evolution*. Newer technologies opened a wave of genetic analysis into organisms once difficult to study from an ecological or evolutionary standpoint, such as bacteria, fungi and nematodes.

Molecular ecology engendered a new research paradigm to investigate ecological questions considered otherwise intractable. Molecular investigations revealed previously obscured details in the tiny intricacies of nature and improved resolution into probing questions about behavioural and biogeographical ecology. For example, molecular ecology revealed promiscuous sexual behaviour and multiple male partners in tree swallows previously thought to be socially monogamous. In a biogeographical context, the marriage between genetics, ecology and evolution resulted in a new sub-discipline called phylogeography.

Relation to the Environment

The environment is dynamically interlinked, imposed upon and constrains organisms at any time throughout their life cycle. Like the term ecology, environment has different conceptual meanings and to many these terms also overlap with the concept of *nature*. Environment "...includes the physical world, the social world of human relations and the built world of human creation." The environment in ecosystems includes both physical parameters and biotic attributes. The physical environment is external to the level of biological organization under investigation, including abiotic factors such as temperature, radiation, light, chemistry, climate and geology. The biotic environment includes genes, cells, organisms, members of the same species (conspecifics) and other species that share a habitat. The laws of thermodynamics applies to ecology by means of its physical state. Armed with an understanding of metabolic and thermodynamic principles a complete accounting of energy and material flow can be traced through an ecosystem. Environmental and ecological relations are studied through reference to conceptually manageable and isolated parts. However, once the effective environmental components are understood they conceptually link back together as a *holocoenotic* system. In other words, the organism and the environment form a dynamic whole (or umwelt). Change in one ecological or environmental factor can concurrently affect the dynamic state of an entire ecosystem.

Ecological studies are necessarily holistic as opposed to reductionistic. Holism has three scientific meanings or uses that identify with: 1) the mechanistic complexity of ecosystems, 2) the practical description of patterns in quantitative reductionist terms where correlations may be identified but nothing is understood about the causal relations without reference to the whole system, which leads to 3) a metaphysical hierarchy whereby the causal relations of larger systems are understood without reference to the smaller parts. An example of the metaphysical aspect to holism is the trend of increased exterior thickness in shells of different species. The reason for a thickness increase can be understood through reference to principals of natural selection via predation without any reference to the biomolecular properties of the exterior shells.

Metabolism and the Early Atmosphere

The Earth formed approximately 4.5 billion years ago and environmental conditions were too extreme for life to form for the first 500 million years. During this early Hadean period, the Earth started to cool, allowing a crust and oceans to form. Environmental conditions were unsuitable for the origins of life for the first billion years after the Earth formed. The Earth's atmosphere transformed from being dominated by hydrogen, to one composed mostly of methane and ammonia. Over the next billion years the metabolic activity of life transformed the atmosphere to higher concentrations of carbon dioxide, nitrogen, and water vapour. These gases changed the way that light from the sun hit the Earth's surface and greenhouse effects trapped heat. There were untapped sources of free energy within the mixture of reducing and oxidizing gasses that set the stage for primitive ecosystems to evolve and, in turn, the atmosphere also evolved.

Throughout history, the Earth's atmosphere and biogeochemical cycles have been in a dynamic equilibrium with planetary ecosystems. The history is characterized by periods of significant transformation followed by millions of years of stability. The evolution of the earliest organisms, likely anaerobic methanogen microbes, started the process by converting atmospheric hydrogen into methane ($4H_2 + CO_2 \rightarrow CH_4 + 2H_2O$).

Anoxygenic photosynthesis converting hydrogen sulfide into other sulfur compounds or water ($2H_2S + CO_2 \rightarrow hv \rightarrow CH_2O \rightarrow H_2O \rightarrow + 2S$ or $2H_2 + CO_2 + hv \rightarrow CH_2O + H_2O$), as occurs in deep sea hydrothermal vents today, reduced hydrogen concentrations and increased atmospheric methane. Early forms of fermentation also increased levels of atmospheric methane. The transition to an oxygen dominant atmosphere (the *Great Oxidation*) did not begin until approximately 2.4-2.3 billion years ago, but photosynthetic processes started 0.3 to 1 billion years prior.

Radiation: Heat, Temperature and Light

The biology of life operates within a certain range of temperatures. Heat is a form of energy that regulates temperature. Heat affects growth rates, activity, behaviour and primary production. Temperature is largely dependent on the incidence of solar radiation.

The latitudinal and longitudinal spatial variation of temperature greatly affects climates and consequently the distribution of biodiversity and levels of primary production in different ecosystems or biomes across the planet. Heat and temperature relate importantly to metabolic activity. Poikilotherms, for example, have a body temperature that is largely regulated and dependent on the temperature of the external environment. In contrast, homeotherms regulate their internal body temperature by expending metabolic energy.

There is a relationship between light, primary production, and ecological energy budgets. Sunlight is the primary input of energy into the planet's ecosystems. Light is composed of electromagnetic energy of different wavelengths. Radiant energy from the sun generates heat, provides photons of light measured as active energy in the chemical reactions of life, and also acts as a catalyst for genetic mutation. Plants, algae, and some bacteria absorb light and assimilate the energy through photosynthesis. Organisms capable of assimilating energy by photosynthesis or through inorganic fixation of H_2S are autotrophs. Autotrophs—responsible for primary production—assimilate light energy that becomes metabolically stored as potential energy in the form of biochemical enthalpic bonds.

Physical Environments

Water

The rate of diffusion of carbon dioxide and oxygen is approximately 10,000 times slower in water than it is in air. When soils become flooded, they quickly lose oxygen from low-concentration (hypoxic) to an (anoxic) environment where anaerobic bacteria thrive among the roots. Water also influences the spectral properties of light that becomes more diffuse as it is reflected off the water surface and submerged particles.

Aquatic plants exhibit a wide variety of morphological and physiological adaptations that allow them to survive, compete and diversify these environments. For example, the roots and stems develop large cellular air spaces to allow for the efficient transportation gases (for example, CO_2 and O_2) used in respiration and photosynthesis.

In drained soil, microorganisms use oxygen during respiration. In aquatic environments, anaerobic soil microorganisms use nitrate, manganic ions, ferric ions, sulfate, carbon dioxide and some organic compounds. The activity of soil microorganisms and the chemistry of the water reduces the oxidation-reduction potentials of the water. Carbon dioxide, for example, is reduced to methane (CH_4) by methanogenic bacteria. Salt water also requires special physiological adaptations to deal with water loss.

Salt water plants (or halophytes) are able to osmo-regulate their internal salt (NaCl) concentrations or develop special organs for shedding salt away. The physiology of fish is also specially adapted to deal with high levels of salt through osmoregulation. Their gills form electrochemical gradients that mediate salt excrusion in salt water and uptake in fresh water.

Gravity

The shape and energy of the land is affected to a large degree by gravitational forces. On a larger scale, the distribution of gravitational forces on the earth are uneven and influence the shape and movement of tectonic plates as well as having an influence on geomorphic processes such as orogeny and erosion. These forces govern many of the geophysical properties and distributions of ecological biomes across the Earth. On a organism scale, gravitational forces provide directional cues for plant and fungal growth (gravitropism), orientation cues for animal migrations, and influence the biomechanics and size of animals. Ecological traits, such as allocation of biomass in trees during growth are subject to mechanical failure as gravitational forces influence the position and structure of branches and leaves. The cardiovascular systems of all animals are functionally adapted to overcome pressure and gravitational forces that change according to the features of organisms (e.g., height, size, shape), their behaviour (e.g., diving, running, flying), and the habitat occupied (e.g., water, hot deserts, cold tundra).

Pressure

Climatic and osmotic pressure places physiological constraints on organisms, such as flight and respiration at high altitudes, or diving to deep ocean depths. These constraints influence vertical limits of ecosystems in the biosphere as organisms are physiologically sensitive and adapted to atmospheric and osmotic water pressure differences. Oxygen levels, for example, decrease with increasing pressure and are a limiting factor for life at higher altitudes. Water transportation through trees is another important ecophysiological parameter dependent upon pressure. Water pressure in the depths of oceans requires adaptations to deal with the different living conditions. Mammals, such as whales, dolphins and seals are adapted to deal with changes in sound due to water pressure differences.

Wind and Turbulence

Turbulent forces in air and water have significant effects on the environment and ecosystem distribution, form and dynamics. On a planetary scale, ecosystems are affected by circulation patterns in the global trade winds. Wind power and the turbulent forces it creates can influence heat, nutrient, and biochemical profiles of ecosystems. For example, wind running over the surface of a lake creates turbulence, mixing the water column and influencing the environmental profile to create thermally layered zones, partially governing how fish, algae, and other parts of the aquatic ecology are structured. Wind speed and turbulence also exert influence on rates of evapotranspiration rates and energy budgets in plants and animals.

Wind speed, temperature and moisture content can vary as winds travel across different landfeatures and elevations. The westerlies, for example, come into contact with the coastal and interior mountains of western North America to produce a rain shadow on the leeward side of the mountain. The air expands and moisture condenses as the winds move up in elevation which can cause precipitation; this is called orographic lift. This environmental process produces spatial divisions in biodiversity, as species adapted to wetter conditions are range-restricted to the coastal mountain valleys and unable to migrate across the xeric ecosystems of the Columbia Basin to intermix with sister lineages that are segregated to the interior mountain systems.

Fire

Plants convert carbon dioxide into biomass and emit oxygen into the atmosphere. Approximately 350 million years ago (near the Devonian period) the photosynthetic process brought the concentration of atmospheric oxygen above 17%, which allowed combustion to occur. Fire releases CO_2 and converts fuel into ash and tar. Fire is a significant ecological parameter that raises many issues pertaining to its control and suppression in management. While the issue of fire in relation to ecology and plants has been recognized for a long time, Charles Cooper brought attention to the issue of forest fires in relation to the ecology of forest fire suppression and management in the 1960s.

Fire creates environmental mosaics and a patchiness to ecosystem age and canopy structure. Native North Americans were among the first to influence fire regimes by controlling their spread near their homes or by lighting fires to stimulate the production of herbaceous foods and basketry materials. The altered state of soil nutrient supply and cleared canopy structure also opens new ecological niches for seedling establishment. Most ecosystem are adapted to natural fire cycles. Plants, for example, are equipped with a variety of adaptations to deal with forest fires. Some species (e.g., *Pinus halepensis*) cannot germinate until after their seeds have lived through a fire. This environmental trigger for seedlings is called serotiny. Some compounds from smoke also promote seed germination.

Biogeochemistry

Ecologists study and measure nutrient budgets to understand how these materials are regulated and flow through the environment. This research has led to an understanding that there is a global feedback between ecosystems and the physical parameters of this planet including minerals, soil, pH, ions, water and atmospheric gases. There are six major elements, including H (hydrogen), C (carbon), N (nitrogen), O (oxygen), S (sulfur), and P (phosphorus) that form the constitution of all biological macromolecules and feed into the Earth's geochemical processes. From the smallest scale of biology the combined effect of billions upon billions of ecological processes amplify and ultimately regulate the biogeochemical cycles of the Earth. Understanding the relations and cycles mediated between these elements and their ecological pathways has significant bearing toward understanding global biogeochemistry.

The ecology of global carbon budgets gives one example of the linkage between biodiversity and biogeochemistry. For starters, the Earth's oceans are estimated to hold 40,000 gigatonnes (Gt) carbon, vegetation and soil is estimated to hold 2070 Gt carbon, and fossil fuel emissions are estimated to emit an annual flux of 6.3 Gt carbon. At different times in the Earth's history there has been major restructuring in these global carbon budgets that was regulated to a large extent by the ecology of the land. For example, through the early-mid Eocene volcanic out gassing, the oxidation of methane stored in wetlands, and seafloor gases increased atmospheric CO_2 concentrations to levels as high as 3500 ppm. In the Oligocene, from 25 to 32 million years ago, there was another significant restructuring in the global carbon cycle as grasses evolved a special type of C4 photosynthesis and expanded their ranges.

This new photosynthetic pathway evolved in response to the drop in atmospheric CO_2 concentrations below 550 ppm. Ecosystem functions such as these feed back significantly into global atmospheric models for carbon cycling. Loss in the abundance and distribution of biodiversity causes global carbon cycle feedbacks that are expected to increase rates of global warming in the next century. The effect of global warming melting large sections of permafrost creates a new mosaic of flooded areas where decomposition results in the emission of methane (CH_4). Hence, there is a relationship between global warming, decomposition and respiration in soils and wetlands producing significant climate feedbacks and altered global biogeochemical cycles. There is concern over increases in atmospheric methane in the context of the global carbon cycle, because methane is also a greenhouse gas that is 23 times more effective at absorbing long-wave radiation on a 100 year time scale.

History

Unlike many of the scientific disciplines, ecology has a complex and winding origin due in large part to its interdisciplinary nature. Several published books provide extensive coverage of the classics. In the early 20th century, ecology was an analytical form of natural history. The descriptive nature of natural history included examination of the interaction of organisms with both their environment and their community. Such examinations, conducted by important natural historians including James Hutton and Jean-Baptiste Lamarck, contributed to the development of ecology. The term “ecology” (German: *Oekologie*) is a more recent scientific development and was first coined by the German biologist Ernst Haeckel in his book *Generelle Morphologie der Organismen* (1866).

Opinions differ on who was the founder of modern ecological theory. Some mark Haeckel’s definition as the beginning, others say it was Eugen Warming with the writing of Oecology of Plants: An Introduction to the Study of Plant Communities (1895). Ecology may also be thought to have begun with Carl

Linnaeus' research principals on the economy of nature that matured in the early 18th century. He founded an early branch of ecological study he called the economy of nature. The works of Linnaeus influenced Darwin in *The Origin of Species* where he adopted the usage of Linnaeus' phrase on the *economy or polity of nature*. Linnaeus made the first to attempt to define *the balance of nature*, which had previously been held as an assumption rather than formulated as a testable hypothesis. Haeckel, who admired Darwin's work, defined ecology in reference to the economy of nature which has lead some to question if ecology is synonymous with Linnaeus' concepts for the economy of nature. Biogeographer Alexander von Humbolt was also foundational and was among the first to recognize ecological gradients and alluded to the modern ecological law of species to area relationships.

The modern synthesis of ecology is a young science, which first attracted substantial formal attention at the end of the 19th century (around the same time as evolutionary studies) and become even more popular during the 1960s environmental movement. However, many observations, interpretations and discoveries relating to ecology extend back to much earlier studies in natural history. For example, the concept on the balance or regulation of nature can be traced back to Herodotos (died *c*. 425 BC) who described an early account of mutualism along the Nile river where crocodiles open their mouths to beneficially allow sandpipers safe access to remove leeches.

In the broader contributions to the historical development of the ecological sciences, Aristotle is considered one of the earliest naturalists who had an influential role in the philosophical development of ecological sciences. One of Aristotle's students, Theophrastus, made astute ecological observations about plants and posited a philosophical stance about the autonomous relations between plants and their environment that is more in line with modern ecological thought. Both Aristotle and Theophrastus made extensive observations on plant and animal migrations, biogeography, physiology, and their habits in what might be considered an analog of the modern ecological niche.

From Aristotle to Darwin the natural world was predominantly considered static and unchanged since its original creation. Prior to *The Origin of Species* there was little appreciation or understanding of the dynamic and reciprocal relations between organisms, their adaptations and their modifications to the environment. While Charles Darwin is most notable for his treatise on evolution, he is also one of the founders of soil ecology. In *The Origin of Species* Darwin also made note of the first ecological experiment that was published in 1816. In the science leading up to Darwin the notion of evolving species was gaining popular support. This scientific paradigm changed the way that researchers approached the ecological sciences.

After the Turn of 20th Century

The first American ecology book was published in 1905 by Frederic Clements. In his book, Clements forwarded the idea of plant communities as a superorganism. This publication launched a debate between ecological holism and individualism that lasted until the 1970s. The Clements superorganism concept proposed that ecosystems progress through regular and determined stages of seral development that are analogous to developmental stages of an organism whose parts function to maintain the integrity of the whole. The Clementsian paradigm was challenged by Henry Gleason. According to Gleason, ecological communities develop from the unique and coincidental association of individual organisms. This perceptual shift placed the focus back onto the life histories of individual organisms and how this relates to the development of community associations.

The Clementsian superorganism concept has not been completely rejected, but it was an over extended application of holism, which remains a significant theme in contemporary ecological studies. Holism was first introduced in 1926 by a polarizing historical figure, a South African General named Jan Christian Smuts. Smuts was inspired by Clement’s superorganism theory when he developed and published on the unifying concept of holism, which runs in stark contrast to his racial views as the father of apartheid. Around the same time, Charles Elton pioneered the concept of food chains in his classical book “Animal Ecology”. Elton defined ecological relations using concepts of food-chains, food-cycles, food-size, and described numerical relations among different functional groups and their relative abundance. Elton's term 'food-cycle' was replaced by 'food-web' in a subsequent ecological text. Elton's book broke conceptual ground by illustrating complex ecological relations through simpler food-web diagrams.

The number of authors publishing on the topic of ecology has grown considerably since the turn of 20th century. The explosion of information available to the modern researcher of ecology makes it an impossible task for one individual to sift through the entire history. Hence, the identification of classics in the history of ecology is a difficult designation to make.

Parallel Development

Ecology has developers in many nations, including Russia's Vladimir Vernadsky and his founding of the biosphere concept in the 1920s or Japan's Kinji Imanishi and his concepts of harmony in nature and habitat segregation in the 1950s. The scientific recognition or importance of contributions to ecology from other cultures is hampered by language and translation barriers. The history of ecology remains an active area of study, often published in the Journal of the History of Biology.

Ecosystem Services and the Biodiversity Crisis

Increasing globalization of human activities and rapid movements of people as well as their goods and services suggest that mankind is now in an era of novel coevolution of ecological and socioeconomic systems at regional and global scales.

The ecosystems of planet Earth are coupled to human environments. Ecosystems regulate the global geophysical cycles of energy, climate, soil nutrients, and water that in turn support and grow natural capital (including the environmental, physiological, cognitive, cultural, and spiritual dimensions of life). Ultimately, every manufactured product in human environments comes from natural systems. Ecosystems are considered common-pool resources because ecosystems do not exclude beneficiaries and they can be depleted or degraded. For example, green space within communities provides common-pool health services. Research shows that people who are more engaged with regular access to natural areas have lower rates of diabetes, heart disease and psychological disorders. These ecological health services are regularly depleted through urban development projects that do not factor in the common-pool value of ecosystems.

The ecological commons delivers a diverse supply of community services that sustains the well-being of human society. The Millennium Ecosystem Assessment, an international UN initiative involving more than 1,360 experts worldwide, identifies four main ecosystem service types having 30 sub-categories stemming from natural capital. The ecological commons includes provisioning (e.g., food, raw materials, medicine, water supplies), regulating (e.g., climate, water, soil retention, flood retention), cultural (e.g., science and education, artistic, spiritual), and supporting (e.g., soil formation, nutrient cycling, water cycling) services.

Policy and human institutions should rarely assume that human enterprise is benign. A safer assumption holds that human enterprise almost always exacts an ecological toll - a debit taken from the ecological commons.

Ecological economics is an economic science that uses many of the same terms and methods that are used in accounting. Natural capital is the stock of materials or information stored in biodiversity that generates services that can enhance the welfare of communities. Population losses are the more sensitive indicator of natural capital than are species extinction in the accounting of ecosystem services. The prospect for recovery in the economic crisis of nature is grim. Populations, such as local ponds and patches of forest are being cleared away and lost at rates that exceed species extinctions.

The WWF 2008 living planet report and other researchers report that human civilization has exceeded the bio-regenerative capacity of the planet. This means that human consumption is extracting more natural resources than can be replenished by ecosystems around the world. In 1992, professor William Rees developed the concept of our ecological footprint. The ecological footprint is a way of accounting the level of impact that human development is having on the Earth's ecosystems. All indications are that the human enterprise is unsustainable as the ecological footprint of society is placing too much stress on the ecology of the planet. The mainstream growth-based economic system adopted by governments worldwide does not include a price or markets for natural capital. This type of economic system places further ecological debt onto future generations.

Human societies are increasingly being placed under stress as the ecological commons is diminished through an accounting system that has incorrectly assumed "... that nature is a fixed, indestructible capital asset." While nature is resilient and it does regenerate, there are limits to what can be extracted, but conventional monetary analyses are unable to detect the problem. Evidence of the limits in natural capital are found in the global assessments of biodiversity, which indicate that the current epoch, the Anthropocene is a sixth mass extinction. Species loss is accelerating at 100–1000 times faster than average background rates in the fossil record.

The ecology of the planet has been radically transformed by human society and development causing massive loss of ecosystem services that otherwise deliver and freely sustain equitable benefits to human society through the ecological commons. The ecology of the planet is further threatened by global warming, but investments in nature conservation can provide a regulatory feedback to store and regulate carbon and other greenhouse gases. The field of conservation biology involves ecologists that are researching the nature of the biodiversity threat and searching for solutions to sustain the planet's ecosystems for future generations.

"Human activities are associated directly or indirectly with nearly every aspect of the current extinction spasm."

The current wave of threats, including massive extinction rates and concurrent loss of natural capital to the detriment of human society, is happening rapidly. This is called a biodiversity crisis, because 50% of the worlds species are predicted to go extinct within the next 50 years. The world's fisheries are facing dire challenges as the threat of global collapse appears imminent, with serious ramifications for the well-being of humanity. Governments of the G8 met in 2007 and set forth 'The Economics of Ecosystems and Biodiversity' (TEEB) initiative: In a global study we will initiate the process of analyzing the global economic benefit of biological diversity, the costs of the loss of biodiversity and the failure to take protective measures versus the costs of effective conservation.

Ecologists are teaming up with economists to measure the wealth of ecosystems and to express their value as a way of finding solutions to the biodiversity crisis. Some researchers have attempted to place a dollar figure on ecosystem services, such as the value that the Canadian boreal forest is contributing to global ecosystem services. If ecologically intact, the boreal forest has an estimated value of US$3.7 trillion. The boreal forest ecosystem is one of the planet's great atmospheric regulators and it stores more carbon than any other biome on the planet.

The annual value for ecological services of the Boreal Forest is estimated at US$93.2 billion, or 2.5 greater than the annual value of resource extraction. The economic value of 17 ecosystem services for the entire biosphere (calculated in 1997) has an estimated average value of US$33 trillion (10) per year. These ecological economic values are not currently included in calculations of national income accounts, the GDP and they have no price attributes because they exist mostly outside of the global markets. The loss of natural capital continues to accelerate and goes undetected by mainstream monetary analysis.

Rainforest

Rainforests are forests characterized by high rainfall, with definitions setting minimum normal annual rainfall between 1750–2000 mm (68-78 inches). The monsoon trough, alternately known as the intertropical convergence zone, plays a significant role in creating Earth's tropical rain forests.

A total of 40 to 75% of all species on the world's habitats are indigenous to the rainforests. It has been estimated that many millions of species of plants, insects, and microorganisms are still undiscovered. Tropical rainforests have been called the "jewels of the Earth", and the "world's largest pharmacy", because over one quarter of natural medicines have been discovered there. Rainforests are also responsible for 28% of the world's oxygen turn over, often misunderstood as oxygen production, processing it through photosynthesis from carbon dioxide and storing it as carbon through biosequestration.

The undergrowth in a rainforest is restricted in many areas by the lack of sunlight at ground level. This makes it possible to walk through the forest. If the leaf canopy is destroyed or thinned, the ground beneath is soon colonized by a dense, tangled growth of vines, shrubs, and small trees called a jungle. There are two types of rainforest, tropical rainforest and temperate rainforest.

Tropical

Many of the world's rainforests are associated with the location of the monsoon trough, also known as the intertropical convergence zone.

Tropical rainforests are rainforests in the tropics, found near the Equator (between the Tropic of Cancer and Tropic of Capricorn) and present in Southeast Asia , Sri Lanka, Sub-Saharan Africa from Cameroon to the Congo, South America, Central America, and on many of the Pacific Islands. Tropical rainforests have been called the "Earth's lungs," although it is now known that rainforests contribute little net oxygen additions to the atmosphere through photosynthesis.

Temperate

Temperate rainforests are rainforests in temperate regions. They can be found in North America (in the Pacific Northwest, the British Columbia Coast, and in the inland rainforest of the Rocky Mountain Trench east of Prince George), in Europe (parts of the British Isles such as the coastal areas of Ireland, Scotland, southern Norway, parts of the western Balkans along the Adriatic coast, as well as in the North West of Spain and coastal areas of the eastern Black Sea, including Georgia and coastal Turkey), in East Asia (in southern China, Taiwan, much of Japan and Korea, and on Sakhalin Island and the adjacent Russian Far East coast), in South America (southern Chile) and also Australia and New Zealand.

Layers

A tropical rainforest is typically divided into four main layers, each with different plants and animals adapted for life in that particular area: the emergent, canopy, understory, and forest floor layers.

Emergent Layer

The emergent layer contains a small number of very large trees called emergents, which grow above the general canopy, reaching heights of 45–55 m, although on occasion a few species will grow to 70–80 m tall. They need to be able to withstand the hot temperatures and strong winds in some areas. Eagles, butterflies, bats, and certain monkeys inhabit this layer.

Canopy Layer

The canopy layer contains the majority of the largest trees, typically 30–45 m tall. The densest areas of biodiversity are found in the forest canopy, a more or less continuous cover of foliage formed by adjacent treetops. The canopy, by some estimates, is home to 50 percent of all plant species, suggesting that perhaps half of all life on Earth could be found there. Epiphytic plants attach to trunks and branches, and obtain water and minerals from rain and debris that collects on the supporting plants. The fauna is similar to that found in the emergent layer, but more diverse. A quarter of all insect species are believed to exist in the rainforest canopy.

Scientists have long suspected the richness of the canopy as a habitat, but have only recently developed practical methods of exploring it. As long ago as 1917, naturalist William Beebe declared that “another continent of life remains to be discovered, not upon the Earth, but one to two hundred feet above it, extending over thousands of square miles.” True exploration of this habitat only began in the 1980s, when scientists developed methods to reach the canopy, such as firing ropes into the trees using crossbows. Exploration of the canopy is still in its infancy, but other methods include the use of balloons and airships to float above the highest branches and the building of cranes and walkways planted on the forest floor. The science of accessing tropical forest canopy using airships, or similar aerial platforms, is called dendronautics.

Understory Layer

The understory layer lies between the canopy and the forest floor. The understory (or understorey) is home to a number of birds, snakes, and lizards, as well as predators such as jaguars, boa constrictors, and leopards. The leaves are much larger at this level. Insect life is also abundant. Many seedlings that will grow to the canopy level are present in the understory. Only about 5% of the sunlight shining on the rainforest reaches the understory. This layer can also be called a *shrub layer*, although the shrub layer may also be considered a separate layer.

Forest Floor

The forest floor, the bottom-most layer, receives only 2% of sunlight. Only plants adapted to low light can grow in this region. Away from riverbanks, swamps, and clearings where dense undergrowth is found, the forest floor is relatively clear of vegetation because of the low sunlight penetration. It also contains decaying plant and animal matter, which disappears quickly due to the warm, humid conditions promoting rapid decay. Many forms of fungi grow here which help decay the animal and plant waste.

Flora and Fauna

More than half of the world's species of plants and animals are found in the rainforest. Rainforests support a very broad array of fauna including mammals, reptiles, birds, and invertebrates. Mammals may include primates, felids, and other families. Reptiles include snakes, turtles, chameleons, and other families while birds include such families as vangidae and Cuculidae. Dozens of families of invertebrates are found in rainforests. Fungi are also very common in rainforest areas as they can feed on the decomposing remains of plant and animal life. These species are rapidly disappearing due to deforestation, habitat loss, and biochemical releases into the atmosphere.

Soils

Despite the growth of vegetation in a tropical rainforest, soil quality is often quite poor. Rapid bacterial decay prevents the accumulation of humus. The concentration of iron and aluminium oxides by the laterization process gives the oxisols a bright red colour and sometimes produces minable deposits such as bauxite. Most trees have roots near the surface as there are not many nutrients below the ground; most of the trees minerals come from the top layer of decomposing leaves (mainly) and animals. On younger substrates, especially of volcanic origin, tropical soils may be quite fertile. If the trees are cleared, the rain can get at the exposed soil, washing it away. Eventually streams will form, then rivers. Flooding becomes possible.

Effect on Global Climate

A natural rainforest emits and absorbs vast quantities of carbon dioxide. On a global scale, long-term fluxes are approximately in balance, so that an undisturbed rainforest would have a small net impact on atmospheric carbon dioxide levels, though they may have other climatic effects (on cloud formation, for example, by recycling water vapour). No rainforest today can be considered to be undisturbed. Human induced deforestation plays a significant role in causing rainforests to release carbon dioxide, as do natural processes such as drought that result in tree death. Some climate models run with interactive vegetation and predict a large loss of Amazonian rainforest around 2050 due to drought, leading to forest dieback and the subsequent feedback of releasing more carbon dioxide. Five million years from now, the Amazon rainforest will have long since dried and transformed itself into a savannah; killing itself in the progress (even if all human deforestation activity ceases overnight). The descendants of our known animals will adapt to the dry savannah of the former Amazonian rainforest and thrive in the new, warmer temperatures.

Human Uses

Tropical rainforests provide timber as well as animal products such as meat and hides. Rainforests also have value as tourism destinations and for the ecosystem services provided. Many foods originally came from tropical forests, and are still mostly grown on plantations in regions that were formerly primary forest. Also, plant derived medicines are commonly used for fever, fungal infections, burns, gastrointestinal problems, pain, respiratory problems, and wound treatment.

Native People

On January 18, 2007, FUNAI reported that it had confirmed the presence of 67 different uncontacted tribes in Brazil, up from 40 in 2005. With this addition, Brazil has now overtaken the island of New Guinea as the country having the largest number of uncontacted tribes. The province of Irian Jaya or West Papua in the island of New Guinea is home to an estimated 44 uncontacted tribal groups.

Central African rainforest is home of the Mbuti pygmies, one of the hunter-gatherer peoples living in equatorial rainforests characterised by their short height (below one and a half metres, or 59 inches, on average). They were the subject of a study by Colin Turnbull, *The Forest People*, in 1962. Pygmies who live in Southeast Asia are, amongst others, referred to as "Negritos."

Deforestation

Tropical and temperate rainforests have been subjected to heavy logging and agricultural clearance throughout the 20th century and the area covered by rainforests around the world is shrinking. Biologists have estimated that large numbers of species are being driven to extinction (possibly more than 50,000 a year; at that rate, says E. O. Wilson of Harvard University, a quarter or more of all species on Earth could be exterminated within 50 years) due to the removal of habitat with destruction of the rainforests.

Another factor causing the loss of rainforest is expanding urban areas. Littoral rainforest growing along coastal areas of eastern Australia is now rare due to ribbon development to accommodate the demand for seachange lifestyles.

The forests are being destroyed at a rapid pace. Almost 90% of West Africa's rainforest has been destroyed. Since the arrival of humans 2000 years ago, Madagascar has lost two thirds of its original rainforest. At present rates, tropical rainforests in Indonesia would be logged out in 10 years and Papua New Guinea in 13 to 16 years.

Several countries, notably Brazil, have declared their deforestation a national emergency. Amazon deforestation jumped by 69% in 2008 compared to 2007's twelve months, according to official government data. Deforestation could wipe out or severely damage nearly 60% of the Amazon Rainforest by 2030, says a new report from WWF.

However, a January 30, 2009 New York Times article stated, "By one estimate, for every acre of rain forest cut down each year, more than 50 acres of new forest are growing in the tropics..." The new forest includes secondary forest on former farmland and so-called degraded forest.

From a new recent report in September 2009, new opportunities are beginning to discover they could save the rainforest. In Brazil, Environment Minister Carlos Minc announced proudly that the rate of deforestation of the Amazon fell by 46 percent last year. That means the lowest logging level since the country began to keep annual statistics 21 years ago. But not only Brazil has reduced deforestation as a whole also slowed the loss of forest down. The annual decline is now over two thousand. Deforestation decreases in a country as it becomes richer and more industrialized. Therefore, there are exceptions in a group of countries where deforestation has become so profitable that it is an important part in the growth of prosperity. New goal is to stop felling the forest, but also in managing the forest long-term, which occurs on a larger scale. More police officers guarding the rainforest, and stifle the illegal logging.

4

Geography and the Tropics

The tropics is a region of the Earth by the Equator. It is limited in latitude by the Tropic of Cancer in the northern hemisphere at approximately 23°□262 □163 □(□or□23.438°□)□N and the Tropic of Capricorn in the southern hemisphere at 23°□262 □163 □(□or□23.438°□)□S. The tropics are also referred to as the tropical zone and the torrid zone.

The tropics include all the areas on the Earth where the Sun reaches a point directly overhead and a point directly underneath at least once during the solar year. Outside the tropics, the Sun never reaches a point directly overhead or a point directly underneath at any time during the year.

Seasons and Climate

"Tropical" is sometimes used in a general sense for a tropical climate to mean warm to hot and moist year-round, often with the sense of lush vegetation.

The seasons in the tropics are dominated by the movement of the tropical rain belt (or ITCZ the intertropical convergence zone) which moves from the northern to the southern tropics and back over the course of a year, resulting in a dry season and a wet season rather than the various temperatures and day lengths indicative of the spring, summer, autumn and winter pattern found in areas outside tropics.

However, the starting dates of the seasons are related to the tropics, despite the fact that these dates only apply in the temperate and polar regions with only the winter solstice date applying in the tropics because the summer solstice occurs when the Sun is at the zenith, which occurs at different dates for different latitudes. Spring begins when the Sun is directly over the Equator (vernal equinox). Summer begins when the Sun is directly over the Tropic of Cancer in the north or when the Sun is directly over the Tropic of Capricorn in the south (summer solstice). Autumn begins when the Sun is again directly over the Equator (autumnal equinox). Winter begins when the Sun is directly over the Tropic of Capricorn in the north or when the Sun is directly over the Tropic of Cancer in the south (winter solstice).

Regions within the tropics may well not have a tropical climate. There are alpine tundra and snow-capped peaks, including Mauna Kea, Mount Kilimanjaro, and the Andes as far south as the northernmost parts of Chile and Argentina. Under the Koppen climate classification, much of the area within the geographical tropics is classed not as "tropical" but as "dry" (arid or semi-arid) including the Sahara Desert and Australian Outback.

Tropical Ecosystems

Tropical plants and animals are those species native to the tropics. Tropical ecosystems may consist of rainforests, dry deciduous forests, spiny forests, desert and other habitat types. There are often significant areas of biodiversity, and species endemism present, particularly in rainforests and dry deciduous forests. Some examples of important biodiversity and/or high endemism ecosystems are: El Yunque National Forest in Puerto Rico, Costa Rican and Nicaraguan rainforests, Brazilian and Venezuelan Amazon Rainforest territories, Madagascar dry deciduous forests, Waterberg Biosphere of South Africa and eastern Madagascar rainforests. Often the soils of tropical forests are low in nutrient content making them quite vulnerable to slash-and-burn techniques, which are sometimes an element of shifting cultivation agricultural systems.

In biogeography, the tropics are divided into paleotropics (Africa, Asia and Australia) and neotropics (Central and South America). Together, they are sometimes referred to as the pantropics. The neotropic region should not be confused with the ecozone of the same name; in the Old World, this is unambiguous as the paleotropics correspond to the Afrotropical, Indomalayan, and partly the Australasian and Oceanic ecozones. About 40 percent of the world’s human population lives within the tropical zone (by 2008 statistics), and by 2060, 60% of the human population will be in the tropics due to high birth rates and migration.

Tropic of Cancer

The Tropic of Cancer is the circle of latitude on the earth that marks the apparent position of the sun at the time of the northern solstice.

Also referred to as the Northern tropic, it is one of the two tropics (with the Tropic of Capricorn) that represent the extremes of the sun’s path across the sky with the change of the seasons.

Because of the tilt of the earth’s axis of rotation relative to the plane of its orbit around the sun, the sun is directly overhead on the Tropic of Cancer at the June solstice. It is the northernmost latitude at which the sun reaches 90 degrees above the horizon at its zenith, with the Northern Hemisphere tilted toward the sun to its maximum extent.

The tropics are two of the five major degree measures or major circles of latitude that mark maps of the Earth, besides the Arctic and Antarctic Circles and the Equator.

The Tropic of Cancer currently (Epoch 2010) lies 23°□262 □163 north of the Equator.

It is drifting south at the rate of almost half a second (0.47) of latitude per year (it was at exactly 23º 27' in year 1917).

North of this latitude are the subtropics and the North Temperate Zone. The equivalent line of latitude south of the Equator is called the Tropic of Capricorn, and the region between the two, centred on the Equator, is the tropics.

Name

The imaginary line is called the Tropic of Cancer because when it was named, the sun was in the direction of the constellation Cancer (Latin for *crab*) at the June solstice. However, this is no longer true due to the precession of the equinoxes. According to International Astronomical Union boundaries, the Sun now is in Taurus at the June solstice.

According to sidereal astrology, which divides the zodiac into 12 equal parts, the Sun is in Gemini at that time. The word "tropic" itself comes from the Greek *τροπη (tropi)*, meaning *turn*, referring to the fact that the sun appears to "turn back" at the solstices.

Circumnavigation

According to the Federation Aeronautique International's rules, for a flight to compete for a round-the-world speed record, it must cover a distance no less than the length of the Tropic of Cancer, as well as cross all of the meridians, and end on the same airfield where it started. This length is set to be 36,787.559 kilometres - a number which implies a precision that certainly does not exist, considering the variations of the Tropic of Cancer as described above.

For an ordinary circumnavigation the rules are somewhat relaxed and the distance is set to a rounded value of at least 37,000 kilometres.

Ocean

An ocean is a major body of saline water, and a principal component of the hydrosphere. Approximately 71% of the Earth's surface (~3.61 X 10^{14} m^2) is covered by ocean, a continuous body of water that is customarily divided into several principal oceans and smaller seas. More than half of this area is over 3,000 metres (9,800 ft) deep. Average oceanic salinity is around 35 parts per thousand (ppt) (3.5%), and nearly all seawater has a salinity in the range of 30 to 38 ppt. Scientists estimate that 230,000 marine life forms of all types are currently known, but the total could be up to 10 times that number.

Overview

Though generally described as several 'separate' oceans, these waters comprise one global, interconnected body of salt water sometimes referred to as the World Ocean or global ocean. This concept of a continuous body of water with relatively free interchange among its parts is of fundamental importance to oceanography. The major oceanic divisions are defined in part by the continents, various archipelagos, and other criteria. These divisions are (in descending order of size):

- Pacific Ocean, which separates Asia and Australia from the Americas
- Atlantic Ocean, which separates the Americas from Eurasia and Africa
- Indian Ocean, which washes upon southern Asia and separates Africa and Australia
- Southern Ocean, which, unlike other oceans, has no landmass separating it from other oceans and is therefore sometimes subsumed as the southern portions of the Pacific, Atlantic, and Indian Oceans, which encircles Antarctica and covers much of the Antarctic
- Arctic Ocean, sometimes considered a sea of the Atlantic, which covers much of the Arctic and washes upon northern North America and Eurasia

The Pacific and Atlantic may be further subdivided by the equator into northern and southern portions. Smaller regions of the oceans are called seas, gulfs, bays, straits and other names.

Geologically, an ocean is an area of oceanic crust covered by water. Oceanic crust is the thin layer of solidified volcanic basalt that covers the Earth's mantle. Continental crust is thicker but less dense. From this perspective, the earth has three oceans: the World Ocean, the Caspian Sea, and Black Sea. The latter two were formed by the collision of Cimmeria with Laurasia. The Mediterranean Sea is at times a discrete ocean, because tectonic plate movement has repeatedly broken its connection to the World Ocean through the Strait of Gibraltar. The Black Sea is connected to the Mediterranean through the Bosporus, but the Bosporus is a natural canal cut through continental rock some 7,000 years ago, rather than a piece of oceanic sea floor like the Strait of Gibraltar.

Despite their names, smaller landlocked bodies of saltwater that are *not* connected with the World Ocean, such as the Aral Sea, are actually salt lakes.

Ocean and Life

The ocean has a significant effect on the biosphere. Oceanic evaporation, as a phase of the water cycle, is the source of most rainfall, and ocean temperatures determine climate and wind patterns that affect life on land. Life within the ocean evolved 3 billion years prior to life on land. Both the depth and distance from shore strongly influence the amount and kinds of plants and animals that live there.

Physical Properties

The area of the World Ocean is 361×10^6 km^2 (139×10^6 mi^2) Its volume is approximately 1.3 billion cubic kilometres (310 million cu mi). This can be thought of as a cube of water with an edge length of 1,111 kilometres (690 mi).

Its average depth is 3,790 metres (12,430 ft), and its maximum depth is 10,923 metres (6.787 mi) Nearly half of the world's marine waters are over 3,000 metres (9,800 ft) deep. The vast expanses of deep ocean (anything below 200 metres (660 ft) cover about 66% of the Earth's surface. This does not include seas not connected to the World Ocean, such as the Caspian Sea.

The total mass of the hydrosphere is about 1,400,000,000,000,000,000 metric tons (1.5×10^{18} short tons) or 1.4×10^{21} kg, which is about 0.023 percent of the Earth's total mass. Less than 3 percent is freshwater; the rest is saltwater, mostly in the ocean.

Colour

A common misconception is that the oceans are blue primarily because the sky is blue. In fact, water has a very slight blue colour that can only be seen in large volumes. While the sky's reflection does contribute to the blue appearance of the surface, it is not the primary cause. The primary cause is the absorption by the water molecules' nuclei of red photons from the incoming light, the only known example of colour in nature resulting from vibrational, rather than electronic, dynamics.

Glow

Sailors and other mariners have reported that the ocean often emits a visible glow, or luminescence, which extends for miles at night. In 2005, scientists announced that for the first time, they had obtained photographic evidence of this glow. It may be caused by bioluminescence.

Exploration

Ocean travel by boat dates back to prehistoric times, but only in modern times has extensive underwater travel become possible.

The deepest point in the ocean is the Mariana Trench, located in the Pacific Ocean near the Northern Mariana Islands. Its maximum depth has been estimated to be 10,971 metres (35,994 ft) (plus or minus 11 meters; see the Mariana Trench article for discussion of the various estimates of the maximum depth.) The British naval vessel, *Challenger II* surveyed the trench in 1951 and named the deepest part of the trench, the “Challenger Deep”. In 1960, the Trieste successfully reached the bottom of the trench, manned by a crew of two men.

Much of the ocean bottom remains unexplored and unmapped. A global image of many underwater features larger than 10 kilometres (6.2 mi) was created in 1995 based on gravitational distortions of the nearby sea surface.

Regions and Depths

Oceanographers divide the ocean into regions depending on physical and biological conditions of these areas. The pelagic zone includes all open ocean regions, and can be divided into further regions categorized by depth and light abundance. The photic zone covers the oceans from surface level to 200 metres down. This is the region where photosynthesis can occur and therefore is the most biodiverse. Since plants require photosynthesis, life found deeper than this must either rely on material sinking from above or find another energy source; hydrothermal vents are the primary option in what is known as the aphotic zone (depths exceeding 200 m). The pelagic part of the photic zone is known as the epipelagic. The pelagic part of the aphotic zone can be further divided into regions that succeed each other vertically according to temperature.

The mesopelagic is the uppermost region. Its lowermost boundary is at a thermocline of 12 °C (54 °F), which, in the tropics generally lies at 700–1,000 metres (2,300–3,300 ft). Next is the bathypelagic lying between 10-4 °C (43 °F), typically between 700–1,000 metres (2,300–3,300 ft) and 2,000–4,000 metres (6,600–13,000 ft) Lying along the top of the abyssal plain is the abyssalpelagic, whose lower boundary lies at about 6,000 metres (20,000 ft). The last zone includes the deep trenches, and is known as the hadalpelagic. This lies between 6,000–11,000 metres (20,000–36,000 ft) and is the deepest oceanic zone.

Along with pelagic aphotic zones there are also benthic aphotic zones. These correspond to the three deepest zones of the deep-sea. The bathyal zone covers the continental slope down to about 4,000 metres (13,000 ft). The abyssal zone covers the abyssal plains between 4,000 and 6,000 m. Lastly, the hadal zone corresponds to the hadalpelagic zone which is found in the oceanic trenches. The pelagic zone can also be split into two subregions, the neritic zone and the oceanic zone. The neritic encompasses the water mass directly above the continental shelves, while the oceanic zone includes all the completely open water. In contrast, the littoral zone covers the region between low and high tide and represents the transitional area between marine and terrestrial conditions. It is also known as the intertidal zone because it is the area where tide level affects the conditions of the region.

Geology

The ocean floor spreads from mid-ocean ridges where two plates adjoin. Where two plates move towards each other, one plate subducts under another plate (oceanic or continental) leading to an oceanic trench.

Climate Effects

Ocean currents greatly affect the Earth's climate by transferring heat from the tropics to the polar regions, and transferring warm or cold air and precipitation to coastal regions, where winds may carry them inland. Surface heat and freshwater fluxes create global density gradients that drive the thermohaline circulation part of large-scale ocean circulation. It plays an important role in supplying heat to the polar regions, and thus in sea ice regulation. Changes in the thermohaline circulation are thought to have significant impacts on the Earth's radiation budget. Insofar as the thermohaline circulation governs the rate at which deep waters reach the surface, it may also significantly influence atmospheric carbon dioxide concentrations. For a discussion of the possibilities of changes to the thermohaline circulation under global warming, see shutdown of thermohaline circulation.

It is often stated that the thermohaline circulation is the primary reason that the climate Western Europe is so temperate. An alternate hypothesis claims that this is largely incorrect, and that Europe is warm mostly because it lies downwind of an ocean basin, and because atmospheric waves bring warm air north from the subtropics.

The Antarctic Circumpolar Current encircles that continent, influencing the area's climate and connecting currents in several oceans.

One of the most dramatic forms of weather occurs over the oceans: tropical cyclones (also called "typhoons" and "hurricanes" depending upon where the system forms).

Biology

Lifeforms native to oceans include:

- Radiata.
- Fish.
- Cetacea such as whales, dolphins and porpoises.
- Cephalopods such as octopus and squid.
- Crustaceans such as lobsters, clams, shrimp and krill.
- Marine worms.
- Plankton.
- Echinoderms such as brittle stars, starfish, sea cucumbers and sand dollars.

Economy

The oceans are essential to transportation: most of the world's goods move by ship between the world's seaports.

Oceans are also the major supply source for the fishing industry. Some of the more major these are shrimp, fish, crabs and lobster.

Ancient Oceans

Continental drift continually reconfigures the oceans, joining and splitting bodies of water. Ancient oceans include:

- Bridge River Ocean, the ocean between the ancient Insular Islands and North America.
- Iapetus Ocean, the southern hemisphere ocean between Baltica and Avalonia.
- Panthalassa, the vast world ocean that surrounded the Pangaea supercontinent.
- Rheic Ocean.
- Slide Mountain Ocean, the ocean between the ancient Intermontane Islands and North America.
- Tethys Ocean, the ocean between the ancient continents of Gondwana and Laurasia.
- Khanty Ocean, the ocean between Baltica and Siberia.
- Mirovia, the ocean that surrounded the Rodinia supercontinent.
- Paleo-Tethys Ocean, the ocean between Gondwana and the Hunic terranes.
- Poseidon Ocean.
- Proto-Tethys Ocean.
- Pan-African Ocean, the ocean that surrounded the Pannotia supercontinent.
- Superocean, the ocean that surrounds a global supercontinent.
- Ural Ocean, the ocean between Siberia and Baltica.

Physics of the Sea: Waves and Currents

In fluid dynamics, wind waves or, more precisely, wind-generated waves are surface waves that occur on the free surface of oceans, seas, lakes, rivers, and canals or even on small puddles and ponds. They usually result from the wind blowing over a vast enough stretch of fluid surface. Some waves in the oceans can travel thousands of miles before reaching land. Wind waves range in size from small ripples to huge rogue waves. When directly being generated and affected by the local winds, a wind wave system is called a wind sea. After the wind ceases to blow, wind waves are called *swell*. Or, more generally, a swell consists of wind generated waves that are not — or hardly — affected by the local wind at the same moment. They have been generated elsewhere, or some time ago. Wind waves in the ocean are called ocean surface waves. Tsunamis are a specific type of wave not caused by wind but by geological effects. In deep water, tsunamis are not visible because they are small in height and very long in wavelength. They may grow to devastating proportions at the coast due to reduced water depth.

Wave Formation

The great majority of large breakers one observes on a beach result from distant winds. Five factors influence the formation of wind waves:

- Wind speed
- Distance of open water that the wind has blown over (called the *fetch*)
- Width of area affected by fetch
- Time duration the wind has blown over a given area
- Water depth

All of these factors work together to determine the size of wind waves. The greater each of the variables, the larger the waves. Waves are characterized by:

- Wave height (from trough to crest)
- Wavelength (from crest to crest)
- Period (time interval between arrival of consecutive crests at a stationary point)
- Wave propagation direction

Waves in a given area typically have a range of heights. For weather reporting and for scientific analysis of wind wave statistics, their characteristic height over a period of time is usually expressed as *significant wave height*. This figure represents an average height of the highest one-third of the waves in a given time period (usually chosen somewhere in the range from 20 minutes to twelve hours), or in a specific wave or storm system. Given the variability of wave height, the largest individual waves are likely to be about twice the reported significant wave height for a particular day or storm.

Types of Wind Waves

Three different types of wind waves develop over time:

- Capillary waves, or ripples
- Seas
- Swells

Ripples appear on smooth water when the wind blows, but will die quickly if the wind stops. The restoring force that allows them to propagate is surface tension. Seas are the larger-scale, often irregular motions that form under sustained winds. They tend to last much longer, even after the wind has died, and the restoring force that allows them to persist is gravity. As seas propagate away from their area of origin, they naturally separate according to their direction and wavelength. The regular wave motions formed in this way are known as swells.

Individual "rogue waves" (also called "freak waves", "monster waves", "killer waves", and "king waves") sometimes occur, up to heights near 30 meters, and being much higher than the other waves in the sea state. Such waves are distinct from tides, caused by the Moon and Sun's gravitational pull, tsunamis that are caused by underwater earthquakes or landslides, and waves generated by underwater explosions or the fall of meteorites — all having far longer wavelengths than wind waves.

Wave Breaking

Some waves undergo a phenomenon called "breaking". A breaking wave is one whose base can no longer support its top, causing it to collapse. A wave breaks when it runs into shallow water, or when two wave systems oppose and combine forces. When the slope, or steepness ratio, of a wave is too great, breaking is inevitable. Individual waves in deep water break when the wave steepness — the ratio of the wave height H to the wavelength λ — exceeds about 0.17, so for $H > 0.17 \lambda$. In shallow water, with the water depth small compared to the wavelength, the individual waves break when their wave height H is larger than 0.8 times the water depth h, that is $H > 0.8 h$. Waves can also break if the wind grows strong enough to blow the crest off the base of the wave.

Three main types of breaking waves are identified by surfers or surf life-savers. Their varying characteristics make them more or less suitable for surfing, and present different dangers.

- Spilling, or rolling: these are the safest waves on which to surf. They can be found in most areas with relatively flat shorelines. They are the most common type of shorebreak
- Plunging, or dumping: these break suddenly and can "dump" swimmers—pushing them to the bottom with great force. These are the preferred waves for experienced surfers. Strong offshore winds and long wave periods can cause dumpers. They are often found where there is a sudden rise in the sea floor, such as a reef or sandbar
- Surging: these may never actually break as they approach the water's edge, as the water below them is very deep. They tend to form on steep shorelines. These waves can knock swimmers over and drag them back into deeper water

Science of Waves

A = At deep water. The orbital motion of fluid particles decreases rapidly with increasing depth below the surface.

B = At shallow water (sea floor is now at B). The elliptical movement of a fluid particle flattens with decreasing depth.

1 = Propagation direction.

2 = Wave crest.

3 = Wave trough.

Wind waves are mechanical waves that propagate along the interface between water and air; the restoring force is provided by gravity, and so they are often referred to as surface gravity waves. As the wind blows, pressure and friction forces perturb the equilibrium of the water surface. These forces transfer energy from the air to the water, forming waves. In the case of monochromatic linear plane waves in deep water, particles near the surface move in circular paths, making wind waves a combination of longitudinal (back and forth) and transverse (up and down) wave motions. When waves propagate in shallow water, (where the depth is less than half the wavelength) the particle trajectories are compressed into ellipses. As the wave amplitude (height) increases, the particle paths no longer form closed orbits; rather, after the passage of each crest, particles are displaced slightly from their previous positions, a phenomenon known as Stokes drift.

For intermediate and shallow water, the Boussinesq equations are applicable, combining frequency dispersion and nonlinear effects. And in very shallow water, the shallow water equations can be used.

As the depth below the free surface increases, the radius of the circular motion decreases. At a depth equal to half the wavelength λ, the orbital movement has decayed to less than 5% of its value at the surface. The phase speed of the surface wave (also called the celerity) is well approximated by.

$$c = \sqrt{\frac{g\lambda}{2\pi}\tanh\left(\frac{2\pi d}{\lambda}\right)}$$

Where:

c = phase speed;

λ = wavelength;

d = water depth;

g = acceleration due to gravity at the Earth's surface.

In deep water, where

$d \geq \frac{1}{2}\lambda$, so $\frac{2\pi d}{\lambda} \geq \pi$ and the hyperbolic tangent approaches 1, the speed c, in m/s, approximates

$1.25\sqrt{\lambda}$ when λ is measured in meters. This expression tells us that waves of different wavelengths travel at different speeds. The fastest waves in a storm are the ones with the longest wavelength. As a result, after a storm, the first waves to arrive on the coast are the long–wavelength swells.

When several wave trains are present, as is always the case in nature, the waves form groups. In deep water the groups travel at a group velocity which is half of the phase speed. Following a single wave in a group one can see the wave appearing at the back of the group, growing and finally disappearing at the front of the group.

As the water depth d decreases towards the coast, this will have an effect: wave height changes due to wave shoaling and refraction. As the wave height increases, the wave may become unstable when the crest of the wave moves faster than the trough. This causes *surf*, a breaking of the waves.

The movement of wind waves can be captured by wave energy devices. The energy density (per unit area) of regular sinusoidal waves depends on the water density ρ, gravity acceleration g and the wave height H (which, for regular waves, is equal to twice the amplitude, a):

$$E = \frac{1}{8}\rho g H^2 = \frac{1}{2}\rho g a^2.$$

The velocity of propagation of this energy is the group velocity.

Wind Wave Models

Surfers are very interested in the wave forecasts. There are many websites that provide predictions of the surf quality for the upcoming days and weeks. Wind wave models are driven by more general weather models that predict the winds and pressures over the oceans, seas and lakes.

Wind wave models are also an important part of examining the impact of shore protection and beach nourishment proposals. For many beach areas there is only *patchy information* about the wave climate, therefore estimating the effect of wind waves is important for managing littoral environments.

Ocean Current

An ocean current is a continuous, directed movement of ocean water generated by the forces acting upon this mean flow, such as breaking waves, wind, Coriolis force, temperature and salinity differences and tides caused by the gravitational pull of the Moon and the Sun. Depth contours, shoreline configurations and interaction with other currents influence a current's direction and strength.

Ocean currents can flow for great distances, and together they create the great flow of the global conveyor belt which plays a dominant part in determining the climate of many of the Earth's regions. Perhaps the most striking example is the Gulf Stream, which makes northwest Europe much more temperate than any other region at the same latitude. Another example is the Hawaiian Islands, where the climate is cooler (sub-tropical) than the tropical latitudes in which they are located, due to the effect of the California Current.

Function

Surface ocean currents are generally wind driven and develop their typical clockwise spirals in the northern hemisphere and counter-clockwise rotation in the southern hemisphere because of the imposed wind stresses. In wind driven currents, the Ekman spiral effect results in the currents flowing at an angle to the driving winds. The areas of surface ocean currents move somewhat with the seasons; this is most notable in equatorial currents.

Ocean basins generally have a non-symmetric surface current, in that the eastern equatorward-flowing branch is broad and diffuse whereas the western poleward-flowing branch is very narrow. These western boundary currents (of which the gulf stream is an example) are a consequence of basic fluid dynamics.

Deep ocean currents are driven by density and temperature gradients. Thermohaline circulation, also known as the ocean's conveyor belt, refers to the deep ocean density-driven ocean basin currents. These currents, which flow under the surface of the ocean and are thus hidden from immediate detection, are called submarine rivers. These are currently being researched by a fleet of underwater robots called Argo. Upwelling and downwelling areas in the oceans are areas where significant vertical movement of ocean water is observed.

Surface currents make up about 10% of all the water in the ocean. Surface currents are generally restricted to the upper 400 m (1,300 ft) of the ocean. The movement of deep water in the ocean basins is by density driven forces and gravity. The density difference is a function of different temperatures and salinity. Deep waters sink into the deep ocean basins at high latitudes where the temperatures are cold enough to cause the density to increase.

Ocean currents are measured in Sverdrup (Sv), where 1Sv is equivalent to a volume flow rate of 1,000,000 m^3 (35,000,000 cu ft) per second.

Importance

Knowledge of surface ocean currents is essential in reducing costs of shipping, since they reduce fuel costs. In the sail-ship era knowledge was even more essential. A good example of this is the Agulhas current, which long prevented Portuguese sailors from reaching India. Even today, the round-the-world sailing competitors employ surface currents to their benefit. Ocean currents are also very important in the dispersal of many life forms. An example is the life-cycle of the eel.

Ocean currents are important in the study of marine debris, and vice versa. These currents also affect temperatures throughout the world. For example, the current that brings warm water up the north Atlantic to northwest Europe stops ice from forming by the shores, which would block ships from entering and exiting ports.

Physics of the Sea: Tides and Seiches

Tides are the rise and fall of sea levels caused by the combined effects of the gravitational forces exerted by the Moon and the Sun and the rotation of the Earth. The tides occur with a period of approximately 12 hours and 25 minutes, and with an amplitude that is influenced by the alignment of the sun and moon and the shape of the near-shore bottom.

Most coastal areas experience two high and two low tides per day. One of these high tides is at the point on the earth which is closest to the moon. The other high tide is at the opposite point on the earth. This is because at the point right “under” the Moon (the sub-lunar point), the water is at its closest to the Moon, so it experiences stronger gravity and is raised. On the opposite side of the Earth (the antipodal point), the water is at its farthest from the moon, so it is pulled less; at this point the Earth moves more toward the Moon than the water does—causing that water to “rise” (relative to the Earth) as well. In between the sub-lunar and antipodal points, the force on the water is diagonal or transverse to the sub-lunar/antipodal axis (and always towards that axis), resulting in low tide.

The sun also exerts a (less powerful) gravitational attraction on the earth which results in a secondary tidal effect. When the earth, moon and sun are approximately aligned these two tidal effects reinforce one another (resulting in higher highs and lower lows). This alignment occurs approximately twice a month (shortly after the full and new moon). These recurring, extreme tides are termed spring tides. The opposite, most moderate tides are termed neap tides (occurring shortly after the first and last quarter moons).

Tides vary on timescales ranging from hours to years due to numerous influences. To make accurate records tide gauges at fixed stations measure the water level over time. Gauges ignore variations caused by waves with periods shorter than minutes. These data are compared to the reference (or datum) level usually called mean sea level.

While tides are usually the largest source of short-term sea-level fluctuations, sea levels are also subject to forces such as wind and barometric pressure changes, resulting in storm surges, especially in shallow seas and near coasts.

Tidal phenomena are not limited to the oceans, but can occur in other systems whenever a gravitational field that varies in time and space is present. For example, the solid part of the Earth is affected by tides.

Characteristics

Tide changes proceed via the following stages:

- Sea level rises over several hours, covering the intertidal zone; flood tide.
- The water rises to its highest level, reaching high tide.
- Sea level falls over several hours, revealing the intertidal zone; ebb tide.
- The water stops falling, reaching low tide.

Tides produce oscillating currents known as tidal streams. The moment that the tidal current ceases is called slack water or slack tide. The tide then reverses direction and is said to be turning. Slack water usually occurs near high water and low water. But there are locations where the moments of slack tide differ significantly from those of high and low water.

Tides are most commonly *semidiurnal* (two high waters and two low waters each day), or *diurnal* (one tidal cycle per day). The two high waters on a given day are typically not the same height (the daily inequality); these are the *higher high water* and the *lower high water* in tide tables. Similarly, the two low waters each day are the *higher low water* and the *lower low water*. The daily inequality is not consistent and is generally small when the Moon is over the equator.

Tidal Constituents

Tidal changes are the net result of multiple influences that act over varying periods. These influences are called tidal constituents. The primary constituents are the earth's rotation, the positions of Moon and the Sun relative to Earth, the moon's altitude above the earth, and bathymetry.

Variations with periods of less than half a day are called *harmonic constituents*. Conversely, *long period* constituents cycle over days, months, or years.

Principal Lunar Semidiurnal Constituent

In most locations, the largest constituent is the "principal lunar semidiurnal", also known as the *M2* (or M_2) tidal constituent. Its period is about 12 hours and 25.2 minutes, exactly half a *tidal lunar day*, which is the average time separating one lunar zenith from the next, and thus is the time required for the Earth to rotate once relative to the Moon. Simple tide clocks track this constituent The lunar day is longer than the earth day because the Moon orbits in the same direction the Earth spins. This is analogous to the minute hand on a watch crossing the hour hand at 12:00 and then again at about 1:05 (not at 1:00).

Semidiurnal Range Differences

When there are two high tides each day with different heights (and two low tides also of different heights), the pattern is called a *mixed semidiurnal tide*.

Range Variation: Springs and Neaps

The semidiurnal range (the difference in height between high and low waters over about a half day) varies in a two-week cycle. Around new and full moon when the Sun, Moon and Earth form a line (a condition known as syzygy), the tidal force due to the Sun reinforces that due to the Moon. The tide's range is then at its maximum: this is called the *spring tide*, or just *springs*. It is not named after the season but, like that word, derives from an earlier meaning of "jump, burst forth, rise" as in a natural spring. When the Moon is at first quarter or third quarter, the Sun and Moon are separated by 90° when viewed from the Earth, and the solar gravitational force partially cancels the Moon's. At these points in the lunar cycle, the tide's range is at its minimum: this is called the *neap tide*, or *neaps* (a word of uncertain origin). Spring tides result in high waters that are higher than average, low waters that are lower than average, *slack water* time that is shorter than average and stronger tidal currents than average. Neaps result in less extreme tidal conditions. There is about a seven day interval between springs and neaps.

Lunar Altitude

The changing distance separating the Moon and Earth also affects tide heights. When the Moon is at perigee the range increases, and when it is at apogee the range shrinks. Every 7½ lunations (the full cycles from full moon to new to full), perigee coincides with either a new or full moon causing perigean spring tides with the largest *tidal range*. If a storm happens to be moving onshore at this time, the consequences (property damage, etc.) can be especially severe.

Bathymetry

The shape of the shoreline and the ocean floor change the way that tides propagate, so there is no simple, general rule that predicts the time of high water from the Moon's position in the sky. Coastal characteristics such as underwater bathymetry and coastline shape mean that individual location characteristics affect tide forecasting; actual high water time and height may differ from model predictions due to the coastal morphology's effects on tidal flow.

However, for a given location the relationship between lunar altitude and the time of high or low tide (the lunitidal interval) is relatively constant and predictable, as is the time of high or low tide relative to other points on the same coast. For example, the high tide at Norfolk, Virginia predictably occurs approximately two and a half hours before the moon passes directly overhead.

Land masses and ocean basins act as barriers against water moving freely around the globe, and their varied shapes and sizes affect the size of tidal frequencies. As a result, tidal patterns vary. For example, in the U.S., the East coast has predominantly semi-diurnal tides, as do Europe's Atlantic coasts, while the West coast predominantly has mixed tides.

Other Constituents

These include solar gravitational effects, the obliquity (tilt) of the Earth's equator and rotational axis, the inclination of the plane of the lunar orbit and the elliptical shape of the Earth's orbits of the Earth.

Phase and Amplitude

Because the M_2 tidal constituent dominates in most locations, the stage or *phase* of a tide, denoted by the time in hours after high water is a useful concept. Tidal stage is also measured in degrees, with 360° per tidal cycle. Lines of constant tidal phase are called *cotidal lines*, analogous to lines on topographical maps. High water is reached simultaneously along the cotidal lines extending from the coast out into the ocean, and cotidal lines (and hence tidal phases) advance along the coast. Semidiurnal and long phase constituents are measured from high water, diurnal from maximum flood tide. This and the discussion that follows is precisely true only for a single tidal constituent.

For an ocean in the shape of a circular basin enclosed by a coastline, the *cotidal lines* point radially inward and must eventually meet at a common point, the amphidromic point. The amphidromic point is at once cotidal with high and low waters, which is satisfied by *zero* tidal motion. (The rare exception occurs when the tide encircles an island, as it does around New Zealand and Madagascar.) Tidal motion generally lessens moving away from continental coasts, so that crossing the cotidal lines are contours of constant *amplitude* (half the distance between high and low water) which decrease to zero at the amphidromic point. For a semidiurnal tide the amphidromic point can be thought of roughly like the centre of a clock face, with the hour hand pointing in the direction of the high water cotidal line, which is directly opposite the low water cotidal line. High water rotates about the amphidromic point once every 12 hours in the direction of rising cotidal lines, and away from ebbing cotidal lines. This rotation is generally clockwise in the southern hemisphere and counter clock wise in the northern hemisphere, and is caused by the Coriolis effect. The difference of cotidal phase from the phase of a reference tide is the *epoch*. The reference tide is the hypothetical constituent equilibrium tide on a landless Earth measured at 0° longitude, the Greenwich meridian.

In the North Atlantic, because the cotidal lines circulate counter clock wise around the amphidromic point, the high tide passes New York harbour approximately an hour ahead of Norfolk harbour. South of Cape Hatteras the tidal forces are more complex, and cannot be predicted reliably based on the North Atlantic cotidal lines.

Physics

History of Tidal Physics

Tidal physics was important in the early development of heliocentrism and celestial mechanics, with the existence of two daily tides being explained by the moon's gravity. More precisely the daily tides were explained by universal gravitation involving the interaction of the moon's gravity and the sun's gravity to cause the variation of tides.

An early explanation of tides was given by Galileo Galilei in his 1632 *Dialogue Concerning the Two Chief World Systems,* whose working title was *Dialogue on the Tides*. However, the resulting theory was incorrect - he attributed the tides to water sloshing due to the Earth's movement around the Sun, hoping to provide mechanical proof of the Earth's movement - and the value of the theory is disputed, as discussed there. At the same time Johannes Kepler correctly suggested that the Moon caused the tides, based upon ancient observation and correlations, which was rejected by Galileo. It was originally mentioned in Ptolemy's Tetrabiblos as being derived from ancient observation.

Sir Isaac Newton (1642–1727) was the first person to explain tides scientifically. His explanation of the tides (and many other phenomena) was published in 1686, in the second volume of the Principia.

Newton laid the foundations of scientific tidal studies with his mathematical explanation of tide-generating forces in the *Philosophiae Naturalis Principia Mathematica* (1687). Newton first applied the theory of universal gravitation to account for the tides as due to the lunar and solar attractions, offering an initial theory of the tide-generating force. Newton and others before Pierre-Simon Laplace worked with an equilibrium theory, largely concerned with an approximation that describes the tides that would occur in a non-inertial ocean evenly covering the whole Earth. The tide-generating force (or its corresponding potential) is still relevant to tidal theory, but as an intermediate quantity rather than as a final result; theory has to consider also the Earth's dynamic tidal response to the force, a response that is influenced by bathymetry, Earth's rotation, and other factors.

In 1740, the Academic Royale des Sciences in Paris offered a prize for the best theoretical essay on tides. Daniel Bernoulli, Leonhard Euler, Colin Maclaurin and Antoine Cavalleri shared the prize.

Maclaurin used Newton's theory to show that a smooth sphere covered by a sufficiently deep ocean under the tidal force of a single deforming body is a prolate spheroid (essentially a three dimensional oval) with major axis directed toward the deforming body. Maclaurin was the first to write about the Earth's rotational effects on motion. Euler realized that the tidal force's *horizontal* component (more than the vertical) drives the tide. In 1744 Jean le Rond d'Alembert studied tidal equations for the atmosphere which did not include rotation.

Pierre-Simon Laplace formulated a system of partial differential equations relating the ocean's horizontal flow to its surface height, the first major dynamic theory for water tides. The Laplace tidal equations are still in use today. William Thomson, 1st Baron Kelvin, rewrote Laplace's equations in terms of vorticity which allowed for solutions describing tidally-driven coastally-trapped waves, known as Kelvin waves.

Others including Kelvin and Henri Poincare further developed Laplace's theory. Based on these developments and the lunar theory of E W Brown, Arthur Thomas Doodson developed and published in 1921 the first modern development of the tide-generating potential in harmonic form: Doodson distinguished 388 tidal frequencies. Some of his methods remain in use.

Forces

The tidal force produced by a massive object (Moon, hereafter) on a small particle located on or in an extensive body (Earth, hereafter) is the vector difference between the gravitational force exerted by the Moon on the particle, and the gravitational force that would be exerted on the particle if it were located at the Earth's centre of mass. Thus, the tidal force depends not on the strength of the lunar gravitational field, but on its gradient (which falls off approximately as the inverse cube of the distance to the originating gravitational body). The solar *gravitational force* on the Earth is on average 179 times stronger than the lunar, but because the Sun is on average 389 times farther from the Earth, its field gradient is weaker. The solar tidal force is 46% as large as the lunar. More precisely, the lunar tidal acceleration (along the Moon-Earth axis, at the Earth's surface) is about 1.1×10^{-7} *g*, while the solar tidal acceleration (along the Sun-Earth axis, at the Earth's surface) is about 0.52×10^{-7} *g*, where *g* is the gravitational acceleration at the Earth's surface. Venus has the largest effect of the other planets, at 0.000113 times the solar effect.

Tidal forces can also be analyzed this way: each point of the Earth experiences the Moon's radially decreasing gravity differently; they are subject to the *tidal forces* of,

The ocean's surface is closely approximated by an equipotential surface, (ignoring ocean currents) commonly referred to as the geoid. Since the gravitational force is equal to the potential's gradient, there are no tangential forces on such a surface, and the ocean surface is thus in gravitational equilibrium. Now consider the effect of massive external bodies such as the Moon and Sun. These bodies have strong gravitational fields that diminish with distance in space and which act to alter the shape of an equipotential surface on the Earth. This deformation has a fixed spatial orientation relative to the influencing body. The Earth's rotation relative to this shape causes the daily tidal cycle. Gravitational forces follow an inverse-square law (force is inversely proportional to the square of the distance), but tidal forces are inversely proportional to the cube of the distance. The ocean surface moves to adjust to changing tidal equipotential, tending to rise when the tidal potential is high, which occurs on the part of the Earth nearest to and furthest from the Moon. When the tidal equipotential changes, the ocean surface is no longer aligned with it, so that the apparent direction of the vertical shifts. The surface then experiences a down slope, in the direction that the equipotential has risen.

Laplace's Tidal Equations

Ocean depths are much smaller than their horizontal extent. Thus, the response to tidal forcing can be modelled using the Laplace tidal equations which incorporate the following features:

1. The vertical (or radial) velocity is negligible, and there is no vertical shear—this is a sheet flow.
2. The forcing is only horizontal (tangential).
3. The Coriolis effect appears as a fictitious lateral forcing proportional to velocity.
4. The surface height's rate of change is proportional to the negative divergence of velocity multiplied by the depth. As the horizontal velocity stretches or compresses the ocean as a sheet, the volume thins or thickens, respectively.

The boundary conditions dictate no flow across the coastline and free slip at the bottom.

The Coriolis effect steers waves to the right in the northern hemisphere and to the left in the southern allowing coastally trapped waves. Finally, a dissipation term can be added which is an analog to viscosity.

Amplitude and Cycle Time

The theoretical amplitude of oceanic tides caused by the Moon is about 54 centimetres (21 in) at the highest point, which corresponds to the amplitude that would be reached if the ocean possessed a uniform depth, there were no landmasses, and the Earth were rotating in step with the Moon's orbit. The Sun similarly causes tides, of which the theoretical amplitude is about 25 centimetres (9.8 in) (46% of that of the Moon) with a cycle time of 12 hours. At spring tide the two effects add to each other to a theoretical level of 79 centimetres (31 in), while at neap tide the theoretical level is reduced to 29 centimetres (11 in). Since the orbits of the Earth about the Sun, and the Moon about the Earth, are elliptical, tidal amplitudes change somewhat as a result of the varying Earth–Sun and Earth–Moon distances. This causes a variation in the tidal force and theoretical amplitude of about ±18% for the Moon and ±5% for the Sun. If both the Sun and Moon were at their closest positions and aligned at new moon, the theoretical amplitude would reach 93 centimetres (37 in). Real amplitudes differ considerably, not only because of depth variations and continental obstacles, but also because wave propagation across the ocean has a natural period of the same order of magnitude as the rotation period: if there were no land masses, it would take about 30 hours for a long wavelength surface wave to propagate along the equator halfway around the Earth (by comparison, the Earth's lithosphere has a natural period of about 57 minutes).

Dissipation

Earth's tidal oscillations introduce dissipation at an average rate of about 3.75 terawatt. About 98% of this dissipation is by marine tidal movement. Dissipation arises as basin-scale tidal flows drive smaller-scale flows which experience turbulent dissipation. This tidal drag creates torque on the Moon that gradually transfers angular momentum to its orbit, and a gradual increase in Earth–Moon separation. The equal and opposite torque on the Earth correspondingly decreases its rotational velocity. Thus, over geologic time, the Moon recedes from the Earth, at about 3.8 centimetres (1.5 in) year, lengthening the terrestrial day. Day length has increased by about 2 hours in the last 600 million years. Assuming (as a crude approximation) that the deceleration rate has been constant, this would imply that 70 million years ago, day length was on the order of 1% shorter with about 4 more days per year.

Observation and Prediction

From ancient times, tidal observation and discussion has increased in sophistication, first marking the daily recurrence, then tides' relationship to the Sun and Moon. Pytheas travelled to the British Isles about 325 BC and seems to be the first to have related spring tides to the phase of the Moon.

In the 2nd century BC, the Babylonian astronomer, Seleucus of Seleucia, correctly described the phenomenon of tides in order to support his heliocentric theory. He correctly theorized that tides were caused by the Moon, although he believed that the interaction was mediated by the pneuma. He noted that tides varied in time and strength in different parts of the world. According to Strabo (1.1.9), Seleucus was the first to link tides to the lunar attraction, and that the height of the tides depends on the Moon's position relative to the Sun.

The *Naturalis Historia* of Pliny the Elder collates many tidal observations, e.g., the spring tides are a few days after (or before) new and full moon and are highest around the equinoxes, though Pliny noted many relationships now regarded as fanciful. In his *Geography*, Strabo described tides in the Persian Gulf having their greatest range when the Moon was furthest from the plane of the equator. All this despite the relatively small amplitude of Mediterranean basin tides. (The strong currents through the Strait of Messina and between Greece and the island of Euboea through the Euripus puzzled Aristotle). Philostratus discussed tides in Book Five of The Life of Apollonius of Tyana. Philostratus mentions the moon, but attributes tides to "spirits". In Europe around 730 AD, the Venerable Bede described how the rising tide on one coast of the British Isles coincided with the fall on the other and described the time progression of high water along the Northumbrian coast.

In the 9th century, the Arabian earth-scientist, Al-Kindi (Alkindus), wrote a treatise entitled *Risala fi l-Illa al-Failali l-Madd wa l-Fazr* (*Treatise on the Efficient Cause of the Flow and Ebb*), in which he presents an argument on tides which "depends on the changes which take place in bodies owing to the rise and fall of temperature." He describes a precise laboratory experiment that proved his argument.

The first tide table in China was recorded in 1056 AD primarily for visitors wishing to see the famous tidal bore in the Qiantang River. The first known British tide table is thought to be that of John, Abbott of Wallingford (d. 1213), based on high water occurring 48 minutes later each day, and three hours earlier at the Thames mouth than upriver at London.

William Thomson (Lord Kelvin) led the first systematic harmonic analysis of tidal records starting in 1867. The main result was the building of a tide-predicting machine using a system of pulleys to add together six harmonic time functions. It was "programmed" by resetting gears and chains to adjust phasing and amplitudes. Similar machines were used until the 1960s.

The first known sea-level record of an entire spring–neap cycle was made in 1831 on the Navy Dock in the Thames Estuary. Many large ports had automatic tide gage stations by 1850.

William Whewell first mapped co-tidal lines ending with a nearly global chart in 1836. In order to make these maps consistent, he hypothesized the existence of amphidromes where co-tidal lines meet in the mid-ocean. These points of no tide were confirmed by measurement in 1840 by Captain Hewett, RN, from careful soundings in the North Sea.

Timing

In most places there is a delay between the phases of the Moon and the effect on the tide. Springs and neaps in the North Sea, for example, are two days behind the new/full Moon and first/third quarter. This is called the tide's *age*.

The local bathymetry greatly influences the tide's exact time and height at a particular coastal point. There are some extreme cases: the Bay of Fundy, on the east coast of Canada, features the world's largest well-documented tidal ranges, 16 metres (52 ft) because of its shape. Some experts believe Ungava Bay in northern Quebec to have even higher tidal ranges, but it is free of pack ice for only about four months every year, while the Bay of Fundy rarely freezes.

Southampton in the United Kingdom has a double high water caused by the interaction between the region's different tidal harmonics. This is contrary to the popular belief that the flow of water around the Isle of Weight creates two high waters. The Isle of Weight is important, however, since it is responsible for the 'Young Flood Stand', which describes the pause of the incoming tide about three hours after low water.

Because the oscillation modes of the Mediterranean Sea and the Baltic Sea do not coincide with any significant astronomical forcing period, the largest tides are close to their narrow connections with the Atlantic Ocean. Extremely small tides also occur for the same reason in the Gulf of Mexico and Sea of Japan. On the southern coast of Australia, because the coast is mainly straight (partly because of the tiny quantities of runoff flowing from rivers), tidal ranges are equally small.

Analysis

Isaac Newton's theory of gravitation first enabled an explanation of why there were generally two tides a day, not one, and offered hope for detailed understanding. Although it may seem that tides could be predicted via a sufficiently detailed knowledge of the instantaneous astronomical forcings, the actual tide at a given location is determined by astronomical forces accumulated over many days. Precise results require detailed knowledge of the shape of all the ocean basins—their bathymetry and coastline shape.

Current procedure for analysing tides follows the method of harmonic analysis introduced in the 1860s by William Thomson. It is based on the principle that the astronomical theories of the motions of Sun and Moon determine a large number of component frequencies, and at each frequency there is a component of force tending to produce tidal motion, but that at each place of interest on the Earth, the tides respond at each frequency with an amplitude and phase peculiar to that locality. At each place of interest, the tide heights are therefore measured for a period of time sufficiently long (usually more than a year in the case of a new port not previously studied) to enable the response at each significant tide-generating frequency to be distinguished by analysis, and to extract the tidal constants for a sufficient number of the strongest known components of the astronomical tidal forces to enable practical tide prediction. The tide heights are expected to follow the tidal force, with a constant amplitude and phase delay for each component. Because astronomical frequencies and phases can be calculated with certainty, the tide height at other times can then be predicted once the response to the harmonic components of the astronomical tide-generating forces has been found.

The main patterns in the tides are;

- The twice-daily variation
- The difference between the first and second tide of a day
- The spring–neap cycle
- The annual variation

The *Highest Astronomical Tide* is the perigean spring tide when both the Sun and the Moon are closest to the Earth.

When confronted by a periodically varying function, the standard approach is to employ Fourier series, a form of analysis that uses sinusoidal functions as a *basis* set, having frequencies that are zero, one, two, three, etc., times the frequency of a particular fundamental cycle. These multiples are called *harmonics* of the fundamental frequency, and the process is termed harmonic analysis. If the basis set of sinusoidal functions suit the behaviour being modelled, relatively few harmonic terms need to be added. Orbital paths are very nearly circular, so sinusoidal variations are suitable for tides.

For the analysis of tide heights, the Fourier series approach has in practice to be made more elaborate than the use of a single frequency and its harmonics. The tidal patterns are decomposed into many sinusoids having many fundamental frequencies, corresponding (as in the lunar theory) to many different combinations of the motions of the Earth, the Moon, and the angles that define the shape and location of their orbits.

For tides, then, *harmonic analysis* is not limited to harmonics of a single frequency. In other words, the harmonies are multiples of many fundamental frequencies, not just of the fundamental frequency of the simpler Fourier series approach. Their representation as a Fourier series having only one fundamental frequency and its (integer) multiples would require many terms, and would be severely limited in the time-range for which it would be valid.

The study of tide height by harmonic analysis was begun by Laplace, William Thomson (Lord Kelvin), and George Darwin. A.T. Doodson extended their work, introducing the *Doodson*

Number notation to organise the hundreds of resulting terms. This approach has been the international standard ever since, and the complications arise as follows: the tide-raising force is notionally given by sums of several terms. Each term is of the form

$$A \cdot \cos(w \cdot t + p)$$

where A is the amplitude, w is the angular frequency usually given in degrees per hour corresponding to t measured in hours, and p is the phase offset with regard to the astronomical state at time $t = 0$. There is one term for the Moon and a second term for the Sun. The phase p of the first harmonic for the Moon term is called the lunitidal interval or high water interval. The next step is to accommodate the harmonic terms due to the elliptical shape of the orbits. Accordingly, the value of A is not a constant but also varying with time, slightly, about some average figure. Replace it then by $A(t)$ where A is another sinusoid, similar to the cycles and epicycles of Ptolemaic theory. Accordingly,

$$A(t) = A \cdot (1 + A_a \cdot \cos(w_a \cdot t + p_a))$$

which is to say an average value A with a sinusoidal variation about it of magnitude A_a, with frequency w_a and phase p_a. Thus the simple term is now the product of two cosine factors:

$$A \cdot [1 + A_a \cdot \cos(w_a + p_a)] \cdot \cos(w \cdot t + p)$$

Given that for any x and y

$$\cos(x) \cdot \cos(y) = ½ \cdot \cos(x + y) + ½ \cdot \cos(x - y)$$

It is clear that a compound term involving the product of two cosine terms each with their own frequency is the same as *three* simple cosine terms that are to be added at the original frequency and also at frequencies which are the sum and difference of the two frequencies of the product term. (Three, not two terms, since the whole expression is $(1 + \cos(x)) \cdot \cos(y)$.) Consider further that the tidal force on a location depends also on whether the Moon (or the Sun) is above or below the plane of the equator, and that these attributes have their own periods also incommensurable with a day and a month, and it is clear that many combinations result. With a careful choice of the basic astronomical frequencies, the Doodson Number annotates the particular additions and differences to form the frequency of each simple cosine term.

Remember that astronomical tides do *not* include weather effects. Also, changes to local conditions (sandbank movement, dredging harbour mouths, etc.) away from those prevailing at the measurement time affect the tide's actual timing and magnitude. Organisations quoting a "highest astronomical tide" for some location may exaggerate the figure as a safety factor against analytical uncertainties, distance from the nearest measurement point, changes since the last observation time, ground subsidence, etc., to avert liability should an engineering work be overtopped. Special care is needed when assessing the size of a "weather surge" by subtracting the astronomical tide from the observed tide.

Careful Fourier data analysis over a nineteen-year period (the *National Tidal Datum Epoch* in the U.S.) uses frequencies called the *tidal harmonic constituents*. Nineteen years is preferred because the Earth, Moon and Sun's relative positions repeat almost exactly in the Metonic cycle of 19 years, which is long enough to include the 18.613 year lunar nodal tidal constituent. This analysis can be done using only the knowledge of the forcing *period*, but without detailed understanding of the mathematical derivation, which means that useful tidal tables have been constructed for centuries. The resulting amplitudes and phases can then be used to predict the expected tides. These are usually dominated by the constituents near 12 hours (the *semidiurnal* constituents), but there are major constituents near 24 hours (*diurnal*) as well. Longer term constituents are 14 day or *fortnightly*, monthly, and semiannual. Semidiurnal tides dominated coastline, but some areas such as the South China Sea and the Gulf of Mexico are primarily diurnal. In the semidiurnal areas, the primary constituents M_2 (lunar) and S_2 (solar) periods differ slightly, so that the relative phases, and thus the amplitude of the combined tide, change fortnightly (14 day period).

In the M_2 plot above, each cotidal line differs by one hour from its neighbours, and the thicker lines show tides in phase with equilibrium at Greenwich. The lines rotate around the amphidromic points counter clock wise in the northern hemisphere so that from Baja California to Alaska and from France to Ireland the M_2 tide propagates northward. In the southern hemisphere this direction is clockwise. On the other hand M_2 tide propagates counter clock wise around New Zealand, but this is because the islands act as a dam and permit the tides to have different heights on the islands' opposite sides. (The tides do propagate northward on the east side and southward on the west coast, as predicted by theory.)

The exception is at Cook Strait where the tidal currents periodically link high to low water. This is because cotidal lines 180° around the amphidromes are in opposite phase, for example high water across from low water at each end of Cook Strait. Each tidal constituent has a different pattern of amplitudes, phases, and amphidromic points, so the M_2 patterns cannot be used for other tide components.

Current

The tides' influence on current flow is much more difficult to analyse, and data is much more difficult to collect. A tidal height is a simple number which applies to a wide region simultaneously. A flow has both a magnitude and a direction, both of which can vary substantially with depth and over short distances due to local bathymetry. Also, although a water channel's centre is the most useful measuring site, mariners object when current-measuring equipment obstructs waterways. A flow proceeding up a curved channel is the same flow, even though its direction varies continuously along the channel. Surprisingly, flood and ebb flows are often not in opposite directions. Flow direction is determined by the upstream channel's shape, not the downstream channel's shape. Likewise, eddies may form in only one flow direction.

Nevertheless, current analysis is similar to tidal analysis: in the simple case, at a given location the flood flow is in mostly one direction, and the ebb flow in another direction. Flood velocities are given positive sign, and ebb velocities negative sign. Analysis proceeds as though these are tide heights.

In more complex situations, the main ebb and flood flows do not dominate. Instead, the flow direction and magnitude trace an ellipse over a tidal cycle (on a polar plot) instead of along the ebb and flood lines. In this case, analysis might proceed along pairs of directions, with the primary and secondary directions at right angles. An alternative is to treat the tidal flows as complex numbers, as each value has both a magnitude and a direction.

Tide flow information is most commonly seen on nautical charts, presented as a table of flow speeds and bearings at hourly intervals, with separate tables for spring and neap tides. The timing is relative to high water at some harbour where the tidal behaviour is similar in pattern, though it may be far away.

As with tide height predictions, tide flow predictions based only on astronomical factors do not incorporate weather conditions, which can *completely* change the outcome.

The tidal flow through Cook Strait between the two main islands of New Zealand is particularly interesting, as the tides on each side of the strait are almost exactly out of phase, so that one side's high water is simultaneous with the other's low water. Strong currents result, with almost zero tidal height change in the strait's centre. Yet, although the tidal surge normally flows in one direction for six hours and in the reverse direction for six hours, a particular surge might last eight or ten hours with the reverse surge enfeebled. In especially boisterous weather conditions, the reverse surge might be entirely overcome so that the flow continues in the same direction through three or more surge periods.

A further complication for Cook Strait's flow pattern is that the tide at the north side (e.g. at Nelson) follows the common bi-weekly spring–neap tide cycle (as found along the west side of the country), but the south side's tidal pattern has only *one* cycle per month, as on the east side: Wellington, and Napier.

Power Generation

Tidal energy can be extracted by two means: inserting a water turbine into a tidal current, or building ponds that release/ admit water through a turbine. In the first case, the energy amount is entirely determined by the timing and tidal current magnitude. However, the best currents may be unavailable because the turbines would obstruct ships. In the second, the impoundment dams are expensive to construct, natural water cycles are completely disrupted, ship navigation is disrupted. However, with multiple ponds, power can be generated at chosen times. So far, there are few installed systems for tidal power generation (most famously, La Rance by Saint Malo, France) which faces many difficulties. Aside from environmental issues, simply withstanding corrosion and biological fouling pose engineering challenges.

Tidal power proponents point out that, unlike wind power systems, generation levels can be reliably predicted, save for weather effects. While some generation is possible for most of the tidal cycle, in practice turbines lose efficiency at lower operating rates. Since the power available from a flow is proportional to the cube of the flow speed, the times during which high power generation is possible are brief.

Navigation

Tidal flows are important for navigation, and significant errors in position occur if they are not accommodated. Tidal heights are also important; for example many rivers and harbours have a shallow “bar” at the entrance which prevents boats with significant draft from entering at low tide.

Until the advent of automated navigation, competence in calculating tidal effects was important to naval officers. The certificate of examination for lieutenants in the Royal Navy once declared that the prospective officer was able to “shift his tides”.

Tidal flow timings and velocities appear in *tide charts* or a tidal stream atlas. Tide charts come in sets. Each chart covers a single hour between one high water and another (they ignore the leftover 24 minutes) and show the average tidal flow for that hour. An arrow on the tidal chart indicates the direction and the average flow speed (usually in knots) for spring and neap tides. If a tide chart is not available, most nautical charts have “tidal diamonds” which relate specific points on the chart to a table giving tidal flow direction and speed.

The standard procedure to counteract tidal effects on navigation is to (1) calculate a “dead reckoning” position (or Dr.) from travel distance and direction, (2) mark the chart (with a vertical cross like a plus sign) and (3) draw a line from the Dr. in the tide’s direction. The distance the tide moves the boat along this line is computed by the tidal speed, and this gives an “estimated position” or EP (traditionally marked with a dot in a triangle).

Nautical charts display the water’s “charted depth” at specific locations with “soundings” and the use of bathymetric contour lines to depict the submerged surface’s shape. These depths are relative to a “chart datum”, which is typically the water level at the lowest possible astronomical tide (tides may be lower or higher for meteorological reasons) and are therefore the minimum possible water depth during the tidal cycle. “Drying heights” may also be shown on the chart, which are the heights of the exposed seabed at the lowest astronomical tide.

Tide tables list each day’s high and low water heights and times. To calculate the actual water depth, add the charted depth to the published tide height. Depth for other times can be derived from tidal curves published for major ports. The rule of twelfths can suffice if an accurate curve is not available. This approximation presumes that the increase in depth in the six hours between low and high water is: first hour — 1/12, second — 2/12, third — 3/12, fourth — 3/12, fifth — 2/12, sixth — 1/12.

Biological Aspects

Intertidal Ecology

Intertidal ecology is the study of intertidal ecosystems, where organisms live between the low and high water lines. At low water, the intertidal is exposed (or ‘emersed’) whereas at high water, the intertidal is underwater (or ‘immersed’). Intertidal ecologists therefore study the interactions between intertidal organisms and their environment, as well as among the different species. The most important interactions may vary according to the type of intertidal community. The broadest classifications are based on substrates — rocky shore or soft bottom.

Intertidal organisms experience a highly variable and often hostile environment, and have adapted to cope with and even exploit these conditions. One easily visible feature is vertical zonation, in which the community divides into distinct horizontal bands of specific species at each elevation above low water. A species' ability to cope with desiccation determines its upper limit, while competition with other species sets its lower limit.

Humans use intertidal regions for food and recreation. Over exploitation can damage intertidals directly. Other anthropogenic actions such as introducing invasive species and climate change have large negative effects. Marine Protected Areas are one option communities can apply to protect these areas and aid scientific research.

Biological Rhythms

The approximately fortnightly tidal cycle has large effects on intertidal organisms. Hence their biological rhythms tend to occur in rough multiples of this period. Many other animals such as the vertebrates, display similar rhythms. Examples include gestation and egg hatching. In humans, the menstrual cycle lasts roughly a month, an even multiple of the tidal period. Such parallels at least hint at the common descent of all animals from a marine ancestor.

Other Tides

When oscillating tidal currents in the stratified ocean flow over uneven bottom topography, they generate internal waves with tidal frequencies. Such waves are called *internal tides*.

In addition to oceanic tides, large lakes can experience small tides and even planets can experience *atmospheric tides* and *earth tides*. These are continuum mechanical phenomena. The first two take place in fluids. The third affects the Earth's thin solid crust surrounding its semi-liquid interior (with various modifications).

Lake Tides

Large lakes such as Superior and Erie can experience tides of 1 to 4 cm, but these can be masked by meteorologically induced phenomena such as seiche. The tide in Lake Michigan is described as 0.5 inches to 1.5 inches or 1 and 3/4 inches.

Atmospheric Tides

Atmospheric tides are negligible at ground level and aviation altitudes, masked by weather's much more important effects.

Atmospheric tides are both gravitational and thermal in origin and are the dominant dynamics from about 80–120 kilometres (50–75 mi) above which the molecular density becomes too low to support fluid behaviour.

Earth Tides

Earth tides or terrestrial tides affect the entire Earth's mass, which acts similarly to a liquid gyroscope with a very thin crust. The Earth's crust shifts (in/out, east/west, north/south) in response to lunar and solar gravitation, ocean tides, and atmospheric loading. While negligible for most human activities, terrestrial tides' semidiurnal amplitude can reach about 55 centimetres (22 in) at the equator—15 centimetres (5.9 in) is due to the Sun—which is important in GPS calibration and VLBI measurements. Precise astronomical angular measurements require knowledge of the Earth's rotation rate and nutation, both of which are influenced by earth tides. The semi-diurnal M_2 Earth tides are nearly in phase with the Moon with a lag of about two hours.

Some particle physics experiments must adjust for terrestrial tides. For instance, at CERN and SLAC, the very large particle accelerators account for terrestrial tides. Among the relevant effects are circumference deformation for circular accelerators and particle beam energy. Since tidal forces generate currents in conducting fluids in the Earth's interior, they in turn affect the Earth's magnetic field. Earth tides have also been linked to earthquakes.

Galactic Tides

Galactic tides are the tidal forces exerted by galaxies on stars within them and satellite galaxies orbiting them. The galactic tide's effects on the Solar System's Oort cloud are believed to cause 90 percent of long-period comets.

Misapplications

Tsunamis, the large waves that occur after earthquakes, are sometimes called *tidal waves*, but this name is given by their *resemblance* to the tide, rather than any actual link to the tide. Other phenomena unrelated to tides but using the word *tide* are rip tide, storm tide, hurricane tide, and black or red tides.

Seiche

A seiche is a standing wave in an enclosed or partially enclosed body of water. Seiches and seiche-related phenomena have been observed on lakes, reservoirs, swimming pools, bays, and seas. The key requirement for formation of a seiche is that the body of water be at least partially bounded, allowing the formation of the standing wave.

The term was promoted by the Swiss hydrologist Francois-Alphonse Forel in 1890, who was the first to make scientific observations of the effect in Lake Geneva, Switzerland. The word originates in a Swiss French dialect word that means "to sway back and forth", which had apparently long been used in the region to describe oscillations in alpine lakes.

Causes and Nature of Seiches

Seiches are often imperceptible to the naked eye, and observers in boats on the surface may not notice that a seiche is occurring due to the extremely long wavelengths. The effect is caused by resonances in a body of water that has been disturbed by one or more of a number of factors, most often meteorological effects (wind and atmospheric pressure variations), seismic activity or by tsunamis. Gravity always seeks to restore the horizontal surface of a body of liquid water, as this represents the configuration in which the water is in hydrostatic equilibrium. Vertical harmonic motion results, producing an impulse that travels the length of the basin at a velocity that depends on the depth of the water. The impulse is reflected back from the end of the basin, generating interference. Repeated reflections produce standing waves with one or more nodes, or points, that experience no vertical motion. The frequency of the oscillation is determined by the size of the basin, its depth and contours, and the water temperature.

The longest natural period for a seiche in an enclosed rectangular body of water is usually represented by the Merian formula:

$$\text{Period}(T) = \frac{2L}{\sqrt{gh}}$$

where L is the length, h the average depth of the body of water, and g the acceleration of gravity.

Higher order harmonics are also observed. The period of the second harmonic will be half the natural period, the period of the third harmonic will be a third of the natural period, and so forth.

Seiches Around the World

Seiches have been observed on both lakes and seas. The key requirement is that the body of water be partially constrained to allow formation of standing waves. Regularity of geometry is not required, even harbours with exceedingly irregular shapes are routinely observed to oscillate with very stable frequencies.

Lake Seiches

Small rhythmic seiches are almost always present on larger lakes. On the North American Great Lakes, seiche is often called *slosh*. It is always present, but is usually unnoticeable, except during periods of unusual calm. Harbours, bays, and estuaries are often prone to small seiches with amplitudes of a few centimetres and periods of a few minutes. Seiches can also form in semi-enclosed seas; the North Sea often experiences a lengthwise seiche with a period of about 36 hours.

The National Weather Service issues low water advisories for portions of the Great Lakes when seiches of 2 feet or greater are likely to occur. Lake Erie is particularly prone to wind-caused seiches because of its shallowness and elongation. These can lead to extreme seiches of up to 5 m (16 feet) between the ends of the lake. The effect is similar to a storm surge like that caused by hurricanes along ocean coasts, but the seiche effect can cause oscillation back and forth across the lake for some time. In 1954, Hurricane Hazel piled up water along the northwestern Lake Ontario shoreline near Toronto, causing extensive flooding, and established a seiche that subsequently caused flooding along the south shore.

Lake seiches can occur very quickly: on July 13, 1995, a big seiche on Lake Superior caused the water level to fall and then rise again by three feet (one meter) within fifteen minutes, leaving some boats hanging from the docks on their mooring lines when the water retreated. The same storm system that caused the 1995 seiche on Lake Superior produced a similar effect in Lake Huron, in which the water level at Port Huron changed by six feet (1.8 m) over two hours. On Lake Michigan, eight fishermen were swept away and drowned when a 10-foot seiche hit the Chicago waterfront on June 26, 1954.

Lakes in seismically active areas, such as Lake Tahoe in California/Nevada, are significantly at risk from seiches. Geological evidence indicates that the shores of Lake Tahoe may have been hit by seiches and tsunamis as much as 10 m (33 feet) high in prehistoric times, and local researchers have called for the risk to be factored into emergency plans for the region.

Earthquake-generated seiches can be observed thousands of miles away from the epicentre of a quake. Swimming pools are especially prone to seiches caused by earthquakes, as the ground tremors often match the resonant frequencies of small bodies of water. The 1994 Northridge earthquake in California caused swimming pools to overflow across southern California. The massive Good Friday Earthquake that hit Alaska in 1964 caused seiches in swimming pools as far away as Puerto Rico. The earthquake that hit Lisbon, Portugal in 1755 caused seiches 2,000 miles (3,000 km) away in Loch Lomond, Loch Long, Loch Katrine and Loch Ness in Scotland and in canals in Sweden. The 2004 Indian Ocean earthquake caused seiches in standing water bodies in many Indian states as well as in Bangladesh, Nepal and northern Thailand. Seiches were again observed in Uttar Pradesh, Tamil Nadu and West Bengal in India as well as in many locations in Bangladesh during the 2005 Kashmir earthquake The 1950 Chayu-Upper Assam earthquake is known to have generated seiches as far as Norway and southern England. Other earthquakes in the Indian sub-continent known to have generated seiches include the 1803 Kumaon-Barahat, 1819 Allah Bund, 1842 Central Bengal, 1905 Kangra, 1930 Dhubri, 1934 Nepal-Bihar, 2001 Bhuj, 2005 Nias, 2005 Teresa Island earthquakes. The February 27, 2010 Chile earthquake produced a seiche on Lake Pontchartrain, Louisiana with a height of around 0.5 feet.

Sea and Bay Seiches

Seiches have been observed in seas such as the Adriatic Sea and the Baltic Sea, resulting in flooding of Venice and St.

Petersburg respectively. The latter is constructed on drained marshlands at the mouth of the Neva river. Seiche-induced flooding is common along the Neva river in the autumn. The seiche is driven by a low pressure region in the North Atlantic moving onshore, giving rise to cyclonic lows on the Baltic Sea. The low pressure of the cyclone draws greater-than-normal quantities of water into the virtually land-locked Baltic. As the cyclone continues inland, long, low-frequency seiche waves with wavelengths up to several hundred kilometres are established in the Baltic. When the waves reach the narrow and shallow Neva Bay, they become much higher — ultimately flooding the Neva embankments. Similar phenomena are observed at Venice, resulting in the MOSE Project, a system of 79 mobile barriers designed to protect the three entrances to the Venetian Lagoon.

Nagasaki Bay is a typical area in Japan where seiches have been observed from time to time, most often in the spring — especially in March. On 31 March 1979, the Nagasaki tide station recorded a maximum water-level displacement of 2.78 metres (9.1 ft), at that location and due to the seiche. The maximum water-level displacement in the whole bay during this seiche event is assumed to have reached 4.70 metres (15.4 ft), at the bottom of the bay. Seiches in Western Kyushu — including Nagasaki Bay — are often induced by a low in the atmospheric pressure passing South of Kyushu island. Seiches in Nagasaki Bay have a period of about 30 to 40 minutes. Locally, *seiche* is called *Abiki*. The word of *Abiki* is considered to have been derived from *Amibiki*, which literally means: the dragging-away (*biki*) of a fishing net (*ami*). Seiches not only cause damage to the local fishery but also may result in flooding of the coast around the bay, as well as in the destruction of port facilities.

Seiches can also be induced by tsunami, a wave train (series of waves) generated in a body of water by a pulsating or abrupt disturbance that vertically displaces the water column. On occasion, tsunamis can produce seiches as a result of local geographic peculiarities. For instance, the tsunami that hit Hawaii in 1946 had a fifteen-minute interval between wave fronts. The natural resonant period of Hilo Bay is about thirty minutes. That meant that every second wave was in phase with the motion of Hilo Bay, creating a seiche in the bay. As a result, Hilo suffered worse damage than any other place in Hawaii, with the tsunami/seiche reaching a height of 26 feet along the Hilo Bayfront, killing 96 people in the city alone. Seiche waves may continue for several days after a tsunami.

Underwater (Internal) Waves

Although the bulk of the technical literature addresses surface seiches, which are readily observed, seiches are also observed beneath the lake surface acting along the thermocline in constrained bodies of water.

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Nature of Cartography

Cartography is the study and practice of making maps (also can be called mapping). Combining science, aesthetics, and technique, cartography builds on the premise that reality can be modeled in ways that communicate spatial information effectively.

The fundamental problems of traditional cartography are to:

- Set the map's agenda and select traits of the object to be mapped. This is the concern of map editing. Traits may be physical, such as roads or land masses, or may be abstract, such as toponyms or political boundaries.
- Represent the terrain of the mapped object on flat media. This is the concern of map projections.
- Eliminate characteristics of the mapped object that are not relevant to the map's purpose. This is the concern of generalization.
- Reduce the complexity of the characteristics that will be mapped. This is also the concern of generalization.
- Orchestrate the elements of the map to best convey its message to its audience. This is the concern of map design.

Modern cartography is closely integrated with geographic information science (GIScience) and constitutes many theoretical and practical foundations of geographic information systems.

History

The earliest known map is a matter of some debate, both because the definition of "map" is not sharp and because some artifacts speculated to be maps might actually be something else. A wall painting, which may depict the ancient Anatolian city of Catalhoyuk (previously known as Catal Huyuk or Catal Huyuk), has been dated to the late 7th millennium BCE. Other known maps of the ancient world include the Minoan "House of the Admiral" wall painting from c. 1600 BCE, showing a seaside community in an oblique perspective and an engraved map of the holy Babylonian city of Nippur, from the Kassite period (14th – 12th centuries BCE). The oldest surviving world maps are the Babylonian world maps from the 9th century BCE. One shows Babylon on the Euphrates, surrounded by a circular landmass showing Assyria, Urartu and several cities, in turn surrounded by a "bitter river" (Oceanus), with seven islands arranged around it. Another depicts Babylon as being further north from the centre of the world.

The ancient Greeks and Romans created maps, beginning at latest with Anaximander in the 6th century BC. In the 2nd century AD, Ptolemy produced his treatise on cartography, Geographia. This contained Ptolemy's world map - the world then known to Western society *(Ecumene)*. As early as the 700s, Arab scholars were translating the works of the Greek geographers into Arabic.

In ancient China, geographical literature spans back to the 5th century BC. The oldest extant Chinese maps come from the State of Qin, dated back to the 4th century BC, during the Warring States Period. In the book of the *Xin Yi Xiang Fa Yao*, published in 1092 by the Chinese scientist Su Song, a star map on the equidistant cylindrical projection. Although this method of charting seems to have existed in China even prior to this publication and scientist, the greatest significance of the star maps by Su Song is that they represent the oldest existent star maps in printed form.

Early forms of cartography of India included legendary paintings; maps of locations described in Indian epic poetry, for example, the *Ramayana*. Indian cartographic traditions also covered the locations of the Pole star, and other constellations of use. These charts may have been in use by the beginning of the Common Era for purposes of navigation.

Mappa mundi is the general term used to describe Medieval European maps of the world. Approximately 1,100 mappae mundi are known to have survived from the Middle Ages. Of these, some 900 are found illustrating manuscripts and the remainder exist as stand-alone documents (Woodward).

The Arab geographer, Muhammad al-Idrisi, produced his medieval atlas *Tabula Rogeriana* in 1154. He incorporated the knowledge of Africa, the Indian Ocean and the Far East, gathered by Arab merchants and explorers with the information inherited from the classical geographers to create the most accurate map of the world up until his time. It remained the most accurate world map for the next three centuries.

In the Age of Exploration, from the 15th century to the 17th century, European cartographers both copied earlier maps (some of which had been passed down for centuries) and drew their own based on explorers' observations and new surveying techniques. The invention of the magnetic compass, telescope and sextant enabled increasing accuracy. In 1492, Martin Behaim, a German cartographer, made the oldest extant globe of the Earth.

Johannes Werner refined and promoted the *Werner map projection*. In 1507, Martin Waldseemüller produced a globular world map and a large 12-panel world wall map (*Universalis Cosmographia*) bearing the first use of the name "America". Portuguese cartographer, Diego Ribero, was author of the first known planisphere with a graduated Equator (1527). Italian cartogapher Battista Agnese produced at least 71 manuscript atlases of sea charts.

Due to the sheer physical difficulties inherent in cartography, map-makers frequently lifted material from earlier works without giving credit to the original cartographer. For example, one of the most famous early maps of North America is unofficially known as the "Beaver Map", published in 1715 by Herman Moll. This map is an exact reproduction of a 1698 work by Nicolas de Fer. De Fer in turn had copied images that were first printed in books by Louis Hennepin, published in 1697, and Francois Du Creux, in 1664. By the 1700s, mapmakers started to give credit to the original engraver by printing the phrase “After [the original cartographer]” on the work.

Technological Changes

In cartography, technology has continually changed in order to meet the demands of new generations of mapmakers and map users. The first maps were manually constructed with brushes and parchment; therefore, varied in quality and were limited in distribution. The advent of magnetic devices, such as the compass and much later, magnetic storage devices, allowed for the creation of far more accurate maps and the ability to store and manipulate them digitally.

Advances in mechanical devices such as the printing press, quadrant and vernier, allowed for the mass production of maps and the ability to make accurate reproductions from more accurate data. Optical technology, such as the telescope, sextant and other devices that use telescopes, allowed for accurate surveying of land and the ability of mapmakers and navigators to find their latitude by measuring angles to the North Star at night or the sun at noon.

Advances in photochemical technology, such as the lithographic and photochemical processes, have allowed for the creation of maps that have fine details, do not distort in shape and resist moisture and wear. This also eliminated the need for engraving, which further shortened the time it takes to make and reproduce maps.

Advances in electronic technology in the 20th century ushered in another revolution in cartography. Ready availability of computers and peripherals such as monitors, plotters, printers, scanners (remote and document) and analytic stereo plotters, along with computer programs for visualization, image processing, spatial analysis, and database management, have democratized and greatly expanded the making of maps. The ability to superimpose spatially located variables onto existing maps created new uses for maps and new industries to explore and exploit these potentials.

These days most commercial-quality maps are made using software that falls into one of three main types: CAD, GIS and specialized illustration software. Spatial information can be stored in a database, from which it can be extracted on demand. These tools lead to increasingly dynamic, interactive maps that can be manipulated digitally.

Map Types

General vs Thematic Cartography

In understanding basic maps, the field of cartography can be divided into two general categories: general cartography and thematic cartography. General cartography involves those maps that are constructed for a general audience and thus contain a variety of features. General maps exhibit many reference and location systems and often are produced in a series. For example, the 1:24,000 scale topographic maps of the United States Geological Survey (USGS) are a standard as compared to the 1:50,000 scale Canadian maps. The government of the UK produces the classic 1:50,000 (replacing the older 1 inch to 1 mile) "Ordnance Survey" maps of the entire UK and with a range of correlated larger- and smaller-scale maps of great detail.

Thematic cartography involves maps of specific geographic themes, oriented toward specific audiences. A couple of examples might be a dot map showing corn production in Indiana or a shaded area map of Ohio counties, divided into numerical choropleth classes. As the volume of geographic data has exploded over the last century, thematic cartography has become increasingly useful and necessary to interpret spatial, cultural and social data.

An orienteering map combines both general and thematic cartography, designed for a very specific user community. The most prominent thematic element is shading, that indicates degrees of difficulty of travel due to vegetation. The vegetation itself is not identified, merely classified by the difficulty ("fight") that it presents.

Topographic vs Topological

A topographic map is primarily concerned with the topographic description of a place, including (especially in the 20th century) the use of contour lines showing elevation. Terrain or relief can be shown in a variety of ways.

A topological map is a very general type of map, the kind you might sketch on a napkin. It often disregards scale and detail in the interest of clarity of communicating specific route or relational information. Beck's London Underground map is an iconic example. Though the most widely used map of "The Tube," it preserves little of reality: It varies scale constantly and abruptly, it straightens curved tracks, and it contorts directions haphazardly. The only topography on it is the River Thames, letting the reader know whether a station is north or south of the river. That and the topology of station order and interchanges between train lines are all that is left of the geographic space. Yet those are all a typical passenger wishes to know, so the map fulfils its purpose.

Map Design

Map Purpose and Informations' Selection

Arthur H. Robinson, an American cartographer influential in thematic cartography, stated that a map not properly designed "will be a cartographic failure." He also claimed, when considering all aspects of cartography, that "map design is perhaps the most complex." Robinson codified the mapmaker's understanding that a map must be designed foremost with consideration to the audience and its needs.

From the very beginning of mapmaking, maps "have been made for some particular purpose or set of purposes". The intent of the map should be illustrated in a manner in which the percipient acknowledges its purpose in a timely fashion. The term *percipient* refers to the person receiving information and was coined by Robinson. The principle of figure-ground refers to this notion of engaging the user by presenting a clear presentation, leaving no confusion concerning the purpose of the map. This will enhance the user's experience and keep his attention. If the user is unable to identify what is being demonstrated in a reasonable fashion, the map may be regarded as useless.

Making a meaningful map is the ultimate goal. Alan MacEachren explains that a well designed map "is convincing because it implies authenticity" (1994). An interesting map will no doubt engage a reader. Information richness or a map that is multivariate shows relationships within the map. Showing several variables allows comparison, which adds to the meaningfulness of the map. This also generates hypothesis and stimulates ideas and perhaps further research. In order to convey the message of the map, the creator must design it in a manner which will aid the reader in the overall understanding of its purpose. The title of a map may provide the “needed link” necessary for communicating that message, but the overall design of the map fosters the manner in which the reader interprets it (Monmonier, 1993).

In the 21st century it is possible to find a map of virtually anything from the inner workings of the human body to the virtual worlds of cyberspace. Therefore there are now a huge variety of different styles and types of map - for example, one area which has evolved a specific and recognisable variation are those used by public transport organisations to guide passengers, namely urban rail and metro maps, many of which are loosely based on 45 degree angles as originally perfected by Harry Beck and George Dow.

Naming Conventions

Most maps use text to label places and for such things as a map title, legend and other information. Maps are often made in specific languages, though names of places often differ between languages. So a map made in English may use the name *Germany* for that country, while a German map would use *Deutschland* and a French map *Allemagne*. A word that describes a place, using a non-native terminology or language is referred to as an exonym.

In some cases the proper name is not clear. For example, the nation of Burma officially changed its name to Myanmar, but many nations do not recognize the ruling junta and continue to use *Burma*. Sometimes an official name change is resisted in other languages and the older name may remain in common use. Examples include the use of *Saigon* for Ho Chi Minh City, *Bangkok* for Krung Thep and *Ivory Coast* for Cote d’Ivoire.

Difficulties arise, when transliteration or transcription between writing systems is required. National names tend to have well established names in other languages and writing systems, such as *Russia*, but for many placenames a system of transliteration or transcription is required. In transliteration, the symbols of one language are represented by symbols in another. For example, the Cyrillic letter *P* is traditionally written as *R* in the Latin alphabet. Systems exist for transliteration of Arabic, but the results may vary. For example, the Yemeni city of Mocha is written variously in English as Mocha, Al Mukha, al-Mukha, Mocca and Moka. Transliteration systems are based on relating written symbols to one another, while transcription is the attempt to spell in one language the phonetic sounds of another. Chinese writing is transformed into the Latin alphabet through the Pinyin phonetic transcription systems. Other systems were used in the past, such as Wade-Giles, resulting in the city being spelled *Beijing* on newer English maps and *Peking* on older ones.

Further difficulties arise when countries, especially former colonies, do not have a strong national geographic naming standard. In such cases, cartographers may have to choose between various phonetic spellings of local names versus older imposed, sometimes resented, colonial names. Some countries have multiple official languages, resulting in multiple official placenames. For example, the capital of Belgium is both *Brussels* and *Bruxelles*. In Canada, English and French are official languages and places have names in both languages. British Columbia is also officially named *la Colombie-Britannique*. English maps rarely show the French names outside of Quebec, which itself is spelled *Quebec* in French. The study of placenames is called toponymy, while that of the origin and historical usage of placenames as words is etymology.

In order to improve legibility or to aid the illiterate, some maps have been produced using pictograms to represent places. The iconic example of this practice is Lance Wyman's early plans for the Mexico City Metro, on which stations were shown simply as stylized logos. Wyman also prototyped such a map for the Washington Metro, though ultimately the idea was rejected. Other cities experimenting with such maps are Fukuoka, Guadalajara and Monterrey.

Map Symbology

The quality of a map's design affects its reader's ability to extract information and to learn from the map. Cartographic symbology has been developed in an effort to portray the world accurately and effectively convey information to the map reader. A legend explains the pictorial language of the map, known as its symbology.

The title indicates the region the map portrays; the map image portrays the region and so on. Although every map element serves some purpose, convention only dictates inclusion of some elements, while others are considered optional. A menu of map elements includes the neatline (border), compass rose or north arrow, overview map, bar scale, projection and information about the map sources, accuracy and publication.

When examining a landscape, scale can be intuited from trees, houses and cars. Not so with a map. Even such a simple thing as a north arrow is crucial. It may seem obvious that the top of a map should point north, but this might not be the case.

Colour, likewise, is equally important. How the cartographer displays the data in different hues can greatly affect the understanding or feel of the map. Different intensities of hue portray different objectives the cartographer is attempting to get across to the audience. Today, personal computers can display up to 16 million distinct colours at a time, even though the human eye can distinguish only a minimum number of these (Jeer, 1997).

This fact allows for a multitude of colour options for even for the most demanding maps. Moreover, computers can easily hatch patterns in colours to give even more options. This is very beneficial, when symbolizing data in categories such as quintile and equal interval classifications.

Quantitative symbols give a visual measure of the relative size/importance/number that a symbol represents and to symbolize this data on a map, there are two major classes of symbols used for portraying quantitative properties. Proportional symbols change their visual weight according to a quantitative property. These are appropriate for extensive statistics. Choropleth maps portray data collection areas, such as counties or census tracts, with colour. Using colour this way, the darkness and intensity (or value) of the colour is evaluated by the eye as a measure of intensity or concentration (Harvard Graduate School of Design, 2005).

Map Generalization

A good map has to provide a compromise between portraying the items of interest (or themes) in the *right place* for the map scale used, against the need to annotate that item with text or a symbol, which takes up space on the map medium and very likely will cause some other item of interest to be displaced. The cartographer is thus constantly making judgements about what to include, what to leave out and what to show in a *slightly* incorrect place - because of the demands of the annotation. This issue assumes more importance as the scale of the map gets smaller (i.e. the map shows a larger area), because relatively, the annotation on the map takes up more space *on the ground*. A good example from the late 1980s was the Ordnance Survey's first digital maps, where the *absolute* positions of major roads shown at scales of 1:1250 and 1:2500 were sometimes a scale distance of hundreds of metres away from ground truth, when shown on digital maps at scales of 1:250000 and 1:625000, because of the overriding need to annotate the features.

Cartographic Errors

Some maps contain deliberate errors or distortions, either as propaganda or as a "watermark" helping the copyright owner identify infringement if the error appears in competitors' maps. The latter often come in the form of nonexistent, misnamed, or misspelled "trap streets". Other names and forms for this are paper townsites, fictitious entries, and copyright easter eggs.

Another motive for deliberate errors is simply cartographic graffiti or prank: a mapmaker wishing to leave his or her mark on the work. Mount Richard, for example, was a fictitious peak on the Rocky Mountains' continental divide that appeared on a Boulder County, Colorado map in the early 1970s. It is believed to be the work of drafts man Richard Ciacci. The fiction was not discovered until two years later.

Geography and Regionalism

Region is most commonly a geographical term that is used in various ways among the different branches of geography. In general, a region may be seen as a collection of smaller units (as in "the New England states") or as one part of a larger whole (as in "the New England region of the United States"). Regions can be defined by physical characteristics, human characteristics, and functional characteristics. As a way of describing spatial areas, the concept of regions is important and widely used among the many branches of geography, each of which can describe areas in regional terms. For example, ecoregion is a term used in environmental geography, cultural region in cultural geography, bioregion in biogeography, and so on. The field of geography that studies regions themselves is called regional geography.

In the fields of physical geography, ecology, biogeography, zoogeography, and environmental geography, regions tend to be based on natural features such as ecosystems or biotopes, biomes, drainage basins, mountain ranges, soil types.

Physiographic Regions

Regions defined on the basis of landform characteristics are called "physiographic" or "geomorphic" regions. Physiography involves the delineation and description of regions from the viewpoint of geomorphology. Geologist Nevin Fenneman defined a classic three-level hierarchical system of physiographic regions for the United States in 1946. The regions are called divisions, provinces, and sections. For example, there are 8 large physiographic divisions, such as the Canadian Shield and the Interior Plains. These are subdivioned into provinces and sections. The Appalachian Highlands division, for example, contains the Valley and Ridge province, which in turn contains three sections, the Tennessee section, the Middle section, and the Hudson section. The Valley and Ridge province approximately corresponds to the more general region known as the Ridge-and-valley Appalachians.

Palaeogeographic Regions

Palaeogeography is the study of ancient geologic environments. Since the physical structures of the Earth's surface have changed over geologic time, palaeogeographers have coined various names for ancient regions that no longer exist, from very large regions such as the supercontinents Rodinia, Pangaea, and Pannotia, to relatively small regions like Beringia. Other examples include the Tethys Ocean and Ancylus Lake. Palaeogeographic continental regions that include Laurentia, Proto-Laurasia, Laurasia, Euramerica (the "Old Red Continent"), and Gondwana. The Paleogeographic region is also where paleontologist find answers in history.

Historical Regions

The field of historical geography involves the study of human history as it relates to places and regions, or, inversely, the study of how places and regions have changed over time.

D. W. Meinig, a historical geographer of America, describes many historical regions in his book *The Shaping of America: A Geographical Perspective on 500 Years of History*. For example, in identifying European "source regions" in early American colonization efforts, he defines and describes the "Northwest European Atlantic Protestant Region", which includes sub-regions such as the "Western Channel Community", which itself is made of sub-regions such as the "English West Country" of Cornwall, Devon, Somerset and Dorset.

In describing historic regions of America, Meinig writes of "The Great Fishery" off the coast of Newfoundland and New England, an oceanic region that includes the Grand Banks. He rejects regions traditionally used in describing American history, like New France, "West Indies", the Middle Colonies, and the individual colonies themselves (Province of Maryland, for example). Instead he writes of "discrete colonization areas", which may be named after colonies, but rarely adhere strictly to political boundaries. Historic regions of this type Meinig writes about include "Greater New England" and its major sub-regions of "Plymouth", "New Haven shores" (including parts of Long Island), "Rhode Island" (or "Narragansett Bay"), "the Piscataqua", "Massachusetts Bay", "Connecticut Valley", and to a lesser degree, regions in the sphere of influence of Greater New England, "Acadia" (Nova Scotia), "Newfoundland and The Fishery/The Banks".

Other examples of historical regions include Iroquoia, Ohio Country, Illinois Country, and Rupert's Land.

Tourism Region

A tourism region is a geographical region that has been designated by a governmental organization or tourism bureau as having common cultural or environmental characteristics. These regions are often named after a geographical, former, or current administrative region or may have a name created for tourism purposes. The names often evoke certain positive qualities of the area and suggest a coherent tourism experience to visitors. Countries, states, provinces, and other administrative regions are often carved up into tourism regions which, in addition to drawing the attention of potential tourists, often provide tourists who are otherwise unfamiliar with an area with a manageable number of attractive options.

Some of the more famous tourism regions based on historical or current administrative regions include Tuscany in Italy and Yucatan in Mexico. Famous examples of regions created by a government or tourism bureau include the United Kingdom's Lake District and California's Wine Country great plains region.

Natural Resource Regions

Natural resources often occur in distinct regions. Natural resource regions can be a topic of physical geography or environmental geography, but also have a strong element of human geography and economic geography. A coal region, for example, is a physical or geomorphological region, but its development and exploitation can make it into an economic and a cultural region. Some examples of natural resource regions include the Rumaila Field, the oil field that lies along the border or Iraq and Kuwait and played a role in the Gulf War; the Coal Region of Pennsylvania, which is a historical region as well as a cultural, physical, and natural resource region; the South Wales Coalfield, which like Pennsylvania's coal region is a historical, cultural, and natural region; the Kuznetsk Basin, a similarly important coal mining region in Russia; Kryvbas, the economic and iron ore mining region of Ukraine; and the James Bay Project, a large region of Quebec where one of the largest hydroelectric systems in the world has been developed.

Religious Regions

Sometimes a region associated with a religion is given a name, like Christendom, a term with medieval and renaissance connotations of Christianity as a sort of social and political polity. The term Muslim world is sometimes used to refer to the region of the world where Islam is dominant. These broad terms are very vague when used to describe regions.

Within some religions there are clearly defined regions. The Roman Catholic Church, the Church of England, the Eastern Orthodox Church, and others, define ecclesiastical regions with names such as diocese, eparchy, ecclesiastical provinces, and parish.

For example, the United States is divided into 32 Roman Catholic ecclesiastical provinces. The Lutheran Church - Missouri Synod is organized into 33 geographic “districts”, which are subdivided into “circuits” (the Atlantic District (LCMS), for example). The Church of Jesus Christ of Latter-day Saints uses regions similar to dioceses and parishes, but uses terms like ward and stake.

Political Regions

In the field of political geography regions tend to be based on political units such as sovereign states; subnational units such as provinces, counties, townships, territories, etc; and multinational groupings, including formally defined units such as the European Union, the Association of Southeast Asian Nations, and NATO, as well as informally defined regions such as the Third World, Western Europe, and the Middle East.

Local Administrative Regions

There are many relatively small regions based on local government agencies such as districts, agencies, or regions. In general, they are all regions in the general sense of being bounded spatial units. Examples include electoral districts such as Washington’s 6th congressional district and Tennessee’s 1st congressional district; school districts such as Granite School District and Los Angeles Unified School District; economic districts such as the Reedy Creek Improvement District; metropolitan areas such as the Seattle metropolitan area, and metropolitan districts such as the Metropolitan Water Reclamation District of Greater Chicago, the Las Vegas-Clark County Library District, the Metropolitan Police Service of Greater London, as well as other local districts like the York Rural Sanitary District, the Delaware River Port Authority, the Nassau County Soil and Water Conservation District, and C-TRAN.

Regional Government in Connecticut

In the U.S. State of Connecticut the roles of county governments are now performed by regional governments not abiding to the present county borders. Ever since the dissolution of county government in Connecticut in 1960, the roles of regional services once provided by the county are now provided by regional agencies of towns. Counties still are used in Connecticut as geographical entities and in some counties they are still used to organize judicial districts, also counties are still used to organize the state marshal system in Connecticut. Counties were also used to organize the sheriff's department of each Connecticut county until 2000, when county sheriff's were eliminated due to mismanagement as was the reason for abolishing the county governments. An example of one former county sheriff's department is the Fairfield County Sheriff's Department which served Fairfield County in Connecticut. All sheriff's departments in Connecticut were not eliminated, only at the county level. Several towns and cities in Connecticut still maintain a sheriff's department such as Shelton with the Shelton Sheriff's Department.

Administrative Regions

The word "region" is taken from the Latin *regio*, and a number of countries have borrowed the term as the formal name for a type of subnational entity (e.g., the *region*, used in Chile). In English, the word is also used as the conventional translation for equivalent terms in other languages.

In Spain the official name of the autonomous community of Murcia is *Region de Murcia*. Also, some single-province autonomous communities such as Madrid use the term *region* interchangeably with *comunidad autonoma*.

Two lan (counties) in Sweden are officially called 'regions': Skane and Vastra Gotaland, and there is currently a controversial proposal to divide the rest of Sweden into large regions, replacing the current counties.

The government of the Philippines uses the term "region" (in Filipino, *rehiyon*) when it's necessary to group provinces, the primary administrative subdivision of the country. This is also the case in Brazil which groups its primary administrative divisions (*estados*; “states”) into *grandes regioes* (greater regions) for statistical purposes, while Russia uses (economic regions) in a similar way, as does Romania and Venezuela.

Traditional or Informal Regions

The traditional territorial divisions of some countries are also commonly rendered in English as “regions”. These informal divisions do not form the basis of the modern administrative divisions of these countries, but still define and delimit local regional identity and sense of belonging. Examples include:

- Finland
- Japan
- Korea
- Norway (*landsdeler*)
- Romania
- Slovakia

Geographical Regions

A region can also be used for a geographical area; with this usage, there is an implied distinctiveness about the area that defines it. Such a distinction is often made on the basis of a historical, political, or cultural cohesiveness that separates the region from its neighbours.

Geographical regions can be found within a country (e.g., the Midlands, in England), or transnationally (e.g., the Middle East).

Similarly, the United Nations Statistics Division has devised a scheme for classifying macrogeographic regions (continents), continental subregions, and selected socioeconomic groupings.

Functional Region

A functional region or Nodal region, is a region that has a defined core that retains a specific characteristic that diminishes outwards. To be considered a Functional region, at least one form of spatial interaction must occur between the centre and all other parts of the region. A functional region is organized around a node or focal point with the surrounding areas linked to that node by transportation systems, communication systems, or other economic association involving such activities as manufacturing and retail trading. A typical functional region is a metropolitan area (MA) as defined by the Bureau of Census. For example, the New York MA is a functional region that covers parts of several states. It is linked by commuting patterns, trade flows, television and radio broadcasts, newspapers, travel for recreation and entertainment. Other functional regions include shopping regions centred on malls or supermarkets, area served by branch banks, and ports and their hinterlands.

Military Regions

In military usage a region is shorthand for the name of a military formation larger than an Army Group and smaller than an Army Theater or simply Theater. The full name of the military formation is Army Region. An Army Region usually consists of between two and five Army Groups. The size of an Army Region can vary widely but is generally somewhere between about 1 million and 3 million soldiers. Two or more Army Regions could make up an Army Theater. An Army Region would typically be commanded by a full General (US four stars), a Field Marshal or General of the Army (US five stars), or Generalissimo (Soviet Union). Due to the large size of this formation, its use is rarely employed. Some of the very few examples of an Army Region would be each of the Eastern, Western, and southern (mostly in Italy) fronts in Europe during World War II. The military map unit symbol for this echelon of formation consists of six Xs.

6

Fields of Physical Geography

Geomorphology

Geomorphology is the scientific study of landforms and the processes that shape them. Geomorphologists seek to understand why landscapes look the way they do: to understand landform history and dynamics, and predict future changes through a combination of field observation, physical experiment, and numerical modelling. Geomorphology is practiced within geography, geology, geodesy, engineering geology, archaeology, and geotechnical engineering. Early studies in geomorphology are the foundation for pedology, one of two main branches of soil science. More recent studies in geomorphology, pioneered and popularized by Henry Posamentier, integrate seismic geomorphology and seismic stratigraphy, leveraging both 2D and 3D seismic data to better understand the paleogeographic distribution of lithologies.

Landforms evolve in response to a combination of natural and anthropogenic processes. The landscape is built up through tectonic uplift and volcanism. Denudation occurs by erosion and mass wasting, which produces sediment that is transported and deposited elsewhere within the landscape or off the coast. Landscapes are also lowered by subsidence, either due to tectonics or physical changes in underlying sedimentary deposits. These processes are each influenced differently by climate, ecology, and human activity.

Practical applications of geomorphology include hazard assessment including landslide prediction and mitigation, river control and restoration, and coastal protection:

- Hydrology is predominantly concerned with the amounts and quality of water moving and accumulating on the land surface and in the soils and rocks near the surface and is typified by the hydrological cycle. Thus the field encompasses water in rivers, lakes, aquifers and to an extent glaciers, in which the field examines the process and dynamics involved in these bodies of water. Hydrology has historically had an important connection with engineering and has thus developed a largely quantitative method in its research; however, it does have an earth science side that embraces the systems approach. Similar to most fields of physical geography it has sub-fields that examine the specific bodies of water or their interaction with other spheres e.g. limnology and ecohydrology.
- Glaciology is the study of glaciers and ice sheets, or more commonly the cryosphere or ice and phenomena that involve ice. Glaciology groups the latter (ice sheets) as continental glaciers and the former (glaciers) as alpine glaciers. Although, research in the areas are similar with research undertaken into both the dynamics of ice sheets and glaciers the former tends to be concerned with the interaction of ice sheets with the present climate and the latter with the impact of glaciers on the landscape. Glaciology also has a vast array of sub-fields examining the factors and processes involved in ice sheets and glaciers e.g. snow hydrology and glacial geology.
- Biogeography is the science which deals with geographic patterns of species distribution and the processes that result in these patterns. Biogeography emerged as a field of study as a result of the work of Alfred Russel Wallace, although the field prior to the late twentieth century had largely been viewed as historic in its outlook and descriptive in its approach. The main stimulus for the field since its founding has been that of evolution, plate tectonics and the theory of island biogeography.

The field can largely be divided into five sub-fields: island biogeography, paleobiogeography, phylogeography, zoogeography and phytogeography.

- Climatology is the study of the climate, scientifically defined as weather conditions averaged over a long period of time. It differs from meteorology, which studies atmospheric processes over a shorter duration, which are then examined by climatologists to find trends and frequencies in weather patterns/phenomena. Climatology examines both the nature of micro (local) and macro (global) climates and the natural and anthropogenic influences on them. The field is also sub-divided largely into the climates of various regions and the study of specific phenomena or time periods e.g. tropical cyclone rainfall climatology and paleoclimatology.
- Pedology is the study of soils in their natural environment. It is one of two main branches of soil science, the other being edaphology. Pedology mainly deals with pedogenesis, soil morphology, soil classification. In physical geography pedology is largely studied due to the numerous interactions between climate (water, air, temperature), soil life (micro-organisms, plants, animals), the mineral materials within soils (biogeochemical cycles) and its position and effects on the landscape such as laterization.
- Palaeogeography is the study of the distribution of the continents through geologic time through examining the preserved material in the stratigraphic record. Palaeogeography is a cross-discipline, almost all the evidence for the positions of the continents comes from geology in the form of fossils or geophysics the use of this data has resulted in evidence for continental drift, plate tectonics and supercontinents this in turn has supported palaeogeographic theories such as the Wilson cycle.
- Coastal geography is the study of the dynamic interface between the ocean and the land, incorporating both the physical geography (i.e coastal geomorphology, geology and oceanography) and the human geography of the

coast. It involves an understanding of coastal weathering processes, particularly wave action, sediment movement and weathering, and also the ways in which humans interact with the coast. Coastal geography although predominantly geomorphological in its research is not just concerned with coastal landforms, but also the causes and influences of sea level change.

- Oceanography is the branch of physical geography that studies the Earth's oceans and seas. It covers a wide range of topics, including marine organisms and ecosystem dynamics (biological oceanography); ocean currents, waves, and geophysical fluid dynamics (physical oceanography); plate tectonics and the geology of the sea floor (geological oceanography); and fluxes of various chemical substances and physical properties within the ocean and across its boundaries (chemical oceanography). These diverse topics reflect multiple disciplines that oceanographers blend to further knowledge of the world ocean and understanding of processes within it.
- Quaternary science is an inter-disciplinary field of study focusing on the Quaternary period, which encompasses the last 2.6 million years. The field studies the last ice age and the recent interstadial the Holocene and uses proxy evidence to reconstruct the past environments during this period to infer the climatic and environmental changes that have occurred.
- Landscape ecology is a sub-discipline of ecology and geography that address how spatial variation in the landscape affects ecological processes such as the distribution and flow of energy, materials and individuals in the environment (which, in turn, may influence the distribution of landscape "elements" themselves such as hedgerows). The field was largely founded by the German geographer Carl Troll Landscape ecology typically deals with problems in an applied and holistic context. The main difference between biogeography and landscape ecology is that the latter is concerned with how flows or energy and material are changed and their impacts on the landscape

whereas the former is concerned with the spatial patterns of species and chemical cycles.

- Geomatics is the field of gathering, storing, processing, and delivering of geographic information, or spatially referenced information. Geomatics includes geodesy (scientific discipline that deals with the measurement and representation of the earth, its gravitational field, and other geodynamic phenomena, such as crustal motion, oceanic tides, and polar motion) and G.I.S. (a system for capturing, storing, analyzing and managing data and associated attributes which are spatially referenced to the earth) and remote sensing (the short or large-scale acquisition of information of an object or phenomenon, by the use of either recording or real-time sensing devices that are not in physical or intimate contact with the object).
- Environmental geography is a branch of geography that analyzes the spatial aspects of interactions between humans and the natural world. The branch bridges the divide between human and physical geography and thus requires an understanding of the dynamics of geology, meteorology, hydrology, biogeography, and geomorphology, as well as the ways in which human societies conceptualize the environment. Although the branch was previously more visible in research than at present with theories such as environmental determinism linking society with the environment. It has largely become the domain of the study of environmental management or anthropogenic influences on the environment and vice a versa.

Physical Geography of India

The geography of India describes the physical features of India, a country in South Asia that lies entirely on the Indian Plate in the northern portion of the Indo-Australian Plate. The country lies to the north of the equator between 8°4' and 37°6' north latitude and 68°7' and 97°25' east longitude. It is the seventh-largest country in the world, with a total land area of 3,287,263 square kilometres (1,269,219 sq mi). India measures 3,214 km (1,997 mi) from north to south and 2,993 km (1,860 mi) from east to west. It has a land frontier of 15,200 km (9,445 mi) and a coastline of 7,517 km (4,671 mi).

India is bounded to the southwest by the Arabian Sea, to the southeast by the Bay of Bengal and the Indian Ocean to the south. Kanyakumari constitutes the southern tip of the Indian peninsula, which narrows before ending in the Indian Ocean. The southernmost part of India is Indira Point in the Andaman and Nicobar Islands. The Maldives, Sri Lanka and Indonesia are island nations to the south of India with Sri Lanka separated from India by a narrow channel of sea formed by Palk Strait and the Gulf of Mannar. The territorial waters of India extend into the sea to a distance of 12 nautical miles (13.8 mi; 22.2 km) measured from the appropriate baseline.

The northern frontiers of India are defined largely by the Himalayan mountain range where its political boundaries with China, Bhutan, and Nepal lie. Its western borders with Pakistan lie in the Punjab Plain and the Thar desert. In the far northeast, the Chin Hills and Kachin Hills, deeply forested mountainous regions, separate India from Burma while its political border with Bangladesh is defined by the watershed region of the Indo-Gangetic Plain, the Khasi hills and Mizo Hills.

The Ganges is the longest river originating in India and forms the Indo-Gangetic Plain. The Ganges-Brahmaputra system occupies most of northern, central and eastern India, while the Deccan Plateau occupies most of southern India. Along its western frontier is the Thar Desert, which is the seventh-largest desert in the world.

Officially, India's highest point is K2 at 8,611 m (28,251 ft), though it lies in Gilgit-Baltistan, part of the disputed Kashmir region. Kanchenjunga in Sikkim at 8,598 m (28,209 ft) is the highest point within India's current geographic boundaries. Climate across India ranges from equatorial in the far south, to Alpine in the upper reaches of the Himalayas.

Geological Development

India is entirely contained on the Indian Plate, a major tectonic plate that was formed when it split off from the ancient continent Gondwanaland. About 90 million years ago, during the late Cretaceous Period, the Indian Plate began moving north at about 15 cm/yr (6 in/yr). About 50 to 55 million years ago, in the Eocene epoch of the Cenozoic Era, the plate collided with Asia after covering a distance of 2,000 to 3,000 km (1,243 to 1,864 mi), having moved faster than any other known plate. In 2007, German geologists determined that the reason the India Plate moved so quickly is that it is only half as thick as the other plates which formerly constituted Gondwanaland. The collision with the Eurasian Plate along the modern border between India and Nepal formed the orogenic belt that created the Tibetan Plateau and the Himalayas. As of 2009, The India Plate is moving northeast at 5 cm/yr (2 in/yr), while the Eurasian Plate is moving north at only 2 cm/yr (0.8 in/yr). India is thus referred to as the "fastest continent." This is causing the Eurasian Plate to deform, and the India Plate to compress at a rate of 4 mm/yr (0.15 in/yr).

Political Geography

India is divided into twenty-eight states (further subdivided into districts) and seven union territories.

States:

1.	Andhra Pradesh	2.	Arunachal Pradesh
3.	Assam	4.	Bihar
5.	Chhattisgarh	6.	Goa
7.	Gujarat	8.	Haryana
9.	Himachal Pradesh	10.	Jammu and Kashmir
11.	Jharkhand	12.	Karnataka
13.	Kerala	14.	Madhya Pradesh
15.	Maharashtra	16.	Manipur
17.	Meghalaya	18.	Mizoram
19.	Nagaland	20.	Orissa
21.	Punjab	22.	Rajasthan
23.	Sikkim	24.	Tamil Nadu
25.	Tripura	26.	Uttar Pradesh
27.	Uttarakhand	28.	West Bengal

Union Territories:

A. Andaman and Nicobar Islands

B. Chandigarh

C. Dadra and Nagar Haveli

D. Daman and Diu
E. Lakshadweep
F. National Capital Territory of Delhi
G. Puducherry

India's borders run a total length of 15,106.70 km (9,387 mi). Its borders with Pakistan and Bangladesh were delineated according to the Radcliffe Line, which was created in 1947 during Partition of India. Its western border with Pakistan extends up to 3,323 km (2,065 mi), dividing the Punjab region and running along the boundaries of the Thar Desert and the Rann of Kutch.

Both nations delineated a Line of Control (LoC) to serve as the informal boundary between the Indian and Pakistan-administered areas of Kashmir. According to India's claim, it shares a 106 km (66 mi) border with Afghanistan in northwestern Kashmir, which is under Pakistani control.

India's border with Bangladesh runs 4,096.70 km (2,546 mi). There are 92 enclaves of Bangladesh on Indian soil and 106 enclaves of India are on Bangladeshi soil. The Teen Bigha Corridor is a strip of land formerly belonging to India on the West Bengal–Bangladesh border which has been leased indefinitely to Bangladesh so that it can access its Dehgram–Angalpota enclaves.

The Line of Actual Control (LAC) is the effective border between India and the People's Republic of China. It traverses 4,057 km along the Indian states of Jammu and Kashmir, Uttarakhand, Himachal Pradesh, Sikkim and Arunachal Pradesh. Both nations lay claim to the Aksai Chin region of northeastern Kashmir, which fell into Chinese control during the Sino-Indian War of 1962.

The border with Burma (Myanmar) extends up to 1,643 km (1,021 mi) along the southern borders of India's northeastern states. Located amidst the Himalayan range, India's border with Bhutan runs 699 km (434 mi). The border with Nepal runs 1,751 km (1,088 mi) along the foothills of the Himalayas in northern India. The Siliguri Corridor, narrowed sharply by the borders of Bhutan, Nepal and Bangladesh, connects peninsular India with the northeastern states.

Physiographic Regions

India is divided into seven physiographic regions. They are

1. The northern mountains including the Himalayas, which includes the Kuen Lun and the Karakoram ranges and the northeast mountain ranges
2. Indo-Gangetic plains
3. Thar Desert
4. Central Highlands and Deccan Plateau
5. East Coast
6. West Coast
7. Bordering seas and islands

Mountains

A great arc of mountains, consisting of the Himalayas, Hindu Kush, and Patkai ranges define the northern Indian subcontinent. These were formed by the ongoing tectonic collision of the Indian Plate with the Eurasian Plate that started around 50 million years ago. The mountains in these ranges include some of the world's tallest mountains which act as a natural barrier to cold polar winds. They also facilitate the monsoon winds which in turn influence the climate in India. Rivers originating in these mountains, flow through the fertile Indo–Gangetic plains. These mountains are recognised by biogeographers as the boundary between two of the Earth's great ecozones: the temperate Palearctic that covers most of Eurasia and the tropical and subtropical Indomalaya ecozone which includes the Indian subcontinent, Southeast Asia and Indonesia.

India has eight major mountain ranges having peaks of over 1,000 m (3,281 ft):

- The Himalayan range is considered as the world's highest mountain range, with its tallest peak Mt. Everest on the Nepal–China border. They form India's northeastern border, separating it from northeastern Asia. They are one of the world's youngest mountain ranges and extend almost uninterrupted for 2,500 km (1,553 mi), covering an area of 500,000 km^2 (193,051 sq mi). The Himalayas extend from Jammu and Kashmir in the west to Arunachal Pradesh in the east. These states along with Himachal Pradesh, Uttarakhand, and Sikkim lie mostly in the Himalayan region. Numerous Himalayan peaks rise over 7,000 m (22,966 ft) and the snow line ranges between 6,000 m (19,685 ft) in Sikkim to around 3,000 m (9,843 ft) in Kashmir. Kanchenjunga—on the Sikkim–Nepal border—is the highest point in the area administered by India. Most peaks in the Himalayas remain snowbound throughout the year. The Himalayas act as a barrier to the frigid katabatic winds flowing down from Central Asia. Thus, North India is kept warm or only mildly cooled during winter; in summer, the same phenomenon makes India relatively hot.

- The Karakoram is situated in the disputed state of Jammu and Kashmir. It has more than sixty peaks above 7,000 m (22,966 ft), including K2, the second highest peak in the world 8,611 m (28,251 ft). K2 is just 237 m (778 ft) smaller than the 8,848 m (29,029 ft) Mount Everest. The range is about 500 km (311 mi) in length and the most heavily glaciated part of the world outside of the polar regions. The Siachen Glacier at 70 km (43 mi) and the Biafo Glacier at 63 km (39 mi) rank as the world's second and third-longest glaciers outside the polar regions. Just to the west of the northwest end of the Karakoram, lies the Hindu Raj range, beyond which is the Hindu Kush range. The southern boundary of the Karakoram is formed by the Gilgit, Indus and Shyok rivers, which separate the range from the northwestern end of the Himalayas.
- The Patkai, or Purvanchal, are situated near India's eastern border with Myanmar. They were created by the same tectonic processes which led to the formation of the Himalayas. The physical features of the Patkai mountains are conical peaks, steep slopes and deep valleys. The Patkai ranges are not as rugged or tall as the Himalayas. There are three hill ranges that come under the Patkai: the Patkai–Bum, the Garo–Khasi–Jaintia and the Lushai hills. The Garo–Khasi range lies in Meghalaya. Mawsynram, a village near Cherrapunji lying on the windward side of these hills,

has the distinction of being the wettest place in the world, receiving the highest annual rainfall.

- The Vindhya range runs across most of central India, extending 1,050 km (652 mi). The average elevation of these hills is 3,000 m (9,843 ft). They are believed to have been formed by the wastes created by the weathering of the ancient Aravali mountains. Geographically, it separates northern India from southern India. The western end of the range lies in eastern Gujarat, near its border with Madhya Pradesh, and runs east and north, almost meeting the Ganges at Mirzapur.
- The Satpura Range begins in eastern Gujarat near the Arabian Sea coast and runs east across Maharashtra, Madhya Pradesh and Chhattisgarh. It extends 900 km (559 mi) with many peaks rising above 1,000 m (3,281 ft). It is triangular in shape, with its apex at Ratnapuri and the two sides being parallel to the Tapti and Narmada rivers. It runs parallel to the Vindhya Range, which lies to the north, and these two east-west ranges divide the Indo–Gangetic plain from the Deccan Plateau located north of River Narmada.
- The Aravali Range is the oldest mountain range in India, running across Rajasthan from northeast to southwest direction, extending approximately 800 km (497 mi). The northern end of the range continues as isolated hills and rocky ridges into Haryana, ending near Delhi. The highest peak in this range is Guru Shikhar at Mount Abu, rising to 1,722 m (5,650 ft), lying near the border with Gujarat. The Aravali Range is the eroded stub of an ancient fold mountain system. The range rose in a Precambrian event called the Aravali–Delhi orogen. The range joins two of the ancient segments that make up the Indian craton, the Marwar segment to the northwest of the range, and the Bundelkhand segment to the southeast.
- The Western Ghats or Sahyadri mountains run along the western edge of India's Deccan Plateau and separate it from a narrow coastal plain along the Arabian Sea. The range runs approximately 1,600 km (994 mi) from

south of the Tapti River near the Gujarat–Maharashtra border and across Maharashtra, Goa, Karnataka, Kerala and Tamil Nadu to the southern tip of the Deccan peninsula. The average elevation is around 1,000 m (3,281 ft). Anai Mudi in the Anaimalai Hills 2,695 m (8,842 ft) in Kerala is the highest peak in the Western Ghats.

- The Eastern Ghats are a discontinuous range of mountains, which have been eroded and vivisected by the four major rivers of southern India, the Godavari, Mahanadi, Krishna, and Kaveri. These mountains extend from West Bengal to Orissa, Andhra Pradesh and Tamil Nadu, along the coast and parallel to the Bay of Bengal. Though not as tall as the Western Ghats, some of its peaks are over 1,000 m (3,281 ft) in height. The Nilgiri hills in Tamil Nadu lies at the junction of the Eastern and Western Ghats.

Indo-Gangetic Plain

The Indo-Gangetic plains, also known as the *Great Plains* are large floodplains of the Indus and the Ganga-Brahmaputra river systems. They run parallel to the Himalaya mountains, from Jammu and Kashmir in the west to Assam in the east and draining most of northern and eastern India. The plains encompass an area of 700,000 square kilometres (270,272 sq mi). The major rivers in this region are the Ganges and the Indus along with their tributaries–Beas, Yamuna, Gomti, Ravi, Chambal, Sutlej and Chenab.

The great plains are sometimes classified into four divisions:

- The Bhabar belt — is adjacent to the foothills of the Himalayas and consists of boulders and pebbles which have been carried down by the river streams. As the porosity of this belt is very high, the streams flow underground. The bhabar is generally narrow with its width varying between 7 to 15 km.
- The Terai belt — lies next to the Bhabar region and is composed of newer alluvium. The underground streams reappear in this region. The region is excessively moist and thickly forested. It also receives

heavy rainfall throughout the year and is populated with a variety of wildlife.

- The Bangar belt — consists of older alluvium and forms the alluvial terrace of the flood plains. In the Gangetic plains, it has a low upland covered by laterite deposits.
- The Khadar belt — lies in lowland areas after the Bangar belt. It is made up of fresh newer alluvium which is deposited by the rivers flowing down the plain.

The Indo-Gangetic belt is the world's most extensive expanse of uninterrupted alluvium formed by the deposition of silt by the numerous rivers. The plains are flat making it conducive for irrigation through canals. The area is also rich in ground water sources.

The plains are one of the world's most intensely farmed areas. The main crops grown are rice and wheat, which are grown in rotation. Other important crops grown in the region include maize, sugarcane and cotton. The Indo-Gangetic plains rank among the world's most densely populated areas.

Thar Desert

The Thar Desert (also known as the *Great Indian Desert*) is the world's seventh largest desert; it forms a significant portion of western India and covers an area of 238,700 km^2 (92,200 $mile^2$). The desert continues into Pakistan as the Cholistan Desert. Most of the Thar Desert is situated in Rajasthan, covering 61% of its geographic area.

About 10 percent of this ecoregion comprises sand dunes, and the remaining 90 percent consist of craggy rock forms, compacted salt-lake bottoms, and interdunal and fixed dune areas. Annual temperatures can range from 0°C in the winter to over 50°C during the summer. Most of the rainfall received in this region is associated with the short July-September southwest monsoon that brings around 100–500 mm of precipitation. Water is scarce and occurs at great depths, ranging from 30 to 120 m below the ground level. Rainfall is precarious and erratic, ranging from below 120 mm (4.72 inches) in the extreme west to 375 mm (14.75 inches) eastward. The soils of the arid region are generally sandy to sandy-loam in texture. The consistency and depth vary as per the topographical features. The low-lying loams are heavier and may have a hard pan of clay, calcium carbonate or gypsum.

Highlands

The Central Highlands comprise of three main plateaus — the Malwa Plateau in the west, the Deccan Plateau in the south (covering most of the Indian peninsula) and the Chota Nagpur Plateau in the east.

The Malwa Plateau is spread across Rajasthan, Madhya Pradesh and Gujarat. The average elevation of the Malwa plateau is 500 metres, and the landscape generally slopes towards the north. Most of the region is drained by the Chambal River and its tributaries; the western part is drained by the upper reaches of the Mahi River. The Deccan Plateau is a large triangular plateau, bounded by the Vindhyas to the north and flanked by the Eastern and Western Ghats. The Deccan covers a total area of 1.9 million km² (735,000 mile²). It is mostly flat, with elevations ranging from 300 to 600 m (1,000 to 2,000 ft). The average elevation of the plateau is 2,000 feet (600 m) above sea level. The surface slopes from 3,000 feet (900 m) in the west to 1,500 feet (450 m) in the east. It slopes gently from west to east and gives rise to several peninsular rivers such as the Godavari, the Krishna, the Kaveri and the Narmada, which drain into the Bay of Bengal. This region is mostly semi-arid as it lies on the leeward side of both Ghats. Much of the Deccan is covered by thorn scrub forest scattered with small regions of deciduous broadleaf forest. Climate in the Deccan ranges from hot summers to mild winters.

The Chota Nagpur Plateau is situated in eastern India, covering much of Jharkhand and adjacent parts of Orissa, Bihar and Chhattisgarh. Its total area is approximately 65,000 km² (25,000 mile²) and is made up of three smaller plateaus — the Ranchi, Hazaribagh, and Kodarma plateaus. The Ranchi plateau is the largest, with an average elevation of 700 m (2,300 ft). Much of the plateau is forested, covered by the Chota Nagpur dry deciduous forests. Vast reserves of metal ores and coal have been found in the Chota Nagpur plateau. The Kathiawar peninsula in western Gujarat is bounded by the Gulf of Kutch and the Gulf of Khambat. The natural vegetation in most of the peninsula is xeric scrub, part of the Northwestern thorn scrub forests ecoregion. In western India, the Kutch region in Gujarat and Koyna in Maharashtra are classified as a Zone IV region (high risk) for earthquakes. The Kutch city of Bhuj was the epicentre of the 2001 Gujarat earthquake, which claimed the lives of more than 20,000 people and injured 166,836 while destroying or damaging near a million homes. The 1993 Latur earthquake in Maharashtra killed 7,928 people and injured 30,000. Other areas have a moderate to low risk of an earthquake occurring.

Coasts

The Eastern Coastal Plain is a wide stretch of land lying between the Eastern Ghats and the Bay of Bengal. It stretches from Tamil Nadu in the south to West Bengal in the north. The Mahanadi, Godavari, Kaveri and Krishna rivers drain these plains and their deltas occupy most of the area. The temperature in the coastal regions exceeds 30 °C (86 °F) coupled with high levels of humidity. The region receives both the northeast and southwest monsoon rains. The southwest monsoon splits into two branches, the Bay of Bengal branch and the Arabian Sea branch. The Bay of Bengal branch moves northwards crossing northeast India in early June. The Arabian Sea branch moves northwards and discharges much of its rain on the windward side of Western Ghats. Annual rainfall in this region averages between 1,000 mm (40 in) and 3,000 mm (120 in). The width of the plains varies between 100 and 130 km (62 to 80 miles). The plains are divided into six regions — the Mahanadi delta, the southern Andhra Pradesh plain, the Krishna-Godavari deltas, the Kanyakumari coast, the Coromandel Coast and sandy coastal.

The Western Coastal Plain is a narrow strip of land sandwiched between the Western Ghats and the Arabian Sea, ranging from 50 to 100 km (30 to 60 miles) in width. It extends from Gujarat in the north and extends through Maharashtra, Goa, Karnataka and Kerala. Numerous rivers and backwaters inundate the region. Originating in the Western Ghats, the rivers are fast-flowing and mostly perennial, leading to the formation of estuaries. Major rivers flowing into the sea are the Tapi, Narmada, Mandovi and Zuari. The coast is divided into 3 parts namely, Konkan, which is situated in Maharashtra, Goa and northern parts of Karnataka; the Kanara in Karnataka and the Malabar Coast in Kerala. Vegetation is mostly deciduous, but the Malabar Coast moist forests constitute a unique ecoregion.

Islands

The Lakshadweep and the Andaman and Nicobar Islands are India's two major island formations which are classified as union territories. The Lakshadweep Islands lie 200 to 300 km (124 to 186 miles) off the coast of Kerala in the Arabian Sea with an area of 32 km² (11 sq mi). They consist of 12 atolls, 3 reefs and 5 submerged banks, with a total of about 36 islands and islets.

The Andaman and Nicobar Islands are located between 6° and 14° North latitude and 92° and 94° East longitude. They consist of 572 isles, lying in the Bay of Bengal near the Myanmar coast. It is located 1255 km (780 miles) from Kolkata (Calcutta) and 193 km (120 miles) from Cape Negrais in Myanmar. The territory consists of two island groups, the Andaman Islands and the Nicobar Islands. The Andaman Islands consists of 204 small islands with a total length of 352 km (220 miles). India's only active volcano, Barren Island is situated here, having last erupted in May 2005. The Narcondum is a dormant volcano and there is a mud volcano at Baratang. Indira Point, India's southernmost land point is situated in the Nicobar islands, and lies just 189 km (117 miles) from the Indonesian island of Sumatra to the southeast. The highest point is Mount Thullier at 642 m (2,140 ft).

Significant islands just off the Indian coast include Diu, a former Portuguese enclave; Majuli, Asia's largest freshwater island; Elephanta in the Bombay Harbour; and Sriharikota barrier island in Andhra Pradesh. Salsette Island is India's most populous island on which the city of Mumbai (Bombay) is located. Forty-two islands in the Gulf of Kutch constitute the Marine National Park.

Water Bodies

India has around 14,500 km of inland navigable waterways. There are twelve rivers which are classified as major rivers, with the total catchment area exceeding 2,528,000 km²

(976,000 sq mi). All major rivers of India originate from one of the three main watersheds:

1. The Himalaya and the Karakoram ranges
2. Vindhya and Satpura range in central India
3. Sahyadri or Western Ghats in western India

The Himalayan river networks are snow-fed and have a perennial supply throughout the year. The other two river systems are dependent on the monsoons and shrink into rivulets during the dry season. The Himalayan rivers that flow westward into Pakistan are the Indus, Beas, Chenab, Ravi, Sutlej, and Jhelum.

The Ganga-Brahmaputra-Meghana system has the largest catchment area of 1,100,000 km^2 (420,000 sq mi). The Ganga originates from the Gangotri Glacier in Uttarakhand. It flows southeast, draining into the Bay of Bengal. The Yamuna and Gomti rivers also arise in the western Himalayas and join the Ganga in the plains. The Brahmaputra, another tributary of the Ganga, originates in Tibet and enters India through the far-eastern state of Arunachal Pradesh. It proceeds westwards, joining the Ganges in Bangladesh.

The Chambal, another tributary of the Ganga originates from the Vindhya-Satpura watershed. The river flows eastward. Westward-flowing rivers from this watershed are the Narmada and Tapti, which drain into the Arabian Sea in Gujarat. The river network that flows from east to west constitutes 10% of the total outflow.

The Western Ghats are the source of all Deccan rivers, which include the Mahanadi River through the Mahanadi River Delta, Godavari River, Krishna River and Kaveri River, all draining into the Bay of Bengal. These rivers constitute 20% of India's total outflow.

The heavy southwest monsoon rains cause the Brahmaputra and other rivers to distend their banks, often flooding surrounding areas. Though they provide rice paddy farmers with a largely dependable source of natural irrigation and fertilisation, such floods have killed thousands of people and tend to cause displacements of people in such areas. Major gulfs include the Gulf of Cambay, Gulf of Kutch and the Gulf of Mannar. Straits include the Palk Strait, which separates

India from Sri Lanka and the Ten Degree Channel, which separates the Andamans from the Nicobar Islands and the Eight Degree Channel, which separates the Laccadive and Amindivi Islands from the Minicoy Island towards the south. Important capes include the Kanyakumari, the southern tip of mainland India; Indira Point, the southernmost location of India; Rama's Bridge and Point Calimere. While, Arabian Sea lies on the western side of India, Bay of Bengal and Indian Ocean lie towards the eastern and southern side respectively. Smaller seas include the Laccadive Sea and the Andaman Sea. There are four coral reefs in India, located in the Andaman and Nicobar Islands, Gulf of Mannar, Lakshadweep and Gulf of Kutch. Important lakes include Chilka Lake, the country's largest saltwater lake in Orissa; Kolleru Lake in Andhra Pradesh; Loktak Lake in Manipur, Dal Lake in Kashmir, Sambhar Lake in Rajasthan and the Sasthamkotta Lake in Kerala.

Wetlands

India's wetland ecosystem is widely distributed from the cold and arid located in the Ladakh region of Jammu and Kashmir, and those with the wet and humid climate of peninsular India. Most of the wetlands are directly or indirectly linked to river networks. The Indian government has identified a total of 71 wetlands for conservation and are part of sanctuaries and national parks. Mangrove forests are present all along the Indian coastline in sheltered estuaries, creeks, backwaters, salt marshes and mudflats. The mangrove area covers a total of 4,461 km^2 (1,722 sq mi), which comprises 7% of the world's total mangrove cover. Prominent mangrove covers are located in the Andaman and Nicobar Islands, the Sundarbans delta, the Gulf of Kutch and the deltas of the Mahanadi, Godavari and Krishna rivers. Parts of Maharashtra, Karnataka and Kerala also have large mangrove covers.

The Sundarbans delta is home to the largest mangrove forest in the world. It lies at the mouth of the Ganges and spreads across areas of Bangladesh and West Bengal. The Sundarbans is a UNESCO World Heritage Site, but is identified separately as the Sundarbans (Bangladesh) and the Sundarbans National Park (India). The Sundarbans are intersected by a complex network of tidal waterways, mudflats and small islands of salt-tolerant mangrove forests. The area is known for its diverse fauna, being home to a large variety of species of birds, spotted deer, crocodiles and snakes. Its most famous inhabitant is the Bengal Tiger. It is estimated that there are now 400 Bengal tigers and about 30,000 spotted deer in the area.

The Rann of Kutch is a marshy region located in northwestern Gujarat and the bordering Sindh province of Pakistan. It occupies a total area of 27 900 km^2 (10,800 mile^2). The region was originally a part of the Arabian Sea. Geologic forces such as earthquakes resulted in the damming up of the region, turning it into a large saltwater lagoon. This area gradually filled with silt thus turning it into a seasonal salt marsh. During the monsoons, the area turns into a shallow marsh, often flooding to knee-depth. After the monsoons, the region turns dry and becomes parched.

Climate

Based on the Koppen system, India hosts six major climatic subtypes, ranging from arid desert in the west, alpine tundra and glaciers in the north, and humid tropical regions supporting rainforests in the southwest and the island territories. Many regions have starkly different microclimates. The nation has four seasons: winter (January–February), summer (March–May), a monsoon (rainy) season (June–September) and a post-monsoon period (October–December).

The Himalayas act as a barrier to the frigid katabatic winds flowing down from Central Asia. Thus, North India is kept warm or only mildly cooled during winter; in summer, the same phenomenon makes India relatively hot. Although the Tropic of Cancer—the boundary between the tropics and subtropics—passes through the middle of India, the whole country is considered to be tropical.

Summer lasts between March and June in most parts of India. Temperatures exceed 40 °C (104 °F) during the day. The coastal regions exceed 30 °C (86 °F) coupled with high levels of humidity. In the Thar desert area temperatures can exceed 45 °C (113 °F). The rain-bearing monsoon clouds are attracted to the low-pressure system created by the Thar Desert. The southwest monsoon splits into two arms, the Bay of Bengal arm and the Arabian Sea arm. The Bay of Bengal arm moves northwards crossing northeast India in early June. The Arabian Sea arm moves northwards and deposits much of its rain on the windward side of Western Ghats. Winters in peninsula India see mild to warm days and cool nights. Further north the temperature is cooler. Temperatures in some parts of the Indian plains sometimes fall below freezing. Most of northern India is plagued by fog during this season. The highest temperature recorded in India was 50.6 °C (123.1 °F) in Alwar in 1955. The lowest was “45 °C (“49.0 °F) in Kashmir.

Geology

India’s geological features are classified based on their era of formation. The Precambrian formations of Cudappah and Vindhyan systems are spread out over the eastern and southern states. A small part of this period is spread over western and central India. The Paleozoic formations from the Cambrian, Ordovician, Silurian and Devonian system are found in the Western Himalaya region in Kashmir and Himachal Pradesh. The Mesozoic Deccan Traps formation is seen over most of the northern Deccan; they are believed to be the result of sub-aerial volcanic activity. The Trap soil is black in colour and conducive to agriculture. The Carboniferous system, Permian System and Triassic systems are seen in the western Himalayas. The Jurassic system is seen in the western Himalayas and Rajasthan. Tertiary imprints are seen in parts of Manipur, Nagaland, Arunachal Pradesh and along the Himalayan belt. The Cretaceous system is seen in central India in the Vindhyas and part of the Indo-Gangetic plains. The Gondowana system is seen in the Narmada River area in the Vindhyas and Satpuras. The Eocene system is seen in the western Himalayas and Assam. Oligocene formations are seen in Kutch and Assam. The Pleistocene system is found over central India. The Andaman and Nicobar Island are thought to have been formed in this era by volcanoes. The Himalayas were formed by the convergence and deformation of the Indo-Australian and Eurasian Plates. Their continued convergence raises the height of the Himalayas by 1 cm each year.

Soils in India can be classified into 8 categories: alluvial, black, red, laterite, forest, arid & desert, saline & alkaline and peaty & organic soils. Alluvial soil constitute the largest soil group in India, constituting 80% of the total land surface. It is derived from the deposition of silt carried by rivers and are found in the Great Northern plains from Punjab to the Assam valley. Alluvial soil are generally fertile but they lack nitrogen and tend to be phosphoric.

Black soil are well developed in the Deccan lava region of Maharashtra, Gujarat, and Madhya Pradesh. These contain high percentage of clay and are moisture retentive. Red soil are found in Tamil Nadu, Karnataka plateau, Andhra plateau, Chota Nagpur plateau and the Aravallis. These are deficient in nitrogen, phosphorus and humus. Laterite soils are formed in tropical regions with heavy rainfall. Heavy rainfall results in leaching out all soluble material of top layer of soil. These are generally found in Western ghats, Eastern ghats and hilly areas of northeastern states that receive heavy rainfall. Forest soils occur on the slopes of mountains and hills in Himalayas, Western Ghats and Eastern Ghats. These generally consist of large amounts of dead leaves and other organic matter called humus.

Natural Resources

India's total renewable water resources are estimated at 1,907.8 km^3/year. Its annual supply of usable and replenshable groundwater amounts to 350 billion cubic metres. Only 35% of groundwater resources are being utilised. About 44 million tonnes of cargo is moved annually through the country's major rivers and waterways. Groundwater supplies 40% of water in India's irrigation canals. 56% of the land is arable and used for agriculture. Black soils are moisture-retentive and are preferred for dry farming and growing cotton, linseed, etc. Forest soils are used for tea and coffee plantations. Red soil have a wide diffusion of iron content.

Most of India's estimated 5.4 billion barrels (860,000,000 m^3) in oil reserves are located in the Mumbai High, upper Assam, Cambay, the Krishna-Godavari and Cauvery basins. India possesses about seventeen trillion cubic feet of natural gas in Andhra Pradesh, Gujarat and Orissa. Uranium is mined in Andhra Pradesh. India has 400 medium-to-high enthalpy thermal springs for producing geothermal energy in seven "provinces" — the Himalayas, Sohana, Cambay, the Narmada-Tapti delta, the Godavari delta and the Andaman and Nicobar Islands (specifically the volcanic Barren Island.)

India is the world's biggest producer of mica blocks and mica splittings. India ranks second amongst the world's largest producers of barites and chromites. The Pleistocene system is rich in minerals. India is the third-largest coal producer in the world and ranks fourth in the production of iron ore. It is the fifth-largest producer of bauxite and crude steel, the seventh-largest of manganese ore and the eighth-largest of aluminium. India has significant sources of titanium ore, diamonds and limestone. India possesses 24% of the world's known and economically-viable thorium, which is mined along shores of Kerala. Gold had been mined in the now-defunct Kolar Gold Fields in Karnataka.

7

The Earth as a Planet

Earth (or the Earth) is the third planet from the Sun, and the densest and fifth-largest of the eight planets in the Solar System. It is also the largest of the Solar System's four terrestrial planets. It is sometimes referred to as the World, the Blue Planet, or by its Latin name, *Terra*.

Home to millions of species including humans, Earth is currently the only place in the universe where life is known to exist. The planet formed 4.54 billion years ago, and life appeared on its surface within a billion years. Since then, Earth's biosphere has significantly altered the atmosphere and other abiotic conditions on the planet, enabling the proliferation of aerobic organisms as well as the formation of the ozone layer which, together with Earth's magnetic field, blocks harmful solar radiation, permitting life on land. The physical properties of the Earth, as well as its geological history and orbit, have allowed life to persist during this period. Without intervention, the planet could be expected to continue supporting life for between 0.5 and 2.3 billion years, after which the rising luminosity and expansion of the Sun—as a result of the gradual but inexorable depletion of its hydrogen fuel—would eventually eliminate the planet's biosphere.

Earth's outer surface is divided into several rigid segments, or tectonic plates, that gradually migrate across the surface over periods of many millions of years. About 71% of the surface is covered with salt water oceans, the remainder consisting of continents and islands which together have many lakes and other sources of water contributing to the hydrosphere. Liquid water, necessary for all known life, is not known to exist on any other planet's surface. Earth's poles are mostly covered with solid ice (Antarctic ice sheet) or sea ice (Arctic ice cap). The planet's interior remains active, with a thick layer of relatively solid mantle, a liquid outer core that generates a magnetic field, and a solid iron inner core.

Earth interacts with other objects in space, especially the Sun and the Moon. At present, Earth orbits the Sun once for every roughly 366.26 times it rotates about its axis. This is a sidereal year, which is equal to 365.26 solar days. The Earth's axis of rotation is tilted 23.4° away from the perpendicular to its orbital plane, producing seasonal variations on the planet's surface with a period of one tropical year (365.24 solar days). Earth's only known natural satellite, the Moon, which began orbiting it about 4.53 billion years ago, provides ocean tides, stabilizes the axial tilt and gradually slows the planet's rotation. Between approximately 3.8 billion and 4.1 billion years ago, numerous asteroid impacts during the Late Heavy Bombardment caused significant changes to the greater surface environment.

Both the mineral resources of the planet, as well as the products of the biosphere, contribute resources that are used to support a global human population. These inhabitants are grouped into about 200 independent sovereign states, which interact through diplomacy, travel, trade, and military action. Human cultures have developed many views of the planet, including personification as a deity, a belief in a flat Earth or in Earth as the centre of the universe, and a modern perspective of the world as an integrated environment that requires stewardship.

Chronology

Scientists have been able to reconstruct detailed information about the planet's past. The earliest dated Solar System material is dated to 4.5672 ± 0.0006 billion years ago, and by 4.54 billion years ago (within an uncertainty of 1%) the Earth and the other planets in the Solar System had formed out of the solar nebula—a disk-shaped mass of dust and gas left over from the formation of the Sun. This assembly of the Earth through accretion was thus largely completed within 10–

20 million years. Initially molten, the outer layer of the planet Earth cooled to form a solid crust when water began accumulating in the atmosphere. The Moon formed shortly thereafter, 4.53 billion years ago.

The current consensus model for the formation of the Moon is the giant impact hypothesis, in which the Moon formed as a result of a Mars-sized object (sometimes called Theia) with about 10% of the Earth's mass impacting the Earth in a glancing blow. In this model, some of this object's mass would have merged with the Earth and a portion would have been ejected into space, but enough material would have been sent into orbit to form the Moon.

Outgassing and volcanic activity produced the primordial atmosphere. Condensing water vapour, augmented by ice and liquid water delivered by asteroids and the larger proto-planets, comets, and trans-Neptunian objects produced the oceans.

The newly formed Sun was only 70% of its present luminosity, yet evidence shows that the early oceans remained liquid—a contradiction dubbed the faint young Sun paradox. A combination of greenhouse gases and higher levels of solar activity served to raise the Earth's surface temperature, preventing the oceans from freezing over. By 3.5 billion years ago, the Earth's magnetic field was established, which helped prevent the atmosphere from being stripped away by the solar wind.

Two major models have been proposed for the rate of continental growth: steady growth to the present-day and rapid growth early in Earth history. Current research shows that the second option is most likely, with rapid initial growth of continental crust followed by a long-term steady continental area.

On time scales lasting hundreds of millions of years, the surface continually reshaped as continents formed and broke up. The continents migrated across the surface, occasionally combining to form a supercontinent. Roughly 750 million years ago (Ma), one of the earliest known supercontinents, Rodinia, began to break apart. The continents later recombined to form Pannotia, 600–540 Ma, then finally Pangaea, which broke apart 180 Ma.

Evolution of Life

At present, Earth provides the only example of an environment that has given rise to the evolution of life. Highly energetic chemistry is believed to have produced a self-replicating molecule around 4 billion years ago and half a billion years later the last common ancestor of all life existed. The development of photosynthesis allowed the Sun's energy to be harvested directly by life forms; the resultant oxygen accumulated in the atmosphere and formed a layer of ozone (a form of molecular oxygen [O_3]) in the upper atmosphere. The incorporation of smaller cells within larger ones resulted in the development of complex cells called eukaryotes. True multicellular organisms formed as cells within colonies became increasingly specialized. Aided by the absorption of harmful ultraviolet radiation by the ozone layer, life colonized the surface of Earth.

Since the 1960s, it has been hypothesized that severe glacial action between 750 and 580 Ma, during the Neoproterozoic, covered much of the planet in a sheet of ice. This hypothesis has been termed "Snowball Earth", and is of particular interest because it preceded the Cambrian explosion, when multicellular life forms began to proliferate.

Following the Cambrian explosion, about 535 Ma, there have been five major mass extinctions. The most recent such event was 65 Ma, when an asteroid impact triggered the extinction of the (non-avian) dinosaurs and other large reptiles, but spared some small animals such as mammals, which then resembled shrews. Over the past 65 million years, mammalian life has diversified, and several million years ago, an African ape-like animal such as *Orrorin tugenensis* gained the ability to stand upright. This enabled tool use and encouraged communication that provided the nutrition and stimulation needed for a larger brain. The development of agriculture, and then civilization, allowed humans to influence the Earth in a short time span as no other life form had, affecting both the nature and quantity of other life forms.

The present pattern of ice ages began about 40 Ma and then intensified during the Pleistocene about 3 Ma. High-latitude regions have since undergone repeated cycles of glaciation and thaw, repeating every 40–100,000 years. The last continental glaciation ended 10,000 years ago.

Future

The future of the planet is closely tied to that of the Sun. As a result of the steady accumulation of helium at the Sun's core, the star's total luminosity will slowly increase. The luminosity of the Sun will grow by 10% over the next 1.1 Gyr (1.1 billion years) and by 40% over the next 3.5 Gyr. Climate models indicate that the rise in radiation reaching the Earth is likely to have dire consequences, including the loss of the planet's oceans.

The Earth's increasing surface temperature will accelerate the inorganic CO_2 cycle, reducing its concentration to levels lethally low for plants (10 ppm for C4 photosynthesis) in approximately 500 million to 900 million years. The lack of vegetation will result in the loss of oxygen in the atmosphere, so animal life will become extinct within several million more years. After another billion years all surface water will have disappeared and the mean global temperature will reach 70 °C (158 °F).

The Earth is expected to be effectively habitable for about another 500 million years from that point, although this may be extended up to 2.3 billion years if the nitrogen is removed from the atmosphere. Even if the Sun were eternal and stable, the continued internal cooling of the Earth would result in a loss of much of its CO_2 due to reduced volcanism, and 35% of the water in the oceans would descend to the mantle due to reduced steam venting from mid-ocean ridges.

The Sun, as part of its evolution, will become a red giant in about 5 Gyr. Models predict that the Sun will expand out to about 250 times its present radius, roughly 1 AU (150,000,000 km). Earth's fate is less clear. As a red giant, the Sun will lose roughly 30% of its mass, so, without tidal effects, the Earth will move to an orbit 1.7 AU (250,000,000 km) from the Sun when the star reaches it maximum radius.

The planet was therefore initially expected to escape envelopment by the expanded Sun's sparse outer atmosphere, though most, if not all, remaining life would have been destroyed by the Sun's increased luminosity (peaking at about 5000 times its present level). However, a more recent simulation indicates that Earth's orbit will decay due to tidal effects and drag, causing it to enter the red giant Sun's atmosphere and be vaporized.

Possible alternatives to this fate include the purposeful displacement of an asteroid from the Kuiper belt, which would repeatedly fly close enough to Earth as to enlarge its orbit, thereby preventing the overheating of its surface. The lifespan of the biosphere could thereby be extended by 5 billion years.

Composition and Structure

Earth is a terrestrial planet, meaning that it is a rocky body, rather than a gas giant like Jupiter. It is the largest of the four solar terrestrial planets in size and mass. Of these four planets, Earth also has the highest density, the highest surface gravity, the strongest magnetic field, and fastest rotation. It also is the only terrestrial planet with active plate tectonics.

Shape

The shape of the Earth is very close to that of an oblate spheroid, a sphere flattened along the axis from pole to pole such that there is a bulge around the equator. This bulge results from the rotation of the Earth, and causes the diameter at the equator to be 43 km larger than the pole to pole diameter. The average diameter of the reference spheroid is about 12,742 km, which is approximately 40,000 km/ð, as the meter was originally defined as 1/10,000,000 of the distance from the equator to the North Pole through Paris, France.

Local topography deviates from this idealized spheroid, though on a global scale, these deviations are very small: Earth has a tolerance of about one part in about 584, or 0.17%, from the reference spheroid, which is less than the 0.22% tolerance allowed in billiard balls.

The largest local deviations in the rocky surface of the Earth are Mount Everest (8848 m above local sea level) and the Mariana Trench (10,911 m below local sea level). Because of the equatorial bulge, the surface locations farthest from the centre of the Earth are the summits of Mount Chimborazo in Ecuador and Huascarán in Peru.

Chemical Composition of the Crust

Compound	Formula	Composition	
		Continental	Oceanic
silica	SiO_2	60.2%	48.6%
alumina	Al_2O_3	15.2%	16.5%
lime	CaO	5.5%	12.3%
magnesia	MgO	3.1%	6.8%
iron(II) oxide	FeO	3.8%	6.2%
sodium oxide	Na_2O	3.0%	2.6%
potassium oxide	K_2O	2.8%	0.4%
iron (III) oxide	Fe_2O_3	2.5%	2.3%
water	H_2O	1.4%	1.1%
carbon dioxide	CO_2	1.2%	1.4%
titanium dioxide	TiO_2	0.7%	1.4%
phosphorus pentoxide	P_2O_5	0.2%	0.3%
Total		99.6%	99.9%

Chemical Composition

The mass of the Earth is approximately 5.98×10^{24} kg. It is composed mostly of iron (32.1%), oxygen (30.1%), silicon (15.1%), magnesium (13.9%), sulfur (2.9%), nickel (1.8%), calcium (1.5%), and aluminium (1.4%); with the remaining 1.2% consisting of trace amounts of other elements. Due to mass segregation, the core region is believed to be primarily composed of iron (88.8%), with smaller amounts of nickel (5.8%), sulfur (4.5%), and less than 1% trace elements.

The geochemist F. W. Clarke calculated that a little more than 47% of the Earth's crust consists of oxygen. The more common rock constituents of the Earth's crust are nearly all oxides; chlorine, sulfur and fluorine are the only important exceptions to this and their total amount in any rock is usually much less than 1%. The principal oxides are silica, alumina, iron oxides, lime, magnesia, potash and soda. The silica functions principally as an acid, forming silicates, and all the commonest minerals of igneous rocks are of this nature. From a computation based on 1,672 analyses of all kinds of rocks, Clarke deduced that 99.22% were composed of 11 oxides. All the other constituents occur only in very small quantities.

Abundance of Elements on Earth

The abundance of a chemical element measures how relatively common the element is, or how much of the element there is by comparison to all other elements. Abundance may be variously measured by the mass-fraction (the same as weight fraction), or mole-fraction (fraction of atoms, or sometimes fraction of molecules, in gases), or by volume fraction. Measurement by volume-fraction is a common abundance measure in mixed gases such as atmospheres, which is close to molecular mole-fraction for ideal gas mixtures (i.e., gas mixtures at relatively low densities and pressures).

For example, the mass-fraction abundance of oxygen in water is about 89%, because that is the fraction of water's mass which is oxygen. However, the mole-fraction abundance of oxygen in water is only 33% because only 1 atom in 3 in water is an oxygen atom. In the universe as a whole, and in the atmospheres of gas-giant planets such as Jupiter, the mass-fraction abundances of hydrogen and helium are about 74% and 23-25% respectively, while the (atomic) mole-fractions of these elements are closer to 92% and 8%. However, since hydrogen is diatomic while helium is not in the conditions of Jupiter's outer atmosphere, the *molecular* mole-fraction (fraction of total gas molecules, or fraction of atmosphere by volume) of hydrogen in the outer atmosphere of Jupiter is about 86%, and for helium, 13%.

Abundance of Elements in the Universe

Solar System's most Abundant Isotopes

Isotope	Mass Fraction in Parts per million
Hydrogen-1	705,700
Helium-4	275,200
Oxygen-16	5,920
Carbon-12	3,032
Neon-20	1,548
Iron-56	1,169
Nitrogen-14	1,105
Silicon-28	653
Magnesium-24	513

Sulfur-32	396
Neon-22	208
Magnesium-26	79
Argon-36	77
Iron-54	72
Magnesium-25	69
Calcium-40	60
Aluminum-27	58
Nickel-58	49
Carbon-13	37
Helium-3	35
Silicon-29	34
Sodium-23	33
Iron-57	28
Hydrogen-2	23
Silicon-30	23

The elements - namely ordinary (baryonic) matter made out of protons and neutrons (as well as electrons) - are only a small part of the content of the Universe. Cosmological observations suggest that only 4% of the universe comprises the visible baryonic matter which constitutes stars, planets and living beings. The rest is made up of dark energy (73%) and dark matter (23%). The latter are forms of matter and energy believed to exist on the basis of theory and observational deductions, but their details are still the subject of research. They have not yet been directly observed and are not well understood.

Most standard (baryonic) matter is found in stars and interstellar clouds, in the form of atoms or ions (plasma), although other unusual kinds of matter can be found in astrophysical settings, such as the high densities inside white dwarfs and neutron stars.

Hydrogen is the most abundant element in the known Universe; helium is second. However, after this, the rank of abundance does not continue to correspond to the atomic number; oxygen has abundance rank 3, but atomic number 8. All others are substantially less common.

The abundance of the lightest elements is well predicted by the standard cosmological model, since they were mostly produced shortly (i.e., within a few hundred seconds) after the Big Bang, in a process known as Big Bang nucleosynthesis. Heavier elements were mostly produced much later, inside stars.

Helium-3 is rare on Earth and sought-after for use in nuclear fusion research. More abundant helium-3 is thought to exist on the Moon. Additional helium is produced by the fusion of hydrogen inside stellar cores by a variety of processes including the proton-proton chain and the CNO cycle.

Hydrogen and helium are estimated to make up roughly 74% and 24% of all baryonic matter in the universe respectively. Despite comprising only a very small fraction of the universe, the remaining "heavy elements" can greatly influence astronomical phenomena. Only about 2% (by mass) of the Milky Way galaxy's disk is composed of heavy elements.

These other elements are generated by stellar processes. In astronomy, a "metal" is any element other than hydrogen, helium or lithium. This distinction is significant because hydrogen and helium (together with trace amounts of lithium) are the only elements that occur naturally without the nuclear fusion activity of stars. Thus, the metallicity of a galaxy or other object is an indication of past stellar activity.

Ten most common elements in our galaxy by mass, estimated spectroscopically.

Z	Element	Mass fraction in parts per million
1	Hydrogen	739,000
2	Helium	240,000
8	Oxygen	10,400
6	Carbon	4,600
10	Neon	1,340
26	Iron	1,090
7	Nitrogen	960
14	Silicon	650
12	Magnesium	580
16	Sulfur	440

Abundance of Elements in the Earth

The Earth formed from the same cloud of matter that formed the Sun, but the planets acquired different compositions during the formation and evolution of the solar system. The history of Earth caused parts of this planet to have differing concentrations of the elements.

Abundance of Elements in the Earth's Crust

This graph illustrates the relative abundance of the chemical elements in Earth's upper continental crust.

Many of the elements shown in the graphic are classified into (partially overlapping) categories:

1. Rock-forming elements (major elements in green field and minor elements in light green field);
2. Rare earth elements (lanthanides, La-Lu, and Y; labelled in blue);
3. Major industrial metals (global production >~3×10^7 kg/year; labelled in bold);
4. Precious metals (italic);
5. The nine rarest "metals" — the six platinum group elements plus Au, Re, and Te (a metalloid).

Note that there are two breaks where the unstable elements technetium (atomic number: 43) and promethium (atomic number: 61) would be. These are both extremely rare, since on Earth they are only produced through the spontaneous fission of very heavy radioactive elements (for example, uranium, thorium, or the trace amounts of plutonium that exist in uranium ores), or by the interaction of certain other elements with cosmic rays. Both of the first two of these elements have been identified spectroscopically in the atmospheres of stars, where they are produced by ongoing nucleosynthetic processes. There are also breaks where the six noble gases would be since they are found in the Earth's crust due to decay chains from radioactive elements and are therefore extremely rare there. The six very rare, highly radioactive elements (polonium, astatine, francium, radium, actinium, and protactinium) are not included, since any of these elements that were present at the formation of the Earth have decayed away eons ago, and their quantity today is negligible.

Oxygen and silicon are notably quite common elements. They have frequently combined with each other to form common silicate minerals.

Rare-earth Element Abundances

"Rare" earth elements is a historical misnomer. The persistence of the term reflects unfamiliarity rather than true rarity. The more abundant rare earth elements are each similar in crustal concentration to commonplace industrial metals such as chromium, nickel, copper, zinc, molybdenum, tin, tungsten, or lead.

The two least abundant rare earth elements (thulium and lutetium) are nearly 200 times more common than gold. However, in contrast to the ordinary base and precious metals, rare earth elements have very little tendency to become concentrated in exploitable ore deposits. Consequently, most of the world's supply of rare earth elements comes from only a handful of sources. Furthermore, the rare earth metals are all quite chemically similar to each other, and they are thus quite difficult to separate into quantities of the pure element.

Differences in abundances of individual rare earth elements in the upper continental crust of the Earth represent the superposition of two effects, one nuclear and one geochemical. First, the rare earth elements with even atomic numbers ($_{58}Ce$, $_{60}Nd$,...) have greater cosmic and terrestrial abundances than the adjacent rare earth elements with odd atomic numbers ($_{57}La$, $_{59}Pr$,...). Second, the lighter rare earth elements are more incompatible (because they have larger ionic radii) and therefore more strongly concentrated in the continental crust than the heavier rare earth elements. In most rare earth ore deposits, the first four rare earth elements - lanthanum, cerium, praseodymium, and neodymium - constitute 80% to 99% of the total amount of rare earth metal that can be found in the ore.

Atmosphere

The order of elements by volume-fraction (which is approximately molecular mole-fraction) in the atmosphere is nitrogen (78.1%), oxygen (20.9%), argon (0.96%), followed by (in uncertain order) carbon and hydrogen because water vapour and carbon dioxide, which represent most of these two elements in the air, are variable components. Sulfur, phosphorus, and all other elements are present in significantly lower proportions.

According to the above graphic, argon, a significant if not major component of the atmosphere, does not appear in the crust at all. This is because the atmosphere has a far smaller mass than the crust, so argon remaining in the crust contributes little to mass-fraction there, while at the same time buildup of argon in the atmosphere has become large enough to be significant.

Ocean

Elemental Composition of Earth's Ocean Water (by Mass)

Element	Percent	Element	Percent
Oxygen	85.84	Sulfur	0.091
Hydrogen	10.82	Calcium	0.04
Chlorine	1.94	Potassium	0.04
Sodium	1.08	Bromine	0.0067
Magnesium	0.1292	Carbon	0.0028

See sea water for abundance of elements in the ocean, but note that that list is by mass - a list by molarity (mole-fraction) would look very different for the first 4 elements; specifically, hydrogen would comprise nearly two-thirds of the number of all atoms because hydrogen itself comprises two of the three atoms of all water molecules.

Internal Structure

The interior of the Earth, like that of the other terrestrial planets, is divided into layers by their chemical or physical (rheological) properties. The outer layer of the Earth is a chemically distinct silicate solid crust, which is underlain by a highly viscous solid mantle. The crust is separated from the mantle by the Mohorovièiæ discontinuity, and the thickness of the crust varies: averaging 6 km under the oceans and 30–50 km on the continents. The crust and the cold, rigid, top of the upper mantle are collectively known as the lithosphere, and it is of the lithosphere that the tectonic plates are comprised. Beneath the lithosphere is the asthenosphere, a relatively low-viscosity layer on which the lithosphere rides. Important changes in crystal structure within the mantle occur at 410 and 660 kilometres below the surface, spanning a transition zone that separates the upper and lower mantle. Beneath the mantle, an extremely low viscosity liquid outer core lies above a solid inner core. The inner core may rotate at a slightly higher angular velocity than the remainder of the planet, advancing by 0.1–0.5° per year.

Human Body

By mass, human cells consist of 65-90% water (H_2O), and a significant portion is composed of carbon-containing organic molecules. Oxygen therefore contributes a majority of a human body's mass, followed by carbon. 99% of the mass of the human body is made up of the six elements: oxygen, carbon, hydrogen, nitrogen, calcium, and phosphorus.

Element	Percent by Mass
Oxygen	65
Carbon	18
Hydrogen	10
Nitrogen	3
Calcium	1.5
Phosphorus	1.2
Potassium	0.2
Sulfur	0.2
Chlorine	0.2
Sodium	0.1
Magnesium	0.05
Iron, Cobalt, Copper, Zinc, Iodine	<0.05 each
Selenium, Fluorine	<0.01 each

Heat

Earth's internal heat comes from a combination of residual heat from planetary accretion (about 20%) and heat produced through radioactive decay (80%). The major heat-producing isotopes in the Earth are potassium-40, uranium-238, uranium-235, and thorium-232. At the centre of the planet, the temperature may be up to 7,000 K and the pressure could reach 360 GPa. Because much of the heat is provided by radioactive decay, scientists believe that early in Earth history, before isotopes with short half-lives had been depleted, Earth's heat production would have been much higher. This extra heat production, twice present-day at approximately 3 billion years ago, would have increased temperature gradients within the Earth, increasing the rates of mantle convection and plate tectonics, and allowing the production of igneous rocks such as komatiites that are not formed today.

Total heat loss from the Earth is 4.2×10^{13} watts. A portion of the core's thermal energy is transported toward the crust by mantle plumes; a form of convection consisting of upwellings of higher-temperature rock. These plumes can produce hotspots and flood basalts. More of the heat in the Earth is lost through plate tectonics, by mantle upwelling associated with mid-ocean ridges. The final major mode of heat loss is through conduction through the lithosphere, the majority of which occurs in the oceans because the crust there is much thinner than that of the continents.

Tectonic Plates

The mechanically rigid outer layer of the Earth, the lithosphere, is broken into pieces called tectonic plates. These plates are rigid segments that move in relation to one another at one of three types of plate boundaries: Convergent boundaries, at which two plates come together, Divergent boundaries, at which two plates are pulled apart, and Transform boundaries, in which two plates slide past one another laterally. Earthquakes, volcanic activity, mountain-building, and oceanic trench formation can occur along these plate boundaries. The tectonic plates ride on top of the asthenosphere, the solid but less-viscous part of the upper mantle that can flow and move along with the plates, and their motion is strongly coupled with convection patterns inside the Earth's mantle.

As the tectonic plates migrate across the planet, the ocean floor is subducted under the leading edges of the plates at convergent boundaries. At the same time, the upwelling of mantle material at divergent boundaries creates mid-ocean ridges. The combination of these processes continually recycles the oceanic crust back into the mantle. Because of this recycling, most of the ocean floor is less than 100 million years in age. The oldest oceanic crust is located in the Western Pacific, and has an estimated age of about 200 million years. By comparison, the oldest dated continental crust is 4030 million years old.

Other notable plates include the Indian Plate, the Arabian Plate, the Caribbean Plate, the Nazca Plate off the west coast of South America and the Scotia Plate in the southern Atlantic Ocean. The Australian Plate fused with the Indian Plate between 50 and 55 million years ago. The fastest-moving plates are the oceanic plates, with the Cocos Plate advancing at a rate of 75 mm/yr and the Pacific Plate moving 52–69 mm/yr. At the other extreme, the slowest-moving plate is the Eurasian Plate, progressing at a typical rate of about 21 mm/yr.

Surface

The Earth's terrain varies greatly from place to place. About 70.8% of the surface is covered by water, with much of the continental shelf below sea level. The submerged surface has mountainous features, including a globe-spanning mid-ocean ridge system, as well as undersea volcanoes, oceanic trenches, submarine canyons, oceanic plateaus and abyssal plains. The remaining 29.2% not covered by water consists of mountains, deserts, plains, plateaus, and other geomorphologies.

The planetary surface undergoes reshaping over geological time periods because of tectonics and erosion. The surface features built up or deformed through plate tectonics are subject to steady weathering from precipitation, thermal cycles, and chemical effects. Glaciation, coastal erosion, the build-up of coral reefs, and large meteorite impacts also act to reshape the landscape.

The continental crust consists of lower density material such as the igneous rocks granite and andesite. Less common is basalt, a denser volcanic rock that is the primary constituent of the ocean floors. Sedimentary rock is formed from the accumulation of sediment that becomes compacted together. Nearly 75% of the continental surfaces are covered by sedimentary rocks, although they form only about 5% of the crust. The third form of rock material found on Earth is metamorphic rock, which is created from the transformation of pre-existing rock types through high pressures, high temperatures, or both. The most abundant silicate minerals on the Earth's surface include quartz, the feldspars, amphibole, mica, pyroxene and olivine. Common carbonate minerals include calcite (found in limestone), aragonite and dolomite.

The pedosphere is the outermost layer of the Earth that is composed of soil and subject to soil formation processes. It exists at the interface of the lithosphere, atmosphere, hydrosphere and biosphere. Currently the total arable land is 13.31% of the land surface, with only 4.71% supporting permanent crops. Close to 40% of the Earth's land surface is presently used for cropland and pasture, or an estimated 1.3×10^7 km^2 of cropland and 3.4×10^7 km^2 of pastureland.

The elevation of the land surface of the Earth varies from the low point of “418 m at the Dead Sea, to a 2005-estimated maximum altitude of 8,848 m at the top of Mount Everest. The mean height of land above sea level is 840 m.

Hydrosphere

The abundance of water on Earth's surface is a unique feature that distinguishes the "Blue Planet" from others in the Solar System. The Earth's hydrosphere consists chiefly of the oceans, but technically includes all water surfaces in the world, including inland seas, lakes, rivers, and underground waters down to a depth of 2,000 m. The deepest underwater location is Challenger Deep of the Mariana Trench in the Pacific Ocean with a depth of “10,911.4 m.

The mass of the oceans is approximately 1.35×10^{18} metric tons, or about 1/4400 of the total mass of the Earth. The oceans cover an area of 361.8×10^6 km^2 with a mean depth of 3,682 m, resulting in an estimated volume of 1.332×10^9 km^3. If all the land on Earth were spread evenly, water would rise to an altitude of more than 2.7 km. About 97.5% of the water is saline, while the remaining 2.5% is fresh water. Most fresh water, about 68.7%, is currently ice.

The average salinity of the Earth's oceans is about 35 grams of salt per kilogram of sea water (35 ‰). Most of this salt was released from volcanic activity or extracted from cool, igneous rocks. The oceans are also a reservoir of dissolved atmospheric gases, which are essential for the survival of many aquatic life forms. Sea water has an important influence on the world's climate, with the oceans acting as a large heat reservoir. Shifts in the oceanic temperature distribution can cause significant weather shifts, such as the El Niño-Southern Oscillation.

Atmosphere

The atmospheric pressure on the surface of the Earth averages 101.325 kPa, with a scale height of about 8.5 km. It is 78% nitrogen and 21% oxygen, with trace amounts of water vapour, carbon dioxide and other gaseous molecules. The height of the troposphere varies with latitude, ranging between 8 km at the poles to 17 km at the equator, with some variation resulting from weather and seasonal factors.

Earth's biosphere has significantly altered its atmosphere. Oxygenic photosynthesis evolved 2.7 billion years ago, forming the primarily nitrogen-oxygen atmosphere of today. This change enabled the proliferation of aerobic organisms as well as the formation of the ozone layer which blocks ultraviolet solar radiation, permitting life on land. Other atmospheric functions important to life on Earth include transporting water vapour, providing useful gases, causing small meteors to burn up before they strike the surface, and moderating temperature. This last phenomenon is known as the greenhouse effect: trace molecules within the atmosphere serve to capture thermal energy emitted from the ground, thereby raising the average temperature. Carbon dioxide, water vapour, methane and ozone are the primary greenhouse gases in the Earth's atmosphere. Without this heat-retention effect, the average surface temperature would be “18 °C and life would likely not exist.

Weather and Climate

The Earth's atmosphere has no definite boundary, slowly becoming thinner and fading into outer space. Three-quarters of the atmosphere's mass is contained within the first 11 km of the planet's surface. This lowest layer is called the troposphere. Energy from the Sun heats this layer, and the surface below, causing expansion of the air. This lower density air then rises, and is replaced by cooler, higher density air. The result is atmospheric circulation that drives the weather and climate through redistribution of heat energy.

The primary atmospheric circulation bands consist of the trade winds in the equatorial region below 30° latitude and the westerlies in the mid-latitudes between 30° and 60°. Ocean currents are also important factors in determining climate, particularly the thermohaline circulation that distributes heat energy from the equatorial oceans to the polar regions.

Water vapour generated through surface evaporation is transported by circulatory patterns in the atmosphere. When atmospheric conditions permit an uplift of warm, humid air, this water condenses and settles to the surface as precipitation. Most of the water is then transported to lower elevations by river systems and usually returned to the oceans or deposited into lakes. This water cycle is a vital mechanism for supporting life on land, and is a primary factor in the erosion of surface features over geological periods. Precipitation patterns vary widely, ranging from several meters of water per year to less than a millimeter. Atmospheric circulation, topological features and temperature differences determine the average precipitation that falls in each region.

The Earth can be sub-divided into specific latitudinal belts of approximately homogeneous climate. Ranging from the equator to the polar regions, these are the tropical (or equatorial), subtropical, temperate and polar climates. Climate can also be classified based on the temperature and precipitation, with the climate regions characterized by fairly uniform air masses. The commonly used Koppen climate classification system (as modified by Wladimir Koppen's student Rudolph Geiger) has five broad groups (humid tropics, arid, humid middle latitudes, continental and cold polar), which are further divided into more specific subtypes.

Upper Atmosphere

Above the troposphere, the atmosphere is usually divided into the stratosphere, mesosphere, and thermosphere. Each layer has a different lapse rate, defining the rate of change in temperature with height. Beyond these, the exosphere thins out into the magnetosphere, where the Earth's magnetic fields interact with the solar wind. An important part of the atmosphere for life on Earth is the ozone layer, a component of the stratosphere that partially shields the surface from ultraviolet light. The Kármán line, defined as 100 km above the Earth's surface, is a working definition for the boundary between atmosphere and space. Thermal energy causes some of the molecules at the outer edge of the Earth's atmosphere have their velocity increased to the point where they can escape from the planet's gravity. This results in a slow but steady leakage of the atmosphere into space. Because unfixed hydrogen has a low molecular weight, it can achieve escape velocity more readily and it leaks into outer space at a greater rate than other gasses.

The leakage of hydrogen into space contributes to the pushing of the Earth from an initially reducing state to its current oxidizing one. Photosynthesis provided a source of free oxygen, but the loss of reducing agents such as hydrogen is believed to have been a necessary precondition for the widespread accumulation of oxygen in the atmosphere. Hence the ability of hydrogen to escape from the Earth's atmosphere may have influenced the nature of life that developed on the planet. In the current, oxygen-rich atmosphere most hydrogen is converted into water before it has an opportunity to escape. Instead, most of the hydrogen loss comes from the destruction of methane in the upper atmosphere.

Magnetic Field

The Earth's magnetic field is shaped roughly as a magnetic dipole, with the poles currently located proximate to the planet's geographic poles. According to dynamo theory, the field is generated within the molten outer core region where heat creates convection motions of conducting materials, generating electric currents. These in turn produce the Earth's magnetic field. The convection movements in the core are chaotic; the magnetic poles drift and periodically change alignment. This results in field reversals at irregular intervals averaging a few times every million years. The most recent reversal occurred approximately 700,000 years ago.

The field forms the magnetosphere, which deflects particles in the solar wind. The sunward edge of the bow shock is located at about 13 times the radius of the Earth. The collision between the magnetic field and the solar wind forms the Van Allen radiation belts, a pair of concentric, torus-shaped regions of energetic charged particles. When the plasma enters the Earth's atmosphere at the magnetic poles, it forms the aurora.

Orbit and Rotation

Rotation

Earth's rotation period relative to the Sun—its mean solar day—is 86,400 seconds of mean solar time. Each second is slightly longer than an SI second because Earth's solar day is now slightly longer than it was during the 19th century because of tidal acceleration.

Earth's rotation period relative to the fixed stars, called its *stellar day* by the International Earth Rotation and Reference Systems Service (IERS), is 86164.098903691 seconds of mean solar time (UT1), or $23^h\ 56^m\ 4.098903691^s$. Earth's rotation period relative to the processing or moving mean vernal equinox, misnamed its *sidereal day*, is 86164.09053083288 seconds of mean solar time (UT1) ($23^h\ 56^m\ 4.09053083288^s$). Thus the sidereal day is shorter than the stellar day by about 8.4 ms. The length of the mean solar day in SI seconds is available from the IERS for the periods 1623–2005 and 1962–2005.

Apart from meteors within the atmosphere and low-orbiting satellites, the main apparent motion of celestial bodies in the Earth's sky is to the west at a rate of 15°/h = 15'/min. For bodies near the celestial equator, this is equivalent to an apparent diameter of the Sun or Moon every two minutes; from the planet's surface, the apparent sizes of the Sun and the Moon are approximately the same.

Orbit

Earth orbits the Sun at an average distance of about 150 million kilometres every 365.2564 mean solar days, or one sidereal year. From Earth, this gives an apparent movement of the Sun eastward with respect to the stars at a rate of about 1°/day, or a Sun or Moon diameter every 12 hours. Because of this motion, on average it takes 24 hours—a solar day—for Earth to complete a full rotation about its axis so that the Sun returns to the meridian. The orbital speed of the Earth averages about 30 km/s (108,000 km/h), which is fast enough to cover the planet's diameter (about 12,600 km) in seven minutes, and the distance to the Moon (384,000 km) in four hours.

The Moon revolves with the Earth around a common barycenter every 27.32 days relative to the background stars.

When combined with the Earth–Moon system's common revolution around the Sun, the period of the synodic month, from new moon to new moon, is 29.53 days. Viewed from the celestial north pole, the motion of Earth, the Moon and their axial rotations are all counter-clockwise. Viewed from a vantage point above the north poles of both the Sun and the Earth, the Earth appears to revolve in a counter clock wise direction about the Sun. The orbital and axial planes are not precisely aligned: Earth's axis is tilted some 23.5 degrees from the perpendicular to the Earth–Sun plane, and the Earth–Moon plane is tilted about 5 degrees against the Earth-Sun plane. Without this tilt, there would be an eclipse every two weeks, alternating between lunar eclipses and solar eclipses.

The Hill sphere, or gravitational sphere of influence, of the Earth is about 1.5 Gm (or 1,500,000 kilometres) in radius. This is maximum distance at which the Earth's gravitational influence is stronger than the more distant Sun and planets. Objects must orbit the Earth within this radius, or they can become unbound by the gravitational perturbation of the Sun.

Earth, along with the Solar System, is situated in the Milky Way galaxy, orbiting about 28,000 light years from the centre of the galaxy. It is currently about 20 light years above the galaxy's equatorial plane in the Orion spiral arm.

Axial Tilt and Seasons

Because of the axial tilt of the Earth, the amount of sunlight reaching any given point on the surface varies over the course of the year. This results in seasonal change in climate, with summer in the northern hemisphere occurring when the North Pole is pointing toward the Sun, and winter taking place when the pole is pointed away. During the summer, the day lasts longer and the Sun climbs higher in the sky. In winter, the climate becomes generally cooler and the days shorter. Above the Arctic Circle, an extreme case is reached where there is no daylight at all for part of the year—a polar night. In the southern hemisphere the situation is exactly reversed, with the South Pole oriented opposite the direction of the North Pole.

By astronomical convention, the four seasons are determined by the solstices—the point in the orbit of maximum axial tilt toward or away from the Sun—and the equinoxes, when the direction of the tilt and the direction to the Sun are perpendicular. In the northern hemisphere, Winter Solstice occurs on about December 21, Summer Solstice is near June 21, Spring Equinox is around March 20 and Autumnal Equinox is about September 23. In the Southern hemisphere, the situation is reversed, with the Summer and Winter Solstices exchanged and the Spring and Autumnal Equinox dates switched.

The angle of the Earth's tilt is relatively stable over long periods of time. However, the tilt does undergo nutation; a slight, irregular motion with a main period of 18.6 years. The orientation (rather than the angle) of the Earth's axis also changes over time, processing around in a complete circle over each 25,800-year cycle; this precession is the reason for the difference between a sidereal year and a tropical year. Both of these motions are caused by the varying attraction of the Sun and Moon on the Earth's equatorial bulge.

From the perspective of the Earth, the poles also migrate a few meters across the surface. This polar motion has multiple, cyclical components, which collectively are termed quasiperiodic motion. In addition to an annual component to this motion, there is a 14-month cycle called the Chandler wobble. The rotational velocity of the Earth also varies in a phenomenon known as length of day variation.

In modern times, Earth's perihelion occurs around January 3, and the aphelion around July 4.

However, these dates change over time due to precession and other orbital factors, which follow cyclical patterns known as Milankovitch cycles. The changing Earth-Sun distance results in an increase of about 6.9% in solar energy reaching the Earth at perihelion relative to aphelion.

Since the southern hemisphere is tilted toward the Sun at about the same time that the Earth reaches the closest approach to the Sun, the southern hemisphere receives slightly more energy from the Sun than does the northern over the course of a year. However, this effect is much less significant than the total energy change due to the axial tilt, and most of the excess energy is absorbed by the higher proportion of water in the southern hemisphere.

Moon

Characteristics	
Diameter	3,474.8 km
	2,159.2 mi
Mass	7.349×10^{22} kg
	8.1×10^{19} (short) tons
Semi-major axis	384,400 km
	238,700 mi
Orbital period	27 d 7 h 43.7 m

The Moon is a relatively large, terrestrial, planet-like satellite, with a diameter about one-quarter of the Earth's. It is the largest moon in the Solar System relative to the size of its planet, although Charon is larger relative to the dwarf planet Pluto. The natural satellites orbiting other planets are called "moons" after Earth's Moon.

The gravitational attraction between the Earth and Moon causes tides on Earth. The same effect on the Moon has led to its tidal locking: its rotation period is the same as the time it takes to orbit the Earth.

As a result, it always presents the same face to the planet. As the Moon orbits Earth, different parts of its face are illuminated by the Sun, leading to the lunar phases; the dark part of the face is separated from the light part by the solar terminator.

Because of their tidal interaction, the Moon recedes from Earth at the rate of approximately 38 mm a year. Over millions of years, these tiny modifications—and the lengthening of Earth's day by about 23 µs a year—add up to significant changes. During the Devonian period, for example, (approximately 410 million years ago) there were 400 days in a year, with each day lasting 21.8 hours.

The Moon may have dramatically affected the development of life by moderating the planet's climate. Paleontological evidence and computer simulations show that Earth's axial tilt is stabilized by tidal interactions with the Moon. Some theorists believe that without this stabilization against the torques applied by the Sun and planets to the Earth's equatorial bulge, the rotational axis might be chaotically unstable, exhibiting chaotic changes over millions of years, as appears to be the case for Mars. If Earth's axis of rotation were to approach the plane of the ecliptic, extremely severe weather could result from the resulting extreme seasonal differences. One pole would be pointed directly toward the Sun during *summer* and directly away during *winter*.

Planetary scientists who have studied the effect claim that this might kill all large animal and higher plant life. However, this is a controversial subject, and further studies of Mars—whose rotation period and axial tilt are similar to those of Earth, but which lacks a large moon or liquid core—may settle the matter.

Viewed from Earth, the Moon is just far enough away to have very nearly the same apparent-sized disk as the Sun. The angular size (or solid angle) of these two bodies match because, although the Sun's diameter is about 400 times as large as the Moon's, it is also 400 times more distant. This allows total and annular solar eclipses to occur on Earth.

The most widely accepted theory of the Moon's origin, the giant impact theory, states that it formed from the collision of a Mars-size protoplanet called Theia with the early Earth. This hypothesis explains (among other things) the Moon's relative lack of iron and volatile elements, and the fact that its composition is nearly identical to that of the Earth's crust.

Habitability

A planet that can sustain life is termed habitable, even if life did not originate there. The Earth provides the (currently understood) requisite conditions of liquid water, an environment where complex organic molecules can assemble, and sufficient energy to sustain metabolism. The distance of the Earth from the Sun, as well as its orbital eccentricity, rate of rotation, axial tilt, geological history, sustaining atmosphere and protective magnetic field all contribute to the conditions believed necessary to originate and sustain life on this planet.

Biosphere

The planet's life forms are sometimes said to form a "biosphere". This biosphere is generally believed to have begun evolving about 3.5 billion years ago. Earth is the only place in the universe where life is known to exist. Some scientists believe that Earth-like biospheres might be rare.

The biosphere is divided into a number of biomes, inhabited by broadly similar plants and animals. On land, biomes are separated primarily by differences in latitude, height above sea level and humidity. Terrestrial biomes lying within the Arctic or Antarctic Circles, at high altitudes or in extremely arid areas are relatively barren of plant and animal life; species diversity reaches a peak in humid lowlands at equatorial latitudes.

Natural Resources and Land Use

The Earth provides resources that are exploitable by humans for useful purposes. Some of these are non-renewable resources, such as mineral fuels, that are difficult to replenish on a short time scale.

Large deposits of fossil fuels are obtained from the Earth's crust, consisting of coal, petroleum, natural gas and methane clathrate.

These deposits are used by humans both for energy production and as feedstock for chemical production. Mineral ore bodies have also been formed in Earth's crust through a process of Ore genesis, resulting from actions of erosion and plate tectonics. These bodies form concentrated sources for many metals and other useful elements.

The Earth's biosphere produces many useful biological products for humans, including (but far from limited to) food, wood, pharmaceuticals, oxygen, and the recycling of many organic wastes. The land-based ecosystem depends upon topsoil and fresh water, and the oceanic ecosystem depends upon dissolved nutrients washed down from the land. Humans also live on the land by using building materials to construct shelters. In 1993, human use of land is approximately:

Land use	Arable land	Permanent crops	Permanent pastures	Forests and woodland	Urban areas	Other
Percentage	13.13%	4.71%	26%	32%	1.5%	30%

The estimated amount of irrigated land in 1993 was 2,481,250 km^2.

Natural and Environmental Hazards

Large areas are subject to extreme weather such as tropical cyclones, hurricanes, or typhoons that dominate life in those areas. Many places are subject to earthquakes, landslides, tsunamis, volcanic eruptions, tornadoes, sinkholes, blizzards, floods, droughts, and other calamities and disasters.

Many localized areas are subject to human-made pollution of the air and water, acid rain and toxic substances, loss of vegetation (overgrazing, deforestation, desertification), loss of wildlife, species extinction, soil degradation, soil depletion, erosion, and introduction of invasive species.

According to the United Nations, a scientific consensus exists linking human activities to global warming due to industrial carbon dioxide emissions. This is predicted to produce changes such as the melting of glaciers and ice sheets, more extreme temperature ranges, significant changes in weather and a global rise in average sea levels.

Human Geography

Earth has approximately 6,803,000,000 human inhabitants as of December 12, 2009. Projections indicate that the world's human population will reach seven billion in 2013 and 9.2 billion in 2050. Most of the growth is expected to take place in developing nations. Human population density varies widely around the world, but a majority live in Asia. By 2020, 60% of the world's population is expected to be living in urban, rather than rural, areas.

It is estimated that only one-eighth of the surface of the Earth is suitable for humans to live on—three-quarters is covered by oceans, and half of the land area is either desert (14%), high mountains (27%), or other less suitable terrain. The northernmost permanent settlement in the world is Alert, on Ellesmere Island in Nunavut, Canada. (82°282 N) The southernmost is the Amundsen-Scott South Pole Station, in Antarctica, almost exactly at the South Pole. (90°S).

Independent sovereign nations claim the planet's entire land surface, except for some parts of Antarctica and the odd unclaimed area of Bir Tawil between Egypt and Sudan. As of 2007 there are 201 sovereign states, including the 192 United

Nations member states. In addition, there are 59 dependent territories, and a number of autonomous areas, territories under dispute and other entities. Historically, Earth has never had a sovereign government with authority over the entire globe, although a number of nation-states have striven for world domination and failed.

The United Nations is a worldwide intergovernmental organization that was created with the goal of intervening in the disputes between nations, thereby avoiding armed conflict. It is not, however, a world government. The U.N. serves primarily as a forum for international diplomacy and international law. When the consensus of the membership permits, it provides a mechanism for armed intervention.

The first human to orbit the Earth was Yuri Gagarin on April 12, 1961. In total, about 400 people visited outer space and reached Earth orbit as of 2004, and, of these, twelve have walked on the Moon. Normally the only humans in space are those on the International Space Station. The station's crew, currently six people, is usually replaced every six months. The furthest humans have travelled from Earth is 400,171 km, achieved during the 1970 Apollo 13 mission.

Cultural Viewpoint

The name "Earth" derives from the Anglo-Saxon word *erda*, which means ground or soil, and is related to the German word *erde*. It became *eorthe* later, and then *erthe* in Middle English. The standard astronomical symbol of the Earth consists of a cross circumscribed by a circle.

Unlike the rest of the planets in the Solar System, mankind did not perceive the Earth as a planet until the 16th century. Earth has often been personified as a deity, in particular a goddess. In many cultures the mother goddess is also portrayed as a fertility deity. Creation myths in many religions recall a story involving the creation of the Earth by a supernatural deity or deities. A variety of religious groups, often associated with fundamentalist branches of Protestantism or Islam, assert that their interpretations of these creation myths in sacred texts are literal truth and should be considered alongside or replace conventional scientific accounts of the formation of the

Earth and the origin and development of life. Such assertions are opposed by the scientific community and by other religious groups. A prominent example is the creation-evolution controversy.

In the past there were varying levels of belief in a flat Earth, but this was displaced by the concept of a spherical Earth due to observation and circumnavigation. The human perspective regarding the Earth has changed following the advent of space flight, and the biosphere is now widely viewed from a globally integrated perspective. This is reflected in a growing environmental movement that is concerned about humankind's effects on the planet.