Environmental Science & its Components

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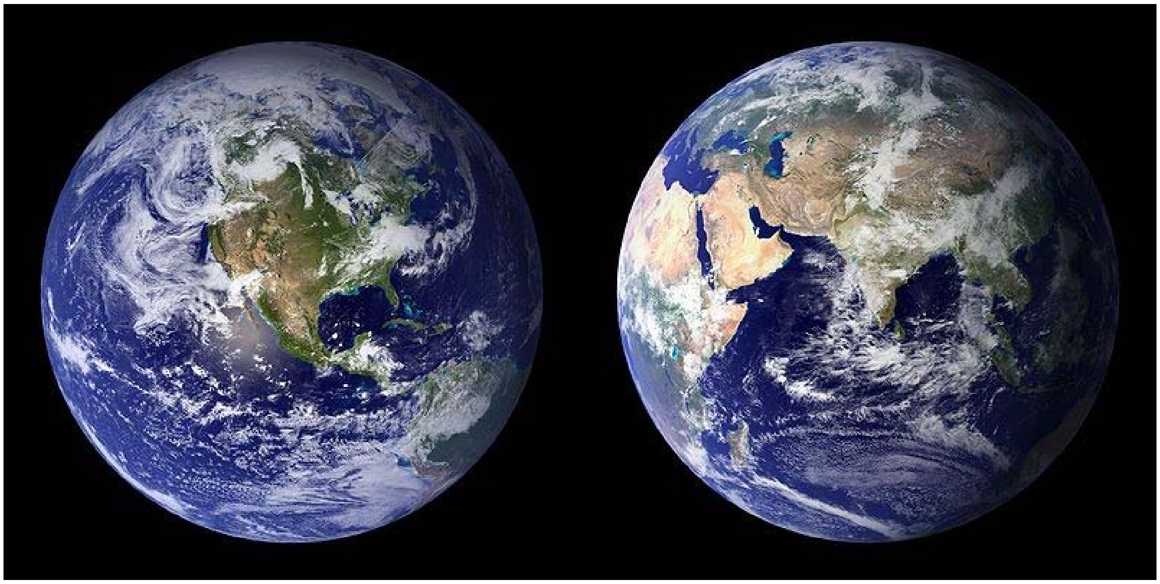
Introduction to Environmental Science



Blue Marble composite images generated by NASA in 2001 (left) and 2002 (right).

Environmental science is an interdisciplinary academic field that integrates physical and biological sciences (including physics, chemistry, biology, soil science, geology, and geography) to the study of the environment, and the solution of environmental problems. Environmental science provides an integrated, quantitative, and interdisciplinary approach to the study of environmental systems.

Related areas of study include environmental studies and environmental engineering. Environmental studies incorporates more of the social sciences for understanding human relationships, perceptions and policies towards the environment. Environmental engineering focuses on design and technology for improving environmental quality.

Environmental scientists work on subjects like the understanding of earth processes, evaluating alternative energy systems, pollution control and mitigation, natural resource management, and the effects of global climate change. Environmental issues almost always include an interaction of physical, chemical, and biological processes. Environmental scientists bring a systems approach to the analysis of environmental problems. Key elements of an effective environmental scientist include the ability to relate space and time relationships as well as quantitative analysis.

Environmental science came alive as a substantive, active field of scientific investigation in the 1960s and 1970s driven by (a) the need for a multi-disciplinary approach to analyze complex environmental problems, (b) the arrival of substantive environmental laws requiring specific environmental protocols of investigation and (c) the growing public awareness of a need for action in addressing environmental problems. Events that spurred this development included the publication of Rachael Carson's landmark environmental book *Silent Spring* along with major environmental issues becoming very public, such as the 1969 Santa Barbara oil spill, and the Cuyahoga River of Cleveland, Ohio, "catching fire" (also in 1969), and helped increase the visibility of environmental issues and create this new field of study.

Components

Atmospheric sciences focuses on the Earth's atmosphere, with an emphasis upon its interrelation to other systems. Atmospheric sciences can include studies of meteorology, greenhouse gas phenomena, atmospheric dispersion modeling of airborne contaminants, sound propagation phenomena related to noise pollution, and even light pollution.

Taking the example of the global warming phenomena, physicists create computer models of atmospheric circulation and infra-red radiation transmission, chemists examine the inventory of atmospheric chemicals and their reactions, biologists analyze the plant and animal contributions to carbon dioxide fluxes, and specialists such as meteorologists and oceanographers add additional breadth in understanding the atmospheric dynamics.

Ecology. An interdisciplinary analysis of an ecological system which is being impacted by one or more stressors might include several related environmental science fields. For example, one might examine an estuarine setting where a proposed industrial development could impact certain species by water and air pollution. For this study, biologists would describe the flora and fauna, chemists would analyze the transport of water pollutants to the marsh, physicists would calculate air pollution emissions and geologists would assist in understanding the marsh soils and bay muds.

Environmental chemistry is the study of chemical alterations in the environment. Principal areas of study include soil contamination and water pollution. The topics of analysis include chemical degradation in the environment, multi-phase transport of chemicals (for example, evaporation of a solvent containing lake to yield solvent as an air pollutant), and chemical effects upon biota.

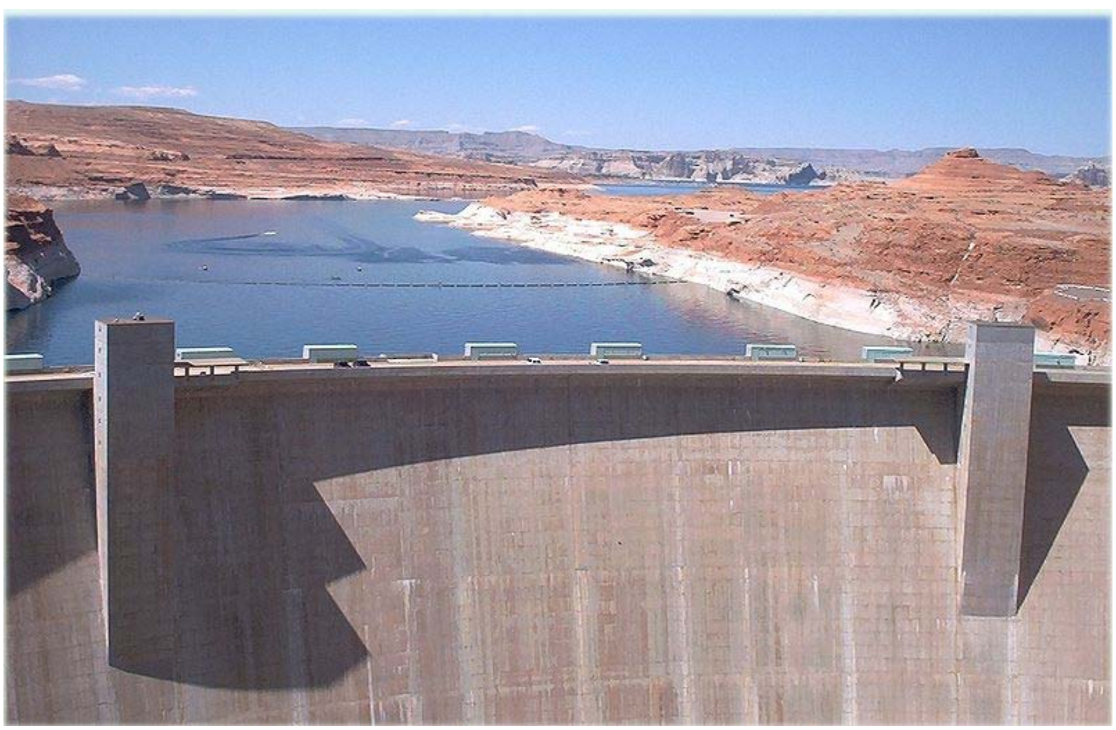
As an example study, consider the case of a leaking solvent tank which has entered the habitat soil of an endangered species of amphibian. As a method to resolve or understand the extent of soil contamination and subsurface transport of solvent, a computer model would be implemented. Chemists would then characterize the molecular bonding of the solvent to the specific soil type, and biologists would study the impacts upon soil arthropods, plants, and ultimately pond-dwelling organisms that are the food of the endangered amphibian.

Geosciences include environmental geology, environmental soil science, volcanic phenomena and evolution of the Earth's crust. In some classification systems this can also include hydrology, including oceanography.

As an example study of soils erosion, calculations would be made of surface runoff by soil scientists. Fluvial geomorphologists would assist in examining sediment transport in overland flow. Physicists would contribute by assessing the changes in light transmission in the receiving waters. Biologists would analyze subsequent impacts to aquatic flora and fauna from increases in water turbidity.

Open-pit coal mining at Garzweiler, Germany

Regulations driving the studies



Environmental science examines the effects of humans on nature (Glen Canyon Dam in the U.S.)

In the U.S. the National Environmental Policy Act (NEPA) of 1969 set forth requirements for analysis of major projects in terms of specific environmental criteria. Numerous state laws have echoed these mandates, applying the principles to local-scale actions. The upshot has been an explosion of documentation and study of environmental consequences before the fact of development actions.

One can examine the specifics of environmental science by reading examples of Environmental Impact Statements prepared under NEPA such as: *Wastewater treatment expansion options discharging into the San Diego/Tijuana Estuary*, *Expansion of the San Francisco International Airport*, *Development of the Houston, Metro Transportation system*, *Expansion of the metropolitan Boston MBTA transit system*, and *Construction of Interstate 66 through Arlington, Virginia*.

In England and Wales the Environment Agency (EA), formed in 1996, is a public body for protecting and improving the environment and enforces the regulations listed on the communities and local government site. (formerly the office of the deputy prime minister). The agency was set up under the Environment Act 1995 as an independent body and works closely with UK Government to enforce the regulations.

Terminology

In common usage, "environmental science" and "ecology" are often used interchangeably, but technically, ecology refers only to the study of organisms and their interactions with each other and their environment. Ecology could be considered a subset of environmental science, which also could involve purely chemical or public health issues (for example) ecologists would be unlikely to study. In practice, there is considerable overlap between the work of ecologists and other environmental scientists.

The National Center for Education Statistics in the United States defines an academic program in environmental science as follows:

A program that focuses on the application of biological, chemical, and physical principles to the study of the physical environment and the solution of environmental problems, including subjects such as abating or controlling environmental pollution and degradation; the interaction between human society and the natural environment; and natural resources management. Includes instruction in biology, chemistry, physics, geosciences, climatology, statistics, and mathematical modeling.

Chapter-1

Atmospheric Sciences

Atmospheric sciences is an umbrella term for the study of the atmosphere, its processes, the effects other systems have on the atmosphere, and the effects of the atmosphere on these other systems. Meteorology includes atmospheric chemistry and atmospheric physics with a major focus on weather forecasting. Climatology is the study of atmospheric changes (both long and short-term) that define average climates and their change over time, due to both natural and anthropogenic climate variability. Aeronomy is the study of the upper layers of the atmosphere, where dissociation and ionization are important. Atmospheric science has been extended to the field of planetary science and the study of the atmospheres of the planets of the solar system.

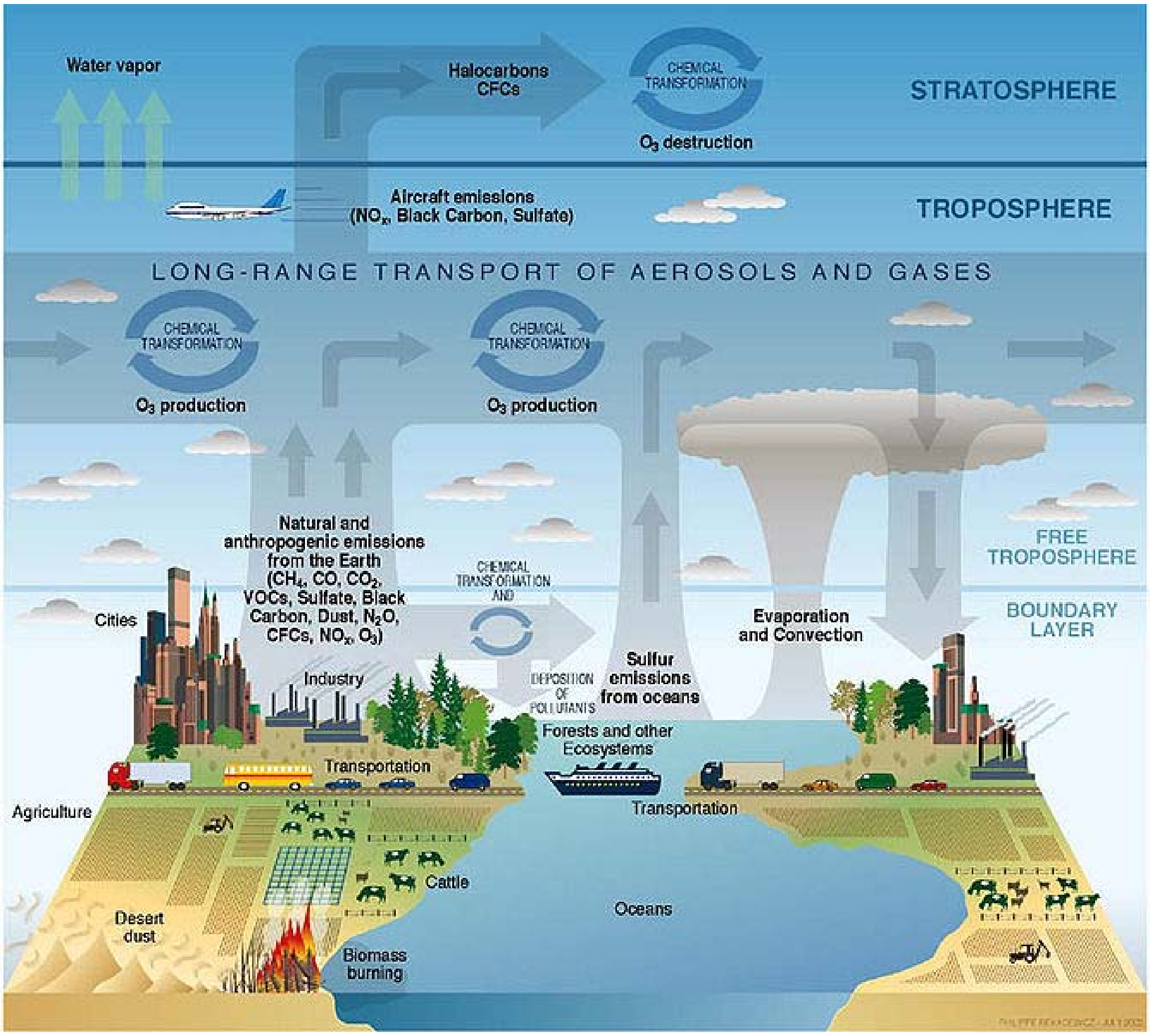
Experimental instruments used in atmospheric sciences include satellites, rocketsondes, radiosondes, weather balloons, and lasers.

The term ***aerology*** is sometimes used as an alternative term for the study of Earth's atmosphere.

Atmospheric chemistry

Atmospheric chemistry is a branch of atmospheric science in which the chemistry of the Earth's atmosphere and that of other planets is studied. It is a multidisciplinary field of research and draws on environmental chemistry, physics, meteorology, computer modeling, oceanography, geology and volcanology and other disciplines. Research is increasingly connected with other areas of study such as climatology.

The composition and chemistry of the atmosphere is of importance for several reasons, but primarily because of the interactions between the atmosphere and living organisms. The composition of the Earth's atmosphere has been changed by human activity and some of these changes are harmful to human health, crops and ecosystems. Examples of problems which have been addressed by atmospheric chemistry include acid rain, ozone depletion, photochemical smog and global warming. Atmospheric chemistry seeks to understand the causes of these problems, and by obtaining a theoretical understanding of them, allow possible solutions to be tested and the effects of changes in government policy evaluated.



Schematic of chemical and transport processes related to atmospheric composition.

Atmospheric composition

Average composition of dry atmosphere, by volume

Gas	**per NASA**
Nitrogen, N_2	78.084%
Oxygen, O_2	20.946%
Argon, Ar	0.934%
Minor constituents (in ppm)	
Carbon Dioxide, CO_2	383
Neon, Ne	18.18
Helium, He	5.24
Methane, CH_4	1.7
Krypton, Kr	1.14

Hydrogen, H_2	0.55
Water	
Water vapour	Highly variable; typically makes up about 1%

Notes: the concentration of CO_2 and CH_4 vary by season and location. The mean molecular mass of air is 28.97 g/mol.

History

The ancient Greeks regarded air as one of the four elements, but the first scientific studies of atmospheric composition began in the 18th century. Chemists such as Joseph Priestley, Antoine Lavoisier and Henry Cavendish made the first measurements of the composition of the atmosphere.

In the late 19th and early 20th centuries interest shifted towards trace constituents with very small concentrations. One particularly important discovery for atmospheric chemistry was the discovery of ozone by Christian Friedrich Schoenbein in 1840.

In the 20th century atmospheric science moved on from studying the composition of air to a consideration of how the concentrations of trace gases in the atmosphere have changed over time and the chemical processes which create and destroy compounds in the air. Two particularly important examples of this were the explanation of how the ozone layer is created and maintained by Sydney Chapman and Gordon Dobson, and the explanation of Photochemical smog by Arie Jan Haagen-Smit. Further studies on ozone issues led to the 1995 Nobel Prize in Chemistry award shared between Paul Crutzen, Mario Molina and Frank Sherwood Rowland.

In the 21st century the focus is now shifting again. Atmospheric chemistry is increasingly studied as one part of the Earth system. Instead of concentrating on atmospheric chemistry in isolation the focus is now on seeing it as one part of a single system with the rest of the atmosphere, biosphere and geosphere. An especially important driver for this is the links between chemistry and climate such as the effects of changing climate on the recovery of the ozone hole and vice versa but also interaction of the composition of the atmosphere with the oceans and terrestrial ecosystems.

Methodology

Observations, lab measurements and modeling are the three central elements in atmospheric chemistry. Progress in atmospheric chemistry is often driven by the interactions between these components and they form an integrated whole. For example observations may tell us that more of a chemical compound exists than previously thought possible. This will stimulate new modelling and laboratory studies which will increase our scientific understanding to a point where the observations can be explained.

Observation

Observations of atmospheric chemistry are essential to our understanding. Routine observations of chemical composition tell us about changes in atmospheric composition over time. One important example of this is the Keeling Curve - a series of measurements from 1958 to today which show a steady rise in of the concentration of carbon dioxide. Observations of atmospheric chemistry are made in observatories such as that on Mauna Loa and on mobile platforms such as aircraft (e.g. the UK's Facility for Airborne Atmospheric Measurements), ships and balloons. Observations of atmospheric composition are increasingly made by satellites with important instruments such as GOME and MOPITT giving a global picture of air pollution and chemistry. Surface observations have the advantage that they provide long term records at high time resolution but are limited in the vertical and horizontal space they provide observations from. Some surface based instruments e.g. LIDAR can provide concentration profiles of chemical compounds and aerosol but are still restricted in the horizontal region they can cover. Many observations are available on line in Atmospheric Chemistry Observational Databases.

Lab measurements

Measurements made in the laboratory are essential to our understanding of the sources and sinks of pollutants and naturally occurring compounds. Lab studies tell us which gases react with each other and how fast they react. Measurements of interest include reactions in the gas phase, on surfaces and in water. Also of high importance is photochemistry which quantifies how quickly molecules are split apart by sunlight and what the products are plus thermodynamic data such as Henry's law coefficients.

Modeling

In order to synthesise and test theoretical understanding of atmospheric chemistry, computer models (such as chemical transport models) are used. Numerical models solve the differential equations governing the concentrations of chemicals in the atmosphere. They can be very simple or very complicated. One common trade off in numerical models is between the number of chemical compounds and chemical reactions modelled versus the representation of transport and mixing in the atmosphere. For example, a box model might include hundreds or even thousands of chemical reactions but will only have a very crude representation of mixing in the atmosphere. In contrast, 3D models represent many of the physical processes of the atmosphere but due to constraints on computer resources will have far fewer chemical reactions and compounds. Models can be used to interpret observations, test understanding of chemical reactions and predict future concentrations of chemical compounds in the atmosphere. One important current trend is for atmospheric chemistry modules to become one part of earth system models in which the links between climate, atmospheric composition and the biosphere can be studied.

Some models are constructed by automatic code generators (e.g. Autochem or KPP). In this approach a set of constituents are chosen and the automatic code generator will then select the reactions involving those constituents from a set of reaction databases. Once the reactions have been chosen the ordinary differential equations (ODE) that describe their time evolution can be automatically constructed.

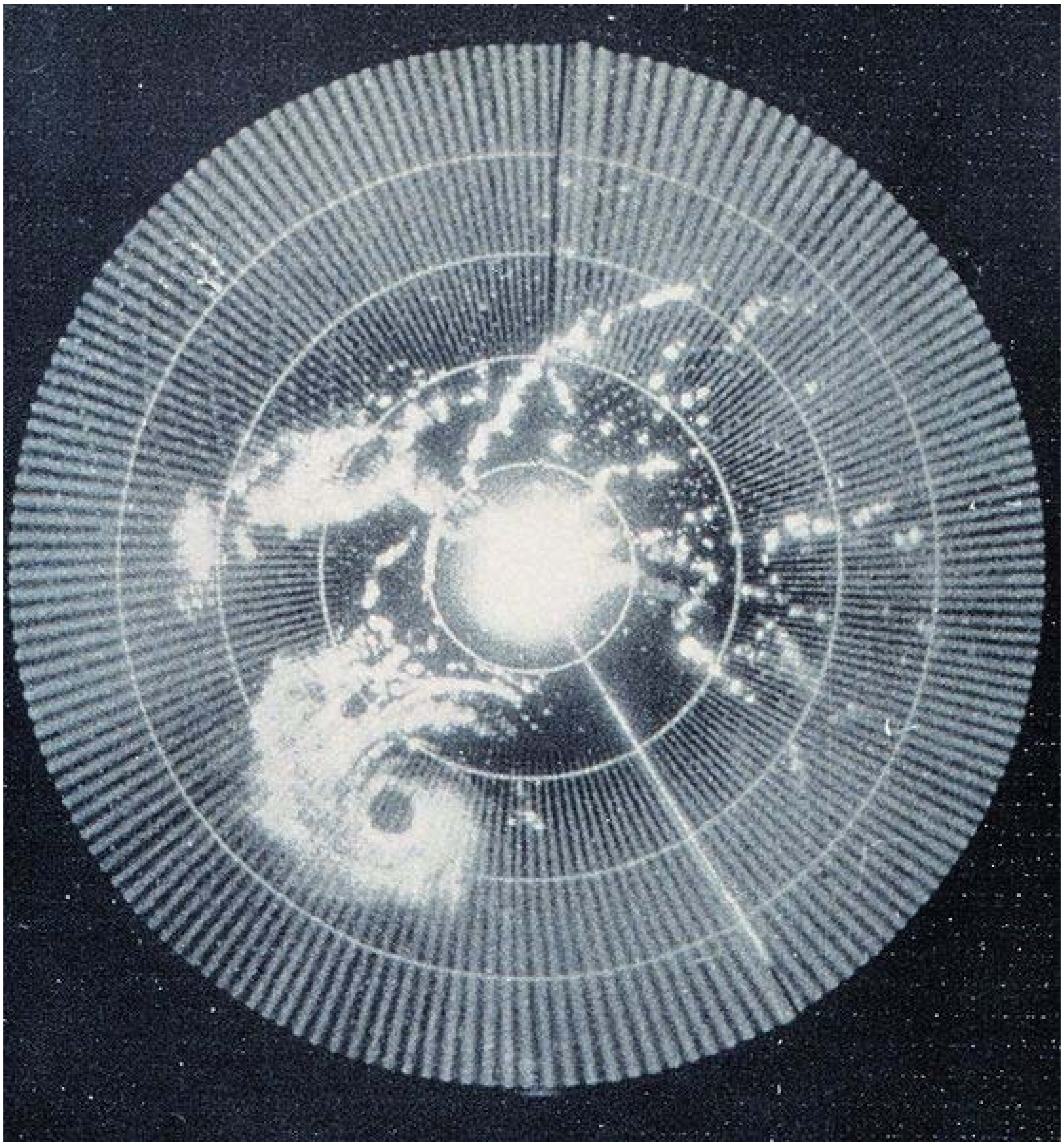
Atmospheric dynamics

Atmospheric dynamics involves the study of observations and theory dealing with all motion systems of meteorological importance. The list includes diverse phenomena as thunderstorms, tornadoes, gravity waves, tropical cyclones, extratropical cyclones, jet streams, and global-scale circulations. The goal of dynamical studies is to explain the observed circulations on the basis of fundamental principles from physics. The objectives of such studies include improving weather forecasting, developing methods for predicting seasonal and interannual climate fluctuations, and understanding the implications of human-induced perturbations (e.g., increased carbon dioxide concentrations or depletion of the ozone layer) on the global climate.

Atmospheric physics

Atmospheric physics is the application of physics to the study of the atmosphere. Atmospheric physicists attempt to model Earth's atmosphere and the atmospheres of the other planets using fluid flow equations, chemical models, radiation balancing, and energy transfer processes in the atmosphere (as well as how these tie in to other systems such as the oceans). In order to model weather systems, atmospheric physicists employ elements of scattering theory, wave propagation models, cloud physics, statistical mechanics and spatial statistics which are highly mathematical and related to physics. It has close links to meteorology and climatology and also covers the design and construction of instruments for studying the atmosphere and the interpretation of the data they provide, including remote sensing instruments. At the dawn of the space age and the introduction of sounding rockets, aeronomy became a subdiscipline concerning the upper layers of the atmosphere, where dissociation and ionization are important.

Remote sensing



Brightness can indicate reflectivity as in this 1960 weather radar image (of Hurricane Abby). The radar's frequency, pulse form, and antenna largely determine what it can observe.

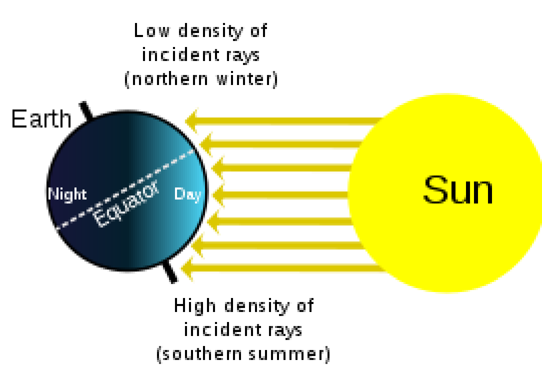
Remote sensing is the small or large-scale acquisition of information of an object or phenomenon, by the use of either recording or real-time sensing device(s) that is not in physical or intimate contact with the object (such as by way of aircraft, spacecraft, satellite, buoy, or ship). In practice, remote sensing is the stand-off collection through the use of a variety of devices for gathering information on a given object or area which gives more information than sensors at individual sites might convey. Thus, Earth observation or weather satellite collection platforms, ocean and atmospheric observing weather buoy platforms, monitoring of a pregnancy via ultrasound, Magnetic Resonance Imaging (MRI), Positron Emission Tomography (PET), and space probes are all examples of remote sensing. In modern usage, the term generally refers to the use of imaging sensor technologies including but not limited to the use of instruments aboard aircraft and spacecraft, and is distinct from other imaging-related fields such as medical imaging.

There are two kinds of remote sensing. Passive sensors detect natural radiation that is emitted or reflected by the object or surrounding area being observed. Reflected sunlight is the most common source of radiation measured by passive sensors. Examples of passive remote sensors include film photography, infra-red, charge-coupled devices, and radiometers. Active collection, on the other hand, emits energy in order to scan objects and areas whereupon a passive sensor then detects and measures the radiation that is reflected or backscattered from the target. RADAR is an example of active remote sensing where the time delay between emission and return is measured, establishing the location, height, speed and direction of an object.

Remote sensing makes it possible to collect data on dangerous or inaccessible areas. Remote sensing applications include monitoring deforestation in areas such as the Amazon Basin, the effects of climate change on glaciers and Arctic and Antarctic regions, and depth sounding of coastal and ocean depths. Military collection during the cold war made use of stand-off collection of data about dangerous border areas. Remote sensing also replaces costly and slow data collection on the ground, ensuring in the process that areas or objects are not disturbed.

Orbital platforms collect and transmit data from different parts of the electromagnetic spectrum, which in conjunction with larger scale aerial or ground-based sensing and analysis, provides researchers with enough information to monitor trends such as El Niño and other natural long and short term phenomena. Other uses include different areas of the earth sciences such as natural resource management, agricultural fields such as land usage and conservation, and national security and overhead, ground-based and stand-off collection on border areas.

Radiation



This is a diagram of the seasons. In addition to the density of incident light, the dissipation of light in the atmosphere is greater when it falls at a shallow angle.

The sun emits radiation as a variety of wavelengths. Visible light has wavelengths between 0.4 and 0.7 micrometers. Shorter wavelengths are known as the ultraviolet (UV) part of the spectrum, while longer wavelengths are grouped into the infrared portion of the spectrum. Ozone is most effective in absorbing radiation around 0.25 micrometers, where UV-c rays lie in the spectrum. This increases the temperature of the nearby stratosphere. Snow reflects 88% of UV rays, while sand reflects 12%, and water reflects only 4% of incoming UV radiation. The more glancing the angle is between the atmosphere and the sun's rays, the more likely that energy will be reflected or absorbed by the atmosphere.

Cloud physics

Cloud physics is the study of the physical processes that lead to the formation, growth and precipitation of clouds. Clouds are composed of microscopic droplets of water (warm clouds), tiny crystals of ice, or both (mixed phase clouds). Under suitable conditions, the droplets combine to form precipitation, where they may fall to the earth. The precise mechanics of how a cloud forms and grows is not completely understood, but scientists have developed theories explaining the structure of clouds by studying the microphysics of individual droplets. Advances in radar and satellite technology have also allowed the precise study of clouds on a large scale.

Atmospheric electricity

Cloud to ground Lightning in the global atmospheric electrical circuit.

Atmospheric electricity is the regular diurnal variations of the Earth's atmospheric electromagnetic network (or, more broadly, any planet's electrical system in its layer of gases). The Earth's surface, the ionosphere, and the atmosphere is known as the **global atmospheric electrical circuit**. Lightning discharges 30,000 amperes, at up to 100 million volts, and emits light, radio waves, x-rays and even gamma rays. Plasma temperatures in lightning can approach 28,000 kelvins and electron densities may exceed $10^{24}/m^3$.

Atmospheric tide

The largest-amplitude atmospheric tides are mostly generated in the troposphere and stratosphere when the atmosphere is periodically heated as water vapour and ozone absorb solar radiation during the day. The tides generated are then able to propagate away from these source regions and ascend into the mesosphere and thermosphere. Atmospheric tides can be measured as regular fluctuations in wind, temperature, density and pressure. Although atmospheric tides share much in common with ocean tides they have two key distinguishing features:

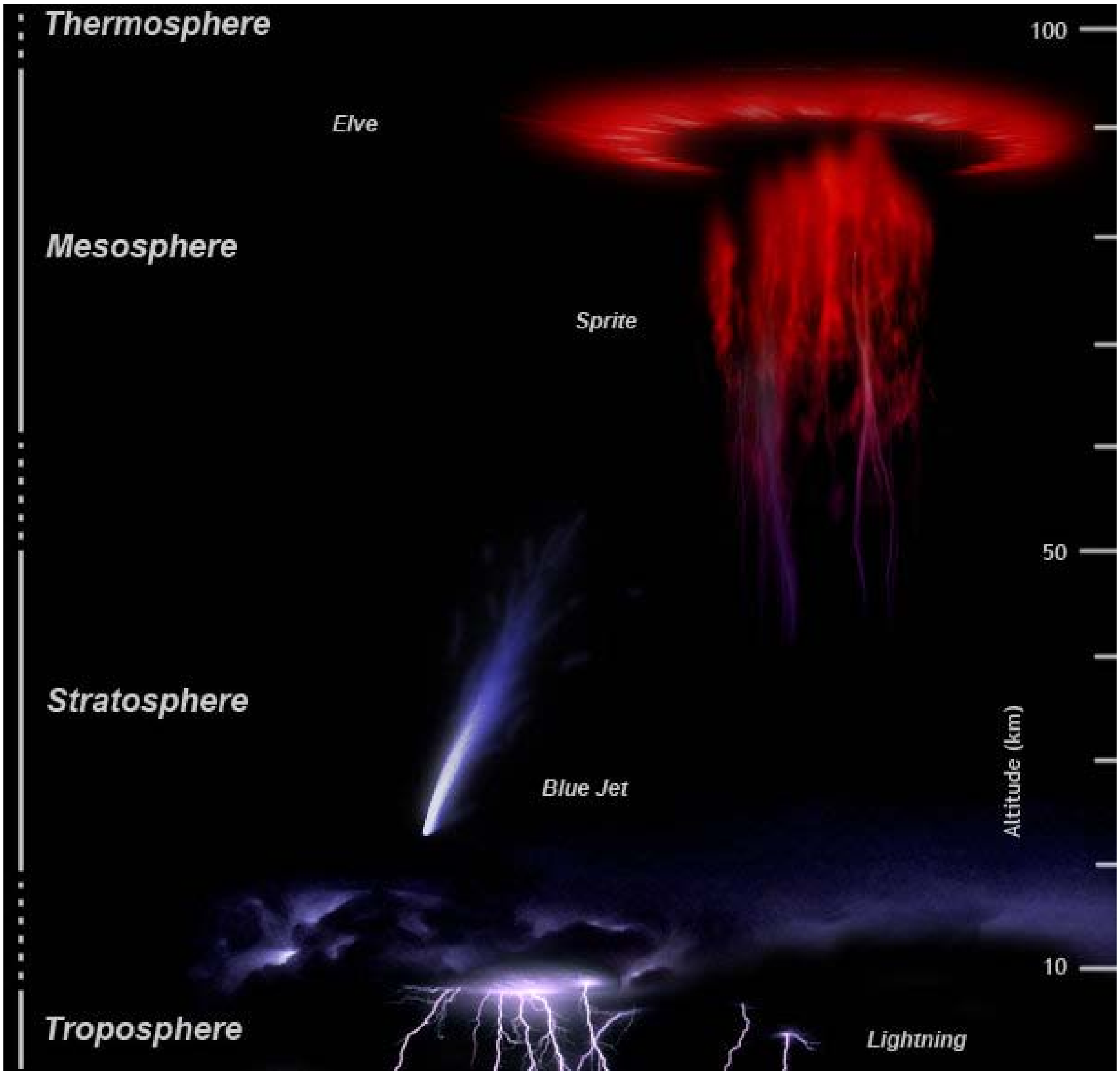
i) Atmospheric tides are primarily excited by the Sun's heating of the atmosphere whereas ocean tides are primarily excited by the Moon's gravitational field. This means that most atmospheric tides have periods of oscillation related to the 24-hour length of the solar day whereas ocean tides have longer periods of oscillation related to the lunar day (time between successive lunar transits) of about 24 hours 51 minutes.

ii) Atmospheric tides propagate in an atmosphere where density varies significantly with height. A consequence of this is that their amplitudes naturally increase exponentially as the tide ascends into progressively more rarefied regions of the atmosphere (for an explanation of this phenomenon, see below). In contrast, the density of the oceans varies only slightly with depth and so there the tides do not necessarily vary in amplitude with depth.

Note that although solar heating is responsible for the largest-amplitude atmospheric tides, the gravitational fields of the Sun and Moon also raise tides in the atmosphere, with the lunar gravitational atmospheric tidal effect being significantly greater than its solar counterpart.

At ground level, atmospheric tides can be detected as regular but small oscillations in surface pressure with periods of 24 and 12 hours. Daily pressure maxima occur at 10 a.m. and 10 p.m. local time, while minima occur at 4 a.m. and 4 p.m. local time. The absolute maximum occurs at 10 a.m. while the absolute minimum occurs at 4 p.m. However, at greater heights the amplitudes of the tides can become very large. In the mesosphere (heights of ~ 50 - 100 km) atmospheric tides can reach amplitudes of more than 50 m/s and are often the most significant part of the motion of the atmosphere.

Aeronomy



Representation of upper-atmospheric lightning and electrical-discharge phenomena

Aeronomy is the science of the upper region of the atmosphere, where dissociation and ionization are important. The term aeronomy was introduced by Sydney Chapman in 1960. Today, the term also includes the science of the corresponding regions of the atmospheres of other planets. Research in aeronomy requires access to balloons, satellites, and sounding rockets which provide valuable data about this region of the atmosphere. Atmospheric tides play an important role in interacting with both the lower and upper atmosphere. Amongst the phenomena studied are upper-atmospheric lightning discharges, such as luminous events called red sprites, sprite halos, blue jets, and elves.

Centers of research

In the UK, atmospheric studies are underpinned by the Met Office, the Natural Environment Research Council and the Science and Technology Facilities Council. Divisions of the U.S. National Oceanic and Atmospheric Administration (NOAA) oversee research projects and weather modeling involving atmospheric physics. The US National Astronomy and Ionosphere Center also carries out studies of the high atmosphere. In Belgium, the Belgian Institute for Space Aeronomy studies the atmosphere and outer space.

Climatology

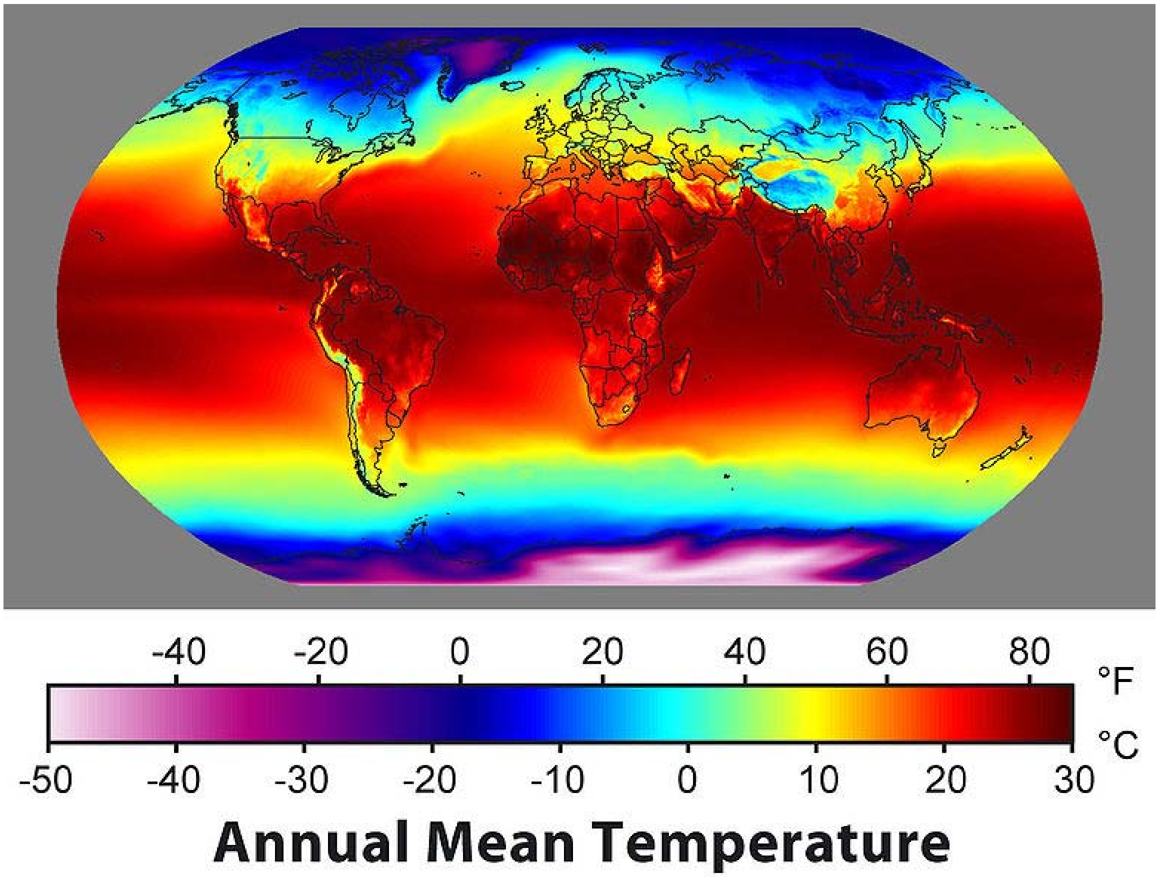
Climatology is the study of climate, scientifically defined as weather conditions averaged over a period of time, and is a branch of the atmospheric sciences. Basic knowledge of climate can be used within shorter term weather forecasting using analog techniques such as the El Niño - Southern Oscillation (ENSO), the Madden-Julian Oscillation (MJO), the North Atlantic Oscillation (NAO), the Northern Annualar Mode (NAM), the Arctic oscillation (AO), the Northern Pacific (NP) Index, the Pacific Decadal Oscillation (PDO), and the Interdecadal Pacific Oscillation (IPO). Climate models are used for a variety of purposes from study of the dynamics of the weather and climate system to projections of future climate.

History

The earliest person to hypothesize the concept of climate change may have been the medieval Chinese scientist Shen Kuo (1031-1095 AD). Shen Kuo theorized that climates naturally shifted over an enormous span of time, after observing petrified bamboos found underground near Yanzhou (modern day Yan'an, Shaanxi province), a dry climate area unsuitable for the growth of bamboo.

Early climate researchers include Edmund Halley, who published a map of the trade winds in 1686, after a voyage to the southern hemisphere. Benjamin Franklin, in the 18th century, was the first to map the course of the Gulf Stream for use in sending mail overseas from the United States to Europe. Francis Galton invented the term *anticyclone*. Helmut Landsberg led to statistical analysis being used in climatology, which led to its evolution into a physical science.

Different approaches



Map of the average temperature over 30 years. Data sets formed from the long-term average of historical weather parameters are sometimes called a "climatology".

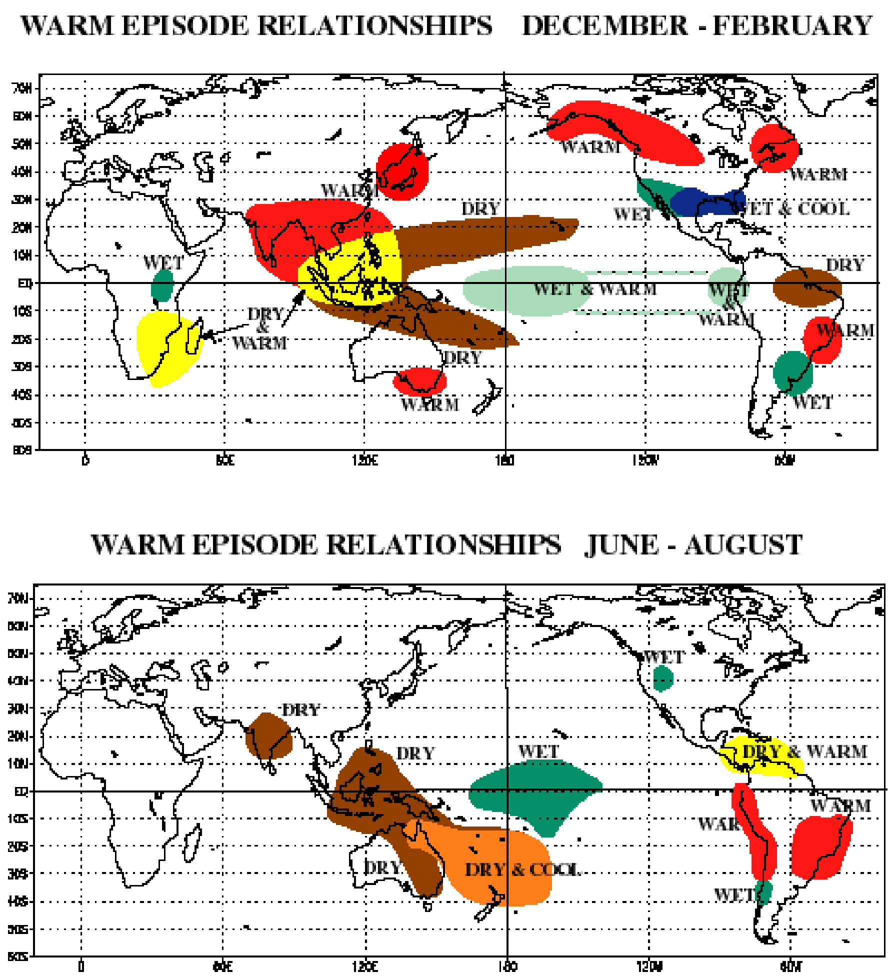
Climatology is approached in a variety of ways. **Paleoclimatology** seeks to reconstruct past climates by examining records such as ice cores and tree rings (dendroclimatology). **Paleotempestology** uses these same records to help determine hurricane frequency over millennia. The study of contemporary climates incorporates meteorological data accumulated over many years, such as records of rainfall, temperature and atmospheric composition. Knowledge of the atmosphere and its dynamics is also embodied in models, either statistical or mathematical, which help by integrating different observations and testing how they fit together. Modeling is used for understanding past, present and potential future climates. **Historical climatology** is the study of climate as related to human history and thus focuses only on the last few thousand years.

Climate research is made difficult by the large scale, long time periods, and complex processes which govern climate. Climate is governed by physical laws which can be expressed as differential equations. These equations are coupled and nonlinear, so that approximate solutions are obtained by using numerical methods to create global climate models. Climate is sometimes modeled as a stochastic process but this is generally accepted as an approximation to processes that are otherwise too complicated to analyze.

Indices

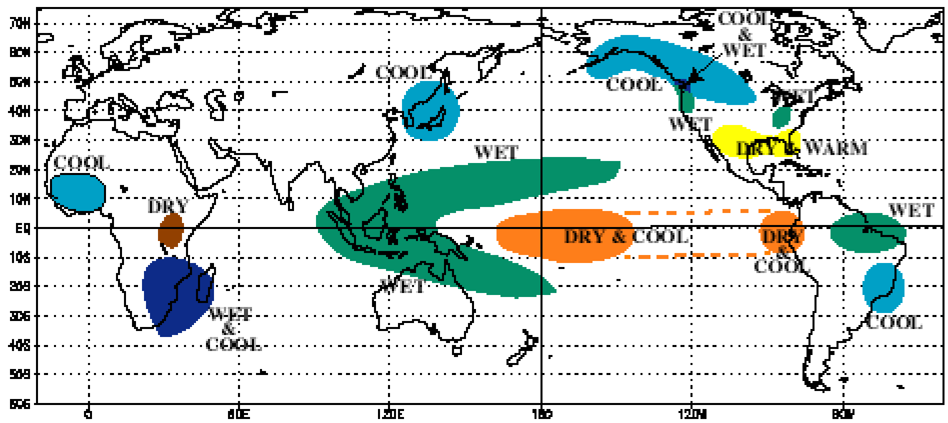
Scientists use climate indices based on several climate patterns (known as modes of variability) in their attempt to characterize and understand the various climate mechanisms that culminate in our daily weather. Much in the way the Dow Jones Industrial Average, which is based on the stock prices of 30 companies, is used to represent the fluctuations in the stock market as a whole, climate indices are used to represent the essential elements of climate. Climate indices are generally devised with the twin objectives of simplicity and completeness, and each index typically represents the status and timing of the climate factor it represents. By their very nature, indices are simple, and combine many details into a generalized, overall description of the atmosphere or ocean which can be used to characterize the factors which impact the global climate system.

El Niño - Southern Oscillation

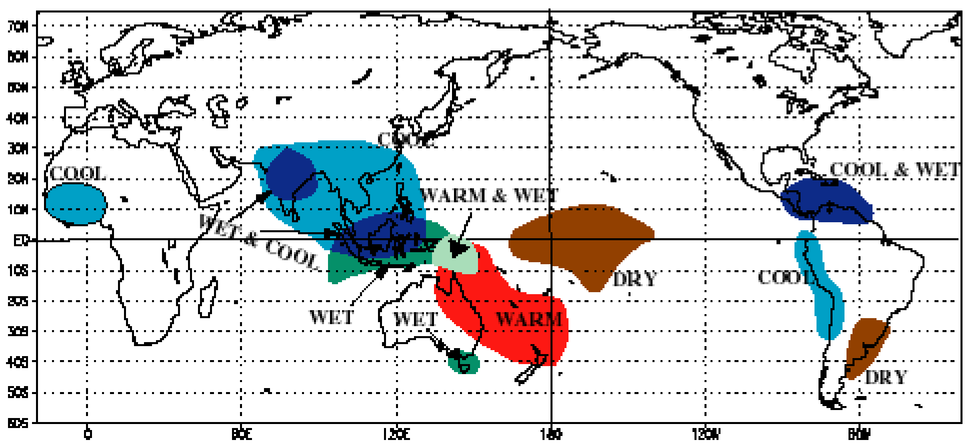


El Niño impacts

COLD EPISODE RELATIONSHIPS DECEMBER - FEBRUARY



COLD EPISODE RELATIONSHIPS JUNE - AUGUST



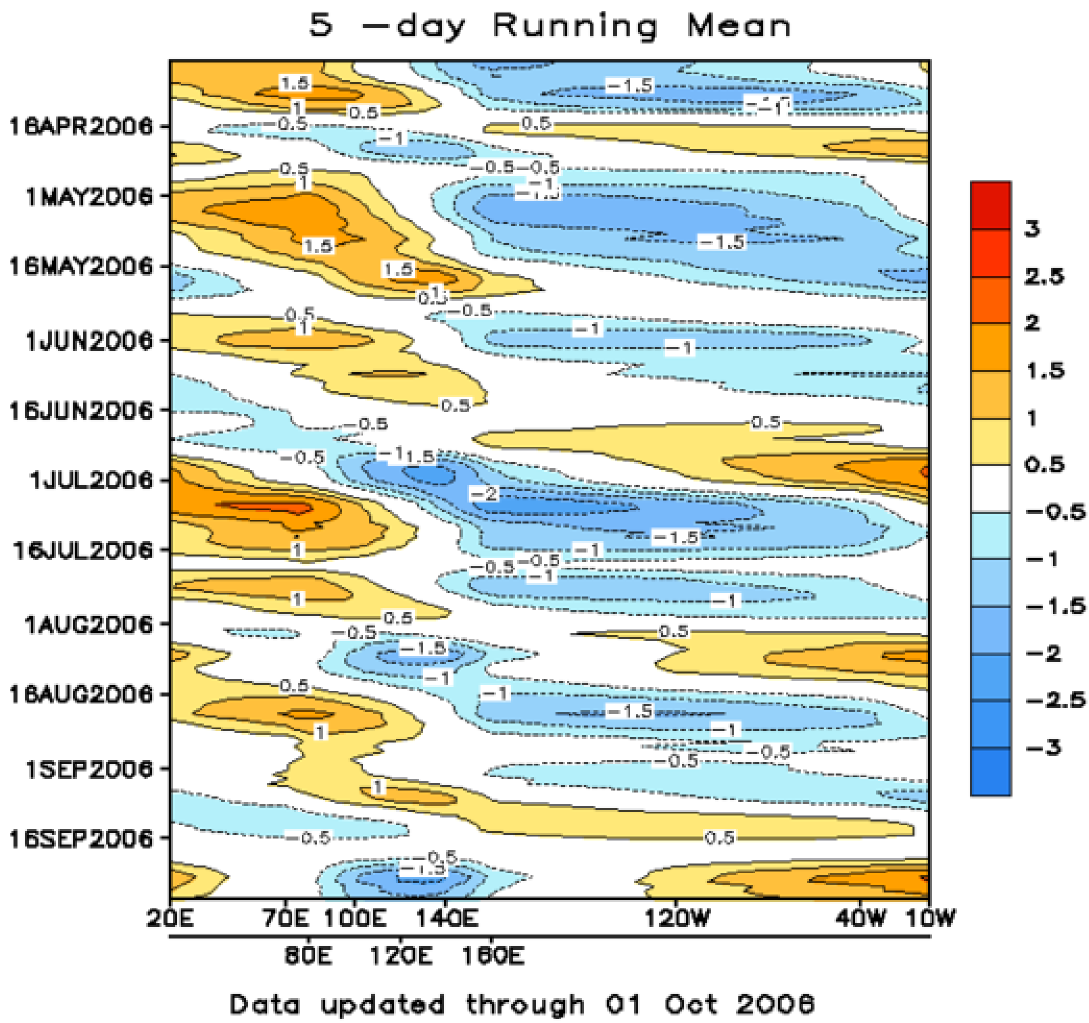
La Niña impacts

El Niño-Southern Oscillation (ENSO) is a global coupled ocean-atmosphere phenomenon. The Pacific ocean signatures, El Niño and La Niña are important temperature fluctuations in surface waters of the tropical Eastern Pacific Ocean. The name El Niño, from the Spanish for "the little boy", refers to the Christ child, because the phenomenon is usually noticed around Christmas time in the Pacific Ocean off the west coast of South America. La Niña means "the little girl". Their effect on climate in the subtropics and the tropics are profound. The atmospheric signature, the Southern Oscillation (SO) reflects the monthly or seasonal fluctuations in the air pressure difference between Tahiti and Darwin. The most recent occurrence of El Niño started in September 2006 and lasted until early 2007.

ENSO is a set of interacting parts of a single global system of coupled ocean-atmosphere climate fluctuations that come about as a consequence of oceanic and atmospheric circulation. ENSO is the most prominent known source of inter-annual variability in weather and climate around the world. The cycle occurs every two to seven years, with El Niño lasting nine months to two years within the longer term cycle, though not all areas globally are affected. ENSO has signatures in the Pacific, Atlantic and Indian Oceans. El Niño causes weather patterns which causes it to rain in specific places but not in others, this is one of many causes for the drought.

In the Pacific, during major warm events, El Niño warming extends over much of the tropical Pacific and becomes clearly linked to the SO intensity. While ENSO events are basically in phase between the Pacific and Indian Oceans, ENSO events in the Atlantic Ocean lag behind those in the Pacific by 12 to 18 months. Many of the countries most affected by ENSO events are developing countries within tropical sections of continents with economies that are largely dependent upon their agricultural and fishery sectors as a major source of food supply, employment, and foreign exchange. New capabilities to predict the onset of ENSO events in the three oceans can have global socio-economic impacts. While ENSO is a global and natural part of the Earth's climate, whether its intensity or frequency may change as a result of global warming is an important concern. Low-frequency variability has been evidenced: the quasi-decadal oscillation (QDO). Inter-decadal (ID) modulation of ENSO (from PDO or IPO) might exist. This could explain the so-called protracted ENSO of the early 1990s.

Madden-Julian Oscillation



Note how the MJO moves eastward with time.

The Madden-Julian Oscillation (MJO) is an equatorial traveling pattern of anomalous rainfall that is planetary in scale. It is characterized by an eastward progression of large regions of both enhanced and suppressed tropical rainfall, observed mainly over the Indian Ocean and Pacific Ocean. The anomalous rainfall is usually first evident over the western Indian Ocean, and remains evident as it propagates over the very warm ocean waters of the western and central tropical Pacific. This pattern of tropical rainfall then generally becomes very nondescript as it moves over the cooler ocean waters of the eastern Pacific but reappears over the tropical Atlantic and Indian Ocean. The wet phase of enhanced convection and precipitation is followed by a dry phase where convection is suppressed. Each cycle lasts approximately 30–60 days. The MJO is also known as the 30-60 day oscillation, 30-60 day wave, or intraseasonal oscillation.

North Atlantic Oscillation (NAO)

Indices of the NAO are based on the difference of normalized sea level pressure (SLP) between Ponta Delgada, Azores and Stykkisholmur/Reykjavik, Iceland. The SLP anomalies at each station were normalized by division of each seasonal mean pressure by the long-term mean (1865-1984) standard deviation. Normalization is done to avoid the series of being dominated by the greater variability of the northern of the two stations. Positive values of the index indicate stronger-than-average westerlies over the middle latitudes.

Northern Annular Mode (NAM) or Arctic Oscillation (AO)

The NAM, or AO, is defined as the first EOF of northern hemisphere winter SLP data from the tropics and subtropics. It explains 23% of the average winter (December-March) variance, and it is dominated by the NAO structure in the Atlantic. Although there are some subtle differences from the regional pattern over the Atlantic and Arctic, the main difference is larger amplitude anomalies over the North Pacific of the same sign as those over the Atlantic. This feature gives the NAM a more annular (or zonally symmetric) structure.

Northern Pacific (NP) Index

The NP Index is the area-weighted sea level pressure over the region 30N-65N, 160E-140W.

Pacific Decadal Oscillation (PDO)

The PDO is a pattern of Pacific climate variability that shifts phases on at least inter-decadal time scale, usually about 20 to 30 years. The PDO is detected as warm or cool surface waters in the Pacific Ocean, north of 20° N. During a "warm", or "positive", phase, the west Pacific becomes cool and part of the eastern ocean warms; during a "cool" or "negative" phase, the opposite pattern occurs. The mechanism by which the pattern lasts over several years has not been identified; one suggestion is that a thin layer of warm water during summer may shield deeper cold waters. A PDO signal has been reconstructed to 1661 through tree-ring chronologies in the Baja California area.

Interdecadal Pacific Oscillation (IPO)

The Interdecadal Pacific Oscillation (IPO or ID) display similar sea surface temperature (SST) and sea level pressure patterns to the PDO, with a cycle of 15–30 years, but affects both the north and south Pacific. In the tropical Pacific, maximum SST anomalies are found away from the equator. This is quite different from the quasi-decadal oscillation (QDO) with a period of 8-to-12 years and maximum SST anomalies straddling the equator, thus resembling ENSO.

Models

Climate models use quantitative methods to simulate the interactions of the atmosphere, oceans, land surface, and ice. They are used for a variety of purposes from study of the dynamics of the weather and climate system to projections of future climate. All climate models balance, or very nearly balance, incoming energy as short wave (including visible) electromagnetic radiation to the earth with outgoing energy as long wave (infrared) electromagnetic radiation from the earth. Any unbalance results in a change in the average temperature of the earth.

The most talked-about models of recent years have been those relating temperature to emissions of carbon dioxide. These models predict an upward trend in the surface temperature record, as well as a more rapid increase in temperature at higher altitudes.

Models can range from relatively simple to quite complex:

- A simple radiant heat transfer model that treats the earth as a single point and averages outgoing energy
- this can be expanded vertically (radiative-convective models), or horizontally
- finally, (coupled) atmosphere–ocean–sea ice **global climate models** discretise and solve the full equations for mass and energy transfer and radiant exchange.

Differences with meteorology

In contrast to meteorology, which focuses on short term weather systems lasting up to a few weeks, climatology studies the frequency and trends of those systems. It studies the periodicity of weather events over years to millennia, as well as changes in long-term average weather patterns, in relation to atmospheric conditions. Climatologists, those who practice climatology, study both the nature of climates - local, regional or global - and the natural or human-induced factors that cause climates to change. Climatology considers the past and can help predict future climate change.

Phenomena of climatological interest include the atmospheric boundary layer, circulation patterns, heat transfer (radiative, convective and latent), interactions between the atmosphere and the oceans and land surface (particularly vegetation, land use and topography), and the chemical and physical composition of the atmosphere.

Use in weather forecasting

A more complicated way of making a forecast, the analog technique requires remembering a previous weather event which is expected to be mimicked by an upcoming event. What makes it a difficult technique to use is that there is rarely a perfect analog for an event in the future. Some call this type of forecasting **pattern recognition**, which remains a useful method of observing rainfall over data voids such as oceans with knowledge of how satellite imagery relates to precipitation rates over land, as well as the forecasting of precipitation amounts and distribution in the future. A variation on this theme is used in Medium Range forecasting, which is known as teleconnections, when you use systems in other locations to help pin down the location of another system within the surrounding regime. One method of using teleconnections are by using climate indices such as ENSO-related phenomena.

Atmospheres on other planets

Earth's atmosphere

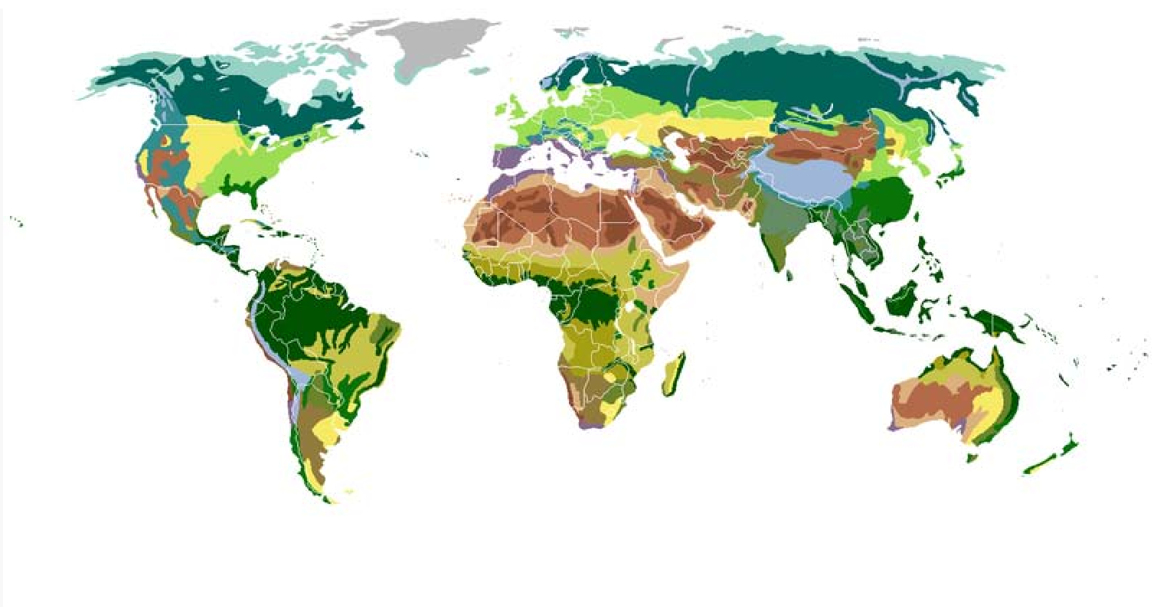
All of the Solar System planets have atmospheres as their large masses mean gravity is strong enough to keep gaseous particles close to the surface. The larger gas giants are massive enough to keep large amounts of the light gases hydrogen and helium close by, while the smaller planets lose these gases into space. The composition of the Earth's atmosphere is different from the other planets because the various life processes that have transpired on the planet have introduced free molecular oxygen. The only solar planet without a true atmosphere is Mercury which had it mostly, although not entirely, blasted away by the solar wind. The only moon that has retained a dense atmosphere is Titan. There is a thin atmosphere on Triton, and a trace of an atmosphere on the Moon.

Planetary atmospheres are affected by the varying degrees of energy received from either the Sun or their interiors, leading to the formation of dynamic weather systems such as hurricanes, (on Earth), planet-wide dust storms (on Mars), an Earth-sized anticyclone on Jupiter (called the Great Red Spot), and holes in the atmosphere (on Neptune). At least one extrasolar planet, HD 189733 b, has been claimed to possess such a weather system, similar to the Great Red Spot but twice as large.

Hot Jupiters have been shown to be losing their atmospheres into space due to stellar radiation, much like the tails of comets. These planets may have vast differences in temperature between their day and night sides which produce supersonic winds, although the day and night sides of HD 189733b appear to have very similar temperatures, indicating that that planet's atmosphere effectively redistributes the star's energy around the planet.

Chapter-2

Ecology



The scientific discipline of **ecology** encompasses areas from global processes (above), to the study of marine and terrestrial habitats (middle) to interspecific interactions such as predation and pollination (below).

Ecology is the scientific study of the relation of living organisms to each other and their surroundings. 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. Ecologists study everything from the role of bacteria 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 behavior.

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, and

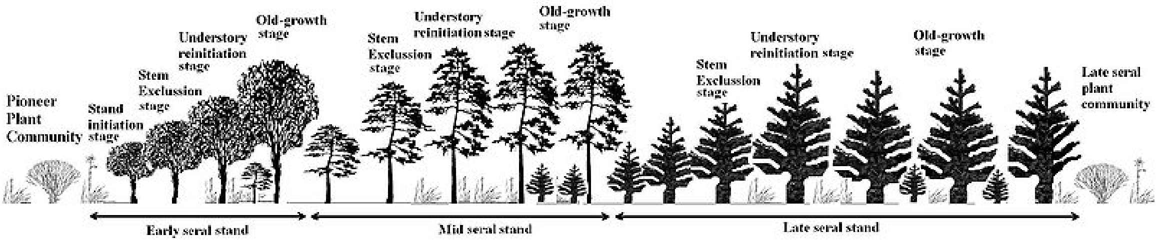
- the abundance and distribution of biodiversity in context of the environment.

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).

Levels of organization and study

Scale and complexity



Ecosystems regenerate after a disturbance such as fire, forming mosaics of different age groups structured across a landscape. Pictured are different seral stages in forested ecosystems starting from pioneers colonizing a disturbed site and maturing in successional stages leading to old-growth forests.

The processes that influence ecological phenomena vary through space and time. It can take thousands of years for ecological processes to mature; the life-span of a tree, for example, can encompass different successional stages. The ecological process is extended even further through time as trees die, decay and provide habitat as nurse logs or coarse woody debris. The area of an ecosystem can vary greatly from tiny to vast. A single tree is of little consequence to the classification of a forest ecosystem, but it is far more significant to smaller organisms. Several generations of an aphid population can exist over the lifespan of a single leaf. Each of those aphids, in turn, support diverse bacterial communities. Tree growth is related to local site variables, such as soil type, moisture content, slope of the land, and forest canopy closure. 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, behavioral, 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 three key levels of organization—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 (an abbreviation of biological diversity) describes the diversity 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 habitat

Termite mounds with varied heights of chimneys regulate gas exchange, temperature and other environmental parameters that are needed to sustain the internal physiology of the entire colony.

There are many definitions of the niche dating back to 1917, but G. 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.

Biodiversity of a coral reef. Corals adapt and modify their environment by forming calcium carbonate skeletons that provide growing conditions for future generations and form habitat for many other species.

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 rate of population change is described by:

$$\frac{dN}{dT} = B - D = bN - dN = (b - d)N = rN,$$

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:

$$\frac{dN}{dT} = aN(1 - \frac{N}{K}),$$

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.

A list of terms that define various types of natural groupings of individuals that are used in population studies

Term	Definition
Species population	All individuals of a species.
Metapopulation	A set of spatially disjunct populations, among which there is some immigration.
Population	A group of conspecific individuals that is demographically, genetically, or spatially disjunct from other groups of individuals.
Aggregation	A spatially clustered group of individuals.
Deme	A group of individuals more genetically similar to each other than to other individuals, usually with some degree of spatial isolation as well.
Local population	A group of individuals within an investigator-delimited area smaller than the geographic range of the species and often within a population (as defined above). A local population could be a disjunct population as well.
Subpopulation	An arbitrary spatially delimited subset of individuals from within a population (as defined above).

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.

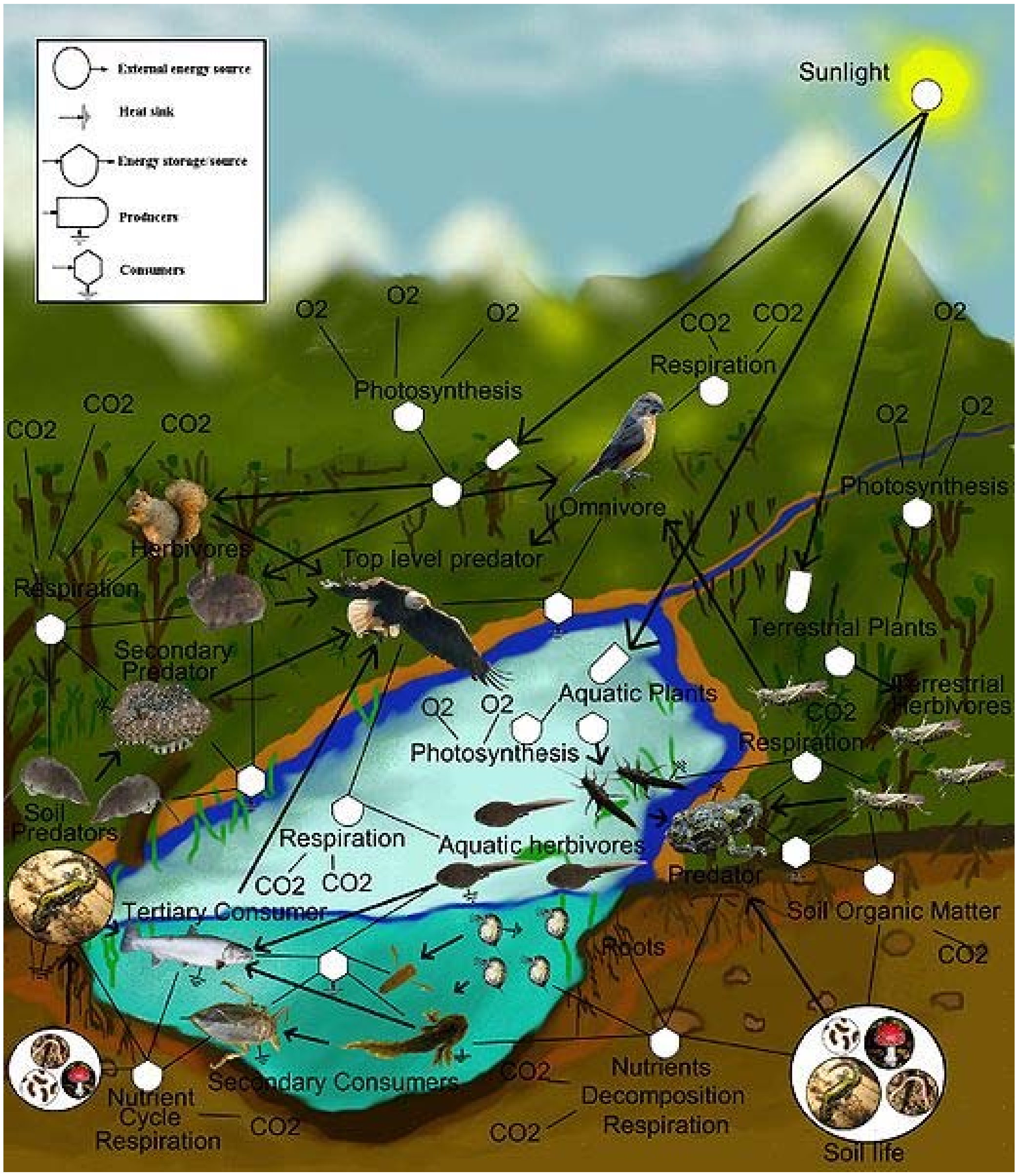
Community ecology

> Community ecology examines how interactions among species and their environment affect the abundance, distribution and diversity of species within communities.
>
> Johnson & Stinchcomb

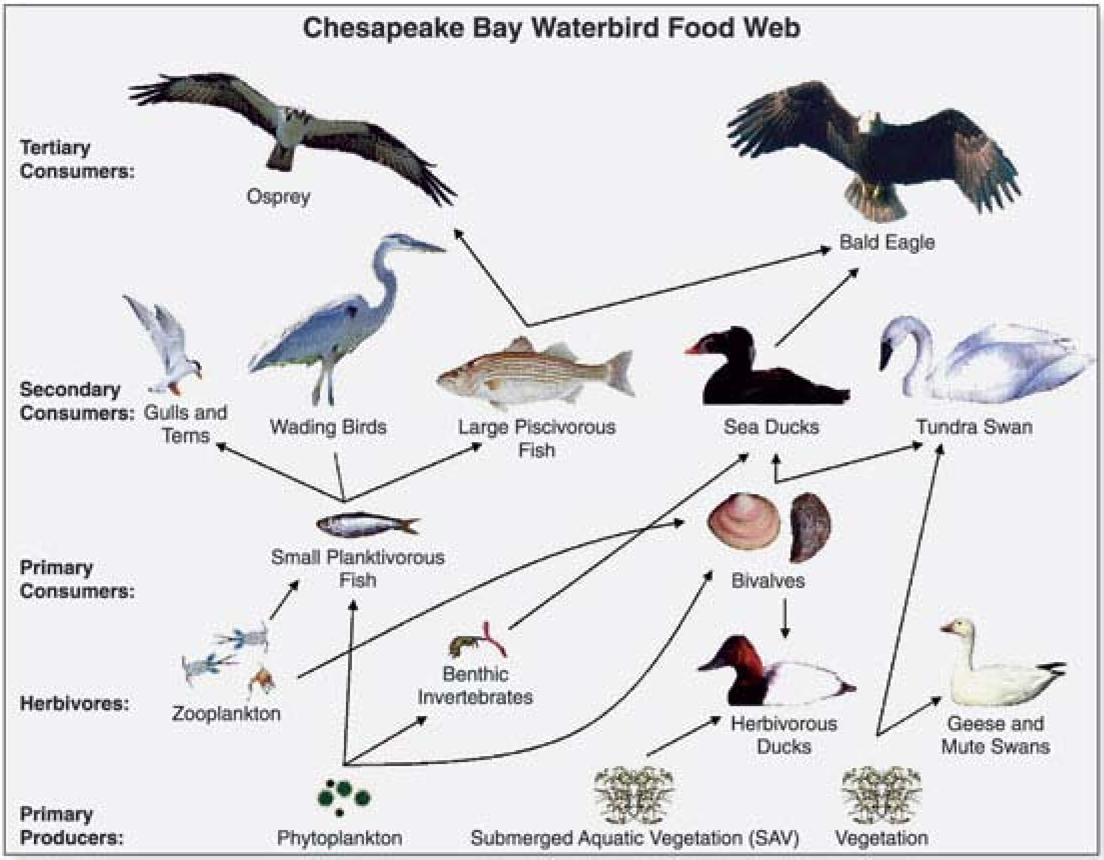
Community ecology is a subdiscipline of ecology which studies the distribution, abundance, demography, and interactions between coexisting populations. An example of a study in community ecology might measure primary production in a wetland in relation to decomposition and consumption rates. This requires 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.



Freshwater aquatic and terrestrial food-webs



Generalized food web of waterbirds from Chesapeake Bay

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) and
- how community structure, function and stability is determined.

Trophic dynamics

The Greek root of the word *troph*, τροφή, trophē, 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 rivaled 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.

List of ecological functional groups, definitions and examples

Functional Group	**Definition and Examples**
Producers or *Autotrophs*	Usually plants or cyanobacteria that are capable of photosynthesis but could be other organisms such as the bacteria near ocean vents that are capable of chemosynthesis.
Consumers or *Heterotrophs*	Animals, which can be primary consumers (herbivorous), or secondary or tertiary consumers (carnivorous and omnivores).
Decomposers or *Detritivores*	Bacteria, fungi, and insects which degrade organic matter of all types and restore nutrients to the environment. The producers will then consume the nutrients, completing the cycle.

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 led 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.

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.
>
> Tansley

The concept of the ecosystem was first introduced in 1935 to describe habitats within biomes that form an integrated whole and a dynamically responsive system having both physical and biological complexes. Within an ecosystem there are inseparable 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.

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.

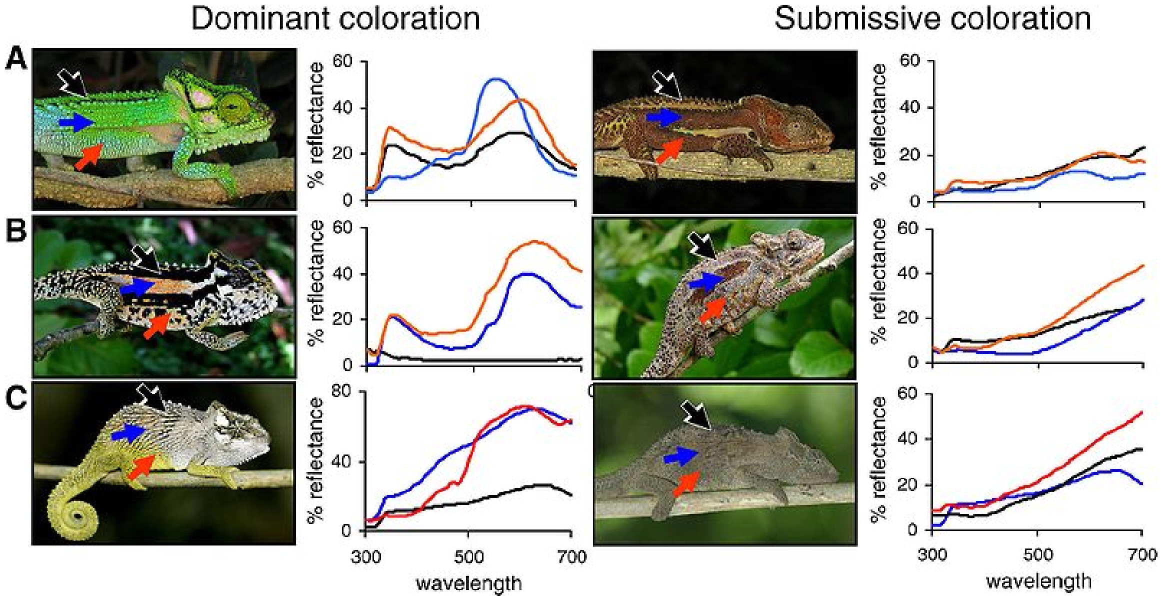
The biosphere

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.

Behavioral ecology



Social display and color variation in differently adapted species of chameleons (*Bradypodion* spp.). Chameleons change their skin color to match their background as a behavioral defense mechanism and also use color to communicate with other members of their species, such as dominant (left) versus submissive (right) patterns shown in the three species (A-C) above.

All organisms are motile to some extent. Even plants express complex behavior, 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 behavioral ecology."International Society for Behavioral Ecology". Behaviors can be recorded as traits and inherited in much the same way that eye and hair color can. Behaviours evolve and become adapted to the ecosystem because they are subject to the forces of natural selection. Hence, behaviors 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 behavior 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.

Symbiosis: Leafhoppers (*Eurymela fenestrata*) are protected by ants (*Iridomyrmex purpureus*) in a symbiotic relationship. The ants protect the leafhoppers from predators and in return the leafhoppers feeding on plants exude honeydew from their anus that provides energy and nutrients to tending ants.

Ecological interactions can be divided into host and associate relationships. A host is any entity that harbors 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.

Parasites: A harvestman arachnid is parasitized by mites. This is parasitism because the spider is being consumed as its juices are slowly sucked out while the mites gain all the benefits traveling on and feeding off of their host. This parasitism may cause the harvestman spider suffering.

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**

A population ecology concept (introduced in MacArthur and Wilson's (1967) book, *The Theory of Island Biogeography*) is r/K selection theory, one of the first predictive models in ecology used to explain life-history evolution.

The premise behind the r/K selection model is that natural selection pressures change according to population density. For example, when an island is first colonized, density of individuals is low. The initial increase in population size is *not* limited by competition, leaving 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. As the population becomes more crowded, it approaches the island's carrying capacity, thus forcing individuals to 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 favors 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 behavioral and biogeographical ecology. For example, molecular ecology revealed promiscuous sexual behavior 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

> Metabolism – the rate at which energy and material resources are taken up from the environment, transformed within an organism, and allocated to maintenance, growth and reproduction – is a fundamental physiological trait.
>
> Ernst et al.

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 vapor. 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.

The leaf is the primary site of photosynthesis in most plants.

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 ($2H_2S + CO_2 \rightarrow h\nu \rightarrow CH_2O \rightarrow H_2O \rightarrow + 2S$ or $2H_2 + CO_2 + h\nu \rightarrow CH_2O + H_2O$), 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, behavior 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

Wetland conditions such as shallow water, high plant productivity, and anaerobic substrates provide a suitable environment for important physical, biological, and chemical processes. Because of these processes, wetlands play a vital role in global nutrient and element cycles.

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 behavior (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

The architecture of inflorescence in grasses is subject to the physical pressures of wind and shaped by the forces of natural selection facilitating wind-pollination (or anemophily).

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

Forest fires modify the land by leaving behind an environmental mosaic that diversifies the landscape into different seral stages and habitats of varied quality (left). Some species are adapted to forest fires, such as pine trees that open their cones only after fire exposure (right).

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.

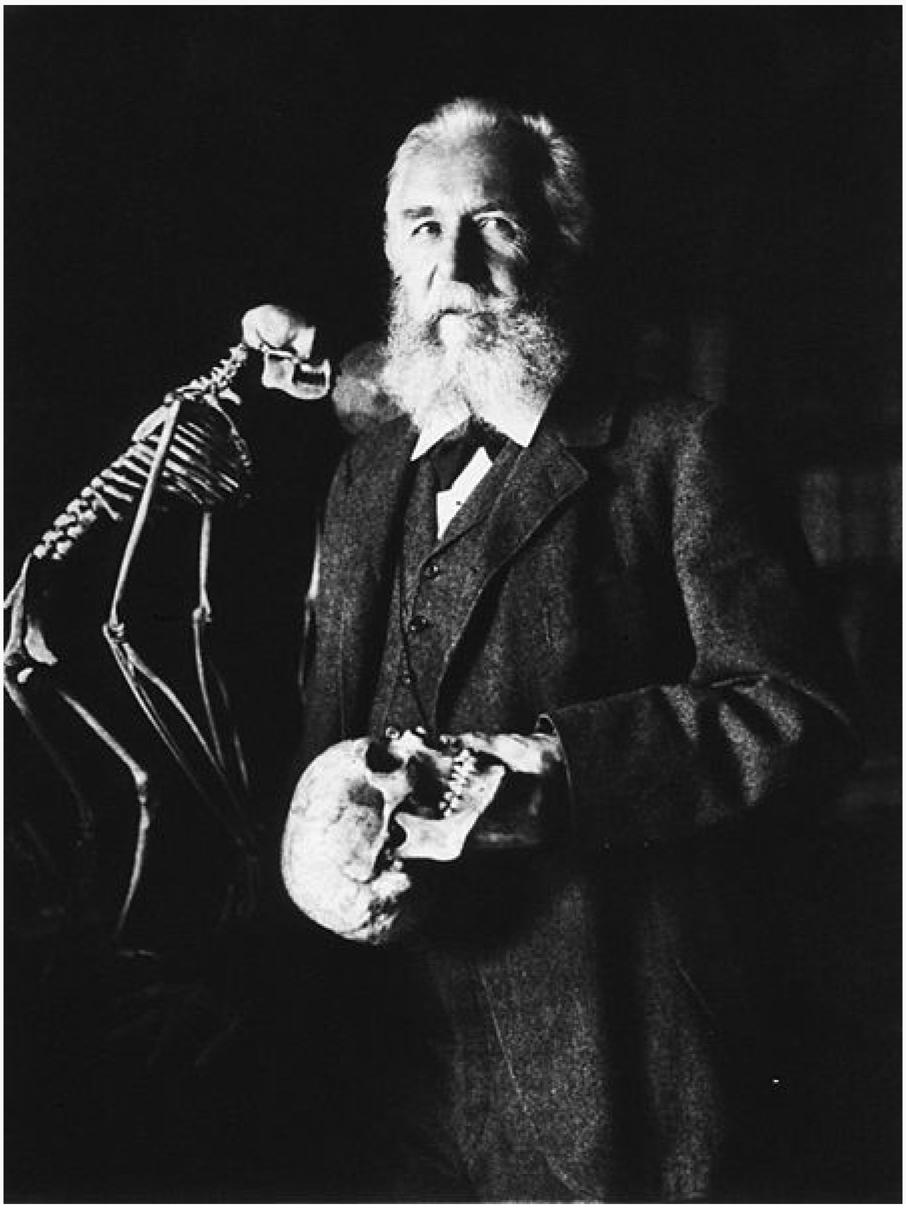
The ecology of global carbon budgets gives one example of the linkage between biodiversity and biogeochemistry. For starters, the Earth's oceans are estimated to hold 40,000 gigatonnes (Gt) carbon, vegetation and soil is estimated to hold 2070 Gt carbon, and fossil fuel emissions are estimated to emit 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 outgassing, 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 scientific disciplines, ecology has a complex 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).

By ecology we mean the body of knowledge concerning the economy of nature-the investigation of the total relations of the animal both to its inorganic and its organic environment; including, above all, its friendly and inimical relations with those animals and plants with which it comes directly or indirectly into contact-in a word, ecology is the study of all those complex interrelations referred to by Darwin as the conditions of the struggle of existence.

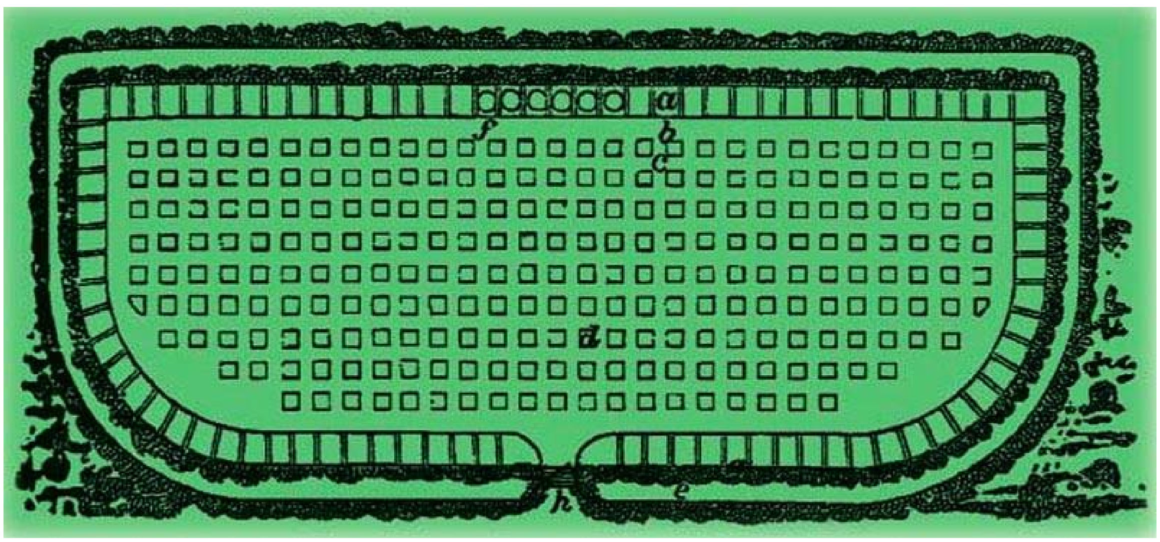
Haeckel's definition quoted in Esbjorn-Hargens



Ernst Haeckel (above) and Eugenius Warming (below), two founders of ecology

Opinions differ on who was the founder of modern ecological theory. Some mark Haeckel's definition as the beginning, others say it was Eugenius 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 led 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.



The layout of the first ecological experiment, noted by Charles Darwin in *The Origin of Species*, was studied in a grass garden at Woburn Abbey in 1817. The experiment studied the performance of different mixtures of species planted in different kinds of soils.

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.

Nowhere can one see more clearly illustrated what may be called the sensibility of such an organic complex,--expressed by the fact that whatever affects any species belonging to it, must speedily have its influence of some sort upon the whole assemblage. He will thus be made to see the impossibility of studying any form completely, out of relation to the other forms,--the necessity for taking a comprehensive survey of the whole as a condition to a satisfactory understanding of any part.

Stephen Forbes (1887)

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 overextended 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.

A bumblebee pollinating a flower, one example of an ecosystem service

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.

While we are used to thinking of cities as geographically discrete places, most of the land "occupied" by their residents lies far beyond their borders. The total area of land required to sustain an urban region (its "ecological footprint") is typically at least an order of magnitude greater than that contained within municipal boundaries or the associated built-up area.

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.

Many human-nature interactions occur indirectly due to the production and use of human-made (manufactured and synthesized) products, such as electronic appliances, furniture, plastics, airplanes, and automobiles. These products insulate humans from the natural environment, leading them to perceive less dependence on natural systems than is the case, but all manufactured products ultimately come from natural systems.

"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 ($10^{12}$) 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.

Chapter-3

Environmental Chemistry

Forests contain many examples of what environmental chemistry encompasses

Environmental chemistry is the scientific study of the chemical and biochemical phenomena that occur in natural places. It should not be confused with green chemistry, which seeks to reduce potential pollution at its source. It can be defined as the study of the sources, reactions, transport, effects, and fates of chemical species in the air, soil, and water environments; and the effect of human activity on these. Environmental chemistry is an interdisciplinary science that includes atmospheric, aquatic and soil chemistry, as well as heavily relying on analytical chemistry and being related to environmental and other areas of science.

Environmental chemistry involves first understanding how the uncontaminated environment works, which chemicals in what concentrations are present naturally, and with what effects. Without this it would be impossible to accurately study the effects humans have on the environment through the release of chemicals.

Environmental chemists draw on a range of concepts from chemistry and various environmental sciences to assist in their study of what is happening to a chemical species in the environment. Important general concepts from chemistry include understanding chemical reactions and equations, solutions, units, sampling, and analytical techniques.

Contamination

A contaminant is a substance present in nature at a level higher than typical levels or that would not otherwise be there. This may be due to human activity. The term contaminant is often used interchangeably with *pollutant*, which is a substance that has a detrimental impact on the surrounding environment. Whilst a contaminant is sometimes defined as a substance present in the environment as a result of human activity, but without harmful effects, it is sometimes the case that toxic or harmful effects from contamination only become apparent at a later date.

The "medium" (e.g. soil) or organism (e.g. fish) affected by the pollutant or contaminant is called a *receptor*, whilst a *sink* is a chemical medium or species that retains and interacts with the pollutant.

Freshwater Environmental Quality Parameters

Freshwater environmental quality parameters are the natural and man-made chemical, biological and microbiological characteristics of rivers, lakes and ground-waters, the ways they are measured and the ways that they change. The values or concentrations attributed to such parameters can be used to describe the pollution status of an environment, its biotic status or to predict the likelihood or otherwise of a particular organisms being present. Monitoring of environmental quality parameters is a key activity in managing the environment, restoring polluted environments and anticipating the effects of man-made changes on the environment.

Characterisation

The first step in understanding the chemistry of freshwaters is to take samples and analyse them for the chemical constituents that are of interest.

Sampling

Freshwaters are surprisingly difficult to sample because they are rarely homogeneous and their quality varies during the day and during the year. In addition the most representative sampling locations are often at a distance from the shore or bank increasing the logistic complexity.

Rivers

Filling a clean bottle with river water is a very simple task, but a single sample is only representative of that point along the river the sample was taken from and at that point in time. Understanding the chemistry of a whole river, or even a significant tributary, requires prior investigative work to understand how homogeneous or mixed the flow is and to determine if the quality changes during the course of a day and during the course of a year. Almost all natural rivers will have very significant patterns of change through the day and through the seasons. Many rivers also have a very large flow that is unseen. This flows through underlying gravel and sand layers and is called the hyporheic zone How much mixing there is between the hyporheic zone and the water in the open channel will depend on a variety of factors, some of which relate to flows leaving aquifers which may have been storing water for many years.

Ground-waters

Ground waters by their very nature are often very difficult to access to take a sample. As a consequence the majority of ground-water data comes from samples taken from springs, wells, water supply bore-holes and in natural caves. In recent decades as the need to understand ground water dynamics has increased, an increasing number or monitoring bore-holes have been drilled into aquifers

Lakes

Lakes and ponds can be very large and support a complex eco-system in which environmental parameters vary widely in all three physical dimensions and with time. Large lakes in the temperate zone often stratify in the warmer months into a warmer upper layers rich in oxygen and a colder lower layer with low oxygen levels. In the autumn, falling temperatures and occasional high winds result in the mixing of the two layers into a more homogeneous whole. When stratification occurs it not only affects oxygen levels but also many related parameters such as iron, phosphate and manganese which are all changed in their chemical form by change in the redox potential of the environment.

Lakes also receive waters, often from many different sources with varying qualities. Solids from stream inputs will typically settle near the mouth of the stream and depending on a variety of factors the incoming water may float over the surface of the lake, sink beneath the surface or rapidly mix with the lake water. All of these phenomena can skew the results of any environmental monitoring unless the process are well understood.

Mixing zones

Where two rivers meet at a confluence there exists a mixing zone. A mixing zone may be very large and extend for many miles as in the case of the Mississippi and Missouri rivers in the United States and the River Clwyd and River Elwy in North Wales. In a mixing zone water chemistry may be very variable and can be difficult to predict. The chemical interactions are not just simple mixing but may be complicated by biological processes from submerged macrophytes and by water joining the channel from the hyporheic zone or from springs draining an aquifer.

Geological inputs

The geology that underlies a river or lake has a major impact on its chemistry. A river flowing across very ancient precambrian schists is likely to have dissolved very little from the rocks and maybe similar to de-ionised water at least in the headwaters. Conversely a river flowing through chalk hills, and especially if its source is in the chalk, will have a high concentration of carbonates and bicarbonates of Calcium and possibly Magnesium.

As a river progresses along its course it may pass through a variety of geological types and it may have inputs from aquifers that do not appear on the surface anywhere in the locality.

A forest stream in the winter near Erzhausen, Germany

Water chemistry between systems varies tremendously.

Atmospheric inputs

Oxygen is probably the most important chemical constituent of surface water chemistry, as all aerobic organisms require it for survival. It enters the water mostly via diffusion at the water-air interface. Oxygen's solubility in water decreases as water temperature increases. Fast, turbulent streams expose more of the water's surface area to the air and tend to have low temperatures and thus more oxygen than slow, backwaters. Oxygen is a by-product of photosynthesis, so systems with a high abundance of aquatic algae and plants may also have high concentrations of oxygen during the day. These levels can decrease significantly during the night when primary producers switch to respiration. Oxygen can be limiting if circulation between the surface and deeper layers is poor, if the activity of animals is very high, or if there is a large amount of organic decay occurring such as following Autumn leaf-fall.

Most other atmospheric inputs come from man-made or anthropogenic sources the most significant of which are the oxides of sulphur produced by burning sulphur rich fuels such as coal and oil which give rise to acid rain. The chemistry of sulphur oxides is complex both in the atmosphere and in river systems. However the effect on the overall chemistry is simple in that it reduces the pH of the water making it more acidic. The pH change is most marked in rivers with very low concentrations of dissolved salts as these cannot buffer the effects of the acid input. Rivers downstream of major industrial conurbations are also at greatest risk. In parts of Scandinavia and West Wales and Scotland many rivers became so acidic from oxides of sulphur that most fish life was destroyed and pHs as low as pH4 were recorded during critical weather conditions.

Anthropogenic inputs

The majority of rivers on the planet and many lakes have received or are receiving inputs from human-kind's activities. In the industrialised world, many rivers have been very seriously polluted, at least during the 19th and the first half of the 20th centuries. Although in general there has been much improvement in the developed world, there is still a great deal of river pollution apparent on the planet.

Toxicity

In most environmental situations the presence or absence of an organism is determined by a complex web of interactions only some of which will be related to measurable chemical or biological parameters. Flow rate, turbulence, inter and intra specific competition, feeding behaviour, disease, parasatism, commensalism and symbiosis are just a few of the pressures and opportunities facing any organism or population. Most chemical constituents favour some organisms and are less favourable to others. However there are some cases where a chemical constituent exerts a toxic effect. i.e. where the concentration can kill or severely inhibit the normal functioning of the organism. Where a toxic effect has been demonstrated this may be noted in the sections below dealing with the individual parameters.

Chemical constituents

Colour and turbidity

Often it is the colour of freshwater or how clear or hazy the water is that is the most obvious visual characteristic. Unfortunately neither colour nor turbidity are strong indicators of the overall chemical composition of water. However both colour and turbidity reduce the amount of light penetrating the water and can have significant impact on algae and macrophytes. Some algae in particular are highly dependant on water with low colour and turbidity

Many rivers draining high moor-lands overlain by peat have a very deep yellow brown colour caused by dissolved humic acids.

Organic constituents

One of the principal sources of elevated concentrations of organic chemical constituents is from treated sewage.

Dissolved organic material is most commonly measured using either the Biochemical oxygen demand (BOD) test of the Chemical oxygen demand (COD) test. Organic constituents are significant in river chemistry for the effect that they have on dissolved oxygen concentration and for the impact that individual organic species may have directly on aquatic biota.

Any organic and degradable material utilises oxygen as it decomposes. Where organic concentrations are significantly elevated the effects on oxygen concentrations can be significant and as conditions get extreme the river bed may become anoxic.

Some organic constituents such as synthetic hormones, pesticides, pthalates have direct metabolic effects on aquatic biota and even on humans drinking water taken from the river. Understanding such constituents and how they can be identified and quantified is becoming of increasing importance in the understanding of freshwater chemistry.

Metals

A wide range of metals may be found in rivers from natural sources where metal ores are present in the rocks over which the river flows or in the aquifers feeding water into the river. However many rivers have an increased load of metals because of industrial activities which include mining and quarrying and the processing and use of metals.

Iron

Iron, usually as Fe^{+++} is a common constituent of river waters at very low levels. As concentrations increase visible orange/brown staining appears and any increase in concentrations is likely to create conditions where complex insoluble oxides, hydroxides and carbonates of iron start precipitating out producing a semi-gelatinous and dense floc carpeting the river bed. Such conditions are very deleterious to most organisms and can cause serious damage in a river system.

Coal mining is also a very significant source of Iron both in mine-waters and from stocking yards of coal and from coal processing. Long abandoned mines can be a highly intractable source of high concentrations of Iron. Low levels of iron are common in spring waters emanating from deep-seated aquifers and maybe regarding as health giving springs. Such springs are commonly called Chalybeate springs and have given rise to a number of Spa towns in Europe and the United States.

Zinc

Zinc is normally associated with metal mining, especially Lead and Silver mining but is also a component pollutant associated with a variety of other metal mining activities and with Coal mining. Zinc is toxic at relatively low concentrations to many aquatic organisms. *Microregma* starts to show a toxic reaction at concentrations as low as 0.33 mg/l

Heavy metals

Lead and silver in river waters are commonly found together and associated with lead mining. Impacts from very old mines can be very long-lived. In the River Ystwyth in Wales for example, the effects of silver and lead mining in the 17th and 18th centuries in the headwaters still causes unacceptably high levels of Zinc and Lead in the river water right down to its confluence with the sea. Silver is very toxic even at very low concentrations but leaves no visible of its contamination.

Lead is also highly toxic to freshwater organisms and to humans if the water is used as drinking water. As with Silver, Lead pollution is not visible to the naked eye. The River Rheidol in west Wales had a major series of lead mines in its headwaters until the end of the 19th century and its mine discharges and waste tips remain to this day. In 1919 - 1921 only 14 species of invertebrates were found were found in the lower Rheidol when Lead concentrations were between 0.2ppm and 0.5ppm. By 1932 the lead concentration had reduced to 0.02ppm to 0.1ppm because of the abandonment of mining and, at those concentrations, the bottom fauna had stabilized to 103 species including three leeches.

Coal mining is also a very significant source of metals, especially Iron, Zinc and Nickel particularly where the coal is rich if pyrites which oxidises on contact with the air producing a very acidic leachate which is able to dissolve metals from the coal.

Significant levels of copper are unusual in rivers and where it does it occur the source is most likely to be mining activities, coal stocking, or pig farming. Rarely elevated levels may be of geological origin. Copper is acutely toxic to many freshwater organisms, especially algae, at very low concentrations and significant concentration in river water may have serious adverse effects on the local ecology.

Nitrogen

Nitrogenous compounds have a variety of sources including washout of oxides of nitrogen from the atmosphere, some geological inputs and some from macrophyte and algal nitrogen fixation. However for many rivers in the proximity of humans, the largest input is from sewage whether treated or untreated. The nitrogen derives from breakdown products of proteins found in urine and faeces. These products, being very soluble, often pass through sewage treatment process and are discharged into rivers as a component of sewage treatment effluent. Nitrogen may be in the form of nitrate, nitrite, ammonia or ammonium salts or what is termed albuminoid nitrogen or nitrogen still within an organic proteinoid molecule.

The differing forms of nitrogen are relatively stable in most river systems with nitrite slowly transforming into nitrate in well oxygenated rivers and ammonia transforming into nitrite/ nitrate. However, the process are slow in cool rivers and reduction in concentration may more often be attributed to simple dilution. All forms of nitrogen are taken up by macrophytes and algae and elevated levels of nitrogen are often associated with overgrowths of plants or eutrophication. These can have the effect of blocking channels and inhibiting navigation. However, ecologically, the more significant effect is on dissolved oxygen concentrations which may become super-saturated during daylight due to plant photsynthesis but then drop to very low levels during darkness as plant respiration uses up the dissolved oxygen. Coupled with the release of oxygen in photosynthesis is the creation of bi-carbonate ions which cause a steep rise in pH and this is matched in darkness as carbon dioxide is released through respiration which substantially lowers the pH. Thus high levels of nitrogenous compounds tends to lead to eutrophication with extreme variations in parameters which in turn can substantially degrade the ecological worth of the watercourse.

Ammonium ions also have a toxic effect, especially on fish. The toxicity of ammonia is dependent on both pH and temperature and an added complexity is the buffering effect of the blood/water interface across the gill membrane which masks any additional toxicity over about pH 8.0. The management of river chemistry to avoid ecological damage is particularly difficult in the case of ammonia as a wide range of potential scenarios of concentration, pH and temperature have to be considered and the diurnal pH fluctuation caused by photosynthesis considered. On warm summer days with high-bi-carbonate concentrations unexpectedly toxic conditions can be created.

Phosphorus

Phosphorus compounds are usually found as relatively insoluble phosphates in river water and, except in some exceptional circumstances, the origin is from agriculture of human sewage. Phosphorus can encourage excessive growths of plants and algae and contribute to eutrophication. If a river discharges into a lake or reservoir phosphate can be mobilised year after year by natural processes. In the summer time, lakes stratify so that warm oxygen rich water floats on top of cold oxygen poor water. In the warm upper layers - the epilimnion- plants consume the available phosphate. As the plants die in the late summer they fall into the cool water layers underneath - the hypolimnion - and decompose. During winter turn-over, when a lake becomes fully mixed through the action of winds on a cooling body of water - the phosphates are spread throughout the lake again to feed a new generation of plants. This process is one of the principal causes of persistent algal blooms at some lakes.

Arsenic

Geological deposits of arsenic may be released into rivers where deep ground-waters are exploited as in parts of Pakistan. Some lead and copper mining also encounters ores containing arsenic which may then be released into local rivers.

Solids

Inert solids are produced in all montane rivers as the energy of the water helps grind away rocks into gravel, sand and finer material. Much of this settles very quickly and provides an important substrate for many aquatic organisms. Many salmonid fish require beds of gravel and sand in which to lay their eggs. Many other types of solids from agriculture, mining, quarrying, urban run-off and sewage may block-out sunlight from the river and may block interstices in gravel beds making them useless for spawning and supporting insect life.

Bacterial, viral and parasite inputs

Both agriculture and sewage treatment produce inputs into rivers with very high concentrations of bateria and viruses including a wide range of pathogenic organisms. Even in areas with little human activity significant levels of bacteria and viruses can be detected originating from fish and aquatic mammals and from animals grazing near rivers such as deer. Upland waters draining areas frequented by sheep, goats or deer may also harbour a variety of opportunistic human parasites such as liver fluke. Consequently there are very few rivers from which the water is safe to drink without some form of sterilisation or disinfection. In rivers used for contact recreation such as swimming, safe levels of bacteria and viruses can be established based on risk assessment.

Under certain conditions bacteria can colonise freshwaters occasionally making large rafts of filamentous mats known as *sewage fungus* – usually *Sphaerotilus natans*. The presence of such organisms is almost always an indicator of extreme organic pollution and would be expected to be matched with low dissolved oxygen concentrations and high BOD vales.

E. coli bacteria have been commonly found in recreational waters and their presence is used to indicate the presence of recent fecal contamination, but E. coli presence may not be indicative of human waste. E. coli are harbored in all warm-blooded animals: birds and mammals alike. E. coli bacteria have also been found in fish and turtles. Sand also harbors E. coli bacteria and some strains of E. coli have become naturalized. Some geographic areas may support unique populations of E. coli and conversely, some E. coli strains are cosmopolitan.

pH

pH in rivers is affected by the geology of the water source, atmospheric inputs and a range of other chemical contaminants. pH is only likely to become an issue on very poorly buffered upland rivers where atmospheric sulphur and nitrogen oxides may very significantly depress the pH as low as pH4 or in eutrophic alkaline rivers where photosynthetic bi-carbonate ion production in photosynthesis may drive the pH up above pH10

Water quality indicators

Algal bloom

Algal blooms can present problems for ecosystems and human society

An **algal bloom** is a rapid increase or accumulation in the population of algae in an aquatic system. Algal blooms may occur in freshwater as well as marine environments. Typically, only one or a small number of phytoplankton species are involved, and some blooms may be recognized by discoloration of the water resulting from the high density of pigmented cells. Although there is no officially recognized threshold level, algae can be considered to be blooming at concentrations of hundreds to thousands of cells per milliliter, depending on the severity. Algal bloom concentrations may reach millions of cells per milliliter. Algal blooms are often green, but they can also be other colors such as yellow-brown or red, depending on the species of algae.

Bright green blooms are a result of blue-green algae, which are actually bacteria (cyanobacteria). Blooms may also consist of macroalgal, not phytoplankton, species. These blooms are recognizable by large blades of algae that may wash up onto the shoreline.

Of particular note are **harmful algal blooms** (HABs), which are algal bloom events involving toxic or otherwise harmful phytoplankton such as dinoflagellates of the genus *Alexandrium* and *Karenia*. Such blooms often take on a red or brown hue and are known colloquially as **red tides**.

Freshwater algal blooms

Freshwater algal blooms are the result of an excess of nutrients, particularly phosphorus. The excess of nutrients may originate from fertilizers that are applied to land for agricultural or recreational purposes, these nutrients can then enter watersheds through water runoff. Excess carbon and nitrogen have also been suspected as causes.

When phosphates are introduced into water systems, higher concentrations cause increased growth of algae and plants. Algae tend to grow very quickly under high nutrient availability, but each alga is short-lived, and the result is a high concentration of dead organic matter which starts to decay. The decay process consumes dissolved oxygen in the water, resulting in hypoxic conditions. Without sufficient dissolved oxygen in the water, animals and plants may die off in large numbers.

Blooms may be observed in freshwater aquariums when fish are overfed and excess nutrients are not absorbed by plants. These are not generally harmful for fish, and the situation can be corrected by changing the water in the tank and then reducing the amount of food given.

Water treatment

Algal blooms sometimes occur in drinking water supplies. In such cases, toxins from the bloom can survive standard water purifying treatments. Researchers at Florida International University in Miami are experimenting with using 640-kilohertz ultrasound waves that create micropressure zones as hot as 3,700 °C. This breaks some water molecules into reactive fragments that can kill algae.

Measurement

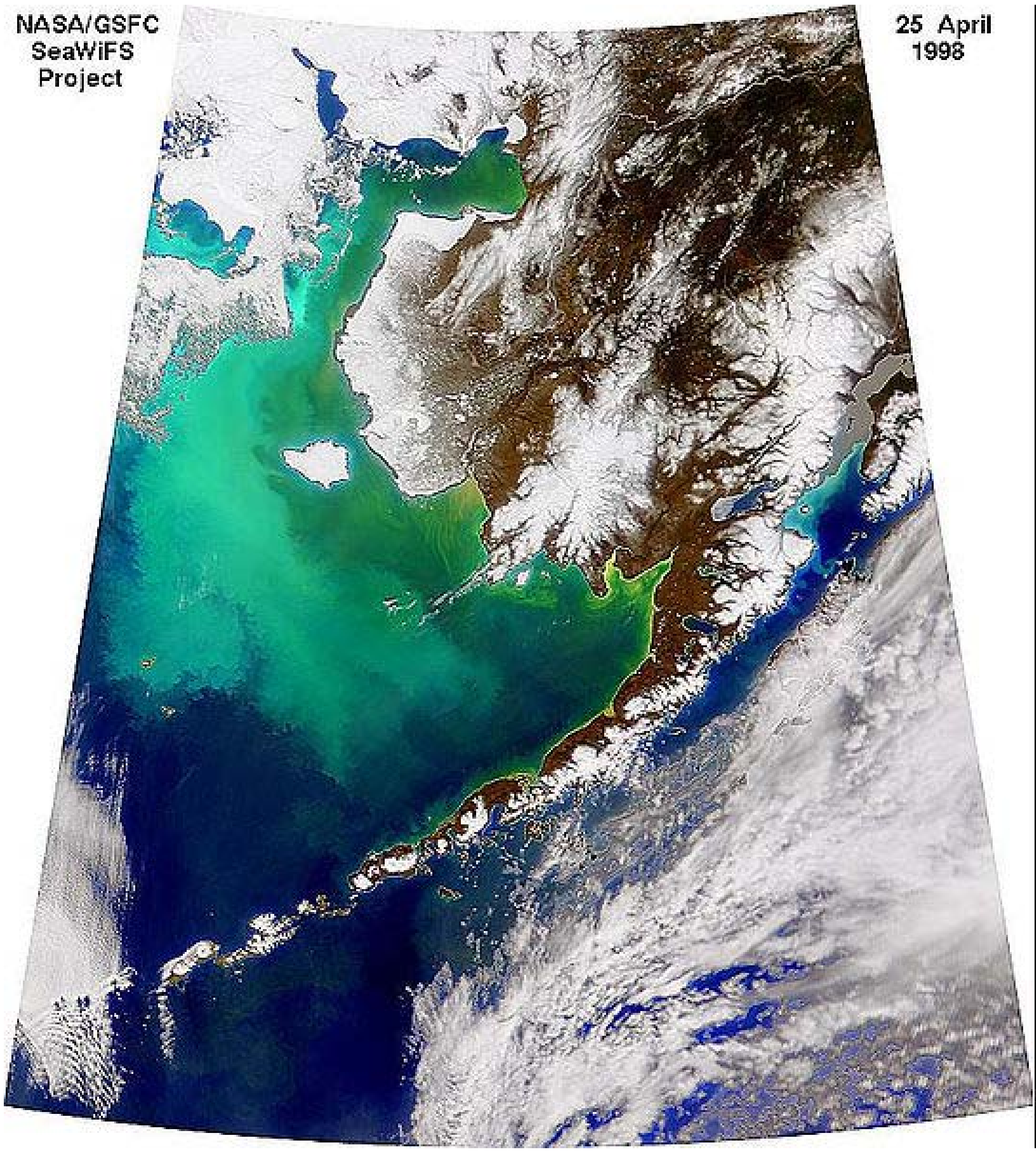
Algal blooms are monitored using biomass measurements coupled with the examination of species present. A widely used measure of algal and cyanobacterial chlorophyll concentration. Peak values of chlorophyll *a* for an oligotrophic lake are about 1-10 μg/l, while in a eutrophic lake they can reach 300 μg/l. In cases of hypereutrophy, such as Hartbeespoort Dam in South Africa, maxima of chlorophyll a can be as high as 3,000 μg/l.

Tai Hu Algal Bloom

Lake Tai in Eastern China has had an algal bloom which has attracted the attention of the ENGO sector. Greenpeace China investigated the algal bloom at Lake Tai and took water samples. Of 25 samples, 20 were too polluted to be used to water plants or in factories.

Harmful Algal Blooms

An algae bloom off the southern coast of England in 1999.



Satellite image of a large coccolithophore bloom in the Bering Sea in 1998.

A **harmful algal bloom** (HAB) is an algal bloom that causes negative impacts to other organisms via production of natural toxins, mechanical damage to other organisms, or by other means. HABs are often associated with large-scale marine mortality events and have been associated with various types of shellfish poisonings.

Background

In the marine environment, single-celled, microscopic, plant-like organisms naturally occur in the well-lit surface layer of any body of water. These organisms, referred to as phytoplankton or microalgae, form the base of the food web upon which nearly all other marine organisms depend. Of the 5000+ species of marine phytoplankton that exist worldwide, about 2% are known to be harmful or toxic. Blooms of harmful algae can have large and varied impacts on marine ecosystems, depending on the species involved, the environment where they are found, and the mechanism by which they exert negative effects. Examples of common harmful effects of HABs include:

1. the production of neurotoxins which cause mass mortalities in fish, seabirds and marine mammals
2. human illness or death via consumption of seafood contaminated by toxic algae
3. mechanical damage to other organisms, such as disruption of epithelial gill tissues in fish, resulting in asphyxiation
4. oxygen depletion of the water column (hypoxia or anoxia) from cellular respiration and bacterial degradation

Due to their negative economic and health impacts, HABs are often carefully monitored.

HABs occur in many regions of the world, and in the United States are recurring phenomena in multiple geographical regions. The Gulf of Maine frequently experiences blooms of the dinoflagellate *Alexandrium fundyense*, an organism that produces saxitoxin, the neurotoxin responsible for paralytic shellfish poisoning. The well-known "Florida red tide" that occurs in the Gulf of Mexico is a HAB caused by *Karenia brevis*, another dinoflagellate which produces brevetoxin, the neurotoxin responsible for neurotoxic shellfish poisoning. California coastal waters also experience seasonal blooms of *Pseudo-nitzschia*, a diatom known to produce domoic acid, the neurotoxin responsible for amnesic shellfish poisoning. Off the west coast of South Africa, HABs caused by *Alexandrium catanella* occur every spring. These blooms of organisms cause severe disruptions in fisheries of these waters as the toxins in the phytoplankton cause filter-feeding shellfish in affected waters to become poisonous for human consumption.

If the HAB event results in a high enough concentration of algae the water may become discoloured or murky, varying in colour from purple to almost pink, normally being red or green. Not all algal blooms are dense enough to cause water discolouration.

"Red Tides"

A red tide

"Red tide" is a term often used to describe HABs in marine coastal areas, as the dinoflagellate species involved in HABs are often red or brown, and tint the sea water to a reddish color. The more correct and preferred term in use is harmful algal bloom, because:

1. these blooms are not associated with tides
2. not all algal blooms cause reddish discoloration of water
3. not all algal blooms are harmful, even those involving red discolouration

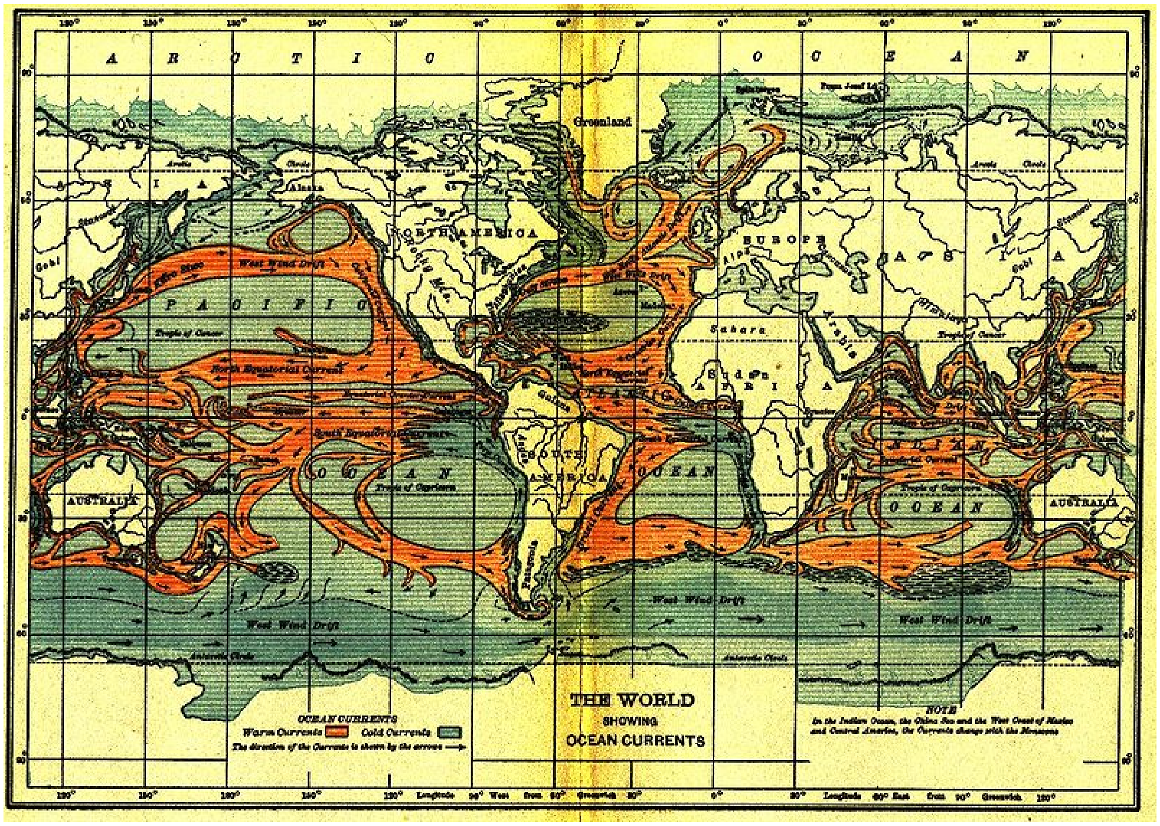
Causes of HABs

It is unclear what causes HABs; their occurrence in some locations appears to be entirely natural, while in others they appear to be a result of human activities. Furthermore, there are many different species of algae that can form HABs, each with different environmental requirements for optimal growth. The frequency and severity of HABs in some parts of the world have been linked to increased nutrient loading from human activities. In other areas, HABs are a predictable seasonal occurrence resulting from coastal upwelling, a natural result of the movement of certain ocean currents. The growth of marine phytoplankton (both non-toxic and toxic) is generally limited by the availability of nitrates and phosphates, which can be abundant in coastal upwelling zones as well as in agricultural run-off. The type of nitrates and phosphates available in the system are also a factor, since phytoplankton can grow at different rates depending on the relative abundance of these substances (e.g. ammonia, urea, nitrate ion). A variety of other nutrient sources can also play an important role in affecting algal bloom formation, including iron, silica or carbon. Coastal water pollution produced by humans and systematic increase in sea water temperature have also been suggested as possible contributing factors in HABs. Other factors such as iron-rich dust influx from large desert areas such as the Saharan desert are thought to play a role in causing HABs. Some algal blooms on the Pacific coast have also been linked to natural occurrences of large-scale climatic oscillations such as El Niño events. While HABs in the Gulf of Mexico have been occurring since the time of early explorers such as Cabeza de Vaca, it is unclear what initiates these blooms and how large a role anthropogenic and natural factors play in their development. It is also unclear whether the apparent increase in frequency and severity of HABs in various parts of the world is in fact a real increase or is due to increased observation effort and advances in species identification methods.

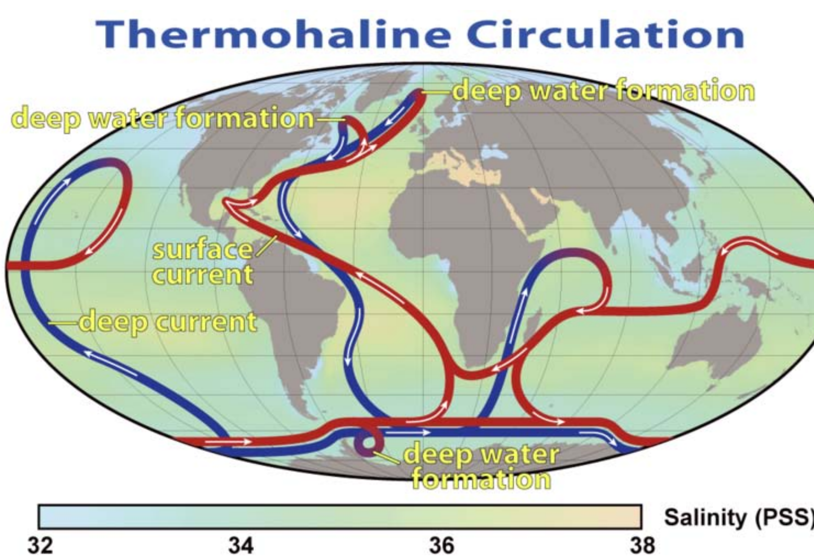
Notable occurrences

- People may experience respiratory irritation (coughing, sneezing, and tearing) when the phytoplankton *Karenia brevis* is present along a coast and winds blow its toxic aerosol onshore. Swimming is usually safe, but skin irritation and burning is possible in areas of high concentration.
- In 1972 a red tide was caused in New England by a toxic dinoflagellate *Alexandrium (Gonyaulax) tamarense*.
- In 2005 the Canadian HAB was discovered to have come further south than it has in years prior by a ship called The Oceanus, closing shellfish beds in Maine and Massachusetts and alerting authorities as far south as Montauk (Long Island, NY) to check their beds. Experts who discovered the reproductive cysts in the seabed warn of a possible spread to Long Island in the future, halting the area's fishing and shellfish industry and threatening the tourist trade, which constitutes a significant portion of the island's economy.
- Brittany, in France, is currently experiencing recurring algal booms caused by the high amount of fertilizer discharging in the sea due to intensive pig farming, causing lethal gas emissions that have already killed.

Anoxic event



As early as 1911, major oceanic currents were well mapped and understood, albeit without today's understanding of how they affect regional and global climatological conditions.



This world perspective on oceanic currents demonstrates the interdependencies of transnational regions on circulating currents.

Oceanic anoxic events or **anoxic events** occur when the Earth's oceans become completely depleted of oxygen (O_2) below the surface levels. Although anoxic events have not happened for millions of years, the geological record shows that they happened many times in the past. Anoxic events may have caused mass extinctions. These mass extinctions were so characteristic they include some of those which geobiologists employ to serve as a time marker in biostratigraphic dating. It is believed oceanic anoxic events are strongly linked to lapses in key oceanic current circulations, to climate warming and greenhouse gases.

Background

Analysis of the geologic records occurring before and after the affected ages are that onsets are rapid and so are recoveries. Both sets of data suggests that a sudden climate threshold or tipping point occurs at about four times the Earth's mean carbon dioxide levels relative to the baseline concentrations of about 280 ppmv in circa 1750. This date is significant in that it is regarded as the beginning of the Industrial age. Strata analysis suggests that in the era when Earth had a predominantly overheated climate, with heavy daily rains and violent storms, the relatively fierce global climate resulted in far heavier erosion which in turn fed more nutrients into the world's waters. At the same time it caused deep water circulation between the poles and the equator to stop in a cataclysmic fashion. This obstruction in oceanic circulation led to 'death in the depths' from oxygen deprivation. The stagnation caused by this lack of circulation could not be offset by natural processes and became a source of mildly poisonous hydrogen sulfides. The stratified waters would support life in the oxygenated surface layer but the deeper layers became a lethal mixture where life was impossible. The toxic lower layers halted scavenger activity along the organically rich ooze, or sapropel, and all creatures that died in it drifted down and accumulated on the abyssal basins and bottoms. All these life forms unwarily drifting into the anoxic or toxic layers would have died and contributed to the continual accumulation of unicellular microorganisms. The surface layer benefited from an explosion in life, spurred by the increased nutrients from the super-greenhouse conditions, which was then killing itself in waste products. Ironically these deposits of sedimentary organic materials may have accumulated into lipid rich deposits. It is now widely believed that most of today's fossil oil reserves formed in several distinct anoxic events in earth's geologic history.

There are currently several places on earth that are exhibiting the features of anoxic events on a localized level such as algae blooms and localized "dead zones". Dead zones exist off the East Coast of the United States in the Chesapeake Bay, in the Scandinavian strait Kattegat, the Black Sea (which may have been anoxic in its deepest levels for millennia, however), in the northern Adriatic as well as a dead zone off the coast of Louisiana. The current surge of jellyfish worldwide are sometimes regarded as the first stirrings of an anoxic event. Other marine dead zones have appeared in coastal waters of South America, China, Japan, and southeast Australia. A 2008 study counted 405 dead zones worldwide.

This is a recent understanding. This picture was only pieced together during the last three decades. The handful of known and suspected anoxic events have been tied geologically to large-scale production of the world's oil reserves in worldwide bands of black shale in the geologic record. Likewise the high relative temperatures believed linked to so called "super-greenhouse events" Oceanic **anoxic events** were in all likelihood caused or stimulated by extreme episodes of volcanic outgassing. These events contributed to the characteristic elevated carbon dioxide levels four to six times current levels that are attributed to these periods. At even a few degrees warmer, rain forests are extremely vulnerable to fire hazards. These forests have little natural resistance to fires, and some conjecture a critical tipping point. Practically overnight the increase of temperature might have been reached and triggered a huge burn-off of planetary forests. This would have released unprecedented amounts of carbon dioxide into the atmosphere. With a change of mean temperatures of three degrees Celsius, the ice caps melted. This triggered a runaway effect. In the super-greenhouse ecologies—the term meaning average temperature rose to or beyond six degrees above today—the seas were so warm, it is believed the water temperatures at the two poles were in the lower 80s°F (i.e. above 27 °C). The Cretaceous and Jurassic eras world ecologies were essentially ice free, had massive storms driven by warm oceans, and were dying from the double hit of lack of oxygen and toxic hydrogen sulfide accumulations at lower layers because of a shut down in the ocean conveyor belts. In this time, most of the world would experience the highly noxious scent of rotten eggs and the seas would have slowly acquired a deep green hue from the high amounts of algae.

Occurrence

Oceanic anoxic events most commonly occurred during periods of very warm climate characterized by high levels of carbon dioxide (CO_2) and mean surface temperatures probably in excess of 25 °C (77 °F). The Quaternary levels, our current period, are just 13 °C (55 °F) in comparison. Such rises in carbon dioxide may have been in response to a great outgassing of the highly flammable natural gas (methane) some have christened an "oceanic burp". Vast quantities of methane are normally locked into the Earth's crust on the continental plateaus in one of the many deposits consisting of compounds of methane hydrate, a solid precipitated combination of methane and water much like ice. Because the methane hydrates are unstable, save at cool temperatures and high (deep) pressures, scientists have observed smaller "burps" due to tectonic events. Studies suggest the huge release of natural gas could be a major climatological trigger, methane itself being a greenhouse gas many times more powerful than carbon dioxide. However, anoxia was also rife during the Hirnantian (late Ordovician) ice age.

Oceanic anoxic events have been recognized primarily from the already warm Cretaceous and Jurassic Periods, when numerous examples have been documented, but earlier examples have been suggested to have occurred in the late Triassic, Permian, Devonian (Kellwasser event/s), Ordovician and Cambrian.

The Paleocene–Eocene Thermal Maximum (PETM), which was characterized by a global rise in temperature and deposition of organic-rich shales in some shelf seas, shows many similarities to oceanic anoxic events.

Typically, oceanic anoxic events last for under half a million years, before a full recovery.

Consequences

Oceanic anoxic events have had many important consequences. It is believed that they have been responsible for mass extinctions of marine organisms both in the Paleozoic and Mesozoic. The early Toarcian and Cenomanian-Turonian anoxic events correlate with the Toarcian and Cenomanian-Turonian extinction events of mostly marine life forms. Apart from possible atmospheric effects, many deeper-dwelling marine organisms could not adapt to an ocean where oxygen penetrated only the surface layers.

Another, economically significant consequence of oceanic anoxic events is the fact that the prevailing conditions in so many Mesozoic oceans has helped produce most of the world's petroleum and natural gas reserves. During an oceanic anoxic event, the accumulation and preservation of organic matter was much greater than normal, allowing the generation of potential petroleum source rocks in many environments across the globe. Consequently some 70 percent of oil source rocks are Mesozoic in age, and another 15 percent date from the warm Paleogene: only rarely in colder periods were conditions favorable for the production of source rocks on anything other than a local scale.

Major oceanic anoxic events

Jurassic and Cretaceous

The timeline data of the Jurassic and Cretaceous

The concept of the oceanic anoxic event (OAE) was first proposed in 1976 by Seymour Schlanger (1927–1990) and geologist Hugh Jenkyns and arose from discoveries made by the Deep Sea Drilling Project (DSDP) in the Pacific Ocean. It was the finding of black carbon-rich shales in Cretaceous sediments that had accumulated on submarine volcanic plateaus (Shatsky Rise, Manihiki Plateau), coupled with the fact that they were identical in age with similar deposits cored from the Atlantic Ocean and known from outcrops in Europe—particularly in the geologic record of the otherwise limestone dominated Apennines chain in Italy, that led to the realization that these widespread intervals of similar strata recorded highly unusual "punctuational" conditions in the world ocean during several distinct discrete periods of geological time.

Sedimentological investigations of these organic-rich sediments, which have continued to this day, typically reveal the presence of fine laminations undisturbed by bottom-dwelling fauna, indicating anoxic conditions on the sea floor, believed to be coincident with a low lying poisonous layer of hydrogen sulfide. Furthermore, detailed organic geochemical studies have recently revealed the presence of molecules (so-called biomarkers) that derive from both purple sulfur bacteria and green sulfur bacteria: organisms that required both light and free hydrogen sulfide (H_2S), illustrating that anoxic conditions extended high into the upper water column.

Such sulfidic (or euxinic) conditions, which exist today in many water bodies from ponds to various land surrounded mediterranean seas such as the Black Sea of today, were particularly prevalent in the Cretaceous Atlantic but also characterized other parts of the world ocean. In an ice free sea of these believed super-greenhouse worlds, oceanic waters were as much as 200 meters higher, in some eras. During the time spans in question, the continental plates are believed to have been well separated, and the mountains we know today were (mostly) future tectonic events—meaning the overall landscapes were generally much lower— and even the half super-greenhouse climates would have been eras of highly expedited water erosion carrying massive amounts of nutrients into the world oceans fueling an overall explosive population of microorganisms and their predator species in the oxygenated upper layers.

Detailed stratigraphic studies of Cretaceous black shales from many parts of the world have indicated that two oceanic anoxic events were particularly significant in terms of their impact on the chemistry of the oceans, one in the early Aptian (~120 Ma), sometimes called the Selli Event (or OAE 1a) after the Italian geologist, Raimondo Selli (1916–1983), and another at the Cenomanian–Turonian boundary (~93 Ma), sometimes called the Bonarelli Event (or OAE 2) after the Italian geologist, Guido Bonarelli (1871–1951).

- Insofar as the Cretaceous OAEs can be represented by type localities, it is the striking outcrops of laminated black shales within the vari-colored claystones and pink and white limestones near the town of Gubbio in the Italian Apennines that are the best candidates.
- The 1-meter thick black shale at the Cenomanian–Turonian boundary that crops out near Gubbio is termed the 'Livello Bonarelli' after the man who first described it in 1891.

More minor oceanic anoxic events have been proposed for other intervals in the Cretaceous (in the Valanginian, Hauterivian, Albian and Coniacian–Santonian stages), but their sedimentary record, as represented by organic-rich black shales, appears more parochial, being dominantly represented in the Atlantic and neighboring areas, and some researchers relate them to particular local conditions rather than being forced by global change.

The only oceanic anoxic event documented from the Jurassic took place during the early Toarcian (~183 Ma). Because no DSDP or ODP (Ocean Drilling Program) cores have recovered black shales of this age – there being little or no Toarcian ocean crust remaining in the world ocean – the samples of black shale primarily come from outcrops on land. These outcrops, together with material from some commercial oil wells, are found on all major continents and this event seems similar in kind to the two major Cretaceous examples.

Mechanism

Temperatures throughout the Jurassic and Cretaceous are generally thought to have been relatively warm, and consequently dissolved oxygen levels in the ocean were lower than today - making anoxia easier to achieve. However, more specific conditions are required to explain the short-period (half a million years or less) oceanic anoxic events. Two hypotheses, and variations upon them, have proved most durable.

One hypothesis suggests that the anomalous accumulation of organic matter relates to its enhanced preservation under restricted and poorly oxygenated conditions, which themselves were a function of the particular geometry of the ocean basin: such a hypothesis, although readily applicable to the young and relatively narrow Cretaceous Atlantic (which could be likened to a large-scale Black Sea, only poorly connected to the World Ocean), fails to explain the occurrence of coeval black shales on open-ocean Pacific plateaus and shelf seas around the world. There are suggestions, again from the Atlantic, that a shift in oceanic circulation was responsible, where warm, salty waters at low latitudes became hypersaline and sunk to form an intermediate layer, at 500 to 1,000 m (1,640 to 3,281 ft) depth, with a temperature of 20 °C (68 °F) to 25 °C (77 °F).

The second hypothesis suggests that oceanic anoxic events record a major change in the fertility of the oceans that resulted in an increase in organic-walled plankton (including bacteria) at the expense of calcareous plankton such as coccoliths and foraminifera.

Such an accelerated flux of organic matter would have expanded and intensified the oxygen minimum zone, further enhancing the amount of organic carbon entering the sedimentary record. Essentially this mechanism assumes a major increase in the availability of dissolved nutrients such as nitrate, phosphate and possibly iron to the phytoplankton population living in the illuminated layers of the oceans.

For such an increase to occur would have required an accelerated influx of land-derived nutrients coupled with vigorous upwelling, requiring major climate change on a global scale. Geochemical data from oxygen-isotope ratios in carbonate sediments and fossils, and magnesium/calcium ratios in fossils, indicate that all major oceanic anoxic events were associated with thermal maxima, making it likely that global weathering rates, and nutrient flux to the oceans, were increased during these intervals. Indeed, the reduced solubility of oxygen would lead to phosphate release, further nourishing the ocean and fuelling high productivity, hence a high oxygen demand - sustaining the event through a positive feedback.

Here is another way of looking at oceanic anoxic events. Assume that the earth releases a huge volume of carbon dioxide during an interval of excessive volcanism; global temperatures rise due to the greenhouse effect; global weathering rates and fluvial nutrient flux increase; organic productivity in the oceans increases; organic-carbon burial in the oceans increases (OAE begins); carbon dioxide is drawn down (inverse greenhouse effect); global temperatures fall, and the ocean–atmosphere system returns to equilibrium (OAE ends).

In this way, an oceanic anoxic event can be viewed as the Earth's response to the injection of excess carbon dioxide into the atmosphere and hydrosphere. One test of this notion is to look at the age of large igneous provinces (LIPs), the extrusion of which would presumably have been accompanied by rapid effusion of vast quantities of volcanogenic gases such as carbon dioxide. Intriguingly, the age of three LIPs (Karoo-Ferrar flood basalt, Caribbean large igneous province, Ontong Java Plateau) correlates uncannily well with that of the major Jurassic (early Toarcian) and Cretaceous (early Aptian and Cenomanian–Turonian) oceanic anoxic events, indicating that a causal link is feasible.

Paleozoic anoxia

The boundary between the Ordovician and Silurian periods is marked by repetitive periods of anoxia, interspersed with normal, oxic conditions. In addition, anoxic periods are found during the Silurian. These anoxic periods occurred at a time of low global temperatures (although CO_2 levels were high), in the midst of a glaciation.

Jeppsson (1990) proposes a mechanism whereby the temperature of polar waters determines the site of formation of downwelling water. If the high latitude waters are below 5 °C (41 °F), they will be dense enough to sink; as they are cool, oxygen is highly soluble in their waters, and the deep ocean will be oxygenated. If high latitude waters are warmer than 5 °C (41 °F), their density is too low for them to sink below the cooler deep waters. Therefore thermohaline circulation can only be driven by salt-increased density, which tends to form in warm waters where evaporation is high. This warm water can dissolve less oxygen, and is produced in smaller quantities, producing a sluggish circulation with little deep water oxygen. The effect of this warm water will propagate through the ocean, and the warmer water has the additional effect of reducing the amount of CO_2 which can be stored in the oceans - causing the release of large quantities to the atmosphere in a short time - tens or thousands of years. The warm waters would also initiate the release of clathrates, further increasing both atmospheric temperature and basin anoxia. Similar positive feedbacks operate during cold-pole episodes, amplifying their cooling effects.

The periods with cold poles are termed "P-episodes" (short for *primo*), and are characterised by bioturbated deep oceans, a humid equator and higher weathering rates, and terminated by extinction events - for example, the Ireviken and Lau events. The inverse is true for the warmer, oxic "S-episodes" (*secundo*), where deep ocean sediments are typically graptolitic black shales. A typical cycle of *secundo-primo* episodes and ensuing *event* typically lasts around 3 Ma.

The duration of events is so long compared to their onset because the positive feedbacks must be overwhelmed. Carbon content in the ocean-atmosphere system is affected by changes in weathering rates, which in turn is dominantly controlled by rainfall. Because this is inversely related to temperature in Silurian times, carbon is gradually drawn down during warm (high CO_2) S-episodes, while the reverse is true during P-episodes. On top of this gradual trend is overprinted the signal of Milankovic cycles, which ultimately trigger the switch between P- and S- episodes.

These events become longer during the Devonian; the enlarging land plant biota probably acted as a large buffer to carbon dioxide concentrations.

The end-Ordovician Hirnantian event may alternatively be a result of algal blooms, caused by sudden supply of nutrients through wind-driven upwelling or an influx of nutrient-rich meltwater from melting glaciers, which by virtue of its fresh nature would also slow down oceanic circulation.

Atmospheric effects

A model put forward by Lee Kump, Alexander Pavlov and Michael Arthur in 2005 suggests that oceanic anoxic events may have been characterized by upwelling of water rich in highly toxic hydrogen sulfide gas which was then injected into the atmosphere. This phenomenon would likely have poisoned plants and animals and caused mass extinctions. Furthermore, it has been proposed that the hydrogen sulfide rose to the upper atmosphere and attacked the ozone layer, which normally blocks the deadly ultraviolet radiation of the Sun. The increased UV radiation caused by this ozone depletion would have amplified the destruction of plant and animal life. Fossil spores from strata recording the Permian extinction show deformities consistent with UV radiation. This evidence, combined with fossil biomarkers of green sulfur bacteria, indicates that this process could have played a role in that mass extinction event, and possibly other extinction events. The trigger for these mass extinctions appears to be a warming of the ocean caused by a rise of carbon dioxide levels to about 1000 parts per million.

Fecal coliform

A **fecal coliform** (sometimes **faecal coliform**) is a facultatively-anaerobic, rod-shaped, gram-negative, non-sporulating bacterium. Fecal coliforms are capable of growth in the presence of bile salts or similar surface agents, oxidase negative, and produce acid and gas from lactose within 48 hours at 44 ± 0.5ºC.

(Total)Coliforms include genera that originate in feces -"Fecal Coliforms" (e.g. *Escherichia*) as well as genera not of fecal origin - "non-Fecal Coliforms." (e.g. *Enterobacter*, *Klebsiella*, *Citrobacter*). The assay is intended to be an indicator of fecal contamination; more specifically of *E. coli* which is an indicator microorganism for other pathogens that may be present in feces. Presence of fecal coliforms in water may not be directly harmful, and does not necessarily indicate the presence of feces.

Fecal coliforms (fecal bacteria) as indicator of water quality

Basics of fecal coliforms

In general, increased levels of fecal coliforms provide a warning of failure in water treatment, a break in the integrity of the distribution system, or possible contamination with pathogens. When levels are high there may be an elevated risk of waterborne gastroenteritis. Tests for the bacteria are cheap, reliable and rapid (1-day incubation).

Potential sources of fecal coliform bacteria in water

The presence of fecal coliform in aquatic environments may indicate that the water has been contaminated with the fecal material of humans or other animals. Fecal coliform bacteria can enter rivers through direct discharge of waste from mammals and birds, from agricultural and storm runoff, and from human sewage. However, their presence may also be the result of plant material, and pulp or paper mill effluent.

Human sewage

Failing home septic systems can allow coliforms in the effluent to flow into the water table, aquifers, drainage ditches and nearby surface waters. Sewage connections that are connected to storm drain pipes can also allow human sewage into surface waters. Some older industrial cities, particularly in the Northeast and Midwest of the United States, use a combined sewer system to handle waste. A combined sewer carries both domestic sewage and stormwater. During high rainfall periods, a combined sewer can become overloaded and overflow to a nearby stream or river, bypassing treatment.

Animals

Pets, especially dogs, can contribute to fecal contamination of surface waters. Runoff from roads, parking lots, and yards can carry animal wastes to streams through storm sewers. Birds can be a significant source of fecal coliform bacteria. Swans, geese, seagulls, and other waterfowl can all elevate bacterial counts, especially in wetlands, lakes, ponds, and rivers.

Agriculture

Agricultural practices such as allowing livestock to graze near water bodies, spreading manure as fertilizer on fields during dry periods, using sewage sludge biosolids and allowing livestock watering in streams can all contribute to fecal coliform contamination.

Problems resulting from fecal contamination of water

Human health hazards

Large quantities of fecal coliform bacteria in water are not harmful according to some authorities, but may indicate a higher risk of pathogens being present in the water. Some waterborne pathogenic diseases that may coincide with fecal coliform contamination include ear infections, dysentery, typhoid fever, viral and bacterial gastroenteritis, and hepatitis A. The presence of fecal coliform tends to affect humans more than it does aquatic creatures, though not exclusively.

Effects on the environment

Untreated organic matter that contains fecal coliform can be harmful to the environment. Aerobic decomposition of this material can reduce dissolved oxygen levels if discharged into rivers or waterways. This may reduce the oxygen level enough to kill fish and other aquatic life. Reduction of fecal coliform in wastewater may require the use of chlorine and other disinfectant chemicals. Such materials may kill the fecal coliform and disease bacteria. They also kill bacteria essential to the proper balance of the aquatic environment, endangering the survival of species dependent on those bacteria. So higher levels of fecal coliform require higher levels of chlorine, threatening those aquatic organisms.

Removal and treatment

Fecal coliform, like other bacteria, can usually be inhibited in growth by boiling water or by treating with chlorine. Washing thoroughly with soap after contact with contaminated water can also help prevent infections. Gloves should always be worn when testing for fecal coliform. Municipalities that maintain a public water supply will typically monitor and treat for fecal coliforms.

Testing

Public health risk monitoring

In waters of the U.S., Canada and other countries, water quality is monitored to protect the health of the general public. Bacteria contamination is one monitored pollutant. In the U.S., fecal coliform testing is one of the nine tests of water quality that form the overall water-quality rating in a process used by U.S. EPA. The fecal coliform assay should only be used to assess the presence of fecal matter in situations where fecal coliforms of non-fecal origin are not commonly encountered. EPA has approved a number of different methods to analyze samples for bacteria.

Analysis

Bacteria reproduce rapidly if conditions are right for growth. Most bacteria grow best in dark, warm, moist environments with food. Some bacteria form colonies as they multiply which may grow large enough to be seen. By growing and counting colonies of fecal coliform bacteria from a sample of water, the amount of bacteria originally present can be determined.

Membrane filtration is the method of choice for the analysis of fecal coliforms in water. Samples to be tested are passed through a filter of particular pore size (generally 0.45 micrometre). The microorganisms present in the water remain on the filter surface. When the filter is placed in a sterile petri dish and saturated with an appropriate medium, growth of the desired organisms is encouraged, while that of other organisms is suppressed. Each cell develops into a separate colony, which can be counted directly, and the results calculated as microbial density. Sample volumes of 1 ml and 10 ml will be used for the water testing, with the goal of achieving a final desirable colony density range of 20 to 60 colonies per filter. Contaminated sources may require dilution to achieve a "countable" membrane.

A 100 ml volume of a water sample is drawn through a membrane filter (0.45 µm pore size) through the use of a vacuum pump. The filter is placed on a petri dish containing M-FC agar and incubated for 24 hours at 44.5 °C (112.1 degrees F). This elevated temperature heat shocks non-fecal bacteria and suppresses their growth. As the fecal coliform colonies grow they produce an acid (through fermenting lactose) that reacts with the aniline dye in the agar thus giving the colonies their blue color.

The Coli Chrome 2 redigel medium is a new and patented formulation for water testing. It contains a sugar linked to a dye which, when acted on by the enzyme beta-galactosidase, turns the colony a red color. Similarly, there is a second sugar linked to a different dye which, when acted on by the enzyme beta-glucuronidase, turns an *E. coli* colony a light blue or blue-green color. Because *E. coli* produces both beta-galactosidase and beta-glucuronidase, the colony grows with a purple color (red + blue). The combination of these two dyes makes possible the unique ability to use one test to differentiate and quantify coliforms and *E. coli*. Because *E. coli* is a member of the coliform group, add the number of purple colonies to the number of red colonies when counting coliforms.

EPA testing requirements

The 1989 EPA Total Coliform Rule (TCR) imposed major monitoring changes for public water systems. The testing requirements for drinking water under the TCR are markedly increased over previous requirements and thus are more thorough. Not only is the number of routine coliform tests increased, especially for smaller water utilities, but the regulation also requires automatic repeat testing from all sources that show a total coliform positive (known as triggered source water monitoring).

The current EPA recommendation for body-contact recreation is fewer than 100 colonies/100 mL; for fishing and boating, fewer than 1000 colonies/100 mL; and for domestic water supply, for treatment, fewer than 2000 colonies/100 mL. The drinking water standard is less than 1 colony/ 100 ml.

As of 2009, EPA is working on revisions to the TCR. Issues being considered by the Agency include sampling locations, sampling frequency and timing, analytical methods and corrective actions to be taken by public water systems.

Color of glaciers

Glaciers are large bodies of ice and snow formed during very cold climates by processes involving the compaction of fallen snow. While snowy glaciers appear white from a distance, up close and when shielded from direct ambient light, glaciers usually appear a deep blue due to the long path lengths of the internal reflected light.

Color of water samples

High concentrations of dissolved lime give the water of Havasu Falls a turquoise color.

Dissolved and particulate material in water can cause discoloration. Slight discoloration is measured in Hazen units (HU). Impurities can be deeply colored as well, for instance dissolved organic compounds called tannins can result in dark brown colors, or algae floating in the water (particles) can impart a green color.

The color of a water sample can be reported as:

- *Apparent color* is the color of the whole water sample, and consists of color from both dissolved and suspended components.

- *True color* is measured after filtering the water sample to remove all suspended material.

Testing for color can be a quick and easy test which often reflects the amount of organic material in the water, although certain inorganic components like iron or manganese can also impart color.

Water quality and color

Glacial rock flour makes New Zealand's Lake Pukaki a lighter turquoise than its neighbors.

The presence of color in water does not necessarily indicate that the water is not potable. Color-causing substances such as tannins may be harmless.

Color is not removed by typical water filters; however, slow sand filters can remove color, and the use of coagulants may also succeed in trapping the color-causing compounds within the resulting precipitate.

Other factors can affect the color we see:

- Particles and solutes can absorb light, as in tea or coffee. Green algae in rivers and streams often lend a blue-green color. The red sea has occasional blooms of red *Trichodesmium erythraeum* algae.

- Particles in water can scatter light. The Colorado river is often muddy red because of suspended reddish silt in the water. Some mountain lakes and streams with finely ground rock, such as glacial flour, are turquoise. Light scattering by suspended matter is required in order that the blue light produced by water's absorption can return to the surface and be observed. Such scattering can also shift the spectrum of the emerging photons toward the green, a color often seen when water laden with suspended particles is observed.

Color names

Various cultures divide the semantic field of colors differently than the English language usage and do not make the blue-green distinction in the same way. An example is Welsh where *glas* is the color of the sea and also that of grass. Sometimes the word *grue* ("green + blue") is used to translate this nuance into English.

Other color names assigned to bodies of water are sea green and ultramarine blue.

Red tide off the Californian coast.

Unusual oceanic colorings have given rise to the terms red tide and black tide.

Furthermore, the Ancient Greek poet Homer uses the epithet "wine-dark sea"; in addition, he also describes the sea as "grey". Some have suggested that this is due to the Ancient Greeks classifying colors primarily by darkness rather than hue.

Applications

Environmental chemistry is used by the Environment Agency (in England and Wales), the Environmental Protection Agency (in the United States) the Association of Public Analysts, and other environmental agencies and research bodies around the world to detect and identify the nature and source of pollutants. These can include:

- Heavy metal contamination of land by industry. These can then be transported into water bodies and be taken up by living organisms.
- Nutrients leaching from agricultural land into water courses, which can lead to algal blooms and eutrophication.
- Urban runoff of pollutants washing off impervious surfaces (roads, parking lots, and rooftops) during rain storms. Typical pollutants include gasoline, motor oil and other hydrocarbon compounds, metals, nutrients and sediment (soil).
- Organometallic compounds.

Methods

Quantitative chemical analysis is a key part of environmental chemistry, since it provides the data that frame most environmental studies.

Common analytical techniques used for quantitative determinations in environmental chemistry include classical wet chemistry, such as gravimetric, titrimetric and electrochemical methods. More sophisticated approaches are used in the determination of trace metals and organic compounds. Metals are commonly measured by atomic spectroscopy and mass spectrometry: Atomic Absorption Spectrophotometry (AA) and Inductively Coupled Plasma Atomic Emission (ICP-AES) or Inductively Coupled Plasma Mass Spectrometric (ICP-MS) techniques. Organic compounds are commonly measured also using mass spectrometric methods, such as Gas chromatography-mass spectrometry (GC/MS) and Liquid chromatography-mass spectrometry (LC/MS). Non-MS methods using GCs and LCs having universal or specific detectors are still staples in the arsenal of available analytical tools.

Other parameters often measured in environmental chemistry are radiochemicals. These are pollutants which emit radioactive materials, such as alpha and beta particles, posing danger to human health and the environment. Particle counters and Scintillation counters are most commonly used for these measurements. Bioassays and immunoassays are utilized for toxicity evaluations of chemical effects on various organisms.

Published analytical methods

Peer-reviewed test methods have been published by government agencies and private research organizations. Approved published methods must be used when testing to demonstrate compliance with regulatory requirements.

Chapter-4

Earth Science

Earth science (also known as **geoscience**, **the geosciences** or **the Earth sciences**), is an all-embracing term for the sciences related to the planet Earth. It is arguably a special case in planetary science, the Earth being the only known life-bearing planet. There are both reductionist and holistic approaches to Earth sciences. The formal discipline of Earth sciences may include the study of the atmosphere, oceans and biosphere, as well as the solid earth. Typically Earth scientists will use tools from physics, chemistry, biology, chronology and mathematics to build a quantitative understanding of how the Earth system works, and how it evolved to its current state.

A volcano eruption is the release of stored energy from below the surface of Earth, originating from radioactive decay and gravitational sorting in the Earth's core and mantle, and residual energy gained during the Earth`s formation.

Fields of study

Lava flows from the Kīlauea volcano into the ocean on the Island of Hawaii

The following fields of science are generally categorized within the geosciences:

- Geology describes the rocky parts of the Earth's crust (or lithosphere) and its historic development. Major subdisciplines are mineralogy and petrology, geochemistry, geomorphology, paleontology, stratigraphy, structural geology, engineering geology and sedimentology.
- Geophysics and Geodesy investigate the shape of the Earth, its reaction to forces and its magnetic and gravity fields. Geophysicists explore the Earth's core and mantle as well as the tectonic and seismic activity of the lithosphere.
- Soil science covers the outermost layer of the Earth's crust that is subject to soil formation processes (or pedosphere). Major subdisciplines include edaphology and pedology.
- Oceanography and hydrology (includes limnology) describe the marine and freshwater domains of the watery parts of the Earth (or hydrosphere). Major subdisciplines include hydrogeology and physical, chemical, and biological oceanography.
- Glaciology covers the icy parts of the Earth (or cryosphere).

- Atmospheric sciences cover the gaseous parts of the Earth (or atmosphere) between the surface and the exosphere (about 1000 km). Major subdisciplines are meteorology, climatology, atmospheric chemistry and atmospheric physics.
- A very important linking sphere is the biosphere, the study of which is biology. The biosphere consists of all forms of life, from single-celled organisms to pine trees to people. The interactions of Earth's other spheres - lithosphere/geosphere, hydrosphere, atmosphere and/or cryosphere and pedosphere - create the conditions that can support life.

Earth's interior

Plate tectonics, mountain ranges, volcanoes, and earthquakes are geological phenomena that can be explained in terms of energy transformations in the Earth's crust.

Beneath the Earth's crust lies the mantle which is heated by the radioactive decay of heavy elements. The mantle is not quite solid and consists of magma which is in a state of semi-perpetual convection. This convection process causes the lithospheric plates to move, albeit slowly. The resulting process is known as plate tectonics.

Plate tectonics might be thought of as the process by which the earth is resurfaced. Through a process called *spreading ridges* (or seafloor spreading), new earth crust is created by the flow of magma from underneath the lithosphere to the surface, through fissures, where it cools and solidifies. Through a process called subduction, crust is pushed underground—beneath the rest of the lithosphere—where it comes into contact with magma and melts—rejoining the mantle from which it originally came.

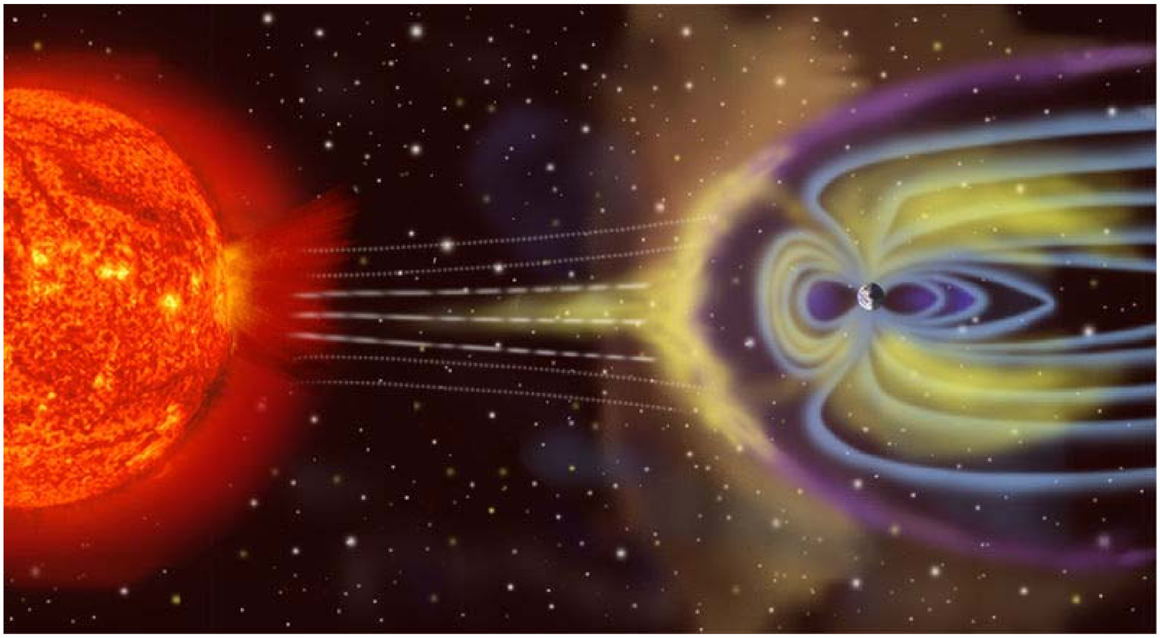
Areas of the crust where new crust is created are called *divergent boundaries*, and areas of the crust where it is brought back into the earth are called *convergent boundaries*. Earthquakes result from the movement of the lithospheric plates, and they often occur near covergent boundaries where parts of the crust are forced into the earth as part of subduction.

Volcanoes result primarily from the melting of subducted crust material. Crust material that is forced into the Asthenosphere melts, and some portion of the melted material becomes light enough to rise to the surface—giving birth to volcanoes.

Earth's electromagnetic field

An electromagnet is a magnet that is created by a current that flows around a soft-iron core. Earth has a soft iron core surrounded by semi-liquid materials from the mantle that move in continuous currents around the core; therefore, the earth is an electromagnet. This is referred to as the dynamo theory of Earth's magnetism. The fact that Earth is an electromagnet helps it maintain an atmosphere suitable for life.

Atmosphere



The magnetosphere shields the surface of Earth from the charged particles of the solar wind. It is compressed on the day (Sun) side due to the force of the arriving particles, and extended on the night side. (Image not to scale.)

Earth is blanketed by an atmosphere consisting of 78.0% nitrogen, 20.9% oxygen, and 1% Argon. The atmosphere has five layers: troposphere, stratosphere, mesosphere, thermosphere, and exosphere; and 75% of the atmosphere's gases are in the bottom-most layer, the troposphere.

The magnetic field created by mantle's internal motions produces the magnetosphere which protects the Earth's atmosphere from the solar wind. It is theorized that the solar wind would strip away earth's atmosphere in a few million years were it not for the Earth's electromagnet. And since earth is 4.5 billion years old, earth would not have an atmosphere by now if there were no magnetosphere.

The atmosphere is composed of 78% nitrogen and 21% oxygen. The remaining one percent contains small amounts of other gases including CO_2 and water vapors. Water vapors and CO_2 allow the Earth's atmosphere to catch and hold the sun's energy through a phenomenon called the greenhouse effect. This allows earth's surface to be warm enough to have liquid water and support life.

In addition to storing heat, the atmosphere also protects living organisms by shielding the Earth's surface from cosmic rays. Note that the level of protection is high enough to prevent cosmic rays from destroying all life on Earth, yet low enough to aid the mutations that have an important role in pushing forward diversity in the biosphere.

Methodology

Like all other scientists, Earth scientists apply the scientific method. They formulate hypotheses after observing events and gathering data about natural phenomena, and then they test hypotheses from such data.

A contemporary idea within earth science is uniformitarianism. Uniformitarianism says that "ancient geologic features are interpreted by understanding active processes that are readily observed". Simply stated, this means that features of the Earth can be explained by the actions of gradual processes operating over long periods of time; for example, a mountain need not be thought of as having been created in a moment, but instead it may be seen as the result of continuous subduction, causing magma to rise and form continental volcanic arcs.

Earth's spheres

Earth science generally recognizes four spheres, the lithosphere, the hydrosphere, the atmosphere, and the biosphere; these correspond to rocks, water, air, and life. Some practitioners include, as part of the spheres of the Earth, the cryosphere (corresponding to ice) as a distinct portion of the hydrosphere, as well as the pedosphere (corresponding to soil) as an active and intermixed sphere.

Partial list of the major earth science topics

Atmosphere

- Atmospheric chemistry
- Climatology
- Meteorology
    - Hydrometeorology
- Paleoclimatology

Biosphere

- Biogeography
- Paleontology
    - Palynology
    - Micropaleontology
- Geomicrobiology
- Geoarchaeology

Hydrosphere

- Hydrology
    - Limnology

- Hydrogeology
- Oceanography
  - Chemical oceanography
  - Marine biology
- Marine geology
  - Paleoceanography
  - Physical oceanography

Lithosphere or geosphere

- Geology
  - Economic geology
  - Engineering geology
  - Environmental geology
  - Historical geology
    - Quaternary geology
  - Planetary geology
  - Sedimentology
  - Stratigraphy
  - Structural geology
- Geography
  - Physical geography
- Geochemistry
- Geomorphology
- Geophysics
  - Geochronology
  - Geodynamics
  - Geomagnetism
  - Gravimetry (also part of Geodesy)
  - Seismology
- Glaciology
- Hydrogeology
- Mineralogy
  - Crystallography
  - Gemology
- Petrology
- Speleology
- Volcanology

Pedosphere

- Soil science
  - Edaphology
  - Pedology

Systems

- Environmental science
- Geography
  - Human geography
  - Physical geography
- Gaia hypothesis

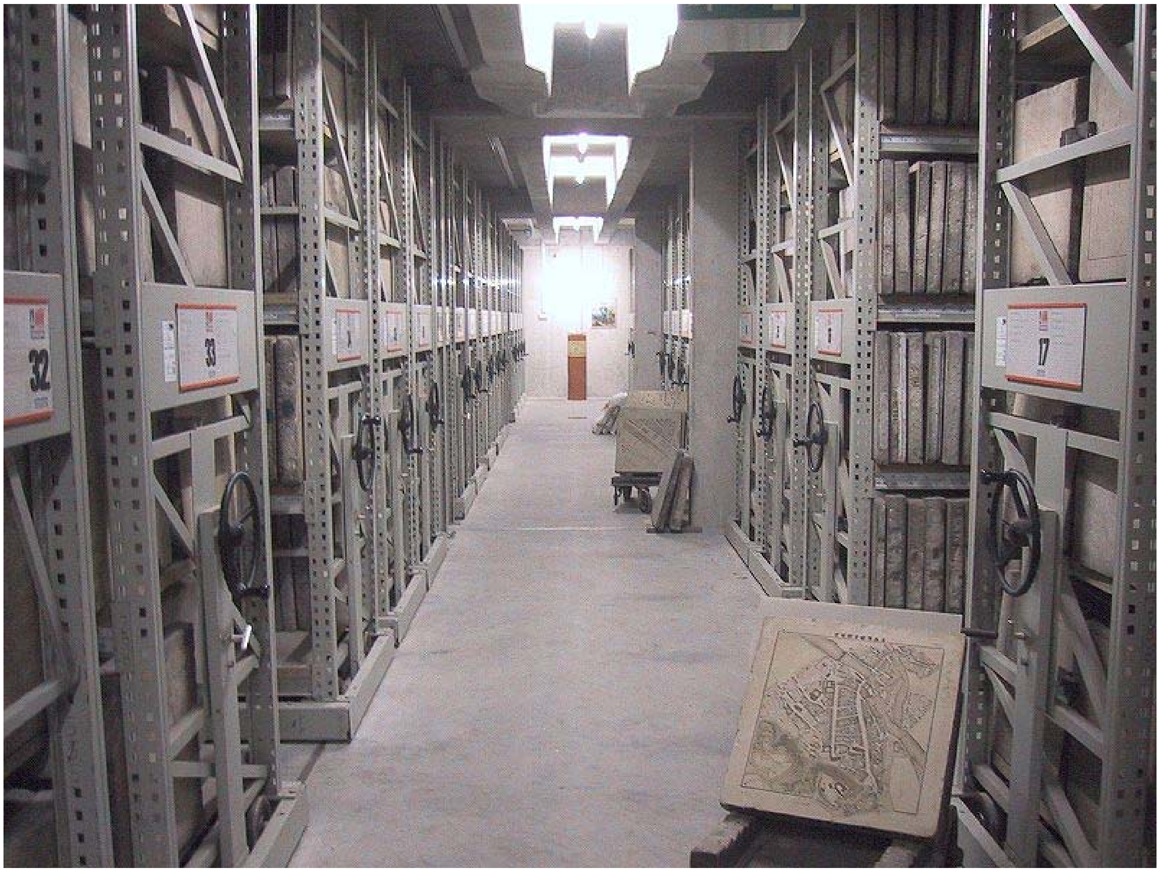
Others

- Cartography
- Geoinformatics (GIS)
- Geostatistics

- Geodesy and Surveying
- NASA Earth Science Enterprise

Geodesy

An old geodetic pillar (1855) at Ostend, Belgium



A Munich archive with lithography plates of maps of Bavaria

Geodesy also named **geodetics**, a branch of earth sciences, is the scientific discipline that deals with the measurement and representation of the Earth, including its gravitational field, in a three-dimensional time-varying space. Geodesists also study geodynamical phenomena such as crustal motion, tides, and polar motion. For this they design global and national control networks, using space and terrestrial techniques while relying on datums and coordinate systems.

Definition

Geodesy is primarily concerned with positioning within the temporally varying gravity field. Somewhat obsolete nowadays, geodesy in the German speaking world is divided into "Higher Geodesy" ("Erdmessung" or "höhere Geodäsie"), which is concerned with measuring the Earth on the global scale, and "Practical Geodesy" or "Engineering Geodesy" ("Ingenieurgeodäsie"), which is concerned with measuring specific parts or regions of the Earth, and which includes surveying.

The shape of the Earth is to a large extent the result of its rotation, which causes its equatorial bulge, and the competition of geological processes such as the collision of plates and of vulcanism, resisted by the Earth's gravity field. This applies to the solid surface, the liquid surface (dynamic sea surface topography) and the Earth's atmosphere. For this reason, the study of the Earth's gravity field is called physical geodesy by some.

Geoid and reference ellipsoid

The geoid is essentially the figure of the Earth abstracted from its topographical features. It is an idealized equilibrium surface of sea water, the mean sea level surface in the absence of currents, air pressure variations etc. and continued under the continental masses. The geoid, unlike ellipsoid, is irregular and too complicated to serve as the computational surface on which to solve geometrical problems like point positioning. The geometrical separation between the geoid and the reference ellipsoid is called the geoidal undulation. It varies globally between ±110 m.

A reference ellipsoid, customarily chosen to be the same size (volume) as the geoid, is described by its semi-major axis (equatorial radius) a and flattening f. The quantity $f = (a-b)/a$, where b is the semi-minor axis (polar radius), is a purely geometrical one. The mechanical ellipticity of the Earth (dynamical flattening, symbol J_2) can be determined to high precision by observation of satellite orbit perturbations. Its relationship with the geometrical flattening is indirect. The relationship depends on the internal density distribution, or, in simplest terms, the degree of central concentration of mass.

The 1980 Geodetic Reference System (GRS80) posited a 6,378,137 m semi-major axis and a 1:298.257 flattening. This system was adopted at the XVII General Assembly of the International Union of Geodesy and Geophysics (IUGG). It is essentially the basis for geodetic positioning by the Global Positioning System and is thus also in extremely widespread use outside the geodetic community.

The numerous other systems which have been used by diverse countries for their maps and charts are gradually dropping out of use as more and more countries move to global, geocentric reference systems using the GRS80 reference ellipsoid.

Coordinate systems in space

The locations of points in three-dimensional space are most conveniently described by three cartesian or rectangular coordinates, X,Y and Z. Since the advent of satellite positioning, such coordinate systems are typically geocentric: the Z axis is aligned with the Earth's (conventional or instantaneous) rotation axis.

Prior to satellite geodesy era, the coordinate systems associated with a geodetic datum attempted to be geocentric, but their origins differed from the geocentre by hundreds of metres, due to regional deviations in the direction of the plumbline (vertical). These regional geodetic datums, such as ED50 (European Datum 1950) or NAD83 (North American Datum 1983) have ellipsoids associated with them that are regional 'best fits' to the geoids within their areas of validity, minimising the deflections of the vertical over these areas.

It is only because GPS satellites orbit about the geocentre, that this point becomes naturally the origin of a coordinate system defined by satellite geodetic means, as the satellite positions in space are themselves computed in such a system.

Geocentric coordinate systems used in geodesy can be divided naturally into two classes:

1. Inertial reference systems, where the coordinate axes retain their orientation relative to the fixed stars, or equivalently, to the rotation axes of ideal gyroscopes; the X axis points to the vernal equinox
2. Co-rotating, also ECEF ("Earth Centred, Earth Fixed"), where the axes are attached to the solid body of the Earth. The X axis lies within the Greenwich observatory's meridian plane.

The coordinate transformation between these two systems is described to good approximation by (apparent) sidereal time, which takes into account variations in the Earth's axial rotation (length-of-day variations). A more accurate description also takes polar motion into account, a phenomenon closely monitored by geodesists.

Coordinate systems in the plane

In surveying and mapping, important fields of application of geodesy, two general types of coordinate systems are used in the plane:

1. Plano-polar, in which points in a plane are defined by a distance s from a specified point along a ray having a specified direction α with respect to a base line or axis;
2. Rectangular, points are defined by distances from two perpendicular axes called x and y. It is geodetic practice—contrary to the mathematical convention—to let the x axis point to the North and the y axis to the East.

Rectangular coordinates in the plane can be used intuitively with respect to one's current location, in which case the x axis will point to the local North. More formally, such coordinates can be obtained from three-dimensional coordinates using the artifice of a map projection. It is *not* possible to map the curved surface of the Earth onto a flat map surface without deformation. The compromise most often chosen—called a conformal projection—preserves angles and length ratios, so that small circles are mapped as small circles and small squares as squares.

An example of such a projection is UTM (Universal Transverse Mercator). Within the map plane, we have rectangular coordinates x and y. In this case the North direction used for reference is the *map* North, not the *local* North. The difference between the two is called *meridian convergence*.

It is easy enough to "translate" between polar and rectangular coordinates in the plane: let, as above, direction and distance be α and s respectively, then we have

$$
\begin{aligned}
x &= s\cos\alpha \\
y &= s\sin\alpha
\end{aligned}
$$

The reverse transformation is given by:

$$
\begin{aligned}
s &= \sqrt{x^2+y^2} \\
\alpha &= \arctan(y/x).
\end{aligned}
$$

Heights

In geodesy, point or terrain *heights* are "above sea level", an irregular, physically defined surface. Therefore a height should ideally *not* be referred to as a coordinate. It is more like a physical quantity, and though it can be tempting to treat height as the vertical coordinate *z*, in addition to the horizontal coordinates *x* and *y*, and though this actually is a good approximation of physical reality in small areas, it quickly becomes invalid for regional considerations.

Heights come in the following variants:

1. Orthometric heights
2. Normal heights
3. Geopotential heights

Each has its advantages and disadvantages. Both orthometric and normal heights are heights in metres above sea level, whereas geopotential numbers are measures of potential energy (unit: $m^2\ s^{-2}$) and not metric. Orthometric and normal heights differ in the precise way in which mean sea level is conceptually continued under the continental masses. The reference surface for orthometric heights is the geoid, an equipotential surface approximating mean sea level.

None of these heights is in any way related to **geodetic** or **ellipsoidial** heights, which express the height of a point above the reference ellipsoid. Satellite positioning receivers typically provide ellipsoidal heights, unless they are fitted with special conversion software based on a model of the geoid.

Geodetic data

Because geodetic point coordinates (and heights) are always obtained in a system that has been constructed itself using real observations, geodesists introduce the concept of a *geodetic datum*: a physical realization of a coordinate system used for describing point locations. The realization is the result of *choosing* conventional coordinate values for one or more *datum points*.

In the case of height datums, it suffices to choose *one* datum point: the reference bench mark, typically a tide gauge at the shore. Thus we have vertical datums like the NAP (Normaal Amsterdams Peil), the North American Vertical Datum 1988 (NAVD88), the Kronstadt datum, the Trieste datum, and so on.

In case of plane or spatial coordinates, we typically need several datum points. A regional, ellipsoidal datum like ED50 can be fixed by prescribing the undulation of the geoid and the deflection of the vertical in *one* datum point, in this case the Helmert Tower in Potsdam. However, an overdetermined ensemble of datum points can also be used.

Changing the coordinates of a point set referring to one datum, so to make them refer to another datum, is called a *datum transformation*. In the case of vertical datums, this consists of simply adding a constant shift to all height values. In the case of plane or spatial coordinates, datum transformation takes the form of a similarity or *Helmert transformation*, consisting of a rotation and scaling operation in addition to a simple translation. In the plane, a Helmert transformation has four parameters; in space, seven.

A note on terminology

In the abstract, a coordinate system as used in mathematics and geodesy is, e.g., in ISO terminology, referred to as a *coordinate system*. International geodetic organizations like the IERS (International Earth Rotation and Reference Systems Service) speak of a *reference system*.

When these coordinates are realized by choosing datum points and fixing a geodetic datum, ISO uses the terminology *coordinate reference system*, while IERS speaks of a *reference frame*. A datum transformation again is referred to by ISO as a *coordinate transformation*. (ISO 19111: Spatial referencing by coordinates).

Point positioning

Geodetic Control Mark (example of a deep benchmark)

Point positioning is the determination of the coordinates of a point on land, at sea, or in space with respect to a coordinate system. Point position is solved by computation from measurements linking the known positions of terrestrial or extraterrestrial points with the unknown terrestrial position. This may involve transformations between or among astronomical and terrestrial coordinate systems.

The known points used for point positioning can be triangulation points of a higher order network, or GPS satellites.

Traditionally, a hierarchy of networks has been built to allow point positioning within a country. Highest in the hierarchy were triangulation networks. These were densified into networks of traverses (polygons), into which local mapping surveying measurements, usually with measuring tape, corner prism and the familiar red and white poles, are tied.

Nowadays all but special measurements (e.g., underground or high precision engineering measurements) are performed with GPS. The higher order networks are measured with static GPS, using differential measurement to determine vectors between terrestrial points. These vectors are then adjusted in traditional network fashion. A global polyhedron of permanently operating GPS stations under the auspices of the IERS is used to define a single global, geocentric reference frame which serves as the "zero order" global reference to which national measurements are attached.

For surveying mappings, frequently Real Time Kinematic GPS is employed, tying in the unknown points with known terrestrial points close by in real time.

One purpose of point positioning is the provision of known points for mapping measurements, also known as (horizontal and vertical) control. In every country, thousands of such known points exist and are normally documented by the national mapping agencies. Surveyors involved in real estate and insurance will use these to tie their local measurements to.

Geodetic problems

In geometric geodesy, two standard problems exist:

First geodetic problem

Given a point (in terms of its coordinates) and the direction (azimuth) and distance from that point to a second point, determine (the coordinates of) that second point.

Second (inverse) geodetic problem

Given two points, determine the azimuth and length of the line (straight line, arc or geodesic) that connects them.

In the case of plane geometry (valid for small areas on the Earth's surface) the solutions to both problems reduce to simple trigonometry. On the sphere, the solution is significantly more complex, e.g., in the inverse problem the azimuths will differ between the two end points of the connecting great circle, arc, i.e. the geodesic.

On the ellipsoid of revolution, geodesics may be written in terms of elliptic integrals, which are usually evaluated in terms of a series expansion; for example, Vincenty's formulae.

In the general case, the solution is called the geodesic for the surface considered. The differential equations for the geodesic can be solved numerically.

Geodetic observational concepts

Here we define some basic observational concepts, like angles and coordinates, defined in geodesy (and astronomy as well), mostly from the viewpoint of the local observer.

- The *plumbline* or *vertical* is the direction of local gravity, or the line that results by following it. It is slightly curved.
- The *zenith* is the point on the celestial sphere where the direction of the gravity vector in a point, extended upwards, intersects it. More correct is to call it a <direction> rather than a point.
- The *nadir* is the opposite point (or rather, direction), where the direction of gravity extended downward intersects the (invisible) celestial sphere.
- The celestial *horizon* is a plane perpendicular to a point's gravity vector.
- *Azimuth* is the direction angle within the plane of the horizon, typically counted clockwise from the North (in geodesy and astronomy) or South (in France).
- *Elevation* is the angular height of an object above the horizon, Alternatively zenith distance, being equal to 90 degrees minus elevation.
- *Local topocentric coordinates* are azimuth (direction angle within the plane of the horizon) and elevation angle (or zenith angle) and distance.
- The North *celestial pole* is the extension of the Earth's (precessing and nutating) instantaneous spin axis extended Northward to intersect the celestial sphere. (Similarly for the South celestial pole.)
- The *celestial equator* is the intersection of the (instantaneous) Earth equatorial plane with the celestial sphere.
- A *meridian plane* is any plane perpendicular to the celestial equator and containing the celestial poles.
- The *local meridian* is the plane containing the direction to the zenith and the direction to the celestial pole.

Geodetic measurements

The level is used for determining height differences and height reference systems, commonly referred to mean sea level. The traditional spirit level produces these practically most useful heights above sea level directly; the more economical use of GPS instruments for height determination requires precise knowledge of the figure of the geoid, as GPS only gives heights above the GRS80 reference ellipsoid. As geoid knowledge accumulates, one may expect use of GPS heighting to spread.

The theodolite is used to measure horizontal and vertical angles to target points. These angles are referred to the local vertical. The tacheometer additionally determines, electronically or electro-optically, the distance to target, and is highly automated to even robotic in its operations. The method of free station position is widely used.

For local detail surveys, tacheometers are commonly employed although the old-fashioned rectangular technique using angle prism and steel tape is still an inexpensive alternative. Real-time kinematic (RTK) GPS techniques are used as well. Data collected are tagged and recorded digitally for entry into a Geographic Information System (GIS) database.

Geodetic GPS receivers produce directly three-dimensional coordinates in a geocentric coordinate frame. Such a frame is, e.g., WGS84, or the frames that are regularly produced and published by the International Earth Rotation and Reference Systems Service (IERS).

GPS receivers have almost completely replaced terrestrial instruments for large-scale base network surveys. For Planet-wide geodetic surveys, previously impossible, we can still mention Satellite Laser Ranging (SLR) and Lunar Laser Ranging (LLR) and Very Long Baseline Interferometry (VLBI) techniques. All these techniques also serve to monitor Earth rotation irregularities as well as plate tectonic motions.

Gravity is measured using gravimeters. Basically, there are two kinds of gravimeters. *Absolute* gravimeters, which nowadays can also be used in the field, are based directly on measuring the acceleration of free fall (for example, of a reflecting prism in a vacuum tube). They are used for establishing the vertical geospatial control. Most common *relative* gravimeters are spring based. They are used in gravity surveys over large areas for establishing the figure of the geoid over these areas. Most accurate relative gravimeters are *superconducting* gravimeters, and these are sensitive to one thousandth of one billionth of the Earth surface gravity. Twenty-some superconducting gravimeters are used worldwide for studying Earth tides, rotation, interior, and ocean and atmospheric loading, as well as for verifying the Newtonian constant of gravitation.

Units and measures on the ellipsoid

Geographical latitude and longitude are stated in the units degree, minute of arc, and second of arc. They are *angles*, not metric measures, and describe the *direction* of the local normal to the reference ellipsoid of revolution. This is *approximately* the same as the direction of the plumbline, i.e., local gravity, which is also the normal to the geoid surface. For this reason, astronomical position determination – measuring the direction of the plumbline by astronomical means – works fairly well provided an ellipsoidal model of the figure of the Earth is used.

One geographical mile, defined as one minute of arc on the equator, equals 1,855.32571922 m. One nautical mile is one minute of astronomical latitude. The radius of curvature of the ellipsoid varies with latitude, being the longest at the pole and the shortest at the equator as is the nautical mile.

A metre was originally defined as the 40-millionth part of the length of a meridian (the target wasn't quite reached in actual implementation, so that is off by 0.02% in the current definitions). This means that one kilometre is roughly equal to (1/40,000) * 360 * 60 meridional minutes of arc, which equals 0.54 nautical mile, though this is not exact because the two units are defined on different bases (the international nautical mile is defined as exactly 1,852 m, corresponding to a rounding of 1000/0.54 m to four digits).

Temporal change

In geodesy, temporal change can be studied by a variety of techniques. Points on the Earth's surface change their location due to a variety of mechanisms:

- Continental plate motion, plate tectonics
- Episodic motion of tectonic origin, esp. close to fault lines
- Periodic effects due to Earth tides
- Postglacial land uplift due to isostatic adjustment
- Various anthropogenic movements due to, for instance, petroleum or water extraction or reservoir construction.

The science of studying deformations and motions of the Earth's crust and the solid Earth as a whole is called geodynamics. Often, study of the Earth's irregular rotation is also included in its definition.

Techniques for studying geodynamic phenomena on the global scale include:

- satellite positioning by GPS and other such systems,
- Very Long Baseline Interferometry (VLBI)
- satellite and lunar laser ranging
- Regionally and locally, precise levelling,
- precise tacheometers,
- monitoring of gravity change,
- Interferometric synthetic aperture radar (InSAR) using satellite images, etc.

Soil science

Soil science is the study of soil as a natural resource on the surface of the earth including soil formation, classification and mapping; physical, chemical, biological, and fertility properties of soils; and these properties in relation to the use and management of soils.

Sometimes terms which refer to branches of soil science, such as pedology (formation, chemistry, morphology and classification of soil) and edaphology (influence of soil on organisms, especially plants), are used as if synonymous with soil science. The diversity of names associated with this discipline is related to the various associations concerned. Indeed, engineers, agronomists, chemists, geologists, geographers, ecologists, biologists, microbiologists, sylviculturists, sanitarians, archaeologists, and specialists in regional planning, all contribute to further knowledge of soils and the advancement of the soil sciences.

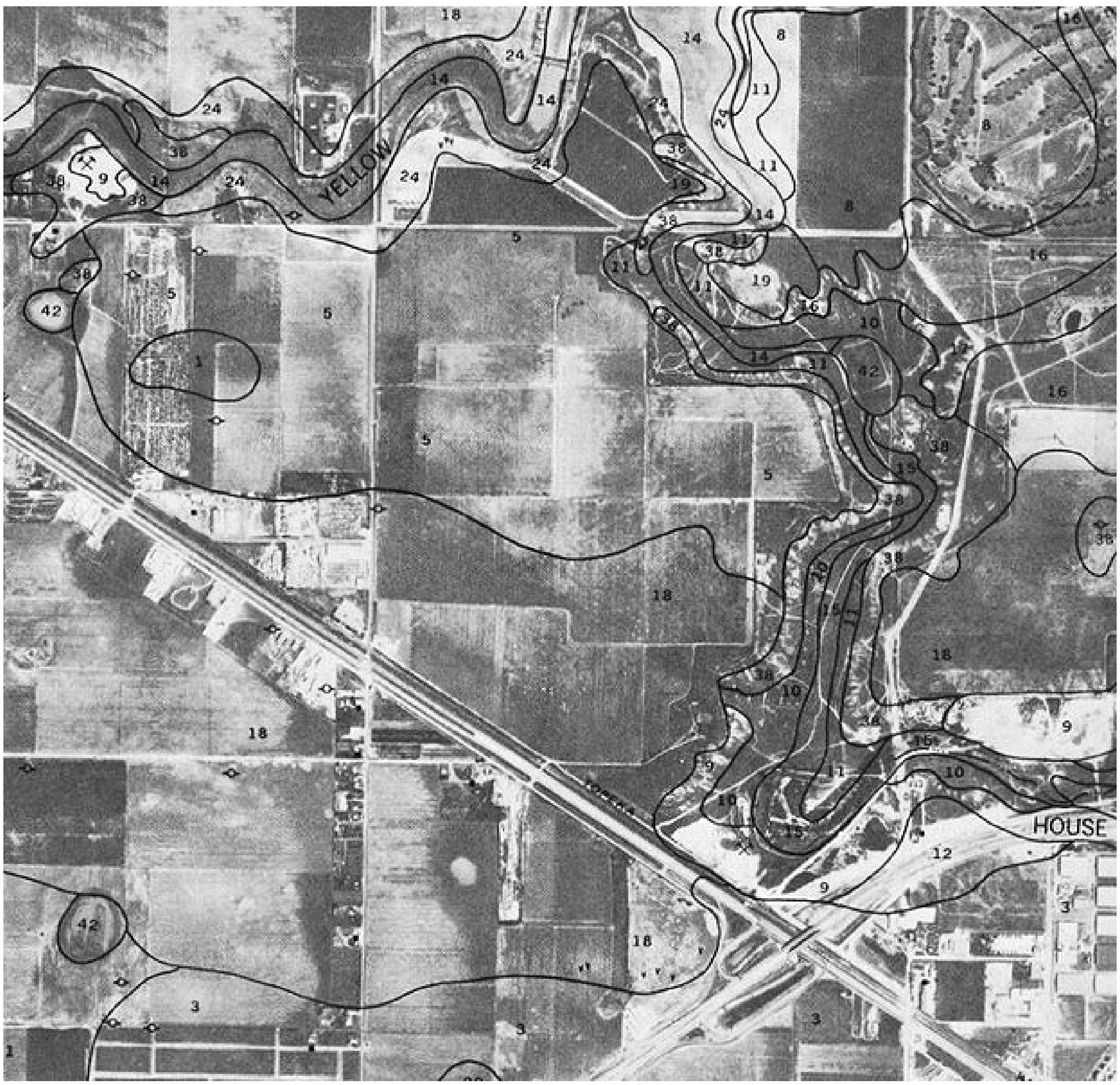
Fields of study

Soil occupies the pedosphere, one of Earth's spheres that the geosciences use to organize the Earth conceptually. This is the conceptual perspective of pedology and edaphology, the two main branches of soil science. Pedology is the study of soil in its natural setting. Edaphology is the study of soil in relation to soil-dependent uses. Both branches apply a combination of soil physics, soil chemistry, and soil biology. Due to the numerous interactions between the biosphere, atmosphere and hydrosphere that are hosted within the pedosphere, more integrated, less soil-centric concepts are also valuable. Many concepts essential to understanding soil come from individuals not identifiable strictly as soil scientists. This highlights the interdisciplinary nature of soil concepts.

Research

Dependence on and curiosity about soil, exploring the diversity and dynamic of this resource continues to yield fresh discoveries and insights. New avenues of soil research are compelled by a need to understand soil in the context of climate change, greenhouse gases, and carbon sequestration. Interest in maintaining the planet's biodiversity and in exploring past cultures has also stimulated renewed interest in achieving a more refined understanding of soil.

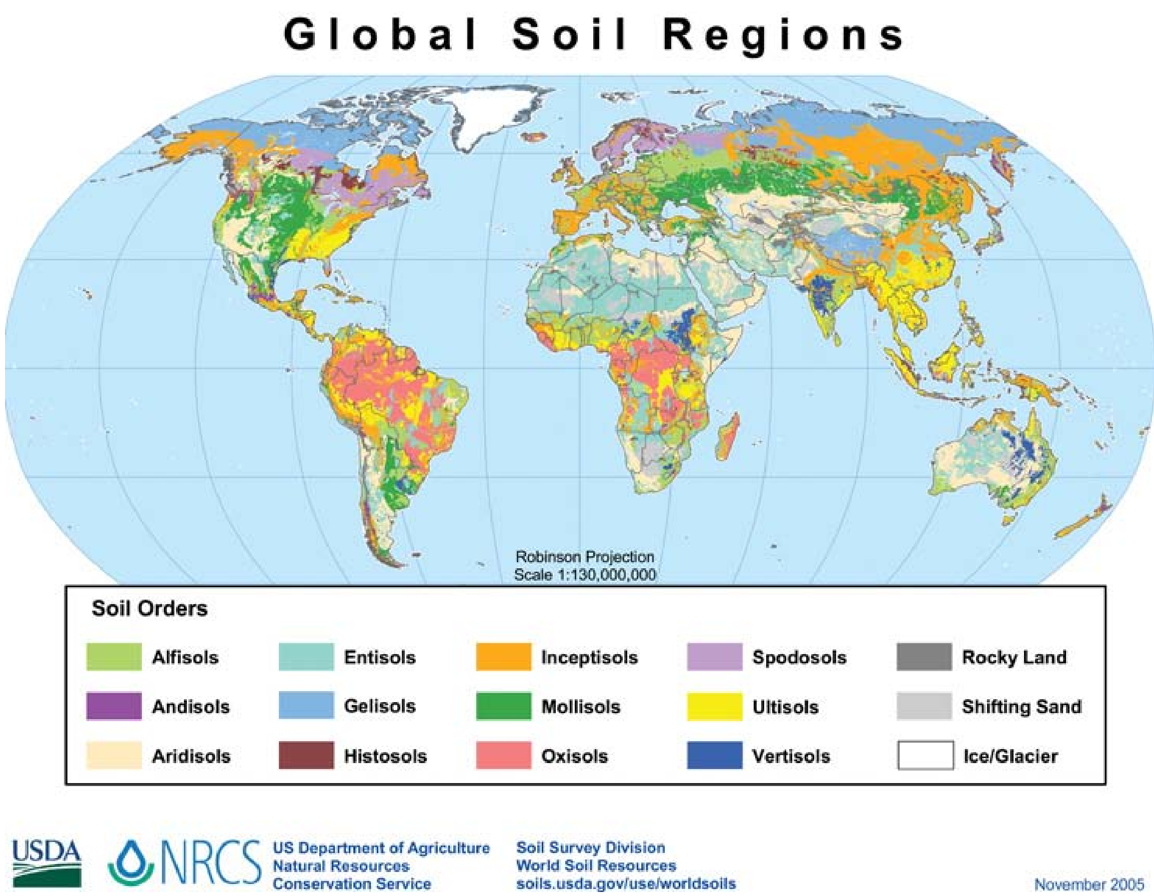
Mapping



Sample of an aerial photo from a published soil survey

Most empirical knowledge of soil in nature comes from soil survey efforts. Soil survey, or soil mapping, is the process of determining the soil types or other properties of the soil cover over a landscape, and mapping them for others to understand and use. It relies heavily on distinguishing the individual influences of the five classic soil forming factors. This effort draws upon geomorphology, physical geography, and analysis of vegetation and land-use patterns. Primary data for the soil survey are acquired by field sampling and supported by remote sensing.

Classification



Map of global soil regions from the USDA

As of 2006, the World Reference Base for Soil Resources, via its Land & Water Development division, is the pre-eminent soil classification system. It replaces the previous FAO soil classification.

The WRB borrows from modern soil classification concepts, including USDA soil taxonomy. The classification is based mainly on soil morphology as an expression pedogenesis. A major difference with USDA soil taxonomy is that soil climate is not part of the system, except insofar as climate influences soil profile characteristics.

Many other classification schemes exist, including vernacular systems. The structure in vernacular systems are either nominal, giving unique names to soils or landscapes, or descriptive, naming soils by their characteristics such as red, hot, fat, or sandy. Soils are distinguished by obvious characteristics, such as physical appearance (e.g., color, texture, landscape position), performance (e.g., production capability, flooding), and accompanying vegetation. A vernacular distinction familiar to many is classifying texture as heavy or light. Light soil content and better structure, take less effort to turn and cultivate. Contrary to popular belief, light soils do not weigh less than heavy soils on an air dry basis nor do they have more porosity.

History

Vasily Dokuchaev, a Russian geologist, geographer and early soil scientist, is credited with identifying soil as a resource whose distinctness and complexity deserved to be separated conceptually from geology and crop production and treated as a whole.

Previously, soil had been considered a product of chemical transformations of rocks, a dead substrate from which plants derive nutritious elements. Soil and bedrock were in fact equated. Dokuchaev considers the soil as a natural body having its own genesis and its own history of development, a body with complex and multiform processes taking place within it. The soil is considered as different from bedrock. The latter becomes soil under the influence of a series of soil-formation factors (climate, vegetation, country, relief and age). According to him, soil should be called the "daily" or outward horizons of rocks regardless of the type; they are changed naturally by the common effect of water, air and various kinds of living and dead organisms.

A 1914 encyclopedic definition: "the different forms of earth on the surface of the rocks, formed by the breaking down or weathering of rocks". serves to illustrate the historic view of soil which persisted from the 19th century. Dokuchaev's late 19th century soil concept developed in the 20th century to one of soil as earthy material that has been altered by living processes. A corollary concept is that soil without a living component is simply a part of earth's outer layer.

Further refinement of the soil concept is occurring in view of an appreciation of energy transport and transformation within soil. The term is popularly applied to the material on the surface of the Earth's moon and Mars, a usage acceptable within a portion of the scientific community. Accurate to this modern understanding of soil is Nikiforoff's 1959 definition of soil as the "excited skin of the sub aerial part of the earth's crust".

Areas of practice

Academically, soil scientists tend to be drawn to one of five areas of specialization: microbiology, pedology, edaphology, physics or chemistry. Yet the work specifics are very much dictated by the challenges facing our civilization's desire to sustain the land that supports it, and the distinctions between the sub-disciplines of soil science often blur in the process. Soil science professionals commonly stay current in soil chemistry, soil physics, soil microbiology, pedology, and applied soil science in related disciplines

One interesting effort drawing in soil scientists in the USA as of 2004 is the Soil Quality Initiative. Central to the Soil Quality Initiative is developing indices of soil health and then monitoring them in a way that gives us long term (decade-to-decade) feedback on our performance as stewards of the planet. The effort includes understanding the functions of soil microbiotic crusts and exploring the potential to sequester atmospheric carbon in soil organic matter. The concept of soil quality, however, has not been without its share of controversy and criticism, including critiques by Nobel Laureate Norman Borlaug and World Food Prize Winner Pedro Sanchez.

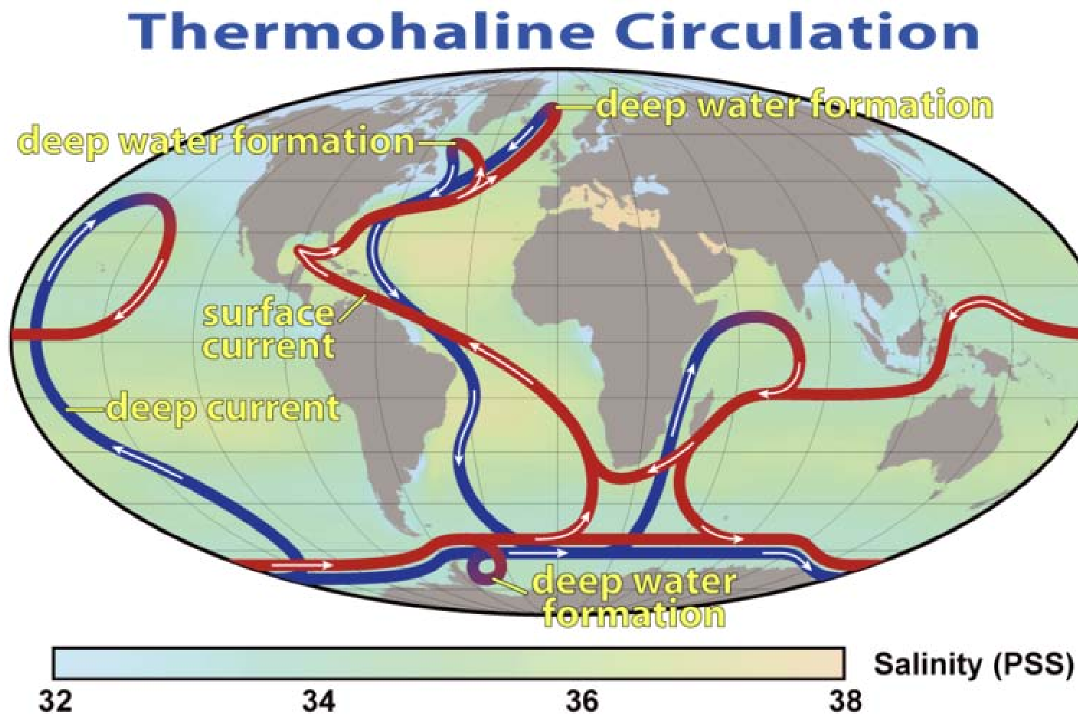
A more traditional role for soil scientists has been to map soils. Most every area in the United States now has a published soil survey, which includes interpretive tables as to how soil properties support or limit activities and uses. An internationally accepted soil taxonomy allows uniform communication of soil characteristics and functions. National and international soil survey efforts have given the profession unique insights into landscape scale functions. The landscape functions that soil scientists are called upon to address in the field seem to fall roughly into six areas:

- **Land-based treatment of wastes**
  - Septic system
  - Manure
  - Municipal biosolids
  - Food and fiber processing waste
- **Identification and protection of environmentally critical areas**
  - Sensitive and unstable soils
  - Wetlands
  - Unique soil situations that support valuable habitat, and ecosystem diversity
- **Management for optimum land productivity**
  - Silviculture
  - Agronomy
    - Nutrient management
    - Water management
  - Native vegetation
  - Grazing
- **Management for optimum water quality**
  - Stormwater management
  - Sediment and erosion control
- **Remediation and restoration of damaged lands**
  - Mine reclamation
  - Flood and storm damage
  - Contamination
- **Sustainability of desired uses**
  - Soil conservation

There are also practical applications of soil science that might not be apparent from looking at a published soil survey.

- **Radiometric dating**: specifically a knowledge of local pedology is used to date prior activity at the site
    - Stratification (archeology) where soil formation processes and preservative qualities can inform the study of archaeological sites
    - Geological phenomena
        - Landslides
        - Active faults
- **Altering soils to achieve new uses**
    - Vitrification to contain radioactive wastes
    - Enhancing soil microbial capabilities in degrading contaminants (bioremediation).
    - Carbon sequestration
    - Environmental soil science
- Pedology
    - Soil genesis
    - Pedometrics
    - Soil morphology
        - Soil micromorphology
    - Soil classification
        - USDA soil taxonomy
- Soil biology
    - Soil microbiology
- Soil chemistry
    - Soil biochemistry
    - Soil mineralogy
- Soil physics
    - Pedotransfer function
    - Soil mechanics and engineering
- Soil hydrology, hydropedology

Oceanography



Thermohaline circulation

Oceanography also called **oceanology, oceanonomy,** or **marine science**, is the branch of Earth science that studies the ocean. It covers a wide range of topics, including marine organisms and ecosystem dynamics; ocean currents, waves, and geophysical fluid dynamics; plate tectonics and the geology of the sea floor; and fluxes of various chemical substances and physical properties within the ocean and across its boundaries. These diverse topics reflect multiple disciplines that oceanographers blend to further knowledge of the world ocean and understanding of processes within it: biology, chemistry, geology, meteorology, and physics as well as geography.

History

Map of the Gulf Stream by Benjamin Franklin, 1769-1770. Courtesy of the NOAA Photo Library.

Humans first acquired knowledge of the waves and currents of the seas and oceans in pre-historic times. Observations on tides are recorded by Aristotle and Strabo. Early modern exploration of the oceans was primarily for cartography and mainly limited to its surfaces and of the creatures that fishermen brought up in nets, though depth soundings by lead line were taken.

Although Juan Ponce de León in 1513 first identified the Gulf Stream, and the current was well-known to mariners, Benjamin Franklin made the first scientific study of it and gave it its name. Franklin measured water temperatures during several Atlantic crossings and correctly explained the Gulf Stream's cause. Franklin and Timothy Folger printed the first map of the Gulf Stream in 1769-1770.

When Louis Antoine de Bougainville, who voyaged between 1766 and 1769, and James Cook, who voyaged from 1768 to 1779, carried out their explorations in the South Pacific, information on the oceans themselves formed part of the reports. James Rennell wrote the first scientific textbooks about currents in the Atlantic and Indian oceans during the late 18th and at the beginning of 19th century. Sir James Clark Ross took the first modern sounding in deep sea in 1840, and Charles Darwin published a paper on reefs and the formation of atolls as a result of the second voyage of HMS *Beagle* in 1831-6. Robert FitzRoy published a report in four volumes of the three voyages of the *Beagle*. In 1841–1842 Edward Forbes undertook dredging in the Aegean Sea that founded marine ecology.

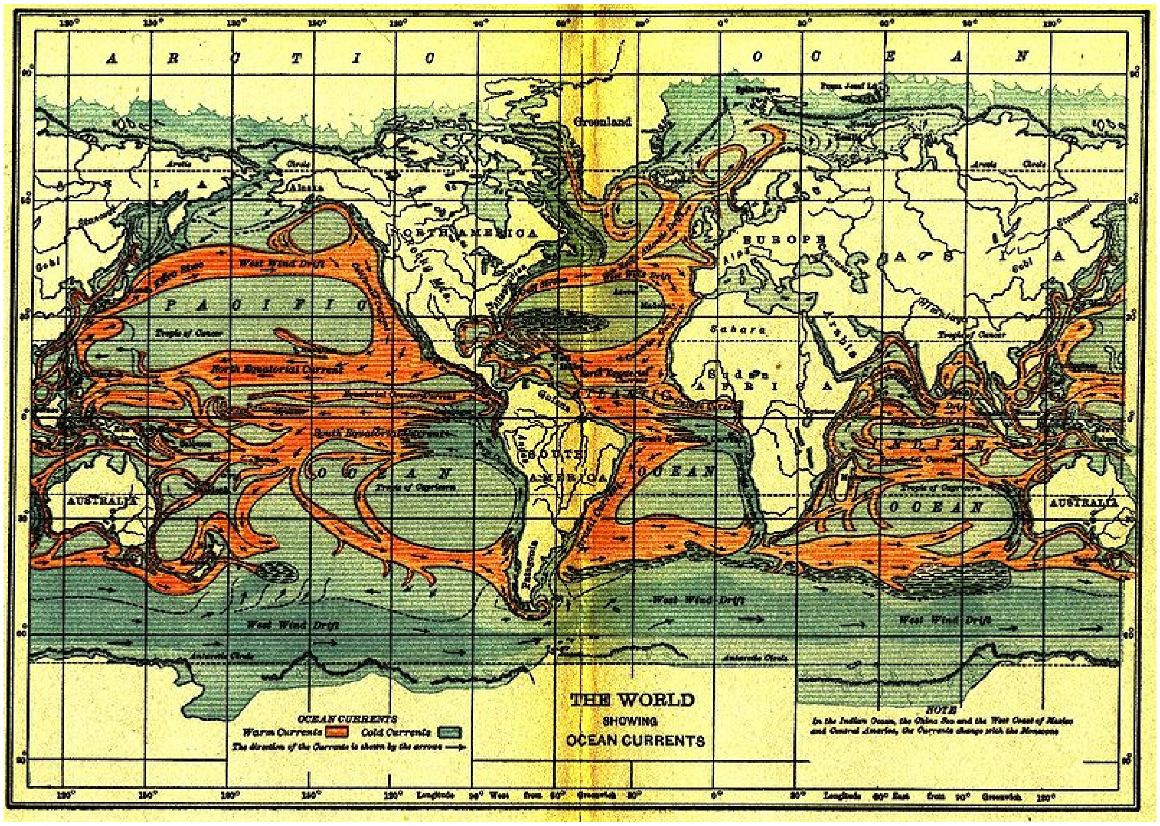
As first superintendent of the United States Naval Observatory (1842–1861) Matthew Fontaine Maury devoted his time to the study of marine meteorology, navigation, and charting prevailing winds and currents. His *Physical Geography of the Sea*, 1855 was the first textbook of oceanography. Many nations sent oceanographic observations to Maury at the Naval Observatory, where he and his colleagues evaluated the information and gave the results worldwide distribution.

The steep slope beyond the continental shelves was discovered in 1849. The first successful laying of transatlantic telegraph cable in August 1858 confirmed the presence of an underwater "telegraphic plateau" mid-ocean ridge. After the middle of the 19th century, scientific societies were processing a flood of new terrestrial botanical and zoological information.

In 1871, under the recommendations of the Royal Society of London, the British government sponsored an expedition to explore world's oceans and conduct scientific investigations. Under that sponsorship the Scots Charles Wyville Thompson and Sir John Murray launched the Challenger expedition (1872–1876). The results of this were published in 50 volumes covering biological, physical and geological aspects. 4417 new species were discovered.

Other European and American nations also sent out scientific expeditions (as did private individuals and institutions). The first purpose built oceanographic ship, the "Albatros" was built in 1882. The four-month 1910 North Atlantic expedition headed by Sir John Murray and Johan Hjort was at that time the most ambitious research oceanographic and marine zoological project ever, and led to the classic 1912 book *The Depths of the Ocean*.

Oceanographic institutes dedicated to the study of oceanography were founded. In the United States, these included the Scripps Institution of Oceanography in 1892, Woods Hole Oceanographic Institution in 1930, Virginia Institute of Marine Science in 1938, Lamont-Doherty Earth Observatory at Columbia University, and the School of Oceanography at University of Washington. In Britain, there is a major research institution: National Oceanography Centre, Southampton which is the successor to the Institute of Oceanography. In Australia, CSIRO Marine and Atmospheric Research, known as CMAR, is a leading center. In 1921 the International Hydrographic Bureau (IHB) was formed in Monaco.



Ocean currents (1911)

In 1893, Fridtjof Nansen allowed his ship "Fram" to be frozen in the Arctic ice. As a result he was able to obtain oceanographic data as well as meteorological and astronomical data. The first international organization of oceanography was created in 1902 as the International Council for the Exploration of the Sea.

The first acoustic measurement of sea depth was made in 1914. Between 1925 and 1927 the "Meteor" expedition gathered 70,000 ocean depth measurements using an echo sounder, surveying the Mid atlantic ridge. The Great Global Rift, running along the Mid Atlantic Ridge, was discovered by Maurice Ewing and Bruce Heezen in 1953 while the mountain range under the Arctic was found in 1954 by the Arctic Institute of the USSR. The theory of seafloor spreading was developed in 1960 by Harry Hammond Hess. The Ocean Drilling Project started in 1966. Deep sea vents were discovered in 1977 by John Corlis and Robert Ballard in the submersible "Alvin".

In the 1950s, Auguste Piccard invented the bathyscaphe and used the "Trieste" to investigate the ocean's depths. The nuclear submarine Nautilus made the first journey under the ice to the North Pole in 1958. In 1962 there was the first deployment of FLIP (Floating Instrument Platform), a 355 foot spar buoy.

Then, in 1966, the U.S. Congress created a *National Council for Marine Resources and Engineering Development*. NOAA was put in charge of exploring and studying all aspects of Oceanography in the USA. It also enabled the National Science Foundation to award *Sea Grant College* funding to multi-disciplinary researchers in the field of oceanography.

From the 1970s, there has been much emphasis on the application of large scale computers to oceanography to allow numerical predictions of ocean conditions and as a part of overall environmental change prediction. An oceanographic buoy array was established in the Pacific to allow prediction of El Niño events.

1990 saw the start of the World Ocean Circulation Experiment (WOCE) which continued until 2002. Geosat seafloor mapping data became available in 1995.

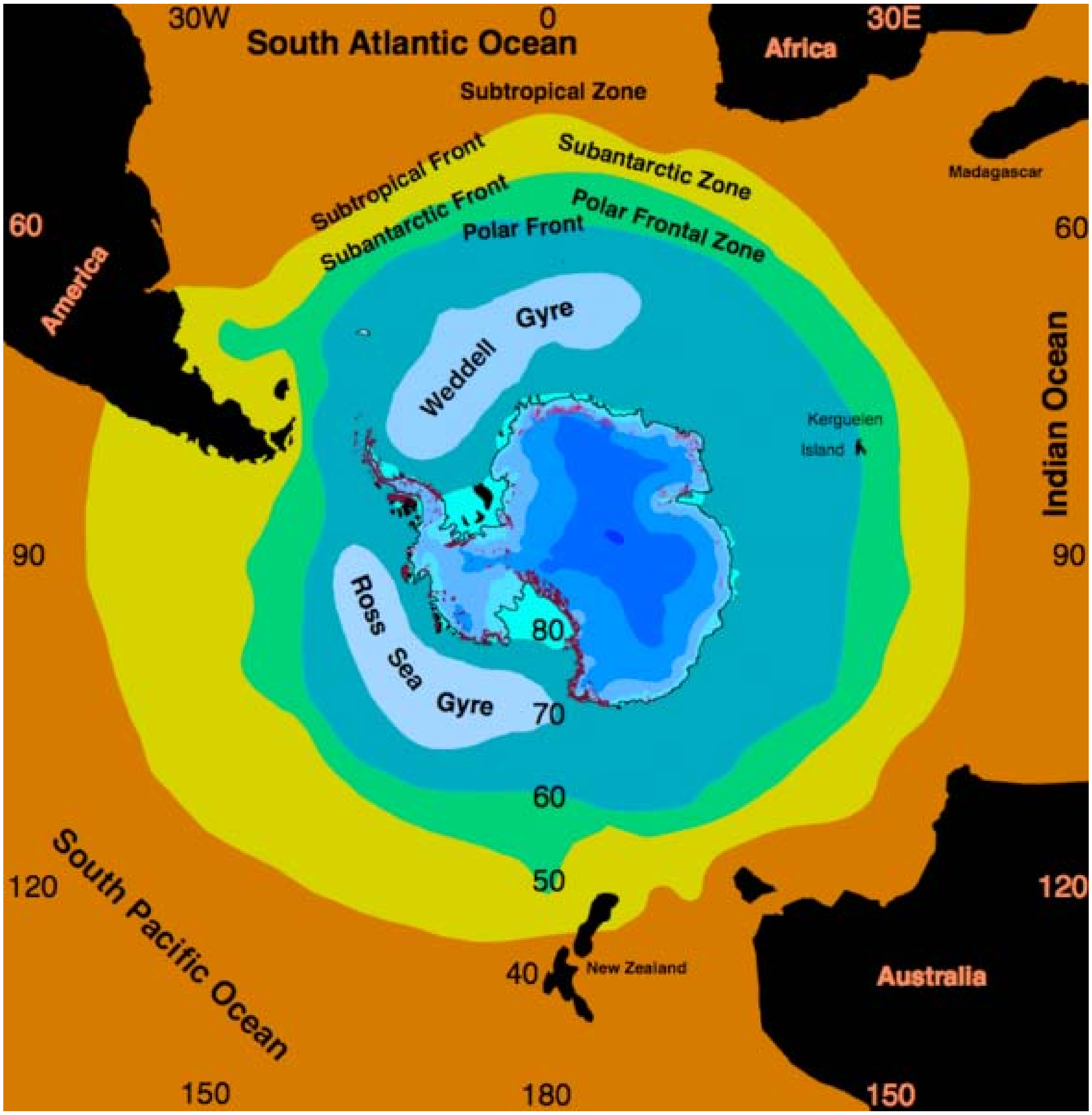
In 1942, Sverdrup and Fleming published "The Ocean" which was a major landmark. "The Sea" (in three volumes covering physical oceanography, seawater and geology) edited by M.N. Hill was published in 1962 while the "Encyclopedia of Oceanography" by Rhodes Fairbridge was published in 1966.

Connection to the atmosphere

The study of the oceans is linked to understanding global climate changes, potential global warming and related biosphere concerns. The atmosphere and ocean are linked because of evaporation and precipitation as well as thermal flux (and solar insolation). Wind stress is a major driver of ocean currents while the ocean is a sink for atmospheric carbon dioxide.

Our planet is invested with two great oceans; one visible, the other invisible; one underfoot, the other overhead; one entirely envelopes it, the other covers about two thirds of its surface.
—Matthew F. Maury, *The Physical Geography of the Seas and Its Meteorology (1855)*

Branches



Oceanographic frontal systems on the Southern Hemisphere

The study of oceanography is divided into branches:

- **Biological oceanography**, or **marine biology**, is the study of the plants, animals and microbes of the oceans and their ecological interaction with the ocean;
- **Chemical oceanography**, or **marine chemistry**, is the study of the chemistry of the ocean and its chemical interaction with the atmosphere;
- **Geological oceanography**, or **marine geology**, is the study of the geology of the ocean floor including plate tectonics;

- **Physical oceanography**, or **marine physics**, studies the ocean's physical attributes including temperature-salinity structure, mixing, waves, internal waves, surface tides, internal tides, and currents. Of particular interest is the behavior of sound (acoustical oceanography), light (optical oceanography) and radio waves in the ocean.

These branches reflect the fact that many oceanographers are first trained in the exact sciences or mathematics and then focus on applying their interdisciplinary knowledge, skills and abilities to oceanography.

Data derived from the work of Oceanographers is used in **marine engineering**, in the design and building of oil platforms, ships, harbours, and other structures that allow us to use the ocean safely.

Oceanographic data management is the discipline ensuring that oceanographic data both past and present are available to researchers.