Solar Spectral Irradiance calculated with the SATIRE model: daily values from 1610 to 2010

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Daily total and spectral solar irradiance data are provided here for the period 1610/01/01 to 2010/12/24 in the spectral range 116-160000 nm. These data have been reconstructed using the Spectral And Total Irradiance REconstruction (SATIRE) model [Fligge et al., 2000, Krivova et al., 2003, Wenzler et al., 2006, Ball et al., 2012], whose underlying assumption is that all solar irradiance variations from days to centuries result from the evolution of the solar photospheric magnetic field. For the dataset provided here, SATIRE is constructed using two versions of the model [Krivova et al., 2011]: SATIRE-S over the Satellite era (from 1974 to present) and SATIRE-T over the Telescope era (i.e. since 1610). The hybrid dataset presented here switches to SATIRE-S on 1974/08/23. The daily values after this date can be considered much more accurate than prior to it.

Both models quantify the disk coverage, or filling factor, of the magnetic features responsible for changes in solar irradiance (sunspot umbra, sunspot penumbra, faculae and network) using observational data (see below). The wavelength- and disc-position-dependent intensity contrasts (i.e. brightness compared to the surrounding field-free quiet Sun) of each component were derived from the appropriate solar model atmospheres. By identifying the contribution of each component and disk-integrating their contribution, spectral irradiance changes of the Sun can be reconstructed.

The brightness spectra for umbra, penumbra and quiet sun as a function of disc position were derived from model atmospheres by Unruh et al. [1999] using the ATLAS9 code [Kurucz, 1993] assuming temperatures of 4600, 5400 and 5777 K, respectively. The facular intensities were derived from the FAL-P model atmosphere [Fontenla et al., 1993]. The model atmospheres assume local thermodynamic equilibrium in the solar atmosphere which can lead to errors in the irradiance variability in strong lines, particularly in the region below 300 nm. To improve the accuracy in these regions, observations from the UARS/SUSIM instrument [Brueckner et al., 1993] are used to extrapolate the model below 270 nm [Krivova et al., 2006]. The spectral resolution is wavelength-dependent: 1 nm sampling below 290 nm, 2 nm between 290 and 1000 nm, 5 nm between 1000 and 1600 nm, 10 nm between 1600 and 3200 nm, 20 nm between 3200 and 6400 nm, 40 nm between 6400 and 10020 nm and 20000 nm spacing up to 160000 nm.

SATIRE-S uses full-disk continuum intensity image and magnetogram observations to identify the locations of each of the components [Wenzler et al., 2006, Ball et al. 2012]. These are available from 1974. There is one free parameter, B_{sat}, which is used to convert observed magnetic flux in magnetograms to the facular filling factor, i.e. how much of each pixel is filled by faculae. The value of B_{sat} is determined by comparing the reconstructed Total Solar Irradiance (TSI) with SORCE/TIM TSI observations over the period 2003/02/23 to 2009/10/31.

SATIRE-T [Krivova et al., 2007; 2010] uses the sunspot group number, R_g [Hoyt & Schatten, 1993], as the primary input to compute the filling factors of all the components. R_g is an indicator of the state of photospheric magnetic activity due to the assumed relationship between sunspots and the internal solar dynamo which drives surface magnetic activity. Magnetic features are divided into active (AR) and ephemeral regions (ER) and open magnetic flux (OMF) that is dragged out into the heliosphere by the solar wind. The magnetic flux emergence, evolution and decay of AR, ER and OMF are described by a coarse physical model by Solanki et al. [2000; 2002] and Vieira & Solanki [2010]. AR and ER emergence rates are calculated using R_g and sunspot cycle length and amplitude. The overlapping activity cycles of the ER and the long decay time of the OMF lead to a built-up of the background magnetic flux, whose amount varies in time and causes secular changes in the solar surface magnetic flux, and thus irradiance.

The assumption in SATIRE-T that the emergence rate of faculae and ERs is related to the evolution of the sunspots is considered a reasonable assumption on timescales of months and longer only. Therefore, the contribution to irradiance from the network and faculae cannot be resolved on a daily basis, and the true shape of the solar cycle and the exact time of solar minima cannot be determined to a high precision. Even though daily data are provided using SATIRE-T, it is not considered accurate on timescales shorter than a few months.

Observational constraints are used to fix the free parameters of the model using: TSI measurements since 1974, UV irradiance at 220-240 nm from UARS/SUSIM since 1992, Ly-alpha irradiance observations and proxy reconstructions since 1947 by Woods et al. [2000], measurements of the solar total magnetic flux since 1968, and the 20th century solar open magnetic flux empirically reconstructed from the aa-index (see Krivova et al., 2010 for more details). The model output agrees well with the activity of cosmogenic isotope ^{44}Ti measured in meteorites [Vieira et al., 2011]. The agreement of SATIRE-T with the empirically reconstructed open flux and the ^{44}Ti activity in meteorites is particularly important for constraining the long-term (secular) change in the irradiance. The estimated change in TSI since the Maunder minimum from SATIRE-T is approximately 1.25 Wm-2, or 0.09% [Krivova et al., 2007; 2010].

The hybrid dataset is essentially constructed by normalising the wavelength-integrated flux of SATIRE-S to SORCE/TIM at the 2008 solar minimum, i.e. to 1360.8 Wm^{-2}. SATIRE-T is then normalised to SATIRE-S so that the integrated flux agrees for the six-month mean centred on the cycle 21/22 minimum in 1986. Then, the mean absolute value of flux at each wavelength in SATIRE-T is shifted to that of SATIRE-S for the same six-month period around the cycle 21/22 minimum so that the long-term relative variation is in good agreement for all wavelengths.

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