A Comparative Assessment of Solar Irradiance Observations and Models at the Dawn of TSIS

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Abstract

A wide variety of research applications require knowledge of total solar irradiance (TSI) and solar spectral irradiance (SSI) on time scales from minutes to centuries. The current satellite data record of TSI and ultraviolet SSI is 40 years long while observations of solar irradiance at visible wavelengths through the near-infrared span 15 years. In late 2017, the NASA Total and Spectral Solar Irradiance Sensor-1 (TSIS-1) mission was deployed on the International Space Station (ISS); these new TSI and SSI datasets are now extending the observational solar irradiance record with a planned 5-year mission. Recognizing the need for ongoing specification of solar irradiance, the National Centers for Environmental Information established the Solar Irradiance Climate Data Record (CDR) in 2014. The CDR includes a composite record of TSI observations and estimates of solar total and spectral irradiance variations during, and prior, to the space-based record based on the Naval Research Laboratory (NRL) models. Utilizing as inputs proxies of sunspot darkening and facular brightening, the models specify TSI and SSI annually since 1610 and daily since 1882. Both the observational composite and the model specifications are updated regularly and will eventually utilize the new TSIS-1 observations, both to extend the observational composite and to validate and improve the models. With the goal of establishing the utility of the NRL models in specifying the time and wavelength dependence of solar variability for the Solar Irradiance CDR, we compare the latest NRLTSI2 and NRLSSI2 modeled irradiances with observations, including composite records, and with independent models of solar irradiance variability. Our assessments quantify current understanding of solar irradiance variability on multiple timescales and identify areas where TSIS-1 observations are expected to provide improved understanding of solar irradiance variability. We use the following datasets in our comparisons: TSIS-1, Solar Radiation and Climate Experiment (SORCE), Ozone Monitoring Instrument (OMI), Solar Irradiance Data Exploitation (SOLID), Spectral and Total Irradiance Reconstructions for the Satellite Era (SATIRE-S), a three-dimensional extension of the SATIRE-S model (SATIRE-3D), and Empirical Irradiance Reconstruction (EMPIRE).

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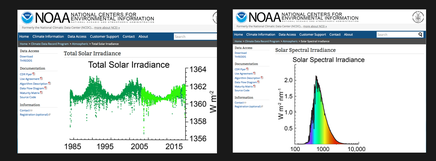
Motivation: Quantify current understanding of solar irradiance variability and establish the utility of the NRLTSI2 and NRLSSI2 models transitioned to the NOAA/NCEI Solar Irradiance Climate Data Record (CDR) through comparisons with observations and independent models.



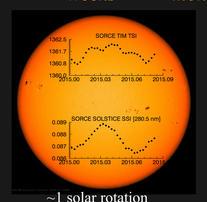
Time Scales of Solar Variability

Flares
Coronal Mass Ejections

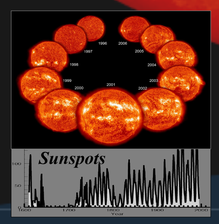
Solar Rotation
Active region evolution

Solar Activity Cycle
Dynamo

minutes *hours* *days* *weeks* *months* *years* *decades*



~1 solar rotation
Jan, 2015



1. Solar Rotation Irradiance Variability

Fig. 1

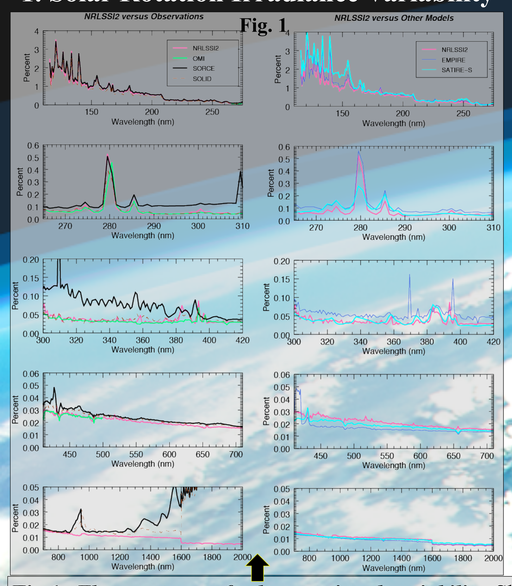


Fig 1: ***The spectrum of solar rotational variability.*** Shown is the 1-sigma std. dev. of rotational variability [absolute value] relative to the mean, in percent.

- NRLSSI2 is similar to SORCE and SOLID composite for λ< 250 nm and similar to OMI from 250-500 nm, except at 280 nm.
- EMPIRE has similar rotational character as NRLSSI2 but systematically greater magnitude than OMI observations below 420 nm (and smaller magnitude above 420 nm).
- SATIRE-S has a different character of rotational variability in the core of the lines and similar to NRLSSI2 in the continuum and it exceeds SORCE observations, particularly λ< 150 nm and exceeds OMI observations from 265-400 nm.

Fig 3: ***The spectrum of solar cycle variability.*** Shown is the 27-day smoothed solar cycle variability normalized to NRLSSI2 scale in 2008.

- Measurement-model differences are larger at some wavelengths [310-400 nm] than others [265-285 nm].
- EMPIRE UV solar cycle variability exceeds all observations.

2. Solar Cycle Irradiance Variability

Fig. 2

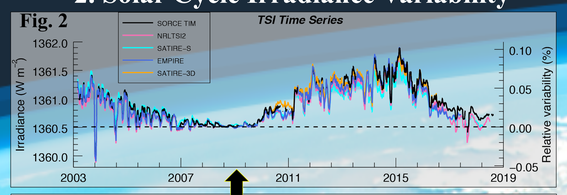
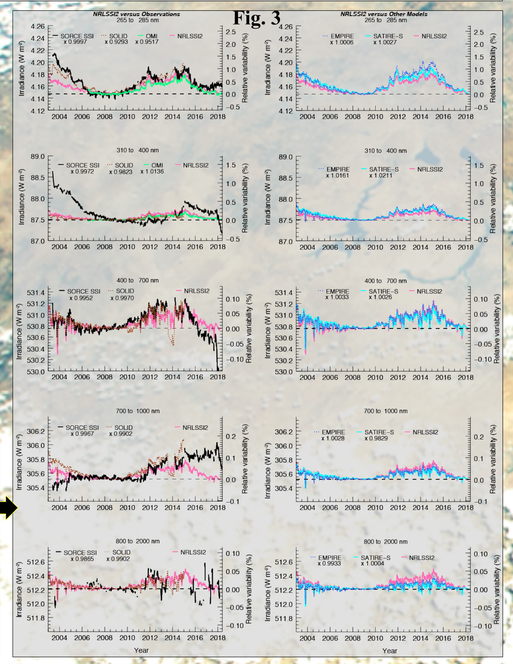


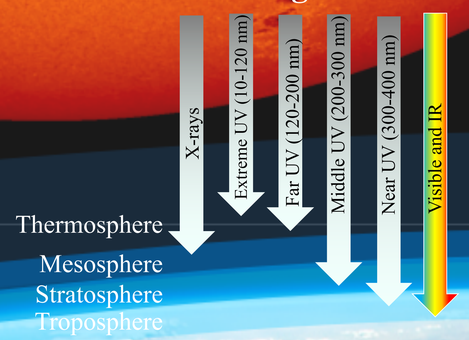
Fig 2: ***TSI solar cycle variability.*** Shown is the 27-day smoothed solar cycle variability normalized to SORCE TIM scale in 2008. Solar cycle TSI variability is ~ 0.1%.

- All models reproduce TSI to within 0.2 W m^{-2}.
- There is a growing measurement-model bias from ~2016 onwards.The root cause – observational issue, model insufficiency, or combination of both – is not yet understood.

Fig. 3



Deposition of Sunlight in the Atmosphere: Wavelength Matters

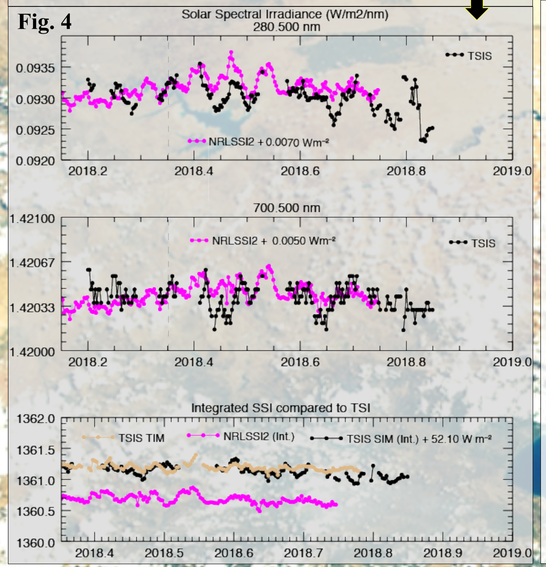


3. Key New Observations

Fig 4: ***TSIS-1 repeatability enables detection of smaller solar irradiance changes than any previous instruments.*** Shown are time series comparisons of solar spectral irradiance (in W m^{-2} nm^{-1}) at individual wavelengths in the UV and visible. Also shown is the integral of the spectrum (with a constant offset of 52 W m^{-2} to represent the energy contributions outside of the TSIS SIM spectral range) with TSIS TSI and the integral of NRLSSI2 (scaled to SORCE TSI level).

- Work is ongoing for implementing instrument calibrations and model validation.
- TSIS-1 data are publically available: https://lasp.colorado.edu/home/tsis/data/.

Fig. 4



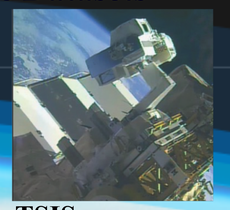
NOAA/NCEI Solar Irradiance CDR

- Publically released in 2014 and operationally updated each quarter.
- Provides TSI and SSI (115 to 100,000 nm), with uncertainties, from 1610 to present day at daily, monthly, and yearly average cadences.
- Produced from observation-based models [i.e. the updated Naval Research Laboratory (NRL) models: NRLTSI2 and NRLSSI2] that determine the changes with respect to Quiet Sun conditions when facular brightening and sunspot darkening features are present on the solar disk, where the magnitude of changes in irradiance are determined from linear regression of the proxy Magnesium II (Mg II) index and sunspot area indices against SORCE irradiance measurements [Coddington et al., BAMS, 2016].

Comparison Solar Irradiance Datasets

SORCE
Solar Radiation and Climate Experiment
2003; [0.1-2400 nm]

OMI
Ozone Monitoring Instrument (on AURA)
2004; [256-500 nm]



TSIS
Total and Spectral Solar Irradiance Sensor
2017; [200-2400 nm]

SOLID SSI Composite: Composite data set of 20 different space instruments for 0.5 -1991.5 nm using a probabilistic methodology spanning 1978-2014. Proxies used to fill in data gaps [Haberreiter et al., JGR Space Physics, 2017].

SATIRE: Spectral and Total Irradiance Reconstructions: a semi-empirical model of SSI and TSI that estimates irradiance change caused by changes in the Sun's surface magnetic field (i.e. sunspots, faculae, and network).SATIRE-S data available from 1974. [Yeo et al., A&A, 2014].

EMPIRE: Empirical Irradiance Reconstruction: a proxy model that derives irradiance change from regression of proxies of solar variability with irradiance observations. Uses a different regression methodology than NRLTSI2/NRLSSI2. [Yeo et al., JGR Space Physics, 2017].

Conclusions

- The Solar Irradiance CDR reproduces TSI solar cycle variability to 0.2 W m^{-2}.
- The Solar Irradiance CDR reproduces SSI rotational variability as observed by SORCE SOLSTICE < 250 nm and at 280 nm. At other wavelengths from 265-500 nm, the CDR best matches OMI. Above 500 nm, the CDR generally has smaller rotational variability than SORCE SIM.
- Key differences were found between the CDR and independent models. SATIRE-S has larger variability than the CDR and observations below 150 nm and in solar emission lines, but matches the CDR in the solar continuum below 400 nm. The EMPIRE model differs systematically from observations, the CDR, and SATIRE-S across the spectrum.
- Greater differences exist in SSI solar cycle (SC) behavior of independent observations and between observations and models. The CDR SC behavior best reproduces OMI observations < 400 nm. EMPIRE UV SC behavior [265-285 nm] exceeds that of observations and independent models.
- TSIS-1 meets climate-quality requirements for accuracy and stability and is performing as expected thus far.
- **Continued, long-term observations of solar irradiance beyond TSIS-1 are essential for validating and improving model estimates.**
- **Ongoing work will incorporate the new knowledge gained from TSIS-1 into a new version of the Solar Irradiance CDR.**