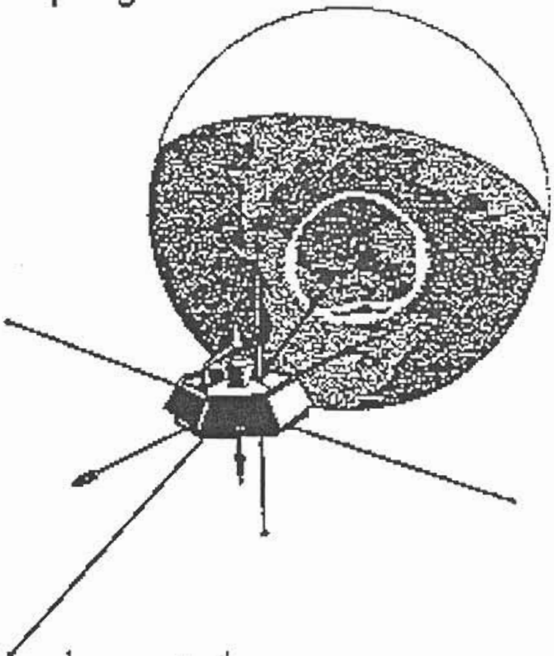
CANOPUS

An automatic ground-based instrumentation array to support space projects



Scientific Objectives and System Description

Prepared by the CANOPUS Science Team

January 1986

C A N O P U S

An Automatic Ground-Based Instrumentation Array to Support Space Projects

Scientific Objectives and System Description

by the CANOPUS Science Team

Edited by A. Vallance Jones (Principal Investigator)

January 1986

INDEX

List of Figures

Tables

FOREWORD

Ground measurements of magnetic field variations and optical and radar observations of aurora have played a central part in building up our understanding of the magnetosphere. In the past it has not always been easy to exploit fully the value of such observations in collaboration with satellite studies because of laborious steps necessary to obtain and reduce ground data obtained at many locations and by many different recording techniques. CANOPUS will for the first time make available a wide range of ground observations in quasi-real time and in a form compatible with the digital data bases of satellite bases studies.

The system name, CANOPUS, was originally an acronym based on the role of the project as a component experiment of the NASA OPEN program. OPEN has now been renamed GGS and integrated into the International Solar Terrestrial Physics program which will involve NASA, ESA and ISAS (the Japanese Space Agency). Since the project has become widely known as CANOPUS we are retaining this name to avoid possible confusion.

The full list of CANOPUS coinvestigators appears as Appendix B. The following are responsible for the principal activities within the project.

Magnetometers and Riometers	J.C. Samson University of Alberta
Radar System	A.G. McNamara National Research Council of Canada
Photometer array	D.J. McEwen University of Saskatchewan
All-sky imager	L.L. Cogger University of Calgary
Data analysis network	J.A.R. Koehler University of Saskatchewan
Project manager	J. Wolfe National Research Council of Canada

SUMMARY

CANOPUS is an array of automatic instruments set up in Northern Canada and transmitting data by satellite telemetry to a central data analysis centre. The array measures electric field and currents as well as optical emissions from the ionosphere. The data obtained involve measurements which can be made only from the ground but which are vital to the scientific objectives of magnetospheric and ionospheric spacecraft studies. CANOPUS was designed as an integral part of the International Solar-Terrestrial Physics Program and was accepted by NASA as a component of that program on an equal footing with over 30 experiments on 4 spacecraft. Over the next five years CANOPUS will also provide essential support to a series of space projects including VIKING, POLAR BEAR, EXOS-D and UARS.

The system is being engineered and constructed to high standards by Canadian industry in recognition of the fact that it should have the same reliability and importance as spacecraft instruments.

General Objectives

The principal objective of the CANOPUS system is to provide, in cooperation with satellite observations, the key data necessary to understanding the processes involving the energization and precipitation of plasma from the magnetosphere into the ionosphere and to study magnetosphere-ionosphere interactions arising through electric fields and currents. Measurements will be made of:

a) Magnetic field disturbances over an extensive area of northern Canada and the derivation of electric currents flowing in the auroral oval and the polar cap. This is achieved by the magnetometer array.

b) Ionospheric plasma drift velocities in a key sector of the auroral oval and derivation of the detailed ionospheric horizontal electric field pattern in this sector. This is achieved by the radar system.

c) Auroral emission and radio absorption profiles across the auroral oval and the derivation of the broad characteristics of the precipitating flux of electrons and protons. This is achieved by the photometer-riometer array.

Specific Scientific Objectives

Specific studies planned with CANOPUS include:

1) Evaluation of ionospheric Joule and particle heating in the auroral oval and cleft in relation to events observed by magnetospheric spacecraft.

2) Studies of dynamic morphology of proton and electron auroral substorms with detailed CANOPUS data supplemented by synoptic satellite imager data.

3) Studies of the relation between pulsations and magnetospheric boundary oscillations directly observed by spacecraft.

4) Studies of Pc 3, 4 and 5 pulsations processes and their latitude variation on the ground together with in situ observations on the corresponding field lines in the magnetosphere.

5) Rapid production of catalogues of substorm onset times and magnetic indices to facilitate magnetospheric studies.

The CANOPUS system

The CANOPUS system is summarized in Fig. 1. An EDFL magnetic coordinate grid (see Appendix A) is superimposed on this figure. The system consists of the following elements:

I Magnetometer and Riometer Array (MARIA)
Stations are shown by squares.

II Bistatic Auroral Radar System (BARS)
Twin auroral radar to measure Doppler shifted drift velocities with a 20 km spatial resolution within the area shown on Fig. 1.

III Meridian Photometer Array (MPA)
Array of photometers measuring meridian profiles in the 5577Å, 6300Å and 4709Å and H-β emissions. The stations are indicated by solid circles on Fig. 1.

IV All-sky imager (ASI)
A CCD imager providing both high resolution monochromatic optical images of aurora and optical intensities corresponding to the BARS radar cells in 5577Å, 6300Å and 4278Å emissions. The field of view is indicated by the large circle centred on Gillam (GI) on Fig. 1.

V Data Collection System (DCS)
An ANIK-based satellite telemetry data collection system making possible the automatic operation of the CANOPUS stations and quasi-real time collection of the data.

VI Data Analysis Network (DAN)
A computer network to carry out quasi-real time processing of the data so as to make it available to the science teams both of CANOPUS and the space programs of which CANOPUS is a part. In particular DAN will link the major centres of space research in Canadian universities to the Ottawa data centre.

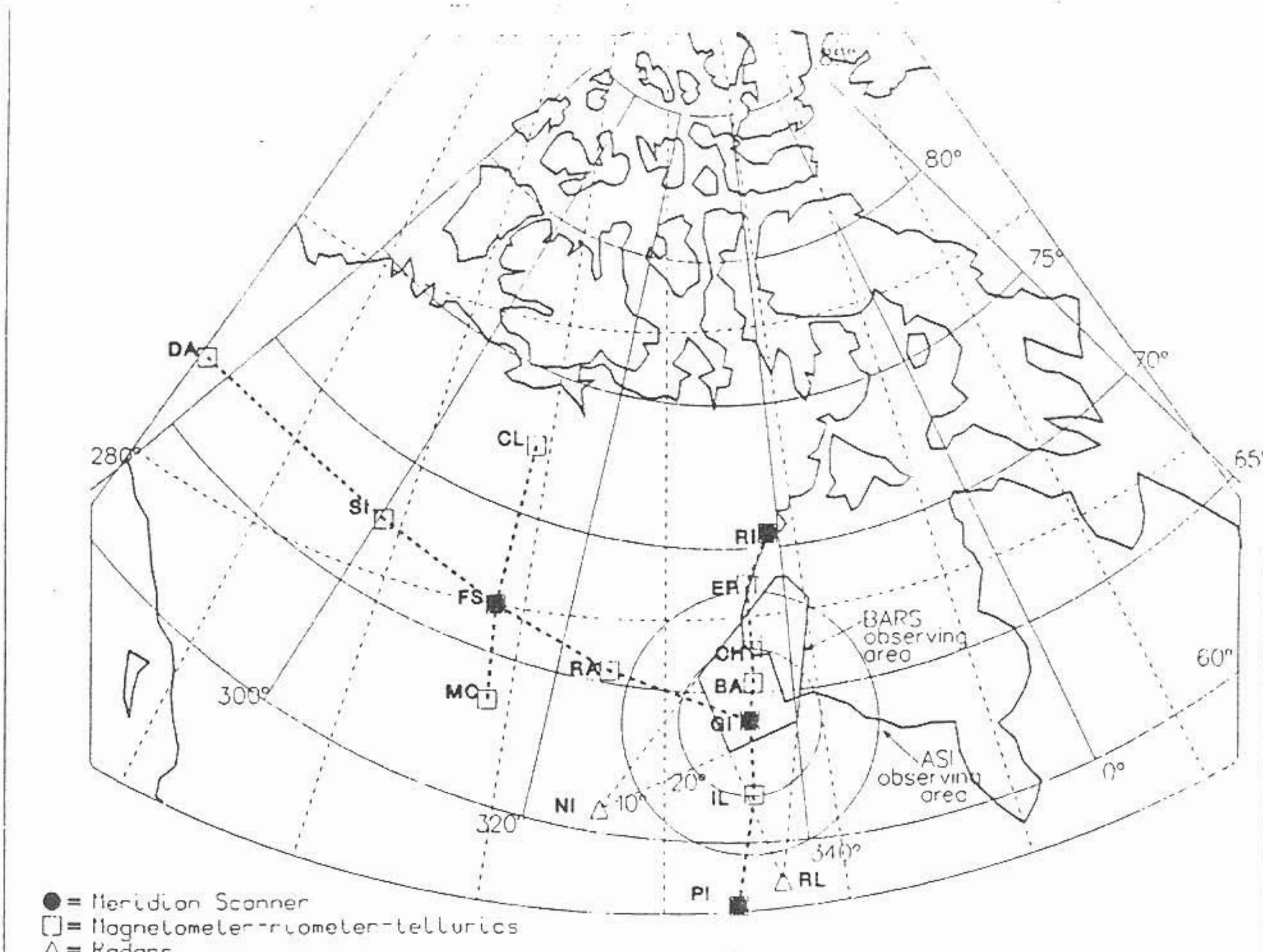
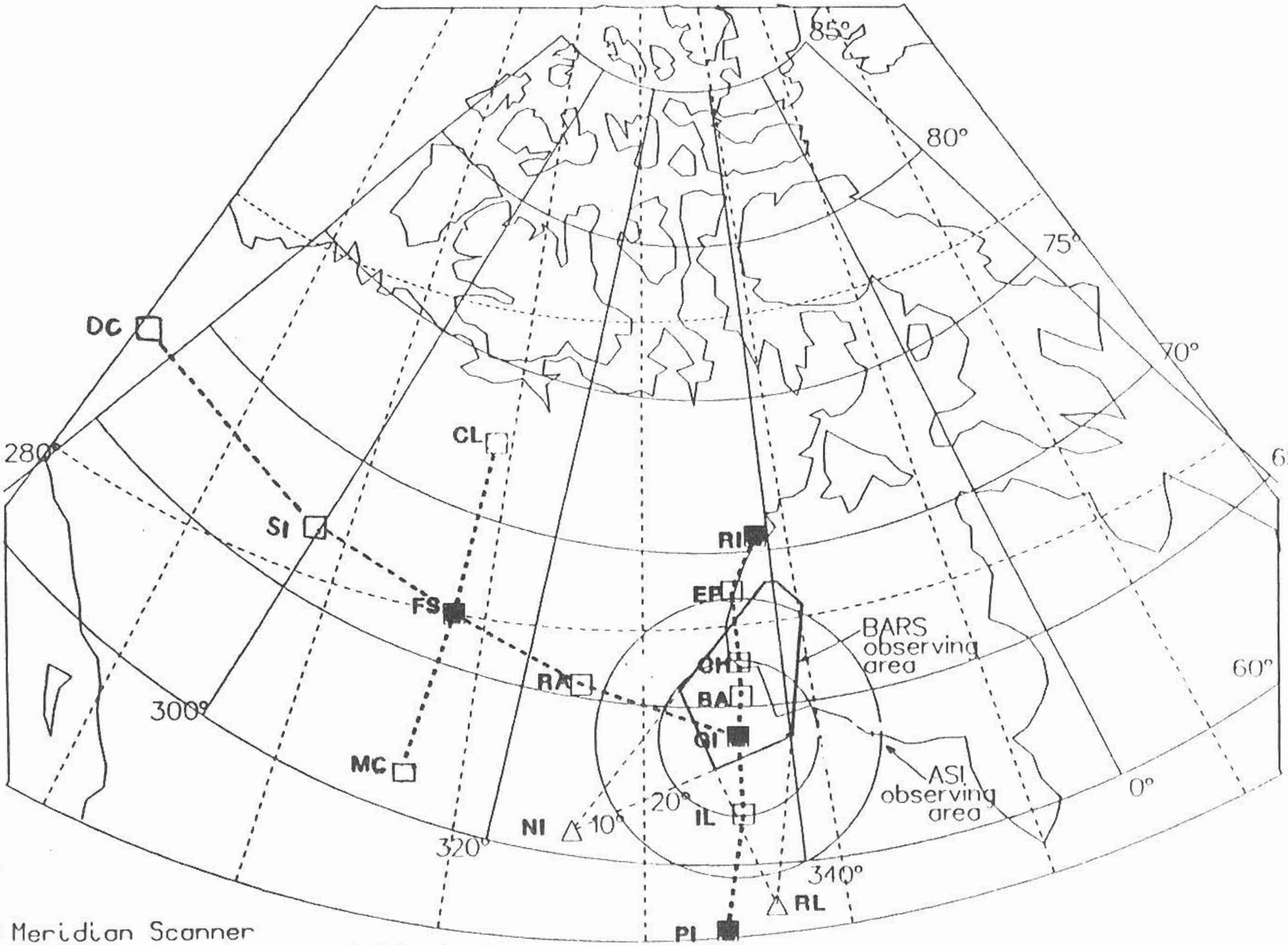


Figure 3.1

Table 1 CANOPUS Stations

MAP ID	Station	Geographic Coordinates Lat.		Long.		Geomagnetic Latitude EDFL	INV	Site * Instruments
DA	Dawson City	64	04	139	25	67.30	65.62	M
SI	Fort Simpson	61	52	121	23	67.49	67.61	M
CL	Contwoyto L.	65	45	111	14	72.46	73.62	M
FS	Fort Smith	60	01	111	58	66.59	67.96	M,P
MC	Fort McMurray	56	44	111	23	63.29	64.79	M
RA	Rabbit L.	58	12	103	40	65.31	67.67	M
RI	Rankin Inlet	62	49	92	07	70.38	73.54	M,P
EP	Eskimo Point	61	06	94	03	68.63	71.77	M
CH	Churchill	58	44	94	06	66.31	69.57	M,I
BA	Back	57	40	94	04	65.18	68.49	M
GI	Gillam	56	22	94	42	63.87	67.18	M,P,I
IL	Island L.	53	51	94	40	61.38	64.73	M
PI	Pinawa	50	09	95	53	57.68	60.95	M,P
NI	Nipiwan	53	25	104	02	60.51	62.90	R
RL	Red L.	50	54	93	28	58.51	61.98	R

*M = Magnetometer, riometer, tellurics (MARIA)
P = Meridian scanning photometer (MPA)
I = All Sky Imager (ASI)
R = Bistatic Auroral Radar (BARS)



● = Meridian Scanner
□ = Magnetometer-riometer-tellurics
△ = Radars

Figure 1 CANOPUS System Map

1. BACKGROUND AND SCIENTIFIC OBJECTIVES

1.1 Introduction

A number of programs, culminating in the proposed International Solar Terrestrial Physics program are scheduled to provide comprehensive studies of magnetospheric processes over the next seven years. For certain important phenomena related to these processes, ground-based observations are essential or complementary. Thus the effects of plasma arriving from the sun will first be monitored in interplanetary space. Next the effects will be followed at the magnetopause, in the cleft region, then in the equatorial plane and deep within the tail. Finally, substorms and other disturbances arising directly or indirectly from the energy carried into the magnetosphere from the solar plasma will be followed in as comprehensive a manner as possible. The ground-based instruments of CANOPUS will make low altitude observations of the ultimate phase of the process which involves the dissipation of energy in the ionosphere by particle precipitation and by the flow of electric currents.

For the ISTP study CANOPUS will provide a very extensive array of magnetometers from which the gross features of the ionospheric current patterns in high latitude regions may be inferred. On a more spatially limited scale, the CANOPUS/BARS radar system will give two-dimensional maps of the horizontal electric field system in the ionosphere near the centre of the magnetometer array. Finally systematic optical observations of the aurora will provide information on incoming particle energy fluxes. The optical observations will be supplemented by riometers which provide a simple and continuous indication of the precipitation of higher energy particles.

This system has been designed and developed using internationally recognized Canadian expertise in the instrumentation employed. The same expertise will be invaluable in the interpretation of the observations.

1.2 Historical Background

For many years, ground instruments including photometers, magnetometers, riometers and all-sky cameras have been used to diagnose the state of ionospheric activity. The history of these studies has been discussed in detail by Vallance Jones (1974). Here we make only a few illustrative references to an endeavour to which a large number of scientists have contributed. The capabilities of ground-based studies were often limited because the observing sites were scattered geographically in a fashion dictated by the presence of centres of population rather than by the nature of the scientific problems which were being addressed. In recent times, coordinated array studies using magnetometers (e.g. Kisabeth and Rostoker, 1971; Bannister and Gough, 1977; Baumjohann et al., 1978; Ahn et al. 1984) have demonstrated an ability to determine both the extent of the auroral oval through the identification of its poleward and equatorward boundaries and the intensity of the three-dimensional current systems flowing in the ionosphere and along field-lines penetrating the oval. The capability of riometer arrays (Berkey et al. 1974; Olson et al. (1980) to monitor the spatial and temporal variations of high energy electron precipitation and the success of scanning photometer arrays in following auroral variations (Vallance Jones et al. 1982) has further demonstrated the value of arrays of ground-based detectors in providing a quantitative evaluation of the dynamics of the auroral oval.

Auroral radars have similarly been used for many years (since the late 1940's in Canada) to study ionospheric activity. The earlier work was mostly concerned with understanding the physics of the radio aurora itself. However over the past ten years it has been demonstrated conclusively that Doppler measurements of radio aurora provide a powerful means of measuring the two-dimensional structure of the ionospheric electric field. The STARE system developed in Europe by R.A. Greenwald (Greenwald et al., 1978; Greenwald, 1983) has been successful in measuring electric fields (electron drift) in a 20 km by 20 km grid covering a large area of the ionosphere (ca. 160,000 km^2). This system is proving to be an important contributor to contemporary ionosphere-magnetosphere research (Sofko et al., 1985; Allan and Poulter, 1984).

Systematic ground-based optical observations of the aurora have historically been very productive. The first really comprehensive studies date from the IGY of 1957-58 when three newly developed techniques were first employed on a large scale. These techniques, which at that time were not all equally successful, remain the basis of modern ground based optical methods. The three techniques are:

i) all-sky cameras (ASC) to photograph the sky with an 180° field of view,

ii) meridan spectrographs which form an 180° image of a meridian strip of the sky on the spectrograph slit and form a spectrum in the orthogonal direction, and,

iii) photoelectric interference filter photometers which obtain meridian profiles in one or more wavelengths by means of a mechanical scan.

In practice, the IGY ASC's were brilliantly successful and it was the analysis of the data they produced that enabled Akasofu (1963) to formulate the first comprehensive model of the development of the auroral substorm. The IGY program showed the power of a continuously operating and extensive network of ground stations to follow the overall development of aurora and to give the first important information as the the processes which must be occurring in the magnetosphere along the field lines connecting to the auroral oval. The immediate success of the ASC is largely due to the simplicity of the technique and the comparitive cheapness of the cameras.

For quantitative studies the ASC is not very satisfactory. However the meridian spectrographs used in the IGY were more successful because contributions from diffuse auroral emissions can be clearly distinguished from contamination due to moonlight and artificial lights. Moreover these instruments were provided with intensity calibration systems. With the help of such data, Sandford (1964, 1968) recognized the existence of the diffuse aurora which he called "mantle aurora". Subsequent to the IGY, meridian chains of these instruments have been used to study the proton aurora and its relationship to the electron aurora both statistically (Wiens and Vallance Jones, 1969) and during substorms (Montbriand, 1971). The meridian scanning photometer is a more recently perfected and numerically accurate instrument for meridian line studies (Romick and Belon, 1967; Vallance Jones et al, 1982).

In the past, the deployment of arrays of these instruments has been severely limited with regard to one or more of the factors of geographical coverage, duration of operation, accessibility of the data and completeness of the set of instruments. As will be illustrated below, there is great scientific merit in the systematic deployment of, and exploitation of the data produced by a complementary set of instruments.

1.3 Scientific Objectives of CANOPUS and role in relation to present and future space projects

A series of space projects will be carried out in the next seven years to make comprehensive studies of the fundamental physics of the sun-earth system. These range from observations of the sun from space, of the solar wind in interplanetary space and of the earth's magnetosphere and upper and lower atmospheres. The most complete and ambitious of these studies will be the International Solar Terrestrial Physics Program which will involve up to eight spacecraft simultaneusly in orbit in a closely coordinated systematic study. Some of the projects with which CANOPUS can play an important role are listed in Table 1.

Table 1. Complementary Space Projects

Project	Launch data	Principal objectives
HILAT	In orbit	F-region observations Optical photometry or aurora Field and particle studies
VIKING	Nov. 1985	UV Auroral imaging and magnetospheric measurements from 2.3 R_e
POLAR BEAR	Oct. 1986	UV Imaging of Aurora F-layer observations from low polar orbit
EXOS-D	1989	UV/visible imaging, particles General magnetospheric studies from high elliptical orbit
UARS-D	1989	Middle and upper atmosphere composition, temperature, winds, aurora
ISTPP	1991-93	Comprehensive solar, interplanetary, magnetospheric observations including auroral imaging

In order for the data from these spacecraft in these programs to be fully exploited it is of importance to have a quantitative measure of the level of activity on field lines intersecting the various satellites and independent estimates of the times of onsets and development signatures of many magnetospheric phenomena (e.g. substorms, pulsations).

This need will be satisfied, in part at least, by the ground-based CANOPUS system which will be an additional contributor to these data bases. The value of CANOPUS arises from the possibility of coordinating its data with those acquired by various spacecraft instruments for collaborative studies of magnetosphere-ionosphere phenomena. We will refer to such studies as experiments. Many experiments will, no doubt, be conceived throughout the coming years. Several illustrative examples are presented below. In addition, CANOPUS data will be routinely analysed to obtain parameters characterizing the state of the magnetosphere and the ionosphere and the interaction between them. These analyses are briefly described in the following sections.

1.3.1 Magnetospheric Substorm Morphology

Collaborative studies of magnetospheric substorms constitute one set of experiments. The interrelation of proton precipitation, electron precipitation, substorm electrojets, Birkeland currents and electric fields needs to be fully determined. Here the ground magnetometer array can provide accurate substorm onset times and data on ionospheric-magnetospheric current systems in the region of the ground array. By combining these with data from other magnetometer chains estimates of the global current systems can be obtained (Ahn et al. 1984). The riometer and photometer arrays will monitor the temporal and spatial properties of particle input. The imagers in spacecraft such as VIKING, EXOS-D and ISTP-POLAR will provide overviews of the spatial and temporal behaviour of the visual aurora. Low orbit or polar satellites near perigee will also be able to measure characteristics of field-aligned currents, electric fields and particle flows. This resolution of substorm sequence details should be possible including energy flows and the interrelationship of various phenomena. With data provided by such satellites, more accurate knowledge of the overall spatial and temporal sequence of events which comprise the magnetospheric substorm should be forthcoming. Also this multi-instrument dataset may provide information regarding the mapping of distended field lines to earth during various substorm phases.

1.3.2 Relation of Field-Aligned Currents to Auroral Forms

We well also attempt to carry out more detailed studies of local field-aligned and horizontal currents in vertical planes through the ionosphere beneath the satellite track in regions of auroral activity. Photometric, imager, riometer and, on appropriate passes, particle observations, will permit the construction of conductivity profiles will then permit detailed current flow patterns to be deduced and Joule heating to be computed and compared to energy input via energetic particles. The effect of field-aligned electric fields the overall energy balance can also be sought. On a broader scale, for suitable polar satellite passes, the integral of the electric field across the oval can be determined and compared with other results to yield analyses of convection properties.

1.3.3 Latitude Characteristics of Pc 3, 4 and 5 pulsations

One possible set of experiments involves collaborative studies of Pc 3, 4 and 5 pulsations which occur on field lines traversed by various spacecraft. For events where one of these spacecraft traverses appropriate field lines, one can compare particle, magnetic and electric field data with ground acquired riometer, magnetometer and auroral radar data. The time sequence of both ground magnetic and ionospheric electric field latitude profiles can be related to their satellite time sequence counterparts. The satellite particle data can be compared with CANOPUS photometer and riometer data to study wave particle interactions. The east-west pulsation phase dependence will be monitored by the magnetometer-riometer array and at times by the BARS radar system. Measurement of this phase dependence, which has been observed for Pc 4 and 5 pulsations (Hughes et al., 1978; Olson and Rostoker, 1978), will be necessary for these studies.

1.3.4 Pulsations and Magnetospheric Boundary Effects

Studies will also be possible concerning the origin of pulsation activity. From multiple magnetopause crossings experienced by spacecraft which have orbits out to and beyond the magnetopause, it is clear that the boundary can be in oscillation, and such oscillations have been clearly related to geomagnetic pulsations on field lines well inside the magnetopause. By combining

a) the ground array to monitor pulsations in the magnetic field, the energetic particle precipition (as monitored by photometers and riometers) and the ionospheric electric field (as monitored by BARS), and

b) satellite observations on appropriate occasions, of the magnetopause position together with satellite polar cap imaging of auroral intensity fluctuations,

the relationship between magnetospheric boundary movement and pulsations should be resolved. Since pulsations occur during recoveries from enhanced levels of magnetospheric activity (Lam and Rostoker, 1978), these investigations are relevant to the determination of the overall geospace energy flow.

1.3.5 Cleft Region Studies

CANOPUS is not well situated for cleft studies since the cleft is only marginally dark at Canadian longitudes and then only for a short time at winter solstice, while the central part of the array including BARS is well equatorward of normal cleft latitudes. Because of the continuous mode of operation there may be times when such observations are possible, that is, for rare great magnetic storms (e.g. Potemra et al. 1978). Another possibility is to make use of cooperative observations in collaboration with campaign observations at Spitzbergen which is well situated to observe the cleft at winter solstice when CANOPUS would be well located for observations of simultaneous events near the midnight sector.

1.3.6 Substorm Mechanism Studies

The ground array will also provide data for one of the most important of magnetospheric probles, namely the definition of the temporal sequence of events in which changes in the interplanetary medium (monitored by spacecraft such as the proposed ISTPP WIND or ESA SOHO) lead to changes in mantle parameters monitored by high polar orbiters, followed by changes in the plasma sheet and tail lobes monitored by spacecraft in the tail of the magnetosphere and finally to auroral oval activity as monitored by the ground array. This array by virtue of accurate timing and quantitative measurement of changes in the magnetosphere-ionosphere system, will play an integral role in unravelling the secret of the nature of the solar-terrestrial interaction.

1.3.7 Other Studies

The connecting thread in the above discussions is that the CANOPUS system can stand on an equal footing with instruments on spacecraft in the sense that it will provide continuously available archived data in a form compatible with spacecraft operations and data processing and distribution. Certainly other joint experiments will suggest themselves as magnetospheric research progresses in the next decade.

1.3.8 Background Data

In addition to the above, CANOPUS data will be routinely analyzed to provide parameters characterizing magnetosphere-ionosphere interactions. These data will also be useful for calibration purposes. A short discussion of these contributions follows.

i) Oval current models

The magnetometer array will provide data on the strength and boundaries of the auroral electrojets. When the western stations of the array are in operation further information will be available. For the ISTPP period more comprehensive information on polar cap currents systems should be derivable from CANOPUS data especially if information from other magnetometer chains becomes available.

ii) AE-type Indices

For those researchers who do not require detailed information on polar cap currents, the full array would be able to supply a sophisticated AU and/or AL index for the North American sector. This would differ from the present AE (AU and AL) indices in that it would utilize forward models and H and Z component information to produce an estimate of the peak H-component disturbance at various local times across North America. The index would then represent a much more accurate measure of auroral activity in the North American sector than is presently available from the existing AE index (which is derived from H-component information only).

iii) Substorm onset times

Identification of the onset times of substorms and decreases in the level of magnetospheric activity is of major importance to researchers who are interested in studying the development and disturbances triggered by solar wind "events". The pulsation detectors developed by Samson and Olson (1980) (see also Samson and Rostoker, 1983) are capable of identifying Pi 2 onsets (associated with substorms) even when the observing station is up to two time zones away from the disturbance region. They are also capable of identifying the onsets of bursts of morning sector Pc 4, 5 activity which typically accompany the relaxation of the magnetosphere from a previously disturbed state. In addition, but under more geographically contained applications, other components of CANOPUS will contribute to onset time determination. Thus the photometers and riometers can sense soft and hard particle onset times, respectively while at the centre of the array, BARS can provide onset times from electric fields which arise from the same hydromagnetic (Alfvén) waves which produce the Pi 2 and Pc pulsations.

iv) Calibration of spacecraft instruments

The ground photometer array will provide both a performance check and an important calibration tool for spacecraft imagers. The absolute sensitivity of visible imagers can be monitored while for UV imaging the absolute brightness of auroral features will be available.

2. DESCRIPTION OF CANOPUS INSTRUMENTS AND OBSERVATIONS

2.1 Magnetometer and Riometer Array (MARIA)

2.1.1 Concept

MARIA will ultimately as indicated in Figure 1 consist of an array of 12 magnetometers and riometers. The station locations are indicated in Table 2. As well, at each MARIA location, it is proposed that telluric (i.e., induced earth currents) measurements will be made. In the early stage of operation, MARIA will consist of seven stations located approximately along a geomagnetic meridian running through Churchill, Manitoba (336.6° EDFL* longitude), and extending from Rankin Inlet (70.4° EDFL latitude, 339.0° EDFL longitude). At a later stage, it is planned that the line will be expanded to an array, consisting of an additional three stations located approximately 30° west of the Churchill line, and another two stations aligned longitudinally to give a roughly H-shaped configuration.

The purpose of the primary north-south magnetometer line is to permit identification of the poleward and equatorward boundaries of the electrojets in the local time sector in which the line is located. Data from this line will also permit the estimation of the electrojet current strengths in the same local time sector.

The western leg of the array, in combination with the east west observations, will permit crude determinations of some longitudinal variations as well as a crude estimate of the local inclination of the auroral oval with respect to lines of constant geomagnetic latitude.

The riometers located at each site will give information simultaneous with the magnetic data, concerning the spatial structure of cosmic noise absorption.

Finally, the earth-current measurements will permit refinement of electrojet models by providing information concerning the conductivity structure below the observation sites.

*See Appendix A for definition of EDFL coordinates; an EDFL magnetic coordinate grid is superimposed on Figure 1.

2.1.2 Method and Procedures

All MARIA instruments have been designed to sample the data streams at a rate of 8 Hz. Following appropriate digital filtering in the field, the data (3 components of magnetic field, 1 riometer measurement, 2 components of electric field) will be transmitted with a sampling rate of 1 set of data every 5 seconds to a central facility located in Ottawa. Here the data will be verified, and undergo processing to produce preliminary usable data within 5 minutes of the time of reception at the central facility. Both the unprocessed and processed data will be archived and available from disk for approximately 2 weeks. Subsequent data retrieval will be from magnetic tape. (See the section on Data Analysis Network for details).

Table 2

MAP ID	Station	Geographic Coordinates Lat(N)	Geographic Coordinates Long(W)	Geomagnetic** Latitude°N EDFL	Geomagnetic** Latitude°N INV	Site* Instruments
CL	Contwoyto Lake, NWT	65°45'	111°14'	72.46	73.62	M
FS	Fort Smith, NWT	60°01'	111°58'	66.59	67.96	M, P
ME	Meanook, Alta.	54°37'	113°20'	61.00	62.28	M
RA	Rabbit Lake, Sask.	58°12'	103°40'	65.31	67.67	M
DC	Dawson, Y.T.	64°04'	139°25'	67.32	65.67	M
RI	Rankin Inlet, NWT	62°49'	92°07'	70.38	73.54	M, P
.P	Eskimo Point, NWT	61°06'	94°04'	68.63	71.77	M
CH	Churchill, Man.	58°44'	94°04'	66.31	69.57	M
GI	Gillam, Man.	56°22'	94°42'	63.87	67.18	M, P, I
IL	Island lake, Man.	53°51'	94°40'	61.38	64.73	M
PI	Pinawa, Man.	50°09'	95°53'	57.68	60.95	M, P
NI	Nipawin, Sask.	53°25'	104.02'	60.51	62.90	R
RL	Red Lake, Ont.	50°54'	93°28'	58.51	61.98	R
BA	Back, Man.	57°40'	94°04'	65.18	68.49	M
SI	Fort Simpson, NWT	61°45'	121°14	67.40	67.52	M

*M = Magnetometer, riometer, tellurics (MARIA)
P = Meridan photometer (MPA)
I = All-sky imager (ASI)
R = Bistatic auroral radar (BARS)

**See Appendix A for discussion of magnetic coordinate systems.

2.1.3 Instrument Description

a) Magnetometers

Each station will be equipped with a 3-component fluxgate magnetometer of the ring-core type. Among the specifications met by these magnetometers are:

Resolution	±0.1 nT at 8 Hz
Range	0 to 100,000 nT for vertical component; ±50,000 nT for the horizontal components
Linearity	±0.1% of full range
Long Term Drift	Not more than 12 nT/week and 50 nT/month excluding platform tilt and ambient temperature components.
Power	20-28 V DC, 15 W dissipation.

The magnetometer platforms are equipped with two tilt meters, with a capability of detecting platform tilts of approximately 0.04°.

Data is sampled at a rate of 8 times/second, and filtered and decimated to a sample rate of one datum/5 seconds. However, the 8 Hz data is available through a "campaign" port.

b) Riometer

Each station will be equipped with one 30 MHz zenith riometer with a strung conductor antenna. These instruments are being supplied by La Jolla Sciences of Solana Beach, California.

2.1.4 Data Reduction and Analysis

The incoming data stream will be verified in terms of valid platform identifiers and cyclic redundancy checking. Data will then undergo preliminary processing which will involve, for example, rotation of the data from sensor coordinates into an appropriate magnetic coordinate system, if necessary; corrections for temperature variation; and corrections for platform tilt. As well, on a periodic basis, baselines for each component and each site will be determined. The riometer data will be corrected for quiet day variations, and converted to dB.

In addition to this, "key parameters" will be extracted from the data. These will be archived, and will be accessible through the data base management system of DAN. These will permit users to rapidly search the MARIA data and extract subsets of the data which are of specific interest to the user.

The key parameters are as follows:

1) Total westward (eastward) Hall current,

2) Central latitude of the westward (eastward) Hall current,

3) Width of the westward (eastward) Hall current,

4) Integral of the riometer absorption,

5) Value of the peak riometer absorption,

6) Location of the peak riometer absorption,

7) Wave phenomena parameterization, including the polarization in 8 frequency bands, and the latitude of the maximum of the polarization.

The electrojet parameters will be based on simple, but physically sound models, and will provide reasonable estimates of gross electrojet characteristics. The riometer integral will provide a measure of the 30 to 100 eV electron precipitation across the auroral oval. The polarization parameters will provide excellent estimates of micropulsation activity within the CANOPUS region.

2.2 Bistatic Auroral Radar System (BARS)

2.2.1 Concept

The system consists of two radars, one in central Saskatchewan (Nipawin) and the other in northwestern Ontario (Red Lake). The locations of these and other sites are given in Table 2. The multiple overlapping beams from the two radars define the viewing area which is shown in Fig. 2. Included within the viewing area are parallels of eccentric dipole latitude and several lines of constant L. This field is the focus of the other ground-based instrument arrays of CANOPUS.

Within the field of view, BARS provides a two-dimensional map, with resolution of ~20 × 20 km^2, of the Doppler velocity components in the plane of intersecting radar beams. These velocity components are a measure of the phase velocity of the plasma waves propagating along each radar k-vector and having a spatial Fourier component at half the radar wavelength. Such plasma waves are usually generated by the streaming of electrons relative to the ions in the auroral electrojet at heights of ~110 km. The Doppler velocities can be converted into estimates of the electric field; i.e., an electric field map can be created. The maximum possible north-south extent of this map is in excess of 650 km. At times, this 650 km will contain the bulk of the auroral oval flow. The BARS receiver systems have a dynamic range variable gain device which maximizes the degree to which scatter is obtained from the entire field. Thus BARS, along with the other CANOPUS instruments, will be able to provide a very good ground reference for comparison with flows deduced from VIKING, HILAT, POLAR BEAR and other satellite observations.

The electric field maps will aid studies of the dynamics of the auroral substorm, the Harang discontinuity, horizontal and field-aligned current systems, hydromagnetic resonances, magnetospheric convection and other phenomena. Since the ionosphere is a boundary of the magnetosphere, BARS (and CANOPUS) data will complement satellite data. In particular, correlative studies with ISTP satellite data will permit us to trace these phenomena throughout the magnetosphere and provide insight into the mechanisms of solar wind/magnetosphere/ionosphere/atmosphere coupling and associated energy flows and storage.

2.2.2 Method and Procedures

Complete data on amplitude and Doppler shifts (or, if desired, autocorrelation functions, etc.) are transmitted in real time to the DAN

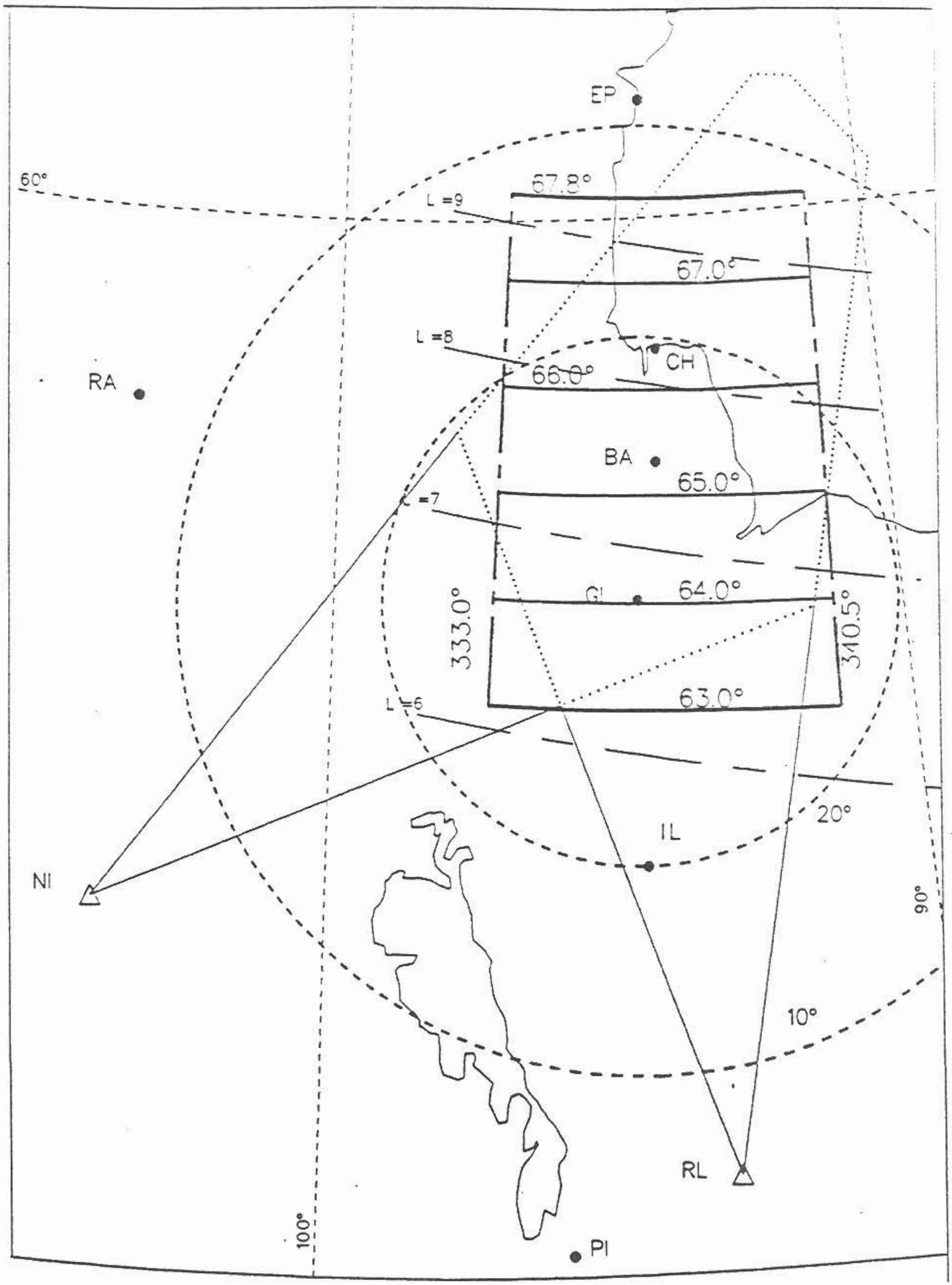


Figure 2. BARS viewing area and grid. The 16×25 cell data grid lies within the heavy solid lines for which the EDFL magnetic coordinates are indicated. The light dashed grid shows geographic coordinates.

facility in Ottawa where the electric field maps are computed. In normal operation, one set of signal amplitude and electric field maps are generated every 20 seconds. In addition, each radar contains a port to facilitate on-site recording of data on magnetic tape for special studies.

2.2.3 Instrument Description

The Canadian BARS is patterned after the STARE system pioneered by R.A. Greenwald, but it has some distinctive features. Canadian experience with auroral radars over many years has shown that 50 MHz auroral echoes are readily obtained at high latitudes and at relatively large off-perpendicular magnetic aspect angles (up to 20°). The location of the BARS viewing area over the eccentric dipole latitude range of 63.0°-68.9°(or L-value range of 6.2-10.7) results in aspect angles ranging over 4°-8° off-perpendicular. To enhance the effective scattering cross-section and to ensure a convertible drift velocity, BARS operates in the 50 MHz region. In other respects, the system design and specifications were scaled to match the STARE system. In addition to the mean Doppler shift, BARS is designed to be capable of full Doppler spectrum determination, when required, to yield maximum information on the scattering medium.

Antenna systems for BARS are designed to yield 16 fan beams with a beam seperation of 3.6°, from which eight beams are selected for processing. The combination of beam width and pulse width permits us to produce a 20 km electric field or velocity grid in the same manner as is done for STARE.

The radars normally transmit in alternating single and double pulse modes to generate maps of 400 echo and 400 drift velocities over the area of coverage. It is also possible to transmit a sequence of variably spaced double pulses to determine some or all of the 400 autocorrelation functions with up to 32 point resolution. These are Fourier transformed to yield Doppler spectra with a temporal resolution of the order of a minute. In addition it is possible to transmit, in appropriate circumstances, a sequence of coherent pulses so as to obtain Doppler spectra with greater resolution.

2.2.4 Data Reduction and Analysis

The Doppler data recorded at each radar site give a measure of the radial velocity components of the flow relative to that radar. When these data arrive at the Ottawa DAN facility, they are (1) archived and (2) after verification that both radars are operating in the proper mode and achievement of temporal alignment of the two data streams, the velocity components are merged to produce the vector drift velocities. This can be done either by assuming the fluid approximation or by using an algorithm developed from a calibration of the system. These drift velocity vectors can converted to an electric field map assuming $E = -v \times B$. The intensity maps are corrected for range and antenna pattern attenuation.

In addition, key parameters and summary data are extracted from the complete data set and archived. The purpose of these data is to permit a rapid search for interesting events. The key parameters, produced at five minute intervals, are:

1) The average over the map of the amplitude of the measured drift velocity vectors,

2) The number of map points with measured drift velocities,

3) The algebraic sum along a NS line of the EW drift velocity components to give a measure of the NS voltage drop, and

4) The algebraic sum along an EW line of the NS drift velocity components to give a measure of the EW voltage drop.

The summary data consists of the key parameters plus a meridian line of 25 values from the velocity vector (or electric field) map.

2.3 Meridian Photometer Array (MPA)

2.3.1 Concept

The array comprises six meridian scanning photometers. The locations are:

i) an eastern line close to the 337° EDFL meridian, with three instruments located at Rankin Inlet (70.4° EDFL), Gillam (63.9° EDFL) and Pinawa (57.7° EDFL), and

ii) a western line close to the 313° EDFL meridian, with three instruments located at Contwoyto Lake (72.5° EDFL), Fort Smith (66.6° EDFL), and Meanook (61.0° EDFL).

The geographic locations of the proposed stations are shown in Fig. 1. The station identification symbols and their geographic coordinates are given in Table 2. The locations coincide with magnetometer sites.

Each line of meridian instruments will permit complete overlapping coverage over the full range of latitudes from approximately 55 to 73° EDFL. This includes the whole range of latitudes where particle precipitation normally occurs, from the southernmost edge of the proton oval to the dayside cleft region in the north. The east-west extension will permit viewing the auroral oval at locations separated in local time by 1-2 hours.

For the support of the ISTP program, these instruments will be operated continously during dark hours, and will provide in quasi real time the absolute intensities of four selected emissions. This capability has several values:

1) to monitor particle input energy and characteristics,

2) to provide a cross section of the auroral oval at comparable resolution to that available from high orbit polar spacecraft (for selected periods, particularly during campaigns, much higher resolution could be otained in the campaign mode).

3) to permit comparison with spacecraft imagers, and

4) to give total auroral energy input data.

The photometer array will also provide basic support for more extensive programs conducted during campaigns, and for satellite studies of interesting events. It is recognized that this array does not include a good cleft station due to the presence of sunlight. Periodic campaign type observations are proposed from Spitzbergen to relate to the night-side observations of this array. The Spitzbergen location has two advantageous features - there is darkness through the noon period for about two months in the mid-winter, and it will permit dayside observations simultaneously with the night-side observations.

2.3.2 Method and Procedures

Each instrument will transmit the uncalibrated intensities of four auroral emissions (4709Å, 4861Å, 5577Å, 6300Å) along the N-S meridian at a rate of one scan per minute, with readings averaged over 0.5° latitude intervals. Two background intensities are also transmitted. There will be some preprocessing of the data to correct for gain nonlinearities.

The data will be stored in a buffer and transmitted to a central receiving station. Preliminary results will be available to investigators in the form of tabulated intensities in close to real time. Within twenty four hours final merged latitude plots of both electron and proton precipitation across the oval will be available.

3.3 Instrument Description

The photometer array will consist of meridian scanning eight-channel filterwheel photometers. Five of the eight channels measure auroral emissions (4709Å, 4861Å (twice), 5577Å and 6300Å). The three remaining channels measure background intensities to correct for contamination caused by blended auroral emissions, and scattered light of solar and/or lunar origin. The background channels measure near 4800Å, 4935Å and 6250Å. The instrument scans the meridian at two revolutions per minute with a sampling rate of 510 samples per scan per channel. Two scans are averaged over 0.5° latitude intervals into seventeen latitude bins centered on the station. With a field of view of 4° and an entrance pupil of 10 cm, the sensitivity is about 25 counts per Rayleigh for each latitude bin.

The transmitted data consist of the four auroral emissions and two background channels giving a data rate of about 125 words per minute per instrument when housekeeping data are included. The housekeeping data include the instrument dark count, the response to a calibration source, and other instrument status parameters. A separate campaign port can provide high speed data readout from all channels fro specific experiments which require higher latitude or time resolution. The instruments are fully automatic, using a two-level dawn-dusk sensor for controlling the operating periods. The interference filters will be temperature controlled, and will be provided with backup power in case of power outages.

2.3.4 Data Reduction and Analysis

After initial corrections for nonlinearities, the data are compressed from eight to six channels by averaging the two 4861Å channels, and the two associated background channels. Then the data are sorted into the seventeen latitude bins before transmission to the central data analysis network. Final calibrations and background subtraction are performed in the mainframe where merged latitude plots for the two lines of stations are prepared for each of the four emissions using assumed emission altitudes.

Summary files are prepared to facilitate searching quickly through data sets. To a first approximation, snapshots of the following variables are recorded every five minutes:

1) header and status,

2) descriptors for data length and content, and

3) I(4851Å), I(5577Å) and I(6300Å) each degree of latitude for the eastern and western lines.

A number of key parameters are also computed and stored for later quick-search purposes:

1) station status and quality index,

2) average peak intensity over 5 min. period for each meridian for I(4709Å), I(4861Å), I(5577Å), and I(6300Å), and

3) intensity distribution index for each meridian.

2.4 All Sky Imager (ASI)

2.4.1 Concept

This instrument is intended to provide quantitative information on visible aurora, expecially over the observation region of the BARS radar. By obtaining 160° all-sky images at three wavelengths (4278Å, 5577Å, 6300Å), it is possible to estimate with high spatial resolution the energy input, and the approximate average energy, of the precipitating electrons. Moreover, the system will provide valuable pictorial information as to the morphology of the aurora within the observing region with much higher spatial resolution than that of the spacecraft imagers.

2.4.2 Method and Procedures

The instrument will be located near Gillam at the magnetometer-photometer site, to provide both easy access and good overlap with the BARS viewing area. The field of view will be at least 160°. Circles showing the edges of the field for 10° and 20° elevation angles are shown in Figures 1 and 2. Exposure times will be related to those of BARS, so as to produce one set of pictures for each BARS electric field map. Normally, the full-resolution images will be binned into BARS-mapped superpixels before transmission to the data analysis network. However, the ASI can also be remotely commanded to record or transmit limited numbers of full resolution images.

2.4.3 Instrument Description

The ASI is designed to perform two-dimensional narrow-band auroral imaging at 4278Å, 5577Å, and 6300Å. Wide-angle optics are used to image the scene on to a CCD array detector. The filterwheel and command and telemetry functions are controlled by a microprocessor, while readout of the CCD is controlled by a flexible Microprogrammable Control Unit (MCU). This subsystem is capable of selecting a portion of the array for readout. Exposure times are selected to enable full images to be read out every 5 secs, so then with a background channel included, a complete set of observations can be made every 20 seconds.

The instrument is designed for flexibility of operation. In the default mode it cycles through the filters every 20 secs, and transmits low resolution images. A campaign mode is also available where the imager is under control of a local operator; this is useful for acquiring high resolution images. Finally, a remote control mode is also available. In this case the imager can be commanded to change operating modes. For example, a single filter could be selected indefinitely, or full-resolution images could be recorded or transmitted at reduced repetition rates.

2.4.4 Data Reduction and Analysis

Image preprocessing will include non-uniformity and background corrections followed by compression to superpixels. After transmission to the central data analysis network final calibrations will be performed, and the data will be archived. Low resolution images will be available within 24 hours.

Summary files with the following entries will be prepared and archived for images acquired during each five minute interval:

1) header and status,

2) average intensity and standard deviation for each emission over the field of view,

3) overhead intensity for each emission,

4) ratios of I(6300)/I(4279) and I(5577)/I(4278) calculated from average intensity,

5) one-dimensional strip intensities.

In addition the following key parameters will be prepared and archived:

1) average image intensity for 4278Å over a 5 min. period,

2) number of clear cells, and

3) standard deviation of I(4278Å).

2.5 Campaign Observations

The CANOPUS instrumentation described above was designed to be run automatically with continuous data collected by telemetry. In this mode of operation, the quantity of data which can be transmitted and stored, limits temporal and spatial resolution. It was however recognized that at certain times there will be a need to acquire much higher resolution data over short periods. To this end most of the instruments have been designed with campaign ports through which data can be recorded locally by means of tape recorders or other systems brought into the field on an expeditionary basis. The types of data available in this way has been noted in the instrument descriptions above.

In addition to campaign recording of the basic instruments it is likely that it will be possible to deploy other instruments during campaign periods for specific cooperative experiments with space projects. The following instruments are likely to be available.

1) High resolution (1°) meridian scanning photometers,

2) Zenith photometers (up to 16 channels 10 Hz bandwidth),

3) ISIT TV cameras; narrow field or all-sky mode,

4) 0.5 m Ebert-Fastie spectrometers,

5) 35 mm film all-sky cameras.

The planning of campaign observations is clearly dependent on the involvement of CANOPUS science team members in specific investigations and also on the funding that is available to team members. Consequently it is not possible to state with assurance that campaign ground observations will be made on a regular basis.

2.6 Data Collection System (DCS)

2.6.1 General Description

Data will be transmitted from the CANOPUS stations by 14/12 GHz satellite telemetry. Remote earth terminals will be installed at each of the sites with links to a central earth terminal to be located at the NRCC facilities in Ottawa. Transmission will be one-way, with blocks of data transmitted according to a time schedule stored in the data platform at each station. Data received will be accepted by a front-end VAX 11/730 computer before local transmission to the DAN (see section 2.7). The data blocks will be approximately 500 bytes in length and will be transmitted roughly once every 2 to 3 minutes from the MARIA instruments and the Meridian Scanning Photometers and once every 10 to 20 secs from the BARS radar sites and the All-Sky Imager.

In principle this system will provide data from the CANOPUS stations ι quasi-real time. Status and housekeeping information from the instruments will also be transmitted so that problems with the equipment can be detected quickly and corrective measures taken.

2.7 Data Analysis Network DAN

DAN was conceived as a distributed data acquisition and analysis system which further would promote the scientific investigative process by permitting participating researchers to interact as though they were in the same room while remaining in their own laboratories. DAN was planned to permit CANOPUS researchers from across Canada to access data acquired from CANOPUS field instrumentation (e.g. BARS, MARIA) and to manipulate this data in a variety of ways. An important portion of DAN is the database management system component (ORACLE) allowing complete access to the data and data extracts (key parameters and summary data) with simple commands. ORACLE is used to catalog the data received and processed by DAN. Ultimately DAN will be interconnected to other scientific data networks, permitting international interactions. This note explores some of the facets of DAN, which is presently in the process of being implemented under contract.

DAN has been implemented initially with NRC owned processors located at the University of Western Ontario, the University of Saskatchewan and at NRC in Ottawa. These nodes have Digital Equipment Corporation VAX 11/750, VAX/780 processors respectively. The Ottawa node will also contain a VAX 11/730 processor to interface with the field instrumentation. Researchers at the ıversities of Alberta, Edmonton, the University of British Columbia, Vancouver, the University of Victoria and York University will interact remotely with the network. All communications are executed via the telephone company DATAPAC service. The University of Calgary, the University of Alberta and York University using other VAX computer facilities will become equal network partners in the near future. Other network nodes may be added as occasion demands.

Up to 40,000,000 bytes of data from CANOPUS field instrumentation will arrive daily in DAN. The data will be processed routinely, with high priority, to a level appropriate to the instrumentation and stored on disk. Subsequent processing under direct control of the instrument teams will further process the data to useful quantities. In either or both of these stages extracts of the data will be made to generate key parameters and data sumamries *for inclusion in the database. Subsequently, instrument teams or individual* researchers will be able to further process the data into whatever form is desired for investigative purposes. At appropriate stages all processed data will be archived. All archived data files will be cataloged under ORACLE. Researchers may access the summary/key parameters or the data itself at any archived stage for subsequent analysis. Colour graphics and hard copy are provided at each of the initial VAX nodes.

It is not possible to retain on-line, all of the data acquired by DAN and processed to the variety of levels envisaged. Raw data will be retained on-line for a few days until it has been processed to a higher form. A "finished" data product will be retained about two weeks. Archived data may be ɔught back on-line at any time in limited quantities. Additionally, instrument teams or individual researchers will be able to keep, in their own disk space allocation, data from a finite number of events for detailed analysis or for program development purposes.

An important facet of DAN is the common room environment (CRE). CRE is to be based upon standard DEC products (DECNET, mailboxes) and a subcontractor supplied product CADPAK. Together these should permit researchers to call up/generate plots of CANOPUS data or its extracts, point to features of these data, generate sketches, and to talk via typewritten comments and separate telephone link to other participating researchers. Part or all of these conversations can be saved for subsequent detailed study or as starting inputs for a subsequent discussions.

REFERENCES

Akasofu, S.-I., 1963, The dynamical morphology of the Aurora Polaris, J. Geophys. Res. 68, 1667.

Ahn, B.-H., Y. Kamide, and S.-I. Akasofu, 1984, Global Ionospheric Current Distributions during Substorms, J. Geophys. Res. 89, 1613.

Allan, W. and E.M. Poulter, 1984, The Spatial Structure of Different ULF pulsation type: a review of STARE radar results, Rev. Geophys. and Space Physics, 22, 85.

Bannister, J.R. and D.I. Gough, 1977, Development of a polar magnetic substorm: a two-dimensional magnetometer array study, Geophys. J. 51, 75.

Baumjohann, W., R.A. Greenwald and F. Küppers, 1978, Joint magnetometer array and radar backscatter observations of auroral currentsin northern Scandinavia, J. Geophys. 44, 373.

Berkey, F.T., V.M. Driatsky, K. Hendriksen, B. Hultquist, D.H. Jelly, T.I. Shchuka, A. Theander and J. Yliniemi, 1974, A synoptic investigation of particle precipitation dynamics for 60 substorms in IQSY (1964-65) and IASY (1969), Planet. Space Sci. 22, 255.

Greenwald, R.A., 1983, New Tools for Magnetospheric Research, Rev. Geophys. and Space Physics, 21, 434.

.eenwald, R.A., W. Weiss, E. Nielsen and N.R. Thomson, 1978, STARE: A new radar auroral backscatter experiment in northern Scandinavia, Radio Sci. 13, 1021.

Hughes, W.J., R.L. McPherron and J.N. Barfield, 1978, Geomagnetic pulsations observed simultaneously on three geostationary satellites, J. Geophys. Res. 83, 1109.

Kisabeth, J.L. and G. Rostoker, 1971, Development of the polar electrojet during polar magnetic substorms, J. Geophys. Res. 76, 6815.

Lam, H.L. and G. Rostoker, 1978, The relationship of Pc 5 micropulsation activity in the morning sector to auroral westward electrojet, Planet. Space Sci. 26, 473.

Montbriand, L.E., 1971, The proton aurora and auroral substorm, in B.M. McCormac (ed.), The Radiating Atmosphere, D. Reidel Publishing Co., Dordrecht-Holland.

Olson, J.V. and G. Rostoker, 1978, Longitudinal phase variation of Pc 4-5 micropulsations, J. Geophys. Res. 83, 2481.

Olson, J.V., G. Rostoker and G. Olchowy, 1980. A study of concurrent riometer and magnetometer variations in the Pc 4-5 pulsation band, J. Geophys. Res. 85, 1695.

Potemra, T.A., Boström C.O., Doering J.P. and Less J.S., 1978, Observations of low energy electrons from AE-C in the South polar cusp during the geomagnetic storm of September 21, 1977, Space Science Revs. 22, 659.

Romick, G.J. and A.E. Belon, 1967, The spatial variation of auroral liminosity - II determination of volume emission rate profiles, Planet. Space Sci. 15, 1695.

Samson, J.C. and J.V. Olson, 1980, Some comments on the descriptions of the polarization states of waves, Geophys. J.R. Astr. Soc. 61, 115.

Samson, J.C. and G. Rostoker, 1983, Polarization characteristics of Pi 2 pulsations and implications for their source mechanisms: influence of the westward travelling surge, Planet. Space Sci. 31, 435.

Sandford, B.P., 1964, Aurora and airglow intensity variations with time and magnetic activity at sourthern high latitudes, J. Atmos. Terrest. Phys. 26, 749.

Sandford, B.P. 1968, Variations of auroral emissions with time, magnetic activity and solar cycle, J. Atmos. Terrest. Phys. 30, 1921.

Sofko, G.J., Korth, A. and Kremser, G., 1985, The August 28, 1978 storm, 1. GEOS 2 Observations of the Initial Magnetopause crossings and STARE observations near the ionospheric convection reversal, J. Geophys. Res. 90, 1449.

Sofko, G.J., R.A. Greenwald, A. Korth and G. Kremser, 1979, STARE Ionospheric electron flows during August 28/78 GEOS-2 magnetopause crossing, in Magnetospheric Boundary Layers, B. Battrick ed., European Space Agency.

Vallance Jones, A., F. Creutzberg, R.L. Gattinger and F.R. Harris, 1982, Auroral Studies with a Chain of Meridian-Scanning Photometers. 1. Observations of Proton and Electron Aurora in Magnetospheric Substorms. Geophys. Res. 80, 553.

Vallance Jones, A., 1974, Aurora, Geophys. and Astrophys. Monographs, D. Reidel Publishing Co., Dordrecht-Holland.

Wiens, R.H. and Vallance Jones, A., 1969, Studies of auroral hydrogen emissions in west-central Canada. III Proton and electron auroral ovals, Can. J. Phys. 47, 1493.

APPENDIX A

ECCENTRIC DIPOLE FIELD LINE MAGNETIC COORDINATE SYSTEM

In view of the hope that CANOPUS will be used to generate geophysical data of wide interest for many years, the Science Team agreed to adopt a magnetic coordinate system which can be readily defined and updated. It was also desired to have a system for which forward and inverse transforms between geographical and magnetic coordinates could be performed easily with a reasonable precision (0.01°).

The eccentric dipole system (Cole 1963) has most of these properties. Some additional advantages can be obtained by using modified eccentric dipole coordinates similar to those described by Wallis et al. (1981). The system provides a way to define magnetic coordinates and to transform between magnetic and geographic coordinates. Magnetic time can also be defined and computed readily.

We propose to use this system, to which we shall refer as ECCENTRIC DIPOLE FIELD LINE (EDFL) coordinates, as the basic coordinate system within the CANOPUS project and database. EDFL coordinates are given for CANOPUS sites in Table 2. The geomagnetic grid on Figure 1 is also in EDFL coordinates.

For comparison we provide values of invariant latitude defined as $\cos^{-1}(L^{-\frac{1}{2}})$, for points in the CANOPUS system. Invariant latitudes have been widely used although there is no real evidence that they are particularly relevant to magnetospheric plasmas in the auroral energy range. However we ill not use invariant longitude and time since these quantities depend on arbitary choices in definition and calculation and cannot be easily updated to follow secular variations in the geomagnetic field.

A more detailed description of the proposed coordinate system follows.

Eccentric Dipole Field Line Coordinates

Eccentric dipole coordinates were introduced for the 1955.0 epoch magnetic field by Cole (1963) as a means of ordering auroral occurrence data (Bond and Jacka, 1962). In this system, the earth's field is approximated by a dipole displaced from the centre of the earth. This displaced dipole provides a better match to the real field (as represented by the best available higher order model) than the oft-used centred dipole approximation. The system as introduced by Cole is easy to employ, since it involves only a translation (to accomodate the displacement of the dipole) and a rotation to align the axis of the system with the dipole axis). Cole's definition was really intended only to define the magnetic coordinates for points on the surface of the earth. It is convenient however to use the magnetic coordinates, at some reference surface, also as labels for real field lines.

In deriving an updated version of the eccentric dipole coordinate system for use in ordering MAGSAT data, Wallis et al. (1981) noted that, as a result of the approximately 500 km displacement of the dipole from the earth's entre, a longitudinal asymmetry was introduced in the dipole latitudes computed at the earth's surface. Thus families of lines having rotational symmetry about the dipole do not lie at constant eccentric dipole latitude because of the variation of r, the distance from the displaced dipole, in the dipole field line equation $r = r_0 . \sin^2$ (dipolelat). Wallis et al. noted that this problem could be overcome if the dipole latitude label for a field line were computed at its intersection with a reference sphere centred on the dipole. In their original work they considered that it was sufficiently accurate to use the dipole field line equation to trace the field lines from points near the earth's surface to the reference sphere. However because Wallis et al. wished to be able to assign magnetic coordinates to field lines intersecting MAGSAT, they incorporated a numerical field line tracing feature (bases on an accurate field line model) into their coordinate system program.

This eccentric dipole coordinate system as originally proposed by Wallis et al., has proven to be viable for the ordering of magnetic perturbations caused by external currents.

In considering magnetic coordinate systems for use with the CANOPUS data, the responsible committee felt that the following criteria would be important.

1) Easy to compute.

2) Easily reversible - to facilitate intercomparison with other data sets. (The suggested closure was 0.1 degree of latitude, equivalent to 1 km spatially.)

3) Orthogonal - so that differentiation and integration of data could be easily performed.

4) Facilitate comparisons with numeric modelling results.

As a result of these criteria, the eccentric dipole system (but now including numerical field line tracing to the reference sphere for coordinate determination, even for points near the earth's surface, was adopted by the entire CANOPUS science team for use in the program. The team made this decision knowing that the proposed system had not been fully tested for its capability to order auroral data. It is suggested that it be tested against other magnetic coordinate systems as a part of the CANOPUS program. In this respect it is noted that close attention to the ordering of auroral data by various magnetic coordinate systems has been neglected in recent years and this may have led to erroneous conclusions. Magnetic local time is very sensitive to the coordinates used at high latitudes. Errors of up to three hours in magnetic time based on out-dated magnetic coordinates were noted during the NRC MAGSAT investigation. Coorected geomagnetic Coordinates are still in use today, even though they are based on a four decade old model of the geomagnetic field. Many researchers now employ canned software, the origin of which they no longer remember, for the presentation of their data. As a result the intercomparison of data is fraught with difficulties - because of the use of many different and often poorly specified coordinate systems in formal and informal publications.

The Eccentric Dipole Field Line Coordinate system is proposed for the following reasons:

1) The real geomagnetic field is varying. Since Vestine's model field (the basis of HAKURA's 1965 system) the displacement of the dipole from the centre of the earth has increased 25%. This variation indicates the need for an updated system.

2) There is no reason to believe that a more complicated system would be better. One could indeed select a magnetic coordinate system based on a more accurate model of the geomagnetic field than the eccentric dipole model proposed here (e.g. the 1980 corrected coordinate system described by Gustafsson, (1979 and private communication)) but there is no evidence that it would be superior in its ordering capabilities for auroral data. Magnetic coordinate systems based on the higher degree and order terms of the spherical harmonic expansion of the geomagnetic field, track the wiggles and distortions present in the field and therefore do not normally meet the second and third criteria above.

3) The proposed system provides for convenient direct and inverse transformations. Systems based on more accurate field models entail much heavier computations and generally are presented only as look-up tables in one direction so that backward computation is difficult.

The actual definition of the EDFL coordinates is quite simple. From the starting point of interest one traces along the geomagnetic field to a reference sphere centered on the displaced dipole. In this tracing process one uses a standard field line tracing algorithm and a reference geomagnetic field (the one chosen for CANOPUS is discussed below). The distance chosen for the reference sphere is arbitrary, and has been fixed at 6371.2 km. This value, which is equal to the mean radius of the earth, minimizes the distance between the reference sphere and the terrestrial surface. The intersection point on the sphere is then subjected to the eccentric dipole transformation exactly as described by Cole (1963) except for the use of a more recent field model. This transformation is merely a translation to an origin at the displaced dipole and a rotation to align the coordinate axes with the dipole direction. The objective of providing an altitude independent label is achieved with the field line tracing.

It was felt that only two geomagnetic field models were potential candidates for the epoch 1985. They were the IGRF 1980 model and the Goddard Space Flight Centre 9/90 model. In practice these models differ by an inconsequential degree in terms of the displacement and orientation of the dipole and consequently either would serve equally well. In considering the field line tracing of the EDFL coordinate system and the future requirement to map spacecraft trajectories on the CANOPUS coordinates, the GSFC9/80 model is probably superior to the IGRF 1980 model in that it includes terms of higher degree and order, is more heavily based on spacecraft measurements of the field, and has significantly better residuals. The comparisons were [illegible] for both models evaluated at epoch 1985.0.

REFERENCES

Bond, F.R. and Jacka, F., 1962, Distribution of auroras in the southern hemisphere. II: Nightly probability of overhead aurora. Australian J. Phys., 15, 261.

Cole, K.D., 1963, "Eccentric Dipole Coordinates", Aust. J. Phys., 16, 423.

Gustafsson, G., 1979, "A revised corrected geomagnetic coordinate system", Arkiv, for Geofysik 5, 595.

Gustafsson, G., Private Communication, "Corrected Geomagnetic Coordinates for Epoch 1980".

Hakura, Y., 1965, "Geomagnetic coordinates corrected for higher order spherical harmonic terms", Rep. Ionos. Space Res. Japan 19, 121.

Wallis, D.D., Burrows, J.R., Hughes, T.J., and Wilson M.D., 1981, "Presentation and analysis of external current effects", Geophs. Res. Lett. 9, 353.

APPENDIX B

CANOPUS SCIENCE TEAM

Name	Organization	Telephone
Principal Investigator		
A. Vallance Jones	Herzberg Institute of Astrophysics NRCC, Ottawa, Ontario, Canada K1A OR6 Telex 053-3715	613-990-0706
Co-Investigators		
A.G. McNamara (BARS Team Leader)	Herzberg Institute of Astrophysics NRCC, Ottawa, Ontario K1A OR6	613-990-0711
D.J. McEwen (Optics Team Leader)	University of Saskatchewan Saskatoon, Sask. S7N OWO	306-966-6440
J.C. Samson (MARIA Team)	University of Alberta Edmonton, Alberts T6G 2J1	403-432-3616
J.A.R. Koehle[illegible] (DAN [illegible]	[illegible]	[illegible]

L.L. Cogger (ASI)	University of Calgary Calgary, Alberta T2N 1N4	403-220-5386
F. Creutzberg	Herzberg Institute of Astrophysics NRCC, Ottawa, Ontario K1A 0R6	613-990-0700
P.A. Forsyth	University of Western Ontario London, Ontario N6A 3K7	519-679-2243
R.L. Gattinger	Herzberg Institute of Astrophysics NRCC, Ottawa, Ontario K1A 0R6	613-990-0707
J.C. Gupta	Earth Physics Branch Dept. Energy, Mines and Resources Ottawa, Ontario K1A 0Y3	613-996-5757
F.R. Harris	Herzberg Institute of Astrophysics NRCC, Ottawa, Ontario K1A 0R6	613-990-0714
R.E. Horita	University of Victoria Victoria, B.C. V8W 2Y2	604-721-7731
T.J. Hughes	Herzberg Institute of Astrophysics NRCC, Ottawa, Ontario K1A 0R6	613-990-0762
R.A. Koehler	York University Downsview, Ontario M3J 1P3	416-667-3843
J.W. MacDougall	University of Western Ontario London, Ontario N6A 3K7	519-679-2437
D.R. McDiarmid	Herzberg Institute of Astrophysics NRCC, Ottawa, Ontario K1A 0R6	613-990-0713
B.A. McIntosh	Herzberg Institute of Astrophysics NRCC, Ottawa, Ontario K1A 0R6	613-990-0704
D.R. Moorcroft	University of Western Ontario London, Ontario N6A 3K7	519-697-2274

R.L. Coles ~~E.R. Niblett~~	Geophysics Division ~~Earth Physics Branch~~ Dept. Energy, Mines and Resources Ottawa, Ontario K1A 0Y3	995-5457 613-~~992-0935~~
P. Prikryl	University of Saskatchewan Saskatoon, Sask. S7N 0W0	305-966-7447
G. Rostoker	University of Alberta Edmonton, Alberta T6G 2J1	403-432-3521
G.G. Shepherd	York Uuniversity Downsview, Ontario M3J 1P3	416-667-3221
G.J. Sofko	University of Saskatchewan Saskatoon, Sask. S7N 0W0	306-966-6444
J.K. Walker	Earth Physics Branch Dept. Energy, Mines and Resources Ottawa, Ontario K1A 0Y3	613-995-5545
D.D. Wallis	Herzberg Institute of Astrophysics NRCC, Ottawa, Ontario K1A 0R6	613-990-0749
T. Watanabe	University of British Columbia Vancouver, B.C. V6T 1W5	604-228-2774