The distention of the magnetosphere on May 11, 1999: High latitude Antarctic observations and comparisons with low latitude magnetic and geopotential data

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Abstract. We examine the Earth's ionospheric response on May 11, 1999, to an unusually tenuous solar wind, focusing on magnetometer, riometer, and optical data from high geomagnetic latitudes in Antarctica. Comparisons are also made with POLAR satellite data during a perigee pass over Antarctica, and with geomagnetic data collected at low latitudes. It is shown that the southern hemisphere was geophysically active, even though the K_p index on May 11 ranged only from 0 to 0+. Furthermore, despite the fact that the IMF and solar wind conditions favored northern hemisphere polar rain, low energy electron precipitation did occur in the southern polar cap. Geomagnetic power levels at low, cusp, and polar cap latitudes were also lower on May 11 than on surrounding days. Although this might be expected, discrete millihertz peaks in ULF power were still evident, especially at cusp latitudes.

Introduction

For an extended time interval on May 11, 1999, the solar wind nearly disappeared [*Farrugia et al.*, 2000]. Rarely does the solar wind density remain below 1.0 cm^{-3} for prolonged periods as it did on May 11, decreasing to $\sim$ 0.3 cm^{-3}, while solar wind velocities were $<$ 350 km/s. Together, these conditions resulted in a solar wind ram pressure less than one-fiftieth of typical values. In addition, the interplanetary magnetic field (IMF) was weakly northward and pointed antisunward, a condition favorable for the preferential entry of the solar wind strahl into the northern polar cap [*Fairfield and Scudder*, 1985]. Thus it is of interest to examine the response of both polar regions to the unusual conditions on this day.

Intuitively, the distention of the magnetosphere when the solar wind decreases greatly would lead one to expect a significant decrease in geomagnetic activity throughout the magnetosphere. However, some geophysical activity was observed at high latitudes in both polar regions [*Anderson et al.*, 2000; *Knipp et al.*, 2000; *Papitashvili et al.*, 2000; and *Rostoker*, 2000]. This paper focuses on magnetometer, riometer, and optical data from high geomagnetic latitudes in Antarctica (see Figure 1 for site locations), and magnetometer and cable potential data from low latitudes on May 11, 1999, and for several surrounding days. These observations are also compared with data taken with the HYDRA instrument onboard the POLAR satellite during a brief perigee pass over Antarctica.

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Data Presentation and Discussion

Ground-based Antarctic Observations: From late on May 10 to early on May 12, 1999, the solar wind density remained below 1.0 cm^{-3}, as depicted in Figure 2. Auroral absorption, photometer, and magnetometer data from South Pole (SPA) and McMurdo (MCM) Stations, along with data collected at the Automatic Geophysical Observatory AGO-P5 (AP5), are also plotted in Figure 2. Although K_p was never higher than 0+ on May 11, small but significant geophysical activity was evident over a wide range of latitudes.

In Figure 2, an increase in the soft electron (few hundred eV) 630.0 nm auroral emission is evident in SPA photometer recordings, commencing just after 0400 UT, followed by several step-like increases. After peaking around 0800 UT, a sharp decrease in intensity is observed, but some 630.0 nm emission at SPA is still evident until at least 1200 UT. The more energetic 427.8 nm emission also intensified during this interval, but little evidence of this emission is observed at SPA after 0830 UT. Sporadic and weak cosmic noise absorption is also observed by the 30 MHz riometer at SPA, peaking at 0.13 dB just before 0500 UT. In the SPA H-component magnetometer, a 40 nT decrease was coincident with the rapid decrease of 630.0 and 427.8 nm photometer intensities just after 0800 UT. The quietest interval at SPA lasted from 13–20 UT (0930–1630 MLT), when solar wind densities reached their lowest values, after which very weak 630.0 nm emission could once again be detected. At the very high latitude AP5 site, only weak magnetic activity was observed throughout the day. This is in contrast to high latitude observations in Greenland that show polar cap magnetic disturbances reaching $\sim$ 200 nT [*Papitashvili et al.*, 2000].

All-sky camera observations at SPA (not shown) indicate that 630.0 nm aurora was observed equatorward of SPA before 0800 UT, and at higher latitudes (poleward) by 0900 UT. This is the signature of the daily rotation of the Earth under the asymmetric auroral oval prior to local magnetic noon ($\sim$ 1530 UT). For SPA, the oval generally moves across the local zenith around 0900–1200 UT. On May 11 this motion happened somewhat earlier between 0700–1000 UT. Then, the oval moved much further poleward than usual. The expected equatorward motion around 1800–2000 UT was not observed and 630.0 nm emission existed above 80° MLAT between 1300–2200 UT. At AGO-P1 (AP1), 630.0 nm aurora was seen below 80° MLAT between

06–12 UT, and above 80° MLAT (up to 83°) for the rest of the day. The 630.0 nm aurora was patchy with several illuminated areas of about 200 km diameter, as shown in Figure 3, with very weak 427.8 nm emission in the center of each patchy structure. From about 14–22 UT (07–15 MLT), 630.0 nm emissions were also detected at MCM, as depicted in Figure 2. There was no corresponding response in riometer absorption at SPA or AP1, suggesting that the precipitation at this time was dominated by lower energy electrons. The increased intensity after 19 UT (and before 05 UT) was due to scattered sunlight.

POLAR Satellite Perigee Pass: From 2230–2300 UT, POLAR made a perigee pass over the southern polar cap, crossing from mid-evening to mid-morning local times (see Figure 1). Figure 4 depicts HYDRA data; plotted are magnetic latitude, ion and electron energy-time spectrograms (differential energy fluxes plotted as a function of energy and time), energy fluxes integrated over all energies and pitch angles (electrons with red trace), and the integrated number fluxes.

An ion energy-latitude dispersion at 2235–2240 UT is indicative of a cusp crossing, and the subsequent lack of ion precipitation up to 2255 UT signals passage over the polar cap. Filamentary electron fluxes significantly over background (by about an order of magnitude) are seen, with peak energies above 1 keV. The activity is strongest in the evening side of the pass. The intense, filamented precipitation on small spatial scales gives the impression of a "polar shower", widely believed to be a $B_z > 0$ phenomenon [*Shinohara and Kokubun*, 1996]. These observations are consistent with the patchy optical structures described above.

It is interesting to compare the HYDRA and ground-based measurements with X-ray data taken with POLAR's PIXIE camera. Although PIXIE observed precipitation spread over the northern polar cap from about 13–20 UT, only an extremely weak auroral arc (as compared to usual) was observed for a portion of this perigee pass. The northern hemisphere X-ray observations were interpreted as being caused by polar rain [*Anderson et al.*, 2000] where the entry of polar rain into the northern polar cap would be favored under the prevailing interplanetary conditions. *Fairfield and*

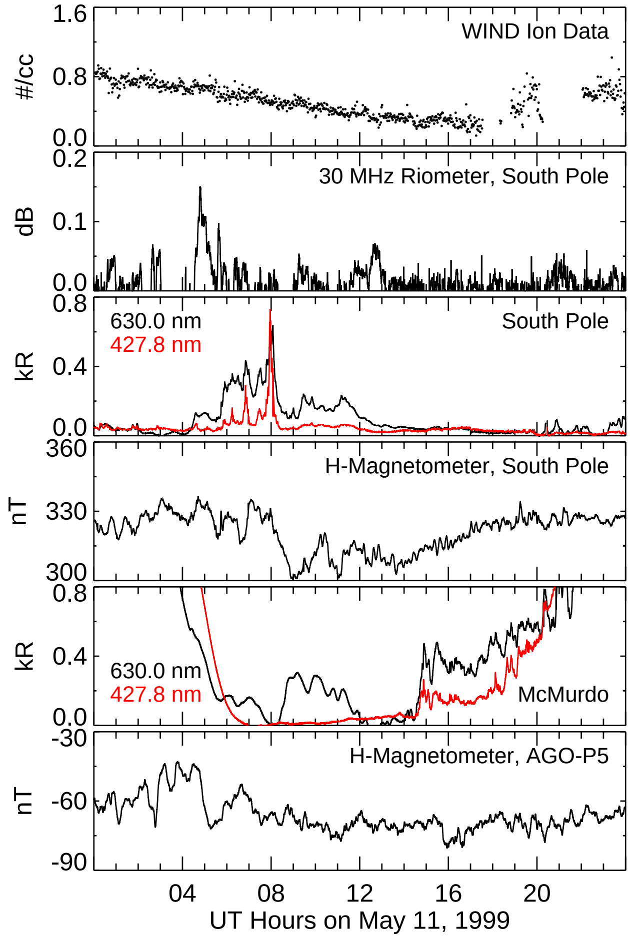

Figure 2. A multi-panel plot depicting the solar wind density along with ground-based geophysical data taken at SPA, MCM, AP5.

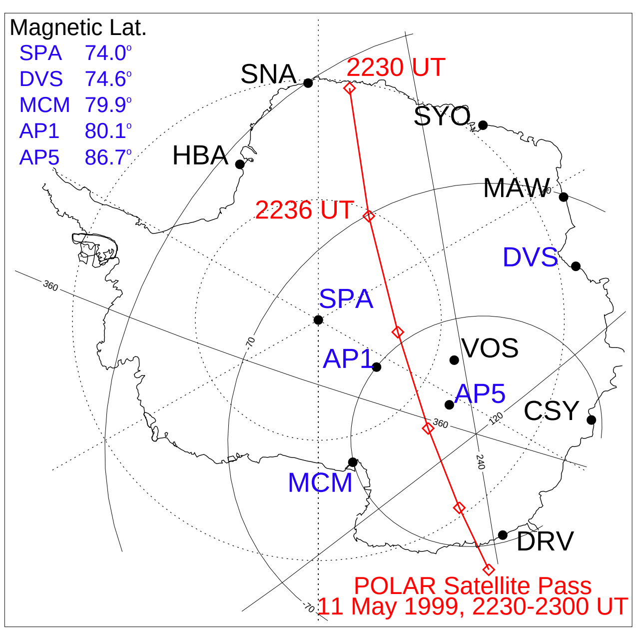

Figure 1. Antarctic observation sites: South Pole Station (SPA); McMurdo Station (MCM); Davis Station (DVS); and AGO-P1 (AP1) and AGO-P5 (AP5). Several other Antarctic stations are also marked for reference. Geographic (geomagnetic) coordinates are given by the dotted (solid) lines.

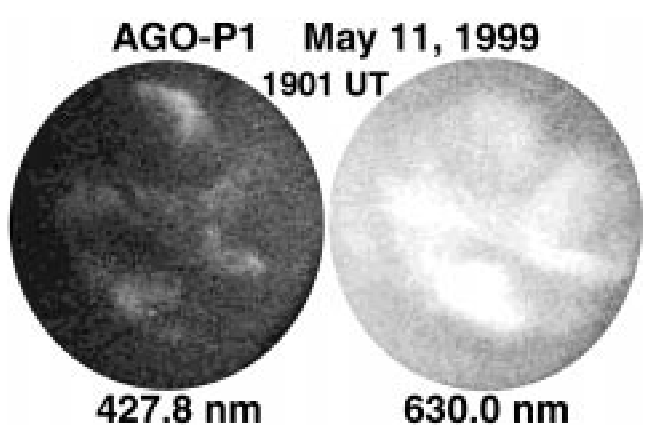

Figure 3. Geographic projections of all sky images depicting patchy 630.0 nm and weak 427.8 nm emission.

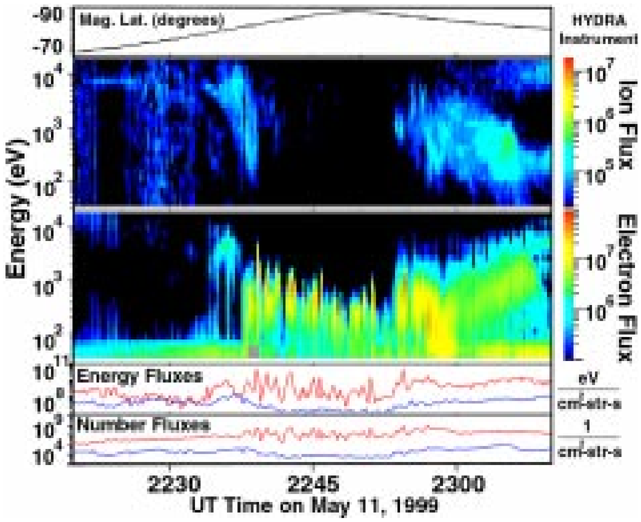

Figure 4. Data obtained with the Hot Plasma Analyzer (HYDRA) instrument onboard the POLAR satellite during a brief perigee pass near 2245 UT.

Scudder [1985] predict that the presence of the solar wind strahl electrons over one pole, but not the other, should lead to north/south asymmetries at high energies, and this prediction is consistent with the X-ray observations. However, changing interplanetary conditions could raise or lower the degree of asymmetry.

Power Level Comparisons: Ground-based magnetometer data acquired from AP5, SPA, and PTA (Point Arena, California, $L = 2$) were studied in order to examine the effects of the very low solar wind density and speed on the ULF energy content of the Earth's magnetosphere. In addition, the electric potential across the Pacific between PTA and Hanauma Bay, Hawaii, was monitored in PTA using the decommissioned AT&T HAW-1 cable. The dominant variations in this geopotential signal occur from changes in ionosphere electrical currents that are driven by the sun, solar wind, and magnetosphere processes.

Power spectra of the H-component magnetic field data from the three sites and of the cable geopotential data were calculated for May 10, 1999, and for the geomagnetically quiet day of May 11. Power spectra for each of the two days are plotted in Figure 5, with the red traces corresponding to the spectra for May 11. Power spectra for May 12 were very similar to those on May 10, and therefore not plotted.

Several striking features are evident from the spectra in Figure 5. In general, comparing the power levels on each day at each location, one finds that for $f > 10^{-3}$ Hz (1 mHz) the power levels tend to be larger at SPA than at AP5 on both days, and both power levels are larger than at PTA. Also, for frequencies $f < 10^{-3}$ Hz, the power levels (magnetic field and cable) at all locations for May 11 are substantially less (factor of nearly 10 or more) than the power levels measured on May 10 at the same locations. However, for frequencies $f > 10^{-3}$ Hz, with the exception of the SPA location, the power levels are similar on the two days. At SPA, the power levels are suppressed on May 11 compared to May 10 across the entire frequency range plotted. This is also seen in observations taken at a similar latitude location at Davis Station (DVS), Antarctica, where power levels are suppressed across the same frequency range (*B.J. Fraser*, personal communication). There is also more evidence for power enhancements at certain frequencies, especially near $\sim 10^{-3}$ Hz, at SPA than at AP5 or PTA. This is especially the case on May 11. On this day, while discrete frequency power enhancements were suppressed at PTA in comparison to May 10, there was still enhanced power at SPA. The geopotential, a geophysical quantity that is used for sizing power supplies on long distance telecommunications lines, is significantly suppressed on May 11, consistent with the decrease in overhead ionosphere currents.

Nighttime ULF activity was also reported by *Rostoker* [2000] in a latitudinally narrow strip, near 73° MLAT, at Contwoyto Lake, Canada. *Rostoker* [2000] speculated that the start of this activity might be causally related to a substorm onset around 0815 UT. Figure 2 shows that geophysical activity peaked near 0800 UT at SPA, indicating the global scale of this disturbance, even during diminished global magnetic activity. Such activity could be associated with resonant oscillations in the magnetotail [*Rostoker*, 2000; *Liu et al.*, 1995].

Concluding Remarks

We have investigated the ionospheric response during a prolonged interval of extremely low solar wind density us-

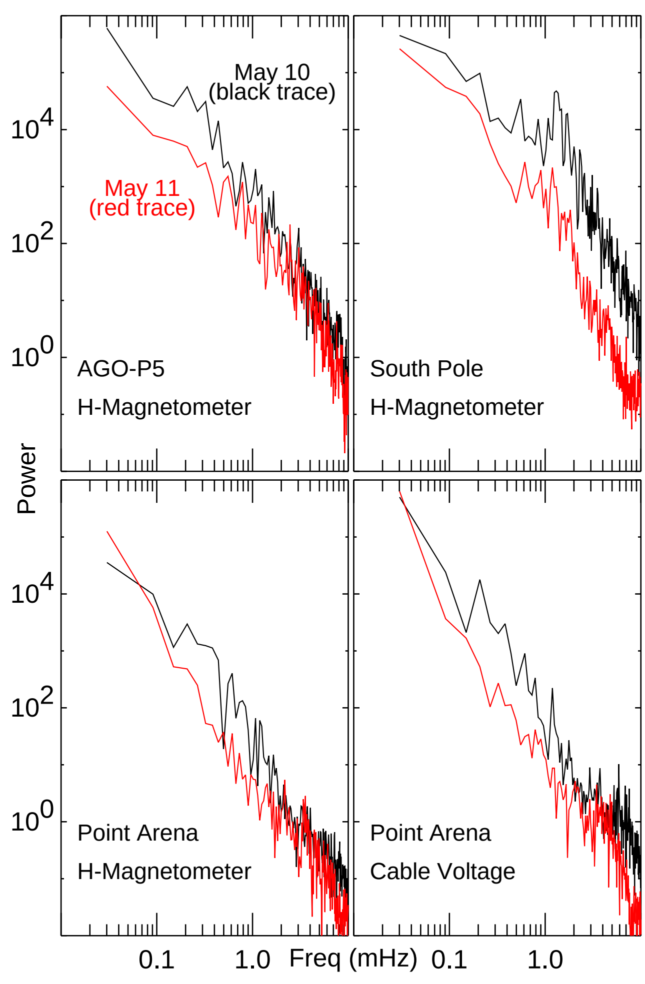

Figure 5. Geomagnetic and geopotential power spectra on May 10 and 11, 1999. Power units are in $(nT)^2$/Hz and V^2/Hz ($\times 10^{-4}$), respectively.

ing ground-based instruments in Antarctica, and compared these results with satellite observations, and low latitude geomagnetic and geopotential recordings. It was shown that the southern hemisphere was geophysically active, even though K_p on May 11 ranged only from 0 to 0+.

Although polar rain was observed in the northern hemisphere by the PIXIE X-ray camera, no evidence of polar rain was seen during brief perigee passes over Antarctica. However, continuous ground-based observations revealed that 630.0 nm emission was pervasive on May 11 in the southern hemisphere, and that more energetic precipitation, as sensed by riometers and 427.8 nm optical instruments, was also present. This could be interpreted as the southern hemisphere extension of polar rain, but the patchy nature of the perturbations and the filamentary precipitation structures observed by HYDRA later in the day, might be more consistent with a polar shower. Such precipitation is usually more structured and contains localized intense electron fluxes that can interrupt polar rain.

An isolated substorm identified in northern hemisphere data by *Rostoker* [2000] near ~ 0815 UT was also observed at South Pole Station. The ULF activity in both hemispheres on this day provides evidence of resonant, global oscillations. Geomagnetic power levels derived from data taken at low, cusp, and polar cap latitudes also showed that magnetic power throughout the Earth on May 11 was lower than on surrounding days, with the greatest suppression occurring at cusp latitudes. However, discrete peaks in power were still evident at these stations, especially at South Pole, and variations in power levels as a function of frequency existed from station to station. The relationship(s) and correlations between power, frequency, and latitude are currently under investigation.

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