Infrared Radiation in the Thermosphere in the Approach to Solar Cycle 25

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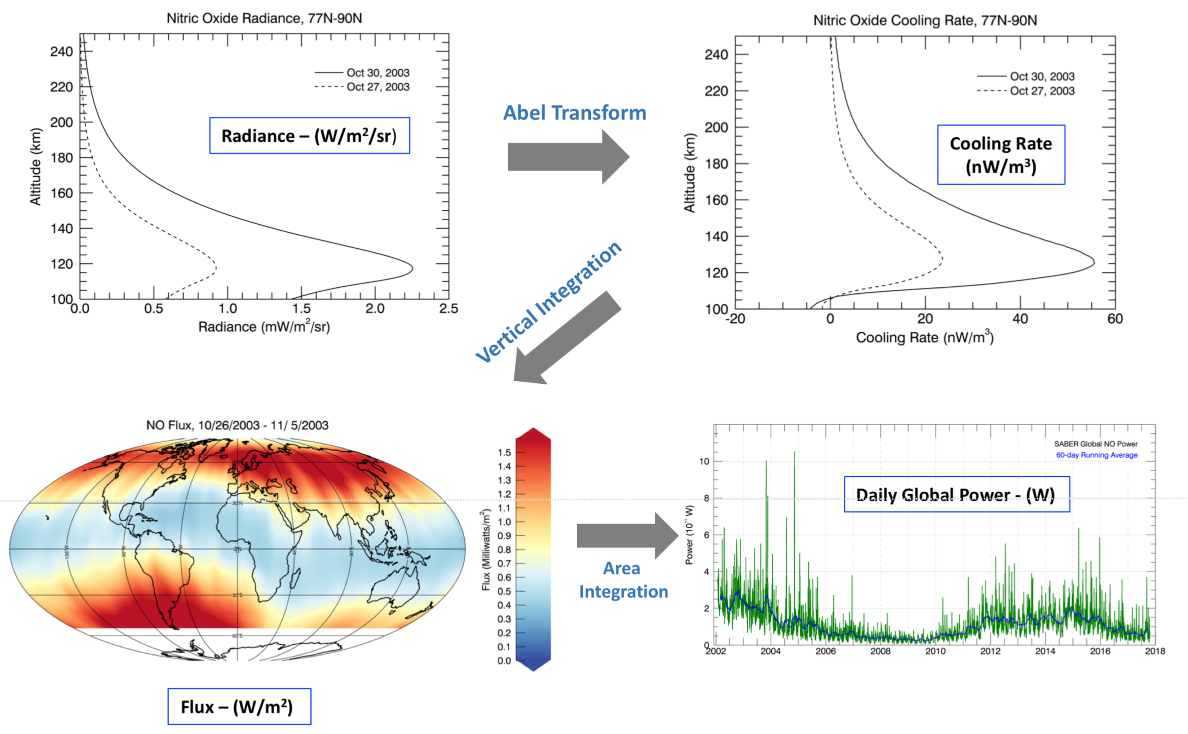
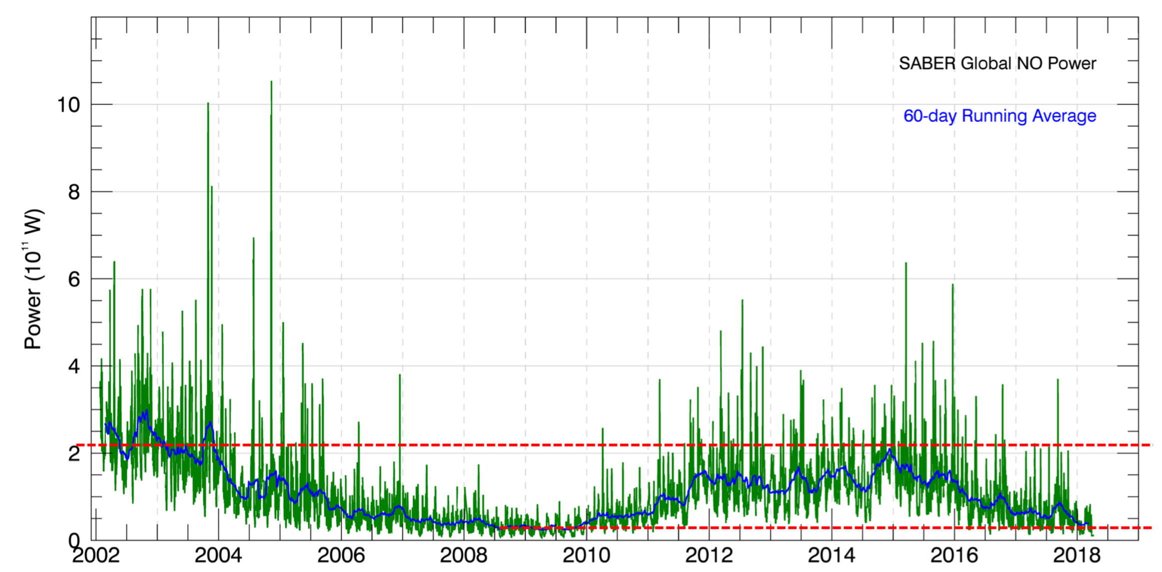
Introduction

The climate of the thermosphere is controlled in part by cooling to space driven by infrared radiation, primarily from nitric oxide (NO, 5.3µm)and carbon dioxide (CO_2, 15µm). The Sounding of the Atmosphere using Broadband Emission Radiometry (SABER) instrument on the Thermosphere-Ionosphere-Mesosphere Energetics and Dynamics (TIMED) satellite measures the vertical distribution of infrared radiation emitted by these species (and others).



SABER was launched in December 2001 and began making measurements in January 2002. From these radiance measurements, we have 17+ years (more than 8.9 million scans/channel of derived cooling rate profiles, scan fluxes and global daily infrared power for energy radiated by NO and CO_2 in the thermosphere. These data are now publicly available for download from:

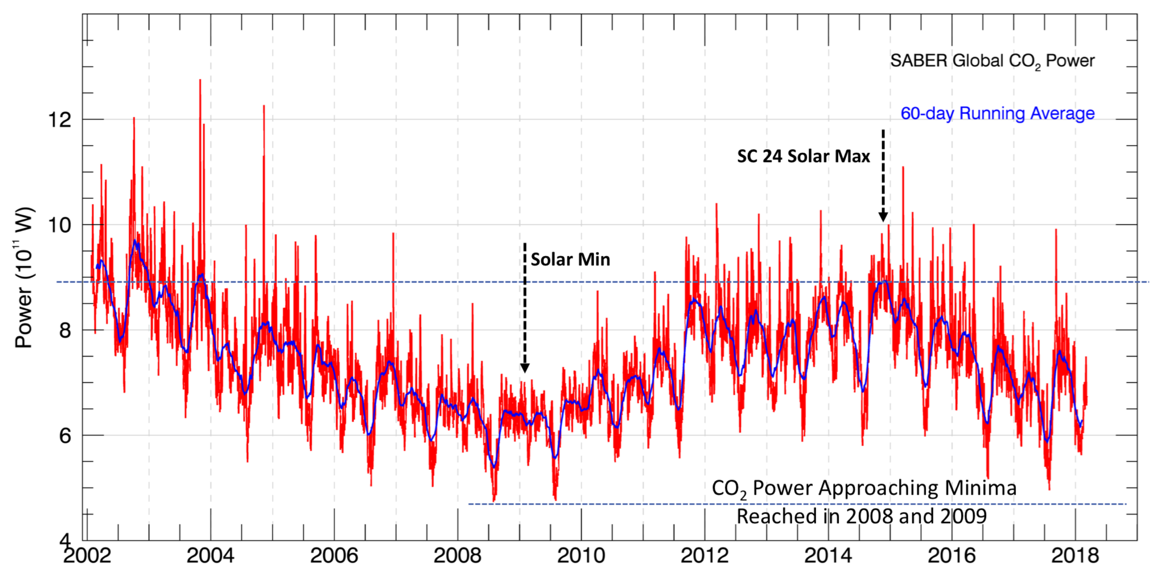


The NO thermosphere global daily power time series above shows:

- Evidence of the ~11 year solar cycle
- Larger excursions in power associated with space weather
- In the 60-day running average (blue curve):
- SC23-24 minimum occurred 4/6/2009 at 2.39E10 W
- SC 24 maximum occurred 12/9/2014 at 2.11E11 W (a level last seen 12/2/2003)

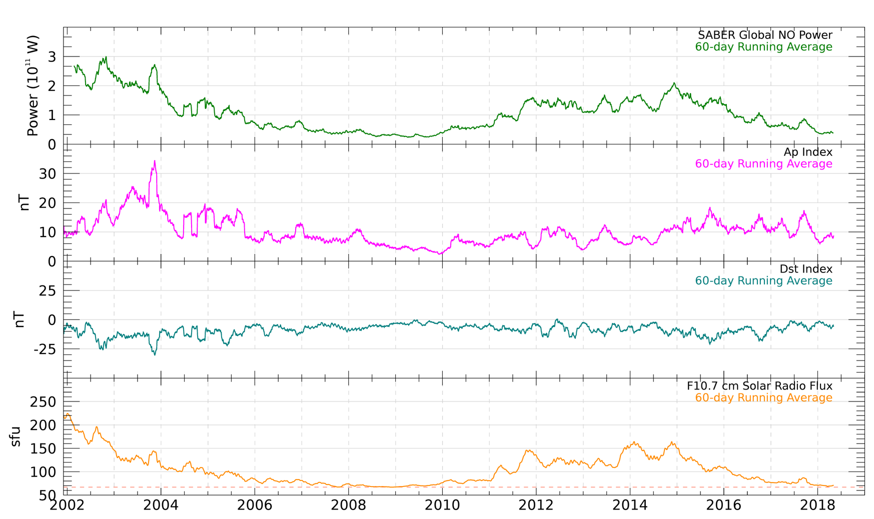
The CO_2 thermosphere global daily power time series below shows:

- Evidence of the ~11 year solar cycle plus annual and semi-annual variability due to processes that originate in the lower atmosphere (not directly solar driven)
- Larger excursions in power associated with space weather
- In the 60-day running average (blue curve):
- SC23-24 minimum occurred 8/1/2008 at 5.39E11 W
- SC 24 maximum occurred 12/4/2014 at 8.93E11 W (a level last seen 11/22/2003

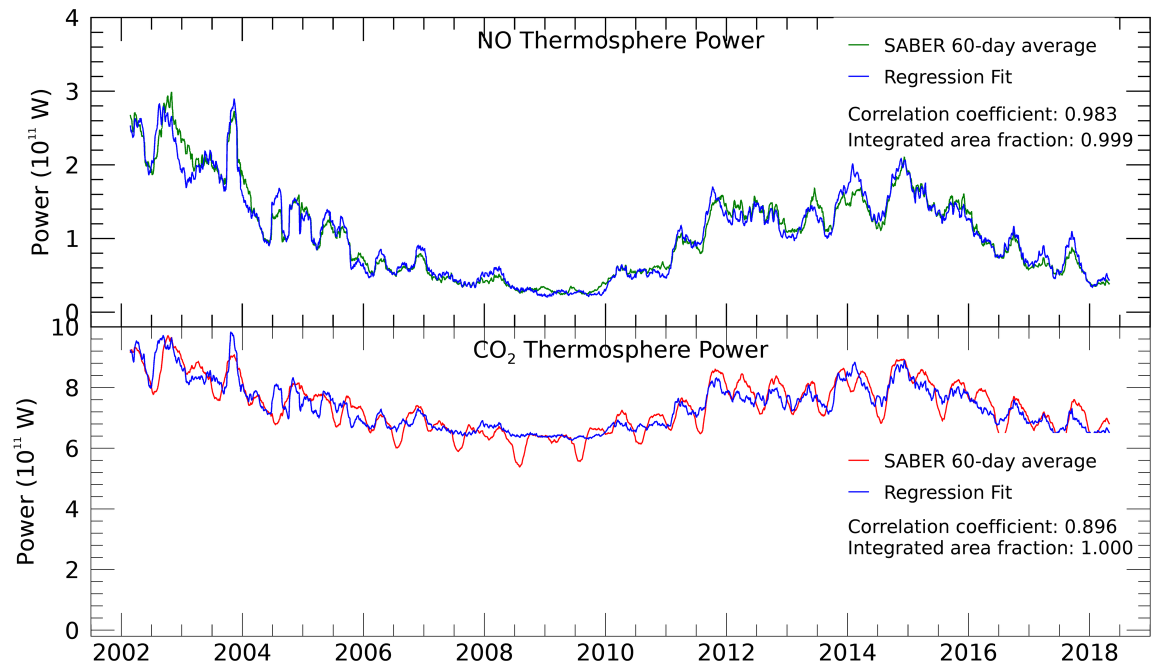


Methodology

- Visual correlations between the Ap, F10.7, and Dst indices and NO power are evident in the 60-day running means shown below.
- These strongly suggest that the NO (and CO_2) power time series can be fit with a multiple linear regression involving these three standard solar and geomagnetic indices.

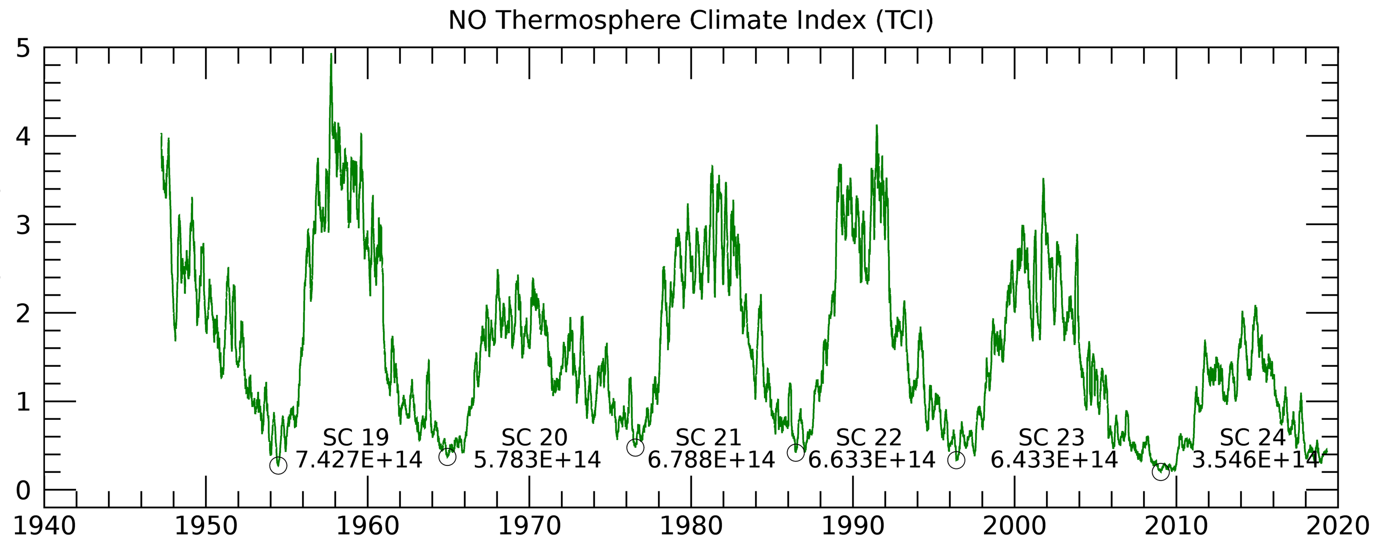


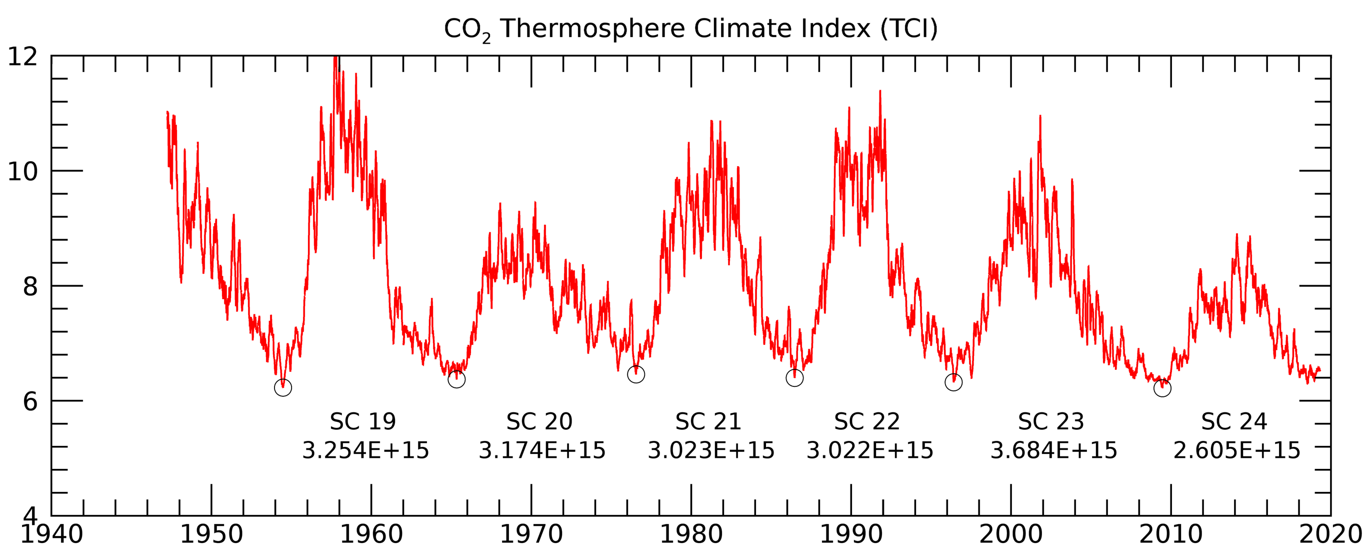
Results



- The plots above show the remarkable fit of the multiple linear regression to the NO and CO_2 global power 60-day running average curves.
- The correlation coefficients for the fits are high and the area under the observed and fit curves is identical in both cases.

- Use of these three indices, which are jointly available back to 1947, allows us to construct a time history of NO and CO_2 cooling back more than 70 years (below), covering five complete solar cycles (SC 19-23) and portions of two others (SC 18 and SC24 to date), a Thermosphere Climate Index (TCI).
- Integrating the infrared global power over each of the five complete solar cycles shows that the total power is very similar despite the visual differences between solar cycles.





Discussion

Solar Cycle Comparison

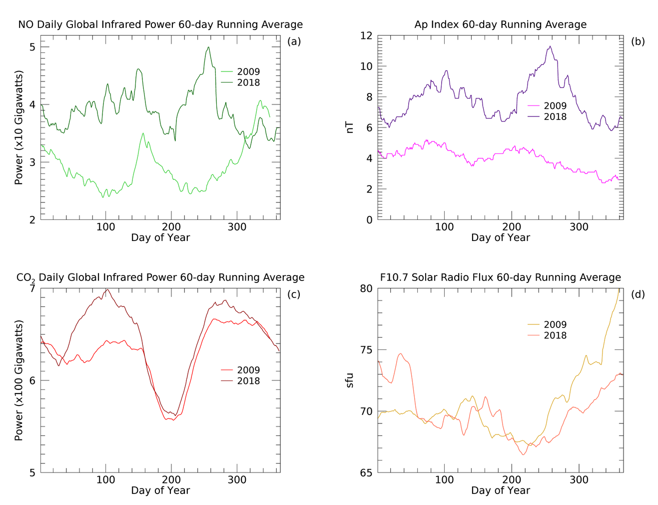
- The variation of integrated infrared power in the five complete solar cycles is quite small; standard deviation of total power is less than 7%.
- SC 24 (to date) is rather different.
  - Solar cycle length is at 92% of the mean length of the five complete solar cycles, but global power values lag well behind.
  - Total power is at 76% of the SC19-23 mean so SC 24 would need to extend another 1200 days or more than 3 years to have the same average power. However, SC 25 start is predicted between July 2019 and Sept 2020.

Solar Cycle	Total Days	NO Power	CO2 Power	Total Power	SRFlux	Ap Index
19	3966	7.43E+14	3.26E+15	4.00E+15	5.42E+05	6.08E+04
20	4245	5.78E+14	3.18E+15	3.75E+15	4.70E+05	5.36E+04
21	3622	6.79E+14	3.02E+15	3.70E+15	4.97E+05	5.67E+04
22	3630	6.63E+14	3.02E+15	3.69E+15	4.85E+05	5.66E+04
23	4774	6.43E+14	3.69E+15	4.33E+15	5.54E+05	5.58E+04
Mean	4047	6.61E+14	3.23E+15	3.89E+15	5.10E+05	5.67E+04
StdDev	431	5.32E+13	2.44E+14	2.45E+14	3.25E+04	2.33E+03
StdDev Pct	10.65%	8.04%	7.54%	6.29%	6.37%	4.12%
24 (to date)	3753.00	3.55E+14	2.61E+15	2.96E+15	3.63E+05	2.19E+04
Percent of Mean	92.73%	53.62%	80.63%	76.04%	71.21%	38.55%

Comparison of NO, CO_2, Ap, and F10.7 60-day Running Averages In 2009 and 2018

SC 24 to date is energetically weaker than the five previous solar cycles. These plots show that:

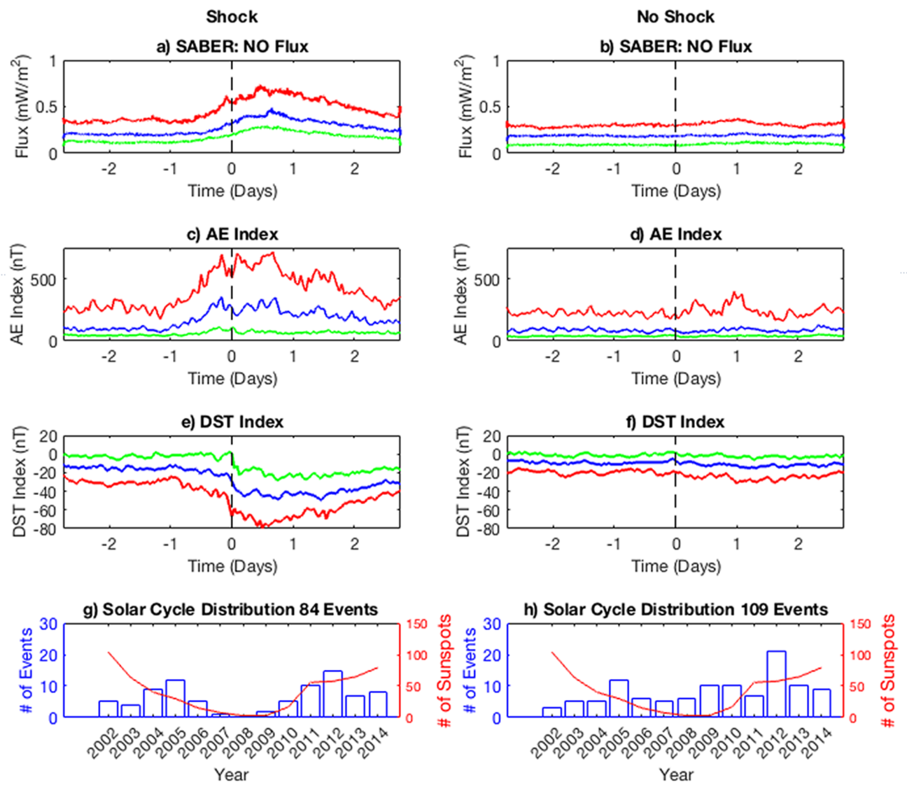
- NO global daily power values (a) are mostly not yet at the low levels reached during the last solar minimum
- This is due to the consistently higher 2018 levels of Ap (b)
- CO_2 values are much closer
- This is partly a result of higher F10.7 in much of 2018 coupled with the semi-annual oscillation coincidence



Discussion, continued

Thermospheric Response to Different Storm Types

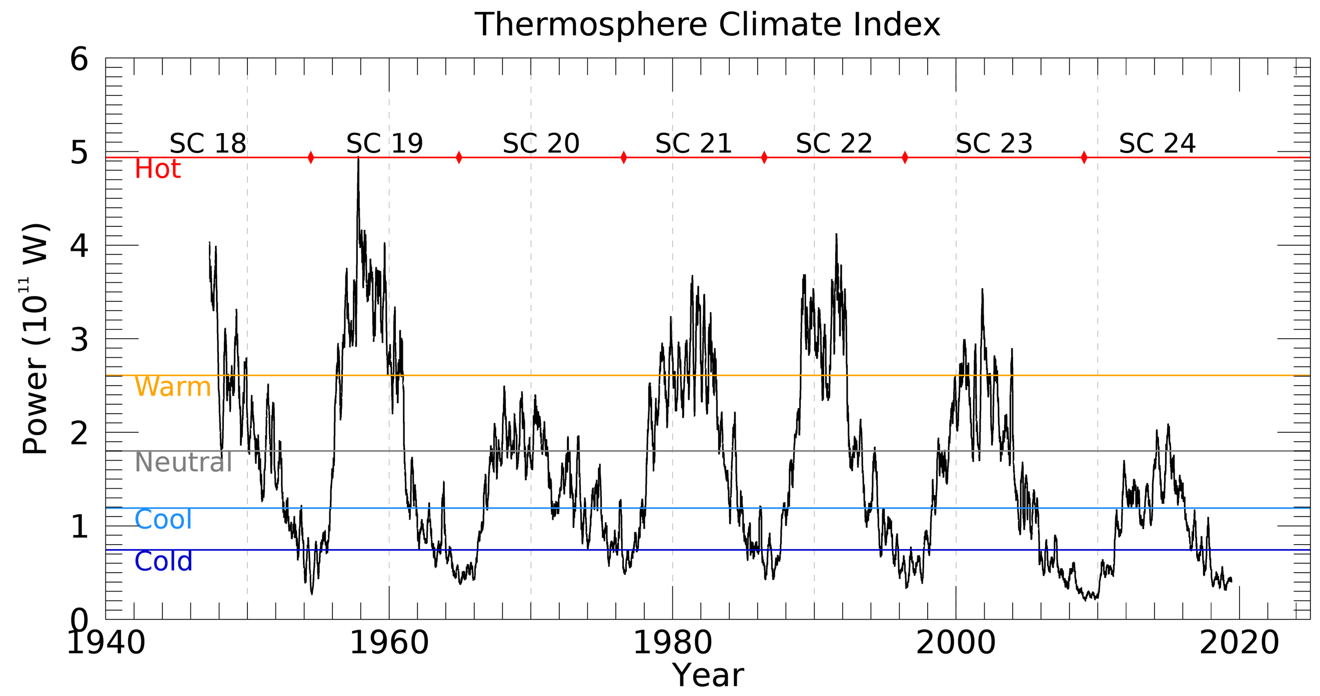
- Geomagnetic storms result in heating and expansion of the thermosphere, which increases the neutral density at fixed altitudes resulting in increased drag on low Earth orbit satellites and orbital debris. The heating creates additional NO which then emits infrared radiation that cools the region, so NO has a “thermostat” effect that counters the influx of solar radiation.
- Shock-led ICMEs often result in early and excessive thermospheric NO production followed by IR cooling. They show NO enhancement both pre- and post-ICME arrival. The NO response for non-shock events is much flatter.
- For the strongest strongest storms, the density increase is halted and and the thermosphere can become “overcooled”



Shock versus no shock events for 192 ICMEs between 2002 and 2014. The colored curves represent the 25th (green), 50th (blue), and 75th (red) percentile responses in the SABER NO emission. The red curve in the two bottom plots is the yearly number of sunspots (Royal Observatory of Belgium, Brussels, SILSO data; http://www.sidc. be/silso/home). Knipp et al., 2017

Outcome

- We proposed that TCI derived from NO cooling become a new, standard solar-terrestrial index due to its larger dynamic range and significant dependence on both solar irradiance and geomagnetic processes.
- Adjectival descriptors of Cold, Cool, Neutral, Warm and Hot based on percentile distributions were assigned to indicate the global state of the thermosphere.
  - Note that in SC 24, the thermosphere was only briefly Warm and has been much cooler than recent preceding solar cycles. Currently the TCI is in the lowest quintile of values, the Cold state.



TCI is Updated Daily On:

Thermosphere Climate Index
today: 4.12×10^{10} W Cold
Max: 49.4×10^{10} W Hot (10/1957)
Min: 2.05×10^{10} W Cold (02/2009)
explanation | more data
Updated 05 Jun 2019

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Acknowledgments

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