How Does the Sun's Spectrum Vary?

Modeling Solar Cycle Irradiance Variations

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- Solar Rotation – days to months, multiple "realizations"
  - relatively well specified
  - issues remain about spectral dependencies – UV vs IR
  - Marchenko, DeLand and Lean, Space Weather and Climate, 2017

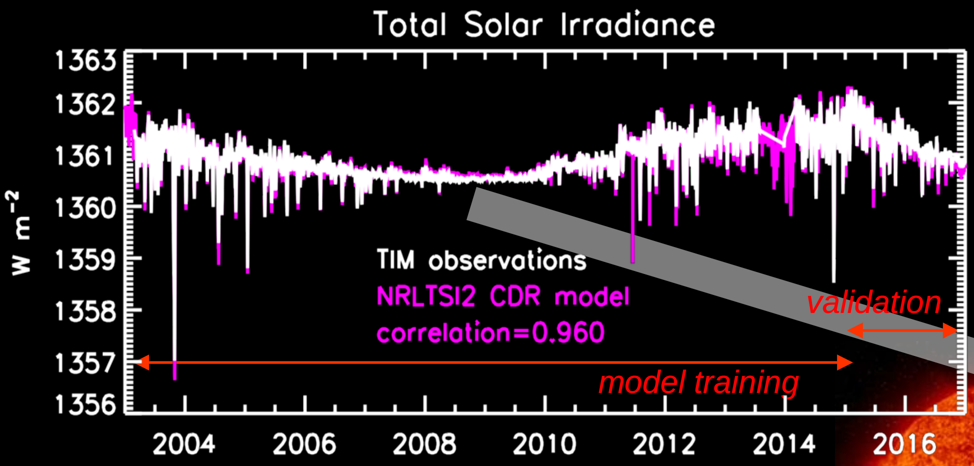
- Solar Cycle – years to decades
  - challenged by instrument sensitivity drifts
  - disagreement among observations and models

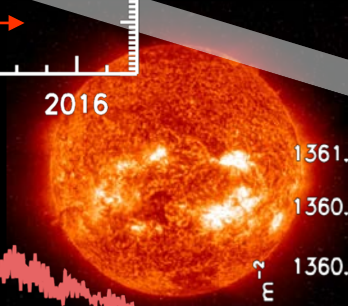
Primary Focus of 2nd Year Effort

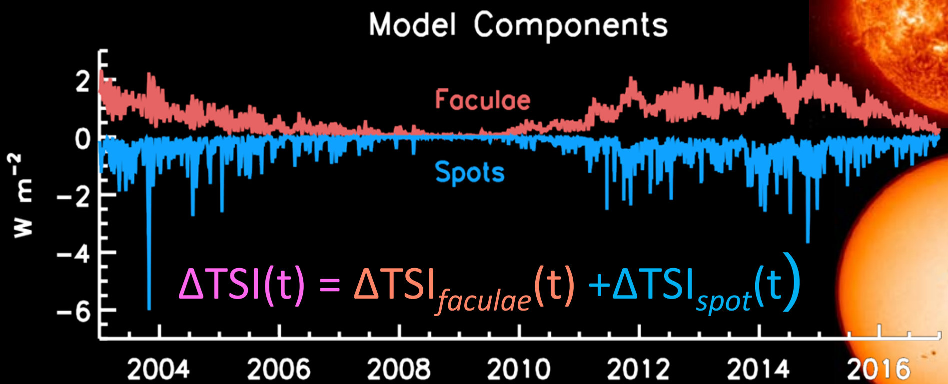
- Long Term – multiple decades
  - speculative; depends on constraining & understanding solar cycle variations

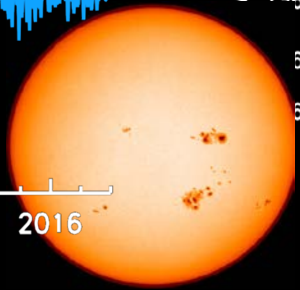
Funded by NASA

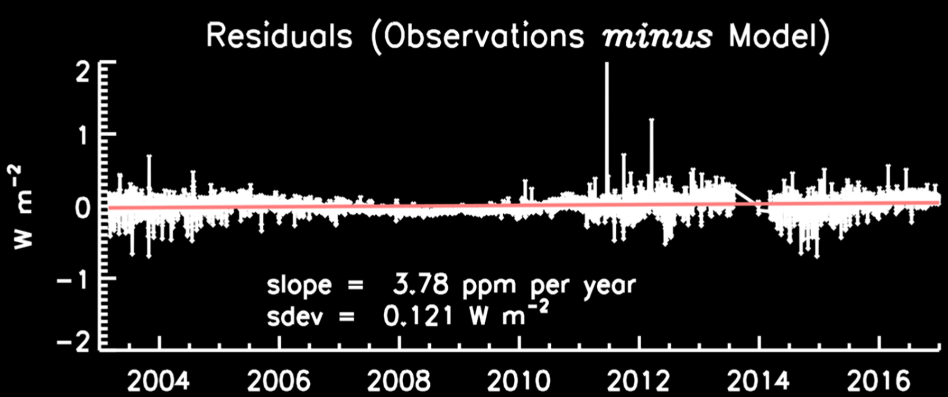
TIM TSI Observations vs NRLTSI2 (NOAA CDR)

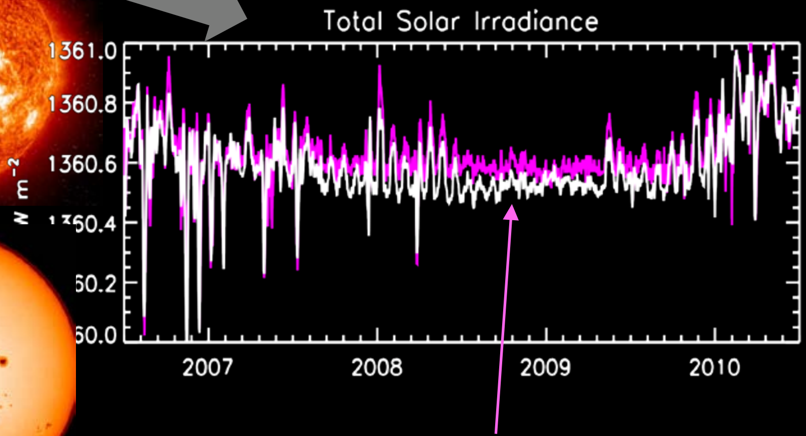










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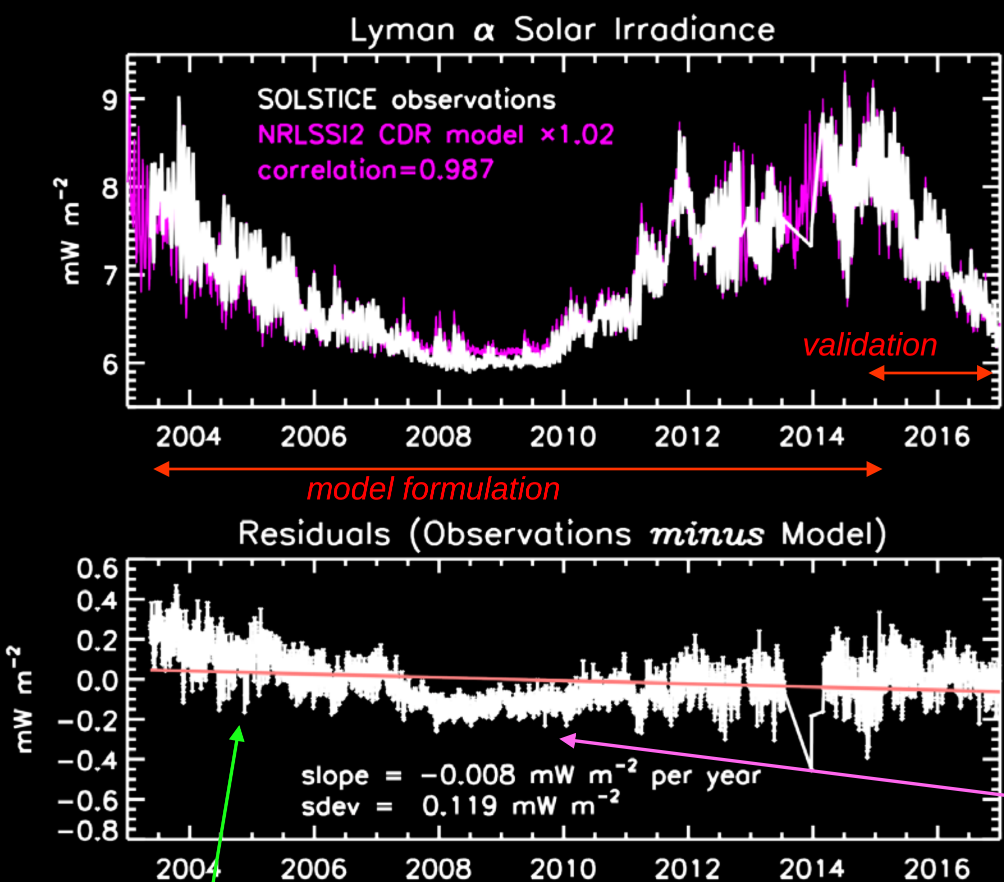
NOAA Climate Data Record (CDR) of Total Solar Irradiance (TSI), NRLTSI Version 2

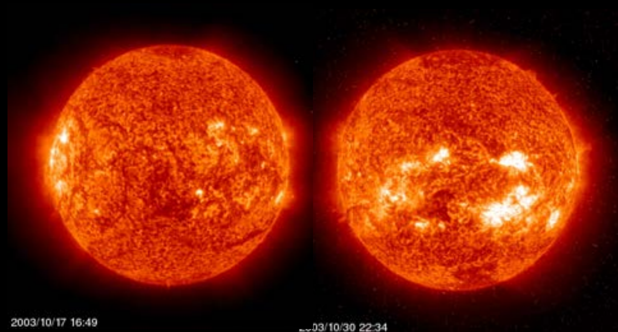
This Climate Data Record (CDR) contains total solar irradiance (TSI) as a function of time created with the Naval Research Laboratory model for spectral and total irradiance (version 2). Total solar irradiance is the total, spectrally integrated energy input to the top of the Earth's atmosphere, at a standard distance of one

SOLSTICE Lyman α Observations vs NRLSSI2



$$\Delta F_{Ly\alpha}(t) = \Delta TSI_{faculae(t)}$$
$$= a + b\times \Delta Mg(t)$$

NRLSSI2 Lyman α irradiance is linear function of Mg index, proxy for faculae



NRLSSI2 model systematically overestimates SOLSTICE Lyα at solar minimum by ~0.1 mW m^{-2} (5% of solar cycle variation)….
when normalized to cycle 24
- consistent with TIM vs NRLTSI2

NRLSSI2 model (faculae) underestimates SOLSTICE Lyα cycle 23 decline
- faculae?
- SOLSTICE?
- something else?

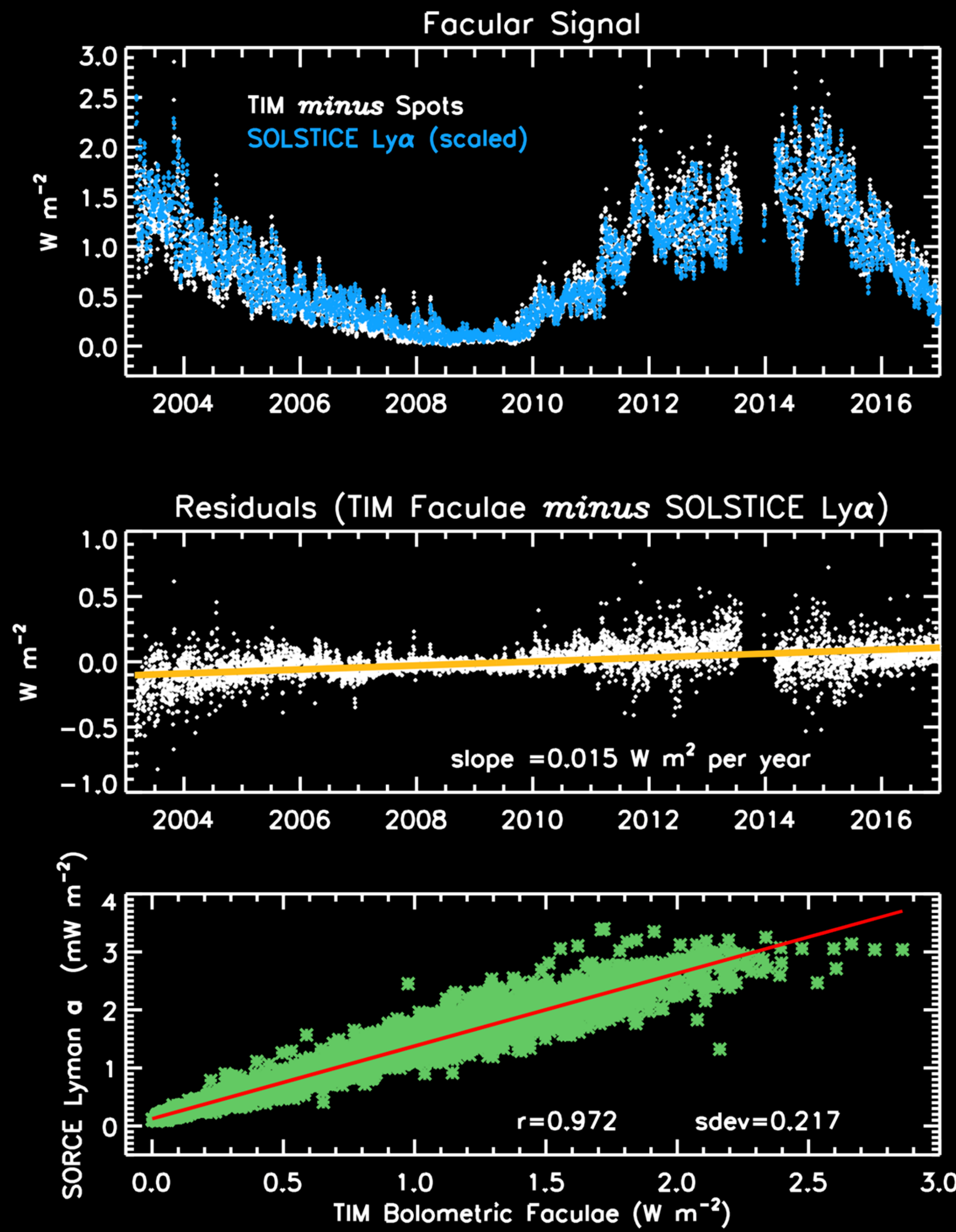
TIM Bolometric Faculae vs. SOLSTICE Lyman α

$$\Delta TSI_{faculae}(t) = \Delta TSI(t) - \Delta TSI_{spot}(t)$$

Residual trend of 0.15 W m^{-2} per decade is 7.5% of solar cycle amplitude

- *SOLSTICE Lyman α overestimates cycle 23 decline relative to TIM bolometric faculae*
- *good agreement at solar minimum*

High correlation of daily TIM bolometric faculae and SOLSTICE Lyman α irradiance

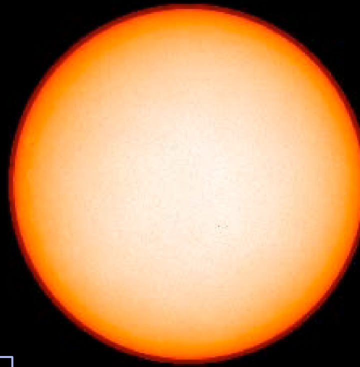


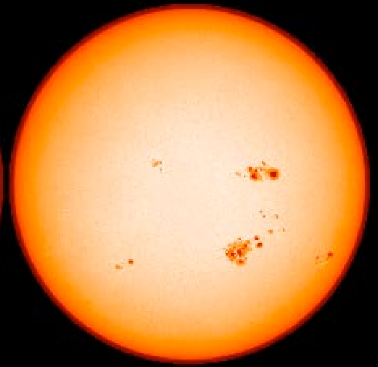
TIM Bolometric Faculae: Insensitive to Sunspot Darkening Index Formulation

Bolometric facular variability:

$$\Delta TSI_{faculae}(t) = \Delta TSI(t) - \Delta TSI_{spot}(t)$$

$$\Delta TSI_{spot}(t) \propto \Sigma A_s C_s\, \mu(3\mu+2)/2$$

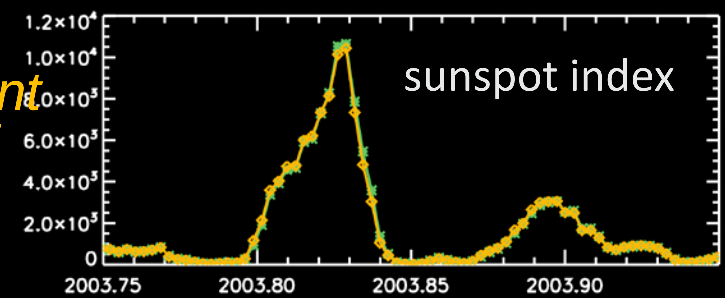




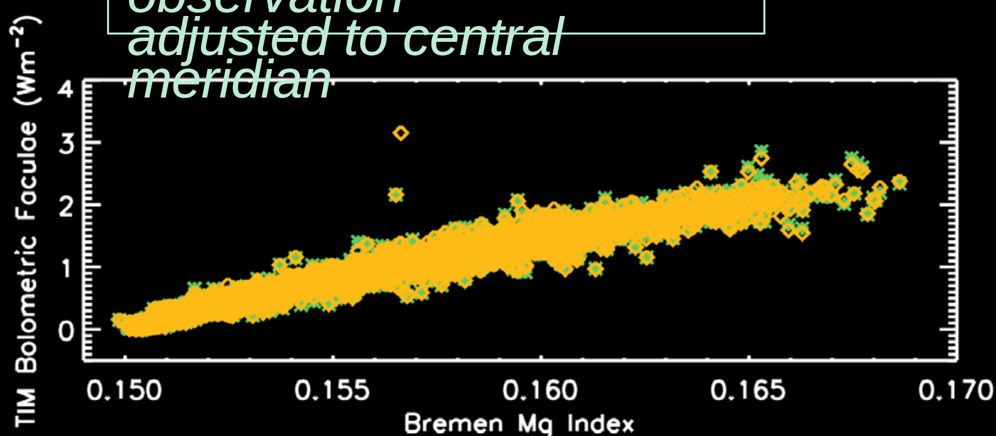
A_s=sunspot area → *all observatories* / *four main observatories*

C_s=sunspot contrast → *area independent* / *area dependent*

μ=cos(lat)cos(long) → *location at time of observation* / *adjusted to central meridian*

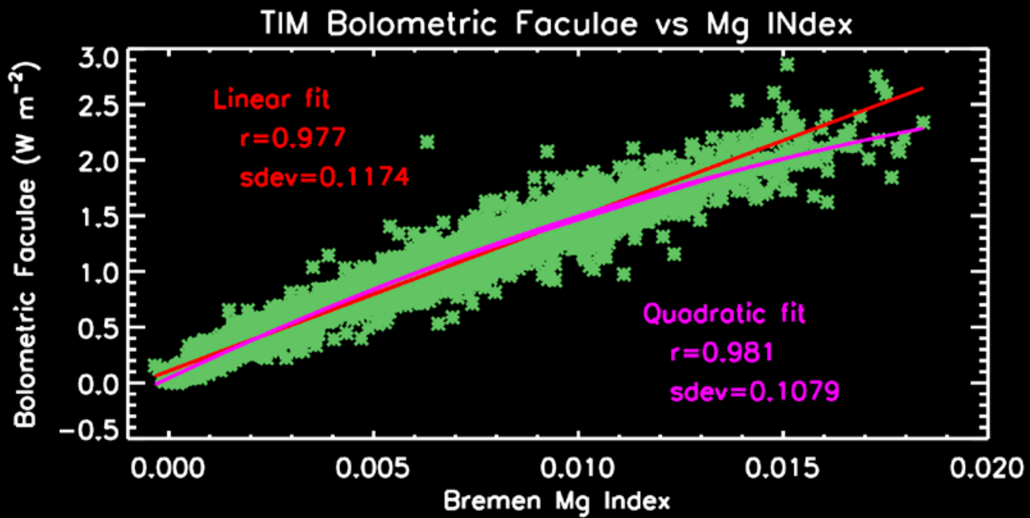


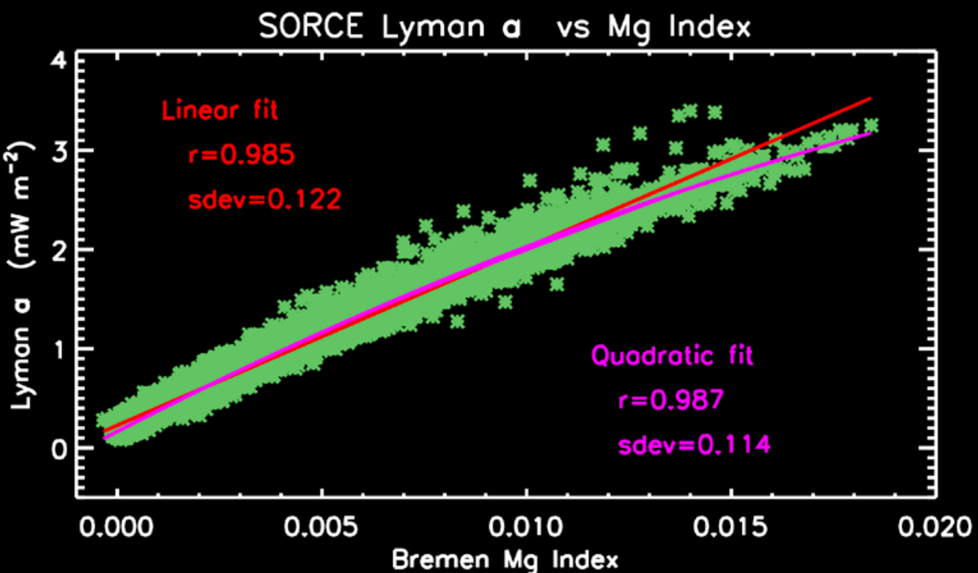
CDR –all observations, area-independent contrast, observed location



four main observations, area-independent contrast, adjusted to central meridian

Dependence of TIM Bolometric Faculae and SOLSTICE Lyman α on Mg Index





For both TIM bolometric faculae and SOLSTICE Lyman α irradiance, quadratic parameterization of Mg index is superior to linear parameterization…

improved facular parameterization might be

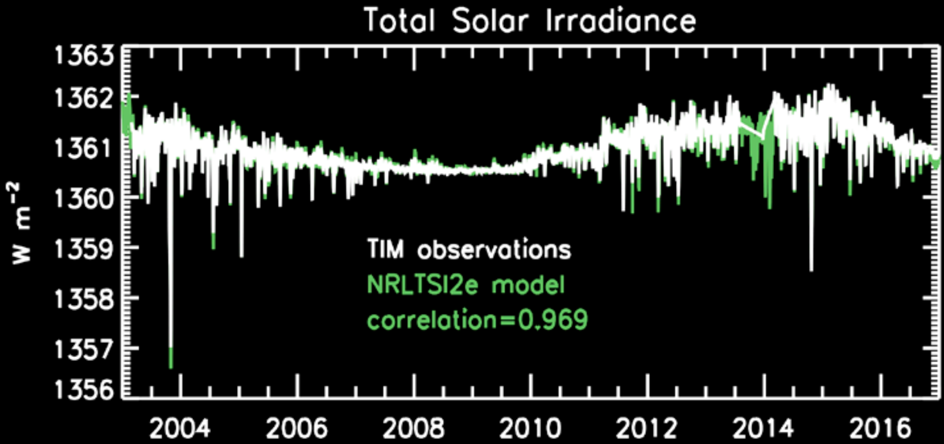
$$\Delta F_{Ly\alpha}(t) = a + b\times\Delta Mg(t) + c\times[\Delta Mg(t)]^{e}$$

New Model of TSI Variability: NRLTSI2e

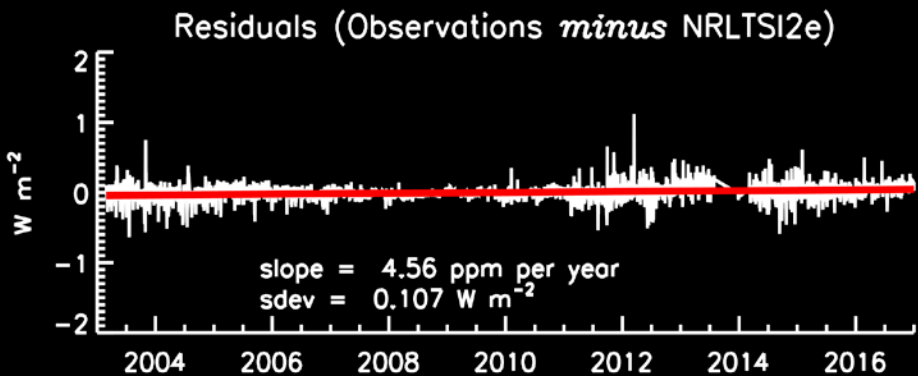
$$\Delta TSI(t) = \Delta TSI_{faculae}(t) + \Delta TSI_{spot}(t)$$

$$= a + b \times Mg(t) + c \times Mg(t)^{e} + d \times P_{s}(t)$$

e=1.2



Correlation with TIM improves from 0.960 to 0.969



Standard deviation of residuals decreases from 0.121 to 0.107 W m^{-2}

Residual trend remains better than TIM's 10 ppm per year repeatability

New Model of SSI Variability: NRLSSI2e

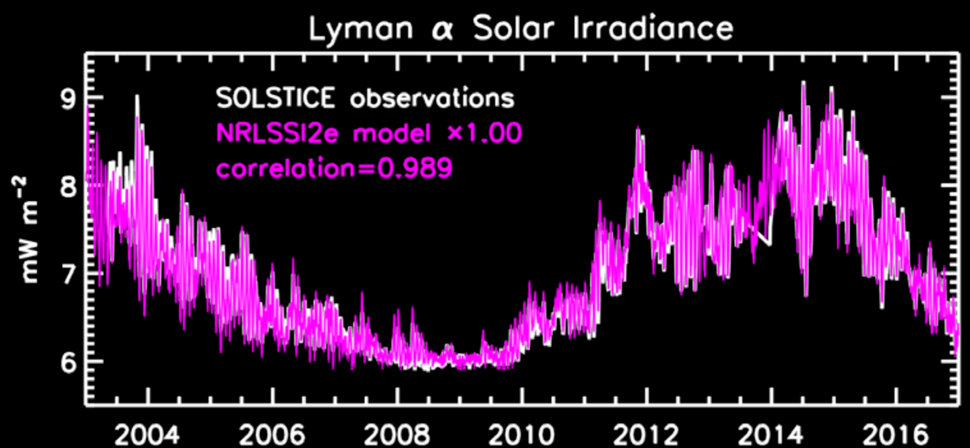
$$F(\lambda,t) = F_{quiet}(\lambda) + \Delta F_{faculae}(\lambda,t) + \Delta F_{spot}(\lambda,t)$$

$$\Delta F_{faculae}(\lambda,t) \propto \Delta TSI_{faculae}(t) = 296.6\times Mg(t) + 377.5\times Mg(t)^{1.2}$$

OR

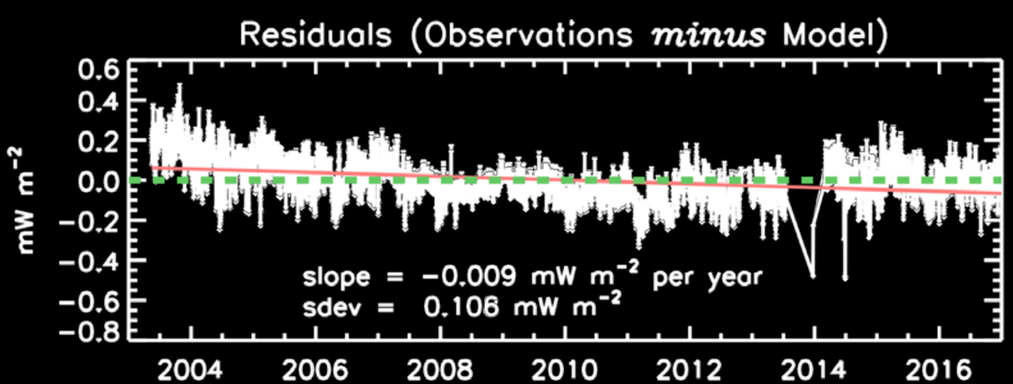
$$\Delta F_{faculae}(\lambda,t) \propto \Delta Ly\alpha_{faculae}(t) = 345.2\times Mg(t) + 376.9\times Mg(t)^{1.2}$$

Correlation of Lyα models using two different $\Delta F_{faculae}$ is 0.9997



Correlation with SOLSTICE improves from 0.987 to 0.989

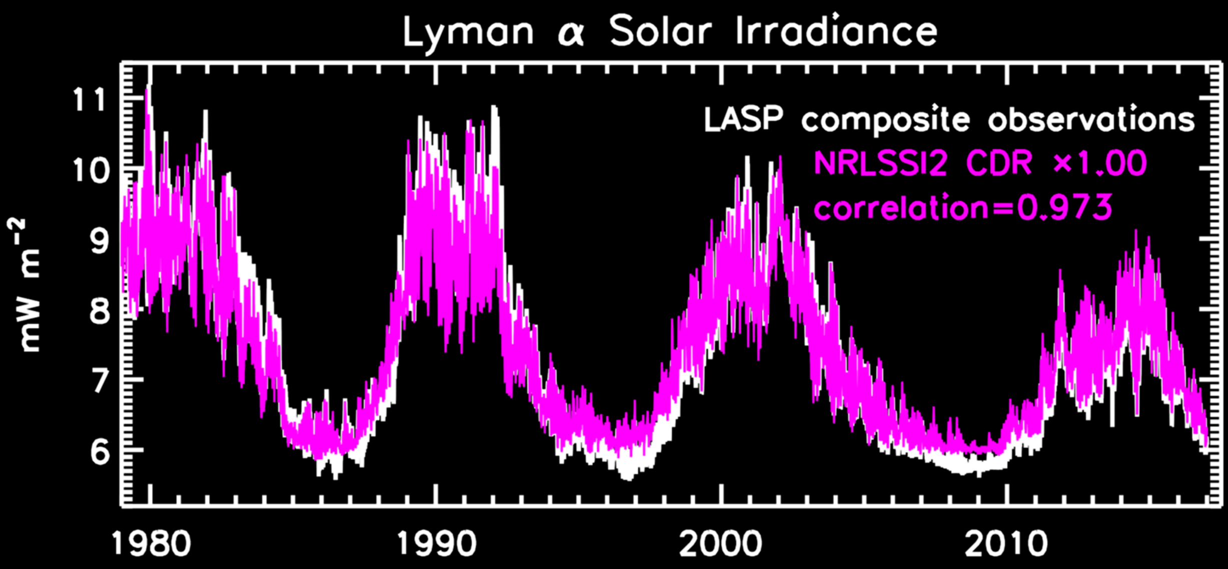
Model constructed using direct (not detrended) SOLSTICE Lyα observations



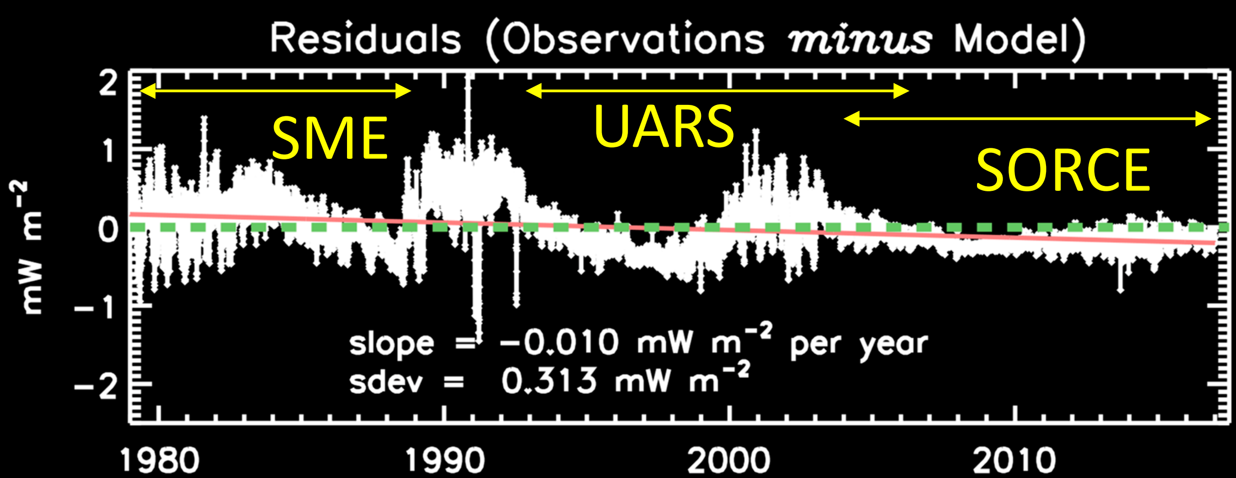
Standard deviation of residuals decreases from 0.119 to 0.106 mW m^{-2}

….slope of residuals is 0.15% per year

Lyα Comparison: NRLSSI2e vs Observations



will NRLSSI2e agree better with ….
- new SIST Lyα composite?
- SOLID composite?



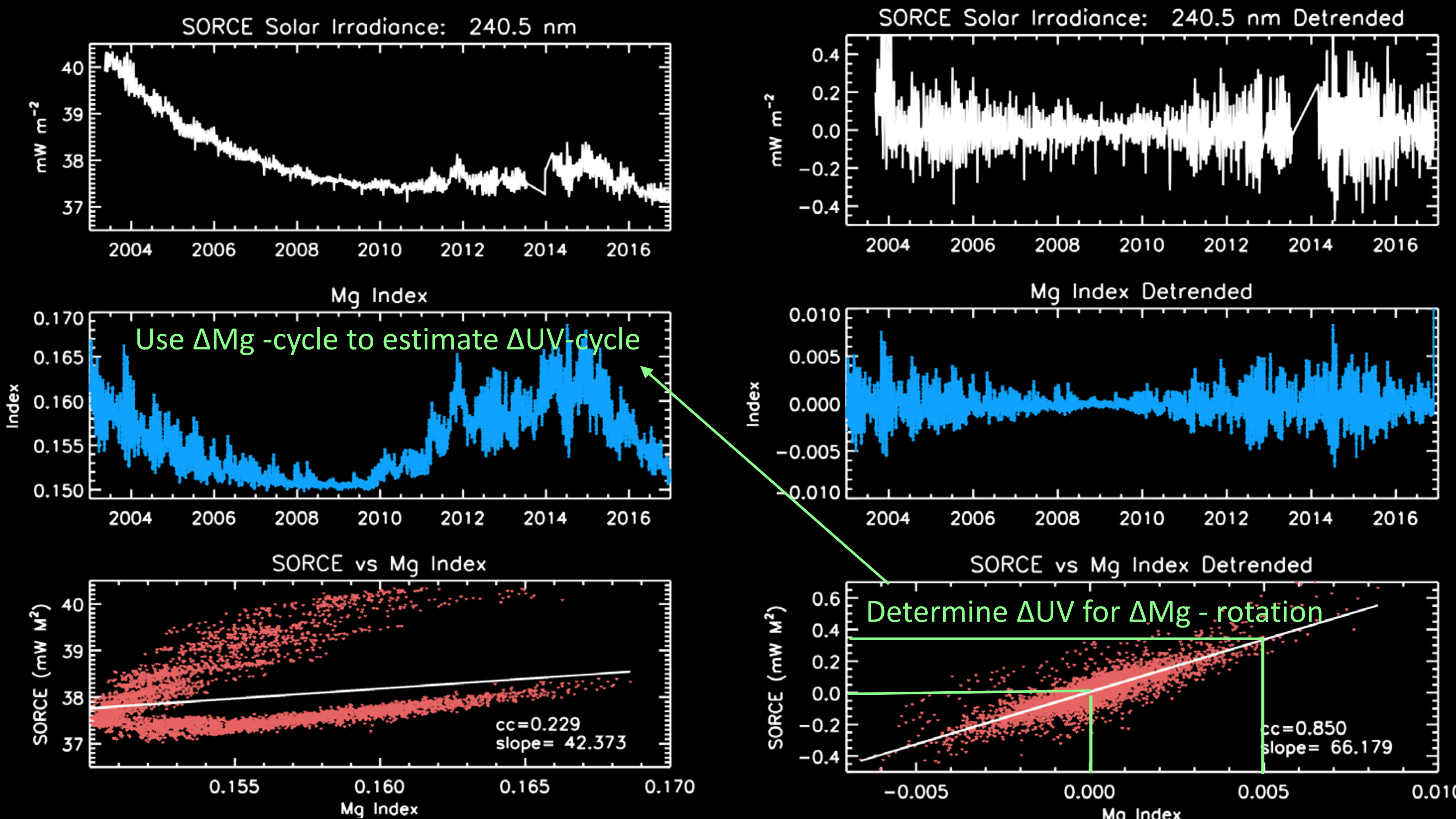
slope of residuals is 0.3% per year

will new SIST Mg composite improve model agreement with observations?

Solar Cycle Irradiance Variations: 240-241 nm

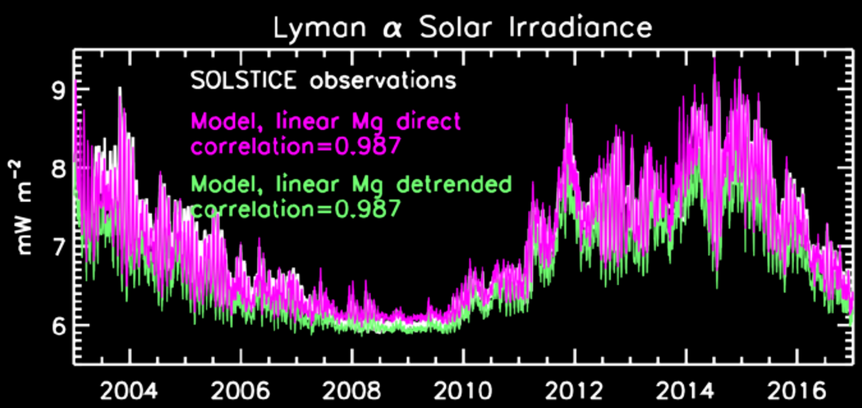
Direct Observations

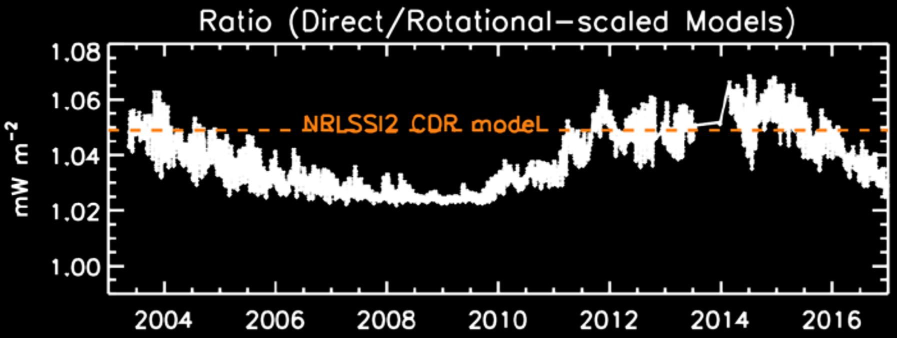
Detrended Observations



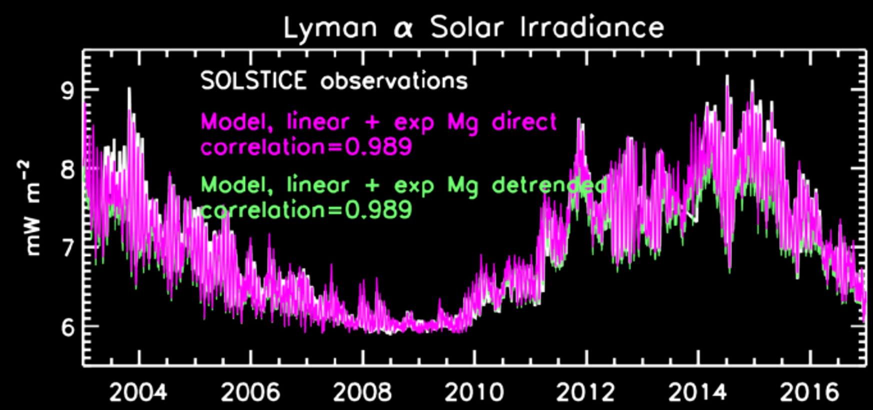
Testing the Scaling of Rotational Modulation to Solar Cycle Modulation

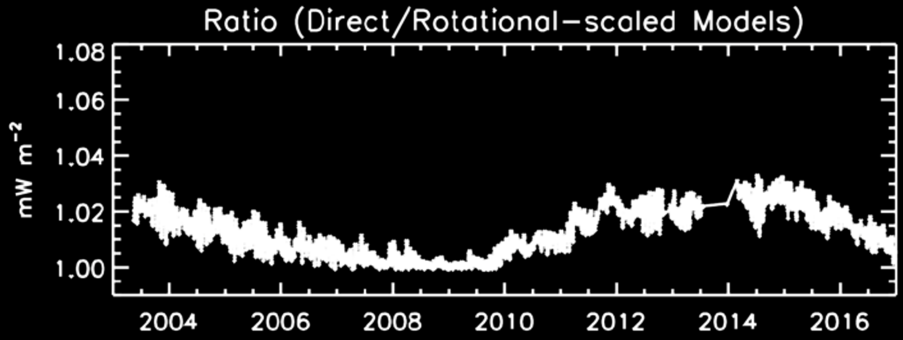
$\Delta F_{Ly\alpha} = a + b \times Mg(t)$





$\Delta F_{Ly\alpha} = a + b \times Mg(t) + c \times Mg(t)^{1.2}$





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SUMMARY, Year 2

Modelling Solar Cycle Irradiance Variations

- demonstrated the mutual consistency of the SORCE TIM TSI and SOLSTICE Lyman α SSI observations over the 11-year cycle

- identified the cause of differences between NRL's CDR models and SORCE TSI and Lyman α observations

- constructed an improved facular index by adding an exponential component of the Mg index to model formulation

- evidence for long-term trend in SOLSTICE Lyman α <0.15% per year

- determined new time-dependent coefficients for scaling facular index from rotation to solar cycle variations, for modeling SSI at longer wavelengths where observations are less stable

Solar Rotation

-Marchenko, DeLand and Lean, Space Weather and Climate, 2017

Long Term

- new white-light coronal irradiance index suggests ACRIM TSI inter-minim trend from 1996 to 2008 is too big

How Does the Sun's Spectrum Vary?

YEAR 3 WORK

- Construct a new version NRLSSI2e spectral irradiance variability model (and uncertainties), over multiple solar cycles, and compare with observations (revised from SIST activities).

- Compare new SME database to measurements of spectral irradiance from other instruments for concurrent time, and with new model

- Continue to validate and explore improvements for sunspot and facular indices and rotation-to-cycle scaling

- Prepare paper(s) describing results of solar cycle change in comparison with existing models of solar spectral irradiance variability, and independent solar irradiance observations.

- Revise and resubmit paper about analysis off LASCO solar irradiance index comparisons with direct observations

<u>In collaboration with other SIST members</u>:.

- Incorporate new total solar irradiance composite to additionally constrain solar cycle spectrum changes

- Analyze and compare facular component of new total solar irradiance composite

- Compare new Lyman α composite with sunspot-corrected new total solar irradiance composite