

# **TSI and Ground-Based Data: What can be learned?**

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# Abstract

The San Fernando Observatory (SFO) has 20+ years of ground-based photometric data taken in the red (672.3 nm), blue (472.3 nm), and Ca II K (393.4 nm) wavelengths. Models using SFO data correlate well with satellite data and can help determine the contribution of sunspots and faculae/network to total solar irradiance (TSI). PSPT provides similar ground-based data. Currently, TSI composites based on data from several different space-borne instruments are being proposed. How well do SFO's models, as well as those using PSPT data, correlate with each of these composites and what can be learned from such an exercise?

# Important Caveats since SORCE Mtg

We learned during the SORCE 2008 meeting from Mark Rast (LASP) that PSPT data prior to 2005 have some peculiarities that we failed to take into account. Please keep this in mind when looking at our PSPT results. With Mark's guidance, we intend to modify our work as soon as possible to reflect this, as well as fill in data gaps. We will then update this poster .

# The Data

- TSI Composites
  - SORCE
  - PMOD
  - RMIB or SARR
  - ACRIM
- Photometry
  - CFDT1 (SFO)
  - CFDT2 (SFO)
  - PSPT

# TSI Composites

- **SORCE:** level 3, version 7;  
[http://lasp.colorado.edu/sorce/data/tsi\\_data.htm](http://lasp.colorado.edu/sorce/data/tsi_data.htm)
- **PMOD:** composite\_d41\_61\_0710.dat; [www.pmodwrc.ch](http://www.pmodwrc.ch)
- **RMIB or SARR:** Sabri Makaouli, private communication;  
Dewitte, *et al.* 2005 *Sol.Phys.* **224** 209.
- **ACRIM:** Version 09/07; [www.acrim.com](http://www.acrim.com)

# Photometric Data

- CFDT1 & 2 (Walton *et al* (1998, *Sol.Phys.* **179**, 31; [www.csun.edu/sfo](http://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 from two co-added scans

# More Photometric Data

- PSPT ([http://lasp.colorado.edu/pspt\\_access](http://lasp.colorado.edu/pspt_access))
  - 2048 x 2048 images, 1.0" square pixels
  - Images produced using CCD camera with high frame rate
  - 607.1 nm red image, 0.5 nm FWHM
  - 393.4 nm Ca II K image, 0.3 nm FWHM
  - 30 exposures co-added for each photometric image

# SFO Image Processing

- San Fernando Observatory produces photometric images in several wavelengths: CFDT1 since 1989; CFDT2 since 1993.
- SFO developed several robust algorithms for producing photometric contrast images and determining relative irradiance contributions of solar surface features (sunspots and faculae) from these images. (Walton *et al* (1998 *Sol.Phys.* **179** 31))
- Several solar parameters are computed from the SFO data for the purpose of TSI modeling. (Preminger, Walton, & Chapman 2001, *Sol.Phys.* **202** 53)
- Photometric Sum ( $\Sigma$ ) has been one of the most successful of these. (Preminger, Walton, & Chapman 2002, *JGR*, **107** 6)

# Photometric Sum ( $\Sigma$ )

- The Photometric Sum ( $\Sigma$ ) represents the sum of all pixels in a full-disk contrast image at a given wavelength.
  - $\Sigma$  measures the relative change in spectral irradiance in filter passband due to all features.
  - $\Sigma$  assumes image noise is symmetric around zero, causing bright and dark noise pixels to cancel, leaving only contributions from real features.
- $\Sigma_r$  measures irradiance contributions from photospheric structures seen in red continuum images.
- $\Sigma_K$  measures variability of the lower chromosphere seen in Ca II K images.

# $\Sigma$ and an empirical TSI model

- We use an empirical model for TSI of the following form:

$$\text{TSI} = a_0 + a_1 \Sigma_r + a_2 \Sigma_K$$

- This model using SFO's  $\Sigma_r$  and  $\Sigma_K$  fits well to satellite-based TSI (Fröhlich and Lean composite) with  $R^2=0.91$  for solar cycle 22 (Preminger *et al.* 2002, *JGR*, **107** 6).
- PSPT data is very similar to that of SFO, therefore we used the same processing techniques, algorithms, and model fits using computed PSPT  $\Sigma$ s.

# Determining Fits

- Three time periods, each increasing in length, and based on the availability of either the photometric data or the TSI time series, were chosen for a series of linear regressions between space-based TSI and ground-based photometry.
- The ultimate start and stop dates were determined by PSPT, whose data starts in March, 1998, and ends in June, 2007, with a large gap at the end of 2006, start of 2007.
- Period 1, 2/25/03 – 6/7/07: start date determined by TSI SORCE.
- Period 2, 4/5/00 – 6/7/07: start date determined by ACRIM3.
- Period 3, 3/16/98 – 6/7/07: start date determined by PSPT.

### Table 1. TSI Regressions

#### Period 1:

**02/25/2003** (when SORCE starts) to **06/07/2007** (when PSPT ends)

<b>R<sup>2</sup></b>	<b>CFDT1</b>	<b>CFDT2</b>	<b>PSPT</b>
<b>TSI Sorce</b>	0.9272	0.9258	0.8158
<b>TSI PMOD (Frohlich)</b>	0.9190	0.9189	0.8123
<b>TSI RMIB (deWitte)</b>	0.8966	0.8961	0.7925
<b>TSI Acrim composite</b>	0.8510	0.8487	0.6931

#### Period 2:

**04/05/2000** (when ACRIMSAT (ACRIM3) starts) to **06/07/2007** (when PSPT ends)

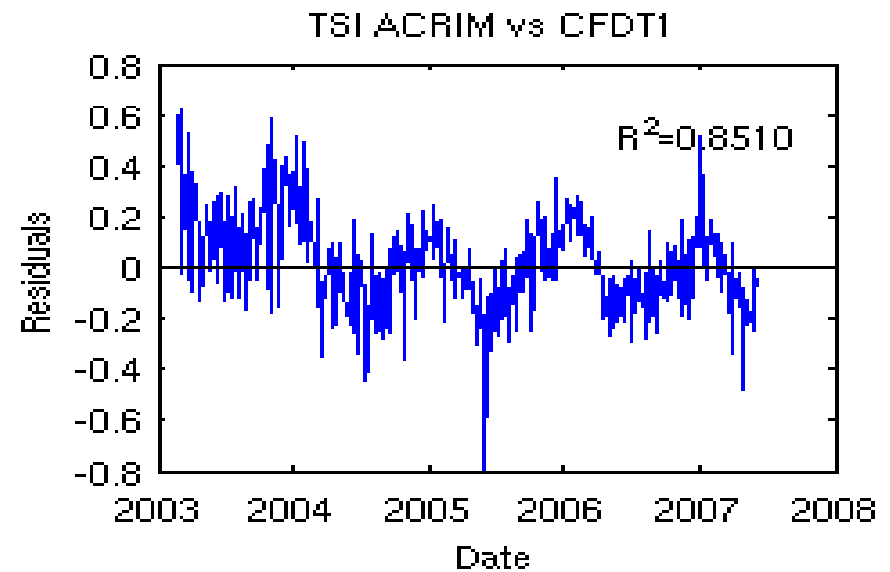
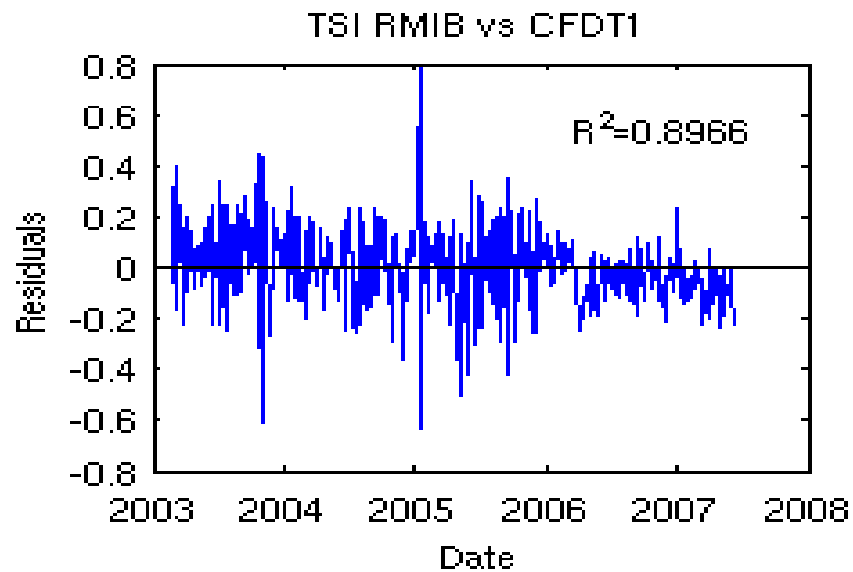
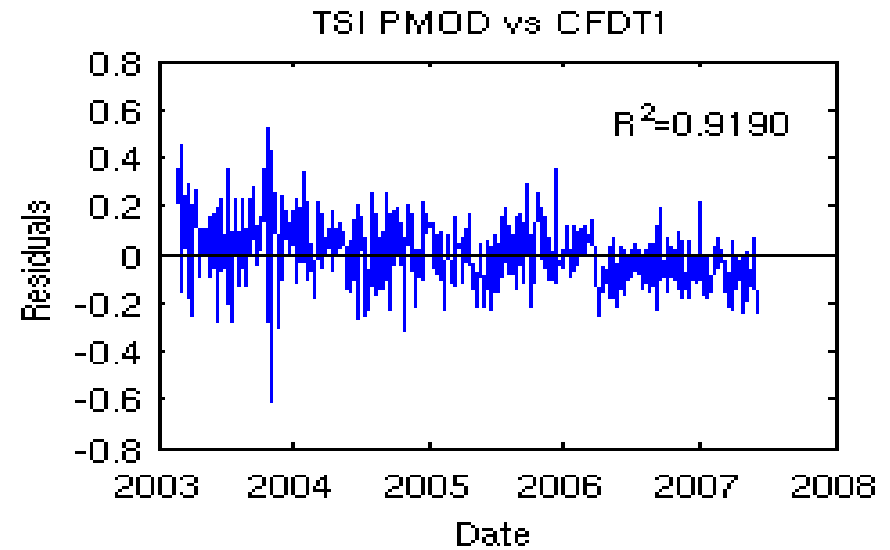
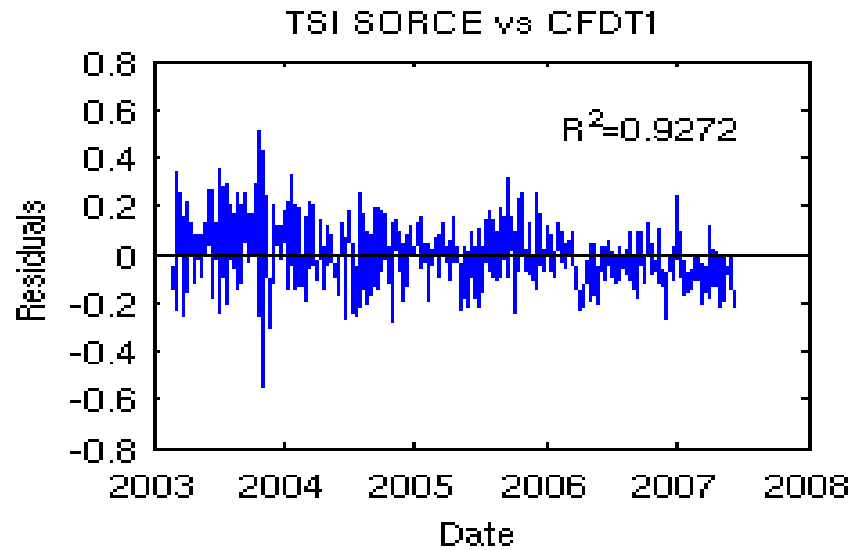
<b>R<sup>2</sup></b>	<b>CFDT1</b>	<b>CFDT2</b>	<b>PSPT</b>
<b>TSI PMOD (Frohlich)</b>	0.9154	0.9209	0.8119
<b>TSI RMIB (deWitte)</b>	0.8860	0.8932	0.7880
<b>TSI Acrim composite</b>	0.8811	0.8855	0.7539

#### Period 3:

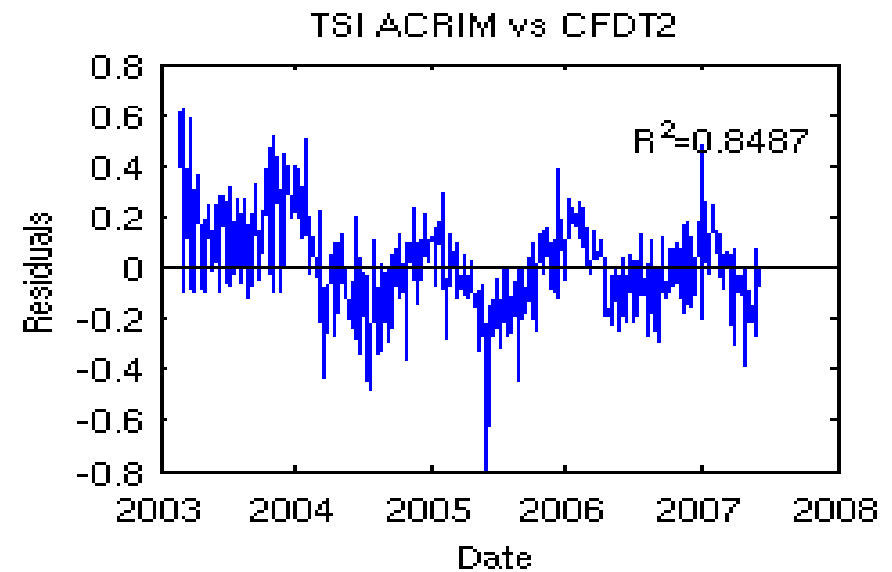
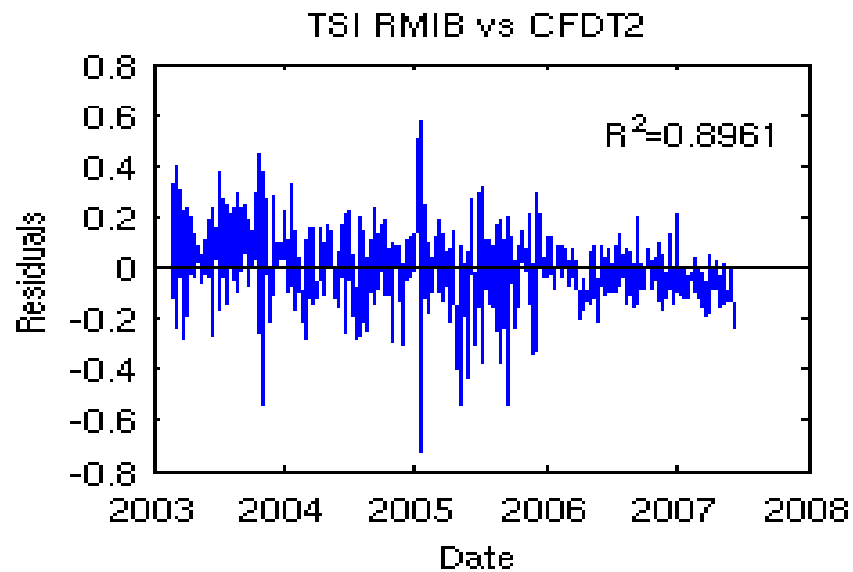
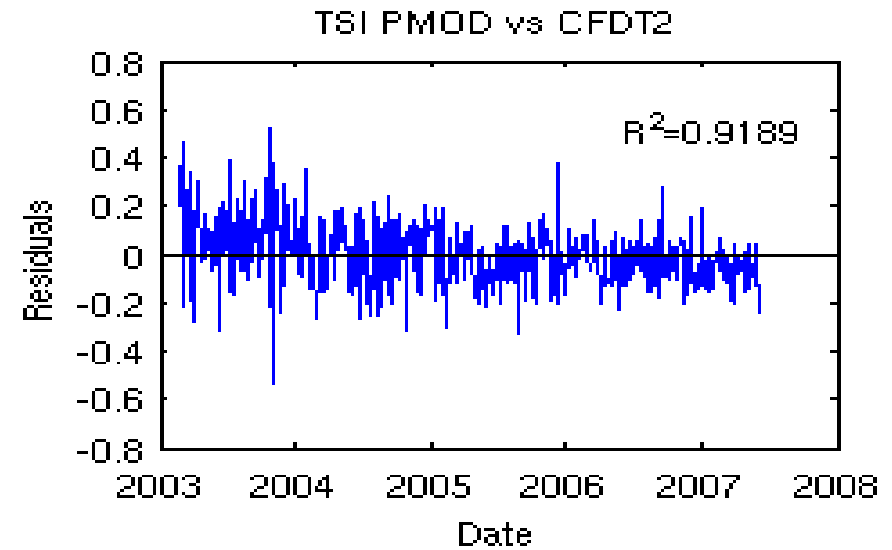
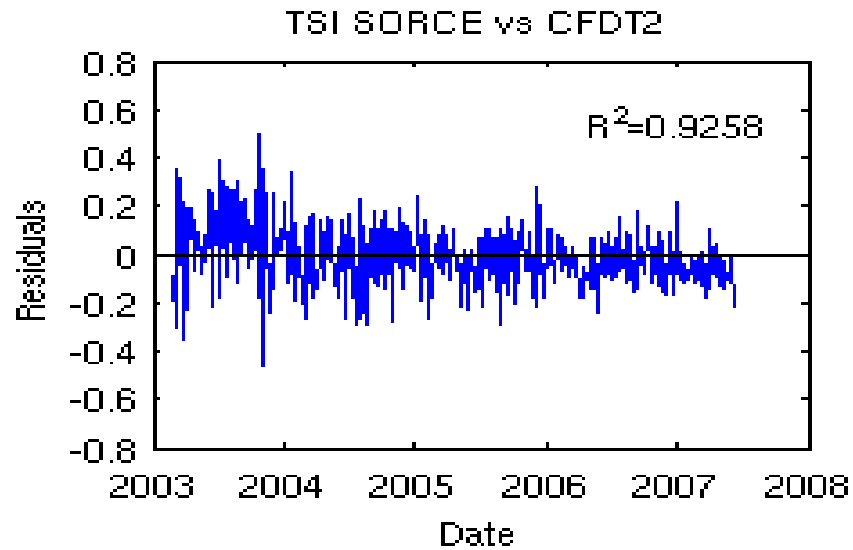
**03/16/1998** (when PSPT starts) to **06/07/2007** (when PSPT ends)

<b>R<sup>2</sup></b>	<b>CFDT1</b>	<b>CFDT2</b>	<b>PSPT</b>
<b>TSI PMOD (Frohlich)</b>	0.9032	0.8998	0.7984
<b>TSI RMIB (deWitte)</b>	0.8785	0.8868	0.7807
<b>TSI Acrim composite</b>	0.8091	0.7946	0.6798

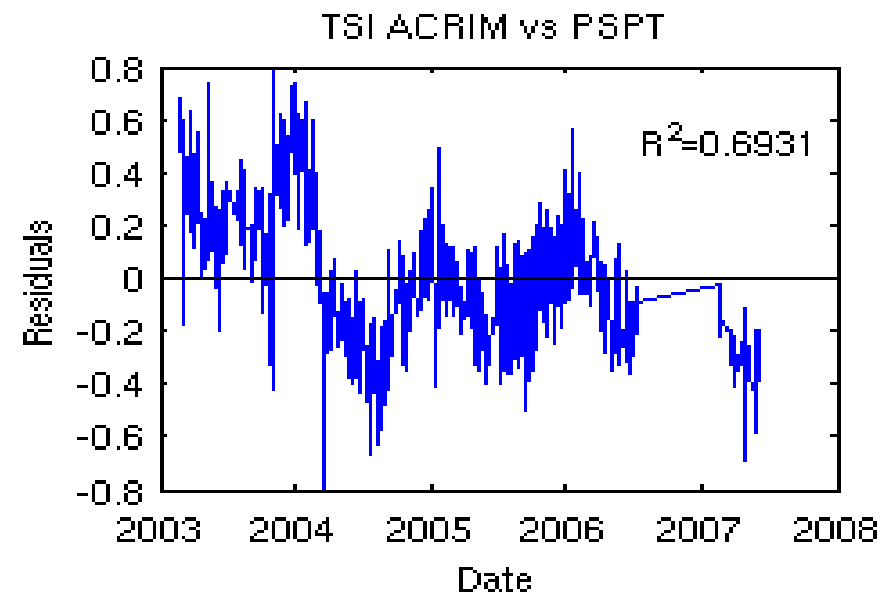
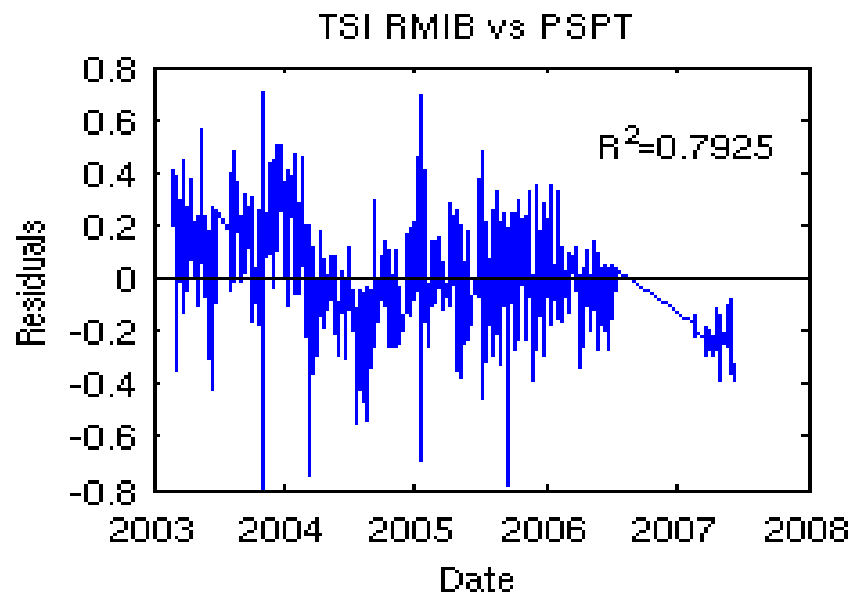
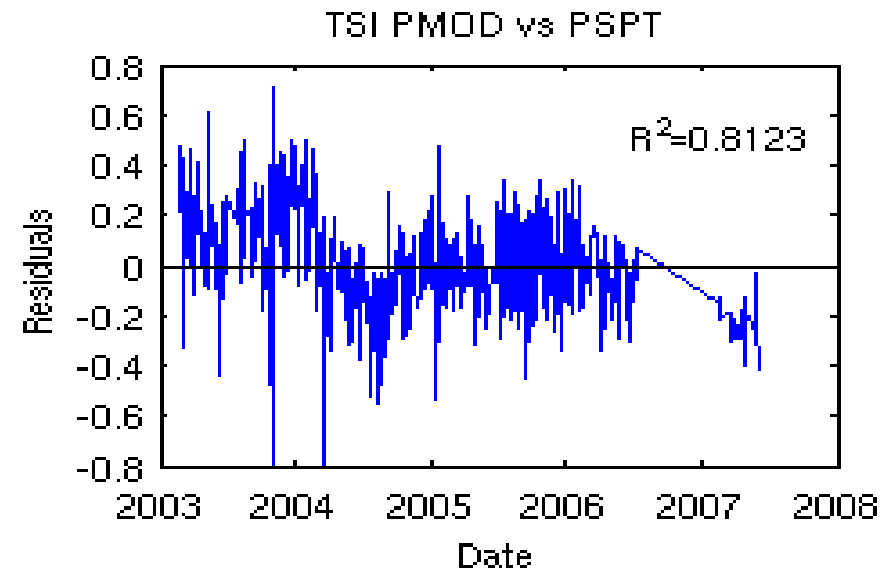
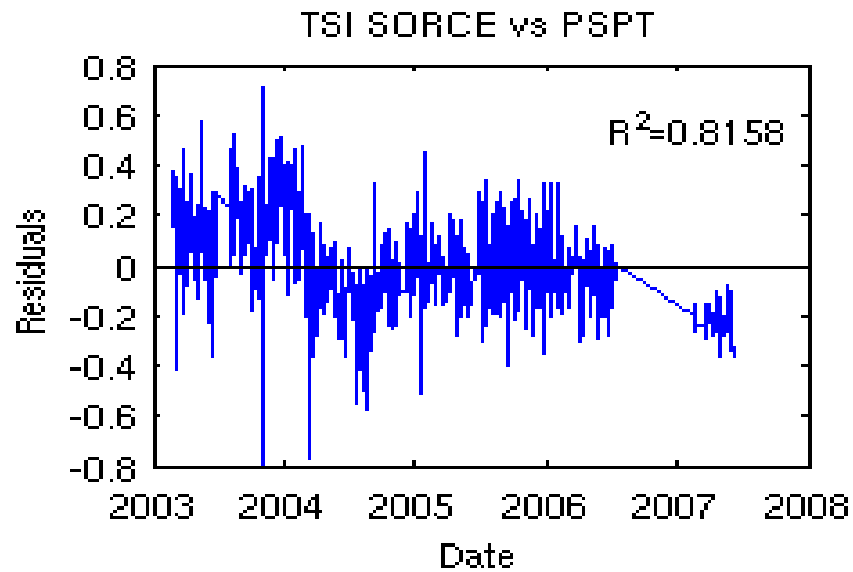
# Period 1: 2/25/03-6/7/07 CFDT1



# Period 1: 2/25/03-6/7/07 CFDT2



# Period 1: 2/25/03-6/7/07 PSPT



# Wait, there's more ...

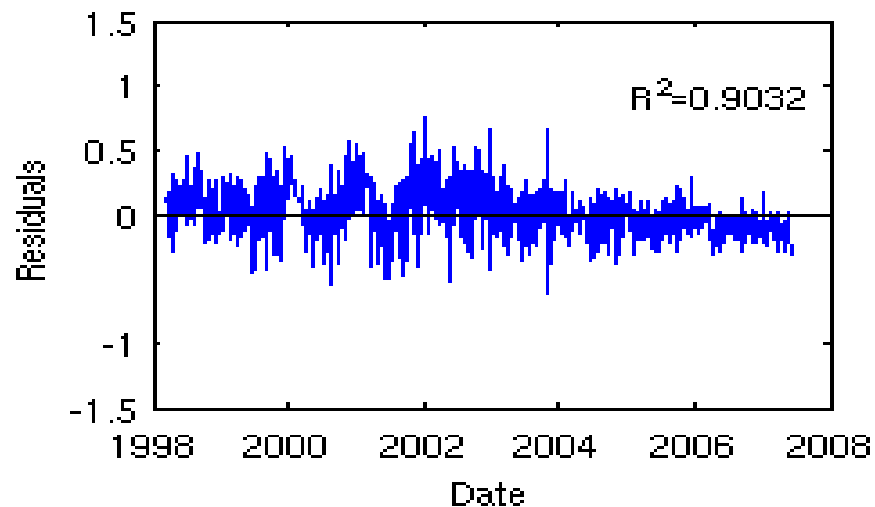
We all know that more graphs will simply make you dizzy, but if you're up for it ...

Following are plots of the fits for the longest period, 3/16/98 to 6/7/07, for additional comparisons. Fits for Period 2 fall between those for Periods 1 and 3, so check the  $R^2$ s in Table 1.

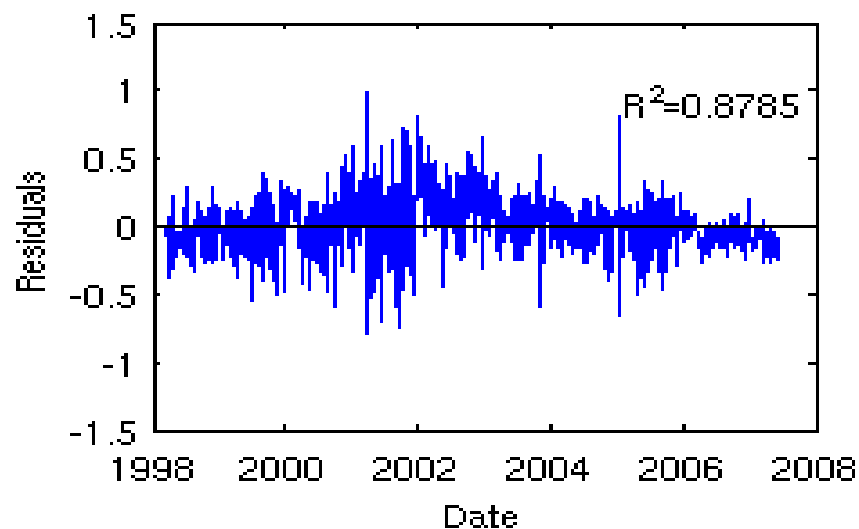
# Period 3: 3/16/98–6/6/07 CFDT1

No SORCE  
Available

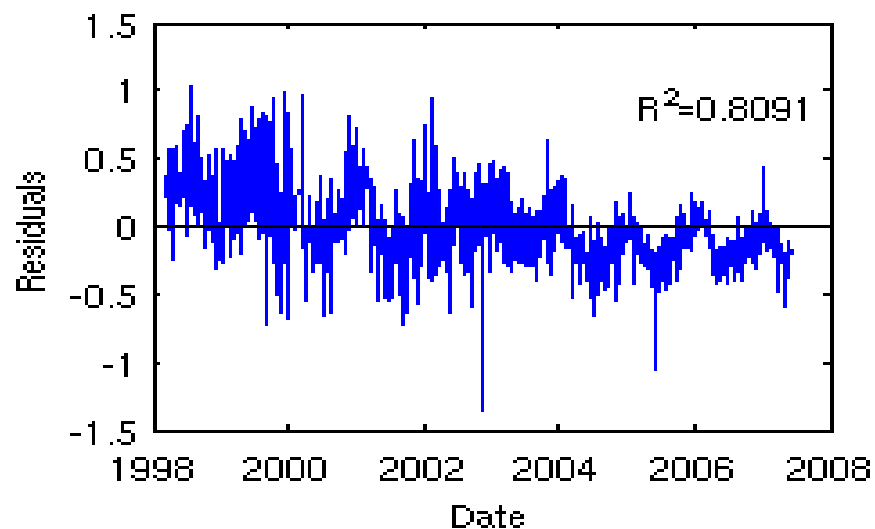
TSI PMOD vs CFDT1



TSI RMIB vs CFDT1



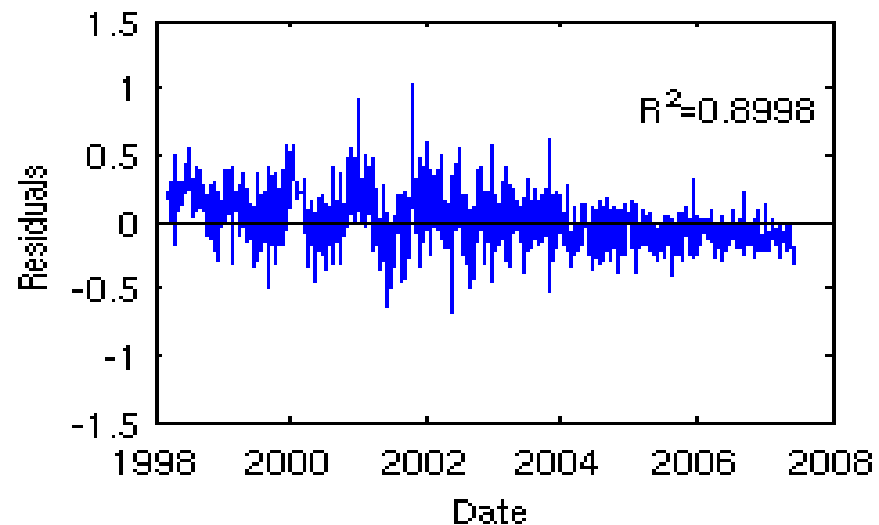
TSI ACRIM vs CFDT1



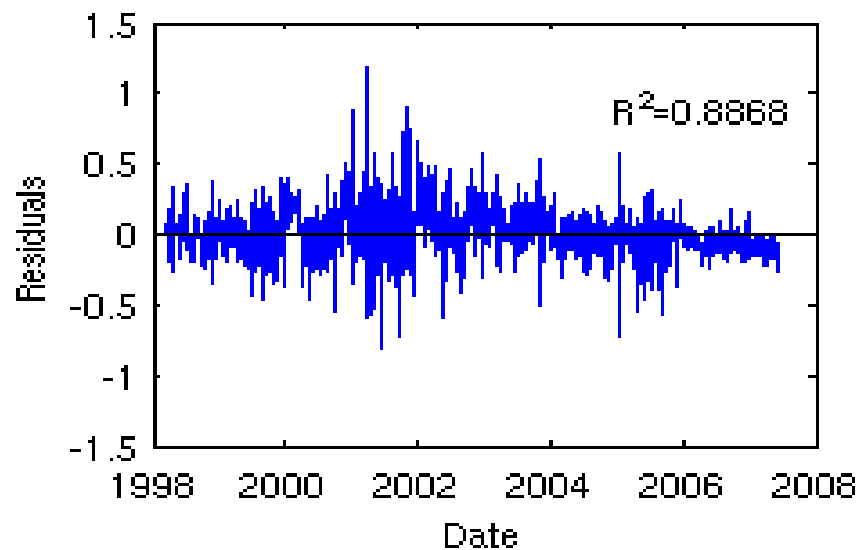
# Period3: 3/16/98-6/7/07 CFDT2

No SORCE  
Available

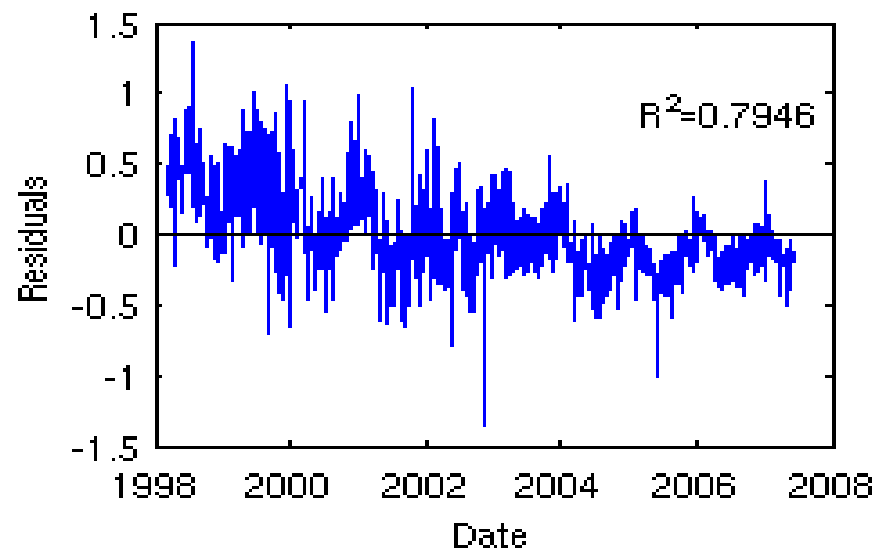
TSI PMOD vs CFDT2



TSI RMIB vs CFDT2



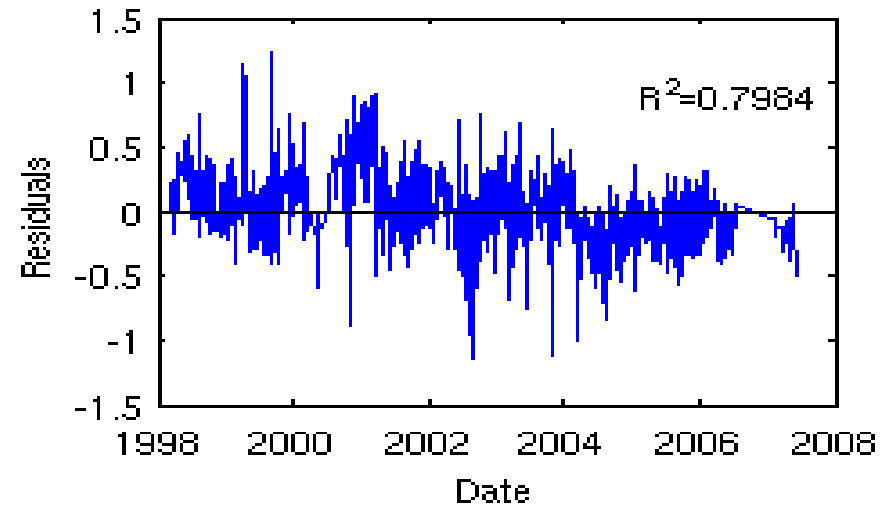
TSI ACRIM vs CFDT2



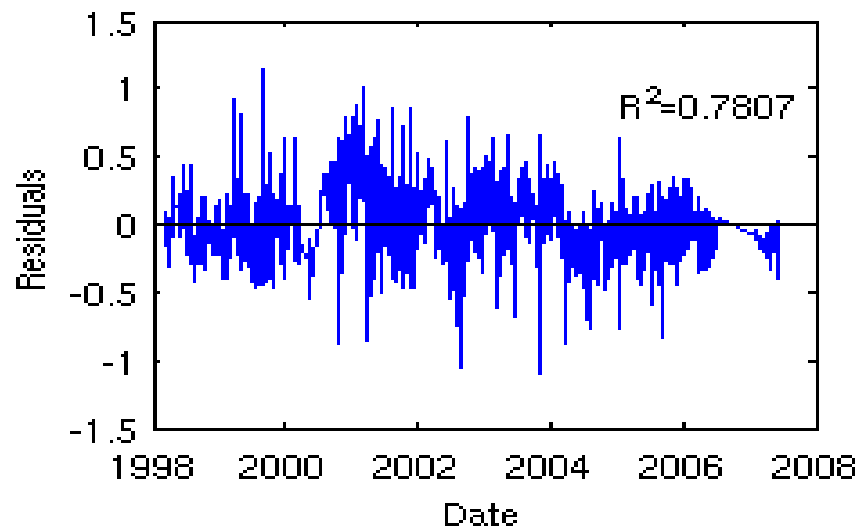
# Period 3: 3/16/98-6/7/07 PSPT

No **SORCE**  
Available

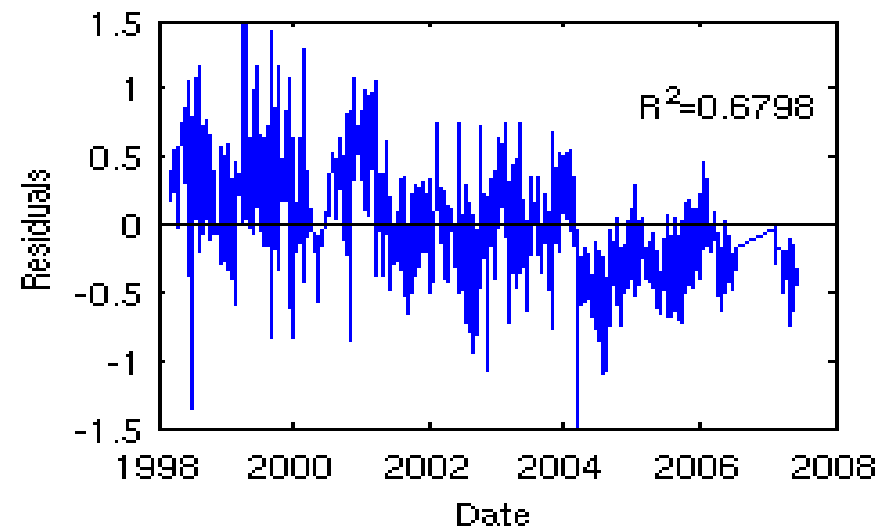
TSI PMOD vs PSPT



TSI RMIB vs PSPT



TSI ACRIM vs PSPT



# The Results

- 50 million linear regressions (or so it seemed) were run (and re-run) on all possible TSI-Data combinations, the results of which can be seen in Table 1.
- The posted graphs illustrate the resulting fits.
- For all three periods, the results were consistently the same:
  - CFDT1 & 2 gave better fits to all TSI composites than did PSPT. Sometimes CFDT1 fits were minimally better than CFDT2 and vice-versa.
  - In all cases, the best fits were first to TSI SORCE, followed by PMOD, RMIB, and ACRIM, in that order. (SORCE only for Period 1.)

# More Results

- Period 1: The greatest difference in  $R^2$  between SORCE and ACRIM was  $\sim 0.12$  for PSPT.
- Period 2: (No SORCE available) The greatest difference in  $R^2$  between PMOD and ACRIM was  $\sim 0.06$  for PSPT.
- Period 3: (No SORCE available) The greatest difference in  $R^2$  between and PMOD and ACRIM was  $\sim .012$  for PSPT.
- The best fits for ACRIM were for Periods 1 & 2, where the composite is based on ACRIM-3. When the composite is extended to include TSI based on ACRIM-2, the  $R^2$ s fall by as much as 0.04 to 0.06.

# More Results

- Since the longest data set begins during the rise of cycle 23 and ends as the next minimum approaches, little can be said about long-term trends. However, it can be pointed out that PMOD, RMIB, and ACRIM give decidedly different patterns against the same photometric data sets. PMOD shows a slight downward trend not seen in RMIB. But RMIB shows a “bump” around solar max not seen in either PMOD or ACRIM. ACRIM also shows a downward trend along with a more cyclical pattern. Three different trends indicate that something is different among the three composites rather than in the ground-based photometry.
- FYI: PSPT data has a large gap from the middle of 2006 to early 2007. Creating a shortened PSPT dataset that ends in 2006 improves the  $R^2$ s somewhat, but only slightly.

# Conclusions

While ground-based photometry cannot measure Total Solar Irradiance, it can help determine the contribution to the TSI of solar magnetic features when used in conjunction with TSI obtained from space-borne instruments. These instruments are relatively short-lived and subject to degradation caused by harsh environmental conditions, possibly compromising some of the data.

For the lengthy data set that TSI and climate studies require, the data from several instruments must be cobbled together. The best way to do this is still in question, but several methods have been proposed. Is there a way to evaluate these methods? **Use of long-term ground-based photometry such as CFDT (20+ yrs) and PSPT (9+ yrs) with current TSI composites provides a helpful evaluation tool.** Although the tool itself cannot be the determining factor, it should be included in the general discussion.

# In Memoriam

Much of the development of SFO's image processing techniques and algorithms were done by our dear friend and colleague, Steve Walton, who passed away November 11, 2006. Words cannot express how much we miss him, but his work still contributes to the solar community.