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Implications of Ground Based Photometric Images for Long Term Solar Irradiance Variations

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Data Description

- Cartesian Full Disk Telescope (CFDT) images from San Fernando Observatory (SFO), 1988–2004
  - 512×512 and 512×512 pixel images, $5''$ square pixels
  - Ca II K filtergrams with 393.4 nm center, 1 nm bandpass; red filtergrams with 672.3 nm center, 10 nm bandpass
  - Analysis of these images previously reported in detail (see http://www.csun.edu/sfo/publications.html)
- Photometric Solar Patrol Telescope (PSPT) from 1998–2004
  - 2048×2048 pixel images, $1''$ square pixels
  - Ca II K filtergrams with 607.095 nm center, 0.273 nm bandpass; red filtergrams with 607.095 nm center, 0.458 nm bandpass

Data Analysis 1

- San Fernando Observatory (SFO) algorithms applied to PSPT images to:
  - Fit an elliptical limb to the images
  - Divide each image by a mean quiet sun (QS) limb darkening (LD) curve
  - Pixel contrast defined as fractional change in brightness of pixel with respect to QS LD at that disk location
- Relative solar irradiance change in filter passband of all images computed by summing all image contrasts times the quiet sun limb darkening curve, suitably normalized:

$$\Sigma = \sum_{\mathrm{entireimage}} C_i \phi(\mu_i)$$

where C_i is the contrast of the i'th image pixel, $\phi(\mu)$ is a suitably normalized limb darkening curve. We denote red and Ca II K Σ with a subscript r and K, respectively. Σ computed from CFDT and PSPT are denoted with superscript C and P, respectively.

Summary of Preminger, Walton, & Chapman 2002, *JGR* (Paper I)

- A fit to TSI S of the form

$$S(t) = S_0 + a\Sigma_r^C(t) + b\Sigma_K^C(t)$$

(S_0, a, b are the fit parameters) is a good model for S during solar cycle 22 (1988 through 1996).

- The variation on solar cycle timescales is captured by Σ_K^C; Σ_r^C is flat during the solar cycle.

- This implies that changes in the depths of spectral lines, not changes in the continuum, dominate solar cycle timescale changes in S.

Data Analysis 2

Work from Paper I extended into cycle 23, and verified using PSPT data.

Fits to S made using:

1. $\Sigma_r^C and \Sigma_K^C$ from 1988 through 2004
2. $\Sigma_r^C and \Sigma_K^C$ for solar cycle 22 alone (1988 through 1996-1-1)
3. $\Sigma_r^C and \Sigma_K^C$ for solar cycle 23 alone (1996-1-1 through 2004-9-13)
4. $\Sigma_r^P and \Sigma_K^P$ for 1998 through 2004-9-13

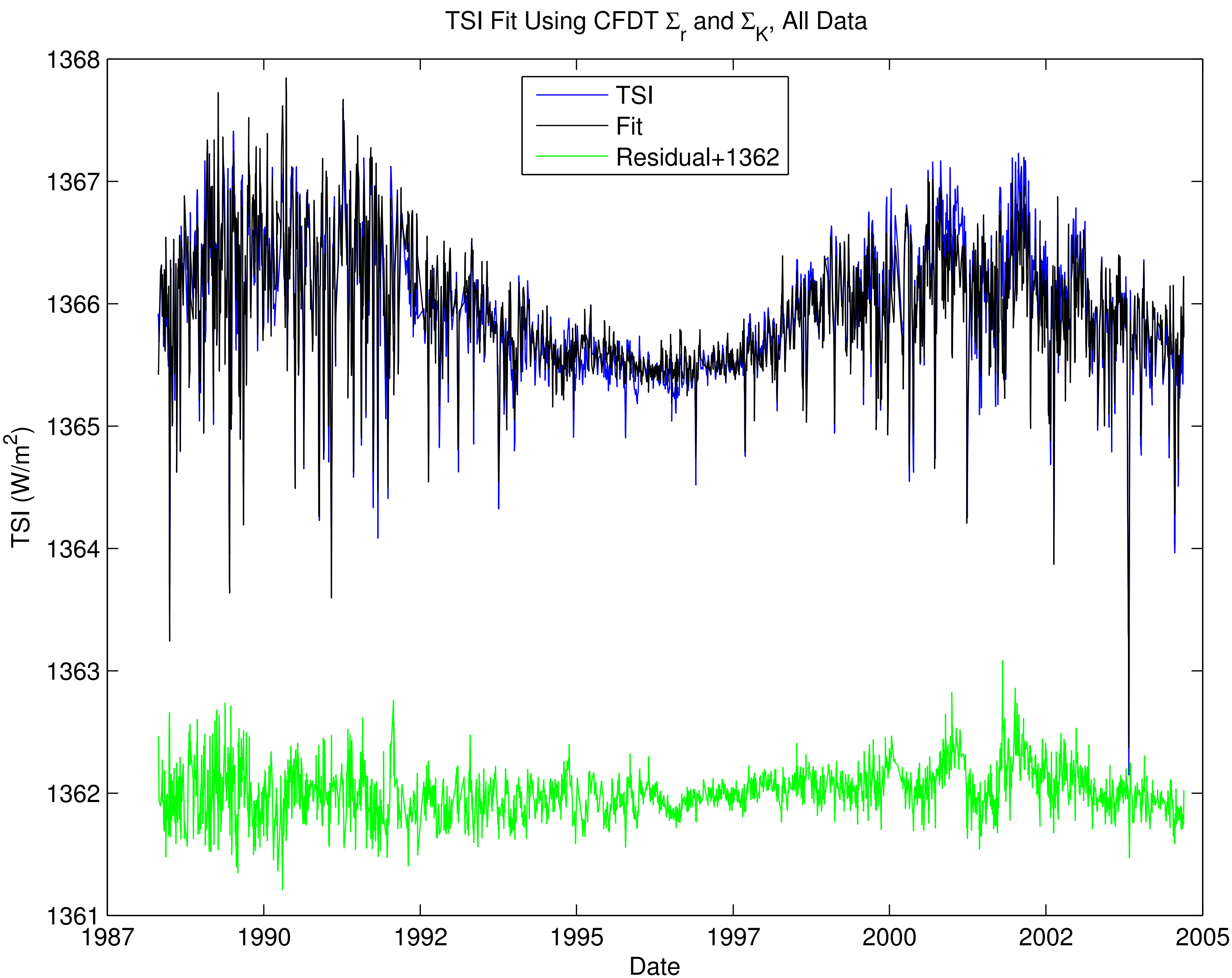
Dual purposes: to check consistency of models between cycles and compare results from CFDT and PSPT

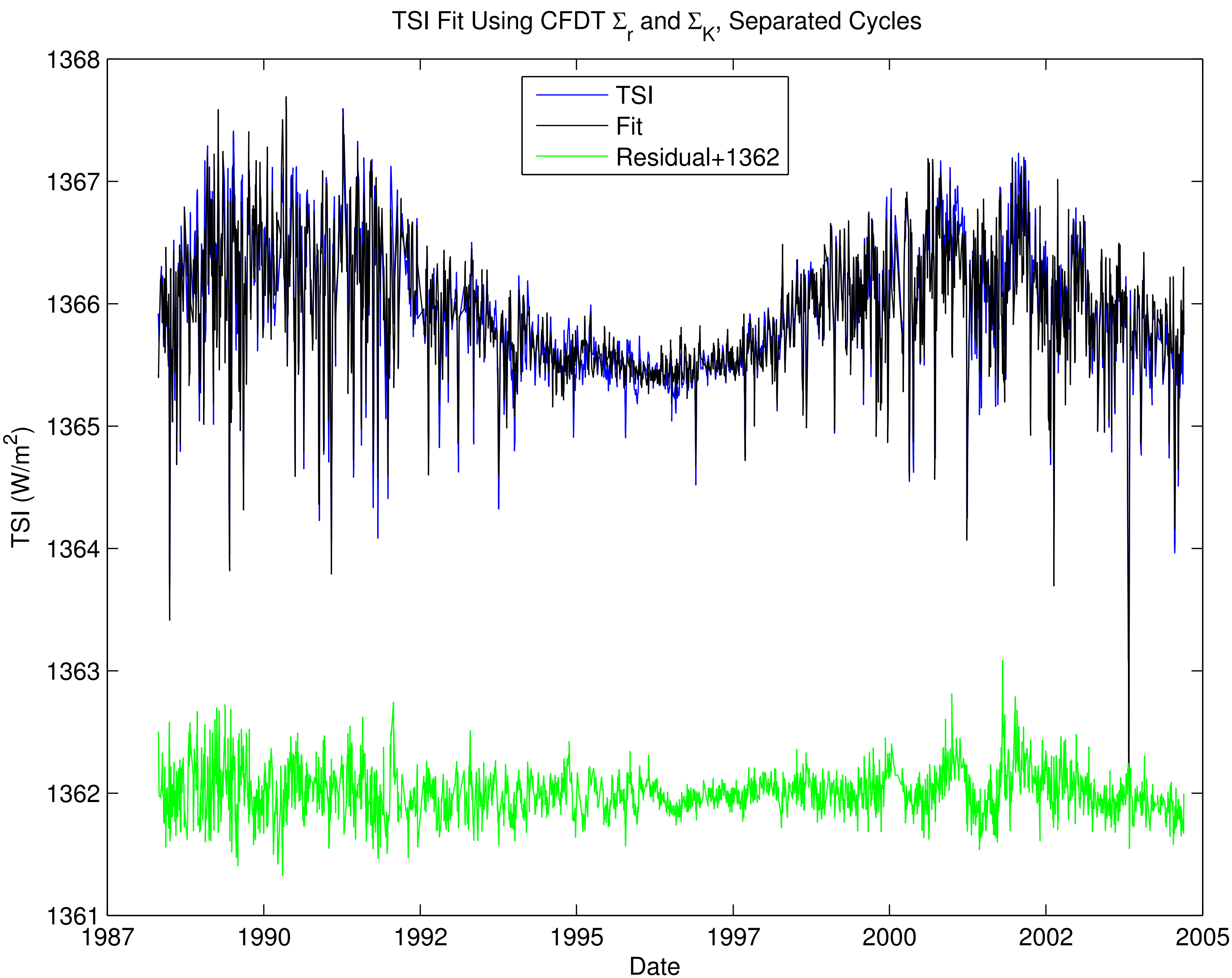
Current TSI Fits

Fit	S_0 (W/m^2)	a (W/m^2)	b (W/m^2)	R^2
1	1365.339 ± 0.068	1308 ± 10	198.8 ± 1.5	0.88
2	1365.309 ± 0.094	1196 ± 14	191.0 ± 1.9	0.89
3	1365.324 ± 0.094	1457 ± 14	219.6 ± 2.3	0.91
4	1365.194 ± 0.026	1254 ± 21	54.8 ± 1.2	0.79

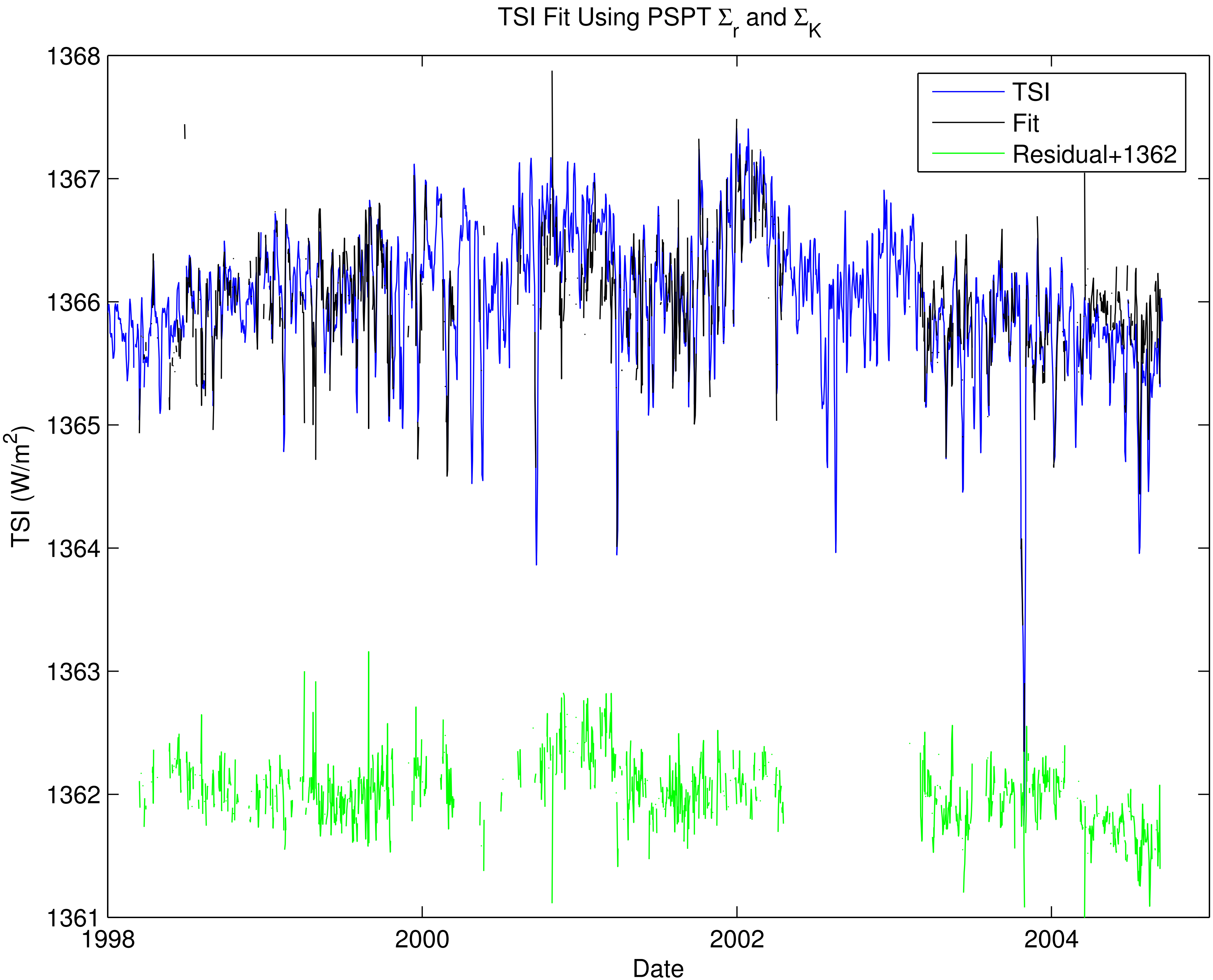
Fits 1, 2, and 3 use CFDT data from 1988–2004, 1988–1996, and 1996–2004, respectively. Fit 4 is from all available PSPT data (1998–2004).

The figures show these fits.


TSI Fit Using CFDT Σr and ΣK, All Data
TSI
Fit
Residual+1362
1368
1367
1366
1365
1364
1363
1362
1361
TSI (W/m2)
1987
1990
1992
1995
1997
2000
2002
2005
Date



TSI Fit Using CFDT Σ_r and Σ_K, Separated Cycles
TSI
Fit
Residual+1362
TSI (W/m^2)
Date
1368
1367
1366
1365
1364
1363
1362
1361
1987
1990
1992
1995
1997
2000
2002
2005


TSI Fit Using PSPT Σ_r and Σ_K
TSI
Fit
Residual+1362
TSI (W/m^2)
Date
1368
1367
1366
1365
1364
1363
1362
1361
1998
2000
2002
2004

Simple Extrapolation to Zero Activity

Calendar year 1996 is taken as year of minimal solar activity for the purposes of computation. The mean TSI for this calendar year is

$$\bar{S}(1996) = 1365.403 \pm 0.008\ \mathrm{W/m^2}$$

(all quoted errors on this page are standard deviations in the mean). The median $S_{\mathrm{med}}(1996)$ is 1365.417 W/m^2.

If we simply take $\Sigma_r = \Sigma_K = 0$, the predicted value of S in the absence of all solar activity is the S_0 term in the above fits. This value is only 0.1 to 0.2 W/m^2 below current solar minimum levels.

Biases in Evaluation of S At No Activity I

There appears to be a slight bias in our computation of Σ_r, such that $\bar{\Sigma}_r(1996)$ is -69.6 ± 4.8. Assuming this value should be zero would raise all values of Σ_r by this amount, and thus decrease S_0 by $a\bar{\Sigma}_r(1996)$. Let this be S_0^{corr} for "corrected" S_0.

For cycle 22:

$$\begin{aligned} S_0^{\text{corr}} &= S_0 - a\bar{\Sigma}_r(1996) \\ &= 1365.309 - 1196(69.6 \times 10^{-6}) \\ &= 1365.23 \text{ W/m}^2 \end{aligned}$$

Mean Σ_K for 1996, $\bar{\Sigma}_K(1996)$, is 1120 ± 27 ppm. Thus

$$\begin{aligned} S_{\text{NA}} &= S_0^{\text{corr}} - b\bar{\Sigma}_K(1996) \\ &= 1365.23 - 198.8(1120 \times 10^{-6}) \\ &= 1365.016 \text{ W/m}^2 \end{aligned}$$

where S_{NA} is then an estimate of S in the absence of all solar activity.

Biases in Evaluation of S At No Activity II

For cycle 23, using the same values of $\bar{\Sigma}(1996)$:

$$\begin{aligned} S_0^{\mathrm{corr}} &= 1365.324 - 1457(69.6 \times 10^{-6}) \\ &= 1365.22\ \mathrm{W/m^2} \end{aligned}$$

$$\begin{aligned} S_{\mathrm{NA}} &= 1365.23 - 219.6(1120 \times 10^{-6}) \\ &= 1364.97\ \mathrm{W/m^2} \end{aligned}$$

Thus, our extrapolations give $S_{\mathrm{NA}} \approx 1365.0\ \mathrm{W/m^2}$, a level about 0.03% below present cycle minimum levels.

Comments

- It has been suggested (Lean et al. 1995, GRL 22, 3195) that S at the Maunder Minimum was about 0.4% below current cycle minimum levels, or $S_{\mathrm{NA}} \approx 1360\ \mathrm{W/m^2}$. Most such estimates are based on extrapolations from photometry of "sun-like" stars (Baliunas and Jastrow 1990, Nature 348, 520) which have more recently been shown to not be very similar to the Sun.

- Our work and others' shows that current TSI variations on all timescales are well represented by measurements based on solar activity (sunspots and faculae)

- This work suggests that values of TSI much lower than presently observed at solar minium would require an additional source of solar irradiance variation. No such mechanism is known.

Acknowledgements

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