Making of composites out of multiple observations: the new Total Solar Irradiance and MgII index composites

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with many thanks to the instrument teams
Outline

- Making a composite: challenges
- Methodology
- TSI composite: results
- MgII composite: results
- Lunch!
The question

How to merge these TSI data into a single composite while making the best out of each?
Not all observations are equally good

Select one only, or take an average?

What if there are no observations at all?

Total Solar Irradiance Data Record

- ERB
- ACRIM1 V1-8907
- NOAA9
- NOAA10
- ACRIM2 V1405-0102
- ACRIM3 V-1309
- SOVA2
- ERBS V-0508
- VIRGO V6-1508
- SORCE/TIM V17-1510
- TCTE/TIM V2-1510
- SOVM
- PREMOS V0-1402

TSI [W/m²]

1375
1370
1365
1360
1980 1990 2000 2010

Year

TSI [W/m²]

1375
1370
1365
1360
200
150
100
50
0

Sunspot Number

1000 ppm

Not all observations are equally good

Select one only, or take an average?

What if there are no observations at all?
An analogy

Not all observations are equally good

Select one only, or take an average?

What if there are no observations at all?

Any resemblance to real persons, living or dead, is purely coincidental
The solution

ISSI team lead by Greg Kopp

- objective: end up with one single composite, based on observations only
- use the original data, as provided by the PIs
Important issue # 1

uncertainties are your best friend
Important issue 1

- The contribution from each instrument should be weighted by a **quantifiable uncertainty** (no bias toward preconceived ideas)

![Graph showing TSI variability over years](image)
Important issue 1

HOWEVER

- Data given in the literature often cannot be meaningfully compared.

THEREFORE

- We need a strategy for estimating uncertainties in an independent and systematic way.
Important issue 1

- Different types of uncertainties: precision, stability, accuracy, bias, ...

- Only precision (random fluctuations) can be easily assessed

Consider autoregressive model [Mann, 1996]

\[ TSI(t) = a_1 TSI(t-1) + a_2 TSI(t-2) + \ldots + a_p TSI(t-p) + \epsilon_p(t) \]

and use \( \sigma = \sqrt{\langle \epsilon^2(t) \rangle_t} \) as the **precision** (includes instrumental but also some solar noise)
Important issue 1

- Precision: example

![Graph showing TSI and ε₄ over time from July 2008 to October 2009.](image)
Important issue 1

- **Crucial point**: How does precision scale with longer time-scales?

- **Solution**: look at the discrepancy between VIRGO/ACRIM3/TIM, the only 3 instruments that have been observing together for > 10 years.
Important issue 1

How precision scales with time-scale $a$

$1/f$ noise

noise is NOT white, but scales more like $1/f$
Important issue # 2

look at the data like your eye does
Important issue 2

Merging should be done on a scale-by-scale basis

![Graph showing TSI [W/m²] from 2005 to 2009 for ACRIM3 and VIRGO]
Important issue 2

We decompose each record into different time scales (undecimated discrete wavelet transform)

\[ TSI(t) = \sum_{a} TSI(a, t) \]
Important issue 2

- composite = average of all records, weighted by their uncertainty (max. likelihood)

$$T SI_{comp}(a, t) = \frac{\sum_j T SI_j(a, t) \ w_j(a, t)}{\sum_j w_j(a, t)}$$

$$w_j(a, t) = \frac{1}{\sigma_j^2(a, t)}$$

- This averaging is done scale by scale

j: instrument  
 a: scale  
w: weight
Important issue # 3

missing data are not a show-stopper
Important issue 3

- No data gaps allowed with wavelet decomposition

- We fill them in by expectation-maximization [DdW, 2011], using the high coherency between instruments

- Interpolated data are flagged, and NOT used for making the composite.

- Multiscale approach bridges gaps in a natural way: no need to tweak the ACRIM gap
Results
Example: time scale of 724 days

characteristic scale = 724 [days]

wavelet coeff of TSI [arb. units]

year


ACRIM1
ACRIM2
ACRIM3
HF
ERBE
VIRGO
TIM
PREMOS

grey = interpolated values (not used in the composite)
The TSI composite

Max likelihood estimate of TSI

![TSI composite graph]

uncertainty based on 1/f noise model

![Uncertainty graph]

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Weighting of the various instruments

weighting is time-scale dependent

scale = 23 days

year


ACRIM1
ACRIM2
ACRIM3
HF
ERBE
VIRGO
TIM
PREMOS
Comparison with other TSI records

yearly averages

TSI [W/m²]


- TSI
- composite
- PMOD
- SATIRE-S
- NRLTSI2
Comparison with other TSI records

Cross-coherence between composite and other TSIs

Cross-coherence between composite and other TSIs

- composite--ACRIM
- composite--PMOD
- composite--SATIRE-S
- composite--NRLTSI2
And now ...

the MgII index
The MgII index

Additional difficulty: no common scale
The composite

Max likelihood estimate of MgII - rescaled to Bremen composite

MgII index

uncertainty based on white noise model, amplitude set by spectral estimate

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Conclusions

- Finally, a robust framework with several assets
  - Data-driven: no bias towards preconceived idea of the TSI
  - Traceable
  - Can handle data gaps

- Next step: agree on the corrections to be applied to the raw (level 2) data

- Next next step:
  - build a composite of the SSI (SOLID project)
  - use a Bayesian framework (bypass some of the assumptions)
Comparison with Bremen composite

Comparison with *Bremen

ML composite
*Bremen

∆MgII × 10^-3

6m average of MgII

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