Solar Spectral Irradiance Variability in Solar Cycle 25 in Direct Observations and in a New, Improved Solar Variability Model

O. Coddington, J. Lean and E. Richard

University of Colorado Boulder, Laboratory for Atmospheric and Space Physics

Outline

- Motivation & Objectives
- Datasets
- Sunspot & Facular Contrast Comparisons
- Solar Irradiance Comparisons
- Summary

Motivation

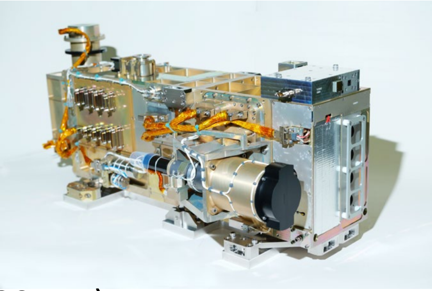
To apply research advances supported by NASA's Solar Irradiance Science Team to develop a new version 4 of the Naval Research Laboratory (NRL) SSI & TSI models.

Objectives

- Resolve significant discrepancies among existing SSI variability models and observations.

- Incorporate the advances into a new NOAA/NCEI Solar Irradiance Climate Data Record, V3 (August, 2024)

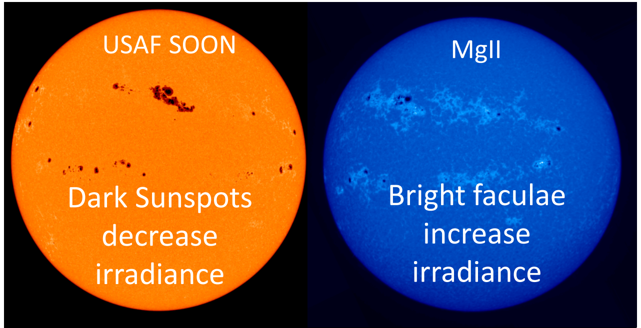
Datasets



- Observations
  - SSI: NASA's TSIS-1 Spectral Irradiance Monitor (SIM):
  - 200-2400 nm; daily observation; ~0.3% accuracy; 0.01%/year stability (> 400 nm)
- Observation-based (Empirical) Model
  - NRLSSI2 – informed from SORCE-era observations and proxies of magnetic variability (USAF/SOON sunspot area, number and location and the University of Bremen Mg II Index) and transitioned to the public as the Solar Irradiance CDR, V2 (Coddington et al., 2016)
- Physics-based (Semi-Empirical) Model
  - SATIRE-S (Yeo et al., 2014) – facular and sunspot contrasts by stellar model atmospheres (Y. Unruh, personal communication) and irradiance variability informed by magnetograms.
- Independent Intensity Contrasts
  - Facular, plage, umbra and penumbra contrasts by solar model atmosphere theory (Fontenla et al., 1999; 2011), with synthetic spectra computed from the Rybicki-Hummer (RH) radiative transfer model (*calculations courtesy of Serena Criscuoli*).
  - Umbra and penumbra contrast observations by Allen, 1955

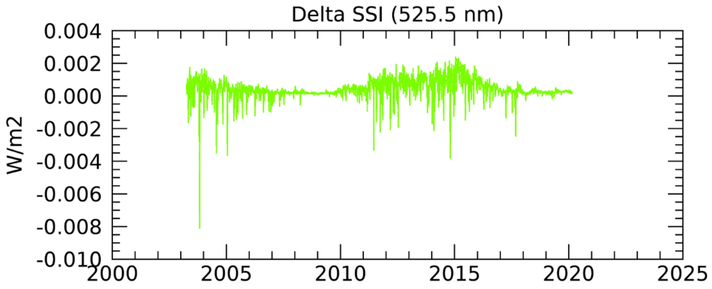
Observationally-Derived Intensity Contrasts

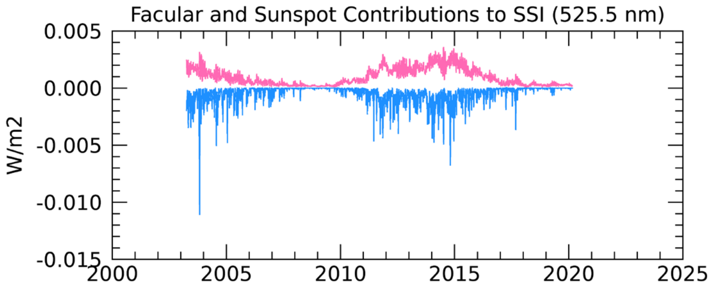
The magnitude of the irradiance changes from Quiet Sun conditions are determined from ***multiple linear regression analysis*** of observations and proxy records of magnetic variability (sunspots & faculae).



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

[Similarly, for $\Delta TSI(t)$]



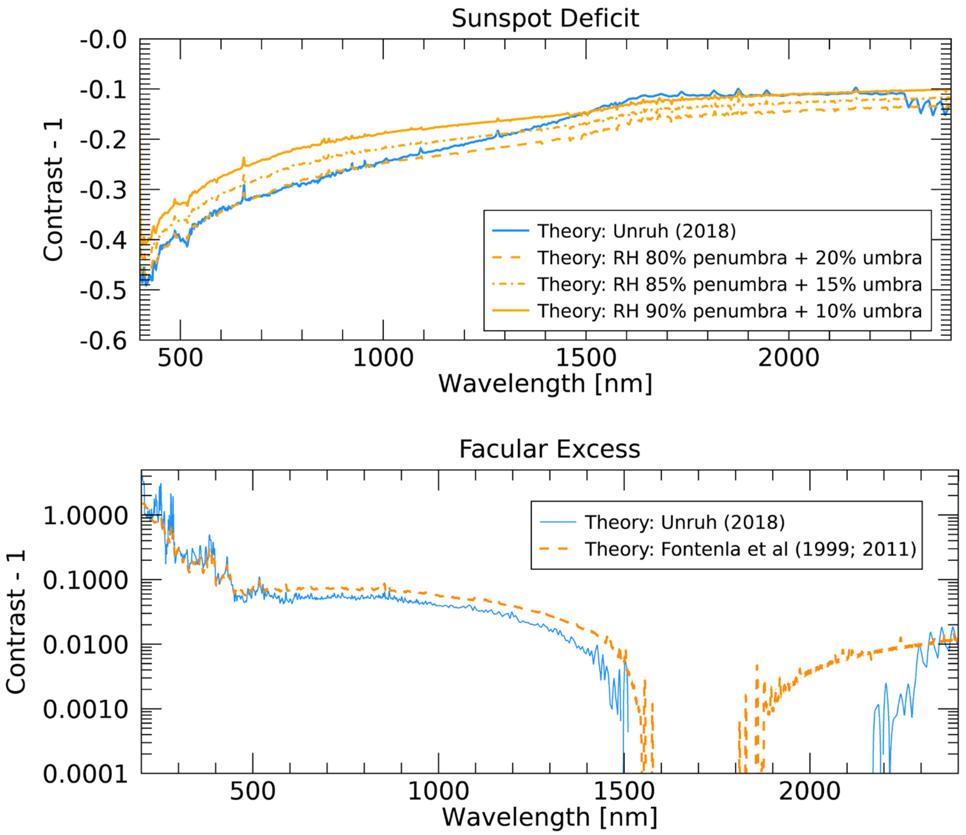


The Sun is brighter when solar activity - and sunspot numbers - are high.

Kopp and Lean, GRL, 2011

After applying a wavelength-independent scaling factor, these regression coefficients – normalized by the Quiet Sun spectrum – can be directly compared to the faculae and sunspot contrasts predicted by theory.

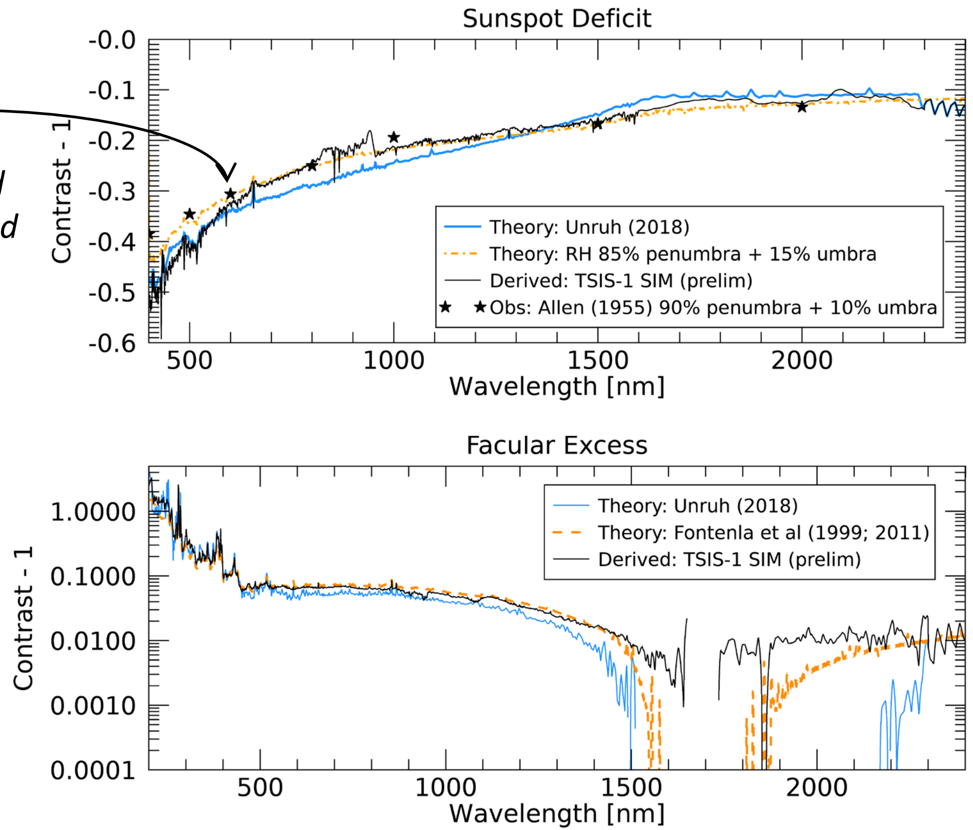
Theoretical Contrasts



Solar & stellar theory predict differences in the magnitude and spectral shape of sunspot and facular contrasts.

Theoretical, Observed & Derived Contrasts

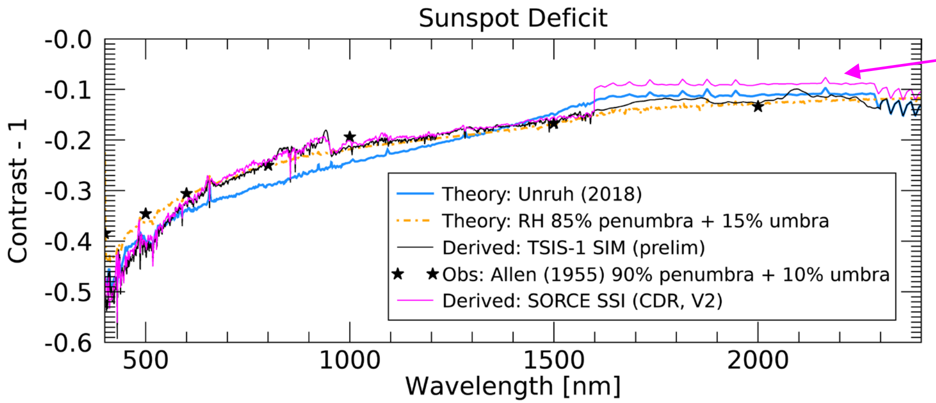
Allen, 1955 sunspot contrast observations support magnitude and spectral shape predicted by solar atmosphere theory.



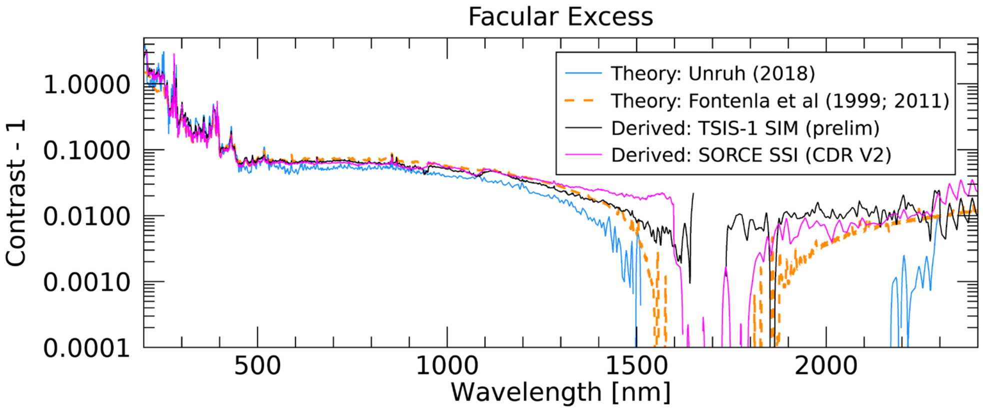
Contrasts derived from TSIS-1 SIM observations (and proxies of spots and faculae) more strongly support spectral shape predicted by the solar atmosphere theory.

TSIS-Derived Contrasts have been adjusted to Unruh, 2018 magnitude at 525.5 nm

Theoretical, Observed & Derived Contrasts



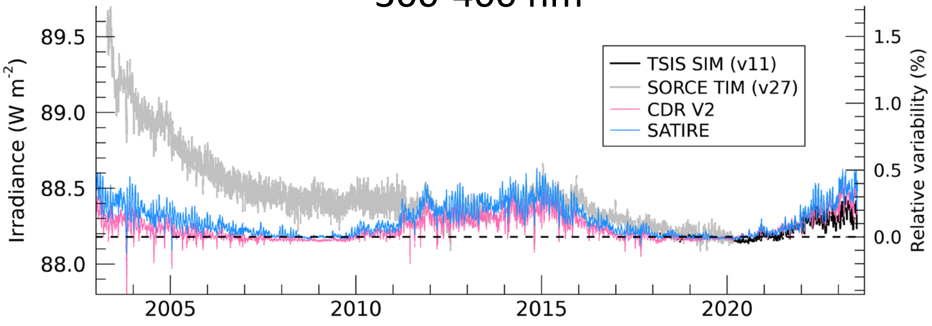
SORCE-Derived Contrasts inform the NOAA/NCEI Solar Irradiance CDR, V2



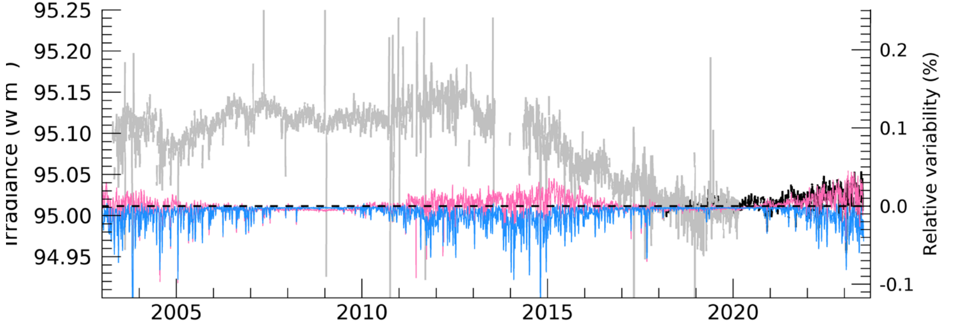
SORCE & TSIS-Derived Contrasts have been adjusted to Unruh, 2018 magnitude at 525.5 nm

Binned Irradiance Comparisons

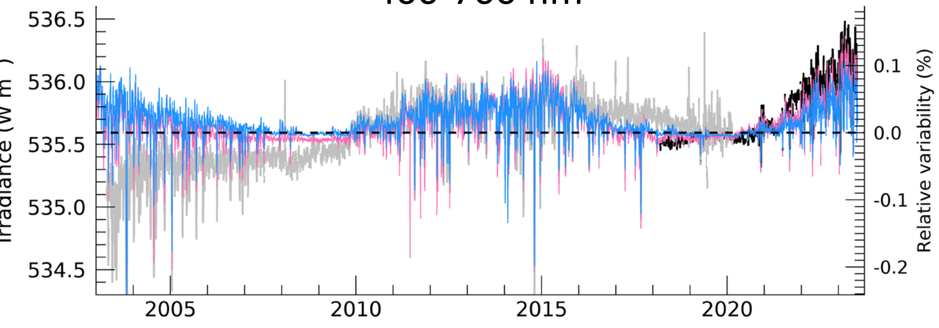
300-400 nm



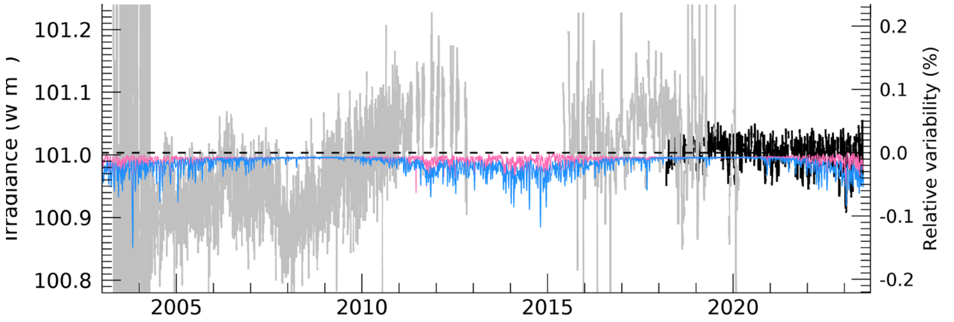
1300-1600 nm



400-700 nm



1600-2400 nm



Differences in intensity contrasts (derived or theoretical) contribute to differences in estimated SSI.

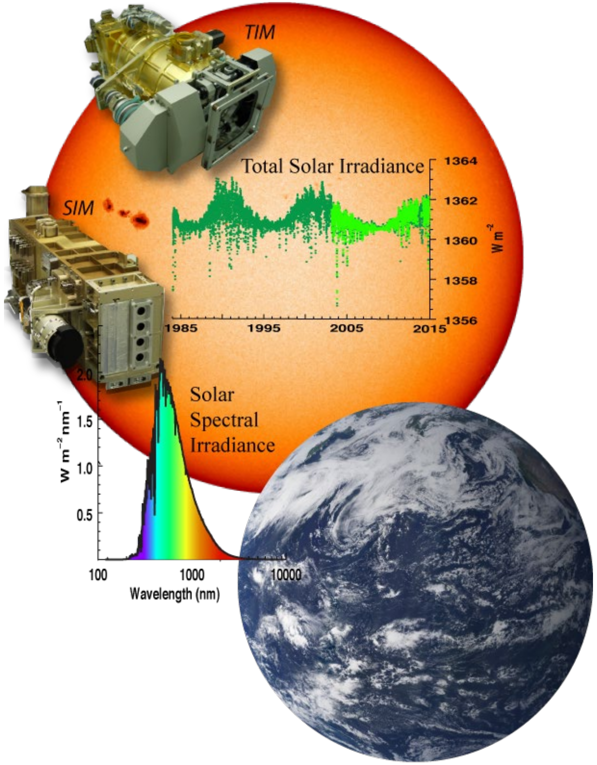
Summary and Future Outlook

- Intensity contrasts of sunspots and faculae are key elements for modeling SSI.
  - Differences exist in theoretical predictions of these quantities (e.g., Unruh/stellar vs Fontenla/solar).
  - Contrasts derived from TSIS-1 SIM, SORCE SSI (and proxies of spots and faculae) more strongly support the spectral shape of the Fontenla/solar contrasts).
- Differences in intensity contrasts directly impact SSI estimates
  - As shown by the CDR V2 irradiances (derived from SORCE SSI observations) compared to the SATIRE estimates (informed by the Unruh/stellar theory).
- Ongoing work is incorporating high-quality TSIS-1 SIM observations to improve and validate a new CDR V3 (that will become operational in 2024).

Backups.

***New/Revised for NRLSSI4*

CDR Deliverables



>20,000 website "hits" since 2016

Product	Type	No. of wavelength bins	Time range, update cadence
TSI composite	Observational composite	Revised! —	1978–2014,
TSI (daily and monthly avg)	NRLTSI2 model output	—	1882–2014,
TSI (yearly avg)	NRLTSI2 model output	—	1610–2014,
SSI (daily and m	Plus SSI Hi-res .SSI2 model output	4,300 (variable width)	1882–2014,
SSI (yearly avg)	.SSI2 model output		1610–2014,
SSI reference spectra	NRLSSI2 model output	200,000 (1-nm bins)	Quiet sun Low, moderate, and Maunder Minimum
Facular brightening and sunspot darkening indices	NRLTSI2/NRLSSI2 model input	—	1882–2014, quarter

Initial delivery will extend through 2023 with periodic updates

New Secular estimate

Documentation	**Climate-Algorithm Theoretical Basis Document**	Revised!
Stewardship	i. Yearly Quality Assurance Reports & replacement of preliminary data with final data ii. Model Input Time Series	

Data Access

CDR Program: https://www.ncdc.noaa.gov/cdr

LASP LISIRD: http://lasp.(TBD .edu/lisird/data/nrl2_files