Sun-Climate Symposium: Session 4, Presentation 12

A Different View of Solar Cycle Spectral Variations

Modeling Total Energy during Six-Month Intervals

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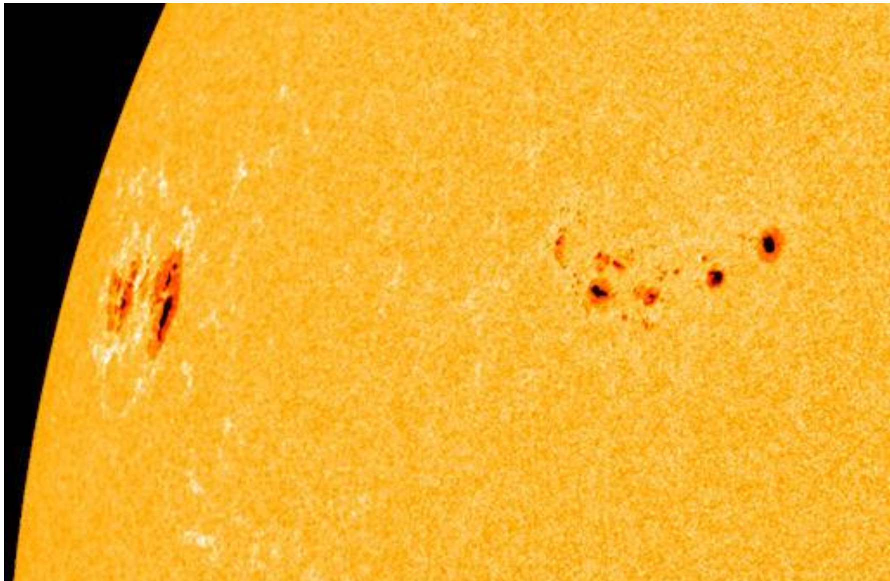
TIMED SEE V11: Frank Eparvier

SFO Proxies: Gary Chapman and Angie Cookson

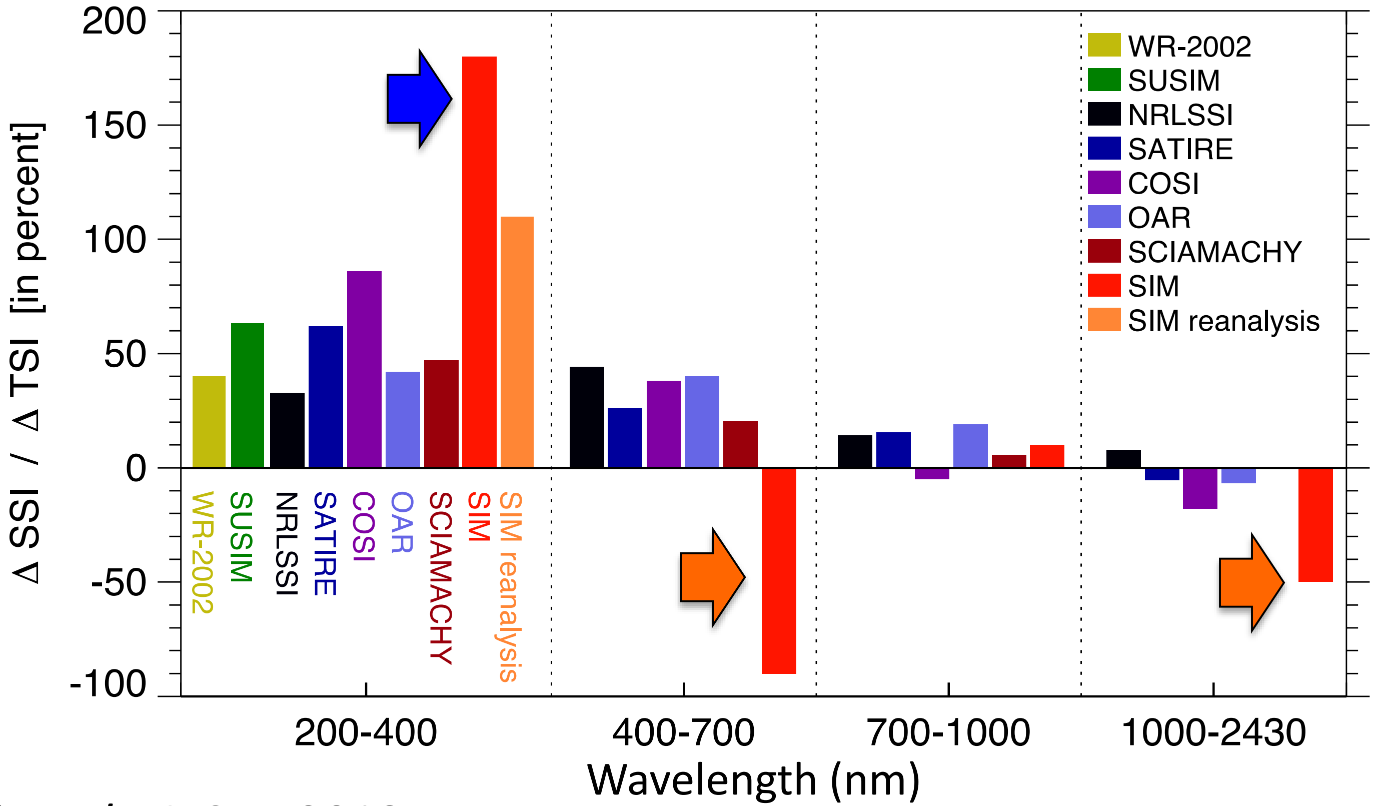


PART 1

MOTIVATION TO MODEL 6-MONTH INTERVALS

Why model six-month intervals?

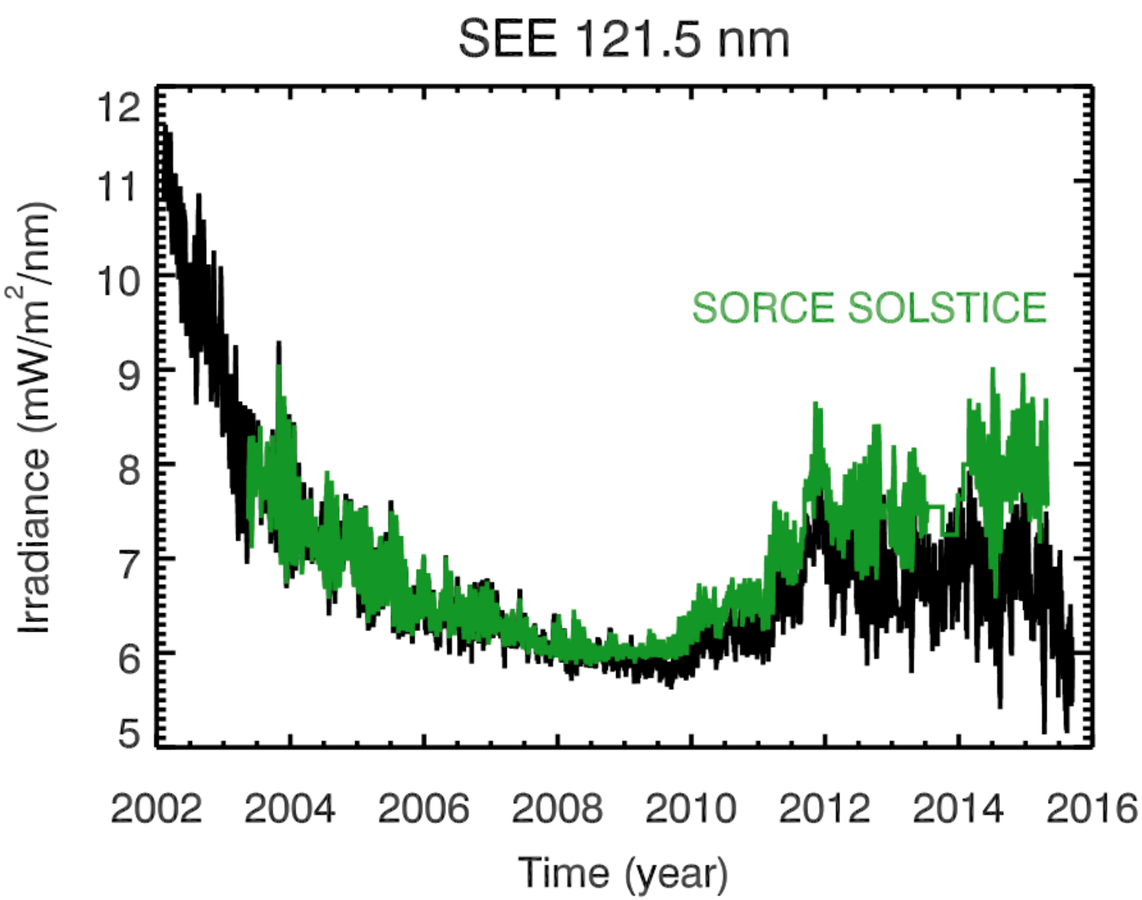
- Different analysis technique could shed some light on the debate about the SORCE SIM results of **out-of-phase variations** for visible and near infrared and **larger ultraviolet variations** (Harder *et al.*, *GRL*, 2009)



From Ermolli *et al.*, *A.C.P.*, 2013

Why model six-month intervals?

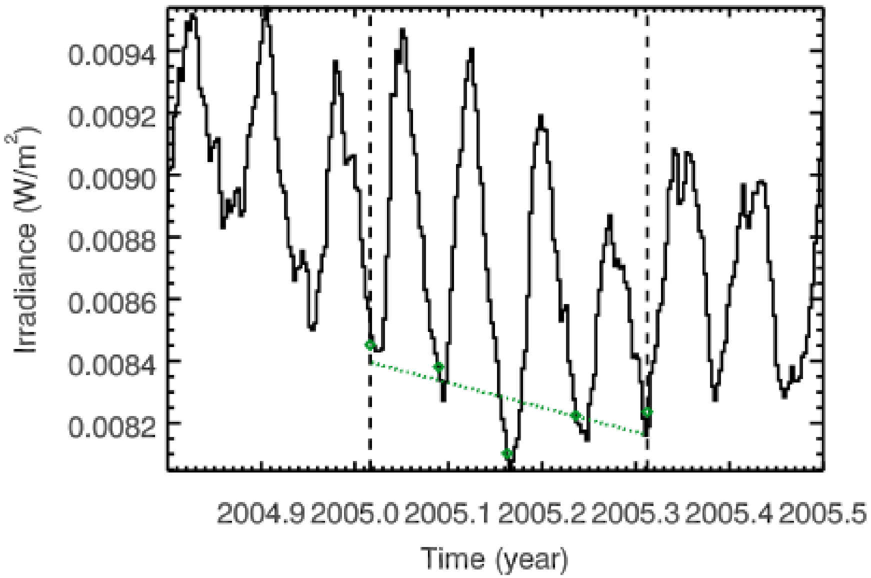
- Modeling longer term (e.g. 11-year solar cycle) variations can be sensitive to instrument degradation trending.



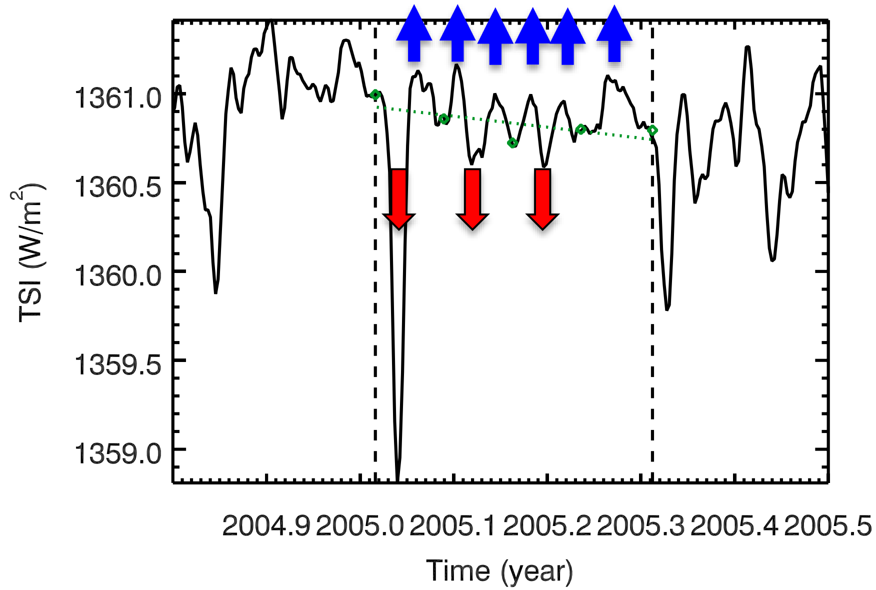
Why model six-month intervals?

- Modeling short-term (e.g. 27-day solar rotation) needs both **positive** and **negative** components for the TSI and NUV-Vis-NIR SSI
- Short-term UV variability only has **positive** component

FUV 115-150 nm: All Positive Peaks



TSI is most similar to 400-1600 nm



Energy == Integration of Irradiance above background over time

UV Energy: always positive

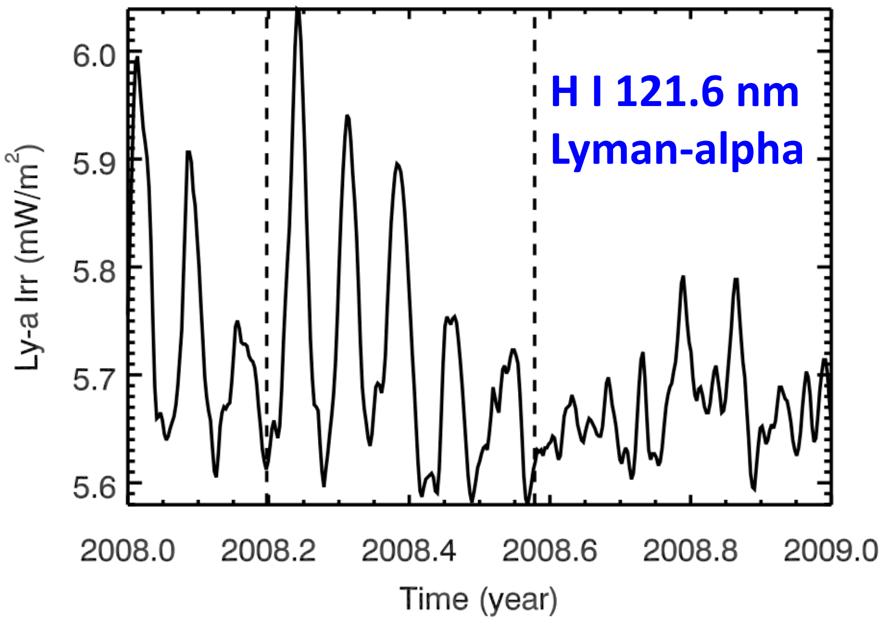
TSI Energy: positive or negative ?

Why model six-month intervals?

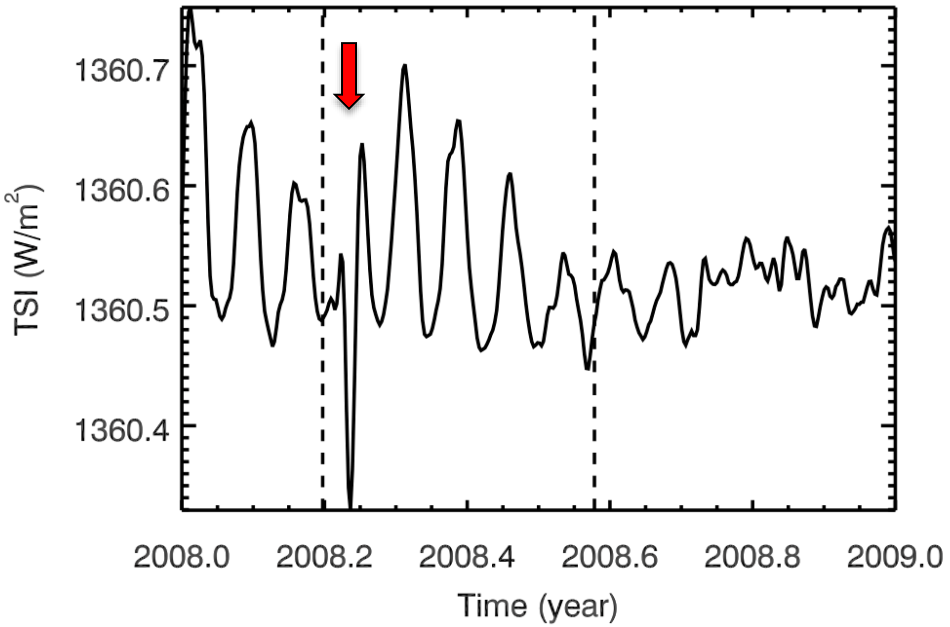
- The lifetime of solar active regions is about 6 months.
  - e.g. Preminger & Walton, *JGR*, 2005
- Woods *et al*. (*Solar Physics*, 2015) explore the energy variability over six-month intervals

<u>Outburst Behavior for New Active Region</u>

Ultraviolet (UV) has large peak followed by weaker peaks for about 5 months.



Total Solar Irradiance (TSI) has dip for new sunspot and then peaks like the UV.



PART 2

MODEL PARAMETERS

Irradiance, Variability, Energy Definitions

Parameter	Equation	Units
Irradiance	I	TSI, Band: W/m^2 SSI: W/m^2/nm
Variability	$V = I - I_{min}$	TSI, Band: W/m^2 SSI: W/m^2/nm
Relative Variability	$V_R = \frac{I - I_{min}}{I_{min}} = \frac{I}{I_{min}} - 1$	%
Energy (outburst, 6 months)	$E = \int_{t_o}^{t_e} V\, dt$	TSI, Band: J/m^2 SSI: J/m^2/nm
Relative Energy	$E_R = \left(\int V_R\, dt \right) / t_{days}$	%

2-Component Solar Variability Model

$$Variability = Daily/Min - 1$$

$$Variability = C_0 + C_E \cdot P_E + C_D \cdot P_D$$

Constant
(ideally zero)

Positive Component
facular Excess

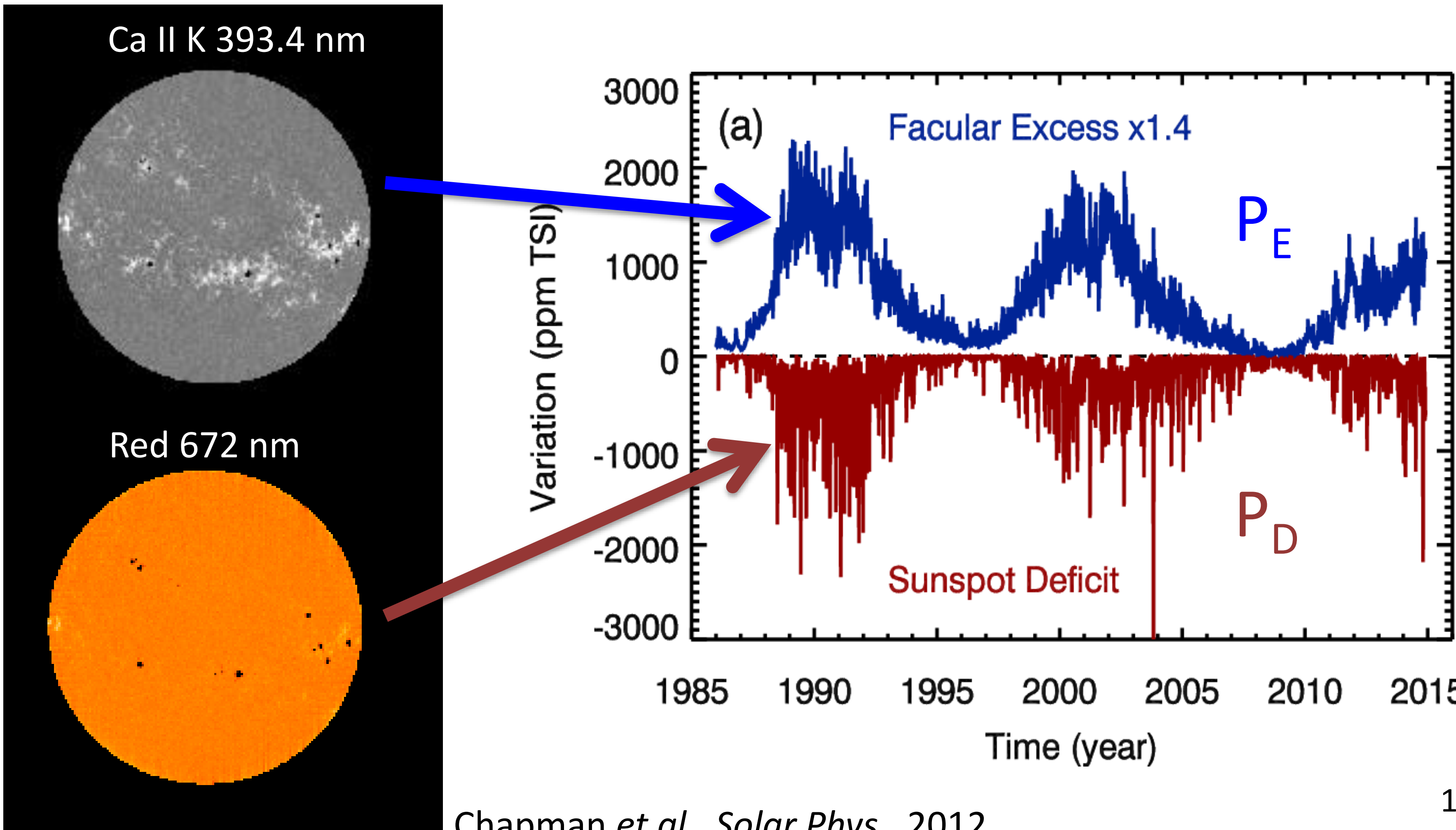
Negative Component
sunspot Deficit

- *Premise: spectral variability for one active region (outburst) can be related to longer term (solar cycle) variations that involves many active regions.*
  - Decomposition of solar images indicate that active regions are the primary source of irradiance variability
    Skumanich *et al*., 1984; Lean *et al*., 1997; Fontenla *et al*., 1999; Worden *et al*., 1998, 1999

Important Change from prior studies: energy variability (E, E_R) is examined instead of irradiance variability (V, V_R)

SFO Proxies for Modeling SSI Variations

- San Fernando Observatory (SFO) processes images of the Sun at 672 nm for Sunspot Deficit and at 393.4 nm (Ca II K) for Facular Excess
  - http://www.csun.edu/sfo/sfosolar.html



Chapman *et al.*, *Solar Phys.*, 2012

Parameters for Energy Variability Model (EVM)

Woods *et al.*, *Solar Physics*, 2015

- Energy (E) is the irradiance (I) integrated over 6-months
- Average energy variability is the average of the energy results for each 6-month period every 2-months over the mission.

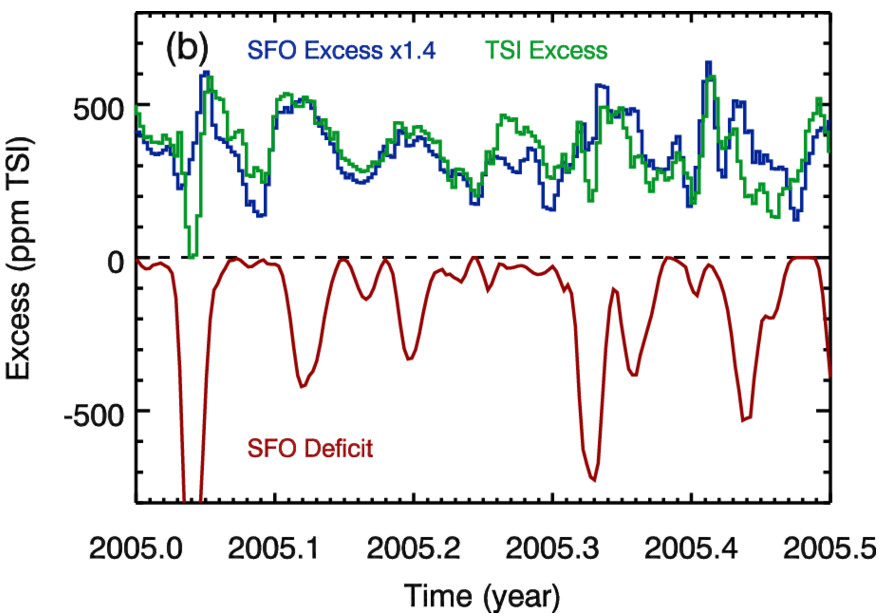
E = Energy:

$$E_R = \left(\int V_R \, dt \right) / t_{days} \qquad V_R = \left(I - I_{min} \right) / I_{min}$$

2 Components: $V_R = C_O + C_E \, P_E + C_D \, P_D$

$$E_R = \left(\int C_E \, P_E \, dt \; + \; \int C_D \, P_D \, dt \right) / \; t_{days}$$

C_O, C_E, and C_D are fit using ***SORCE SSI*** measurements over 6-month periods.



- San Fernando Observatory (SFO) facular excess and sunspot deficit proxies are the P_E and P_D in the model.
  - TSI Excess (TSI – Sunspot Deficit) is used for 300-1600 nm instead of Ca II K facular excess

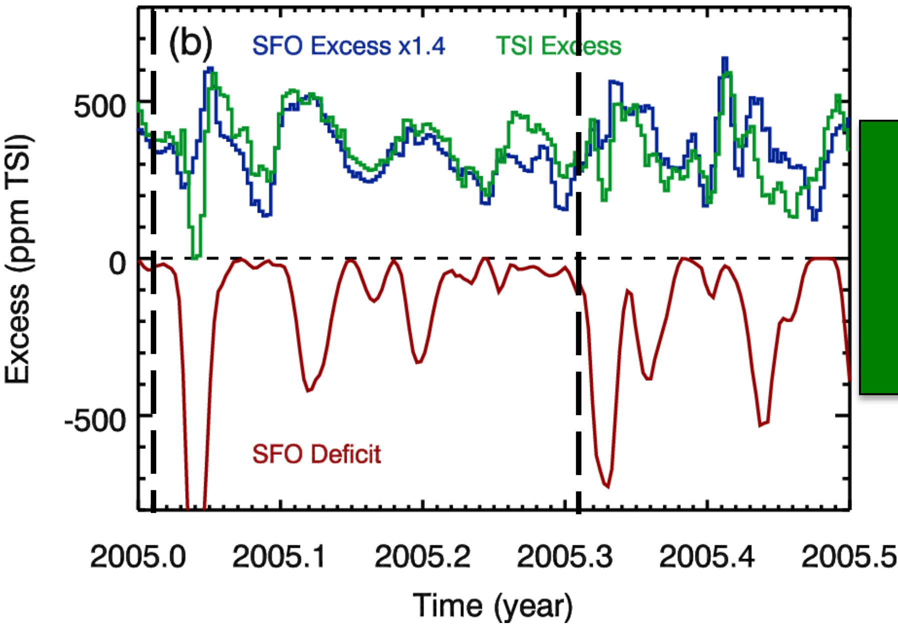
Example Modeling of the 2005 Outburst

- UV variations, such as **H I Lyman-α**, only need the Facular Excess
- NUV-Visible-NIR and **TSI** need both Sunspot Deficit and Facular Excess

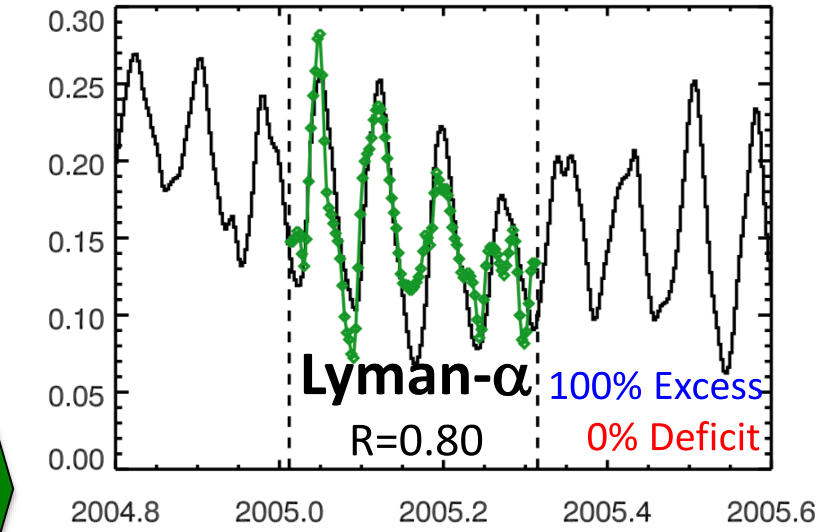
Green is Model Fit

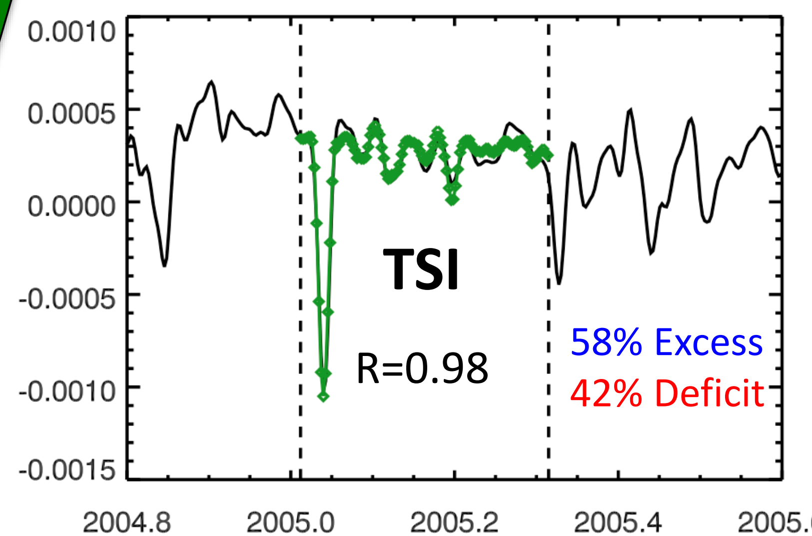
$$Variability = Daily/Min - 1$$

$$Variability = C_0 + C_E \cdot P_E + C_D \cdot P_D$$



Lyman-α SC Variability is large (60%)
TSI SC Variability is small (0.07%)
BOTH are in-phase with solar activity.





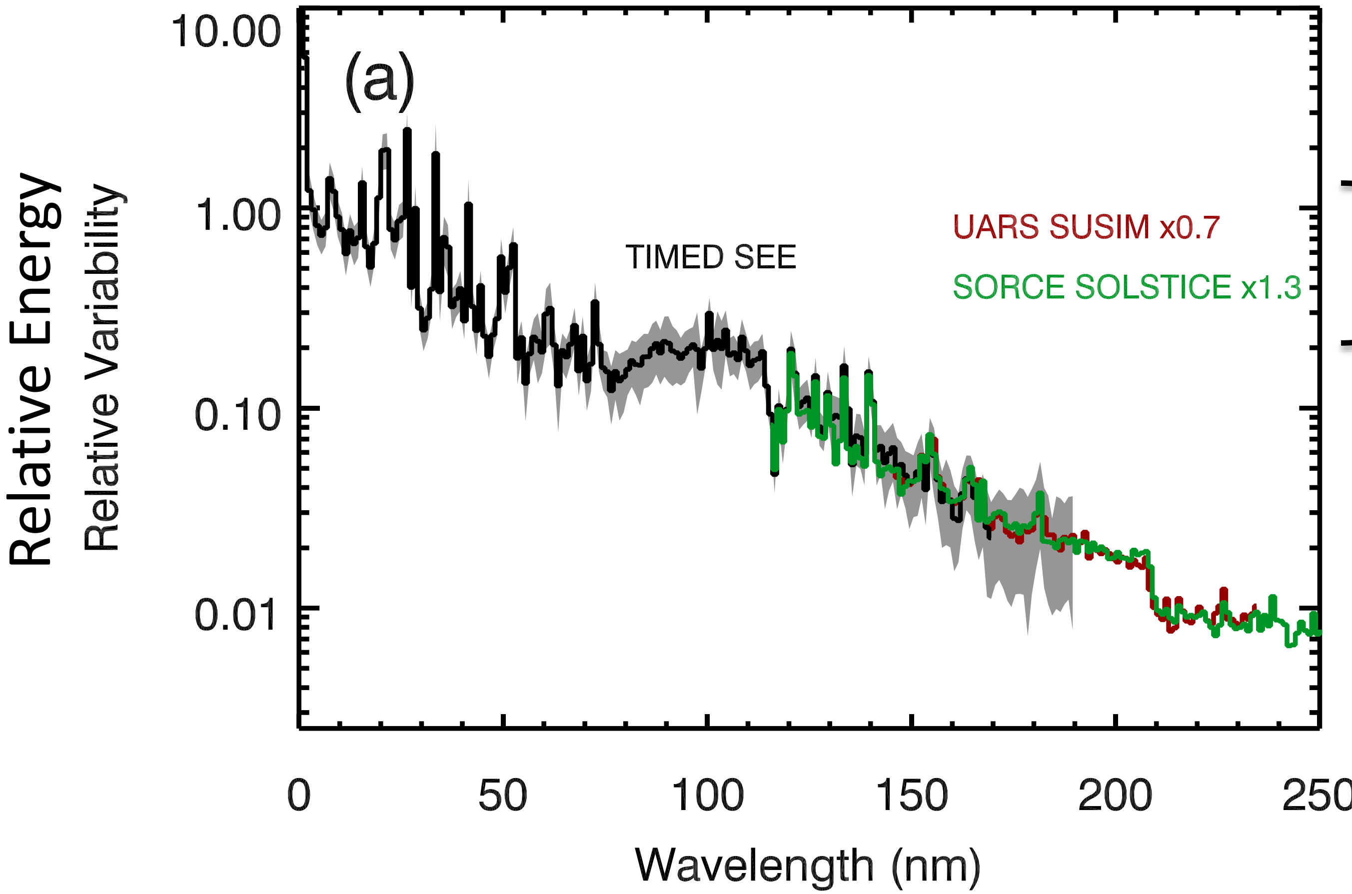
PART 3

VARIABILITY RESULTS

Excess (positive) Component Dominates in UV

- The Excess (positive, in-phase) component is the only component needed for wavelengths < 250 nm.
- The Deficit (negative, out-of-phase) component is <u>zero</u> for 0-250 nm.

Total Variability = Excess + Deficit



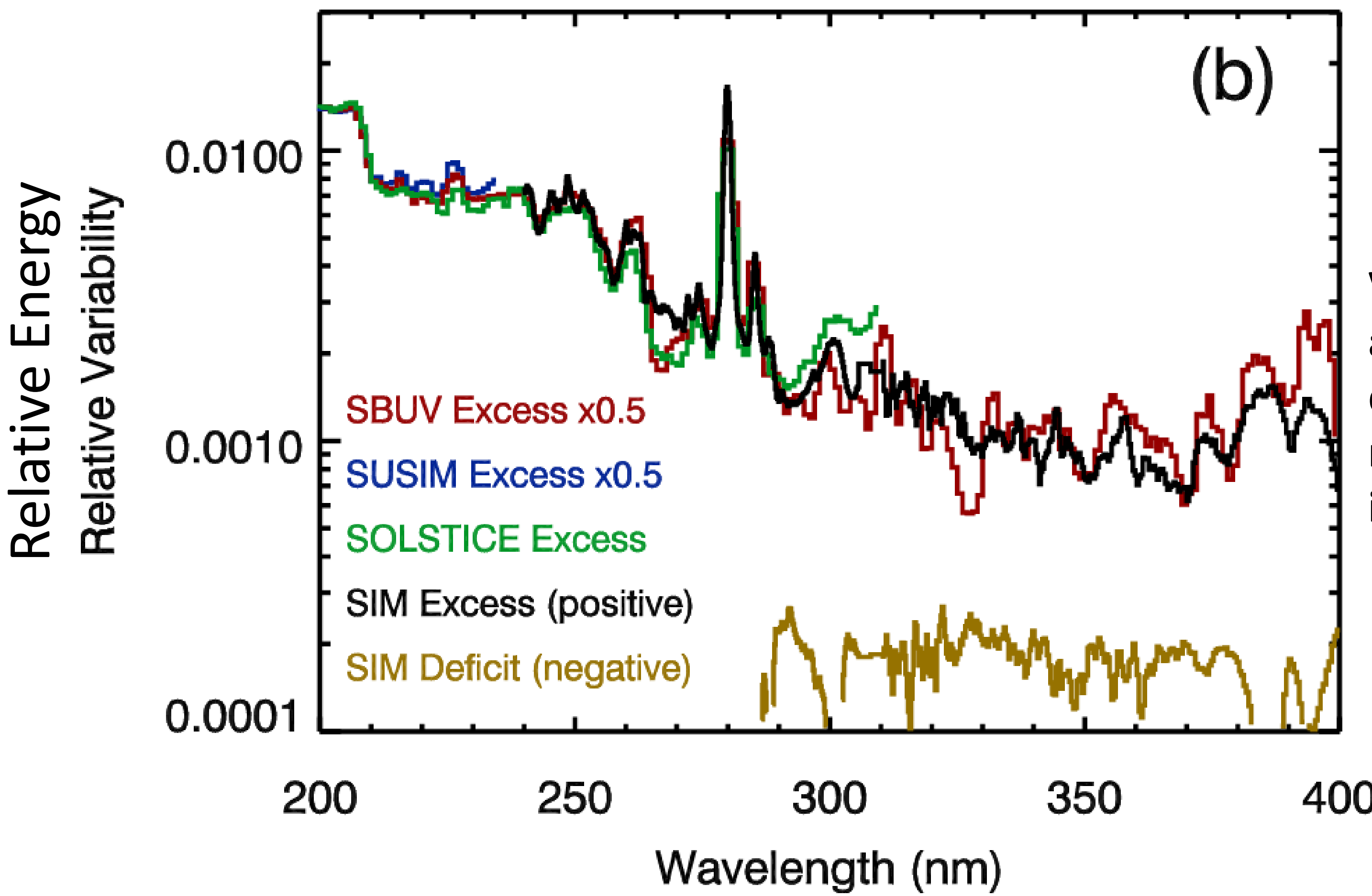
Scale Factors are different because model is fit over different parts of the solar cycle.

Excellent spectral agreement for different solar cycles.

Figure 4a in Woods *et al*. (*Solar Phys*, 2015)

Deficit Component Starts to Show at 290 nm

- The Excess (positive, in-phase) component still dominates up to 400 nm.
  - Excess contributions are shown for NOAA SBUV, UARS SUSIM, SORCE SOLSTICE, and SORCE SIM
- The Deficit (negative, out-of-phase) component appears > 290 nm.
  - Only the SIM deficit contribution is shown for clarity. The deficit is small contribution.

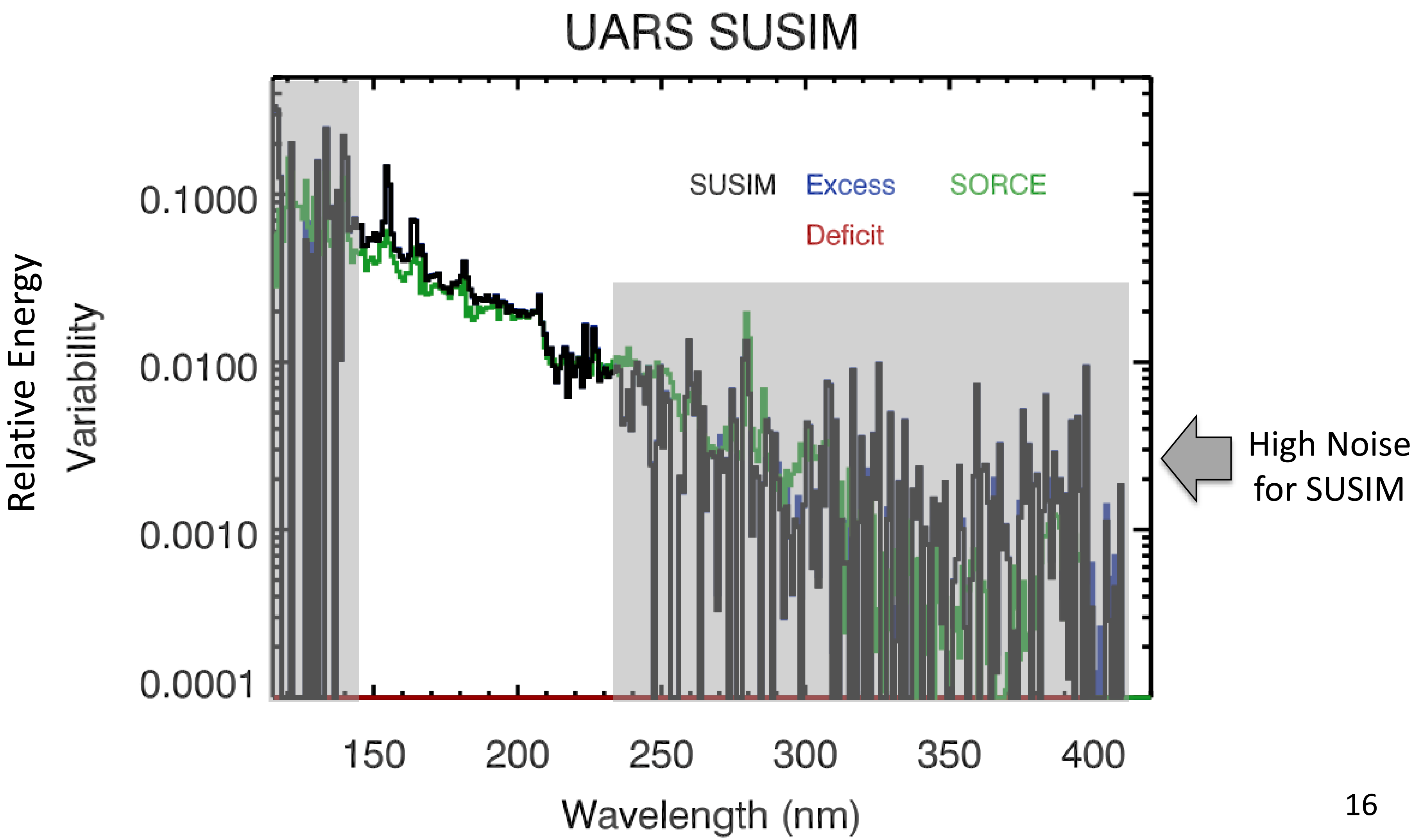


Very good spectral agreement for different solar cycles measured by four (4) instruments.

Figure 7b in Woods *et al*. (*Solar Phys*, 2015)

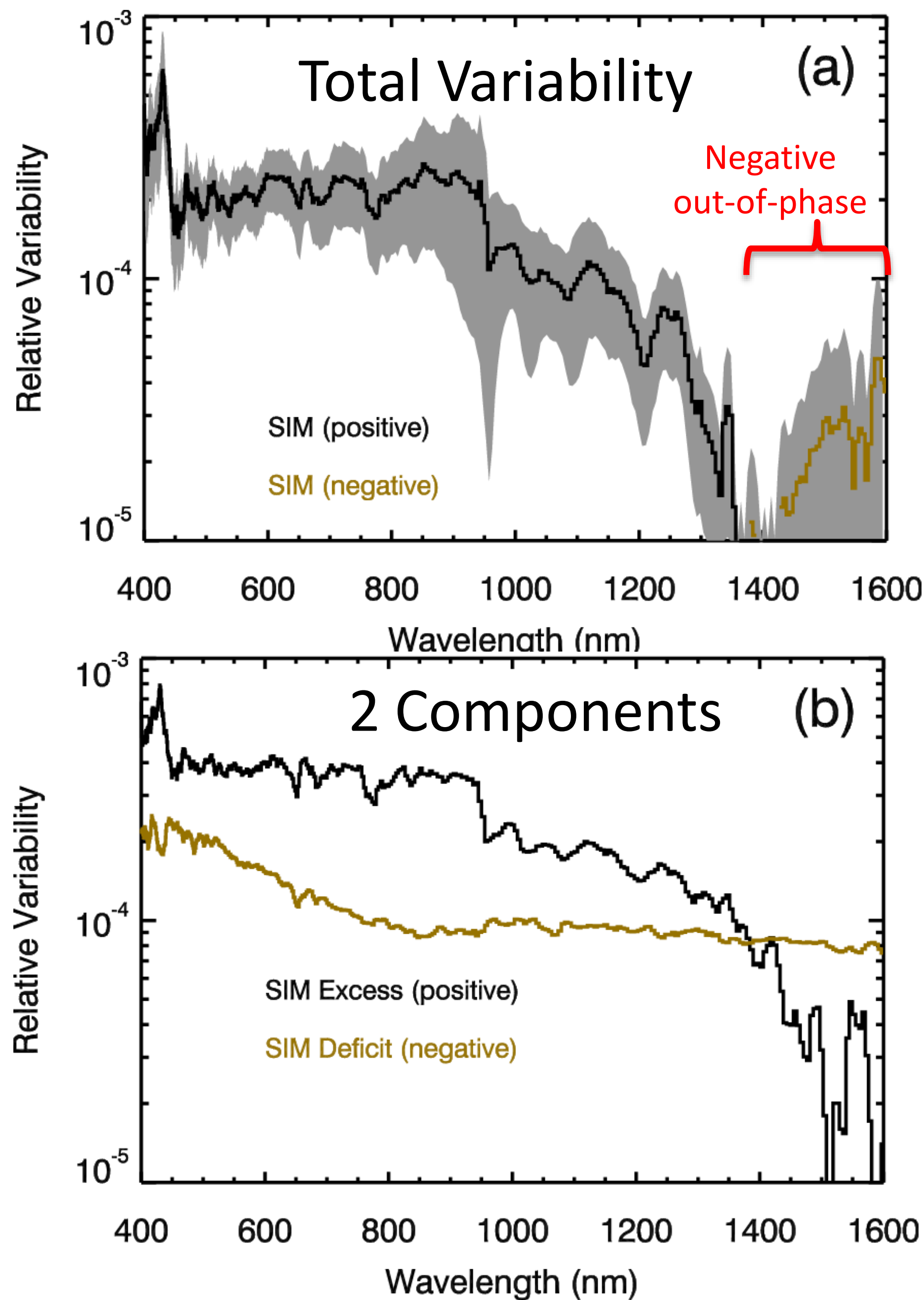
UARS SUSIM provides validation for 145-235 nm

- Day-to-day noise in the SUSIM is too high for precise model fits, except in the 145-235 nm range.



Deficit (negative) is very important in Vis-NIR

- Panel A shows the total energy variation
  - Excess dominates when total is positive (in-phase with solar cycle)
  - Deficit dominates when total is negative (out-of-phase with solar cycle)
- Panel B shows the two components (**excess** and **deficit**). Add these two together for the total shown in Panel A.

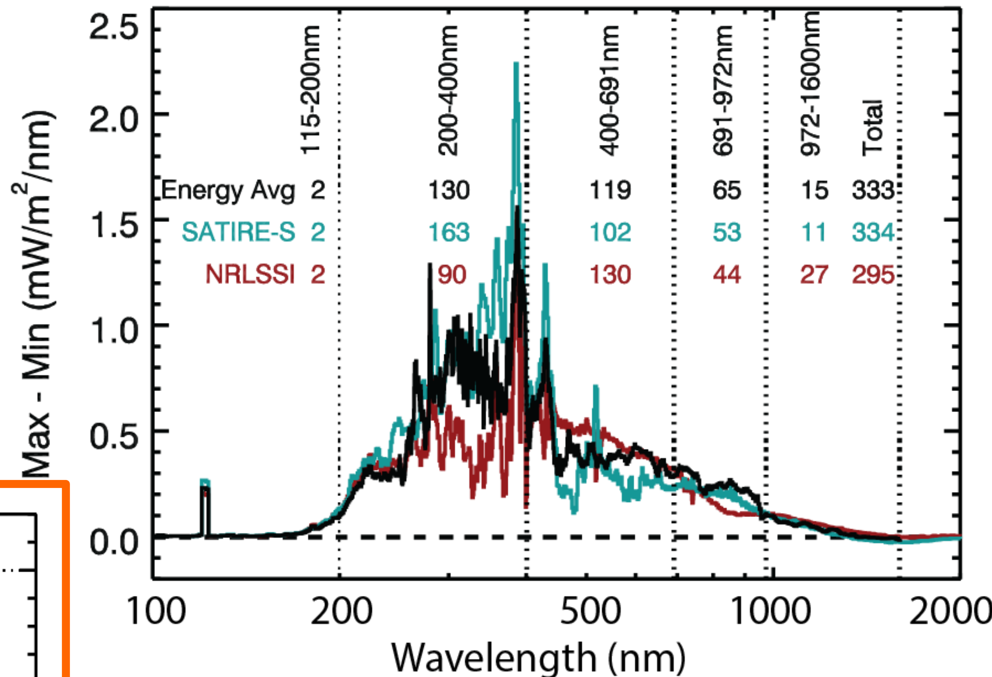


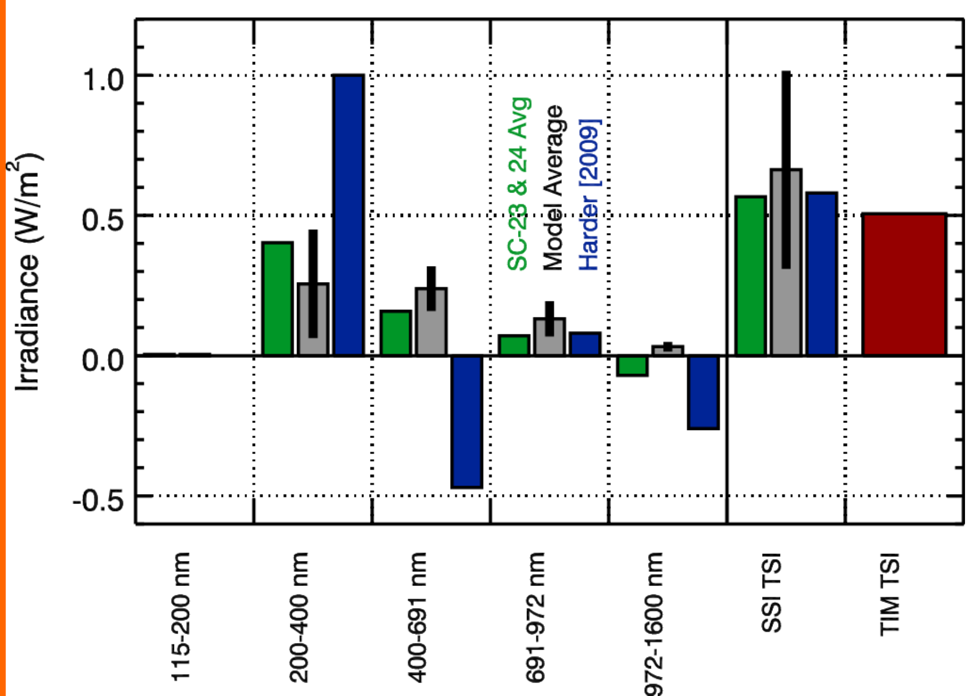
Figures 9a and 9b in Woods *et al*. (*Solar Phys*, 2015)

Comparison of Energy Variability Model Results

Woods *et al.*, *Solar Physics*, 2015

- The out-of-phase (negative) variability is only for 1400-1600 nm for the energy variability model.
- There are factors of 2 differences in variability between the NRLSSI-2 and SATIRE-S models.

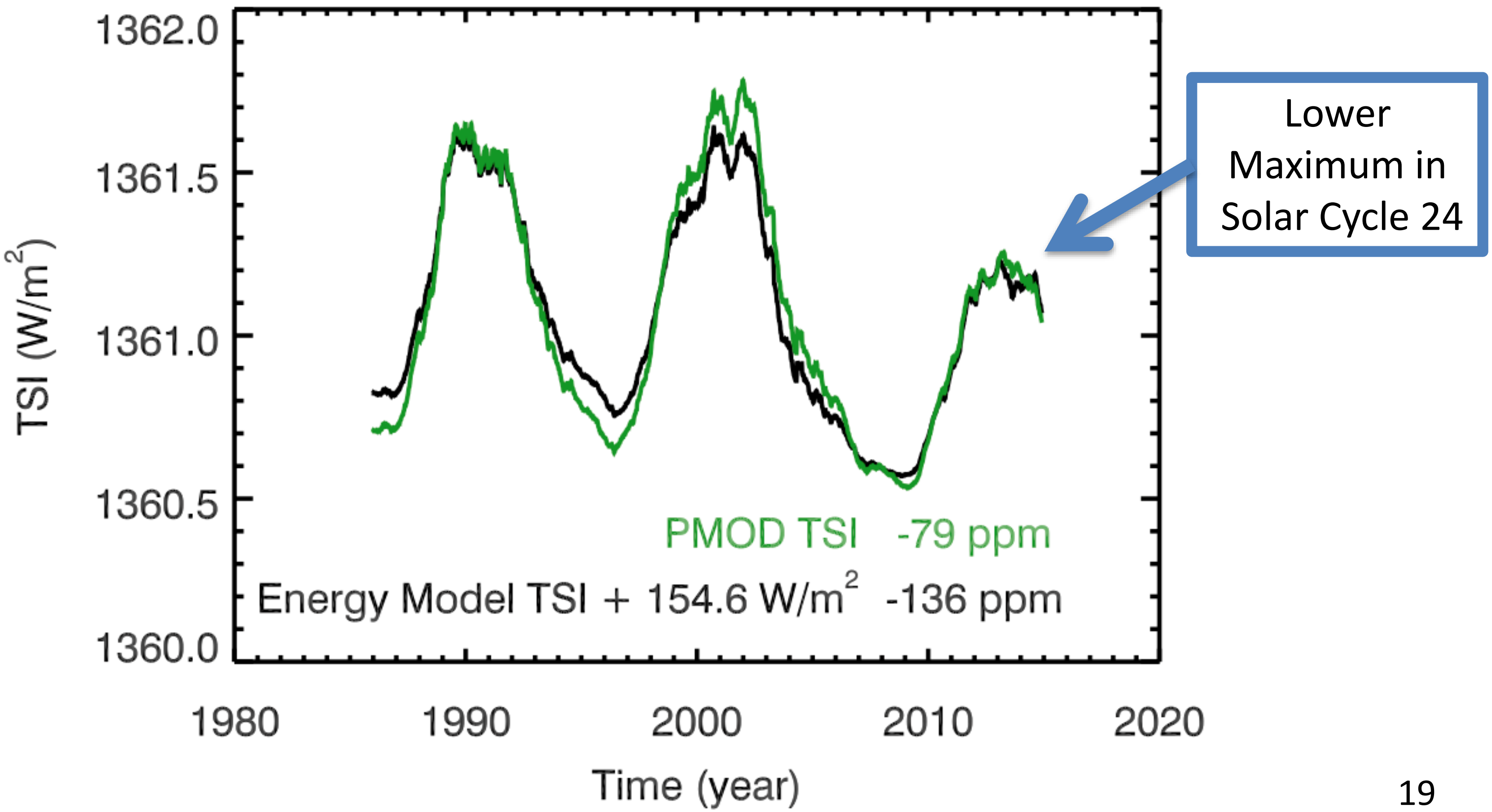




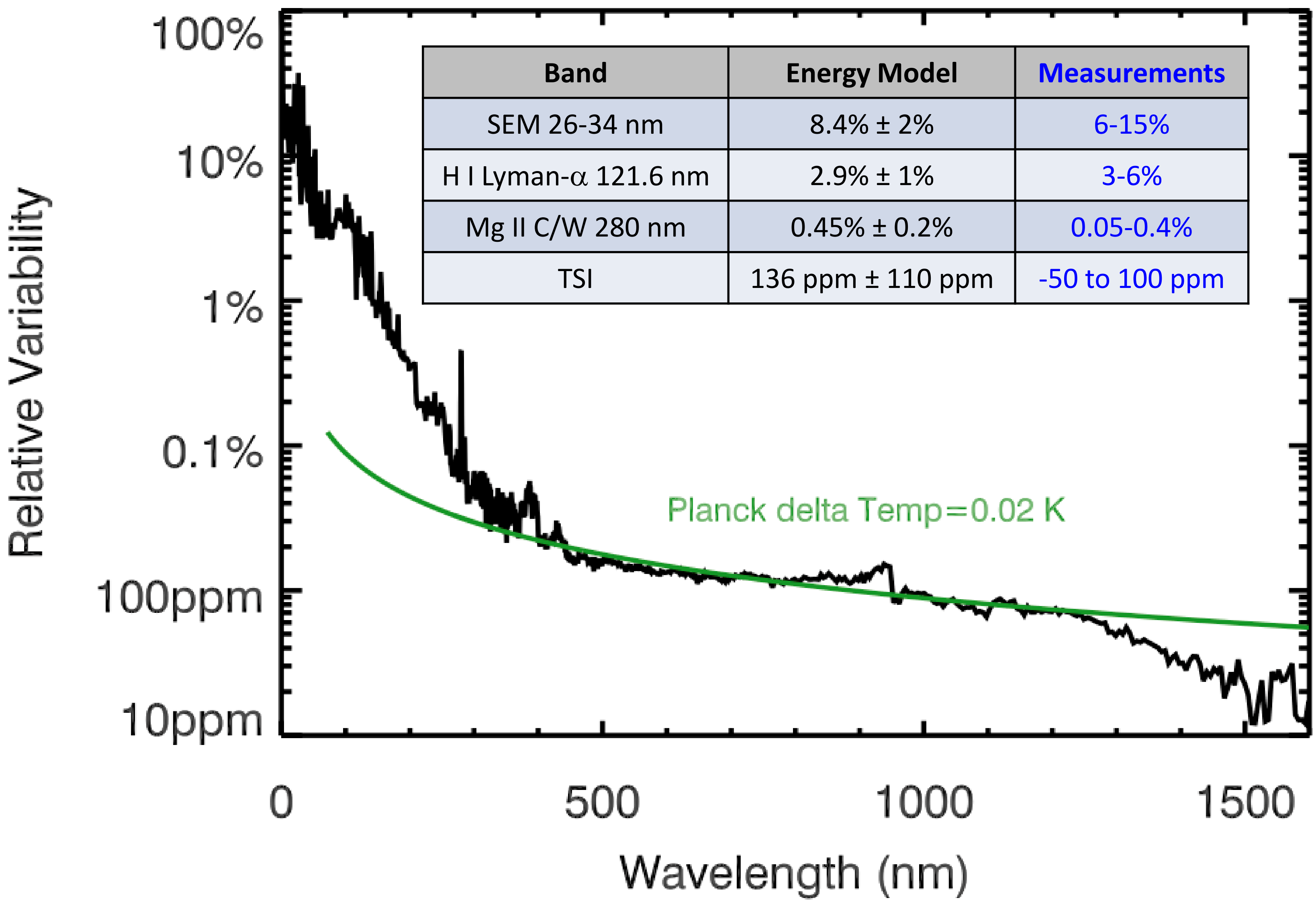
- **Energy Model** and average of solar cycle (SC) 23 & 24 variability are similar but do not have as much out-of-phase variability as Harder et al. [*GRL*, 2009].
- All three agree with TSI variability.

Energy Model Comparison to TSI

- Energy Model TSI = SSI integrated 0-1600 nm + 154.6 W/m^2 offset
- Standard deviation between Energy Model TSI and PMOD is 116 ppm
- Energy Model TSI suggests larger decrease from 1996 to 2008 than the decrease in the PMOD composite TSI



Energy Model 1996 to 2008



Band	Energy Model	Measurements
SEM 26-34 nm	8.4% ± 2%	6-15%
H I Lyman-α 121.6 nm	2.9% ± 1%	3-6%
Mg II C/W 280 nm	0.45% ± 0.2%	0.05-0.4%
TSI	136 ppm ± 110 ppm	-50 to 100 ppm

Conclusions

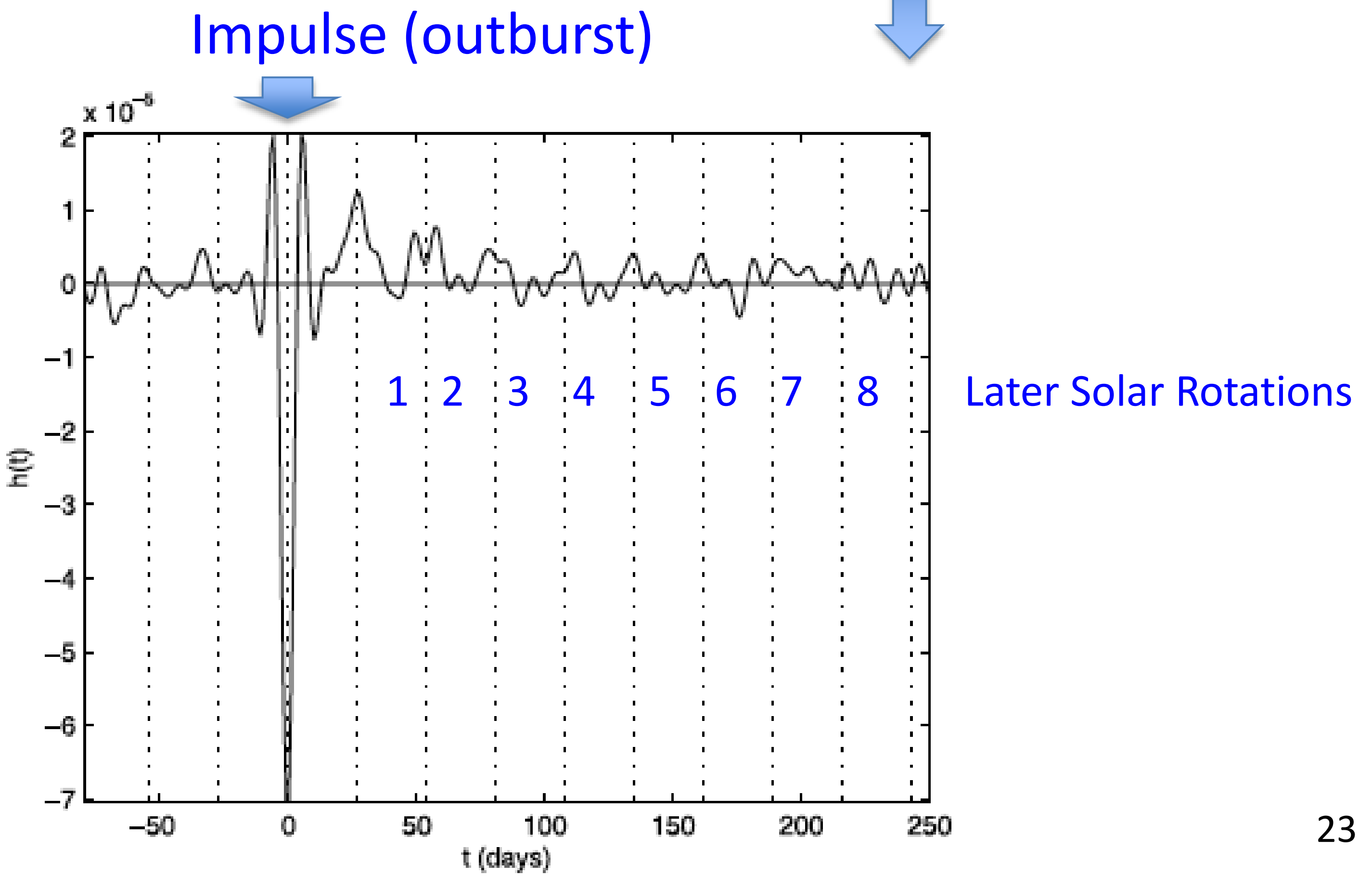
- The energy variability model results indicate very similar spectral variability from three different solar cycles and from different instruments.
- The deficit contribution is most important for the Vis-NIR (400-1600 nm).
- These results provide additional evidence for negative (out-of-phase) variability in the NIR 1400-1600 nm.
  - *Out-of-phase behavior is when Deficit is larger than Excess*
- Assuming most of the variability is from active region evolution, then these 6-month energy variability results could be indicator for solar cycle variability.

- Primary Reference: Woods *et al.*, *Solar Physics*, 2015
  - http://link.springer.com/article/10.1007%2Fs11207-015-0766-0

BACKUP SLIDES

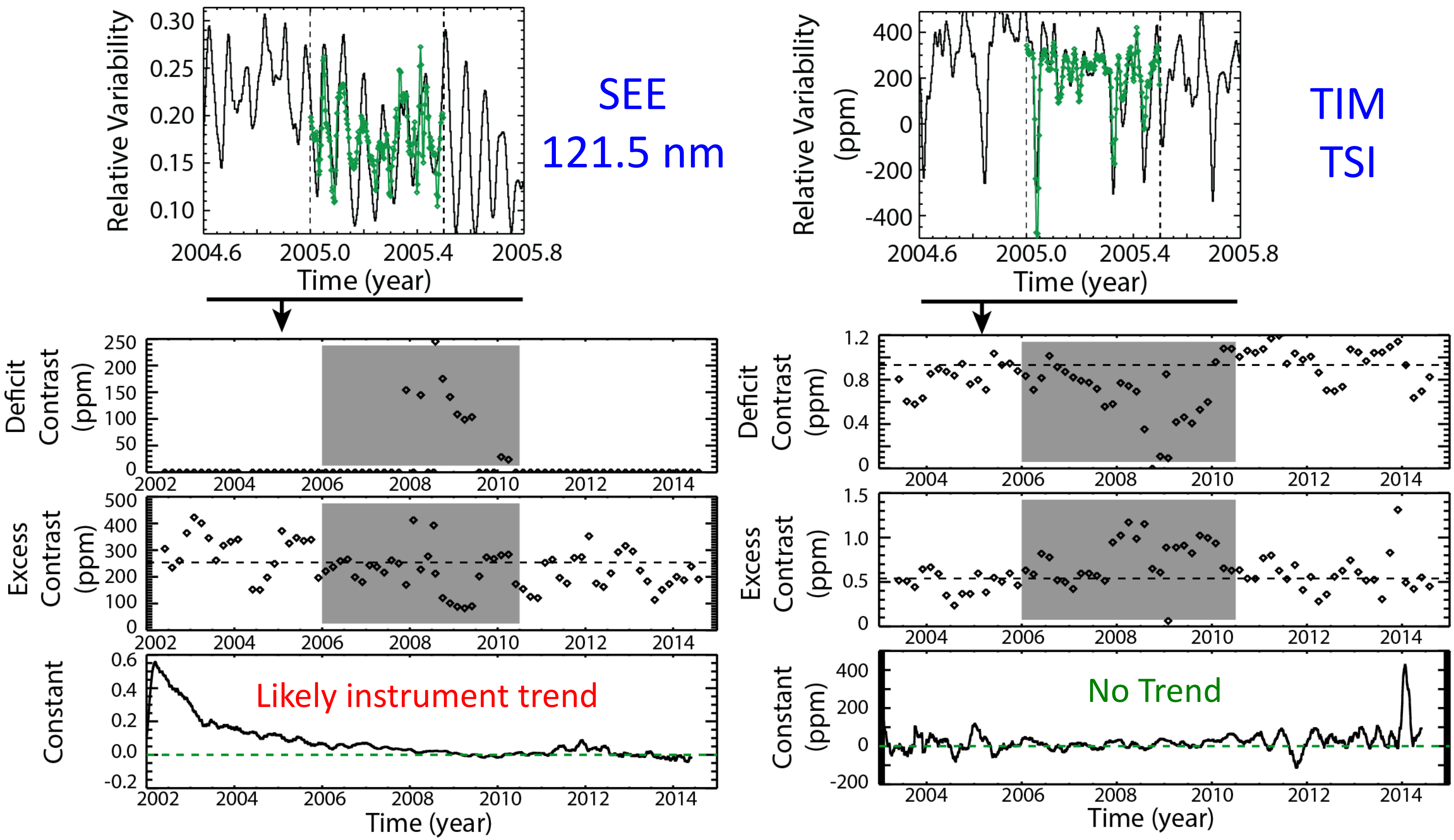
Outburst → Impulse Response Function

- ***Outburst*** is referred to as the ***Energy*** of the irradiance variation from a ***single active region***
- Preminger and Walton (2005) modeled TSI variations with impulse response function (IRF)



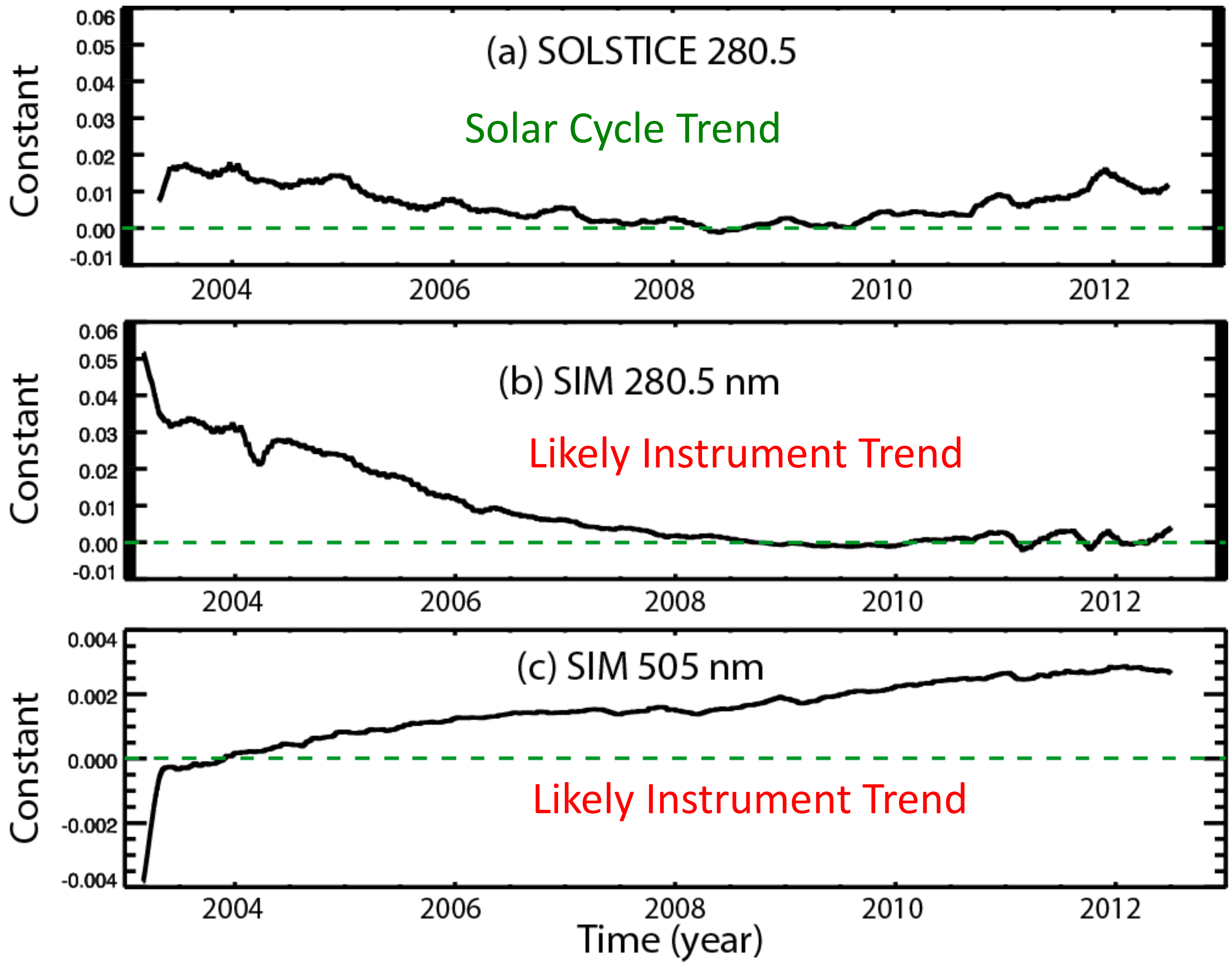
Model Constant could indicate that a 3rd variability component is needed and/or instrument trend

- Average Energy Variability = average excluding solar cycle minimum



Model Constant could indicate that a 3rd variability component is needed and/or instrument trend

- Example model Constant time series for SORCE SOLSTICE and SORCE SIM



More Out-of-Phase Variations is possible at different times during solar cycle

- 2-sigma low Excess contribution combined with 2-sigma high Deficit contribution would indicate out-of-phase (negative) variability near 400 nm and for 1000-1600 nm

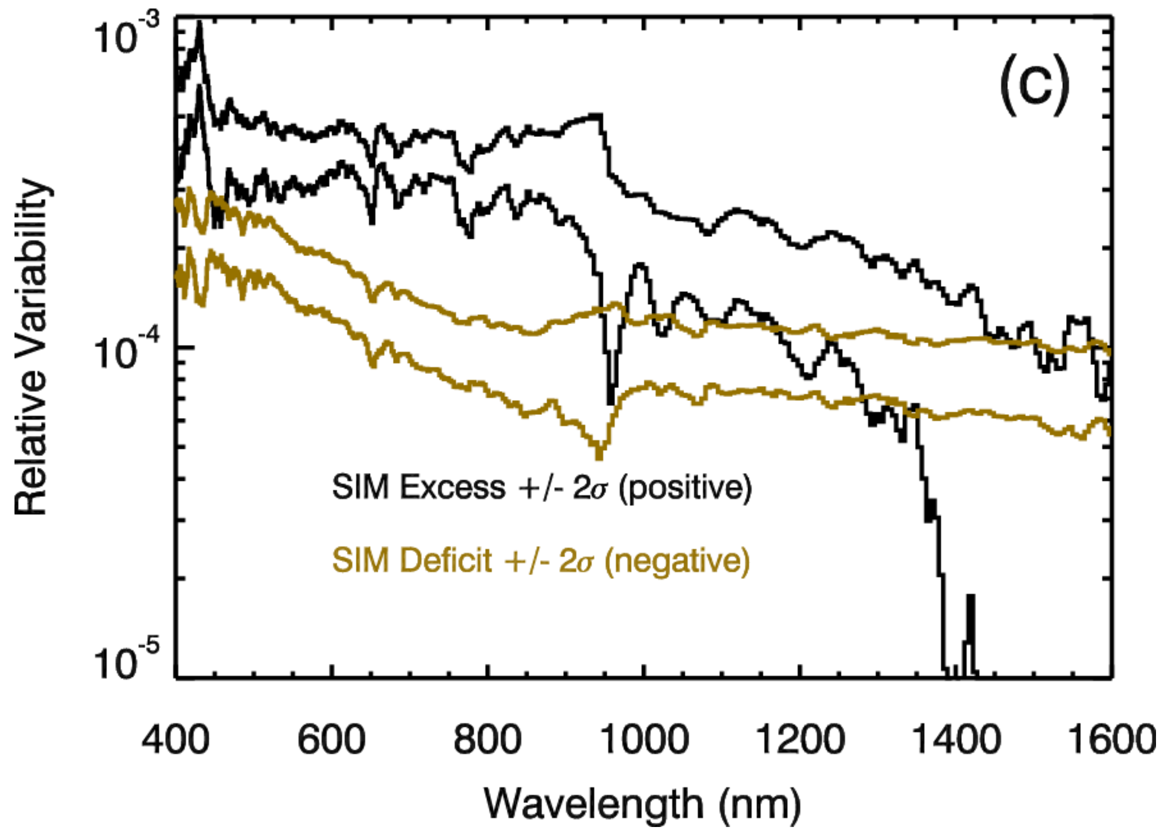


Figure 9c in Woods *et al*. (*Solar Phys*, 2015)

Energy Variability Model Uncertainty

- Variability uncertainty is about 30%
  - e.g., If solar cycle variability is 10%, then uncertainty is 30% * 10% = 3%
- SIM noise in 300-400 nm and in NIR ranges limit model uncertainty

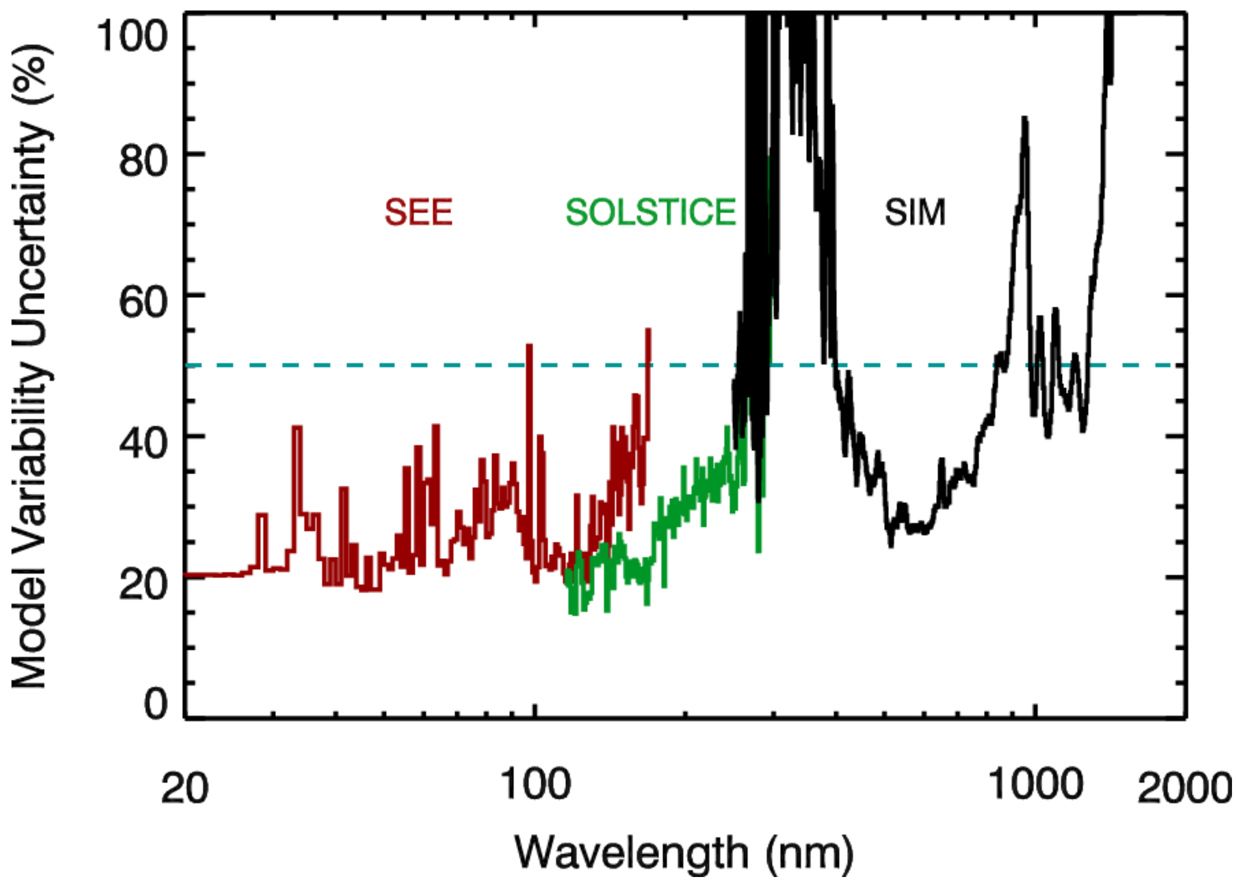
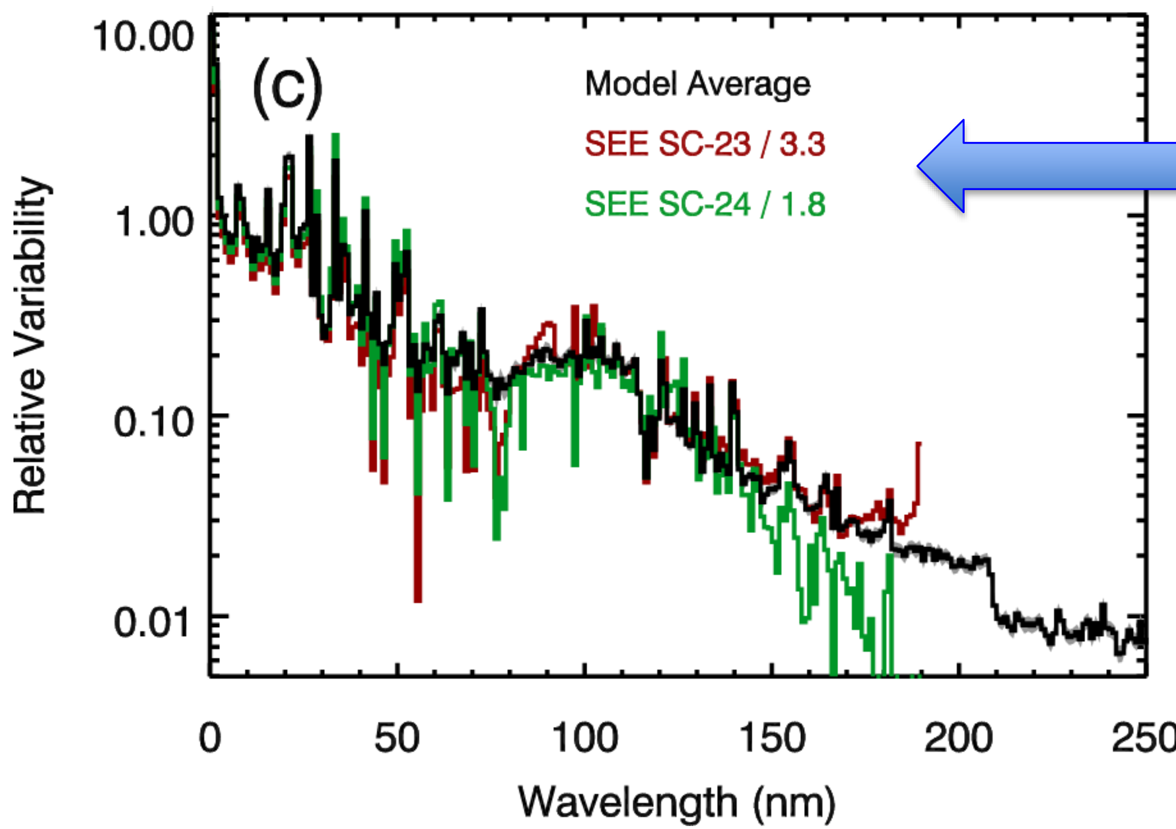


Figure 13 in Woods *et al*. (*Solar Phys*, 2015)

Energy Variability compares well to Solar Cycle Variability in the UV range

- 180-day averages used for solar cycle variability
- SC-23: Aug 2002 – Sep 2008 SC-24: Nov 2011 - Sep 2008



SC-24 variability is factor of about two lower than SC-23

Figure 4c in Woods *et al*. (*Solar Phys*, 2015)

Comparison of Energy Variability Model

- 180-day averages used for solar cycle variability using SORCE and NOAA-11 SBUV data
- Good agreement of solar cycle variability for < 290 nm, but larger differences in 290-400 nm range
  - SIM differences are smaller than the NOAA differences

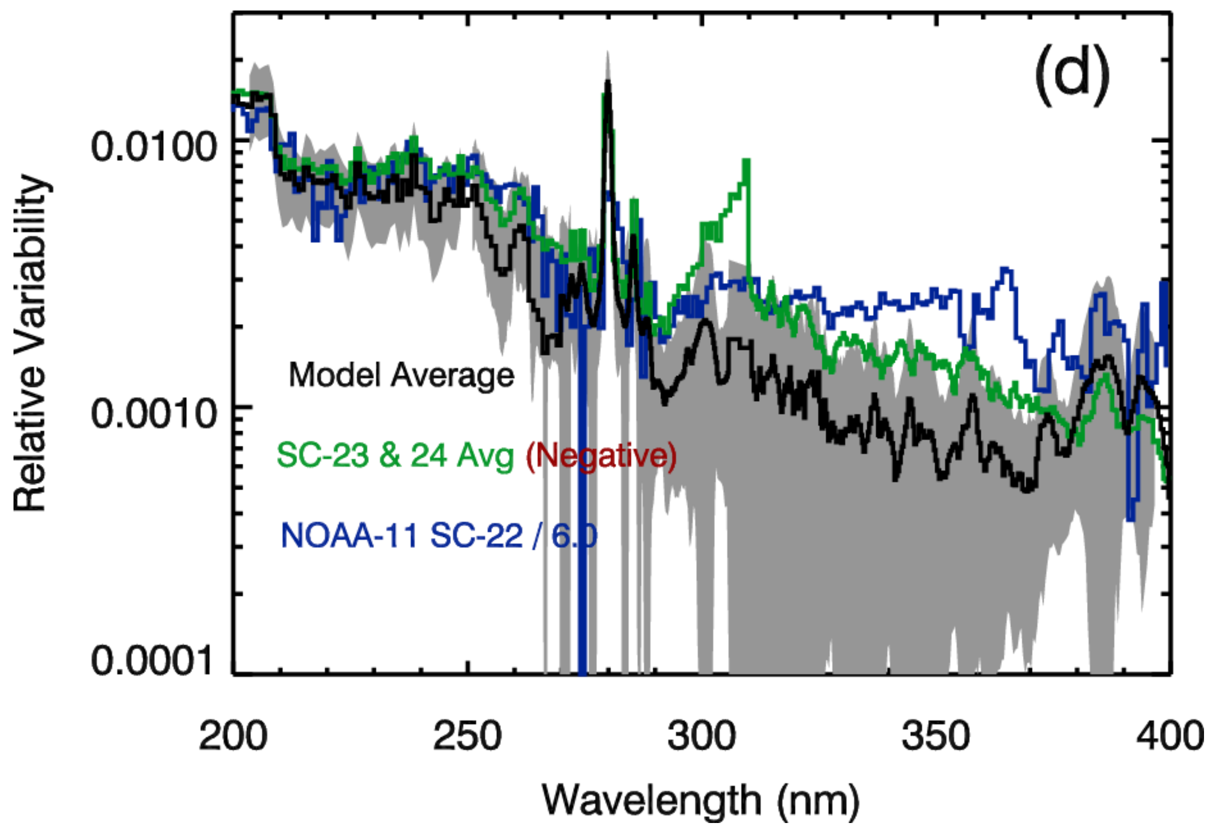


Figure 8d in Woods *et al*. (*Solar Phys*, 2015)

Comparison of Energy Variability Model

- 180-day averages used for solar cycle variability using SORCE SIM data
- Large differences in Vis-NIR 500-1600 nm range

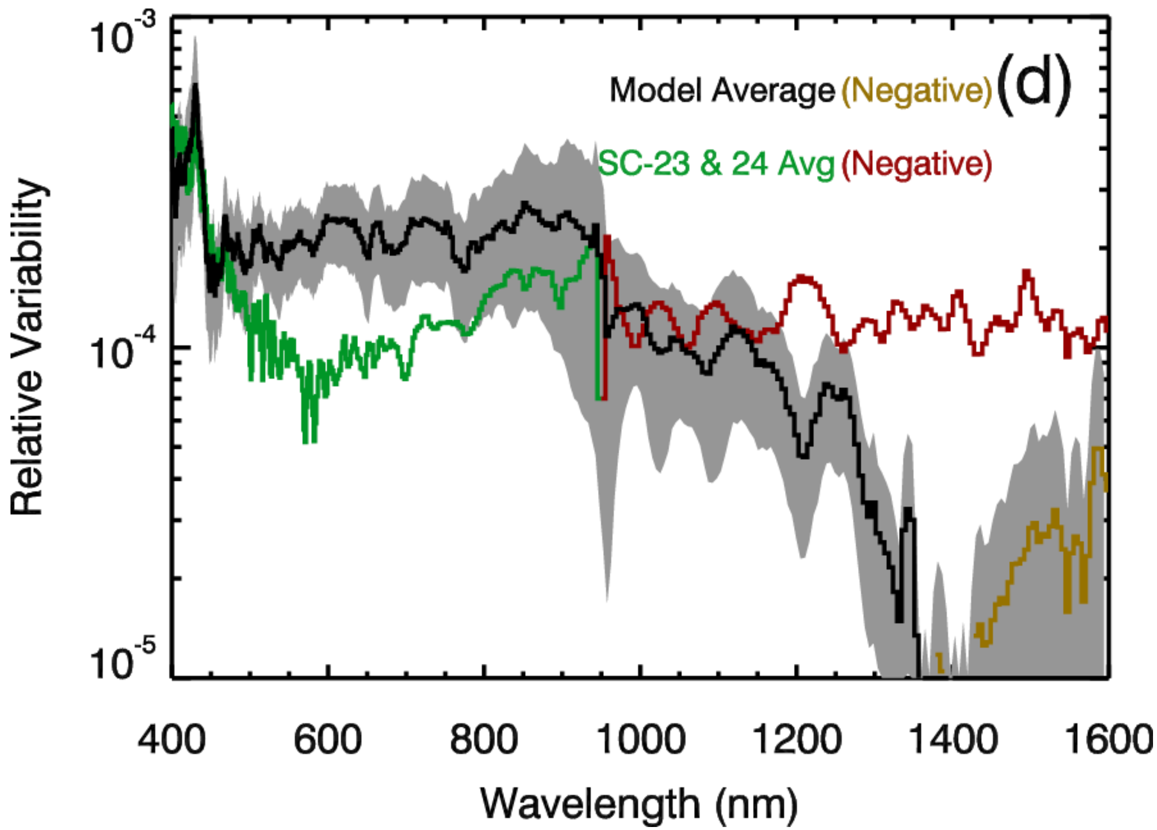
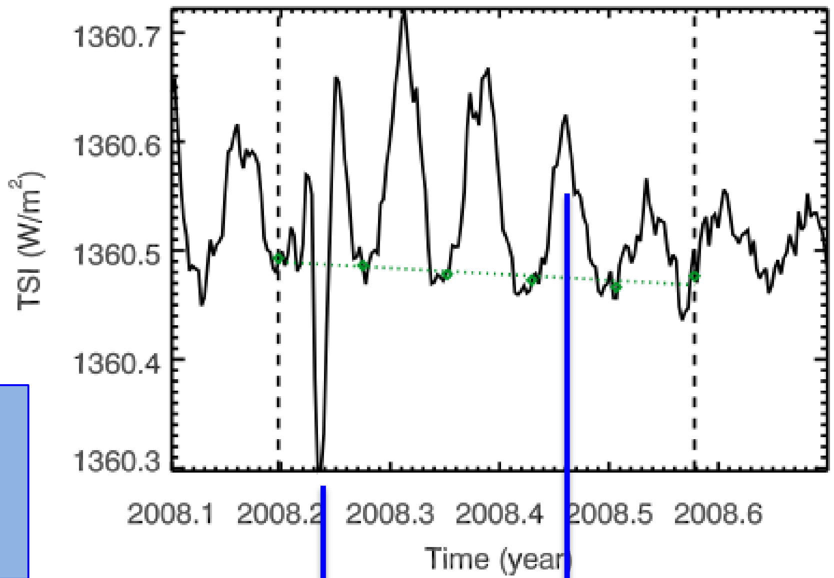


Figure 10d in Woods *et al*. (*Solar Phys*, 2015)

2008 Outburst

MDI Magnetic Field Synoptic Images

Ideal situation with active regions on one side of Sun



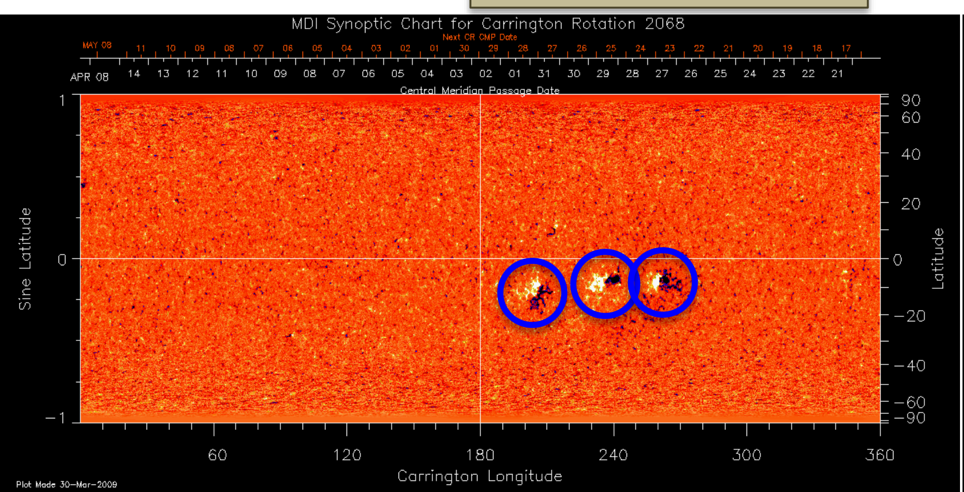
- TSI dips for first rotation
- TSI is bright for the other rotations

3 new Active Regions near disk center

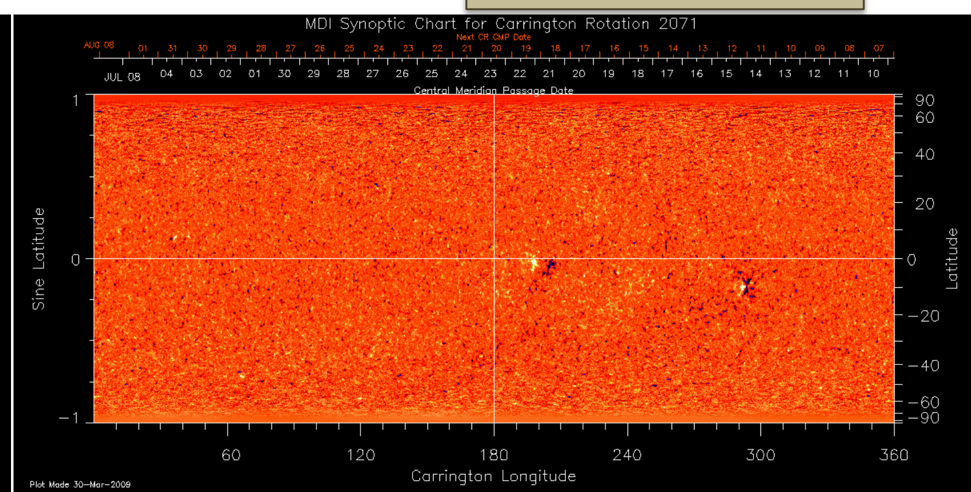
3 decayed Active Regions on disk

WHI 2008 Period

View from Earth



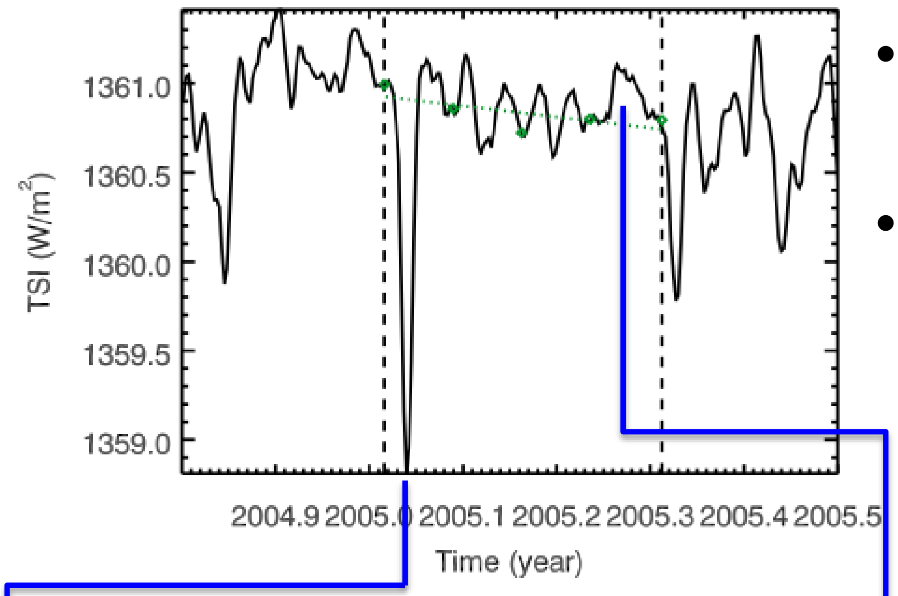
View from Earth



2005 Outburst

MDI Magnetic Field Synoptic Images

Decayed active regions are on both sides of Sun

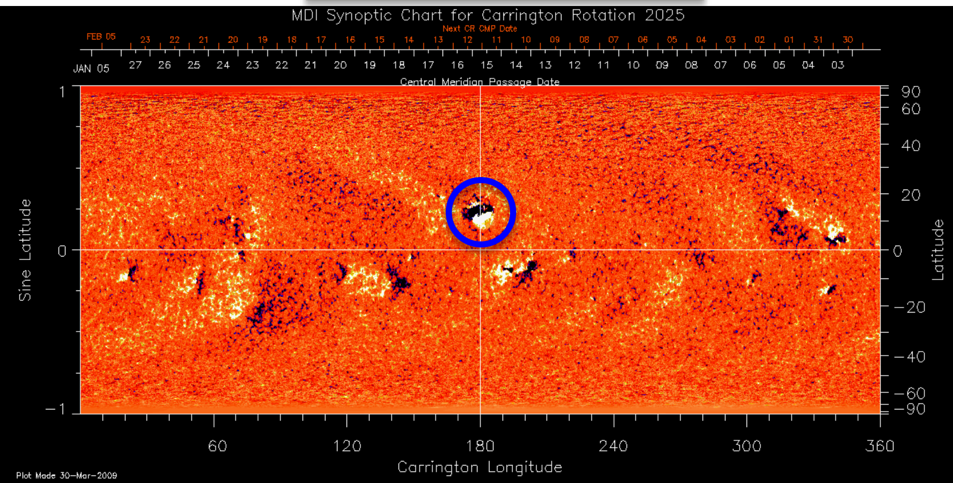


- TSI dips for first three rotations
- TSI is bright for the last rotation

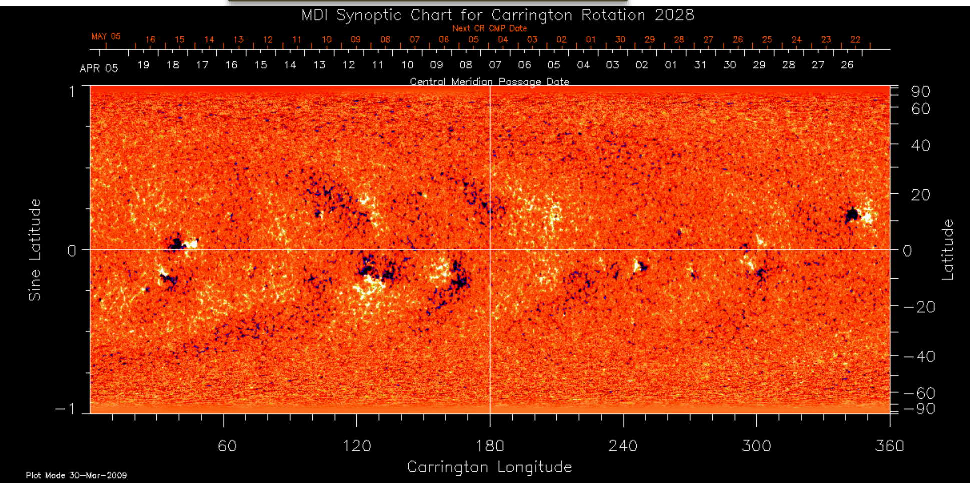
New Active Region at disk center

5 decayed Active Regions on disk

View from Earth

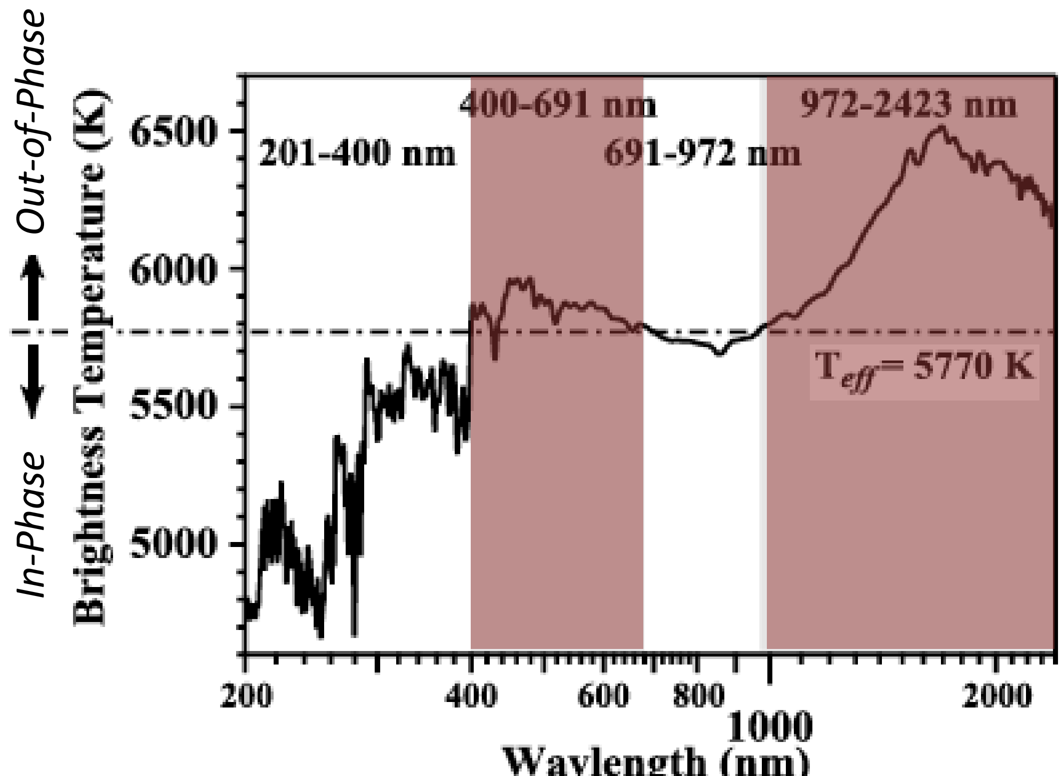


View from Earth



Fontenla's Model prediction for SIM Variability

- Solar Radiation Physical Model (SRPM) has prediction for negative (out-of-phase) variation if brightness temperature is >5770 K [lower photosphere] (Harder *et al.*, *GRL*, 2009)



SFO Model Results

Deficit Larger

1400-1600 nm

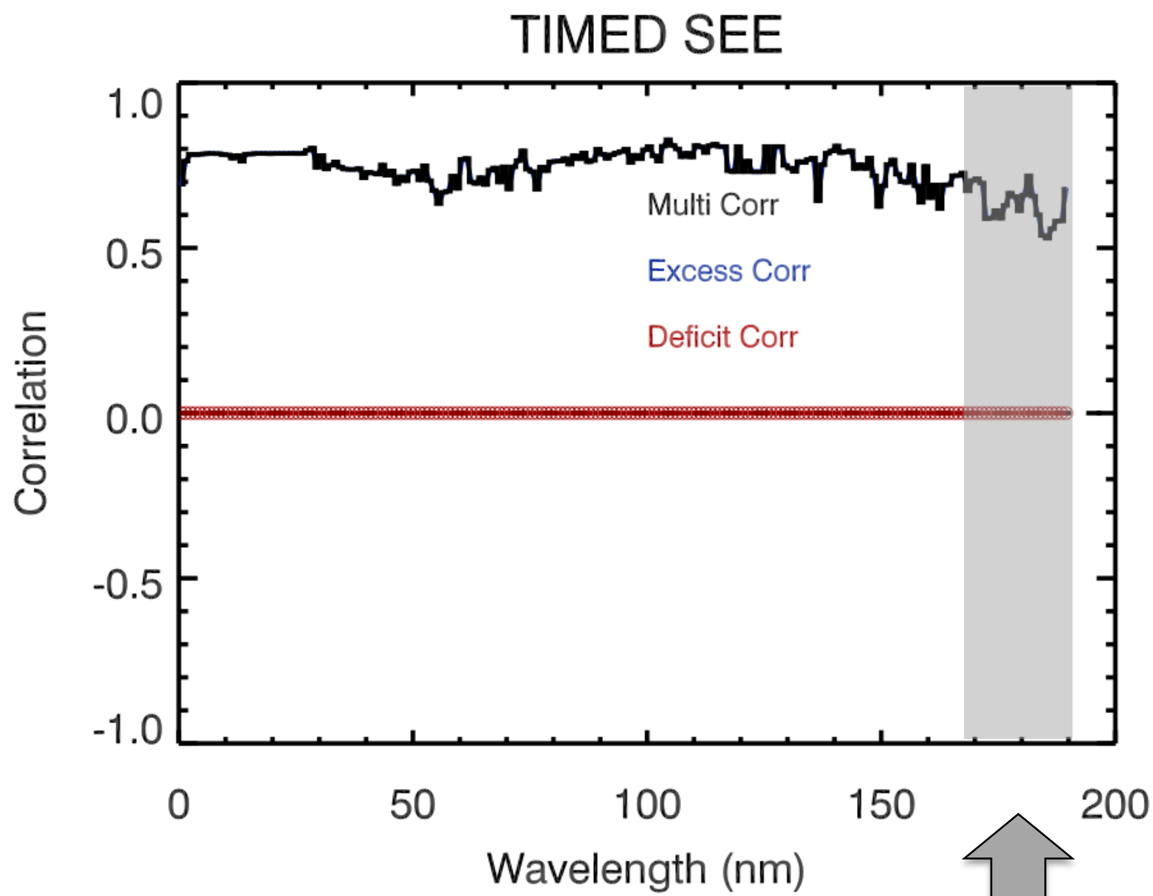
Excess Larger

0-1400 nm

Wavelengths in SRPM that have negative (out-of-phase) SC variation.

SFO Model – SEE Correlation Results

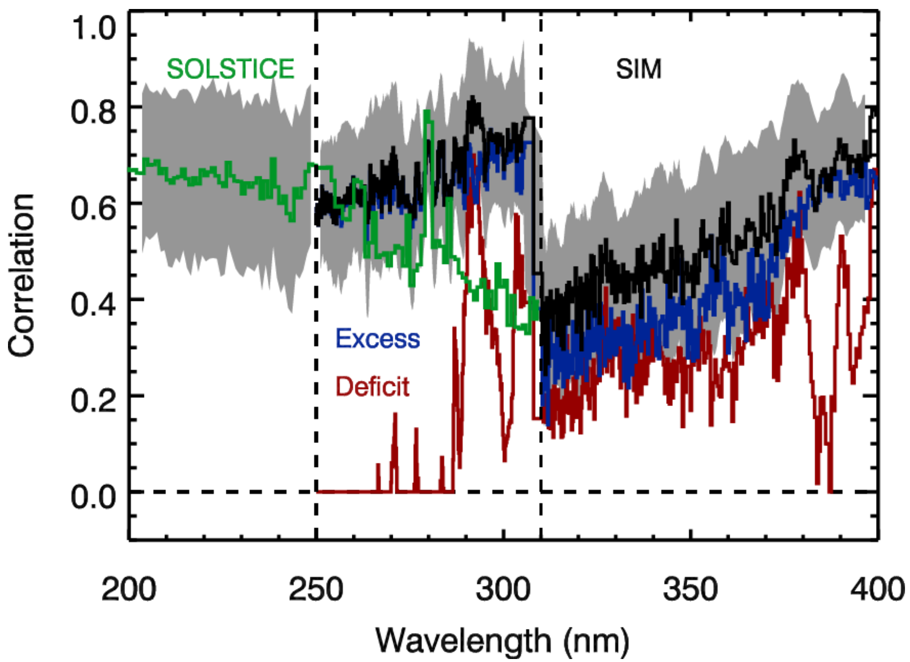
- SEE's low signal in 170-190 nm range causes for poorer correlation



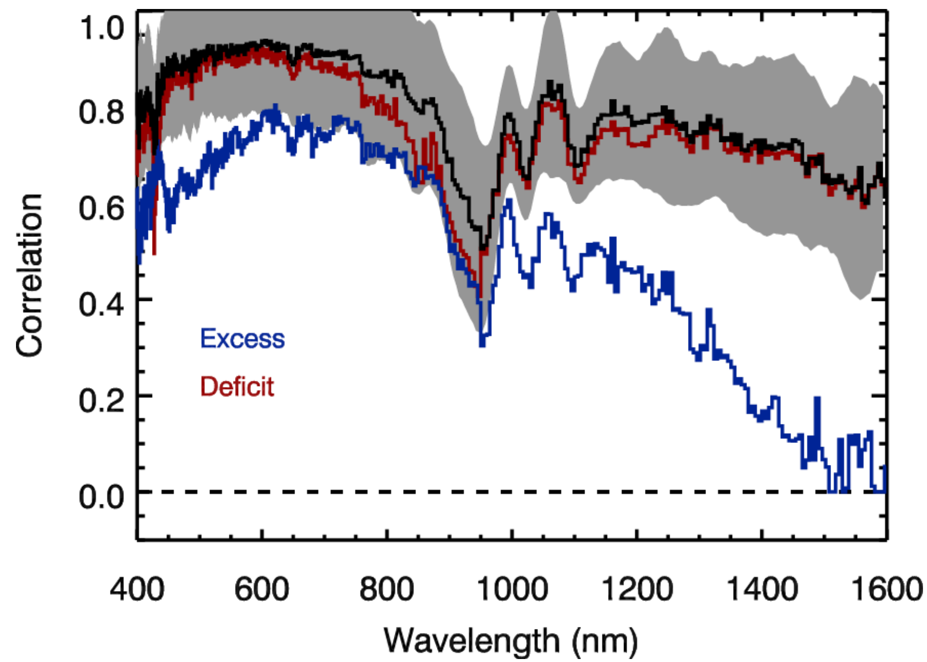
Low Signal
for SEE

SFO Model – SORCE Correlation Results

- SORCE SIM's low signal in 300-400 nm range causes poorer correlation.
- Deficit contribution is not important for shorter than 290 nm.

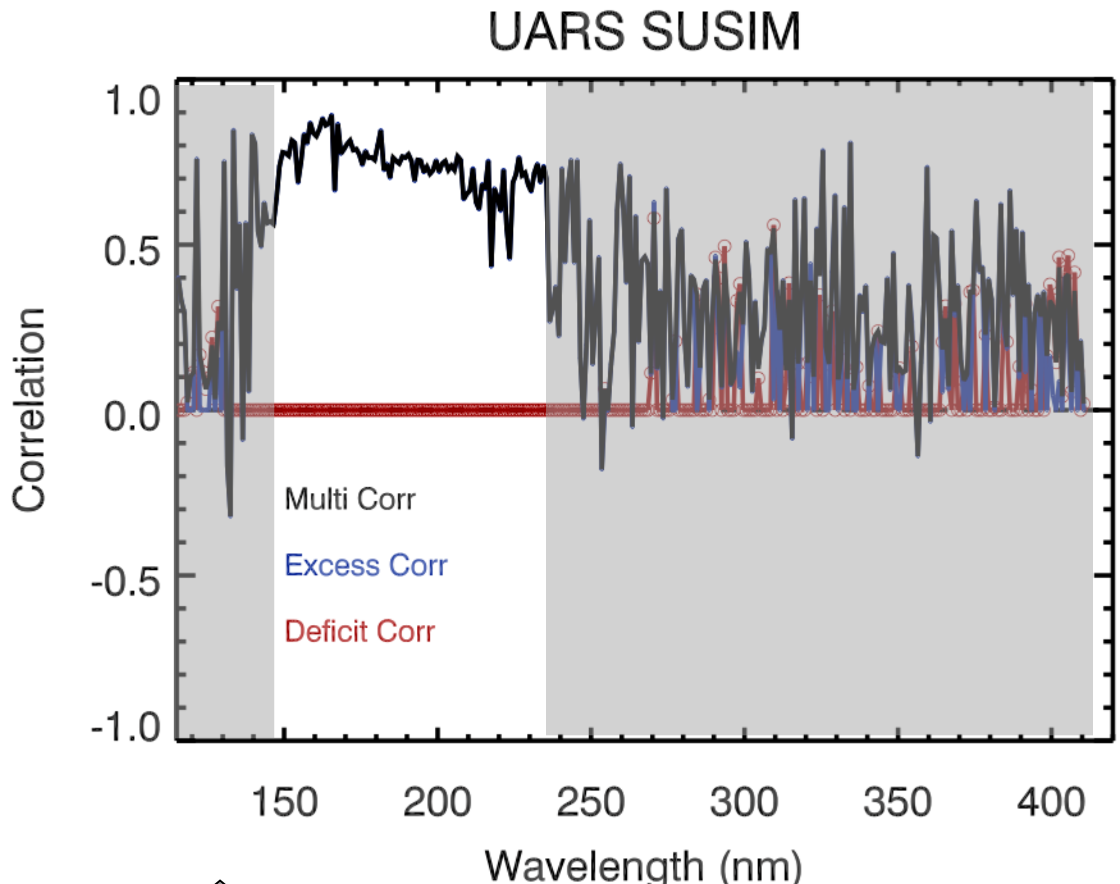


- SORCE SIM's diode gain correction with temperature affects the 800-1000 nm range the most.
- Deficit contribution is important over full 400-1600 nm range.



SFO Model – SUSIM Correlation Results

- UARS SUSIM has high day-to-day noise in 115-145 nm and 235-410 nm ranges, thus poorer correlation in those ranges.



High Noise for SUSIM

High Noise for SUSIM