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Seasonal Dependence of High Latitude Upper Thermospheric Winds:

A Climatological Study Based on Ground and Space Based Instruments

Manbharat S. Dhadly[1]

[1] National Research Council Postdoctoral Fellow
Space Science Division, Naval Research Laboratory, Washington DC, USA

John T. Emmert[2], and Douglas P. Drob[2]

[2] Space Science Division, Naval Research Laboratory, Washington DC, USA

Motivation

- To understand how the quiet-time northern high latitude upper thermospheric (F-region, 200-300 Km) wind circulation respond in magnitude and shape to the changes in seasons.

- Previous seasonal climatological studies (e.g. Killeen et al., [1995], Aruliah et al. [1996], Fejer et al. [2002], Emmert et al. [2006a], Emmert et al. [2006b], etc.) have focused on either:

  ⇛ nighttime climatology or data from individual instruments or limited spatial coverage.

- Ionospheric plasma motions are naturally organized by the geomagnetic field and ion drag is one of the primary drivers of neutral winds at high latitudes; this leads to better organization of neutral winds in geomagnetic coordinates than in geographic coordinates.

- Over the past decade or so, thermospheric wind empirical databases have grown in size to allow accurate representation of both dayside and nightside geomagnetically quiet ($Kp<3$) northern high latitude horizontal wind patterns as a function of season, latitude, and local time in magnetic coordinates.

- In this study, we combined almost all the wind data available (ground-based and space-based optical remote sensing, and in situ measurements) from northern mid to high latitudes to empirically model winds in magnetic coordinates.

- This is the first comprehensive study of high latitude winds by data assimilation in magnetic coordinates.

Neutral Wind Data Sets Used

Data Distribution (TOTAL 12 INSTRUMENTS)

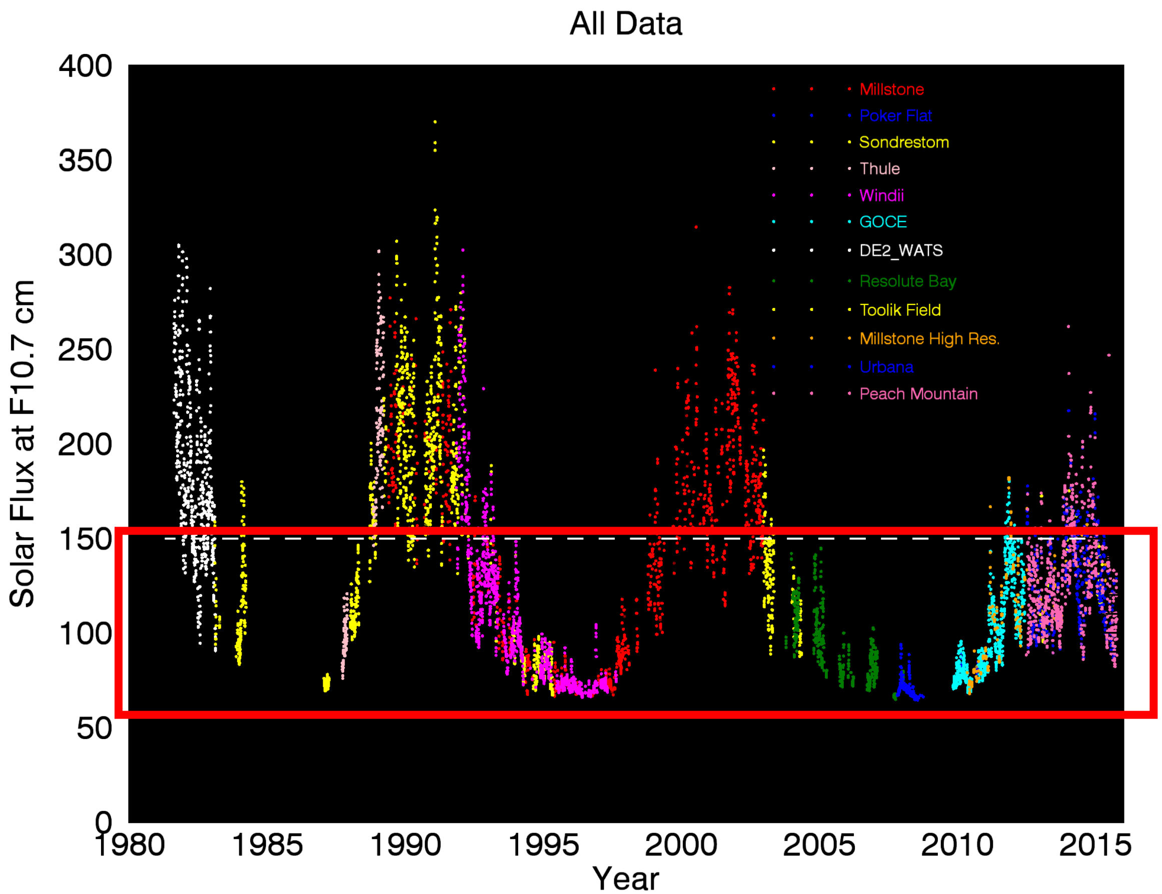

Figure 1: Time distribution of all the empirical data available from 12 instruments. Note that there is a significant overlap between the observations from various instruments.

9 Ground based FPI's and 3 Space based instruments

Acknowledgement: Thanks to our data providers

Kp < 3, F10.7 ≤ 150, ALT:210-320 km

Ground Based station	Magnetic Latitude	Years of Data	Days	Data Points
Thule FPI	84.6 N	1987	57	4949
Resolute Bay FPI	83.4 N	2004-2007	216	8176
Søndre Strømfjord FPI	73.3 N	1983-1984 87-95, 02-04	566	26708
Toolik Field SDI	68.3 N	2012-2014	198	123801
Poker Flat SDI	65.2 N	2010-2012	303	114933
Millstone Hill FPI	53.1 N	1990-2002	533	13267
Millstone High Res FPI	53.1 N	2010-2015	229	11564
Peach Mountain FPI	52 .1 N	2012-2015	507	32968
Urbana FPI	51.1 N	2007-2008 2012-2015	648	53621

Space Based Instrument	Years of Data	Days	Data Points	Data points MLAT > 45
DE2 WATS	1981-83	100	16823	4781
GOCE	2009-12	574	211351	51203
WINDII 557.7 nm	1991-96	348	75835	15465
WINDII Red Line	1991-96	118	31051	2053

Seasonal Data Distribution (1980-2015)

(Kp < 3, F10.7 ≤ 150, Magnetic Coordinates)

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First data selected for quiet time period:

Kp < 3
F10.7 ≤ 150

Then divided data into three seasons:

December solstice:
Nov, Dec, Jan, Feb

Equinoxes:
Mar, Apr, Sep, Oct

June Solstice:
May, June, July, Aug

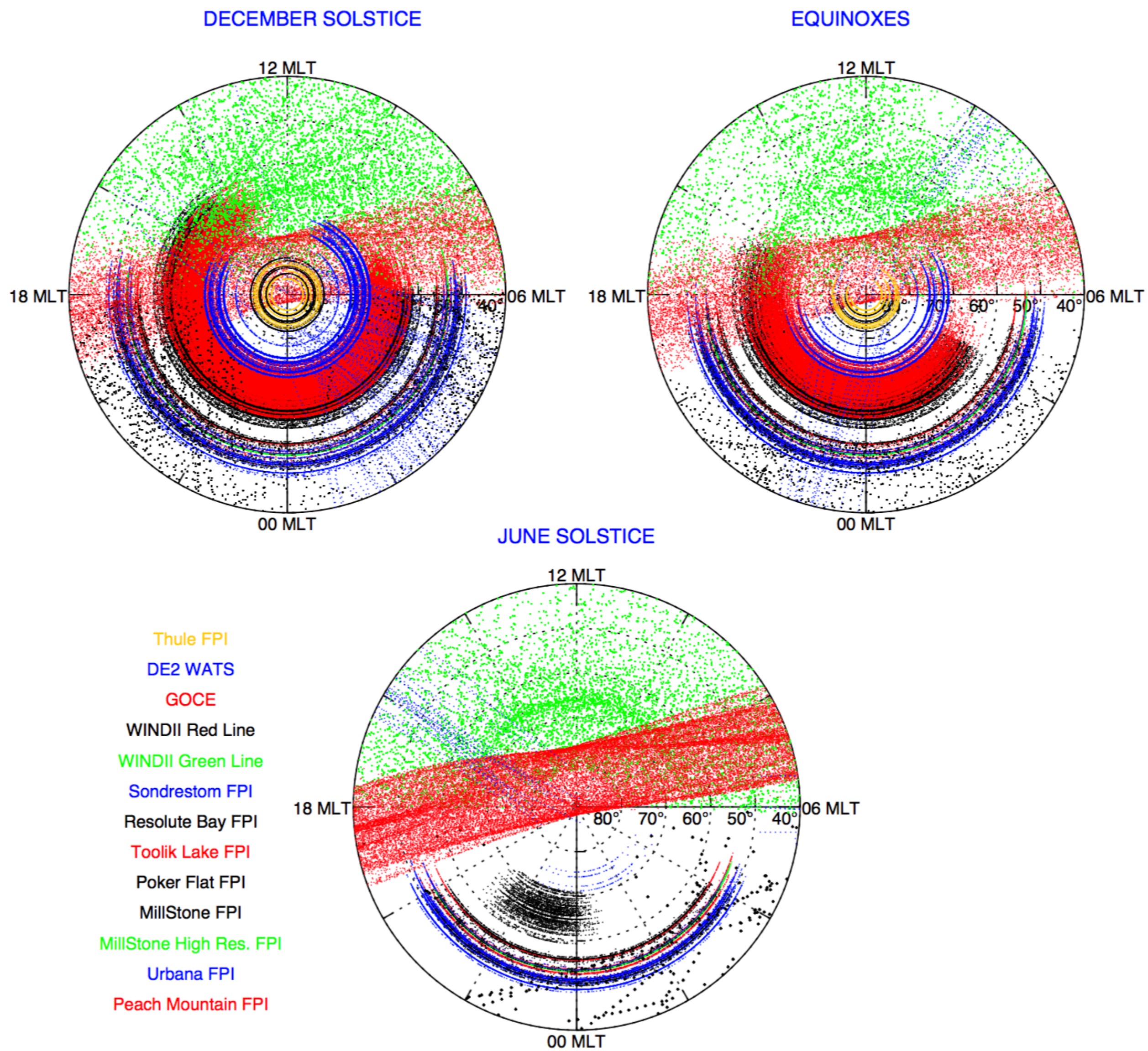

Figure 2: Seasonal distribution of all the data sets used as function of magnetic latitude and local time.

Methodology: Empirical Model Formulation

- We used Vector Spherical Harmonic (VSH) functions *[Swarztrauber, 1993] to* model winds as a function of latitude and local time in magnetic coordinates.

- Quasi-Dipole (QD) coordinates from *Richmond [1995]* were used for the magnetic coordinate system.

- The choice of magnetic coordinates is based on the fact that the high latitude upper thermospheric winds are strongly organized in magnetic coordinates.

- Model wind fits were produced at a resolution of degree 18 in magnetic latitude and order 10 in magnetic local time.

- This latitude and local time resolution is sufficient to represent the structural and dynamic features of high latitude neutral convection (such as strong latitudinal gradients in zonal winds that exist at the equatorward edge of the high latitude circulation and antisunward cross-polar jets in the polar cap) without any obvious spurious variations where data coverage is limited.

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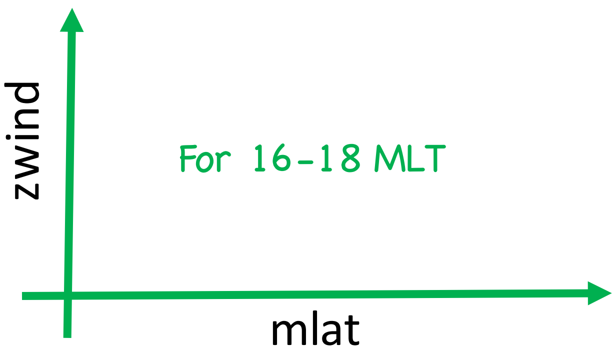
Model Validation: Compare Model Output with its Constituent Data

Model cut: Wind as a function of MLAT



Binplot: Wind as a function of MLT

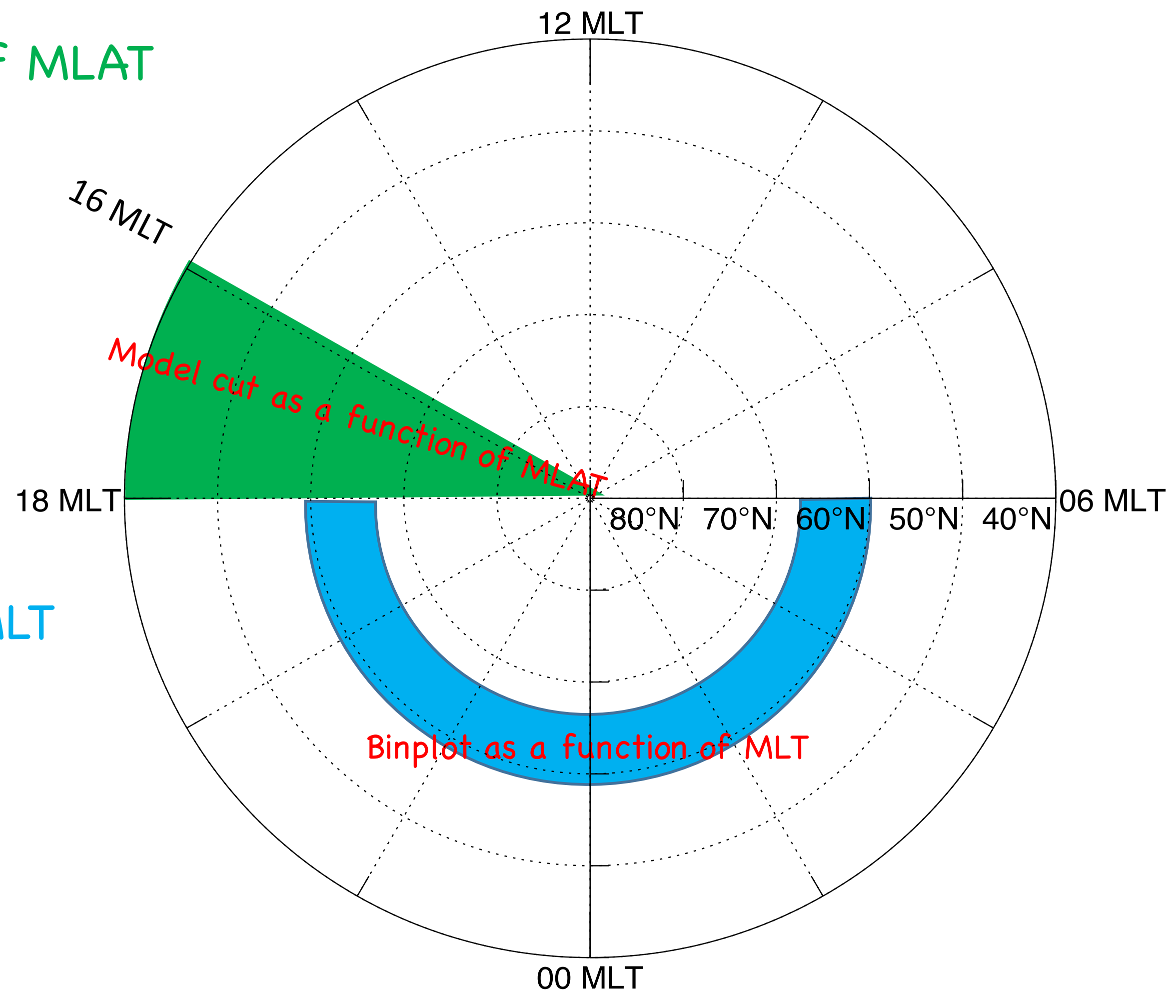


Figure 5: Artistic representation of a binplot and model cut. A model cut is a plot showing time averaged wind as a function of latitude. A binplot is a plot showing latitudinal averaged wind as a function of local time.

Seasonal Model Cuts (Zonal Wind)

STA_INST = TH_FPI
STA_INST = RB_FPI
STA_INST = SS_FPI
STA_INST = UARS_WINDII_RED
STA_INST = UARS_WINDII_GREEN
STA_INST = TF_FPI
STA_INST = PF_FPI
STA_INST = MR_FPI
STA_INST = MH_FPI
STA_INST = DE2_WATS
STA_INST = MODELED_WIND

Zonal wind as a function of latitude (Geomagnetic)

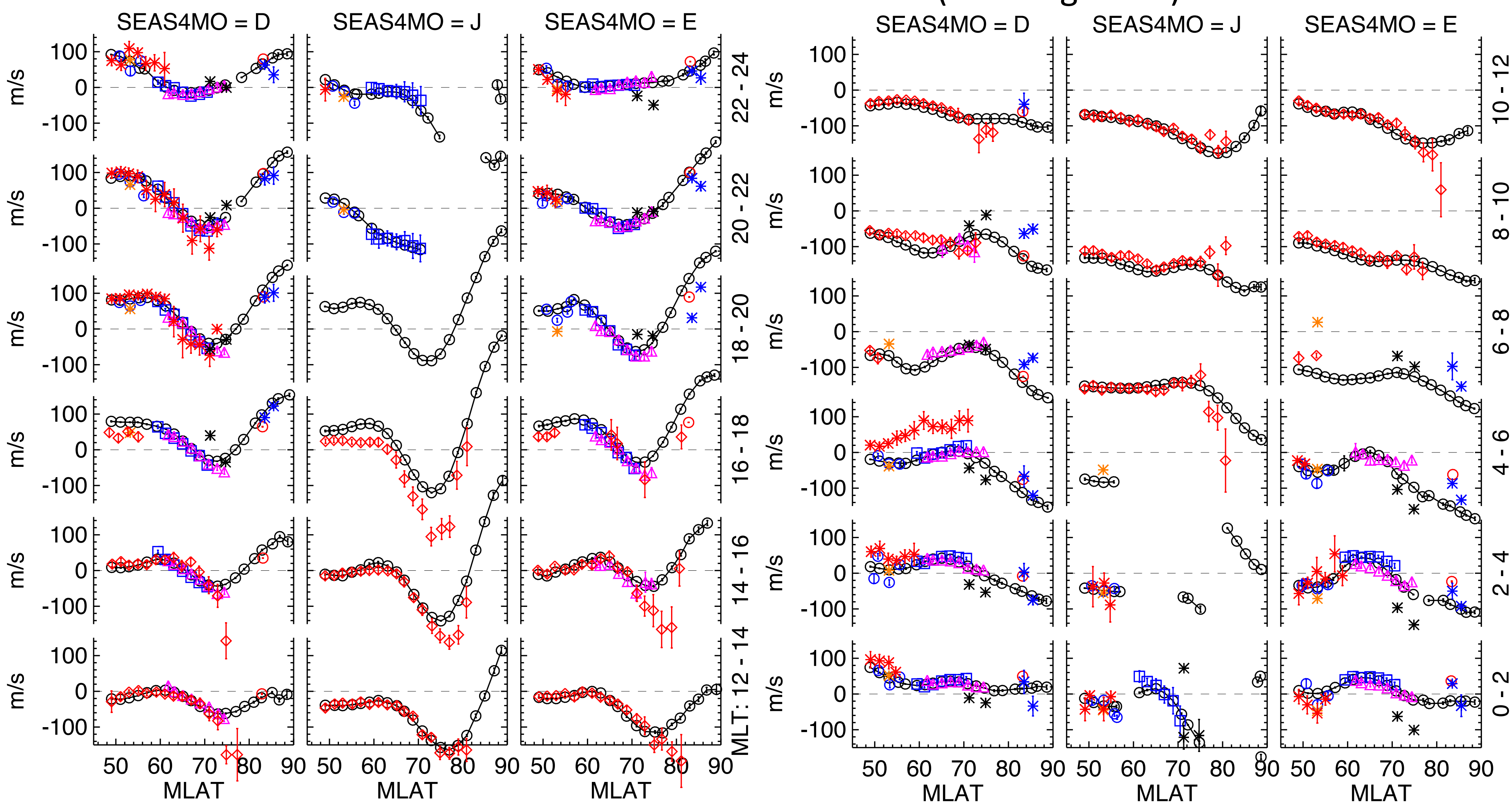


Figure 6: Average magnetic zonal winds computed from ground-based FPI's, WINDII, and DE2 WATS data as a function of magnetic latitude. The black curve shows corresponding results from climatological data assimilation. Error bars denote the estimated uncertainty of the mean. The wind components are in magnetic coordinates, except for WATS zonal winds, which are longitudinally averaged geographic zonal winds. Data from various stations is labeled in colors and symbols (presented at the top left side of the figure).

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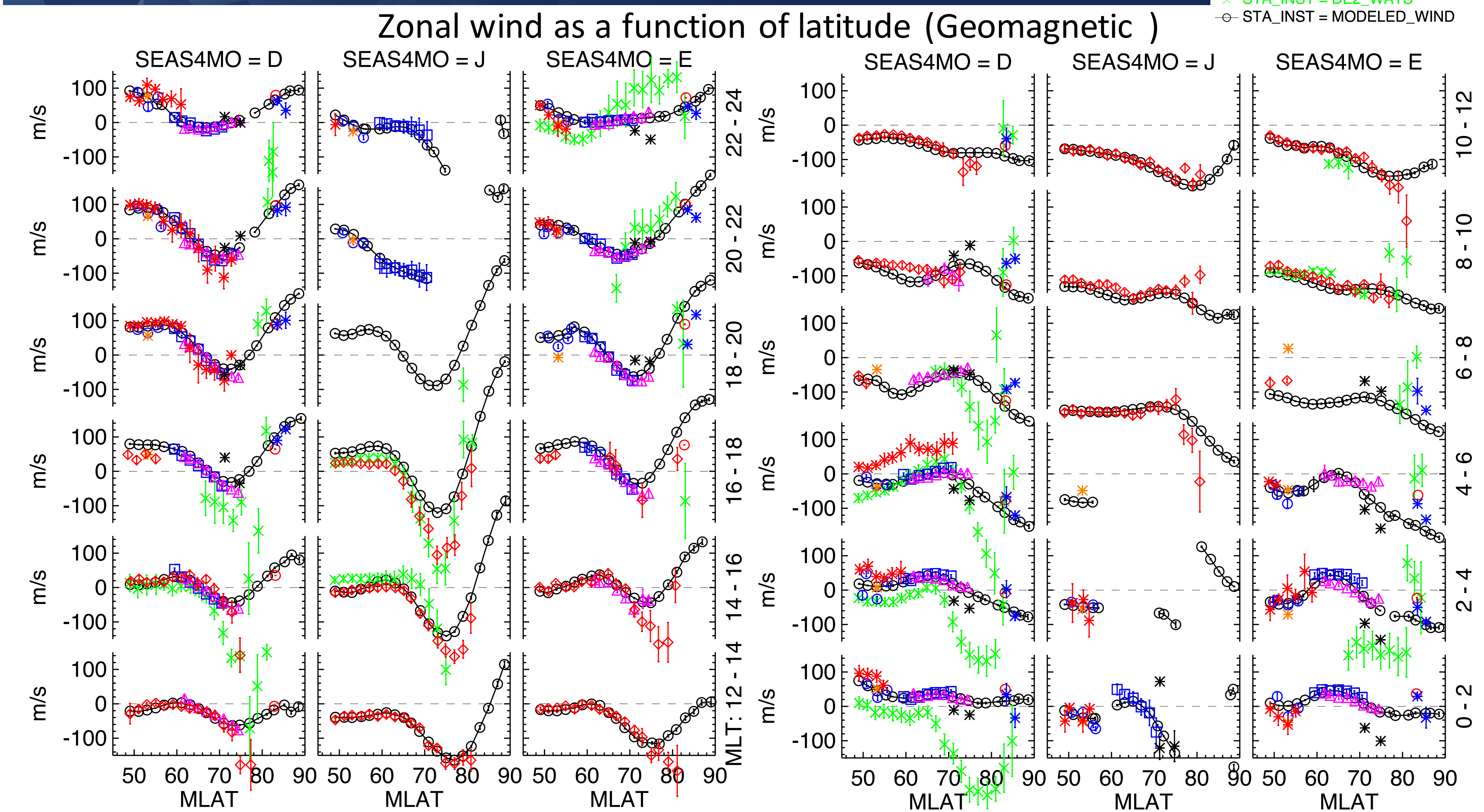
Seasonal Model Cuts (Zonal Wind)



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DE2 Data Comparison with Others

Zonal wind as a function of latitude (Geographic)

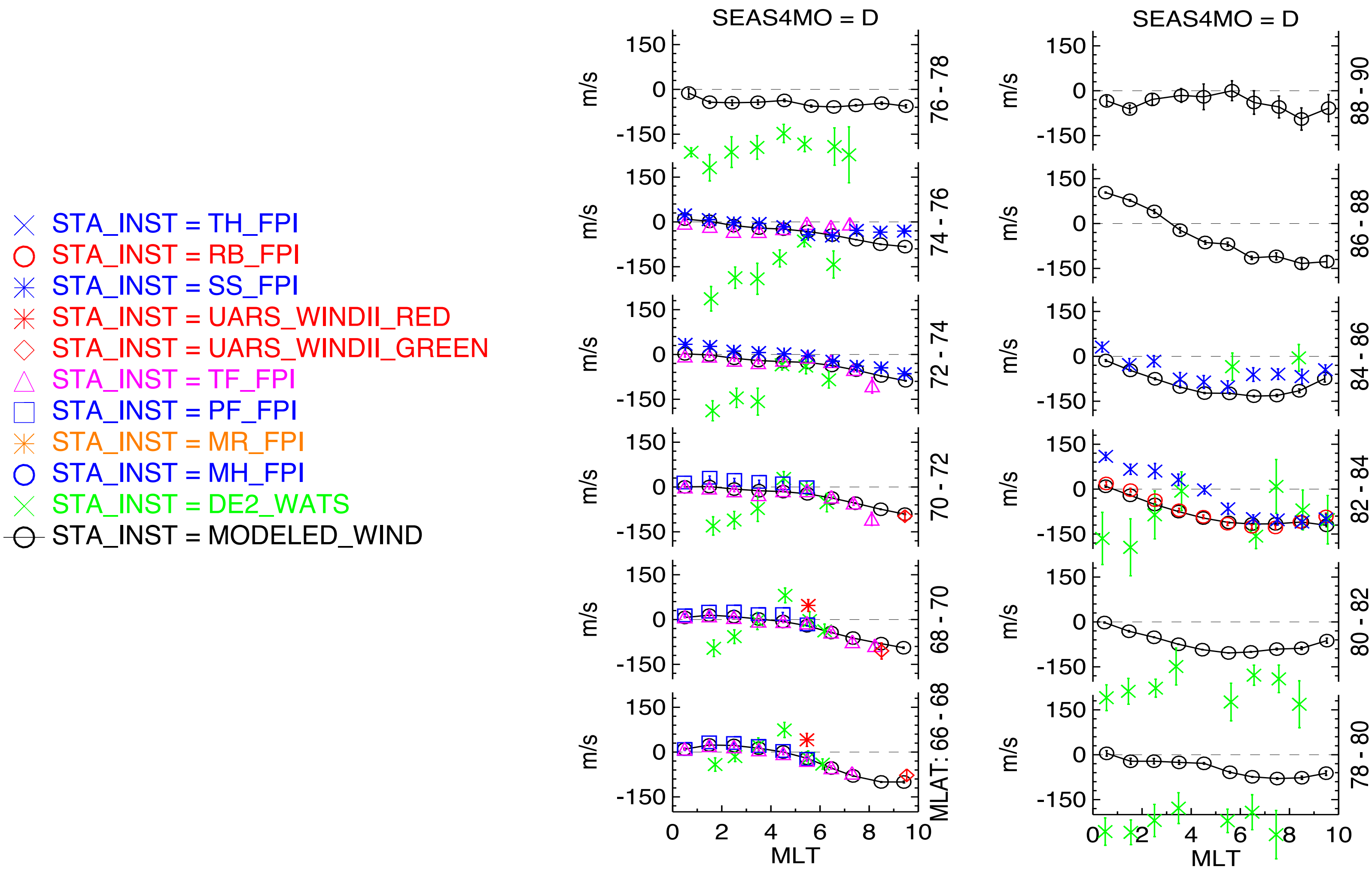


Figure 6: Average GEOGRAPHIC zonal winds computed from ground-based FPI's, WINDII, and DE2 WATS data as a function of magnetic latitude. The black curve shows corresponding results from climatological data assimilation. Error bars denote the estimated uncertainty of the mean. Data from various stations is labeled in colors and symbols (presented at the top left side of the figure).

Seasonal Model Cuts (Meridional Wind)

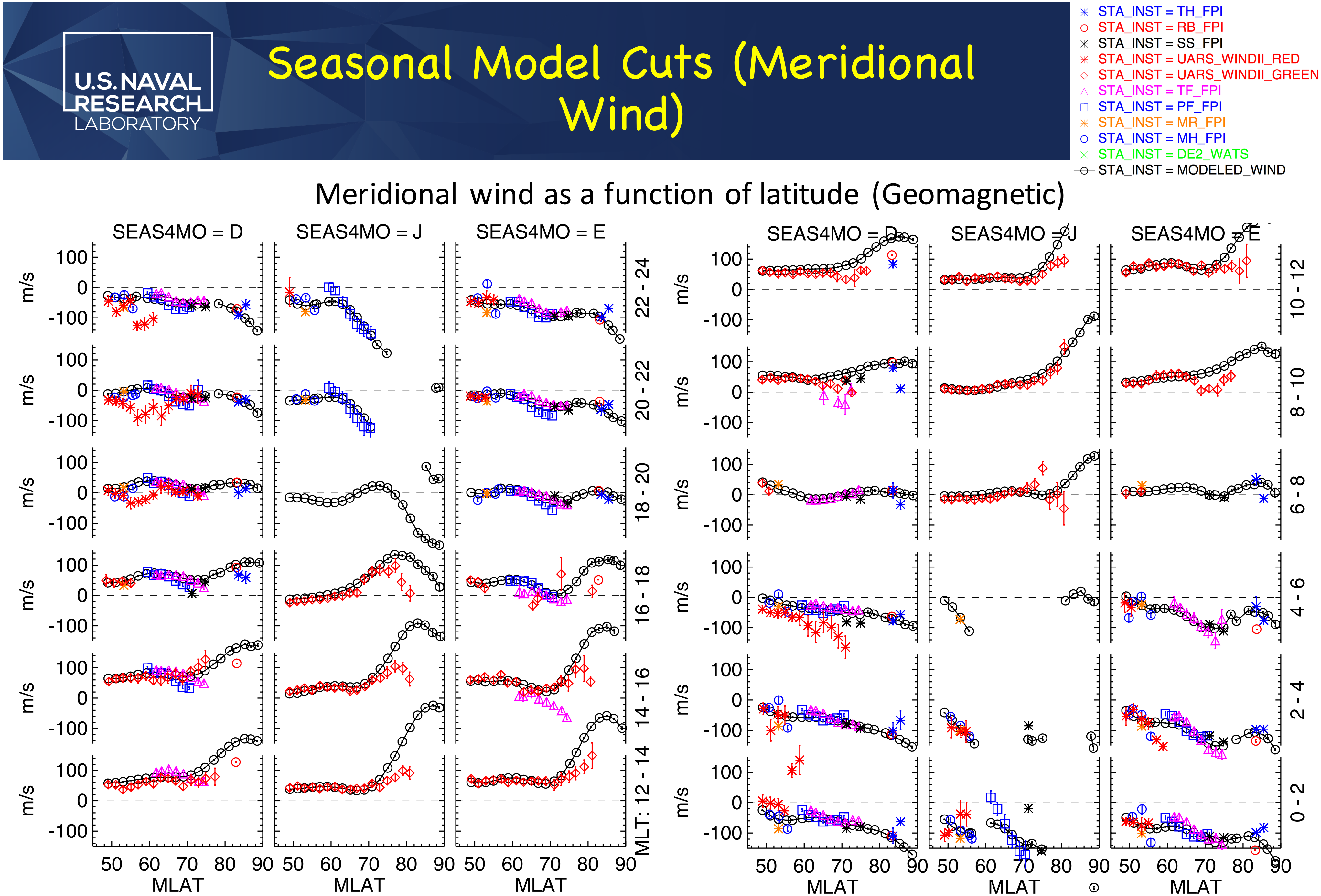
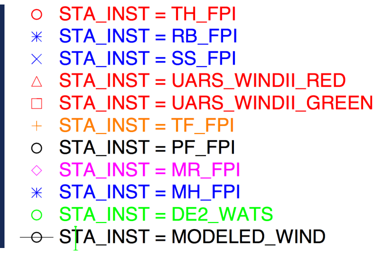


Figure 7: Same as for Figure 6, but in this case the averages are plotted as a function of magnetic local time.

Seasonal Binplots



Zonal wind as a function of local time

Meridional wind as a function of local time

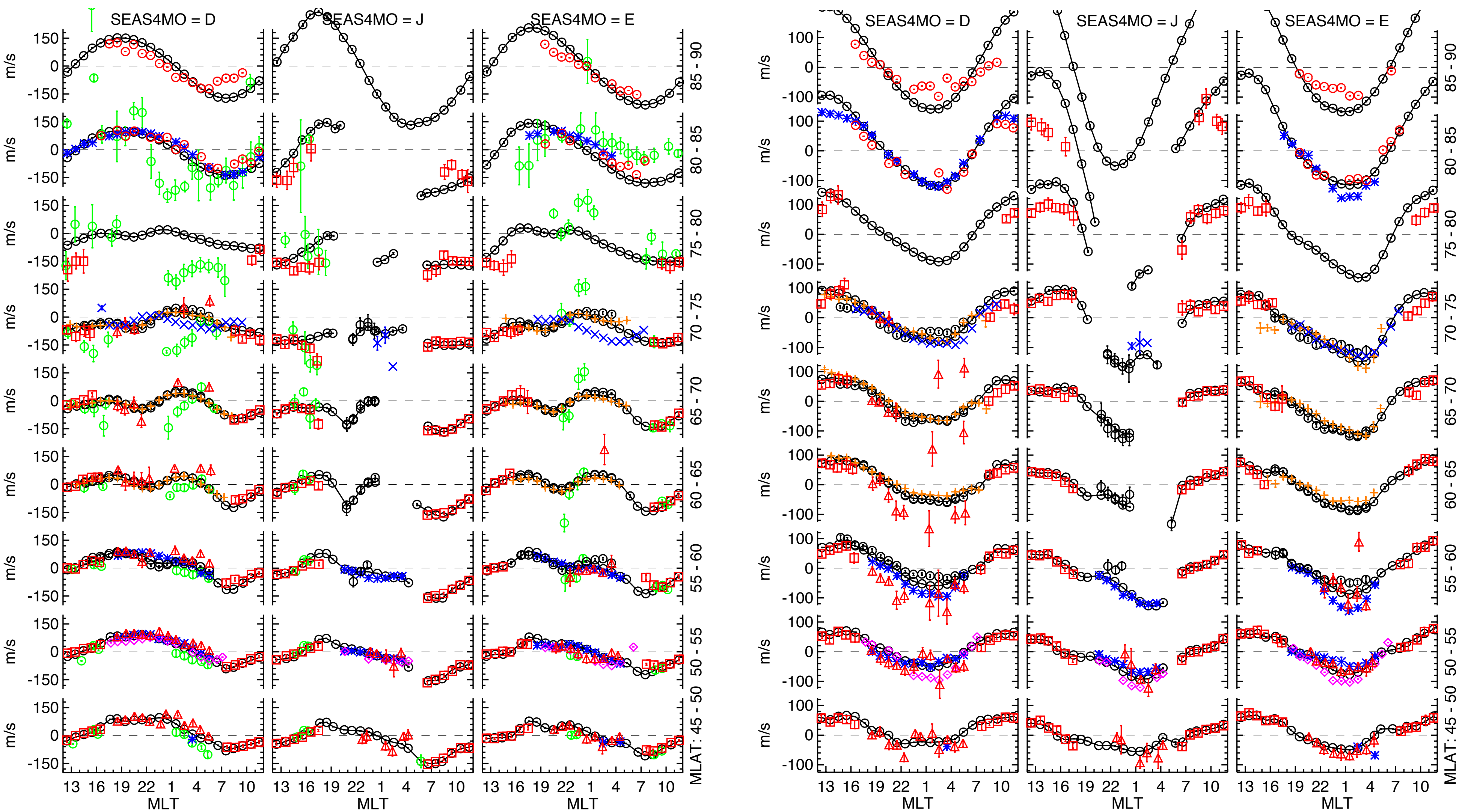


Figure 8: Same as for Figure 6, but in this case averages are computed as a function of local time.

Model Results: Seasonal Neutral Winds

December solstice: Nov, Dec, Jan, Feb

Equinoxes: Mar, Apr, Sep, Oct

June Solstice: May, June, July, Aug

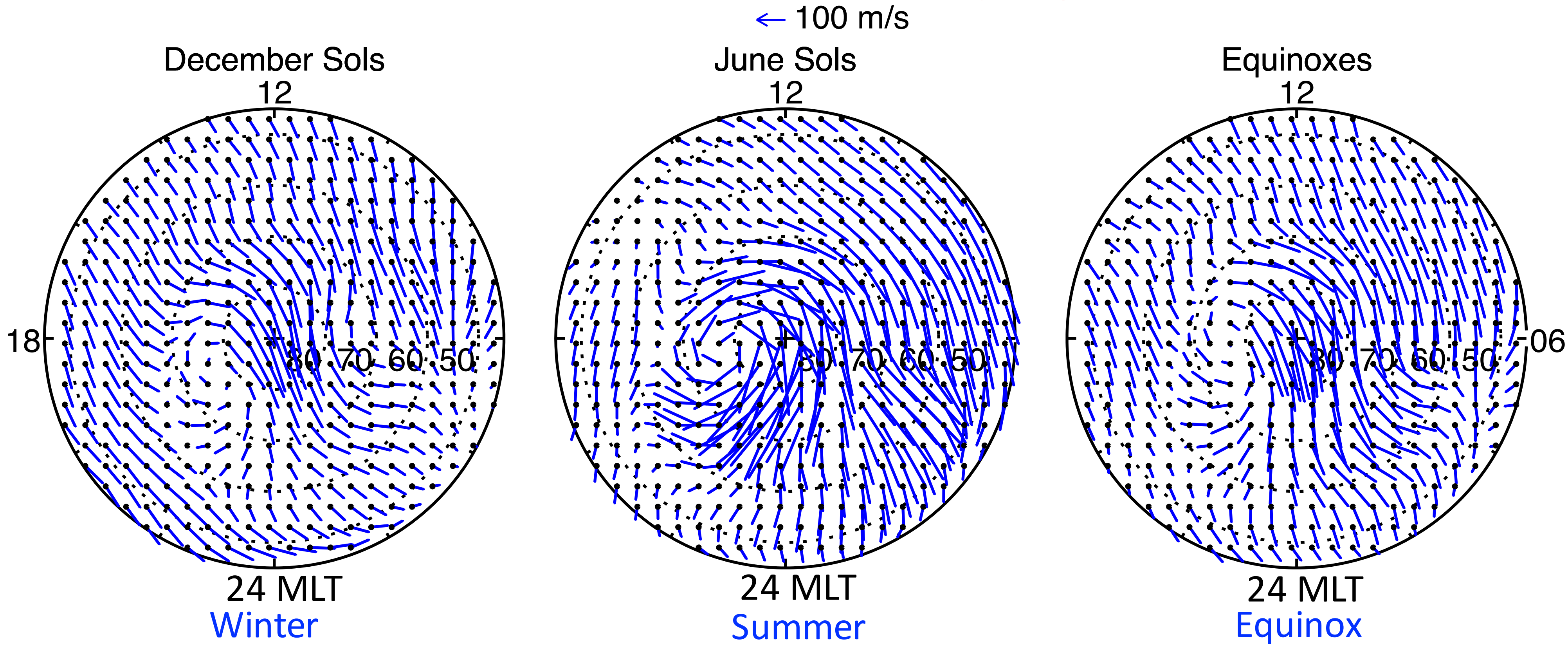


Figure 3: Quiet time average neutral vector winds as a function of magnetic latitude and local time at northern high latitudes for winter, summer, and equinox seasons.

Model Results: Quiet time Seasonal Neutral Vector Wind Comparison

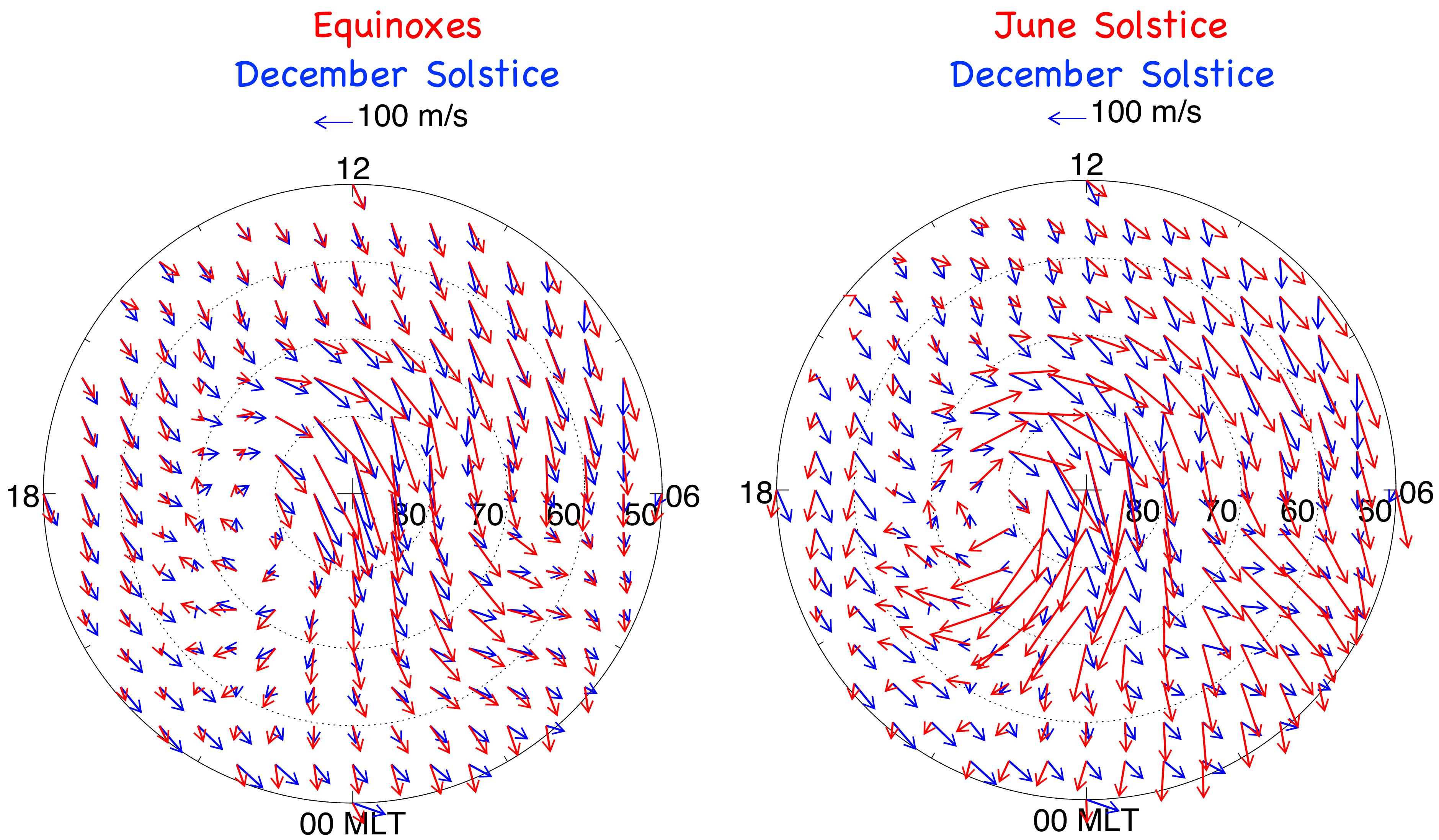


Figure 10: Quiet time average neutral vector winds as a function of seasons, magnetic latitude, and local time at northern high latitudes. The left panel shows equinox (red) and December solstice (blue) winds. The right panel shows June solstice (blue) and December solstice (red) winds.

Seasonal Neutral Wind Field Comparison

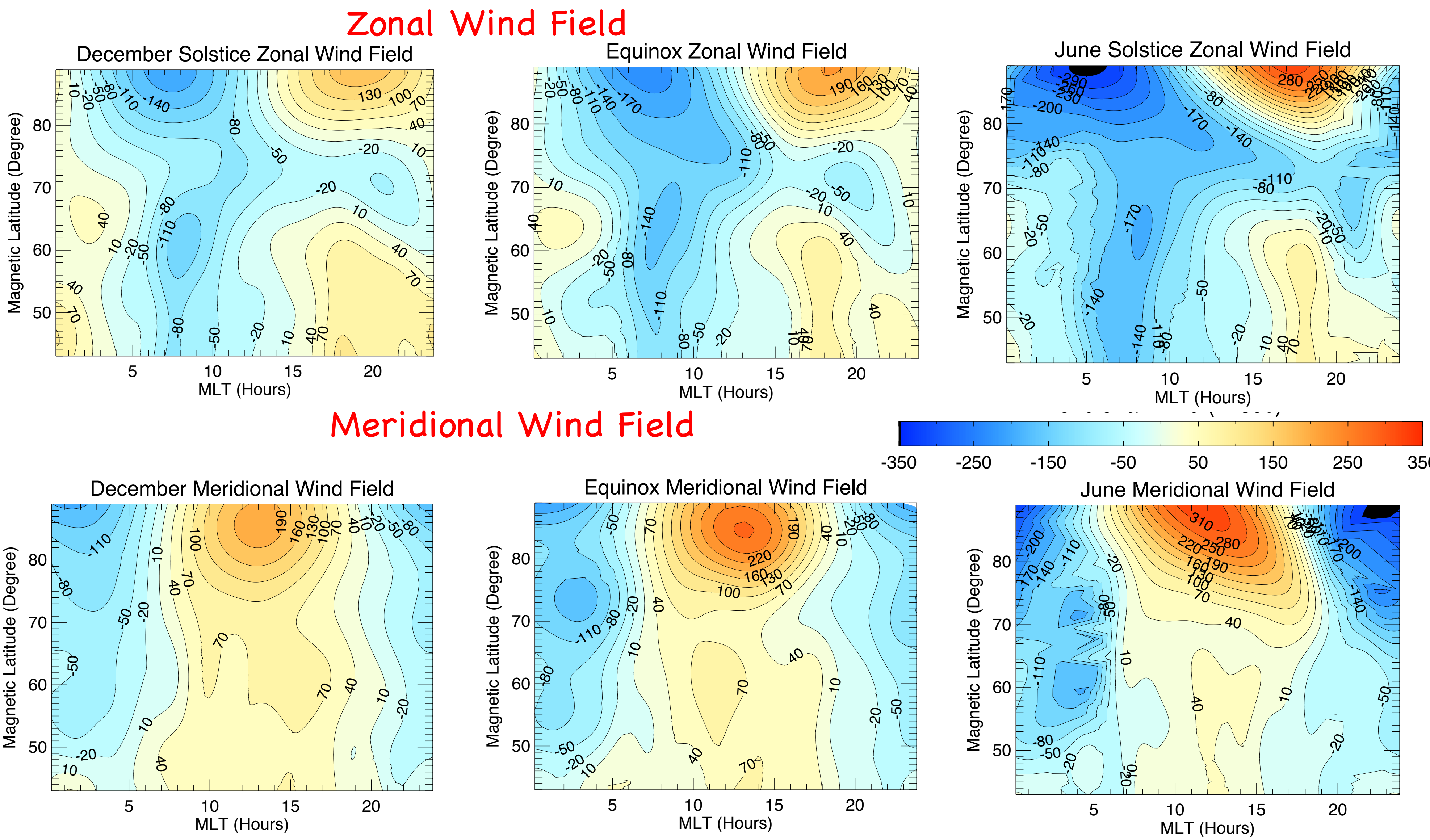


Figure 11: Seasonal climatology of quiet time zonal (top row) and meridional winds (bottom row), as a function of local time and latitude in magnetic coordinates.

Seasonal Vorticity (vertical component) in Wind Field

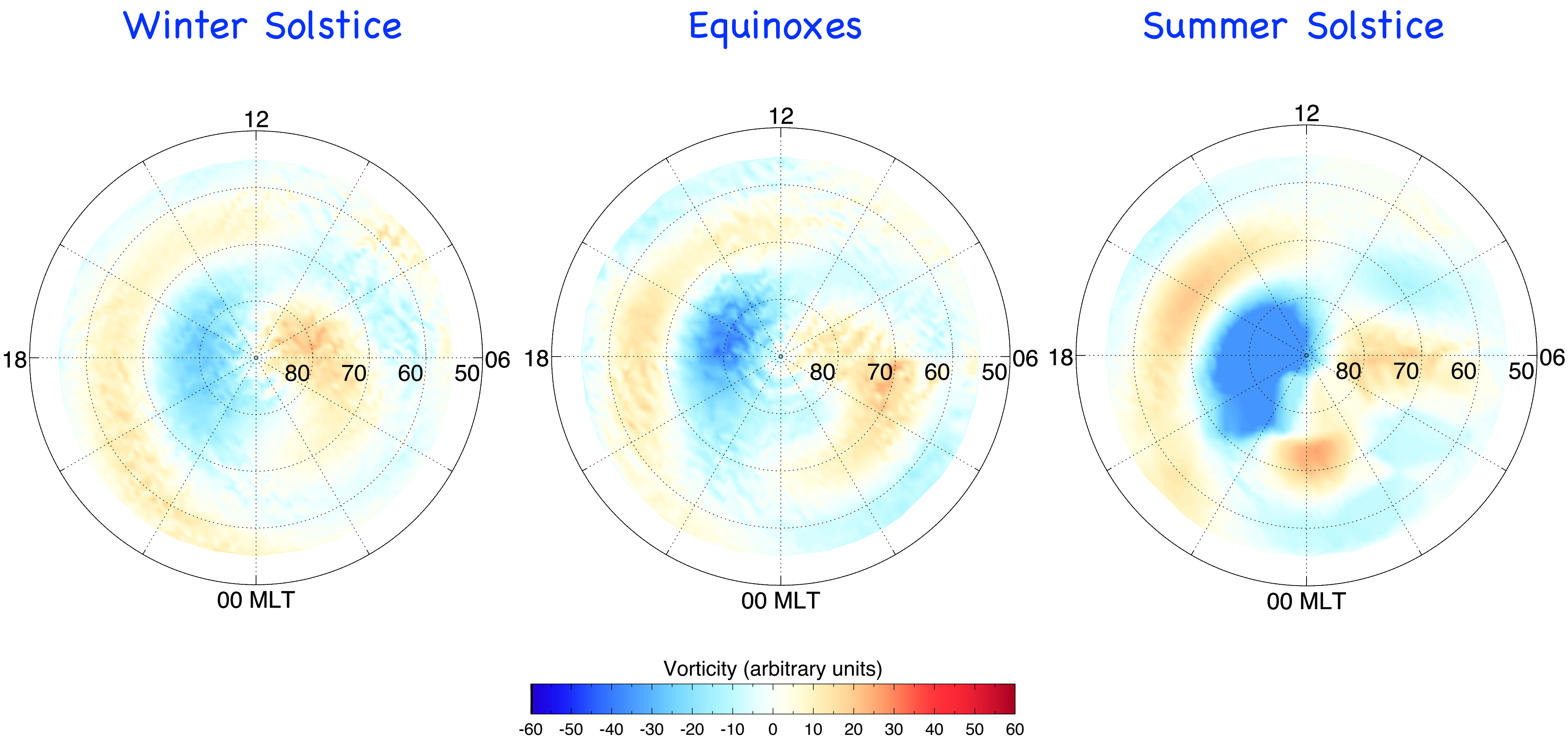


Figure 12: Quiet time vertical component of vorticity of the modeled wind field as a function of local time and latitude in magnetic coordinates.

Seasonal Divergence in Wind Field

Heating due to cusp precipitation?

Signature of direct coupling between thermosphere and magnetosphere?

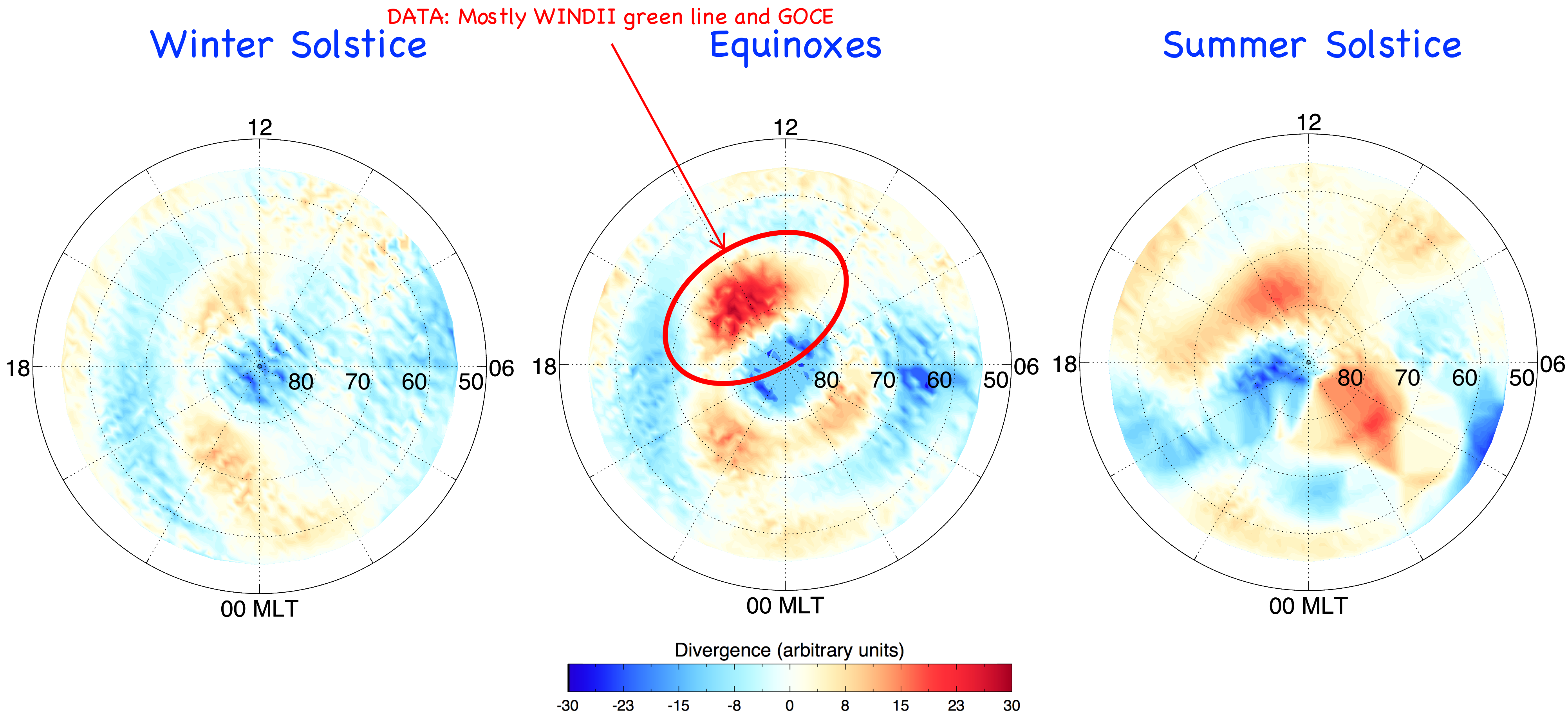


Figure 13: Quiet time divergence of the modeled wind field as a function of local time and latitude in magnetic coordinates. .

Preliminary Results

- We have developed a climatological model that represents the seasonal behavior of quiet time high latitude upper thermospheric neutral winds.

- This is the first comprehensive synthesis of the historical observational record into detailed, magnetically organized high-latitude wind patterns.
  - ⇛ None of the empirical modeling studies (like HWM) have demonstrated such high latitude wind features before. This is most probably due to the use of geographic coordinates instead of geomagnetic. We used magnetic coordinates that none of the empirical models have ever used.

- We found no major discrepancies between data sets (except few isolated cases for WINDII RED LINE and DE2 WATS that are still under investigation).

- Wind patterns indicate the strong influence of ionospheric convection, with a prominent anticyclonic cell on the dusk side of the magnetic pole and a weaker tendency toward a cyclonic cell on the dawn side.

- There is a marked seasonal variation in the patterns.
  - ⇛ In winter time, the neutral wind circulation pattern is confined to only higher latitudes ($\gtrsim 70°$ magnetic latitude); it expands to lower latitudes during summer time.

- The change in vorticity and divergence in upper thermospheric winds with seasons suggests the change in their respective driver and coupling between ionosphere and thermosphere.

FUTURE STEPS:

1. Perform a similar study for southern hemisphere.
2. Ingest these studies into HWM to improve behavior of HWM winds at high latitudes.