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ScienceDirect

Advances in Space Research 55 (2015) 682–687

ADVANCES IN SPACE RESEARCH (a COSPAR publication)

www.elsevier.com/locate/asr

The influence of solar spectral variations on global radiative balance

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Received 20 September 2013; received in revised form 10 September 2014; accepted 21 October 2014
Available online 31 October 2014

Abstract

The total solar irradiance (TSI) has been the sole solar input in many climate models for lack of long and reliable time series of solar spectral irradiance (SSI) measurements currently. However, based on the recent SSI measurements by the Solar Radiation and Climate Experiment, which is able to provide full and accurate SSI measurements, the influence of SSI variations on global radiative balance between the descending phase of previous solar cycle in December 2007 and the ascending phase of the current solar cycle in the first half 2010 has been studied in this paper. The results show that the relatively larger TSI in the first half 2010 was mainly due to the ultraviolet and near infrared radiation enhancements, with average increases of 0.11% in 200–400 nm and 0.05% in 760–4000 nm respectively, while the radiation in visible region of 400–760 nm decreased by 0.05%. According to the measurements of ozone from the Aura-Microwave Limb Sounder satellite, the global average stratospheric ozone increased markedly in the layer of 25–40 km at the same time. The visible radiation decrease and stratospheric ozone increase together contributed to the smaller solar radiation at the tropopause for each month of the first half 2010 as compared with that in December 2007, with the maximum decrease of 0.15 W m^{-2} in March 2010. The study reveals that SSI variations in the ascending solar phase may also cool the Earth-atmosphere system.

Keywords: Sun; Spectral solar irradiance; Earth; Radiative balance

1. Introduction

As indicated in the 4th assessment report (AR4) of the Intergovernmental Panel on Climate Change (IPCC), the global surface mean temperature has risen by 0.74 ± 0.18 °C for 1906–2005 (IPCC, 2007). Since the Sun is the main energy source of the Earth, The question of whether – and to what extent – the Earth's climate is influenced by solar variability remains central to the understanding of anthropogenic climate change (Ermolli et al., 2013). It has been widely accepted that the Sun has long been stable and the global warming is attributed to the enhanced greenhouse effect due to anthropogenic emissions of greenhouse gases, such as CO_2, CH_4 and N_2O, since the Industrial Revolution (IPCC, 2007; Hansen et al., 2008; Montzka et al., 2011). However, other studies consider that solar variations may have been responsible for at least 50% of the warming observed since 1970 and about 80% since the Maunder solar minimum occurred in the 17th century (Scafetta and West, 2006; Scafetta, 2011). The study of Ziskin and Shaviv (2012) also points out that the total solar contribution to the 20th century global warming is 0.27 ± 0.07 °C by taking into account all the standard radiative forcings, and the value is much larger than can be expected from variation in the total solar irradiance (TSI) alone.

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http://dx.doi.org/10.1016/j.asr.2014.10.028
0273-1177/

Although controversial, all these studies are the same in one aspect that they consider only the variations of TSI. So far the TSI has been the sole solar input in many climate models when studying the solar influence on the Earth's climate, while little research has been done on the influence of spectral solar irradiance (SSI) for lack of long and reliable time series of SSI measurements (Ermolli et al., 2013). Solar irradiance includes different spectral composition. ultraviolet radiation provides the photochemical reaction with energy for the formation and destruction of stratospheric ozone, the ultraviolet absorption by stratospheric ozone is estimated to have cooled the Earth's surface by $1\sim2$ °C relative to no ozone layer on long time scale (many decades) (Sheng et al., 2003); while radiation at visible and near-infrared wavelengths mainly reaches and warms the lower atmosphere and the Earth's surface (Haigh et al., 2010). Thus even if the TSI varies very little, the irradiance variations at different solar wavelengths are likely to affect global radiative balance. Just as the results of Shaviv (2008) indicated that the total radiative forcing associated with solar cycles variations is about 5–7 times larger than just those associated with the TSI variations, which implies further the necessary existence of an mechanism that could amplify solar activity variations to give large climatic effects.

Global radiative balance, i.e. whether the net incoming solar radiation flux equals to the outgoing longwave radiation flux, is the basis of the global warming analysis. For the area ratio of the nearly spherical Earth's cross-section to its surface is 1/4, the insolation of the Earth in per unit area is 1/4 of the TSI. Regular space-based measurements of the TSI started in 1978. However, it was not until January 2003, when the Solar Radiation and Climate Experiment (SORCE) was launched by NASA, that the full SSI including visible and near-infrared spectrum was monitored from space, providing unprecedented spectral coverage that affords a detailed characterization of SSI variability (IPCC, 2007). The SORCE spacecraft carries instruments of the Total Irradiance Monitor (TIM) and the Spectral Irradiance Monitor (SIM) which are used to monitor TSI and SSI simultaneously and accurately (Kopp et al., 2005; Lean et al., 2005; Snow et al., 2010).The TIM has high precision and is able to detect 0.1% changes in the TSI caused by variability in solar activity, and the SIM also achieves an absolute calibration uncertainty of approximately 2% and measurement precision of 0.1% or better at most wavelengths (Ermolli et al., 2013). Detailed SORCE data can be obtained from the web site: http://lasp.colorado.edu/sorce.

The paper is organized as follows: in section 2, the variations of TSI during SORCE period are described. In section 3, we compare the SSI in the current ascending solar phase with that in the previous descending solar phase. Section 4 discusses the corresponding stratospheric ozone variations in these two periods and Section 5 analyzes the potential influence of SSI variations on global radiative balance. A summary and concluding remarks are provided in Section 6.

2. TSI variations

The TSI measured by the TIM from March 2003 to February 2012 is plotted in Fig. 1. The variations of TSI correlate closely to the 11-year solar cycle. Over the period of March 2003 to December 2008, the solar activity declined gradually (Haigh et al., 2010), and the TSI also showed a tendency to descend. Unusual low values occurred near the end of October 2003 due to the passage of two extremely large sunspot groups across the Sun (Kopp et al., 2005). After the solar minimum period of December 2008, the solar activity has been in a rising trend once again (Sello, 2012) and so has the TSI. On the whole, during this period, the variation of the TSI is 0.36%, and the average is 1361.05 ± 0.4 W m^{-2}. This value is significantly lower than the currently used canonical value of 1365.4 ± 1.3 W m^{-2} (IPCC, 2007). Two reasons may be responsible for this lower TSI. On the one hand, TIM has greatly reduced the error of scattered light which is a primary cause of the higher irradiance values measured by the earlier generation of solar radiometers (Kopp and Lean, 2011). On the other hand, by the updated predictions, using both precursor and non-precursor methods, further support some early indications of a ''moderately'' weak solar cycle, which is a part of a long-term decline that began in 1985 (Lockwood et al., 2012).

3. SSI variations

The SSI measured by SIM mainly covers wavelengths from 200 to 2400 nm, including ultraviolet, visible and near-infrared three wavebands. Fig. 2 presents the SSI in December 2007 as an example. The irradiance in the region of 200–760 nm shows a rapid increase, amounting for about 54% of the TSI. In addition, relative to the smooth curve in the 760–2400 nm waveband, the irradiance in this narrow region, which accounts for only 25% of the entire waveband, exhibits an obvious fluctuation. The average SSI relative variability at 200–760 nm which is defined as

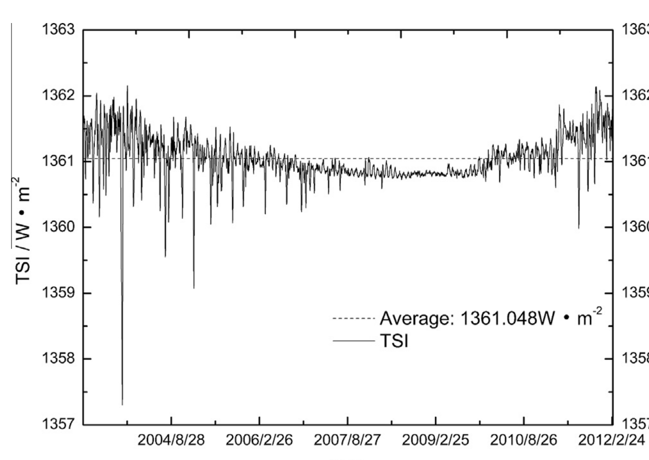

Fig. 1. TSI record as inferred from the SORCE data from March 2003 to February 2012.