

# Space Weather Observation related to SWARM and SMOS missions

---

Raffaele Crapolicchio and Lorenzo Trenchi

28/02/2023

ESA UNCLASSIFIED – For ESA Official Use Only





A number of potential opportunities from Earth observations satellites for Solar flux measurements  
TEC measurements  
Ionospheric irregularities measurements





earth online

MISSIONS

DATA

NEWS

EVENTS

TOOLS

SEE ALL

Satellites expand research on Space Weather and Sun-Earth Interactions

Solar Activity can cause havoc

Strength of the magnetic field at Earth's surface

News / Satellites expand research on ...

Satellites expand research on Space Weather and Sun-Earth Interactions

24 Jan 2023

Space is not a vacuum. It is full of electromagnetic radiation and charged particles and is ever-changing due to unpredictable outbursts from our Sun.

Earth observation data provide vital warnings about the impact of solar activity and strive to unravel the influence



THE EUROPEAN SPACE AGENCY

earth online

MISSIONS

DATA

NEWS

EVENTS

TOOLS

SEE ALL

SMOS data advances space weather and ionospheric research

SMOS data can detect the extent of matter expelled in solar events

Global VTEC maps

News / SMOS data advances space weath...

SMOS data advances space weather and ionospheric research

02 Dec 2022

ESA is taking steps to innovate ways to use SMOS data to support solar scientists and the space weather community, as set out in a workshop held recently in ESRIN.

The first [SMOS for Space Weather workshop](#) was attended by experts in the domain of space weather, solar interactions and the SMOS mission, to explore ways to use L-band SMOS data in space weather models and applications.

[Satellites expand research on Space Weather and Sun-Earth Interactions](#)

[SMOS data advances space weather and ionospheric research - Earth Online \(esa.int\)](#)

earth online

MISSIONS

DATA

NEWS

EVENTS

TOOLS

SEE ALL

Swarm data help estimate the impact of space weather

Poynting Flux

Effects of Space Weather

Solar storms impact u

News / Swarm data help estimate the i...

Swarm data help estimate the impact of space weather

20 Oct 2022

Energy from space weather mostly deposits itself as heat in the upper atmosphere, posing risks to satellites orbiting in the same altitude.

Recent research drawing on nearly seven years of high-resolution Swarm data, shows that the average space weather input is often underestimated.

SMOS Space Weather

November 14, 2022 @ 13:00 - 17:00 UTC+2

ESA-ESRIN



[Swarm data help estimate the impact of space weather - Earth Online \(esa.int\)](#)

[SMOS Space Weather - eo science for society \(esa.int\)](#)

# Swarm – magnetic field explorer

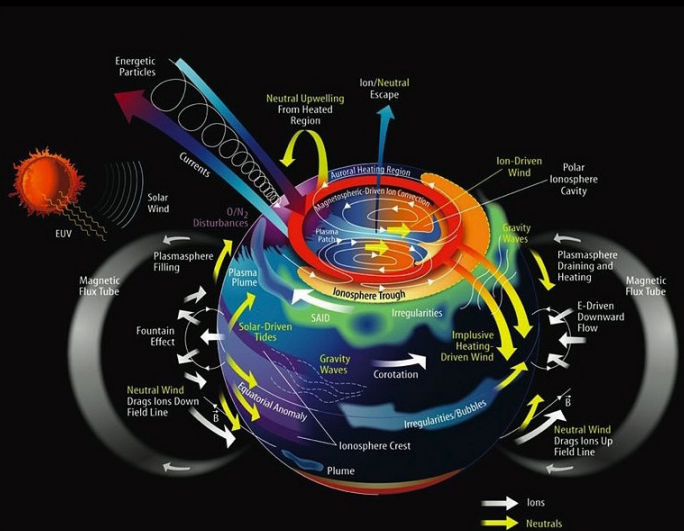
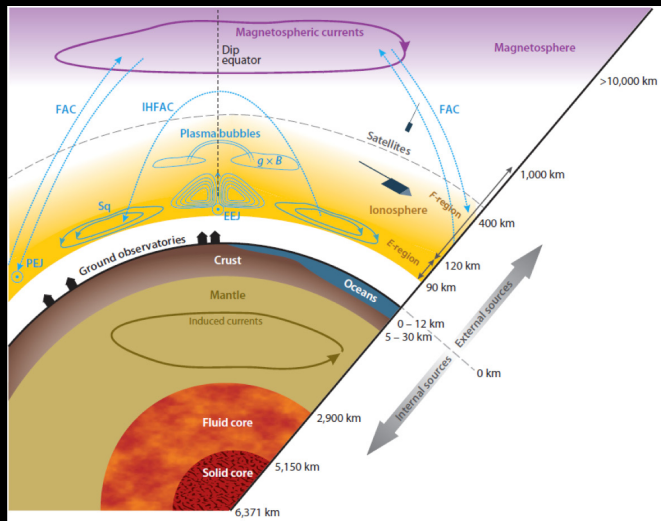
Launched in November 2013 into near polar orbit between 462 and 511 km altitude

To measure the magnetic signal that stem from Earth's core, mantle, crust, oceans, ionosphere and magnetosphere

3 identical spacecraft, 6 instruments on each including:

- magnetic and electric field measurements
- electron and ion measurements
- accelerometer

In March 2018, the CASSIOPE/e-POP mission was integrated into the Swarm constellation as Swarm-E.



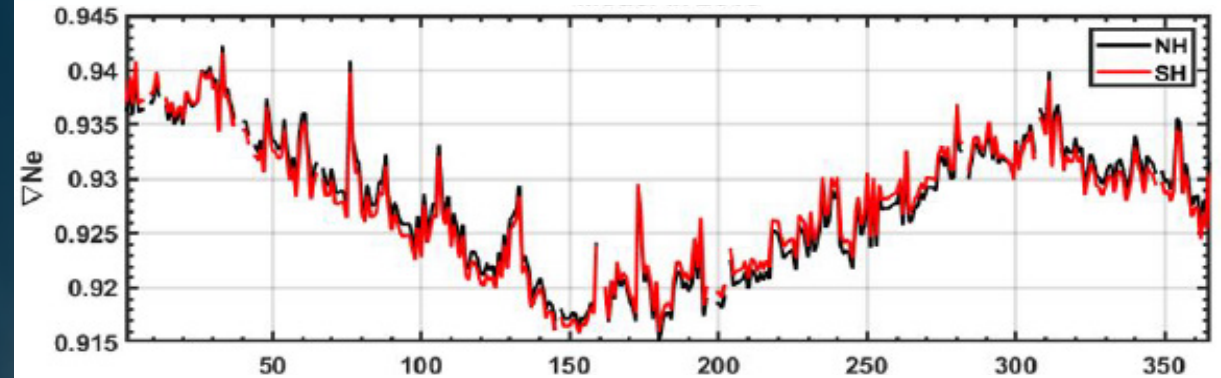


Swarm VIP-project developed a **new empirical model for ionospheric irregularities** as a function of Solar wind and Interplanetary Magnetic Field conditions.

Previous ionospheric models don't include small scales fluctuations, fundamental component of the ionosphere that can cause disturbances in GNSS signals.

The new Swarm based empirical model shows a **significant improvement** in describing small scales electron density irregularities respect to existing models (e.g. TIEGCM) **at polar, auroral and mid-latitude sectors**.

Density gradients from Swarm empirical model – year 2015



Density gradients from Swarm data – year 2015

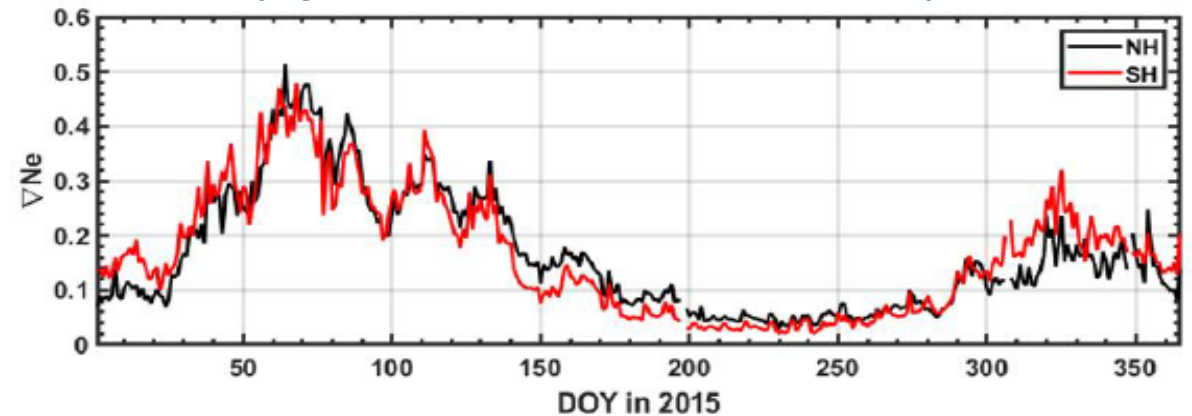


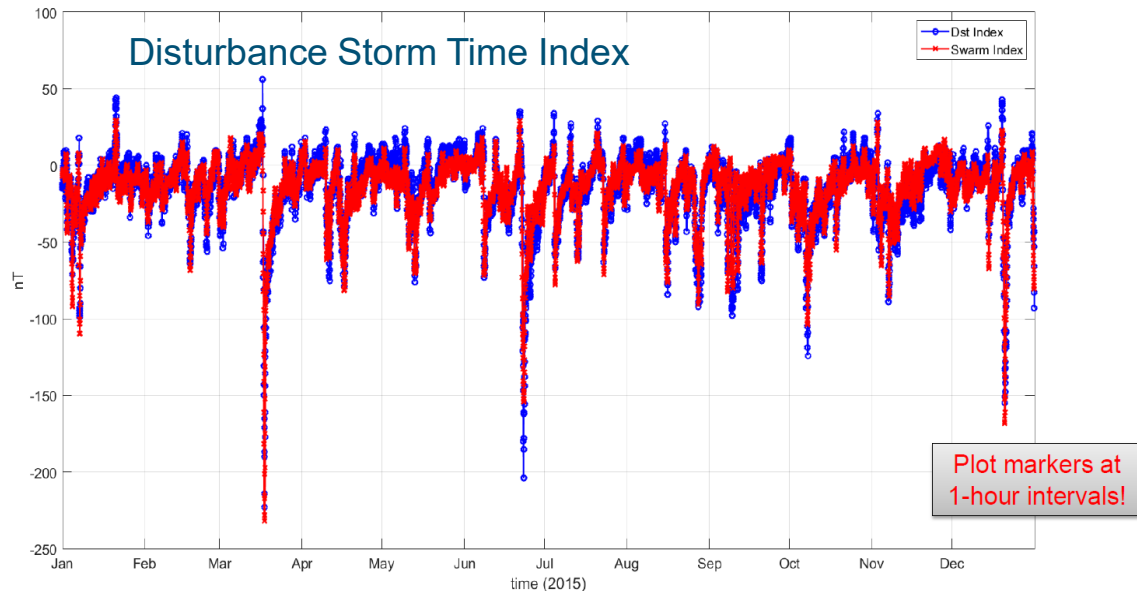
Figure 4.3.8: The modeled density gradients and daily averaged density gradients at mid-latitudes for ascending orbits of Swarm A.

## New geomagnetic indexes based on Swarm data:

- very good correspondence with standard indexes
- **Swarm-AE** covers the **two hemispheres with the same accuracy** => suitable to investigate asymmetries

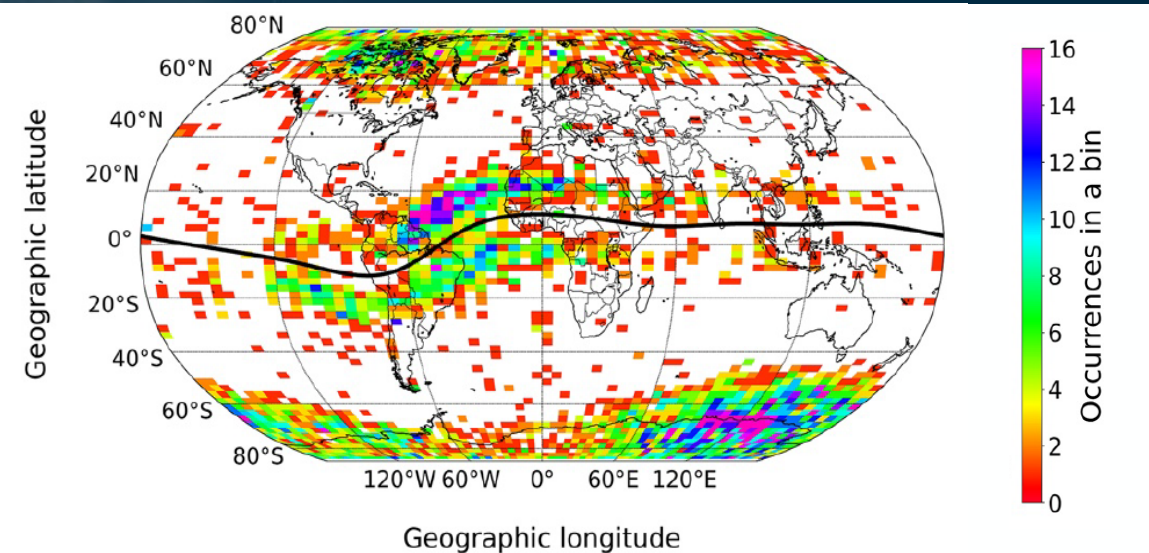
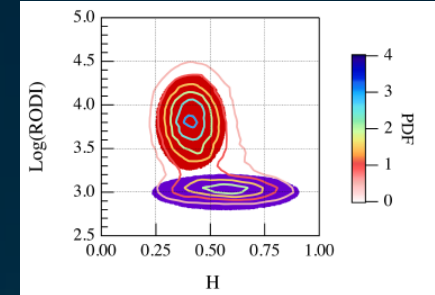
### Dst-like Index From Swarm Data

After Linear Transform



## Ionospheric turbulence and GPS loss of lock

- **Two families of irregularities**, different values of RODI (electron density irregularity index)
- **GPS loss of lock** in association with **high RODI fluctuations** ( $>3$ ), probably due to mesoscale plasma density enhancements (De Michelis+ 2022)

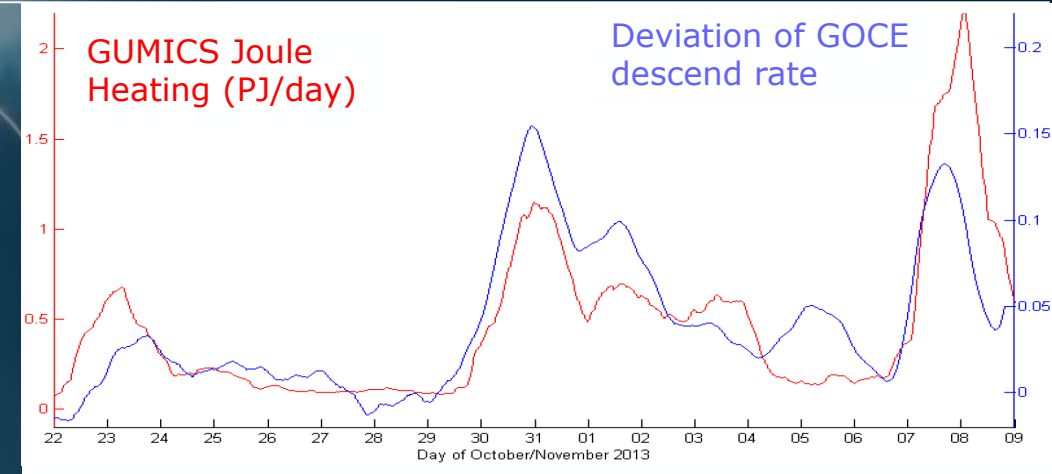




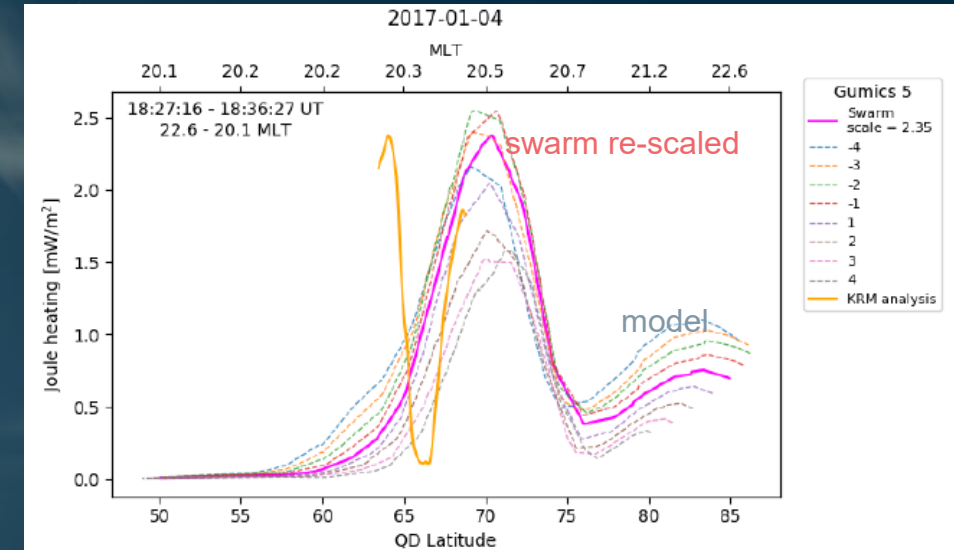
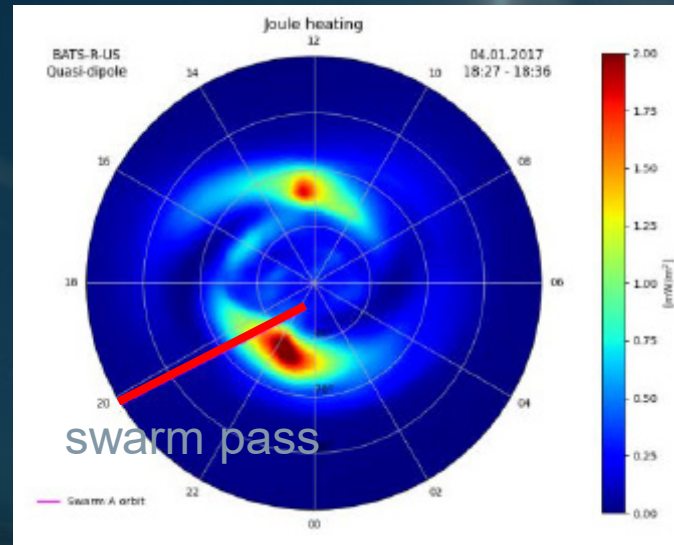
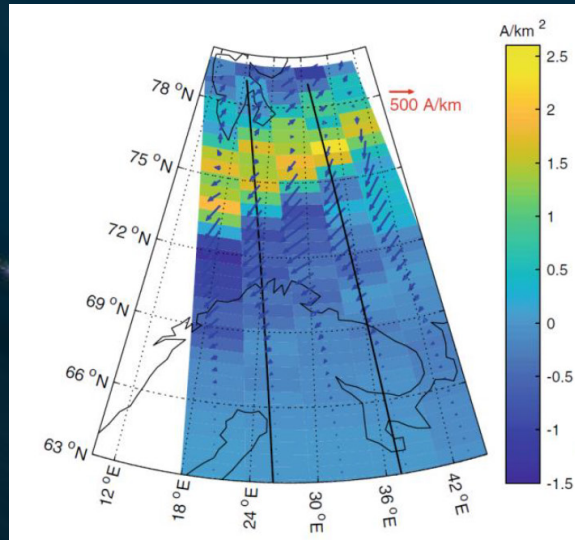
# Swarm - SIFACIT project

Phase2 of SIFACIT-project focussed on **Joule heating in the E-layer ionosphere** due to currents flowing at auroral latitudes.

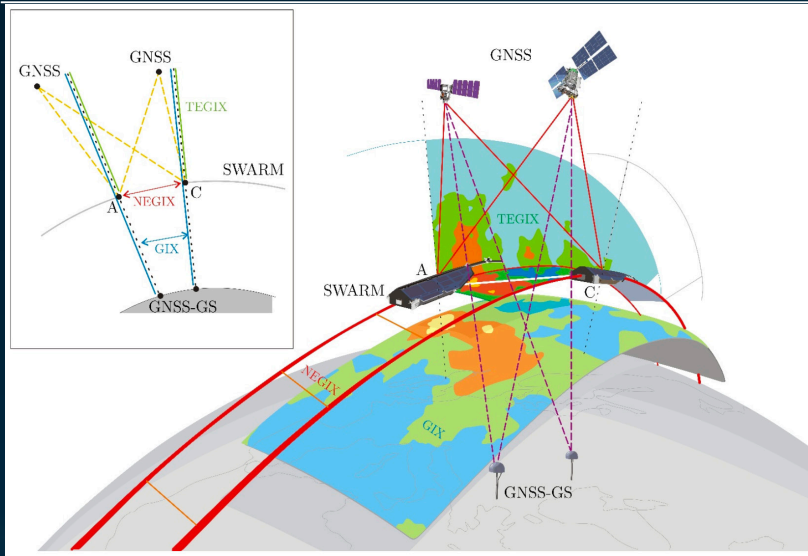
Joule heating is caused mostly by collisions between charged particles and neutrals, and it changes the scale height of the atmosphere, with a significant impact on satellites motion.



SIFACIT studied **JH at various spatial scales**: Swarm data + simulations to validate the values from GUMICS5

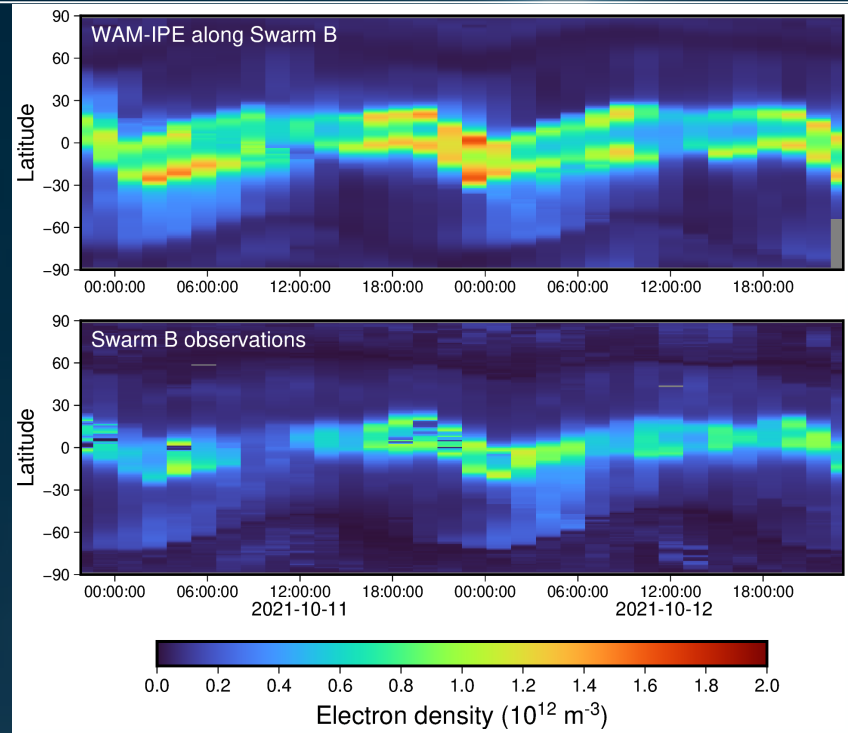


# Swarm Space Weather projects: 3 DISC projects kicked off in 2022



**MIGRAS** - Two new Swarm products to monitor the Ionosphere:

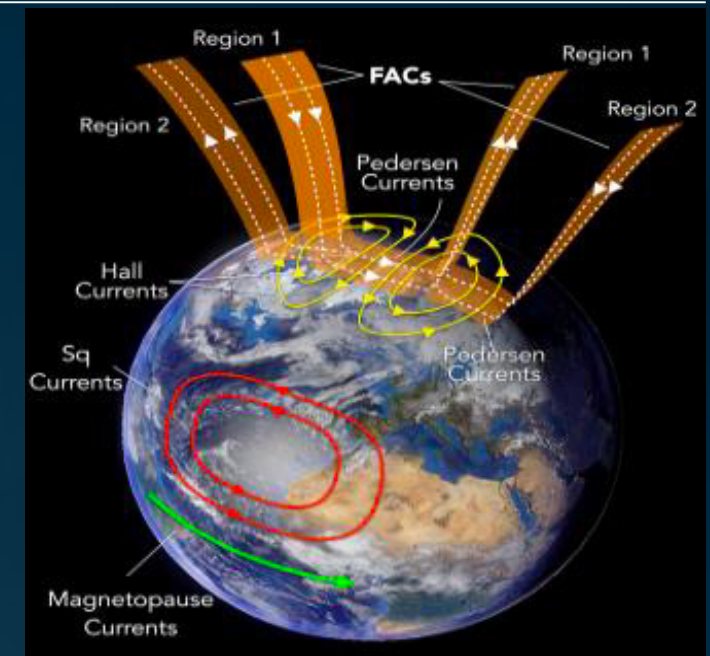
- NEGIX: Spatial Electron density gradients Product
- TEGIX: Spatial TEC gradients Product



**SWITCH** - Combining Swarm data with nowcast/forecast models:

Comparison of Swarm electron density Vs NOAA WAM-IPE for model validation

The next step is to improve the model using data assimilation.



**SWESMAG** – A new current sheet Swarm index to be cross compared with ground-based observations to examine the space weather effect related to Geomagnetic Induced Currents (GIC).



# smos

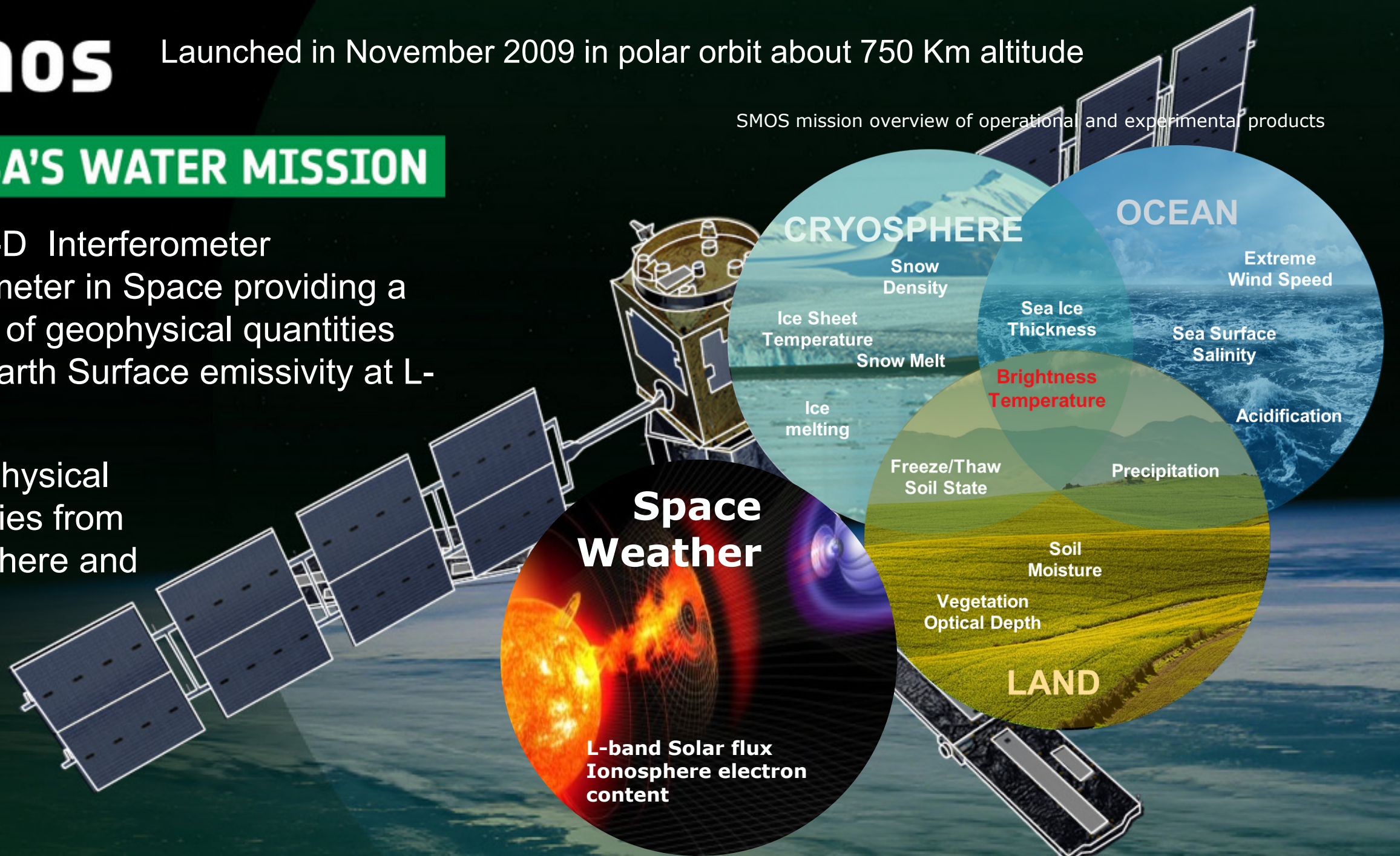
Launched in November 2009 in polar orbit about 750 Km altitude

## → ESA'S WATER MISSION

First 2-D Interferometer Radiometer in Space providing a variety of geophysical quantities from Earth Surface emissivity at L-band

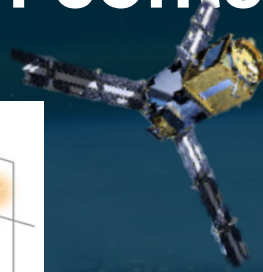
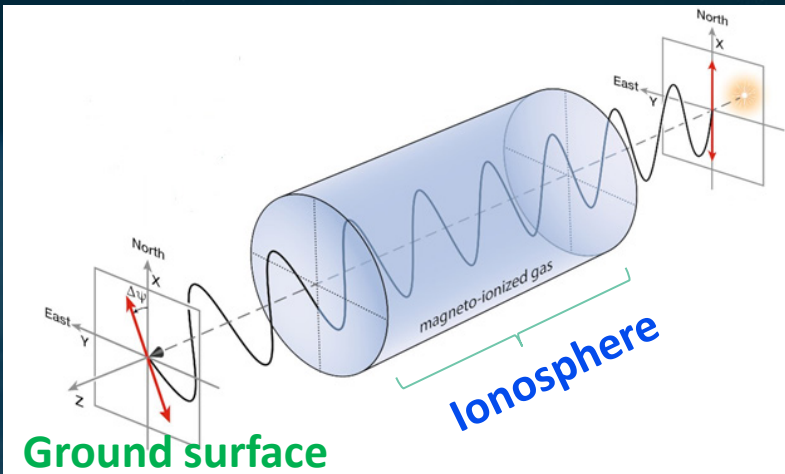
+ geophysical quantities from Ionosphere and Sun

SMOS mission overview of operational and experimental products





# Ionosphere electron content



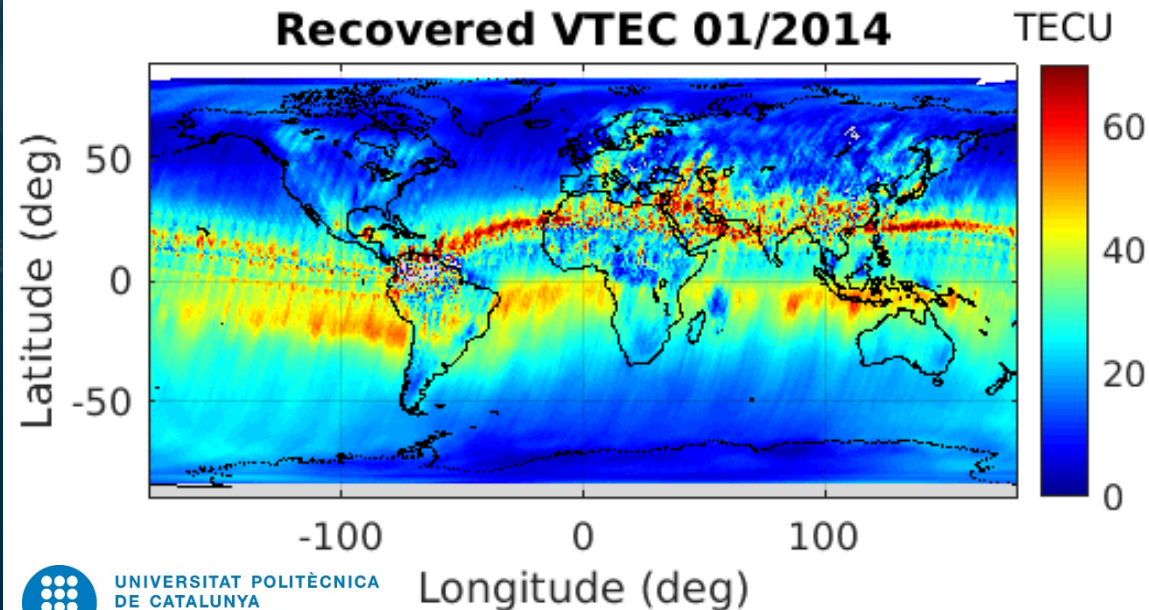
$$\Omega_f = 1.355 * 10^4 * f^{-2} * B_0 * \cos \Theta_B * \sec \theta * VTEC$$

[Yueh, S.H., TGRS 2000]

$$\Omega_f = -\varphi_g - \frac{1}{2} \tan^{-1} \left( \frac{2\Re(T_B^{xy})}{T_B^{xx} - T_B^{yy}} \right) \quad \text{Considering } T_B^{hv} = T_B^{vh} = 0$$

$T_B^{pq}$ : Polarimetric Brightness Temperatures       $\varphi_g$ : geometrical rotation angle

Recovered VTEC 01/2014

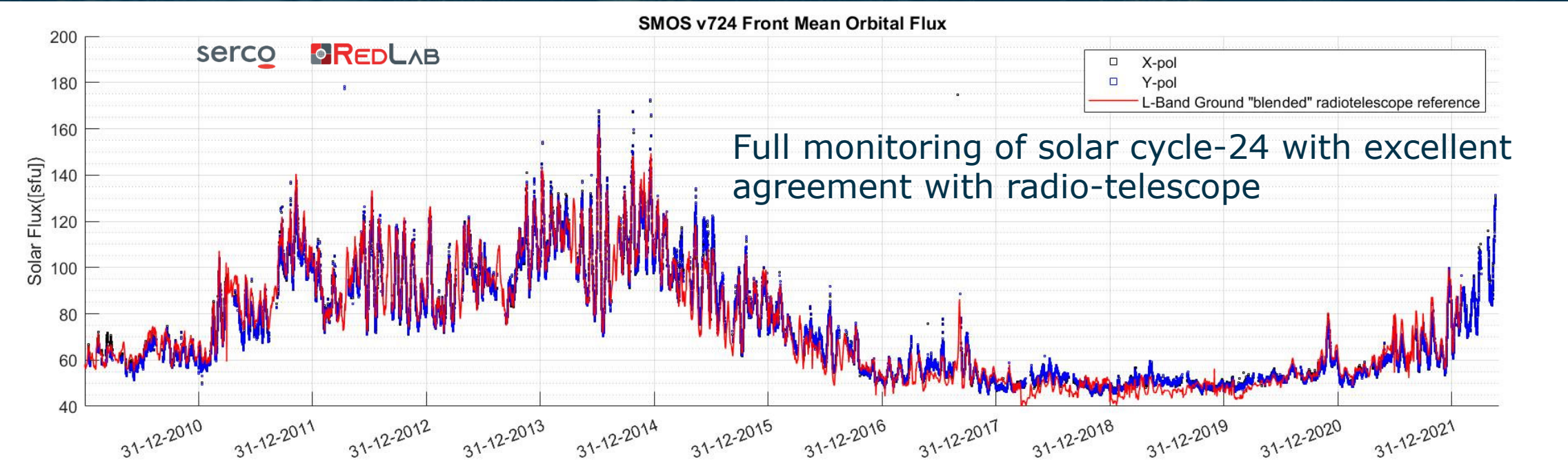
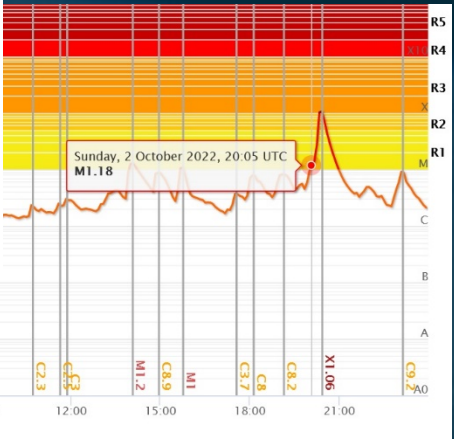
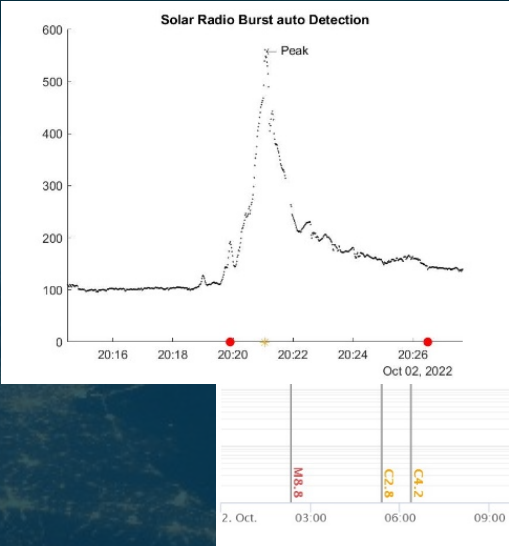
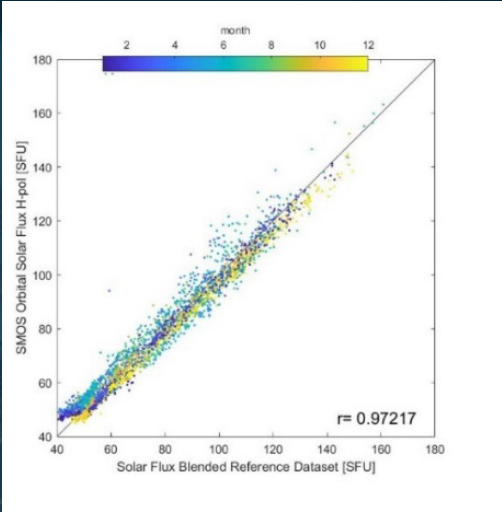
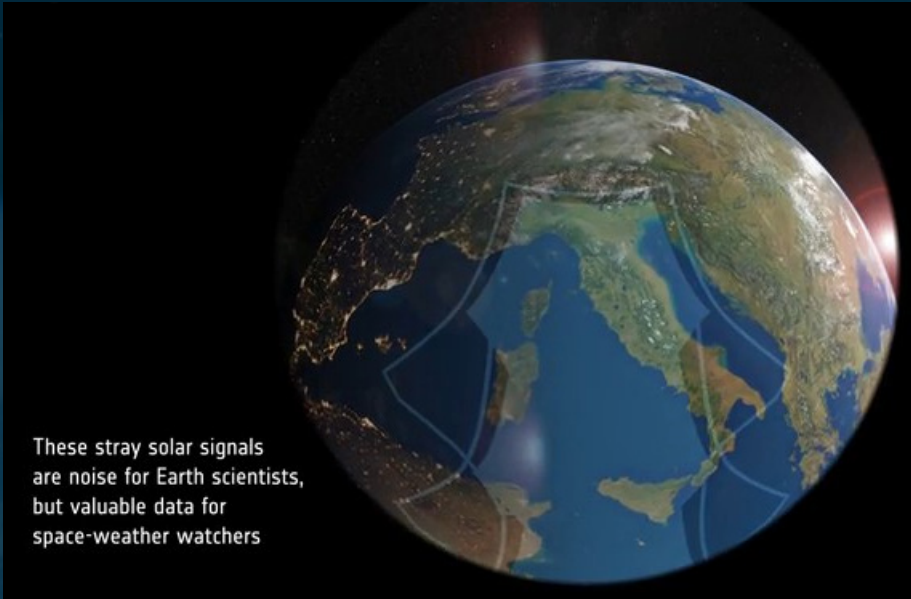


SMOS VTEC can fill on-ground observations gaps in particular over Sea Surface and improve TEC modelling and forecast

SMOS VTEC under validation by DLR, comparison with SWARM TEC by SWARM-DISC experts is on-going



# L-band Solar flux and Solar radio burst

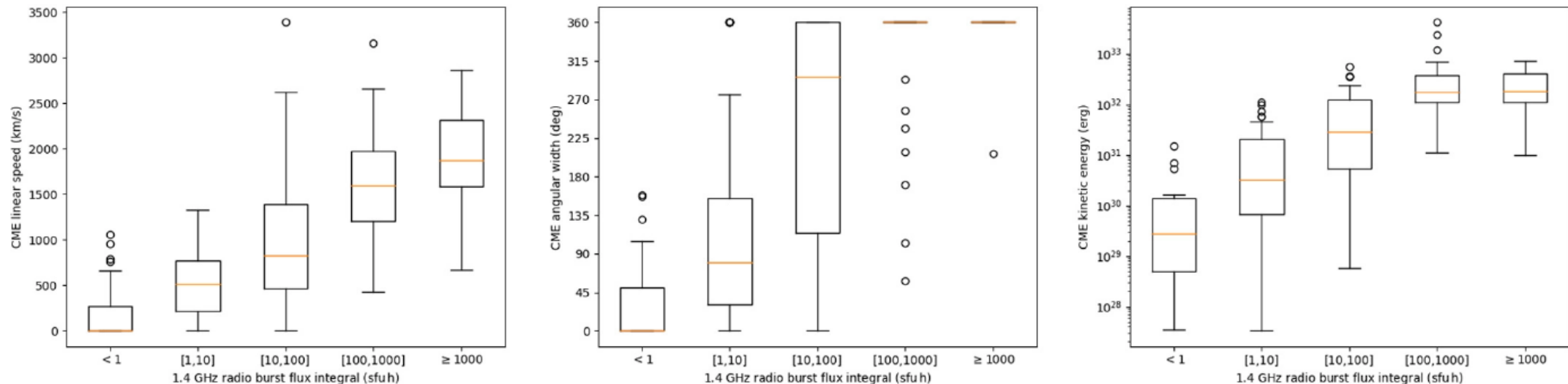


## Monitoring of CME occurrence

Almost every flare with a 1.4 GHz SRB is related to a CME

The amount of flux released at 1.4 GHz correlates with the speed, angular width and kinetic energy of the CMEs

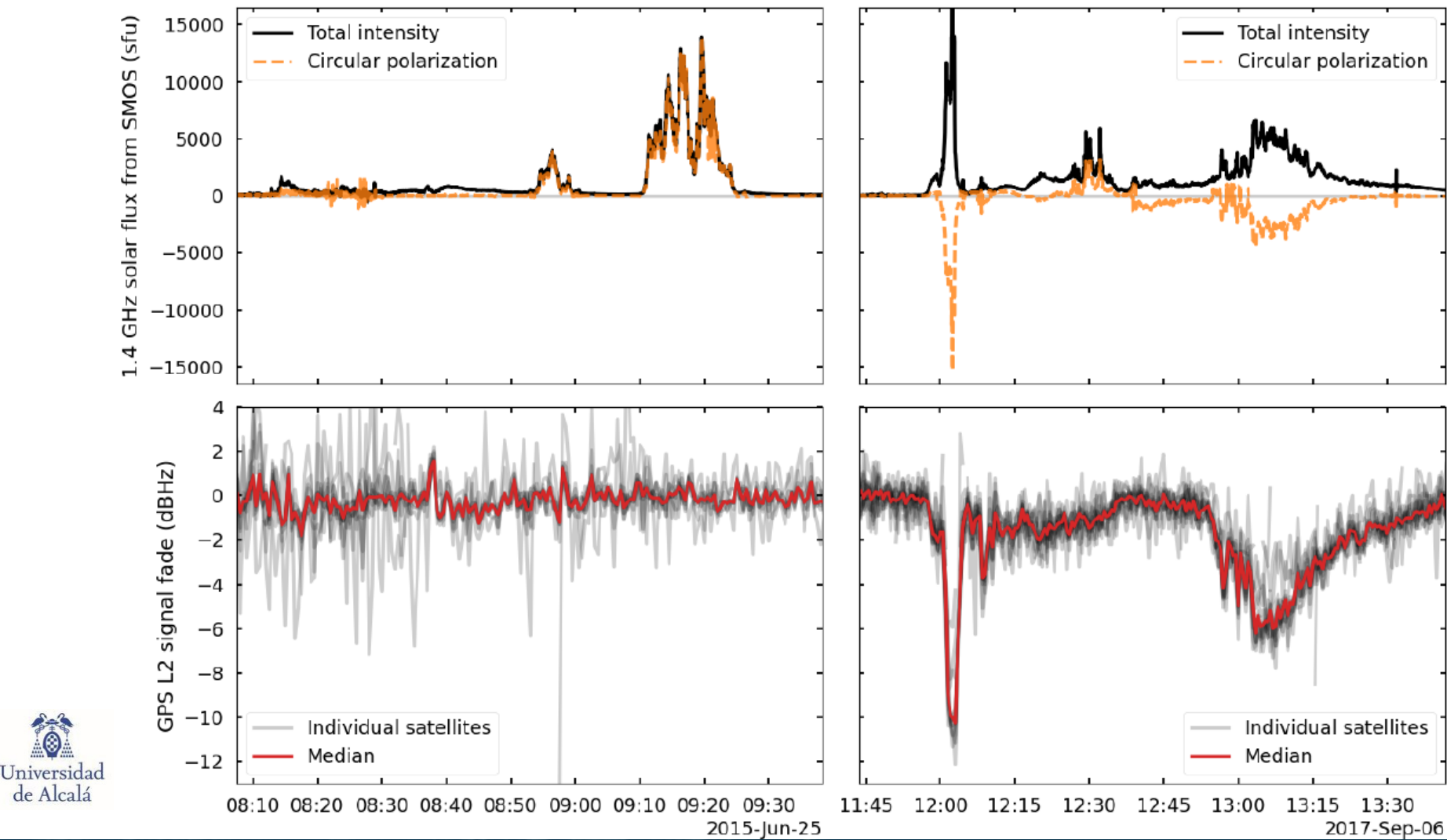
It seems a unique features of the frequency around the L-band !



Flores-Soriano et al. (2021). <https://doi.org/10.1029/2020SW002649>  
CME data from [https://cdaw.gsfc.nasa.gov/CME\\_list/](https://cdaw.gsfc.nasa.gov/CME_list/)



## Importance of SRB polarization



## How good?

Several studies have demonstrated new emerging Space Weather applications for ESA Earth Explorer Missions: SWARM and SMOS

New geomagnetic index's have been derived based on SWARM dataset: Electron density irregular index, Disturbance Storm Time index, Joule Heating

New Products are under development from SWARM Mission: Spatial electron density gradient, Spatial TEC gradients, Current sheet index

New prototype products have been derived based on SMOS dataset: L-band Solar flux, Solar Radio Burst bulletin, VTEC

## What for?

Full coverage measurements, Near real time (SWARM soon) -> Space Weather monitoring, long time series -> post event analysis

Uniqueness of SMOS polarimetry sensor for: Solar Radio burst and CME study, Identification of GPS anomalies

Many thanks for your attention

Point of Contact: [Raffaele.Crapolicchio@esa.int](mailto:Raffaele.Crapolicchio@esa.int)