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LONG-TERM VARIATIONS OF THE THERMOSPHERIC TEMPERATURE AND DENSITY ON THE BASE OF AURORAL CHARACTERISTICS

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Abstract. The long-term data set of the auroral heights according to Störmer's measurements has been analyzed. The mean regular seasonal and solar activity variations have been removed from the data. As a result, the long-term linear negative trend of the mean auroral heights (-0.8 km / yr) at altitudes 160-180 km during period from 1918 to 1944 has been revealed. There is a satisfactory agreement between the atmospheric subsidence for the range of 1918-1944 and that of 1955-1995. Thus, there was a stable process of the middle and upper atmosphere cooling and subsidence over the 20th century.

Introduction

C. Störmer with his colleagues performed almost regular observations of different auroral forms in period from 1911 to 1952 (*Störmer*, 1955). These measurements were made by triangulation method in the southern part of Norway ($\varphi \sim 60°$ N, $\lambda \sim 10°$ E). The latitudes of the photographically registered auroral forms were 55-68° N. 12330 measurements during period of 1917-1943 were made. *Egeland and Omholt* (1966) carried out statistical analysis of these data and found regular diurnal, and seasonal (from September till May) behavior, as well as dependence upon solar activity during 11-year cycle. In this paper the analysis of the long-term variations of auroral ray band heights is presented.

Analysis

At present, the only data available for analysis of long-term variations of auroral heights are those published by *Störmer* (1955, Fig.76, page 110). This figure was also published by *Chamberlain* (1961). However, the there data presented have a peculiarity, namely, all the measured values of vertical projections of auroral rays are given in succession during the years of measurements without indication of their time distribution over each year (Fig. 1a). Nevertheless, the published data of statistical regularities of the seasonal and solar activity variations (*Egeland and Omholt*, 1966) helped to interpret the presented data in the first approximation. For this purpose the mean seasonal height variations of auroral rays for winter periods have been corrected taking into account solar activity changes for each years. After that, each year group of auroral rays has been compared with the mean seasonal changes of heights for this year and its position over the year has been determined on the basis of the most similarity between their mean seasonal behaviours. These results are shown in Fig. 1b. After this procedure the obtained mean seasonal changes for each group have been reduced to winter solstice and minimum solar activity level. Therefore, the reduced heights Z correspond to winter nights for low geomagnetic activities which usually take place for this season (*Yanovsky*,1953).

Results

The reduced mean auroral heights Z are presented in Fig. 2a. The evident long-term trend of heights Z decreasing can be revealed, which is described by the regression equation

$$Z = -0.8\,(t - 30) + 160,$$

where t is the number of the year. The correlation coefficient is -0.540 ± 0.154, the Student coefficient is 2.9. The linear trend is -0.8 ± 0.3 km / yr for the mean height range of 160-200 km.

The long-term variations of the mean annual temperatures of the atomic oxygen emission 557.7 nm are shown in Fig. 2b. The circles mark the interferometric measurements (*Hernandez and Killeen*, 1988). The squares correspond to the lidar data (*She et al.*, 1993). The dots show the temperatures estimated on the basis of the intensities of the 557.7 nm emission, as the rate coefficient of the photochemical reaction of the Barth mechanism excitation of the 557.7 nm emission depends upon temperature (*Semenov*, 1997). Hence,

$$I_t/I_{72} = \{[O]_t / [O]_{72}\}^3 (T_t/T_{72})^{4/3} \exp\{(-1506/T_{72})[1 - (T_{72}/T_t)]\},$$

where T_{72} = 196 K, I_{72} = 262 R, (*Semenov and Shefov*, 1997) T_t and I_t are the temperatures and intensities of the 557.7 nm emission for 1972 and year number t, respectively. The rms error of the mean annual temperature is about $\delta T(K) \sim 0.36\, \delta I$ (%) and $\delta T \leq 4$K for $\delta I \leq 10\%$.

The calculations with using the empirical data of 557.7 nm emission variations (i.e. intensity, temperature and emissive layer) (*Semenov and Shefov*, 1997) and photochemical theory of this emission excitation (*Semenov*, 1997) show that the atomic oxygen abundance decreases by 7 per cent and its layer falls down to some kilometers for solar activity variations from minimum ($F_{10.7}$ = 65) to maximum ($F_{10.7}$ = 200).

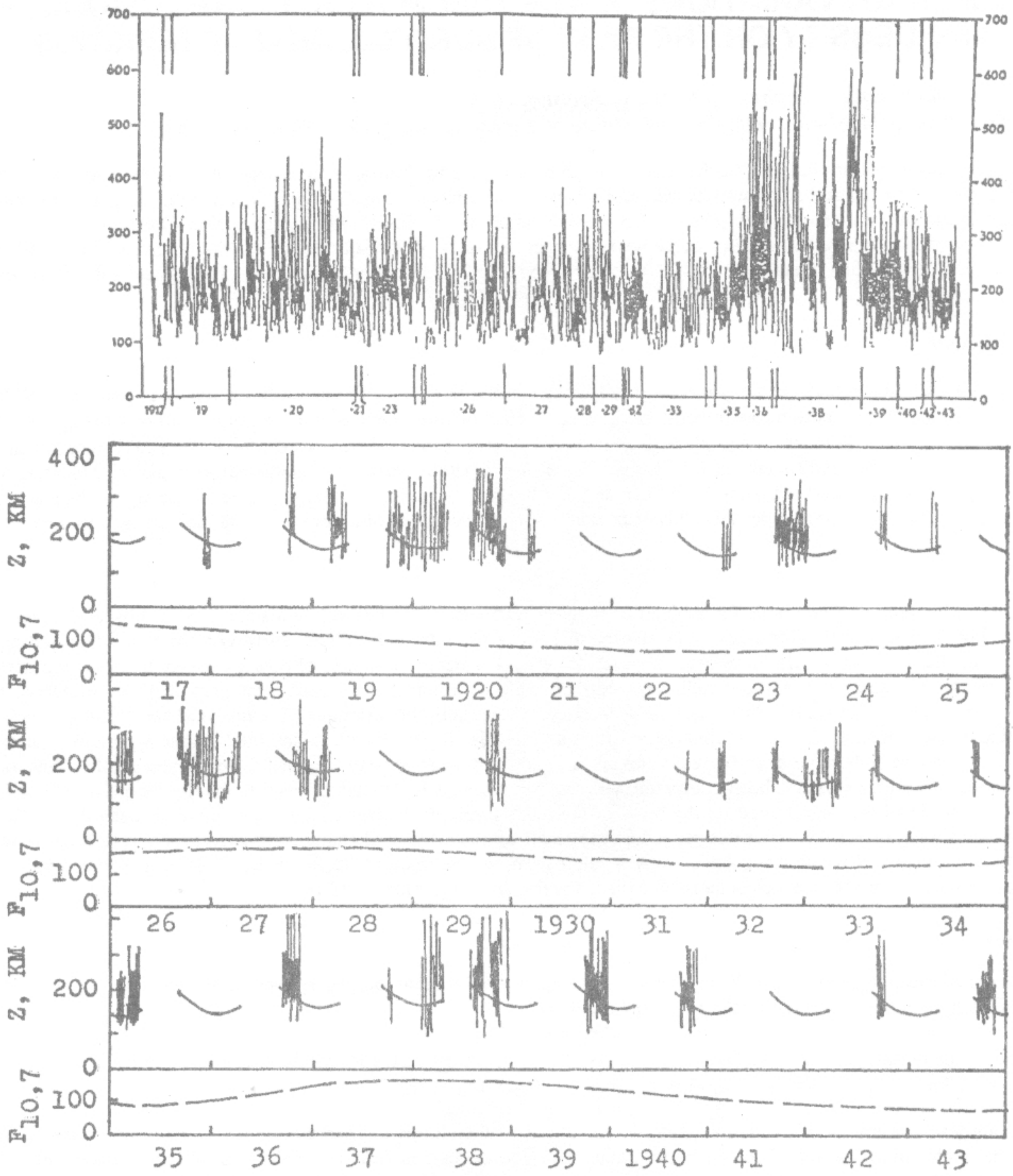

Fig.1. Temporal distribution of Störmer's measurements of the auroral ray vertical projections. (a) is the Figure published after *Störmer* (1955); (b) the data reconstructed from (a). The solid lines show the mean seasonal variations of auroral heights with the solar activity variations being taken into account. The dashed lines are solar activity variations ($F_{10.7}$), which have been calculated from the Wolf numbers according to *Vitinsky et al.* (1986).

Thus,

$$[O]_t / [O]_{72} = 1 - 4.2\ 10^{-4} (F_{10.7} - 130) - 2.1\ 10^{-6} (F_{10.7} - 130)^2$$

According to Fig. 2b the regression equation is

$$T = 196 - 0.097\ (t - 72.5) - 0.080\ (F_{10.7} - 130)$$

The linear trend is -0.1 ± 0.03, the Student coefficient is 3.1.

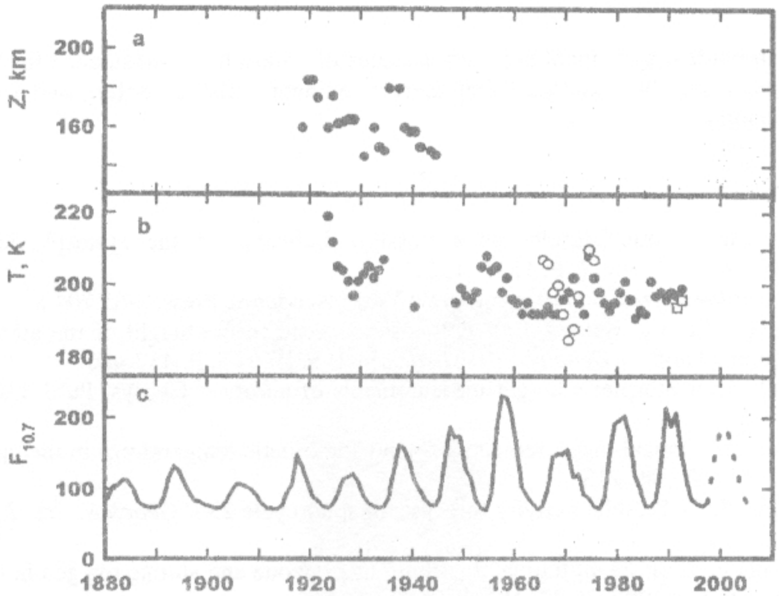

Fig. 2. Long-term variations: (a) the mean auroral ray heights Z reduced to winter solstice and minimum solar activity; (b) the mean annual temperatures at height of 97 km (see the text); (c) the mean annual variation of solar activity ($F_{10.7}$). The dotted line shows prognostic data (*Schatten et al.*, 1996).

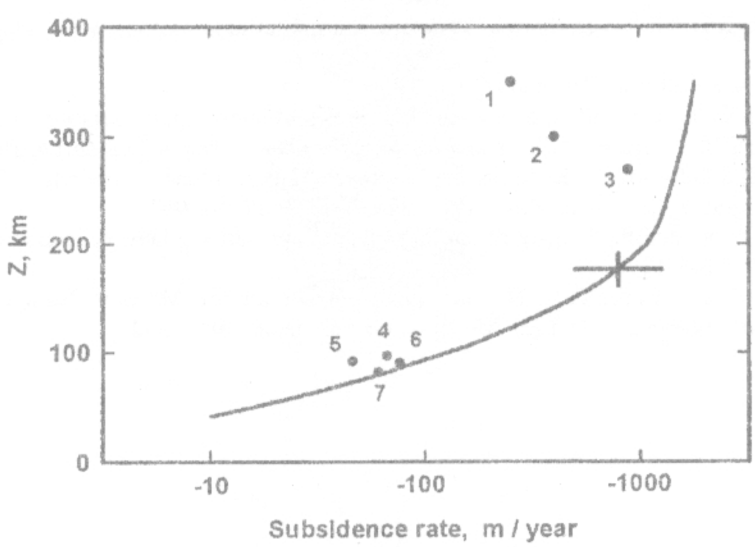

Fig. 3. The subsidence rates of the upper atmosphere versus height. The solid line shows the results of calculations (*Semenov and Lysenko*, 1997); the dots are the data of measurements: (1) and (2) are the F_2 ionospheric layer according to (*Bremer*, 1992) and (*Ulich and Turunen*, 1997), respectively; (3) is the atomic oxygen emission 630 nm (*Semenov and Lysenko*, 1997); (4) is the sodium layer (*Clemesha et al.*, 1992); (5) is the atomic oxygen layer peak height (*Semenov*, 1997); (6) is the ozone layer peak height (*Semenov*, 1997); (7) is the D ionospheric layer (*Taubenheim et al.*, 1991, 1997). The cross marks the subsidence rate according to Fig. 2a. Its vertical size is the range of height variations and horizontal one is doubled rms error of the subsidence rate.

In Fig. 3 the rate of the upper atmosphere subsidence during period of 1955-1995 is shown. The solid line shows the data obtained from calculations of atmospheric density height distribution by the barometric equation for atmospheric temperature profiles for 1955, 1972 and 1995 reduced to $F_{10.7} = 130$ (*Semenov and Lysenko*, 1997). The dots mark the experimental data obtained by different methods. The cross shows a subsidence rate of the thermosphere for period of 1918-1944 according to Fig. 2a. Its vertical size is the range of height variations and horizontal one is doubled rms error of the subsidence rate.

Conclusion

As one can see, there is an evident agreement between the rates of atmospheric subsidence for the first and last halves of the 20th century. Thus, it can be concluded that there is evidently stable cooling and subsidence of the upper atmospheric during this century.

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