SMOS, how an ESA Earth Observation mission can contribute to Solar activity monitoring

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SOLARNET Workshop “Sun in Science and Society”

11 – 15 September 2023 Venezia/Mestre, Italy

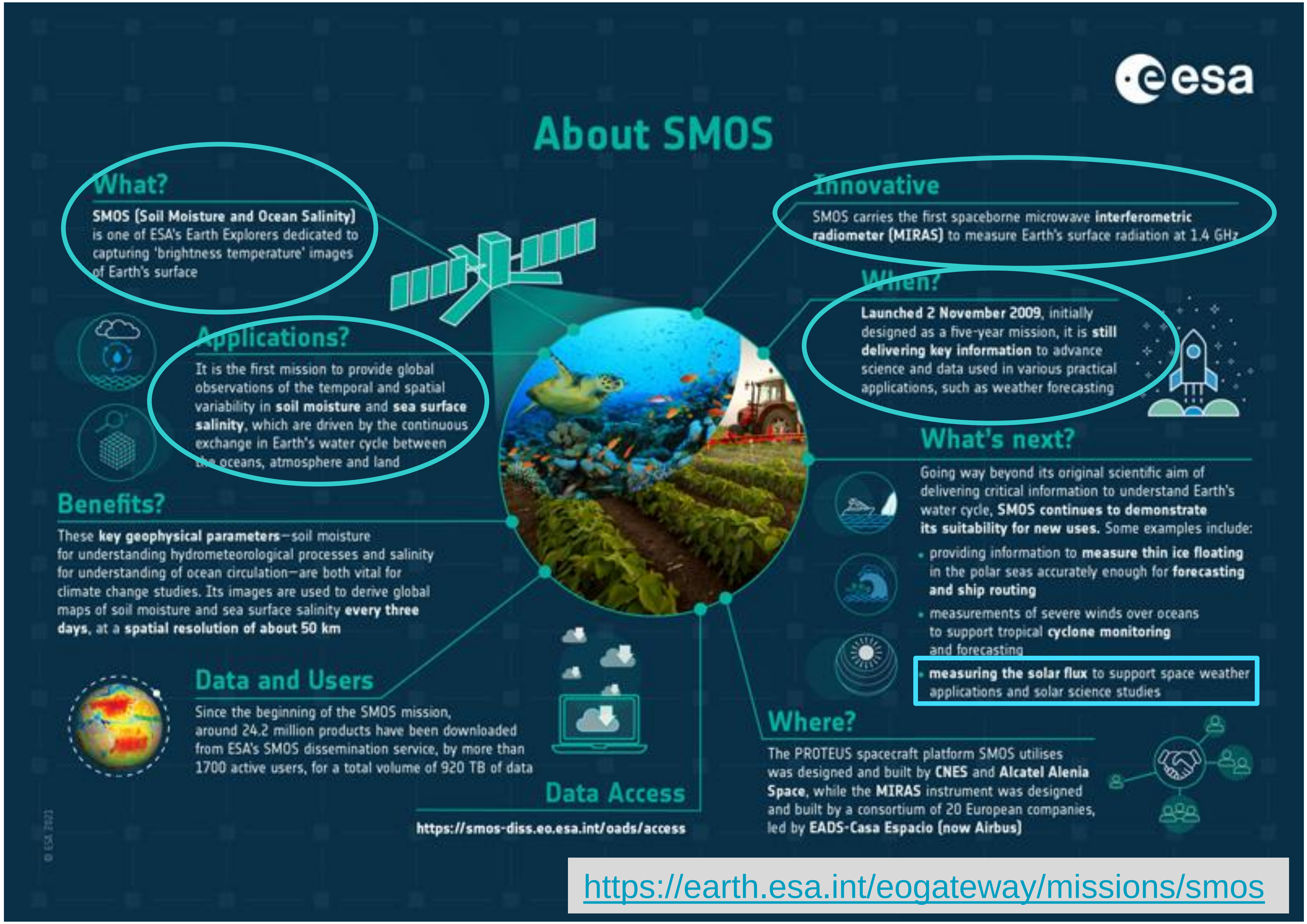
About SMOS

When: Launched in Nov. 2009

Target:
Land products
(soil moisture, Soil freeze/thaw state)
Sea products
(sea surface salinity, sea ice thickness, Sea surface wind speed)

Orbit:
sun-synchronous orbit
(dusk-dawn 6am/6pm)

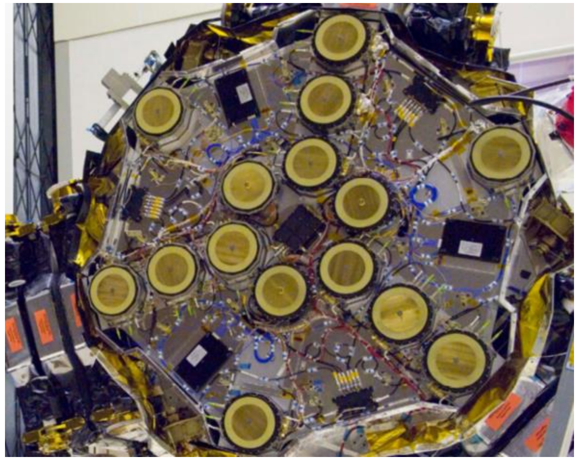
Payload:
L-band Microwave Imaging Radiometer with Aperture Synthesis (**MIRAS**)



https://earth.esa.int/eogateway/missions/smos

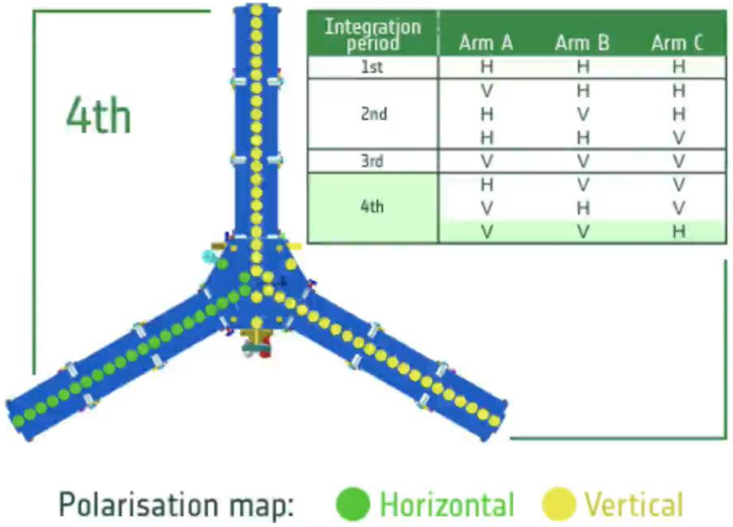
About MIRAS Instrument

Passive microwave **2-D interferometric full polarization radiometer**, operating at **1.413 GHz** (freq. wavelength 21 cm at L-band) within the protected 1400-1427 MHz band.



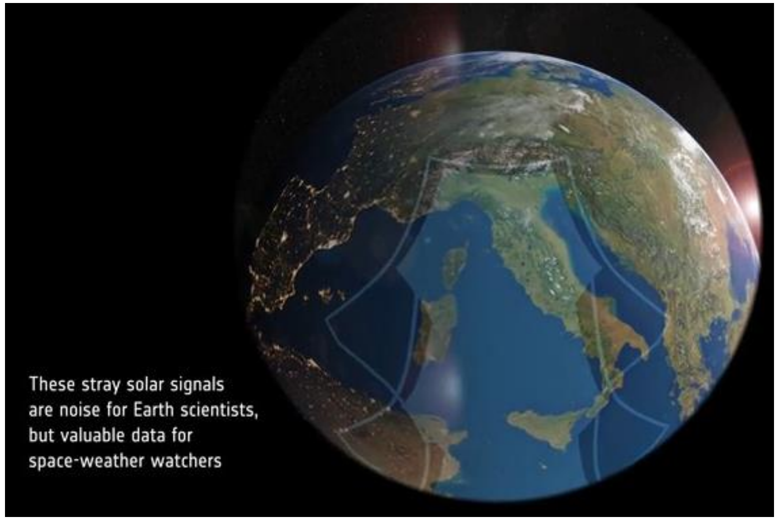
3 arms 120°apart with 23 equally spaced antennae each. Diameter 16.5 cm.

Sampling rate is 1.2 sec
A full polarimetry measurement is acquired in four integration period i.e. **4.8 seconds**.



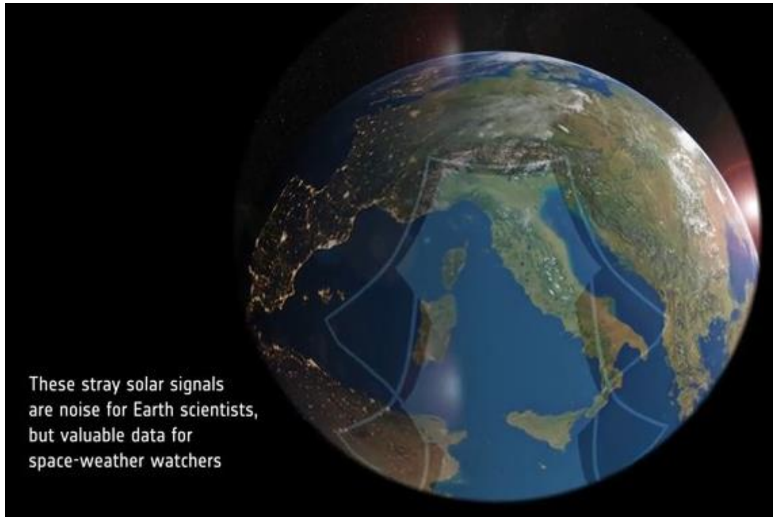
Integration period	Arm A	Arm B	Arm C
1st	H	H	H
2nd	V	H	H
	H	V	H
	H	H	V
3rd	V	V	V
4th	H	V	V
	V	H	V
	V	V	H

Due to antenna size and freq. wavelength, the instrument's field of view (FoV) is large enough to includes full Earth-disk and part of the surrounding Sky including the Sun.



About MIRAS L1B data

Due to antenna size and freq. wavelength, the instrument's field of view (FoV) is large enough to includes full Earth-disk and part of the surrounding Sky including the Sun.

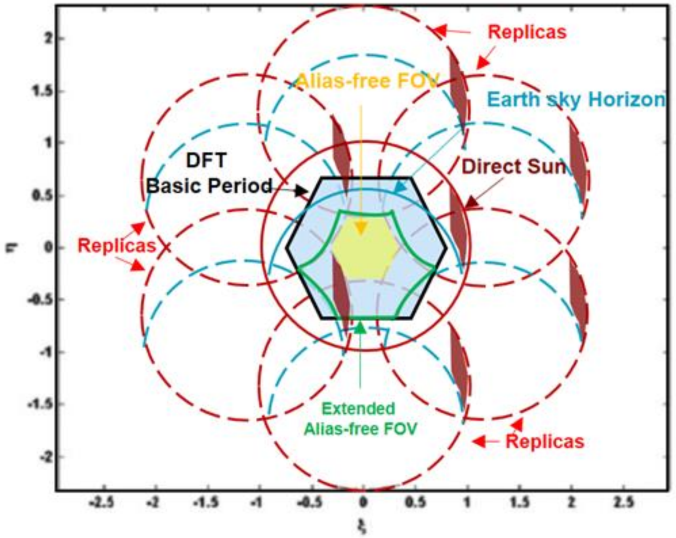


The ancillary parameters from the "Sun removal" algorithm available in the operational L1B v724 products can be used to derive the Sun Brightness Temperature for the entire Stokes vector (Sun BT)

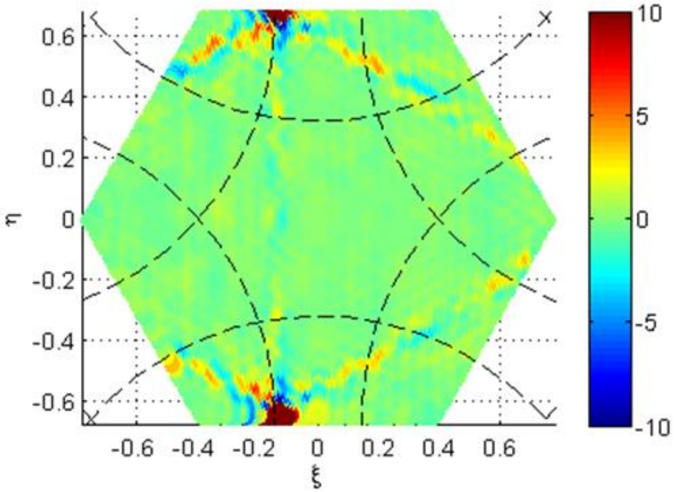
Antenna spacing is 0.875 wavelengths. Part of the FoV is affected by aliasing.

Direct Sun signal appears as a replica in the SMOS image disturbing the sensing of Earth surface emission.

This signal is "removed" by the L1 processor, the result of this removal is annotated in L1B product.



SMOS Field of view and image alias



SMOS image with Solar signal

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

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

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

LUT (Look Up Table) **Calibration**

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

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)

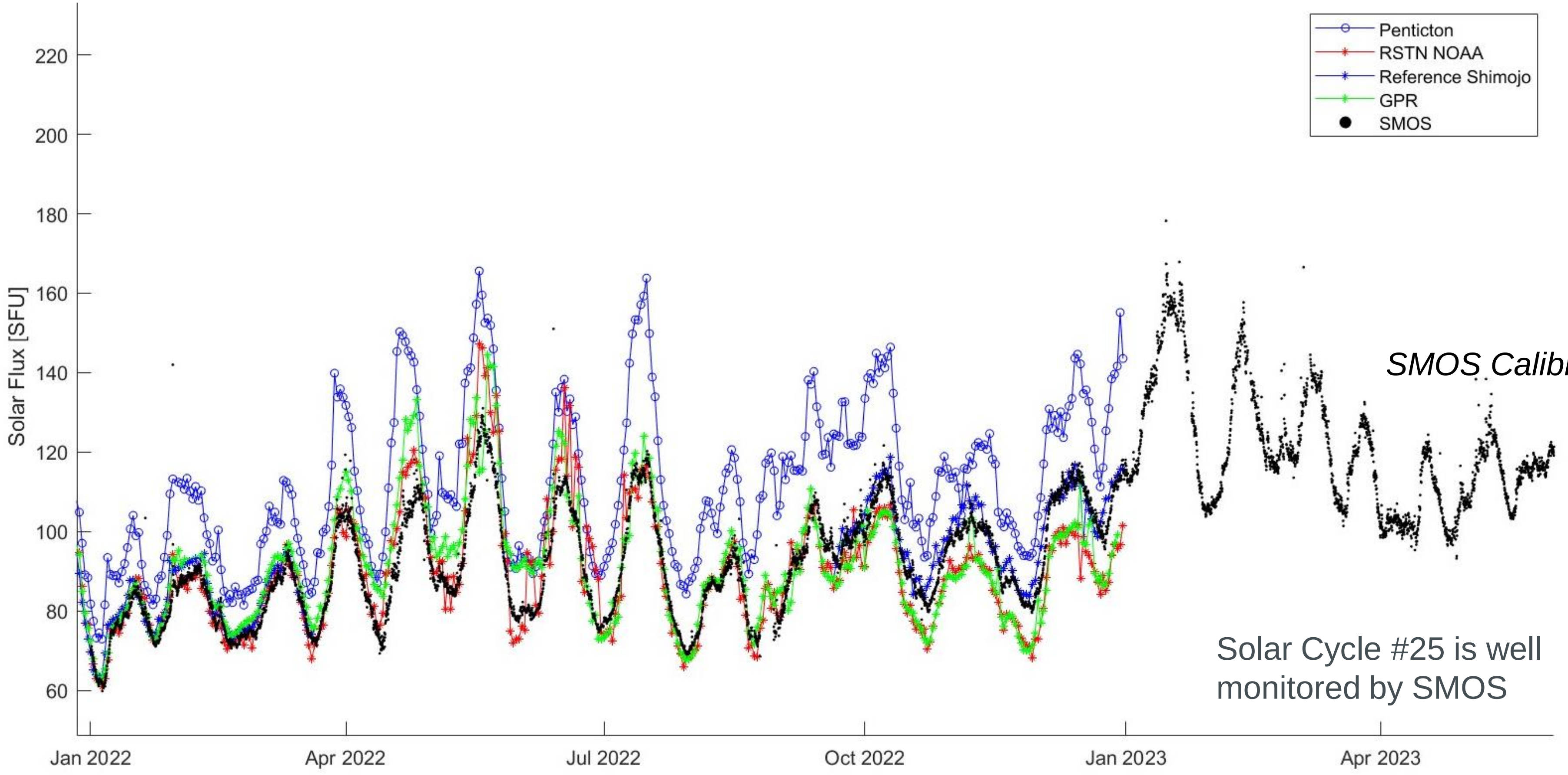
- computation of Sun BT **mean and std** on orbit basis

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**).

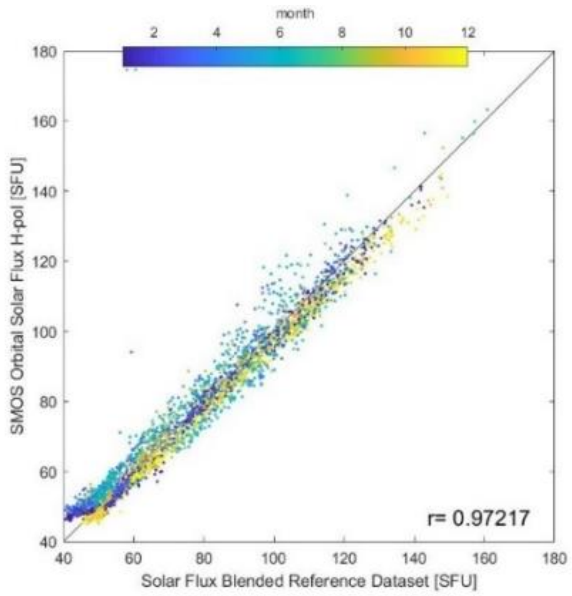
conversion from Sun BT to **Solar Flux**

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

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



SMOS Sun Flux is coherent with radio telescopes measurements



- 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**

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):

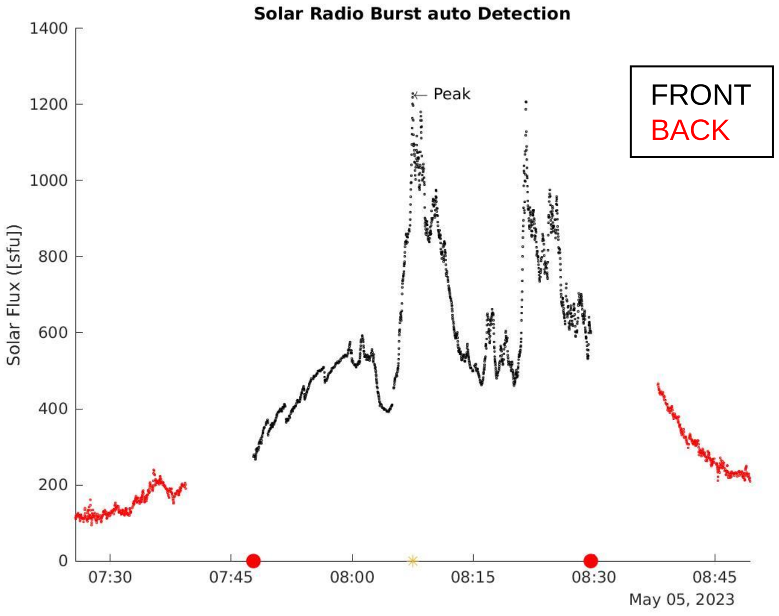
$$DoCP = {}^{V}/_{I} = -{}^{BT_4}/_{BT(Xpol) + BT(Ypol)}$$

$$-1 < DoCP < 1$$

→

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



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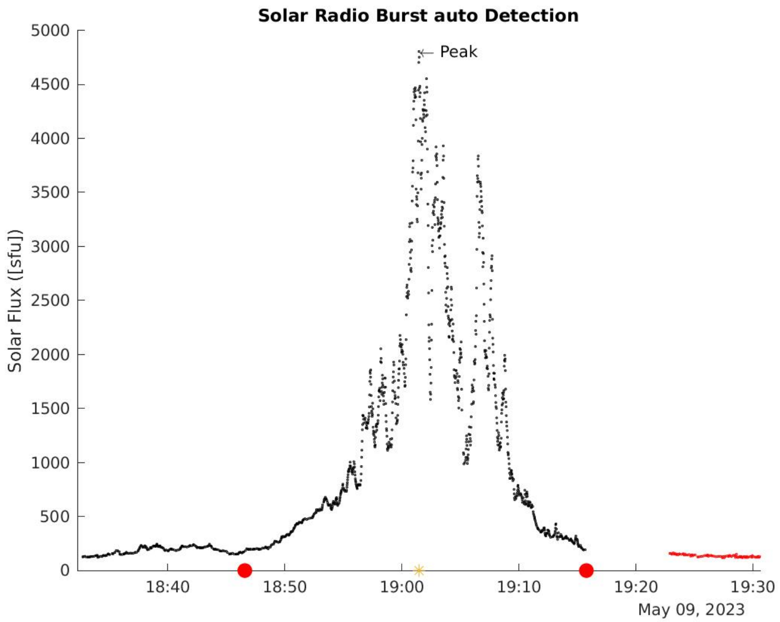
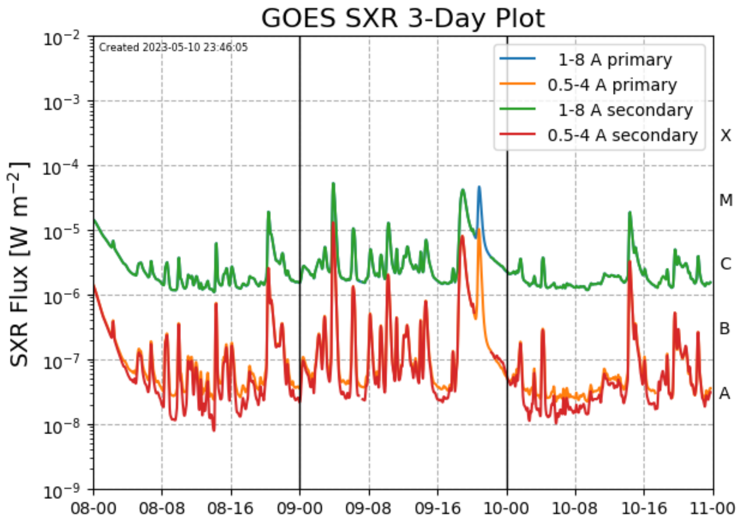
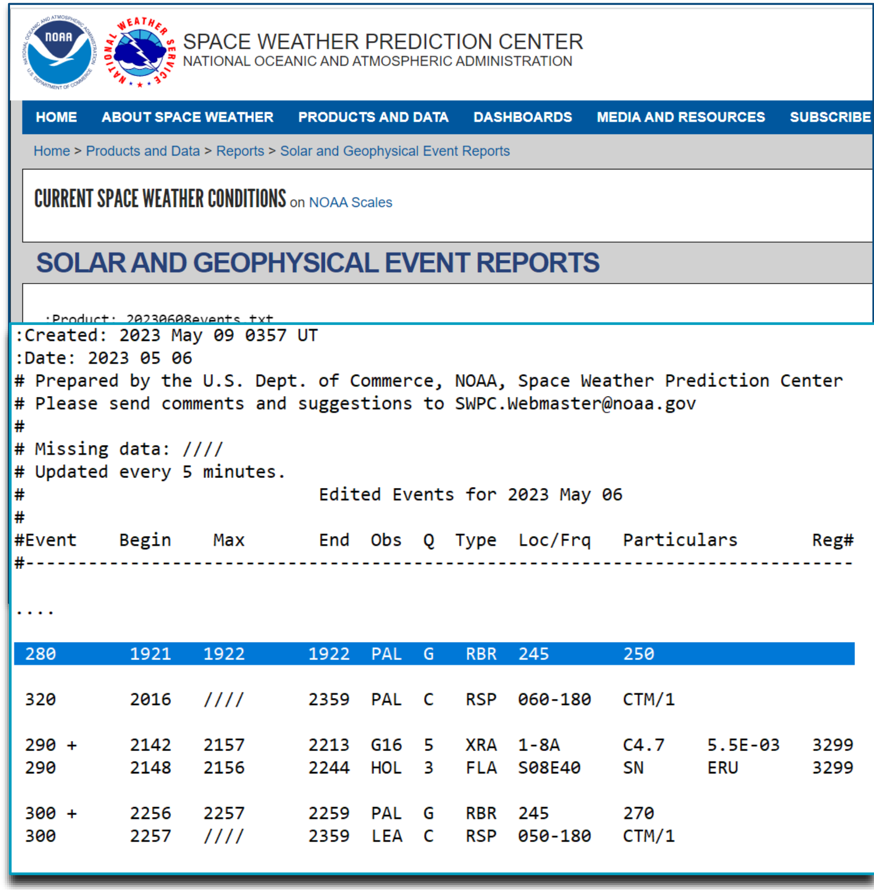
SMOS Solar Radio Burst bulletin validation





SMOS RB detection verification:

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




```
:Product: 20230608events.txt
: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
```

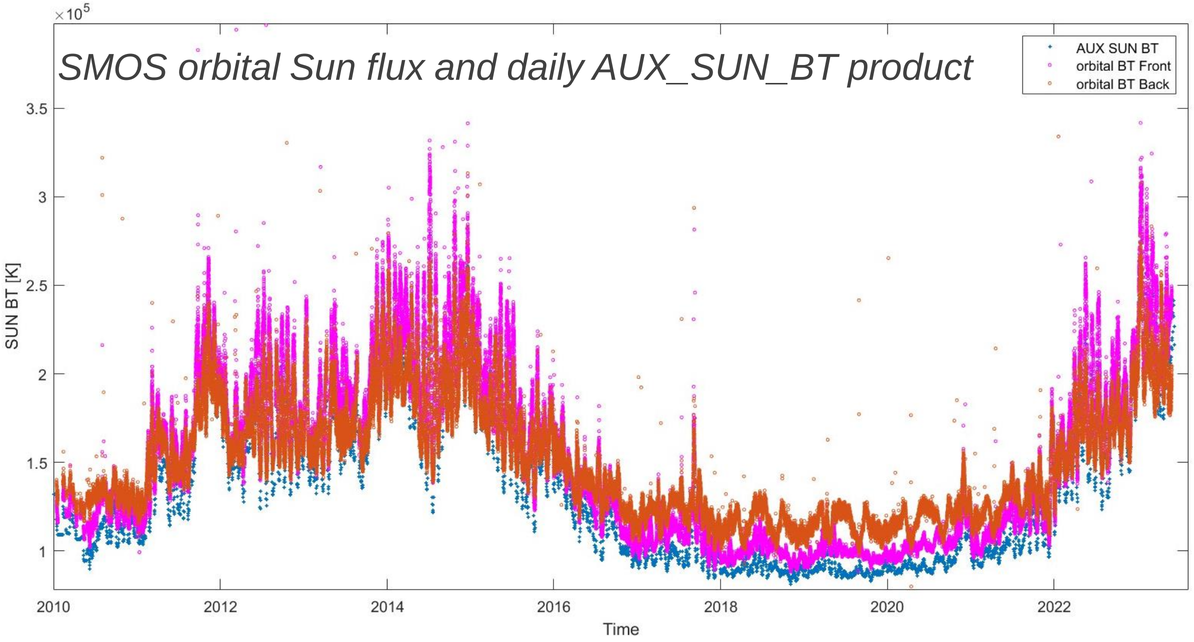
**RBR = Fixed-frequency radio burst*
RSP = Sweep-frequency radio burst

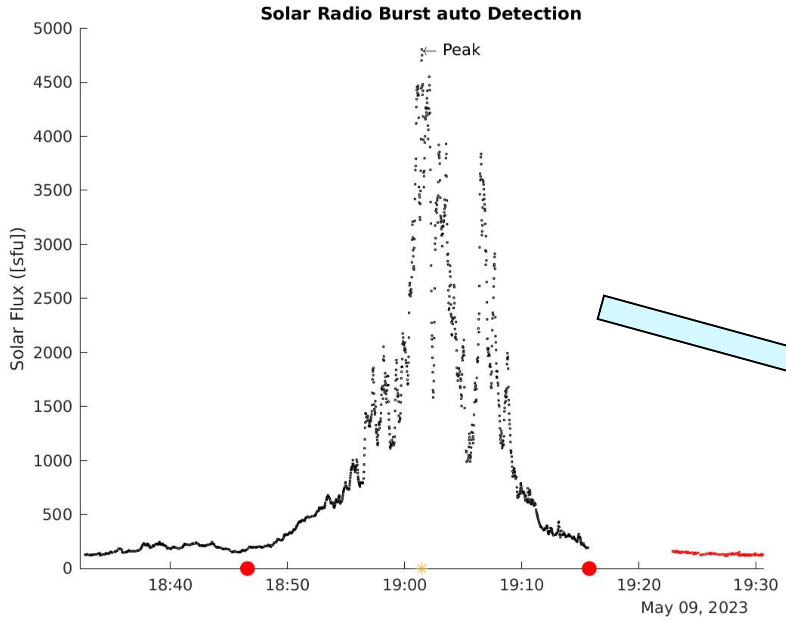
Why SMOS for Solar flux?

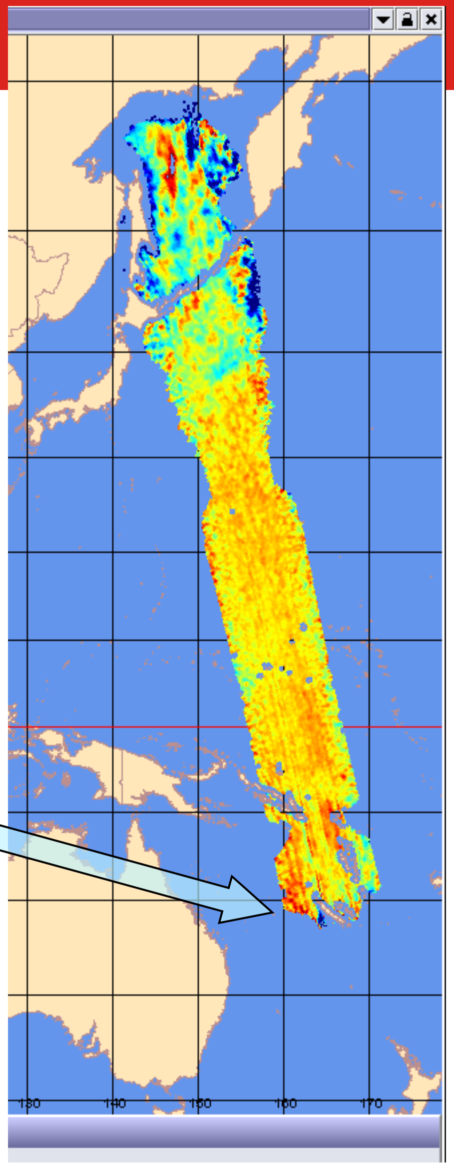
Usage of these products as input for **Earth Observation** data, e.g. SMOS L2 sea surface salinity:

A data processing algorithm is already up and running on **Serco RedLab** machine and distributed to **SMOS Data Payload Ground Segment** to use SMOS derived Sun BT Auxiliary product as **input for SMOS L2 sea surface salinity retrieval.**

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





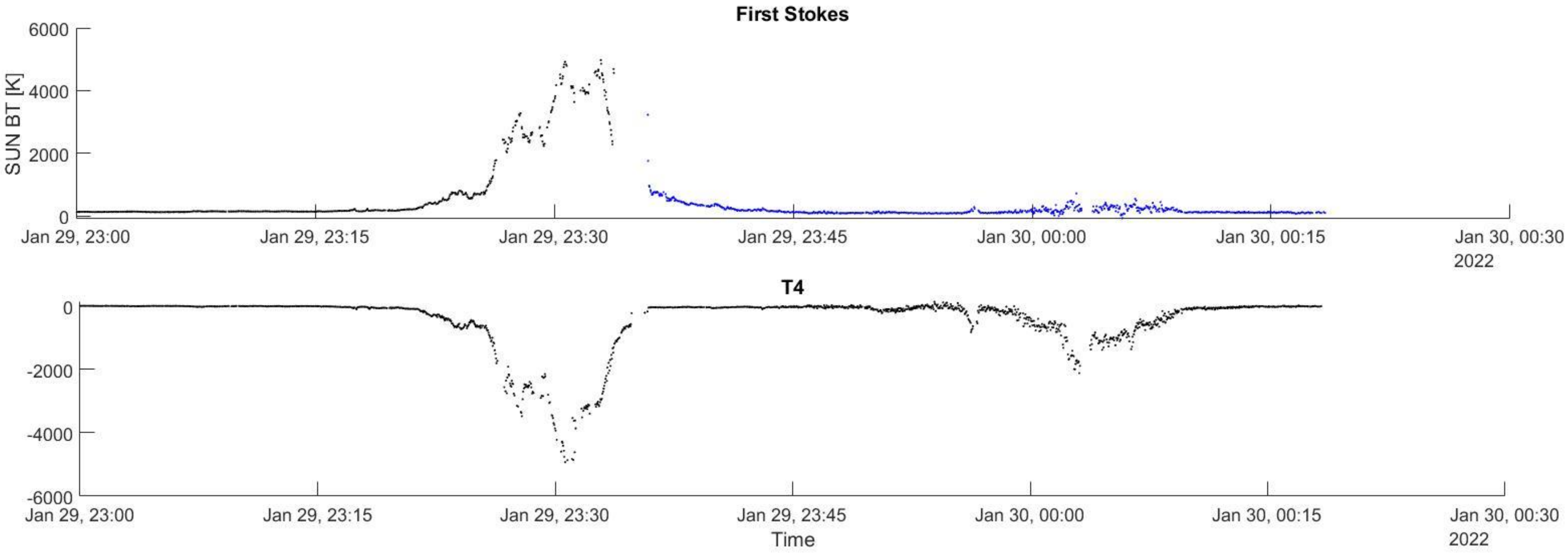


Sea Surface Salinity map during the Solar radio Burst event on 9 May 2023 – visible degradation

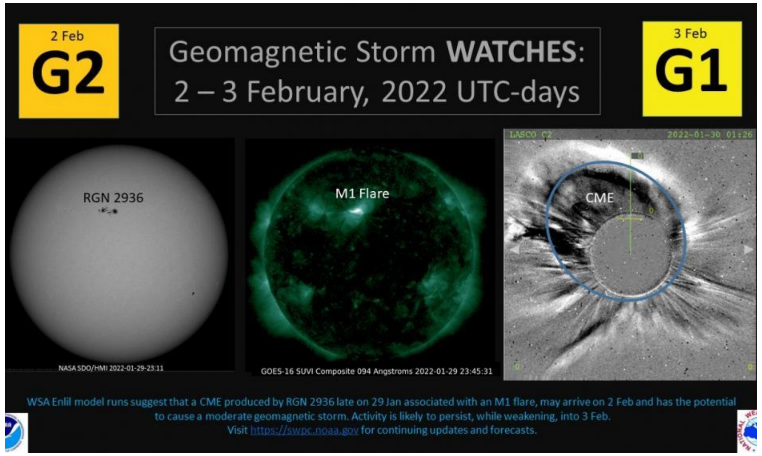
Why SMOS for Solar flux?

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

- **Long 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**:
  - Orbital aggregation: **100 minutes** → suitable for Solar cycle studies and synergies with F10.7 for **ionosphere/thermosphere modelling** (proxy of solar activity)
  - **4.8 seconds** for **Solar RB** studies and 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.



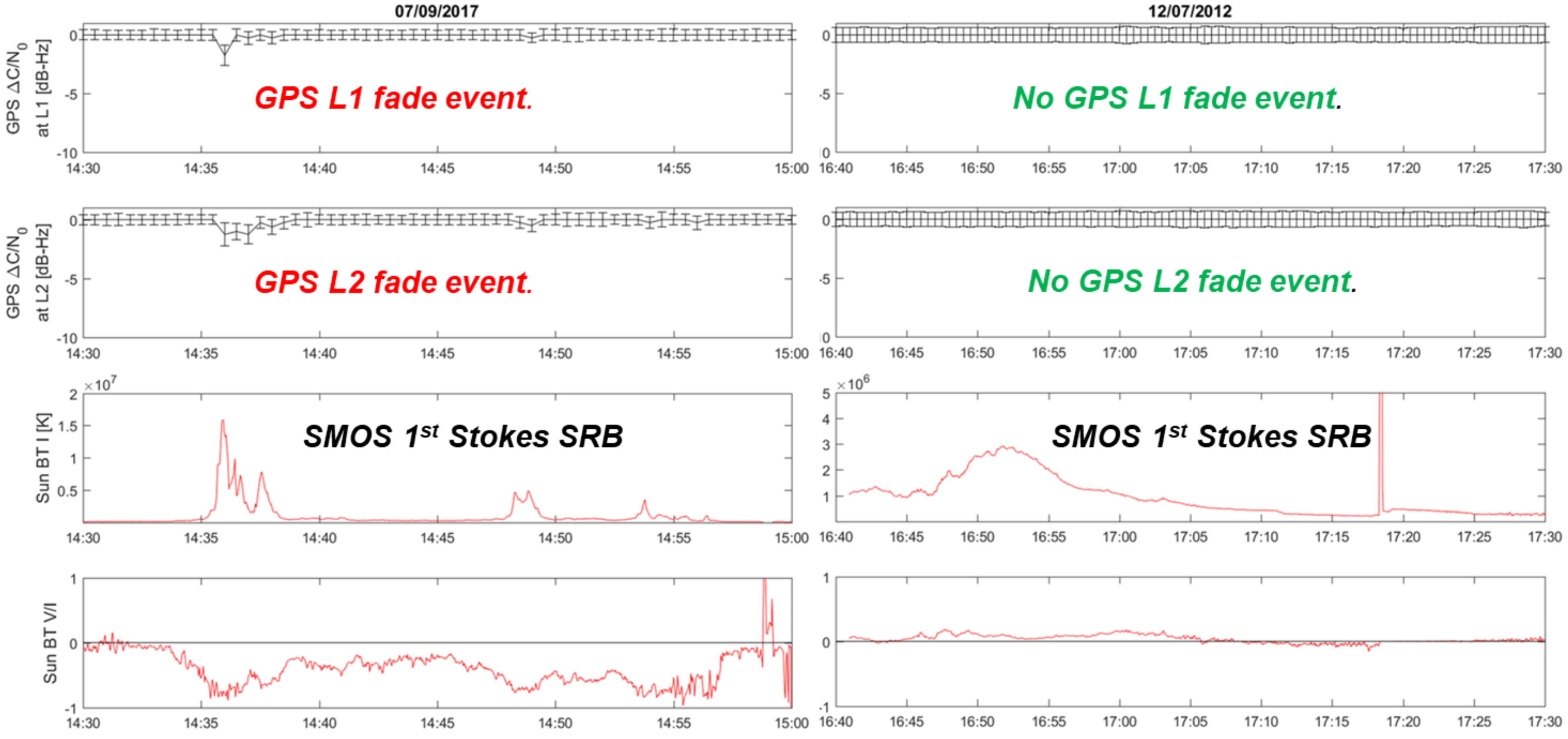
Why SMOS for Solar flux?

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

<u>Solar Flux in **L-band**</u> ⇨ Useful to estimate impact on GNSS

Polarimetric data set at L-band are useful to analyse **circular polarization in Solar Radio Burst** 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 the speed, angular width and kinetic energy of the CME is 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.

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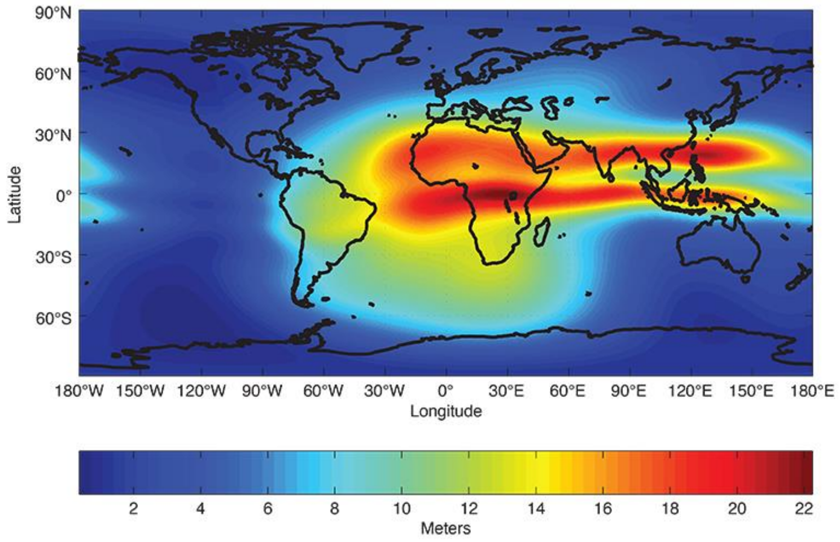
Why SMOS for Solar flux?

- 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.

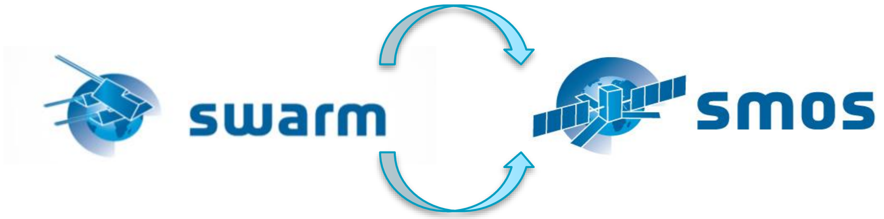
The model values depend on solar activity (given by monthly-mean sunspot number, **solar radio flux F10.7**), season and time.



*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 <u>**Swarm**</u> products

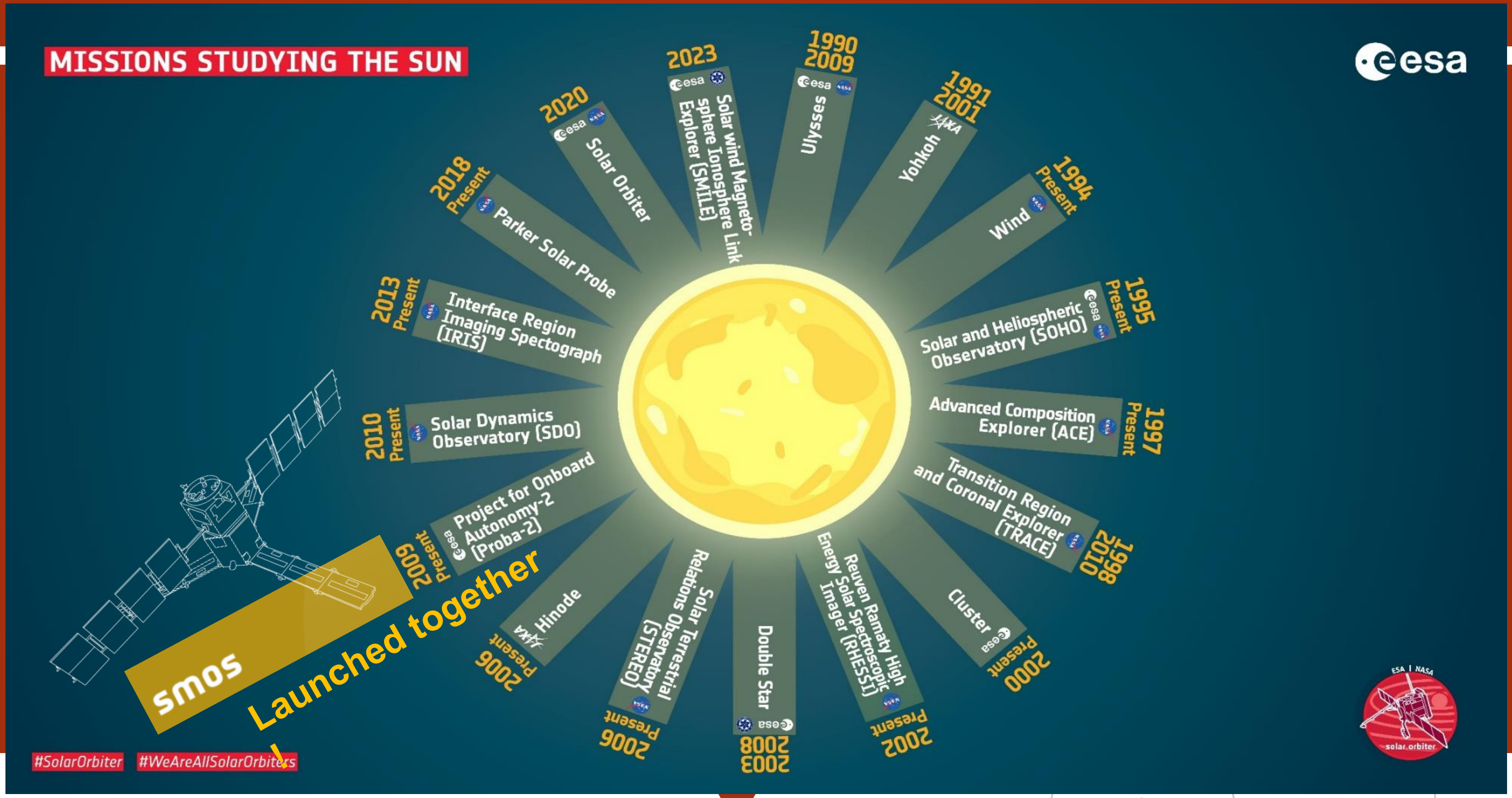


SUN_FLUX product can be used for **Swarm L2 models**:
Many of these models use F10.7 as proxy for solar EUV (main source of ionospheric ionization, and thus plasma density / conductivity in non-polar regions), with 3-months average.

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, <u>1 value per orbit</u>);
- **MIO Model** (Model of non-polar daily geomagnetic variation caused by ionospheric currents, including their variability with season and solar flux);
- Etc…

THANK YOU !



To access SMOS Solar Flux data contact:

redlab-oper@eo-sppa.org