# Understanding Climate

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## What is climate?

At the simplest level the weather is what is happening to the atmosphere at any given time. Climate in a narrow sense is usually defined as the "average weather," or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time.

In a broader sense, climate is the status of the climate system which comprises the atmosphere, the hydrosphere, the cryosphere, the surface lithosphere and the biosphere. These elements determine the state and dynamics of the earth's climate.

The atmosphere is the envelope of gas surrounding the earth. The hydrosphere is the part of the climate system containing liquid water at earth's surface and underground (e.g oceans, rivers, lakes,…). The cryosphere contains water in its frozen state (e.g. glaciers, snow, ice,…). The surface lithosphere is the upper layer of solid Earth on land and oceans supporting volcanic activity which influence climate. The biosphere contains all living organisms and ecosystems over land and oceans.

**Climate Classification**
There are many ways of classifying the climate depending on the user and the level of understanding of the climate system at a given time. Most atlases have maps of temperature and precipitation around the world, and some contain maps of atmospheric pressure, prevailing winds, ocean currents and extent of sea ice throughout the year. Many countries have more detailed classifications for various reasons. For example, the average dates of the first and last killing frost are of value to farmers and growers, as is the average length of the frost-free growing season. In colder places, the number of days below freezing affects building design. The number of degree-days below or above some reference value (such as 18°C for heating and 22°C for cooling) provides a measure of the energy demand for heating, air conditioning and refrigeration in homes and offices.

The most often used classification scheme is that of Vladimir Köppen, first presented in the early 1900s, and revised frequently since representing five principal climate classes: tropical rain forest; hot desert flora; temperate deciduous forest; boreal forest and tundra;

- tropical rain forest is a dense forest of trees containing other plants and animal species in regions of heavy year round rainfall in the tropics ( e.g amazon, Congo,…) and the midlatitudes ( eg. Eastern Australia, florida, south Japan, …);
- hot desert flora are plants mainly composed of ground-hugging shrubs and short woody trees found in tropical arid lands;
- Temperate deciduous forest are plants mostly found in temperate climate. The dominant species are broad-leaved deciduous trees;
- Boreal forest or taiga are found in the northern hemisphere over areas at the interface between temperate and polar climates. The dominant plant species are coniferous trees.
- Tundra is characterized by tree growth hindered low temperatures and short growing season. The vegetation contains dwarf shrubs, sedges and grasses.

All the lesser formations such as the bushlands of the maquis and the chaparral represented subdivisions of one of the main climatic types.

**Perceptions of climate (you get used to the climate where you live)**
Most people come to enjoy the climate where they live. However, they may have to face the challenge of climatic variability, and possibly more radical climate change. The argument that the developed world is becoming increasingly independent of climatic variability is not entirely true: despite a marked decline in mortality and social disruption resulting from climate extremes, the financial consequences of climate variability are increasing. One reason is that rising incomes are enabling people to buy properties in more vulnerable locations, such as close to the seashore, on the flood plains of rivers, or high in the mountains. The losses incurred as a result of extreme weather events in these parts of the world are rising steeply.

In many parts of the world, crowded cities with inadequate services are increasingly susceptible to weather disasters. In particular, building in flood-prone areas, particularly shantytowns without adequate early warning services and infrastructure for evacuation, increases vulnerability, especially to flash floods and mudslides such as those recently experienced in China, Madagascar, Mozambique and Venezuela.

## Earth's Energy Budget

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All parameters of the earth's climate (winds, rain, clouds, temperature, etc) are the result of energy transfer and transformations within the atmosphere, at the earth's surface and in the oceans. Over time, the Earth's climate remains largely stable because the energy received is equal to that lost. Earth is bathed in an average solar influx of 1370 watts per square meter ($W/m^2$). As earth is spherical each square meter receives on average only about 342 $W/m^2$.

The temperature of the earth results from a balance between energy coming into the earth from the sun (solar radiation) and the energy leaving the earth to the outer space. About half of the solar radiation striking the earth and its atmosphere is absorbed at the surface. The other half is absorbed by the atmosphere or reflected back into space by clouds, small particles in the atmosphere, snow,ice and deserts at the earth surface.

Part of the energy absorbed at the earth surface is radiated back (or re-emitted) to the atmosphere and space in the form of heat energy. The temperature we feel is a measure this heat energy. In the atmosphere, not all radiation emitted by the earth surface reaches the outer space. Part of it is reflected back to the earth surface by the atmosphere (greenhouse effect) leading to a global average temperature of about 14°C well above -19°C which would have been felt without this effect.

Given the spherical form of the earth and its position in the solar system, more solar energy is absorbed in the tropics creating differences in temperatures from the equator to the poles. Atmospheric and oceanic circulation contributes to reducing these differences by transporting heat from the tropics to the midlatitudes and the Polar Regions. These equators to pole exchanges are the main driving force of the climate system. Many changes (e.g. increase in the greenhouse effect) and feedbacks in the climate system modify the energy budget.

## Circulation Patterns

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**Atmospheric**

In the tropical regions the planet is girdled by a belt of intense convective activity and rising air, known as the intertropical convergence zone (ITCZ). Here hot air rises, releasing its latent heat energy to the atmosphere. As this rising air cools, moisture condenses to form clouds and rainfall. Where the air rises buoyantly within short-lived convective clouds (called 'hot towers'), rainfall can be very intense. When the rising air reaches an altitude of around 12 to 15 km and virtually all the moisture has been extracted it spreads out. Descending air on each side of the ITCZ creates zones of dry, hot air that maintain the deserts in the subtropical regions of the world. At the surface the Trade Winds flow back towards the ITCZ. First interpreted by George Hadley in 1735, this basic circulation pattern now bears his name.

Further poleward, the middle latitude depressions swirl endlessly around the globe, often steered by concentrated cores of strong westerly winds aloft known as jet streams. These 'rivers' of air are usually found between altitudes of 9 and 12 km. Wind speeds are at a maximum during winter and often average near 180 km/h, although peak speeds can exceed twice this value. Jet streams can be very turbulent and hazardous for aircraft.

**Ocean circulation**

Ocean circulations transport roughly the same amount of energy towards the poles as does the atmosphere. The basic form in both hemispheres is a basin-wide vortex or ciculation known as a gyre, with wind-driven westward flow in low latitudes close to the equator and poleward-directed currents along the western margins. Beyond about 35°N and 35°S the major currents sweep eastward carrying warm water to higher latitudes. This pattern is seen most clearly in the North Atlantic and North Pacific in the form of the Gulf Stream/North Atlantic Current and the Kuroshio/North Pacific Current. To balance the poleward flow there are returning currents of cold water moving toward the equator on the eastern sides of the ocean basins. In the Southern Hemisphere, because of the virtual absence of land between 35°S and 60°S, the ocean gyres are linked with a strong circumpolar current around Antarctica. There are also regions of significant vertical motion associated with these global ocean circulations.

**Hydrological cycle**

The continual recycling of water between the oceans, land surface, underground aquifers, rivers and the atmosphere (the hydrological cycle) is an essential part of the climate system. Ice requires much energy to melt (latent heat of fusion) and water needs even more energy to evaporate (latent heat of vaporization), so the cycling of water through the atmosphere by evaporation and its subsequent precipitation is a significant mechanism through which energy is transported throughout the climate system.

## Influences on the Earth's climate

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**Atmosphere-ocean interactions**

Covering some 71 per cent of the Earth's surface, the oceans are a fundamental component of the climate system. Interactions between the rapidly mixing atmosphere and the slowly changing ocean basins are largely responsible for the climatic variations. The high heat capacity of the oceans damps the much higher temperature changes that would otherwise occur each day, each season and each year — both in coastal areas and often farther inland. The oceans are the birthplace of all tropical cyclones and most mid-latitude storms. Half the heat transported to the poles is carried by ocean currents, which is why western Europe, for example, is such a hospitable place. The oceans are also the single most important sink for carbon dioxide produced by human action. Their carbon pool is 50 times larger than the atmosphere's and, when equilibrium between these reservoirs prevails, the oceans can absorb up to 85 per cent of the additional atmospheric load. Present high emission rates, however, prevent this equilibrium and only about 30 per cent of anthropogenic emissions now seems to enter the oceans.

**Land surface-atmosphere interactions**

Within the atmospheric boundary layer (the first few tens of metres above the ground) there are many complex physical processes at work. Understanding these processes is an essential part of improving our knowledge of climate, developing better climate forecasting models, estimating the impact of human activities on climate, and understanding how a changing climate might affect us. On a hot day, it is cooler within a canopy of leafy trees than where the soil or grass is exposed to direct sunlight. In winter, ground frost develops first on exposed grass rather than under trees.

Until recently, the representation of the land surface in computer models of weather and climate was quite inadequate. Hoever, most coupled models now employ some representation of how vegetation controls evaporation and most can estimate river runoff for the ocean component of the model. Freshwater runoff and local rainfall affect the salinity distribution of the oceans and together are an important part of the development of the latest climate models.

The feedback process whereby climate-induced changes in vegetation affect the climate system, which further affects vegetation, potentially has large climatic implications. So far, however, it has proven difficult to incorporate this feedback process adequately in the coupled-model experiments used to estimate climate sensitivity. Also, the amount of carbon that is either extracted from the soil or stored in it by decaying vegetation is another source of considerable uncertainty. Snow, with its high reflectivity, is an important component of the land surface. Current climate models have some capability in simulating the seasonal cycle of snow extent but tend to underestimate interannual variability. These weaknesses limit confidence in the details of changes, particularly at middle and high latitudes, simulated by current climate models.

**Volcanoes**

Volcanoes can inject vast amounts of dust and, more significantly, sulphur dioxide into the upper atmosphere where aerosol particles remain suspended for up to several years and are spread round the entire globe forming a veil. The particles absorb sunlight and locally heat the stratosphere but at lower levels cause compensating cooling as less solar radiation reaches the Earth's surface.

After large explosive tropical eruptions, the Southern Hemisphere shows a cooling (somewhat smaller than the Northern Hemisphere) in the three years following the eruptions, but the spatial patterns of the responses have been less well studied than in the Northern Hemisphere. The fact that climatically significant eruptions have, in recent centuries, occurred roughly every decade means that they are a significant factor in understanding climatic variability and climate change. Two recent eruptions, El Chicon (Mexico) in 1982, and Mount Pinatubo (Philippines) in 1991, provided the opportunity to make more detailed measurements. Mount Pinatubo appears to have injected the greatest amount of sulphur compounds into the stratosphere in the 20th century. This eruption also produced an extensive dust veil and generated significant cooling for several years. Somewhat surprisingly, however, a warming was observed over the continents of the Northern Hemisphere at higher latitudes in the first winter after the Mount Pinatubo eruption. Overall, the eruption of Mount Pinatubo caused quite a strong cooling of the global surface temperature (about 0.2°C) and in the troposphere (perhaps 0.4°C) from late 1991 to 1994.

**The Sun**

The output of the Sun varies on all timescales. The best-known variation is the regular fluctuation in the number of sunspots, which show up as small dark regions on the solar disk, and affect the energy output of the Sun. Other aspects of solar activity include changes in the solar magnetic field, which influence the number of cosmic rays entering the Earth's atmosphere from deep space, and variations in the amount of ultraviolet radiation from the Sun that may lead to photochemical changes in the upper atmosphere. All these variations have the potential to induce fluctuations in the climate.

Does the Sun's energy output vary enough to affect the climate? Ground-based efforts during the first half of the century to show that there were appreciable changes in the output were plagued by problems in correcting for the effects of atmospheric absorption. It was only in 1980, with the launching of specialized satellite instruments, that it was possible to measure accurately the changes in energy radiated by the Sun. Observations now show a modulation of about 1.5 W/m2 in the solar output received by the Earth over the 11-year solar cycle. This is equivalent to about 0.1 per cent of the average incoming solar radiation (1370 W/m2). These changes cannot, however, be explained in terms of sunspots alone. Sunspots are areas of lower temperature and an increase in their number might be expected to coincide with reduced solar output. On the contrary, the energy output from the Sun peaks when the sunspot number is high.

It is now known that solar output is a balance between increases due to the development of bright areas, known as faculae, at times of high solar activity and the decrease resulting from increased sunspots. Overall the heating effect of the faculae outweighs the cooling effect of the sunspots. Estimates have also been made of the longer-term fluctuations in solar energy output over the past two or three centuries. The possibility that the Sun's energy output may have varied more appreciably in the past could explain the marked parallel between these changes and estimates of the Earth's surface temperature over much of the past four centuries.

**Human influences**

Land-use changes have led to changes in the amount of sunlight reflected from the ground (the surface albedo). The scale of these changes is estimated to be about one-fifth of the forcing on the global climate due to changes in emissions of greenhouse gases. About half of the land use changes are estimated to have occurred during the industrial era, much of it due to replacement of forests by agricultural cropping and grazing lands over Eurasia and North America. The largest effect of deforestation is estimated to be at high latitudes where the albedo of snow-covered land, previously forested, has increased. This is because snow on trees reflects only about half of the sunlight falling on it, whereas snow-covered open ground reflects about two-thirds.

Overall, the increased albedo over Eurasian and North American agricultural regions has had a cooling effect. Other significant changes in the land surface resulting from human activities include tropical deforestation which changes evapotranspiration rates, desertification which increases surface albedo, and the general effects of agriculture on soil moisture characteristics. All of these processes need to be included in climate models, but for climate change studies there are few reliable records of past changes in land use. One way to build up a better picture of the effects of past changes is to combine surface records of changing land use with satellite measurements of the properties of vegetation cover. Such analyses show that forest clearing for agriculture and irrigated farming in arid and semi-arid lands are two major sources of climatically important land cover changes. The two effects tend, however, to cancel out, because irrigated agriculture increases solar energy absorption and the amount of moisture evaporated into the atmosphere, whereas forest clearing decreases these two processes.

Human activity is also changing the composition of the atmosphere. The graph below shows the rising levels of carbon dioxide in the atmosphere caused by such factors as the increased levels of fossil fuel use.