OBSERVATIONS OF SUBSTORM ELECTRODYNAMICS USING THE MIRACLE NETWORK

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Abstract

The recently completed Magnetometers – Ionospheric Radars – All-sky Cameras Large Experiment (MIRACLE) is a two-dimensional network of instruments in Northern Fennoscandia and Svalbard, which monitors mesoscale variations in the auroral ionospheric dynamics. Five newly implemented digital all-sky cameras form an important part of the network. On Nov 3, 1997, the network recorded a small pseudobreakup at 2211 UT, which lasted only a few minutes before the disturbance decayed. We show that the auroral activation was associated with a current vortex and a strong electric field poleward of the auroral activity. Following the breakup, a substorm onset occurred at about 2242 UT to the west of Scandinavia. The MIRACLE chain recorded the expansion of the eastward edge of the auroral bulge and a downward field-aligned current well poleward of the auroral activity and the most intense electric field. We discuss the implications for ionosphere–magnetosphere coupling that can be concluded from a detailed instrument network such as MIRACLE.

1. Introduction

The Magnetometers – Ionospheric Radars – All-sky Cameras Large Experiment (MIRACLE) is a two-dimensional instrument network constructed for mesoscale studies of auroral electrodynamics, which, with the exception of EISCAT, is maintained and operated in collaboration between the institutes listed in the list of authors under the leadership of the Finnish Meteorological Institute. The network covers an area from subauroral to polar cap latitudes over a longitude range of about two hours of local time. The various instruments have different spatial resolutions, but basically the network is designed for studies in the spatial scales from a few tens of km upward.

In the following we will show that the size of the instrument network is suitable for a variety of auroral and magnetospheric studies: The initial current system at substorm onset covers about 500 km in longitude [*Baumjohann et al.*, 1981], and pseudobreakups [*Pulkkinen*, 1996] or other localized auroral forms [*Opgenoorth et al.*, 1994] are often in the scale size that can be recorded with a single all-sky camera (<600 km). Furthermore, the network can be used to monitor the motion of larger-scale structures, such as the westward traveling surge or the eastward expanding auroral bulge.

The International Solar Terrestrial Physics program is designed to study the solar wind – magnetosphere – ionosphere interactions. Several spacecraft are in orbit that monitor the key regions in these processes: the Sun and the upstream solar wind, magnetotail processes, and auroral phenomena. Whereas the global picture of the substorm evolution is now rather generally accepted [*Baker et al.*, this issue], there are a number of missing pieces of information that finally will answer detailed questions such as exactly when substorms will occur or how large the disturbances will be. For these questions, it is necessary to include the mesoscale ionospheric processes, which all can be monitored and examined using the MIRACLE network, planned to be operative until 2004.

2. Instrumentation

2.1. IMAGE Magnetometer Network

The IMAGE magnetometer network consists of 19 fully calibrated magnetometers, and provides three-component measurements of the total geomagnetic field at 10-sec resolution [*Viljanen and Häkkinen*, 1997].

2.2. Coherent and Incoherent Scatter Radars

The STARE bistatic radar system records the two-dimensional horizontal E-region plasma flows over northern Scandinavia. The CUTLASS radars, which comprise two components of the SuperDARN network overlooking Scandinavia [*Greenwald et al.*, 1995], record the larger-scale convection in the E and F-region. Finally, the EISCAT radars provide more detailed looks and altitude dependence of several ionospheric parameters simultaneously in a localized region over Tromsø.

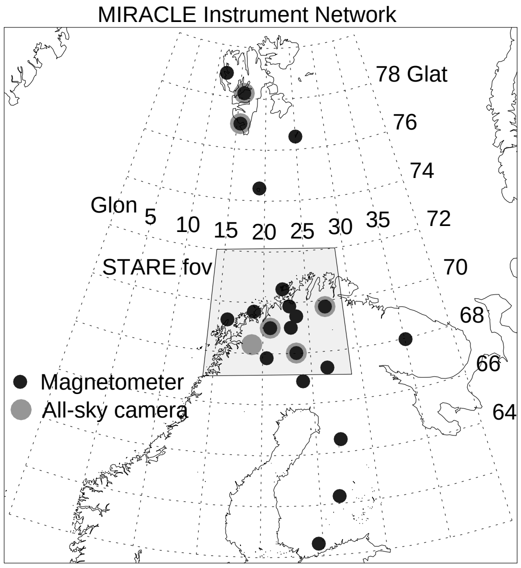

Figure 1: Region where the MIRACLE network operates. Locations of the magnetometer stations, all-sky camera stations, and STARE field of view are shown.

2.3. All-sky camera network

Finnish Meteorological Institute (FMI) started continuous auroral recordings on color film at four stations in Finnish Lapland in 1973. The cameras operated every clear night every year between August and April, most regularly at Kilpisjärvi, Kevo, Muonio, and Hornsund (Svalbard). During the last twenty years FMI has collected over 2.2 million auroral images, which makes it possible to study auroral activity over almost two sunspot cycles.

New digital all-sky cameras were tested during 1995–1996, and based on the prototyping results six units were manufactured. The all-sky imagers were manufactured by *Keo Consultants*, whereas the complete computer setup was designed, built, and programmed at FMI. A new all-sky camera station consists of an imager with a 7-position filter wheel, a station computer, and housekeeping electronics such as uninterruptible power supply.

The digital all-sky cameras have completely replaced the old film cameras, and presently five stations are in operation. The new stations operate autonomously taking images whenever it is sufficiently dark (in Svalbard winter, 24 hours-a-day). The images are stored in a local hard disk for future transfer to FMI. Keograms — time vs latitude quick-look data — are transferred to FMI every noon from every station, and are available for analysis the same day.

Unlike the old cameras, the new computer-based cameras are connected to a network. This makes it possible to download all-sky images and change imaging parameters *in real time*. Usually the cameras take 557.7-nm images at 20-s intervals, 630.0-nm images once a minute, and unfiltered images once an hour, but this configuration can be changed at any time for any station. The exposure time can be varied from video rate exposure to several seconds – for the winters of 1996–1998 the exposure time has varied from 0.1 to 6 seconds.

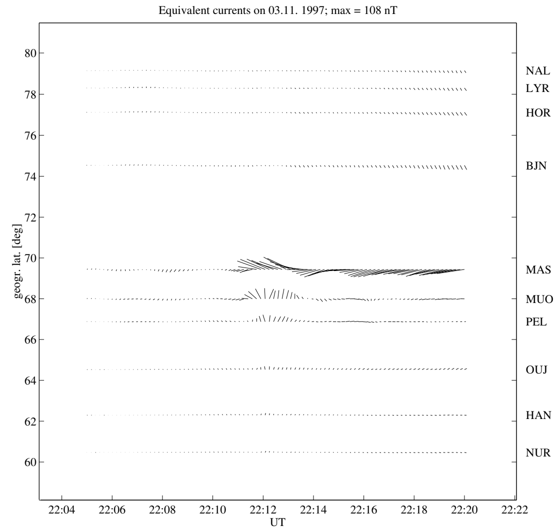

Figure 2: Equivalent current vectors from the IMAGE magnetometer chain.

Thus, MIRACLE provides information about all key ionospheric parameters, the currents, the electric fields, and the conductivities (Figure 1).

3. Observations on Nov 3, 1997

November 3, 1997, was geomagnetically quiet with mostly northward IMF until about 1500 UT when IMF became gradually more negative. Here we concentrate on the substorm activity during 2100–0000 UT. Electron measurements from the geostationary spacecraft 1994-084 indicated two activations, a very small one at about 2215 UT and a larger injection at about 2250 UT (data not shown). Both events displayed distinct dispersion indicating that the onsets were to the west of the spacecraft. The top panel of Figure 3 shows a local *AL*-index computed from the IMAGE observations. Showing two activations, one at about 2211 UT and a later one at 2242 UT (vertical dashed lines).

The next panel in Figure 3 shows a combination of a keogram of the auroral observations made in Kilpisjärvi and the locations of the auroral electrojets as deduced from the magnetometer data. The auroral activity follows mainly the equatorward edge of the westward electrojet. Both activations are clearly visible in the data, the poleward expansion of the westward electrojet is associated with the arrival of

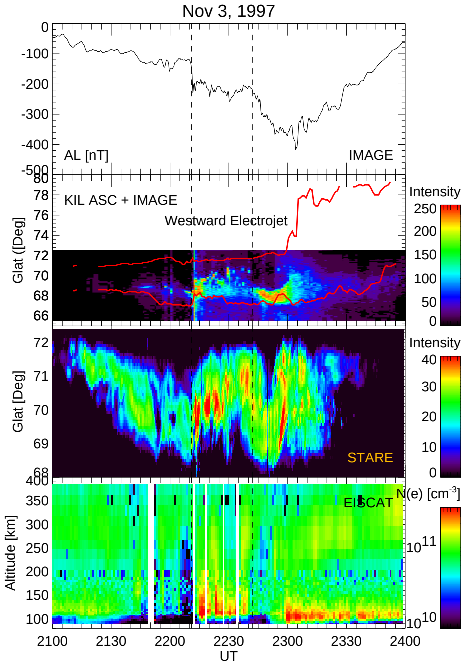

Figure 3: Panels from top to bottom: Local *AL*-index constructed from the IMAGE magnetometer observations. Keogram from KIL ASC observations; the solid lines outline the westward and eastward electrojets. Backscatter intensity vs latitude from the STARE radar in Norway. Electron density vs altitude from EISCAT

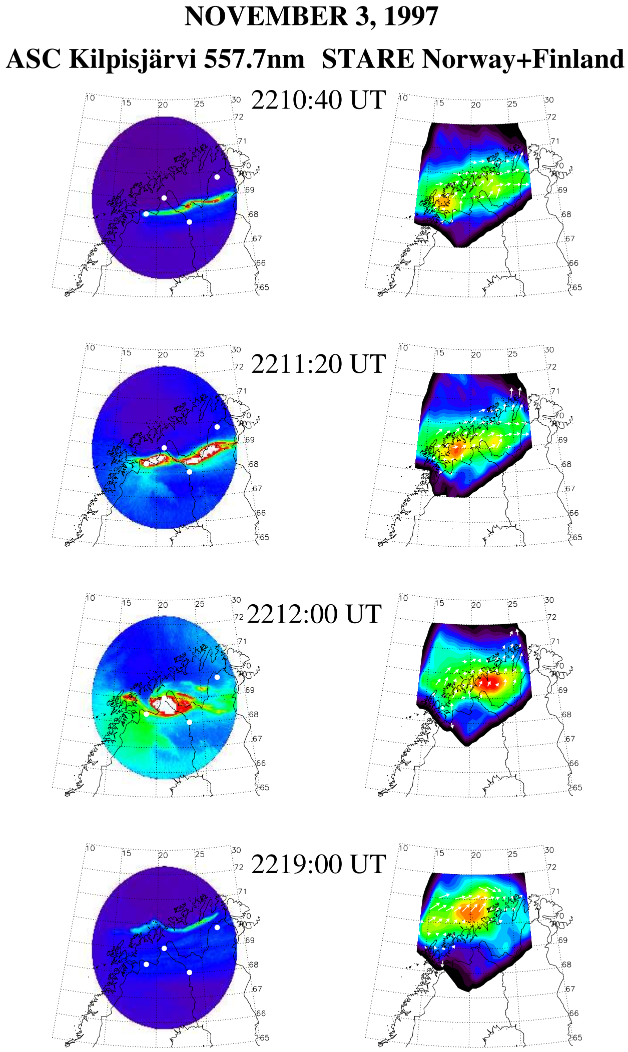

Figure 4: (Left) All-sky images from Kilpisjärvi. (Right) STARE backscatter intensity and flow velocity vectors.

the eastward edge of the substorm current wedge over Scandinavia. The next panel shows the backscatter intensity recorded by the STARE radar (in Norway) that is a function of the E-region electron density and electric field, amongst other factors [*Kustov et al.*, 1993]. The bottom panel shows the electron density from the EISCAT UHF radar located in Tromsø. The E-region electron density is directly related to energetic particle precipitation.

3.1. Pseudobreakup during the growth phase

The MIRACLE chain was well located to observe the pseudobreakup evolution, the network covered the entire extent of the event. Figure 2 shows the equivalent current vectors as time series during the event. The data clearly show the latitudinal and temporal localization of the event; the strongest currents were observed at MAS, and the event covered only a few degrees in latitude. The magnetometer observations indicate the existence of an upward field-aligned current.

All-sky camera observations from Kilpisjärvi show a quiet arc at 2210:40 UT, which broke up at 2211:20 UT; the maximum expansion occurred at 2212:00 UT. At 2219 UT the event is completely over with only a faint, narrow arc within the camera field of view (Figure 4). STARE observed relatively weak electric fields and eastward flow prior to the pseudobreakup. During the event, the flow spiraled around the auroral activation, again indicating a localized upward field aligned current within the auroral form, and the electric field was enhanced poleward of the auroral activity. After the event, the electric field remained enhanced and the flow rather strong. Whereas the electrojet currents and auroral activity were colocated, the electric field was strongest poleward of both the currents and the auroral arc.

3.2. Eastward expanding auroral bulge

After the pseudobreakup quieted, the growth phase continued for another 30 min, and the substorm onset occurred at about 2242 UT to the west of the

MIRACLE chain, which at that time was in the 0200 MLT local time sector. POLAR images from the UVI instrument showed an onset over Iceland and its expansion to the Scandinavian sector (data not shown).

The expansion of the bulge to the MIRACLE field of view caused an intensification of the auroral activity, intensification and rotation of the equivalent current vectors, and an enhancement of the electric field and plasma flow. More detailed comparisons reveal that there was a clear spatial ordering of these activations: The downward field-aligned current was located between Svalbard and the Scandinavian coast. The electric field enhancement was strongest close to the coastline well equatorward of the current and did not maximize near the northern edge of the field of view; unfortunately the STARE field of view does not cover the region of strongest downward current. The POLAR images show that the region of the downward current was almost void of auroral activity. The ASC observations from Kilpisjärvi confirm this observation: the data show an auroral activation from the west, which decayed to diffuse and relatively weak auroral activity by 2305 UT. These observations will be discussed in more detail elsewhere.

4. Discussion

This paper has briefly described the wealth of ground-based observations available from a substorm event on Nov 3, 1997. The observations covered a small pseudobreakup and a following substorm expansion.

During the pseudobreakup the magnetometer, STARE and EISCAT data indicate a localized upward FAC current filament within the breakup arc. Within this current region the precipitating particle energy is only around 10 keV, as estimated from the lower boundary of the EISCAT electron density measurment. This indicates relatively weakly accelerated magnetospheric electrons as the source for the auroral activation and the magnetic disturbance, both originating from the inner magnetosphere (inside ~10–15 R_E).

The eastward expanding auroral bulge reached the Scandinavian sector a few minutes after the substorm onset. STARE showed enhanced electric field intensity poleward of the auroral activity, and the field-aligned current was located poleward of the auroral activity. This is an important point for the conjugate tail–ionosphere observations: the region of auroral brightening in this case is not conjugate with the source region of the field-aligned current; the former is triggered by precipitating electrons equatorward/Earthward of the downward current region [*Opgenoorth et al.*, 1994]. Another key question that can be addressed with this network is the current carriers of the downward current: the tail ions are much too slow for balancing the upward current carried by the downward precipitating electrons [*Pellinen et al.*, 1995].

MIRACLE data are available in World Wide Web at `http://www.geo.fmi.fi`

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