Investigations on upper atmospheric variability on a global scale due to the influence of solar forcing from above and vertical coupling from below

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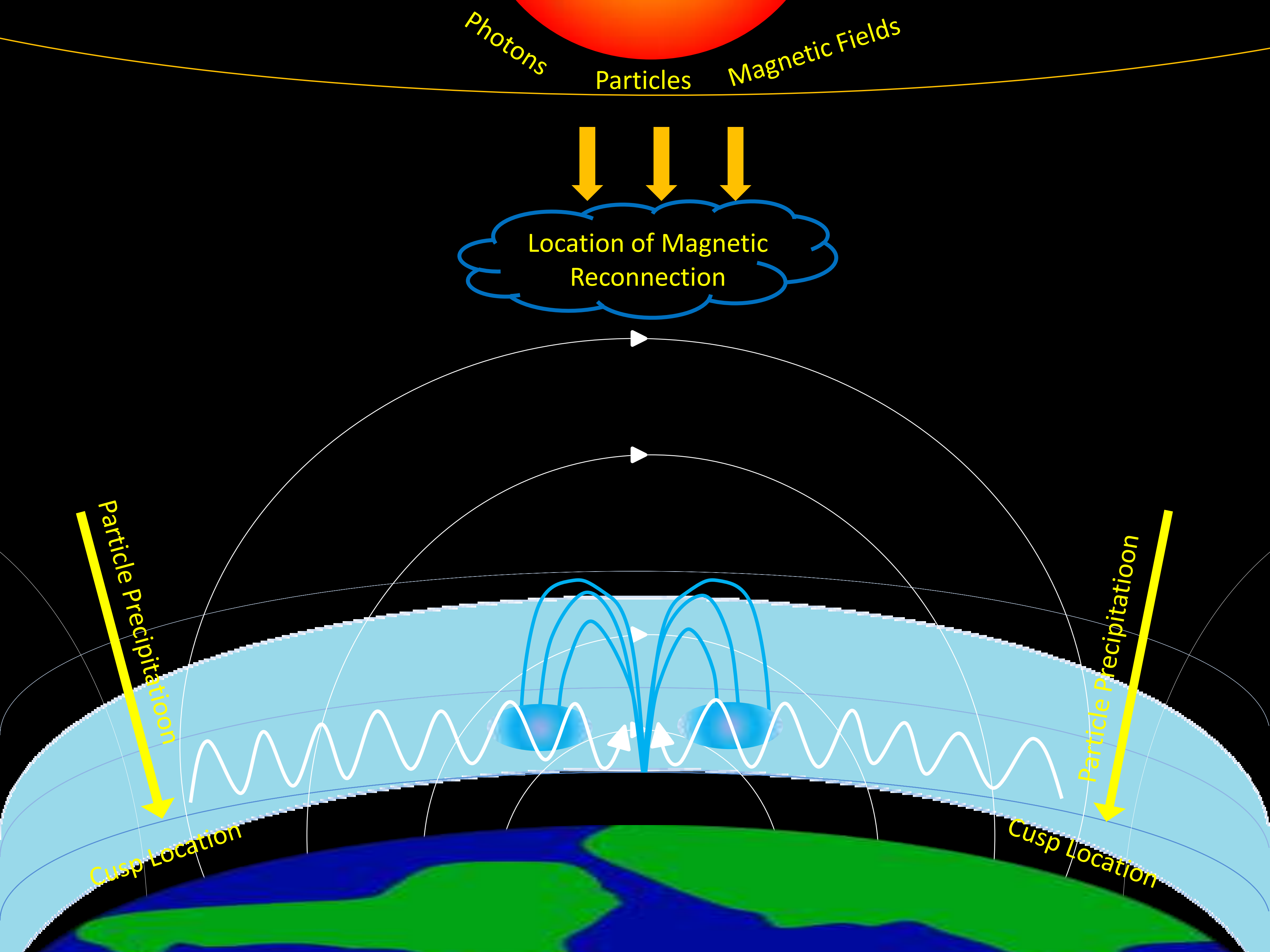
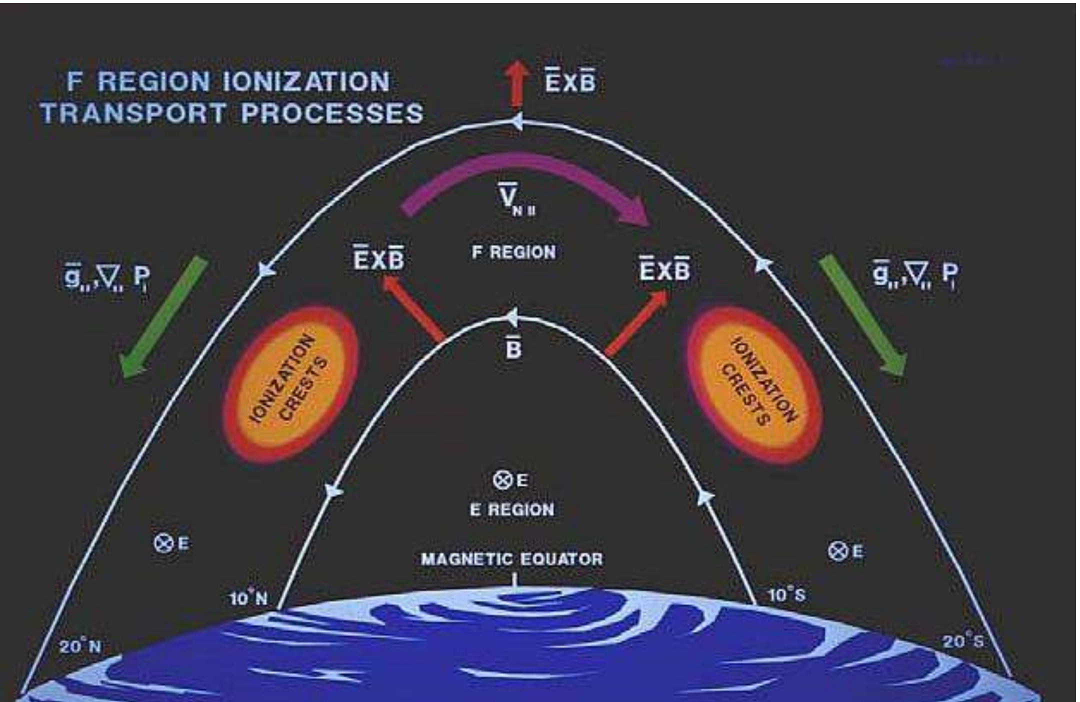
Motivation

- UA receives several energy inputs from above and below that need to be characterized
  - Tidal forces from below
  - Solar flux from above
- Investigations of coupling of different regions through wave dynamics
- Investigations are essential especially in the daytime conditions


Photons
Particles
Magnetic Fields
Location of Magnetic Reconnection
Particle Precipitatioon
Particle Precipitatioon
Cusp Location
Cusp Location

Low- /Equatorial-latitude phenomena

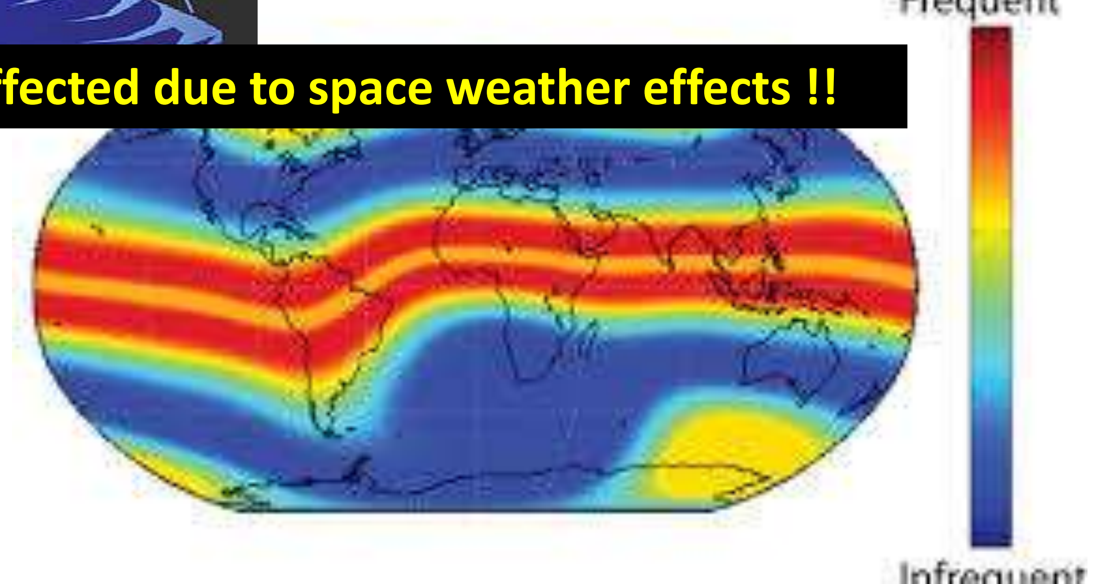


Eq. & Low-lats.: Replete with structured distribution in neutrals and plasmas

- Eq. Electrojet (EEJ)
- Eq. Ionization anomaly (EIA)
- Neutral Anomaly (NA)
- Eq. Temp. and Wind A (ETWA)
- Eq. plasma irregularities
- Eq. plasma bubbles

All these low–lat. phenomena are affected due to space weather effects !!

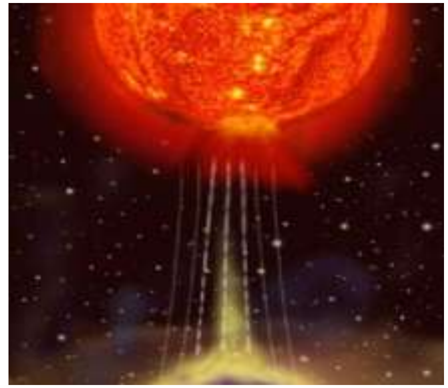
EIA formation through plasma fountain effect



Map showing regions of occurrence of ionospheric scintillations

Science Motivation

1. Forcing from above:
Photons (EM)
Particles (SW origin)
IEF, IMF,



3. How do the low- and high-latitude coupling take place?

Forcing from the sun directly or through polar regions

Upper Atmosphere
[Ionosphere-thermosphere system (ITS)
Neutral-plasma coupling]

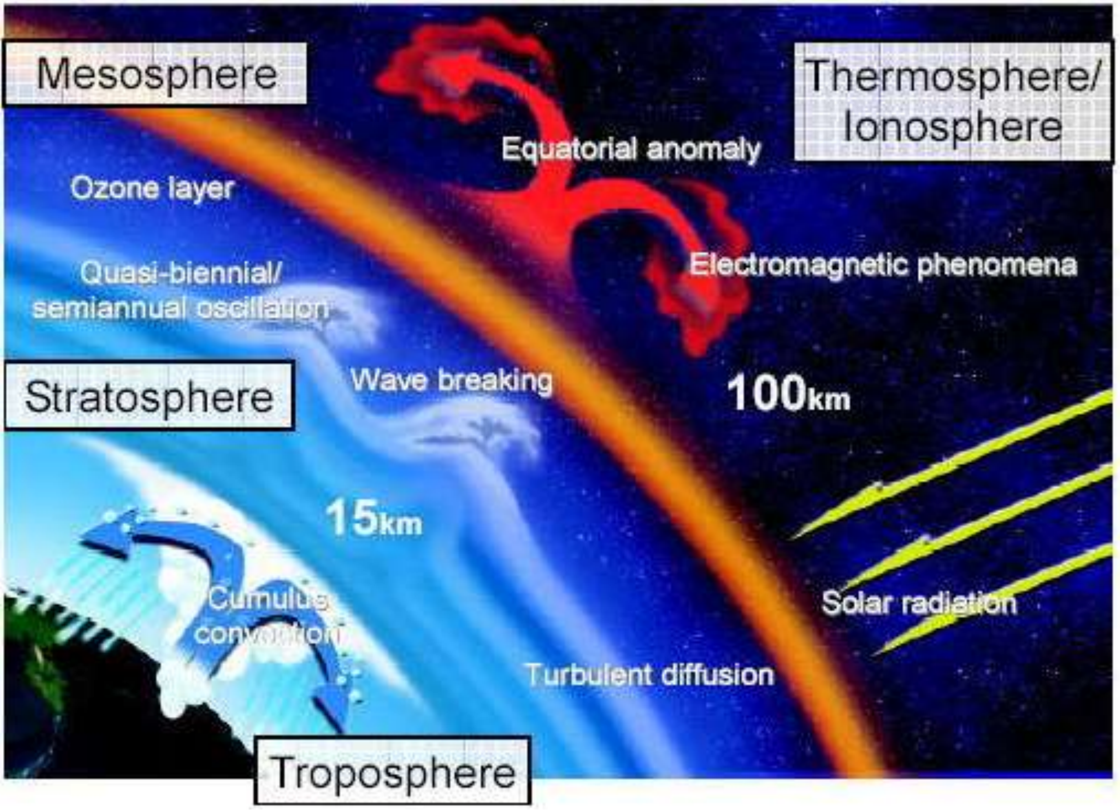
2. Forcing from below:
PW,
Tides, GW,

Forcing from lower atmosphere

Atmospheric waves (PW+Tides+GW)

Vertical coupling of atmospheric regions

- Wave Induced cooling / heating of mesosphere
- Trace wave propagation from ground to the mesosphere (both on short and long time scales)
- Generate multi-dimensional pictures of spatial coupling



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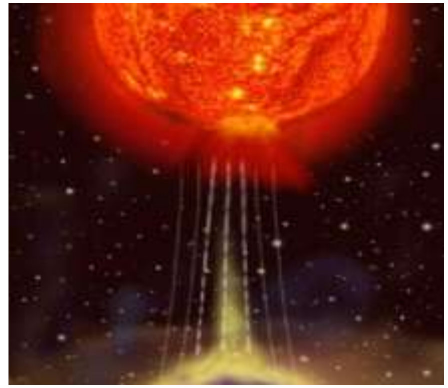

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3. How do the low- and high-latitude coupling take place? [SSW]

Motivation for daytime optical studies

➔ **It is essential to make continuous ground-based measurements of investigation of atmospheric phenomenology, especially for coupling from below.**

➔ **What's the problem?**

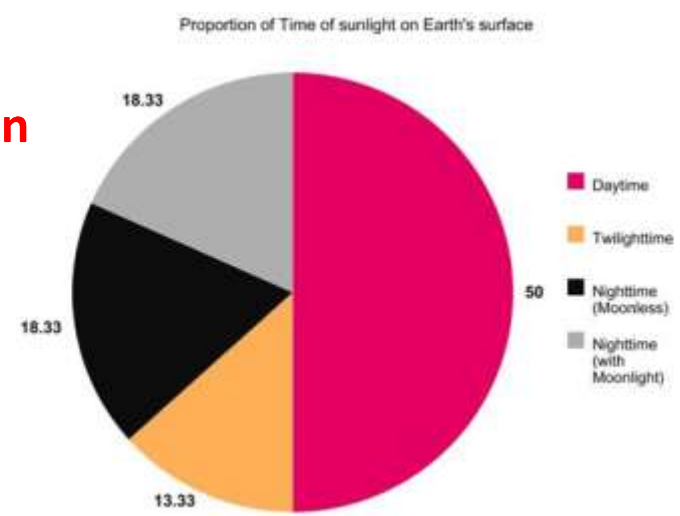
Conventionally optical measurements are carried out in Nighttime (SDA > 20^o)

Therefore, for investigations of waves of planetary scale sizes conventional nighttime optical measurements are not optimal as there is a data gap after every 14 nights due to full moon conditions prevent accurate measurements.

Thus, DAYTIME optical measurements are NEEDED!

➔ **Observational Challenge?**

- Solar Background orders of magnitude greater than the dayTIME optical emissions.

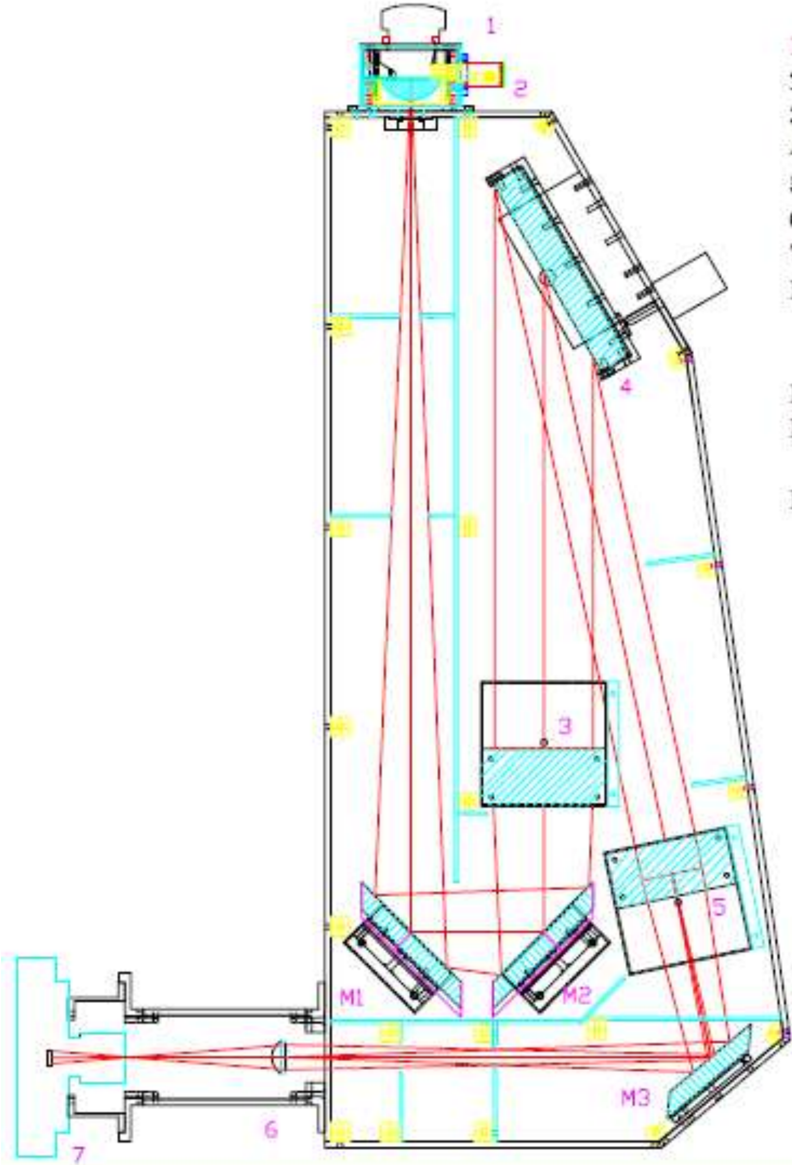


However, in recent times, new Techniques have emerged which have made this possible:

MISE, HIRISE, UVIS, DGP, CDAP

[e.g., Pallamraju et al., 1996, 2002, 2013, 2014]

Multiwavelength Imaging Spectrograph Echelle grating (MISE)



1. Objective lens
2. Slit assembly
3. Collimator, f=1130mm, f/11.3
4. Grating, 100x200mm, Echelle
5. Imaging lens, f=600mm, f/6
6. Mosaic filter + reimaging lens
7. CCD 1kx1k

M1, M2, M3 are folding mirrors

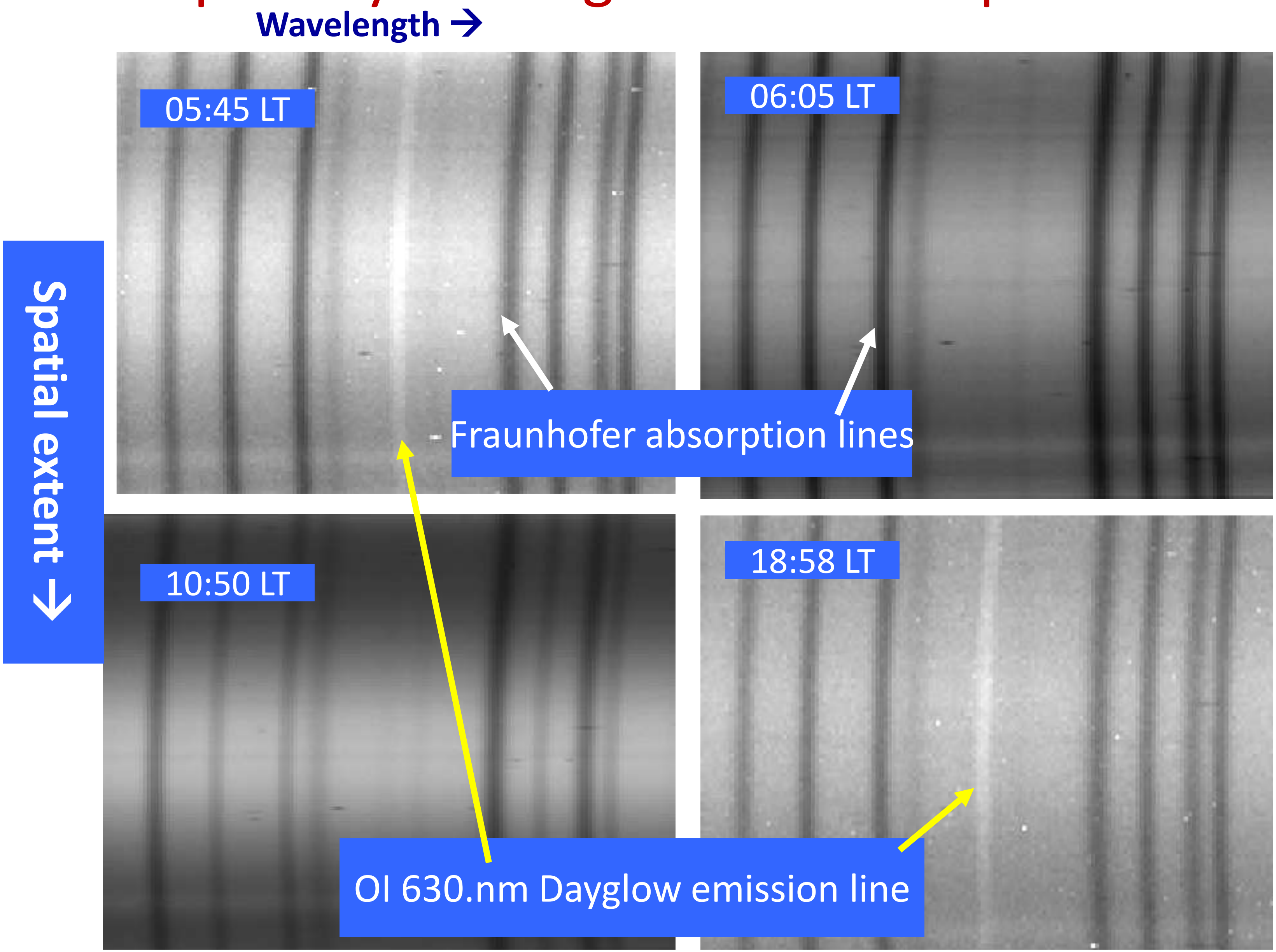
Dispersion=0.004 nm/pix
Resolution=0.012 nm at 557.7nm

Dimension=30.1'' x 46.2''

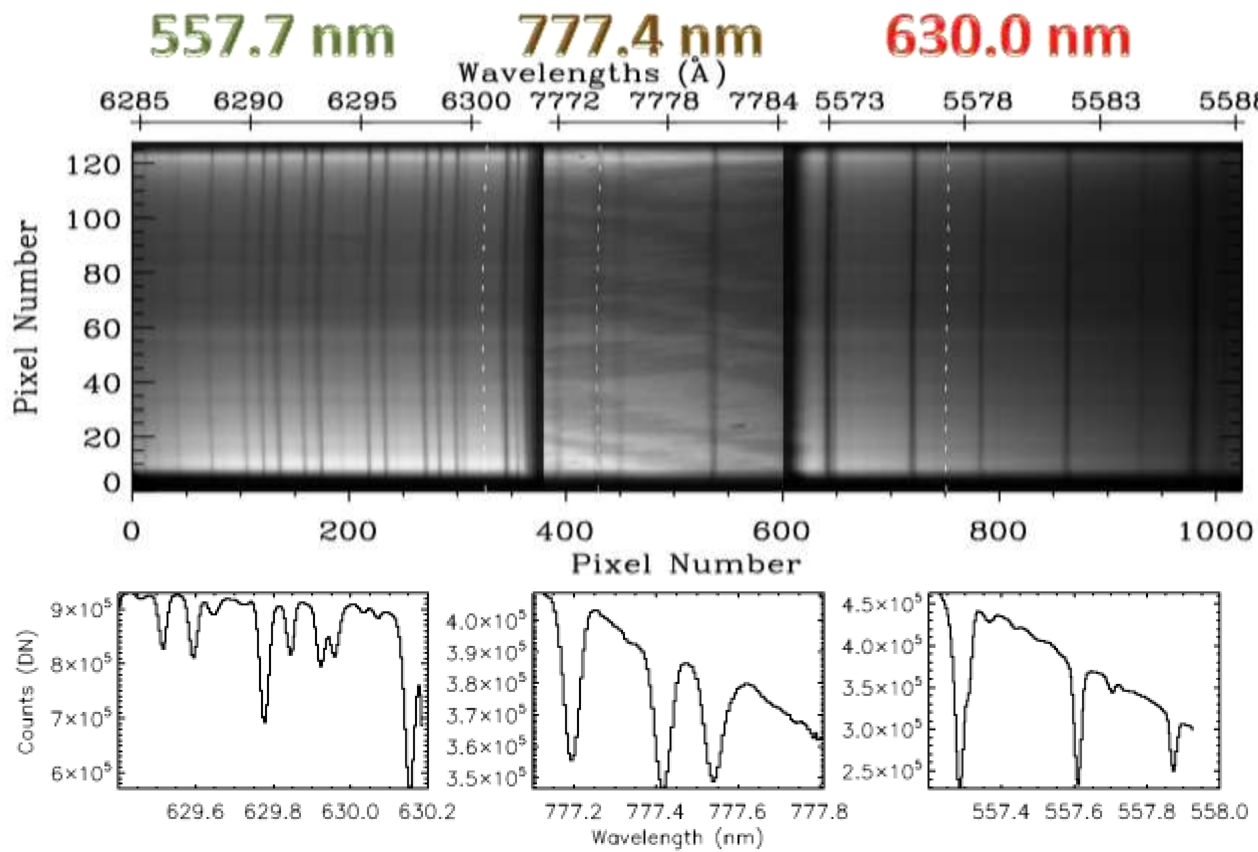
Several results on low-, mid-, and high latitude daytime airglow/auroral phenomena have been obtained using this technique:

Pallamraju et al., 2002, 2013 (JASTP)
2000, 2004, 2005, 2016 (GRL)
2004 (Ann Geophys.)
2001, 2010, 2011, 2014 (JGR)

Sample Daytime high resolution spectral Images



Method of retrieving dayglow signals



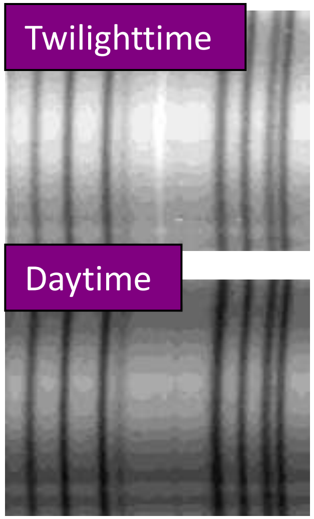
Altitudes of emission (Approx)

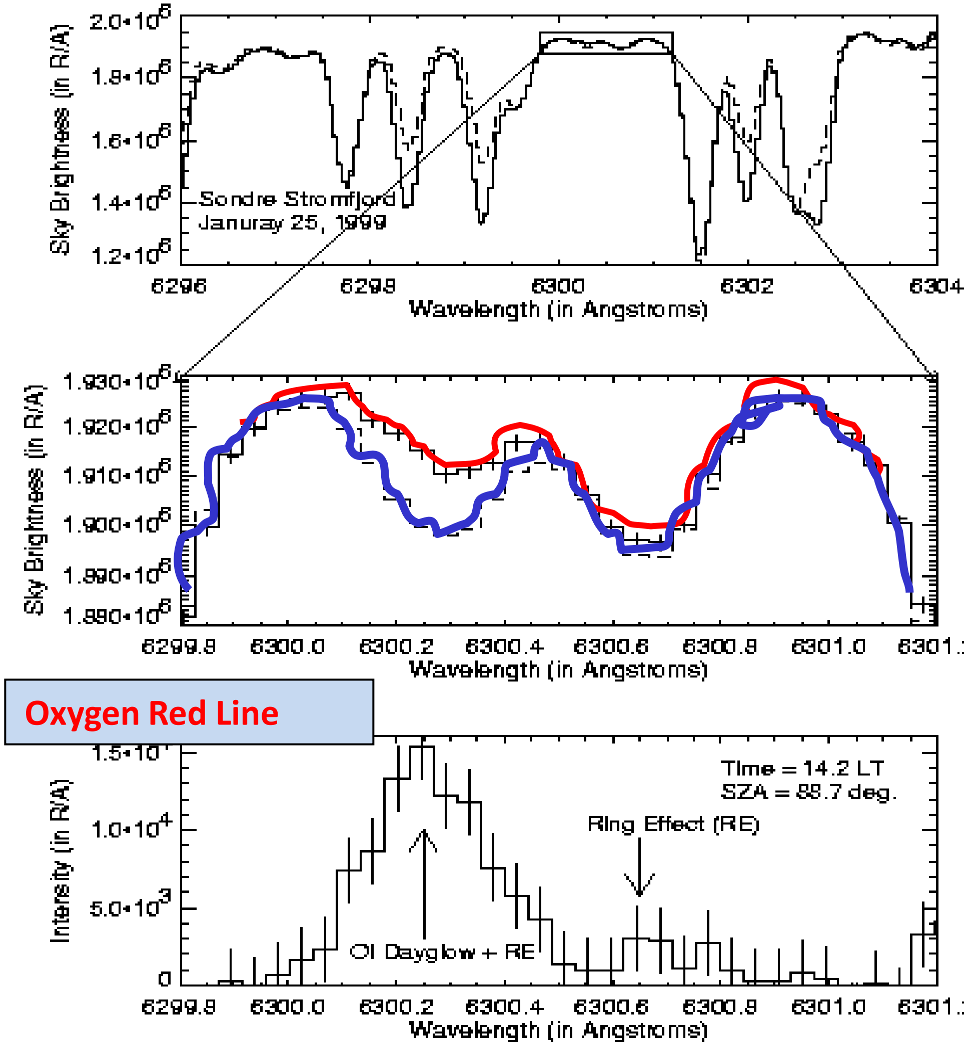
OI 777.4 : 300 km

OI 630.0 : 230 km

OI 557.7 : 130 km

- Blue-sky spectra at different wavelengths compared with the solar spectra
- The difference between these is due to emissions, absorptions and scattering.
- Integrating the difference at the wavelength of emissions (and subtracting RE), dayglow intensities of OI 557.7, 630.0 and 777.4 nm are obtained





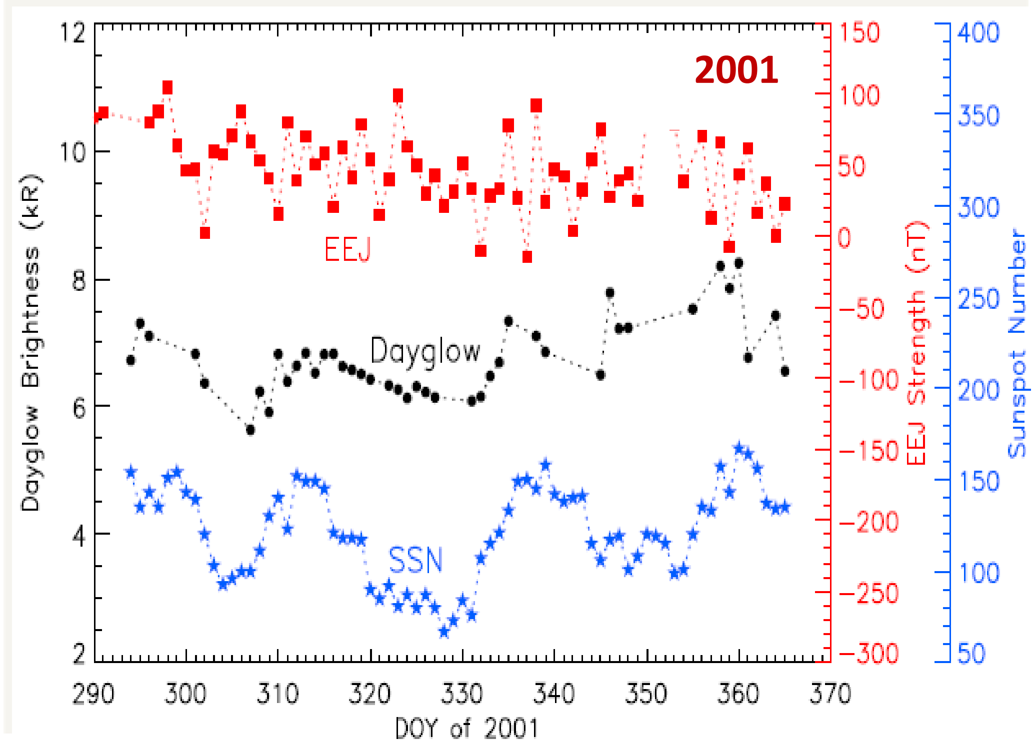
Pallamraju et al., 2002 (JASTP)

Upper atmospheric dynamics: Solar flux vs. waves from below

Upper atmospheric dynamics: Solar flux vs. waves from below

Continuous daytime OI 630.0nm emission behavior (in year 2001; <SSN> = 110) showed the daily variability in emissions to be dependent on solar activity ***[Pallamraju et al., 2010, JGR]***

In year 2011 (when <SSN> = 35), the no influence of solar effects were seen but significant effect of lower atmospheric phenomena in the upper atmospheric dynamics ! ***[Laskar, Pallamraju, et al., 2014, JGR]***

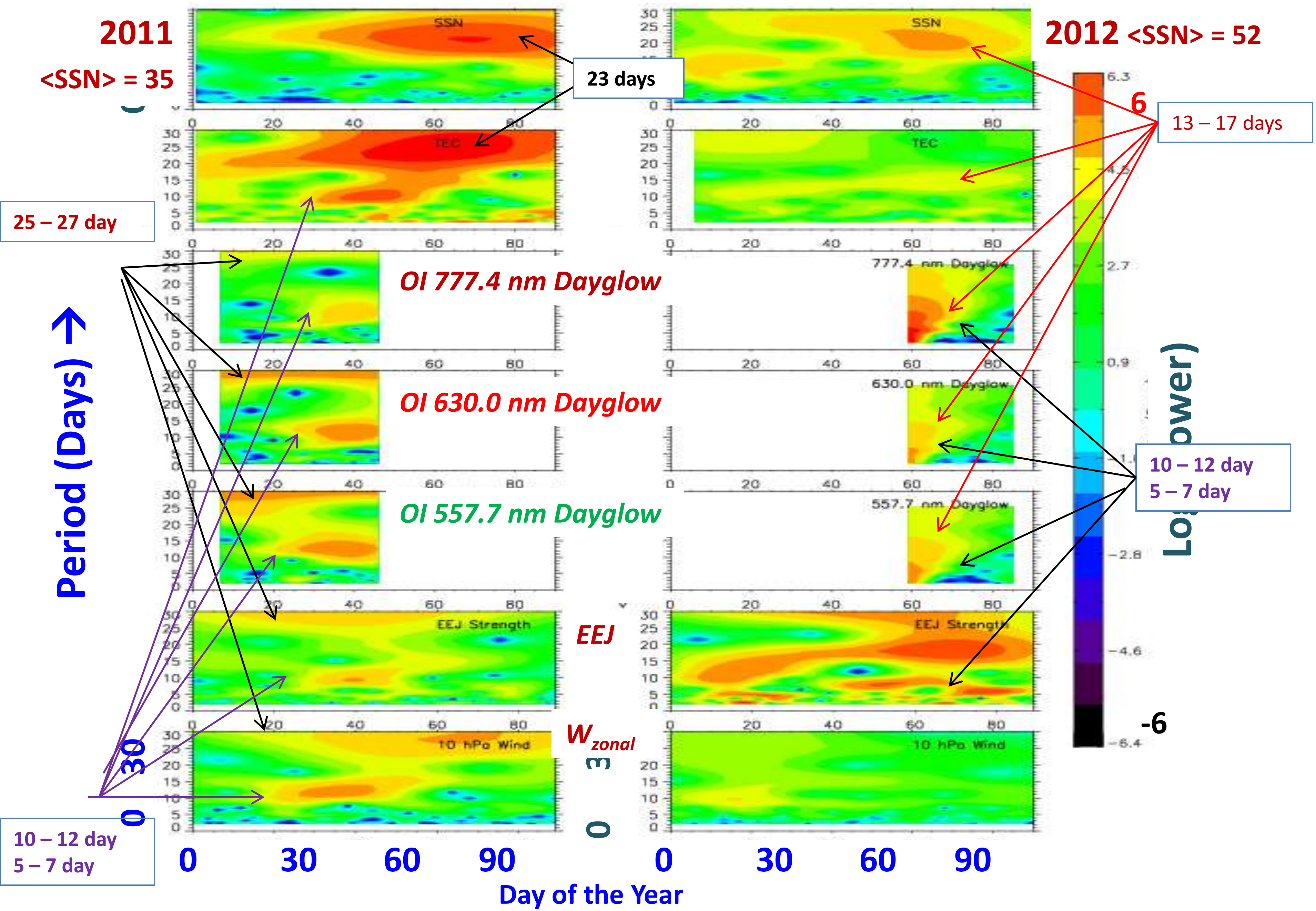


➔ This made us to investigate the atmospheric behaviour at multiple altitudes for large periods of time.

Behavior of the atmosphere at various altitudes has been investigated

Parameter	Alt. of correspondence
Sun spot number	
Total Electron Content	Peak of F-region and above
OI 777.4 nm	Peak of F-region (~300 km)
OI 630.0 nm	~ 230 km
OI 557.7 nm	~ 130 km
Equatorial Electrojet (EEJ)	102 km
Zonal winds	~ 30 km (10 hPa level)

Several common periodicities have been observed amongst these parameters



2011
<SSN> = 35
2012 <SSN> = 52
23 days
13 – 17 days
25 – 27 day
10 – 12 day
5 – 7 day
SSN
TEC
OI 777.4 nm Dayglow
OI 630.0 nm Dayglow
OI 557.7 nm Dayglow
777.4 nm Dayglow
630.0 nm Dayglow
557.7 nm Dayglow
EEJ
EEJ Strength
W zonal
10 hPa Wind
Period (Days)
Log (power)
Day of the Year
6
-6
Laskar et al., 2013 (JGR)

Upper Atmospheric response due to …

Solar forcing (SSN > 110)

Forcing from the sun directly or through polar regions

Transition region (SSN 35 - 110)

Probing through optical techniques

Thermosphere – Ionosphere system
Neutral-plasma coupling

Forcing from below (SSN < 35)

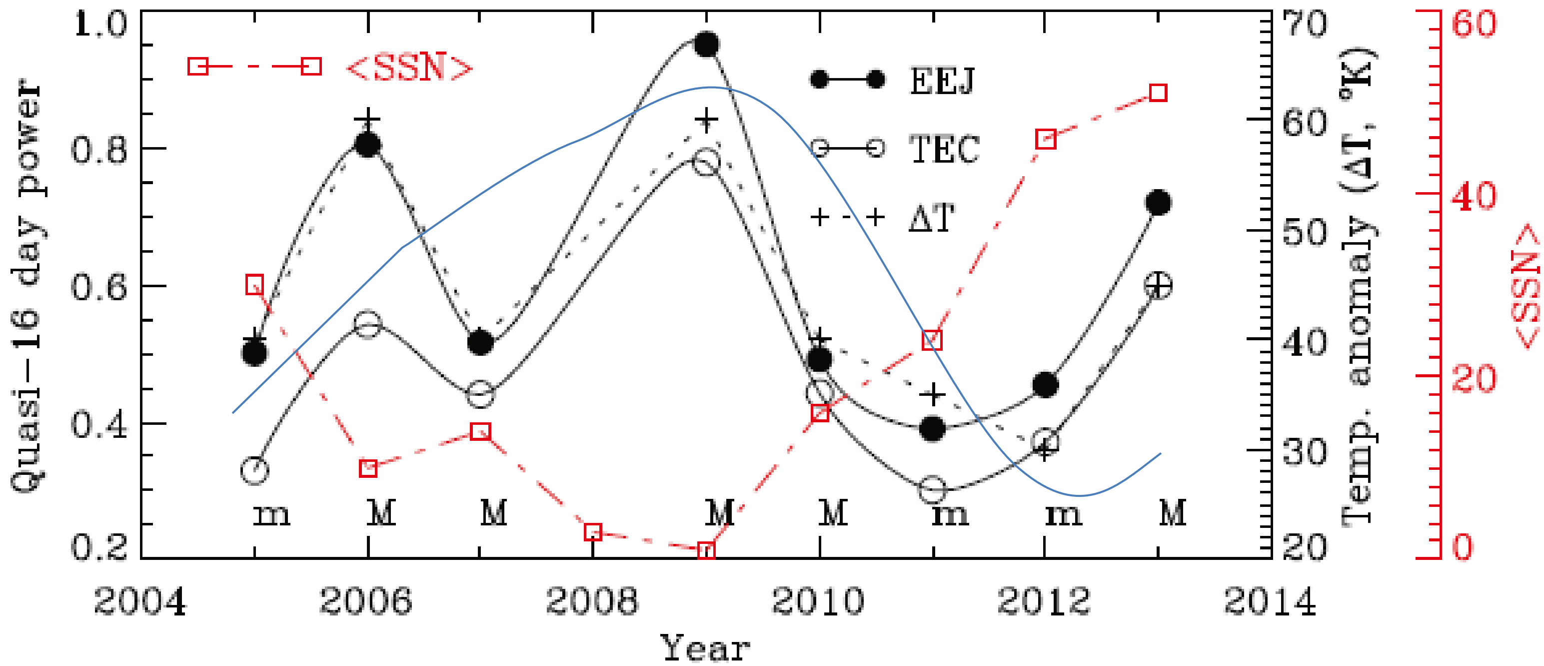
Forcing from lower atmosphere

Pallamraju et al., 2010; JGR
Laskar et al., 2013; JGR
Laskar et al., 2014; EPS
Laskar et al., 2015; ASR

Atmospheric waves (PW+Tides+GW)

Upper Atmospheric response due to solar forcing

- Does this conclusion hold over a solar cycle?
- It is seen that coupling is mostly due to quasi-16 day wave.
- Several parameters, namely EEJ, TEC, stratospheric temperatures, have been analyzed for a 10 year duration



Some years phenomena called "SSW" Stratospheric Sudden Warming occur !! (Major and minor SSW indicated by 'M' and 'm')

Excellent similarity in seen between EEJ, TEC, and Delta_T indicates a clear planetary scale influence on the upper atmospheric parameters !!

Further, the SSW events provide additional energy for lower atmospheric waves to propagate to upper atmosphere even during high solar activity !!

Laskar, Pallamraju, Veenadhari 2014 (EPS)

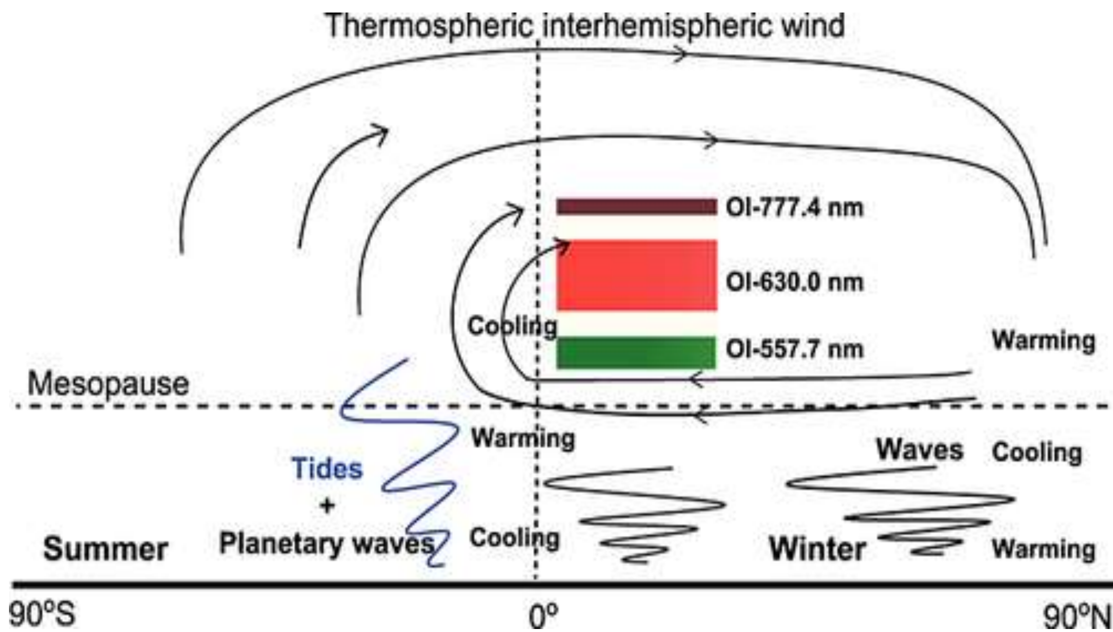
Upper atmospheric dynamics: Setting up of meridional circulation in winds in MLT region during SSW

- OI dayglow emissions from low-latitude location, Hyderabad (17.5°N, 78.5°E), India showed an increase during occurrence of SSW during the years 2010 – 2013.
- To explain this systematic increase in OI dayglow emissions over low latitudes during SSW, it was proposed that a new meridional circulation in wind gets set up from high to low-latitudes.

Response of MLT over low-latitudes due to Stratospheric Sudden Warming: Winds

Setting up of Circulation in Wind System in the MLT Region During SSW

- Over 4 years of MISE OI Dayglow data (2010-14) showed enhancement in emissions
- Stratospheric warming is associated with lower thermospheric (LT) warming over high latitudes.
- This LT warming sets in equatorward winds (*akin* to that due to geomagnetic Storms)
- This circulation brings in "Oxygen rich air" to low latitudes giving rise to an increase in dayglow emission intensities.



Schematic of the wind system postulated

Laskar and Pallamraju, 2015, JGR

Setting up of this poleward wind system during SSW is confirmed by the wind measurements by Meteor wind radars and other supporting data from different regions of the globe. ***Laskar et al., 2019, JGR (under review)***

Upper atmospheric dynamics: Double humped structure in temperatures in Mesosphere during SSW

Response of MLT over low-latitudes due to Stratospheric Sudden Warming: Temperatures

Mesospheric temperature enhancement over low-latitudes during SSW obtained by NIRIS from Gurushikhar, India

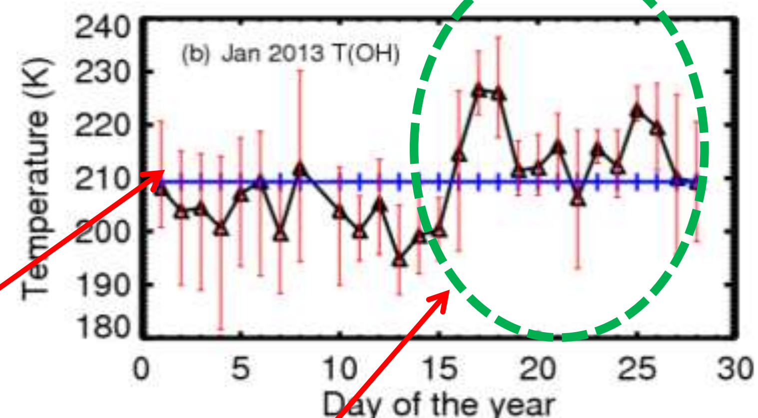
Near InfraRed Imaging Spectrograph

Field of view ~80º, ± 3K

Wavelength coverage 823-894 nm

- NIR OH (6-2) band ~87 km

- O_2 (0-1) band ~94 km



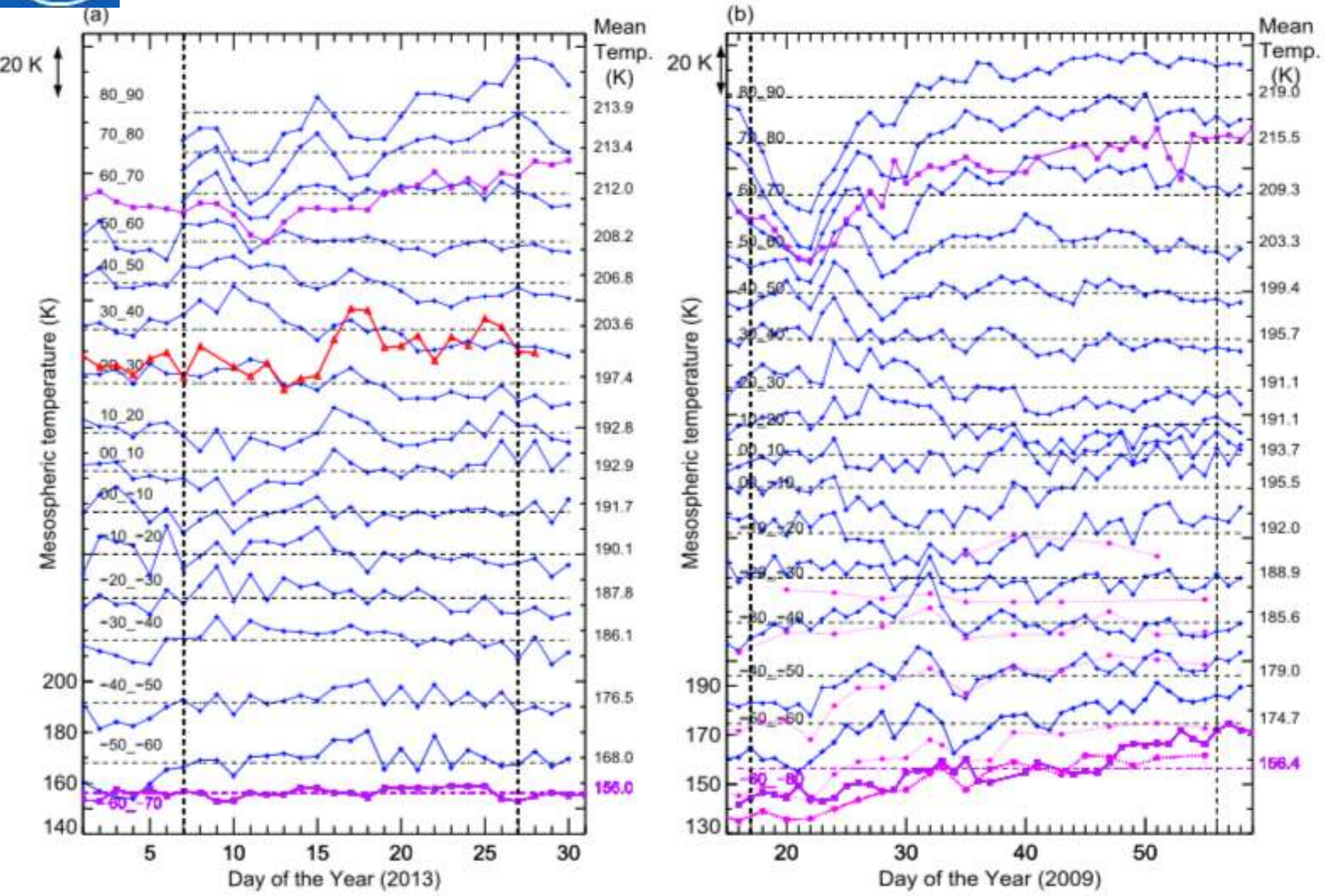
Range in nocturnal temperatures

Enhancement in Mesospheric Temperatures seen during 15 – 20 January 2013 (SSW epoch)

➔ This result triggered a larger investigation (9 SSW events) wherein using satellite data the global mesospheric temp. structure has been characterized.

Singh and Pallamraju, 2015, JGR

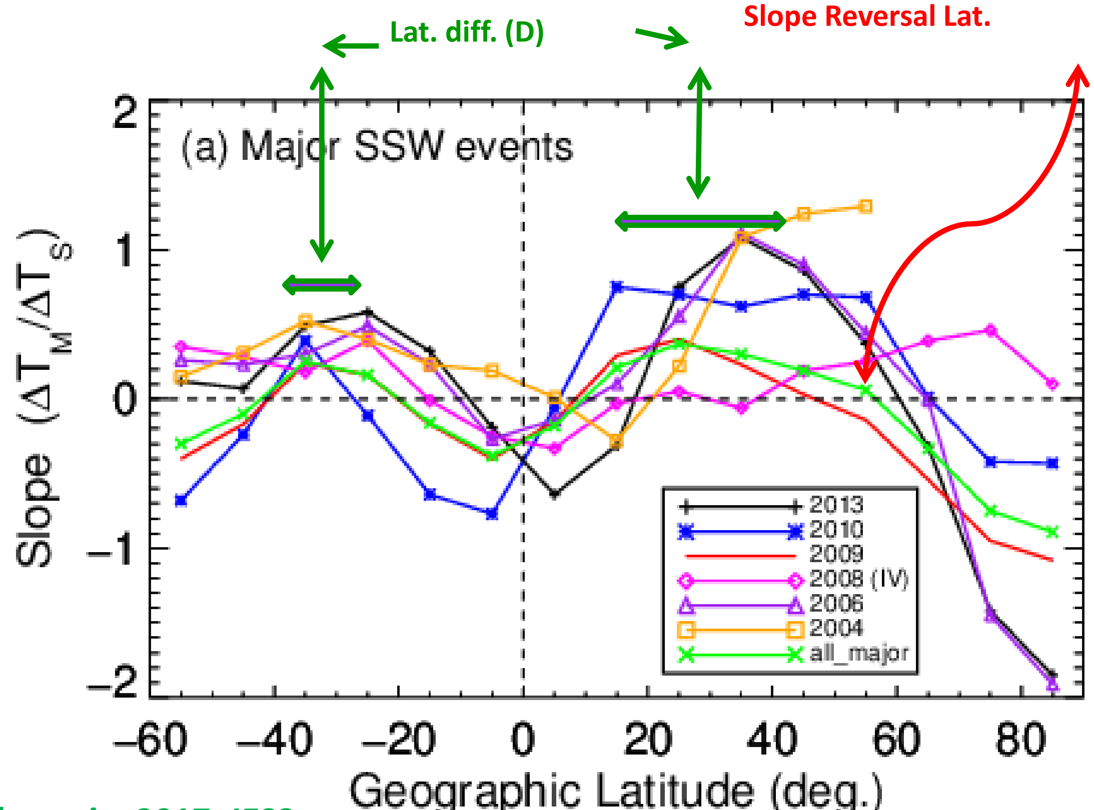
SABER Temperatures



Response of MLT over low-latitudes due to Stratospheric Sudden Warming: Temperatures

Presence of double humped structure in Mesospheric temperatures during SSW

- It is seen that a "double-humped" structure in mesospheric temperature gets formed with an increase over low-latitudes in both the hemispheres.
- The latitudinal difference (D) between the crests shows a direct relation with the max stratospheric temp.



- Correction in temperature (ΔT) to the model as a function of latitude has been suggested for SSW events.

$D = -2.62 \times T_{SMAX} + 709.5$

$\Delta T = -0.13 \times \text{Lat.} - 0.37$

Singh and Pallamraju, 2015, JGR ; Singh and Pallamraju, 2017, JESS

Summary of Results

- SSN<35 UA is purely influenced by LA processes; SSN > 110 its UA is purely influenced by Solar forcing; effect is mixed in between.
- However, the vertical coupling can be stronger during high solar activity in case of occurrence of SSW events.
- A new meridional circulation in winds is set up during SSW events.
- Another discovery has been the existence of double-humped structure in mesospheric temperatures.
- The strength of the crests in mesospheric temperatures have been characterized with respect to stratospheric temperatures.
- Modelling of these global scale behaviour is in progress.

Thank you

Questions? raju@prl.res.in