

Reconstruction of Total Solar Irradiance since the Maunder Minimum

L. Balmaceda

Max-Planck-Institut für Sonnensystemforschung

S.S. Solanki (MPS – U. T. Braunschweig)

N. Krivova (MPS)



ABSTRACT

One principal parameter characterizing solar variability is the so-called “Solar Irradiance” which is the total amount of solar energy registered per second per unit angle at 1 AU. This quantity has been measured since 1979 and the most striking result is that it varies by about 0.1% over the course of the solar cycle. This variation has two main contributions: sunspots, causing darkening of the Sun and faculae, leading to its brightening. The observations, however, do not provide any information on longer-term secular trends in the irradiance needed to assess the magnitude of the solar impact on the Earth’s climate, and models are required to set tighter constraints on this quantity. The aim of this research is to understand the physical mechanisms responsible for solar brightness variations and to reconstruct solar irradiance back to the pre-satellite period by carrying out quantitative modelling of the irradiance variations and of the surface magnetic flux. In a first step the magnetic flux and irradiance since the Maunder Minimum (a time of extended lack of sunspots which coincided with the little ice age) have been reconstructed using a simple but consistent physical model.

Magnetic Flux Reconstruction (Solanki et al., 2000, 2002)

This model describes in a simple way the general behavior of the solar surface magnetic flux with time. It consists of a set of three differential equations which describe the time evolution of each kind of magnetic flux:

$$\frac{d\phi_{act}}{dt} = \varepsilon_{act} - \frac{\phi_{act}}{\tau_{act}} - \frac{\phi_{act}}{\tau_{ta}}$$

$$\frac{d\phi_{eph}}{dt} = \varepsilon_{eph} - \frac{\phi_{eph}}{\tau_{eph}} - \frac{\phi_{eph}}{\tau_{te}}$$

$$\frac{d\phi_{open}}{dt} = \frac{\phi_{act}}{\tau_{ta}} + \frac{\phi_{eph}}{\tau_{te}} - \frac{\phi_{open}}{\tau_{open}}$$

ϕ_{act} : closed flux emerging in active regions
 ϕ_{eph} : magnetic flux in ephemeral regions
 ϕ_{open} : open magnetic flux
 The total flux is given by the sum of these contributions.
 ε_{act} and ε_{eph} are the flux emergence rates of active regions and ephemeral regions respectively
 τ_{act} , τ_{eph} and τ_{open} are the corresponding decay timescales.
 τ_{ta} and τ_{te} are the timescales for flux transfer from active and ephemeral regions to the open flux.

Total Irradiance Reconstruction

SATIRE model: Fligge et al (2000), Krivova et al. (2003), Wenzler et al. (2004)

$$F_{tot}(\lambda, t) = \alpha_u(t)F_u(\lambda) + \alpha_p(t)F_p(\lambda) + \alpha_f(t)F_f(\lambda) + \alpha_n(t)F_n(\lambda) + (1 - \alpha_u(t) - \alpha_p(t) - \alpha_f(t) - \alpha_n(t))F_q(\lambda)$$

- q : quiet Sun
- u : sunspot umbra
- p : sunspot penumbra
- n : network
- f : faculae

- $\alpha(t)_{u,p,n,f}$: the fraction of the solar surface that is covered by each component:
- $F(\lambda)_{q,u,p,f}$: fluxes calculated using the ATLAS9 code of Kurucz (1992) from plane-parallel model atmospheres of each component (Unruh et al., 1999).

- $\alpha(t)_{u,p}$ are extracted from available records of sunspot areas
- $\alpha(t)_{n,f}$ are calculated from the reconstructed magnetic flux of the Sun

Results I – Magnetic Flux

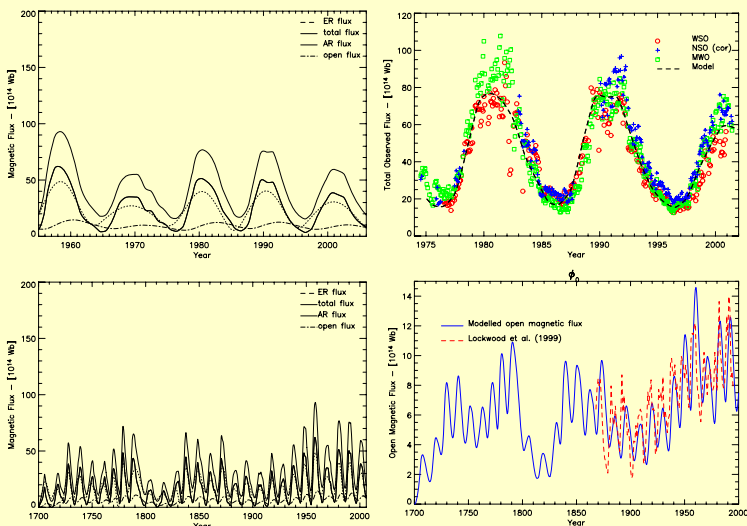


Fig. 1: Left panels: modelled solar magnetic flux. Right – upper panel: comparison between observed values of total magnetic flux and the model. Right – bottom panel: Evolution of open magnetic flux since the end of the Maunder Minimum. The reconstruction from Lockwood et al. (1999) based on geomagnetic data is shown here for comparison.

Results II – Solar Irradiance

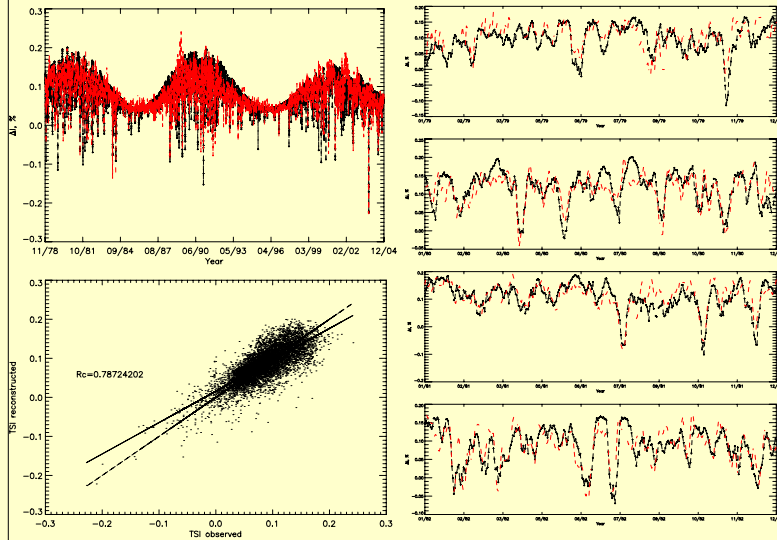


Fig. 2 Left: Comparison of reconstructed total solar irradiance - TSI (black) with observations (red) (top panel). Bottom panel: reconstructed TSI vs. measured TSI. The dashed line represents the expected values, the solid line represents the regression. Right: enlargement of shorter time intervals.

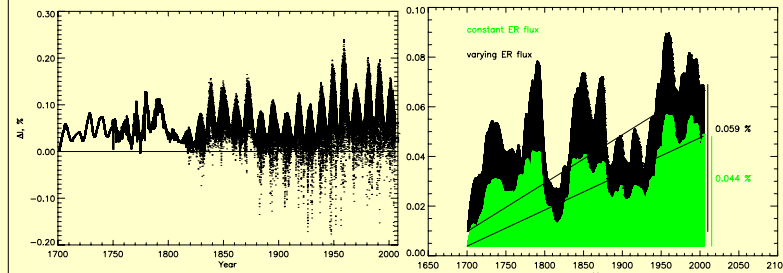


Fig. 3 Left: Long-term TSI reconstruction since the end of the Maunder Minimum, for the case of varying ephemeral regions flux. Right: 11-yr running-means of the reconstructed total solar irradiance for 2 different approaches of the model.

Summary

- Total solar irradiance was reconstructed back to 1700 by assuming that the variations are caused by the evolving magnetic flux at the solar surface. A five-component model is implemented to describe contributions to the irradiance variations.

- The reconstructed magnetic flux reproduces the available data since 1975 and also agrees with the reconstruction based on geomagnetic aa-index since 1868 by Lockwood et al., 1999.

- Reconstructed irradiance is in good agreement with the measurements obtained from satellites since 1978.

- This first physics-based reconstruction of TSI back to the Maunder Minimum suggests an increase of about 0.80 W/m² since 1700, with the lower limit being about 0.60 W/m². This value is much lower than in previous works that may have important implications on Sun-climate relations.