IRRADIANCE RECONSTRUCTIONS

(WITH SATIRE, though not only)

N. Krivova

W. Ball, M. Dasi, S.K. Solanki, Y.C. Unruh

also thanks to Sasha Shapiro
WHERE TO GO?

Satellite era:
- TSI – secular change and minimum 2008?
- SSI – SORCE vs. previous measurements and models

Past irradiance changes:
- Magnitude of the secular change
BASIC ASSUMPTION OF MODELS

All irradiance changes (TSI and SSI) are due to the evolution of the surface magnetic structures.
Irradiance = Quiet Sun brightness (here QS means absolutely quiet, no MF)

+ darkening due to sunspots
+ brightening due to faculae and the network:

\[ S_{tot}(t) = S_{QS} + \Delta S_s(t) + \Delta S_f(t) \]
PROXY MODELS

Earlier simpler models (e.g., NRLSSI) combine sunspots darkening (e.g., PSI) with brightening due to faculae and the network (Facular Proxy, e.g. Mg index, Ca II, F10.7) using linear or multiple regressions:

\[ S_{tot}(t) = S_{QS} + \kappa_1 PSI(t) + \kappa_2 FP(t) \]
PROXY MODELS

PROBLEM:
SSI

SOLUTION:

(1) Use reference spectra: e.g.,
- ATLAS spectra *(Thuillier et al. 2012)*,
- SCIAMACHY *(Pagaran et al. 2009)*
- or combined – observed+theoretical *(NRLSSI - Lean 2000)*

(2) Scale variability using proxies
1. Surface area coverage (filling factors) and possibly positions \textit{(as a function of time)}
1. Surface area coverage (filling factors) and possibly positions (as a function of time)

2. Brightness of each component (as a function of wavelengths and disc position)
1. Surface area coverage (filling factors) and possibly positions \textit{(as a function of time)}

Can be:

disc-integrated, e.g. sunspot number, area, plage area, Mg index, Ca II, F10.7, $^{10}\text{Be}$, $^{14}\text{C}$.... \textit{(SATIRE-T \& SATIRE-H – i.e. before 1974, Shapiro et al. 2012)}

or spatially resolved maps of the full disc, e.g. magnetograms, continuum images, Ca II images etc. \textit{(SATIRE-S, Fontenla et al. 2009, 2011)}
SEMI-EMPIRICAL MODELS

1. Surface area coverage (filling factors) and possibly positions (as a function of time)

Can be:

disc-integrated, e.g. sunspot number, area, plage area, Mg index, Ca II, F10.7, $^{10}$Be, $^{14}$C....

(SATIRE-T & SATIRE-H – i.e. before 1974, Shapiro et al. 2012)

Do not need to be come from observations directly: e.g.
- Surface Flux Transport simulations (Wang et al. 2005, Dasi 2012)
- Monte Carlo simulations (Crouch et al. 2008, Bolduc et al. 2012)

or spatially resolved maps of the full disc, e.g. magnetograms, continuum images, Ca II images etc. (SATIRE-S, Fontenla et al. 2009, 2011)
2. Brightness of each component (as a function of wavelengths and disc position)

Calculated from semi-empirical models of the solar atmosphere (e.g., Kurucz models, Fontenla et al. 1999, 2009, 2011; Unruh et al. 1999; Shapiro et al. 2010) using spectral synthesis codes (e.g., SRPM, COSI or ATLAS9, the latter uses LTE)
Unruh et al. (1999); Fligge et al. (2000); Krivova et al. (2003); Wenzler et al. (2004, 2005, 2006); Ball et al. (2011, 2012)

SATIRE-S
(Spectral And Total Irradiance Reconstructions for the Satellite era)

Magnetograms and continuum images

Semi-empirical model atmospheres

Distribution of features on the solar surface

Brightness of features

changes with time

depends on the wavelength and the position on the solar disc (time independent!)

IRRADIANCE
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SATIRE-S VS. MEASUREMENTS: TSI 1978 - 2010

Unc-ty following Fröhlich (2009)

PMOD

SATIRE (range)

Rc = 0.96

Ball et al, 2012
IRRADIANCE MODELS: TSI
NRLSSI and SATIRE vs. PMOD

Ball et al. 2012
SATIRE-S VS. MEASUREMENTS:
TSI 1978 - 2010

Ball et al, 2012
LONGITUDINAL VARIATIONS OF TSI: TSI 1978 - 2010

OAR (Ermolli et al. 2011) and Monte-Carlo models (Bolduc et al. 2012) also suggest a weaker, if any, decrease between 1996 and 2008 than in PMOD

Ball et al, 2012
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SPECTRAL IRRADIANCE MODELS:
NRLSSI and SATIRE

*Lean 2000; Lean et al. 2005*
*Ball et al., in prep.*
SPECTRAL IRRADIANCE MODELS: NRLSSI and SATIRE

Both models use SSI measurements
SATIRE uses model atmospheres
Both use model atmospheres
Solanki & Unruh 1998
Unruh et al. 1999

Lean 2000; Lean et al. 2005
Ball et al., in prep.
SPECTRAL IRRADIANCE MODELS: NRLSSI and SATIRE

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SATIRE uses model atmospheres

Ball et al., in prep.

Lean 2000; Lean et al. 2005
SPECTRAL IRRADIANCE:
SATIRE

Krivova et al. 2006

- Relative contribution to TSI, %
- Irrad. change
- ≈60%
- ≈8%

λ, nm

50 nm 100 nm 500 nm
SPECTRAL IRRADIANCE: SATIRE

The contribution of the UV is factor of ~2 higher than in NRLSSI.

Supported by SUSIM data (Krivova et al. 2006; Morrill et al. 2011)

Krivova et al. 2006
NOW COMES SORCE/SIM...

T SI: 1360.55 Wm$^{-2}$

Integrated SIM: 1324.25 Wm$^{-2}$

b) 201-300 nm: 14.92 Wm$^{-2}$

c) 300-400 nm: 92.54 Wm$^{-2}$

d) 400-691 nm: 521.40 Wm$^{-2}$

Irradiance change from Ref. Day, W/m$^2$

Harder et al, 2009
NOW COMES SORCE/SIM...

Irradiance change from Ref. Day, W/m²

Significantly stronger change at 200-400 nm

... Compensated by the oppositely directly change in the VIS

Harder et al, 2009
SSI VARIABILITY 2003-2009

NB: SCIAMACHY values must be corrected by roughly 25% (sum over all wavel. is only 76%)
SPECTRAL IRRADIANCE: DATA & MODELS
NRLSSI, SATIRE, COSI, SUSIM, UARS/SOLSTICE, SIM, SORCE/SOLSTICE

Unruh et al, 2012;
Ball et al. 2012;
Shapiro et al. 2011
SPECTRAL IRRADIANCE: DATA & MODELS
NRLSSI, SATIRE, COSI, SUSIM, SIM, SORCE/SOLSTICE

Unruh et al, 2012;
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Ball et al. 2011

Int-SIM (200–1630nm)
Int-SATIRE (200–1630nm)
TIM / SORCE
How reliable they are?

In principle they can be tuned to match SIM variability qualitatively *(Fontenla et al. 2011 vs. Fontenla et al. 2009)*. But this is still not enough though causes problems with TSI *(SRPM – Fontenla et al. 2011 vs. OAR – Ermolli et al. 2012)*.
**Satellite era:**
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SOLAR MAGNETIC FLUX
Secular change

11.11.11  SDO/HMI  16.05.10
SOLAR MAGNETIC FLUX
Secular change

SOLAR CYCLE & EPHEMERAL REGIONS

(K. Harvey, 1994)
MODEL OF THE ER MAGNETIC FLUX

- Take sunspot number as a `proxy´
- ER start earlier
- Open flux decays slowly
- More extended cycles

Solanki et al. (2002)
SATIRE-T
(Spectral And Total Irradiance Reconstructions for the Telescope era)

$\Delta S_{\text{MM}} \approx 1.25 \text{W/m}^2$

Krivova et al. (2007, 2010)
SATIRE-T
(Spectral And Total Irradiance Reconstructions for the Telescope era)

$\Delta S_{MM} \sim 1.25 \text{W/m}^2$

Krivova et al. (2007, 2010)
Since 1878

**SATIRE-T: A NEW APPROACH**

**Spatial resolution of the magnetic features** -> improved days to months time scales.

**ER flux is considered separately.**

**SATIRE-S + Surface Flux Transport:**

- Sunspot positions and areas as input to an SFT model *(Jiang et al. 2010)* -> simulated full-disc magnetograms, describing active regions and open flux.
- Simulated magnetograms are used in combination with semi-empirical spectra to calculate TSI and SSI
Active Region flux and Open Flux included in the SFTM
ER considered separately as in the model of Solanki et al. (2002).

**SATIRE-T: A NEW APPROACH**

Model of ER magnetic flux

- **Surface Flux Transport Models**
  - (Wang et al. 2005; Jiang et al. 2011)
  - Slow decay of OF: YES
  - Overlap of ER: NO
SATIRE-T: SATIRE-S + SFT + ER FLUX

Since 1878

Dasi-Espuig (2012, PhD Th.)
Dasi-Espuig et al. (in prep.)
TSI SINCE THE MAUNDER MINIMUM

Wang et al. (2005)

Krivova et al. (2007), Rg- and Rz- based

Dasi-Espuig et al. (2012), in prep.
TSI SINCE THE MAUNDE MINIMUM

Krivova et al. (2007), Rg- and Rz- based
Wang et al. (2005)

Dasi-Espuig et al. (2012), in prep.

Crouch et al. (2008)
TSI SINCE THE MAUNDE MINIMUM

Krivova et al. (2007), Rg- and Rz- based
Wang et al. (2005)

Dasi-Espuig et al. (2012), in prep.

Crouch et al. (2008)
Schrijver et al. (2011)

Shapiro et al. (2011)
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Dasi-Espuig et al. (2012), in prep.
Crouch et al. (2008)
Schrijver et al. (2011)
Shapiro et al. (2011)

Judge et al. (2012)
SUMMARY

- TSI exhibits a slight decrease to essentially no change over the last 3 cycles

- SSI:
  - Good agreement between SATIRE SSI, other models and measurements on rotational time scales (see also DeLand & Cebula 2012)
  - Good agreement between SATIRE SSI and UARS measurements on longer time scales
  - There are some quantitative differences between models (e.g., factor of ~2-3 for variability at 250-400 nm)
  - Difference between SORCE/SIM results and models is qualitative and is not understood

- Secular change:
  - Most models converge to roughly 0.1% since MM, but uncertainty range remains huge (between 0.2 and 6 [3] W/m²)