



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

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Schmutz

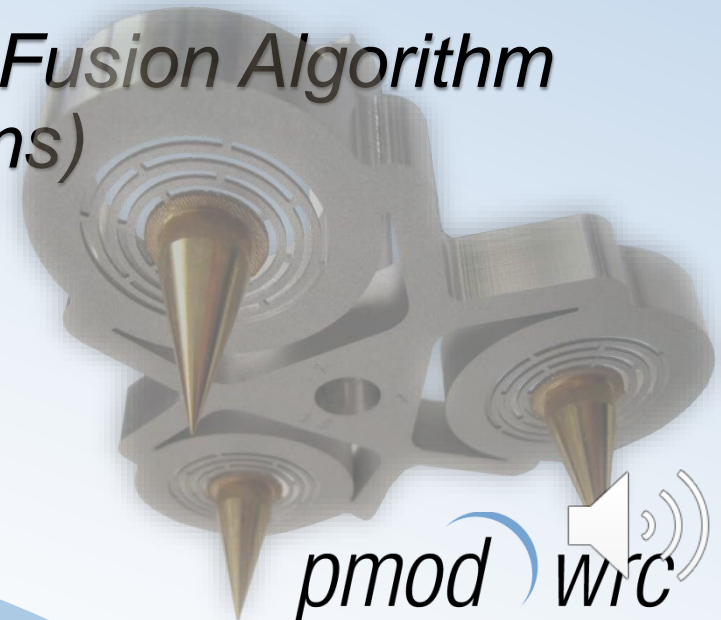
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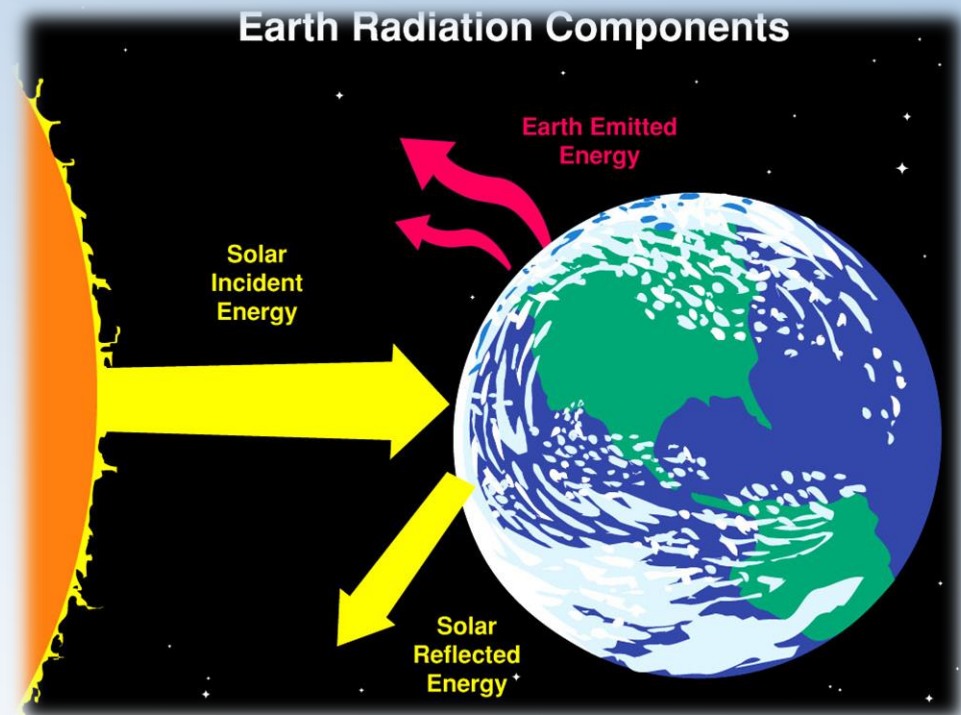
OUTLINE

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



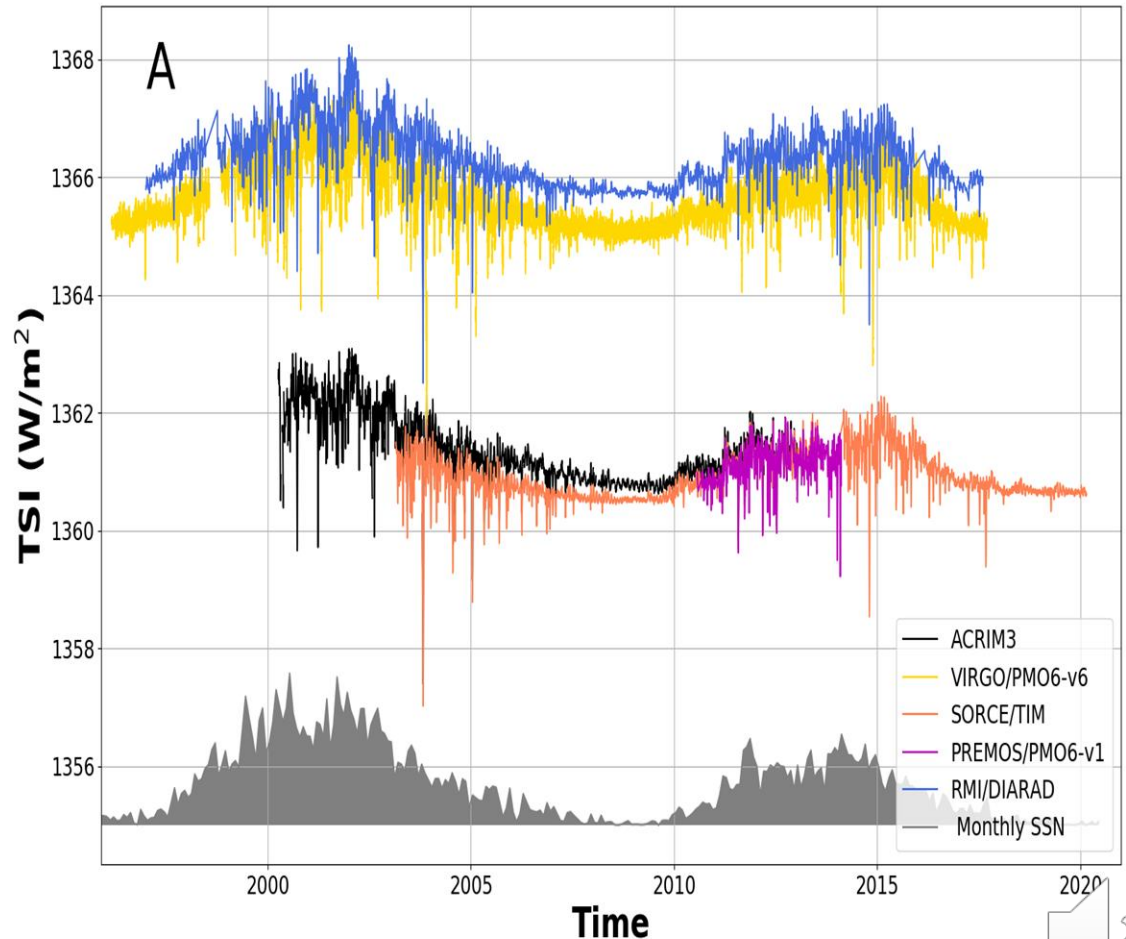
TSI Background & Missions

- 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)



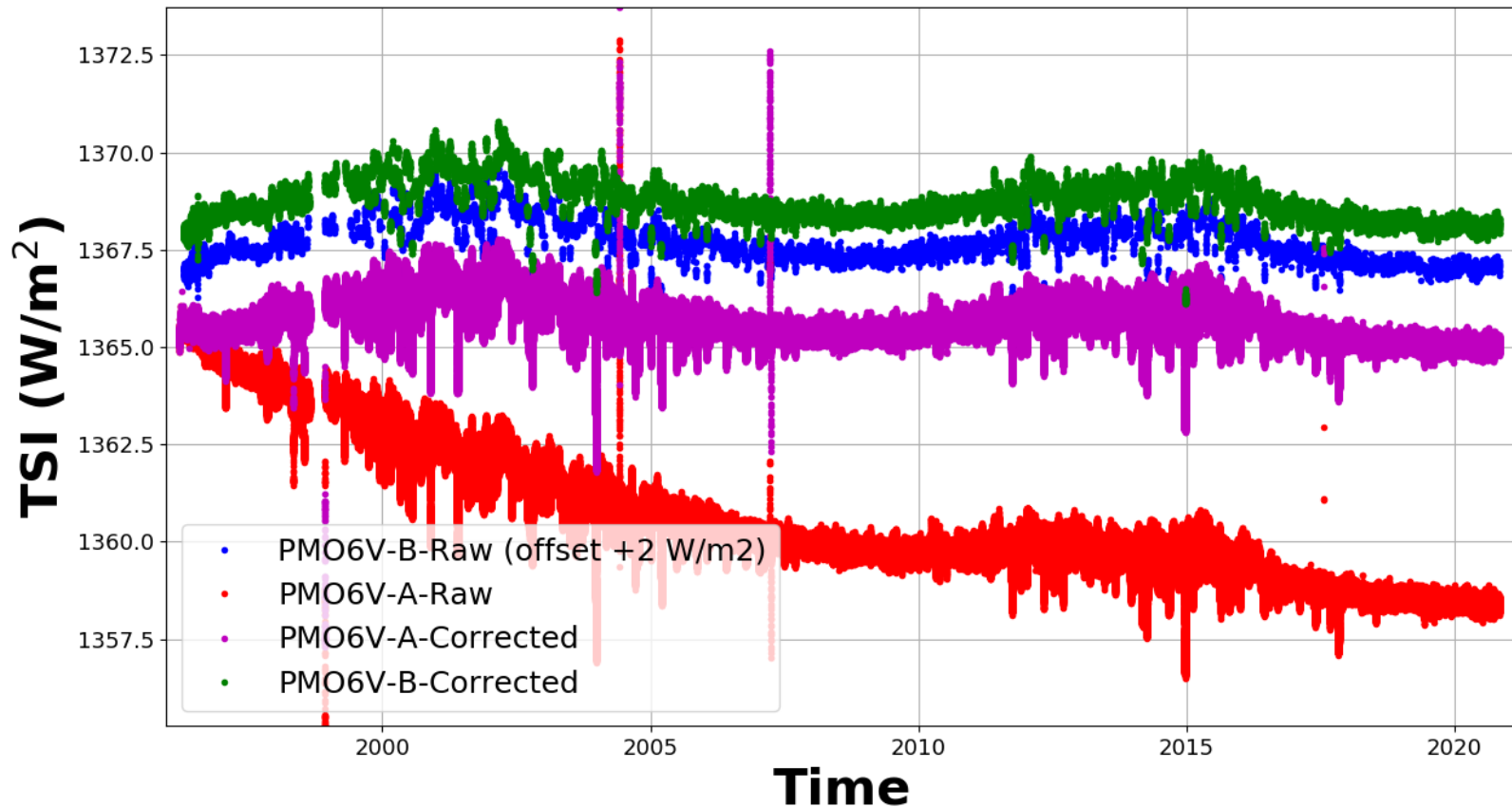
*A few TSI time series from
various missions*

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)

The Algorithm

- **2 major assumptions:**

- 1/ Degradation modeled as a multiplicative effect and value of 1 at 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 Fusion**

- 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:2009.07091](https://arxiv.org/abs/2009.07091)

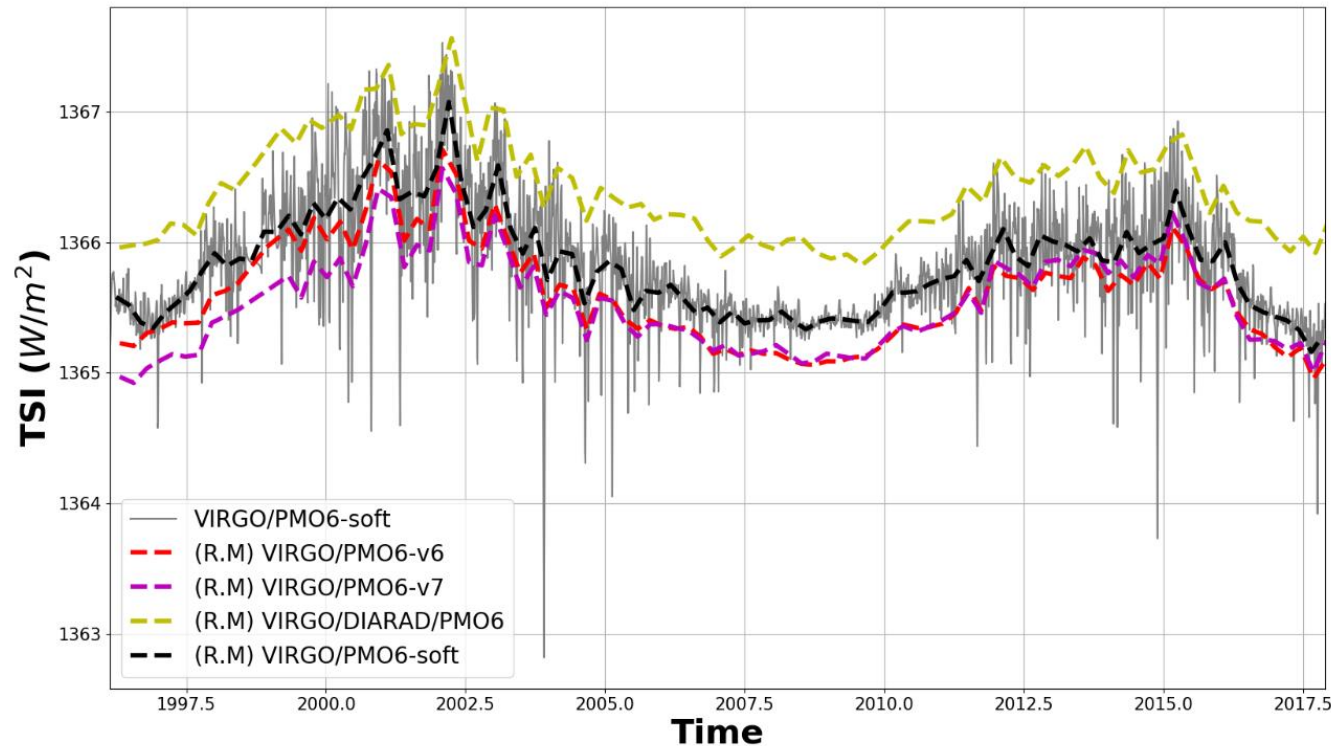


Results ...



Training and Comparing with various datasets from various instruments

Automatically correct Level 1 data for degradation effects with the **development of the algorithm** & tested 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.

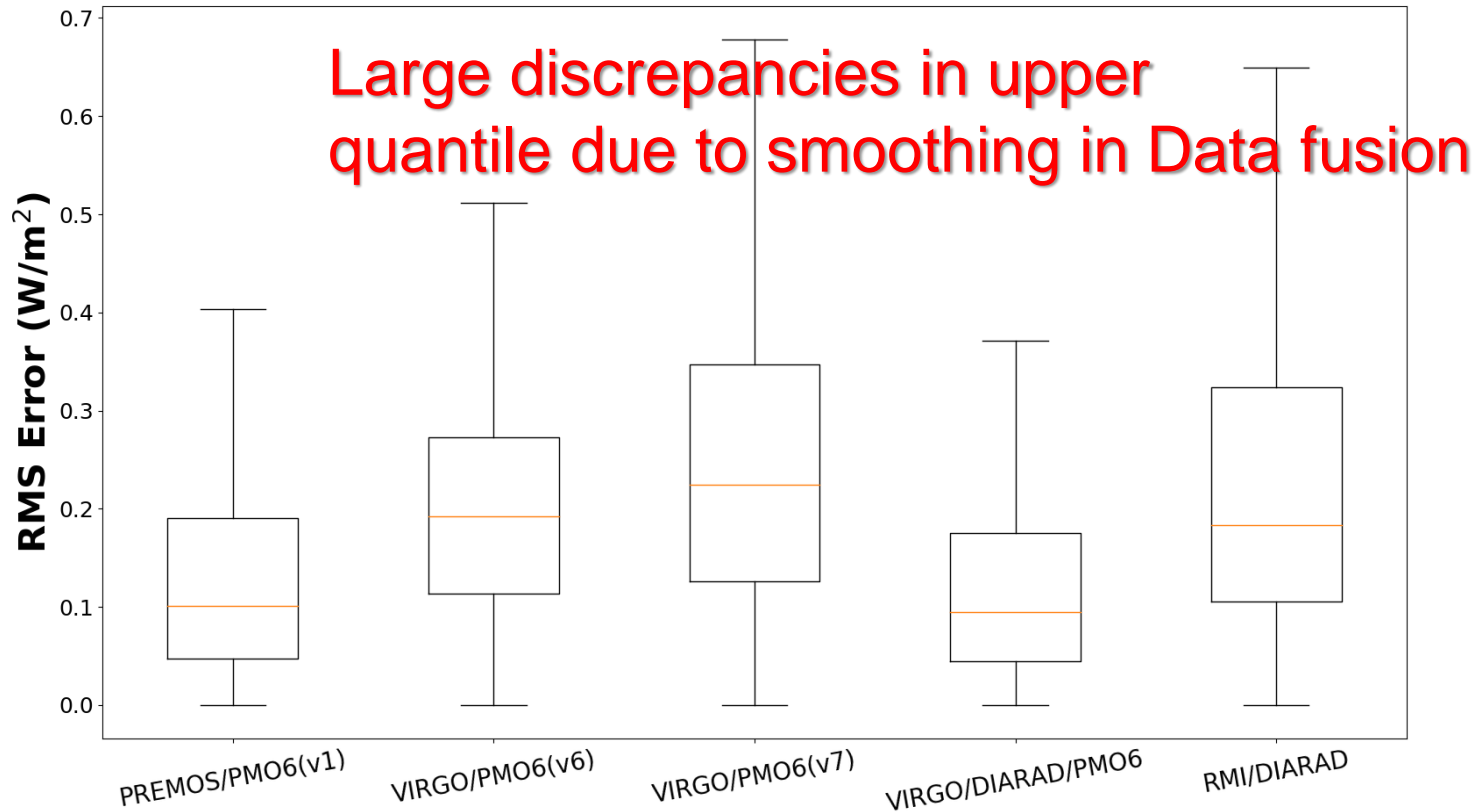
Mean : average value over whole period for each mission/instrument, whereas Solar Min. average value at low activity of the sun between solar cycle 23 & 24 (i.e. 20/09/2008 and 5/5/2009).

	(W/m^2)	Other	PMOD	
		$\mu \pm \sigma$	Ref. $\mu \pm \sigma$	New $\mu \pm \sigma$
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 $0.3 W/m^2$!!



Box Plot Comparison



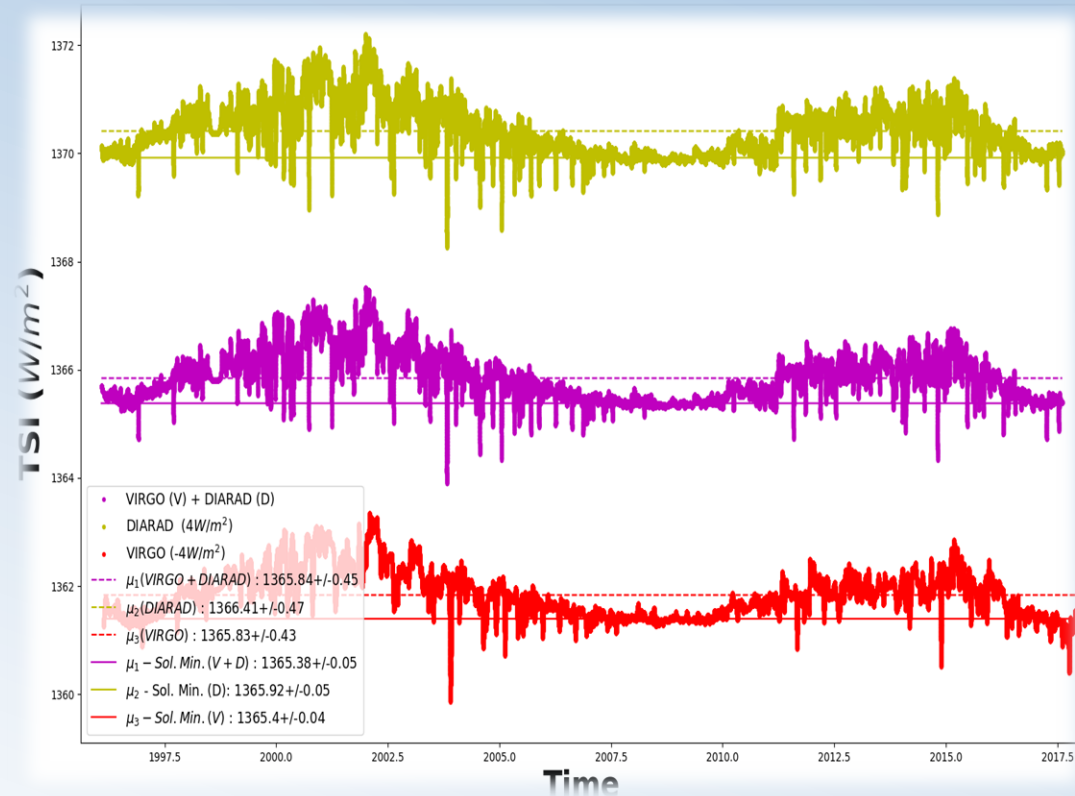
Box-whiskers plot displaying the median quantile (50% - orange line), the upper quantile (75%) and the lower quantile (25%) in terms of the Root Mean Square Error (RMSE) between our estimates (soft) and the previous versions (PREMOS/PMO6v1, VIRGO/PMO6v6, VIRGO/PMO6v7, VIRGO/DIARAD(/PMO6), RMI/DIARAD)

Data Fusion: PMO6VA & B

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 $+4 \text{ W/m}^2$) observations.
- ✓ TSI composites VIRGO/PMO6 and VIRGO/DIARAD obtained in first step by applying algorithm on raw PMO6 and DIARAD raw measurements.

Development of **a new Degradation-Correction Algorithm** based on Machine Learning and data fusion

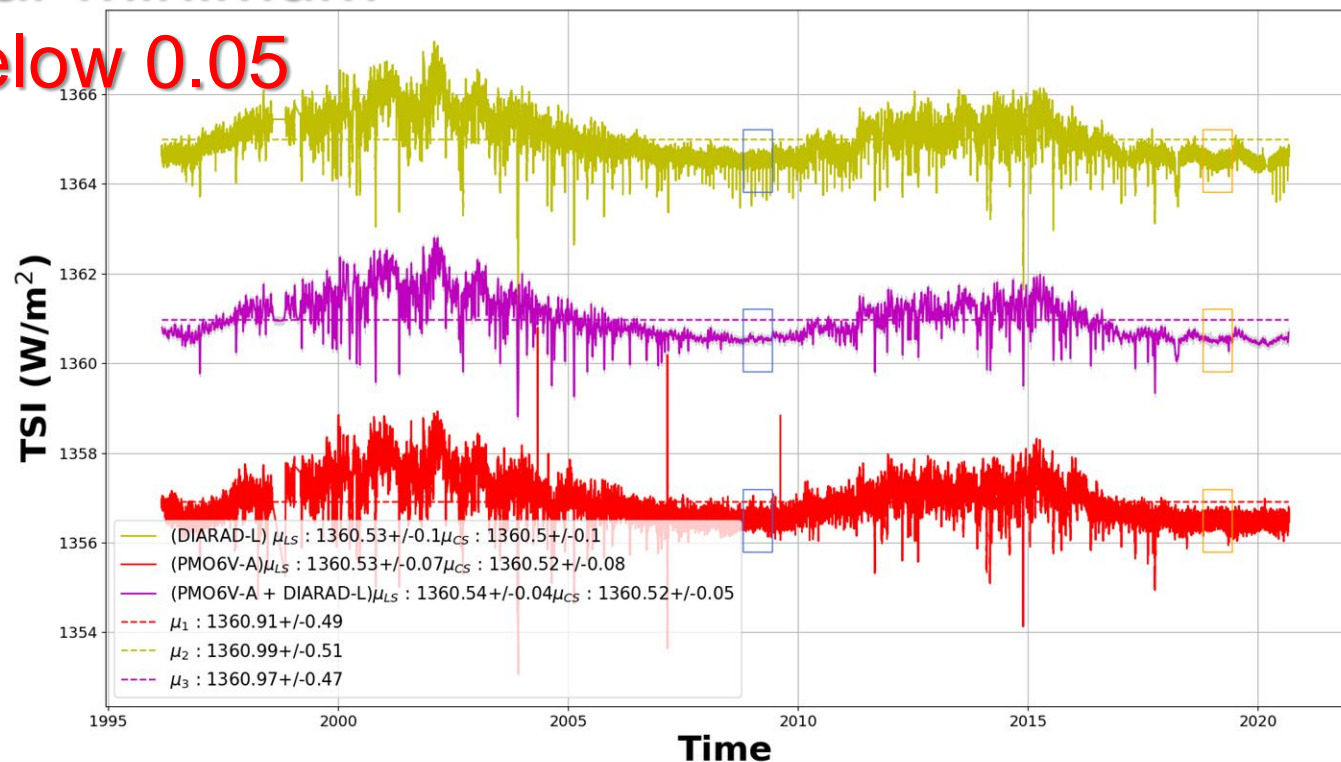


Level 2 TSI Time Series from Processing
VIRGO/DIARAD (green) & VIRGO/PMO6V (red),

A Nice Result ...

- 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 !!!

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