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Long-term trends in F2-layer parameters and their relation to other trends

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Abstract

The method developed and tested by the author earlier was applied to a detailed analysis of the h_mF2 data obtained at the network of ionospheric stations to reveal long-term trends independent of the geomagnetic activity variations during the recent decades (nongeomagnetic trends). Unlike the results on *f*oF2 published by the author earlier, the picture of h_mF2 trends is not homogeneous. For 17 ionospheric stations positive significant trends are obtained. Six stations give negative trends in h_mF2. For three stations no trends were derived. The comparison of the trends in f_oF2 to the trends in the thermospheric density derived from satellite drag data shows their mutual agreement in the scope of current F-region theory. They also agree to the trends predicted in the 1990s for the CO_2 doubling. However, since the doubling has not yet happened, one has to look for other processes responsible for the trends. There is a possibility that the trends in thermospheric density and f_oF2 may be of an anthropogenic origin. A hypothesis is considered according to which both these trends may be due to a decrease (negative trend) of the O concentration in the thermosphere. To relate this assumption to other trends the behavior of the E-layer parameters is considered. It is shown that positive trends in f_oE are consistent with the negative trends of the $[NO^+]/[O_2^+]$ ratio, the latter being governed by the amount of NO. If there is a negative trend in [NO] in the E region during the recent decades, it is most probably due to the intensification (positive trend) of the eddy diffusion. This intensification should inevitably lead to a decrease of [O] in the entire atmospheric column above the E region. Such decrease may be responsible for the density depletion at satellite heights and f_oF2 depletion in the F2-layer.

Keywords: Ionosphere; Long-term trends; F-region; E-region; Nitric oxide

1. Introduction

Studies of the long-term changes (trends) in the parameters of the upper atmosphere and ionosphere are currently very popular. Several groups of authors (Alfonsi et al., 2002; Bencze et al., 1998; Bremer, 1996, 1998, 2001; Danilov, 1997, 2001, 2002a,b, 2003; Danilov and Mikhailov, 1998, 1999, 2001; Givishvili and Leshchenko, 1993, 1994; Jarvis et al., 1998; Marin et al., 2001; Mikhailov, 2002; Mikhailov and Marin, 2000, 2001; Ulich and Turunen, 1997; Ulich et al., 1997; Upadhyay and Mahajan, 1988) studied trends of the F2-layer parameters, h_mF2 and f_oF2. The results of these studies differ significantly both, by the used methods of trend revealing and the results obtained. The detailed review by Danilov (2002a) is already in some points out of date, especially concerning the new approaches published by the A.V. Mikhailov and M.G. Deminov groups. The most thorough review of the problem was recently published by Bremer et al. (2004). We will not discuss here in detail the reason for such "popularity" of the searches for long-term trends in the F2-layer parameters. Neither are we going

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to discuss different approaches to the searches of the long-term trends in f_oF2 and h_mF2 referring the reader to the Bremer et al. (2004) and Danilov (2002a) papers.

We merely note that the main aim is to find an answer to the question whether there happened in the recent decades variations in the thermosphere state independent of solar and geomagnetic activity. In other words, whether there is an anthropogenic component in the long-term variations of the thermosphere parameters and if it exists, how large it is. Evidently out of all ground-based measurements the vertical sounding data are the best material to try to answer the above-formulated question.

2. Trends in h_mF2

The method developed and published by the author earlier (Danilov, 2002b) was used to analyze the trends in the F-region critical frequency (f_oF2) at the network of the vertical sounding stations (Danilov, 2003). The results gave a negative trend in f_oF2 for all 23 stations considered, the averaged over all the stations value of tr(fo) being – 0.0012 per year.

The analysis of the h_mF2 data led to a more complicated picture of h_mF2 long-term trends (Danilov, 2004). We succeeded in finding the data satisfying the main requirement (a series of 30 + 5 years and more long) for 26 ionospheric stations. The results of the analysis were not so well coordinated as in the case of f_oF2. For 17 stations statistically significant positive trends were obtained. Averaging of the values of h_mF2 trend obtained for each station gave tr(hm) = 0.0011 per year with the standard deviation $\sigma = 0.0005$. For six stations significant negative trends were obtained. For three stations (Sodankyla, Irkutsk and Slough) the picture of h_mF2 with years was unstable and no significant trend in h_mF2 was obtained. It should be mentioned here that the method used by Danilov (2003, 2004) is deliberately directed to obtaining long-term trends independent of long-term geomagnetic activity variations (these trends were even called in the original publications (Danilov, 2002b, 2003, 2004) "nongeomagnetic" trends).

Trends in h_mF2 different by sign for different stations were obtained by many authors (Bremer, 1998, 2001; Marin et al., 2001), in spite of different methods of trend derivation. The most probable explanation of this is related to the fact that the reliability of the h_mF2 data determination is considerably lower than that for the f_oF2 data. The latter are read directly (and with high accuracy) from vertical sounding ionograms, whereas the former are recalculated from the initial data (f_oF2 and M3000), and there exist at least two methods of recalculation (Ulich, 2000) giving somewhere different results.

Danilov (2004) found no system in geographic distribution of the stations giving negative values of tr(hm). If by the "majority method" we accept that correct (more typical) are positive trends in h_mF2, than the existence of the stations for which negative trends are obtained or no trends were derived should be explained by the irregularity of the h_mF2 time series used for the analysis. While deriving long-term trends in h_mF2, it is enough to have a small changes in the method of h_mF2 determination within the 30–40 analyzed years to make the picture unstable (at least in the scope of the method used) and as a result a derivation of trends to become impossible or to lead to negative values of tr(hm).

Bremer (2001) in his Fig. 8 presents a good illustration of the cases when there were well pronounced discontinues in trends in hmE caused by technical changes. Evidently similar discontinues may be found in the series of h_mF2 data. It is obvious that with such data series it is impossible to obtain corrected values of h_mF2 trends. Danilov (2004) showed that out of six stations (considered both by him and by Bremer (1998)) for which no positive trends has been obtained by Danilov (2004) for five stations the Bremer's results give negative trends. If we believe that the positive trends are "correct" (more typical), this result confirms that there is something wrong with the series of the initial h_mF2 data, because two different methods give negative trends or no trends at all.

We have indicated in the Introduction that the main importance of looking for f_oF2 and h_mF2 trends is closely related to their probable connection to the problem of possible changes in the thermosphere due to the anthropogenic impact on the latter. Bremer et al. (2004) quite correctly noted that the trends both in f_oF2 and h_mF2 obtained by various groups are too small to be taken into account in current empirical ionospheric models (like IRI or COST). However the presence of the trends in the parameters of the F2 layer should be considered together with trends in other parameters (temperature, density) to analyze the nature of the thermospheric and ionospheric trends.

Also the trends in F-region parameters should be as far as possible related to the trends in the lower atmospheric and ionospheric regions (the mesosphere, ionospheric E and D regions).

3. Comparison of the trends at thermosphere heights

Now we have two nongeomagnetic trends in the F2-layer parameters: in the critical frequency f_oF2 and the height of the layer maximum h_mF2. The trends have opposite signs: f_oF2 decreases with time and h_mF2 increases. As far as by the definition both trends are free from any influence of the long-term variations of solar and geomagnetic activity, there are serious arguments