# Global look at sudden stratospheric warmings with GPS TEC and GIRO

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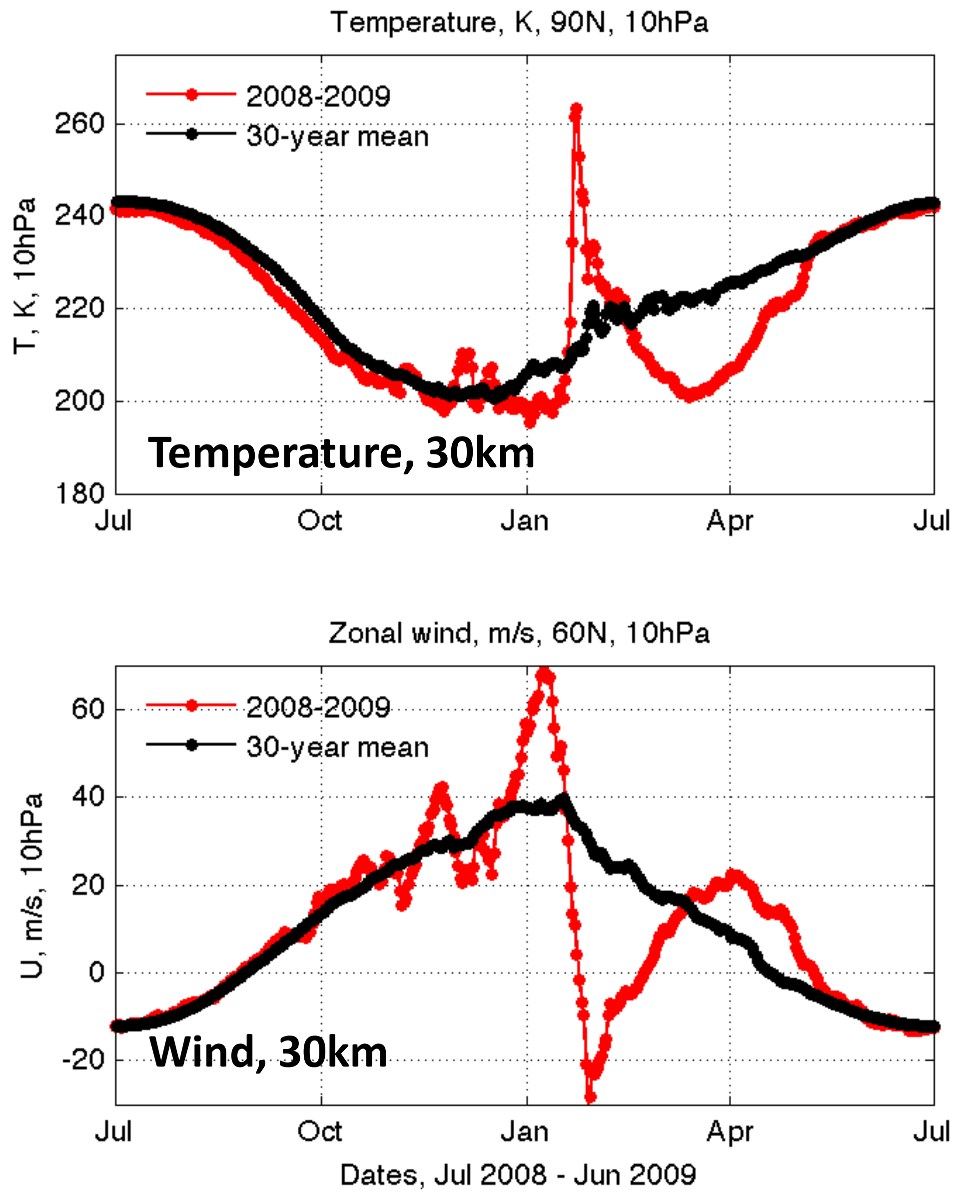
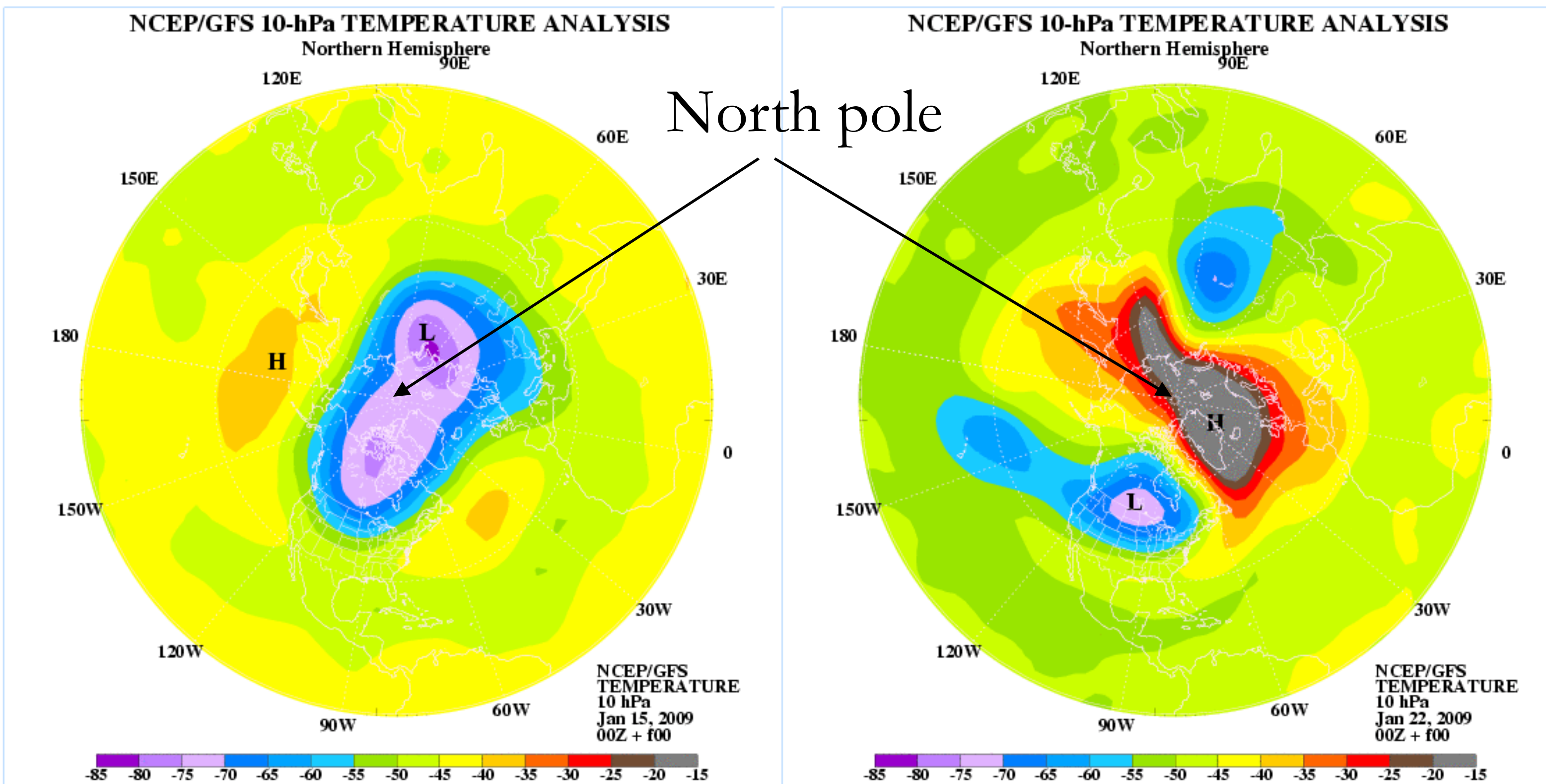
# Sudden stratospheric warming – what is it?




- Largest known meteorological disturbance
- Rapid increase in temperature in the high-latitude stratosphere (25K+); from winter-time to summer-time
- Accompanied by a change in the zonal mean wind

# Stratospheric temperature at 10hPa (~32km)

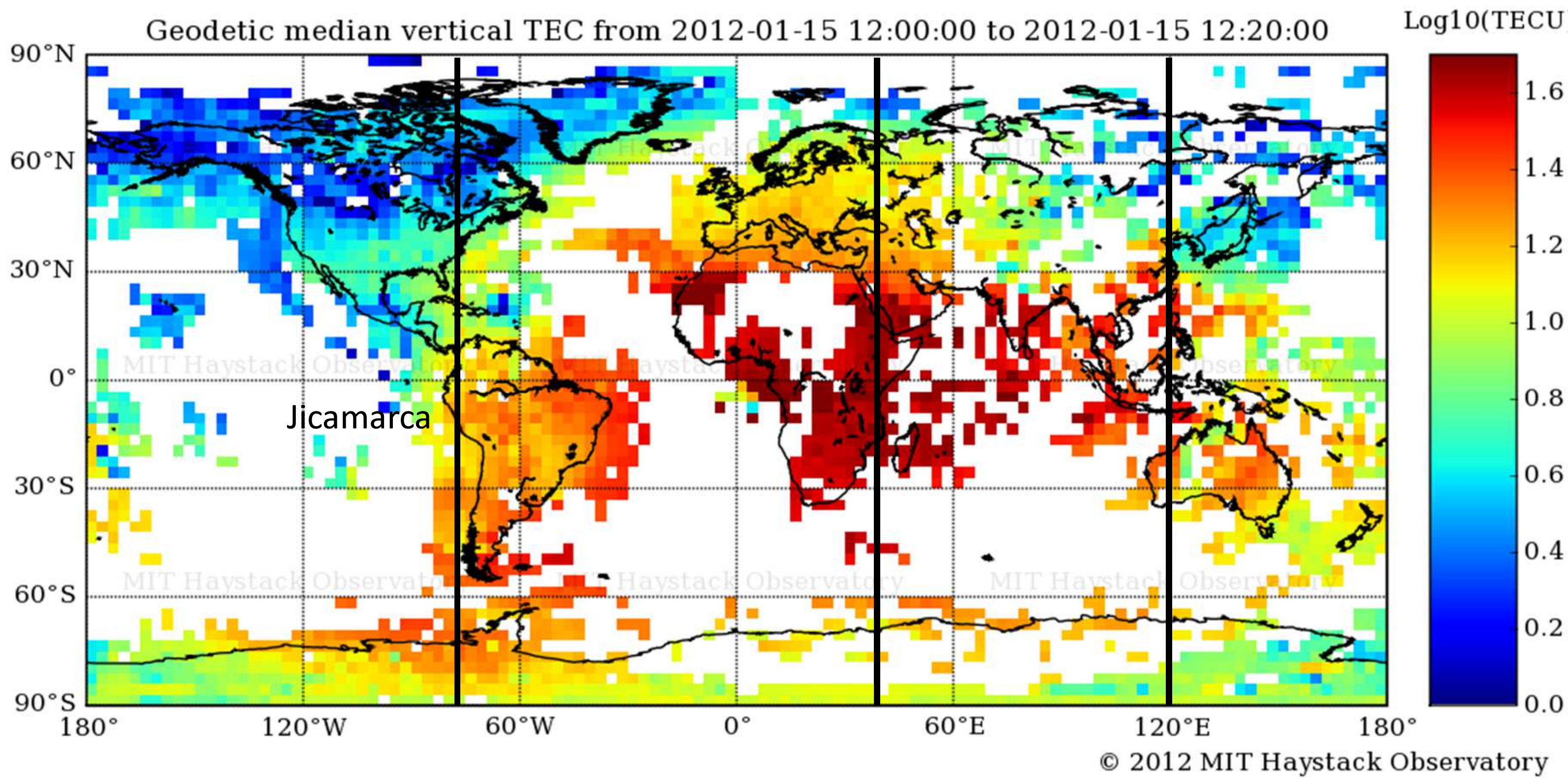
Before warming | During warming




- Stratospheric sudden warming is a large-scale dramatic coupling event in the **winter** polar atmosphere
- Results from interaction of planetary waves with zonal mean flow
- Largest planetary waves recorded in nature
- Involves changes in temperature, wind, gravity wave activity

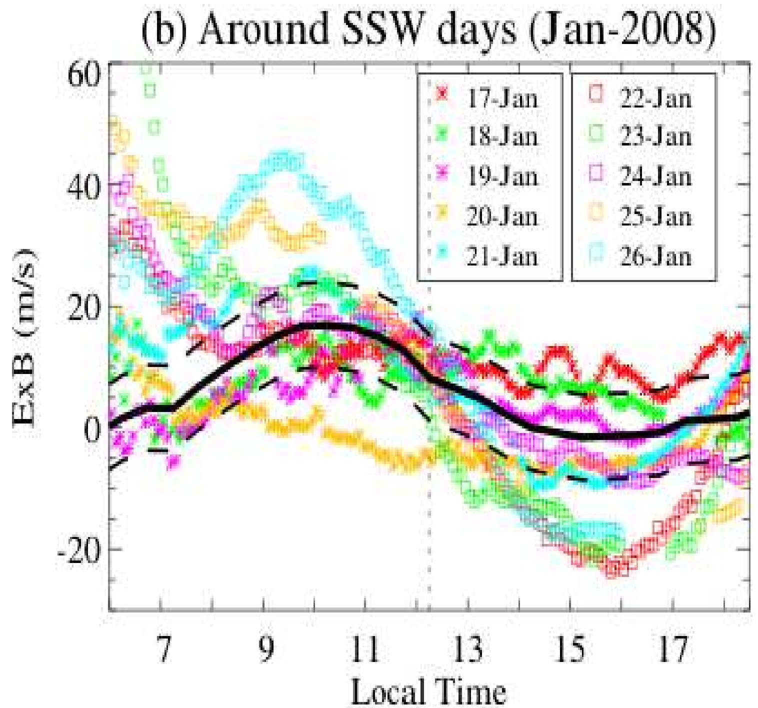
# What do we see in the ionosphere?

# GPS TEC and radar data used

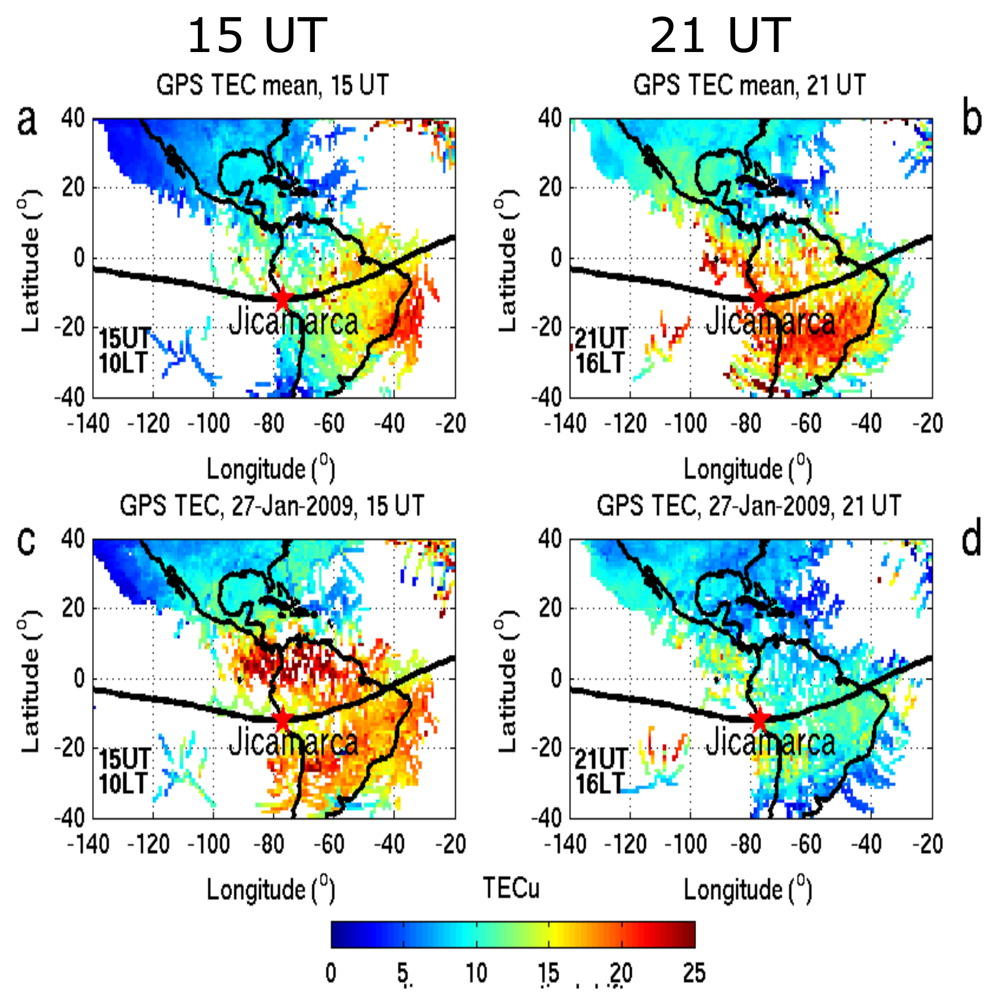



- GPS  TEC, MIT Haystack Observatory:
  - **~3000 GPS receivers, 5 min, 1ºx1º resolution**
  - Longitudes selected: 75ºW, 40ºE, 120ºE
- ISR and JULIA radar at Jicamarca (12ºS,75ºW, magnetic equator), vertical drifts

# Earlier results:
# Ionospheric effects of stratwarming for solar min




*Chau et al., 2009, 2011*

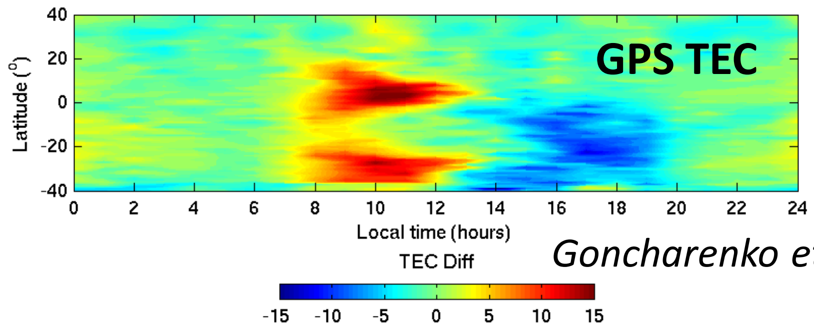



*Goncharenko et al., 2010a*

- Upward drift in the morning, downward in the afternoon -12-h wave
- Interpreted as evidence of enhanced 12-tide & E-region dynamo

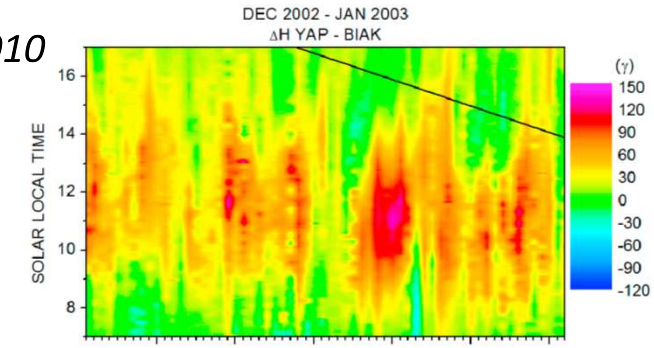
Entire daytime low to mid-latitude ionosphere is affected during stratwarming; Total Electron Content change 50-150%

# Earlier results

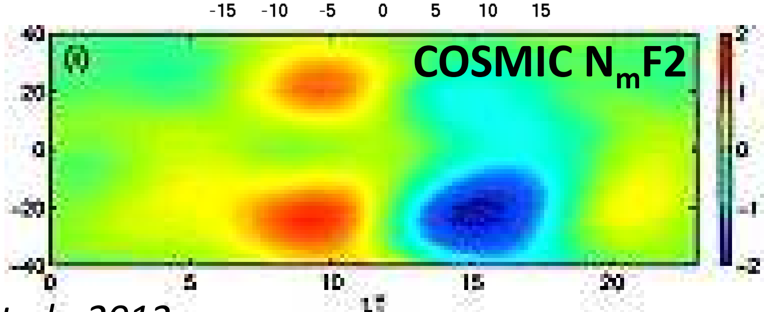



Goncharenko et al., 2010

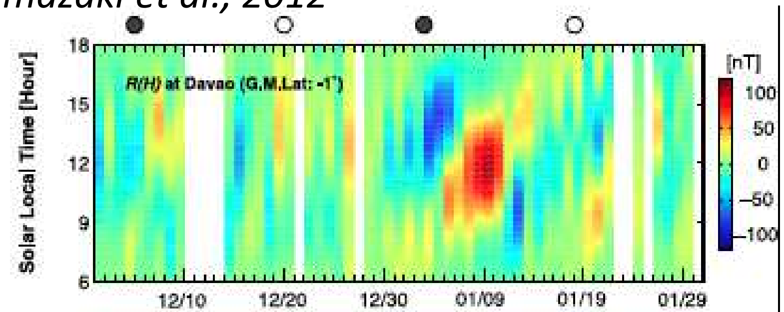
*Fejer et al., 2010*

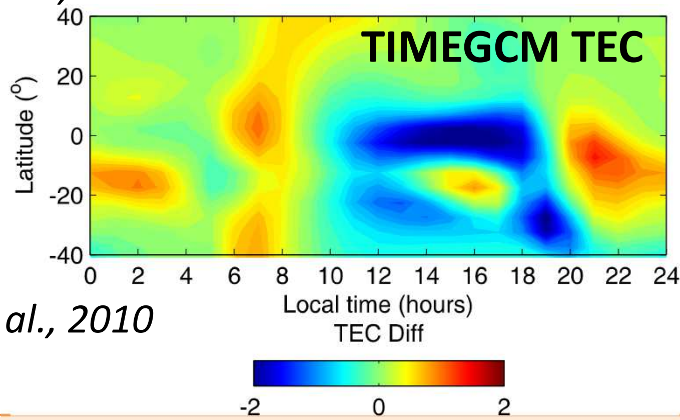



*Yamazaki et al., 2012*



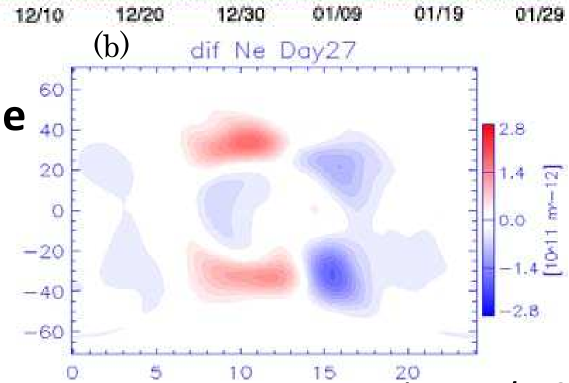

*Lin et al., 2012*




*Liu et al., 2010*

**GAIA Ne**

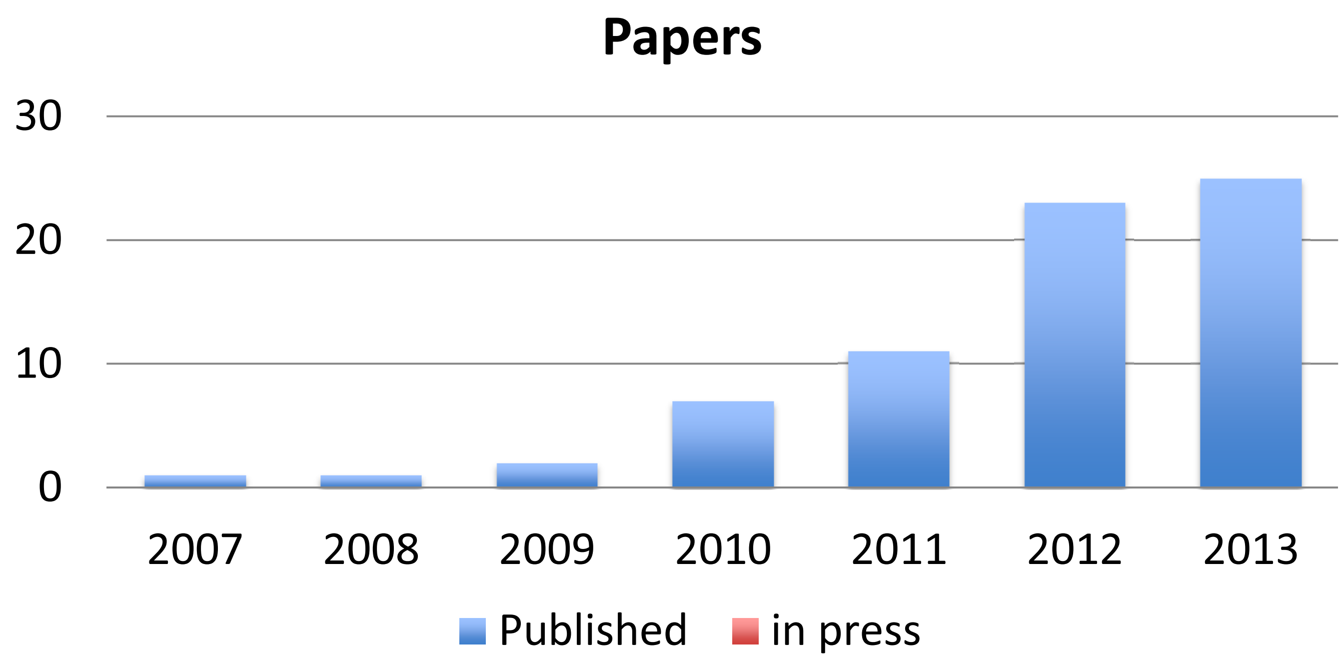



*Jin et al., 2012*

**Review:**
***Chau et al.*, 2012**

Rapid progress: Consistency between different types of observational data and modeling

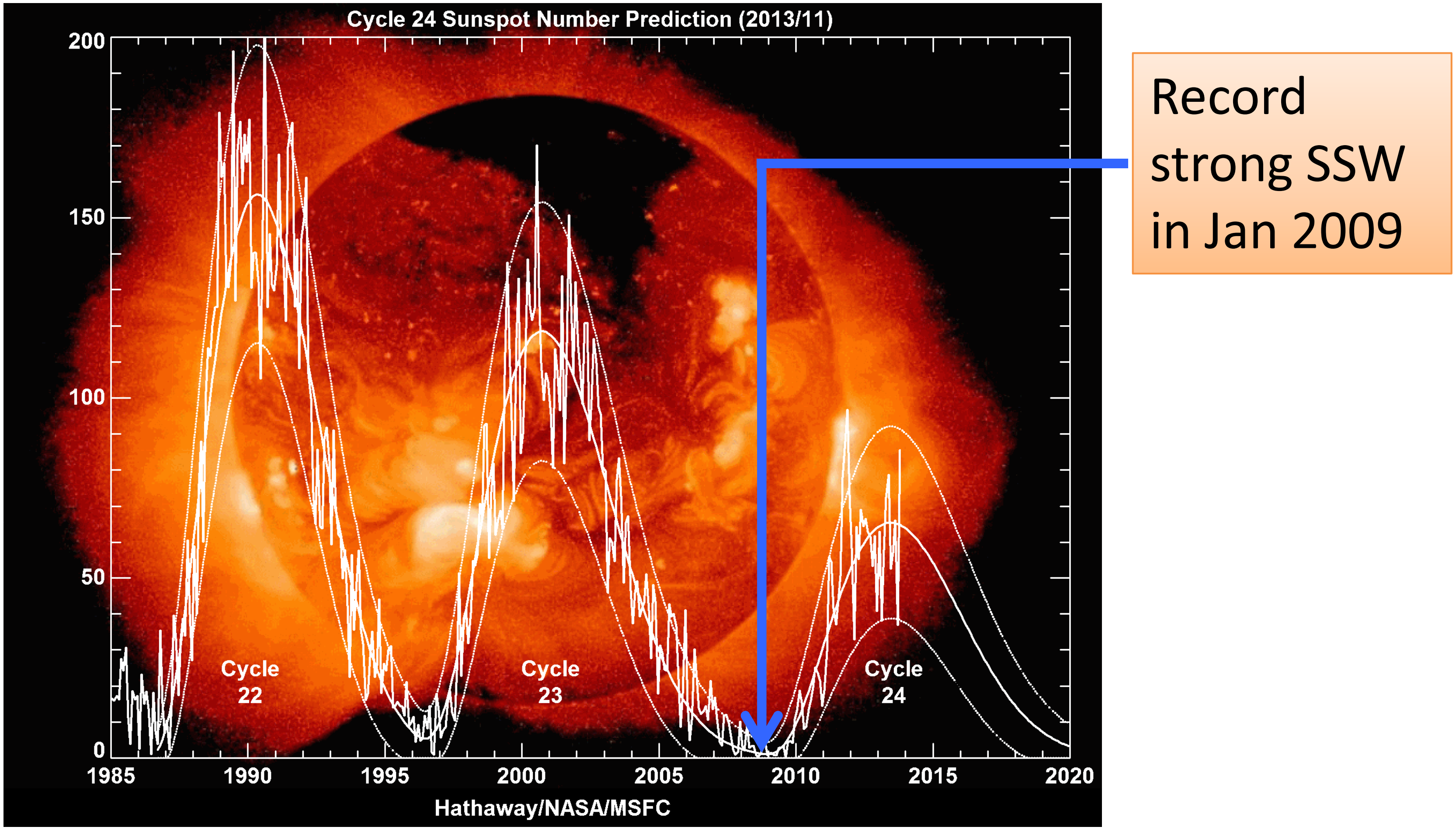
# Ionospheric effects of SSW




- Stratospheric effects of SSW are studied since 1950s
- Mesospheric effects of SSW are studied since 1970s
- **Ionospheric effects of SSW are actively studied since 2009**

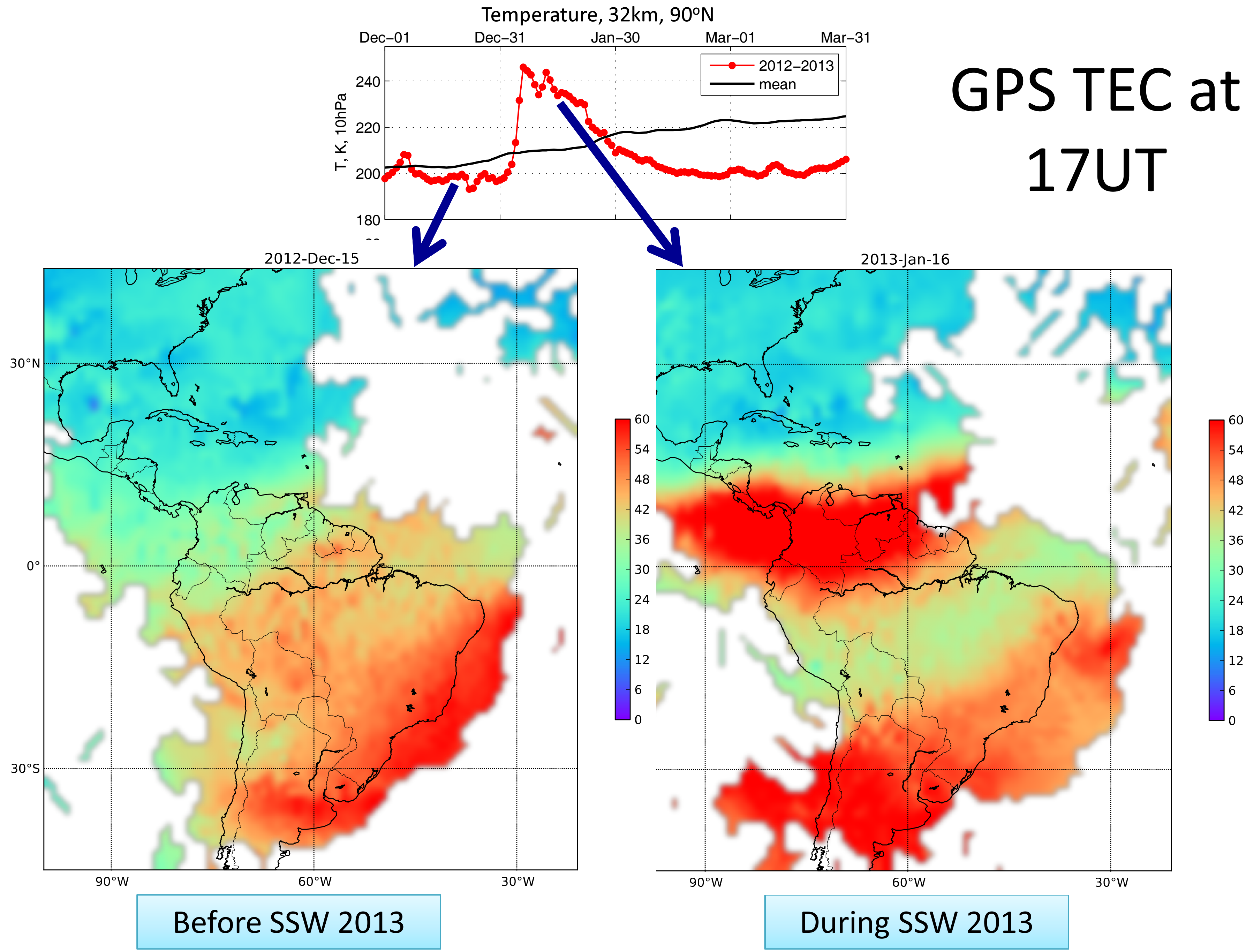
"These new results have triggered an **explosion** of studies of mechanisms and types of possible connections between terrestrial and space weather during SSW and other large-scale perturbations in the lower atmosphere" – *Wang et al*., JGR 2011

# Are there any effects during high solar activity?

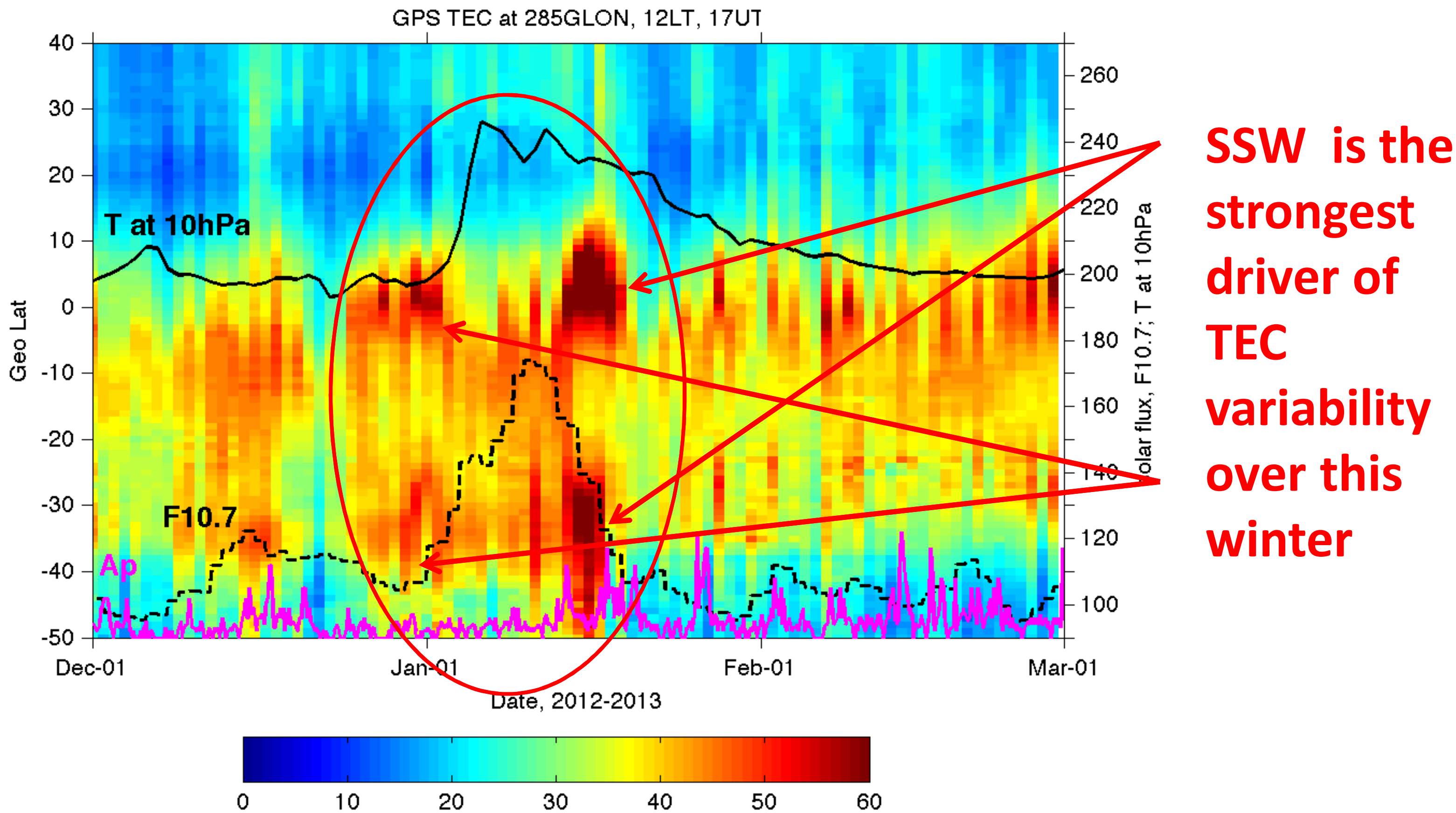



- Low solar flux simplifies studies of lower/upper atmosphere coupling
- During lower solar flux, ionosphere is sensitive to **both** geomagnetic activity and lower atmospheric forcing

# GPS TEC at 17UT



# GPS TEC at 75ºW, 12LT




*Goncharenko et al.*, 2013 GRL

- Major SSW coincides with increase in F10.7 up to 174
- Highest solar flux during current solar max
- Quiet to disturbed geomagnetic conditions

# TEC disturbances at 3 longitudes (%)

Southern crest EIA

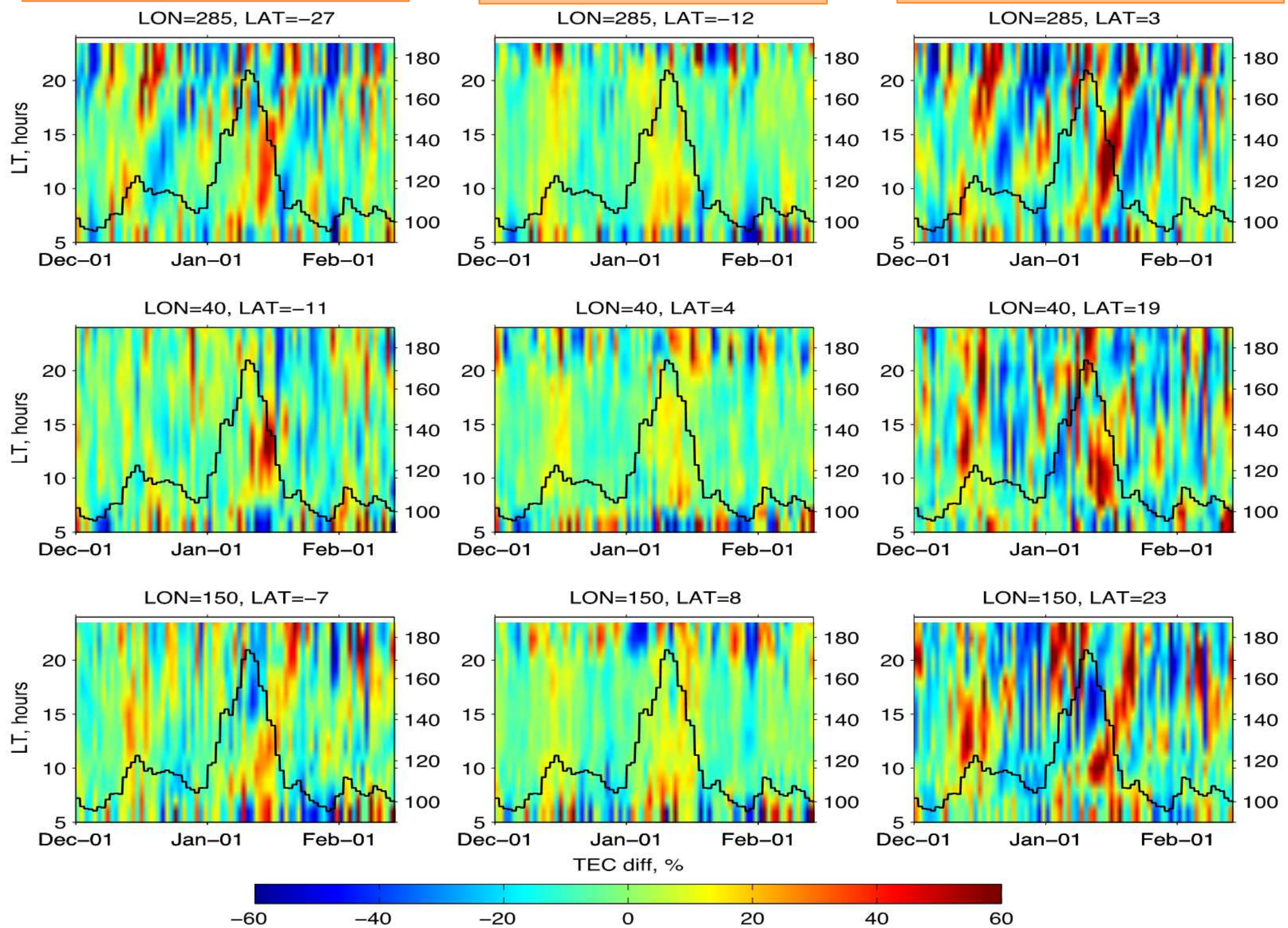
Magn.equator

Northern crest EIA

75°W

40°E

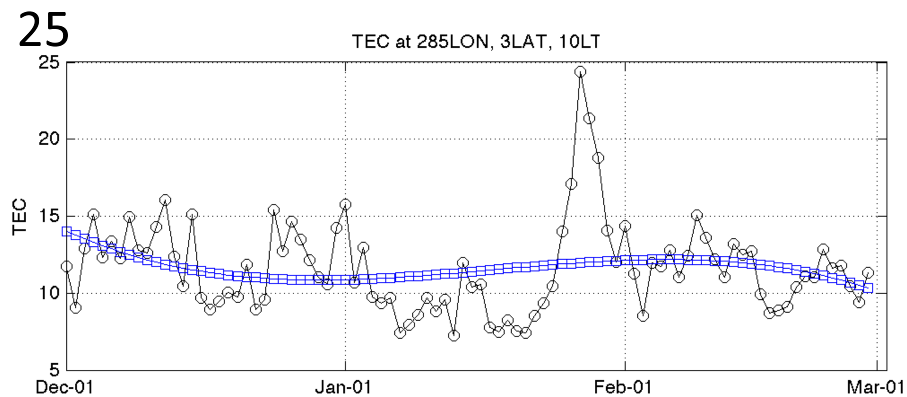
150°E

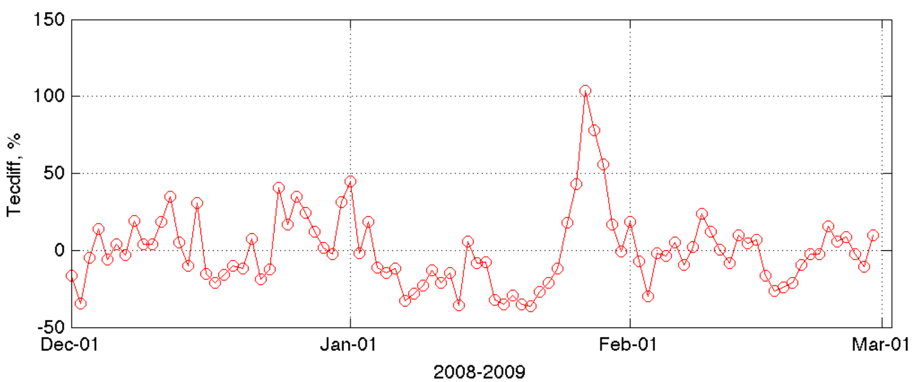



- SSW effects are stronger in the northern hemisphere
- Longitudinal difference in magnitude and timing of TEC variations

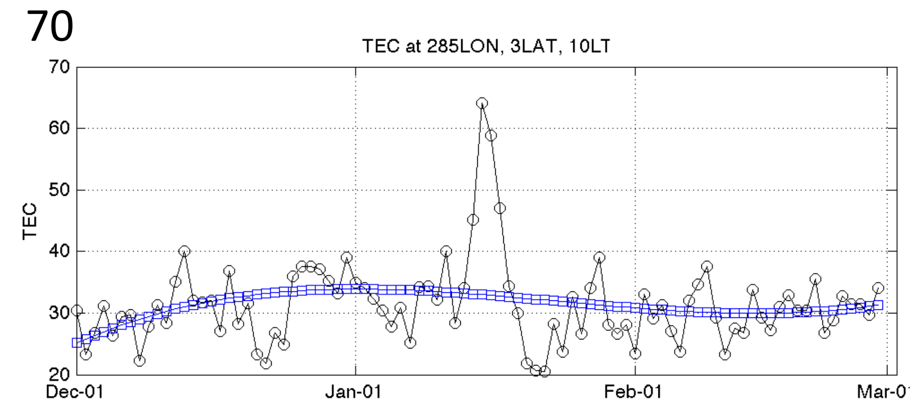
# TEC variations at 3ºN, 75ºW, 10LT

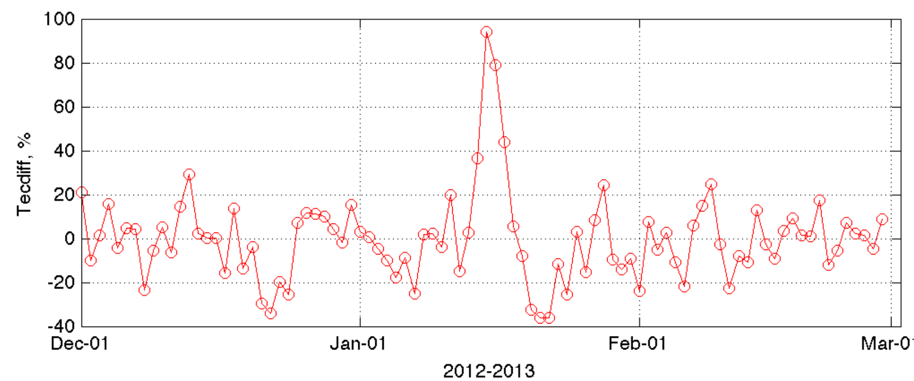
**2009, Solar min**




**2013, Solar max**

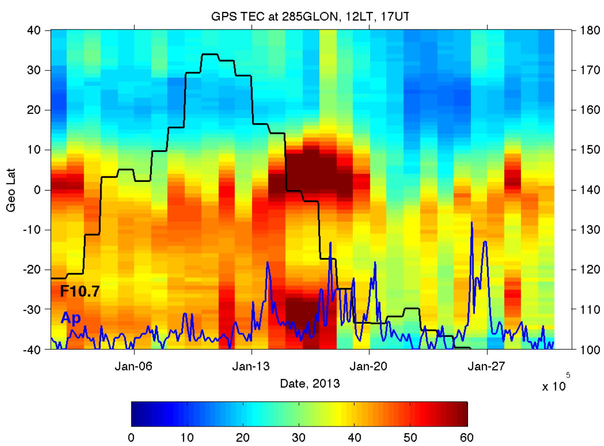


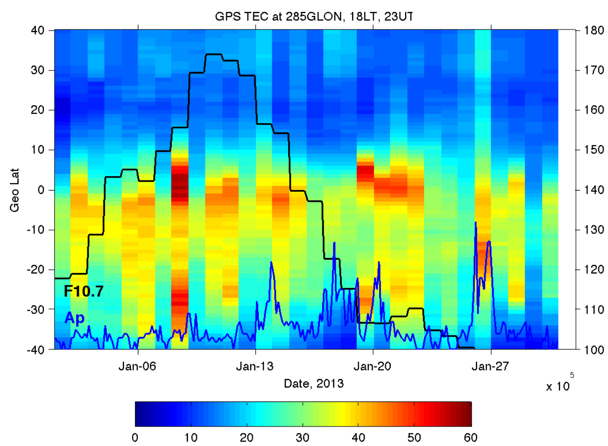

- Absolute TEC variations are larger in 2013
- Relative TEC variations are comparable in 2009 and 2013

SSW can lead to large ionospheric disturbances even during high solar activity

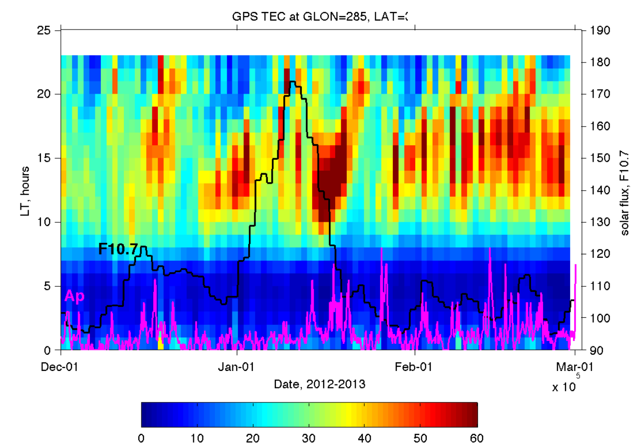
# How do you separate SSW effects from solar and geomagnetic activity?




12LT




18LT

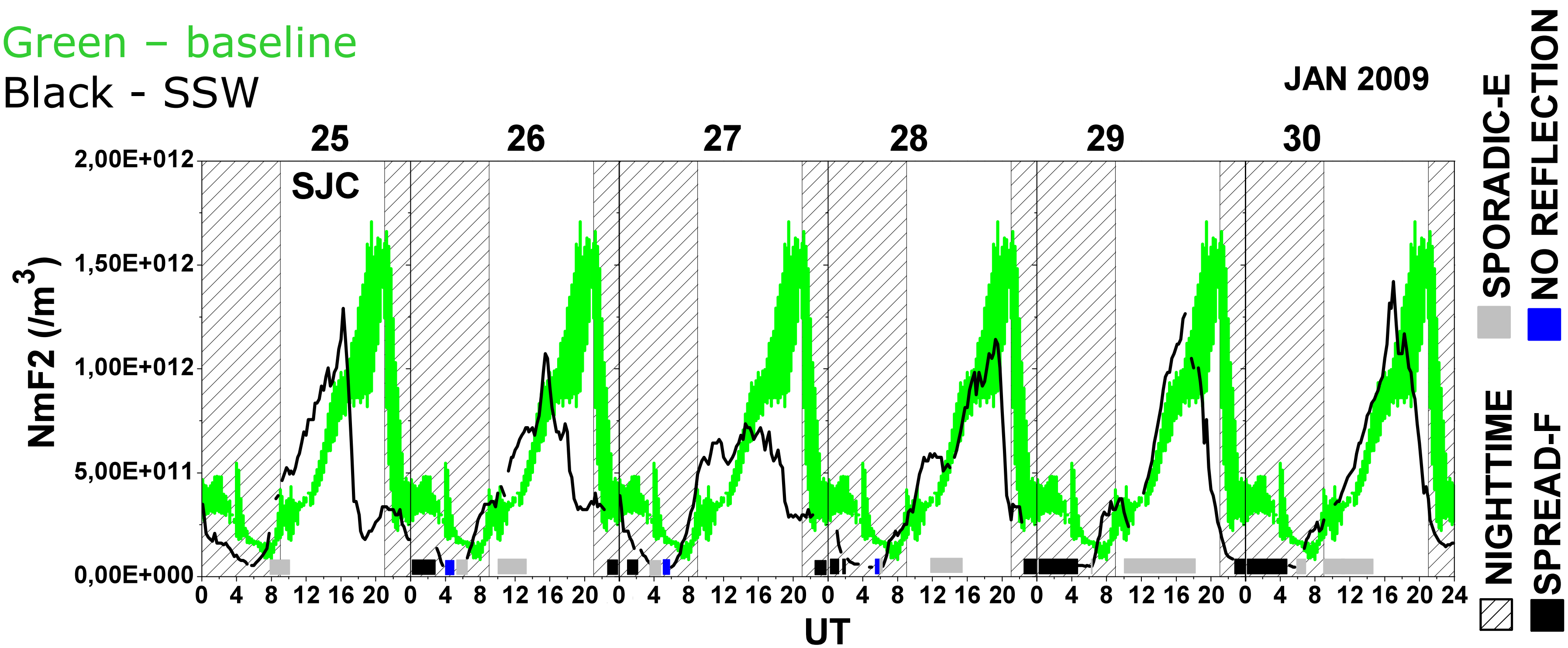



3$^o$N

- Time:
  - Max increase in TEC 7 days after peak F10.7 – not related to F10.7
  - SSW effects have quasi-tidal nature (e.g. peak at 12LT, decrease at 18LT)
  - SSW effects persist for days (or weeks)
  - SSW effects shift to later local time (lunar tide + solar tide)
- Space:
  - Movement of EIA crests to higher latitudes – electric field effect

# South America:
# Variations in NmF2 during stratwarming

Green – baseline
Black - SSW




*Courtesy of Y. Sahai and R. de Jesus*

- São José dos Campos digisonde (23.2 S, 45.9 W), Brazil
- January 2009 SSW event
- Decrease in NmF2 by a factor of 4 at sunset; persistent for several days

UPADHAYAYA AND MAHAJAN: IONOSPHERIC VARIABILITY AND SSW

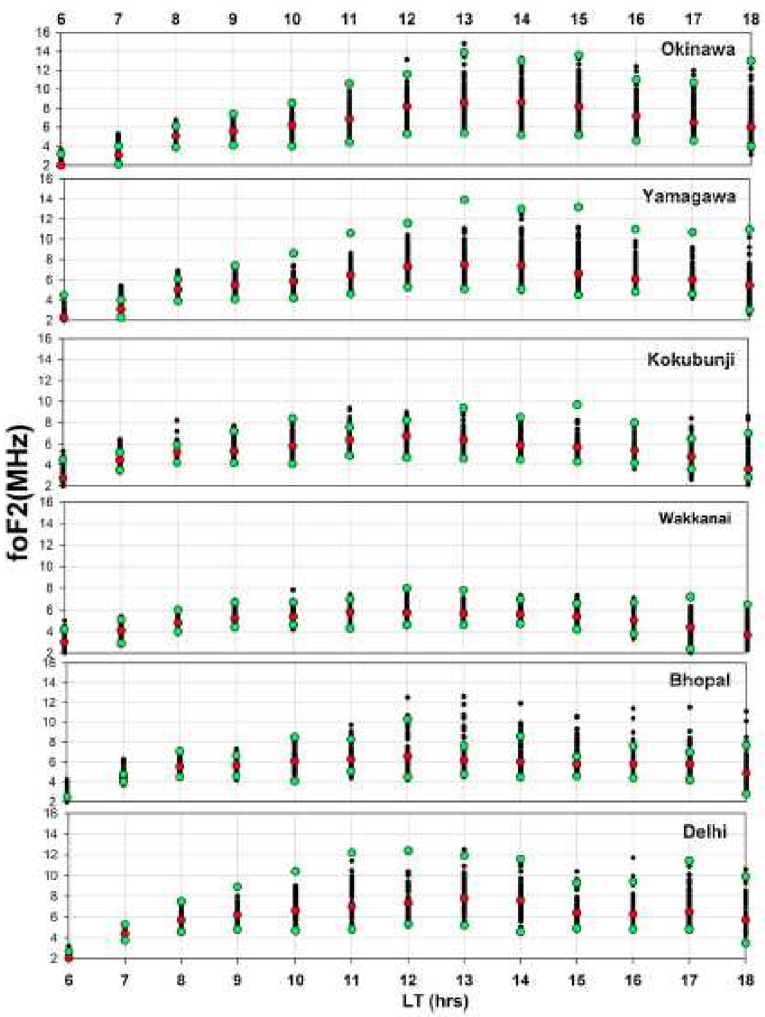



**Figure 12.** Plot of $f_oF_2$ values at various local times for different stations during the first 6 months of the year 2008. The red dots show the median $f_oF_2$ values for the respective local times. The green dots indicate the maximum and the minimum value observed during the warming period.

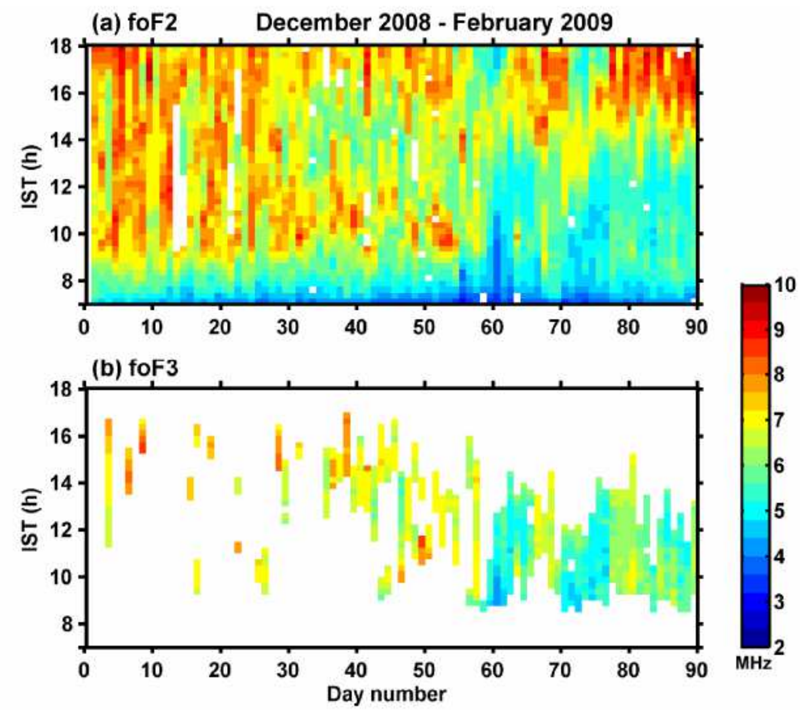



**Figure 6.** Daytime variation in (a) $f_oF_2$ and (b) $f_oF_3$ as a function of day number during December 2008-February 2009.

Upadhayaya and Mahajan, 2013:

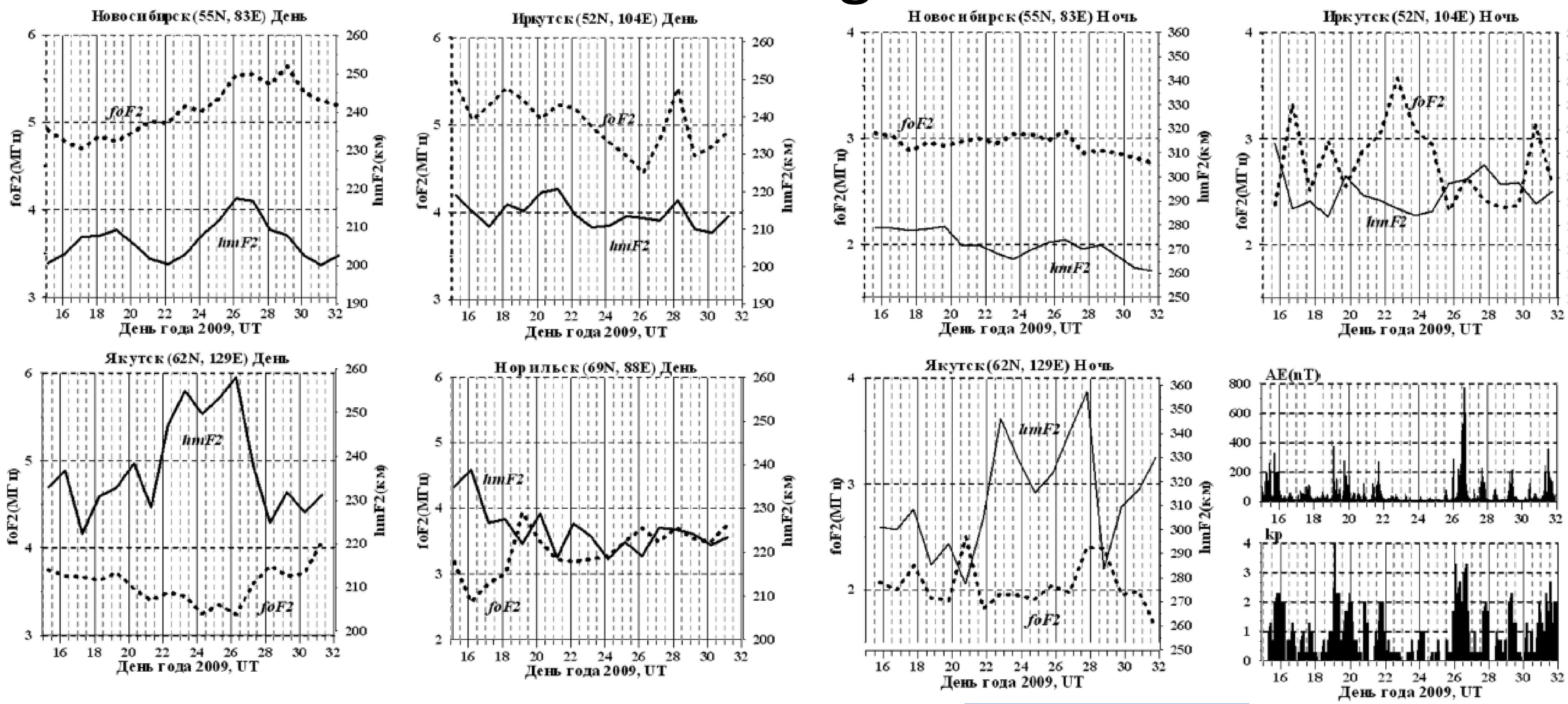
- Asian sector, 23-45°N, 73-140°E

Patra et al., 2014, SSW 2009:

- Indian sector, Gadanki, 13°N
- ~12hrs and ~16-day changes in foF2, foF3
- No blanketing Es
- Weaker F region irregularities

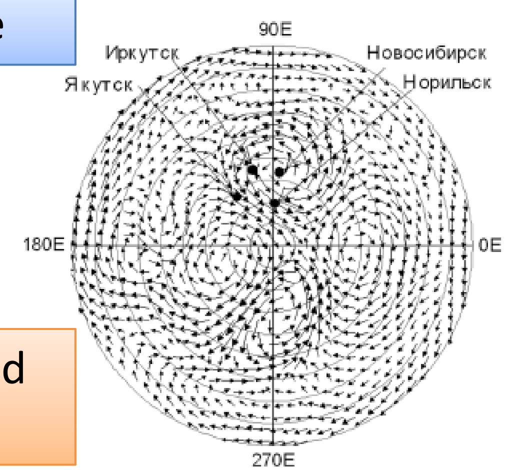
Large and complex variations during SSW in studies using ionosonde data

# Middle and high latitudes




Daytime

Nighttime



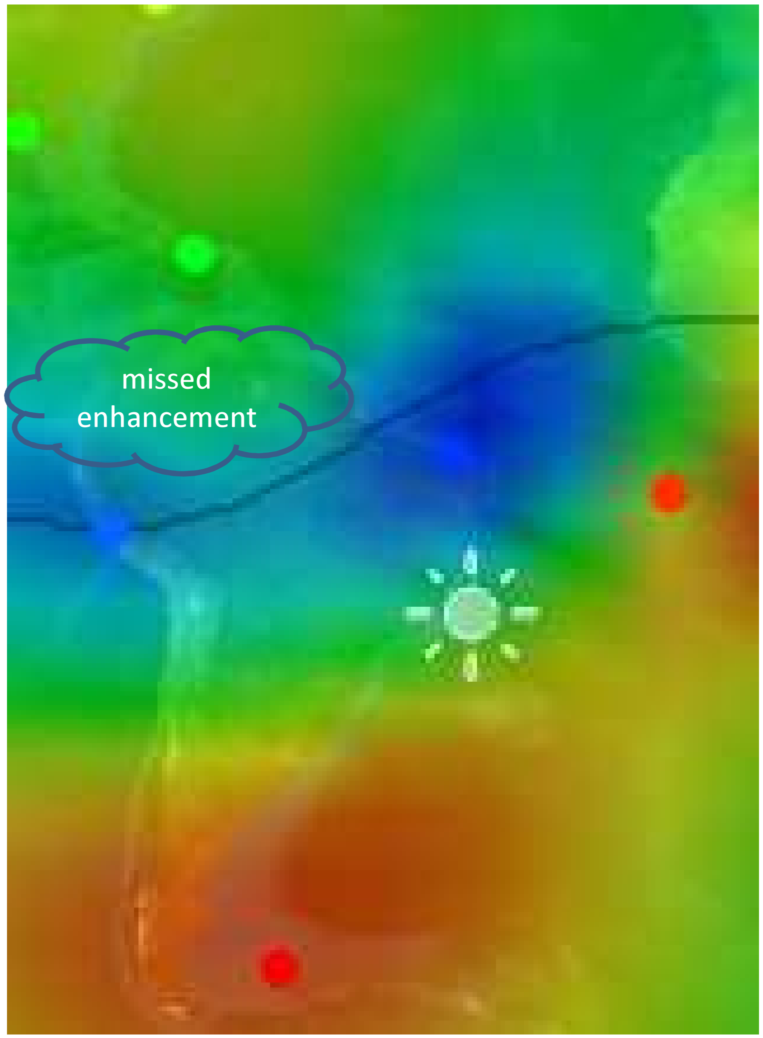

Shpynev et al., 2013:

- Russia, Siberia (80-130°E, 52-69°N)
- Increase in hmF2 by ~50km for 6 days
- Highly localized

Studies of lower/upper atmosphere coupling mechanisms are hindered by the lack of ionospheric data with high space & time resolution

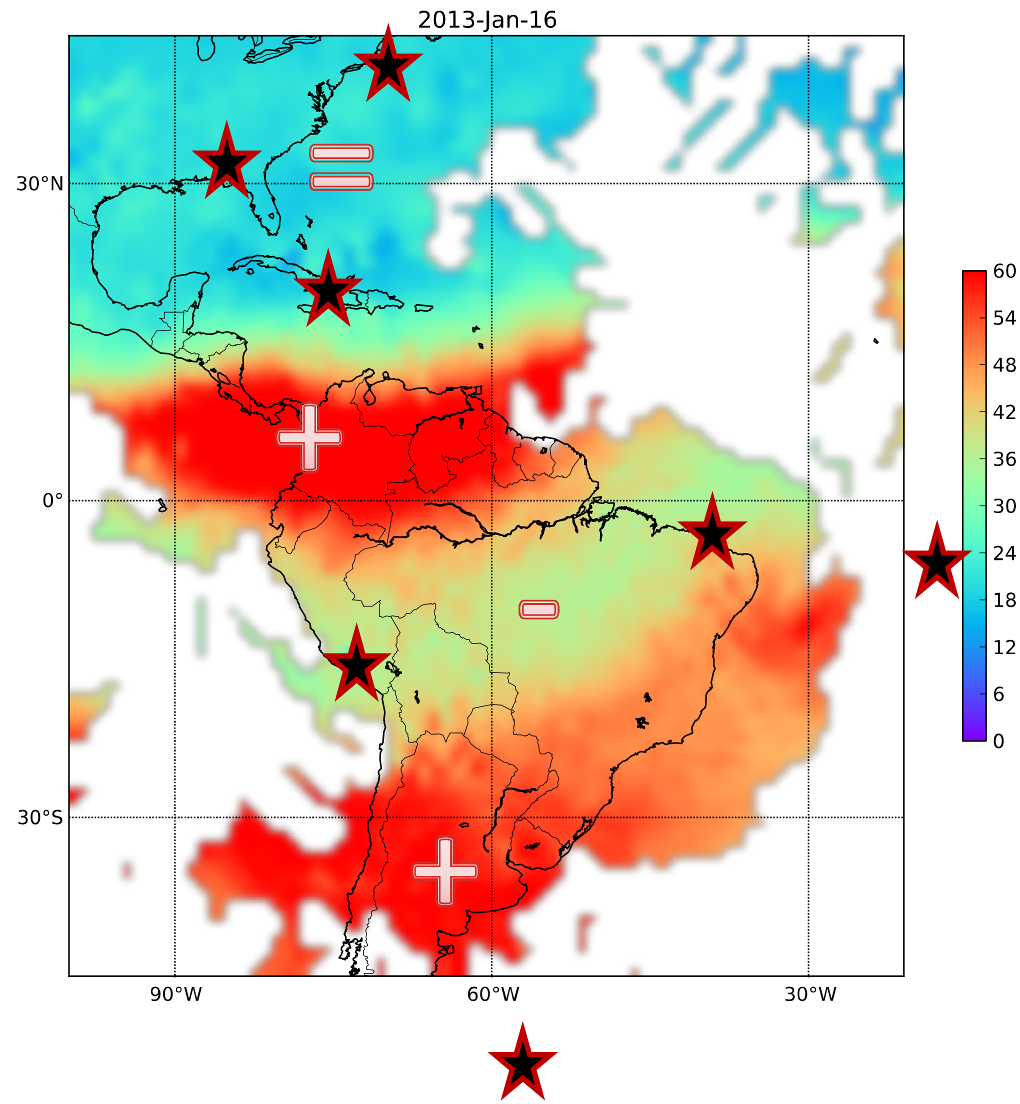
# IRTAM Validation: ΔfoF2 versus GPS TEC

## ΔfoF2



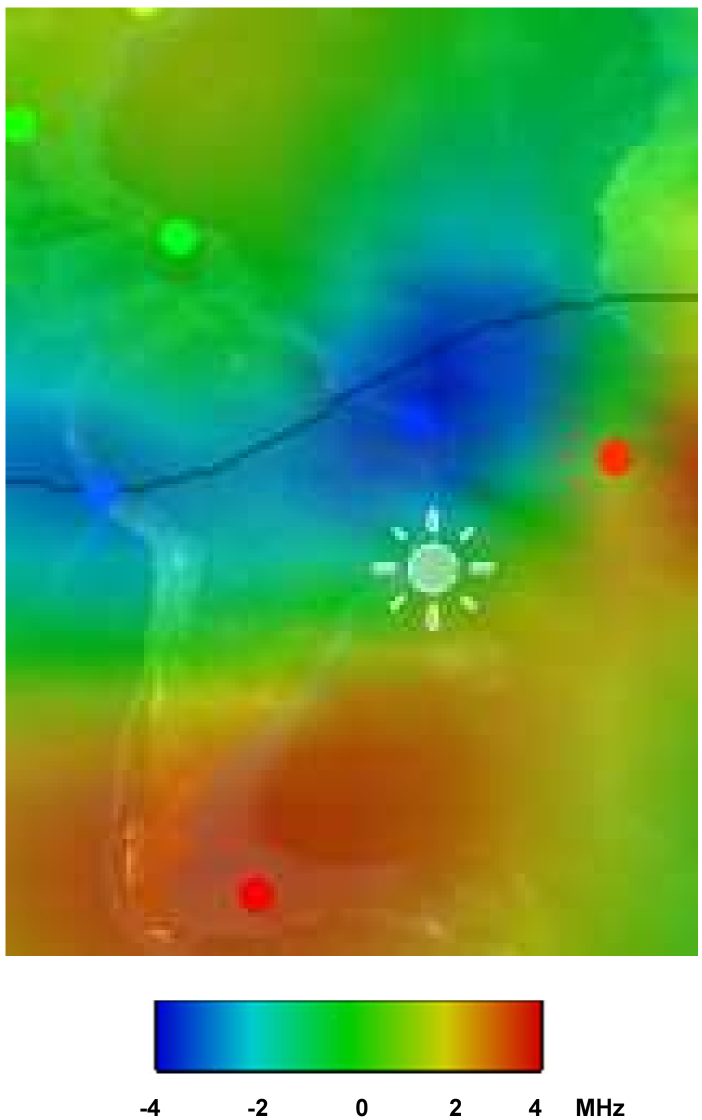

7 sensors

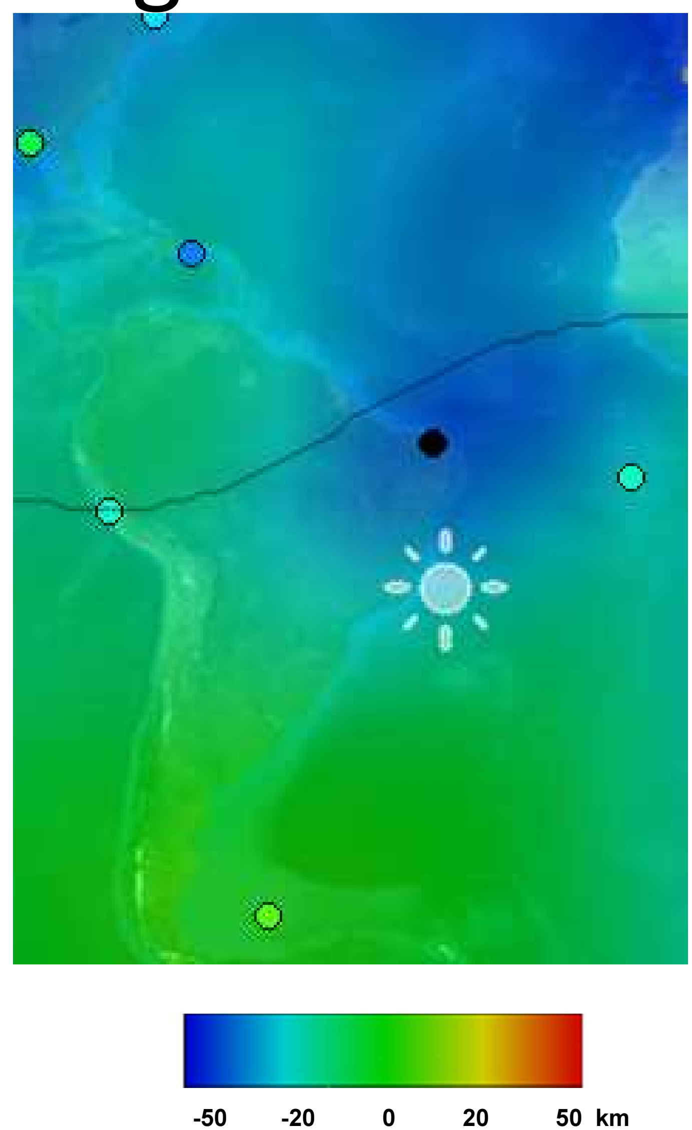
## TEC




100s of sensors

# IRTAM showing vertical plasma restructuring

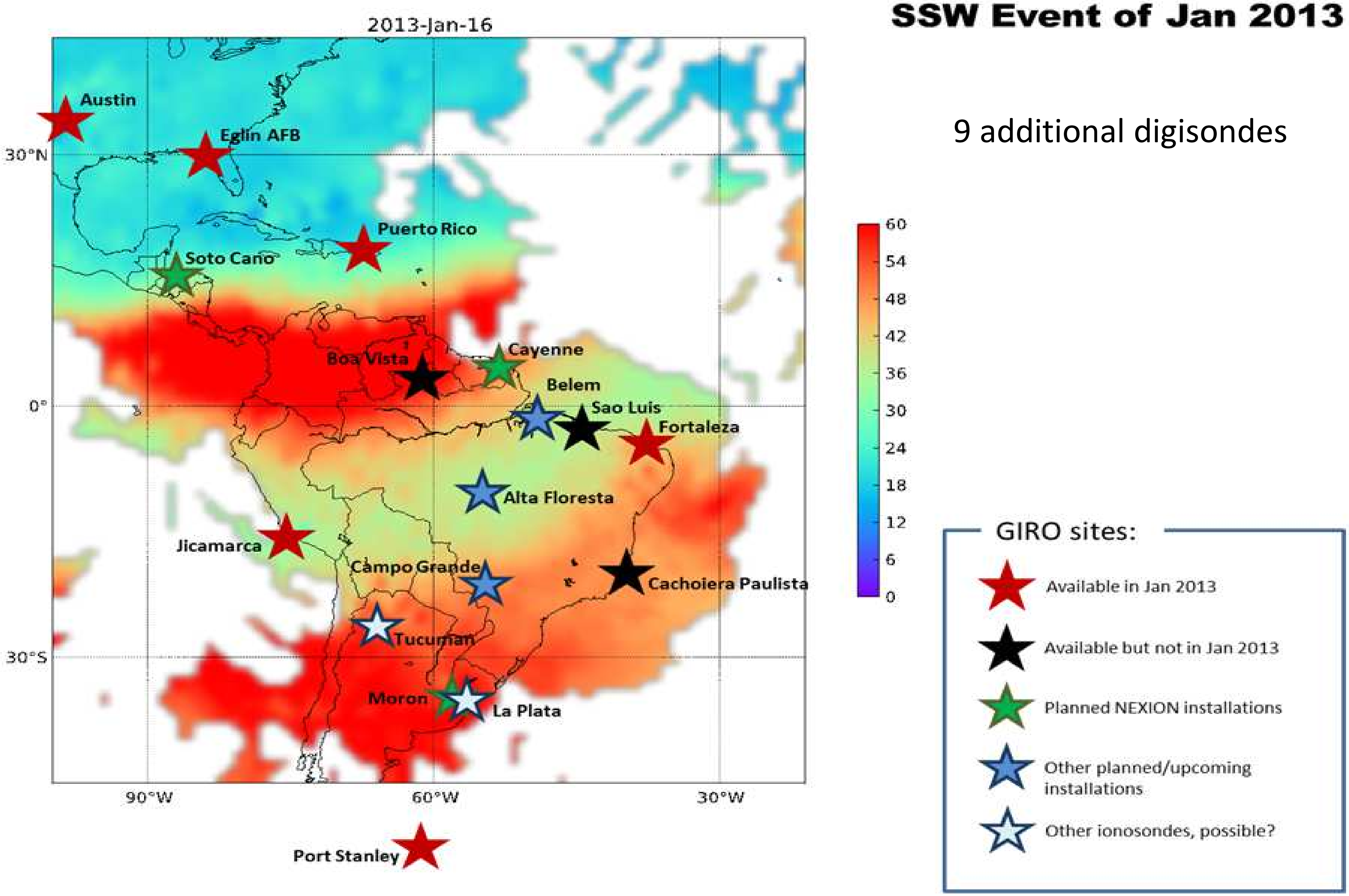


# Digisonde coverage of South American

**SSW Event of Jan 2013**

9 additional digisondes



# Summary

- Sudden stratospheric warmings are a prime example of strong coupling between the lower atmosphere and ionosphere:
  - Effects are strong, TEC variation ~100%
  - Effects are long - > 40 days
  - **Ionospheric effects are strongest at low latitudes**
  - Effects at middle and high latitudes are even more complex
- Ionospheric impact strongly depends on the details of the perturbed wave dynamics in the middle atmosphere
- Coupling mechanisms are an active research topic

Ionospheric effects of lower atmospheric forcing are strong for both solar min and solar max conditions

As we expect lower solar activity for the next few decades, relative importance of lower atmosphere for ionospheric variability is likely to increase

There is a critical need for high resolution, global ionospheric data (IRTAM)