- Maintaining a global network of individuals working at government level, or in institutes, universities and nongovernmental organizations that lecture on environmental health and/or supervise applied research on the health effects of environmental hazards.
- Encouraging the development of national networks of epidemiologists.
- Establishing and strengthening local education and training relating to environmental health hazards and their control; including strengthening of university programs and courses, provision of short training workshops for public health staff and seminars on specific problems, provision of training kits, and 'training of trainers'.
- Facilitating the development of new and improved applied epidemiology research in order to study and resolve local environmental health problems, including provision of advice and information on methodology, funding, undertaking of similar studies elsewhere, research recommendations and cooperative projects.
- Identifying and supporting in each Member State one or several main libraries willing to establish Environmental Health Reference Collections.
- As an information resource on environmental health for the use of all network members in their respective geographic areas.

GEENET's focus is the collaborative activities among members. These are supported by the global coordination centers at WHO headquarters and the environmental health staff in the six WHO Regional Offices. See the website at `http://www.who.int/peh/geenet/`

(*See also* **Reproductive epidemiology**; **Respiratory epidemiology**; **Spatial statistics in environmental epidemiology**)

ABDEL EL-SHAARAWI

Global warming

Global warming refers to the increase of the air temperature near the earth's surface, but the term 'global warming' does not indicate the causes and magnitude of the increase, nor does it imply continuity of the warming into the future. The temperature increase in the last 140 years has mainly been observed through thermometers placed about 2 m above the ground, although numerous other observations also exist, such as sea surface temperature, plant growth, and snow fall. The global average annual mean temperature has increased about half a degree Celsius. This increase, however, is not uniform throughout the world. Some places have had larger temperature increases than others, and some places have even undergone a decrease.

Global warming can have a significant impact on life on earth, although the significance has never been statistically tested. The warming may cause a rise of sea level, more frequent severe weather, redistribution of food systems, extinction of plants and animals, generation and propagation of diseases, increase of crop yield, to name but just a few possibilities.

Global warming has numerous unanswered questions. When did the earth start warming? What is the accurate assessment of the warming magnitude, given a time period? What are the causes of the warming? Will the last century's warming continue to the next century or oscillate back to a cooling period? These are extremely difficult questions, but should be answered in order to predict our future living environment.

Observed Increase of the Earth's Surface Temperature

Figure 1 shows the temperature increase from 1856 to 1999, observed by thermometers over the land areas, including island stations [4]. The curves show the change of the temperature deviation from the temperature normals, which were defined as the mean of the 1961–1990 records. The upper panel demonstrates the northern hemisphere average of the deviation, the middle panel shows the southern hemisphere average, and the lower panel is the global average. Curves like these have been compiled and published by several internationally recognized groups. The groups used different methods of computing temperature deviations and global average, but the difference between all the assessments is small, because all the groups used essentially the same raw data. All global averages indicate an increase of global average annual mean temperature of 0.3–0.6 °C. However, this range

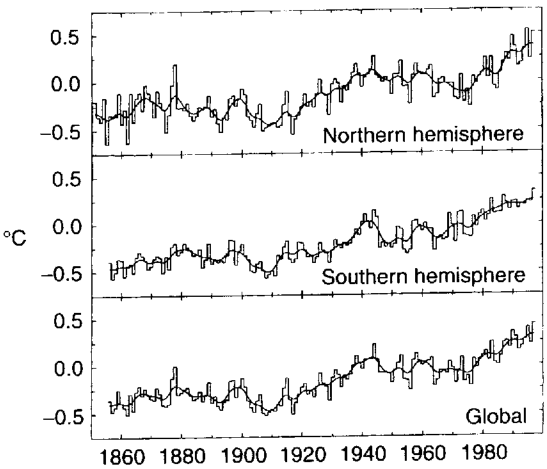

Figure 1 Annual hemispheric and global averages of surface air temperature anomalies (°C), relative to 1961–1990 mean. Reproduced from `www.cru.uea.ac.uk/cru/data/temperature/hemglob.gif` by permission of P.D. Jones

needs an explanation. First of all, this range is too large to assess accurately the global change. Second, it is still not certain what the error bar size is corresponding to this increase assessment. The 1995 Intergovernmental Panel for Climate Change (IPCC) report took a conservative value for the error bar: 0.1–0.15 °C. Modern statistical methods may reduce this error to a much smaller value. Third, the raw data that went into the calculations cover only the land, but 70% of earth is covered with ocean; hence the sea surface temperature, both air and water, should be included in the spatial average. The sea surface temperature, in the past collected by small commercial vessels, can contain systematic bias and the inclusion of these data may result in artificial trends.

Even land observations have systematic bias. The most important bias is the urban heat island effect. The name comes from the fact that observation stations are traditionally located just outside urban areas, typically at airports. It is well known that cities are warmer than the surrounding countryside due to intense human urban activities. City margins gradually grow out toward the airport. The temperature readings show a steady increase. Since urban areas make up only a very small fraction of the earth's surface, this increase is merely because warm cities are encroaching on the fixed observing stations, and does not represent a global trend. Such an urban heat island effect can account for as much as 0.15 °C in the record in the last 150 years, and should be removed when evaluating the data for the curves in Figure 1.

The oscillations in the records are noteworthy. As indicated in Figure 1, the temperature does not increase monotonically; rather it has ups and downs in essentially random periods. This is the so-called natural variability of the earth's climate system (*see* **Climatology**). The most noteworthy of these oscillations is the cooling trend in the northern hemisphere beginning in the 1940s and lasting over 20 years. This trend is absent in the southern hemisphere. Examination of individual station records suggests that the cooling was mainly localized in the Arctic and may have something to do with the Arctic Ocean overturning and the corresponding amplification in the surface temperature by sea–ice feedbacks (*see* **Global circulation**). This appears to be an example of how natural variability can delude us into thinking that a trend has slackened or reversed. (In fact, at the time some careless spokesmen were suggesting a return to Ice Age conditions). These cries ended in the 1970s when it became clear that temperatures were on the rise again in the northern hemisphere.

Another example of natural variability is cooling due to the increase of stratospheric (*see* **Meteorology**) (about 10 km in altitude) aerosol particles, which reflect some solar energy into space and hence prevent some sunlight from reaching earth. Volcanic eruption is the major source of this type of aerosol particle, which can be suspended in the atmosphere for about two years. There was a huge eruption of Mount Pinatubo in the Philippines on 12 June 1991. The fine particles of sulfur oxide compounds were injected into the stratosphere and spread over the tropics and midlatitudes. The global surface temperature of 1992 was lower than those of 1990, 1991, 1993, 1994 and 1995, which is certainly due to the volcanic eruption. Thus, more frequent volcanic eruptions may tend to cool the earth's surface.

While one cannot be unequivocal about it, we can surmise from the curves in Figure 1 that a warming of about 0.5 °C has taken place in the last century. But could such a warming be due to natural variability, as in the cooling from the 1940s to 1970? The answer is probably no. Indeed, the temperature record has considerable uncertainty, but the sharp trend in the 1980s and 1990s and the increase of 0.5 °C in a century are extremely rare. The probability of a warming of 0.25 °C in a century as a result of natural variability is perhaps less than 1/100 [6].

Greenhouse Theory and Greenhouse Gas

Solar energy, consisting of short waves, penetrates through the atmosphere and heats the earth's surface, driving weather and climate. The heated earth, in turn, radiates energy back into space via long-wave radiation. Atmospheric greenhouse gases, like water vapor and carbon dioxide, trap some of the outgoing energy, retaining heat somewhat like the glass panels of a greenhouse. Thus, one may regard the earth's biosphere as a big greenhouse and its long-term mean temperature has a small variation, if not perturbed by dramatic forcings.

The amount of solar energy impinging on the earth is about 340 watts per square meter. Measurements from satellites (*see* **Remote sensing**) indicate that 30% of this energy is reflected directly to space by clouds and other bright features of the earth–atmosphere system. Hence, about 238 watts per square meter (about the heating capacity of a good reading lamp) are absorbed into the climate system and can be used to heat the earth's surface and drive weather and climate. If there was no mechanism to release this heat, the earth's surface temperature would continue to rise, and liquid water exposed at the surface would continue to evaporate indefinitely.

The heated earth releases energy back into space via infrared radiation at a rate that increases as the earth's temperature increases. Subtracting from the energy trapped by greenhouse gases, the net outgoing radiation is about 238 watts per square meter, another fact established by satellite measurement. This outgoing radiation balances the incoming solar energy, also 238 watts per square meter, and maintains the earth's surface temperature around its equilibrium of about 15 °C (59 °F).

If the greenhouse gases were absent, the earth would radiate heat directly into space at a rate of 384 watts per square meter, far exceeding the 238 watts per square meter absorbed. This would lead to a cooling until a new equilibrium state, at which the surface temperature would be −25 °C. The earth would be ice-covered and uninhabitable.

An increase of the amount of carbon dioxide in the atmosphere leads to more outgoing energy being trapped. Doubling the carbon dioxide in the atmosphere reduces the outgoing radiation by 4.2 watts per square meter, according to standard atmospheric theory. We estimate that this retained energy would result in about 2 °C of surface warming. But how good is this atmospheric theory, and how long does the adjustment to the new equilibrium take? Neither question has been answered yet. Our calculation of 2 °C is only a ballpark estimate (it could be as large as 4 °C or maybe as small as 1 °C), and the adjustment time could vary from a few years to many decades [6, 7]. (*See* **Radiation and radiative transfer** for experiments on doubling carbon dioxide in general circulation models for the atmosphere.)

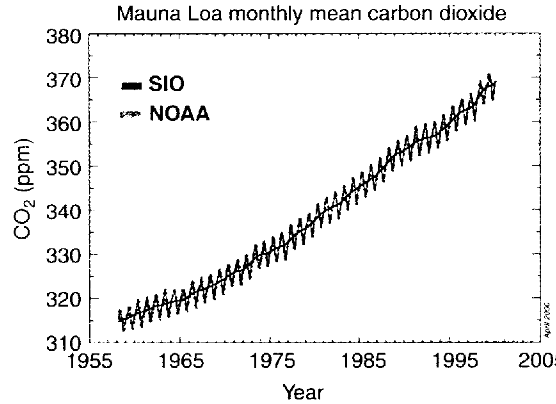

Figure 2 Monthly data of atmospheric carbon dioxide concentration (ppmv = parts per million in volume) taken at Mauna Loa, Hawaii. Reproduced from `www.cmdl.noaa.gov/ccgg/figures/co2mm_mlo.gif` by permission of NOAA/CMDL

Figure 2 shows the steady increase of atmospheric carbon dioxide concentration at Mauna Loa, Hawaii, since 1958. The seasonal oscillation is due to the annual rhythm of the biosphere. Carbon dioxide is released by decaying matter and then taken up during the growing season. During the last two and half centuries, the proxy data derived from the Greenland ice core also show a monotonic increase of the concentration of carbon dioxide and this increase has accelerated in the twentieth century. Figure 2 shows that the carbon dioxide concentration increases at a rate of 0.5% per year. At this rate, the carbon dioxide concentration will double in 140 years.

Climate Models

The future climate may be predicted and the past climate may be simulated by solving mathematical models for climate. When doubling carbon dioxide concentration, the models can help to find some detailed climatic responses, such as the sea level along the east coast of the US, or surface air temperature in western Canada.

A climate model includes a set of governing equations, which can be differential, integral or algebraic equations and describe dynamics of atmospheric motion and physical processes of climate, and a set of initial and boundary conditions, which are determined by observable climate parameters. Various types of climate models exist. In terms of complexity, the models may be classified as simple, such as an energy balance model, and complex, such as a general circulation model [1] (*see* **Global circulation**). In terms of calculation domain, the models may be classified as atmospheric models and atmosphere–ocean coupled models.

These models are discretized onto grid cells in the modeled domain. The boundary and initial conditions are obtained from various observations, including surface weather stations, satellite sensors, radars, radio sounding, and ocean buoys. These observations are interpolated onto the grid cells. The algebraic equations on all the grid cells are solved by computers.

The first numerical model for weather (*see* **Weather prediction**) was set up by Lewis Fry Richardson, an English mathematician, and was published in 1922. Operational numerical forecasting was not possible until the 1950s when electronic computers became available. Despite various kinds of physical and dynamic processes included in different models, every model has a common feature of the climate feedback mechanism, which amplifies or diminishes the climate system's responses to an external disturbance. The most important feedback is the water vapor. A warmer atmosphere induces more evaporation from surfaces of water and wetlands, hence more water vapor enters the atmosphere resulting in higher greenhouse gas concentration, and, consequently, a warmer atmosphere. Thus, this water vapor feedback is an amplifying, or positive, feedback.

The global average of surface temperature and sea level are the two most important climate parameters modelers have tried to predict under the condition of the 1992 carbon dioxide emission level. Models predict a 1.0–3.5 °C increase of surface temperature by 2100 relative to 1990, and the temperature will start to decrease around 2150. The sea level will increase 15–95 cm by 2100 [3].

The error of climate model forecasting has decreased linearly since the 1960s. However, the errors in the model results are still so large that modeling products are always subject to further scrutiny. The errors come mainly from the following three aspects: imperfect or incorrect modeling of physical processes, nonlinearity in the dynamics, and incomplete observations for initial and boundary conditions.

Impacts of Global Warming

Global warming may force a complex network of changes, including ecological systems, food structure, and human living conditions. Warmer temperatures may reshape the freshwater supply system. Faster evaporation due to warmer temperature may dry certain wetlands and freshwater and the heavier precipitation may result in more freshwater in other areas. Water is essential to life. Although it is unknown whether the total amount of freshwater will be reduced, the natural system of freshwater will change, which may force changes in lifestyle, or migration.

A rise of sea level in the next 100 years, although predicted to be less than 95 cm, can cause huge problems for people who live along the coast and on low land in river delta areas. The sea level rise can exacerbate the damage caused by more severe and frequent storms (*see* **Meteorological extremes**), the severity and frequency of which are also increased due to global warming. Regions like Bangladesh and the Nile delta area of Egypt may suffer seriously from sea level rise and severe storms. Bangladesh's storm surge in November 1970 is probably the largest of the world's **natural disasters** in recent times [2].

Warmer temperature may convert dry land into desert. The rate of desertification is currently about 60 000 square kilometers per year or 0.1% per year of the total dry land area (*see* **Soil conservation and remediation**).

Warmer temperature may facilitate the spreading of diseases and increase heat stress in summer. Most insects that carry diseases survive better in warmer temperature. Due to the increase of daily minimum temperature, which is one of the main effects of global warming, consecutive excessively hot summer days cannot get a chance of cooling, thus increase heat stress. The enhanced heat stress has proved to be particularly harmful to old people.

Warmer temperature can also have positive impacts. Increased carbon dioxide concentration can make plants fix carbon at a higher rate and produce better fertilization, and hence generate an increased yield. Plant-growing areas in the northern hemisphere may in the future be extended to the north, which may result in more food supplies.

Detection and Attribution of Global Warming

Global warming detection involves proving or disproving the statistical 'null' hypothesis that an observed change in surface temperature can be explained by natural variability. If the hypothesis is rejected, then we conclude that the forced surface temperature change is detected at a certain statical significance level (*see* **Trend, detecting**). Although the global average annual mean surface temperature has increased 0.3–0.6 °C in the last 100 years and the rate of increase was unusual, it is still to be shown that the forced increase is statistically significant at a 5% significance level.

Global warming attribution is to find causes of the forced temperature change if detected. This requires separating the temperature change signal due to anthropogenic forcing from the natural variability. This cause-and-effect can be studied by numerical models or a statistical filter. The model can simulate the 'effects' when various kinds of combinations of 'causes' are input into the model. The 'causes' may include concentration of carbon dioxide, anthropogenic aerosol, and varying land surface properties. So far, the last century's warming has not been definitely attributed to certain greenhouse gases, although carbon dioxide is suspected to be the major cause. The uncertainty of the conclusion is due to imperfect models, incomplete observations, and nonlinearity.

The cause-and-effect can also be studied by the method of filter and iteration. An optimal filter may be designed to separate the forced signal from natural variability [5]. The filter is constructed based upon the initial information of natural variability and climate signal, which may be obtained from simple climate models and imperfect observations. Then the filter is applied to the observed data and separates the forced signal from natural variability. The separated signal and variability may be used to improve the filter, and the application of the new filter may improve the signal separation. This method may be effective for separating a strong signal from background noise, but still needs further improvement to clearly attribute the global temperature change to anthropogenic forcing.

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(*See also* **Global environmental change**; **Hydrological extremes**; **Meteorology**; **Trend analysis**)

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Goodness of fit *see* Phi-divergence statistic

Graphical displays

The purpose of environmental visualization via graphical displays is to facilitate scientific and public understanding of environmental status, trends, and processes. Such understanding is incremental owing to: