Space Weather in Morocco

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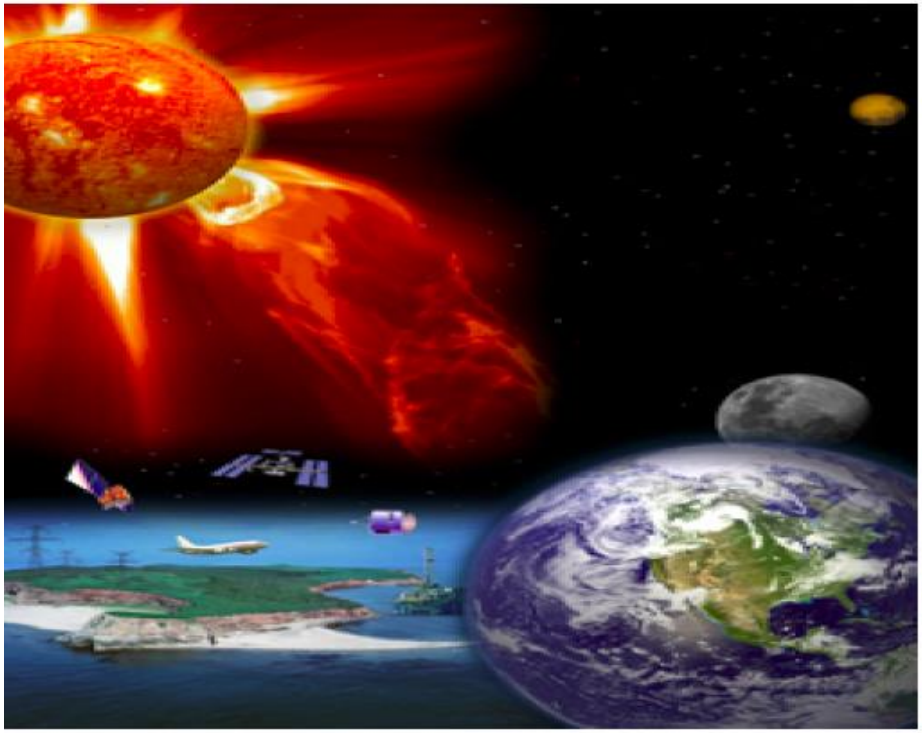
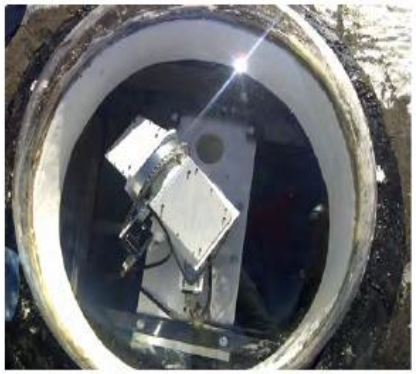


How we get involved in space weather research



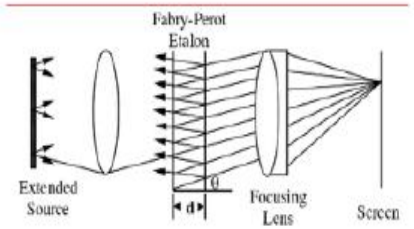
- In 2010 an ISWI delegation arrived to Morocco with proposed installations of observation instruments.

- In November 2013, the RENOIR "Remote Equatorial Nighttime Observatory of Ionospheric Region" experiment in collaboration with the University of Illinois has been depoyed at Oukaimeden Observatory.

- In May 2014, International School on Space Weather at Cady Ayyad University.

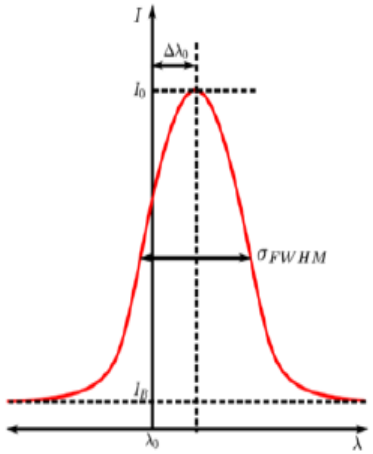
Fabry-Perot interferometer

- Light enters two parallel, partially-reflective glass plates after passing through the redline filter and is then focused onto a CCD
- Plate separation causes phase offsets that create interference on the imaging plane

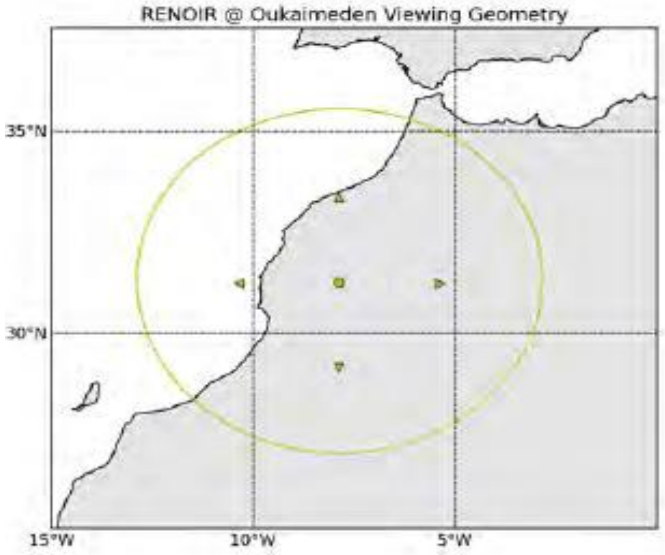


- Fit fringes to model and back out relevant airglow parameters through an inversion

- Background ~ I_B
- Intensity ~ I_0 - I_B
- Velocity ~ $\Delta\lambda_0$
- Temperature ~ σ_{FWHM}

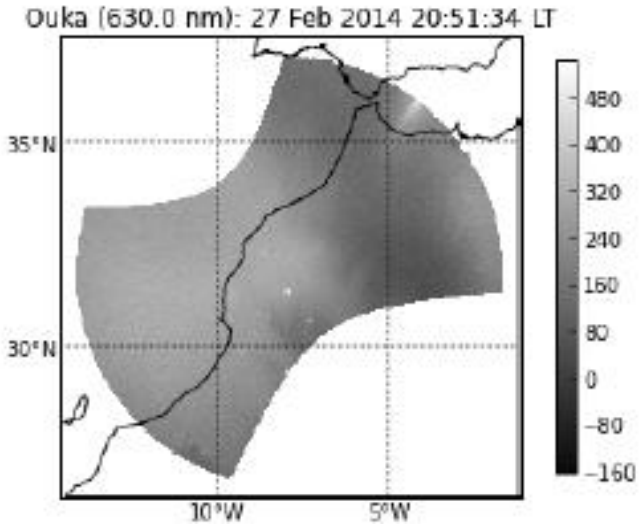


Oukaimeden Observatory (31.206◦N, 7.866◦W, 22.84◦N magnetic)



Picasso Camera

Ionospheric imager
– Measures 630.0- and 777.4-nm emission plus background
– Visualize two dimensional structure of phenomena



Visible phenomena that can be captured :
-- Equatorial Plasma Bubble (EPB)
– Medium-Scale Traveling Ionospheric Disturbance (MSTID)
– Gravity Waves
– Brightness Waves

Stations GPS au Maroc

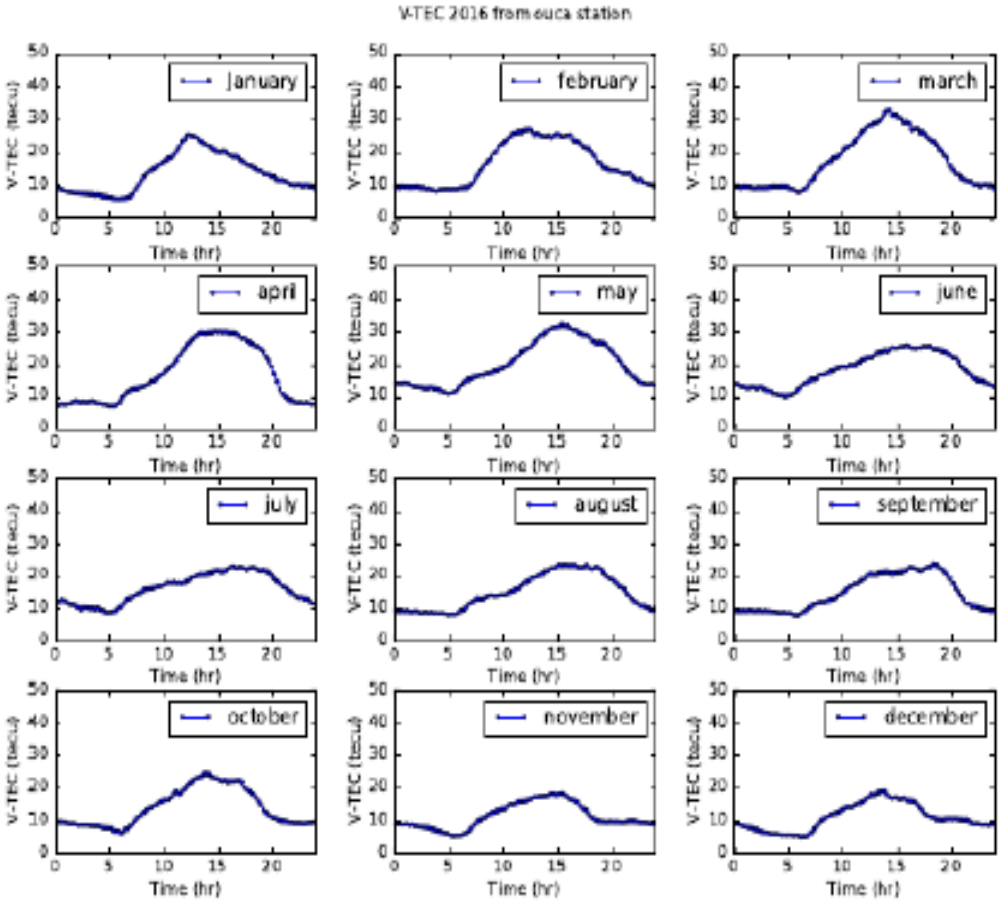
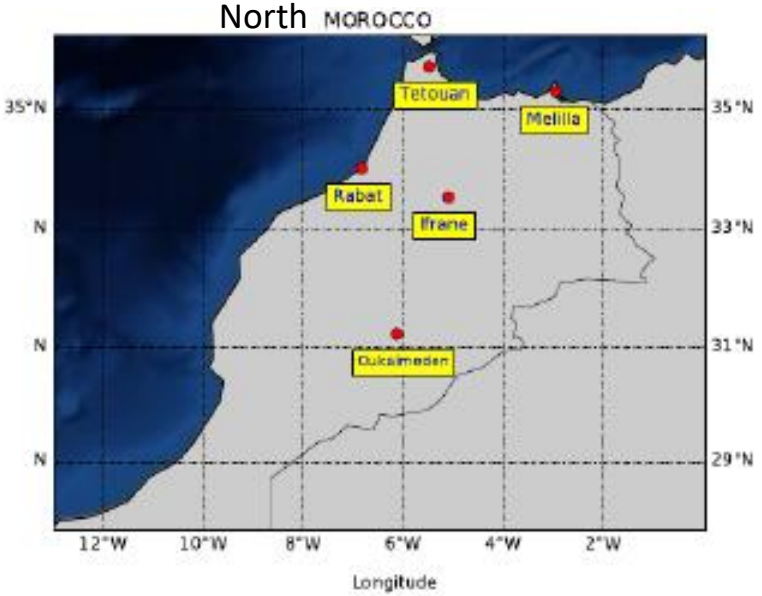
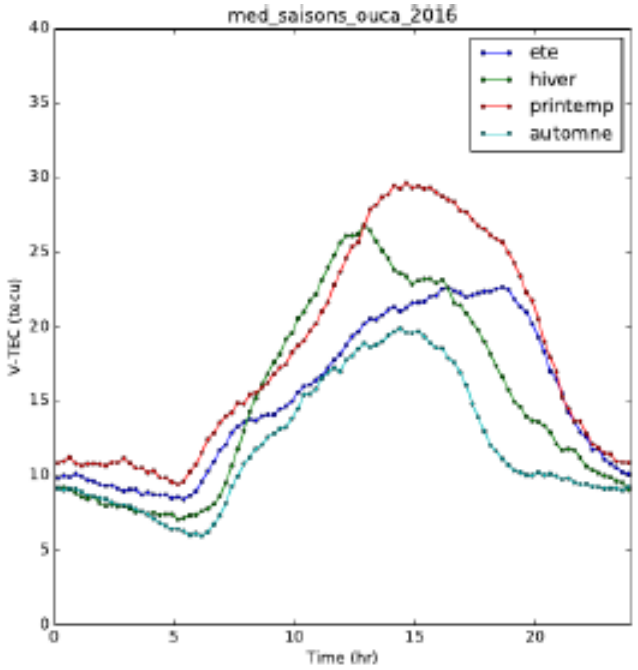


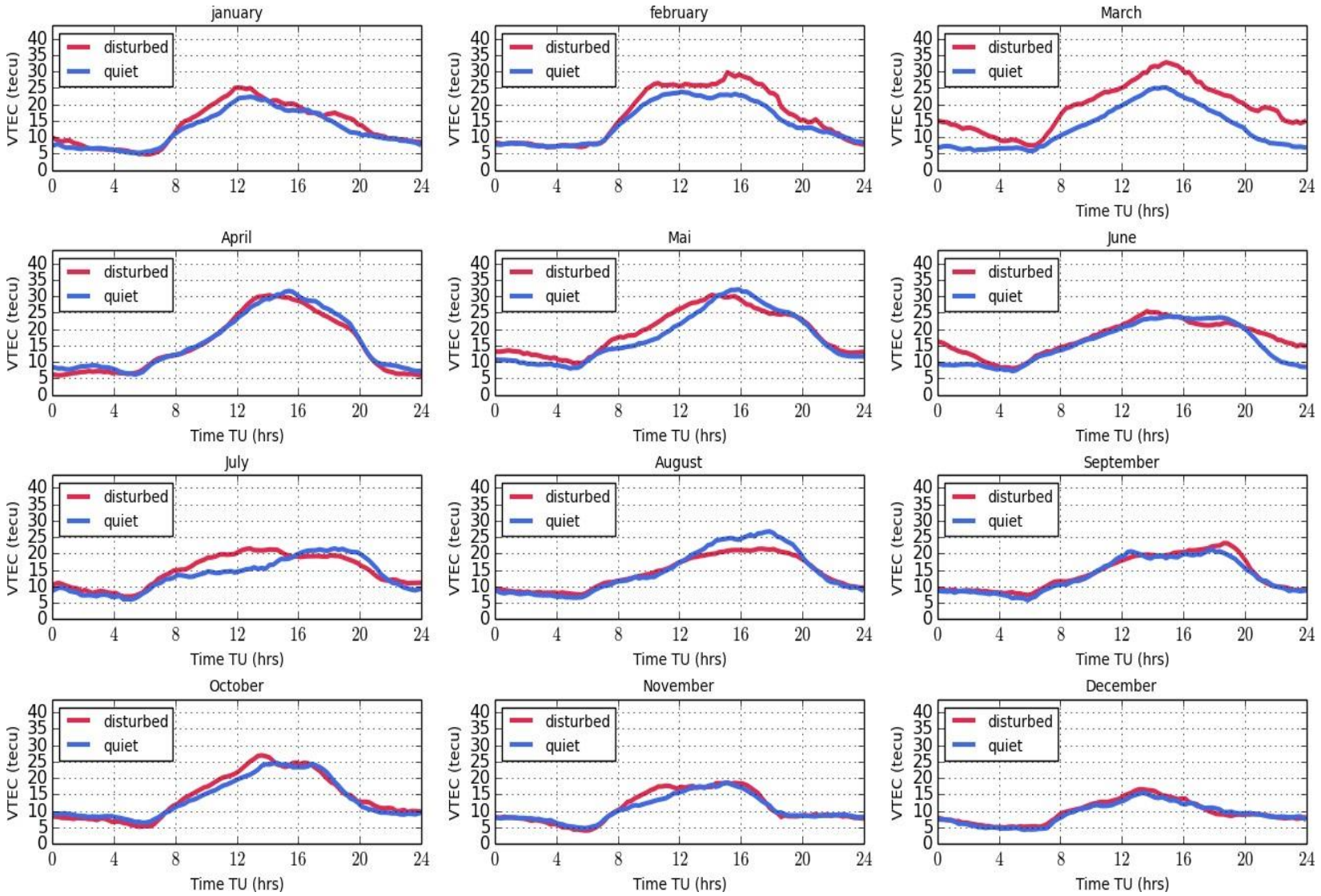
FIGURE 1.3 – La moyenne mensuelle de la station OUCA pour 2016.





Stations GPS au Maroc

Storm times



Scientific objectives and acheivements

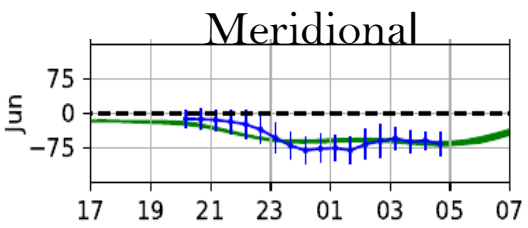
RENOIR experiment at Oukaimeden Obesrvatory: FPI et Camera

- Measurement of **winds**, **temperature** and **ionospheric irregularities** at 250 km of altitude.

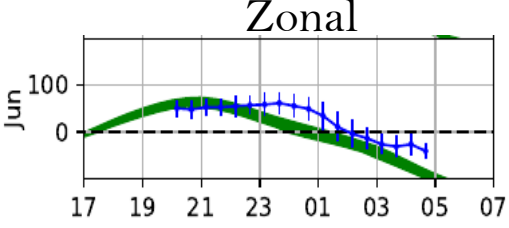
- Thermospheric winds and temperature establishement; Climatology, saisonality, solar cycle dependence, effect of geomagnetic storm …
- Tidal and gravity wave signatures
- Climatologies of EPBs over Africa
- Response of the thermosphere to geomagnetic storms.

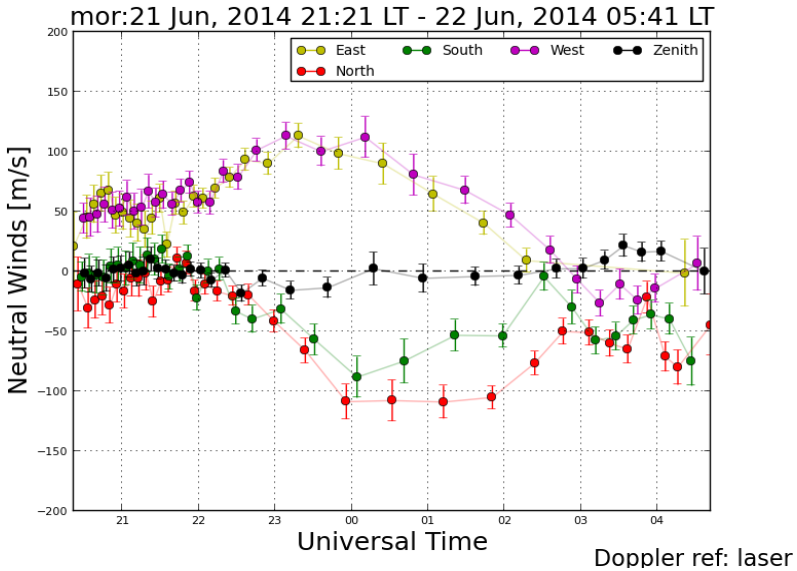
Other data and facilities

* Meaurements of **TEC** : GPS station at Oukaimeden, and other stations in Moroco
* Make use of **satellite data, SWARM**.
* **Comparison to empirical and physics based models :** HWM14, NRLMSIS-00, TIE-GCM and GITM

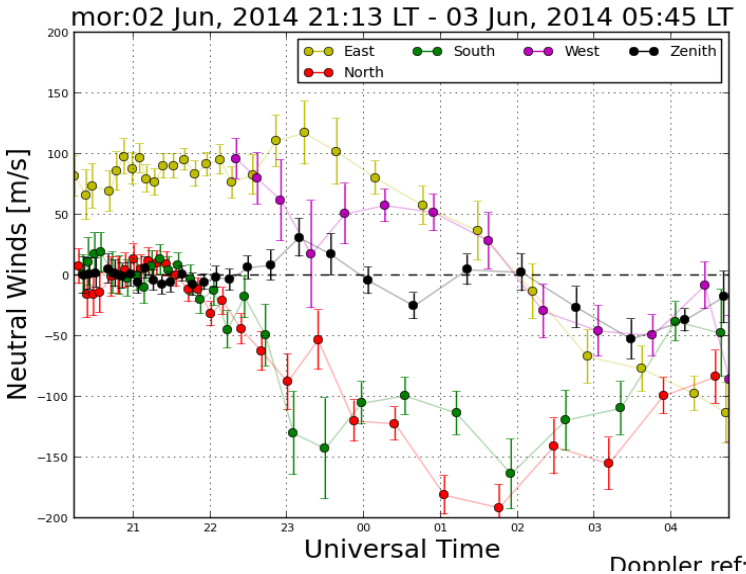


Very Quiet time wind patte

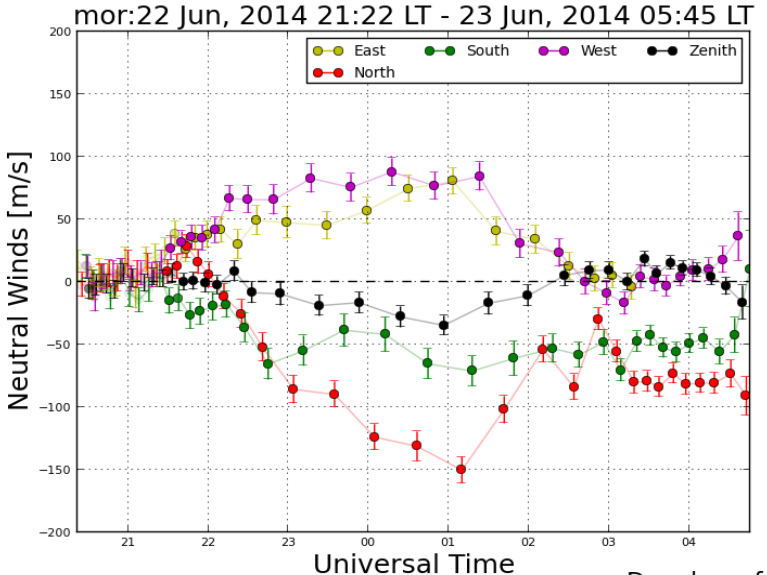


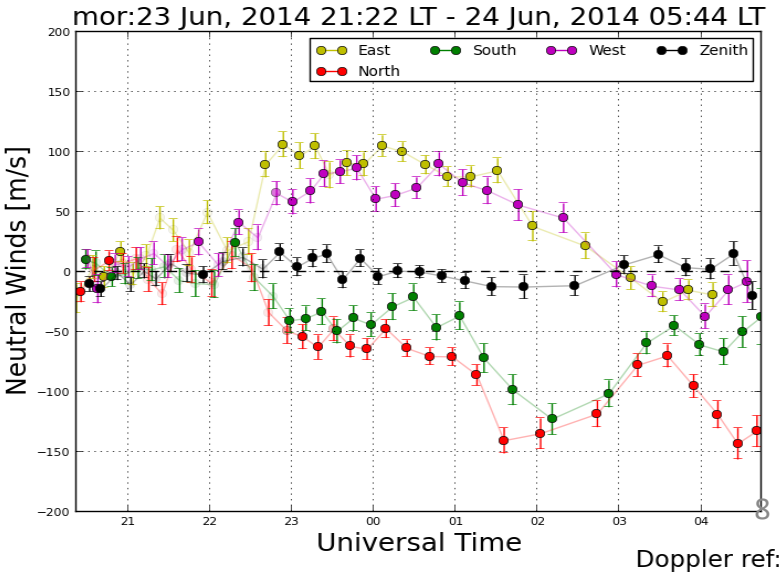


Doppler ref: laser



Doppler ref: laser



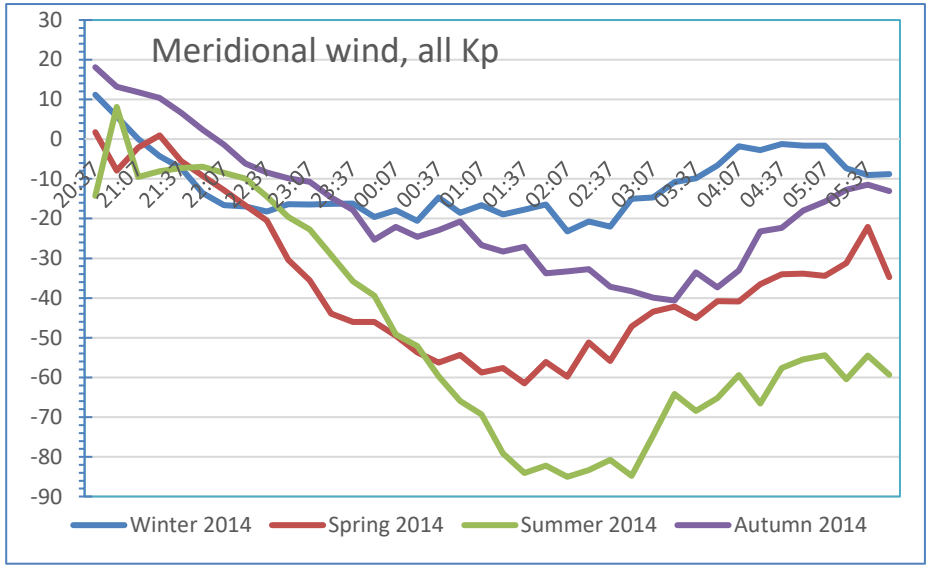


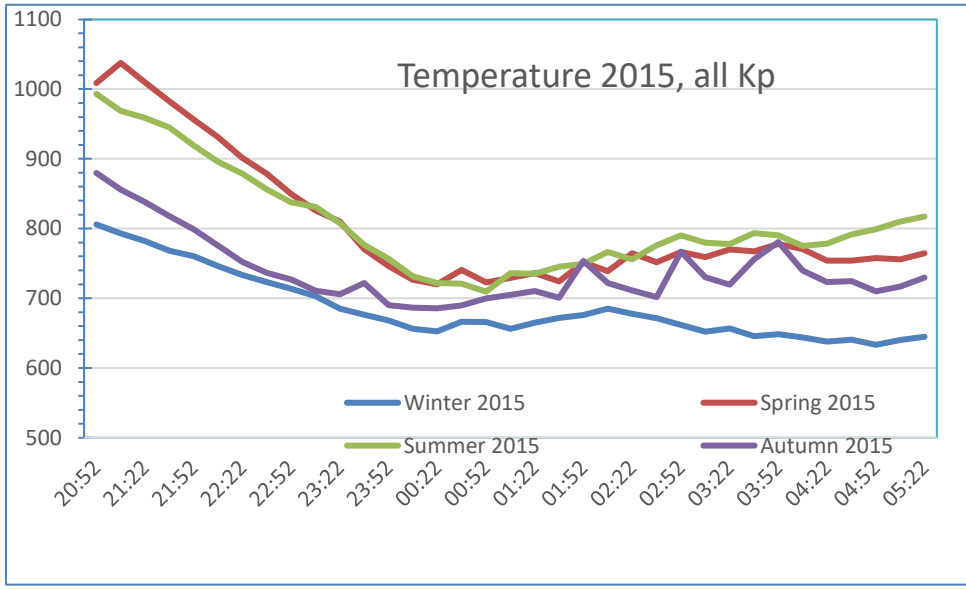
Doppler ref: laser

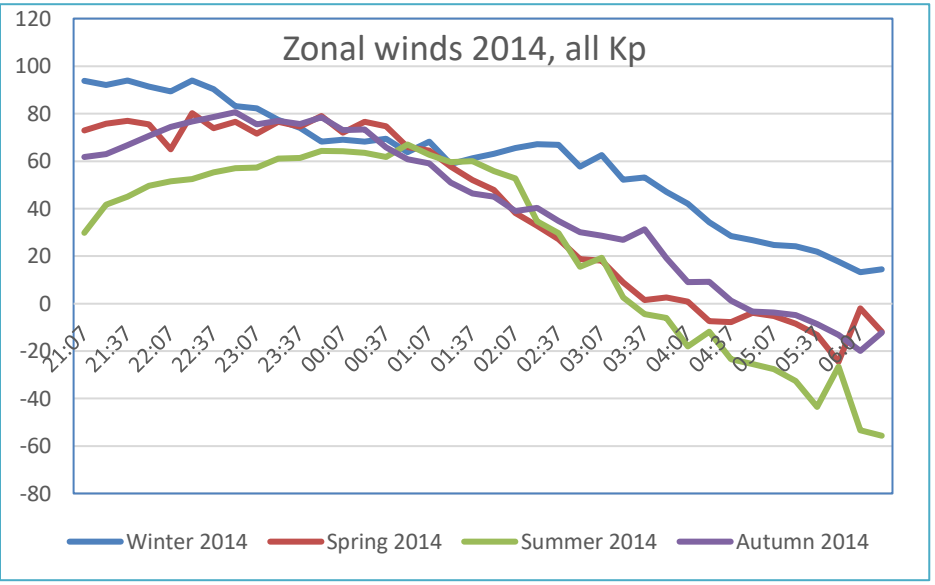
RENOIR Network

- Complements observations made by similar equipment in other locations.
- Four FPIs installed in Ethiopia, Nigeria, Ivory Coast and South Africa allowing comparisons within Africa for the first time.
- Allows for studying latitudinal and longitudinal effects and differences for various phenomena
- Increased coverage to understand storm-time response.
- Wind signature related to ionospheric irregularities.
- Added coincident data from satellite observations and GPS measurements.

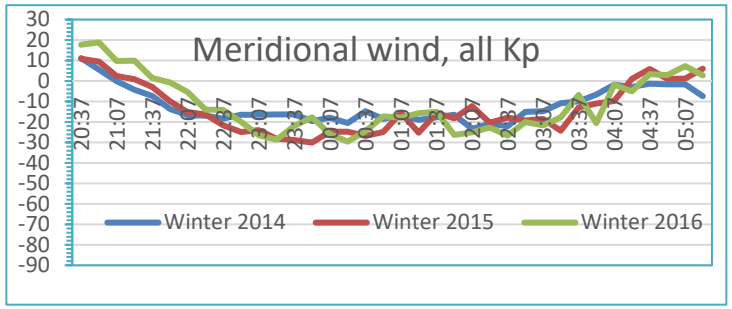
Variability with saisons; Winds and temperature

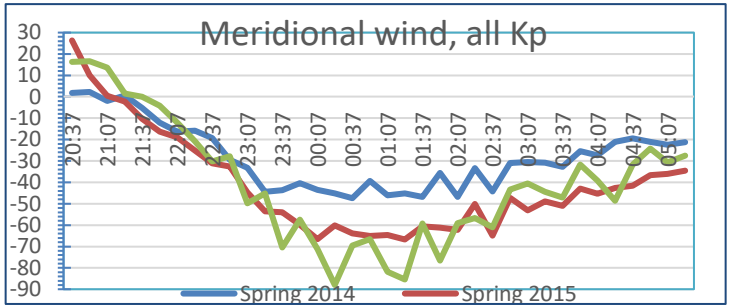


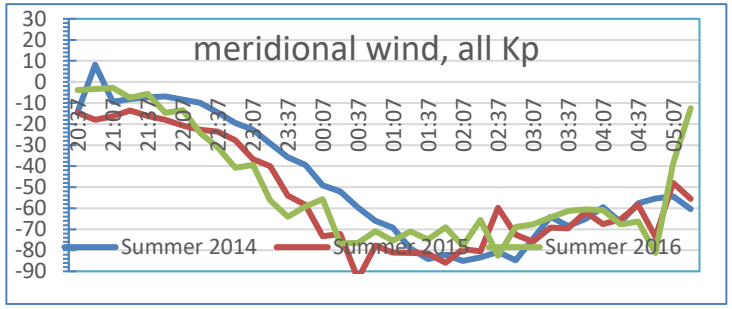


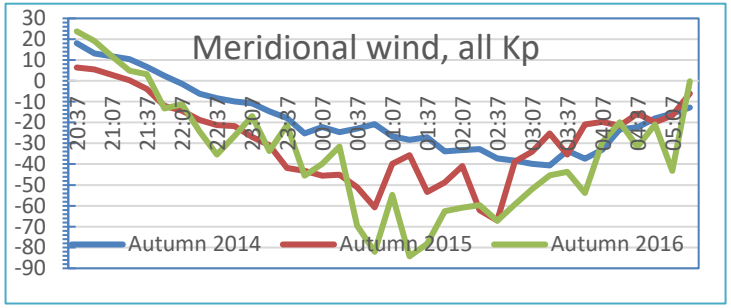


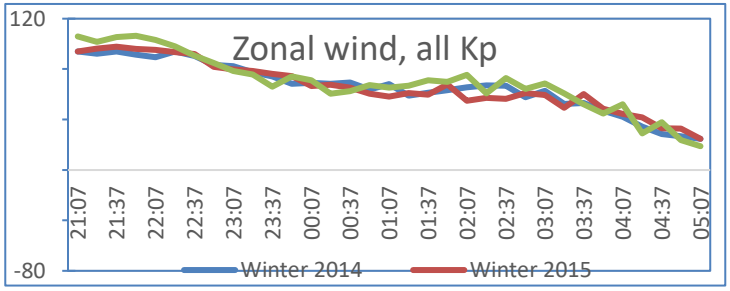
Winds variability with the solar cycle

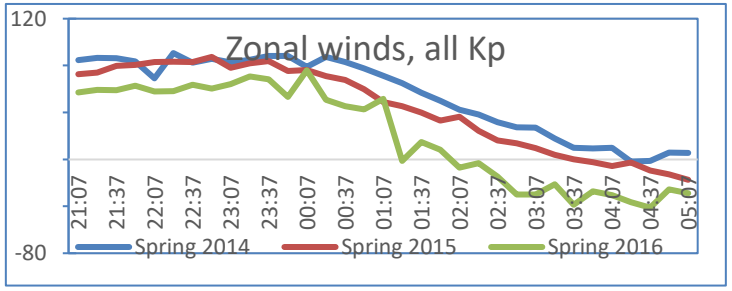


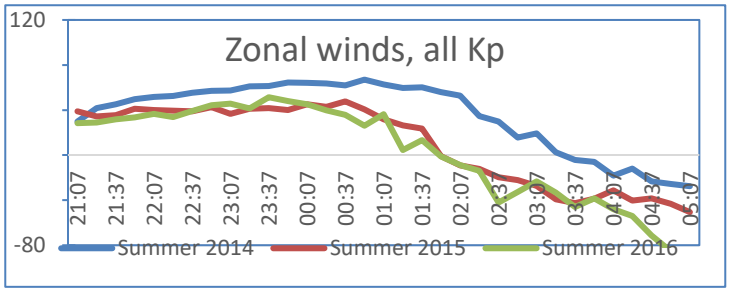


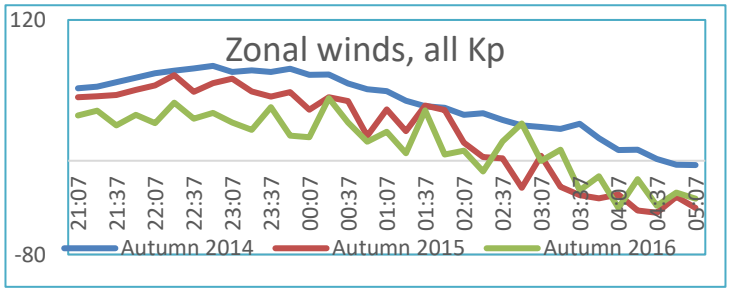












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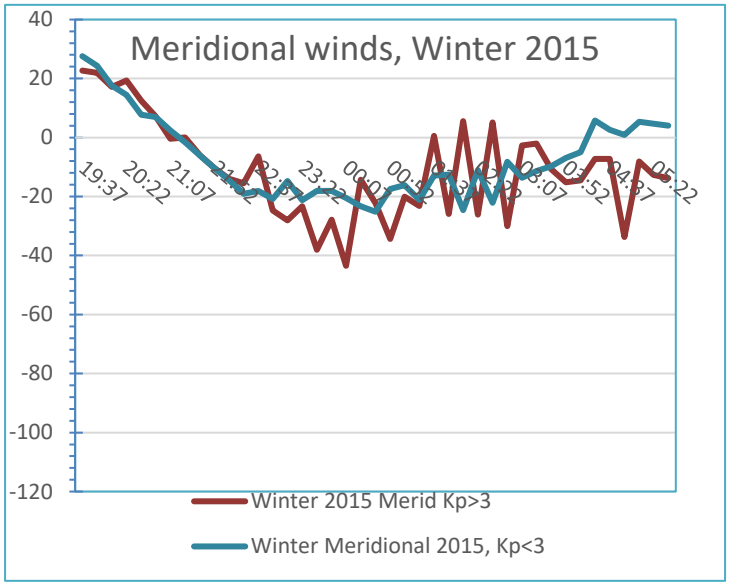
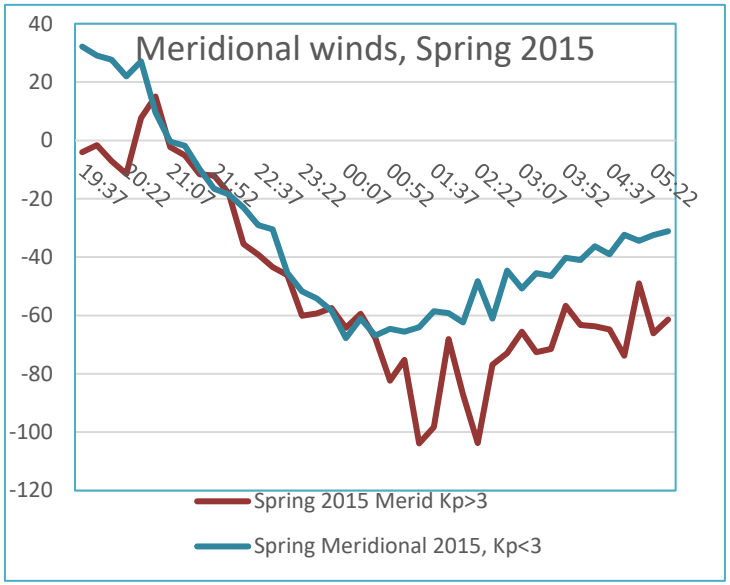
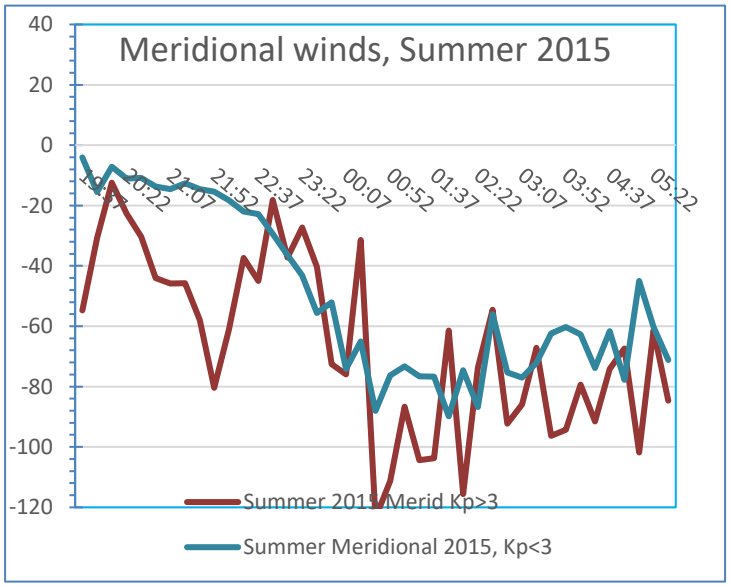
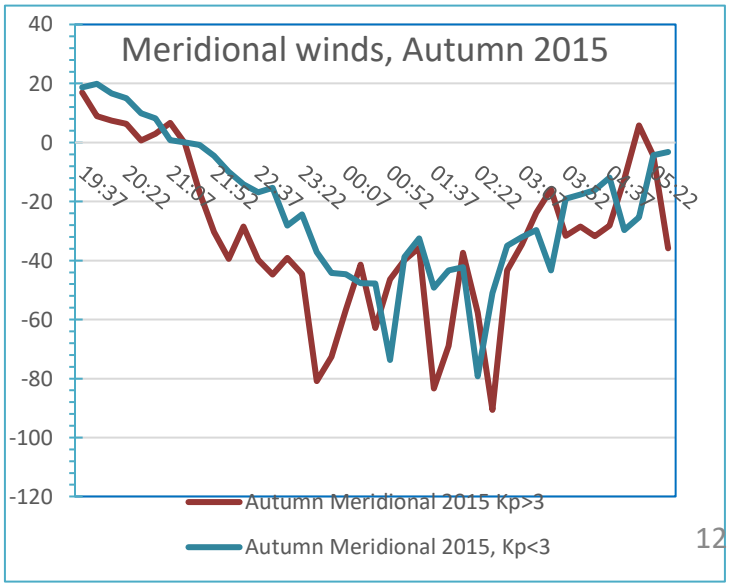
Quiet and Storm time

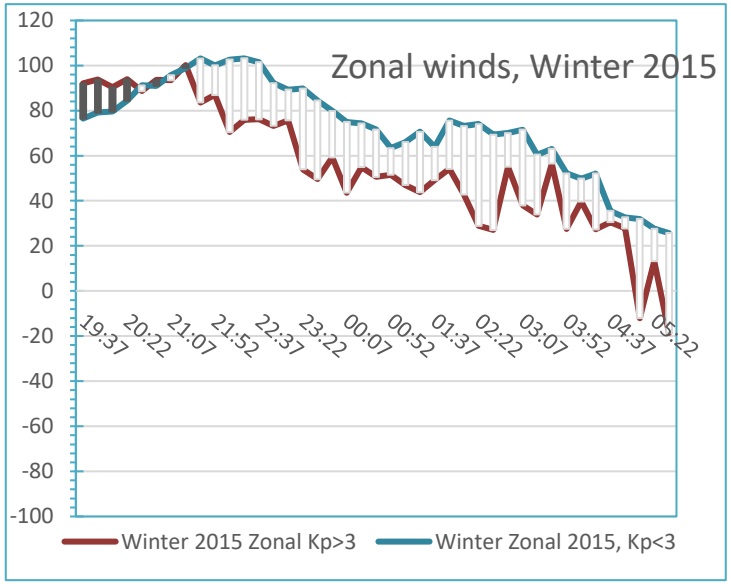


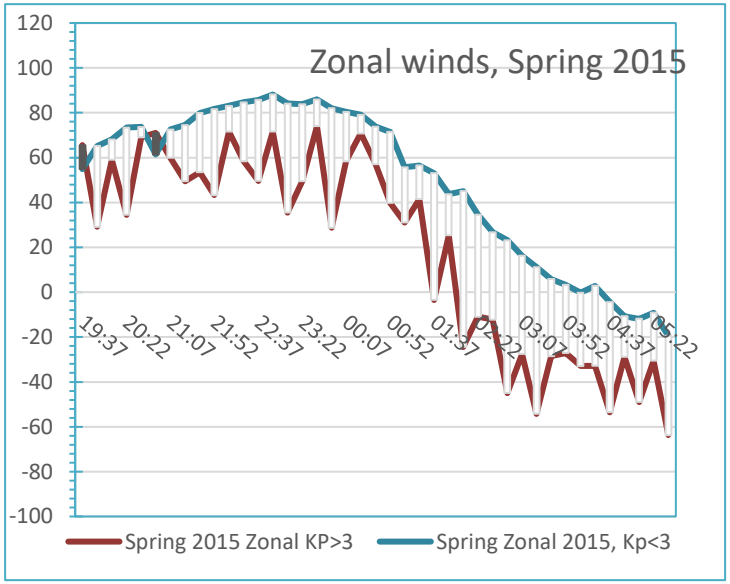


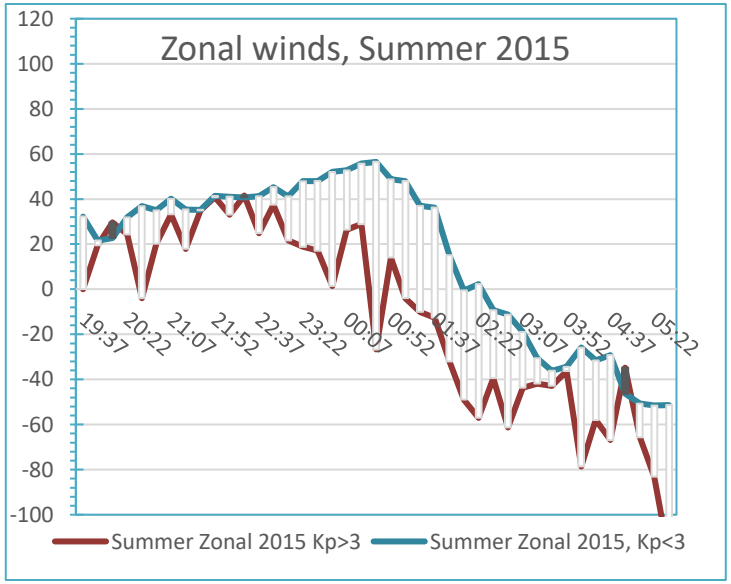


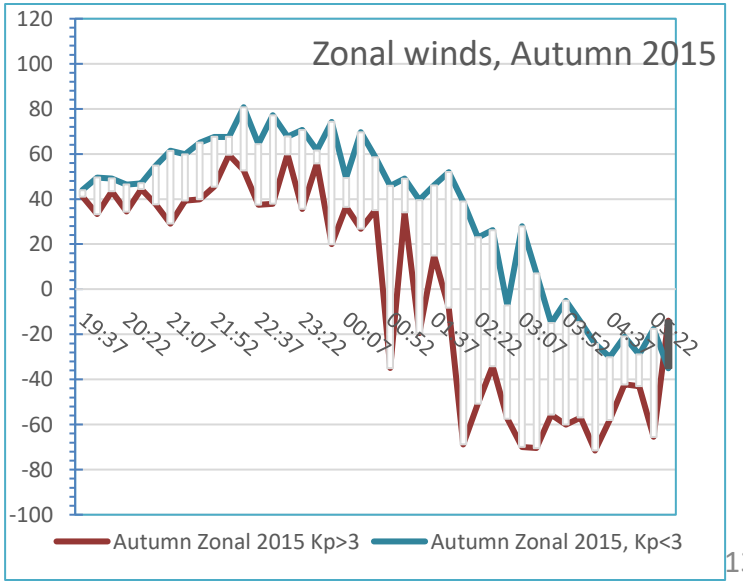


Quiet and Storm time

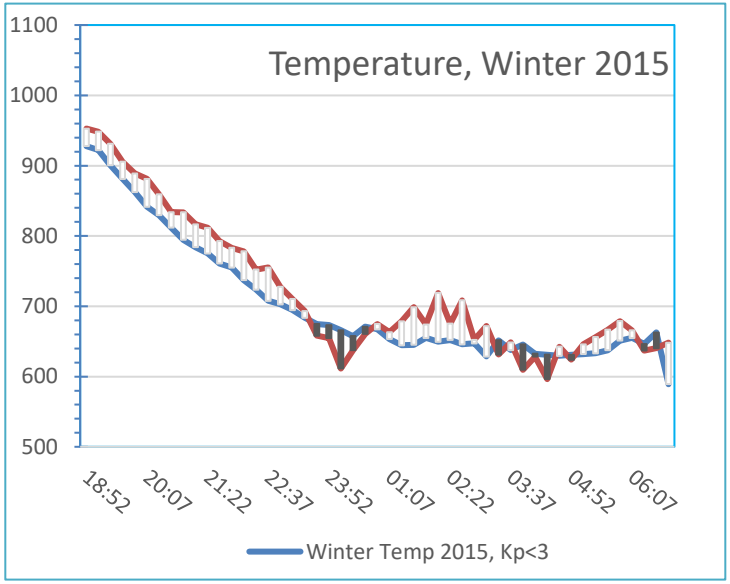


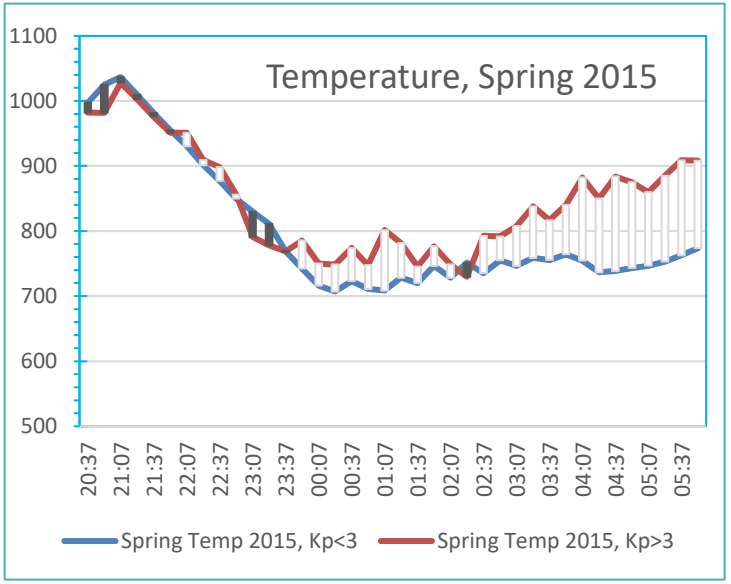


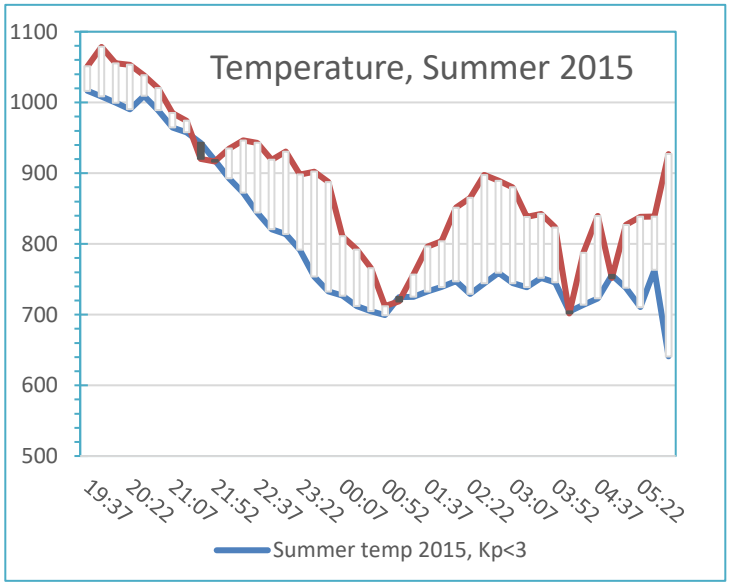


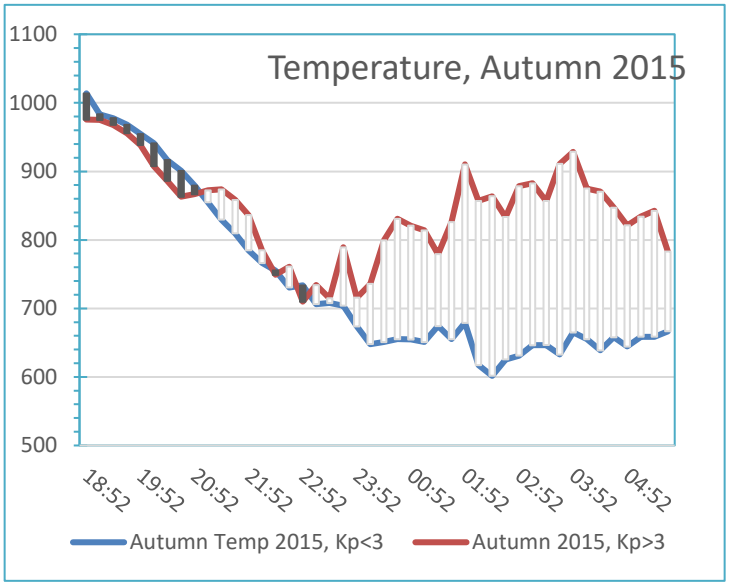


Quiet and Storm time

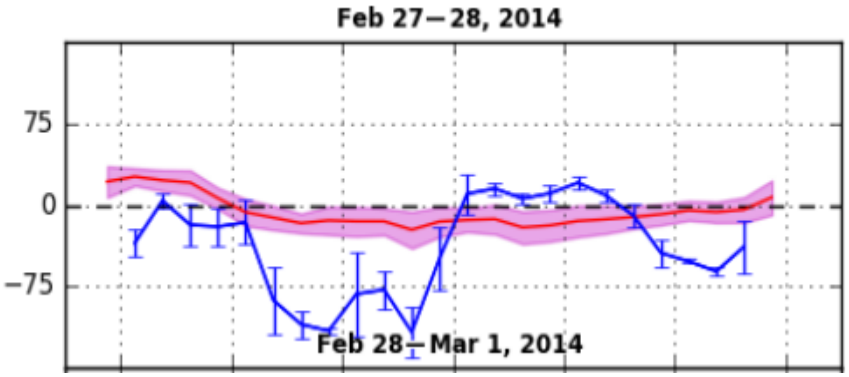


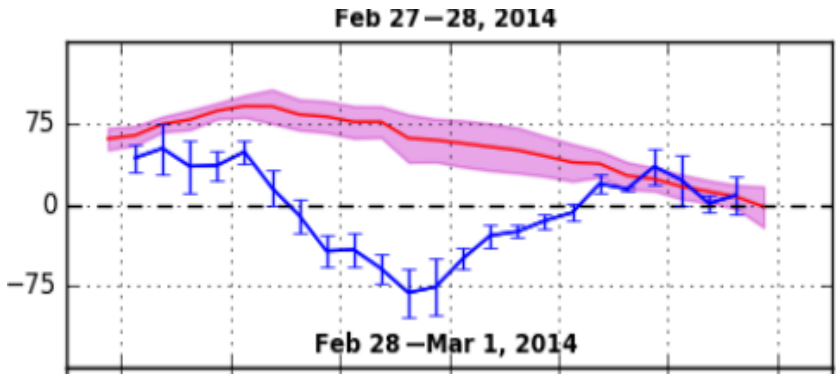


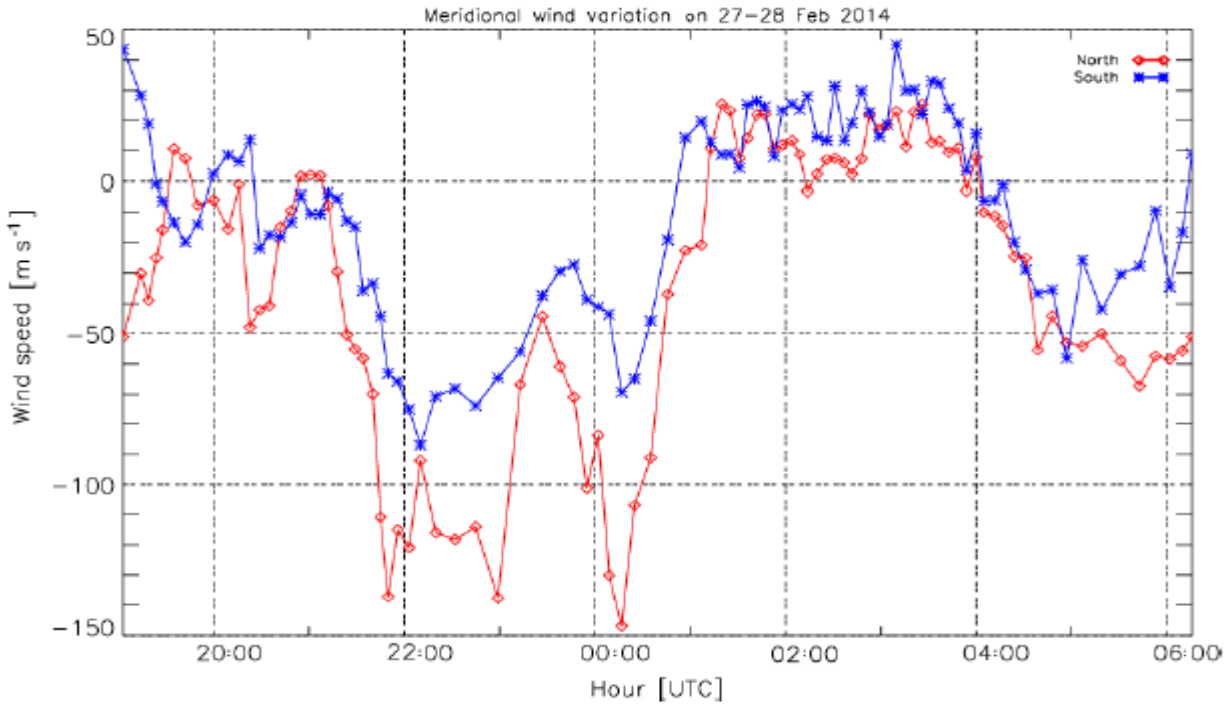




Storm time thermosphere-ionosphere coupling at midlatitude consecutive to an associated flare/CME event; a case study.



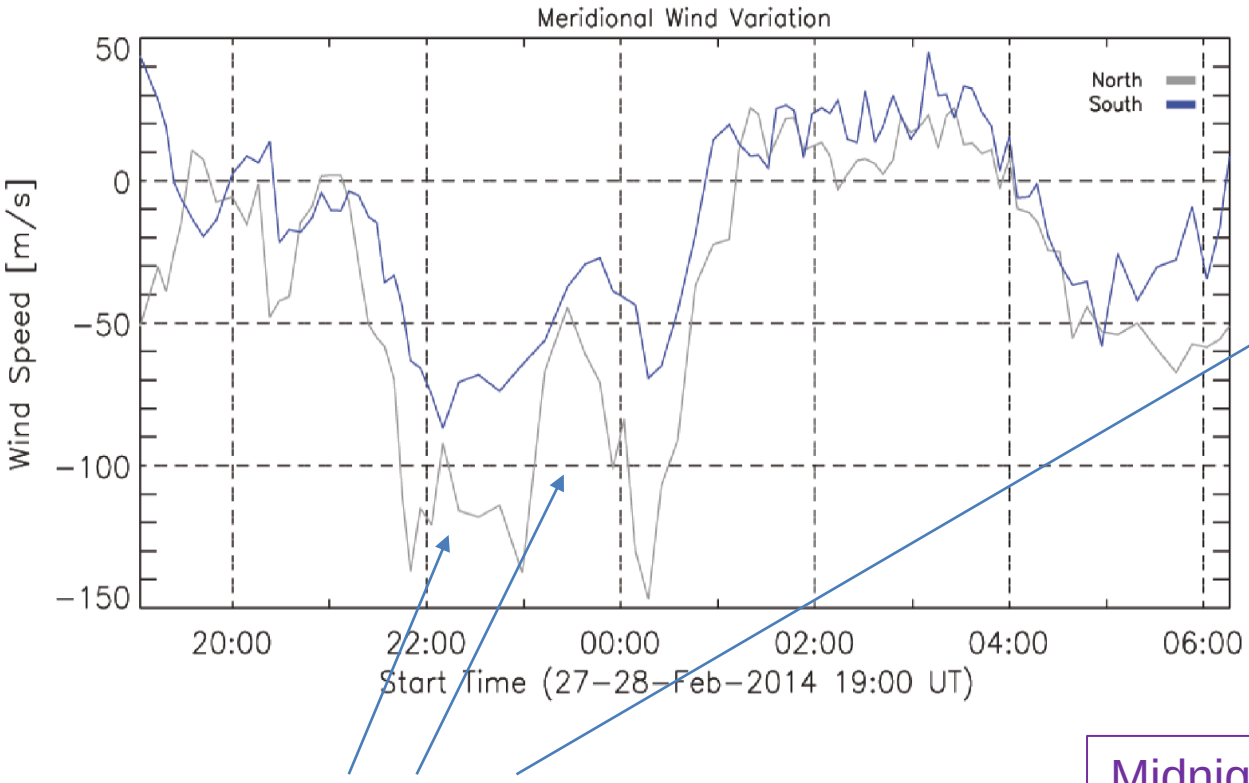


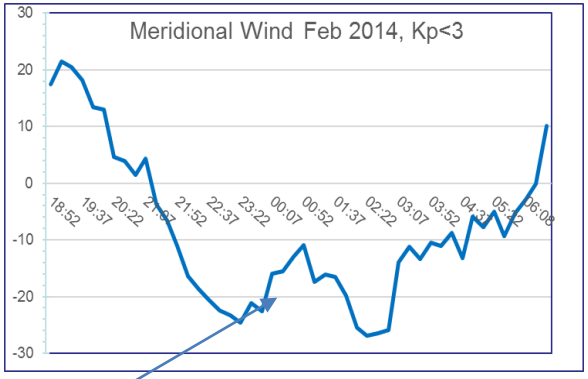


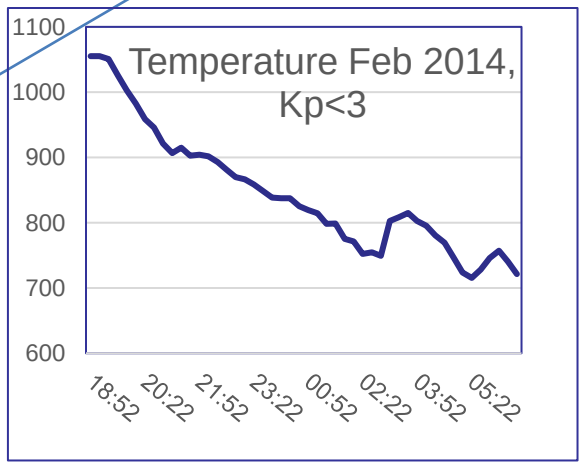
- First TAD coming from the northern hemisphere was captured around 21 LT, **lasted for about 4 hours**; (Vn > Vs) ΔT = 15 mn ------→ **V(TAD) = 550 m/s**
- Second TAD trans-equatorial was captured around 00 LT, **lasted for 3,5 hours**; (Vs > Vn)

Storm time thermosphere-ionosphere coupling at midlatitude consecutive to an associated flare/CME event; 27 February 2014

Thermospheric wind response



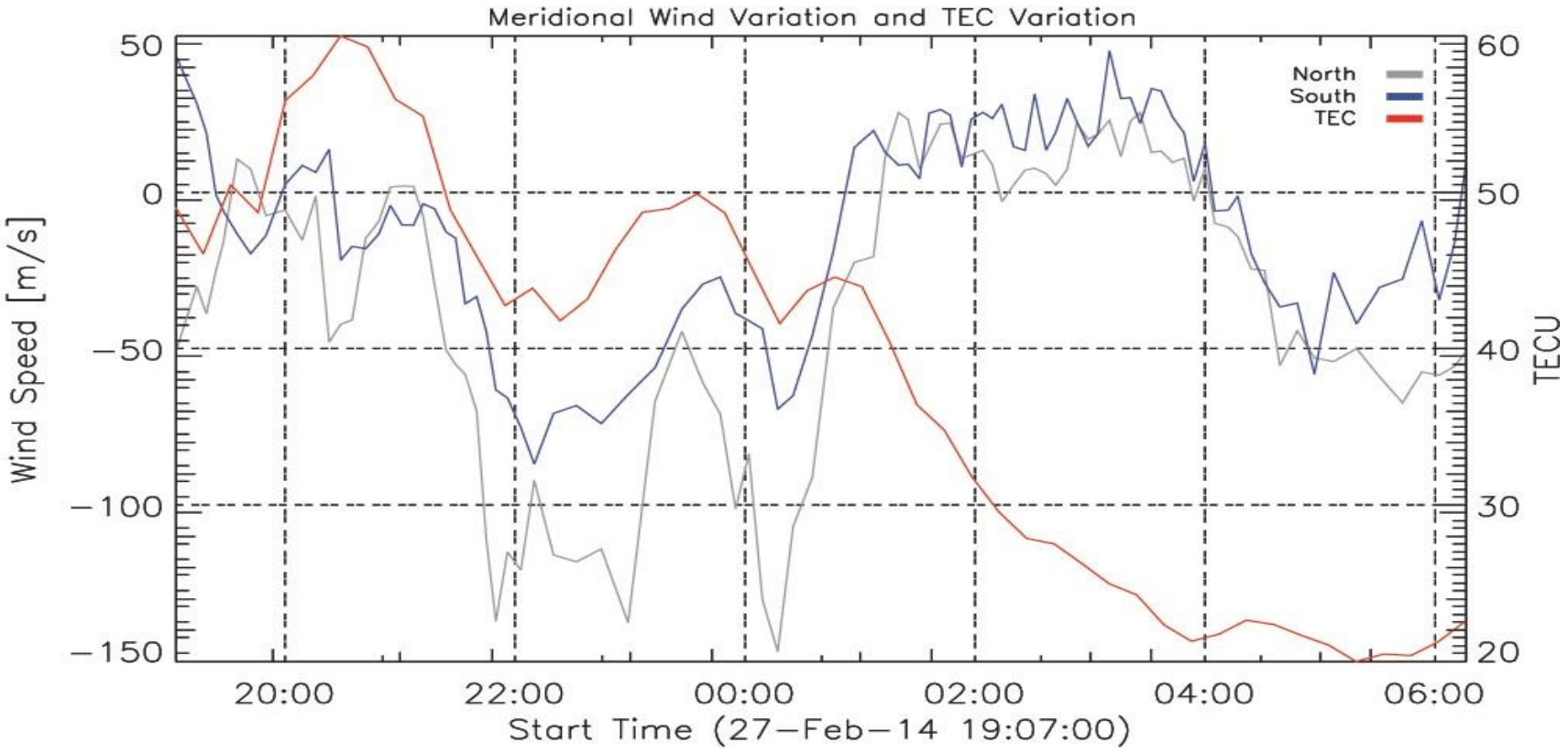




Reactive effects 1 and 2
Enhancement of the MTM phenomena due To storm circulation (ΔV~100 m/s)

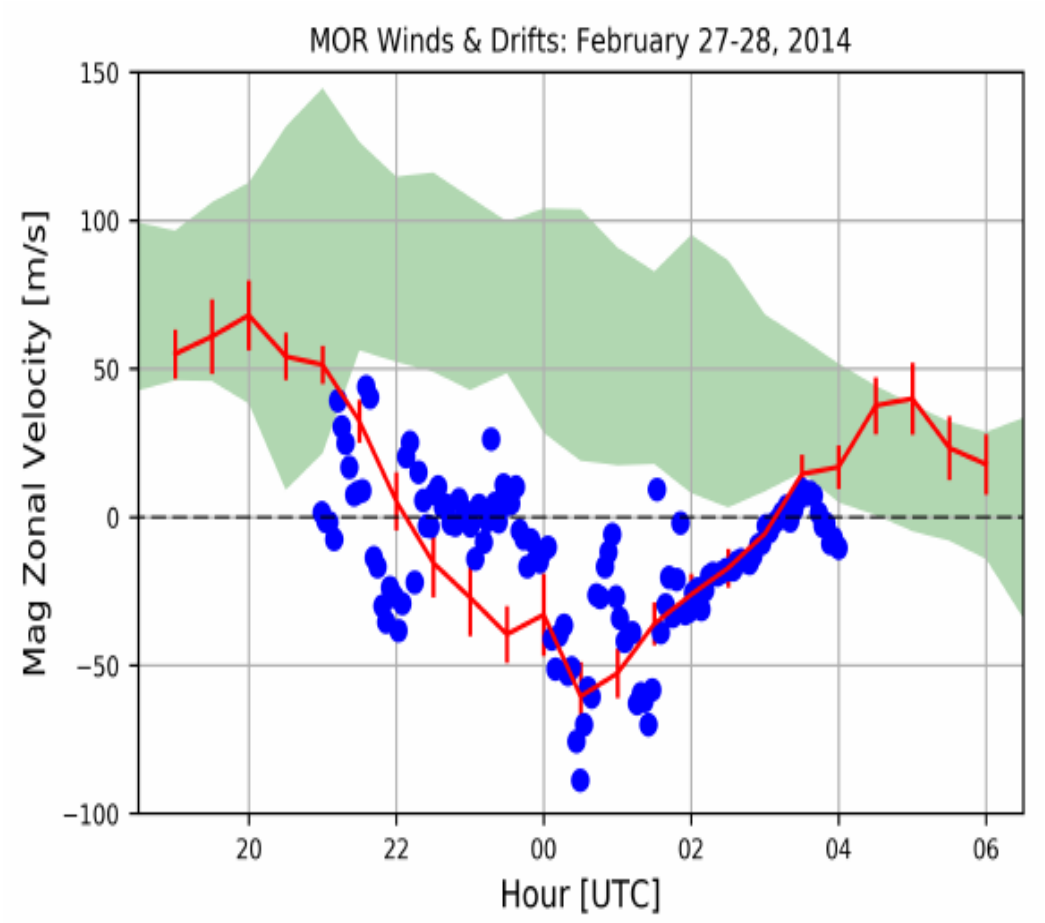
Midnight Temperature Maximum
MTM phenomena
Quiet time
(ΔV~20 m/s)

Storm time thermosphere-ionosphere coupling at midlatitude consecutive to an associated flare/CME event; 27 February 2014



Between 19 and 00 UT, TEC correlates in some ways with the meridional winds.
Equatorward flow ----------→ decrease of the TEC.
Equatorward flow ----------→ raises the HmF2 pick where decrease NmF2 --------→
migration to thermospheric regions of increased mean molecular mass --------→ TAD effect.

Storm time thermosphere-ionosphere coupling at midlatitude consecutive to an associated flare/CME event; 27 February 2014



The plasma drift estimates from cross-correlations are marked as blue dots.

cross-correlation analysis

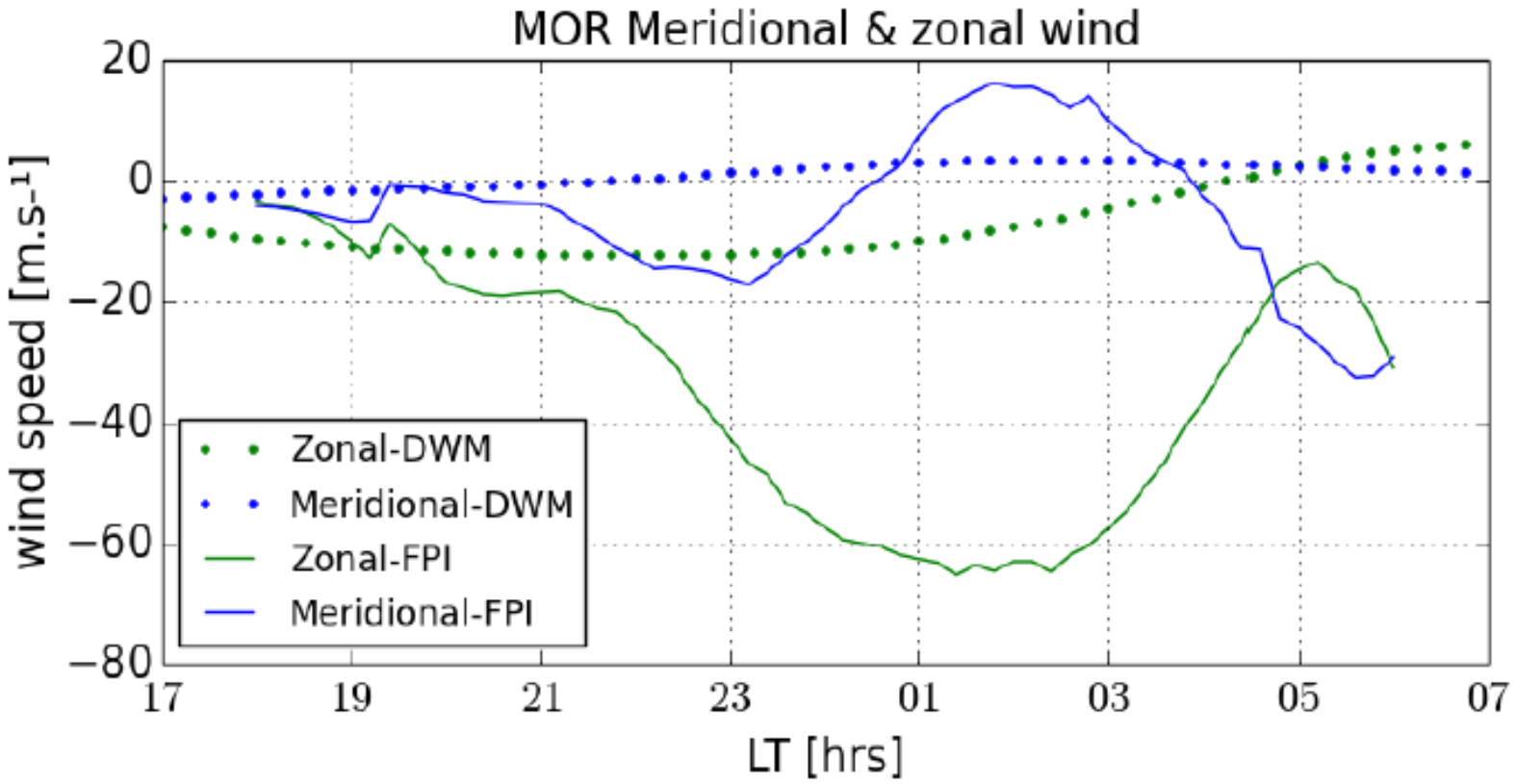
* Westward neutral winds, indicating forcing from the geomagnetic storm.

and

* EPB drifts tend to closely match the neutral winds

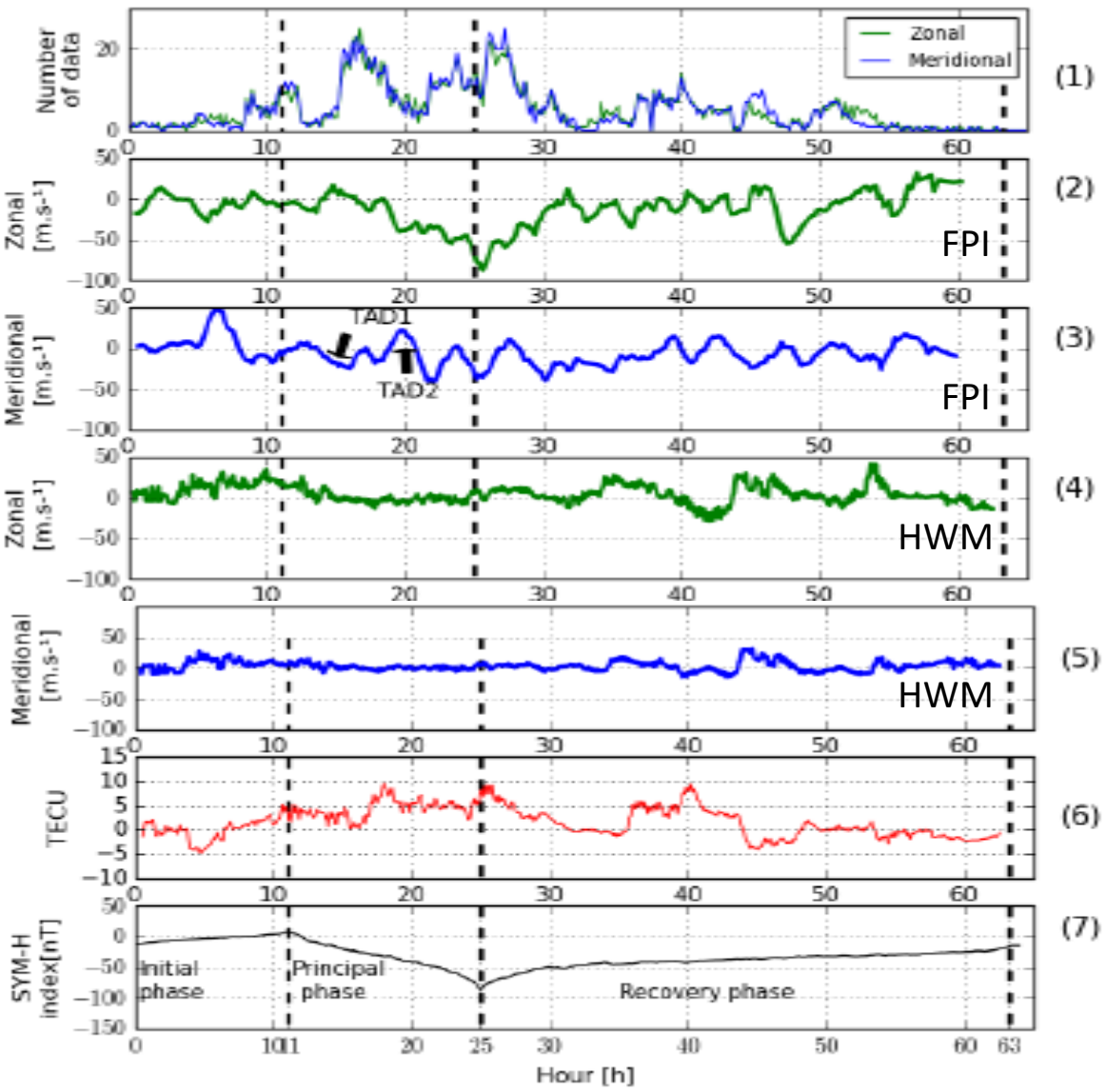
The dynamo is fully activated during this storm.

Storm time winds in general



- 59 % of the cases are characterized by TAD induced circulation.
- 33 % exhibits only slight discrepancies between the disturbed and quiet night.
- 8 % are characterized by the transequatorial wind during the whole the night.

Storm time winds in general



FPI observations and comparisons with thermospheric models: HWM14, NRLMSIS-00, TIE-GCM and GITM

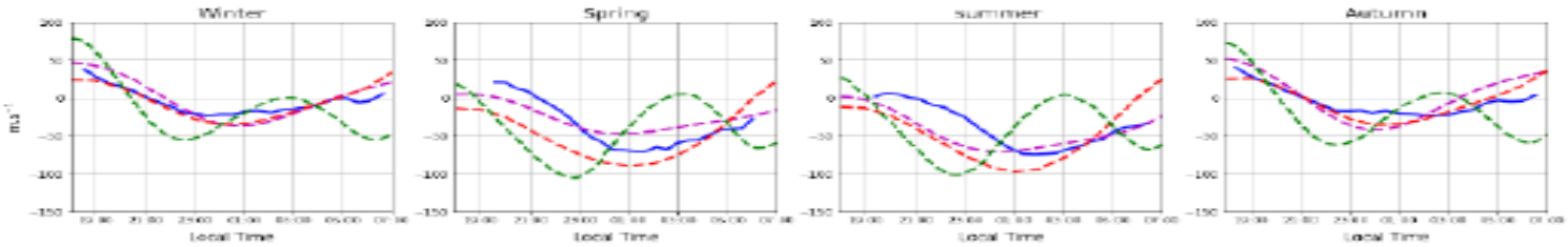


Figure 6. Seasonal comparison of meridional neutral winds between FPI-mesuremennt (bleu) and the HWM14(purple), TIE-GCM(red) and GITM (green) models predictions.

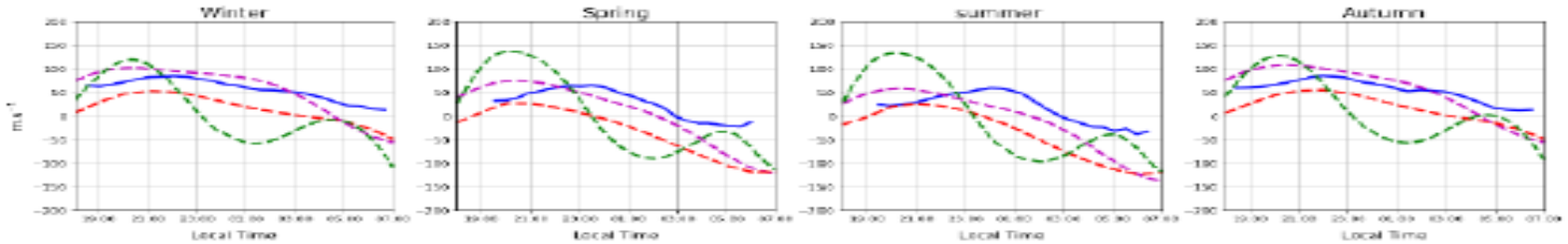


Figure 7. Seasonal comparison of zonal neutral winds between FPI-mesuremennt (bleu) and the HWM14(purple), TIE-GCM(red) and GITM (green) models predictions.

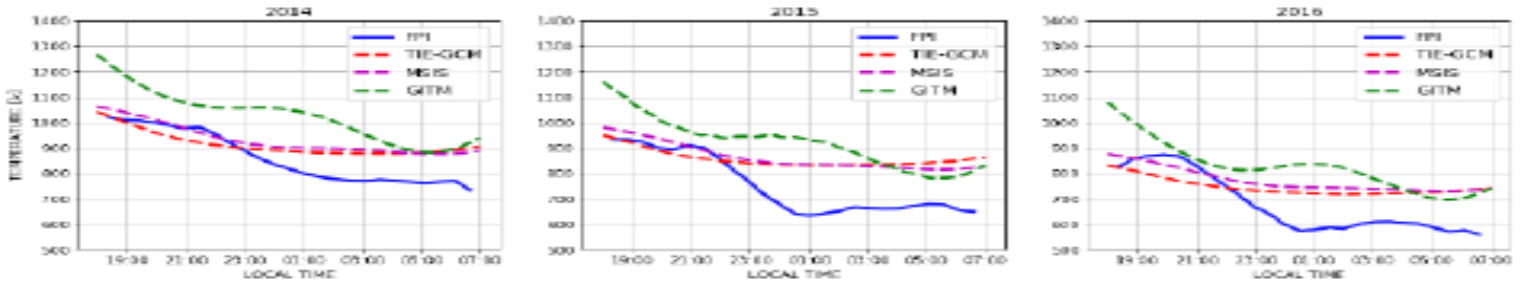


Figure 8. Yearly averages comparison of neutral temperature over three years 2014, 2015 and 2016 between Oukaimden FPI-measurements (bleu) and the simulations of NRLMSIS-00(purple), TIE-GCM(red) and GITM (green).

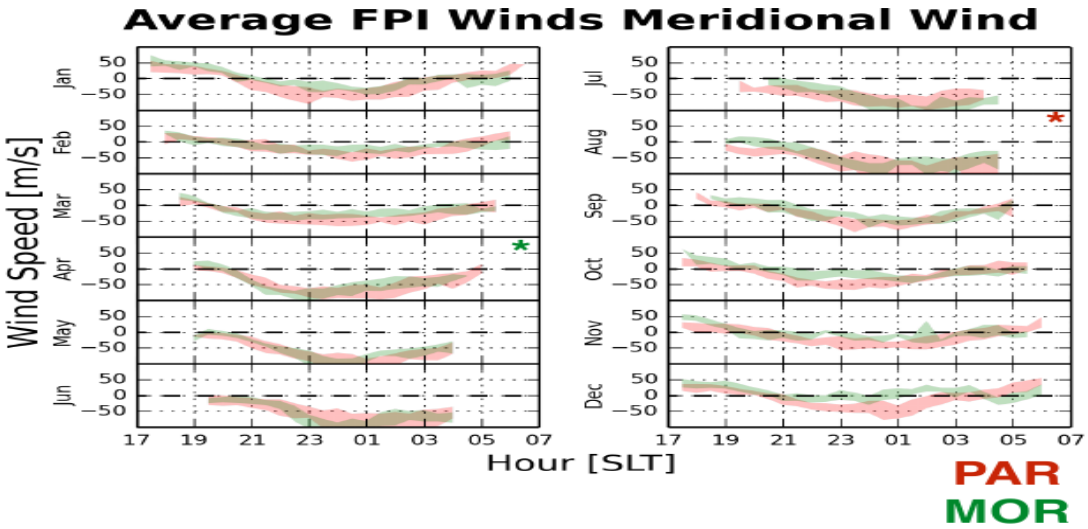
Longitudinal winds variability

Case study of two stations; Oukaimeden and Paris

	Geographic	Geomagnetic
PAR	35.2 N	45.27 N
MOR	31.21 N	22.73 N

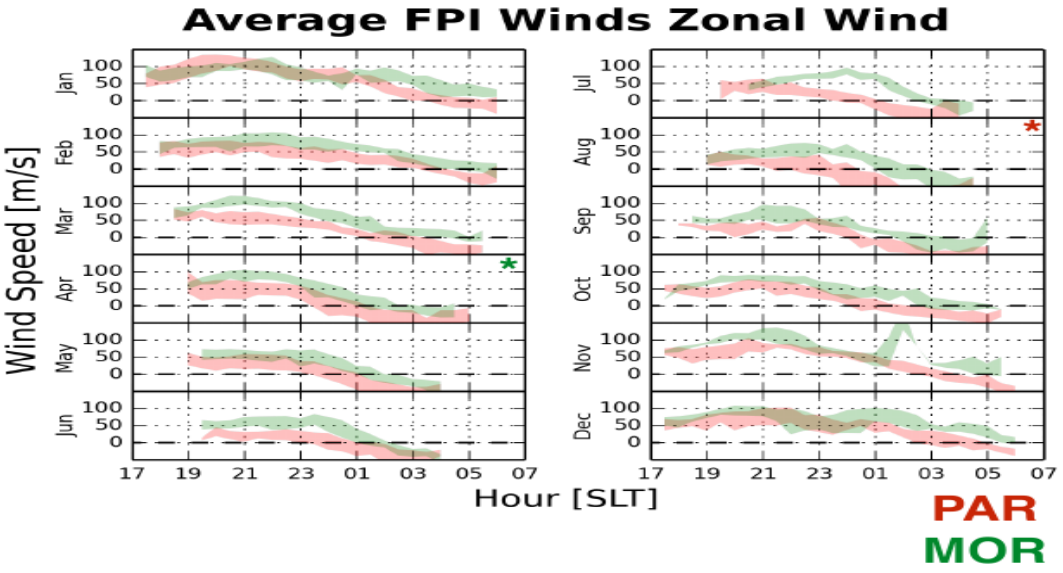
Meridional winds

- Poleward to equatorward reversal ~19-21 LT
- Maximum equatorward flow around local midnight
- Equatorward to poleward reversal ~03-05 LT
- Pattern shifts equatorward from local winter to local summer
  - Reversals presumably occur in sunlight before/ after observations commence
- Generally consistent between MOR and PAR, although local winter equatorward winds appear suppressed over MOR

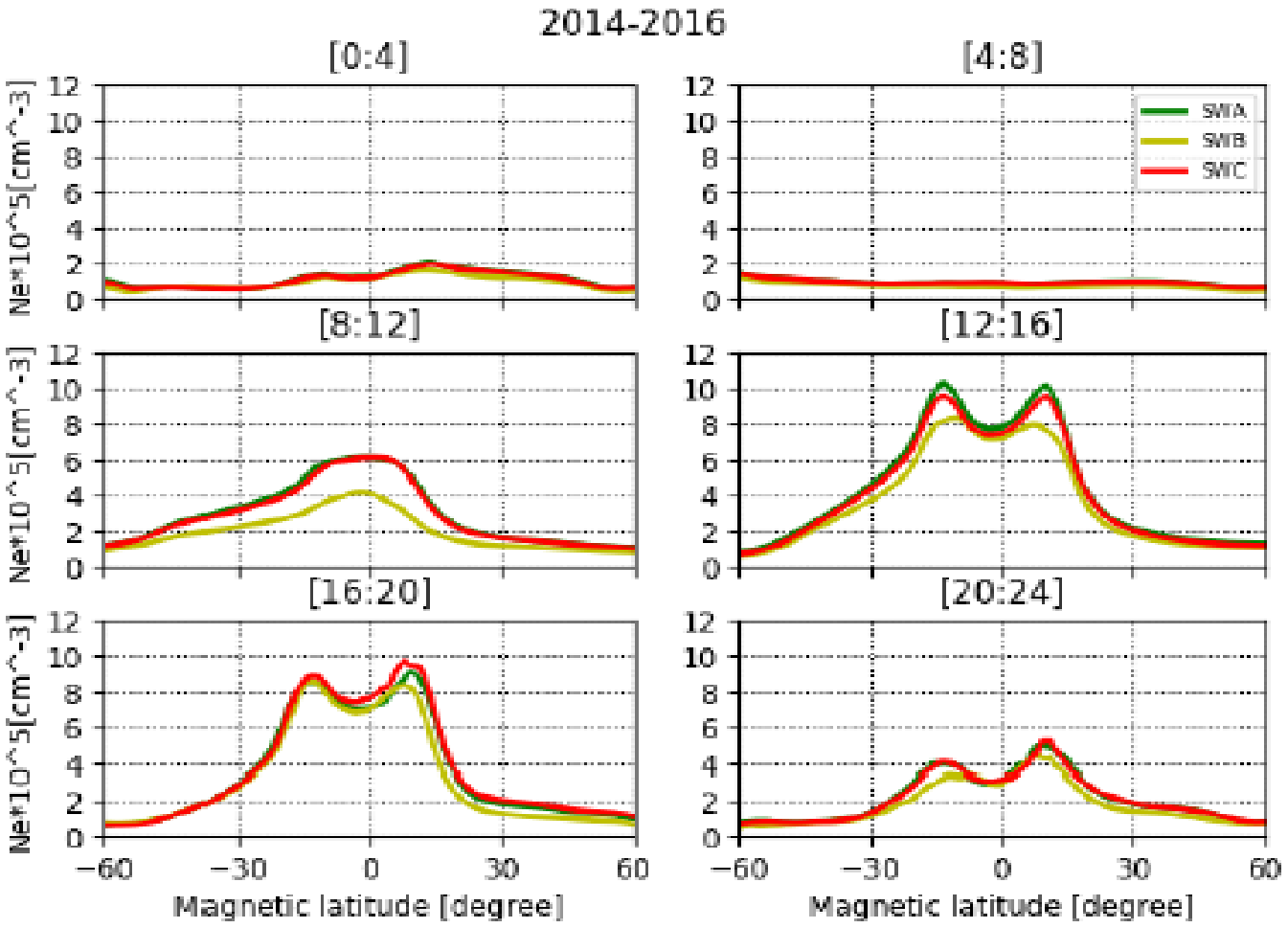


Zonal winds

- Eastward to westward reversal occurs post midnight
  - Reversal occurs ~2 hours earlier over PAR than over MOR
  - Reversal time is a function of season (earlier in local summer)
- Stronger eastward flow over MOR than over PAR, especially during local summer
- Comparatively large phase shift seen over MOR in local summer



Interhemispheric asymmetry of the equatorial ionization anomaly (EIA)

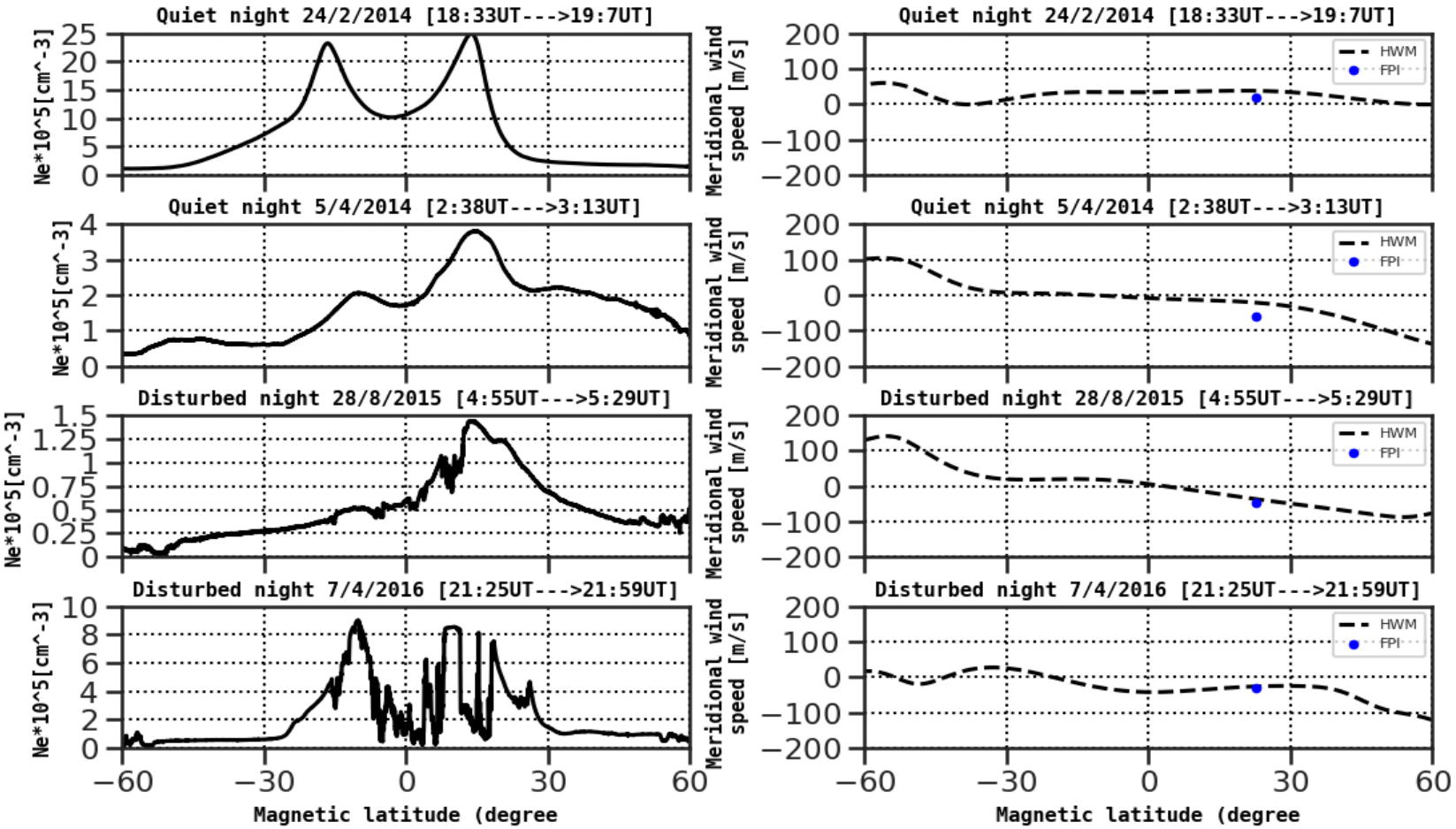


Average of three years of measurements

- From 24 to 8 LT, very low Ne.
- From 8 to 12 LT Ne increases with single crest.
- From 12 to 16 LT symmetric double crest.
- From 16 to 24 asymmetric double crest.

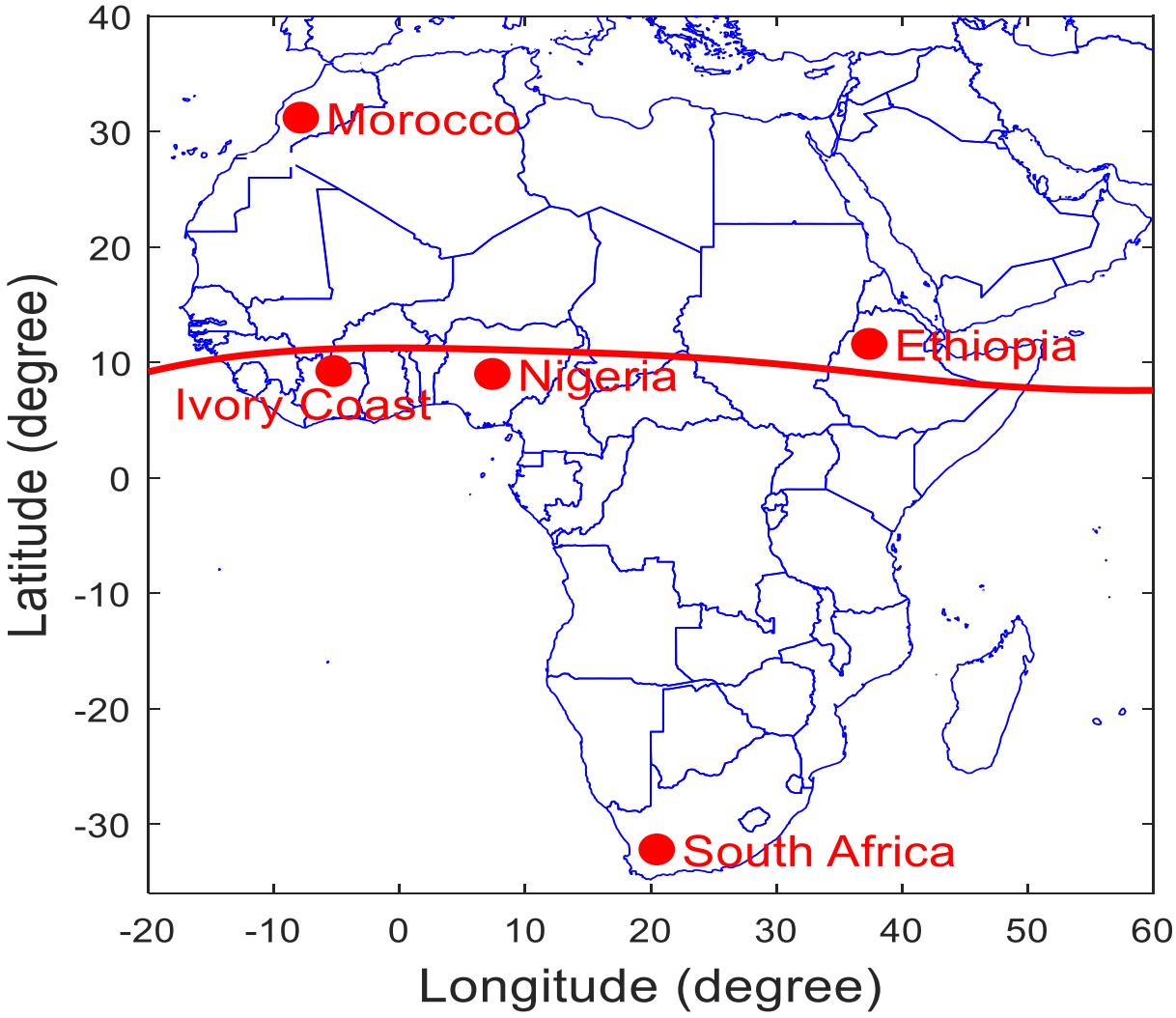
- The trend has in general clear asymmetry between north and south hemisphere.

Effect of meridional neutral winds on equatorial ionization anomaly (EIA)

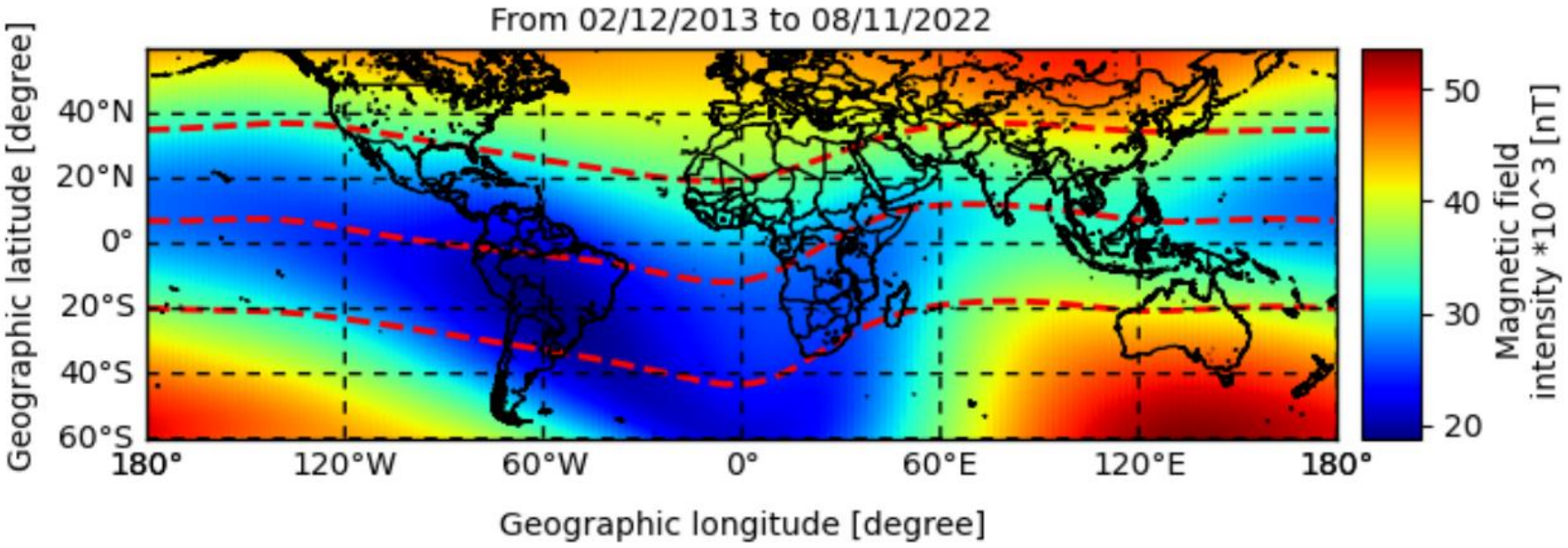


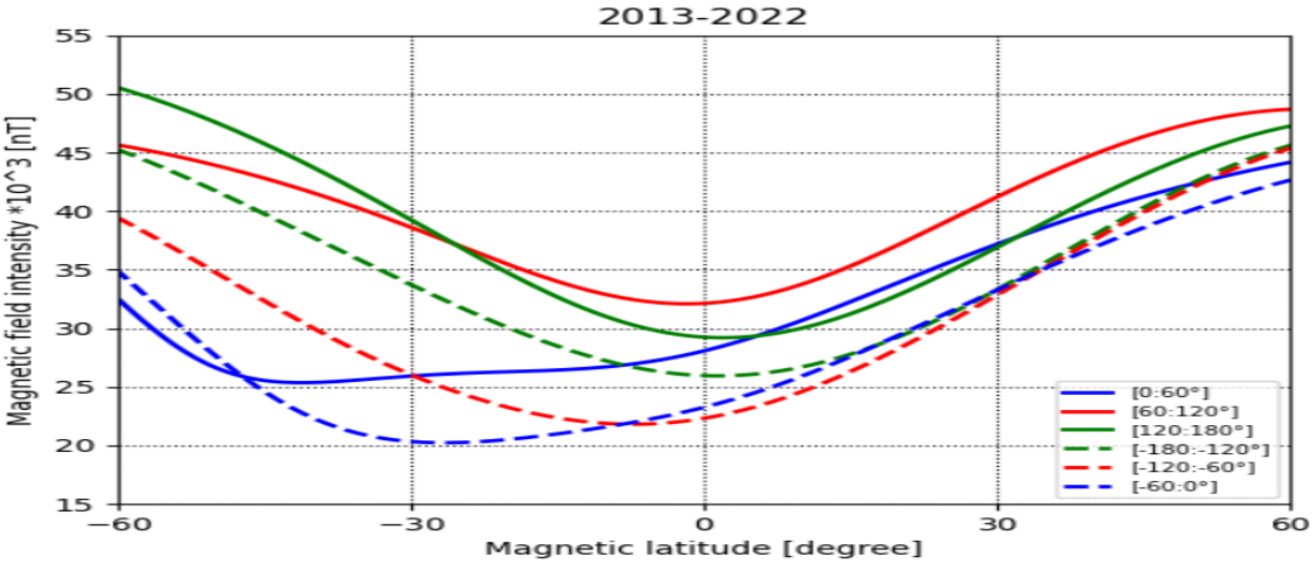
* Symmetrical EIA crests most likely is generated by either weak wind speeds or by converging/diverging winds with about the same velocity in both hemispheres.
* EIA crests asymmetry is observed along with transequatorial winds

Thermospheric winds over Africa



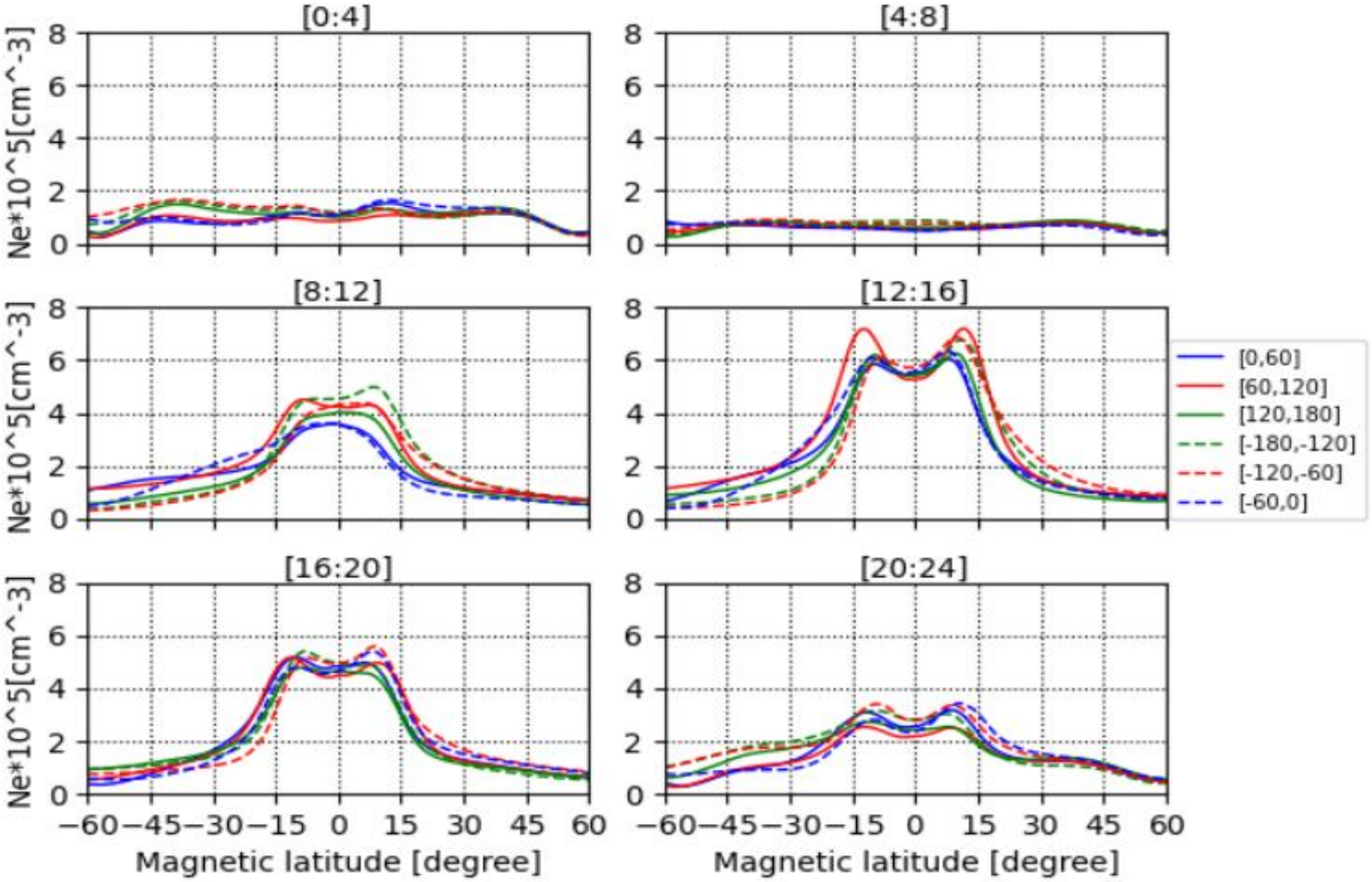
Longitudinal variation of ionosphere electron density





The average of the total magnetic field intensity over 9 years (from December 2, 2013 to November 8, 2022)

Longitudinal variation of ionosphere electron density



Décembre 2013 to November 2022.

Thank you for your attention