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Ministry of Higher Education

And Scientific Research

Al-Mustansiriyah University

College of Science

Atmospheric Sciences Department

Climatology

Lectures for 3rd Class Students

1st Semester

References

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2. The Global Climate System: Patterns, Processes, and Teleconnections, by Howard A. Bridgman, John E. Oliver, Cambridge University Press, 2006.

Chapter 1. Description of the climate system and its components

1.1 Introduction

Climate is traditionally defined as the description in terms of the mean and variability of relevant atmospheric variables such as temperature, precipitation and wind. Climate can thus be viewed as a synthesis or aggregate of weather. This implies that the portrayal of the climate in a particular region must contain an analysis of mean conditions, of the seasonal cycle, of the probability of extremes such as severe frost and storms, etc. Following the World Meteorological Organization (WMO), 30 years is the classical period for performing the statistics used to define climate. This is well adapted for studying recent decades since it requires a reasonable amount of data while still providing a good sample of the different types of weather that can occur in a particular area. However, when analyzing the most distant past, such as the last glacial maximum around 20 000 years ago, climatologists are often interested in variables characteristic of longer time intervals. As a consequence, the 30-year period proposed by the WMO should be considered more as an indicator than a norm that must be followed in all cases. This definition of the climate as representative of conditions over several decades should, of course, not mask the fact that climate can change rapidly. Nevertheless, a substantial time interval is needed to observe a difference in climate between any two periods. In general, the less the difference between the two periods, the longer is the time needed to be able to identify with confidence any changes in the climate between them.

We must also take into account the fact that the state of the atmosphere used in the definition of the climate given above is influenced by numerous processes involving not only the atmosphere but also the ocean, the sea ice, the vegetation, etc. Climate is thus now more and more frequently defined in a wider sense as the statistical description of the **climate system**. This includes the analysis of the behavior of its five major components: the **atmosphere** (the gaseous envelope surrounding the Earth), the **hydrosphere** (liquid water, i.e. ocean, lakes, underground water, etc), the **cryosphere** (solid water, i.e. sea ice, glaciers, ice sheets, etc), the **land surface** and the **biosphere** (all the living organisms), and of the interactions between them (IPCC 2007, Fig. 1.1). We will use this wider definition when we use the word climate. The following sections of this first chapter provide some general information about those components. Note that the climate system itself is often considered as part of the broader Earth System, which includes all the parts of the Earth and not only the elements that are directly or indirectly related to the temperature or precipitation.

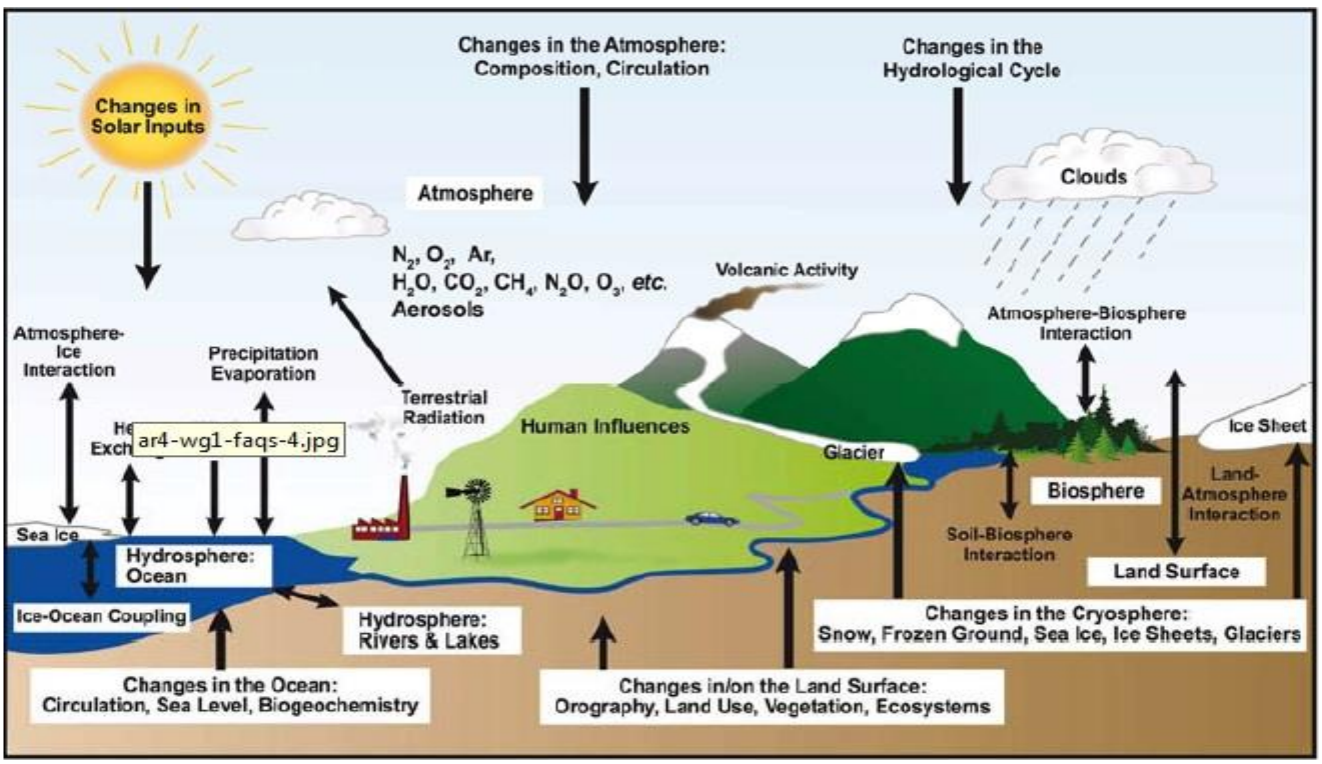

***Figure 1.1**: Schematic view of the components of the climate system and of their potential changes.*

1.2 The Atmosphere

1.2.1 Composition and temperature

Dry air is mainly composed of nitrogen (78.08 % in volume), oxygen (20.95% in volume), argon (0.93% in volume) and to a lesser extent carbon dioxide1 (380 ppm or 0.038% in volume). The remaining fraction is made up of various trace constituents such as neon (18 ppm), helium (5 ppm), methane1 (1.75 ppm), and krypton (1 ppm). In addition, a highly variable amount of water vapour is present in the air. This ranges from approximately 0% in the coldest part of the atmosphere to as much as 5% in moist and hot regions. On average, water vapour accounts for 0.25% of the mass of the atmosphere.

On a large-scale, the atmosphere is very close to hydrostatic equilibrium, meaning that at a height z, the force due to the pressure p on a 1 m2 horizontal surface balances the force due to the weight of the air above z. The atmospheric pressure is thus at its maximum at the Earth's surface and the surface pressure ps is directly related the mass of the whole air column at a particular location. Pressure then decreases with height, closely following an exponential law:

$$P \simeq P_s\, e^{-z/H} \qquad (1.1)$$

where H is a scale height (which is between 7 and 8 km for the lowest 100 km of the atmosphere). Because of this clear and monotonic relationship between height and pressure, pressure is often used as a vertical coordinate for the atmosphere. Indeed, pressure is easier to measure than height and choosing a pressure coordinate simplifies the formulation of some equations.

The temperature in the troposphere, roughly the lowest 10 km of the atmosphere, generally decreases with height. The rate of this decrease is called the lapse rate Γ:

$$\Gamma = \frac{dT}{dz} \qquad (1.2)$$

where T is the temperature. The lapse rate depends mainly on the radiative balance of the atmosphere (see section 2.1) and on convection as well as on the horizontal heat transport. Its global mean value is about 6.5 K km^{-1}, but Γ varies with the location and season.

The lapse rate is an important characteristic of the atmosphere. For instance, it determines its vertical stability. For low values of the lapse rate, the atmosphere is very stable, inhibiting vertical movements. Negative lapse rates (i.e. temperature increasing with height), called temperature inversions, correspond to highly stable conditions. When the lapse rate rises, the stability decreases, leading in some cases to vertical instability and convection. The lapse rate is also involved in feedbacks playing an important role in the response of the climate system to a perturbation.

At an altitude of about 10 km, a region of weak vertical temperature gradients, called the tropopause, separates the troposphere from the stratosphere where the temperature generally increases with height until the stratopause at around 50 km (Fig. 1.2). Above the stratopause, temperature decreases strongly with height in the mesosphere, until the mesopause is reached at an altitude of about 80 km, and then increases again in the thermosphere above this height. The vertical gradients above 10 km are strongly influenced by the absorption of solar radiation by different atmospheric constituents and by chemical reactions driven by the incoming light. In particular, the warming in the stratosphere at heights of about 30-50 km is mostly due to the absorption of ultraviolet radiation by stratospheric ozone, which protects life on Earth from this dangerous radiation.

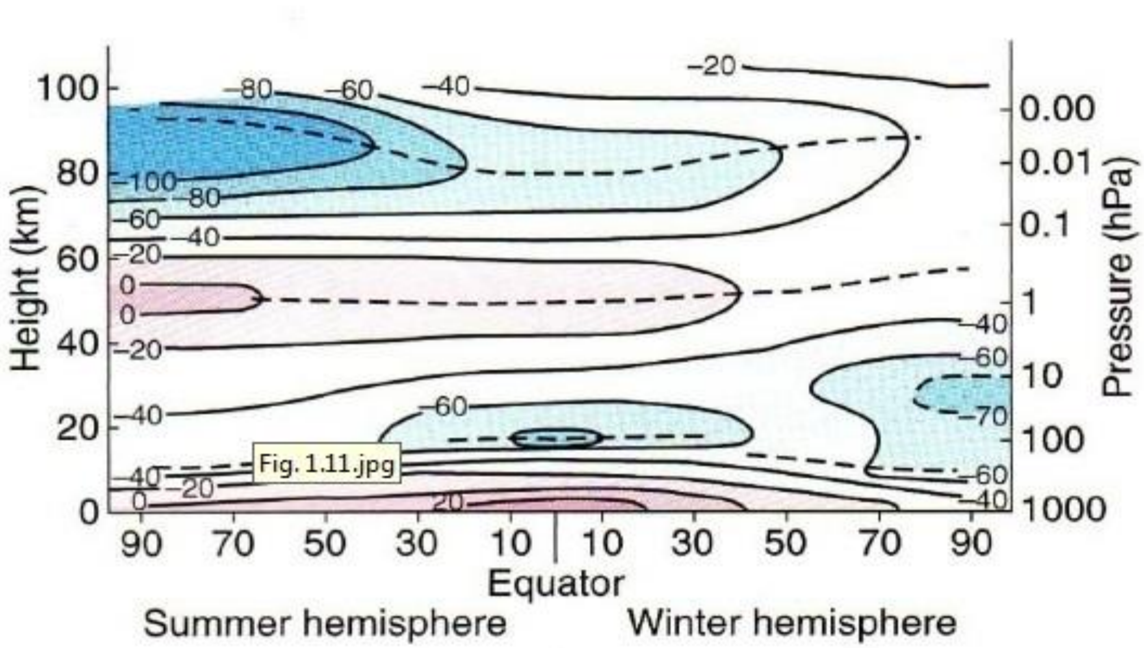

Figure 1.2*: Idealised zonal mean temperature (in °C) in the atmosphere as a function of the height (or of the pressure). The dashed lines represent schematically the location of the tropopause, stratopause and mesopause.*

Atmospheric specific humidity also displays a characteristic vertical profile with maximum values in the lower levels and a marked decrease with height. As a consequence, the air above the tropopause is nearly dry. This vertical distribution is mainly due to two processes. First, the major source of atmospheric water vapour is evaporation at the surface. Secondly, the warmer air close to the surface can contain a much larger quantity of water before it becomes saturated than the colder air further away; saturation that leads to the formation of water or ice droplets, clouds and eventually precipitation.

At the Earth's surface, the temperature reaches its maximum in equatorial regions (Fig. 1.3) because of the higher incoming radiations. In those regions, the temperature is relatively constant throughout the year. Because of the much stronger seasonal cycle at mid and high latitudes, the north-south gradients are much larger in winter than in summer. The distribution of the surface temperature is also influenced by atmospheric and oceanic heat transport as well as by the thermal inertia of the ocean. Furthermore, the role of topography is important, with a temperature decrease at higher altitudes associated with the positive lapse rate in the troposphere.

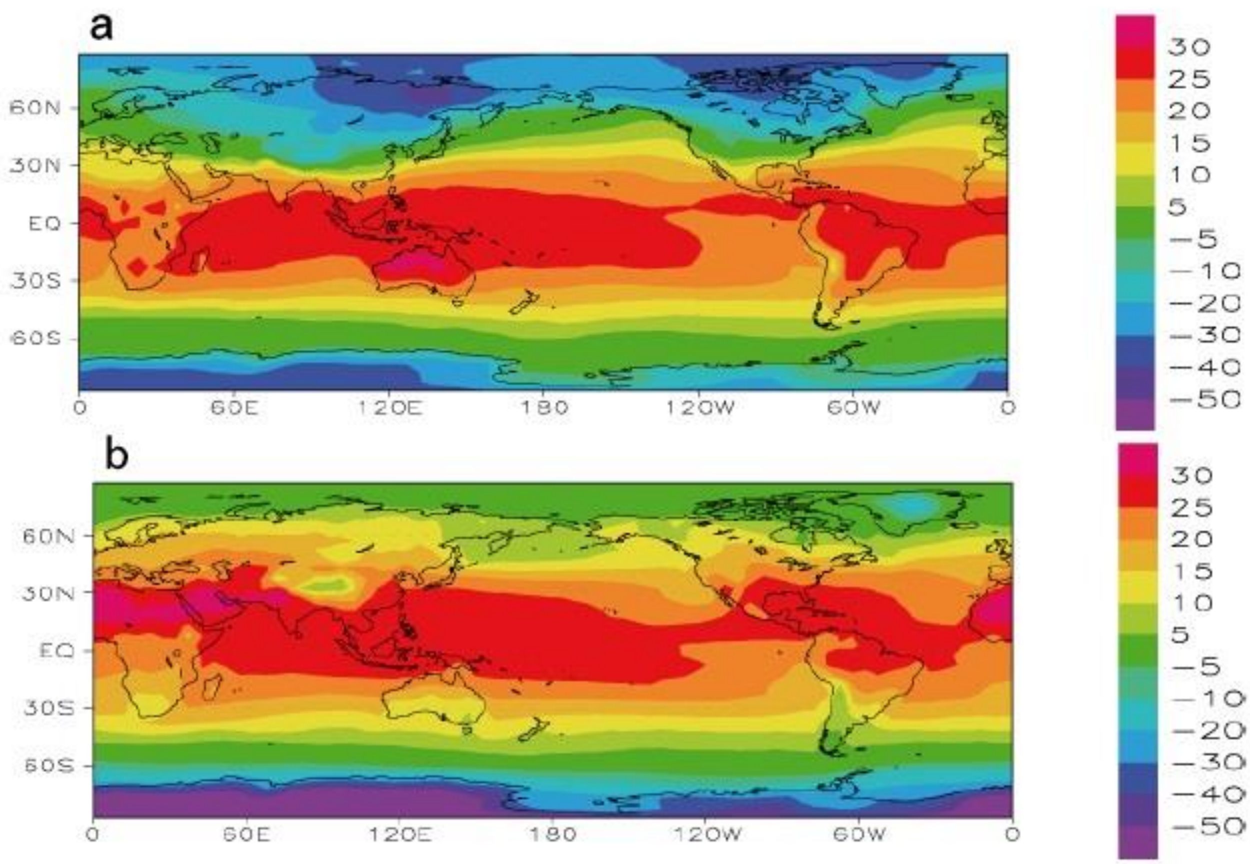

***Figure 1.3**: Surface air temperature (in °C) averaged over (a) December, January, and February and (b) June, July, and August.*