SATIRE-S

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Overview

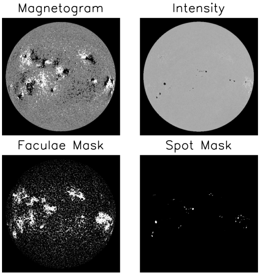


Figure 1 : Identifying faculae & sunspots by the magnetogram signal & intensity.

SATIRE-S (Yeo et al. 2014 & references therein)

Assume Solar surface covered by quiet Sun (Q), faculae (F) & sunspots (S).

Derive Q/F/S surface cover from full-disc intensity images & magnetograms.

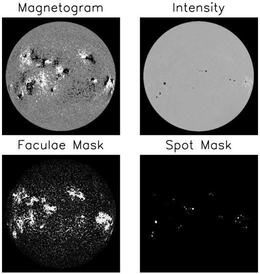
Calculate Q/F/S intensity spectra from model atmospheres & LTE radiative transfer.

Output Solar spectrum = Q cover*Q spectrum
+ F cover*F spectrum
+ S cover*S spectrum

Free parameters? One free parameter.

Other semi-empirical models (c.f. Ermolli et al. 2013)

- SRPM (Fontenla et al.); OAR (Penza/Ermolli et al.); Shapiro et al.
- At present, SATIRE-S is the only semi-empirical model to provide TSI and UV to IR SSI extending the period of satellite observation (i.e., 1978 onwards) at daily cadence.



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How is SATIRE-S affected by

- instrument degradation,
- the LTE assumption,
- and the free parameter?

How is SATIRE-S affected by instrument degradation?

Background

SATIRE-S solar irradiance variability modulated by variation in sunspot/facular surface cover, which is derived from full-disc intensity images & magnetograms.

Question

Is the min.-to-min. decline in SATIRE-S from instrument degradation?

- Faculae identified by the magnetogram signal.
- Magnetographs record profile of a magnetically-sensitive line at each disc position.
- Magnetogram signal determined from line shape changes, rendering it robust to instrument degradation (analogy: Mg II index).
- Magnetographs can become noiser over their lifetimes. This was accounted for. Even if we did not do so, it will lead to an upward drift in modelled variability, not down.
- Secular decline in SATIRE-S TSI/SSI is not from instrument degradation.

How is SATIRE-S affected by the LTE assumption?

Background

SATIRE-S TSI/SSI is given by the surface cover-weighted sum of the intensity spectra of solar surface features, calculated assuming LTE.

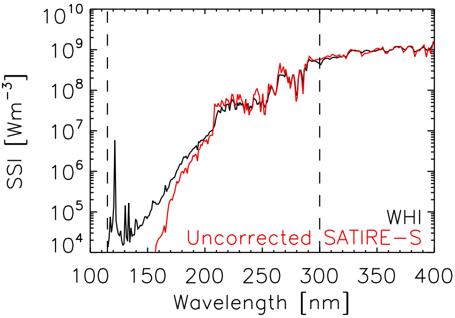

Figure 2 : Measured (Woods et al. 2008 WHI reference, black) and modelled (SATIRE-S, red) solar UV spectrum.

Situation

LTE assumption breaks down in the upper layers of the solar atmosphere, where strong lines in the UV are formed, with the result that modelled spectra diverges from observation below 300 nm.

How is SATIRE-S affected by the LTE assumption?

What we found...

Below 300 nm, shape of modelled spectra wrong but absolute variability agrees with observation down to 160 nm (i.e., over 160-300nm, only the shape of modelled spectra needs to be fixed).

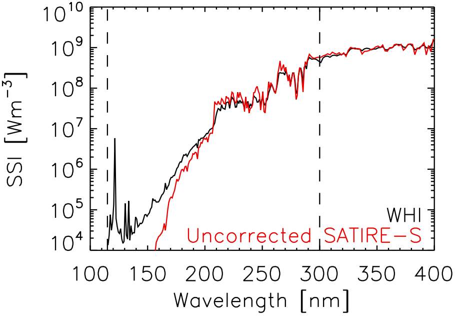

Figure 2 : Measured (Woods et al. 2008 WHI reference, black) and modelled (SATIRE-S, red) solar UV spectrum.

So what did we do?

180-300nm: Put modelled SSI variability on the WHI reference spectrum.

115-180nm: Calculate SSI at each wavelength from 164-174nm integrated SSI. SORCE/SOLSTICE record taken as reference.

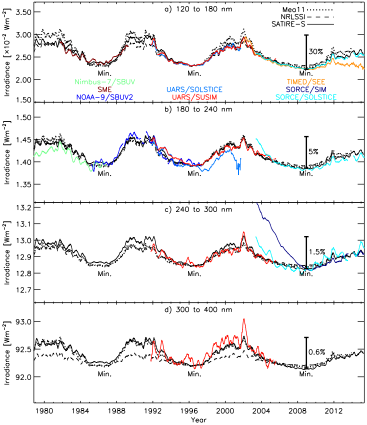

Figure 3 : Measured (colour) and modelled (black) SSI. SSI records where solar cycle variability is obscured by long-term uncertainty excluded (c.f. Yeo et al. 2015).

180-300nm: Put modelled SSI variability on the WHI reference spectrum.

- Modelled variability is not modified in any way. Only the shape of the spectrum is made to fit observation.
- Not unique to SATIRE-S. Proxy models put modelled SSI variability onto a reference spectrum over their entire wavelength range.

115-180nm: Calculate SSI at each wavelength from 164-174nm integrated SSI. SORCE/SOLSTICE record taken as reference.

- This is where SSI records are least afflicted by long-term uncertainty and therefore most reliable for such a step.
- We merely adopted the absolute scale of the SORCE/SOLSTICE record. How SSI changes with time is from the model alone.

How is SATIRE-S affected by the LTE assumption?

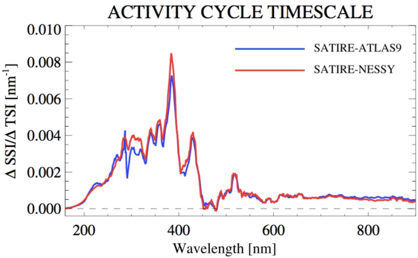

Figure 4 : Solar irradiance variability from SATIRE-S with LTE (blue) and NLTE (red) radiative transfer.

- Future updates to SATIRE-S will feature NLTE radiative transfer.
- SATIRE-S UV SSI variability (>180nm) from LTE and NLTE similar.

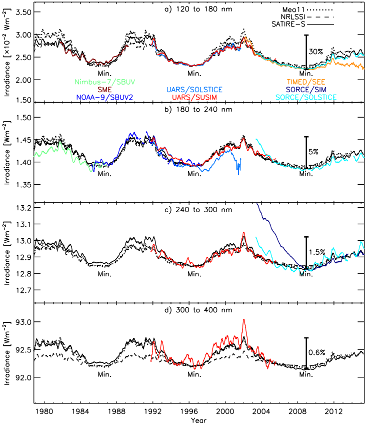

Figure 3 : Measured (colour) and modelled (black) SSI. SSI records where solar cycle variability is obscured by long-term uncertainty excluded (c.f. Yeo et al. 2015).

Summary

- LTE assumption mitigated by certain empirical corrections to 115-300nm SSI.
- Above 180nm, SATIRE-S absolute SSI variability is not adjusted to observations in any way. Agreement between modelled and measured SSI variability is not manufactured. Also, ultimately, whether we execute LTE or NLTE radiative transfer makes no appreciable difference.

How is SATIRE-S affected by the free parameter?

Details...

- Faculae largely unresolved in available magnetograms.
- For a given resolution element, faculae filling factor scales with magnetic field strength.
- Empirical relationship linking faculae filling factor to magnetic field strength with one free parameter assumed.
- Free parameter fixed by comparing model output to measured TSI (PMO6V record).
- See Fligge et al. 2000 & Yeo et al. 2014.

What is important to ask...

- How does modelled variability depend on the value of the free parameter?
- Why did we fix it using the PMO6V record?

How is SATIRE-S affected by the free parameter?

Question

- How does modelled variability depend on the value of the free parameter?
- Why did we fix it using the PMO6V record?

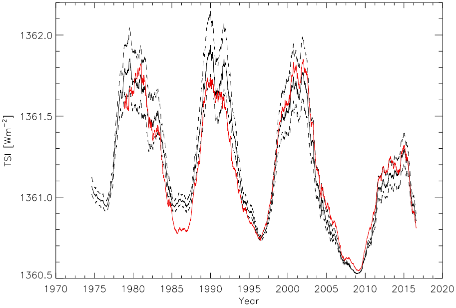

Figure 5 : Black solid: SATIRE-S TSI (free parameter optimized to PMO6V). Black dashed: SATIRE-S TSI if free parameter is optimized to ACRIM3 and DIARAD (IRMB calibration) instead. Red: PMOD TSI composite.

Answer

- The free parameter modulates the amplitude of facular brightening.
- Tuning the free parameter changes the amplitude but not the shape of the overall trend.

Analogy: NRLTSI

- TSI $= K_1$*MgII $+ K_2$*PSI $+ K_3$
- Free parameter in SATIRE-S serves the same purpose as K_1 in NRLTSI.

How is SATIRE-S affected by the free parameter?

Question

- How does modelled variability depend on the value of the free parameter?
- Why did we fix it using the PMO6V record?

Answer

- The free parameter modulates the amplitude of facular brightening.
- Tuning the free parameter changes the amplitude but not the shape of the overall trend.
- To fix the free parameter ideally we must compare modelled TSI to a TSI record where the overall trend has a similar shape. PMO6V, more than ACRIM3, DIARAD or TIM, met this criteria. Secular decline in SATIRE-S not from how we fixed the free parameter.

Taking stock...

We examined how is SATIRE-S affected by

- instrument degradation,
- the LTE assumption,
- and the free parameter.

Key points

- Secular decline in SATIRE-S TSI/SSI not from instrument degradation or how we fixed the free parameter.
- Agreement between SATIRE-S and measured UV SSI (>180nm) not from corrections for the LTE assumption.
- Secular decline and UV SSI variability (>180nm) emerged independently of observations.

Rest of this talk

Secular trend. (Divergence between SATIRE-S and NRLSSI UV SSI variability; c.f. EMPIRE.)

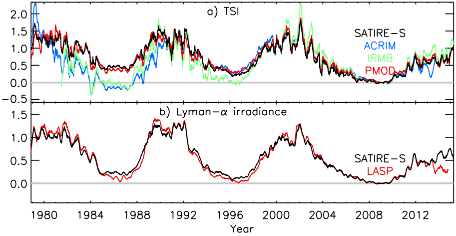

Figure 6 : TSI and Lyman-α irradiance (stretched between 0 and 1 at 2008 minimum and 2000 maximum).

SATIRE-S min.-to-min. decline.

- Consistent with PMOD composite.
- Consistent with Lyman-α irradiance.

Secular trend

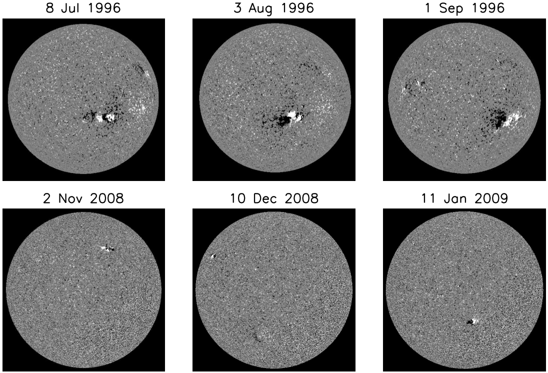

Figure 7 : Magnetogram from most active day each calendar month about the 1996 & 2008 minima.

Where does the min.-to-min. decline in SATIRE-S come from?

The Sun is visibly & indisputably more active at the 1996 minimum than at the 2008 minimum.

Can we see a min.-to-min. decline anywhere else?

- Sunspot number and SFO facular index.
- TSI model based on sunspot area.

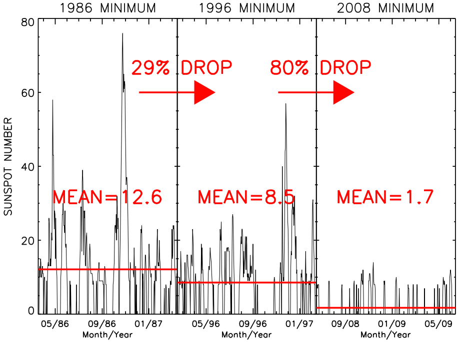

Figure 8 : Sunspot number about the 1986, 1996 and 2008 minima.

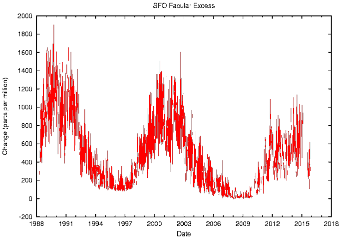

Figure 9 : SFO facular excess index (http://www.csun.edu/sfo/).

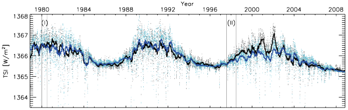

Figure 10 : TSI reconstruction based on sunspot area (SATIRE-T2, blue) and PMOD composite (black) (Dasi-Epuig et al. 2014).

Secular trend

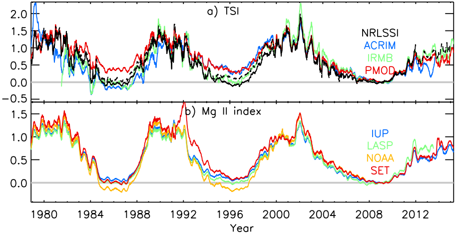

Figure 11 : TSI and Mg II index (stretched between 0 and 1 at 2008 minimum and 2000 maximum).

NRLTSI (solid) & NRLTSI2 (dash)

- NRLTSI used the LASP Mg II index composite.
- NRLTSI2 used the IUP Mg II index composite.
- Available Mg II index composites, differing by the satellite records used, exhibit vastly different secular trends.
- Can we attach any meaning to the secular trend (or lack thereof) in proxy models based on the Mg II index?

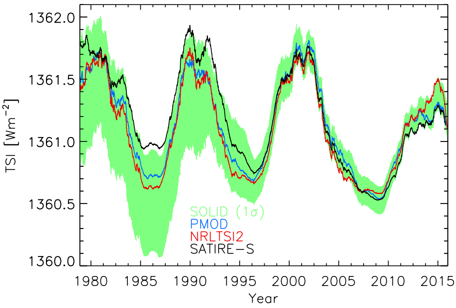

Figure 12 : SOLID, PMOD, NRLTSI2 and SATIRE-S TSI.

SOLID (Dudok de Witt et al. 2017)

- Statistics-driven TSI composite.
- Corrections for known instrumental artefacts still to be incorporated.
- Uncertainty reflects not the method but the limitations of the TSI records.
- The gross uncertainty indicates TSI records are too few and too unstable to give us a reasonable fix on the secular trend in TSI.

Summary

- SATIRE-S exhibits min.-to-min. decline over the 1986, 1996 and 2008 minima.
- Secular decline not from instrument degradation or free parameter.
- Multiple, independent data sets exhibit min.-to-min. decline as well.
- Magnetogram evidence that the Sun is more active at the 1996 minima than the 2008 minima is irrefutable.
- This does not mean the secular decline in SATIRE-S is correct but it should tell us that this is a scenario we cannot dismiss.
- It is doubtful that we can say anything meaningful about the secular trend in solar irradiance from available Mg II index (and therefore, proxy models based on them) and TSI records/composites.