ESA microwave activities - GSICS 2022 report

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ESA ESRIN

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- SMOS Mission status
- SMOS Validation platforms
- SMOS – SMAP intercomparison
- DOMEX experiment
- Technology developments for SMOS follow-on
- RFI activities and reporting
- CIRM status
- Conclusion
- Acknowledge

About SMOS (2009 ->)

What?

SMOS (Soil Moisture and Ocean Salinity) is one of ESA's Earth Explorers dedicated to capturing 'brightness temperature' images of Earth's surface

Innovative

SMOS carries the first spaceborne microwave **interferometric radiometer (MIRAS)** to measure Earth's surface radiation at 1.4 GHz

Applications?

It is the first mission to provide global observations of the temporal and spatial variability in **soil moisture** and **sea surface salinity**, which are driven by the continuous exchange in Earth's water cycle between the oceans, atmosphere and land

When?

Launched 2 November 2009, initially designed as a five-year mission, it is **still delivering key information** to advance science and data used in various practical applications, such as weather forecasting

Benefits?

These **key geophysical parameters**—soil moisture for understanding hydrometeorological processes and salinity for understanding of ocean circulation—are both vital for climate change studies. Its images are used to derive global maps of soil moisture and sea surface salinity **every three days**, at a **spatial resolution of about 50 km**

What's next?

Going way beyond its original scientific aim of delivering critical information to understand Earth's water cycle, **SMOS continues to demonstrate its suitability for new uses.** Some examples include:

- providing information to **measure thin ice floating** in the polar seas accurately enough for **forecasting and ship routing**
- measurements of severe winds over oceans to support tropical **cyclone monitoring** and forecasting
- **measuring the solar flux** to support space weather applications and solar science studies

Data and Users

Since the beginning of the SMOS mission, around 24.2 million products have been downloaded from ESA's SMOS dissemination service, by more than 1700 active users, for a total volume of 920 TB of data

Data Access

https://smos-diss.eo.esa.int/oads/access

Where?

The PROTEUS spacecraft platform SMOS utilises was designed and built by **CNES** and **Alcatel Alenia Space**, while the **MIRAS** instrument was designed and built by a consortium of 20 European companies, led by **EADS-Casa Espacio (now Airbus)**

ESA 2021

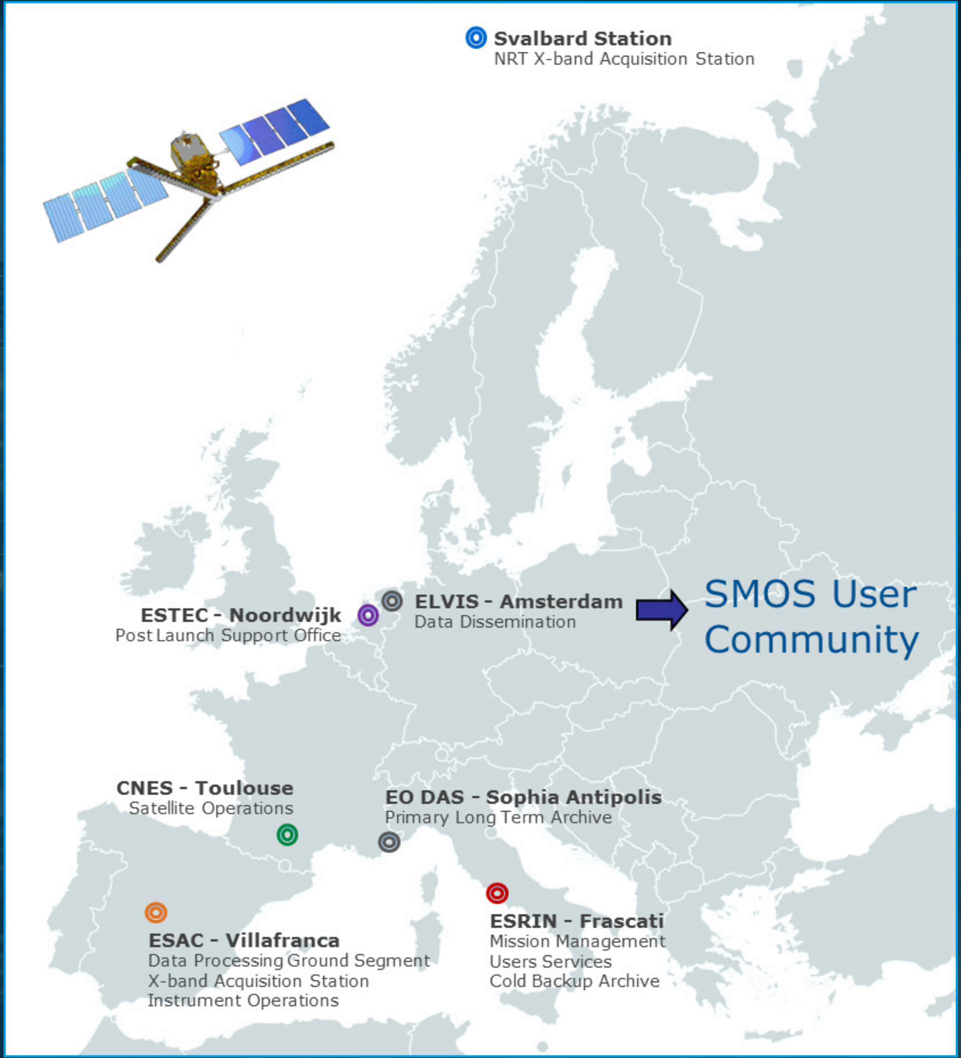
SMOS Payload status

1. After almost 12 years of mission, MIRAS still remains in very good shape.
2. All housekeeping telemetry parameters remain very well within limits.
3. Payload operations are very smooth and well optimised.
4. All known anomalies are covered by their corresponding recovery actions and procedures
5. Minor concerning issues:
    - Arm-A temperature increase. It seems to get stable as confirmed during last eclipse season in winter 2021/2022 (+0.7C).
    - CCU temperature is increasing but far from hard limit value (it should be carefully monitored).

SMOS Ground Segment status

Nominal ground operations providing stable, reliant and high quality data flow to users

- No data loss at acquisition due to redundant system
- Data processed up to level 2 data in 99% of time
- Near-real time (<3 hrs) data provided to users in 95% of time
- New operational data products added
- Continuous data quality monitoring
- Continuous improvements to data products: **Mission reprocessed dataset delivered in May 2021 with the deployment of latest L1 and L2 algorithm baseline (V700) in the data processing facility**
- Radiofrequency Interference worldwide much improved (79% of sources identified by SMOS RFI team switched off)



SMOS Mission products

Land products:

- soil moisture,
- soil state (freeze/thaw),
- vegetation optical depth (*)

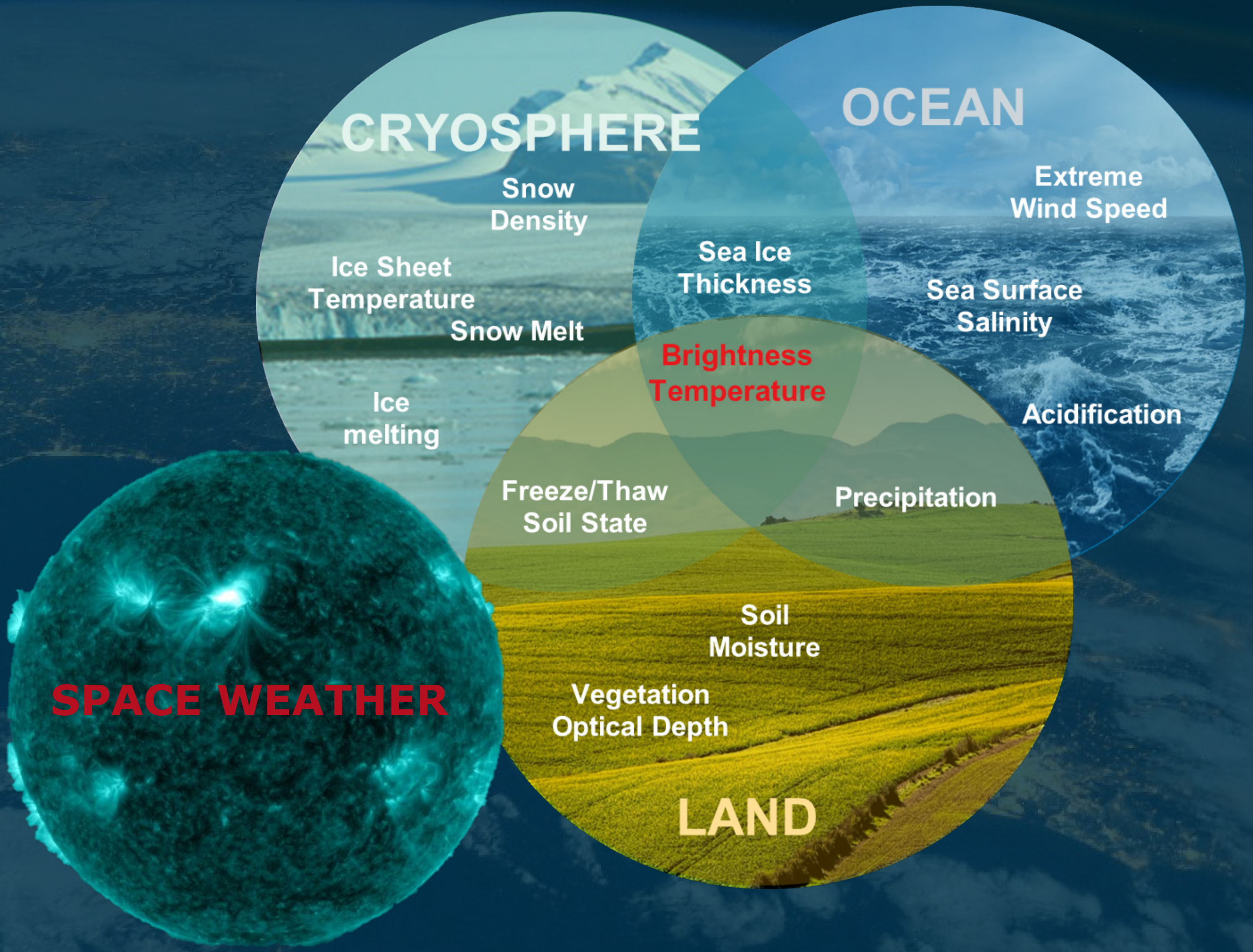
Sea products:

- sea surface salinity,
- sea ice thickness,
- sea surface wind speed
- cyclone wind radii

Space weather products:

- L-band Solar flux (*),
- Ionosphere electron content (*)

(*) under prototyping



SMOS 3rd Mission Reprocessing performances (SM)

Concatenated debiased allsites CalVal Sites Insitu Time Series: 308 kept / total 383 - Ascending orbits
CalVal Series Rejection Correlation Threshold if all scenarios corr < 0.500 or it exits R pvalues > 0.05 or #data < 20

Δ statistics: SMOS - Insitu

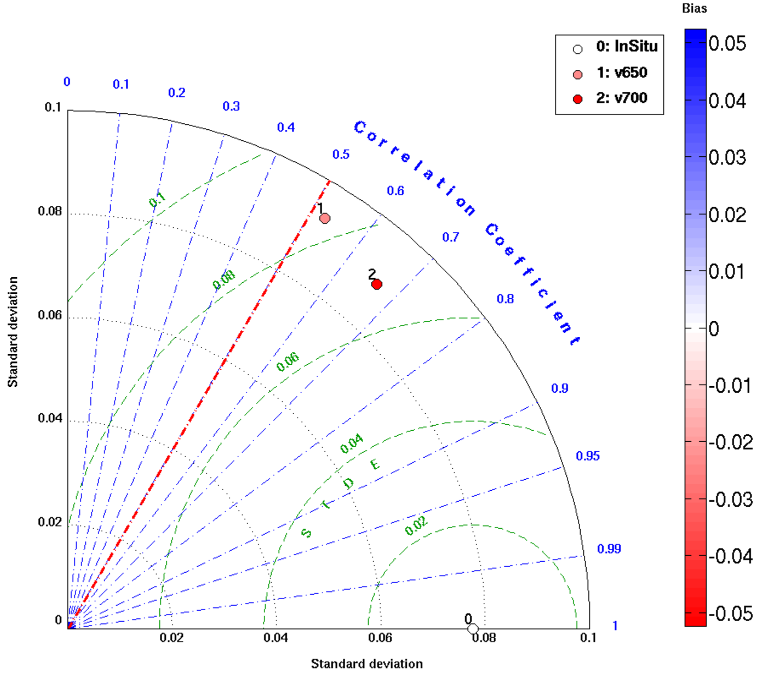
Series	R	Bias	STDD	RMSD	#kept
v650	0.53	-0.022	0.084	0.087	77139
v700	0.67	-0.052	0.069	0.087	93041

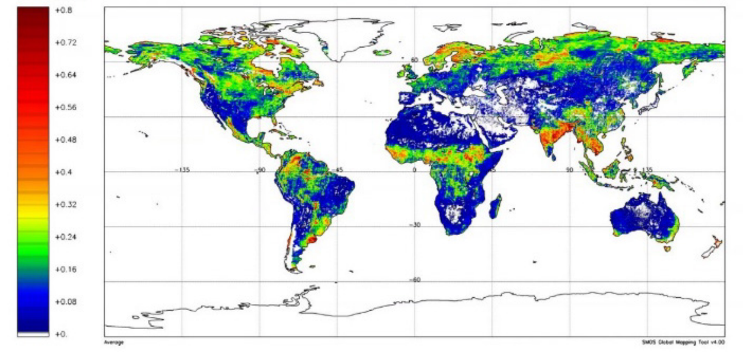
SMOS/Insitu series statistics

Series	$Mean_{SMOS}$	$Mean_{Insitu}$	STD_{SMOS}	STD_{Insitu}
v650	0.190	0.213	0.093	0.078
v700	0.164	0.217	0.089	0.077

Filter Stats

Series	v650 All	v650 Inter	v700 All	v700 Inter
Initial	207764	171444	207852	171519
Retrieved	76.16%	75.57%	76.17%	75.58%
Successful	95.62%	95.66%	97.29%	97.25%
PSchi2	60.79%	61.40%	74.70%	74.17%
PRFI	59.19%	59.67%	72.57%	71.88%
RRFI	59.07%	59.54%	72.46%	71.77%



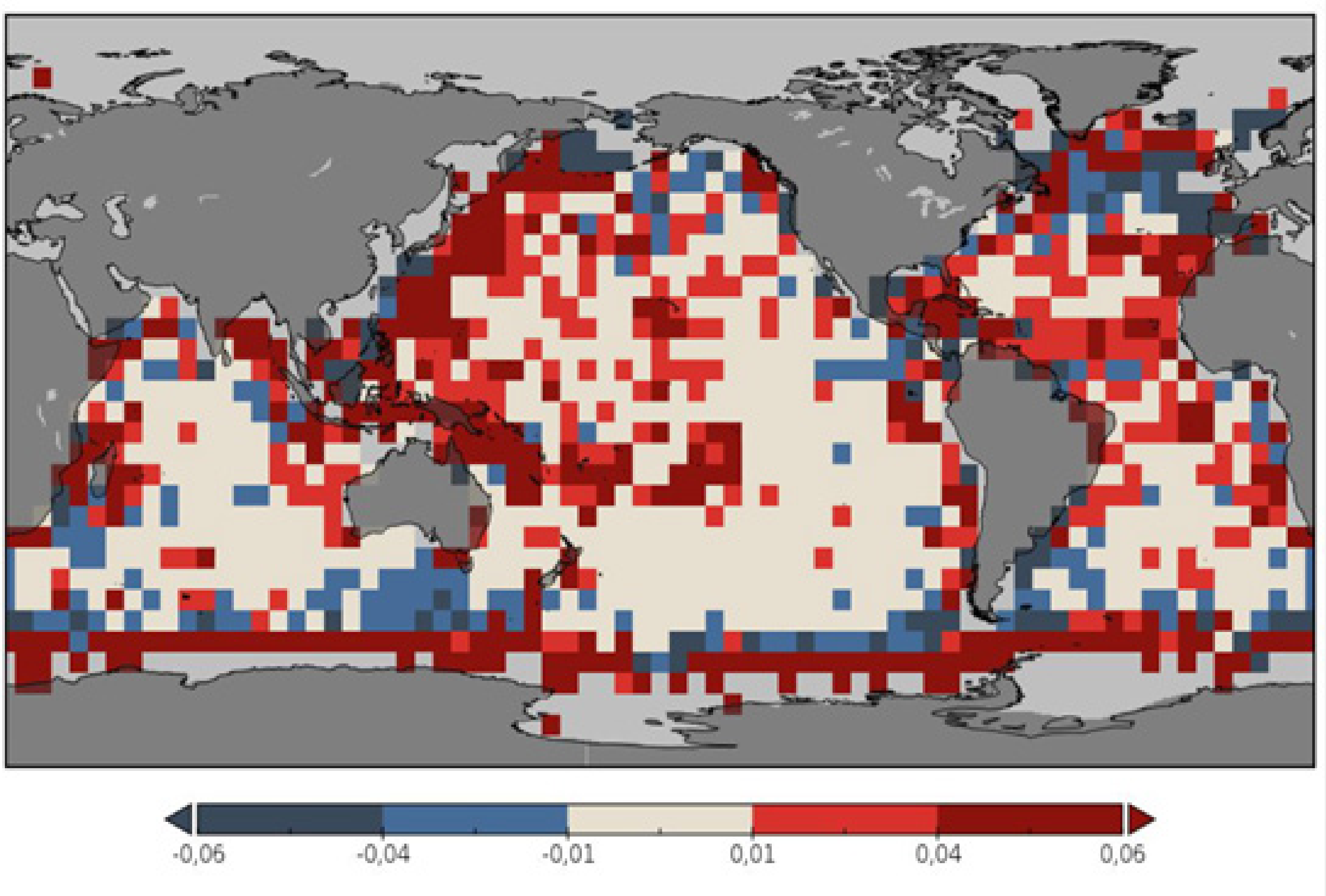


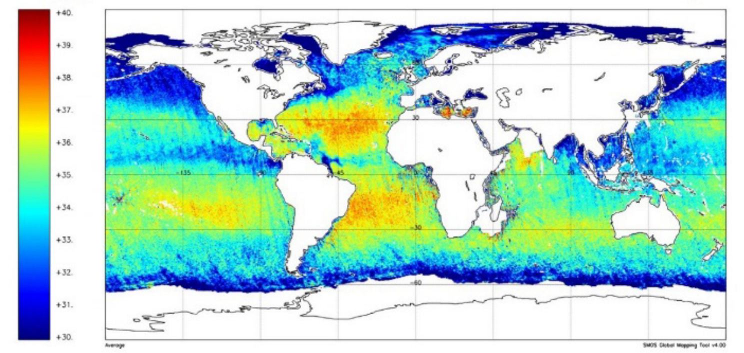
Correlation with in-situ measurements has improved from 0.53 to 0.67 (ascending orbit).

see more on [Release of SMOS level 2 SM products (esa.int)]

→ THE EUROPEAN SPACE AGENCY

SMOS 3rd Mission Reprocessing performances (OS)

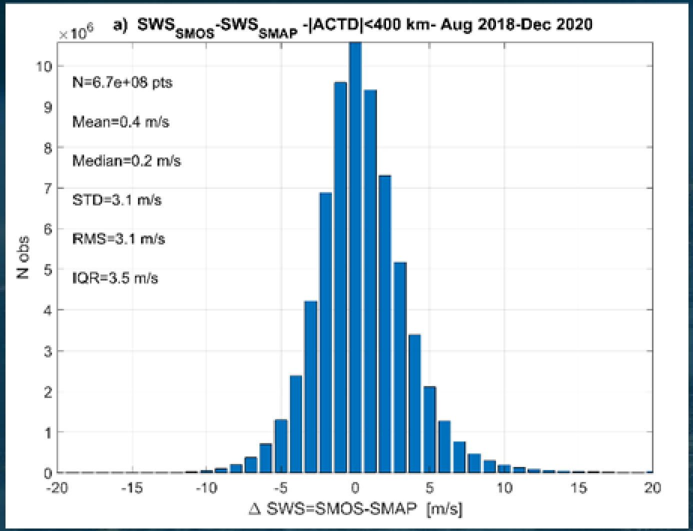


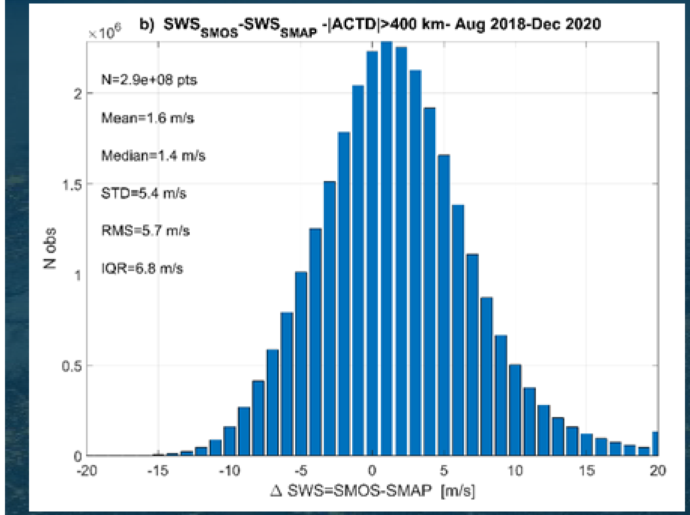


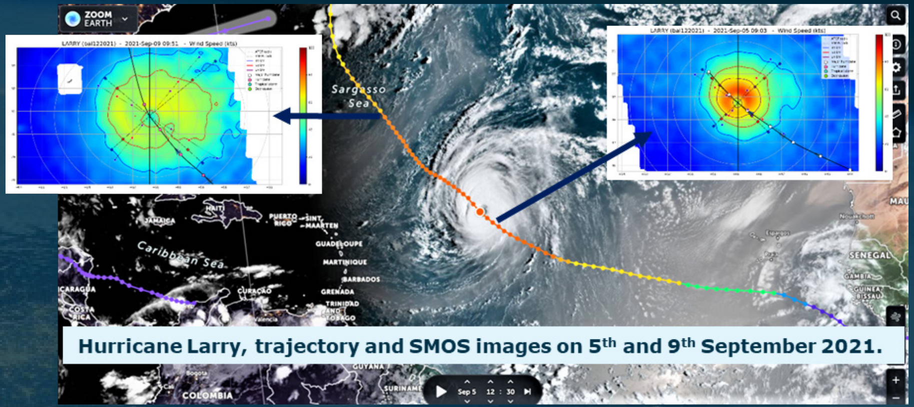
Differences of Salinity STDD (with respect to Argo) between v6 and v7. Red colours indicate a reduction of the STDD (with respect to ARGO data) in v700.

see more on [Release of SMOS level 2 OS: (esa.int))]

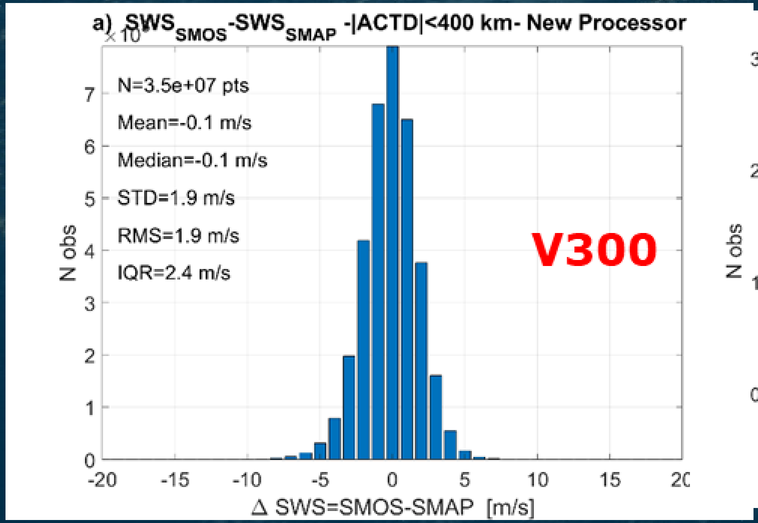
SMOS 3rd Mission Reprocessing performances (winds)

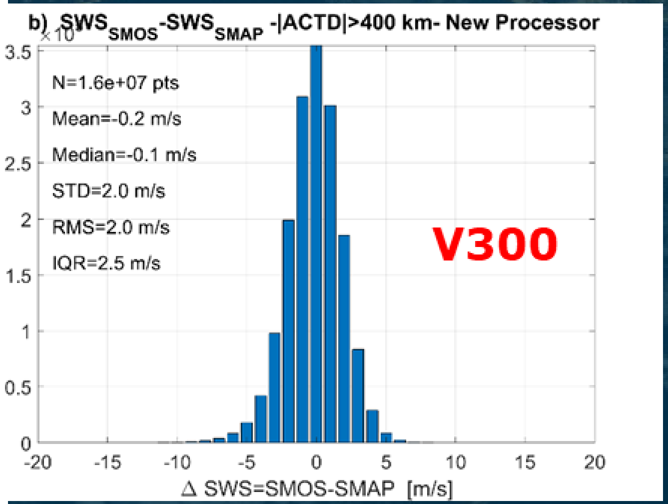






Hurricane Larry, trajectory and SMOS images on 5th and 9th September 2021.

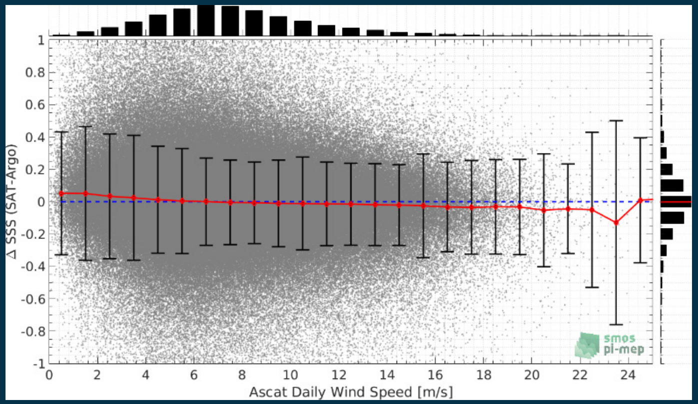


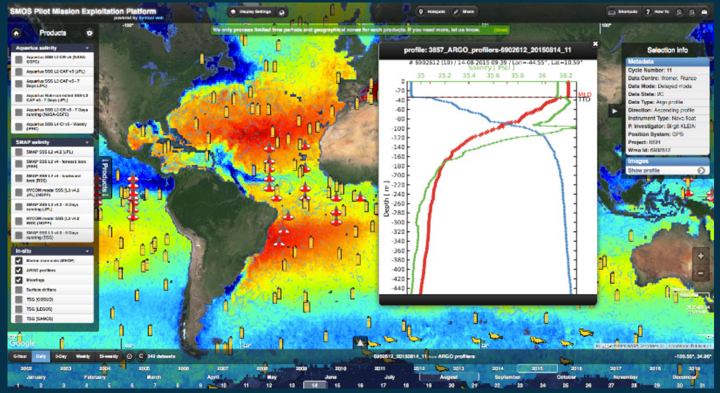


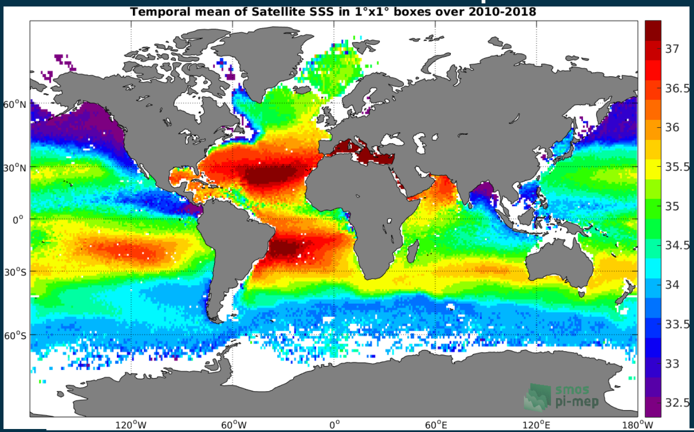
Statistics of the differences (in [m/s]) between the SMOS NRT and SMAP co-localized Sea Wind Speed for different part of the SMOS swath. Left: for SMOS SWS retrieved at across-track distance less than 400 kms. Right: for SMOS SWS retrieved at across-track distance greater or equal than 400 kms. see more on [Release of SMOS level 2 wind (esa.int))]

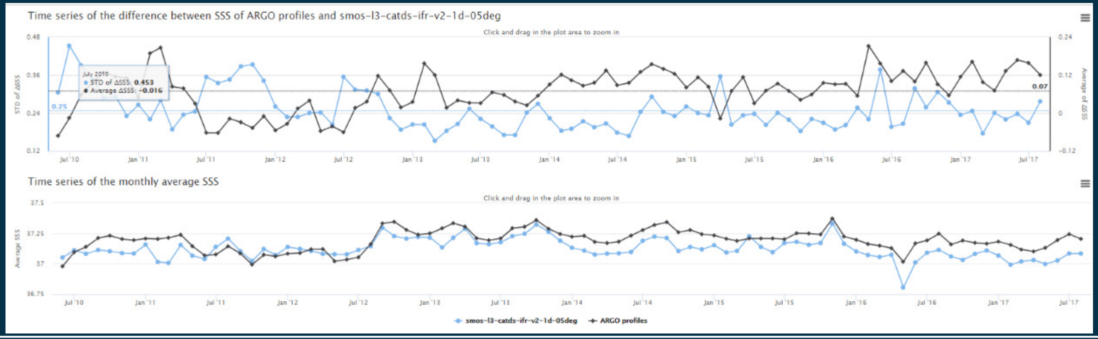
Pi-MEP Salinity – an ESA-NASA Platform

- Single web-based environment to **visualize, validate, monitor,** assess and exploit Satellite Salinity data
- Broad variety of online Tools to extract, inter-compare datasets and compute relevant statistics
- ESA-NASA partnership endorsed by JPPG in 2019; ongoing activities:
  - ❑NASA proposed additional criteria for satellite/in-situ salinity Match-ups - approved by ESA and implemented (still offline).
  - ❑NASA field campaigns (SPURS-1/-2) data added to the list of Case Studies.
  - ❑Triple-collocation analysis plug-in under testing for subsequent implementation into the Platform.







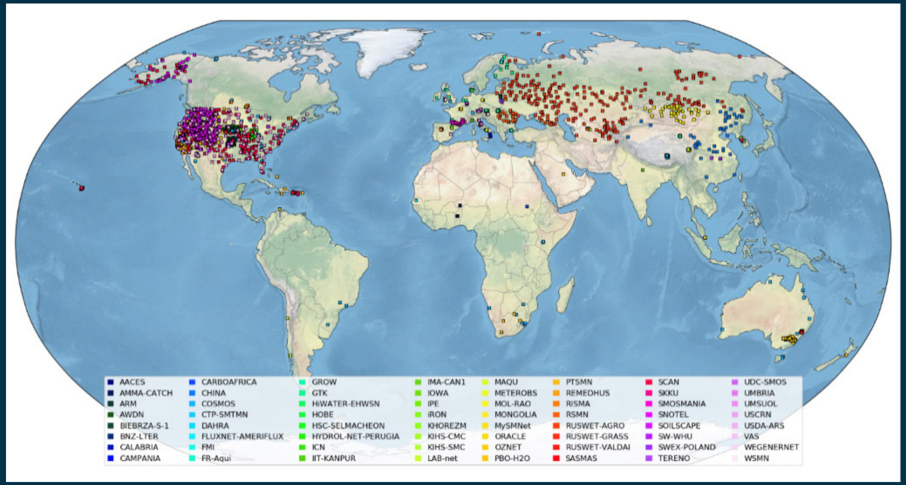


Figures - A variety of metrics and plots extracted by the Platform

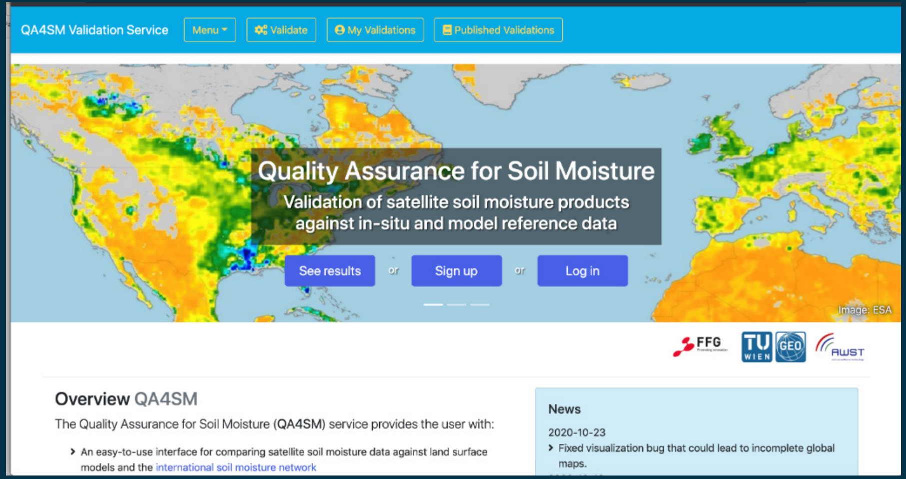
www.salinity-pimep.org

Fiducial reference Measurements for Soil Moisture (FRM4SM)

- project KO-ed May 2021
- Objectives/ambitions:
  - Reinforcement/provision of a SM validation platform -> QA4SM
  - End-to-end use of the ISMN
  - First steps in the FRM framework for SM (metrology)
  - Explore SMOS validation-related scientific aspects
- Dedicated SAG for technical/scientific advisory (filling-up)
- Five identified Tasks:
  - Task-1 - ISMN QA/QC, flagging and R&D
  - Task-2 - FRM4SM qualification
  - Task-3 - QA4SM platform and service maintenance
  - Task-4 - QA4SM platform evolution
  - Task-5 - SMOS SM Validation R&D
    - Committed area concept
    - Organic soil validation
    - Representation (h,v,t) errors

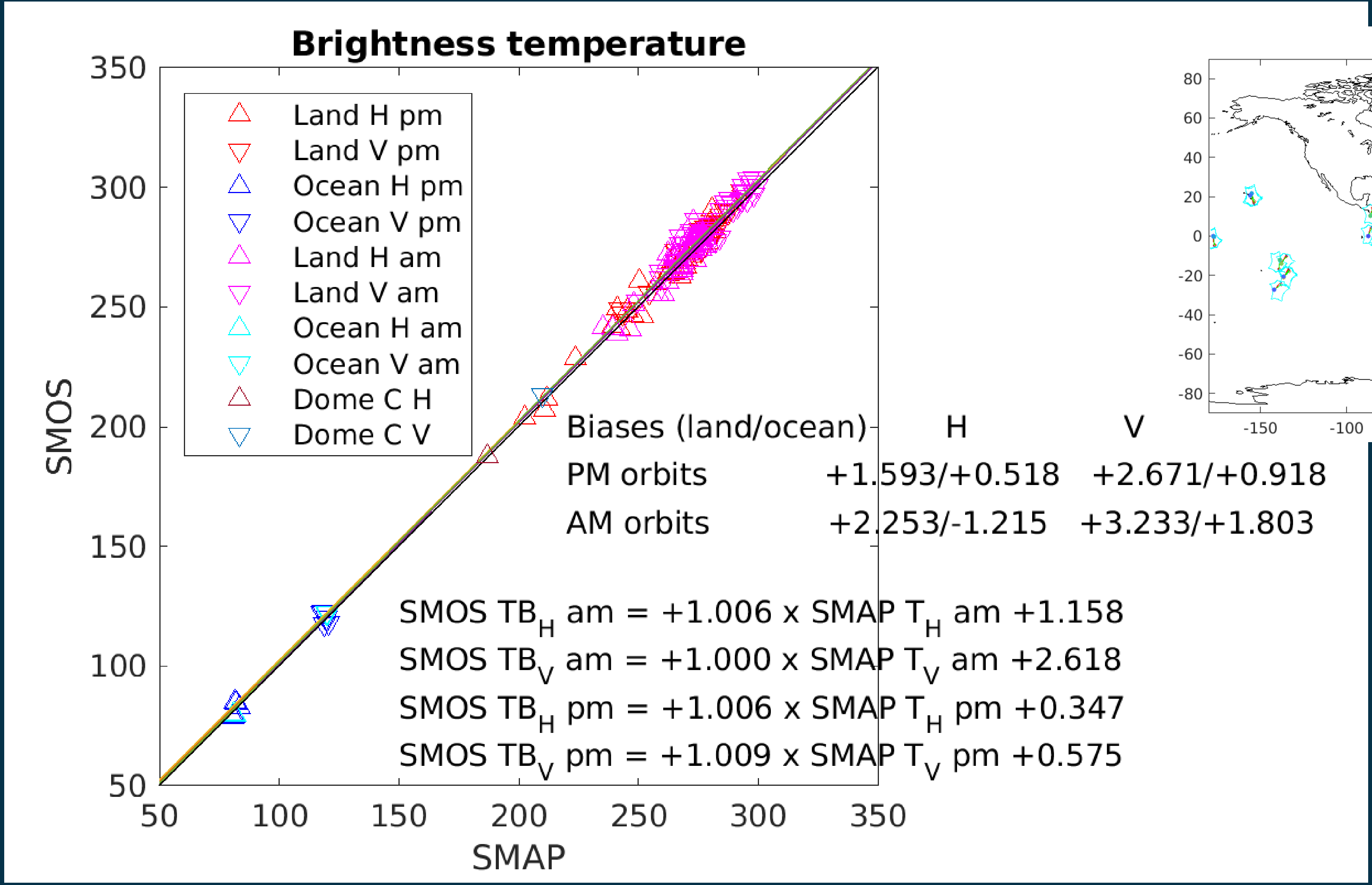


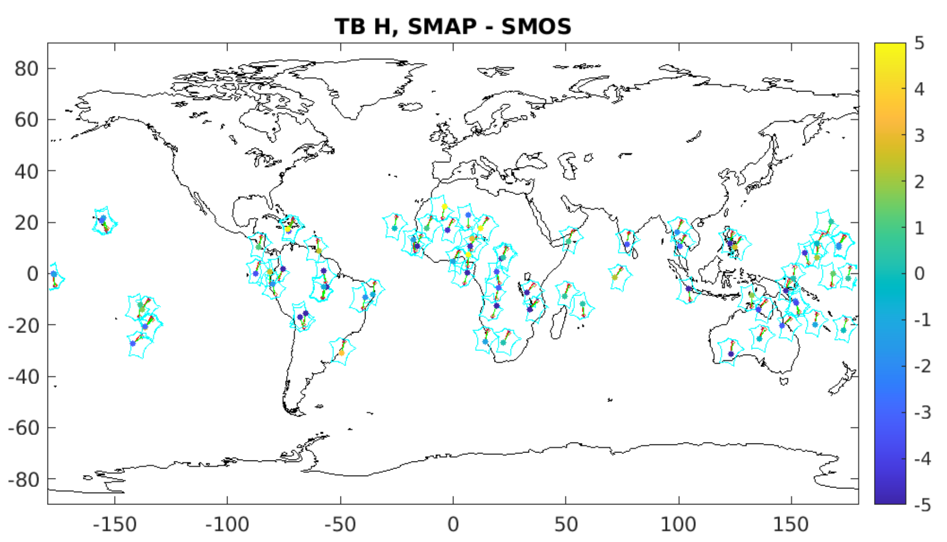
Locations of ISMN networks and sites (status July 2020).



Pilot QA4SM service landing page

SMOS - SMAP intercomparison





Good agreement between the two sensors

DOMEX experiment

From the launch of the SMOS mission particular attention was paid to the region of Dome-C, Antarctica, with the aim of characterizing this area as a potential extended target for calibrating and monitoring low frequency microwave radiometers.

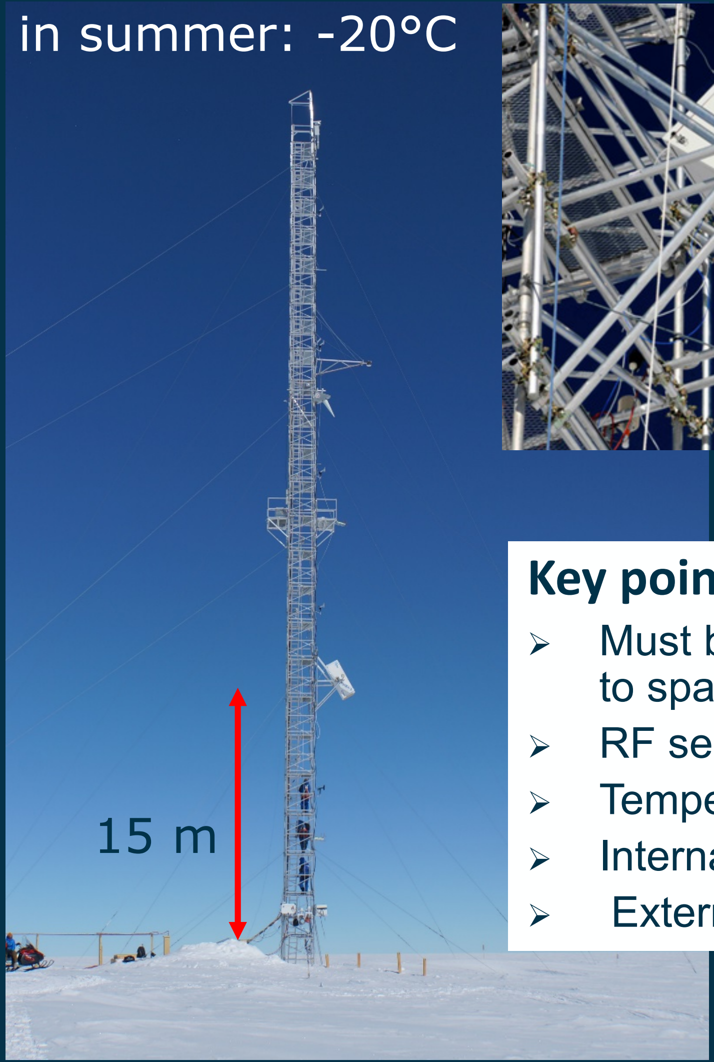
Why Dome –C ?

- High penetration of e.m. waves in the ice sheet and high temporal stability in the physical properties (including temperature below 10 m) . It is theoretically expected that Tb remains stable in time.
- Well covered by SSO satellites (SMOS, SMAP, etc.)
- Spatial homogeneous and small slopes at satellite footprint scale
- Infrastructure (Concordia station) and ancillary data available

Experiments (DOMEX) that include ground-based L-band radiometer (RADOMEX) measurements were conducted at Concordia Station since 2004 and continuously since 2012 supported by ESA and PNRA. The long-term experiment was recommended in order to provide a continuous independent data record of ground-based radiometric measurements covering the SMOS – Aquarius – SMAP era thus verify target stability over time and monitor changes in target characteristics that may affect the long-term reference signal.

RADOMEX: L-band microwave radiometer

Temp in winter: -90°C
Temp in summer: -20°C

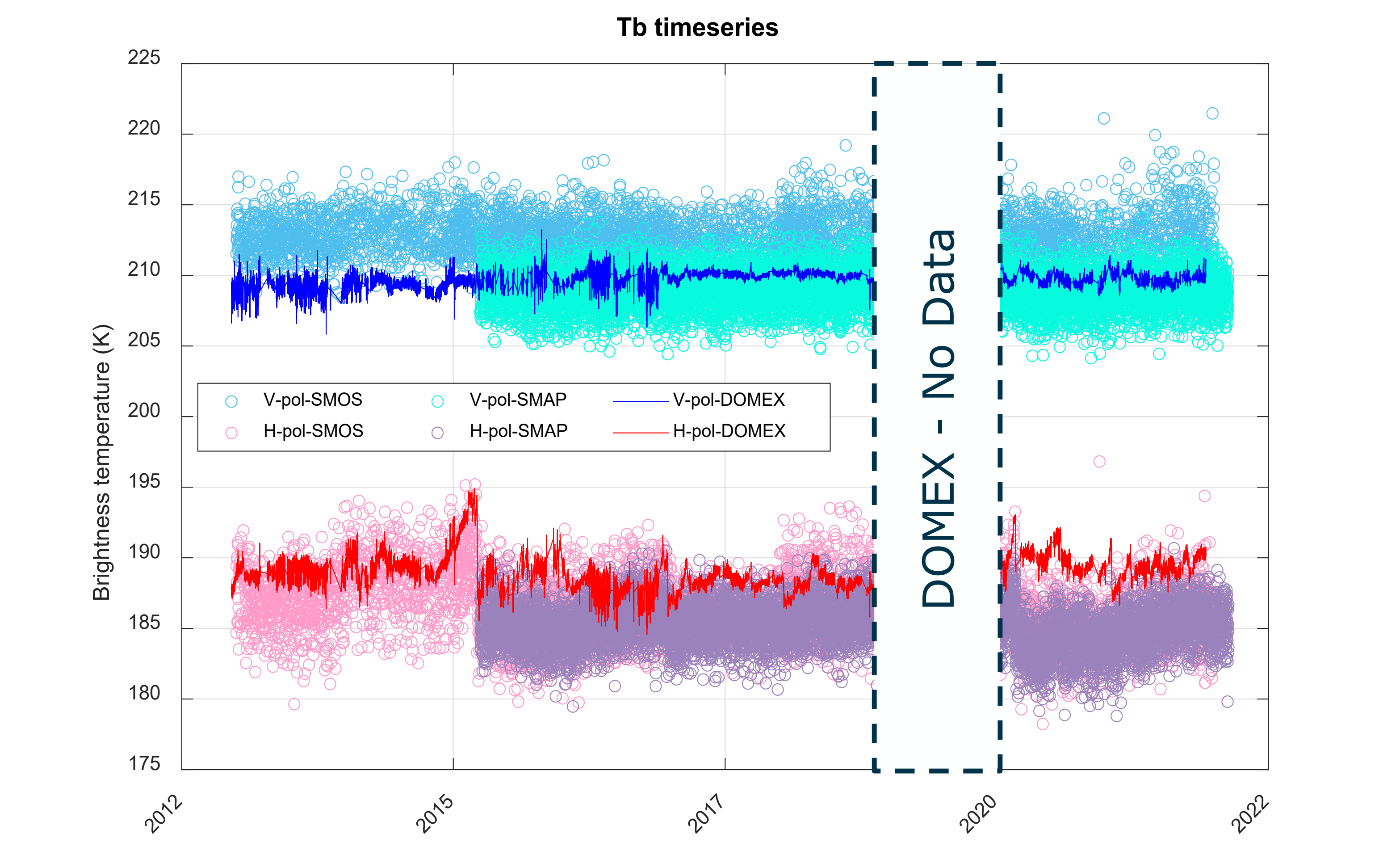


Frequency : 1413 MHz
Bandwidth: 27 MHz
Sensitivity = 0.2 K (Ti =2 sec)
Polarization: H and V
Antenna: Potter Antenna
HPBW: 20°
Active (PID) thermal control
Accuracy : 1 K

Key points:

- Must be robust, failure tolerant and stable in time (unreachable Feb though Nov, quite similar to space!)
- RF section is thermal compensated (stability better than 0.1°C over years)
- Temperature on the cables and connector is measured by PT100
- Internal frequent calibration (every measurement cycle over 4 reference loads
- External calibration (clear sky + hot target) at monthly scale

RADOMEX time series



Sensor	TbV avg (K)	TbV std (K)	TbH avg (K)	TbH std (K)
DomeX-3	209.68	0.53	189.08	1.22
SMOS	212.80	1.48	186.74	2.28
SMAP (40deg)	209.02	1.31	185.22	1.51

- Radiometer demonstrated good performances for long-tem monitoring
- Tb is very stable especially at V polarization
- Tb variability at H polarization is due to modification on surface properties

Preparing the technology for a SMOS follow-on mission

- SMOS has been flying for over 12 years and 4 months, much longer than its design lifetime of 3 years
- ESA is working in the necessary technology that a follow-on L-band radiometer mission would need
- The technology activities have been defined based on lessons learnt from SMOS …
- … and aim at achieving better performance than SMOS:

  → better spatial resolution (better than 40 km)
  → better radiometric resolution (better than 2 K)
  → more resilience to Radio-Frequency Interference (side lobes lower than 20 dB)
  → lower image spatial biases (smaller than 2 K)

Technology activities for SMOS follow-on

- **Optical Harness:** links receivers, correlator and central units (oscillator and calibration) using multi-wavelength
  → uplinks the local oscillator, the sampling clock and the calibration signals
  → downlinks the IQ data in X and Y polarisations

- **Advanced Receiver:**
  → receives X and Y polarisations in parallel, achieving very high sensitivity
  → physically of reduced size, enabling alias-free imaging
  → reduced consumption and mass thanks to a new RF ASIC (DiReRa-2)

- **Correlator with RFI Mitigation Capability:**
  → can host a few tens of thousands of 1-bit correlators, mitigating RFI contamination
  → compatible with different dimensions of antenna arrays

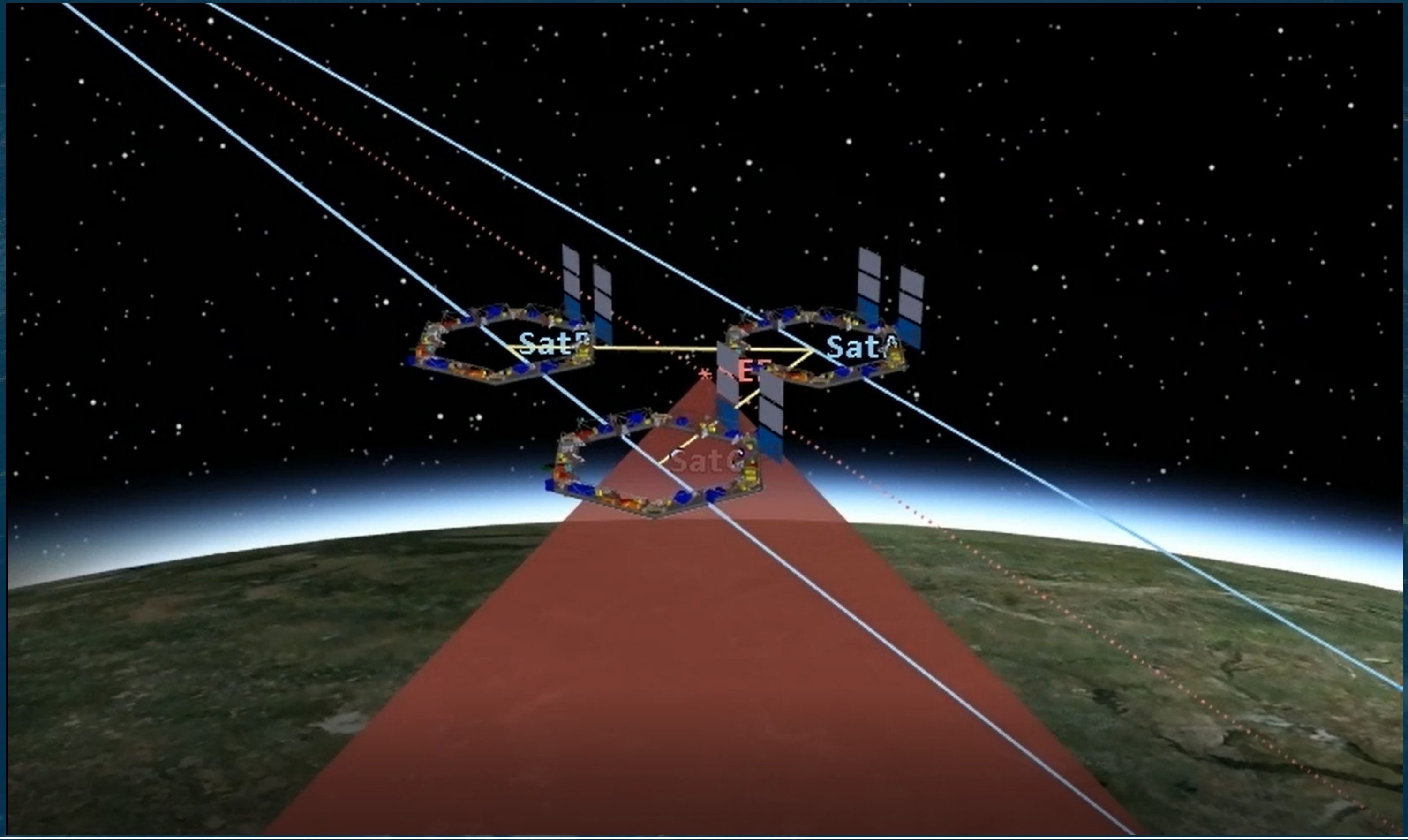
- **Advanced Antenna:**
  → reduced size to allow for alias-free imaging
  → reduced losses, enabling higher sensitivity

Formation Flying L-band Aperture Synthesis (FFLAS)

- **FFLAS achieves:**

  → 10 km spatial resolution and x4 better sensitivity than SMOS

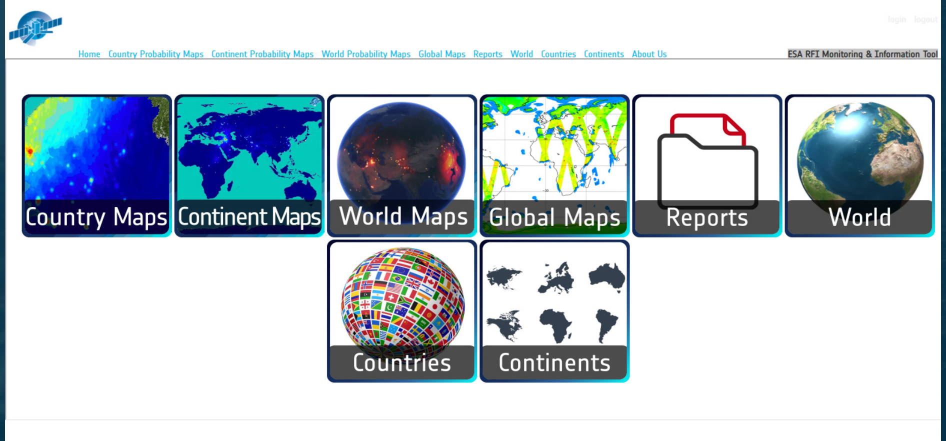
  → requires 3 hexagonal arrays of about 7 m flying in rigid formation

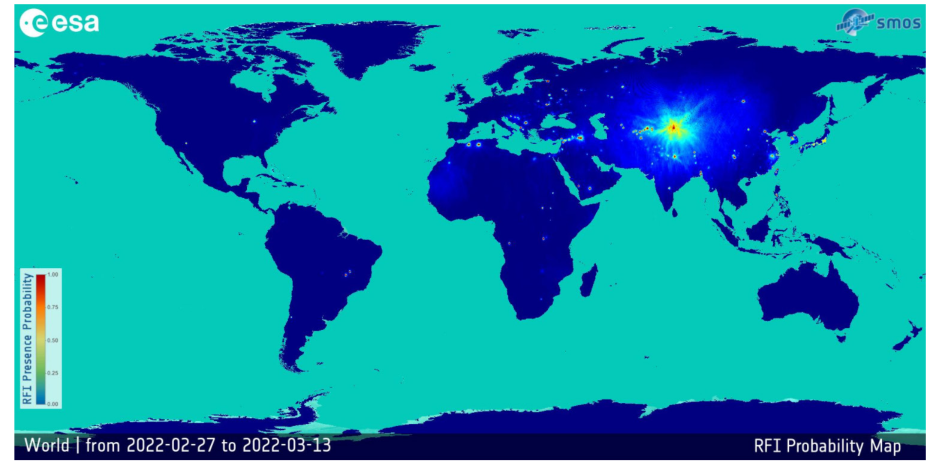


ESA RFI Monitoring & Reporting

RFI monitoring and information tool

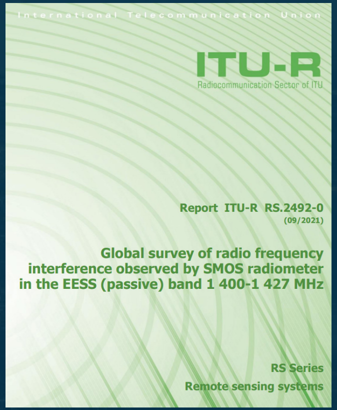
https://rfi.smos.eo.esa.int/





ITU Report on SMOS RFI

https://www.itu.int/pub/R-REP-RS.2492-2021


International Telecommunication Union

ITU-R

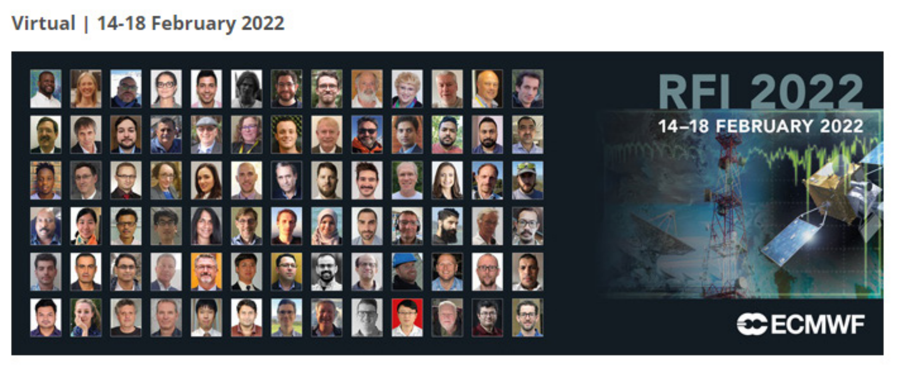
Radiocommunication Sector of ITU

Report ITU-R RS.2492-0
(09/2021)

Global survey of radio frequency interference observed by SMOS radiometer in the EESS (passive) band 1 400-1 427 MHz

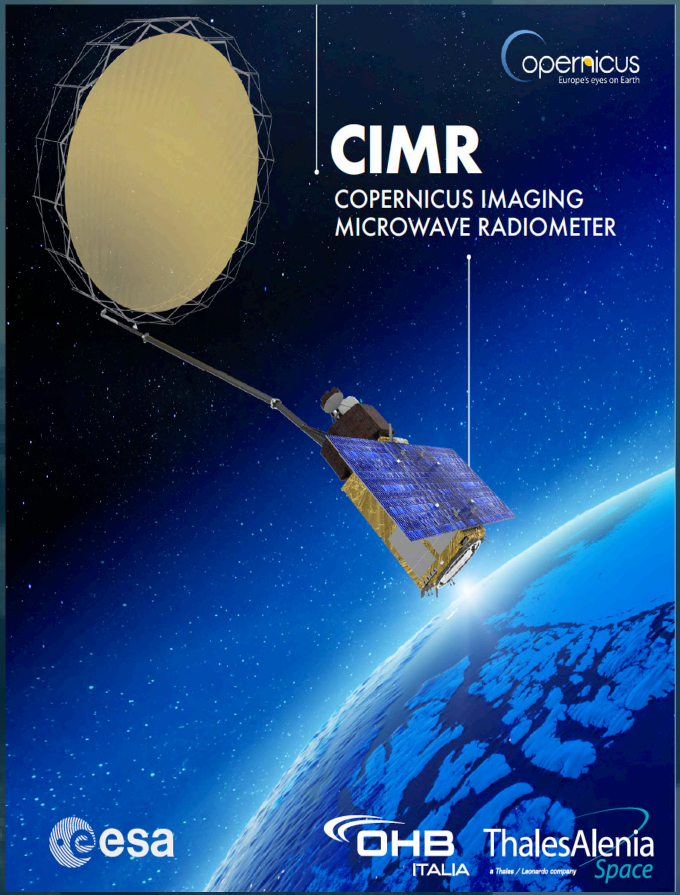
RS Series
Remote sensing systems

Contributions to ECMWF RFI 2022 workshop



The Copernicus Imaging Microwave Radiometer CIMR

The European Commission and the High Representative of the Union for Foreign Affairs and Security Policy issued to the European Parliament and the Council, on 27 April 2016, a joint communication that **proposed "An integrated European Union policy for the Arctic"**



Polar Oceans are fundamental to understanding the global environment

CIMR is designed to:

- **Prevent the anticipated Gap in capability**
- **Be "ready" for an ice free Arctic**
- **Key variables:** *Sea Ice Concentration, Sea Surface Temperature, thin Sea Ice Thickness, Sea Surface Salinity, Wind Speed, soil moisture…*
- Low frequency/High Spatial resolution (5–15 km)
- **Measurements every ~6 hours** in the Polar regions, no hole at the pole
- 95% global coverage every day for **application in all Copernicus Services**

Directly addresses the EU Arctic Policy.

- **A 'Game Changer' for Copernicus**

Atmosphere (CAMS) | **Marine** (CMEMS) | **Land** (CLMS) | **Climate** (C3S) | **Emergency** (EMS) | **Security**

CIMR channel selection

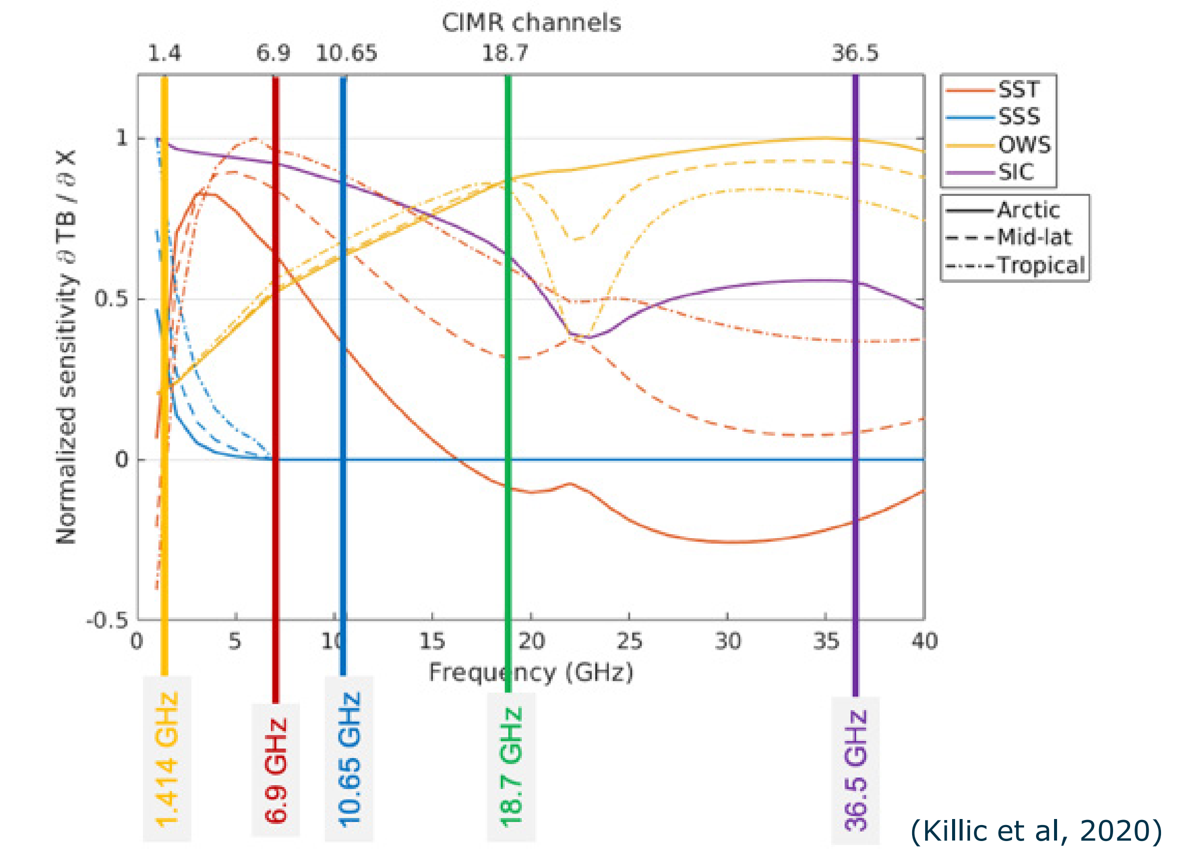
1.4135 GHz: SIT, SIC, SSS, WS, SM, SD

6.9 GHz: SIC, SST, SIT, IST, WS, SID, SM, SD

10.65 GHz: SST, PCP, WS, SD, SM

18.7 GHz: TCWV, LWP, PCP, SIC, SD, SM, SID

36.5 GHz: SIC, SST, LWP, TCWV, PCP, SIC, SWE, SD



SIC = Sea Ice Concentration,
SST = Sea Surface Temperature, SIT = Sea Ice thickness,
SSS= Sea Surface Salinity,
WS = Wind speed,
LWP = Liquid Water Path,
TCWV = Total Column-liquid Water Vapour,
SD = Snow Depth,
SM = Soil Moisture,
SWE = Snow Water Equivalent,
SID = Sea Ice Drift,
PCP=precipitation

Channels (GHz, Full Stokes):	**1.4**	**6.9**	**10.65**	**18.7**	**36.5**
Resolution (km):	**<60**	**≤15**	**≤15**	**≤5.5**	**≤5 (g:4km)**
NEΔT (K @150K):	**≤0.3**	**≤0.2**	**≤0.3**	**≤0.4**	**≤0.7**
Tot. Standard Uncertainty(K):	**≤0.5**	**≤0.5**	**≤0.5**	**≤0.6**	**≤0.8**

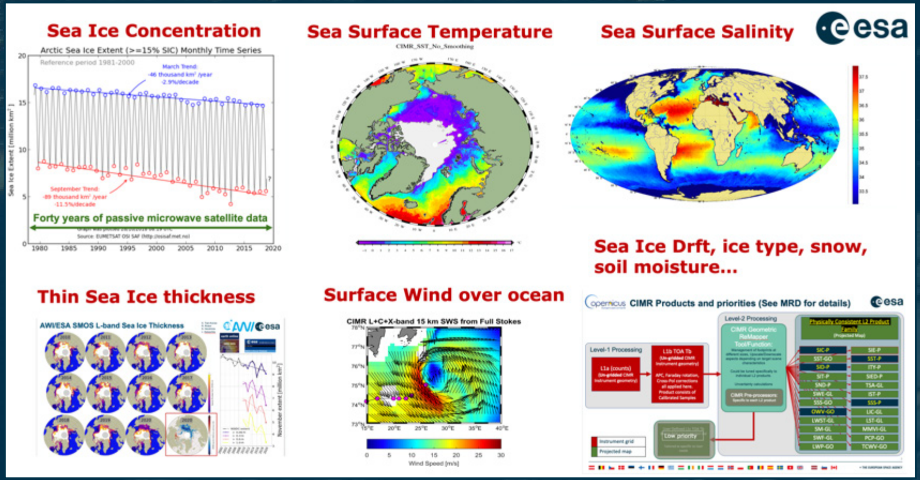
CIMR status

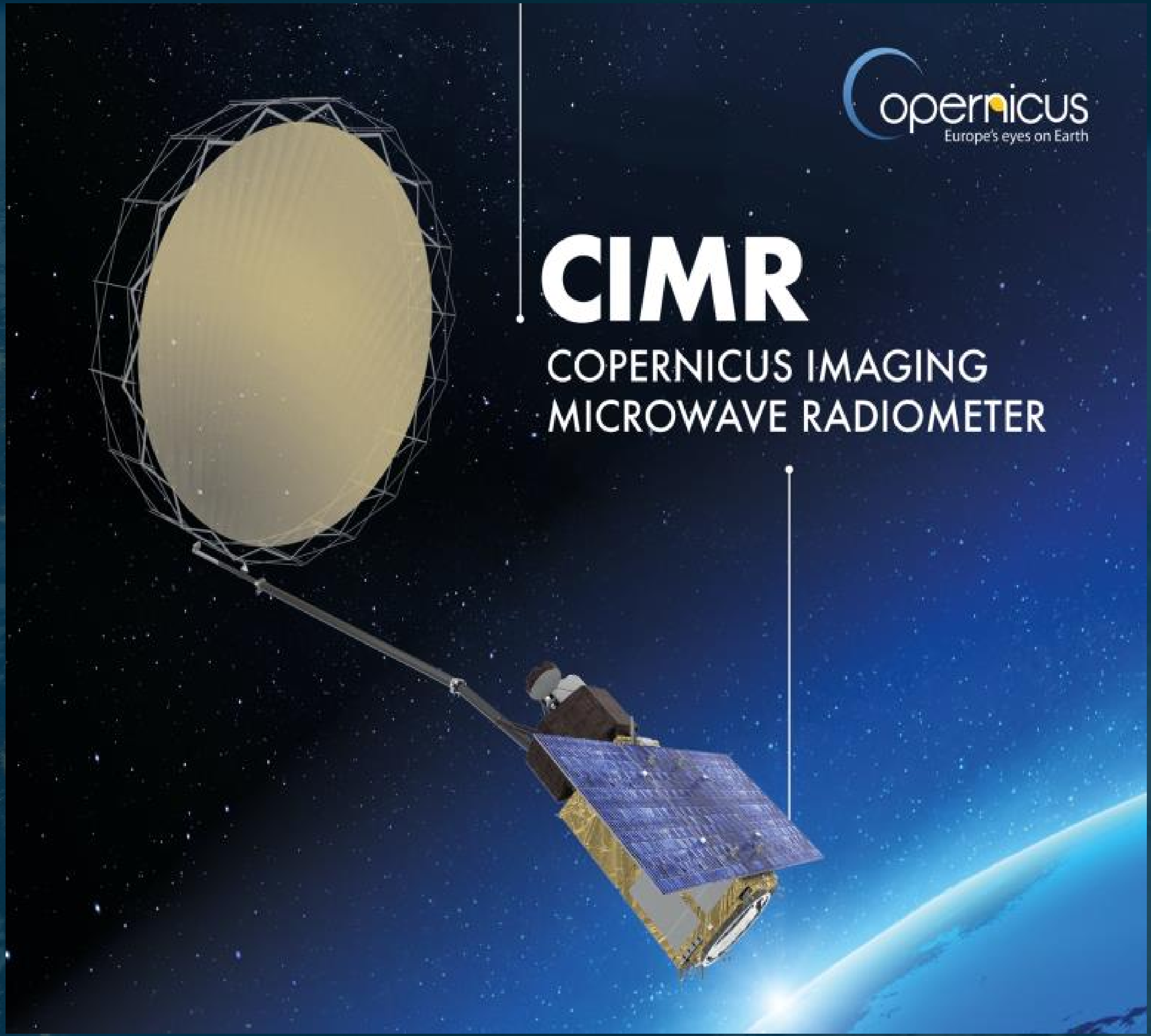
Thales Alenia Italy signed contract to Prime CIMR mission Phase B2/C/D development (13/11/2020)

Preliminary Design Review system and instrument (Oct. 2022)

Mission Requirements Document available at https://esamultimedia.esa.int/docs/EarthObservation/CIMR-MRD-v4.0-20201006_Issued.pdf

Launch of CIMR-A in 2028+ (CIMR-B few years later)





Conclusion

- SMOS mission is in good operational status after more than 12 years in orbit. Good agreement in brightness temperature with SMAP.
- 3rd mission reprocessed L2 dataset has improved quality
- ESA fosters SM and SSS validation activities throughout dedicated platform (PiMep-SSS, QA4SM)
- Fiducial Reference Measurements (FRM) for soil moisture activities have started
- Continuous acquisition of L-band dataset over Dome-C for satellite validation since 2004
- Several technology activities carried out towards a possible high resolution SMOS follow-on mission (SMOSops / FFLAS)
- ESA very active in RFI monitoring and reporting
- Next Copernicus CIMR mission status presented

Acknowledge

Presentation inputs from:

- M. Martin-Neira (ESA)
- Craig Donlon (ESA)
- Roberto Sabia (ESA)
- G. Macelloni (IFAC)
- ESA SMOS RFI team
- SMOS Calibration team
- ESA SMOS Expert Support Laboratories

Thank you for your attention

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