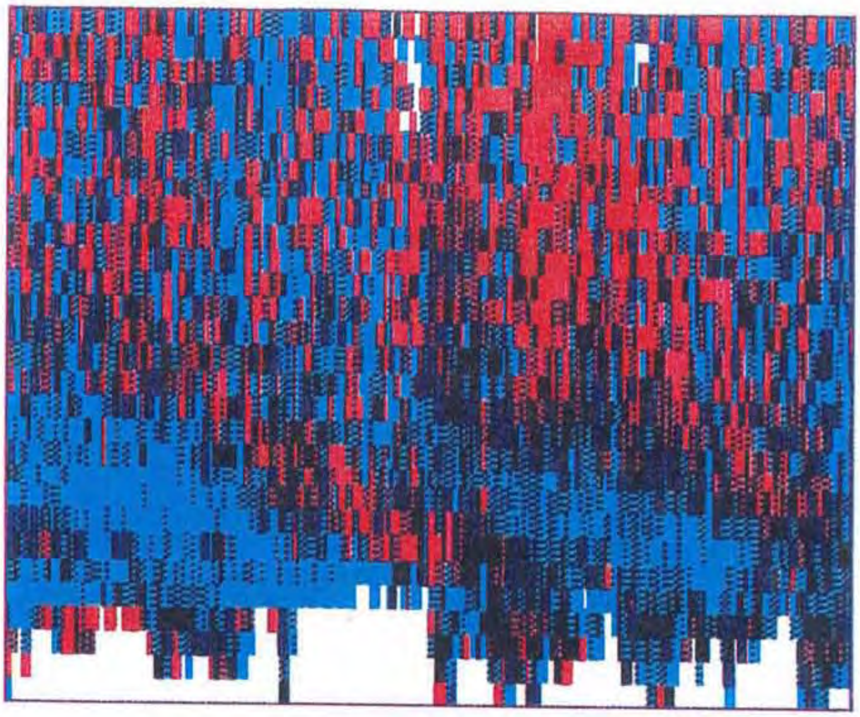
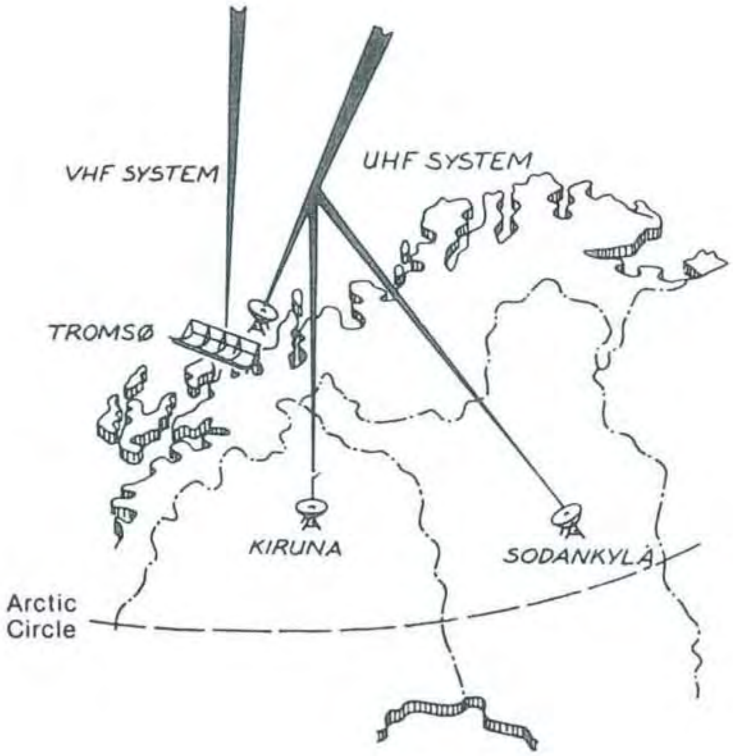


# EISCAT

EUROPEAN INCOHERENT SCATTER SCIENTIFIC ASSOCIATION

## ANNUAL REPORT 1986

S-981 28 KIRUNA, SWEDEN, Phone (0980) 18740




EISCAT, the European Incoherent Scatter Scientific Association, is established to conduct research on the upper atmosphere, ionosphere and aurora using the incoherent scatter radar technique. This technique is the most powerful groundbased tool for studying the upper atmosphere. There exist seven incoherent scatter radars in the world, and EISCAT is one of the highest-standard facilities.

The experimental sites of EISCAT are located in Scandinavia, north of the arctic circle. They consist of two independent radar systems.

The UHF radar of EISCAT operates in the 933 MHz band with a peak transmitter power of 1.5 MW and 32 m parabolic dish antennas, which can be steered omnidirectionally. Transmitter and receiver are in Tromsö (Norway). Receiving sites are also in Kiruna (Sweden) and Sodankylä (Finland), allowing tristatic measurements.

The VHF radar in Tromsö operates monostatically in the 224 MHz band with a peak transmitter power of 2.5 MW (to be raised to 6 MW) and a 120 m x 40 m parabolic cylinder antenna, which is subdivided into four sectors. It can be steered in the meridional plane from 30° south to 60° north of the zenith.

The basic data, which are measured, are the profiles of electron density, electron and ion temperature and ion velocity. A selection of well-designed radar pulse schemes allows the adaption of the data taking routines to many particular phenomena, occurring at altitudes between about 70 km and more than 1000 km. Depending on geophysical conditions, a best time resolution of seconds and an altitude resolution of a few hundred meters can be achieved, whereas typical resolutions are in the order of minutes and kilometers.

The operation of a total of 2000 hours per year is distributed equally between Common Programmes (CP) and Special Programmes (SP). At present, three well-defined Common Programmes are run regularly for 24 or more hours, to provide a data base for long term synoptic studies. A variety of Special Programmes, defined individually by associate scientists, are run to study particular geophysical events.

Details of the EISCAT system and operation can be found in particular EISCAT reports, which can be obtained from EISCAT Headquarters in Kiruna, Sweden.

The investments and operational costs of EISCAT are shared between:
Suomen Akatemia, Finland
Centre National de la Recherche Scientifique, France
Max-Planck-Gesellschaft, W. Germany
Norges Almenvitenskapelige Forskningsråd, Norway
Naturvetenskapliga Forskningsrådet, Sweden
Science and Engineering Research Council, United Kingdom

EISCAT SCIENTIFIC ASSOCIATION

# ANNUAL REPORT 1986

# Contents



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*The cover plot shows the field-aligned ion drift velocity, measured with the EISCAT Common Programme CP-1-F from 08 UT on 5 August 1986 to 08 UT on 6 August 1986. The corresponding plots of the other ionospheric parameters, electron density and electron and ion temperature, which were measured simultaneously, are displayed on page 15 of this Annual Report.*

*In this Common Programme, a special multi-pulse scheme is applied in the monostatic mode. With this scheme the altitude region between 84 km and 168 km is observed with a resolution of 3 km and a basic time resolution of 10 seconds.*

*The ion drift velocity results from the neutral wind driving the ions along the magnetic field line. Its measurement allows the deduction of the velocity of the meridional wind component. The red and blue colours in the cover plot correspond to a southward and northward wind velocity of 150 $ms^{-1}$, respectively. The quasi-periodical variation of this wind velocity with time and altitude vividly displays the presence of a semi-diurnal tidal mode (see also page 22).*

# COUNCIL CHAIRMAN's FOREWORD

During the last year, Council activities developed fairly smoothly without any major event. Fortunately, this does not mean that EISCAT was not very active during that period. The Director's report gives an accurate description of significant achievements which I have no reason to duplicate here.

I would only mention how pleased the Council is with the excellent coordination which was achieved in real time between the VIKING observations and the measurements of various ground-based facilities among which EISCAT certainly played a major role. The Council is confident that excellent results derived from the set of data obtained during these campaigns will soon add to the already impressive scientific output from EISCAT.

*Michel Petit*


*EISCAT Council Meeting, London, November 1986:*
*From left: 1. row: B. Hultqvist, J. Röttger, M. Petit, G. Beynon, G. Haerendel. 2. row: A. Berroir, C. LaHoz, O. Ranta, L. Westgaard, A. Brekke. 3. row: H. Rishbeth, A. Jubier, T. Turunen, A. Siivola, T. Jones. 4. row: B.R. Martin, G. Rowe, M.-O. Ottosson, M. Meinecke.*

# DIRECTOR's PREFACE

The year 1986 included several achievements which deserve mention: In this year the EISCAT Scientific Association had been in existence for a full decade. In this year, five years had passed since the first incoherent scatter echo was detected with EISCAT, and five years had passed since the official inauguration of the facility, which took place in August 1981. In this year 1986, the complete VHF radar with two klystrons was operated, although not yet at full power.

The compilation of an Annual Report provides an opportunity to outline other dominant developments which governed the operation of the EISCAT facilities, and to acknowledge the work and efforts necessary to achieve these. Besides the continued reliable operation, the further service and repair work, as well as general improvements of the EISCAT radar system, some events can be regarded as operational highlights which merit specific comment:

The installation of the new computers is one outstanding event in 1986. The selection of contractor and the order, the delivery, installation, test as well as operational use were all achieved in a period of one year. This was possible only by an effective collaboration between many of our staff. By the end of the year we had gained confidence and experience with the new computer system and had removed unpredictable inconsistencies which occurred in the complex interfaces between the new computers and the radar instrumentation. These could only be detected and analysed during intensive test operations. From the end of the year the complete radar system has been running with the new computers.

A significant amount of work was spent on tedious procedures to bring to operation the Valvo VHF-klystron, understand unforeseen problems with it and to their solution. As a result of our efforts we have gained more experience with the VHF system and were able to take data. A new achievement was the parallel operation of two VHF klystrons — one Varian and one Valvo — feeding the full VHF antenna. This took place close to the end of the year. Although at reduced output power (limited to one megawatt due to the Valvo klystron), the VHF system can now be operated at about one third of its specified sensitivity and some useful data could be acquired. A contract amendment was negotiated and signed with the Valvo company, which shall assure that klystrons working according to specifications will be delivered.

Substantial time had to be devoted to repair, service and maintain the antennas. In particular the Tromsö UHF-antenna suffered major damage to an elevation gear box, but this was quickly repaired in a common effort by staff from all sites without causing a major impact on the operation.

Many parts of the radar system were further extended and improved, such as buffer memories, receiver front-end amplifiers, the system calibration etc. Several new kinds of experiments were run, such as those applying the CCD-spectrum analyser, the digital chirp synthesizer, as well as high resolution codes and the new common programme modes using the GEN-system. Finally, the first test experiments with the VHF radar, carried out by staff and by visiting scientists, must also be mentioned.

Major campaign operations during the year were EISCAT's collaborative experiments with the VIKING satellite. A large group of scientists was involved in several campaigns and the EISCAT data should provide excellent ground-based support for the interpretation of these satellite data.

Furthermore, extensive EISCAT-Heating experiments were carried out which yielded surprising new results, and experiments supporting rocket launches such as Centaur and Aureld-VIP were performed.

Besides particular contributions by single staff members or smaller groups, only the effective collaboration of all staff members and their dedication to work in the EISCAT team made possible the successful achievement of these results in the past year.

I want to acknowledge sincerely all these efforts, thank all staff members for their important work, and to express my belief and confidence in a stable continuation of our collaborative work in the future. We also appreciate very much the cooperation of visiting scientists and the comprehensive support by Council and Committees. Collectively this has allowed EISCAT to achieve a remarkable scientific output, of which some highlights are summarized in this Annual Report. I know that EISCAT will continue to support individual researchers and particular projects as well as to participate effectively in these collaborative international campaigns and in global programs which are anticipated to commence in the near future.

*Jürgen Röttger*

*At the 1986 EISCAT Annual Review Meeting in Olostunturi in Finland the Director presented a special Year's Plate to the Assistant to the Director Mrs. Gurli Hultqvist for her continuous dedicated work for the EISCAT Scientific Association during the first decade of its history. On the photo are from the left to the right: (standing) Gurli Hultqvist, Jürgen Röttger and Peter Hagström of EISCAT-Headquarters, and (seated) the guests Hilkka Ranta and Don T. Farley.*

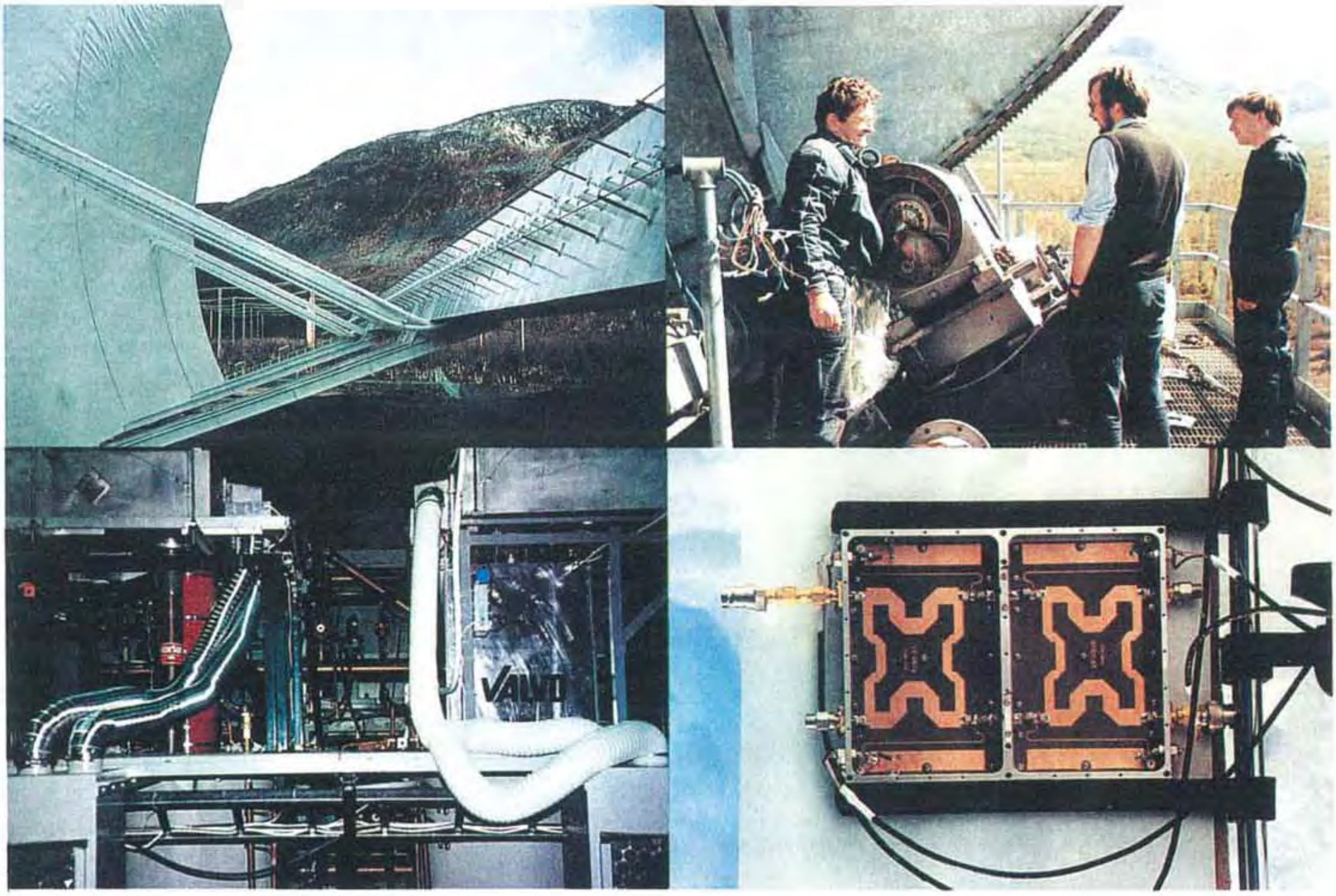


*Fig. 1. The reflector surface and feeder bridge with the crossed-dipole phased-array of the VHF-antenna, which is now fed by the VHF transmitter with two klystrons, one from Varian and one from Valvo (left-hand panels). Repair work on the elevation drive gear box of the Tromsö UHF-antenna; the new design of the low-noise, two-stage GaAsFET preamplifier for the UHF receivers using quarter-wave balanced hybrids in strip-line technology (right-hand panels).*

# TECHNICAL REVIEW OF THE EISCAT RADAR SYSTEMS

During recent years the UHF radar system has improved so much that it can now be regarded as having reached a very high reliability as well as an almost optimum sensitivity. In addition, in the last year the VHF radar system has developed to the extent that it could be used for a considerable number of new experiments, although it is not yet in its final shape. Furthermore all the old Norsk Data ND-10 computers were replaced by new Norsk Data ND-530 computers.

## The UHF System

The dominant achievements, improvements and incidents of the UHF system which occurred in the year 1986 were:

* Extension of the correlator buffer memories to 16 kWords and the extension of the correlator result memories to 4 kWords which contain 64 bit words. This allows more flexibility and optimization of multichannel radar programs which are needed to improve time and range resolution as well as the sensitivity. The newly designed memories are furthermore perfectly insensitive to digital noise and thus absolutely reliable.

* The CCD spectrum analyser was finally incorporated into the system and used in experiments together with the correlator. The advantage is that its high computing speed allows 10 MHz sampling rate and simultaneous observations of both the ion line and the plasma line spectra.

* The prototype cryogenic GaAsFET preamplifier was completed (Fig. 1). Its test on the bench yielded a noise temperature of 25 K. It is thus similarly sensitive and comparably qualified as the old parametric amplifiers and is initially in use at the remote sites. The newly developed preamplifiers are even regarded superior to the old devices because they are much less susceptible to breakdowns, less expensive, more reliable and much easier to service.

* The polarizer calibration at the remote sites has been substantially improved, and the old noise injection concept has been replaced by an exactly calibrated and stabilized system. Due to this totally new arrangement an improved estimate of the scattered power received at the remote sites is achieved, which improves the accuracy of the derived ionospheric parameters.

* A signal simulator was built and a new system test program was applied to check and calibrate the analogue and the digital part of the receiver system, particularly the programmable matched filters. This procedure ameliorates the performance of the data acquisition process.

* A digital chirp synthesizer, brought from the Arecibo Observatory by the former EISCAT director Professor Tor Hagfors, was successfully implemented for a couple of months in the EISCAT system in Tromsö This device is used for sensitive plasma line observations (Fig. 2), and a similar instrument is now being developed by EISCAT staff.

* Further new methods were developed to improve the radar control and data acquisition algorithms. These make use of adding up several channels, applying new pulse schemes which are needed for instance for low altitude D-region experiments, as well as for high time resolution requirements which now allow data dumps as fast as every second. By time slicing of dumps a best temporal resolution down to a few tens of milliseconds can be obtained.

* Improvements of the timing-system and the radar controller time synchronization were achieved, further post-detection filters were constructed, the portable monitor for the remote system operation was routinely utilized and many minor, but valuable improvements were implemented into the system alongside the continuous routine service and maintenance of the instruments.

* The UHF transmitter performed reliably as usual, at nominally 1.2 — 1.5 MW peak

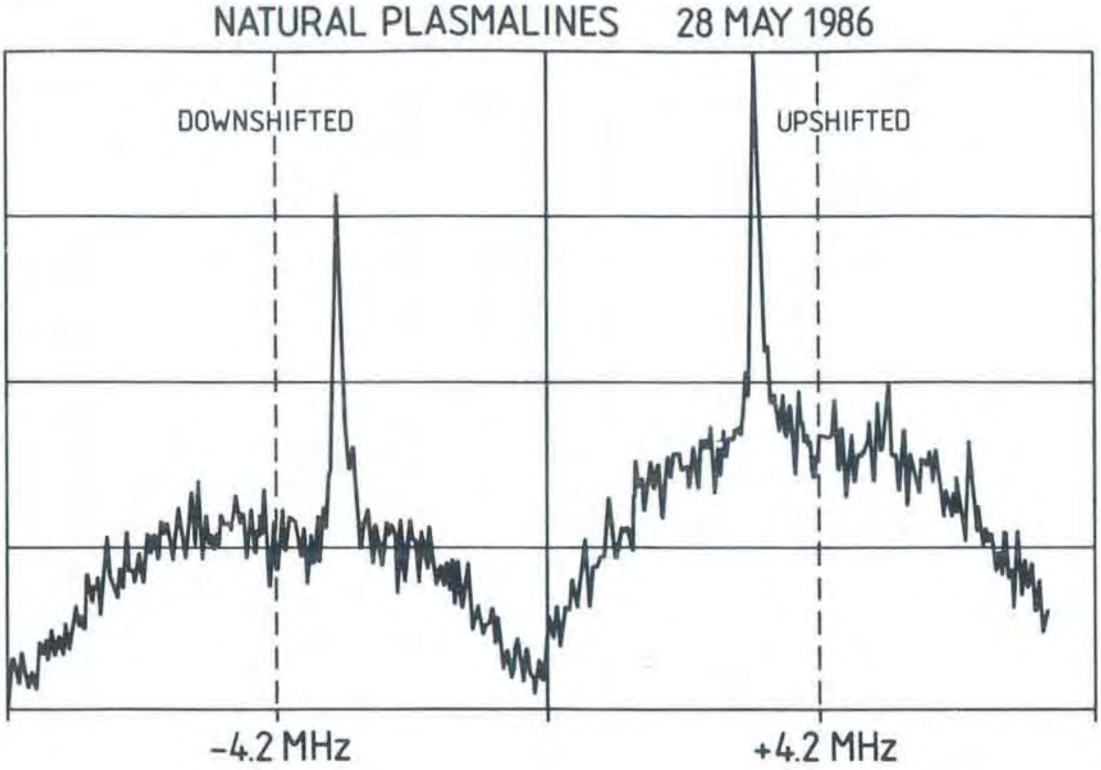



*Fig. 2. First observations of the natural plasma lines at 4.2 MHz using the digital chirp synthesizer with the UHF radar on 28 May 1986 at 1247 UT. The figure shows the spectra ($\pm$ 0.5 MHz bandwidth) of the downshifted and upshifted plasma lines as the sharp peaks rising above the background noise. The signal-to-noise ratio (SNR) per unit bandwidth is slightly larger than 1 due to the enhancement by the chirp technique. An SNR of only 0.02 would have been obtained if the conventional method had been used. This means that these plasma lines would have been undetectable at the integration time of 30 seconds used here. First estimates of the altitude and the electron density give 161.5 km and $4.09 \cdot 10^{11}$ $m^{-3}$, with relative errors of 0.25 and 0.37 %, respectively.*

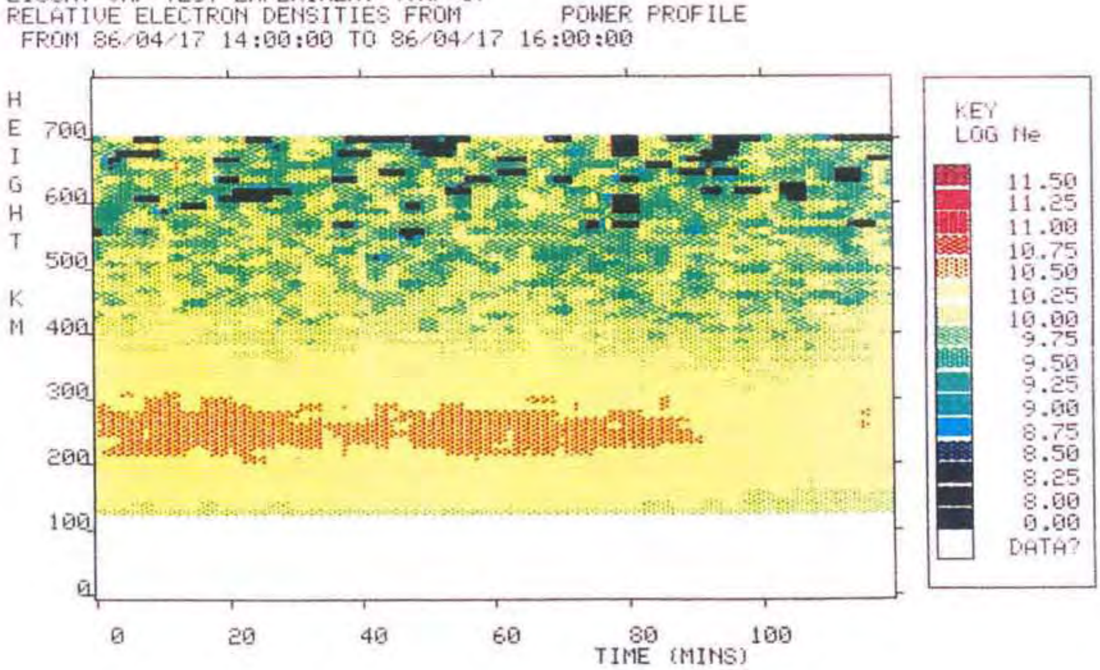



*Fig. 3. First test results achieved with the Valvo-VHF-klystron on 17 April 1986, using about 800 kW peak power and half the antenna. This raw electron density plot (yet uncalibrated) was derived from power profile measurements with 22.5 km altitude resolution.*

power. The klystron in the transmitter and the spare klystron are in good shape. Some break-downs in power supply circuitries, in the modulator or of switch tubes were quickly fixed and did not cause critical shut-downs. However, transmitter crowbars still disrupt sensitive digital equipment such as radar controller, correlator or even the new computers, — a problem which may not immediately be solvable.

* A major failure of the UHF antenna in Tromsö happened in summer 1986 when the gear box of one elevation drive motor broke (Fig. 1). The problem was solved in a common and fast effort by replacing the housing box without causing a major impact on the experiment routines.

## The VHF System

In the year 1986 the VHF system could at long last be run with a Valvo-klystron and it also became possible towards the end of the year to run both sides of the transmitter together, one with the Valvo and the other with the Varian klystron. It thus became possible to operate for the first time the complete transmitter with the full antenna (see Fig. 1), although only at one third of its specified power.

After the first Valvo klystron YK 1320/1 was delivered in the beginning of the year and installed in Tromsö, it was soon apparent that it did not perform according to specifications. A long aging process over more than 300 hours also did not improve its high voltage capability. It was not possible to operate it at a beam voltage higher than 90 kV, whereas more than 100 kV is necessary to achieve the maximum output power. However, it was possible to operate this klystron up to about 1.2 MW power on a few selected frequencies and first tests showed reasonable echoes (Fig. 3). More detailed investigations also indicated some instabilities which distort the RF purity and showed a power notch in the middle of the frequency pass-band. By cooperation between Valvo engineers, distinguished consultants, namely Jim Tallmadge of SRI International and Professor Tore Wessel-Berg of NTH Trondheim, and EISCAT staff the main problems were located and analysed. It was recognized by the experts that klystrons with new and unconventional parameters, such as the VHF klystrons for EISCAT, have to be subject to extrapolated design data since computer simulation and modelling is still inadequate today. It has to be regarded that a certain amount of trial and error is an inevitable part of the normal design procedure. The following possibilities for curing the remaining deficiencies of the Valvo klystron design were worked out and agreed upon:

* Redesign three of the five cavities in order to shift the frequency of higher order modes which caused the notch in the operational pass-band.

* Attach a load to the second cavity and increase the coupling of the output cavity to minimize the chances for instabilities.

* Redesign the gun region in order to improve the high-voltage capability.

* Readjust the magnetic field and the electron beam shape to reduce the hazard of instabilities.

These technical proposals for rebuild were considered as most likely to yield the optimum chance for achieving acceptable klystrons. They were presented to the EISCAT Council together with a financing proposal, in which Valvo and EISCAT share the additionally arising costs. The Council then authorized an amendment to the contract to rebuild both Valvo klystrons. The delivery of the rebuilt klystron YK 1320/2 is now expected in late summer 1987 and the klystron YK 1320/1 will then be returned to Valvo for rebuild and be reinstalled in Tromsö in early 1988. The Valvo klystron YK 1320/1, although limited in bandwidth and output power (1.2 MW max), can be operated in Tromsö until YK 1320/2 will be installed.

Many further efforts, such as waveguide, control circuitry and cooling system installations etc., were undertaken in the year 1986 to insert the remaining Varian klystron into side A of the VHF transmitter. In early December 1986 it became possible to run both klystrons, the Valvo and the Varian, together at 2 x 1.2 MW. The VHF system has since then been officially used in extensive tests and fairly successful experiments. Reasonable results were achieved in low-altitude, high-altitude and long range (polar cap) observations and heating experiments. Analysable echoes could be detected from heights as low down as 75 km and as high

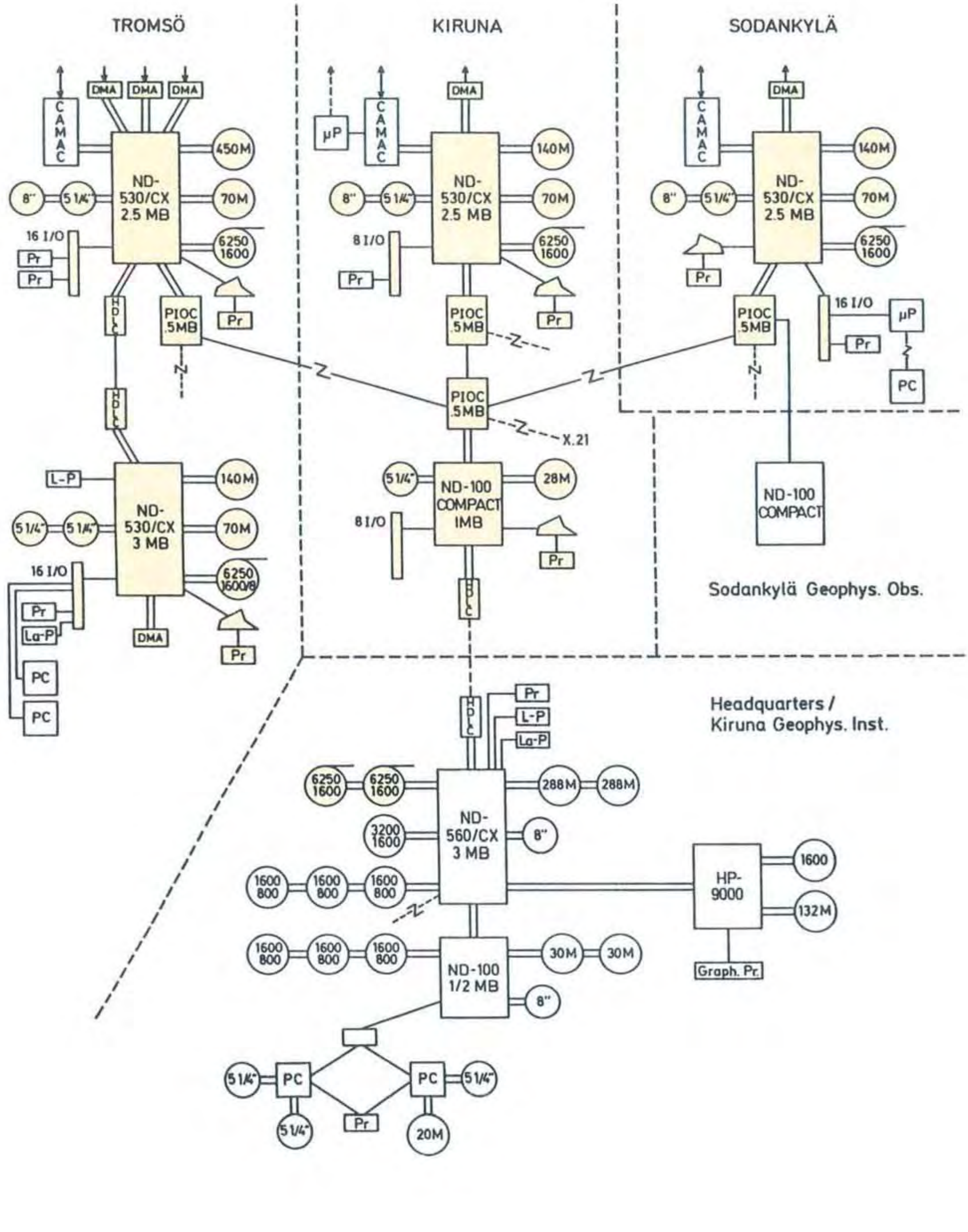



*Fig. 4. The schematics of the new EISCAT computer system, which was installed in 1986. The orange colour indicates the new parts of the system acquired from ND Norsk Data.*

up as 1200 km with good time resolution of some minutes.

It is also to be noticed that further calibrations of the phase paths between the transmitter sides and antenna sections as well as between the latter and receiver input ports were performed. Also new pre-amplifiers for the VHF system were developed, which have a very low noise figure, are quite inexpensive and are insensitive to crowbar disturbances. Measures were also undertaken to minimize interference to electronic equipment in the vicinity of the site.

One can now feel that also the VHF radar of EISCAT is getting over its initial difficulties and is gradually developing into a usable system.

### The New Computers

During the year 1986 the exchange of the complete set of computers at the sites in Tromsö, Kiruna and Sodankylä took place. For various reasons it was decided to continue with computers of the ND Norsk Data Company, and it turned out that this arrangement was an optimum since the entire turn-over from the old to the new computers was achieved without serious implications for the routine operations. The new computer configuration, which is outlined in Fig. 4, is based on Norsk Data ND-530 minicomputers with an ND-100 Compact computer as the experiment independent communication centre at the Kiruna site. The second computer in Tromsö is used for the real-time analysis and display of the derived parameters as well as program development and other background applications such as the analysis of earlier recorded data. Additionally, Headquarters acquired two new high-density tape drives.

The essential improvements and advantages of the new system are many, first because the operational reliability is raised since the old computers were crashing more and more frequently. Furthermore, the data recording is via five separate Camac-independent DMA-channels directly to disk with subsequent dump on 6250 bpi tapes. Due to hardware-control independent data channels the time resolution can be made as good as one second. The real-time monitoring possibilities are expanded and can be easily adapted to any experiment and monitoring device, including remote monitoring. The data recording to disk provides the possibility of retrieving and post-integrating data at any time, investigating the recorded data via computer links, transferring the data to other sites, producing additional tape copies with possible separation of data from different sources etc. The new communication system between the computers, although still awaiting some contractor-designed software for the peripheral input/output controller, is fully integrated. Any information can now be retrieved by just specifying its origin, and output devices anywhere in the system can be treated like local periphery. Possibilities of further connections into national and international networks using the X.21 protocol are prepared and will be implemented in the future.

## OPERATIONS

The aforementioned technical review of the EISCAT facilities indicates a gradual system evolution which took place alongside the regular maintenance, service and the routine operation.

In 1986 a total of 2011 hours of real data recording was performed with the UHF system. This is summarized in Fig. 5. A total of 1001 hours of Special Programme operation was carried out and the hours per associate (Finland, France, Germany, Norway, Sweden and United Kingdom as well as for EISCAT staff including the special chirp synthesizer experiment) are depicted by the solid line columns in Fig. 5. The hatched part of the columns of the associate countries indicate the hours used in a pool to support the EISCAT—VIKING cooperation. The hatched part of EISCAT indicates 15 hours used by Tor Hagfors in the chirp experiments. The column MS indicates 354 hours of maintenance, service and test runs of the UHF transmitter. The accumulated special programme time is for Finland 192 hours (5.4 %), France 876 hours (24.6 %), Germany 656 hours (18.4 %), Sweden 349 hours (9.8 %), United Kingdom 1099 hours (30.8 %) and EISCAT staff 157 hours.

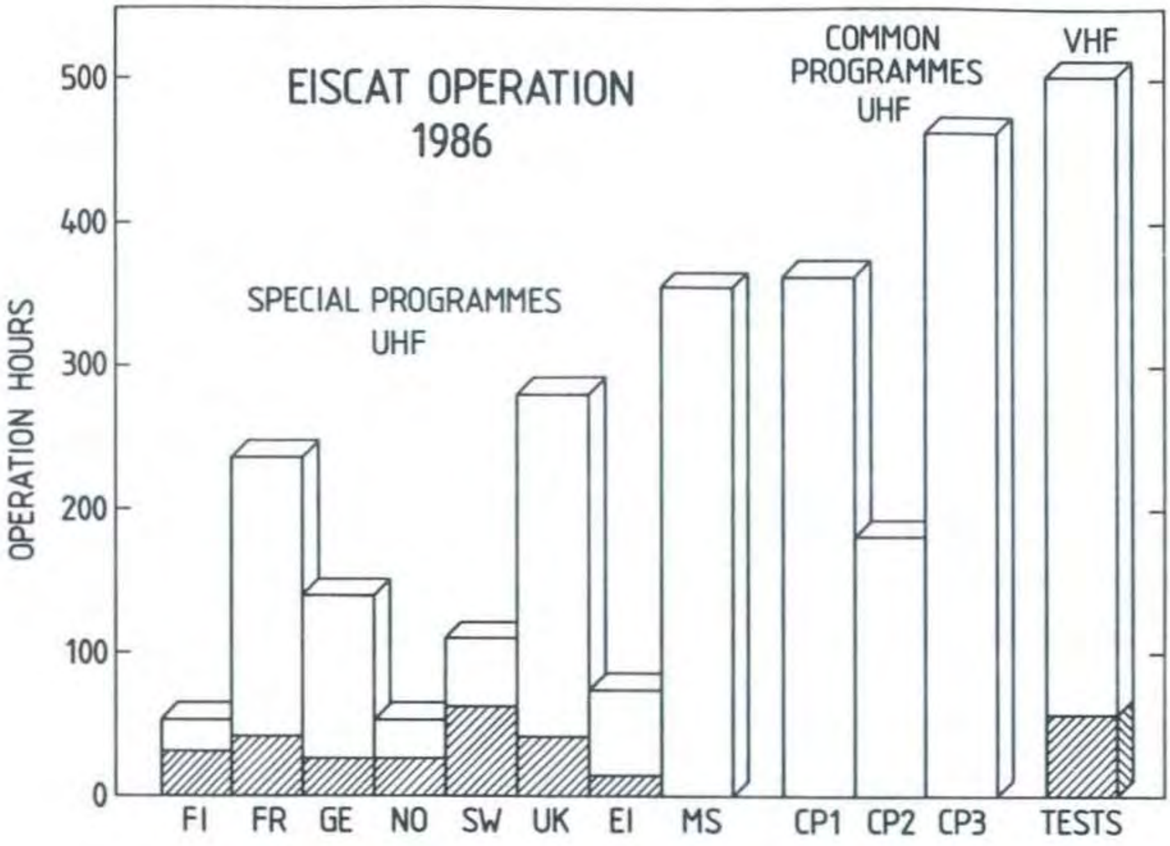



*Fig. 5. Histogram of hours of operation of the UHF and the VHF-radar system. The solid line columns indicate the operation hours, and the dashed and dotted lines the accumulated percentage values as defined in the text. The hatched parts symbolize VIKING campaign operations or digital chirp experiments (EI) with the UHF-system, respectively.*

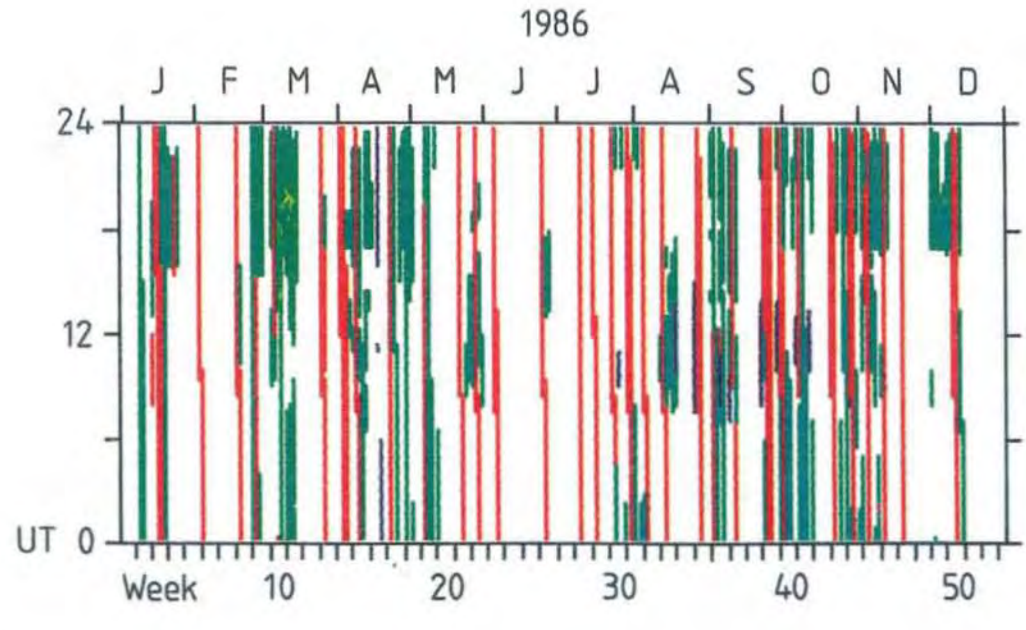



*Fig. 6. Seasonal and diurnal distribution of the operating periods of EISCAT in the year 1986. The colours indicate Common Programmes (red) and Special Programmes (green) with the UHF radar, and test experiments (blue) with the VHF radar.*

A total of 1010 hours of Common Programme operation took place in 1986, which corresponds almost exactly to the 50 % of experimental operation assigned for this purpose. One uninterrupted five day experiment took place in January 1986, and three other common programme runs lasted for three days. Such long experiments are technically possible and turned out to be successful, although demands on personnel become quite stretched during these extended routine operations. Ten common programme runs, most of them CP3, were associated with Incoherent Scatter Coordinated World Days, and the total of World Day operations of EISCAT was 383 hours, i.e. 38 % of the common programmes. All common programme schemes were changed in 1986 to the new versions CP-1-H, CP-2-D and CP-3-E, which are based on the GEN-algorithm. The ratio of operation hours of the three common programmes CP1/CP2/CP3 matches about the prescribed percentage of 40/20/40 %. The actual operating hours per common programme as well as the corresponding percentage for 1986 is given in Fig. 5.

The right-hand column of Fig. 5 shows the operating hours of the VHF system, resulting mainly from 507 beam hours of the Valvo-klystron. Most of this time was only used to age and test the performance of this klystron, whereas 58 hours were used to test real experiments and record data (indicated by the hatched part of the column). The dotted line in the VHF column shows that about 17.5 % of the total operation time of the UHF/VHF radar system of 2872 hours was used for VHF tests and operation.

In addition to the routine operation a total of 12.5 weeks, and usually one day per week, were utilized for maintenance and service. This added up to about 560 hours of regular working time. In summary it means that the EISCAT system was in use for experiments, maintenance or tests over one third of all hours in the year, which can be regarded as a highly efficient operation for an incoherent scatter radar facility.

The overall annual and diurnal coverage of operations is shown in the colour plot of Fig. 6. It again indicates maxima of Special Programme operations in the geophysically most interesting time period before midnight, and minima in the early morning hours, whereas the Common Programme operations cover all times of the day approximately uniformly. The minimum of operation in March was due to a transmitter break-down which resulted from an unpredicted powerline cutoff, the minimum in June was due to the antenna repair in Tromsö and the minimum in December due to the Christmas holidays. The operation peak in autumn reflects the extensive experiments in collaboration with the VIKING satellite.

In the last year 17 campaigns were carried out by the associate countries and 7 campaigns by the VIKING cooperation, resulting in a total of 24 campaigns. The duration of three of these was under 14 hours whilst one was over 100 hours. Some of the campaigns involved cooperation with other instruments: A Swedish campaign was carried out in cooperation with the rocket CENTAUR II to study ion conics and beams. Several United Kingdom experiments took place in cooperation with satellites, e.g. ISEE and AMPTE, in attempts to detect flux transfer events. A German campaign was coordinated with the PROMIS project. Other German campaigns were performed in cooperation with the Heating facility. Another Swedish campaign was carried out in support of AURELD-VIP rockets, and a United Kingdom - German experiment was coordinated with simultaneous experiments at other incoherent scatter radars.

In the year 1986 more than 60 visiting scientists were registered at the sites, and an increasing tendency for cooperation between scientists in the associate countries and EISCAT staff scientists was noted. In August 1986 a Nordic Summer School on Incoherent Scatter was organized by the University of Tromsö. About 30 students and 30 lecturers participated, and the EISCAT instruments at the Tromsö site were utilized to give practical instruction in the design and conduction of incoherent scatter radar experiments.

The regular development in the use of the EISCAT facilities in performing experiments can be recognized in Fig. 7, where the total hours per year used for data recording in Common Programmes and in Special Programmes is displayed. It indicates that after the first three years of system improvements, the operation has about stabilized since 1984 at an annual total of about 1000 hours each for Common and for Special Programmes. In total somewhat more than 8000 hours of data have been acquired since 1981. These are stored on almost 8500 data tapes at Headquarters, consisting of the original raw and analysed data tapes from all three sites and the corresponding back-up tapes. In the year 1986 a total of 821 original raw data tapes were acquired, and 1211 tape copies were made. Since June 1986 all the tape handling of EISCAT data has been done via Headquarters instead of using a contractor. Experience shows that this newly established procedure is considerably advantageous as compared to the earlier procedure.

Common Programme data are analysed by EISCAT and this is now done by on-line processing at the sites in combination with the experiment operation. The analysed data are collected at Headquarters, where they are quality controlled, displayed on hardcopies (see Fig. 8), copied on tape for distribution to the associate countries as well as archived. The World Day Common Programme data are also dispatched to the Incoherent-Scatter Radar Data Base at the National Center for Atmospheric Research in Boulder, USA. The purpose of this data base is to make these World Day data from all the incoherent scatter radars, namely Arecibo, EISCAT, Jicamarca, Millstone Hill, Sondrestromfjord/Chatanika and St. Santin, readily accessible for scientific research by the worldwide scientific community.

The analysis of all Common Programme data back to the middle of 1984 is now finished at Headquarters. It is interesting to note that many scientists are frequently using this extending and continuous set of geophysical data for performing case studies and statistical evaluations as well as for inclusion into atmospheric models.

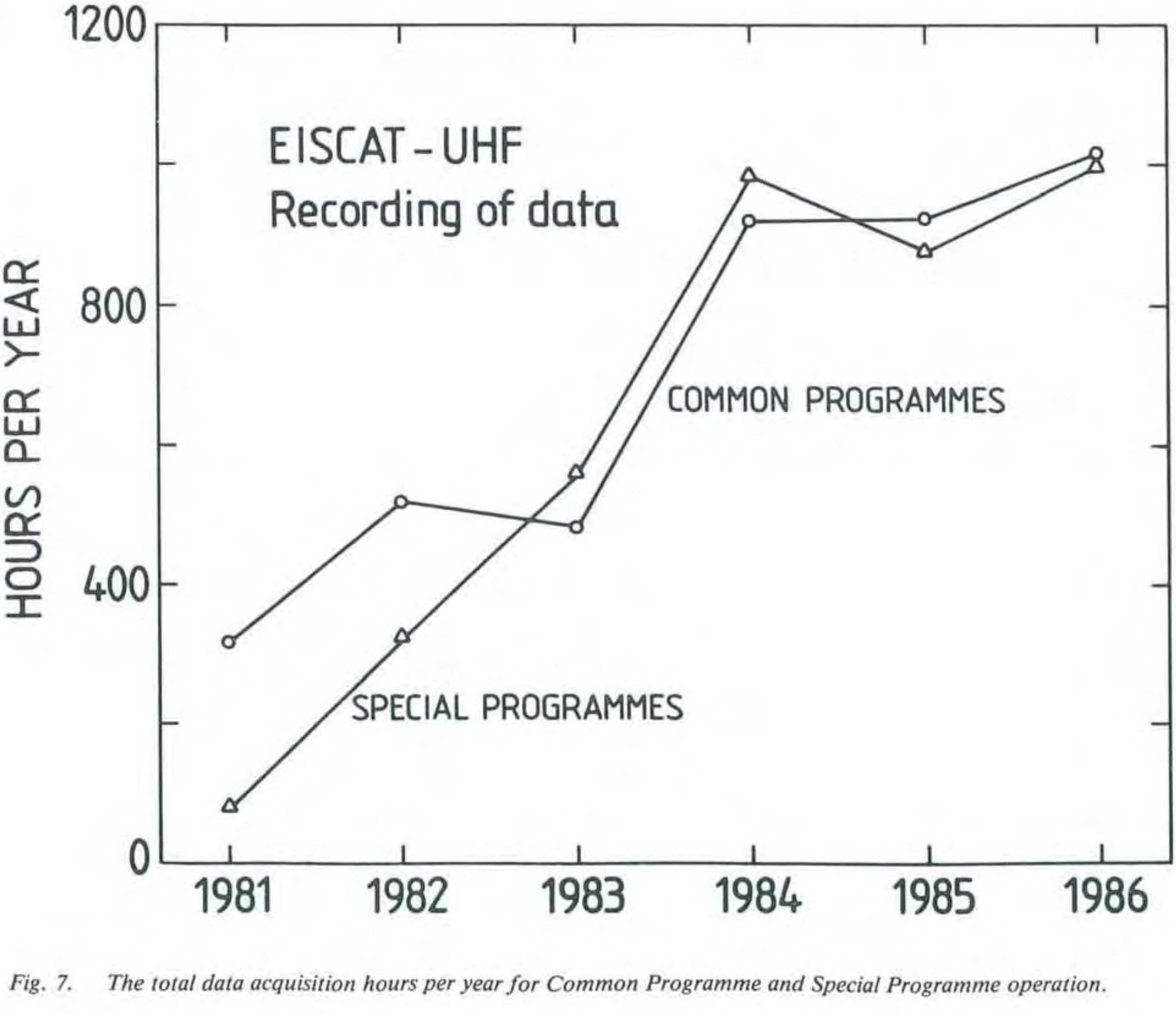



*Fig. 7. The total data acquisition hours per year for Common Programme and Special Programme operation.*

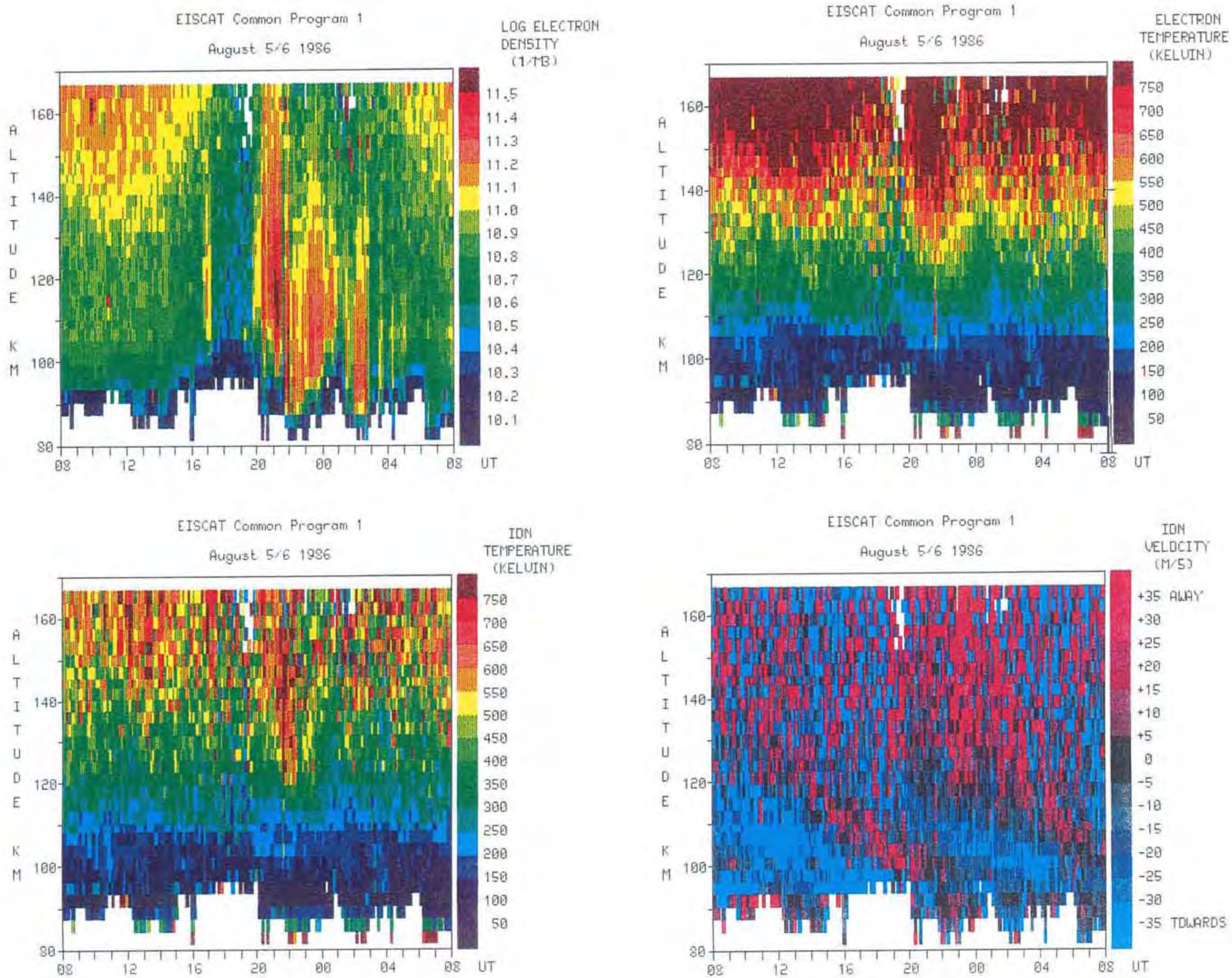



*Fig. 8.* For quality control and scrutinizing the analysed data to search for interesting geophysical events, colour plots are very useful, such as these prepared at Headquarters for the Common Programme results. These plots show the electron density, electron temperature and ion temperature and the field-aligned ion velocity, and complement the corresponding plot presented on the front cover of this Annual Report.

The steady employment of the EISCAT facility in scientific experiment operation is quite obvious from Fig. 7. It is noteworthy that in the first years the trend in publishing results from these experiments, which is depicted in the publication summary of Fig. 9, was quite similar to the trend in the increasing number of operation hours. The publication of 25 papers from the Second International EISCAT Workshop in the Journal of Atmospheric and Terrestrial Physics in 1986 (Volume 48, pages 765—1035) has expectedly increased the number of papers. The complete list of the publications adding up to 38, which refer to research done with EISCAT and which appeared in 1986 in refereed journals, is given on pages 42—43 of this Annual Report.

The increase in the number of publications is likely to continue, since already at the end of the year 1986 about 20 other papers were in press or submitted. During the year 1986 more than 100 oral presentations were given by associate or EISCAT staff scientists at meetings, workshops, symposia or conferences. The number of authors of papers, reports etc. (which can be regarded as a good estimate of the number of scientists involved in a direct or indirect manner with EISCAT projects), is more than 135. A considerable number of students in several countries are performing their thesis work by using EISCAT data and many multinational collaborations between institutions in EISCAT associate countries and abroad have been established and are being actively maintained.

During the past years EISCAT has participated in many campaign-mode operations of other radar, satellite, rocket and balloon experiments. Some of these were: Scandinavian Twin Auroral Radar Experiments (STARE), Sweden and Britain Radar Experiment (SABRE), the French HF-Doppler radar studies of field-aligned irregularities (EDIA), the Polar Region and Outer Magnetosphere International Study (PROMIS), the project SUNDIAL to study ionospheric processes and their role in the sun-earth system, the campaign Winter in Northern Europe of the Middle Atmosphere Program (MAP/WINE), Coordinated EISCAT - Balloon Experiments (CEBO), Coordinated Auroral Experiments using Scatter and Rocket investigations (CAESAR), CENTAUR and AURELD-VIP rocket campaigns, EISCAT - Heating and

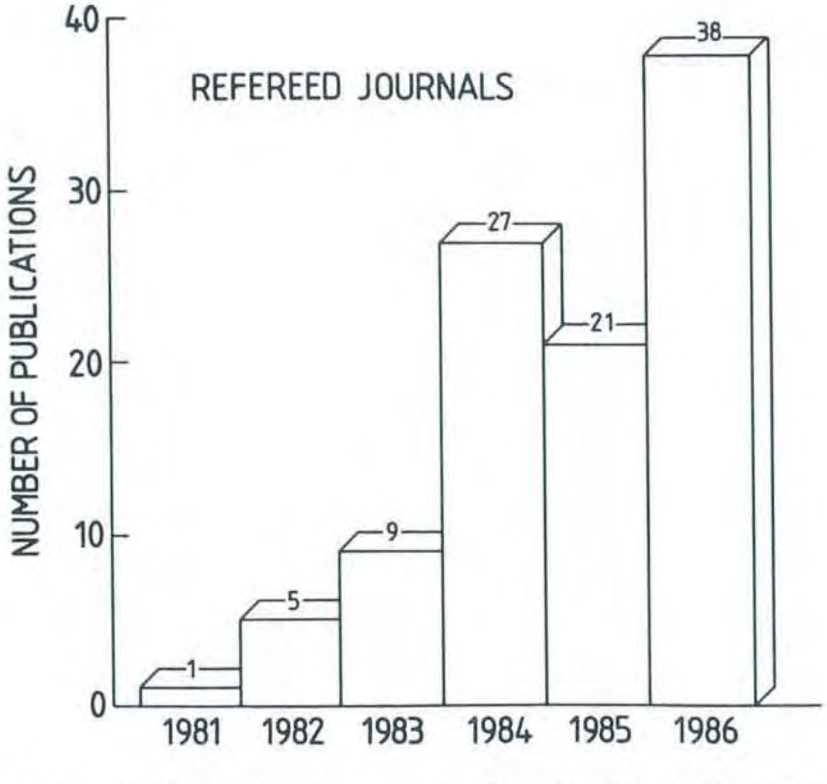



*Fig. 9. Number of publications with scientific results achieved with EISCAT.*

Partial-Reflection Radar (PRE) cooperation as well as coordinated experiments with many satellites such as ARCAD 3, GEOS 2, NNSS, EXOS-C, HILAT, AMPTE/IRM, Dynamic Explorer and VIKING. The data analyses of these programs are continuing, several results have been achieved in 1986 and more are to be expected.

Together with the other incoherent scatter radars and groundbased instruments, EISCAT has participated in quite a few international programmes. The major ones are: GISMOS, the Global Incoherent Scatter Measurements of Substorms, which is a continuation of the earlier MITHRAS to study globally-simultaneous and local-time effects in high latitude ionospheric/thermospheric processes. By means of GTMS, The Global Thermosphere Mapping Study, a global view particularly on neutral dynamical processes in the thermosphere has been obtained. The WAGS project, namely the World Acoustic-Gravity Wave Study, is directed at the investigations of the sources and propagation characteristics of neutral wave motions in the atmosphere. There are other international programs being established, such as the World Ionosphere Thermosphere Study (WITS), the Global Ionosphere-Thermosphere Coupling and Dynamics program (GITCAD), and the Lower Thermosphere Coupling Study (LTCS), and EISCAT is well prepared to participate in these programs.

During its fall meeting in 1986 the Scientific Advisory Committee of EISCAT evaluated the scientific merits of EISCAT. It was stated that many new discoveries have already been made with EISCAT, the number of good publications is steadily increasing and EISCAT has developed unique instrumentation and experimental schemes which allowed and will continue to support high standard scientific research.

In the pages which follow some major scientific achievements, which were compiled from contributions received from scientists in the EISCAT associate countries and from EISCAT staff, are summarized. This compilation was not selected and screened in a particular reviewing procedure, but it should rather emphasize the broad field of scientific research done with EISCAT. Unless specifically mentioned, all the results shown were achieved with the UHF-radar. Reference is made to published papers and reports (see lists on pages 42—43) by inclusion of the first author's name and the entry of the year 1986, as well as to papers to be published or to ongoing work, by inclusion of the names of the scientists involved and titles of corresponding papers to be published.

## Development of New Measurement Methods

In an advanced statistical theory of incoherent scatter radar measurements the relation of the measured correlation function to the ionospheric plasma cross section function was studied in some detail, and a general formalism was derived to estimate the measurement accuracy. Using a statistical inversion theory it was also possible to infer multi-pulse zero lag estimates which significantly improves the power profile measurements. Also a new method of radar pulse coding was developed which provides significantly better correlation function estimates than can be obtained by the frequency commutated multi-pulse measurements which are presently used. This scheme is called the alternating code. Fig. 10 shows the range ambiguity functions for the second lag of such a code sequence of 16 single phase coded pulses, indicated by the plus/minus signs on the right hand side. (Lehtinen, 1986)

Another algorithm was developed and successfully implemented in UHF and VHF experiments, which uses a pulse-to-pulse approach with Barker code pattern to study the altitude region between 70 and 114 km with 1.05 km resolution. It belongs to the GEN-algorithm family. (T. Turunen, 1986)

The frequency shift of the natural plasma-line relative to the ion-line depends on the electron density and temperature. Therefore, the use of plasma-line information together with the ion-line is a possible way to improve the multiparameter fit in the incoherent scatter data analysis. The problem of distinguishing between variations in ion composition and variations in temperature may be solved this way. Simultaneous observations of ion- and plasma-lines in the F-region have been made to test this idea. So far the results seem promising and will be pursued.

In a rocket experiment from Andoya Rocket Range in November 1985 EISCAT was used

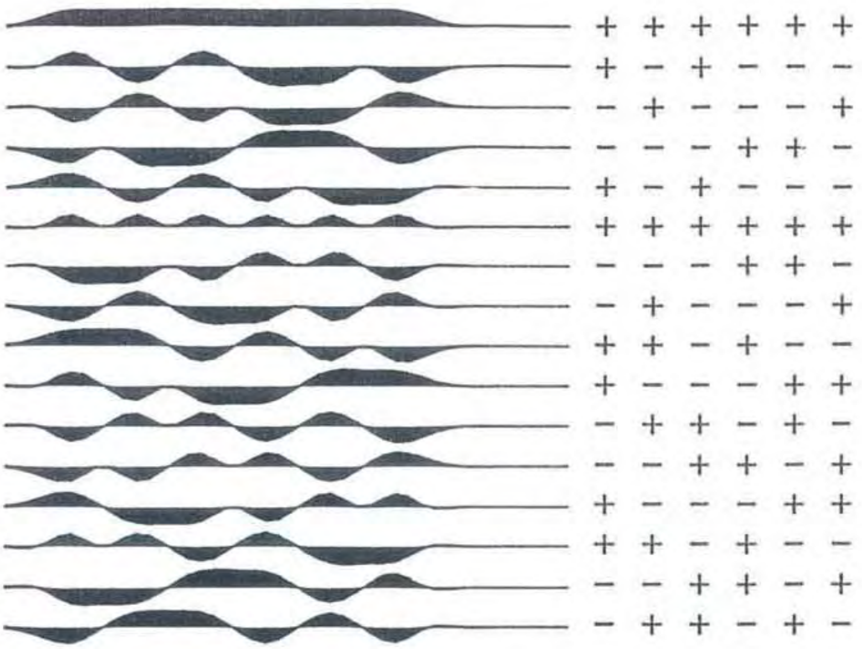



*Fig. 10. Range ambiquity function for lag 2, and the phase coding scheme of the new alternating code.*

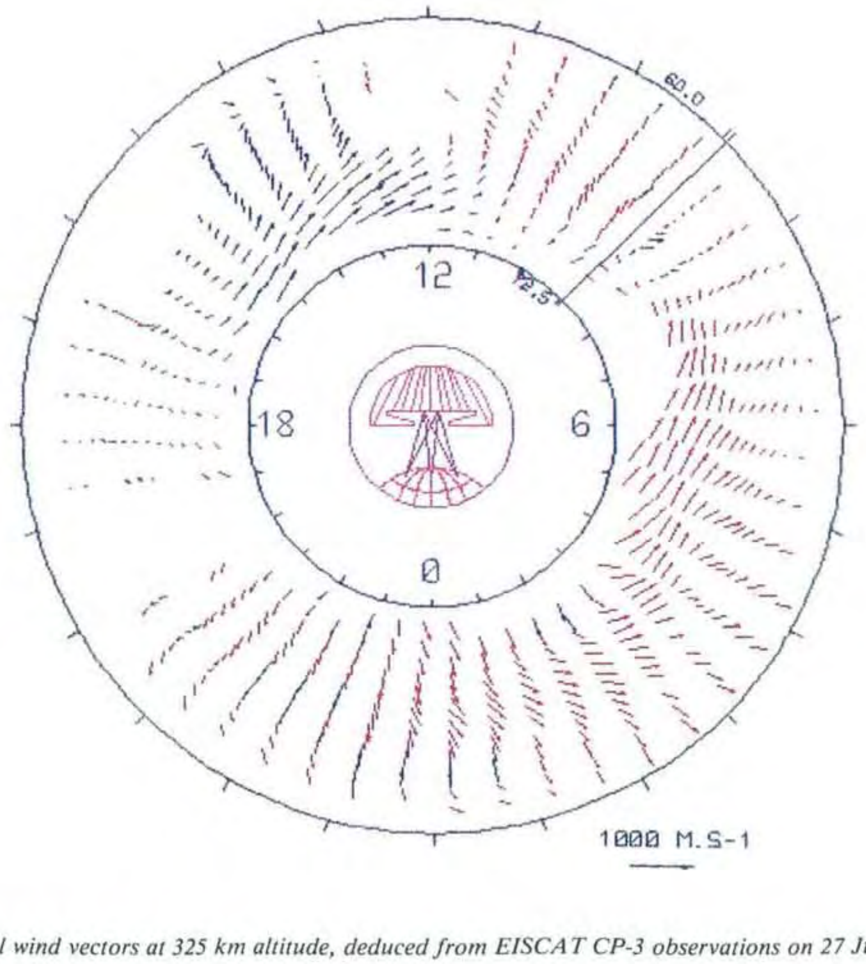



*Fig. 11. Neutral wind vectors at 325 km altitude, deduced from EISCAT CP-3 observations on 27 June 1984.*

to measure the plasma properties at several points along the trajectory. Apart from contributing valuable information to the experiment, it was demonstrated that EISCAT can be used to measure close to a rocket payload. The radar cross section of the payload appeared to be several orders of magnitude less than the geometric cross section, and useful data were obtained except when the payloads entered the main lobe of the UHF-antenna. (Hansen and Maehlum)

## Detection of Plasma Lines with the Chirp Technique

During 1986 the chirp pulse compression technique was introduced at EISCAT. This technique, which for soft targets was first suggested by T. Hagfors, applies a linear sweeping of the radar transmitter oscillator at exactly the same rate as the change of the plasma frequency with range and a corresponding de-chirping of the radar receiver oscillator. In this way one effectively "concentrates" the plasma line energy to a narrow range of frequencies in the plasma line channel, thus increasing the effective signal to noise ratio by a substantial amount.

The first EISCAT experiment of this kind was carried out in May 1986. The chirp technique was tested on the natural plasma line and was found to work excellently (see Fig. 2). Even with a relatively poor frequency resolution in the raw data it was still possible to detect frequency shifts due to electron drifts. Drift components along the vertical and along the magnetic field line were seen. With the data analysis still in progress, these observations have so far been tentatively attributed to field aligned current densities of up to 20 $\mu A/m^2$. It is emphasized that this new technique for diagnostics of the auroral ionosphere may prove to be very useful in the future. (Hagfors, Birkmayer, Thidé, Nordling, Kofman, LaHoz et al.)

## The Neutral Atmosphere

### Mean Winds and Temperatures

A method has been developed to infer neutral temperature and winds in the thermosphere from EISCAT CP-3 observations. As a first step of this method the neutral temperature versus latitude and time is derived by solving the ion energy equation, in which frictional effects between ions and neutrals are neglected However, periods of high convection velocities are not taken into account for the neutral temperature estimates. One gets, therefore, a temperature model which best fits the data outside those regions and periods where frictional heating is suspected to be important. In a second step, this initial temperature model is used to solve the ion energy equation during the periods of large frictional heating, which then also yields the frictional heating term. Using the central position of the CP-3 scan in order to deduce the meridional neutral wind from the field-aligned ion velocities, the zonal component of neutral winds can then be estimated. An example of neutral wind velocities derived by this method is shown in Fig. 11. (Alcaydé and Fontanari, 1986)

Measurements performed by EISCAT in the low thermosphere have been compared with models. The observed neutral temperature in winter at 100 km has been found to be lower by about 15 Kelvin than predicted by the MSIS model and closer to the temperature predicted by the Jacchia 71 model. This feature is well illustrated in Figure 12. It was also shown that the neutral mass, inferred from the temperature and scale height, is about 26—28 a.m.u.. This value is also lower than the corresponding value of the MSIS model. (Kofman et al., 1986)

### Tides

Most EISCAT experiments are primarily designed for observations in the auroral zone during disturbed conditions, but other experiments use EISCAT to study the undisturbed ionosphere and atmosphere. In 1985 there were five days when Common Programme CP-1 was run under quiet conditions and tides in the neutral atmosphere could be clearly observed at E-region altitudes via the ion velocity. The colour plots of Fig. 13 as well as the front cover of this Annual Report show striking examples of field-aligned ion velocities due to periodic meridional wind variations. The dominant periodicity was due to the semidiurnal tide, and by determining the variation of phase with height the (2,4) tidal mode could be identified (Virdi et al., 1986). It was also possible from CP-1 analyses to deduce tidal variations of neutral temperatures and densities in the lower thermosphere. (Kirkwood, 1986)

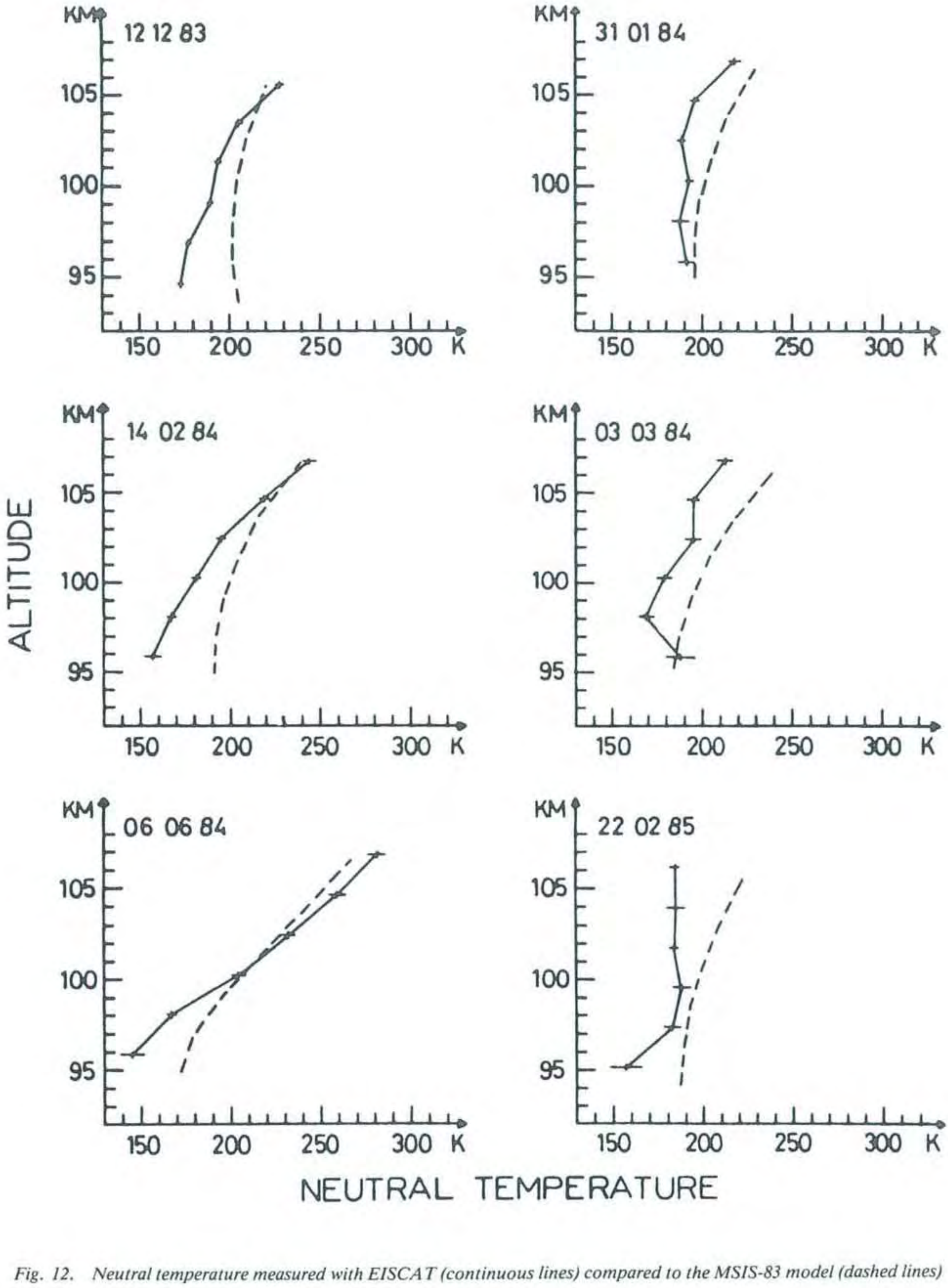



*Fig. 12. Neutral temperature measured with EISCAT (continuous lines) compared to the MSIS-83 model (dashed lines)*

Tidal observations in the lower thermosphere (E-region altitudes) were extended to the mesosphere during the MAP/WINE operations. During this campaign EISCAT UHF radar measurements were combined with measurements using meteorological rockets from the Andoya Rocket Range. The radar yielded horizontal wind profiles between about 80 km and 105 km (see Fig. 14) and the rockets between 60 km and 90 km. It was also found that the (2,4) mode of the semidiurnal tide was the dominating neutral wind contribution between 80 km and 105 km, but the tidal amplitudes got very weak ($<5$ m/s) below 80 km. (Röttger and Meyer: Tidal wind observations with incoherent scatter radar and meteorological rockets during MAP/WINE)

**Atmospheric Gravity Waves**

In October 1985 scientists from the United Kingdom and Germany organized a major campaign as part of the World Acoustic Gravity Wave Study (WAGS). EISCAT ran uninterrupted for a total of 108 hours from 13 to 18 October 1985. With the acquired data the sources which can generate gravity waves in the auroral region were investigated. These are the Joule and particle heating processes as well as the Lorentz force (Crowley and Williams: Observations of the source and propagation of atmospheric gravity waves). With the help of a neutral density model (CIRA 72) the corresponding heating rates and forces were calculated from the EISCAT data. Joule heating is usually most effective at altitudes between 120 and 130 km, whereas particle heating and the Lorentz force show their main contributions below 110 km altitude. All three quantities exhibit a strong temporal variation due to the fluctuation in electron density, and in the case of Joule heating and the Lorentz force also due to electric field fluctuations. The temporal variability of the gravity wave source parameters can be most conveniently studied using height-integrated values of the three quantities mentioned above. Figure 15 shows an example in the afternoon of one of the WAGS days. The source parameters were inserted into a gravity wave simulation model (provided by A.D. Richmond) and produced gravity waves in the thermosphere. (Schlegel, Crowley, McCrea: Gravity wave sources in the high-latitude ionosphere)

Gravity waves propagating over the United Kingdom were monitored during the WAGS campaign by a network of instruments which included five ionosondes, HF-Doppler systems, a meteor radar and a radio telescope. The observations included one day of very quiet auroral conditions, several days of moderate activity and one very disturbed period. The following results have been established:

* Joule heating was usually an order of magnitude greater than heating by precipitating particles. Both Joule heating and Lorentz forcing were effective in generating large-scale atmospheric gravity waves, which could be detected south of the source region in polar latitudes.

* The auroral source often had a marked periodicity, corresponding to intrinsic periodicity in both the bursts of particle precipitation and in the magnetospheric electric field. Fig. 16 shows the power spectrum of the variations in electron density, electron temperature and ion velocity over a 12-hour period on 15—16 October. For all three parameters and over a large height range there is a strong peak for periods of about 60 minutes.

* The chain of ionosondes saw strong waves propagating southward on the disturbed days but not on the quiet day. These waves had periods in the range 30—70 minutes.

* The HF-Doppler system observed strong wave activity in the evening on all disturbed days, with spectral peaks in the range 30—70 minutes, but wave activity was far weaker on the quiet day. Cross-spectral analysis of the data showed that the longer period waves were travelling southwards with velocities of 300 m/s or more. This is a signature of large-scale gravity waves.

* On both 13 and 18 October the time of onset of enhanced Joule heating and Lorentz forcing, and the intrinsic periodicity observed in the auroral region agreed with the time of arrival and periodicity of the waves observed by ionosondes and HF-Doppler. On both occasions there was consequently a strong evidence to relate the auroral source with the wave observed at mid-latitudes. (Williams et al.: The generation and propagation of atmospheric gravity waves observed during the World Acoustic Gravity Wave Study)

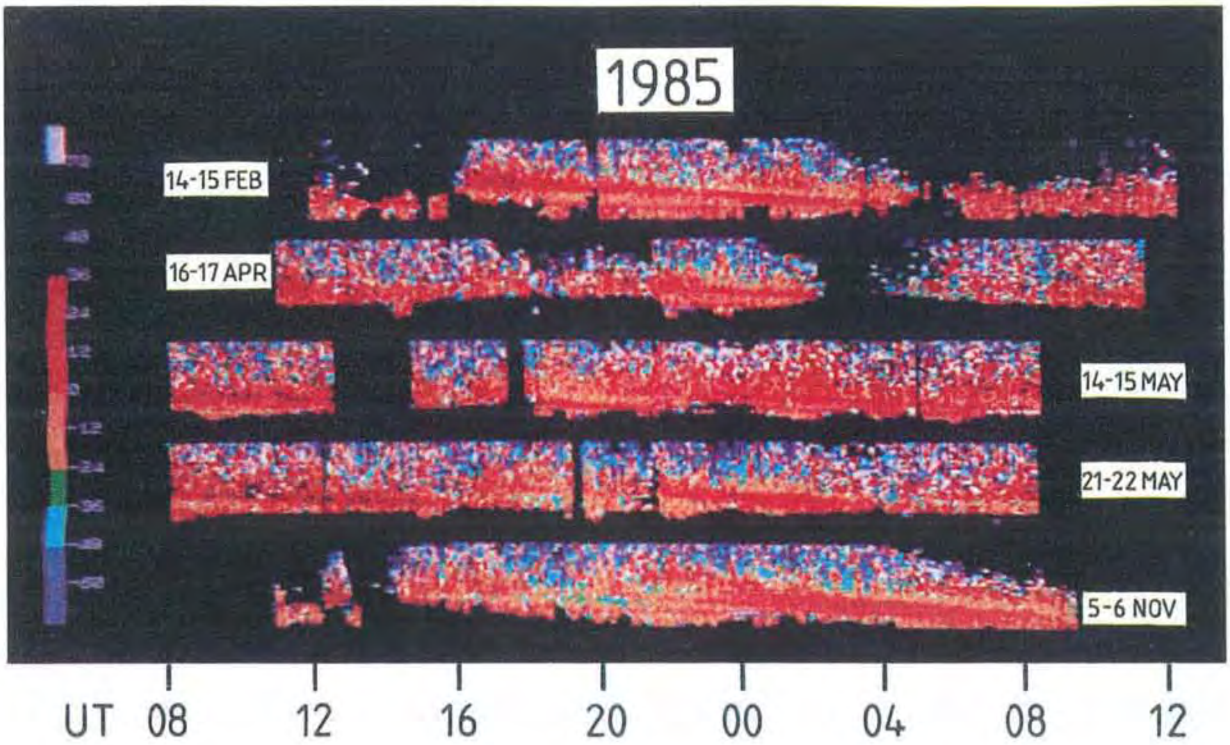



*Fig. 13. Colour contours of the field-aligned ion velocity plotted against altitude (89—168 km) and time on five days in 1985, which clearly show semi-diurnal tidal variations.*

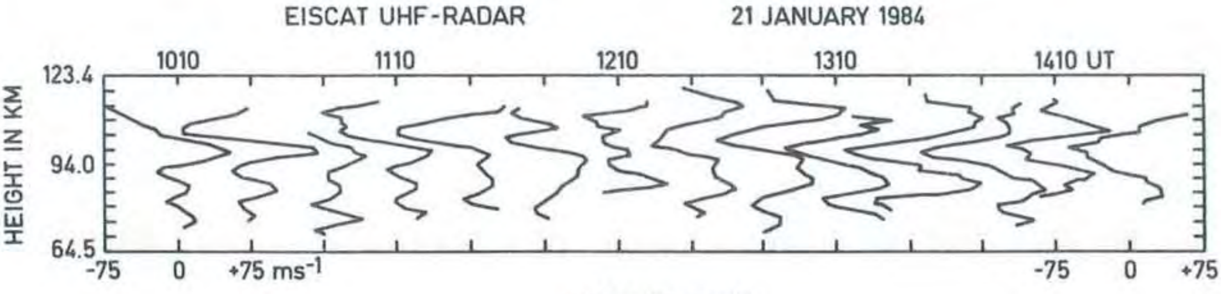
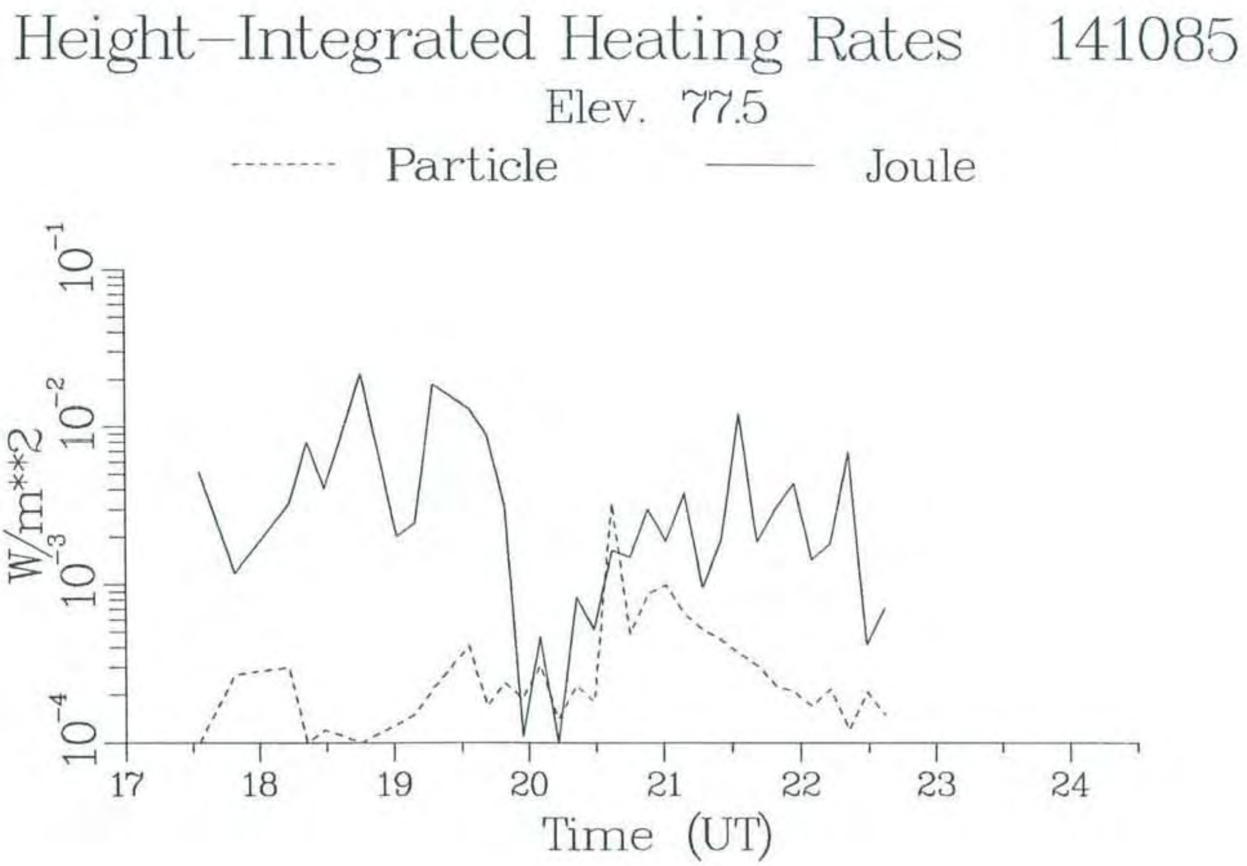



*Fig. 14. Zonal wind velocity indicating semi-diurnal tidal variations.*



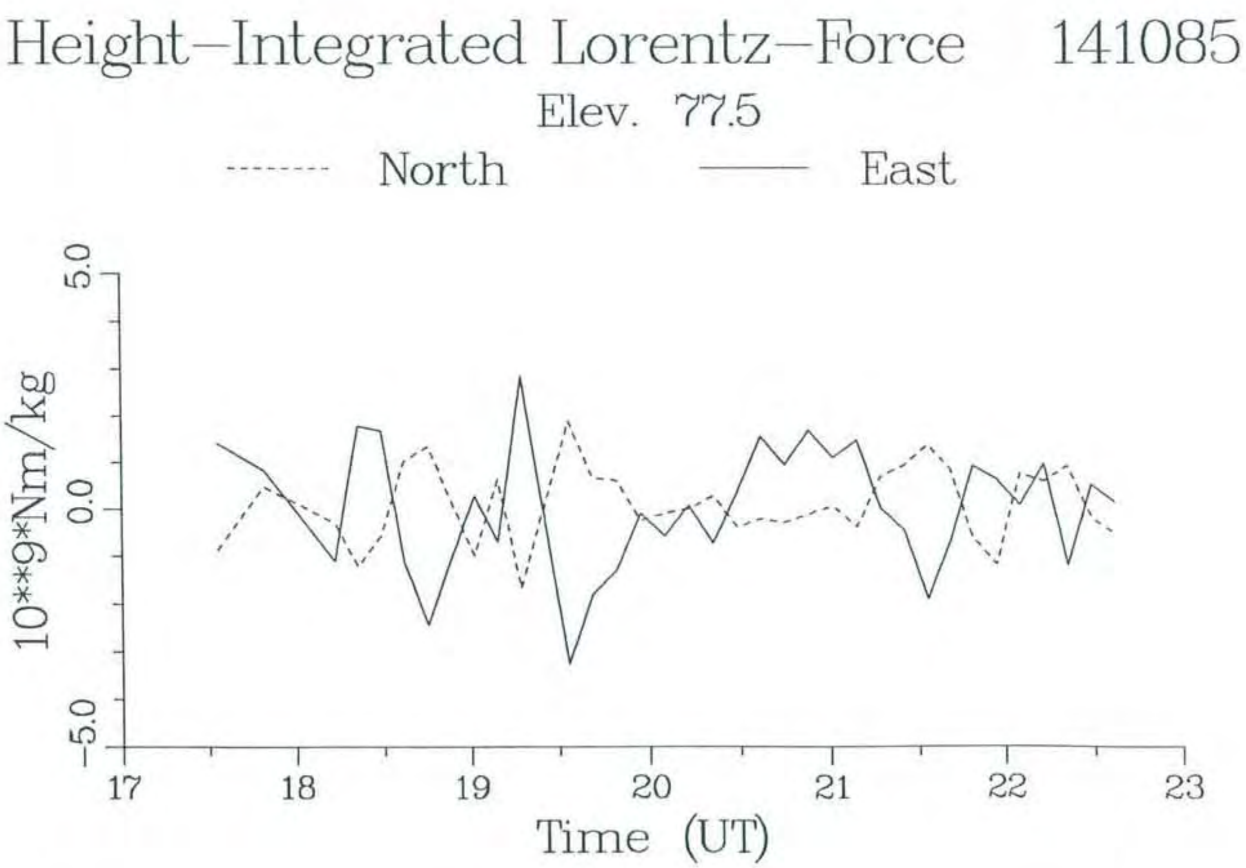




*Fig. 15. Temporal variation of gravity wave source parameters, namely heating rates and Lorentz force.*

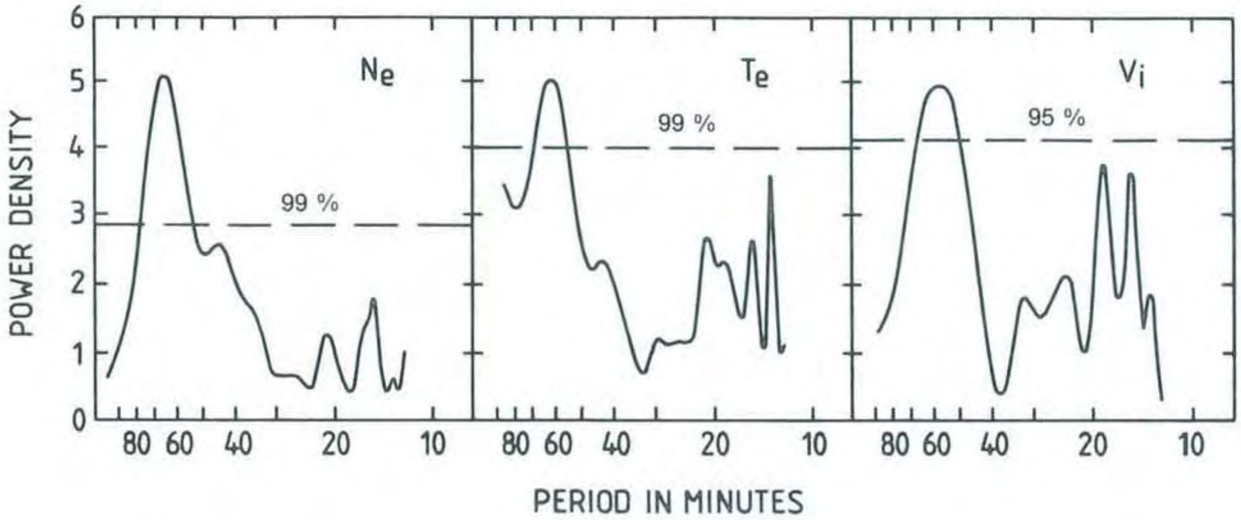



*Fig. 16. Spectra of temporal variations of electron density $N_e$, electron temperature $T_e$ and ion velocity $V_i$ at an altitude of 266 km between 16 UT on 15 October and 04 UT on 16 October 1985. The percentage values indicate the significance limits.*

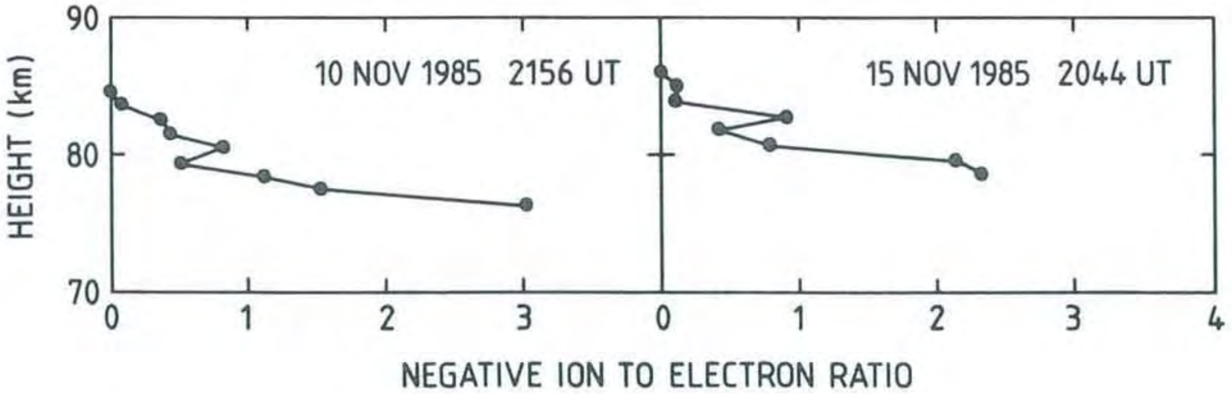



*Fig. 17. Profiles of negative ion to electron density ratio for 10 November 1985. The errors are of the order of ± 0.1 at 85 km, and ± 1.0 at 75 km.*

## D-region Studies

Energetic particles which penetrate below 100 km cause substantial ionization in the D-region. This can be used to study the particle precipitation itself or to use it as a "tracer" to study the mesosphere.

A pulsation event observed by magnetometers and riometers was studied in detail by EISCAT. Rapid fluctuations in electron density occurred at all ionospheric heights, and were interpreted as evidence for a relative hardening and softening of particle precipitation accompanied by very large changes in the flux of energetic electrons. (Devlin et al.)

D-region spectral measurements using pulse-to-pulse correlation resulted in good spectra down to 77 km. The measurements confirmed that the mesospheric incoherent scatter spectra are Lorentzian in shape, and the spectral width can be related to the ratio of negative ion density to electron density. A persistent feature of the profile of this ratio is its increase with decreasing altitude (see Fig. 17), (Hall et al.: Negative ion to electron number density ratios from EISCAT mesospheric spectra). Incoherent scatter spectra were obtained from the summertime mesosphere in July 1985. The spectral width decreased with decreasing altitude (Fig. 18), as expected from the effect of increasing ion-neutral collision frequency. A striking feature of increased coherence time lasting for 20 minutes in a limited altitude range was interpreted as a localised region of increased positive ion mass. (Collis, Turunen and Turunen: Incoherent Scatter Spectral Measurements of the Summertime High Latitude D-Region)

Short pulse power profile results have been used to study the statistical behaviour of D-region electron densities over a one year period (Kirkwood and Collis: The high latitude lower ionosphere observed by EISCAT), and event studies have shown significant changes in density over short time scales and small horizontal distances. (Collis and Kirkwood: Localised features in the auroral D-region observed by EISCAT)

Electron densities were measured in the ionospheric D-region during the polar cap event of 16 February, 1984, and have been compared with production rates computed from proton fluxes measured on the geosynchronous satellite GOES. Profiles of the effective recombination rate were determined which show a general consistency with previous estimates but differ in details. There is evidence for a progressive change of recombination coefficient as the polar cap absorption event proceeds. (Hargreaves et al.: Observation of the polar cap absorption event of February 1984 by the EISCAT radar)

A sophisticated D-region EISCAT experiment was run on 27 October, 1985. During extremely quiet magnetic conditions the effect of sunset in the altitude range 70—100 km could be monitored. With time integration of only 2.5 minutes the threshold of 500 electrons per cubic centimeter could be located to be between 80 and 90 km during the sunset. This experiment used a basic height resolution of 1.05 km with a 91 µs long 13-bit Barker code. The comparison between the electron density determined with EISCAT and detailed ion-chemical models of the D-region shows a good agreement for solar zenith angles less than 90 degrees, while for zenith angles greater than 90 degrees a difference is seen, which could be due to a change in the ion chemistry. (E. Turunen and T. Turunen: Continuous monitoring of the ionospheric D-region by the EISCAT incoherent scatter radar)

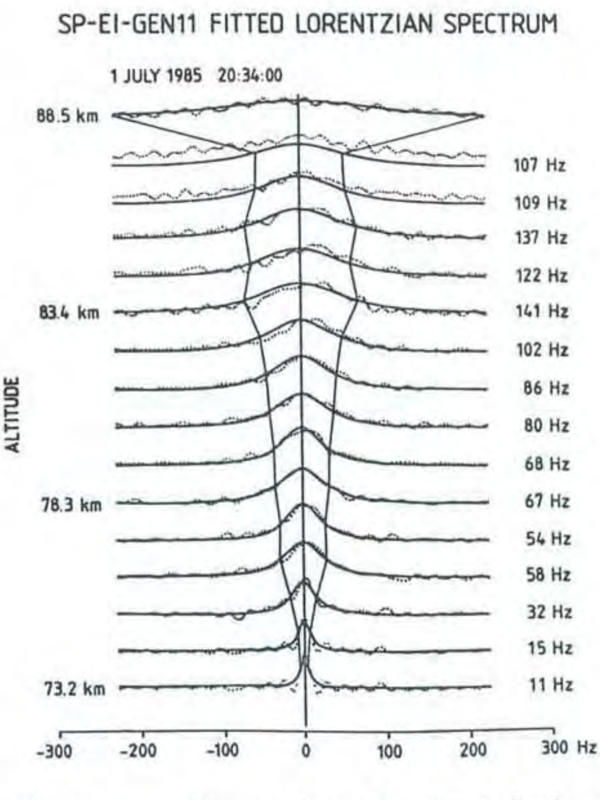



*Fig. 18. Spectra of D-region echoes, indicating a narrowing of the spectrum width between 85 and 87 km.*

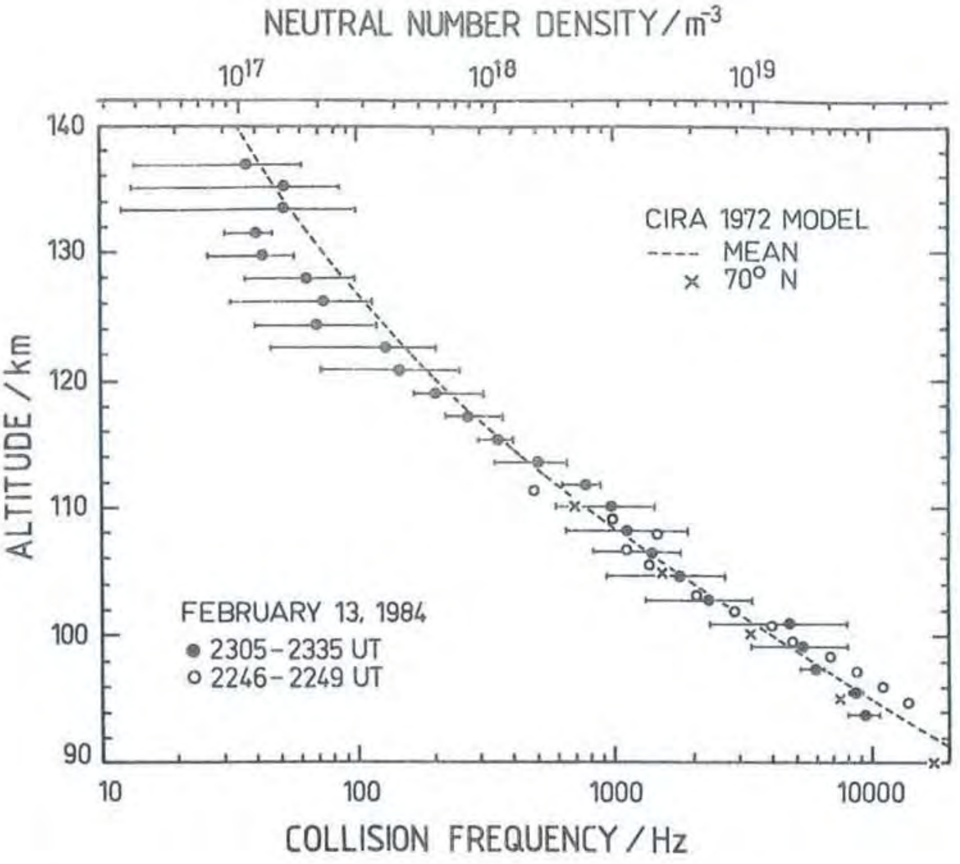



*Fig. 19. Ion neutral collision frequencies deduced from vertical ion speeds and from the shape of the scattered spectrum*

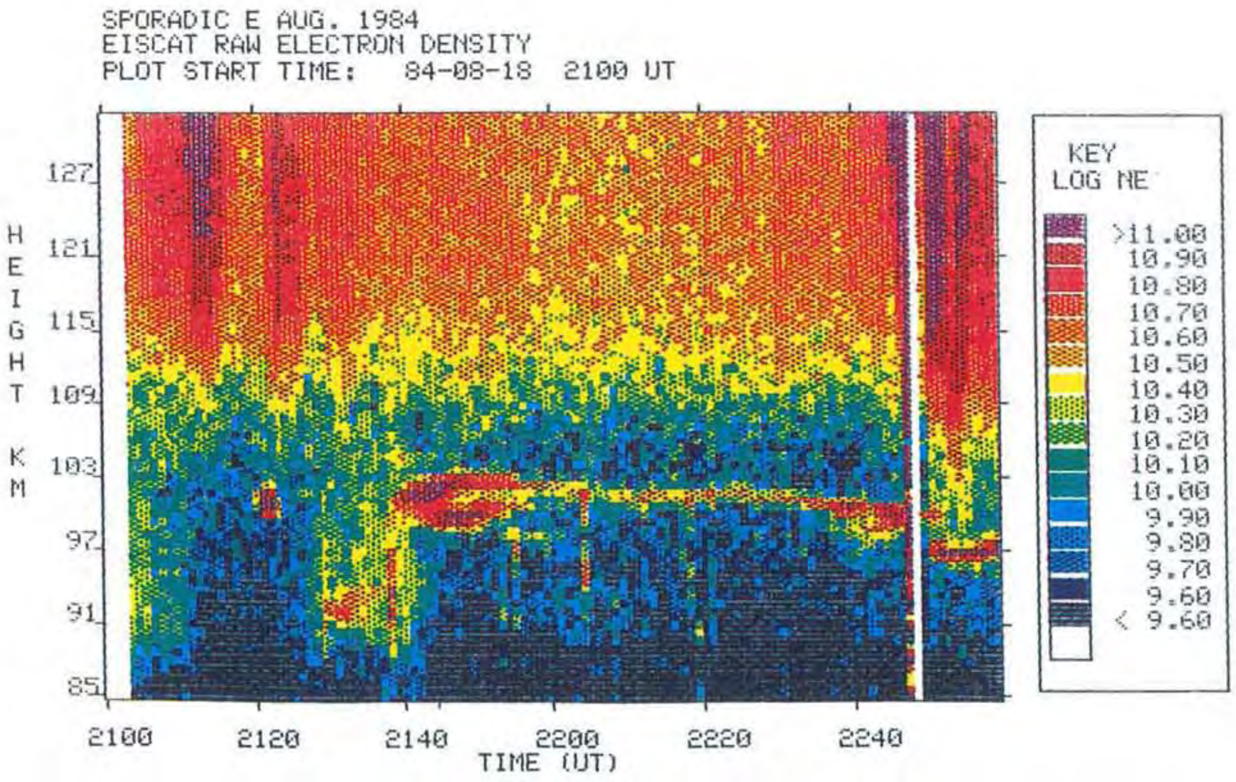



*Fig. 20. Sporadic E-layer observation: The double layer observed between 2140 and 2200 UT probably contains heavy ions in the upper and light ions in the lower part.*

## Ion-Neutral Collisions, Composition and Sporadic E-layers

A new method of measuring the ion-neutral collision frequency using incoherent scatter radar has been developed by which the collision frequency has been determined directly from the vertical ion drift caused by an electric field. A time interval with small neutral wind and strong electric field has been selected for this purpose. The method allows the determination of the collision frequency up to 130 km altitude and the results (shown in Fig. 19) are in a reasonable agreement with those obtained using the conventional method below 110 km altitude. (Nygren et al.: A new method of measuring the ion-neutral collision frequency using incoherent scatter radar)

During the EISCAT balloon campaign CEBO in 1984 600 m-resolution observations of the E-layer above Tromsö were made. The data revealed a multitude of different features of sporadic-E. The event in Figure 20 indicates one of several interesting features which were found: temperature analysis assuming a constant composition with altitude results in a drop of 50 Kelvin in the upper layer but no change in the lower layer. Since a temperature variation like this is assumed to be unrealistic, the result is interpreted as a variation in composition. Knowing that sporadic E-layers contain long-lived metallic ions, it is suggested that the upper layer consisted of an appreciable amount of heavy ions (e.g. Fe) while the lower one was dominated by lighter ions (e.g. Mg). (Björnå, Huuskonen et al.: Determination of ion composition in sporadic E-layers)

A Barker-coded high resolution experiment has been tested during the end phase of an intense sporadic E-layer at an altitude of about 100 km and slightly ascending with time (Fig. 21). Since the layer thickness was 1.5—2 km, it was possible with the height resolution of 300 m to obtain 5—7 independent gates in the layer, which will allow a search for composition changes within this layer. (T. Turunen, Nygren, Jalonen and Huuskonen)

## E-region Irregularities

Strong electric fields, which drive the auroral electrojet and which can be determined by EISCAT when measuring the ion drift in the F-region, also create small-scale irregularities in the E-region, which can be studied by coherent radars (also known as auroral radars).

F-region drifts measured by EISCAT and E-region drifts measured by the Swedish- and British-Radar-Equipment (SABRE) were compared. These comparisons verified that SABRE progressively underestimates the higher drift velocities. New theories of current-driven plasma instabilities in the high-latitude E-region have been developed which indicate that non-linear wave heating effects limit the phase speed of the plasma irregularities to the ion acoustic speed. The comparisons of EISCAT and SABRE velocities are broadly consistent with this theory. (Robinson, 1986)

EISCAT was also used to investigate the E-region volume from which the KRM and ESY auroral radars in Karelia/USSR received coherent echoes. A comparison was made between the electron concentration and electric field strength measured by EISCAT and the strength of the echoes received by the KRM and ESY radars. This indicated that for electric fields stronger than 30 mV/m the level of plasma wave turbulence saturates at a fluctuation level of about 2.5 %. A comparison was also made between the electric field strength and the enhancement of the electron temperature at the altitude of 108 km (Fig. 22). This also proved consistent with the theory of non-linear wave heating. (Williams et al.)

In March 1986 a campaign was performed to do simultaneous EISCAT observations in the volume probed by the CUPRI 46.9 MHz radar in Lycksele. This new Cornell University Portable Radar Interferometer is particularly designed to study echoes from auroral plasma instabilities with high temporal and spatial resolution. Of particular interest are sharp peaked spectra showing high Doppler shifts. These are thought to be connected to ion-acoustic waves travelling in the auroral electrojet at temporarily elevated plasma acoustic velocities, because of similarly elevated electron temperatures. The EISCAT program was specifically modified to allow high-time resolution measurements applying an eightfold 5-pulse multipulse scheme. On several occasions high electron temperatures have been observed with EISCAT at the same time and location where the CUPRI system detected high Doppler shifts. (Farley et al.: Simultaneous VHF coherent radar and EISCAT studies of auroral plasma instabilities)

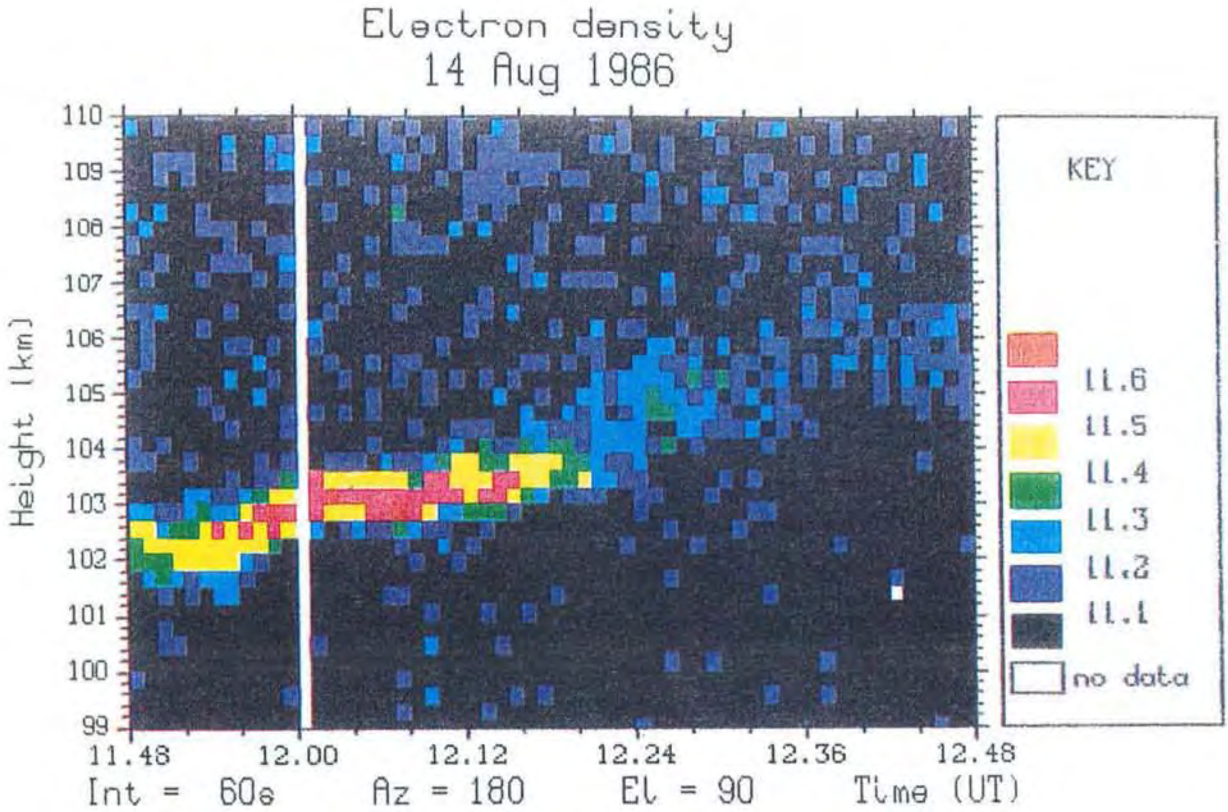



*Fig. 21. A sporadic E-layer observed with a height resolution of 300 m.*

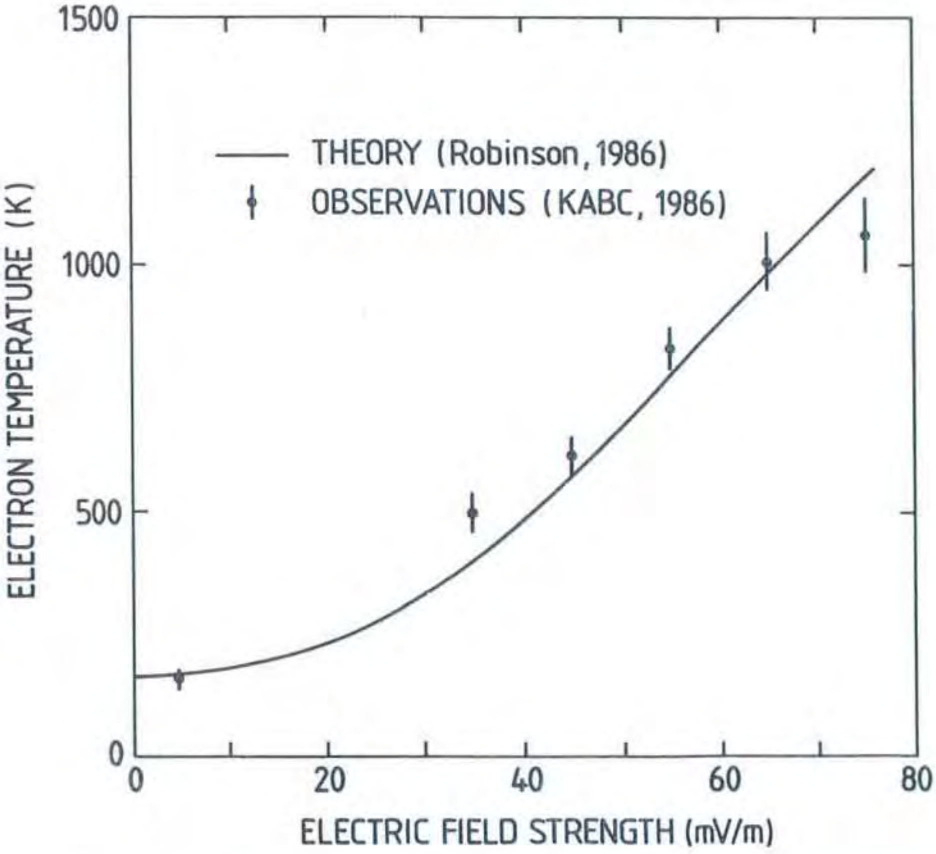



*Fig. 22. The relationship between electron temperature and electric field strength at a height of 112 km, observed on 13 March 1983.*

### Relative Motion of Auroral Arcs and Background Plasma

For the understanding of the structure and physics of auroral arcs it is important to know how the auroral arcs move with respect to the background plasma. A campaign was carried out in October 1983 to compare EISCAT radar measurements of the ion velocity with the motion of arcs. The latter was determined from records taken at Abisko with photographic- and TV-cameras of the Max-Planck-Institut für Extraterrestrische Physik. Useful data were obtained for only one event, when a quiet arc occurred above Abisko before the onset of a substorm (Fig. 23). It was found that both the arc and the F-region plasma moved slowly southward in an oscillatory manner with periods between 3 and 4 minutes. The arc, however, was faster by an average of 24 m/s. The phase of its oscillation preceded that of the plasma by 2 minutes. The tangential velocity of the F-region plasma was directed westward. The results can be interpreted in the framework of oblique Alfvén waves reflected at the ionosphere. The theory provides a relation between the average relative arc motion (24 m/s), the period of the waves (3—4 min) and the thickness of the arc (a few km), which is confirmed by the data. The interpretation is, however, not yet final. (Haerendel, Buchert, La Hoz and Rieger)

### Incoherent Scatter and Magnetometer Observations of Pulsations

Geomagnetic storms are often associated with so-called Ps 6 pulsations of the magnetic field measured on the Earth's surface. The periods are typically 10 to 40 minutes and the pulsations are observed almost exclusively in the morning sector. On 21 April 1985 between 0300—0415 UT during the recovery phase of a geomagnetic substorm, which was one in a series of several strong substorms, an unusually strong Ps 6 pulsation event was recorded by the EISCAT magnetometer cross in northern Scandinavia. Simultaneously, EISCAT measured the E- and F-region plasma parameters, $N_e$, $T_e$, $T_i$, and $V_i$, with a latitudinal scanning program (see Fig. 24). The observed 4 cycles of the pulsations had an amplitude of about 1200 nT and a quasi-period between 15—20 minutes. The integrated conductivities showed amplitudes of 50 and 20 Siemens for the Hall and Pedersen conductivities, respectively, and they had periodicities and phases that were in correspondence with those of the magnetic pulsations. By cross-correlating the measurements from different magnetometer stations, the eastward drift velocities of the pulsation fronts were calculated, yielding values between 100 and 1300 m/s. Both the direction and magnitude of the drift velocity agree roughly with the background ion drift velocities measured by EISCAT. The wave-lengths of the pulsations were estimated to be about 1600 km. (Buchert, Haerendel, Baumjohann, LaHoz and Lühr)

### Ion Heating by Magnetic Pulsations and Joule and Particle Heating Rates

A study of the ion heating due to ULF (ultra-low-frequency) magnetic pulsations of periods as low as 3 min has been performed. Ion temperature fluctuations as measured by EISCAT are well correlated to magnetic ULF PC5 pulsations. A method has been proposed, by which estimates of these ion temperature enhancements from the ion velocity measurements can be obtained. (Lathuillere et al., 1986)

Data from EISCAT have been used to determine Joule and particle heating rates. As CP-3 programs perform scans in the meridian plane of Tromsö, the latitudinal extents of these heating rates have been deduced. They are shown in Fig. 25 for a period of 24 hours on 18—19 January 1984. (Duboin, 1986)

### Electron Energy Spectra and Electrostatic Cyclotron Waves

An auroral precipitation event lasting several hours in the dusk sector on 2 June 1982 has been studied in conjunction with three instruments: EISCAT, the European geostationary satellite GEOS-2, and the French-Soviet polar satellite ARCAD-3. Electron energy spectra between about 1 and 10 keV were computed from EISCAT measurements of E-region electron density profiles by the "Untangle" method. They were in agreement with direct observations onboard ARCAD-3 during a diffuse aurora period. They also compared well with the plasma sheet component of 3—10

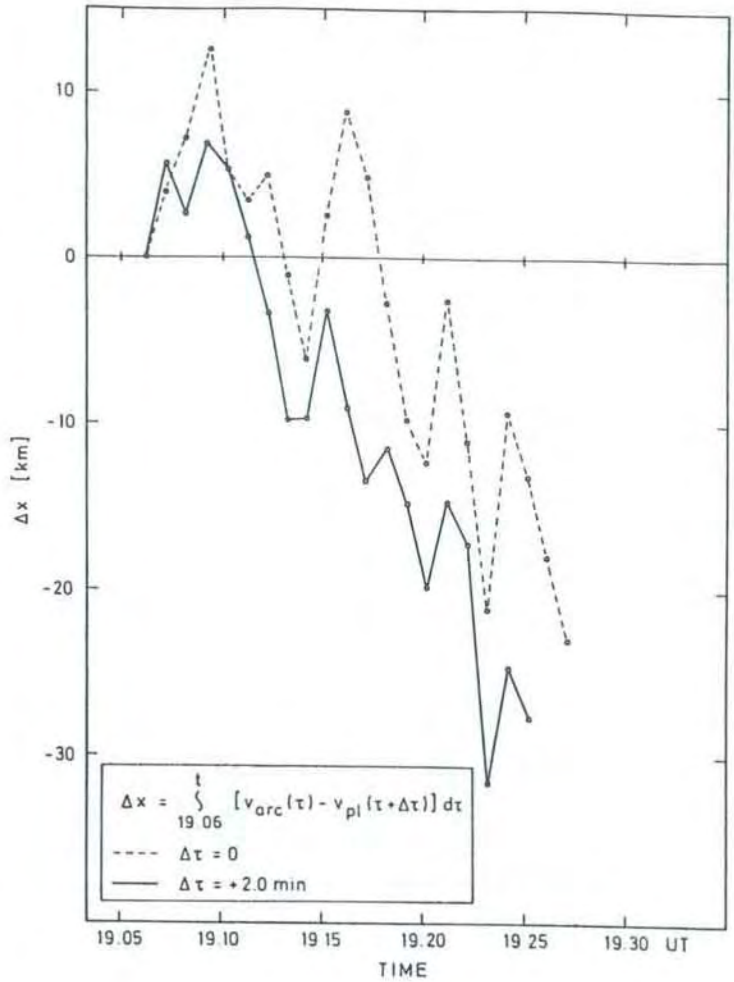



*Fig. 23. The displacement of an auroral arc relative to the background plasma in the direction normal to the arc, observed on 10 October 1983.*

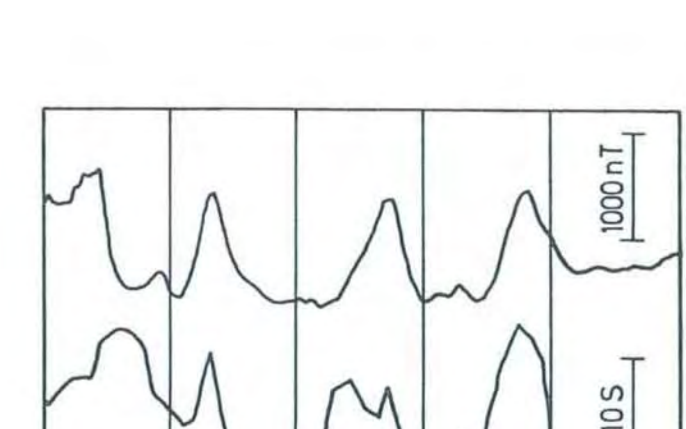



*Fig. 24. Variations of the east-west component of the magnetic field at Soroya (upper panel) and the corresponding variations of the height integrated Pedersen conductivity (lower panel), deduced from EISCAT observations.*

keV measured onboard GEOS-2. The correspondence with large pitch-angles suggests a quasi-isotropy of equatorial electron fluxes. The electrostatic electron cyclotron harmonic waves, which are also observed onboard GEOS-2, were not found to be intense enough to cause the strong pitch-angle diffusion of electrons of a few keV. These observations thus allowed the conclusion that, even if these electrostatic waves contributed to the auroral precipitation, they could not be its unique cause. (Fontaine et al., 1986)

## Non-Maxwellian Velocity Distributions, Large Electric Fields and Frictional Heating

One of the most important energy sources of the auroral upper atmosphere is Joule heating caused by friction between neutrals and the ions which are drifting due to magnetospheric electric fields. Incoherent scatter radars have been shown to be extremely useful for the investigation of this process, because they can directly measure both the electric field and the ion temperature, which are the key parameters for this process. For large electric fields ($\geq 40$ mV/m), however, the theory predicts an increasing deviation of the ion distribution function from a Maxwellian distribution function, which would invalidate the currently applied determination of the ion temperature.

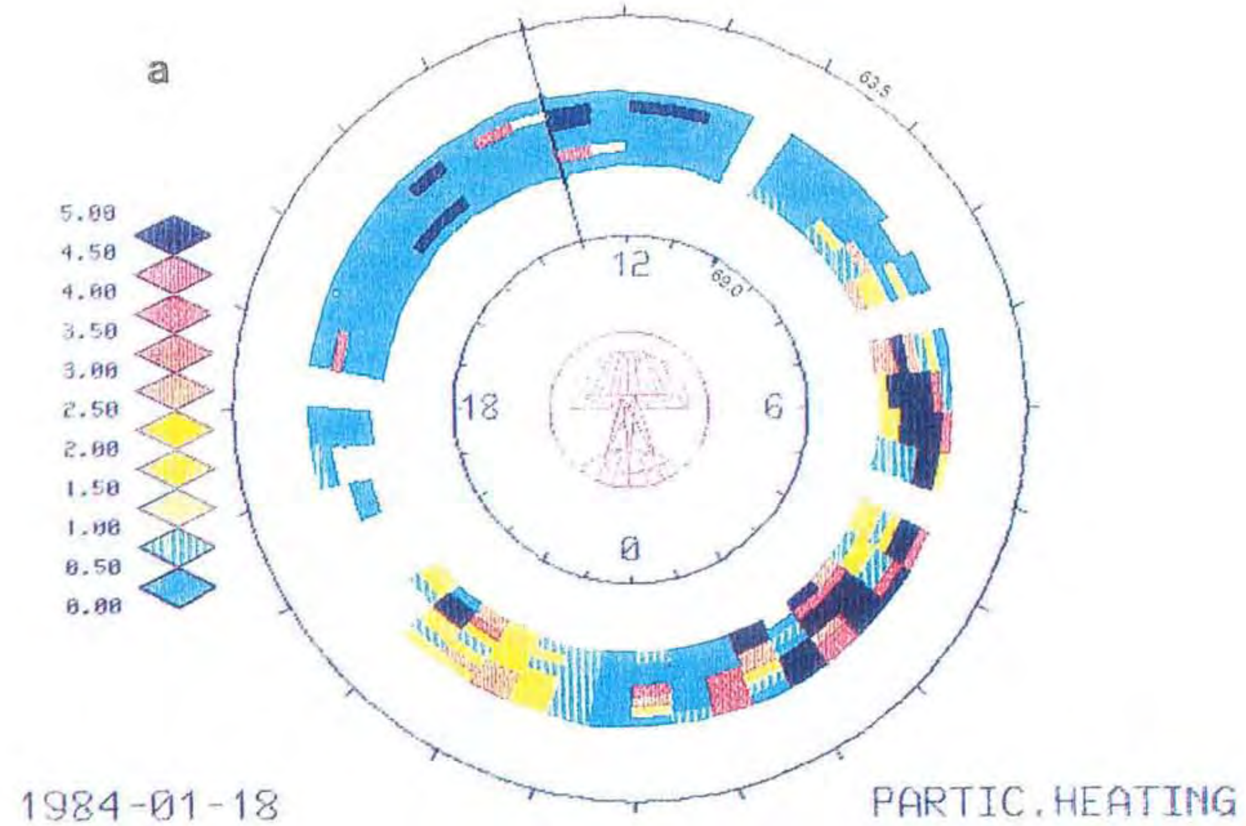
Clear examples of the characteristic spectra of radar echoes from a non-thermal plasma were identified on 27 October 1984 using the EISCAT-UK-POLAR experiment. For a brief period during a flux transfer event ion velocities of up to 2 km/s were measured and when the ion drift exceeded the neutral thermal speed the familiar double-humped spectra were replaced by spectra with a single central peak (see Fig. 26). These spectra have been compared with theoretical studies for a toroidal ion distribution. (Lockwood et al.: Non-Maxwellian ion velocity distribution observed using EISCAT)

Similar measurements were carried out on a very disturbed day, 21 April 1985 (Kp = 8 +), using the EISCAT tristatic radar. Among other interesting events, several exceptionally intense ion heating events took place in association with strong plasma convection. In the morning sector ion drift velocities perpendicular to the geomagnetic field reached values of up to 3 km/s corresponding to a perpendicular electric field $E \leq 150$ mV/m. Assuming Maxwellian particle distribution functions and an enhanced fraction of molecular ions (compared to a standard model) the estimated ion temperatures, $T_i$, associated with the strongest convection velocities reached values of 10 000 K, about 6 times the temperature of the electrons, $T_e$.

The validity of the fits in the case of non-Maxwellian ion distribution functions, was investigated. Theoretical incoherent scatter spectra were calculated using distribution functions for such a non-thermal plasma suggested in other works. It was found, that for an increasing ratio $T_i/T_e$ the error due to a Maxwellian interpretation of the spectra becomes less significant. For the case of the observations from 21 April 1985, good agreement with the measured spectra can be achieved with both, Maxwellian and non-Maxwellian distribution functions (Fig. 27). Other uncertainties like the unknown ion composition are also important. It is concluded, that within the mentioned uncertainties the ion temperature enhancements can fully be attributed to Joule heating. (Buchert and LaHoz: Measurements of ionospheric parameters for large electric fields)

## Field-aligned Plasma Velocities, Magnetospheric Convection and Flux Transfer Events

The effects of driving plasma through the neutral atmosphere at a high velocity have also been studied using data from 18 days of EISCAT Common Programmes. Near midnight the sudden reversal of the plasma velocity in the auroral zone caused an immediate increase in ion temperature which often coincided with substantial Joule heating of the neutral atmosphere. The heating of both, the ionised and the neutral atmosphere, led to large upward velocities which rapidly depleted the ionosphere and contributed to the formation of the high-latitude trough in electron density. This upwelling was observed at the latitude of Tromsö in the form of field-aligned plasma velocities of about 100 m/s. Further north, at the boundary of the polar cap, upward velocities of over 300 m/s were measured, associated with very large values of Joule heating. (Williams and Jain, 1986; Winser, Jones and Williams: Variations in field-aligned



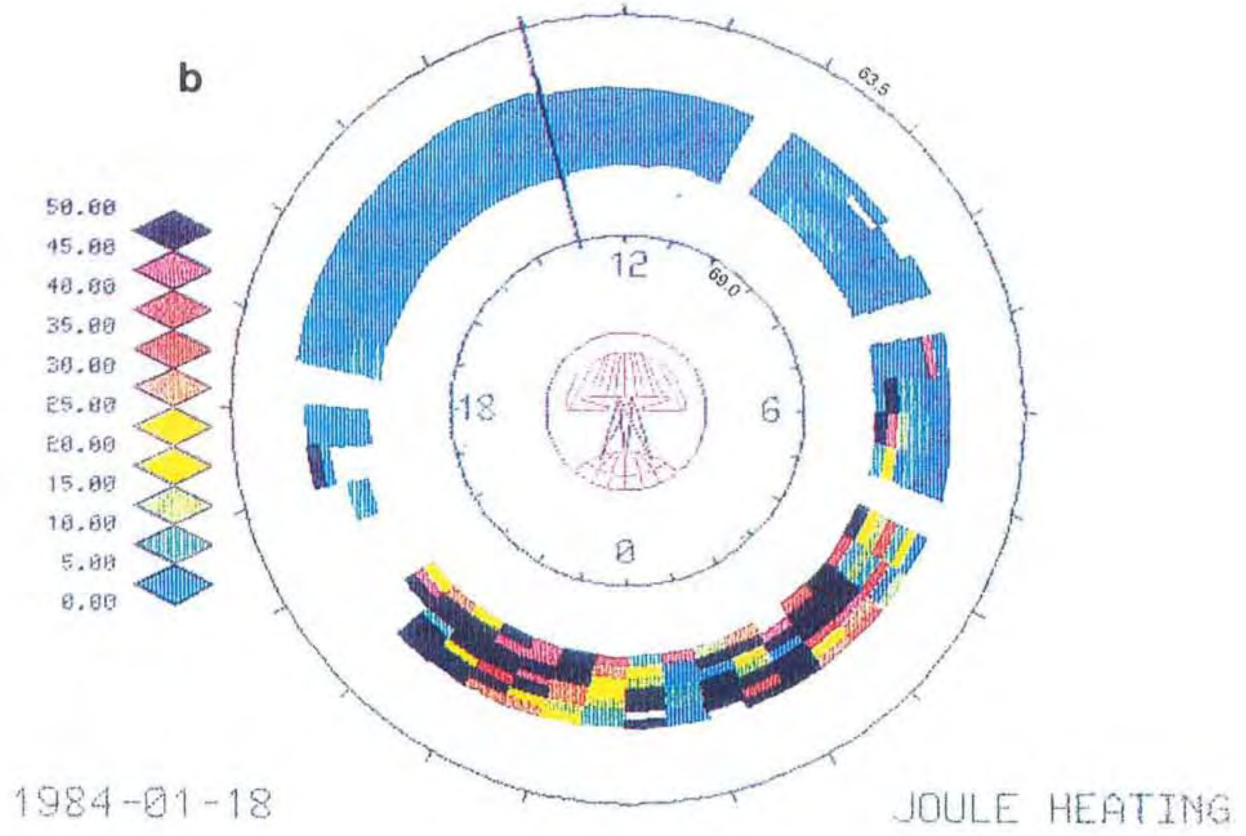




*Fig. 25. (a) Height-integrated particle heating rates for 18—19 Januari, 1984. Polar coordinates are MLT (magnetic local time) and invariant latitude. The colour scale is given in 0.1 $mW/m^2$.*
*(b) Same as (a), but height-integrated Joule heating rates are displayed. The colour scale is given in 0.1 $mW/m^2$.*

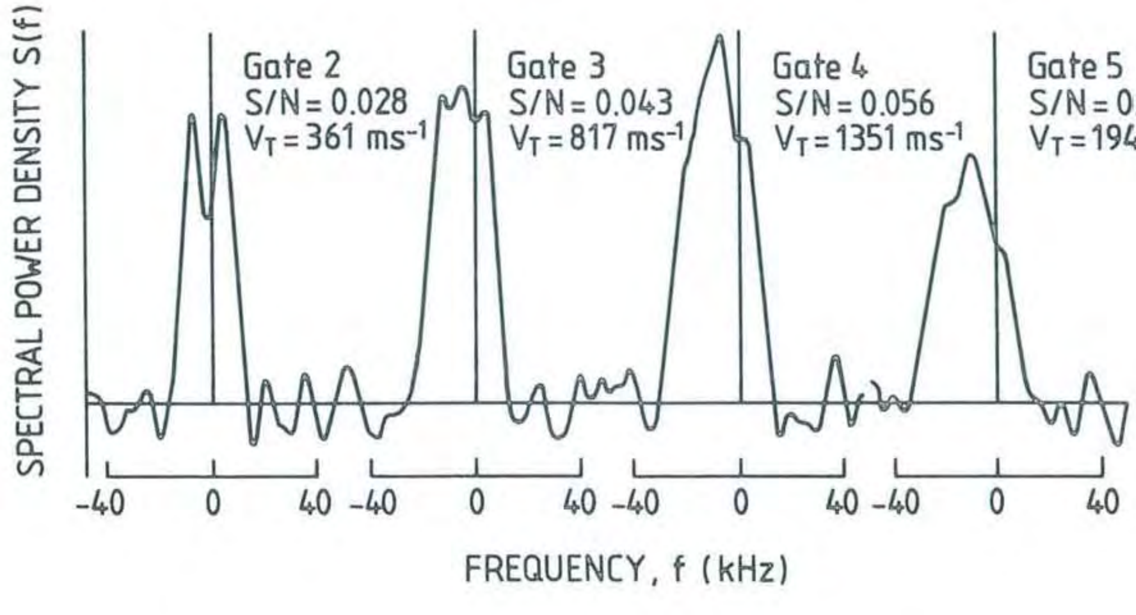



*Fig. 26. Signal spectra for the integration period 06:35:45—06:36:00 UT on 27 October 1984 for four distant gates observed by EISCAT using the Special Programme SP-UK-POLAR. The spectra for line-of-sight velocities greater than 800 $ms^{-1}$ correspond to non-Maxwellian velocity distributions.*

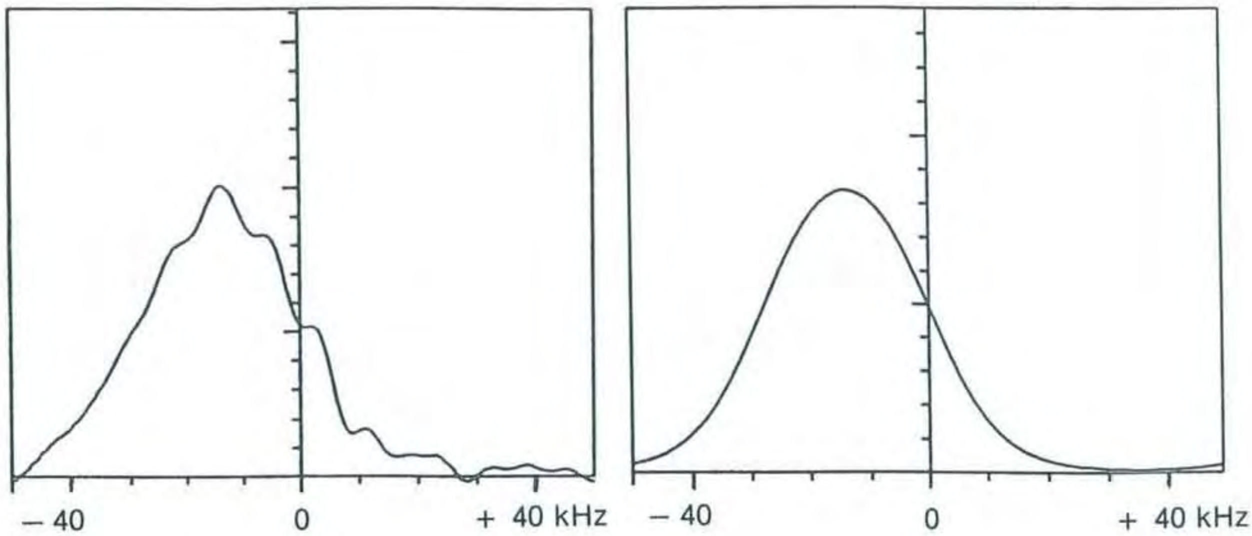



*Fig. 27. Measured (left) and fitted (right) radar spectra for $E$ = 139 mV/m and $T_i$ = 9543 K. The fit routine assumes Maxwellian distribution functions. The EISCAT measurements were on 21 April 1985, 03:21 UT.*

plasma velocities with altitude and latitude in the auroral zone)

Data obtained from the EISCAT-UK-POLAR experiment have been used to study large-scale expansions of the polar cap. Following a southward turning of the interplanetary magnetic field, as observed by the AMPTE-UKS satellite, the sluggish, contracted convection pattern was replaced by an enhanced pattern which expanded over the field of view of the POLAR experiment (Lockwood et al., 1986). On another occasion the expansion was observed jointly by EISCAT and by the Sondrestromfjord radar. The observed rate of expansion showed that the cross-cap potential had increased by 200 kV, and during this expansion the satellite Dynamics Explorer 1 observed the electric field, field-aligned current and up-going ion-flow signature of an inverted-V structure, which moved equatorward with the polar cap boundary at the convection speed. (Lockwood et al.: Low energy ion outflows from the ionosphere during a major cap expansion — evidence for equatorward motion of inverted-V structures)

In addition many bursts of rapid poleward flow were observed in the dayside auroral ionosphere. These were consistent with the predicted ionospheric signature of Flux Transfer Events at the dayside magnetopause. The data revealed spatially-confined (< 400 km) twin-vortex flow patterns with poleward flow of up to 2 km/s at the centre. These were transient and lasted only a few minutes, but they tended to recur with a period of 5—10 minutes. (Todd et al., 1986)

## EISCAT—VIKING Cooperative Observations

One major international collaboration during 1986 was dedicated to coordinated observations with the first Swedish satellite, VIKING. This satellite was equipped with instruments measuring particle precipitation, electric and magnetic DC and AC fields, and optical auroral emissions with a temporal and spatial resolution superior to other magnetospheric satellites. The eccentric orbit of VIKING was initially positioned above or within those magnetospheric regions where auroral particle acceleration occurs. Simultaneous measurements at the same field line in the magnetosphere (by VIKING) and in the ionosphere below (by EISCAT) were performed to allow conclusions about the nature of auroral particle acceleration and the associated electric fields and currents. Both VIKING and EISCAT data furthermore complement each other in the interpretation of the observed variations of ionospheric and magnetospheric parameters in terms of temporal or spatial developments.

In order to secure an even coverage of EISCAT data for the closest and most interesting VIKING passages an international pool of EISCAT Special Programme time was provided by all EISCAT associate countries. This allowed coverage of over 50 of the most interesting VIKING passages during 8 interactive campaigns. Following a Swedish initiative an international working group, consisting of scientists from all associate countries, developed and operated a number of special programs. These EISCAT/VIKING programs were designed to cover some of the most interesting geophysical situations, which were expected to occur. One programme was designed to observe active auroral forms and travelling phenomena, when it is best to make observations with a stationary antenna along the field line. Another program was for moderately disturbed conditions, when a meridional scan can be more useful to map ionospheric parameters and to follow slow changes.

An example of the signatures of an auroral westward travelling surge passing through the EISCAT beam recorded with high time resolution is shown in the Figure 28, and Fig. 29 shows the same surge some minutes later, as photographed by the VIKING satellite from an altitude of more than 12 000 km. Interesting particle spectra and electro-magnetic and electric field patterns were observed in the vicinity of the surge. The comparison of EISCAT and VIKING results is expected to give new insights on the mechanisms of particle acceleration during magnetospheric substorms and ionospheric reactions to the magnetospheric energy input. The fact that the surge decayed soon after the passage of the VIKING satellite might help in understanding the mechanisms which limit the release of substorm associated energy in the magnetosphere. (Opgenoorth, Bromage, Fontaine, LaHoz, Huuskonen, Kohl, Lövhaug and Wannberg: Coordinated EISCAT/VIKING observations — Outline of experiments and description of observations)

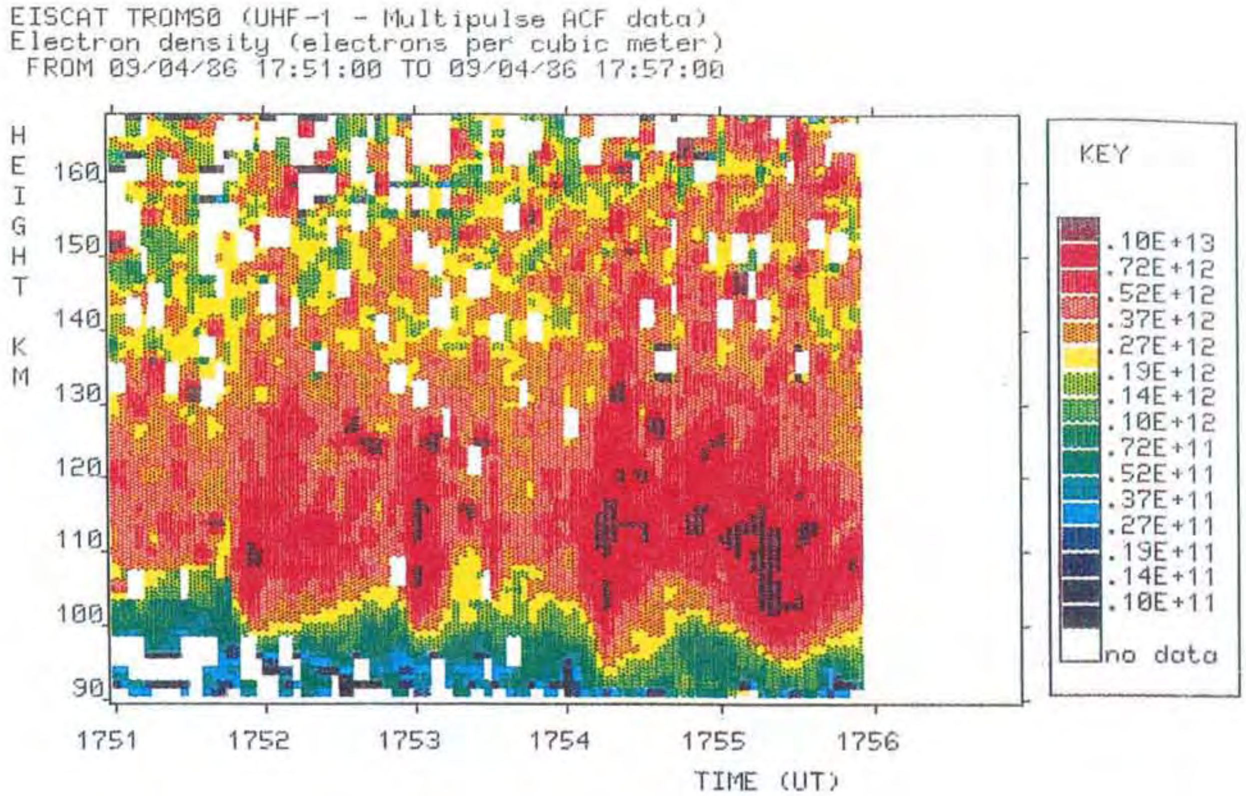



*Fig. 28. Colour plot of electron density versus altitude and time measured in the VIKING/EISCAT campaign during the passage of an auroral westward travelling surge, using multipulse data with 5 sec time resolution.*

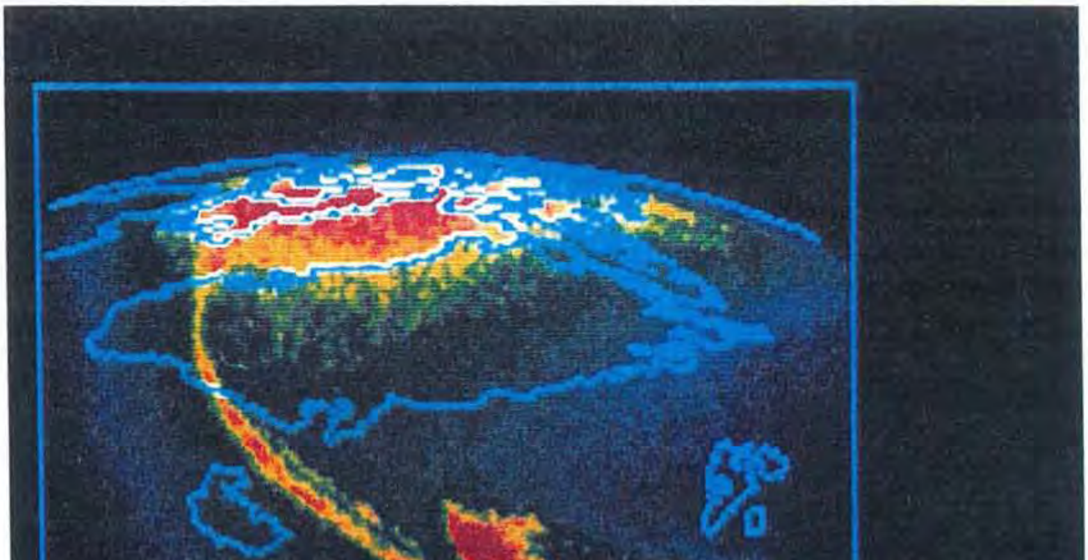



*Fig. 29. The westward travelling surge as photographed by the VIKING satellite imaging system about 15 minutes after it passed through the EISCAT beam (courtesy of J.S. Murphree, University of Calgary).*

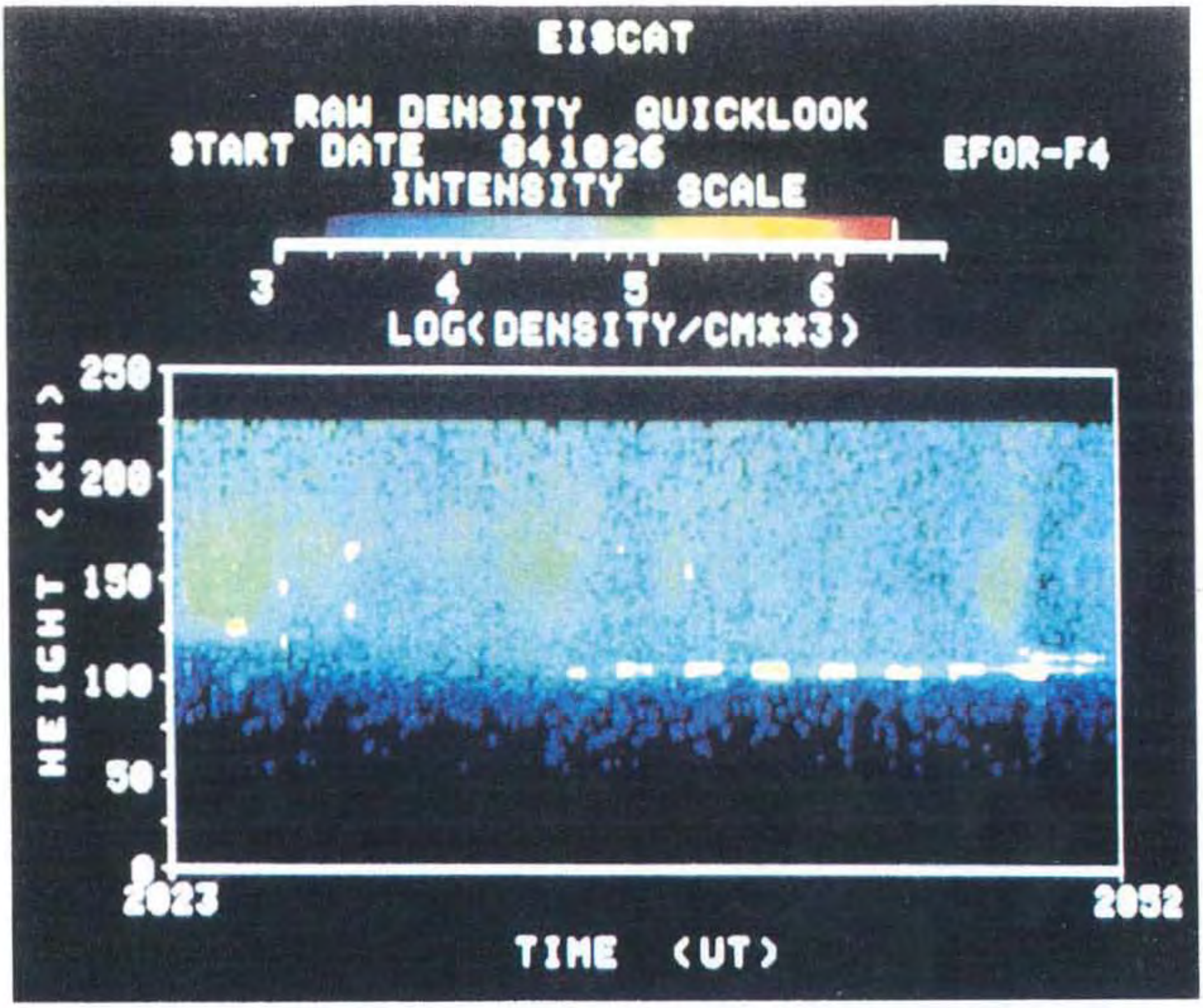



*Fig. 30. Signatures of ionospheric modifications (heating) in EISCAT observations of the auroral E-region. The heater operated in a 1-minute-on, 1-minute-off mode.*

## EISCAT - Heating Collaborations

The EISCAT UHF- and VHF-radars were used in different diagnostic modes during ionospheric modification experiments with the Ramfjordmoen Heating facility of the Max-Planck-Institut für Aeronomie. Several new results are outlined here:

### Heating of the Polar E-Region

On 26 October 1984 the heater transmitted radio waves on a frequency of 3.324 MHz with an effective power of 240 MW vertically into the ionosphere in a 1-minute-on, 1-minute-off mode. EISCAT observed the auroral E-region with a multipulse program allowing a 3 km height resolution and a tristatic velocity estimate at 172 km altitude.

The effect produced by the heating was a strong increase of the EISCAT backscatter amplitude in a very narrow height range, either around 127 km or around 109 km. The latter echoes all occurred after 2030 UT when a weak precipitation event raised the E-region electron density at this altitude to about 1.5 $10^{11}$ $m^{-3}$. The EISCAT echoes clearly showed the heater modulation pattern (Fig. 30). The spectra of the EISCAT echoes looked quite different to the usual spectra observed from this altitude. They were very narrow indicating an unusually long correlation time and thus probably a coherent scatter process. Interestingly, the spectra observed with the two remote stations looked quite normal and could be evaluated with the usual incoherent scatter formalism. It is thus assumed that the irregularities giving rise to the strong backscatter have a spatial scale of 16 cm along the magnetic field line.

It was also found that these strong echoes were not related to the DC electric field which was measured with EISCAT. It was noticed previously that the heater can induce irregularities which can be detected with an auroral radar. In the described case the electric field was too low to excite the modified-two-stream instability.

There are a number of plasma instabilities which can account for the observed phenomena. The most probable one is the so-called oscillating two-stream instability. It is excited if the local plasma frequency exceeds the heater frequency. The electron densities measured by EISCAT indicate that this condition was fulfilled sporadically before 2030 UT at an altitude of 127 km and continuously at 109 km after 2030 UT. (Schlegel, Rietveld and Maul: A modification event of the auroral E-region as studied with EISCAT and other diagnostics)

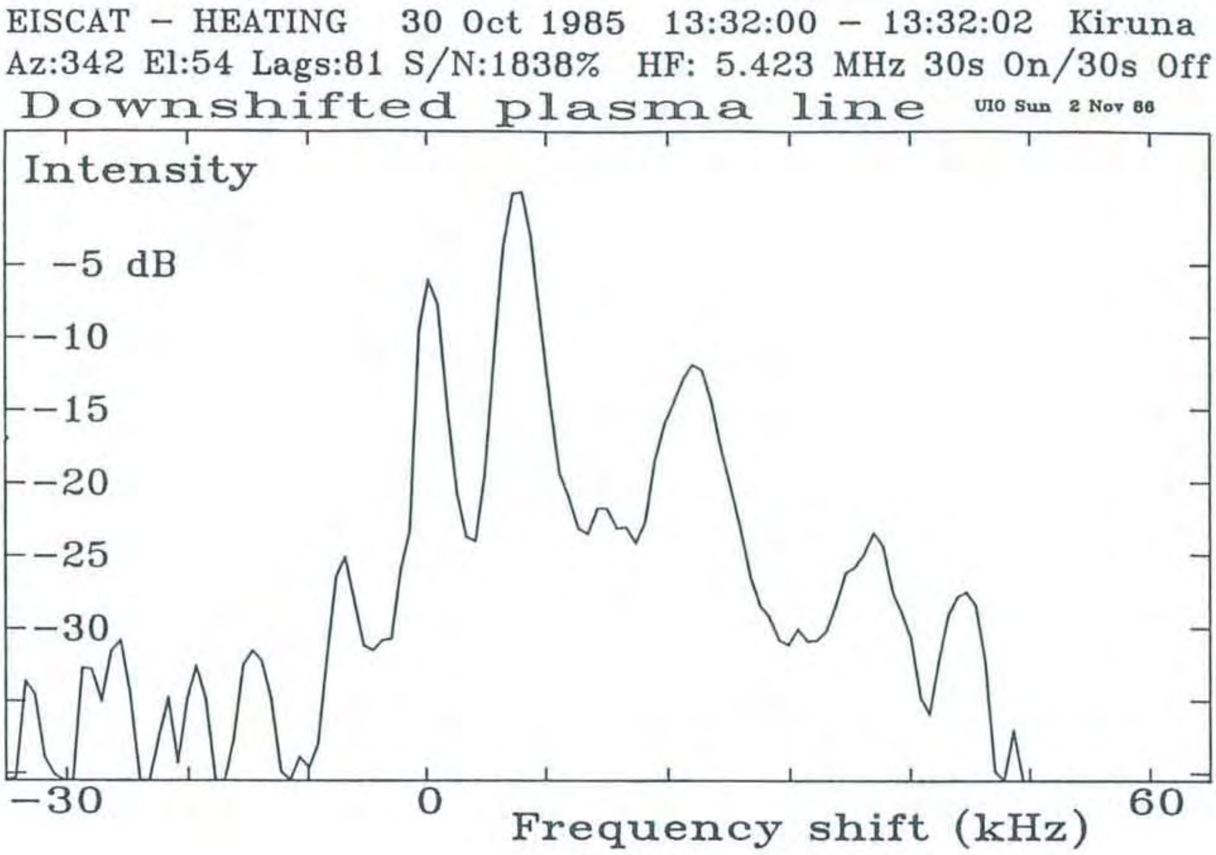
### Enhanced Plasma and Ion Line observed at the Remote Site Kiruna

During the joint EISCAT-Heating campaign of October and November 1985, the Kiruna receiver was operated in a high spectral resolution mode, producing data from both plasma line bands with a basic resolution of 624 Hz. At Kiruna, the antenna was interactively pointed to the point of strongest plasma line returns as indicated by the power profile recorded at Tromsö. The scattering geometry was such that with the transmitter beam directed tangential to the magnetic field, the scattering half-angle was of the order of 22—23 degrees, i.e. about half of that obtained in heating experiments at the Arecibo Observatory, offering interesting possibilities for studying the angular dependence of the scatter spectra.

Comparing the spectra received simultaneously at Tromsö and Kiruna shows the Kiruna spectra to be generally more broadened than the Tromsö spectra. This is what should be expected if the signals received at Kiruna are scattered off secondary Langmuir waves some distance from the region of the strongest parametric decay.

Some elevation scanning was done over limited regions of a few beam widths during conditions of persistent plasma line backscatter. At altitudes a few kilometers above and below the point of most intense scatter, signals could still be received in both plasma line channels. The spectra obtained away from the region of strongest backscatter seem to be less damped than those recorded at its centre. However, all spectra contain prominent features located between the ordinary cascade lines, similar to those observed at Tromsö. An example is shown in Fig. 31, where two 2-second averages of the upshifted and downshifted plasma lines are depicted.

Another intriguing phenomenon is the appearance of a transient spike at zero frequency



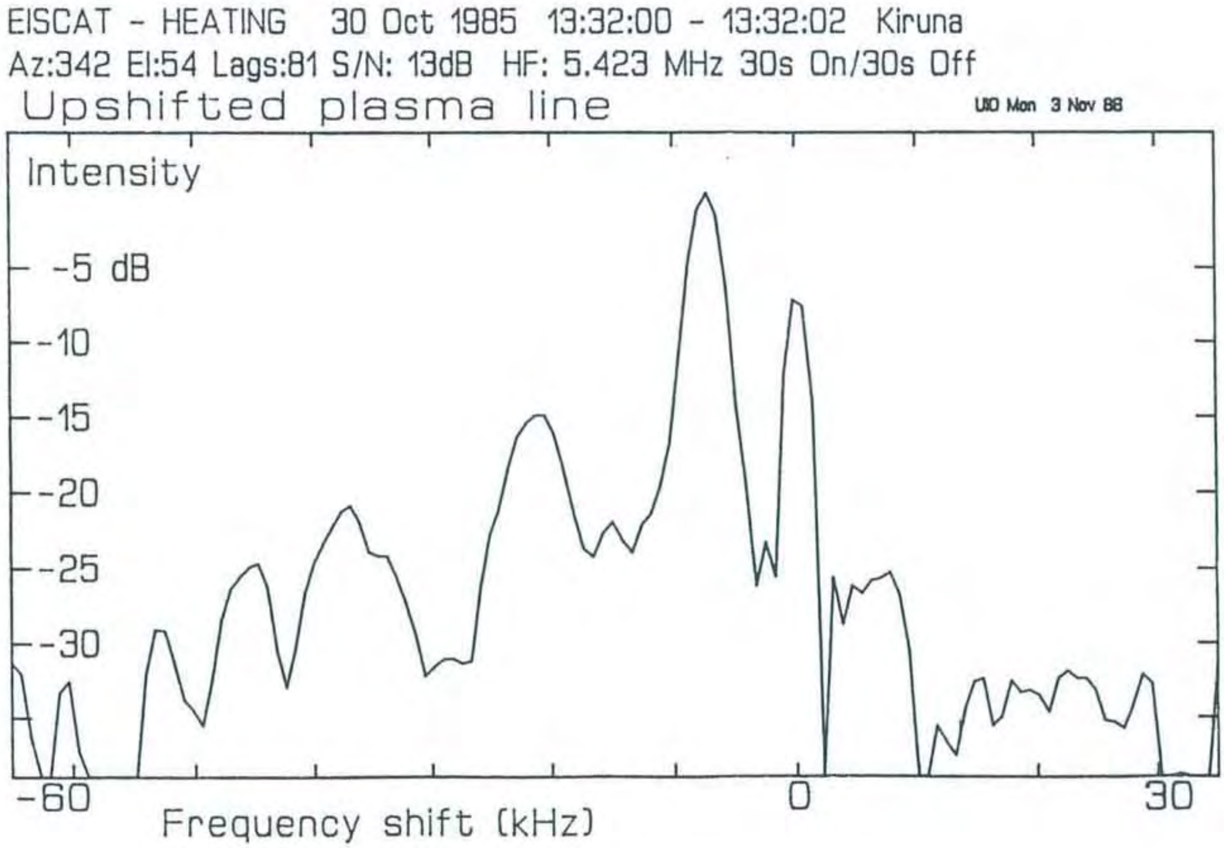




*Fig. 31. Spectra of heater-enhanced plasma lines observed at the remote site Kiruna.*

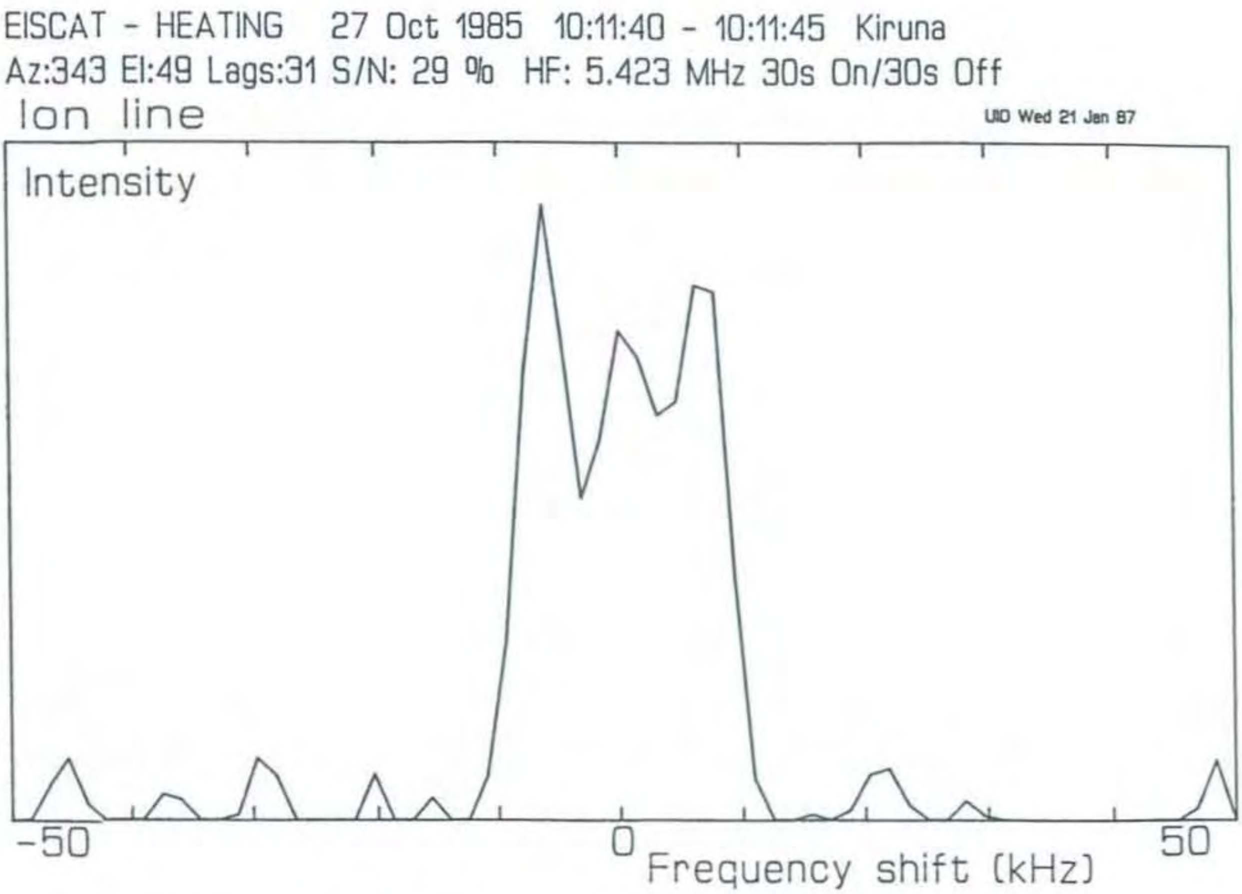



*Fig. 32. Heater-modified ion line spectrum, measured at the remote site Kiruna.*

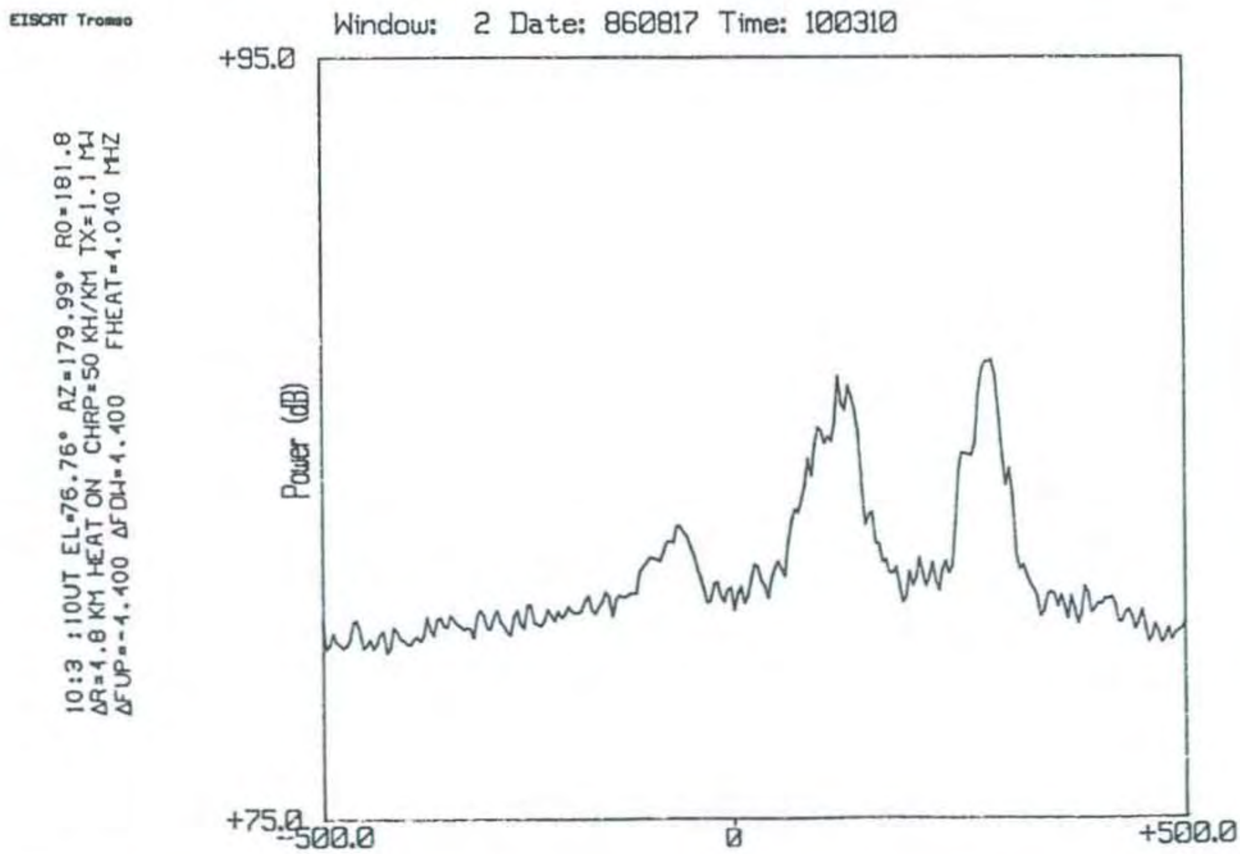



*Fig. 33. Anomalous large frequency shifts of the heater-enhanced plasma line, measured in Tromsö. The zero frequency corresponds to the offset by the heater frequency of 4.04 MHz.*

offset in the ion line spectrum at about 10—15 seconds after heater turnoff. An example is shown in Fig. 32. As no energy is being pumped into the plasma at this point, it is likely that the zero frequency line is the result of Bragg scattering off small-scale striations produced in the successive decay of the much larger scale striations which are known to be formed by prolonged heating. (Wannberg, Kohl, LaHoz, Kopka, Nordling, Opgenoorth, Stubbe)

**Anomalous Frequency Shifts**

In August 1986 a Heating experiment was carried out and the EISCAT digital chirp experiment was applied for diagnostics. The aim was to try to confirm the chirped plasma line signatures observed earlier in similar experiments at the Arecibo Observatory. This was taken as the first direct evidence of heater-excited solitary structures, which are also called cavitons. However, the EISCAT signatures were very different from these and extremely surprising: Instead of an expected offset of the enhanced plasma lines from the radar frequency by the heater frequency, several distinct plasma line features were detected hundreds of kHz further out in the spectrum (Fig. 33). Running alternately with the radar in the chirped and in the unchirped mode it was found that the features seemed to emanate from very localised regions. The analysis has not been completed yet but the characteristics indicate that the signals are probably not due to instrumental effects but that a plasma-physical phenomenon not observed in the ionosphere before has been discovered. (Hagfors, Isham, Thidé, Nordling, Kofman, LaHoz, Stubbe, Kopka et al.)

**First VHF-Radar Diagnostics in Heating Experiments**

The first experiments to observe plasma line features using the VHF-radar were performed in August 1986. In contrast to experience with the UHF radar, plasma lines were found to be more easily observable with the VHF radar. A number of surprisingly new phenomena have already been detected:

* The instabilities could be seen even with the radar pointing northward up to about 15° off-vertical. However, the measured intensities showed a minimum when the radar pointed vertically.
* Purely growing modes could be observed only at very low intensities, if they could be detected at all.
* It is known from power stepping experiments that the full power heater produces an electric field which is about 10—20 db above the threshold value which should produce several cascade lines. However, one hardly ever could detect more than two cascade lines in this VHF experiment. This again emphasizes the problem of the saturation of the parametric decay process.
* Excitations at a higher frequency than the heater frequency are often seen, which is in contradiction to common theory.

Fig. 34 shows an interesting example obtained with the VHF radar. In the power profiles of all three channels (down-shifted and up-shifted plasma lines and ion line) strong excitations occur over an altitude region of almost 100 km. At the same time the corresponding spectra do not show extra-ordinary features. These observations are at present difficult to interpret as they seem to imply a constant plasma frequency over the whole relevant altitude region. A possible explanation could be, that the ionosphere was so strongly disturbed, that irregularities occurred over a large altitude range.

Because of the strangeness of this phenomenon is was thoroughly considered, whether it could be attributed to instrumental effects. Although this possibility cannot be absolutely excluded, the experimenters regard it to be unlikely. (Kohl, Kopka, LaHoz and Stubbe)

It is foreseen that further diagnostics using the EISCAT radars will shed more light into all these newly detected phenomena.

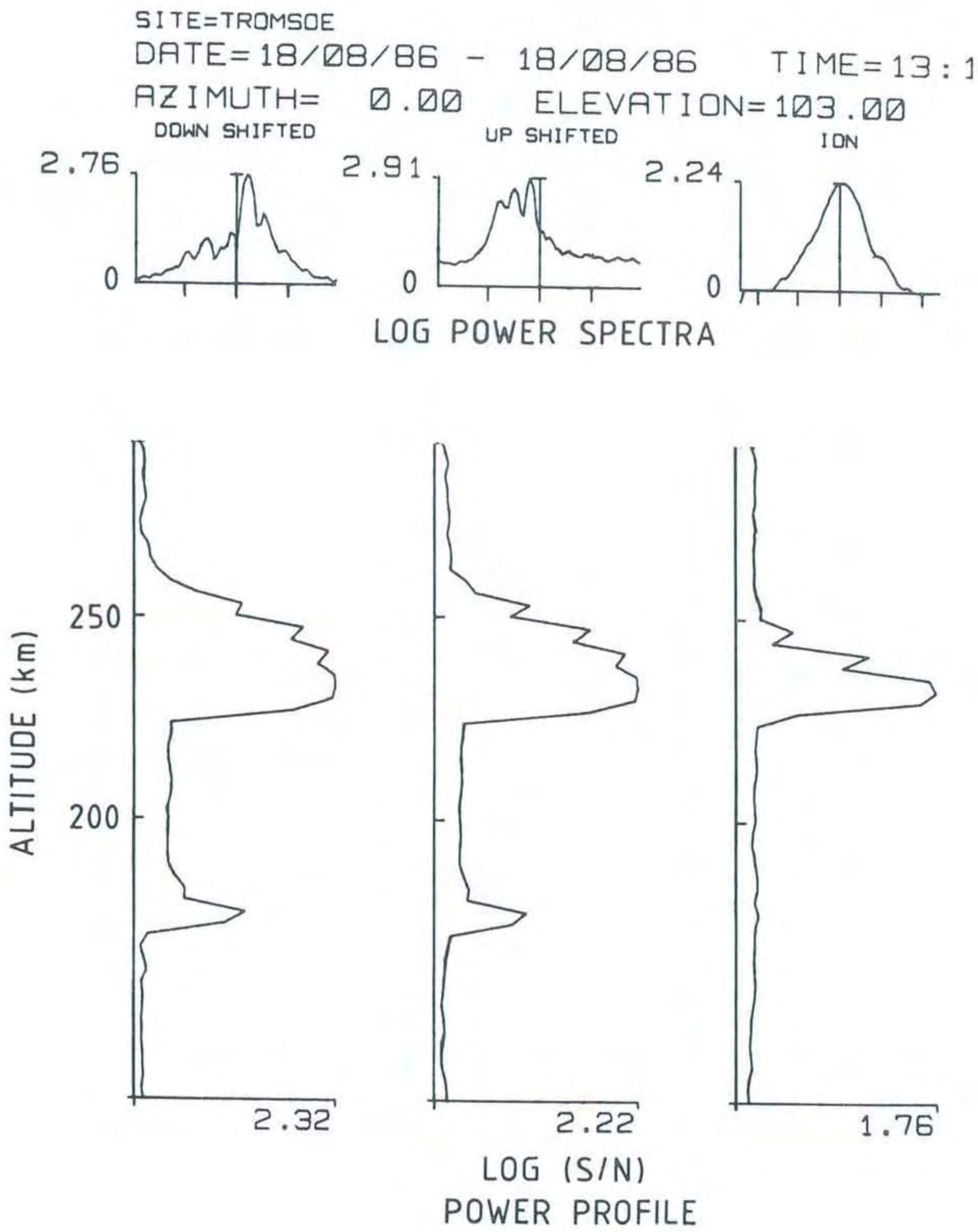



*Fig. 34. Power profiles and spectra of the plasma lines and the ion line measured with the EISCAT VHF radar during ionospheric heating experiments.*

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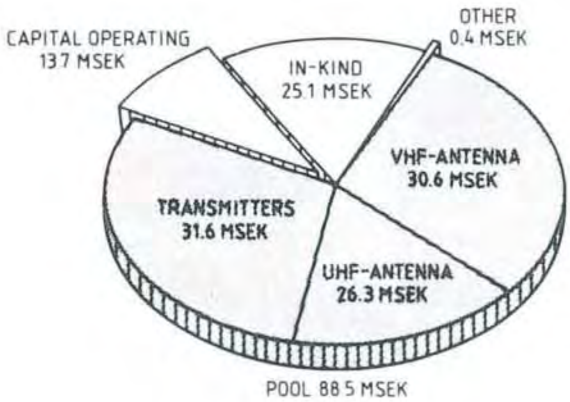
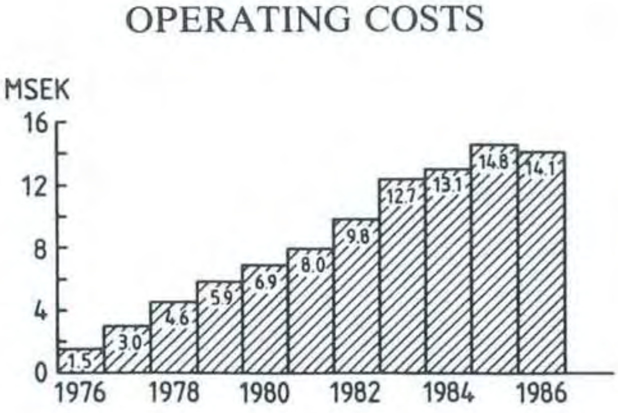
| | | | |
|---|---|---|---|
| COUNCIL | 27th meeting | 21—22 May | Helsinki, Finland |
| | 28th meeting | 6—7 November | London, UK |
| SAC | 30th meeting | 13—14 March | Kiruna, Sweden |
| | 31st meeting | 16—17 October | Grenoble, France |
| AFC | 26th meeting | 10 April | Stockholm, Sweden |
| | 27th meeting | 18—19 September | Sodankylä, Finland |

CAPITAL INVESTMENTS




OPERATING COSTS




# Personnel and Budget

A total of 33 EISCAT staff positions are distributed over Headquarters (10, whereof 1.5 temporary), Tromsö site (13), Kiruna site (5) and Sodankylä site (5). In addition to the positions of the director, two assistant directors and the business manager, they consist of 4 scientific, 3 engineering, 11 technical, 5 computing, 4 administrative/secreterial and 2 caretaker positions. In 1986 a few positions were temporarily vacant due to some turnover in Tromsö, but in general the personnel situation was stable.

The capital investments for the EISCAT facilitites have accumulated to a total of 127.7 MSEK by 1986. They are distributed as follows: Transmitters 31.6 MSEK, UHF antennas 26.3 MSEK, VHF antenna 30.6 MSEK, capital operating 13.7 MSEK, in-kind contributions 25.1 MSEK and other 0.4 MSEK.

Since the beginning of EISCAT in 1976, the total operating costs have fairly constantly increased by an average of 1.45 MSEK per year and have reached the level of 14.1 MSEK in 1986, which consist of 6.7 MSEK for salaries, 3.8 MSEK for operations and 3.6 MSEK for administration.

The balance sheet at 31 December 1986 is given on the following page.

# BALANCE SHEET AT 31 DECEMBER 1986

MSEK

| Assets | At Dec. 31, 1985 | Additions | | | Depre-ciation | At Dec. 31, 1986 |
|---|---|---|---|---|---|---|
| | | Pool | Cap.Op. | Other | | |
| FIXED ASSETS | | | | | | |
| Buildings | 8.6 | | | 0.1 | 0.2 | 8.5 |
| Transmitters | 29.1 | 0.5 | | | 1.6 | 28.0 |
| UHF-antenna | 17.4 | | | | 1.3 | 16.1 |
| VHF-antenna | 21.7 | | | | 1.5 | 20.2 |
| Receivers | 2.3 | | | | 0.8 | 1.5 |
| Computers etc. | 2.1 | | 5.0 | | 0.5 | 6.6 |
| Other | 2.4 | | 0.5 | | 0.6 | 2.3 |
| Total | 83.6 | 0.5 | 5.5 | 0.1 | 6.5 | 83.2 |
| CURRENT ASSETS | | | | | | |
| Debtors | 1.1 | | | | | 2.7 |
| Prepayments and accrued income | 0.2 | | | | | 0.1 |
| Cash and Ordinary Bank Accounts | 9.3 | | | | | 8.3 |
| Special Accounts | 0.3 | | | | | 0.2 |
| Total | 10.9 | | | | | 11.3 |
| GRAND TOTAL | 94.5 | | | | | 94.5 |

MSEK

| Liabilities | At Dec. 31, 1985 | At Dec. 31, 1986 |
|---|---|---|
| CAPITAL | | |
| Contributions | | |
| Pool | 88.0 | 88.5 |
| Capital Operating | 8.1 | 13.7 |
| In Kind | 24.8 | 25.1 |
| Other | 0.7 | 0.4 |
| | 121.6 | 127.7 |
| Depreciations | 38.0 | 44.5 |
| Total Capital | 83.6 | 83.2 |
| RESERVES | | |
| Pool | 4.6 | 4.2 |
| Capital Operating | 0.7 | 0.5 |
| Other | 2.4 | 0.6 |
| Total Reserves | 7.7 | 5.3 |
| Special Accounts | 0.3 | 0.2 |
| LIABILITIES | | |
| Provisions | 0.4 | 0.2 |
| Other Liabilities | 2.5 | 5.6 |
| Total Liabilities | 2.9 | 5.8 |
| GRAND TOTAL | 94.5 | 94.5 |

Totals may not match because of rounding.

# EISCAT SCIENTIFIC ASSOCIATION 1986

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SAC = Scientific Advisory Committee, AFC = Administrative and Finance Committee, * = Chairman
Non-Associate SAC member: D.T. Farley

HEADQUARTERS SENIOR STAFF

| | | |
|---|---|---|
| Director | — | J. Röttger * |
| Assistant Director | — | C. LaHoz |
| Assistant Director | — | T. Turunen |
| Business Manager | — | P. Hagström |

* on secondment of MPG

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