Perplexing atmospheric connections

Larisa P. Goncharenko, Research Scientist, Massachusetts Institute of Technology, Haystack Observatory, USA (lpg@haystack.mit.edu)
Jorge L. Chau, Senior Research Scientist, Jicamarca Radio Observatory, Peru (jchau@jro.igp.gob.pe)
Han-Li Liu, Scientist, High Altitude Observatory, National Center for Atmospheric Research, USA (liuh@ucar.edu)

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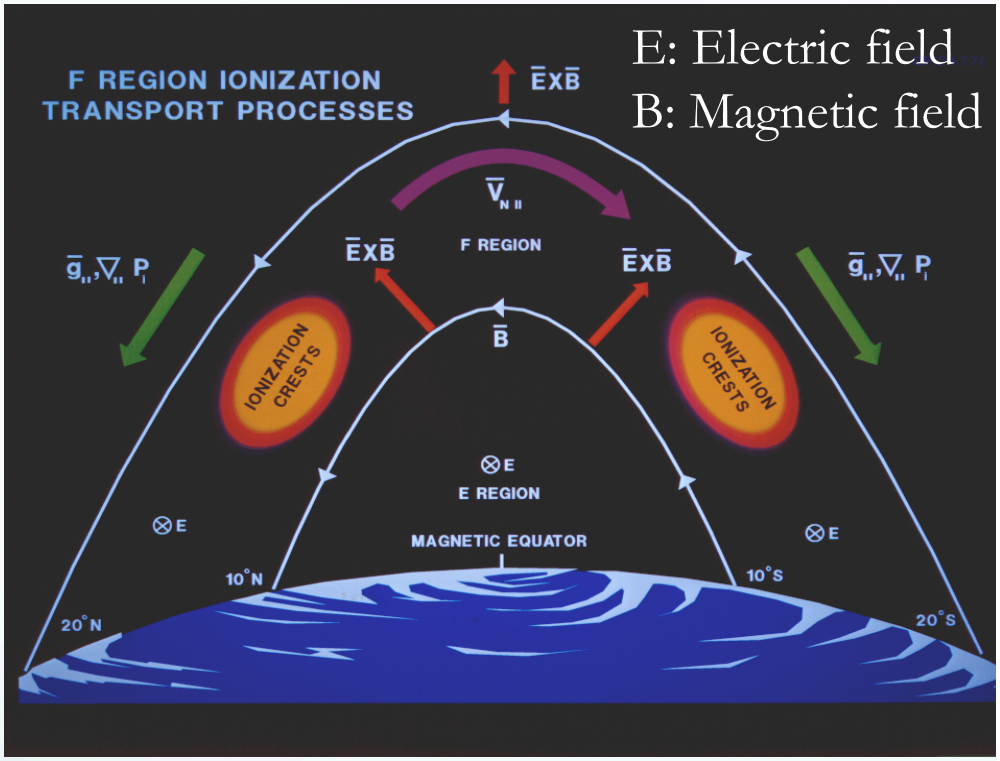
What we know now

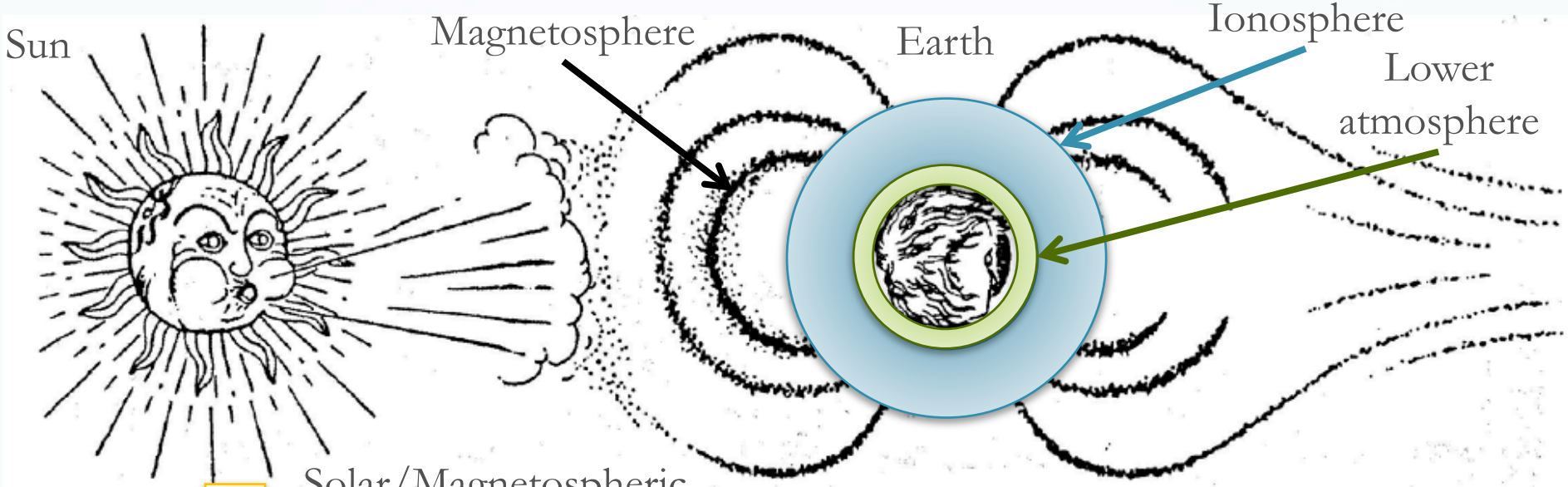
- Space weather. It is well-known that the Ionosphere (**upper atmosphere** or **space** closest to Earth) is affected by solar activity. However, when the Sun is "quiet", there is still significant upper atmosphere variability that is not understood, and therefore the understanding of the ionosphere weather is poor.
- We have clear evidence that the Ionosphere weather is strongly affected by lower atmospheric forcing. We have observed electric field, electron density and temperature variations, in connection with sudden stratospheric warming.
- New modeling results point to the propagation of lower atmospheric waves as one of the major causes of the reported ionospheric anomalies.

Ionosphere and Society



- GPS signal is affected by the total electron density in the Ionosphere.
- In most applications, such effect needs to be corrected, e.g.,
  - Tectonic plate drift monitoring and earthquake prediction
  - Global temperature and humidity monitoring (climate change)
  - Air and ground navigation (errors could be tenths of meters or signal can be lost)

Ionosphere Forcing



[adapted from *Marchavilas*, 2007]

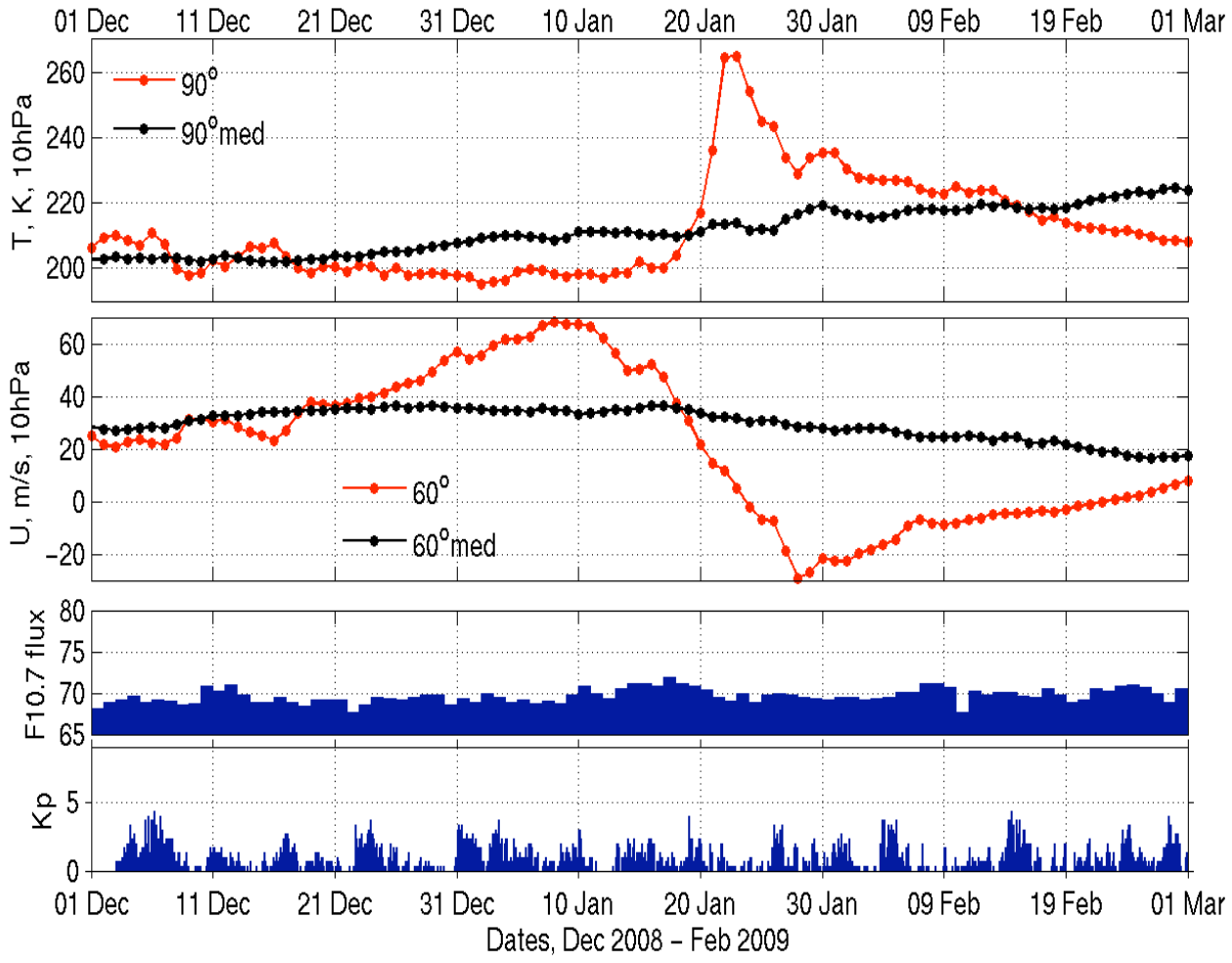
Solar/Magnetospheric forcing, e.g., geomagnetic storms

Ionosphere

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

- These forces produce ionospheric changes: electric fields, electron density, temperature, composition, …
- During solar minimum, Solar/Mag forcing is small, allowing the separation of lower atmosphere impact from the solar impact.

Sudden Stratospheric Warming and Solar Parameters [Jan 2009]



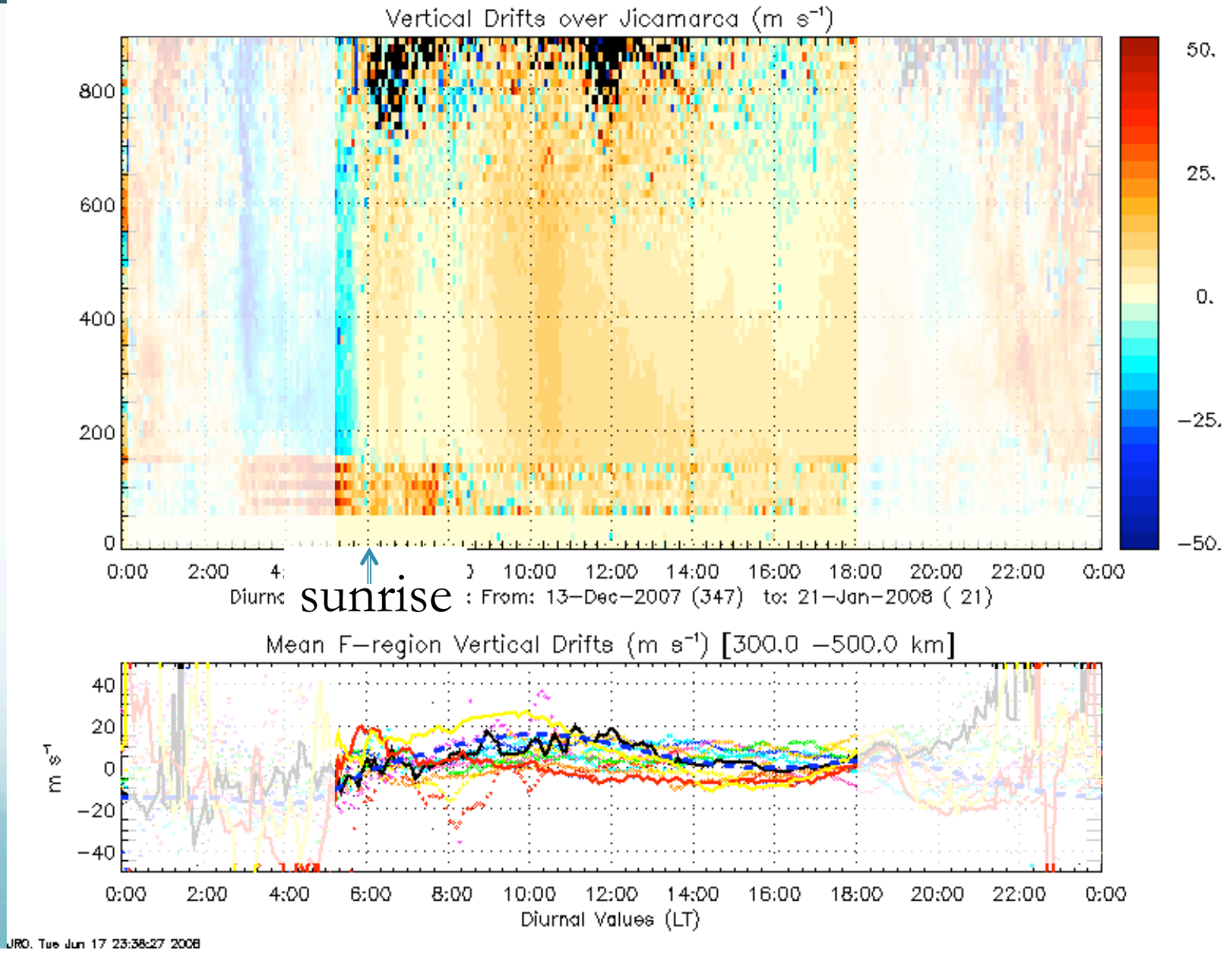
Stratospheric Temperature over the Arctic

Stratospheric Zonal wind at 60°N

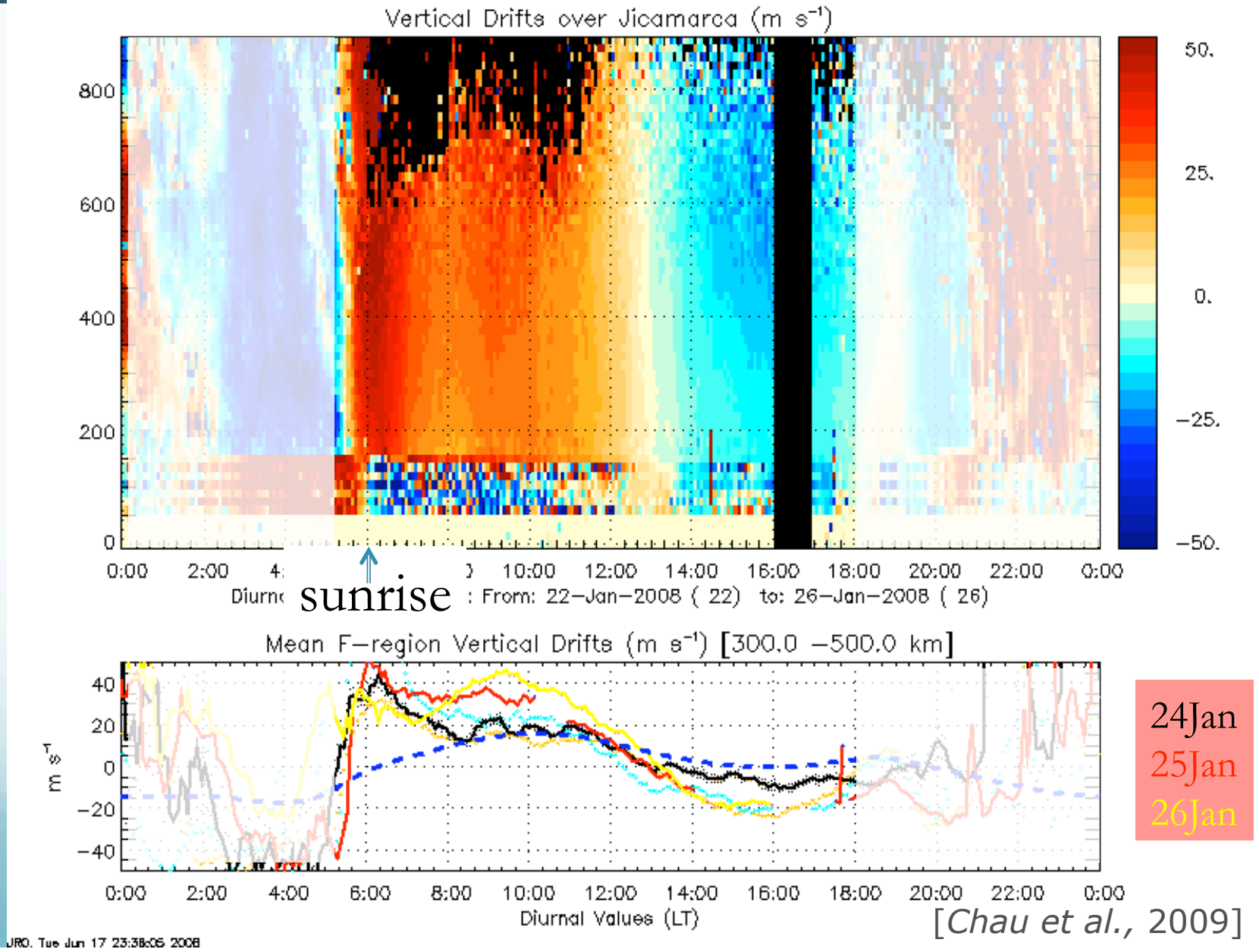
Solar activity
Minimum: F10.7< 80

Magnetic activity
Quiet: Kp < 3

Equatorial Ionospheric Drifts: Diurnal values before stratospheric warming

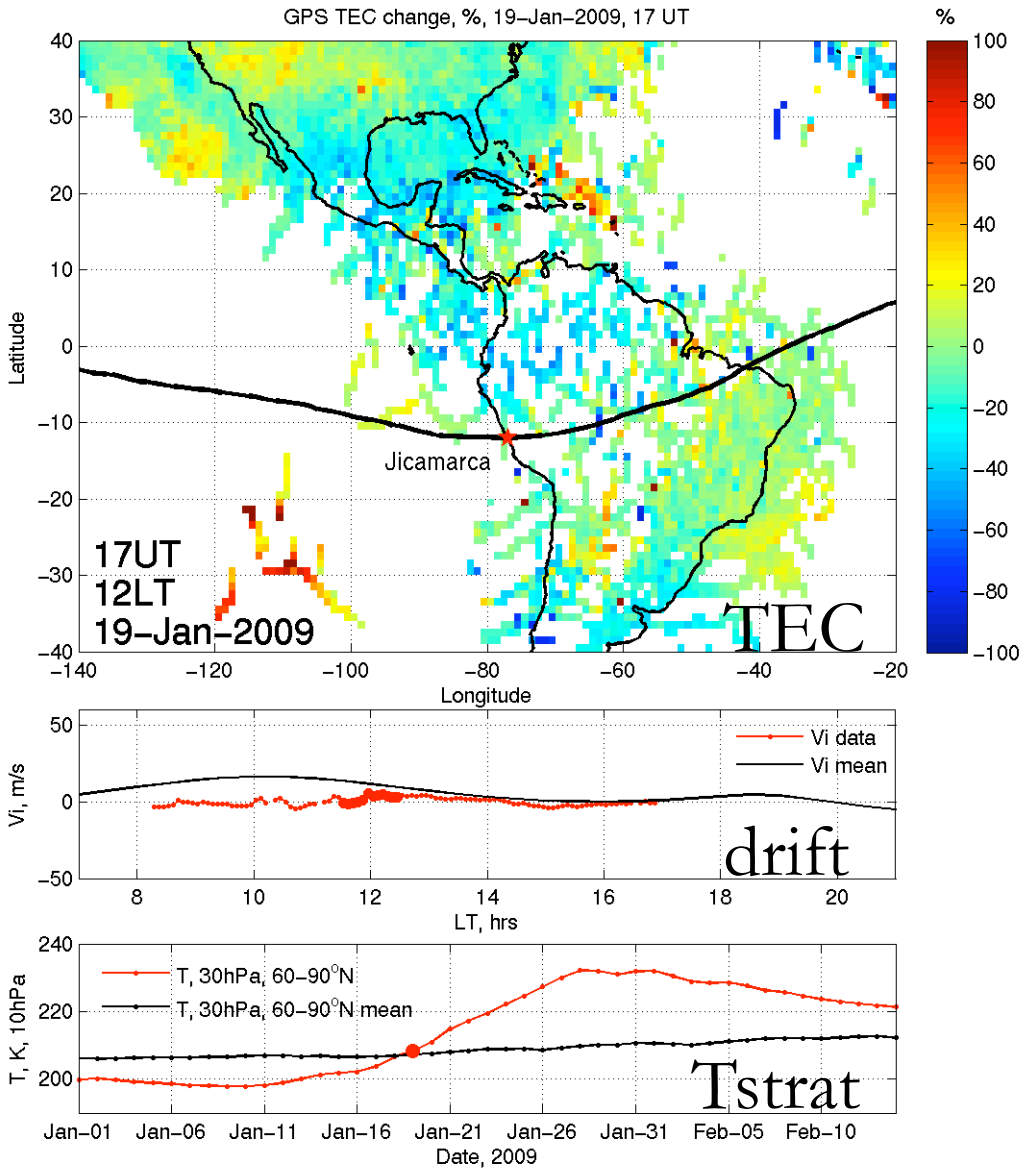


Equatorial Ionospheric Drifts: Diurnal values during stratospheric warming



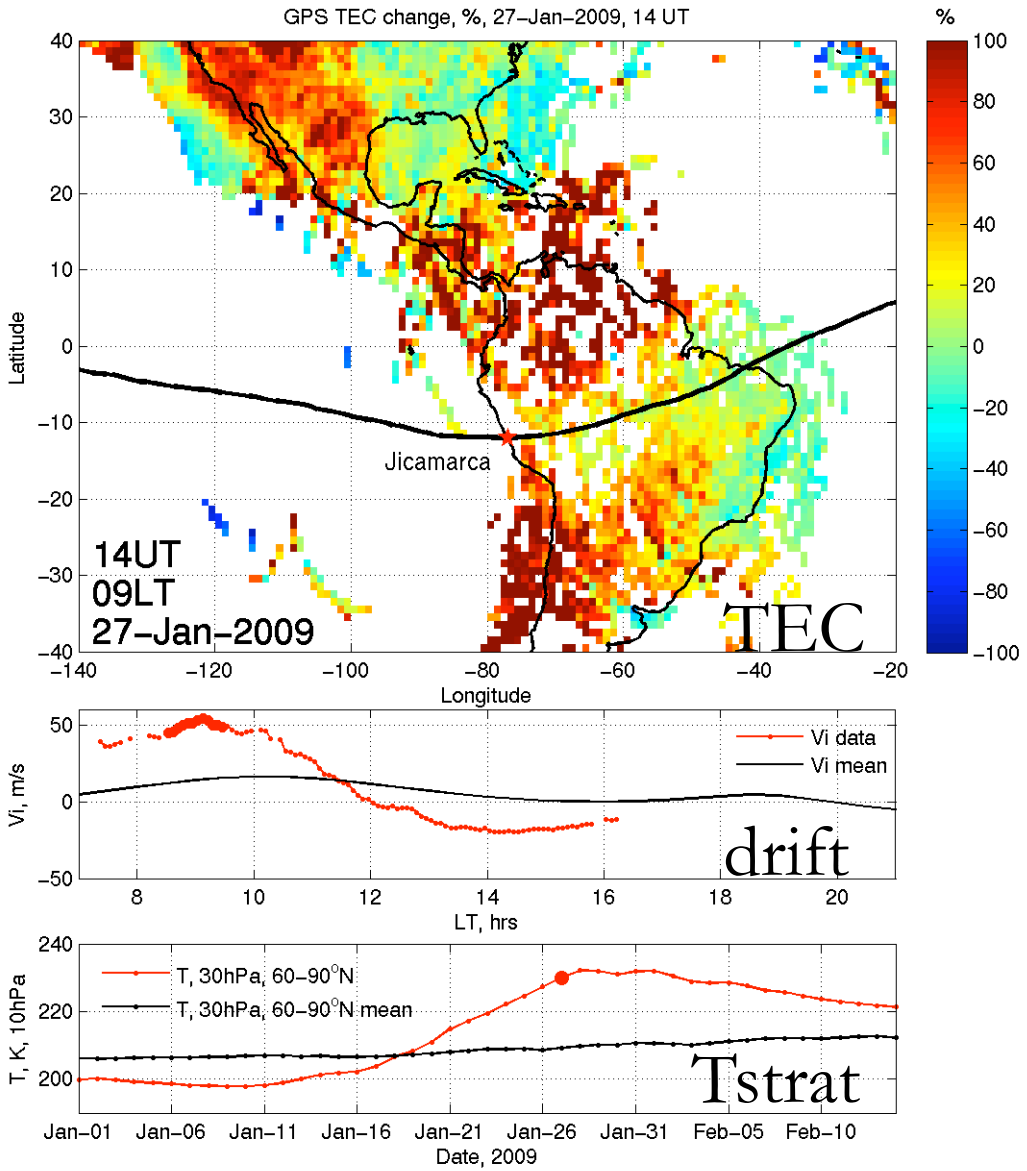
[*Chau et al.*, 2009]

GPS Total Electron Content change – no warming



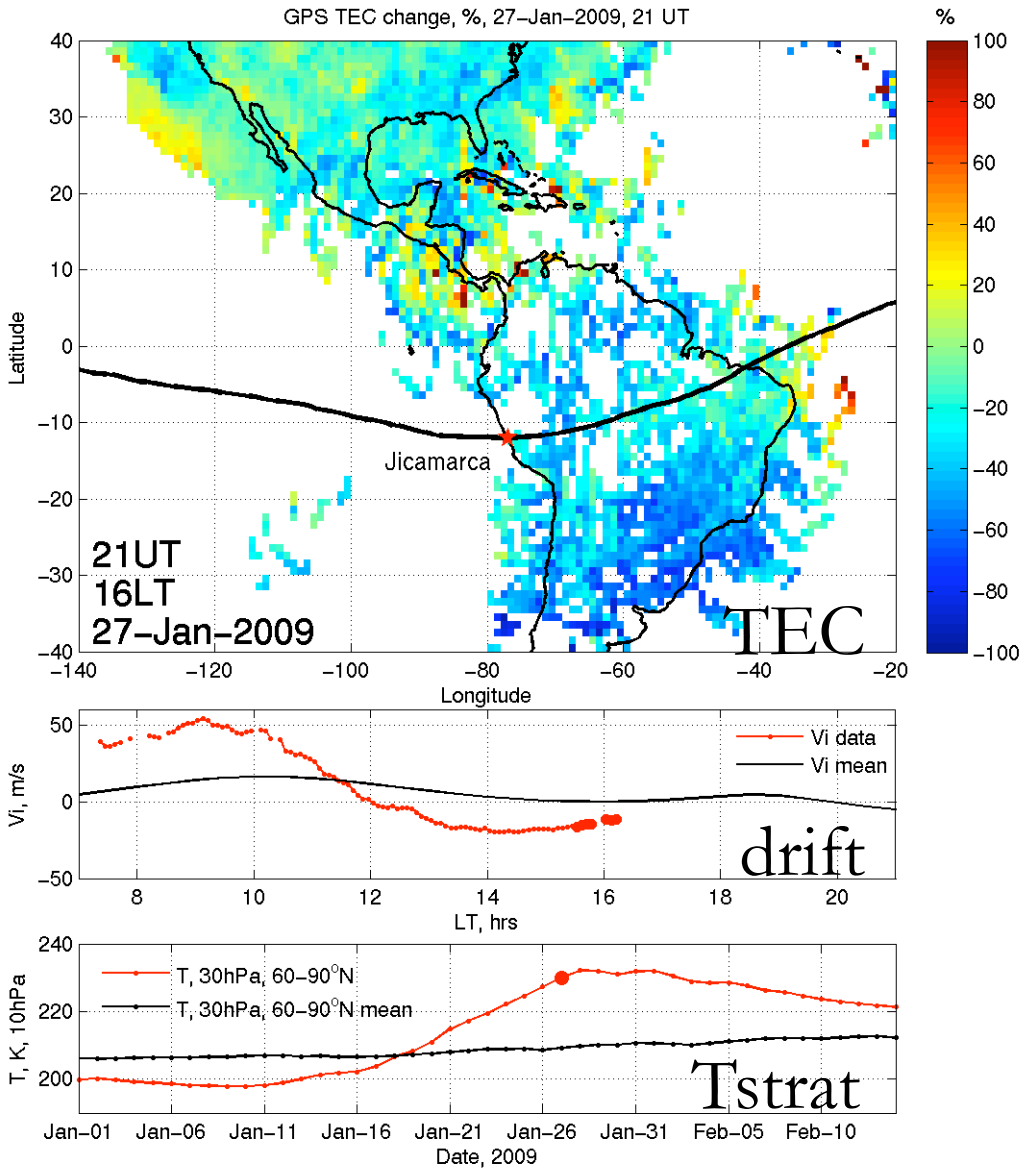
- GPS TEC (Total Electron Content) data show large-scale picture of ionospheric behavior
- Before the warming, TEC change is 10-20% from mean and vertical drift is small

GPS TEC during warming: morning sector



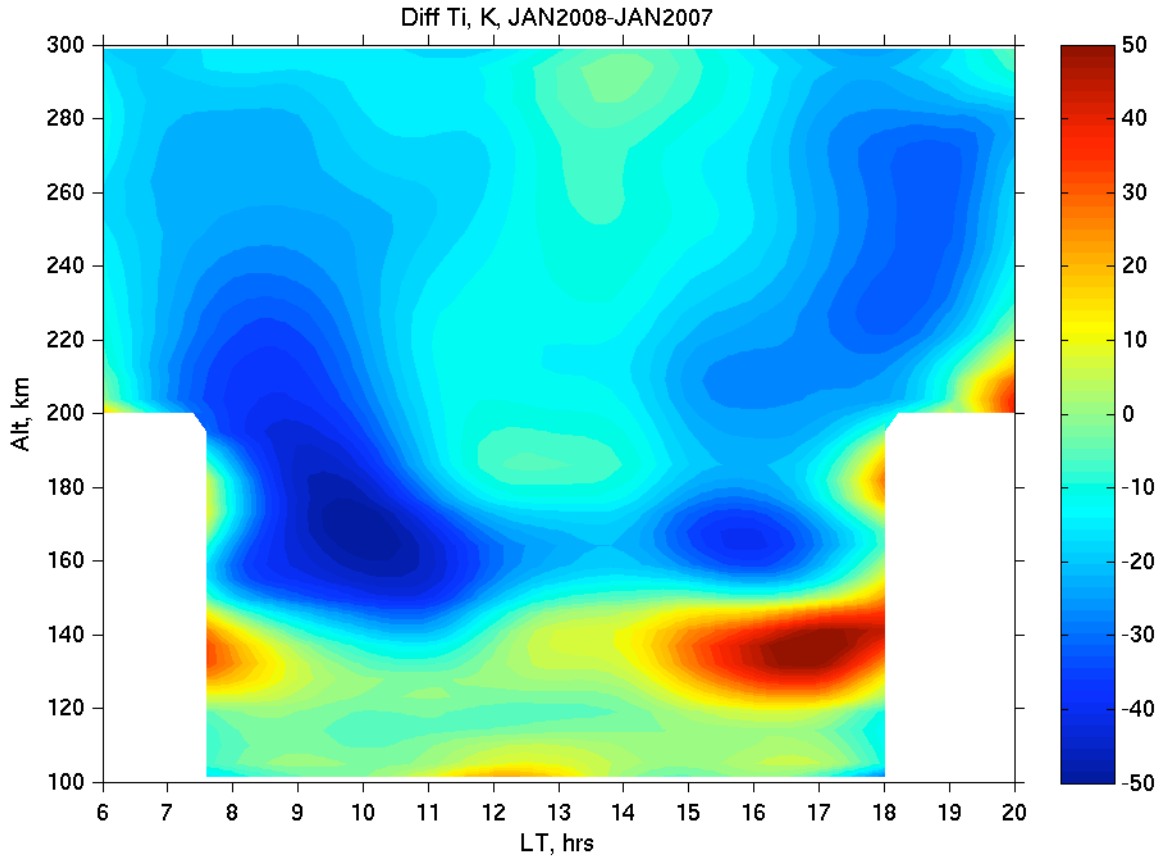
- During stratwarming, TEC increases by 50-100% in the morning
- Large upward drift in the morning
- The magnitude of increase is similar to effects of severe geomagnetic storms

GPS TEC during warming: afternoon sector



- During stratwarming, TEC decreases by ~50% in the afternoon
- Large downward drift in the afternoon
- The entire daytime ionosphere is affected

Middle latitude Ionospheric Ion Temperatures

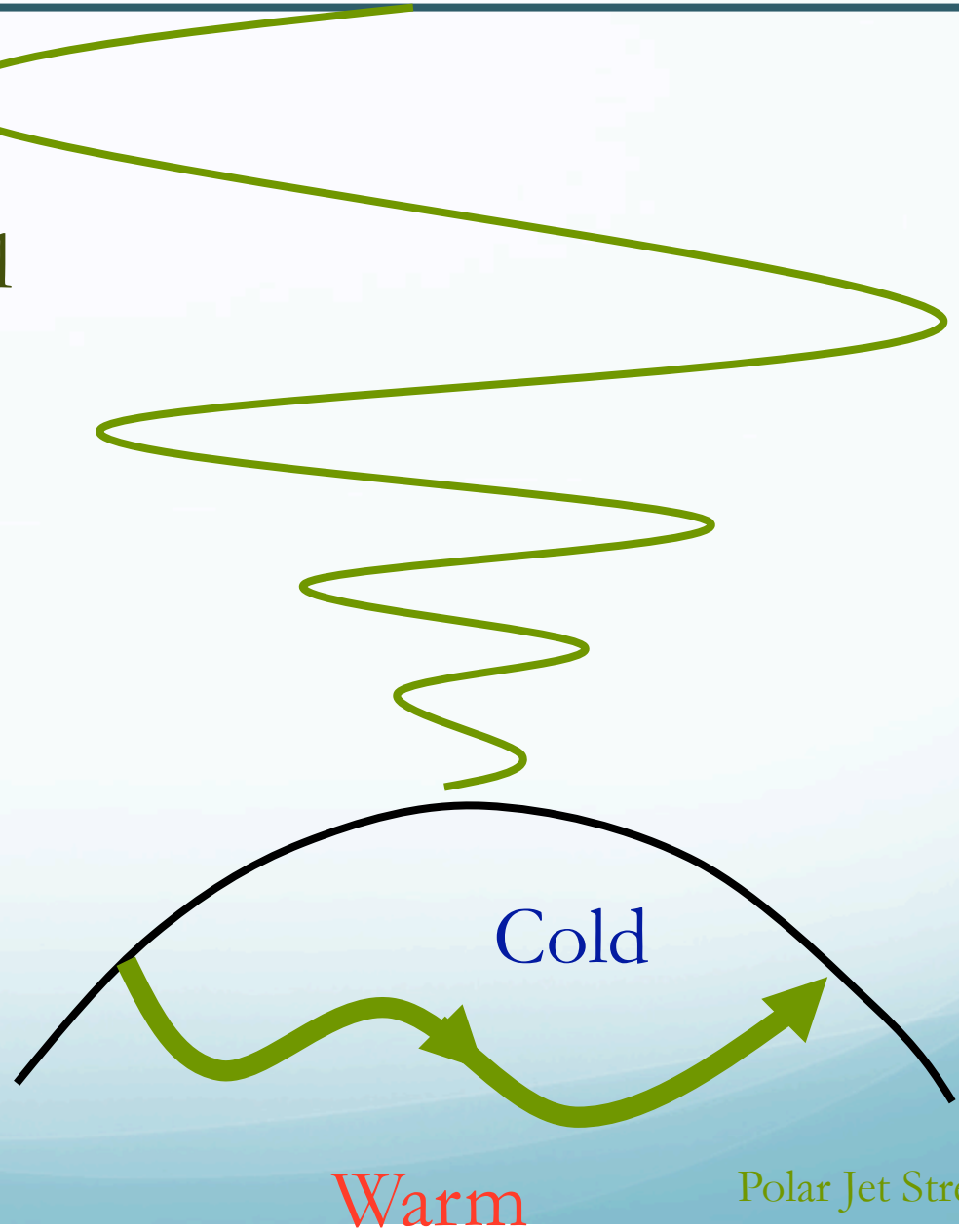


[*Goncharenko and Zhang*, 2008]

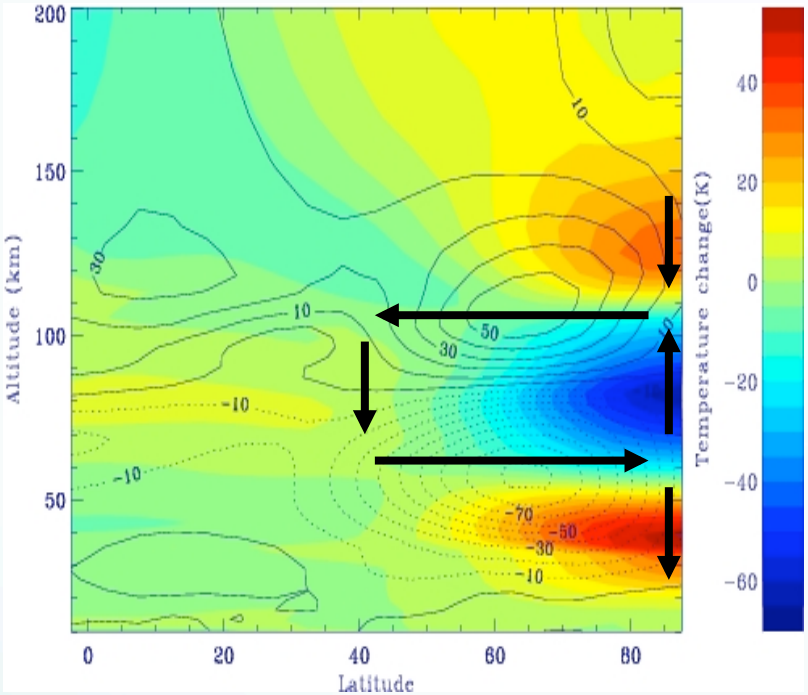
- Difference field of ion temperature (Jan 2008 – Jan 2007)
- Warming at 120-140km; cooling above ~150 km; 12-hour wave
- First experimental evidence of SSW effects in the ionosphere

Physical interpretation

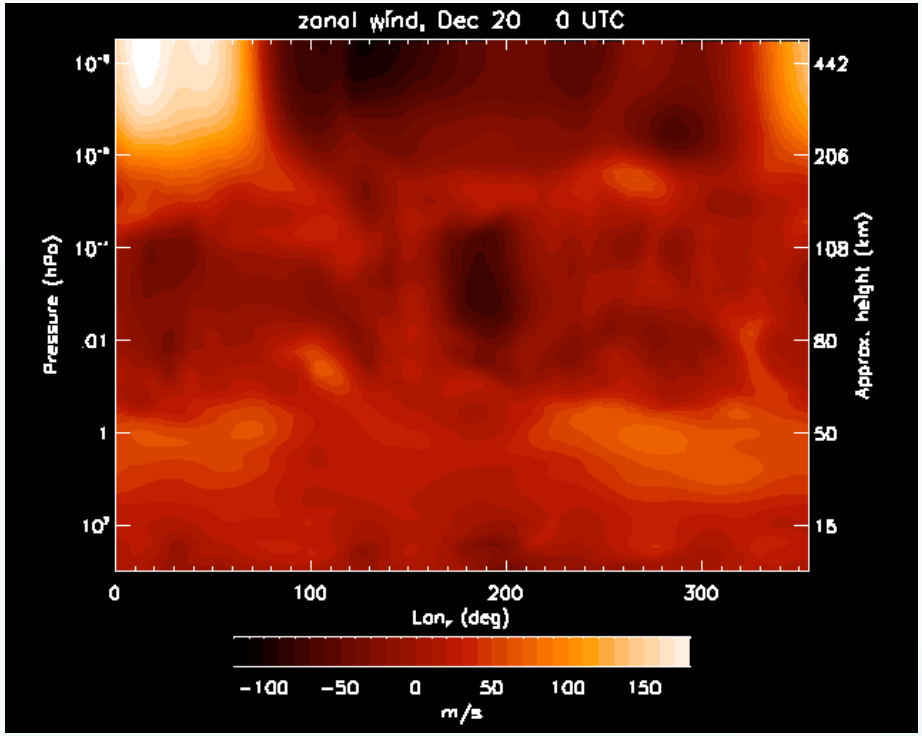
Atmospheric thermal tides from solar heating (e.g. ozone absorption of solar UV)



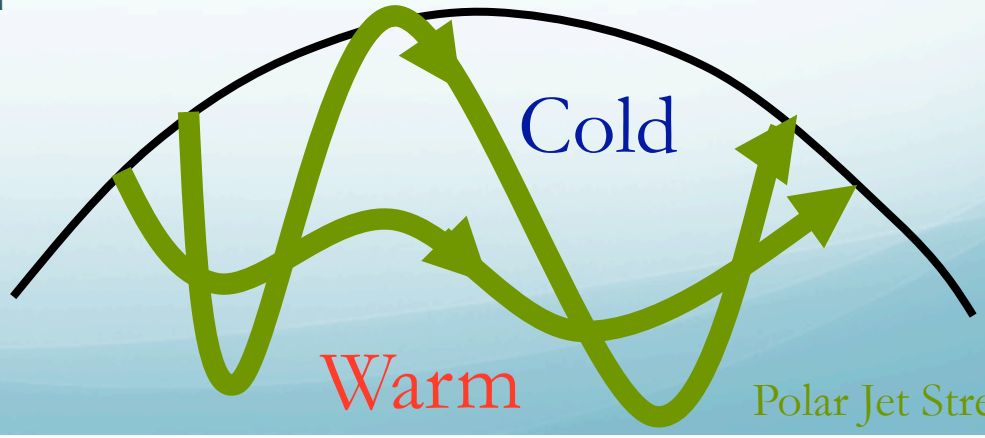
Development of stratospheric warming



[*Liu and Roble*, 2002]

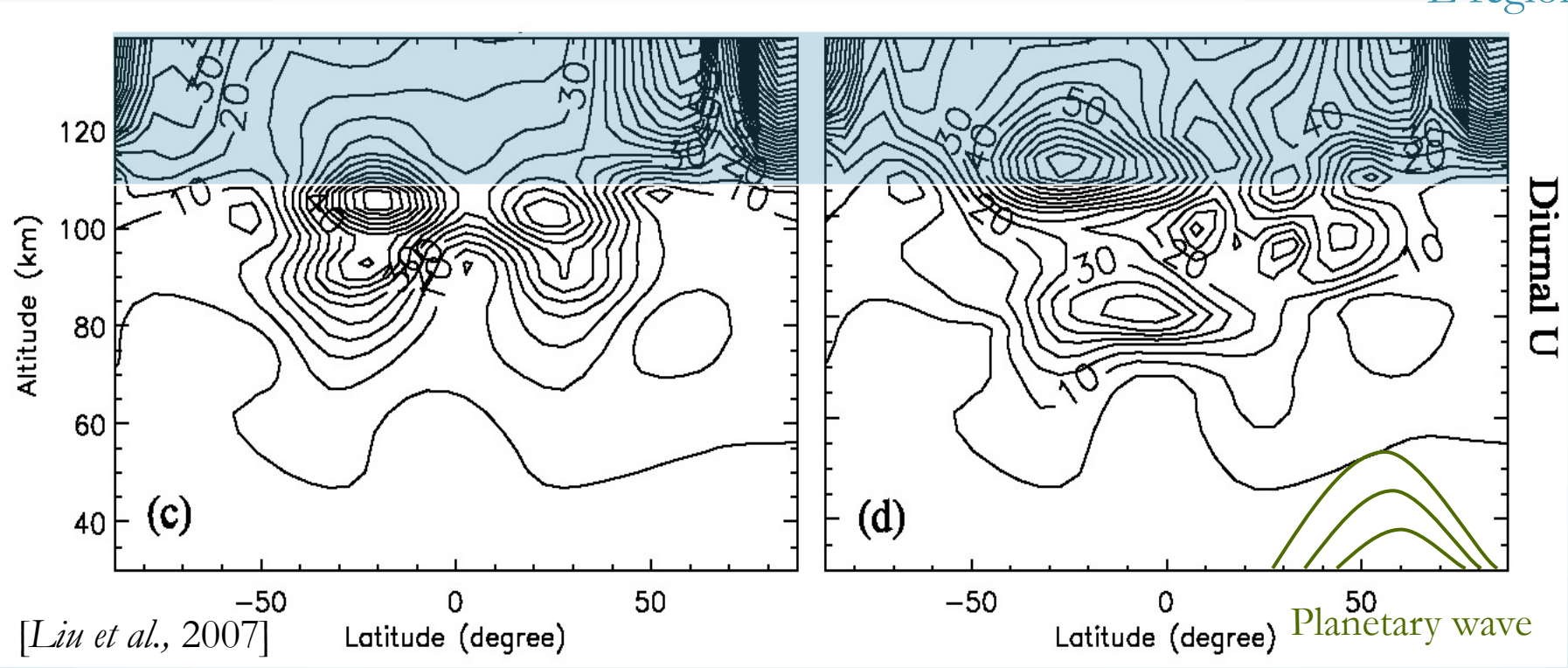


Normal
Stratospheric Warming



Effects of Planetary Waves on Winds

Ionosphere
E region

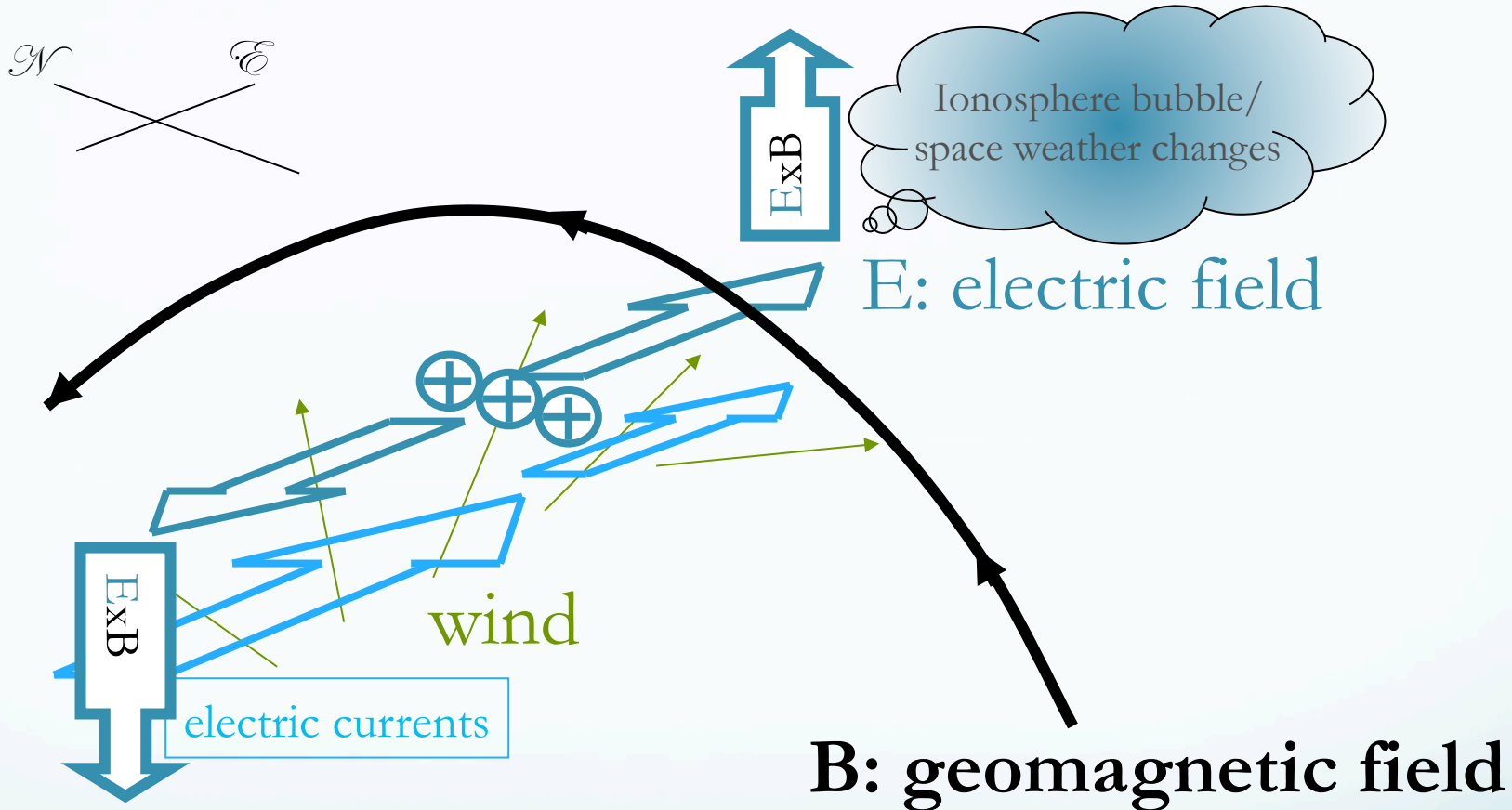


[*Liu et al.*, 2007]

Diurnal Zonal Wind
without Planetary waves

Diurnal Zonal Wind
with Planetary waves

Impact on Electric Field

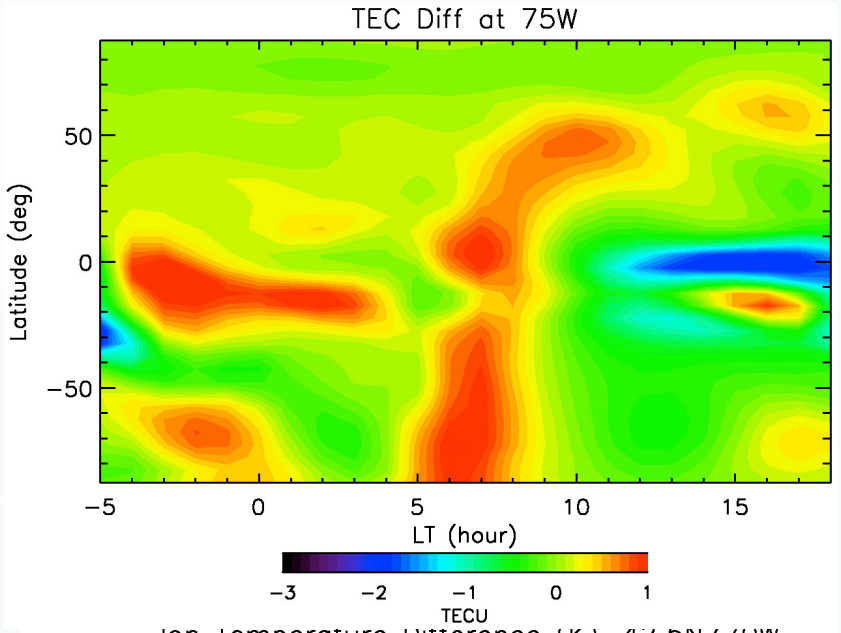


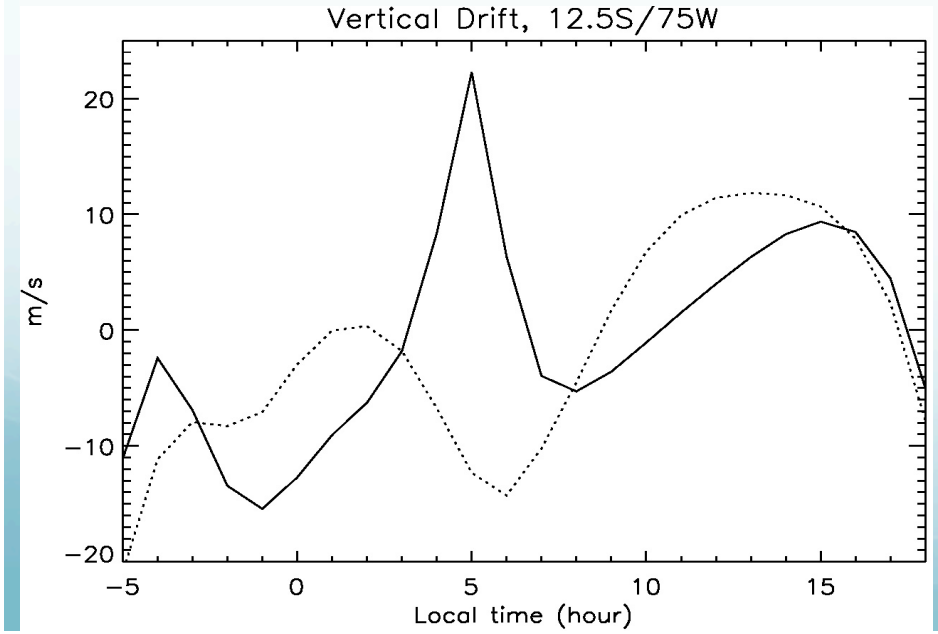
Planetary waves $\otimes$ *Tides* $\Rightarrow$ *wind structures* $\Rightarrow$ *current structures*

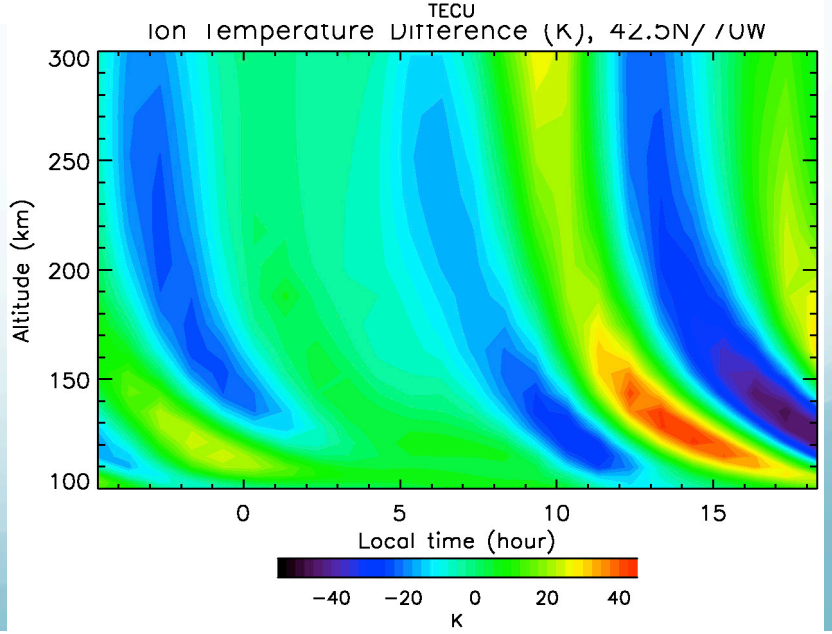
$\Rightarrow$ *electric field structures* $\Rightarrow$ *Space Weather Changes*

Effects of Planetary Waves in the Ionosphere

- Large electric fields around sunrise (Jicamarca observations)
- Total electron content (GPS results)
- Wave structure in Ion temperature differences (Millstone Hill observations)







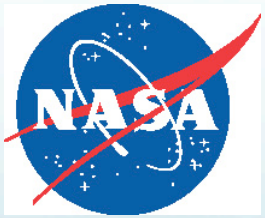
What do we do next?

- Clear observational evidence of lower atmosphere connection with the upper atmosphere, i.e., changes in electric field, electron densities, temperatures, associated to stratospheric warming events.
- New modeling results point to the propagation of lower atmospheric waves as one of the major causes of ionospheric variability.
- The connection is an important step for space weather, and also lead to some important questions:
  - Further confirm the mechanism, e.g. through measurement of neutral winds in the ionosphere.
  - Role of planetary waves/tides under varying seasonal, solar and geomagnetic conditions.
  - Understand initiation of actual space weather events by planetary waves/tides.

More information

- Larisa P. Goncharenko, Research Scientist, Massachusetts Institute of Technology, Haystack Observatory, USA (lpg@haystack.mit.edu, 781-981-5622)
- Jorge L. Chau, Senior Research Scientist, Jicamarca Radio Observatory, Peru (jchau@jro.igp.gob.pe, 511-421-3842)
- Han-Li Liu, Scientist, High Altitude Observatory, National Center for Atmospheric Research, USA (liuh@ucar.edu, 303-497-1564)

- Link to movies: http://www.haystack.mit.edu/swfx/ep4/index.html



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