

# Calibration of EISCAT incoherent scatter radar electron densities and the anomaly of 23-25 October 2003

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## Abstract

The calibration of electron densities from incoherent scatter radars has always been an important but sometimes neglected feature of the data analysis. This report documents the software tools available to compare peak densities from the EISCAT radars with the peak density derived from foF2 obtained by the Tromsø dynasonde, and shows the results of such comparisons up to September 2004. A particularly striking case in October 2003, where the 'system constant' of the Tromsø 929 MHz radar deviated from the norm by a factor of more than two, is examined in detail. It would appear that wet snow in the UHF antenna can seriously reduce the effective aperture.

## Introduction

The deduction of physical parameters from incoherent scatter radar (ISR) spectra requires no calibration to first order except for the electron density which is determined largely by the scattered power which depends on many system parameters.

The radar equation for scatter from a soft target is given by (e.g. eq. 9 of Farley, 1996) expresses the power (in watts) received by an antenna at a distance  $R_s$  from a unit volume:

$$P_r = P_t G_t / (4\pi R_i^2) \sigma_{\text{radar}} V_s A_r / (4\pi R_s^2) \quad (1)$$

Where  $P_t$  and  $G_t$  are the transmitter power and antenna gain,  $R_i$  is the distance from the transmitter to the scattering volume ( $V_s$ ),  $\sigma_{\text{radar}}$  is the radar scattering cross section, and  $A_r$  is the effective receiving antenna area.

For the case of backscatter (monostatic radar, like ESR and VHF and UHF radars at Tromsø), both ranges are the same and the scattering volume is determined by the beam solid angle  $4\pi/G_t$  and the transmitted pulse length,  $\Delta T$ , so that (1) reduces to:

$$P_r = P_t \sigma_{\text{radar}} c \Delta T A_r / (8\pi R^2) \quad (2)$$

where  $c$  is the speed of light. The cross section, which is proportional to the electron density, is the variable we wish to obtain. The pulse length, range, and  $c$  are known with high precision, so the accuracy of the cross-section depends on how well the *received power*, *transmitted power* and *effective antenna aperture* are measured or known.

### Uncertainties in ISR parameters

The measurement of transmitter power ( $P_t$ ) is recognised as one of the most likely sources of error. Sometimes simple errors in the number of klystrons used during the measurement (resulting in factors of 0.5 or 2) were made and needed to be corrected. Up to the time of writing the power was calculated from the high voltage applied to the tubes, using measured calibration formulas relating output power to voltage. At low voltages these formulas may be inaccurate. These calibration curves are measured for a particular frequency or set of frequencies, and using a different set of frequencies may cause a slightly different output power. Another source of error may be that in long pulses the output drops with time as the capacitor driving the klystron discharges, so that signals obtained from the trailing edge of a pulse, as in some D or E-region measurements, may assume an average transmit power that is higher than that effectively used.

Another source of error in using only the high voltage is introduced when the input drive level of the klystrons, normally fixed, is changed. This, and the way the power of two klystrons in the UHF (since 2000) is combined, has shown the need for a more direct measurement of peak power, which has been implemented since the spring of 2004 and is presently being evaluated.

The measurement of received power ( $P_r$ ) is normalised to that of a calibration noise source, which is regularly switched on during each pulse reception interval. If the calibration source strength changes with time, that would also contribute to a changing calibration.

The effective aperture ( $A_r$ ), although perhaps difficult to measure accurately, should not change with time since it is largely determined by the antenna structure and geometry which is stable. We now believe, however, that the aperture can indeed change significantly when there is wet snow lying on the reflector surface, as is discussed later.

Because each of the above three quantities is difficult to measure accurately, they are usually combined together into the system constant which hopefully does not change. Nevertheless, an independent method is needed to check this assumption. Two methods of checking the derived electron densities are the use of critical frequencies from ionosondes and plasma line measurements from the ISR itself.

### Plasma line measurements

A normally weak feature of the incoherent scatter spectrum is an enhanced signal offset from the radar frequency by the local (warm) plasma frequency. Since this

involves measuring only the frequency and height of the signal, which can be done accurately, we have an accurate density which can be used to calibrate the results of the ion line measurements. Because the plasma lines are weak and variable, the technique has not been easy to use routinely in the past. Since the recent upgrades in receivers and signal processing, EISCAT now routinely measures plasma lines in its tau2pl program on the UHF radar in Tromsø since early 2003, and in the steffe program on Svalbard since January 2004, and in the tau8 program on the VHF radar in Tromsø. The use of these data for calibration is just beginning and will not be reported here.

## Ionosonde data

The easiest way up to now to check the ISR densities is to compare values at an ionospheric layer peak with the that obtained from an ionosonde. An ionosonde measures the radio frequency, apparent range, and often several other parameters of ionospheric echoes, which are due to total reflection. Because of the geomagnetic field there are usually two echoes, one called the ordinary mode and one the extraordinary mode. The highest o-mode reflection frequency, foF2 is related to the peak electron density through the simple formula:

$$foF2 \text{ [MHz]} = \sqrt{(N_m[\text{m}^{-3}] / (1.24 \cdot 10^{10}))} \quad (3)$$

where  $N_m$  is the peak electron density.

We use here data from the EISCAT dynasonde, which makes ionograms usually every 5 minutes at present, although 6 and 12 minute-intervals were frequently used in the past. Dynasonde data have been recorded regularly since the computer and software were upgraded in November 1992 (see <http://www.eiscat.uit.no/heating/Dynasonde/logs/cdr-log/>) for a complete list). Before that the dynasonde was operated since 1979 in campaigns only and in a format that may be difficult to retrieve. Data in microfiche or other formats from this period may be obtained from the first author, or maybe J. W. Wright.

Since 1992 there is also a digisonde at Ramfjordmoen, owned by Qinetiq and operated by Tromsø Geophysical Observatory (<http://geo.phys.uit.no/ionosonde/>), but data from this instrument is not used here. Up to 1992 there was another ionosonde run by the Auroral Observatory in Tromsø, the data from which is available at <http://geo.phys.uit.no/ionodata/index.html>

A scatter plot of ISR peak density versus ionosonde density would ideally give a slope (m) of one.

## Past results

The calibration of the EISCAT electron densities involving comparison with ionosondes was done fairly regularly, by hand. The results of such comparisons were sent out to the EISCAT associate data representatives. These documents and some plots have been scanned and are available at:

<https://e7.eiscat.se/groups/datahandling/Analysed-data/calibrations/Old%20CP%20letters/>.

Some studies of the mainland UHF radar calibrations with ionosondes were published by Kirkwood et al., (1986); Wright et al., (1988); (1990); Sedgemore et al., (1996); and Lilensten et al., (2004).

The calibration of the EISCAT Svalbard Radar (ESR) data since 1996 is in a much poorer state since there has only been an ionosonde from the University of Leicester operating there sporadically since 1999 and plasma line capability has only recently been added. Some comparisons with mainland densities in a common volume were made by Holt and van Eyken (2000). An early comparison with the ionosonde data were made by Hall et al., (2000) and later comparisons were made by Bempong (2001) and van Eyken (2001). A routine is presently being added to the GUIDAP8.4 analysis package, similar to `calib_ne` described in the appendix, to use the plasma line data to calibrate the standard electron densities from the two ESR antennas.

### **Uncertainties in the scaling results**

Obtaining the peak O-mode reflection from the F2 layer, known as the critical frequency ( $f_oF2$ ), and from the E-layer ( $f_oE$ ) using the dynasonde ionograms has been automated, but both the automated and manually derived  $f_oF2$  can be subject to errors. For example, the presence of noise and interference can obscure ionospheric echoes. Echoes can come a wide range of angles, and determining  $f_oF2$  in the presence of spread echoes can be difficult or ambiguous. Indeed, this could be an interesting project to compare the different estimates of  $f_oF2$ , as are made by the DSND analysis, in the with ISR data. Details of the dynasonde-derived data are presented in the appendix.

### **Results of calibrations**

Using Guisdap8 analysis the peak F-region and E-region densities have been routinely compared with that obtained from the dynasonde. We are working backwards through the data as well as doing all new experiments in near real time. Table 1 shows the scatter-plot slopes ( $m$ ) obtained as of 8 September 2004. It is an extract from the table, made available at <https://e7.eiscat.se/groups/datahandling/Analysed-data/calibrations/calibration%20tables/>. The table in the web also contains slopes from the E-region peak but these comparisons are not mentioned further here. In general there are more and better quality data available, from both ISR and ionosonde, for the F-region peak than for the E-region, for various reasons. Those  $m$  values which have an error given in percent were obtained using the `ui_cal` program (see appendix) while those with absolute errors were obtained with `calib_ne`. We have marked in yellow those days where the slope is less than 0.7.

There are not many VHF comparisons because the VHF antenna is usually pointed at low elevation, making a comparison with Tromsø ionosonde data more circumspect for calibration purposes. Comparisons with low elevation programs and D/E-region programs are also made, and documented in separate files at the same link listed above.

The ‘magic\_constant’, assumed to be one unless explicitly listed, is a multiplying factor used to derive the densities from the ISR data. The few cases listed where it differs from one, although not always fully understood, are likely to be for technical

reasons related to the transmitter power or received power measurement being in error. A value of 1.367 is now used for all VHF programs after a careful calibration on 28 April 2004 for the present antenna and 1-klystron configuration.

The 'new snow' column, included for reasons mentioned below, is information from the Norwegian Meteorological Service for the interval from 1 September 2003 to 29 February 2004. It is the collected snow depth on a plate measured at 07 each morning, after which it is wiped clean.

Most values of the slope of the scatter plot (m) lie close to 1. A noticeable anomaly occurs in the interval 23-25 October 2003, which is marked in yellow in the table and will be studied in more detail in the next section.

Table 1 F-region peak electron density ratios.  $m < 1$  means ISR density is less than ionosonde density

Date	UHF type	m (foF2)	err	magic const	Snow	Date	Type	m (foF2)	err	magic const	Snow
						16-Feb-03	tau2	0.90	±0.12		
24-Feb-01	cp1l	1.00	± 3%			18-Feb-03	tau2	No HF			
21-Sep-01	cp1l	1.04	±0.08	0.54		24-Feb-03	tau2	No HF			
22-Sep-01	cp1l	1.13	±0.23	0.54		24-Feb-03	tau3	0.95	±0.07		
23-Sep-01	cp1l	1.04	±0.19	0.54		25-Feb-03	tau2	0.40	±0.06		
08-Nov-01	tau2	0.96	±0.10	0.54		26-Feb-03	tau2	0.73	±0.03		
09-Nov-01	tau2	1.04	±0.15			02-Mar-03	arc1	0.99	±0.11		
11-Nov-01	tau2	2.55	±1.14			03-Mar-03	arc1				
12-Nov-01	tau2	1.02	±0.16	0.54		05-Mar-03	arc1	1.01	±0.11		
19-Nov-01	tau2	1.07	±0.25			06-Mar-03	arc1	0.80	±0.13		
						14-Mar-03	tau2pl	0.89	±0.01		
04-Mar-02	tau2	1.48	±0.20			28-Mar-03	tau2pl	1.07	±0.03		
06-Mar-02	tau2	1.15	±0.64			03-Apr-03	tau2	0.93	±0.15		
07-Mar-02	tau2	0.90	±0.20			14-May-03	tau2pl	1.03	±0.04		
08-Mar-02	tau2	0.69	±0.15			15-May-03	tau2pl	1.06	±0.03		
09-Mar-02	tau2	1.05	±0.16			23-May-03	cp1l	0.94	±0.05		
10-Mar-02	tau2	0.76	±0.23			27-May-03	tau2pl	0.97	± 5%		
25-Mar-02	pia	1.00	± 3%			28-May-03	tau2pl	0.98	± 3%		
26-Mar-02	pia	1.01	± 1%			29-May-03	tau2pl	0.99	± 5%		
27-Mar-02	pia	1.04	± 2%			30-May-03	tau2pl	0.86	± 6%		
28-Mar-02	pia	1.04	± 1%			31-May-03	tau2pl	0.94	± 4%		
04-Apr-02	pia	1.17	±14%			05-Jun-03	tau2pl	0.96	± 9%		
12-Jul-02	pia	0.93	±0.08			23-Jun-03	tau1	No HF			
03-Nov-02	tau2	1.08	±0.28			24-Jun-03	tau1u	0.84	±0.13		
04-Nov-02	tau2	1.10	±0.36			25-Jun-03	tau1u	0.93	±0.09		
05-Nov-02	tau2	0.99	±0.17			26-Jun-03	tau1	0.90	±0.06		
07-Nov-02	arc1	1.37	±0.30			26-Jun-03	tau1u	0.86	±0.08		
06-Dec-02	tau2					27-Jun-03	tau2pl	0.90	±11%		
12-Dec-02	tau3	1.17	±0.28			22-Sep-03	tau2pl	0.69	±0.19		
						23-Sep-03	tau2pl	0.87	± 4%		
05-Jan-03	tau3	0.38	±0.05			24-Sep-03	tau2pl	0.82	± 7%		2 cm
14-Feb-03	tau2pl	1.03	±0.02	0.26	Test run	25-Sep-03	tau2pl	0.67	± 3%		
						26-Sep-03	tau2pl	0.90	± 2%		

Date	Type	m (foF2)err	magic const	Snow	Date	Type	m (foF2)err	magic const	Snow
13-Oct-03	tau1u	0.96±0.02			12-Mar-04	tau2pl	0.87± 4%		
14-Oct-03	tau2pl	0.86±0.09			17-Mar-04	tau2pl	1.05±29%		
16-Oct-03	tau1u	0.96±0.02			22-Mar-04	tau2pl	0.82±31%		
21-Oct-03	tau1u	0.71±10%			24-Mar-04	tau2pl	1.03±17%		
22-Oct-03	tau1u	0.72± 8%		4 cm	25-Mar-04	tau2pl	1.16±12%		
23-Oct-03	tau1u	0.65± 1%		3 cm	27-Mar-04	tau2pl	0.85± 7%		
24-Oct-03	tau2pl	0.57± 3%		14 cm	28-Mar-04	tau2pl	0.80± 1%		
25-Oct-03	tau2pl	0.41± 4%		13 cm	13-May-04	tau1u	0.79±0.06		
29-Oct-03	tau2pl	HF blackout			17-May-04	tau1u	0.79±0.07		
30-Oct-03	tau2pl	HF blackout			18-May-04	tau1u	0.77±0.04		
31-Oct-03	tau2pl	0.96± 8%			19-May-04	tau1u	0.78±0.09		
01-Nov-03	tau2pl	0.91± 4%			20-May-04	tau1u	0.77±0.05		
02-Nov-03	tau2pl	0.90± 4%			01-Jun-04	tau2pl	0.87±0.07		
07-Nov-03	tau2pl	No HF			02-Jun-04	tau2pl	0.79±0.05		
11-Nov-03	tau2pl	0.93±24%			03-Jun-04	tau2pl	0.79±0.04		
12-Nov-03	tau2pl	0.96±13%			04-Jun-04	tau2pl	0.73±0.05		
13-Nov-03	tau2pl	0.86±39%			08-Jun-04	tau2pl	0.80±0.01		
14-Nov-03	tau2pl	0.91±11%			09-Jun-04	tau2pl	0.72±0.04		
15-Nov-03	tau2pl	1.00±23%			10-Jun-04	tau2pl	0.78±0.03		
16-Nov-03	tau2pl	1.06± 9%			11-Jun-04	tau2pl	0.76±0.04		
17-Nov-03	tau2pl	0.84±12%			12-Jun-04	tau2pl	0.80±0.02		
18-Nov-03	tau2pl	0.90± 7%			14-Jun-04	tau2pl	0.75±0.07		
19-Nov-03	arc1	0.88±14%			15-Jun-04	tau2pl	0.70±0.06		
19-Nov-03	tau2pl	0.90± 5%			16-Jun-04	tau2pl	0.78±0.07		
21-Nov-03	arc1	0.78±47%			17-Jun-04	tau2pl	0.81±0.04		
21-Nov-03	tau2pl	0.82± 5%			18-Jun-04	tau2pl	0.78±0.06		
22-Nov-03	arc1	1.21±14%			05-Jul-04	tau2pl	0.86±0.05	1.35	
23-Nov-03	tau2pl	0.97±14%			06-Jul-04	tau2pl	0.91±0.06	1.35	
03-Dec-03	arc1	0.91±0.05			06-Jul-04	tau2pl	0.97±0.04	1.35	
03-Dec-03	arc1	0.86±36%							
04-Dec-03	arc1	0.96± 3%							
05-Dec-03	arc1	0.88±23%		1 cm					
13-Feb-04	tau2pl	0.83±27%							
15-Feb-04	tau2pl	0.79±26%		13 cm					
17-Feb-04	tau2pl	0.97± 6%		11 cm					
18-Feb-04	tau2pl	0.75±35%		9 cm					
18-Feb-04	tau1u	0.85±35%		9 cm	21-Oct-03	tau8	0.73± 6%		
19-Feb-04	arc1	1.00± 6%			22-Oct-03	tau8	0.71± 4%		4 cm
20-Feb-04	arc1	0.86±59%			23-Oct-03	tau8	0.80± 2%		3 cm
22-Feb-04	tau2pl	0.86± 9%		19 cm	28-Apr-04	tau8	0.74±0.03		
23-Feb-04	tau1u	0.70±12%		9 cm	28-Apr-04	tau8	1.00±0.02	1.367	
23-Feb-04	arc1	0.97±16%		9 cm	01-Jun-04	tau8	1.02±0.07	1.367	
24-Feb-04	tau2pl	0.86±22%		8 cm	02-Jun-04	tau8	1.02±0.05	1.367	
04-Mar-04	tau1u	0.98± 3%			03-Jun-04	tau8	1.00±0.07	1.367	
05-Mar-04	tau2pl	0.93± 1%			04-Jun-04	tau8	1.06±0.05	1.367	
10-Mar-04	tau2pl	0.83± 5%							
11-Mar-04	tau2pl	0.92± 7%							

### The anomaly of 24-25 October 2003

Figures 1 and 2 show the standard summary colour plots of the analysed EISCAT UHF data for 24 and 25 October respectively. These plots can be downloaded from the Madrigal database (<http://www.eiscat.se/madrigal/>). There was a sudden storm around noon on 24 October causing the electron densities to drop suddenly and to stay low for several days. Figure 3 shows the ISR and the ionosonde peak densities from the F region plot plotted as a function of time in the upper plots, and against each other in the lower plots. The quality of both data sets is not in doubt, as careful checks showed. A reason for the low densities obtained by ISR was sought in the usual technical reasons such as the transmitter power decreasing, calibration source changing and so on. However these could be eliminated. For example, the system temperature plotted in the figures, which is calculated using the noise calibration source, remains quite constant. That the low densities were not the result of a permanent change in the calibration is shown by data a few days later on 1 November 2003 which agrees well with ionosonde data, as is shown in Figure 4.

In studying the anomalous data, the densities obtained at the Kiruna and Sodankylä receiving stations at an altitude of 292 km were also examined. The absolute densities between the three sites do not necessarily agree for reasons related to the common volume, and may therefore depend on antenna pointing accuracy. But relative changes should remain the same for a given common volume. Therefore the ratios of densities were normalised to those averaged on 1 and 2 November, when everything appeared normal. The actual density ratios on each of those two days were:

Date	Ne (T:K)	Ne (T:S)	Ne (K:S)
1 November 2003	$1.163 \pm 0.4\%$	$1.493 \pm 0.6\%$	$1.299 \pm 0.5\%$
2 November 2003	$1.136 \pm 0.9\%$	$1.563 \pm 1.2\%$	$1.370 \pm 1.4\%$

Figure 5 shows the density ratios obtained between Tromsø ISR and ionosonde, and between the three ISR sites, as well as the collected snow in Tromsø. It appears that the Tromsø ISR densities drop in a similar way compared to the Sodankylä densities as they do with the ionosonde densities. They also show a similar trend compared to Kiruna up to 23 October, but then the trend flattens out and reverses. Note however that the ratio Kiruna to Sodankylä also increases these two days.

These ratios show that variation in the transmitter power cannot explain the anomaly because the densities at all sites should be equally affected. One of us (IH) suggested that snow in the antenna might be the reason, based on an occurrence during a Japanese experiment on 1 February 1997, when apparently tipping the snow out of the antenna caused echoes to appear when formerly there were none. MTR recalled that there were indeed several days of heavy snow during the October 2003 radar operations. He also remembers it as being rather heavy and therefore wet. Moreover the antenna was stationary while pointed  $12^\circ$  south of zenith (field-aligned) for many days so that snow could accumulate. Information on snow was obtained from the Norwegian weather service. In figure 5 is shown the amount of snow collected on a plate, measured every morning after which the plate is wiped clean. We also show this quantity integrated starting from the first day of snow in October. This quantity may be more representative of the amount of collected snow in the antenna than snow

depth (not shown) measured in Tromsø, which never went to zero. There does seem to be a good correlation between the decrease of T/iono and the onset of snowfall.

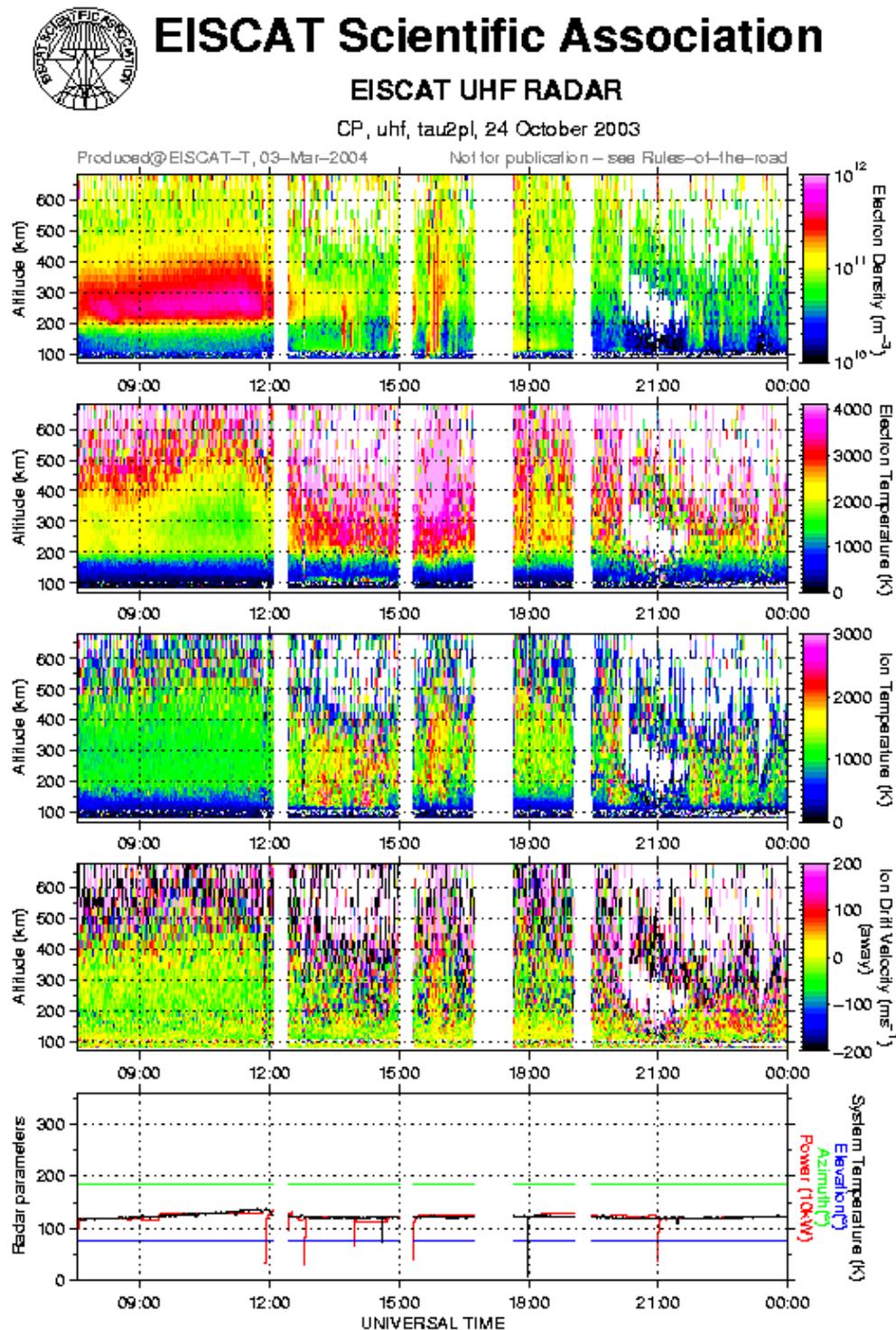


Fig. 1 Analysed data for 24 October 2003.



# EISCAT Scientific Association

## EISCAT UHF RADAR

CP, uhf, tau2pl, 25 October 2003

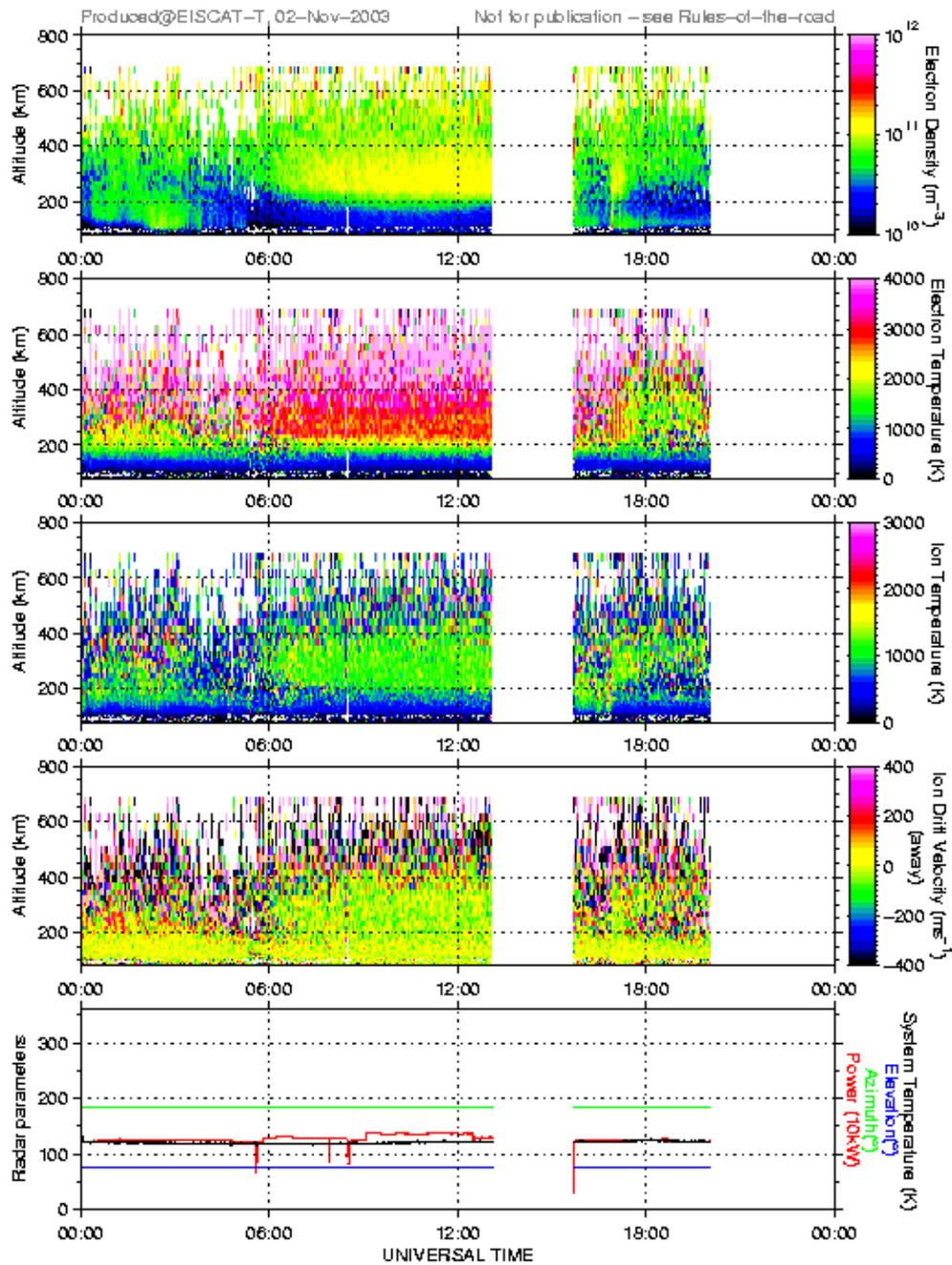


Fig. 2 Analysed data for 25 October 2003.

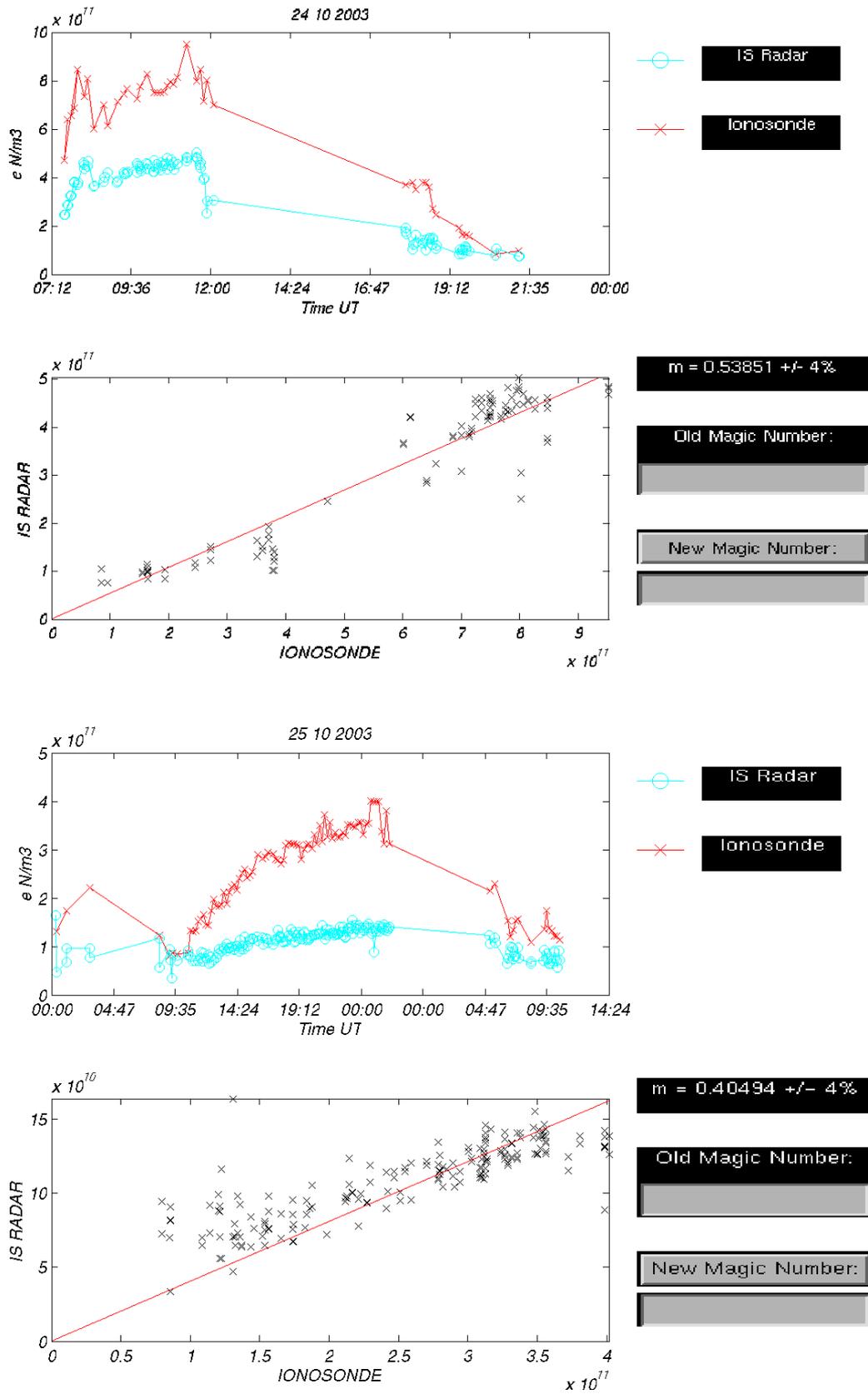


Fig.3 Peak densities from the F region compared with ionosonde data for 24 and 25 October 2003. Ideally the slope ( $m$ ) should be 1. The time axis is in error on 25 October 2003.

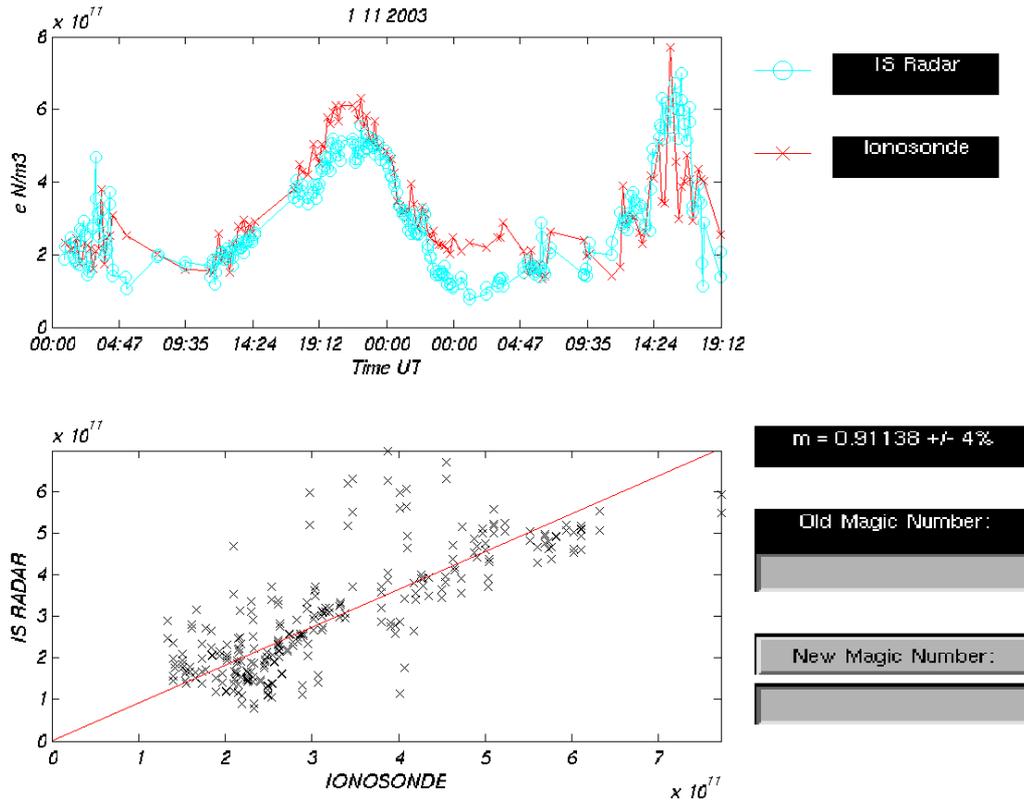


Fig. 4 Peak densities from the F region compared with ionosonde data for 1 and 2 November 2003. The time axis is in error: the peaks are near noon. The slope is much closer to 1 compared to a few days earlier.

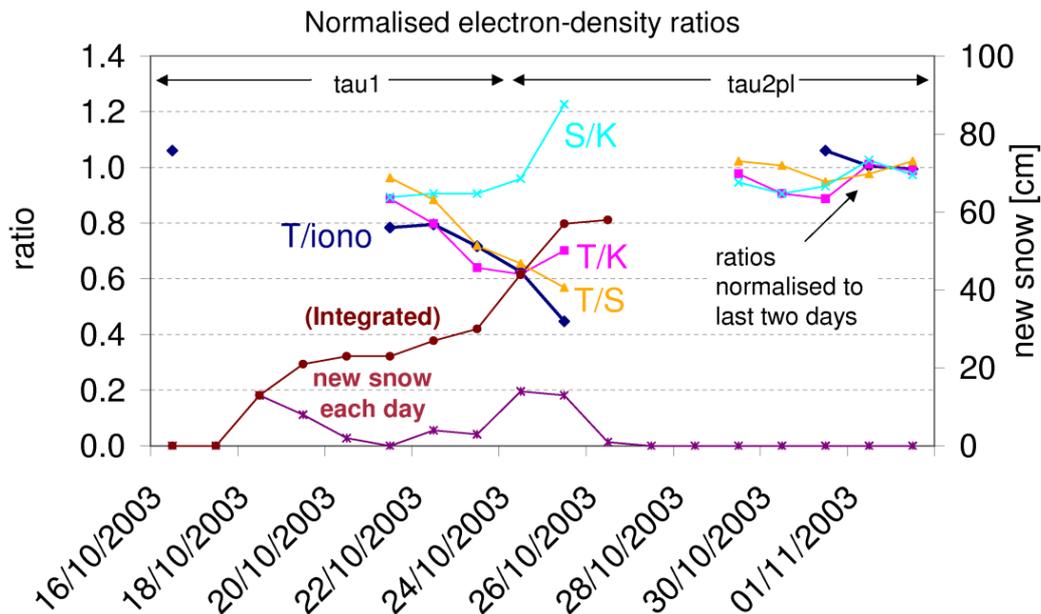


Fig. 5 Electron density ratios averaged for each day, as a function of time. Peak F region densities obtained between Tromsø ISR and ionosonde (T/iono). The ratios between the ISR sites at the common volume at 292 km height (T/K, T/S, S/K), normalised to the average of the last two days. At the bottom we show the new snow each day at Tromsø, measured on a plate which is then wiped clean at 07 every morning, as well as its integrated value.

On 28 October there was a polar cap absorption event lasting until 2 November resulting in so much absorption that there were no HF echoes to provide ionosonde calibrations. It also resulted in special measurements by both VHF and UHF antennas at low elevation, down to 60° at least on UHF on 28 October, probably resulting in accumulated snow to fall out of the reflector.

Having exhausted all other conceivable explanations, we must conclude that accumulated snow in the Tromsø antenna is the reason for the anomalously low densities between 22 and 25 October 2003.

### **The effect of snow on the radar**

Snow is a mixture of water, air and ice, and its dielectric constant ( $\epsilon$ ) is a weighted average of the dielectric constant of its three components. The dielectric constants for air, ice and water are 1, 3.2 and 80 respectively. So the dielectric constant for wet snow is much greater than for dry snow, which is considered to be a mixture of air and ice (see [http://snobear.colorado.edu/Markw/SnowHydro/energy.html#em\\_rad](http://snobear.colorado.edu/Markw/SnowHydro/energy.html#em_rad)).

Clearly, wet snow could cause the refractive index to change significantly over many, even tens of centimetres, over a part of the UHF antenna reflector. This means that the gain and beam direction may change, and that the effective collecting area  $A_r$  may be decreased because all parts of a plane wave entering the antenna will not add up in phase at the subreflector. If the change in beam direction and in effective beam-width is not too large, then the effect on the remote site signals will be minimal because the Tromsø beam will still be within their much wider beam in the common volume. So for the remote sites the scattering volume is again proportional to  $1/G_t$  causing the dependence on  $G_t$  to cancel out in equation (1). A decrease in the power density of the transmitting beam is compensated for by an increase in the scattering volume. However, the receiving aperture at Tromsø will still be decreased whereas that at the remote sites remains unaffected thereby resulting in weaker signals at Tromsø compared to Kiruna and Sodankylä.

The fact that the ratio of the S/K and T/K increases slightly on 25 October suggests that either snow was also affecting the Kiruna antenna on that day, or that the Tromsø beam was tilted so far in the east-west plane as to move out of the mainly northward oriented Kiruna beam but to remain in the mainly westward oriented Sodankylä beam.

## **Discussion**

It is clear from table 1 that there were other occasions where snow fell during field-aligned operations. It is notable that the snowfall on 24 September 2003 was followed a day later by an anomalously low  $m$ , and that the low  $m$  on 23 February 2004 was also in a period of snow. Nevertheless there are extended periods of snow from 15 to 18 February and 22-24 February without large decreases in  $m$ . There could be several factors involved such as the wetness of the snow, which is not measured quantitatively, and the fact that the snow measurements made on the top of the island of Tromsø may not necessarily be representative of the snow in the antenna reflector. For example, there may have been occasions when the antenna was tipped or the reflector surface heated between non-continuous measurements, events which are rarely documented.

It may seem odd that after more than 20 years of operating ISRs in the arctic, we still do not know much about the effect that snow in the antennas has on the received signals. It would seem that the much better data and software available to us now, from both the ionosonde and ISR, have allowed us to monitor changes in the system constant almost continuously so that the effects of snow have become convincingly obvious for the first time.

## **Conclusions**

Generally the calibration factor of the UHF radar has been quite stable over the last two years. Nevertheless, after careful study of several days of extremely low signals at Tromsø on October 2003 and being able to reject other explanations, it appears that (wet) snow in the reflector can decrease the received power, and hence electron densities, by more than a factor of two. This highlights the importance of continual monitoring of the absolute electron density, using both ionosondes and plasma lines.

## **Recommendations**

Based on the results of this study it would be useful to:

- 1) Find and study some of the other cases where snow may have affected the UHF calibration.
- 2) Implement some means of monitoring the amount of snow in the reflector, so that it can be removed by tipping or melting when necessary.
- 3) Investigate the effects of snow in the VHF reflector.
- 4) Monitor the ratio of electron densities from the three sites more closely.
- 5) Do some simple modelling of the effect of wet snow on the focusing properties of the EISCAT antennas

## **Acknowledgements:**

We thank C. Davis and P. Gallop from Rutherford Appleton Lab for the development and use of the software used to do the comparisons between EISCAT and dynasonde data. J. W. Wright from NOAA developed the real-time scaling software of the dynasonde data, and Gudmund Wannberg from EISCAT (Kiruna) pointed out that the probable explanation for the snow-effect on only the Tromsø densities was the effect on antenna aperture at Tromsø. We thank Stein-Erik Øines from Vervarslinga for Nord-Norge, for the Tromsø snow data. EISCAT is funded by agencies and institutes in Finland, France, Germany, Japan, Norway, Sweden and the United Kingdom.

## Appendix: Description of software used to compare EISCAT densities with dynasonde densities.

### Dynasonde data

The dynasonde produces sounding files (raw data) that contain the radio-frequency information of ionospheric echoes. Basically this is frequency, virtual range, amplitude and phase on each echo obtained on up to 6 spaced receiving antennas. Details of the dynasonde hardware and processing software can be found in the references at <http://www.ngdc.noaa.gov/stp/IONO/Dynasonde/biblio.html>.

These raw data soundings are processed, now in real-time, by a software package called DSND, written largely by J. W. Wright, NOAA, USA. This is done both on-site at Tromsø and at NOAA using the most modern version of this package. At the NOAA site data from several other dynasondes is also processed. Another offline processing package, called dyAn,

([http://www.eiscat.rl.ac.uk/dynasonde/dyna\\_anal.html](http://www.eiscat.rl.ac.uk/dynasonde/dyna_anal.html), a now stale link) is based on a program written by Owen Jones (formerly BAS) and implemented at RAL by Chris Davis. Both packages produce physical quantities from the raw soundings, like precision group range, Doppler velocity, direction of arrival, chirality, amplitude, and a residual error phase. DSND calculates additional outputs like critical frequencies, irregularity parameters, vector velocities from E- and F-regions, electron density profiles and so on.

The automatically calculated values of foE and foF2 are available in real-time from Tromsø at <http://dynamite.eiscat.uit.no/jww/AUTO/autodsnd.fef> and archived monthly .FEF. files are available at: <http://dynamite.eiscat.uit.no/a/jww/AUTO/archive/>.

There are two useful MATLAB programs, **calib\_ne** and **ui\_cal**, which read in time series of dynasonde ionosonde data and EISCAT ISR data and do a cross correlation between the foF2 electron densities derived the ionosonde data and the peak electron densities derived from the ISR data. Both programs, each of which has its merits, are now described. When you log on to matilda@eiscat.uit.no in Tromsø as user **eiscat** the scripts ui\_cal, g2n, guisdap and others are already in the path.

### A) calib\_ne

This was written by Ingemar Häggström and available in March 2004, after the development and experience gained with ui\_cal (see below). It is run from a command line, is fairly automated and therefore suitable for routine analysis. It finds the relevant dynasonde files (.FEF files, both archived and real-time) from the web automatically. FEF files have been produced routinely only since May 2002, but at the time of writing data going back to 2000 have been re-analysed. Figure 6 shows a comparison of peak E-region densities made using calib\_ne.

- It automatically leaves out points that are more than n standard deviations (n=1 is the default) from the median (green points in the lower panel).
- It can be run immediately after making summary plots with vizu: (EISCAT Matlab data files are already loaded).
- Error of slope is given absolutely.



# EISCAT Scientific Association

## EISCAT UHF RADAR

SP, uhf, tau2, 3 November 2002

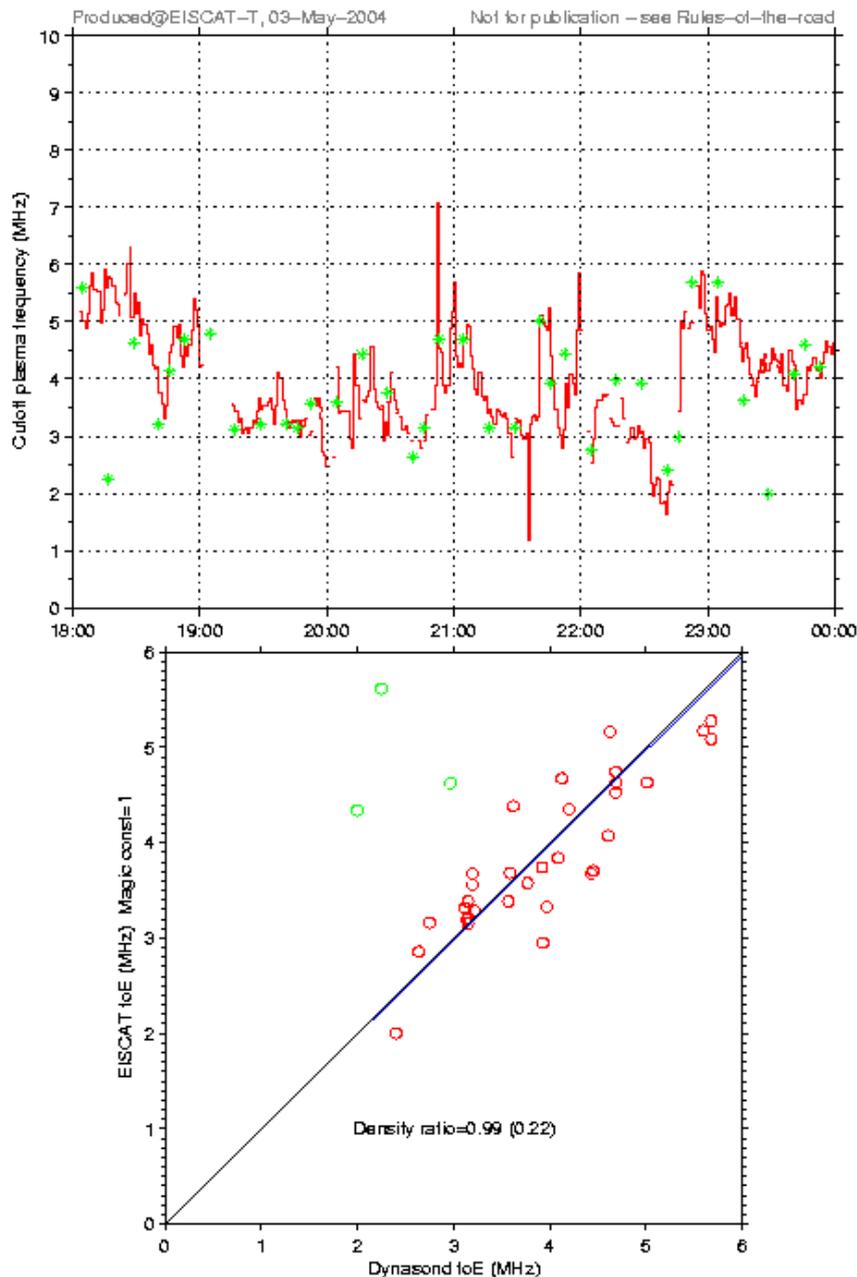


Fig. 6. Comparison of E-region densities using calib\_ne. The dynasonde data are the green crosses in the upper panel. The green circles in the scatter plot are rejected in the final least-squares fit because they are greater than one standard deviation from the median.

As of March 2004, the easiest way to do the calibrations is using a script in the Guisdap8.4 environment. It can compare peak densities from the analysed EISCAT

data with those from .FEF files. It automatically gets the monthly .FEF files or the real-time file from the dynasonde web server.

### How to run calib\_ne:

Type **guisdap**

Type **calib\_ne** or **calib\_ne(r, [h1,h2], sd, minel)**  
 where r = 1 for foE, =2 for foF2  
 h1 and h2 are the height limits in km to look for a peak density in the EISCAT data  
 sd = number of standard deviations from the median beyond which data points are rejected for the linear least squares fit.  
 minel = minimum elevation of EISCAT radar

## **B) ui\_cal**

Ui\_cal is a MATLAB script written by Chris Davis from Rutherford Appleton Lab (RAL), UK, and was used a lot for calibrations at Tromsø. Lately it has been superseded by calib\_ne for routine use because the later is more automated and integrated into the whole guisdap analysis and plotting procedure. Ui\_cal has a graphical user interface, is very interactive and has some useful features that calib\_ne does not have. For example it can show individual EISCAT profiles, ionograms, and spurious points can be removed or corrected from either. Figures 3 and 4 were produced using ui\_cal.

- It can remove individual dynasonde data points, and edit foF2 values if 'dyna' files have been used.
- It can select EISCAT pointing direction and dynasonde echo direction of arrival cone (the latter if 'dyna' files have been used).
- It can be used on most older dynasonde data since 1992 by using the software available at RAL where the original soundings are also archived.
- Error of slope is given in %.

**ui\_cal** accepts two types of dynasonde data, a) analysed files from dyAn (.dyna files) and b) real-time tables (.FEF files) of foF2, foE and other standard frequencies. The .dyna files have to be produced at RAL, where a copy of the dynasonde data also exists. The .FEF files have been produced in Tromsø in real-time since about May 2002 and have been produced by off-line processing back to the year 2000.

## **I. How to get analysed dynasonde data from RAL for use with ui\_cal**

(1) Log on to matilda as user eiscat, then log on to the RAL computer

```
eiscat@matilda> ssh <user>@c2.stp.rl.ac.uk (user rietveld get password from him)
```

(2) Use DYNACAT and dyAn to get a list of the soundings

As an example, to get all the processed Dynasonde data from 17 October 2001, type  
 > DYNACAT 200110170000 200110180000 tro 'b\_g' | get\_dyna | dyAn | dyAn2mat > 2001-10-17.dyna

This command may be saved in a script file, e.g. dynacatscript, and executed using "source dynacatscript".

RUTHERFORD APPLETON LABORATORY  
DYNASONDE ANALYSIS v4.0  
Developed from code supplied by British Antarctic Survey.

Ignore these error messages:

```
Stager: Error: EACCES file: chkfileis.c line: 204
Stager: Permission denied: Checked stager dir "/stager/isonde", try again for read
access only.
Stager: Error: EACCES file: chkfileis.c line: 204
Stager: Permission denied: Checked stager dir "/stager/x", try again for read access
only.
```

Be patient because the tape may have to be loaded and read (this is done automatically).

```
PRANGE-PHSFUN-warning pdum= 47030.40      0.0000000E+00
PRANGE-PHSFUN-warning pdum= 52046.67      0.0000000E+00
GETMOR EOF
GETMOR EOF
Error reading PCT/echo data
0 P02 blocks processed, 2472 echo records written to disc
END OF FILE LIST REACHED
```

See [http://www.eiscat.rl.ac.uk/eiscat-cms/eiscat/intro/software\\_notes/section\\_13](http://www.eiscat.rl.ac.uk/eiscat-cms/eiscat/intro/software_notes/section_13) (**now stale link !**) for more details about DYNACAT.

(3) Compress the output file

The output file (2001-10-17.dyna in this example) may be compressed, for example using

```
> gzip <file>   or   > compress <file>
```

(4) Transfer and uncompress the dynasonde file

Transfer this to matilda@puny:/analysis/calibration/ as follows:

```
eiscat@matilda> scp <user>@c2.stp.rl.ac.uk:~/2001-10-17.dyna.gz
/analysis/calibration/2001-10/ where ".gz" denotes a gzip file and ".Z" would be a
"compress" file. This command may be saved in a script file, e.g. scpscript, and
executed using "source scpscript".
```

```
Then eiscat@matilda> gunzip 2001-10-17.dyna.gz   or   eiscat@matilda>
uncompress 2001-10-17.dyna.Z
```

## II. How to compare electron densities from EISCAT Tromsø with those from the Tromsø Dynasonde

Do the following tasks from user eiscat on matilda.

## (1) Dynasonde HF data

The Dynasonde soundings may be processed at RAL using DYNACAT and dyAn as described in part I above. The resulting files are of the form 2001-10-17.dyna and should be located on matilda in the corresponding monthly directory, for example /analysis/calibration/2001-10.

Alternatively, listings of foF2 may be obtained from <http://dynamite.eiscat.uit.no/jww/AUTO/autodsnd.fef>. These .fef files may also be used for calibration, but do not have the analysis flexibility of the files produced using the RAL analysis programs. They are just a table of foF2 values, but points may be removed using the right mouse button once they are displayed as a time series. Monthly archives of these files are at <http://dynamite.eiscat.uit.no/a-a.jww/AUTO/archive>

## (2) EISCAT ISR data

The raw ISR data must be analysed by Guisdap

(2a) There are now (as of Oct 2003) two ways of reading the analysed EISCAT data. The easiest way is to read the guisdap output files directly, by choosing the /analysis/results/<directory> and choosing the file filelist.dat which should be there.

The older way is to convert the analysed data to RAL NCAR format using the script g2n.

(2b) On matilda, create a filelist of the analysed EISCAT data in the directory containing the data, e.g.

```
> ls -l /analysis/results/2001-10-17_cp7hv_lp_60_vhf0/*.mat > filelist.dat
```

```
> mv filelist.dat /analysis/results/2001-10-17_cp7hv_lp_60_vhf0/
```

Guisdap 1.8 will create a filelist during analysis. To verify that it is correct, run

```
> wc /analysis/results/2001-10-17_cp7hv_lp_60_vhf0/filelist.dat
```

```
> ls -l /analysis/results/2001-10-17_cp7hv_lp_60_vhf0/*.mat | wc
```

and compare the line counts, or run

```
> ls -l /analysis/results/2001-10-17_cp7hv_lp_60_vhf0/*.mat > filelist.dat
```

```
> diff filelist.dat /analysis/results/2001-10-17_cp7hv_lp_60_vhf0/
```

There should be no differences.

(2c) Run g2n on the EISCAT analysed data. Type g2n -h for help. E.g. on matilda

```
> g2n -d /analysis/results/2001-10-17_cp7hv_lp_60_vhf0/ 2001-10-17_cp7hv_lp_60_vhf0.rslt
```

## (3) Run the calibration program ui\_cal

The program allows you to interactively choose, modify, and delete data points.

To begin, on matilda type

Type **ui\_cal** to get the graphics user interface up.

The right-hand mouse button can be used to delete individual data points.

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