WAVE MOTIONS IN THE ATMOSPHERE AND RELATED IONOSPHERIC PHENOMENA

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Abstract. We review important studies in the field of stratosphere-ionosphere coupling, including recent studies of wave motions of planetary waves, atmospheric tides and internal gravity waves in the atmosphere. The interrelation between stratospheric sudden warmings and winter anomaly of radio absorption, a dynamical model of stratospheric sudden warmings and some production mechanisms of intensified electron density in the $D$ region are discussed. Other topics presented are atmospheric tides in the lower thermosphere including dynamo action, and internal gravity waves, by which we intend to explain travelling ionospheric disturbances in the $F_2$ region and sporadic $E$ layer at mid-latitude (wave-enhanced sporadic $E$). Thermospheric winds are also reviewed and wind effects on the $F_2$ layer are discussed. For each atmospheric event systematic observations of suitable physical quantities with proper time and spatial intervals are desirable.

1. Introduction

For many years the ionosonde has been the main tool for ionospheric research. The present-day ionosonde, of which a variety of models exist, has an operating frequency that is swept or stepped over the range from about 1–20 MHz. The electron density in the $D$ region has been investigated with 1–3 MHz range by cross-modulation, partial reflection, radio wave absorption and so on. The sweep-frequency sounding technique has been extended to satellite operation in the top-side sounder, which probes the ionosphere to determine its shape and structure above the level of maximum ionization. Furthermore, the observation of incoherent scattering from free electrons is available for studying the upper ionosphere and exosphere (e.g. Evans, 1972). Measurements of density fluctuations by laser radar also give important information on the lower thermosphere (Kent and Wright, 1970, 1971; Kent et al., 1972). In addition to ground-based observations, rocket-borne probes and several other experiments are important for the exploration of the ionosphere. Many anomalous ionospheric phenomena are observed in the data obtained. We note that some of these abnormal phenomena cannot be explained in terms of photochemical processes, solar particle injections or solar flare effects. It seems likely that there are some events due to the effects of atmospheric oscillations, such as the winter anomaly of radio absorption, travelling ionospheric disturbances, sporadic $E$ and so on. Ionospheric storms are not considered in the present paper, but were reviewed by Matuura (1972). Recent studies of static electron density profiles in the ionosphere are briefly introduced below and a classification of wave motions in the atmosphere is considered. Each wave motion is reviewed at each section and its effect on the ionosphere is discussed.

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1.1. Static electron density profiles

A good deal of data about the electron density profiles of $E$ and $D$ regions obtained by rocket soundings at as many stations as possible in middle latitudes has been compiled by Maeda, K. (1969). He attempted to draw some average daytime electron density profiles for some selected levels of solar activity and some average night-time profiles to establish a 'reference ionosphere'. Daytime data have been classified into three groups depending on the solar zenith angle at the time of sounding, and night-time data into five groups depending on local time. As most of the rocket data on the electron density obtained so far have been concentrated in periods of low solar activity, daytime profiles during lower solar activity have been obtained in a more or less improved form by adding some more material supplied by a number of investigators (Maeda, K., 1970a).

As reported by Lauter (1973), Bremer and Singer (COSPAR Meeting, 1973) have presented electron density profiles for the $D$ region for various solar zenith angles for the summer season which also fit observed radio propagation at high, medium and low frequencies in middle latitude. But these mean profiles do not show the clear structuring of the electron density profiles as often observed in the rocket measurements (Mechtl, COSPAR Meeting, 1973).

Maeda, K. (1970b) reviewed the rocket measurement of electron density profiles in the lower ionosphere using radio wave techniques (Figure 1). Further, a general profile in the $E$ region at middle latitudes has been worked out, covering all seasons and a wide range of solar activity (1971), including some theoretical study on the formation of the $E$ layer. Furthermore, he studied the mid-latitude $E$ region electron density profiles, especially around noon in each season for each solar activity, night-time profiles and nocturnal variation of the peak density (1972a), the electron density profile in the $F_1$ region (1972b), and solar activity dependence of the $E$ region peak electron density (with Fukao, 1972).

Knight (1972) classified night-time electron density profiles according to the time after sunset at which the measurements were made, while those measured in the sunrise period have been classified according to solar zenith angle. A set of idealized electron density profiles for the night-time and sunrise has been derived.

Yonezawa (1970) has calculated theoretically expected electron density profiles in the $F_2$ layer for the CIRA 1965 model atmosphere and found that the calculated peak electron density and the height of the peak of the $F_2$ layer increase linearly with the intensity of solar 10.7-cm radio wave radiation. Each of these solar-cycle variations can be expressed in a simple form in terms of solar zenith angle, magnetic dip and the values at 300 km of such parameters as the scale height for atomic oxygen, the ambipolar diffusion coefficient and the electron loss coefficient.

Becker (COSPAR Meeting, 1971) showed that the lower side semi-thickness of the $F_2$ layer $y_m$ for noon and the electron density $N$ could be represented empirically by

$$y_m = 37.6 + 0.783 (\phi \cos \chi) - 1.254 \times 10^{-3} (\phi \cos \chi)^2,$$  \hspace{1cm} (1)