A New Methodology to Process the Total Solar Irradiance observations Using Machine Learning and Data Fusion

Jean-Philippe Montillet[1], Wolfgang Finsterle[1], and Werner Schmutz[1]

[1]PMOD WRC Physical Meteorological Observatory Davos and World Radiation Center

November 23, 2022

Abstract

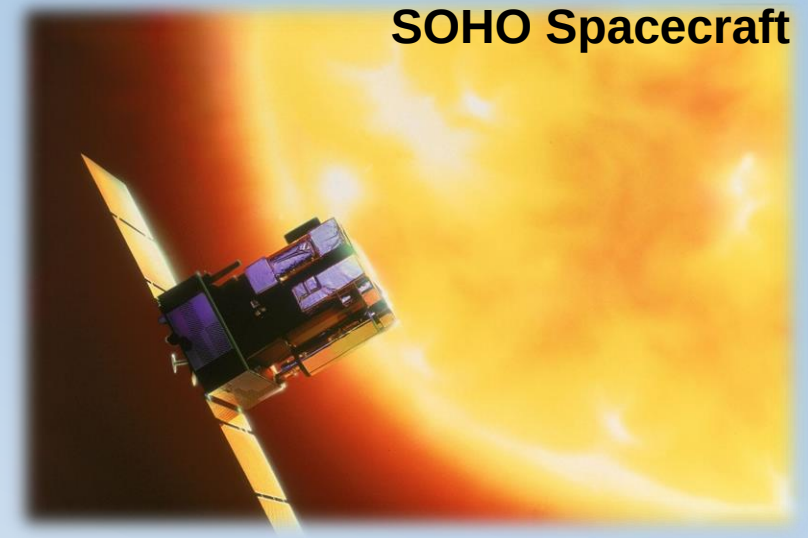
Across the last decades, various space missions have measured thetotal solar irradiance (TSI) such as the Variability of Irradiance andGravity Oscillations (VIRGO) experiment on the Solar and HeliosphericObservatory (SOHO) starting in 1996. Since the beginning of itsrecording time, one challenge is to correct the measurements from thedegradation of the TSI sensors in space. Various groupshave proposed different methodologies to produce a continuous TSI timeseries (TSI composite) which is essential to monitor the sun activityand its influence on the Earth's climate. However, the benchmark to test all those solutions is source of adebate in the community. Moreover, the input data for the TSI compositeare the degradation-corrected measurements provided by each individualinstrument team. Here, we propose a different approach using amachine learning and data fusion algorithm to produce automatically thedegradation-corrected TSI time series based on a small number of genericassumptions. The algorithm is applied to the VIRGO/PMO6, VIRGO/DIARADand PREMOS/PMO6 data. The time series agree between each other in termsof mean value with a difference of ˜ 0.14 W/m2 (PREMOS), ˜ 0.23 W/m2(VIRGO) and ˜ -0.18 W/m2 (DIARAD). Finally, taking a conservative valueof 0.3 W/m2 between our different TSI products, induces a variation ofthe global mean surface temperature of ˜ 0.02 K based on global climatesimulations, which is within the uncertainties of simulated global meansurface temperatures, hence not impacting significantly any climateforcing scenarios.

A NEW METHODOLOGY TO PROCESS THE TOTAL SOLAR IRRADIANCE OBSERVATIONS USING MACHINE LEARNING AND DATA FUSION

Jean-Philippe Montillet, Wolfgang Finsterle, Werner Schmutz

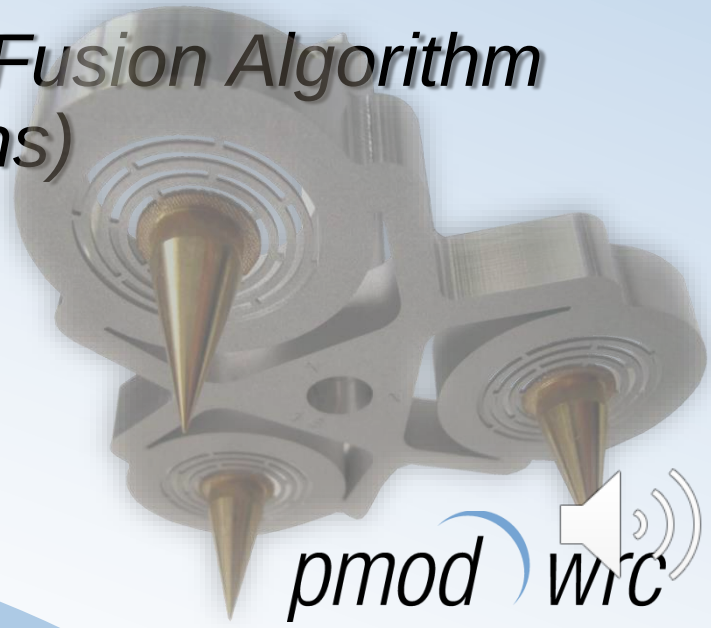
[PMOD/WRC, Davos, Switzerland]

em: Jean-Philippe.montillet@pmodwrc.ch


SOHO Spacecraft

OUTLINE

- *Total Solar Irradiance (TSI) Background and Introduction*
- *Machine Learning and Data Fusion Algorithm (including observations/missions)*
- *Results*
- *Next Steps*

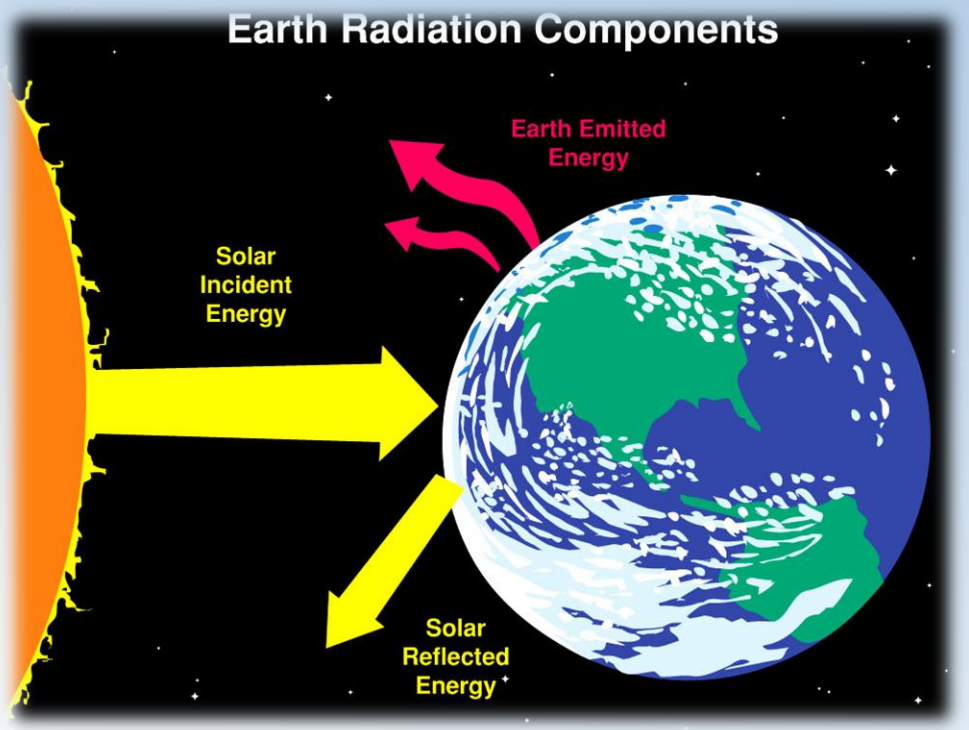


pmod wrc

TSI Background & Missions

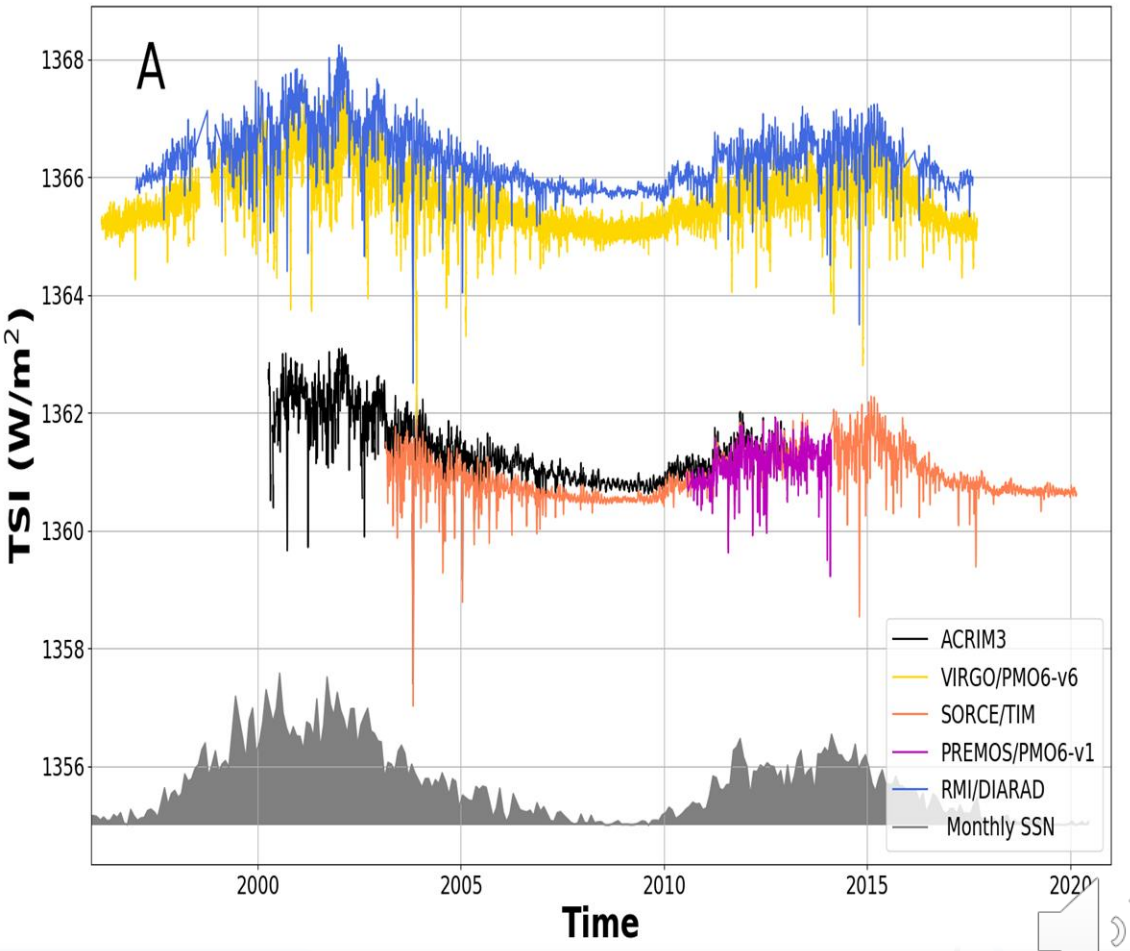
- Since the early 80's TSI observations used to measure energy received by the sun – part of the Earth radiation budget

- TSI observations used to constrain global climate simulations (anthropogenic effect)

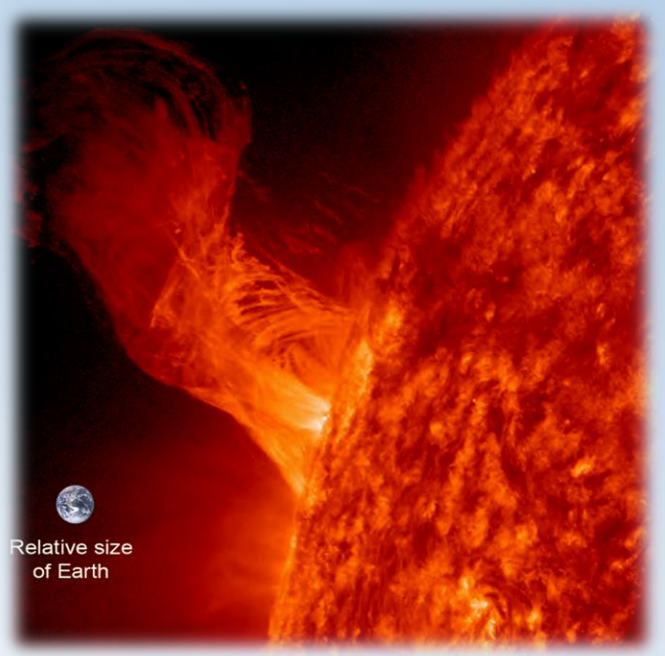


TSI Background & Missions

At PMOD, analyse SOHO/VIRGO (1996- now), PICARD/PREMOS (2010-2014) and the next gen. CLARA (2017 - now) and PROBA3/DARA (JTSIM/DARA)



A few TSI time series from various missions

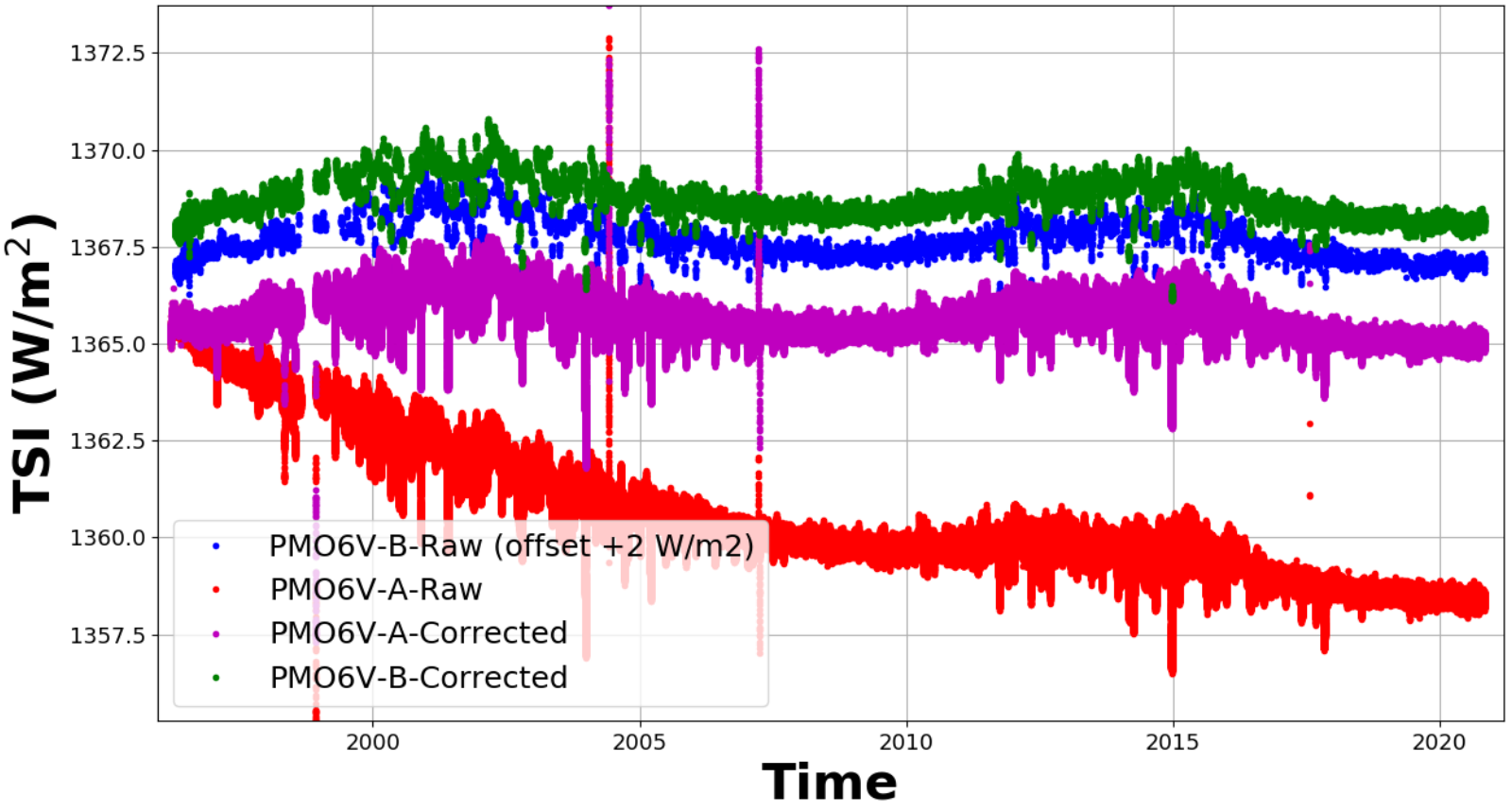


Challenges

- ✓ Radiometer in space suffers from the accumulated UV and EUV radiations
- ✓ Degraded Observations
- ✓ Correction using 1 or multiple backup channels operated as a much lower rate

➢ How to produce TSI time series degradation corrected & reduced noise with minimum assumptions?

Example: VIRGO PMO6V – 2 cavities (A &B), A operating continuously (every minute), B for 39 minutes every 10 days



Correction of VIRGO/PMO6V-A (raw –red, corrected -purple)

pmod wrc

The Algorithm

- **2 major assumptions:**

1/ Degradation modeled as a multiplicative effect and value of 1at time 0
At beginning two non-degraded instruments.
2/ Degradation is a decreasing function (neglect an “early” increase effect)

- **Algorithm** based on 2 parts**: Degradation Correction & Data Fusio**n

1/ *Degradation Correction* based on the ratio of the observations on the 2 channels.
Fitting of the function based on various models (e.g., exponential, monotonic) &
Solved by iterative algorithm (Levenberg-Marquadt)

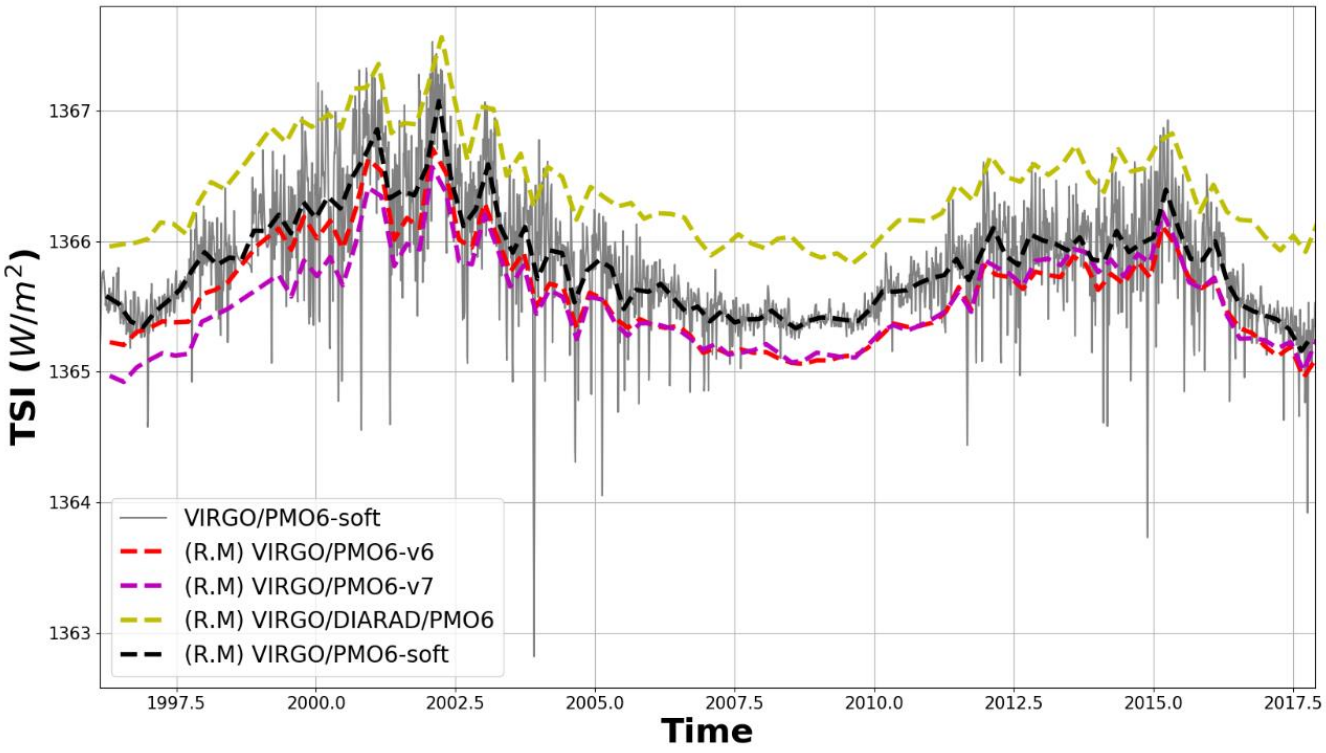
2/ *Data Fusion* based on stochastic properties of the TSI observations using a dual kernel white noise and coloured noise (Gaussian Process) – using main & backup chan.

See Sikonja et al. DOI: arXiv:2009.03091

Results …

Training and Comparing with various datasets from various instruments

Automatically correct Level 1 data for degradation effects with the **development of the algorithm** & **t**ested on various datasets PMO6V, DIARAD, PREMOS.



VIRGO/PMO6V TSI time series (soft) compared with previous TSI composites released by PMOD (Running Mean [R.M.] -81 days)

Development of Degradation-Correc. Algorithm based on Machine Learning and data fusion

Comparison with previous data releases from PMOD & others

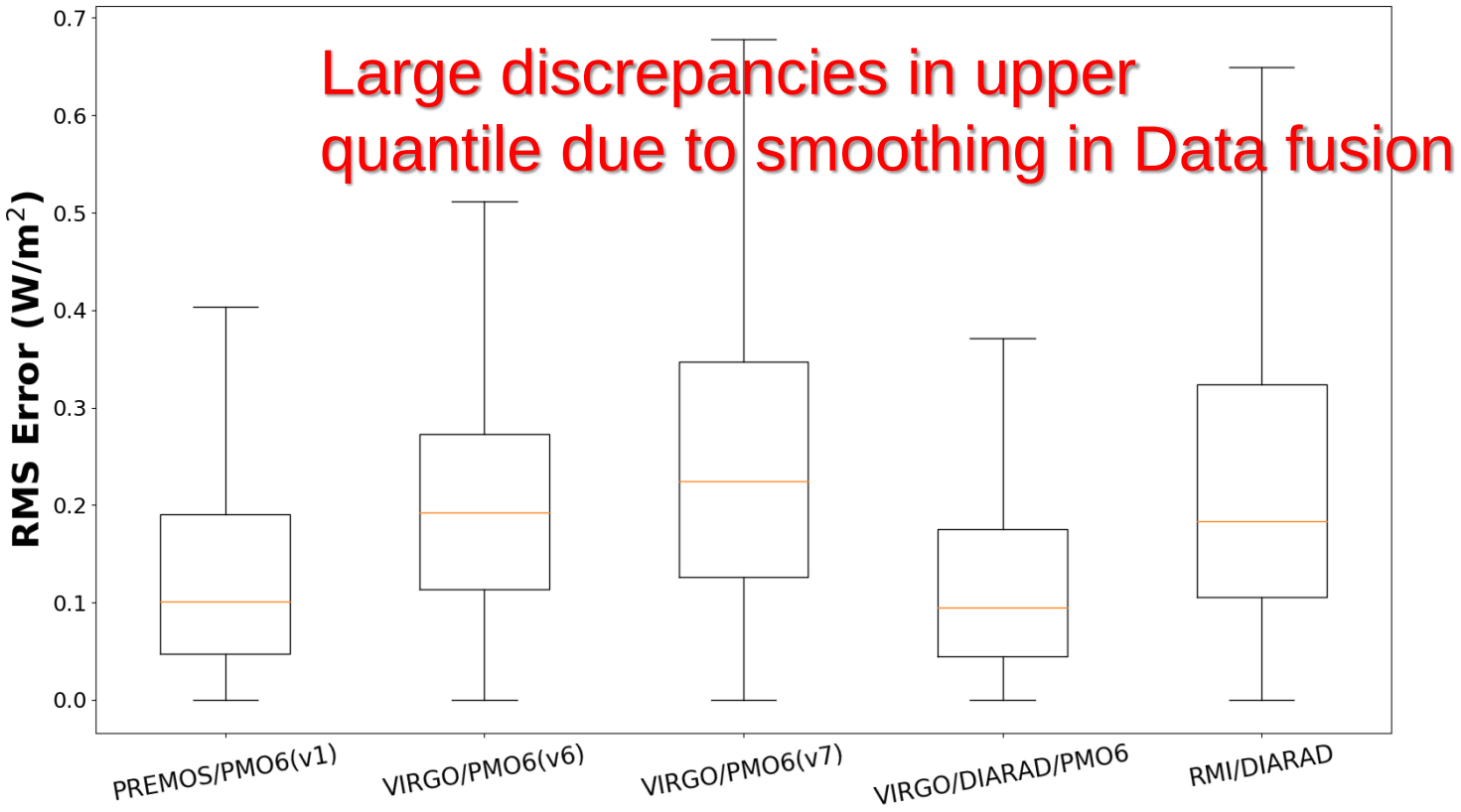
Comparison of the statistics (mean and std. [σ]) of various TSI series using either PMOD or other (e.g., ACRIM, RMI) from various missions/instruments.

Mean : average value over whole period for each mission/instrument, whereas Solar Min. average value at low activity of the sun between solar cycle 23 & 24 (i.e. 20/09/2008 and 5/5/2009).

(W/m^2)		Other	PMOD	
			Ref.	New
		$\mu \pm \sigma$	$\mu \pm \sigma$	$\mu \pm \sigma$
Mean	SORCE/TIM	1360.90 ± 0.41	✓	✓
	ACRIM3	1361.32 ± 0.57	✓	✓
	VIRGO/PMO6 (v6)	✓	1365.59 ± 0.51	1365.77 ± 0.48
	VIRGO/PMO6 (v7)	✓	1365.52 ± 0.51	1365.75 ± 0.45
	SOHO/DIARAD	1366.29 ± 0.52	1366.59 ± 0.48	1366.41 ± 0.47
	PREMOS/PMO6 (v1)	✓	1361.10 ± 0.34	1361.14 ± 0.32
Solar Min.	SORCE/TIM	1360.53 ± 0.04	✓	✓
	ACRIM3	1360.78 ± 0.06	✓	✓
	VIRGO/PMO6 (v6)	✓	1360.59 ± 0.07	1360.86± 0.05
	VIRGO/PMO6 (v7)	✓	1360.63 ± 0.07	1360.86 ± 0.05
	SOHO/DIARAD	1361.26 ± 0.05	1361.39 ± 0.04	1361.42 ± 0.05

Agree with previous releases below 0.3 W/m2 !!

Box Plot Comparison



Box-wishkers plot displaying the median quantile (50% - orange line), the upper quantile (75%) and the lower quantile (25%) in terms of the Root Mean Square Error (RMSE) between our estimates (soft) and the previous versions (PREMOS/PMO6v1, VIRGO/PMO6v6, VIRGO/PMO6v7, VIRGO/DIARAD(/PMO6), RMI/DIARAD)

pmod wrc

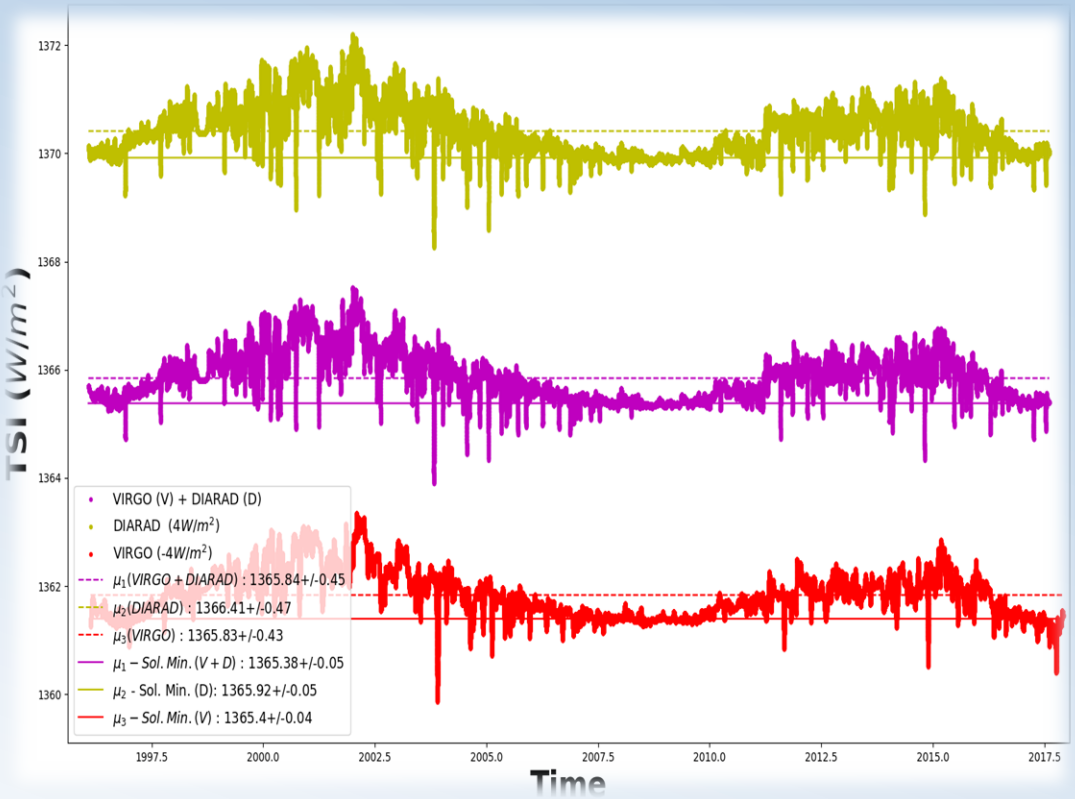
Data Fusion: PMO6VA &B

Development of a new Degradation-Correc. Algorithm based on Machine Learning and data fusion

This algorithm allows us:

- ✓ **The first SOHO/VIRGO composite (purple) fusing VIRGO/PMO6** (red – shifted of -4 W/m^2) and VIRGO/DIARAD (green – shifted of +4 W/m^2) observations.

✓ TSI composites VIRGO/PMO6 and VIRGO/DIARAD obtained in first step by applying algorithm on raw PMO6 and DIARAD raw measurements.



Level 2 TSI Time Series from Processing VIROG/DIARAD (green) & VIRGO/PMO6V (red),

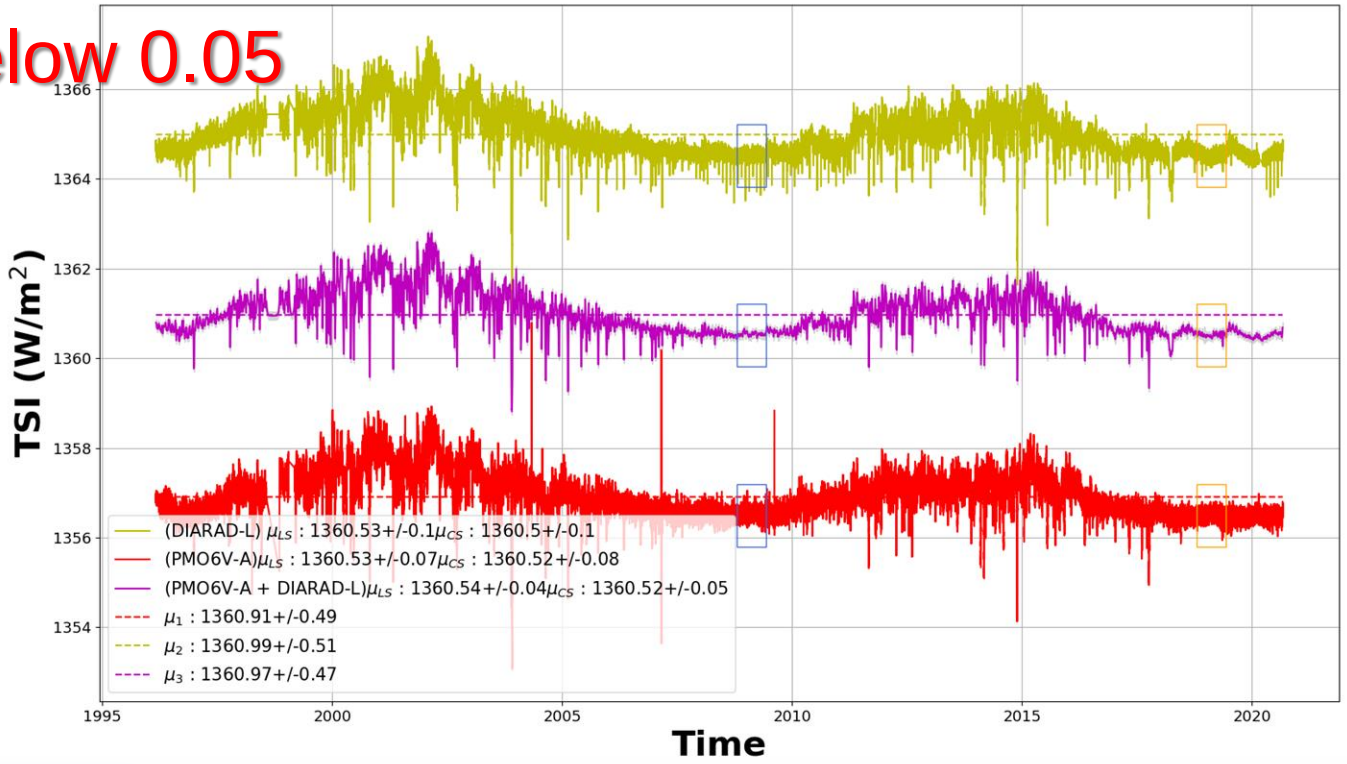
pmod wrc

A Nice Result …

Development of A new Degradation-Correc. Algorithm based on Machine Learning and data fusion

- Estimation of the new Solar minimum (cycle 23-24)

Both solar minimum agree below 0.05 W/m2



Degradation Corrected time series (PMO6V-A (Red), DIARAD-L (Green), Merged (Purple) – Orange Box New Solar minimum – Blue Box Previous S.M.

Next …

- Continue to learn from the TSI data and to improve the algorithm (e.g., the «early» increase)

- Data Fusion : multiple dataset from the last 40 Years and produce a 40 year long TSI composite (ERBS +ACRIM1 + …)

- Adapting the algorithm to current and future missions (CLARA, PROBA3 - DARA)

Thank You for Listening !!!

em: Jean-Philippe.montillet@pmodwrc.ch