Solar Noise in 40-year long Total Solar Irradiance Composite Time Series

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Abstract

Since the late 70's, successive satellite missions have been monitoring the sun's activity, recording total solar irradiance observations. These measurements provide estimates of the Earth's energy imbalance, i.e. the difference of energy absorbed and emitted by our planet. With this amount of TSI data, solar irradiance reconstruction models can be better validated which can also improve studies looking at past climate reconstructions (e.g., Maunder minimum). Various algorithms have been proposed to merge the various TSI measurements recorded over the last 4 decades. We develop a 3-step algorithm based on data fusion, including a stochastic noise model to take into account the short and long-term correlations. We develop a wavelet filter in order to eliminate specific correlations introduced by the data fusion. Comparing with previous products,the mean value difference is below 0.1 W/m2and the discrepancy with the solar minima is mostly below 0.05 W/m2. Next, we model the frequency spectrum of this 40-year TSI composite time series with a Generalized Gauss-Markov model(with white noise) due to an observe flattening at high frequencies. It allows us to fit a linear trend in these TSI time series by joint inversion with the stochastic noise model via a maximum-likelihood estimator. Our results show that the amplitude of such trend is -0.009+/-0.01 W/(m2.yr). We conclude that the trend in these composite time series is mostly an artifact due to the solar noise.

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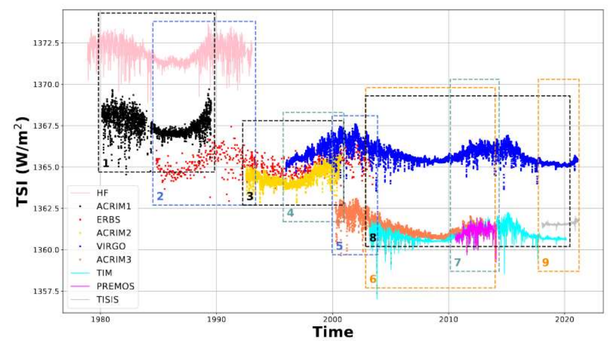
ABSTRACT

Since the late 70's, successive satellite missions have been monitoring the sun's activity, recording total solar irradiance observations. These measurements provide estimates of the Earth's energy imbalance, i.e. the difference of energy absorbed and emitted by our planet. With this amount of TSI data, solar irradiance reconstruction models can be better validated which can also improve studies looking at past climate reconstructions (e.g., Maunder minimum). Various algorithms have been proposed to merge the various TSI measurements recorded over the last 4 decades. We develop a 3-step algorithm based on data fusion, including a stochastic noise model to take into account the short and long-term correlations. We develop a wavelet filter in order to eliminate specific correlations introduced by the data fusion. Comparing with previous products, the mean value difference is below 0.1 W/m^2 and the discrepancy with the solar minima is mostly below 0.05 W/m^2. Next, we model the frequency spectrum of this 40-year TSI composite time series with a Generalized Gauss-Markov (GGM) model(with white noise) due to an observe flattening at high frequencies. It allows us to fit a linear trend in these TSI time series by joint inversion with the stochastic noise model via a maximum-likelihood estimator. Our results show that the amplitude of such trend is ~ −0.009±0.010 W/(m^2.yr). We conclude that the trend in these composite time series is mostly an artifact due to the solar noise.

RAW DATASET : 41 yr of Monitoring Solar Irradiance



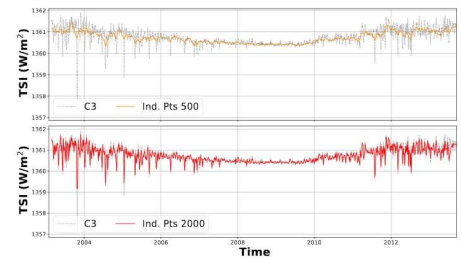
(A) Various satellite missions recording TSI observations since the end of the 70's. Within each box, all the time series are fused together.

MERGING 41 YEARS OF DATA : Data Fusion + Adaptive Filter + Wavelet

A 3-step algorithm has been developed :-

Step 1: Merging Multiple Dataset with Data Fusion

a/ Fusing missions with overlapping periods of more than 6 months (observations within each box).b/Modelling the TSI time series associated with each instrument as a Gaussian Process, with uncorrelated additive and zero-mean noise. c/ dual Kernel coloured + white noise to fuse the observations from the various radiometers. d/ Training the kernel with inducing points: The number of inducing points is crucial to avoid smoothing common small-scale variations due to solar activities (i.e., sunspots).



(B) Time series ofC3(Fröhlich, 2006) and the sub-time series in Box 8(see Figure A) fusing VIRGO/SOHO, ACRIM 3 and TIM/SORCE using various numbers of inducing points (500, 2000)

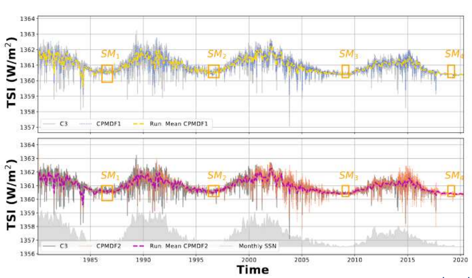
Step 2: Producing the 41-year composite time series with a modified adaptive filter

- Data fusion gives N partially overlapping time series. We use a modified adaptive filter to produce a continuous TSI composite time series (from fusing data in each box [1,9] – see Figure A) .
- Rescale the TSI composite similar to C3 (Fröhlich, 2006) : the average TSI for Solar Cycle 23 scale to the nominal TSI value 1361W/ m^2 as recommended by the IAU 2015 Resolution B3
- New product called Composite PMOD Data Fusion - CPMDF

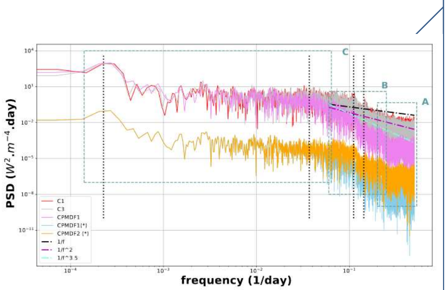
Step 3: Filtering the Composite with a Wavelet Filter

- Data fusion inserts unwanted correlation –bandwidth noise
- Affect the frequency spectrum with steeper slope
- Develop a wavelet filter to remove this bandwidth noise – increases white noise in TSI composite

TIME-FREQUENCY ANALYSIS



New Composite (blue) with wavelet filter (orange). For comparison C3 (Fröhlich, 2006) also shown (grey line). A 30-day running mean yellow/purple dash line. Orange boxes associated with solar minima (SM) for each solar cycle (see Table)



PSD of the TSI C1(Dudok de Wit et al., 2017),C3(Fröhlich, 2006), and new TSI composite CPMDF1 and applying the wavelet filterCPMDF2.
The (∗) means that shift by rescaling the amplitude by~(4 W/m^2) ^{2}·day in log-log plot.
Box ***A*** centered on high frequency (~3 days) showing flattening
B the power-law due to coloured noise (correlations between 20 and 6 days)
C low frequency associated with the stochastic and deterministic parts of the solar cycle.
Dash lines - various power-law models

DISCUSSION: TREND IN SOLAR MINIMA

1- ***Study of possible trend by looking at difference between solar minima – see Table below***

- Difficult to see a trend, only between Cycle 22/23, 23/24 and 24/25 with value of -0.1 +/- 0.05 and -0.04+/-0.02 W/m^2. Perhaps, presence of a linear trend, but large fluctuations due to solar noise which induces Large uncertainties (up to 10 times).

TSI level ($\mu \pm \sigma$ [W/m^2])		Name of the Composites									
		C1		C2		C3		CPMDF1		CPMDF2	
		μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
Solar Cycle 21/22	*Minimum* (SM_1)	1360.30	0.14	1362.82	0.12	1360.58	0.12	1360.57	0.11	1360.57	0.12
	$\Delta I_{21/22-20/21}$	-	-	-	-	-	-	-	-	-	-
Solar Cycle 22/23	*Minimum* (SM_2)	1360.68	0.14	1362.90	0.16	1360.57	0.15	1360.56	0.14	1360.56	0.14
	$\Delta I_{22/23-21/22}$	**0.38**	**0.14**	**0.08**	**0.14**	**-0.01**	**0.14**	**-0.01**	**0.11**	**-0.01**	**0.13**
Solar Cycle 23/24	*Minimum* (SM_3)	1360.53	0.04	1362.89	0.04	1360.42	0.06	1360.46	0.05	1360.46	0.05
	$\Delta I_{23/24-22/23}$	**-0.15**	**0.12**	**-0.01**	**0.13**	**-0.15**	**0.12**	**-0.10**	**0.10**	**-0.10**	**0.12**
Solar Cycle 24/25	*Minimum* (SM_4)	-	-	1362.88	0.07	-	-	1360.41	0.08	1360.41	0.09
	$\Delta I_{24/25-23/24}$	-	-	**-0.01**	**0.06**	-	-	**-0.05**	**0.04**	**-0.05**	**0.07**

Table:E stimation of TSI at solar minimum (Minimum) over last 41 years from Dudok de Wit et al. (2017)(C1), Dewitte and Nevens (2016) (C2) and Fröhlich (2006) (C3). New TSI composite is abbreviated to (CPMDF1) and after using the wavelet filter (CPMDF2)

2- Study of global fluctuations by fitting a linear trend in The 41 yr long TSI composite time series

- Full inversion of functional and stochastic noise Models: functional model defined by sum of periodic Signals; stochastic model defined by General Gauss Markov due to flattening at high frequencies
- Results based on C1, C2, C3 and new composites The amplitude of the trend is ~ -0.009 +/- 0.10 W/(m^2.yr) Cannot conclude of any trend.

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Dudok de Wit et al. (2017) –
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