Journal of Atmospheric and Solar-Terrestrial Physics 174 (2018) 28–31

Contents lists available at ScienceDirect

Journal of Atmospheric and Solar-Terrestrial Physics

journal homepage: www.elsevier.com/locate/jastp

Thermosphere climate indexes: Percentile ranges and adjectival descriptors

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ABSTRACT

Thermosphere Climate Indexes (TCI) represent the 60-day running average of the global infrared cooling power radiated from the thermosphere by nitric oxide and by carbon dioxide. The TCI are accurately expressed as linear combinations of the 60-day running averages of the F10.7, Ap, and Dst indexes, thus providing terrestrial context to the long record of solar and geomagnetic indexes. We examine the percentile distribution in quintiles of the TCI generated using solar and geomagnetic indexes covering five complete solar cycles. We further assign adjectival descriptors (Cold, Cool, Neutral, Warm, or Hot) to these quintiles as the TCI largely indicate the global thermal state of the thermosphere. We suggest that the TCI are valuable new solar-terrestrial indexes due to the information they contain about the global thermosphere and due to their ease of calculation from standard indexes. Specifically, given dynamic range of the TCI associated with NO cooling, and its significant dependence on both solar irradiance and geomagnetic processes, we recommend that it be included henceforth as a new, standard solar-terrestrial Index. The NO TCI data show that the thermosphere was "Warm" only for a brief period of time at the maximum of solar cycle 24 and thus experienced the coolest solar maximum of the past seven solar cycles. As of February, 2018, the thermosphere power is in the lowest quintile of values, to which we assign the level of 'Cold.'

1. Introduction

Indexes are widely used in aeronomy to express the current state and variability of the Sun, geospace, and the Earth's magnetic field. These indexes include the widely used solar radio flux at 10.7 cm wavelength (F10.7) and the Ap and Kp indexes which gauge the degree of perturbations to the Earth's magnetic field during disturbances arising from the solar wind, solar coronal mass ejections, and other solar ejecta. A description of geomagnetic indexes is given by Mayaud (1980). However, none of the standard solar and geomagnetic indexes, by themselves, give direct terrestrial context in terms of a key property of the atmosphere.

Mlynczak et al. (2015, hereafter, M1) presented a combined solar and geomagnetic index using the F10.7, Ap, and Dst indexes to accurately represent the observed 15-year record of global infrared power (W) at 5.3 μm wavelength radiated from Earth's thermosphere by the nitric oxide (NO) molecule. The observations were made by the Sounding of the Atmosphere using Broadband Emission Radiometry (SABER) instrument on the NASA Thermosphere-Ionosphere-Mesosphere Energetics and Dynamics (TIMED) satellite. Mlynczak et al. (2016, hereafter, M2) extended this concept to the global infrared power at 15 μm wavelength radiated from Earth's thermosphere by the CO_2 molecule. In addition, M2 used the extant record of solar and geomagnetic indexes to extend the record of infrared cooling by NO and CO_2 back over 70 years to 1947, covering five complete solar cycles (SC, 19 through 23), and part of SC 18. M2 found that the infrared radiated energy from the thermosphere, integrated over a solar cycle, was nearly constant for the five complete solar cycles examined. Recently, Varotsos and Efstathiou (2018) examined both the observed NO and CO_2 infrared power and the empirically derived NO and CO_2 power extending back to 1947. They found no evidence of power-law behavior in either the observed or derived infrared radiation time series, implying they have the same intrinsic properties, and thus, the empirically derived time series is statistically consistent with the observed time series.

In the next section, we evaluate the distribution of the ranges of the empirically-derived NO and CO_2 infrared power, henceforth referred to as Thermosphere Climate Indexes (TCIs) over the five complete solar cycles covered in the empirically derived time series. These NO and CO_2 TCI time series, covering just over 20,000 days, are analyzed in terms of percentiles based on frequency of occurrence of observed power levels radiated by each molecule. The NO TCI is then shown from 1947 to 2018. Given its larger dynamic range relative to the CO_2 TCI, the NO TCI is recommended as a new solar-terrestrial index. As the NO TCI largely reflects the thermal state of the thermosphere, the adjectival descriptors of "Cold, Cool, Neutral, Warm, and Hot" are applied from the lowest to highest quintiles of the NO TCI. The new Index will be updated regularly

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https://doi.org/10.1016/j.jastp.2018.04.004
Received 23 February 2018; Received in revised form 3 April 2018; Accepted 7 April 2018
Available online 9 April 2018

and will be publicly available for download at the SABER project web site. A Summary concludes the paper.

2. Results

Shown in Fig. 1 are the empirically-derived time series of NO and CO_2 infrared power radiated by the thermosphere above 100 km, from M2. These cover SC 19 through 23, beginning on June 24, 1954 and running through June 19, 2009, 55 years in total. The CO_2 power is larger overall than the NO power because it primarily originates below the NO emission where the atmosphere is more dense and hence there is more thermal energy to radiate. The peak altitude of the CO_2 emission is

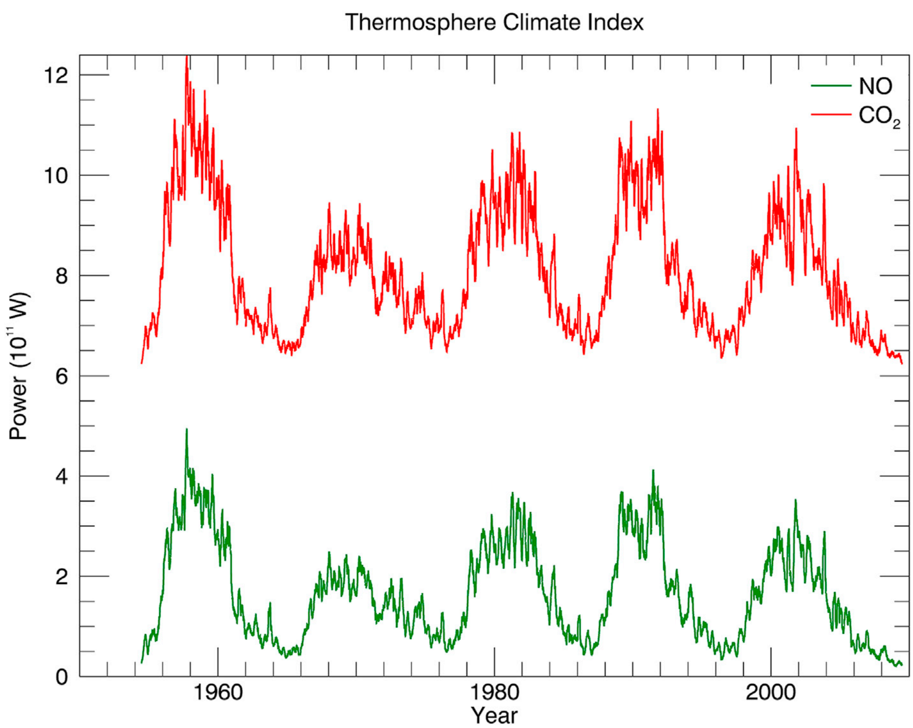

Fig. 1. Time series of NO and CO_2 Thermosphere Climate Indexes from 1955 to 2009 covering 5 complete solar cycles.

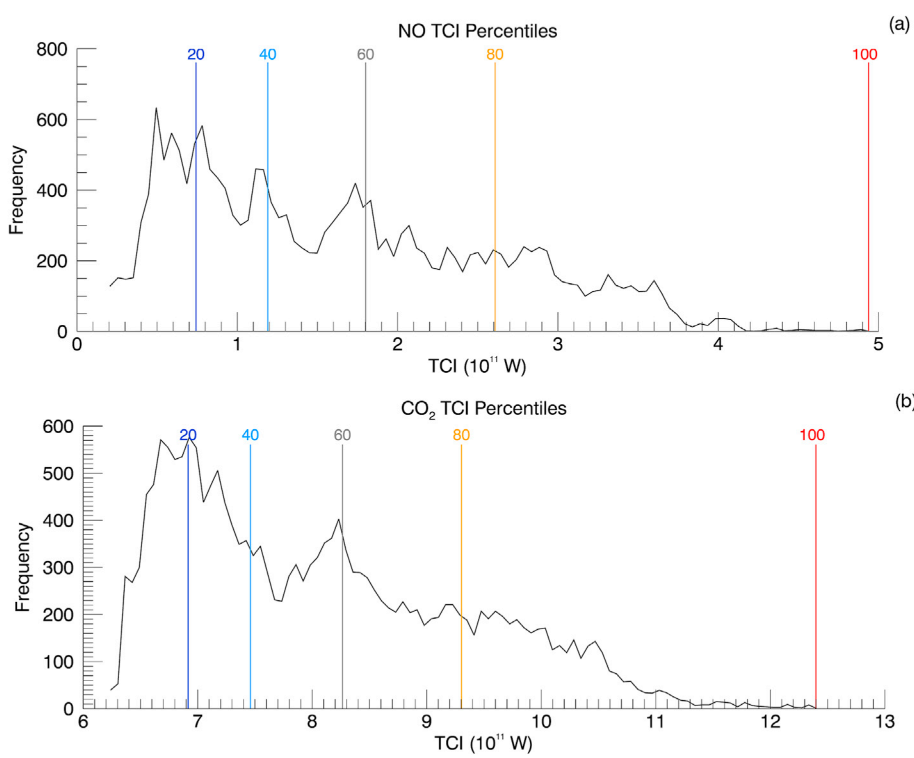

Fig. 2. Histograms of frequency of occurrence of power for NO (top) and CO_2 (bottom) over the 55 years of the time series shown in Fig. 1. The quintiles of each distribution are indicated by vertical lines.