Equatorial and Low latitude Ionospheric Effects due to Planetary Wave Atmospheric forcing

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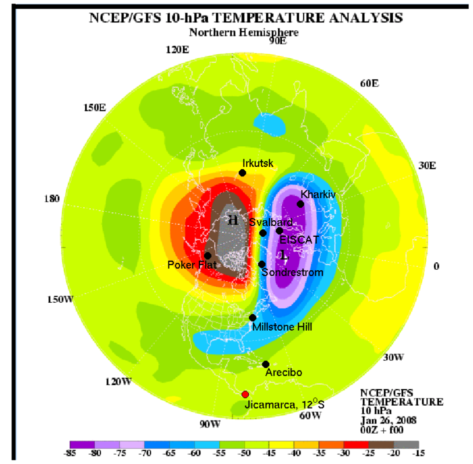
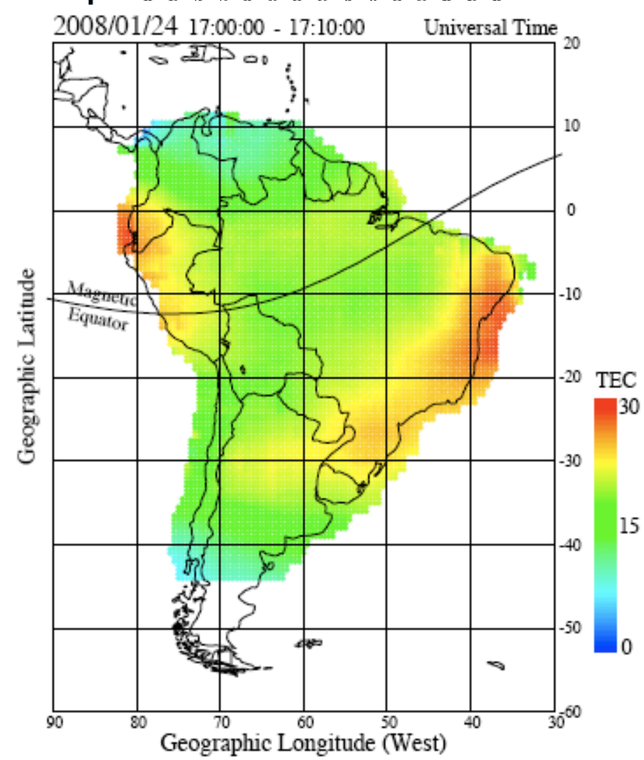
Outline

- Ionosphere forcing
- Sudden Stratospheric Warming Event and Equatorial ExB drifts: 2008
- Quiet-time Equatorial ExB drifts
  - Measurements at Jicamarca
  - Empirical models: Mean and variability
- SSW and Equatorial Ionosphere
  - ExB drifts
  - Total electron content (TEC)
  - Longitude and Lunar dependence
- Possible Scenario
- Conclusions

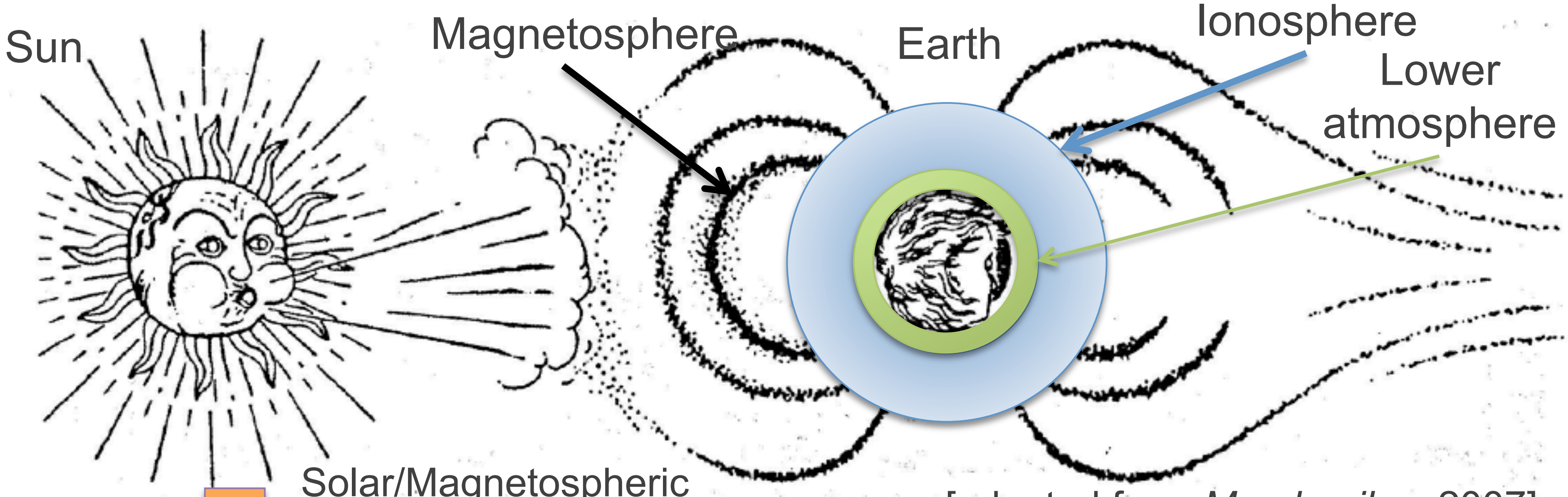




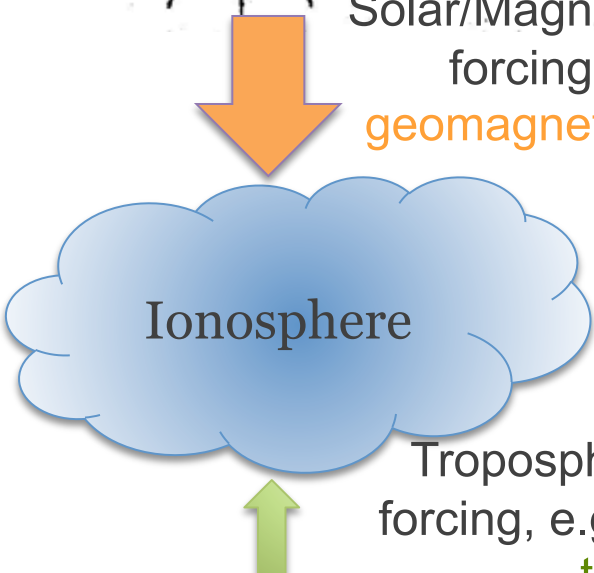
“The search for links between F-region phenomena and the lower atmosphere has a long history and few real outcomes”

H. Rishbeth, JASTP, 2006

Ionosphere Forcing



[adapted from *Marchavilas*, 2007]



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

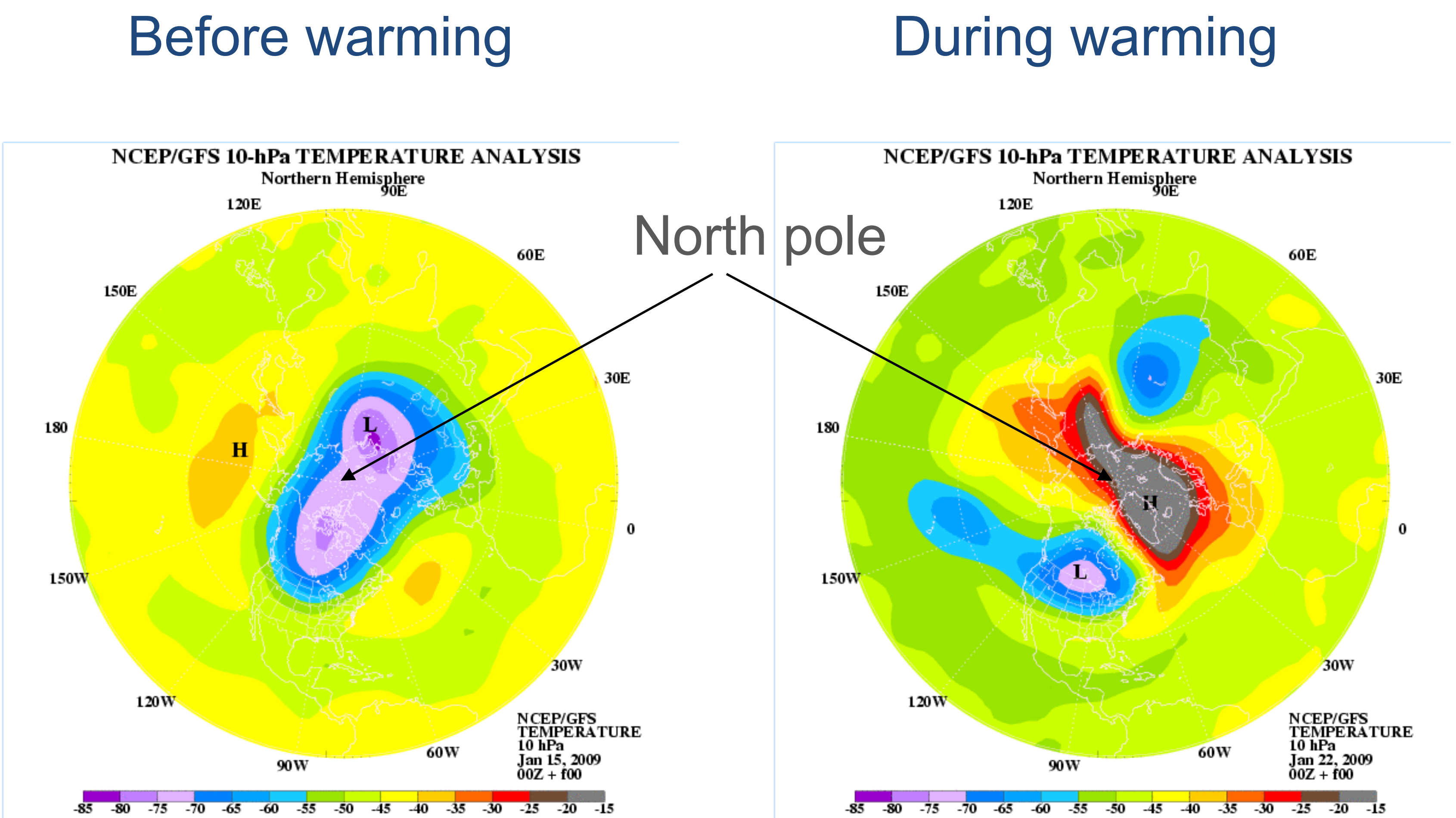
Tropospheric/Stratospheric forcing, e.g., planetary waves, tides, GWs

- 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.

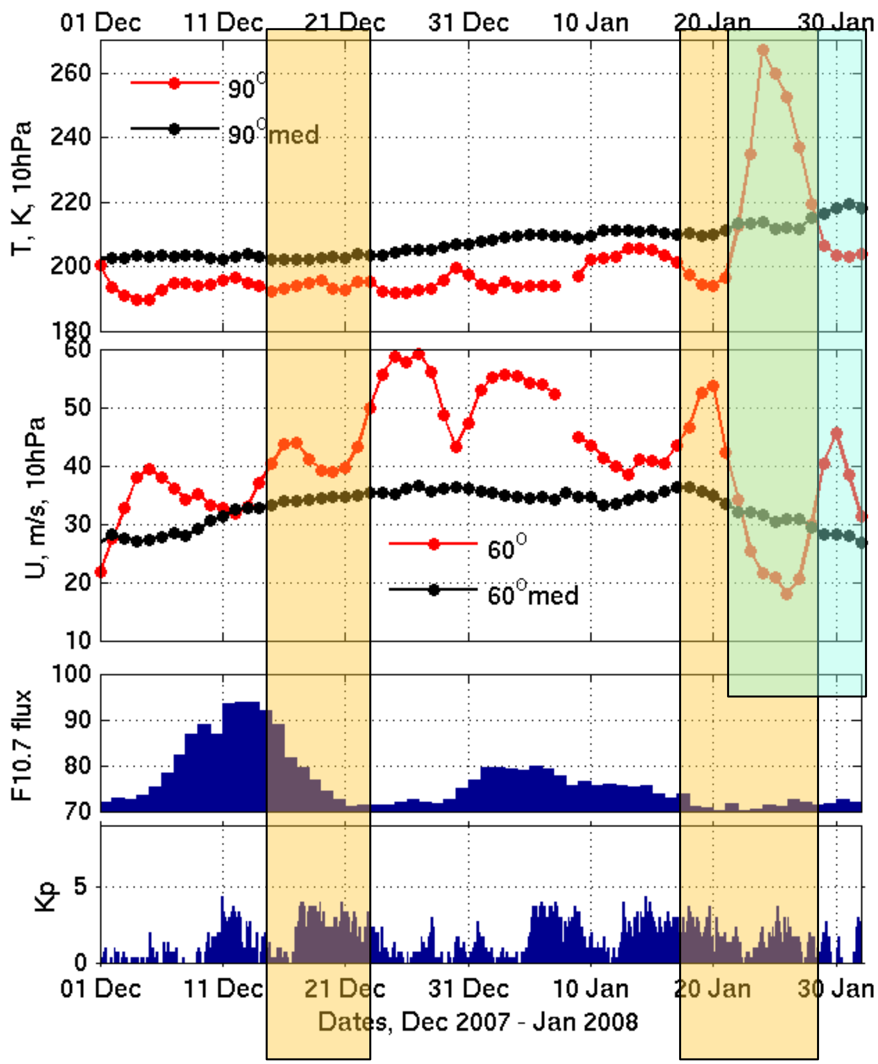
Sudden Stratospheric Warming events

- 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

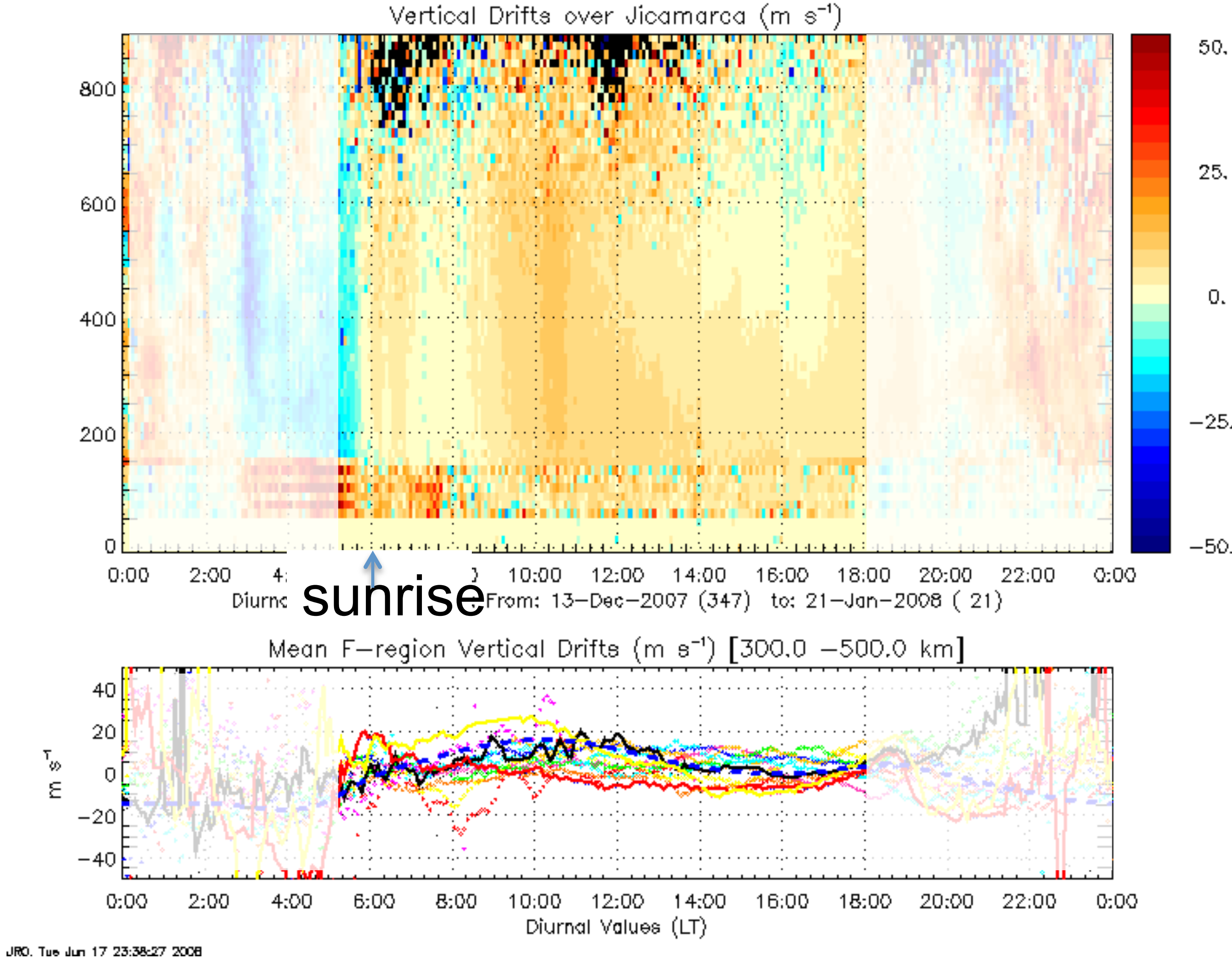


SSW Jan 2008: SSW Main parameters

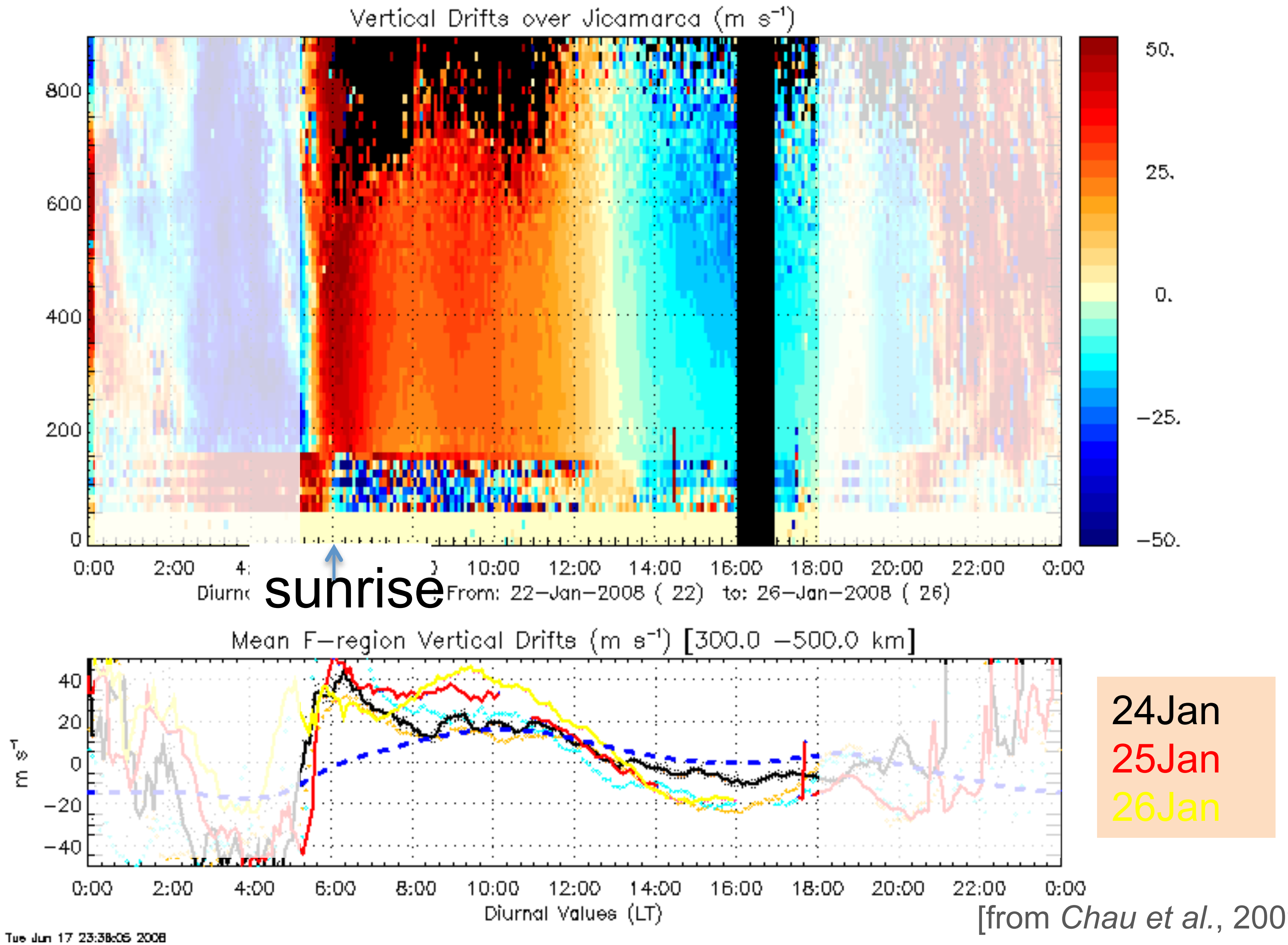


- Minor SSW event. Westerly winds slowed down
- One of the largest temperature increases in the last 30 years.
- Low solar flux (close to 70)
- Magnetically quiet conditions
- Many ground-based instruments operated 8-10 days in December 2007 and 10-14 days in January 2008.

Equatorial ExB Drifts: Diurnal values before SSW

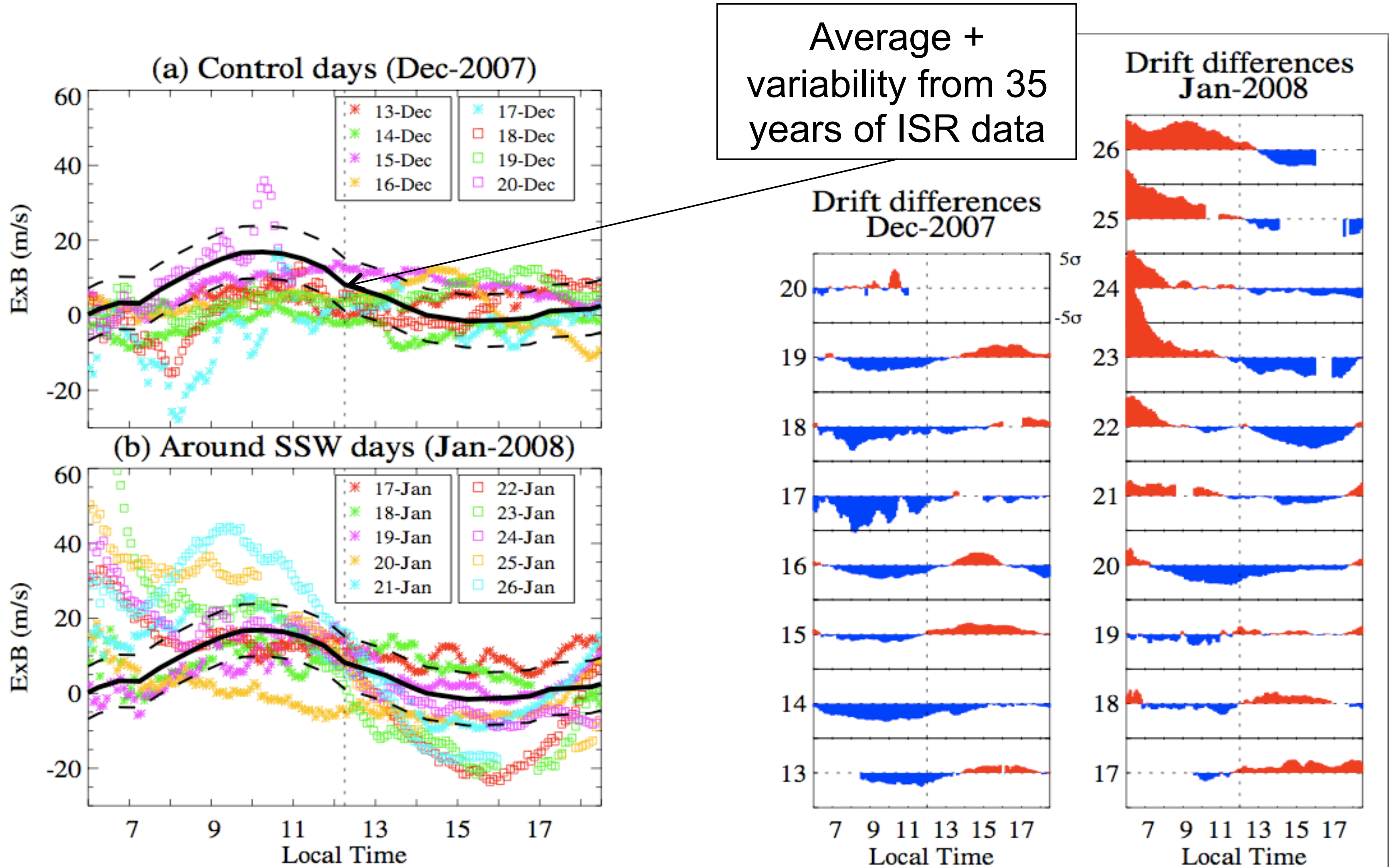


Equatorial ExB Drifts: Diurnal values during SSW



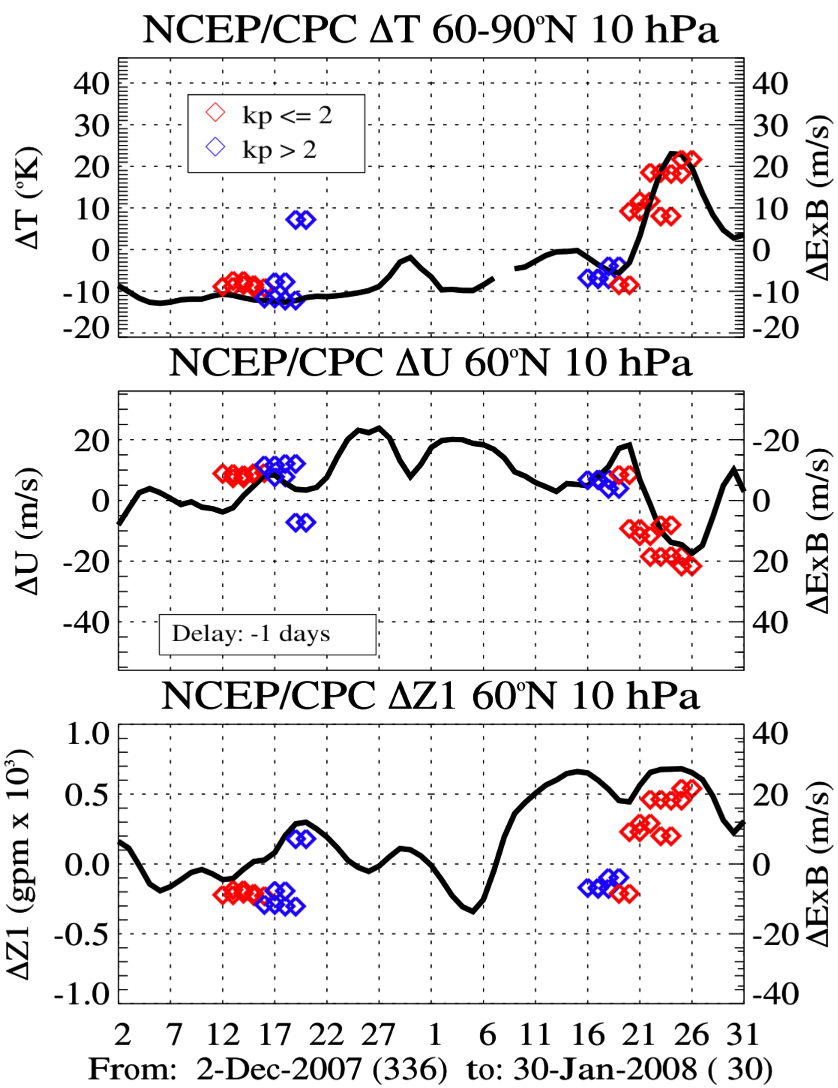
[from *Chau et al.*, 2009]

SSW Jan 2008: ExB Daytime Drifts



[from *Chau et al.*, 2009]

SSW Jan 2008: ΔSSW vs ΔExB

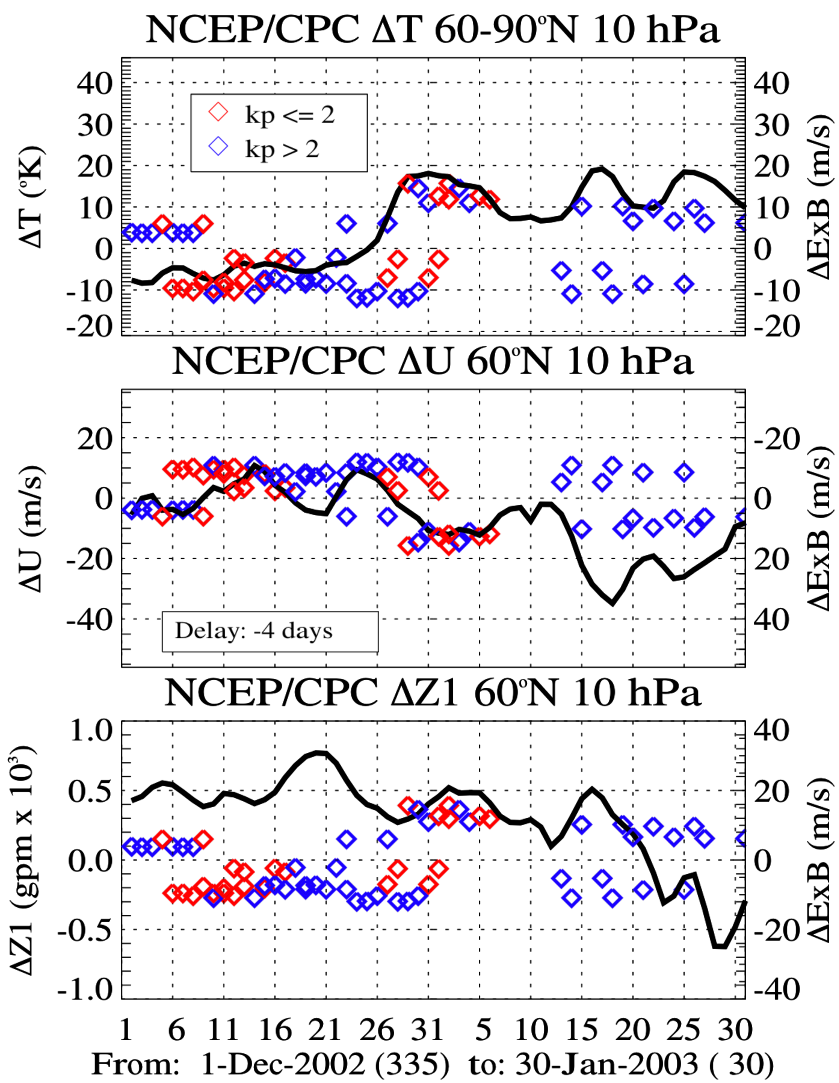


- ΔExB: Morning amplitude ExB difference with respect to expected averages, after fitting a semidiurnal wave.
- ΔSSW: differences with respect to 30-year median values.
- High correlation/anticorrelation: ΔExB vs. ΔT/ΔU during SSW.
- Note the "persistence" of the ExB drift pattern during SSW period.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

Correlation ≠ Causality

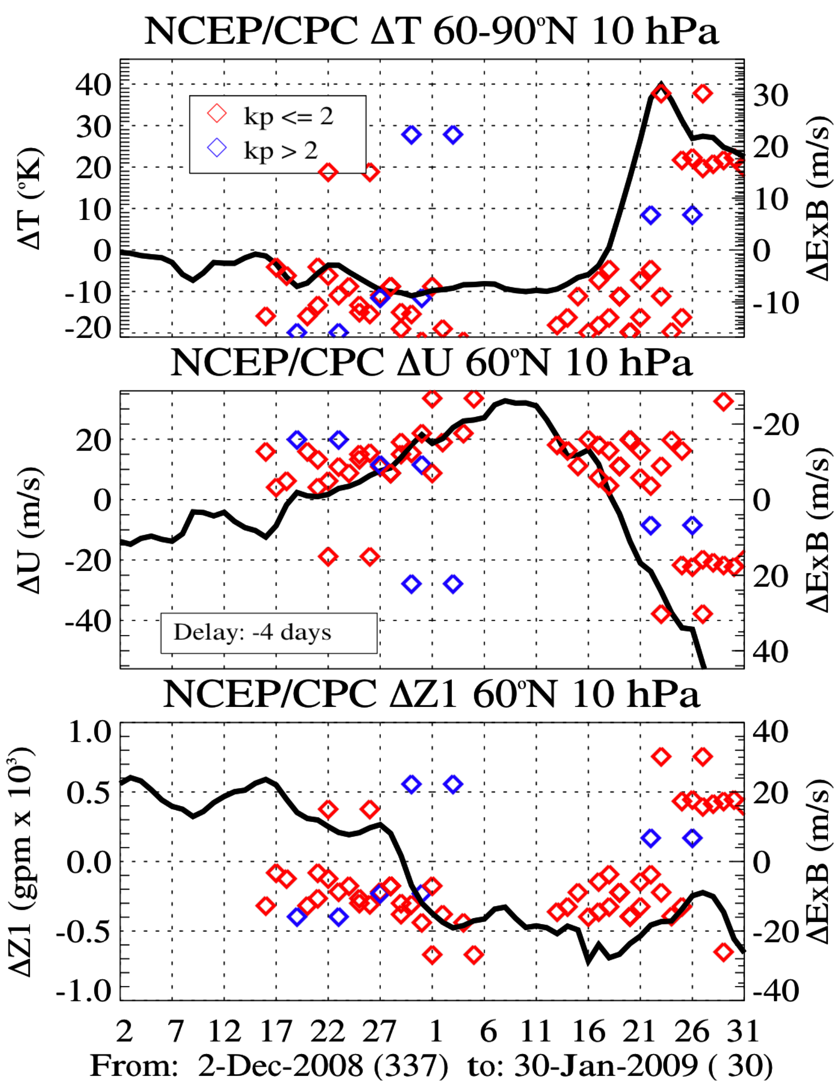
[from *Chau et al.*, 2009]

SSW Jan 2003: ~5 days delay



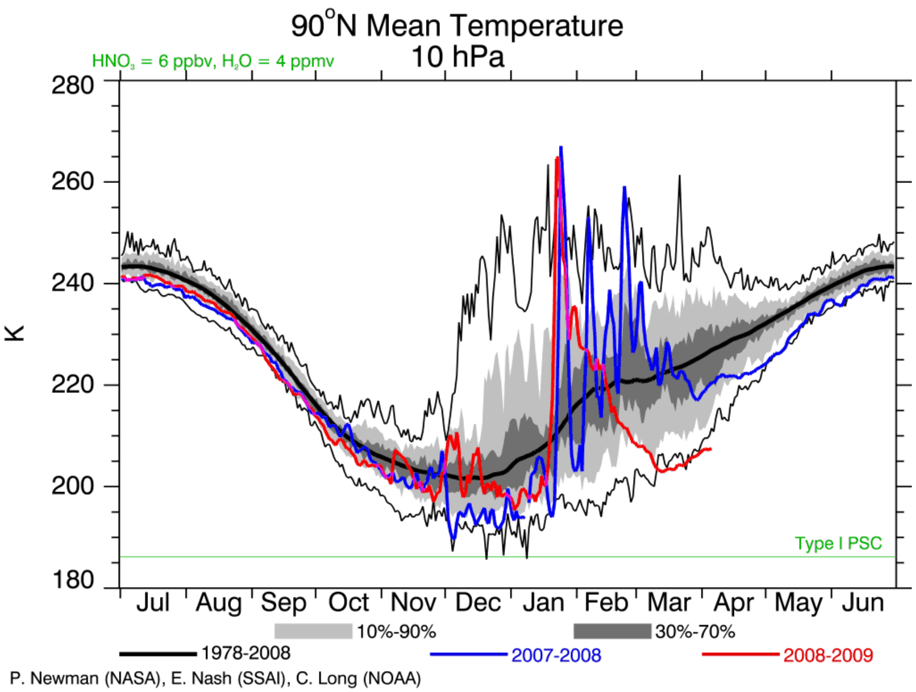
- Minor (?) SSW, westerly wind decreased
- Moderate to high solar conditions
- Magnetically quiet and active conditions.
- Semidiurnal pattern between Jan 2-6, showing "persistence".
- ExB peak difference occurs after ~4-5 days the occurrence of the highest SSW Temp.

SSW Jan 2009: ~4 days delay



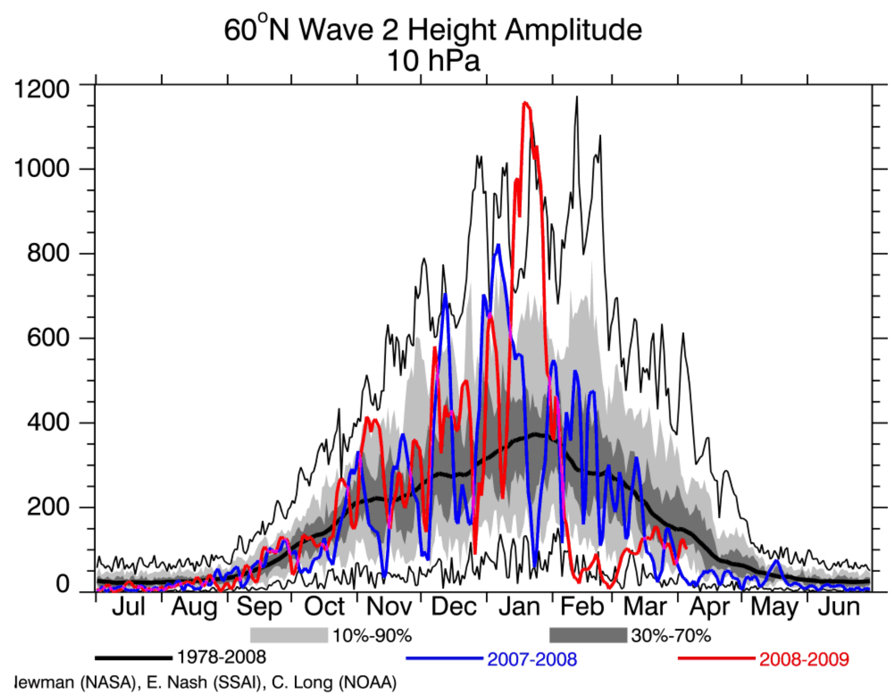
- Again, comparing peaks we find:
  - The highest ExB drift amplitude difference occurs ~4 days after the peak in SSW temperature occurs.
  - Once the highest value is reached, a moderate amplitude persist for few days, in a correspondence with the SSW temperature behavior.

SSW and Planetary Wave Activity



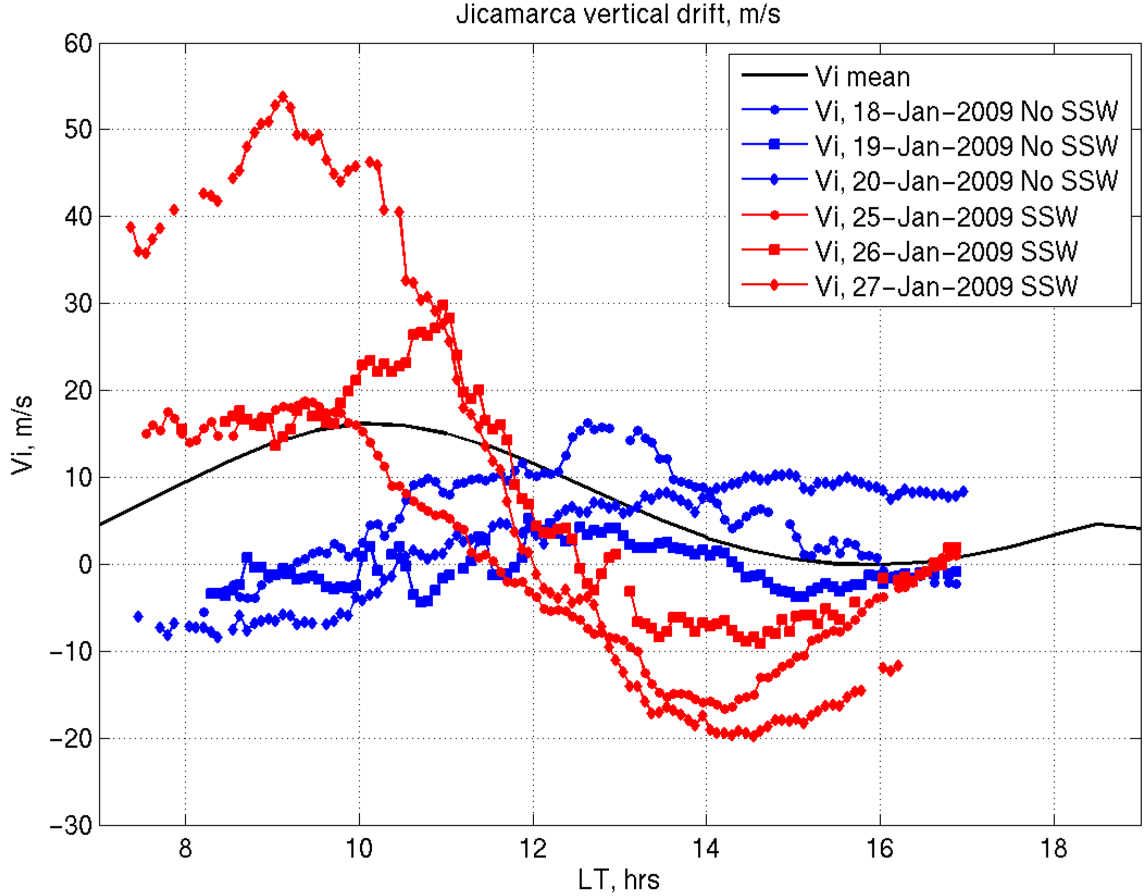
Record SSW in January 2009…

…preceded by a record increase in planetary wave 2 activity



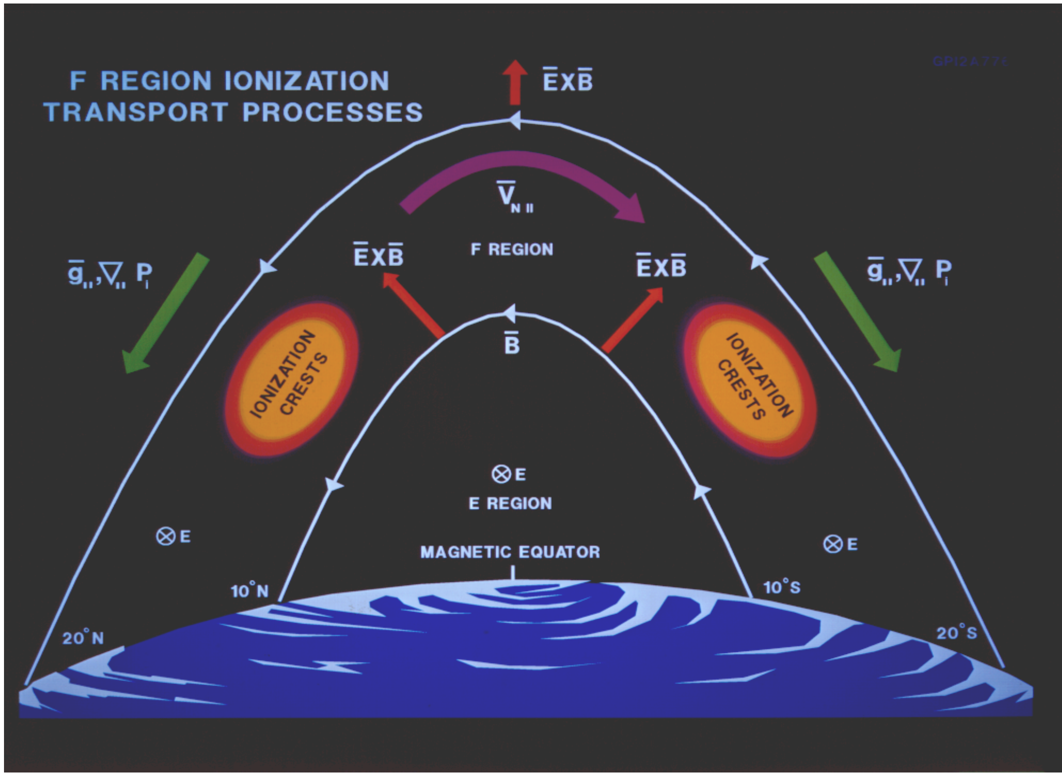
Solar min + record stratwarming = ideal case scenario

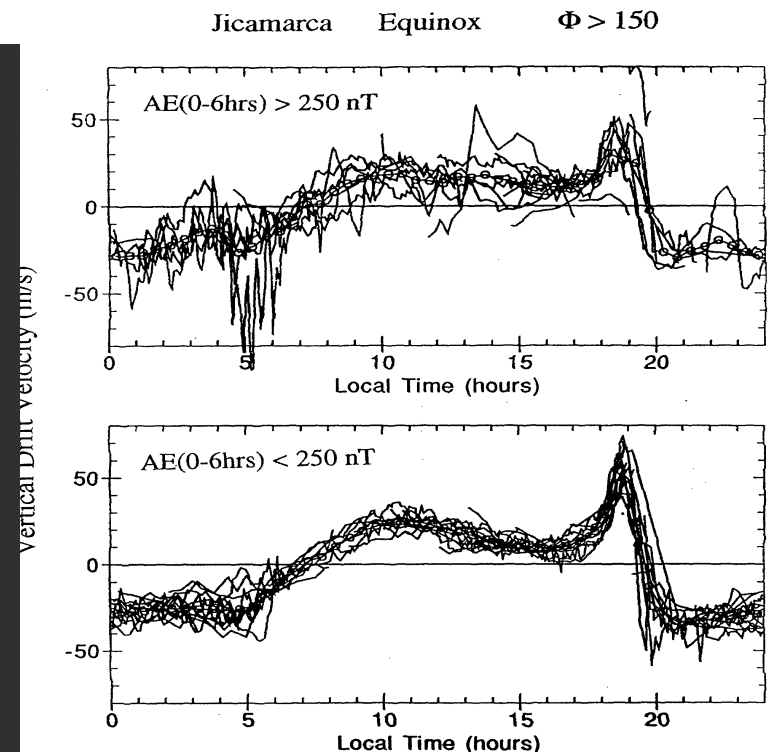
ExB Drifts: Jicamarca Jan 2009



- Strong 12-h perturbation in vertical drift
- Persistent for several days during stratwarming
- Similar to the drift during stratwarming of Jan 2008 (Chau et al., 2009)

Equatorial Ionosphere





[from *Fejer et al*, 1999]

- **B** field is nearly horizontal
- Daytime:
  - *E*-region E is eastward
  - Off-equatorial E maps to F above mag. Equator -> Upward ExB
  - Formation of Appleton Anomaly
- Around sunset, *F* region dynamo develops and competes with *E*, generates PRE and ExB goes downward (E westward)
- At night upward density gradient is opposite in direction to g, Rayleigh-Taylor unstable, allowing plasma density irregularities to form.

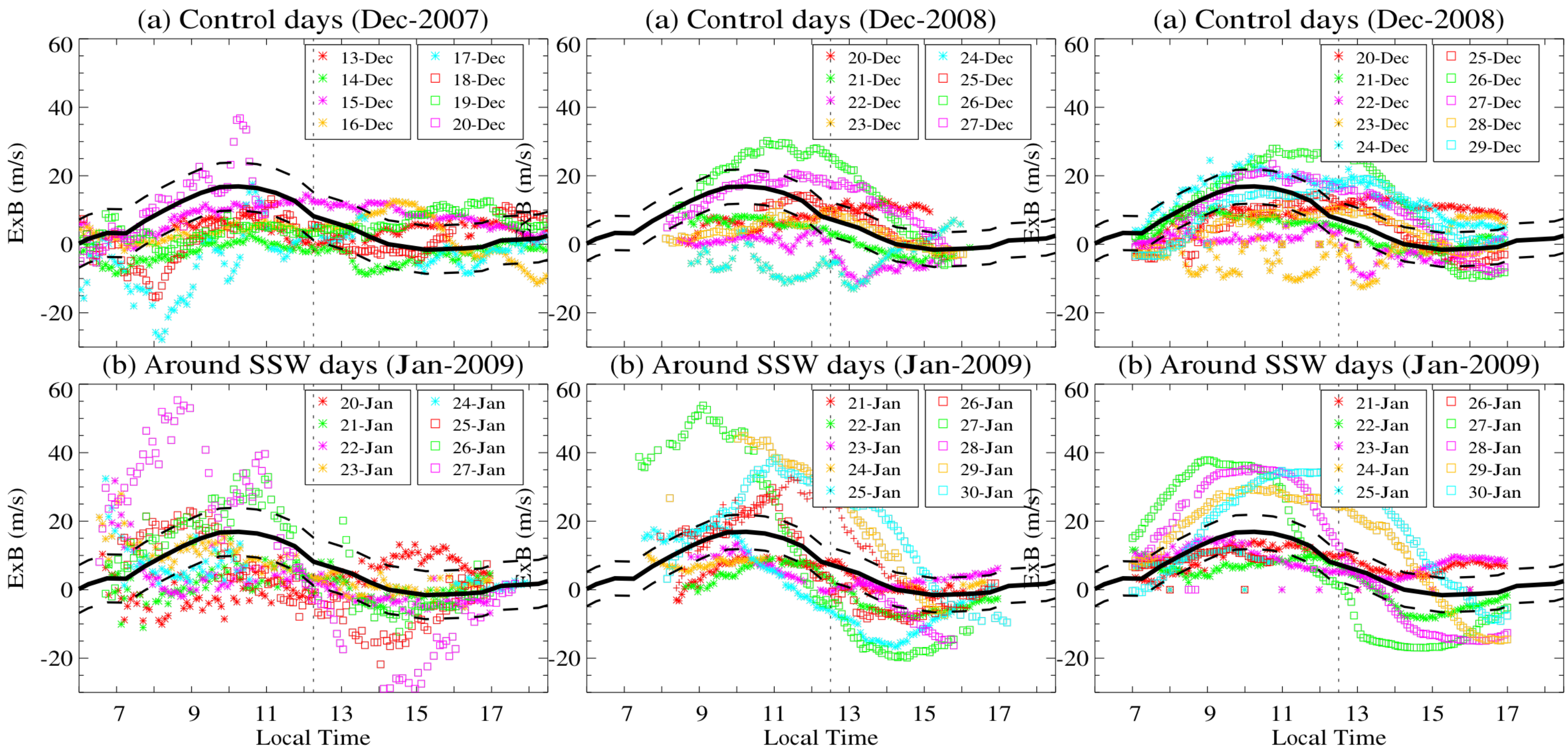
Equatorial ExB measurements at Jicamarca (1)

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]

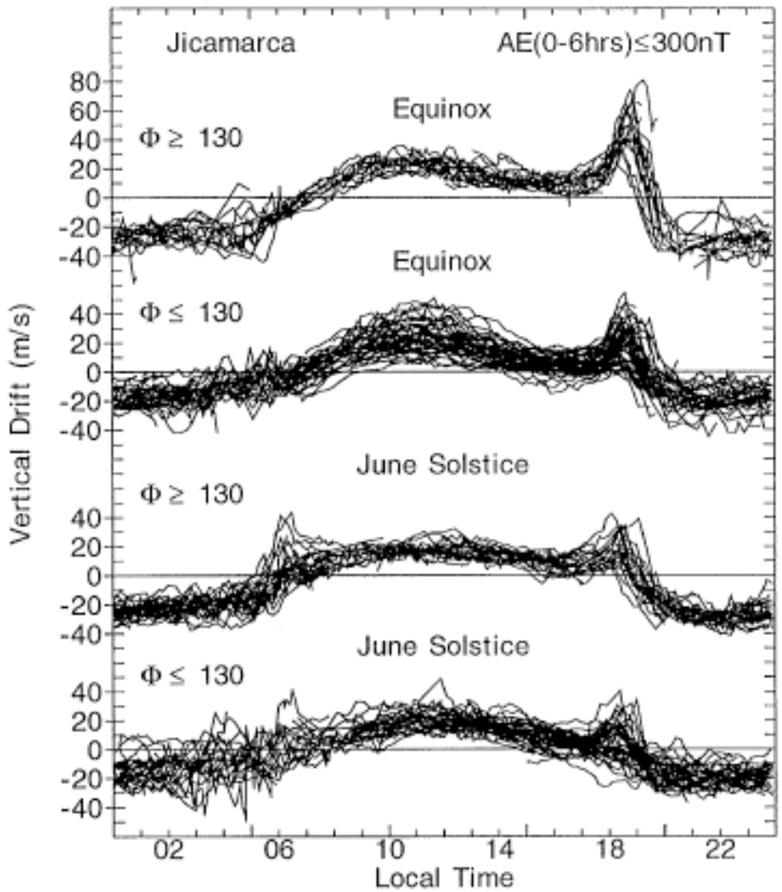
*except when strong ESF echoes are present

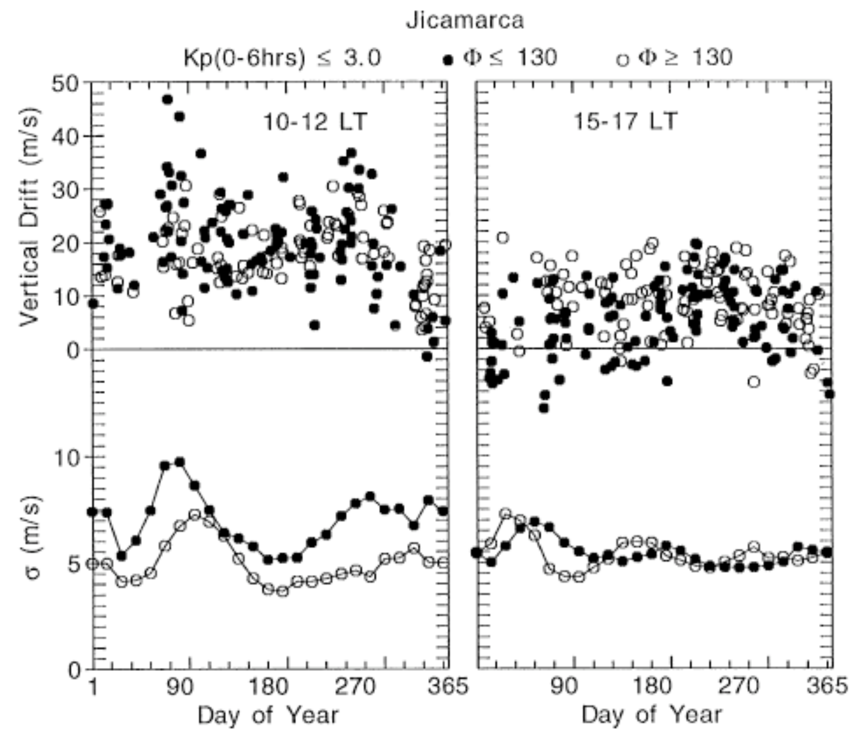
Equatorial ExB measurements at Jicamarca (2)

ISR 150-km ΔH



Quiet Daytime ExB: Mean and variability (1)



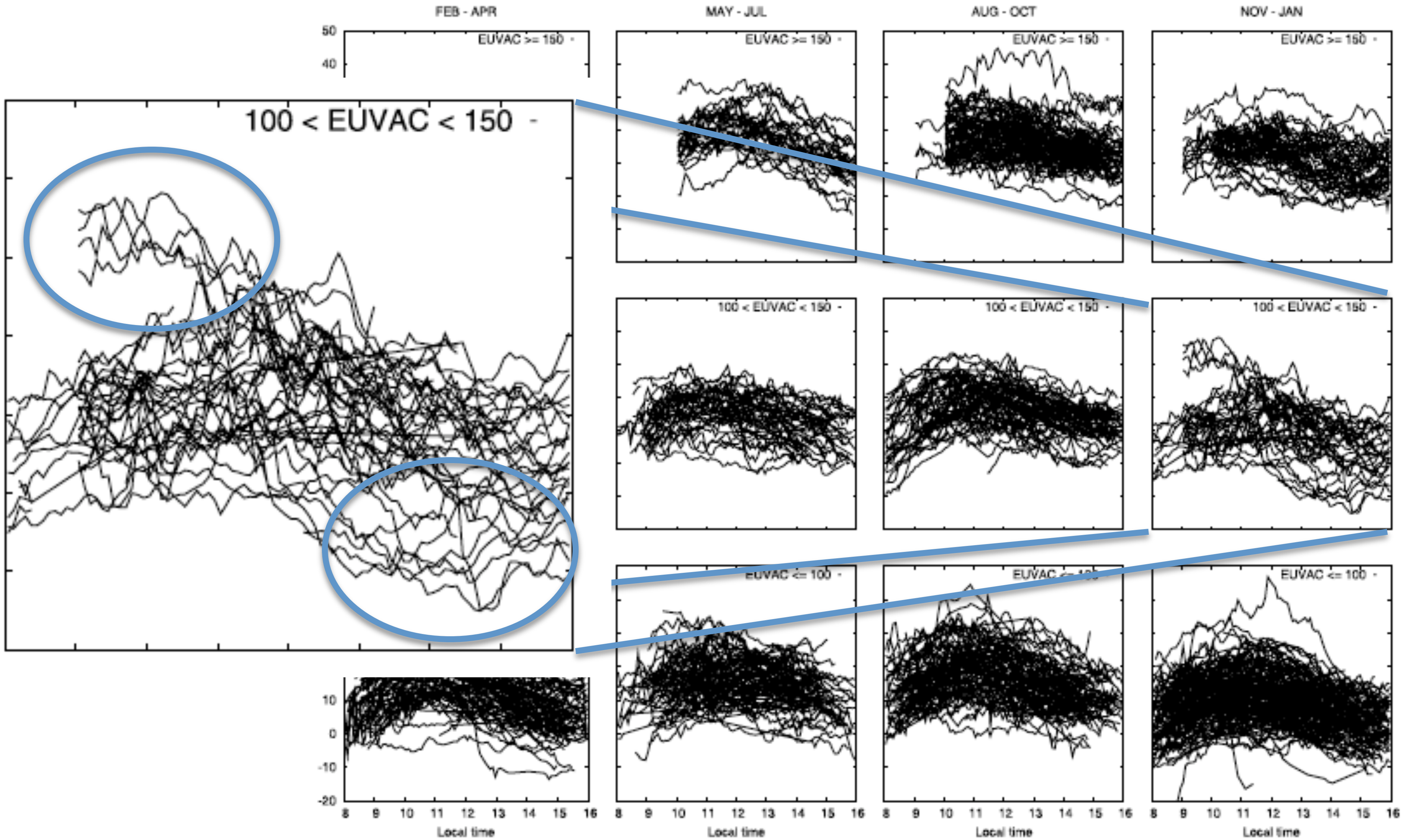


- Daytime average drifts do not vary much with solar activity.

- 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)



[from *Alken.*, 2009]

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

Quiet Daytime ExB: Empirical Models

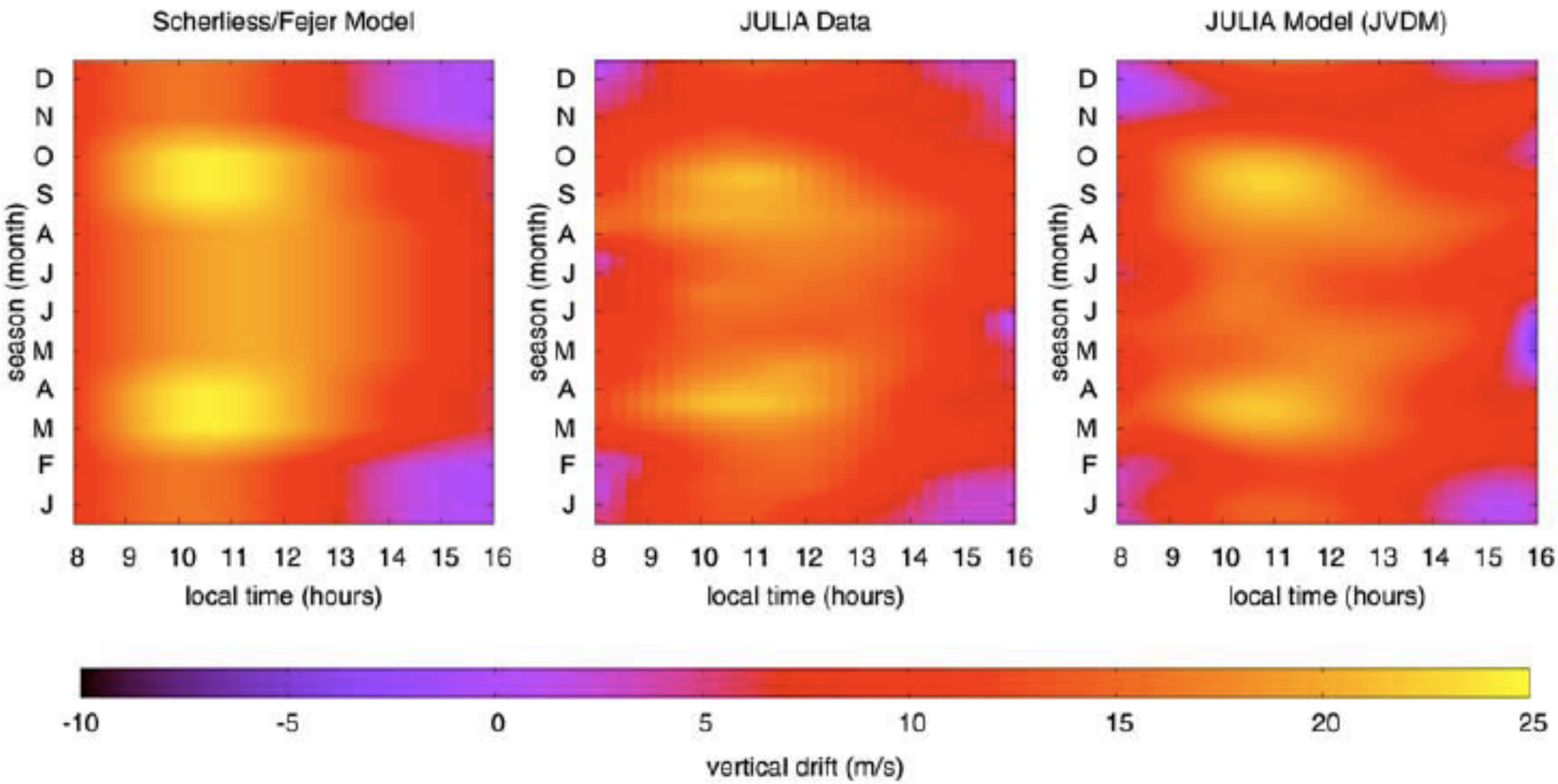
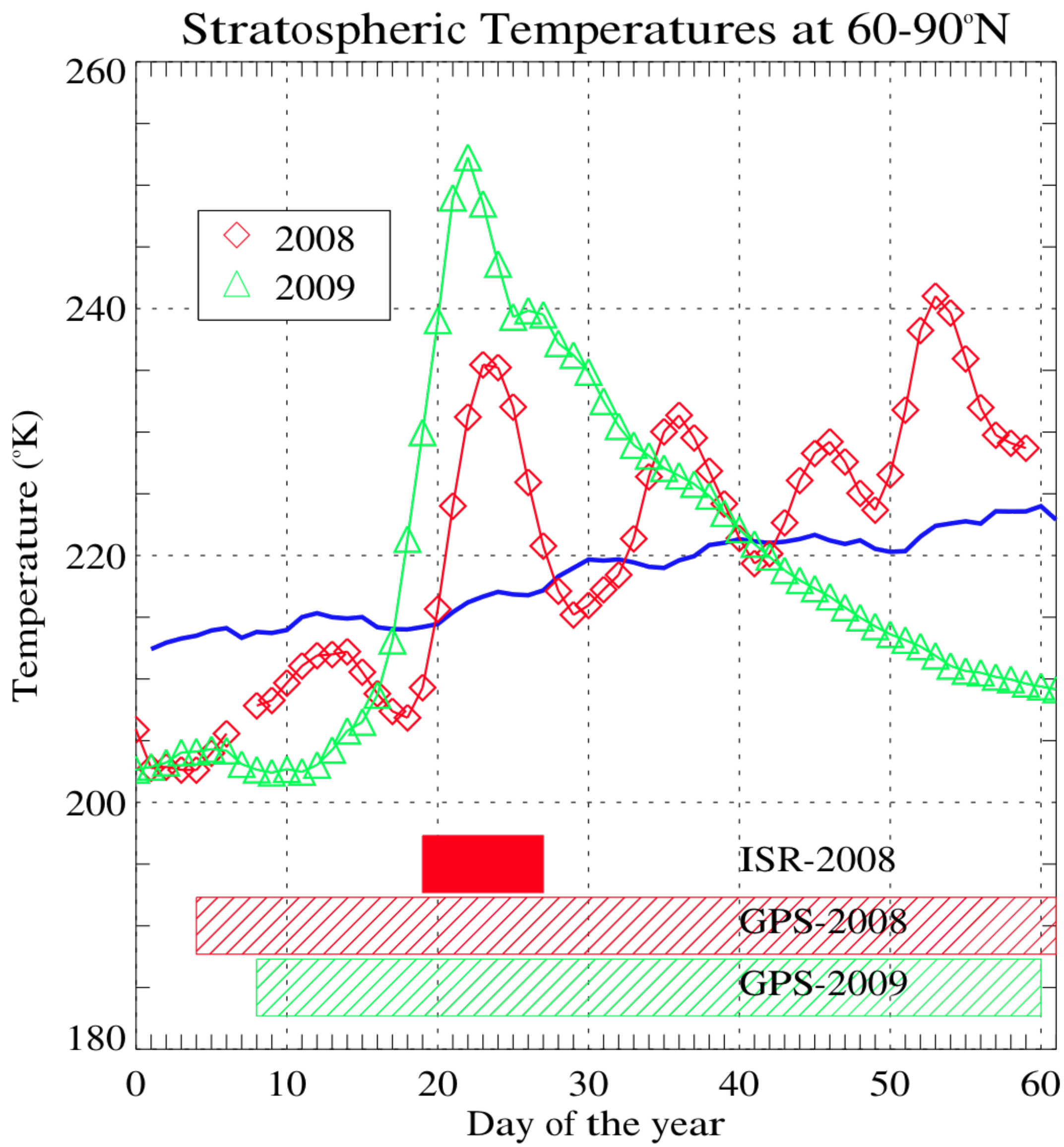


Figure 4. (left) Scherliess and Fejer model output, (middle) raw JULIA vertical drift data, and (right) JULIA Vertical Drift Model output using an EUVAC index of 80.

[from *Alken.*, 2009]

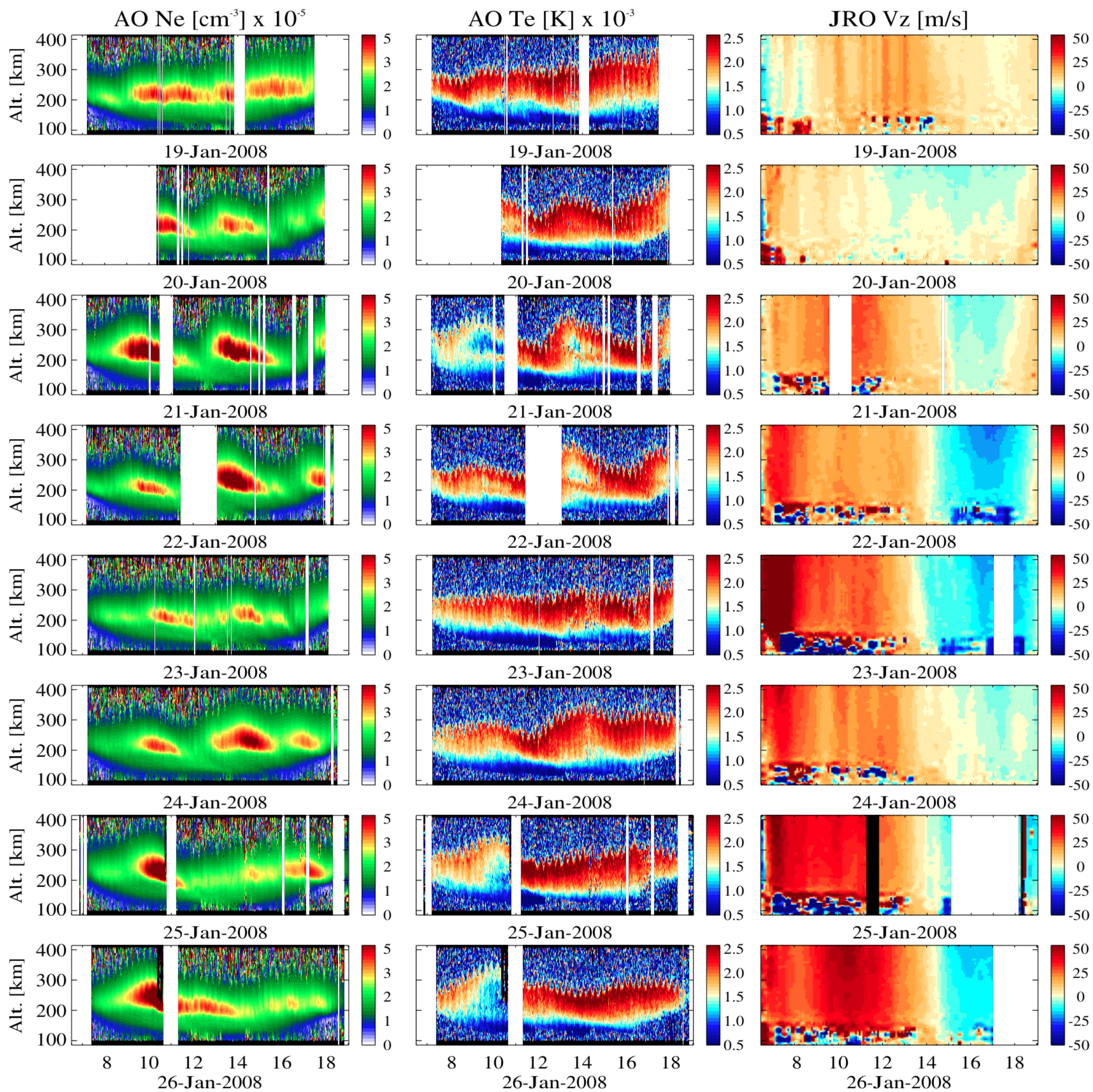
SSW Events: 2008, 2009



ISR Parameters: Arecibo-Jicamarca

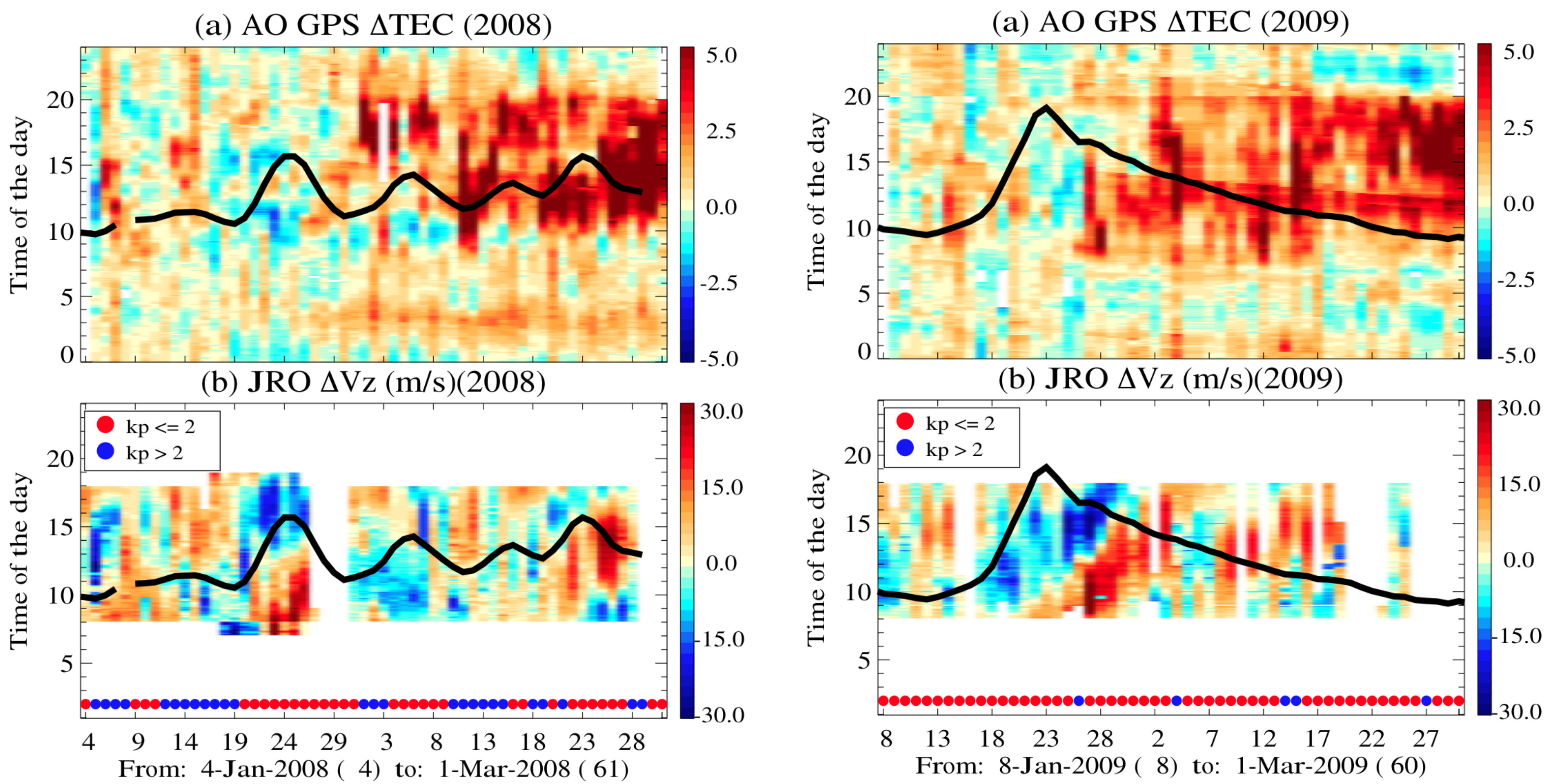
AO Ne shows unusual behavior

AO Te increases when AO Ne decreases



[*Chau et al.*, 2010]

AO ΔTEC – JRO ΔVz – SSW ΔT



[*Chau et al.*, 2010]

SSW Jan 2009 SSW: JRO ExB and GPS TEC

15 UT mean

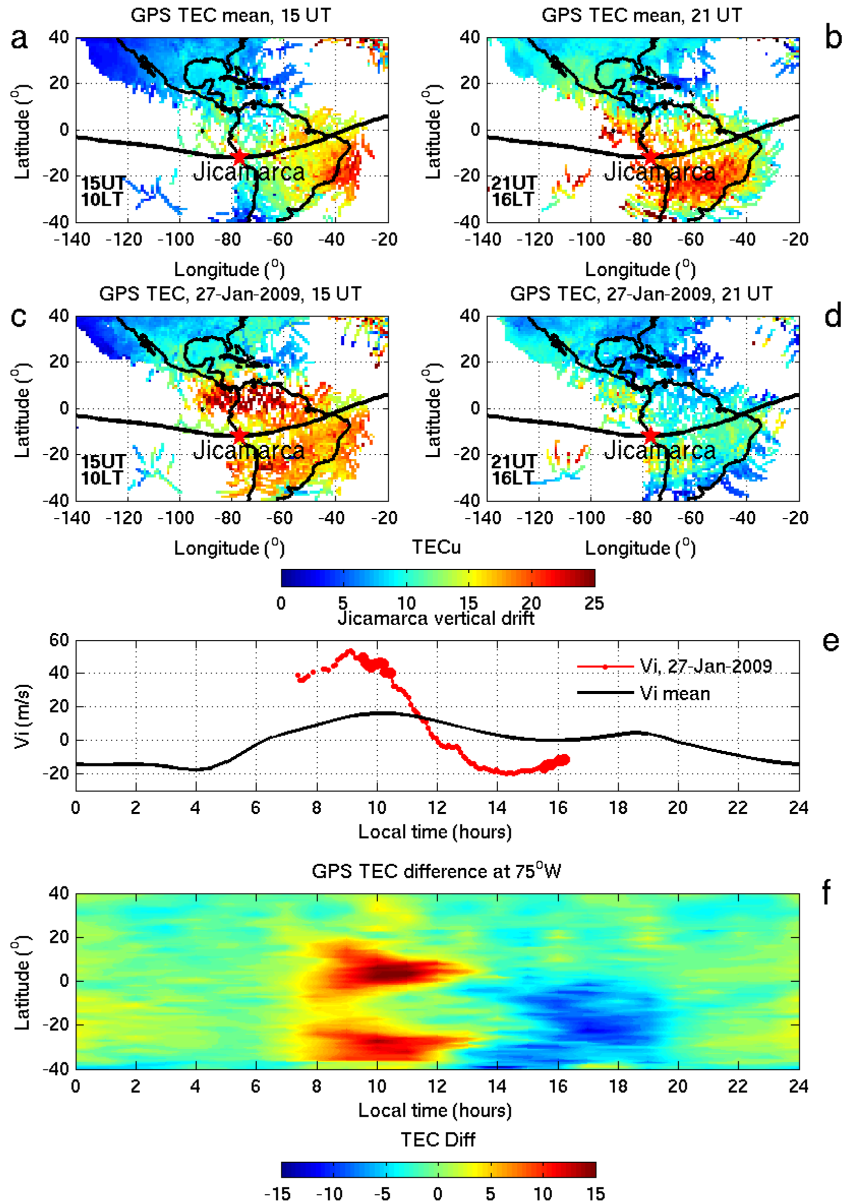
21 UT mean

15 UT SSW

21 UT SSW

Jicamarca drift

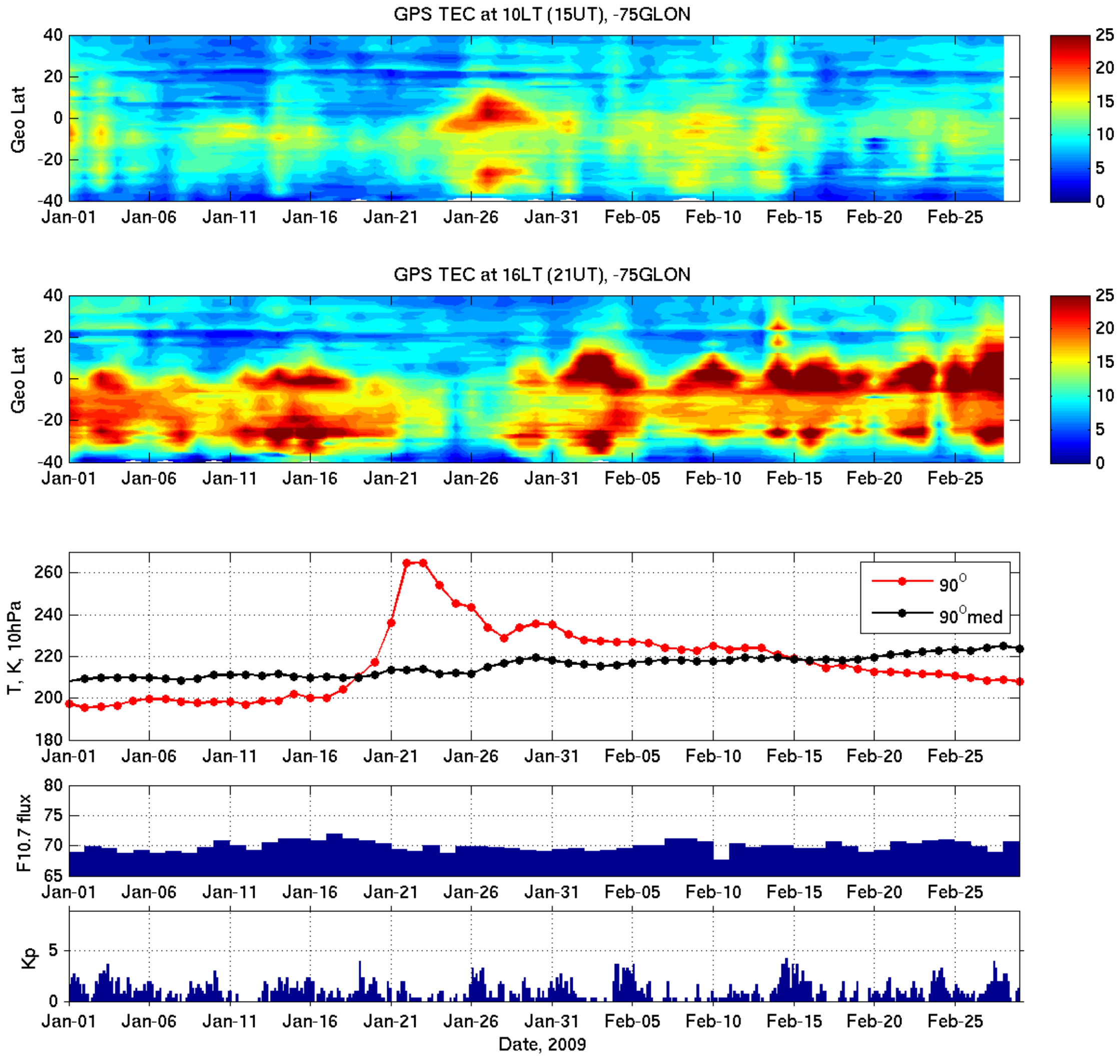
TEC change



Entire daytime low to mid-latitude ionosphere is affected during stratwarming

[*Goncharenko et al.*, 2010a]

SSW Jan 2009: GPS TEC at 75ºW

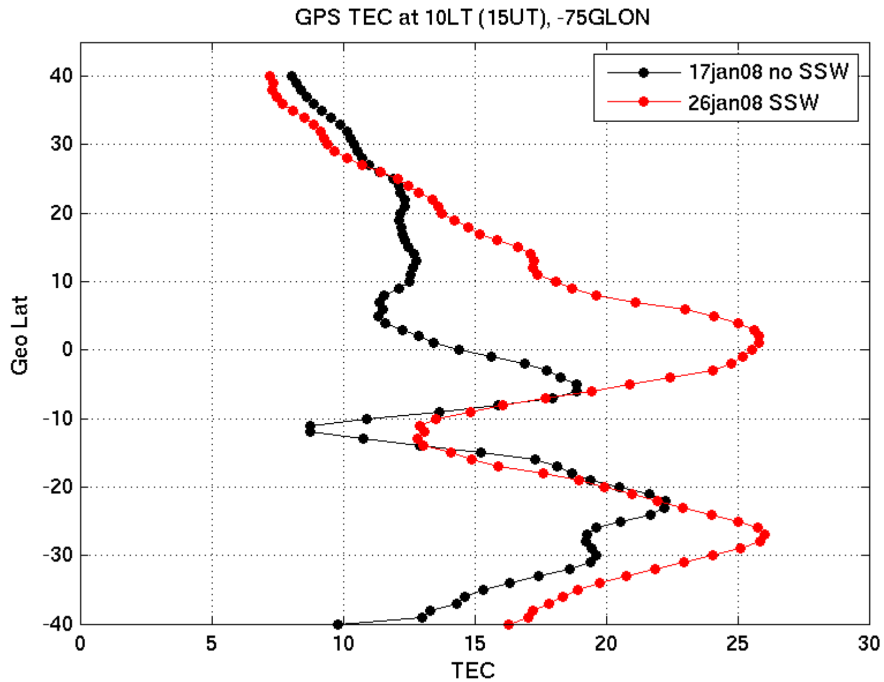


10 LT

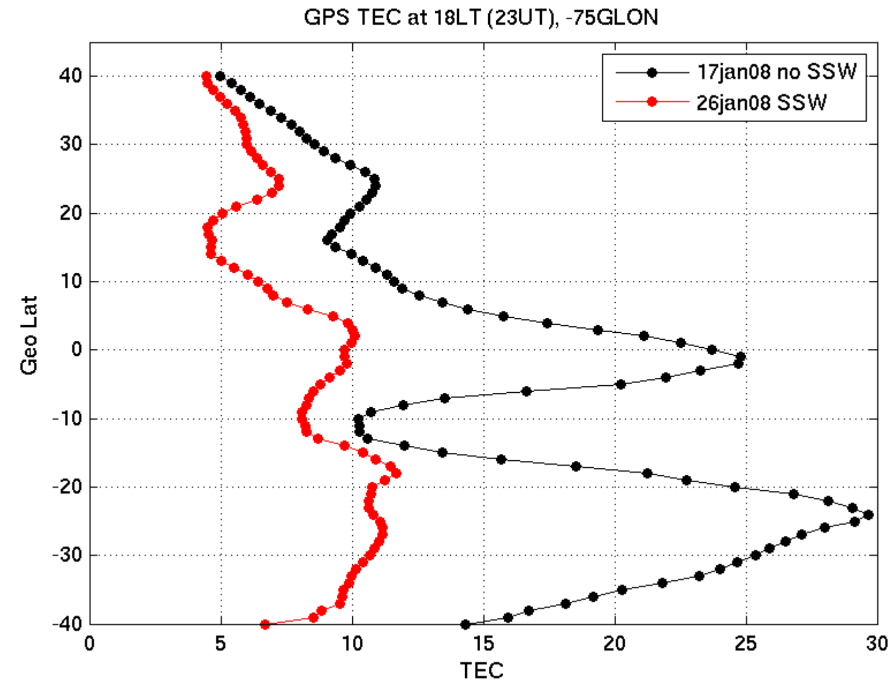
16 LT

SSW Jan 2008: GPS TEC at 75ºW

Morning sector



Afternoon sector



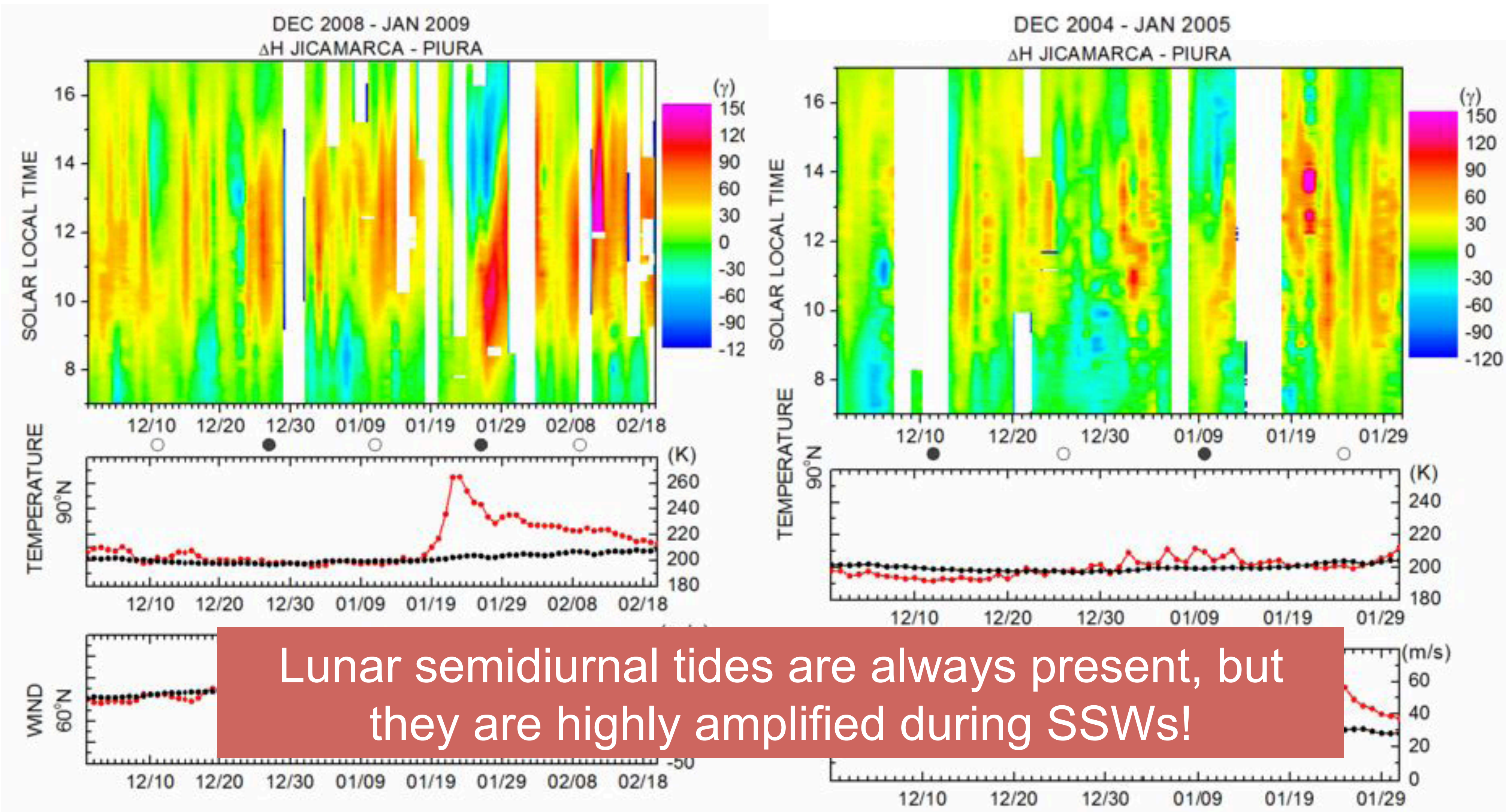
- Equatorial anomaly is enhanced in the morning sector by 20-40%
- Crest locations moved to higher latitude

- Equatorial anomaly is suppressed in the afternoon sector by a factor of 2-3

During the stratospheric warming, equatorial fountain is turned on in the morning and turned off in the afternoon

[*Goncharenko et al.*, 2010b]

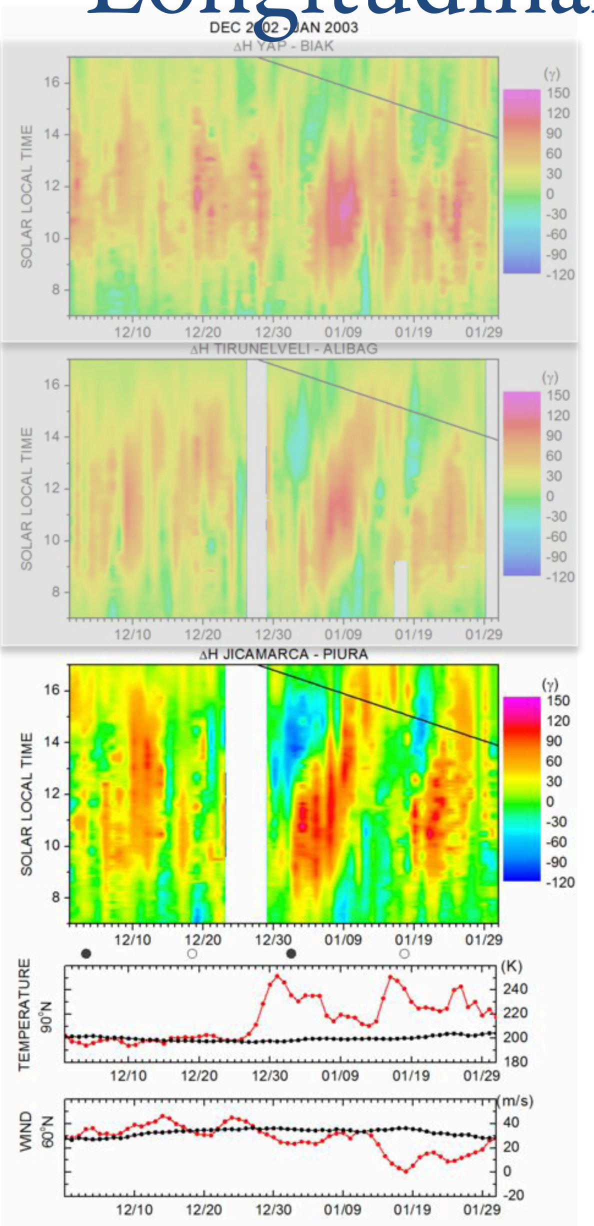
Time delay and lunar dependence

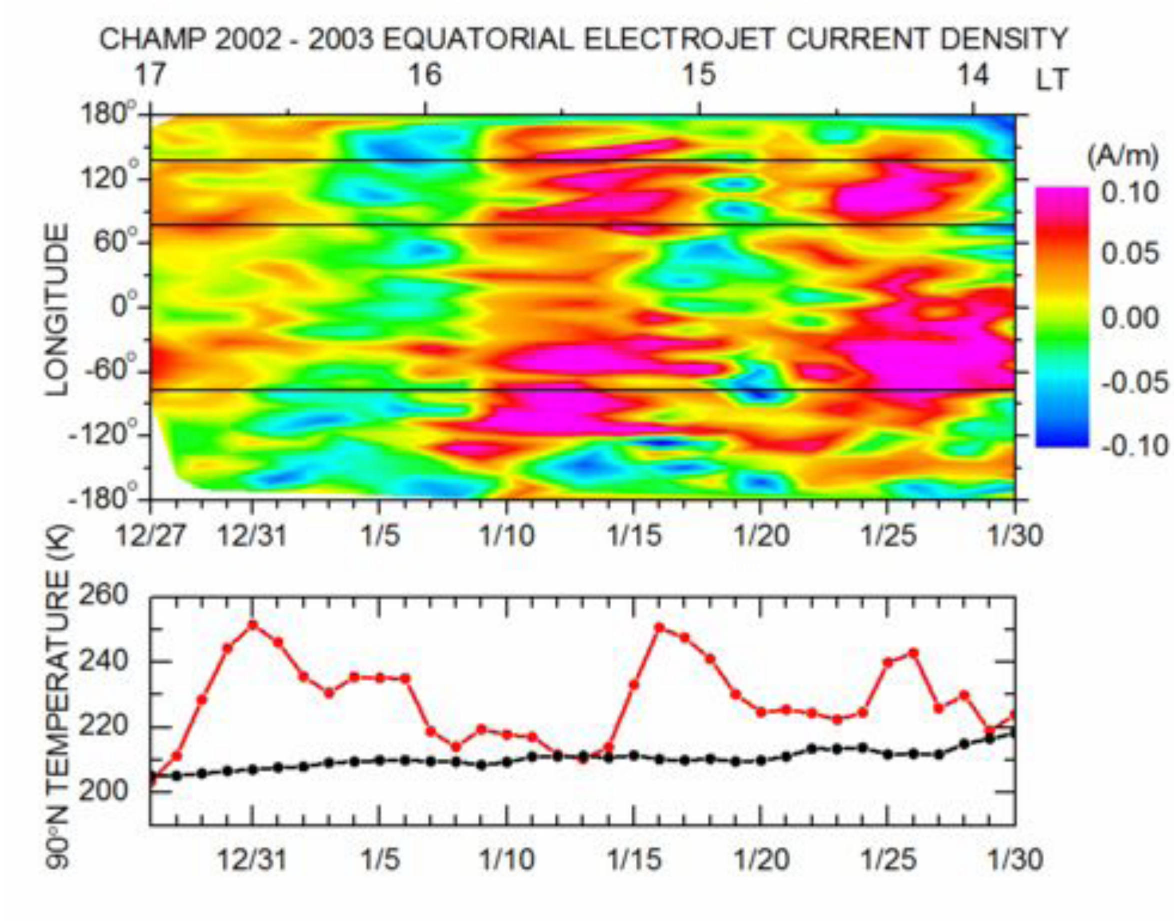


Lunar semidiurnal tides are always present, but they are highly amplified during SSWs!

[from *Fejer et al.*, 2010]

Longitudinal Response: ΔH + CHAMP



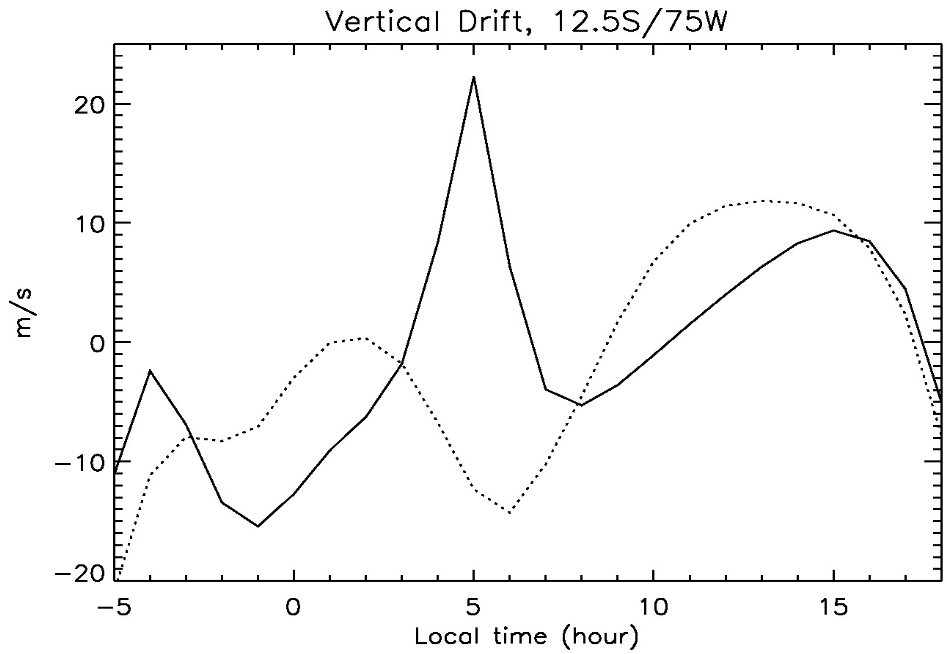


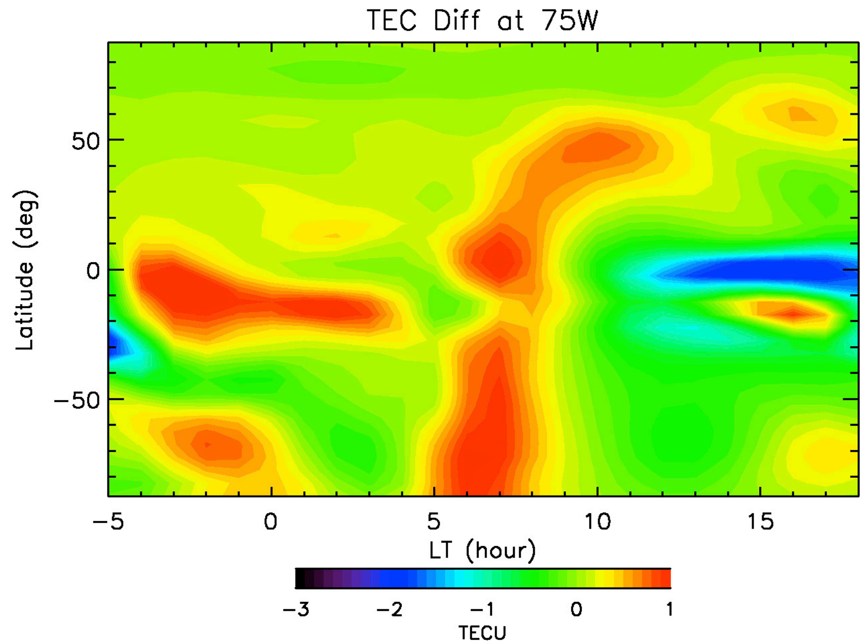
[from *Fejer et al.*, 2010]

TIMEGCM Numerical Experiments

- Numerical experiment setup: TIME-GCM simulations without and with a planetary wave perturbation at the lower boundary.
- Equinox (September-October): transient planetary wave.
- Solstice (December-January): quasi-stationary planetary wave.
- Under geomagnetic quiet and solar min conditions (f10.7=70).

TIMEGCM: Without and with PWs

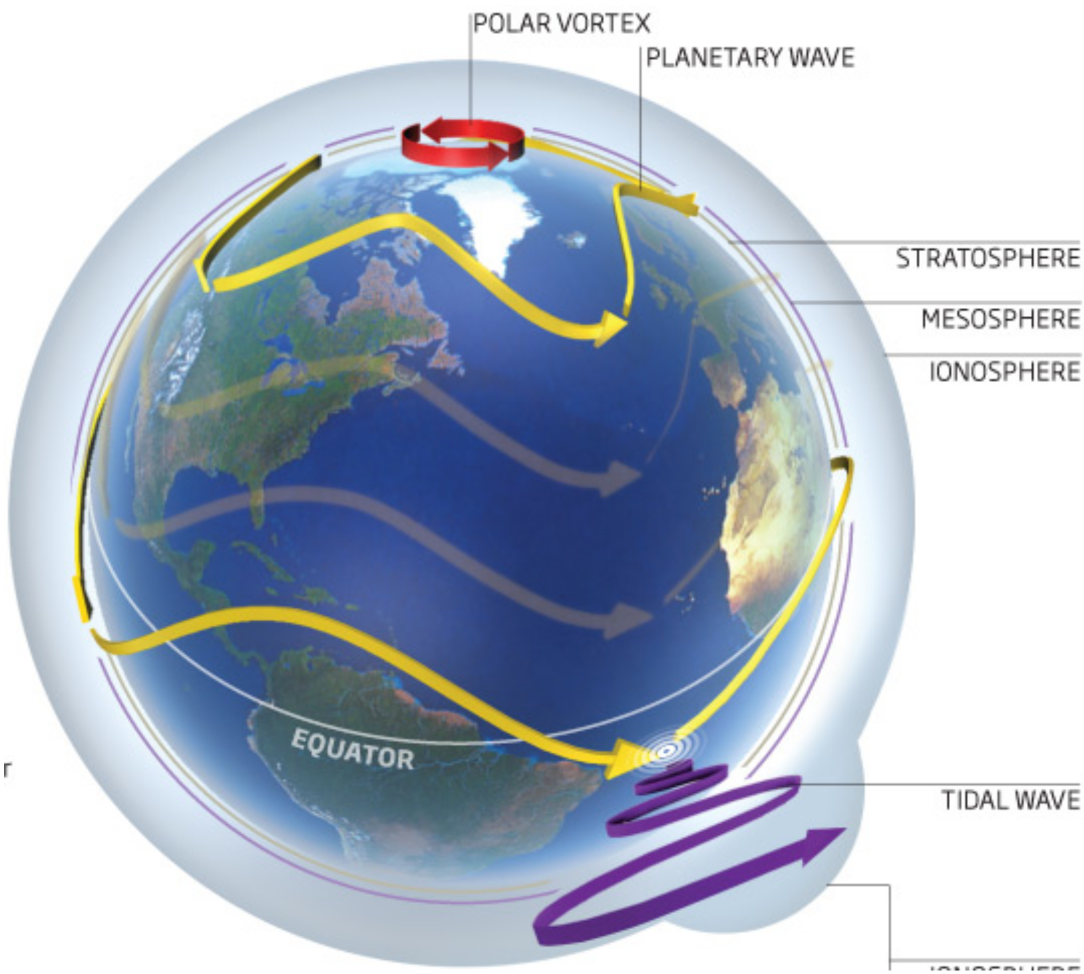




- Large electric fields change around sunrise
- Total electron content change
- Consistent with observations by Jicamarca ISR and GPS TEC, but smaller magnitude
- In addition, it shows longitudinal dependence, consistent with CHAMP, Magn. data.

[*Liu 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 (Lunar?)

↓

Wind structure changes

↓

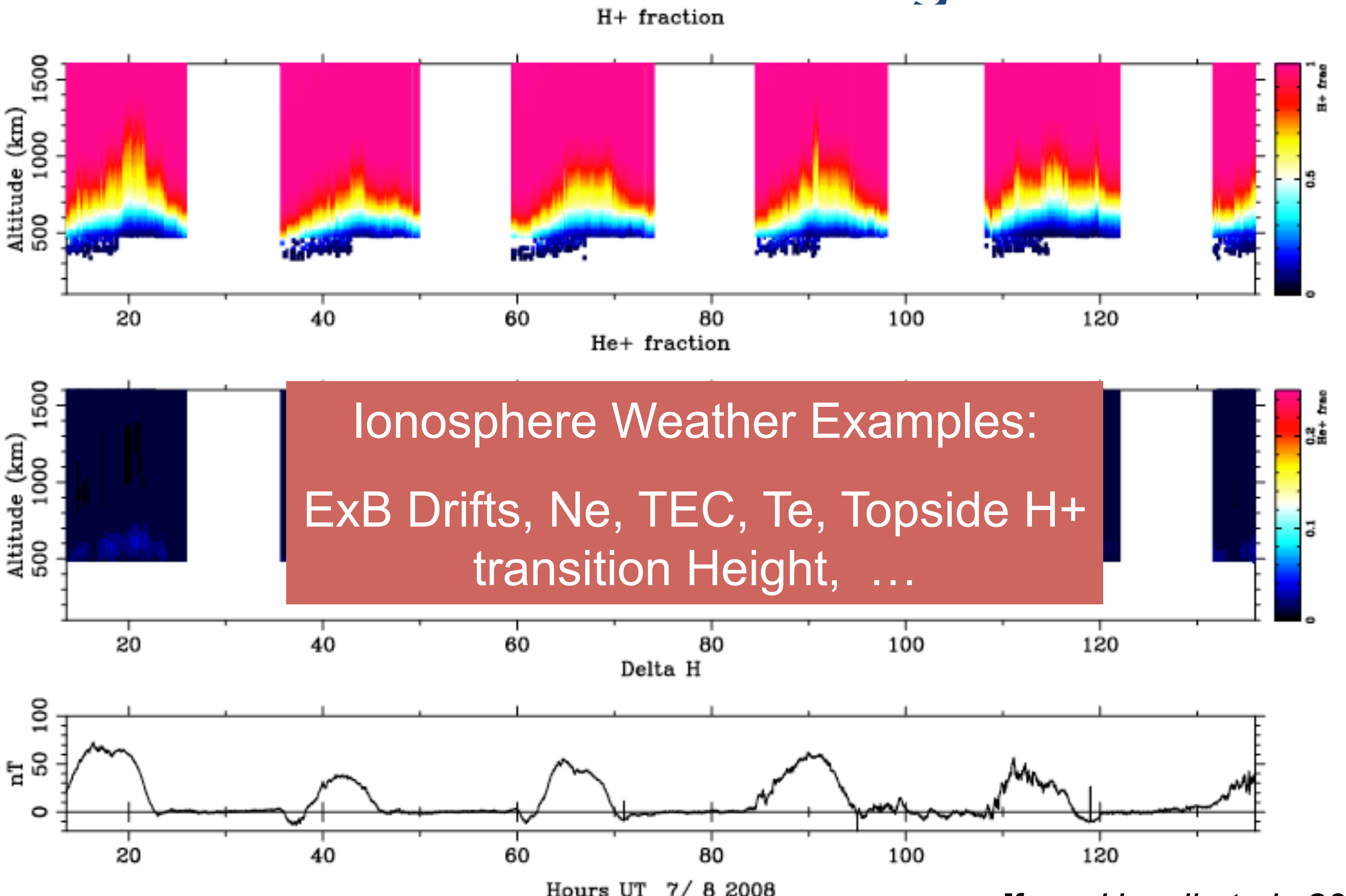
Current and plasma drift changes in the Equatorial E region dynamo

↓

Ionosphere weather

[courtesy of *Hanli Liu*]

ExB vs H+ Transition Height



[from *Hysell et al.*, 2009]

Outstanding Questions

- Would this “clear” case study help in the understanding of the ionosphere/lower atmosphere coupling?
- How is the coupling occurring? Direct and/or indirect vertical propagation?
- Why a dominant semidiurnal wave gets amplified?
- Why does this effect is observed around December solstice periods? (connected to SSW dependence NH winter?)