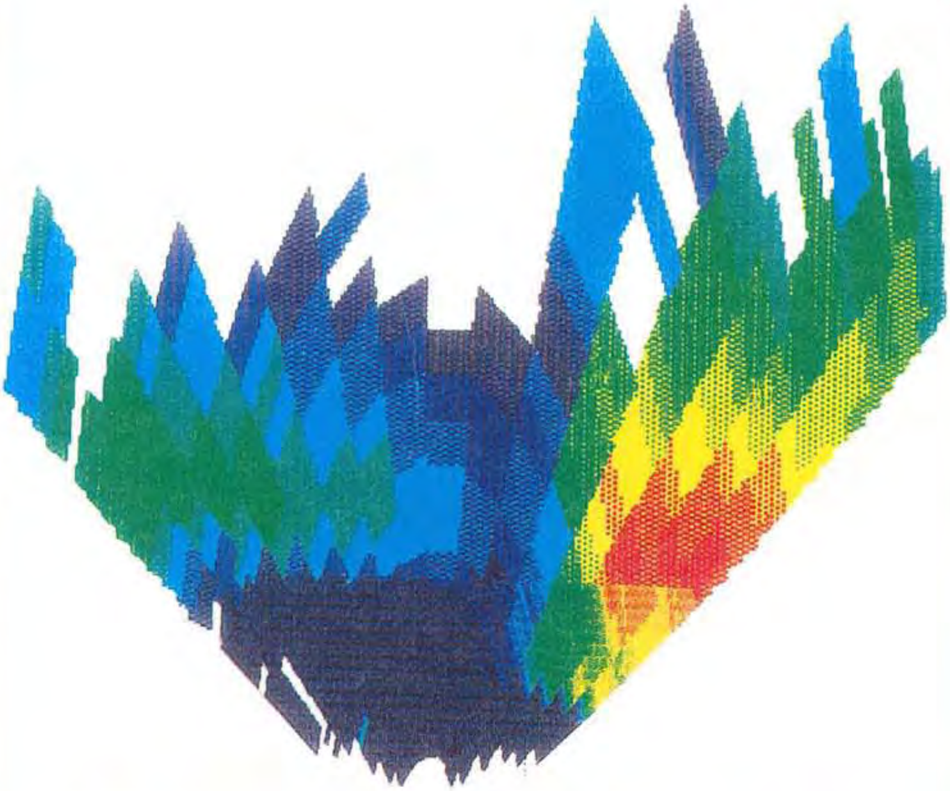
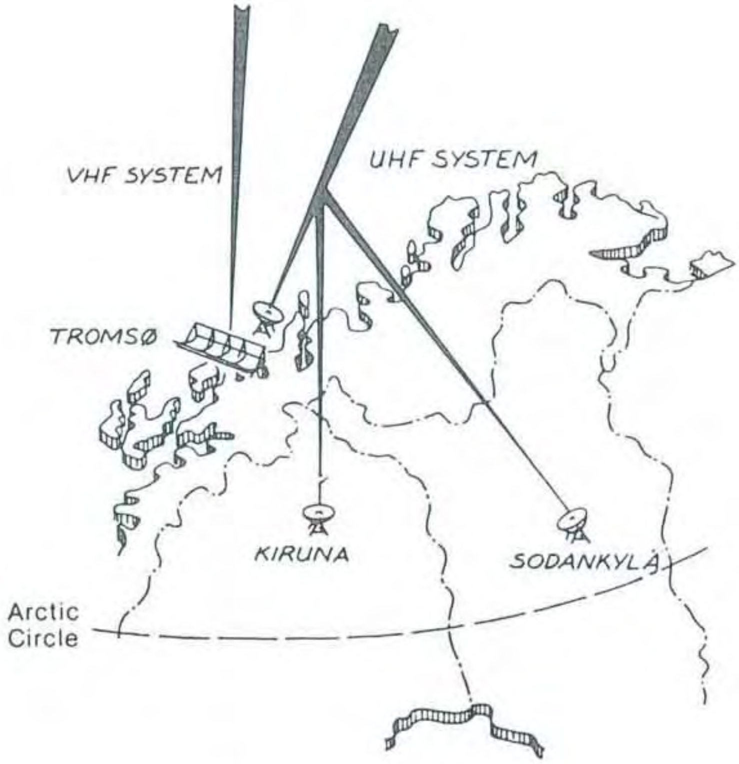


E I S C A T

EUROPEAN INCOHERENT SCATTER SCIENTIFIC ASSOCIATION

ANNUAL REPORT 1987

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



The EISCAT Radar Systems

(see page 2 for a more detailed description)

The cover illustration is a colour-coded representation of electron density measurements from a CP-3-E experiment on 15 December 1987. The display shows the results from a single north-south (north to the right) meridian scan between 14:30 and 14:57 UT, and provides a cross-section through three of the main ionospheric features observed at the latitudes probed by EISCAT. In the equatorward half of the scan (on the left) can be seen the solar-produced, daytime F-region (green and pale blue), which terminates abruptly almost vertically above Tromsö (the centre of the scan) where the ionosphere is severely depleted due to the occurrence of the main ionospheric trough (dark blue). Electron densities are highest (red) on the poleward side of the trough in the region of the auroral oval, where the precipitation of electrons causes ionization down into the E-region.

EISCAT SCIENTIFIC ASSOCIATION

ANNUAL REPORT 1987

EISCAT, *the European Incoherent Scatter Scientific Association, is established to conduct research on the middle and upper atmosphere, ionosphere and aurora using the incoherent scatter radar technique. This technique is the most powerful ground-based tool for these research applications. EISCAT is also being used as a coherent scatter radar for studying instabilities in the ionosphere as well as for investigating the structure and dynamics of the middle atmosphere and as a diagnostic instrument in ionospheric modification experiments (Heating).*

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 (see scheme on the inside of the cover page).

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 omni-directionally. Transmitter and receiver are in Tromsö (Norway). Receiving sites are also in Kiruna (Sweden) and in Sodankylä (Finland), allowing tristatic measurements.

The VHF radar in Tromsö operates monostatically in the 224 MHz band with a peak transmitter power of 1.5 MW (to be raised to 5 MW) and a 120 m x 40 m parabolic cylinder antenna, which is subdivided into four sectors. It can be steered mechanically in the meridional plane from 30° south to 60° north of the zenith.

The basic data, which are measured with the incoherent scatter radar technique, 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 60 km and more than 1000 km. Depending on geophysical conditions, a best time resolution of one second and an altitude resolution of a few hundred meters can be achieved, whereas typical resolutions are of 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 four well-defined Common Programmes are run regularly about 30 times per year for 24 or more hours to provide a data base for long term synoptic studies. Three Unusual Programmes (UP) can be started ad hoc during particular geophysical conditions. A large number of Special Programmes, defined individually by associate scientists, are run to study a variety of 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

CONTENTS of the EISCAT ANNUAL REPORT 1987:

Appendix:

COUNCIL CHAIRMAN's FOREWORD

The year 1987 has been another good year for EISCAT. The UHF radar system has worked very well and a large number of interesting scientific results have been obtained by a growing number of EISCAT scientific users. The VHF radar has been partially available to users with one klystron and therefore limited power output. Even so it has offered a number of new measurement possibilities which have been rapidly exploited by the community.

A long term continuous effort by the EISCAT staff to improve various parts of the complex EISCAT system has in recent years, including 1987, resulted in improved capabilities in several different respects. The most notable examples of such improvements are found on the software side, where improved coding methods has made it possible to increase the temporal and spatial resolutions by an order of magnitude. The exploitation of new solid state technologies on the preamplifier side has decreased the effective receiver temperatures considerably, thereby improving the signal to noise ratio by another large factor. These improvements, which have been undertaken by the EISCAT staff - partly in cooperation with EISCAT scientists in member countries - as part of the maintenance and general development work without any interference with the operation and without any particular investment directly visible in the budget, have in fact improved the sensitivity and resolutions to such an extent that investments of many tens of millions of crowns would have been required if one had chosen to increase the sensitivity and resolution figures by the same amounts by increasing transmitter power and/or antenna sizes.

As Council Chairman I want to express the appreciation and thanks of the Council to the Director and his staff and also to the participating EISCAT scientists in member countries for these very important contributions to the well-being of EISCAT today and to the basis of a good future of the EISCAT enterprise.

It is true that we have also during 1987 become well aware of some important future problems for EISCAT. They have to do with radio frequency interference - by EISCAT and to EISCAT. The high standards of EISCAT and the very good support that it has in all member countries is the best possible basis for a successful handling of these problems in the next few years.

Bengt Hultqvist

DIRECTOR's PREFACE

It is satisfying to present another Annual Report in which the continuation of the reliable operation, as well as further improvements of the EISCAT radar facilities, can be outlined, together with an overview of the scientific results which were achieved by our users. It is a sign of continuity that the EISCAT radars were again operated for almost 2000 hours during the year 1987, - 12 % of which were now with the VHF radar. It is on the other hand not unexpected, that - with such a complex and advanced facility - some failures arise and unpredictable problems had to be resolved. When faults did occur, they were eliminated by common and unselfish efforts within a minimum of time, such that sequences of experiment operations were very seldom interrupted for long periods. Some radio frequency interference problems, on the other hand, still await a satisfactory solution.

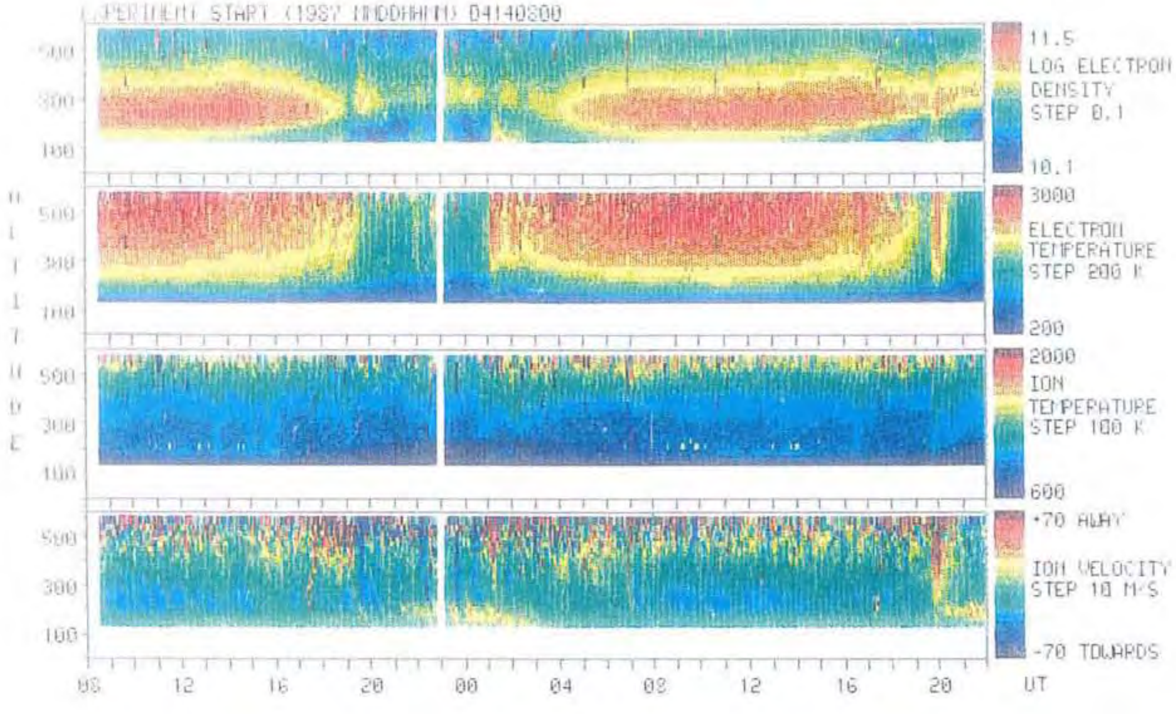
The reports which we frequently receive from visiting experimenters, stating the reliable and satisfying operation during many special programme experiments, are much appreciated by myself and the EISCAT staff. Many interesting results have already been achieved within the limited operating capabilities of the VHF system. It is unfortunate, however, that the VHF system cannot yet been operated with full power. This is not under EISCAT's control, particularly due to the delayed delivery of the klystrons, although considerable efforts were undertaken to resolve the problems as soon as was possible.

The following Review of the Year at EISCAT will begin with an overview of the technical status of the antennas, the UHF and the VHF transmitter and receiving systems, including the progress report on the rebuild of the Valvo VHF-klystrons. An outline will be given of the situation of the interference which affects our UHF and VHF operation. Then follows a brief summary on digital hardware and software improvements as well as on some evolutionary instrumental developments. A brief review of the experimental operation, EISCAT's participation in campaigns, the data analysis and some scientific results, which have an impact on future analysis and operating procedures of EISCAT, will follow. Furthermore, some general developments and EISCAT's participation in international activities will be outlined and a summary of the EISCAT personnel and budget development will be given. In order to serve the information demands of our users, more details of the Review of the Year on the technique, operations, data analysis and the list of published papers are given in the Appendix of this Annual Report. Particular scientific results, which were achieved by the experimenters from many countries, are highlighted in the section following the Review of the Year.

I would like to thank all EISCAT staff for their collaboration and all their efforts to reliably operate and to improve the EISCAT system. The scientific part of this year's Annual Report was again prepared from contributions received from the scientists in the Associate countries. I acknowledge their support as well as the reviewing efforts of W. Baumjohann, D.T. Farley and W. Kofman. I particularly wish to thank all the colleagues of EISCAT, namely P. Collis, C. La Hoz, W. Schmidt, G. Wannberg, as well as Gurli Hultqvist, S. Buchert and P. Hagström and the site leaders, R. Jacobsen, M. Postila and I. Wolf, for their support and assistance in compiling and editing this report.

I hope that this Annual Report 1987 will again give a representative overview of the operations and the scientific achievements of the EISCAT Scientific Association. The exciting scientific results, together with the improved instrumental capabilities of EISCAT, give me the confident expectation of further rewarding operations in the years to come.

Jürgen Röttger



This illustration, used on the EISCAT Christmas card for 1987, shows altitude profiles of (top to bottom) electron density, electron temperature, ion temperature and line-of-sight ion drift velocity measured with the long pulse technique during the CP-1-H experiment between 08 UT on 14 April and 22 UT on 15 April, 1987. The antenna beam is kept stationary along the geomagnetic field direction in CP-1-H. Geophysical conditions were almost undisturbed during this experiment, and the major variations in the four parameters show the ionospheric response to the diurnal variation of solar radiation. This is evident as increased F-region electron density and electron temperature during daytime, and changes in magnitude and direction of the ion drift as the earth's rotation carries the radar under the high latitude plasma convection system. The ion temperature shows less variation with time, though the shorter, more impulsive increases correspond to impulsive changes in velocity and increases in F-region electron temperature and E-region electron density, indicative of auroral activity (Fig. 1).

REVIEW OF THE YEAR

In this section of the Annual Report the notable developments and events at EISCAT are recorded, with some emphasis on those details which had a marked influence on the operation of the facilities and its scientific experiments. Further descriptions, of particular interest to the users, can be found in the Appendix.

Antennas

Some of the major investments of the EISCAT Scientific Association are the UHF and VHF antennas, built some 8-10 years ago. These have to withstand arctic weather conditions, and the UHF antennas usually undergo many movements during operations. Thus it was not totally unexpected, but unpredictable in detail, that erosion of the concrete basements of the UHF antenna rails occurred in Sodankylä and Kiruna. Special investigations were carried out to find the optimum way to refill gaps and haircracks in the porous concrete basements of the antenna rails. The repair was done during the summer time by injecting epoxy material into the haircracks, and fast-hardening concrete into larger cracks. These materials are supposed to withstand very high mechanical forces and low temperatures. After the repair the mechanical deviation of the rail structure was proved to be an order of magnitude smaller than before the repair work. However, a final assessment of the success of the repair is only possible after operation during winter periods.

In Sodankylä an azimuth drive motor of the UHF antenna broke, and this failure also has to be regarded as due to natural aging of the isolating material of motor coils. Some sectors of the pintle bearing also had to be replaced.

In Tromsö, repairs were made to several dipole elements of the VHF antenna which had been cracked by frozen condensation water in the dipole tubes. All the antennas have been brought back into good condition.

Transmitters and the New VHF Klystron

In July 1987 it appeared that the UHF transmitter and the UHF klystron had failed and after the transmitter repair the spare klystron had to be inserted. However, the old klystron, although having served EISCAT for about 10000 hours of operation, was able to be refurbished and is now stored as a spare. Further adjustments of the transmitter circuitry as well as improvements of the protection and monitoring periphery have raised the system performance. It is evident that the UHF transmitter and the UHF system as a whole is in a very reliable shape, generally allowing continuous operation at the 1.5 MW peak power level over periods of several days with at most some minor interruptions. The data series displayed in the colour plot on page 5 (Fig. 1) represents an example of a long operation of a Common Programme with only a minor interruption.

Up until the summer of 1987 we were able to operate the VHF radar with the combination of the Varian klystron and the Valvo klystron. The maximum power however, was limited to about 1 MW, but the full antenna system could be used. Exceptional echoes were observed from mesospheric altitudes (see Fig. 2). For the first time the UHF and the VHF system were run simultaneously in very successful plasma line observations (see page 37). Several advancements of the control and monitoring circuitry of the VHF transmitter were done, the water cooling system was modified, the modulator oil circulation and filtering was improved and the adjustments of operating parameters such as the klystron RF drive power can now more easily be done remotely from the control room. In July 1987 the Valvo klystron YK 1320/1 had to be disconnected because the vacuum had deteriorated. A little later a major break in the cooling system flooded part of the VHF transmitter. Without having any indication of a causal relation, the Varian klystron also showed an extremely poor vacuum after this accident. Further checks discovered an unsettled behaviour of the filament current and it was no longer possible to modulate the klystron beam. More detailed investigations confirmed that this last Varian VHF klystron VKP-8264/103 has a defective filament and it is considered to be lost.

In the meantime the redesign and re-build of the second Valvo VHF klystron had been satisfactorily completed at the Valvo factory in Hamburg. It was installed into the EISCAT transmitter in Tromsö and initial tests at the end of August 1987 showed that it performed much better than the first klystron. Further aging, cavity- and output-tuning, filament and magnet current adjustments as well as RF input drive optimization had to follow. In the beginning of November 1987 a status test was carried out in the presence of the consultants J. Tallmadge and Prof. T. Wessel-Berg, who had been permanently involved in the entire rebuilding process. It was found that the high-voltage capability is now greatly improved and the detrimental passband notches due to unsuitable cavity resonance modes had been eliminated. It was demonstrated that the rebuilt Valvo klystron YK 1320/2 can be operated at the 2.5 MW peak power level. Some inconsistencies still existed, however, when using the 3 lowest of the 16 available frequency channels. Furthermore some additional protection circuitry has to be built into the transmitter. This is necessary to prevent overheating of the collector during high power operation when the RF modulation would drop below a given limit during a fault.

An advantage of the rebuilt klystron is that its efficiency is larger than 45%, which allows operation with less electrical power consumption and at lower high-voltage levels of around 90 kV. This latter evidence is advantageous because it simplifies the simultaneous operation of the VHF radar and the UHF radar, since both can consequently be operated with equal voltage levels.

In view of the quite reasonable behaviour of the VHF klystron YK 1320/2, an acceptance was negotiated with Valvo, which resulted in a reduced payment as a consequence of the somewhat diminished operating capabilities of this klystron. The according second contract supplement was signed at the end of December 1987. This klystron YK 1320/2 has since then been used by EISCAT in test operations. The first klystron YK 1320/1 was returned to the Valvo plant in Hamburg for rebuilding and the re-installation in Tromsö is planned for the autumn of 1988.

Some Interference Problems

Research radar and radio facilities at several locations in the world have been known to suffer interference problems and had to avoid radiation hazards. It was therefore not unexpected that EISCAT is also facing a similar situation. Detailed investigations of the radar instrument performance, equipment adaption and field-strength measurements had been done to reduce the interference to electronic equipment which is caused under certain circumstances by the VHF radar transmitter. Modifications of the VHF antenna were discussed, and feasibility studies were performed to further improve the interference situation and to eliminate any radiation hazard which may occur when the VHF radar eventually is operated with full power.

The remote UHF receiving sites in Sodankylä and Kiruna are facing a passive interference situation because base stations of the public mobile telephone system NMT 900, which transmit close to the frequency bands used by EISCAT, are being operated in the vicinity of the sites. In order to avoid overloading and intermodulation effects in the receivers, filters are being implemented and receiver components exchanged at our remote sites. We have contacts with the Nordic telecommunication authorities in order to settle agreements on interference minimization and prolongated operating permissions which would allow an undisturbed continuation of our scientific experiments.

Receivers, Digital Hardware and Software

Further adjustments and fine tuning of the cryogenic GaAsFET preamplifier stages at the remote site receivers has yielded a considerably stable and very low system temperature of 25-35 Kelvin.

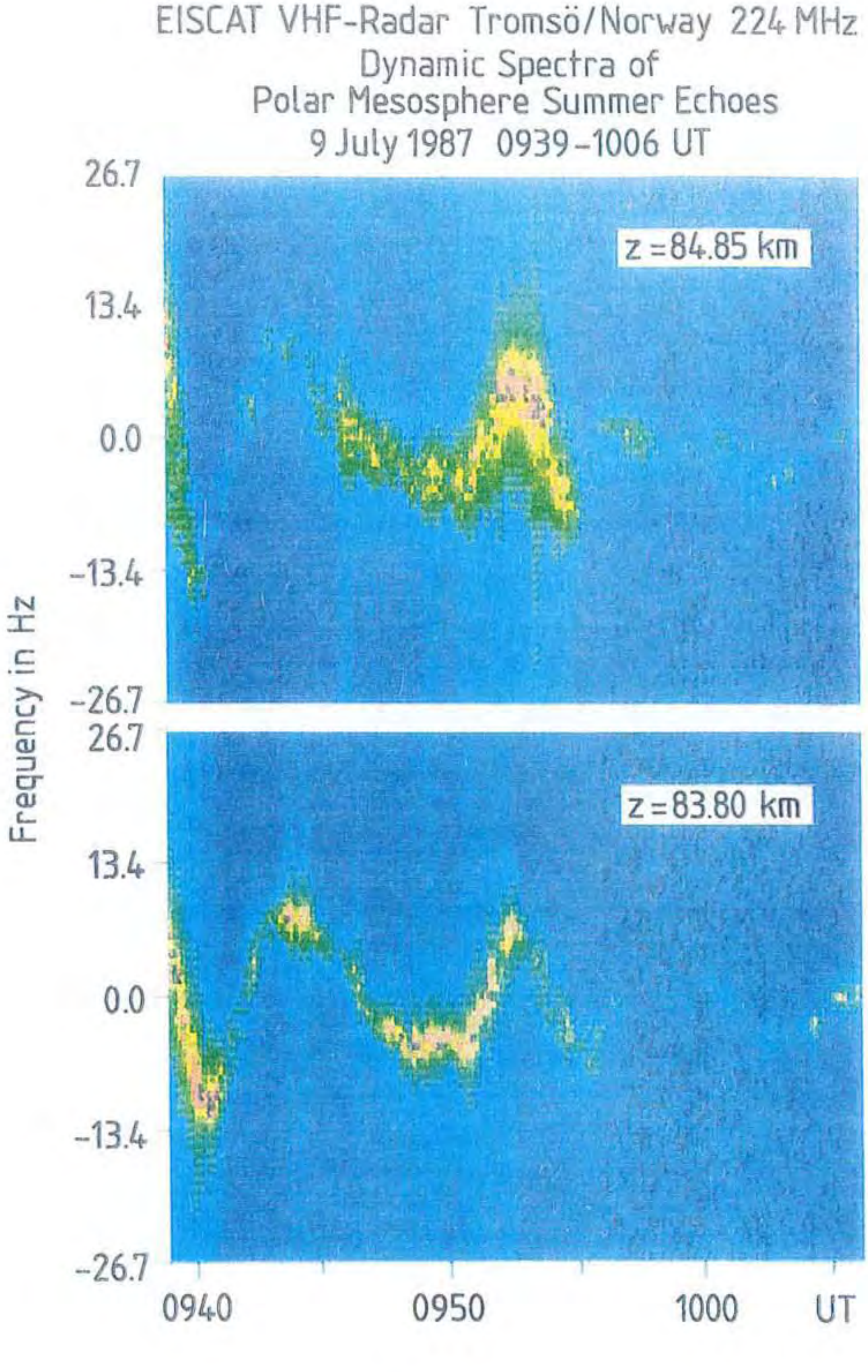


Fig. 2. The first observations of coherent echoes from the mesosphere with the EISCAT VHF Radar in summer 1987. These dynamic spectra display the intermittency and the wavelike oscillations of the scattering regions. The red colour indicates signal levels, which are an order of magnitude above the noise level. The Doppler frequency 26.7 Hz corresponds to a vertical velocity of 17.9 ms^{-1}. *See pages 20-21 for more detailed explanations (there PMSE).*

Combined with the exceptionally better reliability as compared to the previous parametric amplifiers and with the improved calibration noise injection system, they comprise one of the major improvements of the remote receiving sites. A modified version of these preamplifiers is constructed for Tromsö and should substantially reduce the system noise after its implementation in spring 1988. Several possibilities to substitute the time standards of EISCAT, still relying on expensive Cs tubes, were further examined, such as obtaining timing signals from the Global Positioning Satellite system.

The improvement and development of digital hardware and software continued in the same manner as we have become accustomed to from previous years' experience. Quite a lot of impressive results were achieved, such as the amelioration of the correlator loading problem, the reliable change of correlator programs during experiment operation, the automatic recovery of the correlator and the radar controller after breaks, an improved stability and immunity of the CAMAC system (and particularly the computers) to transmitter crowbars. The implementation of an on-call operation-alarm and monitoring system in Kiruna, more reliable inter-site experiment control, and communication of transmitter operating parameters to the remote sites as well as computer telex messages between the sites made the system even more user-friendly. The coded-long-pulse modulation technique was tested. New real-time graphics displays with inter-site access, the preparation of special data taking programs for radio astronomy observations and the loading of preselected data series (e.g. code sequences) into the buffer memory to allow on-line decoding are further advances. The phase-lock of the Norsk Data computer central processing units to the EISCAT real-time clocks now provides an exact synchronization of the computers to the radar control system.

Some evolutionary technical developments, such as the design of the digital chirp synthesizer for improved plasma line studies and of the multi-channel finite-impulse-response integrator/decoder (acronym: MUFFIN) made substantial progress. The final version will allow on-line preprocessing of most complicated phase-coding schemes such as those of the alternating code. More details of these evolutions are described in the special section on technical developments in the Appendix of this Annual Report.

The new Norsk Data computers which were installed in 1986 are a welcome improvement, not only because of their larger capacity and higher speed but particularly since they have greatly contributed to the increase in reliability of our experiment operation. Occasional break-downs are fixed promptly and properly within the service contracts.

Operations

During the year 1987 EISCAT was operated for 1146 hours in Common Programmes (UHF only) and for 804 hours in Special Programmes or special EISCAT programmes (for detailed diagrams depicting the 1987 operation see the special section on pages 58 to 60 in the Appendix). 231 hours of these 804 Special Programme hours were with the VHF radar and the remaining 573 hours were with the UHF radar. This operation adds up to a total of 1950 hours of experimental data taking, which is close to the allocated 2000 hours per year. It is assumed that less Special Programmes were run than the apportioned 1000 hours because scientists might have expected more frequent access to the VHF radar system.

The development of the Special Programme and the Common Programme operating time over the 7 years of EISCAT operation can be followed in the diagram of Fig. 3. We also notice from this diagram that the Special Programme time of VHF radar experiments has obviously been rising during the three years after the first operation of the VHF radar. The distribution of Common Programme time between CP-1, CP-2 and CP-3 (see the Operation and Analysis overview in the Appendix on pages 61-62 for an explanation of these three Common Programmes) was 41%, 19% and 39%, very close to the prescribed ratio 40 : 20 : 40.

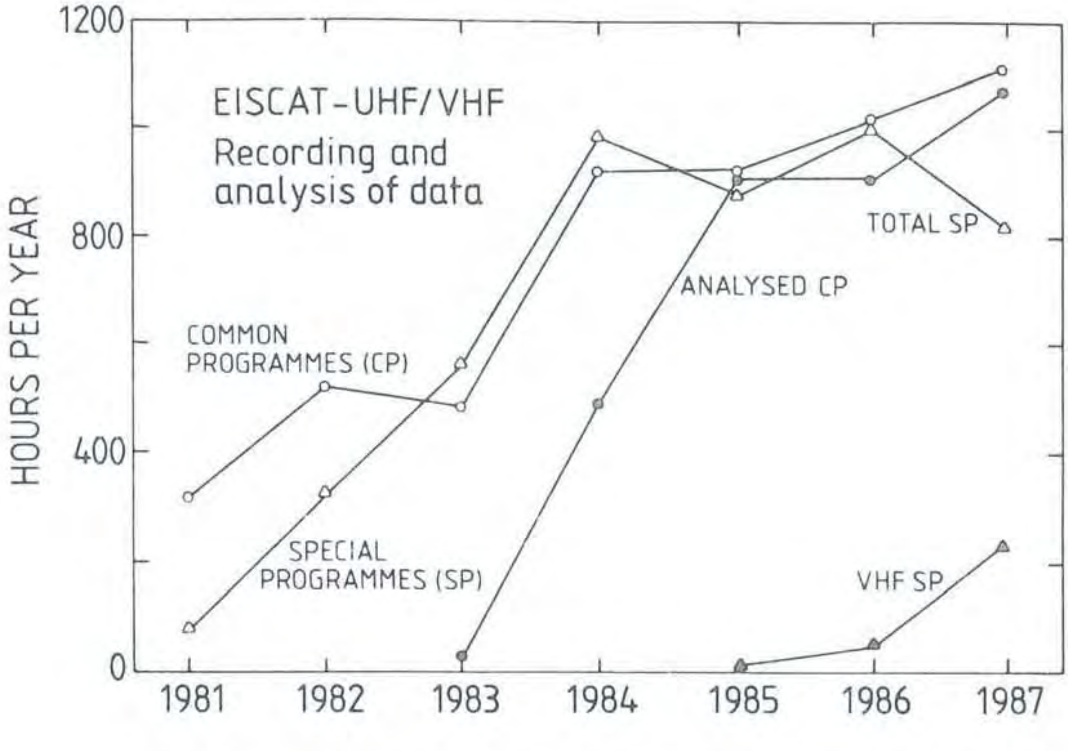


Fig. 3. Development of the yearly operating hours of Common Programmes, the analysed Common Programme data (UHF radar), and the total Special Programme operations (UHF and VHF radar). The Special Programme operations with the VHF radar are traced separately.

The Special Programme time used and accounted in the year 1987 was:

Germany:	236 hours (29.4%)
United Kingdom:	210 hours (26.1%)
Norway:	102 hours (12.7%)
France:	99 hours (12.3%)
EISCAT:	62 hours (7.7%)
Finland:	49 hours (6.1%)
Sweden:	46 hours (5.7%)

In 1987 some 16 campaigns of special experiments were performed. Some of the special scientific goals of these campaigns were: auroral arc studies, high altitude VHF radar observations, sporadic E-layer investigations, atmospheric gravity wave studies, search for coherent E-layer echoes with the UHF radar, plasma-line observations with the UHF and the VHF radar, ion composition measurements using the new alternating code pulse scheme, the Middle Atmosphere Cooperation campaigns MAC/SINE (Summer in Northern Europe) and MAC/Epsilon for studies of the D-region and the mesosphere in combination with other ground-based instruments and rockets launched from the Andöya Rocket Range.

In addition to the usual regular Common Programme operations for 24-36 hours, two longer Common Programme runs took place over several days, one related to the worldwide project GISMOS (Global Incoherent Scatter Measurements of Substorms) in the beginning of June 1987 and one at the end of September 1987 related to LTCS (Lower Thermosphere Coupling Study), which is a project of the WITS program (World Ionosphere Thermosphere Study) of SCOSTEP.

In addition to these Special and Common Programme operations, 9.5 weeks of system maintenance and repair took place and another 6 weeks were used for the installation of the rebuilt Valvo VHF klystron. Furthermore, some time was used for general radar and experiment tests, particularly to develop the three new Unusual Programmes, UP-1 for D-region observations, UP-2 for auroral arc and related studies and UP-3 for high resolution sporadic E-layer studies. These Unusual Programmes are supposed to be started at very short notice as soon as the suitable geophysical conditions exist. Also another new Common Programme, CP-4, was introduced, which is based on the Special Programme SP-UK-POLAR and covers the latitudes up to almost 80° N, corresponding to about 77° invariant latitude.

The Special Programme time which has been accumulated per Associate from the beginning of operations in 1981 until the end of 1987 is:

United Kingdom:	1209 hours (27.3%)
France:	975 hours (22.0%)
Germany:	892 hours (20.2%)
Norway:	495 hours (11.2%)
Sweden:	395 hours (8.9%)
Finland:	241 hours (5.5%)
EISCAT:	219 hours (4.9%)

The total number of experiment operation hours with data taking accumulated to about 9800 hours from the beginning of the operations in 1981 to the end of the year 1987. These consist of about 4400 hours of Special Programme operation and of about 5400 hours of Common Programme operation. It appears that this is a quite impressive number, which is confirmed by the frequently received comments and reports from visiting scientists who express their satisfaction with the reliable and outstanding operation of the EISCAT radar system. Our remaining desire is to bring the VHF system up to maximum power such that the long lasting requests for high altitude and high latitude observations can also be fulfilled soon.

Data Analysis

The on-line analysis procedures were further developed. Now one general purpose program is used for the analysis of all Common Programmes. This program is also available for Special Programme analysis which visitors can do at the EISCAT sites or at Headquarters. During some experiments the analysis program and a suitable graphics program were used to study the temporal development of the ionospheric parameters in quasi real-time. In addition to the standard real-time graphics display this provides helpful support for real-time decisions during campaigns which aim for particular geophysical events and conditions.
All the Common Programme data of 1987 are analysed which adds up to about 1070 hours of data on electron density, electron temperature, ion temperature and ion velocity from Tromsö, 1049 hours from Kiruna and 1013 hours from Sodankylä. The analysed data of 6 of the total 27 Common Programme runs are World Day data and tape copies were sent to the Incoherent Scatter Radar Data Base at NCAR in Boulder/USA. The analysis of Common Programme data of earlier years is continuing at Headquarters and the hours of analysed data is also displayed in Fig. 3. In total, about 3400 hours of Common Programme operation from all sites (Tromsö, Kiruna, Sodankylä) are analysed, which is about two thirds of all existing Common Programme data. The summary listing of analysed data in the Appendix on pages 63-66 gives more details of when these Common Programmes were run.

A Brief Summary of the Scientific Output and Some Particular Scientific Experiments

During the experiment operation and the subsequent analyses we have encountered many exciting geophysical events and several new scientific discoveries were made. Part of these are due to the extra-ordinary technical capabilities of the EISCAT radars. In the section on scientific results quite a few details are described. Other results are treated in great detail in theses, reports and notes, of which some 20 were published in 1987. Additionally, 34 scientific papers were published in 1987 in the refereed literature (see Fig. 4). Almost 50 publications have been accepted or are being submitted to Journals for publication in the year 1988. Between 1981 and 1987 some 140 publications have appeared which deal with results obtained with EISCAT or matters referring to EISCAT.

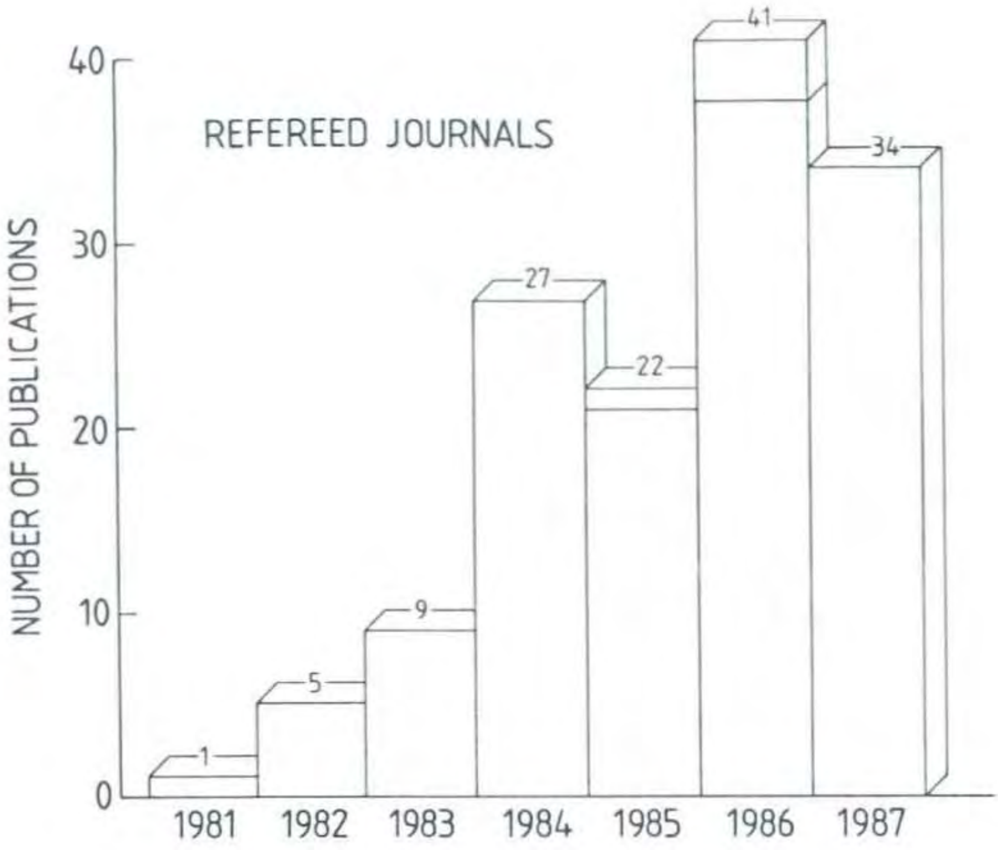


Fig. 4. Number of publications dealing with EISCAT science. The column separations in 1985 and 1986 indicate supplements.

Only a few scientific highlights should be mentioned here which have an influence on the design of the data taking and analysis procedures which we have to apply. These are for instance the quite frequently observed non-Maxwellian spectra, the occurrence of coherent echoes from the E-region and from the D-region, the possibilities for improved plasma-line observations (with the UHF and the VHF radar) and the application of the alternating code, allowing for improved range and spectrum resolution.

Meetings, Workshops and Visitors

Many of the technical and operational developments are usually discussed and evaluated by EISCAT staff at EISCAT's traditional Annual Review Meetings. During these meetings scientist guests from the Associate countries also participate, who report, together with the staff scientific advisors, about recent scientific results and interpretations. In addition to the direct interaction between staff and visitors during Special Programme campaigns and

Fig. 6. Prof. E.W.J. Mitchell, Chairman of SERC, is shown the EISCAT VHF antenna by the Director.

operations, these Annual Review Meetings constitute a proper means to inform the EISCAT staff directly about the scientific outcome of experiments and requirements for evolutions.

The Annual Review Meeting 1987 took place in Skibotn near Tromsö in Norway and we notice all the participants on the photo of Fig. 5. Besides the Annual Review Meeting, we usually have one or two Executive and Budget Meetings at Headquarters, at which the Site Leaders, the Head of Computer Operations, the Business Manager and the Assistant Directors negotiate with the Director about financial, administrative, personnel, operational and organizational matters.

EISCAT staff participation at external meetings mainly consisted of attendance at courses and seminars by the technicians, programmers and engineers. The scientific staff participated actively at several workshops and conferences, such as the GISMOS/GITCAD Workshop, the Workshop on Ionospheric Informatics, the World Ionosphere Thermosphere Study Workshop, the Workshop on Gravity Waves and Turbulence as well as the IUGG/IAGA and the URSI General Assembly.

The major event in 1987 was the Third EISCAT International Workshop held in March 1987 in Bad Lauterberg, W.Germany. We are indebted to our colleagues of the Max-Planck-Institut für Aeronomie for organizing this excellent workshop at which some 80 scientists from all EISCAT Associate countries and from abroad participated. It is very obvious that this kind of workshop brings together all the experts working with EISCAT as well as with the other related radars used to study the upper atmosphere. It was appreciated that the two former Directors of EISCAT, Prof. Tor Hagfors and Dr. Murray Baron, also participated.

In April 1987 we had the honour of the Chairman of the Science and Engineering Council of the United Kingdom, Prof. E.W.J. Mitchell, visiting EISCAT in Kiruna and Tromsö. The Director of EISCAT explained to him the operation of the EISCAT radars (see Fig. 6), and other EISCAT staff presented to him and his company further overviews of operation scientific experiments. In July 1987 the Director of the Rutherford Appleton Laboratory/UK, Dr. P.R. Williams and his Associate Director, Dr. J.E. Harries, visited the

Fig. 5. The participants of the EISCAT Annual Review Meeting 2-5 March 1987 in Skibotn, Norway.

From left to right, **front row:** U.-P. Hoppe (standing most left) and T. Hansen (guests from Norway), U.-P. Lövhaug (T), B. Hanssen (T), C. La Hoz (T), J. Röttger (H), A.-L. Tiuraniemi (S), A. Knutsen (T), G. Hultqvist (H) and P. Collis (H). **Back row:** A. Farmer (guest from the UK), T. Laakso (S), H. Boholm (T), G. Wannberg (guest from Sweden), N. Sunna (H), J.B. Henriksen (T), M. Postila (S), M. Halvorsen (T), E.R. Albrigtsen (T), C. Hall (guest from Norway), S. Furan (T), J. Markkanen (S), A. Stenberg (T), I. Wolf (K), L.-G. Vanhainen (K), R. Larsen (T), A. Björk (K), K.-O. Johansson (K), R. Jacobsen (T) and M. Rietveld (guest from W. Germany).

H indicates staff from Headquarters, K from Kiruna, S from Sodankylä and T from Tromsö.

Fig. 7. The EISCAT Scientific Advisory Committee visited the EISCAT site during its autumn meeting in Tromsö (From left to right: K. Schlegel, W. Baumjohann, H. Opgenoorth, J. Röttger, P.J.S. Williams, G. Wannberg, D.T. Farley, W. Schmidt, C. La Hoz, D. Fontaine, N. Björnå, W. Kofman and J. Kangas).

Tromsö site. We appreciate the comments of these distinguished persons that EISCAT is an excellent example of a well-run and splendid international organization at the forefront of world science with well-formulated plans for the future.

The 33rd Meeting of the EISCAT Scientific Advisory Committee took place in Tromsö in October 1987. One day of the meeting was held at the Ramfjordmoen site (Fig. 7) and the SAC members used this opportunity to talk with the site staff and to experience at first hand the site organization and operation.

Personnel and Budget Developments

In July 1987 Dr. Tauno Turunen finished his three years term as Assistant Director of EISCAT. Tauno had been deeply involved in many technical and experimental details of our operations and had very substantially contributed to improvements of the instruments and the data acquisition procedures. Just one of Tauno's many achievements, namely the development of the so-called GEN algorithms and correlator programs, should be mentioned here again. This sophisticated data acquisition algorithm permits the combination of long pulses, multi-pulses, Barker-coded pulses and power profiles to be processed in a flexible and optimised way and allows the EISCAT system to be used at maximum capabilities. Tauno was also involved in the implementation of the most elaborate alternating code data acquisition procedure. His achievements are embodied in the present Common Programme schemes, which all use the GEN algorithms as also do most of the Special Programmes. The outstanding contributions of Dr. Tauno Turunen were honoured in a special colloquium which was held in October 1987 in Kiruna. We would all like to thank Tauno for his important services.

His successor as Assistant Director, Dr. Gudmund Wannberg, joined EISCAT in July 1987. Gudmund had already been involved with the EISCAT facilities for many years as the leader of the Kiruna site, and he is well acquainted with the EISCAT instrumentation and experiments. We are confident that the new Assistant Director will contribute substantially to the further evolution of our facilities.

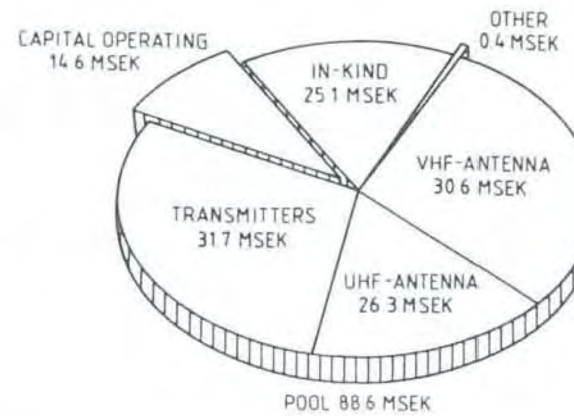
A total of 33 EISCAT staff positions are distributed over Headquarters (10, whereof 1.5 are temporary), Tromsö site (13), Kiruna site (5) and Sodankylä site (5). In addition to the position of the Director, two Assistant Directors and the Business Manager, they consist of 4 scientific, 3 engineering, 11 technical, 5 computing, 4 administrative/secretarial and 2 caretaker positions. In 1987, very few positions were temporarily vacant and in general the personnel situation was very stable.

The capital investments for the EISCAT facilities have accumulated to a total of 128.7 million Swedish Crowns (MSEK) by 1987. They are distributed as shown in the diagram of Fig. 8.

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 15.4 MSEK in 1987 (see Fig. 8). These operating costs consist of 7.5 MSEK for salaries, 4.3 MSEK for operations and spare parts and 3.6 MSEK for administration. The balance sheet as of 31 December 1987 is given in the Appendix on page 72.

The investments and the operations costs of EISCAT are shared between the Centre National de la Recherche Scientifique, France (25%), Max-Planck-Gesellschaft, W.Germany (25%), Science and Engineering Research Council, UK (25%), Naturvetenskapliga Forskningsrådet, Sweden (10%), Norges Almenvitenskapelige Forskningsråd, Norway (10%) and the Suomen Akatemia, Finland (5%).

Capital Investment



Operating Costs

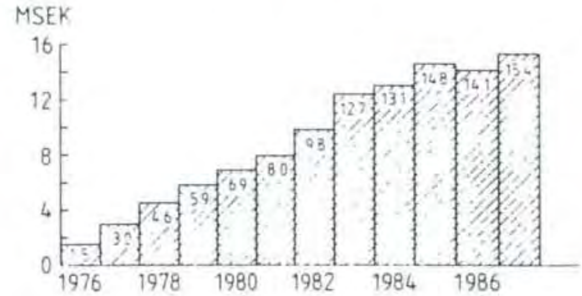


Fig. 8 Capital investment and development of operating costs.

OBITUARY

In March 1987 we received the sad news that our fellow scientist and colleague

Johan Nordling

of Uppsala had died in a tragic accident when participating in a scientific campaign at the Arecibo Observatory. We lost with Johan Nordling a very promising young scientist. The loss particularly struck all attendants of the Third EISCAT International Workshop, where Johan had intended to present his scientific results of using EISCAT as diagnostic instrument during Heating experiments. We will remember Johan as a very congenial and pleasant colleague.

SCIENTIFIC RESEARCH

On the pages which follow, many scientific achievements, which were compiled from contributions received from scientists in the EISCAT associate countries and from EISCAT staff, are summarized. Reference is made to published papers and reports (see list in the Appendix on pages 67-70) by inclusion of the authors' names and the entry of the year of publication. Contributions on ongoing work or in the publication process are marked by inclusion of the researchers' names and the titles of papers if they are known to be in print.

New Experimental Techniques

Alternating Code

The first alternating code experiment has been designed and implemented in 1987 at EISCAT. The experiment consists of a 16-pulse alternating code group satisfying the strong condition (Lehtinen and Häggström, 1987). The code is changed at two-second intervals leading to a cycle time of 64 s. The sampling period is 10 μs leading to a possibility of using "fractional" lags and multiple spatial resolutions. The first test, performed on 30 April 1987, produced good data (see Figures 9 and 10) and a longer run of 24 hours was performed in October 1987. Preliminary analysis shows that it is possible to analyse ion composition with 20 min

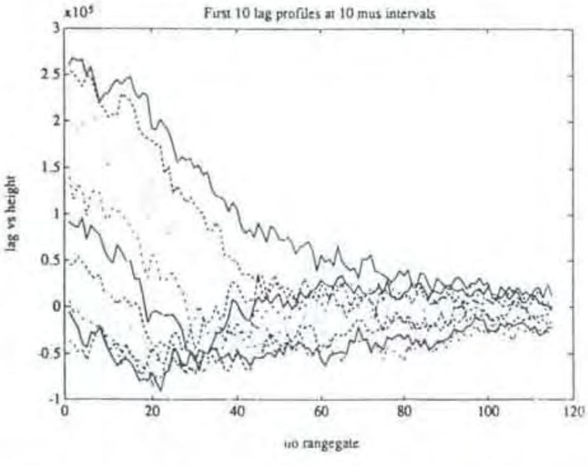


Fig. 9. Lag profiles produced by an alternating code experiment. Separation of range gates is 4.5 km and integration time is 64s.

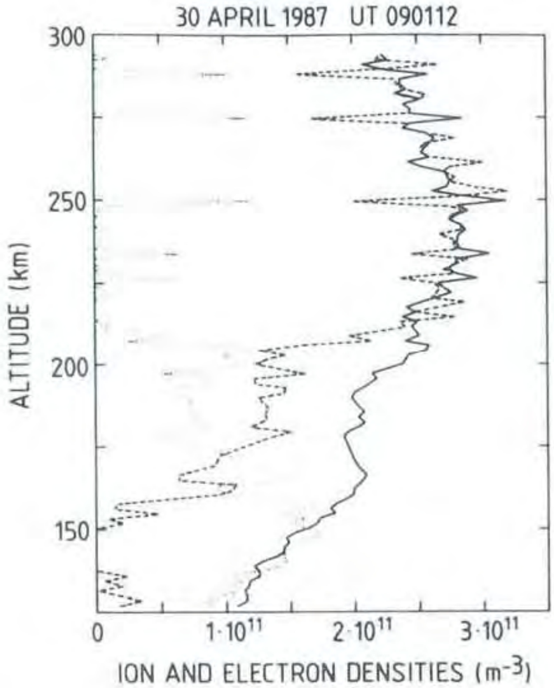


Fig. 10. Molecular (30.5 AMU, dotted line), atomic (16 AMU, dashed line) and electron (full line) densities analysed from an alternating code experiment. Integration time is 20 min.

time resolution and 4.5 km range resolution leading to 10% error bars. (Lehtinen, Vallinkoski, T. Turunen and Häggström).

Common Programme Design

A new kind of EISCAT experiment has been tested in 1987 in order to suit the objectives of the international Lower Thermosphere Coupling Study, LTCS. It combines a latitudinal scanning of the ionosphere with a vertical sounding along the magnetic field line of Tromsö in the middle of the scan. The main purpose of this experiment is to observe the dynamics of the neutral atmosphere while exploring simultaneously the electrodynamic environment. The total cycle time for E-region measurements and plasma convection measurements in the F-region is 30 minutes. In the latest version the correlator program is similar to that of CP-1-H, and the radar controller program changes at different positions of the scan in order to maintain a roughly uniform altitude coverage like in the Common Programme CP-3. After the new Common Programme CP-4 (basing on SP-UK-POLAR) has been implemented to allow measurements as far as 80°N latitude, the described experiment for lower thermosphere coupling study should become the new Common Programme CP-5 (Lathuillère, Kofman, Lilensten, La Hoz).

Range Ambiguity Reduction

Barker-coding is an efficient way to design multi-pulse experiments with a high range resolution. Drawbacks of this technique are the range ambiguities of the code, which can be clearly seen in the residual of the data fitting procedure. The resulting systematic errors have been studied and a correction method to remove their effects has been developed. This method was applied to data from the ESLA-T4 experiment, and it was found that the residual of the fitting procedure is reduced by an order of magnitude. It is concluded that the correction works well for altitudes below 120 km, where Barker coded pulse schemes are most frequently applied (Huuskonen, Pollari, Nygrén and Lehtinen, Range ambiguity effects in Barker-coded multi-pulse experiments with incoherent scatter radars).

Improved Parameter Estimation

It has become possible to estimate the effect of noise on the estimation of errors of plasma parameters deduced from incoherent scatter measurements. This is possible with greater precision than so far by using Bayesian parameter estimation in the context of the statistical inversion theory. The estimates of plasma parameters are obtained by fitting simultaneously several parameters to the measured autocorrelation functions. The estimation errors may be obtained by calculating the linearised a-posteriori errors from the theoretical expressions of the plasma autocorrelation functions for the fitted values. Since the expression of the a-posteriori errors does not depend on measured values, the method can be applied to a variety of experimental situations. For example, Table 1 shows the estimation errors in a few

N_e/N_o	T_i/T_o	T_e/T_i	O^+	v/v_o
0.014	fixed	fixed	fixed	fixed
0.015	0.026	fixed	fixed	fixed
0.035	0.052	0.072	fixed	fixed
0.117	0.817	0.282	0.936	fixed
0.308	0.858	0.599	2.058	1.073

Table 1. Estimation errors of the plasma parameters for a non-drifting plasma. The fixed parameters were $N_e=N_o=10^{11}\ m^{-3}$, $T_i=T_o=300$ K, $T_e/T_i=1$, $v=0$ Hz and O^+-content 0.3. v_o is 2500 Hz.

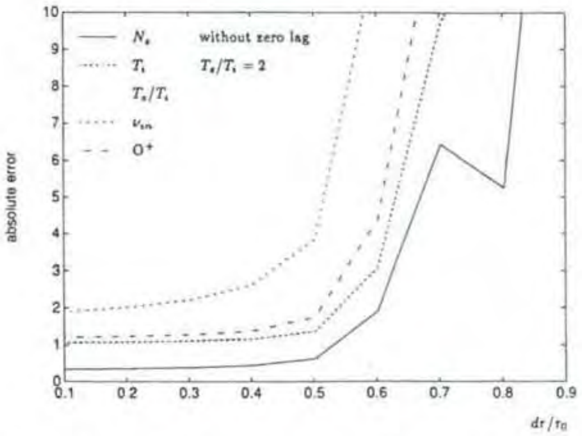


Fig. 11. The behaviour of errors in 5-parameter fits as a function of the sampling interval for $T_e/T_i=2$. The zero lag data is used in the inversion.

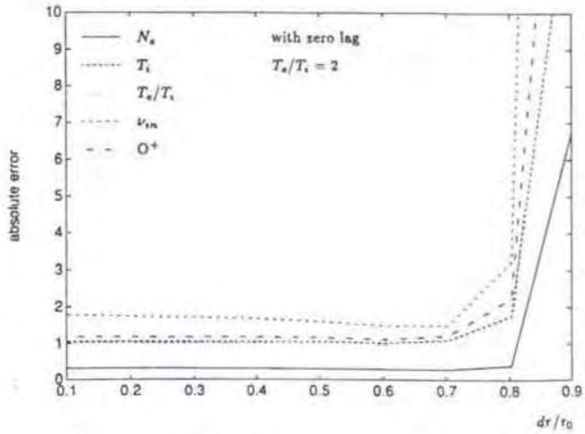


Fig. 12. The behaviour of errors in 5-parameter fits as a function of the sampling interval for $T_e/T_i=2$. The zero lag data is not used in the inversion.

typical fits of the plasma parameters. In particular, the method can be applied to estimate the requirements on the measurement of the plasma auto-correlation functions to find the minimum possible lag resolution and lag extent. Figures 11 and 12 show some examples of these computations. (Vallinkoski).

A mathematical theory of measurements is under development. The alternating codes and the multi-pulse zero lag inversion method, as well as the research concerning minimal lag resolution and lag extent originally emanated from a study of the statistical inversion theory. A mathematical paper concerning conditional probabilities for generalized stochastic processes has been prepared. It is believed that this ongoing research on the "Theory of Measurements" will give rise to many new methods which can be used to maximize the information that can be obtained from incoherent scatter radar measurements. Here EISCAT provides a large and excellent data set to demonstrate the new ideas in practice (Lehtinen, 1987; Rantanen, 1987; Päivärinta, Somersalo and Haario).

Mesosphere and D-region Studies

Polar Mesosphere Summer Echoes

In addition to the usual incoherent scatter echoes from the D-region strong coherent echoes were observed with the EISCAT VHF radar from altitudes between 80 km and 90 km during the MAC/SINE campaign in summer 1987. Following conventional theories of turbulence scattering applied to the standard mesosphere-stratosphere-troposphere (MST) radars, such mesospheric echoes should not be detectable at 224 MHz because electron density irregularities caused by neutral turbulence should not

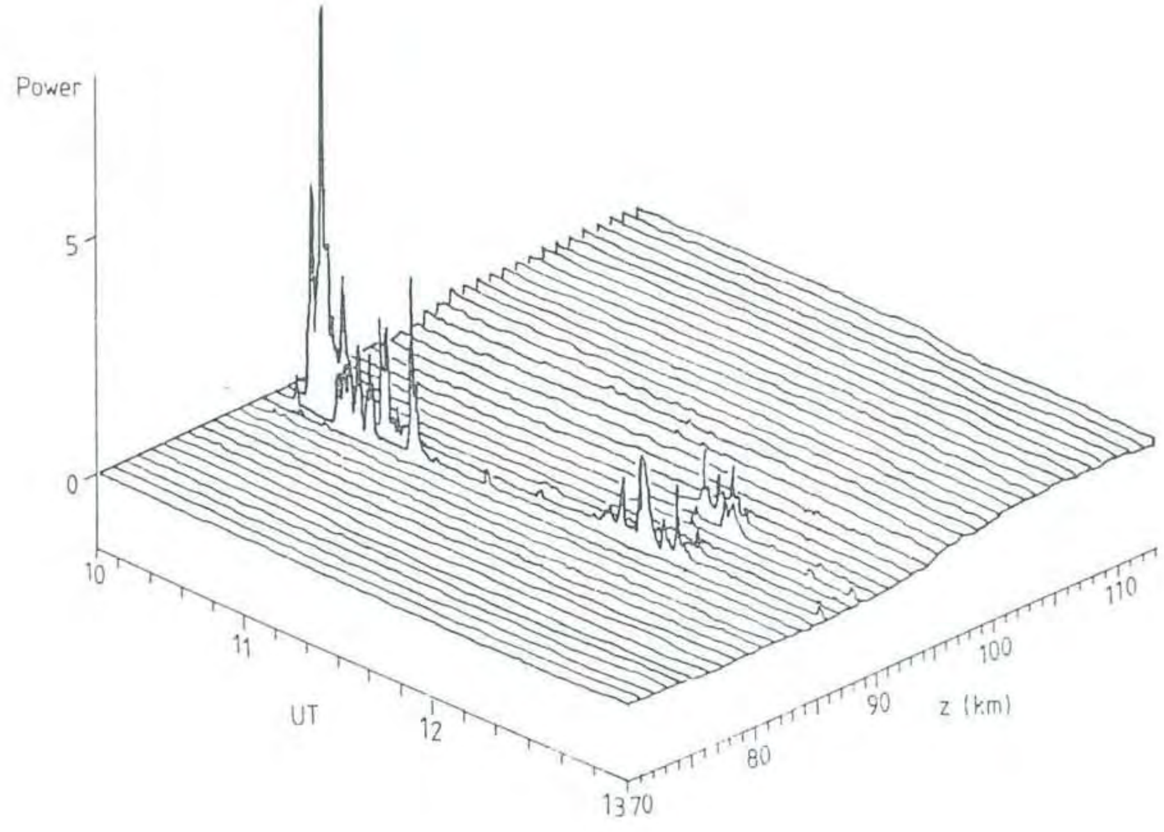


Fig. 13. Range-normalized power profiles showing intense coherent Polar Mesosphere Summer Echoes detected with the EISCAT VHF radar between 80 and 90 km altitude.

be present at the corresponding radar Bragg wavelength of 67 cm. Heavy cluster ions, however, which do occur in the cold arctic mesopause region (confirmed by EISCAT UHF radar measurements, see page 23), could have the effect that the ambipolar diffusion of electrons would be weakened. Fluctuations in the electron gas, resulting from mesospheric neutral air turbulence, could then extend to much smaller scales than usually possible. As a result, coherent echoes from the mesosphere might also be detected at the short 67 cm Bragg wavelength of the EISCAT VHF radar (Farley, Kelley, and Röttger, 1987).

In Fig. 13 the temporal development of a range-normalized power profile measured with the VHF radar and vertical beam is shown, which indicates the gentle increase of the background electron density above about 85 km. On top of this normal electron density profile, which is caused by incoherent scatter, enhanced intermittent echoes occur. Their power can be two orders of magnitude stronger than the background echo power due to incoherent scatter, and their spectra are much narrower. These coherent echoes, which in some way are related to mesospheric turbulence or noctilucent clouds, are called Polar Mesosphere Summer Echoes (PMSE), and correspond to similar echoes detected earlier and elsewhere with 50 MHz MST radars. The occurrence of the PMSE on 224 MHz is supposed to give support to the suggested extension of electron gas irregularities to scales which are smaller than those of neutral gas irregularities.

Fig. 2 on page 7 displays dynamic spectra measured with vertical beam. This figure illustrates the intermittency of the PMSE, their variable spectrum width and their often oscillating Doppler shift. The latter is due to atmospheric gravity waves. The investigations of these PMSE in terms of the interrelation of waves and turbulence contributes to our understanding of the dynamical and chemical structure of the mesopause region (Hall, Hoppe, La Hoz, Röttger, First observations of summer polar mesospheric backscatter echoes with a 224 MHz radar).

Some of the polar mesosphere summer echoes are characterised by an amplitude variation of several 10 minutes period. A periodicity of 45 minutes, which was observed in the PMSE, was also detected in the geomagnetic H-component recorded at Tromsö, but its relationship to the VHF echoes has yet to be established (Rishbeth et al., EISCAT VHF radar observations of periodic mesopause echoes).

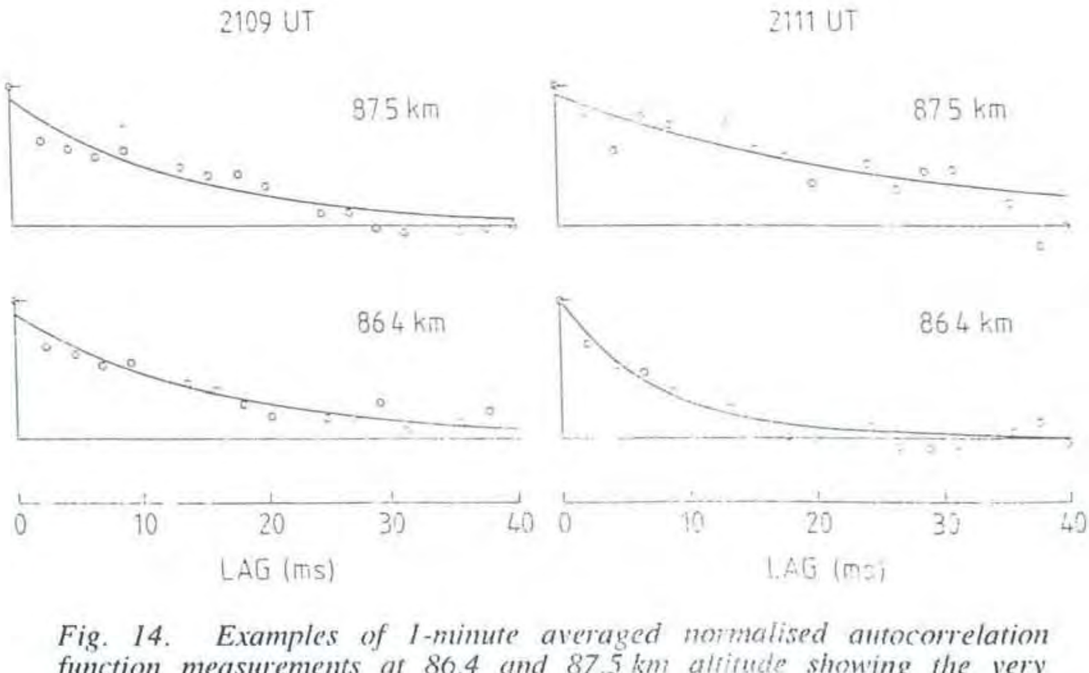


Fig. 14. Examples of 1-minute averaged normalised autocorrelation function measurements at 86.4 and 87.5 km altitude showing the very large correlation times indicative of heavy positive ions.

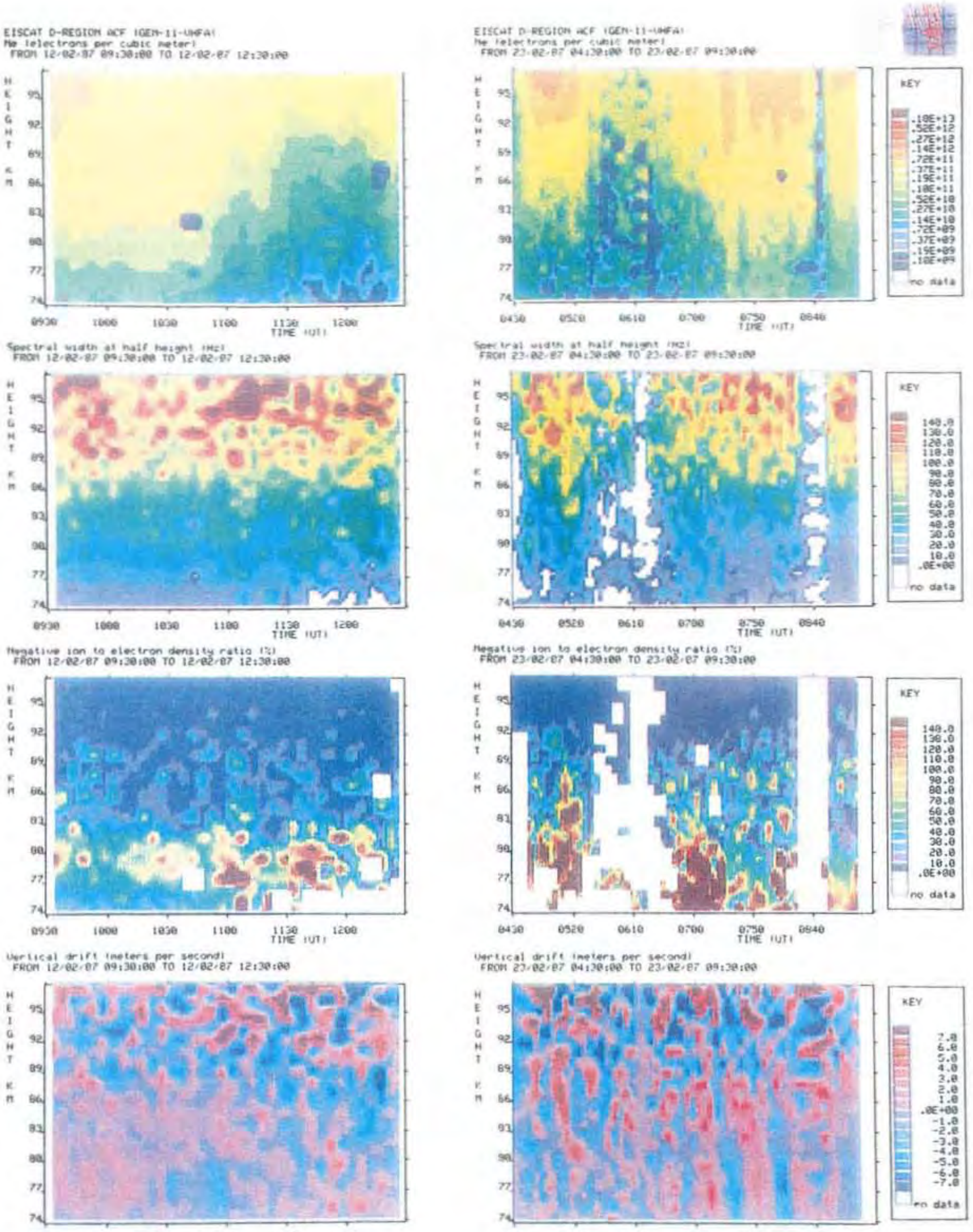


Fig. 15. Parameters of the mesosphere (electron density, spectrum width, negative ion and density and vertical ion drift) derived from VHF measurements made on 12 February 1987 (left-hand column) and 23 February 1987 (right hand column).

Heavy Positive Ions

Summertime UHF radar measurements of abnormally long correlation times of echoes from altitudes near the mesopause (Fig. 14) were interpreted as the effect of very heavy positive ions with mean masses of several hundred AMU. The circumstances of the experiment were coincident with the observations of noctilucent cloud conditions. The ions were probably hydrated protons with a large number of clustered water molecules attached (Collis, T. Turunen and E. Turunen, Evidence of heavy positive ions at the summer arctic mesopause from the EISCAT UHF incoherent scatter radar).

Atmospheric Gravity Waves

In February 1987 mesosphere observations with the VHF radar were made in a joint campaign of United Kingdom and Norway. The results let suggest, that atmospheric gravity waves can be generated by the solar terminator. Although the system sensitivity was only 12% of the specified one, 5-minute integration was sufficient to determine the spectra of the scattered signal over the height range 74-92 km. Profiles of electron density, negative ion concentration and vertical plasma velocity were calculated (Fig. 15). At dawn on 23 February 1987 the velocity profiles showed the descending wave-fronts of an atmospheric gravity wave. Analysis confirmed that the horizontal wave velocity was equal to the velocity of the solar terminator. A gravity wave, which could be generated by the sub-sonic passage of the terminator, has never before been reported. The terminator is only subsonic at high latitudes, so EISCAT is ideal for observing this phenomenon (Hall et al., 1987).

A 12-hour special D-region experiment using the GEN-11 modulation with the EISCAT VHF radar was successfully run on 27 April 1987. Some precipitation events, which were also recorded by riometer, occurred during the early evening. A preliminary analysis of the D-region data reveals well-defined atmospheric gravity wave oscillations with 20 minutes period and vertical phase velocity of around 30 ms^{-1}. The downward progressing phase of this wave event is typical and indicates a source below the lowest height of observation. The wave has an upper cut-off just above 90 km, which can be attributed to increased damping in the mesopause region or possibly to nonlinear effects caused by electrodynamical processes (E. and T. Turunen).

E-region, Irregularities and Waves

Coherent Echoes at 933 MHz

E-region coherent backscatter at 933 MHz has been detected for the first time by EISCAT. Pointing the Tromsö antenna at a very low elevation angle of 10° towards NE, magnetic-field aspect angles of 4°-6° could be achieved using all three EISCAT sites. Coherent echoes from E-region irregularities caused by the two-stream and/or the gradient-drift plasma instabilities had been detected at these aspect angles with lower frequency auroral radars at irregularity scale sizes of 1 m. For the first time such coherent echoes have been detected with EISCAT at 16 cm irregularity wave length. Fig. 16 shows an example of such an event. The backscattered power expressed in apparent electron density was about two orders of magnitude higher than the true E-region electron density, the latter measured before and after the event. The electron and ion temperatures fitted in the usual way from the data obtained during this event, have extremely low apparent values indicating that the spectra of the observed echo must have been considerably narrower than normal incoherent scatter spectra. Fig. 17 shows that the width of these coherent scatter spectra is indeed only half the width of usual E-region incoherent scatter spectra. The spectra are skewed in a typical way as is also observed with the common auroral radars. It is possible with the EISCAT UHF system to obtain the absolute backscatter cross section of the irregularities. Some values are given to the right of the spectra in Fig. 17. The threshold of the Ex<u>B</u> drift to create the 16 cm irregularities is about 50% higher than the one which creates the 1 m irregularities which is in agreement with theoretical estimates. The backscattered power also increases with increasing Ex<u>B</u> drift. Estimates of the aspect angle dependence of the backscatter amplitude using all three EISCAT sites yielded values around 10 dB per degree, in agreement with corresponding auroral radar data (Moorcroft and Schlegel, E-region coherent backscatter at short wavelength and large aspect angle, and EISCAT as a tristatic auroral radar).

Heating by Plasma Waves

Simultaneous observations of auroral E-region plasma waves and electron heating were carried out with the EISCAT UHF radar and the Cornell University Portable Radar Interferometer (CUPRI) operating on 50 MHz. CUPRI was positioned in Sweden to look perpendicular to the magnetic field to observe unstable plasma waves over Tromsö, while EISCAT measured the ambient ionospheric conditions in the unstable region. On two nights EISCAT detected intense but short lived (less

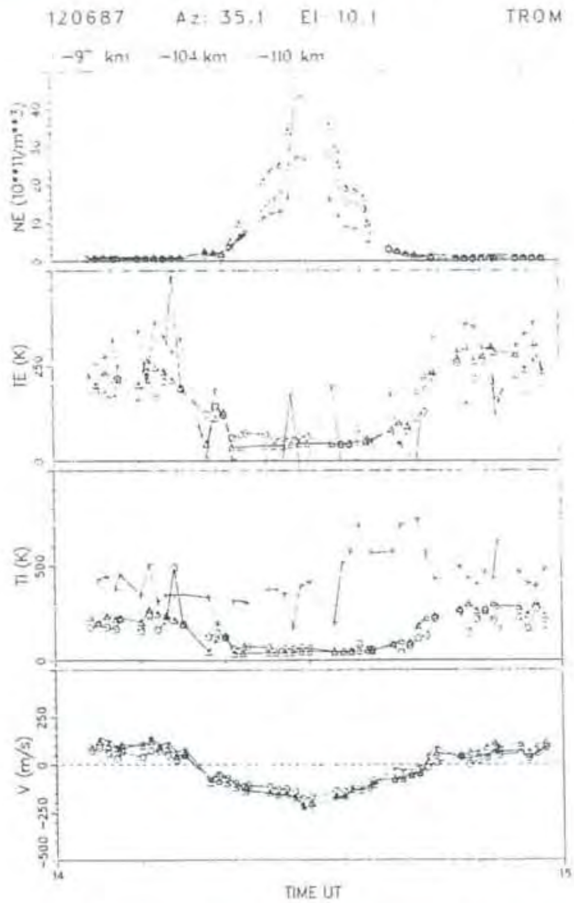


Fig. 16. Coherent echo event detected with EISCAT on 12 June 1987. The figure shows apparent electron density, apparent electron and ion temperature, and the line of sight drift velocity at E-region heights.

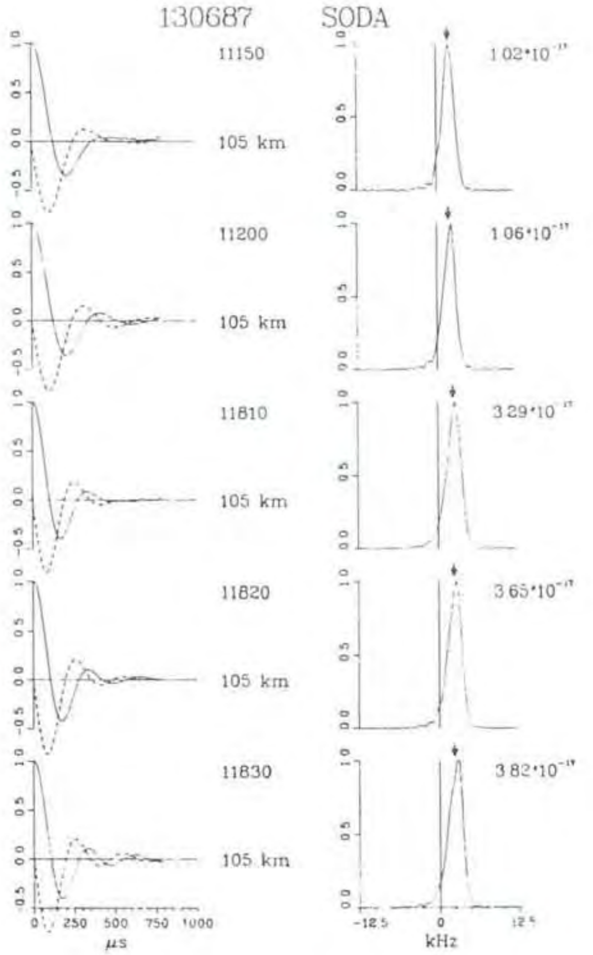


Fig. 17. Examples of coherent scatter autocorrelation functions and spectra measured at Sodankylä in June 1986 with 10 seconds integration time. The arrows indicate the Doppler shift, the numbers to the right of the spectra the volume backscatter cross section of the corresponding 16 cm irregularities in m^{-1}.

than 1 min) electron heating events during which the electron temperature suddenly increased by a factor of 2-4 at altitudes near 108 km and the electron densities were less than $7x10^{10}$ m^{-3}. On one of these nights CUPRI was operating and detected strong plasma waves with very large phase velocities at precisely the altitudes and times at which the heating was observed. The altitudes, as well as one component of the irregularity drift velocity, were determined by interferometer techniques. It is concluded that the electron temperature increases were caused by plasma wave heating and not by either Joule heating or particle precipitation (Providakes, Farley, Fejer, Sahr, Swartz, Häggström, Hedberg and Nordling).

Sporadic E-layers

The horizontal extent and vertical motions of an exceptionally strong sporadic-E layer were studied using measurements from CP-3. Although the resolution of the 60-µs power profile did not allow detailed measurements through the layer itself, the location in latitude and altitude could be accurately mapped. The initial downward and subsequent upward motion of the layer were taken as evidence of the actions of atmospheric tides and ionospheric electric fields, respectively. The surprising observation was that although the layer persisted for many hours, it was very patchy in extent, and could vary from very intense to absent in adjacent antenna positions (Collis and T. Turunen).

The metal ion composition in sporadic-E layers has been studied. The experiment utilized the multi-channel Barker-coded modulation scheme called ESLA-T4, which provides a range resolution of 600 m. Eight sporadic-E layers at altitudes 95 km to 114 km were studied. Heavy ions, most probably Fe^+ ions, were found to be present in most layers with relative abundances of 30% to 80%. One of the layers was probably composed of light metal ions, such as Mg^+. The most interesting event was that two layers were seen simultaneously with a height difference of 2-3 km (Fig. 18). The ion density profiles show that the upper layer was mainly composed of Fe^+ ions whereas the lower layer contained light metal ions, probably Mg^+ (Huuskonen, Nygrén, Jalonen, Bjornå, Brekke, Hansen and Turunen, Ion composition in sporadic-E layers measured by the EISCAT UHF radar).

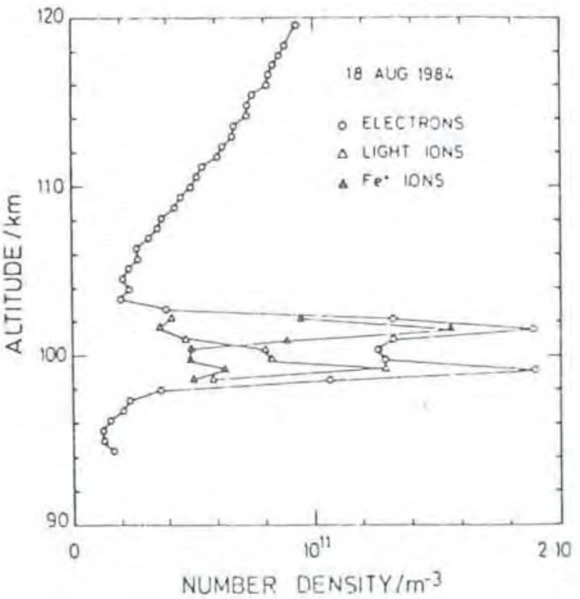


Fig. 18. Altitude profiles of electron density and ion concentration. Two separate layers can be distinguished, the upper one composed mainly of iron ions, and the lower layer possibly composed of magnesium ions.

Auroral Structure and Dynamics

Electric Fields and
Auroral Intensifications

Experiments of latitude scanning covering a narrow range of latitudes, typically about 2 degrees, have a better horizontal resolution (10-20 km) than the usual extended scans. This mode is well suited to explore medium-scale structures such as auroral arcs. For example, a structure of two arcs, revealed by density increases in the E-region, was observed in the radar field of view (see Fig. 19). The electric field component tangential to the structure should remain constant across the structure. This property permits to find out the arc direction. The electrodynamic parameters are then computed in the frame of reference of the arc structure. In particular, the polarization electric fields related to the structure are estimated, and the electric current circulation perpendicular and parallel to the magnetic field lines can be determined (Girard and Senior).

EISCAT measurements were also used to study the relationship between reductions of the F-region meridional wind and auroral intensifications. In particular, the EISCAT measurements showed that the electric field and the neutral wind had consistent patterns of behaviour well before any evidence of auroral brightening. It was suggested that the increased electric field gave rise to increased Joule heating which blocked the flow of the equatorward wind. It was also speculated that these low-altitude changes could act as some sort of precursor in the ionosphere-thermosphere interactions associated with the auroral intensifications (Steen, Collis, Rees and Murphree, What role does the F-region neutral wind play in auroral intensifications?).

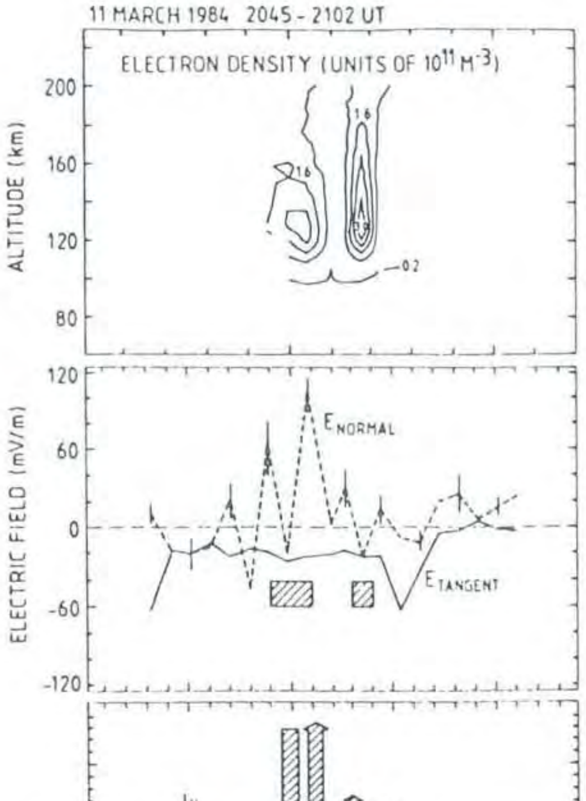


Fig. 19. EISCAT scanned through a structure of two arcs marked by two increases of electron densities in the E-region (top panel). The arc direction is found by solving Maxwell's equations. The components of the electric field tangent and normal to the arc are shown in the middle panel. The electric current circulation in the structure and above it along magnetic field lines is schematically represented in the bottom panel.

Combined Radar and Ground-based Optical Observations of Aurora

The development of an auroral arc, from diffuse to discrete form with subsequent large-scale folding, was recorded by an all-sky camera in Kiruna (Fig. 20). The major fold in the arc propagated eastward directly over the radar. Prior to the main fold, two attempted foldings were evident in the optical data, both of which were accompanied by large increases in F-region ion temperature and the electric field. These observations were taken as evidence that the distortion of the arc was the result of a Kelvin-Helmholtz instability in the magnetosphere. (Steen, Collis and Häggström, On the development of folds in auroral arcs).

During another auroral break-up in the zenith above Kiruna, recorded by a high time-resolution imaging device, EISCAT provided diagnostic information on the poleward propagation of the activity following break-up. It was concluded that the observations were again consistent with the action of a Kelvin-Helmholtz instability, which may go through more than one sequence of activation before being destroyed by the final break-up (Steen and Collis, High time-resolution imaging of auroral arc deformation at substorm onset).

A campaign to measure the relative motion of auroral arcs and the background plasma was carried out in September 1987 using the EISCAT UHF radar and sensitive photographic and TV cameras located at Kilpisjärvi/Finland. On several occasions optical aurora was observed above Kilpisjärvi simultaneously with plasma measurements being made by EISCAT. In Fig. 21 the speed of an auroral arc and the plasma velocity normal to it are compared for one event. The arc moved through the radar beam at about 19:10 UT. The two velocities show significant differences, namely, the plasma moves relative to the arc at some times. (Buchert, Haerendel, Raaf, Rieger and La Hoz).

A movie of EISCAT E-region electron densities and simultaneous all-sky camera images has been produced. The movie shows the development and movement of auroral arcs recorded with an all-sky camera and electron density profiles measured simultaneously with EISCAT (Fig. 22). EISCAT electron density profiles were transposed on 16 mm film with a micro-fiche plotter and this film was then mixed electronically with the original all-sky camera video tape on a second video tape. Whenever the auroral arc moved over the intersection point of the EISCAT Tromsö beam (see Fig. 22) a large increase in E-

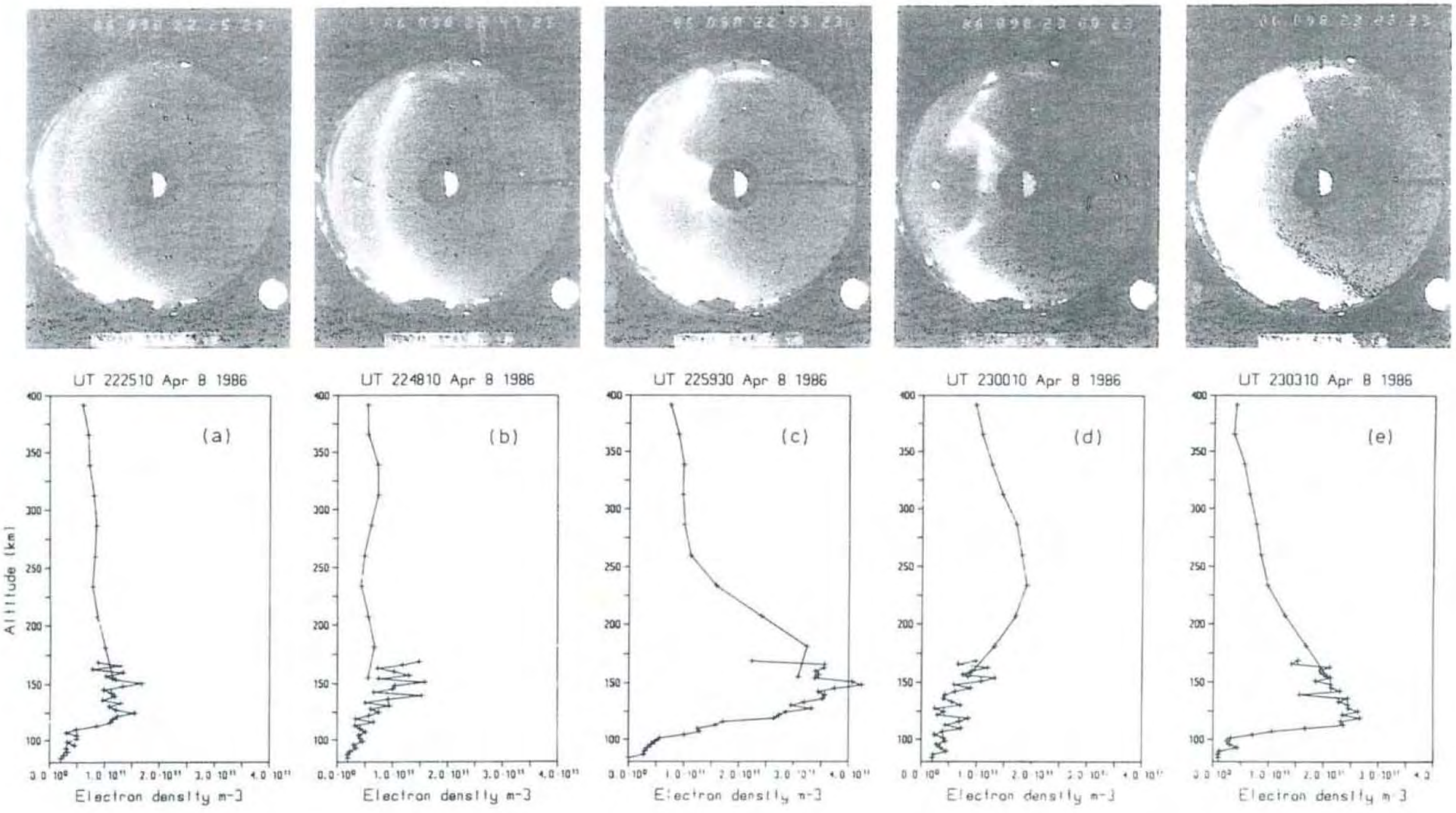


Fig. 20. (Top) An eastward drifting fold in an auroral arc observed by the all-sky camera in Kiruna. (Bottom) Simultaneously measured electron density profiles from EISCAT during the passage of the fold. The leading edge of the fold (panel c) is characterised by increased E-region electron densities, but the hole in the fold (panel d) is associated with broad F-region ionization.

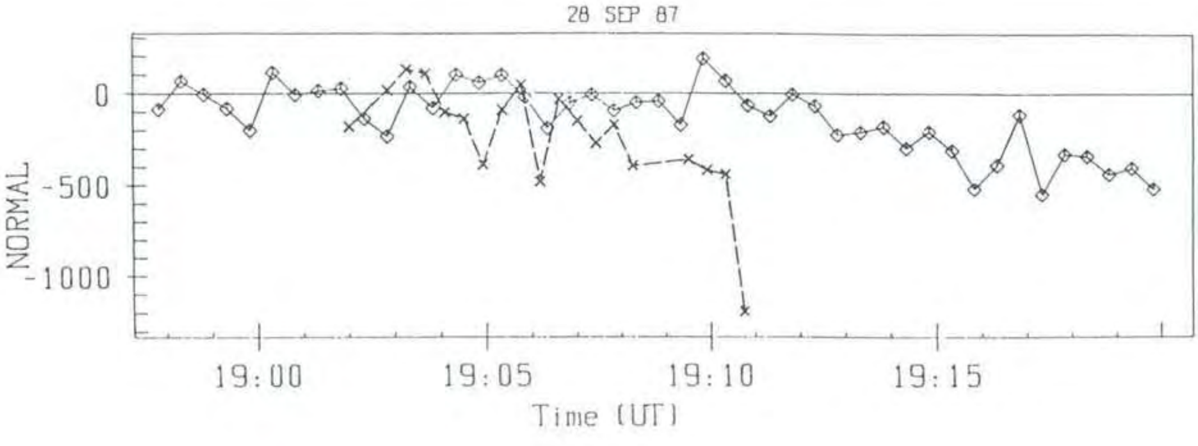


Fig. 21. The curve with ◇-symbols shows the plasma velocity normal to an auroral arc (in ms^{-1}) measured by EISCAT. The curve with x-symbols gives the speed of the arc calculated from the optical recordings. The arc was elongated in the east-west direction, its average motion was southward.

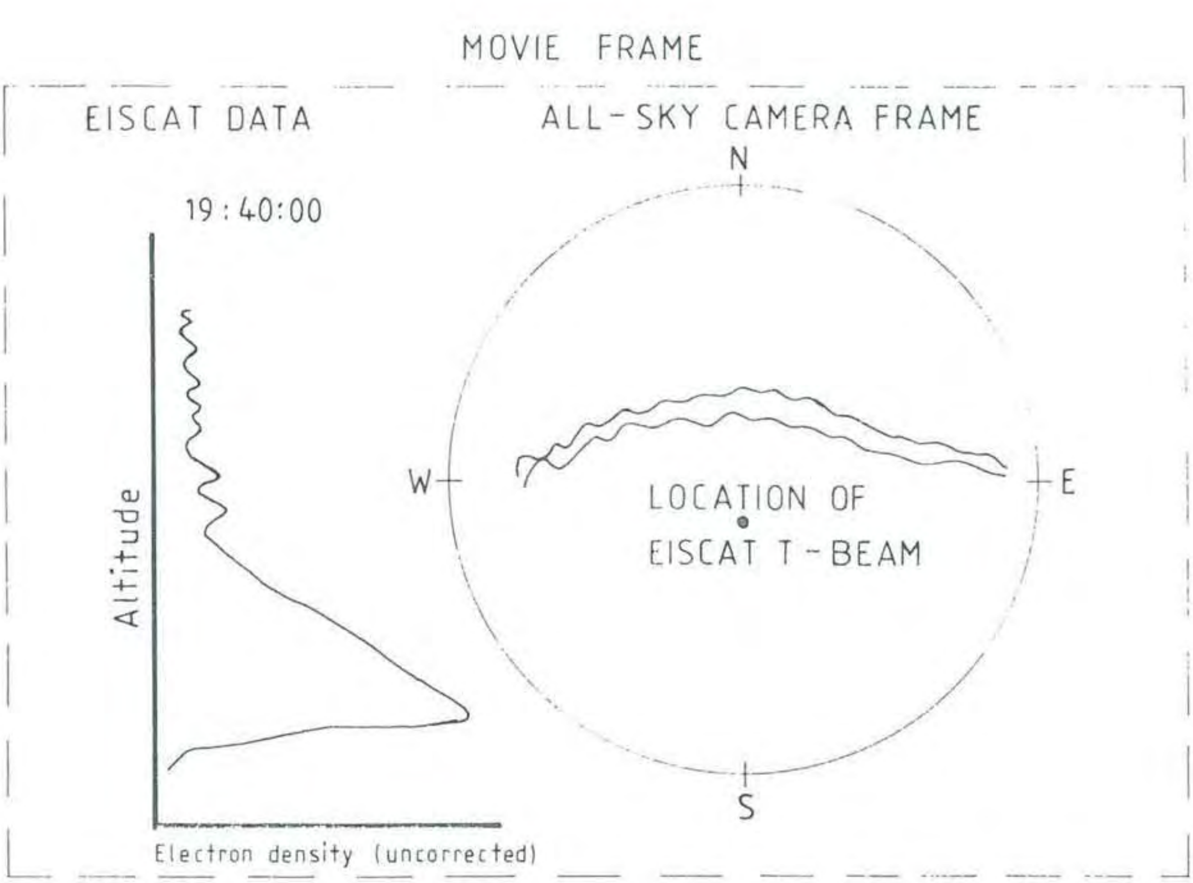


Fig. 22. Schematic picture of one frame of the video tape showing the EISCAT electron density profile to the left and the all-sky camera image to the right. The movie covers the time 19:40-19:54 UT on 30 January 1984.

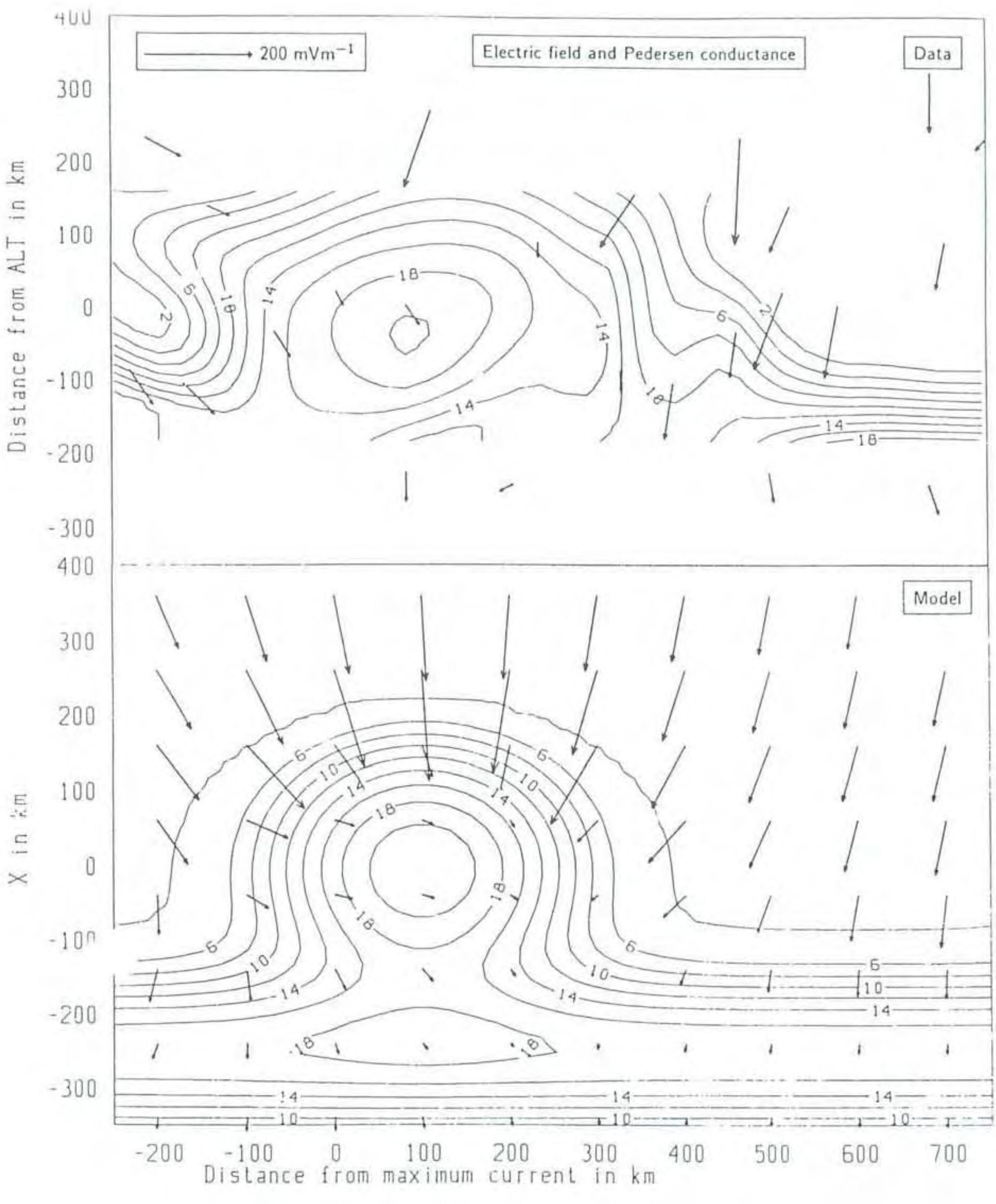


Fig. 23. Measured two-dimensional distribution of conductance and electric fields in an Ω-band (upper panel); results from the model computations for Ω-bands (lower panel).

region ionization was visible in the electron density profiles. The movie demonstrates evidently that a 10 s integration time of the EISCAT data is often too long for resolving fast auroral events (Schlegel, Piepenbrink and Rothwell, Some information about the video film on simultaneous EISCAT electron densities and all-sky camera pictures).

Pulsations

A distinct ps6 structure was measured by the EISCAT UHF radar and by the EISCAT magnetometer chain on 21 April 1985. The ps6 pulsations are known to be relatively stationary eastward travelling structures rather than wave phenomena. The corresponding auroral forms are the Ω-bands: luminous "tongues" extending poleward from a band of diffuse aurora. Combining the magnetometer data and radar measurements it was possible to reconstruct the two-dimensional distributions of the conductances and electric field vectors as shown in Fig. 23. The conductance distribution is quite similar to that of the optical intensity of an Ω-tongue. The electric field vectors tend to be parallel to the gradients of the conductances and the electric field strength is reduced in areas of enhanced ionization. These observations are explained by an electrostatic model, which assumes that both the E-region ionization and the upward field-aligned current are caused by precipitating energetic electrons. Starting from a given distribution of field-aligned currents, ionospheric conductance, electric fields and currents are calculated. The observed conductances as well as magnetic and electric fields are reproduced very well by this model (Buchert, Baumjohann, Haerendel, La Hoz and Lühr, Magnetometer and incoherent scatter observations of an intense ps6 pulsation event).

Auroral Arc Studies by EISCAT and the CAESAR Rocket

To study auroral arc physics the CAESAR-programme (Coordinated Auroral Experiment using Scatter And Rocket Investigations) was performed in January 1985, which combined high resolution in-situ measurements using rocket-borne instrumentation and ground-based observations with EISCAT. Of specific importance for this project was the investigation of the electric field configuration in the vicinity of an auroral arc. Therefore, EISCAT was operated to measure the plasma drift vector using a scan with seven common volumes on magnetic field lines which were also connected with the nominal CAESAR trajectory. One scan took 15 min (the same time as the expected flight duration) and these measurements were conducted before, during and after the rocket flight. The EISCAT measurements showed that before and after the CAESAR II flight the plasma drift corresponded to the normal convection field. The disturbance started when the plasma drift turned direction to the west and increased its magnitude up to ~ 1000 ms^{-1}. A strong eastward Hall current or electrojet was observed, in agreement with the magnetometer measurements (Wilhelm, Rinnert, Schlegel, Kohl, Klöcker, Lühr, Oel-

Fig. 24. Comparison of plasma drifts measured by EISCAT at 140 km altitude and those deduced from d.c. electric field measurements along the CAESAR II trajectory (projected along the magnetic field lines to the altitude of 140 km).

schlägel, Dehmel, Gough, Holback and Oyama, 1987).

Fig. 24 is a composite of the EISCAT and CAESAR II plasma drift measurements. The dense series of arrows represents plasma drifts calculated from DC-electric fields measured by the rocket along the trajectory assuming ExB-drift and projected down along magnetic field lines to the altitude of the EISCAT measurements at 140 km. Both data sets are in excellent agreement for latitudes below about 71.6^0 which is south of the arc within the east jet. The differences in the plasma drifts of both data sets at latitudes above ~ 71.6 degrees north is real and indicates a localized precipitation event characterized by an upward directed field-aligned line current centered at about 14.5 degrees east and 72 degrees north (and probably a corresponding downward directed line current centered at 13.5 degrees east and 72.5 degrees north). Further plasma parameters measured by EISCAT and on board the rocket payload are found in good agreement (Schlegel and Oyama, 1987).

Field-aligned Currents

Fig. 25 displays the large-scale distribution of field-aligned currents, measured on a quiet and stationary day. It is found to be consistent in location and in magnitude with the usual pattern of Ijima and Potemra (1978), involving region-1 and region-2 current systems. The phases of the field-aligned current pattern in region-2 and of the corresponding electrostatic convection pattern are compared. The results show a phase opposition, which is found to be irreconcilable with the mechanism generally admitted as the generator of field-aligned currents in the inner magnetosphere, namely that the charge separation is due to gradient drifts of energetic particles at the inner edge of the ring current. It is suggested that the precipitation of convected energetic electrons may produce azimuthal pressure gradients able to drive field-aligned current systems most of the time (Caudal).

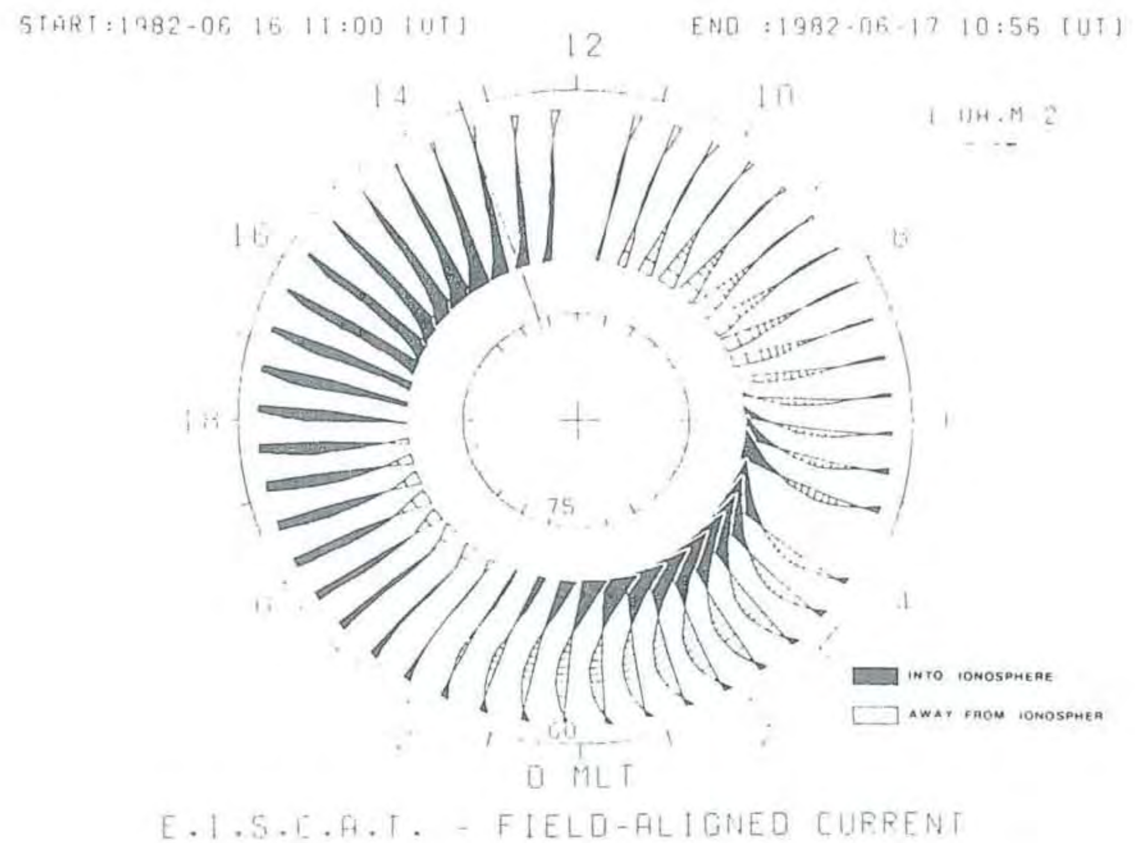


Fig. 25. Distribution of field-aligned currents.

EISCAT - VIKING Coinvestigations

Auroral Substorms

The EISCAT data set collected during 1986 in operations coordinated with the Viking satellite is being used to study auroral substorms. The development of the substorms is studied using auroral images from the Viking satellite and from ground based measurements from the all-sky camera, magnetometer and riometer networks in order to put the EISCAT measurements in context. Results so far show that ionospheric conductances in the zone of diffuse aurora carrying the main substorm electrojet are close to the values which have previously been assumed in modelling work. Conductances in the active aurora leading the westward and northward substorm expansion, however, are 3-5 times higher than previously assumed. Electric field measurements show that, at least in some cases, the electric field within a break-up arc can be very small and the ionospheric current must be largely driven by the neutral wind. Further, strong fluctuations in conductances with periods of 1-2 minutes are seen in almost every case at substorm onset. In those cases where EISCAT measures under the northward expansion of the "auroral bulge", these fluctuations correlate closely to both local and mid-latitude pi2 pulsations. These effects are illustrated in

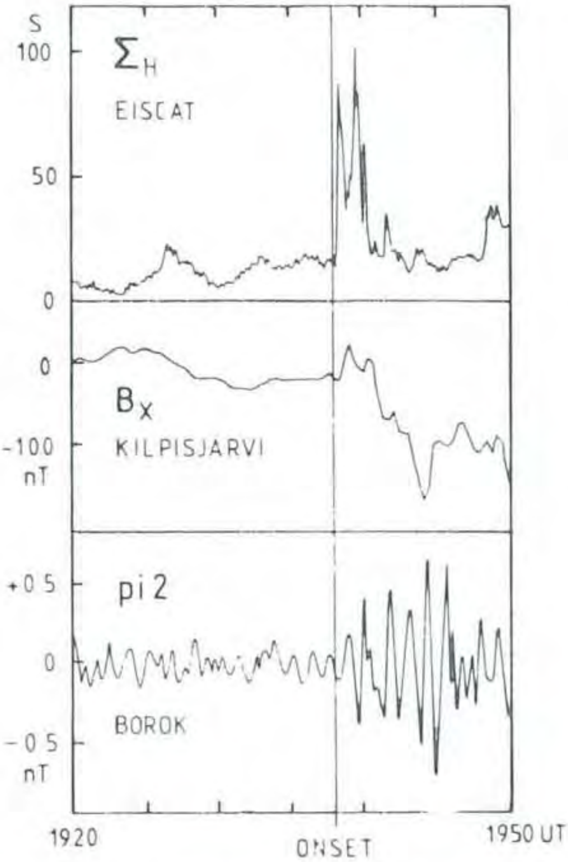


Fig. 26. Signatures of substorm onset: ionospheric Hall conductance measured by EISCAT showing very high values at onset; local magnetic perturbations from Kilpisjärvi, Finland, showing pi2 pulsations correlated with the conductance fluctuations superimposed on the negative substorm bay; simultaneous mid-latitude pi2 pulsations recorded at Borok, USSR.

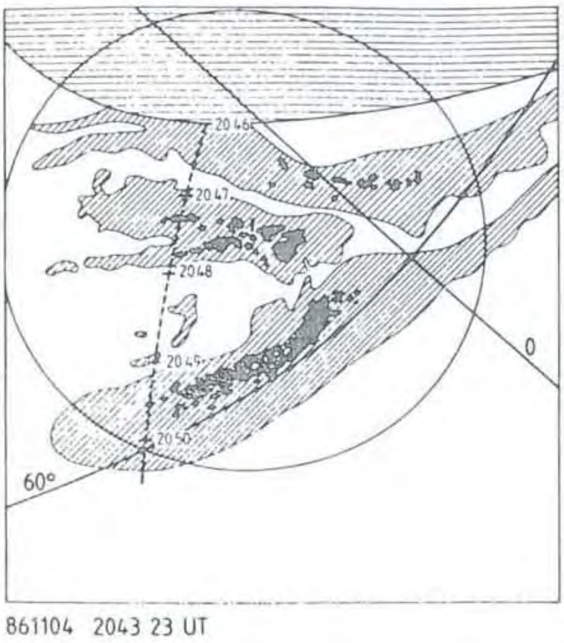


Fig. 27. A sketch of an auroral image obtained by Viking at 20:43:23 UT - 22 seconds after the Aureld-VIP-High launch. The point of the exclamation mark at the center of the circle shows the location of the launch (Esrange) and the line above indicates the rocket trajectory and the area where the EISCAT measurements were performed. The dashed line is the approximate projection of the Viking trajectory to 100 km level. The big circle is the all-sky camera field of view from Esrange defined by the intersection of an 85 degrees half angle cone with the 100 km altitude level. Also included are the 60 degrees magnetic latitude circle and the magnetic local time midnight meridian. The northern part of the image is disturbed by baffle scattering.

Fig. 26 (Kirkwood, Opgenoorth and Murphree, Ionospheric conductivities, electric fields and currents associated with auroral substorms measured by the EISCAT radar; and Troitskaya and Kirkwood).

From the combined EISCAT and Viking data set a number of substorm studies have been initiated. From these studies it has been realized that the current model for the development of the magnetospheric substorm might need a major revision. The "well known" features of a substorm, including distinct features and a more pronounced expansion at the westward edge of the active region, appear to be only one of several possibilities for auroral behaviour after substorm onset. Cases of stationary intensifications, or pronounced eastward expansions appear to be as common as "typical" substorm bulges. The set of EISCAT data co-ordinated with the Viking satellite data contains sufficient material to start a critical discussion of the classical substorm model.

During the EISCAT/Viking project a Swedish EISCAT - Aureld-VIP - Viking campaign was carried out. The rocket Aureld-VIP-High was launched to an altitude of 206 km on 4 November 1986 in coordination with a close pass of the satellite and during a magnetic storm. At the launch the auroral oval was very broad with an intrusion of the plasma sheet boundary layer into the central plasma sheet. During the rocket flight EISCAT measured the electric field at 250 km altitude at three close points above the rocket trajectory. The EISCAT results together with rocket data indicate that the measurements were made at the edge of a polarization field developed in intense auroral structures as a result of the increased conductivity caused by precipitating particles. Fig. 27 shows an auroral image obtained by the Viking satellite and the geometry of the rocket flight (Sandahl et al., 1987).

After the rocket flight EISCAT was scanning between Tromsö and Kiruna. The electric field and the electron density profiles from this measurement indicate that there was a northward moving structure which can be seen in three successive scans. Because the weather was cloudy no comparisons with all-sky camera pictures can be done. This study is still continuing since all the data from all the instruments involved have not yet been analysed (Pellinen-Wannberg, Wannberg, Sandahl, Lundin, Holback, Opgenoorth, Soraas and Murphree).

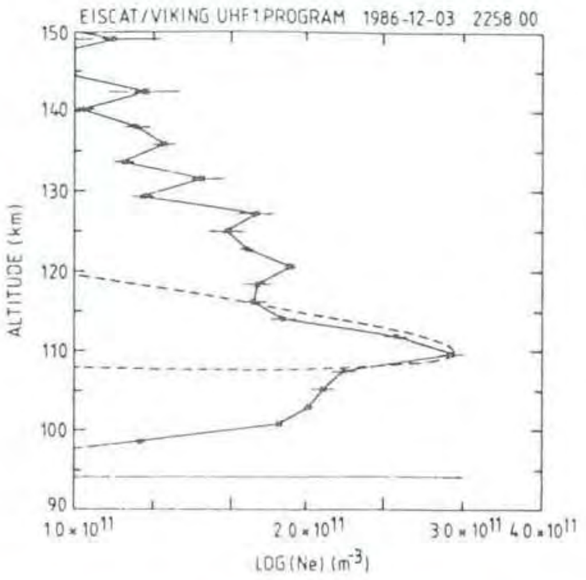


Fig. 28. An example of an anomalously thin layer of enhanced electron density during pulsating aurora. For comparison a theoretically derived profile (dashed line) is shown, which corresponds to collisional ionization by a mono-energetic field-aligned electron beam (6.5 keV). The altitude extent and particularly the sharp decrease of electron density at the upper boundary of the layer can hardly be explained even by this most tailored model for particle precipitation, which is not likely to occur in nature. Hence, unconventional mechanisms must be sought.

Thin Auroral Layers

Another result from the EISCAT/Viking data set was the observation of anomalously thin ionization layers associated with pulsating aurora. During a two hour long event of pulsating aurora, thin layers of ionization of the type displayed in Fig. 28 were observed with the EISCAT/Viking program UHF1 (stationary field-aligned antenna pointing). The program provides an altitude resolution of 2.7 km with slightly overlapping range gates. The observed thin layers of ionization are typically seen in no more than 2 range gates. In spite of an apparent broadening of the observed layer by a too long integration (1 min), the derived electron density profiles can hardly be explained by normal collisional ionization from precipitating electrons. The dashed line in Fig. 28 shows the ionization profile produced by collisional energy deposition of an ideal beam of mono-energetic electrons, which might produce a layer of only slightly larger altitude extent. Such an ideally tailored precipitation is, however, most unlikely to occur in nature, and no such observations have been reported from spacecraft observations above pulsating aurora. The observed direction of the field-aligned ion drift velocity in this case also excludes neutral wind shear, which is the agent for the formation of the well known non-auroral sporadic-E layers, as an alternative production mechanism. Hence, we conclude that for the first time a feature has been observed in the ionospheric ionization which might correspond to very thin auroral luminosity layers. The occurrence and possible production mechanisms of such auroral layers, common in all kinds of active aurora and particularly within pulsating patches, have been discussed extensively in the literature since their discovery about eight years ago. The described observations of the thin ionization layers adds a new dimension to these discussions (Wahlund, Opgenoorth and Rothwell).

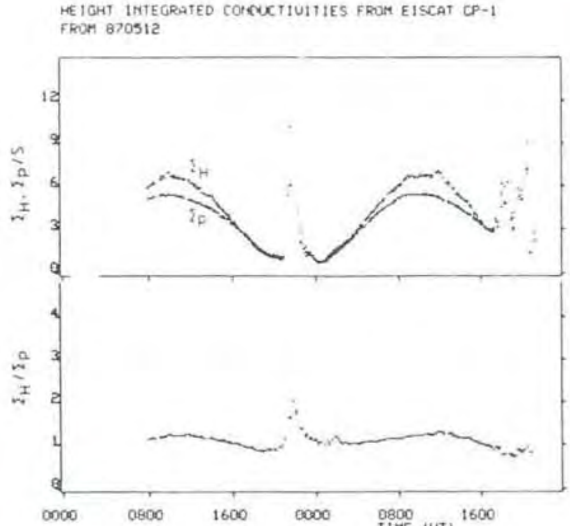


Fig. 29. Hall- to Pedersen-conductances obtained for 12-13 May 1987 (upper panel). The solar zenith angle dependence is reflected by the smoothly varying curves between 08:00 and 21:00 UT on 12 May, and between 00:00 and 16:00 UT on 13 May. Conductances derived during disturbed events are observed between 21:00 and 24:00 UT on 12 May and after 16:00 UT on 13 May. Hall- to Pedersen-conductance ratios for the same period as above (lower panel). During quiet periods the ratio is varying between 0.9 and 1.3 while values close to 2.0 are derived during the precipitation event at midnight.

Ionospheric Conductivities

Electron densities measured by EISCAT have been used to make a study of ionospheric conductivities and conductances. It is found that the Hall and Pedersen conductances are well behaved functions of the solar zenith angle during quiet time conditions. The Hall to Pedersen conductance ratio is found to be about 1.3 at quiet time but can increase to 4 during disturbed conditions. (see Fig. 29). A method has been developed to derive energy spectra of the precipitating particles for electron density profiles observed during disturbed conditions. The characteristic energies (represented by the root mean square energy, E_{rms}) is correlated with the Hall to Pedersen conductance ratio, R, calculated from the same electron density profiles. An empirical relation was found which allows the characteristic energy to be derived from observations of conductance ratios during disturbed conditions, see Fig. 30 (Brekke, Hall and Hansen).

A statistical study of E-region conductivities at low solar activity covering 2 years, 1985-1986, has been carried out. A large number of 8337 E-region conductivity profiles have been calculated at 5 min averages. From these profiles the height of the conductivity maxima for the Hall and Pedersen conductivities (H_{max}), the height-integrated Hall (Σ_H) and Pedersen (Σ_P) conductivities and the ratio Σ_H/Σ_P have been computed.

Histograms as well as average values of these quantities are displayed as a function of Kp and of magnetic local time. Fig. 31 shows an example. The results show quantitatively the increase of the conductivities and the decrease of H_{max} with increasing magnetic activity (Schlegel, Auroral zone E-region conductivities during solar minimum derived from EISCAT data).

The ionospheric height-integrated Hall conductivities are derived from EISCAT measurements of electron density along the magnetic field line at Tromsö, and a neutral atmospheric model. The results, obtained during an early Common Programme CP-0 on 18 October 1983, are compared to the conductivities computed from simultaneous observations of ionospheric electric fields by the STARE radar and of

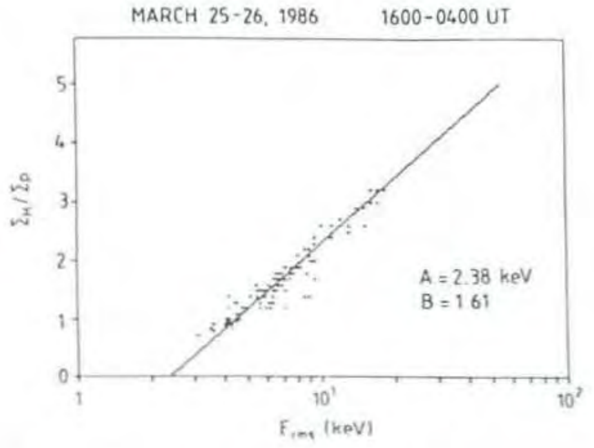


Fig. 30. The Hall- to Pedersen-conductance ratio, R, on 24-25 February 1987 plotted versus the root mean square energy, E_{rms}, derived from the same electron density profiles during disturbed conditions. The straight line represents a least squares fit to the empirical formula: $R=R_0\ exp(E/E_{rms})$.

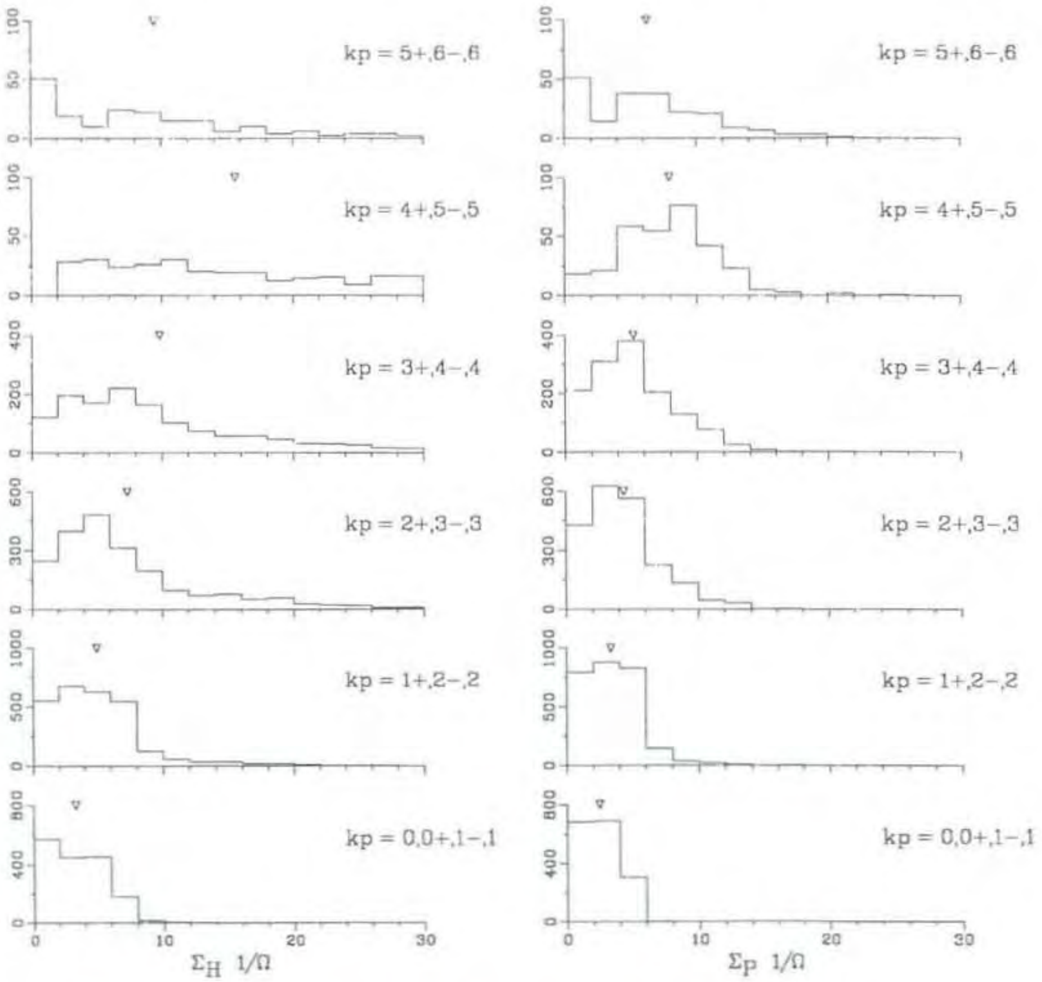


Fig. 31. Histograms of the height-integrated Hall Σ_H and Pedersen Σ_P conductivities for different Kp ranges. They are obtained from 8337 conductivity profiles derived from two years of EISCAT data.

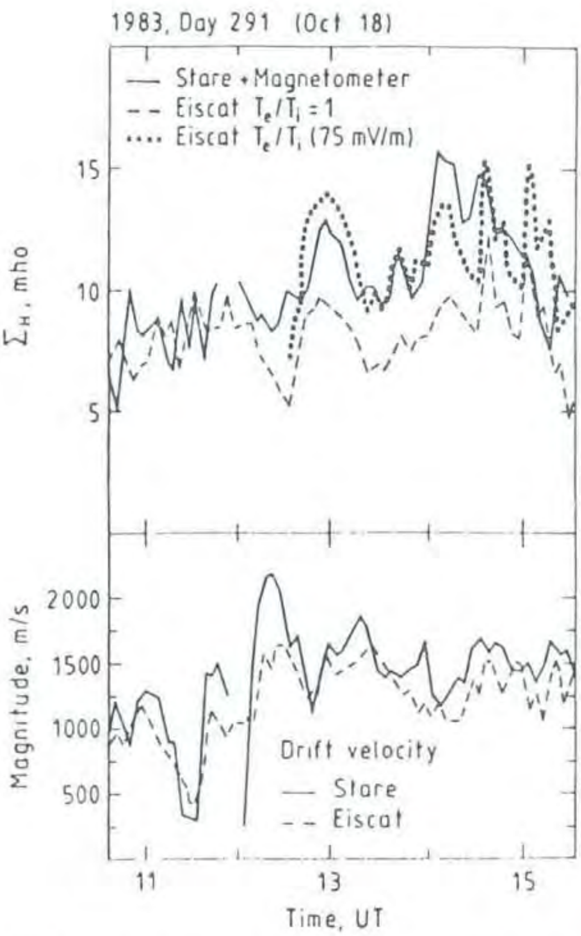


Fig. 32. Comparison of conductivities and drift velocities deduced from EISCAT and (STARE + magnetometer) measurements.

magnetic fields measured by ground-based facilities. The results are shown on Fig. 32. Whereas drift velocities are in agreement, the conductivities deduced from EISCAT, with the standard assumption for single pulse experiments of identical electron and ion temperatures, appear underestimated for the case of large electric fields. A better agreement is found for electron temperatures greater than ion temperatures in the E-region, following the statistical model of Nielsen and Schlegel (1983). This increase of electron temperature is interpreted as the result of heating produced by unstable short-scale plasma waves in the E-region (Nielsen, Senior and Lühr).

F-region Irregularities

Large-scale F-region irregularities were studied over a two year period in an experiment involving EISCAT and the NNSS satellites. Scintillations in the signals transmitted from NNSS satellites at 150 MHz and 400 MHz were monitored at Kiruna while EISCAT was programmed to follow the satellite path, measuring electron density, electron and ion temperatures and the electric field. 36 satellite passes were covered during the two-year observing period and the data yielded interesting results on the mechanisms producing irregularities in the F-region. Scintillations were observed in the vicinity of a long-lived steep equatorward gradient in electron density during a period of southward plasma flow. This suggested that the gradient-drift mechanism was responsible with an instability growth time of about 4 minutes (Kersley et al.).

Examples were also found of scintillation in the vicinity of plasma-density enhancements and high electron temperature caused by soft-particle precipitation, and the most likely explanation is a shearing of the high-velocity plasma flow in the region adjacent to a density blob. Similar examples were observed by comparing NNSS data with EISCAT data from CP-3. In one case scintillation was found in a region crossed by field-aligned currents suggesting that the plasma was driven unstable by the current-convective process (Kersley et al.).

Campaigns of coordinated measurements were organized in 1984-1985 between EISCAT and the HF radar EDIA, based in France, with the purpose to examine the morphology of F-region irregularity regions and their production mechanisms. EISCAT was operated in a scanning mode covering 8 degrees of latitude southward of the radar, while EDIA observed northward up to 67 degrees of geographic latitude. The continuous presence of small-scale irregularities in the F-region was detected for several hours at night time by the EDIA radar. Their location is not associated with any large-scale horizontal density gradients measured by EISCAT at 350 km F-region altitude. However, it is well correlated with strong north-south gradients at lower altitudes (150-200 km), indicating the equatorward boundary of energetic particle precipitation. The examination of the different mechanisms able to

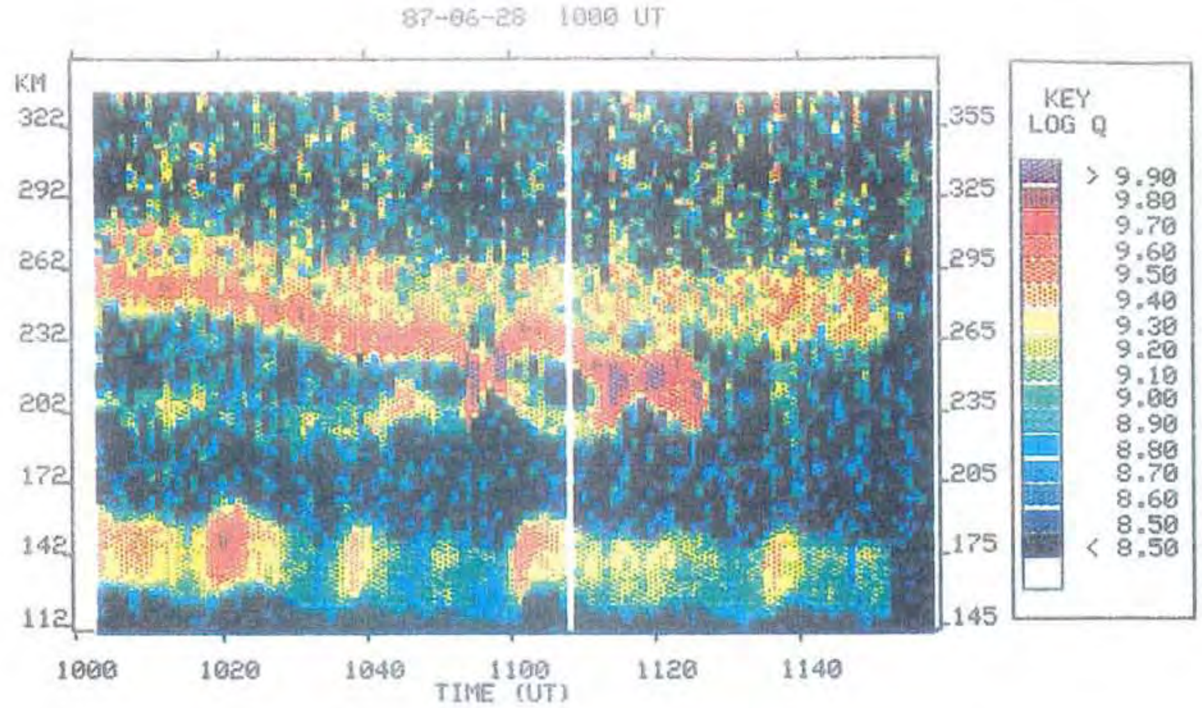


Fig. 33. Plasma-line signals detected with the VHF radar. Q is essentially the range-corrected power, but not adjusted for the size of the scattering volume. The pulse scheme consists of two single pulses transmitted at different frequencies. The altitude scales on the right and left apply to the pulses transmitted with offsets of 4.2 and 4.8 MHz, respectively.

produce F-region irregularities suggests that structured precipitation is probably an important source of irregularities of several hundred meters scale sizes, which could cascade to small-scale irregularities by the universal drift mode (Bourdillon and Fontaine).

Natural Plasma Lines

In June 1987 the first EISCAT two-frequency radar plasma-line experiment was carried out. Photoelectron enhanced plasma lines were measured simultaneously with the UHF radar and the VHF radar in the altitude region 140-280 km. It is concluded that under favourable conditions at midsummer photoelectrons in the proper energy ranges (1-2 eV for the UHF radar and 20-40 eV for the VHF radar) are present in sufficient number for a successful combined EISCAT UHF/VHF experiment. This kind of experiment provides a new means of deriving the electron temperature from the difference between the UHF and VHF plasma-line offsets (Hagfors and Lehtinen, 1981). Fig. 33 shows plasma-line returns detected with the VHF radar. At 1120 UT there is a strong signal at an offset of 4.8 MHz from altitudes around 220 km. The UHF data show a return at 5.20 MHz from the same altitude. This difference in offset gives an electron temperature of 2410 K with an uncertainty of about 10%. The ion-line result is T_e=2210 K. For accurate temperature measurements better height, time and frequency resolutions are needed. This can be obtained with the chirp technique, which is being prepared (see page 56) for permanent implementation into the EISCAT system (Fredriksen, Björnå and Hansen).

Another plasma-line experiment which was run in summer 1987 used the EISCAT PLASMA-D program with the UHF radar and the CCD spectrum analyzer to study the altitude region 105-130 km with a 5 km gate separation. The preliminary analysis shows that plasma-line signals are detected in all range gates (Trondsen, Fredriksen, Hansen, Björnå).

Atmospheric Gravity Waves

A specific mechanism of energy and momentum transfer from the magnetosphere to the ionosphere and to the neutral atmosphere is through the generation of atmospheric gravity waves. Detailed studies of the data obtained during the WAGS campaign (World Acoustic-Gravity Wave Study) confirm two cases where a clearly-defined auroral source generated an atmospheric gravity wave which was detected in the far-field. On 13 October 1985, an east-west electric field with a strong 60-minute component was observed by EISCAT in the interval 18:00 to 22:00 UT. A 60-minute wave was later observed by the HF-Doppler network centred at Leicester/UK, travelling in a direction 20° west of south at a speed of 400 ms^{-1}, with maximum intensity in the interval 19:30-22:30 UT. Wave activity with a period of 60 minutes was also observed by the ionosonde at Dourbes commencing at 19:45 UT. The delay of 90 minutes between the onset of periodic activity in the auroral zone and the arrival of a wave with the same period observed in the UK was entirely consistent with the velocity of the wave, as determined by the HF-Doppler network.

Similar consistency was noted on 18 October 1985. At 15:40 UT EISCAT observed the sudden onset of an auroral electric field with an intrinsic period of about 33 minutes and a strong harmonic at 17 minutes. It is well known that shorter period waves are more strongly attenuated when propagating over long distances. It is not surprising, therefore, that when a propagating gravity wave was later observed by the ionosondes at Wick and South Uist/UK the 33-minute wave was dominant. The 33-minute wave was also seen by the HF-Doppler network (note the similarity of the power spectra in Fig. 34) travelling southward at 350 ms^{-1}, which agreed well with the time lag between the onset of the auroral activity and the appearance of the 33-minute wave over the HF-Doppler network at 17:00 UT ± 15 min (Williams et al.).

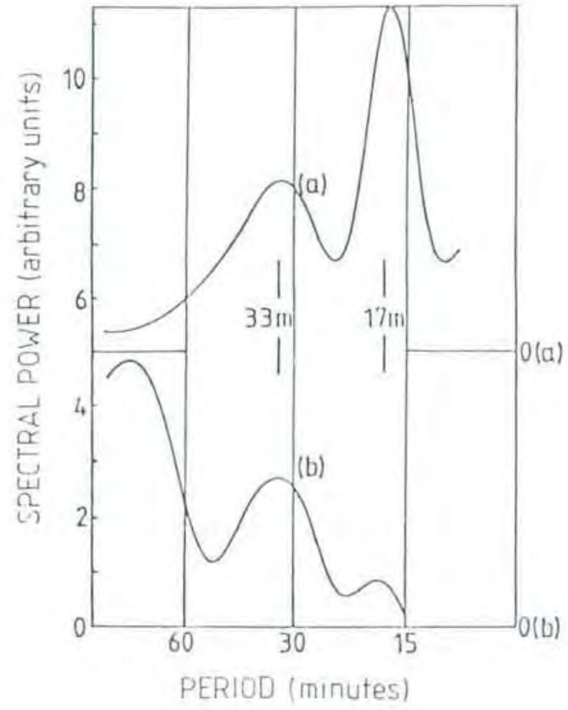


Fig. 34. Spectrum of the time-variations in (a) the square of electric field strength measured by EISCAT between 16:00 and 19:00 UT and (b) the frequency offset (reflection height changes) of the signal received by the HF-Doppler system from 17:00 to 20:00 UT on 18 October 1985.

Energy and Momentum Balance

The Common Programmes CP-1 or CP-0, with the Tromsö antenna fixed along the magnetic fieldline, are extensively used to sound the altitude structure of the ionosphere with the best time resolution and to infer its dynamic behaviour. These experiments address many topics. Great attention is given to the evaluation of the energy budget at each altitude in the ionosphere and of the dynamic response of the ionospheric parameters in presence of large electric fields: ion temperatures, ion composition, ion velocity distribution functions, conductivities, neutral winds, energy dissipation.

The large plasma velocities driven by magnetospheric electric fields transfer energy and momentum to the neutral atmosphere but the models of the exchange are very complex. To evaluate them it is necessary to make simultaneous measurements of both the ionized and neutral atmosphere. The experiment INDI was designed to combine simultaneous EISCAT and Fabry-Perot interferometer observations of the ionosphere-thermosphere system. The initial measurements have been used to test the simplified forms of the ion-energy and the ambipolar-diffusion equations. These describe the energy balance in the high latitude ionosphere to a first approximation but there are discrepancies which seem to indicate an extra heat source not accounted for in the model. One result of this experiment is the finding that the O - O^+ collision frequency in the F-region is lower than currently accepted values by a factor of 2 to 3 (Winser et al.).

Common Programme CP-3 data has been used as the main input for the numerical solution of the coupled energy equation of the ions and momentum equation of the middle thermosphere at heights between 130 and 500 km in polar regions. This, in addition to modeling of some neutral parameters (UV-radiation, IR-loss of the atomic oxygen, etc.), allows the calculation of the horizontal velocity and temperature of the neutral gas. By combining these results with the energy equation of the neutral gas it is, in addition, possible to estimate the vertical neutral gas velocity. Fig. 35 shows the calculated neutral gas velocities at a height of 205 km at latitudes between 66°N and 72°N. The complicated pattern of the velocity is due to the combination of very disturbed polar thermospheric temperatures and the rapidly changing ion gas velocities, as measured by EISCAT. The calculated neutral gas velocity is in good agreement with those provided by Fabry-Perot measurements by the University College London (Figueroa and Kohl).

A tool to interpret observations made along the geomagnetic field line is provided by a computer program to calculate the electron transport in the ionosphere and the energy dissipation at each altitude resulting from a source of precipitating particles at the top of the ionosphere. This code is being applied to EISCAT observations in order to determine the contribution of the different processes involved in the energy balance (Lilensten, Kofman and Wisemberg).

Observations along the magnetic field lines were also performed during measurement campaigns coordinated between EISCAT and VIKING, especially when the spacecraft was well conjugated above the radar field of view. The main objective is to investigate electrodynamic processes aligned along magnetic field lines from two points of observations, in the ionosphere and in the magnetosphere (Fontaine, Girard, Lilensten).

Ionospheric Trough

Observations of the main (or mid-latitude) ionospheric trough were used to study the relationship of the trough to the F-region ion convection, to the precipitation of auroral electrons, and to the level of magnetic disturbance. Using EISCAT scans through the trough during the local afternoon/evening sector from 17 days, an empirical relationship between Kp and trough location in geomagnetic latitude and local time was determined. From a detailed study of four days, it was shown that the trough F-region density minimum was a region of strong westward ion flow, and that the edge of this flow cell was 1°-2° equatorward of the trough minimum. The poleward side of the trough was co-located with the edge of the auroral oval, identified by enhanced E-region electron densities due to the precipitation of auroral electrons of energy of a few keV.

Fig. 36 shows the electron densities as a function of latitude and time for the four days studied (Collis and Häggström, Plasma convection and auroral precipitation processes associated with the main ionospheric trough at high latitudes).

Fig. 37 shows an example of a high-latitude trough, associated with a plasma drift reversal (G.O.L. Jones et al.).

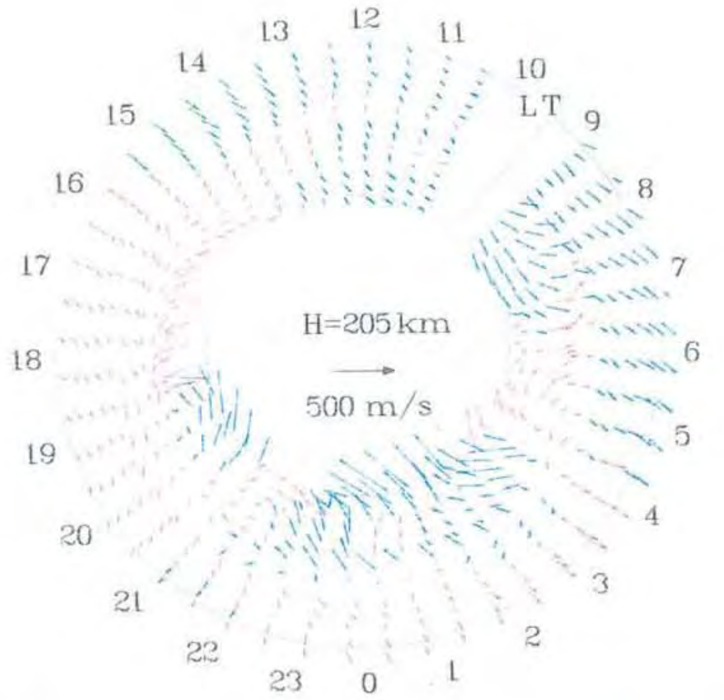


Fig. 35. Neutral gas velocities at 205 km altitude 28/29 January 1987.

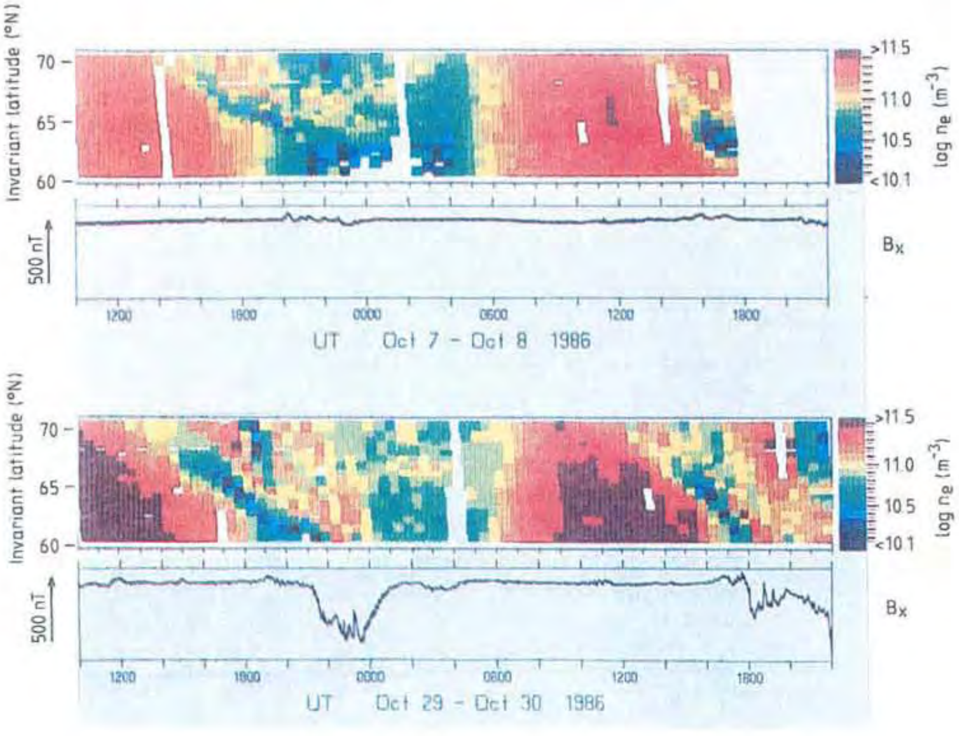


Fig. 36. Electron densities at 275 km altitude over a 10° span of invariant latitude from 4 days of measurements by experiment CP-3-E during October 1986. The main trough is the apparently equatorward-moving region of depleted densities following the daytime maxima. Also shown is the magnetic X-component from Kiruna indicating the lack of correlation between trough position and local magnetic activity.

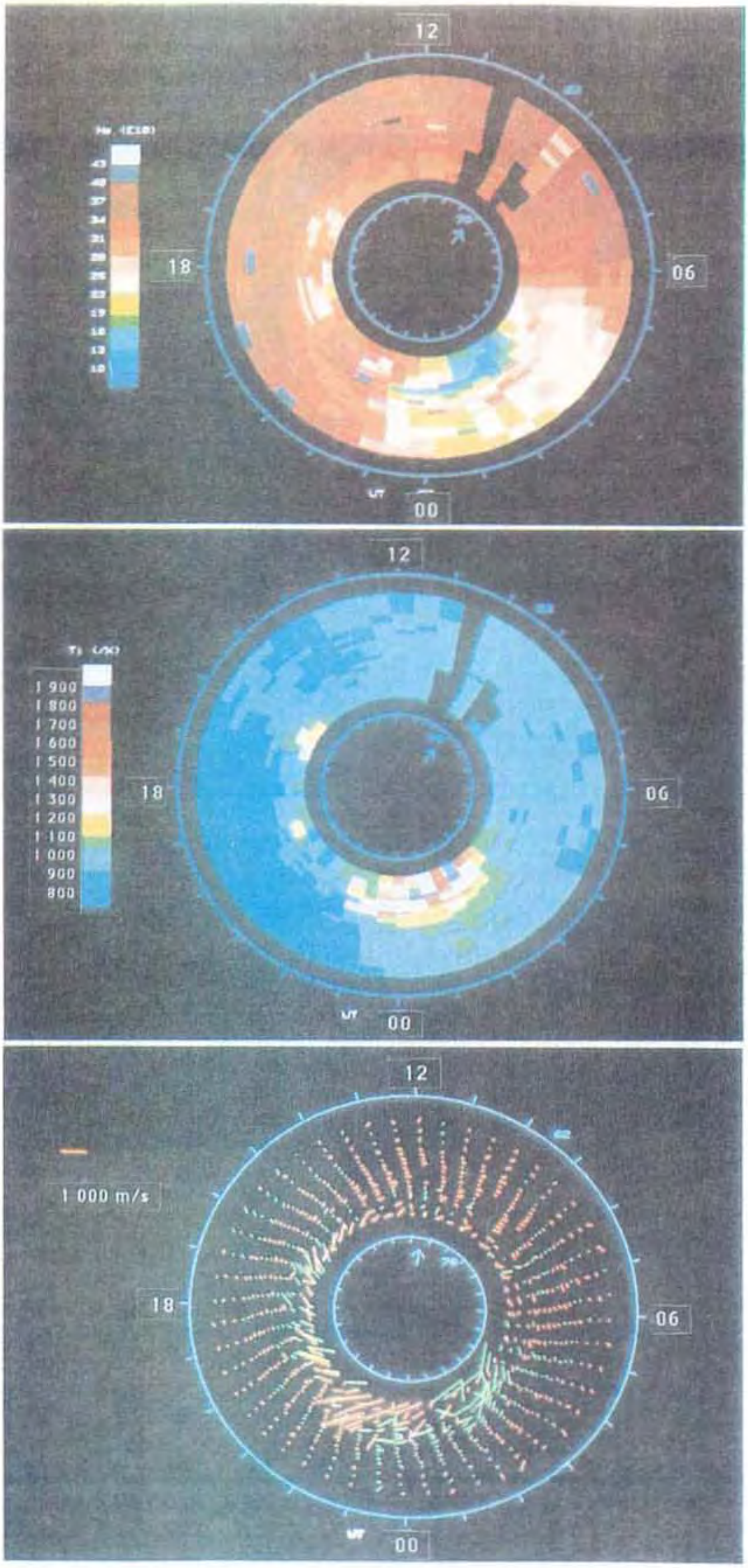


Fig. 37. Electron density, ion temperature and ion velocity perpendicular to the fieldline, measured with CP-3-E on 19-20 May 1987 showing an example of a high latitude trough with reduced electron density and enhanced ion temperature, associated with the reversal of the plasma velocity at about 1 UT.

Ionospheric Ion Composition

The different chemical and physical processes which can lead to a variation of the ionospheric F1-region composition are reviewed, mainly in cases of auroral energy deposition. A quantitative study of a disturbed period on 16-17 April 1985 showed an abrupt variation in composition occurring during the night and can be explained by the combined effects of particle precipitation and Joule heating (Lathuillère).

The vertical structure of E- and F-regions can be predicted by a one-dimension model of the ionosphere which solves the chemical equations of the different species. In order to investigate the effects of convection electric fields, EISCAT observations are used as input parameters in the transport equations. The evolution of the ion composition inside flux tubes can be computed along the equipotential lines, which are inferred from EISCAT electric field observations (Taieb).

Ionospheric Convection

The Common Programme CP-3 and similar experiments that make extended latitudinal scans of more than 10 degrees explore the latitudinal distribution of the ionospheric plasma. They are essentially used to investigate the large-scale electrodynamics of the auroral zone. Indeed, the accurate determination of electric fields from three-dimensional measurements of ion velocities, and of conductivities by height-integration of electron density profiles, allows reasonable evaluations of large-scale electrodynamic parameters, such as the convection electric field, the electrostatic convection potential, the horizontal and the field-aligned currents. This is the objective of the experimental studies which may have implications for theories, for example concerning the mechanisms for driving field-aligned currents or the mechanisms producing F-region small-scale instabilities, as explained below. Another group of studies focus upon modeling: EISCAT observations are then used as input parameters for models or as an element of test and comparison.

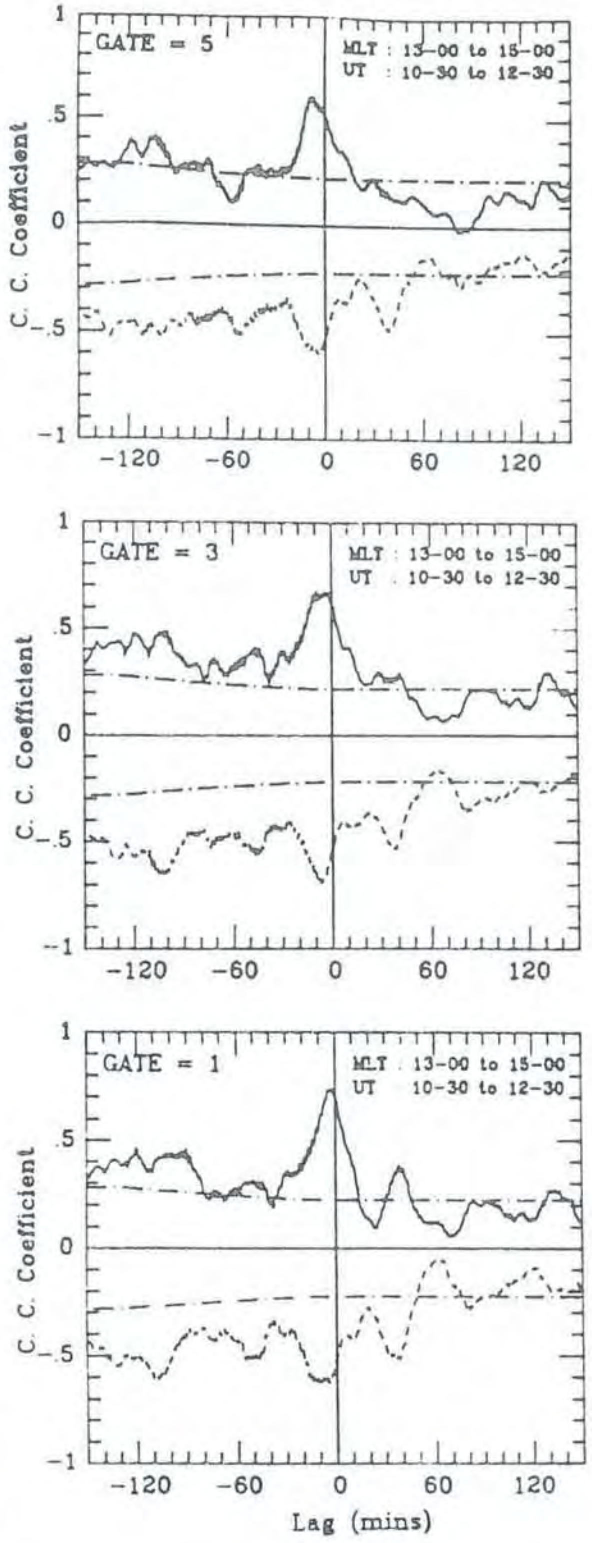


Fig. 38. Results of the cross-correlation analysis between measurements of v^2B_z in the solar wind and the east-west (——) and north-south (-----) components of ionospheric flow for the 2 hour interval from 13:00 to 15:00 MLT and for gates 1, 3 and 5 of the POLAR experiment. For negative lag the solar wind leads the ionosphere.

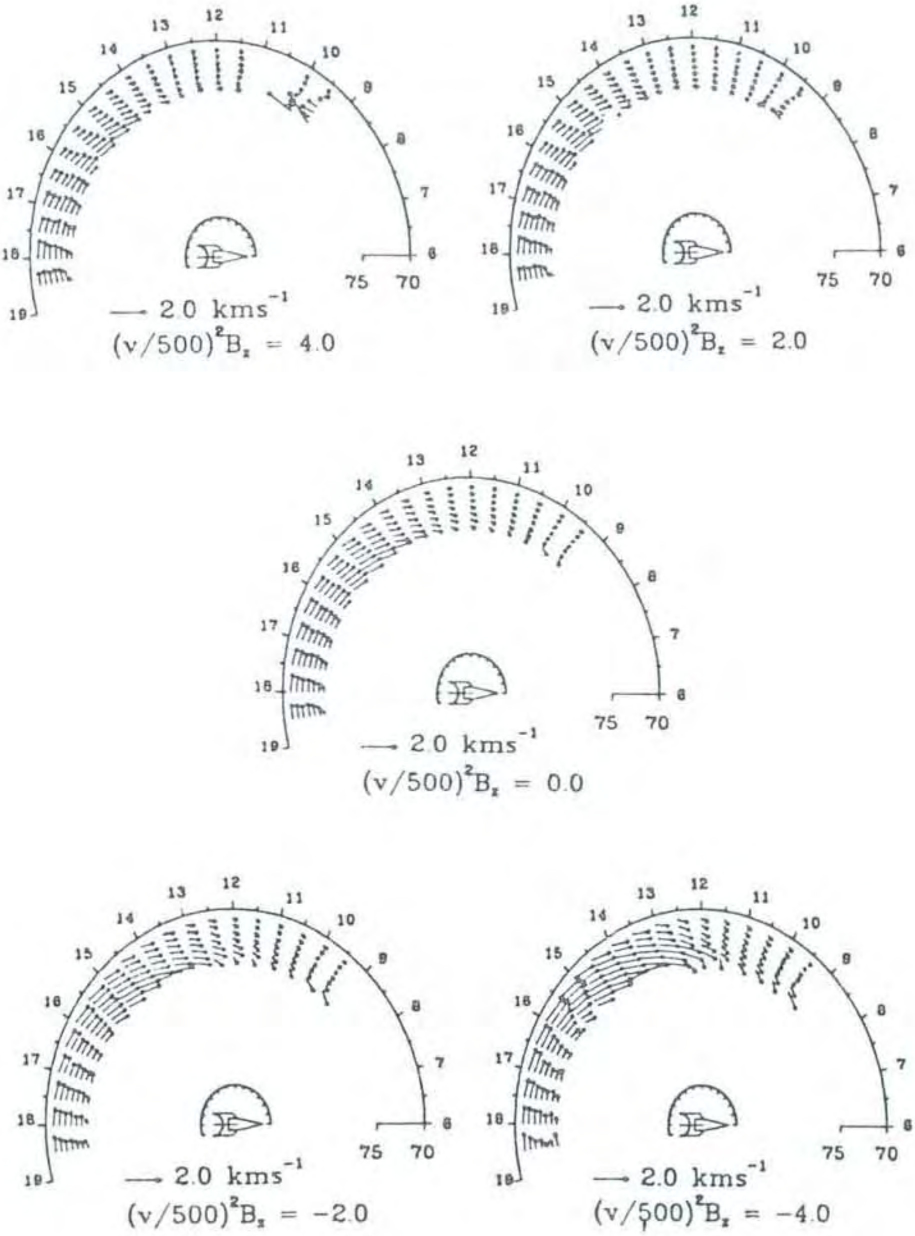


Fig. 39. Vector flows determined from the POLAR experiment are plotted against MLT and latitude for fixed values of $(v/500)^2B_z$ (viz. 0, ± 2 and ± 4 nT).

The campaigns of coordinated measurements organized in 1986 between EISCAT and Viking included such experiments of extended scanning. EISCAT data can give an image of the global electrodynamic state of the ionosphere, such as electric fields, electrostatic potential, field-aligned currents etc. Corresponding measurements were performed on-board Viking in the magnetosphere at 1-2 earth radii. The purpose here is to determine the nature of the electric coupling between the ionosphere and the magnetosphere, and to quantify the involved electric fields, currents and particle precipitations (Fontaine).

The relationship between the B_z component of the interplanetary magnetic field and the two-cell convection of the ionosphere in the polar cap has been studied. Correlograms for the early afternoon sector are shown in Fig. 38 for latitudes 70.8°, 72.0° and 73.2°. The plasma velocity shows a very prompt response to changes in v^2B_s where v is the solar wind speed and B_s is the rectified value of B_z. Overall the data in this sector suggest a delay of only 4±2 minutes in the ionospheric response to changes in the IMF appearing at the subsolar magnetosphere, and only a few minutes longer at earlier and later local times. These delays in the convective flow are much shorter than the 30-60 minute delays typical of the substorm response to the IMF. By making a separate study of the south-north plasma velocity, v_N, and the west-east velocity, v_E, detailed vector maps of the flow for various B_z can be derived. The main effects, shown in Fig. 39, are the increasing size of the flow system and the increasing strength of the flows as B_z becomes more negative. The strong positive correlation between line-of-sight flow and B_z changes to a weaker anti-correlation near dusk. This is ascribed to expan-

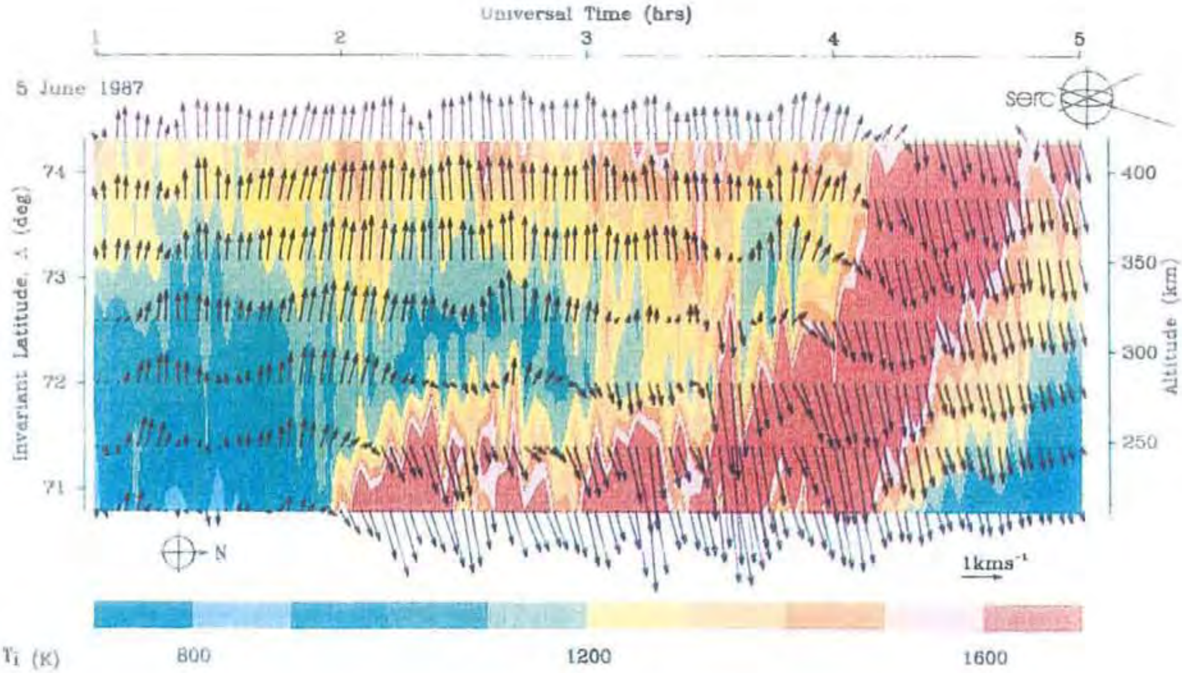


Fig. 40. EISCAT observations of a contracting polar cap boundary, taken as part of the international GISMOS collaboration. The boundary is seen as a rotation of plasma flow vectors from westward (plotted up the page to avoid congestion) through northward to eastward, and moves northward across the field of view between 0200 and 0410 UT. An enhancement in ion temperature is observed in an annulus immediately outside the boundary, as predicted by Lockwood and Fuller-Rowell.

sions and contractions of the polar cap: when B_z becomes increasingly negative and the convection cells expand, the radar field-of-view moves into the poleward part of the flow cell and the flow speed diminishes (Etemadi et al., 1987; Todd et al.).

One period when the polar cap was contracting was studied in detail. The results, illustrated in Fig. 40, showed flux entering the polar cap near dawn, across the polar cap boundary. The ions were found to be strongly heated with non-thermal velocity distributions in a ring immediately outside the contracting polar cap, as predicted for such an event (Lockwood and Fuller-Rowell, 1987).

EISCAT observations of large-scale electric fields have been used in a study of magnetospheric convection modeling. The linear, semi-analytical and time-dependent magnetospheric convection model of Senior and Blanc (1984), was adapted to the predictions of the time variation of midlatitude electric fields induced by known variations of the electrostatic potential drop across the polar cap. Simulations were conducted for periods of the International Cooperations GISMOS and the Coordinated Data Analysis Workshop CDAW, for which a large amount of data were available. The cross-polar-cap potential was calculated from the IMF data, using a formula given by Reiff and Luhmann (1986), and the input parameters of the model were adjusted to available high-latitude data. In particular, EISCAT data were used to determine (i) the time at which the potential at the upper boundary of the model was maximum, (ii) the auroral conductivity, and (iii) the boundaries polar cap/auroral zone and auroral zone/mid-latitude region. The model was tested against the observed mid-latitude electric field disturbances. The agreement between observations and model predictions was found to be excellent for two of the three days studied. This result represents a very positive test of the capacity of our model to predict the convection electric fields generated at mid-latitudes by the closure of high-latitude currents through the ionospheric conductor (Senior and Blanc).

Non-thermal Plasma, Convection and Up-flow

The study of non-thermal ion velocity distributions has proved to be an exciting feature of EISCAT work in 1987. For over a decade it had been predicted that the action of ion-neutral collisions in the presence of ion drifts faster than the neutral thermal speed would create non-Maxwellian ion velocity distributions. The large velocities observed in the auroral ionosphere near the cusp or in the post-midnight sector, and the bursts of rapid poleward flow thought to be the ionospheric signature of flux transfer events, have all proved ideal for generating such distributions and after the first clear identification of non-thermal spectra many examples have been studied (Lockwood et al., 1987).

A study has been made of cases of non-Maxwellian velocity distributions using data from Common Program CP-3. Beyond similar investigations by different authors, measured autocorrelation functions have been fitted for the first time to a theoretical model of non-Maxwellian velocity distributions. This model developed by Raman and St.-Maurice (1981) is based on a relaxation collision model and a pure O^+ ion composition. The degree of deviation from a Maxwellian ion velocity distribution is characterized in this model by a parameter D^* that depends on the ion drift velocity, the neutral wind velocity and the neutral thermal velocity. The distortion parameter D^* was obtained by the fit together with the usual plasma parameters like ion and electron temperature and electron density. It was found that for values $D^* \leq 0.6$ the ion-velocity distribution differs only slightly from a Maxwellian, and thus a determination of smaller values is not possible by these fits. The obtained values of D^* allow an estimate of the neutral temperature and the neutral wind which were in satisfactory agreement with current models (Moorcroft and Schlegel, Evidence for non-Maxwellian ion velocity distributions in the F-region).

During a period of large westward convection in the afternoon sector, a data set from CP-3 has provided unique

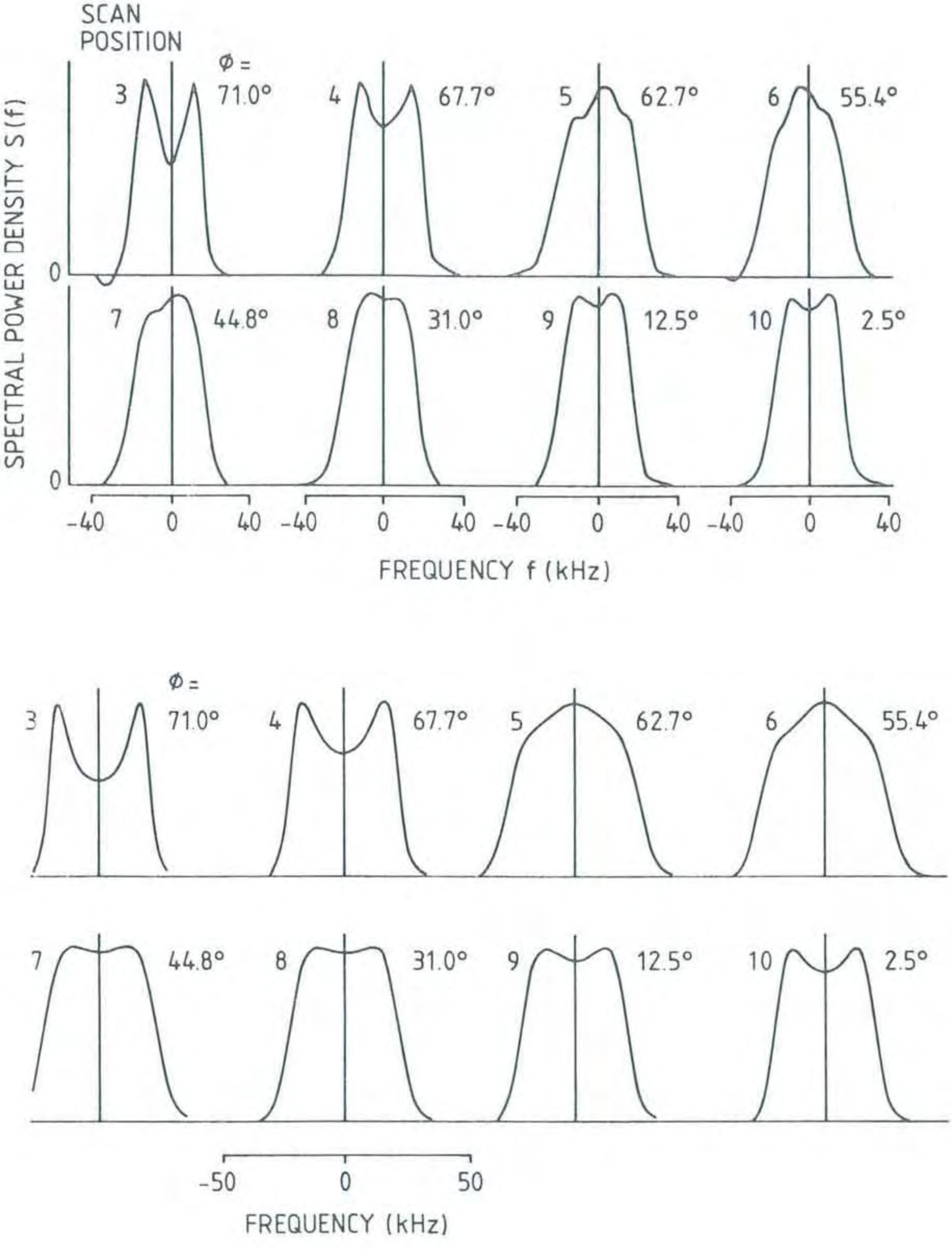


Fig. 41. Observed and best-fit non-Maxwellian fits to an elevation scan of CP-3-E, as a function of aspect angle ϕ . The fits shown here assume a pure O^+ ion plasma. The fitted D^* values range from nearly zero (Maxwellian) to 1.2 and increase smoothly with the ion drift.

evidence that confirms the presence of non-Maxwellian ion distributions. A feature of the predicted spectra for such an ion distribution is that the distortion in the line-of-sight distribution depends on aspect angle (the angle between the viewing direction and the magnetic field line). On this occasion the large westward drift was almost constant over a range of latitudes but the shape of the observed spectra (see Fig. 41) varied with position in the way predicted (Winser et al., 1987).

If a bi-Maxwellian distribution had been assumed in determining the ion and electron temperatures from such spectra the values derived would have been incorrect, showing a spurious anti-correlation and an ion temperature anisotropy too high for the observed rise in the parallel ion temperature. The analysis program at Rutherford Appleton Laboratory has been modified to fit spectra arising from non-Maxwellian plasma, using a spectrum synthesis program. The use of this program to analyse UK-POLAR data confirms that the plasma is non-thermal with shape-distortion factor D^* increasing with ion drift speed to peak values of 1.3 ± 0.1, in accordance with simulations made for a realistic mixture of polarisation scatter and resonant charge exchange. There is evidence for a saturation mechanism which begins to operate near $D^*=1.3$, suggesting the growth of micro-instabilities (Suvanto et al.).

The presence of instabilities is also indicated by the anomalously high power sometimes scattered from non-thermal plasma. The additional power is always at the down-shifted ion-acoustic frequency. This effect is only found at lower altitudes, and above 300 km the power observed agrees with the value predicted for homogeneous non-Maxwellian plasma (Lockwood et al.).

Very high ion temperatures, greater than 8000 K, were observed in the F-region while large electric fields were present (see Fig. 42). For disturbed periods, the Joule heating energy input is estimated by two methods: from electric field measurements, and from temperature measurements. Both estimations are found in good agreement,

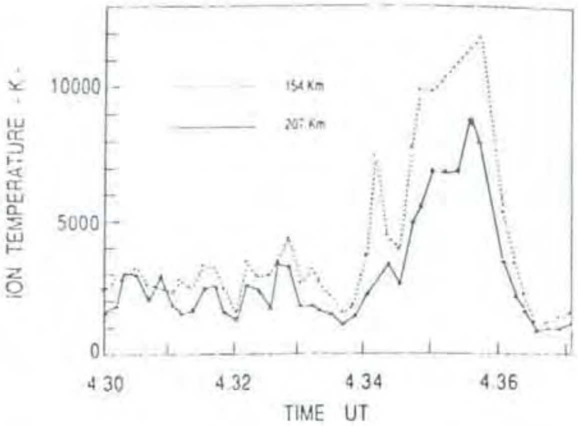


Fig. 42. High ion temperatures observed at EISCAT.

especially when a specific ion composition model is used. This shows that these first observations of such high temperatures could be explained by frictional heating between fast moving species. In addition, the ion temperatures observed at the two remote sites of EISCAT display a strong anisotropy in the F-region, indicating non-Maxwellian ion velocities. Electron and ion temperatures obtained at lower altitudes from multi-pulse measurements indicate anomalous heating in the E-region (Kofman and Lathuillère).

Measurements of very large convection velocities in the F-region of the ionosphere of up to 3.8 km/s corresponding to electric fields of 190 mV/m have been made during disturbed geomagnetic conditions. The large convection event was accompanied by rapid heating of the ions up to 12000 K. Additional calculations depict a scenario where the molecular ion composition and the zonal neutral wind increase dramatically. These results represent a concrete illustration of the controlling role that geomagnetic electrodynamics exert on the thermosphere. Events of this type are possibly connected to recent observations by various orbiting spacecraft of the existence of molecular ions in the plasma sheet, as an intermediate mechanism is necessary to transport or create molecular ions at the altitudes where ion acceleration mechanisms such as ion conics and ion beams are known to be effective (Buchert and La Hoz, Extreme ionospheric effects in the presence of high electric fields).

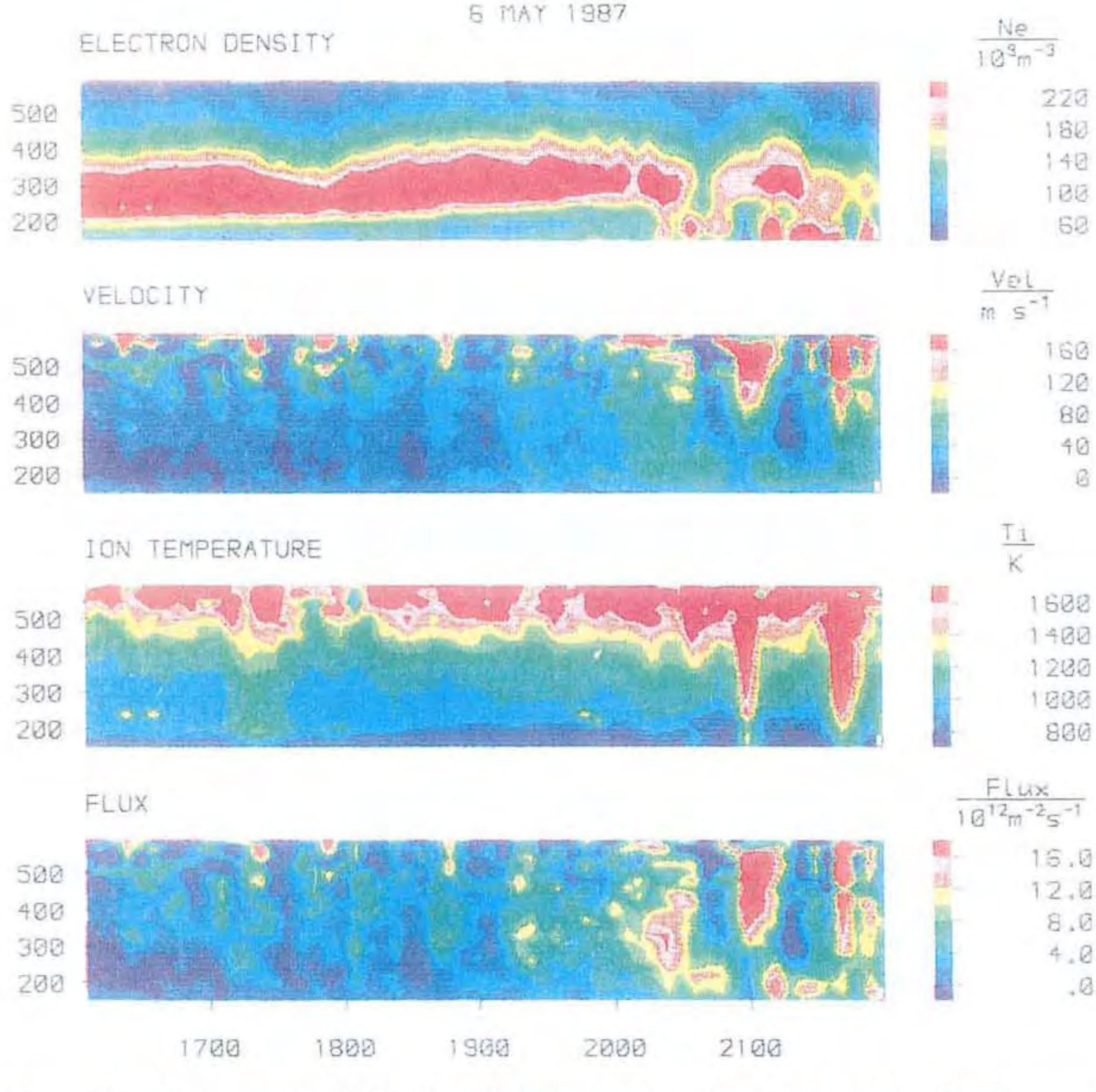


Fig. 43. Large upward field-aligned fluxes of ions observed by CP-2-D in association with strong, transient ion heating events. Two events occur after 2100 UT and the ion fluxes are exceptionally large ($>10^{13}\ m^{-2}s^{-1}$) implying ionospheric fluxes are escaping to the magnetosphere, consistent with recent theoretical studies.

In the presence of large-scale electric fields, the ion velocity distribution functions are not Maxwellian, and the resulting incoherent scatter spectra are distorted from their normal shape. This distortion of spectra increases with the electric field intensity and with the direction of observation of the radar relative to the magnetic field. The range of values of the electric field where the assumption of a Maxwellian ion distribution is correct has been determined as a function of the direction of observation for two different populations: O^+, NO^+. Outside this range, the plasma parameters obtained by the usual interpretation can be dramatically overestimated or underestimated. The errors evaluated for electric fields reach 120 mV/m, for a single population of O^+ and NO^+, respectively. The study of a mixed population of oxygen and molecular ions is in progress and the influence of non-Maxwellian distributions on ion composition determination will be estimated (Hubert and Lathuillère).

Ionospheric Ion Up-flows

It has been found that strong convection velocities are also associated with large ion up-flows observed near the polar cap boundary, usually in the period following the Harang discontinuity. Field-aligned velocities larger than 200 ms^{-1} have been measured and the magnitude of the corresponding 0^+ flux is an order-of-magnitude greater than that required to support the light-ion polar-wind outflow at greater altitudes. Fig. 43 shows an example of such an event where the up-flows are along the Tromsö field line so that the measured value of the upward flux has very low experimental error. These fluxes always correspond to regions where there is a significant increase in both Joule heating of the neutral atmosphere at E-region heights and frictional heating of the ion population in the F-region. Models show that both these factors can contribute to an enhanced upward velocity (Winser et al.).

However, the same conditions create non-thermal ion velocity distributions and in an inhomogeneous magnetic field these distributions have considerable consequences for the field-aligned dynamics of F-region plasma (Suvanto et al.).

Magnetospheric Cavity Modes

EISCAT has provided the first observational evidence of the role of cavity modes in the coupling of energy from the magnetopause into the field line resonance mechanism for the generation of ULF waves. EISCAT estimates of the height integrated Pedersen conductivity provide theoretical damping rates of two pc5 pulsations. These are larger than the measured damping rates from the amplitude decrease observed by a ground based magnetometer at Tromsö. This discrepancy suggests that energy was continually fed into the pulsation and a possible source of this energy is the hydromagnetic cavity mode coupled to the field line resonance. It is important to note that, from the energy dissipation measured by EISCAT, cavity modes would have initial amplitudes of approximately 0.2 nT and would, therefore, be difficult to detect with existing space-borne magnetometers. EISCAT has, therefore, played an important part in establishing the validity of the new theories involving the coupling between cavity modes and field line resonances (Crowley, Hughes and Jones, 1987).

APPENDIX TO THE EISCAT ANNUAL REPORT 1987

CONTENTS

TECHNICAL DEVELOPMENTS

Alternating Codes

Over the past few years, the multi-frequency, multi-channel capabilities of the EISCAT systems have been brought into active use to an extent which surely could not have been foreseen by those who planned the system well over a decade ago. The resulting improvement in sensitivity is in some applications equivalent to a doubling of the transmitter power, or more. For certain tasks, such as the study of ionospheric ion composition with extreme altitude resolution throughout the E- and F-regions, these improvements are still not sufficient to make the experiments truly feasible. In such cases, coding must be applied to the transmitted pulses in order to increase the altitude resolution without any undue loss of signal-to-noise ratio.

1987 witnessed the first ever use of the newly invented alternating code in a real experiment. This is a major landmark in the history of EISCAT, as it represents the first case in which somebody from the EISCAT user community successfully implements a new modulation scheme, which has not been previously used elsewhere (Lehtinen and Häggström, 1987).

Various coding/decoding schemes have been applied to incoherent scatter radar measurements in the past. A feature which most of these methods have in common is that the coding and the decoding are both performed in the complex amplitude domain. This is true of, e.g. the Barker codes of different lengths often applied in D- and E-region experiments, as well as of the pairs of complementary codes used in MST radar work. Unfortunately, the range ambiguity functions of all known single-pulse codes contain side lobes, while the complementary code pairs require the target to remain coherent during a whole interpulse period of the radar. Because of this, none of these codes is well suited for use above the E-region.

The alternating code method is based on a different approach. Firstly, the modulation cycle does not repeat after each transmitted pulse. Instead, different modulation patterns are used on successive transmissions until, after a certain number of pulses, the cycle repeats. The received signals are sampled with a time resolution at least as good as that of the modulation, and all possible cross products formed from the samples. The decoding is then performed in the power domain, and because of this, phase stability is not a prerequisite for successful decoding. However, the decoding must be performed over the total sequence of coded pulses, so the statistical properties of the scattering medium must remain stationary over the length of the transmission cycle. This may sometimes pose a practical problem.

It has been shown by the inventors of the method that codes having the desired properties can be formed using Walsh sequences as a starting point. Walsh sequences are binary orthogonal sequences, which possess qualities that simplify the search for useful code patterns drastically. Modulating patterns of length 4 to 64 have been found by a computer search. Common to all of these is that the ambiguity functions for all non-zero lags is unique and localized in an exact sense. It is in this respect that the alternating code approach differs fundamentally from similar methods developed elsewhere.

The alternating code method offers possibilities for improvements of existing experiments mainly in two distinct respects. Firstly, for a given spatial resolution, the number of independent estimates per unit time can be increased by a large factor for most lags. If the presently used multi-pulse scheme of the CP-1 and CP-2 were to be replaced with an alternating code, for instance, the improvement would be about a factor of four for short lags!

Secondly, for a given lag extent, the spatial resolution can be improved by a factor equal to the number of subpulses in the transmitted pulse, i.e. by 4-16 times in practical cases. This offers interesting possibilities for detailed studies of e.g. the 150-250 km altitude region, where the transition from molecular to atomic ions takes place.

The first experiment using alternating codes was performed in April 1987, see Fig. 9 on page 18. Since no device suitable for on line decoding of this coding scheme was available, the experimenters devised an ingenious method whereby 32 different codes were transmitted, received and the cross products formed for two seconds each in an overall cycle of length 64 seconds. The data from each two second interval were dumped to tape separately and the decoding later performed off line.

For the purpose of this experiment, which was to study diurnal and other variations in the ion composition of the ionosphere, the coarse time resolution did not represent a major limitation. However, a similar technique could not have been applied to a study of e.g. auroral substorm dynamics, where the time scales involved are of the order of seconds. With a coding scheme as elaborate as the alternating code, it is evidently necessary to provide on-line decoding, if the full advantages of the method are to be realized.

The MUFFIN Project

For special applications, the use of other coding schemes may still be attractive, but even here EISCAT is faced with the limitations of the existing "matched filter", which is hardwired to handle only Barker codes. There are thus several good reasons for adding power and flexibility to our signal processing hardware, and so we have embarked on a design study of the MUltichannel Fir Filter and INtegrator (MUFFIN) project.

The MUFFIN, a block diagram of which is shown in Fig. A1, is planned as a fully programmable device, which should interface to the existing ADC and correlator. In its basic form, it will be capable of decoding any phase coded signal of reasonable length on any of the eight receiver channels. Modulation patterns can be freely mixed and both modulated and unmodulated signals handled within the same cycle with none of the limitations of the old matched filter. Since the device contains an integrator, it can also perform the coherent integration commonly used in MST experiments but hitherto impossible at EISCAT.

The basic decoding unit of the MUFFIN consists of a pipeline of programmable ALUs. The design would work with just one ALU, but it would then become intolerably slow. However, ALU stages can be added on to the pipeline as the demand grows, making it possible to adapt it to the prevailing demands. A practical unit might have four or eight pipeline stages.

The prototype version of the MUFFIN does not have any built-in means for handling alternating codes (it lacks a multiplier). If the data are first passed through the correlator and then recirculated through the MUFFIN, it can however perform the decoding of any reasonable length alternating code sequence in real time. It is planned, that the operational version of the MUFFIN will include a set of multipliers, which in practice will replace the existing correlators and make the external recirculation of data unnecessary.

In order to simplify the construction and integration of the MUFFIN project, all subunits will be built to conform to the IEEE P1014/VME bus standard, thus relieving the designers of one of the most complicated parts of systems design, while making future expansion much more feasible than the case would have been using in-house bus formats. Design and proto-typing work is now in progress at the Sodankylä site. As this project is almost an order of magnitude more ambitious than any digital construction work undertaken in EISCAT so far, new techniques must be used. It is anticipated that surface mounting must be used in order to accommodate all components of the delay elements on a single card each. To aid the engineers in their work, a PC-based CAD system for electronic design and PC board layout has been acquired.

Complementary Codes for MST Work

While certainly superior in versatility to other devices presently available at

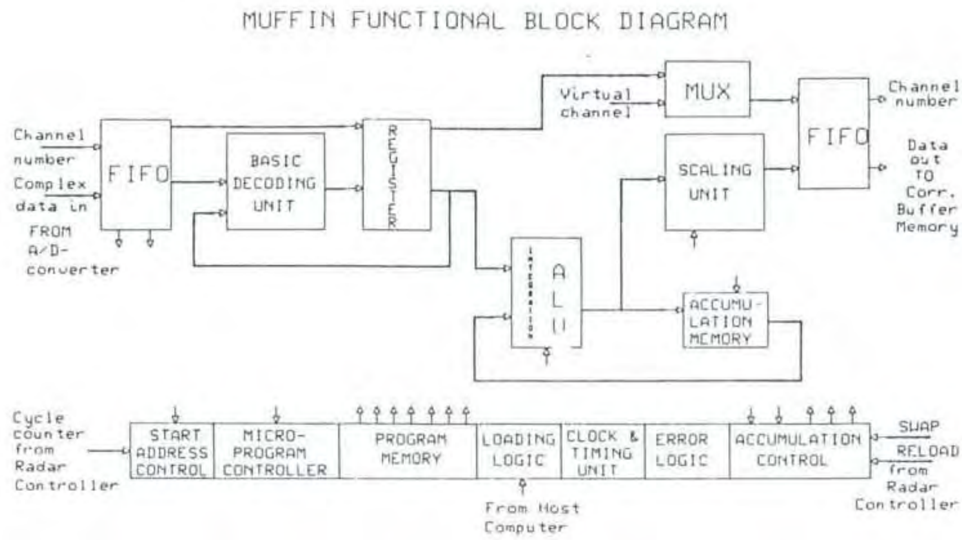


Fig. A1. Functional block diagram of the MUFFIN prototype. In this version, the MUFFIN functions only as a (completely general) decoder, which must be interfaced to the existing correlator. The operational units will contain a complex multiplier, attached to the accumulation memory, thereby upgrading the MUFFIN to a self-contained signal processor. The throughput rate of the prototype device is of the order of 2 Msamples/s, thereby making it at least 25% faster than the present "matched filter". Later revisions may become substantially faster.

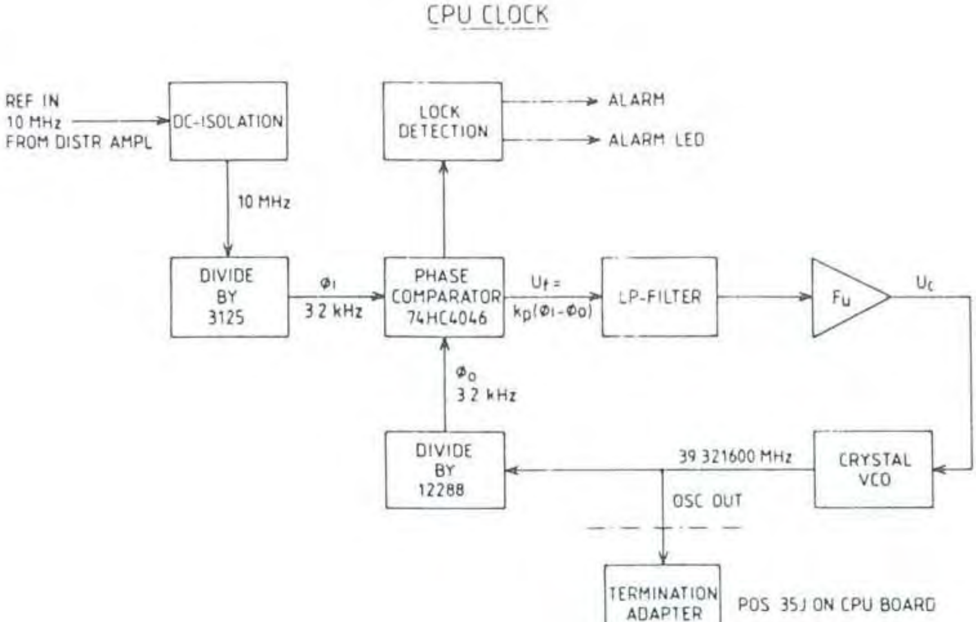


Fig. A2. Block diagram of the phase-locked CPU clock installed in the ND-500 process control computers. The VCO is crystal controlled and has an extremely limited frequency control range of the order of a few hundred Hz. Because of this, the unit may run in the unlocked mode for several hours before the phase error accumulates to one basic time unit of the CPU (=20 ms). The computer can thus operate without external reference in an emergency and will remain in fair synchronism with the overall system for many hours. With the VCO running locked, the long term stability is as good as that of the 10 MHz Cs reference.

EISCAT, the MUFFIN is unlikely to leave the prototype stage for another few years. At the same time, a widespread interest in the use and application of EISCAT as an MST radar has emerged both within the established user community as well as in other quarters. This interest was further enhanced by the detection of the coherent VHF radar echoes from the mesosphere, see pages 20-21. As any serious attempt to evaluate the capabilities and short-comings of EISCAT in this application requires the use of a signal pre-processor, we have investigated how the existing signal processing hardware could be applied in this context.

The tasks of a signal pre-processor as applied to an MST radar are mainly twofold: the received signals are sampled and the complex samples integrated by gates for some time, whereupon a decoding of the sample series into a true profile of complex amplitudes is performed. Both of these operations enhance the instantaneous signal-to-noise ratio of the received signal. Moreover, the data flow is compressed by an order of magnitude or more.

The operations are usually performed in the described order simply because it is convenient and minimizes the number of numerical operations per unit time. It is however equally possible, and in fact mathematically strictly correct, to perform the decoding first on each sample series separately and then to integrate the decoded of amplitude profiles. A correlator with a built-in integrator is ideally suited for this task, since the decoding process is equivalent to a cross-correlation of the received sample series with a replica of the transmitted code. This replica code can be generated by a signal generator, commanded by the radar controller, and feeding into one of the receiver ADCs, thus producing a master sample series at some convenient buffer memory address. However, in order for the scheme to be more practical, it should be possible to generate and store arbitrary code sequences in the correlator buffer memory without tying up part of the receiver hardware or requiring special attachments.

When the new buffer memories were redesigned and built some years ago, a provision for loading data into selected addresses of the memory map was prepared for. We have now written and tested the necessary micro-code for the buffer control logic, as well as the CAMAC drivers necessary to download arbitrary data to both halves of the swinging buffer. A special correlator program using this feature is under preparation, which will enable users to apply both coherent integration and complementary decoding in practical experiments, limited only by the small result memory (4k of 2x32 bit words) and the coarse resolution of the ADCs (8 bits).

CPU Synchronization

The Norsk Data ND 530 computer systems delivered in 1986 have by now proved themselves to be highly reliable and quite powerful tools for the computing needs of EISCAT. The changeover was not quite painless from the technical point of view, however; the new computers quite unexpectedly lacked any provisions for synchronizing the CPU clock oscillators to an external reference. As delivered, the oscillators even lack a tuning adjustment and may run at a frequency slightly offset from the nominal one. In the machines delivered to EISCAT, the offsets were large enough to accumulate to time drifts of the order of a second per day relative to UTC. Such large drifts are very inconvenient, as the real time execution of experiment programs at the three sites rapidly will get out of phase. For the first few months after the replacement, we circumvented the problem with the help of a special real time program, which updated the CPU time to UTC from the cesium clock several times a day.

As Norsk Data had no solution to offer, we were granted permission to remove the internal master oscillators of the CPUs and to replace them with outboard oscillators of our own design without invalidating the warranty and service contract. The frequency required, 39.21660 MHz, is sufficiently "odd" that no packaged frequency synthesizer chip can generate it directly. Therefore, an in-house design was made, based on a voltage controlled crystal oscillator and standard TTL. The crystal oscillator is phase-locked to the 10 MHz cesium derived standard frequency and thus does not drift at all relative to it. As an additional advantage, the crystal control ensures that the basic oscillator never deviates from the desired frequency by more than about 2 parts in 10^5, even if the phase lock is momentarily lost. This ensures that the computers will remain in synchronism for several hours, even if the reference signal should fail for any reason.

The circuit was successfully tested at the end of 1987 and installed in the Kiruna process control computer under supervision of Norsk Data staff. This unit has operated continuously since with no problems. In Tromsö a similar clock was installed thereafter and Sodankylä is awaiting delivery. The time keeping of the background computer in Tromsö and the communication computer at the Kiruna site is "slaved" to the phase-locked machines at these sites through software driven time transfer over the communication link. This proceeds completely transparent to the user, making the timekeeping in EISCAT truly unified.

The Chirp Synthesizer

Finally, as an example of evolution in a quite different direction, the digital chirp synthesizer for plasma line studies should be mentioned. The EISCAT unit, which is based on the Arecibo design, is now under construction. The heart of this synthesizer is a set of programmable direct digital synthesis generators operating at about 20 MHz. Both the chirp rate and the chirp characteristic (linear or quadratic) can be rapidly programmed from the host computer, although it is very unlikely that quadratic chirp will ever be used in practice.

As is well known, the purpose of the chirp generator is mainly to introduce a linear frequency modulation of the transmitted pulses, such that the frequency-vs.-height characteristic of each pulse matches the plasma frequency profile at some altitude. On receiving the scattered signal and demodulating it with a replica of the transmitted pulse, spectral compression of the plasma line returns by a factor of 50 or more may be achieved. The gain is twofold: the plasma frequency below the F-layer peak can be determined with much greater accuracy than before, and extremely weak plasma line returns become detectable through the signal-to-noise enhancement resulting from the frequency compression.

The chirp technique is particularly attractive in connection with observations of naturally occurring plasma line returns. It becomes very powerful when it can be applied to both the VHF and the UHF systems in parallel, as this would enable simultaneous determination of plasma density and electron temperature with unprecedented accuracy. For this reason, the ultimate aim is to have the chirp synthesizer permanently connected to both systems and controlled by the radar controller. The designs of the exciters are sufficiently similar that this will be possible. Until this becomes ready, the chirp system must be temporarily wired into the receiver/transmitter whenever it is to be used in experiments.

COMPUTER STATUS

Overview

The year 1987 was mainly used to stabilize the system with the new ND-500 process computers at all sites. As the experiment statistics shows this was rather successful: the computer caused experiment problems have drastically decreased compared to the previous years. The software development concentrated on those areas where a new approach was utilised: the data transfer from correlators to the computer (DMA programs), the transfer further to disc or tape and the data retrieval from the disc to the final tape, and the monitor programs, mainly the graphics display program for raw-data monitoring, RTGRAPH, and the implementation of a routine analysis of the data during the experiment.

Other changes to the process software were aimed at an increase in system flexibility, safety and reliability.

The synchronisation of the computer clocks with the EISCAT real-time clocks was tested with an extra designed interface, which is being installed at all sites as soon as possible.

The crowbar sensitivity of the Tromsö computers is again drastically improved by modified grounding means.

Modifications to the Software

Nearly all commands are now available from any command terminal, local or via remote-link and from ELAN files. This includes the access to the VHF system in Tromsö from Kiruna and Sodankylä. Additionally the system is prepared to accept commands simulated by an application program which is no standard part of EROS.

Some of the modifications to the process software are listed below:

A new command was introduced in autumn 1987 to allow fast changes between different experiments without stopping the transmitter. It allows the loading of 2 independent radar-controller programs into the controller memory. The access is controlled via EROS with the standard commands for loading and starting the controller. This is equivalent to merging the program source files of two experiments except that only one experiment has to be known before while the second can be dynamically changed during an experiment campaign. The time to load a program into the radar controller was reduced from 5 to 2 seconds.

On the receiver side the process software can now set any available filter type in any position. Opposed to earlier though the verification of this setting contains some ambiguities due to hardware limitations.

The UHF antenna system in Sodankylä was used successfully during the 2nd half of 1987 for passive experiments using a more general software approach and the standard EISCAT receiver and correlator hardware.

The data recording procedure was completely modified during the transit to the new computer system. According to the gained experiences some modifications were made: changes between different output devices ("disc-sets") are sped up. The recovery possibilities after failure are improved. The background programs related to data recording were further developed and offer now a high degree of flexibility to the user including some on-line help.

The on-line analysis is performed since the beginning of 1987 in parallel with all Common Programme and some Special Programme experiments. This makes the geophysical parameters available directly after enough measured data were post-integrated to allow their analysis. The results are available at all three sites and available on tapes directly after the experiment. For this purpose the on-line information about the UHF transmitter parameters is now always available at the two remote sites and will be updated whenever any change in the high voltage exceeds 1%.

The graphics monitoring program is developed into a very powerful monitoring tool based on a control file for initial set up and allows displaying of raw data with post-integration in real time or from disc and tape, thereby offering a "look-back" possibility. Images may be stored in intermediate files, printed out or combined in the graphics workstations. The program is simultaneously available to any user with independent set up possibilities.

Inter site communication: a background program Telex available in each EISCAT computer gives a simple possibility to exchange information. They will be printed on a dedicated printer at each selected site. Any combination of sites may be selected.

OPERATIONS

In Table A1 the EISCAT operations in 1987 are summarized. Figures A3 to A9 depict in a graphical manner these operations, namely the amount of experiment hours and its distribution in various categories.

The goal of 2000 hours per year has been nearly achieved, the actual number being 1950 hours. The partition of this number into 1146 hours of Common Programme operations and 804 hours of Special Programme experiments (including 62 hours used by EISCAT staff) shows an inbalance however, as each should be 1000 hours. The distribution of the Common Programme operations is approximately equal to the goals themselves of 40, 20, and 40 percent for CP-1, CP-2 and CP-3 respectively. On the other hand, the distribution of the accumulated time of Special Programme experiments per associate country shows the same trends as in previous years, namely that France and Germany are below the goal of 25%, whereas the UK is above the goal.

The distribution of Common Programme operations and Special Programme experiments per month and of Common Programme operations per week are revealing. The paucity of Common Programme experiment hours during July and August (weeks 27 to 37) was due mainly to unexpected repair of the transmitter and the remote site antennas (cf. page 7, Antennas). One can also see that four months (January, October, November and December) have produced about 50% of the Common Programme experiment time. This is mainly the result of a purposedly accomodation of the scheduling of the Common Programmes in deference to Special Programmes.

The distribution of Common Programme operations per week also shows a marked increase in the number of runs that last more than 24 hours. Between week 3 and week 23 there were 15 Common Programmes of which 12 lasted 36 hours or more. Between weeks 39 and 51 there

EISCAT OPERATIONS 1987

CP	1146 hours
SP	742
EI	62
TOTAL	1950

Distribution of Special Programmes

	1987 hours	Acc. 1986 hours	Acc. 1987 hours	Acc. 1987 %
FI	49	192	241	5.73
FR	99	876	975	23.16
GE	236	656	892	21.20
NO	102	393	495	11.77
SW	46	349	395	9.39
UK	210	1099	1209	28.74
EI	62	157	219	

Distribution of Common Programmes

CP-1	470.5 hours	41.0 %
CP-2	215.6	18.8
CP-3	443.5	38.7
New	16.4	1.5
TOTAL	1146.0	

Table A1. EISCAT operations in 1987. CP stands for Common Programme, SP for Special Programme, EI for EISCAT directors and staff, FI for Finland, FR for France, GE for Germany, NO for Norway, SW for Sweden and UK for United Kingdom.

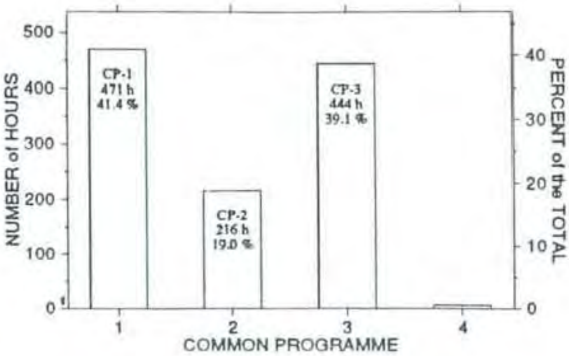


Fig. A3. Distribution of Common Programme operations in 1987; total 1146 hours.

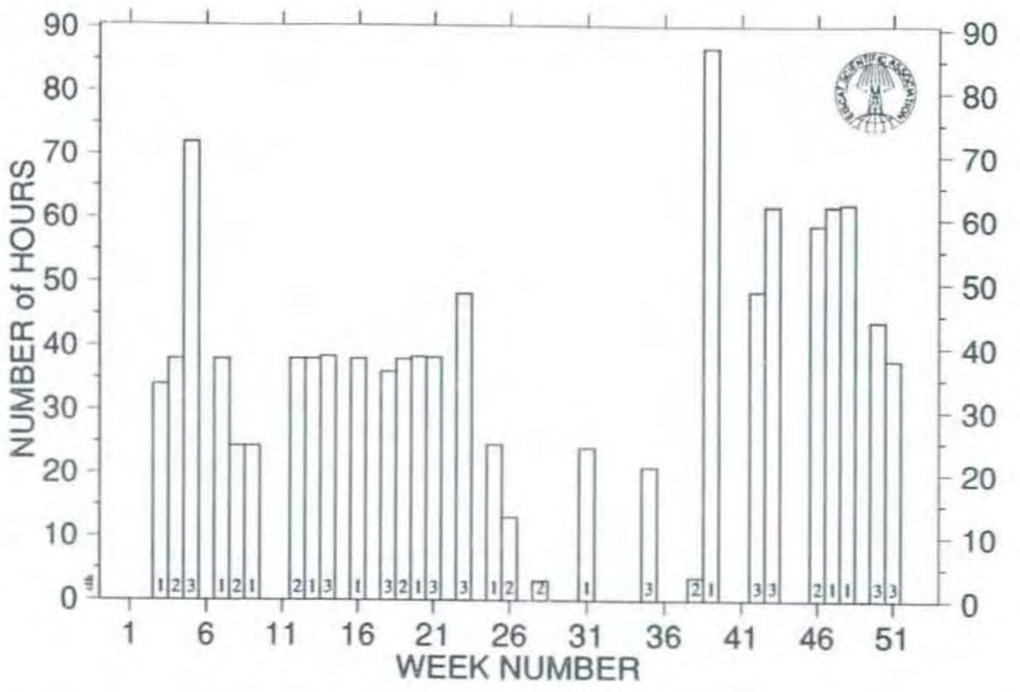


Fig. A4. Distribution of Common Programme time per week in 1987.

were 8 Common Programmes of which 4 were 60 hours long, one was 87 hours long, and the remaining 3 were between 40 and 50 hours long. The extended duration of the later group of 8 Common Programme operations was designed in part to compensate for the shortage of Common Programme runs in July and August, although the evidence available at the time of a decrease of Special Programme hours also played a role.

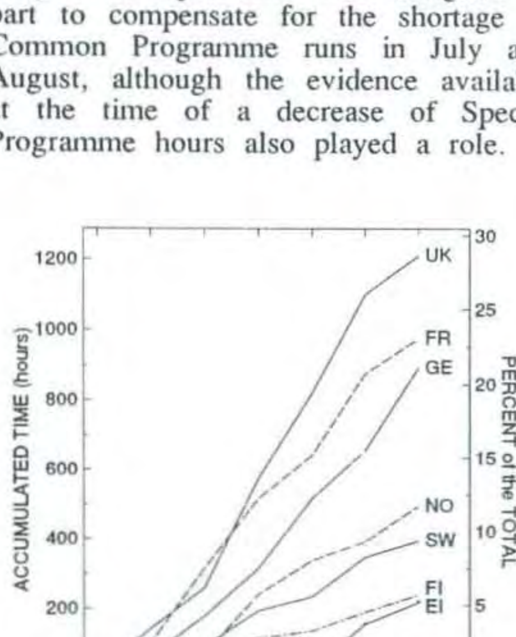


Fig. A5. Time of Special Programme operations for each country in absolute hours and in percentage of the total operating hours (4426), accumulated in the years 1981 to 1987.

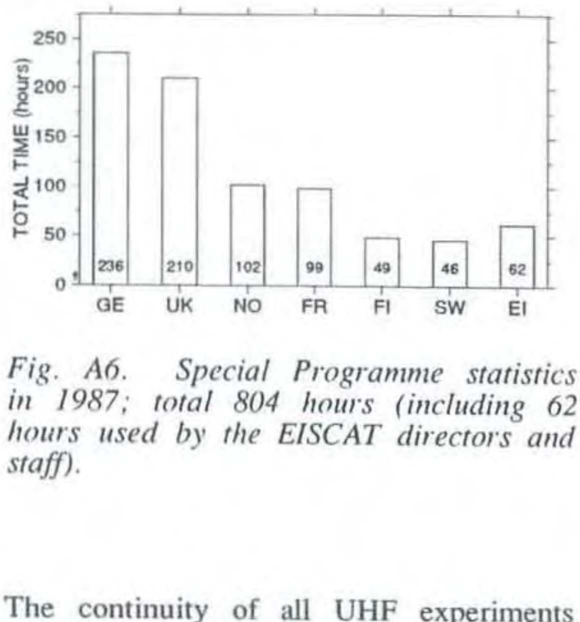


Fig. A6. Special Programme statistics in 1987; total 804 hours (including 62 hours used by the EISCAT directors and staff).

The continuity of all UHF experiments has increased considerably in all sites during the last year. It is not unusual any more that a 24 hour experiment can go on without a single interruption.

From the perspective of the radar operations and the consequent scientific results, the VHF activity in 1987 has been remarkably productive with a total of 231 hours of Special Programme experiments carried out. The proof that this achievement is indeed remarkable can be found in the sections on Transmitters and the New VHF Klystrons (page 7) and on Scientific Research (pages 18-49) in this report.

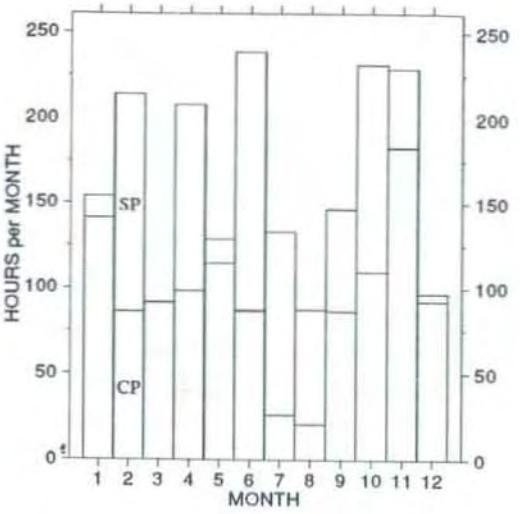


Fig. A7. Special Programme and Common Programme distribution per month in 1987; total 1950 hours.

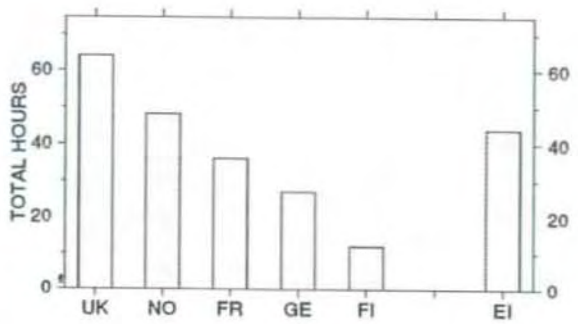


Fig. A8. VHF operations in 1987; total 231 hours.

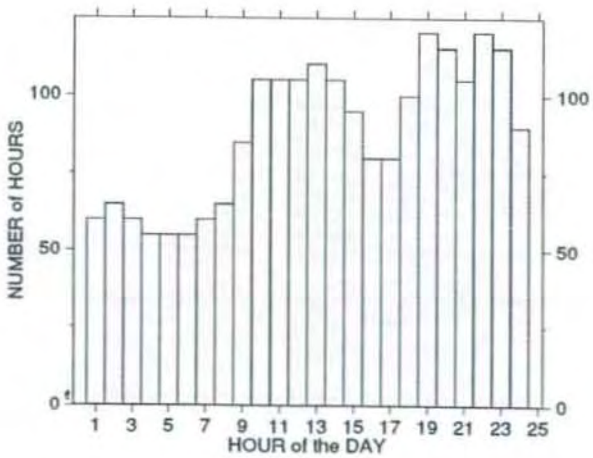


Fig. A9. Distribution of operation time in 1987 as a function of time of day.

COMMON PROGRAMMES

Analysis Procedures

Data from many of the Common Programme experiments during 1987 were analysed during the course of the experiments themselves, ie. the measurements were processed by the standard programs to obtain values of electron density, ion and electron temperatures, line-of-sight ion drift velocity, and, where appropriate, ion-neutral collision frequency. Throughout 1987, the three Common Programmes (CP-1-H, CP-2-D and CP-3-E) each had their own dedicated integration and analysis programs for Tromsö data, whilst remote site measurements could be handled by one integration program and one analysis program for all three experiments. All information necessary for integration and analysis of data from these experiments was hard-coded within the computer programs.

In parallel with the routine operation of analysing Common Programme data in 1987, a second scheme was developed to generalise the procedure such that one integration program and one analysis program could be used both for Common Programme data analysis and for the analysis of data from special experiments. The major difference between the new approach and the one originally in use was that experiment-dependent details and any auxiliary information needed by the integration and analysis programs were obtained from the graphics definition file (type :GDEF). This scheme was used for several special program applications during 1987, and was also tested with Common Programme data.

Integration of data from an experiment is most conveniently done by a real-time program reading the data directly from computer memory, which can be started from the :ELAN file of that experiment. This is the method usually used, though sometimes it is necessary to retrieve the raw data from the recording medium (only tape in the past, but now also from the disc sets), and to process these with an integration program. Provided that the raw data are still on disc, this is a quick and easy process; if tapes have to be used it takes more time.

The analysis program can be started at any time, as soon as there are data integrated. This program can also be stopped at any time, or left running with the experiment, in which case the results of the analysis are available with a delay of only a few seconds after the end of the post-integration interval.

Results

The following list indicates all Common Programme (CP) experiments from the beginning of 1983 to the middle of April 1988. All experiments from November 1984 onwards have been processed to extract values of the ionospheric parameters from the raw data, together with about 16 days prior to November 1984. Tapes containing the results from all these experiments have been distributed to the EISCAT Associates, and further results continue to be distributed as more data are collected and analysed.

Results from the so-called 'incoherent scatter coordinated observation days' (or 'world days') are also sent to the incoherent scatter radar data base at the National Center for Atmospheric Research (NCAR) in Boulder, USA, following an agreement made by the EISCAT Council. World day experiments are indicated in the table below with (3) if the results have been sent to NCAR.

The table also contains information about when the data were processed, when the results were mailed to the Associates, on which tapes the results from any particular CP experiment can be found, and approximately how many hours of good results were available from the three EISCAT sites for all processed experiments. A code (2) in the remarks column indicates that results are not available for the whole experiment due to too low signal levels from the ionosphere - a not uncommon phenomenon during the winter nights of 1984/5 and 1985/6 when solar activity was at a minimum between cycles 21 and 22.

The name of the experiment is specified in the table below by its usual abbreviation, eg CP-1-H is Common Programme type one, version H. Common Programmes are of three different basic types, designated CP-1, CP-2 and CP-3 (CP-0 was a predecessor of CP-1). The version of a Common Programme, specified by the final letter in the name, is updated by taking the next letter in the alphabet whenever the design of that experiment is changed. These changes are made either with the consent of, or at the request of, the EISCAT Scientific Advisory Committee (SAC). Some experiment versions may not exist as Common Programmes if they were run only as tests and subsequently changed further. An example is CP-1-G. The exception to this nomenclature in the list below is CP-M2-D (common program type minus two, version D), which was the last of the early series of Common Programmes identified by a 'minus' in the name, but now superceded by the usual form of CP-1, CP-2 and CP-3.

Concepts of Common Programmes

Common Programme CP-1 uses a fixed transmitting antenna, pointing along the geomagnetic field direction. This experiment is thus able to provide results with very good time resolution for a fixed ionospheric volume, and is suitable for the study of substorm phenomena when conditions may change rapidly. On longer time scales, CP-1 measurements also allow studies of diurnal changes (eg. atmospheric tides), seasonal variations, and eventually solar cycle variability will be able to be studied when sufficient data have been collected. The latest version, CP-1-H, provides power profile measurements between 67 and 170 km altitude with a gate separation of 2.6 km, and between 73 and 425 km altitude with a separation of 4.4 km. ACF measurements using the multi-pulse technique are obtained between 88 and 243 km altitude with a separation of 2.6 km altitude, and with the single pulse technique between 146 and 586 km altitude with a separation of 22 km. Remote site measurements are obtained at heights of 101, 109, 120, 133 and 279 km in a 10 minute cycle, allowing the determination of electric fields and neutral winds.

Common Programme CP-2 is designed to obtain measurements from a small, rapid scan. One aim of this is to identify wave-like phenomena with length- and time-scales comparable with, or larger than, the scan (few 10's km, 10 or more minutes). The present version is CP-2-D, which consists of a four-position scan covered in six minutes. The first three measurements in the scan form a triangle from transmitter vertical to south to south-east, and the final direction is along the geomagnetic field. The pulse scheme, and thus the description of the Tromsö data, are identical with those of CP-1-H above, but the altitude coverage for the 'triangle' of profiles depends on their elevations (90, 63 and 60 degrees) and can be scaled from those for 77.5 degrees along the field-line. The cycle time is so rapid that the remote sites do not have time to scan in altitude, and measurements are made only in the F-region in each of the four positions.

Common Programme CP-3 covers a wide range of latitudes in a 17 position, 30 minute cycle. The measurements are made in the magnetic meridian plane through Tromsö and Kiruna, and the remote site antennas follow the transmitter beam in the F-region. CP-3-E is the present version, which contains six radar controller programs to give better altitude resolution and coverage as the transmitter elevation is changed. Power profile measurements are obtained between 75 and 447 km altitude in the vertical position, and between 80 and 228 km altitude at the extremes of the scan. Single pulse ACF measurements are obtained between 200 and 956 km altitude in the vertical direction, and between 180 and 521 km altitude at the extremes of the scan. Remote site measurements are made at 275 km altitude, which covers the latitude range 64 to 75 degrees north.

EISCAT COMMON PROGRAMME OPERATIONS 1981-1987

START YY-MM-DD HH		END MM-DD HH		EXPT	REM	ANALYSIS COMPLETED YY-MM	TAPE NUMBER YYMMDD	APPROX HOURS T	K	S
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81-08-20	16UT	08-20	21UT	CP-M1-B						
81-09-16	09UT	09-17	07UT	CP-M1-B						
81-09-23	09UT	09-24	08UT	CP-M1-B						
81-09-30	11UT	10-01	09UT	CP-M1-C						
81-10-02	08UT	10-02	11UT	CP-M1-C						
81-10-06	22UT	10-08	09UT	CP-M1-C						
81-10-14	14UT	10-15	09UT	CP-M1-C						
81-10-21	09UT	10-22	09UT	CP-0-D						
81-10-25	16UT	10-26	09UT	CP-0-E						
81-11-04	09UT	11-05	09UT	CP-0-E						
81-11-11	09UT	11-11	15UT	CP-0-F						
81-11-18	09UT	11-19	09UT	CP-0-F						
81-11-25	09UT	11-26	09UT	CP-M2-B						
81-11-29	10UT	11-30	10UT	CP-M3-A						
81-12-08	15UT	12-09	07UT	CP-M3-B						
81-12-15	15UT	12-16	19UT	CP-M3-A						
1982										
82-01-19	16UT	01-19	24UT	CP-M3-A						
82-01-20	15UT	01-20	23UT	CP-M3-A						
82-01-26	15UT	01-27	23UT	CP-3-A						
82-01-31	10UT	02-01	01UT	CP-3-A						
82-04-14	13UT	04-15	08UT	CP-0-G						
82-04-21	10UT	04-21	13UT	CP-M2-C						
82-04-25	12UT	04-26	10UT	CP-3-A						
82-05-09	10UT	05-10	10UT	CP-0-G						
82-05-12	18UT	05-12	24UT	CP-3-B						
82-05-18	16UT	05-19	23UT	CP-M2-C						
82-05-20	18UT	05-20	24UT	CP-3-B						
82-05-26	10UT	05-27	10UT	CP-3-B						
82-06-02	10UT	06-03	10UT	CP-0-G						
82-06-06	10UT	06-07	12UT	CP-M2-C						
82-06-16	11UT	06-17	11UT	CP-3-B						
82-07-07	11UT	07-08	10UT	CP-M2-C						
82-07-26	..UT	08-01	..UT	CP-3-B	5)					
82-08-04	12UT	08-05	10UT	CP-M2-C						
82-08-11	10UT	08-12	10UT	CP-0-G						
82-08-17	11UT	08-18	11UT	CP-M2-C						
82-11-24	14UT	11-24	18UT	CP-0-H						
82-11-25	10UT	11-26	10UT	CP-0-H						
82-11-28	16UT	11-28	18UT	CP-3-B						
82-11-30	10UT	12-01	10UT	CP-0-H						
82-12-14	13UT	12-14	24UT	CP-3-B						
1983										
83-01-11	10UT	01-12	22UT	CP-0-H	4)					
83-06-22	10UT	06-23	10UT	CP-0-H						
83-06-29	10UT	06-30	09UT	CP-3-C						
83-07-13	10UT	07-14	10UT	CP-3-C	4)					
83-07-20	08UT	07-21	24UT	CP-M2-D						
83-08-02	09UT	08-03	10UT	CP-0-H						

START YY-MM-DD	HH	END MM-DD	HH	EXPT	REM	ANALYSIS COMPLETED YY-MM	TAPE NUMBER YYMMDD	APPROX HOURS T	K	S
83-08-09	10UT	08-10	11UT	CP-3-C						
83-08-16	09UT	08-17	23UT	CP-3-C	4)					
83-08-25	13UT	08-26	10UT	CP-0-H						
83-08-30	11UT	08-31	10UT	CP-0-H						
83-10-04	10UT	10-05	24UT	CP-3-C	4)					
83-10-11	10UT	10-12	10UT	CP-3-C		86-11		22	23	23
83-10-18	10UT	10-19	10UT	CP-0-H						
83-11-01	10UT	11-02	14UT	CP-3-C	4)					
83-11-08	10UT	11-09	10UT	CP-M2-D						
83-11-14	11UT	11-15	21UT	CP-3-C						
83-11-29	10UT	11-30	10UT	CP-0-H						
83-12-06	15UT	12-07	15UT	CP-0-H						
83-12-13	09UT	12-14	09UT	CP-3-C	4)					
1984										
84-01-04	10UT	01-05	12UT	CP-0-H						
84-01-17	10UT	01-19	24UT	CP-3-C	3)	86-09	840117	59	62	62
84-01-24	18UT	01-25	16UT	CP-1-C						
84-01-31	10UT	02-01	10UT	CP-1-C						
84-02-07	10UT	02-08	24UT	CP-3-C	4)	86-10	840117	38	38	38
84-02-14	10UT	02-15	10UT	CP-1-C						
84-02-28	10UT	02-29	10UT	CP-1-C						
84-03-06	10UT	03-07	24UT	CP-3-C	4)					
84-03-13	11UT	03-14	17UT	CP-M2-D						
84-04-24	11UT	04-25	11UT	CP-3-C						
84-05-02	10UT	05-03	10UT	CP-1-D						
84-05-08	13UT	05-09	24UT	CP-3-C	4)					
84-05-15	10UT	05-16	10UT	CP-2-B						
84-05-29	12UT	05-30	07UT	CP-1-D						
84-06-06	12UT	06-07	12UT	CP-1-D						
84-06-12	10UT	06-13	08UT	CP-3-C		85-10	840821	19	14	19
84-06-26	07UT	06-28	24UT	CP-3-C	3)	86-03	840626	55	55	37
84-07-12	13UT	07-13	13UT	CP-1-D						
84-07-23	12UT	07-24	22UT	CP-3-C		85-06	840723	32	22	33
84-08-21	13UT	08-22	22UT	CP-3-C	4)	85-10	840821	30	17	28
84-08-29	07UT	08-30	07UT	CP-2-B	1)	84-12	840723	24	15	24
84-09-12	07UT	09-13	07UT	CP-1-D						
84-09-19	13UT	09-20	07UT	CP-1-D	4)					
84-09-20	08UT	09-21	08UT	CP-3-C		85-05	840723	24	24	24
84-09-25	13UT	09-26	13UT	CP-2-B	1)	85-02	840723	23	18	23
84-10-03	14UT	10-04	09UT	CP-1-F	(2X4 PULSE)					
84-10-16	13UT	10-18	08UT	CP-3-C	1,4)	85-01	841016	39	40	38
84-11-06	16UT	11-07	08UT	CP-1-D						
84-11-13	12UT	11-14	23UT	CP-3-C	1,2,4)	85-02	841016	35	30	30
84-11-20	13UT	11-21	13UT	CP-2-B	1,2)	85-02	841016	24	7	7
84-11-26	13UT	11-27	13UT	CP-1-F	2)	86-03	840626	24	16	16
84-12-12	12UT	12-13	12UT	CP-1-F	2)	86-03	840626	24	16	14
84-12-18	14UT	12-20	00UT	CP-3-C	1)	85-03	841016	34	34	6
1985										
85-01-15	12UT	01-18	12UT	CP-3-C	2)	85-07	850115	70	48	30
85-01-28	12UT	01-29	12UT	CP-1-F		85-07	850128	24	23	23
85-02-14	12UT	02-15	12UT	CP-1-F		85-12	850214	24	24	24
85-02-19	14UT	02-20	14UT	CP-2-C	1)	85-04	850115	22	15	17
85-02-26	09UT	02-27	09UT	CP-3-C	1,2)	85-04	850115	24	24	18
85-03-19	12UT	03-22	12UT	CP-3-C	2,4)	85-05	850319	67	67	54

START YY-MM-DD	HH	END MM-DD	HH	EXPT	REM	ANALYSIS COMPLETED YY-MM	TAPE NUMBER YYMMDD	APPROX HOURS T	K	S
85-04-10	13UT	04-11	13UT	CP-2-C		85-05	850410	24	24	23
85-04-16	11UT	04-17	11UT	CP-1-F		85-11	850214	24	24	24
85-05-07	07UT	05-08	07UT	CP-2-C		85-06	850410	24	23	24
85-05-14	08UT	05-15	08UT	CP-1-F		85-11	850214	21	16	22
85-05-21	08UT	05-22	12UT	CP-1-F	3)	85-11	850214	24	24	24
85-06-04	08UT	06-05	08UT	CP-3-C		85-06	850410	24	23	22
85-06-25	12UT	06-26	12UT	CP-1-F	3)	85-11	850214	24	24	24
85-07-02	08UT	07-03	08UT	CP-2-C		85-10	850702	24	24	24
85-07-16	08UT	07-17	08UT	CP-3-C		85-10	850702	24	24	24
85-08-06	08UT	08-07	08UT	CP-1-F		85-12	850806	23	23	23
85-08-13	08UT	08-14	15UT	CP-1-F	3)	85-12	850806	29	29	29
85-08-20	08UT	08-21	08UT	CP-3-C	2)	85-10	850702	24	15	20
85-09-03	08UT	09-04	22UT	CP-1-F		85-12	850806	38	38	38
85-09-10	08UT	09-11	22UT	CP-1-F	3)	85-12	850806	38	38	38
85-10-08	09UT	10-09	23UT	CP-3-C	2)	85-10	850702	35	35	12
85-10-14	23UT	10-18	12UT	CP-2-C	3)	85-10	851014	80	80	80
85-10-29	09UT	10-30	09UT	CP-1-F		85-12	851029	24	23	24
85-11-05	09UT	11-06	09UT	CP-1-F		85-12	851029	24	22	24
85-11-12	09UT	11-13	23UT	CP-1-F	3)	85-12	851029	38	37	38
85-11-19	09UT	11-20	23UT	CP-3-C	2)	86-01	851119	38	36	20
85-12-03	09UT	12-04	23UT	CP-1-F	2)	86-01	851119	38	35	38
85-12-10	09UT	12-11	23UT	CP-3-C	2)	86-01	851119	38	37	20
1986										
86-01-14	16UT	01-17	16UT	CP-3-C	2,3)	86-02	860114	66	60	50
86-02-18	09UT	02-19	09UT	CP-1-F		86-03	860218	24	21	18
86-02-25	09UT	02-26	09UT	CP-1-F		86-03	860218	24	22	17
86-03-05	12UT	03-05	15UT	CP-3-C	3)	86-03	860218	3	3	3
86-03-25	09UT	03-26	09UT	CP-1-F		86-04	860218	24	24	24
86-04-01	12UT	04-04	16UT	CP-3-E	3)	86-04	860401	64	60	60
86-04-08	08UT	04-09	08UT	CP-1-F		86-04	860218	24	22	24
86-04-22	08UT	04-23	08UT	CP-2-C		86-05	860401	23	20	23
86-05-06	08UT	05-07	16UT	CP-3-E	3)	86-06	860506	32	30	30
86-05-21	08UT	05-22	08UT	CP-2-C		86-06	860506	24	21	24
86-05-27	08UT	05-28	08UT	CP-1-F		86-06	860506	24	24	24
86-06-04	08UT	06-05	12UT	CP-3-E	3)	86-08	860506	28	23	23
86-07-09	08UT	07-10	07UT	CP-3-E	3)	86-08	860709	20	20	20
86-07-15	12UT	07-16	12UT	CP-1-F		86-08	860709	21	22	21
86-07-22	08UT	07-23	08UT	CP-1-F		86-08	860709	23	23	23
86-07-29	08UT	07-30	22UT	CP-1-F		86-08	860709	38	38	38
86-08-05	08UT	08-06	08UT	CP-1-F		86-08	860709	24	24	19
86-08-12	08UT	08-13	08UT	CP-1-F		86-09	860812	24	24	24
86-08-27	08UT	08-28	22UT	CP-3-E	3)	86-09	860812	34	30	34
86-09-02	08UT	09-03	11UT	CP-1-F		86-09	860812	27	27	27
86-09-23	13UT	09-26	24UT	CP-3-E	3)	86-10	860923	77	77	80
86-09-30	09UT	10-01	17UT	CP-2-C		86-10	860930	31	26	22
86-10-07	09UT	10-08	17UT	CP-3-E		86-10	860930	31	31	31
86-10-21	09UT	10-22	23UT	CP-2-C		86-11	860930	38	38	37
86-10-29	10UT	10-30	23UT	CP-3-E	3)	87-01	861029	36	12	35
86-11-04	15UT	11-05	23UT	CP-3-E		87-01	861029	30	27	28
86-11-11	15UT	11-12	23UT	CP-2-D	2)	87-01	861111	31	31	31
86-11-19	14UT	11-20	23UT	CP-2-D		87-02	861119	32	32	27
86-12-10	09UT	12-11	23UT	CP-1-H	3)	87-02	861119	25	22	20
1987										
87-01-13	14UT	01-14	23UT	CP-1-H		87-02	870113	33	23	18

START YY-MM-DD	HH	END MM-DD	HH	EXPT	REM	ANALYSIS COMPLETED YY-MM	TAPE NUMBER YYMMDD	APPROX HOURS T	K	S
87-01-20	09UT	01-21	23UT	CP-2-D		87-01	870120	35	34	18
87-01-27	09UT	01-30	09UT	CP-3-E	2,3)	87-01	870127	66	62	66
87-02-10	09UT	02-11	23UT	CP-1-H		87-04	870127	37	37	37
87-02-17	09UT	02-18	09UT	CP-2-D		87-04	870217	23	23	23
87-02-24	09UT	02-25	09UT	CP-1-H		87-04	870217	24	24	24
87-03-17	09UT	03-18	23UT	CP-2-D		87-06	870317	36	37	34
87-03-24	09UT	03-25	23UT	CP-1-H		87-06	870113	34	33	33
87-03-31	09UT	04-01	22UT	CP-3-E	3)	87-04	870113	38	37	37
87-04-14	08UT	04-15	22UT	CP-1-H		87-07	870414	38	38	38
87-04-28	10UT	04-29	22UT	CP-3-E	3)	87-05	870414	36	36	36
87-05-05	08UT	05-06	22UT	CP-2-D		87-05	870505	36	36	36
87-05-12	08UT	05-13	22UT	CP-1-H		87-05	870414	38	38	38
87-05-19	09UT	05-20	22UT	CP-3-E		87-05	870519	37	36	33
87-06-01	08UT	06-03	08UT	CP-3-E	3)	87-06	870519	47	47	47
87-06-16	08UT	06-17	08UT	CP-1-H		87-06	870519	24	24	24
87-06-23	08UT	06-23	18UT	CP-2-D		87-06	870623	12	10	10
87-07-28	08UT	07-29	08UT	CP-1-H		87-09	870623	23	23	23
87-08-27	12UT	08-28	10UT	CP-3-E		87-09	870623	20	20	7
87-09-21	08UT	09-25	08UT	CP-1-H	3)	87-09	870921	80	80	80
87-10-13	09UT	10-15	09UT	CP-3-E		87-10	870921	48	48	48
87-10-20	09UT	10-22	23UT	CP-2-D		87-10	871020	60	60	60
87-11-10	12UT	11-12	23UT	CP-1-H		87-11	871022	59	59	59
87-11-17	09UT	11-19	23UT	CP-1-H		87-11	871117	62	62	62
87-11-24	09UT	11-26	23UT	CP-3-E	4)	87-11	871117	54	54	54
87-12-08	09UT	12-09	23UT	CP-3-E	2)	87-12	871208	38	38	38
87-12-15	09UT	12-16	17UT	CP-3-E		87-12	871208	32	30	30

Remarks:

1) Originally sent to CNES 2 May 1985. Velocity sign inverted, according to NCAR specifications, indicated by absence of "positive up" in velocity code 590.

2) Upper estimate of available data - other gaps exist due to low signal-to-noise ratio.

3) World day - data sent to NCAR, Boulder.

4) World day - data to be sent to NCAR.

5) Several short operations.

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Meeting reports:

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EISCAT Meetings No. 87/12, 1987

Meetings 1987:

COUNCIL	29th meeting	12-13 May 1987	Oulu, Finland
	30th meeting	12-13 November 1987	Paris, France
SAC	32nd meeting	27 March 1987	Bad Lauterberg, Germany
	33rd meeting	8-9 October 1987	Tromsö, Norway
AFC	28th meeting	2 April 1987	Hamburg, Germany
	29th meeting	1 October 1987	Hamburg, Germany

BALANCE SHEET AT 31 DECEMBER 1987

MSEK

Assets	At 31 Dec. 1986	Additions Pool	Additions Cap.Op.	Additions Other	Depreciation	At 31 Dec. 1987
FIXED ASSETS						
Buildings	8.4				0.2	8.2
Transmitters	28.1	0.1			1.6	26.6
UHF-antenna	16.0				1.3	14.7
VHF-antenna	20.2				1.6	18.6
Receivers	1.5				0.7	0.8
Computers etc.	6.6		0.3		1.1	5.8
Other	2.4		0.6		0.8	2.2
Total	83.2	0.1	0.9		7.3	76.9
CURRENT ASSETS						
Debtors	2.7					0.3
Prepayments and accrued income	0.1					0.3
Cash and Ordinary Bank Accounts	8.3					8.6
Special Accounts	0.2					0.1
Total	11.3					9.3
GRAND TOTAL	94.5					86.2

MSEK

Liabilities	At 31 Dec. 1986	At 31 Dec. 1987
CAPITAL		
Contributions		
Pool	88.5	88.6
Capital Operating	13.7	14.6
In Kind	25.1	25.1
Other	0.4	0.4
	127.7	128.7
Depreciations	44.5	51.8
Total Capital	83.2	76.9
RESERVES		
Pool	4.3	4.3
Capital Operating	0.6	0.8
Other	0.6	0.8
Total Reserves	5.5	5.9
Special Accounts	0.2	0.1
LIABILITIES		
Provisions	0.2	0.3
Other Liabilities	5.4	3.0
Total Liabilities	5.6	3.3
GRAND TOTAL	94.5	86.2

Totals may not match because of rounding. (MSEK = Million Swedish Crowns.)

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* on secondment of MPG

EISCAT Scientific Association
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