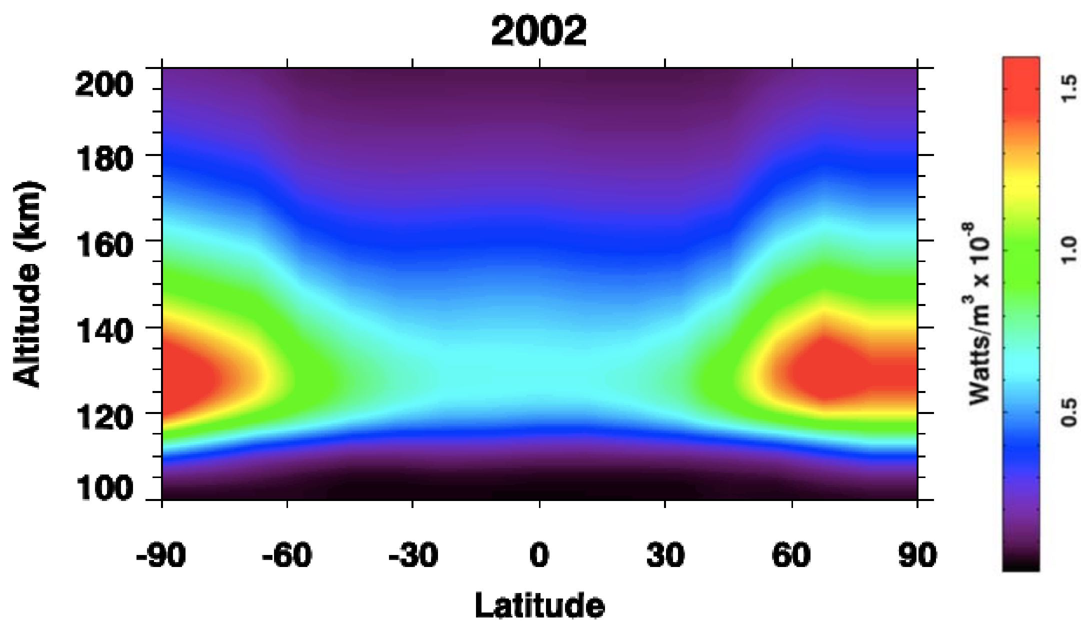
Energetic Particle Precipitation Effects on the Energy Balance of the Thermosphere and Ionosphere



HEPPA 2009

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[3]NCAR High Altitude Observatory

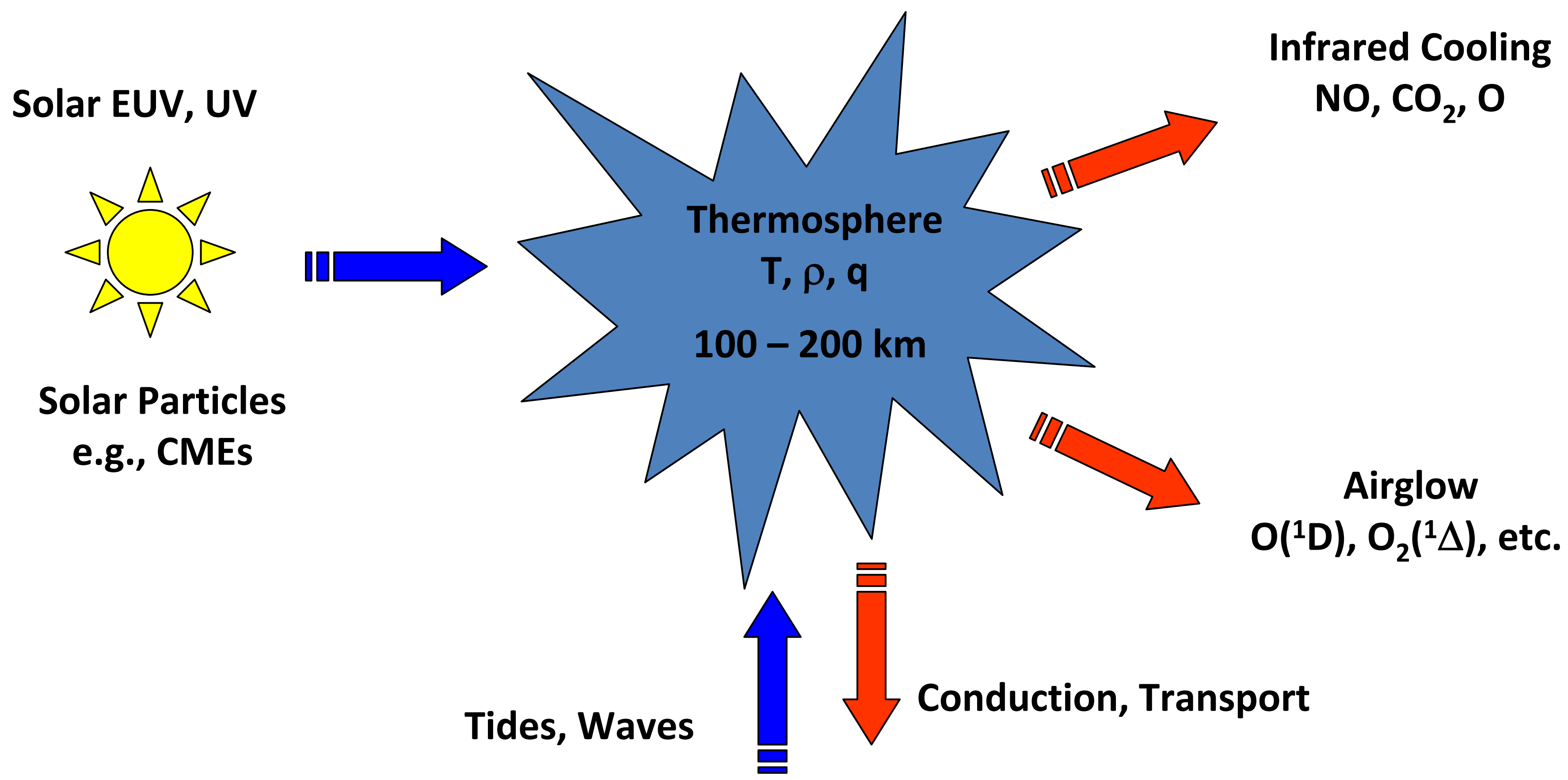
Acknowledgement

- NASA TIMED Project and SABER Experiment Team
- NASA Heliophysics Guest Investigator Program
- NASA Langley Research Center
- Cora Randall and the HEPPA Organizing Committee

Outline

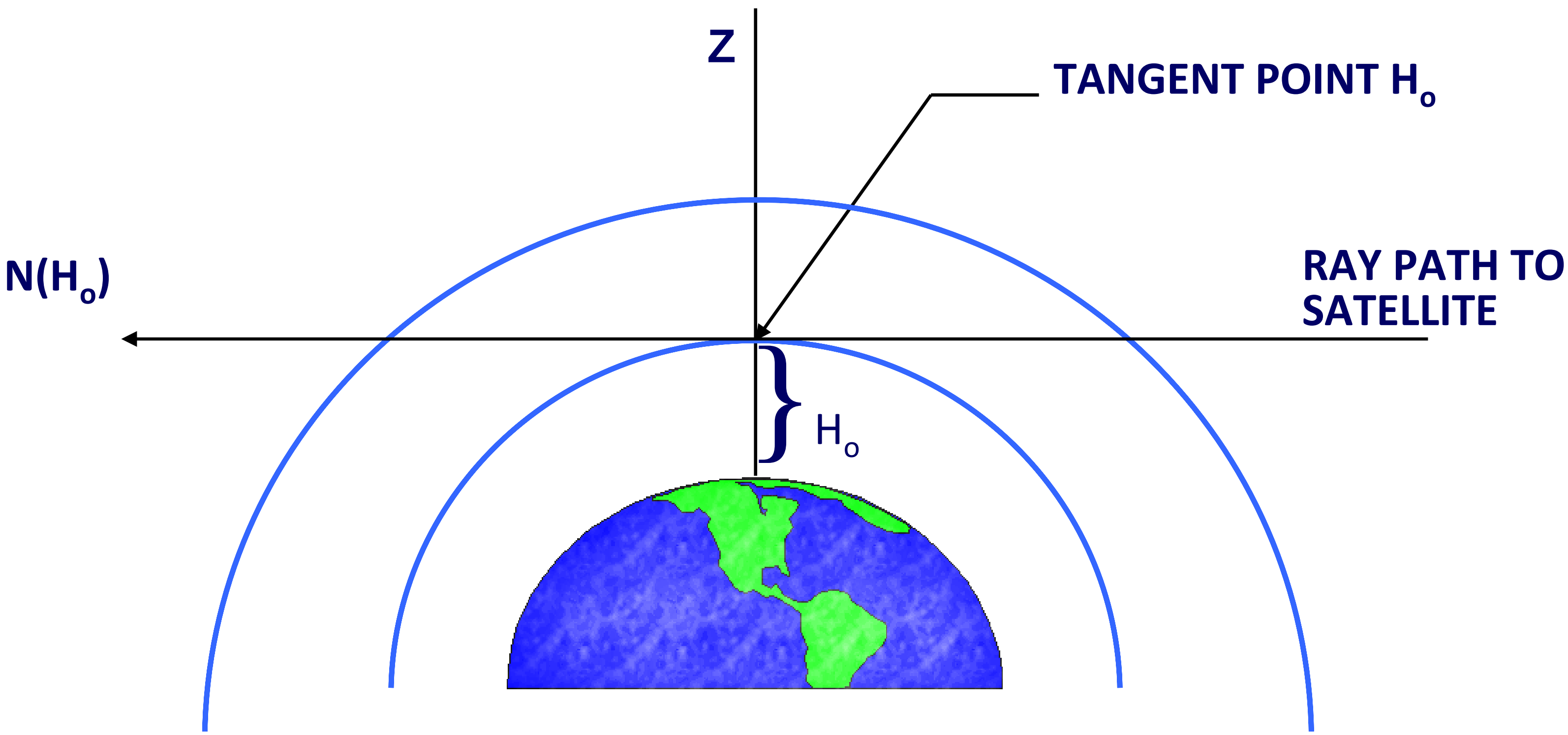
- Introduction
  - TIMED Mission, SABER Experiment
  - Energy Balance and Radiative Cooling concepts
  - Derivation of radiative cooling from SABER data in thermosphere
- Effects of Particle Precipitation: Short-Term
  - Short-term periodicities from a long-term record
  - 9-day, other periods in NO, CO_2 cooling
  - Evaluation of a high-speed solar wind event
- Effects of Particle Precipitation: Long-Term
  - NO cooling and large-scale dynamics of thermosphere
- Summary, Future Work
  - Generation of climate data records for GCMs

Thermospheric Energy Balance




THE JOHNS HOPKINS UNIVERSITY
TIMED
NASA
Thermosphere • Ionosphere • Mesosphere • Energetics • Dynamics
Launched December 2001
74.1 Degree Inclination
625 km Circular Orbit
Routine Operations ~ 8 Years
Ongoing to 2013!
4110DIL97

SABER Experiment Limb Viewing Geometry



$$N(H_o) \cong \int_{\Delta\nu}\int_{\Delta x} J_\nu(x) \frac{d\tau\,(\nu,q,T,P)}{dx}\,dx\,d\nu$$

SABER Channels and Data Products

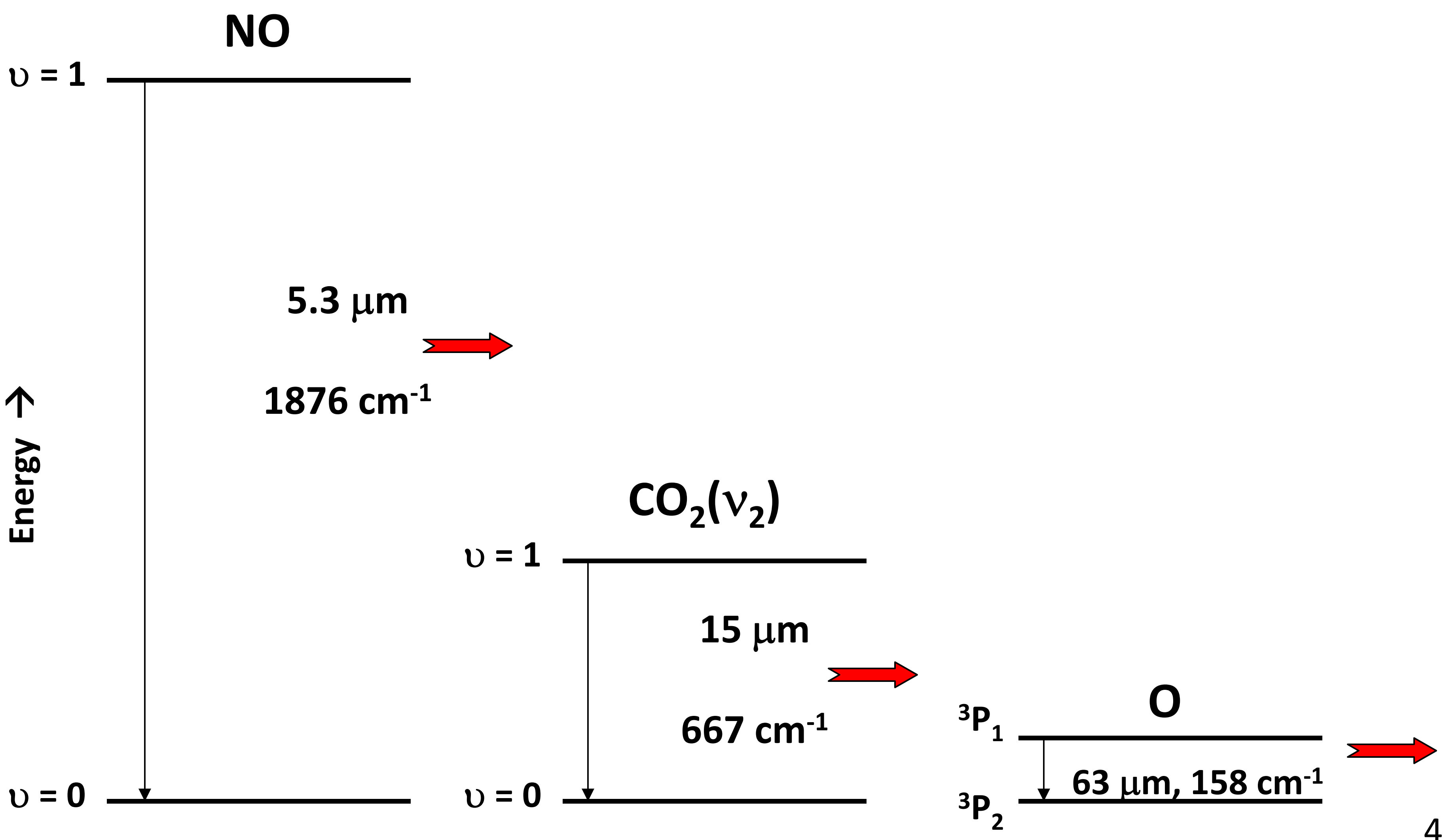
Almost Eight Years and Counting!!

Channel	Wavelength	Data Products	Altitude Range
CO_2	15.2 μm	Temperature, pressure, cooling rates	15-100 km
CO_2	15.2 μm	Temperature, pressure, cooling rates	15-100 km
CO_2	14.8 μm	Temperature, pressure, cooling rates	15-100 km
O_3	9.6 μm	Day and Night Ozone, cooling rates	15 - 95 km
H_2O	6.3 μm	Water vapor, cooling rates	15-80 km
CO_2	4.3 μm	Carbon dioxide, dynamical tracer	90-160 km
NO	5.3 μm	Thermospheric cooling	100 - 300 km
$O_2(^1\Delta)$	1.27 μm	Day O_3, solar heating; Night O	50-100 km
$OH(\upsilon)$	2.0 μm	Chemical Heating, photochemistry	80-100 km
$OH(\upsilon)$	1.6 μm	Chemical Heating, photochemistry	80-100 km

Over 30 data products including T, CO_2, O_3, VER, O, H, $\partial T/ \partial t$

Thermospheric Radiative Cooling Mechanisms

- figure is to scale in energy -



Radiative Cooling Derivation from SABER Radiances

- **NO cooling: Three parameters**
  - Cooling Rates ($W\ m^{-3}$)
    - Abel inversion of limb radiance: $W\ m^{-2}\ sr^{-1} \rightarrow W\ m^{-3}$
  - Radiant Fluxes ($W\ m^{-2}$)
    - Vertically integrated cooling rates: $W\ m^{-3} \rightarrow W\ m^{-2}$
  - Radiant Power (W)
    - Zonally integrate fluxes w/r/t Area: $W\ m^{-2} \rightarrow W$
  - Meridional Integration to obtain Daily Global Power

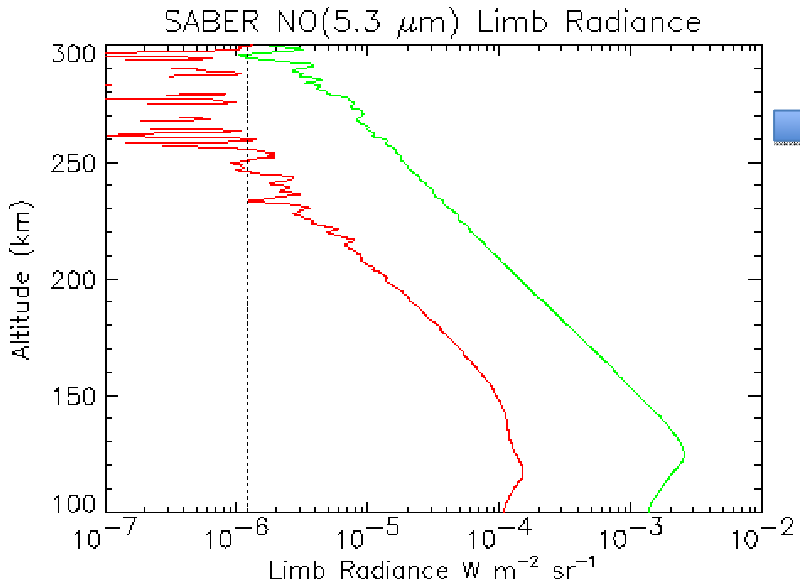
Radiative Cooling Derivation from SABER Radiances

- **CO_2 cooling: Three Parameters**
  - Cooling rates Q (W m^{-3})
    - Invert radiances to T_K and "regular" cooling rates (K/day)
    - W m^{-2} sr^{-1} → T_K and $\partial T_K/\partial t$

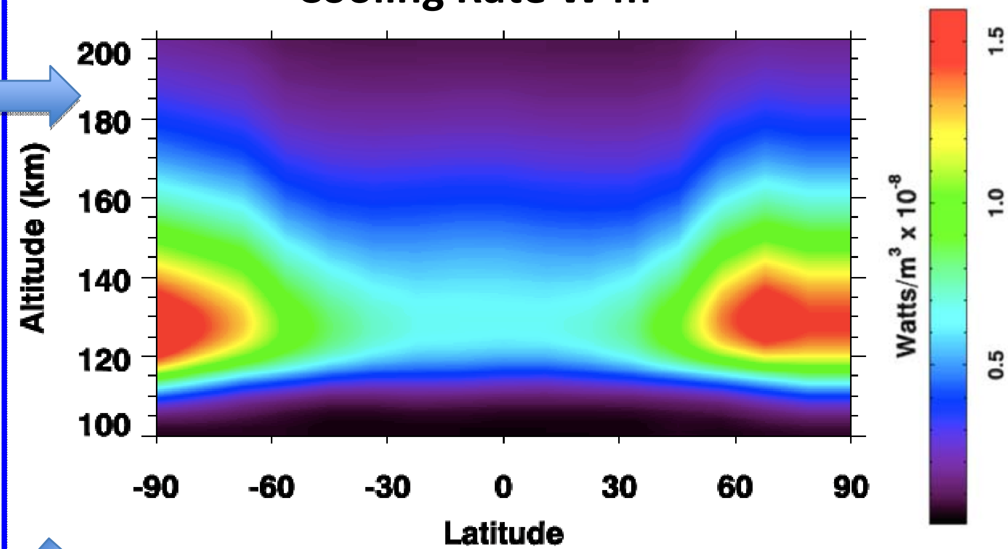
$$Q = \frac{p}{R\,T_K} C_p \frac{\partial T_K}{\partial t}$$

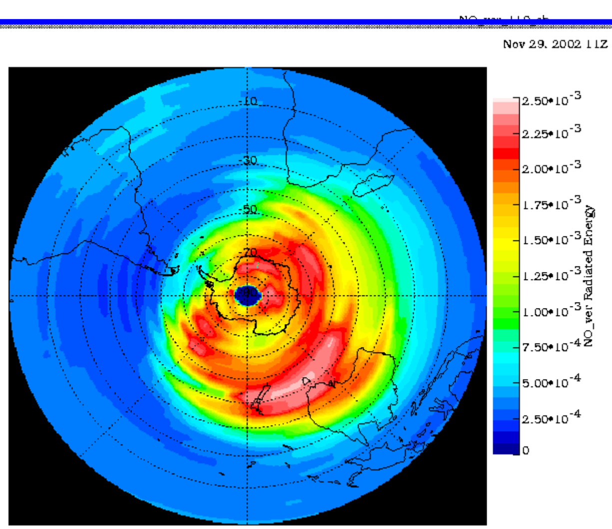
  - Radiant Fluxes (W m^{-2})
    - Vertically integrated cooling rates: W m^{-3} → W m^{-2}
  - Radiant Power (W)
    - Zonally integrate fluxes w/r/t Area: W m^{-2} → W
  - Meridional Integration to obtain Daily Global Power

Example: NO Radiance → Cooling Rate → Flux → Power

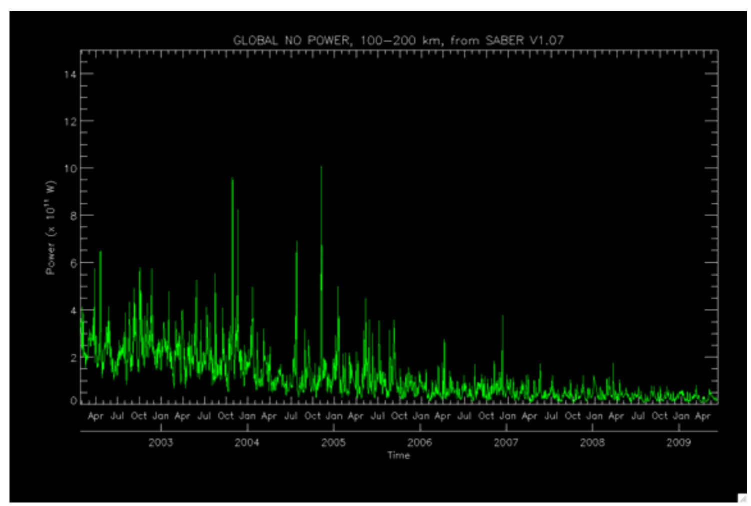


Cooling Rate W m^{-3}





Radiated Flux W m^{-2}



Daily Radiated Power (W)

Effects of Particles: Short-Term

- Examine Time Series of Global Radiated Power for NO and Geomagnetic Indices
- Annual Basis: 2002 to 2009 (7.5 years)
- Look for occurrence of short-term periodicities in the long-term record
- Lomb Normalized Periodograms are tool of choice

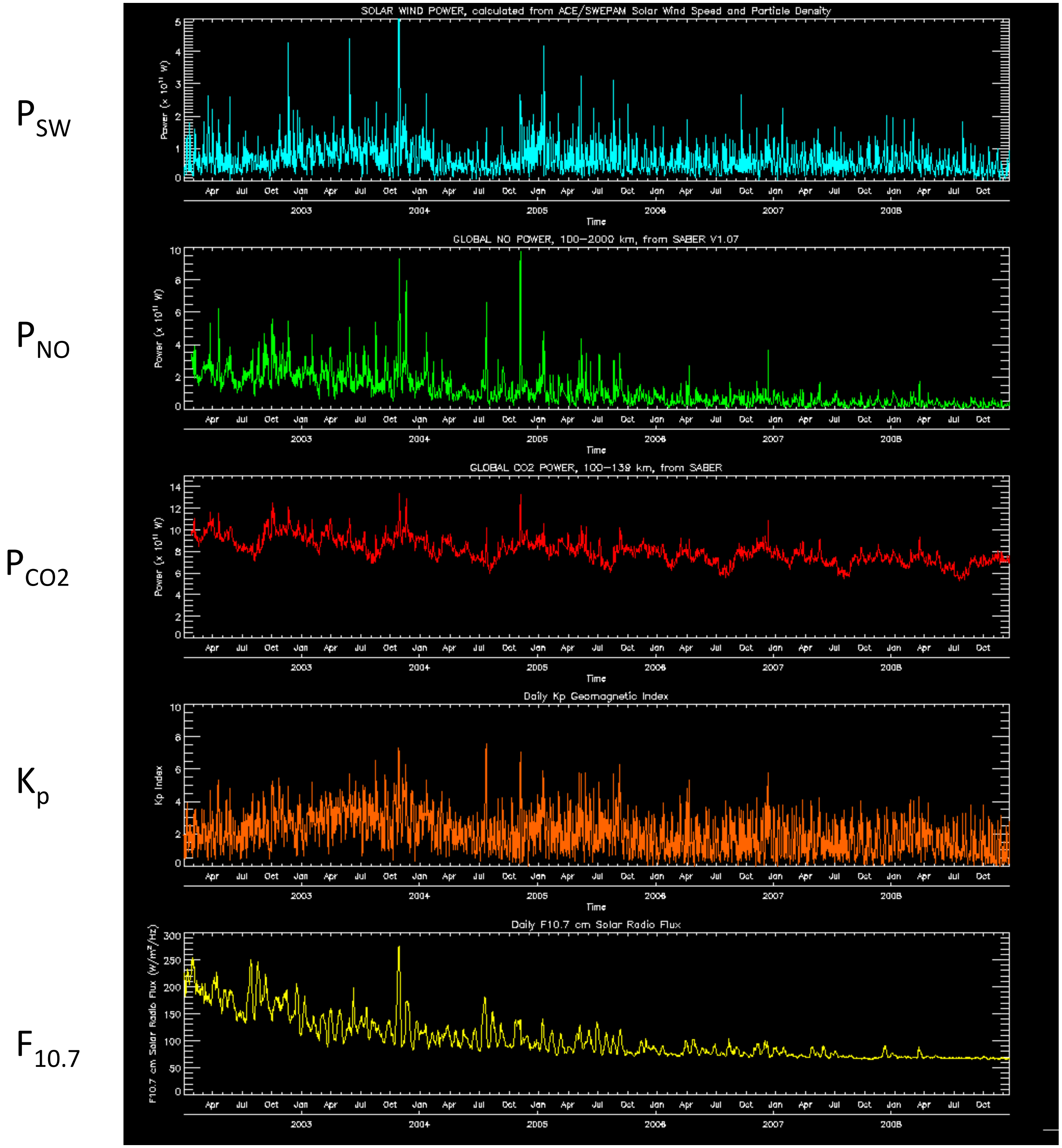
Solar, Geomagnetic
&
Thermospheric Data

7.5 Years

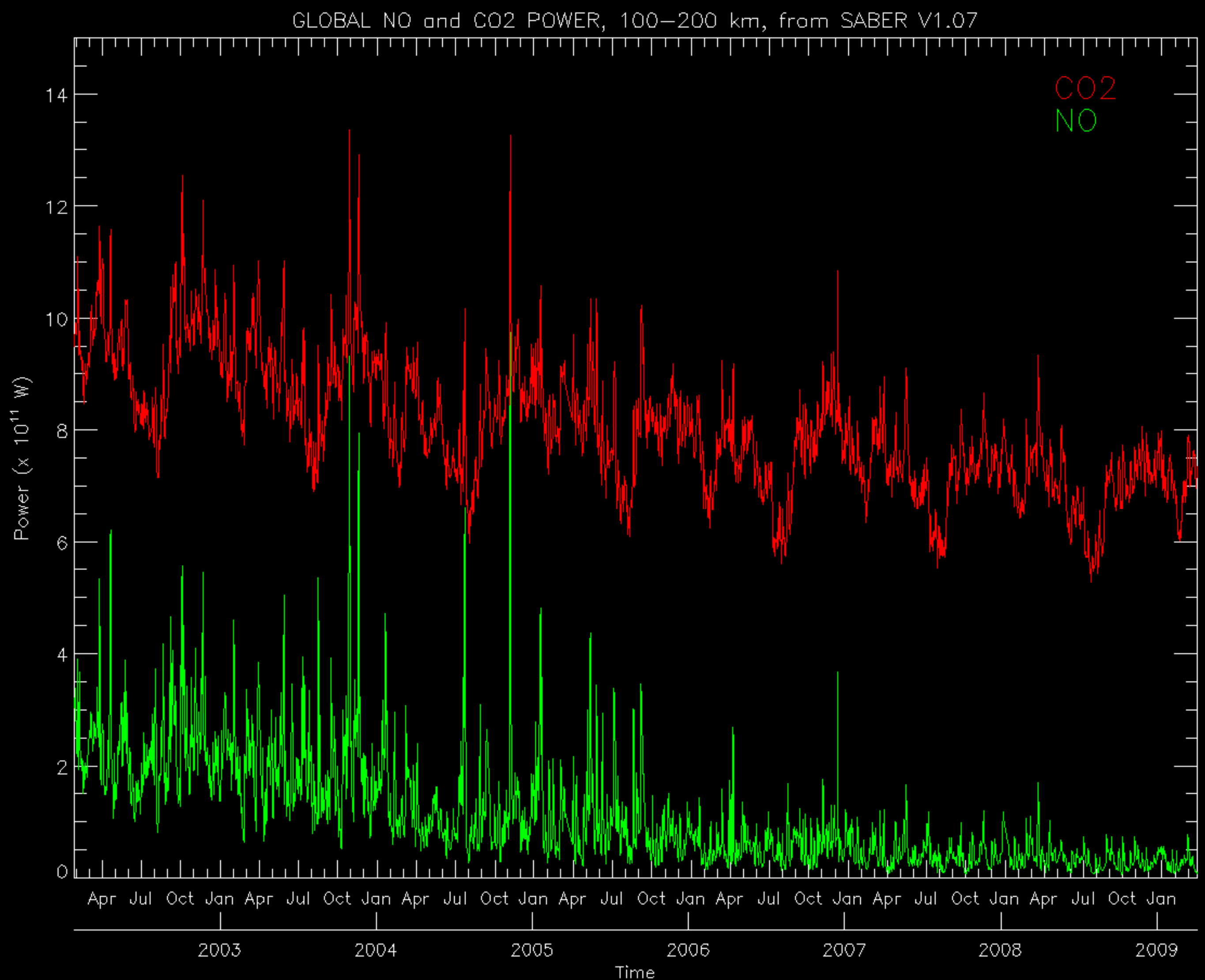
Short-Term Variability In Solar Wind, K_p

Long-Term Variability In F10.7

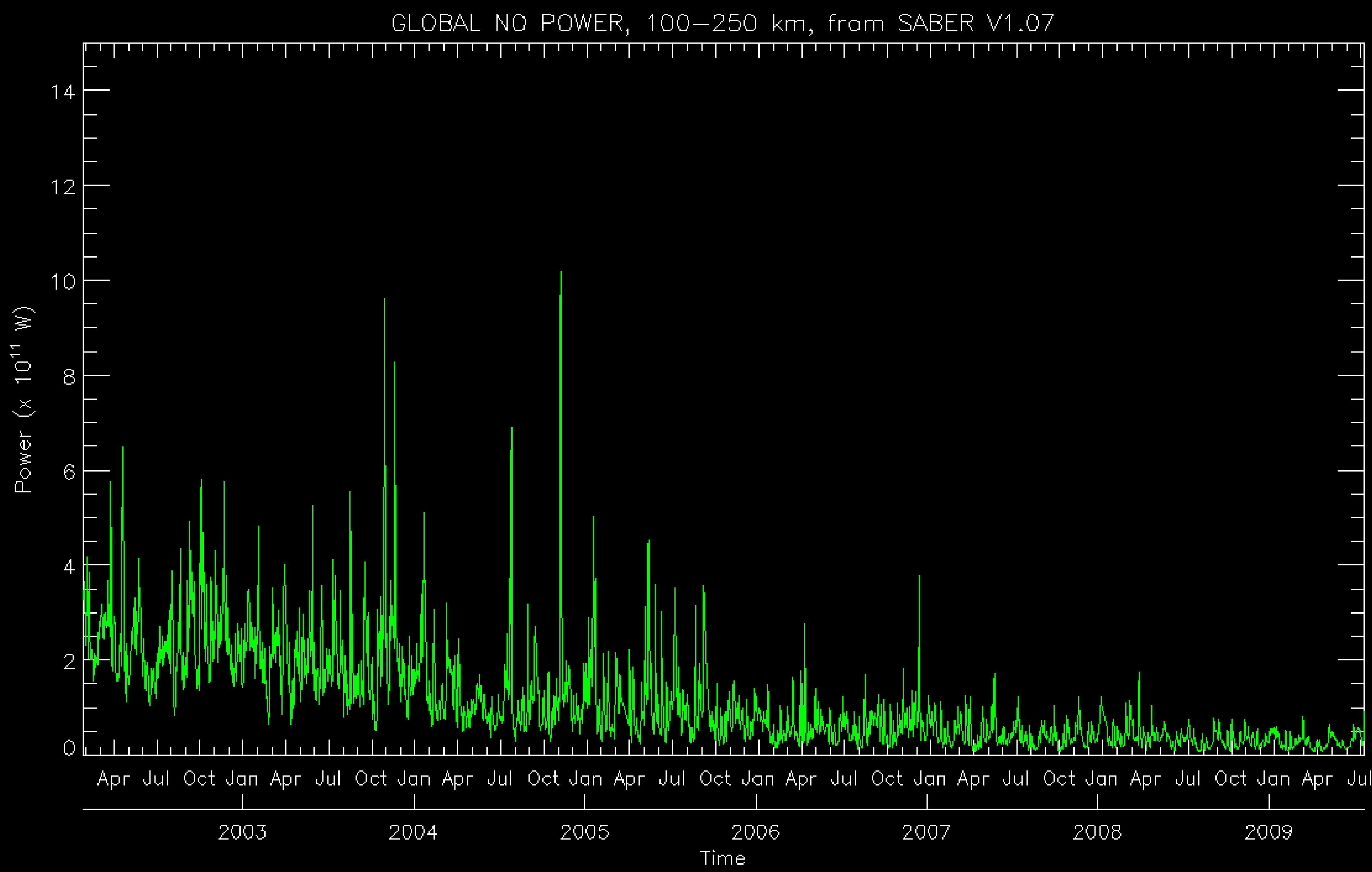
Short, Long Term Variability in Radiative Cooling



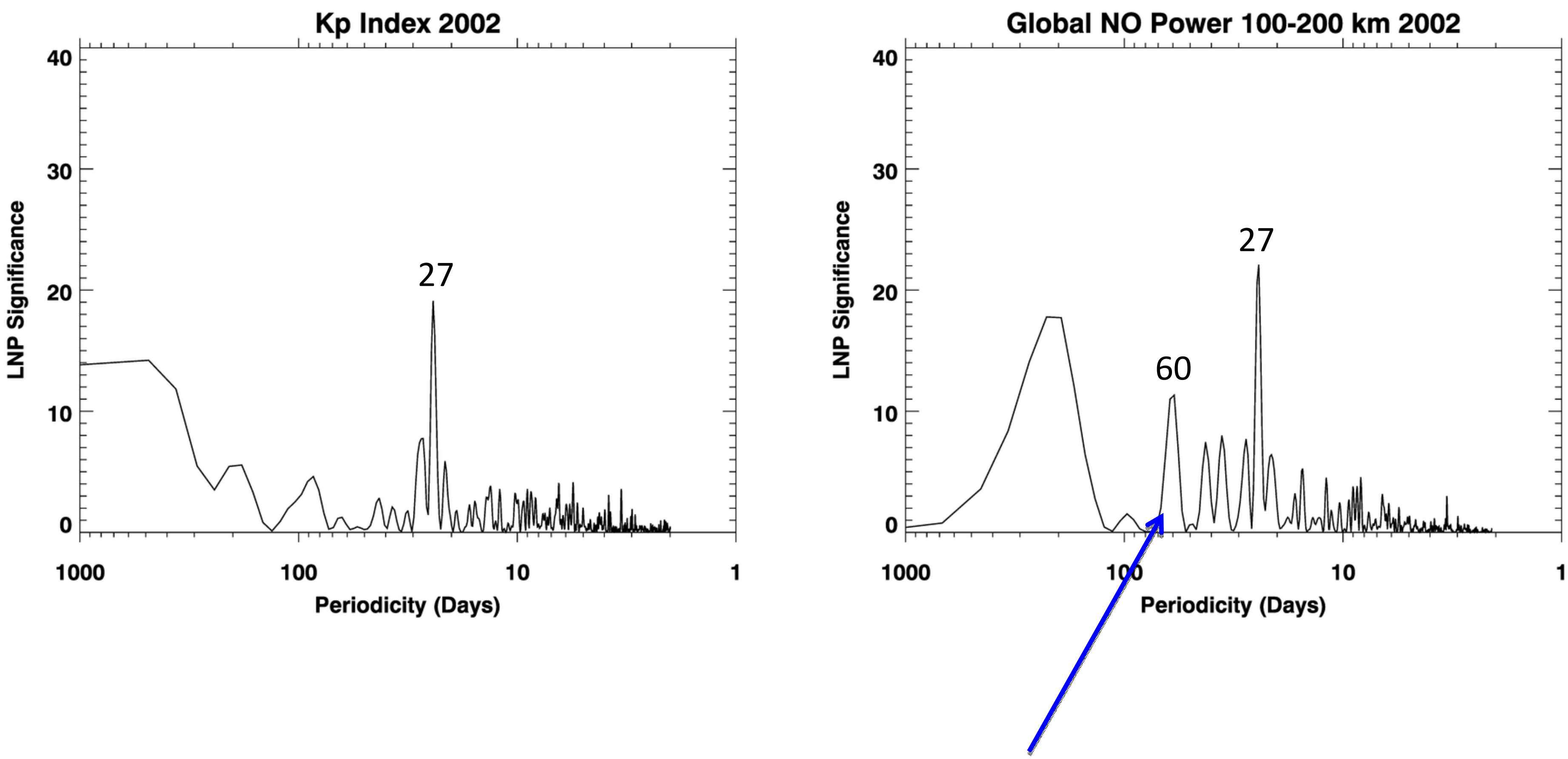
Global Radiated Power (W)
NO and CO_2: 2002 through 2008



Global NO Power (W): 2002 to 2009

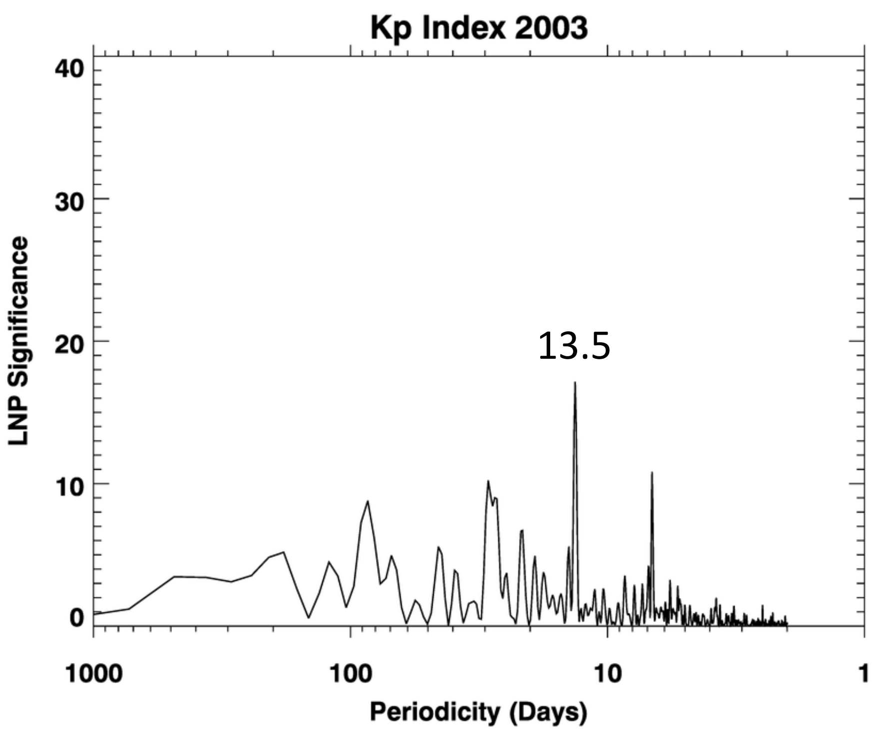


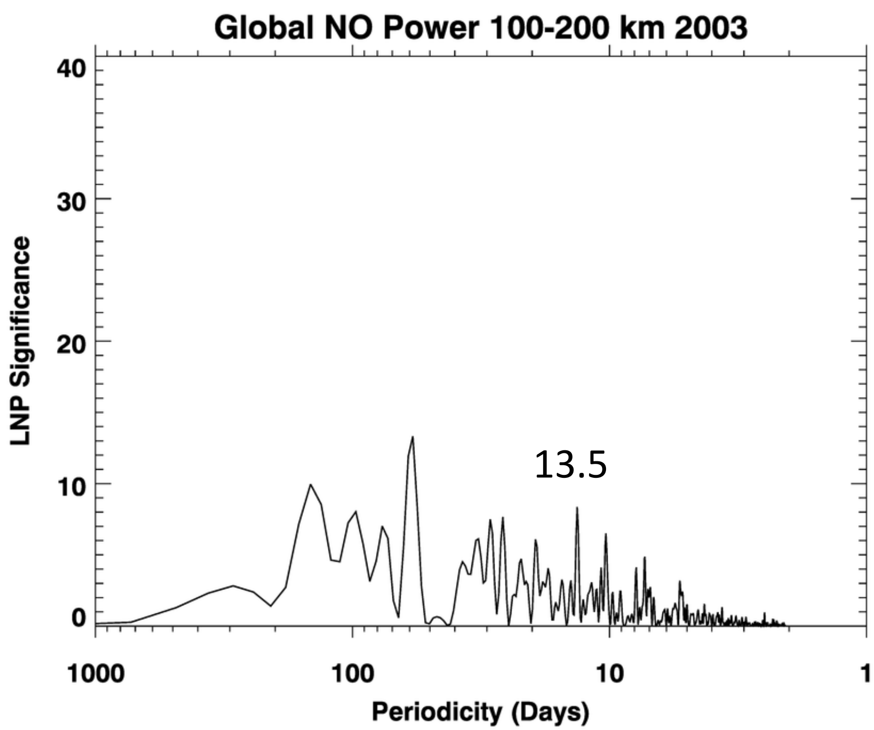
Lomb Normalized Periodigrams
K_p and NO - 2002



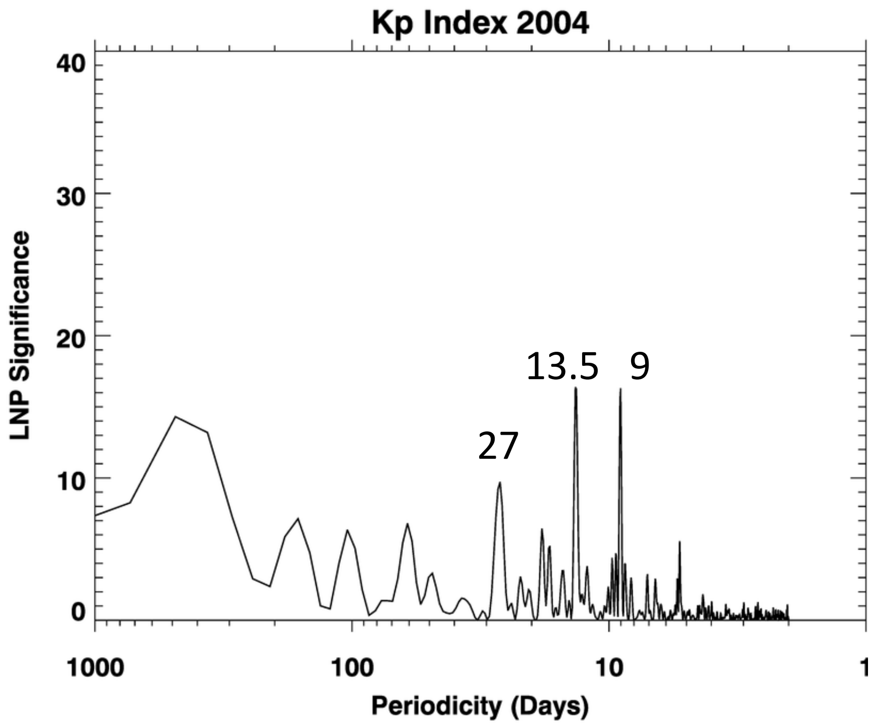
60-day period corresponds to the TIMED satellite yaw period

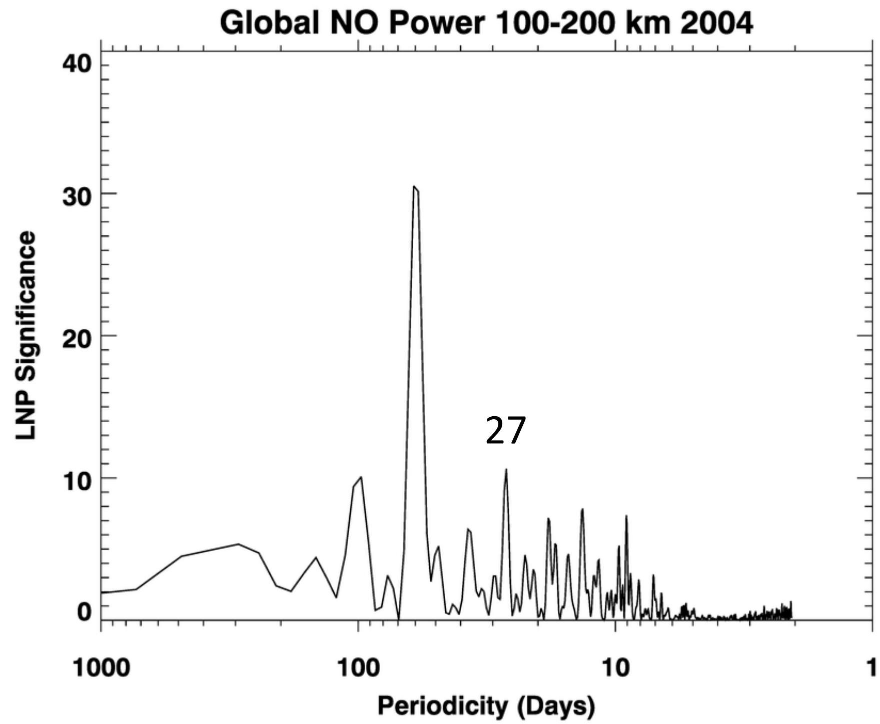
Lomb Normalized Periodigrams
K_p and NO - 2003



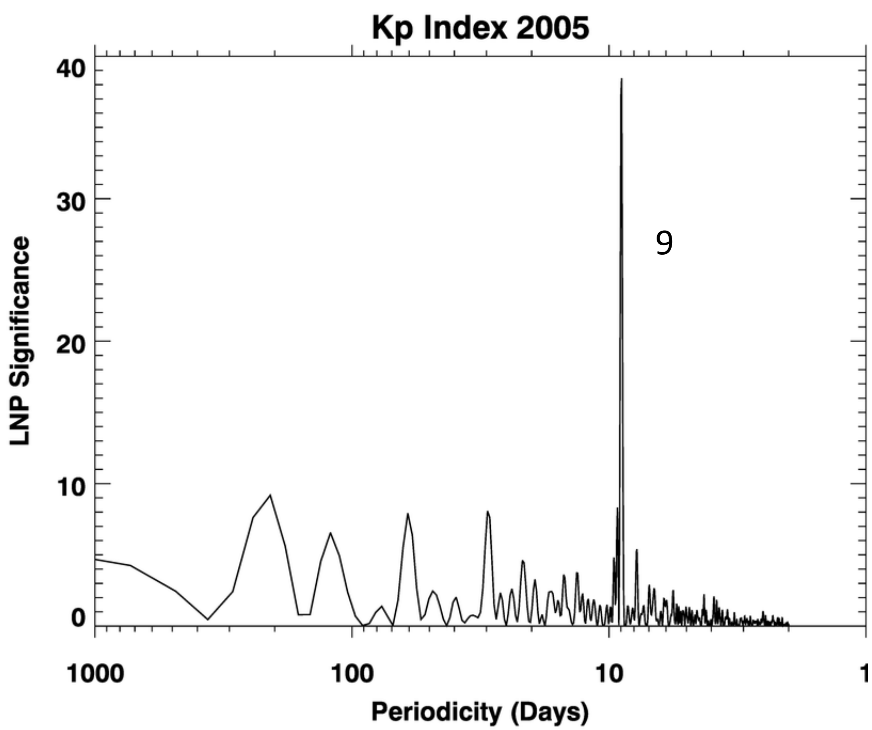


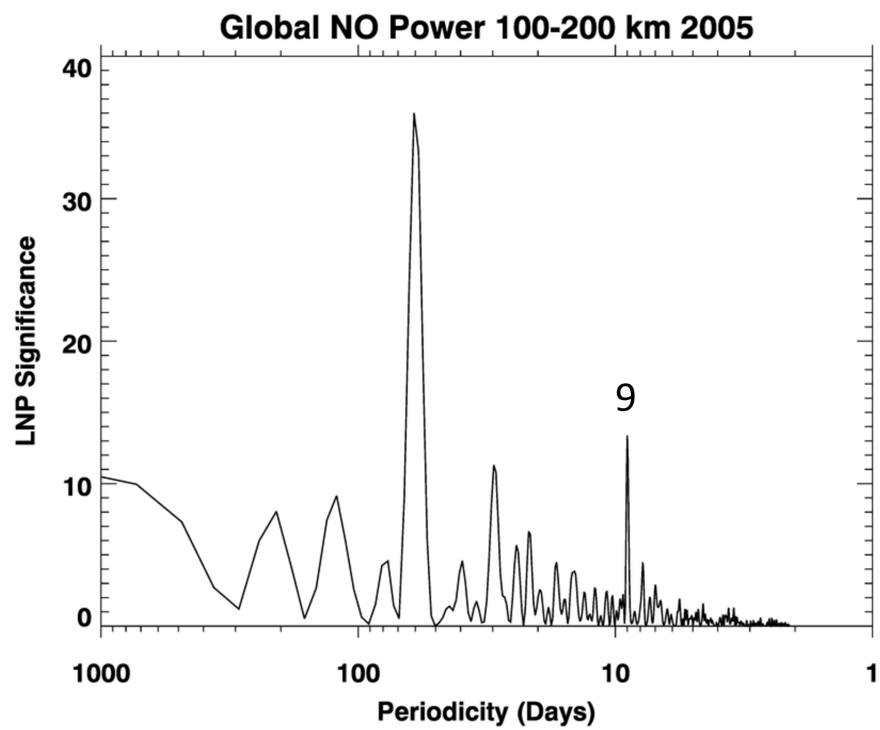
Lomb Normalized Periodigrams
K_p and NO - 2004



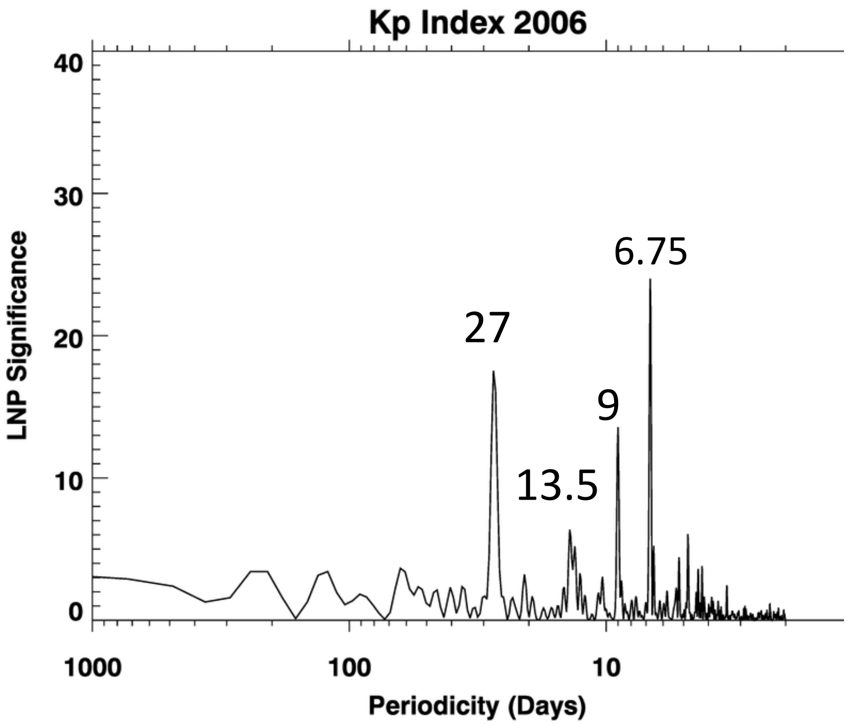


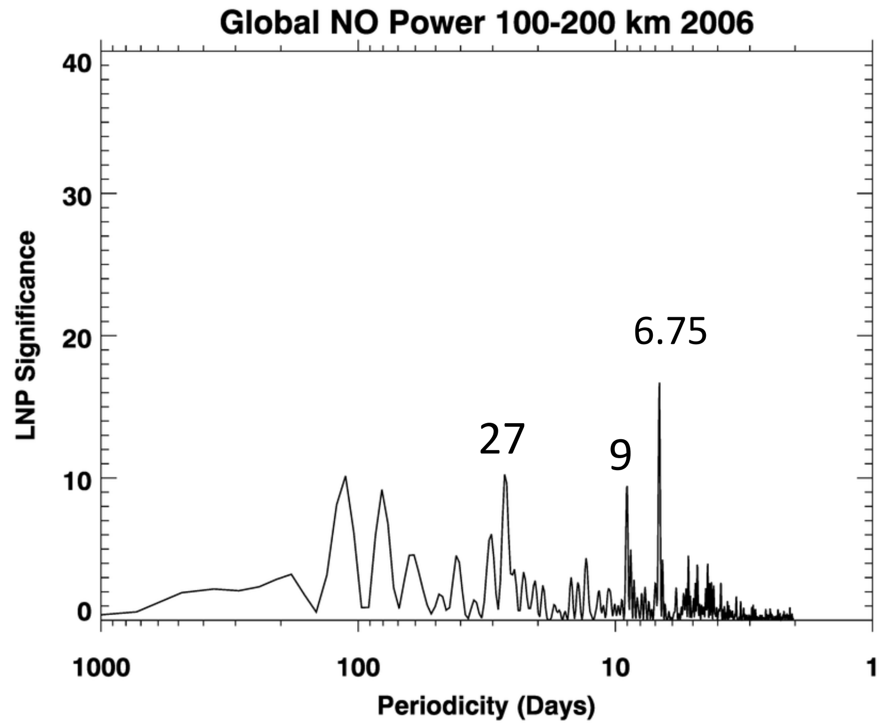
Lomb Normalized Periodigrams
K_p and NO - 2005



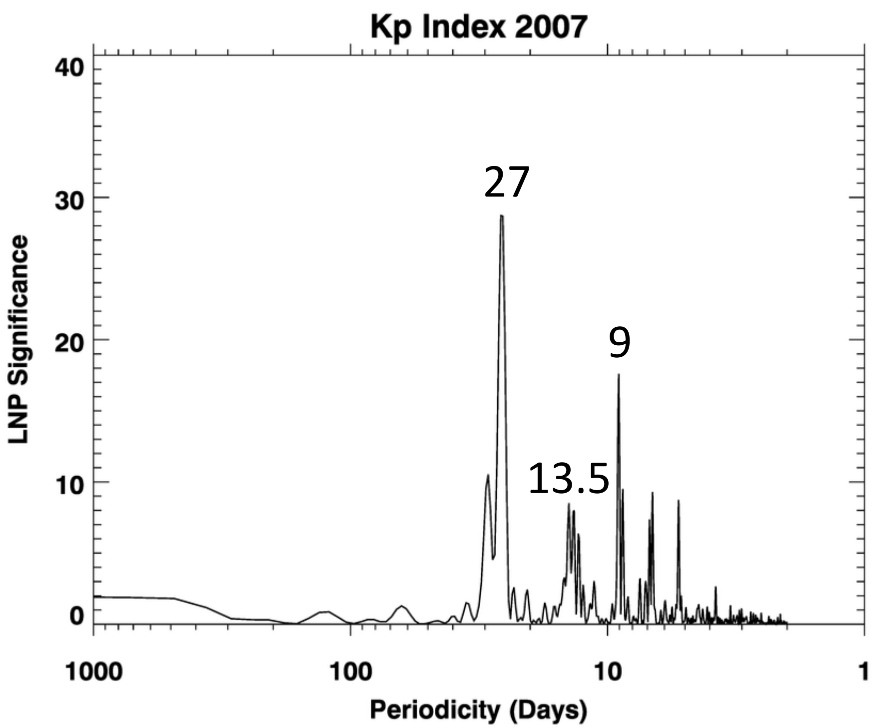


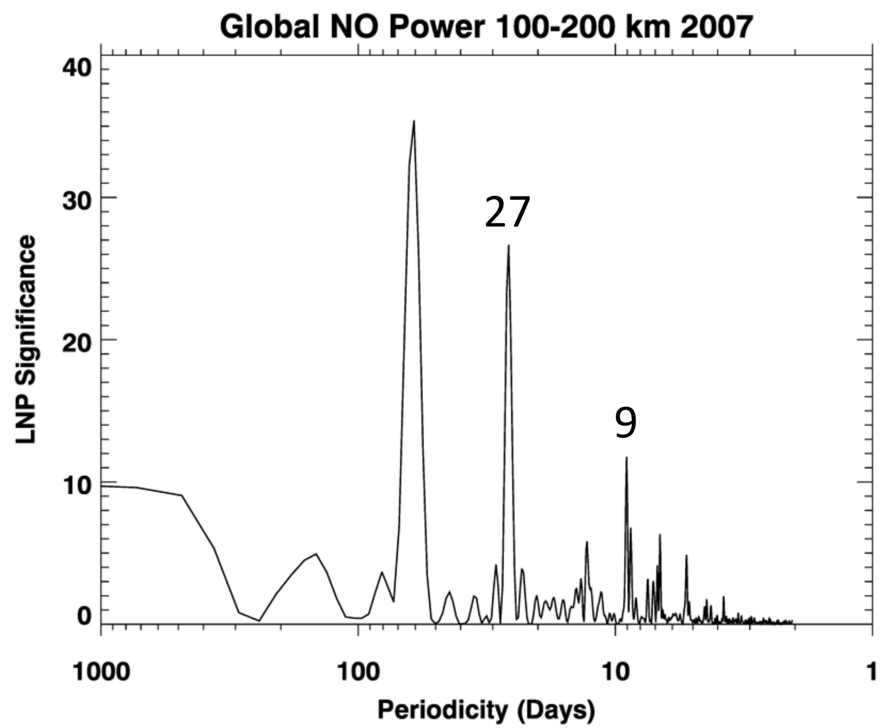
Lomb Normalized Periodigrams
K_p and NO - 2006



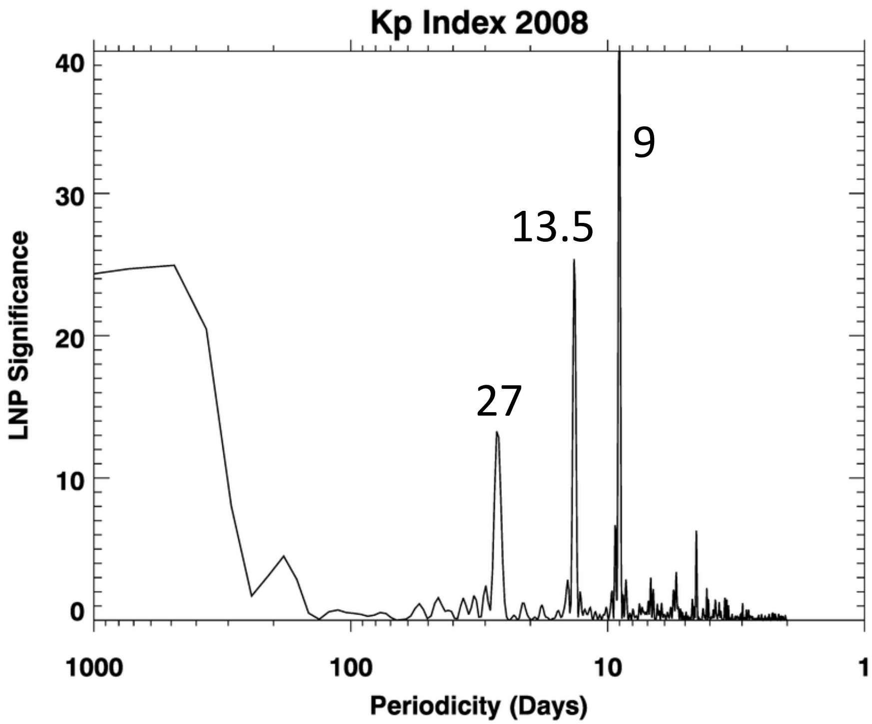


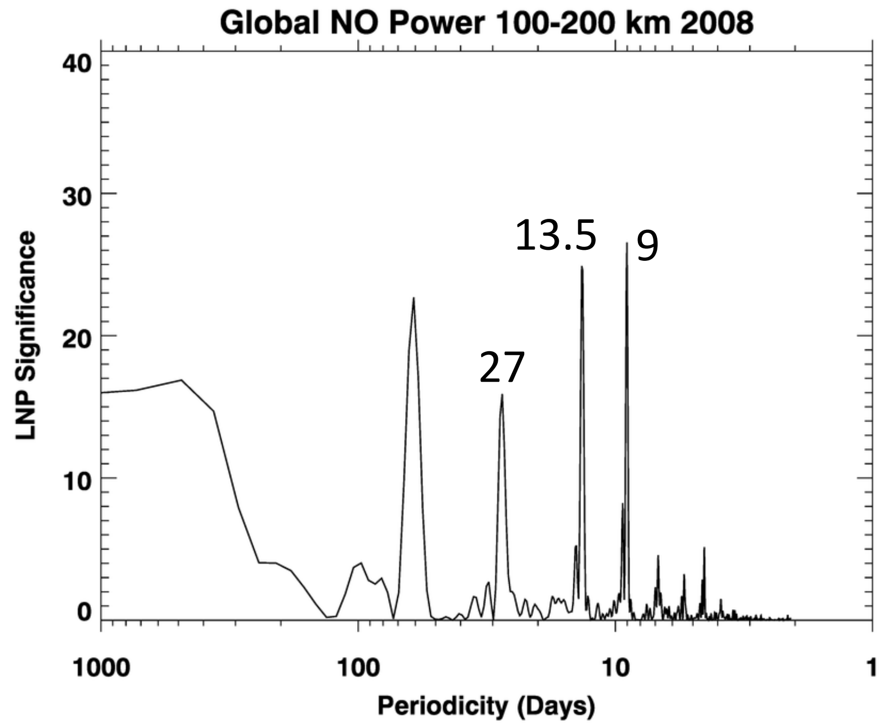
Lomb Normalized Periodigrams
K_p and NO - 2007





Lomb Normalized Periodigrams
K_p and NO - 2008





Short-Term Effects: Summary

- Time series of global cooling in radiated infrared power reveals many short-term periodicities 27 days and shorter
- Most common are 27-day, 13.5-day, and 9-day
- The periodicities in all cases occur in the K_p index as well
- In 2006 a 6.75-day period (27/4) occurred in NO and Kp
- Higher order harmonics (27/5, 27/6, 27/7) in NO are often seen but are not statistically significant
- Results imply continuous geomagnetic coupling but with variable temporal effects
- Short-term effects are then tied to particle deposition – solar UV output is not variable on these shorter timescales

Case Study: Response to High Speed Solar Wind Stream Event

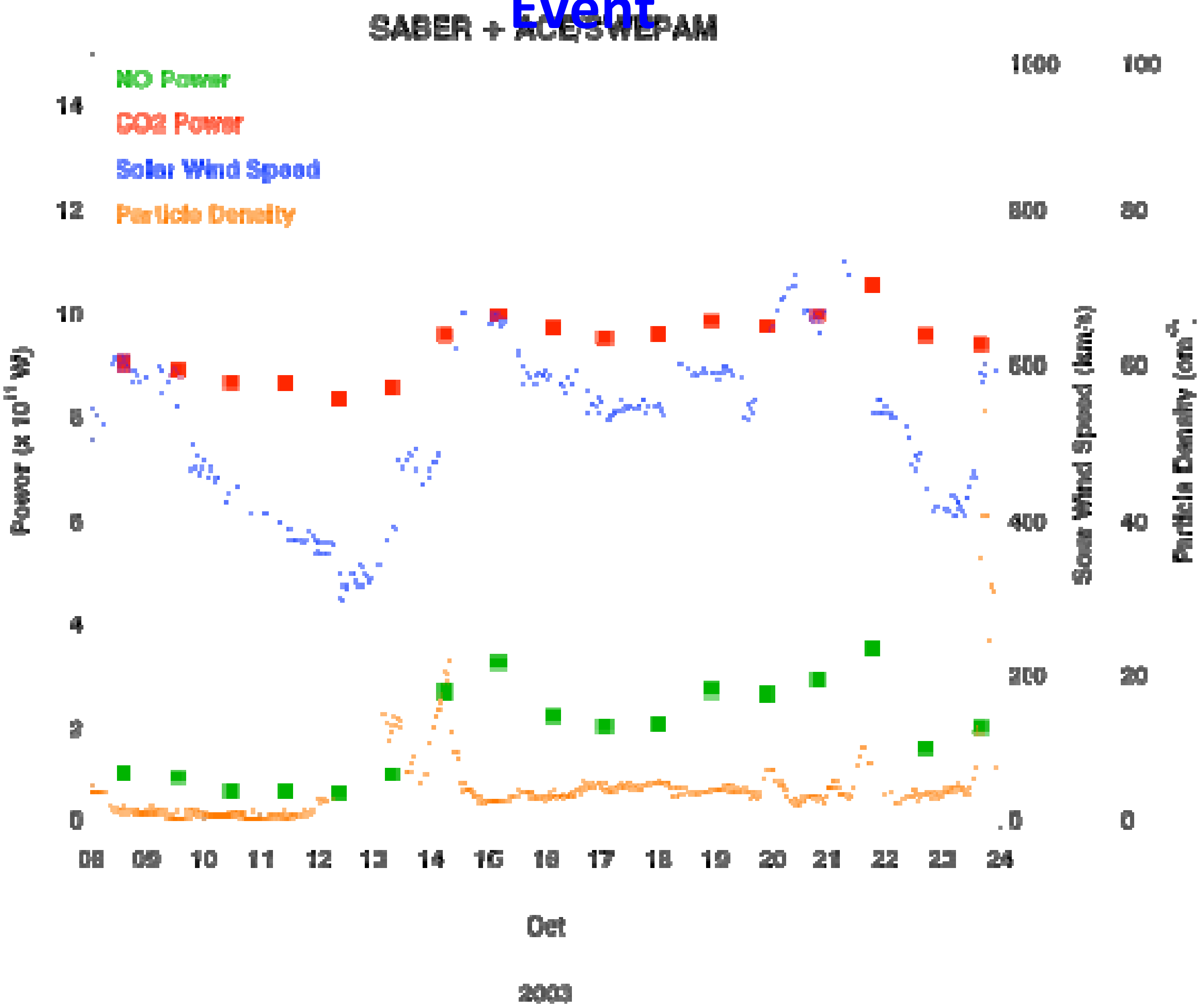
- October 10 to 22, 2003

- Approach
  - Plot global NO, CO_2 power vs. solar wind speed and particle density

- General Results
  - NO, CO_2 power (hence thermospheric cooling) track the solar wind variations almost directly

  - Even on these short timescales (few days) the infrared cooling responds (thermostat effect)

Infrared Cooling, Solar Wind Parameters, October HSS Event



October 05 – 27 2003

“Movie” of Radiative cooling

Zonal averages in 11 deg latitude bins

Evolution of radiative cooling by NO

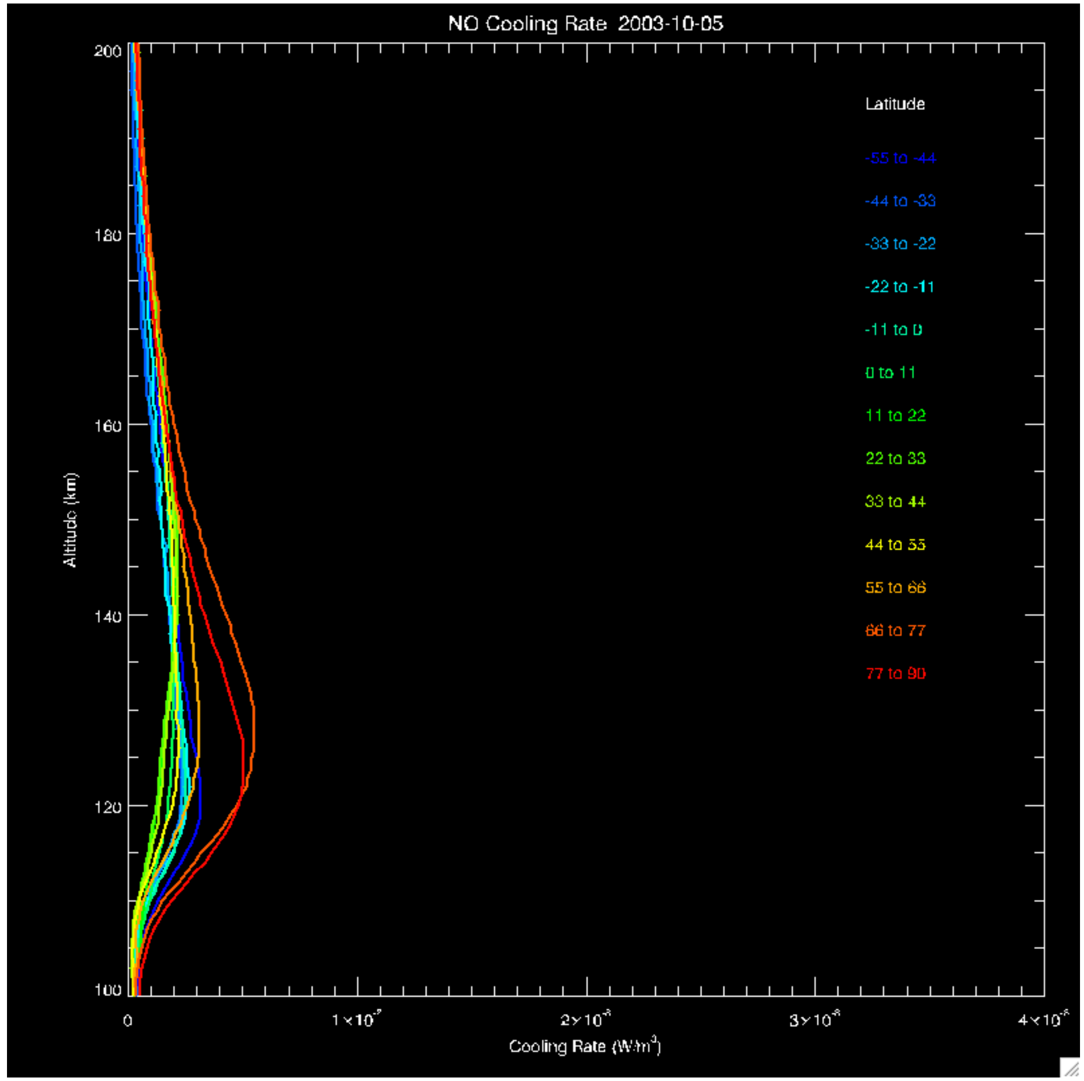
100 to 200 km

5 October to 27 October 2003

High Speed Event 10 to 22 October

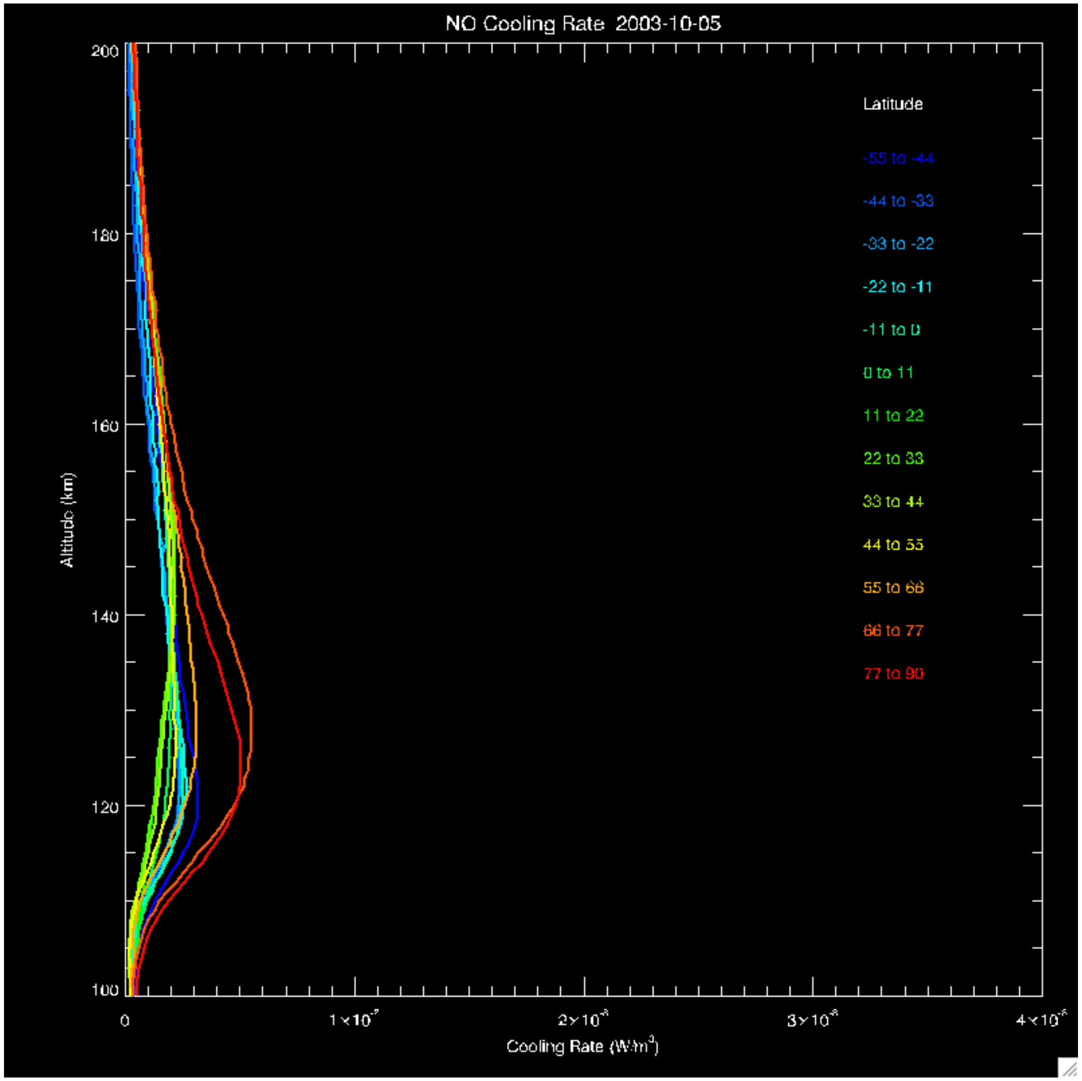
Substantial increase in cooling observed during high speed event, especially October 14-22

Event influences entire thermosphere

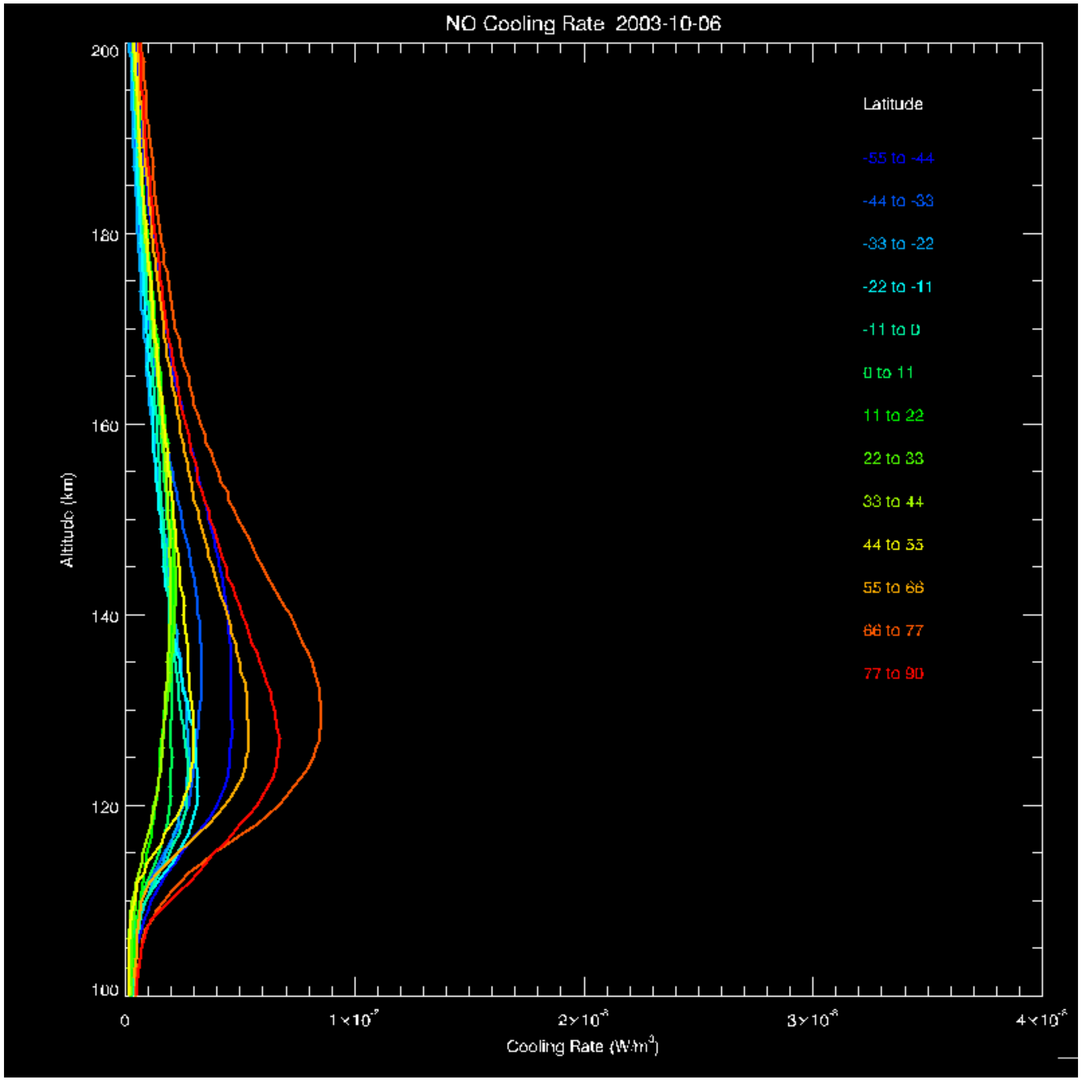


Study Period
October 10 – 22 2003

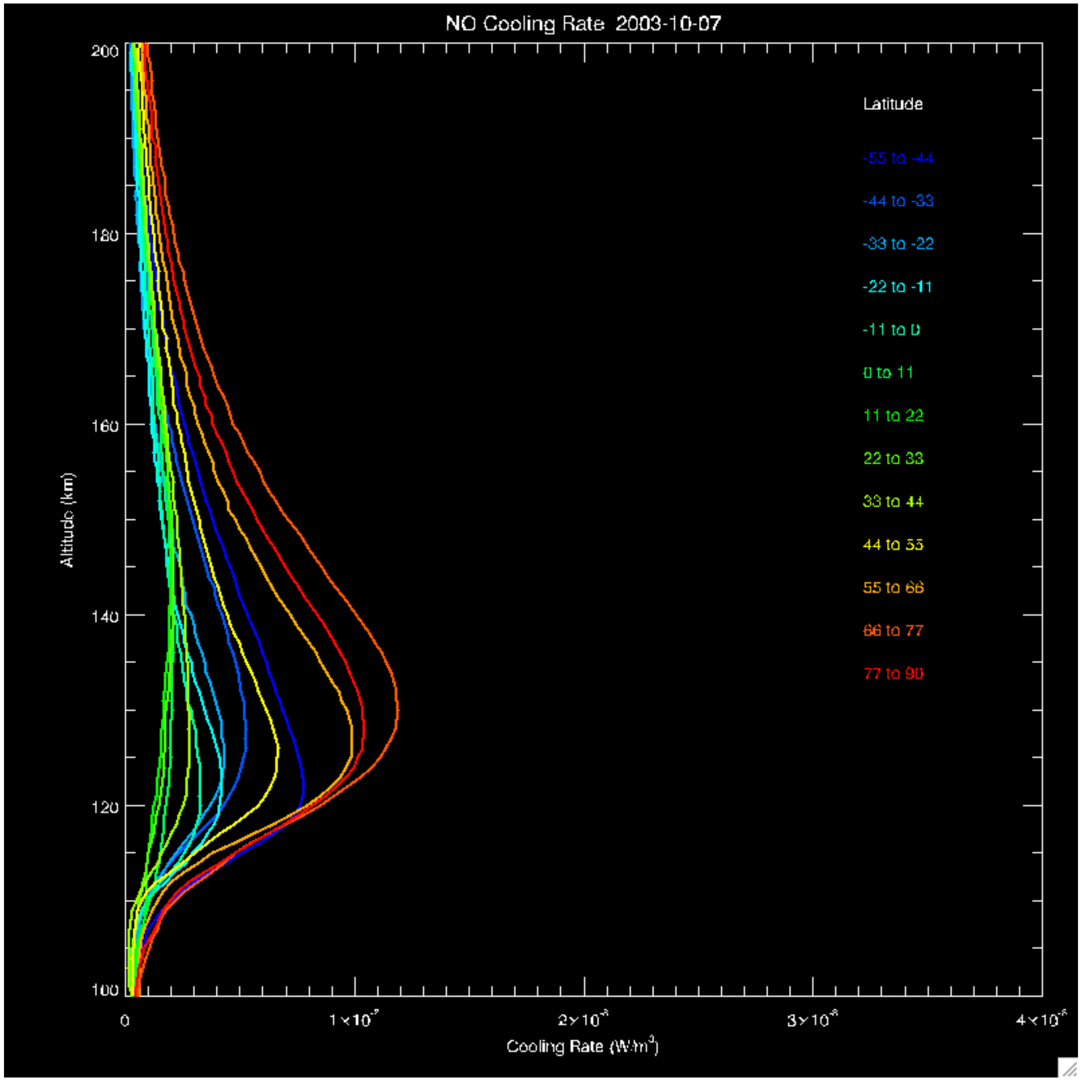
October 05 2003



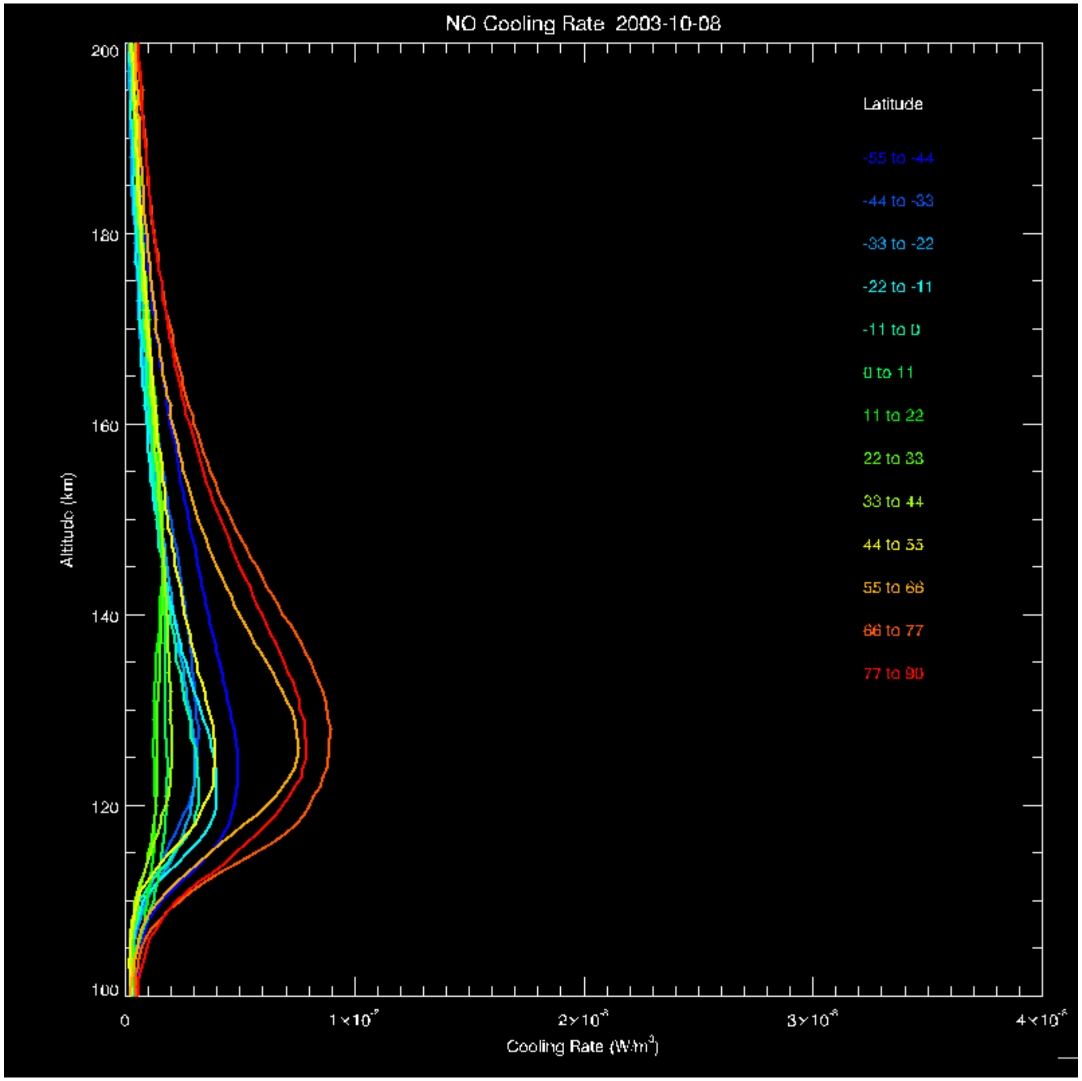
October 06 2003



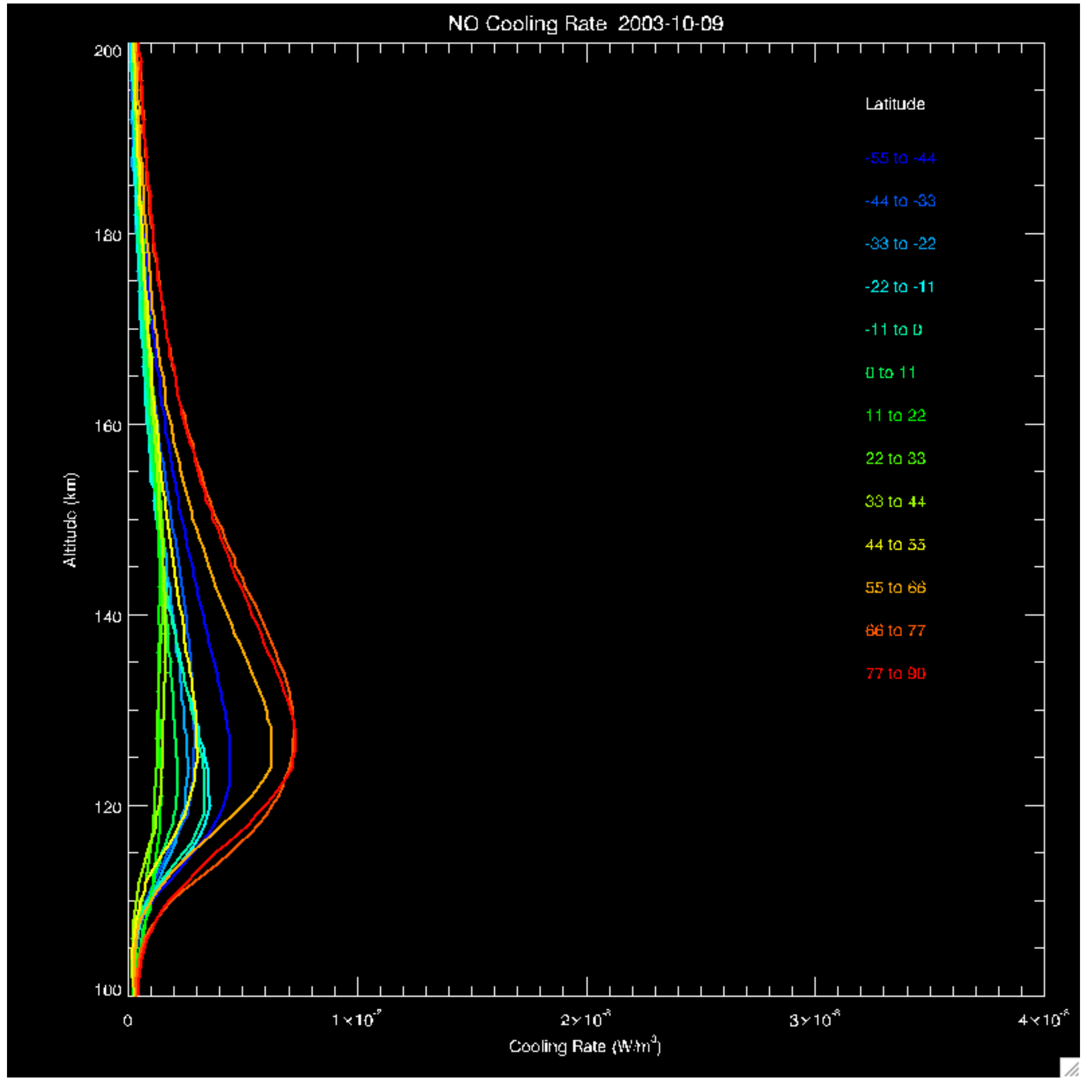
October 07 2003



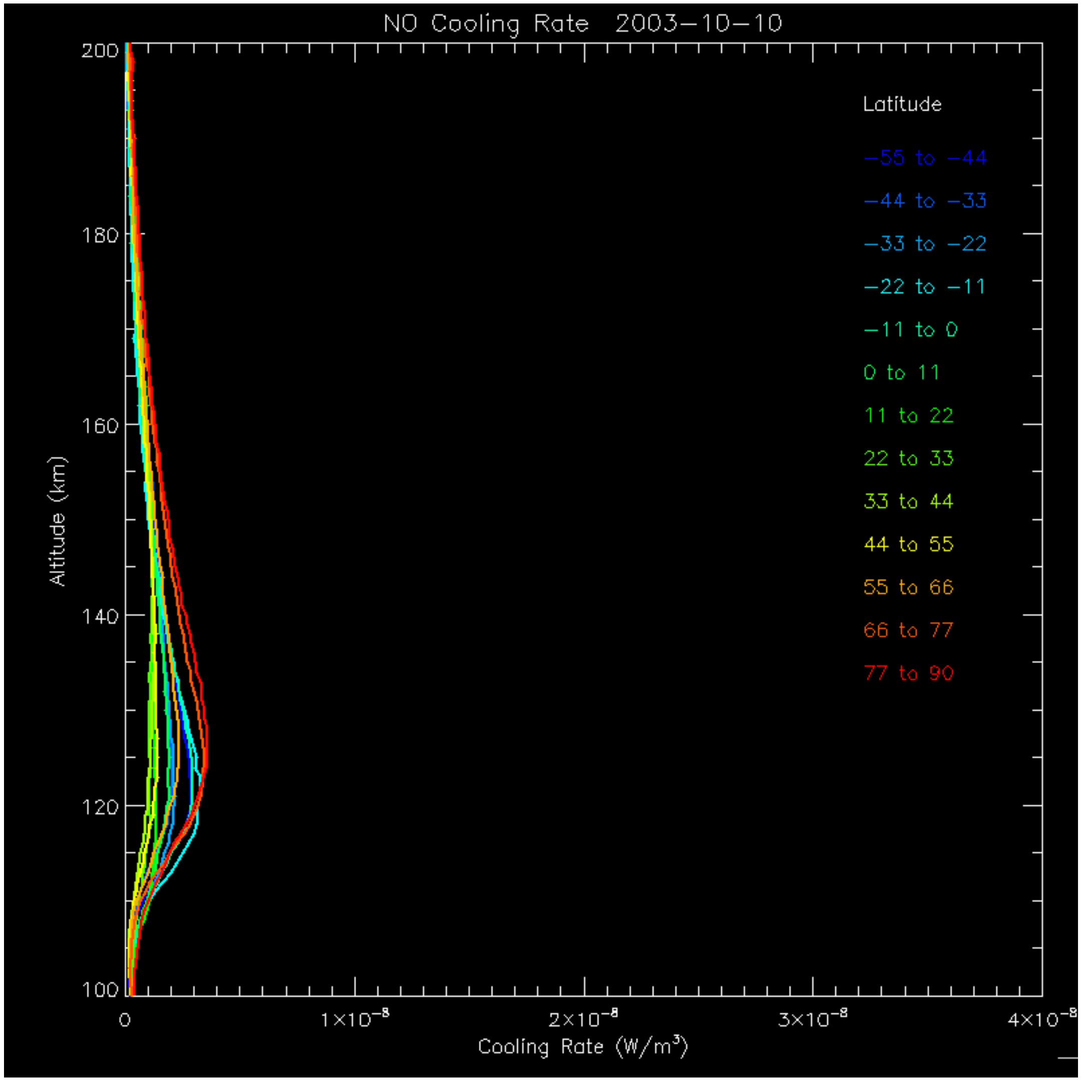
October 08 2003



October 09 2003



October 10 2003



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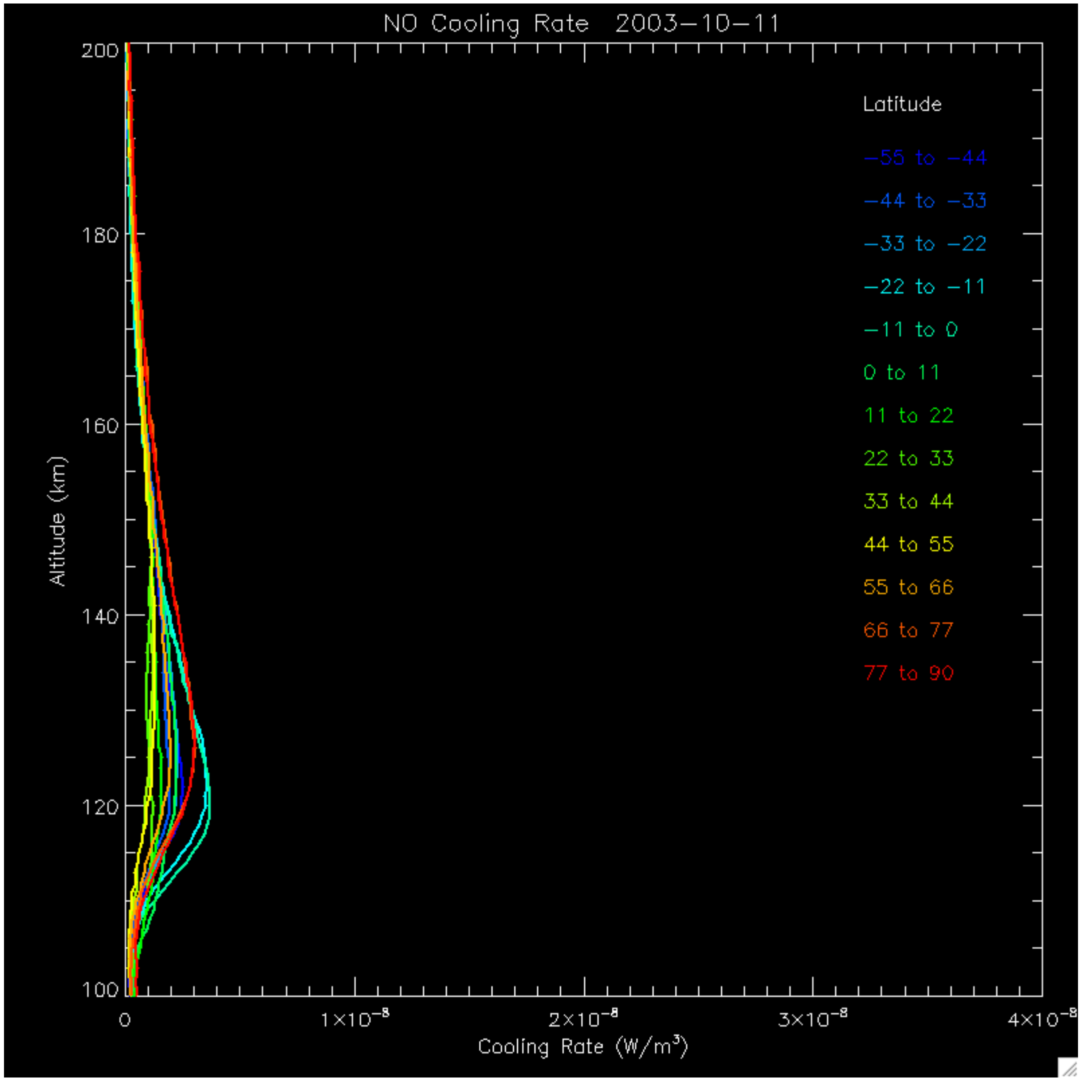

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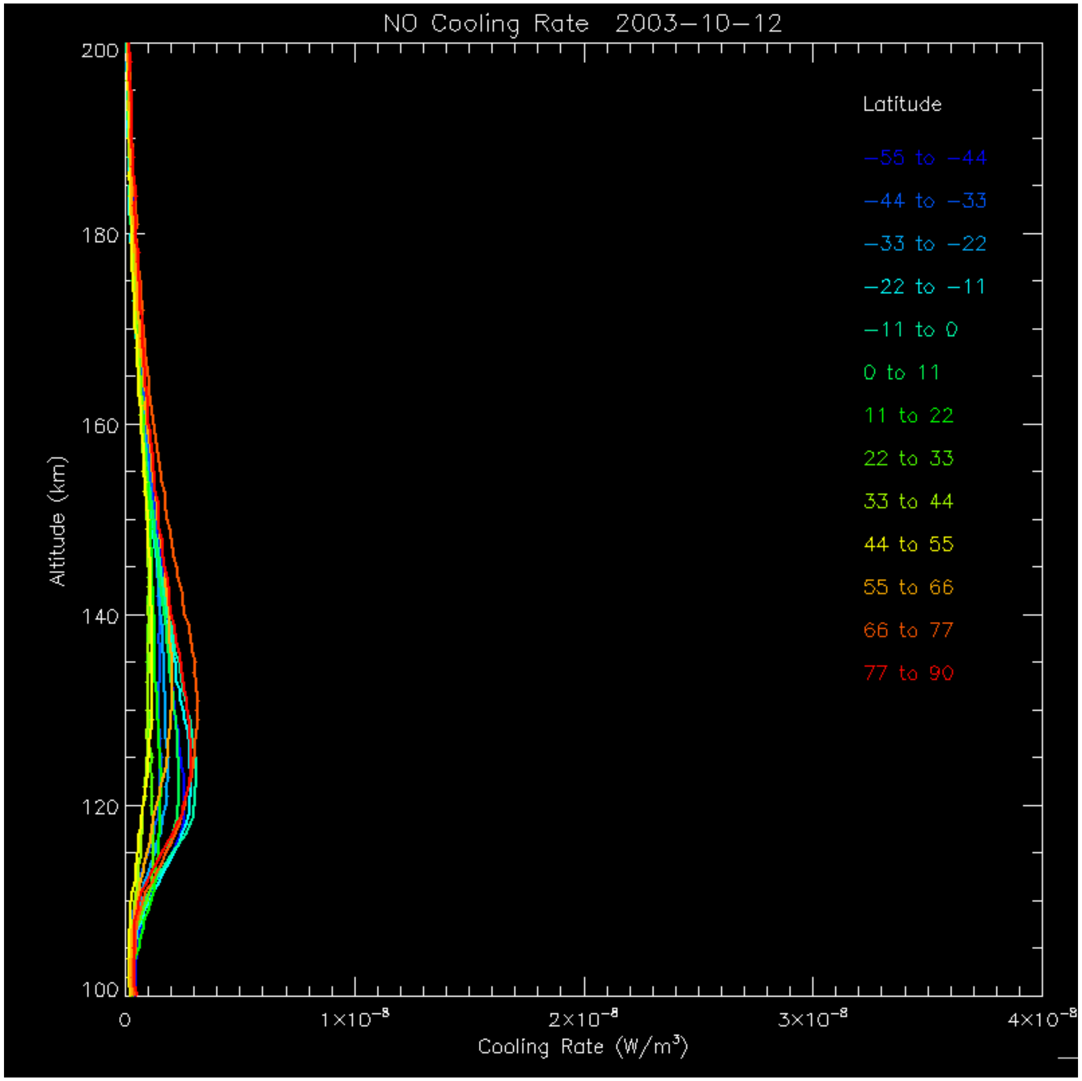

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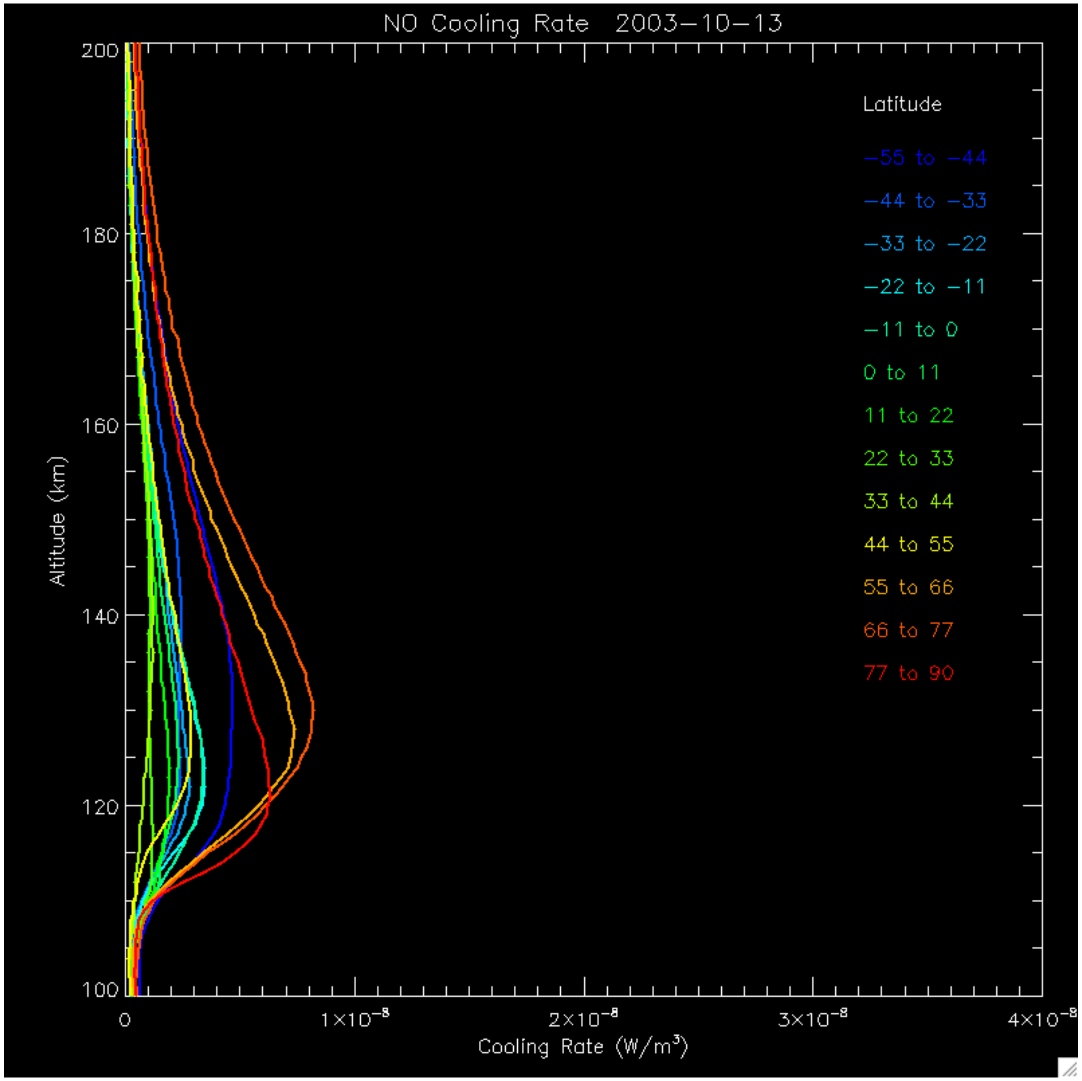

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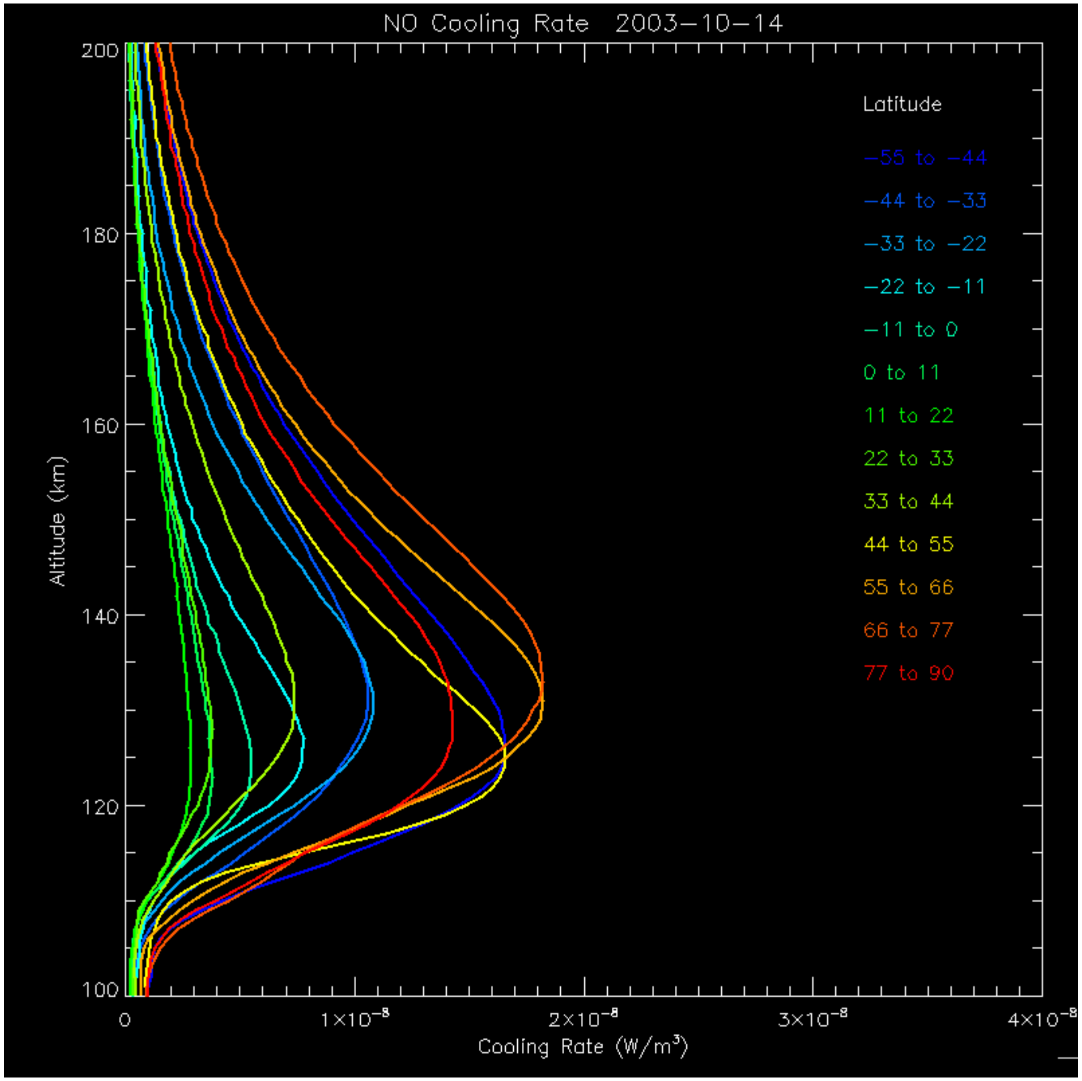

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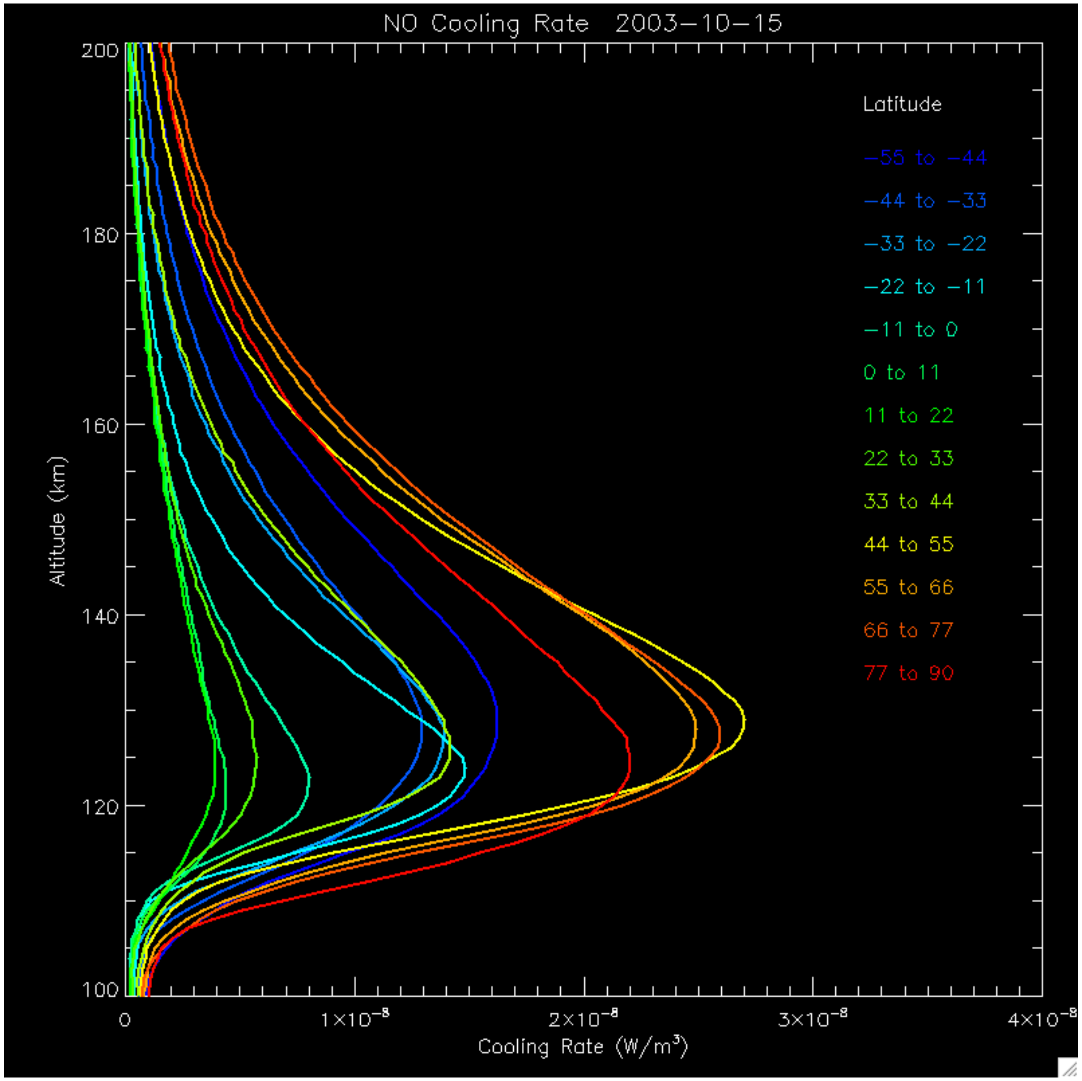

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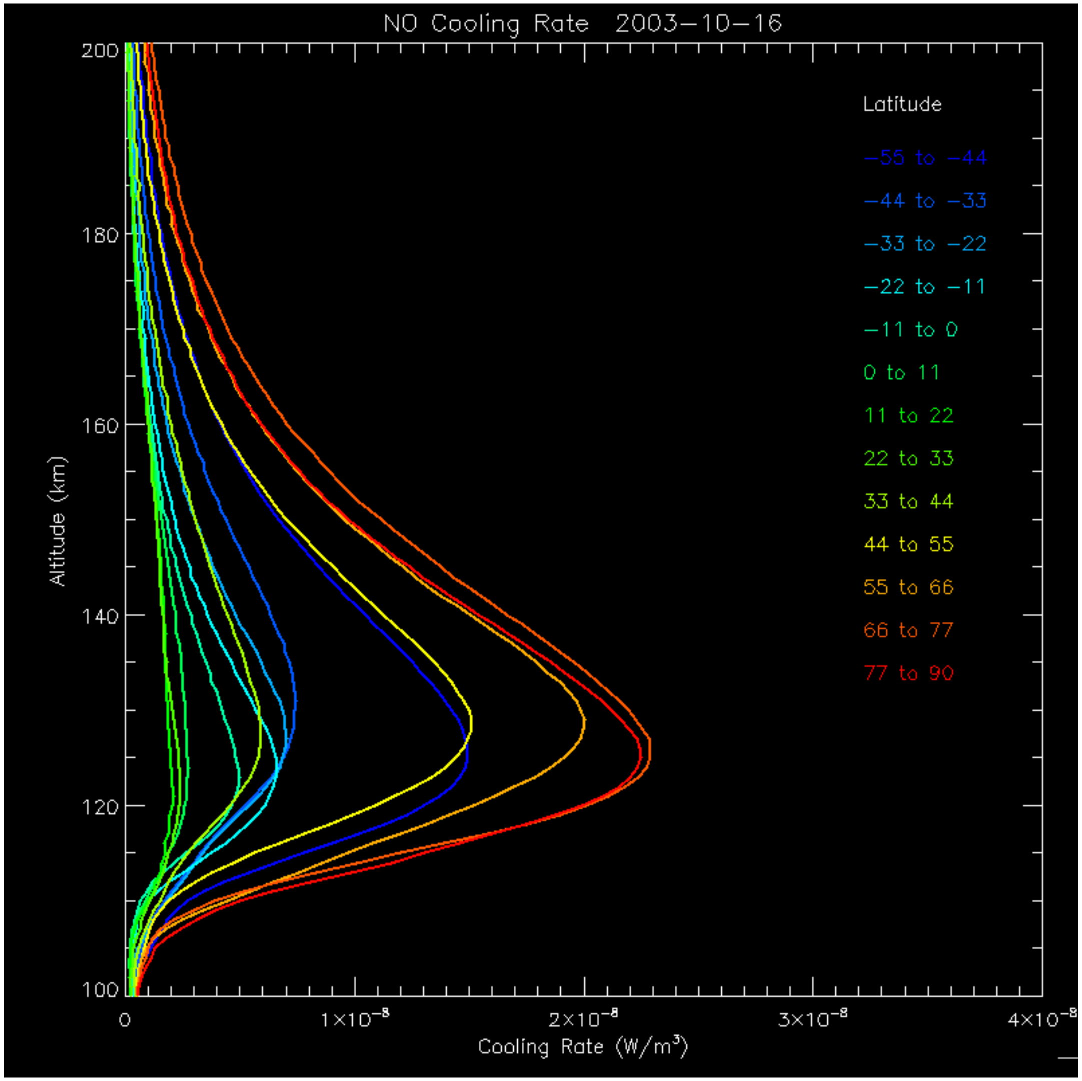

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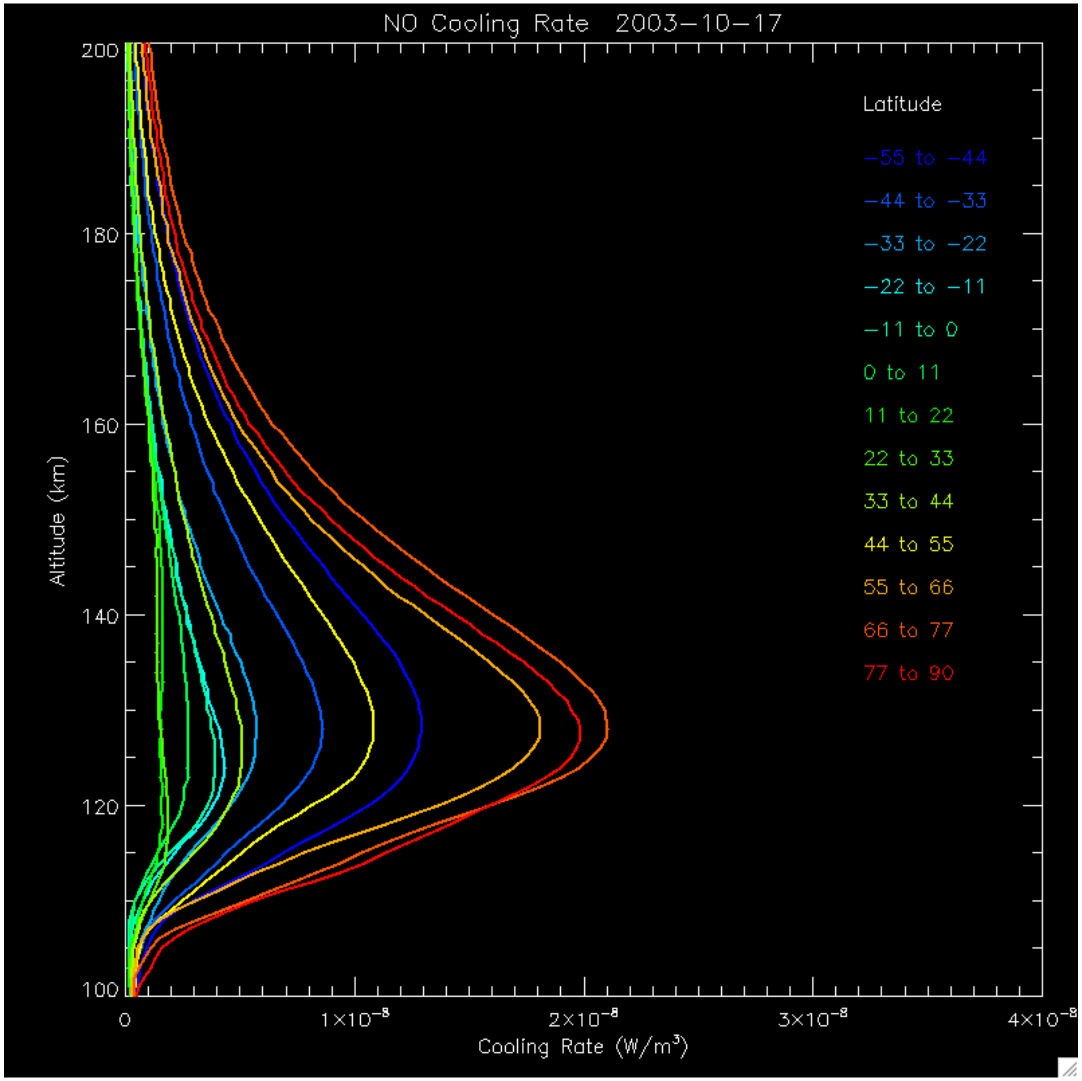

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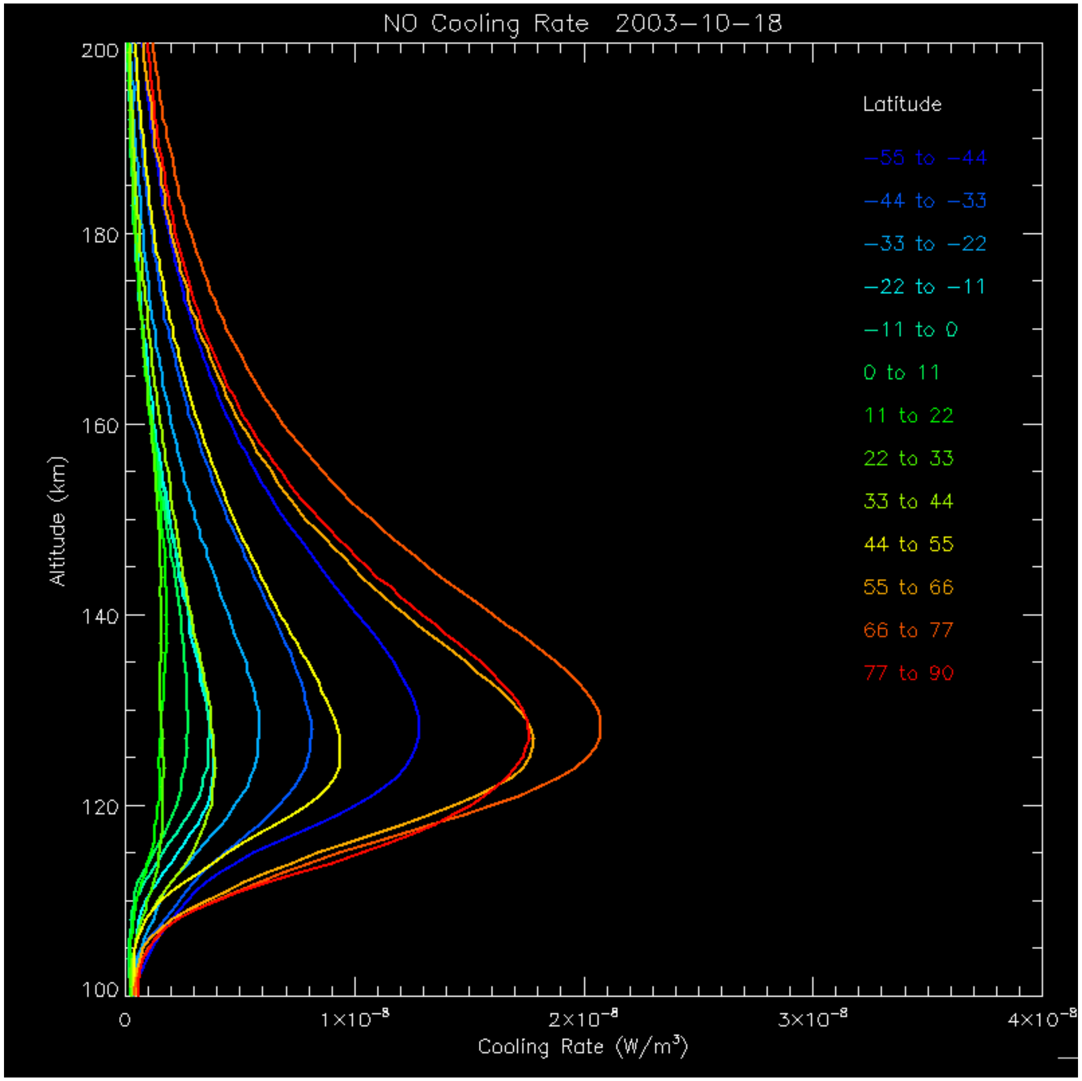

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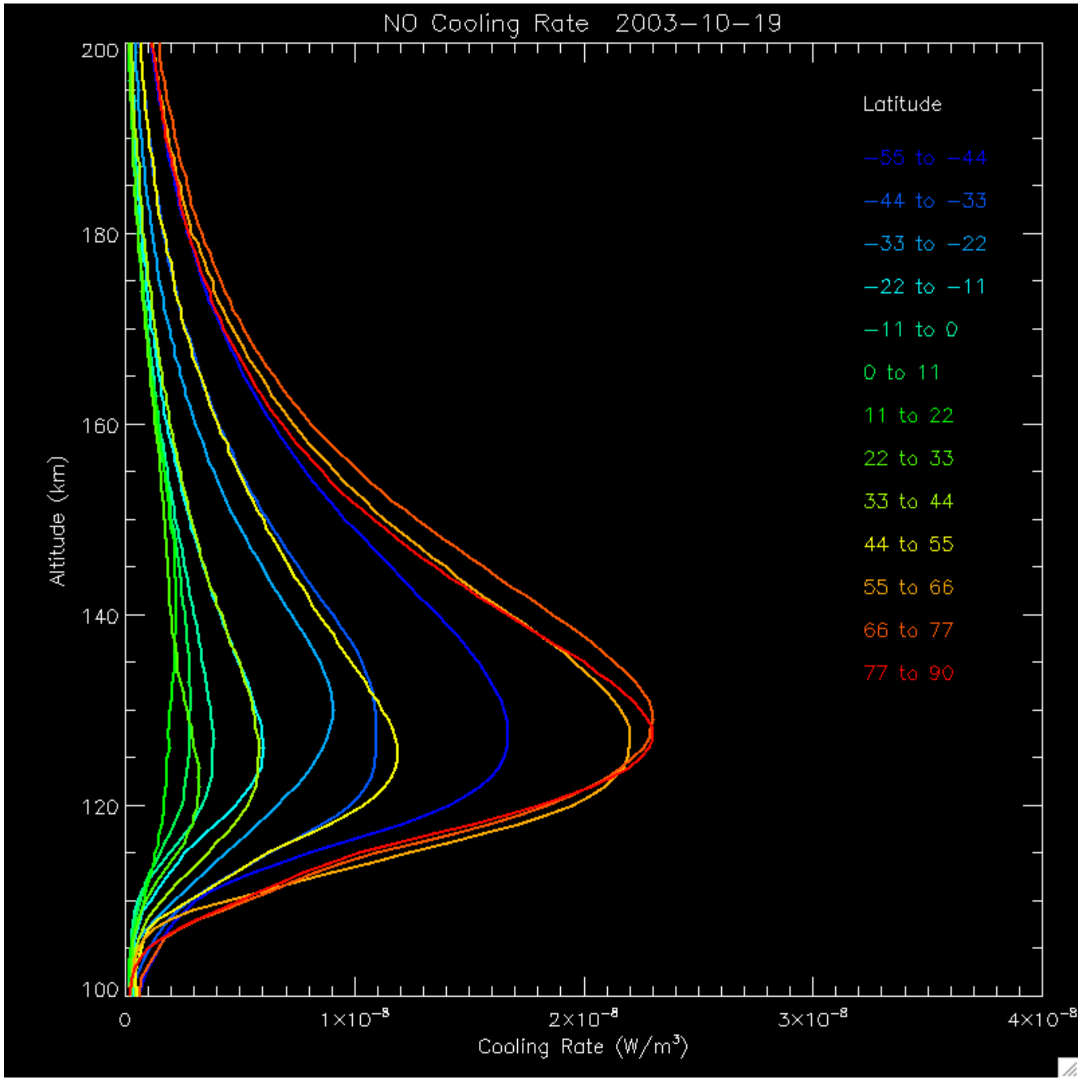

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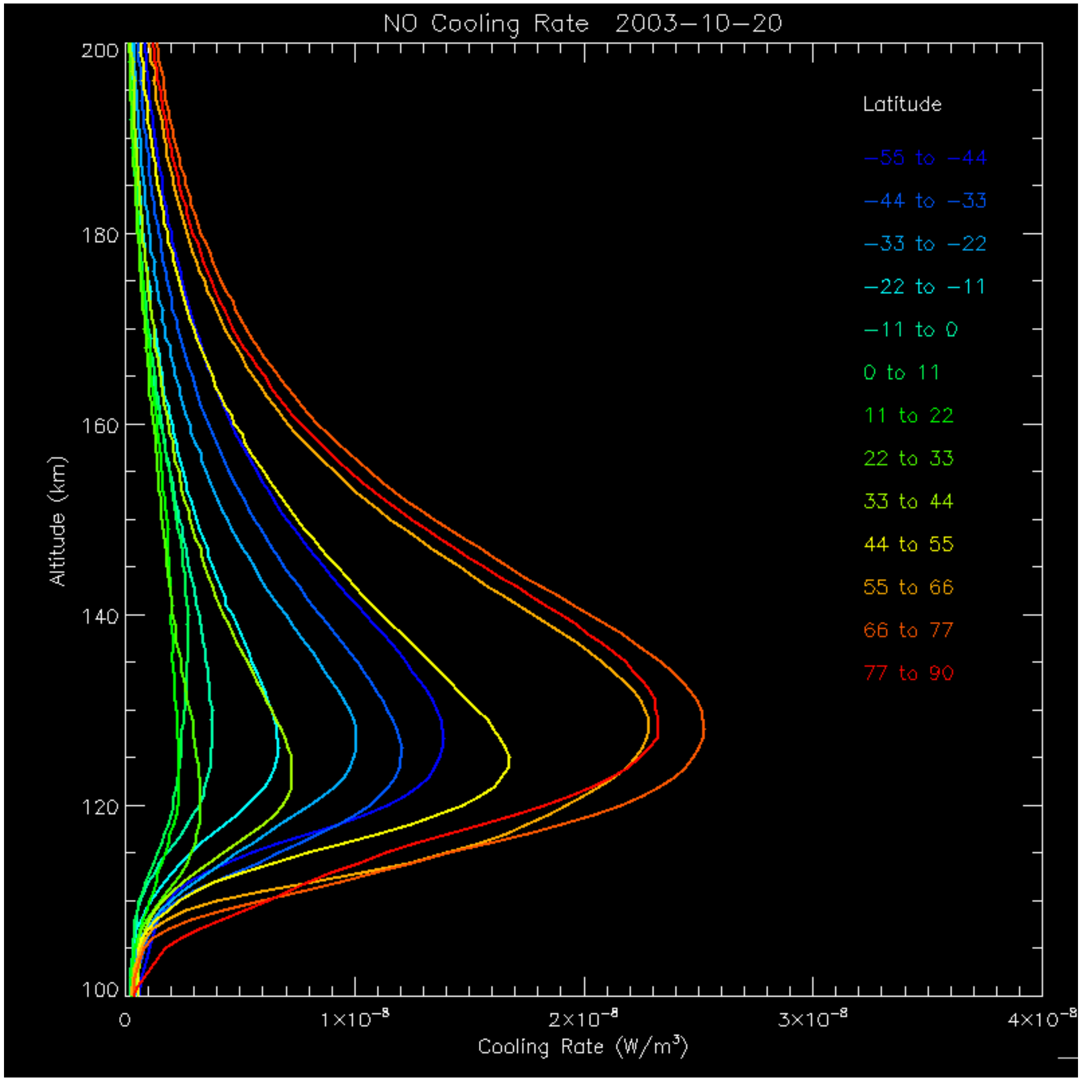

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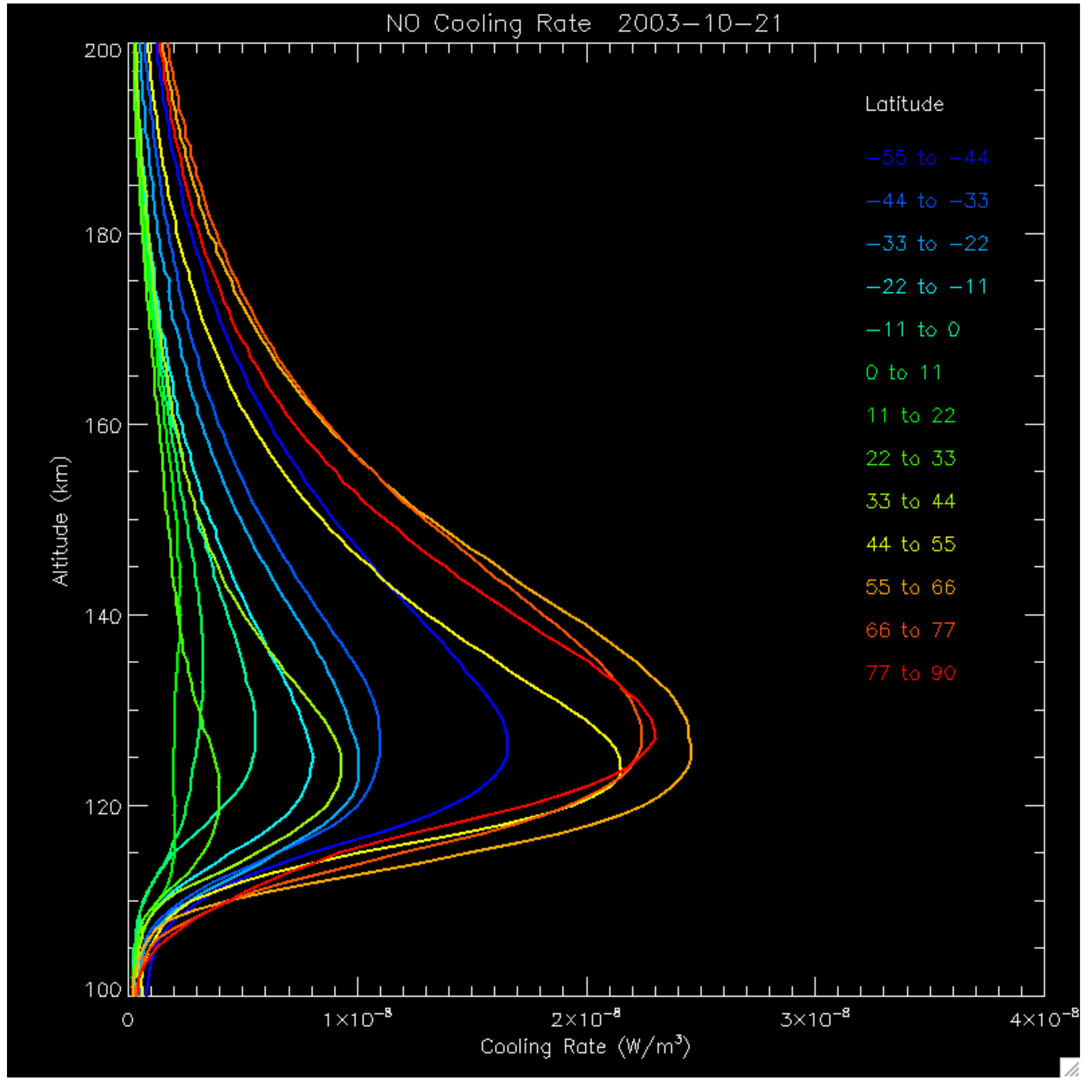

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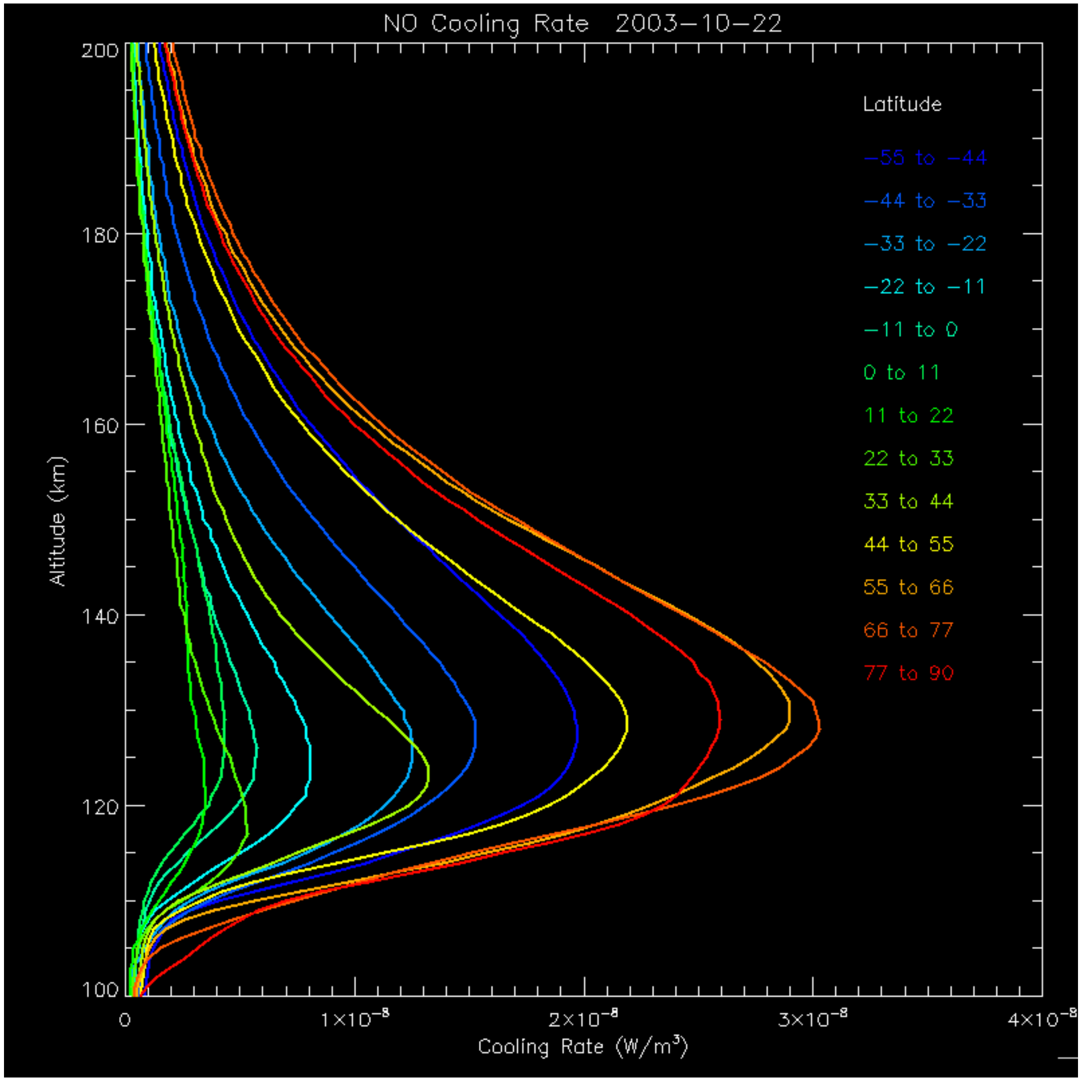

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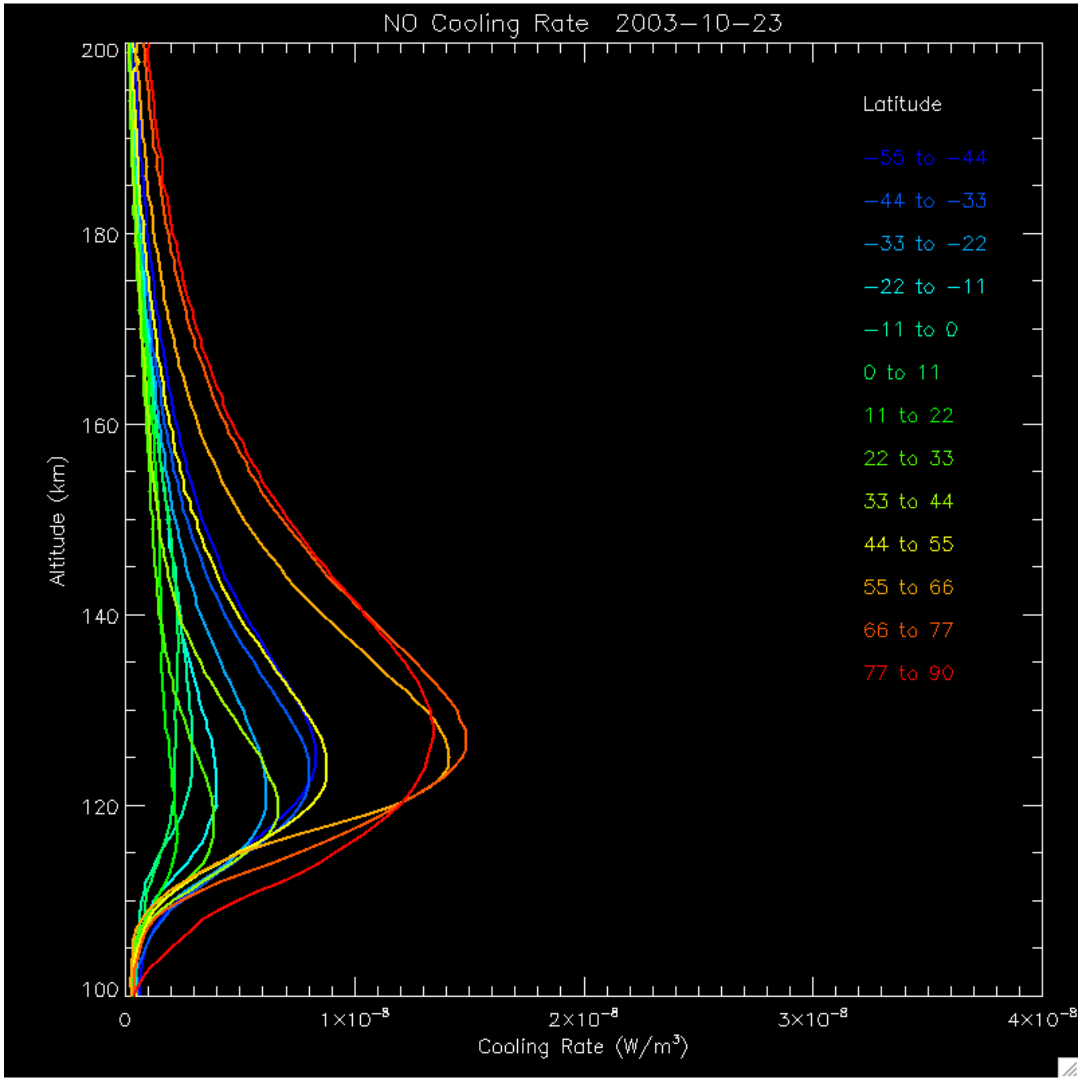

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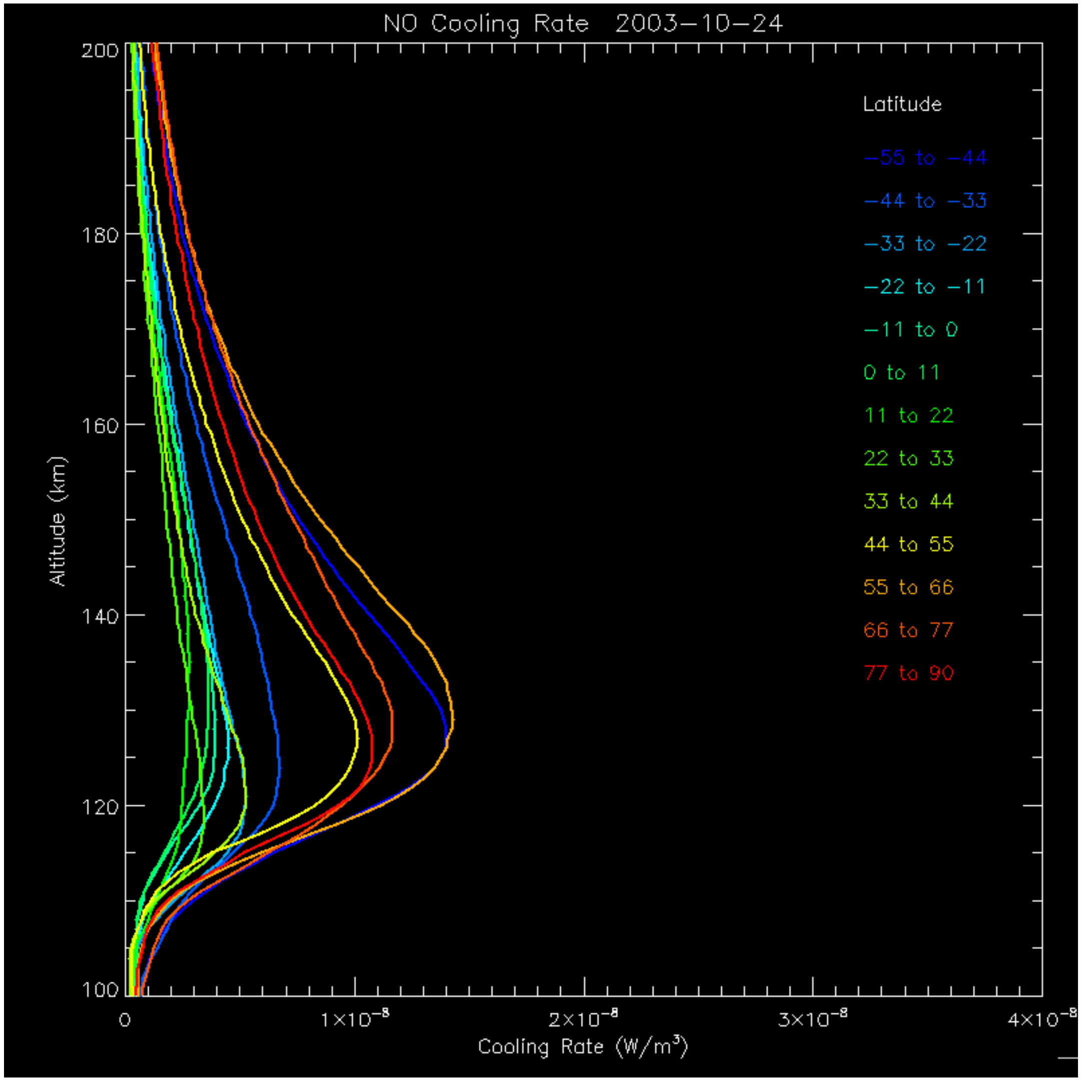

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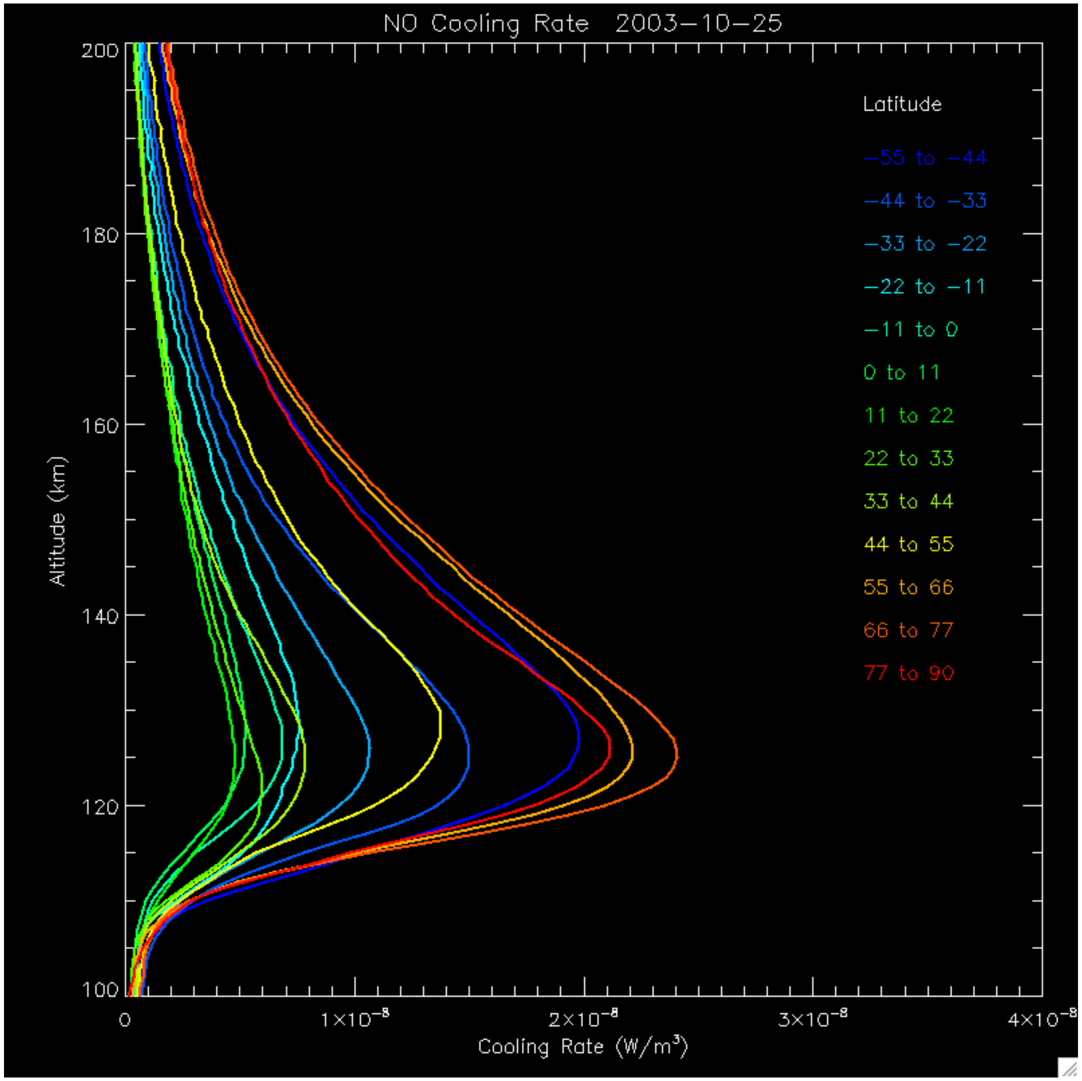

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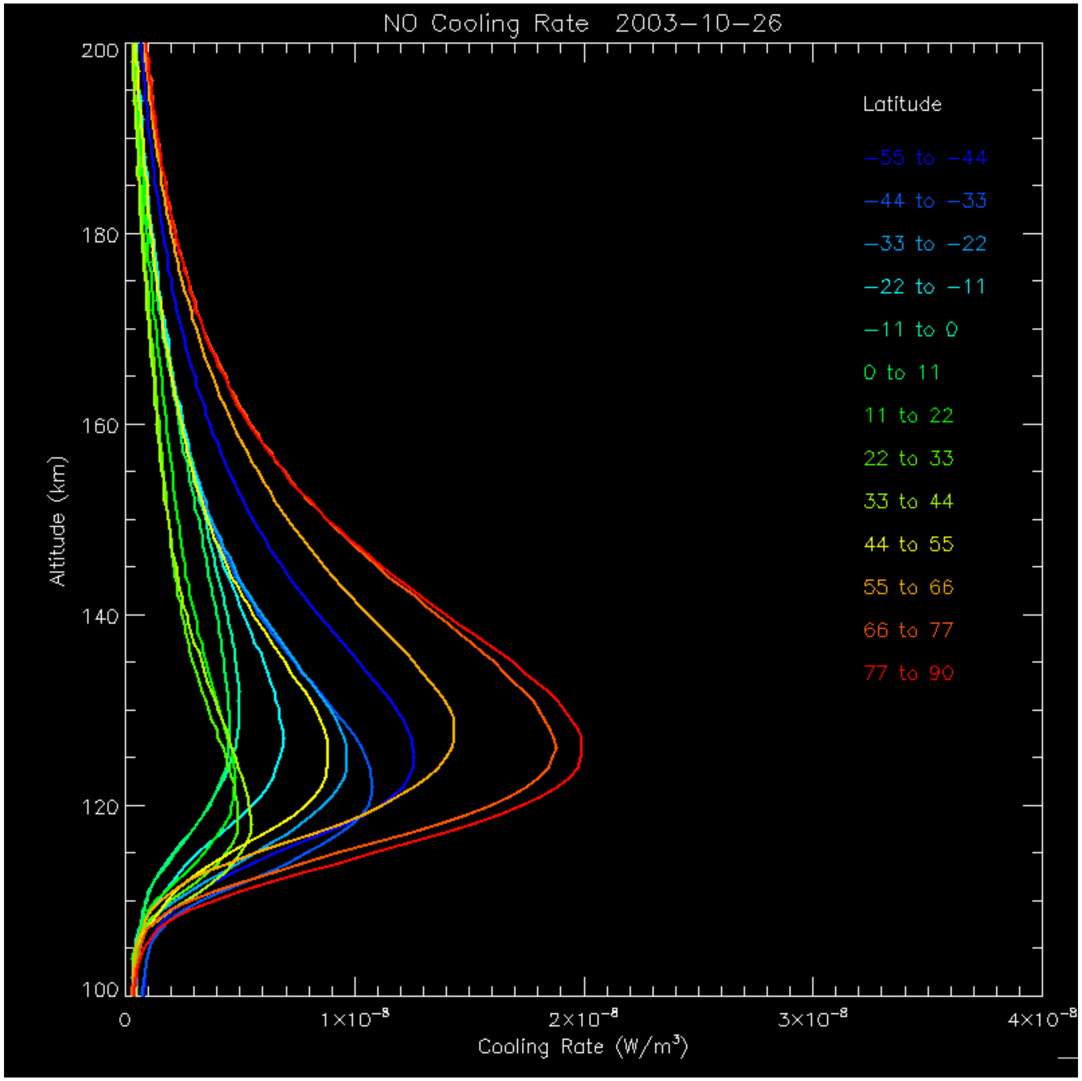
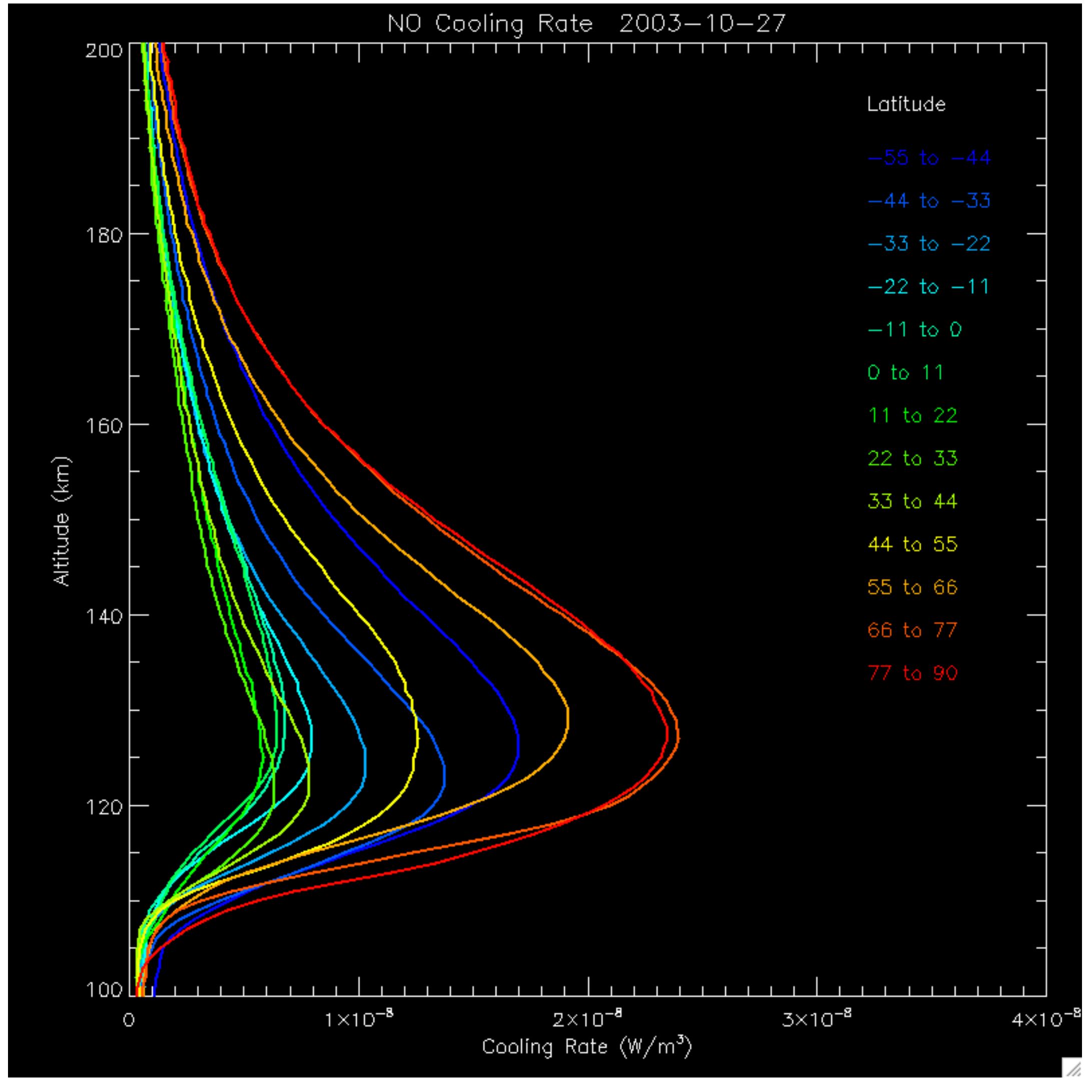


October 27 2003

End of study period



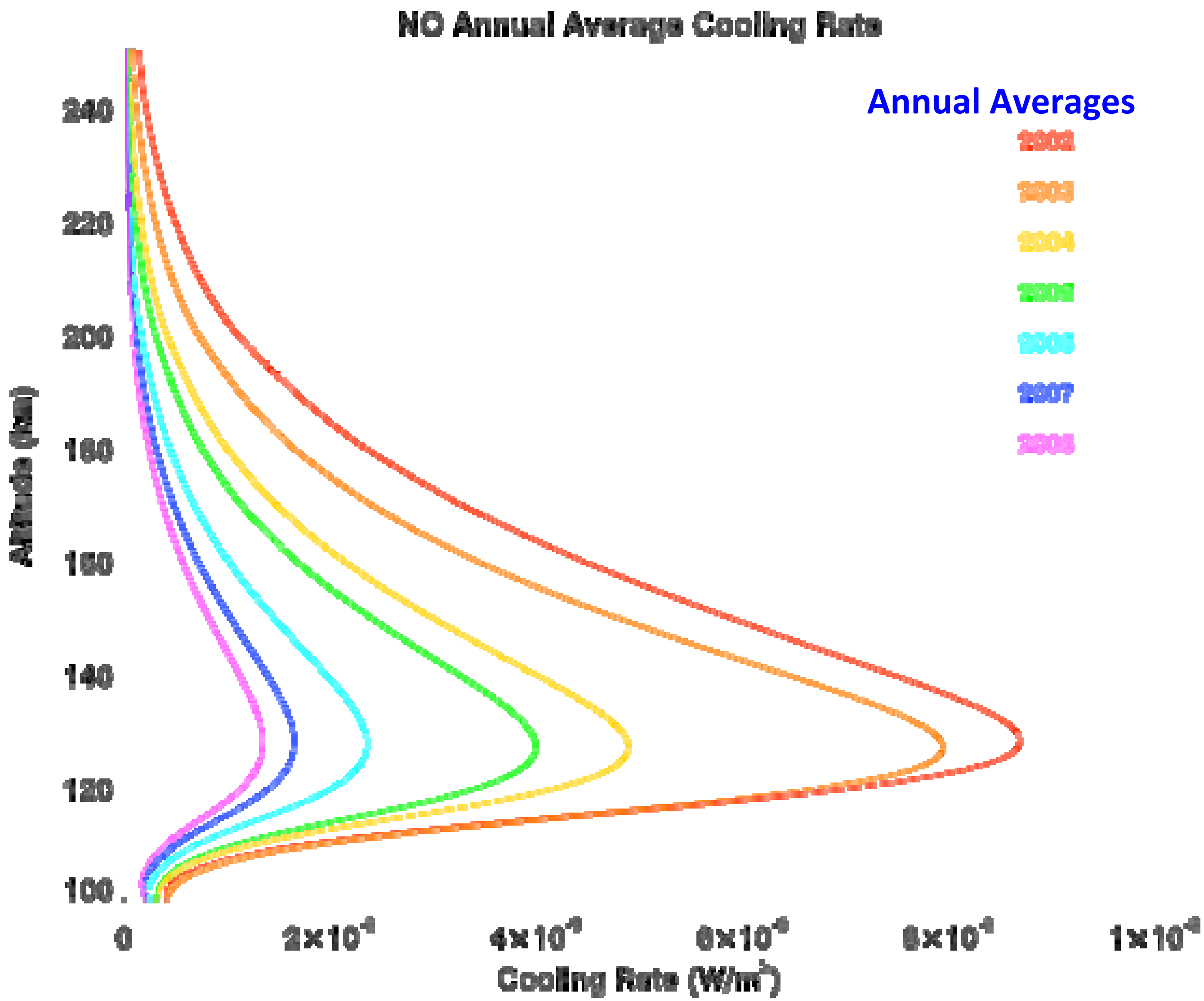
High Speed Event Summary

- Both NO and CO_2 cooling increase with onset of HSS event
- Both emissions track changes in solar wind speed during the events
- NO cooling response greatest at high latitudes
- Effects present throughout entire thermosphere below 200 km altitude

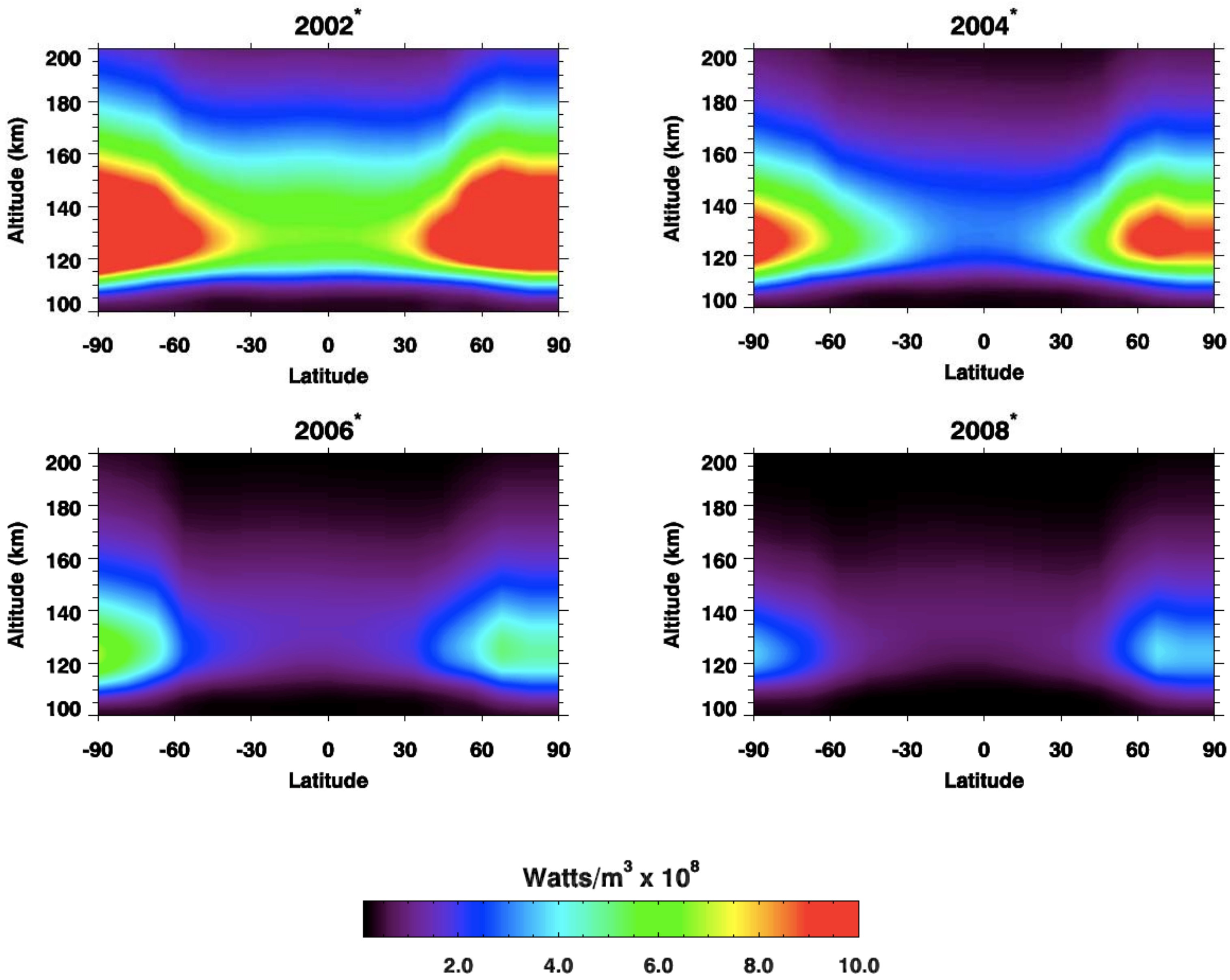
Effects of Particles: Long-Term

- Cooling data offer unique look at effects of solar cycle on radiative cooling of the atmosphere
- Examine Cooling Rates (W m^{-3}) and over the 7 complete years to date
- Results show NO cooling dominates the changes over this time
- Largest changes in cooling are in polar regions where particle precipitation dominates
- Suggests strong link between solar wind, chemistry of NO, and large-scale dynamics of thermosphere

Nitric Oxide Radiative Cooling 2002 – 2008



Zonally Averaged Annual NO Cooling Rate W m^{-3}



Summary

- Infrared cooling measurements from SABER offer unique insight into solar-terrestrial coupling on time scales from a few days to 11-year solar cycle
- The “natural thermostat” effect of NO is highly efficient in removing energy deposited from solar wind particle events
- Short-term periodic features in radiative cooling are observed and shown to have geomagnetic origins
- Long-term changes in radiative cooling have both geomagnetic and solar – ultraviolet causes
- Results imply a strong coupling between both particles and photons from the Sun and long-term changes in thermospheric neutral dynamics

Future Work

- **The SABER NO and CO_2 data constitute the first long-term climate data record of cooling rates, fluxes, and power in the thermosphere**

- **These data are the fundamental for validating the basic energetics in all upper atmosphere general circulation models**

- **These data are available – just ask!**

Reference:

Observations of infrared radiative cooling in the thermosphere on daily to multiyear timescales from the TIMED/SABER instrument, M. Mlynczak et al., *JGR-Space*, almost accepted, 2009.

Thank You from 500 hPa!
Marty Mlynczak

Cerro Toco, Chile, @ 17,500 Feet
Site of the RHUBC-II/FORGE Campaign