20th Century operation of the Tromsø Ionosonde

C. M. Hall and T. L. Hansen
Tromsø Geophysical Observatory, University of Tromsø, Norway

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Abstract. A history of ionospheric soundings from Tromsø and its vicinity in northern Norway (69°N, 19°E) between 1932 and 1999 is given.

Introduction

The recent reviews by *Rishbeth* [2001] and *Schröder* [2002] tell us something of the history of solar-terrestrial physics. The successful transatlantic radio transmissions performed by Marconi in 1901 lead Kennelly and Heaviside to hypothesize the existence of some reflecting layer in the atmosphere. Experiments in the 1920s by *Appleton and Barnett* [1926] and *Breit and Tuve* [1926] confirmed this. The Second International Polar Year was to be in 1932-3 and the Tromsø Auroral Observatory stood complete in the summer of 1929. Under the URSI umbrella, Sir George Simpson proposed ionospheric measurements in Northern Norway and was therefore invited to Tromsø by Lars Vegard, the then President of the Norwegian Institute of Cosmic Physics. Thus surprisingly few years elapsed between these first experiments and Sir Edward Appleton's arrival in Tromsø (69°N, 19°E), in 1932 in order to perform ionospheric soundings at auroral latitudes. Figure 1 shows the locations of Tromsø and the environs encompassing the various locations that will be referred to in the course of this review.

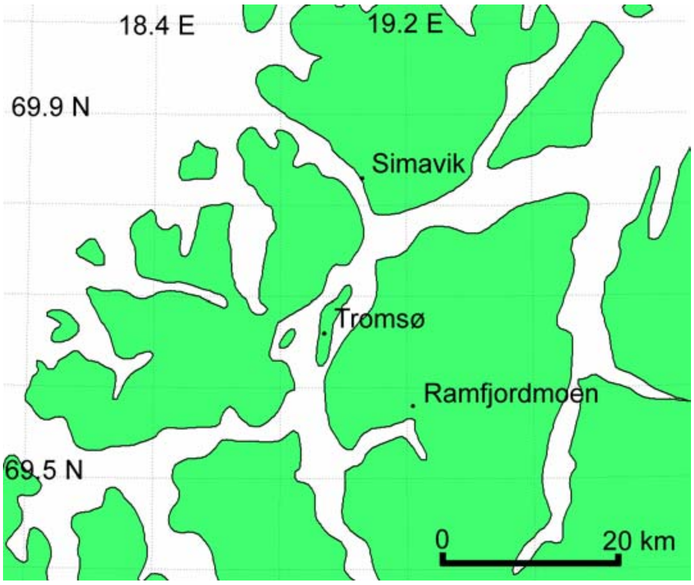

Fig. 1. Map showing the location of Tromsø and nearby locations referred to in the text.

These first ionospheric soundings were intended to establish and map the little understood Kenelly-Heaviside layer (later to be the E-layer together with the Appleton- or F-layer). The practical use of such information was clear: the importance of radio communications prior to the period of increasing unrest in Europe at that time could not be understated. During WWII transatlantic communication became a vital tool and this carried on through the subsequent cold-war years. Today, with satellite communications and high bandwidths commonplace, monitoring the ionosphere is becoming gradually less important. In the 1920s, climatic change was a concept that received little attention; in the 21st century, however, it is even on the curricula of many junior schools. Who in Slough and Tromsø in 1924 could have foreseen the application of ionospheric sounding to climatic research? *Rishbeth and Clilverd* [1999] provide a most accessible insight, with *Rishbeth and Roble* [1992] and *Roble and Dickinson* [1989] giving more depth.

Many time-series of ionospheric data exist. One notable example is that from the Sodankylä instrument in northern Finland and described by *Ulich and Turunen* [1997]. The Sodankylä dataset is very special because the analysis ("scaling" in ionosonde parlance) has been performed by the same person throughout, and therefore susceptibility to systematic error is rather less than if a succession of employees had performed the work during the almost half a century of operation. In contrast, although ionospheric soundings at Tromsø currently span almost 70 years, many different persons have performed the scaling. Not only that, but both the instrument and its precise location have changed during that course of time. Historical information about the instrument must be taken into account when analysing time series because abrupt systematic changes in derived ionospheric parameters due to subjectivity of the scaling operation, calibration of the instrument etc., may easily be interpreted incorrectly as a trend. Exploratory trend analyses of Tromsø data have recently been performed by *Hall and Cannon* [2001, 2002] following a feasibility study *Hall* [2001a]. These studies, however illustrated the need to document the history of the Tromsø ionosonde; much information is still in living memory, but will not always remain so. This sad fact is the inevitable consequence of time-series durations exceeding not only the careers of scientists but also their lifetimes.

We shall divide the history into three sections for ease of accessibility: (i) the early years, from Appleton's expedition in 1932 until the true start of comprehensive ionogram analysis in 1951, (ii) the stable "middle"years, 1951 to 1980, and (iii) the later years, 1980 to present, somewhat characterised by technological, administrative and funding changes. Table 1 summarises the various events in chronological order.

1932-1950: Appleton and the war years

The very first operations at Simavik near Tromsø (see Figure 1) are described in no little detail by *Appleton et al.* [1937]. Simavik, some 17 km almost due N of Tromsø was selected for the transmitter location due to power supply considerations; this seems remarkable today since although the transmitter was initially operated at 3kW, subsequent operation for the Polar Year was only 100W. The receiver, on the other hand was located at Tromsø. Table 2a gives the salient features of the sounder; otherwise, the instrument is described exhaustively by *Appleton et al.* [1937]. It appears that assembly was performed in less than a week! (between 15th and 22nd July). Rather than the more familiar continuous observing programme used today, specific dates were allocated specific types of measurement. Each of the four measurement types was performed on one occasion each month between August 1932 and August 1933. Observations concentrated on critical frequencies almost exclusively: variation of E- and F-region critical frequencies with local time was studied and many comparisons were made with geomagnetic observations. Total absorption appears to be a feature *Appleton et al.* [1937] found considerably interesting since it was not a common occurrence at Slough.

The success of the 1932-33 observations clearly impressed the leadership of the Auroral Observatory and help was obtained to construct a copy of the Slough instrument, this being of a slightly different design to the Simavik instrument, again detailed by *Appleton et al.* [1937] (Table 2b). Funding was provided by the Norwegian Scientific Research Fund (literal translation) and the Norwegian Broadcasting Company, totalling 11,000 Norwegian Crowns (around €1400). This new, Norwegian instrument came on the air in April 1935, and this time both transmitter and receiver were located at the Auroral Observatory. *Harang* [1937] describes the instrument and the operating method, and goes on to provide details of the results. Again, only critical frequencies were recorded, although by now thrice daily and including some comments regarding the appearance of the echo. Figure 2 shows the transmitter unit as it looked in 1936. Figure 3 shows some of the early results from May 1935 along with the interpretations [from *Harang*, 1937].

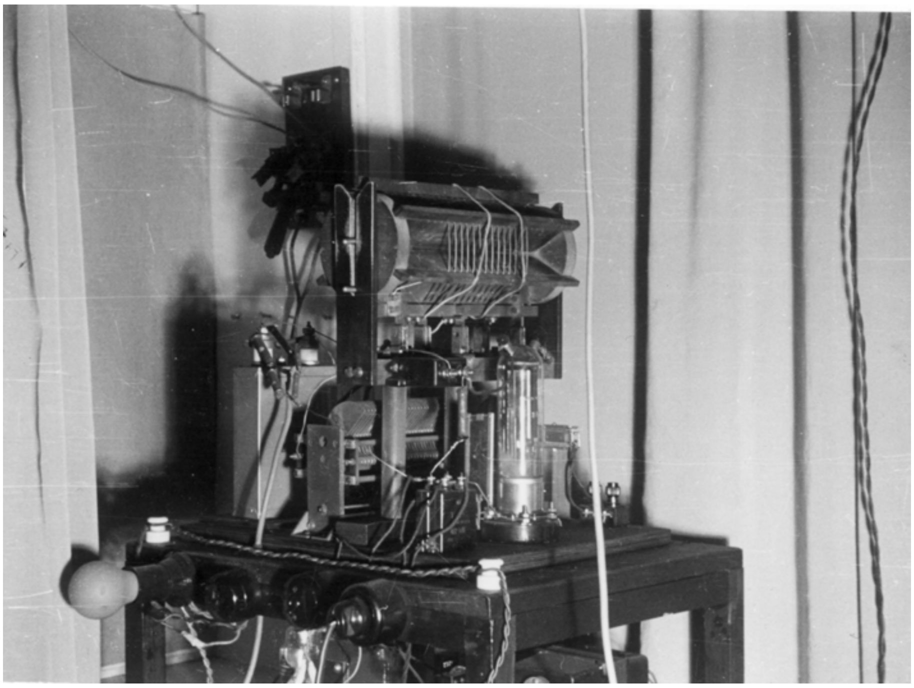

Fig. 2. The first Norwegian ionosonde transmitter, copied from the Slough instrument, from 1936 [*Larsen and Berger*, 2000].

The instrument remained in operation throughout the war years; however, a German instrument was also in operation only a few hundred metres from the Auroral Observatory during WWII. This ionosonde was acquired by the Norwegians eventually and the delta-antennae re-located and used together with the original Norwegian instrument from 1946 onwards. After the war, the British National Physical Laboratory (NPL) produced a better ionosonde and one of these was purchased by the Norwegian Defence Research Establishment (NDRE) in Kjeller near

Oslo at the end of 1949. Eventually, a similar system was installed in Tromsø, finally replacing the original in Autumn 1950 after almost 16 years of service.

1951-1980: The cold war

The arrival of the NPL ionosonde (Table 2c and Figure 4) heralded a more organised publication of results, and, importantly a fuller scaling of each ionogram.

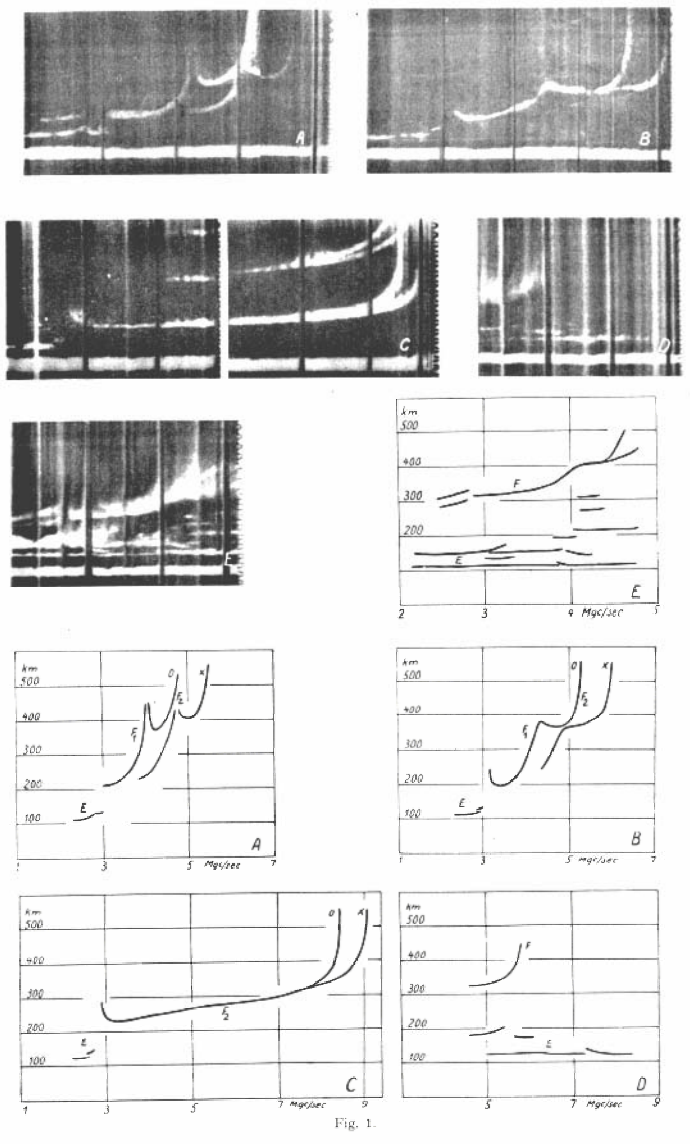

Fig. 3. Early results from the first Norwegian ionosonde on a variety of days between May 1935 and October 1936. The line drawings show the operators' interpretations of the echoes, and, importantly the calibrations necessary for any re-analysis of the archived photographic recordings [*Harang*, 1937]

Heights were read off the ionograms and the transmission parameter M(3000)F2 determined. Furthermore, soundings were taken more often, and monthly summaries of median values were published. There is evidence that antenna improvements were made in 1956, presumably for the International Geophysical Year (IGY 1957); sadly, these are undocumented, except for the existence of a somewhat uninformative photograph (not reproduced here)..

A disadvantage with the NPL ionosonde was that it took around 5 min to obtain a full sounding. In the 1960s a Swedish company, “Magnetic AB”, began manufacturing faster and more automated instruments; one of these was purchased (Table 2d and Figure 5) and replaced the NPL unit in the spring of 1968. Despite considerable demands for maintenance, the improved quality of ionograms was considered to give such improved final results that the effort was worthwhile. While the preceding ionosondes had made recordings onto photographic paper, the Magnetic AB device recorded to 35mm film, each ionogram occupying 72mm; the earliest such film in the Auroral Observatory archives being dated 3rd November 1969.

Fig 4. The NPL ionosonde [*Larsen and Berger*, 2000].

Meanwhile, a field station at nearby Ramfjordmoen (see Figure 1) was built with a view to housing both a new MF radar [*Hall* 2001b] and ionosonde. A new 60m mast was obtained for the purpose, but the Magnetic AB ionosonde’s fate was for it to remain at the Auroral Observatory where it stands today. Instead, recognising the advances in technology since the development of the Magnetic AB instrument, the Auroral Observatory staff decided to build an ionosonde themselves. This new instrument was taken into operation in January 1980 at Ramfjordmoen and the Magnetic AB instrument discontinued on 27th December 1979.

Fig. 5. The “Magnetic AB” ionosonde receiver and recorder. (Photo: Chris Hall)

1980-2000: The newer technologies

Due to the presence of the MF radar at and the plans for establishing an incoherent scatter radar nearby (i.e. the European Incoherent Scatter facility, “EISCAT”) the Ramfjordmoen site presented a scientifically attractive location for an ionosonde. With the large log-periodic antenna hanging from the 60m mast, higher power, and sophistications such as Barker and complementary coded pulses made this a considerably more powerful and flexible instrument than the predecessors (Figure 6, Table 2e) [*von Zahn and Hansen*, 1988].

Fig. 6. The Auroral Observatory ionosonde [*Larsen and Berger*, 2000].

Initially recording was done to film with each ionogram lying transversely across 18mm of a 35mm film. Eventually film recording was phased out in favour of exclusive recording to magnetic tape. Today, film records exist until the end of 1984, and approximately half of these have been scanned into digital form at the time of writing. The magnetic tape records have been extracted to other formats for safe archiving. The Auroral observatory ionosonde proved an invaluable addition to calibration of the newly established EISCAT radar and not least as a diagnostic for geophysical conditions during EISCAT observations. The publications resulting from EISCAT and MF-radar studies in which ionosonde data was involved to some degree are numerous and no attempt will be made to compile an exhaustive list here. Due to lack of interest in long-term routine activities, however, regular scaling of the ionograms fell by the wayside during this period. The reports giving daily scaling parameters and monthly means/medians have been sorely missed since 1980. Moreover, due to the large number of soundings performed (typically one every 15 minutes) the task of scaling the data *a posteriori* is virtually insurmountable. Steps are being taken to scale ionograms from local midday only, as an ongoing project.

In 1992, the British Defence Research Agency ("DRA"), later the Defence Evaluation and Research Agency ("DERA") and currently QinetiQ provided a University of Massachusetts Lowell DPS-4 [*Reinisch et al.*, 1992] sounder which was connected to the simultaneously improved antenna in place of the Auroral Observatory instrument. The Lowell instrument has the capability of real-time scaling of ionograms using the ARTIST-4 system. While still requiring a degree of manual validation (ARTIST-4 is not felt to be 100% reliable by everyone!) the task of producing regular reports of ionospheric sounding parameters is no longer insuperable. The Web-based information given by the above URLs is supplemented by Table 2f. Figure 7 shows the current sounder, while Figure 8 shows the antenna with the rhombic transmitter elements that the constituted the upgrade in 1992. Reception is on loop antennae.

Fig. 7. The Lowell ionosonde. The Lowell unit itself is beneath the computer monitor. The rack to the left contains frequency reference equipment including synchronisation with nearby instruments. (Photo: Bjørnar Hansen)

Fig. 8. The current transmitter antenna arrangement at Ramfjordmoen. (Photo: Chris Hall)

Summary

We have seen that only a decade after the first ionospheric soundings, measurements were already being made in the auroral zone at Tromsø (69°). Thus the establishment of regular soundings at such a remote location in the mid 30's was quite noteworthy. The war years and subsequent cold-war prompted considerable development of ionosondes, but at the same time events caused somewhat interrupted operation, at least until 1950 and changing configuration of the instrument. In later years, after 1980, changes in political and economical climates and, not least, in scientific philosophy again introduced changes in ionosonde operation. While, prior to 1980, funding had favoured manpower demanding work (instrument maintenance and manual analysis and report-writing), more expensive hardware investments characterised the last two decades of the millennium, the “exciting” new equipment leading to reductions in personnel involvement in the more “boring” tasks of maintaining the long-term observation sequences. Although modern computing techniques and signal processing concepts such as neural networks have enabled automatic ionogram scaling, the results are not so reliable that manual quality control is superfluous. This means that at the time of writing the automatic scaling of ionograms by the Lowell instrument still requires manual checking before the data may be used for scientific purposes, and funding to perform this task is scarcely available.

Despite these difficulties, the Tromsø dataset represents one of the longest, if not the longest at such high latitude. Efforts are being made to standardise the dataset such that time series of selected parameters will be available to the scientific community for the entire period 1932 to present with minimal interruption. In order to evaluate the resulting dataset, documentation of the instrument’s history will be necessary in order that changes in instrumentation and analysis procedures will not be misinterpreted as effects of the solar-terrestrial system.

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Table 1.

year(s)	Event	Reference
1932-33	Instrument similar to that at Slough installed: transmitter at Simavik, receiver at Tromsø	Appleton et al., 1937
1935	Copy of Slough instrument installed at Auroral Observatory	Appleton et al., 1937
1946	Antennae replaced with delta antennae	Larsen and Berger, 2000
1950	NPL Mk II ionosonde installed at Auroral Observatory	Appleton, 1947
1956	Antenna improvements	undocumented
1968	Magnetic AB unit replaced NPL unit	Rosén, 1967
1980	Magnetic AB unit (at Auroral Observatory) superceded by Auroral Observatory unit at Ramfjordmoen	von Zahn and Hansen, 1988
1992	Lowell ionosonde replaced the Auroral Observatory unit (collaboration between Univ. Tromsø and QinetiQ)	Reinisch et al., 1992

Table 2. Instruments overview

	(a) Polar Year instrument (1932-1933)	**(b)** Copy of Slough instrument (1935-1950)	**(c)** NPL Mk II instrument (1950-1968)	**(d)** Magnetic AB "J5W" instrument (1968-1979)	**(e)** Auroral Observatory instrument (1980-1992)	**(f)** Lowell instrument (1992-present)
location	Transmitter at Simavik, 69.8° N, 19.0°E and receiver at Tromsø, 69.7° N, 18.9°E	Tromsø, 69.7° N, 18.9°E	Tromsø, 69.7° N, 18.9°E	Tromsø, 69.7° N, 18.9°E	Ramfjordmoen, 69.6° N, 19.2°E	Ramfjordmoen, 69.6° N, 19.2°E
antenna type	thought to be crossed dipoles 30km apart	crossed dipoles (same location); delta from 1946	delta	delta [*Larsen and Berger*, 2000]	inverted log-periodic	rhombic
pulse repetition frequency	50 Hz	50 Hz	50 Hz	50 Hz	N/A (asynchronous)	200 Hz
pulse type	single, 100 μs duration	single, 100 μs duration	single, presumably 100 μs duration	single,70-100 μs duration	2 x 8 bit complementary code with 20μs elements	2 x 16 bit complementary code with 17μs elements
peak power(normal operation)	100 W	not known	1-1.5 kW	35 kW	2kW	300 W
range resolution	30 km	not known	better than 5% (calibration in 1955)	height marks every 20 km, accurate to 5%	6 km	5 km
frequency coverage	0.6-10.0 MHz	1-12 MHz	0.7-24.6 MHz	0.25-20 MHz	1 -16 MHz programmable	Typically 1-12.0 MHz, but programmable
frequency resolution	250 kHz	2 cm photographic paper / MHz	marks at every 100 kHz	marks at every 1 MHz, accurate to 5%	240 frequencies linearly or logarithmically distributed	50 kHz
sweep time (typical frequency range)	determined by operator	1 min	5 min	1 min	2-3 min	5-6 min