Solar Flux from SMOS operational L1B v724 dataset

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2nd Workshop on SMOS for Space Weather

University of Alcalá, Alcalá de Henares (Madrid, Spain)

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SMOS Solar Flux

*The stray solar signal, noise for Earth measurements, is removed by the L1 processor, via a **"Sun removal" algorithm**, and annotated in L1B v724products. So it can be used to derive the **Sun Brightness Temperature** for the entire Stokes vector!*

Proposal for value-added products derived from SMOS:

- Solar Flux and Sun Brightness Temperature product
- Solar Radio Burst bulletin product
- Auxiliary product for Sun Brightness Temperature
- Overview of SMOS derived products possible applications:

  Space Weather, Earth Observations science, Climatological models, GNSS systems, etc…

SMOS Solar Flux daily product algorithm

Sun BT from SMOS L1B data

- Data **aggregation**

semi-orbit merging on daily basis

- **Filtering**

(RFI, Eclipse, Sun position Front/Back, Sun elev.angle threshold <0.2 rad)

- Earth-Sun distance **correction**

normalization to 1AU

Correction for obliquity factor

$$BT_{Corr\ El.} = {BT}/{\cos\left(\frac{\pi}{2} - e\right)}$$

Where $e = \arccos(\sqrt{xi^2 + eta^2})$

LUT (Look Up Table) **Calibration**

$$BT_{Corr\ El.}^{LUT\ cal} = BT_{Corr\ El.} * \boldsymbol{m} + \boldsymbol{q}$$

Resampling

linear interpolation for X and Y polarization to resample to a common timeline based on Snapshot Time

Computation of **First half Stokes** parameter

$$\mathrm{BT} = {I}/{2} = \frac{[BT(Xpol) + BT(Ypol)]}{2}$$

(representative measure of Sun BT)

- **Orbital Data** time selection

(from ANX to ANX)

- Moving window **filter**

(to remove outlier and burst)

- computation of Sun BT **mean and std** on orbit basis

conversion from Sun BT to **Solar Flux**

$$SF = BT_{CorEl}^{Sun} \frac{2\,K_b}{\lambda^2}\ \Omega_{Sun}(day)$$

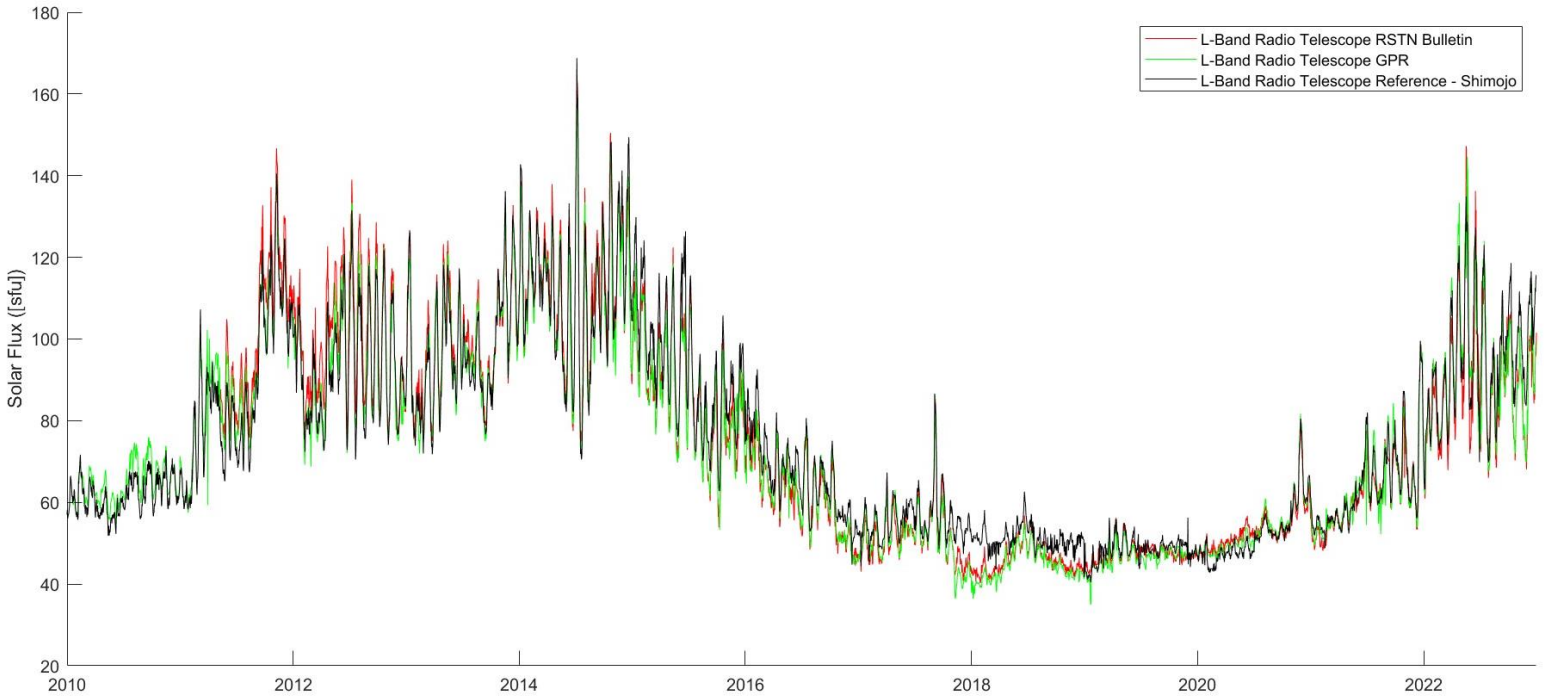
SunFlux and SunBT Data distributed via **ftp**
Available **from BoM to 'yesterday'**
File type: **ASCII**
SF and BT value for each single orbit, separated between Front and Back (semi-orbit data with **~50 mins cadence**).

SMOS Solar Flux algorithm: calibrated reference

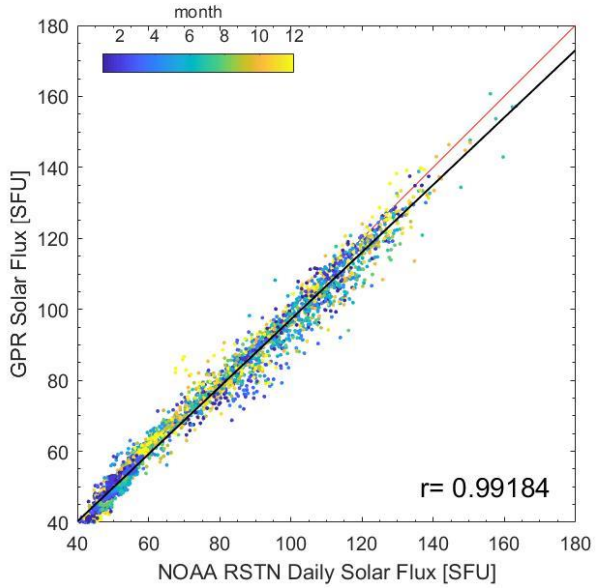
Calibration with Look Up Table (LUT)

$$BT_{Corr\ El.}^{LUT\ cal} = BT_{Corr\ El.} * \boldsymbol{m} + \boldsymbol{q}$$

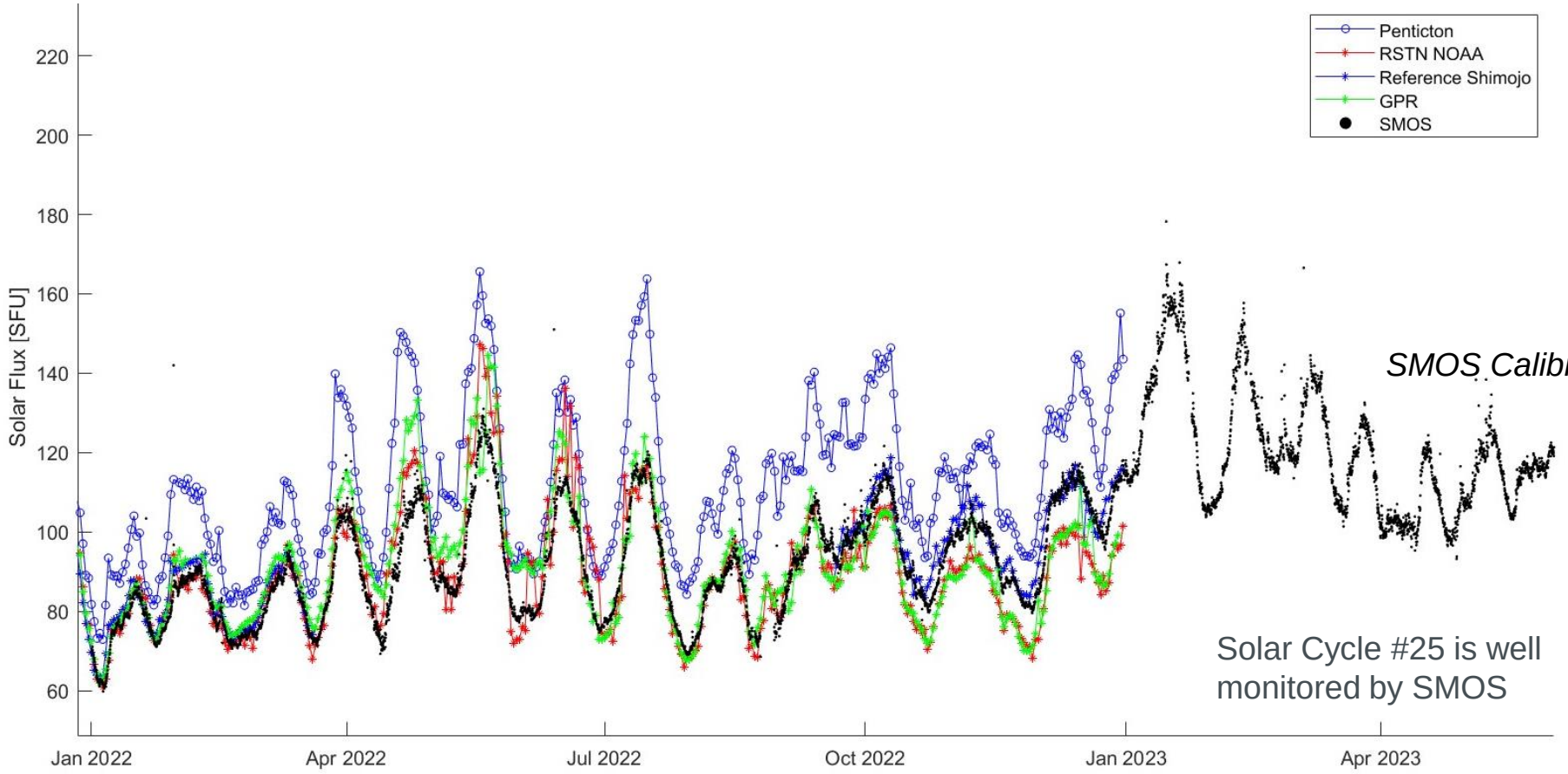
- **m,q** coefficients are based on linear regression model between **calibrated Solar flux from radio-telescope** measurements and SMOS Sun removal ancillary information F.
- **m,q** are derived for both Sun position in front and in the back of the antenna plane (xi, eta) along the satellite orbit allowing 24h continuous estimation of the Solar flux



Good agreement between derived inter-calibrated reference:



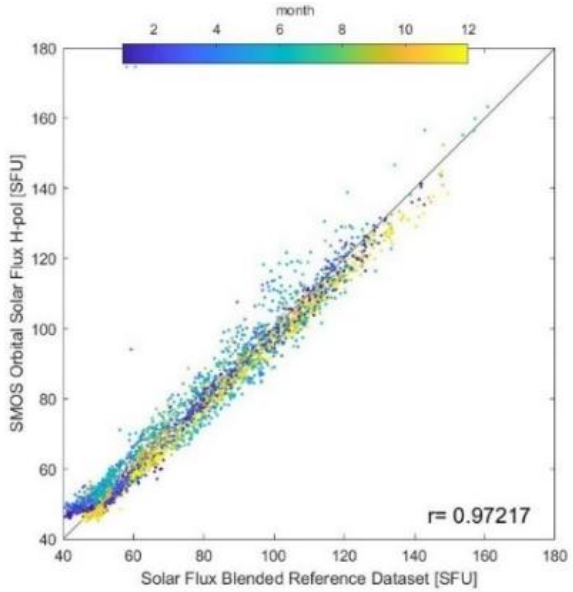
SMOS Sun Flux calibrated with L-Band Ground Radio Telescope references



SMOS Sun Flux is coherent with radio telescopes measurements

SMOS Calibrated Solar Flux

Solar Cycle #25 is well monitored by SMOS



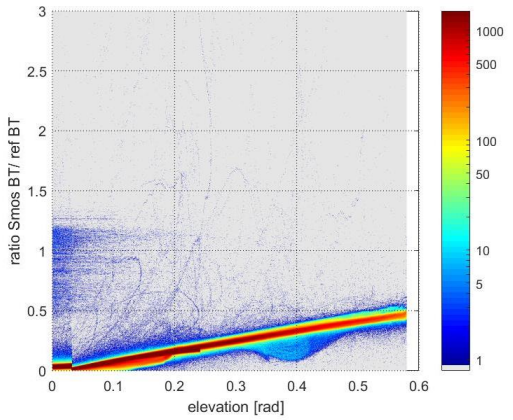
- Good consistency among L-Band ground radio telescope references computed with different approaches (Blue line: Penticton observations at 2.8 GHz reported for info)
- Good consistency with NOAA L-band solar flux daily bulletin dataset (not inter-calibrated)
- **Good consistency between our inter-calibrated L-band solar flux reference and SMOS Mean Orbit value calibrated**

From annotated Sun BT to Calibrated Sun BT v724 (Front)

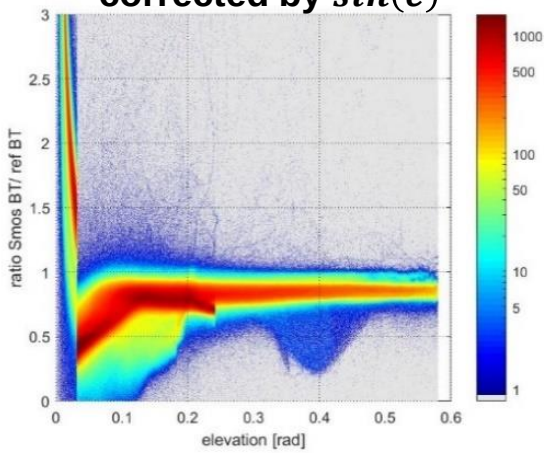
Annotated SMOS Sun BT divided by Sun BT from radio telescopes

v724 Polarization X:

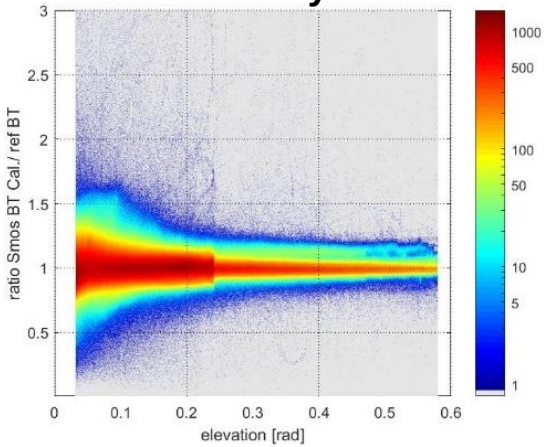
Sun BT



corrected by $sin(e)$

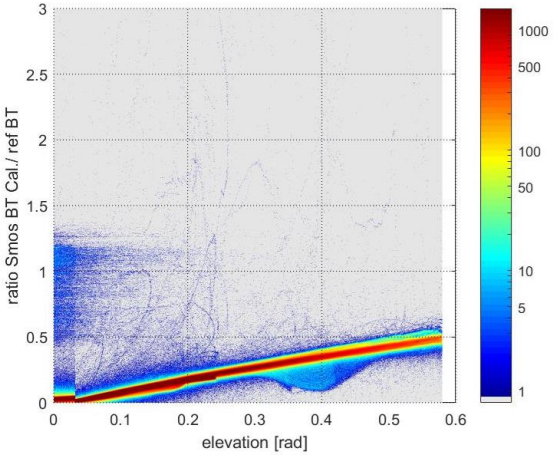


calibrated by LUT

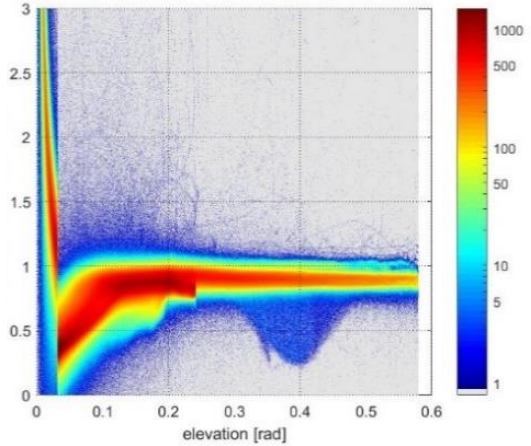


v724 Polarization Y:

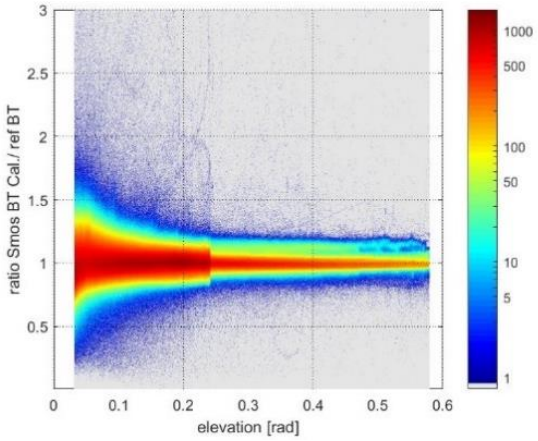
Sun BT



corrected by $sin(e)$



calibrated by LUT



SMOS Solar Radio Burst detection bulletin

- **BT correction**
- **calibration**
- **resampling** of X, Y, T3, T4 polarizations

(Same as Sun Flux computation)

→

Energy Computation

comparison between Energy computed as Solar Flux Integral on specified Δt and Solar energy reference computed from mean solar flux

→ if difference exceed 4% → possible RB

→

Estimate of **burst peak time** and **duration**

→

False positive check

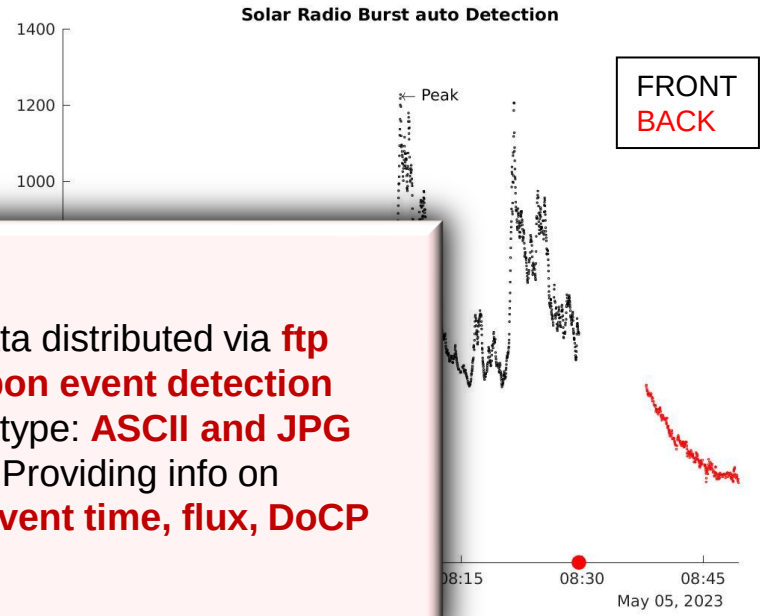
compute **Degree of Circular Polarization** from Stokes parameters (with corrected BT):

$$DoCP = {}^{V}/_{I} = -{}^{BT_4}/_{BT(Xpol) + BT(Ypol)}$$

$$-1 < DoCP < 1$$

→

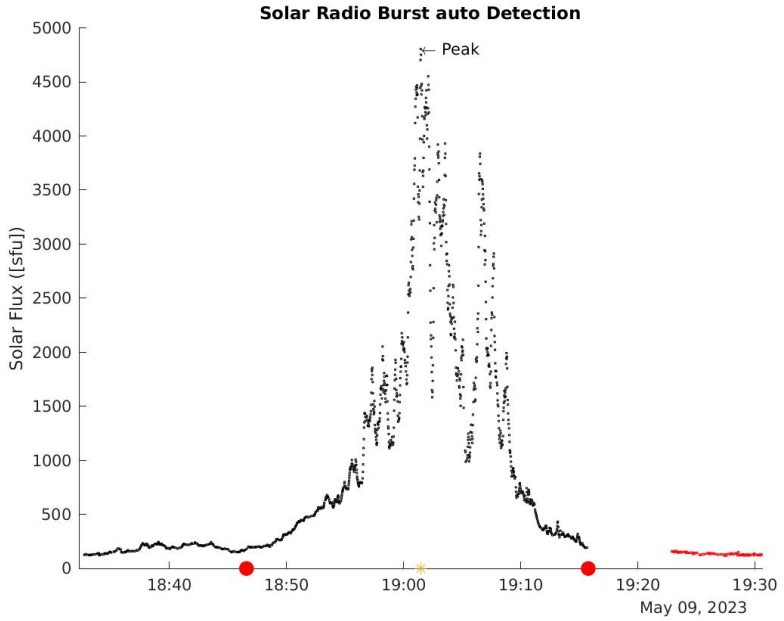
Radio Burst warning product generation



Data distributed via **ftp upon event detection**
File type: **ASCII and JPG**
Providing info on
RB event time, flux, DoCP

REDLAB

SMOS Solar Radio Burst bulletin validation



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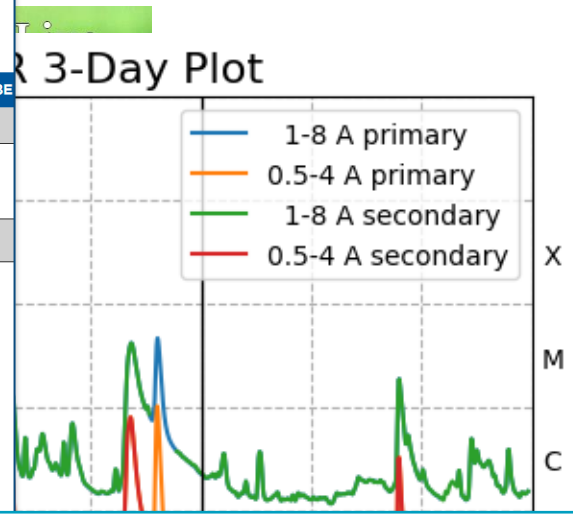
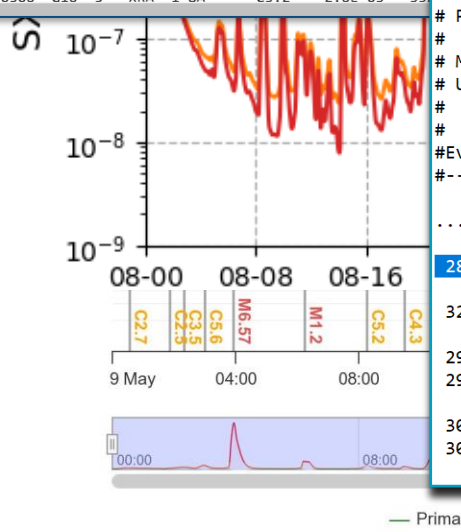
CURRENT SPACE WEATHER CONDITIONS on NOAA Scales

SOLAR AND GEOPHYSICAL EVENT REPORTS

```
:Product: 20230608events.txt
:Created: 2023 Jun 08 2017 UT
:Date: 2023 06 08
# Prepared by the U.S. Dept. of Commerce, NOAA, Space Weather Prediction Center
# Please send comments and suggestions to SWPC.Webmaster@noaa.gov
#
# Missing data: ////
# Updated every 5 minutes.
#                          Edited Events for 2023 Jun 08
#
#Event    Begin    Max      End  Obs  Q  Type  Loc/Frq   Particulars       Reg#
#-----------------------------------------------------------------------------
 610 +     0209   0216     0222  G16  5   XRA  1-8A      C1.6    1.2E-03   33
 620 +     0248   0258     0306  G16  5   XRA  1-8A      C3.2    2.6E-03   33
```





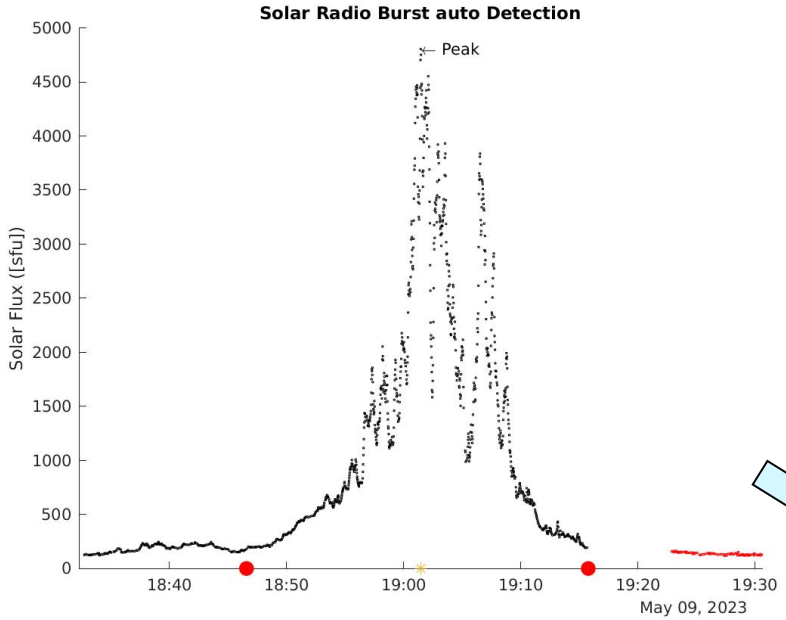

```
:Created: 2023 May 09 0357 UT
:Date: 2023 05 06
# Prepared by the U.S. Dept. of Commerce, NOAA, Space Weather Prediction Center
# Please send comments and suggestions to SWPC.Webmaster@noaa.gov
#
# Missing data: ////
# Updated every 5 minutes.
#                          Edited Events for 2023 May 06
#
#Event    Begin    Max      End  Obs  Q  Type  Loc/Frq   Particulars       Reg#
#-----------------------------------------------------------------------------
....

280       1921   1922     1922  PAL  G   RBR  245       250
320       2016   ////     2359  PAL  C   RSP  060-180   CTM/1
290 +     2142   2157     2213  G16  5   XRA  1-8A      C4.7    5.5E-03   3299
290       2148   2156     2244  HOL  3   FLA  S08E40    SN      ERU       3299
300 +     2256   2257     2259  PAL  G   RBR  245       270
300       2257   ////     2359  LEA  C   RSP  050-180   CTM/1
```

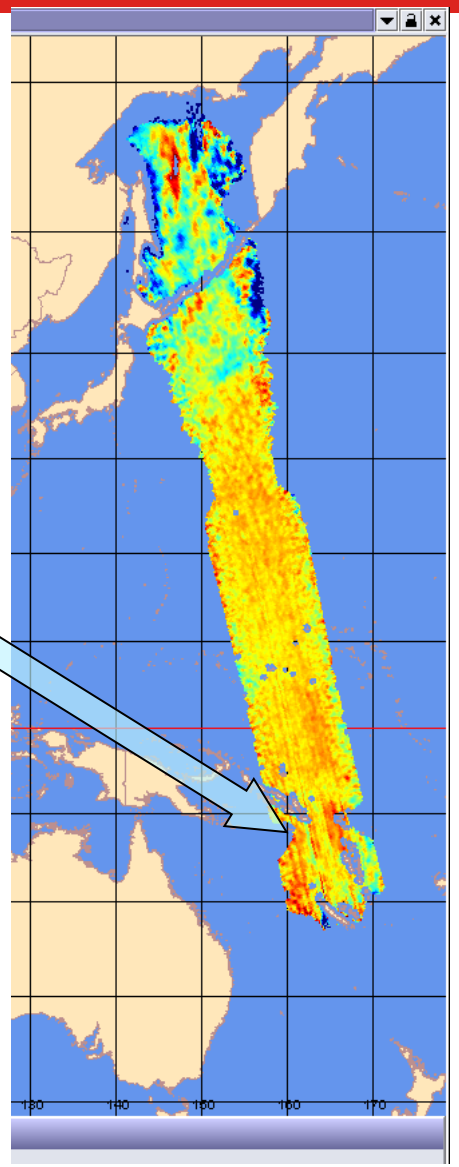
SMOS RB detection verification:

- www.spaceweatherlive.com – solar flares detection
- www.solarmonitor.com – GOES X-rays observation
- www.swpc.noaa.gov – Events report (RBR)

*RBR = Fixed-frequency radio burst
RSP = Sweep-frequency radio burst

SMOS Solar Radio Burst bulletin application





SMOS solar flux derived products can be used as input for **Earth Observation** data, e.g. for SMOS L2 sea surface salinity

Solar radio bursts detection is useful as they **impact** SMOS L2 OS products **data quality and availability**

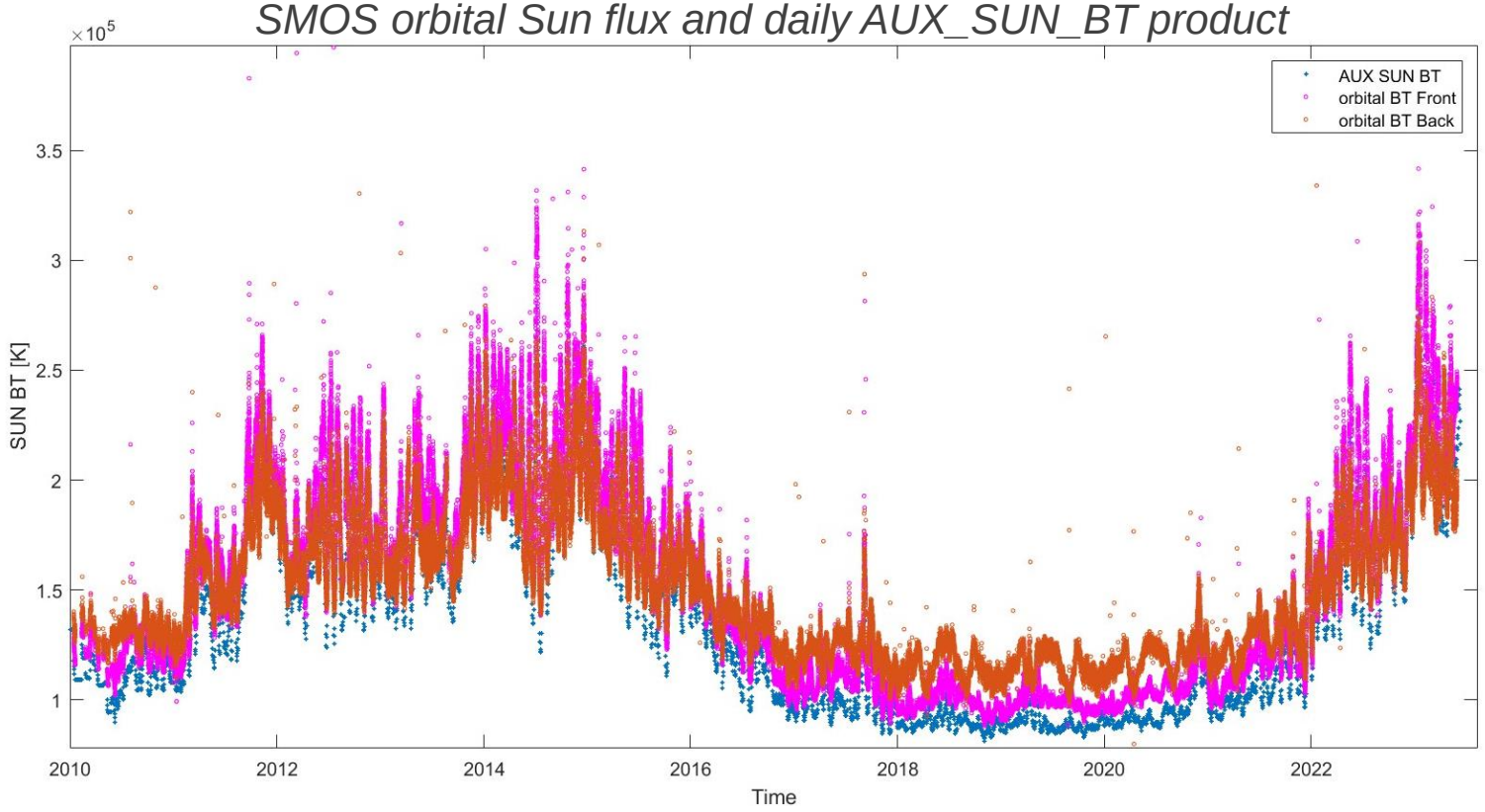
Sea Surface Salinity map during the Solar radio Burst event on 9 May 2023 – visible degradation

Auxiliary product from SMOS Solar flux

The Solar Flux, and Sun BT derived from SMOS measurements, could be employed as input for other scientific products:

A data processing algorithm is already up and running on **RedLab** machine and distributed to SMOS Data Payload Ground Segment to use it as **input for SMOS L2 sea surface salinity product:**

SMOS orbital Sun flux and daily AUX_SUN_BT product



from mean orbit **SUN_FLX** product
- FRONT -
Extract BT (1AU)

↓

convert to actual value (BT/**Earth-Sun distance Factor**)

↓

Compute **daily** value

↓

Correct for estimated **calibration factor**:

$0.9 * median\ [sun\ BT]_{[daily]}$

↓

AUX_SUN_BT product generation

Gaps filled with latest available value

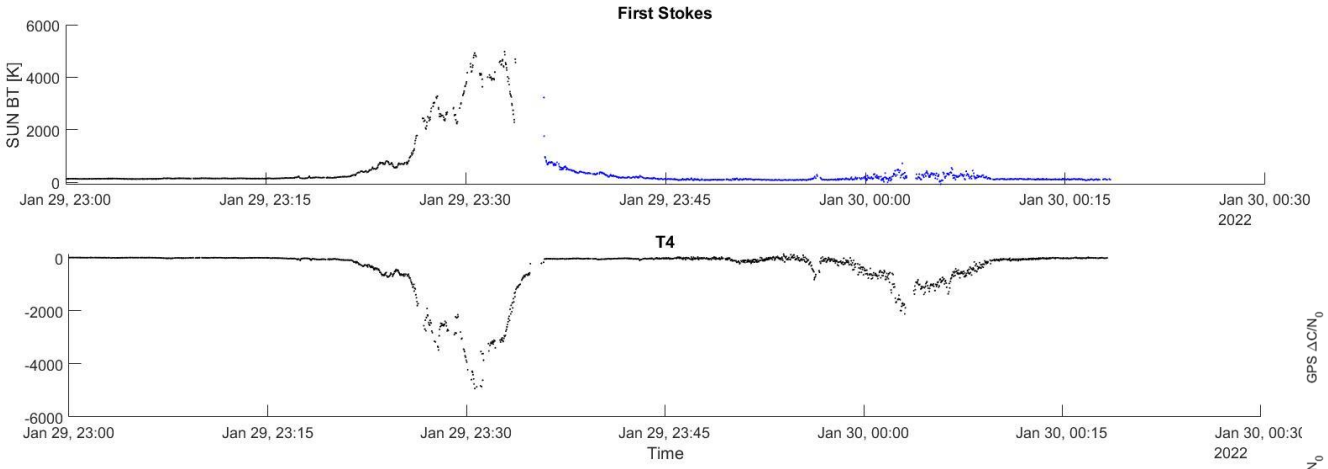
Coverage extended to 7 days ahead (using last computed value)

Data distributed internally to SMOS DPGS

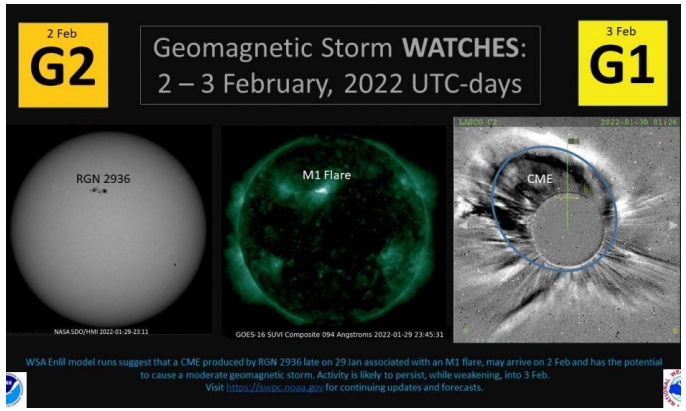
Why SMOS for Solar flux?

Possible application of SMOS solar flux in **solar physics** and **space weather** studies:

- **Solar RB detection** can be applied to studies on RB triggering, and to synergies with **Solar flare/CME monitoring/forecast**



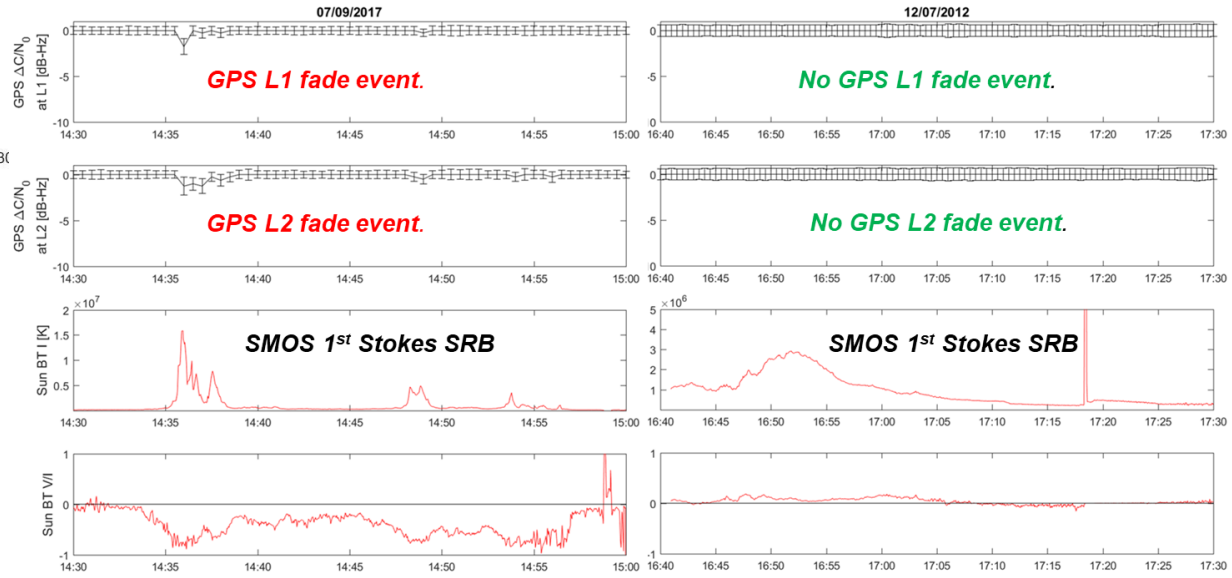
NOAA AR2936 produced an M1 flare (R1-Minor Radio Blackout) on 29Jan2022 at 23:32 UTC. Associated with asymmetric, full halo CME as observed in NASA/SOHO LASCO coronagraph imager.



- **Solar Flux in L-band** ⇨ Useful to estimate impact on GNSS

Polarimetric dataset at L-band: useful to analyse **circular polarization in Solar RB** which impacts **GNSS** signal reception. (SMOS frequency is right in the middle of the two L1 and L2 GPS signal)

Correlation between amount of Solar flux at L-band and: speed, angular width and **kinetic energy of the CME** (helpful for CME impact assessment)



SMOS degree of circular polarization in agreement with GPS fade event.

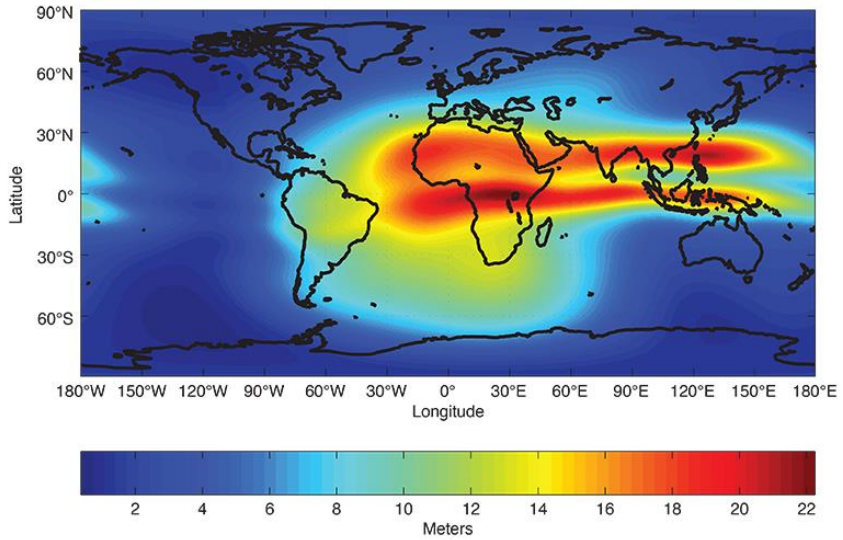
SMOS degree of circular polarization in agreement with No GPS fade event.

Why SMOS for Solar flux?

- Possible usage of SMOS AUX in **NeQuick** model:

quick-run ionospheric electron density model, for trans-ionospheric propagation applications.
NeQuick-G: adapted for Galileo real-time single-frequency users, to compute ionospheric delay corrections.

The model values depend on solar activity (given by monthly-mean sunspot number, **solar radio flux F10.7**), season and time.



*The NeQuick package includes routines to evaluate the **electron density along any ground-to-satellite** straight **line ray-path** and the corresponding **Total Electron Content (TEC)** by numerical integration.*

- Possible **multimission** applications:

usage of SMOS_SUN_FLUX as input for **Swarm** products

swarm smos

SUN_FLUX product can be used for **Swarm L2 models**: Many of these models use F10.7 as proxy for solar EUV (main source of ionospheric ionization, and thus plasma density / conductivity in non-polar regions), with 3-months average.

Could be interesting to better describe the day-to-day variability of

- **Solar quiet current (Sq)**;
- **EEJ current** (**Equatorial ElectroJet**, that uses equatorial electric field, 1 value per orbit);
- **MIO Model** (Model of non-polar daily geomagnetic variation caused by ionospheric currents, including their variability with season and solar flux);
- Etc…

Why SMOS for Space Weather?

The Solar Flux, and Sun BT derived from SMOS measurements, with their peculiar temporal resolution and characteristic bandwidth, have several possible application in space weather field:

- **Long time coverage data**: 13+ years of observation → suitable for Space Weather models
- Could be available in "**near-real time**" within 3 hours from acquisition
- Different **temporal resolution**:
  - **4.8 seconds** → for **Solar RB** studies and synergies with **Solar flare/CME monitoring/forecast**
  - Orbital aggregation: **100 minutes** → suitable for Solar cycle studies and synergies with F10.7 for **ionosphere/thermosphere modelling** (proxy of solar activity)
  - **Daily data** → could be employed as input for other scientific products (e.g. AUX_SUN_BT), and for data calibration
- Solar Flux in **L-band** → useful to estimate impact on GNSS
- **Polarimetric** measurements → useful for studies on characterization of Solar CME magnetic properties

DATA distribution

SMOS orbital data for Sun BT and **Solar Flux**

→ distributed via **ftp**
Available **from BoM to 'yesterday'**
File type: **ASCII**
SF and BT value for each single orbit, separated between Front and Back (semi-orbit data with **~50 mins cadence**).

Accessible upon request

Radio Burst warning product generation

→ Data distributed via **ftp**
upon event detection
File type: **ASCII and JPG**
Providing info on
RB event time, flux, DoCP

Accessible upon request

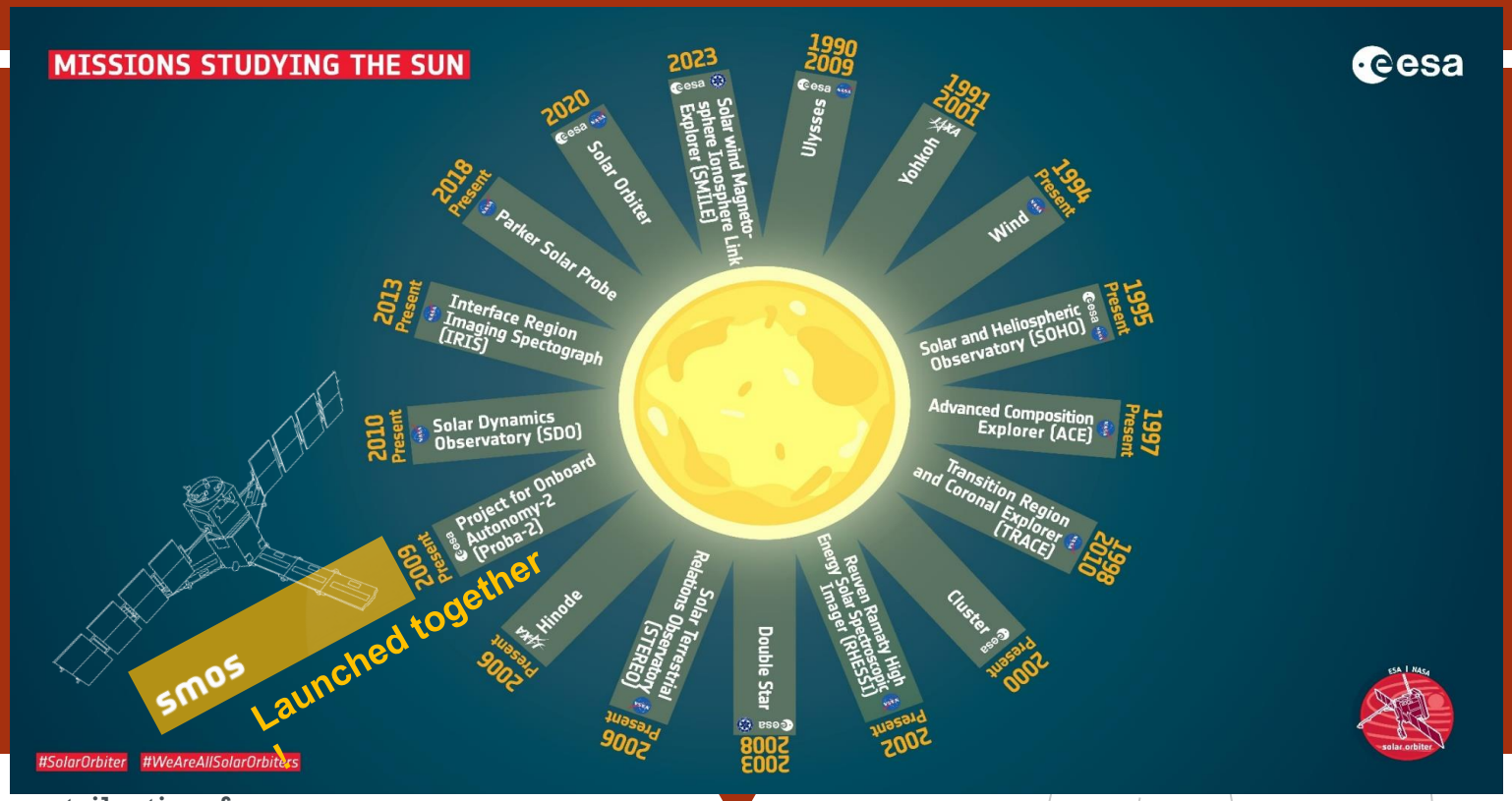
AUX_SUN_BT product

→ **Daily** data distributed **internally** to SMOS Ground Segment

distribution could be set up if there is interest from possible users

Please contact: redlab-oper@eo-sppa.org

THANK YOU !



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