their activities. Explicit mention of Agenda 21 is muted in the 2000 period onwards, either because it was too ambitious in its scope, because the concern about environment has overtaken it, or perhaps because its vocabulary has been widely accepted and some moves towards implementation have been made.

See also: CLIMATE CHANGE, GLOBAL CONVENTIONS AND TREATIES, POPULATION GROWTH, RECYCLING, SUSTAINABLE DEVELOPMENT, UN PROGRAMMES

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CLIMATE CHANGE

Climate change refers to the variations of Earth's climates over various timescales relative to variability or average weather from decades to millions of years. These changes evolve due to variations from within the Earth–atmosphere system, from extraterrestrial processes, or from human activities, such as greenhouse gas emissions and land-use changes. The term 'climate change' is generally used to refer to ongoing climate changes in contemporary times, which are highlighted, for example, by the average rise in air temperature, commonly known as global warming. The extraterrestrial factors include variability of solar radiation and what can be called the 'Earth–Sun geometry' (how the Earth's orbital shape differs, and the tilt and wobbling of Earth's axis of rotation differs).

Within the Earth's environment, there are changes that can control climate. These changes involve the deep oceans and ocean surface temperatures, as well as terrestrial changes in the biosphere and periodic events such as volcanic eruptions. Time and space scales must be considered an analysis of climate change. These can range from millions of years for the entire Earth to regional and local short-term changes. Glaciers, for example, are recognized as sensitive indicators of climate change, advancing due to climate cooling such as Little Ice Age, and retreating during climate warming such as during the last century. Since the last century, however, glaciers have not been able to regenerate enough ice in winter months to account for the ice and snow lost in the summer. In fact, the most important climate processes of the last several million years have been the glacial and interglacial cycles of the ice ages. Orbital variations explain overall the ice age cycles. However, continental ice sheets and 130 m sea-level change played a role in climate response geographically. Glacial variations can influence climate without major effects of orbital changes. On the scale of decades, climate changes result from less-understood variability within the ocean/atmospheric systems. Many climate conditions, notably El Niño/Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO), the North Atlantic Oscillation (NAO), and the Arctic Oscillation (AO), have all been recognized as drivers of short-term phenomena within the climate system. On longer timescales, the thermohaline circulation plays a significant role in altering heat storage in the climate system, and as a result, impacts climate variability. Diverse aspects of the environment react at variable rates to a climate change and thus reinforce in the direction of that change or may act to reduce the impact of that change. These responses are feedbacks in the climate system discussed under **CLIMATE FORCING AND FEEDBACK**. Current studies indicate that radiative forcing by greenhouse gases is the primary cause of global warming (Table 50 after Miehl *et al.* 2004). Greenhouse gases have also been important in understanding Earth's climate history. Over the last 600 million years, carbon dioxide concentrations have varied from >5000 ppm to less than 200 ppm, due primarily to the impact of geological processes and biological changes. The Paleocene–Eocene thermal maximum, the Permian–Triassic extinction event, as well as the end of the Varangian snowball Earth event are examples of rapid changes in greenhouse gases in the Earth's atmosphere that have in turn led to global warming.

Since the 1950s, increased carbon dioxide levels have been related to be a major cause of global warming. Notations of solar activities are based on observing sunspots and beryllium isotopes. On the longest timescales, the Sun itself is getting brighter as it continues to evolve. Early in Earth's history, the Sun was too cold to bring about liquid water to the Earth's surface. This early history is known as the Faint young sun paradox time. On more modern time scales, there are also many forms of solar variation, including the 11-year solar cycle, and longer-term modulations. These variations have triggered the Little Ice Age and caused the beginning of warming observations in the 1900s. Milankovitch cycles are due to mutual interactions of the Earth, its moon, and other planets. These variations are considered the driving factors underlying the glacial and interglacial cycles of the present ice age. Anthropogenic factors or human

Table 50 *Global temperature change relative to 1900 (in degrees Celsius)*

	1940	1970	1994
Greenhouse gases	0.10	0.38	0.69
Sulphate emissions	–0.04	–0.19	–0.27
Solar forcing	0.18	0.10	0.21
Volcanic forcing	0.11	–0.04	–0.14
Ozone	–0.06	0.05	0.08

After data from Miehl *et al*. (2004).

activities have changed the environment and influenced climate. The biggest factor of present concern is increases in CO_2 levels due to emission from fossil fuel combustion, followed by aerosols which counter the warming effect through filtering out energy in the atmosphere. Other factors, for example, which impact climate are land use, ozone depletion, and deforestation. Starting with the Industrial Revolution in the 1850s, the human consumption of fossil fuels has elevated CO_2 levels from a concentration of ~280 ppm to more than 370 ppm to present day. These increases are projected to reach more than 560 ppm before 2100. Prior to widespread fossil fuel use, humans' largest impact on local climate resulted from land use. Urbanization and agriculture basically changed the environment. For example, the climate of Mediterranean countries was changed by widespread deforestation between 700 BC and 0 BC, with the result that the modern climate in the region is significantly hotter and drier and the species of trees in the ancient world being extinct. A number of important feedbacks exist in the climate system. It has been documented that orbital variations provide the timing for the growth and retreat of ice sheets. However, the ice sheets themselves reflect sunlight back into space and hence promote cooling and their own growth, known as the ice-albedo feedback. Falling sea levels and expanding ice decrease plant growth and in turn lead to declines in carbon dioxide and methane, which leads to further cooling. Rising temperatures caused by anthropogenic emissions of greenhouse gases lead to retreating snow lines, revealing darker ground underneath, and as a consequence absorbing more sunlight. It is unclear whether rising temperature promotes or inhibits vegetative growth. Depending on the direction of the change, carbon dioxide would be effective and in turn could impact the temperature of the Earth. Alterations in water vapour, clouds, and precipitation may occur with global warming which can further produce feedbacks in the carbon cycle in Earth's temperature.

See also: CLIMATE FORCING AND FEEDBACK

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Tyndall Centre for Climate Change Research, Norwich, UK at http://www.tyndall.ac.uk/

CLIMATE FORCING AND FEEDBACKS

Climate forcing and feedbacks include processes among atmospheric constituents that sway the climate in given directions from its equilibrium condition. The combined effects of climate forcing lead to alteration of the Earth's radiation budget (Fig. 74). Changes in radiation are not only affected by changing concentrations of gases and particles in the atmosphere, but also by external sources such as Earth–Sun orbital factors. Any change that causes enhanced changes in the same direction is a positive feedback. Conversely, if a change in the environment leads to a process that dampens any change, it is a negative feedback. In most climate change research, the focus is on the atmospheric radiation forcing the climate system. Major research has focused on radiative forcing associated with the steadily increasing concentrations of different gases in the atmosphere – the so-called greenhouse gases: CO_2, CH_4, N_2O, CFC-gases etc, and particles. Other changes in the environment can also lead to changes in the radiative budget, such as desertification, forestation, and other changes in land use and air pollution (ozone, SO_4-aerosols, and contrails). Natural changes are important in perturbing the radiative balance, such as fluctuations in the solar output and volcanic activity. Important positive feedback mechanisms include the ice-albedo mechanism, lower tropospheric water vapour content changes, and ocean warming.

A negative feedback mechanism might include cloud development and aerosol cooling. Clouds are known to have a negative impact on the surface temperatures in the present climate system. However, a changing climate may involve changes in the types of clouds with both positive and negative effects on the radiative balance. It is unclear whether the total effect of these changes will be a negative or positive feedback. Sulphates in the atmosphere filter the