PART I

THE CLIMATE ENGINE OF THE EARTH: ENERGY

Chapter 1

Why are there many different climates on Earth?

At any one place, the climate is defined essentially by the prevailing temperature and by the rainfall. These two quantities, both in their annual averages and in their seasonal variations, are distributed unevenly over the surface of the planet. The result is a mosaic of extremely varied climates. *Why is this? What are the factors that produce such a wide range of temperatures that water exists in abundance in all its three phases (gas, liquid and solid), and that our planet occupies a unique place in the solar system? What factors govern the distribution of temperature and rainfall?* The primary driving force is the annual amount of energy arriving at the surface of the Earth, and its seasonal distribution. The guiding principle of this energy distribution will become apparent as we introduce the various relevant parameters.

1. First, we enquire into the source of energy that continuously supplies the Earth's surface and sets the operating range of temperature. *This is the Sun alone*, all the other sources of energy being incomparably weaker. The flow of energy is defined primarily by the Sun's radiation and is a function of its *activity*. The amount of solar energy received on the Earth also depends on the *distance between the Earth and the Sun*. The position of the Earth in the solar system is thus the first key factor that, unlike our neighbouring planets, enables it to host life in abundance.
2. The second characteristic of planet Earth is its *atmosphere*, which by its composition modifies the flow of energy arriving at the surface. The greenhouse gases (GHGs) in our atmosphere play a leading role in this flow, increasing the energy available at the surface of the planet and raising its average temperature.

Climate Change: Past, Present and Future, First Edition. Marie-Antoinette Mélières and Chloé Maréchal.

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3. Since the Earth is practically *spherical*, the solar flux falling on its surface is spread very unevenly over the different latitudes. At higher latitudes, the Sun's rays become increasingly tilted with respect to the surface and, on moving from the Equator to the poles, less and less energy is received per square metre (Part I, Note 1). This property defines the first major characteristic of climates on Earth: temperature decreases from the Equator to the polar regions.
4. The temperature difference between the Equator and the poles is nonetheless *attenuated* by the universal principle that heat propagates from hot regions to cold regions. Heat is transferred from the tropics towards higher latitudes by three transport mechanisms: atmospheric circulation, ocean circulation and the water cycle.
5. Owing to the tilt of the axis of rotation of the Earth in the ecliptic (the plane in which the Earth moves around the Sun during the year), the slope of the Sun's rays, and hence the energy delivered to each point on the Earth, oscillates throughout the year. This gives rise to the different *seasons,* as described in Box 1.1.
6. Finally, since the *orbit* of the Earth around the Sun is slightly elliptical rather than perfectly circular, the Earth–Sun distance varies over the course of the year. This is accompanied by variations in the amount of energy received during the year, but these variations are much smaller than those that give rise to the seasons. Over thousands of years, however, their slow changes have a major impact.

BOX 1.1 THE SEASONS

In the course of a year, the Earth travels in an almost circular orbit around the Sun, in a plane called the ecliptic plane (Fig. B1.1). The axis of rotation of the Earth (the polar axis) is at present tilted at 23°27' with respect to the normal to this plane. At any given place, therefore, the angle of the Sun's rays at zenith (i.e. the angle of the rays with respect to the normal to the Earth's surface) varies throughout the year, with accompanying changes in the amount of sunlight each day. At latitude 45°N, for example, this angle varies between 21°33' (summer solstice) and 68°27' (winter solstice). At the Equator, it varies in the range ± 23°27'. The amount

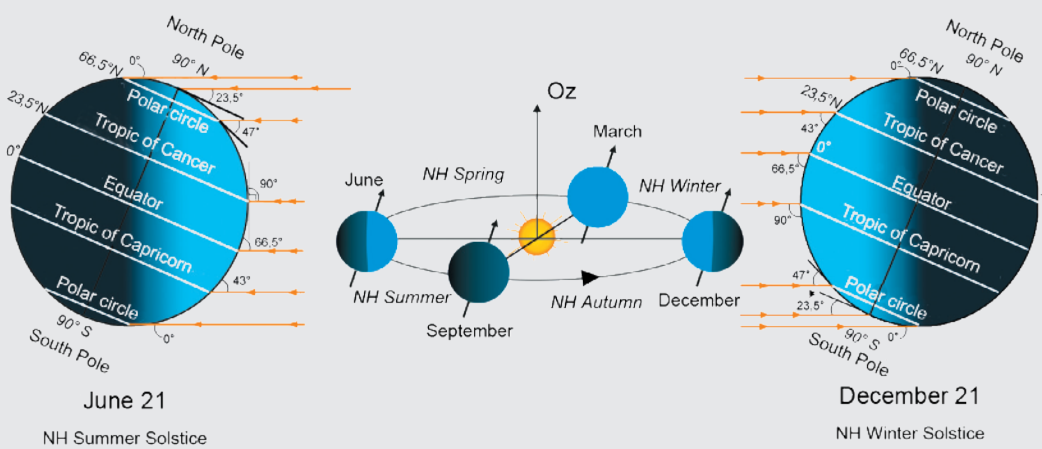

Fig. B1.1 The position of the Earth at different seasons. The 23°27' tilt (obliquity) of the Earth's axis with respect to the normal to the ecliptic plane defines the Tropic of Cancer (23°27'N) and the Tropic of Capricorn (23°27'S). At those latitudes, the rays from the Sun at zenith fall perpendicularly on the surface of the Earth at the June and December solstices, respectively. The obliquity also defines the polar circles (66.33°N and 66.33°S). Between the pole and the polar circle, the day lasts for 24 hours at summer solstice.

of solar energy received, also called the *solar irradiance* (in W/m^2), varies during the year, bringing in its train the succession of seasons. In each hemisphere, the year is marked by four dates that define the beginning of each season: the two solstices, summer and winter, when the irradiance is at a maximum (summer solstice) and then at a minimum (winter solstice) at latitudes situated between the tropics and the poles, and the two equinoxes (spring and autumn) when the day and night have the same duration.

At the equinox of 20 March – the spring equinox in the Northern Hemisphere (NH) and autumn in the Southern Hemisphere (SH) – the Sun's rays strike the Earth vertically at the Equator and tangentially at the poles. Day and night have the same length (12 hours) over the whole planet, from the North Pole to the South Pole. Then, in the NH, for example, between 20 March and 21 June, the daily irradiance gradually increases in latitudes situated above the Tropic of Cancer (23°27'N), reaching a maximum on 21 June, the longest day of the year. On this date, the Sun's rays at solar zenith fall vertically on the surface of the Earth at the Tropic of Cancer, and the irradiance is at a maximum. This is the summer solstice in the NH, which marks the beginning of summer. North of the Polar Circle (67°33'N), daylight lasts for 24 hours. Then, after 21 June, from the Tropic of Cancer to the North Pole, the daily irradiance decreases, together with the length of the day. At the 22 September equinox (the autumn equinox in the NH), day and night are once again of the same length over the whole planet and, at solar midday, the Sun's rays fall perpendicularly on the Earth's surface at the Equator. After that, the irradiance continues to decrease further until 21 December (the NH winter solstice), on which date the length of the day is at a minimum. Beyond the NH polar circle, the night lasts for 24 hours. In the SH, the situation is reversed.

These different mechanisms, which are listed in Table 1.1, generate differences in temperature and average rainfall that enable a great variety of climates to flourish on Earth. From frozen regions or scorching deserts to very wet zones, which may be either cool or warm, each zone is a home to *suitably adapted forms of life*.

TABLE 1.1 SUCCESSIVE STEPS IN THE DISTRIBUTION OF AVAILABLE ENERGY AT GROUND LEVEL ON THE EARTH'S SURFACE. CONTROLLING FACTORS ARE SHOWN IN RED. (a) THE AVERAGE ENERGY AVAILABLE AT THE SURFACE OF THE EARTH DEPENDS ON: (I) THE ACTIVITY OF THE SUN; (II) THE DISTANCE OF THE EARTH FROM THE SUN; AND (III) THE ENERGY TRANSFER THROUGH THE ATMOSPHERE. IN THIS TRANSFER, THE COMPOSITION OF THE ATMOSPHERE PLAYS A MAJOR ROLE. (b) THE AMOUNT OF SOLAR ENERGY RECEIVED AT THE SURFACE VARIES WITH LATITUDE AND SEASON. THE CONTROLLING FACTORS ARE: (I) THE SPHERICAL SHAPE OF THE PLANET; (II) THE ENERGY TRANSFER FROM THE EQUATOR TO THE POLES BY OCEAN AND ATMOSPHERIC CIRCULATION, TOGETHER WITH THE WATER CYCLE; AND (III) THE TILT OF THE POLAR AXIS, WHICH GOVERNS THE SEASONS.

(a) The average energy available at ground level on the Earth

Sun	→	Earth (top of atmosphere)	→	Earth (ground level)
Average flux radiated		*Average flux received*		*Energy available at surface*
Solar activity		*Earth–Sun distance*		*Atmosphere*

(b) The distribution of energy over the Earth's surface

Geographical distribution at top of atmosphere	→	Geographical distribution at ground level	→	Seasonal distribution
Sphericity of Earth		*Atmospheric circulation*		*Tilt of polar axis on the ecliptic*
		Ocean circulation		
		Water cycle		

In Parts I, II and III of this book, we focus on the mechanisms that give rise to the average climate at the surface of our planet. In this first step, the orders of magnitude in the climate are identified. We also briefly discuss the circulation of the atmosphere and of the oceans, since they play a major role in defining the pattern of rainfall over the planet and also in transferring heat from the Equator to the poles. But first we present an overview of the various climates that prevail on Earth, and their relationship to life forms. This will put into perspective what is at stake in climate change and what its implications are for society.