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THE CHANGING IONSOPEHRE: AN UPDATE

K.K. Mahajan
National Physical Laboratory, New Delhi 110012 INDIA
E-mail: kkmahajan@mail.nplindia.ernet.in

ABSTRACT
Theoretical models predict a cooling of about 50 K in the thermosphere due to doubling of the atmospheric greenhouse gas CO_2 thus resulting in some permanent changes in the ionosphere. Examination of ionospheric data recorded during the last several years has revealed that the ionosphere has indeed changed, but some changes are not in exact agreement with the theoretical predictions. The models for example predict a lowering of the F2-layer peak height but the experimental data show rise as well as lowering. Some stations show no change. Implication of these results is also discussed.

1. INTRODUCTION

Carbon dioxide and other greenhouse gases can trap the outgoing radiation which may increase the temperature at the surface and at the lowest portion of the Earth's atmosphere. At higher altitudes, however, the situation reverses. There the absolute concentration of the green house gases decreases due to nearly constant mixing ratio, and the temperature may decrease because of the increased infrared radiation to space. Roble and Dickinson [1] studied the effect of doubling the mixing ratios of CO2 and CH4 at mesospheric heights (upto 60 km) by using their globally averaged model of the coupled mesosphere-thermosphere-ionosphere system and predicted that mesosphere would cool by 10 K and the thermosphere by 50 K. These authors also predicted that the ionosphere structure would also be altered, with lowered E and F-region peak densities and smaller topside plasma heights, though no numerical details were presented. Based upon the principle, that the peak of each ionospheric layer forms at a fixed level of atmospheric pressure, Rishbeth [2] from simple calculations estimated that 50 K cooling in the thermosphere would lower the height of the E-layer peak by about 2 km and of the F2 peak by 15-20 km with little effect on the peak electron densities of these layers. From rigorous calculations using the NCAR Thermosphere/Ionosphere General Circulation Model (TIGCM), Rishbeth and Roble [3] confirmed earlier estimates of [2] by predicting that the doubling of the greenhouse gases, carbon dioxide and methane, will lower the thermospheric temperature by 30-40 K and decrease air density at heights of 200-300 km by 20-40%. The peak heights of the E-and F2-layer will decrease by about 2.5 and 15 km respectively, with a slight decrease in the peak electron density of the F2-layer and a small increase in the peak densities of F1-and E-layers..

2. ANALYSIS OF IONOSONDE DATA

Bremmer [4] was the first to test the predictions made by [2] and used the long-term ionosonde measurements at the midlatitude stations Juliusruh, Poitiers and Slough for this purpose. Since hmF2 was predicted to show a long term decrease due to thermospheric cooling, [4] examined this parameter by deriving it from the MUF factor M(3000)F2 (an important ionospheric parameter obtained during the routine scaling of ionograms) using the empirical relation given by Bilitza [5]. Since hmF2 and other ionospheric parameters are greatly influenced by solar activity (and to a somewhat smaller degree by geomagnetic activity), [4] eliminated these solar and geomagnetic related variations and found that hmF2 had indeed shown a long term decrease, with no significant changes in the peak electron densities of the E-and F2-layers- a result in agreement with predictions of [2] and [3]. Analysis of ionosonde data at a few more individal stations (e.g. at Sondakyla by Ulich and Tarunen [6] and at Ahmedabad by Sharma et al [7], again showed results which were consistent with the theoretical predictions.

Realising that the thermospheric cooling due to increase in the concentration of greenhouse gases has to be a global phenomenon, Upadhyay and Mahajan [8], analysed ionosonde data from 31 stations located at various places on the globe and studied the long term trends in hmF2 and foF2. These data were extracted from the two CD-Roms produced by the World Data Center at Boulder, CO, USA covering the period from IGY to the year 1990. Rcgression coefficients for hmF2 and foF2 as a function of solar activity were obtained for each station and departures from expected values were derived for both of these parameters. From an analysis of hmF2 and foF2 anomalies, these authors found negative trends for some stations and positive for others, while some stations showed no trends. Bremmer [9], at about the same time investigated trends of foE, h'E, foF1, foF2, and hmF2 for 31 European stations and concluded similar results

for the F2 layer. Additionally [9] found some evidence of longitudinal effect in these trends. However, [9] found that the trends in the E-layer (decrease of h'E and increase of foE) and in the F1 layer (increase of foF1) to be in general agreement with the model predictions, though the observed E-layer trends were significantly stronger than the theoretical predictions.

3. TRENDS IN THERMOSPHERIC DENSITIES

In their theoretical studies [3] had also predicted that the air-density at heights of 200-300 km will be reduced by 20-40% due to doubling in the concentration of greenhouse gases. These authors had also pointed out that the detection of thermospheric cooling should not be limited to changes in the ionosphere but should also be examined in the thermospheric density. Keating et al. [10], following the suggestion of [3], studied the atmospheric density values obtained from the orbital decay of five Earth satellites with perigee altitudes averaging near 350 km for the years 1976, 1986 and 1996. These were the years of the minimum of the 11-year solar activity cycle where the 10.7 cm solar radio flux was 73, 74, and 72 flux units for 1976, 1986 and 1996 respectively. These authors selected these solar minimum years so that large corrections, which are required to account for solar activity variations in obtaining atmospheric densities, are not needed. From this analysis [10] found an average decline of $9.8 \pm 2.5\%$ in the thermospheric density during this 20-year period from 1976-1996, with values varying from 4.35% to 17.46% amongst the five satellites. These authors also found that the trend for the 10-year period from 1976 to 1986 was uncertain when standard error was applied but was consistent with the more accurately determined 20-year trend, thus providing a substantial evidence of long term cooling of the upper atmosphere.

4. LATEST RESULTS

Bremmer [11] extended his earlier analysis [9], which was limited to European stations only, to all the data available from all the stations all over the World. The parameters studied included foF2, foF1, foE, hmF2, and h'E. As before hmF2 was obtained from M(3000)F2 by using the method suggested by [5]. Fig. 1 taken from [11] basically summarizes his major conclusions which are, (1) the trends in the E-region (lowering of h'E and increase of foE) are in qualitative agreement with model predictions, though these are 3-5 times stronger than the model results, (2) the mean trend in the F1-region (increase of foF1) is in good agreement with the model predictions and (3) there is a large scatter in the individual F2-region trend data (foF2 and hmF2) and the mean global trends are rather small – a result in agreement with the works of [8] which were reported about three years earlier. Longitudinal effect seen in these trends by [9] earlier was not found in the latest analysis of [11].

5. CONCLUDING REMARKS

From above one conclusion is quite clear – the earth's thermosphere and ionosphere have changed at least during the last 50 years, the period for which ionospheric data from several ionosonde stations is now available. While some of these changes are in qualitative agreement with the model predictions, some differ a lot from the models. For example, the trends in the E-region on the lowering of h'E have indeed been observed, though these are 3 to 5 times stronger than the predictions. On the other hand, there is a large scatter in the F2-region trends in hmF2 of the individual stations. Some stations show a long-term decrease in this parameter, while others do not show any long-term change. The mean trends in hmF2 are rather small and are not significantly different from zero. Further some stations have shown very large long-term trends, both positive and negative in the peak density of the F2-layer, something that the models do not predict. Thermospheric densities at 350 km have shown a decline of about 10% during the 20-year period, which is rather much larger than expected from models, which predict a decrease of 20-40% in about a 100-year period.

Thus, these long-term changes in the ionosphere and thermosphere, though not quite consistent with theoretical predictions, need to be examined in more detail. An important assumption in all the trend analysis done so far, is that the dynamical parameters, which are so important in the ionospheric F2 region, do not have any long term trend. Similarly it is assumed that there are no long-term trends in solar and magnetic activity related effects. These assumptions need to be checked [12]. Further there have been reports about some technical changes in the equipment at some stations and there have been changes in scaling procedures at others. All these aspects need to be examined. Thus the problem of long-term trends in the ionosphere is still an active area of research.

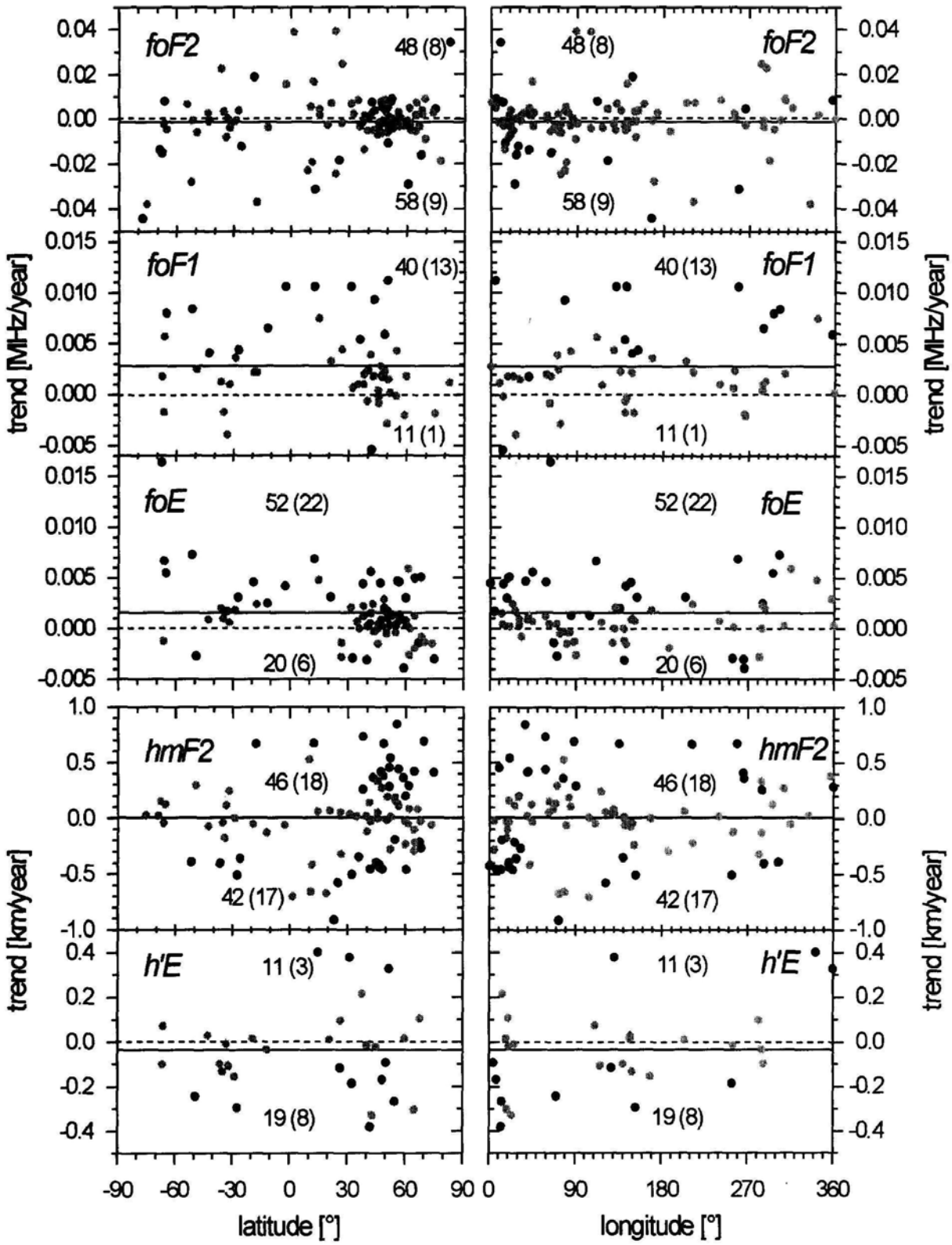

Fig. 1 Trends of different ionosonde parameters (foF2, foF1, foE, hmF2, h'E) derived at individual stations in dependence on latitude (left part) and longitude (right part). Significant trends (95 %) are presented by black, other trends by grey dots. The global mean values are shown by full, zero levels by dashed lines. The numbers in individual pictures are the total numbers of the positive and negative trends (in brackets the corresponding numbers of significant trends). [After Bremer, 2001]

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REFERNCES

[1] R.G. Roble and R.E. Dickinson, "How will changes in carbon dioxide and methane modify the mean structure of the mesosphere and thermosphere", *Geophys. Res. Lett.*, 16, 1441-1444, 1989.

[2] H. Rishbeth, "A greenhouse effect in the ionosphere?", *Planet. Space. Sci.*, 38, 945-948, 1990.

[3] H. Rishbeth and R.G. Roble, "Cooling of the upper atmosphere by enhanced greenhouse gases - modelling of thermosphere", *Planet. Space Sci.*, 40, 1011-1026, 1992.

[4] J. Bremer, "Ionospheric trends in midlatitudes as possible indicator of the atmospheric greenhouse effect", *J. Atmos. Terr. Phy.*, 54, 1501-1511, 1992.

[5] D. Bilitza, N.M. Sheikh and R. Eyrig, "A global model for the height of the F2-peak using M3000 balues from the CCIR numerical map", *Telecom. J.*, 46, 549-553, 1979.

[6] T. Ulich and E. Tarunen, "Evidence for long-term cooling of the upper atmosphere in ionosonde data", *Geophys. Res. Lett.*, 24, 1103-1106, 1997.

[7] S. Sharma, H. Chandra and R.D. Vyas, "Long term trends over Ahmedabad" *Geophys. Res. Lett.*, 26, 433-436, 1999.

[8] H.O. Upadhyay and K.K. Mahajan, "Atmospheric green house effect and ionospheric trends", *Geophys. Res. Lett.*, 25, 3375-3378, 1998.

[9] J. Bremer, Trends in the ionospheric E and F regions over Europe", *Ann. Geophys.*, 16, 986-996, 1998.

[10] G.M. Keating , R.H. Tolson and M.S. Bradford, "Evidence of long term global decline in the Earth's thermospheric densities apparently related to anthropogenic effects", *Geophys. Res. Lett.*, 27, 1523-26, 2000.

[11] J. Bremer, "Trends in the thermosphere derived from global ionosonde observations", *Adv. Space. Res.*, 28(7), 997-1006, 2001.

[12] K.K. Mahajan, "The chnaging ionosphere – Long term trends", *Ind. J. Rad. Space Phys.*, 34, 151-152, 2005.