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The 11-year solar-cycle effects on the temperature in the upper-stratosphere and mesosphere: Part I—Assessment of observations

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Abstract

Three independent temperature datasets have been analyzed for quantifying the influence of the 11-year solar cycle modulation of the UV radiation. The datasets used include: US rocketsondes, the OHP lidar, and the global temperature database made by the successive SSU on the NOAA satellites, adjusted and provided by the UK Meteorological Office. These measurements cover the upper stratosphere and the mesosphere, where the direct photochemical effect is expected. The improvement of the analysis compared to previous ones was possible because the overall quality and the continuity of many data series have been checked more carefully during the last decade in order to look for anthropogenic fingerprints and the one used here have been recognized as the best series according to their temporal continuity. The analysis of the different data set is based on the same regression linear model. The 11-year solar temperature response observed presents a variable behavior, depending on the location. However, an overall adequate agreement among the results has been obtained, and thus the global picture of the solar impact in the upper stratosphere and lower mesosphere has been obtained and is presented here. In the tropics, a 1–2 K positive response in the mid and upper stratophere has been found, in agreement with photochemical theory and previous analyses. On the opposite, at mid-latitudes, negative responses of several Kelvin have been observed, during winters, in the analyses of the datasets analyzed here. In the mesosphere, at sub-tropic and mid-latitude regions, we observe a positive response all the year round increasing by a factor of two during winter.

Keywords: Solar-cycle; Temperature; Stratosphere; Ultra-violet

1. Introduction

In order to assess the impact of human activity on climate, it is necessary to place the possible human-induced changes in the context of natural variability. Despite the fact that the solar irradiance is one of the main drivers for earth climate, the mechanism by which its short-term variation influences atmospheric parameters is controversial and difficult to prove, especially at ground level where the atmospheric variability is high. However, the quantification of climate change due to anthropogenic sources has reactivated the search for sun-climate relations. As the expected magnitude of the

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changes in radiative fluxes may be of the same order as those involved in the radiative forcing of climate by greenhouse gases, both need to be considered to extract signatures from the adequate data records. The response of the middle atmosphere to solar variability is expected to be small compared to the atmospheric variability on shorter timescales, while it is thought to be nearly undetectable in the available data series. However, observations exhibit unexpected large responses correlated with solar changes. The best-known case is the stratospheric response of the polar winter lower stratosphere found by Labitzke and van Loon (1988). The solar correlation is found to be larger when data is separated according to the phase of the equatorial quasi-biennial oscillation (QBO). The nature of the mechanisms, by which, small changes in solar radiation, which affects predominantly the middle atmosphere, could significantly impact the Earth's surface, remains to be better understood. The amplitude of the change in total solar irradiance from solar minimum to solar maximum being only 0.1%, cause an undetectable surface temperature increase of around 0.1 K if only due to direct radiative effects alone. The changes in solar irradiance are not evenly distributed across the solar spectrum, but are concentrated in the ultraviolet: wavelengths less than 400 nm contribute about to 9% of the change, and 32% of the radiation variation over a solar cycle occur below 250 nm (Lean, 1989). Changes in the solar ultraviolet output has, thus the largest potential to alter directly the upper stratospheric ozone and hence modulate temperature and climate indirectly. Despite the fact that other ideas are also developed such as the variations of cosmic ray and global cloud coverage (Svensmark and Friss-Christensen, 1997).

One possible explanation of solar induced atmospheric changes involves solar ultraviolet irradiance variations affecting ozone, which then changes the temperature and wind patterns in the stratosphere. Then a modulation of the planetary wave energy propagating from the troposphere is expected (review of Hood, 2004). This in turn alters tropospheric planetary wave energy, wind temperature advection, and other climate phenomena. This concept, of a downward propagation of the direct solar UV-induced effects, from the upper stratosphere to the lower stratosphere, and first proposed by Hines (1974), was recently reactivated by various authors (Haigh, 1994; Kodera, 1995; Hood et al., 1993). These mechanisms were first simulated using unrealistic solar forcing (Kodera, 1991; Balachandra and Rind, 1995) and subsequently with a new generation of Global Climate Models, some including interactive ozone chemistry (Haigh, 1996; Shindell et al., 1999). They have produced responses even thought comparable with observations with smaller amplitudes and different spatial patterns (Labitzke et al., 2002). Some numerical models extend only to the mid-stratosphere, which may restrict their ability to properly simulate planetary wave propagation and thus their effects.

Despite indirect effects that may induce some surface or tropospheric climate features, the direct effects expected in the upper stratosphere have surprisingly never been fully described on the time-scale of the 11-year solar cycle. Some studies have suggested that at least some of the observed variability attributed to solar variability, actually reflects other influences such as volcanoes (Salby and Shea, 1991; Solomon et al., 1996) or internal climate oscillations (Mehta and Delworth, 1995; Halliwell, 1998). Data sets covering the middle atmosphere during several 11-year solar cycles are not numerous and measurements may suffer from temporal discontinuities. The US rocketsonde data sets, above tropical and subtropical regions, has been recently investigated (Dunkerton et al., 1998; Keckhut and Kodera, 1999). The solar response in the upper stratosphere has been clearly identified in ozone datasets, firstly on the 27-day timescale (Hood, 1986) and more recently on the 11-year timescale (McCormack and Hood, 1996). Temperature observations for the upper stratosphere look more complex as some responses sometime even appear with opposite signs. Long-term temperature trend studies performed during the last decade in the middle atmosphere in the framework of the stratospheric processes and their role in climate (SPARC) project have lead to considerable improvements in data analyses and have allowed to investigate inter-annual variability (Ramaswamy et al., 2001). Reliable long data sets and their potential discontinuities are now better documented.

This work does not intend to be a reanalysis of all data sets neither be a review of all solar responses obtained during the last decade. In this study, we have analyzed several temperature datasets covering the middle atmosphere that have been selected for their specific quality of temporal continuity that have been checked and reviewed (Ramaswamy et al., 2001), to be able to assess a coherent solar signature. This work uses a single multivariable regression analysis. In the first section, the data and the analysis used are presented. The temperature changes associated with solar changes as a function of altitude and latitude and season are presented in the second section. In the third section, common features are reported. Then comparisons with models are performed. This is followed by a discussion and conclusions, and recommendations for future observation and programs.

2. Data sets and data analyses

One of the largest temperature dataset has been provided by routine historical meteorological rocket launches, archived from 1969 up to the 1990s.