Dependence of low-latitude thermospheric wind on geomagnetic disturbance

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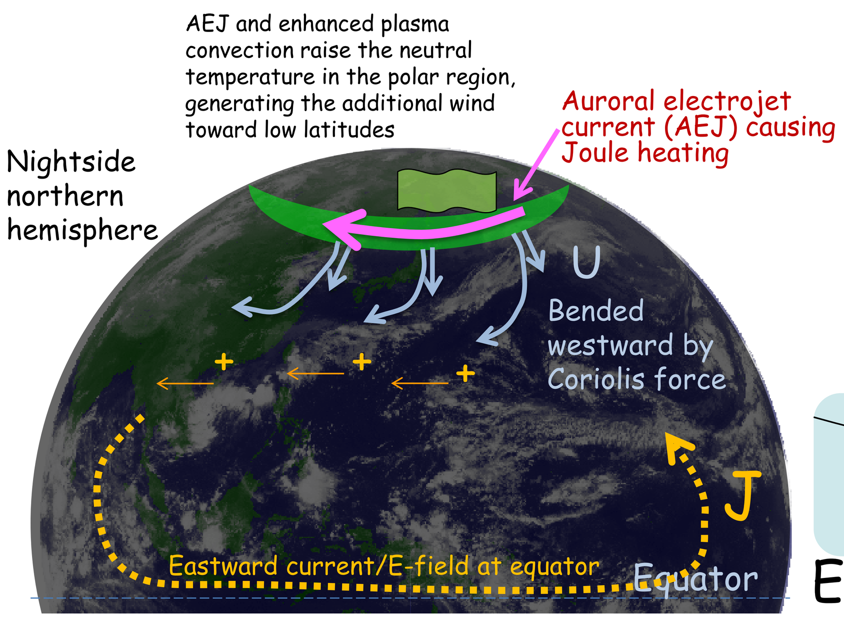
Abstract

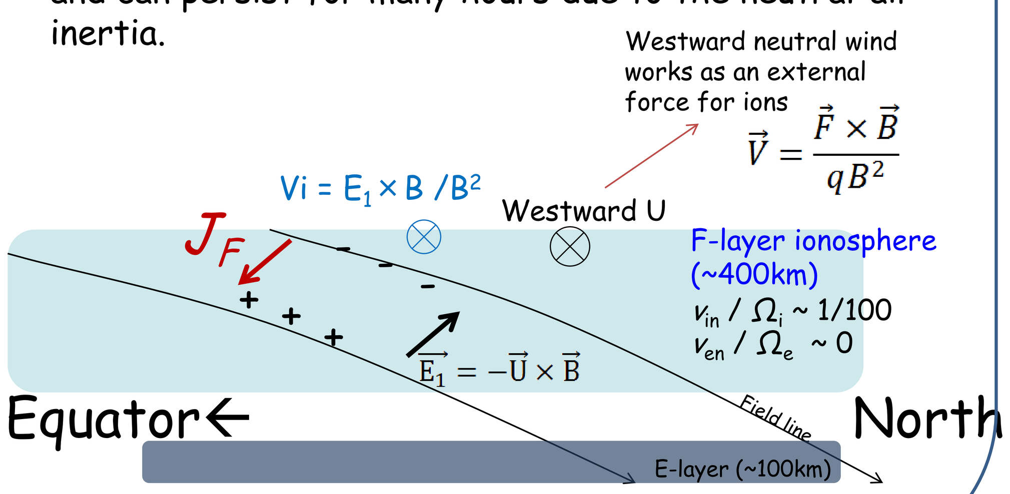
A statistical study has been made on variations in horizontal neutral wind velocity in the thermosphere at altitudes of ~250 km observed as Doppler shifts in 630 nm wavelength night airglow taken by the Fabry-Perot Interferometer (FPI) at Shigaraki (34.8N, 136.1E). The goal of the present study is to examine characteristics of the low-latitude thermospheric wind during geomagnetically active periods and address its role in evolving disturbance dynamo. For this purpose, unlike most of the past studies examining correlations with the Kp index, the present study focuses on correlations with the AE index which directly reflect the Joule heating in the polar region. On the basis of the long-term (2000-2009) FPI data with the filter for 630 nm, we firstly construct the quiet-time model of large-scale thermospheric wind above Shigaraki by sorting the data with very low AE activities by local time, season, and solar activity and then averaging them for each condition. Subtracting the quiet-time averages from the observed wind velocities, we conduct superposed epoch analyses on evolution of the residual wind velocity associated with auroral electrojet activities by referring to the AE index. As a result, the thermospheric wind velocity starts shifting westward and slightly southward 2-3 hours after AE rises from the quiet to high (~several hundreds of nT or greater) level. In particular, the westward shift of low latitude thermospheric wind becomes larger with increasing intensity and duration of AE activity. These changes of wind velocity with AE activities are basically consistent with the scenario of disturbance dynamo that the Joule heating caused by enhanced auroral electrojets in the polar region generates an additional, large-scale equatorward wind and the equatorward wind changes its direction to the west as it comes over to the low-mid. latitude region where the interaction of the westward neutral wind with ionospheric plasma drives a dynamo for an eastward current in the night-time equatorial ionosphere. Our detailed statistics also reveal that the westward shift is more evident in the post-midnight sector than pre-midnight and this local time asymmetry becomes clearer during summer. These spatial structures may be formed by mechanical interactions between the disturbance wind component and the global background wind primarily driven by the thermaltide caused by the Sun.

Introduction

Disturbance dynamo theory
by Blanc and Richmond [1980]

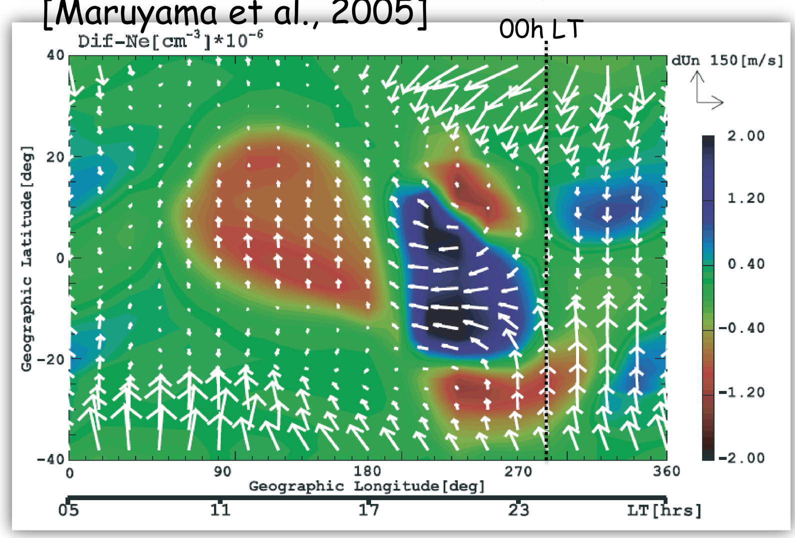


The disturbance electric field driven by disturbance dynamo is driven by the storm-time neutral winds through the action of the ionospheric dynamo processes [e.g., Blanc and Richmond, 1980]. The global neutral wind system responds to the high latitude energy and momentum input into ionosphere and thermosphere from the magnetosphere. It develops over a period of hours and can persist for many hours due to the neutral-air inertia.



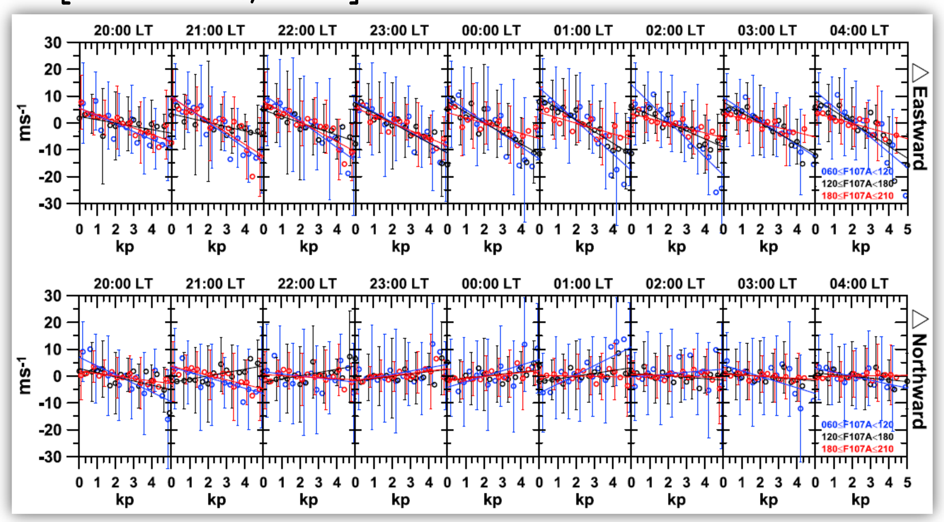
Previous studies

Thermosphere-Ionosphere coupled simulation [Maruyama et al., 2005]



Recent T-I coupled simulations have incorporated the effects of Joule heating by auroral electrojet, which is believed to play a main role in giving rise to disturbance dynamo during geomagnetic disturbances (storm, substorm), to reproduce the disturbance thermospheric wind.

Statistical study using Arecibo FPI data [Brum et al., 2012]



On the other hand, almost all observational studies on thermospheric wind give statistics sorted by the Kp index. Kp reflects any kinds of geomagnetic disturbance, not suitable for identifying single kind of them.

Therefore, it is desirable to conduct statistical studies of thermospheric wind by referring more directly to auroral electrojet evolution.

Motivations & Objectives

It is **hard to distinguish disturbed time E-fields of various origins** (direct penetration E, overshielding E, disturbance dynamo E). Observations based on ionized atmosphere are suffered from the effects of all E-fields.

In order to study the spatio-temporal propeties of disturbance dynamo (DD) separately, Thermospheric wind observations using the neutral atmosphere as a tracer are essential.

→ **Fabry-Perot interferometer data is suitable** for the above study!

The numerical simulations indicate that DD is driven by a westward neutral wind in the F-layer ionosphere at low-mid latitudes, which originates from the atmosphere heating in the polar region caused by aurora.

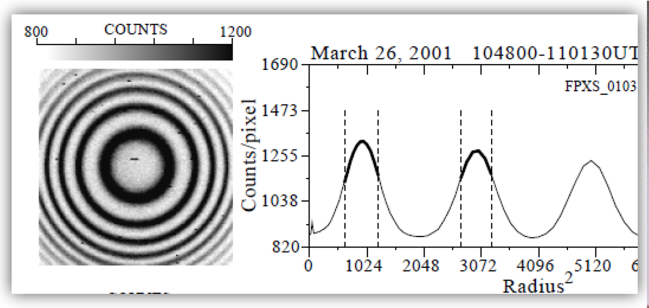
The **goal of the present study** is to address **the evolution (development & decay) of DD by examining how the low-lat. thermospheric wind varies with evolution of the auroral electrojet.**

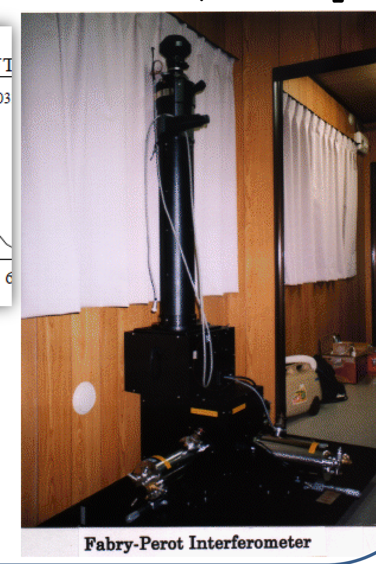
Instrument & Method

[Shiokawa et al., 2005]

We analyzed the neutral wind velocity data obtained by the Fabry-Perot Interferometer (FPI) at Shigaraki (34.8N, 136.1E, Mag. Lat ~ 25.4N) [Shiokawa et al., EPS, 2005]. The FPI measures the Doppler shift of the airglow emissions (558 and 630 nm) from the four azimuthal directions (N,S,E, and W) by taking a difference in the interference fringe locations (N-S and E-W). For the present study we used the wind velocity data deduced from the 630 nm band emission coming from the thermosphere at altitudes of ~250 km.

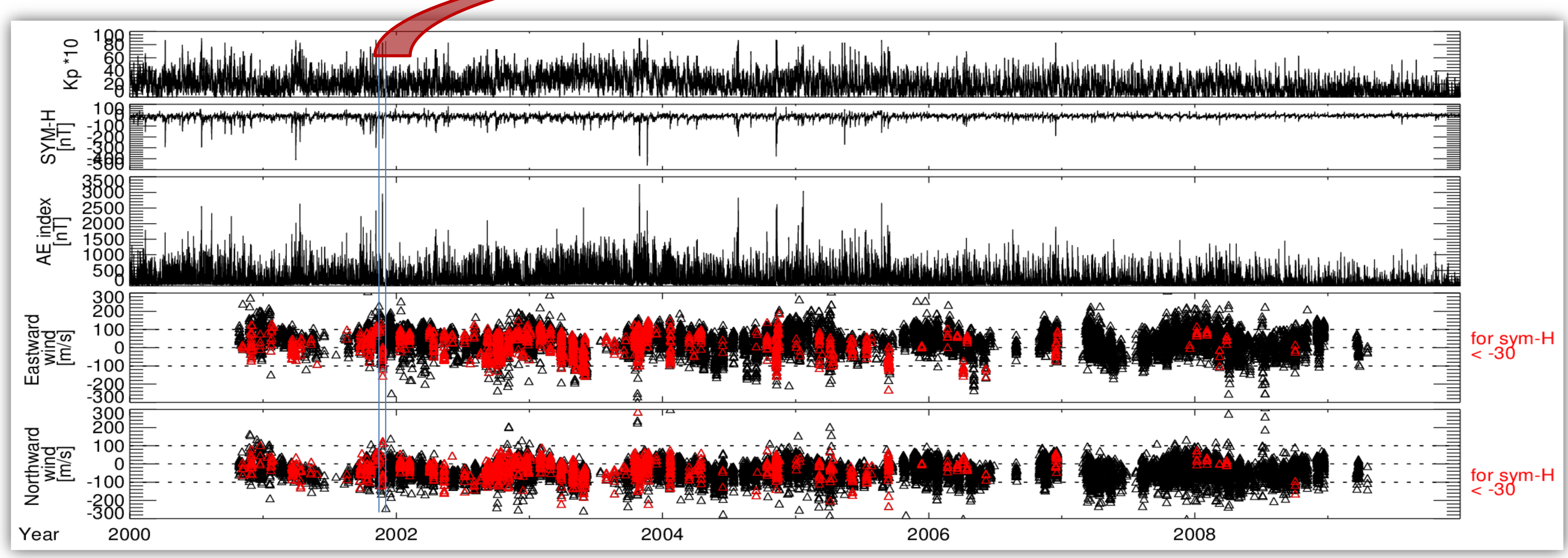
The data analysis for the present study has been done by using the iUgonet Data Analysis Software suite (UDAS) developed by the IUGONET project. (http://www.iugonet.org)





Fabry-Perot Interferometer (FPI) at Shigaraki, Japan (34.8N, 136.1E)

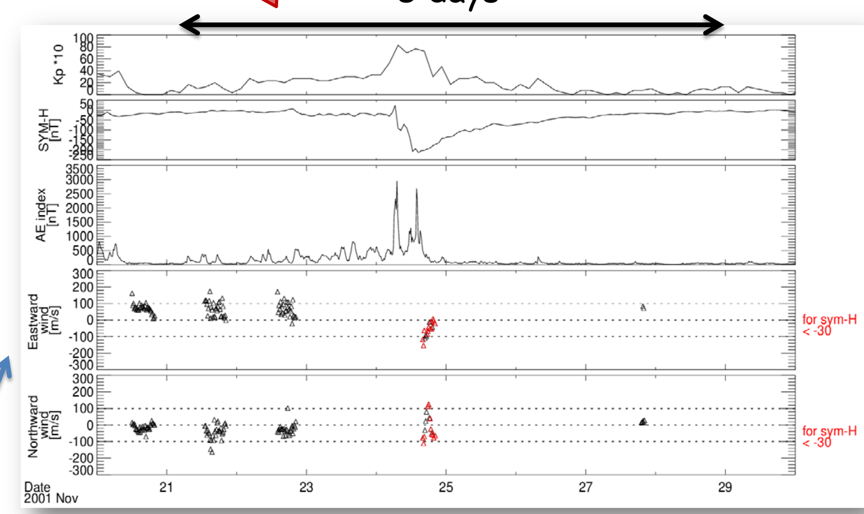
Case study



(Left panel)

The entire data set of horizontal thermospheric wind obtained by FPI at Shigaraki is compared with the Kp, SYM-H, and AE indices. Red triangles are a subset for SYM-H < -30 nT. Correlation with the geomagnetic indices is not clear on this time scale, but ... *(please proceed to the right plot)*

8 days



(Left panel)

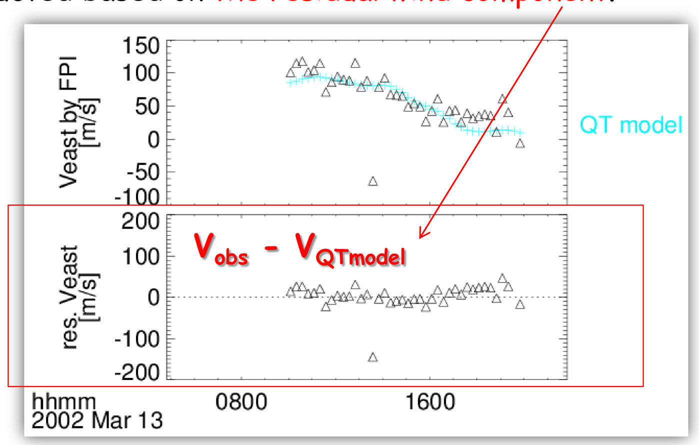
Taking a closer look at the variations of a time scale of geomagnetic storm, the neutral wind profile changes drastically during a storm time and then returns to the quiet-time profile as a storm decays.

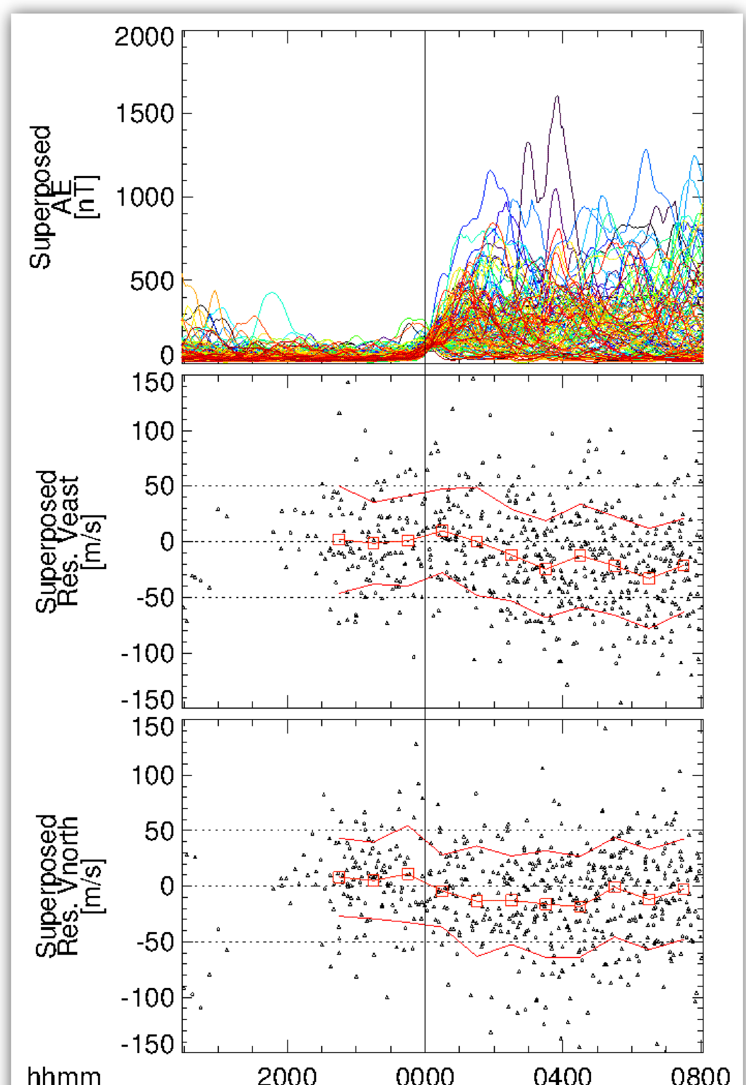
Statistical study

The horizontal wind velocity data obtained by the FPI at Shigaraki with the 630 nm band for 2000-2009 were used for the present statistical study. The 15 min data for 18-06 LT (night time only) were sorted by 2 hour LT bins to examine their local time dependence.

We used the AE index as a proxy to measure the auroral electrojet activity. The AE data up to 36 hours before each FPI measurement were used for statistics considering the history of AE variation.

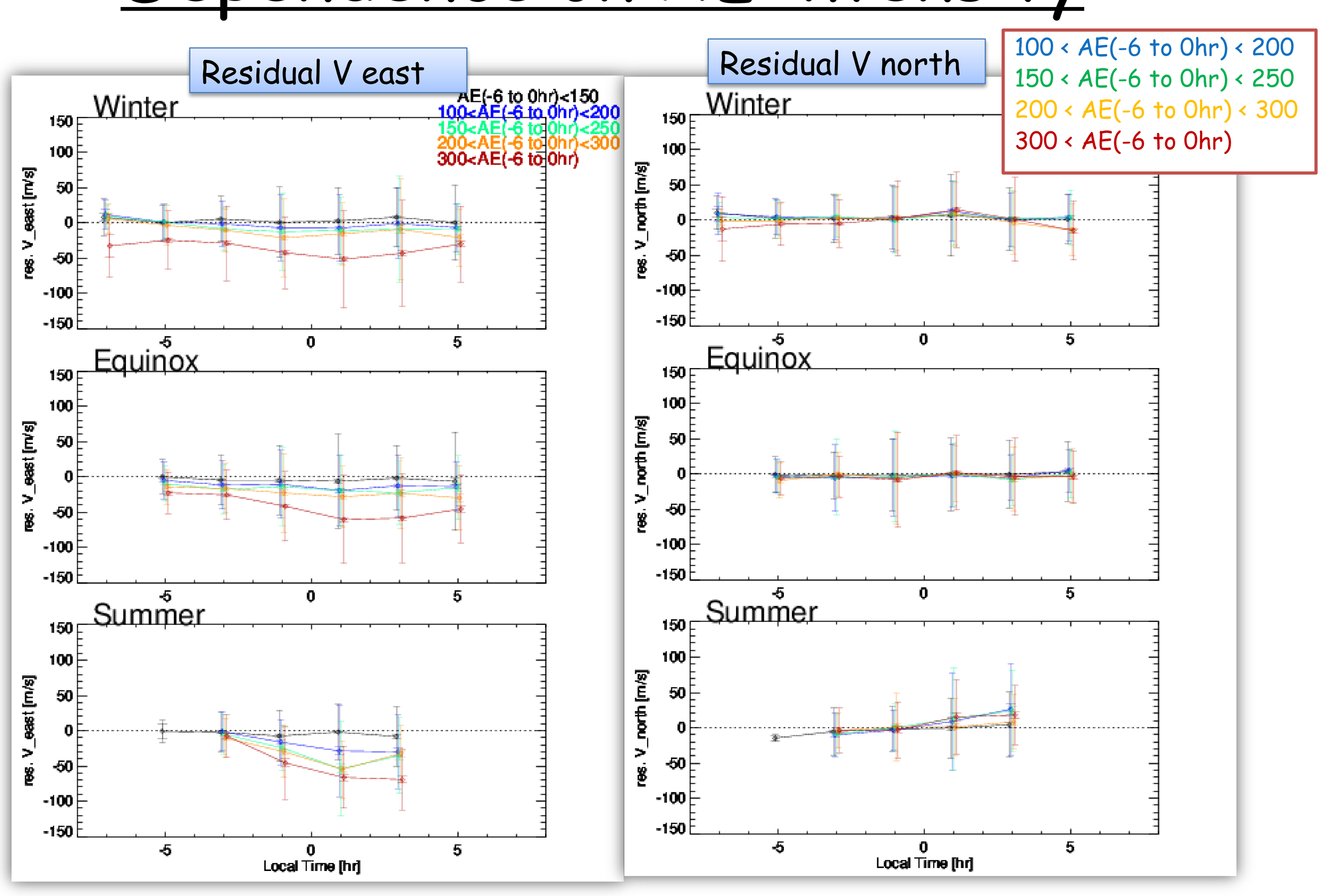
The quiet-time wind velocity model has been obtained by averaging the quite-time data for each season (Winter, Equinox, Summer), local time bin, and solar activity (measured by F10.7). Here the "quiet time" is defined as times preceded by an 8-hour low AE period (ave. AE < 100 nT). The present statistics are conducted based on the residual wind component.





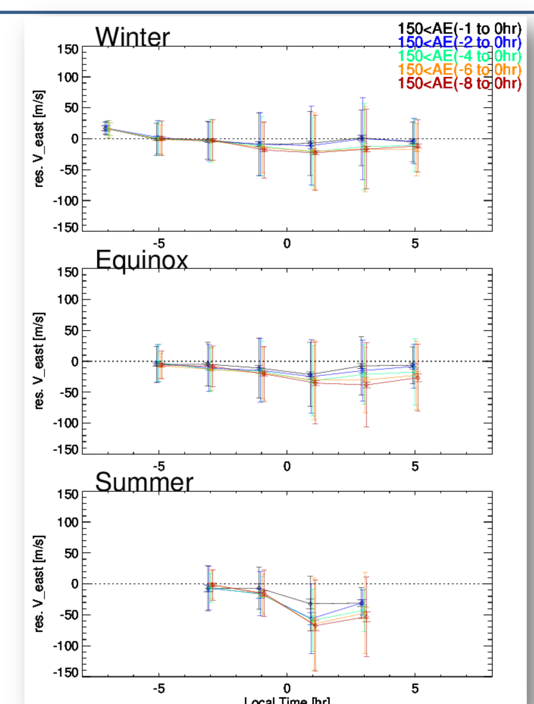
(← Left plot)
Superposed epoch analysis of residual wind referring to AE activity for LT = 22 – 02h. Residual wind show a westward shift in 2-3 hours after AE rise and the westward shift lasts for several hours, while the southward shift is weak and does not last as long.

Dependence on AE intensity



Residual Veast
- Larger westward shift for larger AE.
- More sensitive to AE for summer than Equinox/Winter.
- Dawn-dusk asymmetry: larger shift at midnight to dawn

Residual Vnorth
- AE dependence is very weak.

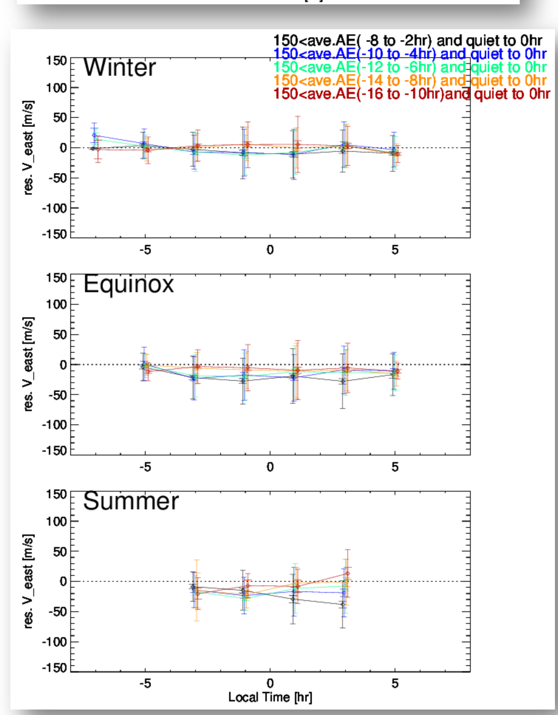


10 hour quiet time precedes, then ... | Various length of AE activity before FIP measurement

AE(-1 to -11hr) < 150 and 150 < AE(-1 to 0hr)
AE(-2 to -12hr) < 150 and 150 < AE(-2 to 0hr)
AE(-4 to -14hr) < 150 and 150 < AE(-4 to 0hr)
AE(-6 to -16hr) < 150 and 150 < AE(-6 to 0hr)
AE(-8 to -18hr) < 150 and 150 < AE(-8 to 0hr)

Dependence on duration of AE activity

- Longer AE activity gives larger westward shift of the wind.
- The westward shift appears in a few hours after AE rise, even in an hour for summer.
- The westward shift is larger for summer than for equinox, and very small for winter (with this AE criterion of < 150 nT).



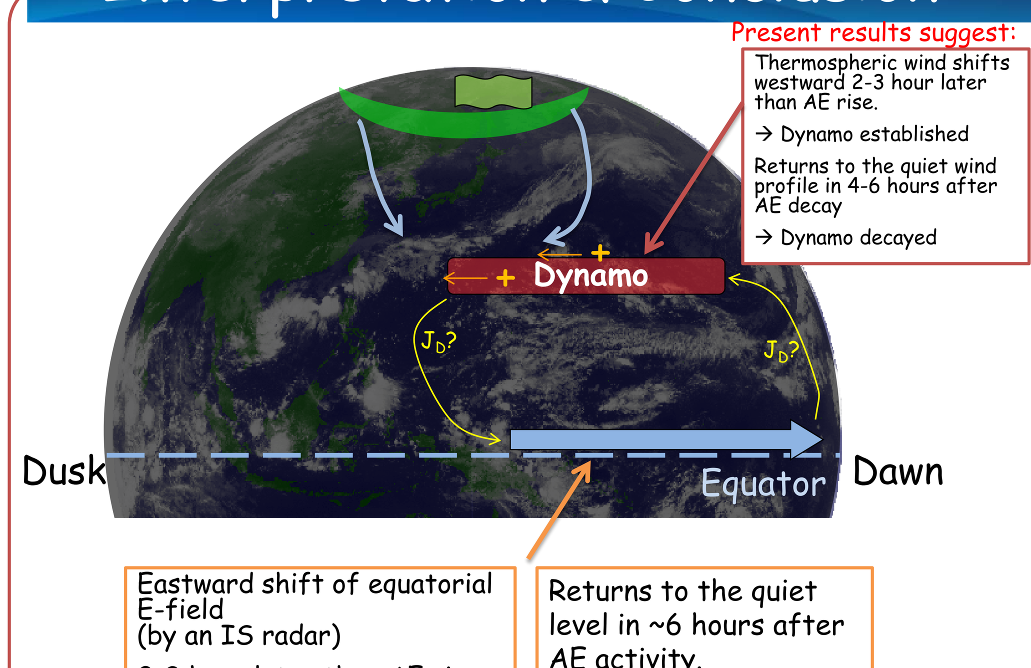
High AE activity for 6 hours precedes, then ... | Various length of quiet time before FIP measurement

150 < AE(-8 to -2hr) and AE(-2 to 0hr) < 150
150 < AE(-10 to -4hr) and AE(-4 to 0hr) < 150
150 < AE(-12 to -6hr) and AE(-6 to 0hr) < 150
150 < AE(-14 to -8hr) and AE(-8 to 0hr) < 150
150 < AE(-16 to -10hr) and AE(-10 to 0hr) < 150

Decay of disturbance wind after AE activity ceases

- The westward shift decays on the time scale of ~6 hours.

Interpretation & Conclusion



[e.g., Scherliess and Fejer, 1997]

Conclusion

Based on the statistics of AE dependence of thermospheric neutral wind at ~250 km over Shigaraki, we conclude:

- The thermospheric wind shifts westward (ΔV ~ tens of m/s) as AE activity rises.
  → consistent with a scenario that atmosphere heating by aurora causes the disturbance dynamo.
- A larger and longer AE activity gives a larger westward shift.
  → A more intense heating by aurora may cause a larger effect of disturbance dynamo.
- The disturbance wind appears at midnight to dawn
  → implying the electric circuit connecting to the disturbance E-field at equator in the similar local time range.