Chapter One

Climate change

1.General consideration

In many parts of the world, the climate has varied sufficiently within the past few thousand years to affect patterns of agriculture and settlement. As will become clear, the evidence is now overwhelming that human activities have begun to influence climate.

Realization that climate is far from being constant came only during the 1840s, when indisputable evidence of former Ice Ages was obtained. Studies of past climate began with a few individuals in the 1920s and gained momentum in the 1950s. Instrumental records for most parts of the world span only the past 100 to 150 years, and are typically assembled at monthly, seasonal or annual time resolution.

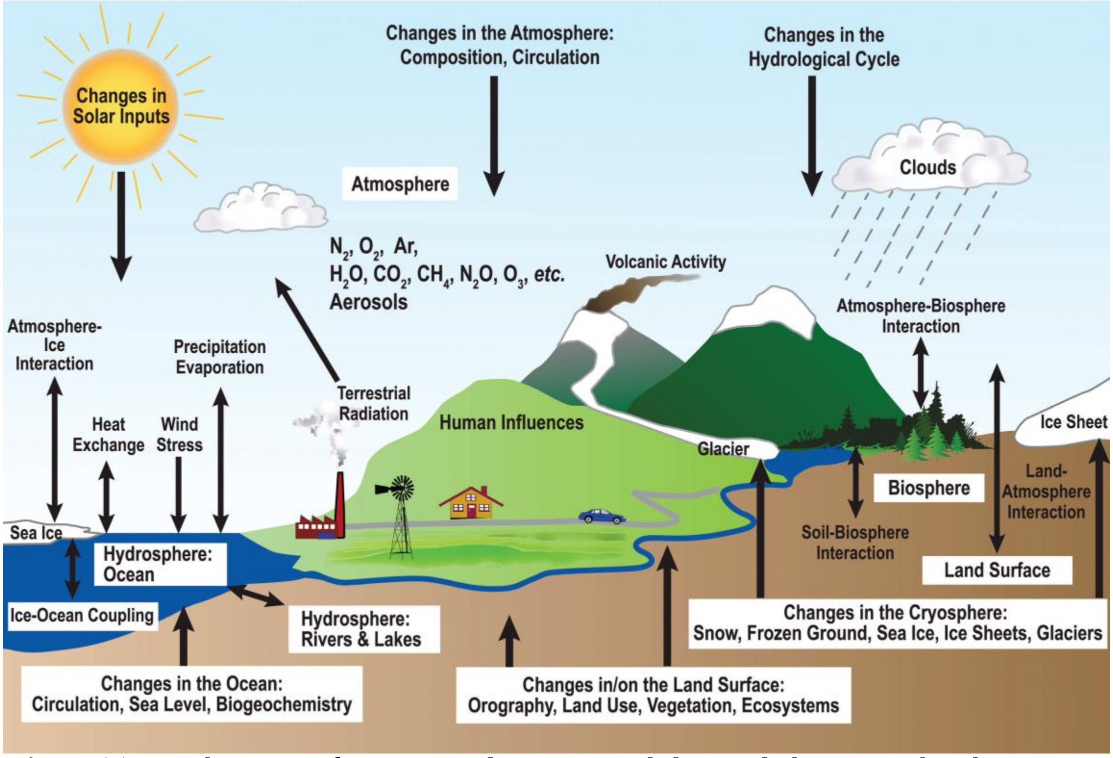
However, proxy indicators from tree rings, pollen in bog and lake sediments, ice core records of physical and chemical parameters, and ocean foraminifera in sediments provide a wealth of paleoclimatic data. Tree rings and ice cores can give seasonal or annual records. Peat bog and ocean sediments may provide records with 100 to 1000-year time resolution.

In any study of climate variability and change, one must pay careful attention to possible artifacts in the records. For instrumental records, these include changes in instrumentation (e.g., rain gauge types), observational practices, station location, or the surroundings of the instrumental site, or even errors in transcribed data. Proxy records may suffer from errors in dating or interpretation. Even when climate signals are real, it may be difficult to ascribe them to unique causes owing to the complexity of the climate system, a system which is characterized by myriad interactions between its various components on a suite of spatial and temporal scales (Figure 1).

What is the distinction between climate variability and change? Climate variability, as defined by the Intergovernmental Panel on Climate Change (IPCC), refers to fluctuations in the mean state and other statistics (such as the standard deviation, extremes, or shape of frequency distribution, see Note 1) of climate elements on all spatial and temporal scales beyond those of individual weather events. Variability can be associated with either natural internal processes within the climate system, or with variations in natural or anthropogenic climate forcing. Climate change, by contrast, is viewed by the IPCC as a statistically significant variation in the mean state of the climate or in its variability persisting over an extended period, typically decades or longer.

Climate change may be due to natural internal processes, natural external forcings, or persistent anthropogenic-induced changes in atmospheric composition or land use.

Given that climate variability as viewed by the IPCC includes fluctuations on all spatial and temporal scales beyond synoptic weather events, one could legitimately view all of the behaviors in the figure as expressions of variability.



Figure(1): *A schematic of processes driving variability and change in the climate system.*

The United Nations Framework Convention on Climate Change (UNFCCC) offers a different definition that can help to resolve some of these problems. They define climate change as 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the atmosphere and which is in addition to natural climate variability observed over comparable timescales'. This definition is useful in that it makes a clear distinction between natural processes and anthropogenic influences. The remainder of this chapter will view climate change in this context. Variability, in turn, will be viewed as associated with natural processes.

2.Climate forcing, Feedback and Response

The most fundamental measure of the earth's climate state is the global mean, annually averaged surface air temperature. Year-to-year and even decadal-scale variations in this value can occur due to processes purely internal to the climate system. When considering timescales of decades or longer, thinking must turn to climate *forcings* and attendant *feedbacks*. Forcing factors represent imposed perturbations to the global system, and are defined as positive when they induce an increase in global mean surface temperature, and negative when they induce a decrease. Forcing factors may in turn be of natural or anthropogenic origin. The magnitude of the global temperature response to forcing depends on the feedbacks. Positive feedbacks amplify the temperature change while negative feedbacks dampen the change.

A. Climate forcing

Many different types of climate forcing can be identified. Key forcings are associated with the following processes:

• *Plate Tectonics*. On geological timescales, plate tectonics have resulted in great changes in continental positions and sizes, the configuration of ocean basins and (through associated phases in volcanic activity) atmospheric composition. While there is little doubt that such changes altered the globally averaged surface albedo and greenhouse gas concentrations, plate movements have also altered the size and location of mountain ranges and plateaus. As a result, the global circulation of the atmosphere and the pattern of ocean circulation were modified. In 1912, Alfred Wegener proposed continental drift as a major determinant of climates and biota, but this idea remained controversial until the motion of crustal plates was identified in the 1960s.

• ***Astronomical periodicities***. the earth's orbit around the sun is subject to long-term variations, leading to changes in the seasonal and spatial distribution of solar radiation incident to the surface. These are known as Milankovich forcings after the astronomer Milutan Milankovich, whose careful calculations of their effects built upon the work of nineteenthcentury astronomers and geologists. There are three principal effects: the eccentricity (or stretch) of the orbit influencing the strength of the contrast in solar radiation received at perihelion (closest to sun) and aphelion (furthest from sun), with periods of approximately 95,000 years and 410,000 years; the tilt of the earth's axis (approximately 41,000 years) influencing the strength of the seasons; and a wobble in the earth's axis of rotation, which causes seasonal changes in the timing of perihelion and aphelion (Figure 2). The range of variation of these three components and their consequences are summarized in Table 1. Astronomical periodicities are associated with global temperature fluctuations of ±2–5°C per 10,000 years. The timing of orbital forcing is clearly represented in glacial–interglacial fluctuations with the last four major glacial cycles spanning roughly 100,000 years (or 100ka). The astronomical theory of glacial cycles became widely accepted in the 1970s after Hays, Imbrie and Shackleton provided convincing evidence from ocean core records.

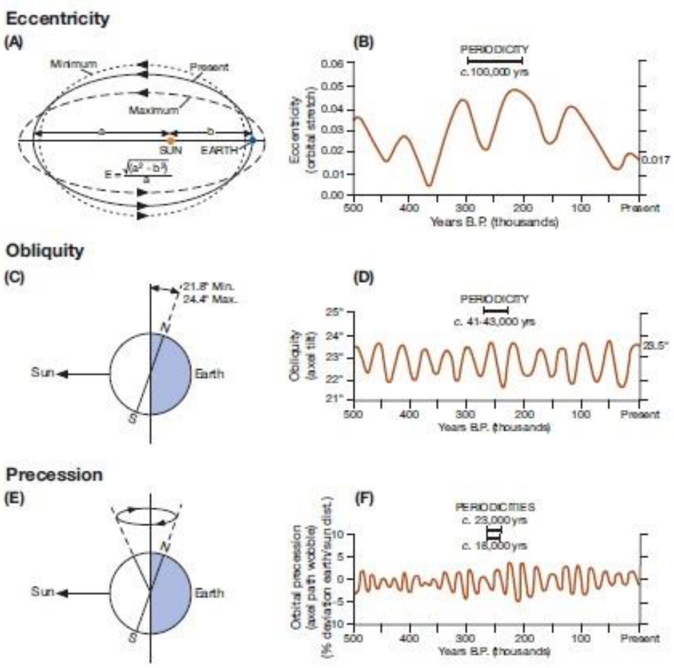


Figure (2): *Summary of astronomical (orbital) effects on solar irradiance and their relevant timescales over the past 500,000 years. A and B: Eccentricity or orbital stretch; C and D: Obliquity or axial tilt; E and F: Precession or axial path wobble.*

Table 13.1 Orbital forcings and characteristics

Element		Index range	Present value	Average periodicity
Obliquity of Ecliptic (′) (Tilt of axis of rotation) Effects equal in both hemispheres, effect intensifies poleward (for caloric seasons)		22–24.5°	23.4°	41 ka
Low ′ Weak seasonality, steep poleward radiation gradient	High ′ Strong seasonality, more summer radiation at poles, weaker radiation gradient			
Precession of Equinox (v) (Wobble of axis of rotation) Changing earth–sun distance alters seasonal cycle structure; complex effect, modulated by eccentricity of orbit		0.05 to –0.05	0.0164	19, 23 ka
Eccentricity of Orbit (e) Gives 0.02% variation in annual incoming radiation; modifies amplitude of precession cycle changing seasonal duration and intensity; effects opposite in each hemisphere; greatest in low latitudes		0.005 to 0.0607	0.0167	410, 95 ka

• ***Solar variability***. The sun is a variable star. The approximately 11-year solar (sunspot) cycle (and 22-year magnetic field cycle) are well known. The 11-year sunspot cycle is associated with ±1W m–2 fluctuations in solar irradiance (i.e., a departure from the solar constant; in terms of radiation receipts globally averaged over the top of the atmosphere, the effective value is only 0.25W m–2). Effects on ultraviolet radiation are proportionally larger in terms of percent change. There is also evidence for longer-term variations. Intervals when sunspot and solar flare activity were much reduced (especially the Maunder Minimum of AD 1645–1715) may have been associated with global temperature decreases of about 0.5°C. Solar variability also seems to have played a role in decadal-scale variations of global temperature until the latter part of the twentieth century, when anthropogenic effects became dominant. Turning to the distant past, it is known that solar irradiance three billion years ago (during the Archean) was about 80 percent of the modern value. Interestingly, the effect of this faint early sun was offset, most likely, by a concentration of carbon dioxide that was perhaps 100 times higher than