Total solar irradiance correlated with sunspot area, sunspot number, and group sunspot number at different temporal scales using wavelet analysis

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ISAC

Influence of solar activity cycles on Earth's climate

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- Swedish Institute of Space Physics (IRF)
- Space and Atmospheric Physics, Blackett Laboratory, Imperial College (IC), UK
- # ESA funded project 2004 2006

% http://www.isac-esa.org/

ISAC DATABASE (6 OF 28)

STSI: Composite record (Fröhlich and Lean, 1998).
ftp.ngdc.noaa.gov/STP/SOLAR_DATA/SOLAR_IRRADIANCE/composite_d25_07_0310a.dat

SSA: Sunspot area (Steinegger et al., 1996; Györi, 1998).
<u>http://science.nasa.gov/ssl/pad/solar/greenwch/daily</u> area.txt

Rz: Solar Influences Data Analysis Centre (SIDC).
<u>http://sidc.oma.be/DATA/dayssn</u> import.dat

Rg: Group sunspot number (Hoyt and Schatten, 1992, 1998). ftp://ftp.ngdc.noaa.gov/STP/SOLAR DATA/SUNSPOT NUMBERS/GROUP SUNSPOT NUMBERS/ monthrg.dat

MWSI: Mt. Wilson Sunspot Index (Parker et al., 1997; Ballester et al., 2004) (B>100 Gauss). ftp://howard.astro.ucla.edu/pub/obs/mpsi data/index.dat

MPSI: Magnetic Plage Strenth Index (10<B<100 Gauss).</p>

MAIN QUESTION

How is TSI related to solar indices on different temporal scales?

(But also other parameters within ISAC.)

- For high resolution (days, months) the darkening due to sunspots is present in the data and can be modelled by location, area and contrast, and facular brightening using Ca K (Lean et al. 1998).
- For long-term reconstruction (SSA, Rz, Rg only) using temporal averaging, or preferably low-pass filtering, the brightening of TSI may be modelled due to a statistical relation between SSA and facular brightening.
- 2nd order fit of Rz and TSI + slow component (2 month running averages) + fast component (difference) (Solanki and Fligge, 1999).
- * TSI reconstruction using different approaches depending on short term or long term (Lockwood, 2005).
- Relation to SSA via finite impulse response filter transformation (Preminger and Walton, 2007).



TSI vs. Rz, daily values

 $S = 1365.43 + 1.61 \cdot 10^{-2} Rz - 5.5 \cdot 10^{-5} Rz^2$

Temporal separation Slow component (faculae): $\langle \Delta S_{obs} \rangle$ two month running means

Fast component (sunspots): $\Delta S_{\rm obs} - \langle \Delta S_{\rm obs} \rangle$

Solanki and Fligge, 1999.

RZ AND TSI: EFFECT OF AVERAGING



Compensate for autocorrelation when computing confidence limits [Quenouille, 1952; Wilks 1995; von Storch, 1999].

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Maximal Overlap Discrete Wavelet Transform

 $\{x(t)\} \to \{W_j(t), V(t)\} \ j = 1, 2, \dots, J$

Energy decomposition: $\sum_{t} x^2(t) = \sum_{j} \sum_{t} W_j^2(t) + \sum_{t} V^2(t)$

Additive decomposition: $x(t) = \sum_{j=1}^{J} D_j(t) + A(t)$

Averages: $\langle D_j(t) \rangle = 0$, $\langle A(t) \rangle = \langle x(t) \rangle$ Width of filter: $L_j = (2^j - 1)(L - 1) + 1$ [Percival and Walden, 2002]

WAVELET VARIANCE Level *j* is associated with periods $[2^j, 2^{j+1}]$ Variance at level $j: \nu_j = 1/N \sum_t W_j^2(t) \approx 2 \int_{1/2^{j+1}}^{2^j} S(f) df$



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SCALE-BASED CORRELATION

$$C_j = \text{CORR}(W_j^{(x)}, W_j^{(y)})$$

excluding the

 $L_j = (2^j - 1)(L - 1) + 1$

points affected by the boundary.

95% confidence interval is computed taking into account the autocorrelation in the time series.



TSI and SSA











RECONSTRUCTION ON DETAILS AND APPROXIMATIONS SEPARATELY

$$TSI_R = a_0 + \sum_{j=J}^{12} a_{j-J+1} D_j + a_{12-J+1} A_{12}$$



OTHER INDICES









How does ...

this

fit with this?







$PSI \propto SSA$ [Lockwood, 2005]

"Darkening by sunspots is quantified by PSI."

CONCLUSIONS

- ** All parameters correlate around 11 year scales => Makes physical interpretation difficult.
- Among the studied parameters TSI shows the most complex correlation over scales from days to years.
- SSA (MWSI, Rz) and TSI are significantly anti-correlated at scales of 1 to 4 months.
- ** For reconstruction on short scales (<1.4 years) SSA and MWSI works best, followed by Rz.
- Rg and MPSI are uncorrelated with TSI on scales <1.4 years.</p>
- * The statistical confidence is weak on scales above the 11year variability due to the (limited) extent of TSI.

EXTRA MATERIAL

WAVELET VARIANCE MONTHLY DATA



WAVELET POWER



So

SA





Rz and MWSI





SSA and Rz





SSA and MWSI











BOLOMETRIC BRIGHTNESS

Figure 9 in Lean et al. (1998) shows the ACRIM II brightness with the sunspot darkening removed (grey line) together with the reconstructed brightness from Ca K. Carefully studying the figure shows that the Ca-reconstructed brightness consistently underestimates the ACRIM-SSA brightness. Coupling to SSA-TSI wavelet correlation??

$$\Delta S_{\text{FAC}} = S - S_Q - S_Q \sum_{i=1}^{N} \frac{\mu(3\mu + 2)}{2} \times A_{\text{WDC}} \left[0.2231 + 0.0244 \log_{10}(A_{\text{WDC}}) \right]$$









Coeff. level 6

Details level 6 $x(t) = \sum_{j=1}^{J} D_j(t) + A(t)$

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Coeff. level 11

Details level 11

3, Montana State University, Bozeman, Montana, USA



RECONSTRUCTION AT DIFFERENT LEVELS OF APPROXIMATIONS

 $TSI_J = TSI_R + \epsilon$

 $TSI_R = a_0 + a_1 A_J$

Approximation level 3 (>16 days)



Approximation level 8 (>1.4 years)



Details 4 to 12 and approximation (>16 days)

