Geophysical Institute
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Imaging FPI Observations of Thermospheric Dynamics in Antarctica

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Abstract

During the austral summer of 2015 - 2016 the Geophysical Institute of the University of Alaska Fairbanks installed all-sky imaging Fabry-Perot spectrometers in Antarctica at the United States' South Pole and McMurdo Sound research stations. Both of these sites are located at geomagnetic latitudes corresponding to the equatorward edge of the polar cap under quiet to moderate levels of geomagnetic activity. As of June 2017, they have each collected 1.5 seasons of observational data. Between 2007 and 2014 the South Pole instrument was located at different site: Mawson, Antarctica. Mawson is at a lower geomagnetic latitude and lies within the auroral oval during quiet to moderate levels of activity. These data sets allow us to compare how the transition from the auroral oval to the polar cap affects thermospheric wind circulation under a range of activity levels. The behavior of this transition is examined here, by forming and comparing statistical average wind fields from the three sites. McMurdo and South Pole observations from the 2016 winter season show mostly uncomplicated wind fields blowing roughly anti-sunward at all local times. These data are heavily biased toward geomagnetically quiet conditions. By contrast, winds above Mawson are more complex, even under quiet conditions.

Antarctic Scanning Doppler Imager Instruments

In the mid 1990's the University of Alaska's Geophysical Institute developed a new type of Fabry-Perot spectrometer for remote sensing thermospheric wind and temperature fields. Installed at Poker Flat in Alaska and dubbed the "Scanning Doppler Imager" (SDI), its salient features included a low-light imaging detector with high time resolution, a capacitance-stabilized etalon capable of piezo-electric separation scanning at $5\,\mathrm{Hz}$ or faster, and wide-angle fore optics arranged to place a sharp image of the sky onto the detector [*Conde & Smith*, 1995, 1997, 1998]. The instrument resolves the sky scene into a software-defined set of sub-regions, and compiles a high-resolution Doppler spectrum of the source illumination originating from each one. These spectra are then used to infer two-dimensional maps of vector wind and scalar temperature at the height of the atmospheric optical emission layer. Low-resolution monochromatic all-sky images of the aurora are also obtained as a by-product of the spectral acquisition process.

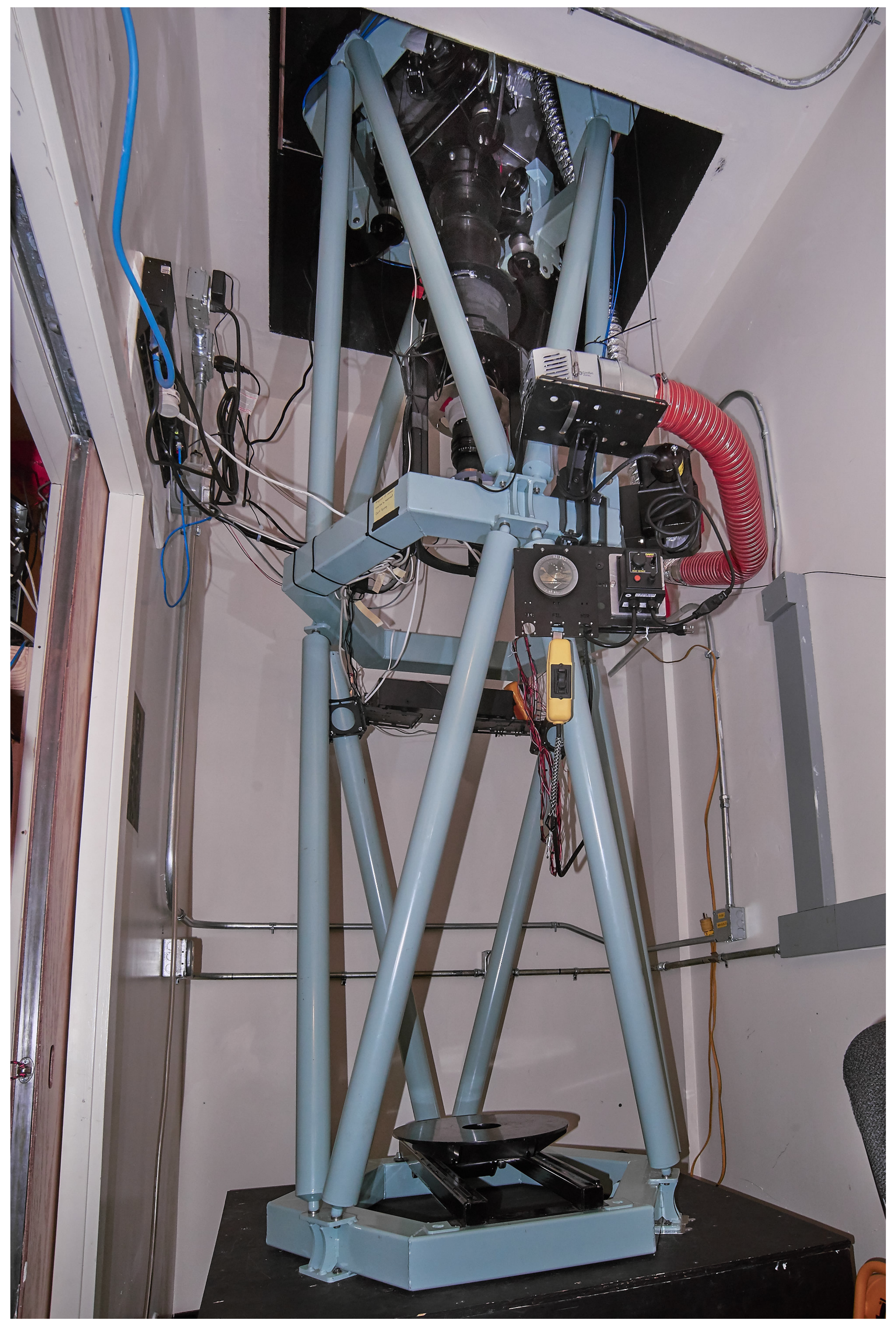

Figure 1: The SDI instrument operating at Amundsen-Scott South Pole Station.

A number additional instruments have subsequently been built and deployed elsewhere. Here we focus on comparison of SDI wind observations from three sites in Antarctica: McMurdo, South Pole, and Mawson. The geographic and geomagnetic coordinates of these three sites are tabulated below. The three stations are ordered from the highest magnetic latitude (McMurdo) to the lowest (Mawson.) Figure 1 is a photograph of the SDI currently operating at the South Pole, whereas Figure 2 is a map showing where the three SDI instruments used here were located relative to the Antarctic continent.

Name	Geo Lon	Geo Lat	Mag Lon	Mag Lat
McMurdo	166.666667	-77.85	-32.8876	-79.9353
South Pole	0.0	-90.0	18.8357	-73.9615
Mawson	62.873889	-67.602778	89.7768	-70.1198

Table 1: Geographic and Geomagnetic Locations of the SDI Instruments

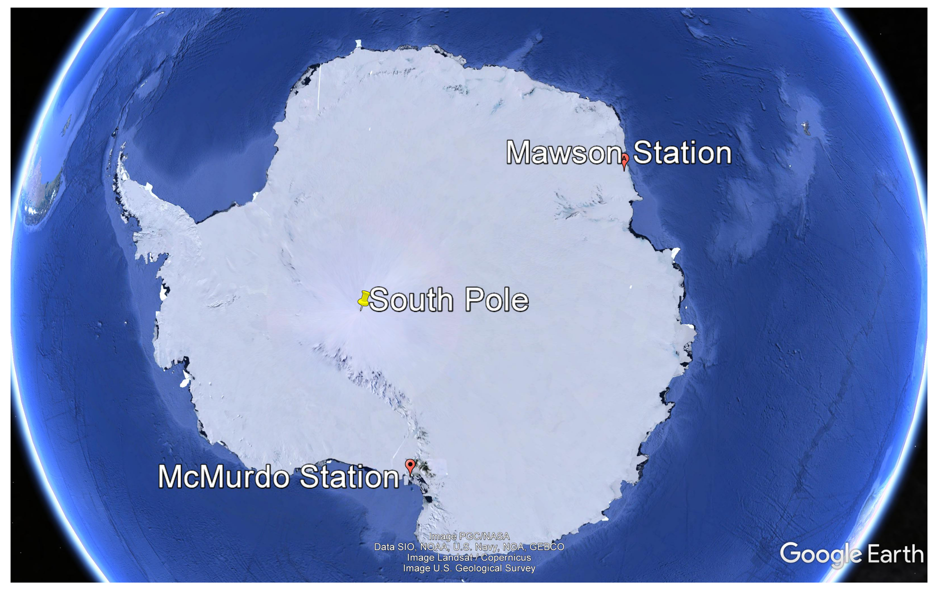

Figure 2: Geographic map of Antarctica, showing the locations of the SDI sites at McMurdo, South Pole, and Mawson stations.

Scientific Motivation

The reason for this comparison is motivated by the work of Emmert et al. [2008], in which they developed their "Disturbance Wind Model" of upper thermospheric winds derived from observations by seven ground-based FPIs, DE-2 WATS, and UARS-WINDII. Figure 3 below (adapted from this paper) shows the variation of thermospheric zonal and meridional "disturbance winds" as a function of magnetic latitude and magnetic local time. These data are roughly indicative of K_p 5 conditions in the upper thermosphere. The feature to note is the large shear in zonal wind that occurs poleward of roughly $\pm 70^\circ$ magnetic latitude at times of dawn and dusk (06 and 18 hours mlt, respectively.) It is due to the transition from sunward zonal winds at auroral latitudes to antisunward flow in the polar cap.

As can be seen from the above table, our three SDI sites nicely span the range of magnetic latitudes over which this shear occurs, and should be ideally suited for studying it in detail observationally. Similar instrumentation has been operating in Alaska for many years, but the Alaskan north coast does not allow us to place an instrument at a high enough geomagnetic latitude to study this shear zone as effectively as we can do in Antarctica.

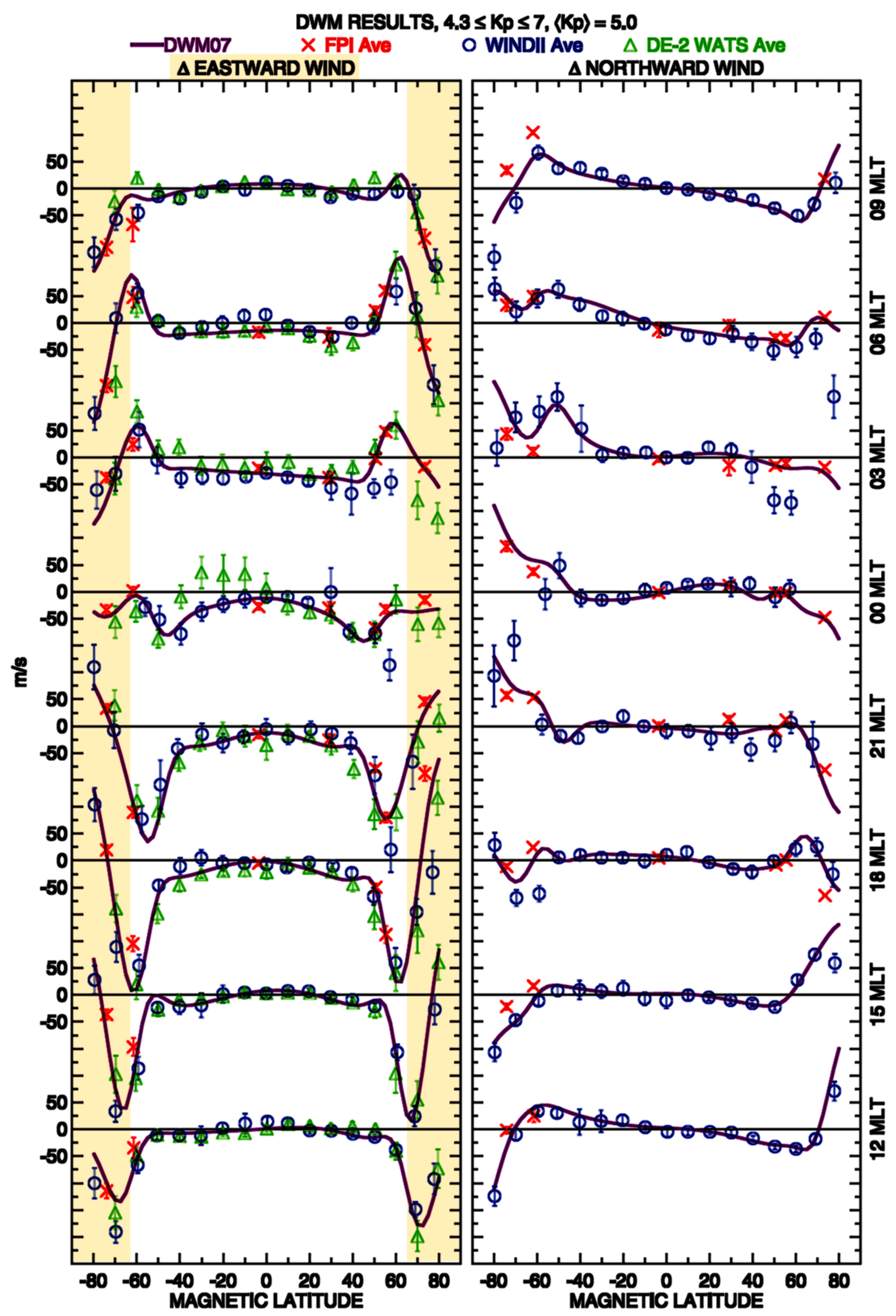

Figure 3: Zonal and meridional winds from the Disturbance Wind Model. Adapted from Figure 7 of Emmert et al. [2008]

Data Sets

For each of the SDI instruments used here, data from $630\,\mathrm{nm}$ spectra were assimilated from multiple observing nights to enable calculation of statistical average wind fields. These winds are indicative of conditions at a height of approximately $240\,\mathrm{km}$. For the newly-deployed SDI instruments at McMurdo and South Pole, the data used here were acquired during the austral winter of 2016. Mawson data were comprised of 5,482,643 observations taken between 2011 and 2013, from 572 separate observing nights. The assimilation software used various quality indicators calculated from the spectra and from the fitted winds to automatically filter out periods of poor instrumental performance, low signal, or cloudy skies.

Figure 4 presents histograms showing the statistical distributions of the A_p geomagnetic index and the $10.7\,\mathrm{cm}$ solar radio flux during the times covered by the "good" observations used from each instrument. As can be seen, the distribution of magnetic activity was similar for all instruments. However, the Mawson data were acquired during years 2011 to 2013, which were close to solar maximum, so the distribution of the $F_{10.7}$ index contains many more instances of high values in the Mawson data.

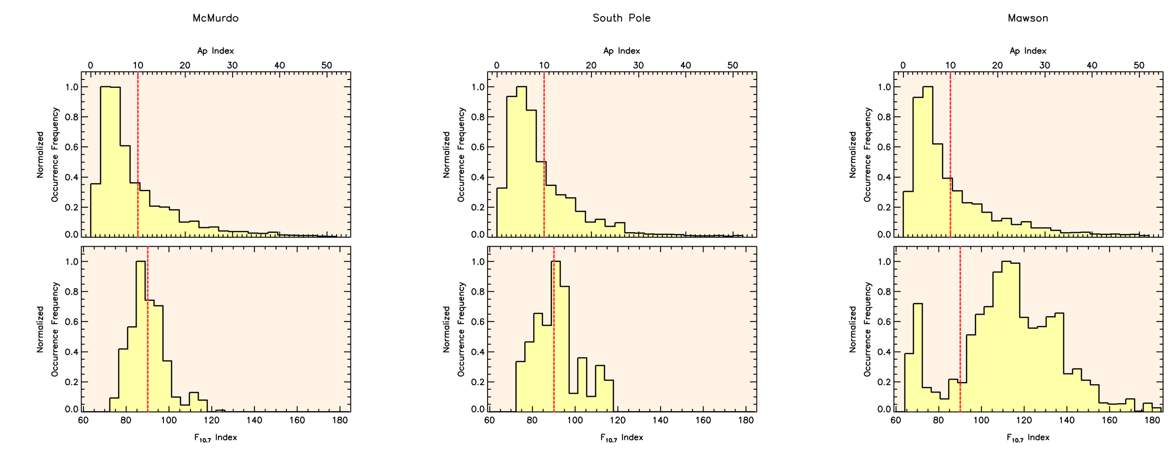

Figure 4: Distributions of geophysical indices A_p and $F_{10.7}$ during the observing periods sampled by the three SDI instruments. Vertical dashed red lines are for reference; they indicate $Ap = 10$ and $F_{10.7} = 90$ in the upper and lower panels respectively.

Figure 5 presents and example of vector wind fields derived from $630\,\mathrm{nm}$ spectra observed from McMurdo and South Pole SDI at 06:42 UT on 04-May-2016, along with SuperDARN ion convection vectors and an extended map of the auroral forms that were occurring at this time. The small yellow dot in this figure indicates the longitude of the sub-solar point. A line from it to the south geographic pole indicates the anti-solar direction on this plot, which is evidently aligned approximately with the general direction of wind flow above both South Pole and McMurdo stations.

Our observing cadence allows us to generate plots like Figure 5 every few minutes, which we typically assemble into movies to provide an overview of the wind behavior. Results of examining many days of such movies show that:

- Overall thermospheric winds generally blow anti-sunward above both McMurdo and South Pole although, at times of elevated auroral activity, ion-neutral coupling can cause the winds to deviate from this alignment and instead swing around to blow parallel to the local ion convection direction as indicated by SuperDARN. Figure 5 shows some indication of this happening above McMurdo; the winds appear to deviate to the left of the anti-sunward direction, and instead align with SuperDARN ion convection vectors.
- Winds above Mawson respond far more directly to ion-drag forcing. Ion drag can completely reverse the tidally-driven antisunward flow, especially in the dusk local time sector, if there is strong sunward ion motion and bright aurora occurring over Mawson.

These behaviors are consistent with the predictions of Figure 3, in which the large shears in zonal wind poleward of 70° magnetic latitude at dusk and dawn indicate a transition from sunward wind at auroral latitudes to antisunward flow in the polar cap.

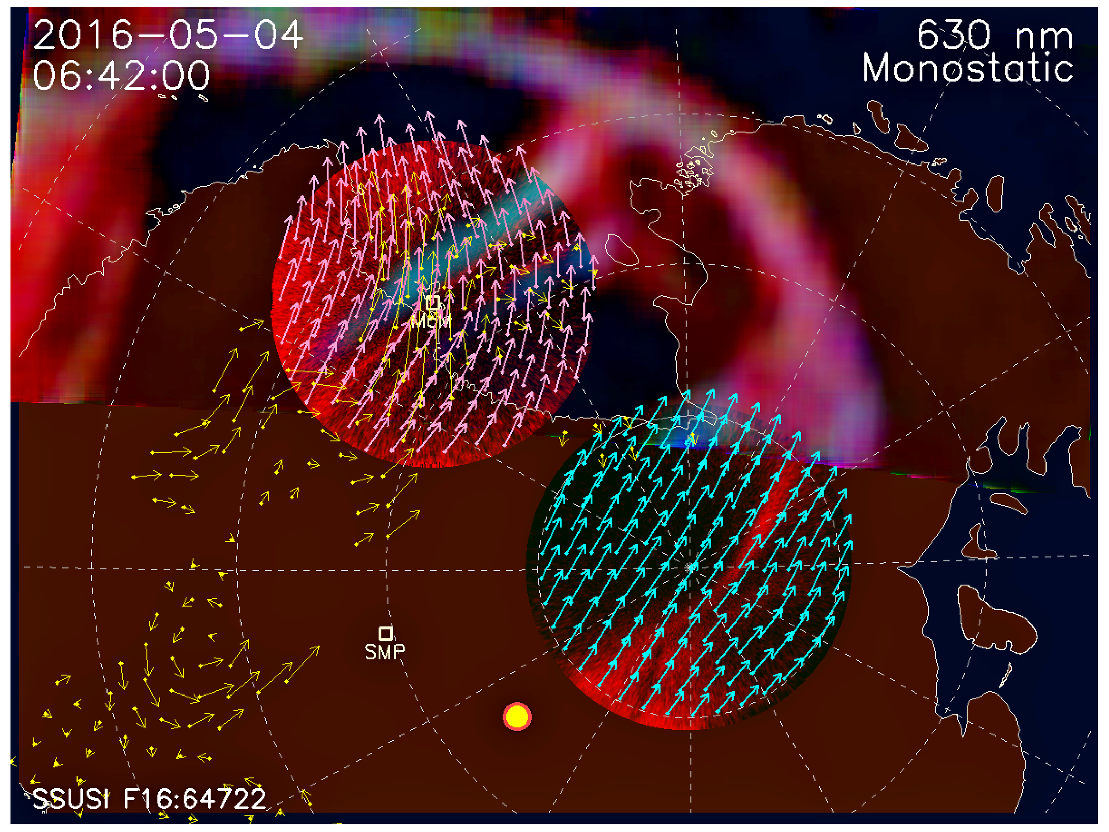

Figure 5: Vector wind fields (pink and blue arrows) derived from the McMurdo and South Pole SDI data at 06:42 UT on 04-May-2016. Yellow arrows depict ion velocities inferred from observations by the SuperDARN radar network. The background auroral image is a montage assembled from DMSP-SSUSI data plus the low-resolution all-sky images of the aurora taken by the SDI instruments themselves. The yellow dot indicates the longitude of the sub-solar point at this time.

Average Wind Fields

To further test whether the shears shown in Figure 3 are a common feature of thermospheric winds in the geomagnetic latitude band covered by our SDI instruments, we compiled the average wind fields shown in Figure 6. The data were sorted into four categories, based on quiet and disturbed activity levels of both the A_p and $F_{10.7}$ indices. Here we show only the data for periods when both indices had low values (left column) or both indices had high values (right column.) Our data sets corresponded mostly to quiet conditions, so "high value" indices in these figures are at most indicative of moderately disturbed conditions.

Presented in this form, the shear behavior predicted by Figure 3 is not apparent. Winds above both McMurdo and South Pole blow antisunward on average, with slight deviations around this direction. Winds above Mawson are also often antisunward, although here the flow can reverse easily under appropriate auroral conditions. The right-side "active" panel for Mawson clearly shows that this behavior occurs often enough during the dusk local time sector for antisunward flow to be prominent, even on average. However, it does not develop as easily in the dawn sector, and shows no corresponding dawn signature in the averages. Examination of intermediate activity levels in the (much larger) Mawson data set shows that antisunward flow develops on the dusk side in response to even very modest auroral conditions.

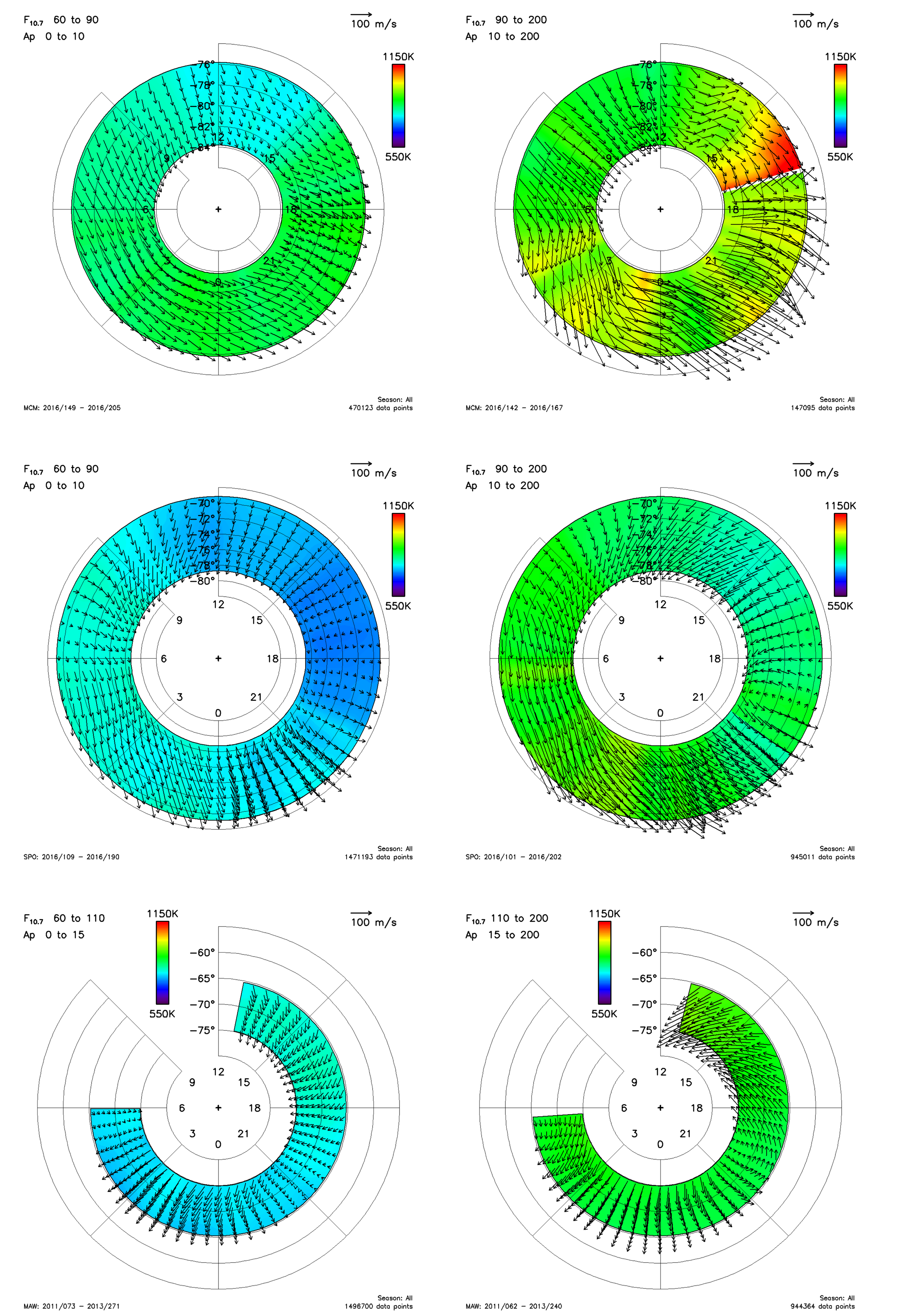

Figure 6: These panels show average wind fields for McMurdo (top), South Pole (middle) and Mawson (bottom). The left column shows winds derived from averages of data recorded under very quiet conditions ($A_p < 10$ and $F_{10.7} < 90$). The right column shows averages for data recorded when $A_p > 10$ and $F_{10.7} > 90$. Although these conditions are more disturbed than those of the left column, index histograms in Figure 4 show that the actual data sets available here did not contain many highly disturbed periods. The format is in magnetic latitude and local time coordinates, with the antisunward direction aligned down the page at all times, and the poleward direction points inward toward the center of the circles. Background colors indicate average temperatures derived from Doppler widths of the $630\,\mathrm{nm}$ spectra.

Conclusions

Our original question was whether our SDI instruments would verify the existence of the strong shears seen in Figure 3 poleward of 70° geomagnetic latitude during local times of dusk and dawn under active geomagnetic (K_p 5) conditions. Taken together, the average wind fields shown in Figure 6 do suggest this shear is common in the dusk sector, and would typically occur between the latitudes of Mawson and McMurdo. But no such corresponding shear was found on the dawn side. This is not unexpected; many studies have shown that the dawn-side cell of the high-latitude the ion convection pattern is far less effective at imprinting a corresponding circulation into the neutrals than is possible at dusk. This is because the Coriolis force reinforces the dusk cell, whereas it disrupts the dawn cell. And, indeed, although Figure 3 does predict prominent shear should occur at both dusk and dawn, the dawn shear Figure 3 is shown to be weaker. These preliminary results are based on only one year of data from McMurdo and South Pole, and do not contain many instances of highly disturbed conditions. It is expected that as activity increases we may see shears extending above South Pole and even perhaps McMurdo, but we will need a number of years more data to verify this expectation.

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References: Conde, M. & R. Smith (1995), *GRL*, 22, 3019-3022; Conde, M & R. Smith (1997), *Appl. Opt.*, 36, 5441-5450; Conde, M. & R.Smith (1998), *JGR*, 103, 9449-9471; Emmert, J. et al. (2008), J. *Geophys. Res.*, 113, A11319, doi:10.1029/2008JA013541.;