TRINITY COLLEGE FOR WOMEN NAMAKKAL
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ATMOSPHERIC PHYSICS
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The atmosphere as a physical system

The Earth's atmosphere is a natural laboratory, in which a wide variety of physical processes takes place. The atmosphere consists of a mixture of ideal gases: although molecular nitrogen and molecular oxygen predominate by volume, the minor constituents carbon dioxide, water vapour and ozone play crucial roles. The forcing of the atmosphere is primarily from the Sun, though interactions with the land and the ocean are also important.

The atmosphere is continually bombarded by solar photons at infra-red, visible and ultra-violet wavelengths. Some solar photons are scattered back to space by atmospheric gases or reflected back to space by clouds or the Earth's surface; some are absorbed by atmospheric molecules (especially water vapour and ozone) or clouds, leading to heating of parts of the atmosphere; and some reach the Earth's surface and heat it. Atmospheric gases (especially carbon dioxide, water vapour and ozone), clouds and the Earth's surface also emit and absorb infra-red photons, leading to further heat transfer between one region and another, or loss of heat to space. Some of these **radiative-transfer** processes are discussed in Solar photons may also be energetic enough to disrupt molecular chemical bonds, leading to photochemical reactions;

The atmosphere is generally close to hydrostatic balance in the vertical, except on small scales; that is, the weight of each horizontal slab of atmosphere is supported by the difference in pressure between its lower and upper surfaces. An alternative statement of this physical fact is that there is a balance between vertical pressure gradients and the gravitational force per unit volume acting on each portion of the atmosphere.

On combining the equation describing hydrostatic balance with the ideal gas law we find that, in a hypothetical isothermal atmosphere, the pressure and density would fall exponentially with altitude In the real, non-isothermal, atmosphere the pressure and density variations are usually still close to this exponential form, with an *e*-folding height of about 7 or 8 km. Gravity thus tends to produce a **density stratification** in the atmosphere.

Given a density stratification of this kind, a small portion of air that is displaced upwards from its equilibrium position will be negatively buoyant compared with its surroundings and hence will fall back towards equilibrium, under gravity; similarly a downward-displaced portion will rise back towards its equilibrium position. Buoyancy therefore acts as a restor- ing force; the atmosphere is said to be **stably stratified**. The strength of the stability of the stratification varies from one part of the atmosphere to another.

Thermodynamic principles are essential for describing many atmospheric processes. For example, any consideration of the effects of atmospheric heating or cooling will make use of the First Law of Thermodynamics. The concept of entropy (or the closely related quantity, potential temperature) frequently assists interpretation of atmospheric behaviour. Knowledge of changes in phase between vapour, liquid and solid forms of the water in the atmosphere is crucial for an understanding of the formation of rain and snow.

Moreover, the associated latent heating and cooling can provide important contributions to heat transfer within the atmosphere–ocean system; for example, evaporation of a droplet of sea water at one location and subsequent condensation of the resulting water vapour into a droplet at another location in the atmosphere transfers heat from the ocean to the atmosphere.

In atmospheric physics we use the usual macroscopic definitions of the temperature and pressure of a gas. From the kinetic theory of gases, these have well-known interpretations in terms of the mean kinetic energy of molecules and the mean transfer of momentum by molecules, respectively. When considering dynamical processes – that is, the response of atmospheric motions to applied forces – we can average other physical quantities such as density and velocity over many molecules and regard the atmosphere as a continuous fluid; individual molecular motions need not be taken into account. It is clear from the most cursory weather observations that the resulting bulk fluid motion of the atmosphere is still very complex. However, when the motion is viewed on a large scale (say hundreds of kilometres in horizontal extent), some simplifying features appear..

In particular, Coriolis forces play significant roles: these forces result from the rotation of the Earth and tend to deflect a moving portion of air to the right of its motion in the Northern Hemisphere and to the left in the Southern Hemisphere. A near balance between Coriolis forces and horizontal pressure gradient forces leads to wind motions that circulate along isobars (surfaces of constant pressure) at a given height. The sense of the circulation is anticlockwise around low-pressure regions and clockwise around high-pressure regions in the Northern Hemisphere and vice versa in the Southern Hemisphere

An important feature of the buoyancy restoring effect in a stably stratified atmosphere is that it can support fluid-dynamical waves, known as **gravity waves**,[1] in which the fluid pressure, density, temperature and velocity fluctuate together. These waves may propagate, allowing one part of the atmosphere to 'communicate' over great distances with other parts, without a corresponding transport of mass. The Coriolis force can also act as a restoring force, giving rise to further types of fluid wave motion. In particular, on large scales we find **Rossby waves**, which depend crucially on the rotation and the spherical geometry of the Earth and are associated with many observed large-scale disturbances in the troposphere and the stratosphere. As in many other branches of physics, the study of wave motions is an essential part of atmospheric physics

As noted above, solar radiation can initiate photochemical reactions by dissociating atmospheric molecules. A host of other types of chemical reaction between atmospheric molecules, both natural and man-made, can also occur. Atmospheric chemistry is a large and highly complex subject; in this book we focus on one small but significant branch of the subject, namely the chemistry of stratospheric ozone. This provides a good example of physical principles in operation and is highly topical, with direct application to the Antarctic ozone hole and global depletion of ozone;. It also demonstrates the importance of atmospheric transport processes, by which the winds blow chemical species from one part of the globe to another.

No study of the atmosphere can make progress without suitable observations, and all observational techniques rely to some extent on physical principles. One important type of observational technique is that of **remote sounding**, which depends on the detection of electromagnetic radiation emitted, scattered or transmitted by the atmosphere. we describe several examples of remote sounding, looking both at space-borne and at ground-based methods.

Climate change is a topic of great current concern. An understanding of how the Earth's climate has changed in the past, what determines its current state, and how it will change in the future depends on a detailed knowledge of a wide variety of physical processes, some of which are touched upon in this book. An outline of some of the more important physical concepts and processes associated with climate change.

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