Observations of Solar Induced Variability in the Thermosphere and Mesosphere Over the Past 14 Years – and Longer!

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The SABER Science Team

Outline

- Acknowledgement
- Introduction
- Overview of Thermosphere Energy Budget
- Radiative Cooling in the Thermosphere
- A View to the Past
- A View to the Future

Acknowledgement

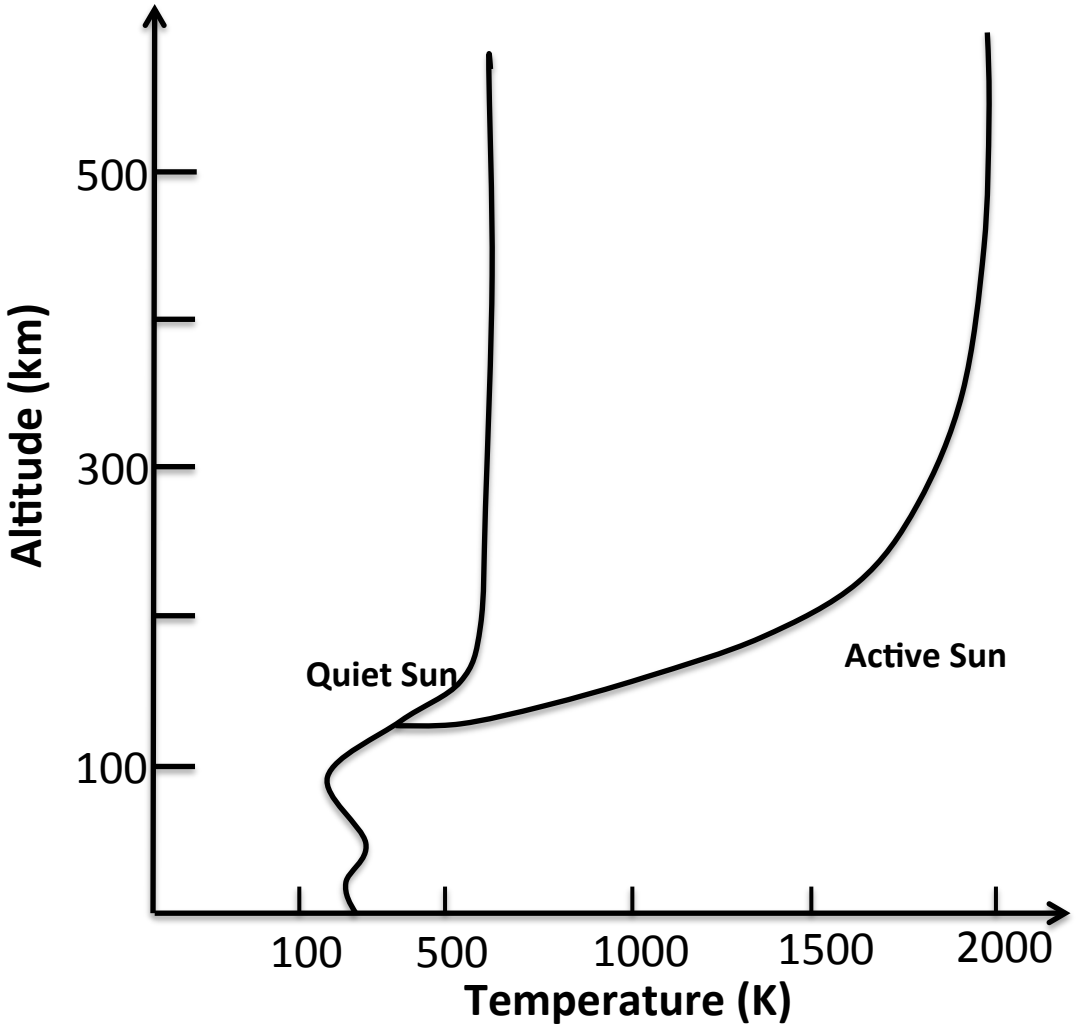
- Today we will look at data from the NASA TIMED satellite and the SABER instrument that was launched over 14 years ago on 7 December 2001.

- This talk is possible only because in the late 1990's, numerous engineers, project managers, resource analysts, and technicians did an excellent job of building and testing the TIMED instruments and satellite

- This talk is dedicated to them, for the outstanding job they did, which provides all of us the privilege of doing science with the data

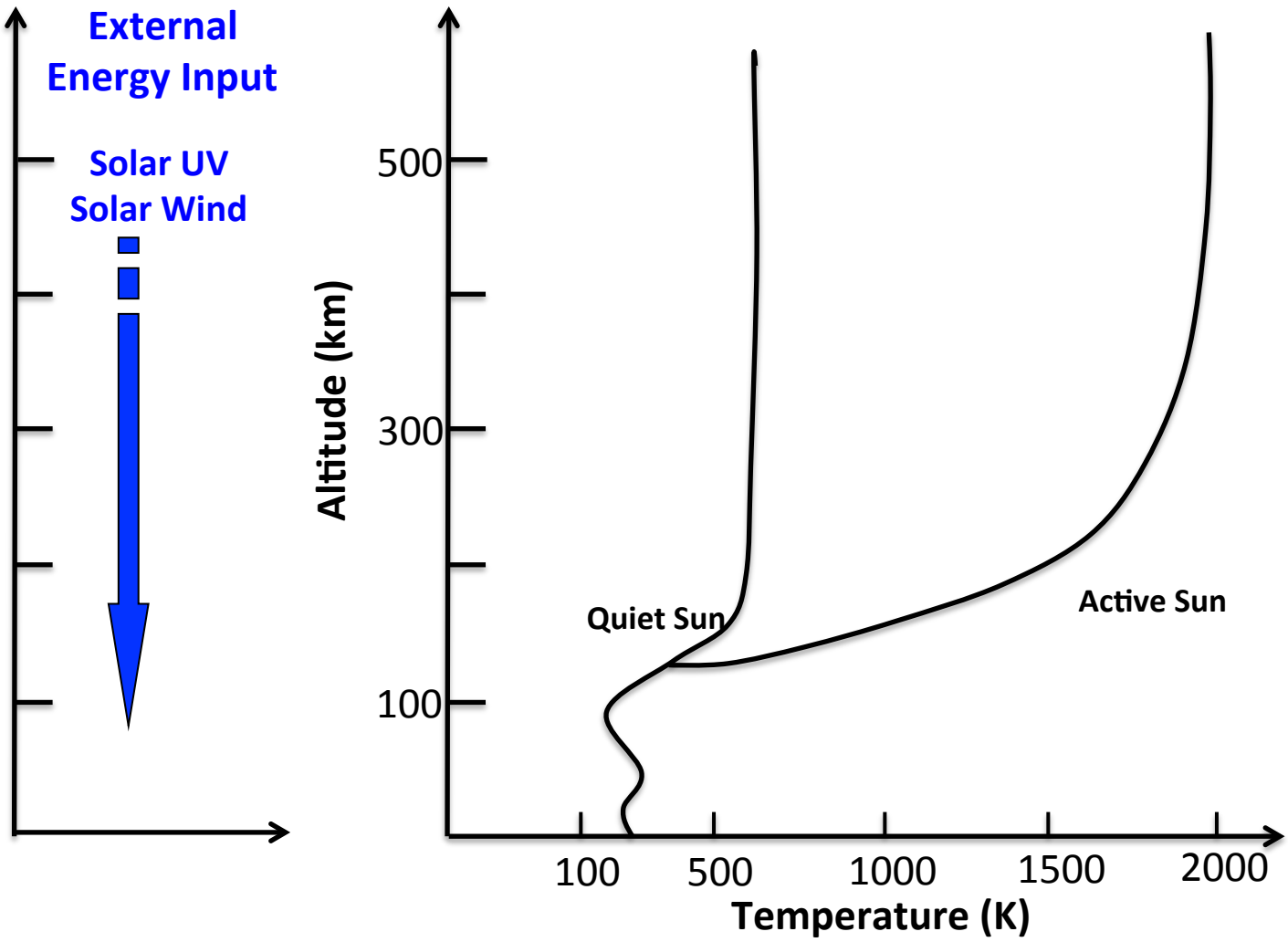
1. Overview of the Thermosphere Energy Budget

Thermosphere Energy Balance – Thermal Structure

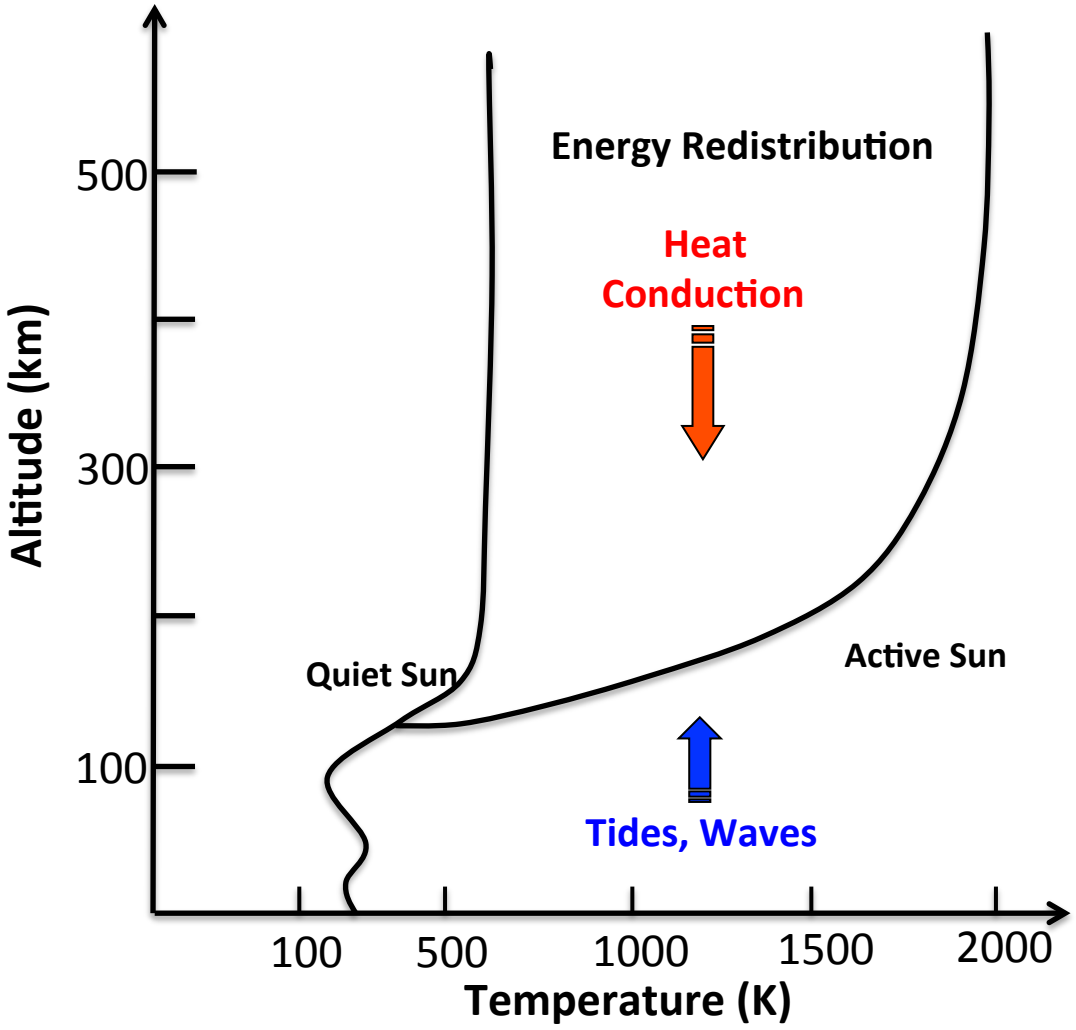


Banks and Kockarts, 1973

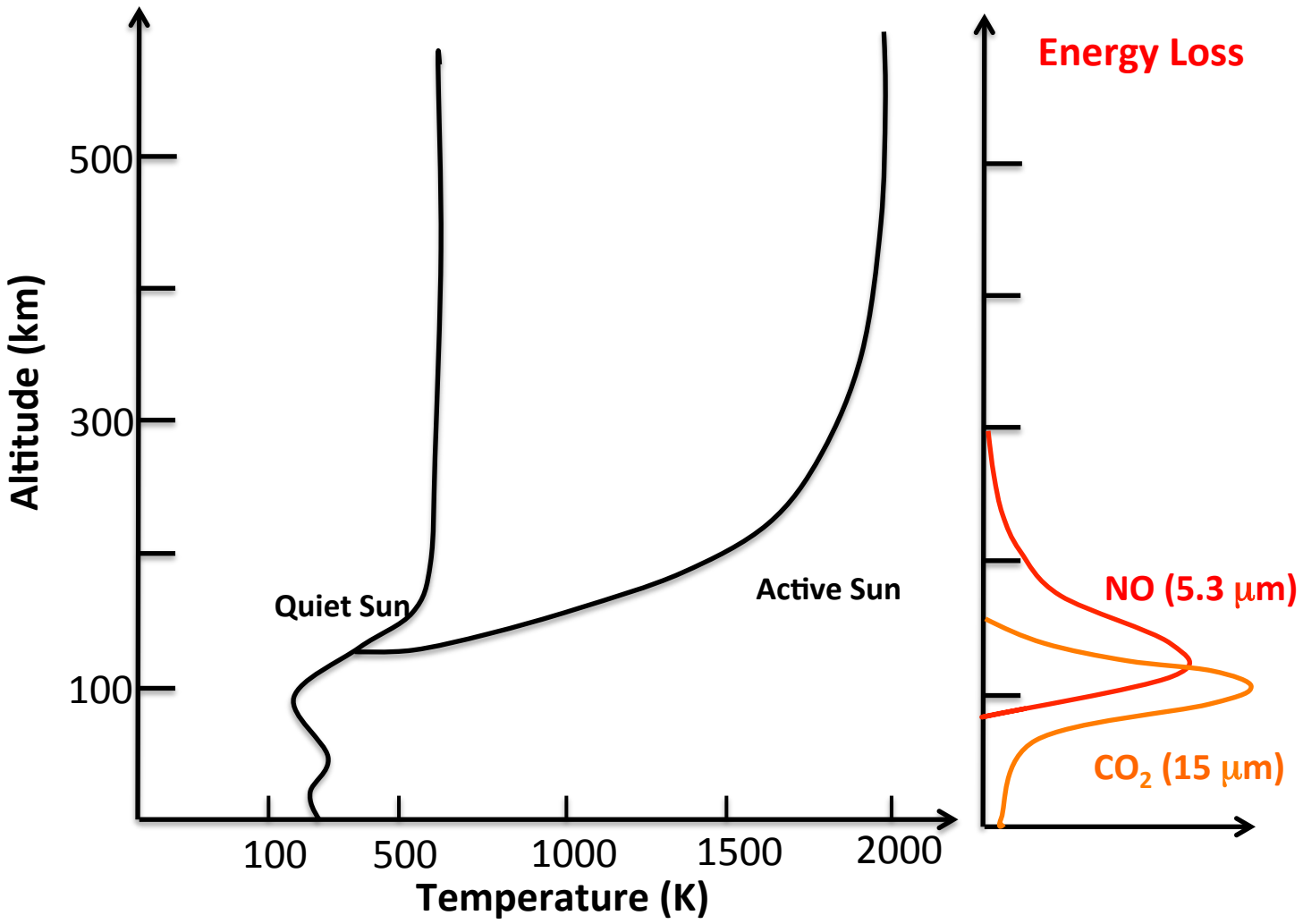
Thermosphere Energy Balance – Energy Inputs



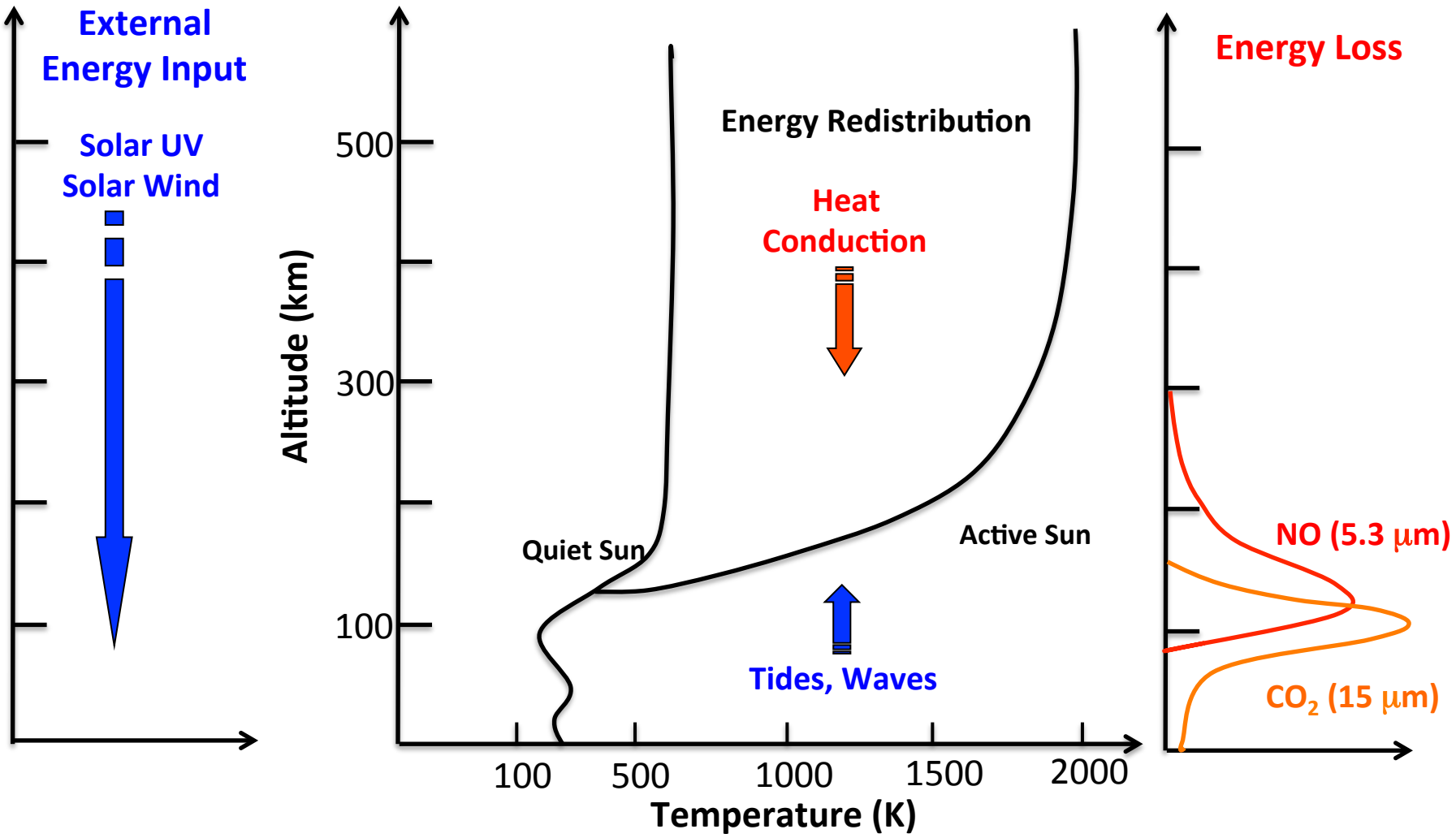
Thermosphere Energy Balance – Energy Redistribution



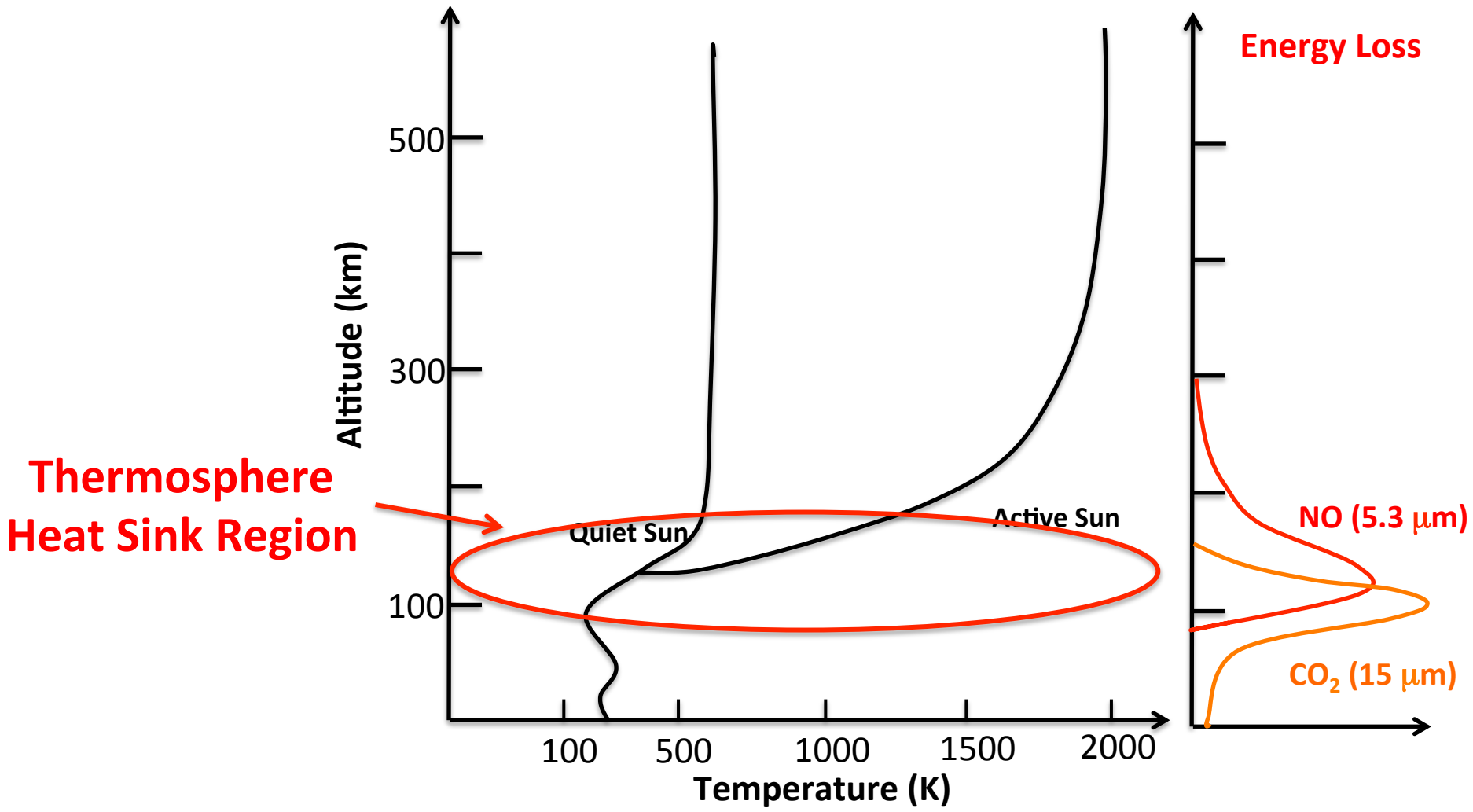
Thermosphere Energy Balance – Energy Outputs



Thermosphere Energy Balance – Basic Elements



Thermospheric Heat Sink



2. Radiative Cooling in the Thermosphere

Radiative Cooling in the Thermosphere

- Radiative cooling is the action of infrared radiation to reduce the kinetic temperature of the neutral atmosphere

- It is accomplished almost entirely by two species:
  - Carbon Dioxide (CO_2, 15 μm)
  - Nitric Oxide (NO, 5.3 μm)

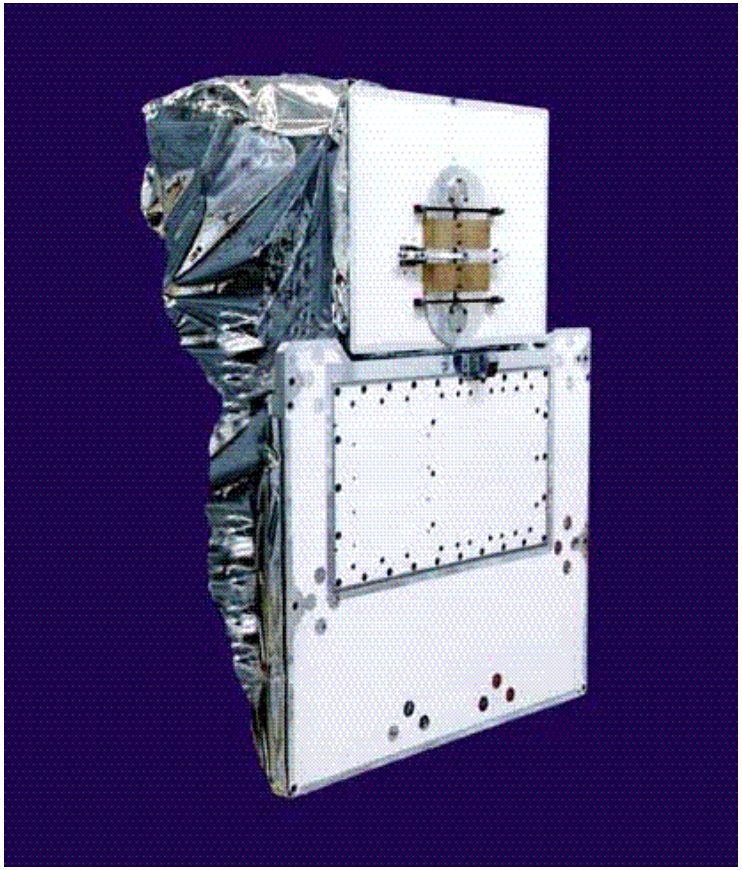
- Collisions between atomic oxygen (O) and CO_2 and NO initiate the cooling process
  - NO (υ = 0) + O → NO (υ = 1) + O (Kinetic Energy Removal)
  - NO (υ = 1) → NO (υ = 0) + hν (5.3 μm) (Kinetic Energy Loss)
  - NO (υ = 1) + O → NO (υ = 0) + O (Kinetic Energy Returned)

- Collisional process are highly temperature dependent!

Sounding of the Atmosphere using Broadband Emission Radiometry -- SABER --

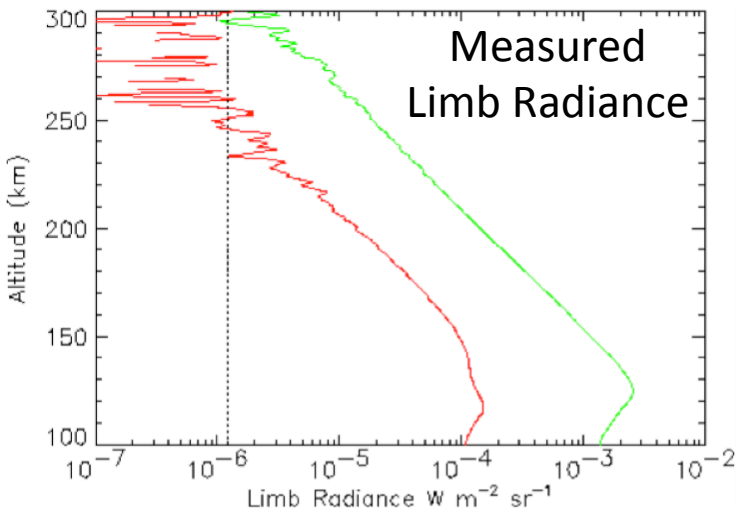
SABER Experiment

- Limb viewing, 400 km to Earth surface
- Ten channels 1.27 to 16 μm
- Over 30 routine data products including energetics parameters
- 8.3 million radiance profiles – per channel!
- Cryo-cooler operating excellently at 77 K
- Noise levels at or better than measured on ground
- Now in 15th year of on-orbit operation
- **Over 1100 referreed journal articles!**

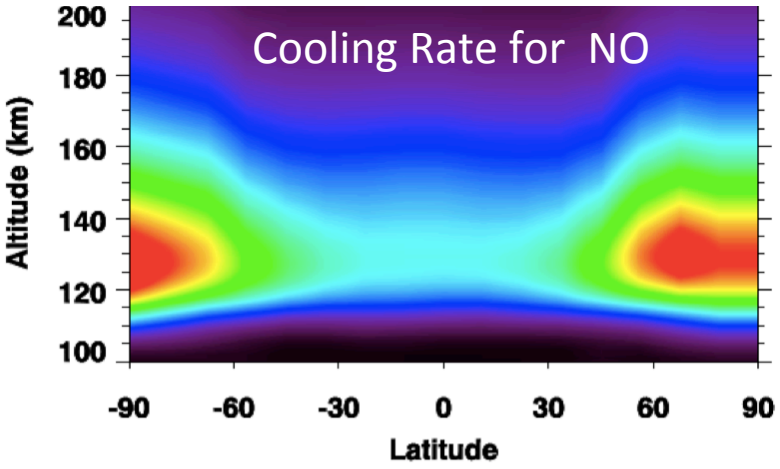


75 kg, 77 watts, 77 x 104 x 63 cm, 4 kbs

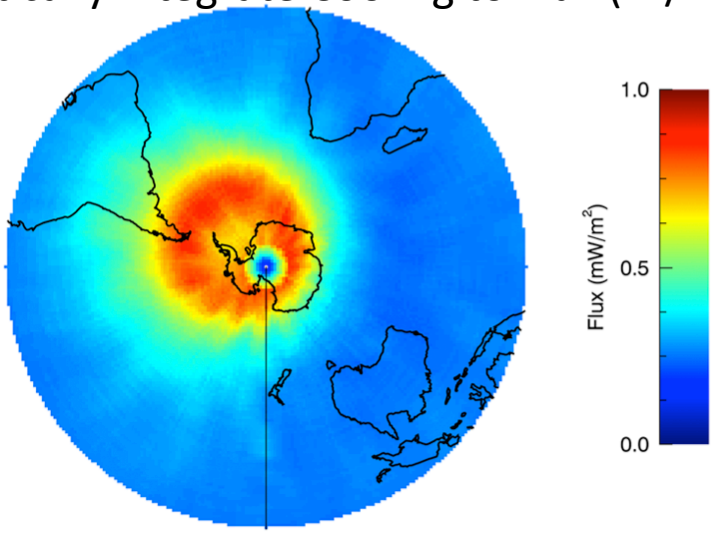
NO and CO_2 Cooling Parameter Derivations by SABER



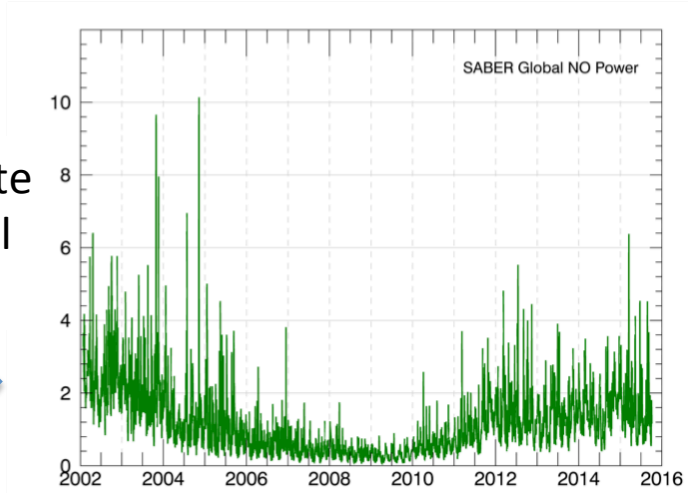
Abel Inversion to Cooling Rate (W/m^3)



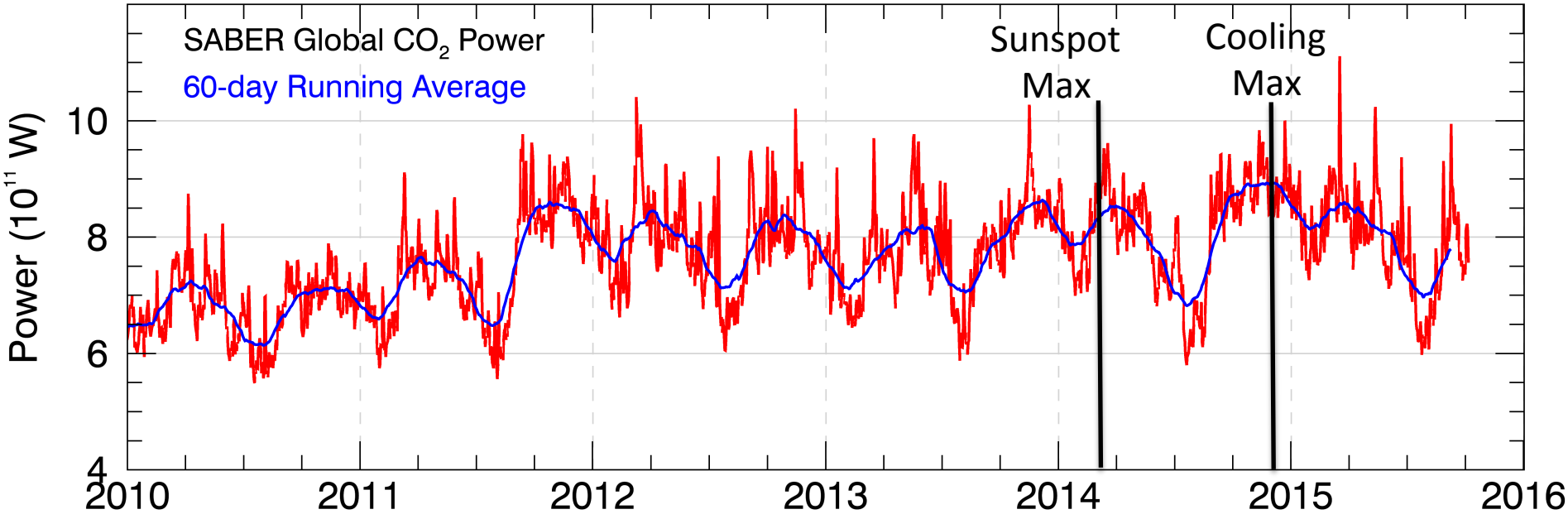
Vertically Integrate Cooling to Flux (W/m^2)



Area integrate to get global power (W)



SABER Global Power from CO_2
Jan 2010 – Dec 2015; 100 – 140 km



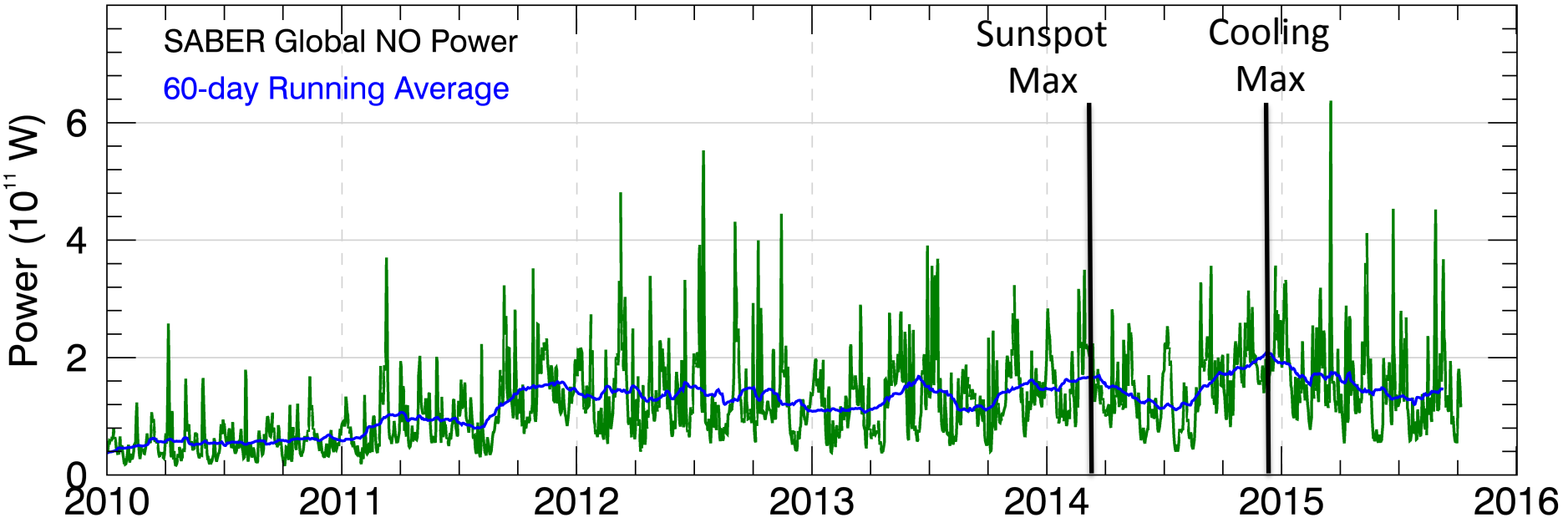
Sunspot Maximum Occurred in April 2014

CO_2 Cooling Maximum Occurred in 12/2014

Sunspot and Cooling Maxima not Coincident

SABER Global Power from NO

Jan 2010 – Dec 2015; 100 – 250 km



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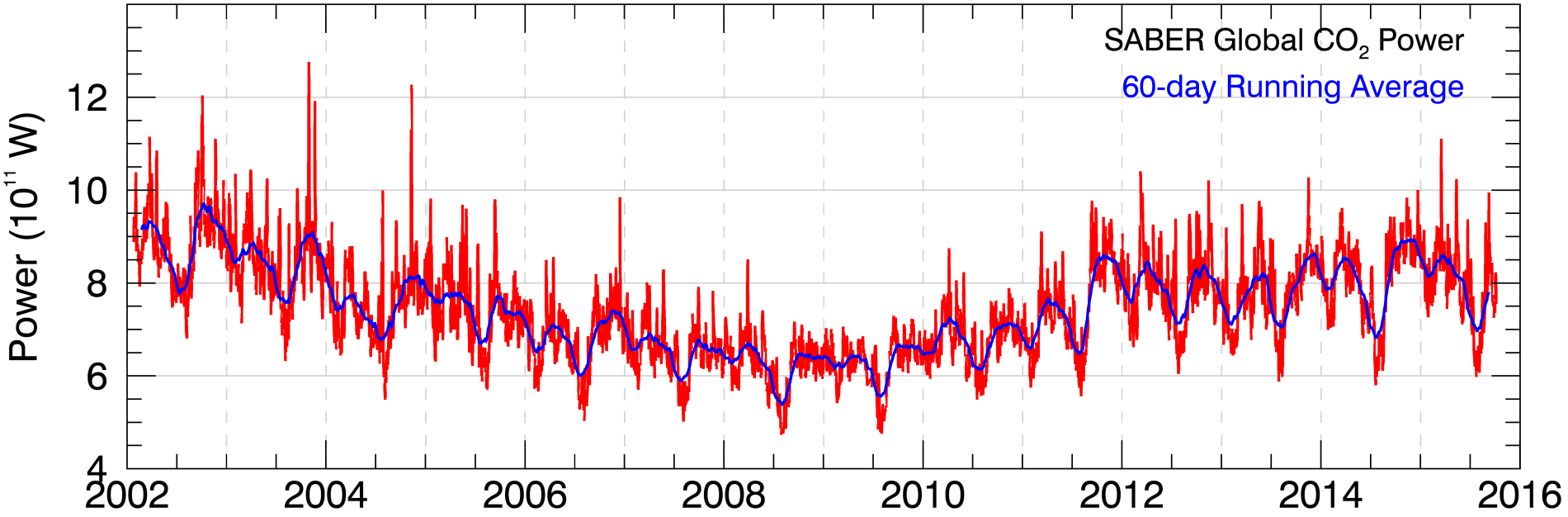
Sunspot and Cooling Maxima not Coincident

We are now heading to solar minimum!

SABER Global Power from CO_2
Jan 2002 – Dec 2015; 100 – 140 km

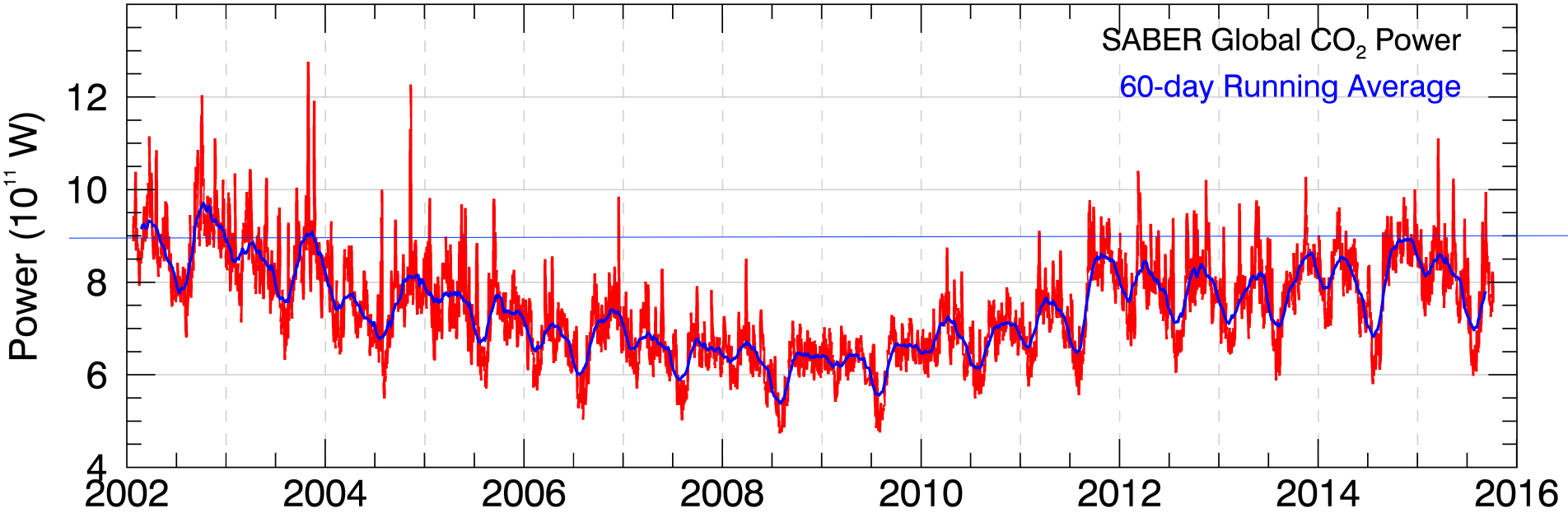
Over 5050 days of data!



Strong semi-annual cycle evident in global cooling

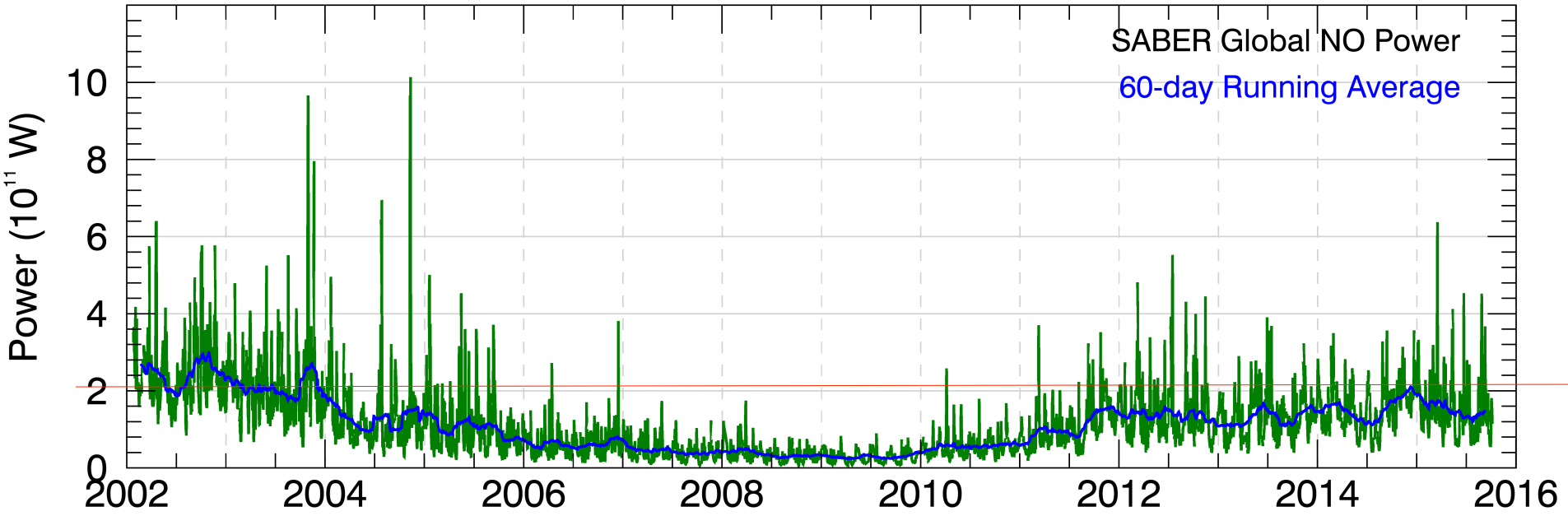
Evidence of response to geomagnetic activity in each "spike"

SABER Global Power from CO_2
Jan 2002 – Dec 2015; 100 – 140 km



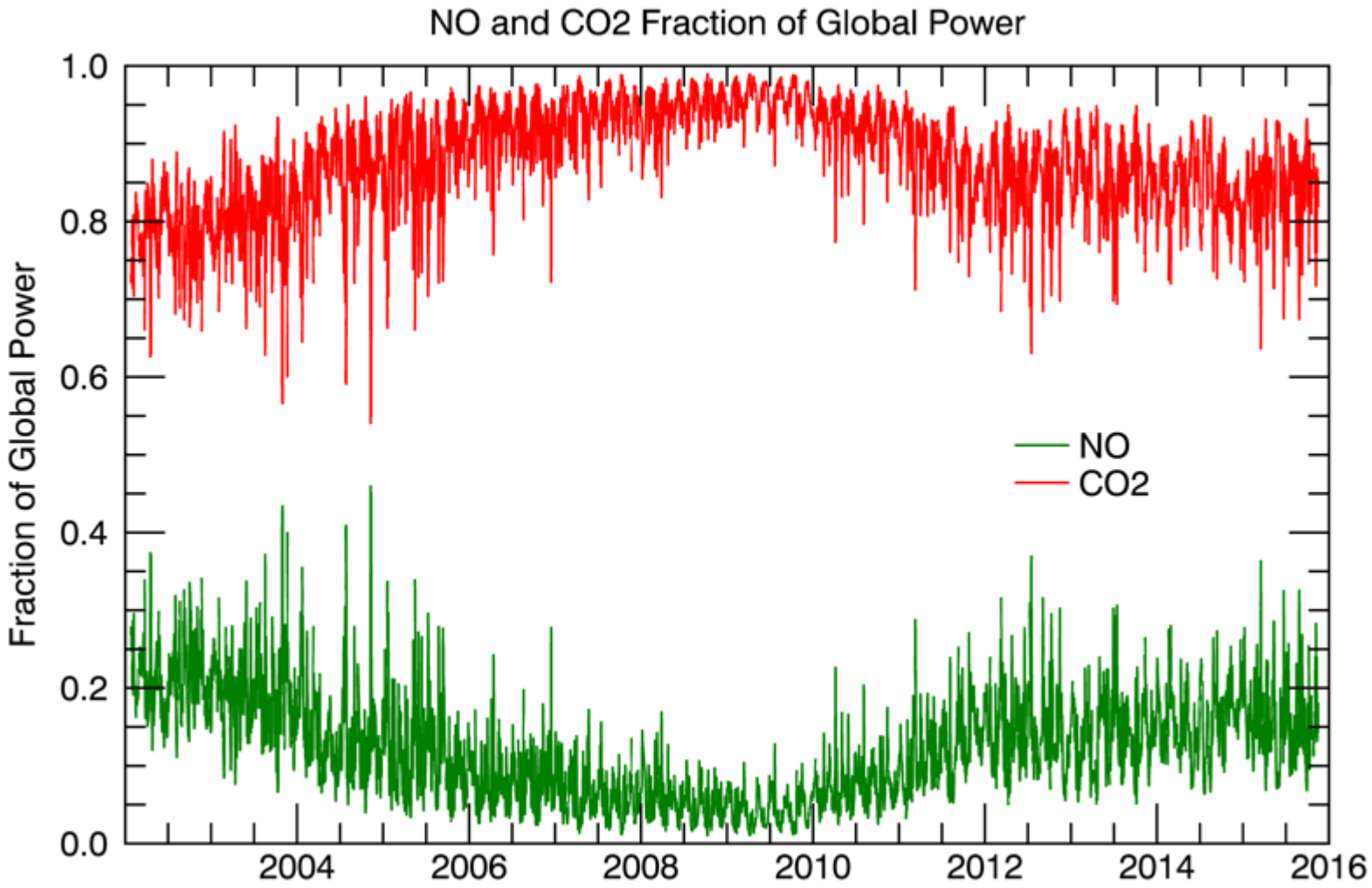
SC 24 solar max (12/2014) as warm as 12/2003 – 11 years
SC 24 clearly weaker than SC 23
Minimum cooling in 2008 coincident with semi-annual cycle

SABER Global Power From NO
Jan 2002 – Dec 2015: 100 – 250 km

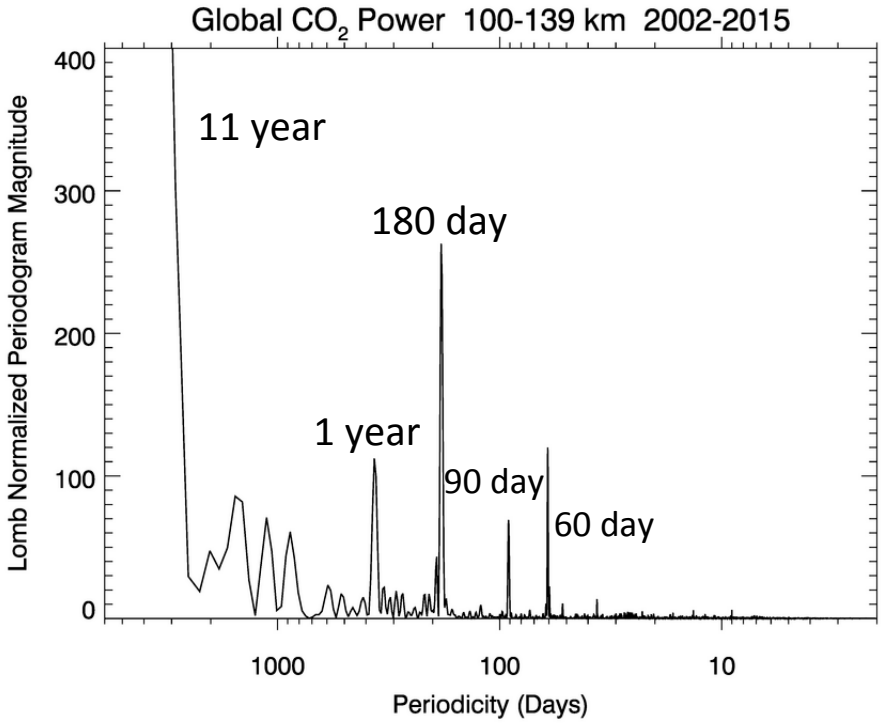


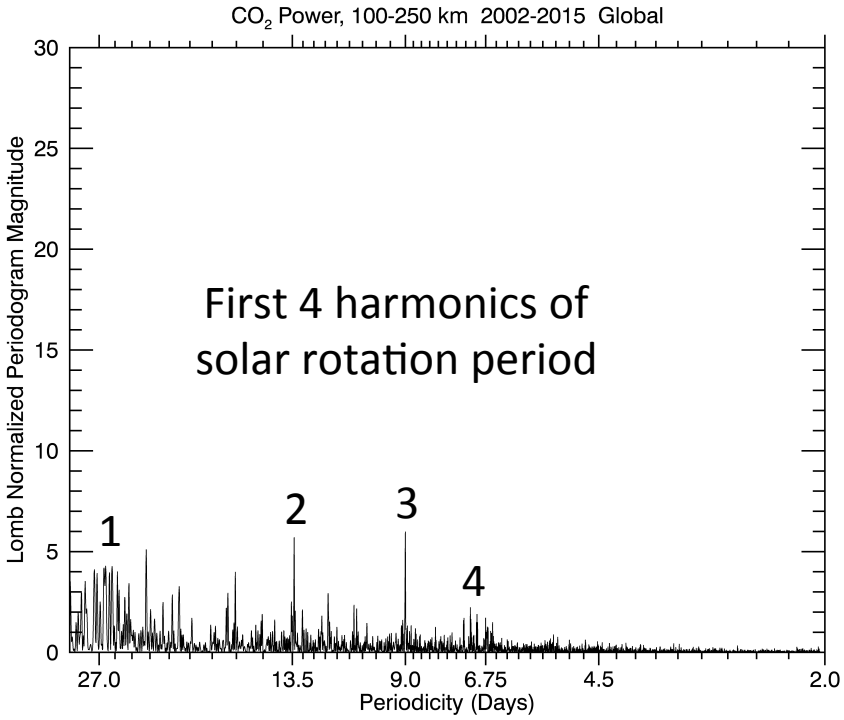
NO Cooling at Peak of SC 24 (12/2014) was highest level since 12/2003

Fraction of Thermosphere Global Infrared Power - CO_2 and NO -



CO_2 Global Power 2002 - 2015
Lomb Normalized Periodogram





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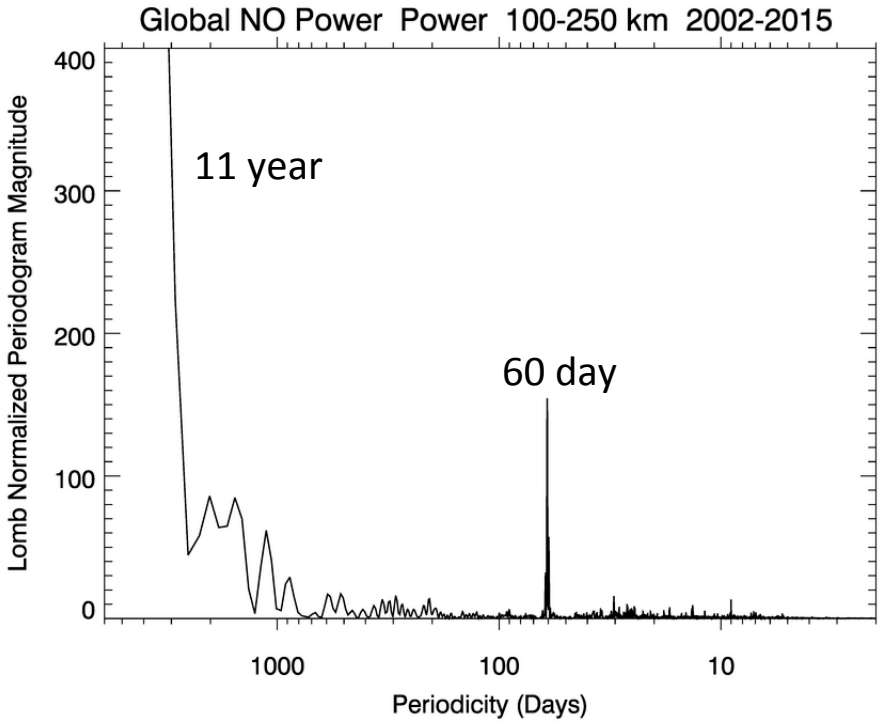
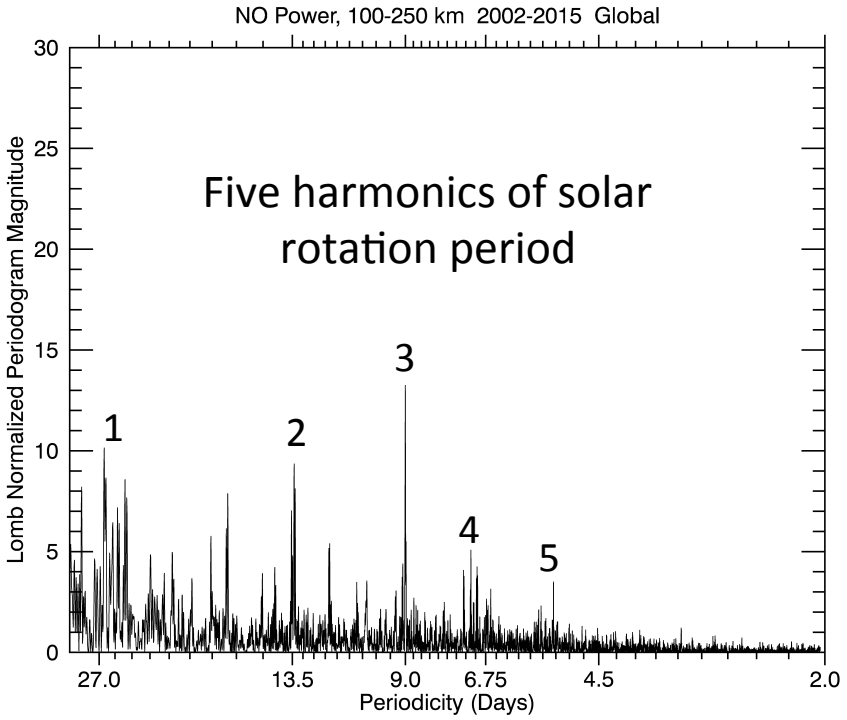
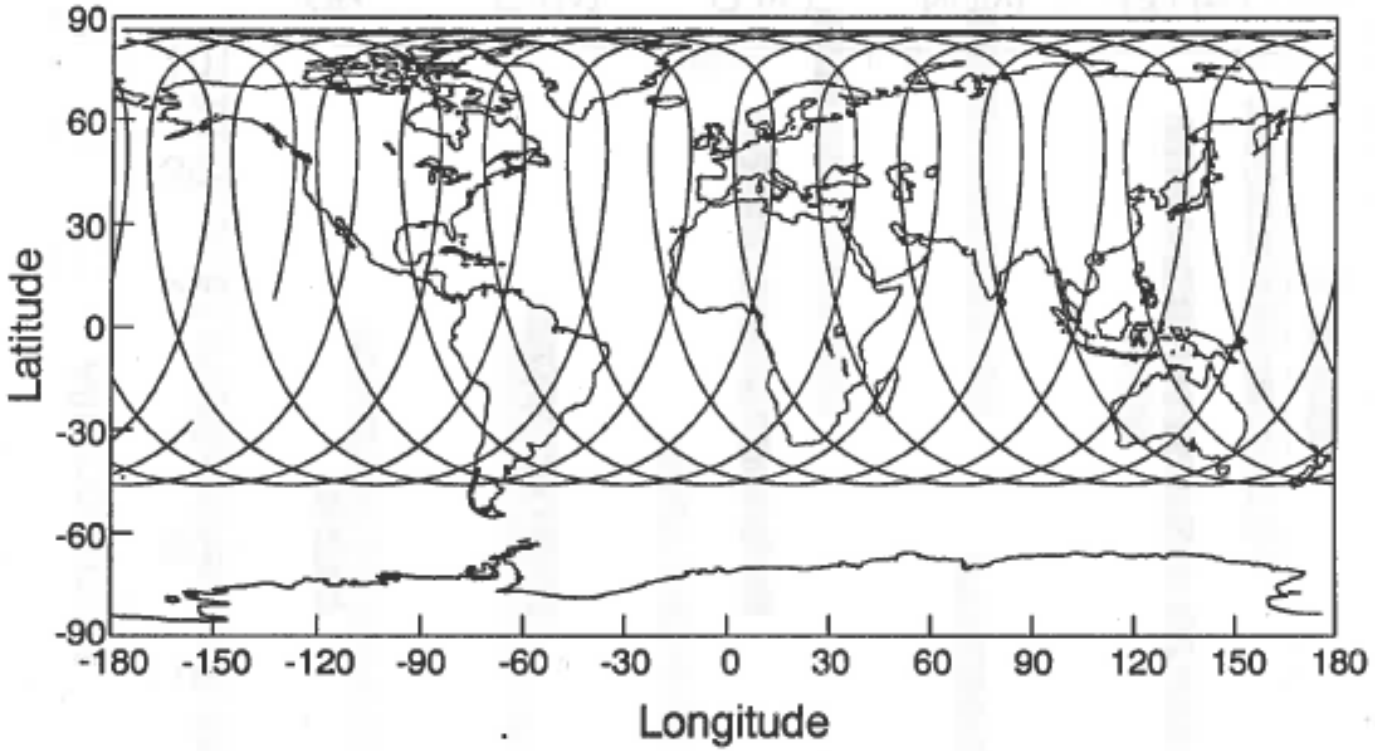




Infrared power as a function of Latitude



SABER alternately samples poleward of ~ 55 Deg every 2 months

Examine data in 4 blocks: 0 – 55 N; 0 – 55 S; 55 – 90 N; 55 – 90 S

Hemispheric and Polar Infrared Power (GW) Averages Over 14 Years of SABER Data

	Global (GW)	0 – 55 N	0 – 55 S	55 – 90 N	55 -90 S
Carbon Dioxide	744.2	307.6	301.5	68.4	66.7
Fraction of CO_2 Cooling	-	41.3%	40.5%	9.2%	9.0%
Fraction of Atmospheric Area		41%	41%	9%	9%
Nitric Oxide	113.1	39.4	40.8	16.1	16.8
Fraction of NO Cooling	-	34.8%	36.1%	14.2%	14.9%
NO Fraction of Total	13%	11%	12%	19%	20%

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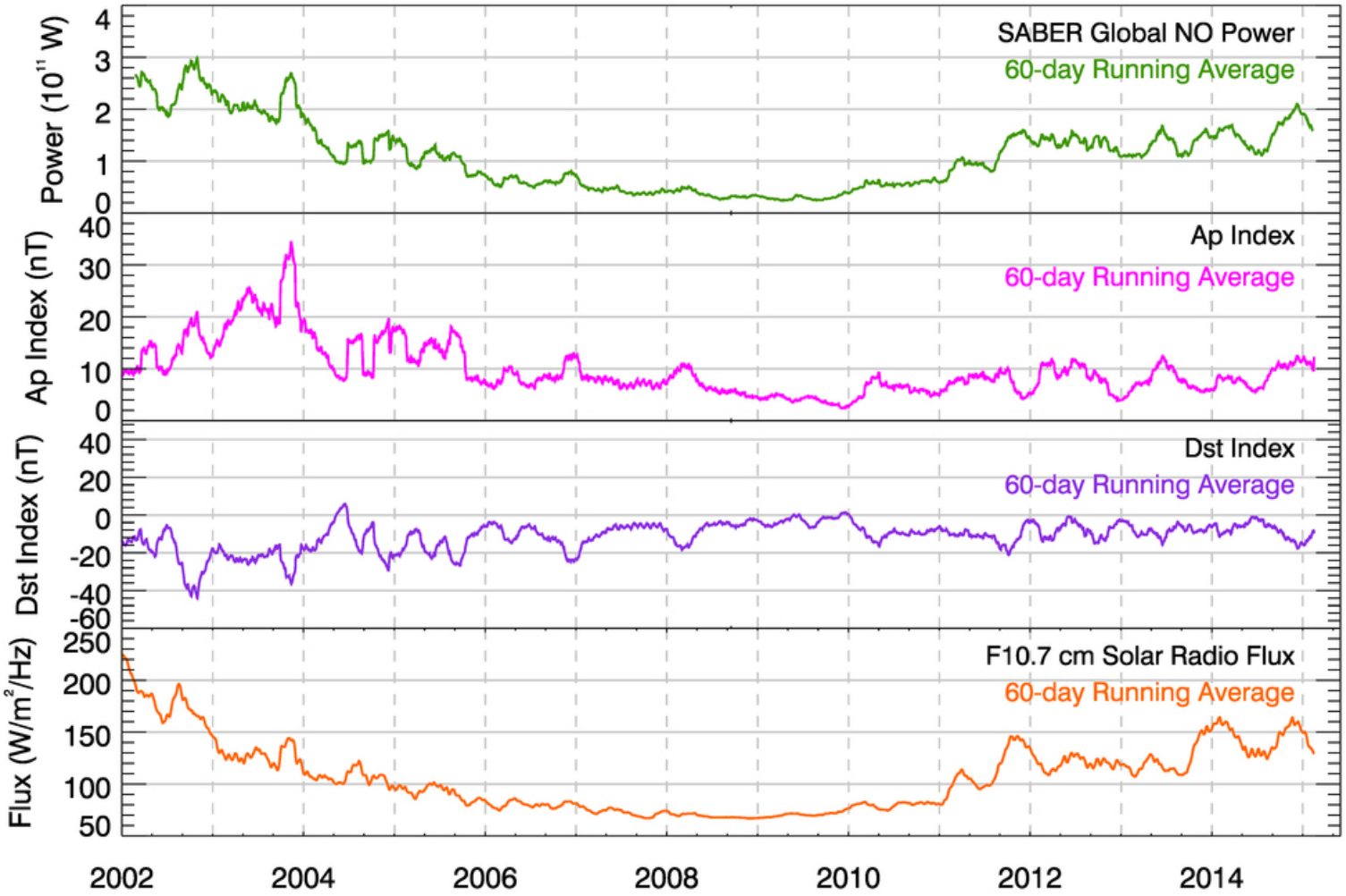
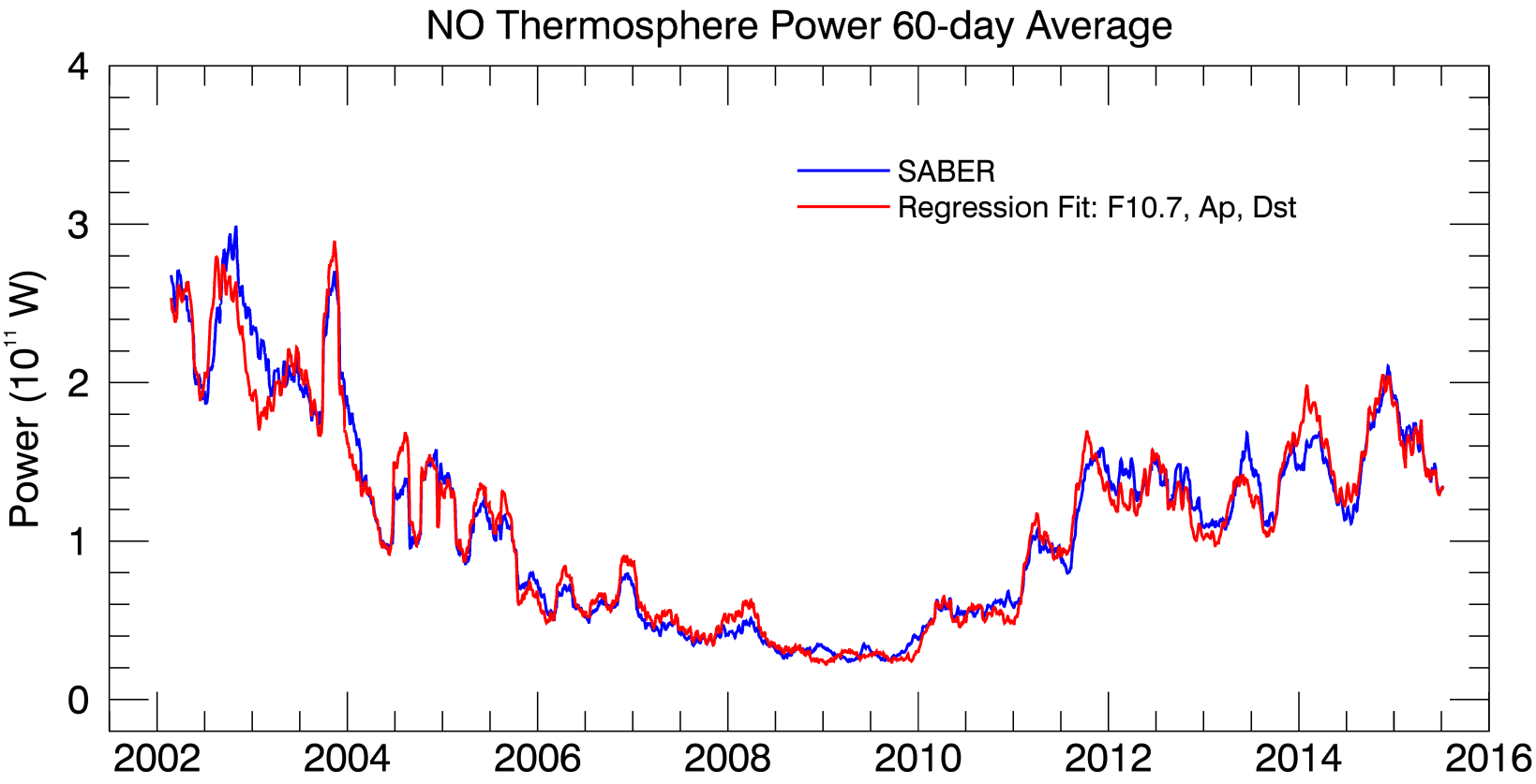
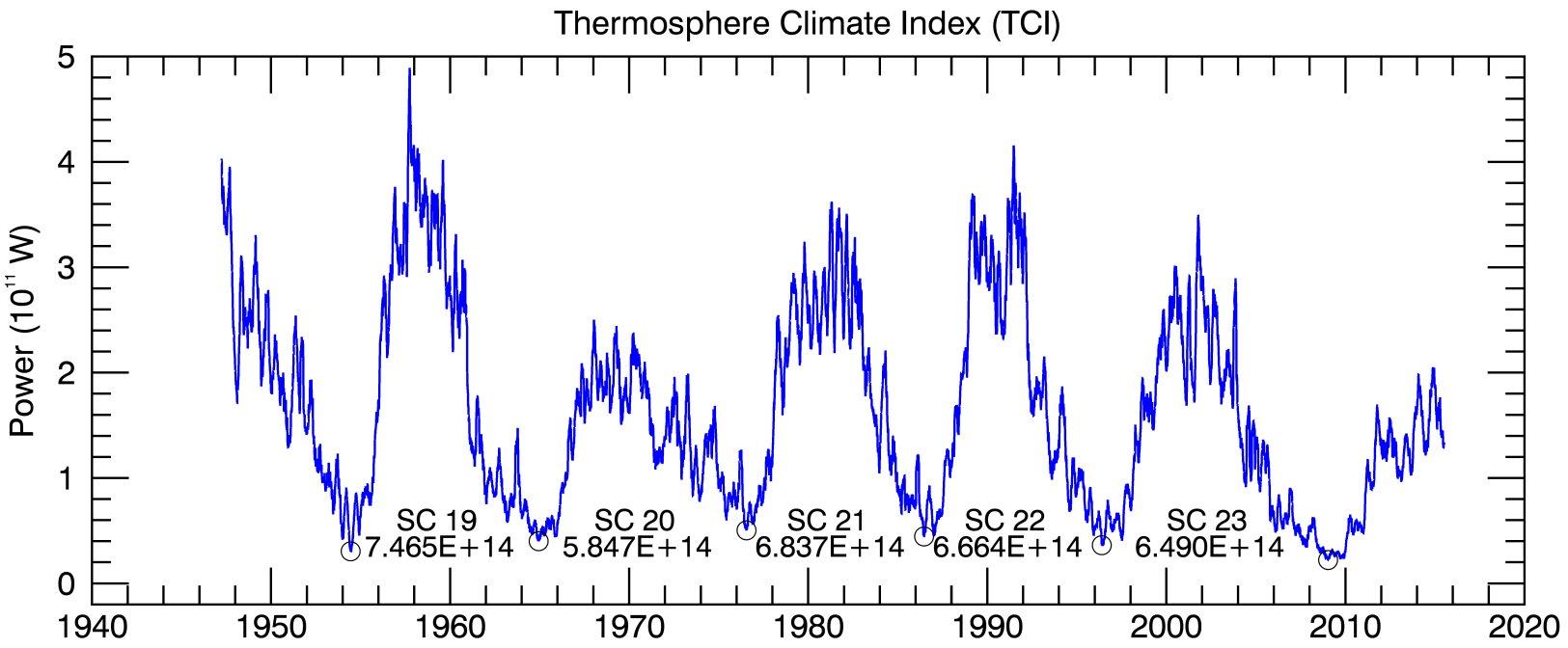
4. A View to the Past


SABER Global NO Power
60-day Running Average
Power (10^{11} W)
Ap Index
60-day Running Average
Ap Index (nT)
Dst Index
60-day Running Average
Dst Index (nT)
F10.7 cm Solar Radio Flux
60-day Running Average
Flux (W/m^2/Hz)
2002
2004
2006
2008
2010
2012
2014

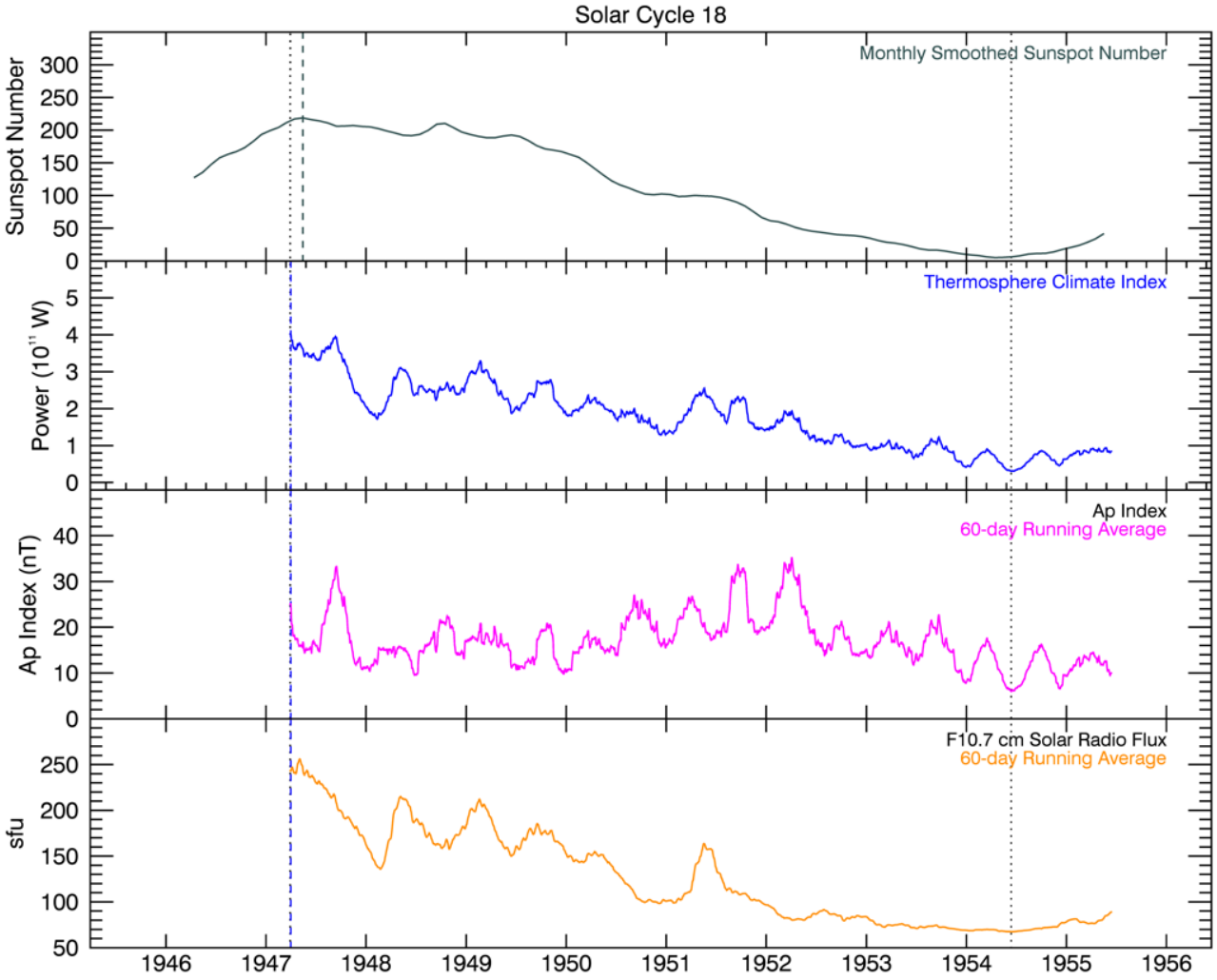

NO Thermosphere Power 60-day Average
Power (10^{11} W)
4
3
2
1
0
2002
2004
2006
2008
2010
2012
2014
2016
SABER
Regression Fit: F10.7, Ap, Dst

Nitric Oxide Power for Past 5 Solar Cycles



Solar Cycle	NO Infrared Power (W)
19	7.46×10^{14}
20	5.84×10^{14}
21	6.84×10^{14}
22	6.66×10^{14}
23	6.49×10^{14}

Occurrence of Sunspot and Cooling Maxima



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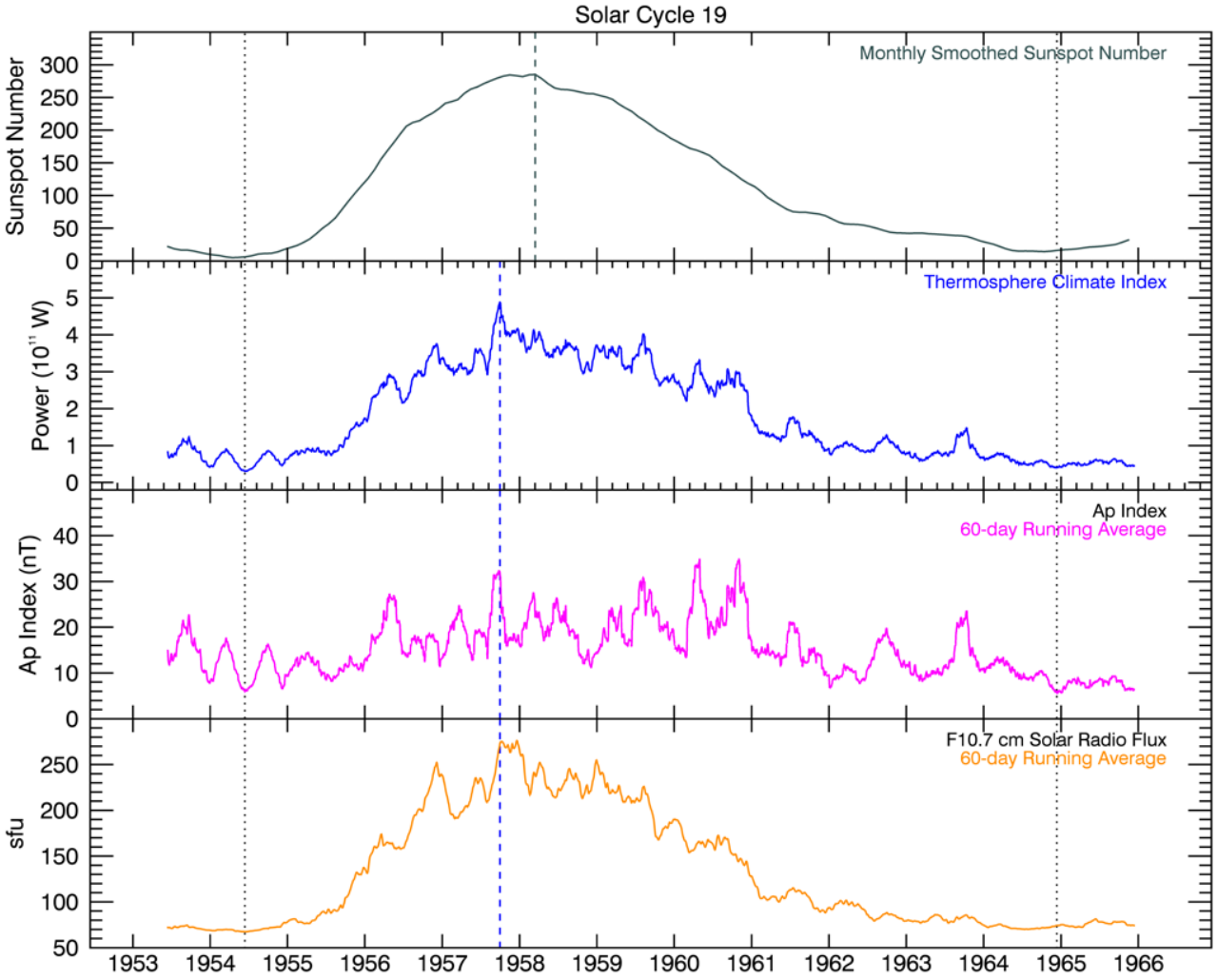

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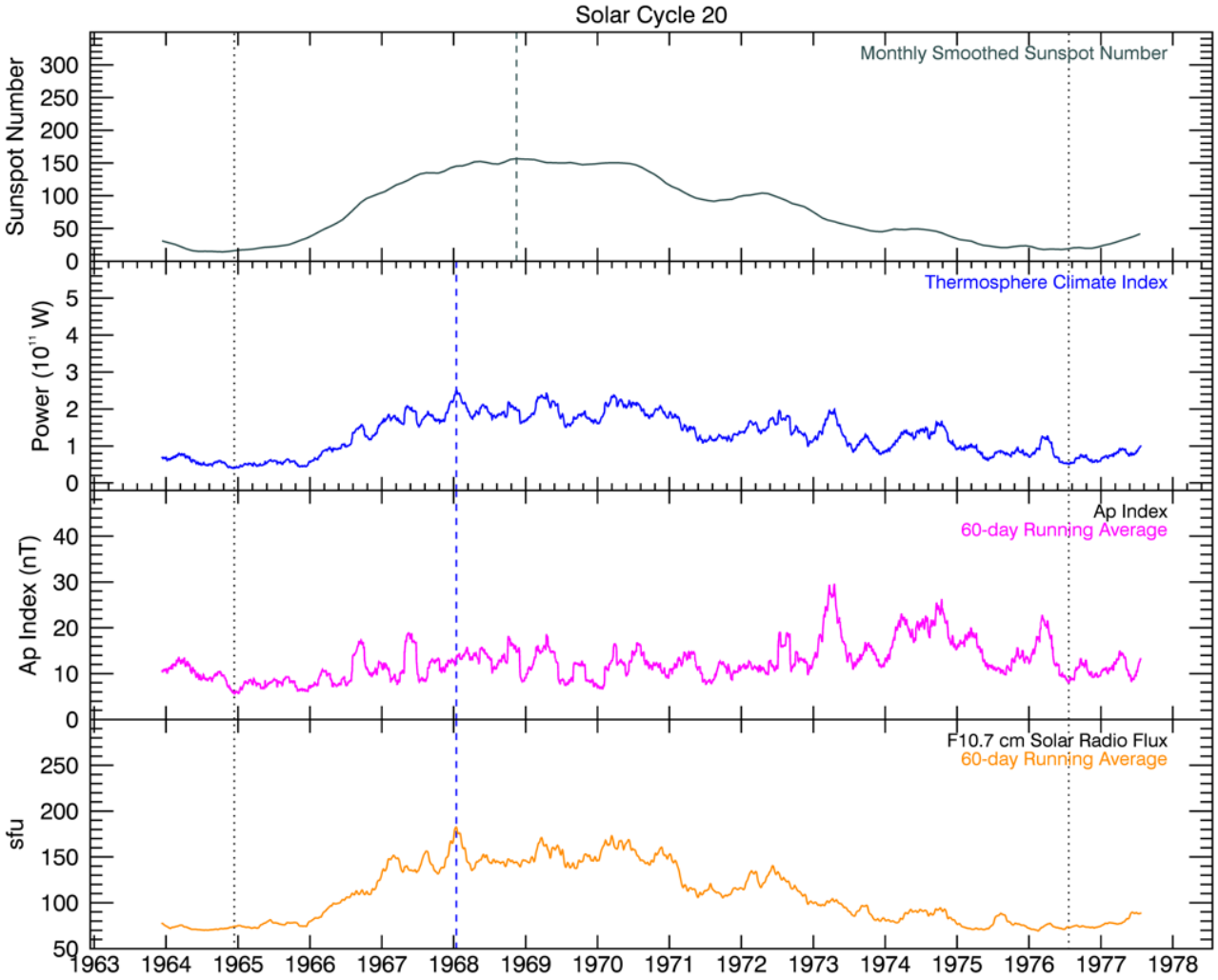

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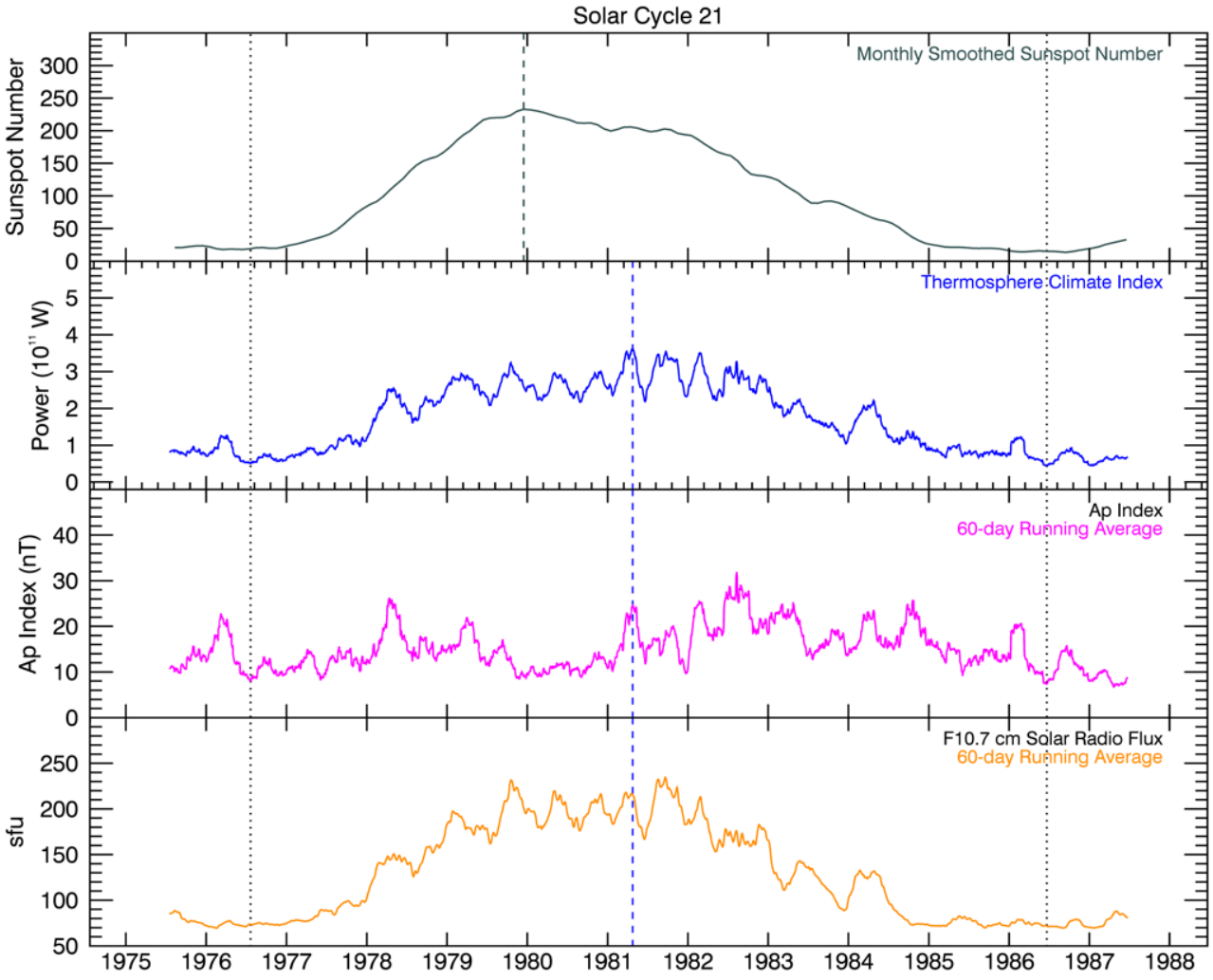

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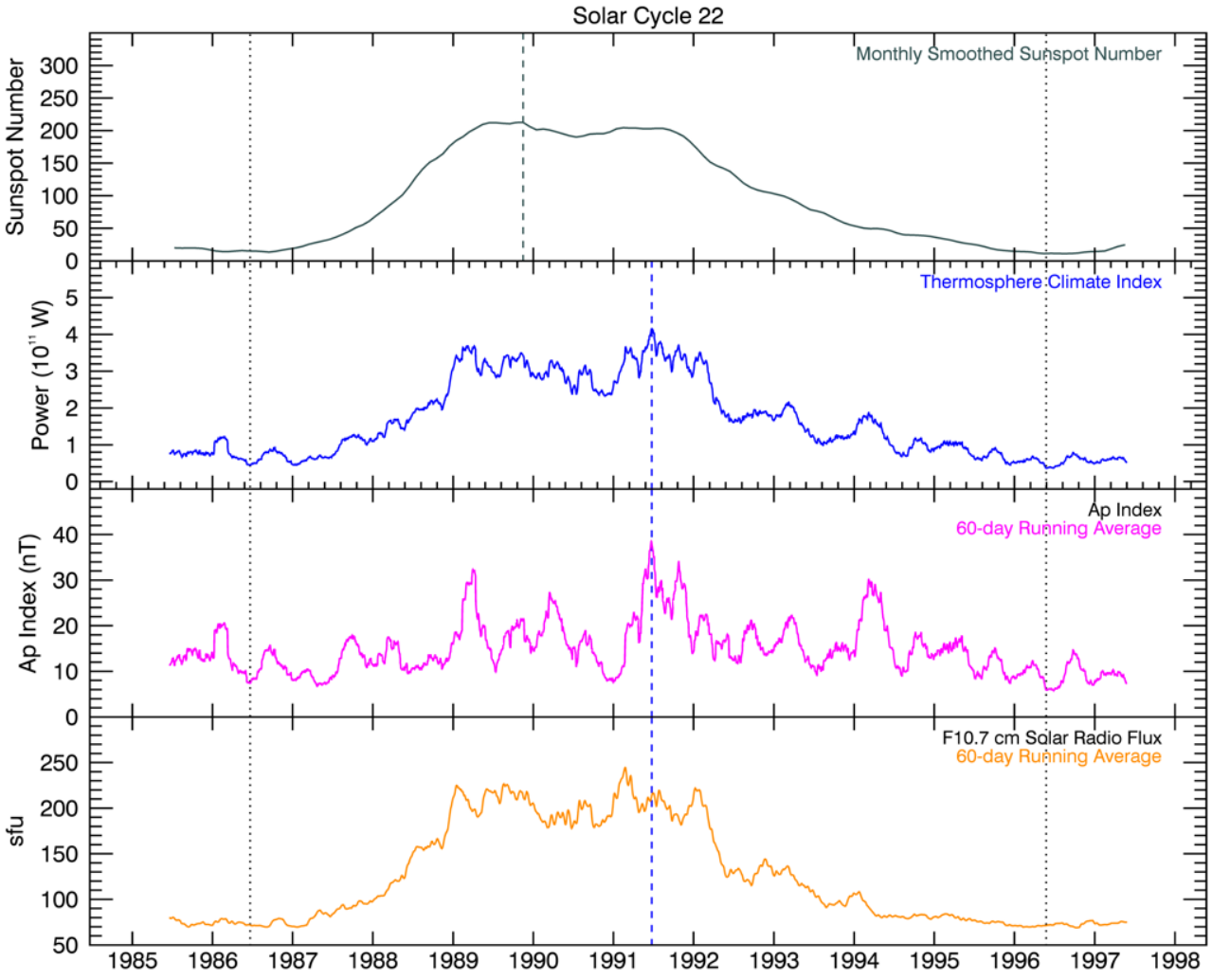

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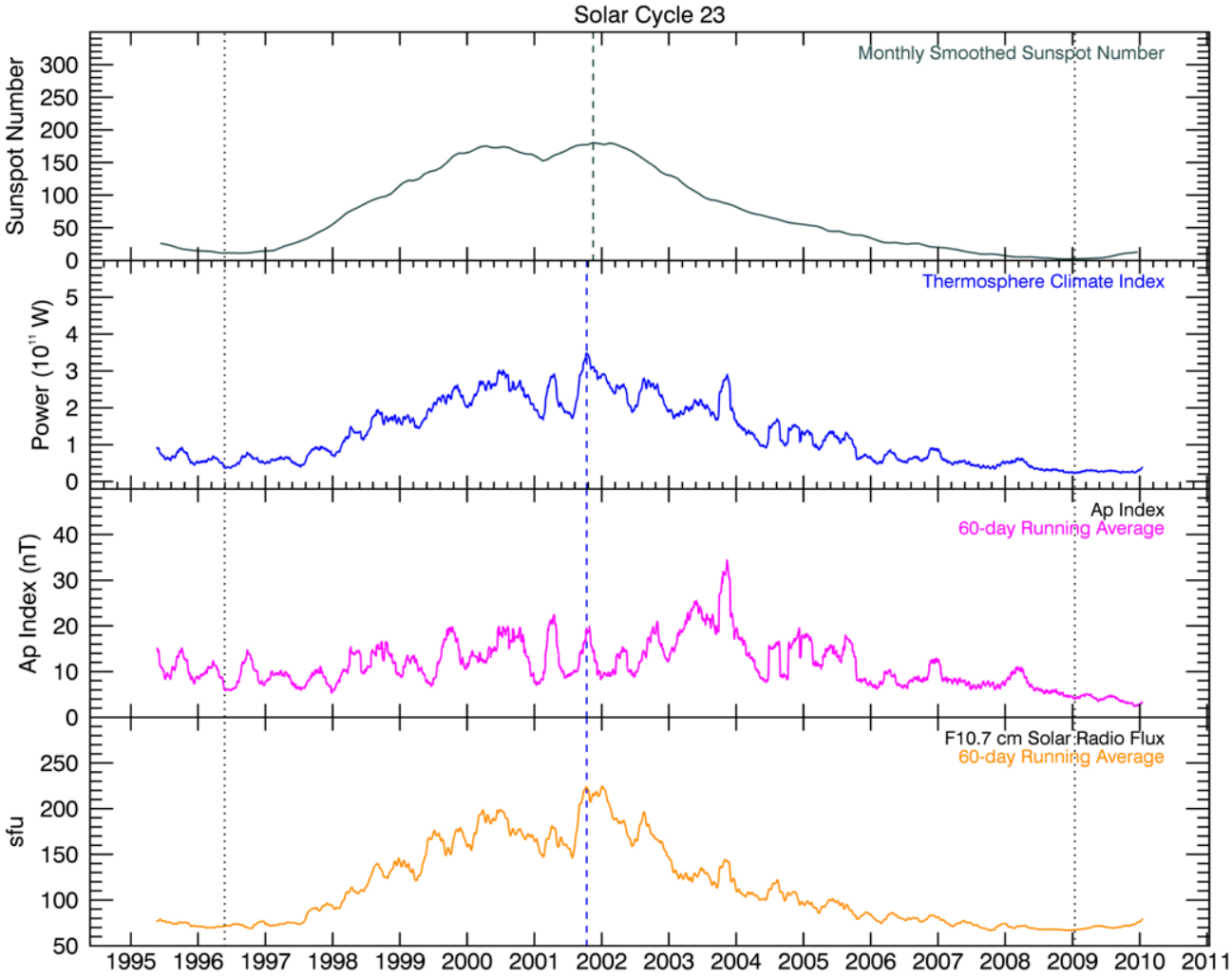
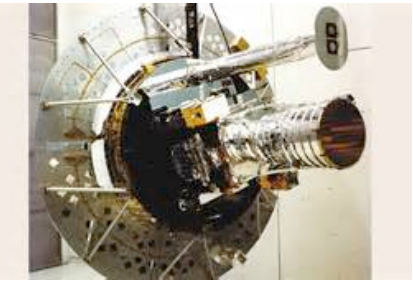


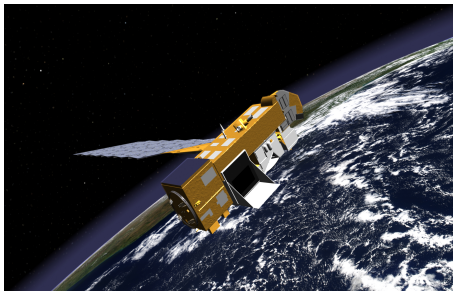
5. A View to the Future

1975 – 2015
The Golden Age of Upper Atmosphere Science?



SME

UARS



Aura

EnviSat

TIMED

Nimbus VII

SORCE

Upper Atmosphere Satellite Instruments and Missions

- 1970's -- LRIR, LIMS, AE, SAM
- 1980's -- DE-1, DE-2, SAGE-II, SME
- 1990's -- UARS, POAM
- 2000's -- Aura, TIMED, Envisat, ODIN, SciSat, SAGE-III, SORCE, SMILES, AIM
- 2010's -- SAGE III (2016); ICON; GOLD
- 2020's -- ????
  - No missions in preparation for middle atmosphere science

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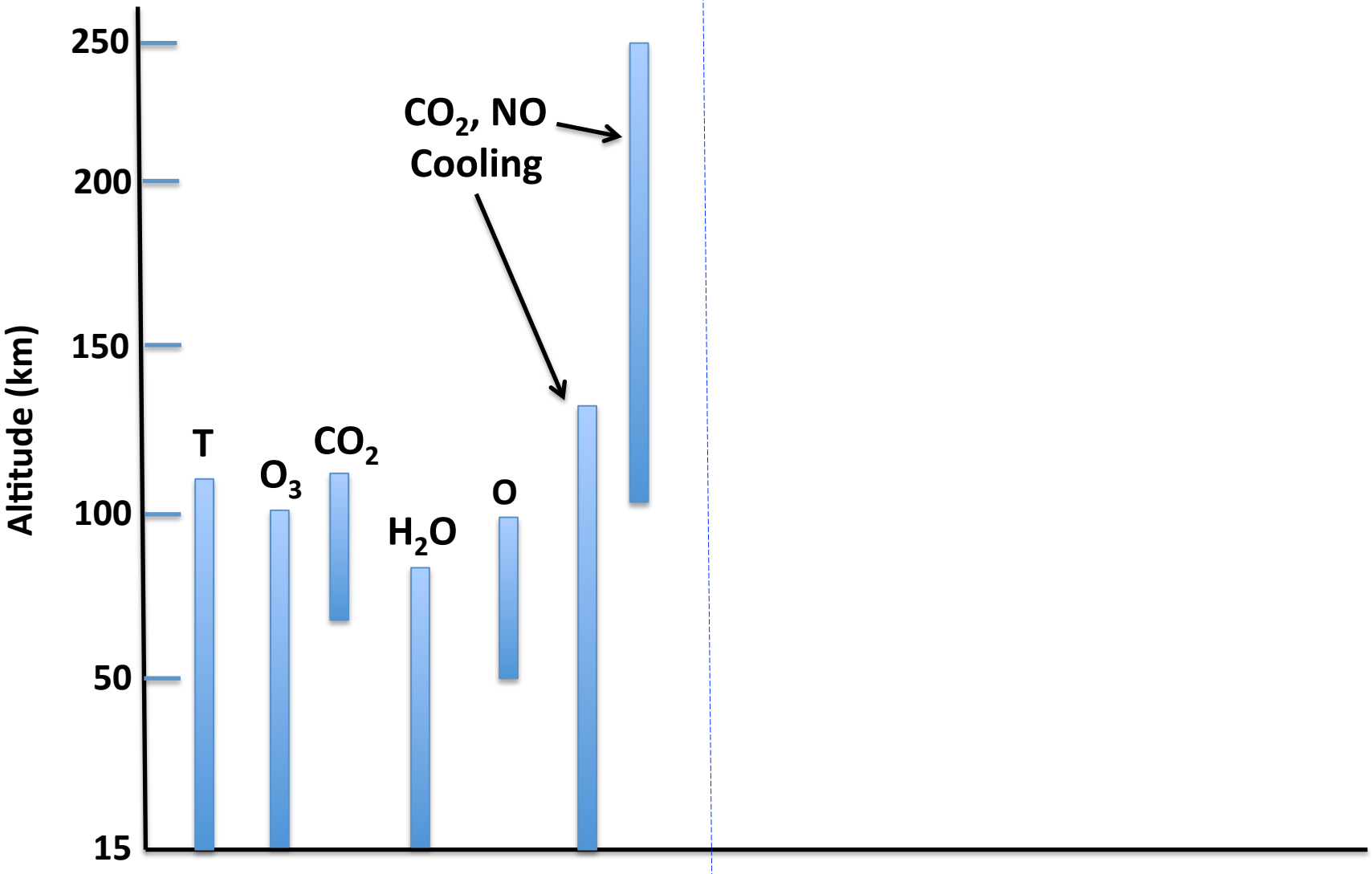
A gap in thermal structure and chemical composition measurements after 2020 seems inevitable

Existing Capability



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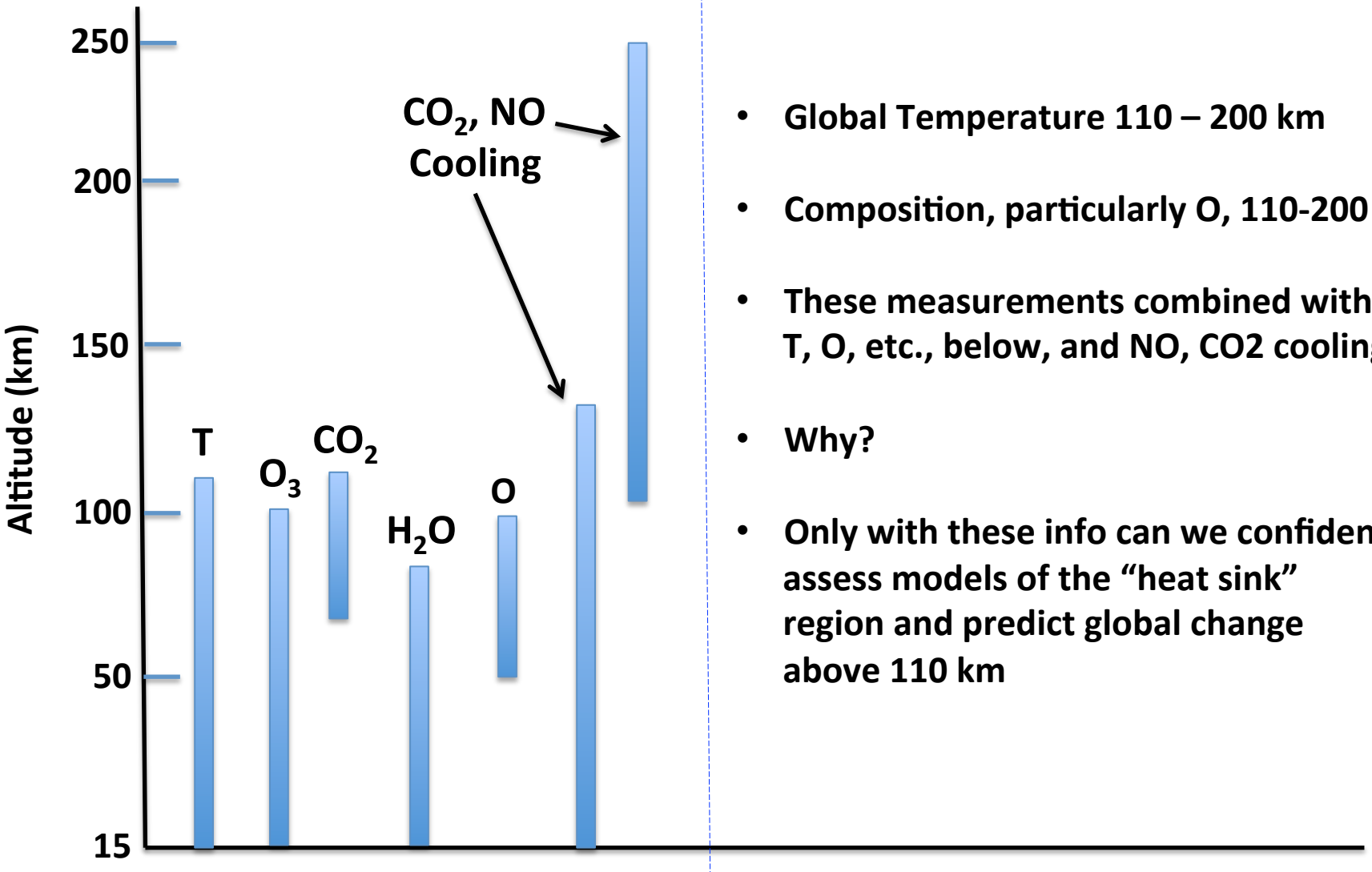
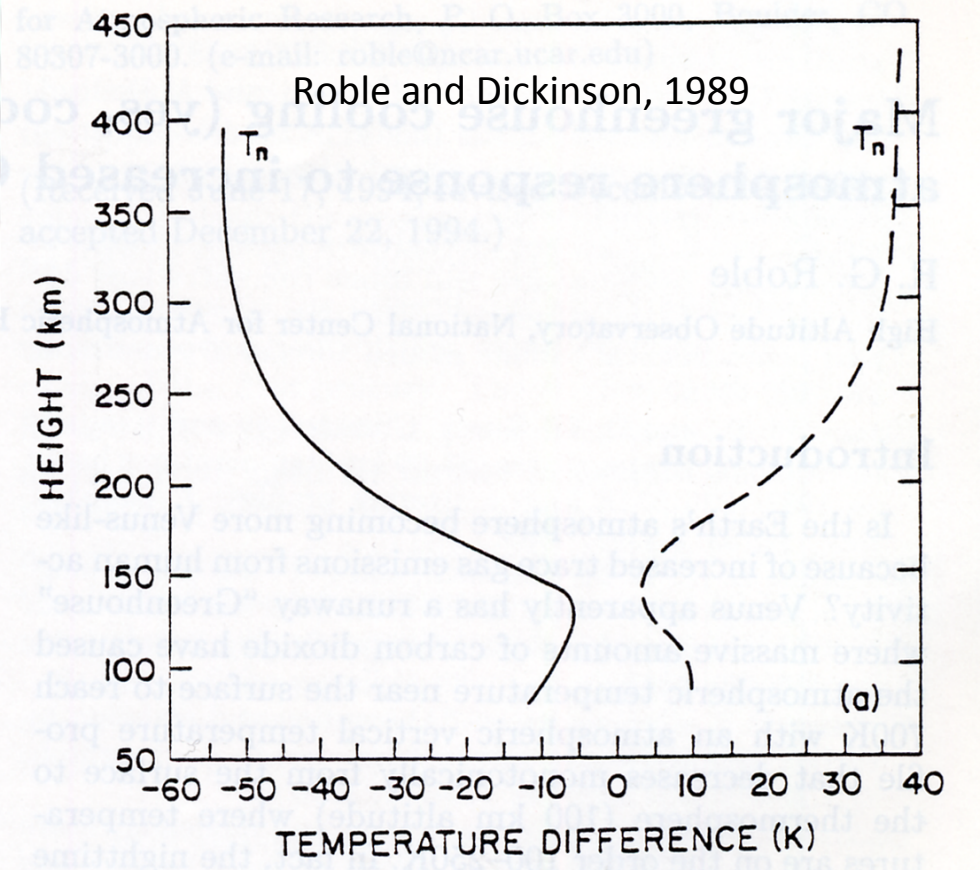


What's Still Missing?

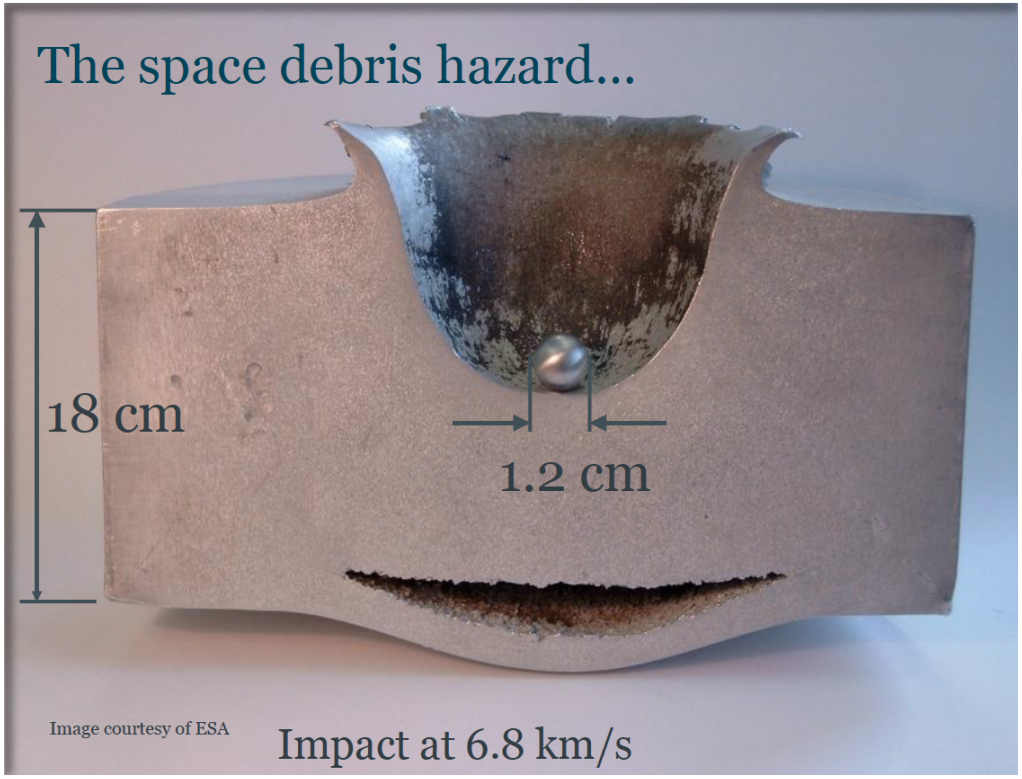
- Global Temperature 110 – 200 km
- Composition, particularly O, 110-200
- These measurements combined with T, O, etc., below, and NO, CO2 cooling
- Why?
- Only with these info can we confidently assess models of the "heat sink" region and predict global change above 110 km

Global Cooling due to Increasing CO_2



Understanding the future of the atmosphere above 200 km implies detailed understanding of the atmosphere 100-160 km

Beyond the Science: The Space Debris Hazard

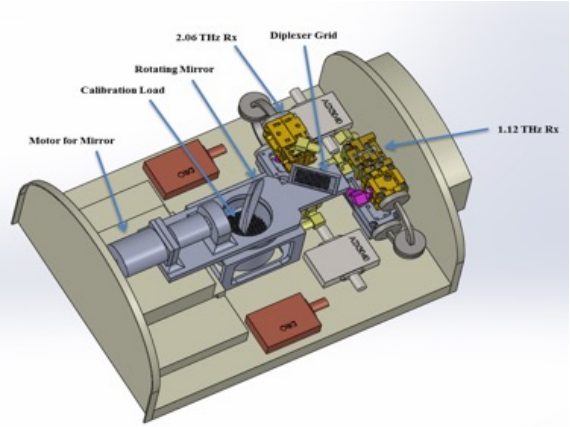


Increasing CO_2 → Cooler, Less Dense Atmosphere
Increases Satellite Lifetimes
Increases Orbital Debris LIfteimes

Do We Understand the Energy Budget of the Atmospshere above 100 km?

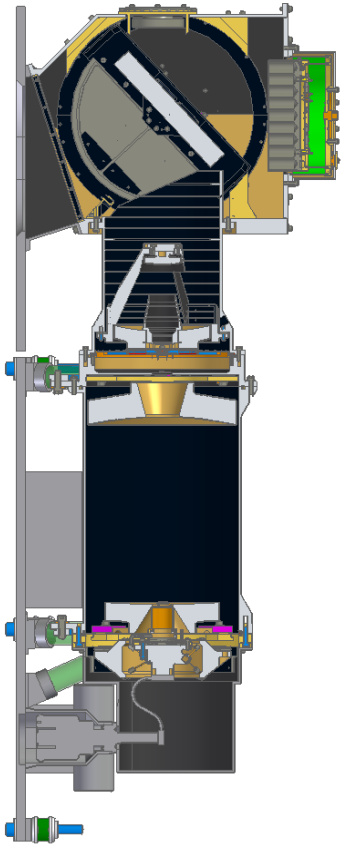
Solar-Terrestrial Coupling Explorer - SOLTEX

- SOLTEX is a mission to explore the thermosphere above 100 km
- SOLTEX will continue legacy measurements from SABER



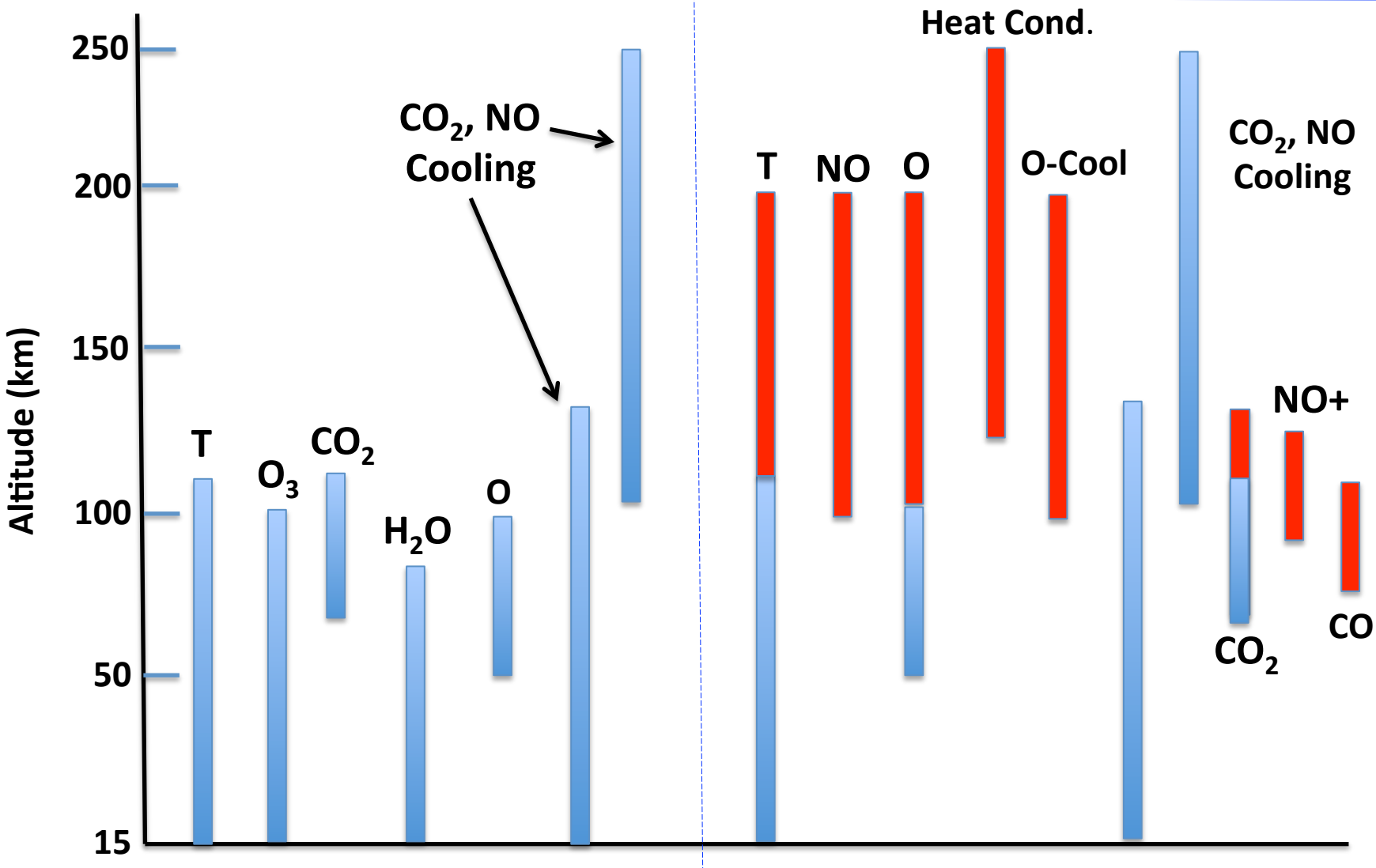
TLS Instrument (S. Yee, APL)
T, O, winds – 100 to 160 km
15 kg
25 W

SABER-II Instrument
35 kg, 35 W
100% SABER Heritage
½ mass, ½ power, 1/3 volume
Identical radiometric performance



Existing Capability

SOLTEX Mission Capability



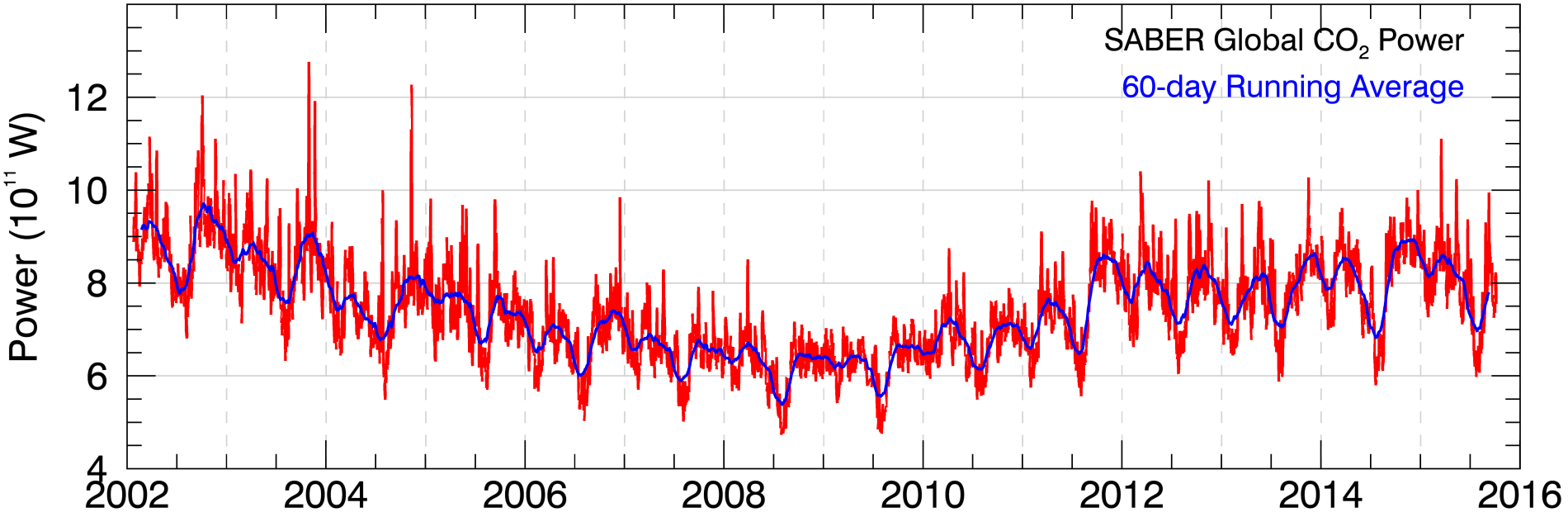
Summary

- SABER data illustrate a very complex and interesting thermosphere that responds to solar variability on timescales from days to decades
- Solar maximum, from the atmosphere's perspective, does not have a consistent relationship to the sunspot number, over at least the past 6 solar cycles
- CO_2 cooling is uniform over the Earth in direct proportion to atmospheric area, while NO cooling
- We are now slowly heading to solar minimum based on thermosphere radiative cooling data
- The fate of the upper atmosphere due to CO_2 increase depends on understanding T and composition 100-160 km
- SOLTEX is a new mission to explore the "heat sink" region of the atmosphere

Backups

SABER Global Power from CO_2
Jan 2002 – Dec 2015; 100 – 140 km

Over 5050 days of data!



Strong semi-annual cycle evident in global cooling

Evidence of response to geomagnetic activity in each "spike"