

Climatology

Climatology, once the study of ‘average weather’, now encompasses the atmosphere, hydrosphere, cryosphere, land surface and biosphere [1]. Modern climatology includes not only these components but importantly their interactions involving detailed global observing systems and complex computer-based numerical models. People’s interest in climatology has been and is likely to continue to be concerned with social issues of habitability and **sustainability**. We tend to evaluate climate in personal terms: Is it too hot or too cold? Is the air pleasant to breathe? Is there enough water for drinking and for growing crops? Does it feel comfortable? These characteristics are interdependent, together forming the climate system and posing a larger question: Can this planet continue to sustain life?

Today, the atmosphere is undergoing global changes unprecedented in human history (*see* **Global environmental change**) and, although changes as large as those that we are witnessing have occurred in the geological past, relatively few have happened with the speed which also characterizes today’s climate changes. Concentrations of greenhouse gases are increasing, stratospheric **ozone** is being depleted and the changing chemical composition of the atmosphere is reducing its ability to cleanse itself through oxidation. These global changes are threatening the balance of climatic conditions under which life evolved and is sustained. Temperatures are rising, ultraviolet radiation is increasing at the surface and pollutant levels are increasing. Many of these changes can be traced to industrialization, **deforestation** and other activities of a human population that is itself increasing at a very rapid rate. Climatology today embraces the study of all these characteristics, components, interactions and feedbacks [2].

Global climate system changes resulting from human influence have been described as ‘climatological catastrophes’. They are slow to develop and, therefore, may not become apparent until their effects have become dangerously advanced. The iconic example of a modern ‘climatological catastrophe’ is the 1985 British discovery of declining ozone abundance over the Antarctic station of Halley Bay. Research showed that the so-called Antarctic ozone hole had been increasing in depth since the late 1970s and today stratospheric ozone concentrations at the

South Pole in spring (October) are less than half of their values only 30 years ago [5].

Climatology is concerned with the study of chemical changes and with the radiative balance of the earth. Trace gases emanating from human activities today equal, and perhaps even exceed, emissions from natural sources (*see* **Trace gas emissions**). Some, the greenhouse gases which absorb infrared radiation (water vapour, carbon dioxide, ozone, methane, nitrous oxide and the chlorofluorocarbons (CFCs)), play a major role in the earth’s energy budget and climate through the greenhouse effect [3, 4]. The earth’s radiative budget is controlled by the amount of incident solar radiation that is absorbed by the planet and by the thermal absorptivity of the gases in the atmosphere which controls the balancing emitted infrared radiation (*see* **Radiation and radiative transfer**).

Radiation from the sun drives the climate of the earth and, indeed, of the other planets. Solar radiation is absorbed and, over the mean annual cycle, this absorption is balanced by radiation emitted from the earth. This global radiative balance, which is a function of the surface and atmospheric characteristics, of the earth’s orbital geometry and of solar radiation itself, controls the habitability of the earth, mean temperatures, the existence of water in its three phase states. These characteristics, together with the effects of the rotation of the earth on its axis, determine the dynamics of the atmosphere and ocean, and the development and persistence of snow and ice masses. Over very long time-scales, those commensurate with the lifetime of the earth, astronomical, geological and biological processes control persistence of ice caps and glaciers; the biota; rock structures and global geochemical cycling [6].

There are two different and complementary time frames of importance in climatology. The first is the evolutionary time-scale which controls the very long-term aspects of the climate components and those factors which force it such as the physics and chemistry of the planet itself and the luminosity of the sun. Viewed in this time frame, the earth’s climate is prey to the forces of astro- and geophysics. Within this very long time-scale it is possible to take a ‘snapshot’ view of the climate system and, in this ‘quasi-instantaneous’ view, the shortest time-scale processes are most evident. Of these, the most important are the latitudinal distribution of absorbed solar radiation (large at low latitudes and much less

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near the poles) as compared to the emitted thermal infrared radiation which is roughly the same at all latitudes. This latitudinal imbalance of net radiation for the surface-plus-atmosphere system as a whole (positive in low latitudes and negative in higher latitudes) combined with the effect of the earth's rotation on its axis produces the dynamical circulation system of the atmosphere [7] (*see Meteorology*).

The latitudinal radiative imbalance tends to warm air which rises in equatorial regions and would sink in polar regions were it not for the rotation of the earth. The westerly waves in the upper troposphere in mid-latitudes and the associated high and low pressure systems are the product of planetary rotation affecting the thermally-driven atmospheric circulation. The overall atmospheric circulation pattern comprises thermally direct cells in low latitudes, strong waves in the mid-latitudes and weak direct cells in polar regions. This circulation, combined with the vertical distribution of temperature, represent the major aspects of the atmospheric climate system [8].

The state of the climate system at any time is determined by the forcings acting upon it and the complex and interlocking internal feedbacks that these forcings prompt. In the broadest sense, a feedback occurs when a portion of the output from an action is added to the input so that the output is further modified. The result of such a loop system can either be an amplification (a positive feedback) of the process or a dampening (a negative feedback): positive feedbacks enhance a perturbation whereas negative feedbacks oppose the original disturbance. If some external perturbation, say an increase in solar luminosity, acts to increase the global surface temperature then snow and ice will melt and their overall areas reduce in extent. These cryospheric elements are bright and white (i.e. their *albedo*, the ratio of reflected to incident radiation, is high), reflecting almost all the solar radiation incident upon them. The surface albedo, and probably the planetary albedo (the reflectivity of the whole atmosphere plus surface system as seen from 'outside' the planet), will decrease as the snow and ice areas reduce. As a consequence, a smaller amount of solar radiation will be reflected away from the planet and more absorbed so that temperatures will increase further. A further decrease in snow and ice results from this increased temperature and the

process continues. This positive climate feedback mechanism is known as the ice-albedo feedback mechanism [10].

Paleo-reconstructions of the earth's climate system, particularly from the most recent record over the past 100 000 years, indicate that climate does not respond to forcing in a smooth and gradual way. Instead, responses can be rapid, and sometimes discontinuous, especially in the case of warm forcing. If this is correct, a lesson we might learn from the past is that a possible response of the climate system to human-induced greenhouse gas build-up could come in 'jumps' whose timing and magnitude are very hard, perhaps impossible, to predict. Another message is that climate models, with which we hope to predict future climates, must be able to capture such paleoclimate records, particularly apparent discontinuities [11].

Although we cannot as yet predict future climatological states, we often behave as if we can. Policy development, business, financial and even personal decisions are made every day around the world as if we knew what climates people will face in the future. While local-scale climatic dependencies may seem rather weak, technology and engineering, international trade and aid, food and water resources are likely to become increasingly dependent on, and even an integral part of, the climate system. This is the reason for the development of international conventions and treaties designed to try to protect the climate, in particular, the Montreal Protocol which aims to reduce the substances that deplete stratospheric ozone and the Kyoto Protocol which is intended to reduce human contributions to the global greenhouse gas burden [9] (*see Global warming; Meteorology; Radiation and radiative transfer*).

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(See also **Weather prediction**)

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