Decoupling Solar Variability and Instrument Trends using the Multiple Same-Irradiance-Level (MuSIL) Analysis Technique

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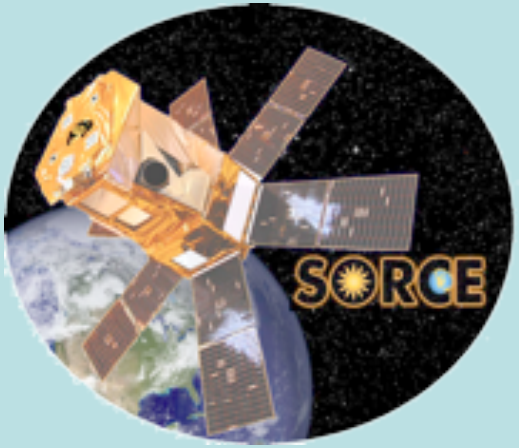
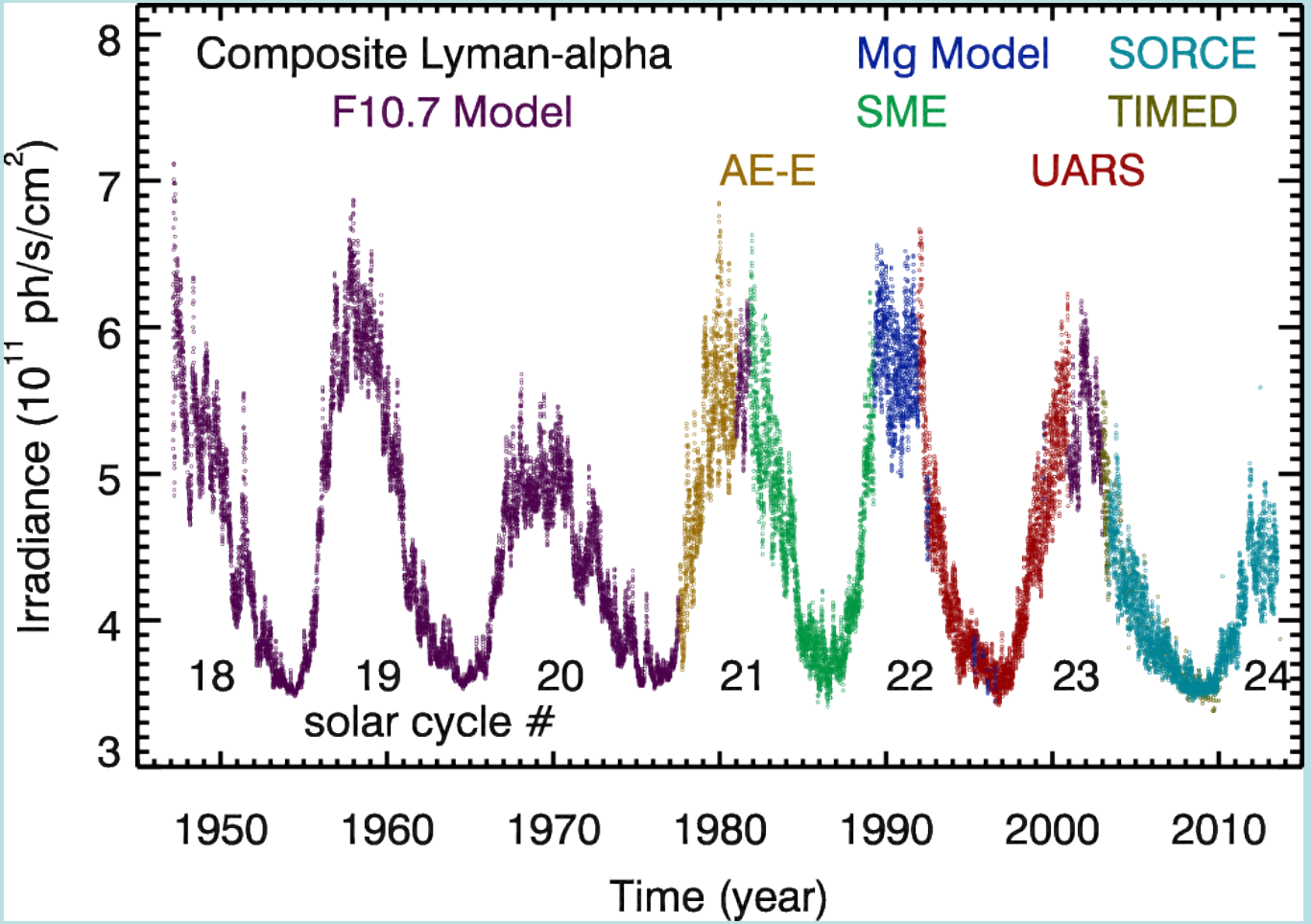


Key Goal is Creating Long-term Composite Record

Example of SSI Composite Record at H I Lyman-α (121.6 nm)



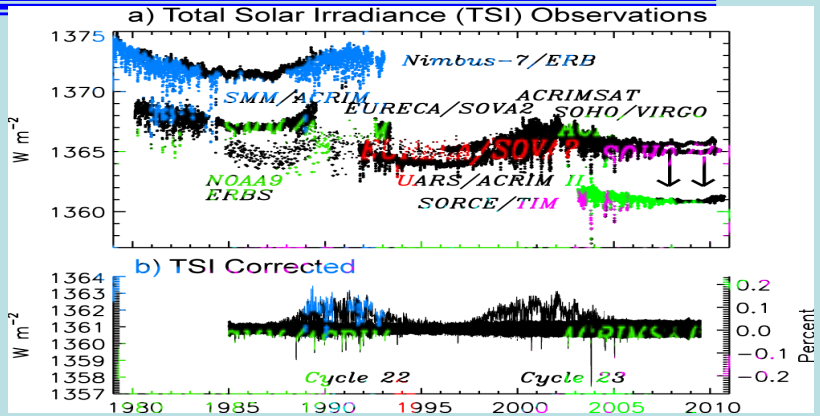
- Woods & Rottman, *J. Geophys. Res.*, 1997
- Woods, Tobiska, Rottman, & Worden, *J. Geophys. Res.*, 2000

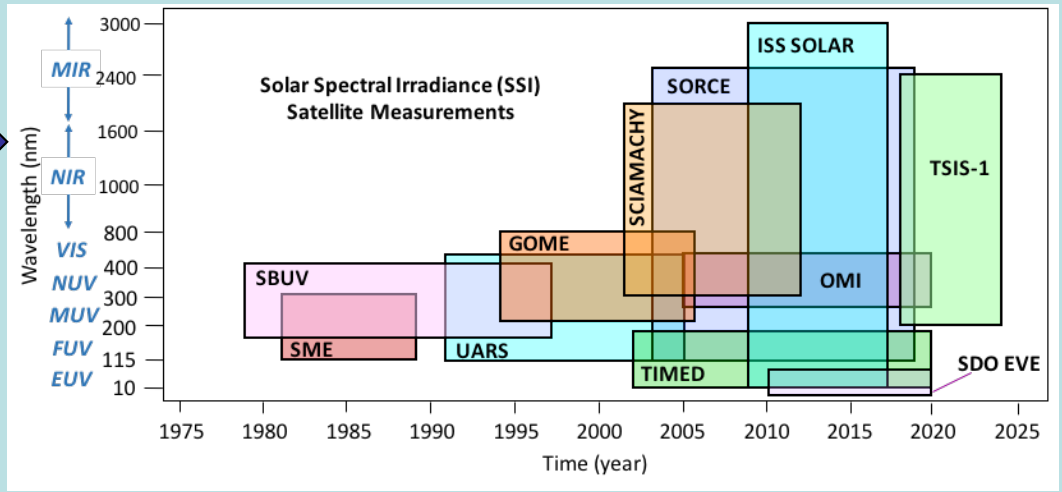
Challenges for Making SSI Composite Records

1) Different Levels of Irradiance

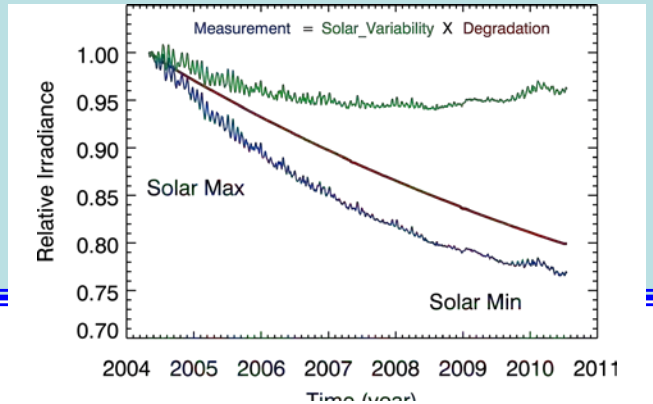
2) Incomplete Spectral and Temporal Coverage

3) Instrument Degradation Correction





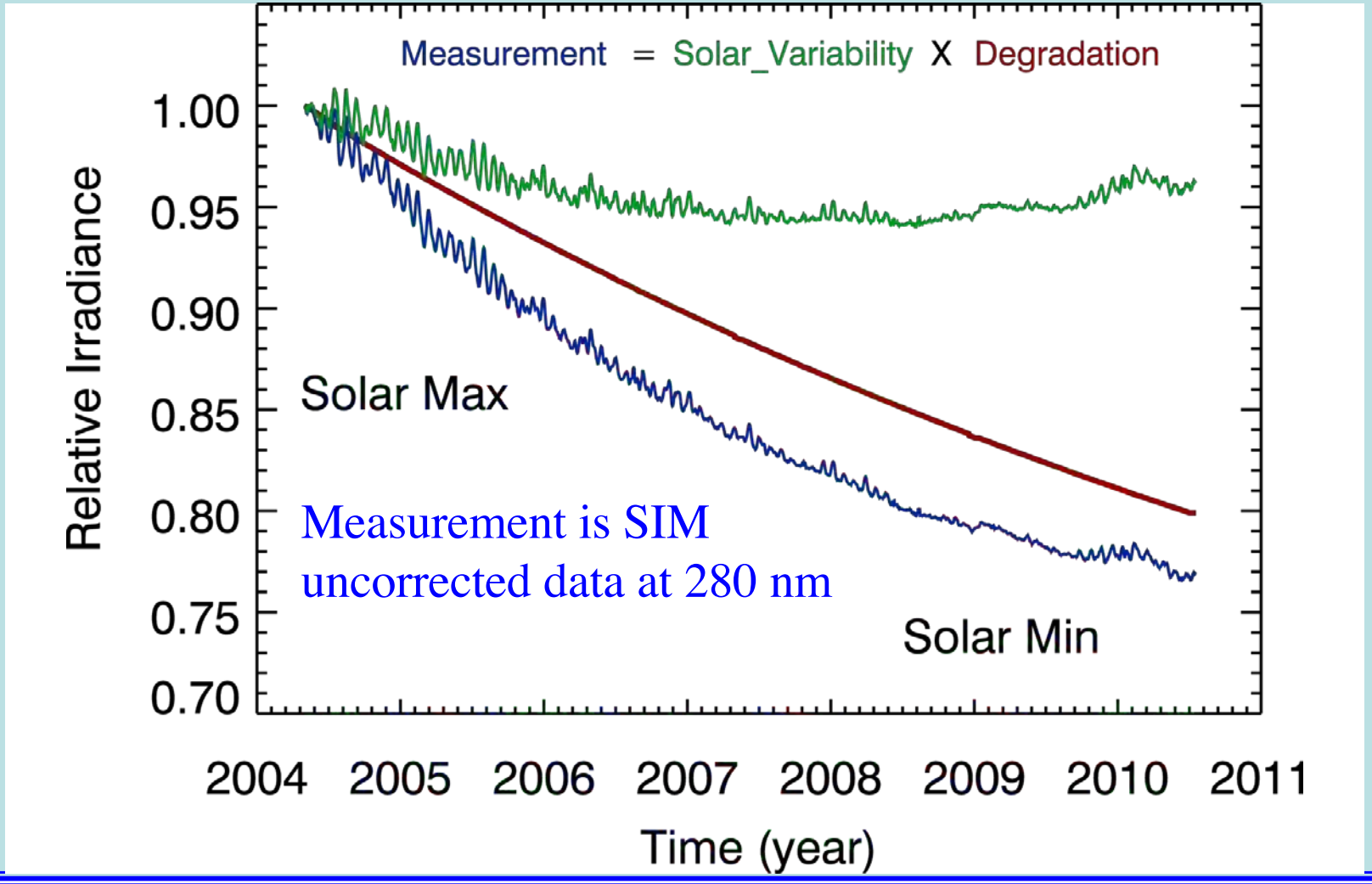
SC-21 | SC-22 | SC-23 | SC-24 | SC-25



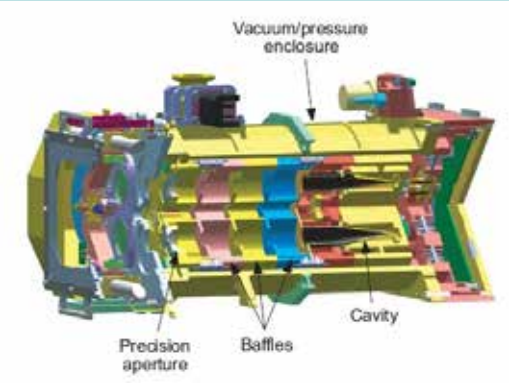
Figures are from Kopp & Lean (*GRL*, 2011) and LISIRD web site.

Challenge 3: Instrument Degradation Correction

- Understanding instrument degradation is critical for obtaining accurate solar cycle variations.



In-flight Calibration Techniques



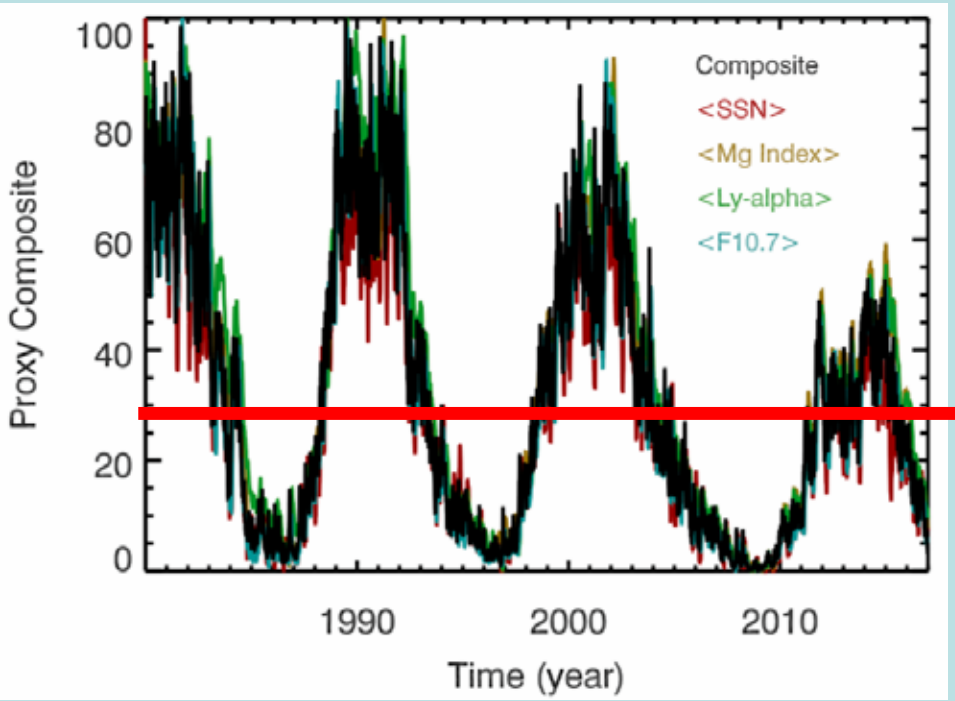
- Redundant Channels
- One channel is used daily, and others have low-duty cycle (weekly or monthly)
- Trending assumes exposure-related degradation
- Challenge is for non-exposure related degradation

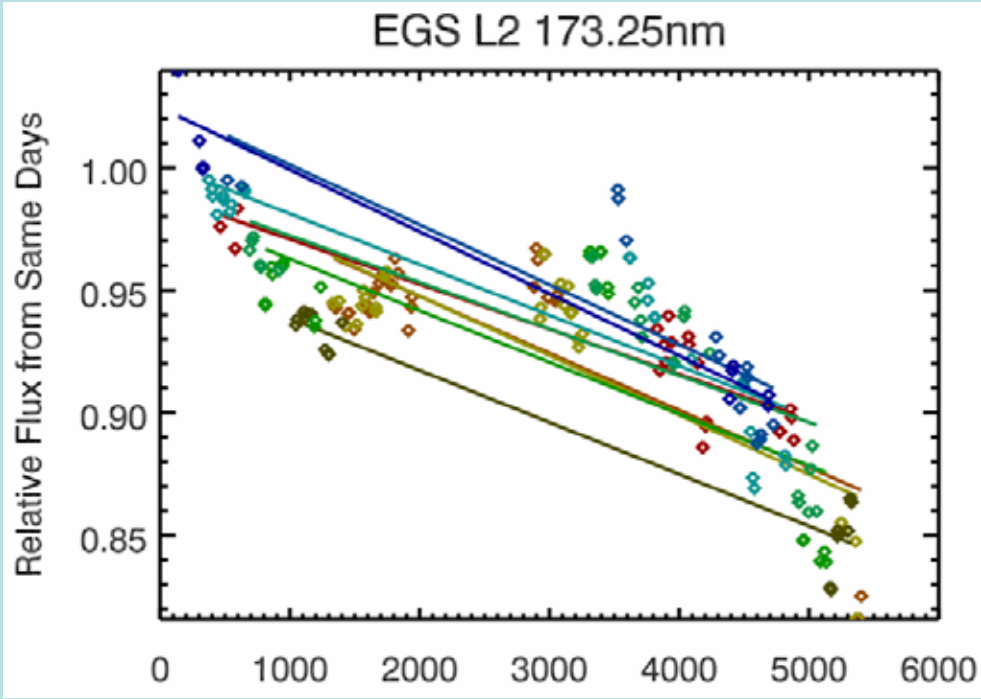
- On-board Lamps
- Calibrated lamps are used with low-duty cycle during flight
- Trending assumes lamp is stable
- Challenge is that lamps can degrade and have often burned out in-flight

- Underflight Campaigns
- Identical instrument has underflight with satellite
- Transfers fresh calibration to satellite instrument
- Limited to the EUV-FUV because of calibration accuracy

New Technique to Validate Time Series

- The Multiple Same-Irradiance-Level (MuSIL) analysis technique was developed to identify uncorrected instrument degradation trends.

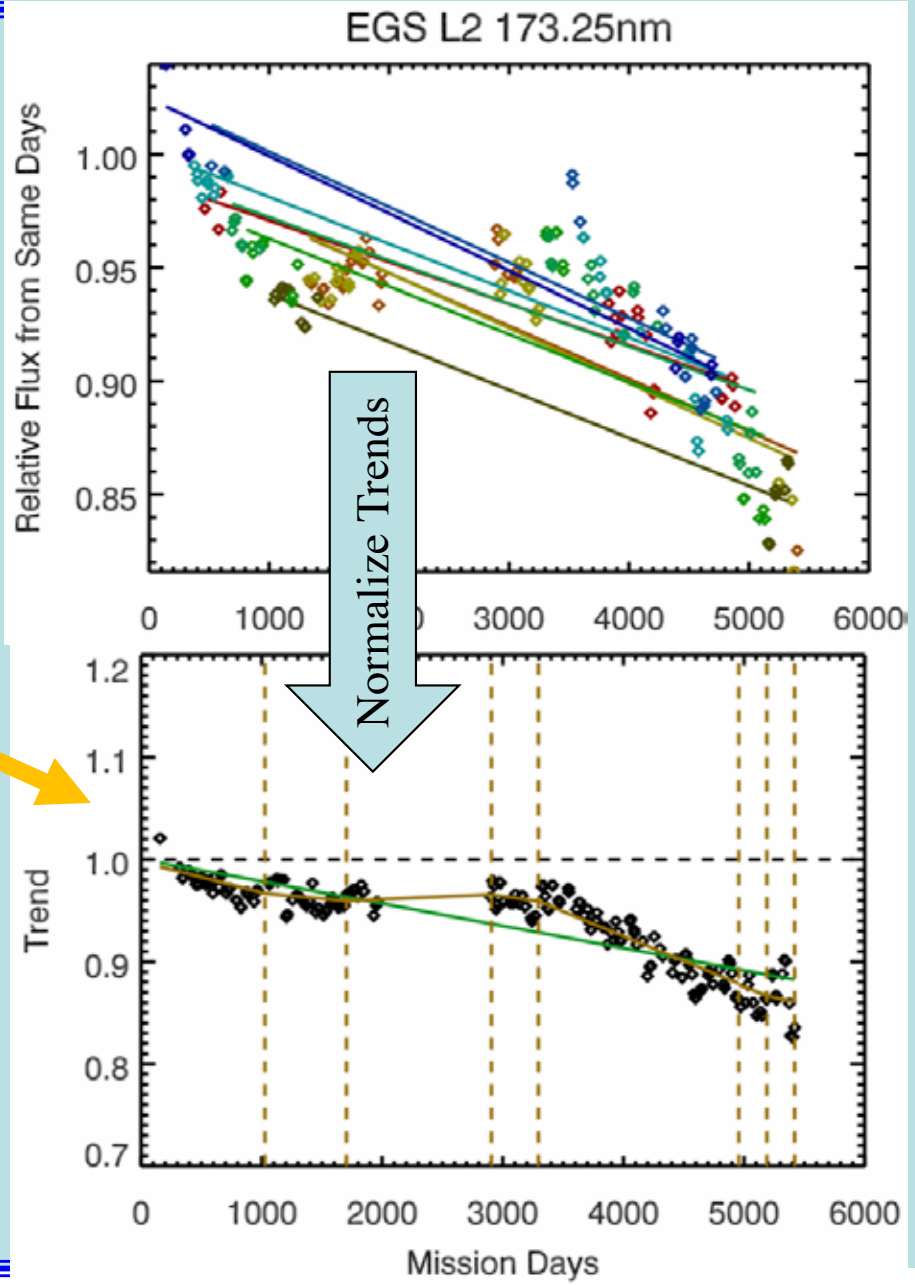




Same-Irradiance-Level → solar cycle and instrument trends

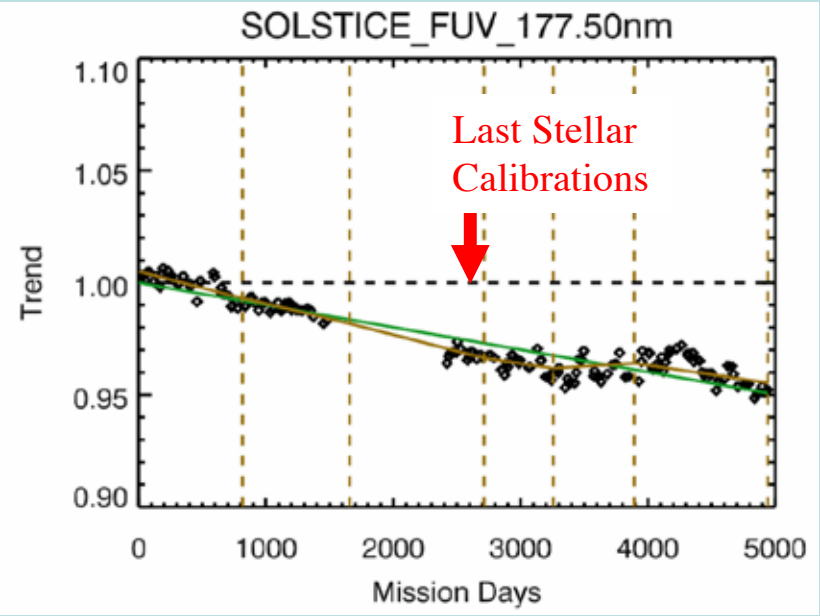
New Technique to Validate Time Series

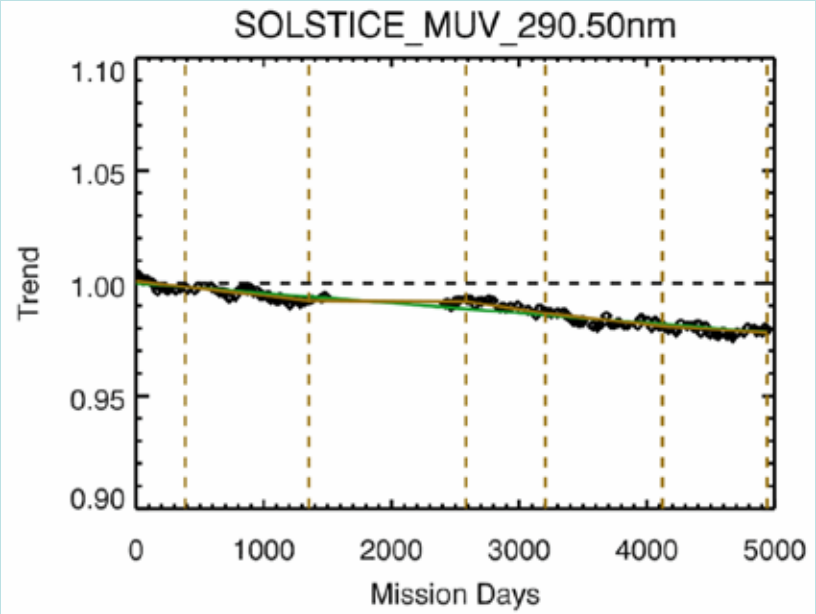
- Combining the trends from 8 levels provides a trend that indicates an uncorrected instrument degradation trend.
  - *This is NOT proxy model of the data.*
- This trend is fit with piecewise linear fits (gold lines).
- Uncertainty is estimated to be 5-10% of solar cycle variability.
- *Method weakness is that it leaves gap during solar cycle minimum.*



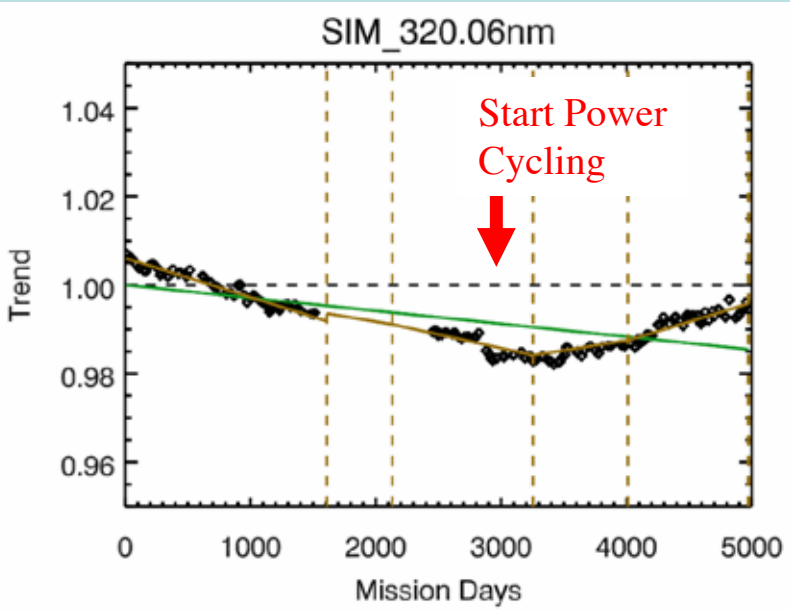
Example Instrument Degradation Trends using MuSIL Method

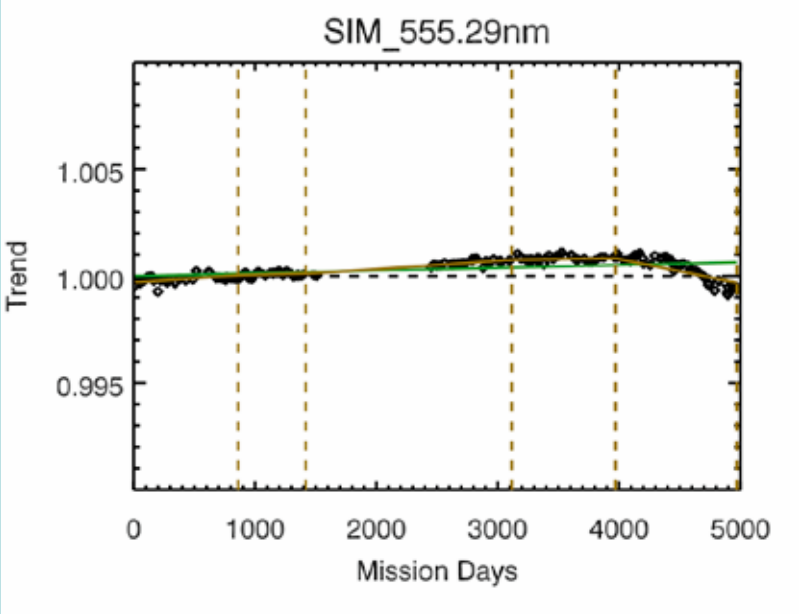
SORCE SOLSTICE





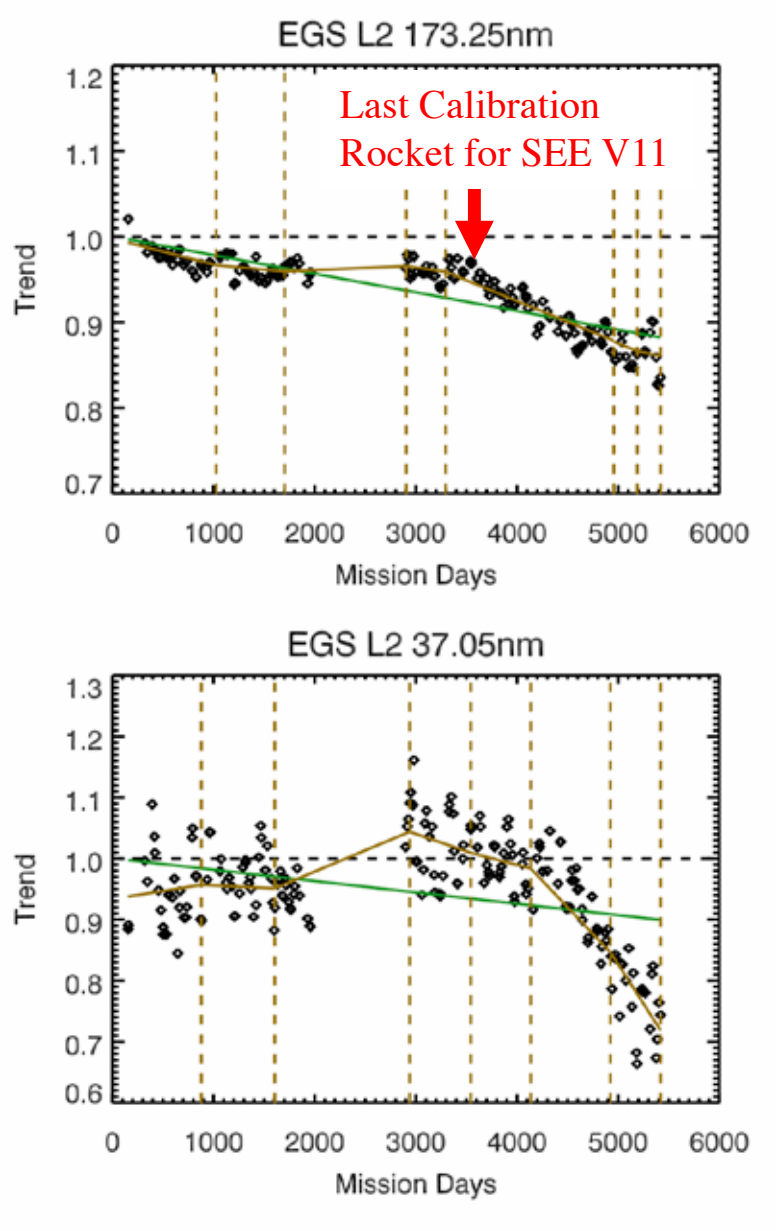
SORCE SIM



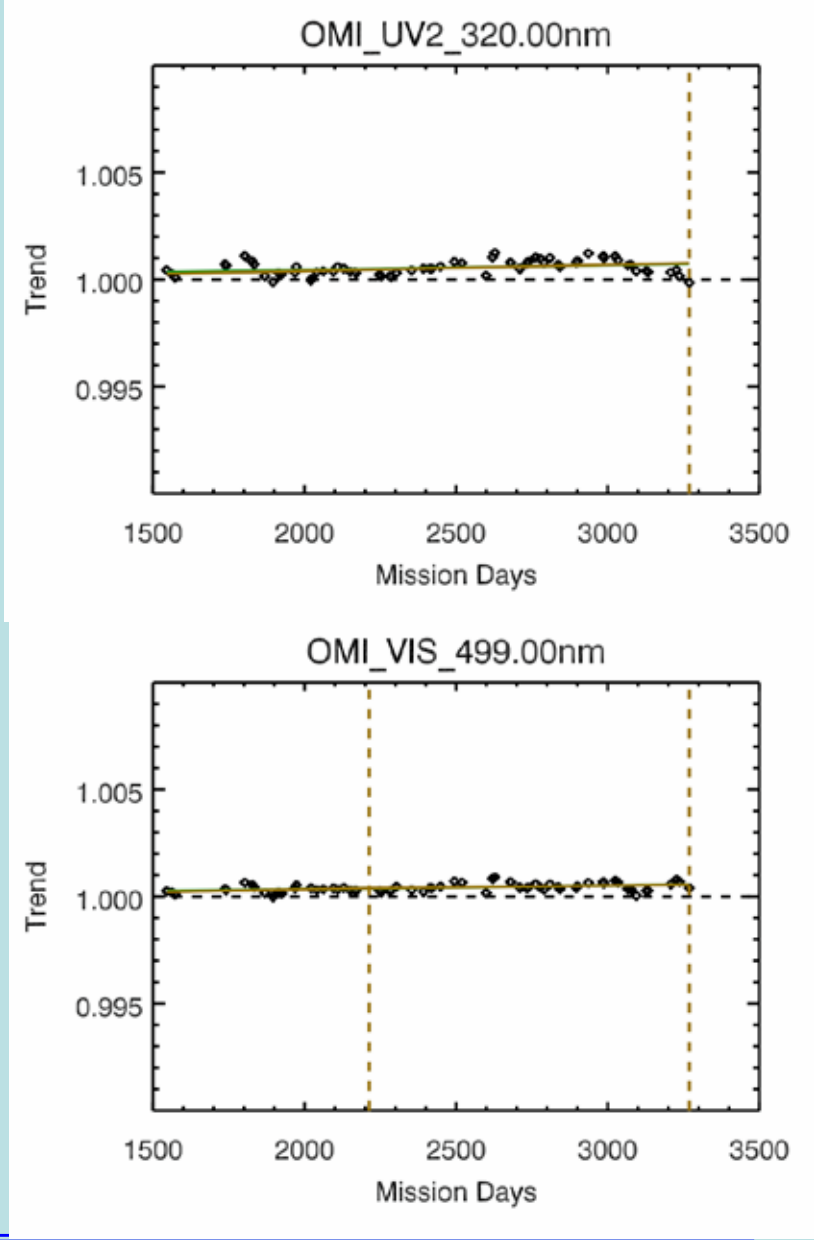


Example-2 Instrument Degradation Trends using MuSIL Method

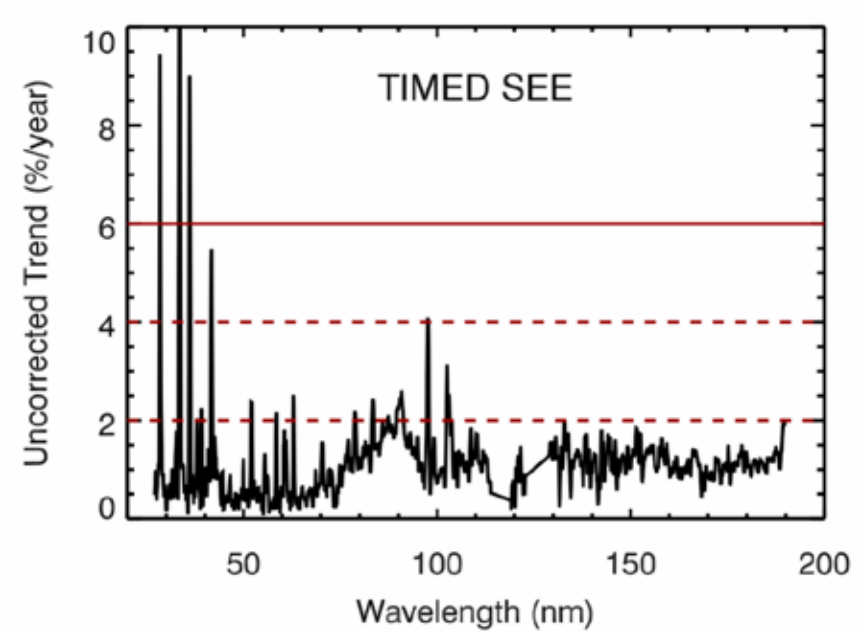
TIMED SEE EGS

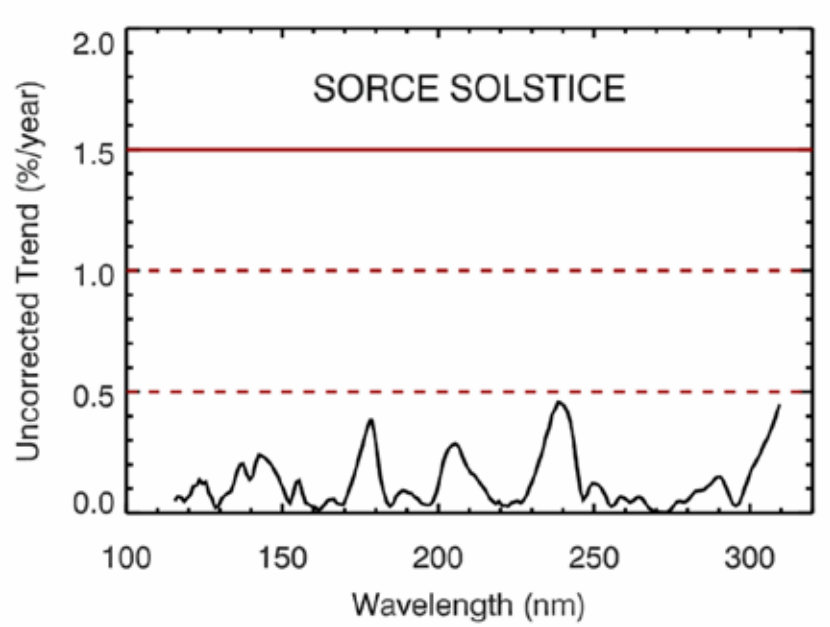


OMI Solar

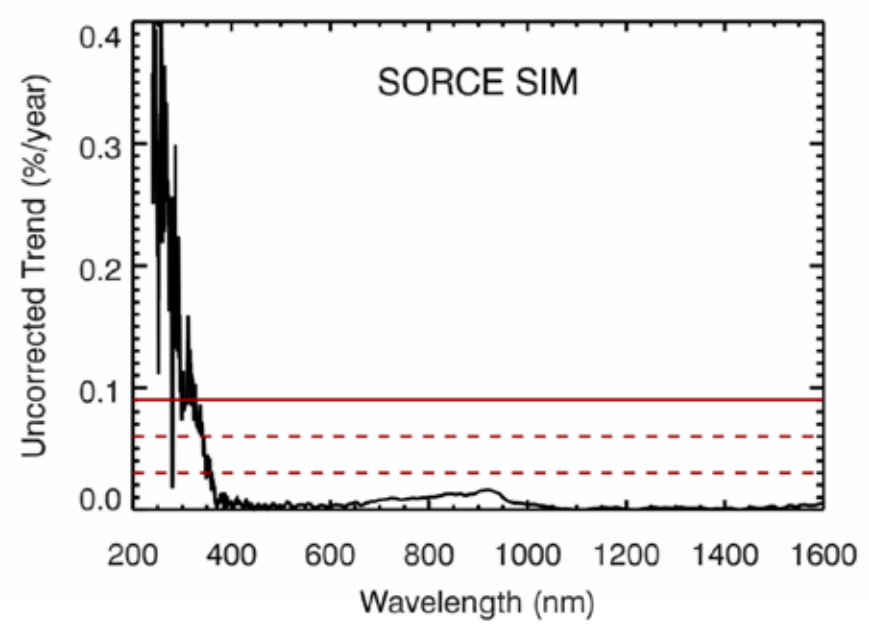


MuSIL Results are Less Than Degradation Uncertainties



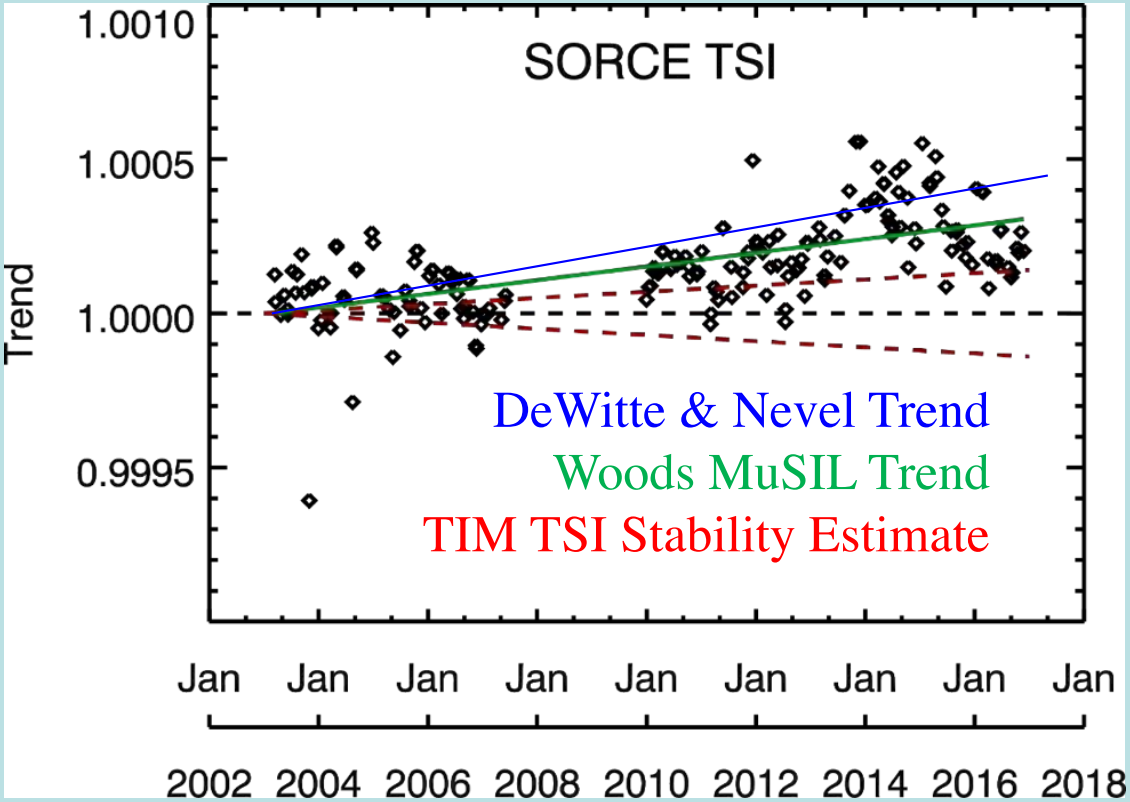


- Average rates for uncorrected degradation trend are shown.
- Original data product's estimated stability uncertainties are shown in red as 1-σ, 2-σ and 3-σ levels.

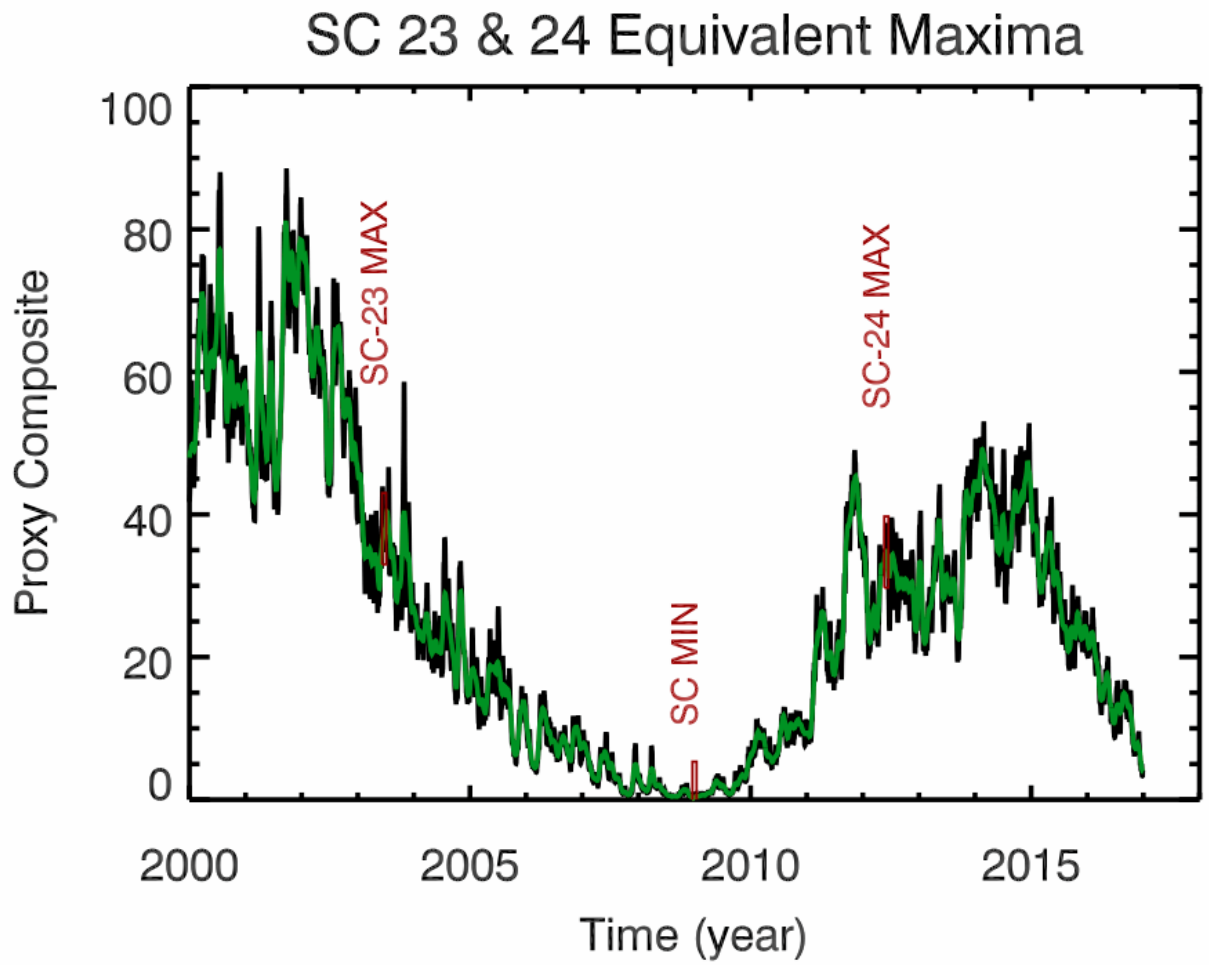


SORCE TIM TSI Trend

- MuSIL analysis of TIM TSI is used to validate the MuSIL technique, but it does show an upward trend.
  - **MuSIL Trend is within 2-σ of** TIM's stability estimate of 10 ppm/year
- DeWitte & Nevel [2016] suggest there is SORCE TSI trend in comparison to other TSI records.



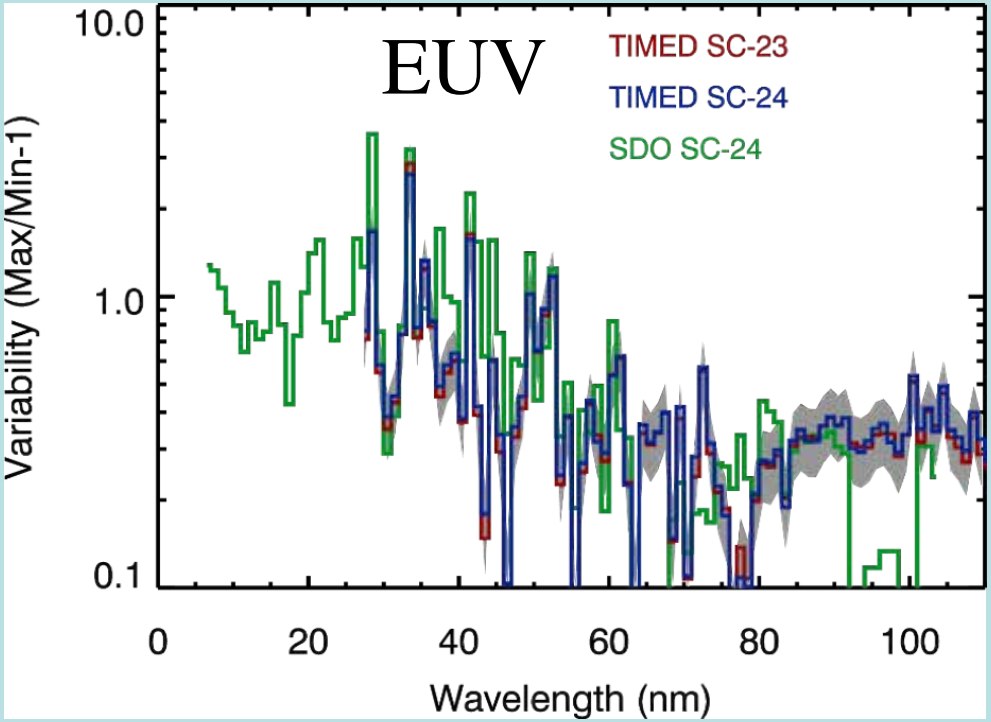
Pick 27-day Averages for Equivalent Maxima

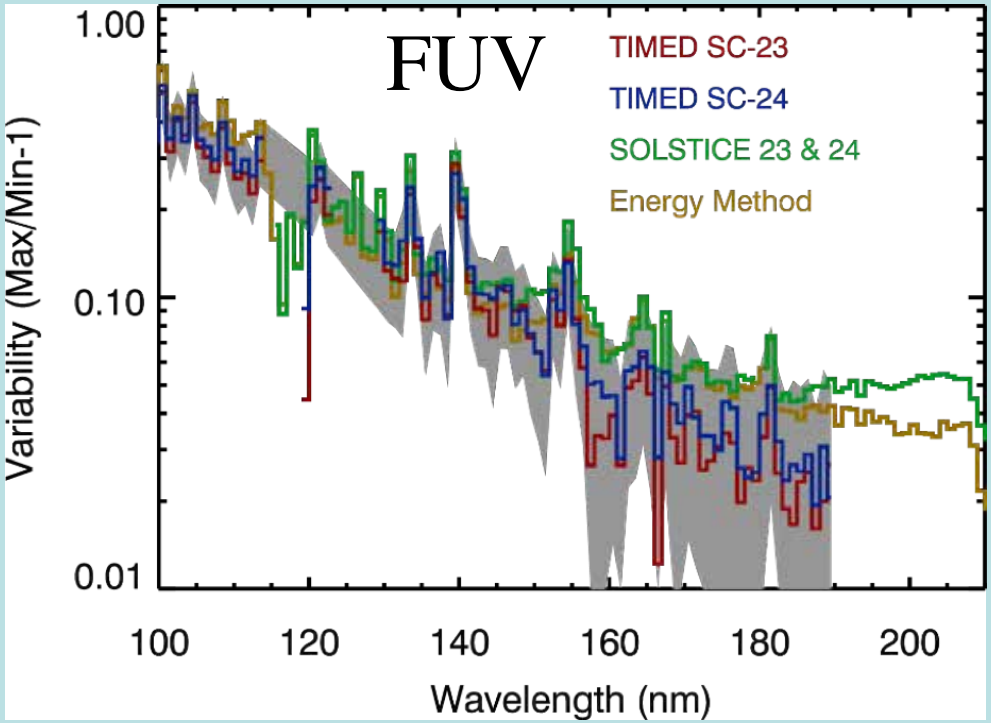


- *SC-23 Maximum*
  - *June 21, 2003*
- *Minimum*
  - *Jan. 1, 2009*
- *SC-24 Maximum*
  - *June 2, 2012*

Expect SC-23 MAX and SC-24 MAX to have similar SSI variability

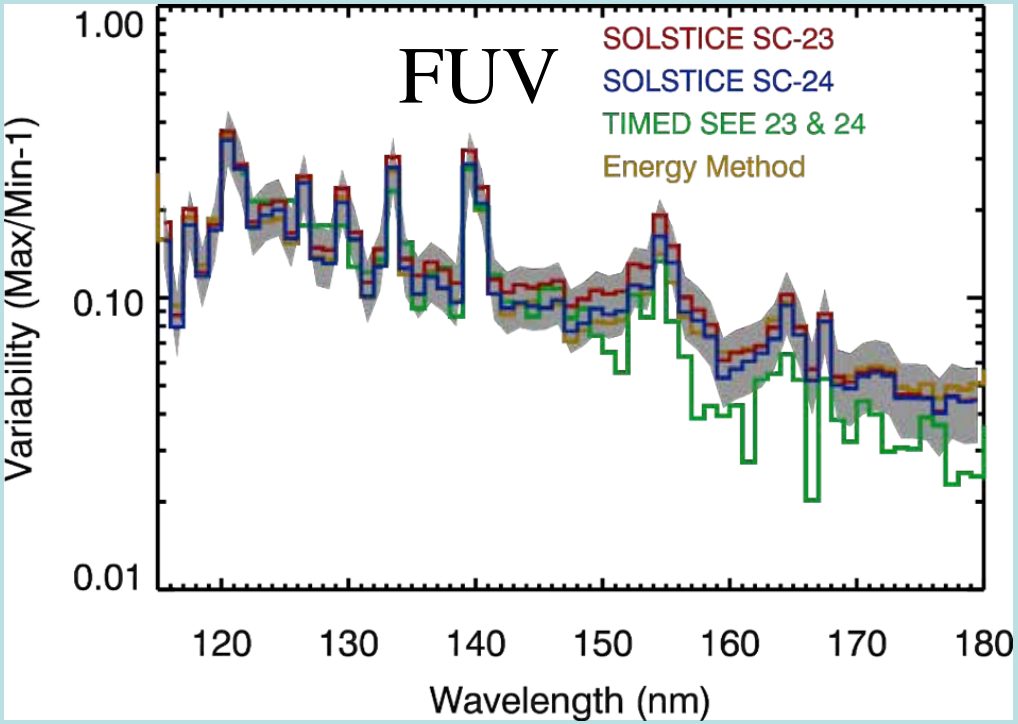
New Solar Cycle Variability Results: TIMED SEE

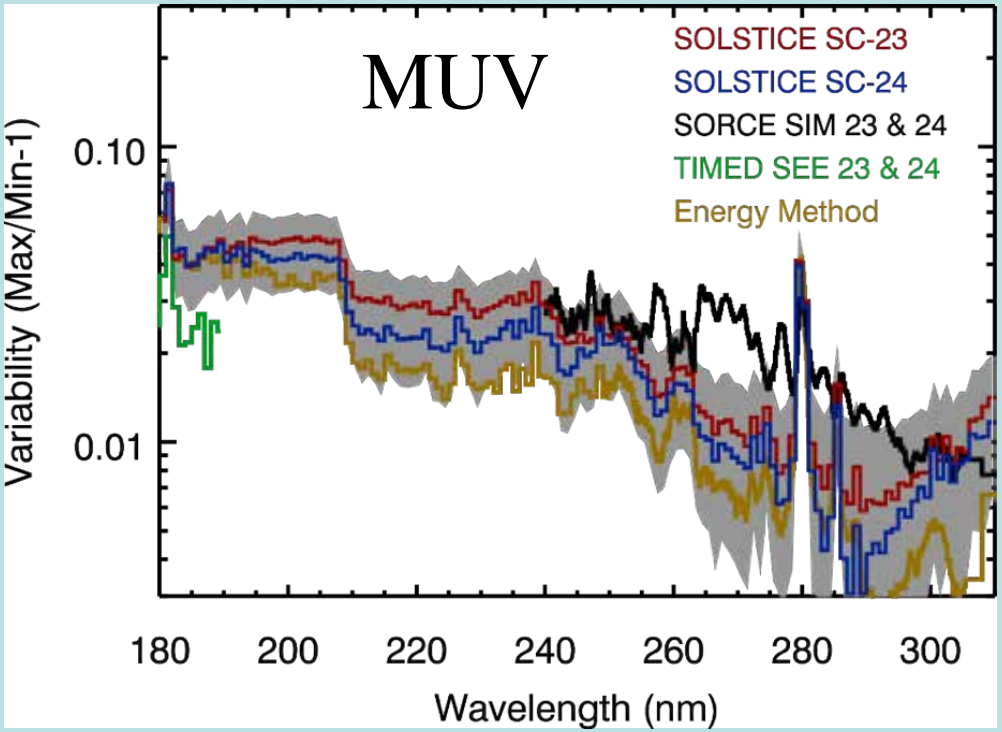




- TIMED SEE Extreme Ultraviolet (EUV) and Far Ultraviolet (FUV) at < 150 nm are consistent with other estimates.
- **New MuSIL result has improved results for TIMED SEE solar cycle variability, primarily for wavelengths > 150 nm.**

New Solar Cycle Variability Results: SOLSTICE



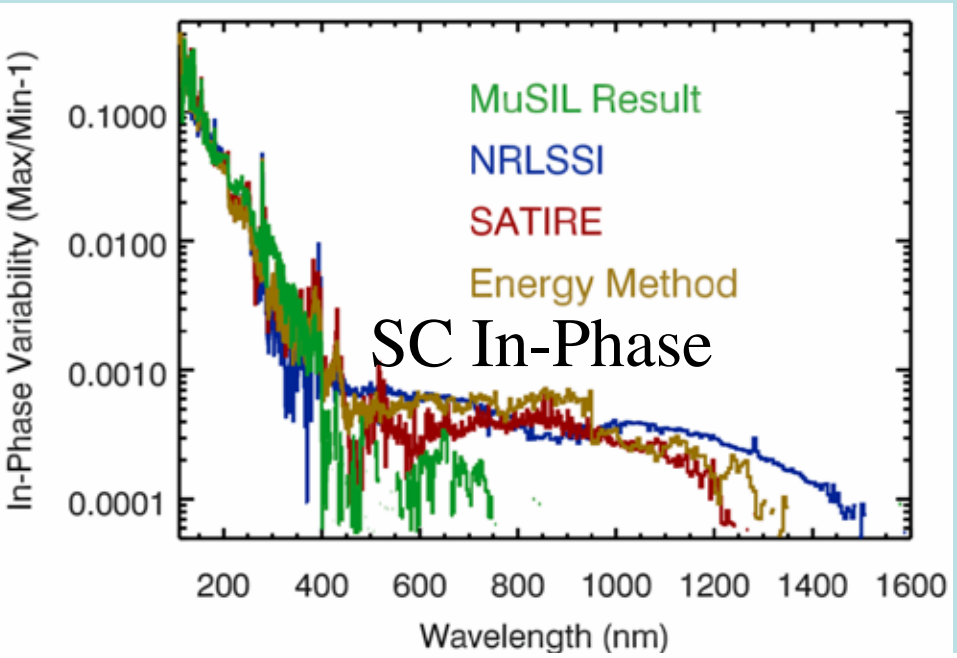


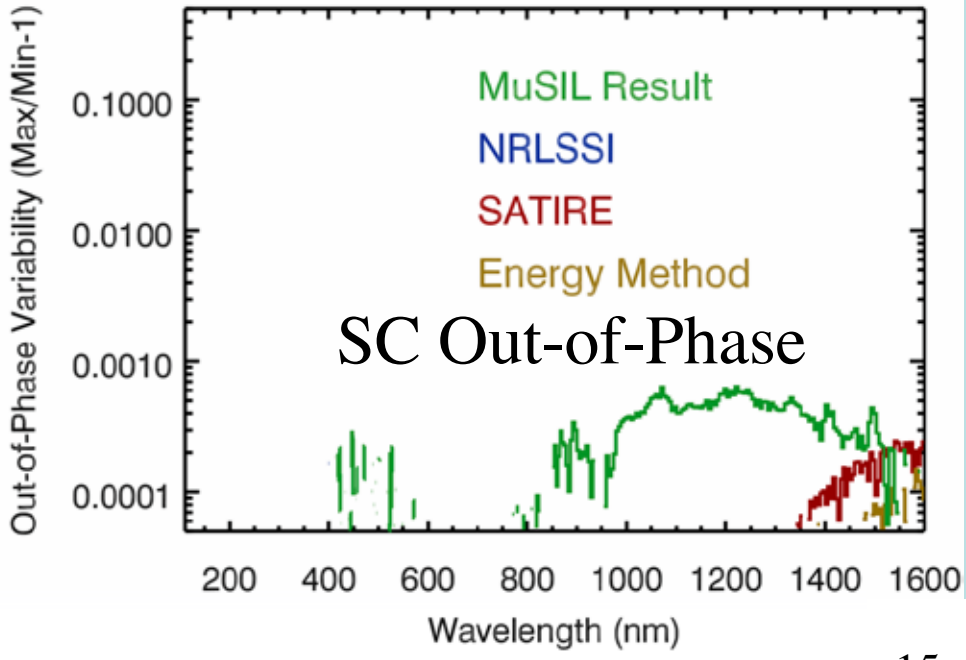
- SORCE SOLSTICE Far Ultraviolet (FUV) and Middle Ultraviolet (MUV) are consistent with other estimates.
- **New MuSIL result has improved results for SOLSTICE solar cycle variability, primarily for wavelengths > 210 nm.**

New Solar Cycle Variability Results: SORCE SIM

- SIM provides results in the Near Ultraviolet (NUV), Visible, and Near Infrared (NIR).
- The SIM NUV solar cycle variability at < 400 nm is consistent with other estimates.

- New MuSIL result has out-of-phase wavelengths for 800 nm to 1600 nm. This is more consistent with Harder *et al.* [2009] result than the models.

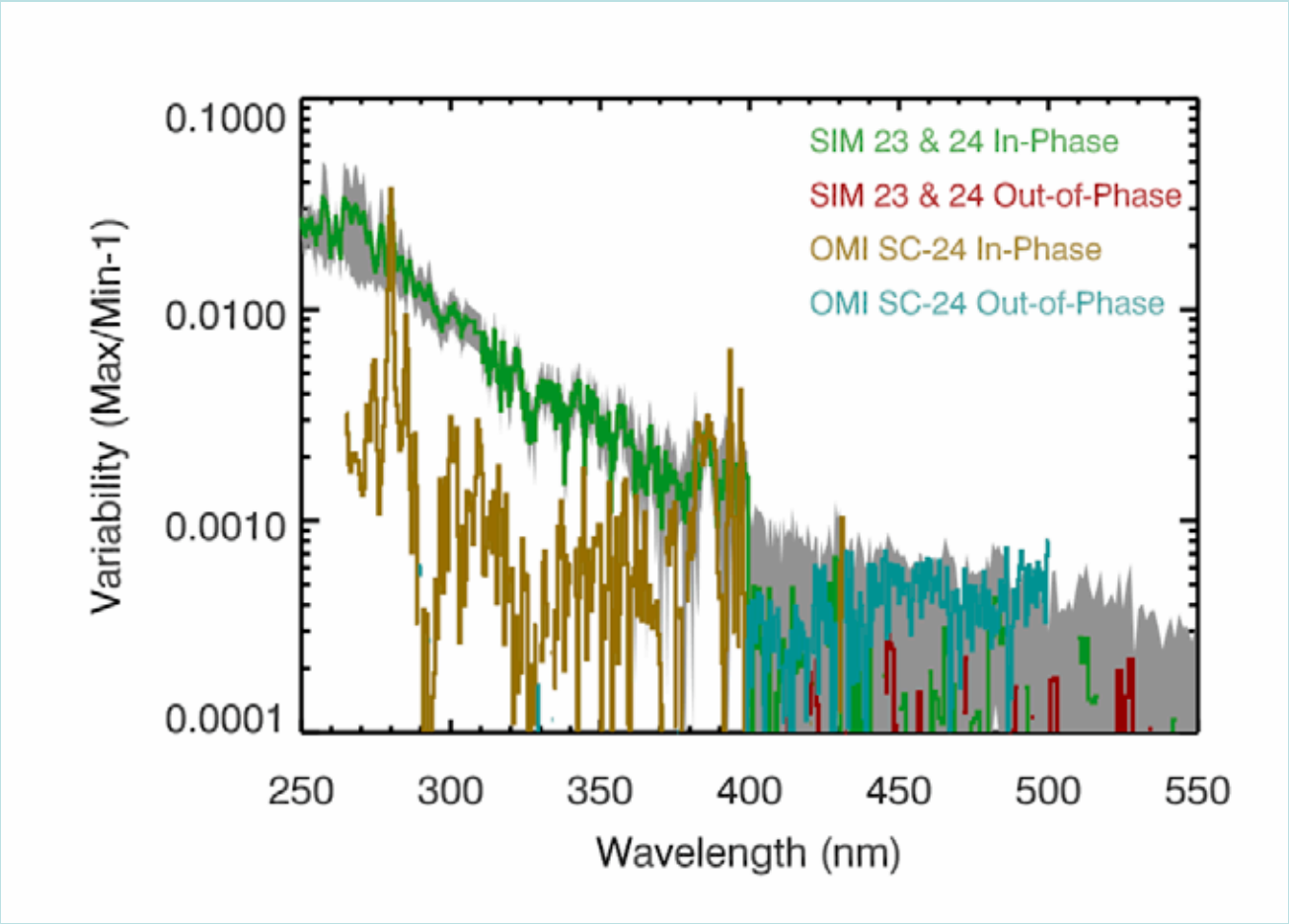




Comparison of SORCE SIM and OMI Results

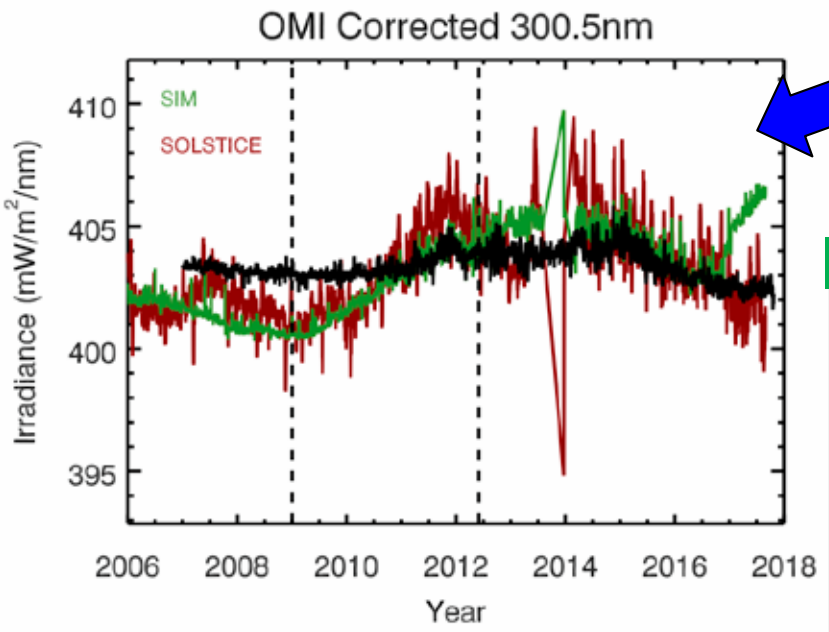
SORCE SIM
200-2400 nm

OMI solar
265-500 nm



- SIM and OMI agree best for the Mg and Ca chromospheric emissions near 280 nm and 390 nm.
- Solar cycle variability longer than 400 nm are less certain.

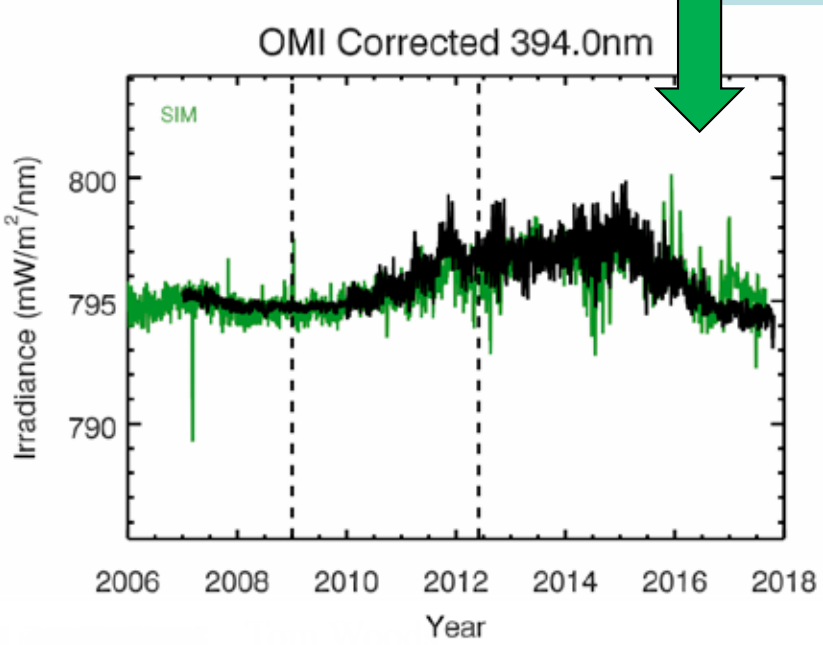
Comparisons of SORCE SIM and OMI Time Series

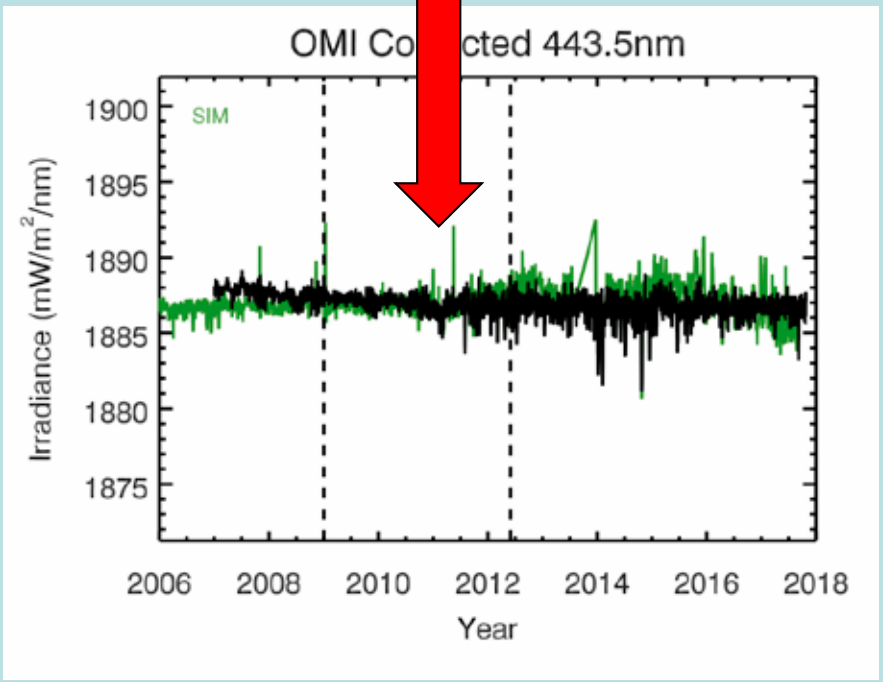


SORCE SIM and SOLSTICE indicate more MUV variability

SORCE & OMI agree well at some wavelengths

- OMI also has out-of-phase results

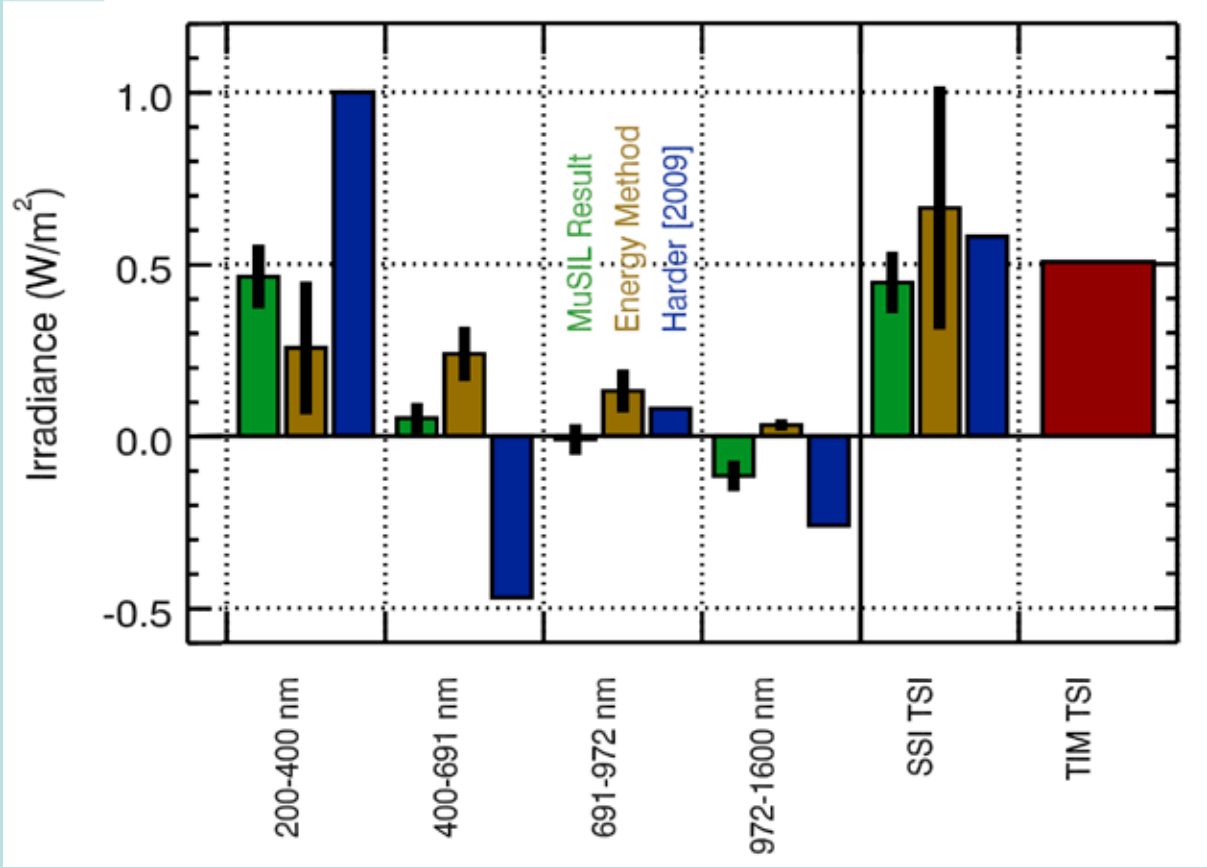




SORCE SSI Solar Cycle Variability Comparison

- Harder et al. (*GRL*, 2009)
  - Half-cycle can be ***sensitive*** to instrument degradation trend
  - 4/2004 (Max) – 2/2008 (Min)
- Multiple Same-Irradiance-Level (MuSIL) Analysis
  - New technique developed to identify uncorrected instrument degradation trend (Woods, 2017)
- Energy Method Model
  - SFO excess and deficit proxies fitted over 6-month periods are integrated over time (energy)
  - Modeling over 6-month periods is ***not sensitive*** to long-term instrument trends
  - Woods et al., *Solar Phys.*, 2015

Variability = Max - Min



Summary of Results

- New solar cycle variability results show better consistency between different solar cycles and different measurements from 6 nm to 1600 nm for 2002-2017 (SC 23-24).
- Future work is to extend the MuSIL technique for other data sets during SC 21-22 and then to improve the SSI composite record from the 1970s to the present.

Solar Cycle	Instrument	Spectral Range
SC 22	UARS SUSIM & SOLSTICE	117-410 nm
SC 21	SME / SBUV	115-300 nm / 160-400 nm

- More details about the MuSIL method are available in a paper:
  - Woods *et al.*, Decoupling Solar Variability and Instrument Trends using the Multiple Same-Irradiance-Level (MuSIL) Analysis Technique, *Solar Physics*, in review, 2018