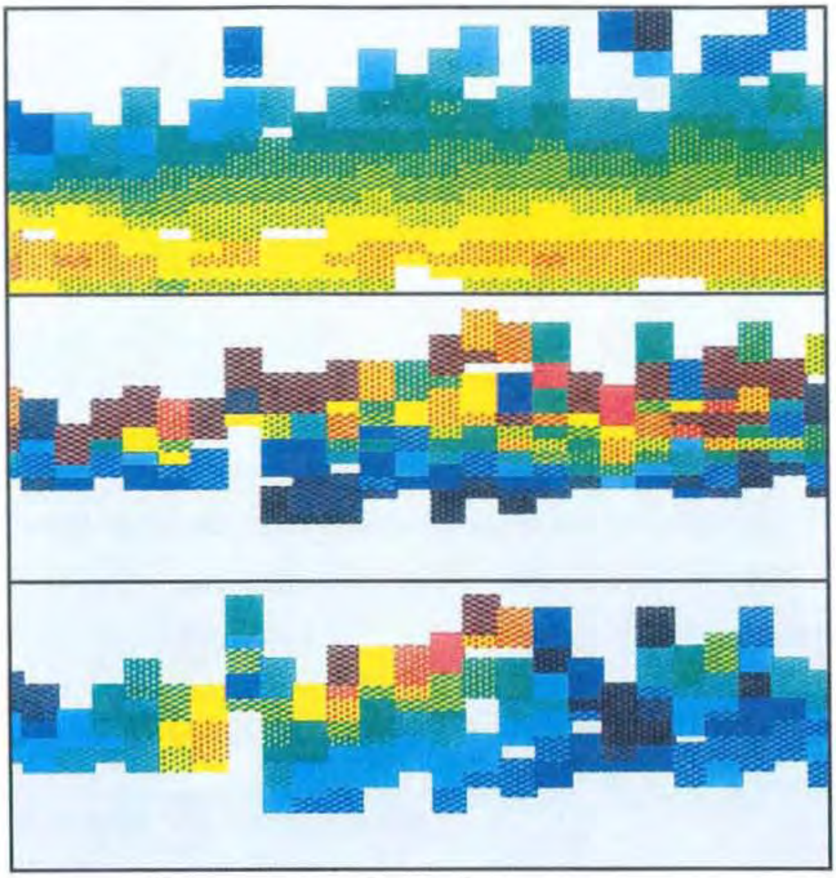
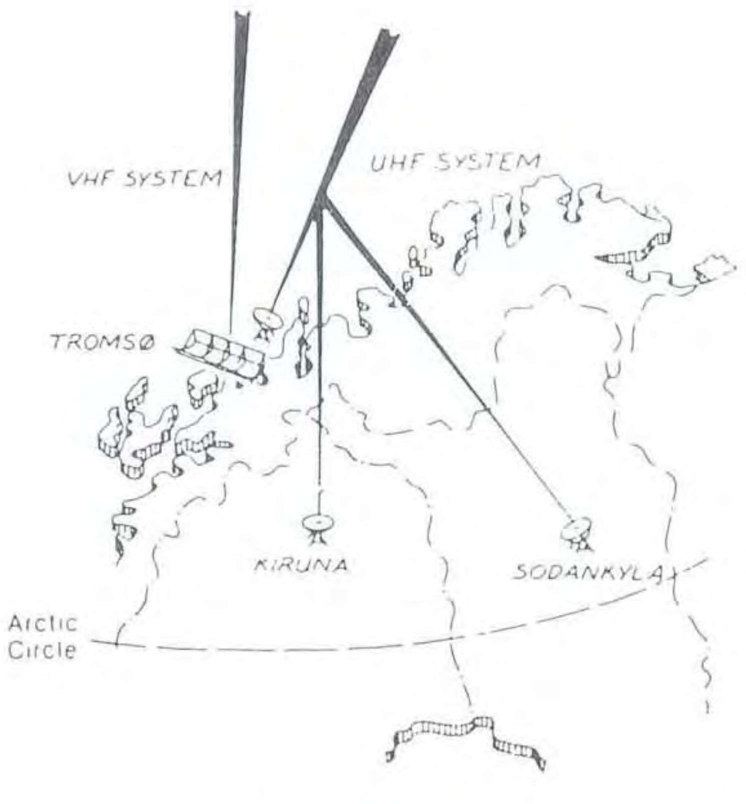


EISCAT

EUROPEAN INCOHERENT SCATTER SCIENTIFIC ASSOCIATION

ANNUAL REPORT 1990

S-981 28 KIRUNA, SWEDEN



The EISCAT Radar Systems - Operating Parameters 1990

	UHF Radar	VHF Radar
Centre operating frequency:	931.5 MHz	224.0 MHz
Tuneable bandwidth:	8 MHz	3 MHz
Pulse peak power:	1.5 MW	1.5 MW
(Nominal):		(5 MW)
Average power:	280 kW	140 kW
(Nominal):		625 kW
Pulse duration:	1 μs - 10 ms (phase/frequency coded)	1 μs - 1 ms (phase/frequency coded)
Minimum pulse interval:	1 ms	1 ms
Antennas:	Parabolic dishes 32 m diameter	Parabolic cylinder 40 m x 120 m
Feed systems:	Cassegrain	128 Crossed dipole line
Gain:	48.1 dB	43.1 dB
Polarization:	Circular (Tromsø) Any (Receiving sites)	Circular, Linear
System Temperature:	90-110 K (Tromsø) 30-35 K (Receiving sites)	250-300 K

Geographic coordinates:		
Tromsø:	69.59° N,	19.23° E
Kiruna:	67.86° N,	20.44° E
Sodankylä:	67.36° N,	26.63° E
Invariant Latitude (Tromsø):	66.26° N	
L-shell (Tromsø):	6.17	

The cover illustration shows the first direct analysis of the hydrogen component in EISCAT's VHF Common Programme Seven, CP-7, high altitude data. The horizontal scale covers the period 0000-0200 UT on 27 September 1990 and the vertical scale runs from zero to 1500 km on each panel. The upper panel shows the conventional analysis of the oxygen ion density component of the ionospheric plasma, the middle panel shows the percentage composition of hydrogen ions (dark red being ≥8%) and the lower panel shows the corresponding hydrogen ion velocity (dark blue to dark red corresponding to -200 ms^{-1} to +600 ms^{-1}). These data were produced using a specialized integration program, to remove unwanted satellite echoes, and a modified version of the standard analysis software.

EISCAT SCIENTIFIC ASSOCIATION

ANNUAL REPORT 1990

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 are seven incoherent scatter radars in the world, and EISCAT operates two 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 schematic and operating parameters on the inside of the front cover).

The EISCAT UHF radar operates in the 931 MHz band with a peak transmitter power of 1.5 MW and 32 m, fully steerable parabolic dish antennas. The transmitter and one receiver are in Tromsø (Norway). Receiving sites are also located near Kiruna (Sweden) and Sodankylä (Finland), allowing continuous tristatic measurements to be made.

The monostatic VHF radar in Tromsø operates in the 224 MHz band with a peak transmitter power of 1.5 MW (to be raised to 4 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 vertical to 60° north of the zenith; limited east-west steering is also possible using alternative phasing cables.

The basic data measured with the incoherent scatter radar technique are profiles of electron density, electron and ion temperature and ion velocity. Subsequent processing also allows a wealth of further parameters, describing the ionosphere, upper atmosphere and mesosphere, to be derived from these. A selection of well-designed radar pulse schemes allows the adaptation of the data-taking routines to many particular phenomena, occurring at altitudes between about 50 km and more than 1700 km. Depending on geophysical conditions, a best time resolution of better than one second and an altitude resolution of a few hundred meters can be achieved, whereas typical resolutions are of the order of minutes and kilometres.

Each year, 2000 operating hours (nominal) are distributed equally between Common Programmes (CP) and Special Programmes (SP). At present seven well-defined Common Programmes are run regularly, for between one and five days, about 30 times each year to provide a data base for long term synoptic studies. Three Unusual Programmes (UP) are 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 specific geophysical events.

The Annual Reports present a summary of EISCAT's operations, developments, scientific results, publications and budget for each year. Further details of the EISCAT system and operation can be found in various EISCAT reports, including an illustrated brochure, 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, Federal Republic of Germany
Norges Almenvitenskapelige Forskningsråd, Norway
Naturvetenskapliga Forskningsrådet, Sweden
Science and Engineering Research Council, United Kingdom

EISCAT ANNUAL REPORT 1990

CONTENTS

Annual Report 1990 of the EISCAT Scientific Association

EISCAT Headquarters, Kiruna, Sweden

Finishing and Printing by:
Birgitta Määttä and Stig Björklund,
Institutet för Rymdfysik, Kiruna, Sweden

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COUNCIL CHAIRMAN'S PAGE

During this year a major step was undertaken in the evolution of EISCAT with the decision by Council to formally proceed with the planning of a new incoherent scatter radar which will enable observations to be made well within the Polar Cap region. At the May Council meeting in Tromsø a report from the United Kingdom, outlining possible scientific and technical aspects of such a radar, was presented and Council then formed its own sub-committee to develop this report into a full EISCAT proposal. The last two days of the Council meeting were held on Svalbard and members were able to see at first hand the range of facilities available and to examine some possible sites for the new radar.

The sub-committee, tasked to produce the EISCAT proposal for the Svalbard radar, was chaired by Professor N Bjørnå and he and his colleagues are to be congratulated for producing an excellent document within a very limited time period. This report was presented to Council at the November meeting in Hamburg, where it was enthusiastically accepted. Following Council's formal decision to proceed with the EISCAT Svalbard Radar (ESR), EISCAT staff have now started to work on the new project. This project is a major milestone in the development of EISCAT and will enable a whole range of scientific topics to be addressed for the first time.

It is perhaps worth noting that the ESR is an extension of the EISCAT facility and at this point in time there is no intention to reduce the level of activity at the existing EISCAT facilities. In order to construct the new radar, additional finances will be required and all the EISCAT Associates will be able to make some contribution to the new project. It is also envisaged that new partners can be found and there is particular interest from our Japanese colleagues in a collaboration with EISCAT to build a radar within the Polar Cap.

The EISCAT systems have continued to produce excellent science and papers based on EISCAT observations have been presented at all the major conferences held during the year. EISCAT science now covers a very wide variety of topics ranging from neutral turbulence in the mesosphere to outward flows of ions into the magnetosphere. The takeover of the Max-Planck-Institut für Aeronomie Heating facility at Tromsø is progressing well and an EISCAT scientist with special responsibility for the heating programme will be appointed.

It was with great regret that Council received the resignation of Sir Grenville Beynon and, in recognition of his long and outstanding service to EISCAT, Council unanimously resolved that he should be elected an 'Honorary Associate member' of EISCAT. Council also established a Beynon medal and prize to be awarded annually (jointly with the European Geophysical Society) for outstanding research in EISCAT, or EISCAT related, science; Sir Grenville would be the first recipient.

It has been a great pleasure and privilege for me to have served as EISCAT Council Chairman and I am particularly grateful to the Director and all his staff for their very strong support and dedication to EISCAT during my period as Chairman. The construction of the ESR will ensure that EISCAT will continue to play a leading role in atmospheric and space plasma geophysics well into the next century.

Tudor Jones

THE YEAR 1990 REVISITED BY THE DIRECTOR

In 1990 EISCAT attained four notable milestones: first, dual radar operation became practical on a regular basis; second, EISCAT crossed the landmark in experiment operations of fifteen thousand hours of recorded data; third, the total number of papers dealing with EISCAT science and technology, published in the refereed literature, passed three hundred (See Fig. 1a and b). Finally, the EISCAT Council decided to work on a feasibility study for an additional radar site on Spitsbergen, Svalbard (Fig. 2), to be regarded as the main direction of the long-term evolution of EISCAT.

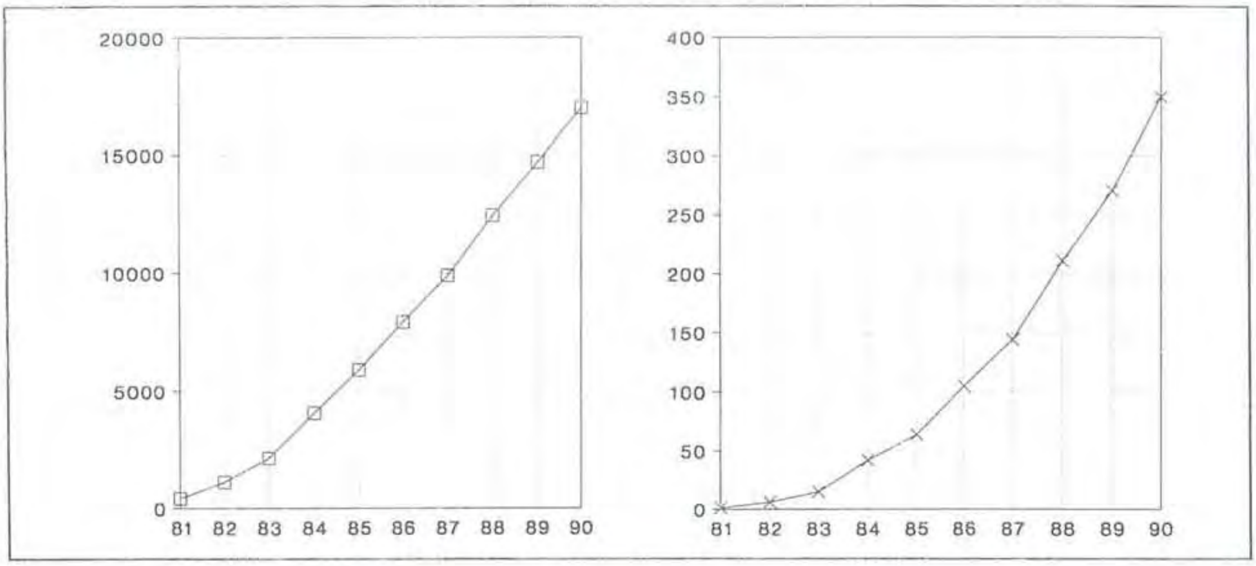

Fig. 1. (a) Accumulated experiment operating hours, (b) Accumulated publications.

EISCAT is now a true dual radar system, supporting simultaneous UHF and VHF radar operation. During the year 1990 many experimenters made use of this ability, which is totally unique amongst the World's incoherent scatter radar facilities. Whereas the EISCAT UHF system has the great advantage of tristatic observations, the EISCAT VHF system is most suitable for complementary observations of both exospheric altitudes, above 1000 km, and the lower ionospheric altitudes down to 50 km. The data quality of both the UHF and VHF radars is reported to be excellent. EISCAT has thus become the most capable incoherent scatter radar in the World for studies of the coupling between the magnetosphere, ionosphere, thermosphere and mesosphere.

Dual radar operation accounted for almost 1000 hours in the year 1990, and the total experiment operating time was close to 2300 hours. The large number of Special Programme hours (1300) demonstrates the strong demand from user scientists to carry out their own particular experiments, frequently yielding the greatest proportion of the exciting science. Furthermore, some 240 hours of passive observations were performed with the three UHF receiving sites.

The Special Programme time (in hours) used by the Associates and EISCAT in 1990 was (the number in brackets is the accumulated usage since 1981):

France	336	25%	(2058)	(25%)
United Kingdom	277	21%	(2189)	(25%)
Germany	273	20%	(1681)	(21%)
Sweden	208	15%	(810)	(10%)
Norway	157	12%	(790)	(10%)
EISCAT	28	2%	(362)	(4%)
Finland	64	5%	(375)	(5%)

UHF Common Programmes One to Five (CP-1 to 5), Unusual Programme UP-1 (using the VHF radar at short notice during particular D-region events) as well as VHF Common Programmes Six (CP-6, D-region) and Seven (CP-7, high altitude) were run quite frequently, giving a total time of 950 hours in 1990. The latter VHF programmes were operated during some 16% of the total Common Programme time. A detailed break-down of the EISCAT operation during 1990, including descriptions of the Common Programme modes, starts on page 13 of this Annual Report.

All Common Programme data for 1990 have been analyzed with the EISCAT standard analysis programmes and the result tapes sent to the Associates; the World Day result data tapes were, as usual, also sent to the NCAR Data Base in Boulder, USA. Furthermore, all the data from Unusual Programme operations have also been analyzed; preliminary analyses of the VHF Common Programme data are being completed and the evaluation of the results is underway. The analysis procedure for alternating codes has been further developed and the new Finnish analysis system has been tested. Most of the Special Programme data are now routinely analyzed at the EISCAT sites by the visiting experimenters themselves, using EISCAT integration and analysis routines, during or shortly after the experiment.

In the year 1990 EISCAT performed operations for many international programmes including: GEM (Geospace Environmental Modelling), DYANA (Dynamics Adapted Network for the Atmosphere), GITCAD (Global Ionosphere-Thermosphere Coupling and Dynamics), SuperWAGS (World Acoustic Gravity Waves), MLTCS (Mesosphere-Lower Thermosphere Coupling Study), HLPS (High Latitude Plasma Structure), GISMOS (Global Ionospheric Simultaneous Measurements of Substorms) and SUNDIAL. Special Programme campaigns focussed, for instance, on high altitude ion outflows, comparison of EISCAT ionospheric measurements with interferometer (MICADO) neutral wind measurements, the observation of enhanced electron temperatures observed by EISCAT and rocket borne instruments (NEED), plasma line experiments to measure field aligned currents, observations of polar mesosphere summer echoes (PMSE), coherent echoes from high altitude and E-region (COSCAT) plasma instabilities, Sporadic E observations combined with lidar, and (passive) interplanetary scintillation measurements to study the solar wind as well as using the EISCAT radars for diagnosing ionospheric modifications during Heating experiments. An impressive event was also captured by EISCAT when the polar ionosphere was observed during the transition of the Galileo spacecraft through the Earth's magnetotail in early December 1990. These experiments are only a sample from the wide variety performed during the year and more detailed results are expected to be found in future Annual Reports, after all the data had been analyzed and interpreted by the scientists. A record 78 papers and 19 other publications (see page 40 and following) were also published in 1990.

1990's EISCAT operations were possible because of the high system reliability in general and the intense use of the VHF system in particular; this can also be seen in the summary of operations starting on page 13.

Despite continuing interference problems, VHF radar system use has been further increased during the year 1990. Klystron focussing magnet sets, which were destroyed by coolant water following a break of a pipe, were rebuilt using a completely new design. The Philips VHF klystron, YK1320/1 performed without problems, but intentionally at limited power below 1.5 MW. The replacement klystron, YK1320/2A, after careful overhaul and reassembly at the factory in Hamburg, was delivered to Tromsø in autumn 1990 and started to be aged and tuned. It worked satisfactorily, but acceptance was delayed into the new year. The preparation of a fall-back solution for replacing the klystrons by a modular tube transmitter was abandoned, but the experience gathered was usefully applied to the studies of a transmitter system for the planned EISCAT Svalbard Radar.

The summer months were again used for some necessary servicing of the VHF antenna. Some broken dipoles had to be repaired and a number of destroyed dummy loads were detected in the power distribution system. All this, however, did not seriously affect the generally very adequate performance of the VHF system.

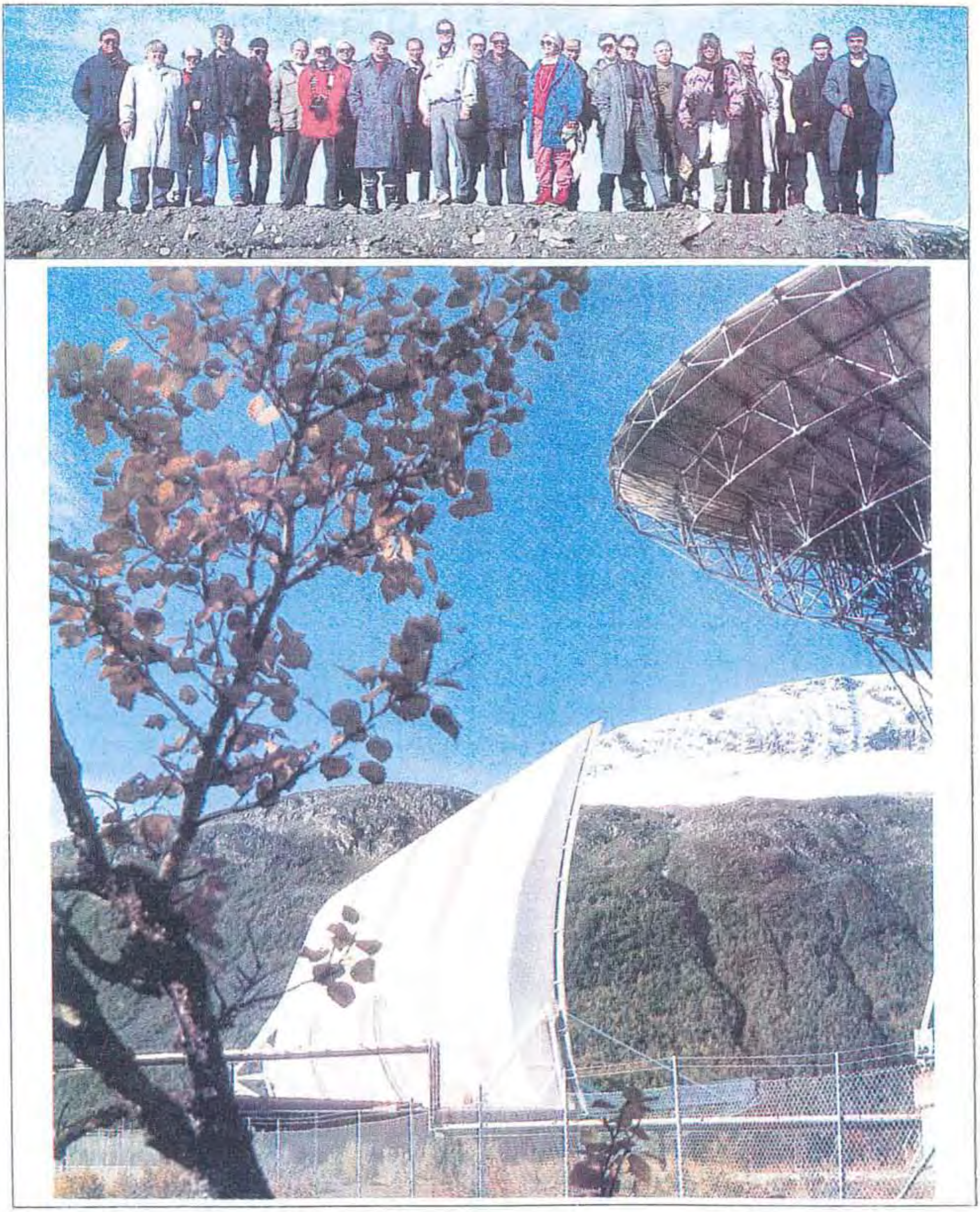

Fig. 2. The EISCAT Council members, and others, at the potential EISCAT Svalbard Radar site near Longyearbyen on Spitsbergen, Svalbard (top) and the EISCAT Ramfjordmoen antennas (bottom). The participants on Svalbard were (left to right): I.L. Midson, T. Turunen, T. Lien, G. Wannberg, H. Overvaag, J. Holtet, J. Röttger, L.A. Heløe, G. Caudal, B. Hultqvist, J. Kangas, P. Bauer, B. Benterud, P. Skancke, O. Havnes, A. Brekke, A. Orheim, U.P. Løvhaug, J. Gustavsson, R. Grammeltvedt, O.D. Mjøs and R. Jacobsen; also present were: W.I. Axford, A.P. van Eyken, P. Hagström, T.B. Jones, B.R. Martin and D.M. Willis.

The UHF radar system worked solidly as usual. In the spring, klystron SN 101 was swapped with the spare klystron, SN 102, in a regular preservation procedure. However, klystron SN 102, which at that time had accumulated almost 10000 operating hours, indicated signs of degenerating vacuum. SN 101, which was placed into storage as the spare, had accumulated 5500 operating hours and remains in good condition. The centre frequency of the UHF system was changed to 931.5 MHz, following the advice of the Norwegian Telecommunication Administration, to further minimize interference with NMT 900 and Short-Range-Radio systems. The control and monitoring of the UHF transmitter is now performed by a new computer system and the VHF transmitter will later also be controlled by a similar device.

Very high priority is placed on antenna maintenance and a specially abridged maintenance manual was introduced for this purpose. Bolt tightening on all three UHF antennas was performed during the summer months, a procedure which has to recur every few years. After the major repair of the rail substructure a few years ago, rail motion on all the UHF antennas is regularly measured. The antenna foundation in Sodankylä was inspected; special heating cables, temperature and ground water level sensors were installed and concrete cavities found in the basement were filled to satisfy the requirements for withstanding the expected rise in the water level of the nearby Kitinen river.

The interference caused to the EISCAT UHF system by NMT 900 mobile telephone systems is now under effective control. This was achieved by means of a much improved receiver front end, new first local oscillator and filter equipment as well as through much appreciated cooperation with the national telecommunication authorities of Finland, Norway and Sweden, resulting in the movement of the local NMT 900 transmitter frequencies away from the EISCAT UHF band. However, some limitations remain in using the upper EISCAT channels, particularly affecting upshifted plasma line observations. This kind of interference now occurs at all three sites, Kiruna, Sodankylä as well as Tromsø.

Radiation by the EISCAT VHF radar into poorly designed electronic equipment belonging to EISCAT's neighbours in Tromsø has caused an assortment of problems. It was even suggested that this radiation might be hazardous and the problem of environmental impact was also aired through the local newspapers. Very careful evaluation, well calibrated measurements and formal contacts with the national administration have proved, however, that the RF radiation level generated by EISCAT is more than an order of magnitude below the official public exposure limits for such radiation. In order to further reduce the EISCAT created field strength, by orders of magnitude below official limits, and to minimize disturbances to our neighbours' home equipment, it was decided to restrict antenna directions of the VHF radar to angles from the vertical to the north. However, certain kinds of electronic home equipment remain over-sensitive to even the lowest levels of electromagnetic fields created and even the most painstaking hardening of this equipment against RF intrusion does not solve the problem. It therefore had to be further decided to shield some properties in the neighbourhood of EISCAT to eliminate the disturbance to this equipment. We presume that all these propositions to mitigate the interference and to minimize the radiation level, which were undertaken by EISCAT, are properly safeguarding our operation and our environment. Because of these additional expensive efforts it was decided to postpone further the planning of the automatic east-west steering of the VHF antenna beam, which had been a priority evolutionary development during the recent years.

EISCAT has a large and unique software base for system control and data handling which is constantly improved and adapted to new experiment requirements. A major upgrade became necessary to allow for the simultaneous radar control and data acquisition requirements of dual radar experiments (UHF and VHF radars simultaneously). This led to the development, and pending introduction, of an upgraded version of the EISCAT Real Time Operating System as EROS-2D. EROS-2D will be available for the purpose of dual radar operation as well as supporting more user-friendly system operation. Necessary memory capacity was also added with additional hard disk drives, which have substantially improved the experimental performance and the possibilities for real-time analysis. Local Area Networking of PCs at the Tromsø site makes the functioning of the system more efficient and user-friendly. The detailed description of these facilities is available in the upgraded version of the EISCAT Users' Guide.

Fig. 3. Reproduction of the cover, back and central pages of the EISCAT Brochure, which was published in 1990.

In parallel with the software upgrades, the digital hardware is also evolving and has almost reached the intrinsic limits of the present system. For instance, additional memory has been added to the radar controller, allowing the application of longer coding schemes such as alternating codes. The correlators were equipped with decoders for these alternating codes, allowing real-time decoding using downloaded codes in the radar controller. The Multichannel FIR filter and Integrator project (MUFFIN), which is in the test phase, will yield further substantial improvements in on-line decoding of the most complicated code schemes. Another device, the FFT processor for on-line spectrum analysis, is being tested with the VME interface. We are further preparing a new digital system layout, based on modern digital signal processing equipment and workstations, which could replace the present radar control, data acquisition and data analysis hardware in due course.

Some problems were again noted in the reliability of the communication links between the sites and Headquarters. Tests and coordination with the telecommunication companies continue to ameliorate this difficulty and also to speed up the communication links in future. The timing system of EISCAT still relies on Cesium clocks with Loran-C receivers as a back-up. In addition to possibilities investigated to use the GPS satellites for time synchronization, recent studies have shown that television satellite transmissions from TELE-X could be used to synchronize the timing at the EISCAT sites.

The take-over of the MPAE-Heating facility at Tromsø was prepared according to plans. The final transition will take place on 1 January 1993.

The EISCAT Annual Review Meeting took place at the end of March 1990 in Harstad, a small city located on the Norwegian coast about half the way between Tromsø and Narvik. EISCAT staff members, together with Norwegian guests, discussed and evaluated the status and development of the EISCAT systems. We also used the chance of being close to the island of Andøya to visit the Andøya Rocket Range from which many rockets are launched in coordinated research campaigns together with EISCAT. In addition to these Annual Review Meetings, regular Executive and Budget Meetings with the site leaders and executives take place, usually in February and September, to coordinate technical developments, optimize expenditures, review staff development, decide about operational procedures and discuss instrumental evolution.

In August 1990 an open house took place at Headquarters and the EISCAT Kiruna site, together with a similar event at the collocated Swedish Institute of Space Physics (IRF). For the purpose of improved public relations, a brochure on EISCAT was prepared and published in the year 1990. Examples of some pages of this EISCAT Brochure are shown in Fig. 3.

In the year 1990 the EISCAT staff situation was very stable. A total of 33 staff members worked for EISCAT, whereof three were directing, four administrative, five scientific, five computing, three engineering, eleven technical and two caretaking. They were distributed over the sites with Kiruna having five, Sodankylä five, Tromsø thirteen, and Headquarters ten positions; there were also two additional, temporary, technical positions. The total recurrent budget was 17.6 MSEK, and the capital investment budget was 3.2 MSEK. The breakdown of the recurrent budget is illustrated in Fig. 4. 364 kSEK was spent in connection with EISCAT Svalbard Radar planning and partially covered by specific contributions from some Associates.

Several scientists, who are supporting or using EISCAT, were honoured by awards during 1990. Professor Bengt Hultqvist was awarded the King's Medal and the COSPAR Medal for International Cooperation 1990; he was also elected a Fellow of the American Geophysical Union. Dr. Mike Lockwood was awarded the Zel'dovich Award of Commission C of COSPAR and the Isaac Koga Gold Medal of URSI. We congratulate these two scientists for these high ranking honours.

The EISCAT Scientific Advisory Committee (SAC) had its autumn meeting in Tromsø and the EISCAT staff were pleased to welcome the SAC members at the Ramfjordmoen site for the meeting as well as for an interesting guided tour through the operations buildings.

The EISCAT Council also had its spring meeting on the Tromsø site, where the members were shown the status of the radar systems. During the meeting, the EISCAT Council elected Professor Sir Grenville Beynon as an honorary member of the EISCAT Scientific Association in recognition of his role in the foundation of the Association and his distinguished contribution to EISCAT. The Council members travelled to Longyearbyen on Spitsbergen, Svalbard, to continue the meeting and to be shown the existing infrastructure together with a potential site for a new radar (Fig. 2, top). At its meeting in Longyearbyen on 11 May 1990 the Council concluded that there was sufficient optimism among the EISCAT Associates that it decided to set up a working group to bring an international proposal to the next EISCAT Council meeting. This working group, consisting of members from all the Associates together with the Director, met several times and the preliminary system specifications are given in Table 1 on page 12. A special antenna pre-feasibility study was prepared and the working group produced the report "The EISCAT Polar Cap Radar - A report on the design specifications for an incoherent scatter radar facility based on the archipelago of Svalbard". Several EISCAT staff members also contributed to this report. The draft report was presented to the EISCAT Council at its meeting in November 1990.

All Associates of EISCAT agreed that the radar facility on Svalbard represents the next most important evolutionary step for the development of the EISCAT facilities. This project is now known as the EISCAT Svalbard Radar (ESR).

This challenging task represented by a new direction in the evolution of EISCAT guides us into the new decade and there is general confidence that it will lead to another advanced radar system which, together with the present EISCAT system and other ground based and space based instrumentation, will yield a wealth of new science in the study the Earth's environment.

As usual, I would like to express my sincere thanks to all the scientists who contributed to the success of EISCAT in the last year and whose work is reflected in this report and particularly to Tony van Eyken who took care of the editing and layout of this 1990 Annual Report.

Jürgen Röttger

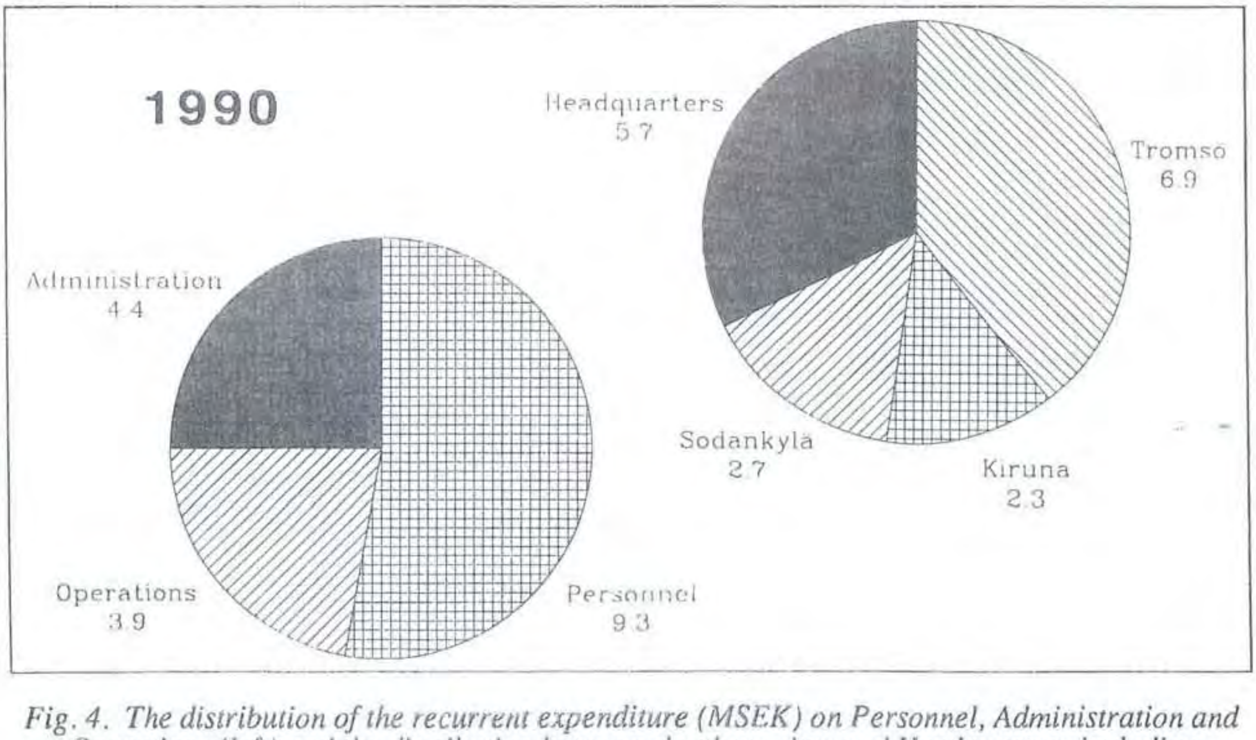

Fig. 4. The distribution of the recurrent expenditure (MSEK) on Personnel, Administration and Operations (left) and the distribution between the three sites and Headquarters including expenditure for Council and Committee meetings (right).

The planned EISCAT Svalbard Radar
Preliminary System Specifications

Location:	near Longyearbyen on Spitsbergen, Svalbard	
Operating Frequency:		between 400 - 500 MHz
Bandwidth:	Transmitting:	± 2 MHz
	Receiving:	± 10 MHz
Antenna:	Beamwidth:	1.6° Gain: 42 dBi
	Aperture:	≈ 500 m² (3x ?)
	Beams:	≥ 3 (2), sep. by ≈15°
	Polarisation:	circular
	Steerability:	all azimuths, horizon to zenith
Antenna Alternatives:		3 (2) parabolic dishes 1 phased array system 1 triple cylinder 1 multi-feed dish
Transmitter:	Peak Power:	3 (1.5) MW
	Duty Factor:	0.12
	Pulse Length:	1 μs - 2 ms
	Modulation:	Phase coding
	Interpulse:	min. 0.1 ms
Transmitter Alternatives:		High Power Klystron(s) TV-Klystrons Klystrodes MSDC Klystrons Power Grid Tubes Solid State Amplifiers (modular system)
Receiver:	Channels:	≥ 8 Noise Figure: ≤ 30 K
	System Noise:	≤ 120 K Dynam. Range: 90 dB
System Figure of Merit:		Peak Power x Aperture per System Temperature: 10 GW· m²/K

Table 1. Preliminary system specifications for the planned EISCAT Svalbard Radar.

EISCAT OPERATIONS IN 1990

EISCAT operations (see Tables 2 and 3) throughout 1990 were characterized by heavy use of the VHF radar system, usually together with the UHF system, and substantially greater Special Programme than Common Programme operations. All seven Common Programme modes (see descriptions on page 15) were used extensively this year, together with a few hours of one of the Unusual Programme modes to cover a polar cap absorption event. The UHF radar recorded 2168 hours of data while the VHF radar recorded 1058 hours; the two radars were operated together for 971 hours and the year totals are completed by 40 hours of passive observations.

COMMON PROGRAMMES 1990

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Tot	%	
CP1	32			30		30	30		60	12	30		224	23	
CP2			48		30					30	83		191	20	
CP3		53				101		48	30	5			237	24	
CP4												38	38	4	
CP5		98											98	10	
CP6						30	34	30					94	9	
CP7	3							30		29			62	6	
UP1			6										6	0	
Total	35	151	54	30	30	161	64	108	90	76	113	38	950	100	%
%	3	15	5	3	3	16	6	11	9	8	11	4	100	%	

Achieved									Target								
CP1	CP2	CP3	CP4/ CP5		CP6/ CP7		UPs		CP1	CP2	CP3	CP4/ CP5		CP6/ CP7		UPs	
23	20	24	14		16		0	%	25	20	25	15		15			%

Table 2. EISCAT Common Programme operations in 1990, showing the distribution by month and programme type.

SPECIAL PROGRAMMES 1990

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Tot	%	
EI	17			6				5					28	2	
FI								4	24			36	64	4	
FR	64	103					17			6		146	336	24	
GE		24	84			11			48		106		273	20	
NO	19	19	11			14	13	28	12	6		35	157	11	
SW		33	10					71		1	47	46	208	15	
UK	151					60	5	13	48				277	20	
Total	251	179	105	6	0	86	35	121	132	14	153	263	1345	100	%
%	18	13	7	0	0	6	2	9	9	1	11	19	100	%	

EI	FI	FR	GE	NO	SW	UK			
2	4	24	20	11	15	20	100	%	
2	6	33	27	15	20	27	135	%	(Of 1000 hrs)

Table 3. EISCAT Special Programme operations in 1990, showing the distribution by month and Associate. Also shown is the proportion of the total Special Programme time used by each Associate.

Operations peaked heavily during the winter months, Fig. 5, with more than 50% of the total hours being concentrated in the four months January, February, November and December. Nearly 50% of the dual radar operations were concentrated into the last three months of the year.

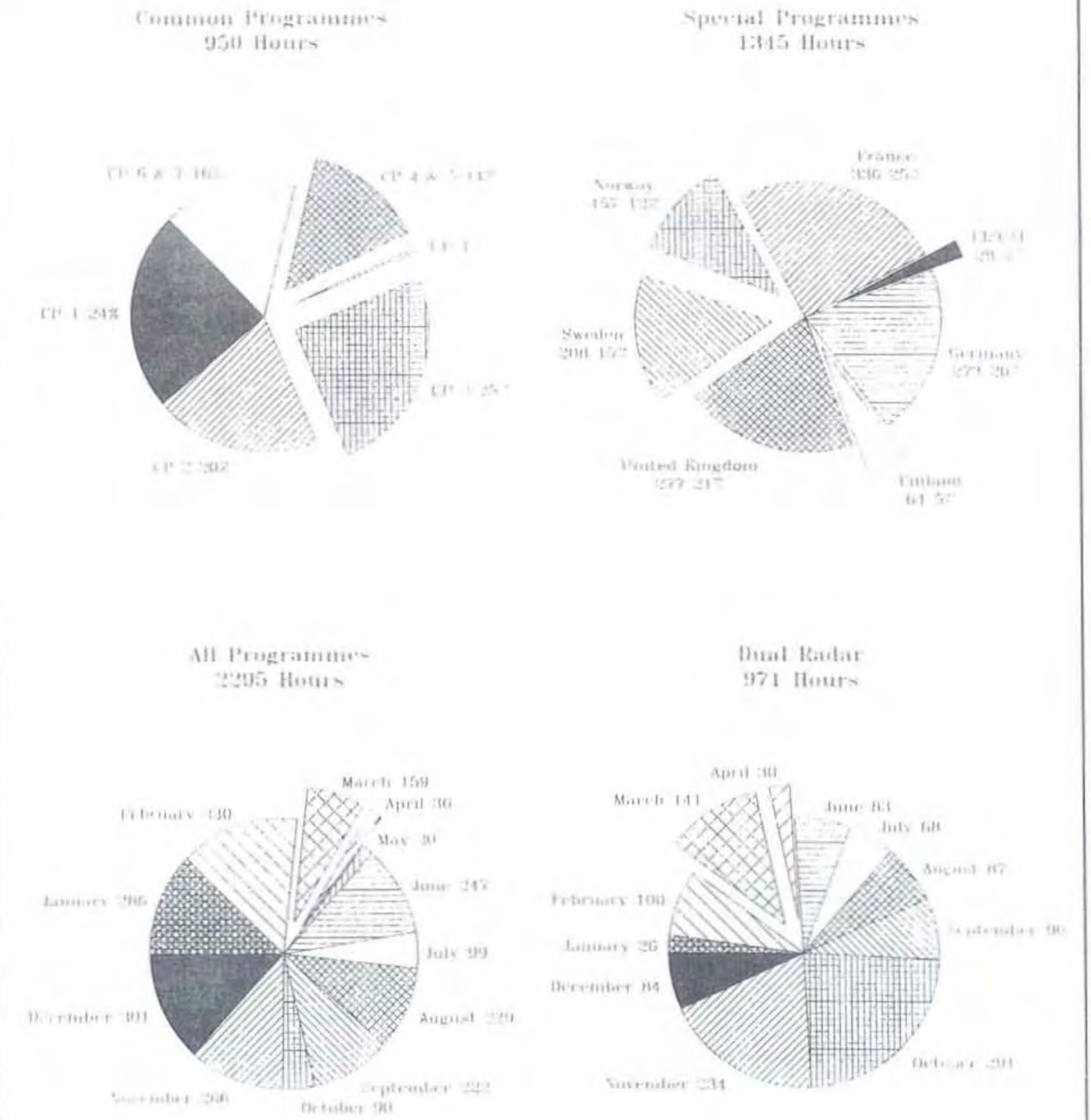

Fig. 5. Total EISCAT Common and Special Programme operations in 1990 distributed by programme (upper left) and Associate (upper right), respectively. The lower panels show the monthly distribution of total operating hours (left) and dual radar hours (right).

COMMON AND UNUSUAL PROGRAMME OPERATIONS AND ANALYSIS

START YY-MM-DD	HH	END MM-DD	HH	EXPT
COMMON PROGRAMME* DATA 1990				
90-01-24	*10UT*	*01-25*	*16UT*	*CP-1-I**
90-02-12	*16UT*	*02-16*	*16UT*	*CP-5-A**
90-02-21	*10UT*	*02-23*	*16UT*	*CP-3-F**
90-03-20	*15UT*	*03-22*	*16UT*	*CP-2-D**
90-04-09	10UT	04-10	16UT	CP-1-I
90-05-21	*10UT*	*05-22*	*16UT*	*CP-2-D**
90-06-05	10UT	06-06	16UT	CP-1-I
90-06-12	08UT	06-13	14UT	CP-1-I
90-06-25	*15UT*	*06-29*	*21UT*	*CP-3-F**
90-07-02	10UT	07-03	16UT	CP-1-I
90-07-30	19UT	08-01	04UT	CP-1-I
90-08-14	10UT	08-16	10UT	CP-3-F
90-09-20	*10UT*	*09-21*	*16UT*	*CP-3-F**
90-09-25	10UT	09-27	22UT	CP-1-I
90-10-09	09UT	10-09	21UT	CP-1-I
90-10-09	21UT	10-10	02UT	CP-3-F
90-10-10	11UT	10-11	16UT	CP-1-I
90-10-24	10UT	10-25	16UT	CP-2-D
90-11-13	*11UT*	*11-15*	*16UT*	*CP-2-D**
90-11-20	15UT	11-21	16UT	CP-2-D
90-11-27	10UT	11-28	16UT	CP-1-I
90-12-07	17UT	12-09	07UT	CP-4-A
UNUSUAL PROGRAMME* DATA 1990				
90-03-20	09UT	03-22	16UT	UP-1

Table 4. EISCAT Common and Unusual Programme operations and data analysis overview for 1990. Marked entries indicate World Day operations, for which the results have also been sent to NCAR, Boulder.

* OPERATING MODES EMPLOYED IN 1990

Common Programme One, CP-1, uses a fixed transmitting antenna (see Fig. 6), pointing along the geomagnetic field direction. The three-dimensional velocity and anisotropy in other parameters are measured by means of the receiving stations at Kiruna and Sodankylä (see map, inside front cover). CP-1 is capable of providing results with very good time resolution and is suitable for the study of substorm phenomena, particularly auroral processes where conditions might change rapidly. On longer time scales, CP-1 measurements support studies of diurnal changes, such as atmospheric tides, and seasonal variations. Solar cycle variability will also be studied when sufficient data have been collected.

Common Programme Two, CP-2, is designed to make measurements from a small, rapid transmitter antenna scan. One aim is to identify wave-like phenomena with length and time scales comparable with, or larger than, the scan (few ten km and about ten minutes). The present version consists of a four position scan which is completed in six minutes. The first three positions form a triangle with vertical, south and south-east positions, while the fourth is aligned with the magnetic field. The receiver site antennas make three-dimensional velocity measurements in the F-region.

Common Programme Three, CP-3, covers a 10° latitudinal range (in the F-region) with a 17 position scan up to 74°N in a 30 minute cycle. The observations are made in a plane defined by the magnetic meridian through Tromsø and the Kiruna and Sodankylä antennas make continuous measurements in the F-region.

Common Programme Four, CP-4, covers latitudes up to almost 80°N (77°N invariant latitude) using low elevation, azimuth beam swinging. CP-4 is particularly suitable for studies of high latitude plasma convection.

Common Programme Five, CP-5, has been designed to suit the objectives of lower thermosphere coupling studies. It combines a latitudinal scan with detailed measurements along the Tromsø magnetic field line. The primary aim of this experiment is to observe the dynamics of the neutral atmosphere, while simultaneously exploring the local electrodynamic environment.

Common Programmes One to Five are run on the UHF radar. Two further programmes are designed for use with the VHF system. Common Programme Six, CP-6, is designed for low altitude studies, and Common Programme Seven, CP-7, for high altitude, particularly polar wind, work. Both CP-6 and CP-7 have been operated several times in 1990. CP-6 also runs in in the guise of UP-1, below, with which it is identical.

Three Unusual Programmes have been defined: UP-1 for D-region observations, UP-2 for auroral arc and related studies and UP-3 for high resolution sporadic E-layer (E_s) work. These programmes are started at short notice when suitable geophysical conditions are detected.

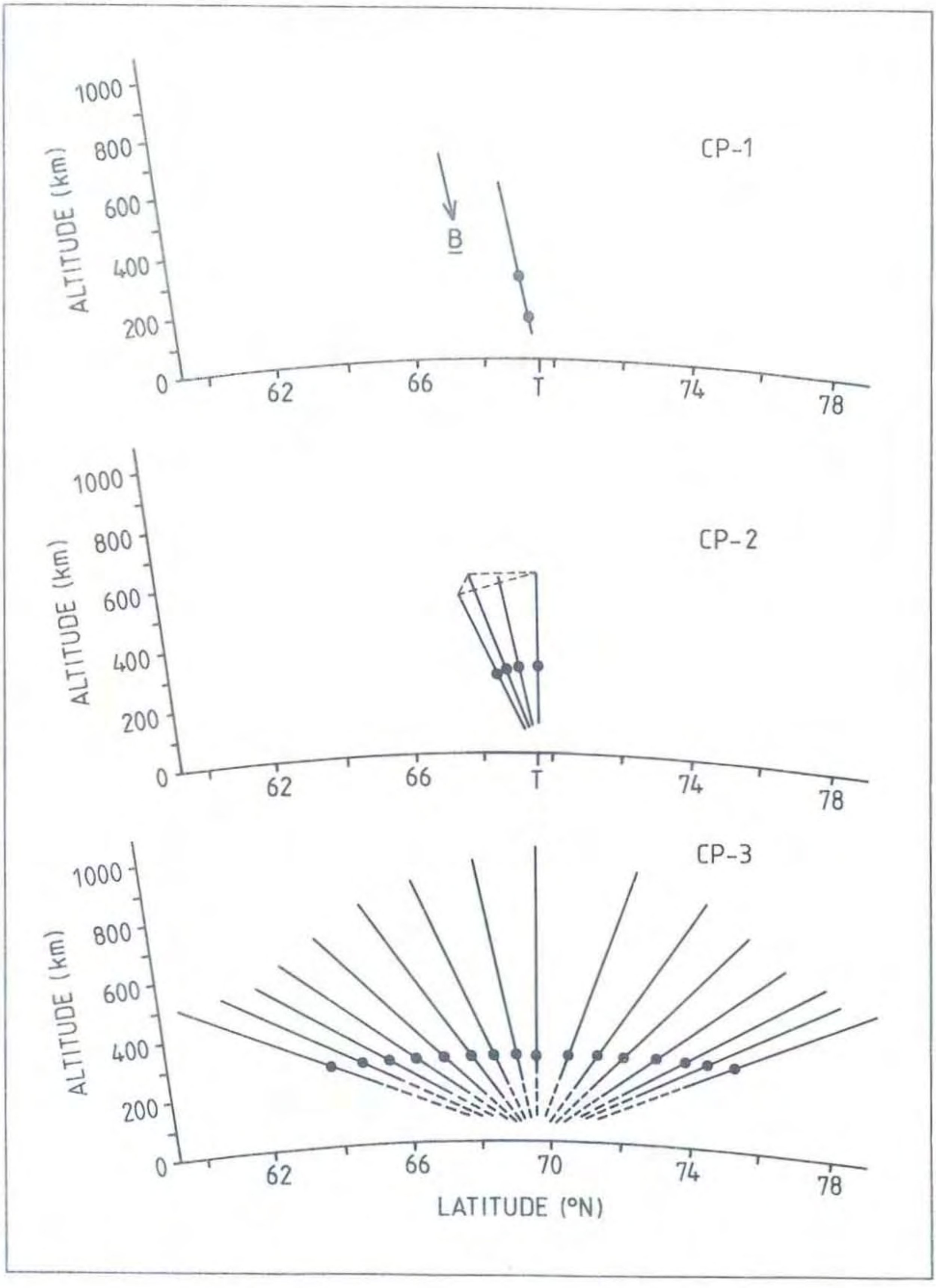

Fig. 6. Pointing geometry for Common Programme modes One, Two and Three; filled circles indicate the points at which the remote site measurements are made.

MESOSPHERE AND D-REGION

During one of the Solar Proton Events (SPE) in 1990 the VHF radar was used to measure spectra from the D-region at altitudes down to about 55 km, by tilting the antenna to the north. Anomalously large backscattered power levels were occasionally observed in the vicinity of a large shear in the velocity of the neutral wind within the scattering potential refractive index gradient and the turbulence energy dissipation rates are large enough (Collis, Rietveld, Röttger and Hocking)*.

D-region measurements were made using the EISCAT UHF radar and the University of Lancaster riometer network during two morning sector particle precipitation events. Electron density profiles are interpreted in

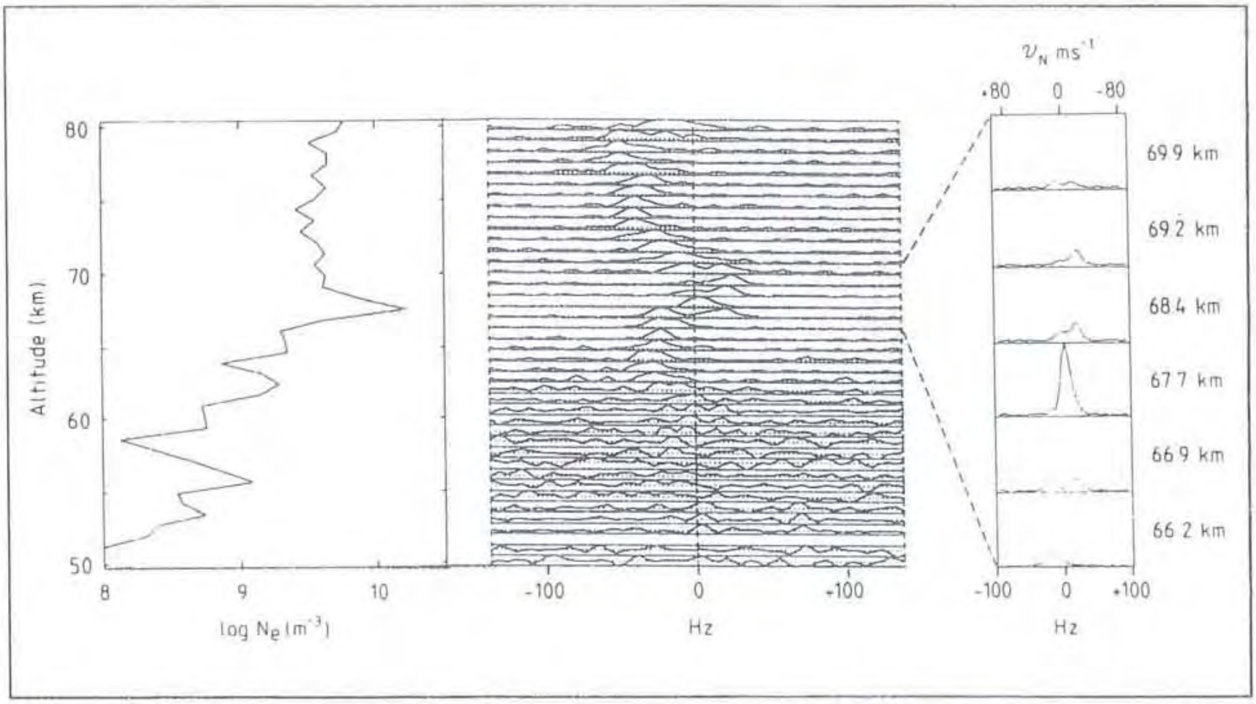

Fig. 7. Electron density and spectra during the SPE on 21 March 1990 at 0610 UT. Note that the thin layer in the electron density profile at 68 km is due to increased backscatter from turbulence, and should not be interpreted as electron density.

volume at altitudes near 68 km. Fig. 7 shows profiles of electron density and spectra from this event. The velocity shear, which appears as two separated peaks in the spectra, is thought to cause neutral turbulence in narrow layers which is the cause of the enhanced backscatter. Events were observed where the turbulent scatter appeared as a third peak in the scattered spectrum indicating that the turbulent layer was very thin. Calculations of the expected backscatter power levels at 224 MHz for incoherent scatter and for turbulence scatter show that the turbulence component can be dominant at heights below about 68 km if the terms of the incoming spectrum of energetic electrons by use of a computer model. One event (Fig. 8) was characterised by a hardening spectrum during the growth phase followed by a softening during the decay phase. It was shown that simple ideas based upon gradient curvature drift of trapped electrons are insufficient to explain the observations (Hargreaves and Devlin, 1990).

* References given without dates indicate work in progress, or in press. Others can be found in the reference lists, starting on page 40.

Two sharp onsets of electron precipitation measured by the EISCAT UHF system have been studied at very high time resolution (ten seconds). The electron energy spectra deduced from the measurements indicate that each onset is associated with a complex influx of soft and hard particles. An onset which occurred after midnight had a simultaneous influx of hard and soft particles which cannot be explained by gradient curvature drift and it is therefore concluded that the influx is due to direct particle precipitation from the plasma sheet (Burns et al., 1990).

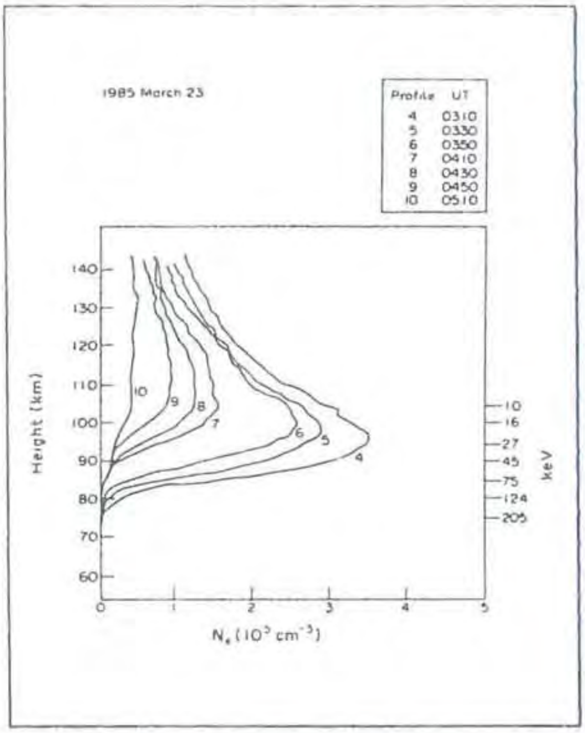

Fig. 8. Electron density profiles observed by EISCAT during a slowly varying absorption event. The layer lifted with time, indicating a softening of the incoming energetic electron spectrum.

Electron density profiles measured by the EISCAT UHF and VHF radars during summer have been used as constraints for chemical modelling of the quiet E- and D-region. Two ion-chemical models were used: the Mitra-Rowe simplified six-ion model and a 35 ion model developed at the Sodankylä Geophysical Observatory. The modelling strategy involved adjustment of the solar flux to obtain a fit at E-region altitudes, followed by adjustment of the nitric oxide profile for further improvement at all altitudes. Keeping the same model inputs, the effect of a change in solar zenith angle is then compared with observations. Good agreement is seen between the final models and observations over the altitude range 80-110 km. The derived nitric oxide profiles resemble those observed at disturbed times by other means, peak concentrations being just less than $2\ 10^9\ m^{-3}$. These high concentrations could be due to an enhancement of thermospheric nitric oxide by energetic particle precipitation in the morning sector (Burns, E. Turunen, Matveinen, H. Ranta and Hargreaves).

E-REGION STUDIES

A statistical study of the undisturbed E-region has also been completed and has shown some significant shortcomings in the present aeronomical models. In particular, the valley between the E- and F-regions which is predicted by such models is found to be absent in the measurements, and a layer of strongly enhanced electron density, peaking below 100 km altitude, is found to be a consistent feature of the winter-time ionosphere. This lower layer cannot be explained on the basis of solar radiation and the neutral atmosphere's major constituents but measurements made in parallel with a sounding rocket launch from Esrange (the ANODE payload) in February 1990 should allow the assessment of the role of nitric oxide as a minor constituent (Kirkwood).

Theoretical and experimental studies of the formation of Sporadic E layers by strong electric fields at EISCAT latitudes have been a major topic of study during the year. The results show that most of the layers appearing below 105 km altitude can be explained by the action of electric fields directed between westward and south-eastward. In many cases the observed electric fields alone are sufficient to explain the layers but in some cases some additional compressional effect is needed to account for the thinness of the layers. Experiments to study the details of ion flow within layers, with the purpose of studying the cause of the extra compression, have been performed during the summer of 1990 and the results are being assessed (Kirkwood).

In February and March of 1990 an extensive international campaign of radar and sounding-rocket measurements took place with the aim of studying the dynamics of the mesosphere and lower thermosphere (DYANA). An alternating code program has provided some of the best measurements so far obtained of the strong tidal winds occurring in the 80-120 km altitude interval. The observations also included several short-lived Sporadic E layers close to 100 km altitude, all apparently formed by strong electric fields, and in one case correlated with a similarly short-lived (less than three minutes) sudden sodium layer (Kirkwood and von Zahn).

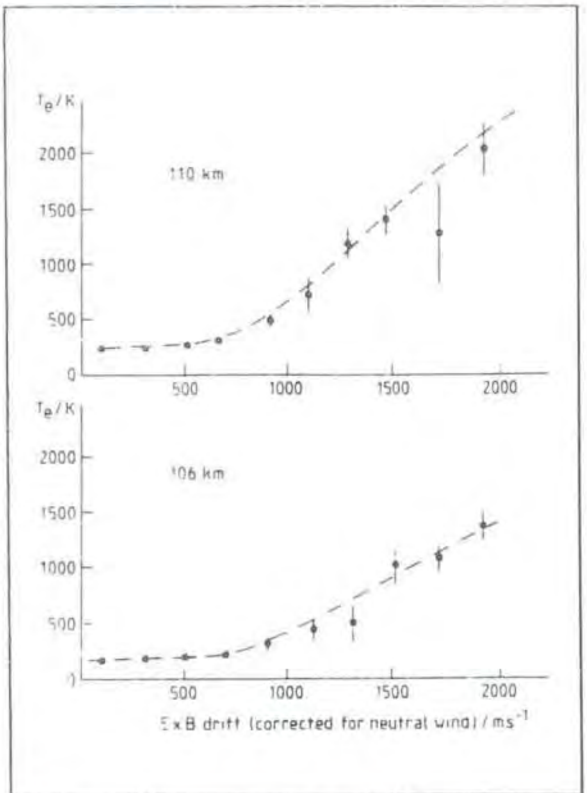

Fig. 9. A comparison between the average relationship of electron temperature and ExB drift measured by EISCAT and the predictions of the Robinson (1986) theory.

EISCAT measurements, using alternating codes, have been used to compare the electric field strength applied across the magnetic field in the F-region with increases in E-region electron temperature. The alternating codes provide both excellent height resolution and time resolution of 90 seconds or even less. The most recent analysis of the data has taken account of the semi-diurnal tide mode to correct the effect of the neutral wind on the relative drift velocity of the electrons and ions. With these corrected results the comparison with the predictions of the theory of electron-plasmon collisions at 106, 110 and 115 km (Fig. 9) was found to be extremely good at all three altitudes (B. Jones, Schlegel, Robinson and Häggström; Williams, B. Jones and G. Jones).

The SPORE experiment, with its high spatial resolution (600 m in the E-region) continues to provide important data for the study of Sporadic E layers, gravity waves and tides. The addition of long pulse measurements between 120 and 400 km allows the tracing of phase fronts resulting from gravity wave activity through both the E- and F-regions. Similarly, the effect of tidal waves can be studied through the whole height range providing the data set is long enough. The observed day-to-day variability of the semi-dirurnal tide in August 1988 may have been due to the interaction of the tide with gravity waves. Complex patterns of gravity waves observed on three days were found to break into discrete frequency ranges when subjected to filtering.

Sporadic E layers were often seen to form and descend through the E-region; such layers act as good tracers for both the main tidal feature and the superimposed gravity waves. These layers are generated by a wind shear associated with the semi-diurnal tide, even at the high latitudes of EISCAT. The effect on the layers of interference between gravity waves, in the oscillation height and in the changes in intensity, have also been studied (Nygrén et al., 1990; Lanchester, Nygrén, Huuskonen, Turunen and Jarvis).

AURORAL STUDIES

It is generally believed that pressure gradients created by the adiabatic convection of the magnetospheric plasma are responsible for the flow of region-2 field-aligned currents. However, it has already been shown that other mechanisms are needed to fully explain the observed distributions of field-aligned currents in region 2. The role of ion losses has been analysed, and it was shown that the assumption of strong pitch angle diffusion provides estimates consistent with the observed precipitation fluxes. The efficiency of the charge exchange process is generally found to be weak relative to ion precipitation. Finally, these loss terms were included into a simplified model of magnetospheric transport. The agreement with observations reveals the importance of ion losses in the generation of region-2 field-aligned currents (Peymirat, Fontaine and Senior).

Extremely strong electric fields in the close vicinity of auroral arcs continue to be examined. This feature was seen in the data from the 1988 ERRRIS campaign and it was suspected that very localized intense electric fields on just one side of narrow auroral arcs are of ionospheric origin and closely related to the formation of the three-dimensional ionospheric-magnetospheric current systems associated with such structures.

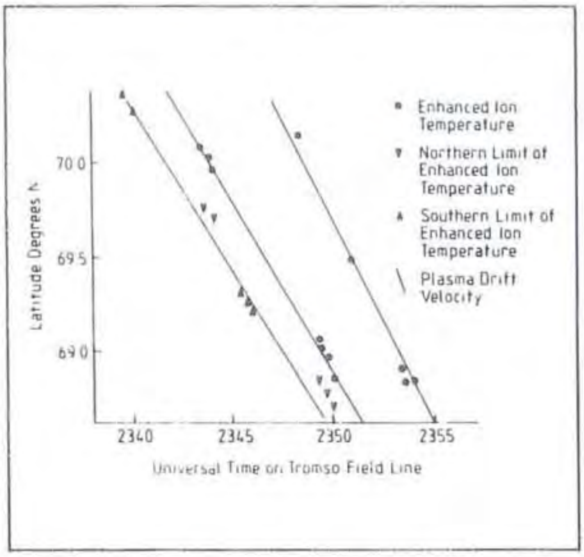

Fig. 10. Evidence for the southward drift of auroral arcs shown by enhanced ion temperatures and by plasma drift velocity.

A new EISCAT scan experiment was also conducted in order to understand the two-dimensional nature of these features better. The data analysis from the campaign in November 1990 is to-date only very preliminary. Since data from similar experiments clearly indicate that these narrow regions of strong electric fields are not short lived, but, in fact, form a part of the auroral arc current system, we expect valuable insights into the formation of auroral forms (Opgenoorth).

The EISCAT experiment FLUX is designed to scan the Tromsø antenna rapidly in a four part cycle between pointing directions north of the magnetic field line, along the field line, south of the field line and back along the field line, with a cycle time of four minutes. During one set of observations a series of auroral arcs appeared to pass overhead travelling equatorwards. Ahead of each arc was a band of enhanced electric field, corresponding to an enhanced east-west velocity, and as this band moved equatorward, the electric field caused frictional heating along the magnetic field lines passing through the band. When the antenna was pointing northwards, this frictional heating could therefore be seen over a narrow range of altitudes and descending with time. When the antenna was pointing along the field line however, the ion heating occurred simultaneously at all heights, and when the antenna was pointing southwards the height range of heated ions was seen rising in altitude. Comparing the times at which each band of enhanced electric field was observed at different heights in the three different pointing directions allows the determination of the southward velocity of each band. The velocity of the auroral features equalled the average southward plasma velocity measured by EISCAT as shown in Fig. 10 (Williams, G. Jones and Opgenoorth).

F-REGION STUDIES

The NEED project combined rocket and incoherent scatter experiments designed to investigate non-linear processes in the auroral F-layer during particle precipitation. A modified version of EISCAT Common Programme One was used to obtain F-layer data from the same volume of space as that traversed by the rocket. During count-down, real-time data were transmitted from Tromsø to the Andøya Rocket Range where they were used to identify the required launch conditions. In-situ measurements from the F-layer were obtained during two rocket flights (November 1988 and October 1990) and data analysis is proceeding (Svenes)

Travelling Ionospheric Disturbances (TIDs) are quasi-periodic variations of ionospheric parameters seen to be the ionospheric response to atmospheric gravity waves.

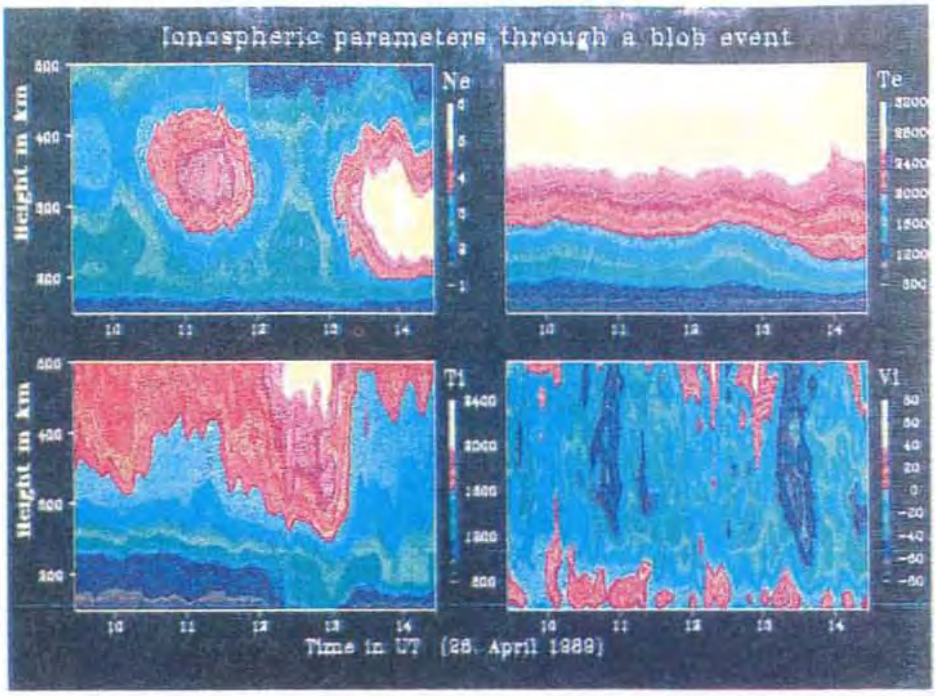

Fig. 11. The general behaviour of the ionospheric parameters throughout a blob event on 26 April 1989. Shown are the unfiltered EISCAT CP2 data. The upper left frame shows the vertically measured electron density (10^{11} m^{-3}); the upper right frame shows the vertical electron temperature; in the lower left the vertical ion temperature and in the lower right the field aligned ion drift.

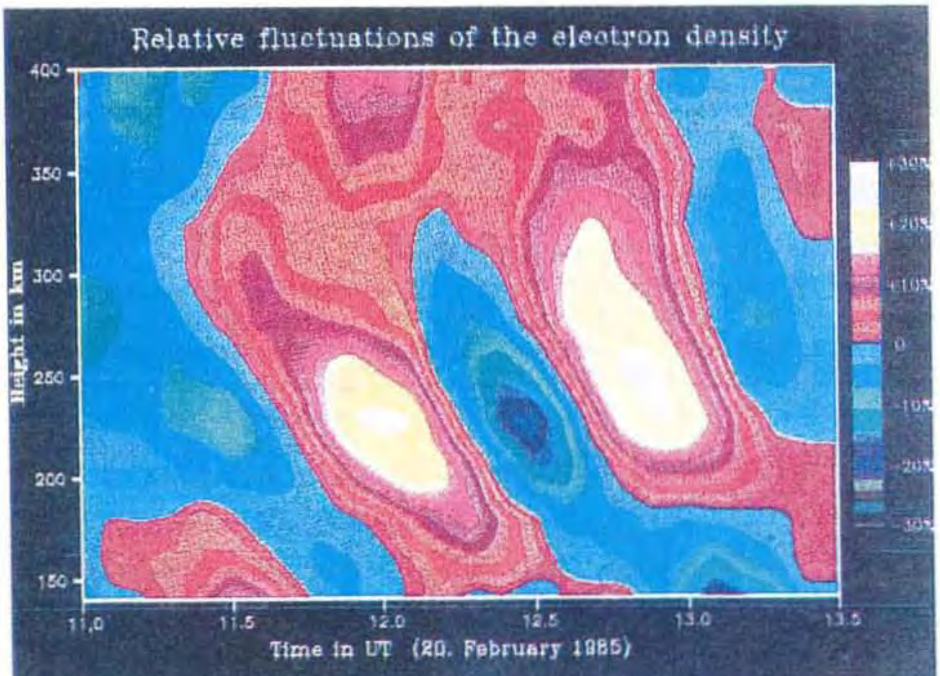

Fig. 12. Relative fluctuation of the vertically measured electron density between 1100 and 1330 UT on 20 February 1985. This kind of 'big flat' TID has nearly horizontal wave fronts. The important point is that it has a vertical wavelength of about twice the thickness of the F-layer resulting in a compressive motion of the upper and lower part of the F-region.

EISCAT Common Programme Two measurements are an ideal base for extensive TID studies. Six sets of Common Programme Two data have been analysed in great detail in order to derive the horizontal phase velocity. The evaluation showed that totally different kinds of TIDs exist, some of which produce large temperature fluctuations and others which produce large electron density fluctuations.

Beside these gravity wave induced TIDs there are some other large wave-like ionospheric disturbances in the auroral F-region. These are the high latitude trough, heating events and blobs. The name 'heating event' is applied only to cases of additional electron temperature enhancement, though there is an ion temperature enhancement for all three kinds of events. Electron density decreases and increases of the ion drift at greater heights are also in phase with the enhanced ion temperature in all three kinds of events. EISCAT Common Programme Two is also the optimum method for studies of these effects especially since it has the ability to address the temporal and spatial dynamics. The general behaviour of the trough appearing in two of the six data sets, and the good correlation between the onset time of a trough and the time of E-region sunset for about 25 other troughs identified in Common Programme One or Two data, suggest that the high latitude trough may be connected with the behaviour of the terminator at auroral latitudes.

Blobs are generally seen as moving plasma clouds. Fig. 11 nevertheless shows that they may appear wavelike, despite the fact that the motion of the blob is more complicated than simple wave or cloud motion. If the blob is seen as a wave it would move to the south with a velocity of more than 100 ms^{-1}. The wave front would be a little bit steeper than the magnetic field line. If a blob were a plasma cloud, it would move with $\underline{E}x\underline{B}$ drift to the west and other parts of the cloud that have been further south would follow in a westward motion.

Another very interesting disturbance is presented in Fig. 12. It is a gravity wave related TID that produces big plasma clouds. Such 'big flat TIDs' have phase fronts close to horizontal with an angle to the vertical between 70° and 80°. The other outstanding characteristic is that it seems as if such a TID would enormously enhance the undisturbed F-region electron density. In the event shown from 20 February, 1985 the electron density is almost doubled. Taking the relative disturbances this means only a fluctuation of 30% though the background electron density only seems to be enhanced and not depleted. Such a kind of TID is not a rare phenomenon. The special behaviour is caused by its flatness. The vertical wavelength is reduced to about twice the thickness of the F-layer. This results in a compressive motion of the upper and lower parts of the F-region that is really measured. If such a TID had produced an area of enhanced electron density it may be that this plasma is transported via the $\underline{E}x\underline{B}$ drift like a plasma cloud. In this way such a kind of gravity wave related TID is a possible candidate for plasma cloud production (Mauelshagen).

Experiments designed to study the F-region ionosphere south of EISCAT have led to a different interpretation of the F-region trough. Height profiles of electron density to the north and south of the trough are often very different, suggesting that the maintenance and decay of plasma in the poleward and equatorward boundaries are often more important than the generation of the plasma depletion (Farmer et al., 1990c).

Comparisons between the three dimensional UCL-Sheffield coupled ionosphere-thermosphere numerical model data and EISCAT data have demonstrated the difficulty in finding the 'typical' conditions usually studied by numerical modellers. Intense study of specific intervals illustrates that more dynamic numerical modelling and substantial improvements in the scale size of the inputs to the numerical models are necessary (Farmer et al. 1990a, b).

Thirty-two EISCAT Common Programme One experiments between October 1981 and August 1986 have been analysed for statistical purposes in terms of ion composition in the altitude region from 150 to 300 km. The diurnal variation of the transition altitude between molecular and oxygen ions is found to be 26 km, which is much larger than the seasonal variation: 8 km between summer and winter, and the

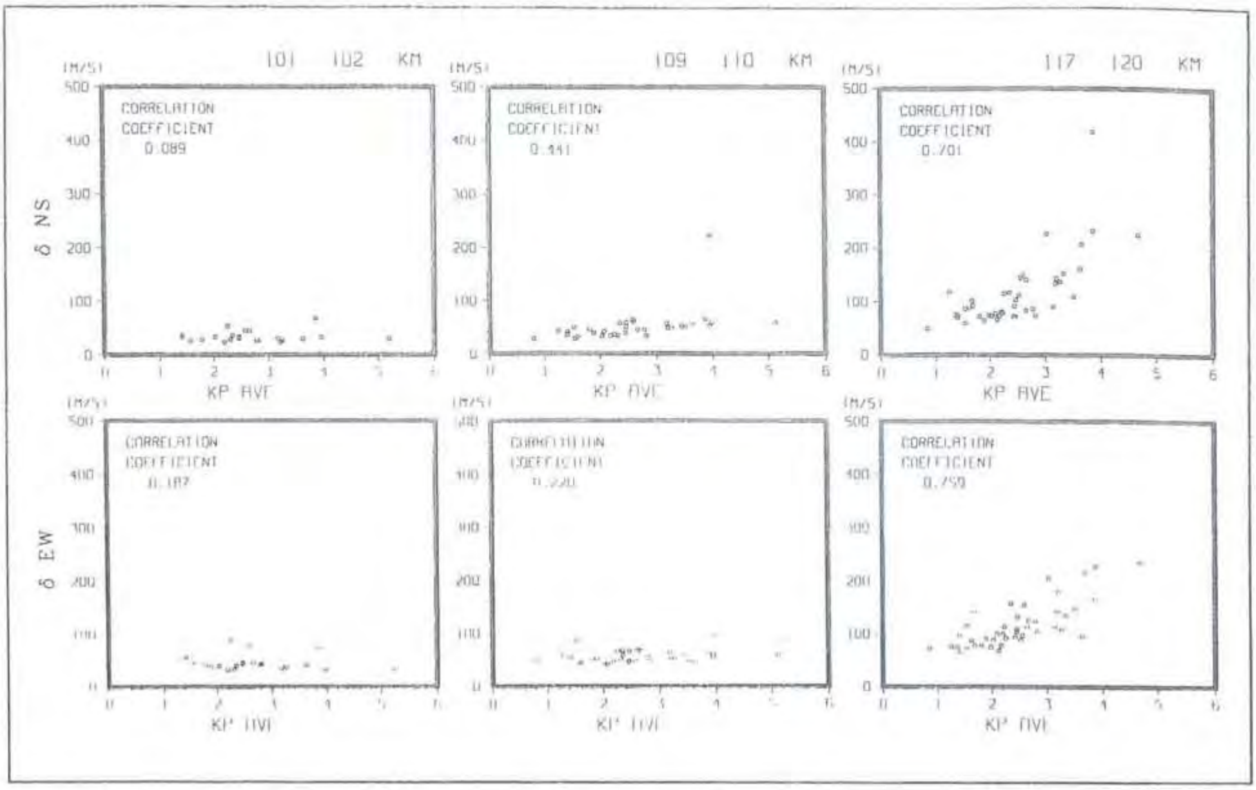

Fig. 13. Correlation of residual δ and geomagnetic index Kp for three different height ranges.

magnetic activity variation: 10 km for Kp ranging from 0 to 4. In addition, it is found that the extension of the transition region increases with the transition altitude. Finally a simple analytical model of ion composition, including only diurnal variation, is proposed for use in EISCAT incoherent scatter data analysis (Lathuillère and Pibaret).

A detailed analysis of ion heating events caused by large changes in the ion velocity has lead to interesting new results on the altitude variation of the parallel ion temperature partition coefficient β_{para}. Analysing only data parallel to the magnetic field, thus reducing the effects of non-Maxwellian spectra, it has been demonstrated that β_{para} increases with altitude from a value of about 0.3 near the F-region peak to a value of about 0.5 in the topside F-region. This shows that the temperature is becoming more isotropic (ie $\beta_{para} = 0.66$) with altitude. As yet no definite explanation has been forthcoming but it is proposed that Coulomb collisions become more important in the topside ionosphere (McCrea, Lester, St. Maurice, Wade and T. Jones).

NEUTRAL ATMOSPHERE

Ion-neutral dynamics remains a topic of considerable interest. Studies comparing neutral winds measured by Fabry-Perot interferometers (FPI) with those derived from EISCAT have cast doubts on the technique employed to obtain reliable neutral velocities from measurements of ion velocities. Although this technique appears to be successful at lower latitudes, a detailed analysis of the ion energy and momentum balances together with a detailed error analysis demonstrate that individual experiments give poor results around 70° N latitude. However, statistical surveys may be used effectively to study average conditions and the existing special programme database is being augmented with conjunctions of Common Programme data with FPI measurements (Farmer et al., 1990d)

During the 1988-89 and 1989-90 Winters, coordinated campaigns were conducted between EISCAT and the French Michelson interferometer, MICADO, which was installed at Sodankylä. Specific experiments were developed in order to measure, or derive, neutral winds and temperature from the same atmospheric volume using the two instruments. Neutral winds measured by MICADO in the E-region, using the O_1S line are in good agreement with Chatanika statistical results. In the F-region, differences are found between inferred EISCAT neutral meridional winds and those measured by MICADO using the O_1D emission. Most of the discrepancy is due to the presence of vertical winds during observations made when the magnetic activity was high (Thuillier et al., 1990).

The technique for deriving the horizontal component of the thermospheric wind in the magnetic north-south meridian from incoherent-scatter radar observations is now being used for global scale studies; the resulting meridional neutral winds are being combined with winds determined from other techniques and compared with sophisticated numerical models. It was therefore appropriate to re-examine their derivation and their dependence on parameters such as ion composition, neutral densities, ion-neutral collision frequencies and thermal diffusion, as well as on the experimental modes of the individual radars. Observations taken on 26-28 June 1984 at various radar sites were used to study in detail the derivation of the meridional wind. The atmospheric model (O and N_2), or the collision frequencies (particularly $O^+ \leftrightarrow O$) were found to be extremely important in the wind determination; an error in these parameters can lead to systematic errors that are most significant during the night. Ion composition and thermal diffusion are not found, in practice, to have significant effects (Wickwar, Burnside, Salah, Duboin and Alcaydé).

EISCAT Common Programme One data collected between 1985 and 1990 have been used to study the daily and annual variation of the neutral wind at 102, 110 and 120 km altitude. Since it is well known that the neutral wind exhibits sinusoidal variations with 12 h and 24 h periods, the neutral wind obtained from the ion drift measurements at these altitudes was analysed in terms of these semi-diurnal and diurnal tides to derive amplitudes and phases together with a constant mean wind. Five constants thus determine the neutral wind in the meridional and another five in the zonal direction. These ten parameters have been calculated for 109 days from the above time interval covering all seasons.

If the fit of the measured wind vectors detailed above is unsatisfactory, this is an indication that frequency components with periods other than 12 h and 24 h are present in the data. This is expected during disturbed days when the electric field affects the neutral wind. The goodness of the fit is thus a measure of the disturbance of the neutral wind by such effects. Fig. 13 shows the residual of the fit (rms) as a function of the geomagnetic index Kp for different altitudes. It is obvious that a correlation with Kp exists, particularly at the upper altitude level, where the influence of the disturbing electric fields is strongest. At lower altitudes this effect decreases as expected. The residuals at these altitudes indicate that there are other spectral components in the neutral wind which are not geomagnetically controlled, but stem from components with a 16, 35 or 54 hour period which have been occasionally found (Kunitake and Schlegel).

Attempts to model tidal modes in the lower thermosphere have employed coupled models of the thermosphere and ionosphere which assume a semi-empirical forcing function at a height below 100 km. The Thermosphere-Ionosphere General Circulation Model (TIGCM) was forced with a semi-diurnal oscillation derived from a purely theoretical/numerical model. Solar heating was estimated on the basis of the Covington index of solar radio flux while high-latitude forcing was estimated on the basis of measurements of the interplanetary magnetic field and Kp. For the Lower Thermosphere Coupling Study (LTCS) of 21-25 September 1987, the zonal and meridional winds predicted by the TIGCM could be compared with the actual observations made by EISCAT. Fig. 14 illustrates the very good agreement obtained, which provides a powerful vindication of the model. A similar comparison between the predictions of the TIGCM and the winds observed at Sondrestromfjord gave a much poorer agreement, almost certainly because Sondrestromfjord is at a higher geomagnetic latitude and is far more seriously affected by ionospheric convection in the polar cap (Johnson and Virdi).

Daily observations of the semi-diurnal oscillation in the meridional neutral wind in the lower thermosphere were possible during the ERRRIS campaign in spring 1988. The height profile of the field aligned plasma velocity frequently showed a clearly defined waveform with a vertical wavelength of about 32 km, a descending wavefront, and a period of 12 hours. This oscillation was identified with the (2,4) tidal mode. The phase of this mode was almost constant from day-to-day at all heights but the amplitude was very strongly modulated. The average amplitude of the semi-diurnal oscillation over the height range 105-130 km during the eleven day ERRRIS campaign can be fitted with a 53 hour period modulation, which agrees well with the period of planetary waves which are prominent at Tromsø (Williams and Virdi).

HIGH ALTITUDE STUDIES

Initial EISCAT-VHF operations demonstrated capabilities in probing the topside ionosphere. A method has been established which allows for computing the H^+ vertical velocity from the main ionospheric parameters measured by the radar. In order to test this method, a fully controlled sequence has been established consisting of generating an ideal ionosphere by solving the coupled continuity and momentum equations for a two ion plasma (O^+ and H^+). Synthetic autocorrelation functions (ACFs) are then generated and used as actual measurements to compute H^+ vertical velocities which can be compared with the true ones. A generally good agreement is found within the altitude range 200-1000 km, which shows that the method of computing H^+ vertical velocities is reliable (Blelly, Fontanari, Alcaydé, Wu, Blanc, Lathuillère and Barakat)

Following this study, initial VHF observations were used to study the vertical flows of O^+ and H^+ in the topside ionosphere. Two particular nights, one very quiet, and the second with moderate magnetic activity, were used to provide a first study of the morphology and orders of magnitude of ion outflow fluxes over Tromsø. Preliminary trends were identified which require confirmation by further observations, namely: near zero, or downward, O^+ flows most of the time, strongly correlated with magnetic activity,

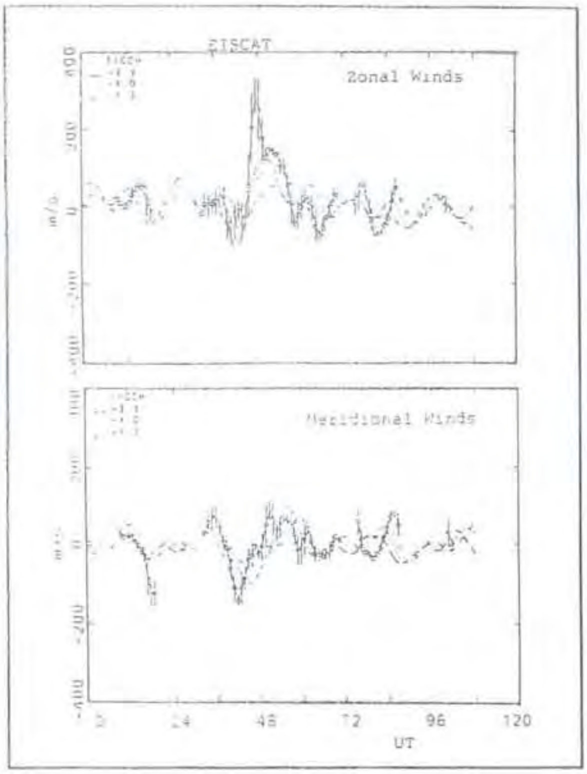

Fig. 14. A comparison of zonal and meridional winds measured by EISCAT and those predicted by the TIGCM at approximately 115, 125 and 135 km.

and mostly driven by downward diffusion; always upward H^+ topside ion fluxes, with velocities reaching 1000 ms^{-1} and maximum flux values of $10^{12}\,m^{-2}s^{-1}$, suggesting a permanent subsonic outflow at 1000 km; reasonable consistency of the observations with numerical models (Wu, Blanc, Alcaydé, Fontanari and Kofman).

Further studies require comparison of observations with numerical simulations at similar atmospheric and ionospheric conditions. In this respect, the neutral atmosphere plays a key role as a source of H^+ ions (charge exchange processes) and also as a sink of momentum and energy via the ion-neutral collision processes. In order to characterize the upper atmosphere temperature and composition, use was made of the ion energy equation (including convection, work and conduction terms) for determining the neutral oxygen temperature and density, and the H^+ continuity equation (including the dynamical term) for the estimate of the neutral hydrogen density. While a generally good agreement is found between the oxygen temperature and density

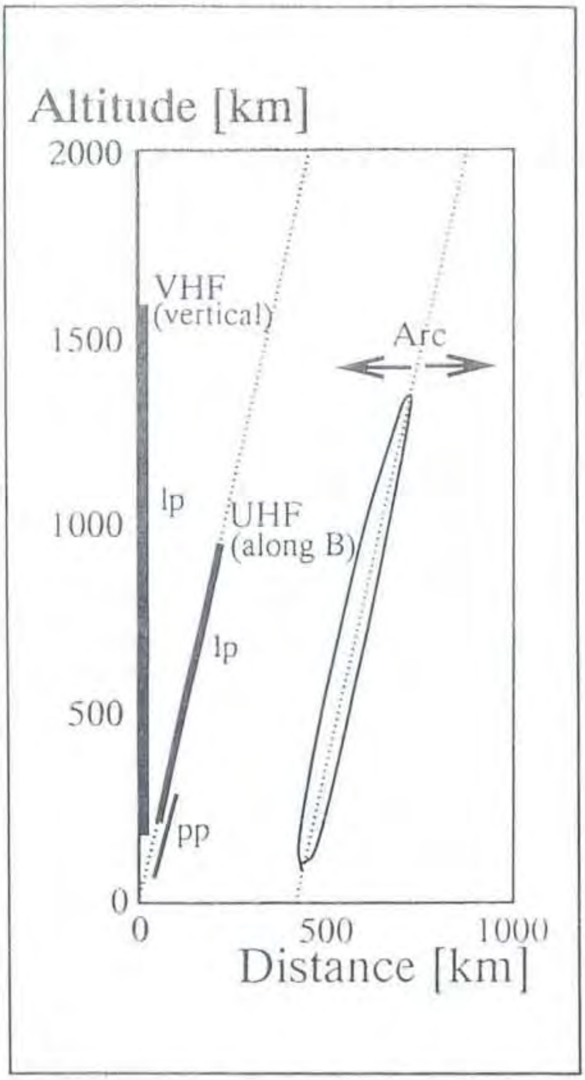

Fig. 15. Geometry sketch for the combined VHF and UHF EISCAT experiment. The thicker lines indicate the altitude coverage of the different radar modulation schemes. The sketched auroral feature is meant to illustrate the discussion in the text.

determined by the EISCAT VHF radar and the CIRA-86 model, the determined hydrogen densities are generally larger than the model by factors ranging from 2 to 5; an extreme case was found for which observed hydrogen densities were more than 20 times larger than the model (Blelly, Fontanari, Alcaydé, Wu, Blanc and Hansen).

A tool to aid the interpretation of the ion escape observed in the upper ionosphere by the VHF radar has been produced in the form of a numerical code simulating the thermal plasma that expands from the F-region reaching high altitudes in the protonosphere. The coupled continuity and momentum equations are solved for O^+ and H^+ as a function of time and altitude, taking into account the inertial term. Ion and electron temperatures together with initial velocities and concentrations for each ion are obtained from the VHF measurements. A finite difference method is used for the numerical solution. The simulation results are in good agreement with the radar observations; comparative results show that the electric field and meridional neutral wind play an important role. When the electric field vector is known, from simultaneous UHF radar observations, one can get a very good estimate of the vertical and meridional winds up to about 600 to 700 km. From 1988 to 1990 the VHF observations never revealed supersonic velocities for H^+. Extrapolated calculations at higher altitudes than the observations can give supersonic velocities if the plasma pressure is low enough at the high altitude boundary. This means that, for some geophysical conditions which are to be studied, very large upward velocities can be encountered (Wu, Taieb, Blanc, Alcaydé, Fontanari and Kofman).

An alternative approach has allowed the hydrogen parameters to be fitted directly to the measured radar data (see cover). The data sets produced by Common Programme Seven are almost always contaminated by spurious satellite echoes and a special data integration program has been constructed to remove these returns on a gate by gate basis; the output of this package is clean enough to allow H^+ composition, temperature and velocity to be directly determined under some conditions (Løvhaug and van Eyken).

As noted in earlier annual reports, one of the unexpected results from the analysis of the coordinated EISCAT/VIKING dataset was the discovery of large outward flows of the bulk ion population in the topside ionosphere. These fast and intense outflows were always found to be associated with auroral particle precipitation, and often also with extremely enhanced electron temperatures in the F-region above auroral arcs.

To gain further insight into the ionospheric processes behind these observations, a new EISCAT experiment was developed, using both the UHF and VHF facilities for studies of the topside ionosphere.

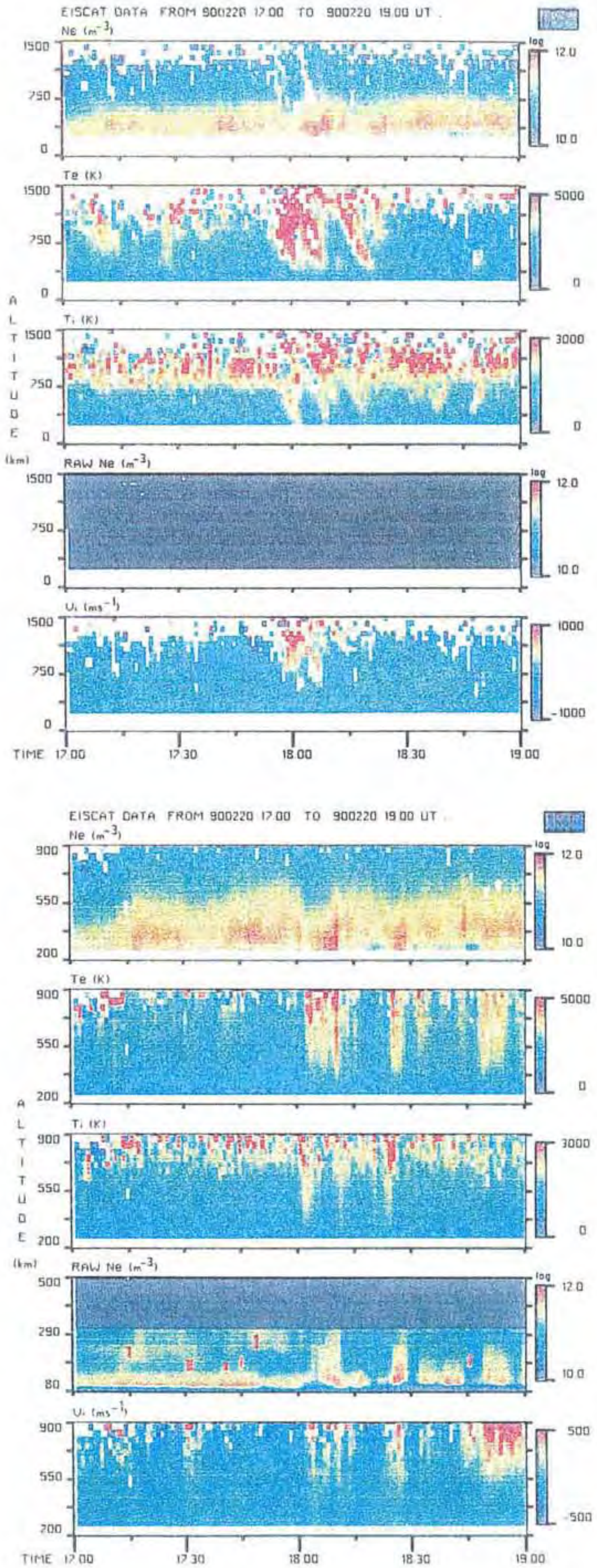

Fig. 16. Example of altitude/time diagrams for different ionospheric plasma parameters from the combined UHF (lower) and VHF (upper) EISCAT experiments for high altitudes. The passage of a triple auroral structure can clearly be recognized around 1800 UT.

In two campaigns in February and November 1989 new data were collected from altitudes as high as 900 km with the UHF system and 1500 km with the VHF system. The campaigns were very successful and the data analysis is still in progress. As a first result it could be shown that the upward acceleration of ions continues to increase towards higher altitudes and that the ion outflow is associated with narrow auroral structures.

The spatial geometry of the combined EISCAT UHF and VHF experiment is shown in Fig. 15, while Fig. 16 shows examples of UHF and VHF data from a disturbed period. It can easily be understood that the structure in the EISCAT data around 1800 UT must have been produced by a multiple southward drifting system of auroral arcs. It can also be seen that the energy spectrum of precipitating electrons must have been very wide, containing a relatively large proportion of low energy particles (see Fig. 16, Raw N_e). The associated effects in topside electron temperature and ion velocity are observed by the VHF radar at consequently decreasing altitudes, and slightly later simultaneously at all altitudes by the UHF radar. Since the observed flux reaches values of almost $1.8\ 10^{14}$ particles m^{-2} it is not believed that the acceleration process can be of thermal character.

The study has revealed that there seem to exist two types of field-aligned bulk ion outflows in the nightside auroral oval. One type is associated with strong horizontal electric fields, which heat ions effectively at all ionospheric altitudes, thereby producing a thermal bulk outflow. The other type, referred to here, occurs only above auroral precipitation and no particular ion heating can be observed on the same magnetic field-line. However, during these events the high altitude electron temperatures are often elevated to extreme values of several 1000 K. The observed ion outflows of the second type are so common and so intense that they must constitute a major source for the magnetospheric ion population of heavier ions (Wahlund, Opgenoorth, Häggström, Winser and Jones).

Different phenomena contribute to the heating of the high latitude ionosphere; they have been reviewed and their relative importance discussed. Amongst these processes, the magnetospheric electron fluxes precipitating at the top of the auroral ionosphere dissipate their energy and heat the ambient electron gas. The Boltzmann transport equation that leads to the heating rate has been solved and used to explain the high electron temperatures observed above EISCAT (Kofman and Lilensten).

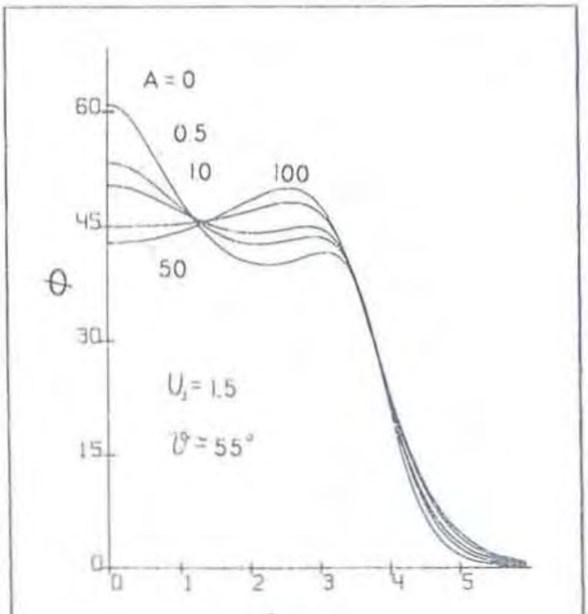

Fig. 17. Incoherent scatter spectra for different values of $A = \nu_{ii}/\nu_{in}$ and $u_{perp} = 1.5$ (in units of the thermal speed of the neutrals). It was assumed that $T_e = 1080$ K. The frequency scale is valid for the EISCAT VHF system.

NON-MAXWELLIAN PLASMAS

It is well known that, during periods of large electric fields, ion-neutral collisions can produce a non-Maxwellian velocity distribution, which results in an incoherent scatter spectrum different from that which is normally observed. In particular a spike in the middle of the spectrum may occur while its shoulders are decreased. It was now investigated whether ion-ion collisions can also significantly modify the velocity distribution function and thus the incoherent scatter spectrum. Fig. 17 shows calculations of the incoherent scatter spectrum for different values of the ratio $A = \nu_{ii}/\nu_{in}$ and for a drift velocity of $u_{perp} = 1.5$ (in units of the thermal speed of the neutrals). A BGK collision model was used for the calculations. It is seen that ion-ion collisions tend to bring the spectra back to their normal shape. This is because the momentum transfer by ion-ion collisions has no privileged direction, while in the case of ion-neutral collisions the drift velocity of the ions is a privileged direction. Thus ion-ion collisions operate against anisotropies in the distribution function. From Fig. 17 it is clear that this effect becomes important when $A \geq 1$. Fig. 18 shows ν_{ii} and ν_{in} versus altitude for three periods where the electric field was ≥ 50 mVm^{-1}. The collision numbers are calculated from formulae given by Schunk and Nagy (1980). The values of ion density and temperature inserted into these formulae were taken from EISCAT CP-1 data, while the MSIS 86 model was used for the neutral density. It is seen that above about 280 km ν_{ii} begins to exceed ν_{in}; thus, above this altitude, incoherent scatter spectra are probably less influenced by anisotropic ion velocity distributions than previously believed (V. Tereshchenko, E. Tereshchenko and Kohl).

HIGH LATITUDE CONVECTION AND MAGNETOSPHERIC RESPONSES

Electric fields and conductivities derived from EISCAT during two GISMOS campaigns in January 1984 and September 1986 were included in the NCAR data base and combined with other observations from incoherent and coherent radars, ground-based magnetometers and satellites, with IMF-dependent electrostatic potential models, and with models of solar-produced conductivity to map the instantaneous large-scale electric potential in the auroral and polar regions, using the Assimilative Mapping of Ionospheric Electrodynamics (AMIE) technique described by Richmond and Kamide (1988). This technique also yields estimates of horizontal and field-aligned currents, of the Joule heating, and of the total cross-polar-cap potential drop, which have been compared to independent estimations of these quantities. The instantaneous convection patterns obtained for different orientations of the interplanetary magnetic field were shown to be generally consistent with statistical patterns (Richmond et al., 1990; Emery et al., 1990).

In the morning sector, a marked depression of the electron density is often observed in a narrow range of latitudes (few degrees) between 200 and 400 km altitude. It is correlated with high measured values of the ion temperature, higher than first expected such that the anisotropy had some consequences on the data processing. A three dimension thermal plasma code was run and showed that the depression was primarily a consequence of an increased rate of chemical recombination (Taieb).

EISCAT Common Programme Three experiments conducted between June 1984 and November 1987 have been used to construct empirical statistical models of convection electric fields and electrostatic potential as a function of the Kp magnetic index. These models, given by a set of coefficients which describe their latitudinal and local-time variations between 61 and 72° invariant latitude, provide quantitative evaluations of the total potential drop in the field of view of the radar, of the convection cells spatial extensions and rotations relative to the noon-midnight meridian, and of the penetration of electric fields towards mid-latitudes. They show how these convection characteristics vary with magnetic activity. The same CP-3 experiments have also been used to study the solar radiation and particle contributions to the height-integrated conductivities. A model of solar produced conductances was deduced, which shows that they vary roughly as the cosine of the solar zenith angle. This model was subtracted from the measured values to yield the particle-produced conductances which were compared to the statistical model of Hardy et al. (1989) obtained from precipitating electron characteristics measured on board the DMSP satellites. It was shown that the EISCAT-derived particle-produced conductances agree well with the DMSP model in the morning sector, but that they are systematically larger than the model in

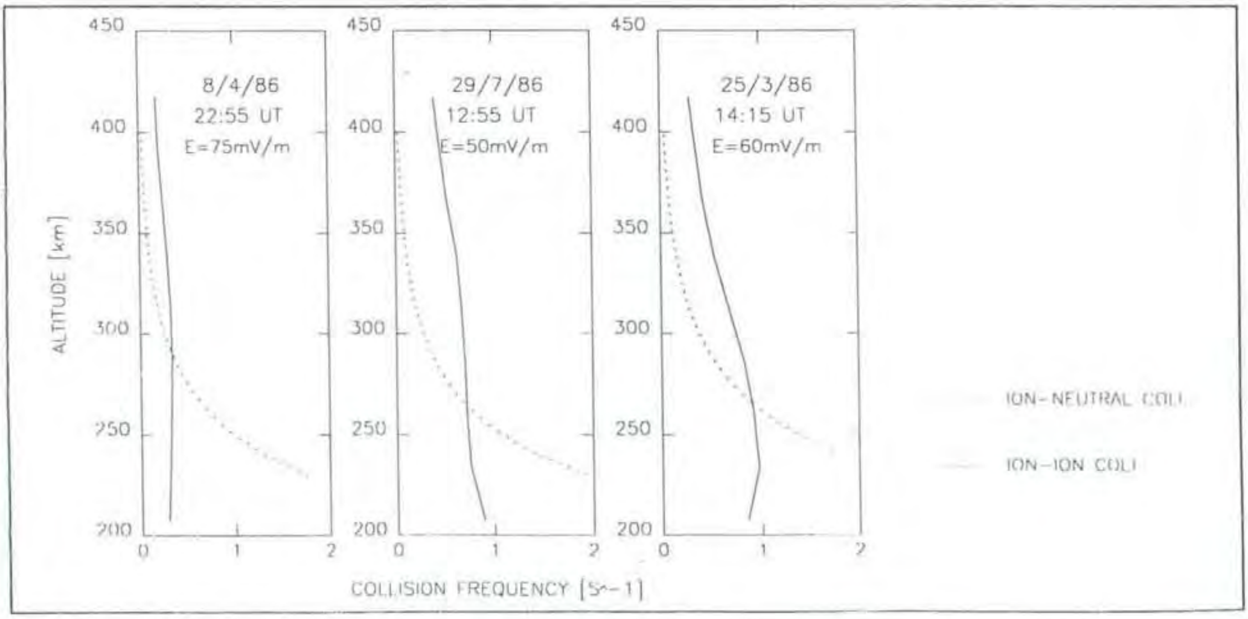

Fig. 18. Ion-ion and ion-neutral collision frequencies calculated from formulae by Schunk and Nagy (1980) using EISCAT CP1 data and the MSIS 86 model.

the evening sector (see Fig. 19). This difference was attributed to E-region electron production by energetic ion precipitation which occurs preferentially in the evening sector (Senior et al., 1990; Senior).

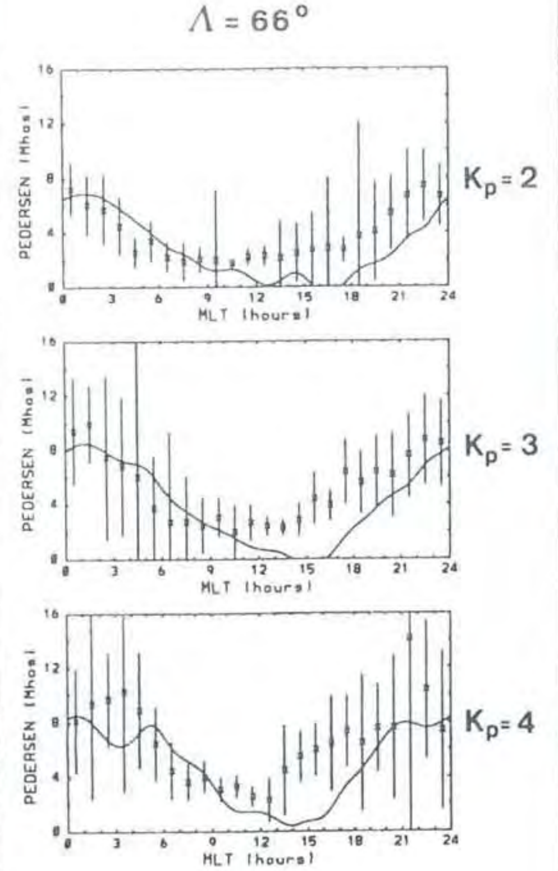

Fig. 19. Magnetic-local-time distribution of the particle-produced Pedersen conductance at 66° invariant latitude for three ranges of Kp ([2-,2+], [3-,3+], [4-,4+], from top to bottom). The crosses and vertical bars are the mean particle-produced conductances and their standard deviations derived from EISCAT data, while the continuous lines are from the model of Hardy et al. (1989).

Data from five incoherent scatter radars, including EISCAT, were used to study the penetration of auroral electric fields towards middle and low latitudes during a GISMOS campaign in January 1984. It was shown that the theoretical models of plasma convection in the inner magnetosphere reproduce roughly the main characteristics of the observed electric fields, and that the differences between theory and data can be attributed to the effects on the electric field of the delayed response of the neutral wind to heating of the auroral zone (Fejer et al., 1990).

MAGNETOSPHERE-IONOSPHERE COUPLING

Observations of the dayside aurora by optical instruments on Svalbard have been made in conjunction with EISCAT measurements of ionospheric plasma flows. Detailed study of the ion temperature within flow bursts associated with transient 630.0 nm and 557.7 nm auroral events reveals the flow to be a continual series of bursts during southward Interplanetary Magnetic Field (IMF) conditions, with velocities ranging from below 1 kms^{-1} to more than 4 kms^{-1} on time scales of a few minutes. The two examples of transient flow bursts and associated ion temperature enhancements in Fig. 20 at 0845 UT and 0910 UT are coincident in time and space with 630.0 nm and 557.7 nm auroral transients, observed by photometers and all-sky cameras at Ny Ålesund, Svalbard. Similar events have been associated with magnetopause flux transfer events. The plasma velocity vectors derived from the beamswinging technique indicate an increase in flow speed from below 500 ms^{-1} to over 4 kms^{-1}, which is consistent with the fourfold increase in ion temperature. For the second flow burst, however, the temperature increase occurred at 0903 UT in the western azimuth of the POLA experiment, but not until 0910 UT on the eastern azimuth. Hence, between these times the assumptions inherent in the beamswinging method utilised in this experiment are certainly invalid and the northeastern flow at event onset is probably in error. Despite this, the flows are definitely poleward as the line of sight velocities are away from the radar (Lockwood et al., 1990a).

Observations of both auroral transients and ion flow bursts at 1600 UT on the same day indicate that these events have different characteristics from those near magnetic noon.

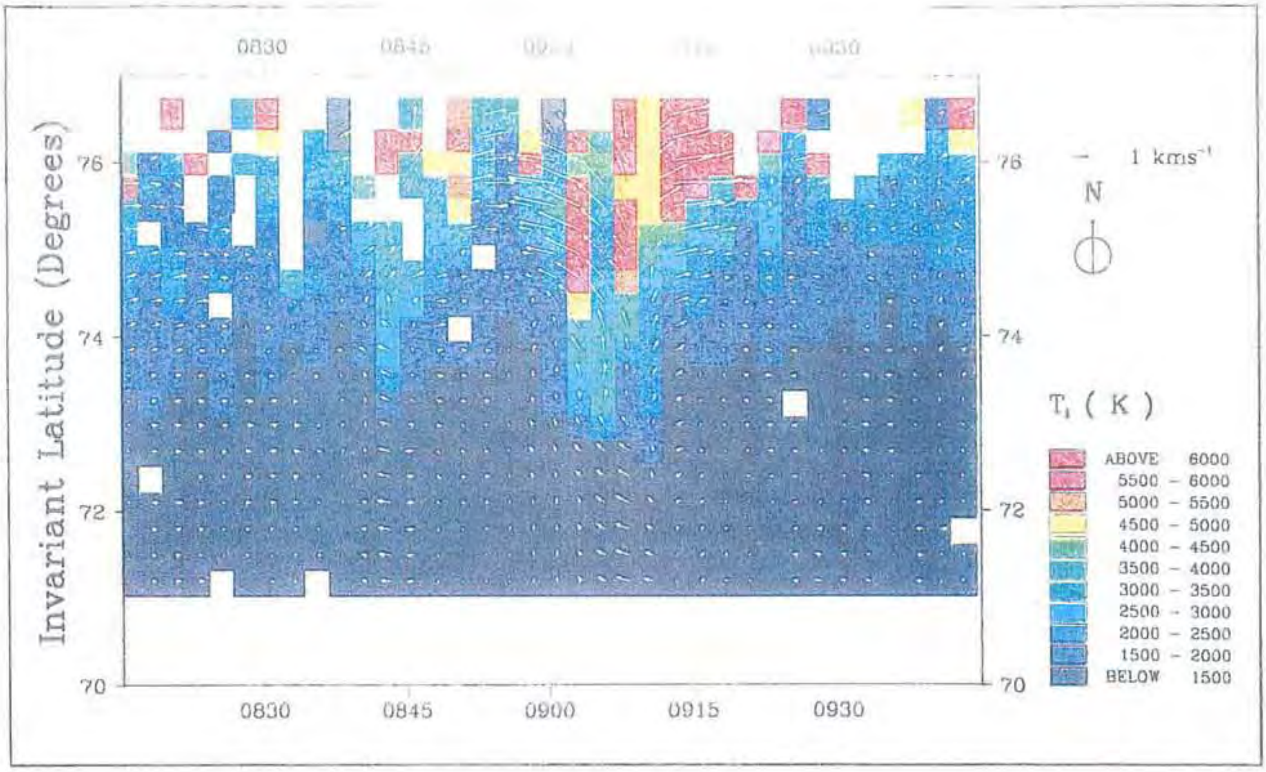

Fig. 20. Transient dayside flow bursts seen by the EISCAT POLA experiment at magnetic noon on 9 January 1989 over Spitzbergen in association with dayside auroras (Lockwood et al., 1990d).

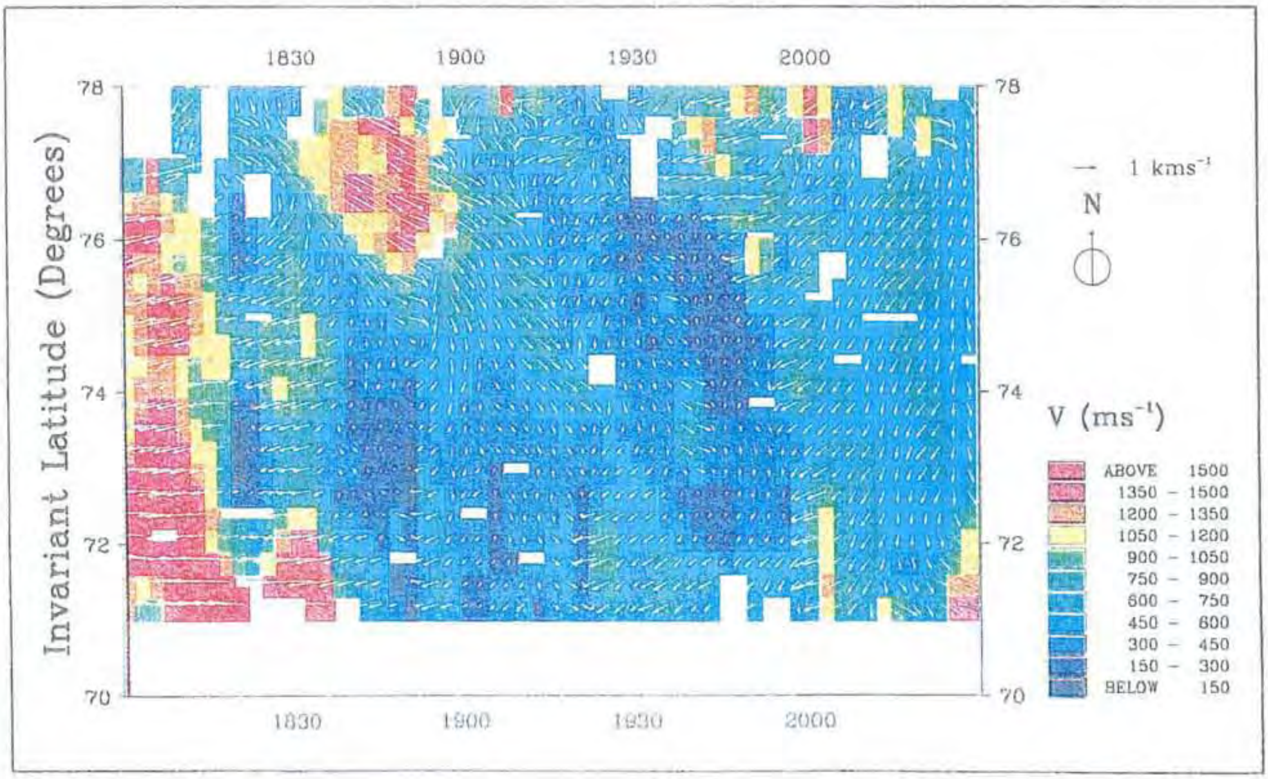

Fig. 21. Plasma flow data from the EISCAT POLA experiment during a complete substorm cycle observed on 17 October 1989. Velocity vectors are superimposed on colour contours of the flow magnitude (Lester, Lockwood, Yeoman and Orr)

A persistent shear flow reversal, Fig. 22, at the convection polar cap boundary is co-located at all times with the poleward edge of the background 630.0 nm aurora (between the dot-dash and the dashed lines). The growth phase of a substorm commences following a southward turning of the IMF and is marked by an equatorward motion of the rotational convection reversal boundary after 1830 UT, due to the growth of the polar cap. The expansion phase of the substorm is defined by a network of magnetometers to begin near 1920 UT and is marked by the appearance of eastward flow in the polar cap. In the recovery phase these flows slowly evolve to anti-sunward. The background aurora, which has characteristics consistent with the cleft/Low Latitude Boundary Layer (LLBL), lies entirely in the region of sunward convection flow. There are two equatorward jumps of the convection reversal and the auroral boundaries, each following a transient 557.7 nm aurora (solid lines). These events have a two component form; a lower latitude arc fragment which brightens and fades in a limited longitudinal sector and a fragment on the convection/auroral boundary which moves anti-sunward. The cause of these quasi-periodic auroras and filamentary field-aligned currents is not yet understood (Sandholt and Lockwood, 1990; Sandholt et al., 1990).

The dimensions of the transient events near noon have been calculated from both the radar and optical data and have been found to be elongated in the east west direction with characteristic dimensions 200-300 km north/south and 1500-2000 km east/west. This elongated ionospheric signature is very suggestive of the extended X-line models of Flux Transfer Events (FTEs). Analysis of the implications of these EISCAT observations has lead to an important new concept of the cusp as a continually pulsed source, rather than a steady injection of magnetosheath particles into the ionosphere. In particular the dimensions of the events detected by EISCAT are similar to those of

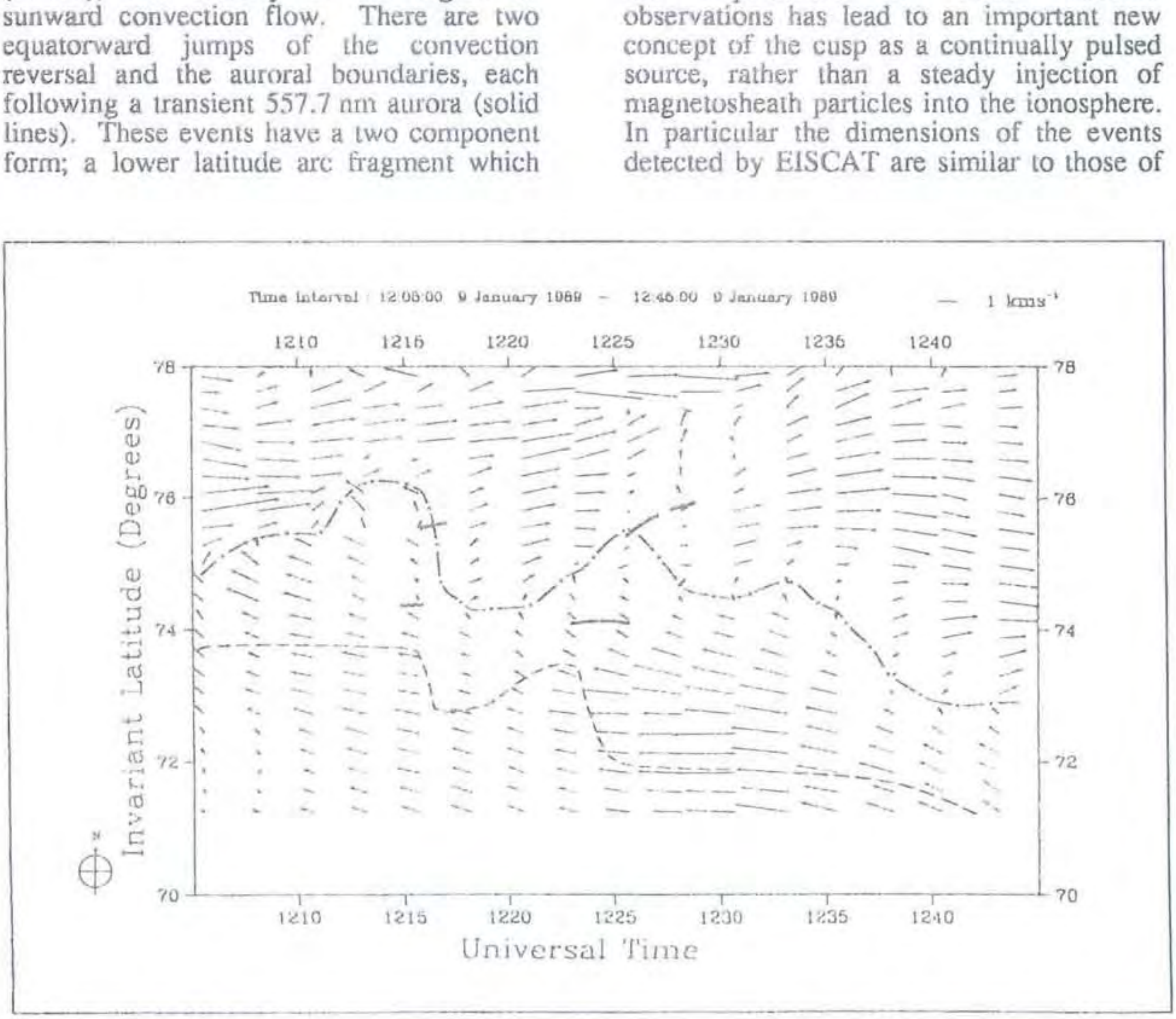

Fig. 22. Transient flow and auroral events observed near 16 MLT on 9 January 1989 and auroral observations at Ny Ålesund, Svalbard. Auroral events are observed quasi-periodically (period about ten minutes) close to the collocated convection reversal and auroral boundary which move equatorward after each event (Sandholt and Lockwood, 1990).

the statistical mean cusp identified by spacecraft particle detectors. Tests of this model are at present underway and data taken by EISCAT during the first Geospace Environment Modelling (GEM) observational campaign in 1990 will focus on this problem. Initial results have revealed interesting spatial structure and IMF dependencies of the northward IMF cusp (Lockwood et al., 1990b; Elphic et al., 1990; Carlson, Lockwood, Reiff and van Eyken; Reiff, Carlson, Weber, Lockwood and van Eyken).

The coupling between the magnetosphere and ionosphere on the nightside is mainly through the explosive release of energy during magnetospheric substorms. Combined observations of auroral surges and substorms using the EISCAT and Sondrestromfjord radars have continued. During the substorm auroral forms in the midnight sector are seen to expand poleward at Sondrestromfjord and in one case the polar cap boundary, measured by EISCAT, contracts polewards in the dawn sector at the same time (Robinson et al., 1990).

Several multi-point studies of substorms are underway with EISCAT data forming a key segment of the work. It is clear from a study of an isolated substorm during the SUNDIAL campaign of 1987, when EISCAT was in the post midnight sector, that the start of the substorm growth phase, identified by enhancement of the plasma flow in response to a southward turning of the IMF, differed depending upon the local time at the radar. The growth phase began earliest at radars nearest local noon and latest at the radars near midnight and lowest latitude. The expansion phase onset results in the rapid motion of the nightside flow reversal westward in the classic manner of the motion of the Harang discontinuity. Another isolated substorm occurred during the Dual Auroral Radar Network (DARN) observational campaign of October 1989 when EISCAT was in the pre-midnight sector and observing in the POLA experiment mode. On this occasion, the growth phase in the pre-midnight sector began shortly after the southward turning of the IMF and was identified by the equatorward expansion of the polar cap boundary. This suggests that the response to the growth phase not only depends on local time but also on latitude. The flows immediately after the substorm onset at 1926 UT are remarkably weak at EISCAT (Fig. 21), despite the longitude of the auroral break-up region being identified a few degrees to the west of the measurement meridian. (Lester, de la Beaujardière, Foster, Ruohoniemi, Swider, Lühr, Lepping and Lazarus; Lester, Lockwood, Yeoman and Orr).

OTHER SCATTERING PHENOMENA

About 240 h of passive observations of Interplanetary Scintillation (IPS) were recorded in 1990, mainly at Kiruna and Sodankylä. By comparing the scintillations of compact radio sources recorded along lines of sight passing close to the sun, the mechanisms responsible for the acceleration of the solar wind have been investigated. Acceleration profiles which cannot be explained by current theories have been recorded (Coles, Esser, Markkanen and Løvhaug).

High-resolution measurements of natural photoelectron-enhanced plasma lines have been made using a chirped (frequency modulated) transmitter pulse with the EISCAT UHF radar. Results from two different experiments have been investigated; the first was run in May 1986 near solar minimum and the second in July-August 1989 near solar maximum. The enhanced detectability and time resolution of spectral plasma-line measurements was demonstrated. The frequency resolution allows for direct measurements of field-aligned electron currents larger than $10\,\mu Am^{-2}$ at electron densities less than $2\,10^{11}\,m^{-3}$. However, due to quiet ionospheric conditions, unambiguous current values of this magnitude could not be measured from the available data (La Hoz and Fredriksen).

Strongly enhanced ion acoustic shoulders of the incoherent scatter spectrum at 933 MHz at altitudes from 138 to 587 km have been found during several Common Programmes. The enhancements approach nearly two orders of magnitude in total backscattered power and occur at either one or both of the ion acoustic shoulders. Fig. 23 shows an example of five successive 10 second

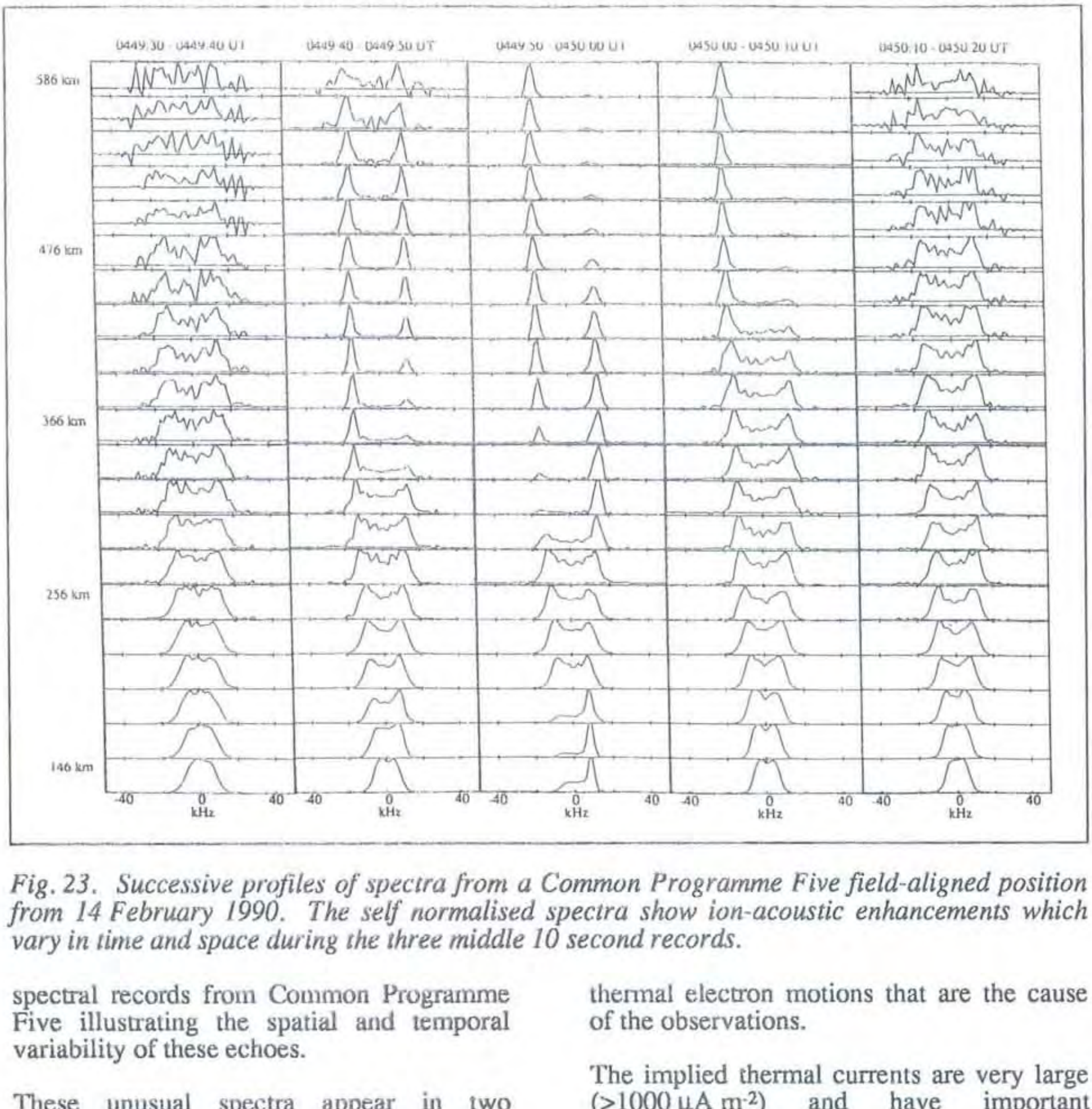

Fig. 23. Successive profiles of spectra from a Common Programme Five field-aligned position from 14 February 1990. The self normalised spectra show ion-acoustic enhancements which vary in time and space during the three middle 10 second records.

spectral records from Common Programme Five illustrating the spatial and temporal variability of these echoes.

These unusual spectra appear in two preferred height regions having different characteristics, the upper E-region between 138 and 200 km, and the topside ionosphere above about 300 km. The enhancements are associated with geomagnetic disturbances, high electron temperatures, auroral arcs, and red aurora in the F-region. The EISCAT observations, which are mainly along the magnetic field direction, indicate that field-aligned thermal electron drifts are destabilizing the ion acoustic waves. It is suggested that field-aligned flows of soft electrons depositing their energy at horizontally poorly conducting F-region heights result in parallel electric fields in the ionosphere which in turn produce the thermal electron motions that are the cause of the observations.

The implied thermal currents are very large ($\geq$1000 μA m^{-2}) and have important implications for studies of auroral arc processes and magnetosphere-ionosphere coupling. These spectral enhancements, which are rare, short-lived and have some characteristics similar to satellite echoes, have probably been rejected as such in the past (Rietveld, Collis and St. Maurice).

Three experimental campaigns involving measurements with the COSCAT facility took place during 1990, following the initial observations in October 1989. The measurements make use of an additional low-power transmitter, located at Oulu, which makes it possible to observe field-aligned auroral irregularities of 16 cm wavelength, by means of the EISCAT receiving antennas at Kiruna and Sodankylä. The majority of the observations have been performed by using these two antennas passively, although a short interval of active observations has been undertaken to obtain measurements of F-region electric fields on magnetic field lines corresponding to the observed coherent backscatter.

Coherent echoes were observed on the majority of nights for which observations were made. The backscatter fluctuations are very dynamic on timescales of a few seconds. The spectra appeared similar to those observed in previous EISCAT studies at greater aspect angles. They are typically skewed, with a steep fall-off at high Doppler shifts. Occasionally, more complex forms have been seen, including double-peaked spectra which seem likely to be caused by spatial variations of the plasma flow within the large scattering volume. A strong correlation has been noted between the Doppler velocity of the irregularities and their backscattered power, while an anticorrelation exists between backscatter power and spectral width.

An unexplained feature of the observations is that the smallest spectral widths appear to be associated with velocities of around ± 420 ms^{-1}. One possibility is that these spectra arise from 16 cm wavelength irregularities stabilised by anomalous collisions. The observed velocity is some 30% larger than the ion acoustic speed at 100 km altitude, and agrees with the predictions of the resonance broadening theory (Robinson and Honary) for the velocity of stabilised waves. The optimum azimuth and elevation for backscatter observations from the two receiving sites also suggests that the irregularities originate at heights close to 100 km, thus providing further support for this interpretation (Schlegel et al., 1990; McCrea, Schlegel, Nygrén and Jones).

IONOSPHERIC MODIFICATION (HEATING)

EISCAT continues to be a key diagnostic during High Power Radio Wave modification experiments of the ionosphere with the Heating Facility at Tromsø. The most recent analysis of electron density and temperature measurements in the F-region indicates that large (of order 100%) enhancements in electron temperature occur in a narrow altitude region near the reflection height of the heater beam. These enhancements decay in intensity with increasing distance from the peak (at about 200 km) in a direction along the magnetic field, both above and below the interaction height. These EISCAT observations of electron temperature enhancement profiles are in very good agreement with model calculations which assume a delta function heat source at the interaction height. Observation of the onset and decay times of the heater induced temperature enhancements were also undertaken and these were also consistent with the model calculations. The decay times for both experiments and two types of model are illustrated in Fig. 24. The good agreement between the model and observations with regard to both the temporal and spatial characteristics of the electron temperature confirm the validity of currently accepted values of the transport coefficients in the auroral F-region (Stoker, Honary, Robinson, T. Jones, Stubbe and Kopka).

Observations of the electron density response to heating are much more variable than those of electron temperature. This is to be expected since EISCAT measurements of electron density are less reliable than those of temperature in the presence of heater induced turbulent fluctuations and the response may involve an increase or decrease in density depending on whether photochemistry or transport effects dominate. Near 200 km altitude, these two effects are finely balanced and it is difficult to predict which is the more important.

A particular ionospheric HF-modification experiment was carried out in 1986. The EISCAT system used the chirped and normal plasma and ion line receivers. The ion lines were observed at the lower reflection level and at the topside of the F region ($\omega_p/\omega = 1$).

Heater induced plasma lines were observed only in the first 10 s integration interval, indicating a strong overshoot. Multiple unusual simultaneous lines were observed, normally originating within one kilometre of the critical region, but sometimes from lower heights. The frequency of the most common line is offset some 250 kHz from the heating frequency. The usual plasma line enhancement at frequencies close to the heater frequency was not seen and the natural photo-electron enhanced plasma line was absent throughout the experiment, probably due to strong Landau damping corresponding to the ionospheric conditions (Isham et al., 1990).

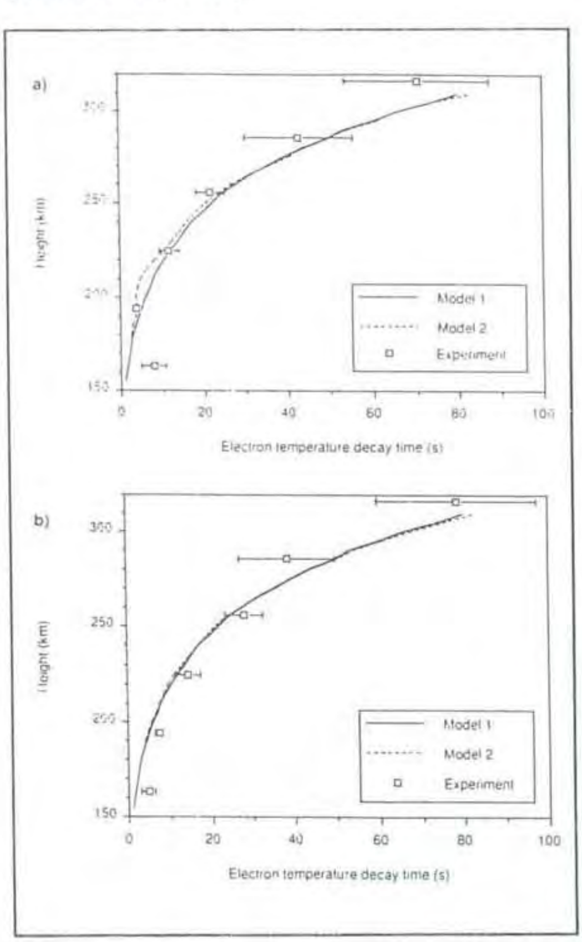

Fig. 24. A comparison between the decay time of the enhanced electron temperature measured by EISCAT as a function of height (squares) during a heating interval and the estimated decay time from two separate models (full line and dashed line). The top panel is for an interval when the heater was at full power and the lower panel when the heater was run at 50% full power.

Two EISCAT-Heating campaigns were performed in 1990, one of them in collaboration with a US group (F. Djuth and M. Sulzer) who brought special data taking equipment which was used to record the analogue output of the receivers directly to tape for subsequent analysis. The superior capabilities of this method promise many interesting results, especially in comparison with Arecibo measurements. Detailed results are not yet available because the vast amounts of data need longer times for evaluation. However, a first clear result was that plasma lines are observed at higher altitude by the VHF system than by the UHF system. This is expected from conventional weak turbulence theory and represents, therefore, a strong argument in favour of this theory. Another, at first glance surprising, result was the rather regular up and down pumping of the intensity of the ion line with quasi-periods of a fraction of a millisecond. This may be an indication of spatial coherence in the excitation and will be further investigated (Kohl, Kopka, Rietveld and Stubbe).

DIGITAL SIGNAL ACQUISITION AND HARDWARE IMPROVEMENTS

The alternating code decoder system has now reached full operational status. Decoder units have been installed in all EISCAT correlators, and all necessary hardware modifications are also completed. The radar has thus become ready for the application of practical, commonly available alternating-code based experiments. To simplify matters for external users, and also to gain experience, considerable effort has been spent on the design of device driver software for the decoder, as well as on its integration into the EISCAT Real-time Operating System (EROS) environment.

The new features have also been applied in actual experiment design. A few different algorithms have been written and tested. One of these is functionally very similar to the Common Programme One algorithm, but uses a 16 baud alternating codes set for the E- and F1-region monostatic part, rather than the interlaced multipulses of the current Common Programme One. It is expected to perform particularly well under conditions of low density or high T_e/T_i, when it will be about two to three times faster than the present Common Programme One algorithm. The new algorithm was used in a number of tests and was also operated in a real time demonstration during the autumn SAC meeting at the Tromsø site. SAC have since commissioned the development of a full-featured alternating-code based experiment algorithm, which should eventually be used in the next generation Common Programme One, Two and Five programmes.

Another algorithm which has been developed uses a combination of alternating codes and Barker codes to achieve high spatial resolution (450 m) in the E-region and, at the same time, almost complete freedom from the range ambiguities which are common in Barker-coded multipulse experiments. A version of this algorithm was run extensively during a campaign in December producing exceptionally clean data which was successfully analyzed without requiring any prior corrections. It is believed that this is the first ever scientific operation of a Barker-coded alternating codes experiment.

Both these basic algorithms are being developed further. Several versions of each, with different range resolutions and coverages, will eventually be available.

In Tromsø, the UHF receiver upgrade program was continued with the installation of a large-dynamic-range first mixer, similar to those already adopted at the Kiruna and Sodankylä sites. It was also necessary to replace the existing first local oscillator systems with very low phase-noise devices in order to combat reciprocal mixing. This is a process which can occur in any mixer, or other non-linear device, which has several strong signals imposed on it. Expressed in simple terms, every signal which is strong enough to drive the device into non-linearity can act as a local oscillator signal, regardless of through which port it enters the mixer. Strong, unwanted signals just outside the band of interest will enter the receiver mixer through the RF port and mix with any noise sidebands that may be present in the receiver local oscillator power spectrum, which in this case will act as a "signal" - hence the term reciprocal mixing. The mixing process translates the oscillator noise sideband to the IF range, where it appears as an increase in the overall noise level.

The very strong NMT-900 base station carriers, which are constantly present just above the EISCAT UHF band, cause a significant amount of reciprocal mixing to occur over a certain range of antenna pointing directions at both the Kiruna and Sodankylä sites. In order to reduce the attendant system noise increase to a negligible amount, the first local oscillators were replaced by devices having better than -150 dBc Hz^{-1} noise sideband power density at 1 MHz frequency offset from the carrier. This could only be achieved by discarding the previous technique, of frequency multiplying a signal generated at a frequency just above 100 MHz, because the multiplication process raises the phase noise spectral density by almost 20 dB/Hz. Phase locked oscillators running directly at the required output frequency of 812.0 MHz were ordered. In the interim, a similar unit operating in the original frequency range has been tested with the multiplier system in Sodankylä and found to perform acceptably. However, this solution still shows traces of reciprocally mixed noise, which indicates that the new high performance oscillators are undoubtedly needed to obtain receivers meeting the highest standards.

The frequency shift of the UHF system which had been planned for some time was finally executed in August. All transmitter channels were downshifted by 2 MHz, placing the new band centre at 931.5 MHz, and the receiver frequencies adjusted to match. This move was a prerequisite for the prolongation of the operating permit by the Norwegian frequency management authority, and it improved the EISCAT/NMT 900 compatibility situation substantially. The primary EISCAT band no longer overlaps with the NMT base station band, and it is now much simpler to protect the receivers against overload without losing some of the assigned channels.

The EISCAT computers

Fig. 25 shows the network of computers from Norsk Data which has been built up over the last few years and which represent the main machines for radar operation and control as well as data storage, analysis and archiving.

The ND530/CX model has a 32-bit CPU with hardware support for floating-point arithmetic and a 16-bit front-end for input/output. The ND110/CX model has essentially only the 16-bit unit. The ND5400 at the Headquarters is an upgraded, faster ND500 model.

The I/O for the radar control is through a standard CAMAC interface, with the exception of the VHF antenna elevation control, which is connected via the RS232 terminal interface. The raw data come through a Norsk Data 16-bit DMA interface.

The computers communicate using Norsk Data HDLC cards and a serial hardware protocol. Between the sites, lines are leased from the national telephone companies and use the V.29 protocol; the software protocol is Norsk Data's COSMOS/XMSG. Each computer has interfaces for up to 8 or 16 serial terminals, printers or modems. In Tromsø, and at the Headquarters, printers and personal computers (PCs) are connected to the main EISCAT systems using Ethernet local area networks (LANs).

During the year the temporary data storage capacity was greatly increased at all sites through the installation of additional hard disks. In Tromsø, for example, there is now a 450 MByte unit available on the process computer, which permits simultaneous VHF/UHF operation for extended periods and/or dumping at high data rates without running out of disk space.

The terminals in use are mainly Tandberg TDV types, though there are also several Tektronix terminals with colour graphics capabilities. IBM compatible PCs are used for administration, documentation, hardware and software development, or as intelligent graphics terminals; most of these use the Intel 386 processor.

At Headquarters the ND5400 computer is being connected to a larger LAN, operated by the Swedish Institute of Space Physics (IRF), with six host computers and numerous personal computers and workstations. The network is a sub-net of Internet, presently the largest research network in the world. The IP number of the ND5400 computer is 192.71.13.4. and a suitable user id, with password, can be obtained by contacting the Headquarters. In general, however, if one reaches the ND5400 via Ethernet further access to EISCAT's ND computers is prevented for security reasons. The ND operating system does not possess an Internet compatible electronic mail (e-mail) facility. E-mail to any of the EISCAT staff at Headquarters should be addressed to eiscathq@hp.irf.se until further.

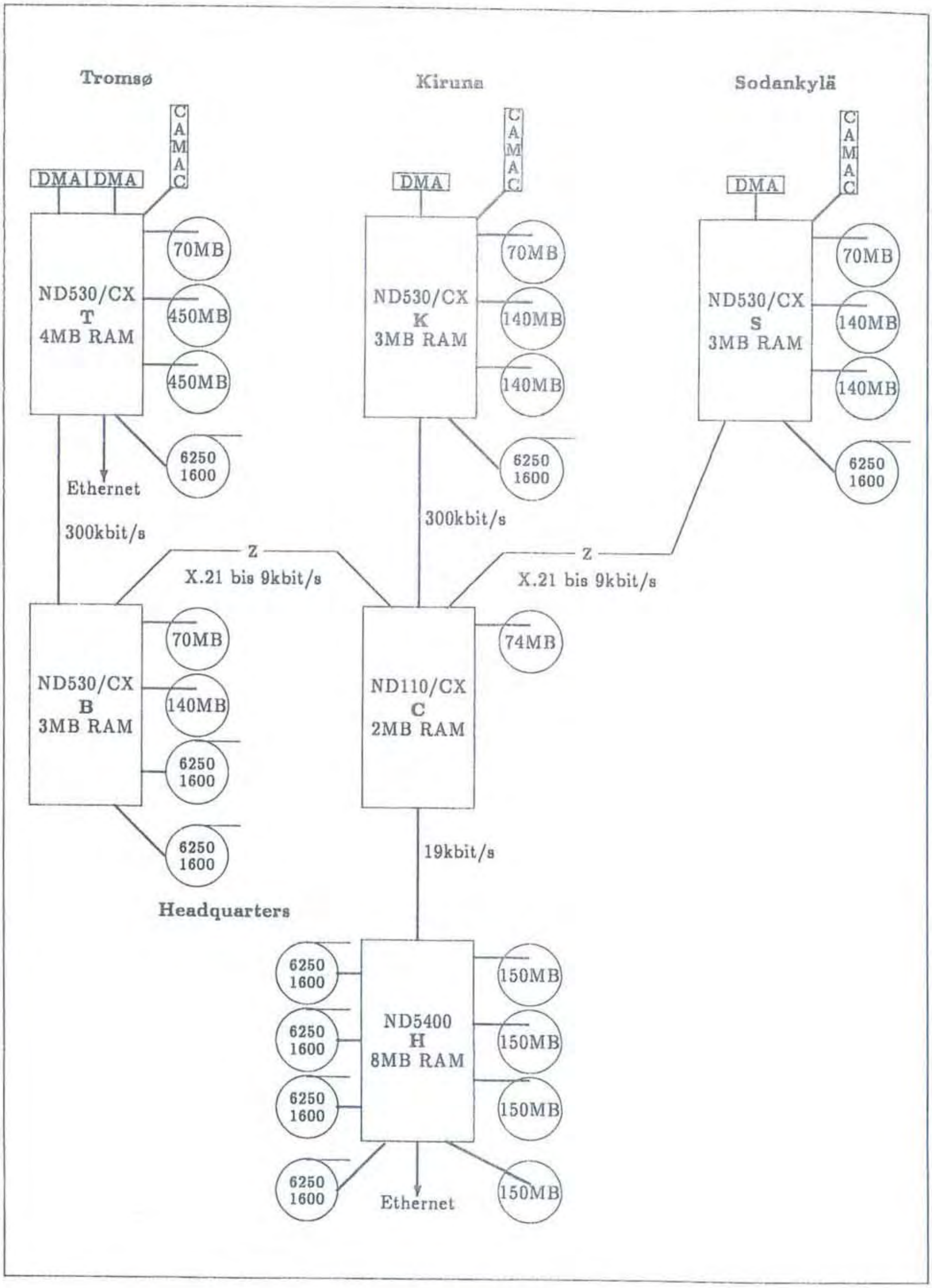

Fig. 25. The EISCAT network of Norsk Data computers used for radar operation and control as well as data storage, analysis and archiving.

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SAC	38th meeting, 23 April 39th meeting, 17-18 October	Copenhagen, Denmark Tromsø, Norway
AFC	34th meeting, 5 April 35th meeting, 3-4 October	Hamburg, Federal Republic of Germany Munich, Federal Republic of Germany

BALANCE SHEET AT 31 DECEMBER 1990

MSEK

Assets	At 31 Dec 1989	Additions: Pool	Additions: Cap Op	Additions: Other	Depre-ciations	At 31 Dec 1990
FIXED ASSETS						
Buildings	7.8				0.2	7.6
Transmitters	27.4	0.5			1.8	26.1
UHF Antennas	12.1				1.3	10.8
VHF Antenna	15.6				1.5	14.1
Computers, etc	4.2		0.8		1.0	4.0
Other	2.5		1.8		0.7	3.6
Total	69.6	0.5	2.6		6.5	66.2
CURRENT ASSETS						
Debtors	1.3					1.4
Prepayments and accrued income	0.3					
Cash and Ordinary Bank Accounts	7.4					6.8
Special Accounts	2.3					0.2
Total	11.3					8.4
GRAND TOTAL	80.9					74.6

MSEK

Liabilities	At 31 Dec 1989	At 31 Dec 1990
CAPITAL		
Contributions		
Pool	92.8	93.4
Capital Operating	17.2	19.7
In Kind	25.1	25.1
Other	0.4	0.4
	135.5	138.6
Depreciations	65.9	72.4
Total Capital	69.6	66.2
RESERVES		
Pool	0.5	1.3
Capital Operating	1.0	1.6
Other	4.0	3.1
Total Reserves	5.5	6.0
Special Accounts	2.3	0.2
LIABILITIES		
Provisions	0.4	0.2
Other Liabilities	3.1	2.0
Total Liabilities	3.5	2.2
GRAND TOTAL	80.9	74.6

Total budget outcome in 1990 (MSEK): Recurrent chapter:

Personnel:	9.26
Administration:	4.44
Operations:	3.93
EISCAT Svalbard Radar:	0.36
Total:	17.99

Totals may not match because of rounding, MSEK = Million Swedish Crowns

EISCAT SCIENTIFIC ASSOCIATION 1990

31 December 1990

	France	Finland	Federal Republic of Germany	Norway	Sweden	United Kingdom
COUNCIL	P. Bauer A. Berroir G. Caudal	J. Kangas A. Siivola	W.I. Axford G. Haerendel G. Preiss	O. Havnes B. Benterud	B. Hultqvist J. Gustavsson	S.W.H. Cowley T.B. Jones* D.M. Schildt
SAC	D. Fontaine D. Alcaydé	T. Turunen*	W. Baumjohann K. Rinnert	N. Bjørnå	H. Opgenoorth	S.W.H. Cowley P.J.S. Williams
AFC	C. Blamont	E. Ikonen	M. Meinecke*	A. Andersen	J. Gustavsson	C.G. Brooks

SAC = Scientific Advisory Committee AFC = Administrative and Finance Committee * = Chairman

EISCAT Senior Staff

Director: J. Röttger (on secondment from MPG)
Deputy Director: G. Wannberg
Business Manager: P. Hagström

Senior Scientist: A.P. van Eyken
Head of Computer Operations: S. Buchert

Site Leaders: Kiruna: I. Wolf
Sodankylä: M. Postila
Tromsø: R. Jacobsen

During 1990, W.J.G. Beynon and B.R. Martin (UK) also served on the Council; W. Kofman (France) on the SAC and D. Morrell (UK) on the AFC.

THE EISCAT ASSOCIATES

CNRS
Centre National de la Recherche Scientifique
France

SA
Suomen Akatemia
Finland

MPG
Max-Planck-Gesellschaft
Federal Republic of Germany

NAVF
Norges Almenvitenskapelige Forskningsråd
Norway

NFR
Naturvetenskapliga Forskningsrådet
Sweden

SERC
Science and Engineering Research Council
United Kingdom

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