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Scientific note

Climatic mesospheric cooling: Employing the long time-series of ionospheric soundings from Norwegian stations

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Abstract: While so-called greenhouse gases are responsible for global warming in the lower atmosphere, they can also cause cooling in the middle atmosphere. Cooling of the middle atmosphere in turn causes shrinking. One consequence of this is that the ionosphere occurs at lower altitude. Observations at several global locations have indicated that the ionospheric F2 layer, at least, is sinking. Here, these phenomena and observations will be briefly reviewed. At Tromsø (69°N), ionosonde observations exist since 1935 and a *précis* history will be given. Furthermore, similar datasets, albeit rather less extensive, exist for other Norwegian stations, notably Svalbard (≈80°N). In the light of work in other countries, we shall examine the potenial of the Norwegian data for studying climatic change in the arctic and sub-arctic. The importance of such archives and also future maintenance of ionospheric observations cannot be overstated.

1. The shrinking atmosphere

The so-called greenhouse gases, primarily carbon dioxide (CO_2) and methane (CH_4) with sources at the earth's surface emit efficiently in the infrared. In the troposphere, this infrared radiation is trapped as in a greenhouse and thus the equilibrium temperature is higher for correspondingly higher greenhouse gas concentration. In the middle atmosphere, these greenhouse gases are still present, and heat is similarly dissipated by long-wave radiation. However, the middle atmosphere is largely outside the "roof" of the "greenhouse" such that the re-emitted radiation is free to escape into space. In this way, CO_2 and CH_4 effectively remove heat from the middle atmosphere —in fact from any part of the atmosphere above the cloud layers— and cool it. Roble and Dickinson (1989) describe the process in detail. To summarise, one thinks of "greenhouse warming" in the troposphere, but of "greenhouse cooling" in the middle and upper atmosphere. The pertinent regions of the atmosphere are sketched in Fig. 1, although for a fuller description, the reader should refer to a text such as Hargreaves (1992).

As the atmosphere cools it occupies less space: it shrinks. Obviously, lower air densities will occur at lower altitudes as a consequence, and it may be deduced that ionisation similarly occurs at lower altitude. This cooling effect and its consequences for the heights of the ionospheric layers have been derived elsewhere: Rishbeth and Roble (1992) model the effect in detail; the effect on the ionospheric layers is summarised by Rishbeth (1990);

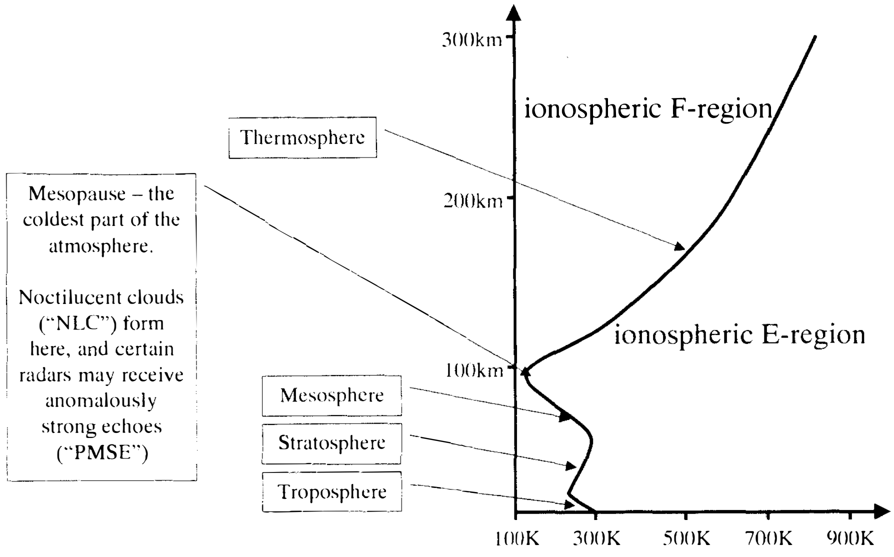

Fig. 1. *Schematic of the atmosphere showing, in an extremely simplified fashion, the ionospheric F2 and E layers and their relation to the neutral regions characterised by their temperature behaviour.*

an excellent review containing many references may be found in Rishbeth and Clilverd (1999). Increasing frequency of noctilucent cloud (NLC) occurrence is attributable to a combination of increasing water vapour concentration due to oxidisation of methane and also due to lowering of the mesopause temperature (Thomas *et al*., 1989). Thomas (*e.g.* 1996) has explicitly identified the increase in NLC occurrence with climatic cooling of the middle atmosphere. Changes in solar flux could conceivably be responsible for such changes also; however, since sunspot number and 10 cm flux measurements exist as long time-series, it is easy to rule out such effects, and we a faced with the conclusion that the cause lies in the biosphere.

There is observational evidence of this cooling from ionospheric soundings also, as proposed by Bremer (1992). At high latitude (67°N), Ulich and Turunen (1997) have identified a systematic decrease in the height of the ionospheric F2 layer using a sequence of observations from 1958. At mid-latitude, similarly unambiguous results have been reported by Bremer (1998). The above references are not intended to be exhaustive; nevertheless, many references to the phenomena described here can be found therein. While ionosondes measure only the virtual heights of the atmospheric layers (due to group delay of the radio wave in the underlying ionosphere), the studies mentioned here employ a different (frequency-related) parameter combined with models to estimate the true F2 layer height.

The important result of Ulich and Turunen (1997) for Sodankylä in northern Finland is reproduced in Fig. 2. Despite seasonal and solar-cycle fluctuations, these authors found a trend of around 14 km reduction in F2 layer height over a 40 year period. At mid-latitude (55°N) Bremer (1998) reports 8 km for the same time period. This leads us to wonder whether the sub-arctic station at Tromsø (69°N) yields similar results to that at Sodankylä. Perhaps even more importantly, is the effect more pronounced nearer the poles? (Upwelling

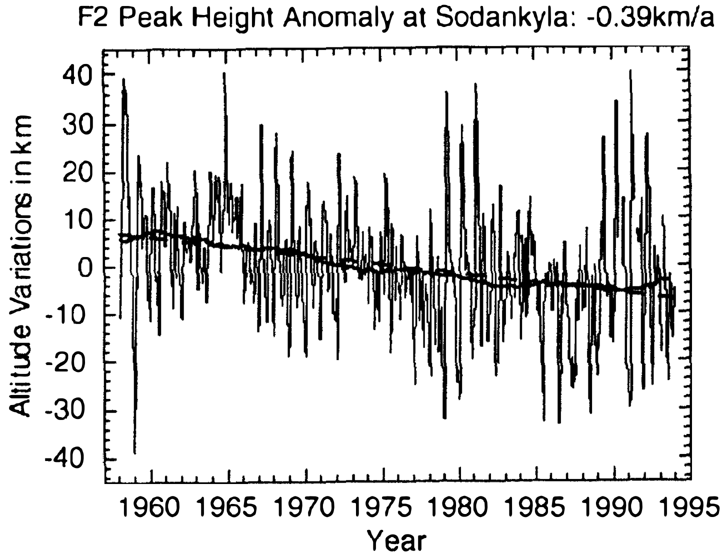

Fig. 2. *The results of Ulich and Turunen (1997) showing the sinking of the F2 layer and here over the 41-year period from 1958–1999 (courtesy of Thomas Ulich). Despite the seasonal and solar-cycle fluctuations, the trend is undeniable.*

near the poles transports greenhouse gases into the mesosphere at high latitude.) In the next section, we shall examine the data availability for potentially useful Norwegian stations.

Focus hitherto has been on the *F*-region. This is because the height changes are expected to be greater for these layers than for the *E*-region. While doubling of CO_2 and CH_4 are predicted to cause the F2 layer to cool by 30–40 K and fall by 17–20 km, the corresponding figures for the *E*-region are 10 K and 3–4 km respectively; the timescale for this change being around 50 years from present. It would be challenging to look for the predicted changes in the *E*-region also but a longer time-series will be desirable if the result is to be unambiguous.

2. Norwegian ionospheric observations at Tromsø

Ionospheric soundings at the Auroral Observatory in Tromsø were first performed during the Second Polar Year, 1932–33 by British expedition under the direction of Sir Edward Appleton, and simultaneously by a German expedition from Berlin. Soundings of the ionosphere on a regular basis in Tromsø commenced in April 1935 as described by Harang (1937). The British Radio Research Station in Slough, England allowed their ionosonde to be copied, the construction of the instrument being financed by the (then) Norwegian Scientific Research Fund (now Norges Forskningsråd) and The Norwegian Broadcasting Company (now Norsk Rikskringkasting), apparently to a total sum of 11000 Norwegian Crowns. The instrument featured two CRTs, one for visual observation, and the other for photographic recording. Figure 3 shows a page from Harang (1937) illustrating the photographic records of the time. The frequency was adjusted by hand, usually from 1 to 12 MHz. While one operator tuned to progressively higher transmission frequency, the critical frequencies of the ionospheric layers were noted by a second operator (O. Harang,

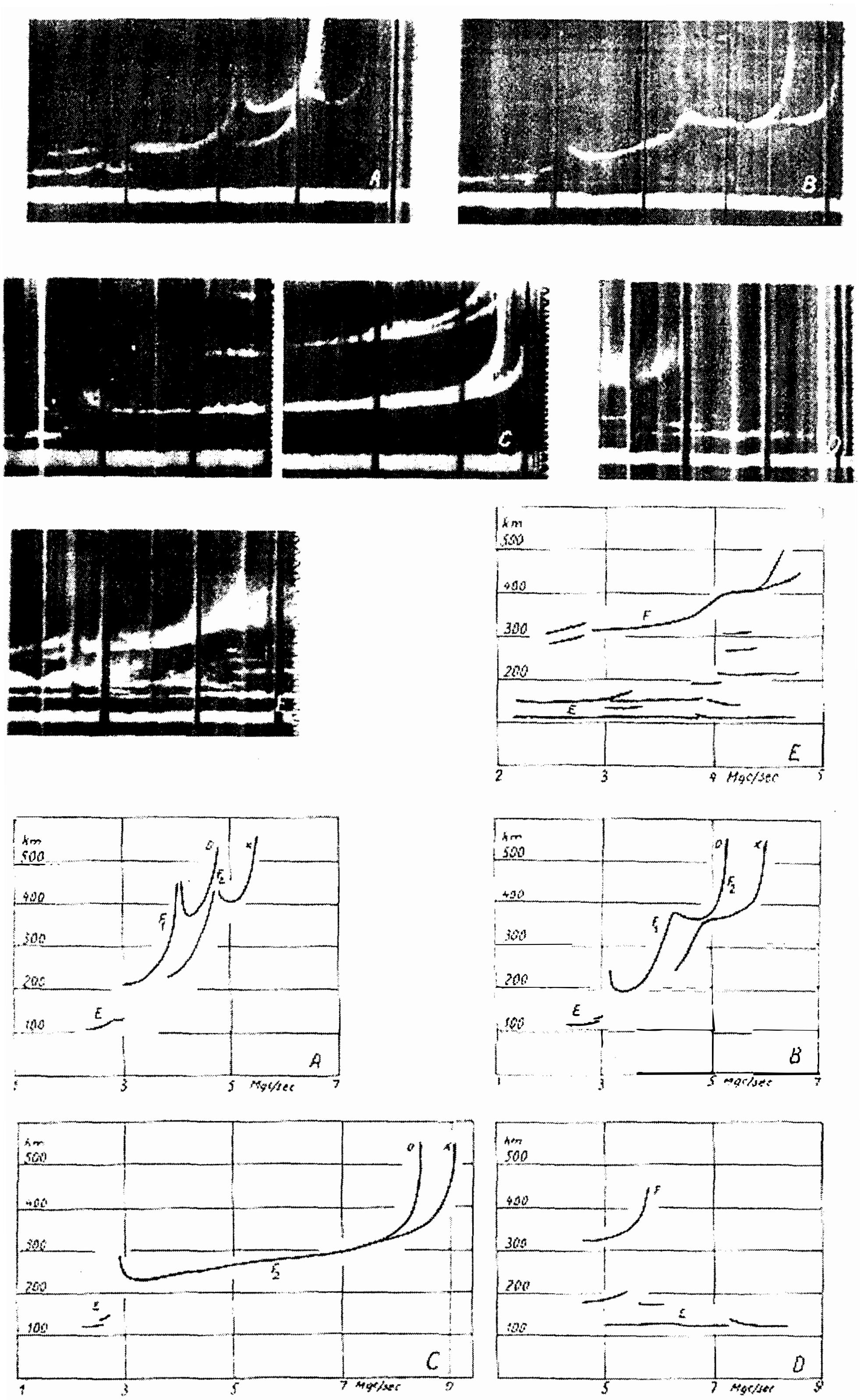

Fig. 3. *A page from Harang (1937), the first of a series of annual reports summarising ionosonde observations at Tromsø. The page contains both examples of photographic ionograms from the instrument installed in 1935 and the operators' interpretation of the signal.*

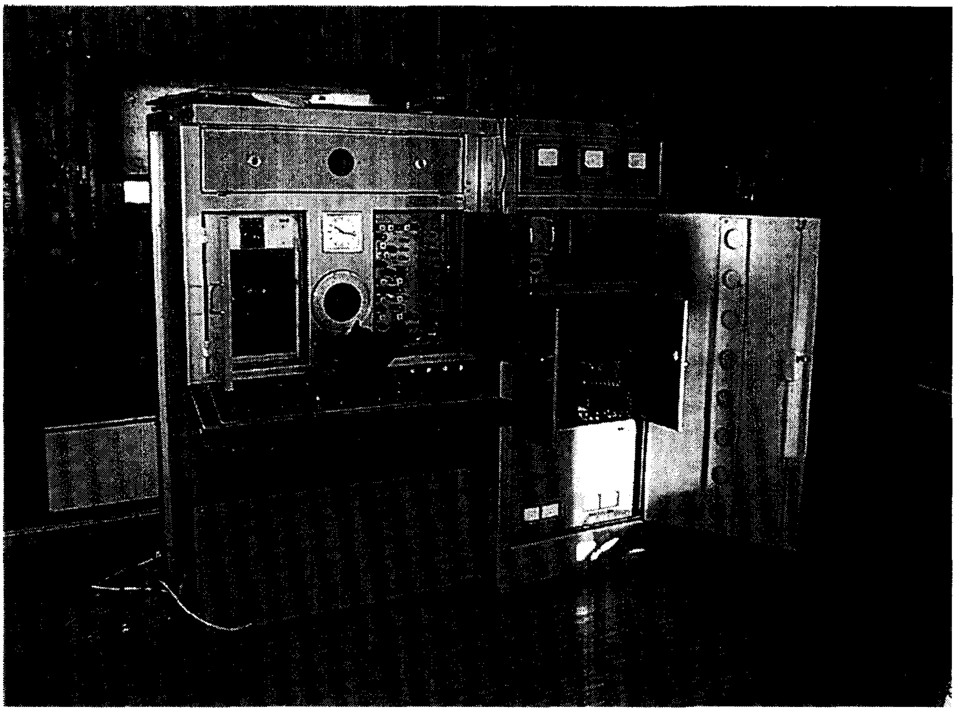

Fig. 4. The 1935 instrument was upgraded to this semi-automatic version in 1950.

private communication). During the first years, only the critical frequencies were noted and not the echo height, and observations were only made at 09, 11 and 13 UT. Observations were somewhat erratic during the war years 1939–45, but became regular from 1951. Hourly measurements were made by virtue of a more automatic instrument, installed in 1950 (Fig. 4), and heights were also recorded. These results were assembled in regular reports until 1972. Today, scaling (extraction of critical frequencies and reflection heights) is performed by computer, sadly, because pattern recognition by the human eye is still more reliable than that by computer, at least for ionogram analysis. The original raw data recording onto photographic paper was superseded by film recording in 1968. In the early 80s, a new film format was introduced which operated in parallel with recording to magnetic tape. The digital recording proved itself reliable and photographic recording was phased out in 1983.

The period from 1972 until 1992, while yielding much data of good quality was devoid of scaling; the published reports were apparently discontinued in 1972 with the exception of an isolated report in 1978. Nevertheless, the photographic data remain, and the digitally recorded data are also being preserved, and thus it will be possible to scale these data with appropriate resources.

The present instrument, located at Ramfjordmoen, a few kilometres to the east of the site of the original 1935 installation, is a University of Massachusetts Lowell DPS-4 digisonde, owned and operated jointly by the Defence Evaluation and Research Agency of the UK and the University of Tromsø. Details of this instrument may be found at http://ulcar.uml.edu/.

3. Data coverage

The Sodankylä dataset used by Ulich and Turunen (1997) is probably unique in that not only have the data been regularly scaled since inception of the instrument in 1958, but also the scaling has been performed by the same person. For long time series in which one is to look for climatic change, particularly in the E-region height, such luxury is unattainable since measurements must be made over duration longer than that of an observer's career. In Table 1, the time series for the various Norwegian stations are compared, along with that for Sodankylä. The geographic locations of these stations are illustrated by Fig. 5. The observations for Kjeller (near Oslo) and Longyearbyen (Svalbard) are erratic. A new instrument (University of Leicester, England) is currently operating on Svalbard. Some data gaps exist for the Tromsø dataset, but the real challenge will be in scaling these ionograms while at the same time ensuring that no systematic change is introduced.

Table 1. Ionosonde data availability.

Station	Latitude	Earliest year
Sodankylä	67°	1958
Kjeller (Oslo)	60°	1952
Tromsø	69°	1935
Longyearbyen (Svalbard)	79°	1956

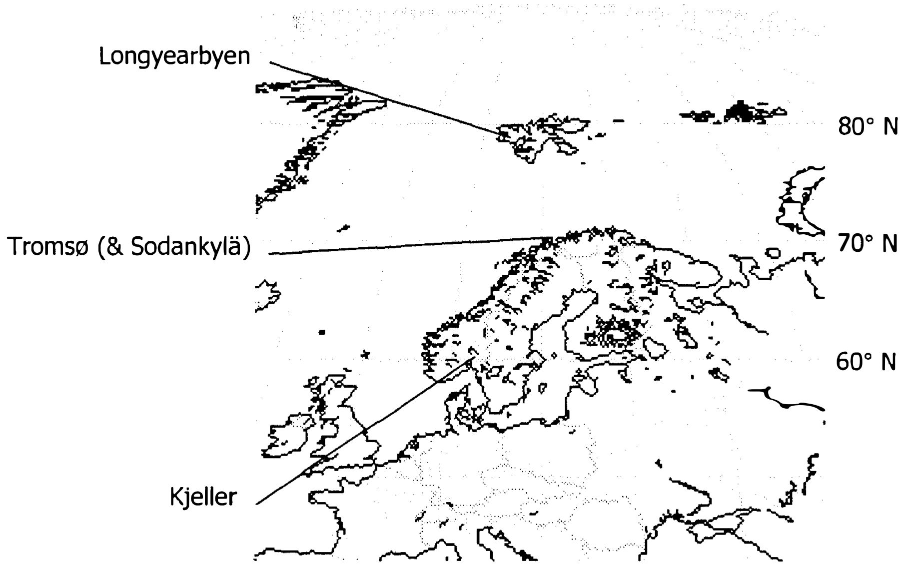

Fig. 5. Geographic locations of the Norwegian stations. The Finnish station, Sodankylä, is at almost the same latitude as Tromsø.

4. Conclusions

First, it should be reiterated that a climatic cooling is indeed occurring in the mesosphere. Although this report has focussed on the response of the height of the ionosphere to this cooling, and the detection of the cooling by ionospheric observation, this is by no means the sole evidence. Changing H_2O concentrations combined with lowering of the mesopause temperature are the only viable explanation of the increasing NLC occurrence, not only with time, but also by equatorward spreading (Thomas, 1996). Temperature data from lidar and satellite (*e.g.* Aikin *et al.*, 1991) and sodium layer height (Clemesha *et al.*, 1992) all support the indication of climatic change.

In turn, this cooling can affect the atmosphere in many ways. Increasing NLC coverage will, principle, increase the planetary albedo, although this will be a marginal effect due to the tenuous nature of the clouds. Perhaps more importantly, if the temperature structure changes such that atmospheric stability is affected, the spatial destribution of gravity wave energy dissipation will change. Such factors give feedback into the overall energy budget in a way that predictions become non-trivial. In an attempt to investigate these climatic changes, the heights of the ionospheric layers can and should be monitored. One must recall that originally, ionosondes were constructed to study radio wave propagation; little thought was given to the possibility that they could yield information on climate. With this thought in mind, the importance of maintaining measurements over extended periods of time cannot be overstressed, even though the exact future use of the data may not be evident *a priori*. One can also understand that it is desirable to establish two or more independent means of monitoring temperature (for example by the means mentioned earlier) and then maintain these observations. All efforts will be made to analyse the existing data from Norwegian stations, and furthermore efforts must be made to ensure that such observations continue indefinitely.

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