The Equatorial and Low Latitude Ionosphere during Stratospheric Sudden Warming events

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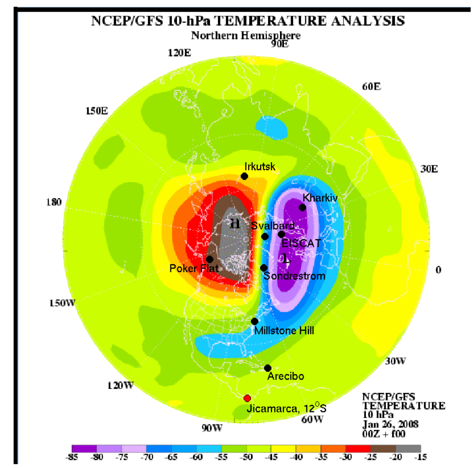
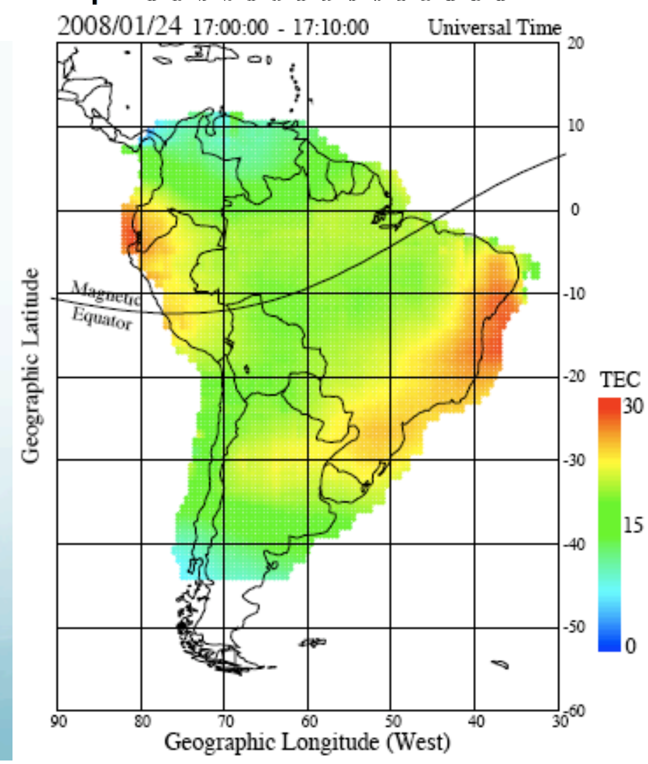
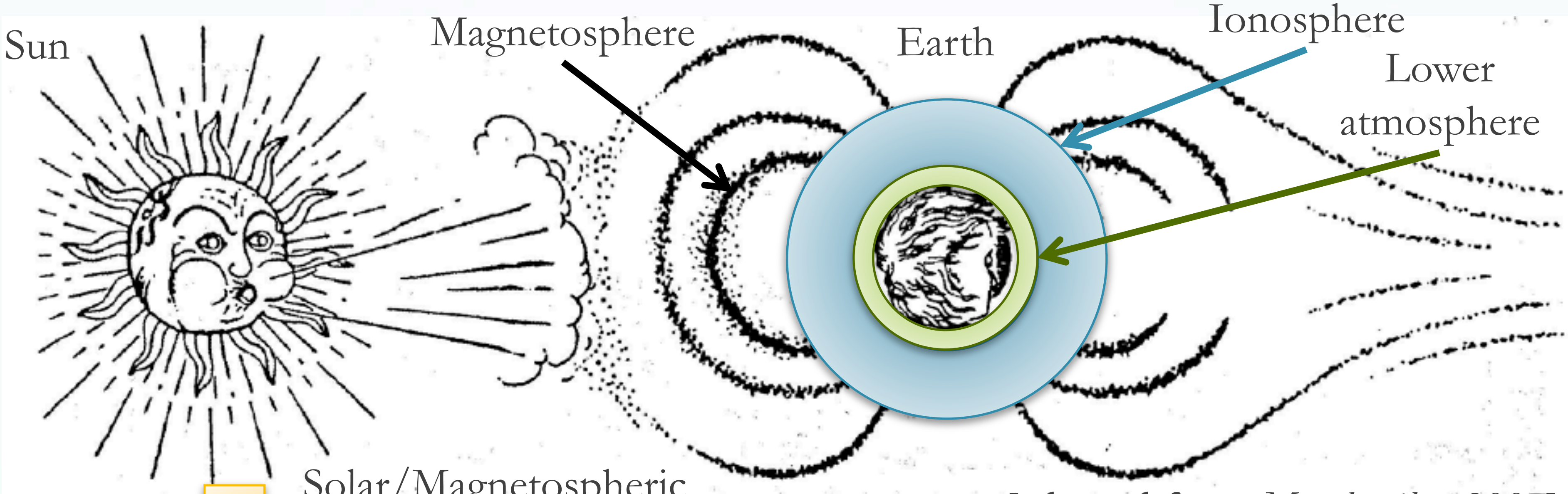
Outline

- Ionosphere forcing
- Quiet-time Equatorial ExB drifts
  - Measurements at Jicamarca
  - Empirical models: Mean and variability
- SSW and Equatorial Ionosphere
  - ExB drifts
  - Time delay and Lunar response
- SSW and Low latitude Ionosphere
  - TEC maps
  - Observations over Arecibo
- Possible scenario and Conclusions

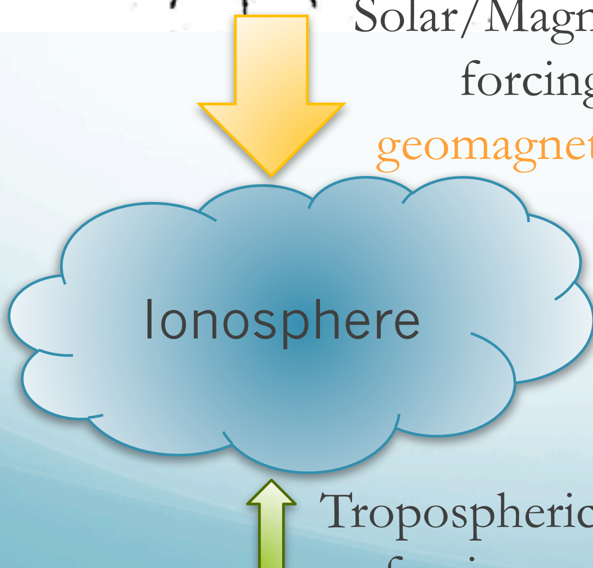




Ionosphere Forcing



[adapted from *Marchavilas*, 2007]



Solar/Magnetospheric forcing, e.g., geomagnetic storms

Tropospheric/Stratospheric forcing, e.g., planetary waves, tides, GWs

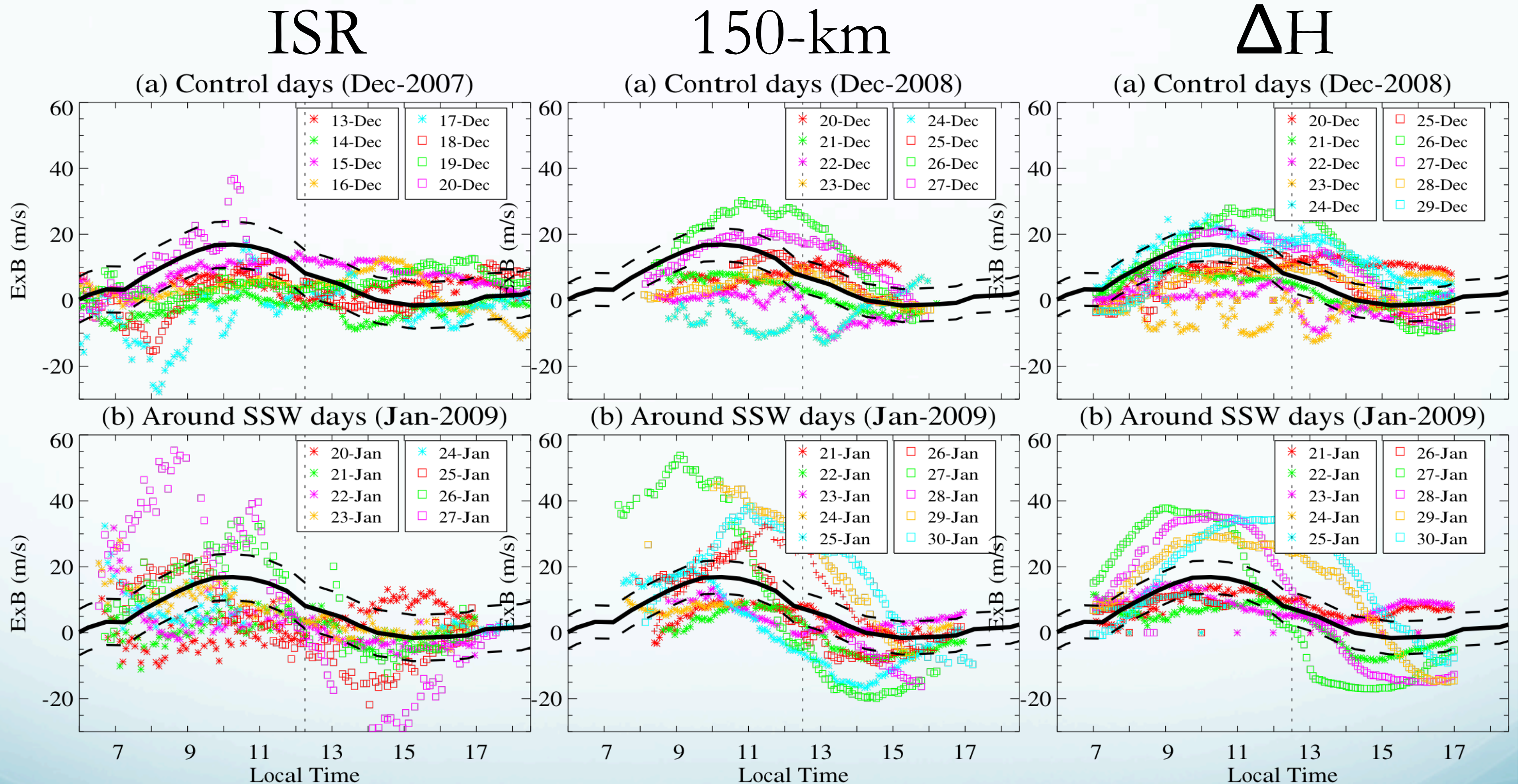
- These forces produce ionospheric changes: plasma drifts, electron density, temperature, composition, …
- During solar minimum, Solar/Mag forcing are small, allowing an "easier" identification of lower atmosphere forcing.

Equatorial ExB measurements at Jicamarca (1)

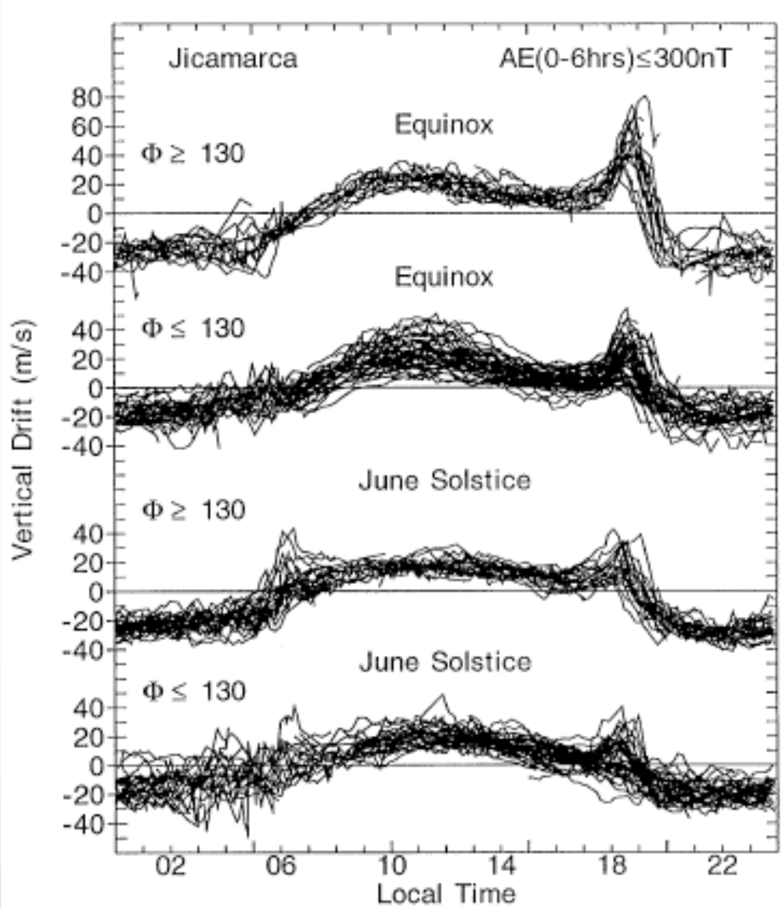
Value	ISR	150-km echoes	Mag. ΔH
Instrument	Jicamarca ISR	JULIA	Mag. At JRO and Piura
Annual Coverage	~20 days	> 150 days	> 300 days
Since	1968	2001	2000
Time coverage	All day*	07-18 LT	09-17 LT
Time res.	5 min	1-5 min	1 min
Accuracy	< 1m/s	< 1 m/s	< 3 m/s
Altitudes	150-1000 km	Mean F region	Mean F region
Reference	*Kudeki et al*, [1999]	*Chau and Woodman*, [2004]	*Anderson et al.*, [2002]

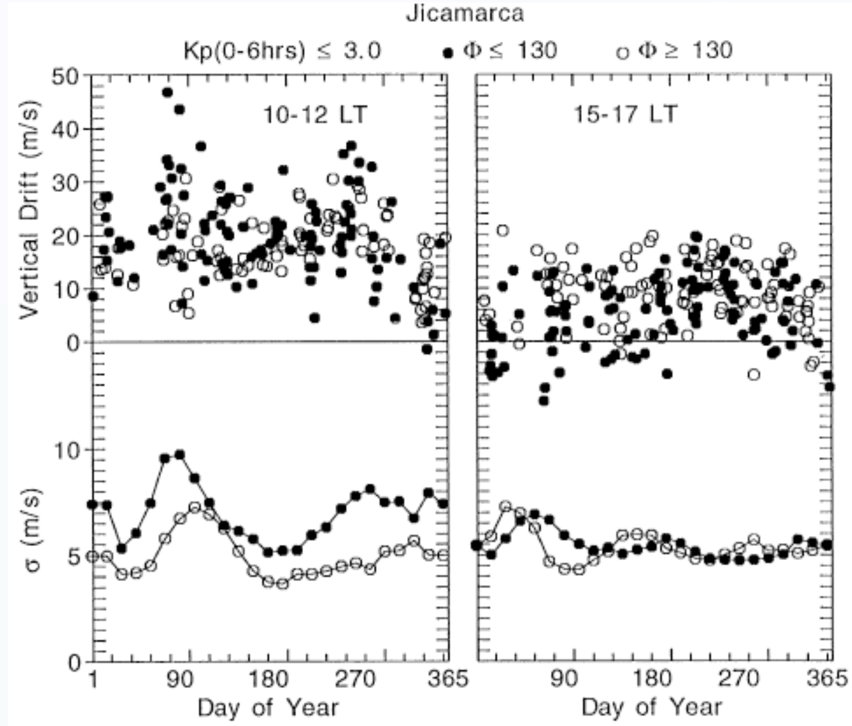
*except when strong ESF echoes are present that contaminates nighttime values

Equatorial ExB measurements at Jicamarca (2)



Quiet Daytime ExB: Mean and variability (1)





- Daytime average drifts do not vary much with solar activity.
- Variability is local time, seasonal, solar cycle dependent.
- Variability is largest in the dawn-noon sector and during solar-minimum conditions

[from *Fejer and Scherliess*, 2001]

Quiet Daytime ExB: Mean and variability (2)

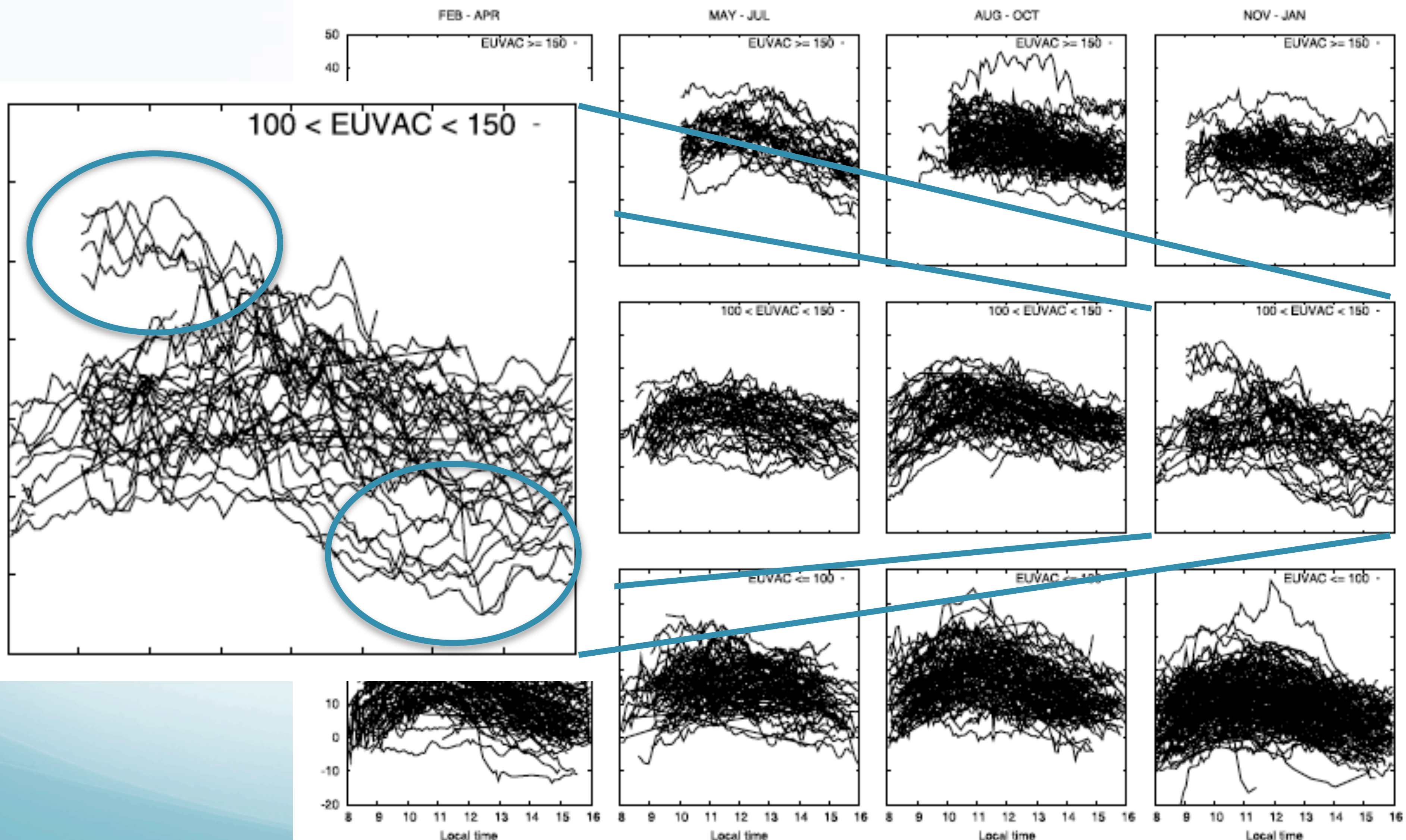


Figure 1. Local time profiles of JULIA quiet time (Kp $\leq$ 3) vertical drifts for low, medium, and high solar activity and different seasons.

[from *Alken*., 2009]

Quiet Daytime ExB: Mean and variability (3)

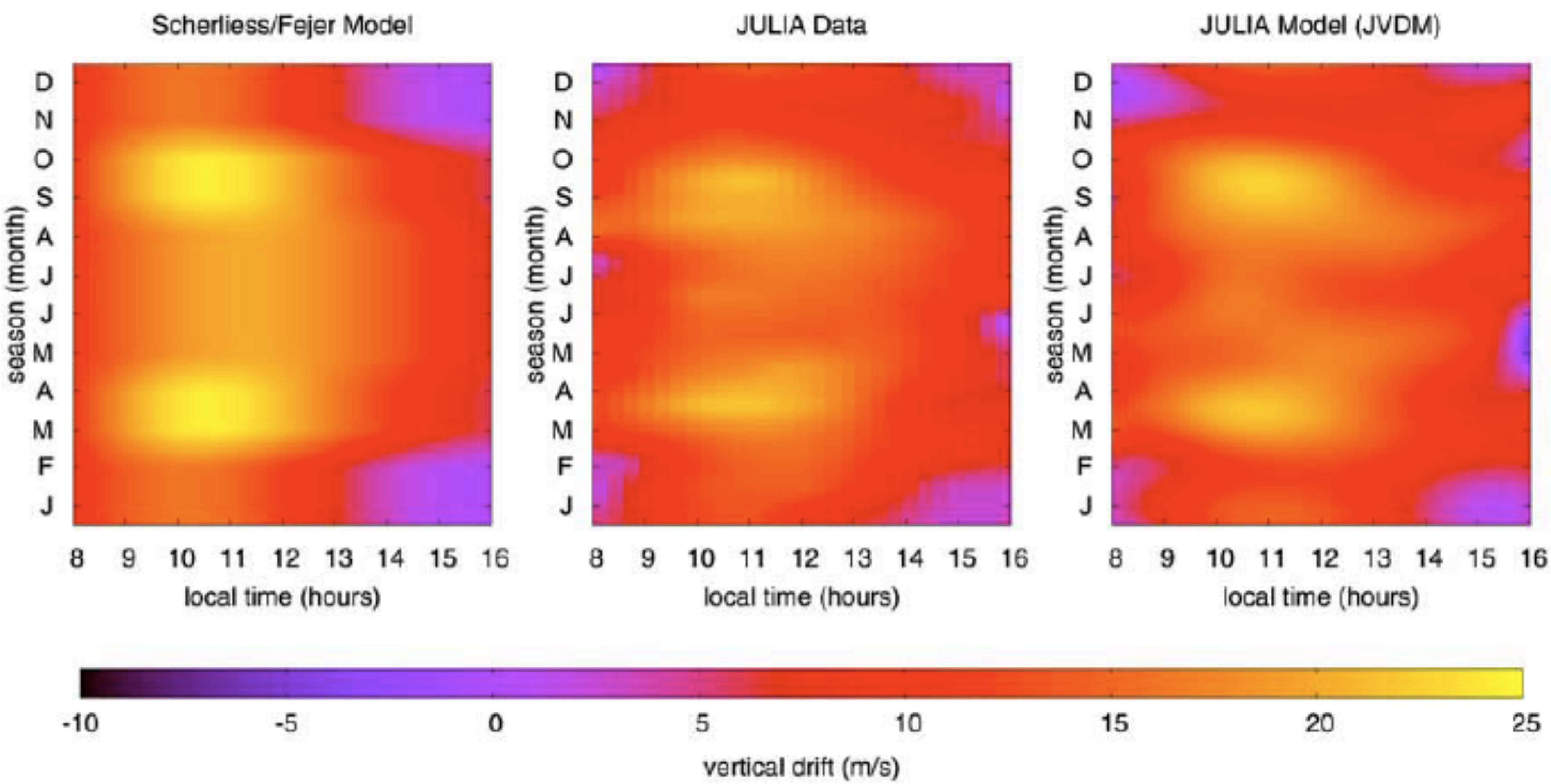


Figure 4. (left) Scherliess and Fejer model output, (middle) raw JULIA vertical drift data, and (right) JULIA Vertical Drift Model output using an EUVAC index of 80.

[from *Alken.*, 2009]

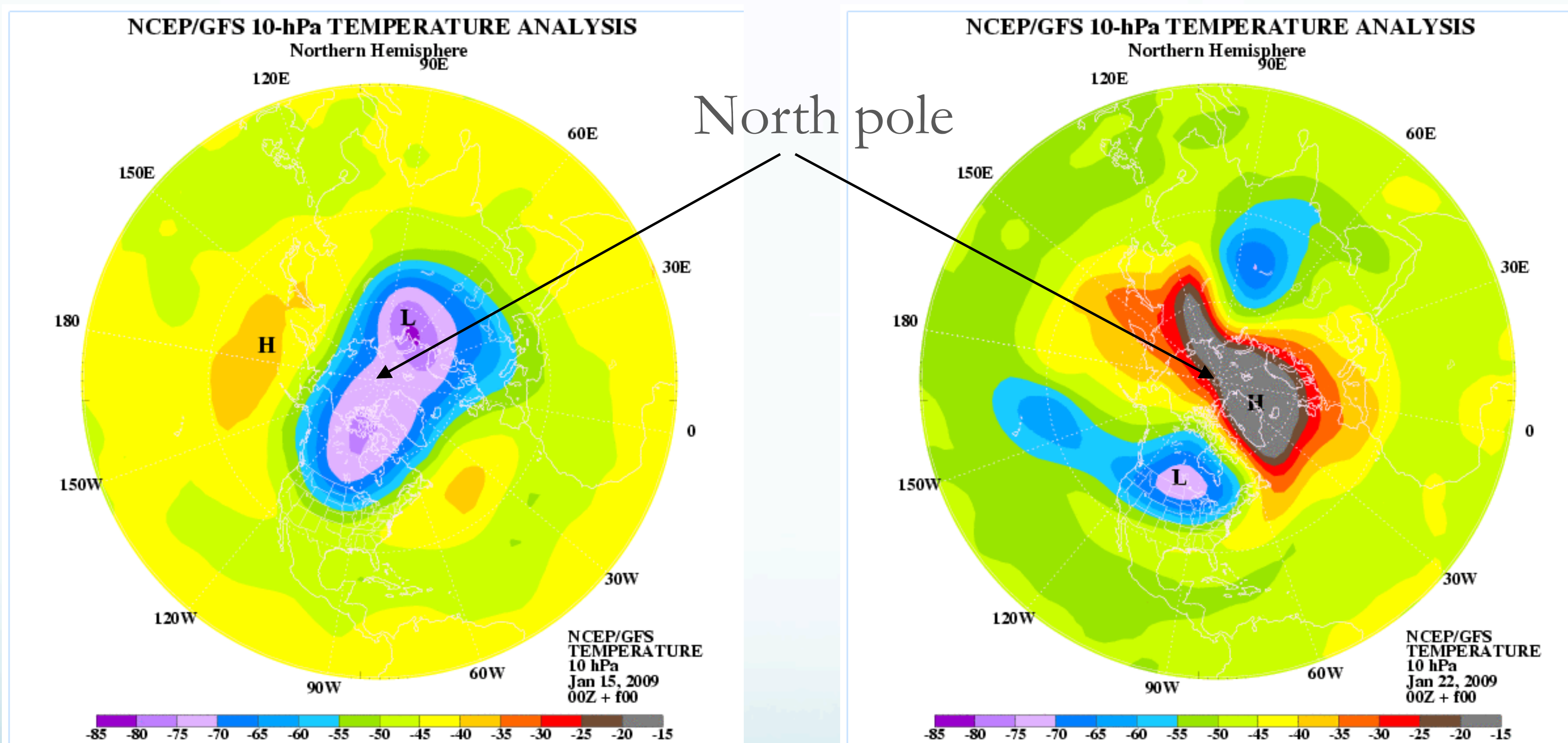
Sudden Stratospheric Warming events

- SSW is a large scale meteorological process in the winter hemisphere lasting several days or weeks.
- A SSW is an event where the polar vortex of westerly winds in the Northern winter hemisphere abruptly slows down (i.e., in a few days time) or even reverses direction, accompanied by a rise of stratospheric temperature by several tens of degrees.
- Key mechanism: the growth of planetary waves propagating upward from the troposphere and their non-linear interaction with the zonal mean flow.
- At high latitudes, changes in the zonal wind induce downward/upward circulation in the stratosphere/mesosphere causing adiabatic heating/cooling.

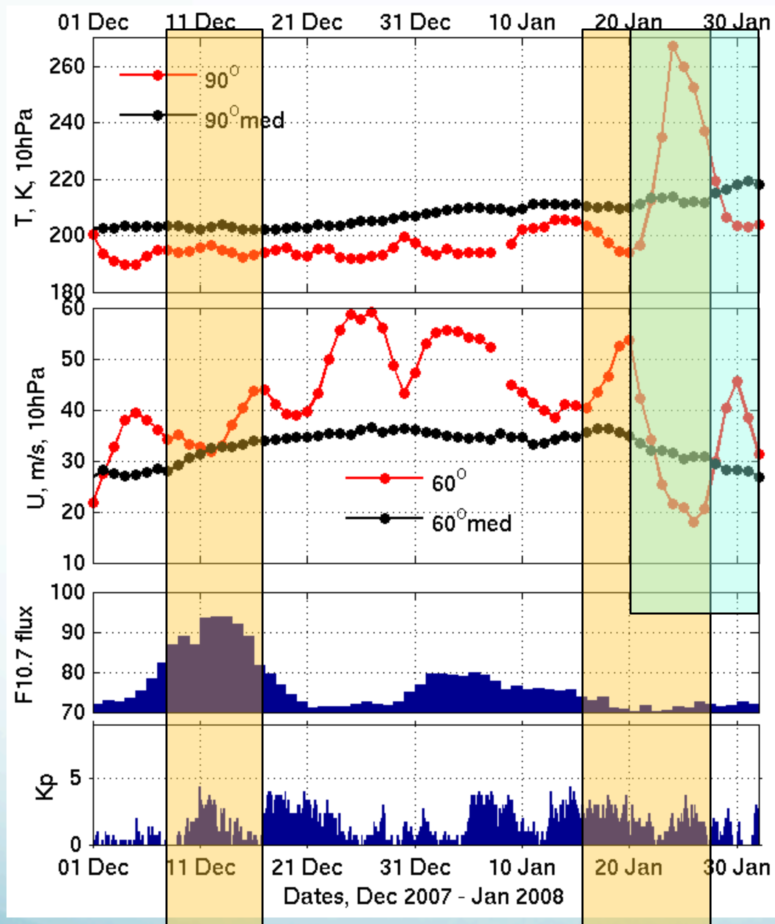
Stratospheric temperature at ~32km

Before warming

During warming

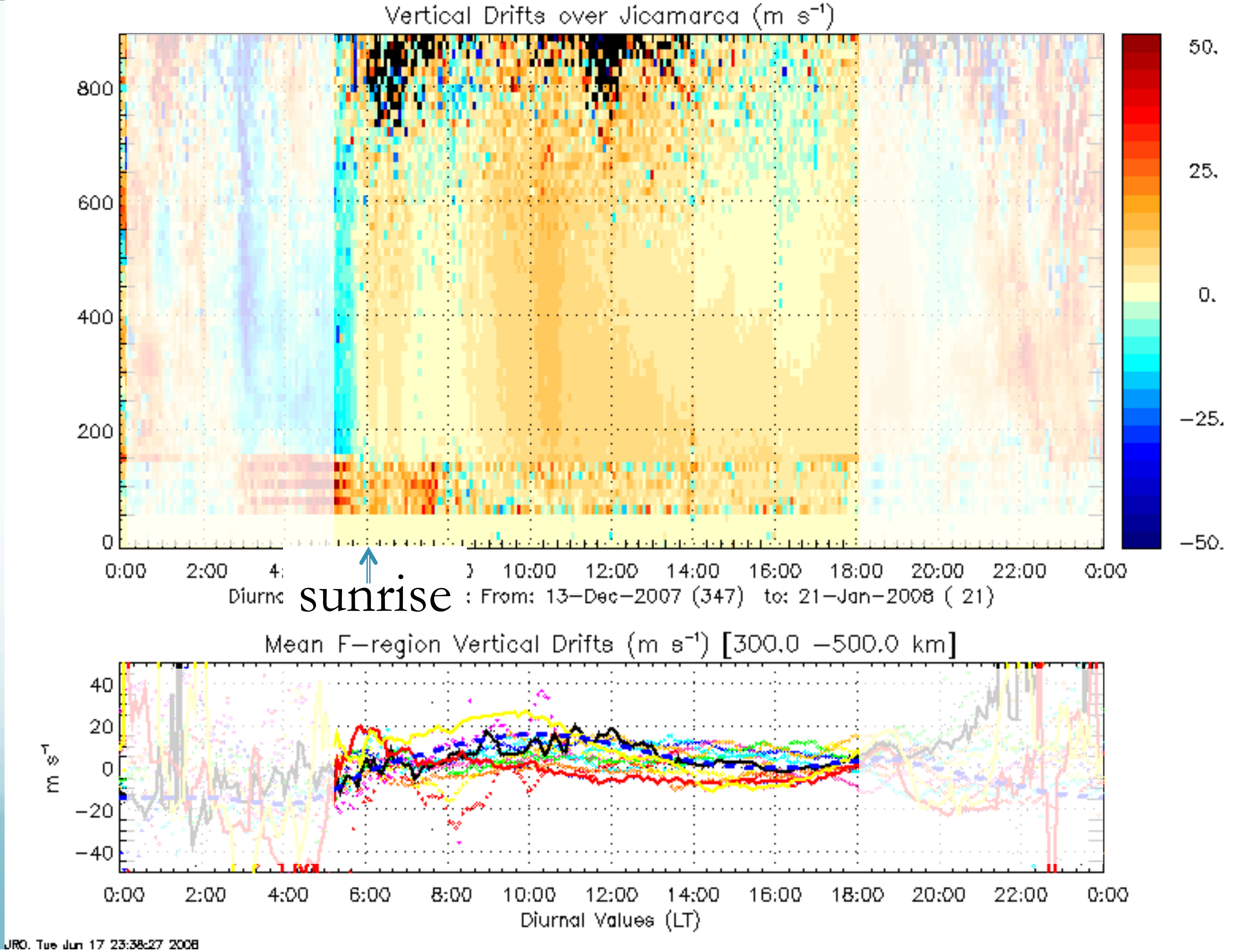


SSW Jan 2008: SSW Main parameters

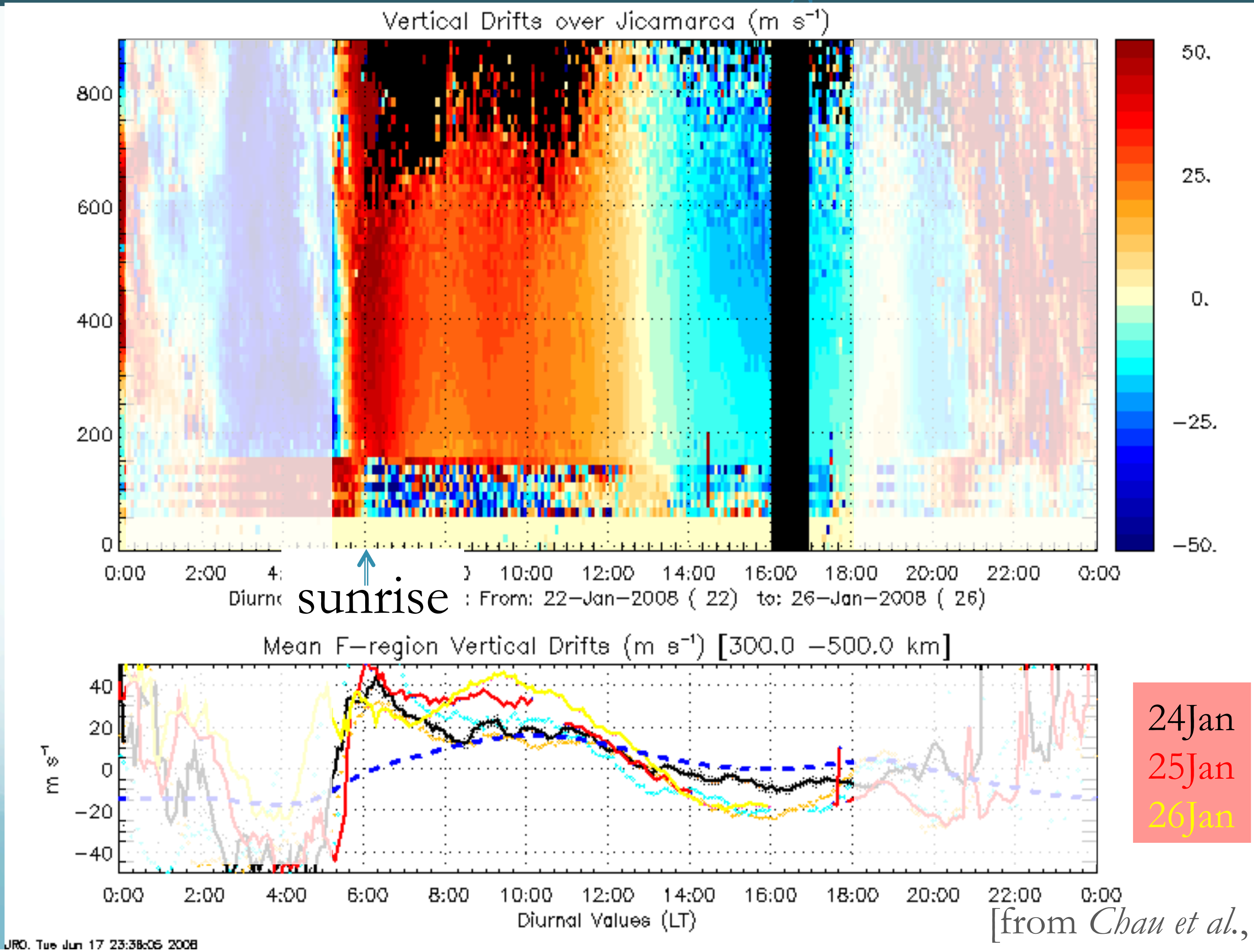


- Minor SSW event. Westerly winds slowed down
- One of the largest temperature increases in the last 30 years.
- Low solar flux (close to 70)
- Magnetically quiet conditions
- Many ground-based instruments operated 8-10 days in December 2007 and 10-14 days in January 2008.

Equatorial ExB Drifts: Diurnal values before SSW

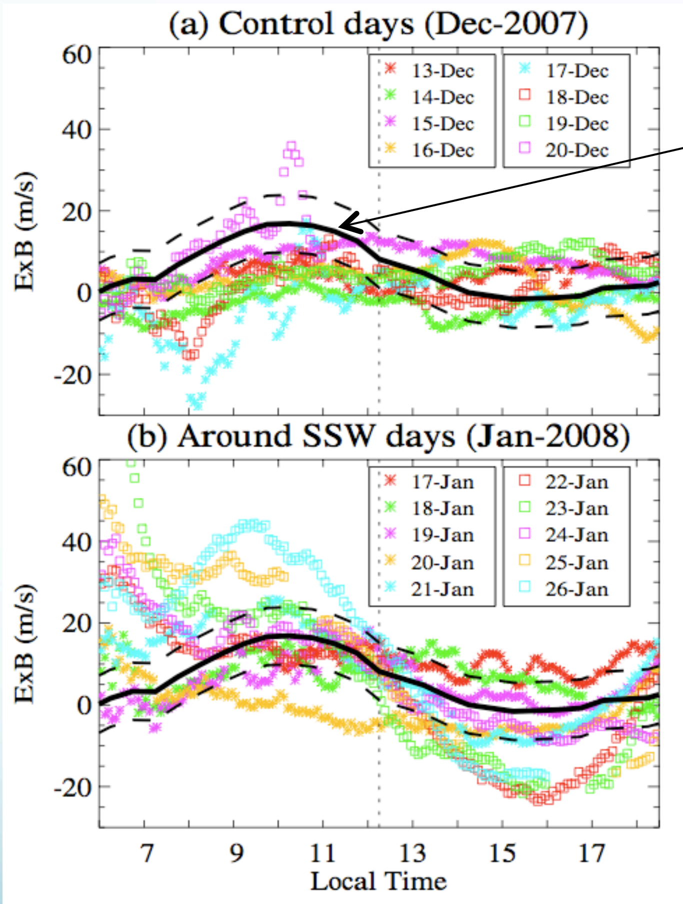


Equatorial ExB Drifts: Diurnal values during SSW

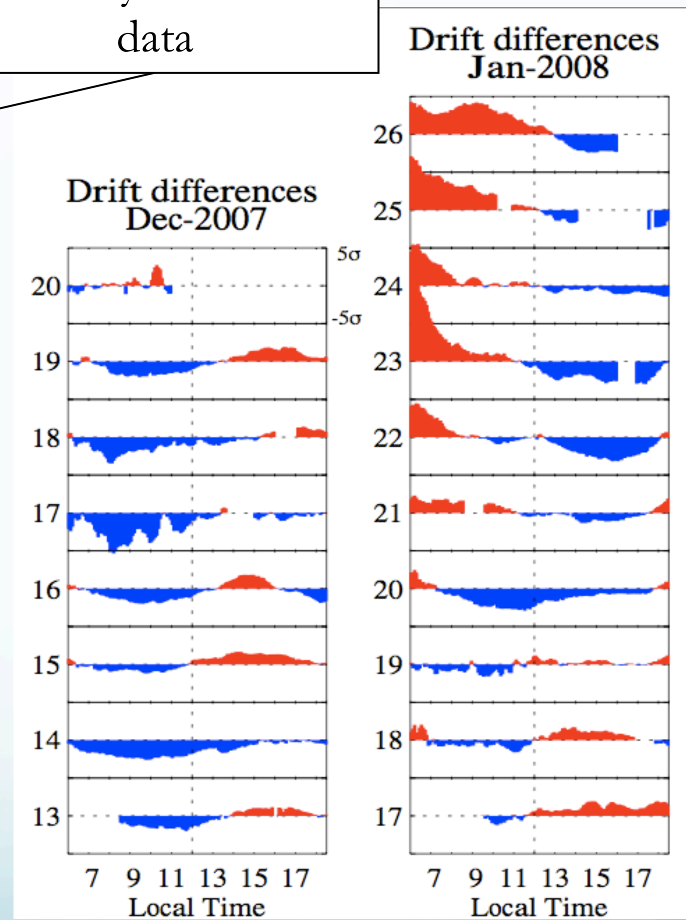


[from *Chau et al.*, 2009]

SSW Jan 2008: ExB Daytime Drifts

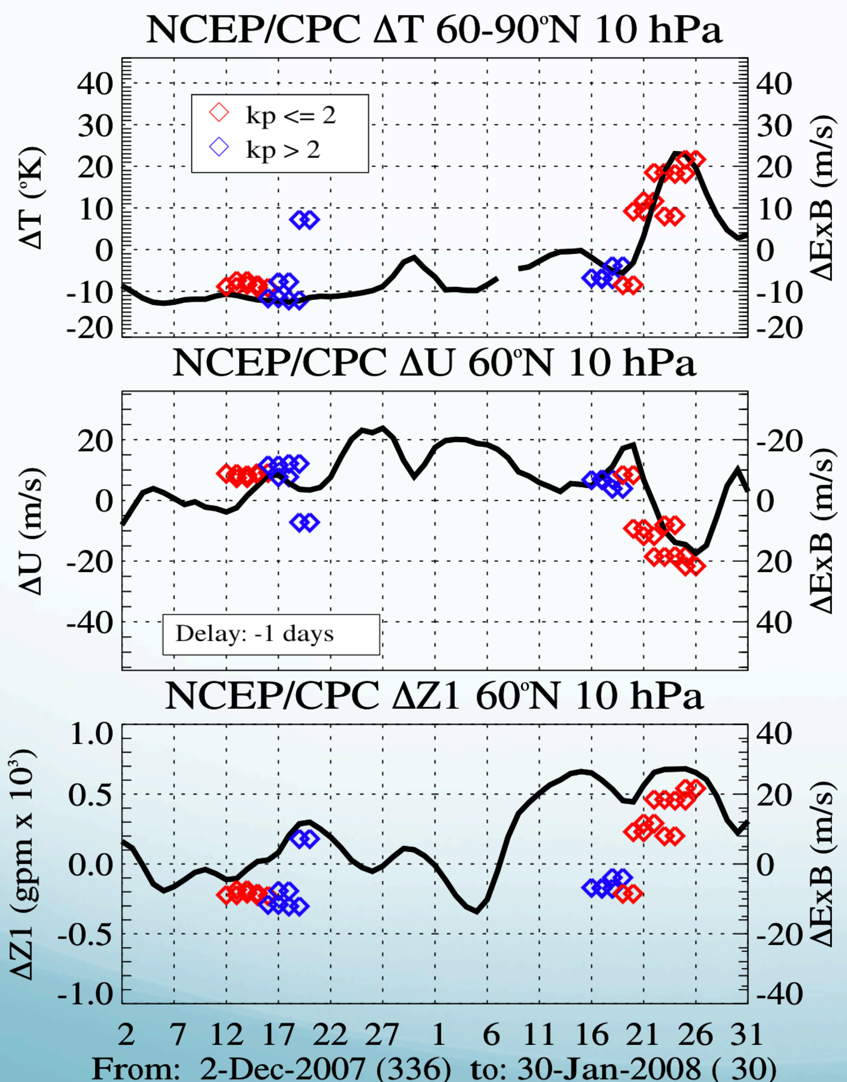


Average + variability from 35 years of ISR data



[from *Chau et al.*, 2009]

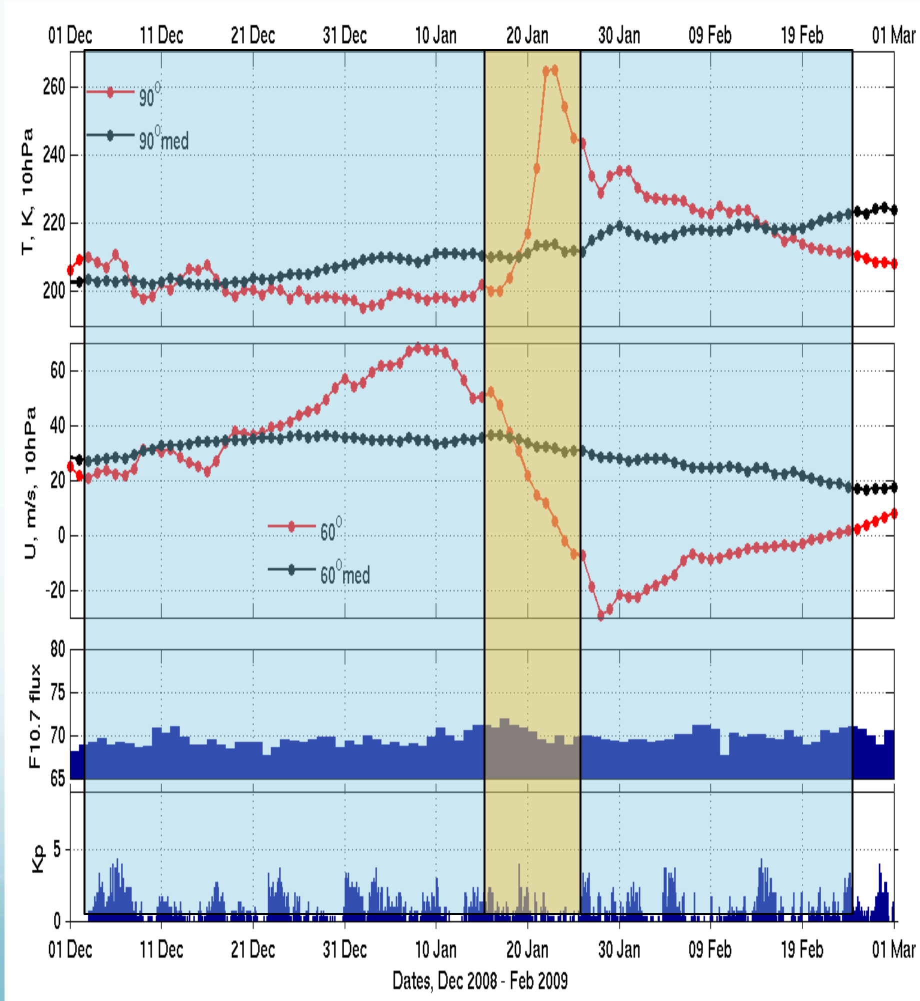
SSW Jan 2008: ΔSSW vs ΔExB



- ΔExB: Morning amplitude ExB difference with respect to expected averages, after fitting a semidiurnal wave.
- ΔSSW: differences with respect to 30-year median values.
- High correlation/anticorrelation: ΔExB vs. ΔT/ΔU during SSW.
- Note the "persistence" of the ExB drift pattern during SSW period.
- Comparing peaks (Highest temperature difference and Highest ExB difference), ExB drift peak occurs ~1 day after SSW temperature peak.

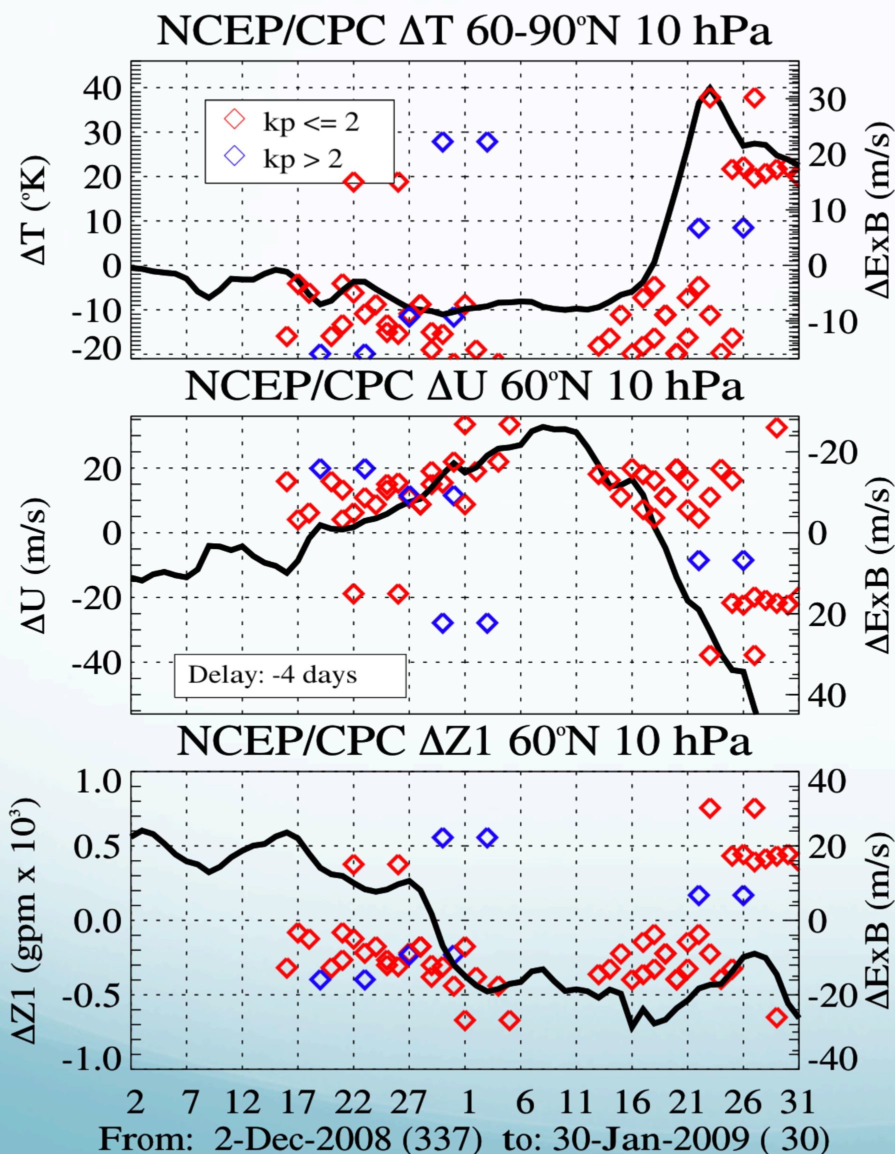
[from *Chau et al.*, 2009]

SSW Jan 2009: SSW Main parameters



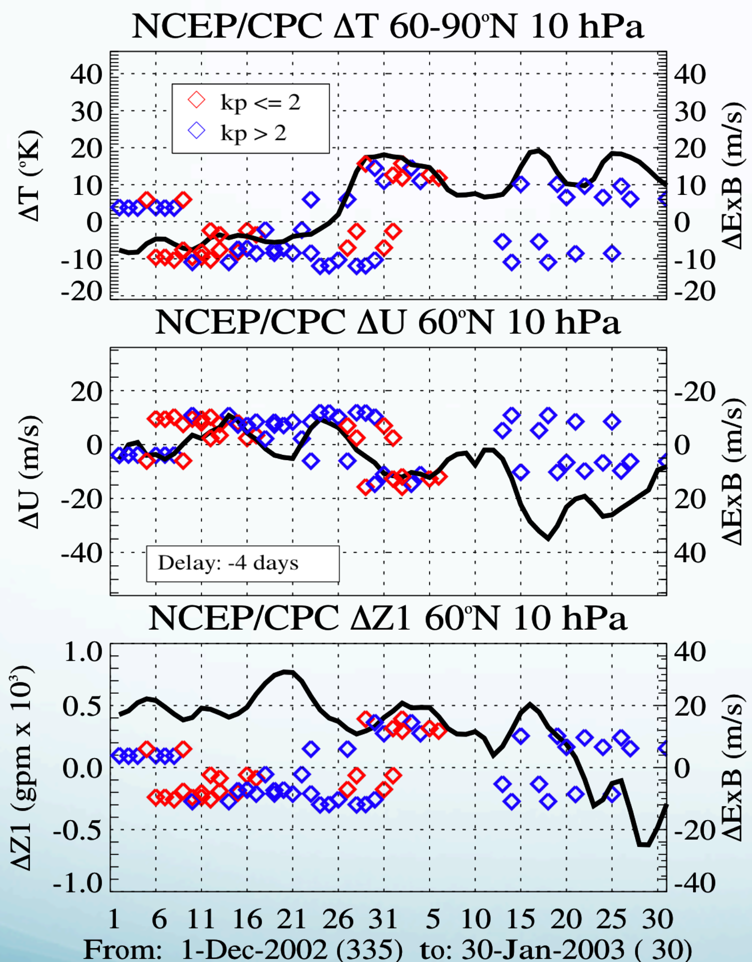
- Major SSW event. Westerly winds slowed down and reversed direction
- The largest temperature increase in the last 30 years and the longest lasting.
- Low solar flux (close to 70)
- Magnetically quiet conditions
- 11 days coverage with ISR drifts and densities, and mesospheric dynamics.
- More than 30 days ExB drifts from ground-based magnetometers and 150-km echoes.

SSW Jan 2009: ~4 days delay



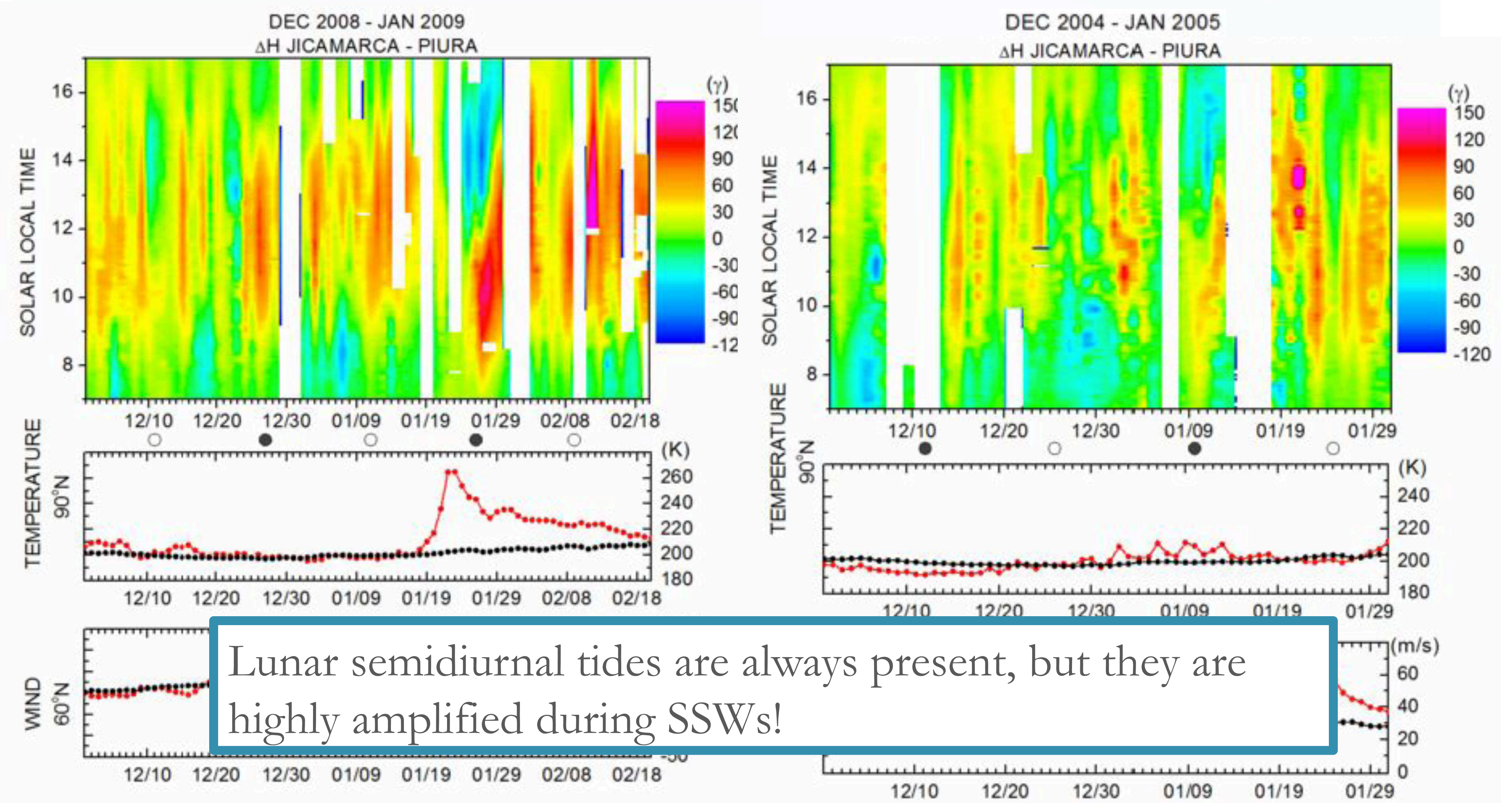
- Again, comparing peaks we find:
  - The highest ExB drift amplitude difference occurs ~4 days after the peak in SSW temperature occurs.
  - Once the highest value is reached, a moderate amplitude persist for few days, in a correspondence with the SSW temperature behavior.

Jan 2003: SSW vs. Jicamarca Drifts



- Minor (?) SSW, westerly wind decreased
- Moderate to high solar conditions
- Magnetically quiet and active conditions.
- Semidiurnal pattern between Jan 2-6, showing "persistence".
- ExB peak difference occurs after ~4-5 days the occurrence of the highest SSW Temp.

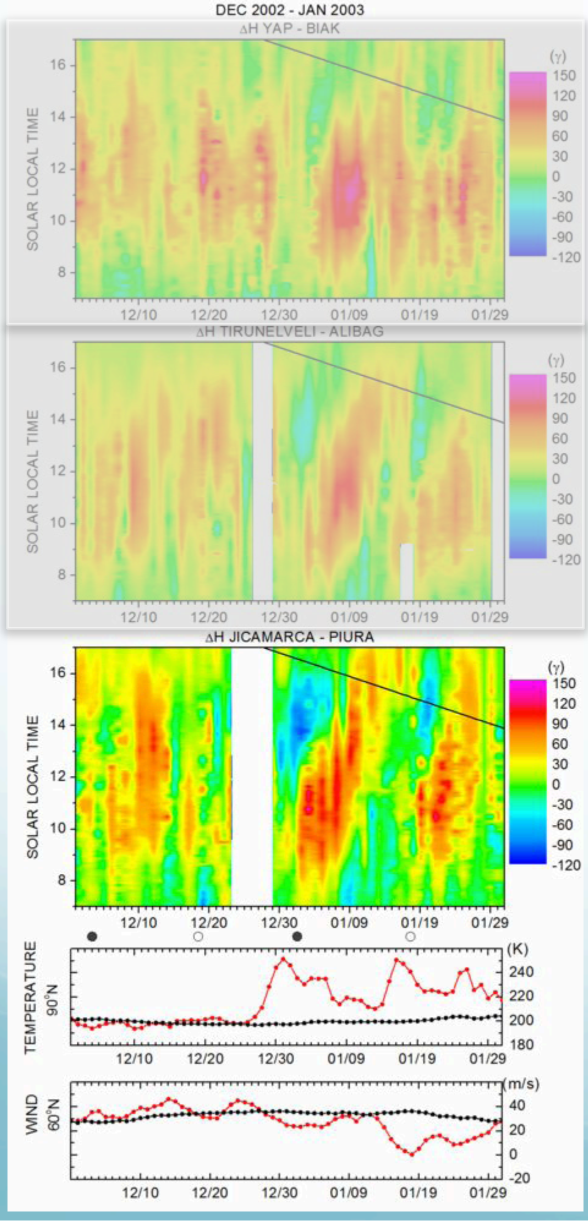
Time delay and lunar dependence

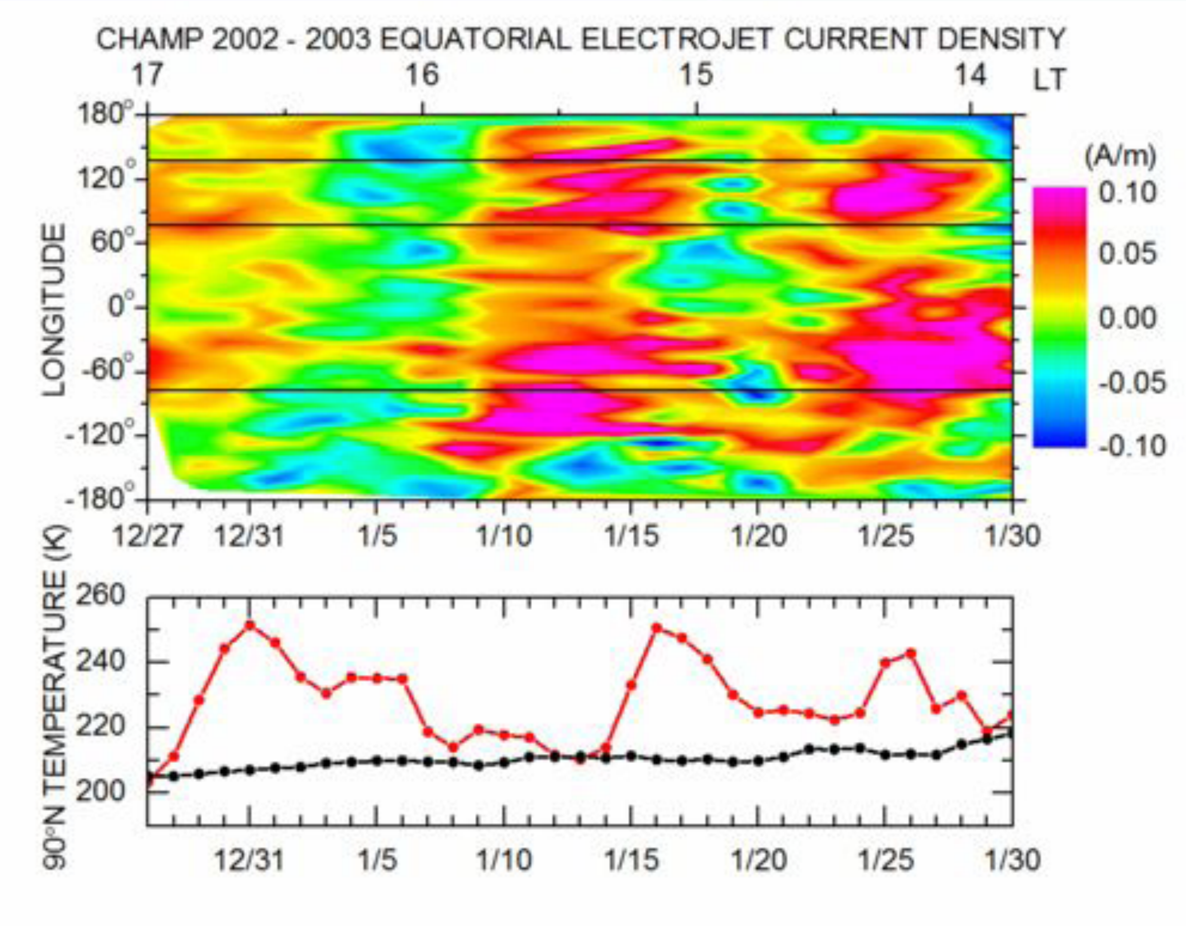


Lunar semidiurnal tides are always present, but they are highly amplified during SSWs!

[from *Fejer et al.*, 2010]

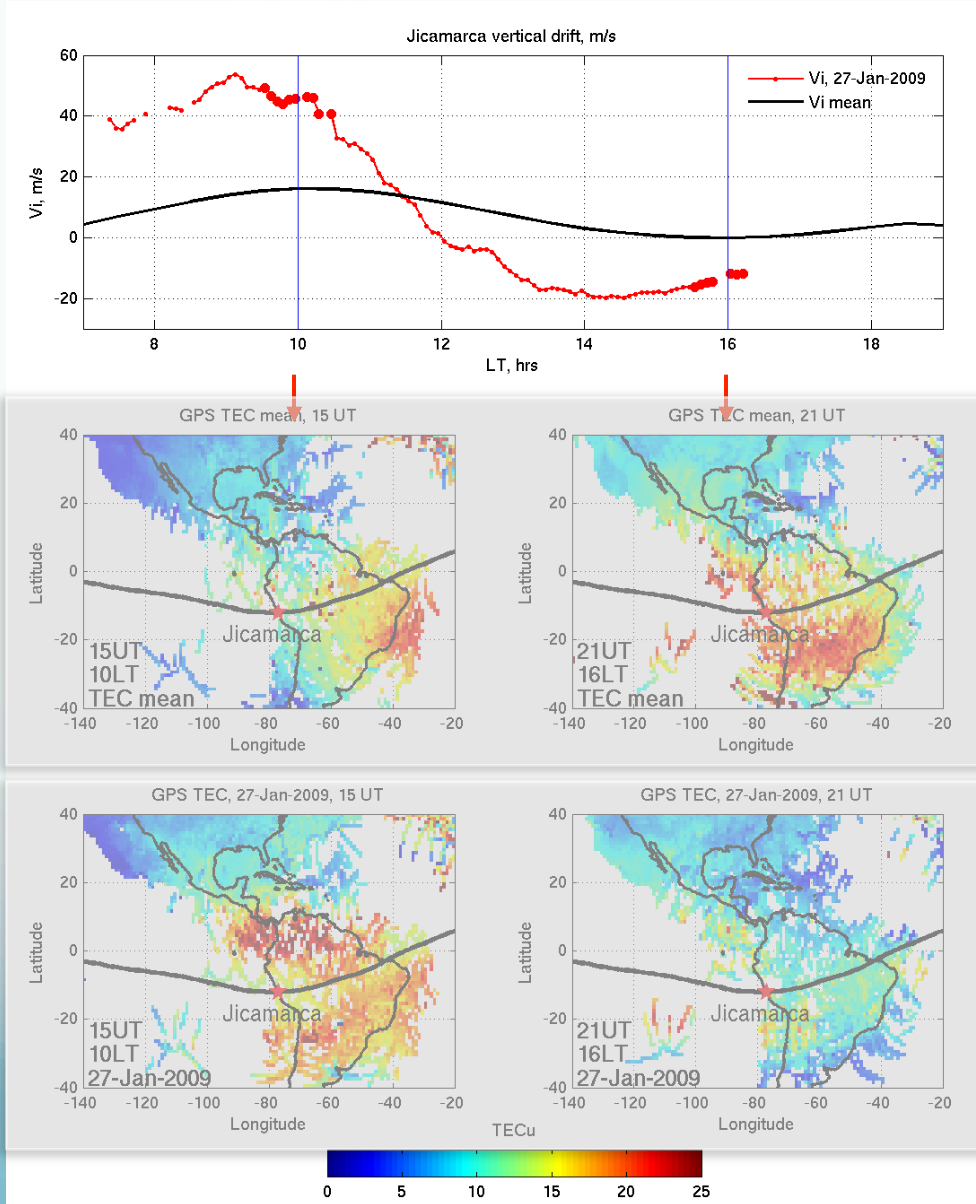
Longitudinal Response: ΔH + CHAMP





[from *Fejer et al.*, 2010]

SSW Jan 2009: ExB drifts and TEC for



Jicamarca ExB drift

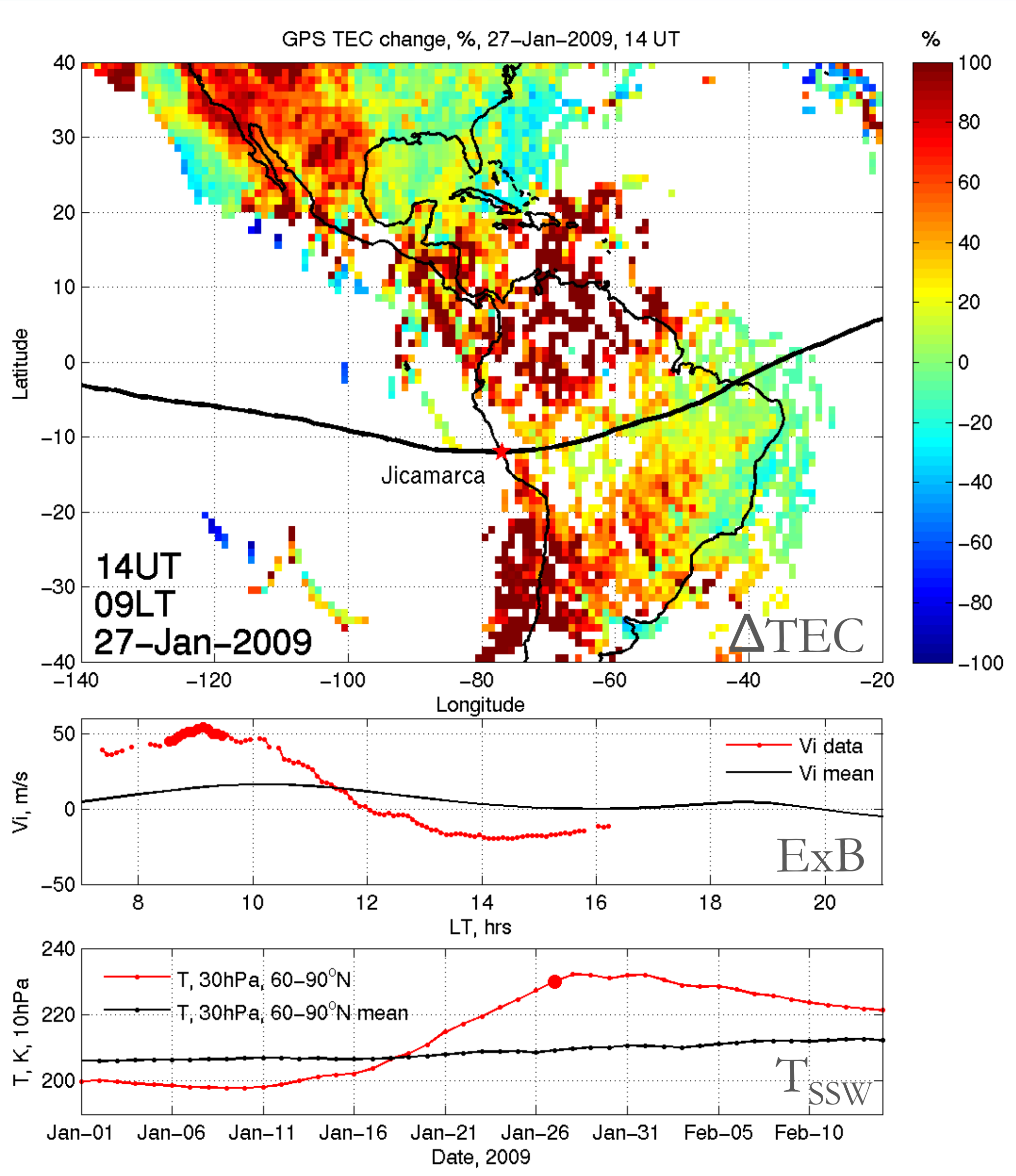
LT=UT – 5

Ten-day mean TEC at 15UT and 21UT before SSW

TEC at 15UT and 21UT during SSW

[from *Goncharenko et al.*, 2010]

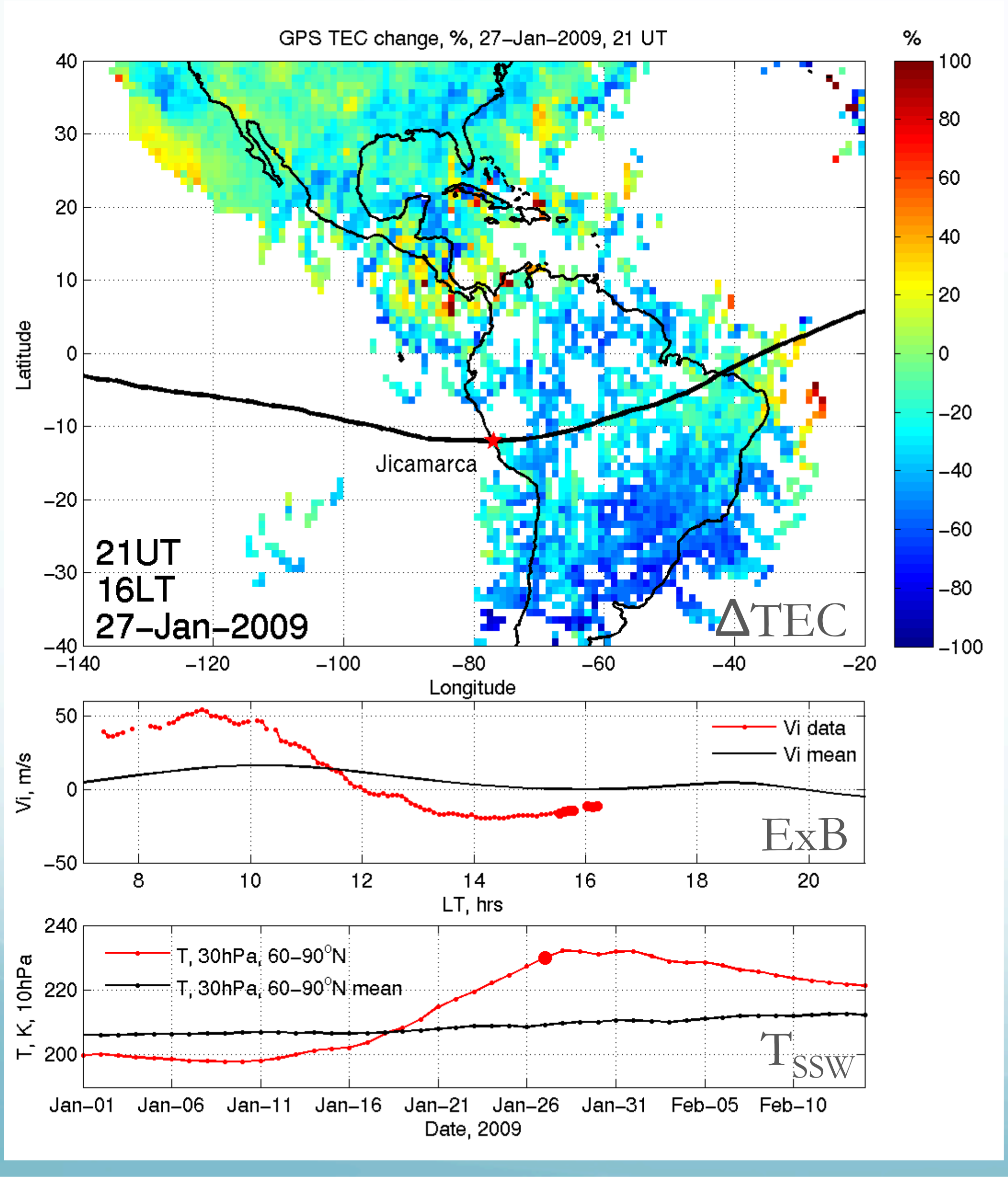
ΔTEC during SSW: Morning sector



- During SSW, TEC increases in excess of 50-100% in the morning
- Large upward ExB drift at Jicamarca
- The magnitude of increase is similar to effects of severe geomagnetic storms

[from *Goncharenko et al.*, 2010]

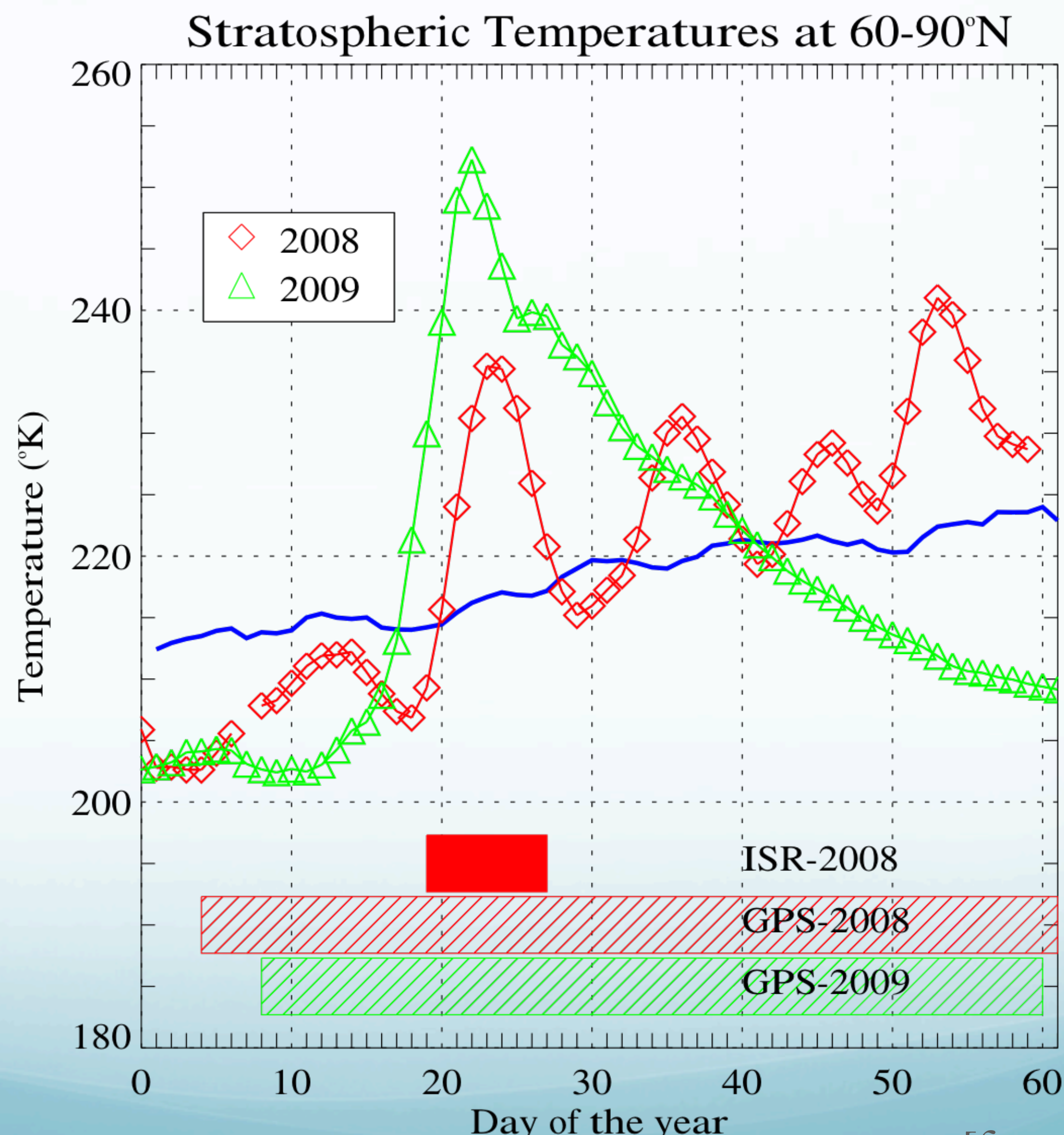
ΔTEC during SSW: Afternoon sector



- During SSW, TEC decreases by ~50% in the afternoon
- Large downward drift at Jicamarca

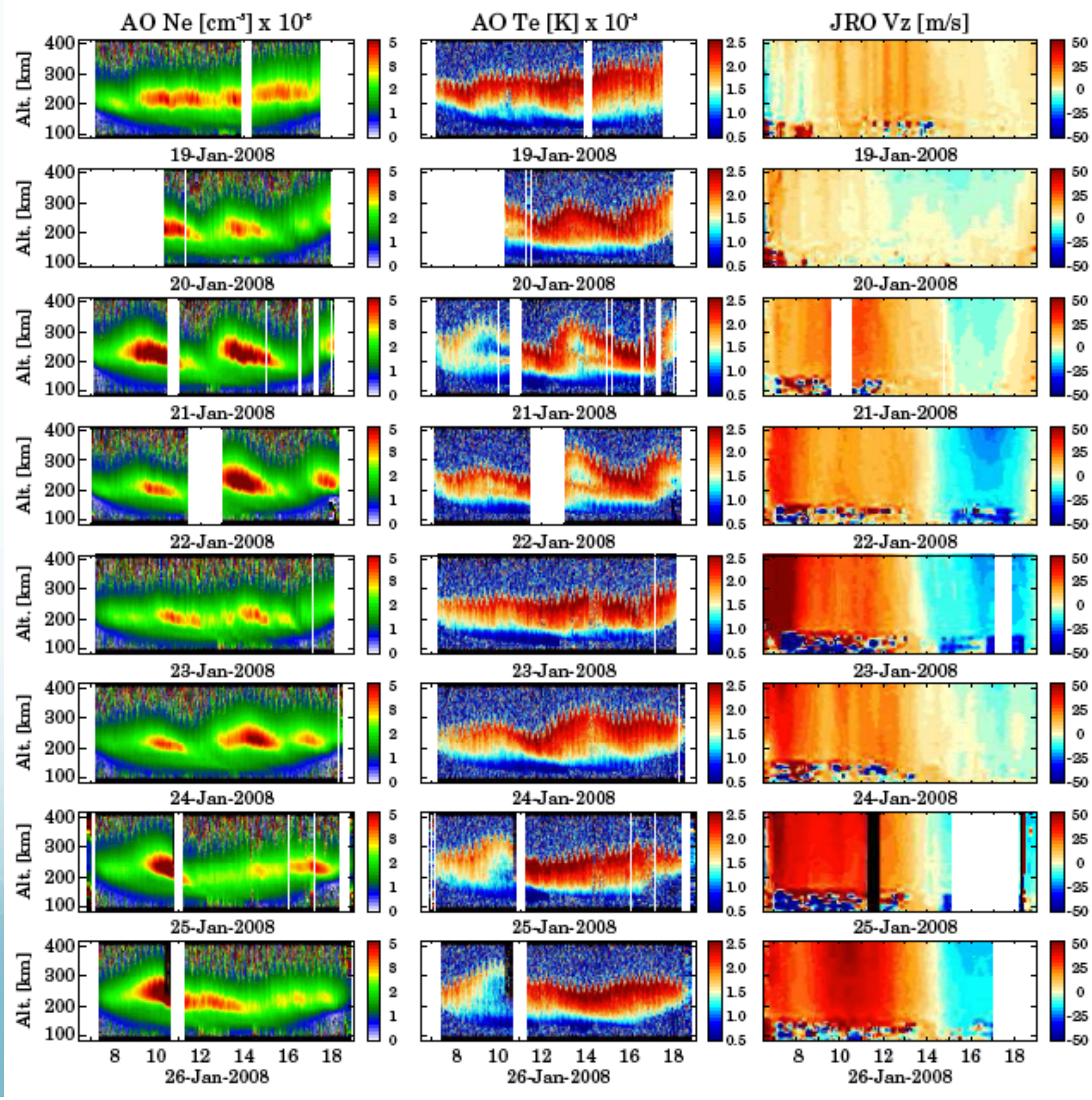
[from *Goncharenko et al.*, 2010]

SSW effects over Arecibo



[from *Chau et al.*, 2010]

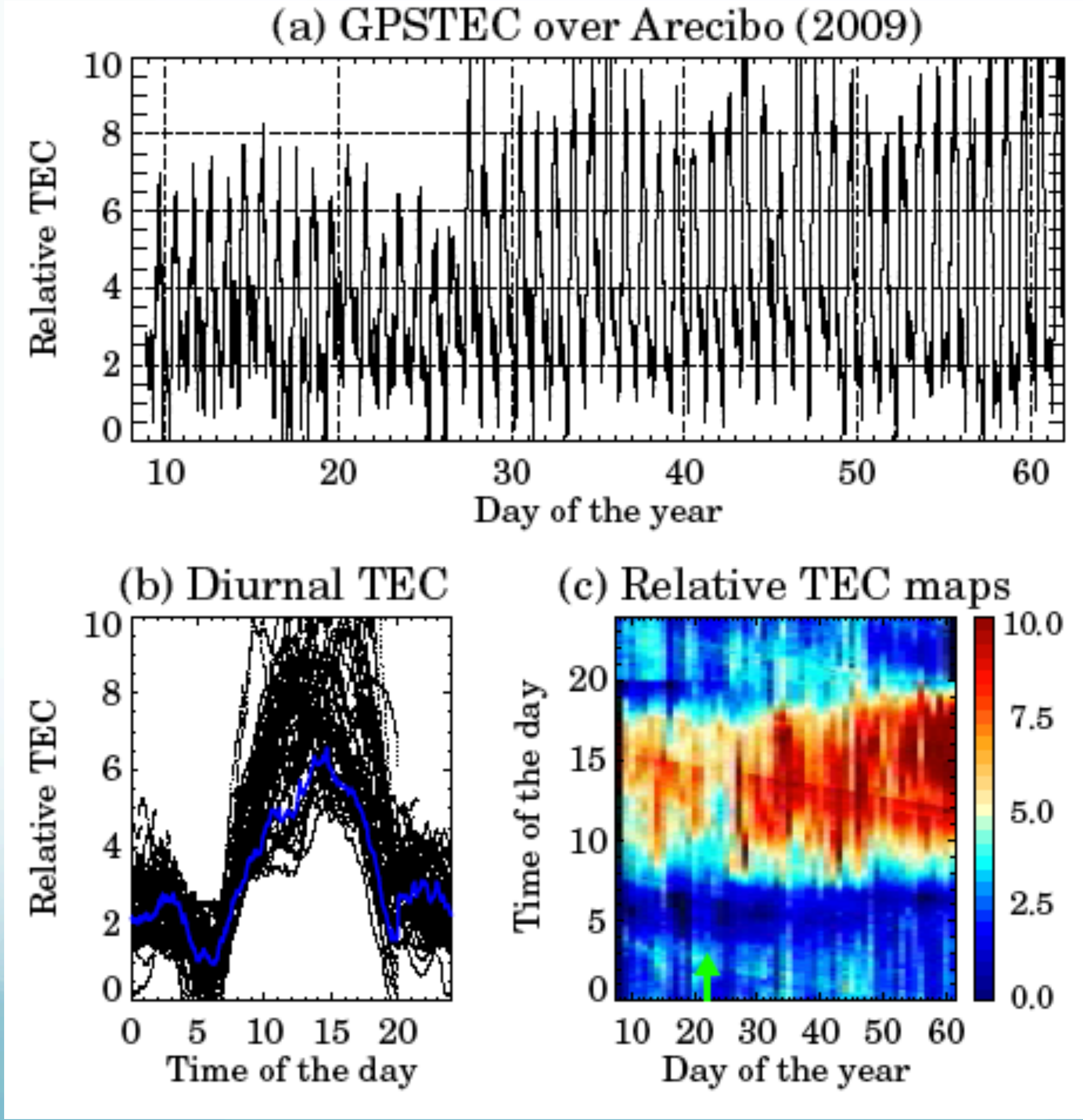
AO Ne, Te and JRO Vz



Over Arecibo, the electron temperature is anti-correlated with electron density!

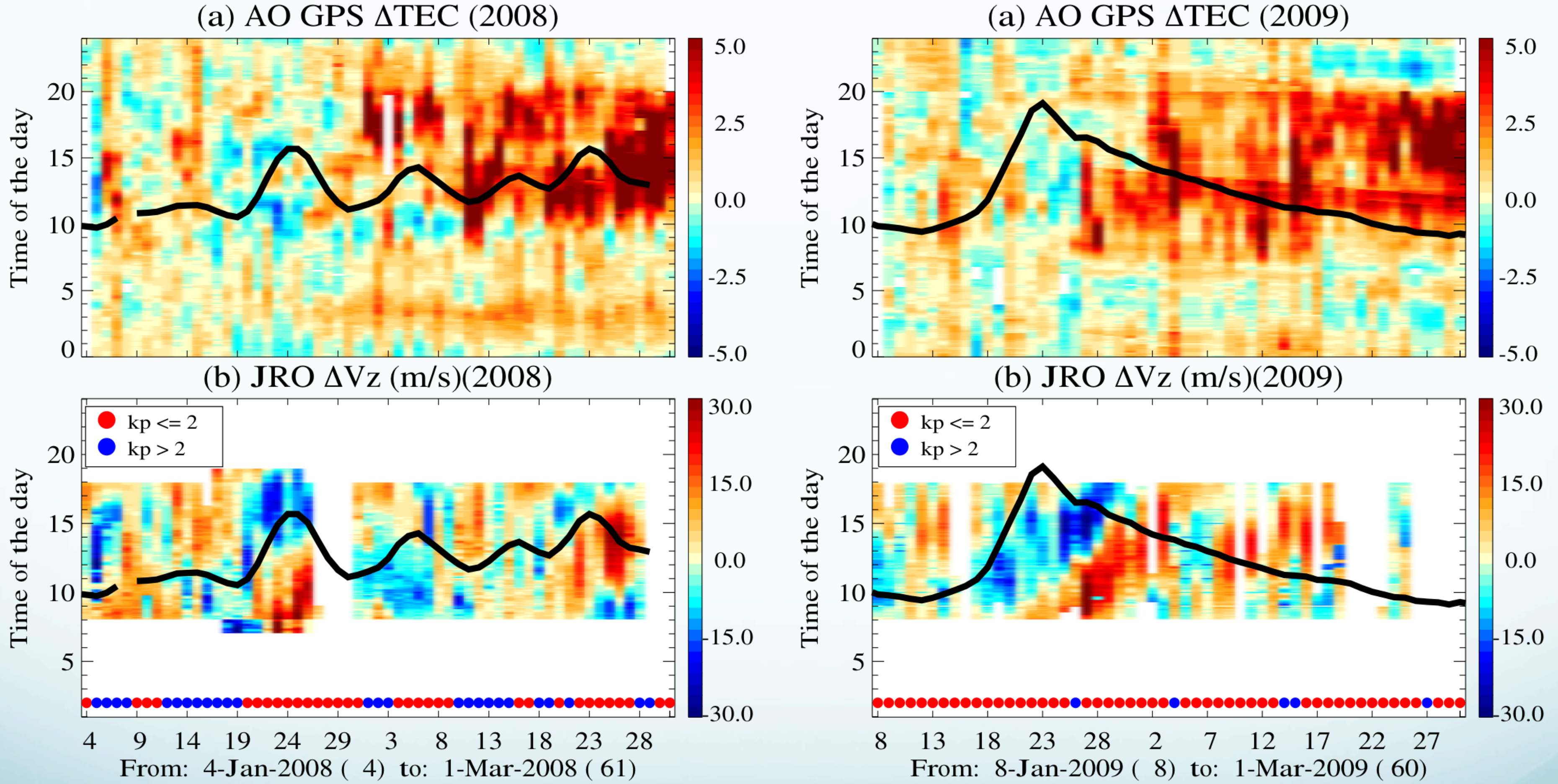
[from *Chau et al.*, 2010]

TEC over Arecibo



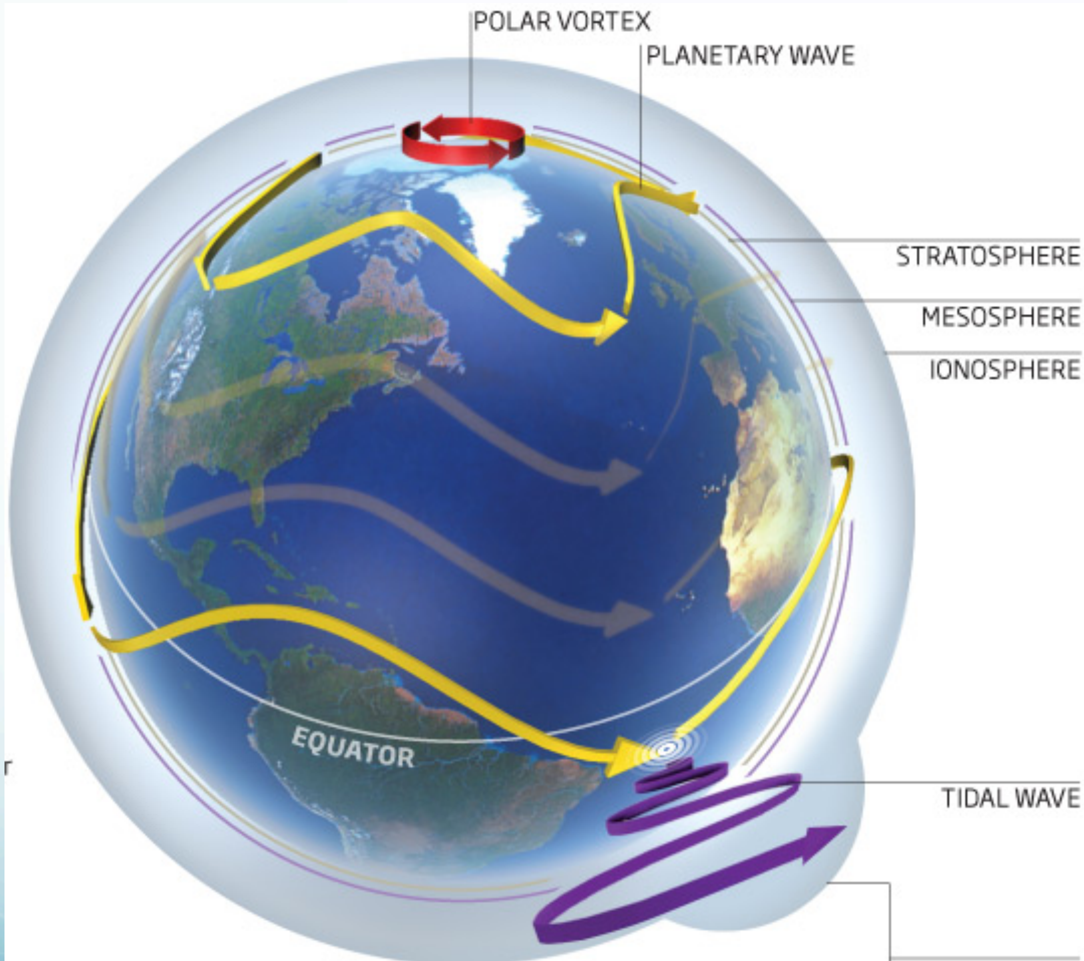
[from *Chau et al.*, 2010]

AO ΔTEC vs JRO ΔVz



[from *Chau et al.*, 2010]

Possible scenario



[artistic view from New Scientist article
"Phantom storms: How our weather links into space"
by J. Cartwright]

Planetary waves (SSW)

↓

Tidal amplification

↓

Wind structure changes

↓

Current and plasma drift changes in the Equatorial E region dynamo

↓

Ionosphere weather

[courtesy of *Hanli Liu*]

Conclusions (1)

- Lower atmospheric forcing has been long postulated as the main source of the ionospheric quiet-time variability, but how this link works has been difficult to identify.
- Based on our results, it is clear that indeed the low latitude ionosphere behavior (drifts and TEC) is closely correlated to the occurrence of SSW events.
- Major features: persistence, large departures from expected quiet time variability, amplification of 12-hour semidiurnal wave.

Conclusions (2)

- We do not think one event causes the other, however both events appear to be related through the global effects of planetary waves, i.e., planetary waves effects are indirectly propagated to the low and mid latitude ionosphere by changing the electric fields in the E region.
- Time delay is associated to the lunar phases. Lunar semi-diurnal tidal wave effects are highly enhanced during SSWs.
- All longitudes are affected almost simultaneously.