Progress towards a high-resolution, high-accuracy solar reference spectrum based on TSIS-1 SIM

Odele Coddington, Erik Richard, Peter Pilewskie, and Dave Harber
University of Colorado Boulder / LASP

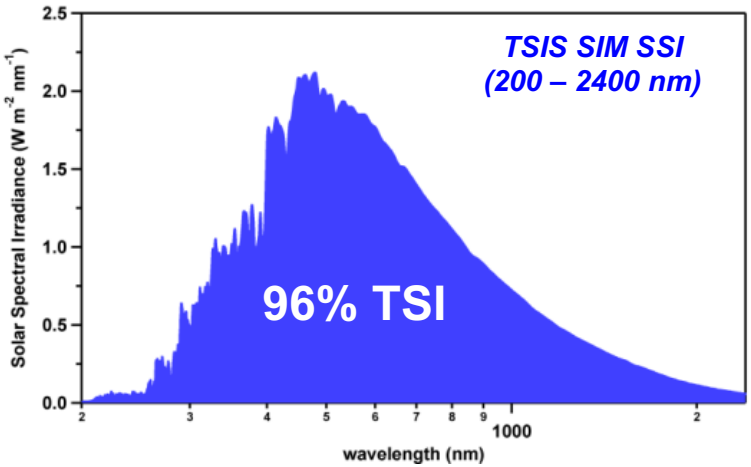
Sun-Climate Symposium
Tucson, AZ
Jan 30, 2020

Outline

- Motivation
  - new, high-accuracy TSIS-1 SIM
  - Comparisons of TSIS-1 SIM to CSIM
  - Comparisons of TSIS-1 SIM to other common solar reference spectra
- Developing a high-resolution, high-accuracy solar reference spectrum
  - Methodology
  - Available high-resolution solar irradiance datasets
  - Example of re-calibrating a high-resolution dataset to TSIS-1 absolute scale
- Next steps

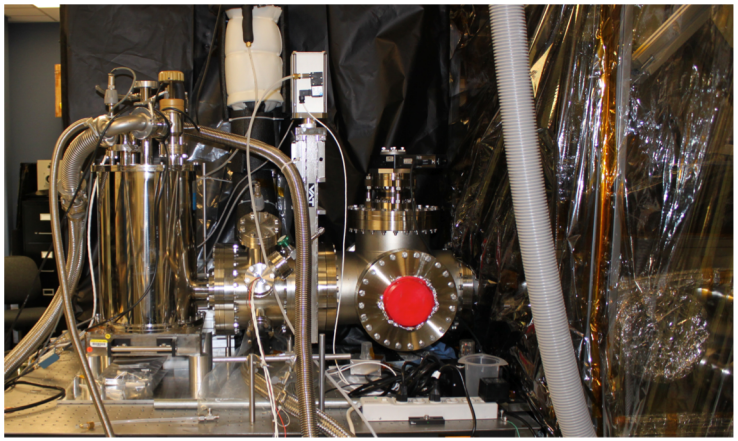
Motivation

- Knowledge of solar spectral irradiance (SSI) magnitude and variability is important for:
  - attribution of climate forcing,
  - solar irradiance variability modeling,
  - radiative transfer modeling,
  - conversion of measured satellite reflectance to radiance,
  - satellite calibration and on-orbit stability tracking
  - and much more.
- TSIS-1 SIM is designed, characterized, calibrated and validated to quantify and track SSI variability.
  - TSIS-1 SIM absolute accuracy *performance* is **<u>0.41% (uv) and 0.24% (vis/nir)</u>**
  - Pre-TSIS SSI absolute accuracy is **<u>2-8%</u>**



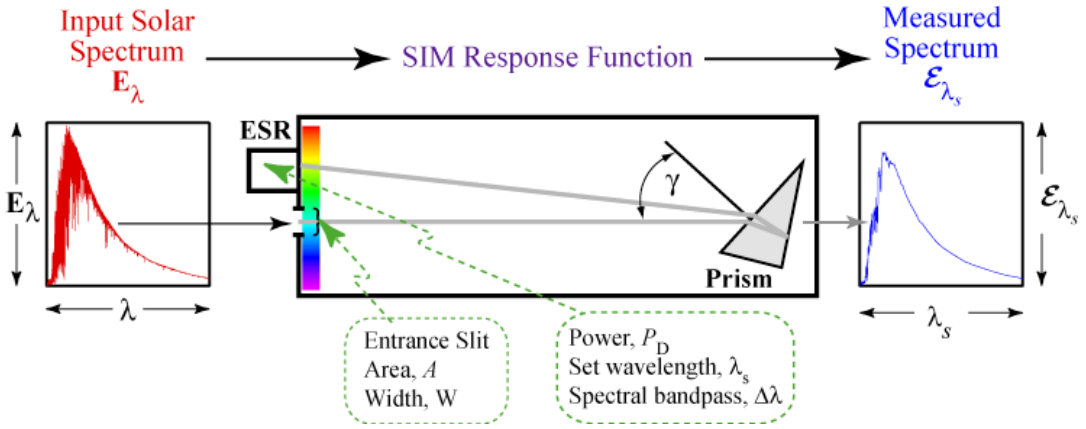
Detector-based calibration is key to high accuracy

- TSIS-1 SIM is the first, solar-viewing spectroradiometer using an electrical substitution radiometer that traces its accuracy to a primary detector-based standard.
  - detector-based radiometry allows for ~***5x improvement*** in accuracy (~0.05% unc) versus blackbody sources (~0.25% unc.) [*H. Yoon, Calcon, 2013*]
- For radiometric calibration, you can build a more accurate detector than a source (lamps, blackbodies, etc.).
  - LASP built the Spectral Radiometer Facility



LASP Spectral Radiometer Facility

TSIS SIM Measurement Principle

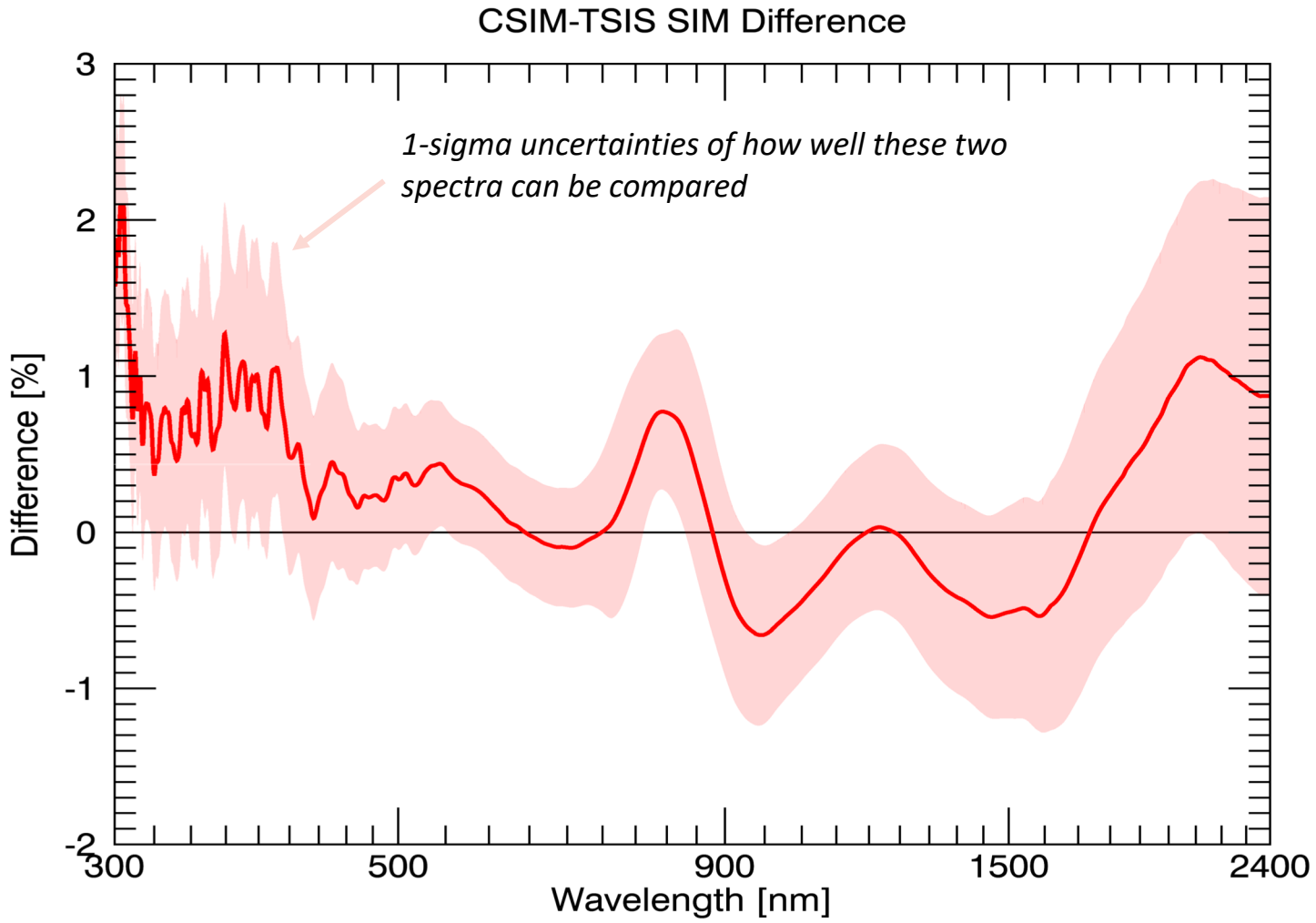


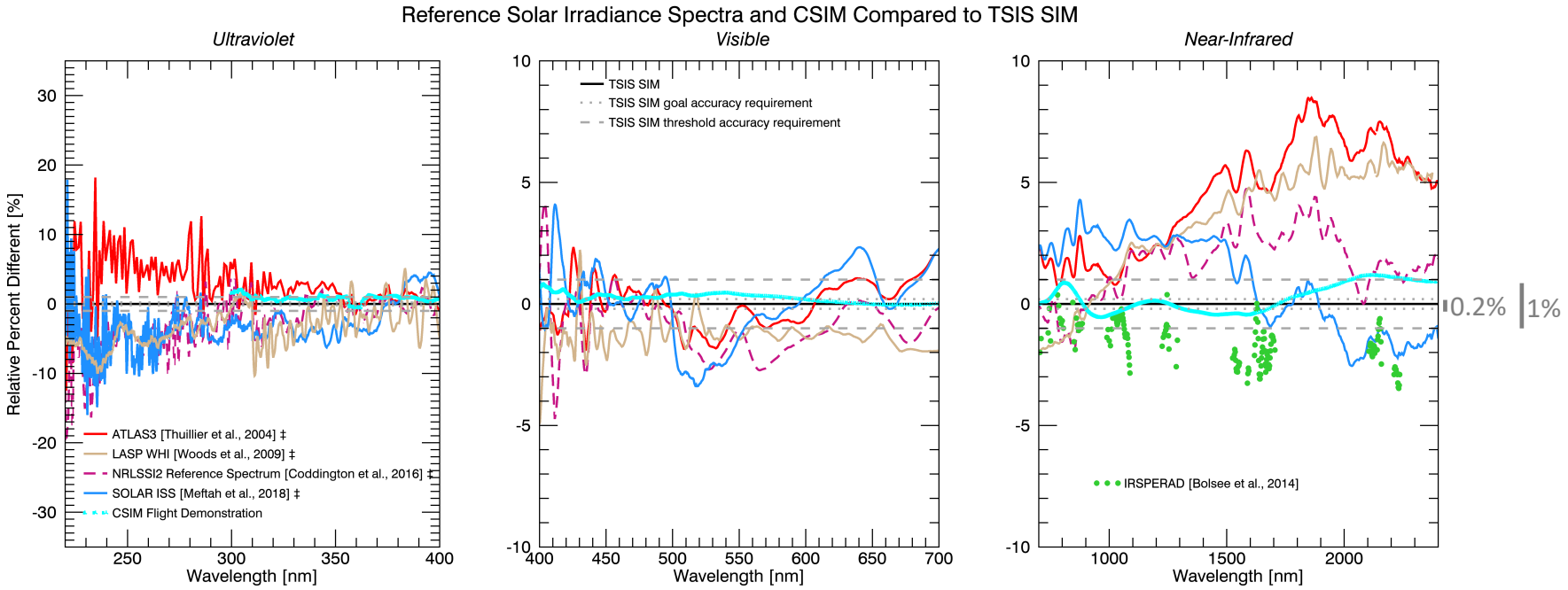
$$\mathcal{E}_\lambda(\lambda_s) = \frac{P_D(\lambda_s)}{A \cdot \Delta\lambda(\lambda_s)} \quad \text{units: } \frac{\text{W}}{\text{m}^2 \cdot \text{nm}}$$

P_D is the optical power directly measured by the SIM ESR

CSIM and TSIS-1 SIM Difference

- The Compact SIM (CSIM) technology demonstration mission (launched early 2019) shows on-orbit agreement to TSIS-1 SIM to 1%.





*All datasets except CSIM and IRSPERAD have been convolved to TSIS SIM resolution.

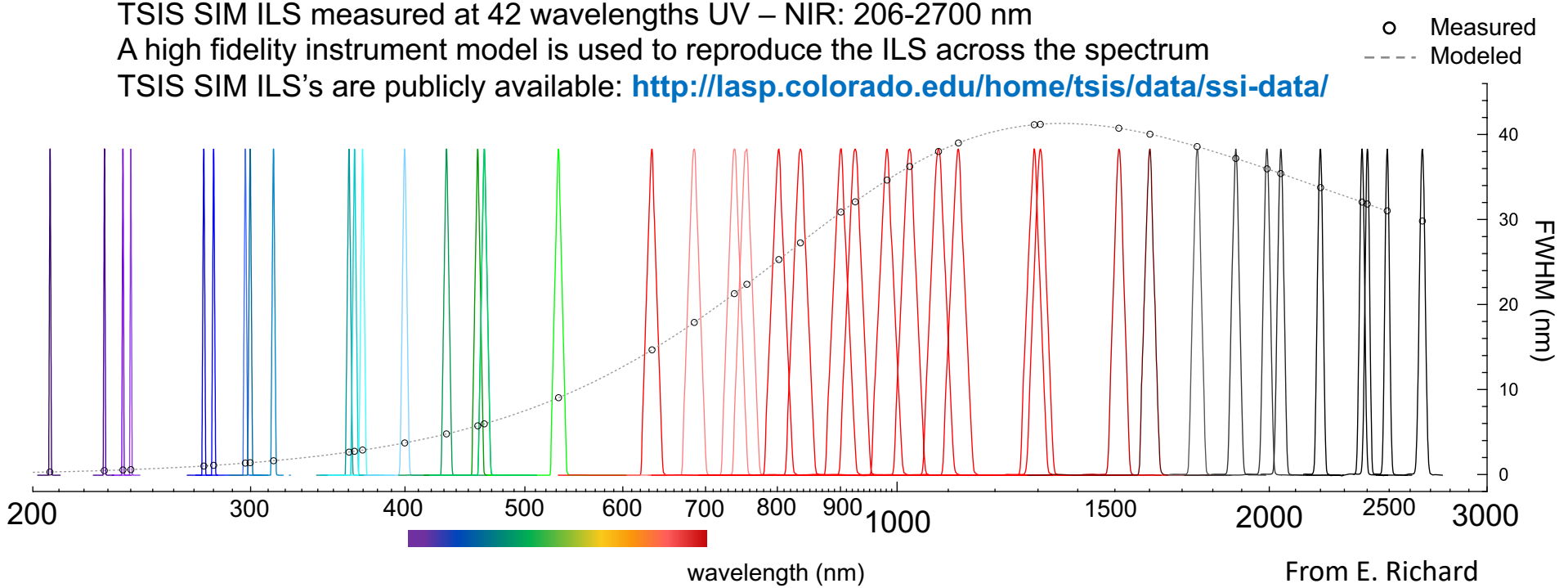
TSIS-1 SIM sets a new standard for SSI accuracy.

Name	Accuracy	Spectral Resolution	Spectral Range
ATLAS 3	2-4%	0.25 nm - 0.5 nm	0.5 nm - 2400 nm
LASP WHI	2-3%	0.1 nm < 310 nm 1 – 34 nm > 310 nm	0.1 nm - 2400 nm
SOLAR-ISS, v1.1	1.26% (mean)	0.6 nm – 9.5 nm	265 nm – 3000 nm
NRLSSI2	LASP WHI & ATLAS 3	0.1 nm < 300 nm 1 nm; 300-1000 nm	115 nm – 2400 nm (obs) 2400 nm - 100,000 nm (theory)
IRSPERAD	1%	10 nm	600 nm – 2300 nm; discrete bands
CSIM	<1% 300-2000 nm ~8% 230 nm	Variable <1 nm – 42 nm	200-2800 nm

Developing a high-accuracy, high-resolution reference

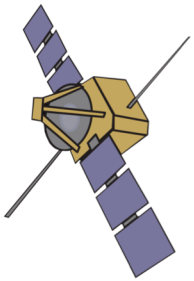
- Methodology to re-calibrate a high-resolution dataset to the lower resolution TSIS-1 SIM scale
  - Spectral ratio method [e.g. Dobber et al. 2008; Kang et al., 2017]
  - Scaling factor = the ratio of the TSIS-1 SIM to the high-resolution spectrum ***convolved to the TSIS-1 SIM spectral resolution***
  - Convolution requires good knowledge of TSIS-1 SIM instrument line shape (ILS)

TSIS SIM ILS measured at 42 wavelengths UV – NIR: 206-2700 nm
A high fidelity instrument model is used to reproduce the ILS across the spectrum
TSIS SIM ILS's are publicly available: **http://lasp.colorado.edu/home/tsis/data/ssi-data/**



From E. Richard

SPTS (empirical)

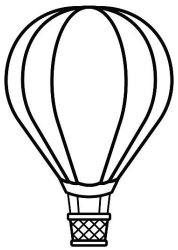


ATMOS

ACE

GOSAT

Which high-resolution data set to use? So many choices!



AFGL

MKIV

TCCON

CAVIAR2 (has gaps)

QASUME/FTS

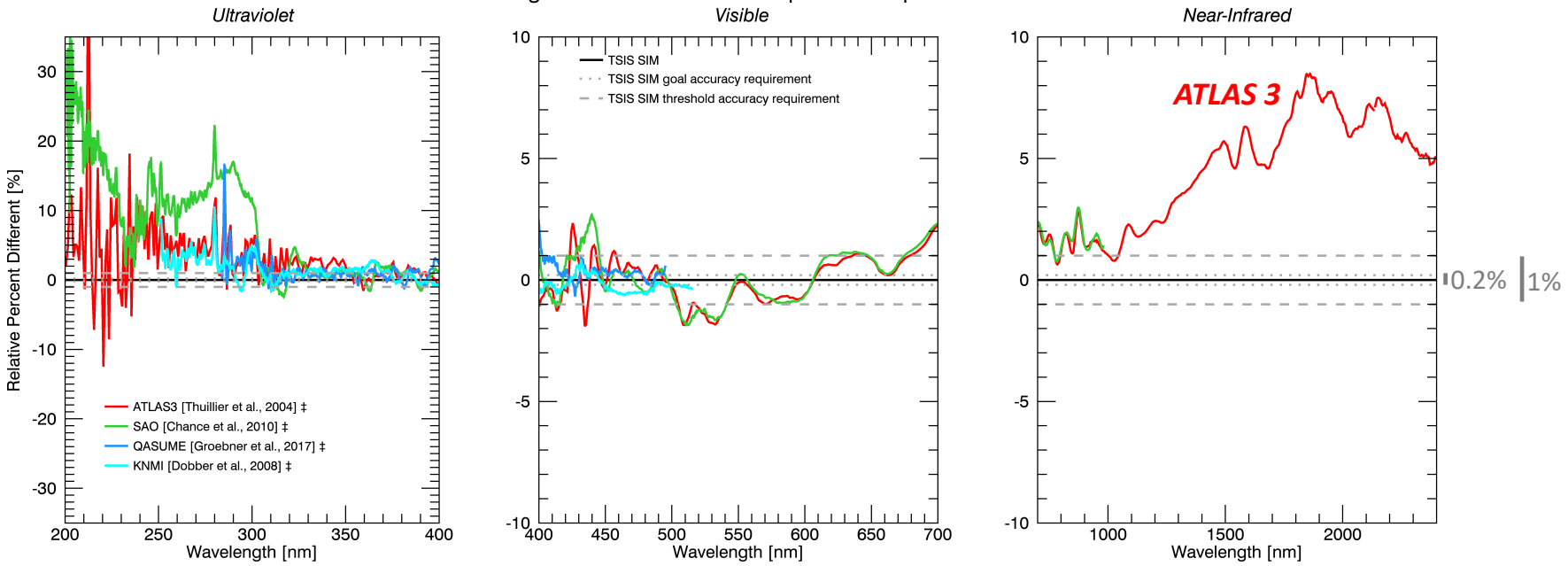
KPNO (solar irradiance atlas)

KPNO (solar flux atlas)

200 400 600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600 2800

(nm)

Convolved High Resolution Reference Spectra Compared to TSIS SIM

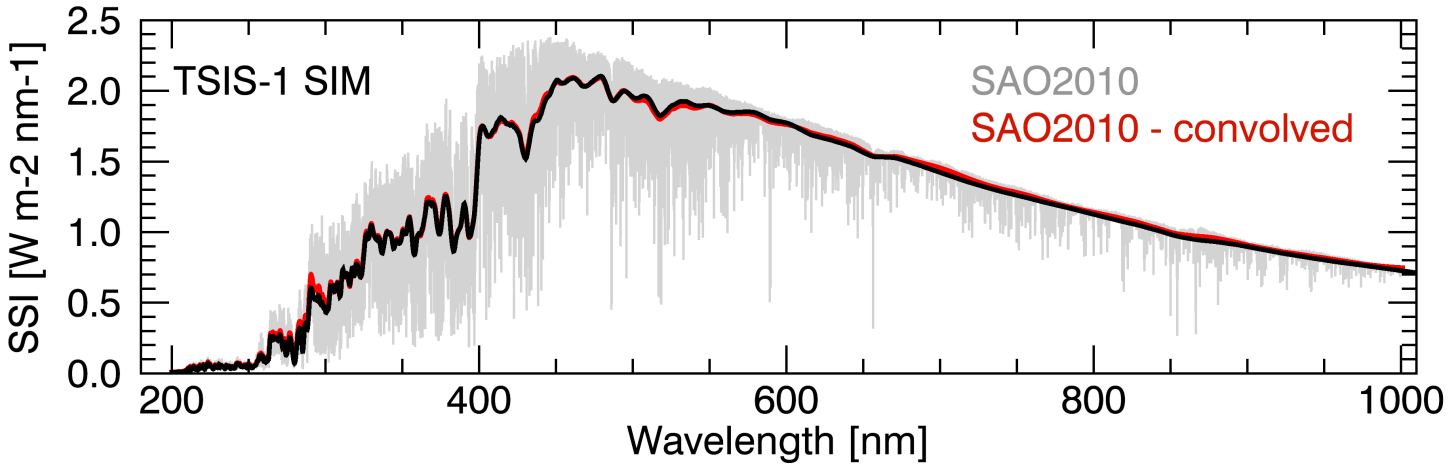


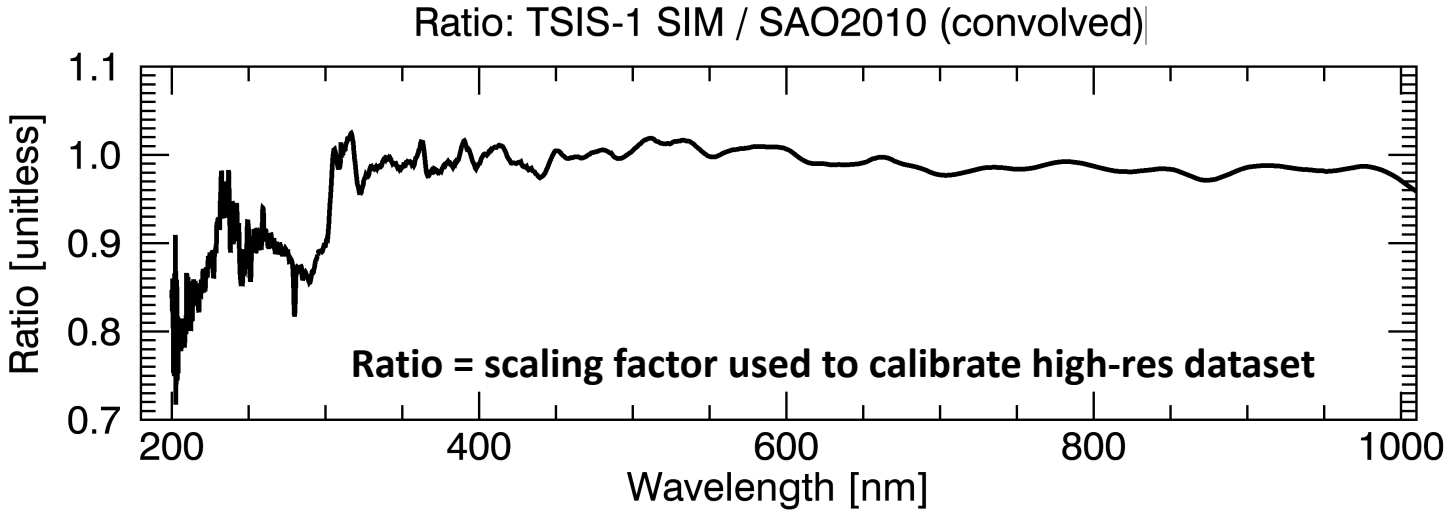
*All datasets have been convolved to TSIS SIM resolution.

Name	High Resolution Dataset(s)	"Radiometric" Dataset	Accuracy
SAO2010	AFGL and KPNO	ATLAS 3 > 305 nm	5-30% < 305 nm 5% > 305 nm
QASUME/FTS	QASUME/FTS and KPNO	QASUME	4% at 300 nm 2% 310-500 nm
KNMI	AFGL and KPNO	SUSIM/UARS < 410 nm SCIAMACHY ballon val > 400 nm	2%

Let's 're-calibrate' this one…

Re-calibrating SAO2010 to TSIS-1 SIM





Next Steps

- Produce the high-resolution reference spectrum at TSIS-1 SIM irradiance scale:
  - 200-2800 nm (extended from 2400 nm with CSIM; pending conclusion of CSIM analysis)
  - ~0.001 nm spectral resolution and 0.00025 nm sampling.
  - K. Chance, R. Kurucz, and M. Kang to advise on high resolution datasets
  - Report to GSICS in March, 2020.
  - Finalize analysis and report at IRS in July, 2020.
- Our Sun is a variable star
  - TSIS-1 SIM launched near to solar minimum (“first light” spectrum)
  - The ‘WHPI campaigns’ will define the “Quiet” Sun period, based on irradiance and solar activity metrics
- Define uncertainties, wavelength-dependent, with contributions from:
  - TSIS-1 SIM accuracy
  - The small offset needed to scale (reduce) CSIM to TSIS-1 SIM at 2400 nm.
  - A metric of how well the re-calibrating of the high-resolution data to TSIS SIM scale can be performed
  - Uncertainties in wavelength scale (propagated into irradiance)
  - Others sources?