The State of the Thermosphere over Seven Decades

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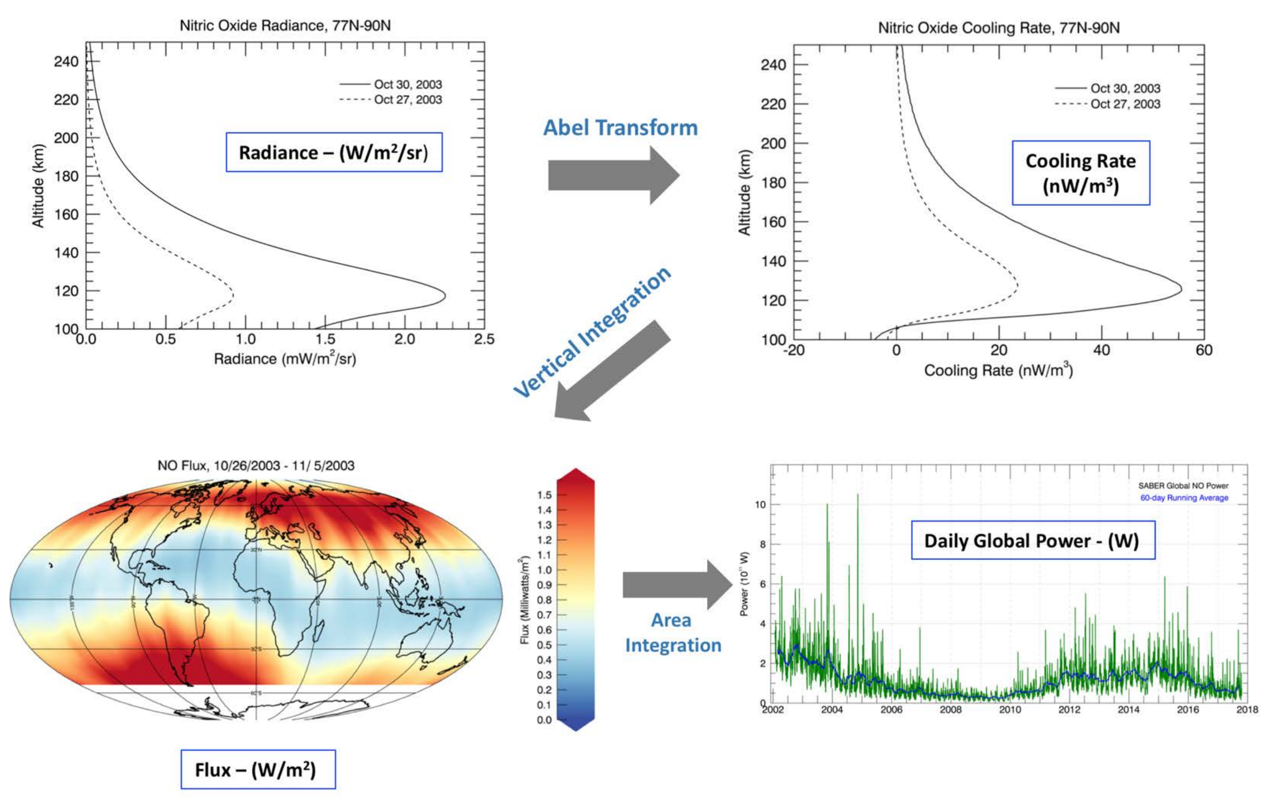
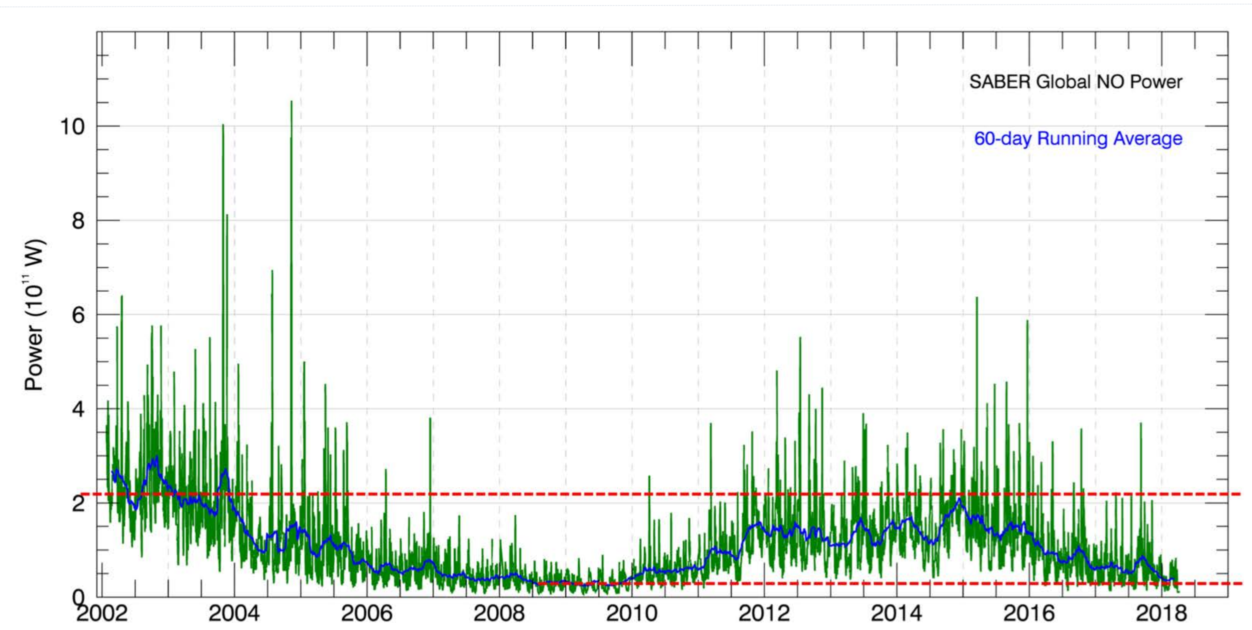
Introduction

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 more than 16 years (more than 6000 days!) 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:

ftp://saber.gats-inc.com/Version2_0/SABER_cooling



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:

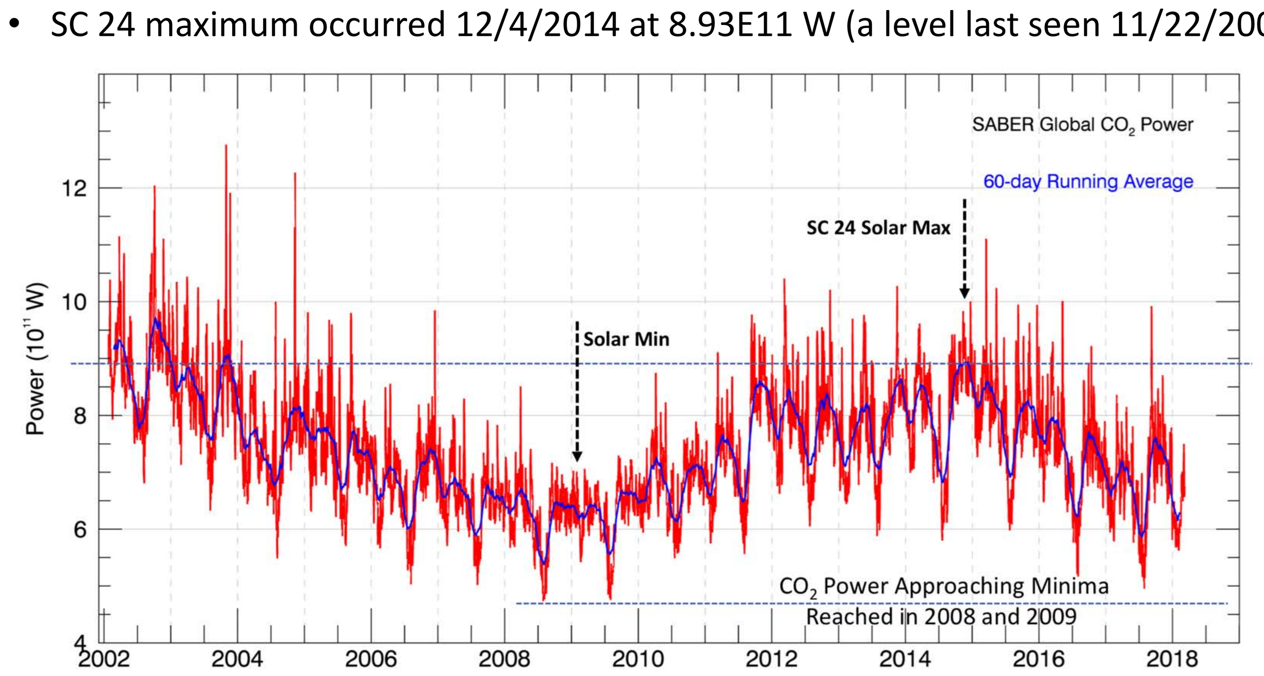
- SC23-24 minimum occurred 4/6/2009 at 2.39E10 W
- SC 24 maximum occurred 12/9/2014 at 2.11E11 W (a level last seen 12/2/2003)

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

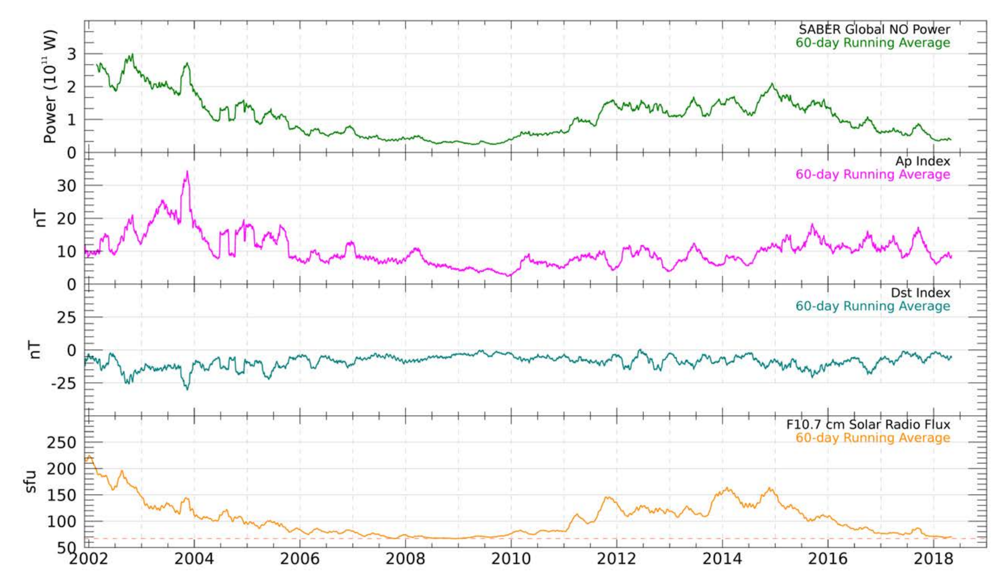
In the 60-day running average:

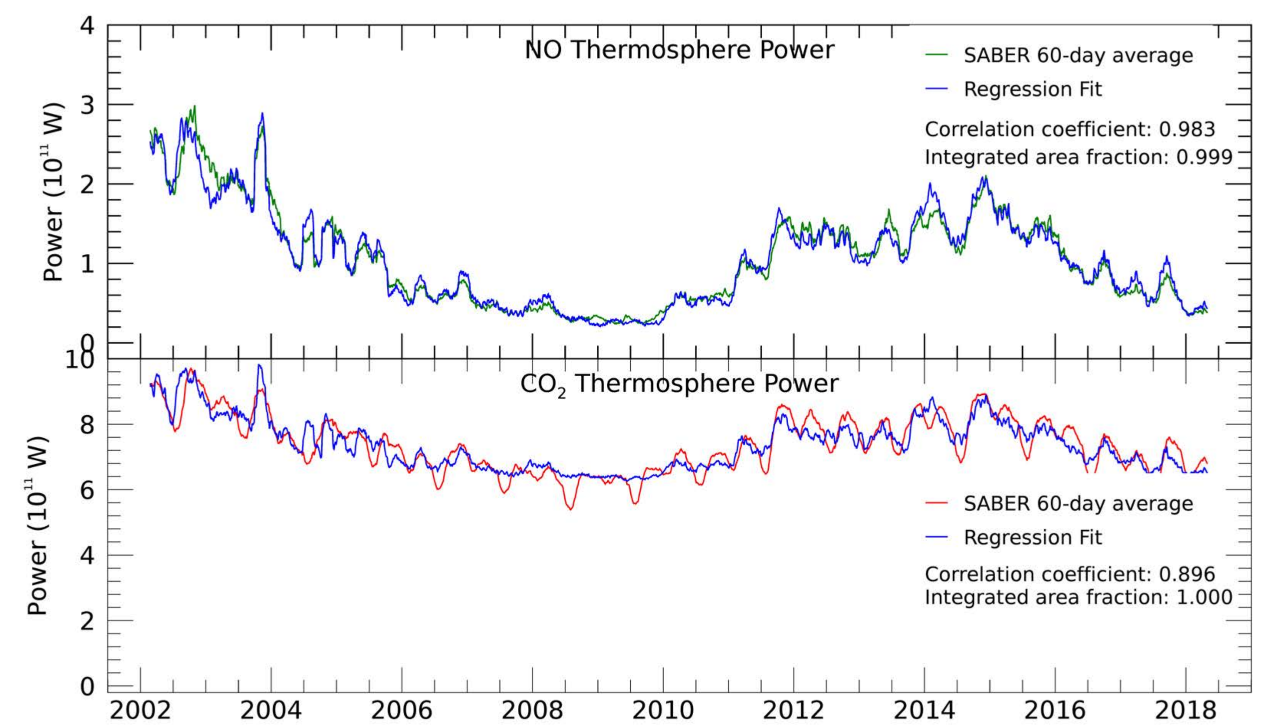
- SC23-24 minimum occurred 8/1/2008 at 5.39E11 W
- SC 24 maximum occurred 12/4/2014 at 8.93E11 W (a level last seen 11/22/2003



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 power time series can be fit with a multiple linear regression involving these three standard solar and geomagnetic indices.

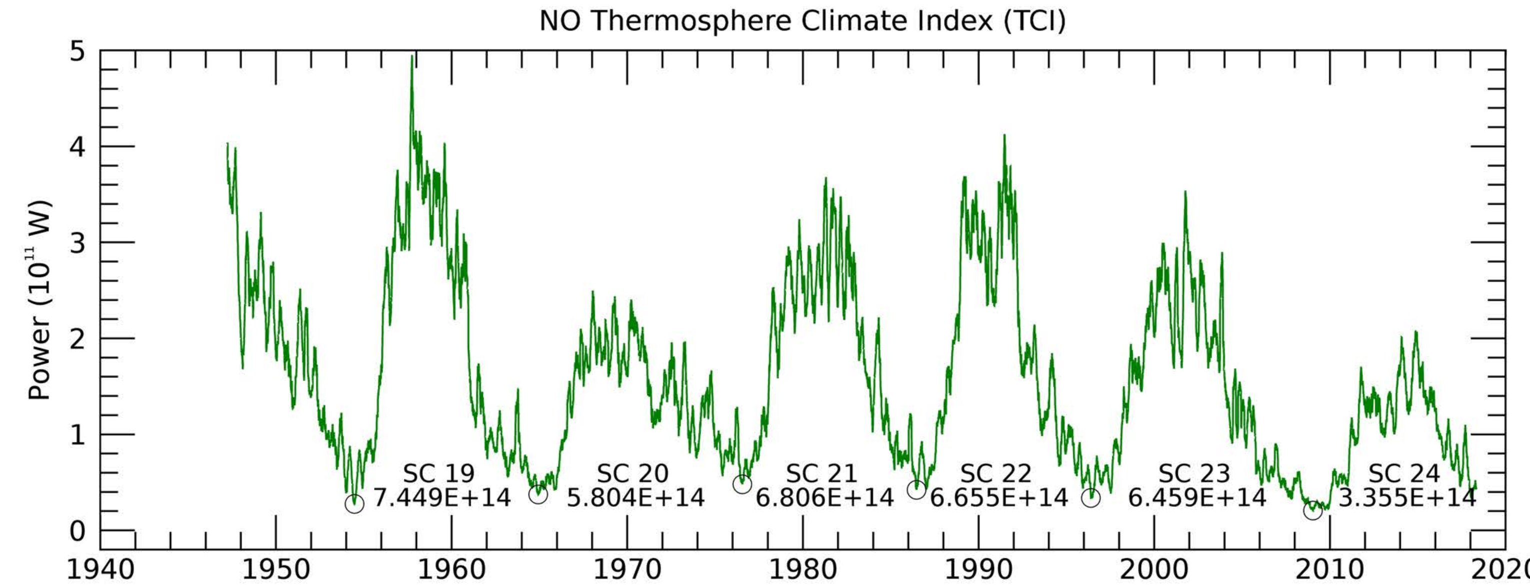


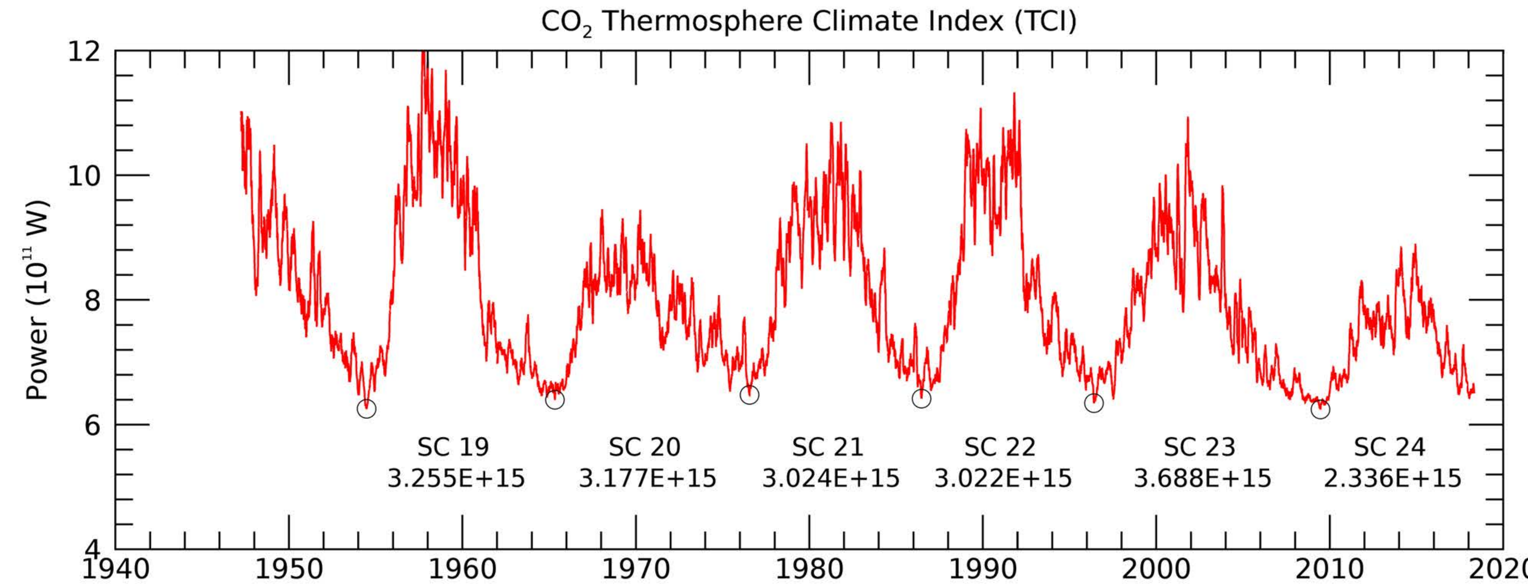


Results

The plots above show the remarkable fit of the multiple linear regression to the NO and CO2 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 CO2 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.



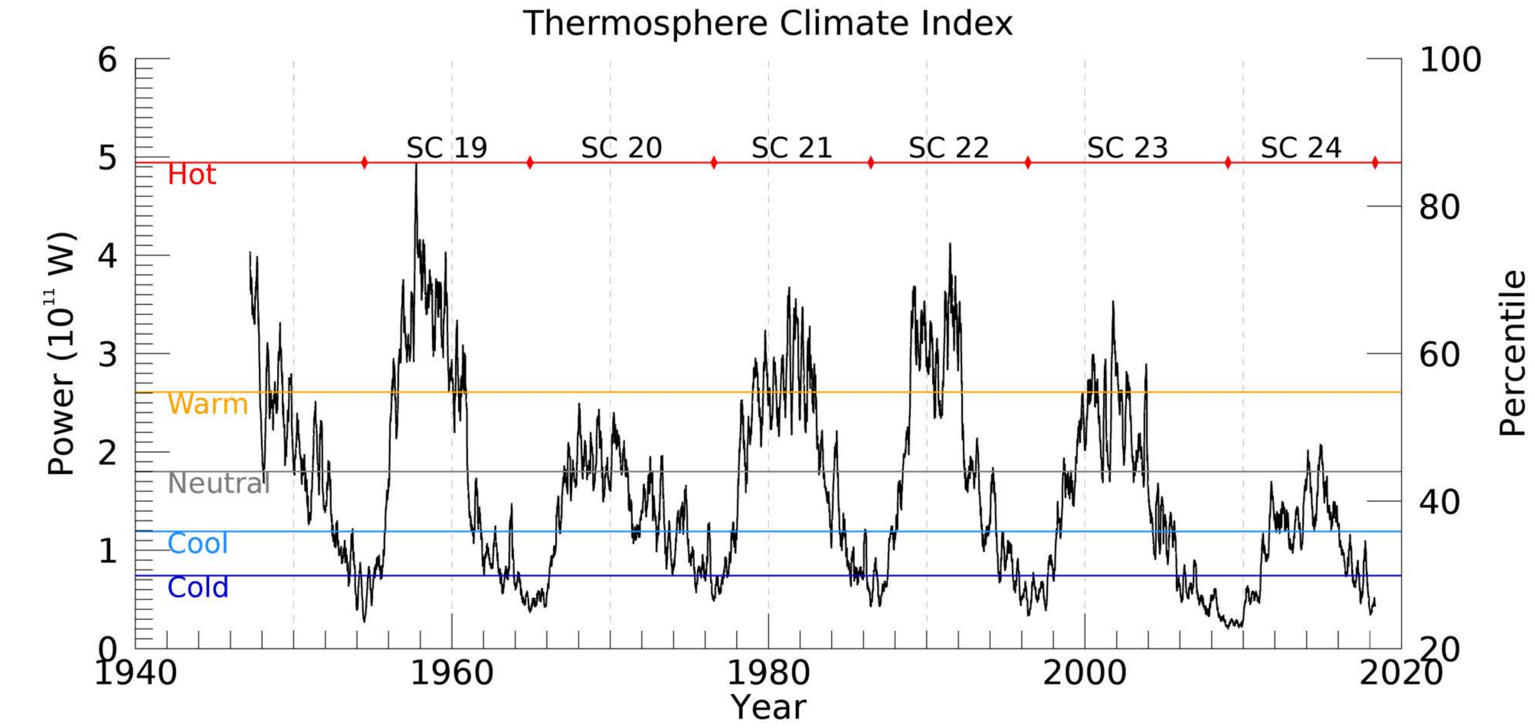


Discussion

As shown in the table below, the variation of integrated infrared power from one solar cycle to the next is quite small. The standard deviation of total power is less than 7% over the five complete solar cycles. However, SC 24 (to date) is rather different. The solar cycle length is at 84% of the mean length of the five complete solar cycles, but the global power values lag well behind, making SC24 quite different from previous solar cycles.

Solar Cycle	Length (days)	NO Power (10^{14} W)	CO2 Power (10^{15} W)	Total Power (10^{15} W)
19	3966	7.45	3.26	4.01
20	4245	5.81	3.18	3.75
21	3622	6.81	3.03	3.71
22	3630	6.66	3.02	3.69
23	4774	6.46	3.69	4.34
Mean	4047	6.64	3.23	3.90
Std Dev	10.65% (431 days)	7.99%	7.56%	6.37%
24	3394	3.36	2.34	2.67
% of Mean	83.9%	50.6%	72.3%	68.4%

Given the larger dynamic range of the TCI derived from NO cooling and its significant dependence on both solar irradiance and geomagnetic processes, we propose that this be considered a new, standard solar-terrestrial index. Examining the percentile distributions of the data, we assign adjectival descriptors of Cold, Cool, Neutral, Warm and Hot to indicate the global state of the thermosphere. Note that in SC24, 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.



References

Mlynczak, M. G., L. A. Hunt, B. Thomas Marshall, J. M. Russell III, C. J. Mertens, R. Earl Thompson, and L. L. Gordley (2015), A combined solar and geomagnetic index for thermospheric climate, Geophys. Res. Lett., 42, doi:10.1002/2015GL064038.

Mlynczak, M. G., L. A. Hunt, J. M. Russell III, B. T. Marshall, C. J. Mertens, and R. E. Thompson (2016), The Global Infrared Energy Budget of the Thermosphere from 1947 to 2016 and Implications for Solar Variability, Geophys. Res. Lett., 43, doi:10.1002/2016GL070965.

Mlynczak, M.G., Hunt, L.A., Russell, J.M., Marshall, B.T., Thermosphere climate indexes: Percentile ranges and adjectival descriptors, *Journal of Atmospheric and Solar- Terrestrial Physics* (2018), doii:10.1016/j.jastp.2018.04.004

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