The NOAA/NCEI Solar Irradiance Climate Data Record

Recent Advances and Comparisons with Independent Datasets

O. Coddington, J. Lean, P. Pilewskie, M. Snow, G. Kopp, E. Richard, M. DeLand, S. Marchenko, and T. Baranyi

Outline

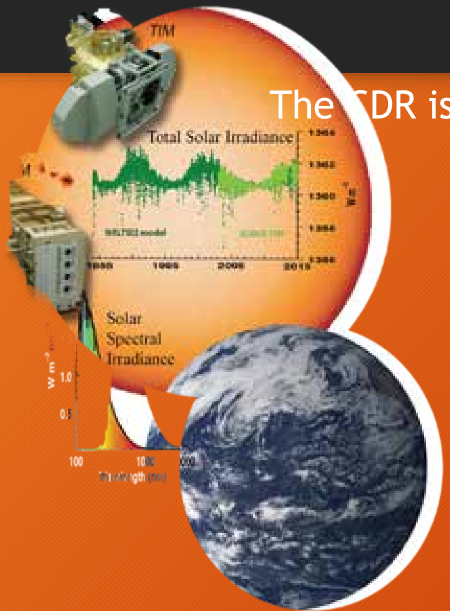
- NOAA Solar Irradiance CDR Overview
- Model and Measurement Comparisons
- New historical solar irradiance estimate
- New parameterizations of sunspots and faculae
- New version of NRL models
- Concluding Statements

Satellite Observations:
SORCE - SOLSTICE, SIM and TIM
OMI

Solar Irradiance Models:
EMPIRE
SATIRE
NRLTSI2 & NRLSSI2 (the NOAA Solar Irradiance Climate Data Record)

*see my poster for additional results, including comparisons with the SOLID SSI composite.

NOAA Solar Irradiance CDR Overview



The CDR is observation-based.

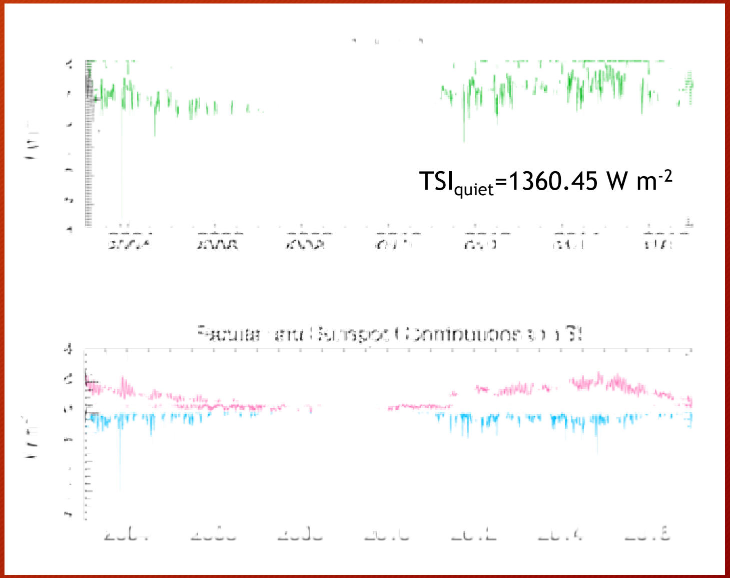
SORCE,
TCTE,
TSIS1,
TSIS2…

Observation-based models extend the direct observations in time and spectrum on a fixed wavelength grid.

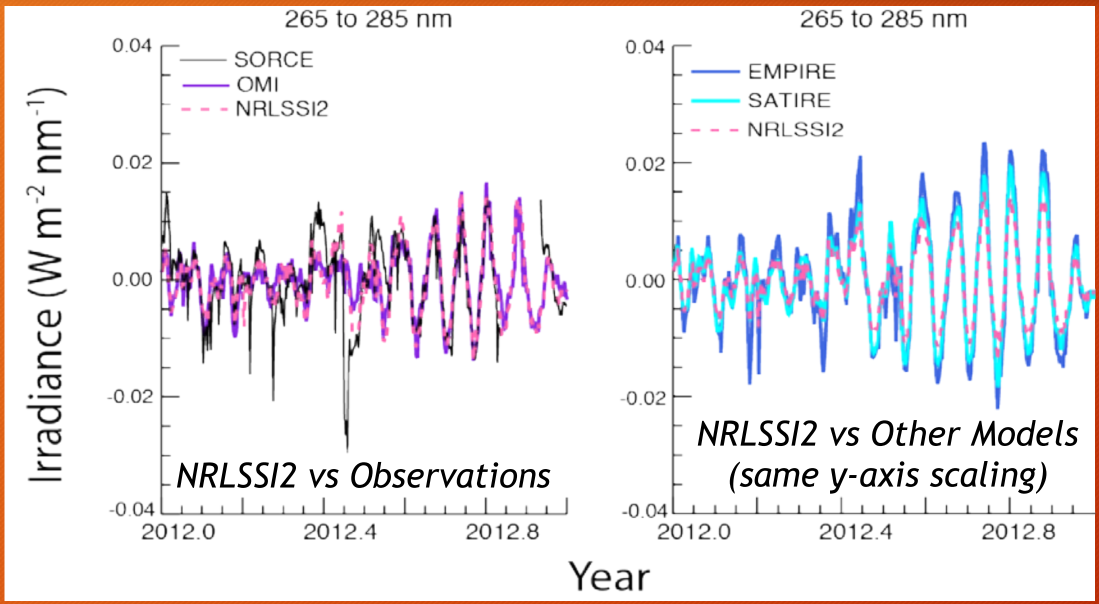
Model Formulation: The magnitude of the irradiance changes from Quiet Sun conditions are determined from ***multiple linear regression*** analysis of observations and proxy records of magnetic variability (sunspots & faculae).

$$\Delta TSI(t) = \Delta TSI_{faculae}(t) + \Delta TSI_{spot}(t)$$

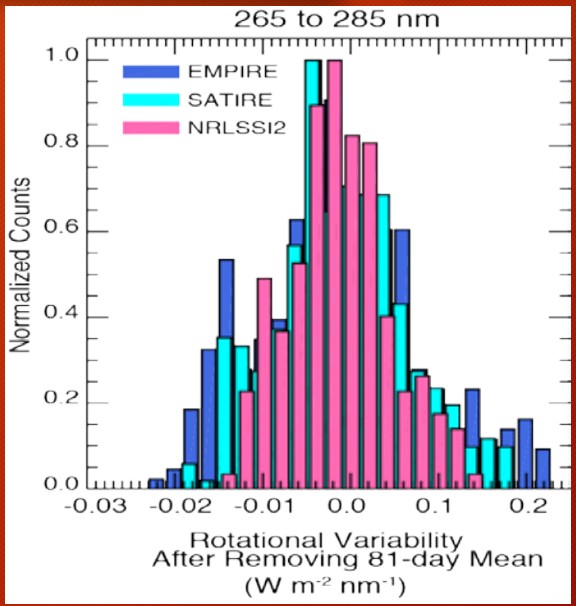
$$\Delta SSI(\lambda,t) = \Delta SSI_{faculae}(\lambda,t) + \Delta SSI_{spot}(\lambda,t)$$



Solar Rotation: Model & Measurement Comparisons



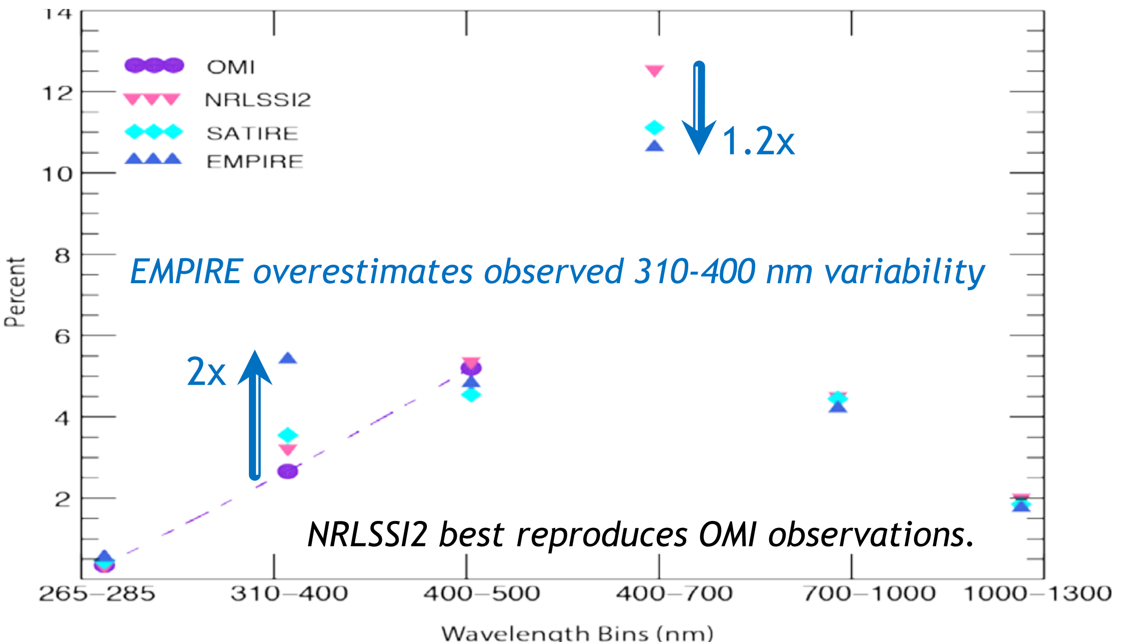
Detrended Data for 2012: All Days
(i.e. removal of 81-day running mean)



EMPIRE has greater spread → greater rotational modulation

Solar Rotation Comparisons (cont)

% Std. Dev. Of Absolute Rotational Variability after removing 81-day mean

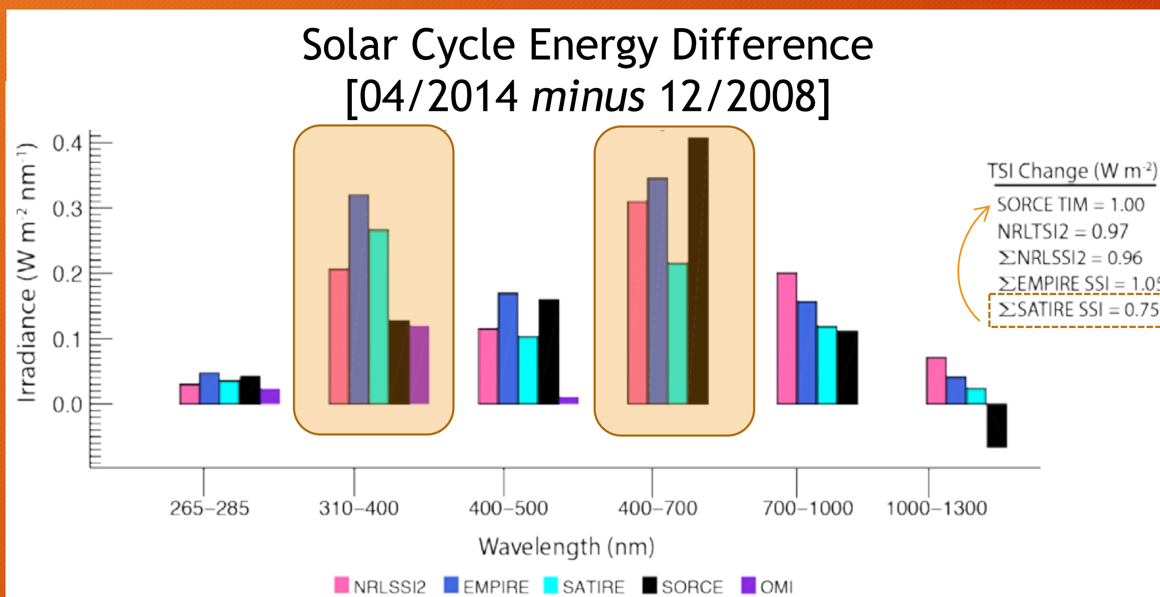


Detrended Data 2012-2015: All Days

TSI Dataset	Percent Standard Deviation of absolute rotational variability after removing 81 day mean (%)
SORCE TIM TSI	26.2
∑ NRLSSI2	24.6
∑ EMPIRE SSI	24.9
∑ SATIRE SSI	22.1

All models integrate to SORCE TIM TSI and approx. conserve TSI rotational modulation.

Solar Cycle: Model & Measurement Comparisons



OMI solar cycle variability will be discussed further in S. Marchenko's talk.

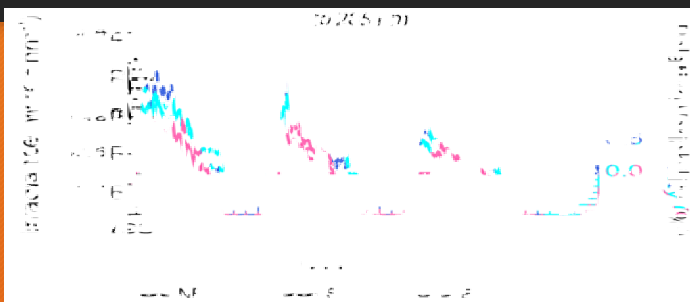
The general characteristics of solar rotational variability and solar cycle variability are similar for NRLSSI2 and SATIRE but differ for EMPIRE.

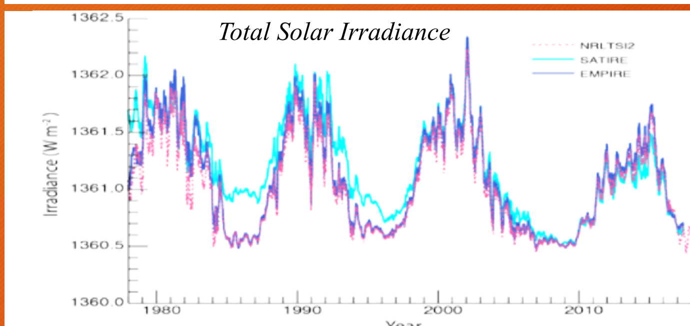
solar rotation (previous slide):
SATIRE>NRL in UV, SATIRE<NRL in Vis
EMPIRE>NRL in UV, EMPIRE<NRL in Vis

solar cycle:
SATIRE>NRL in UV, SATIRE<NRL in Vis
EMPIRE>NRL in UV, EMPIRE>NRL in Vis

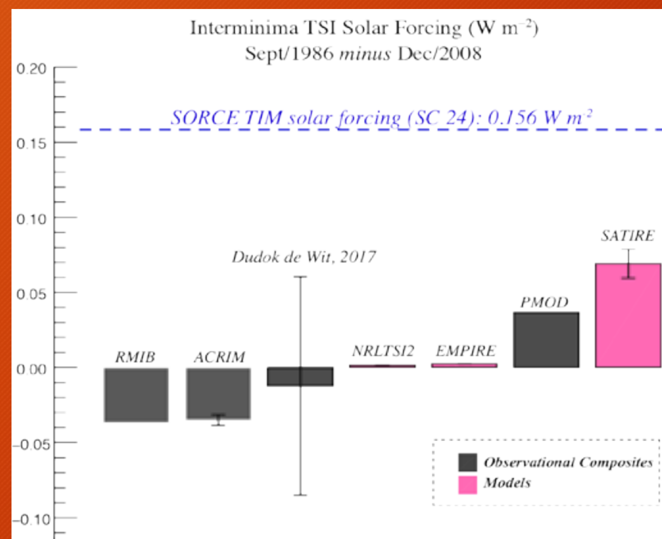
SATIRE does not reproduce the SORCE/TIM TSI energy change in SC 24.

Space Era: Model & Measurement Comparisons





Interminima TSI Solar Forcing



However, proxy models (EMPIRE and NRLSSI2) correlate better with composite TSI record than SATIRE [Dudok de Wit, 2017].

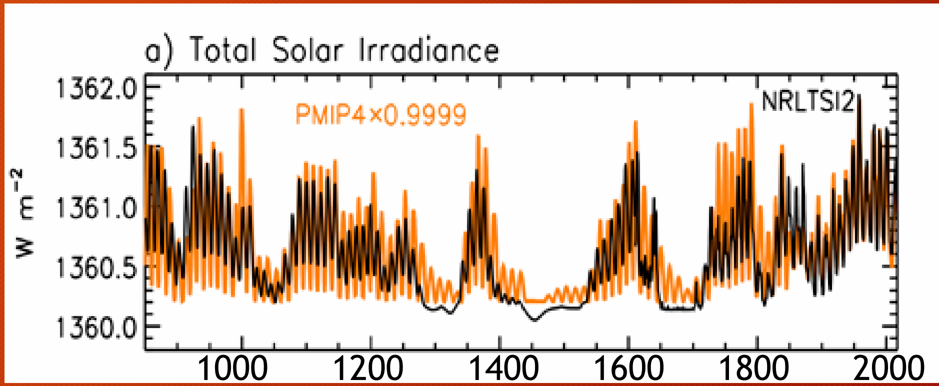
Irradiance models have increasing differences in magnitude of variability and in baseline irradiance values. TSI observational record can't be used to resolve disagreement *based on magnitude of uncertainties* [Dudok de Wit, 2017].

Historical Solar Irradiance Estimates

A new TSI and SSI solar irradiance estimate from 850 to 1610 is consistent with the NOAA CDR from 1610 to 2016.

It uses cosmogenic indices to parameterize the NRLTSI2 and NRLSSI2 irradiance variability.

The new estimate correlates better with cosmogenic indices than PMIP4 solar irradiances.

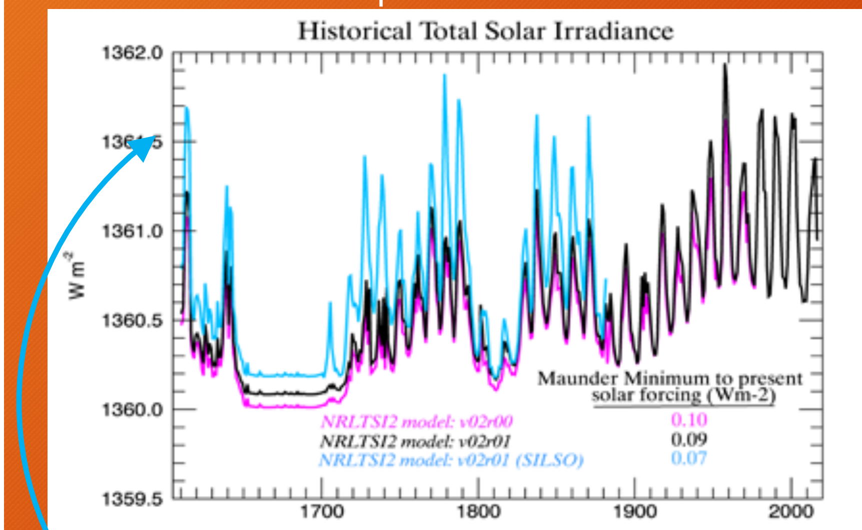


J. Lean, Estimating Solar Irradiance Since 850 CE, *Earth & Space Sci.*, in press.

Sunspot Blocking Parameterizations

What assumptions in sunspot blocking were the NRL2 models sensitive to?

The scaling factor to reconcile USAF/SOON and RGO sunspot area databases



v02r01 and v02r00 differ < 1978.

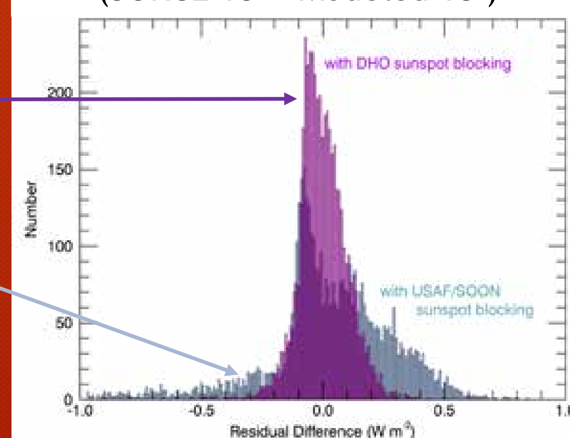
Combined effect of scaling and using SILSO SSN < 1882.

Different sunspot area and location databases.

With PSI from Debrecen Heliophysical Observatory

With PSI from USAF SOON stations

Histogram of Residual Difference (SORCE TSI – Modeled TSI)

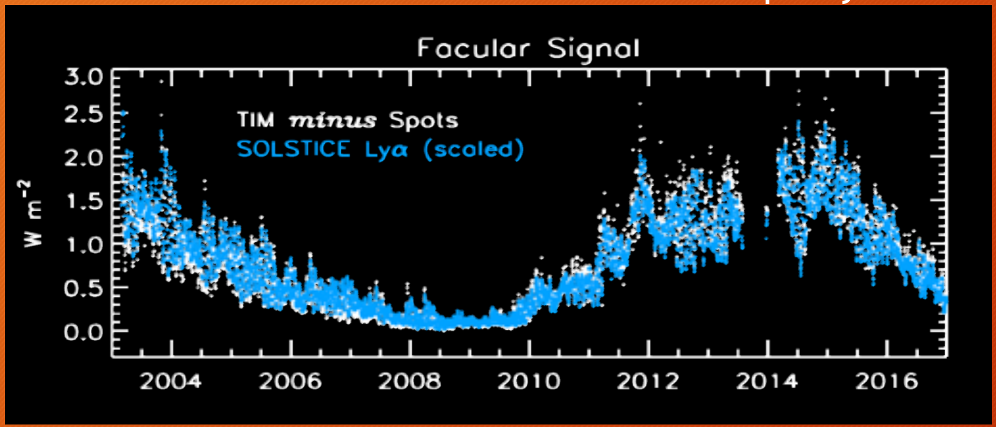


A New Facular Proxy

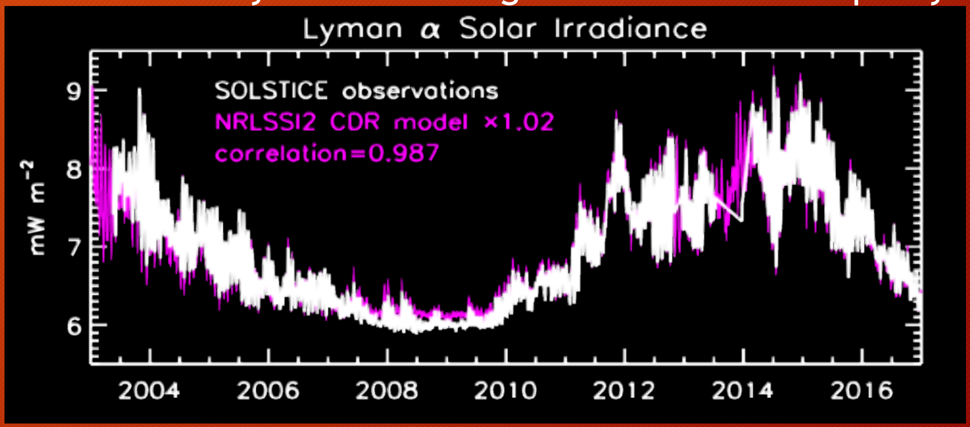
Credited to Judith Lean

"TIM Bolometric Faculae" = $\Delta TSI_{faculae}(t) = \Delta TSI(t) - \Delta TSI_{spot}(t)$

With TIM bolometric faculae as facular proxy



With University of Bremen Mg II index as facular proxy

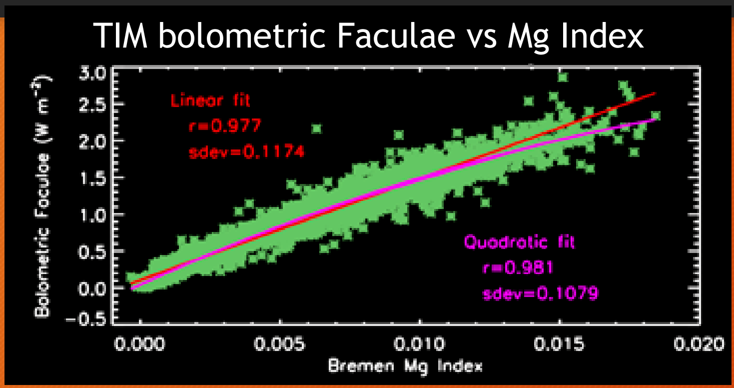


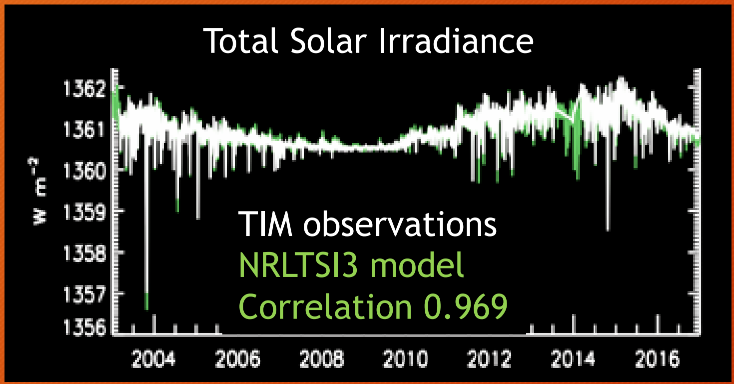
Using the TIM bolometric faculae as the proxy of chromospheric emission improves the agreement of the NRL model with observations at solar minimum

→ *same rotational variability with SLIGHT increase in solar cycle variability.*

New Model Formulation

Credited to Judith Lean





A **quadratic parameterization** of Mg index
→ *improved facular parameterization*

[Exponent = 1.1]

$$\Delta TSI_{TIM\_faculae}(t) = a + b\times\Delta Mg(t) + c\times[\Delta Mg(t)]^{e}$$

New TSI Variability model: NRLTSI3

$$\Delta TSI(t) = \Delta TSI_{faculae}(t) + \Delta TSI_{spot}(t)$$
$$= b\times Mg(t) + c\times Mg(t)^{e} + d\times P_s(t)$$

We find similar improvement for SOLSTICE Lyman alpha proxy

→ *new SSI variability model:* NRLSSI3

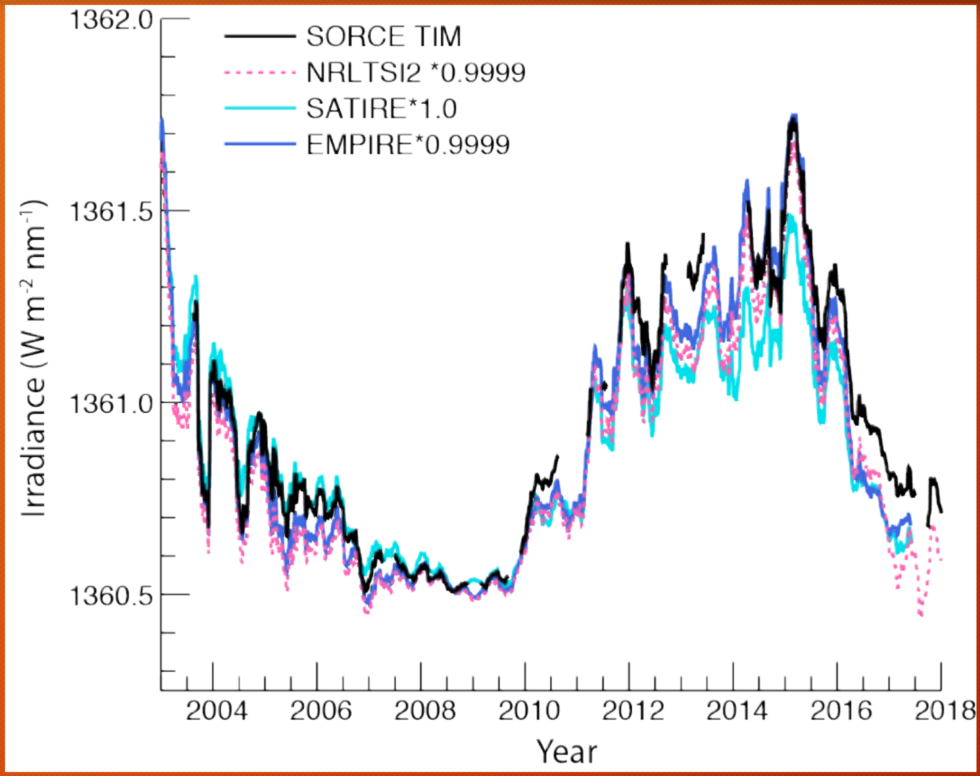
Conclusions

TSIS and improved OMI measurements will be used to further validate and improve the observation-based NRL2 models (and NRL3, etc.).

- Model-Measurement Comparison Findings:
  - EMPIRE and SATIRE overestimate mid and near-UV variability relative to NRLSSI2 and OMI observations.
  - EMPIRE's rotational-to-solar cycle variability is inconsistent with NRLSSI2 and SATIRE.
  - Proxy models correlate better with Dudok de Wit TSI composite than SATIRE.
  - SATIRE does not reproduce SC 24 TSI energy change.
- NRL2 was extended back in time to 850
- We identified improvements in proxy datasets of sunspots and faculae.
- NRL3 models have the same rotational variability as NRL2 models with *slight* increase in solar cycle variability.

Backups

TSI Variability: Solar Cycle 24



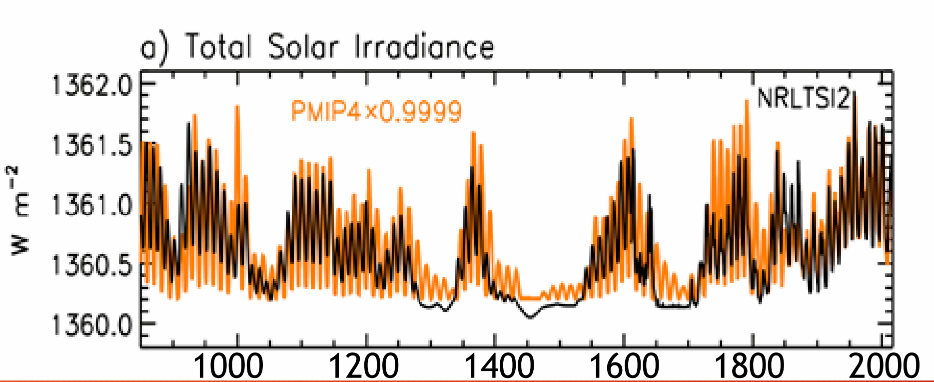
All data smoothed with an 81-day running mean.

Models have been normalized to match SORCE/TIM at 2008 solar minimum.

Historical Solar Irradiance Estimates

A new TSI and SSI solar irradiance estimate from 850 to 1610 is consistent with the NOAA CDR from 1610 to 2016.

It uses cosmogenic indices to parameterize the NRLTSI2 and NRLSSI2 irradiance variability.



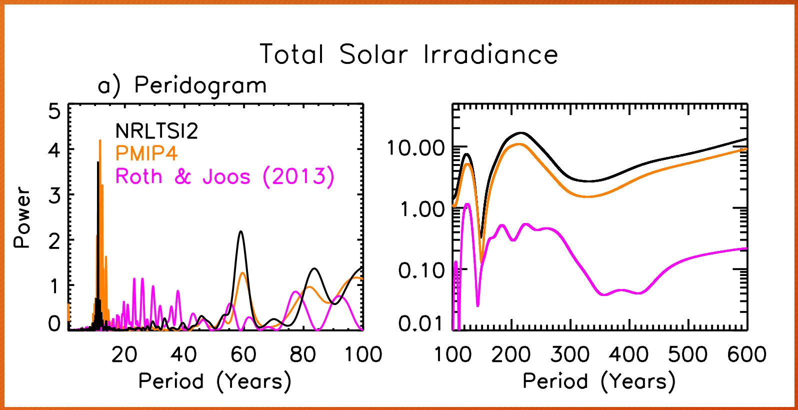
The new estimate correlates better with cosmogenic indices than PMIP4 solar irradiances.

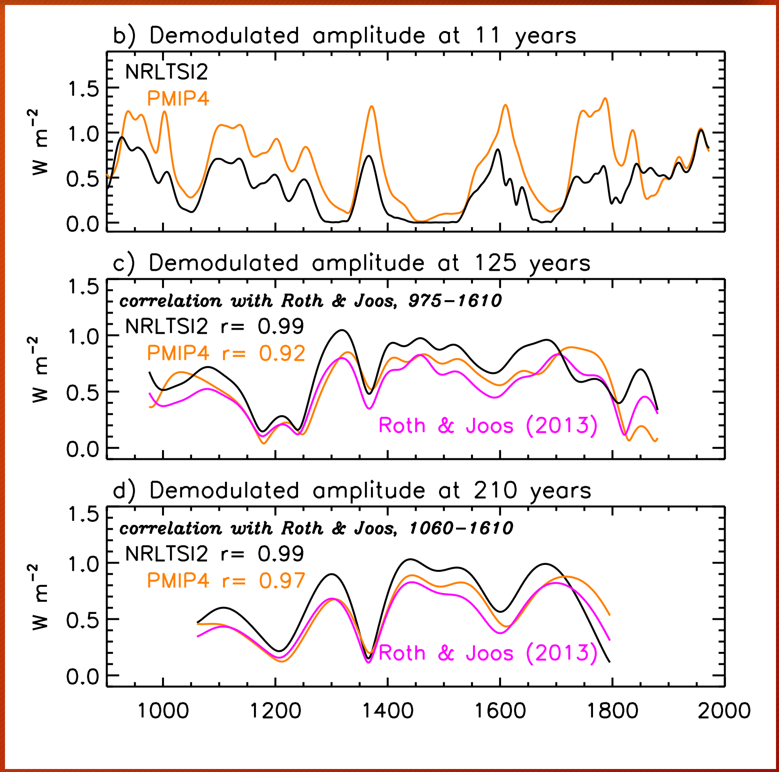
a) Total Solar Irradiance

	Roth & Joos (2013)	Steinhilber et al. (2009)	Delaygue & Bard (2011)
1610-2016			
NRLTSI2	0.75	0.72	0.71
PMIP4	0.63	0.62	0.55
850-1610			
NRLTSI2	0.86	0.69	0.71
PMIP4	0.61	0.51	0.52

J. Lean, Estimating Solar Irradiance Since 850 CE, *Earth & Space Sci.*, in press.

Historical Solar Irradiance Estimates





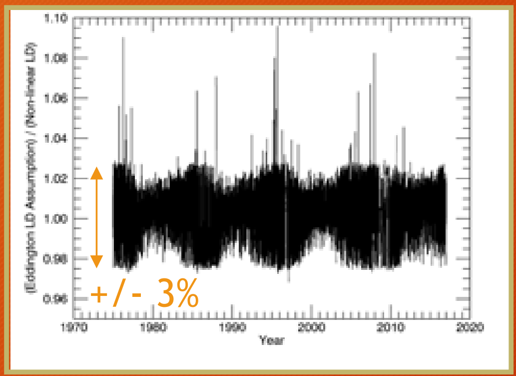
Sunspot Blocking Parameterizations

NRLTSI2 is *insensitive* to assumptions in :

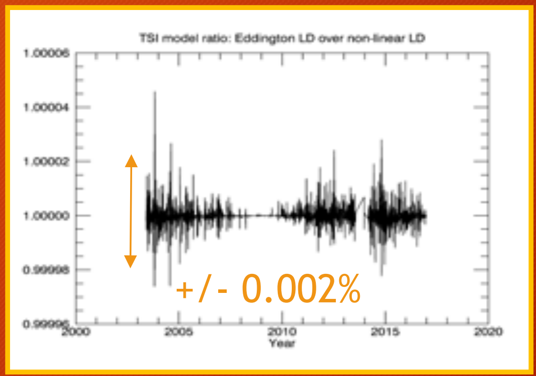
- area dependency in sunspot contrast,
- time dependency of sunspot area reports,
- all or a subset of USAF/SOON observatories, and
- linear or nonlinear dependency in limb-darkening.

$$PSI = \sum_{N\ spots} A_S C_S LD$$

A_S = sunspot area
C_s = sunspot contrast
LD = limb darkening



Ratio of PSI with linear LD to PSI with nonlinear LD



Ratio of TSI models: with PSI (linear LD) to PSI (nonlinear LD)

Nonlinear limb-darkening expression [Claret, 2000] had a +/- 3% effect on sunspot blocking (far left) but negligible impact on modeled TSI (left).