SOLAR SPECTRAL VARIABILITY AND THE EARTH'S ATMOSPHERE

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The thermal structure and composition of the Earth's atmosphere depend fundamentally on the radiation coming from the Sun. At ultraviolet (UV) wavelengths solar radiation dissociates atmospheric molecules, initiating chains of chemical reactions and providing the major source of heating for the middle atmosphere, while radiation at visible and near-infrared wavelengths reaches and warms the lower atmosphere and the Earth's surface. In the stratosphere the decomposition of molecular oxygen into its component atoms, by UV radiation at wavelengths less than 242 nm, initiates the processes which create ozone, while radiation at longer wavelengths controls its removal. Thus the ratio of spectral solar irradiance (SSI) at shorter to longer wavelengths largely determines the concentration of ozone and other constituents, as well as temperature. It follows that changes in that ratio have the potential to significantly affect the composition and thermal structure of the middle atmosphere. Furthermore, it has been demonstrated that solar UV heating of the stratosphere can influence the regional climate of the lower atmosphere and surface through dynamical coupling processes (Simpson et al. 2009) and also that it may be a useful indicator in seasonal and decadal weather prediction(Ineson et al. 2011). In addition, the spectral composition of solar radiation determines the radiative energy entering the lower atmosphere, driving climate and potentially contributing to climate change. Finally, longer wavelength UV radiation penetrates to the Earth's surface where it can be biologically damaging. Thus the spectral composition of solar radiation is fundamental to atmospheric composition, climate and life on Earth.

Measurements of SSI at UV wavelengths have been obtained by several space-borne instruments since the mid-1970s and estimates of SSI variability are also available from semi-empirical models based on indicators of solar activity such as sunspot area, e.g. the SATIRE model (Fligge and Solanki 2000; Krivova et al. 2003) or the NRLSSI model (Lean et al. 2005). Before the launch of the SORCE mission (Rottman et al. 2005) in 2003, it was generally accepted that changes over the "11-year" solar cycle (SC) between 115 and 150 nm were around 10-60%, decreasing to below 5% at 220 nm and below 1% at 300 nm e.g.(Krivova et al. 2006; Lean 2000). At wavelengths > 300nm the uncertainty exceeded the cycle changes (Floyd et al. 2003).

The SORCE mission, with two instruments observing UV wavelengths, shows larger cycle trends (e.g. (Ermolli et al. 2013; Harder et al. 2006)). Changes observed by its SOLSTICE instrument (observing between 115 and 310 nm, although with little confidence at $\lambda > 290$nm) remain in reasonable agreement with older missions for $\lambda < 180$ nm but both SOLSTICE and SIM instruments (observing between 200 and 2400 nm) instruments suggest larger SC variations at $\lambda >$ 200 nm (Ball et al. 2011). The very large variations given by early versions of SIM have been suggested to be due to incomplete degradation corrections (DeLand and Cebula 2012; Lean and Deland 2012; Morrill et al. 2014) but, even if the SORCE results are at the lower limit of their range, modelling studies have shown that they imply very different estimates for SC variability in ozone and other constituents (Ball et al. 2014a; Swartz et al. 2012; Wang et al. 2013).

The SORCE satellite is currently operating on reduced power, with declining frequency and quality of output, and its remaining lifetime is unknown. The successor mission, the Total Solar Irradiance Sensor, is not expected to launch until mid-2017. With no other measurements across the solar spectrum having the calibration required for the investigation of multi-year trends there will not only be a gap in the SSI record but also it will be many years before there are enough new data to confirm, or otherwise, the SORCE measurements.

On the timescales of a few hundred years relevant to recent climate change there are no observational data on solar radiation. The models used to reconstruct variations of SSI on these long timescales e.g. (Krivova et al. 2010; Wang et al. 2005) use spectral information gained from knowledge of SSI changes over the SC to scale values over centuries. This provides another critically important motivation for the acquisition of accurate SSI data.

Here we present a new approach in which Bayesian inference is used to deduce wavelength-dependent changes in solar irradiance from measurements of atmospheric properties such as ozone concentration and temperature. The basis of this approach is a demonstration that changes in response to variations in the solar spectrum of the vertical profile of ozone in the equatorial middle atmosphere can be accurately represented by a linear combination of its response in a limited number of spectral bands. This having been established we use Bayesian inference to obtain the probability distributions of solar cycle changes in each of the bands, constraining the ranges by invoking prior information. Typical constraints are that shorter wavelengths have larger relative solar cycle changes than longer ones, or values restricted to the (wide) range that encompasses the cycle changes that have been observed and modelled.

We discuss our results to date, their limitations and potential for future development. We show that, given measurement uncertainties in both ozone and SSI datasets, it is not currently possible to distinguish between observed or modelled SSI datasets using available estimates of ozone change profiles. We suggest, however, that the technique has the potential, using wider datasets and other well-informed constraints, to provide better understanding of both variations in SSI and the atmospheric response (Ball et al. 2014b).

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