Neutral Winds in the Equatorial Thermosphere as Measured With the SOFDI Instrument

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Prelude

- Second-generation, Optimized, Fabry-Perot Doppler Imager (SOFDI), a triple-etalon Fabry-Perot interferometer, is the relocatable FPI system which is currently deployed and operating near the geomagnetic equatorial latitude in Huancayo, Peru (Geo:12.1°S, 75.3°W; Mag: 1.9°N), and utilized the OI 630-nm emission for 24-hour thermospheric wind observations.
- Measurements and understandings of thermospheric wind dynamics can support to address many questions regarding geospace phenomena, e.g., equatorial spread-F, HR radio disruption, spacecraft drag, auroral zone heating, gravity, tidal and planetary waves, ULF wave heating, the impact of particle precipitation, that severely impact our space-based technologies.

Early SOFDI Observations in 2011

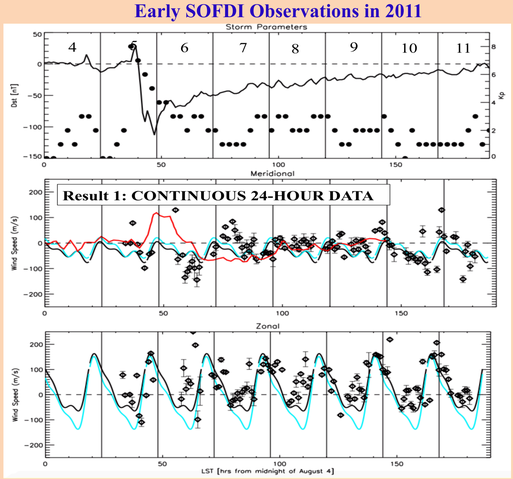


Figure-1:

Top panel:
The black line corresponds to Dst on the left, while points indicate Kp on right, for August 4-11 of 2011.

Middle Panel:
SOFDI meridional winds, in 1-hour data realizations, with 1-σ uncertainty bars, are shown as data points. The red line is meridional winds from C/NOFS HWM instrument. The black (light blue) lines are from Horizontal Wind Model-93 (HWM-93) for strong (quiet) activity.

Bottom Panel:
Same as the middle panel but for zonal winds case.

Comparison of Measured and Modeled Wind Climatology

Figure: 3 (a)

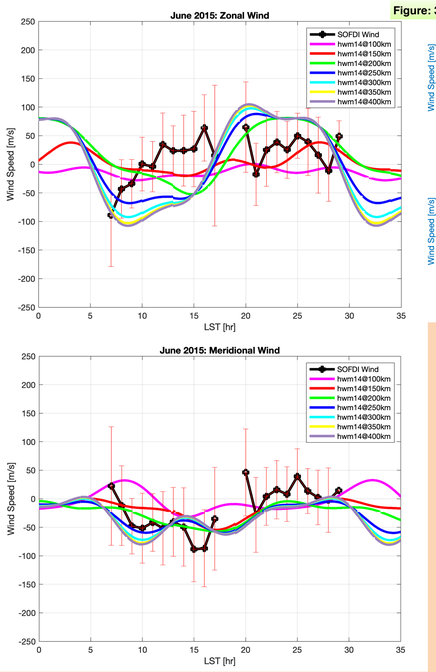


Figure: 3 (b)

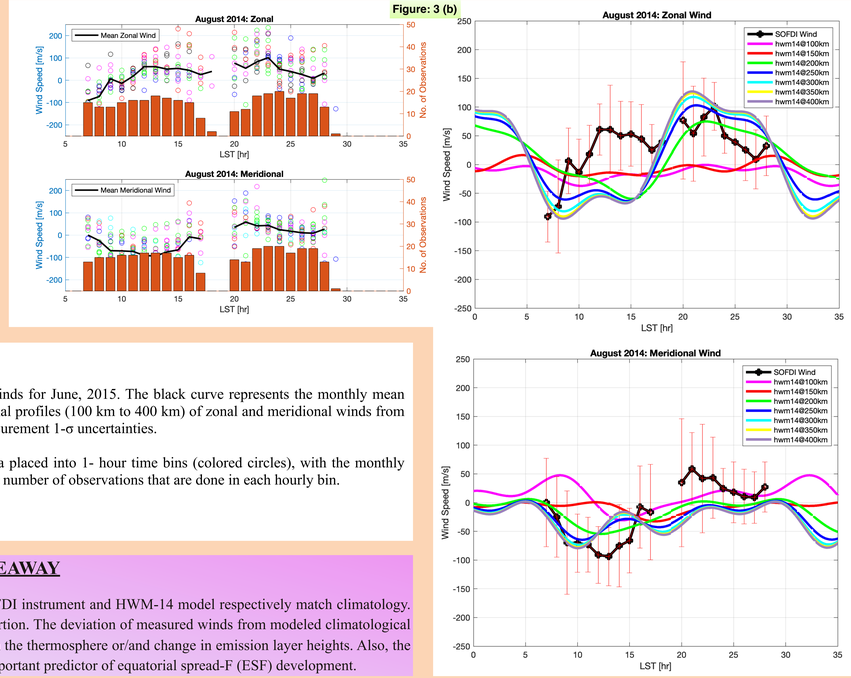


Figure-3 (a):

Left Panel: The zonal (top) and meridional (bottom) 630-nm winds for June, 2015. The black curve represents the monthly mean wind measured by SOFDI, and the colored curves show altitudinal profiles (100 km to 400 km) of zonal and meridional winds from the HWM-14 empirical model. The vertical red bars are the measurement 1-σ uncertainties.

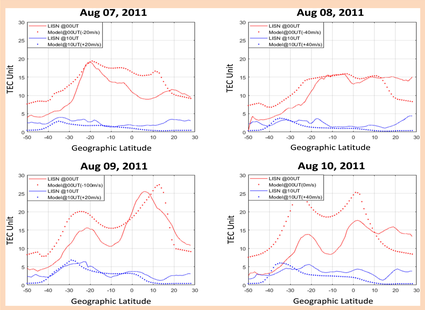
Right Panel: The zonal (top) and meridional (bottom) wind data placed into 1- hour time bins (colored circles), with the monthly mean indicated by a black curve. The red bar graphs showing the number of observations that are done in each hourly bin.

Figure-3 (b): Same as Figure-3 (a), but for August, 2014.

TAKEAWAY

The measured and modeled meridional winds obtained from SOFDI instrument and HWM-14 model respectively match climatology. Zonal winds are likewise consistent, EXCEPT for the daytime portion. The deviation of measured winds from modeled climatological averages might be due to lower atmospheric waves dripping up in the thermosphere or/and change in emission layer heights. Also, the timing of the afternoon reversal of the zonal wind would be an important predictor of equatorial spread-F (ESF) development.

Wind on EIA Asymmetry



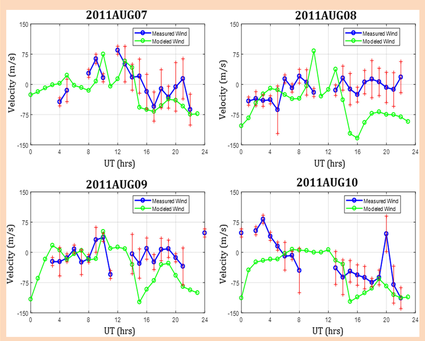


Figure-2:

Top Plots:
Comparison of LISN (Low Latitude Ionospheric Sensor Network)-measured (continuous curves) and LLIONS (Low Latitude IONospheric Sector)-modeled (dotted curves) TEC (Total Electron Content) variations against geographic latitude. TEC values are binned in every degree of latitude.

Bottom Plots:
The blue (green) curve represents meridional wind velocity observed by SOFDI instrument (LLIONS model) at the geomagnetic equatorial latitude, and the vertical red lines represent the error bars of the SOFDI wind.

[Source: *Khadka et al., 2018; Radio Science*]

TAKEAWAY

The meridional neutral wind profiles can be estimated using the physics-based LLIONS model, which utilizes vertical drift measured from Jicamarca ISR as one of the inputs. The modeled meridional winds show reasonably good agreement within the error range of measurements by SOFDI instrument at the geomagnetic equator for similar conditions, which strengthens the confidence of our results. It also plays a decisive role in the generation of asymmetry structure in the EIA (Equatorial Ionization Anomaly).

Wind Variability and PRE

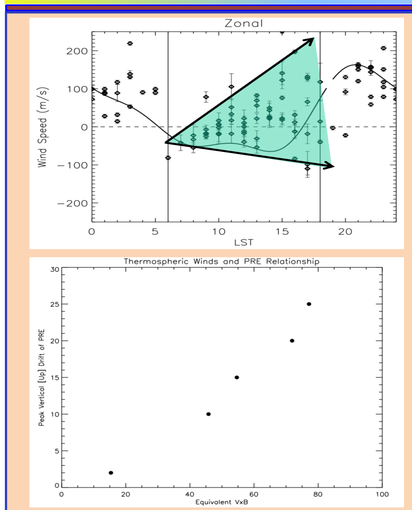


Figure-4:
Top Left: Zonal wind variability throughout the day. Bottom Left: Correlation of the measured vxB induced by the wind to the strength of the PRE (Pre-Reversal Enhancement). Right: The measured geophysical variability of the 630-nm winds as measured from the distributions in June (top) and August (bottom). Total wind variability is in black, zonal is in blue, meridional is in red, and the vertical dashed black line indicates local noon.

TAKEAWAY

Thermospheric wind variability increases throughout the day, peaking in the sunset period. Such variability plays a role in the pre-reversal enhancement and ESF formation. The cause for the increase in variability is speculated to be due to the synoptic variability in the atmospheric tides and gravity wave structures that are forced from lower altitudes.

Wind from WINDII

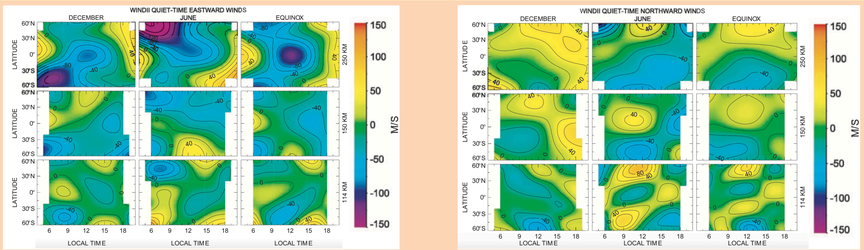


Figure-5:
Showing quiet time ($Kp < 3$) average zonal (left plot) and meridional (right plot) wind patterns derived from WINDII (Wind Imaging Interferometer) measurements as a function of local time and geographic latitude. Focussing on WINDII-wind patterns in June plot ~250 km at geomag. equatorial latitude (geog.~11°S), results seem to support the SOFDI wind (except for dayside zonal) observations. [Source: *Emmert et al., 2002; JGR-Space Physics*]

Conclusions

- We have a relatively large SOFDI data set of continuous, 24-hour winds from the magnetic equator spanning 2011-2019. The SOFDI wind data system can be used as a benchmark for validating various thermospheric neutral wind models and also be used as inputs or boundary conditions for physics-based models of the upper atmosphere.
- Generally, the measured SOFDI meridional winds correspond well to both models, LLIONS (physics-based numerical) and HWM-14 (empirical) model, and to the WINDII satellite observations, EXCEPT for the daytime eastward winds seen in the 630-nm emission.
- Wind amplitudes increase throughout the day, peaking in the late afternoon. Lower atmospheric forcing is a possible driver of this variability via waves.
- The meridional neutral wind plays a very significant role in the development of the EIA asymmetry by transporting the plasma up the field lines. A precise observation of the meridional wind contributes to forecasting fluctuations in the upper atmosphere, including the thermosphere.

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