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Temperature of the F region of the Ionosphere over Kodaikanal

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ABSTRACT. Night temperature of the F region of the ionosphere over Kodaikanal has been computed by the scale height method for the months of June and December. The temperature at a height of 300 km is found to be round about 1200°K. It is also observed that winter temperatures are higher than summer temperatures. This summer to winter warming up may be due to the winds in the ionosphere

1. Introduction

In order to understand the properties of the ionosphere and the processes taking place in it a knowledge of the temperature of the region is essential. The results of various investigations, both theoretical and experimental, made so far for regions above 100 km differ widely. Mitra (1952) has summarised the various methods of estimating the temperature distribution above the 100-km level and he concludes that all the methods point to the existence of the temperature of the order of 1500 to 2500°K in the region of the $F2$ layer of the ionosphere. Gowan (1928) has shown that in the region of and above 60 km a high temperature should exist. Whipple (1935) referring to Gowan's conclusion says that the hypothesis of high temperature will have to be abandoned in favour of the view that the lightness of the atmosphere is due to the dissociation of oxygen. Das (1936, 1937) has given a tentative theory of the high temperatures of the earth's outer atmosphere that neutral atomic oxygen which forms the principal constituent of the atmosphere between the 100 and 200-km levels absorbs out of the solar and stellar radiations the forbidden lines λ2972, λ5577, λ6300 and λ6364 and attains a high equilibrium temperature at which the absorbed radiations can be re-emitted. Spitzer (1949), Bates (1951) and Johnson (1956) have studied the heat balance of the upper atmosphere on the basis of conduction.

Gerson (1951) has given a critical survey of ionospheric temperatures. Various ionospheric parameters have been used to determine the temperature of the ionosphere. The methods relate temperature to (*a*) collisional frequency, (*b*) recombination coefficient, (*c*) ionospheric scale height and (*d*) diurnal and nocturnal variations in electron concentrations.

The present investigation is undertaken to determine the temperature of the F region of the ionosphere over Kodaikanal (geographical latitude 10°·2 N, longitude 77°·5 E and geomagnetic latitude 0°·6 N) by the ionospheric scale height method.

2. Data and Analysis

The scale height H and the absolute temperature T of the region at a height Z_0 are connected by the relation

$$H = \frac{kT}{\mu m_0 g}\left(1 + \frac{Z_0}{R_0}\right)^2 \qquad (1)$$

where μ and m_0 are respectively the mean molecular weight of the region and the mass of an atom of hydrogen (*i.e.*, the product $\mu\ m_0$ gives the mean molecular mass of the region), g the acceleration

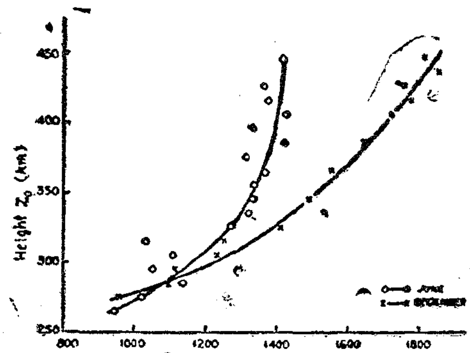

Fig. 1. Diagram showing the variation of temperature with height

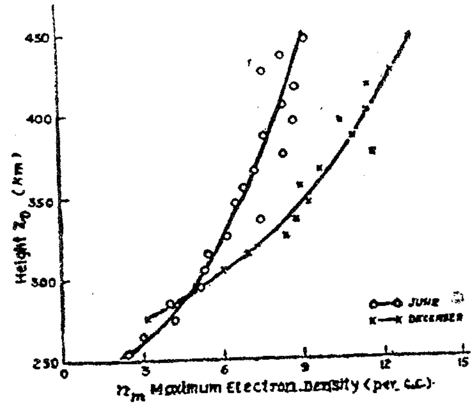

Fig. 2. Diagram showing the variation of maximum electron density with height

due to gravity at the earth's surface, R_0 the radius of the earth and k the Boltzmann constant. In the case of the region under consideration, oxygen is atomic and therefore $\mu = 24$.

The scale height H and the height of maximum ionisation Z_0 are obtained using the following formula due to Guha (1949)—

$$\frac{h_v - Z_0}{H} = -\ 2\cdot6672 - \frac{2\cdot794}{a} + \frac{3\cdot274}{a^{\frac{1}{2}}} + \frac{2}{a^{\frac{1}{2}}} \sinh^{-1} \frac{1}{(a-1)^{\frac{1}{2}}} \qquad (2)$$

where $a = (f_c/f)^2$ and h_v is the virtual height corresponding to the frequency f and f_c is the critical frequency.

The ionograms obtained at the Kodaikanal Observatory using the National Bureau of Standards (U.S.A.) C-3 type vertical sounding Multifrequency Ionosphere Recorder are used for determining the critical frequency f_c and the virtual height h_v corresponding to any frequency f. The values of h_v corresponding to any two values of f are substituted in equation (2) and solving simultaneously, Z_0 and H are calculated. Thus Z_0 and H are obtained for the period from 0000 to 0500 hrs for June of 1956, 1957 and 1958 and for the the same hours of December 1955, 1956 and 1957. From the values of H so obtained the temperature T at the height Z_0 is calculated using equation (1). The maximum electron density n_m is calculated using the relation

$$n_m = 1\cdot24 \times 10^4 \times f_c^2 \qquad (3)$$

Having obtained the temperature T corresponding to the height Z_0 for the hours mentioned above for the summer and winter months separately the temperatures are grouped together for each 10-km interval, *e.g.*, 251-260 km, 261-270 km and so on upto 441-450 km. The mean temperature of each class is calculated and this has been taken to represent the temperature corresponding to the mean height of each class. Thus the mean temperatures corresponding to the heights 255, 265.... 445 km are obtained and curves connecting heights and temperatures are drawn separately for June and December (Fig. 1). In a similar manner the mean maximum electron densities for the same heights are obtained and height *versus* electron density curves are drawn separately for the two months (Fig. 2).

From the curves the temperatures and the electron densities for different heights for the summer and winter months are read off; these are tabulated in Table 1.

TABLE 1

Temperatures and electron densities at different heights

Serial No.	Height Z_0 (km)	June		December	
		Temperature (°K)	Electron density n_m	Temperature (°K)	Electron density n_m
1	300	1160	$5 \cdot 1 \times 10^5$	1220	$5 \cdot 7 \times 10^5$
2	350	1330	$6 \cdot 9 \times 10^5$	1510	$9 \cdot 3 \times 10^5$
3	400	1400	$8 \cdot 2 \times 10^5$	1700	$11 \cdot 5 \times 10^5$

3. Results and Discussion

From Table 1 it is seen that the temperature of the ionosphere during the night at a height of 300 km is round about 1200°K. This night temperature agrees fairly with the theoretical value of the order of 650° to 1400° K given by Das (1936). Das had deduced temperatures of the order of 2000°K (actually varying between 1400°K and 2900°K) during the day. Since the period considered (1955 to 1958) happens to be a period of high sunspot activity bifurcation of the *F*1 and *F*2 layers is not clear in the day time ionograms of the Kodaikanal Observatory due to the thickening of the layers. As such the parameters of the *E* and *F*1 layers could not be obtained with certainty in order to apply retardation correction in computing the *F*2 region scale-height during the day. Hence day time temperatures could not be derived for the period considered. However, attempt is being made to compute the day time temperatures of the *F*2 region over Kodaikanal for the years 1952 to 1954, a period of low sunspot activity, when bifurcation of the *F*1 and *F*2 layers is fairly well seen in the Kodaikanal ionograms.

It is also seen from Table 1 that both the temperatures and the electron densities are higher in winter than in summer in the *F* region of the ionosphere over Kodaikanal. [On the other hand, Baral (1951) has obtained for Calcutta values of temperature higher in summer than in winter]. The mean relative sunspot numbers for June and December for the periods considered are almost the same. Hence the higher temperatures in December cannot be attributed to any difference in solar activity as indicated by the Zurich mean relative sunspot numbers. Wexler (1950) refers to the work of Gutenberg who has found for the region between 20 and 60 km higher winter temperatures; this apparent excess of winter temperature over that of summer has been shown to be caused by wind difference between summer and winter. It is probable that over Kodaikanal also the winds in the ionosphere are responsible for the apparent summer to winter warming up. However, in the absence of ionospheric wind measurements over Kodaikanal, no check of this tentative conclusion is possible.

Ionospheric winds or drifts of ionized air have been tracked at various stations in all the layers of the ionosphere. Seaton (1948) on the basis of his temperature investigations suggests the existence of large scale vertical movements as well as horizontal motions in the *F* region. His results show that cells of high and low temperatures are systematically developed in the northern and southern hemispheres and that the temperature gradients present suggest strong wind systems, pronounced convection currents and considerable turbulence. Yerg (1951) has postulated a general circulation resulting from periodic heating and cooling to account for the wind velocities in the ionosphere and has indicated that since winds would cause the electrons of the ionosphere to move up or down the magnetic meridians it is likely that ionospheric data would show some variation associated with systematic wind patterns. Winds are generated by the electrodynamic forces due to electric currents caused by electric fields communicated from a lower region. The $F2$ region is linked electrically to the dynamo region by the highly conducting lines of geomagnetic force. The polarization (electric) field in the lower dynamo region is substantially modified in both form and magnitude by the Hall conductivity of the the dynamo region (Baker and Martyn 1952). The drifts measured have been attributed in form and magnitude to the 'dynamo' potential field. Martyn (1954) has made an analysis of the drift velocity of the (neutral) ionization in a uniform ionosphere under the influence of an electric field and/or atmospheric wind and has arrived at the following conclusions—

(*i*) In the F regions ionization cannot be moved by winds transverse to the earth's magnetic field. Thus an east-west wind here can produce no appreciable movement of ionization. A local north-south wind causes the F region ionization to move along the direction of the earth's field with (very nearly) the velocity of the wind component in that direction ($C_0 \cos X$); then the north-south horizontal drift is $C_0 \cos^2 X$. High east-west drift velocities can be produced in the F regions only by north-south electric fields communicated from elsewhere.

(*ii*) Vertical velocities due to either winds or electric fields are small below 100 km, save in the immediate vicinity of the magnetic equator; near this equator east-west fields can produce noticeable vertical drifts at heights of 90 km and upwards.

(*iii*) In the F regions notable vertical drift is produced by east-west fields and/or by local north-south winds; in the latter case the wind simply blows the ionization along the direction of the earth's field, the vertical component of drift being $C_0 \sin X \cos X$. North-south fields or east-west winds produce no appreciable vertical drift. Purslow (1958) has measured the drifts in the $F2$ region of the ionosphere over Singapore, 10°·0 south of the geomagnetic equator and has shown that the drift of ionization in the $F2$ region at Singapore is predominantly in an east-west direction. The consistent easterly drifts during the night of upto about 90 m sec^{-1} and less consistent westerly drifts during the day of upto about 30 m sec^{-1} and the fact that these movements are in clear phase opposition to those determined at higher latitudes provide a confirmation of the predictions of Martyn (1955). Ramachandra Rao and Bhagiratha Rao (1958) also have made measurements of drifts at Waltair (Mag. Lat. 9°30′N) and have confirmed the predictions of Martyn regarding the phase reversal of $F2$ drifts at a latitude of 35° and the variation of the maximum east-west component of drift with latitude. According to Martyn's theory the maximum westward drift by day near the magnetic equator should reach 200 m sec^{-1}; but so far no observational evidence is available to check this point. Since Martyn's theory has been so successful in other respects it is important to examine whether or not this conclusion is also confirmed by observation. Thus the measurements of the drifts in the F region over a station like Kodaikanal, which is almost on the geomagnetic equator has a special interest and importance. Furthermore, Greenhow's (1954) systematic wind measurements at altitudes of 80-100 km have led him to the conclusion that the drifts of columns of ionization are due only to true wind motion of air molecules and to no other cause. He also finds a reversal in direction of the prevailing wind and attributes it to the change in atmospheric temperature between summer and winter. Likewise, the apparent higher temperatures in the F region of the ionosphere over Kodaikanal during the winter month of December compared to those in the summer month of June may well be due to a seasonal variation in winds and drifts in the region. This possibility again emphasises the need for making systematic measurements of winds in the F region at stations, such as Kodaikanal, very close to the geomagnetic equator.

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