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# **Solar Variability and Impacts on Earth's Thermosphere during the Space Age**

## **WHPI Workshop**

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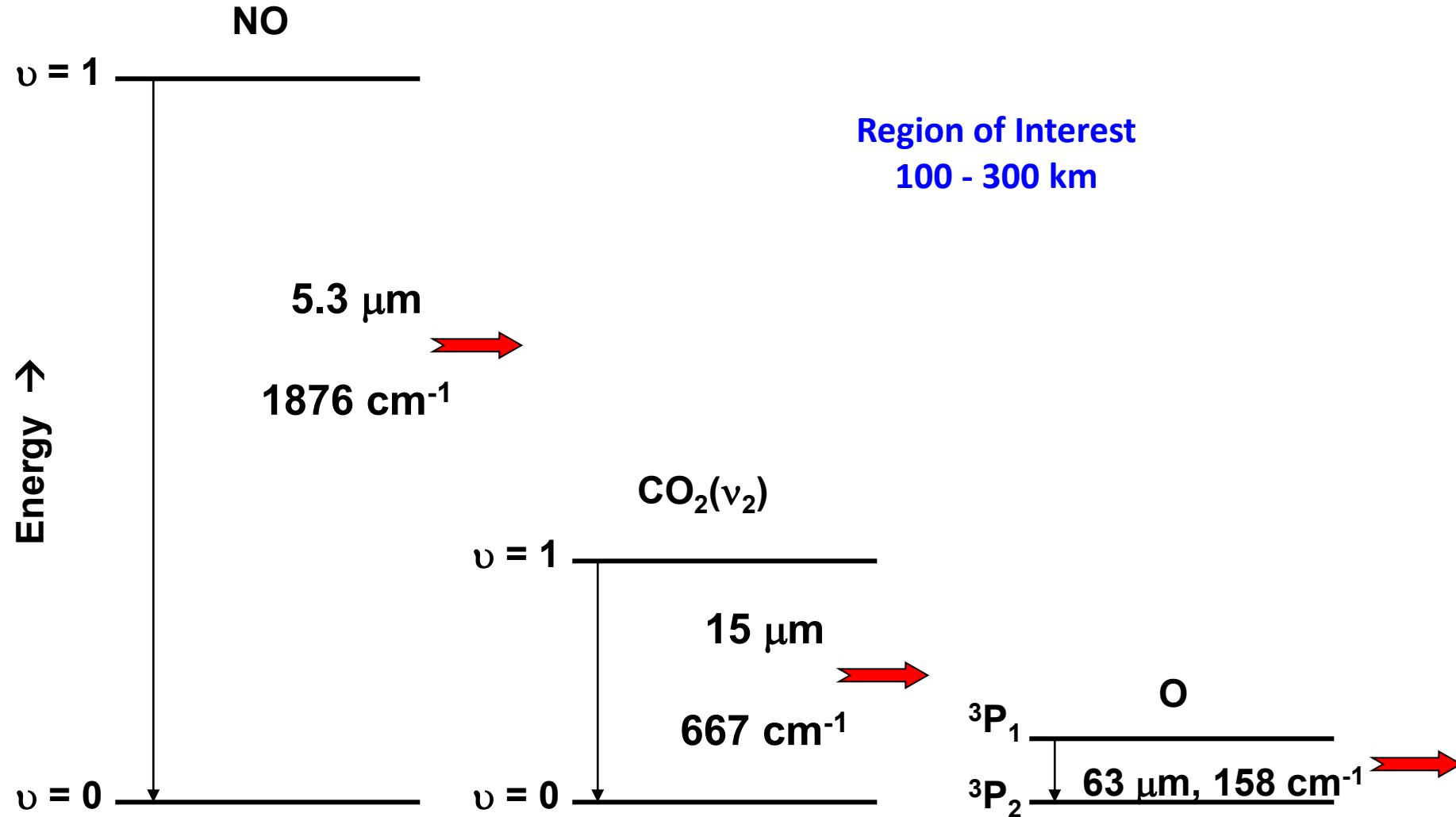
# Introduction

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- **Solar and Geomagnetic variability strongly affect the thermal structure, density, and composition of the thermosphere above 100 km**
- **Ongoing decrease in intensity of solar cycles since the start of the Space Age gives a reduction in thermosphere temperature and density**
- **Increasing CO<sub>2</sub> also reduces thermosphere temperature and density**
- **Can we monitor the state of the global thermosphere in the absence of continual space-based observations?**
- **Yes! - The Thermosphere Climate Index (TCI) provides information on the global thermosphere energy budget and thermal state**
- **The TCI is an index derived from long-term observations of the infrared radiative cooling of the thermosphere by nitric oxide (NO) by SABER on TIMED**

# Thermospheric Radiative Cooling Mechanisms

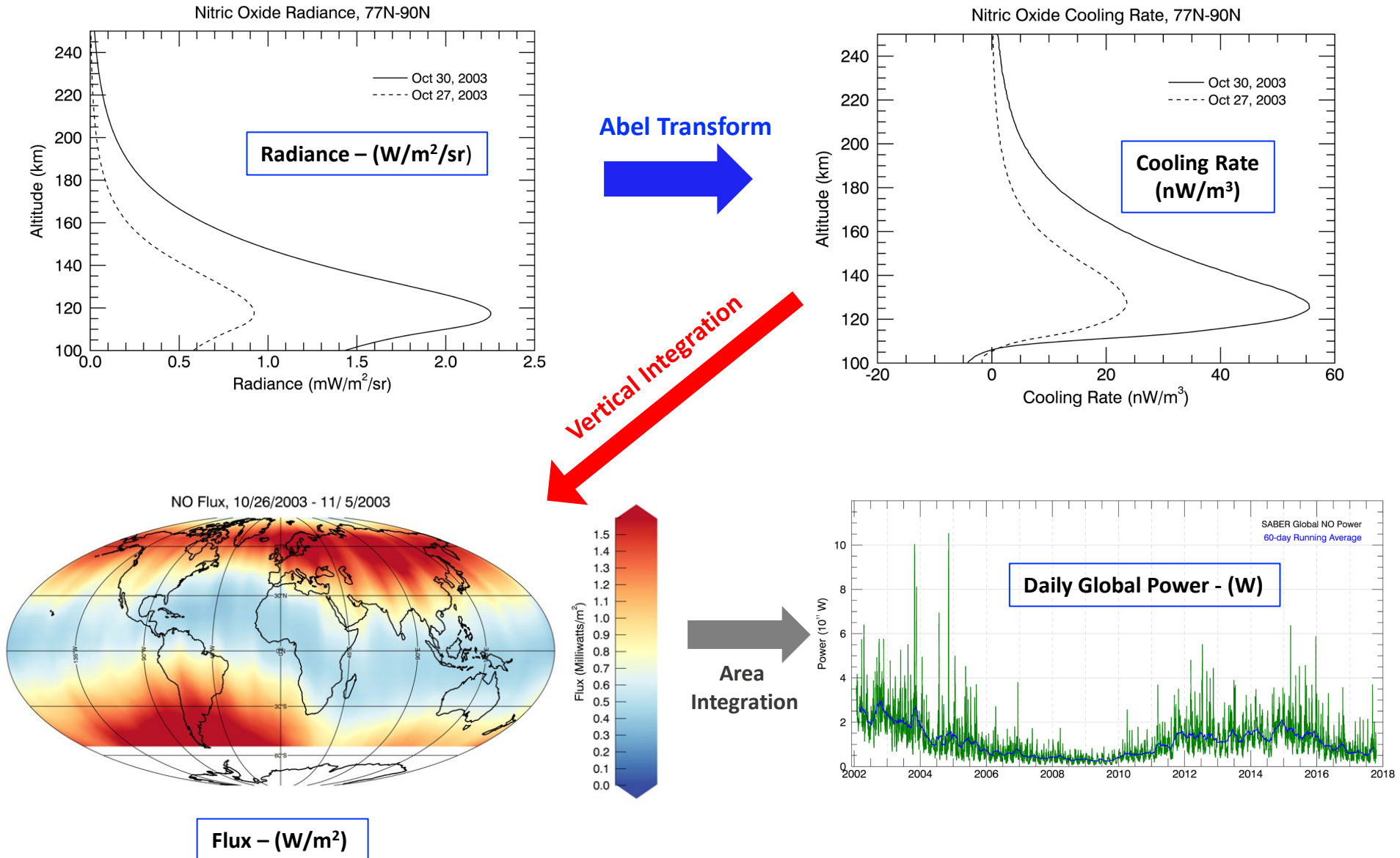
- figure is to scale in energy -



# Infrared Radiative Cooling by NO in the Thermosphere

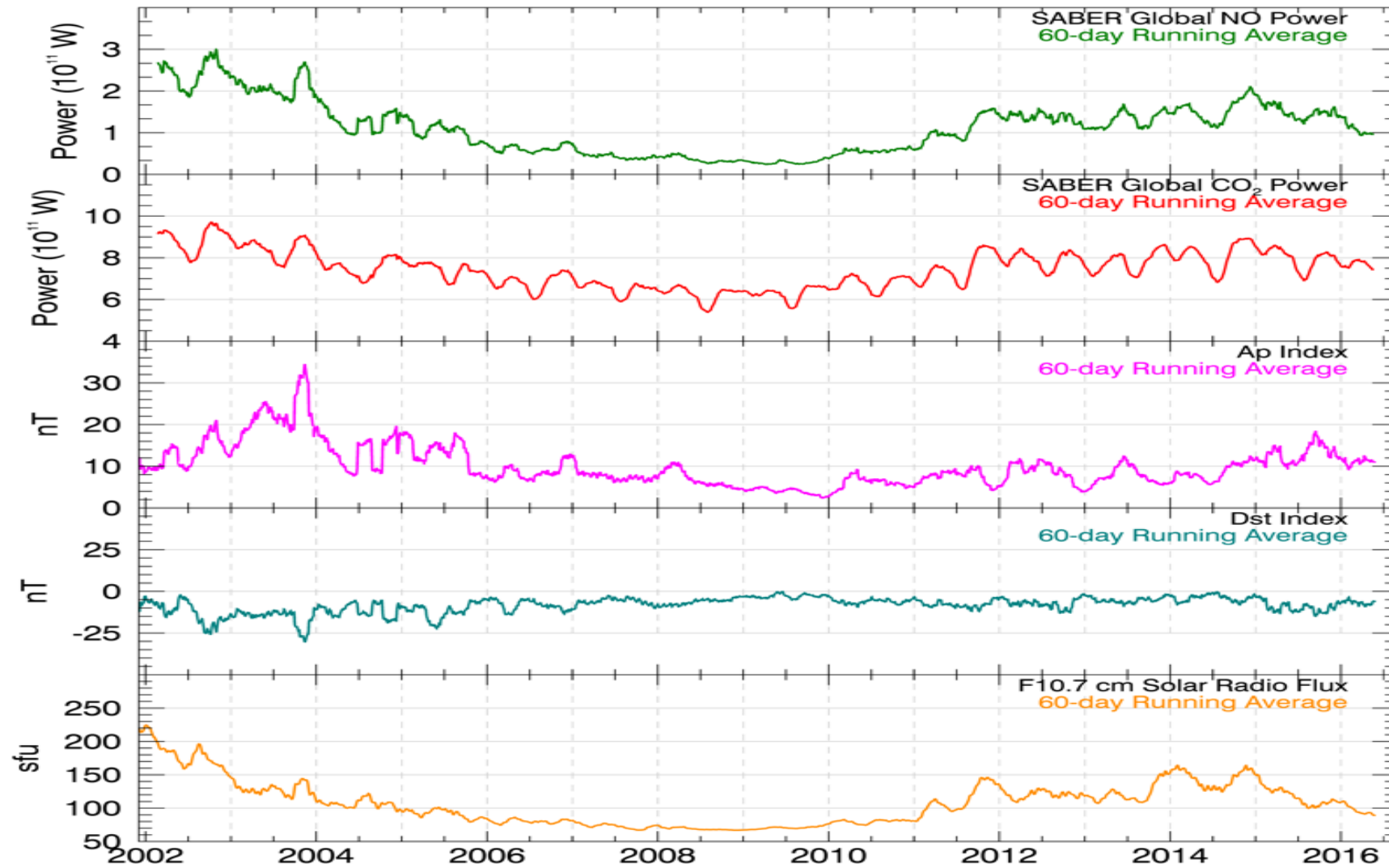
- Radiative cooling is the action of infrared radiation to reduce the kinetic temperature of the neutral atmosphere
- Collisions between atomic oxygen (O) and NO initiate the cooling process
  - $\text{NO} (\nu = 0) + \text{O} \rightarrow \text{NO} (\nu = 1) + \text{O}$  (Kinetic Energy Removal)
  - $\text{NO} (\nu = 1) \rightarrow \text{NO} (\nu = 0) + h\nu (5.3 \mu\text{m})$  (Kinetic Energy Loss)
  - $\text{NO} (\nu = 1) + \text{O} \rightarrow \text{NO} (\nu = 0) + \text{O}$  (Kinetic Energy Returned)
- Radiative cooling by NO is dependent on temperature ( $\exp(2700/T)$ ) and is very sensitive indicator of the thermal state above 100 km
  - NO cooling is a 'natural thermostat' above  $\sim 115$  km

# From SABER Limb Radiances to Global Infrared Power



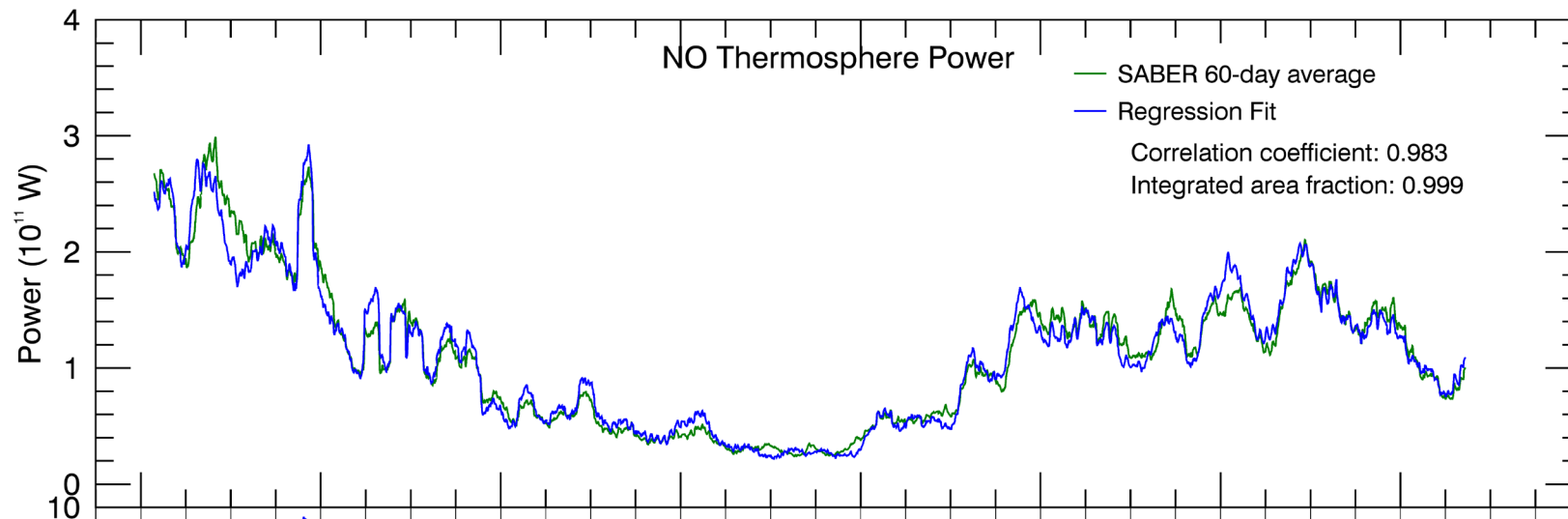
# 60-day Running Means – Global Nitric Oxide Power

## *Strong Visual Correlation in NO, Ap, Dst, F10.7*



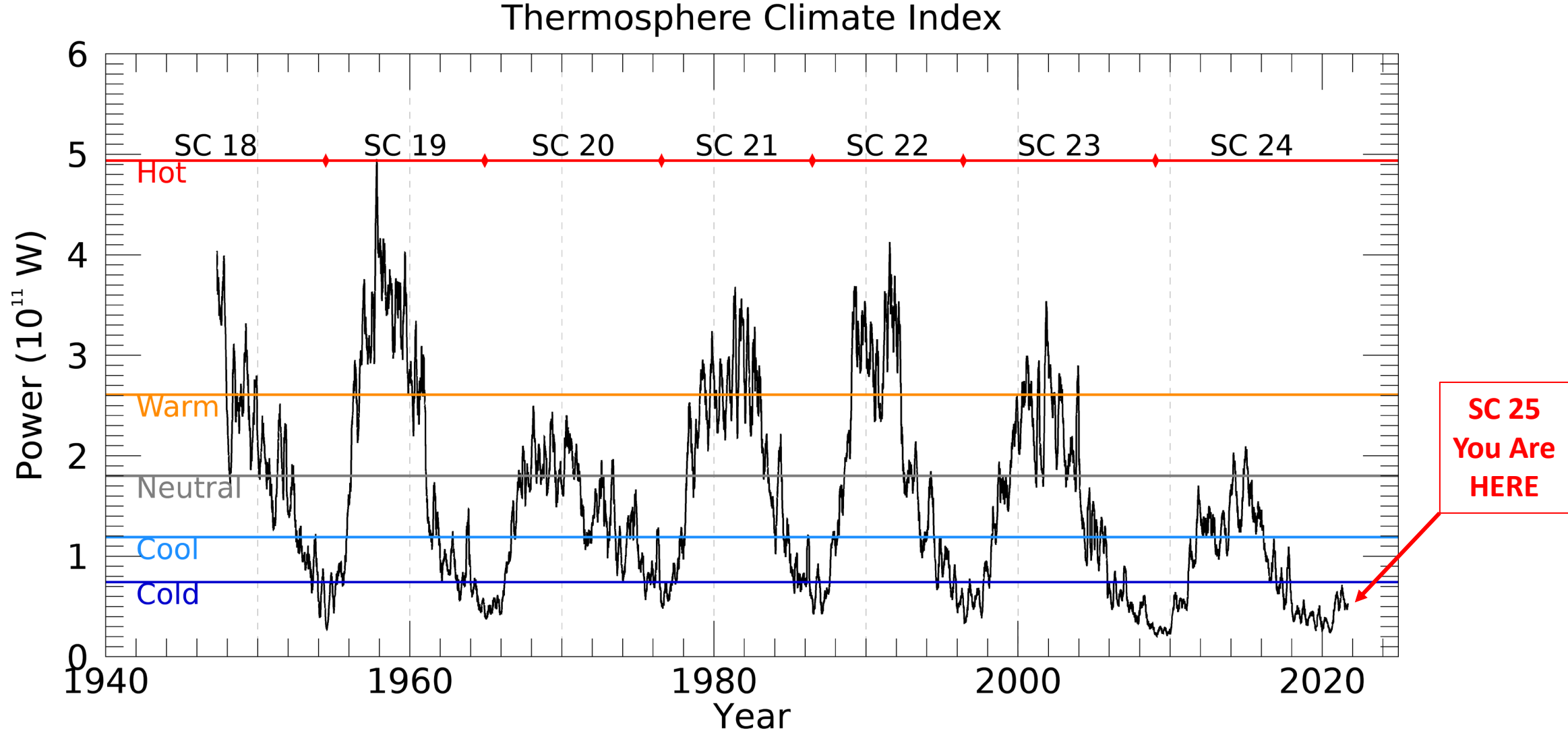
# Multiple Linear Regression Fit

## SABER NO Power as Function of F10.7, Ap, Dst



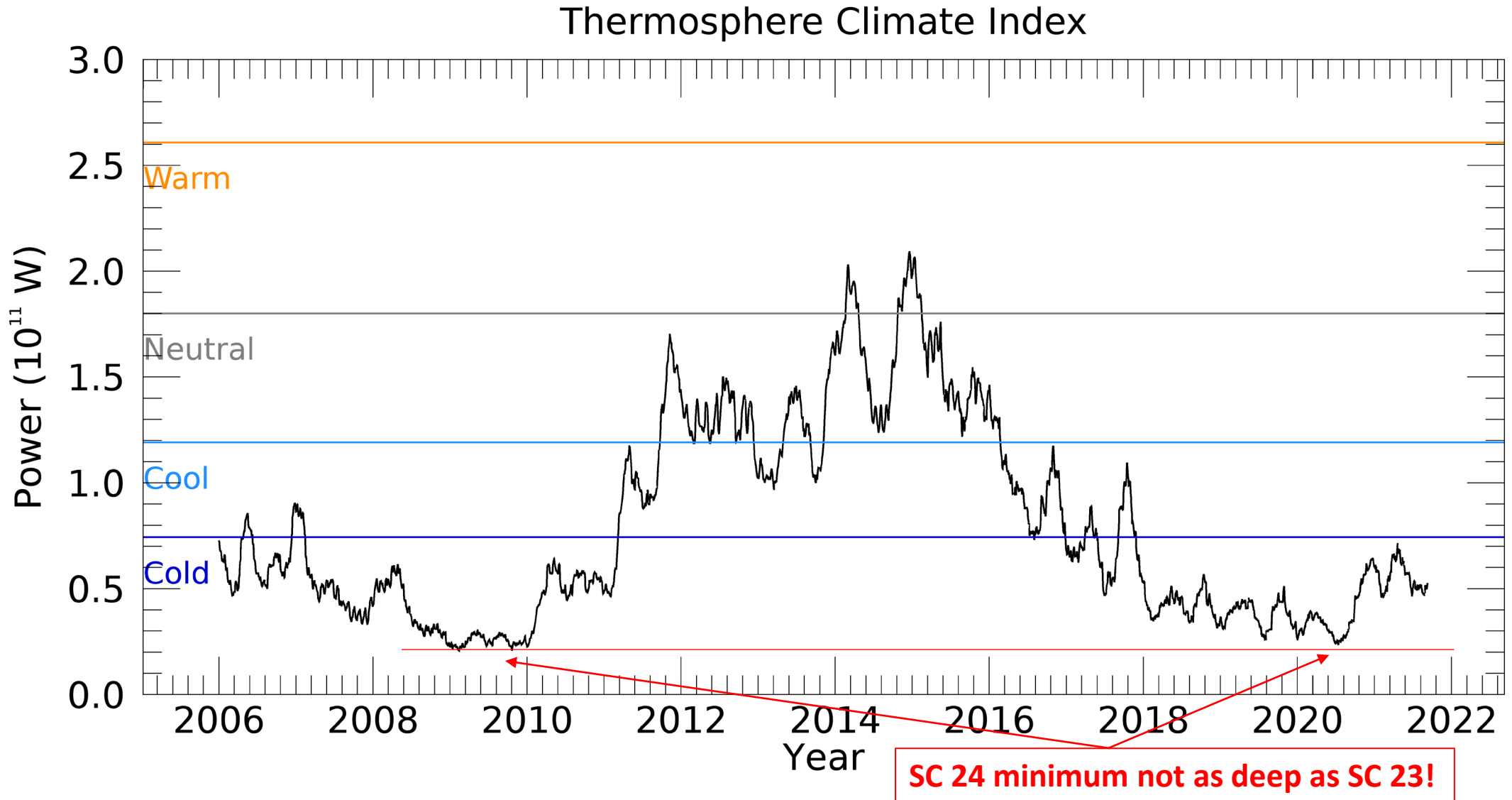
- The TCI represents the average of the prior 60 days of global daily average of infrared power emitted from 100 km to 250 km by NO
- The fit shown (blue) here is to the observed SABER NO power (green)
- With extant datasets of F10.7, Ap, Dst, the TCI can be extended back to 1947
- The TCI combines solar and geomagnetic indexes to provide the first index with direct terrestrial context – and can be computed indefinitely into the future!

# Thermosphere Climate Index – May 1947 up to Sept. 8, 2021

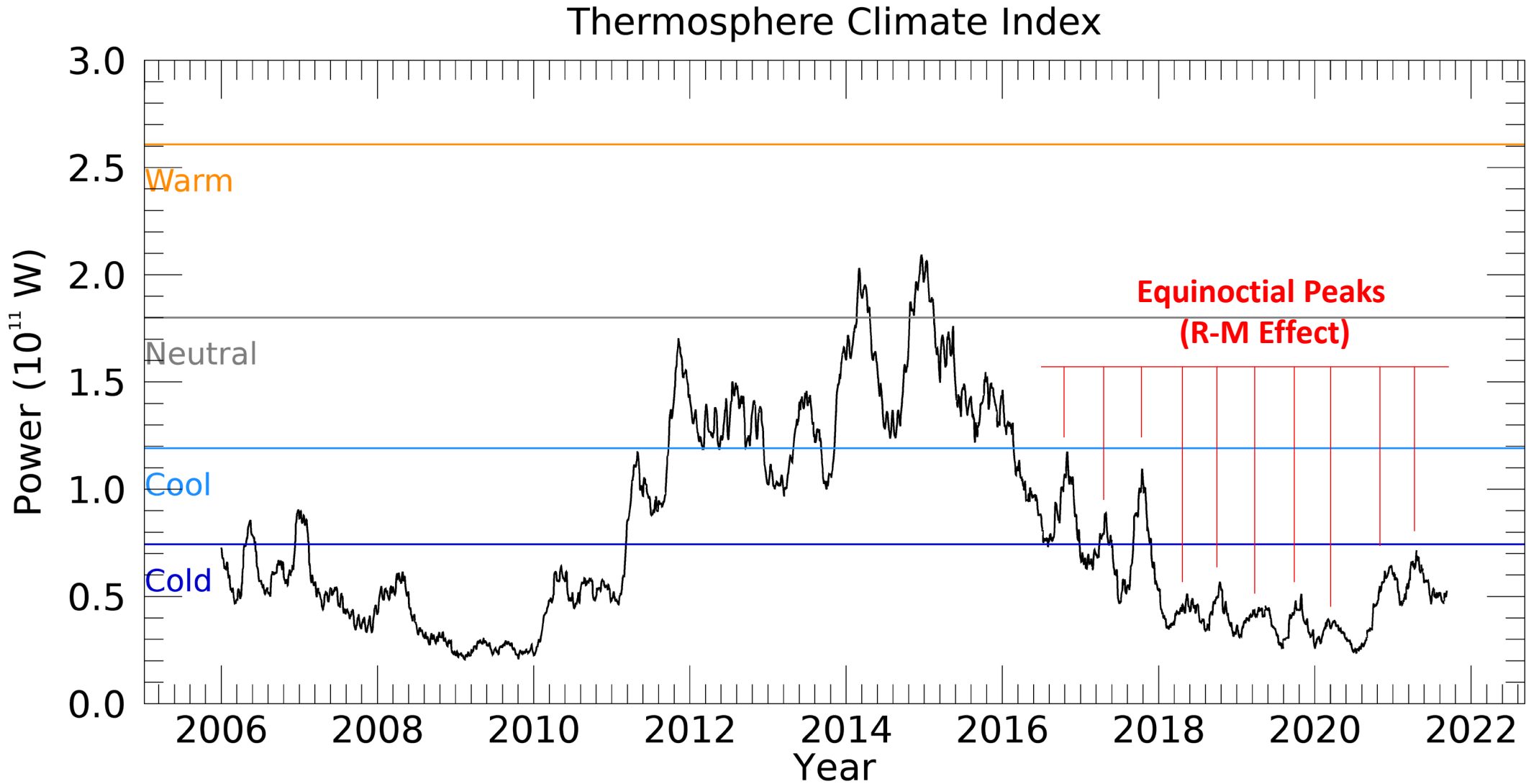




# TCI from January 1, 2006 to September 7, 2021

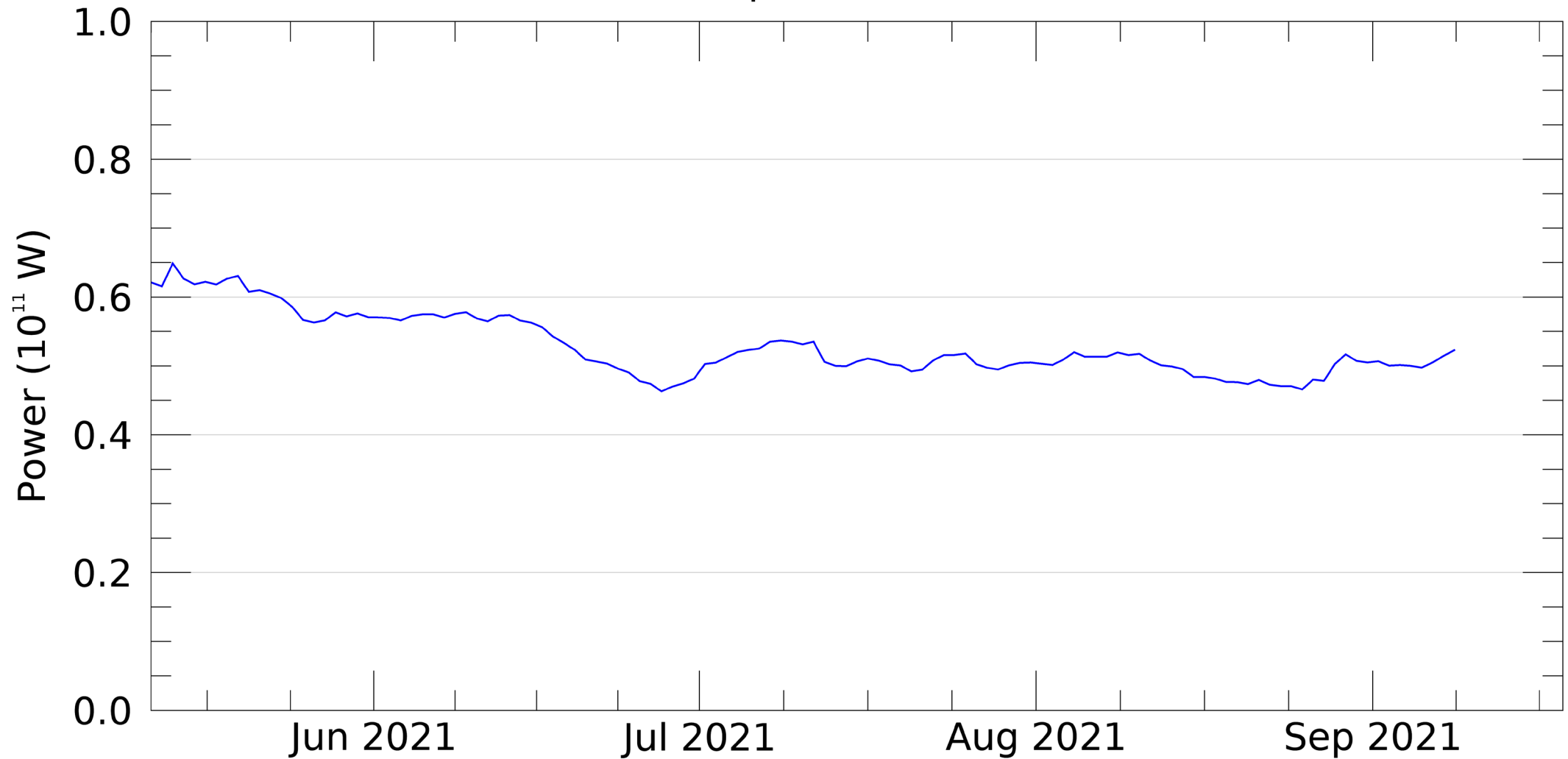


# TCI from January 1, 2006 to September 7, 2021



# TCI From May 2021 to Sept. 8, 2021

Thermosphere Climate Index



# Summary

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- The TCI is a new solar-terrestrial index combining both solar (F10.7) and geomagnetic (Ap, Dst) indexes
- The TCI provides direct terrestrial context – the global power radiated by NO in the thermosphere
- The TCI is a very sensitive indicator of global thermospheric temperature due to the non-linear dependence of NO infrared emission on temperature
- TCI has been decreasing for several months, presently about 70% of what it was in May 2021 – starting a slight increase in past few days
- Pronounced visual evidence for semi-annual variability in NO power (Russell-McPherron effect) in SC 24 and SC 25
- From the thermosphere's perspective, SC 25 has begun, but it is not monotonically increasing in intensity
- The TCI can be used forever into the future (so long as F10.7 and Ap are measured)