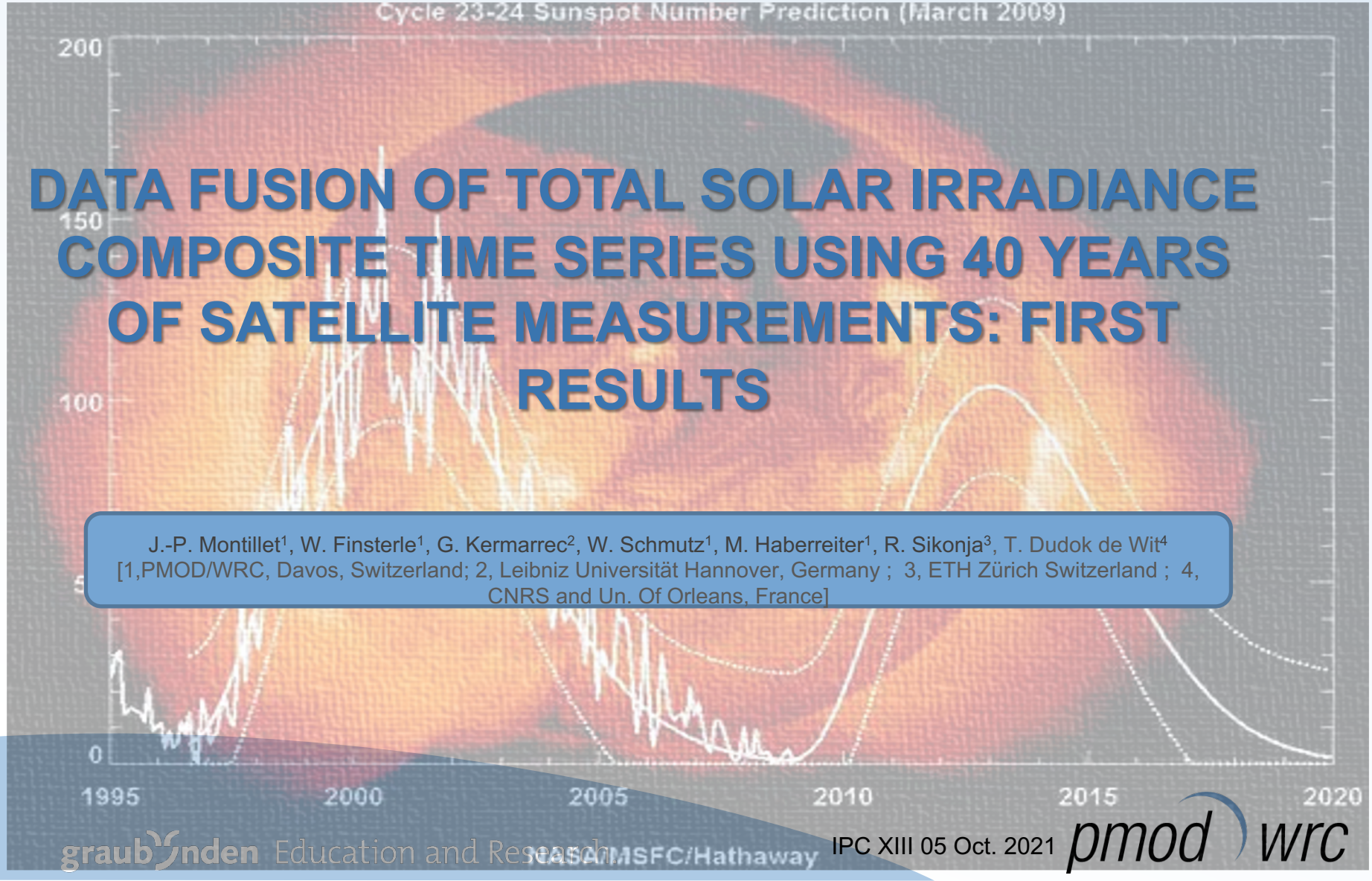

DATA FUSION OF TOTAL SOLAR IRRADIANCE COMPOSITE TIME SERIES USING 40 YEARS OF SATELLITE MEASUREMENTS: FIRST RESULTS

J.-P. Montillet[1], W. Finsterle[1], G. Kermarrec[2], W. Schmutz[1], M. Haberreiter[1], R. Sikonja[3], T. Dudok de Wit[4]
[1,PMOD/WRC, Davos, Switzerland; 2, Leibniz Universität Hannover, Germany ; 3, ETH Zürich Switzerland ; 4, CNRS and Un. Of Orleans, France]

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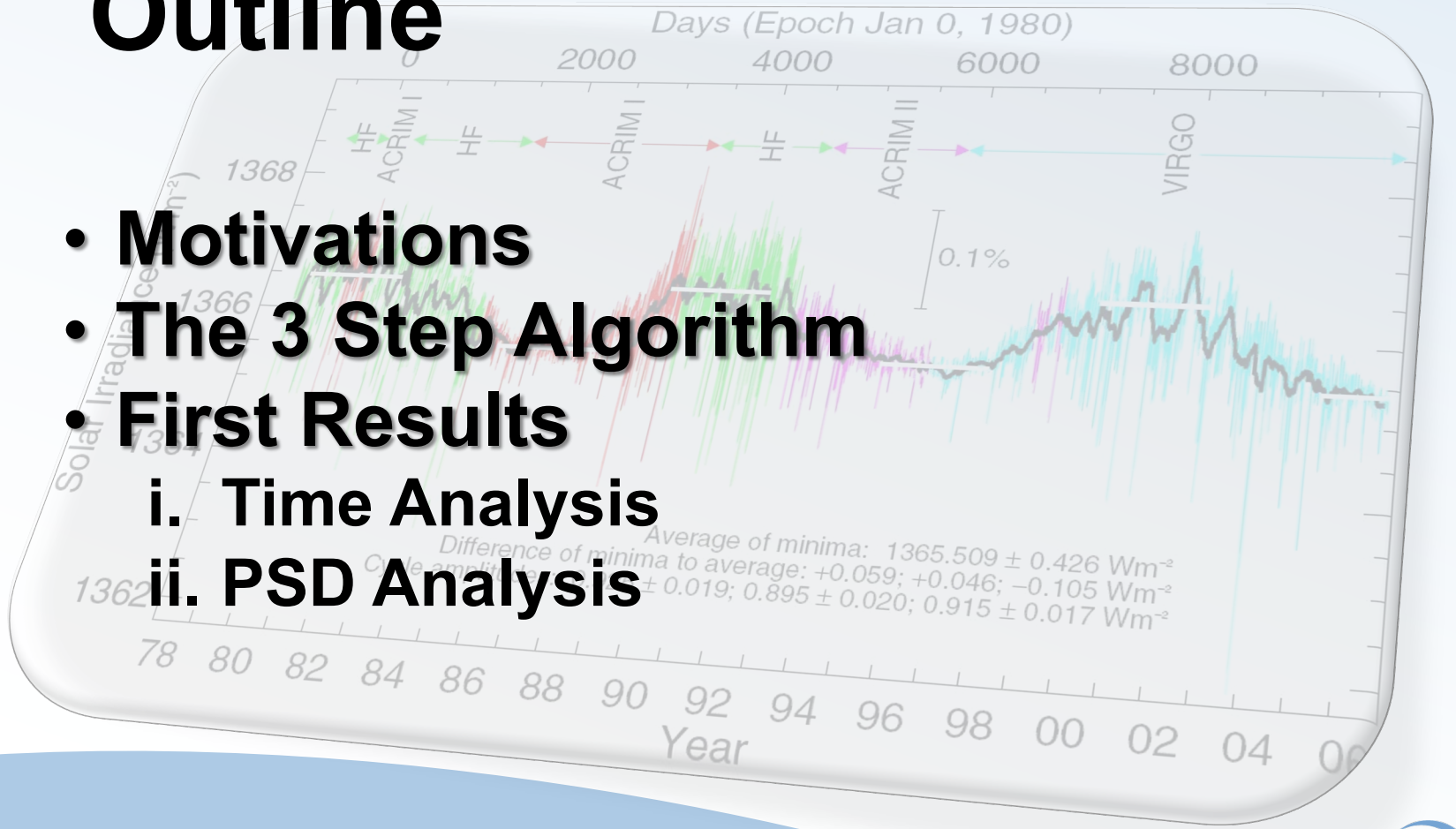
Outline



- **Motivations**
- **The 3 Step Algorithm**
- **First Results**
  i. **Time Analysis**
  ii. **PSD Analysis**

Mission/Experiment/Instrument	Version	Start Date	End Date
HF/NIMBUS-7 ERB		11/1978	1/1993
ERBE/ERBS	10/1984	8/2003	
SOHO/VIRGO (PMODv21)	a	01/1996	03/2021
PICARD/PREMOS/PMO6 (v1)	1	06/2010	03/2014
ACRIM1/SMM	a	2/1980	7/1989
ACRIM2/UARS	b	10/1991	9/2000
ACRIMSAT/ACRIM3	11/13	04/2000	11/2013
SORCE/TIM	18	02/2003	02/2020
TISIS/TIM	3	11/01/2018	-

41 years of TSI data various missions

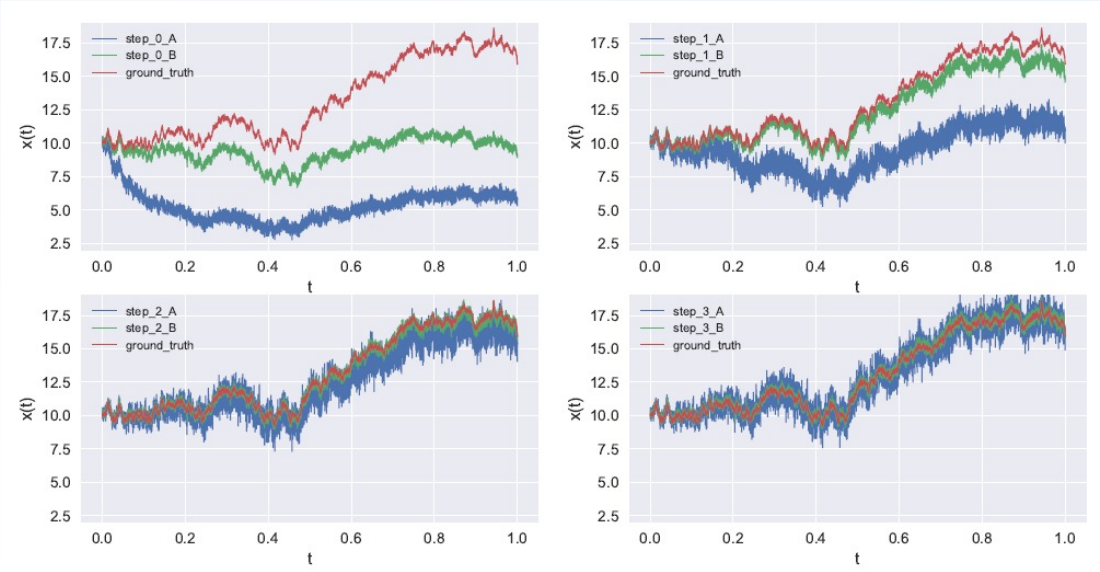
Key Points

- ✓ Propose a new composite TSI time series fusing 41 years of solar observations to continue former work at PMOD (C. Fröhlich)
- ✓ Comprehensive time-frequency analysis to characterise stochastic processes and solar noise
- ✓ Future investigation of variations in solar minima to distinguish between solar noise and possible underlying phenomena

Technical challenges

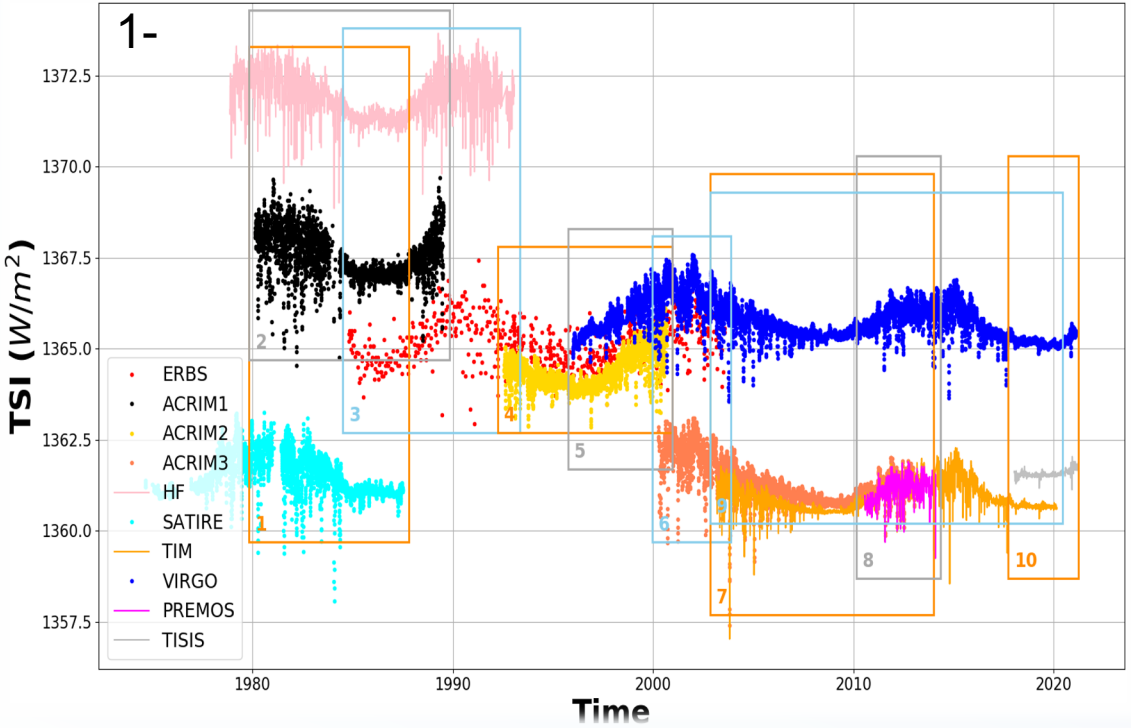
Modifying previous software (Montillet et al., AGU 2020, Finsterle et al., 2021) to do fusion of N-time series (degradation corrected), using Gaussian processes with white + Matern kernel (temporal correlations).

Ref: Finsterle W, Montillet JP, Schmutz W, et al. The total solar irradiance during the recent solar minimum period measured by SOHO/VIRGO. Scientific Reports. 2021 Apr;11(1):7835. DOI: 10.1038/s41598-021-87108-y.



Simulations of merging random signals (Kolar et al., 2021)

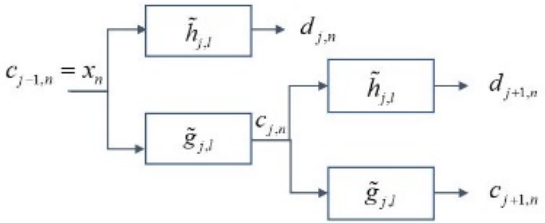
1-



Producing composite (1980-2021) a 3-step process

- 1/ Partioned time series into sub-time series and fused overlapping TS (at least 6 months)
- 2/ Stiching overlaping TS to produce a 40-year long time series with modified adaptive algorithm
- 3 / Filtering unwanted noise on the 41 year TS (bandwidth noise) with wavelet algo.

3-



The 2 level wavelet filter

2-

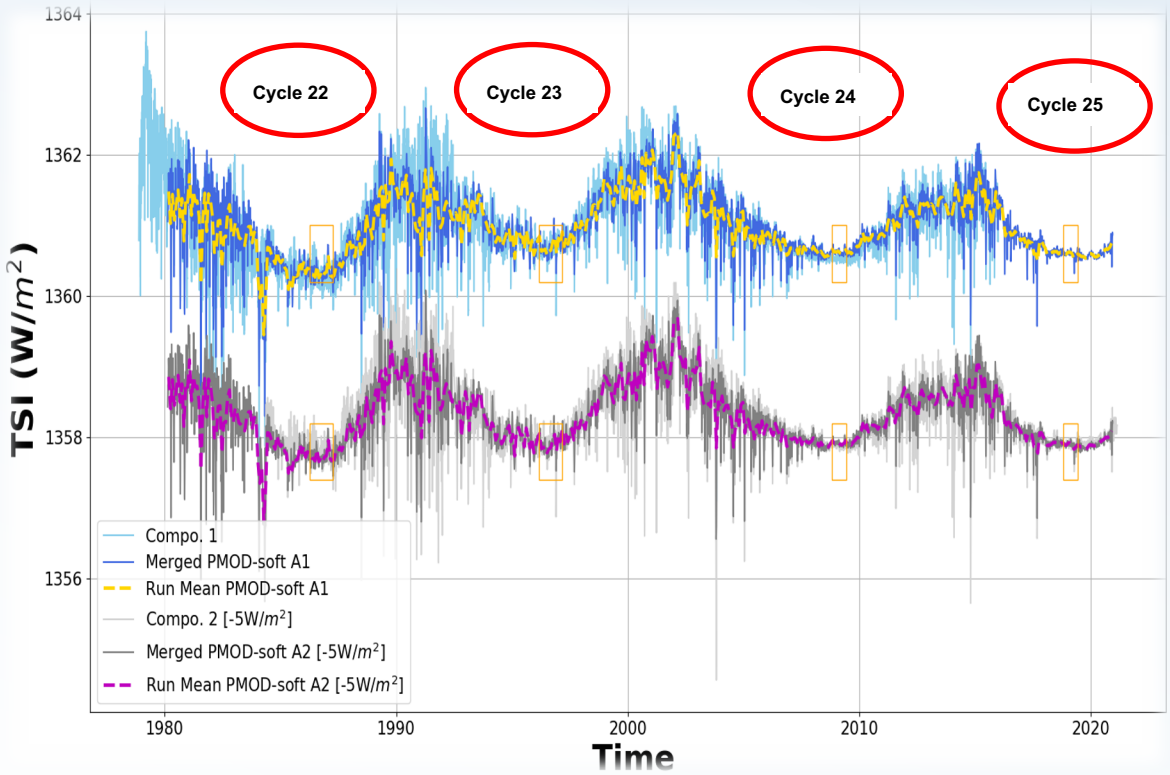
$$\begin{cases} y(t) = & y_1(t) * w(t) + y_2(t) * (1 - w(t)), \\ w(t) = & \alpha_1^2(t)/(\alpha_2^2(t) + \alpha_1^2(t)) \\ \alpha^2(t) = & 0.5 * (\alpha_2^2(t) + \alpha_1^2(t)) \end{cases} \quad (3)$$

with t the time spanning the period 1978-2021, with the sampling of 1 JD. The two time series overlapping are y_1 and y_2 and associated uncertainties α_1^2 and α_2^2 respectively. Note that y_1 is chosen in order to satisfy the condition $\alpha_1^2 \leq \alpha_2^2$,

Time Analysis

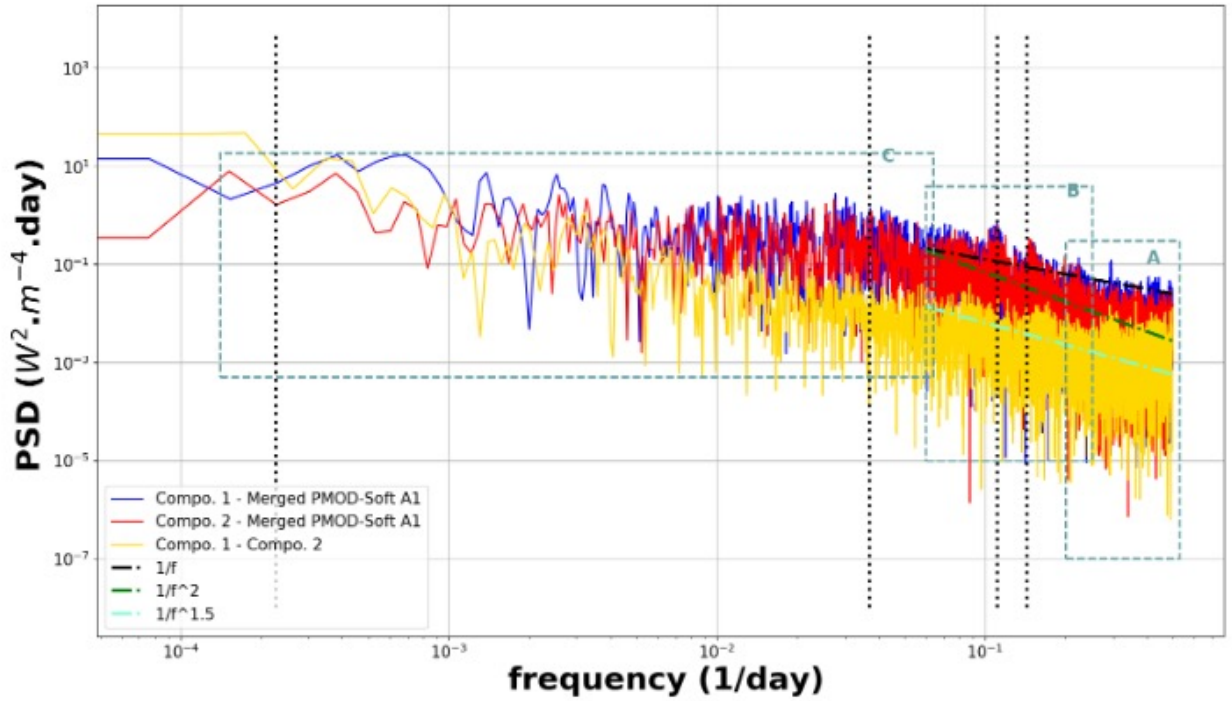
Table 2. Estimation of the solar minimum over last 40 years from the TSI time series (mean μ and standard deviation σ) released by Dudok de Wit *et al.* (2017) (Compo. 1), by Dewitte *et al.* (2004) (Compo. 2) and by Fröhlich (2006) (Compo. 3). We use these TSI composite time series as baseline to align our solution, with the statistics displayed in *Soft*.

W/ m^2		Compo. 1		Compo. 2		Compo. 3	
			Soft.		Soft.		Soft.
Cycle 22	μ	1360.30	1360.33	1362.82	1362.73	1360.58	1360.53
	σ	0.14	0.11	0.12	0.11	0.12	0.11
Cycle 23	μ	1360.68	1360.70	1362.90	1362.91	1360.57	1360.56
	σ	0.14	0.12	0.16	0.12	0.15	0.12
Cycle 24	μ	1360.53	1360.63	1362.89	1362.92	1360.42	1360.49
	σ	0.04	0.04	0.04	0.04	0.06	0.04
Cycle 25	μ	-	1360.59	1362.88	1362.89	-	1360.45
	σ	-	0.05	0.07	0.05	-	0.05



Advantages

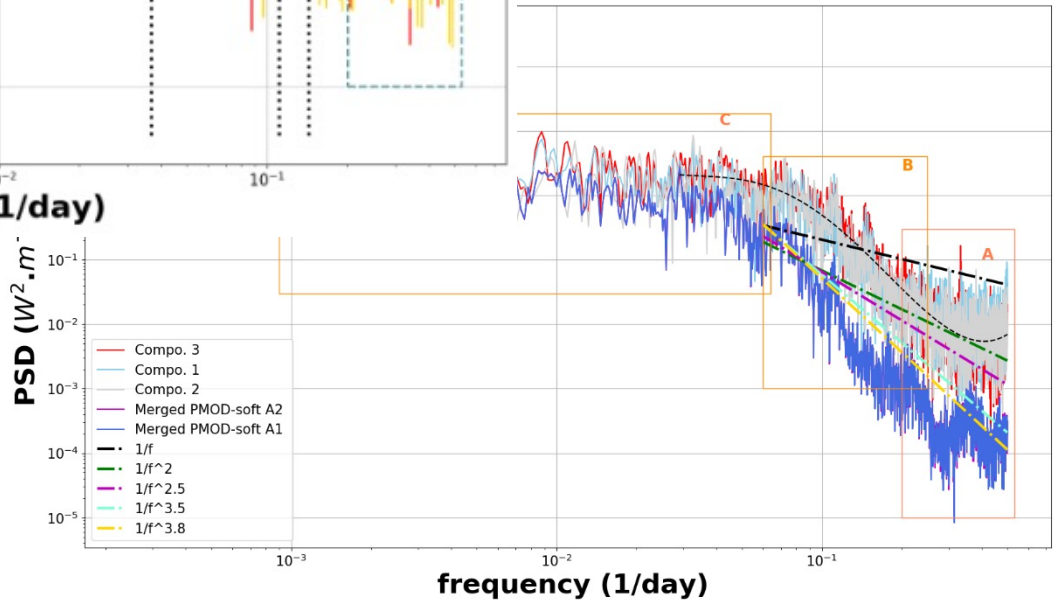
- *Fusion process* based on not many assumptions on input observations (stochastic processes assumed to be mixed white (Gaussian) noise and coloured noise). Proper kernel training (inducing points) capture short-term correlations and solar cycle.
- **Stiching process** requires baseline, thus easy to compare with previous composites (e.g., PMOD -2016, Dudok de Wit et al. -2017)



A flattening of the curve at high frequencies
1JD resolution (meso granulations)

B frequency ramp due to unknown diffusion proces
orrelation between 4 to 20 days (meso and super
ations). Higher with data fusion, therefore filtering
avelet

C long-term correlations and Solar cycle



Drawbacks

- Data fusion introduces correlation between observations (bandwidth noise) in fused TS, requiring large number of inducing points (> 5000 pts), hence **heavily time consuming**. Process not done in real time.
- More correlation between estimates , thus **steeper PSD ramp** > See Box B in the Figure
- Data fusion smoothes observations, thus **less power in PSD**

What's Done

- **Data fusion** process - many advantages (few assumptions on data, flexibility)
- Able to **produce a new composite** TSI time series with 41 years of data –agrees at 0.3 W.m2 with previous products
- **Time-Frequency** Analysis shows features related to solar noise and stochastic Processes, but some processes need to be more investigated

To Do

- Product will be released after the publication (next year). BUT can be requested to PMOD if you need it before the official release (jean-philippe.montillet@pmodwrc.ch)
- Study of variations of solar minima

Thanks and Enjoy IPC XIII !!!