1. TERRESTRIAL AND PLANETARY AERONOMY

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ABSTRACT

A brief overview of some topics covered by members of the Institute of Aeronomy are summarized. The subjects discussed in this report deal with physics and chemistry of neutral and ionized atmospheres. This report is not exhaustive and other contributions from the Institute of Aeronomy are presented in this issue.

INTRODUCTION

The word "AERONOMY" created by Sidney Chapman was officially introduced during the General Assembly of the International Union of Geodesy and Geophysics held in Rome in 1954, a few years before the launch of the first artificial satellite. The purpose of this interdisciplinary field is to study any atmospheric region (earth, planet, satellite, comet) where ionization and photodissociation processes play a role. This implies that any concept, method or technique developed for the terrestrial atmosphere can be adapted to other bodies of the solar system. This report does not cover all the fields in which the Institute of Aeronomy is or has been involved. Other papers by some of my colleagues in this volume deal with different aspects belonging to the same discipline. Two books [1-2] which are still considered as valuable references have been published in 1973.

In order to give a broad view of the atmospheric regions covered by aeronomy,
Fig. 1 shows the vertical distribution of the temperature in the earth's atmosphere and the vertical electron distribution in the ionosphere which is essentially a direct consequence of the ionizing effect of the solar ultraviolet radiation. The atmospheric nomenclature is indicated near the neutral temperature distribution. It can be seen that above 100 km altitude the atmosphere is much more variable with solar activity then at lower heights. High values correspond to maximum solar activity, and low values occur during the minimum of the eleven years solar cycle. Similar phenomena occur on other planets and the major objective of the present report is to indicate where the Institute of Aeronomy contributed to our present knowledge of the solar system.

COMPOSITION OF THE NEUTRAL ATMOSPHERE

At ground level atmospheric air contains essentially 78 % of molecular nitrogen N_2, 21 % of molecular oxygen O_2 and 1 % of argon Ar. When these gases are transported towards higher altitude, solar ultraviolet radiation progressively dissociates molecular oxygen. As a consequence of this dissociation atomic oxygen O becomes the most important constituent in the thermosphere. The general hydrodynamic regime of the atmosphere evolves from mixing conditions below 100 km towards diffusive conditions for which light constituents decrease less with height.

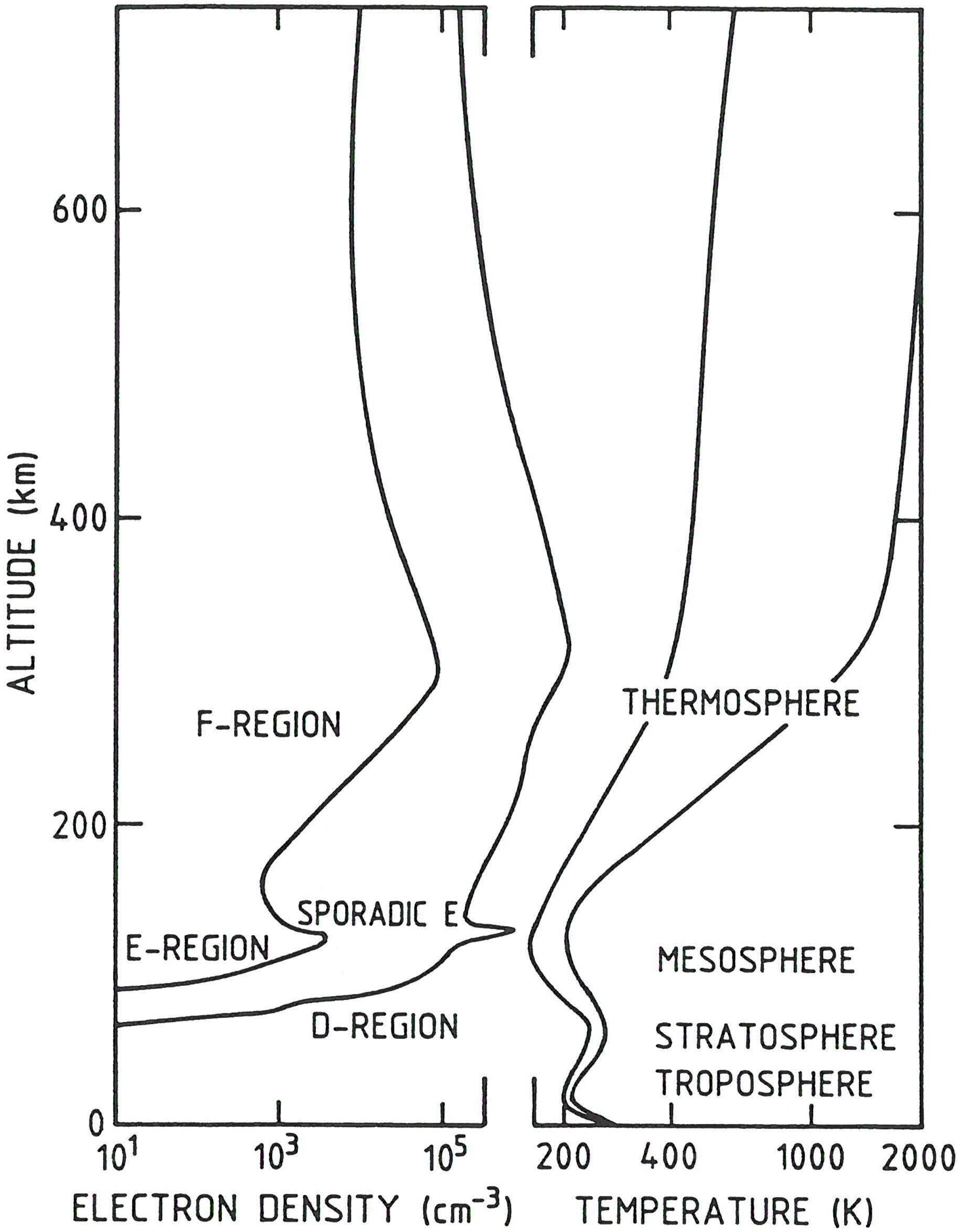

Figure 1 : Temperature distributions in the neutral atmosphere and electron concentrations for maximum and minimum solar activity

Observations of the decrease of the perigee of the satellite Echo 1, launched in 1960 at an altitude of 1000 km indicated the amount of atomic oxygen present at these heights is to low to give a satisfactory explanation. Among a long list of minor constituents present at ground level, one has to find one with two particular properties: it has to be very light so that the diffusive transport can bring it at high altitudes in the thermosphere and it must not be transformed by solar ultraviolet radiation or by chemical reactions. Helium He, produced by radioactive decay of uranium and thorium in the crust and in the mantle of the earth, was a good candidate. It has been shown that a helium belt is surrounding the earth at heights above 500 km [3-5]. Many concepts such as mean molecular mass, scale heights, transport properties in the thermosphere had to be adapted to this new situation [6-9]. A problem is still not completely solved, namely the escape of helium from the atmosphere. Various mechanisms have been proposed but none is sufficient to explain why an accumulation of helium over geological times is not observed [10].

Since the beginning of the space age, a huge effort has been made to obtain upper atmospheric models capable to represent all variations observed above 100 km (see Vercheval in this volume for drag data analysis). Even isolated rocket experiments were used to test individual models [11]. These models have contributed to define the Cospar International Reference Atmosphere and they reflect efficient international collaboration [12-18].

Sometimes a very small paper [19] can lead to a long and fruitful collaboration. Atomic hydrogen has an isotope called deuterium which is present approximately for 1 part in 10000 in water. Photodissociation of water vapor is the major source of atomic hydrogen in the upper atmosphere. Since atomic hydrogen is observable through the resonant scattering of solar Lyman alpha radiation at 121.6 nm, deuterium should be detectable by the same technique. The first optical detection was performed during the Spacelab 1 mission [20-22] in 1983. This technique allows also observations of terrestrial atomic hydrogen as well as interplanetary hydrogen [23]. During the ATLAS 1 mission in 1992, a more sensitive instrument lead to excellent data on deuterium and atomic hydrogen [24]. These measurements are related to the loss of water vapor in the interplanetary medium. A similar mechanism occurs on Mars and Venus, where the temperature and pressure conditions are completely different then on Earth.

RELATION WITH LABORATORY MEASUREMENTS

The analysis of the penetration of solar radiation in an atmosphere requires a good knowledge of atomic and molecular quantities such as line positions, oscillator strength and absorption cross sections.

The Schumann-Runge bands of molecular oxygen between 175 nm and 205 nm are a significant example since the absorption cross section can vary by several orders of magnitude over a very short wavelength interval. The 21 % abundance of molecular oxygen below 100 km altitude indicates that the physical properties of this molecule should be well known in order to compute the effects of solar radiation absorption, particularly in relation with the various concerns on ozone abundance in the stratosphere.

Two experimental steps were undertaken at the Institute of Aeronomy. The spectroscopic structure of the Schumann-Runge bands was determined [25] and absorption cross sections at very sharp defined wavelengths were measured [26]. With this better laboratory data it was possible to compute [27] the penetration of solar radiation in the Schumann-Runge bands with very high resolution. Such computation requires high computer resources if it should be implemented in multidimensional atmospheric models dealing simultaneously with chemistry and dynamics. Therefore, suitable approximations taking the temperature dependence of the cross sections into account were developed [28]. More recent cross sections measurements were used for other approximations [29], but the whole problem is not yet completely solved.

Such an example indicates that space research is also depending on laboratory data which are not necessary available in the scientific literature.

THERMAL STRUCTURE OF THE NEUTRAL ATMOSPHERE

A fundamental problem in any planetary atmosphere is the temperature distribution which depends on the various heating and cooling mechanisms. Fig 1. indicates that wide a range of temperatures exists in the earth's atmosphere and that important variations with solar activity occur in the thermosphere.
The first theoretical models only used an infrared cooling by atomic oxygen [30-31] at 63 μm. However with an increasing knowledge of the various heat sources [32-33], it appears that the atomic oxygen infrared cooling mechanism is not sufficient to provide a correct thermal balance in the thermosphere. The additional mechanism [34] results from the infrared emission at 5.3 μm by nitric oxide *NO* which is always a minor constituent in the thermosphere.
The major thermospheric heat source is due to the absorption of solar ultraviolet radiation above 100 km. Since this flux is highly variable during the eleven years solar cycle, strong variations occur in the thermosphere but at lower height the solar cycle effect is not predominant [35]. The heating of the atmosphere is accompanied by dynamical effects and this interaction is very complicated since it is influenced by the presence of the ionosphere. By solving the mass, momentum and energy conservation equations, it appears [36] that vertical and horizontal transport effects have to be included in the energy balance equation.

IONOSPHERIC STUDIES

Incoherent scattering is an extremely powerful technique to obtain information on the ionosphere and on the neutral atmosphere. In the late 1950', it was noted that the development of radar power and sensitivity had reached a point where it was theoretically possible to measure the very weak signal scattered incoherently by free electrons in the ionosphere.
From the power spectrum it is also possible to deduce information on the temperature, molecular nitrogen concentration and turbulent state of the lower thermosphere around 100 km altitude [37] where there exist no satellite data and only a few rocket data. These results are now included in semi-empirical atmospheric models.
Incoherent scatter data obtained at Saint-Santin (France) between 1969 and 1972 showed the existence of a daytime valley in the ionospheric F1 region [38]. This valley was explained by a downward ionization drift for solar minimum conditions [39].
The ionospheric D region, below 100 km altitude, is characterized by the presence of molecular negative ions resulting from the attachment of electrons to atoms or molecules. More then 60 chemical reactions involving negative ions and more then 100 chemical reactions involving positive ions lead to a complicated system. A new technique [40] based on signal flow graph theory made it possible to reduce the complicated model to an simple model with only three species, i.e electrons, one fictitious positive ion and one fictitious negative.
The presence of negative ions in the D region requires a modification of the incoherent scattering theory. This was achieved [41] by taking into account chemical fluctuations. Actually a new incoherent scattering mechanism [42-43] was introduced by considering the chemical reactions from a stochastical point of view. This means that reaction rates are not considered as deterministic quantities, but they represent a probability for a reaction to occur.

PLANETARY STUDIES

In any atmospheric study one needs to know how the sun illuminates the atmosphere as a function of astronomical quantities such as the period of revolution, the rotation period, the position on the orbit, the inclination of the planet, the planetocentric latitude and longitude [44-49]....
Changes resulting from global dust storms have been studied at the surface of Mars [50]. The insolation calculated for Pluto [51-52] indicate a great sensitivity to modifications in the obliquity.

After the Voyager encounter with Titan, the question of the vertical distribution of molecular hydrogen was reassessed [53]. Furthermore, a thermospheric temperature distribution was developed [54] for the future Huyghens-Cassini mission. Future programmes for the atmosphere of Mars are discussed by C. Muller in this volume.

CONCLUSIONS

The variety of topics briefly described in this report indicates that since the beginning of the space age the Institute of Space Aeronomy has been involved with success in many fields. Theoretical and experimental contributions have lead to a recognized international competence.
The domain of aeronomy is still expanding and, with a reasonable financial support, the Institute of Aeronomy will be able to fulfill the duties assessed in its creation chart.

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