Glossary of Terms (Prepared by UCSD)

http://earthguide.ucsd.edu/virtualmuseum/Glossary_Climate/gloss_s-z.shtml

Absorption lines - (n.)

Any portion of the electromagnetic spectrum (including visible light) that is trapped by free atoms or molecules in the path of the radiation, thus reducing their transmission. In the climate context, this is important for the greenhouse effect since water vapor, carbon dioxide and methane absorb certain wavelengths of infrared radiation.

Adiabatic expansion/compression - (n.)

Expansion (or compression) of a gas (e.g. air) without exchange of heat with the surroundings. Air cools upon expansion and heats up upon compression, and this is the main reason for the vertical temperature gradient seen in the lower atmosphere (i.e. the troposphere). The adiabatic temperature gradient in dry air is near 1°C for every 100 m change in elevation. The actual gradient on Earth is less because of the presence of water in the air.

Aerosol - (n.)

Any small particle, solid or fluid, that is suspended in air. Abundance values typically range from 100 to 10,000 particles per cubic centimeter for air over land with higher values found in cities. Sizes vary greatly, but typically are near 0.1 μm or less. The particles originate from wind-blown sea-salt or dust, volcanic eruptions, burning of vegetation, combustion of coal and petroleum products, and other natural and anthropogenic processes. Aerosol particles serve as nuclei for condensation of water droplets and for growth of ice crystals and also influence the radiation balance directly. In the lower stratosphere, concentrations are extremely low; much of the aerosol here consists of droplets of sulfuric acid.

Agassiz, Jean Louis Rudolphe -

(1807-1877): Swiss naturalist, paleontologist and geologist. He received his degree in medical sciences 1830 and followed by studying with Cuvier at the Musée d'Histoire Naturelle in Paris (1831-32). In 1832 he became a professor in Neuchâtel, and then in 1848 he served as professor at Harvard, where he founded the Museum of Comparative Zoology in 1858. A world expert on fishes, mollusks and echinoderms, Agassiz was also the originator of the concept of the "Great Ice Age," an idea which proved to be useful for the investigation of climate change and for the reconstruction of ice age history. He was the last distinguished paleontologist to reject Darwin's evolutionary theories in favor the ideas of repeated extinction and creation events, in the tradition of d'Orbigny and Cuvier.

Albedo - (n.)

Meaning "whiteness, albedo is a measure of the reflectivity of a surface. If a surface has an albedo of 40%, it means that 40% of the light falling on a surface is reflected. The planetary albedo of Earth is its reflectivity as seen from space (near 30%). Also, there is cloud albedo and ground albedo. The ocean, on the whole, has a low albedo, as do forests. The deserts have high albedo, while fresh snow has the highest albedo of the common surfaces on Earth.

Alleroed - (n.)

A village in Denmark whose name is used for a warm period at the end of the last glacial.

Arrhenius, Gustaf -

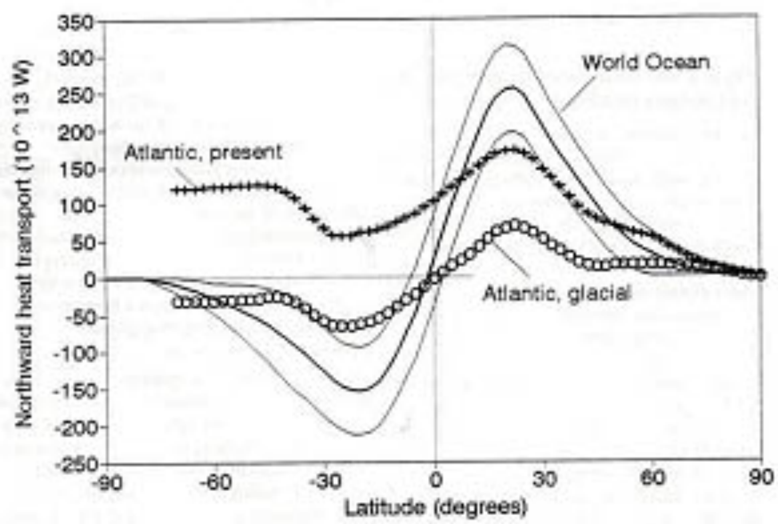
(born 1922): Swedish-American geochemist and a member of the Swedish Deep-Sea Expedition (1947-1949). He discovered cyclic sedimentation in the long cores taken in the equatorial Pacific and related these observations to climate cycles in the ice ages. He is currently a professor at the Scripps Institution of Oceanography at UC San Diego.

Arrhenius, Svante -

(1859-1927): Swedish physicist and chemist who discovered ionic dissociation and its role in making solutions conduct an electric current. He predicted global warming from the release of carbon dioxide to the atmosphere and made calculations on the magnitude of the effect.

Atlantic Heat Conveyor - (n.)

The considerable heat transfer from south to north by near-surface waters moving across the equator in the Atlantic. This movement is required to balance a southward flow of water in the ocean depths. This deep water, called the "North Atlantic Deep Water," moves sluggishly but the flow is considerable - some 20 Sverdrup - and is rather cold (between about 2°C and 4°C). So since the North Atlantic trades cold water for warm, it gains lots of heat in the process. This is the reason regions well north of 60°N, such as in Scandinavia, have comparably mild climates. The graph below shows the flow of heat (in units of 10^{13} Watts) across the present Atlantic (+ symbol), across the Atlantic during glacial times (o symbol), and the world ocean average (thick solid line bordered by thin lines that represent the upper and lower limits). The general trend to take from the graph is that heat is transported from southern to northern latitudes.



Axelrod, Daniel I. -

(1910-1998): American paleoecologist who who reconstructed past climates, vegetation types, and entire landscapes from fossil impressions of leaves, stems, cones, and fruits.

Barron, Eric -

American climatologist who pioneered the application numerical climate models to climate history and change.

Index: A to F | G to L | M to R | S to Z

Berger, André L. -

Belgian astronomer and climatologist. He calculated the solar input on Earth's surface on a very detailed time scale, for millions of years into the past and into the future. His calculations provided the basis for assigning a detailed ice age chronology using Milankovitch theory (see below, **Milutin Milankovitch**).

Bergeron, Tor H. P. -

(1891-1977): Swedish meteorologist. While working at the Geophysical Institute in Bergen, Norway, he conducted research on cloud formation and, in 1935, he proposed that the formation of ice crystals is crucial in producing rain in a paper entitled, "On the Physics of Clouds and Precipitation." His contributions include the theory of polar fronts (in collaboration with Jacob Bjerknes), methods of weather forecasting, and studies on the growth of ice sheets.

Berger, Wolfgang H. -

(born 1937): German-American geologist and oceanographer currently working at Scripps Institution of Oceanography, UC San Diego. His research includes the history of carbonate sedimentation and ice age climate as recorded in ocean sediments as well as contributions to the history of ocean productivity.

Berner, Robert -

American geochemist. His contributions to biogeochemistry include the reconstruction of the carbon dioxide content of the atmosphere through the last 100 million years.

Biogeochemistry - (n.)

Life on our planet is made up of an incredible variety of carbon molecules - in essence, life processes can simply be viewed as carbon chemistry. Conversely, the carbon cycle, the movement of carbon atoms through the various reservoirs in the climate-driven part of Earth, is intimately tied to life processes. In the study of the carbon cycle, biology and geochemistry merge to form a new scientific discipline, called "biogeochemistry." Biogeochemists study the carbon cycle in its interconnections with the cycles of other elements involved in life processes, mainly nitrogen, oxygen and phosphorus, but also sulfur and iron and certain trace metals. Also, the water cycle helps drive the carbon cycle, and this is where climate and the carbon cycle are most intimately connected.

Biogeochemistry includes the history of the great carbon reservoirs in the crust of the Earth, the limestones and the coal deposits, as well as the distribution of nitrate and phosphate in the ocean. It seeks to explain the composition of the atmosphere, consisting of nitrogen, oxygen and the trace gases, as a result of bacterial action and photosynthesis. And it records the exchange of matter at the interfaces such as the decay of organic matter in soils and the resulting gases released into the air, the uptake of oxygen by the ocean and its utilization at depth, and the leaching of nutrients from the soil and their transport into the sea. In a sense, biogeochemistry treats the dynamic systems near the surface of Earth as a few interacting organisms living in symbiosis, where the waste products of one become the stuff of life for the other. For example, the ocean takes up oxygen (the waste product of plants) and releases an equivalent amount of carbon dioxide (the waste product of decay and the stuff of growth for plants). The all-important role of life processes in maintaining Earth's environments was stressed early in the 20th century by the Russian chemist Vladimir Vernadsky (1863-1945), who may be considered the father of biogeochemistry, although that term had not been invented at the time. The American limnologist and geochemist G. Evelyn Hutchinson (1903-1991) first outlined the broad scope and principles of the new field and led the way. More recently, the basic elements of the discipline of biogeochemistry have been restated and popularized by the British engineer and science writer James Lovelock (born 1919) under the label of the "Gaia Hypothesis." Lovelock emphasizes a concept that life processes regulate the radiation balance of Earth to keep it habitable.

Biological pump - (n.)

On short time scales, when compensating geochemical adjustments (e.g. changes in weathering processes on land and deposition and dissolution of calcium carbonate-rich sediments) can be neglected, the ocean's productivity (see definition below) is an important control on the partial pressure of atmospheric CO_2. The biological pump runs on photosynthesis, which can be visualized as the fixation of dissolved carbon into particles, and relies on the settling of such particles out of the sunlit zone into deeper waters. In this manner, the biological pump removes carbon from the interface between ocean and atmosphere. The atmosphere, as a result, has less carbon dioxide than it would have otherwise. The efficiency of the pump is controlled by the amount of nutrients available to drive the process. Thus, if somehow the nutrient content of the ocean were increased, the biologic pump would be more efficient, and the CO_2 of the atmosphere would drop. An increase in nutrients in the ocean during glacial periods was proposed by Wallace Broecker to explain the lowered CO_2 content of the atmosphere measured in the air recovered from polar ice. The effect is one of many that must be considered when attempting to explain the fluctuations in CO_2 during the ice ages.

Bjerknes, Jacob -

(1897-1975): Norwegian meterologist (son of **Vilhelm Bjerknes**, see above). His theory of polar fronts (in collaboration with Tor Bergeron) applied the term "front" to the boundaries between two air masses having different properties (temperature, vapor content, density). The polar front theory was used to explain the origin of cyclones (low-pressure centers) from interaction between warm and cold air masses in the northern Atlantic

Ocean.

Bjerknes, Vilhelm -

(1862-1951): Norwegian meteorologist who developed mathematical models of atmospheric and oceanic motions, and co-founded modern physical oceanography.

Breakthrough - (n.)

An unexpected solution to a difficult problem of long standing. Finding a breakthrough is like winning the scientific lottery. Breakthroughs are claimed and rejected (e.g. cold fusion) in a manner akin to drawing a check on expected winnings but with the wrong number on the ticket.

Broecker, Wallace S. -

(born 1931): American oceanographer who made many important contributions in the study of the ocean's carbon cycle, rates of deep circulation and heat transport, nutrient budget, and climate history during the ice ages. He has been a Professor of Geology at Columbia University since 1961 and a member of the staff of the Lamont-Doherty Earth Observatory in Palisades, New York.. His major project, GEOSECS, is a global net of profiles through the ocean designed to define the chemical properties of the ocean in detail.

Brückner, Eduard -

(1862-1927): Austrian meteorologist. He was a pioneer in reconstructing climatic conditions in northern Europe for the last 1000 years and discovered the 35-year fluctuations of damp-cold and warm-dry intervals known as "Brückner Cycles." He co-authored a major work with Albrecht Penck on the geology of the Alps as well as contributing to our understanding of the dynamics of mountain glaciers.

Bryan, Kirk -

American climatologist. He applies computer models toward the comparison of the atmosphere and the ocean and their complimentary roles in the global heat and water balance. He also uses ocean-atmosphere models to determine climate predictability in middle and high latitude areas.

Btu - (n.)

British Thermal Unit is a unit of energy (energy is the ability to do work). The definition for Btu is the amount of energy required to raise the temperature of 1 pound of water 1 degree Fahrenheit (°F). Practically speaking, a Btu is equivalent to about the heat from a kitchen match. The unit 1 quadrillion Btu (10^{15} Btu) is often used for reporting fossil fuel use.

Budyko, Mikail I. -

Russian climatologist. By applying mathematical climate modeling and climate history reconstruction, Buyko was one of the first scientists to attempt calculation of carbon dioxide levels for the distant past.

Buffer factor - (n.)

See Revelle Buffer Factor.

Carbon isotopes - (n.)

Both the stable isotope carbon-13 and the unstable carbon-14 are used as tracers of climate-related processes. (see also "radiocarbon." for more on carbon-14) Carbon isotopes are useful in documenting the rate and amount of input of carbon dioxide into the atmosphere from human activities (the burning of fossil fuels and deforestation) and in tracing the path of this added carbon through the carbon cycle. Carbon dioxide in the atmosphere provides the raw material for making the wood in tree trunks and analysis of tree rings shows how the composition of the atmosphere changed. Since 1950, there has been a marked decrease in the ratio of ^{14}C to ^{12}C due to the input of ^{14}C-free carbon from fossil fuels (a phenomenon known as the "Suess Effect"). A similar change is seen in the ratio of ^{13}C to ^{12}C because fossil fuels have less ^{13}C than does the atmosphere (as is true for all carbon compounds derived from photosynthesis). Long-term trends in ^{14}C in tree rings show that the atmospheric concentration of this isotope has changed in the past several thousand years due to natural causes, including changes in production within the atmosphere and changes in the exchange between atmosphere and ocean. On long time-scales, ^{13}C in marine carbonates is useful in reconstructing the productivity history of the ocean, as well as yielding clues to CO_2 levels in the geological past.

Climate contrarians - (n.)

See "greenhouse skeptics."

Climate versus weather - (n.)

Weather is the day-to-day pattern of atmospheric flow with its associated cloud cover, temperature, and humidity. To answer the question "Will it rain in Los Angeles tomorrow?" a weather forecast is required. The season-to-season or year-to-year variability of weather in an overall or average sense is called **climate.** To address the question "Will the ongoing drought persist for another two years?", a climate forecast is required to find the probable answer. **Climate** is typically described by the regional patterns of seasonal temperature and precipitation. Average annual temperature, average rainfall, average cloud cover, and average depth of frost penetration are typical climate-related statistics.

Clouds - (n.)

Clouds consist of fine water particles floating in air and which are dense enough to prevent the direct transmission of light. The particles can be frozen, as with ice clouds. Condensation of water occurs when the moisture in the air exceeds the capability of the air to hold the water vapor (upon cooling moist air or mixing it with cold air) and when microscopic particles called aerosols are present on which the vapor can condense. Clouds come in many different types, depending on particle size and density, temperature and phase, thickness and elevation, cloud size and dynamics of change. The properties and the response of different types of clouds is crucial to the improvement of prediction of how the Earth's climate will respond to global warming. On the whole, higher temperature will produce greater moisture in the air, which will favor the formation of clouds in the cool regions of the atmosphere, which may move upward as the surface warms. The general increase of pollution of the atmosphere that is associated with increased human activity (e.g. burning, agriculture, and diesel engines) should favor the availability of cloud nuclei. Clouds also provide for "cloud albedo," since they reflect much of the sunlight into space, but they also trap infrared radiation. How the balance between these two effects will shift is uncertain. From a geological viewpoint (considering the climate patterns on a warm Earth, before the presence of large glaciers) it seems reasonable to expect that increasing clouds in the tropics will cool the tropics and increasing clouds in high latitudes will warm the cold regions.

Coastal upwelling - (n.)

Along many coastlines, especially at the western coasts of continents, there is a strong upward motion of cold deep waters called "coastal upwelling." Coastal upwelling is driven by winds related to the trade-wind system. Strong seasonal coastal upwelling occurs off the shores of California (whose cold water forces surfers wear wetsuits), Peru, northwestern Africa, Namibia, and in the Arabian Sea. The cold water coming from below the surface layer is rich in the nutrients nitrate and phosphate. The nutrients stimulate the growth of microscopic green algae called phytoplankton. These serve as food for small animals called zooplankton. The plankton is eaten by fish, mostly anchovies and sardines, which are in turn caught by bigger fish, sea lions, birds, and people. See also productivity, below. (Side note: whales off the coast of Namibia feed in the green upwelling waters, hence the name "Walvis Bay," given during the heydays of whaling.)

Columbus, Christopher -

(1451-1506): Genoese explorer and adventurer. He first crossed the Atlantic at its widest and discovered the trade wind route from the Canary Islands to the Bahamas. Commonly credited with discovering America, he commanded three modest-size vessels, the "Santa Maria", the "Niña" and the "Pinta", which set out from Spain to discover a westward passage to India. On making landfall in the Bahamas in October 1492 after a 36 day voyage across the Atlantic, he wrote in his logbook: "What will we get to see? Marble bridges? Golden-roofed temples? Spice gardens? People like us, or some strange race of giants? Did we reach an island or Japan itself?" What he found were harmless natives, "mighty forests", a clear brook, and "enormous unknown fruits" - but no signs of wealth. Columbus named the island "San Salvador", made contact with the friendly "Indians", claimed their land for the Spanish Crown, and started looking for Japan, thinking it could not be far off.

Concentration Units - (n.)

For very small concentrations of gases, atmospheric scientists use the following units:

ppmv: parts per million (10^6) by volume; the fraction of volume of gas occupied by a component multiplied by 1,000,000. If there is 3 ppm of CO_2 in a bottle filled with gas, then for every 1,000,000 molecules in the bottle, 3 of those molecules are CO_2.

ppbv: parts per billion (10^9) by volume; the fraction of volume of gas occupied by a component multiplied by 1,000,000,000. If there is 3 ppb of CO_2 in a bottle filled with gas, then for every 1,000,000,000 molecules in the bottle, 3 molecules of those are CO_2.

pptv: parts per trillion (10^{12}) by volume; the fraction of volume of gas occupied by a component multiplied by 1,000,000,000,000. If there is 3 ppt of CO_2 in a bottle filled with gas, then for every 1,000,000,000,000 molecules in the bottle, 3 of those molecules are CO_2.

Coriolis Force - (n.)

A force describing the acceleration on particles on a rotating sphere, in the case where the rotating sphere is the frame of reference. In principle, this force works as follows when considering motions on the surface of Earth: any particle at any latitude rotates east around the Earth's axis once in 24 hours. At the equator, this movement is associated with a maximum velocity. Here a particle moves by 1/24 of the circumference of Earth each hour (close to 1000 miles per hour). Places away from the equator have a lower eastward velocity equal to 1/24 of the circumference times the sine of the latitude per hour. Therefore, if a particle moves from the equator to higher latitudes, it will tend to outrun whatever is there already, deflecting it to the east (e.g. the westerlies). Conversely, if a particle moves toward the equator, it will tend to lag behind what is there already, and therefore be deflected to the west, with respect to the Earth's surface (e.g. the trade-winds). Particles that initially move straight east will tend to stay on a great circle, by inertia, and soon find themselves crossing latitudes, which again results in the familiar deflection, and the same is true for particles initially moving straight west. Due to the Coriolis Force, movement in gyres, cyclones and anticylones is the natural way for air and ocean currents to move on the rotating sphere of the Earth.

Craig, Harmon -

American geochemist. A chief scientist on numerous ocean expeditions, his work includes major contributions to the understanding of Earth's carbon cycle and the application of helium and argon isotope analysis to oceanography. After being trained in Chicago by his Ph.D. adviser, Harold Urey, Craig came to Scripps Institution of Oceanography at UC San Diego in 1955, and has worked there since. He is deeply involved in the GEOSECS project, a global net of profiles through the ocean designed to define the chemical properties of the ocean in detail.

Crutzen, Paul J. -

(born 1933): Dutch meteorologist and a world expert on the chemical interactions of trace gases and trace components in the atmosphere. He is originator of a viable theory for the causes of rapid ozone loss in the Antarctic winter and was involved in international negotiations regarding the restriction of the use of CFCs (Chloroflourocarbons) that destroy ozone. In 1980, he became director of the Department of Atmospheric Chemistry at the Max Planck Institute for Chemistry in Mainz. In 1995 Crutzen, M.J. Molina and F.S. Rowland together won the Nobel Prize with for their work on the depletion of the ozone layer.

Cuvier, Georges Leopold Chrétien Frédéric Dagobert -

(1769-1832). A pioneer of paleontology, this French zoologist and statesman began his studies in business administration at the Academie Caroline in Stuttgart but subsequently became an expert in natural sciences while making a living as a private instructor in Normandy. A leading vertebrate expert of his time, Cuvier wrote a formal description of the now extinct mammoth as a zoological species and applied fossils in stratigraphy. He also believed in immutability of species. He was a professor of natural history at the Ecole Centrale in Paris and a professor for anatomy at the Musée d'Histoire Naturelle in Paris in 1795. He became Chancellor of the University of Paris in 1814 and a member of the Académie Franaise in 1818. In 1819 Cuvier received the title of baron.

Cyclones - (n.)

Weather is typically described by a weather map, showing lines of equal pressure (**isobars**), boundaries between air masses (**fronts**), and direction of motion. A commonly seen map, in mid-latitudes, describes a large **cyclonic eddy** in the air, which forms when a tongue of warm, moist tropical air invades cold, dry polar air masses. The center of the cyclone is a region of low pressure (indicated by the letter L on maps). There are two fronts (air-mass boundaries): a **warm** front and a **cold** front. An observer on the ground sees first the warm front, as the cyclone moves eastward. Air pressure drops, temperature rises with the arrival of the tropical air, and so does humidity. Cloudiness increases and a rainstorm may follow. The reason for the rain is that warm air surrounded by cold air must rise, and as it rises, it cools and loses its ability to hold water. The condensation of the water vapor within the rising air releases heat, so that the air warms and keeps rising until condensation stops. A few days later the cold front arrives, restoring cooler, drier weather. The cyclones are separated by high pressure centers (marked by the letter H). Air moves clockwise around these H centers (**anticyclonic circulation**), while it flows anti-clockwise within the cyclones in the northern hemisphere. The reason that the air moves in eddies, rather than in straight paths, is the rotation of the Earth. The great centers of cyclone creation in the northern hemisphere are the Aleutian Low and the Iceland Low. Cyclones are extremely common in the bad-weather belt in the sub-Antarctic, with the worst region being the Drake Passage.

Dansgaard, Willi -

(born 1922): Danish climatologist. He applies environmental isotopes to meteorological, hydrological, and glaciological problems, particularly to the climate of the last 100,000 years. With his groundbreaking work in the early 1960s, Dansgaard made careful measurement of the oxygen isotope levels in Greenland ice cores and was thereby able to reconstruct the climatic history of the last 100,000 years.

Doldrums - (n.)

Zone, on or close to the equator, where the air shows mainly vertical motion and there is little wind. A doldrum is a dull person or a long sleeper, and **Doldrums** refers to the becalmed ships with flapping sails (as in the phrase, "in the doldrums," a depressed state). See also Intertropical Convergence Zone.

Douglass, Andrew Ellicott -

(1867-1962): An American astronomer who established the science of dendrochronology. As a professor of astronomy and physics at the University of Arizona, Douglass was interested in the history of the 11-year sunspot cycle and searched for this cycle in tree rings hoping that trees would respond to climate change provoked by the solar cycle. He was able to produce a 2000-year chronology for the Southwest, and his Arizona Tree-Ring Laboratory became the leading institution in the world for tree-ring studies.

Duplessy, J.C. -

French paleoceanographer who reconstructed deep-sea circulation through the ice ages.

El Niño - (n.)

(Pronounced El Nin-yo) The term refers to the Christ Child and originates with the fishermen in Ecuador and Peru who apply it to a warm current that appears every few years in their fishing areas around Christmas. Normally, the cold Peru Current (or Humboldt Current) flows offshore from south to north. Associated with the cold current is a process called "coastal upwelling, the rising of cold subsurface water. This water is rich in nutrients, nitrate and phosphate. The nutrients stimulate the growth of microscopic green algae, called phytoplankton, that produces food for zooplankton and fish. Whenever the warm current appears, upwelling ceases and phytoplankton production is greatly diminished. This happens every three or four years or so, in December (hence the term Christ Child) but not on a predictable schedule. The appearance of the warm current off Peru is a spill-over from a much larger event: a general warming in the eastern tropical Pacific during certain years. Normally, the Pacific trade winds move warm tropical surface waters to the west, piling it up in the "warm pool" region between Indonesia, the Philippines and New Guinea. The water there has a year-round temperature close to 29°C (85°F). For some reason, during certain years, the trade-winds weaken and warm surface water is no longer carried westward. On the contrary, during El Niño the piled-up warm-pool water starts moving east, taking the convection region with it, and the tropical rain that is associated with warm surface waters. The surface waters in the eastern region become warm. Now suddenly tropical storms occur in the region of Tahiti,and the coral there suffer from being too warm, shedding their color-giving algal symbionts. In contrast, drought strikes in the western areas, which are no longer in the convection center (e.g. New Guinea, Indonesia). Extraordinary events of precipitation in southern California (which produce high stream flow or flooding) are commonly associated with El Niño conditions, when the eastern Pacific is unusually warm. Winter storms, generated in the North Pacific, move farther south than at "normal" times and have the opportunity to pick up moist tropical air along the way. Absent an offshore high which acts as a barracade, the storm systems can invade the region and dump their load. The question is why El Niño events occur at all, and why they come at intervals of typically three or four years. The answer is not known, but apparently, the buildup of the western warm pool by the trade winds sets up an unstable situation. Once decay of the pool is triggered, the process feeds on itself since the redistribution of warm water interferes with normal trade wind patterns. It then takes well over a year to get things back to "normal."

How will global warming change affect the occurrence of El Niño events? Using variations in several indicators (air pressure, temperature, cloud, etc.), climatologists observe a tendency toward more frequent occurrence in El Niño conditions, for the last twenty years. Also, there are fewer "colder-than-normal" conditions, with especially strong trade winds and a corresponding warm pool pile-up. It is not clear, at this point, whether this change is permanent and whether mankind's activities have anything to do with it. Conceivably, the ongoing addition of greenhouse gases to the atmosphere is making conditions more favorable for the development of El Niño conditions. Alternatively, the climate system will eventually return to a previous state of fewer and less pronounced El Niño events, and their recent greater abundance is simply part of long-term climate cycles. Research on laminated sediments in

Santa Barbara Basin, which contain a record of floods in the drainage region of Santa Barbara, suggests that such long-term cycles exist. One prominent cycle lasts a hundred years or so, another about fifty years. The answers will come from a more detailed study of the historical record, and from improved models of climate, which will including the strange anomalies called El Niño. See the table below for a list of the El Niño years in San Deigo since 1950.

Table of years of El Niño conditions in San Diego County (From 1950 onward, these years had strong rains in December):

1864	1914	1953	1980
1867	1918	1957	1982
1871	1923	1958	1983
1877	1925	1963	1986
1884	1930	1965	1992
1891	1932	1969	1993
1899	1939	1972	1995
1902	1940	1973	1997
1907	1943	1976	
1911	1951	1977	

Emiliani, Cesare -

(1922-1995): Italian paleoceanographer who applied Urey's oxygen isotope method to deep-sea sediments recovered during the Swedish Deep-Sea Expedition and by subsequent expeditions carried out by Lamont Geologic Observatory and the University of Miami. He discovered that the temperature of the ocean and the ice masses on Earth changed through time in cycles and showed that these cycles could be recognized and correlated throughout the Atlantic. On the basis of oxygen isotopes in sediment samples from the seafloor he suggested an overall cooling of the deep ocean since Eocene time. Emiliani also pioneered deep drilling into the seafloor for the purposes of climate reconstruction.

Export production - (n.)

The amount of matter produced in the photic zone of the oceans (where light can penetrate) which is then exported to deeper waters. It is commonly used to mean organic matter export or organic carbon flux downward. When measuring the amount of material settling from the sunlit zone it is found that the export production is much greater in the coastal ocean close to land than in the open ocean. However, there is one exception to this rule: right at the equator the export also is rather large over much of the ocean, due to the high productivity found there. See also "Productivity."

Ferrel, William -

(1817-1891): American meteorologist. His major work was **Essay on the Winds and Currents of the Oceans**, written in 1856. He studied reflection of air and ocean currents by the rotation of the Earth and found that air tends to move in circles, especially in the higher latitudes. Other contributions include the understanding of cyclonic storms.

Flohn, Hermann -

(1912-1997): German meteorologist who emphasized the importance of cross-equatorial heat flow from the southern to the northern hemisphere and related this asymmetry to the presence of the large ice mass on Antarctica.

Franklin, Benjamin -

(1706-1790): Although known as a statesman and and experimenter on electricity in lightning, Franklin also made a map of the Gulf Stream and determined that the Gulf Stream formed a link between the westward flowing North-Equatorial Current and the eastward flowing North Atlantic Current.

Gaia Hypothesis - (n.)

"Gaia" is the name for the goddess of Earth in Greek mythology. The English words geology, geochemistry, geography all contain the same root referring to Earth. "Gaia" and "Gaia Hypothesis" are concepts introduced by the British engineer and science writer James Lovelock (born 1919). They represent the thought that the dynamic life support systems of Earth (including the ocean, air, soil and the flux of elements) act much like an organism and appear to be internally controlled. An analogous concept from the early history of economics was Adam Smiths "Invisible Hand" that controls market dynamics. "Gaia" is the "Invisible Hand" of biogeochemistry. Lovelock suggests that life processes regulate the radiation balance of Earth to keep it habitable. Since Earth is indeed habitable, and since the carbon cycle has helped to keep it that way throughout Earth history despite any changes in the Sun's brightness, there can be little argument that the "Gaia hypothesis" cannot be falsified. Some critics have made much of the fact that this personified Life cannot be expected to do things for future life. Yet, somehow life processes did help to keep the system "in check" - if this were not so, humans would not be here. Nevertheless, just as the "Invisible Hand" does not prevent market crashes, thus also "Gaia" cannot prevent major setbacks to life on Earth, from outside disturbance or even from internal runaway processes. While not strictly a "hypothesis" in the scientific sense since it cannot be falsified, the "Gaia hypothesis" has great merit as an educational tool, regarding the concepts of biogeochemical cycling. Do biogeochemical processes indeed combine forces to favor life on Earth? Critics suggest that the processes of living organisms in the past were not necessarily favorable for the long-term survival of the then existing life. For example, the growth of oxygen in the atmosphere, through expanding photosynthesis, greatly diminished opportunities for anaerobic organisms. However, new life forms evolved that took advantage of the new situation (for example, highly mobile multicellular organisms, including humans). See also Biogeochemistry and the people glossary entries, Vernadsky and Hutchinson.

Gates, William L. -

American climatologist. A pioneer in climate modelling.

Gauss, Karl Friedrich -

(1777-1855): German mathematician and astronomer at the observatory in Göttingen. Sometimes called the "Prince of Mathematics," he is considered along with Newton, Euclid and Archimedes to be one of the great mathematicians of all time. His major work, **Disquisitiones Arithmeticae**, was published in 1801. He invented mathematical statistics (i.e. Gaussian distribution and Gaussian error calculation) as well as making contributions to the science of geomagnetism and planetary motions. Much of his work remained unpublished during his lifetime and was later rediscovered in the later 19th century.

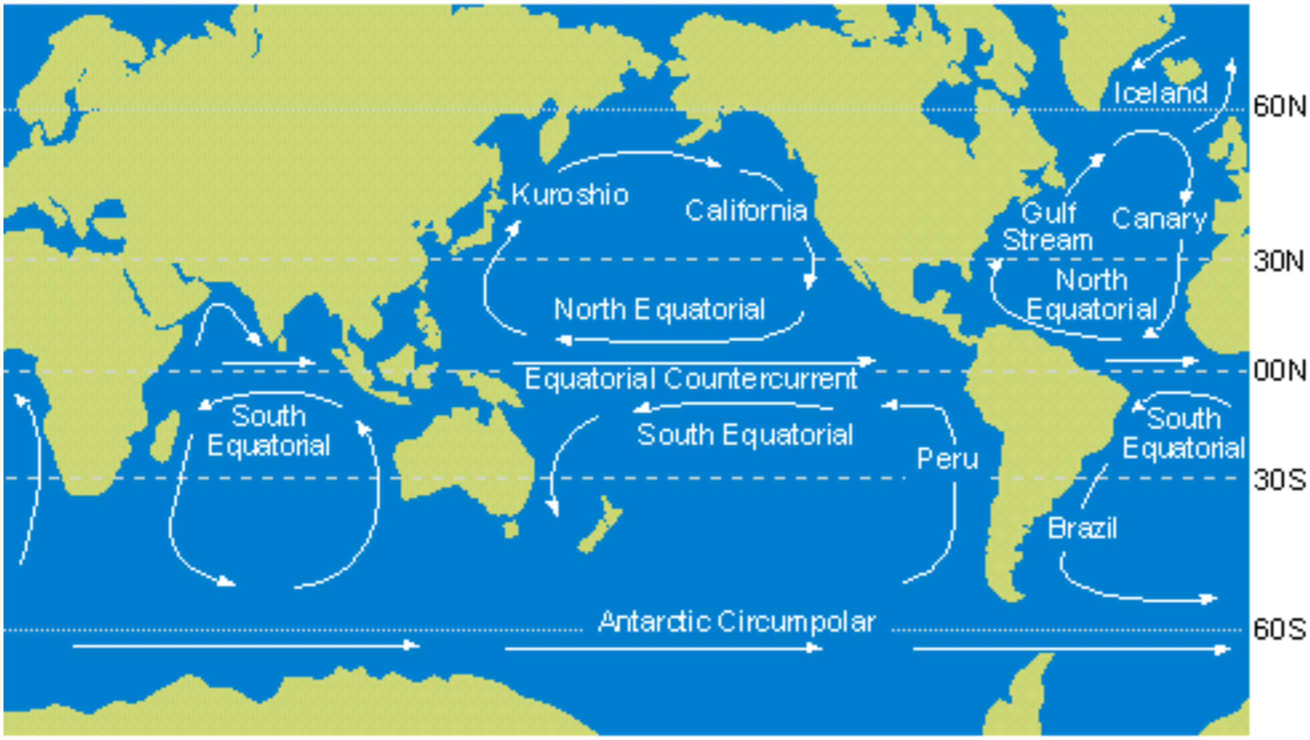
General circulation of the atmosphere - (n.)

The science of meteorology may well be said to have begun when George Hadley, in 1735, attempted to explain from physical principles why the trade winds exist. The **trades** are the easterly winds north and south of the equatorial **doldrum** belt. The trades got their name from English sailors, for their steadiness (as in "the wind blows trade," i.e. on track). **Doldrums** refers to the becalmed ships with flapping sails (as in the term "in the doldrums"). Hadley pointed out that equatorial solar heating would make tropical air lighter than air at high latitudes. Tropical air would thus rise, high latitude air would sink, winds at the surface would blow towards the equator, and winds aloft would blow towards the poles. Hadley realized that the rotation of the earth would cause the surface wind blowing toward the equator to veer towards the west, thus producing the system of trades familiar to the mariners of his day. This picture is quite realistic as concerns the trades and the doldrums. It had to be modified considerably, however, to account for the other global wind belts, notably the westerlies. The physicist Carl-Gustaf Rossby did this in the 1930's and 1940's, thus founding modern meteorology. Not one, but several circulation cells are involved, with air rising not only at the tropics, but also at the **polar front**, and with air descending in the zone separating the westerlies and the trades, the great high pressure belt which contains the centers of the ocean gyres and the deserts on land.

A general scheme of circulation has the following elements: Moist air rises in a low pressure zone along an equatorial belt. This is the **Intertropical Convergence Zone**, or ITCZ. In the Northern Hemisphere, the ITCZ tends to move north in summer and south in winter. Also, it is deflected away from the equator by monsoonal winds, especially in the Indian Ocean region, and over Africa. Away from the ITCZ the de-watered air sinks, heating up while doing so, and produces an **inversion** on top of the trades. The term "inversion" refers to a vertical temperature profile that discourages convection (that is, it describes slower-than-normal cooling upward). North and south of the ITCZ, air is being sucked in close to the sea surface, just as Hadley envisioned. This air, moving toward the equator, picks up moisture (and heat) from the tropical ocean. The air's motion is deflected to the right on the northern hemisphere, and to the left on the southern hemisphere. The reason for the deflection is the rotation of the Earth, which subjects moving objects and fluid particles to the **Coriolis Force**. The Coriolis Force deflects every moving particle toward the right on the northern hemisphere and toward the left on the southern hemisphere. It is responsible for converting the Hadley convection into zonal winds. In the mid and high latitudes, the actual flow is much more complicated than a zonal scheme would suggest. The belt around the polar front region (roughly at 35 to 50°N), where the zone of excess heat meets that of heat deficiency, is dominated by **cyclones**. These are the eddies of counter-clockwise winds. The reason for the formation of eddies is that temperature gradients, heat exchange, and Coriolis forces are at a maximum here in mid-latitudes. This makes zonal air flow highly unstable. The distribution of land and sea, in mid-latitudes, greatly influences where high pressure centers and low pressure centers will develop. On the whole, the ocean gives off heat to the atmosphere. Thus, air tends to rise over the sea which establishes low pressure centers especially where warm water penetrates into high latitudes. The prime examples for more or less fixed low pressure centers resulting from this mechanism are the Iceland Low and the Aleutian Low.

General circulation of the ocean - (n.)

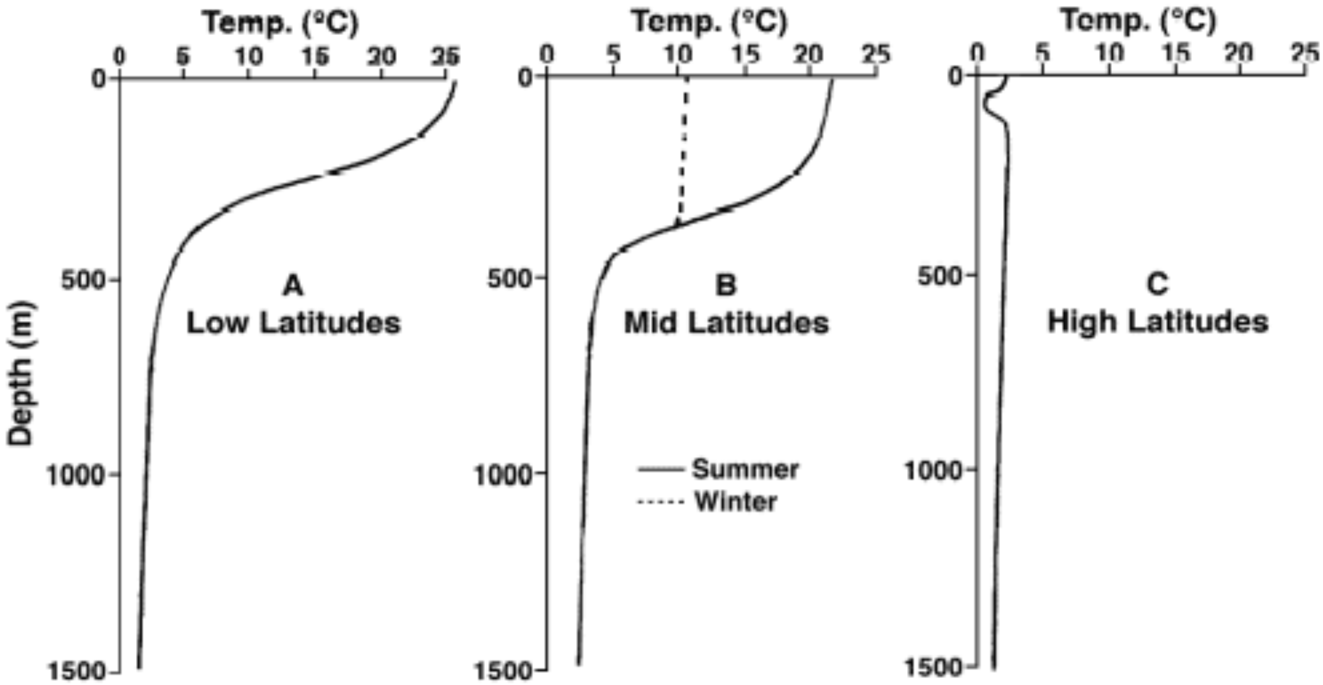
When studying the map of temperature distributions in surface waters of the world ocean, it will be noted that the lines of equal temperature (**isotherms**) do not follow latitudes entirely faithfully, but are deflected especially in coastal regions. This deflection of isotherms results from surface currents, especially from **boundary currents** at the edges of the ocean. Surface currents tend to follow surface winds. The winds, in turn, are part of the atmospheric convection system set up by the sun's radiation (**atmospheric circulation**). The most important wind belts are the **trade-winds** on either side of the equator, and the **west winds** or **westerlies** in mid-latitudes. The trades blow from the east, the westerlies from the west. Since the ocean basins are bounded by land, the currents corresponding to the trade winds and westerlies cannot run around the globe, but close to form large **central gyres**. See figure below.



The central gyres dominate the surface circulation patterns of all oceans, except in the Arctic and Antarctic regions. Since there is no barrier to zonal flow in the Antarctic, water flows around the Earth in the great **circumpolar current**. This is the greatest current in the ocean, about twice as big as the Gulf Stream. In involves not only surface waters, but reaches several miles down. The Gulf Stream itself is also impressive: it has velocities up to 4 knots (about a persons jogging speed) and transports some 100 million tons of water per second: more than one hundred times the outflow of all the world's rivers combined.

Surface currents move water in the uppermost layer of the oceans. Over most of the oceans (except at high latitudes), a thin layer of warm surface waters overlies the much colder deep waters. The zone of abrupt temperature decrease, as we pass from surface to deep water, is called the **thermocline** and typically lies between depths of one hundred to one thousand meters.

Typical Temperature Profiles



The circulation of the cold water sphere is poorly known. The water is cold because it "originated" in high latitudes, where the surface waters these in cold regions were cooled, sank, and filled up the deep ocean basins. This process is constantly happening, and without it the abyssal waters would be warm in a few thousand years from the Earth's heat flow through the ocean floor. If waters sink at high latitudes, they must rise at low latitudes. They do so at an overall rate of about 1 cm/day. Most of the abyssal bottom water of the world ocean "originates" (i.e. sinks from the surface) around Antarctica. The other important deep water source is the northernmost North Atlantic (the Norwegian Sea and Labrador Sea). This is know from mapping the temperature and oxygen content of near-bottom water. As the water moves away from its surface source (i.e. as it "ages") it gradually warms. Also, it slowly loses oxygen because of the respiration of organisms in the deep sea. Thus, "young" water is cold and oxygen-rich, "old" water is less cold and has less oxygen. Most of the deep water in the Atlantic is young, while that of the North Pacific is old.

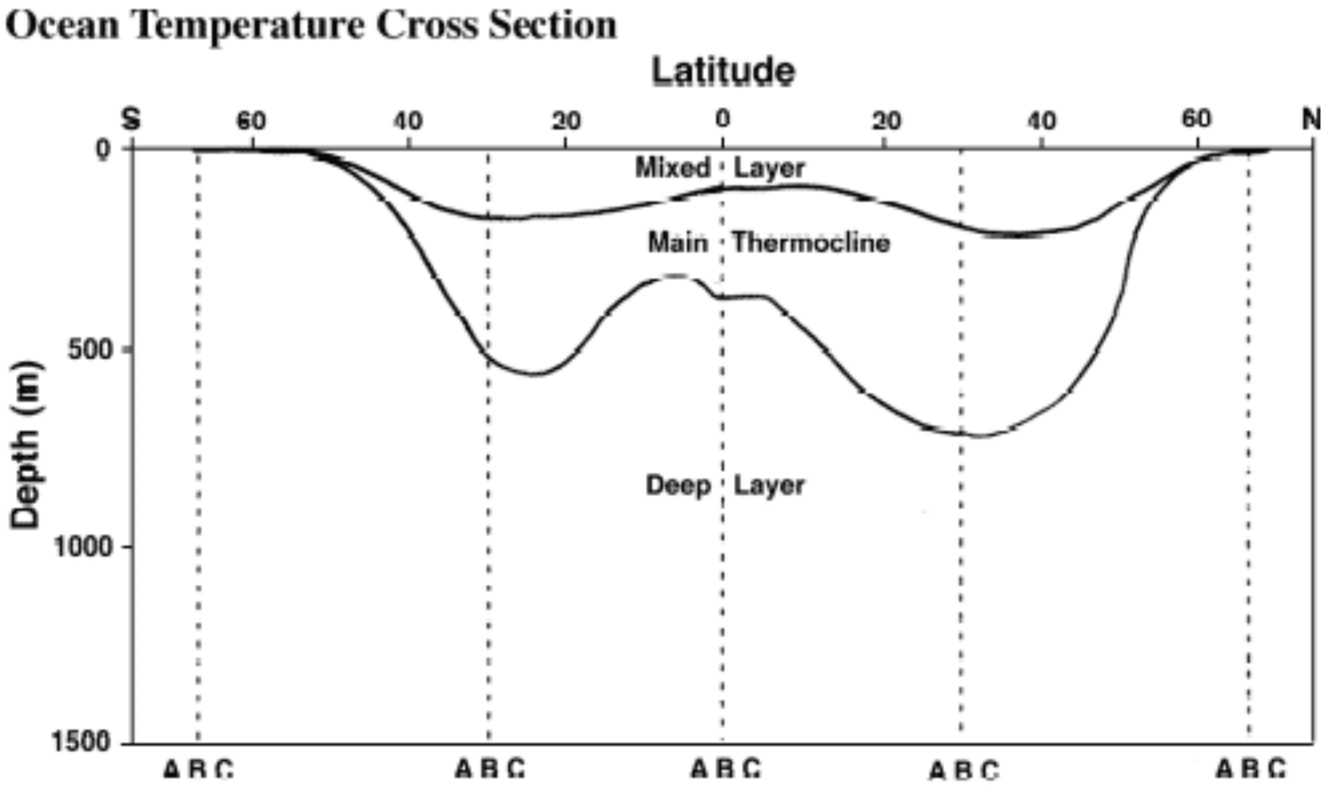


Table of Approximate Rates of Flow for Major Ocean Currents:

Current	Approximate Rate (Sv)
Circumpolar Current	150
Gulf Stream	80
Antarctic Bottom Water	10
North Atlantic Deep Water	8

Georg Wüst -

(1890-1977): German physical oceanographer. He used the distribution of ocean properties to obtain clues about motions within the ocean. Wüst also invented the concept of the "core layer," the layer of water within the ocean that has the most extreme values with respect to one or more properties and therefore is the least mixed and thus shows the path of motion.

Global warming - (n.)

The phrase "global warming" is used in a number of different ways. Observations show that the Earth has warmed overall in the last 150 years by almost 2°F (nearly 1°C), especially in the northern hemisphere (Observations in the southern hemisphere are not good enough to determine this.). The reasons for this warming are not clear, however, such warming is within the range expected for an increased greenhouse effect from human activities, including the emission of carbon dioxide from burning wood, coal and petroleum, and the emission of methane from the stomachs of cattle and from the soils of rice fields. "Global warming" is also used to describe the unusual warming seen for the last two decades, when maximum temperatures and also average temperatures were commonly outside the range experienced for the last 1000 years. Much or most of this warming seems to be a result of human activities resulting in an increase in greenhouse gases in the atmosphere. A third use of the phrase is in the framework of expectations for the future. Continued release of greenhouse gases is expected to lead to "global warming" according to the best available computer models of climate dynamics. Many climate scientists eschew the phrase "global warming" because the warming is not necessarily general. In some areas there may be no change, and in others there may be cooling associated with an average warming. Also, warming by itself may not be the most important effect of the change seen. When taking account of these caveats, the phrase "global change" is used in preference to "global warming."

Greenhouse Effect - (n.)

The "greenhouse effect" denotes the trapping of heat radiation within the atmosphere by certain trace gases contained in air, mainly water vapor, carbon dioxide and methane. Earth must radiate heat into space to balance the energy received from the Sun. The greenhouse effect makes it impossible to achieve the balance by re-radiation from the surface of Earth, thus forcing a warming of the ground and the lower atmosphere. Balance is then achieved through radiation from a level within the atmosphere, on average at 5000 m elevation. The term "greenhouse effect" also is used in connection with the emission of greenhouse gases associated with human activities, including industrial compounds (chlorofluorocarbons or CFCs). This is more correctly referred to as the "excess greenhouse effect" or "additional greenhouse effect," unless the meaning is clear from the context.

Greenhouse gas - (n.)

These atmospheric gases tend to absorb the infrared radiation from the Sun as it is reflected back towards space, thus trapping the heat in the atmosphere. The major greenhouse gases include both naturally occurring species, like water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and several anthropogenically designed gases, like chlorofluorocarbons (CFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6). Their relative ability to trap heat can be measured in terms of their Global Warming Potential (GWP), the ratio of global warming both direct and indirect from one unit mass of a greenhouse gas to that of one unit mass of carbon dioxide over a period of time. Table 1 summarizes the GWP of some of the major greenhouse gases. Table 2 shows the latest changes in US emissions, in terms of the equivalent amounts of carbon.

Table 1: Global Warming Potentials on a 100 Year Time Horizon (Source:IPCC 1996)

Gas	GWP	Gas	G
Carbon dioxide (CO_2)	1	HFC-152a	
Methane (CH_4)	21	HFC-227ea	2
Nitrous oxide (N_2O)	310	HFC-236fa	6
HFC-23	11,700	HFC-4310mee	1
HFC-125	2,800	CF_4	6
HFC-134a	1,300	C_2F_6	9
HFC-143a	3,800	C_4F_{10}	7
		C_6F_{14}	7

Table 2: U.S. Anthropogenic Greenhouse Gas Emissions, 1990-1999 (Source: US Department of Energy; http://www.eia.doe.gov/oiaf/1605/ggrpt/)

Measurement	Carbon Equivalent
Estimated 1999 Emissions (Million Metric Tons)	1,832.6
Change Compared to 1990 (Million Metric Tons)	177.6
Change from 1990 (Percent)	10.7%
Average Annual Increase, 1990-1999 (Percent)	1.1%

Greenhouse skeptics - (n.)

"Greenhouse skeptic" is a term commonly applied by the media to both scientists and nonscientists who cast doubt on any or all of the following statements, which have been made by climate scientists: the Earth has been warming during the last 150 years; a substantial portion of that warming results from the addition of greenhouse gases to the atmosphere, especially in the last 50 years; most of the addition of greenhouse gases is from human activities; human activities contribute noticeably (or even substantially) to the observed warming; warming has potentially negative effects on living conditions on the planet, for plants and animals, and people; and policies should be worked out to deal with possible effects of global warming. The most basic approach in greenhouse skepticism is to say that the climate machine is complicated and we don't understand it very well, and therefore many of the above statements remain unproven. A prominent exponent of the "too-complicated-to-say-anything" approach is Prof. Richard Lindzen at the Massachusetts Institute of Technology. The most advanced form of greenhouse skepticism is to say that a warm climate is beneficial to human societies, and that carbon dioxide is good for growing food and other plants (i.e. the more the better). A prominent exponent of the "warming-is-good-for-you" approach is Prof. Mikhail Budyko of the Hydrometeorological Institute in Moscow. Budyko thinks Siberia should become a bread basket.

Hadley, George -

(1685-1768): English meteorologist. He related the direction of trade winds to the rotation of the Earth in his famous paper "Concerning the Cause of the General Trade Winds," published in 1735. His name is attached to Hadley cells, the air circulation that attributes the trade winds as part of a cell driven by rising air in the tropics (a concept first postulated by Edmond Halley in 1686).

Halley, Edmond -

(1656-1742): English astronomer and geophysicist but also diplomat and commander in the Royal Navy. He catalogued the stars of the southern skies and mapped magnetic variation, winds, tides, and related elevation to atmospheric pressure. Other topics he studied included evaporation and salinity of lakes, optics of the rainbow, mortality tables, size of the atom, acceleration of the moon, proper motion of stars, astronomy of comets. He predicted the return of a major comet ("Halley's Comet") for the year 1758.

Hansen, James -

American climatologist and a world expert on climate modelling and climate change. He was one of the first scientific experts to publicly state that global warming has begun.

Hasselmann, Klaus -

(born 1931): German climatologist who developed three-dimensional modeling of ocean-atmosphere interaction.

Hays, James -

(born 1933): American micropaleontologist and researcher at the Lamont Doherty Earth Observatory of Columbia University. He was the lead author of the scientific paper that first supported the Milankovitch Theory by investigating the stratigraphy in deep-sea sediment cores from the southern Indian Ocean. In the cores were clear imprints of Milankovitchs proposed cycles. In his paper he wrote, "We are certain now that changes in the earths orbital geometry caused the ice ages. The evidence is so strong that other explanations must now be discarded or modified."

Heat radiation - (n.)

See Infrared radiation.

Hegel, Georg Friedrich Wilhelm -

(1770-1831) German philosopher. Studied the patterns of (European) history with a view to the (metaphysical) meaning of history and its underlying rationality. He believed that history reflected goals beyond human understanding (rather than being the chance product of interacting communitites). He also believed that Great Men make history (including himself) rather than, say, availibility of resources, weapons, development, epidemics or climate change. Freedom, Hegel believed, is to internalize the necessary laws so that they are no longer felt as external coersion. He assumed that the laws of the Russian kingdom were good- a kind of pinnacle of human history. For a Prussian citizen this was a convenient conclusion. It is a type of conclusion that is often found with other thinkers in other countries as well.

Herschel, John -

(1792-1871): British astronomer who attributed ocean currents to the action of wind and investigated the nature of the Milky Way Galaxy.

Heyerdahl, Thor -

(born 1914): Norwegian explorer and amateur archeologist. He proposed that ancient seafarers from the Mediterranean brought cotton, beans, and the idea to build pyramids to central America. Heyerdahl supported his contention by building two ships made from papyrus reed, the Ra I and the Ra II, resembling those depicted in ancient Egypt and sailing them from the ancient Phoenician port of Safi, Morocco across the Atlantic, roughly along the path of the voyage of Columbus. In 1970, the Ra II made landfall in Barbados after a 3,300 mile voyage that took 57 days. By comparison, Columbus's first voyage from Las Palmas, Spain to the Bahamas took 36 days.

Houghton, J. T. -

Climatologist and lead author on the Intergovernmental Panel on Climate Change reports, designed to provide an authoritative international statement of scientific opinion on climate change.

Humboldt, Alexander von -

(1769-1859): German naturalist and explorer who described the current off Peru that is named after him as well as making contributions to biogeography, geology and geography.

Hutchinson, G. Evelyn -

(1903-1991): American limnologist and geochemist and a pioneer of the field of biogeochemistry. His work included studies of the geochemical regulation of biotic productivity.

Hutton, James -

(1726-1797): Scottish medical doctor, farmer, businessman and geologist. He is probably best known as the inventor of the uniformitarian theory that states that present processes on earth can explain the geologic record. He is also discoverer of the rock cycle and first scientist to insist on an extremely old age of the Earth. His major work, **Theory of the Earth**, was written in 1795.

Imbrie, John -

American paleontologist and oceanographer. He is a leading figure in the reconstruction of the ice ages from deep-sea sediments and developed methods to tell past surface temperatures from the composition of fossil assemblages on the seafloor.

Infrared radiation - (n.)

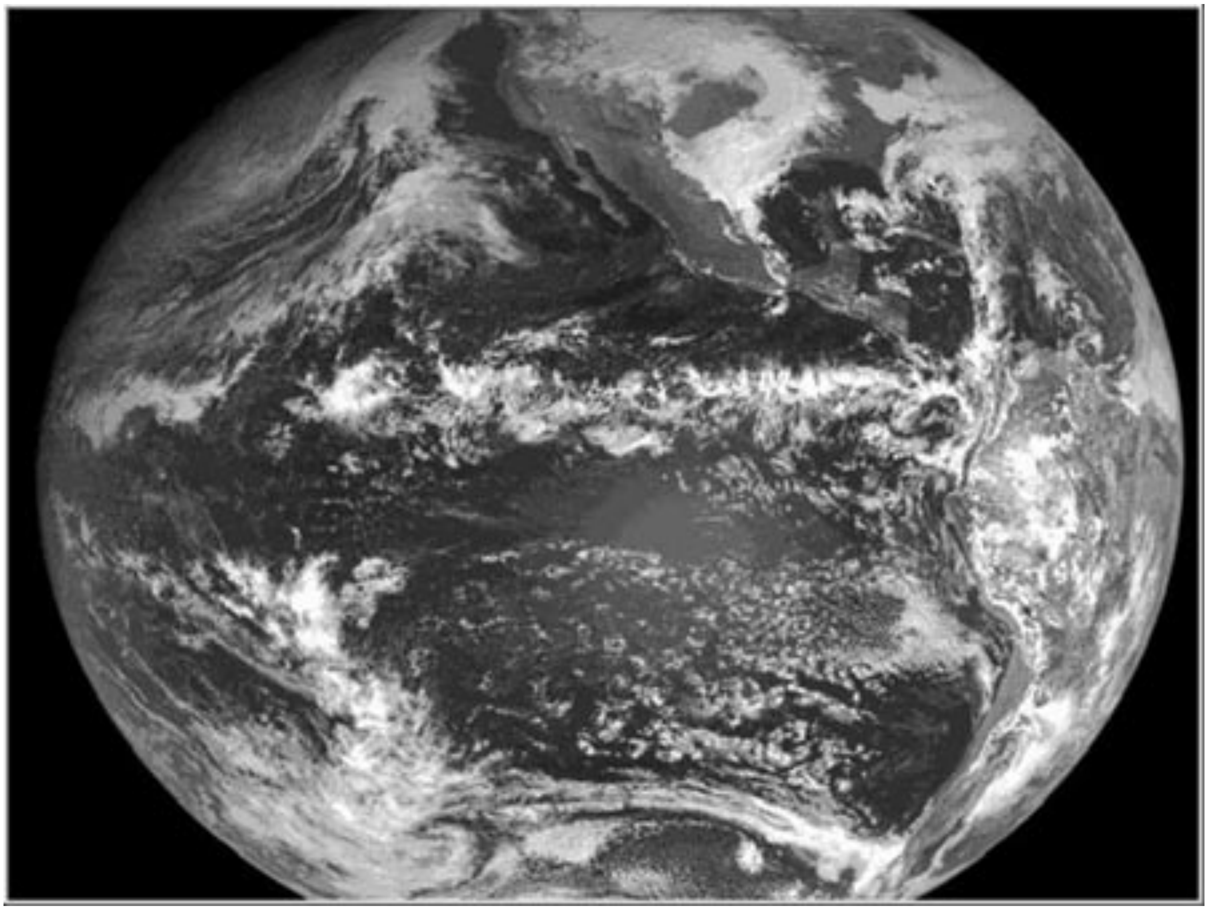
Infrared radiation is in all respects similar to visible light, except that the wave length of the electromagnetic radiation is longer than that of light. Infrared radiation is also called "heat radiation." Our eyes cannot detect infrared radiation, although at high intensity they can get damaged by it. It is however readily sensed when holding your hand or face some distance from a hot object. Your hand or face feels warm even if the air between the skin and the hot object is quite cold. By employing special instruments, infrared radiation can be used for "seeing" in the dark. Many snakes use infrared sensors for hunting small mammals. (An interesting aside: pound for pound, mammals radiate much more energy in the infrared than the Sun does in visible light!)

Input - (n.)

Amount of matter entering an Earth biogeochemical reservoir per unit time. In geochemical models, the input is usually taken as equal to the output, which is the necessary condition for keeping a reservoir constant in size.

Intertropical Convergence Zone (ITCZ) - (n.)

A zone close to the equator (usually somewhat north to it, on the "heat equator") where the trade-winds converge and air rises high into the upper reaches of the "troposphere." In the Hadley Cell, the ITCZ is the portion that supplies the upward motion in the cell. The strong updraft in the ITCZ raises the **tropopause**, the upper boundary of the troposphere, to about 15 km height. In the ITCZ, cumulus convective systems can grow to enormous size. Their central cores are protected from dilution by the large diameter of the systems: the heat released by condensation is trapped within. These giant cumulus systems or **hot towers** are commonly 35,000 feet tall, and some may be as high as 50,000 feet. At any moment there are several thousand of them active. Each one releases an amount of latent heat energy into the atmosphere equivalent to a hydrogen bomb explosion during a life-time of an hour or so and they make the ITCZ a zone of persistent rainfall and cloudiness readily identifiable on satellite photographs, as below. Note the line of clouds located near the equator, indicated the ITCZ.


It is this process of latent heat release that warms the air of the ITCZ rather than direct heating by the sun as Hadley had supposed. Because of the rising air, rain is common and cloudiness (never complete, but broken up by blue sky) is the hallmark of this convection. Within the upper troposphere, winds have a component toward the pole, compensating the flow of the trade-winds. The ITCZ is not usually precisely centered on the equator, but moves north and south, but most of the time it resides north of the equator because the northern hemisphere is warmer than the southern hemisphere (a result of the large ice sheet on Antarctica and the circumpolar air and ocean currents). See also General Circulation of the Atmosphere.

Isotopes - (n.)

"Isotopes" are atoms of the same element that have different atomic masses. **Radioactive isotopes** emit radiation and change to other atoms while **stable isotopes** do not change through time. The simplest of the elements, hydrogen, has three isotopes: normal hydrogen, deuterium, and tritium. Normal hydrogen consists of one proton and one electron. Deuterium ("heavy hydrogen", which makes "heavy water" with oxygen) has a neutron in addition to one proton and one electron, for an atomic mass of 2. It is stable. Tritium has yet another neutron, for an atomic mass of 3, and is radioactive with a half life of 12.3 years. It decays into helium-3 by emitting beta radiation (which changes a neutron to a proton). The word "isotope" means "same place," referring to the fact that isotopes of a given element have the same atomic number and hence occupy the same place in the Periodic Table. Thus, they are very similar in their chemical behavior. This similarity - and the subtle differences in behavior that arise from the differences in atomic mass - make isotopes useful as tracers of climate-related processes in atmosphere, ocean and biosphere, as well as in the reconstruction of climate history. Such history is contained in tree-rings, corals, mountain glaciers, polar ice, sedimentary deposits in lakes and on the seafloor, and a host of other geological repositories (e.g. soils, loess sequences, cave deposits, pack rat middens, evaporite and reef accumulations).

Keeling, Charles David -

American geochemist. Originator of the famous "Keeling Curve" which depicts the inexorable rise of carbon dioxide in the atmosphere since 1957, with its annual variations superimposed on the accelerating trend of increase. After receiving his Ph.D. at Northwestern University, Keeling came to Scripps Institution of Oceanography at UC San Diego in 1956 to begin the carbon dioxide monitoring program that he has led to this day.

Koeppen, Wladimir Peter -

(1846-1940): Russian-German pioneer of climatology. Between

1900 and 1936 he developed a climate classification system based on temperature, rainfall and vegetation, the basic philosophy of which is still widely used today. This system distinguished five general climate types: tropical rainy, dry, warm temperate, cold forested, and polar. Modifications to these basic types were derived from seasonal information (i.e. climate with no dry periods, with a dry winter period, and with a dry summer period) and from general geography (i.e. steppe, desert, tundra, and perpetual frost).

Kukla, George J. -

American paleoclimatologist, born in Czechoslovakia who was the first to apply records of loess, deposits of silt laid down by wind, to reconstruct the ice age climate.

Kutzbach, J. E. -

American climatologist and a pioneer in applying climate models to climate history.

Ladurie, Emmanuel Le Roy -

French historian. He is leader in the reconstruction of climate from historical records. His major work is **Times of Feast, Times of Famine: A History of Climate Since the Year 1000**.

Lamb, Hubert Horace -

(1913-1997): British climatologist. He was one of the first to reconstruct climate from historical records. He invented the "dust-veil index" for volcanic eruptions, showing that such eruptions cool the climate (e.g. the Krakatoa explosion in 1883). His major work, published in 1972 and again in 1977, was **Climate: Present, Past and Future**.

Lamont-Doherty Earth Observatory - (n.)

One of the leading oceanographic institutes in the USA, it is engaged in a wide variety of studies concerning the solid Earth, the ocean and the atmosphere. It was prominent in the history of discoveries leading to the understanding of plate tectonics. It was founded in 1949 by Maurice Ewing (1906-1974) and named the "Lamont Geological Observatory" after the estate of Thomas W. Lamont upon which it was built.

Laplace, Pierre Simon -

(1749-1827): Marquis de Laplace was a French mathematician and astronomer. He worked on celestial mechanics and perturbations in the motions and rotations of planet and determined that the obliquity of Earth's axis is not constant, but varies cyclically.

Latent heat - (n.)

The energy contained in water and in water vapor, relative to ice or water, respectively. When water vapor condenses, the latent heat is released, warming the surrounding air. This heat powers storms, including the great hurricanes. When water freezes, latent heat is also released, warming the air in contact with the forming ice. Latent heat plays an important role in the redistribution of heat on the surface of Earth, especially through evaporation in the tropics and subtropics and the subsequent precipitation in higher latitudes.

Libby, Willard Frank -

(1908-1980): American chemist who developed the radiocarbon dating method at the University of Chicago from 1948 to1950, for which he received a Nobel Prize. The application of the radiocarbon dating method revolutionized research in climate history and archeology.

Lorenz, Edward N. -

American climatologist. He investigates climate models and the predictability of weather. He discovered the Butterfly Effect in which slight differences in a few variables in a computer model result in highly unpredictable results. Applying this concept to climate and weather in his famous 1963 paper, Lorenz argued that a butterfly flapping its wings in Beijing could, in theory, affect the weather thousands of miles away some days later.

Lorius, Claude -

French physicist and climatologist and major figure in the reconstruction of the climate record from Antarctic ice cores. In 1979, he helped discover a large change in the concentration of carbon dioxide between glacial and postglacial conditions.

Lovelock, James -

(born 1919): British engineer, science writer and originator of the "Gaia Hypothesis." He was the first to measure ozone-depleting CFCs (chlorofluorocarbons) in the air at very low concentrations.

Lyell, Charles -

(1797-1875): Scottish naturalist, geologist and geographer. He suggested that similarity of fossil assemblages in the stratigraphic sequence suggested a relationship of rocks of similar age over a distance. He also promoted James Huttons theory uniformitarianism, which states that processes observable at present can explain what happened in the past, and he openly opposed Cuviers theory of catastrophism. He believed in "glacial drift," the distribution of glacial-age deposits by debris-carrying ice floes. From 1830 to 1833 he wrote the first textbook in geology, **Principles of Geology**.

Manabe, Syukuro -

(born 1931): Japanese climatologist and a pioneer of mathematical climate modeling as applied to the climate change from the increase of carbon dioxide in the atmosphere. He also succeeded in estimating the contribution of atmospheric water vapor in enhancing the greenhouse effect and applying climate models to the reconstruction of past climate. He is currently director of the Global Warming Research Program in Japan.

Mass Units - (n.)

When dealing with the enormous quantities of carbon discussed in global climate change studies, scientists use the following units:

tonne: a unit of weight equal to 1000 kg (10^3 kg).

kt: kilotonnes; equal to 1000 tonnes or 10^6 kg.

GtC: gigatonnes of carbon; 1 GtC is equal to 10^9 tonnes of carbon or 10^{12} kg. 3.7 Gt carbon dioxide will give 1 GtC. To give you an idea how big this unit is: in 1997 the total supply of petroleum for the USA (including imports) was approximately 1 Gt per year.

TgC: teragrams of carbon or 10^{12} grams of carbon.

PgC: petagrams of carbon or 10^{15} grams of carbon; 1 PgC is equal to 1 Gigatonne of carbon.

Maunder, Edward Walter -

(1851-1928): British astronomer who tied historic observations to reduced sunspot activity between 1645 and 1715, a period is now known as the "Maunder minimum� which occurs in the central portion of the "Little Ice Age," a time with an increased abundance of cool summers and exceptionally cold winters in Europe.

Maury, Matthew Fontaine -

(1806-1873): American oceanographer and director of the U.S. Naval Observatory and Hydrographic Office. He is most famous for his handbook on ocean currents, compiled from information supplied by merchant ships, which was very popular with seagoers and went through many editions.

Methane clathrate, methane hydrate or methane ice - (n.)

In the presence of high concentrations of certain gases in the water, at low temperatures and high pressures, "clathrates" can form: open-structured water ice hosting gases such as methane, carbon dioxide or hydrogen sulfide. Methane clathrate is such an icy compound where the trapped gas is methane. One unit of ice, by volume, can contain as much as 164 units of methane gas, by volume. Methane ice is present in permafrost regions in Siberia and North America and is widespread on the seafloor in the vicinity of continents, below regions of high productivity, at depths of more than 300 m and temperatures near freezing. When methane is formed by bacterial decay within organic-rich sediments in, it rises to escape into the water. As it rises, it enters into a colder zone, since heating within the Earth produces a temperature increase downward within the sediment. When the stability zone (lying somewhat below the seafloor within the sediment) for methane clathrate is reached it forms, thereby trapping the gas underneath. This typical sequence �a layer of gas-rich sediment below a layer of ice-rich sediment �provides a strong reflector for sound. When sending sound waves from a ship and listening to the return, within the sediment (a technique called "acoustic profiling") this strong echo layer is readily recognized, as a "bottom-simulating reflector" or "BSR." In this fashion, methane ice distribution has been mapped worldwide. In places, methane ice has been recovered by dredging or drilling, and thus its properties are quite well known. Methane clathrate can also be made in the laboratory.

Methane ice may be involved in the fluctuations of atmospheric methane seen in polar ice cores. From this record, it is known that methane rose rapidly whenever climate changed from glacial to interglacial conditions (during "deglaciation"). Warming of water bathing the seafloor could have led to large-scale release of methane from the melting of methane ice. Evidence for such a process is seen on the floor of the Barents Sea, which is the shelf sea north of Norway and forms part of the Arctic. Fields of giant craters have been detected within that sea off the coast of Norway, in a region rich in methane clathrate deposits. The biggest of the craters was measured as 700 m wide and 30 m deep, indicating catastrophic explosions of methane. It is thought that these craters were formed during deglaciation. Direct measurements show that large amounts of methane can escape from the Sea of Okhotsk on occasion, where the seafloor is rich in organic matter and harbors methane ice. Pressure is increased on the seafloor during deglaciation (from the rise in sea level). Thus, if the seafloor is the source of the methane increase seen in ice cores, a marked rise in temperature must be responsible for release of methane. This would imply that intermediate waters must have been considerably colder than now, during glacial time. Also, the contribution of large amounts of methane would provide an additional source for the increase of carbon dioxide observed during deglaciation. Evidence for catastrophic release of methane has been found in the more distant geologic record as well, within deep-sea sediments, for a period at the end of the Paleocene about 55 million years ago.

The event led to widespread extinctions in the fauna living on the deep-sea floor.

Some good references on methane clathrates: **Flammable ice**. by E. Suess, G. Bohrmann, J. Greinert and E. Lausch. Scientific American, 281 (5) 76-83, 1999; **Probing Gas Hydrate Deposits**. By Robert Kleinberg & Peter Brewer. American Scientist, Vol. 89 (No. 3) 2001; **Gas hydrates: relevance to world margin stability and climate change.** Edited by J.-P. Henriet and J. Mienert. Geological Society Special Publications, vol. 137, 1998; **Potential effects of gas hydrate on human welfare.** by K. A. Kvenvolden, in Proceedings of the National Academy of Sciences USA, Vol. 96, 3420-3426, 1999.

Mixed layer - (n.)

The uppermost layer of the ocean containing the surface waters. It is mixed by the wind and its thickness ranges from about 10 m, in upwelling regions, to 150 m, in regions where warm water converges.

Monsoon - (n.)

The word **monsoon** comes from an Arabic word meaning �season.� Monsoon winds are giant sea and land breezes produced by the seasons. Summer is analogous to daytime, and winter corresponds to nighttime. Summer monsoons, in essence a giant sea breeze, bring moisture and rainfall. Winter monsoons, in contrast, tend to bring drought. The strongest monsoonal patterns are in the tropics, with the Indian monsoon being the outstanding example. The seasonal winds within this system extend over East Africa, Arabia, India, and the Arabian Sea. Their existence has been known for a long time: an Arab navigator used the summer monsoon to speed Vasco da Gama from East Africa to India, in 1498. The summer monsoon in India is a product of the low pressure zone which begins to form early in summer, over the Asian highlands. Following the

Sun's apparent path to the north, the southwesterly winds appear first in Ceylon, at the end of May, and arrive at the foot of the Himalayas in July. Here they drop an enormous amount of rain, up to several meters in three months. The winter monsoon in the region is essentially indistinguishable from the easterly trade wind pattern that is normal for this region. The West African monsoon also is well known. Summer winds bring rain to the forests and savannas south of the Sahara (Sahel), from the Gulf of Guinea. Winter produces the dusty, dry **Harmattan** which blows from east-northeast and brings red dust into the Atlantic (along with the occasional locust). Monsoonal winds also occur in North America, in the Gulf region. In summer, low pressure regimes commonly develop over the heated land, and humid marine air may then be pulled in from the southeast, across Texas. During winter, northeastern winds are quite frequent, generated by the high atmospheric pressure over the cold interior. These monsoonal influences, however, are commonly masked by the complexities of mid-latitude air circulation. Here the air flow is dominated by the interaction between polar and tropical air masses (**polar front**) producing cyclones. See also "cyclones.�

Montreal Protocol - (n.)

a landmark international agreement designed to protect the stratospheric ozone layer. The treaty was originally signed in 1987 and substantially amended in 1990 and 1992. The Montreal Protocol stipulates that the production and consumption of compounds that deplete ozone in the stratosphere (chlorofluorocarbons (CFCs), halons, carbon tetrachloride, and methyl chloroform) are to be phased out by 2000 (2005 for methyl chloroform). Once emitted to the atmosphere, these compounds significantly deplete the stratospheric ozone layer that shields the planet from damaging UV-B radiation.

Munk, Walter -

(born 1917): Austrian-American oceanographer and currently a professor of oceanography at Scripps Institution of Oceanography, UC San Diego. He received his Ph.D. in 1947 at UCLA with Harald Sverdrup (see entry below) as his advisor and served as director of the Institute of Geophysics and Planetary Physics from 1960 to 1982 at Scripps Institution of Oceanography. His major contributions are to the understanding of ocean circulation, waves and tides. He is also co-originator of the ATOC project, a large-scale experiment that began in 1995 to measure the warming of the ocean by recording changes in sound velocity within it over large distances.

Newell, Reginald E. -

American climatologist and pioneer in modeling climate change, currently at MIT (Massachusetts Institute of Technology). His work includes the generation of global data sets for studies of global warming; the influence of volcanic activity on global temperature; sea-air interaction using ocean and satellite data; and the global oceanic and atmospheric energy balance.

Newton, Sir Isaac -

(1642-1727): English physicist and mathematician. He was also a bible scholar and was given the post of �Master of the British Mint� in 1695. Considered by many to be one of the greatest scientists who ever lived, Newton discovered the laws of gravity and explored the nature of light. He invented calculus independently of Gottfried Leibniz (1646-1716). He formulated the basic laws of physics, fundamental to celestial mechanics, which describe the gravitational attraction between two bodies (i.e. product of masses divided by square of distance). One of his most important books was **Philosophiae Naturalis**

Principia Mathematica (Mathematical Principles of Natural Philosophy first published in 1687. This text contains the three laws of motion: a body at rest or in uniform motion will retain that state unless a force is applied; force equals the mass of a body multiplied by the acceleration produced by application of the force; if a body exerts a force on another, that body exerts an equal and opposite force on the first body. Newton used these laws to explain a wide variety of motions, from the Moon and planets to tides. Newton's laws are an integral part of describing all motions on Earth, including winds and ocean currents.

Nordic heat pump - (n.)

The Nordic heat pump is a feature associated with the production of North Atlantic Deep Water, made in the regions east and west of southern Greenland. Here surface water is cooled and sinks after it has given up much of its heat. It is then replaced by more warm water from the south. Cold deep water is exported from the region in return for the warm water imported. This process helps stabilize the Iceland Low, which in turn helps drive warm winds into the northern North Atlantic. See also �Atlantic Heat Conveyer.�

Normal distribution - (n.)

In statistics, a normal distribution of a population of values follows the equations given by the mathematician Gauss, whereby a decreasing probability of occurrence is ascribed to values with increasing distance from the mean. This distance is measured in terms of "standard deviation." About 68 percent of a given population of numbers in such a distribution are within **one standard deviation** about the mean. The proportion of values within **two standard deviations** of the mean is 95.5%. The proportion of values within **three standard deviations** of the mean is 99.7 percent. Many properties of commonly observed classes of objects follow the normal distribution, including: the weight of house cats in San Diego, the number of minutes it takes to commute to work, the number of miles obtained per gallon of fuel for cars on the freeway, the number of phone calls coming in to the University on Thursdays, or the number of points made by a given basketball team in a given year. If the observations change their mean or standard deviation through time, disturbing factors are suspected; for instance, in reference to the previous examples: the distance between home and office changed, people bought more trucks and SUV�s, people switched to cell phones, or the team lost its best player to injury during the middle of the year. Mathematical statistics, by comparing distributions, can help determine whether a change has indeed occurred, or whether a perceived change is more likely within the range of normal variations. Ultimately, statistics answers the question: If I say there is a change, what is my chance of being wrong?

Oeschger, Hans -

(1927-1998): Swiss physicist and climatologist. A major figure in the reconstruction of climate change from Greenland ice cores, he discovered that there was a large change in carbon dioxide between the glacial and postglacial time, independently of Claude Lorius who made the same discovery.

Output - (n.)

Amount of matter exiting an Earth biogeochemical reservoir per unit time. In geochemical models, the output is usually taken as equal to the input, which is the necessary condition for keeping a reservoir constant in size.

Oxygen isotopes - (n.)

Among the most commonly studied stable isotopes in climate research are those of oxygen, especially the ratio between oxygen-16 (the common atom) and oxygen-18 (the rarer form).

Water containing oxygen-18 (or deuterium) enters the vapor phase less readily than normal water with an oxygen-16 atom and two hydrogen atoms. Also, the water with a heavier isotope condenses more easily from vapor during precipitation as rain or snow. Thus, the distribution of these isotopes in natural waters (including the ocean) reflects evaporation and precipitation processes (and, in the oceans, the motion and mixing of different water masses). The precipitation history of a parcel of air with its associated vapor is largely controlled by temperature changes. Thus, the ratio between heavy and light isotopes of hydrogen and of oxygen in polar ice can be used to reconstruct the temperature of the precipitation of snow on a given glacier. In the reconstruction of ice age cycles, the content of oxygen-18 within the shells of foraminifers (small one-celled organisms) has proved crucial. The ratio of ^{18}O to ^{16}O (expressed as the deviation δ from the ratio in a standard: $\delta^{18}O$ = [sample ratio]/[standard ratio]-1) changes in marine carbonate shells as a function of both the temperature of the water in which the shells (made of $CaCO_3$) are precipitated, and the amount of water that has been extracted from the ocean and locked up in polar ice. The polar ice is enriched in oxygen-16 relative to the ocean, and thus the ocean is enriched in oxygen-18 whenever ice shields are large. Maximum polar ice buildup during the last several hundred thousand years changes the ocean's delta value by about 1.2 ‰ (or 0.12 percent), corresponding to a change of 0.1 ‰ for each 10 m of sea level change. The portion of a change in isotope ratio that is due to temperature change follows the rule that 0.2 ‰ of change in the delta value corresponds to a change in temperature of 1°C. (‰ is the symbol for permil, in contrast to %, the symbol for percent.)

Penck, Albrecht -

(1858-1945): German geologist. He mapped the moraines and gravel deposits in the periphery of the Alps and related them to major glaciations. He rejected cyclicity and astronomic forcing as important aspects of ice-age climates. His major work, written with E. Br�ckner, was **Geologie der Alpen** (Geology of the Alps).

Permafrost - (n.)

A permanently frozen layer of soil, often hundreds of meters thick, found in the polar tundra. In the summer, the upper layer of the permafrost melts, resulting in muddy, swampy conditions. There is concern among climatologists that the increased temperature resulting from global warming will melt much of the Earth�s permafrost, with severe implications for soil stability and tundra ecology. See also �thermokarst.�

Pettersson, Hans -

(1888-1966): Swedish oceanographer. He led the Swedish Deep-Sea Expedition of 1947-1948, a circumnavigation of the Earth that was the first systematic collection of long cores from the seafloor. This expedition resulted in a new understanding of the ocean's role in creating ice-age climate.

Philander, S.G.H. -

American climatologist and physical oceanographer. He is leader in research on the ENSO (El Nino, Southern Oscillation) phenomenon.

Photosynthesis - (n.)

Process carried out by chlorophyll-bearing organisms whereby carbon dioxide and water are converted into living organic matter, using nutrients, trace elements and sunlight.

Phytoplankton - (n.)

Microscopic photosynthesizing organisms adrift in the sunlit surface waters of the ocean. The most important types of phytoplankton are "diatoms" and "dinoflagellates." Diatoms have shells made of silica (precipitated from silicate in seawater) and built on the pillbox principle. Diatoms are ubiquitous, but are most abundant in upwelling regions. Dinoflagellates have cell walls made of organic matter, and a tail, called a "flagella," which is used to move the organism through the water. Both diatoms and dinoflagellates are unicellular organisms.

Pollard, D. -

American geophysicist at Oregon State University. He gave a correct time scale for the ice age history of the last million years by creating a model that combined Milankovitch Theory with isostatic bedrock response and ice-sheet calving.

Pratt, John Henry -

(1809-1871): British geophysicist. He proposed "isostasy," the principle that mountains are high because they have deep roots of less dense material than the upper mantle that provide for a gravitational force corresponding to the difference in weight of root and mantle material. Isostasy is important in modeling ice age climate because the buildup and decay of large ice masses changes the elevation of the continental crust that bears the ice.

Productivity - (n.)

The amount of carbon fixed by photosynthesis in the uppermost layers of the ocean. Radiocarbon measurements suggest a total productivity of 30 billion tons of carbon per year. About half of this is fixed within a few hundred kilometers of the coast, the "green" coastal ocean, and the rest is found in the vast expanses of the "blue" ocean. This pattern reflects the fact that vertical mixing is greatest in the coastal ocean. Along many coastlines, also, there is a strong upward motion of cold deep waters from the thermocline, called "coastal upwelling." Strong seasonal coastal upwelling occurs off the shores of California (where this cold upwelling water makes surfers wear wetsuits), off Peru, off northwestern Africa, off Namibia, and in the Arabian Sea. In these areas productivity is especially high and fish are potentially plentiful. There is one important exception to this overall blue-ocean/green-ocean dichotomy: a strip of high productivity along the equator. The equatorial upwelling results from effects introduced by the rotation of the Earth, on the motion of water masses driven westward by the trade winds. It is especially strong in the eastern equatorial regions of the Pacific and the Atlantic, and high-sea fisheries are correspondingly intense in these regions.

Proxy - (n.)

In paleoclimatic reconstruction, a proxy is a measure of climate conditions of the past. A proxy (or proxy variable) yields clues as to temperature, precipitation, productivity, or other environmental conditions. Examples of proxies are: presence and absence of fossils; the abundance ratios of fossils; and the chemical composition of fossils, growth rings of trees and corals. Proxies can be classified according to the type of properties of a sediment they describe (physical, chemical, isotopic, or biological remains) or according to the target which they are supposed to represent. The first approach equates proxies (correctly) with sediment properties (e.g. oxygen isotope ratio in fossil shells). The second approach emphasizes climate-relevant parameters, such as temperature. Thus, in the case where proxies are classified by the targets they are thought to represent, we speak of temperature proxies, sea-level proxies, and rainfall proxies.

Punctuated equilibrium - (n.)

Proposition regarding evolution of life introduced by paleontologists Nils Eldredge and Stephen Jay Gould in 1972. It views evolution as a series of episodically branching speciations superimposed on long intervals of species stability (called a "stasis"). The idea is reminiscent of earlier ideas on the alternation of times of slow evolution with times of rapid species "radiation." All such concepts depend on whether the changes in morphology of fossils in presumed sequences of ancestors and descendants correctly reflects the rate of genetic change. Although this cannot be proven, it seems reasonable that the rate of change in a given lineage of organisms should not be constant, but should vary between slow and fast, presumably in response to changes in climate.

Radiocarbon - (n.)

Carbon-14 (^{14}C), radioactive with a half-life near 6000 years, is used as a tracer for assessment of rates of change and for dating. It is generated in the atmosphere, by interaction of ^{14}N with neutrons in cosmic radiation, and eventually decays back to ^{14}N. The ocean receives ^{14}C at its surface, through exchange of carbon with the atmosphere. Since its deep waters are isolated from the atmosphere, the loss of ^{14}C from decay is not replenished there. Thus, the distribution of radiocarbon in the deep ocean defines the age of deep water masses, their direction and rate of motion, as well as the overall mixing time of the ocean.

Radiometric dating - (n.)

Besides radiocarbon (see entry above), other radioactive isotopes used for dating are isotopes of uranium (U-238, U-235, with half-lives of 4.5 billion yr and 0.7 billion yr, respectively) beryllium (^{10}Be, with a half-life of 2.5 million yr) and potassium (^{40}K, some of which decays to argon-40 and has a half-life of

1.24 billion yr). The long-lived radioisotopes are mainly of interest to geochemists, but can also serve to date long-term climatic trends and events.

Ramanathan, Venkatarathnam -

Indian-born climatologist and a leader in research on atmospheric chemistry and radiation balance. He was one of the scientists who led the INDOEX (Indian Ocean Experiment) expedition, which investigated the impact of pollutants on climate change. He is currently a professor at the Scripps Institution of Oceanography at UC San Diego.

Redfield, Alfred -

(1890-1983): American oceanographer. He made major contributions to the understanding of the chemistry and fertility of the ocean. In particular, he is known for establishing the major patterns of composition in phytoplankton and demonstrating that the ratios of the main elements in marine organic matter are similar to those in seawater. Redfield wrote on physical oceanography, including tides, and he also wrote on the effects that deep circulation in the oceans has on the major patterns of nutrient chemistry of the ocean.

Reid, Joseph L. -

Physical oceanographer at Scripps Institution of Oceanography, UC San Diego. He conducted systematic mapping of the properties of the ocean including temperature, salinity, density, oxygen, phosphate, nitrate, and silicate distributions. He then constructed the motions of ocean water at the different depth levels from the distribution of these properties and made contributions toward understanding the great asymmetry in water mass properties between Pacific and Atlantic ocean basins.

Reservoir - (n.)

In geochemistry, a reservoir is the mass of an element (such as carbon) or a compound (such as water) within a defined �container� (such as the ocean or the atmosphere or the biosphere). The definition is arbitrary, in principle, but may coincide well with actually existing bodies on Earth (such as the ocean). Reservoir properties are �size� and �reactivity,� with the latter given as the ratio of input to size.

Residence Time - (n.)

In geochemistry, it is the average time spent by an atom or molecule with the reservoir, between the time it entered and exited it. Residence time is calculated by dividing the reservoir size by the input (or the output).

Revelle Buffer Factor - (n.)

The "buffer factor" compares the sensitivity of the two reservoirs, the ocean and the atmosphere, in their abilities to a change in their total carbon dioxide content. The value of the factor depends on the extent to which equilibrium with carbonate sediments has been achieved in a given situation. In a now-famous article published in the journal **Tellus** in 1957, Revelle and Suess applied previous scientists� work with their buffer factor to calculate the amount that CO_2 would increase over the century, and they expressed concern that �human beings are now carrying out a large-scale geophysical experiment of a kind that could not have happened in the past nor be reproduced in future.� The "buffer factor" was also discovered and discussed independently by a scientist named G.N. Plass.

Revelle, Roger R. -

(1909-1991): American geologist and geophysicist. He was a professor at the University of California, co-founder of the UC

San Diego campus, director of Scripps Institution of Oceanography (SIO) from 1950-1964, and director of the Institute for Population Studies at Harvard from 1964-1976. He led SIO into world-wide ocean exploration using an expanding fleet of ocean-going ships. In the 1950�s Revelle recognized the importance of studying the Earth�s carbon cycle and the impact of the emission of carbon dioxide by the activities of a growing human population, a process that he described as a "large-scale one-time geophysical experiment" with "the entire planet as laboratory."

Rossby, Carl-Gustaf Arvid -

(1898-1957): Swedish-American meterologist. He studied the wind field of the upper atmosphere using balloons and established circumpolar westerly winds at high altitudes in the polar front zone. When these winds are strong they cause a familiar sequence of cyclones and anticyclones in high temperate latitudes. However, when these winds are weak polar air can penetrate into low latitudes (i.e. jet stream control). His name is associated with �Rossby waves,� the circumpolar sinusoidal air currents found around a sequence of high and low pressure centers and commonly pegged on the Icelandic and Aleutian low-pressure areas.

Rubbish - (n.)

A term applied by some British philosophers (e.g. Bertrand Russell) to statements resulting from wishful or fuzzy thinking in scientific discussion (i.e. statements without scientific merit). To detect rubbish, it is useful to ask whether the purportedly scientific statement is based on goal-oriented thinking or disinterested scientific analysis and whether it is in any way useful in guiding further research or action. Both overemphasis on the uncertainty of a scientific theory (e.g. evolution) and the neglect of uncertainty (e.g. possible effects of global warming) can easily result in rubbish. Common candidates are statements offering a simple solution to complex problems (when correct, these are called "breakthroughs"). Other candidates are statements predictable from circumstances. For example, a study by the "Good-Smokes Institute" might come up with the finding that the pleasures of smoking greatly outweigh the potential costs in terms of health risks. Likewise, a study funded by the "Coal-Forever Research Institute" might be expected to discover that the use of coal has many proven benefits and comparatively few proven drawbacks.

Saltzman, Barry -

American climatologist currently at Yale University and a pioneer of modeling climate change. He has helped to develop a quantitative theory of large-scale climatic patterns and their evolution, based on the known laws of hydrodynamics and thermodynamics, taking into account the migratory high and low pressure systems of middle and high latititudes.

Sarnthein, Michael -

German paleoceanographer. He works on reconstruction of ice age climate from ocean sediments.

Schneider, Stephen H. -

American climatologist and a pioneer of three-dimensional climate modeling. He has written several popular books on climate change, including **Laboratory Earth: The Planetary Gamble We Can't Afford to Lose**. He was one of the scientists to speak out early on the risks associated with global warming.

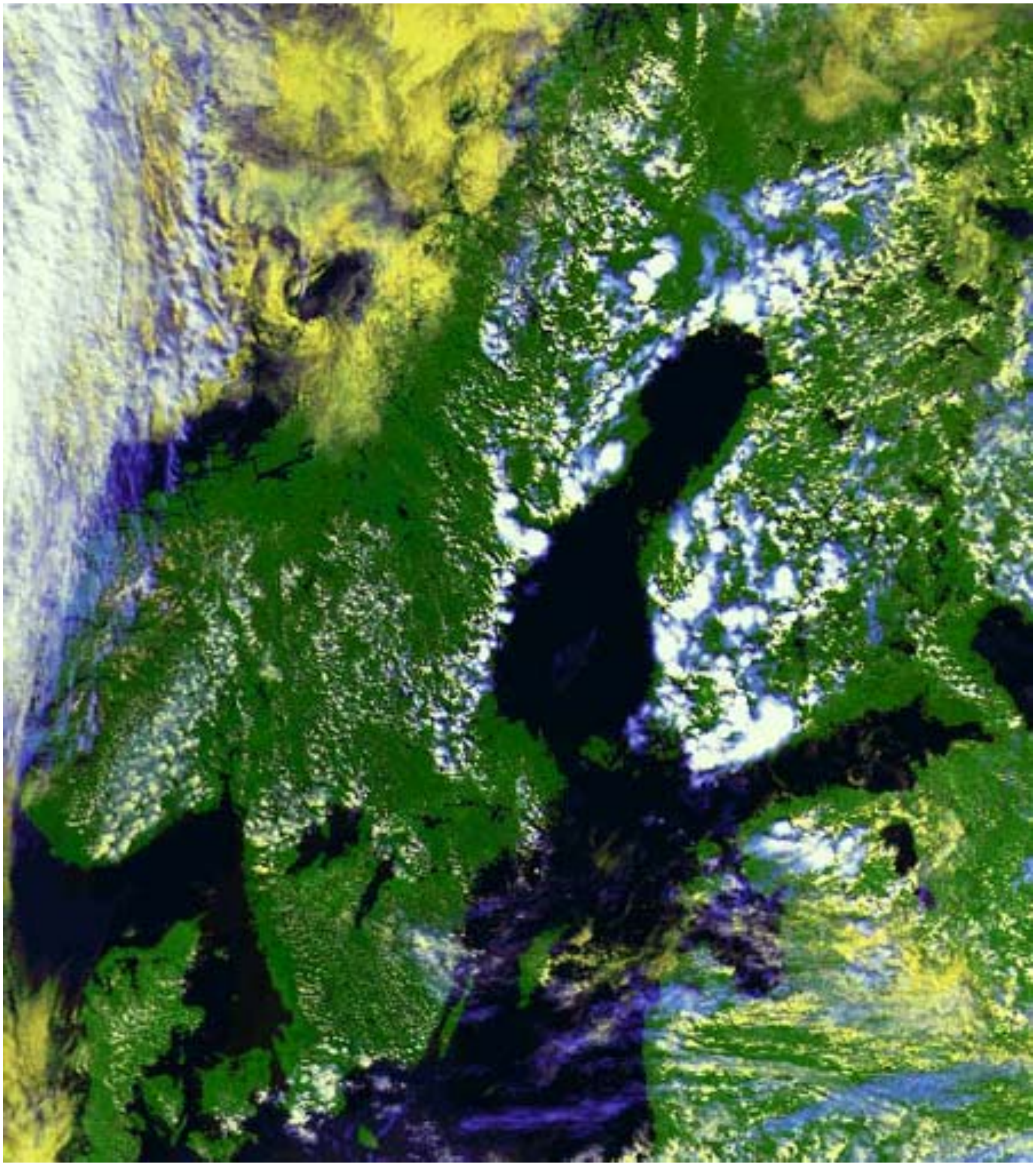
Scientific Notation - (n.)

Fraction	Prefix	Symbol	Multiple	Prefix	Symbol
10^{-1}	deci	d	10	decca	da
10^{-2}	cent	c	10^2	hecto	h
10^{-3}	milli	m	10^3	kilo	k
10^{-6}	micro	μ	10^6	mega	M
10^{-9}	nano	n	10^9	giga	G
10^{-12}	pico	p	10^{12}	tera	T
10^{-15}	femto	f	10^{15}	peta	P
10^{-18}	atto	a			

Sea breeze - (n.)

The sea breeze is the familiar gentle wind from the sea that one experiences on a warm summer day. During hot summer days, it brings relief to coastal dwellers by blowing marine air inland. In the later afternoon, the sea breeze dies, and sometime at night the wind reverses, producing a land breeze. Sea and land breezes are caused by the difference in heat capacity of sea and land surface. During the day, when the sun shines both on the ocean and on the land surfaces, the land heats up much faster than the sea. The air above the land is heated from below and expands. As it expands, it becomes **lighter** than the surrounding air masses, and it rises. This same principle moves air up the smoke stacks and lifts hot-air balloons. The light rising air exerts less pressure on the land surface than did the air at equilibrium. Consequently, a low pressure center develops on the land surface. Air moves in from the periphery, along the pressure-gradient, from sea to land and the sea breeze is created. The rising air over the land, incidentally, keeps expanding and cools as it moves to ever-higher altitudes, until it begins to lose water, eventually forming clouds. On satellite photos,like the one below, the rising air is commonly clearly marked by puffy clouds over the coastal region, with a perfectly clear sky over the land.

One reason for the unequal heating of land and sea is obvious: the great heat capacity of water. It takes 1000 calories to raise the temperature of one kilogram of water by 1°C, but only 200 calories to do the same for one kilogram of rock. Thus, given a certain influx of heat from the sun's radiation, a rock will warm up about 5 times faster than water. Conversely, rock will also cool faster at night compared with water. Consequently, the pressure gradient in the air reverses at night. Another reason for the unequal heating is both more subtle and more important than specific heat: the surface of the ocean, as far as diurnal heating is concerned, is much thicker than that of the land. The sunlight readily penetrates the ocean surface, and light is absorbed within a layer more than 10 meters thick. The thickness of the soil layer which is warmed by the sun (by downward conduction of surface heat) is more like 10 **centimeters**. The land surface is effectively more than 100 **times thinner** than the sea surface. Depending on the wetness of the soil, it is between 100 and 500 times less resistant to temperature change than the sea surface, given a certain solar radiation input. This makes it clear why diurnal temperature ranges in the deserts of California can readily go over 30°C, while those of the nearby ocean will rarely exceed a fraction of one degree.



Seasons - (n.)

The seasons in the middle and high latitudes depend on the variation in sunlight received throughout the year, as a result of the inclination of Earth's axis relative to the orbital plane. At northern summer solstice, the north pole of the Earths axis points toward the Sun, so that the Sun reaches its highest noontime position in the northern sky, being directly overhead at 23.5°N, at the tropic of Cancer. The day of northern summer solstice has the longest daylight in the year in the northern hemisphere, with the shortest night. At winter solstice, the north pole of the axis points away from the Sun, and the Sun reaches its lowest noontime position in the northern sky, being directly overhead at 23.5°S, at the tropic of Capricorn. The day of northern winter solstice has the shortest daylight on the northern hemisphere, and the longest night in the year. At equinox, the Sun is directly overhead at noontime on the Equator. The equinox following winter is called spring equinox, the one following summer is the fall equinox. During equinox, day and night are exactly of equal length everywhere on Earth. The seasons on northern and southern hemispheres are exactly opposite. The tropic of Cancer and the tropic of Capricorn get their names from a time when summer and winter solstice were reckoned by following the path of the Sun through the constellations of the zodiac, in the sky, rather than by looking in a printed calendar, as we do now. Though no longer the case, at that time the Sun was in the constellations Cancer and Capricorn during northern summer and winter solstice, respectively. (Puzzle: When was that?) Questions to ask yourself: How high above the horizon is the Sun at noon in Boulder, Colorado, on the day of northern summer solstice (Hint: Boulder is at 40°N.)? What about Oslo, Norway? From where can the midnight sun be seen on that day? How high above the horizon is the Sun at noon, in Boulder, on the day of northern winter solstice? What about Oslo, Norway? From where can the midnight sun be seen on that day?

Sellers, W.D. -

American climatologist. He was one of the first to apply mathematical climate models based on radiation balance.

Sensible heat - (n.)

The energy contained in a warm body, relative to a cold body of the same material and mass. Warm water that is heated in the tropics and cooled in high latitudes brings sensible heat toward the pole. Warm winds carry sensible heat from one place to another.

Shackleton, Ernest -

(1874-1922): Explorer famous for the failed **Endurance** expedition, which set out to the Weddell Sea in 1914 to land on its southern shore in an attempt to cross the Antarctic by sled. His ship was crushed in the pack ice, and the expedition members consisting of Shackleton and a crew of 27 men spent the winter on ice floes until they reached Elephant Island off the end of Palmer Peninsula. From there Shackleton set off with five selected men to cross the Drake Passage in a 22-foot boat, to reach the South Georgia Islands and find help for a rescue operation. Against all odds, all men were rescued and reached England safely. (For more information see the book, **Endurance**, by A. Lansing, Carroll and Graf, New York, 1959.)

Shackleton, Nicklas J. -

English paleoceanographer. Working with scientists from Lamont-Doherty Earth Observatory, he has applied Milankovitch theory to the reconstruction of ice age cycles from deep-sea sediments with emphasis on chronology. He has also contributed to our understanding of the marine carbon cycle by applying the carbon isotope record and extended high-resolution climate stratigraphy into pre-Quaternary time by applying Ocean Drilling Program materials.

Scripps Institution of Oceanography (SIO) - (n.)

The largest and oldest of the oceanographic institutes in the United States, SIO is engaged in a wide variety of studies concerning the solid Earth, the ocean and the atmosphere. Its prominent research includes the circulation of the ocean, waves and tides, earthquakes, carbon cycle chemistry, atmosphere and climate, ocean productivity, marine bacteria, and ocean sediments. Founded in 1903, its most renowned directors were the Norwegian oceanographer Harald U. Sverdrup (1888-1957) and the American geologist and geophysicist Roger R. Revelle (1909-1991).

Smagorinski, J. -

American climatologist who helped pioneer climate physics and modeling in the 1960s.

Solar constant - (n.)

The amount of energy received from the Sun at the top of the atmosphere, per time unit and per unit area. The value of the constant is near 2 cal/cm^2 per second, which corresponds to about 1350 watts per square meter. The solar "constant" is actually thought to vary by at least 0.1 percent on time scales of decades and perhaps by as much as 0.5 percent on time scales of centuries.

Solomon, Susan -

American atmospheric chemist. She is a leader in research on the ozone hole in the Antarctic. She led the team of scientists that measured chlorine dioxide, which was among the first chemical observations showing that chlorine from chlorofluorocarbons was the cause of the ozone hole.

Some Chemical Symbols - (n.)

O_2: molecular oxygen

O_3: ozone

N_2: molecular nitrogen

N_2O: nitrous oxide

NO: nitric oxide

NO_3: nitrate radical

NO_x: Sum of NO and NO_2

NO_3- : nitrate ion

HNO_3: nitric acid

NH_3: ammonia

NH_{4+} : ammonium ion

H_2: molecular hydrogen

H_2O: water

OH: hydroxyl

HO_2: hydroperoxyl

HO_x: the sum OH and HO_2

C: carbon; there are 3 isotopes: ^{12}C, ^{13}C, ^{14}C

CO: carbon monoxide

CO_2: carbon dioxide

F_2: molecular fluorine

Cl_2: molecular chlorine

Br_2: molecular bromine

CFC: chlorofluorocarbon

CFC-11: $CFCl_3$ or trichlorofluoromethane

CFC-12: CF_2Cl_2 or dichlorodifluoromethane

CFC-113: $C_2F_3Cl_2$ or trichlorotrifluoroethane

CFC-114: $C_2F_4Cl_2$ or dichlorotetrafluoroethane

CFC-115: C_2F_5Cl or chloropentafluoroethane

Spectrum - (n.)

A plot of wavelengths (or equivalent measures of cyclicity) against amplitude (or other measures of energy content). For visible light, the spectrum includes all colors between violet and dark red. For electromagnetic radiation, the spectrum includes everything from gamma radiation and x-rays to radio waves, with visible light in between. For water waves, the spectrum includes everything between wind ripples to tides. For seismic waves, the spectrum ranges from barely noticeable vibrations to the great long-wave oscillations that are so dangerous to buildings. For climate fluctuations, the spectrum spans the gamut from daily temperature fluctuations to annual seasons to the great ice age cycles. Everything we know about distant stars and galaxies comes from analyzing the spectrum of their electromagnetic radiation, and almost everything we know about the interior of the Earth comes from analyzing the spectrum of various types of seismic waves. The mathematics of spectral analysis are based on the work of the great French physicist and mathematician J.B. Fourier (1768-1830).

Starr, V.P. -

American climatologist who completed classic studies on the physics of climate.

Suess, Hans -

(1909-1989): Austrian-American chemist. He determined the amount of radioactive carbon in the ocean to find out how fast carbon dioxide in the atmosphere exchanges with the ocean's reservoir. Suess also worked on the radiocarbon content in tree-rings, finding a short-term variability (called "Suess wiggles") which he explained as indicating that climate changes occur on a decadal scale.

Sverdrup, Harald U. -

(1888-1957): Norwegian oceanographer and Arctic explorer. A professor of geophysics at the University of Oslo and director of the Norsk Polarinstitutt and director of Scripps Institution of Oceanography from 1936-1948. Sverdrup made fundamental contributions to the understanding of the circulation of the ocean and was the lead author of the textbook that defined the modern field of oceanography (Sverdrup, H. U., M. Johnson, R. H. Fleming, **The Oceans, their physics, chemistry, and general biology**. Prentice-Hall, Englewood Cliffs, 1942.).

Temperature Units - (n.)

Degrees Celsius (°C): Introduced by a Swedish astronomer, Andres Celsius, 1°C is defined as 1/100 of the temperature difference between water freezing point and boiling point by a pressure of 1 atmosphere. The thermometer freezing point is 0° and the boiling point is 100°.

Degrees Fahrenheit (°F): Named for the German-born scientist, Gabriel Daniel Fahrenheit, 1 °F is defined as 1/180 of the temperature difference between water freezing point and boiling point. The thermometer freezing point is 32° and the boiling point is 212°.

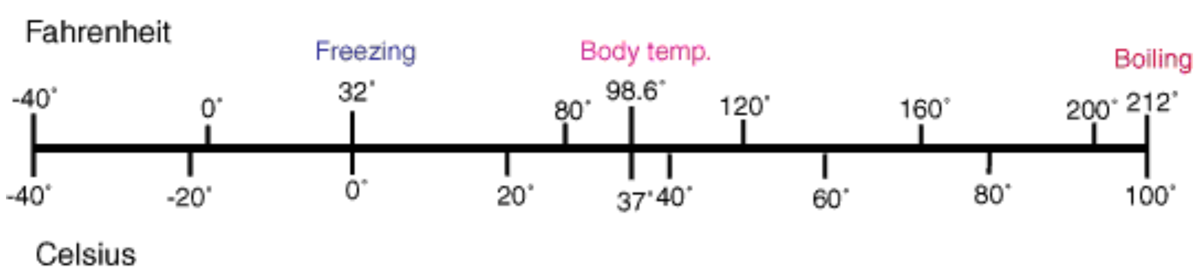
Degrees Kelvin (°K): Invented by William Thomson, Lord Kelvin, a 19th Century British scientist, this scale is based upon the fact that the coldest it can get (theoretically) is -273.15 degrees Celsius. The value, -273.15 degrees Celsius, is called "absolute zero." At this temperature it is thought that molecular motion stops. Since it cannot get any colder than 273.15 °C, the Kelvin scale uses this number as zero. Its unit, the degree Kelvin, is equal to the degree Celsius.

Conversion Equations:

To convert Fahrenheit to Celsius use:
Celsius = (Fahrenheit 32) * 5/9

To convert Celsius to Fahrenheit use:
Fahrenheit = (Celsius * 9/5) +32

To convert Celsius to Kelvin use:
Kelvin = Celsius + 273



Thermocline - (n.)

A rapid change in the temperature of water from the ocean surface to the ocean floor.

Thermokarst - (n.)

a range of features formed in areas of low relief in the tundra when permafrost with excess ice thaws. Thermokarst terrain is made of irregular depressions and include features such as mud flows on sloping ground and other forms of thaw settlement that account for many of the engineering problems found in tundra landscapes. Global warming may result in irregular melting of the permafrost, resulting in an increase in this terrain. See also permafrost.

Time Units - (n.)

bp: (years) before present

kbp: thousands of years before present

mbp: millions of years before present

Toon, Brian O. -

American climatologist who modeled the climate that would result from a "nuclear winter."

Trade winds - (n.)

Air flow from east to west and toward the equator (or the Intertropical Convergence Zone) roughly in the zone between the tropics of Cancer and Capricorn, although it can blow somewhat beyond those latitudes in some places. The trades got their name from English sailors, for their steadiness (as in the phrase, "the wind blows trade," i.e. on track). See also General Circulation of the Atmosphere.

Upwelling - (n.)

Upwelling is a process whereby cold water from below the warm surface layer comes to the sunlit zone, where the cold nutrient-rich water causes much growth of microscopic plankton, which feeds zooplankton, which in turn feeds fish. Upwelling regions, therefore, are favorite fishing areas. Most of the upwelling in the ocean occurs in two settings: along the shores bathed by eastern boundary currents (the eastern portions of the great central gyres) and along the equator. Normally, the upwelling water derives from depths between 100 and 300 m, a factor that depends on the strength of the upwelling motion. Upwelling is driven by winds and both the coastal upwelling along the eastern boundary currents and equatorial upwelling rely on the trade winds. See also Coastal Upwelling.

Ultraviolet light - (n.)

Also known as UV light, this form of electromagnetic radiation is emitted by the Sun and is invisible to the naked eye. Lying in the electromagnetic spectrum between violet light and X-rays, UV light can be harmful to living organisms, most notably by damaging DNA. UV light comes in three main forms: UV-A, UV-B, and UV-C. UV-C is the shortest and most dangerous wavelength, but it is largely absorbed by the Earth's ozone layer. UV-A, a longer wavelength, usually induces skin tanning in humans, while UV-B, a shorter wavelength, causes sunburns and is most often associated with skin cancer in humans. While the Earths ozone layer absorbs about half of the UV-B radiation, UV-A radiation is not absorbed by our atmosphere.

van Loon, Harry -

(born 1925): Climatologist who has made contributions to the understanding of climate oscillations.

Vernadsky, Vladimir -

(1863-1945): Russian geochemist and mineralogists. He introduced the notion that life processes control the chemistry of the surface of the Earth and is regarded as the founder of the theory of the biosphere.

Wallace, John M. -

Climatologist at the University of Washington. His work has improved our understanding of global climate and its year-to-year and decade-to-decade variations, including ENSO and climate oscillations, by making use of observational data.

Warm pool - (n.)

In the western equatorial Pacific, this is a region of warm surface waters with a temperature close to 29°C (85°F) and covers an area roughly the size of North America. Normally, the warm pool is fed by Pacific trade winds moving warm tropical surface waters to the west, piling it up in the region between Indonesia, the Philippines, and New Guinea. Warm water gives off heat and moisture to the atmosphere, so the western tropical region becomes a great center for convection and rainfall on the globe. Also, the heat from the warm pool feeds energy to tropical storms there. For reasons yet unknown, during certain years, the trade-winds weaken, and warm surface water is no longer carried westward. On the contrary, the piled-up warm-pool water starts moving east, taking the convection region with it. The surface waters in the eastern region become warm, and now suddenly the tropical storms occur in the region of Tahiti. The coral there suffer from being too warm, and shed their color-giving algal symbionts. In contrast, drought strikes in the western areas, which are no longer in the convection center (e.g. New Guinea and Indonesia). This change in condition produces the "El Niño" effect. See also El Niño

Washington, W. M. -

Climatologist at NCAR (National Center for Atmospheric Research) in Boulder, Colorado. He is a leading expert in three-dimensional modeling of climate change.

Water and heat storage - (n.)

How does water react to heating or cooling? How much energy can it store? It turns out that water is much more efficient in storing heat than any other common substance on Earth. To increase the temperature of fluid water by one degree Centigrade takes one calorie of heat energy for each gram of water. To do the same for a rock, for comparison, takes 0.2 calories per gram, and for petroleum requires 0.5 calories per gram. To change a gram of ice into water (without increasing the temperature) takes 80 calories. Conversely, when water freezes, it releases this amount of heat into the environment. To change a gram of water into vapor takes 580 calories. This means that evaporation is the best cooling mechanism around! Our body takes advantage of this fact when cooling itself by sweating: the evaporation of the sweat extracts heat from the surroundings, lowering the temperature of the skin. The heat expended in the **phase change** of water to vapor is not lost, but is contained in the vapor in a **latent** form. When the vapor condenses, the heat is freed for warming the surrounding air. This release of heat during condensation is the ultimate driving force for hurricanes.

The phase changes of water combined with its unique heat-related properties are intimately involved in all aspects of climate and weather. Water transfers and stores heat on an immense scale, and thereby evens out the temperature differences between day and night, summer and winter, and tropics and polar areas. Consider the temperature differences between day and night: they are largest in the water-starved desert, whereas in areas where water is abundant evaporation during the day tends to lower the temperature, and condensation during the night (the familiar dew) tends to raise it. During the day, clouds protect the ground from the heat of the sun, and at night, from the black coldness of space. Seasonal differences are similarly tempered by the great heat reserves of water, hence the mildness of coastal climates. Likewise, geographic differences are moderated by the transfer of heat through water motion and water phase changes. Most of this transfer is by water vapor in the air. Warm winds blowing over warm ocean regions pick up the water, cooling the sea surface. In cold regions, the air becomes unable to hold the vapor. The vapor condenses and gives off its heat of **evaporation**. If it freezes to snow, it also gives off its **heat of fusion**, to the surrounding air. Thus, a blizzard brings warmth: a somewhat unexpected conclusion, perhaps, to those who have been surprised by a snowstorm during a hike in the mountains.

Westerlies - (n.)

Near-surface winds blowing from the west, toward the equatorial portion of the "polar front" regions, where cold air from high latitudes meets the warmer air from the temperate latitudes. Westerlies typically carry cyclonic disturbances eastward.

Wyrtki, Klaus -

Oceanographer at the Geophysical Institute in Hawaii. He has pioneered studies on the ENSO phenomenon in the central Pacific.

Zooplankton - (n.)

A large variety of non-photosynthesizing organisms comprise the zooplankton, creatures that drift with the currents at all depths in the ocean. Zooplankton is concentrated especially in surface waters, where they feeds on phytoplankton. The smallest zooplankton consists of unicellular organisms such as foraminifers and radiolarians. The most commonly caught zooplankton, using nets with a mesh of 0.5 mm, consists of various kinds of copepods and other small crustaceans, like Antarctic krill. The largest zooplankton are among the jellyfish, which reach a diameter of several feet, and trail tentacles tens of feet long to ensnare smaller zooplankton and small fish.