A southern high-latitude geomagnetic index: AES-80

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Geomagnetic measurements obtained at McMurdo Station (Arrival Heights) and at two of the U.S. automatic geophysical observatories (AGO-1; AGO-4) are being combined with measurements made at Casey and Dumont D'Urville to construct a Southern Hemisphere geomagnetic index for the geomagnetic latitude 80°S. The calculation of the index is modeled on the calculation of the Northern Hemisphere auroral electrojet index AE and is thus called the AES-80 index.

The AE index was developed to monitor geomagnetic activity at auroral zone latitudes in the Northern Hemisphere (Davis and Sugiura 1966) and indicates the level of auroral electrojet currents and in particular the occurrence of substorms (Baumjohann 1986). It is calculated as the difference between the upper (AU) and the lower (AL) envelope of magnetograms from 12 observatories located at northern geomagnetic latitudes between 60° and 70° and rather uniformly distributed over all longitudes. Because of the land mass distribution in Antarctica, it is impossible to have ground observatories located uniformly at geomagnetic latitudes between 60° and 70°S (*see* figure 1). Unlike in the Northern Hemisphere, however, it is possible in Antarctica to have reasonable ground coverage at 80°S geomagnetic latitude.

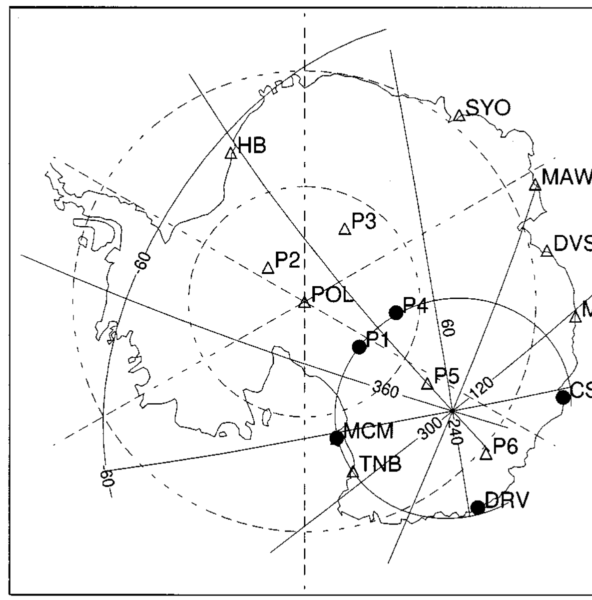

Figure 1. Map of Antarctica, with the stations used to calculate the AES-80 index shown as filled circles.

Data used for calculating the AES-80 parameter are the geomagnetic north-south (H) components at 1-minute resolution from the five antarctic stations shown as filled circles in figure 1, all of which are located at corrected geomagnetic coordinates approximately 80°S (McMurdo, AGOs P1 and P4, Casey, and Dumont D'Urville). [Information about the AGO stations can be found in Rosenberg and Doolittle (1994).] The time period analyzed in this article covers May and June 1994. Where only geographically oriented components (X, Y) were available (Casey and Dumont D'Urville), the geomagnetic H component was calculated via the equation $H = X\cos(\theta) + Y\sin(\theta)$, where θ is the angle between the geographic and geomagnetic direction computed via the GEOCGM program (developed by N.E. Papitashvili and V.O. Papitashvili, and described in Gustafsson, Papitashvili, and Papitashvili 1992) available from the National Aeronautics and Space Administration/Goddard Space Flight Center database. For each station, the average value of H was calculated for the two quietest days of each month and was subtracted from the data. After this subtraction, the H lower (ALS-80) and the H upper (AUS-80) envelopes and their difference were calculated (AES-80 = AUS-80 –ALS-80) at 1-minute resolution, in a manner similar to that used to produce the AE index.

To investigate relationships between AES-80 and AE and the Northern Hemisphere Kp index, Dst, and the IMF-Bz, correlation coefficients have been calculated separately for each 2-hour universal time (UT) time range. Hourly averages were used for all the indices except Kp; the same Kp value was used for each of the 3 hours to which it corresponds. The results are plotted in figure 2, where correlation coefficients for AU and AUS-80 are shown in the top panels, for AL and ALS-80 in the middle panels, and for AE and AES-80 in the bottom panels. The number of data points in each correlation interval for Kp and Dst is between 114 and 122. For the correlations with the IMF-Bz component, the number of data points is much fewer (between 50 and 70) due to limited satellite data availability. (One-hour average IMP-8 data from the U.S. National Space Science Data Center database are used.) The best correlation is found with the Kp index, indicating that both AE and AES-80 are in good agreement with activity on a planetary level. In addition, there is good agreement between AE and AES-80 independent of time (bottom panels). For the AL and AU components, this agreement is less satisfactory; in particular, the correlation of Kp with AUS-80 (top left panel) between about 6 and 22 UT is low.

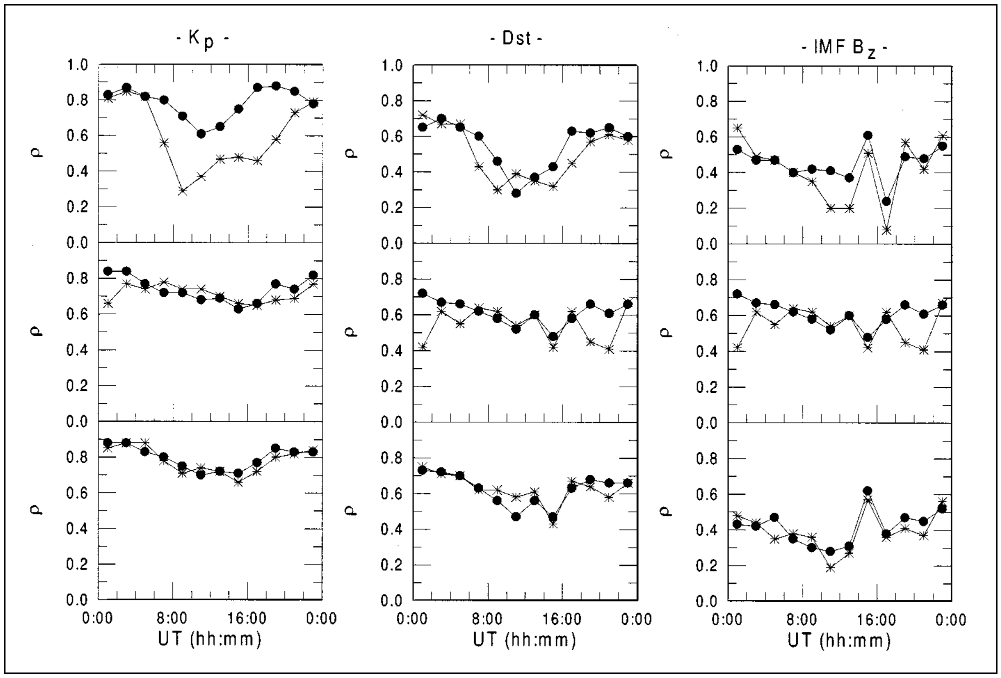

Figure 2. Correlations vs. time of geomagnetic indices with Kp, Dst, and IMF-Bz component; the top panels show correlation coefficients for AU (·) and AUS-80 (*), the middle panels show correlation coefficients for AL (·) and ALS-80 (*), the bottom panels for AE (·) and AES-80 (*); each point is shown at the center of the 2-hour interval to which it refers.

Because the average position of the auroral electrojet is at a lower latitude than that of stations contributing to AES-80, it is expected that, in general, ionospheric currents detected by AES-80 should be of lower intensity than those monitored by AE. To determine whether there are times when the southern index measures a perturbation higher than classical AE, we calculated the hourly ratios between AES-80 and AE to find the percentage of the maximum currents detected by the AE index that are also measured by the southern index. These ratios have been binned into a number of ranges, and the average values of Kp and Dst have been computed separately for the data in each interval. Figure 3 plots the Kp and Dst values vs. the ratio bins for the AES-80/AE ratio. One can see that the quietest periods correspond to data with AES-80/AES greater than 1, implying that when the auroral oval is sufficiently contracted poleward, generally under conditions of Bz positive, AES-80 measures auroral currents better than AE.

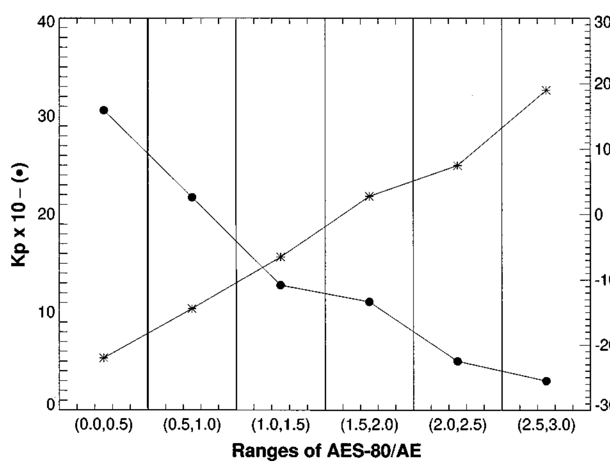

Figure 3. Average values for Kp (·) and Dst (*) for the data binned into the AES/AE ratio ranges indicated on the abscissa. (nT denotes nanoteslas.)

The correlations of AES-80 with Kp, Dst, and Bz in figure 2 indicate that AES-80 can be considered as a global average geomagnetic activity level indicator. The correlations are very similar to those obtained for the AE index at all UT times, indicating a good relationship between the two indices. The main difference is in the AUS-80 parameter in the time range about 6–22 UT, when AUS-80 shows features that differ from AU with respect to their correlations with Kp; these may be related to seasonal dependence or to the distribution of the contributing stations and require further study.

Further, more detailed discussions of the relationships of the AES-80 index to global geomagnetic activity are contained in two papers that have been submitted for publication.

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Long-period hydromagnetic waves at very high geomagnetic latitudes

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Magnetospheric phenomena occurring at the highest geomagnetic latitudes (above approximately 70°) are produced by plasma physics phenomena on the dayside magnetopause and along the boundary of the geomagnetic tail (e.g., Troitskaya and Bol'shakova 1977; McHarg and Olson 1992). Unfortunately, measurements at very high geomagnetic latitudes, whether made in space or on the ground, present difficult challenges—for many different reasons. The plasma phenomena are most often highly localized in space and quite highly time variable on scales ranging from electron and ion gyrofrequencies to bulk plasma flow velocities. The Polar Experiment Network for Geophysical Upper-atmosphere Investigations (PENGUIN) program, using automatic geophysical observatories (AGOs) that are designed for the harsh antarctic environment, was devised specifically to place geophysical investigations at very high latitudes (the 1994 review issue of *Antarctic Journal* contains initial reports from the AGO program). The present AGO program is designed to investigate the latitudinal dependence of magnetospheric and ionospheric phenomena to 90°. The "final" installation of the AGOs includes two locations at approximately 74°S (around Amundsen–Scott South Pole Station), two locations at approximately 80°S, and the fifth and sixth units spanning 90°S latitude, separated by 12 hours in local time.

Active analysis is now in progress to use the acquired data to obtain new understanding of high latitude, upper atmosphere phenomena. Presented in this report is an example of some ongoing research in studies of long-period (approximately 500-second) Alfven waves at these latitudes. Data are presented from the AGO stations P3, P1, and P4, and the South Pole Station (figure 1).

Shown in figure 2 are the results of dynamic power spectral analyses of data (south-north, H, component) from the four stations for 3 March 1995. This day was quiet geomagnetically, with an average K_p=1+. Local noon and midnight are indicated by open and closed triangles, respectively. This day is only one of many being analyzed and is chosen because it illustrates some of the new information that can be derived from such spaced high-latitude locations. Four-second data values for 60 minutes were used to calculate each spectra. Each successive spectra is computed from a data set that has been incremented in time by 15 minutes from the end of the

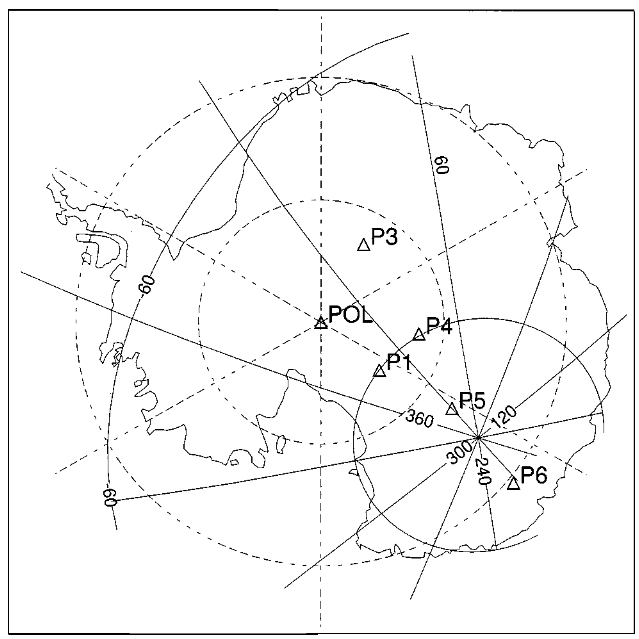

Figure 1. Locations of South Pole and several AGO stations in geomagnetic coordinates.

previous set. Each spectra is calculated using five prolate spheroidal data windows (e.g., Thomson 1982) in the time domain prior to calculating the spectra using a fast Fourier transform algorithm. After calculating a spectrum, a second-order polynomial is fit to the spectra. The fit is then subtracted from the computed spectrum, and the residual values are plotted as gray-coded values in figure 2.

Low decibel (dB) values of the spectra at approximately 1 millihertz (mHz) in all of the panels are artificial "enhancements" in the power, resulting from the subtraction of the quadratic fit to the individual spectra, and should not be interpreted. Such "enhancements" occur in all panels during the nighttime hours, about 20 universal time (UT) to about 03 UT. At P1 and P4, these false power enhancements occur at other times as well, because the geomagnetic fluctuations are quite low during this quiet day at these 80° latitude stations.

Enhancements in power appear at the 80° latitude stations at about 12 mHz around 10 UT and at about 8 mHz near 23 UT. There are also small increases in the power levels between approximately 1 and 2 mHz in the local morning and prenoon hours.

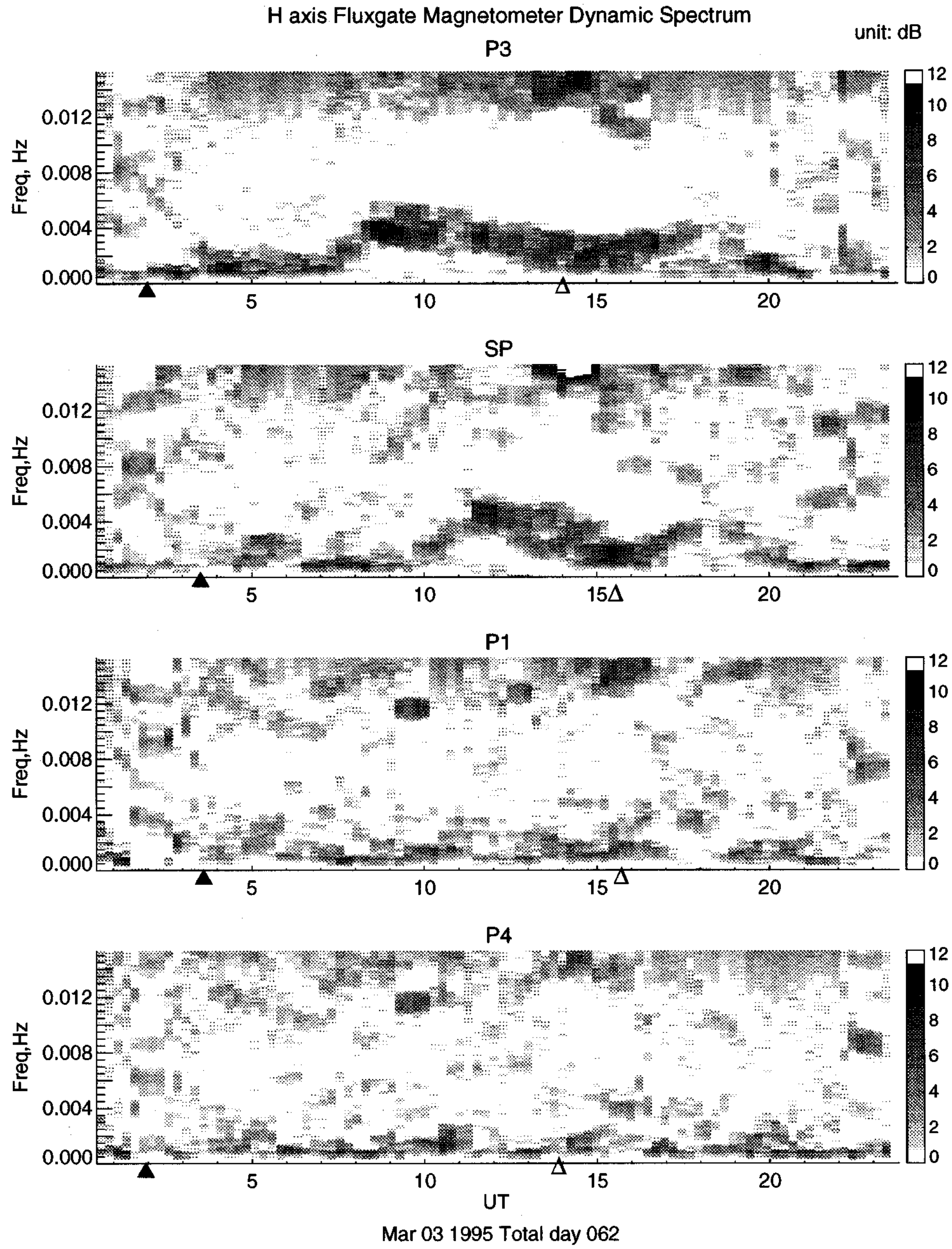

Figure 2. Dynamic spectral analyses of magnetic field fluctuations for 3 March 1995.

The most significant features in the four spectra in figure 2 are the strong enhancements of the power in the range approximately 2 to 5 mHz during the local morning hours at P3 and South Pole. No similar accompanying increases are evident at the higher latitudes at P1 and P4.

Thus, there is a dramatic difference in the dominant frequency in the Earth's space environment over a spatial scale of only about 5° to 6° in latitude. A similar change in frequency across a narrow latitude range was found in studies of Alfven waves in the region of the Earth's plasmapause (e.g., Fukunishi and Lanzerotti 1974), where ground-based data in Quebec and the northeastern United States and in the conjugate region at Siple Station, Antarctica, were used for the investigations. The "disruptions" in the dynamic spectra at P3 and South Pole that occur during hour 17 UT in figure 2 are associated with a switch in direction of the interplanetary magnetic field from a northward to a southward direction (not shown here). Such a shift in field direction produces enhanced geomagnetic activity in the magnetosphere.

Although analysis and interpretations of the new measurements, acquired over a wide range of geomagnetic states of the magnetosphere, are ongoing, it is possible to interpret qualitatively the spatial effects shown in figure 2 as evidence of a spatial gradient in the plasma parameters of the dayside magnetosphere. This gradient is probably the magnetopause. This is similar to the studies of Fukunishi and Lanzerotti (1974), where the plasma gradients they mapped were produced by the plasmapause interior to the magnetosphere. In this study, the higher frequencies seen at the lower latitude stations are characteristic of the frequencies of the "last" closed field lines of the dayside magnetopause under quiet geomagnetic conditions (Samson, Jacobs, and Rostoker 1971). Much of the time difference between the two stations South Pole and P3 when the shift to higher frequency occurs arises from the local time and slight latitudinal differences of these two locations (P3 is at a slightly lower geomagnetic latitude than is South Pole and earlier in local time; see figure 1). Thus, from a local night polar location, station P3 will rotate under the magnetopause and into the closed field, dayside magnetosphere region before South Pole.

The interpretation of the results in figure 2 in terms of the magnetopause boundary is different than that of McHarg, Olson, and Newell (1995) wherein they interpret a narrow-banded feature at approximately 5 mHz obtained by a search coil magnetometer at Svalbard (about the same magnetic latitude as South Pole) in terms of particle precipitation in the magnetospheric cusp region. At this time in our understanding, such a particle precipitation interpretation would not readily account for the facts that the frequency enhancements that we report here are seen both at South Pole and at P3 (which is at a lower geomagnetic latitude than South Pole), and for the frequency shift with local time during the time of observations, especially the decrease in frequency as local noon is approached. These aspects of the new observations are being examined further, as are other similar events that can be used to define the dayside structure of the magnetopause.

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Multistation and conjugate observations of ultra-low-frequency substorm signatures at very high latitudes

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Several recent studies of magnetospheric substorms have attempted to use impulsive ultra-low-frequency (ULF) wave bursts, known as Pi 1 and Pi 2 pulsations (with periods of 1–40 and 40–150 seconds, respectively) as markers of the time of substorm onset. Bösinger and Yahnin (1987), for example, attempted to ascertain whether Pi 1 is a better timer for substorms than Pi 2 because their shorter periods might make it easier to get an onset or maximum time. To study the temporal and spatial characteristics of Pi 1 bursts as a substorm signature, a large-scale array of magnetometers is needed. The U.S. AGO (automatic geophysical observatories) network is one such array. Another array of stations very useful for this type of study is the MACCS (Magnetometer Array for Cusp and Cleft Studies) array in Arctic Canada. Two pairs of nominally conjugate stations are Amundsen–Scott South Pole Station and Pangnirtung and AGO P1 and Clyde River.

Magnetometer data from antarctic stations including four AGOs, South Pole Station, and McMurdo Station, which are all equipped with search coil magnetometers, were studied in search of Pi 1 events as described by Heacock (1967). In this article, we focus on data in the frequency range from 0 to 1,000 millihertz (mHz) from 18:00 universal time (UT) on 7 May 1995 to 04:00 UT on 8 May 1995. Many Pi 1 bursts occurred throughout this 10-hour interval, which was characterized by large values of the planetary Kp index (4–5) and a high solar wind velocity [700–800 kilometers per second (km/sec)]. The most powerful burst, which occurred near 23:30 UT, was seen at all stations except McMurdo, which is located much farther west than the other stations. Since this burst is the most powerful and extends well beyond 500 mHz at the AGOs and South Pole, it will be the focus of further investigation.

Many stations in the Northern Hemisphere observed similar activity as that seen in Antarctica on 7–8 May 1995. Six of these are MACCS stations that are equipped with fluxgate magnetometers. The stations near 75° magnetic latitude include Cape Dorset, Coral Harbour, and Pangnirtung. Those near 79° magnetic latitude include Gjoa Haven, Pelly Bay, and Clyde River. All of these stations recorded the Pi 1 burst near 23:30 UT, but it was clearly stronger at the 75° stations. The 79° stations observed a much weaker burst, which became more faint as one moved westward across the chain of stations.

Figure 1 shows summed power over 300–500 mHz vs. universal time. Each graph summarizes 2 hours of data centered around midnight UT on 7 May 1995 for the five antarctic stations that see the Pi 1 activity near 23:30 UT. The time of the first large, sharp peak is indicated on each graph. The timing between stations is shown below the AGO P4 graph. One can see, pairs with similar latitude near 80° occur within 1 minute of each other. The pairs near 70° magnetic latitude occur more than 6 minutes apart. The pairs with similar longitude show that the Pi 1 burst occurs first at the 70° stations and then propagates poleward.

Figure 2, which is of the same format as figure 1, shows the Arctic MACCS stations for the same interval. The pattern that is seen in the Antarctic is seen here as well. The Pi 1 bursts seen at the MACCS stations near 80° MLAT occur within 10 seconds of one another. These 80° stations range over 55.9° of magnetic longitude. The bursts at the 75° stations, ranging over 30.6° longitude, occur over a much larger timescale, with a delay of on the order of 1–4 minutes.

Although the timing of this Pi 1 burst is interesting among stations within a hemisphere, it is also very important to study the timing between conjugate stations. To get the timing needed, we compare figure 1 and figure 2. The first conjugate pair, Pangnirtung and South Pole, occur about 45 seconds apart. The second pair, Clyde River and AGO P1 occur about 30 seconds apart. This example day with nightside Pi 1 activity indicates that such activity occurs nearly simultaneously at conjugate sites near both 75° magnetic latitude (MLAT) and 80° MLAT.

Previous studies of midlatitude stations using the Air Force Geophysics Laboratories (AFGL) midlatitude chain across the United States starting in the 1970s have shown that the Pi 1 bursts had the same onset time at many different nighttime longitudes (Knecht and Singer 1981). This simulataneous onset time does not appear to be the case at high-latitude arrays such as MACCS and the U.S. AGO network where, as shown above, onset times at stations with similar latitudes

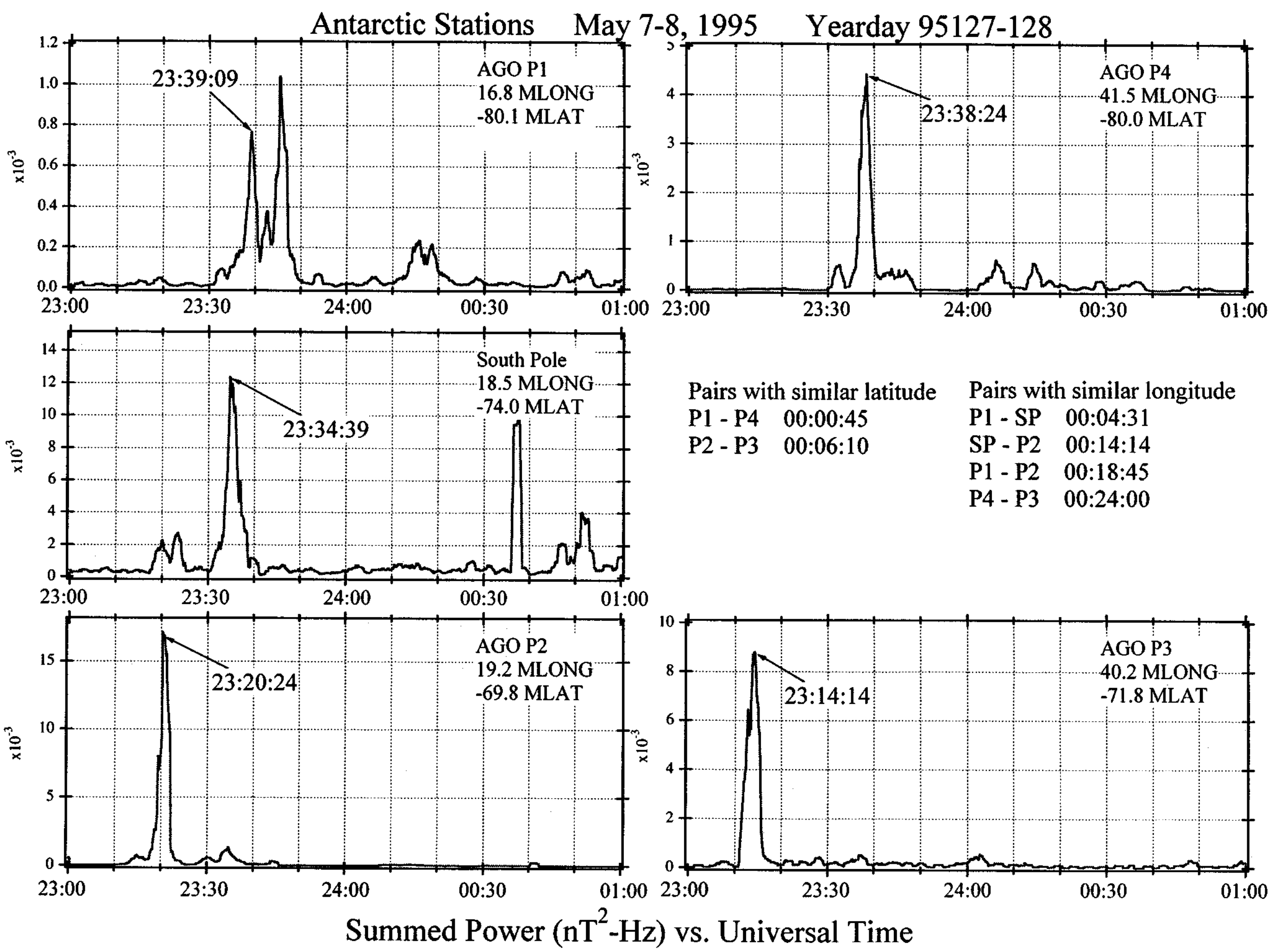

Figure 1. Graphs showing summed power over 300–500 mHz vs. Universal Time. Each panel summarizes 2 hours of data centered around midnight UT on 7 May 1995 for the five antarctic stations that observe the Pi 1 activity near 23:30 UT. The time of the first large, sharp peak is indicated on each graph. The timing between stations is shown below the AGO P4 graph. (MLONG denotes magnetic longitude. nT2-Hz denotes nanoteslas squared-hertz.)

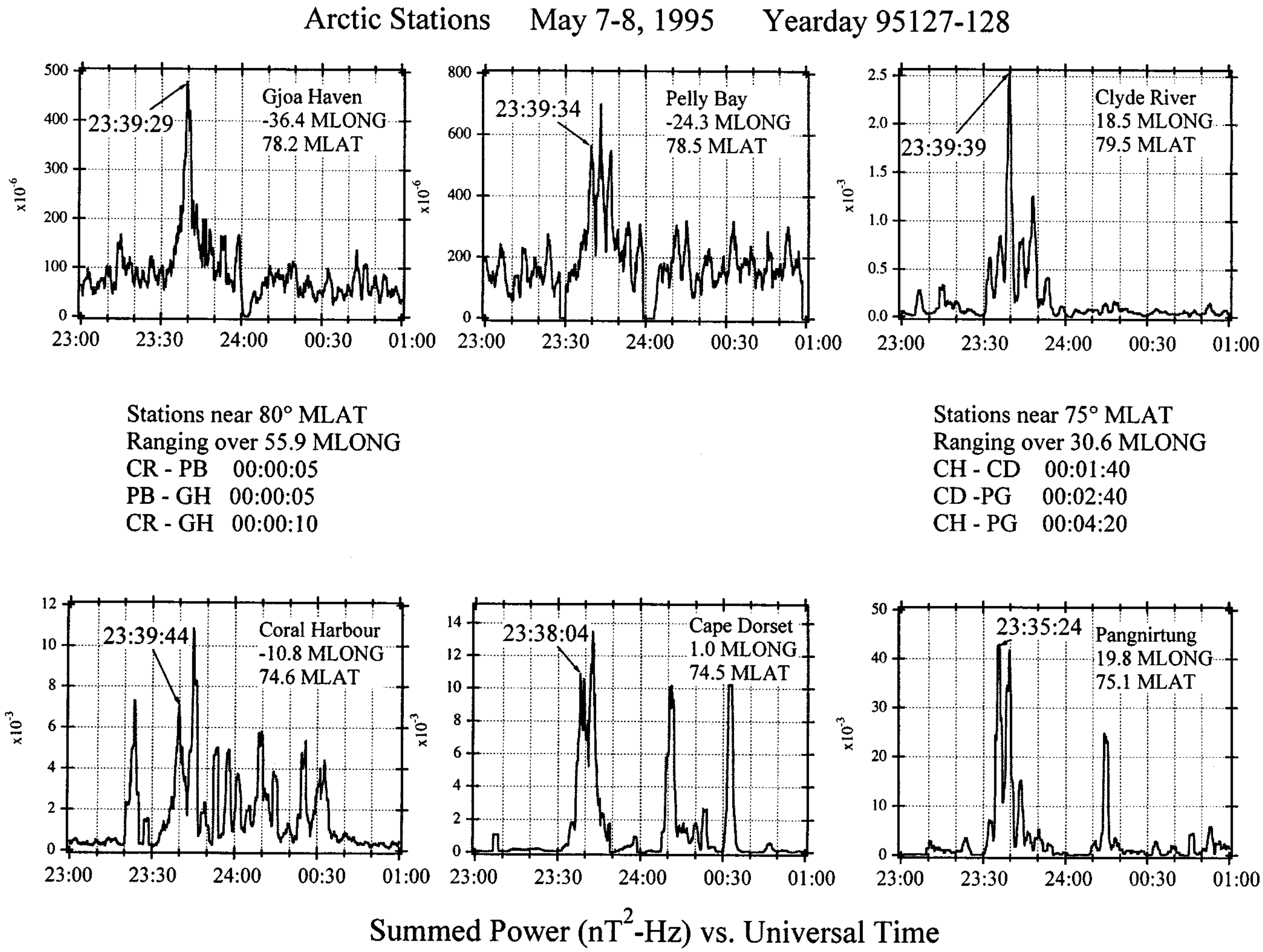

Figure 2. Graphs as in figure 1 showing the data from Arctic MACCS stations. The Pi 1 bursts seen at the MACCS stations near 80° MLAT occur within 10 seconds of one another. These 80° stations range over 55.9° of magnetic longitude. The bursts at the 75° stations, ranging over 30.6° of longitude, occur over a much larger scale with a delay on the order of 1–4 minutes. (MLONG denotes magnetic longitude. nT^2-Hz denotes nanoteslas squared-hertz.)

and different longitudes may vary from 10 seconds to 6 minutes, depending on the latitude of the chain of stations. Onset times at stations with similar longitudes and different latitudes varied by as much as 24 minutes (figure 1). This latitudinal effect of the Pi 1 burst onset time could just be the auroral motion poleward after break-up as suggested by Kokubun et al. (1988). This example has also shown that activity does not occur simultaneously at sites with different latitudes or longitudes. Important to note, however, is that stations near 80° MLAT varied less in time (approximately 1 minute or less) than stations near 70°–75° MLAT, which varied by as much as 6 minutes.

Possibly, Pi 1 could serve as a ground signature of ion cyclotron waves that are believed to be the source of the anomalous resistivity of the auroral acceleration region. Further study of the conjugate Pi 1 bursts to look for seasonal effects will be needed to understand more fully the importance of the simultaneous nature of Pi 1 bursts.

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Conjugate magnetic substorm occurred deep in both the southern and northern polar caps

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Magnetic disturbances caused by magnetospheric substorms are the most prominent near magnetic midnight at latitudes of the auroral oval. Morphologically, they are divided into the substorm growth, expansion, and recovery phases. The substorm onset separates the growth and expansion phases. At that time, the DP1 westward auroral electrojet ("substorm current wedge") develops near midnight, and it can be well determined from auroral magnetograms.

The question of how deep into the polar cap the substorm current wedge can progress is still unresolved. Some evidences indicate that substorms can occur deep in the polar caps during quiet (i.e., northward interplanetary magnetic field, IMF) conditions (e.g., Nielsen et al. 1988). Sergeev, Yakhnin, and Dmitrieva (1979) have also shown that magnetic substorms usually can take place deep in the polar cap when the solar wind speed is significantly high [velocity (V) greater than 500 kilometers per second (km s^{-1})]. Another evidence of a substormlike event has recently been reported by Weatherwax et al. (1997) from the riometer observations made by the U.S. antarctic automatic geophysical observatories (AGO) at the corrected geomagnetic (CGM) latitude (Φ) equaling approximately –80°. A conjugate substorm development occurring deep in both the southern and northern polar caps has not yet been reported, however.

In 1994–1996, a cooperative project was undertaken to deploy and operate digital magnetometers at the permanent Russian antarctic stations Mirnyy and Vostok. Two additional autonomous magnetometers were also deployed at the antarctic sites called Sude (approximately 170 km southward from Pionerskaya) and Komsomolskaya by the Russian Antarctic Expedition snow traverse on the route from Mirnyy to Vostok (Musko, Clauer, and Papatashvili 1995). All sites are revisited annually.

This chain is magnetically conjugate to the northern portion of the Greenland magnetometer arrays (Clauer et al. 1995; see also figure 1 in Papitashvili et al. 1996). This allows us to investigate geomagnetic disturbances occurring simultaneously deep in both the southern and northern polar caps. We report here an event around 02 universal time (UT) on 6 May 1995 when the magnetic substorm occurred in both polar caps at Φ approximately 80°, but the IMF was southward, the solar wind velocity was high (V equaling approximately 700 km s^{-1}), and the planetary geomagnetic activity index (Kp) was 5_+.

During the reported event, the IMF B_{zs} equaled approximately –5 nanoteslas (nT) during the preceding hour (figure 1). Figure 2 shows magnetic disturbances (horizontal components H and E, vertical component Z) in the data obtained from stations Nord (Greenland) and Sude (Antarctica). These stations are located at Φ = ±81° in the early morning sector (the local magnetic midnight occurred at these stations at approximately 20 UT). One can see a simultaneous development of the magnetic disturbances in both polar caps; this simultaneity is unusual because the magnetic field lines at these stations are generally considered to be open rather than closed, but the analysis presented here supports the latter.

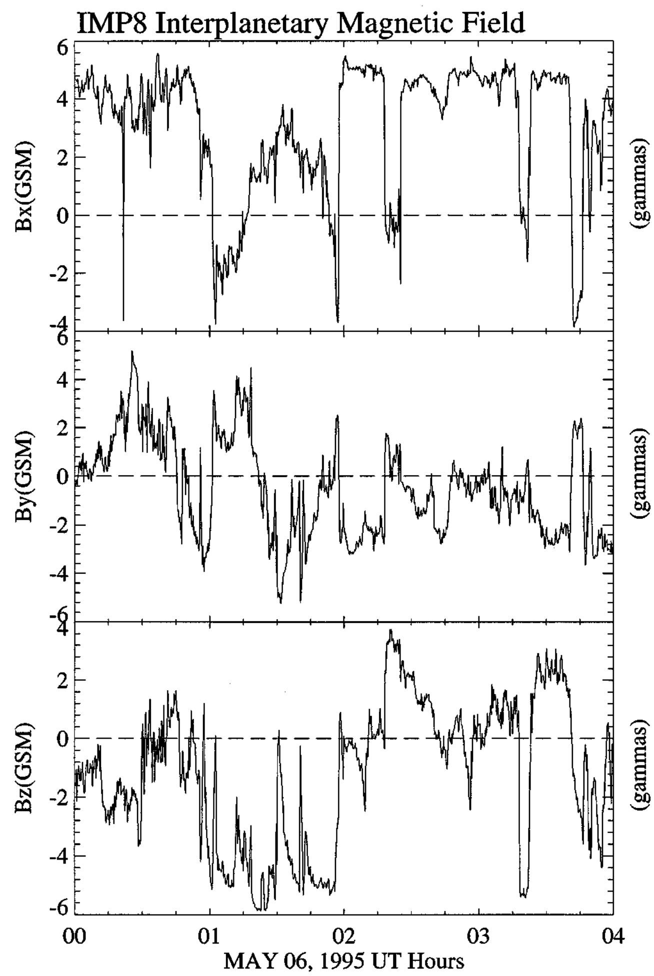

Figure 1. The IMP 8 spacecraft observations of the IMF B_x, B_y, and B_z components from midnight to 04 UT on 6 May 1995.

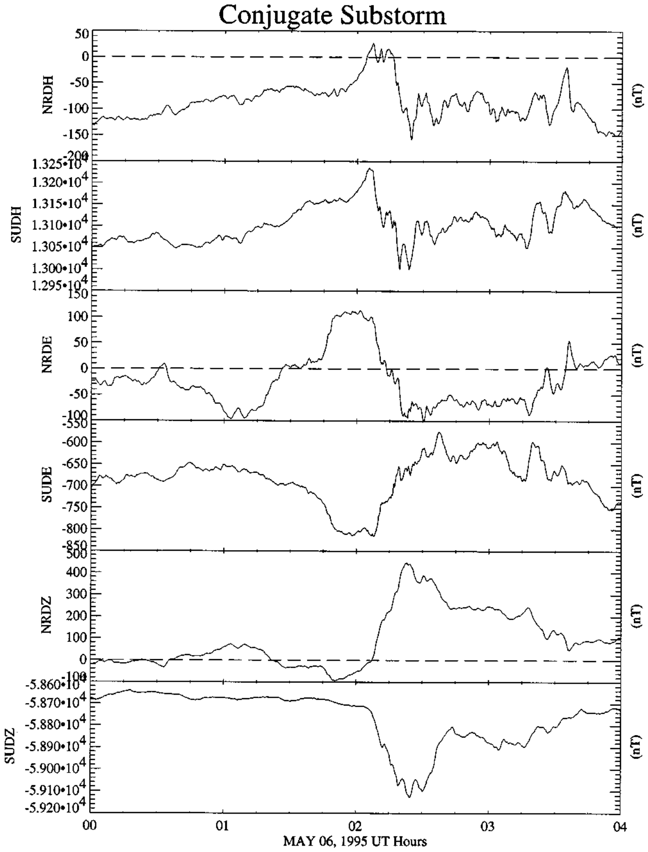

Figure 2. The H, E, and Z component magnetic variations observed at Greenland station Nord (NRD) and antarctic station Sude (SUD) from midnight to 04 UT on 6 May 1995.

In total, six spikelike northward fluctuations are observed in the IMF after its southward turn at 00:45 UT; the IMF turned northward again at 01:56 UT. The Greenland west coast stations located near magnetic midnight (occurring at approximately 02 UT) show clearly the poleward progression of a magnetic substorm from auroral latitudes to the deep polar cap. The first substorm onset occurred at 01:18 UT at auroral latitudes; this onset corresponds to the IMF B_{ZS} fluctuation at 01:04 UT. Ground Z component variations show that the DP1 electrojet was located at Φ equal to approximately 69°; the substorm recovery phase lasts until approximately 02:05 UT.

Combined analysis of Greenland and antarctic high-latitude magnetometer data (e.g., west coast Greenland stations and antarctic stations Vostok, Sude, and AGO P1 and P4) confirms that this substorm progressed poleward simultaneously in both polar regions. The second substorm onset occurred at Φ equal to approximately 73° on 01:21 UT; the third at Φ equal to approximately 75° on 01:30 UT; and the fourth at Φ equal to approximately 78° on 01:45 UT. The last significant IMF excursion occurred at 01:56 UT; the IMF turned to be near 0 and then northward. This excursion is clearly manisfested on the ground magnetograms from the higher latitude Greenland and antarctic stations (Φ equals approximately 78–85°) as a substormlike disturbance occurred on 02:07 UT. This observation is also supported by a sharp enhancement in ionospheric absorption observed by the AGO P1 and P4 riometers (Weatherwax personal communication) and a significant brightening over the all-sky camera "field-of-view" at AGO P4 (Frey personal communication). The Defense Meteorological Satellite Program (DMSP) satellite F12 shows strong precipitating particles over the southern polar cap exactly at 02:07 UT (Rich personal communication).

Based on the observations presented here, we conclude that field-aligned currents driving intense, nearly conjugate, substorm electrojets may develop in the midnight sector at high CGM latitudes (approximately 80°) in both the northern and southern polar caps at the peak of the expansion phase. According to the Tsyganenko T89c magnetospheric field model (*http://nssdc.gsfc.nasa.gov/space/cgm/ext.html*), the magnetic field lines from approximately 80° magnetic latitude near midnight go far into the magnetospheric tail to distances of 70–80 R_E (Earth radii) during the conditions of high geomagnetic activity ($Kp=5_+$). Thus, we may infer that these high-latitude magnetic field lines may actually be closed at the peak of the substorm expansion phase.

We plan a further study of these very-high-latitude conjugate geomagnetic disturbances. Particularly, we plan to use data from other high-latitude magnetometers in both hemispheres identifying the regions over which disturbances are observed and mapping these regions to the outer magnetosphere.

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All-sky imager observation of aurora and airglow at South Pole Station

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Since 1957, when Amundsen–Scott South Pole Station was opened as one of the key stations for the International Geophysical Year (IGY), the National Institute of Polar Research (NIPR) has processed auroral image data from South Pole Station; data have been provided to NIPR by the University of Alaska and Utah State University (NIPR 1995). NIPR has acted as the World Data Center (WDC) C2 for aurora since 1980.

Until now, image gathering has been done using an all-sky-camera and 35-millimeter (mm) film. We have developed an all-sky optical imager (ASI), which was installed at South Pole Station during the 1996–1997 austral summer season. ASI is a highly sensitive (monochromatic and panchromatic) optical imager with high spatial and time resolutions. ASI is a digital CCD (charge coupled device) imager. Its digital image data can be stored and easily archived in a computer, so that users can access the data through a computer network. The ASI instrument at South Pole Station itself is being monitored and controlled via satellite by an NIPR computer in Japan.

The South Pole is a unique place for an auroral observation during austral winter season. We can observe

- the dayside polar cusp/cleft aurora connected to the direct entry of the solar wind,
- afternoon aurora closely associated with the night-side magnetospheric storm/substorm activities, and
- the polar cap aurora, depending upon the polarity of the interplanetary magnetic field.

It remains an open question how the polar cap aurora is causally connected to the night-side high-latitude aurora, although various studies have been done since the IGY in 1957. Furthermore, the South Pole is a singular point of the Earth's rotation, so its location also provides us with a unique opportunity to observe the airglow and, thus, to study effective multiwavelength (i.e., at different altitudes) characteristics of acoustic gravity waves at the polar region. With a recent improvement in the CCD imager sensitivity, the optical observations of aurora have been noticeably developed. These kinds of observational investigations cannot be performed in the Northern Hemisphere because there is no observational site on land. It is evident that the ground-based optical imagings of aurora/airglow can distinguish temporal and spatial changes of the phenomena; these two types of changes cannot be separated in the in situ observations by the rockets and satellites. To investigate the physical causalities of these geophysical phenomena, however, the data analysis of ASI at South Pole Station will be closely coordinated with the satellite experiments. High-frequency radars at Halley Bay, Sanae, and Syowa Station also give us the velocity vector of ionospheric plasma over the South Pole. Automatic geophysical observatories (AGOs), developed in the polar cap region of Antarctica, will be coordinated with ASI data gathered at South Pole Station. NIPR has installed an all-sky camera at Chinese Zhongshan Station, Antarctica, located on the polar cap. These international collaborations will contribute to greater understanding of the magnetosphere, ionosphere, and upper/middle atmosphere physics.

The ASI is equipped with interference filters for auroral emissions of N_2^+ (nitrogen molecule ion first negative band) 427.8 nanometers (nm), OI (oxygen green line) 557.7 nm, and OI (oxygen red line) 630.0 nm. An OH (730 nm) filter was also assembled, and a panchromatic image can be obtained without the filter. An objective lens is a Fisheye Nikkon with F 1.4 and f=6 mm. The image sensor is a back-illuminated air-cooled CCD camera with 512×512 pixels. The time required to read out a full frame is only 1.2 seconds. The field test of the ASI was carried out at the Zao Observatory of Tohoku University on the night of 10 October 1996. The OI 557.7 nm airflow emissions were imaged every 2 minutes at an exposure time of 60 seconds. On that night, the ASI could detect a moving wave structure on the OI 557.7-nm images with a spatial extent of as small as about 4 kilometers, in addition to large-scale structures of a few tens of kilometer. This detection level is a new finding of the atmospheric gravity-wave phenomena.

After this field test, the ASI was sent to the South Pole. S. Okano and M. Okada had been at the Amundsen–Scott South Pole Station in November 1996. They installed the ASI with the glass radome on the highest roof of the Sky Tower.

With help from Chris Cleavelin of Antarctic Support Associates, who took care of our instrument at South Pole Station, we started the operation (initial performance tests) of the ASI in April 1997. We found some malfunctions of the workstation/digital linear tape drive. After we fixed this problem, normal observations have been carried out from June, and all operations of the ASI were shut down on 2 September 1997. The special campaign in cooperation with high-frequency radar network (called SuperDARN) were successfully carried out 16–20 June, 15–19 July, and 1–5 and 14–17 August 1997.

The initial scientific results have been reported at the Sapporo Meeting in October 1997 and also at the American Geophysical Union Fall Meeting in December 1997. Sample data are already available on the Web site (*http://www.nipr.ac.jp/~asi-dp*), which will be updated after receiving all the data (digital linear tapes).

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High-resolution infrared spectroscopy at South Pole and McMurdo Stations

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The University of Denver operates two Fourier transform infrared (FTIR) spectrometers on the continent of Antarctica. These instruments have been upgraded in the last 2 years. The Amundsen–Scott South Pole Station instrument, installed in 1995, is an emission spectrometer capable of atmospheric observations during both the austral winter and summer. The instrument at McMurdo Station, installed in 1996, is a solar absorption instrument in use during the austral summer.

South Pole Station operations

The University of Denver Atmospheric Emission Radiometric Interferometer–Extended (AERI-X) was installed in the annex of Antarctic Submillimeter Telescope and Remote Observatory (AST/RO) at South Pole Station in December 1995 by John Olson and Renate Van Allen. In December 1996, John Olson and Linda Wigoda (a high school teacher from St. Charles, Louisiana, participating in the National Science Foundation Research Opportunity Awards program) traveled to South Pole Station to perform routine maintenance and calibration tasks. As of this writing, the instrument has collected data over two austral winters and parts of two austral summers.

AERI-X is a Michelson-type interferometer that is described in detail in Olson et al. (1996). This instrument detects atmospheric emission in the range of 650–1,250 inverse centimeter (cm^{-1}) with a spectral resolution of 0.1 cm^{-1}. This region includes an atmospheric transmission window, at 12 microns, allowing for the quantification of stratospheric constituents, including nitric acid (HNO_3) and water vapor (H_2O). This analysis uses an atmospheric line-by-line model. A comparison between calculated emission spectra and observed spectra, is presented in figure 1.

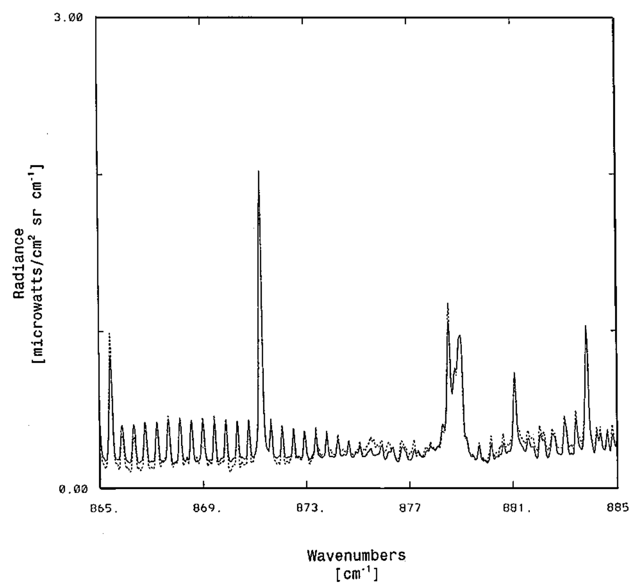

Figure 1. Clear-sky emission spectrum from the South Pole on 26 February 1996, taken at 82.5° zenith angle. Expanded view of the 12-micron window, showing emission lines of nitric acid (HNO_3) and water vapor (H_2O). Solid line: calculated spectrum. Dashed line: measured spectrum.

A consistent series of observations using the AERI-X allows for the study of seasonal variability of important stratospheric constituents. For example, figure 2 shows the denitrification of the stratosphere in the austral fall and the subsequent slow recovery of HNO_3 during the austral spring in 1996 (*see also* Van Allen, Liu, and Murcray 1995). A paper on the observed denitrification in connection with the dehydration of the atmosphere is in preparation.

The spectral range of the AERI-X instrument also encompasses two of the carbon dioxide (CO_2) emission bands, at 11.1 and 15 microns. These bands, important in radiative transfer calculations, may also lead to methods for atmospheric sounding. By careful analysis, these bands may be used to retrieve the temperature profile of the atmosphere as a function of altitude.

The AERI-X represents an improvement over previously deployed instruments. This improvement is rather broad

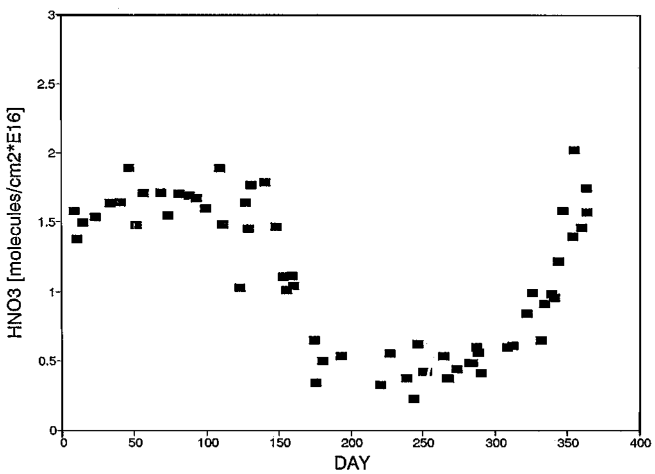

Figure 2. The seasonal variation of nitric acid (HNO_3) vapor over the South Pole in 1996.

based. Earlier instruments of this type had a resolution of 1 cm^{-1} (Van Allen, Murcray, and Liu 1996), and although these instruments performed well, higher spectral resolution benefits both studies involving stratospheric chemistry and radiative transfer measurements. Data are now collected continuously rather than twice a day. This improved time resolution allows for a complete monitoring of changes developing over the course of hours.

McMurdo Station operations

An FTIR spectrometer has been operated on Arrival Heights since 1989 by the University of Denver. This instrument is operated in the Antarctic New Zealand observatory by their science technicians. Until December of 1996, a Bomem DA-2 was in operation there. This instrument was replaced at that time by a Bruker 120m FTIR spectrometer. The new instrument is capable of solar absorption measurements in the spectral region 800–5,000 cm^{-1} at a spectral resolution of 0.0025 cm^{-1}, a factor of four better than the older instrument. The Bruker instrument uses two detectors and five optical filters to span this spectral region. This replacement was motivated by the desire to install a more versatile instrument capable of obtaining a higher resolution data set. The Bruker instrument was installed at the Antarctic New Zealand observatory at Arrival Heights in December 1997 by Thomas M. Stephen and Shaima Nasiri (an undergraduate National Science Foundation Research Experience for Undergraduates participant) from the University of Denver and Steve Wood and John Robinson of the National Institute of Water and Atmosphere, Crown Research Institute, New Zealand.

The solar absorption instrument at Arrival Heights differs from the previously discussed AERI-X instrument at a very fundamental level. The AERI-X measures the emission of radiation from molecules present in the atmosphere; therefore, the atmosphere itself is the source. The Bruker instrument is configured to measure the absorption of radiation by molecules in the atmosphere. It generally uses the Sun as a spectral source, although the Moon can also be used after some modification to the instrument. A solar absorption spectrometer is much more sensitive to trace gas constituents, can be used to profile a wide variety of atmospheric species (Nakajima et al. in press), and is generally better able to provide column amounts for a variety of atmospheric constituents. It is the accurate determination of total column amounts of stratospheric constituents that is a driving force for this research for the Network for the Determination of Stratospheric Change (for general information on this program see the Web page at *http://climon.wwb.noaa.gov*).

The new spectrometer has been in operation for less than a year now, 3 months of sunlight. It is still undergoing a "shake-down" period. Preliminary results of observations of chlorine nitrate ($ClONO_2$) during the austral spring will be presented at the 1997 Winter American Geophysical Union (AGU) meeting.

Conclusions

New instruments have been installed at South Pole Station and at McMurdo Station. These instruments will allow for a higher temporal density of data taken at higher resolution. The high resolution obtained by these instruments will allow for more intensive modeling efforts in both the fields of atmospheric chemistry and radiative transfer.

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