Response of solar irradiance to sunspot-area variations

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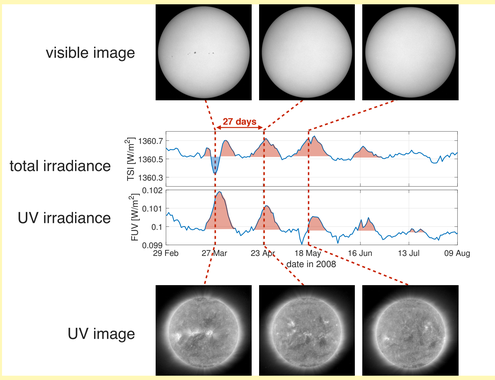
1. Motivation

Our objective

Can long-term solar variability (months to years) be adequately reconstructed by models that describe short-term variations only (days to months), using solar proxies ?

The sunspot area (a proxy for magnetic flux emergence) is widely used to model solar irradiance, as it is associated with a deficit of irradiance (in the visible) or an excess (in the UV), or a mix of the two.



A sunspot that lasted for one solar rotation only and its impact of the total solar irradiance and on the UV.

The red area expresses the excess of irradiance produced by that single spot.

2. What we know

Preminger and Walton [2005-2007] have shown that the spectral irradiance does **not** respond instantaneously to magnetic flux emergence. The delayed response can be adequately described by its linear impulse response.

What is the impulse response ?

In linear system theory, the impulse response h(t) describes the reaction of a system (here the change in total irradiance TSI or spectral irradiance SSI) to a trigger (here the daily sunspot area DSA) by means of a convolution

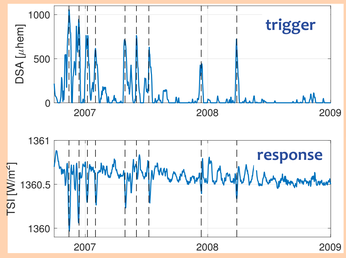
$$SSI(t) = DSA(t) * h(t)$$

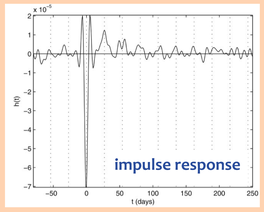
In Fourier space

$$SSI(\omega) = DSA(\omega) \times H(\omega)$$

where the transfer function $H(\omega)$ is the Fourier transform of h(t).

The impulse response h(t) tells us by how much the SSI on average varies after a sunspot that would last for one day and then disappear.





Impulse response of the total solar irradiance (TSI) to the daily sunspot area (DSA) [Preminger and Walton, GRL, 2005]

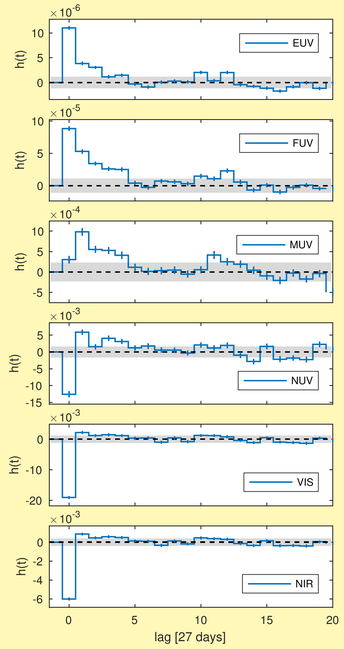
3. An improved impulse response model

Problem: The model by Preminger & Walton mixes variations caused by solar rotation and by true sunspot evolution. We want the latter only.

Solution: We separate the two effects two by taking a snapshot once every solar rotation (every 27 days)

- *Advantage* : We eliminate the effect of solar rotation-induced variations
- *Disadvantage* : We cannot resolve variations occurring on timescales < 27 days

We estimate the impulse response h(t) by using SSI observations from TIMED/SEE, SORCE/SOLSTICE, and SORCE/SIM (2003-2015).



EUV band (10-120 nm): facular brightening persists for 3-5 rotations

FUV band (122-200 nm): facular brightening persists for 3-5 rotations

MUV band (200-300 nm): initial competition between darkening and brightening

NUV band (300-400 nm): initial darkening, followed by facular brightening.

VIS band (400-600 nm): initial darkening, followed by weak facular brightening

NIR band (600-2000 nm): initial darkening, followed by weak facular brightening

Impulse response h(t) for different spectral bands, without the effect of solar rotation. Grey band = level of significance (±1σ).

6. Conclusions

- We provide an improved model of the response of the SSI to changes in sunspot area. This model avoids spurious variations that are caused by solar rotation.
- The impulse response clearly reveals the competition between darkening/brightening at each wavelength.
- SSI variations cannot be described solely in terms of a response to sunspot area. An additional contribution is required. This has two important consequences:
  - We can establish an energy budget for short-term variations only (a few months), not for the solar cycle.
  - Irradiance models that rely on sunspot numbers or on sunspot area only may not describe long-term variations adequately

For more details, read [Dudok de Wit et al., ApJ 853 (2018) 197]

4. Can this model describe long-term variations ?

Problem : Past studies relied on a classical transfer function model

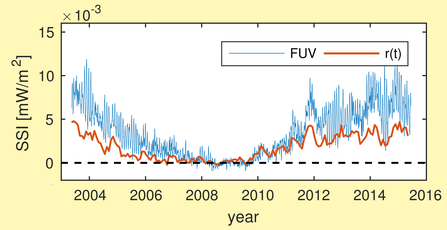
$$SSI(\omega) = DSA(\omega) \times H(\omega)$$

Solution : We find that the response of the irradiance requires an additional (« residual ») contribution $R(\omega)$ that varies independently of the sunspot area

$$SSI(\omega) = DSA(\omega) \times H(\omega) + R(\omega)$$

Consequence : SSI variations cannot be described solely in terms of their response to the DSA. An additional term $R(\omega)$ is needed, which evolves differently. Therefore, models that rely on the DSA only (or on the sunspot number) to describe SSI variations may fail at longer timescales.

The physical origin of this additional term $R(\omega)$ is currently being investigated.

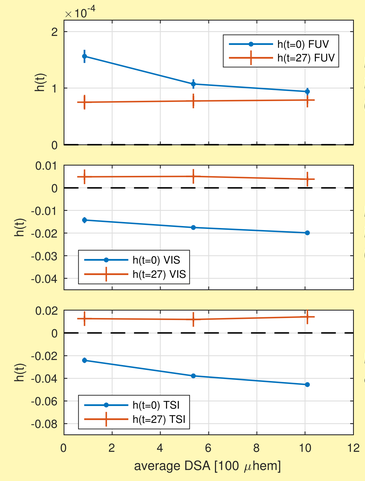


Contribution of the residual term r(t) to the variability of the SSI in the FUV band (122-200 nm)

5. Nonlinear response of the irradiance

The magnitude of the impulse response is weakly solar-cycle dependent

- Initial brightening during flux emergence is weaker at solar maximum = lower ratio of facular area to sunspot area. This was expected [Foukal, 1993] but we now quantify it.
- Facular brightening (once the sunspot has vanished) does **not** depend on the level of solar activity



Impulse response in the FUV (122-200 nm)

Impulse response in the visible (400-700 nm)

Impulse response of the TSI

Impulse response h(t) during flux emergence (t=0) and one solar rotation later (t=27 days), when the sunspot has vanished.

Three levels of solar activity are shown: low, intermediate and high. Larger DSA corresponds to higher solar-activity levels

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