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# Atmospheric Trends Above Finland: I Mesosphere and Thermosphere

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*Abstract*

*In the present study we analyse various long-term data series of measurements run by the Sodankylä Geophysical Observatory for possible indications of cooling trends in the upper atmosphere. We review trends seen in the ionospheric F2 peak altitude measured by ionosondes and compare them with the Finnish ionosondes at Nurmijärvi and Sodankylä as well as with comparable observations of the EISCAT incoherent scatter radars. Furthermore we study trends seen in the data of the Finnish riometer network at 7 different latitudes. While some of the observed trends suggest cooling, a consistent signal of upper atmospheric cooling, caused possibly by increasing amounts of greenhouse gases, cannot be deduced from the data.*

*Key words: Ionosphere, global change, evolution of the atmosphere, ionosphere/atmosphere interactions, atmospheric composition and structure, atmosphere*

## *1. Introduction*

Extensive model calculations show that increasing greenhouse gas concentrations in the air cause a cooling of the entire middle and upper atmosphere. According to *Keeling et al.* (1995), the concentration of atmospheric $CO_2$ on the ground in Mauna Loa, Hawaii, increased between 1958 and 1994 by about 13.5 %, about 56 % of which are estimated to be of anthropogenic origin. Based on a scenario of doubling $CO_2$ and $CH_4$ concentrations, *Brasseur and Hitchman* (1988) predict a cooling of the stratosphere of 8 to 15 K. *Roble and Dickinson* (1989) foresee the mesosphere and lower thermosphere to cool by 10 K and 50 K, respectively. As a consequence, the upper atmosphere is expected to shrink. *Rishbeth* (1990) estimated analytically, that the altitude of maximum electron density of the ionosphere, the so-called F2 layer peak height (*hmF2*), will lower by 15-20 km if the underlying atmosphere cools by 50 K. Later, *Rishbeth and Roble* (1992) verified this estimate using the Thermosphere/Ionosphere General Circulation Model (TIGCM) of NCAR, Boulder.

*Bremer* (1992) was first to provide observational evidence for thermospheric cooling with the data of the ionosonde in Juliusruh on the Northern German island of

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Rügen. At this mid-latitude location, the F2 peak lowered by about 185 m per year during almost 40 years of operation. Later, *Ulich and Turunen* (1997a) found a similar lowering trend of 390 m per year at the high latitude station Sodankylä, and *Bencze and Poor* (1997) reported negative trends of 160 m and 300 m per year for the Japanese stations Wakkanai and Kokubunji, respectively. Recently, *Jarvis et al.* (1998) compared the trends seen in Juliusruh and Sodankylä with their geographically conjugate stations on the southern hemisphere, Argentine Islands and Port Stanley. Also here, evidence for lower thermospheric cooling is found. At Argentine Islands the altitude of the F2 peak changes between +200 m and –500 m per year, depending on the month, while at Port Stanley all trends are negative and lie between –100 m and –900 m per year. The monthly trends observed at Port Stanley seem to be seasonally correlated to the trends of Sodankylä. All stations show consistent cooling trends, which agree qualitatively with the model estimates, but which are stronger than predicted.

In 1997, however, *Ulich and Turunen* (1997b) presented a trend study of the F2 layer peak height of 69 stations all over the world and found that the trends vary greatly between +1 km and –1 km per year. Recently, two groups published their multi-station trend studies simoultaneously and report the same. Firstly, *Bremer* (1998) studied 31 European stations, and finds in agreement with *Ulich and Turunen* (1997b), that stations west of 30° E generally show lowering of the F2 peak, while stations east of 30° E show a rising F2 peak, thus questioning the observed trends to be due to a global greenhouse effect. Secondly, *Upadhyay and Mahajan* (1998) studied 31 global stations using the same analysis method as *Ulich and Turunen* (1997a), and showed again a great number of different trends, varying between +860 m and –580 m per year. They conclude that a signal of a greenhouse gas induced cooling of the upper atmosphere cannot be inferred from these data.

However, most sites show consistent up or down trends of the F2 peak altitude and thus they indicate long-term change with regional consistency. The great variety of trends as well as the fact, that the observed negative trends are often stronger than the models predict for the current amount of $CO_2$ and $CH_4$ in the atmosphere, show that an enhanced greenhouse effect, i.e., a change of the chemical composition of stratosphere and mesosphere, is not sufficient to explain the trends.

Subsequently, we will study data measured by a number of Finnish stations at various altitudes and latitudes. Part I (this study) deals with the measurements in the ionosphere, while Part II (*Kivi et al.*, 1999) deals with the troposphere and the stratosphere. Here, we study the F2 peak heights (typically around 300 km) measured by the Finnish ionosondes in Sodankylä and Nurmijärvi. We compare the trend in their data with the one obtained by the EISCAT incoherent scatter radars in Northern Fennoscandia. Furthermore we analyse the behaviour of the long-term absorption measurements of 9 Finnish riometers, which relate to the ionospheric D region, i.e. mainly 70–100 km altitude.

## 2. *F2 layer peak altitude: ionosondes*

We reanalyse the behaviour of the ionosperic F2 layer altitude at two sites in Finland: Nurmijärvi, which is situated near Helsinki in Southern Finland (60° 30′ N, 24° 39′ E), and Sodankylä in Finnish Lapland (67° 22′ N, 26° 38′ E).

The ionosonde in Nurmijärvi started operations in January 1957. The instrument hardware was changed once in March 1974. The later version had a frequency range of 1 to 16 MHz and one sweep took 160 s. It used photographic 35 mm film for its hourly recording of ionograms. The recordings in Nurmijärvi ended in December 1987.

The ionosonde in Sodankylä is in operation since August 1957. During this time, the instrument was updated once in 1977. The present version of the ionosonde, which sweeps in 160 s through frequencies between 1 and 16 MHz, and which uses rhombic wires on a 64 m mast as aerials, records ionograms half-hourly on photographic 35 mm film. Since 1957, the scaling of the ionograms is done by the same person throughout, and great care has been taken to correct for the changes of the ionosonde hardware, thus the data can be regarded as of very high quality and continuity.

The data used for the present study are based on monthly median values of *hmF2*, which in turn have been obtained from the maximum usable frequency M3000F2 and the critical frequencies of the E and F layer by an empirical formula by *Bilitza et al.* (1979). Thereafter, the *hmF2* values were averaged over five hours around local noon (1000 LT to 1400 LT). The signal of solar activity has been removed from the data by correlating it to 10.7 cm radio flux emission rates. For a detailed description of the analysis method as well as a verification of the applicability of the empirical estimate of *hmF2*, see *Ulich and Turunen* (1997a). Figure 1a shows the anomaly of the F2 layer peak height of Sodankylä. A clear down trend of (390 ± 119) m per year is seen at 95% confidence level. Figure 1b shows the corresponding data of Nurmijärvi. The overall trend, at 95% confidence level, is (354 ± 283) m per year downwards, and thus agrees with the observations at Sodankylä. However, large gaps in the data of Nurmijärvi leave some doubt to the validity of this linear trend.

## 3. *F2 layer peak altitude: EISCAT incoherent scatter radar*

For comparison with the *hmF2* trends seen in ionosonde data, we analyse 12 years of data obtained by the UHF radars of the European Incoherent Scatter Scientific Association (EISCAT), which form a tristatic system with a transmitter and receiver site in Norway (Tromsø) and additional receiver sites in Sweden (Kiruna), and Finland (Sodankylä). Electron density profiles are extracted from all of the so-called Common Programme 1 (CP-1) experiments from 1985 to 1993 inclusive. We select profiles measured at Tromsø (69° 35′ N, 19° 13′ E) between 1000 LT and 1400 LT. From these the height of the F2 peak was determined by fitting a polynomial to each profile. The altitudes are thereafter averaged over the noon times of each day, and the signal of solar activity is subtracted by means of correlating with 10.7 cm radio flux emission rates in

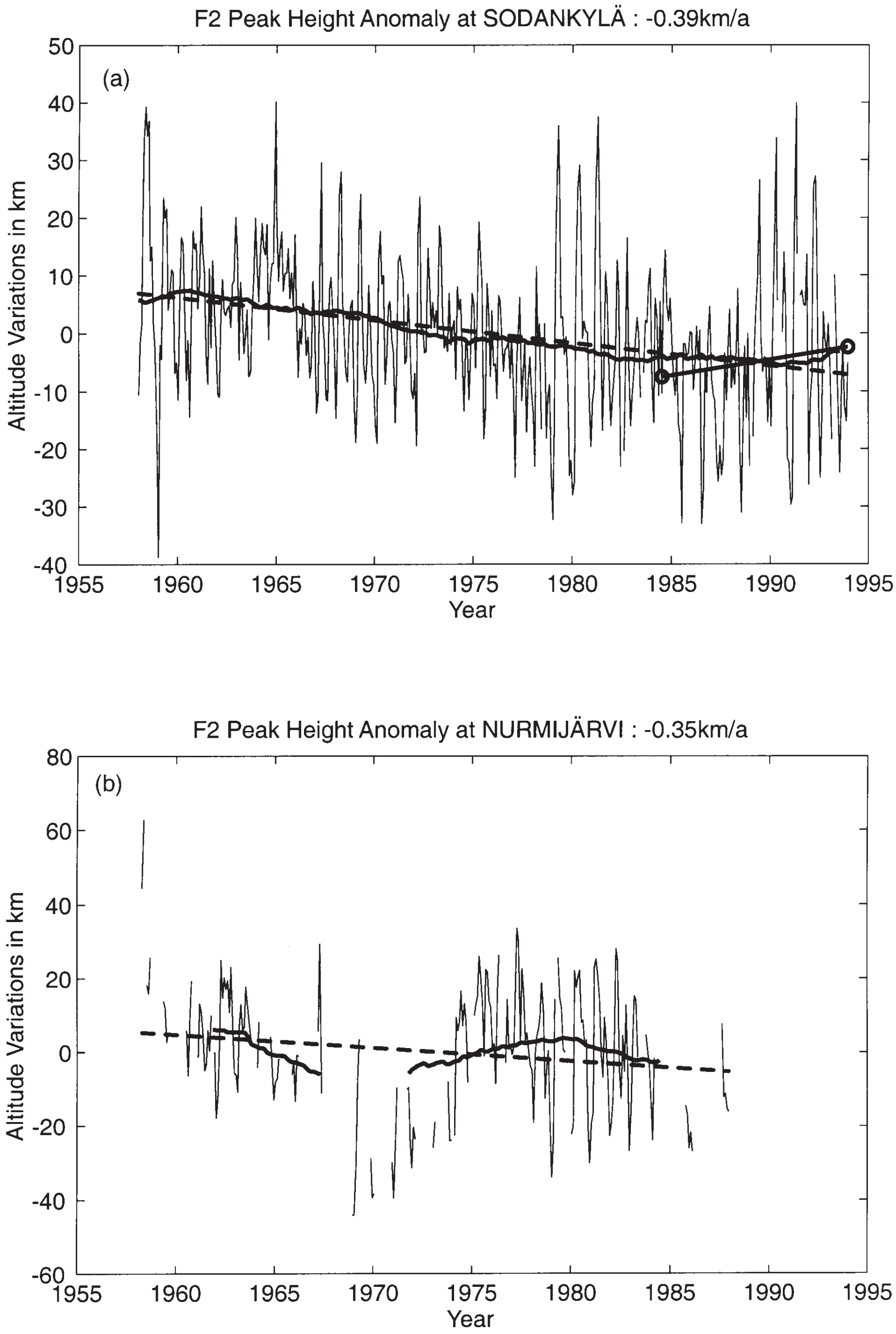


Fig. 1. The F2 peak height (hmF2) anomaly (thin line) is plotted together with its regression line (dashed) and its 11 years (one solar cycle) smoothing (heavy line). Panel (a) shows data of Sodankylä (67° 25′ N), Panel (b) shows data of Nurmijärvi (60° 31′ N). Panel (a) shows additionally a regression line (solid with circles) for the same period as the EISCAT measurements of hmF2 (see Figure 2).

analogy to the handling of the ionosonde data (*Ulich and Turunen*, 1997a). A linear trend analysis gives a rate of (1.59 ± 0.76) km per year at 68% confidence level during the operation time of EISCAT (Figure 2). However, until 1989 the data show a clear negative trend, and they data appear to be more noisy thereafter, which reflects in the error of the regression coefficient. A further study investigating this behaviour is currently under way.

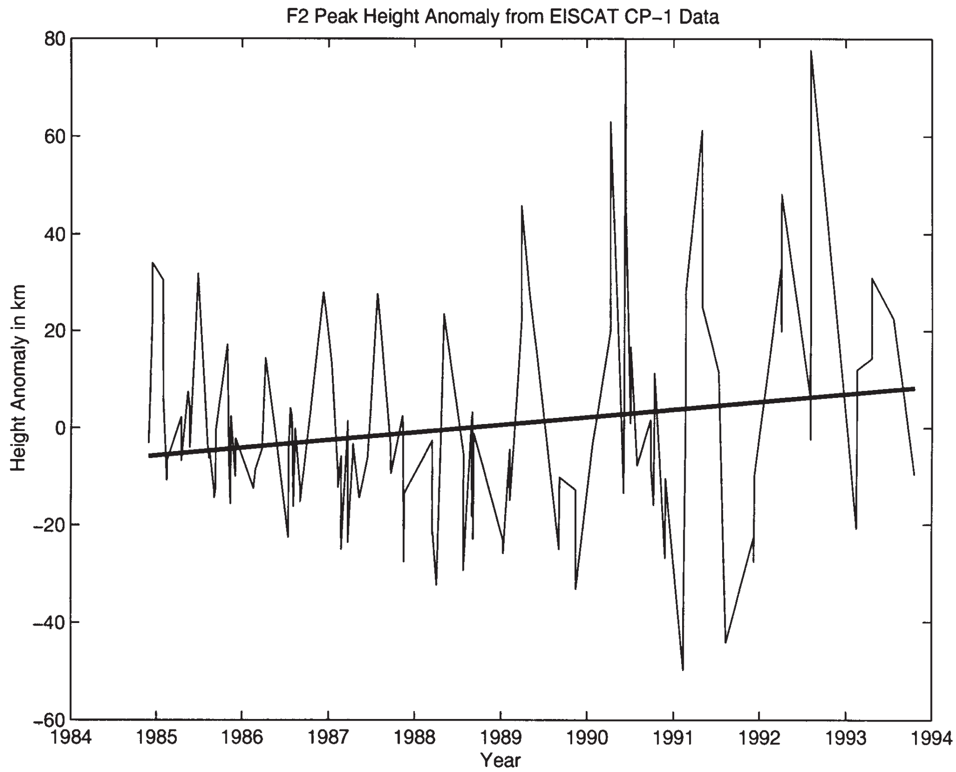


Fig. 2. The F2 peak height anomaly (thin line) obtained from CP-1 experiments of the EISCAT incoherent scatter radars between 1985 and 1993 and its linear regression (heavy line).

Comparison with the same time interval of the Sodankylä ionosonde shows qualitatively the same trend, but not as strong. Between 1984 and 1993, the F2 peak in Sodankylä has risen at a rate of (544 ± 479) m per year at 68% confidence level (Figure 1a). The large errors in the trend estimates for EISCAT CP-1 and the recent years of Sodankylä ionosonde data are partly a result of the sparcity of the data.

## 4. *Absorption of cosmic radio noise*

A riometer measures the intensity of the cosmic radio noise that has passed through the ionosphere. Since the galactic radio flux is constant over long periods of time, the day-to-day changes of apparent intensity are due to variations in ionospheric attenuation. The amount of absorption is obtained by comparing the measured cosmic radio noise with the one expected at the same sidereal time in absence of absorption. The expected background cosmic noise power as a function of sidereal time, the so-called “quiet day curve”, is obtained from the data as described in detail in *Ranta et al.* (1983). In Fennoscandia, the Sodankylä Geophysical Observatory operates 14 different riometers of which 9 are currently in use. Those riometers situated in Finland, whose data are used in this study, are listed in Table 1.

Table 1. Overview of the riometers of the Sodankylä Geophysical Observatory, which are situated in Finland. We show only those instruments, whose time series of data is of long duration and not redundant with other riometers. The station's name is printed in bold font, if the riometer is still operational.

| **Riometer Stations of the Sodankylä Geophysical Observatory** | | | |
|---|---|---|---|
| **Station** | **Geographic Coordinates** | **Frequency** | **Time** |
| Kevo | 69° 45′ N 27° 01′ E (L=6.0) | 27.6 MHz | 02/1968 – 02/1993 |
| **Ivalo** | 68° 33′ N 27° 17′ E (L=5.5) | 27.6 MHz<br>30.0 MHz | 03/1972 – 10/1991<br>01/1992 – today |
| Sodankylä | 67° 25′ N 26° 23′ E (L=5.1) | 20.0 MHz | 03/1969 – 01/1986 *) |
| **Sodankylä** | 67° 25′ N 26° 23′ E (L=5.1) | 27.6 MHz<br>30.0 MHz | 02/1964 – 05/1991<br>11/1994 – today |
| Sodankylä | 67° 25′ N 26° 23′ E (L=5.1) | 40.0 MHz | 03/1969 – 01/1994 |
| **Sodankylä** | 67° 25′ N 26° 23′ E (L=5.1) | 50.0 MHz<br>51.4 MHz | 03/1969 – 02/1985<br>11/1984 – today |
| **Rovaniemi** | 66° 34′ N 25° 56′ E (L=4.8) | 27.6 MHz<br>32.4 MHz | 11/1974 – 09/1985<br>10/1985 – today |
| **Oulu** | 65° 06′ N 25° 32′ E (L=4.3) | 27.6 MHz<br>29.7 MHz<br>30.0 MHz | 07/1967 – 02/1993<br>03/1993 – 04/1996<br>12/1995 – today |
| **Jyväskylä** | 62° 25′ N 25° 17′ E (L=3.7) | 27.6 MHz<br>32.4 MHz | 09/1974y – 09/1985<br>10/1985 – today |
| Nurmijärvi | 60° 31′ N 26° 38′ E (L=3.3) | 27.6 MHz | 11/1967 – 07/1992 |

*) not used in this study.

*Taubenheim et al.* (1990) observe a significant down trend in the reflection heights of low frequency radio waves (typically around 80 km) at the Kühlungsborn Observatory on the German coast of the Baltic Sea. They consider the trend to be quantitatively consistent with a decrease of air temperature due to greenhouse cooling. *Serafimov and Serafimova* (1992) suggest that measurements of radio wave absorption would be the most sensitive indicators of the possible climate change in the ionosphere. Radio wave absorption basically depends upon electron density and electron-neutral collision frequency, which, in turn, is a function of neutral air temperature T, and neutral particle density *N*:

$$\nu_{\mathrm{en}} \propto N \times T^{1/2} \tag{1}$$

The effect of a cooling on the collision frequency is not obvious, since a temperature decrease implies a pressure increase. However, constant pressure levels should lower when the temperature falls. Between 1980 and 1990, lidar measurements over Southern France show a cooling of about 2.5 K between 50 and 60 km (*Aikin et al.*, 1991), and of about 4 K between 60 and 70 km altitude (*Hauchecorne et al.*, 1991). The riometer records are about 25 years long, and the mesosphere would cool by 10 K at the latter rate. *Ulich et al.* (1997) used the Sodankylä Ion Chemistry (SIC) model (see, e.g., *Turunen et al.*, 1996), to model the effect of a 10 K cooling of the entire mesosphere on radio noise absorption at 30 MHz. They found, that at certain altitudes between 50 and 100 km the density increase due to cooling outnumbers the temperature decrease, and thus the altitude profile of absorption is complicated, but the net effect is a decrease in absorption.

Figure 3 shows the long-term data of the Finnish Riometer Chain, i.e. the monthly averages of the absorption during the first minute of each hour. The absorption is given conventionally in dB; it is calculated from the ratio of the received cosmic noise power $P$ to the cosmic noise power under quiet conditions $P_0$ by the formula

$$A = 10 \log_{10} (P_0 / P). \quad (2)$$

Due to the logarithmic definition of the absorption, a meaningful trend can be calculated only from the power ratios. For the data considered in this study, however, it is only for a few stations possible to obtain a reasonable linear trend estimate (68% confidence level at power ratios). For the Ivalo and the 30 MHz Sodankylä riometer (Figure 3, 2$^{nd}$ and 3$^{rd}$ panel) the trends in power ratios are negative, ($-0.0028 \pm 0.0007$) per year and ($-0.0021 \pm 0.0006$) per year, respectively. Jyväskylä (Figure 3, 8$^{th}$ panel) shows a positive trend of ($0.0013 \pm 0.0003$) per year.

A mathematical analysis of the raw monthly averaged data at other sites shows so large errors in the linear trend estimates, that it is not possible to draw any reliable further conclusions from this kind of analysis. However, the trends observed by riometers operated at 30 MHz seem to hint on a possible latitudinal dependency of the trend.

## *5. Conclusions*

The motivation for this study was to check if our long-term data sets show evidence of upper atmospheric cooling due to increasing amounts of greenhouse gases as predicted by various authors. We have shown long-term data of the ionosondes of Nurmijärvi and Sodankylä, of the EISCAT incoherent scatter radars, and of 9 riometers at 7 different latitudes in Finland. Many of the data show linear trends and we have fitted regression lines to some of the data in order to describe their behaviour. Some of the trends agree with the proposed cooling, some do not.

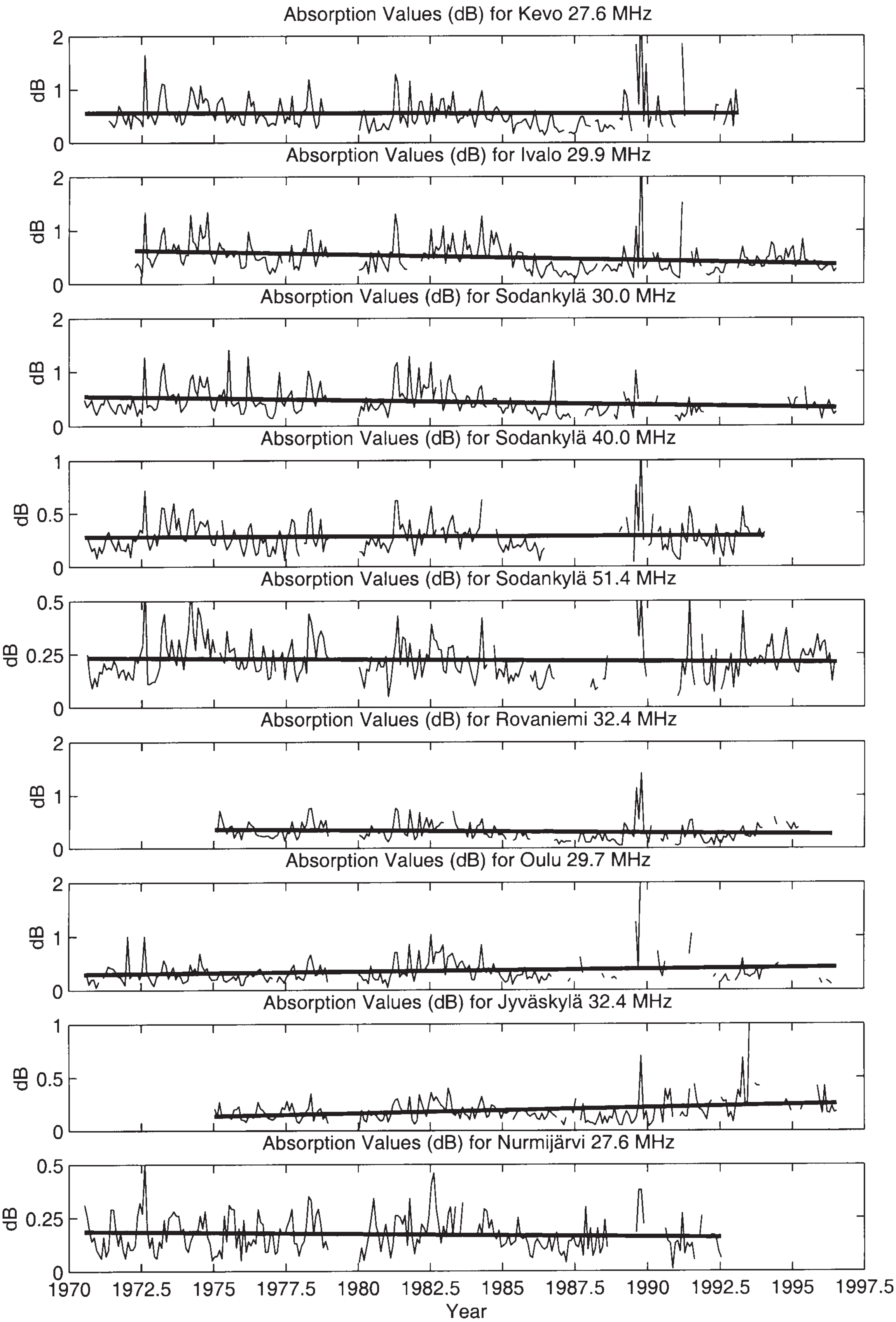


Fig. 3. Trends seen in the longest records of riometers in Finland: the data (thin line) is plotted together with a linear regression line (heavy line) obtained in the power ratios (see text). Refer to Table 1 for further information on the riometers and their locations.

Both ionosonde records show a lowering of the altitude of the F2 layer peak, thus hinting on a cooling of the underlying atmosphere. The trends observed are, however, stronger than predicted. A linear trend analysis of the F2 peak height observed by the EISCAT radars shows a strong rising trend, which can be said to be in agreement with the trend seen at the same time in the Sodankylä ionosonde data, although the statistical analysis of the short data periods shows fairly large errors in the trend estimates. A change of concentrations of atmospheric greenhouse gases is not sufficient to explain these different trends.

Additionally, we have shown data of the Finnish Riometer Chain, covering the latitudinal range from about 60° N to 70° N. On first sight, the riometer data exhibits a variety of trends, possibly hinting on a latitude dependency of the trends obtained from the 30 MHz riometers. However, the linear trend estimates are accompanied by large errors and it is difficult to make any conclusive statements about the trends.

A greenhouse cooling of the ionospheric D region cannot be inferred from these data. A further investigation of the riometer data is in preparation. In order to study the change of the atmospheric response to absorption events, we are planning to use hourly maximum absorption values instead of the absorption measured during the first minute of each hour. However, these data are not currently available in digital form. Furthermore, an extension of the EISCAT study to include the recent years (1994–today) and a revised data processing algorithm is currently being worked on.

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