angie.cookson@csun.edu; gary.chapman@csun.edu;
dora.preminger@csun.edu

San Fernando Observatory (SFO), Cal State Northridge
18111 Nordhoff St, Northridge, CA 91330-8268

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Mind the Gap: How well can SFO ground-based photometry construct future missing TSI measurements?

Angie Cookson, Gary Chapman, and Dora Preminger
San Fernando Observatory
California State University, Northridge

Abstract

Use of multi-wavelength ground-based photometric data has been debated as a way to bridge gaps in spacecraft TSI measurements. To assess the ability to produce meaningful TSI values from photometric data, based on fits to spacecraft TSI measurements, we look at single-instrument TSI measurements for the 7-year period 2003-03-02 to 2010-05-04. These instruments either stand alone (SORCE/TIM) or are incorporated into long-term TSI composites (PMOD/VIRGO, IRMB/VIRGO, and ACRIMSAT/ACRIM3). We regress TSI from each instrument against Σ_r and Σ_K, photometric indices derived from San Fernando Observatory (SFO) full-disk images at 672.3 nm (red) and 393.4 nm (Ca II K-line), for this period. Based on the best fit (SORCE/TIM R^2=0.947), we construct an artificial TSI for this instrument going backwards in time to encompass the full 22-year SFO photometric dataset, then compare this artificial TSI with each of the TSI composites.

Abstract, continued

The SORCE/TIM vs PMOD/VIRGO correlation for this 7-year period is R^2=0.96 while the correlation between the PMOD/VIRGO composite and the *artificial* SORCE TSI is R^2=0.916. The 22-year correlation for the PMOD *composite* and long-term *artificial* SORCE TSI is R^2=0.862. Other composites give similar, but less-well correlated, results. With long-term photometric datasets, we can produce meaningful TSI values for short-term data gaps, help to scale values from multiple instruments, and identify instrument anomalies.

The Data: TSI Measurements

- **SORCE/TIM**: 6-hr averages, single instrument

  http//lasp.colorado.edu/sorce

- **PMOD/VIRGO**: Composite

  www.pmodwrc.ch

- **ACRIMSAT/ACRIM3**: Composite

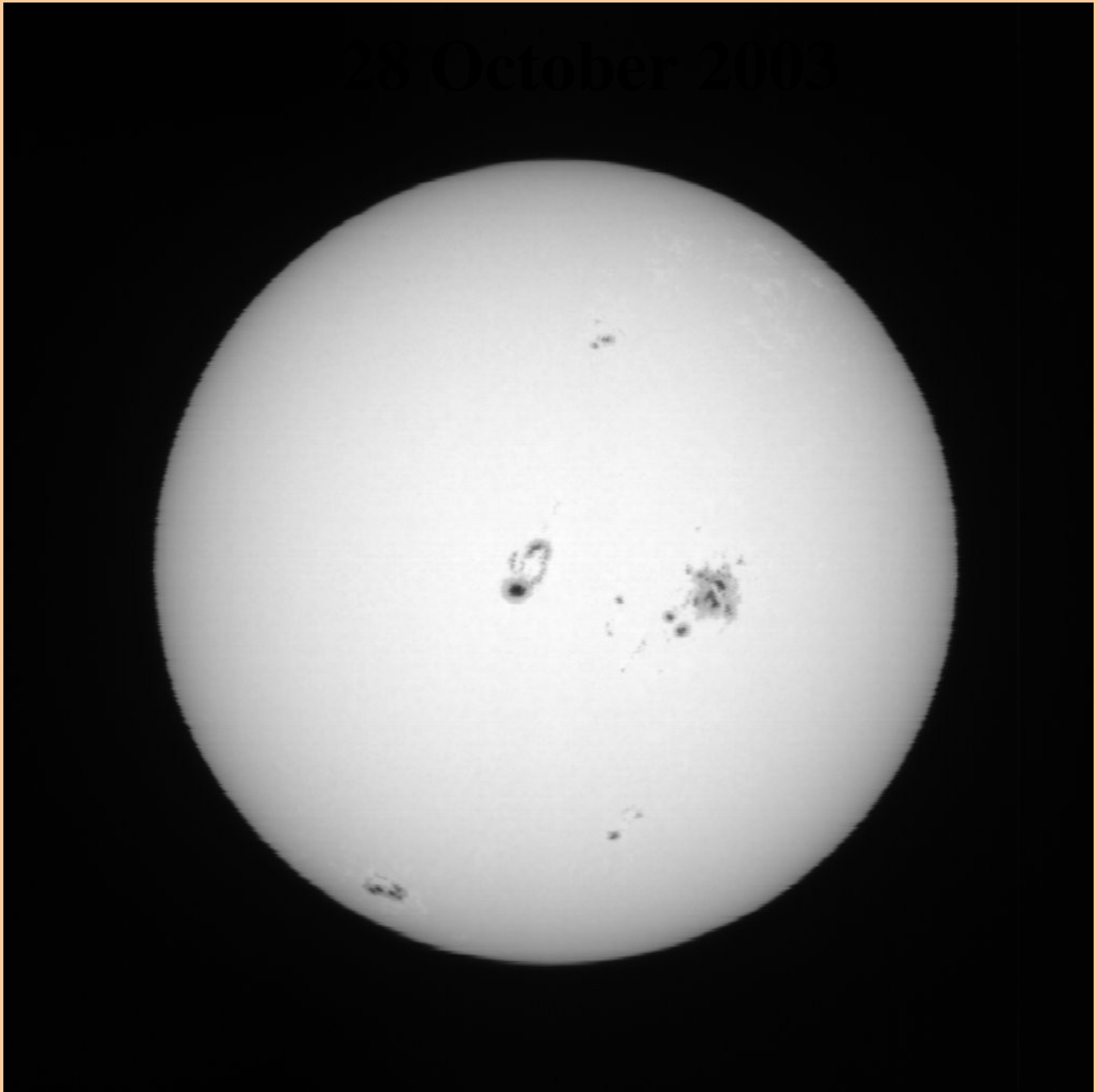
  www.acrim.com

SFO Photometric Data

CFDT1 & 2 (Walton *et al* (1998,*Sol.Phys.* **179**, 31; www.csun.edu/sfo)

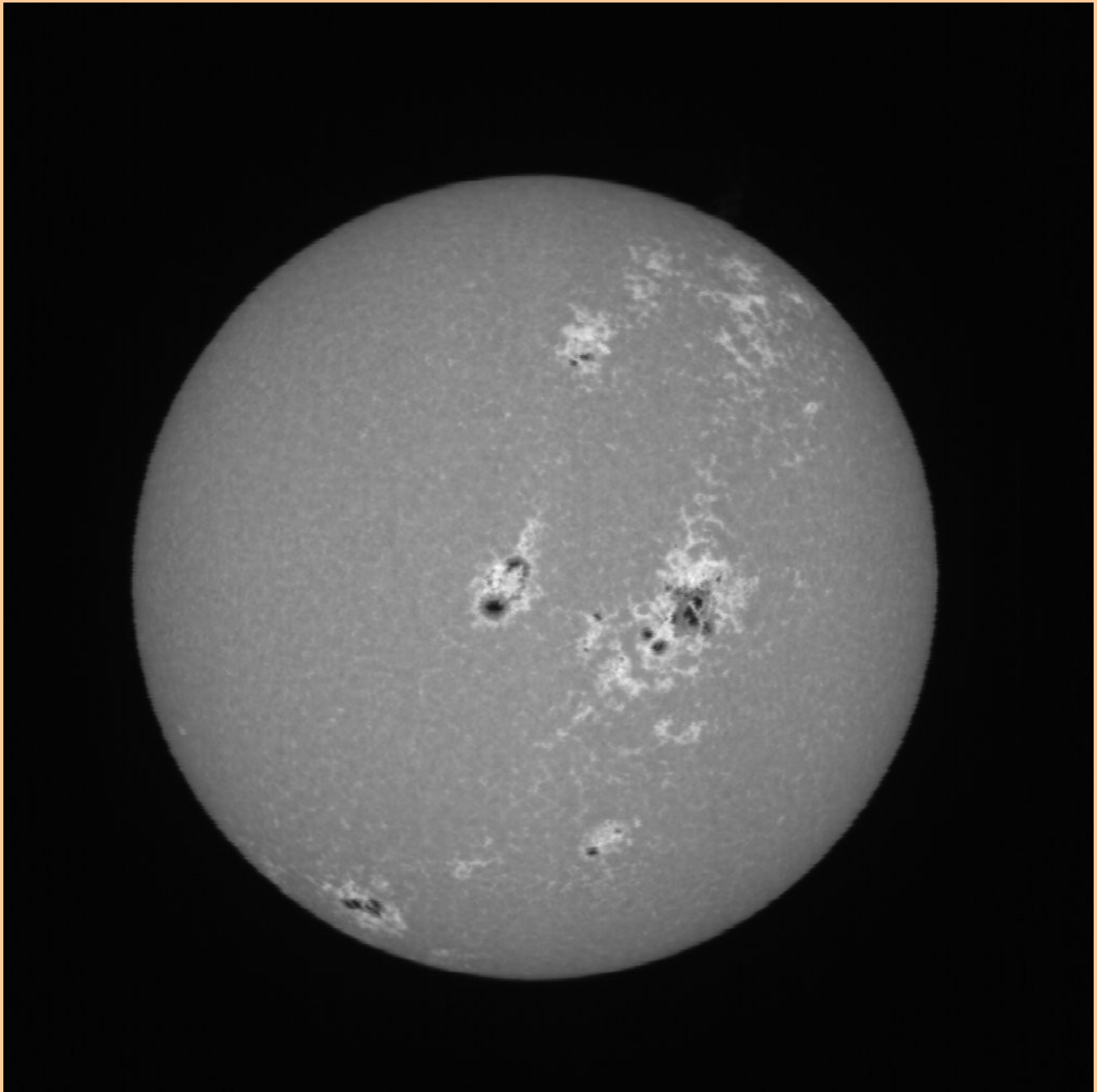
- 512 x 512 CFDT1 images, 5” square pixels
- 1024 x 1024 CFDT2 images, 2.5” square pixels
- Images produced by 512 or 1024 scans of a 512- or 1024- linear diode array
- 672.3 nm (red), 10 nm bandpass
- 393.4 nm (Ca II K), 10 nm bandpass
- Single red image; Ca II K image produced from two co-added scans

SFO Red image at 672.3 nm



SFO Ca II K image at 393.4 nm

28 October 2003



SFO Image Processing

- Photometric images produced in several wavelengths: CFDT1 since 1988; CFDT2 since 1992.
- Several robust algorithms developed for producing photometric contrast images and determining relative irradiance contributions of solar surface features (sunspots, faculae, and plage) from these images. (Walton *et al* (1998 *Sol.Phys.* **179** 31))
- Several solar indices computed, including photometric sums (Σ), sunspot areas and deficits, and faculae areas and excesses, for the purpose of TSI modeling. (Preminger, Walton, & Chapman 2001, *Sol.Phys.* **202** 53)

SFO Photometric Sum ($\sum$) Index

- Photometric Sum ($\sum$) has been one of the most successful photometric indices produced. (Preminger, Walton, & Chapman 2002, *JGR*, **107** 6)
- $\sum_r$ and $\sum_K$, used in a multi-variable linear regressions against space-based TSI, produce the best results.
- $\sum_r$ and $\sum_K$ are disk-integrated sums determined from red and Ca II K-line contrast-image pixels, respectively; each pixel is weighted by the appropriate limb-darkening.
- $\sum_r$ and $\sum_K$ do not require feature identification, i.e., determining whether a pixel belongs to a sunspot, facula, or network.

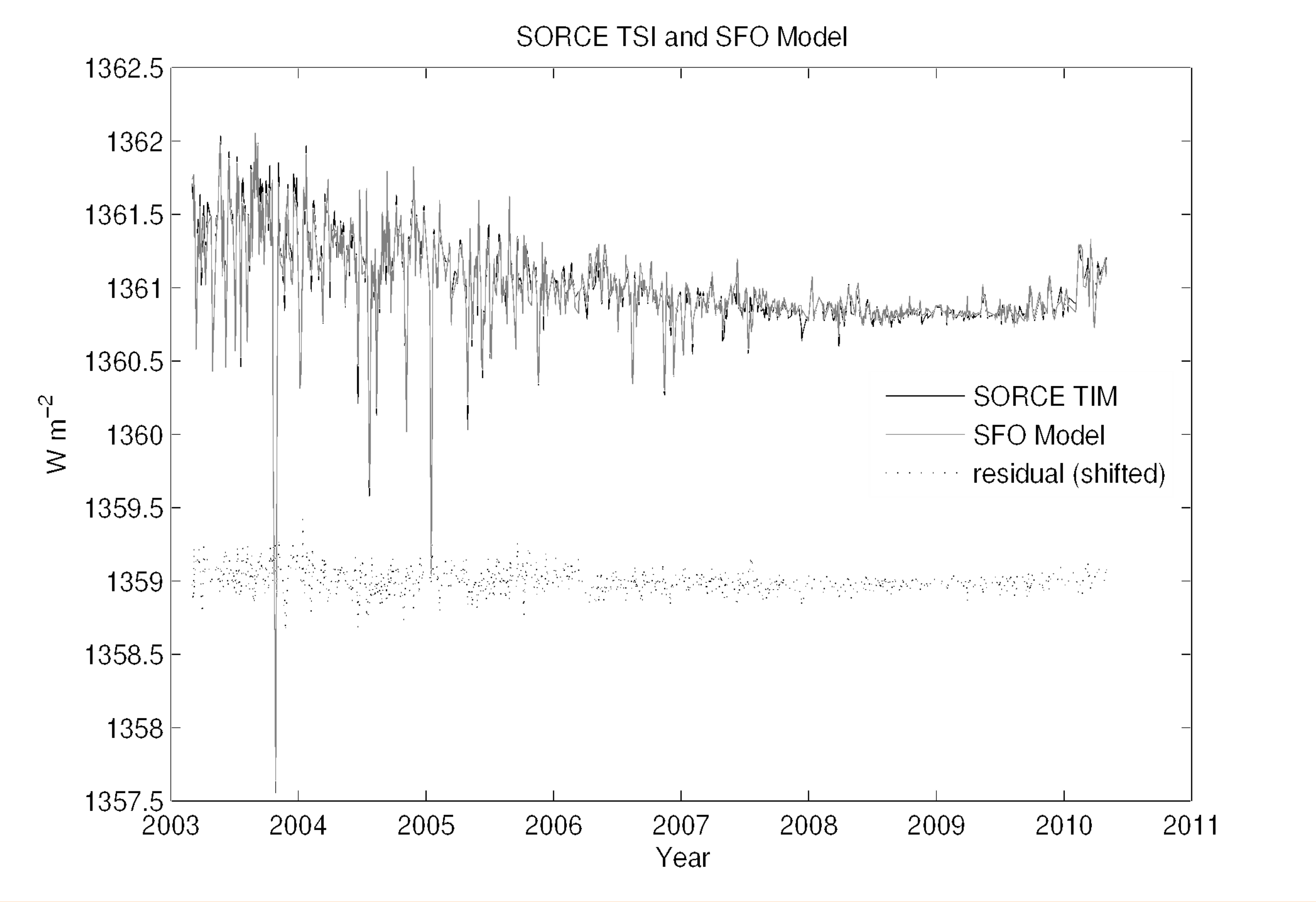
SFO Photometric Sum (Σ), continued

- Σ
  - measures the relative change in spectral irradiance in filter passband due to all features
  - assumes image noise is symmetric around zero, causing bright and dark noise pixels to cancel, leaving only contributions from real features
- Σ_r measures irradiance contributions from photospheric structures seen in red continuum images
- Σ_K measures variability of the upper photosphere/lower chromosphere seen in Ca II K images

Method

- Regress SFO $\sum_r$ and $\sum_K$ against SORCE TSI from 2003-3-02 to 2010-05-04 (~7yrs)
- Construct *artificial* SORCE TSI, based on regression results, going backwards in time, using SFO $\sum_r$ and $\sum_K$ from 1988-11-14 to 2010-05-04 (~22 yrs)
- Determine correlation of *artificial* SORCE-based TSI against PMOD and ACRIM composite TSIs
- Compare correlations of *artificial* SORCE TSI vs PMOD & ACRIM TSI composites to correlations of real SORCE TSI vs PMOD & ACRIM composites

SORCE/TIM TSI vs $(\Sigma_r + \Sigma_K)$ R^2=0.947



Results

For *Real* TSI datasets	**2003-03-02 to 2010-05-04 (~7yrs)**
• SFO fit to SORCE	R^2=0.947
• SFO fit to PMOD	R^2=0.920
• SFO fit to ACRIM	R^2=0.747
• SORCE vs PMOD	R^2=0.960
• SORCE vs ACRIM	R^2=0.792

For composite TSI only	**1988-11-14 to 2010-05-04 (~22yrs)**
• SFO fit to PMOD	R^2=0.865
• SFO fit to ACRIMSAT	R^2=0.639

Results, continued

Short-term

For *artificial* SORCE-based TSI 2003-03-02 to 2010-05-04 (~7yrs)

- SORCE-based vs PMOD R^2=0.916
- SORCE-based vs ACRIM R^2=0.748

Long-term

For *artificial* SORCE-based TSI 1988-11-14 to 2010-05-04 (~22 yrs)

- SORCE-based vs PMOD R^2=0.862
- SORCE-based vs ACRIM R^2=0.663

Conclusions

SFO photometric indices derived from active regions observed in the red and Ca II K-line bands are linearly regressed against several satellite TSI datasets. Based on the best fit (SORCE/TIM R^2=0.95), a 22-year artificial TSI can be constructed backwards in time from SFO photometric data.

Comparing this artificial dataset with the PMOD composite TSI for the same short-term and long-term periods gives R^2=0.92 and R^2=0.87, respectively. ACRIM TSI is less-well correlated.

Using the relationships between different satellite TSI datasets and long-term SFO photometric data, it is possible to use ground-based photometric data to produce meaningful TSI values for short-term data gaps, help to scale values from multiple instruments, and identify instrument anomalies.