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

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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 $\sum r$ and $\sum K$, 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


- 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

28 October 2003
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 ($\Sigma$), sunspot areas and deficits, and faculae areas and excesses, for the purpose of TSI modeling. (Preminger, Walton, & Chapman 2001, Sol.Phys. 202 53)
Photometric Sum ($\Sigma$) has been one of the most successful photometric indices produced. (Preminger, Walton, & Chapman 2002, *JGR*, 107 6)

- $\Sigma_r$ and $\Sigma_K$, used in a multi-variable linear regressions against space-based TSI, produce the best results.

- $\Sigma_r$ and $\Sigma_K$ 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.

- $\Sigma_r$ and $\Sigma_K$ do not require feature identification, i.e., determining whether a pixel belongs to a sunspot, facula, or network.
SFO Photometric Sum ($\sum$), continued

- $\sum$ 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.

- $\sum_r$ measures irradiance contributions from photospheric structures seen in red continuum images.

- $\sum_K$ 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.