Reference solar spectrum for earth observation

S. Dewitte[1]*, S. Nevens[1]

Abstract
For the calibration or intercalibration of earth observing satellite instruments, a reference solar spectrum is needed. We review the spectral solar irradiance variability and conclude that is mostly below 1 % for wavelenths above 285 micron. We extend the well known measured Atlas-3 reference spectrum to wavelengths beyond 2400 nm using the synthetic Kurucz spectrum, and normalise the spectrum to the Total Solar Irradiance. The estimated absolute accuracy of the spectrum is 3 %.

Keywords
Solar Spectral Irradiance — Earth Observation

[1] *Royal Meteorological Insitute of Belgium*
***Corresponding author**: steven.dewitte@meteo.be

Contents

Introduction

The goal of the Global Space-based Inter-calibration System (GSICS) created under the umbrella of the World Meteorological Organisation (WMO) is to promote the intercalibration of worldwide space-based observations for climate monitoring, weather forecasting, and environmental applications [1]. In this context, for the intercalibration of space instruments that observe reflected solar radiation from the earth in VISible (VIS) or Near-InfraRed (NIR) wavelengths, a reference spectrum for the incoming solar radiation is needed. In section 1, we will review Spectral Solar Irradiance (SSI) variability and derive an upper limit of the variability to be expected in the spectral range of concern for GSICS purposes. In section 2, we will derive the currently best available absolute SSI.

1. Relative Spectral Solar Irradiance variability

1.1 Total Solar Irradiance

Total Solar Irradiance (TSI) is monitored continuously from space since 1978. Figure 1 shows the TSI values from 1984 to the present following [2].

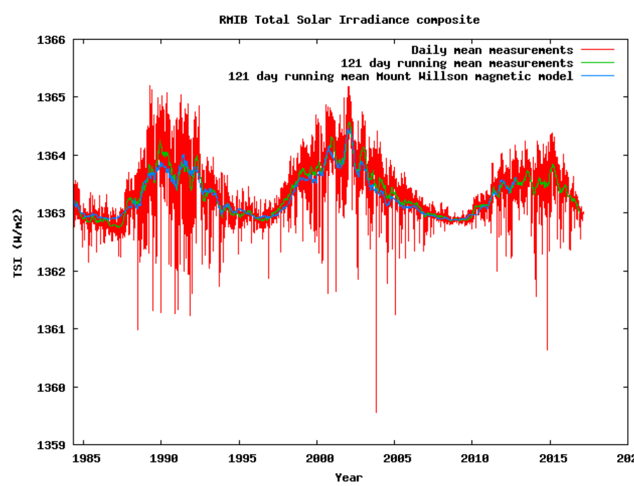

Figure 1. Total Solar Irradiance composite. Red curve: daily mean values.

The TSI measurements can be well reproduced by a regression model which includes two components:

1. Long term increase of the TSI in phase with the 11 year solar cycle. This increase is due to the facular brightening effect.
2. Short term decrease of the TSI visible as downward spikes due to the passage of dark sunspots. This is the sunspot darkening effect.

1.2 Physical origins of solar irradiance variations

The physical origins of solar irradiance variations are illustrated below with images of the Atmospheric Imaging Assembly (AIA) on the Solar Dynamics Observatory (SDO) satellite [3].

Figure 2 show a false color image of the sun taken at the UltraViolet (UV) wavelength of 170 nm during 23 October 2014. At this time the largest sunspots of the currently ongoing solar cycle 25 occured.

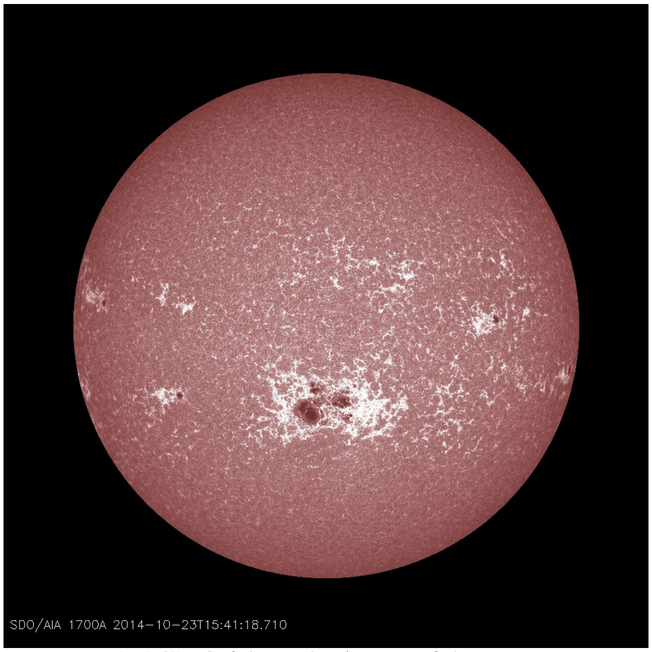

Figure 2. AIA/SDO false color image of the sun at UV wavelength of 170 nm for 23 October 2014.

The sunspots are visible as the two dark circular spots surrounded by white colors below the center of the image. Sunspots are caracterised by a strong magnetic field and have a relative short lifetime. When they decay, they disintegrate into zones of intermediate magnetic field strengths which look bright in the UV, these are the facula. The facula can be recognised as the white zones in the image.

Figure 3 show an RGB image of the sun taken at the Extreme UltraViolet (EUV) wavelengths of 9.4, 33.5 and 19.3 nm during 23 October 2014. At these wavelengths the sun doesn't look as a simple disc, one can also see the structure of the magnetic field lines emanating from the solar disc. However, the solar EUV radiation is totally absorbed high in the earth's atmsophere and hence is not relevant for the GSICS purposes.

1.3 Spectral Solar Irradiance

A recent assesment of the SSI variability based on the available space observations was made in [4]. As the TSI variability, the VIS and NIR SSI variability is adequately described by facular brightening and sunspot darkening. For the UV wavelengths only the facular brightening is relevant.

In figure 4 the relative solar cycle variability according to the so-called NRLSSI2 model of [5] is shown as a function of wavelength.

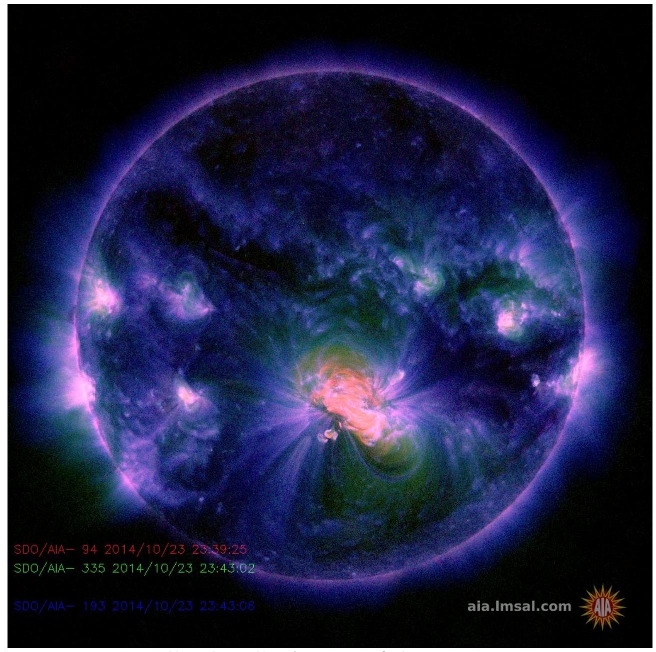

Figure 3. AIA/SDO RGB image of the sun at EUV wavelengths of 9.4, 33.5 and 19.3 nm for 23 October 2014.

We can conlude that for wavelengths higher than 285 nm, the SSI solar cycle variability is not larger than 1 %.

2. Absolute Spectral Solar Irradiance

2.1 Atlas-3 and Kurucz reference spectra

The Solspec instrument [6] is specifically designed for the absolute measurement of the solar spectrum. It consists of three separate monochromators for the UV, VIS and NIR regions. Pre-flight it is calibrated with absolute calibration sources, and in-flight its ageing is monitored by on-board calibration sources. Two solspec reference spectra have been published in [7], with a stated absolute accuracy of 3 %. A widely used Solspec based reference spectrum is the Atlas-3 spectrum, which corresponds to the high solar activity during November 1994, see also figure 1. The Atlas-3 spectrum covers the spectral range from 0.1 to 2400 nm.

The Kurucz synthetic spectrum covering the wavelength range from 250 to 10000 nm was calculated by [8].

Figure 5 shows the Atlas-3 and Kurucz reference spectra.

2.2 Homogenisation

Figure 6 shows the ratio between the Kurucz and the Atlas-3 spectrum in the Solspec NIR range of 870 to 2400 nm.

It can be seen that the ratio varies mostly within 0.97 +/- 0.03 and that the ratio is close to 0.97 at 2400 nm. Therefore we divide the Kurucz spectrum by 0.97 beyond 2400 nm to extend the Atlas-3 spectrum. The resulting homogenised Atlas-3/Kurucz spectrum is shown in figure 7.

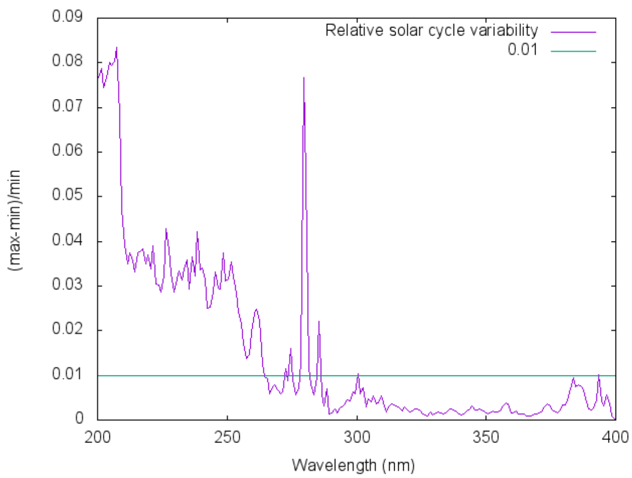

Figure 4. Relative solar cycle variability of the SSI according to the NRLSSI2 model.

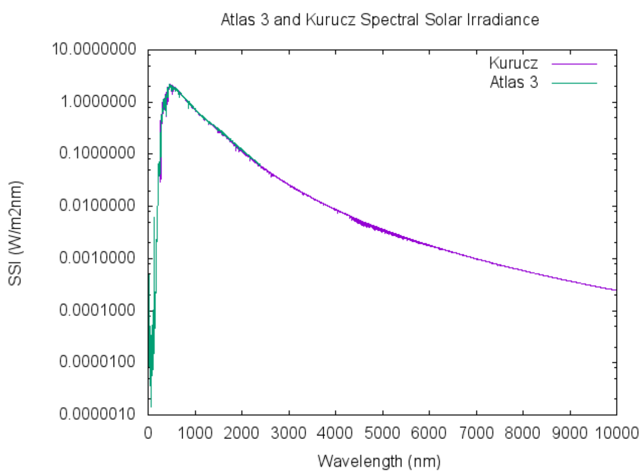

Figure 5. Green curve: Atlas-3 spectrum covering the range from 0.1 nm up to 2400 nm. Purple curve: Kurucz spectrum covering the range from 250 to 10000 nm.

2.3 TSI normalisation

The integral of the Atlas-3/Kurucz spectrum obtained in section 2.2 is 1382.3 W/m^2. This is to be compared with the TSI value of 1363.3 W/m^2 during the Atlas-3 period of November 1994. The difference is 1.4 %, which is compatible with the stated absolute accuracy of 3 % of the Atlas-3 spectrum.

Figure 8 shows our best estimate of the complete solar spectrum. It is obtained as the homogenised Atlas-3/Kurucz spectrum rescaled to the TSI.

3. Conclusions

SSI varies systematically during the 11 year solar cycle. For all wavelengths except the EUV, the SSI solar cycle variation can be described adequately by a combination of long term facular brightening and short term sunspot darkening.

For wavelengths higher then 285 nm the SSI solar cycle variability is not larger than 1 %.

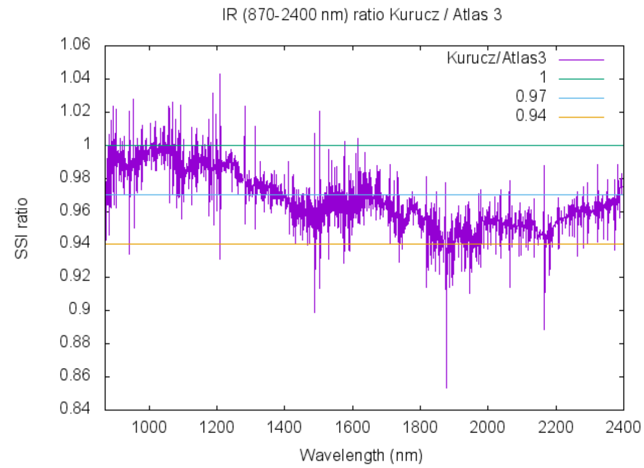

Figure 6. Purple curve: Ratio between Kurucz and Atlas-3 spectrum in IR range from 870 to 2400 nm.

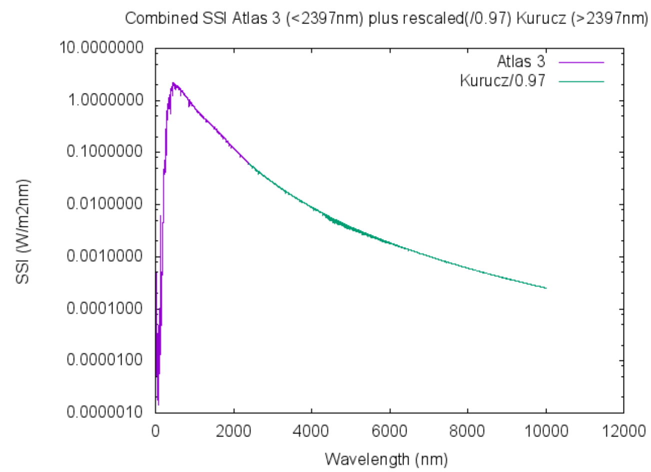

Figure 7. Green curve: Atlas-3 spectrum. Purple curve: Kurucz spectrum rescaled to Atlas-3.

We have extended the widely used Atlas-3 spectrum covering wavelengths up to 2400 nm with a stated absolute accuracy of 3 % with the synthetic Kurucz spectrum up to wavelengths of 10000 nm.

We normalise our spectrum by rescaling it to a TSI value of 1363.3 W/m^2. This rescaling is compatible with the stated absolute accuracy.

Acknowledgments

The Solspec instruments were developed in a collaboration between the French research institute Latmos (formerly Service d'Aeronomie) and the Belgian Institute for Space Aeronomy.

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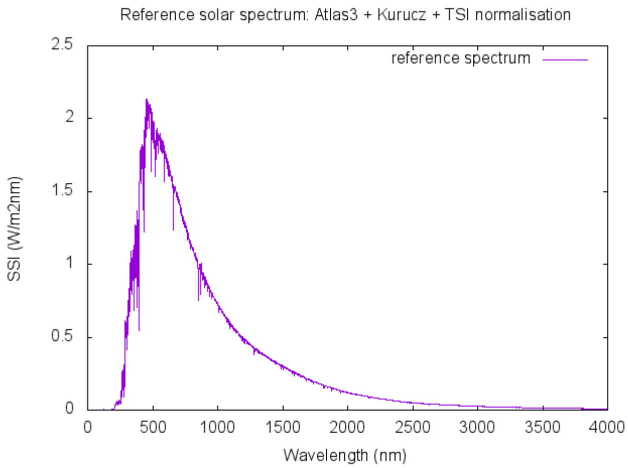

Figure 8. Total spectrum rescaled to Total Solar Irradiance.

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