

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.
PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE (DD-MM-YYYY) 28-05-2003		2. REPORT TYPE Final Report		3. DATES COVERED (From - To) 28 May 2002 - 28-May-03	
4. TITLE AND SUBTITLE Combined Svalbard Optical and Radar Observations for Polar Cusp/Cap research				5a. CONTRACT NUMBER F61775-02-WE053	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Professor Jøran Moen				5d. PROJECT NUMBER	
				5d. TASK NUMBER	
				5e. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) University of Oslo Box 1048 Blindern N-0316 Oslo Norway				8. PERFORMING ORGANIZATION REPORT NUMBER N/A	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) EOARD PSC 802 BOX 14 FPO 09499-0014				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S) SPC 02-4053	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.					
13. SUPPLEMENTARY NOTES					
20040210 113					
14. ABSTRACT This report results from a contract tasking University of Oslo as follows: The contractor will investigate the ionosphere using meridian scanning photometers, all-sky imagers and the incoherent scatter radar on Svalbard. The main aim of this research proposal is to obtain a reliable understanding of disturbances in the polar ionosphere, which is important to current space research and its application in space weather activities. In particular, the contractor will focus on locating the boundary between open and closed magnetic field lines and then determine which processes occur on open and which one on closed field lines.					
15. SUBJECT TERMS EOARD, Ionosphere, Polar Cap/Cusp					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UL	18. NUMBER OF PAGES 9	19a. NAME OF RESPONSIBLE PERSON MICHAEL KJ MILLIGAN, Lt Col, USAF
a. REPORT UNCLAS	b. ABSTRACT UNCLAS	c. THIS PAGE UNCLAS			19b. TELEPHONE NUMBER (Include area code) +44 (0)20 7514 4955

SPC 02-4053
Contract No: F61775-02-WE053

FINAL REPORT

on

COMBINED SVALBARD OPTICAL AND RADAR OBSERVATIONS FOR POLAR CUSP/CAP RESEARCH

by

Professor Jøran Moen, PI

28 MAY, 2003

Correspondence to:
Prof. Jøran Moen
Department of Physics
P.O. Box 1048, Blindern
N-0316 Oslo, Norway
e-mail: jmoen@fys.uio.no

1. BACKGROUND INFORMATION

The EISCAT incoherent radar facilities consist of 3 radar systems. The UHF (933 MHz) and the VHF (224 MHz) located in northern Scandinavia, and the EISCAT Svalbard Radar (ESR) located in Longyearbyen, Svalbard. The UHF is the only three static incoherent scatter radar system in the world, with a transmitting and receiving antenna (32 m parabolic dish) located at Tromsø, and two additional receiving antennas in Sodankylä, Finland and Kiruna, Sweden. The Tromsø VHF system has a 5000 m² reflector with a meridional beam steering. ESR represents a new generation incoherent radar, located inside the polar cap most of the time. The system comprises two parabolic dish antennas sharing the same transmitter and receiver system, working at 500 MHz. ESR-1, is a 32-m diameter antenna, which can swing 540° in azimuth and from 0 to 180° in elevation. ESR-2, 42 m in diameter, is a fixed beam oriented along the magnetic field line. The ESR radar facility is located on the mountain of Mine 7, within 6 km from the Longyearbyen Auroral Station. With the three EISCAT radar systems working together it is possible to provide a spatial radar coverage of up to ~20° in magnetic latitude, with high time and spatial resolution.

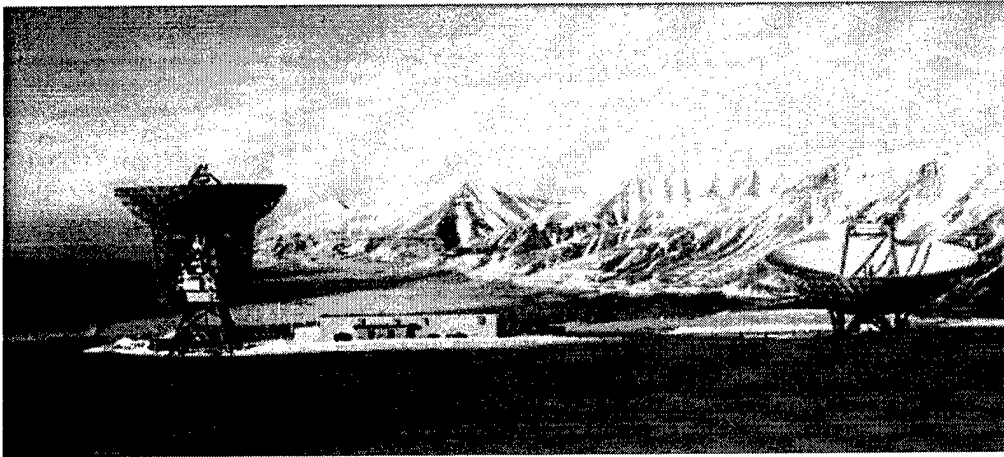


Figure 1: The EISCAT radar site on Svalbard with view down the valley towards Logyearbyen

Svalbard provides a unique platform in the Northern Hemisphere for studies of dayside polar cap auroras as well as related phenomena within the cusp and polar cap boundary layers. Svalbard is nearly 12 hours separated in magnetic time from the Alaska sector and its conjugacy to stations in Antarctica makes Svalbard even more attractive. The Svalbard climate - due to the Gulf Stream is unusual mild. Thus, there is no other place at the same latitudes as our stations on Svalbard in which the comforts of modern living can be enjoyed, and is so accessible from the world's largest metropolises.

The Ny-Ålesund (geogr. lat 78.9°N; geomagnetic lat. 76.07°) and Longyearbyen Auroral observatories (geogr. lat 78.2°N; geomagnetic lat. 75.12°) are the master stations in our

Svalbard network. The main optical instruments are meridian scanning photometers (MSP) and All-Sky CCD imagers at different wavelengths.

The CUTLASS HF radar complements the EISCAT and optical ground-measurements with a 2-dimensional field of view above the Svalbard archipelago. The coherent scattered signals from the CUTLASS radar (part of SuperDARN) constitute a powerful tool for investigations of both temporal and spatial behaviour of the polar cap electrodynamics.

Whenever possible, our ground observations have also been correlated with in-situ measurements from low-altitude polar orbiting satellites (NOAA, DMSP, Polar and Cluster) as well as space platform observations of the solar wind (ACE, Wind and IMP-8).

2. OBSERVATIONS CARRIED OUT

We carried out optical campaigns at Ny-Ålesund in December 2002 and January 2003. Observation time is listed in the table below. During the December campaign we operated ESR, and provided diagnostics of launch conditions for NASA's cusp rocket (PI. Dr. R. Pfaff).

<i>Date</i>	<i>Time (UT)</i>	<i>Instrument</i>	<i>Quality</i>
2002-12-01	16:50-20:00	ASC, ESR	Partly cloudy
2002-12-02	05:15-10:35	ASC, ESR	Partly cloudy
2002-12-03	07:00-11:00	ESR	Overcast
2002-12-04	07:00-11:00	ESR	Overcast
2002-12-05	07:00-11:00	ESR	Overcast
2002-12-06	06:00-10:04	ASC, ESR	Partly cloudy
2002-12-07	17:34-23:59	ASC, ESR	Partly cloudy
2002-12-08	00:00-09:03	ASC, ESR	Partly cloudy
2002-12-09	06:15-15:08	ASC, ESR	Partly cloudy
2002-12-10	06:13-19:05	ASC, ESR	Partly cloudy
2002-12-11	05:45-12:35	ASC, ESR	Partly cloudy
2002-12-12	09:08-14:07	ASC, ESR	Partly cloudy
2002-12-13	07:41-14:42	ASC, ESR	Partly cloudy
2002-12-14	10:04-12:11	ASC, ESR	Overcast
2002-12-15	06:30-12:25, 12:30-15:45	ASC, MSP, ESR	Clear sky
2002-12-16	07:30-12:53	MSP, ESR	Clear sky
2003-01-02	12:00-23:59	ASC, MSP	Clear sky
2003-01-03	00:00-23:59	ASC, MSP	Clear sky
2003-01-04	00:00-23:59	ASC, MSP	Clear sky
2003-01-05	00:00-06:30	ASC, MSP	Overcast
2003-01-06	13:08-16:12	ASC, MSP	Overcast
2003-01-07	05:20-23:59	ASC, MSP	Clear sky (mostly)
2003-01-08	00:00-23:59	ASC, MSP	Clear sky
2003-01-09	00:00-10:30	ASC, MSP	Partly cloudy
2003-01-10	05:25-12:10, 16:15-23:59	ASC, MSP	Clear sky
2003-01-11	00:00-14:04, 18:30-23:59	ASC, MSP	Partly cloudy
2003-01-12	00:00-12:00	ASC, MSP	Clear sky (mostly)

3. SCIENTIFIC RESULTS

Cusp studies based on combined ground-space observations:

The optical observations from Svalbard is the basic element in our program of describing and understanding the spatio-temporal structure of the dayside aurora in terms of solar wind-magnetosphere interaction processes. The emphasis has been placed on the establishment of the ionospheric response to magnetopause reconnection events.

The ultimate goal of these studies is to establish the magnetopause reconnection topology and the detailed evolution of magnetopause reconnection events as a function of IMF orientation. This is an important element in the process of understanding solar wind-magnetosphere coupling, which is a major task in magnetospheric physics. The focus is on multi-instrument and multi-point observations of spatio-temporal structure in the cusp region. Spacecraft observations (Cluster, Polar, and DMSP) have been combined with the continuous ground observations of the aurora and plasma convection. The latter observations represent a critical element in the continuous monitoring of solar wind-magnetosphere coupling processes.

Auroral footprints of cusp boundary layers during magnetopause reconnection events:

It has been found in recent studies that the auroral response to reconnection events involves a wide variety of different plasma sources and particle precipitation regimes which are typically manifest in the ~ 0900 - 1500 MLT/ 70 - 80° MLAT sector. We recently documented the coherent reconnection responses involving the different auroral forms/precipitations, such as the CPS, precipitation void, dayside BPS, and the LLBL/cusp/mantle (Papers 2, 3, 11, 13, 14). The phenomenon of poleward moving auroral forms (PMAFs), which has been established as a signature of pulsed magnetopause reconnection, also referred to as flux transfer events (Russell and Elphic, 1978, Paschmann et al., 1982), occur within the regime of LLBL/cusp/mantle precipitation. PMAFs are often preceded by an auroral intensification at the cusp equatorward boundary, so-called equatorward boundary intensifications (EBIs), typically containing electron fluxes extending up to 1-2 keV energy. These auroral features (EBIs) are discussed in relation to specific sub-structures of cusp boundary layers, where strong field-aligned currents are generated, possibly due to the presence of viscous stresses (on open field lines), as envisaged by e.g. Sonnerup and Siebert (2003). The identification of the boundary layer substructure (Phan et al., 1996; Vaisberg et al., 2001) and its auroral signature, may allow us to determine the spatio-temporal scales of the same boundary layer structure. The present discussion of auroral features (e.g., EBIs) within the context of the electron edge (Gosling et al., 1990) of LLBL precipitation and the dayside BPS regime (Papers 7, 14), represents one step forward towards this goal.

PMAFs in the context of plasma convection:

In Paper 11 we combined optical auroral observations and plasma convection data obtained by the CUTLASS Finland radar and other radars in the SuperDARN network.

We focused on intervals characterized by auroral events belonging to the category of PMAF activity. The aurora-convection events could be subdivided in two main phases. The initial, brightening phase, during IMF $B_z < 0$; $B_y > 0$ conditions, is characterized by enhanced westward convection and a westward-expanding auroral form in the 1200-1500 MLT sector. In the later phase, when the auroral motion/expansion is mainly directed poleward, primarily in the 0900-1200 MLT sector, plasma convection in the same sector is also directed poleward. The latter convection events are often referred to as pulsed ionospheric flows (PIFs). Thus, we documented the coherent spatio-temporal evolution of auroral and plasma convection events that have been in previous work connected with a pulsed magnetopause reconnection process.

The IMF regulation of magnetopause reconnection processes and their ionospheric signatures: Implications concerning reconnection topology:

One of the big issues in magnetospheric physics today is the question of antiparallel versus component (subsolar) reconnection at the dayside magnetopause. These are two different hypotheses concerning the requirements of the amount of magnetic shear across the magnetopause current sheet which is necessary for reconnection to occur. According to one view (component reconnection) there is no strong restriction on the magnetic shear, i. e., the reconnection rate approaches zero only when the angle between the reconnecting fields goes to zero (Gonzales and Mozer, 1974; Hill, 1975; Cowley, 1976; Moore et al., 2002). The antiparallel hypothesis limits the process to regions of large field shear (Crooker, 1979; Luhmann, et al., 1984). Thus, very different reconnection geometries are predicted in the two cases during conditions of B_y -dominant (east-west) IMF orientation. In this case reconnection in the subsolar region is either present (component reconnection along tilted X-line) or absent (the antiparallel case). The different reconnection modes are expected to give rise to differences in ionospheric footprints in the form of plasma convection (Coleman et al., 2001; Rodger et al., 2003) and auroral precipitation (Papers 5, 6, 11). In a recent study (Paper 14) we pointed out that the occurrence of poleward moving auroral forms (PMAFs) is restricted to a more limited range of IMF orientations (as parametrized by the clock angle) than previously thought. For example, PMAFs are found to be absent for the state of strongly south IMF orientation (clock angles >150 deg). A possible explanation for this behaviour, as suggested in Paper 14, is that PMAFs constitute an auroral signature which is uniquely related to antiparallel reconnection, taking place at high magnetopause latitudes. This interpretation is supported by a recent study (Paper 15) of isolated PMAF events occurring during a long interval of steady south-east directed IMF (clock angle = 135 deg.) In this case auroral brightenings in the pre- and postnoon sectors are bracketed by a 500 km wide longitudinal gap in the auroral emission. This is taken to be a signature of the absence of open LLBL flux in the subsolar region. The latter is one of the predictions of the antiparallel merging model. Thus, we conclude that the aurora provides evidence complementary to that found in plasma convection data, which is in favour of the importance of antiparallel merging in solar wind-magnetosphere-ionosphere coupling.

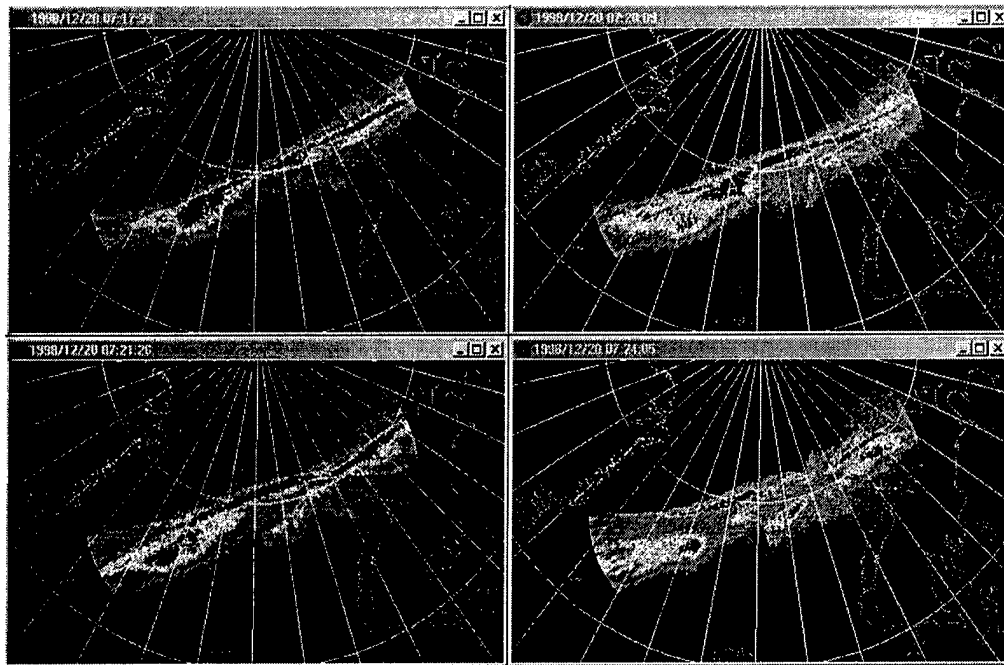


Figure 1: Images from the Ny Ålesund and Heiss Island imagers projected to 250 km altitude and merged in a common geographic frame. Notice the north-south motion of the dayside aurora and the formation of auroral forms from the main trace.

In collaboration Dr. Cesar Valladares we have carried out multisite-site observations of the association between cusp aurora and plasma convection in the cusp polar cap (Paper 16). Figure 1 shows six pairs of 630.0 nm images from the Heiss Island and the Ny-Ålesund imagers that have been merged and projected into a common geographic frame (software developed by the University of Oslo). The top left frame (0708 UT) shows the cusp aurora divided longitudinally in two broad regions. This configuration persists for few minutes until 0710 UT when the western aurora dims and the eastern side brightens. There are also three forms re-brightening near the eastern end of the aurora, which are seen to drift poleward and increase their extension toward the west. At 0714 UT the main auroral trace starts retreating poleward. However, this motion is not uniform along the east-west extension of the aurora; the westward part seems to leap poleward first. This is followed by a brightening of the red and green (data not shown) line emissions propagating westward along the newly formed aurora. The images of 0717 and 0720 UT show that the intensity at the poleward boundary of the aurora decreases sharply, and the equatorward edge presents smaller auroral features emanating from the main band. The images in the bottom panels, corresponding to 0721 and 0724 UT, show that the equatorward auroral forms continue moving equatorward and westward. These two auroral forms grow from two regions that are separated in the east-west direction by

~1000 km, one of them located near Ny-Ålesund and the other over Heiss Island. At 0724 UT the western form, seen equatorward of the main band, continues moving westward and the eastern region displays a rayed structure. After 0726 UT (images not shown) a more stable and typical type 1 cusp auroral forms (attributed to magnetopause merging) at the equatorward side of the arcs described above. The cusp aurora, seen with both imagers, may map to an extended reconnection line located solely in the northern hemisphere. Future research based on data from our pair of imagers should enable us to test the component versus the anti-parallel merging hypothesis.

4. PERSONNEL

The key persons on this project are:

Dr. Jøran Moen, Professor, University of Oslo (also at UNIS, Svalbard)
Dr. P.E. Sandholt, Professor, University of Oslo
Dr. Alv Egeland, Professor, University of Oslo
Dr. Bjørn Lybekk, Senior Engineer, University of Oslo
Mr. Espen Trondsen, Senior Engineer, University of Oslo
and graduate students at University of Oslo.

5. LIST OF PUBLICATIONS

1. Sandholt, P. E., C. J. Farrugia, S. W. H. Cowley, M. Lester, S. Milan, W. F. Denig, B. Lybekk, and E. Trondsen, Multi-stage substorm expansion: Auroral dynamics in relation to plasma sheet particle injection, precipitation, and plasma convection, *J. Geophys. Res.*, 107(A11), 1342, doi:10.1029/2001JA900116, 2002.
2. Sandholt, P. E., and C. J. Farrugia, Monitoring the magnetosheath-magnetosphere interconnection topology from the aurora, *Ann. Geophys.*, 20, 629, 2002.
3. Sandholt, P. E., and C. J. Farrugia, The aurora as monitor of solar wind-magnetosphere interactions, in P. T. Newell and T. Onsager (editors), pp. 335-349, *Earth's Low-Latitude Boundary Layer, Proceedings of Chapman Conference on LLBL dynamics*, New Orleans, April 2001, Geophysical Monograph 133, AGU, Washington DC, 2003.
4. Farrugia, C. J., and P. E. Sandholt, Magnetosphere-ionosphere coupling at midmorning local times: Dependence on IMF parameters, in P. T. Newell and T. Onsager (editors), pp.351-359, *Earth's Low-Latitude Boundary Layer, Proceedings of Chapman Conference on LLBL dynamics*, New Orleans, April 2001, Geophysical Monograph 133, AGU, Washington DC, 2003.

5. Maynard, N. C., W. J. Burke, P. E. Sandholt, J. Moen, D. M. Ober, D. R. Weimer, A. Egeland, and M. Lester, Observations of simultaneous effects of merging in both hemispheres, *J. Geophys. Res.*, 106, 24551, 2001.
6. Maynard, N. C., W. J. Burke, J. Moen, P. E. Sandholt, M. Lester, D. M. Ober, D. R. Weimer, and W. W. White, Bifurcation of the cusp: Implications for understanding boundary layers, in P. T. Newell and T. Onsager (editors), *Proceedings of Chapman Conference on LLBL dynamics*, New Orleans, April 2001, *Geophysical Monograph* 133, AGU, Washington DC, 2003.
7. Sandholt, P. E., W. F. Denig, C. J. Farrugia, B. Lybekk, and E. Trondsen, The electron edge in low-latitude boundary layer precipitation in relation to auroral forms and activities in the 1100-1300 MLT sector, *J. Geophys. Res.*, 107(A9), 1235, doi:10.1029/2001JA005081, 2002.
8. Sandholt, P. E., A. Egeland and H. Carlson, *Dayside and Polar Cap Aurora*, *Astrophysics and Space Science Library*, Vol. 270 (pp. 1-287), Kluwer Academic Publishers, Dordrecht, Holland, 2002 (ISBN 1-4020-0447-8).
9. Sandholt, P. E., C. J. Farrugia, J. Moen, and W. F. Denig, The cusp in rapid transition, *J. Geophys. Res.*, 107(A12), 1235, doi:10.1029/2001JA009214, 2002.
10. Cowley, S. W. H., J. A. Davies, A. Grocott, H. Khan, M. Lester, K. A. McWilliams, S. E. Milan, G. Provan, P. E. Sandholt, J. A. Wild, and T. K. Yeoman, Solar wind-magnetosphere-ionosphere interactions in the Earth's plasma environment, *Roy. Astron. Soc. (Phil. Trans A)*, in press 2002.
11. Sandholt, P. E., J. Moen, C. J. Farrugia, S. W. H. Cowley, M. Lester, S. E. Milan, C. Valladares, W. F. Denig, and S. Eriksson, Multi-site ground-based observations of the association between aurora and plasma convection in the cusp/polar cap during south-eastward IMF orientation, *Ann. Geophys.*, 21, 539, 2003.
12. Khan, H., M. Lester, J. A. Davies, S. E. Milan, and P. E. Sandholt, Multi-instrument study of the dynamic cusp during dominant IMF By conditions, *Ann. Geophys.*, in press 2002.
13. Sandholt, P. E., C. J. Farrugia, W. F. Denig, S. W. H. Cowley, and M. Lester, Spontaneous and driven cusp dynamics: Optical aurora, particle precipitation, and plasma convection, *Planet. Space Sci.*, in press 2003.
14. Sandholt, P. E., C. J. Farrugia, and W. F. Denig, Dayside aurora and the role of IMF |By/Bz|: detailed morphology and response to magnetopause reconnection, *Ann. Geophys.* in press, 2003.

15. Sandholt, P. E., and C. J. Farrugia, Does the aurora provide evidence for the occurrence of antiparallel magnetopause reconnection?, *J. Geophys. Res.*, submitted 2003.

16. Valladares, C. E., J. Moen, P. E. Sandholt, W. F. Denig, and O. Troshichev, Simultaneous observations of dayside aurora from Heiss Island and Ny-Ålesund, *Geophys. Res. Lett.*, 29(24), 2202, 10.1029/2002GL016001, 2002.