# Data assimilation study of global ionospheric response to Sudden Stratospheric Warming events

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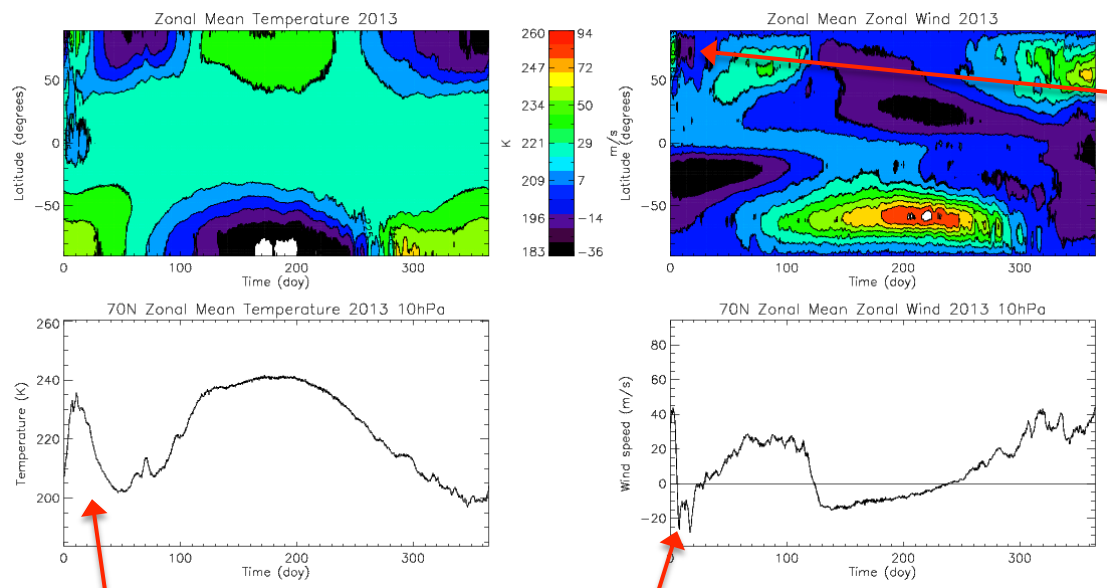
# Outline



1. Sudden Stratospheric Warming Events
2. Why it matters
3. Goals
4. IDA4D
5. Recent studies
6. Global results
7. Affects on the Appleton anomaly
8. Conclusion

**Sudden Stratospheric Warming:** when the polar stratospheric temperatures increase rapidly with time, leading to a poleward increase of zonal-mean temperatures and, on occasion, a reversal of zonal-mean zonal winds to an east to west direction (Andrews, Holton, Leovy 1987).

- Minor: temperature increases, the polar night jet not reverse direction
- Major: temperature increases, reversal of the polar night jet and the polar vortex splits into regions.




Zonal wind reversal

Stratospheric warming

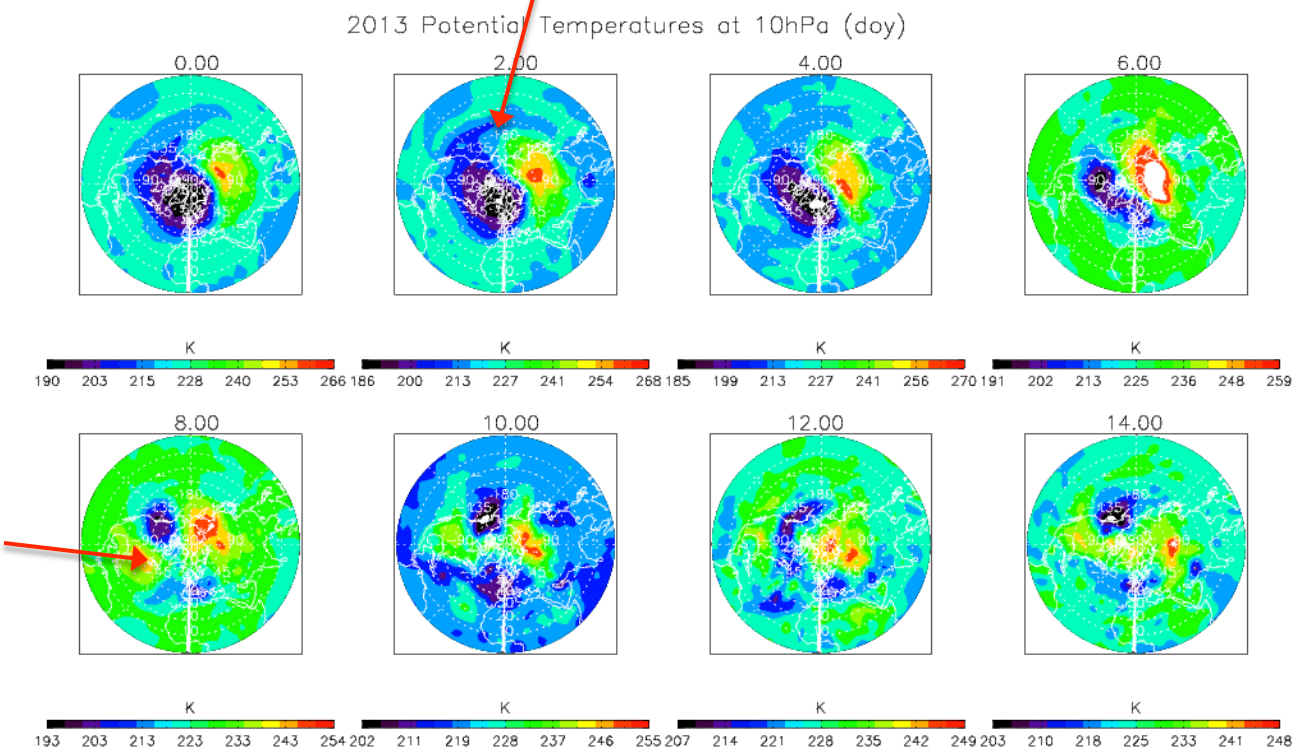
Zonal wind reversal

Data from NCEP

# Polar Vortex

**Polar Vortex:** a planetary-scale cyclonic circulation, generally centered in the polar regions, extending from the middle troposphere to the stratosphere (American Meteorology Society).

Polar vortex




Polar vortex split

Data from NCEP

# Earths Atmosphere

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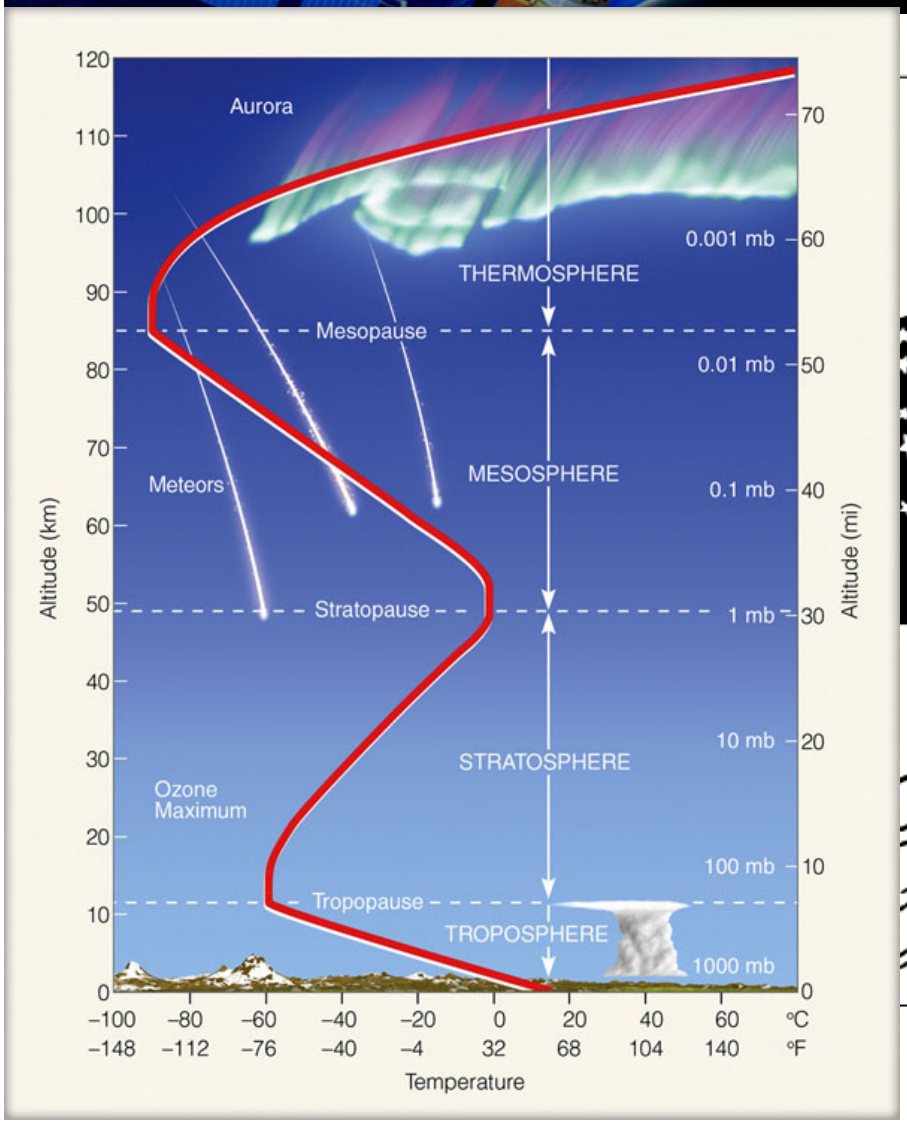



Pierce college

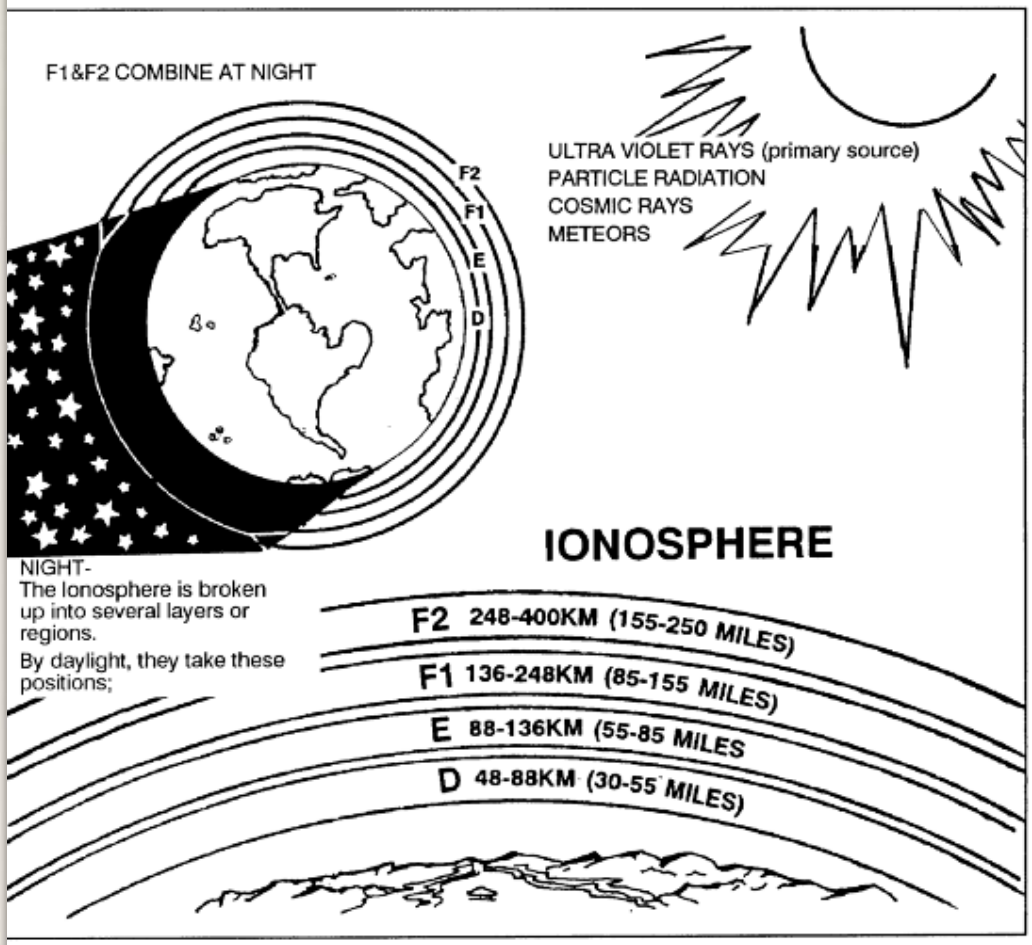



Figure D-3. Structure of the ionosphere.

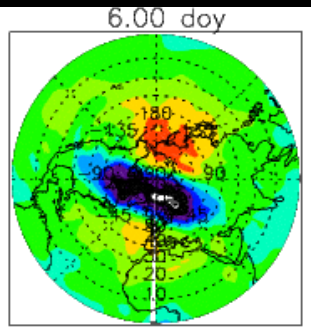
Military

# Why it Matters

January 6th 2014 Polar vortex in Chicago

Temp: -16$^0$ F

Wind chill: -42$^0$ F




Disturbed polar vortex

~210 K (-80$^0$ F)

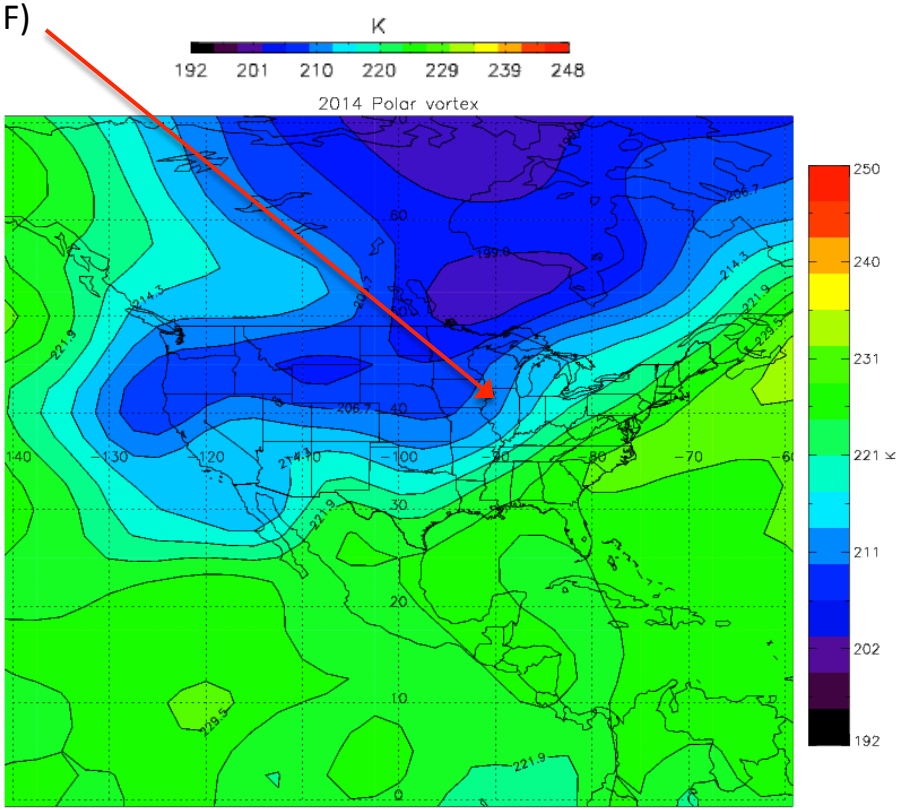



Photo: Hank Cain

# Why it Matters

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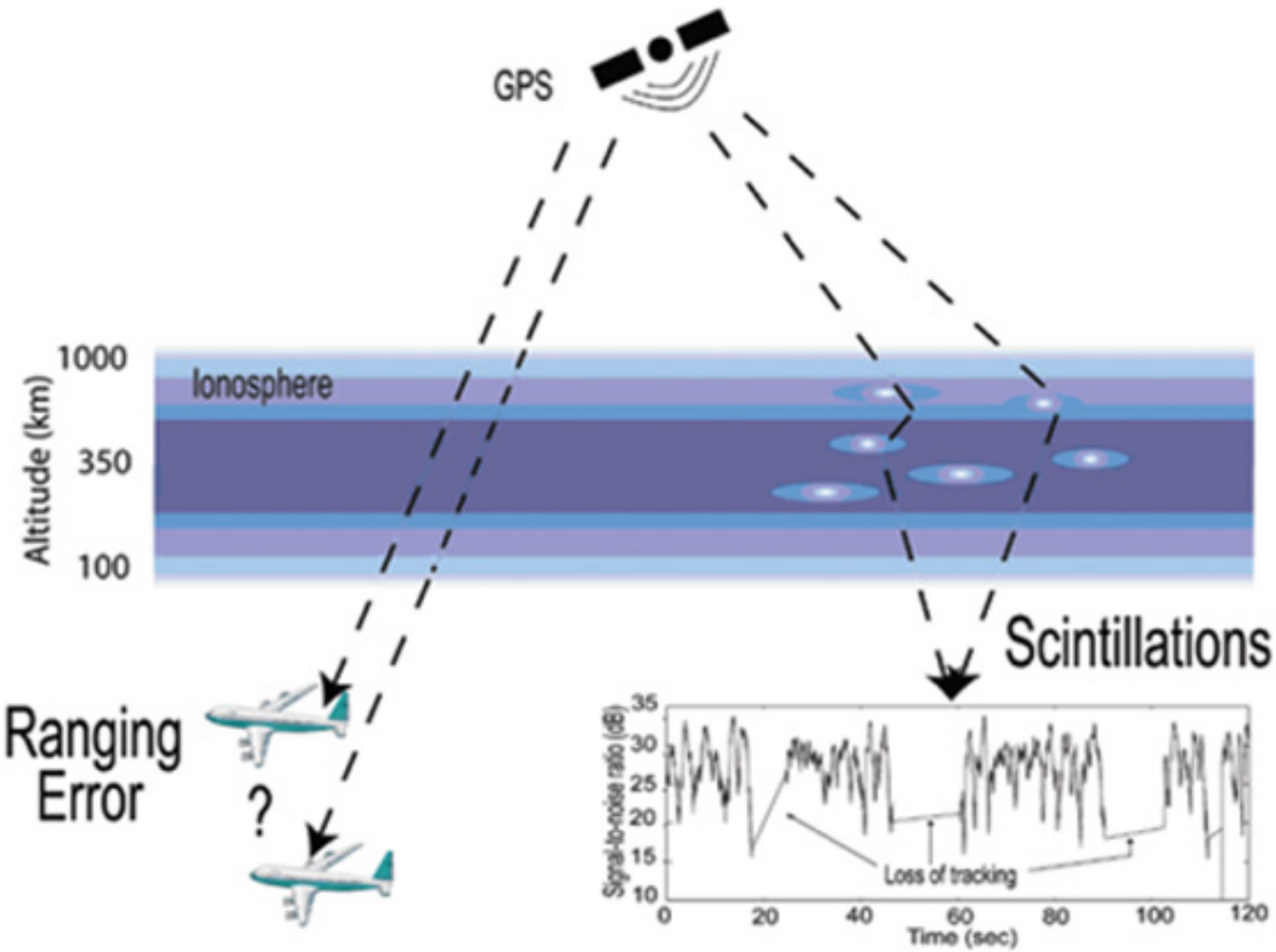
- Affects positioning -Affects Radio propagation




Credit: Kinter

# Goals



- Characterize, unambiguously, the ionospheric global response to SSW in four dimensions.

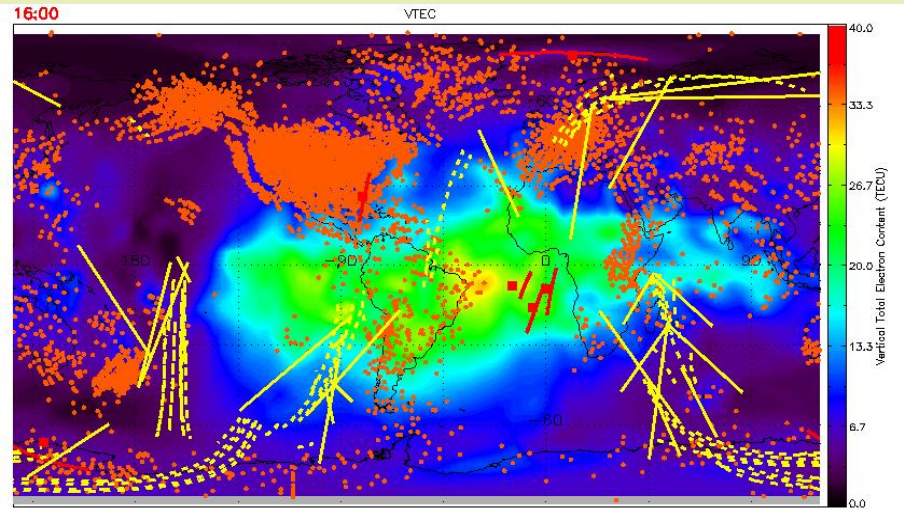
- Obtain a comprehensive view of how the ionosphere recovers.

- Utilize the Ionospheric Data Assimilation Four Dimensional (IDA4D) algorithm to characterize the global distribution of TEC and the full vertical profiles of the ionospheric electron density during SSW events.

**Ionospheric Data Assimilation four-Dimensional (IDA4D) algorithm**

Typical data sources used by IDA4D include:

1. Ground-based GPS slant total electron content (TEC)
2. Ground-based digisonde and incoherent scatter radar
3. Ground-based DORIS tx and ~4 low earth orbit satellites with DORIS rx
4. Space-based GPS occultation measurements of TEC
5. Space-based topside GPS TEC
6. Space-based *in-situ* electron density (DMSP)
7. Space-based UV airglow derived electron density (GUVI/SSUSI)



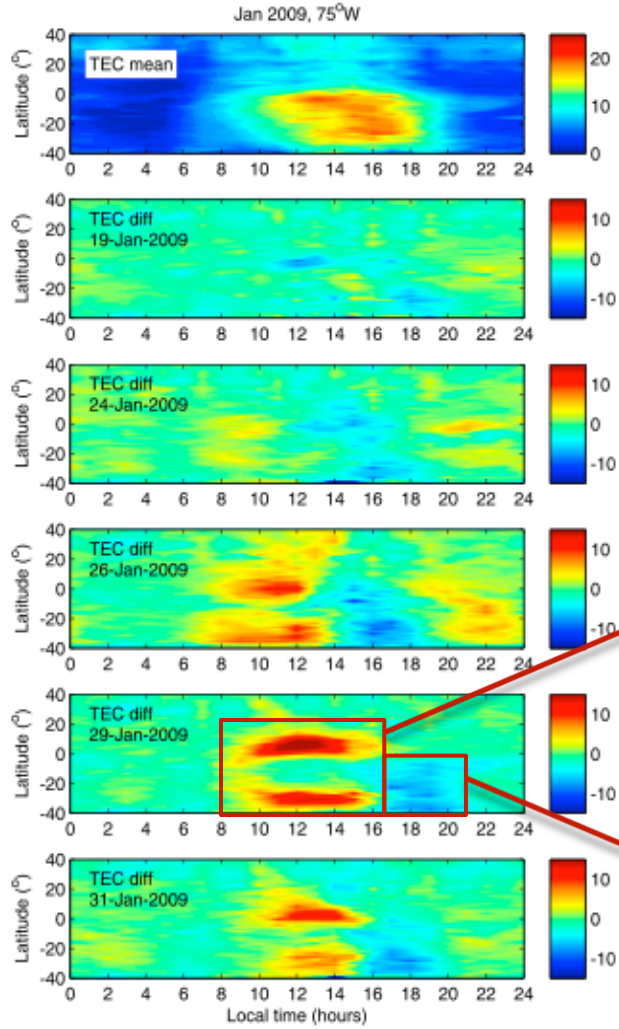

- **Orange dots: 350 km IPP of ground-based GPS**
- **Red squares: Ground DORIS transmitters**
- **Red lines: 350 km intercept to the satellite from DORIS transmitters**
- **Solid yellow lines: GPSRO traces**
- **Dashed yellow lines: Topside TEC**

Azeem

# Recent Studies

Impact of sudden stratospheric warmings on equatorial ionization anomaly
Goncharenko et al. [2010]

- Studied 2009 SSW
- Ground-based GPS receivers in South America
- Total Electron Content (TEC)
- Results:
  - Morning TEC increase
  - Afternoon TEC decrease




Morning TEC increase

Afternoon TEC decrease

# 2009 & 2013 SSW

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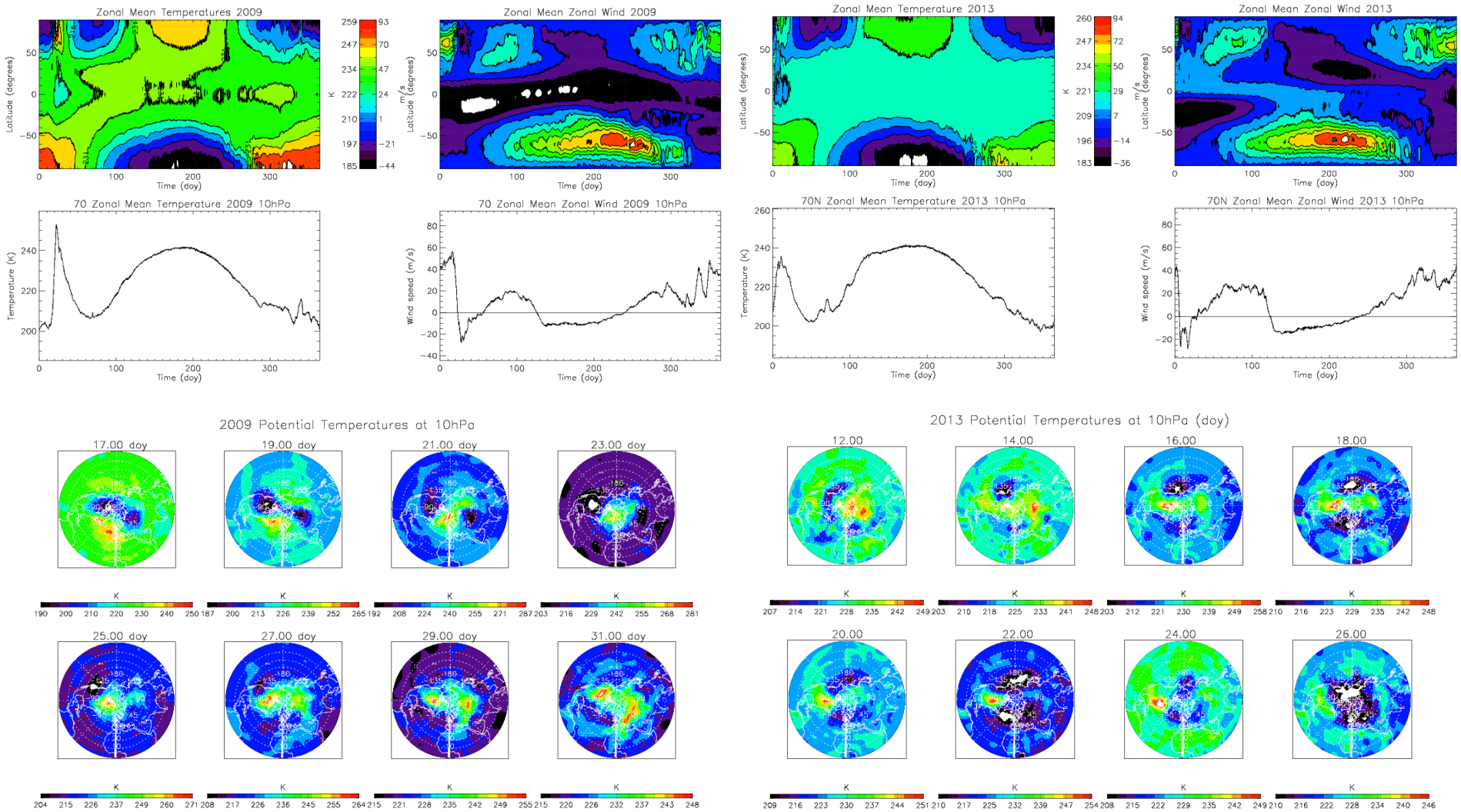
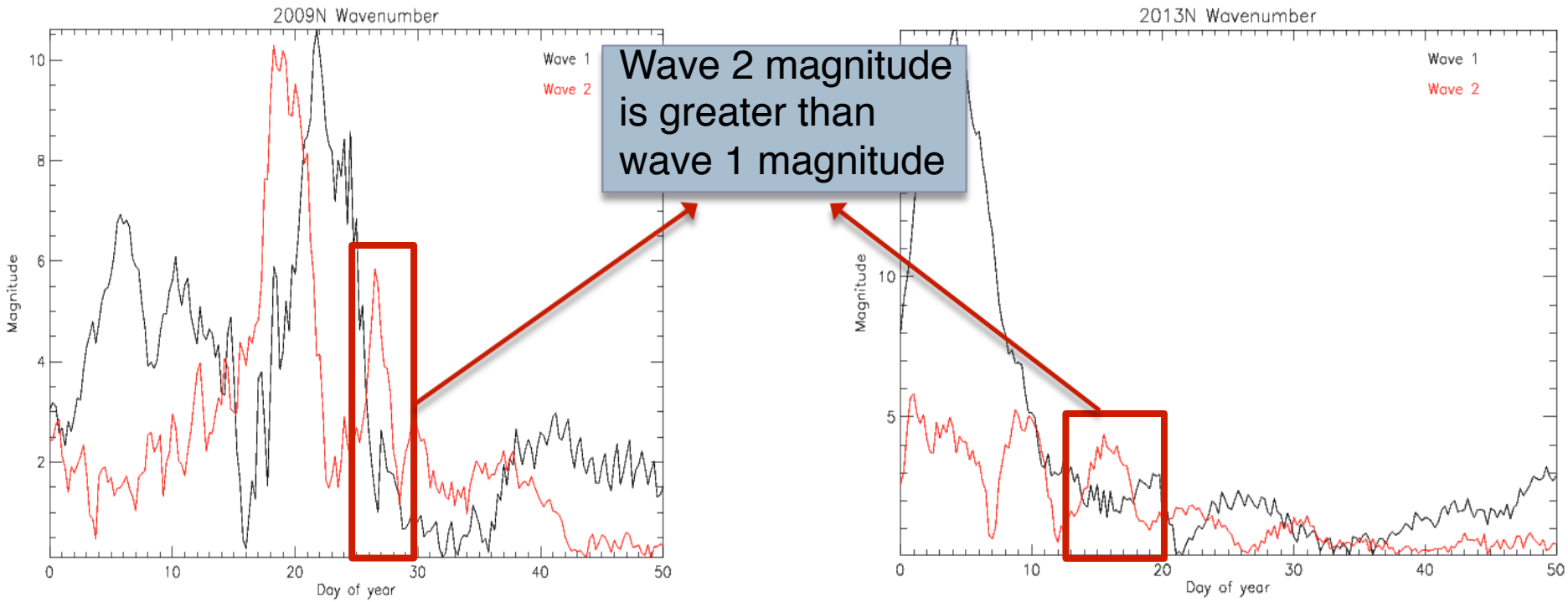



NCEP Data

# Wavenumber

**Wavenumber:** the spatial frequency of a wave.

- If wave 1 has a larger magnitude than wave 2 during a warming event , then the event is classified as minor.
- If wave 2 has a larger magnitude than wave 1 during a warming event , then the event is classified as major.



# TEC Response

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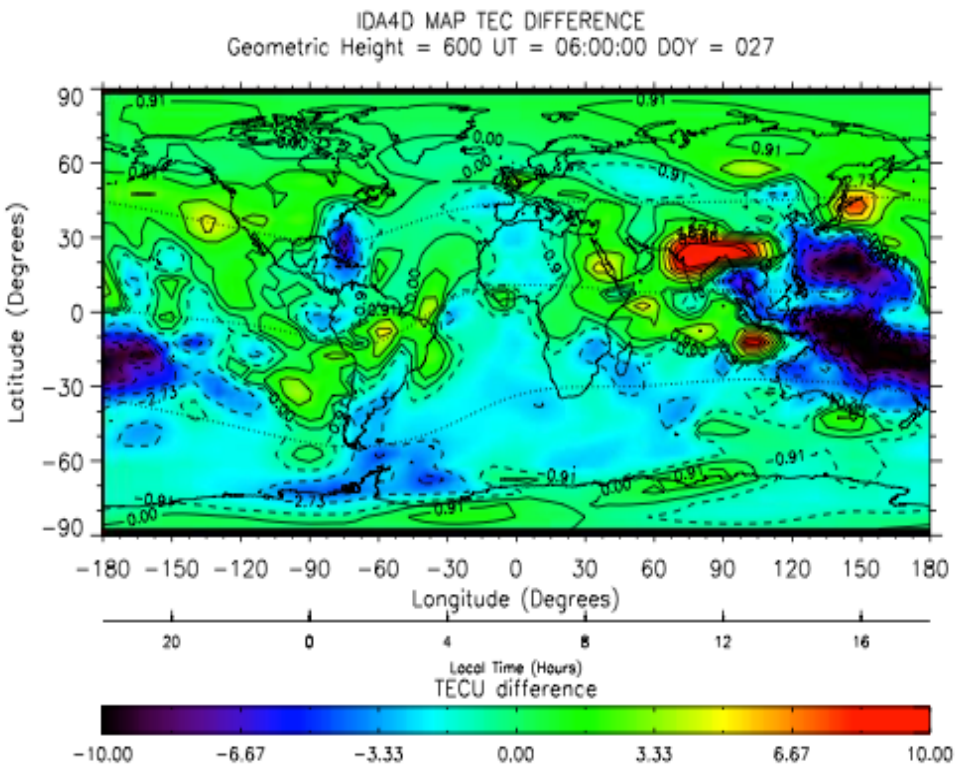
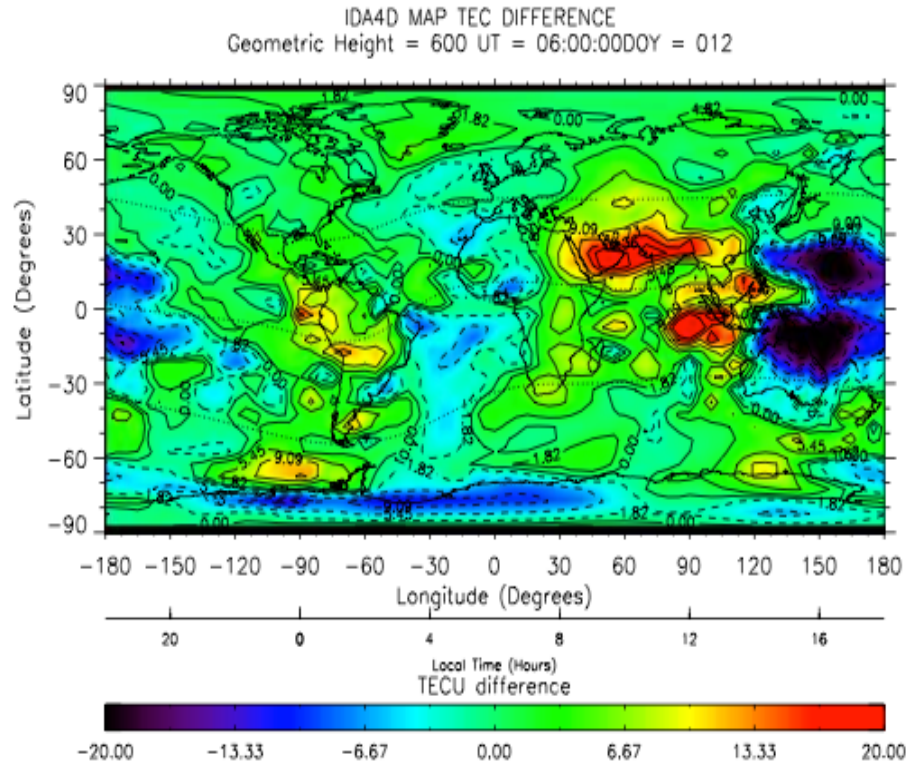
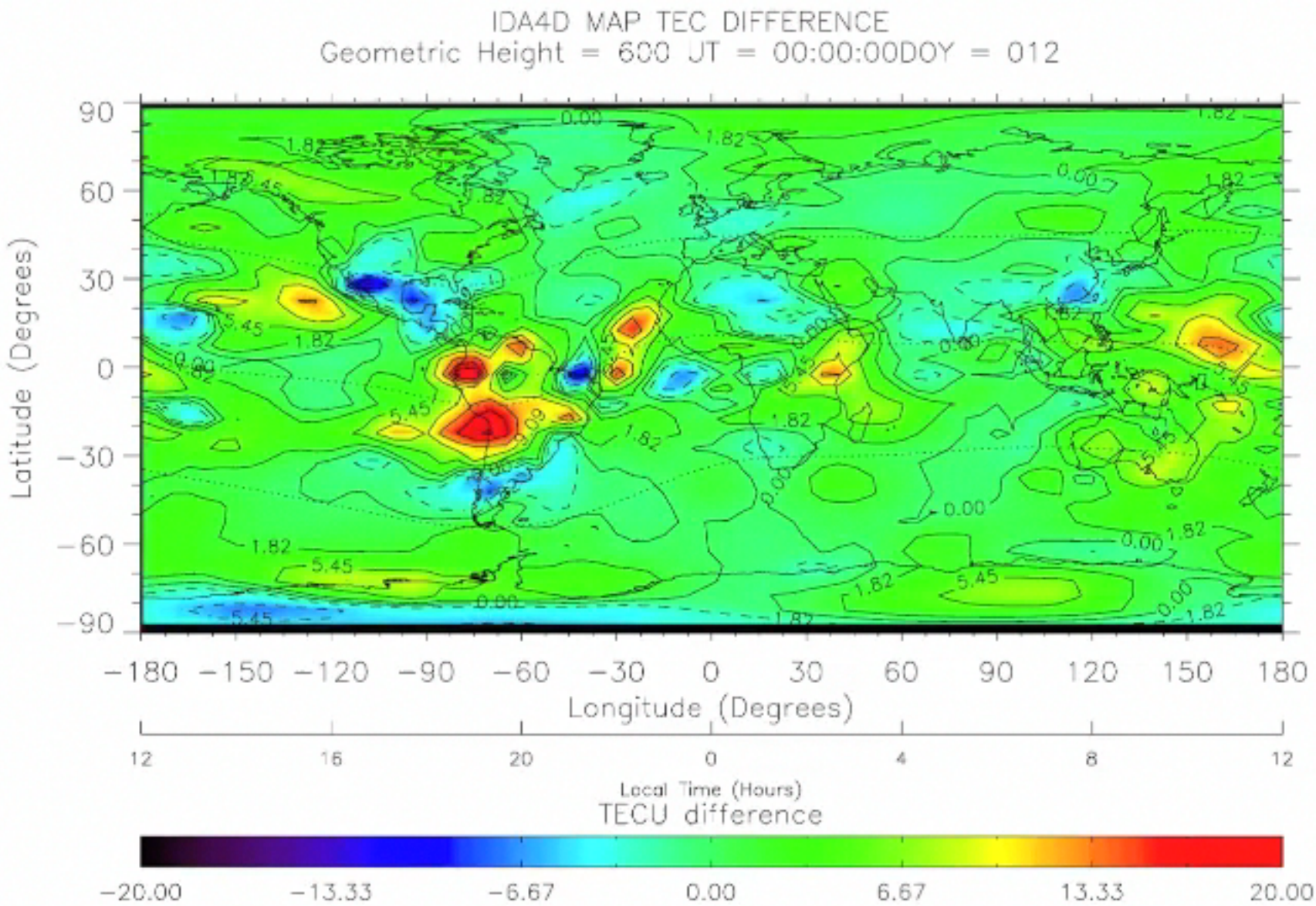



Colorbar scales are different

2013 TEC response to the SSW event is 2 times larger than in 2009.


IDA4D MAP TEC DIFFERENCE
Geometric Height = 600 UT = 00:00:00DOY = 012
Latitude (Degrees)
90
60
30
0
−30
−60
−90
−180 −150 −120 −90 −60 −30 0 30 60 90 120 150 180
Longitude (Degrees)
12 16 20 0 4 8 12
Local Time (Hours)
TECU difference
−20.00 −13.33 −6.67 0.00 6.67 13.33 20.00

# Daytime TEC Response

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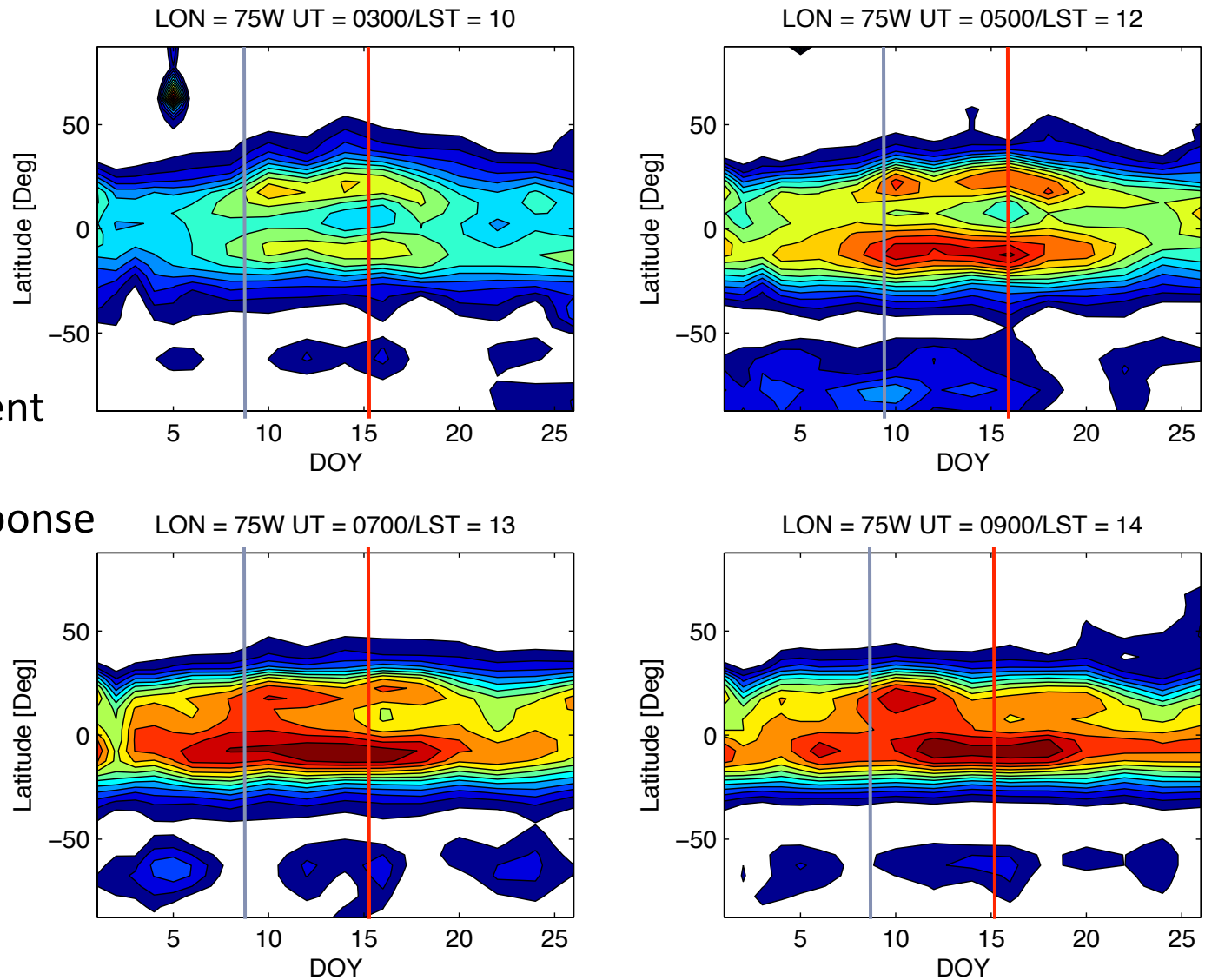
SSW event

TEC response



# Nighttime TEC Response

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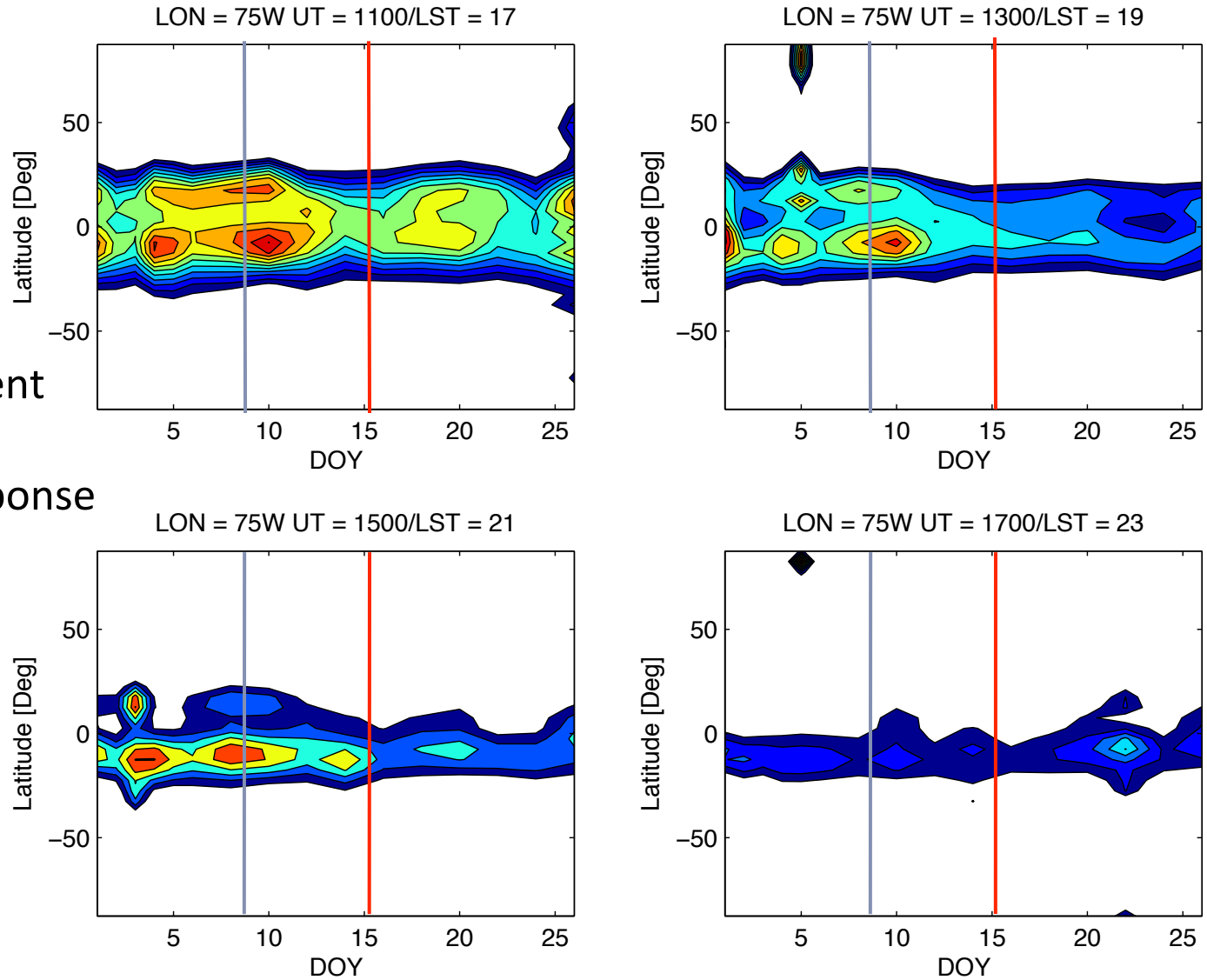
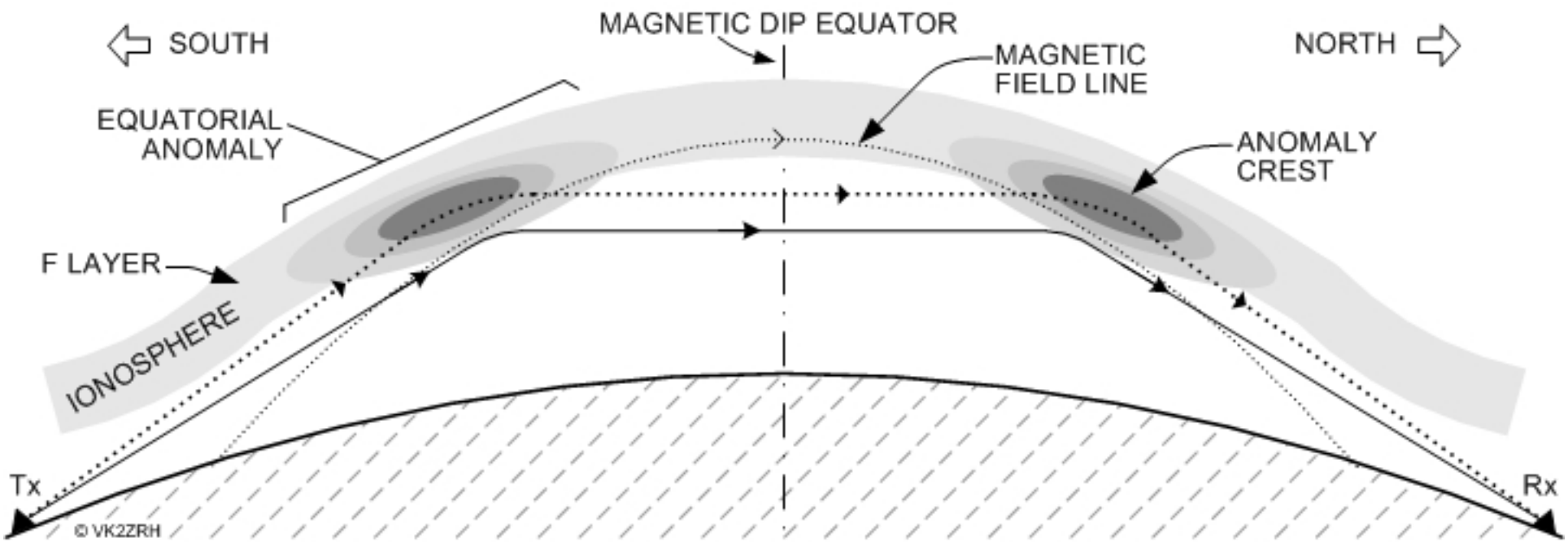
SSW event

TEC response



# Appleton Anomaly

**Appleton Anomaly:** vertical electrodynamic drift at the equator, creating a trough at the magnetic equator, and plasma diffusion along geomagnetic field lines, creating crests on both sides of the equator (Martyn, 1959).




AFTERNOON TYPE TRANSEQUATORIAL PROPAGATION (aTEP)

Harrison

# 2009 Appleton Anomaly

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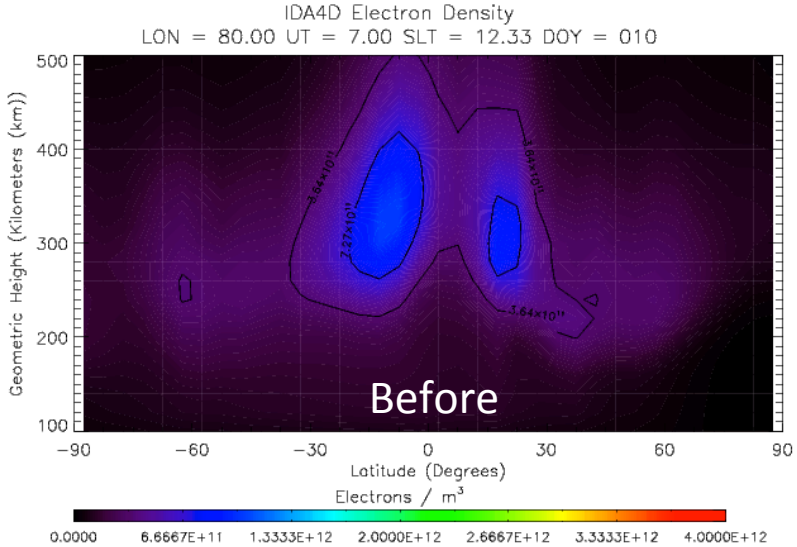
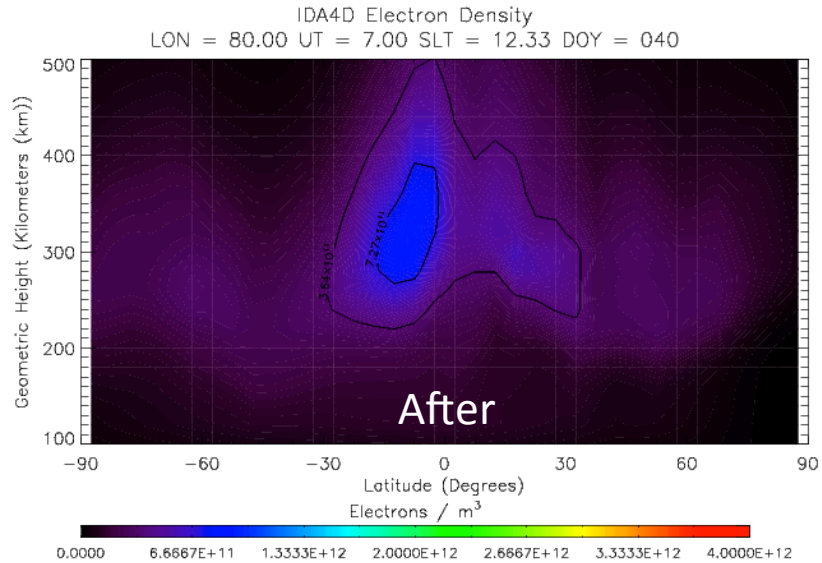
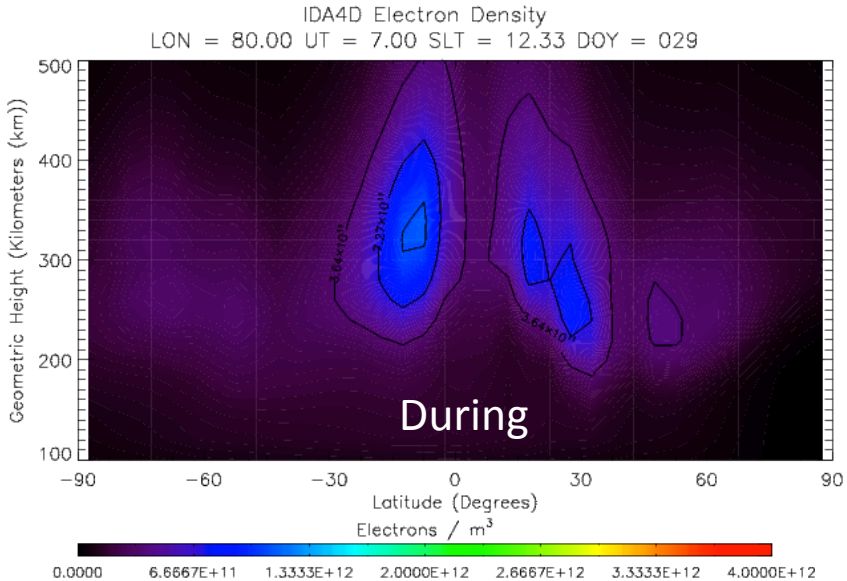



Longitude: 80E
UT: 7.00
SLT: 12



# 2013 Appleton Anomaly

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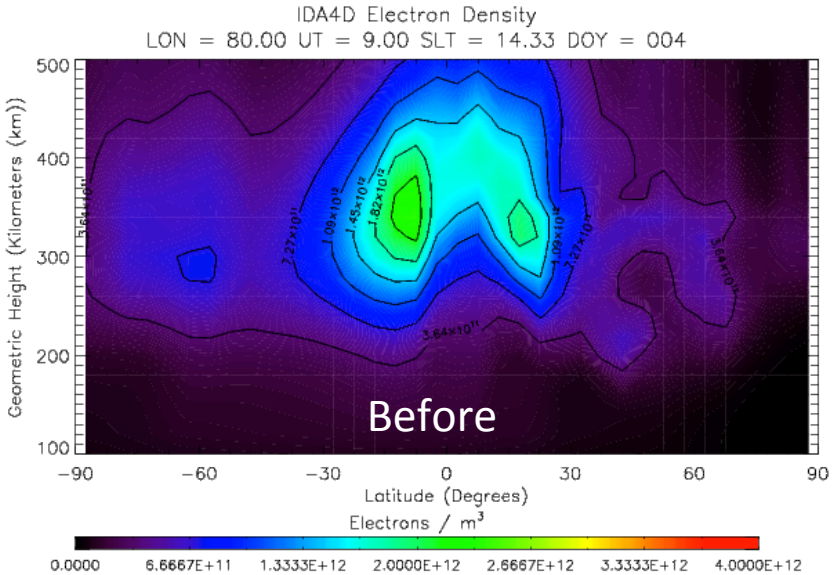
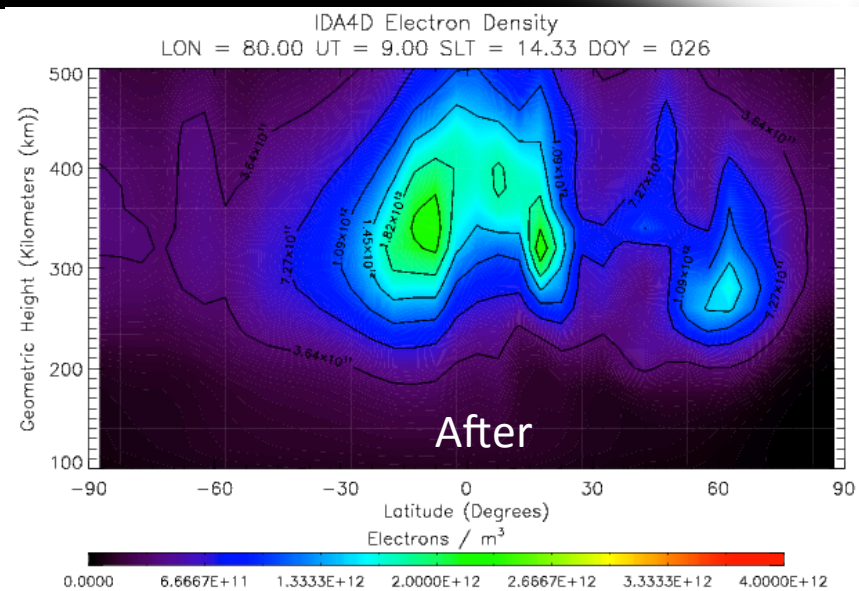
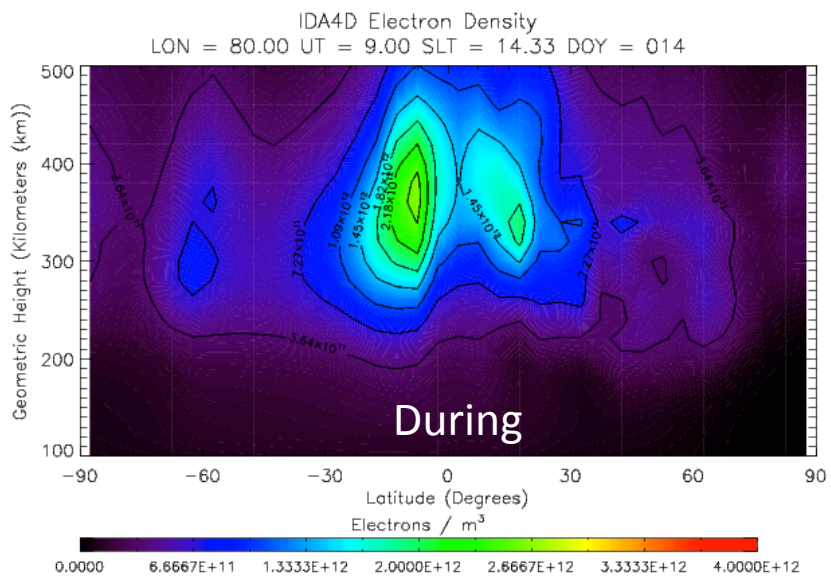



Longitude: 80E
UT: 9.00
SLT: 14



# 2013 Appleton Anomaly

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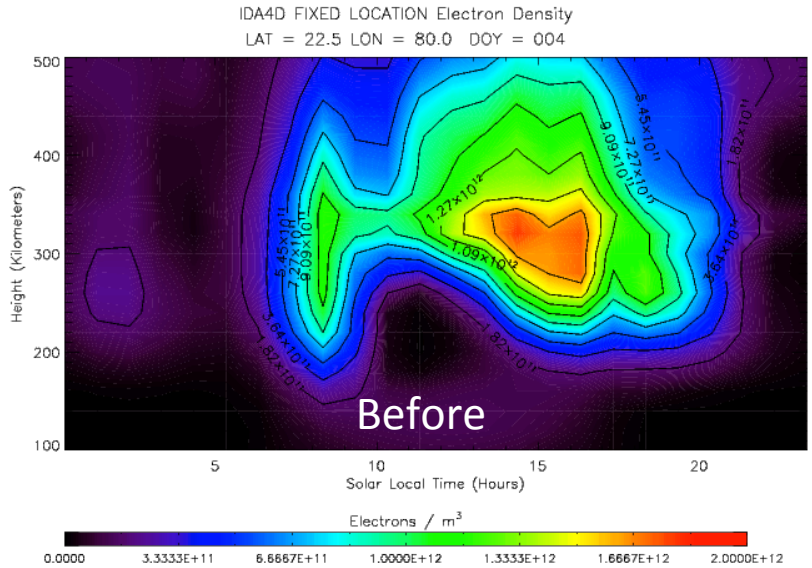
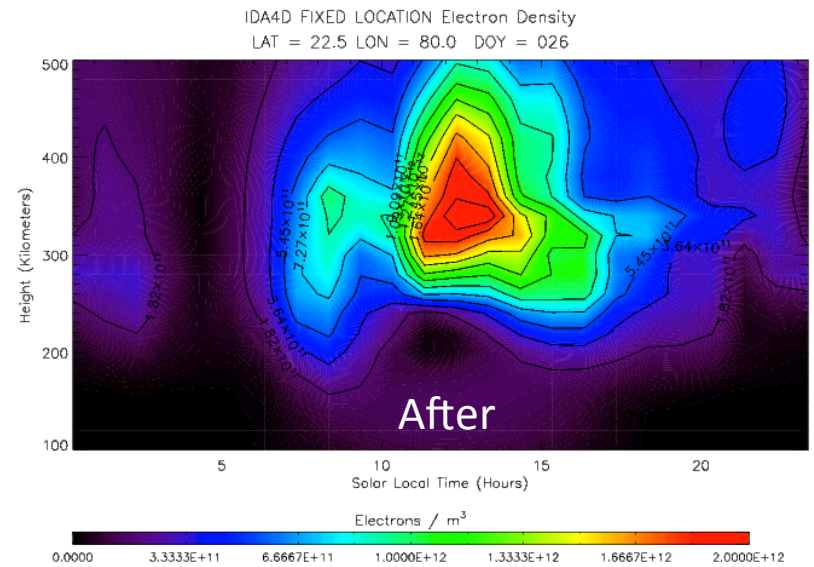
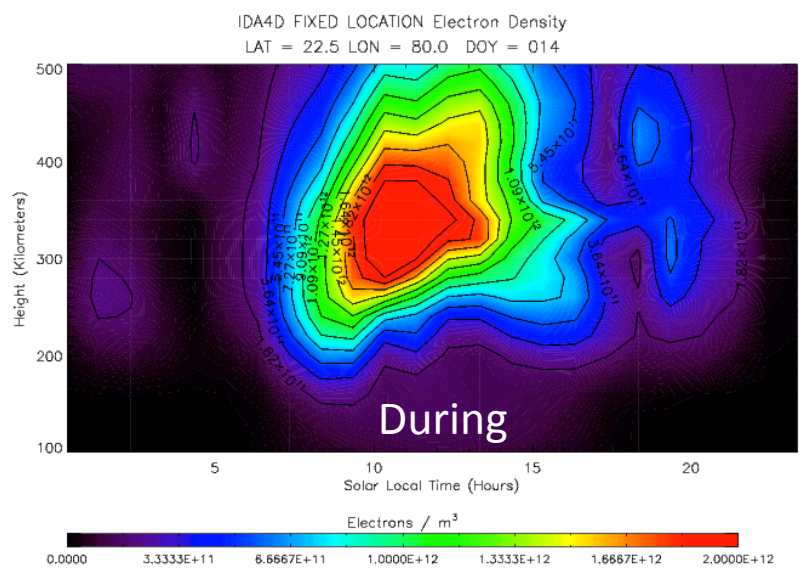



Longitude: 80E
Latitude: 22.5N



# Conclusion



- The 2009 SSW event had a stronger wavenumber magnitude but low TEC and electron density response compared to 2013 SSW event.
- Morning TEC increase and evening TEC decrease was observed globally for both warming events as a function of local time.
- During the 2013 SSW event at 75W and 80E the southern Appleton anomaly has a greater response than the northern anomaly. This is also seen in the 2009 event at 80E but does not show as great a response.
- The 2013 northern Appleton anomaly occurs earlier in the day during the warming event. This is not present in the 2009 event possibly because of the low TEC and electron density response.
- Further work is needed to understand why the ionospheric of response to SSW event in 2009 was weaker than the response in 2013 even though the 2009 event was stronger.

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# Thank you

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