AERONOMIC PHENOMENA

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Summary

Aeronomy deals with the structure and chemistry of the middle and upper atmosphere. The middle atmosphere includes the stratosphere and mesosphere. The most important feature of the former is the ozone layer: the layer of O_3 molecules that screens the life on the Earth surface from the dangerous biologically active ultraviolet radiation of the sun (UV-B). The pollution of the terrestrial atmosphere by various compounds (especially by complicated halogen-carbon-hydrogen chemicals) led to a permanent exhaust of the ozone layer in the 1980s and 1990s. A widely known manifestation of this exhaust became the so-called "ozone hole," the springtime depletion of the total ozone content above the Antarctic.

A significant feature of the mesosphere is noctilucent clouds. They are observed in June–July at high latitudes at an altitude of about 82–83 km and are related to very low temperatures and high humidity of the polar summer mesosphere. In the ionosphere three regions are distinguished: D, E, and F. In the lowest region (D) the electron concentration is relatively small and negative ions are presented in its lower part. The ion composition is rather complicated due to the existence of clusters of ions and neutral particles called "clustered ions." The intermediate E region is the simplest in its structure and ion composition. The behavior of the F region is complicated by so-called "ionospheric storms" which follow geomagnetic storms. During ionospheric storms the electron concentration in the F region may both increase (the positive phase) and decrease (the negative phase). Such behavior of the F region is due to changes of the neutral composition of the thermosphere at F-region heights and toward the equator horizontal winds, both factors arising due to a heating of the thermospheric gas in the polar region during magnetic storms. During the recent decade there have appeared indications of systematic monotonous changes of some aeronomical parameters (temperature, minor constituent concentration) on the time scales exceeding the 11-year

solar cycle. These long-term changes may be a manifestation of the changes in the middle and upper atmosphere occurring because of their contamination by the processes of industrial activity.

1. Introduction

The term "aeronomy" was introduced at the start of the 1960s by the Belgian scientist Marcel Nicolet. He was also the first to write a book dedicated completely to aeronomical problems.

Initially aeronomy was considered as a branch of geophysics dealing with the structure and chemistry of the atmospheric gas from the stratosphere up to the upper thermosphere. It is worth noting here that the entire terrestrial atmosphere is divided into conventional spheres (regions) according to the temperature gradient (see *Aeronomy and the Magnetosphere*).

In the lowest part of the atmosphere, the troposphere, the temperature decreases with height up to the tropopause, the boundary between the troposphere and stratosphere. In the latter the temperature increases with height up to the next boundary, the stratopause. From there the mesosphere begins and goes up to the mesopause; the temperature gradient is negative as in the troposphere. In the mesopause region the lowest temperature in the entire atmosphere is observed. Above the mesopause the thermosphere begins where the temperature behavior with height is the most complicated: first it increases up to about a height of 180–200 km and then keeps constant. The approximate heights of the tropopause, stratopause, and mesopause are about 10–16 km (rather changeable), 50 km, and 87 or 100 km (Figure 1). The troposphere is sometimes referred to as the lower atmosphere. In the mid-1970s there was a great deal of interest in the stratosphere and mesosphere, they were referred to as the "middle atmosphere." And, finally, the thermosphere is often referred to as the "upper atmosphere."

The structure and chemistry (or rather photochemistry, because solar radiation is involved in important chemical processes) of the middle and upper atmosphere were the first—and still the main—objects of aeronomical studies. Later on, in the course of a better understanding of the physics of the atmospheric "spheres," dynamical processes became included in aeronomical studies because very often it was impossible to explain the behavior of this or that chemical compound only by the chemical processes it was involved in. However, there is no commonly accepted opinion whether the dynamics of the middle and upper atmosphere should be part of aeronomy. The development of this part of atmospheric science since the early 1960s was so tremendous (various kinds of wave processes, including internal gravity waves and planetary waves, were studied in detail, the role of various kinds of horizontal circulation both in quiet periods and during magnetic storms became a special branch of thermospheric physics, and so on) that many specialists prefer to consider it as a separate part of atmospheric physics: dynamics of the middle and upper atmosphere. In the following we will stick to the initial M. Nicolet understanding of aeronomy as a branch of geophysics dealing with the structure and chemistry of the middle and upper atmosphere.

2. Structure of the Atmosphere

In the Introduction we have already described the principal features of temperature behavior in the various atmospheric "spheres." We saw that this behavior changes dramatically with height. Contrary to that, the behavior of the pressure of the atmospheric gas is the same through all the spheres: the pressure monotonously decreases with height (see Figure 1).

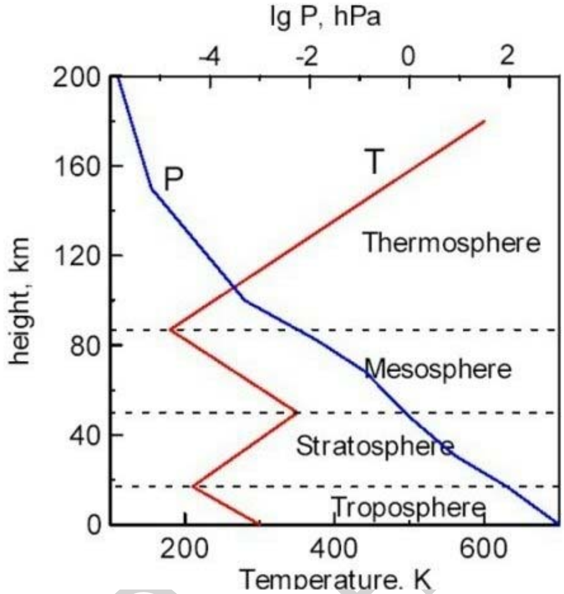

Figure 1.Division of the atmosphere into the "spheres" by temperature behavior and schematic vertical profiles of the temperature T and pressure P

The changes of the pressure P with height in the first approximation may be described by a simplified formula:

$$P(h) = P(h_0) \exp(-(h-h_0)/H) \quad (1)$$

Where P(h) is the pressure at the height h, $P(h_0)$ is the pressure at the initial height h_0, and H is the so-called scale height. The physical sense of the scale height is very simple: it shows at what altitude you should ascend above the reference level h_0 to have the pressure of the ambient gas decreased by a factor of e as compared with $P(h_0)$. The scale height H is (in some approximation) simply related to the gas temperature T and mean molecular weight of the air M:

$$H = RT/Mg \quad (2)$$

where R is the universal gas constant and g is the gravity acceleration.

In the air near the Earth, where there are many oxygen and nitrogen molecules, M is high and T is relatively low, thus H is also low. In the mesosphere it is about 6–8 km. In the thermosphere, where M is small (atoms dominate in the atmospheric gas) and T high, the scale height is large and may reach a value of 50–100 km.

Moving upward through the atmosphere from, say tropopause, we see that not only the temperature and pressure of the atmospheric gas are changing with height, but the chemical composition of the gas as well. Near the Earth's surface the atmospheric gas contains about 78% of molecular nitrogen N_2, 21% of molecular oxygen O_2, and slightly less than 1% of argon Ar. There are also various minor constituents having a concentration much lower than 1% but playing an important role in the atmospheric physics and chemistry. We will discuss them in Section 3.

Up to about 110 km (this level is often called "homopause") the atmospheric gas is mixed due to strong processes of eddy mixing. Due to this mixing we find at, say, 100 km the same percentage of nitrogen molecules (about 78%) as in the air near the surface. The same is true for Ar and almost true (because the dissociation of O_2 molecules by the solar radiation begins) for O_2. And all this is true in spite of the fact that the pressure (that is, the total amount of molecules and atoms in a cubic centimeter of the gas) at 100 km is by a factor of about 10^6 (million!) lower than near the surface. From the surface to the homopause the entire atmosphere follows formula (1) with M standing for the molecular mass averaged over all the constituents available.

Above the homopause the picture changes dramatically. The eddy mixing does not provide complete mixing of the gas any more and the molecular diffusion becomes the governing process. Contrary to the eddy mixing, the molecular diffusion tends to provide a separate distribution for each atmospheric gas according to its molecular weight. Now each gas has a vertical distribution according to formula (1) but with its own M. This means that, according to formula (2), heavier gases (for example, argon with M = 40) will decrease with height more rapidly that lighter gases (for example, atomic oxygen with M = 16). This process leads to the increase of the portion of lighter gasses with height and the depletion or complete disappearance of heavy gases. For example, at altitudes of the ionospheric F2 layer at about 300 km the dominant gas is atomic oxygen, the portion of N_2 is less than 1% (rather changeable depending on the conditions) and there are no traces of argon.

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Biographical Sketch

Professor **Alexey D. Danilov,** is a professor in geophysics. He got his PhD from the Moscow University in 1962 and his DrS degree from the Institute of Applied Geophysics in 1971. Since his graduation from the Moscow University A. Danilov works in the Institute of Applied Geophysics. Now he is a Head of the Ionospheric Division of the Institute. His main research interests are in the area of the chemistry and structure of the middle atmosphere and ionosphere. In the mid-1970s he was one of the organizers of the big international project, Middle Atmosphere Program (MAP). Currently he is involved in studies of the long-term trends of aeronomical parameters of the middle atmosphere and ionosphere and their possible relation to atmospheric contamination.