Are different total solar irradiance records consistent with each other ?

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We will be on attendance
Thursday from 17:30-19:00

Summary

Various Total Solar Irradiance (TSI) observations have been made since 1978, but they disagree and the possible existence of a long-term trend has been hotly disputed. Building a single composite out of these records has become a major issue. We use a novel statistical technique to stitch these observations together and build a series of composites that are statistically consistent with the observations. These reconstructions allow to compare the different observations and determine when they disagree most.

1. Why stitch together TSI records ?

More then 10 different Total Solar Irradiance (TSI) measurements have been made since the 1980's and yet, there is little overlap in time between them. These records disagree in their absolute level but mostly agree in their relative variations.
How can they be stitched together ?

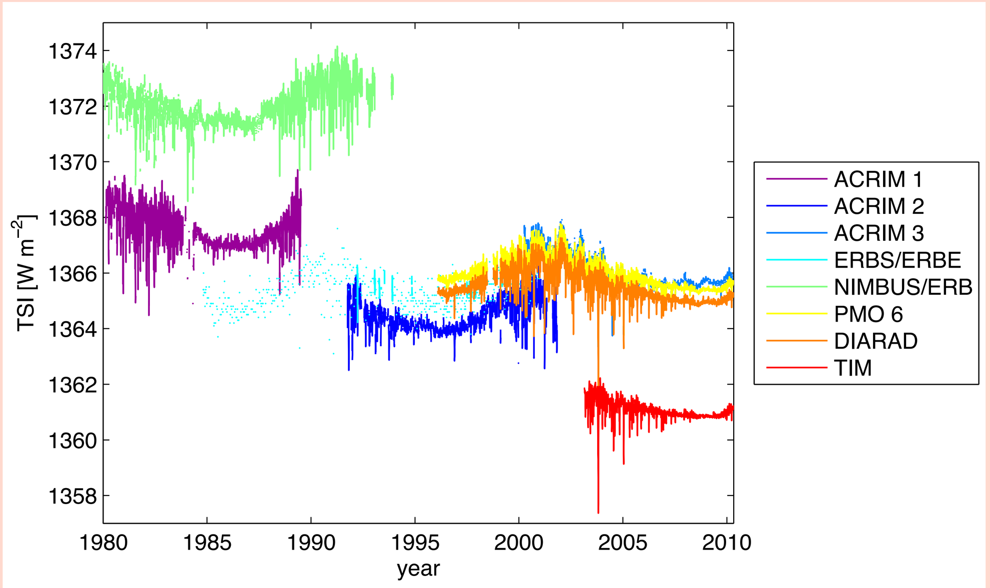

***Figure 1**. Overview of TSI observations made since 1980.*

This stitching is a delicate task and has also become a topic of considerable debate [Krivova et al., Fröhlich & Lockwood, Willson & Scafetta, etc.] because of the implications of a possible long-term trend in the TSI.

Here we show how this stitching can be done automatically, by exploiting only the statistical properties of the data.

This is actually part of a more general problem: *how to self-consistently interpolate data gaps in multivariate records ?*

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2. Our assumptions

The observations are extremely coherent because they all exhibit the same temporal variations. **We assume that each TSI record is made out of the *same* and *small* set of common "sources"** S(t)

$$\mathrm{TSI}_k(t) = A_{k,0} + \sum_i A_{k,i}\, S_i(t) \;+\; \mathrm{error}_k \qquad k = 1, 2, 3, \ldots$$

with variable offsets $A_{k,0}$. Measurement errors are assumed to be white and Gaussian. The proper method for extracting the sources that best describe the observations (in a least squares sense) is the Singular Value Decomposition (SVD).

Key idea : use this to extrapolate each record of observations back- and forward in time by assuming that its statistical properties with respect to the other records remain unchanged.

We consider TSI observations from 1/1980 till 12/2010.

3. The analysis procedure

To compute the sources S(t) and fill the missing values in each record we estimate the SVD iteratively.

Algorithm

1) in each record, replace gaps with a time-averaged value
2) compute the SVD to express each variable as a linear combination of the sources
3) use a subset of the 2-3 dominant sources to fill the gaps with the approximation
4) Go back to 2) and iterate until convergence.

Similar approaches have already been used in other contexts [Everson & Sirovich, J. Opt. Soc. America (1995); Schneider, J. Climate (2001), ...].

At each iteration we perform a wavelet decomposition to reconstruct different scales (solar rotation, solar cycle) separately. This considerably improves the reconstruction.

We obtain **a powerful technique for stitching together similar observations that only partly overlap in time.** The reconstruction error can be estimated by bootstrapping.

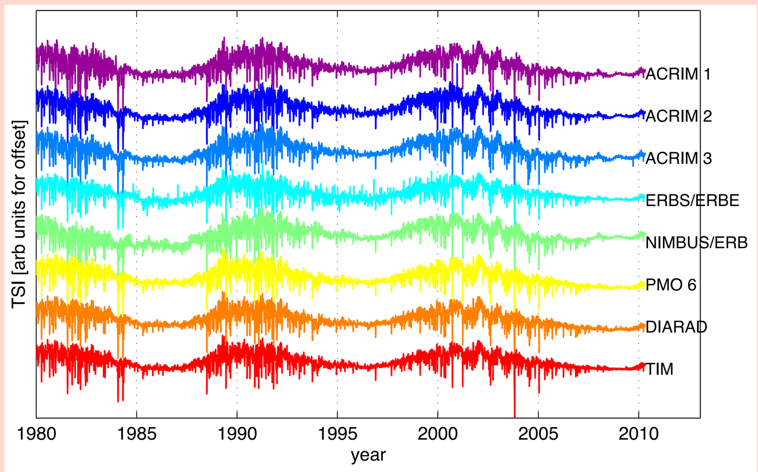

***Figure 2**. Extrapolated TSI records using 2 sources out of 8*

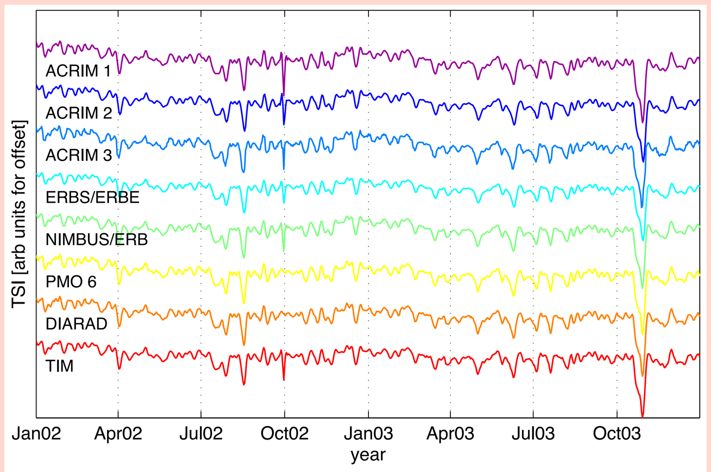

***Figure 3**. Same as above, but showing an excerpt only*

4. How are the TSI records distributed ?

We can now estimate the probability distribution of the TSI at each time.

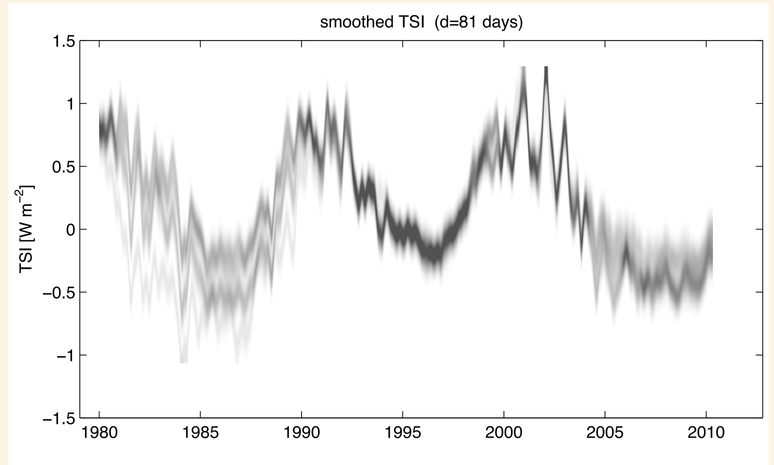

***Figure 4.** Probability distribution of the 8 TSI records (by kernel density estimation). Offsets have been adjusted by assigning the same mean value for the 1994-98 solar minimum.*

This plot reveals an excellent agreement between all records between the last two solar minima, and a clear divergence during the last minimum (> 2004) and before the ACRIM gap (< 1989).

How do the 3 existing composites compare to this ?

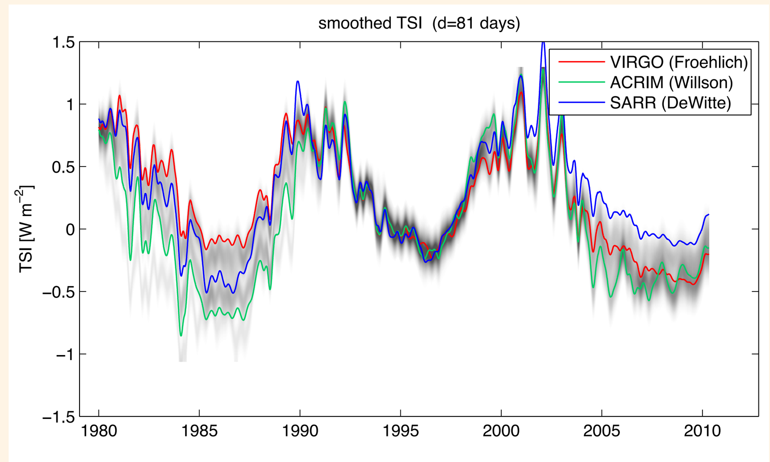

***Figure 5.** Same as above, with 3 composites overlaid.*

Before 1990 **the VIRGO and ACRIM composites don't describe the most probable value of the TSI** but rather the upper and lower tails of the distribution. The agreement is better for the last solar cycle, except for the SARR composite.

5. What the classification of the TSI tells us

We use a dendrogram to classify the TSI records according to their degree of similarity

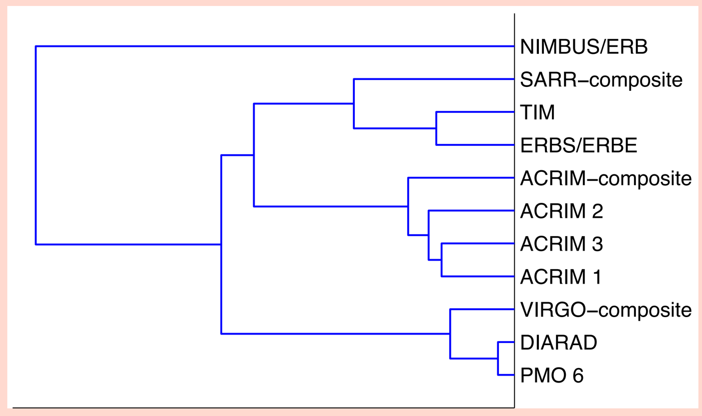

***Figure 6.** Dendrogram for the long-term time evolution of the TSIs. The longer the distance, the more dissimilar they are. A median distance is used.*

Conclusions

- Records coming from the same team (e.g. ACRIM) or the same satellite (e.g. PMO6 & DIARAD) are consistent with each other = the way they are postprocessed has a major influence.
- The TSI from NIMBUS/ERB does not agree with the other observations.
- SARR is the composite that departs the most from all the observations. The ACRIM and VIRGO composites truly correspond to *2 different choices*.
- The recent observations from TIM do not allow to be more in favour either of the ACRIM or of the VIRGO composite.