Recurrent Geomagnetic Activity Driving a Multi-Day Response in the Thermosphere and Ionosphere

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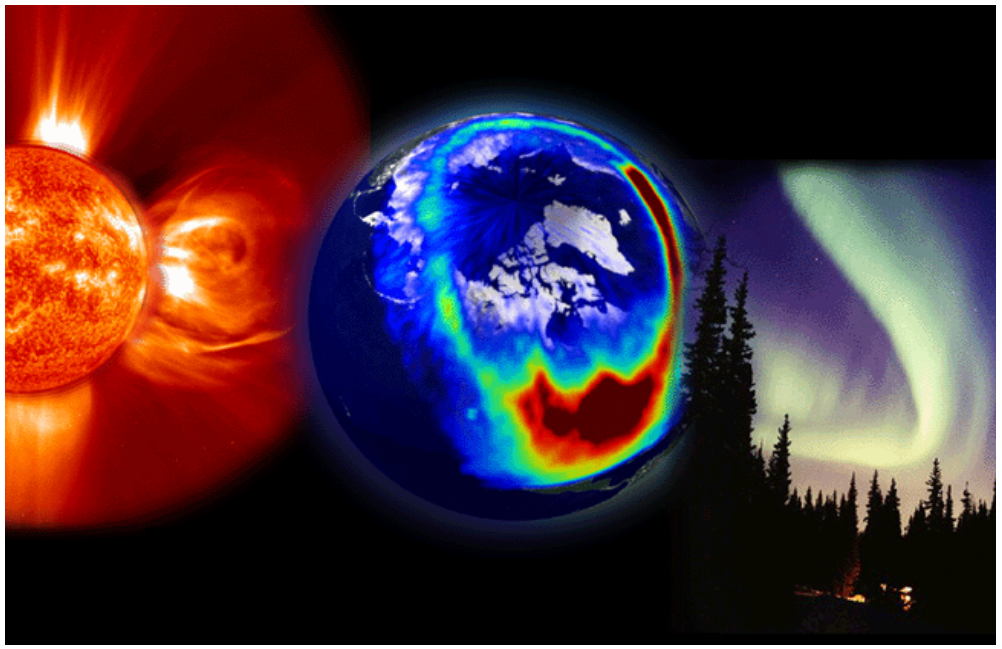
Upper Atmosphere Episodes of Change at Multi-Day Periodicities

Discovery: Recent satellite measurements have discovered episodes of change in the Earth's upper atmosphere at periods near **5, 7 and 9 days** that are attributed to recurrent high speed solar wind stream disturbances and coronal hole distributions on the sun.

Lei, J., J. P. Thayer, J. M. Forbes, E. K. Sutton, and R. S. Nerem (2008), Rotating solar coronal holes and periodic modulation of the upper atmosphere, *Geophys. Res. Lett.*, 35, L10109, doi:10.1029/2008GL033875.

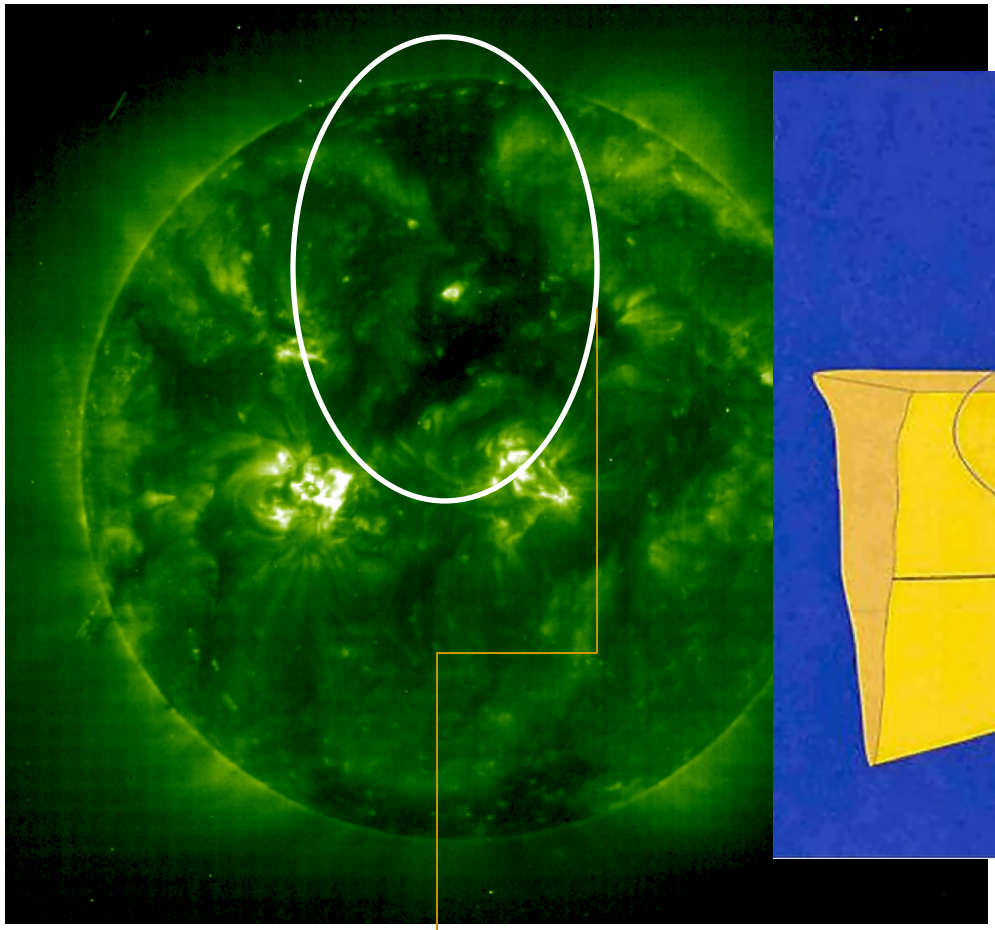
Thayer, J. P., J. Lei, J. M. Forbes, E. K. Sutton, and R. S. Nerem (2008), Thermospheric density oscillations due to periodic solar wind high-speed streams, *J. Geophys. Res.*, 113, A06307, doi:10.1029/2008JA013190.

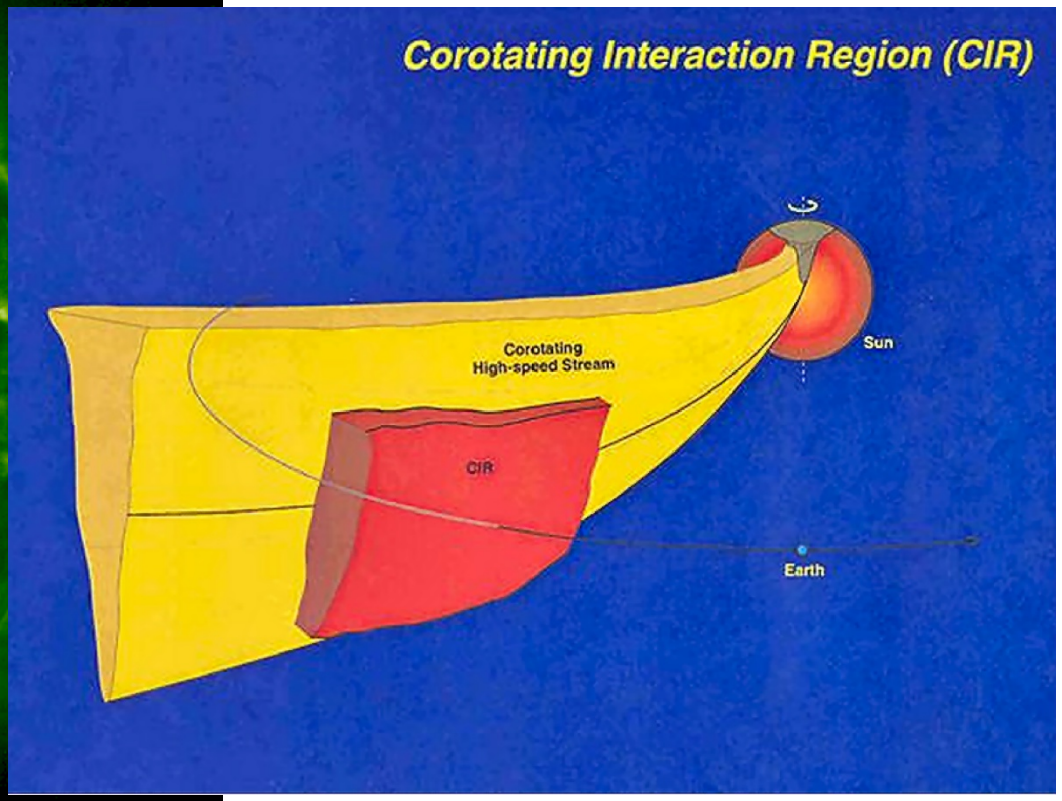
Mlynczak, M. G., F. J. Martin-Torres, C. J. Mertens, B. T. Marshall, R. E. Thompson, J. U. Kozyra, E. E. Remsberg, L. L. Gordley, J. M. Russell III, and T. Woods (2008), Solar-terrestrial coupling evidenced by periodic behavior in geomagnetic indexes and the infrared energy budget of the thermosphere, *Geophys. Res. Lett.*, 35, L05808, doi:10.1029/2007GL032620.



SOHO/EIT 195A image of the Sun – April 9, 2005

Courtesy of Vic Pizzo, NOAA/SEC and Leslie Mayer, CU/CIRES





Equatorward extension of the northern polar coronal hole

2005 Periodograms – Subharmonics of a Solar Rotation

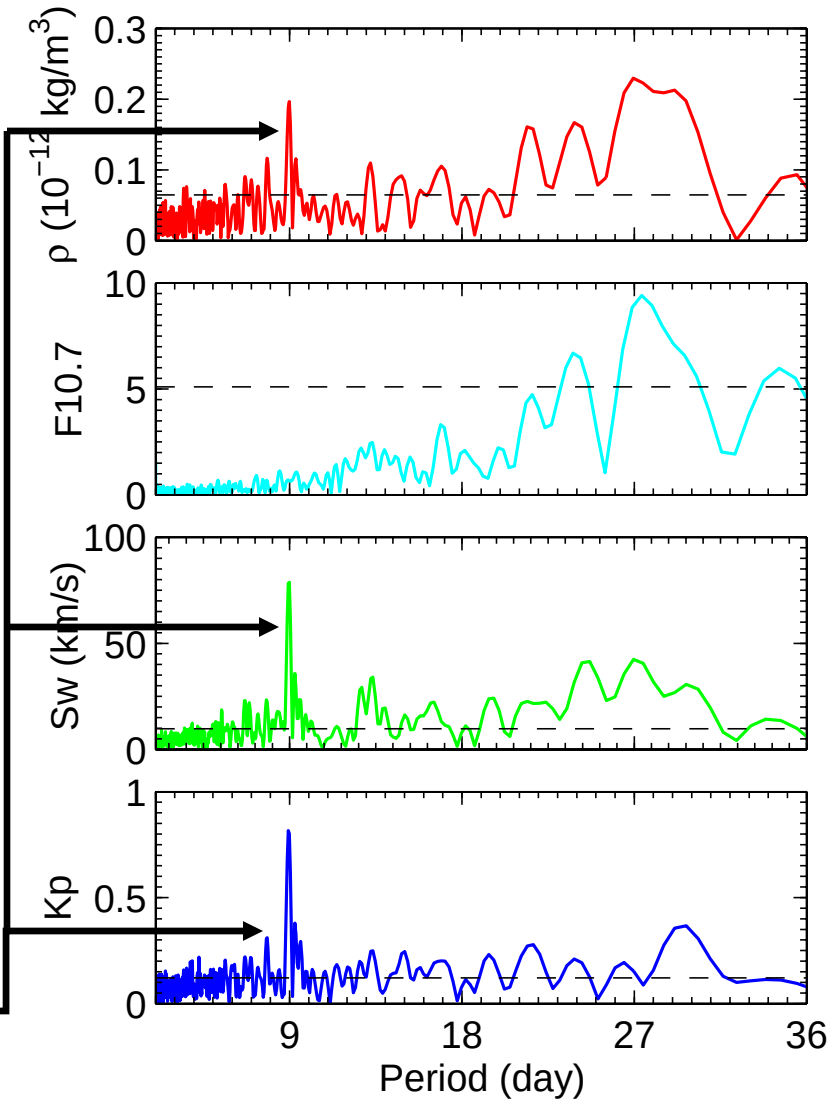
Density - 400km altitude

Solar EUV flux index

Solar wind speed

Geomagnetic Activity Index

27 days/3



These studies demonstrated…

- A solar-terrestrial connection of persistent solar surface effects (coronal holes) to ITM response enabling a level of predictability
- Recurrent periodic forcing that enabled identification and coherency of multiday responses in the ITM at periods of 5.4, 6.75 and 9 days
- Independence of geomagnetic forcing from EUV forcing on the ITM at periods less than 13 days enabling isolation of geomagnetic effects on the ITM.

In addition…

The current solar minimum with nearly steady low solar flux allows for investigation of how the preconditioned state of the ITM responds to recurrent geomagnetic activity .

Preconditioning of the Thermosphere Response to Recurrent Geomagnetic Activity in 2008

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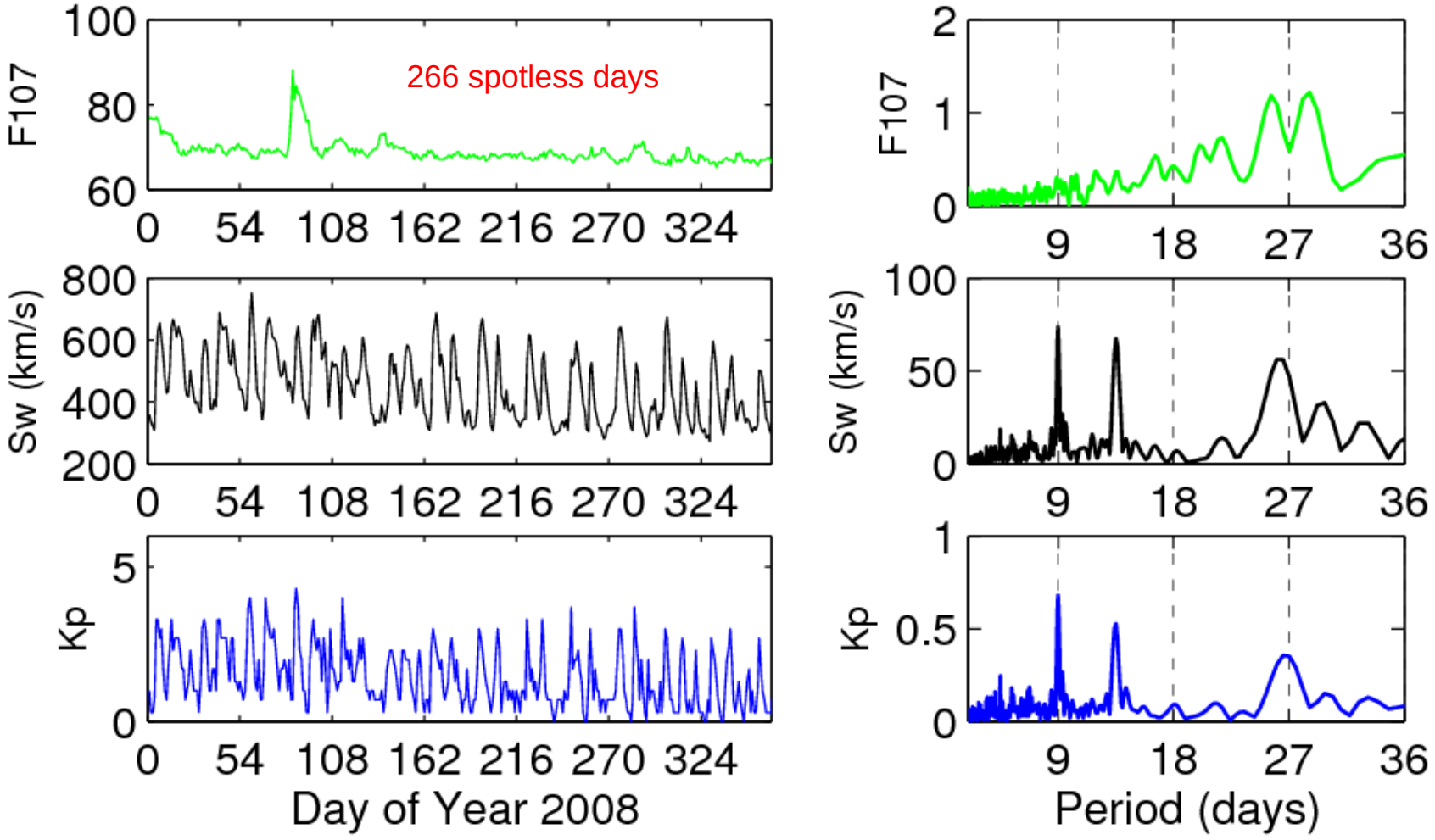
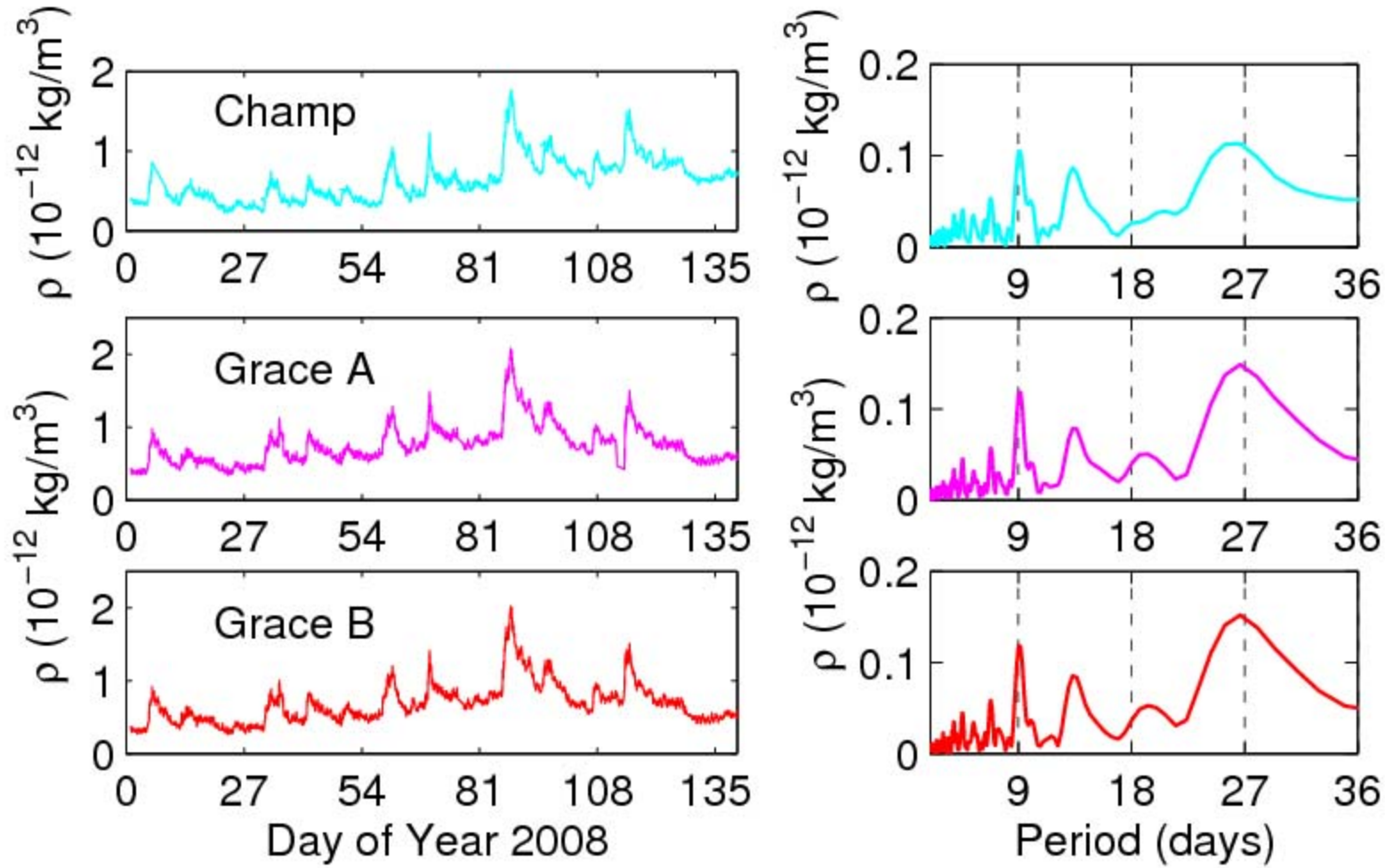
High speed solar wind streams in 2008



Geospace was not quiet!

Thermosphere Mass Density Response in 2008



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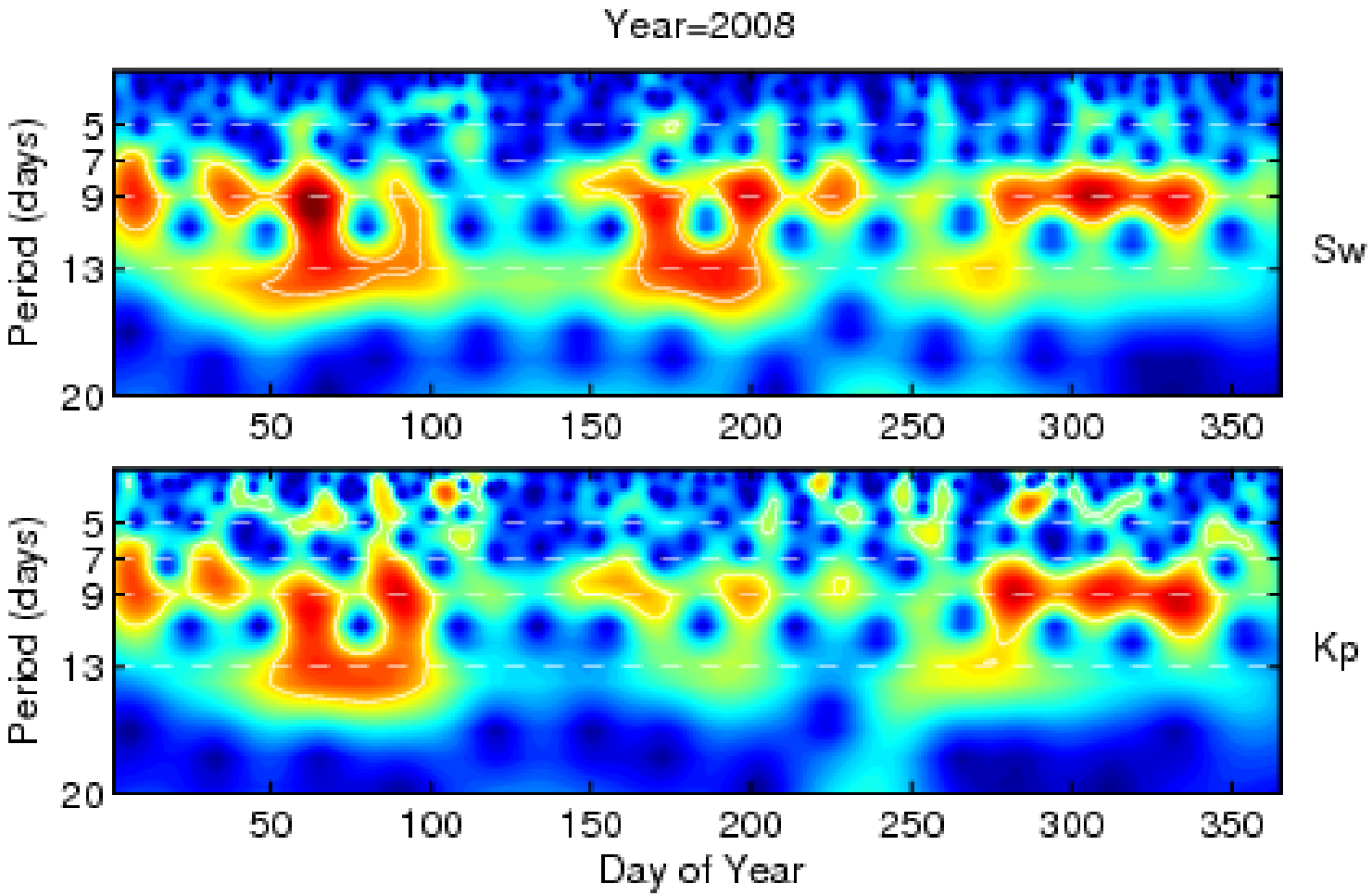
Spectrogram of Solar Wind Velocity and Kp Index for 2008



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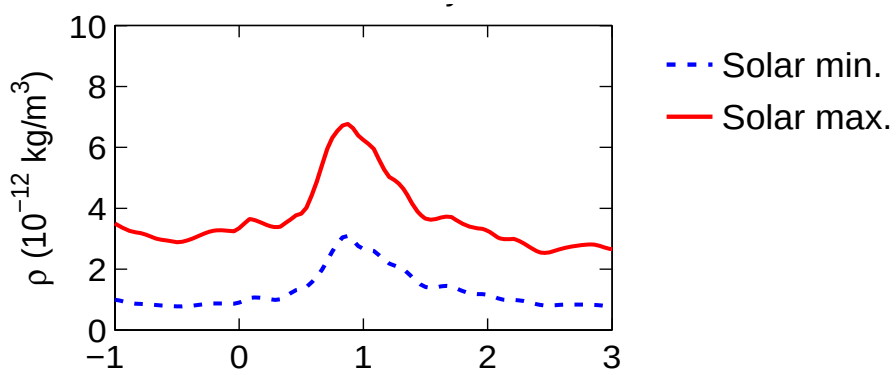
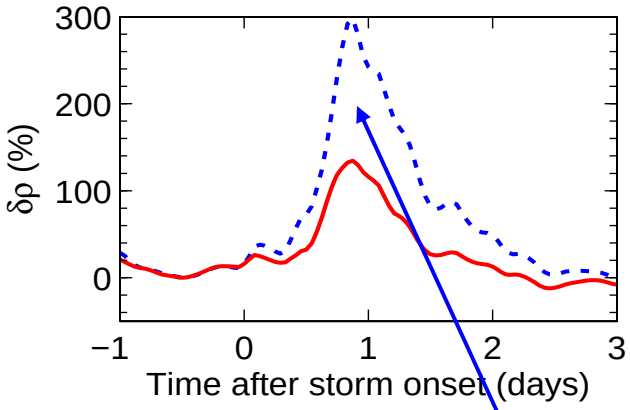
Thermosphere response to geomagnetic forcing: Preconditioning

Density at 400 km



Relative Perturbations



Relative changes in thermosphere density response to geomagnetic forcing is stronger under low activity condition

Isolation of the Global MLT Thermal Response to Recurrent Geomagnetic Activity

Loren C. Chang, Jeffrey P. Thayer, Jiuhou Lei, and Scott E. Palo

Department of Aerospace Engineering Sciences

University of Colorado

Acknowledgements: The SABER Science Team

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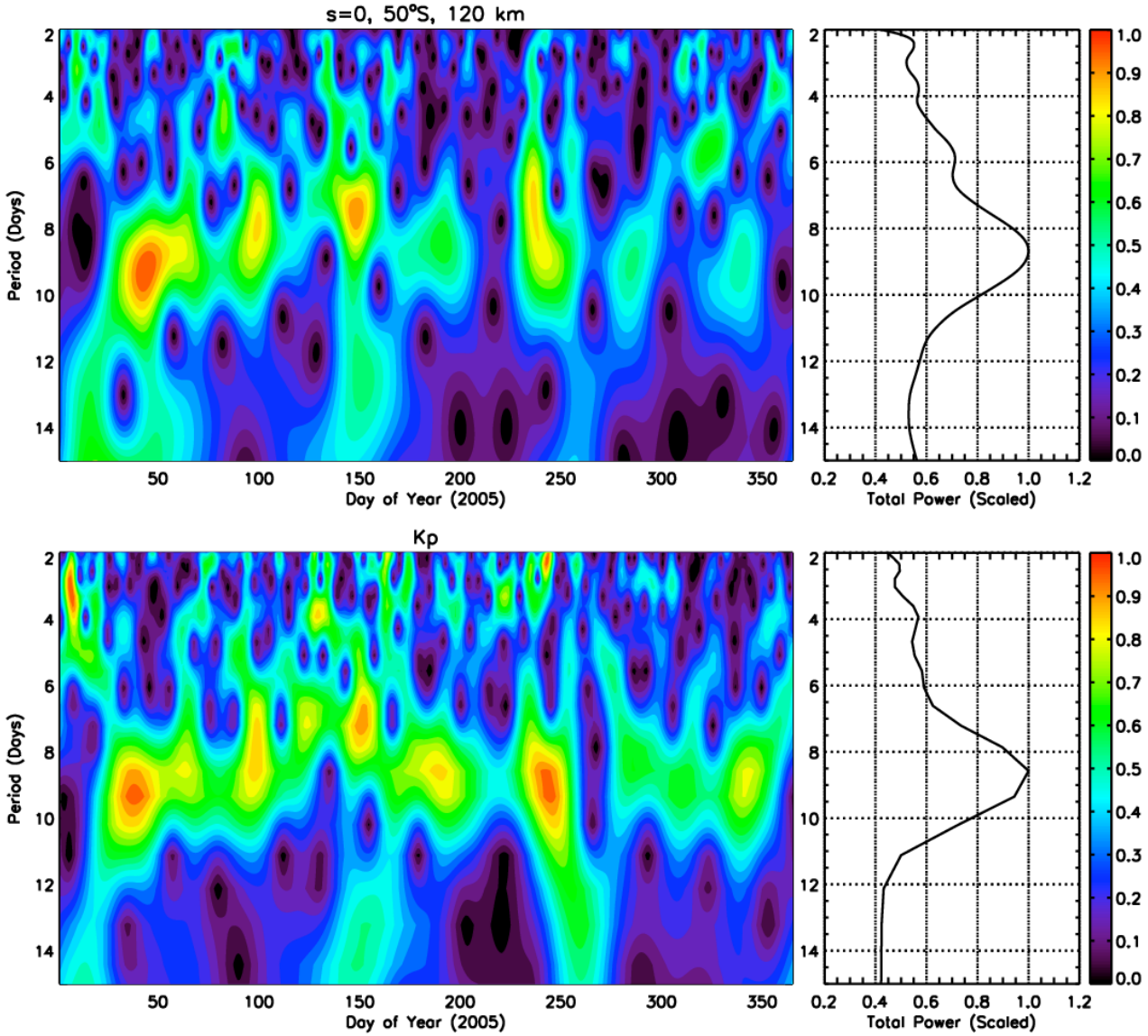
Dataset and Analysis

- SABER Version 1.07
  - Continuous temperature coverage from 50°S - 50°N in the MLT region.
  - Data from 2005 binned into 5° latitude grid, between 80 - 120 km altitude.
  - Zonal average taken at each latitude bin for each day, forming a time series of the zonally symmetric (s=0) components.
    - Use of s=0 component eliminates possible contributions from propagating planetary waves in the MLT excited from lower atmosphere.
  - Spectrogram for resulting s=0 time series computed using wavelet analysis.

SABER & Kp Wavelet Spectra

s=0 Component, altitude of 120 km, latitude 50°S



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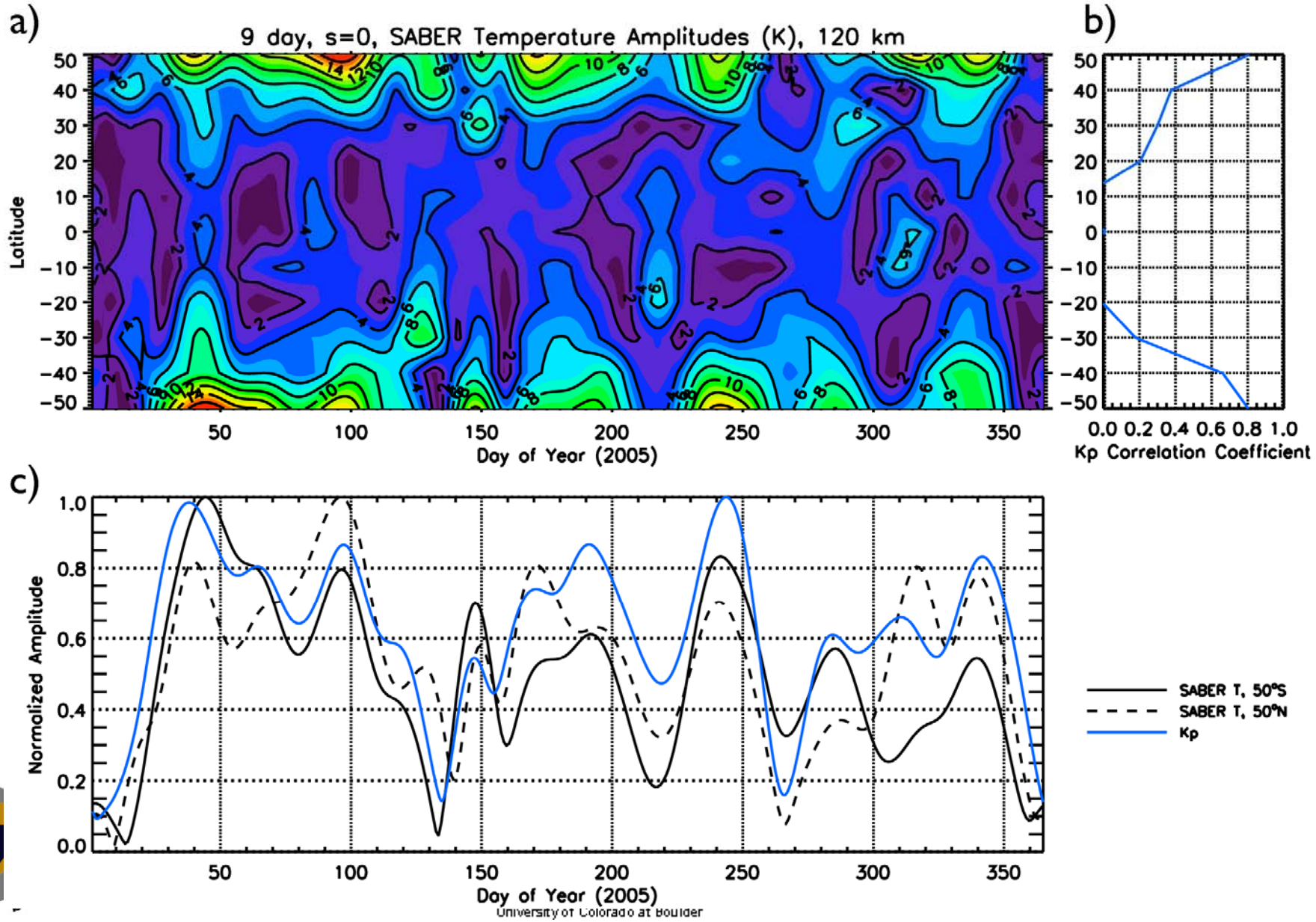
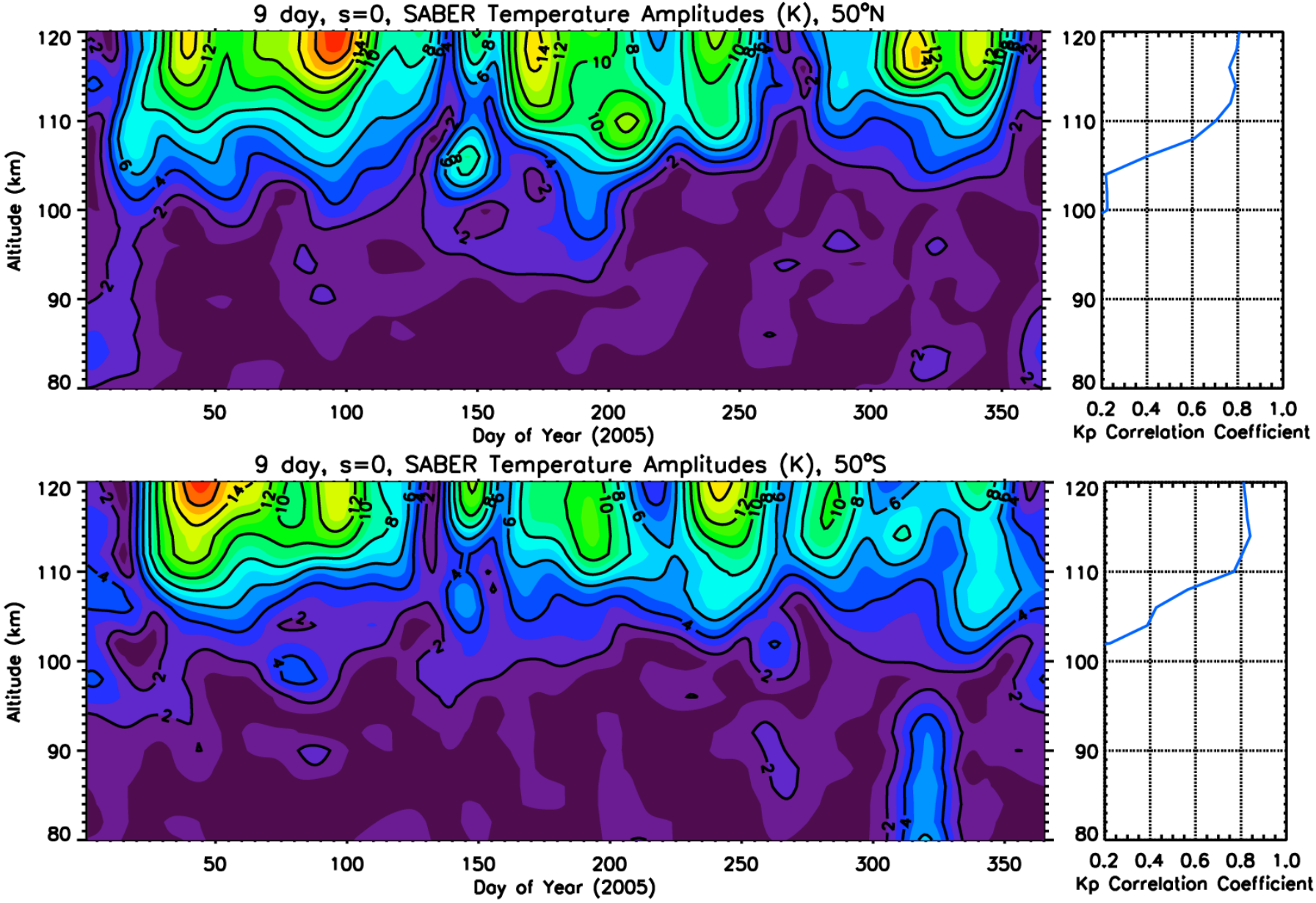
Temperature and Kp Correlations with Latitude

SABER 9 day s=0 Component



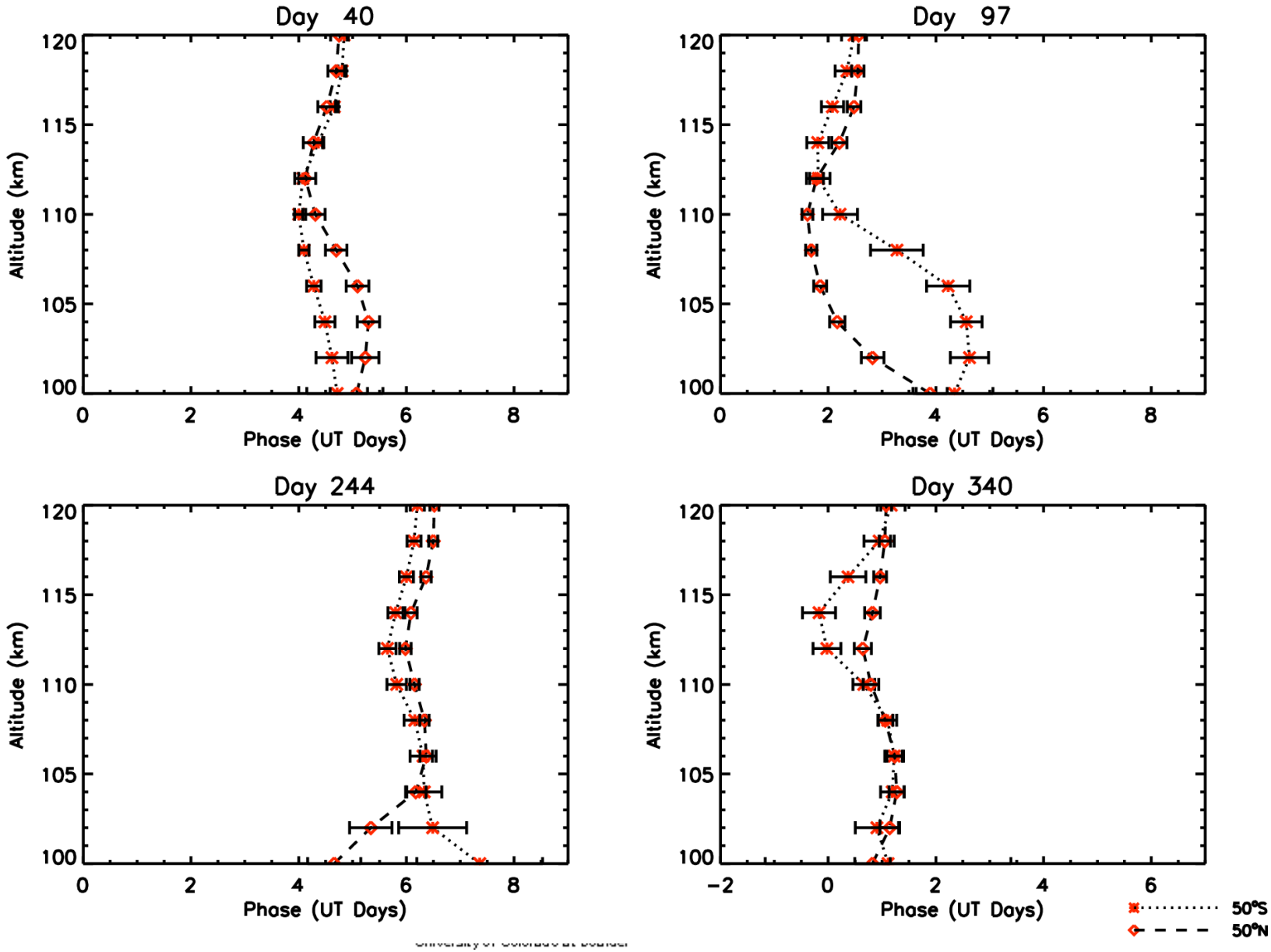
Temperature and Kp Correlations with Altitude

SABER 9 day s=0 Component, 50°N & 50°S



Temperature Phase Maxima for Select Disturbed Days

SABER 9 day s=0 Component, 50°N & 50°S



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Study Outcome

• The zonally symmetric nature, inter-hemispheric phase coherence, and correlation to *Kp* of such disturbances makes them distinct from propagating planetary waves in the same region, excited from the lower atmosphere.

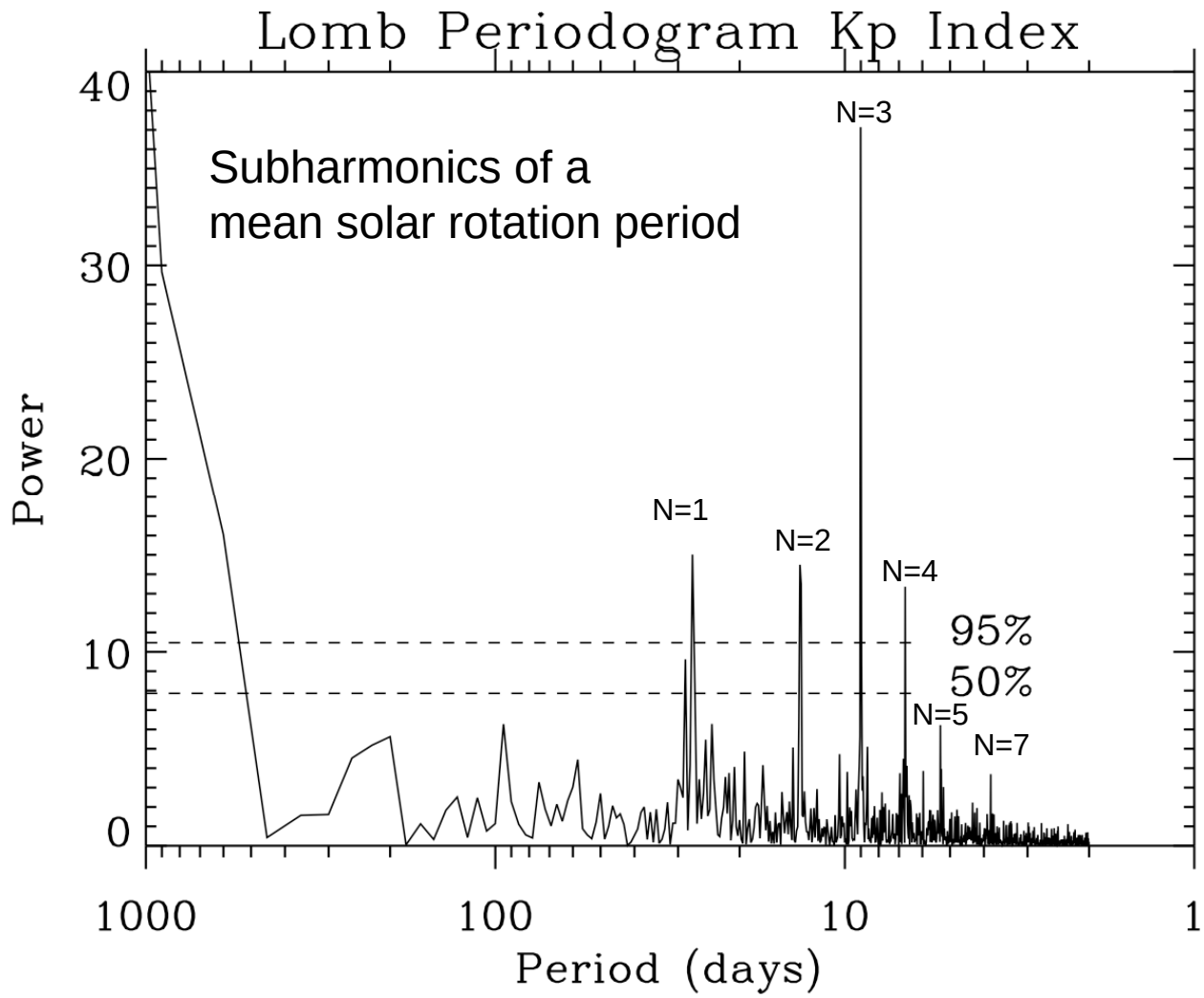
• CIR forced geomagnetic disturbances can be a source of thermal variability in the mesosphere and lower thermosphere region.

• Identified zonally symmetric disturbances at 9 day period in 2005 SABER temperatures above 100 km and poleward of 40 degrees latitude correlated positively with similar fluctuations in *Kp,*.

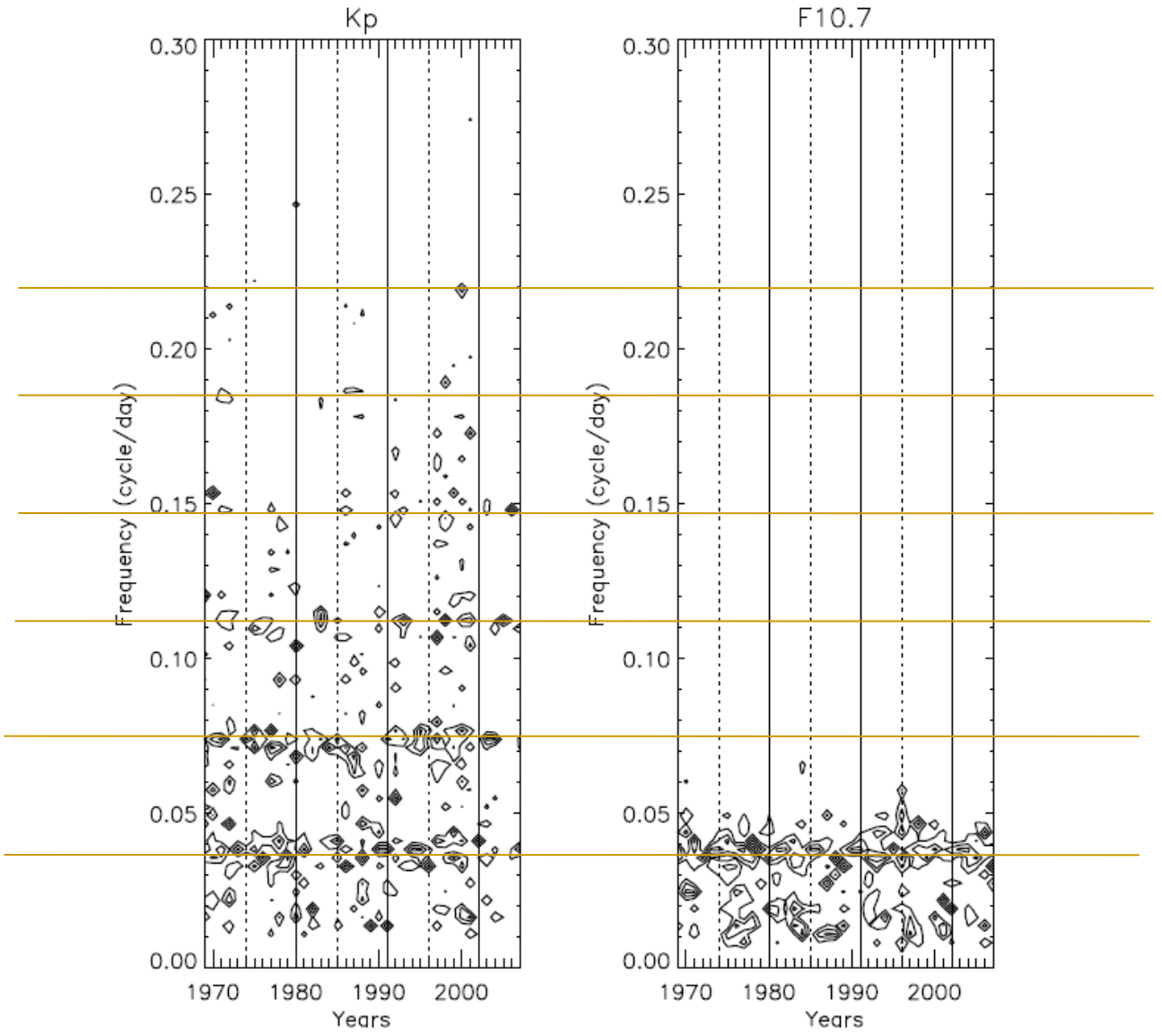
• Such temperature disturbances are in phase between the high latitudes of both hemispheres, with phase analysis showing disturbances occurring first around 110 km. Not clear as to the cause of the phase behavior.

Chang, L. C., J. P. Thayer, J. Lei, and S. E. Palo (2009), Isolation of the global MLT thermal response to recurrent geomagnetic activity, *Geophys. Res. Lett.*, 36, L15813, doi:10.1029/2009GL039305.

Periodogram Analysis of Kp Index 2002-2006



Kp Index Periods for Four Solar Cycles



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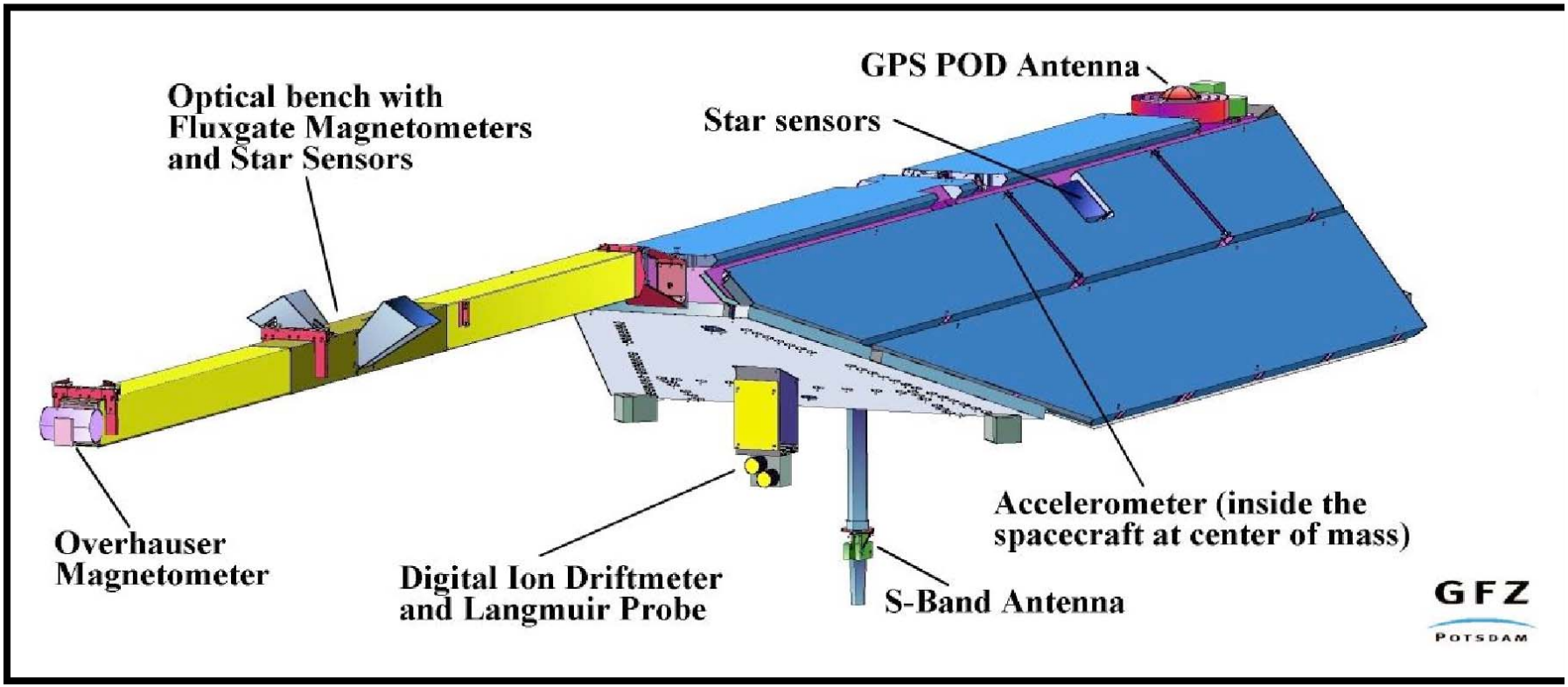
Concluding Remarks

- **Recurrent EPP events at 9 and 6.75, 5.4 day periods should be prevalent throughout the declining and minimum phase of this solar cycle;**

- **These EPP events can be isolated owing to little correlation with solar flux ($F_{10.7}$) and their energetics may be related to solar wind-M-I coupling processes**

- **Care must be taken for data sets that are taken aperiodically or infrequently as aliasing of these natural periodicities will occur.**

CHAMP Satellite launched in July 2000 at 450 km altitude in a near circular orbit with an inclination of 87.3° and a local time precession of 5.44 min/day (12 hours / 133 days)

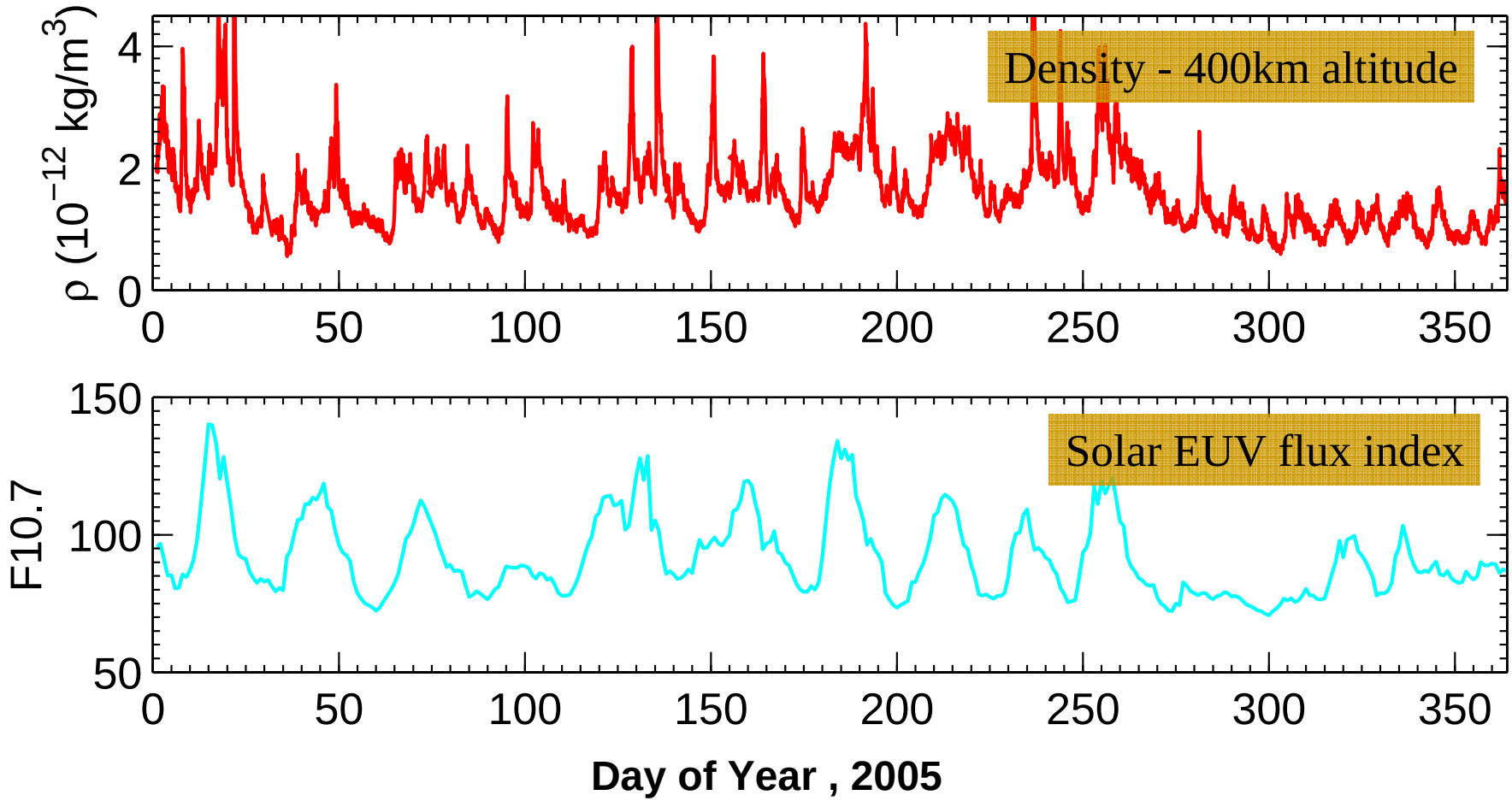


The physical parameters of the CHAMP satellite are:

- **Total Mass 522 kg**
- **Length (with 4.044 m Boom) 8.333 m**
- **Area to Mass Ratio 0.00138 m^2kg^{-1}**
- **Height 0.750 m**
- **Width 1.621 m**

Sutton et al., *J. Spacecraft and Rockets*, 2007

Periodic Thermosphere Mass Density Perturbations for Year 2005



Note: Orbit-averaged density with an overall estimated error (systematic and statistical) of less than 10%

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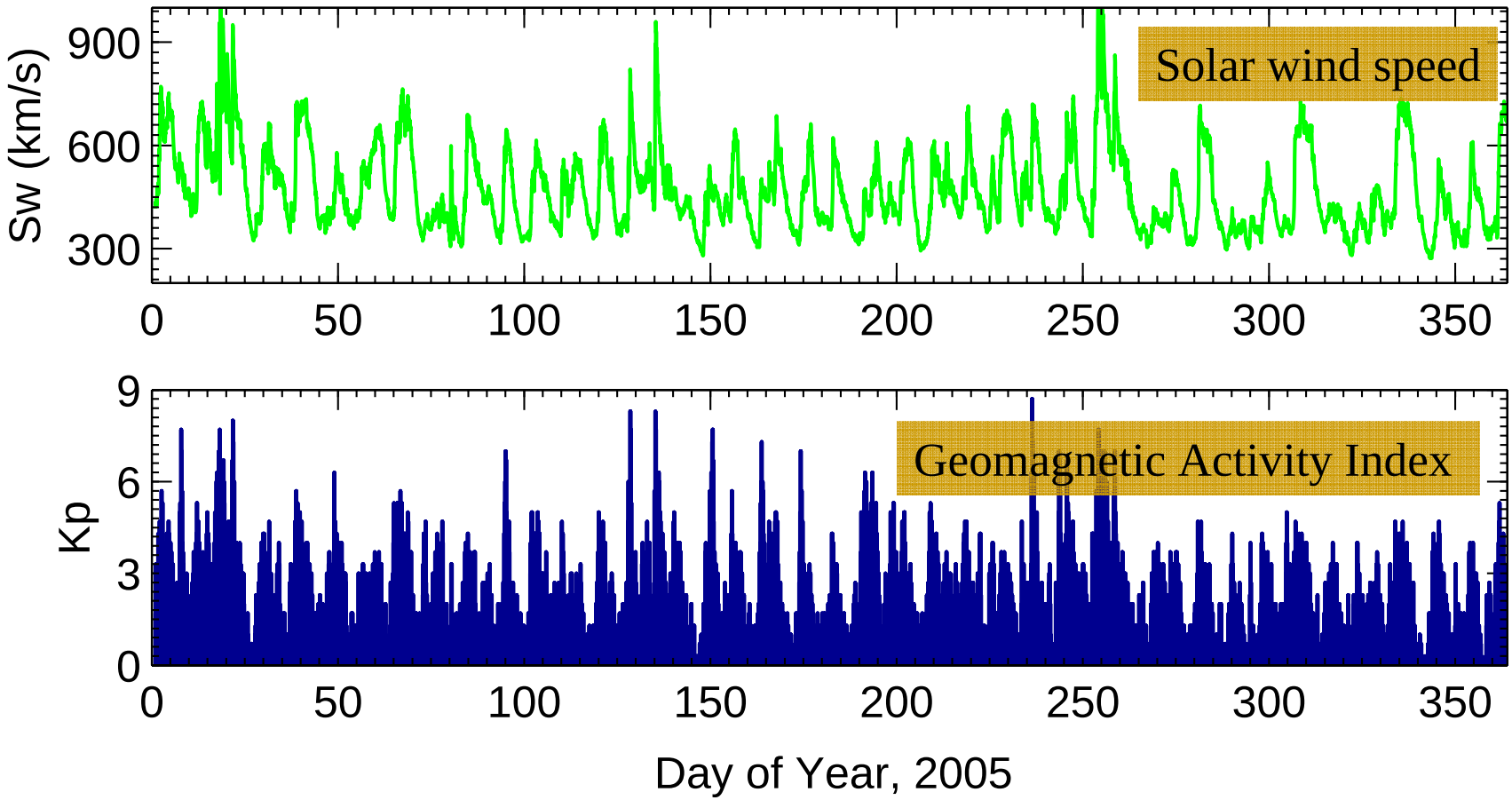
Solar Wind and Geomagnetic Activity for Year 2005



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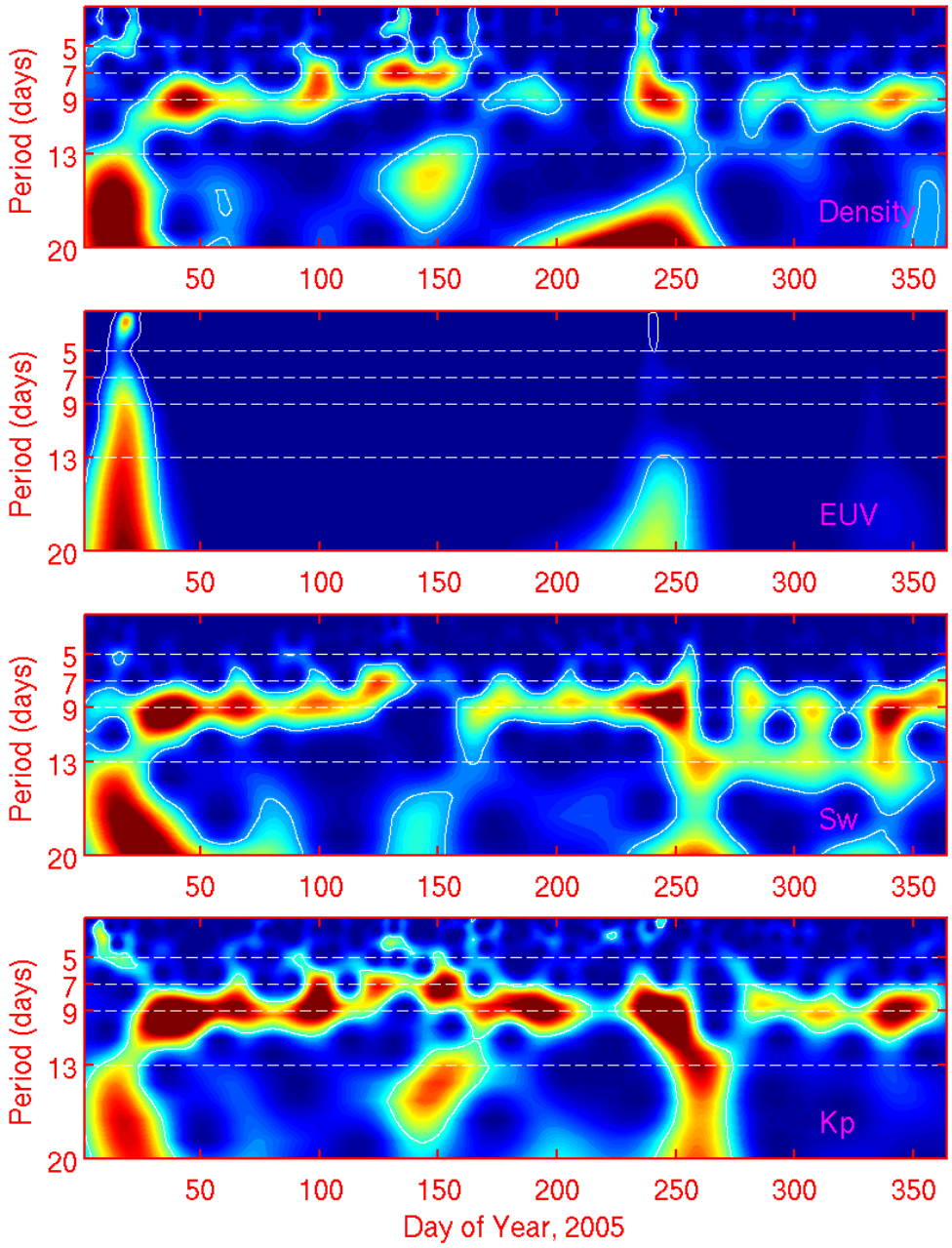
2005 Wavelet Analysis

Density - 400km altitude

Solar EUV flux index

Solar wind speed

Geomagnetic Activity Index



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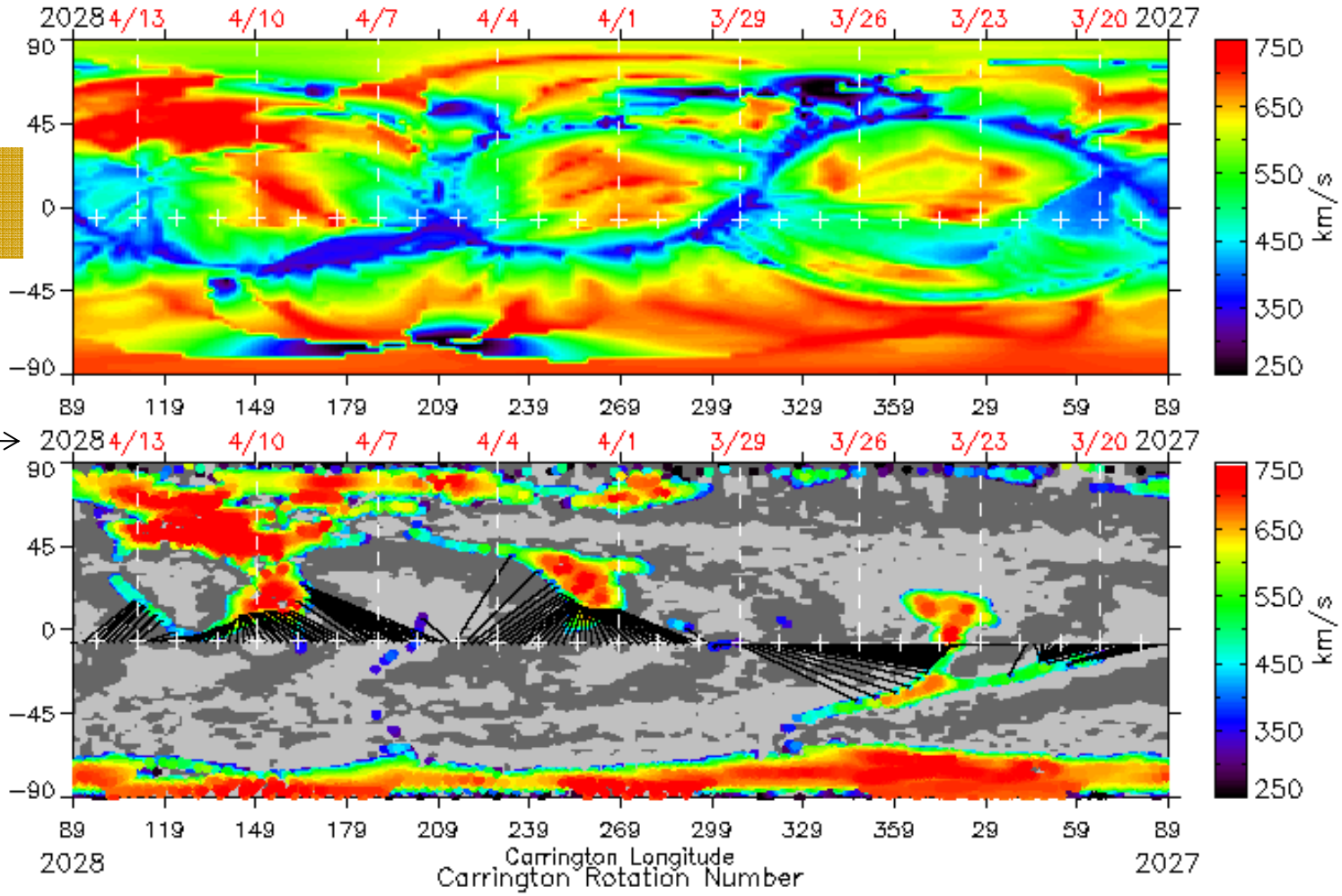
Coronal Hole and Solar Wind Speed with Heliolongitude Distribution

Solar Wind Speed
NSO

Date longitude lies in the Sun-earth line →

Derived Coronal Holes
NSO



Courtesy of Vic Pizzo, NOAA/SEC and Leslie Mayer, CU/CIRES

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CIR Eve
2005)

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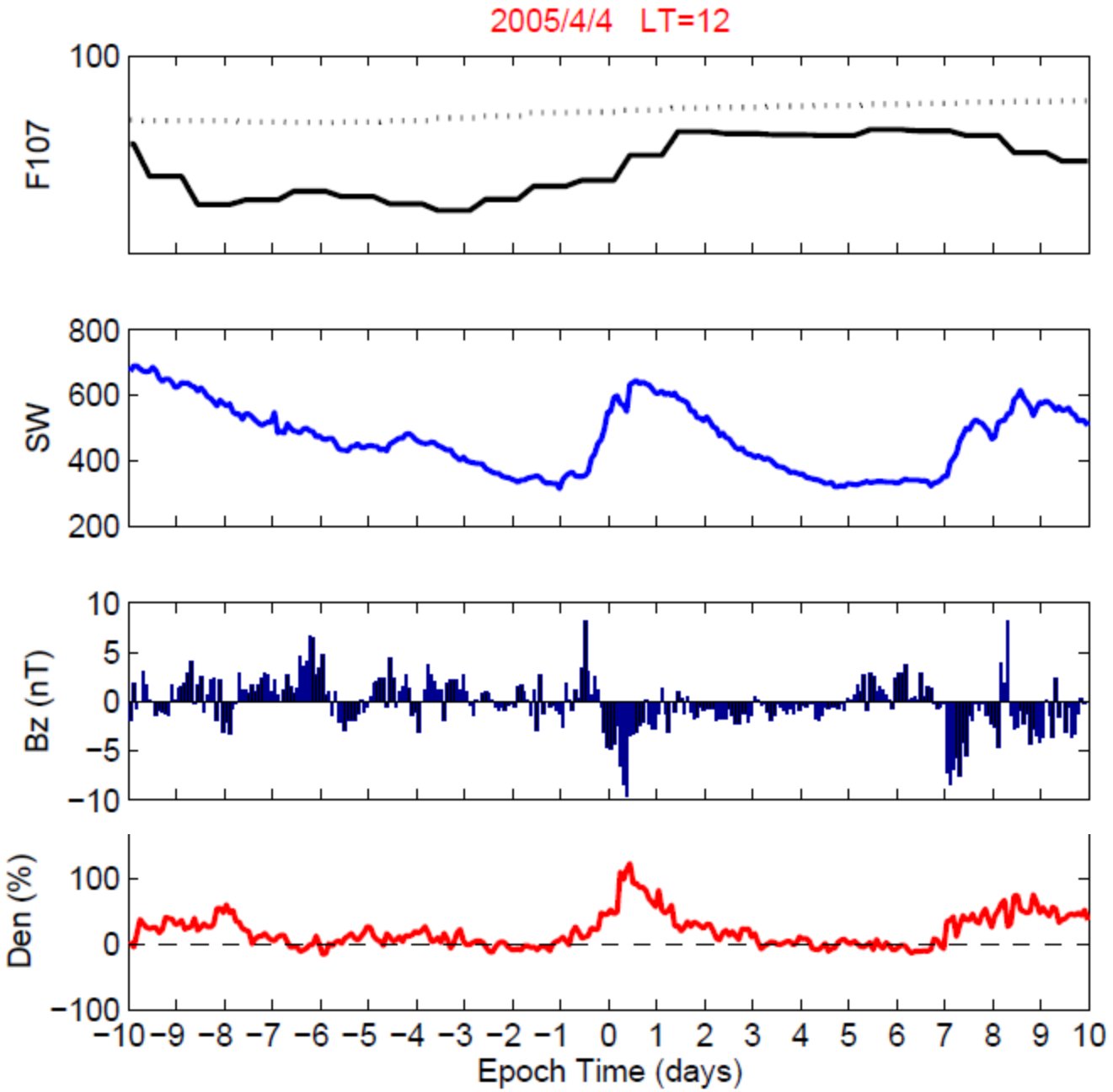

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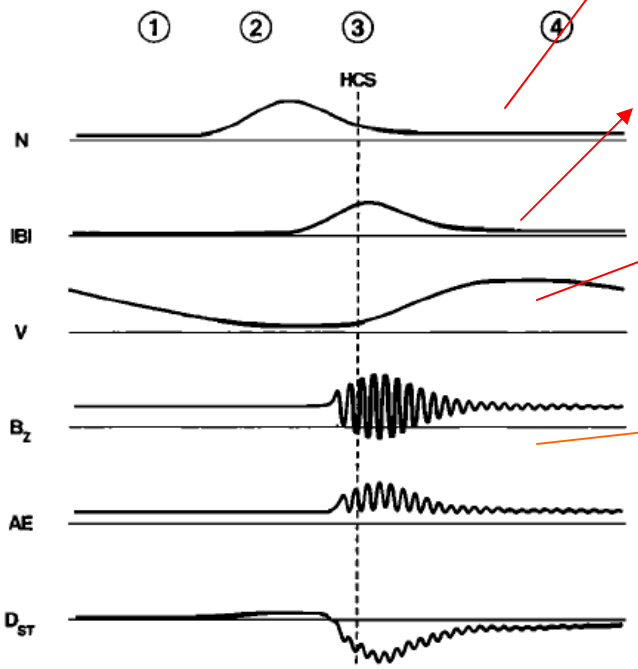
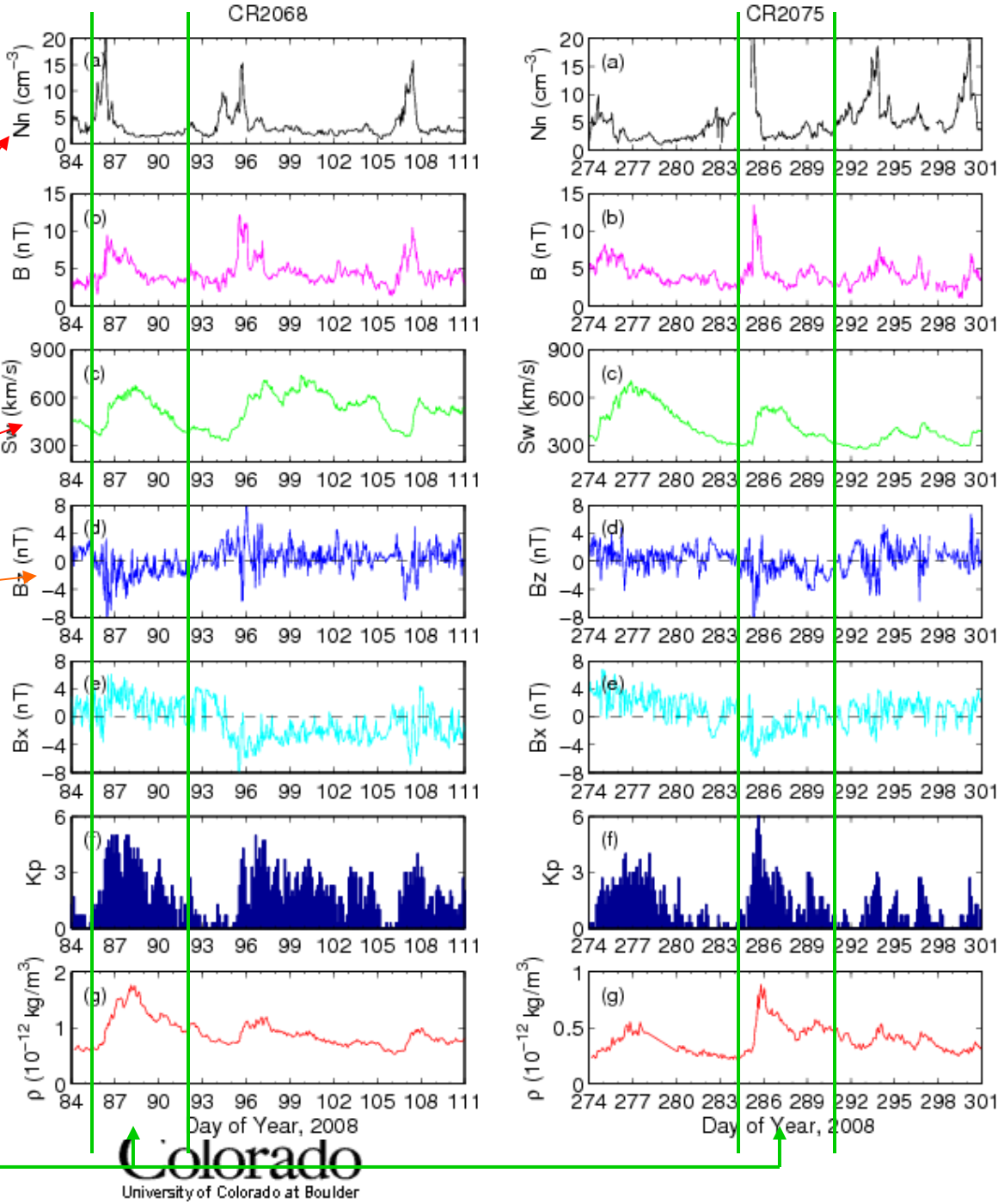
Classical CIR



Tsurutani et al., JGR, 1995



Russell-McPherron effect

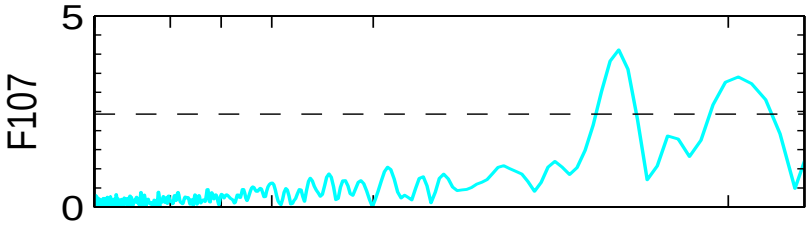
Changes in Atmosphere Density at Satellite Altitudes Caused by…

Changes in solar extreme ultraviolet (EUV) radiation, electrical energy extracted from the solar wind (geomagnetic activity), planetary and tidal wave activity from the lower atmosphere

- Known Solar EUV effects
  - Episodic – flares
  - Periodic – 11 year solar cycle, 27 day equatorial rotation
- Known Geomagnetic Activity
  - Episodic – coronal mass ejections
  - Periodic – coronal holes, solar wind high speed streams, co-rotating interaction regions (CIRs)
- Known Lower Atmosphere Waves
  - Diurnal and Semidiurnal tides
  - Atmospheric planetary waves at 2, 5, 9-10 and12-18 day periodicity

2006 Periodograms

Solar EUV flux index



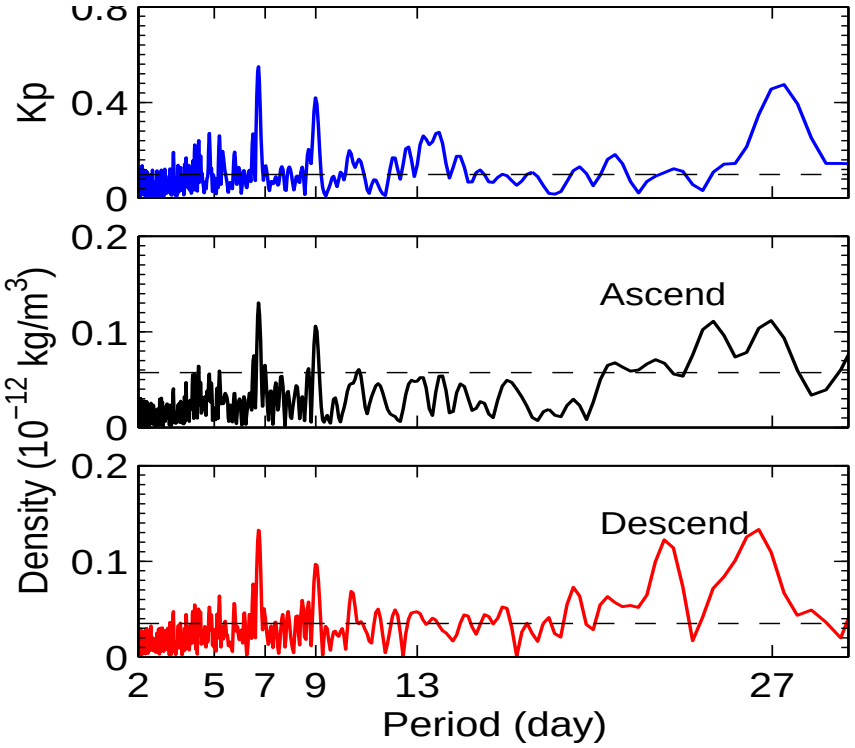
Lei, J., J. P. Thayer, J. M. Forbes, E. K. Sutton, and R. S. Nerem (2008), Rotating solar coronal holes and periodic modulation of the upper atmosphere, *Geophys. Res. Lett.*, 35, L10109, doi:10.1029/2008GL033875.

Thayer, J. P., J. Lei, J. M. Forbes, E. K. Sutton, and R. S. Nerem (2008), Thermospheric density oscillations due to periodic solar wind high-speed streams, *J. Geophys. Res.*, 113, A06307, doi:10.1029/2008JA013190.

Geomagnetic Activity Index

Density - 400km altitude

Density - 400km altitude



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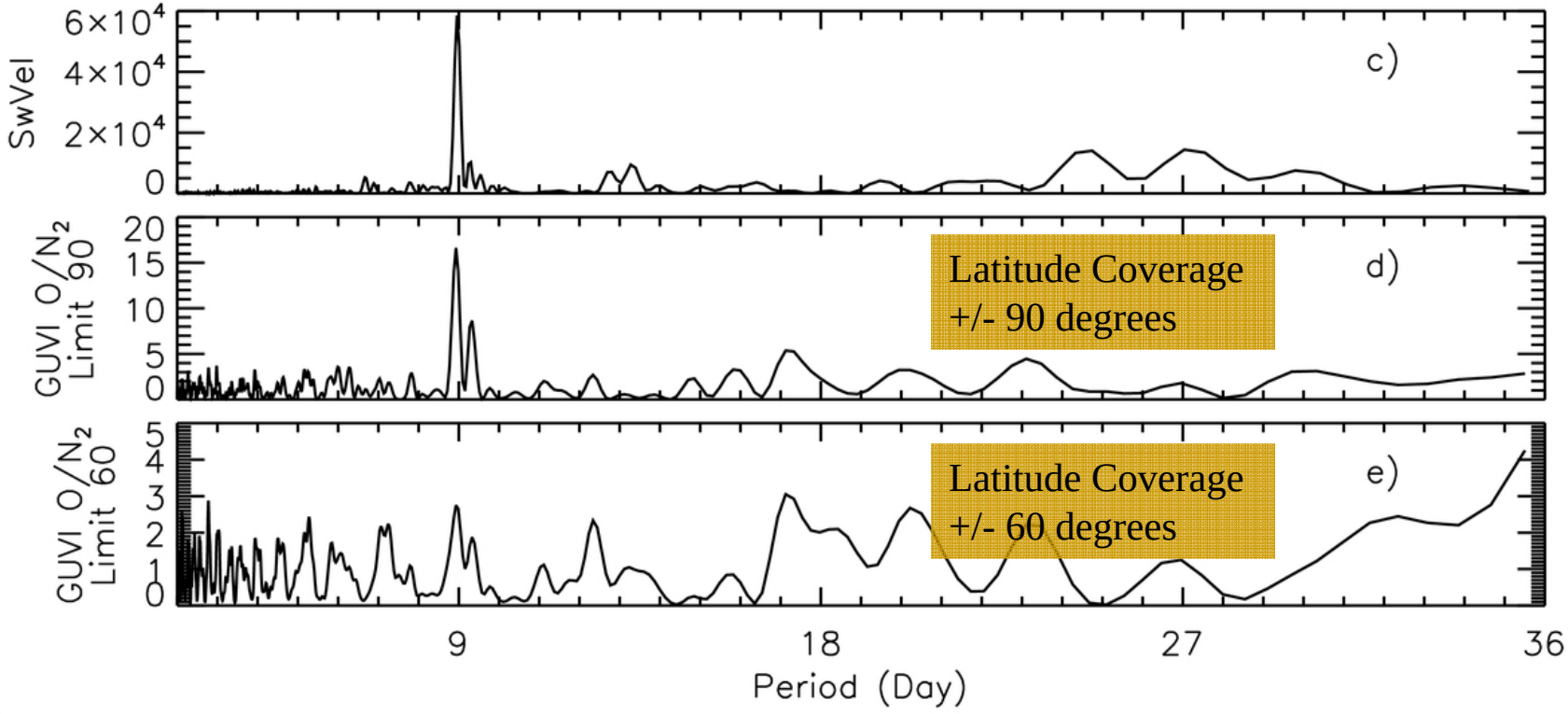
Periodogram of GUVI Orbit-Averaged $\Sigma O/N_2$ ratio for 2005

Crowley, G., A. Reynolds, J. P. Thayer, J. Lei, L.J. Paxton, A.B. Christensen, Y. Zhang, R.R. Meier, D.J. Strickland (2008), Periodic Modulations in Thermospheric Composition by Solar Wind High Speed Streams, *Geophys. Res. Lett.*, 35, L21106, doi:10.1029/2008GL035745.



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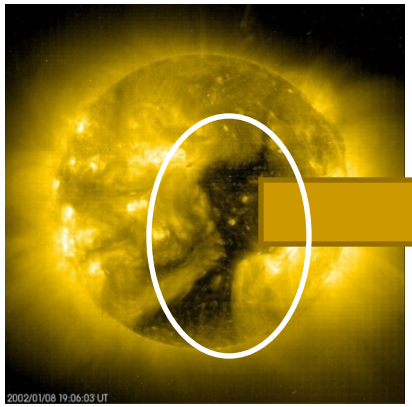
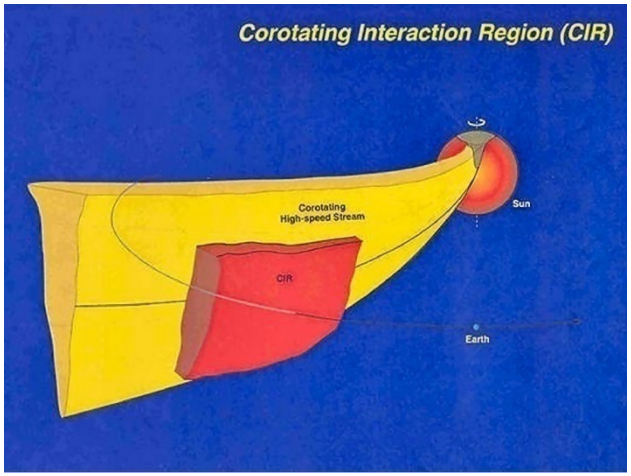
Solar Coronal Holes

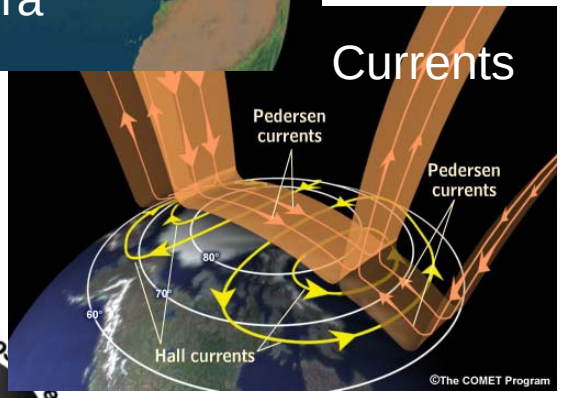


High Speed
Solar Wind Streams

Interplanetary Medium

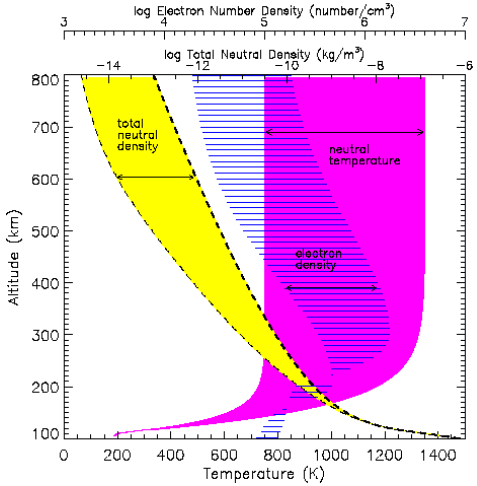


Geomagnetic Storm



Global Thermosphere
Heating

Thermosphere Breathing



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Atmosphere Breathing Modes – Makes the News

NATIONAL GEOGRAPHIC NE
NATIONALGEOGRAPHIC.COM/NEWS

Earth Atmosphere "Breathes,'

Victoria Jaggard in San Francisco
National Geographic News

December 16, 2008

Earth's upper atmosphere "breathes," expanding and contrac
say scientists who have measured the phenomenon for the f

The steady rhythm of "breaths" is linked to the ebb and flow
winds—charged particles streaming outward from the sun—a

The breathing cycle seems to reach its peak when solar featu
in the sun's corona—a sort of solar atmosphere—are areas
pressurized solar wind, sending the "winds" toward Earth at

As the fast winds streaming from coronal holes approach Ea
and expand, then cool down and contract, changing the upp

Web address:
http://www.sciencedaily.com/releases/2008/12/081215184317.htm

Earth's Upper Atmosphere Tied
rbances

study shows the periodic "breathing" of Earth's upper atmosphere that
yclic solar wind disturbances, a finding that should help engineers
forecasts for electronic communication disruptions.

Associate Professor Jeff Thayer said the outer, gaseous shell of the
nown to expand and contract as it exchanges energy with the space
re density. Changes in thermosphere density can alter the atmospheric
m their predicted paths and complicating tracking and orbital

sun is the dominant mechanism that causes the thermosphere to
es high-speed wind from the sun triggers independent breathing
es, heating the thermosphere and altering its density. The wind streams
are generated by relatively cool pockets on the sun's surface known as solar coronal holes that periodically rotate
around the sun's surface, said Thayer.

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