Table of Contents

Executive Summary 3

1 Introduction 4

2 Status of Proposed Studies 5

2.1 Relocation to ISAS, University of Saskatchewan 5

2.2 F-layer Patches and the Convection Electric Field 6

2.2.1 Patch Signatures Study 6

2.2.2 Convection Inference Study 7

2.2.3 Cusp Processes and Patch Formation Study 8

2.3 Polar Cap Auroras and Magnetic Field Topology 9

2.3.1 Faint Arc Characteristics Study 9

2.3.2 Polar Auroras and Magnetospheric Topology Study 11

2.3.3 Polar Auroras as Storm Precursors Study 11

2.3.4 Single-Point Stereoscopy of Auroral Arcs 12

2.4 Neutral Atmosphere Dynamics 13

2.4.1 Polar Mesopause Wave Spectrum Study 13

2.4.2 Stratospheric Warmings Study 13

2.4.3 Stratospheric Disturbances Study 14

2.4.4 Wave Spectrum Evolution Study 14

3 Efforts to Obtain Additional Research Funding 15

3.1 NSERC Research Grant 15

3.2 NSERC Collaborative Special Project Grant 15

4 Efforts to Obtain Permanent Employment 15

4.1 University of Saskatchewan Bridging Appointment 15

4.2 Undergraduate Teaching at University of Saskatchewan 16

5 Concluding Remarks 17

6 Scientific Activity 17

6.1 Manuscripts (accepted and submitted) 17

6.2 Conference Presentations 17

6.3 Other Presentations 18

7 References 18

Executive Summary

A wide-ranging proposal spanning high-latitude ionospheric convection, magnetospheric topology, and neutral atmospheric dynamics at the polar mesopause was accepted by the Canadian Space Agency for support under the Canadian Network for Space Research Transition Funding programme. The Principal Investigator elected to move from the University of Calgary to the University of Saskatchewan in order to exploit the concentration of polar data there. This move entailed short-term disruptions of the research effort, and a delay in research progress until a suitable computing platform was obtained.

A case study of discrete F-region ionization patches on Dec. 8, 1993 showed that ionospheric convection velocities could be inferred from sequences of images of the atomic oxygen red line emission at 630.0 nm wavelength. The velocities agreed well with measurements from a nearby Canadian Advanced Digital Ionosonde (CADI). A strong correlation of zenith data from the two instruments suggests that red line brightness images may serve as a proxy for the F-region plasma distribution, which is highly nonuniform in patch events and more complex than can be resolved by the ionosonde. A fuller study of red line images and ionization profiles from the CADI is at an early stage.

Synthetic images of patch emission along a noon-midnight swath, created in the case study, revealed spatial variations indicative of the plasma-structuring processes presumably operative at the dayside. Fuller study of these processes is warranted, both by direct observations at the dayside and by patch observations at Eureka. A major step in this direction has been taken by a wide-ranging investigation led by Dr. Paul Prikryl, Communications Research Centre, in which the Principal Investigator collaborated. The investigation uncovered new connections between the solar wind and interplanetary magnetic field, processes on closed dayside magnetic field lines, and F-region patch formation. This investigation consitutes a valuable advance in the study of patch formation mechanisms, and addresses one of the objectives of the proposed contract research.

Early in the term of the contract the Principal Investigator discovered an apparently new phenomenon at high latitudes: the occurrence of "surfaces" of faint, diffuse aurora or airglow, emitting only 50 to 200 R of atomic oxygen red line. A preliminary study was made which identified several characteristics features connecting the diffuse emissions with the magnetosphere and the polar ionosphere. By virtue of the Principal Investigator's appointment as an Adjunct Professor in the Department of Physics and Engineering Physics, an application has been submitted to NSERC for funding to pursue this exciting new phenomenon.

Another new study was injected into the framework of the planned activities in order to collaborate with Dr. Israel Oznovich on a new technique for determining auroral heights from single ground stations alone. The technique is based on well-known characteristics of the auroral red line, and is especially valuable for observations in the polar cap where

rules of thumb applicable to the auroral zone do not always apply. A presentation at the Fall Meeting of the American Geophysical Union demonstrated the accuracy of the technique as applied to Polar Camera images from Eureka, when compared with simultaneous measurements from a satellite overflight.

In addition to these studies of ionospheric phenomena a collaborative effort has begun to develop an algorithm for interpreting Polar Camera images of OH emission from the mesopause region. This effort is a necessary precursor to the use of these data for the study of neutral atmospheric dynamics at and above the mesopause. The development of such an algorithm promises to be a greater challenge than was at first expected, and this has delayed progress on this class of studies, as have the delays mentioned in the first paragraph. These have also affected proposed studies related to polar patches and arcs. Further delay has resulted from the Principal Investigator's acceptance of undergraduate teaching responsibilities. However, this is seen as a necessary step toward possible permanent employment in the Department of Physics and Engineering Physics.

1 Introduction

This contract was let on the basis of a proposal to the Canadian Space Agency entitled "Spectral Imaging Diagnostics of the Mesosphere, Thermosphere, and Ionosphere at Very High Latitudes". The proposal set out a number of research studies to be undertaken by the Principal Investigator (P.I.), in collaboration with other national and international investigators. These studies were to take advantage of the unique data set provided by a highly sensitive all-sky camera dubbed the "Polar Camera" which was developed under the sponsorship of the Canadian Network for Space Research (CNSR).

Studies were proposed in three areas of interest to the Canadian Solar-Terrestrial Research (STR) programme: structure of the convection electric field in the center of the polar cap, as revealed by ground-based images of convecting plasma in the F-region of the polar ionosphere; topology of the high-latitude magnetic field, as revealed by the dynamics and evolution of polar auroral arcs; and remote sensing of the wave spectrum at the mesopause by imaging the OH emission distribution and temperature. In each area, a number of issues were identified that could be addressed effectively using data from the Polar Camera, together with complementary data sets from other ground-based experiments at Eureka and other polar sites, as well as satellite experiments and theoretical/computational models.

Schedules were defined for each of the proposed studies. These were intended to allow early progress in each of the areas that could guide the later work, or indeed suggest new directions of potentially greater value than those set out in the proposal.

In the following report I first discuss my move from the Institute for Space Research (ISR), University of Calgary, to the Institute of Space and Atmospheric Studies (ISAS), University of Saskatchewan, because of the effect of that move on my research. I then discuss the status of each of the studies proposed, as well as two additional studies

undertaken to exploit unique opportunities. I discuss my efforts to obtain additional funding to support the continued operation and maintenance of the Polar Camera, and my research. I discuss my efforts to obtain permanent employment, and to position myself to take advantage of future opportunities for employment within the University of Saskatchewan. I conclude with some remarks on the year that has passed and the work that lies ahead.

2 Status of Proposed Studies

In this part of the report I discuss the status of each of the studies that were to have begun before the date of this report. In §2.1 immediately following, however, I first discuss the reasons for my move from Calgary to Saskatoon, and the effects that move had on the work done subsequently.

2.1 Relocation to ISAS, University of Saskatchewan

ISAS was the headquarters for the CNSR Polar Environment Project, and data from nearly all of the experiments operated at the Eureka Polar Observatory are centrally archived there. In order to work most effectively on polar science I chose to move from ISR to ISAS, anticipating that this would be in the best interests of the proposed research, despite the inevitable short-term dislocations such a change would entail both before and after the move. The move took place at the end of July 1995, and after a two week period of settling my family in our new home I began work at ISAS in mid-August.

Through the kindness of Prof. L. L. Cogger, ISR, I had the loan of a PC equipped with hardware and software to enable access to Polar Camera data archived on 4mm DAT. This PC enabled me to work with data in limited quantities, and develop software for data analysis, as well as to make the changes necessary to enable the IDL data reduction software to interact smoothly with the PC's Windows operating system rather than the Unix environment in which the software was developed. Unfortunately, the PC's data storage capacity was too small to hold even one day of raw data, and its processor was too slow to keep up with the flow of data once the Polar Camera resumed observations for the winter at Eureka. For example, I was unable to assess properly the new data acquired at Eureka. I could not process raw data into calibrated intensity images, and could not map existing intensity images, read from archive tapes, to geographic or geomagnetic coordinates. Thus, it was obvious that a more suitable PC would be required.

I had foreseen this, however, and had rearranged my project budget and estimated the maximum amount I could safely divert from other priorities. Immediately on starting work at the University of Saskatchewan I solicited quotes from local, national, and international vendors for a suitable PC but found nothing within my budget. I considered other, less expensive options such as a slower processor or adding IDL and needed peripherals to an existing computer but found them unsuitable. I continued to search for a PC while pursuing my work as best I could with the resources available. It was not until

mid-November that a local vendor was found who could supply a suitably equipped, Canadian-made computer at a price consistent with my budget, and three weeks later before the computer was delivered and configured for use as intended. In summary, a delay of four months was experienced in acquiring computing resources adequate to the needs of the project, and this delay had a major impact on my productivity during the period.

2.2 F-layer patches and the convection electric field

A common phenomenon at Eureka, and throughout the polar cap, is the occurrence of discrete "patches" of plasma at F-region heights, separated by regions of much lower plasma density. These patches convect antisunward across the polar cap in response to the dawn-to-dusk magnetospheric electric field. The following studies address patch formation and evolution, and what they can tell us about the convection electric field.

2.2.1 Patch Signatures Study

This study was intended to address the question of the relation between the optical appearance of a patch, its ionosonde signature, and the mesoscale structure of the ionosphere. It was to take advantage of the joint measurements (by the Polar Camera and the Eureka Canadian Advanced Digital Ionosonde (CADI)) of patch optical emissions and their ionization distributions. A two-year study was proposed, beginning on July 1, 1995, with an interim report issued at midterm, and concluding with a refereed publication.

A manuscript (Steele and Cogger, 1996) comparing Polar Camera and Eureka CADI observations of an extended sequence of patches on December 8, 1993, was prepared for submission to Radio Science. The manuscript has been accepted and will appear in a special issue on the Second Peaceful Valley Workshop on Plasma Structuring. This workshop was held in June, 1994, and was jointly sponsored by the U.S. National Science Foundation (NSF) Coupling, Energetics, and Dynamics of Atmospheric Regions (CEDAR) program working group on High Latitude Plasma Structures (HLPS) and the Solar Terrestrial Energy Program (STEP) working group on Global Aspects of Plasma Structuring (GAPS).

The patch sequence of December 8, 1993 occurred during a period of strong southward interplanetary magnetic field (IMF), and high geomagnetic activity. Patches were observed at the center of the polar cap almost continuously for at least nine hours. The patch emissions were clearly imaged by the Polar Camera down to a threshold of less than 50 R at [OI] 630.0 nm (Figure 1), as well as at [OI] 557.7 nm for some of the brighter patches which stood out against the high E-region airglow background. Although the images were blurred slightly by the motion of the patches during the 60-s time exposures, the patch displacements between consecutive images could be measured quite accurately. From these displacements a record of the ionospheric convection velocity (speed and direction) at the geomagnetic pole was developed. These measurements compared very favourably with simultaneous data from the CADI at Eureka (Figure 2). Grant *et al*.

(1995) have shown that Resolute Bay CADI convection measurements are consistent with those from the SuperDARN radars.

The convection speeds inferred from optical patch motions depend linearly on the assumed height of optical emission. We took this as 250 km for all patches, although the CADI record of 4.012 MHz (2.0×10^5 cm^{-3} contour) virtual reflection heights showed minimum values at patch center ranging from 260 to 290 km. The optically-inferred convection speeds tended to exceed those measured by the CADI, and the excess was greatest for those patches with the minimum virtual reflection heights. This suggests that for these cases our assumed emission height of 250 km was in fact too high, and that a value approaching 225 km might be a better approximation. For all patches observed on this date, then, a discrepancy of roughly 40 km appears to exist between the best estimate for the peak optical emission height and the virtual reflection height at the 2.0×10^5 cm^{-3} density contour. This discrepancy should be assessed by calculations of group retardation for reasonable electron density profiles.

We observed that the virtual reflection heights during patch transits showed quite a clear anticorrelation with the 630.0 nm zenith brightness. The column-integrated zenith brightness reflects the height-integrated production of O(^{1}D) through charge exchange between O^+ and O_2 (the rate-limiting step), and subsequent dissociative excitation of the O_2^+ ion. At altitudes below about 300 km the subsequent quenching of the long-lived O(^{1}D) atom must be folded in as well. The major factor in determining the column brightness is the O^+ density (or approximately the electron density) below about 300 km where there is still sufficient O_2 to allow the charge-exchange reaction to produce O_2^+. On the other hand, the reflection height is related to the lowest height at which the required electron density (2.0×10^5 cm^{-3}) is found. A general anticorrelation between these two quantities therefore provides *prima facie* support for use of the column brightness as a proxy for the F-region plasma distribution. However, the specific relationship between the zenith brightness and the vertical ionization distribution revealed by ionograms should be investigated in order to put this interpretation of the optical data on a stronger footing. Modelling work by Sojka *et al*. (1994) suggests that a simplistic interpretation of the optical data can be misleading.

While the results presented in this manuscript are encouraging as to the prospects for comparing optical and radiowave signatures of patches, the larger-scale study envisaged in the proposal has not yet been undertaken. CADI data from February 1995 were provided to me by Prof. John MacDougall of the University of Western Ontario (U.W.O.), the CADI P.I., along with analysis software. However, for reasons discussed above in §2.1 no further progress has been made, and this study is behind schedule.

2.2.2 Convection Inference Study

Sequences of patch images such as those analyzed in the Dec. 8, 1993 event study show that patches, in addition to being translated by the convection electric field, sometimes

appear to rotate during their transit through the Polar Camera field of view. This may be taken as evidence of shear in the convection velocity field, caused by nonuniformity in the cross-polar cap electric field. Such nonuniformity is frequently observed by other techniques, including primarily satellite-borne ion drift meters. However, such techniques provide only a snapshot of the electric field distribution along a single slice through the polar cap, and are ill-suited to study of the time evolution of the field distribution. The SuperDARN experiment provides two-dimensional electric field maps at regular brief intervals, but cannot extend to the highest polar latitudes. Ionosonde data may be adaptable to infer convection shears, but are somewhat limited by signal-to-noise considerations. Therefore, it is important to use the high information density of optical images of patches to attempt to assess deviations from uniformity in the convective flow of the ionosphere. In this study it was proposed to do just that, not only with the Polar Camera images but also with images from other polar stations such as Qaanaaq, Sondre Stromfjord, and possibly Resolute Bay. Extended spatial coverage such as might be afforded by the larger net of stations could confirm and extend accurate measurements of flow variations, and/or provide correction for inaccurate ones.

This study was to begin on October 1, 1995 and to extend for two years, with an interim report at midterm and publication of the conclusions. Although little progress has been made beyond the apparent identification of shear in the Dec. 8, 1993 event, for the same reasons (see §2.1), I have received ion drift data from the SSIES experiment on the DMSP F8 satellite, which crossed the polar cap several times along the dawn-dusk meridian during the Dec. 8, 1993 event. These data will provide a point of comparison for the apparent convection shear inferred from the ground-based images.

2.2.3 Cusp Processes and Patch Formation Study

While there is consensus that processes on the dayside, probably in and near the auroral oval, control the structuring of plasma which ultimately appears as discrete patches within the polar cap, there are many views as to the key mechanism(s) by which this structuring is accomplished. Several studies have attempted to determine which mechanisms operate, but the picture is not yet clear. A by-product of the Dec. 8, 1993 event study was a montage view of the 630.0 nm emission distribution seen over Eureka for a period of 9 hours (Figure 3). This montage may be interpreted as a larger-scale view of the "tongue of ionization" that flows antisunward across the polar cap from its dayside point of entry.

I believe it would be useful to attempt to correlate the time history and spatial distribution of plasma in the tongue of ionization convecting over Eureka with a detailed time history of processes in and near the dayside cusp. These processes would include large-scale plasma convection as measured by SuperDARN and possibly the Millstone Hill and Sondre Stromfjord radars, magnetic disturbances as recorded by the extensive network of ground-based magnetometers throughout the Arctic, satellite measurements of particle precipitation and ion drift, especially near the cusp, and of course IMP-8 and/or WIND measurements of the IMF and solar wind, as it is believed that these ultimately initiate the processes that lead to plasma structuring.

A study of this type was to have begun on January 1, 1996, to run for two years with an interim report at midterm and a final publication. The study has been deferred owing to my teaching responsibility, and will not begin before May 1, 1996.

However, it should be noted that the P.I. has collaborated in a study of this type, led by Dr. Paul Prikryl of the Communications Research Centre, which examined a very wide range of observations and physical processes that took place on Dec. 2, 1993, just 6 days before the event studied by Steele and Cogger (1996). The study, which has been submitted to the *Journal of Geophysical Research*, identified a possible cause-effect relationship between, in turn, IMF B_y oscillations, Pc5 field line resonances on closed field lines equatorward of the cusp, pulsed magnetic reconnection on the magnetopause adjacent to the resonating L shells, flow channel events featuring strong horizontal electric fields that heated E-region electrons and F-region plasma, and subsequent detachment of patches into the polar cap. The study suggests that ionization associated with Pc5 bands drifting into the cusp contributed to the formation of polar patches.

2.3 Polar Cap Auroras and Magnetic Field Topology

A simple picture of polar arc electrodynamics is now fairly well established, in which arcs are caused by upward Birkeland currents along shears in the magnetospheric electric field where the **E** field divergence is negative. This picture suggests that arcs may serve as tracers of shear regions, fixing the earthward end of the magnetic field lines on which shear is occurring in the large-scale magnetospheric convection. The following studies pertain to this characteristic of polar arcs.

2.3.1 Faint Arc Characteristics Study

Polar arcs, first detected visually by Mawson in the Antarctic, have been observed to occur with increasing frequency as the minimum detectable brightness has been reduced by advances in instrumentation. The faintest arcs detected thus far have brightnesses of only tens of Rayleighs, and typically occur at significantly higher altitudes than those in the auroral zone. It is necessary to investigate how the characteristics of these faint arcs (occurrence frequency, brightness, altitude, extent, lifetime, motion, multiplicity) relate to those of brighter polar arcs, such as those observed by satellite imagers (DMSP, DE 1, Viking, Freja).

This study was to have begun on April 1, 1995 and conclude with a final report and submission of a manuscript for publication on March 31, 1996, i.e., at the end of this contract year. Early in the study period I decided to start another study in preference to this one, on a related but distinct phenomenon: diffusely emitting surfaces, possibly of auroral origin, that were observed frequently during the 1994-95 winter at Eureka. This study is described in the following paragraphs. As a result of this decision, and other circumstances described in §2.1, the planned study of faint arc characteristics has not been

undertaken. I still regard such a study as worthwhile, and intend to undertake one using Polar Camera data in the next year.

While reviewing the Polar Camera 630.0 nm images from the winter 1994-95, I observed 15 - 20 instances of what, to my knowledge, is a previously unreported phenomenon: diffusely emitting 'surfaces' that drifted toward and past the geomagnetic pole from the dawn or dusk sector of the polar cap (Figure 4). These emitting regions appeared to be associated with polar auroral arcs and yet distinct from them. I examined each case for which I had optical images, and acquired supporting data from the Eureka CADI, the Magnetic Fields Investigation and the Solar Wind Experiment on board the WIND satellite, and the SSJ/4 precipitating plasma sensor on board the DMSP satellites F10 - F12. With these data I was able to establish the following characteristics of the diffuse emission regions:

1. Emission was predominantly (if not exclusively) at 630.0 nm; no emission above background was detectable at 557.7 nm ([OI]) and 785 nm (N_2^+ Meinel (2,0) band). Typical brightness at 630.0 nm was 50 - 200 R, well below the detection threshold of most all-sky cameras.

2. Emission occurred on one side of a roughly linear and sun-aligned leading-edge boundary, that drifted toward or past the geomagnetic pole in the direction (in the Northern hemisphere) of the y component of the IMF.

3. Emission was associated with polar arcs and occurred during northward Bz conditions.

4. Ionospheric drifts as measured by CADI had a component in the same direction as the motion of the emission boundary.

5. The polar cap as defined by DMSP particle precipitation was strongly contracted in the dusk and dawn sectors, with oval precipitation extending up to 80° GM latitude.

6. Particle precipitation above the diffuse emission regions was very weak but showed slightly enhanced electron and ion fluxes.

I presented these findings in preliminary form at a Polar Science Workshop, held at Windermere Manor, U.W.O., on May 25-27, 1995. A fuller presentation, with supporting evidence in the form of a video presentation of an image sequence, was given at the XXI General Assembly of the International Union of Geodesy and Geophysics (IUGG) held at Boulder, CO, on July 2-14, 1995. A manuscript on the work in its current form is being prepared for submission to *Geophysical Research Letters*. I have also applied to NSERC for funding to expand this preliminary work to include other years of observations and other ground- and space-based data sets. The bulk of the requested funding is to support

a graduate student who will undertake the major task of drawing together the various data sets needed to give a full picture of the phenomenon.

2.3.2 Polar Auroras and Magnetospheric Topology Study

This study is intended to capitalize on the simultaneous operation of several sensitive all-sky imagers in the Arctic over the last few winters. As shown in Figure 5, imagers located at Eureka, Qaanaaq, Nord, Sondre Stromfjord, Resolute Bay, and Ny Alesund provided quite extensive coverage of the central polar cap, especially at magnetic local times near 2200 UT and 0200 UT (shown in Figure 5) when three or four imagers were roughly aligned along the noon-midnight meridian. The objective of the study is to assemble quasi-simultaneous images from multiple stations showing the large-scale morphology of polar arcs in relation to the auroral oval, in the hope that the polar cap boundary can be identified, and the source region(s) for the arc(s) can be determined, both from their location with respect to the closed field line boundary, and from precipitating particle characteristics and/or ion drift data when simultaneous DMSP or other satellite overflights occur.

This study was to commence July 1, 1995 and run for two years with an interim report midway and publication at the close of the study. It has been delayed, at first by preparations for shipping the Polar Camera to Eureka and moving myself and my family to Saskatoon, and subsequently by the lack of a large computer, as merged images such as that in Figure 5 require large amounts of computer memory to create. The study has not yet begun, and will not do so before May 1, 1996 when my teaching responsibilities are complete.

2.3.3 Polar Auroras as Storm Precursors Study

This study aims at investigating whether polar auroras may give early indication of the onset of major geomagnetic storms. There is evidence of such behaviour from two different storms that occurred during the CNSR observations at Eureka. The study was to begin October 1, 1995 and run for two years with a midterm report and final publication, along with a concluding report to industry. For reasons already discussed the project has not yet begun.

However, there is an opportunity for progress in this direction to be made within the scope of the U.S. National Science Foundation (NSF) CEDAR/GEM (Geospace Environment Modelling) study of Space Weather, which focuses on solar-terrestrial events during the first 10 days of November 1993. This study encompasses extensive observations from virtually every ground- and space-based observing system that was in operation during the period, and promises to advance our understanding of how solar disturbances, mediated by the solar wind and IMF, couple into the magnetosphere. I am planning to submit an abstract for a session on this study at the Spring AGU meeting in Baltimore, May 20-24, 1996.

2.3.4 Single-Point Stereoscopy of Auroral Arcs

This, together with the study described above of polar diffuse aurora, was undertaken as a "study of opportunity". On my arrival here at ISAS, my colleague Dr. Israel Oznovich invited me to collaborate with him on a study of the altitudes of auroral arcs observed optically from the ground at multiple visible wavelengths including 630.0 nm ($O(^1D)$). He had used model height profiles (Meier *et al.*, 1989) of 630.0 nm emission for 0.25 keV and 2 keV electron spectra to synthesize meridian scans through red line arcs for various zenith distances. His results showed that the zenith angle of peak column emission rate of the red line varied by less than 1.5° between arc widths of 5 and 50 km, and 0.25 and 2 keV characteristic electron energy. This behaviour made the red line emission peak a useful benchmark from which to estimate the emission peak of a lower- altitude emission on the same magnetic field line, such as $O(^1S)$ 557.7 nm, N_2^+ 1NG (0,1) 428 nm, or the related emission N_2^+ M (2,0) 785 nm. The peak emission height of the lower-altitude emission could be determined from the "known" height of the red line emission, and the observed angular separation of the red and green arcs along the meridian perpendicular to the arcs. Such estimates would be valuable, at minimum, for mapping imaged arcs to geographic or geomagnetic coordinates at the appropriate emission height, and could aid in inferring the characteristic energy of the precipitating particles.

I agreed to collaborate with him, and provided examples of Polar Camera data from both Rabbit Lake, in the auroral zone, and Eureka in the polar cap. We decided to begin with Eureka, since the field lines so near the pole are essentially vertical and the arc geometry is therefore simpler. We examined a case from October 23, 1993 (Figure 6), when two arcs traversed the sky at Eureka within 20 min of each other, and were both overflown within the Polar Camera field of view by the DMSP F8 satellite which measured the precipitating particle fluxes. Although the arcs drifted from one horizon to the other, we identified intervals when they were essentially stationary and inferred peak 557.7 nm emission heights of 180 - 190 km, which were unusually high for the green line, although consistent with the predominantly red emission from the arc. DMSP F8 measured electron spectra peaking at 200 - 400 eV, consistent with the high emission altitude, and also gave a fix on the horizontal position of the arc where it overflew it. Comparing the zenith distance of the green arc as seen from Eureka with the arc coordinates yielded an emission height of 185 km, fully consistent with the altitude inferred from the angular distance between the red and green emissions. These results were presented at the 1995 Fall Meeting of the American Geophysical Union (AGU), held December 11-15, 1995 in San Francisco, CA.

This first test of the algorithm yielded very encouraging results on a challenging test case, where the angular distances were reduced by the high green line altitude. We plan to expand our test data base to further verify the value of the algorithm, and publish the results in a refereed journal, possibly the *Canadian Journal of Physics*.

2.4 Neutral Atmosphere Dynamics

Along with auroral emissions, the Polar Camera images two portions of the OH Meinel (6-2) band, which is emitted from the mesopause. The two portions of the band emission vary independently with the rotational temperature of the band, which reflects the ambient temperature at the mesopause. The two images, acquired simultaneously, should in principle allow the mesopause temperature to be inferred. This, together with the total band brightness inferred from the portions of the band sampled, should allow a measurement of Krassovsky's ratio, which has been shown by recent modelling to be a sensitive diagnostic of the particular mode of disturbance when waves are passing through the mesopause and perturbing both the ambient temperature and the column brightness of the OH emission layer. The following studies aim at using the OH image data to infer the dynamics of the mesopause as just described.

2.4.1 Polar Mesopause Wave Spectrum Study

This study was to develop the technique sketched above for the particular data acquired by the Polar Camera, and apply the results to a measurement of the wave spectrum at the mesopause above Eureka, both for particular cases and on a statistical basis. The success of the study is predicated on being able to derive the rotational temperature from the OH images. The analysis necessary to do this derivation had not been performed at the time this study was proposed, but it was assumed that it would be relatively straightforward. My efforts since that time have persuaded me that this view was naive.

The study was to begin April 1, 1995 and run for two years, much as those above. Although the study was late starting for reasons mentioned above, work has at last begun on interpreting the OH images, in collaboration with Prof. L. L. Cogger of the University of Calgary. It is difficult to predict how this analysis will turn out. It would therefore be pointless to attempt to predict the outcome of the study at this juncture. The same is true of the other studies listed below, which also depend on the interpretation of the OH images in terms of mesopause temperature.

2.4.2 Stratospheric Warmings Study

This study was intended to examine how the mesopause wave spectrum varies, if at all, when stratospheric warmings are in progress. These warmings are characteristic features of the Northern hemisphere winter, which reverse the meridional temperature gradient in the stratosphere and strongly perturb the high-latitude circulation. Inasmuch as gravity waves and other upward-propagating waves pass through the stratosphere on their way to the mesopause it is of interest to examine any changes that may appear in the characteristics of these waves during stratospheric warmings. Such changes would be important in their own right for their effect on the energy budget of the mesopause, and could also shed light on stratospheric warmings themselves.

This study was to begin on July 1, 1995 and run for one year. It has not yet begun, and as indicated above, projections as to its progress would be unjustifiable.

2.4.3 Stratospheric Disturbances Study

This study was intended to examine whether stratospheric disturbances (i.e., gravity waves, tides, planetary waves) observed at Eureka (e.g., by AES radiosondes and/or the Institute for Space and Terrestrial Science (ISTS) lidar at the Arctic Stratospheric Ozone (ASTRO) Laboratory) are subsequently observed at Eureka as airglow variations at the mesopause and above. Some stratospheric disturbances, particularly short-period gravity waves, are known to dissipate before reaching the mesopause, and others propagate largely horizontally. If a causal connection could be found between particular stratospheric and mesopause disturbances observed above Eureka, it would reveal an unusual and interesting mode of propagation worthy of close inspection.

This study was to begin October 1, 1995 and run for two years. It has not begun, and cannot be undertaken with Polar Camera images until the work described above in §2.4.1 has been successfully completed. However, since the study depends, first, on identifying intervals where both radiosonde/lidar and mesopause airglow data show disturbances that may be coupled, it should be possible to begin the study using airglow data from the other optical instruments at Eureka. Wave signatures in the data from these instruments are already understood, and the process of searching the data, while tedious, poses no new problems. Therefore, it may be possible to begin this study within the next few months, subject to availability of suitable radiosonde and lidar data.

2.4.4 Wave Spectrum Evolution Study

As mentioned in the previous section, not all wave disturbances initiated at low altitudes can propagate to the mesopause or beyond. Higher frequency disturbances produce increasingly steep temperature gradients as they move upward, becoming unstable and dissipating where the temperature gradient exceeds the local adiabatic lapse rate. Waves moving parallel to the wind velocity may cease to propagate if their horizontal wave number falls to zero. Similar processes operate at all altitudes and, in particular, at altitudes between the nominal emission altitudes of OH (~87 km), Na (~92 km), and [OI] (~97 km). Differences in the wave spectrum observed by means of these emissions reflect conditions through which the waves travelled at these altitudes, and constitute an important tool for remote sensing of this height region.

The study of these differences was to begin January 1, 1996, and to conclude December 31, 1996 with a refereed publication. The study has not yet begun, in part because of the status of the Polar Camera OH data, but chiefly because of my teaching responsibilities, as described below in §4.2. If necessary, this study could be undertaken using airglow data from only the other optical instruments at Eureka. Oznovich *et al*. (1995) have already found close agreement between observations at the three levels noted above, for 8-h disturbances having similarities to both inertio-gravity waves and non-migrating tides.

3 Efforts to Obtain Additional Research Funding

The terms of the CNSR Transition Funding contracts require "that every effort ... be made by the Principal Investigator/Project Scientist to obtain funding to maintain the facility from other sources". The following section details my efforts to fulfil this requirement.

3.1 NSERC Research Grant

Immediately upon deciding to move to the University of Saskatchewan I requested appointment as an Adjunct Professor in the Department of Physics and Engineering Physics, in order to be eligible to apply for an NSERC Research Grant. I was so appointed, and in October prepared an application for an individual research grant, entitled "Polar Diffuse Aurora and its Magnetospheric Implications". I requested a total of $119,100 over four years, with $43,850 earmarked for shipment of the Polar Camera, and its further development and maintenance. If this application is successful it will provide stable support for both the continued operation of the Polar Camera as a world-class research instrument, and the pursuit of new scientific directions indicated by its unique observations. The preparation of this application diverted about two weeks of my time from the conduct of the studies formally set out in the contract, but its success would more than justify the cost in time.

3.2 NSERC Collaborative Special Project Grant

An application for a Collaborative Special Project Grant for Polar Space Science was submitted in late May 1995, on which I was named as a co-investigator. This application would not have supported shipment or maintenance of the Polar Camera, but would have supported its operation at Eureka for the term of the grant. Unfortunately this application was rejected and the work at Eureka has gone on this winter on a shoe-string budget. I have been most fortunate to have funds available to support the operation of the Polar Camera.

4 Efforts to Obtain Permanent Employment

The CNSR Transition Funding contract also requires that "the individuals supported by these funds ... actively seek permanent employment during this transition phase." My efforts to fulfil this requirement are detailed in this section.

4.1 University of Saskatchewan Bridging Appointment

Early in 1995 a tenure-track position was announced in the Department of Physics and Engineering Physics at the University of Saskatchewan. The position was intended to bridge against the retirement in 1997 of Prof. D. J. McEwen. I applied for the position, with references from Prof. J. S. Murphree, Head-Elect of the Department of Physics and

Astronomy, University of Calgary, Prof. L. L. Cogger of the same department, Prof. J. J. Sojka, Head, Center for Atmospheric and Space Sciences, Utah State University, and Prof. D. J. McEwen. Unfortunately, I was not selected for the position, which went instead to Dr. A. Koustov, another CNSR Transition Funding awardee.

4.2 Undergraduate Teaching at University of Saskatchewan

When I applied for Adjunct status in the Department of Physics and Engineering Physics at the University of Saskatchewan, it was with the understanding that Adjunct Professors were expected to contribute to graduate training, and that this could take the form of lecturing where the individual concerned possessed specialist knowledge and skills that made him or her the best available instructor. The written regulations concerning Adjunct Professors made no mention of them being expected to share in the Department's work of undergraduate instruction. Therefore, it was with some surprise that I learned of the Department's "expectation" that I would be available for undergraduate teaching, without remuneration, of one 3-credit course per year.

I initially declined to teach, reasoning that the concomitant reduction in my research production would outweigh the personal gain in knowledge and experience that teaching would provide, and the political benefits that might accrue from obliging the Department. To my dismay, my decision and the reasons for it were not well received; rather, it was made clear that there would be a cost associated with such a decision. However, I subsequently enjoyed a conversation with Dr. D. Kendall of the Canadian Space Agency, in which I was assured that the CSA would regard teaching, in my circumstances, as consonant with the objectives of the contract. In further discussions with the Acting Head, I was told that other junior scientists in my position were most eager for a chance to teach, as they recognized that it was an important way to gain a foothold in a department. On the basis of the CSA's assurance, and the perceived benefit to my career aspirations of acceding to the Department's invitation, I reversed my earlier decision and agreed to teach a 3rd year course combining fluid mechanics and 3-dimensional rigid-body dynamics.

At that point (mid-November) there was relatively little time left for preparation, and I had never taken, much less taught, a course in fluid mechanics, so I began earnest preparation for the course. Apart from completing the presentation given at the AGU Fall Meeting, and configuring the new PC I had just acquired (see §2.1), I devoted much of my time to lecture preparation. Since the start of term, I have been able to start a collaboration on the OH image analysis with Prov. L. L. Cogger, and write reports, but the bulk of my time has been devoted to lecture preparation and associated duties. While this has had its frustrations, I have already realized one benefit: a significantly better understanding of fluid mechanics. I hope to apply this to research problems when the course has finished.

5 Concluding Remarks

My experiences over the past 11 months have changed my views on research in general, and on the particular research I first proposed to the CSA. While I have in the past been happy to collaborate with other workers when invited to do so (e.g., Prikryl *et al*., 1996; Steele and Oznovich, 1995), it has been my temperament to work individually as far as possible. I now see that satisfactory completion of the tasks I set myself in my proposal is absolutely out of reach unless each of the efforts is collaborative from the outset.

Even having come to this realization, I am still doubtful whether all of the initially proposed work can be accomplished within the original schedule. My main concern is with the OH airglow work, if it is to be based on the Polar Camera data. Considerable work remains to be done to verify their adequacy for the intended task, and to develop an algorithm that makes fullest use of the information they contain, prior to their use in any scientific studies. This essential preliminary work will delay the proposed studies and prevent their being carried out in the time initially envisaged. As noted above, Prof. L. L. Cogger at The University of Calgary has begun collaborating with me on the study of the OH images, so there is reason to hope that the preliminary work will progress in timely fashion. However, it would be prudent to review this preliminary work each quarter, in addition to those proposed studies that may be undertaken using other data sets, in order that changes may be made to the terms of the contract, if necessary.

6 Scientific Activity

6.1 Manuscripts (accepted and submitted)

1. Steele, D. P. and L. L. Cogger, Polar patches and the "tongue of ionization", *Radio Science*, in press.

2. Prikryl, P., I. F. Grant, J. W. MacDougall, C. W. S. Ziesolleck, D. P. Steele, G. J. Sofko, and R. A. Greenwald, Observations of polar patches generated by solar-wind-driven Pc5 field line resonances and pulsed magnetic reconnection at the dayside magnetopause, submitted to *Journal of Geophysical Research*, September 1995.

6.2 Conference Presentations

1. Steele, D. P., Observations of diffuse aurora at the geomagnetic pole, paper GAA51C-24 presented at XXI General Assembly, International Union of Geodesy and Geophysics, Boulder, CO, July 2 - 14, 1995.

2. Steele, D. P., and I. Oznovich, Single-point stereoscopy for ground based space research (abstract), *EOS Trans. AGU*, **76**, Fall Meeting Supplement, F483, 1995.

6.3 Other Presentations

1. Steele, D. P. and L. L. Cogger, Observations of diffuse aurora over geomagnetic pole, presented at CNSR Polar Science Workshop, Windermere Manor, University of Western Ontario, May 25-27, 1995.

2. Steele, D. P., The CNSR/University of Calgary Polar Camera, presentation to CANOPUS All-Sky Imager Science Team, University of Calgary, June 14, 1996.

3. Steele, D. P., High latitude magnetosphere-ionosphere interactions, presentation to I.S.A.S. Advisory Committee, November 26, 1995.

7 References

1. Grant, I. F., J. W. MacDougall, J. M. Ruohoniemi, W. A. Bristow, G. J. Sofko, J. A. Koehler, D. Danskin, and D. Andre, Comparison of plasma flow velocities determined by the ionosonde Doppler drift technique, SuperDARN radars, and patch motion, *Radio Science*, **30**, 1537-1549, 1995.

2. Sojka, J. J., R. W. Schunk, M. D. Bowline, and D. J. Crain, Ambiguity in multi-instrument technique identification of polar cap F-region patches (abstract), *EOS Trans. AGU*, **75**, Fall Meeting Supplement, F???, 1994.

3. Meier, R. R., D. J. Strickland, J. H. Hecht, and A. B. Christensen, Deducing composition and incident electron spectra from ground-based auroral optical measurements: A study of auroral red line processes, *J. Geophys. Res.*, **94**, 13541-13552, 1989.

4. Oznovich, I., D. J. McEwen, and G. G. Sivjee, Temperature and airglow brightness oscillations in the polar mesosphere and lower thermosphere, *Planet. Space Sci.*, **43**, 1121-1130, 1995.