ESA microwave activities - GSICS 2023 report

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ESA ESRIN

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Content

- SMOS Mission status
- DOMEX experiment status (L-band radiometer in Antarctica)
- SMOS Validation platforms
- RFI activities and reporting
- Technology developments: TriHex
- CIRM Mission
- Conclusion
- Acknowledge
- Backup slides

smos

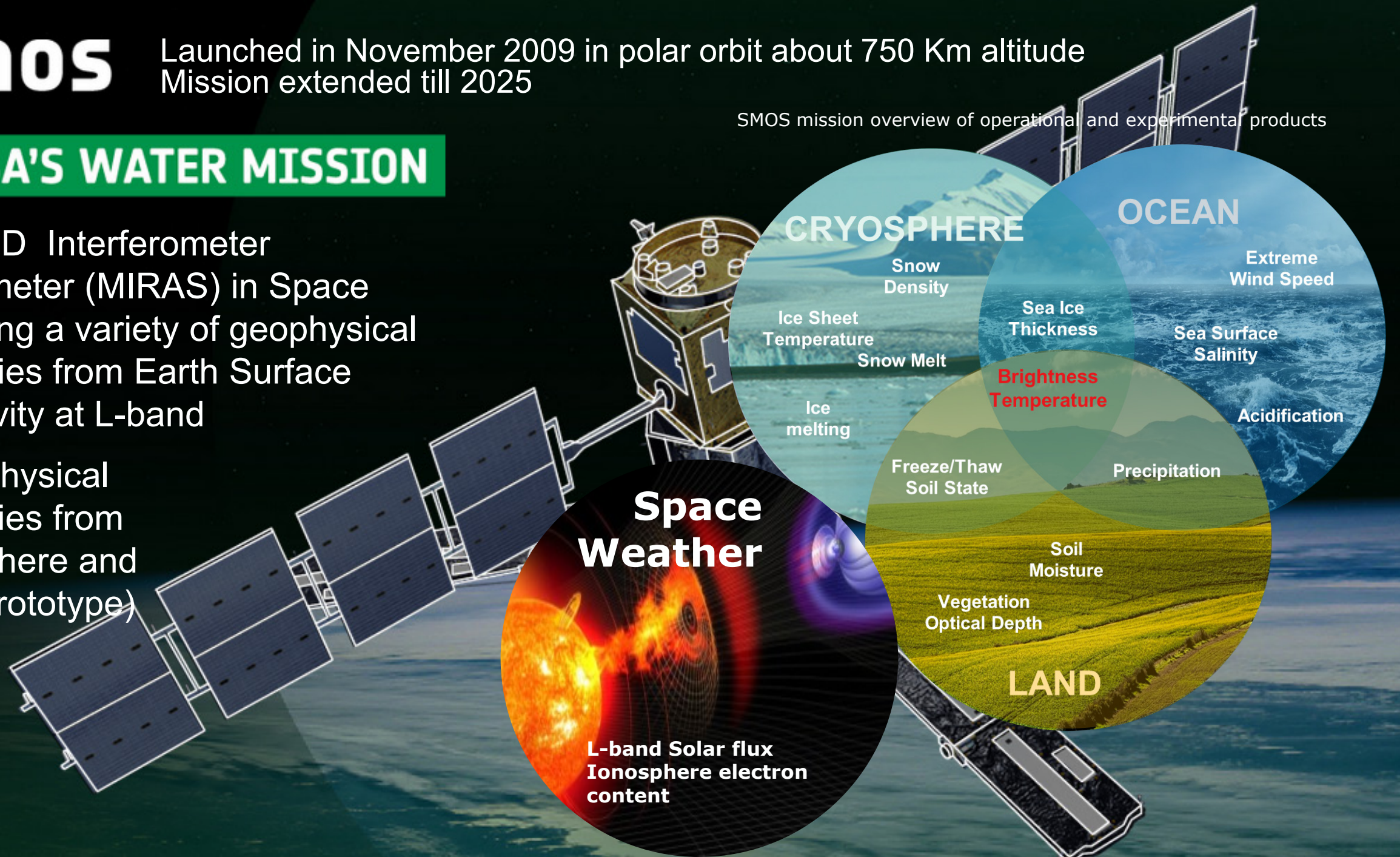
Launched in November 2009 in polar orbit about 750 Km altitude
Mission extended till 2025

→ ESA'S WATER MISSION

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

+ geophysical quantities from Ionosphere and Sun (prototype)

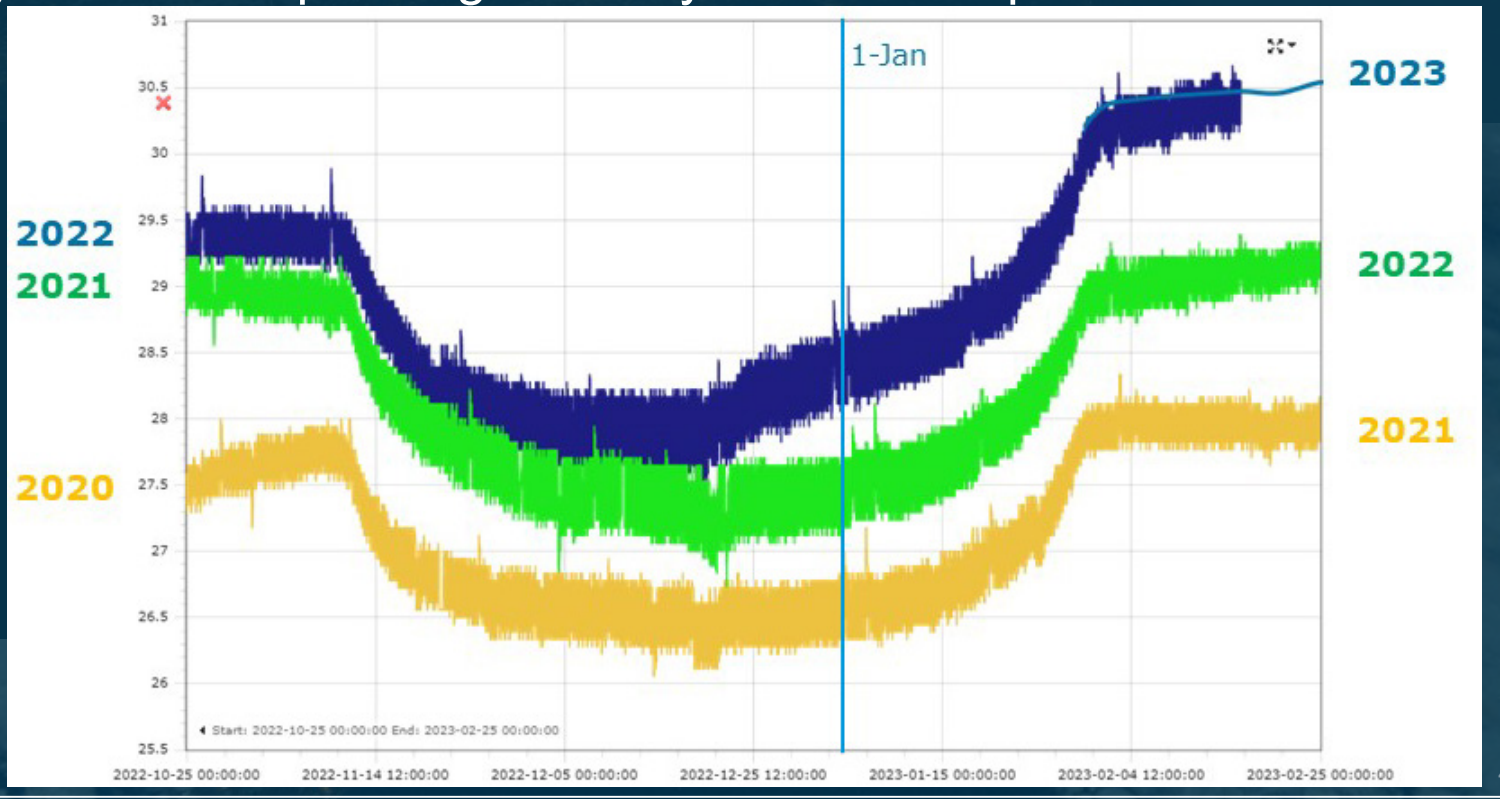
SMOS mission overview of operational and experimental products



MIRAS SMOS Payload status

1. After more than 13 years in orbit, 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:

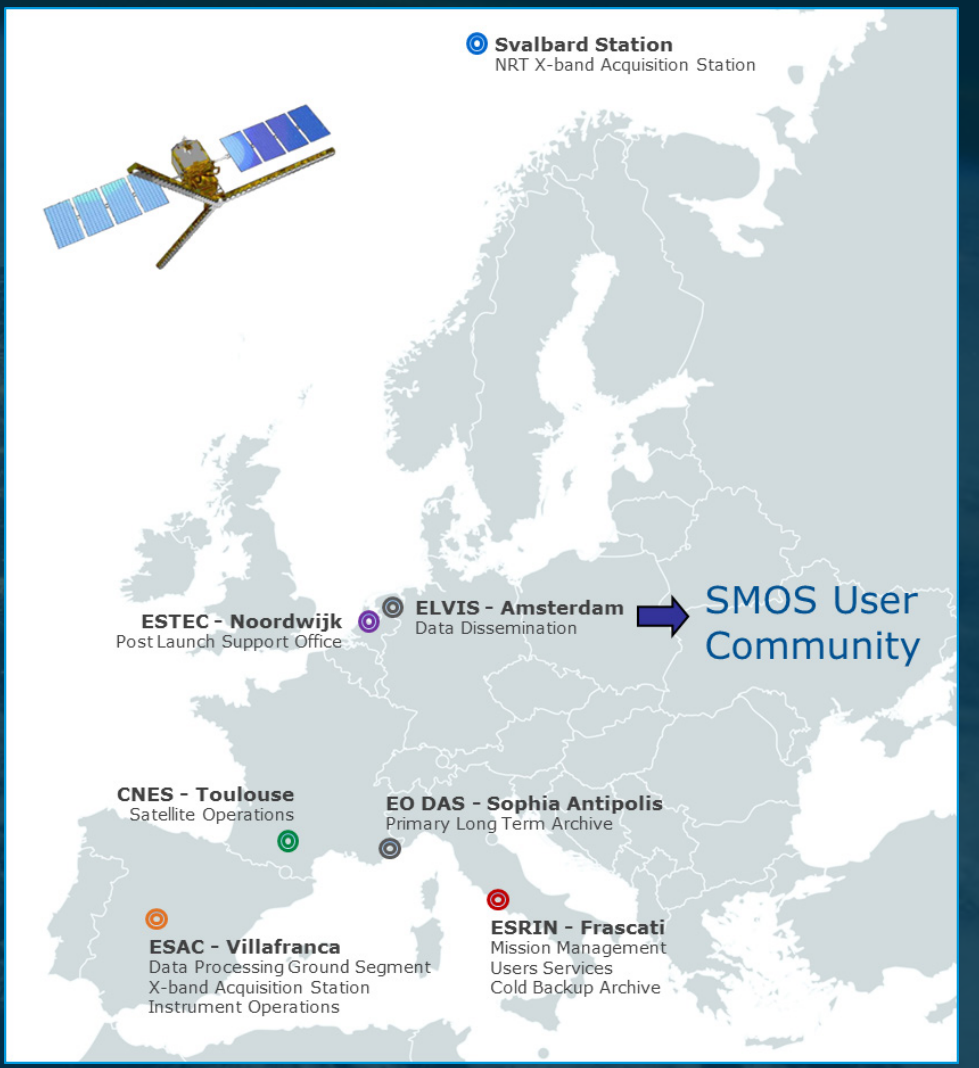
- Arm-A temperature increase. It is stable as confirmed during last eclipse season in winter 2022/2023
- CCU temperature is increasing (+1.5C from 2022) but far from hard limit value (it is carefully monitored).



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 above 99%
- Near-real time (<3 hrs) L1 data provided to users (e.g. soil moisture, sea wind speed) in 95.9% of time
- Continuous data quality monitoring
- Continuous improvements to data products: **New version of L4 Sea Ice thickness products v205; minor update for the L2 high wind speed product v302; new version of L3 Freeze and Thaw soil state coming soon.**
- **Revisit L1 and L2 algorithms in preparation for 4th mission reprocessing (2024)**

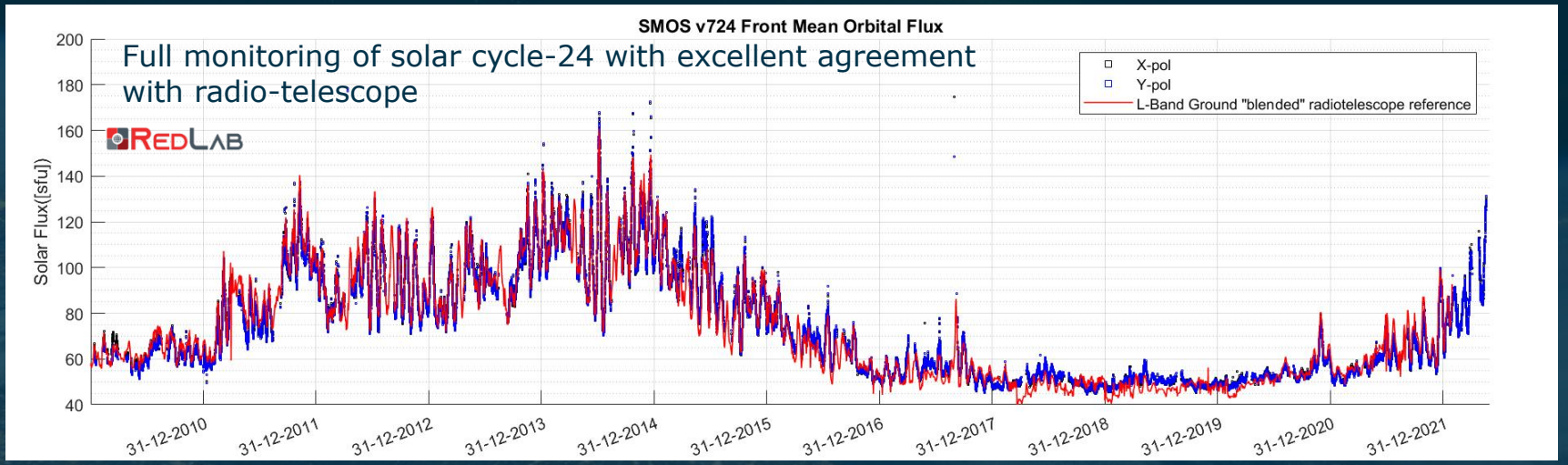


Emerging SMOS products for Space Weather

Space weather products:

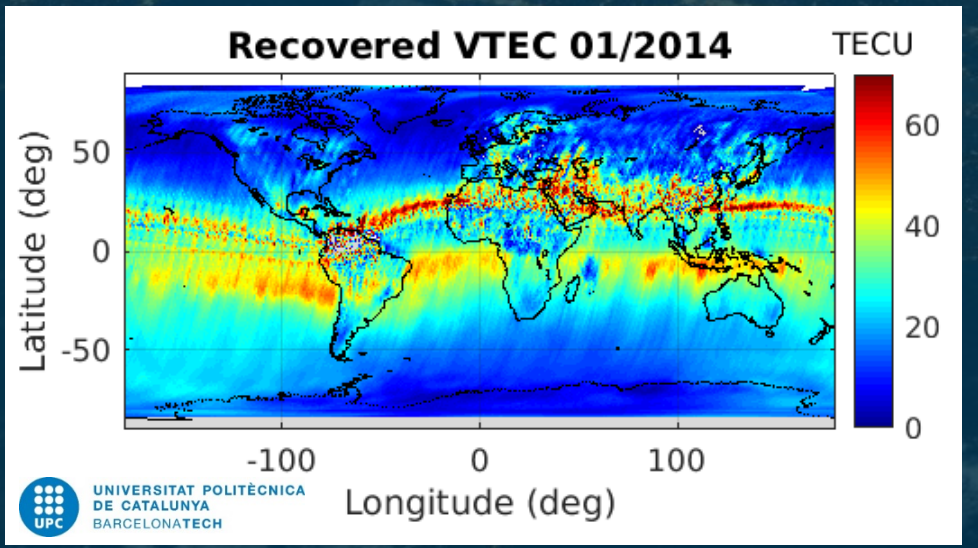
- L-band Solar flux (*),
- Radio Burst bulletin (*)
- Ionosphere electron content (*)

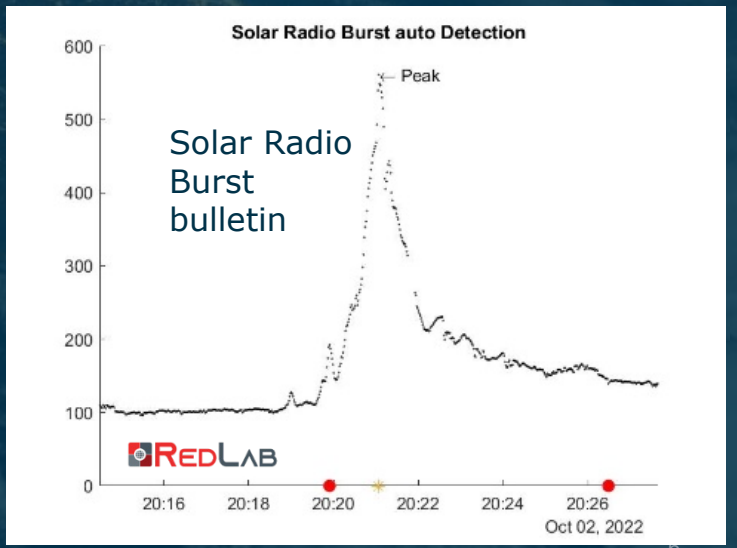
(*) under prototyping



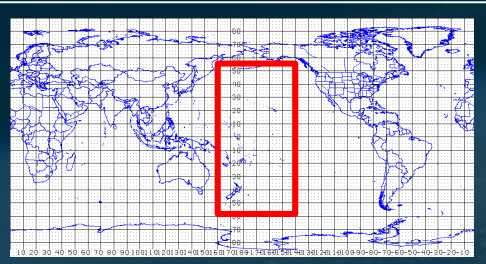
SMOS Space weather workshop November 2022

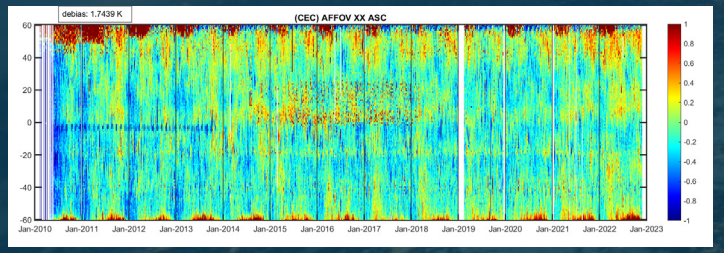
SMOS Space Weather - eo science for society (esa.int)





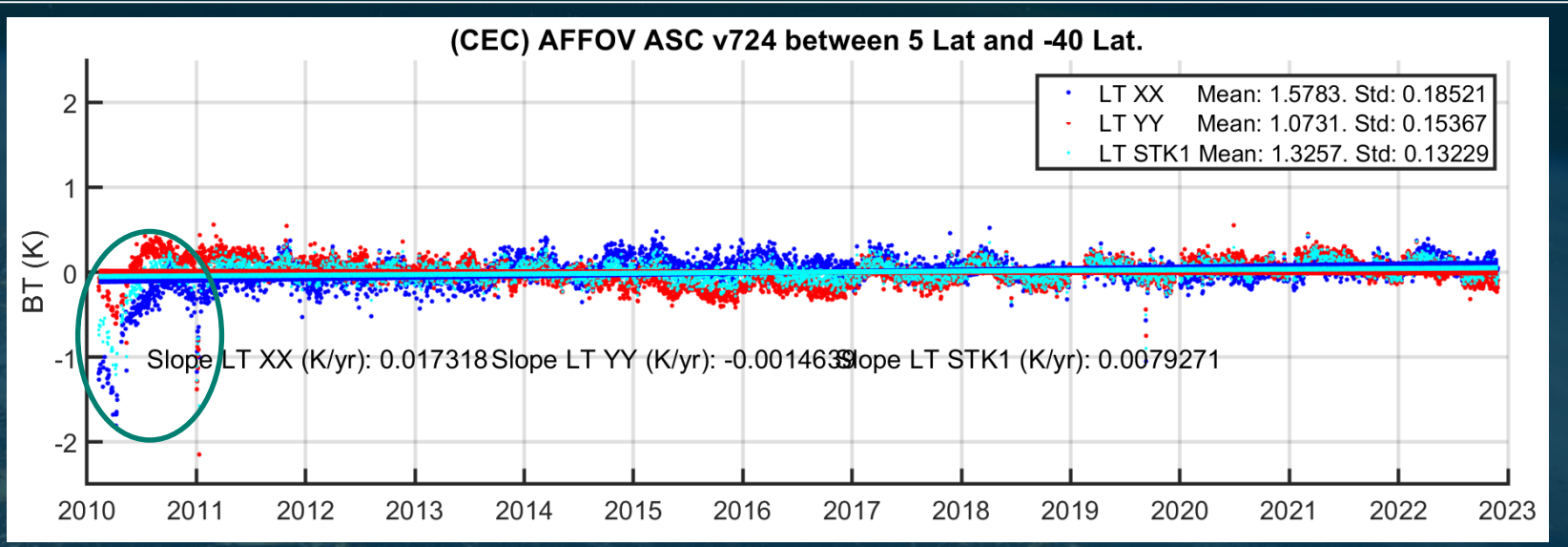
Brightness Temperature performances (Ocean)

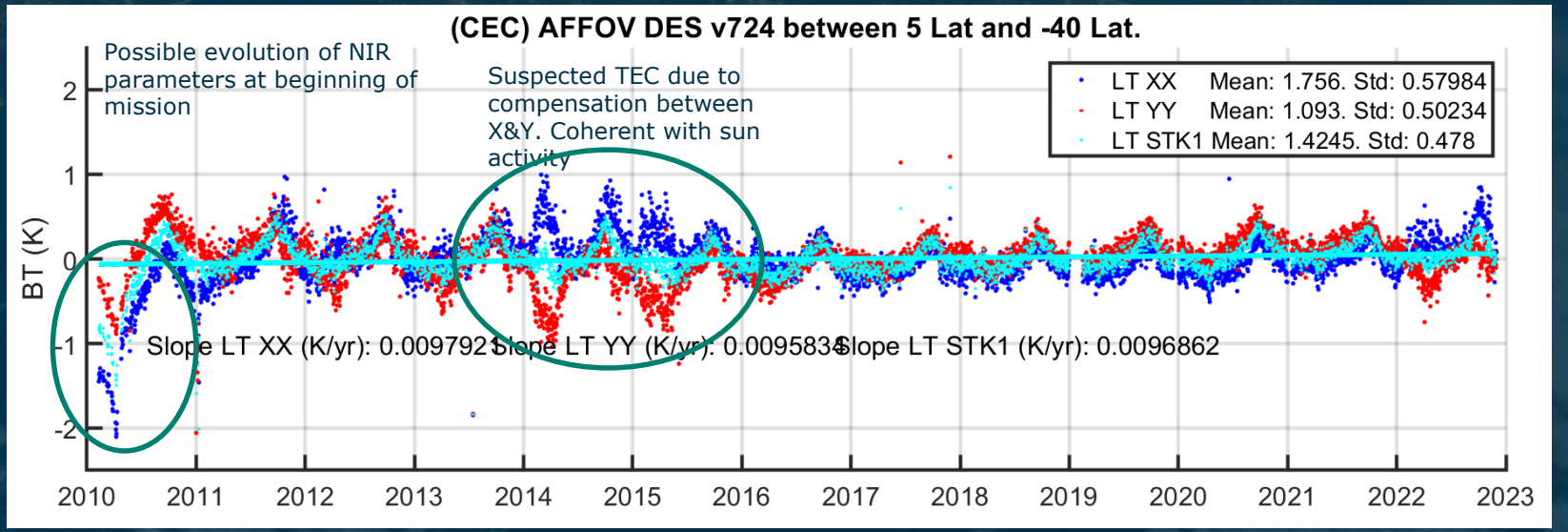




2010 2023

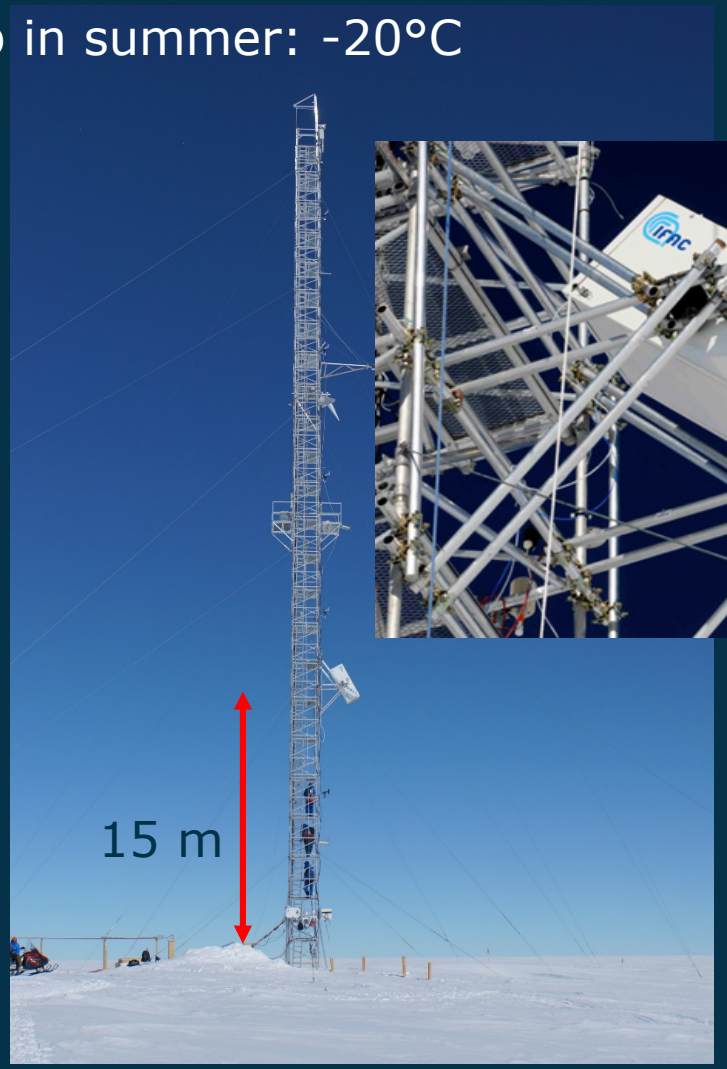
- Bias between BT from Ocean Forward Model and SMOS over a selected Pacific Ocean area
- Salinity model: ISAS up to Sep21, WOA09 onwards
- Others geophysical parameters from ECMWF forecast
- Metrics: Hovmöller tool & trends





RADOMEX: L-band microwave radiometer @ Concordia

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



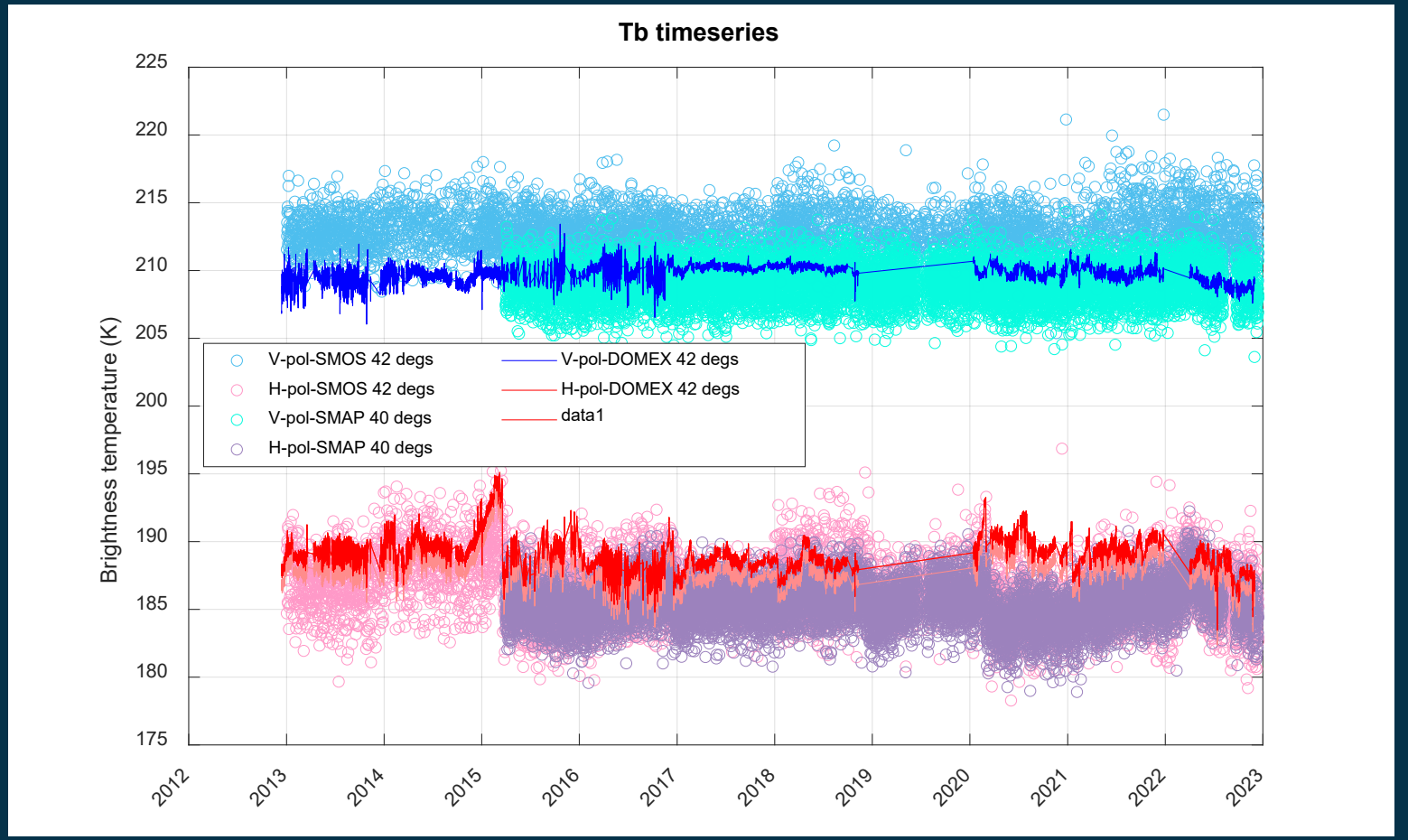
From the launch of the SMOS mission particular attention was paid to the region of Dome-C, Antarctica, with the aim of characterizing this area as a potential extended target for calibrating and monitoring low frequency microwave radiometers.

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, SMOS and SMAP Brightness Temperature (Ice)



Sensor	TbV avg (K)	TbV std (K)	TbH avg (K)	TbH std (K)
DomeX-3	209.68	0.56	189.04	1.23
SMOS	212.84	1.52	186.71	2.29
SMAP (40deg)	209.02	1.32	185.31	1.56

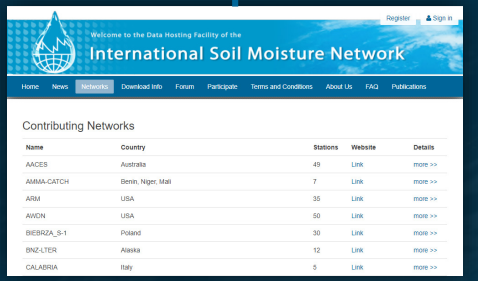
- Radiometer demonstrated good performances for long-tem monitoring
- Long-term consistency for Radomex, SMOS and SMAP
- Tb is very stable especially at V polarization
- Tb variability at H polarization is due to modification on surface properties

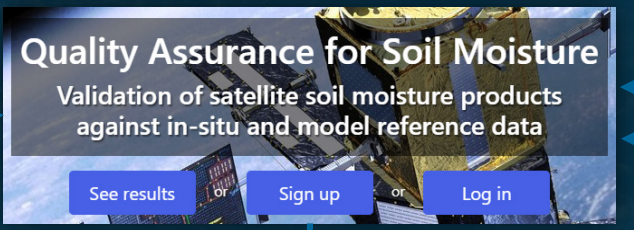
Quality Assurance for Soil Moisture (QA4SM) https://qa4sm.eu

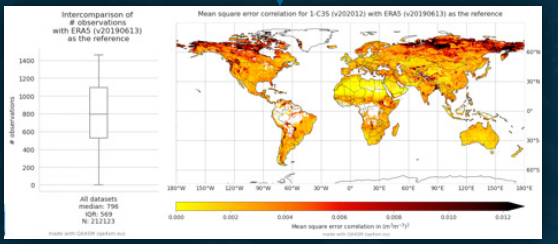
- QA4SM = on line validation service, provides a standardized validation system for soil moisture satellite derived measurements vs in situ observation and models
- QA4SM platform is maintained and evolved by ESA in the framework of the Fiducial Reference Measurements for Soil Moisture (FRM4SM) project lead by AWS, TU Vienna and Cesbio.
- Next QA4SM release 2 (March 2023) includes:

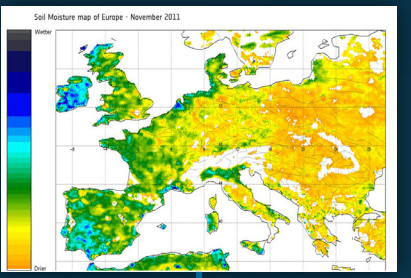
- Access to selected "Fiducial" reference in situ dataset from International Soil Moisture Network (ISMN)
- Feature to upload own user dataset
- community agreed standards for satellite soil moisture validation: Pre-processing: data filtering, matching, scaling. Metric calculation (R, ubRMSD, Bias, SNR, ...)

'FRM super site' selection based on QIs and **FRM Protocols and Procedures (FPP_SM)** developed in FRM4SM







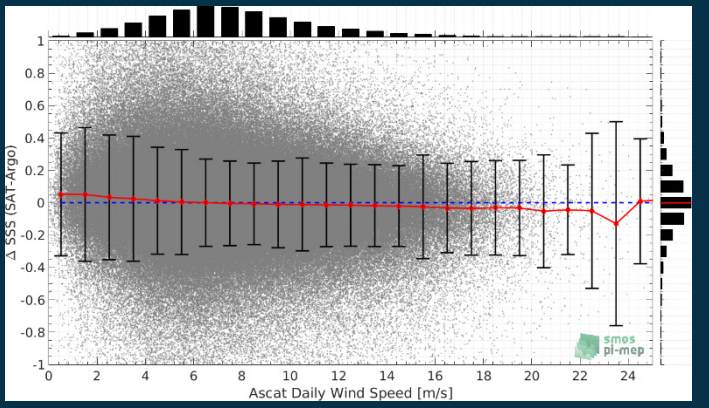


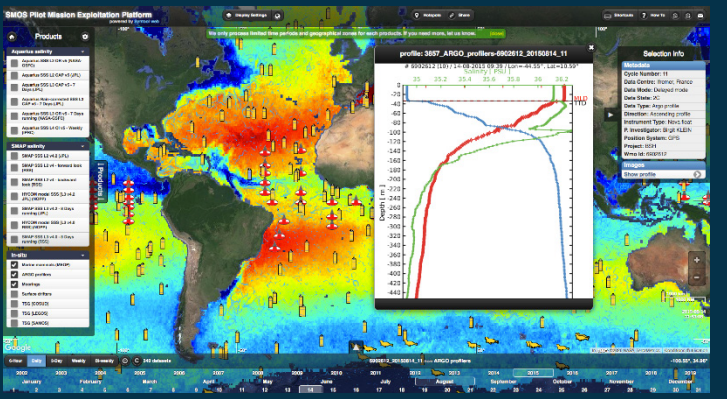
Gruber et al. (2020): *"Validation practices for satellite soil moisture retrievals: What are (the) errors?"*. DOI: 10.1016/j.rse.2020.111806

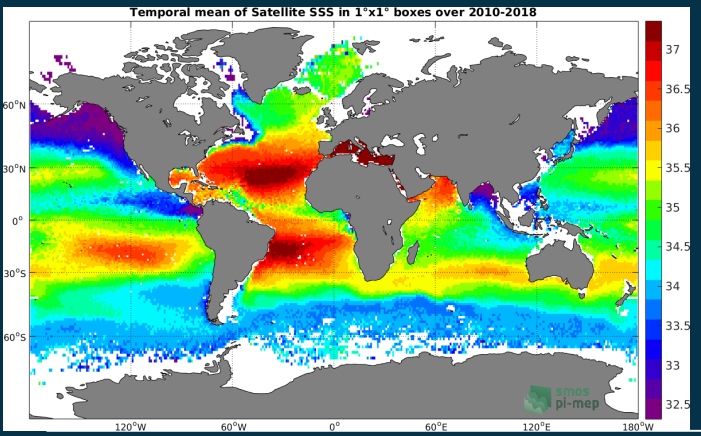
Montzka et al. (2020). *"Soil Moisture Product Validation Good Practices Protocol"*. CEOS WGCV LPV. DOI: 10.5067/doc/ceoswgcv/lpv/sm.001

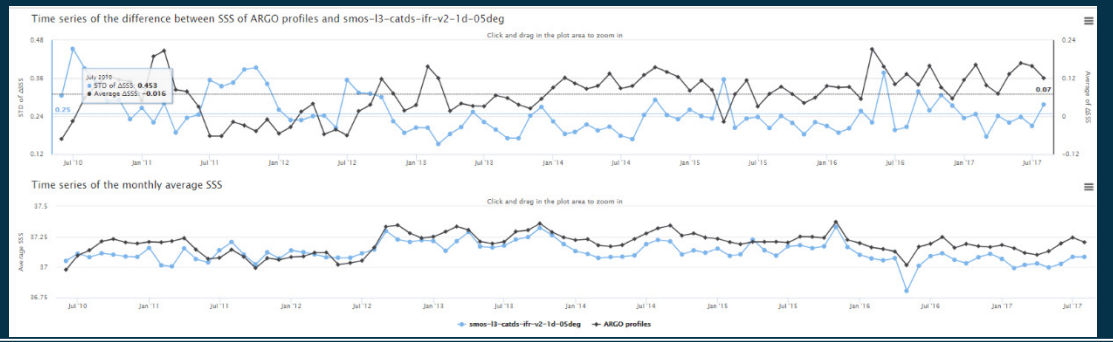
Pi-MEP Salinity – an ESA-NASA Platform

- 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:
  - ❑ Representation errors quantification by using a high-resolution model.









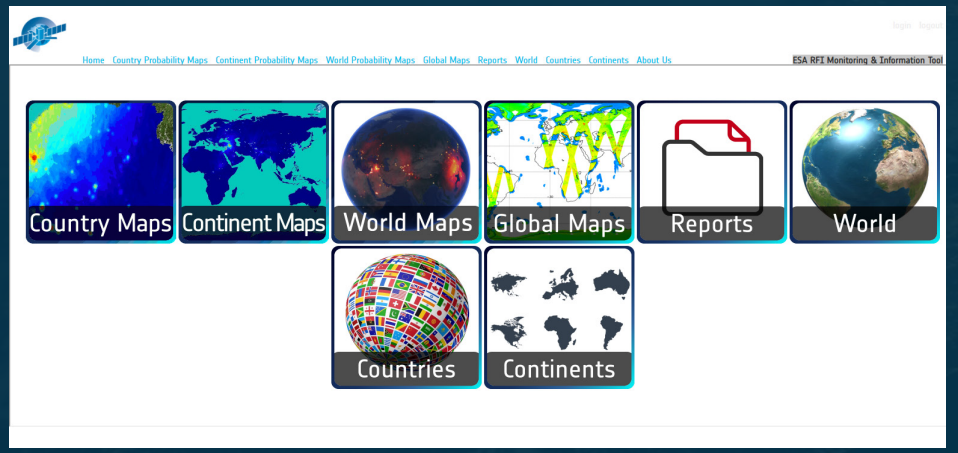
Figures - A variety of metrics and plots extracted by the Platform

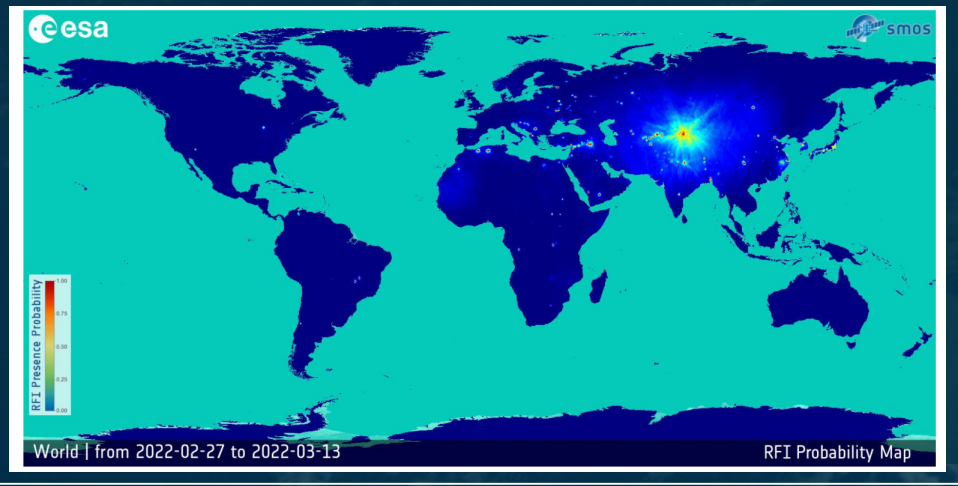
www.salinity-pimep.org

ESA RFI Monitoring & Reporting

RFI monitoring and information tool

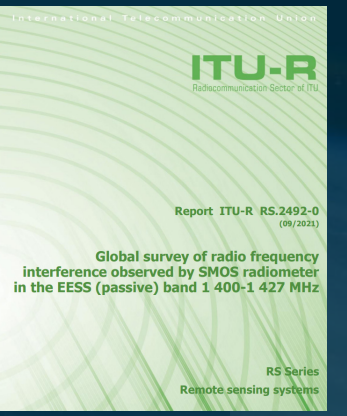
https://rfi.smos.eo.esa.int/

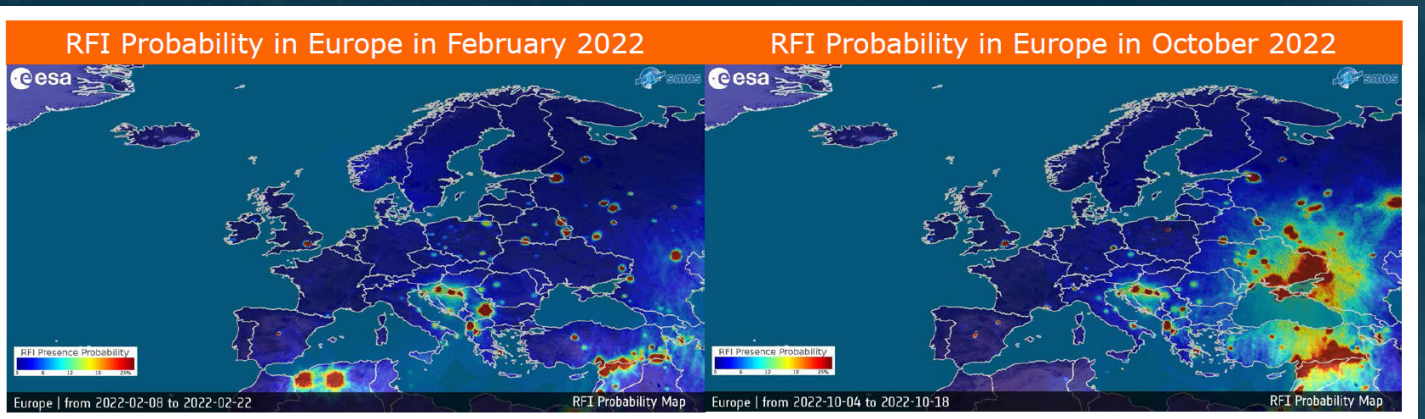




ITU Report on SMOS RFI

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





- The RFI scenario in Eastern Europe has been degraded due to military events in Ukraine and Western Russia.
- An increase in the occurrence of RFIs has also been observed at the southern and eastern borders of Turkey.
- In general, RFI maps can show geopolitical and military events around the world.
- Unfortunately, these interferences are impossible to handle using the reporting tools available.

Preparing the technology for TriHex

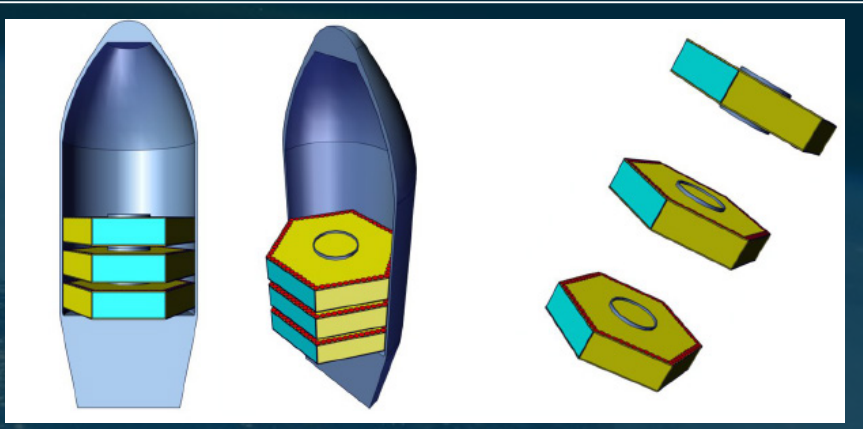
- TriHex is a technological concept to achieve high resolution passive L-band observations
- It is being developed by ESA, based on SMOS experience and industrial contracts
- TriHex combines four major ingredients to achieve high resolution (~15 km):

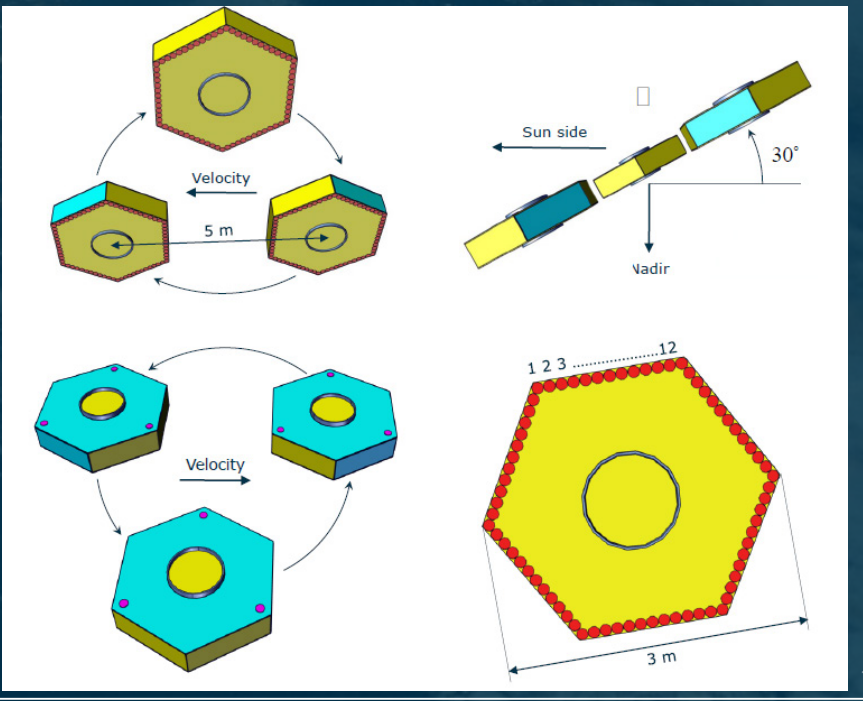
  → formation flying of 3 spacecraft at very close range (5 to 7.4 meters apart)

  → General Circular Orbits

  → Alias-free imaging

  → Low orbital altitude (around 500 km)





CIMR status (https://cimr.eu/)

CIMR 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

- Preliminary Design Review system and instrument was successfully achieved end 2022
- Mission is now in phase C-D
- Mission Requirements Document available at https://cimr.eu/documents
- Launch of CIMR-A in 2028+ (CIMR-B few years later)

Copernicus mission (active/passive) commonalities

ROSE-L

- Deformation, Landslides and urban subsidence
- Flooding
- Forest Biomass and structure
- Land over and land cover change
- High resolution soil moisture
- Sea ice characterization
- Ice sheets and glacier velocity
- Grounding line
- Snow Water Equivalent
- Permafrost thawing and extent
- Ocean surface wind vectors
- Swell properties
- Iceberg location, size and drift
- Vessel location, size and velocity
- Oil spill location and morphology

CRISTAL

- Sea-Ice thickness and snow depth
- Ice sheets surface elevation and changes
- Polar glaciers surface elevation and changes
- Ice caps surface elevation and changes
- Grounding line migration
- Global ocean topography
- Observation of water level at coasts, rivers and lakes
- Snow cover and permafrost
- Iceberg detection and change
- Ice shelf volume and change

CIMR

- Sea-Ice Concentration
- Sea-Ice Extent
- Sea-Ice, sea and land Temperature
- Sea-Ice Drift Vectors
- Thin Sea-Ice thickness
- Ice type/Stage of development
- Snow depth on Sea-Ice
- Total Snow Area
- Snow Water Equivalent
- Sea Surface Salinity
- Wind speed over ocean
- Soil moisture
- Freeze/thaw state
- Precipitation over ocean
- Terrestrial surface water extent
- Vegetation indices

CIMR Level-2 Product Families

Level-1 (independent of coverage domain)

L1a | L1b | L1c

ESA
EUMETSAT

Level-2 (families as function of coverage domain and timeliness)

Polar			Global Land		Global Ocean		Global Atmosphere	
NRT1H	***NRT3H***	***NTC***	***NRT3H***	***NTC***	***NRT3H***	***NTC***	***NRT3H***	***NTC***
SIC	SIC	SIC	TSA	TSA	SST	SST	PCP	PCP
SIED	SIE	SIE	SWE	SWE	SSS	SSS	LWP	LWP
SID	SST	SST	LSWT	LSWT	OWV	OWV	TCWV	TCWV
OWS	SIT	SIT	LIC	LIC				
	SIED	SIED	FT	FT				
	SID	SID	LST	LST				
	ITY	ITY	SM	SM				
	SND	SND	MMVI	MMVI				
	SIST	SIST	SWF	SWF				
	SSS	SSS						
	OWV	OWV						

ESA/EUMETSAT responsibilities

- ESA will operate the CIMR Mission and generate Level-1a, Level-1b and Level-1c products.
- For Polar Regions and Global Land product families, ESA will develop Level-2 pipelines for all relevant products.
- EUMETSAT will develop separate pipelines for Global Ocean and Atmosphere product families starting from ESA Level-1 products.
- The ESA and EUMETSAT pipelines at Level-2 are thus independent by design.
- Validation and quality control aspects are thus the responsibility of each respective Agency with respect to Level-2 Mission Requirements.

Summary

- SMOS Mission (https://earth.esa.int/eogateway/missions/smos) extended till end 2025
  - Platform and Payload in good condition, no criticality
  - New version of L4 sea-ice product, product delivered, new L3 Freeze and Thaw soil state coming soon
  - Preparation for full mission reprocessing (4th) in 2024 is on-going (revisit L1 calibration, L2 retrieval algorithms and auxiliary files)
  - Emerging Space Weather applications (Solar Flux and VTEC products from SMOS)
- SMOS – SMAP Brightness Temperature inter-comparison continues to show good agreements between the two sensors
- Validation platforms for soil moisture (QA4SM: https://qa4sm.eu/ui/home) and sea surface salinity (PiMep: https://www.salinity-pimep.org/) have been upgraded (e.g. new products and functionalities)
- DOMEX experiment (L-band radiometer in Antarctica) has continued with nominal operations
- RFI monitoring and reporting has continued (https://rfi.smos.eo.esa.int/)
- TriHex mission concept developed (flight formation L-band interferometer)
- CIRM mission (https://cimr.eu/) implementation has progressed well (e.g. algorithm prototyping and product definitions) now in Phase C/D. Preliminary L1 and L2 products definition.

Acknowledge

Presentation inputs from:

- Manuel Martin-Neira (ESA)
- Michele Scagliola (ESA)
- Roberto Sabia (ESA)
- Giovanni Macelloni (IFAC)
- ESA SMOS RFI team
- SMOS Calibration team
- ESA SMOS Expert Support Laboratories

Thank you for your attention

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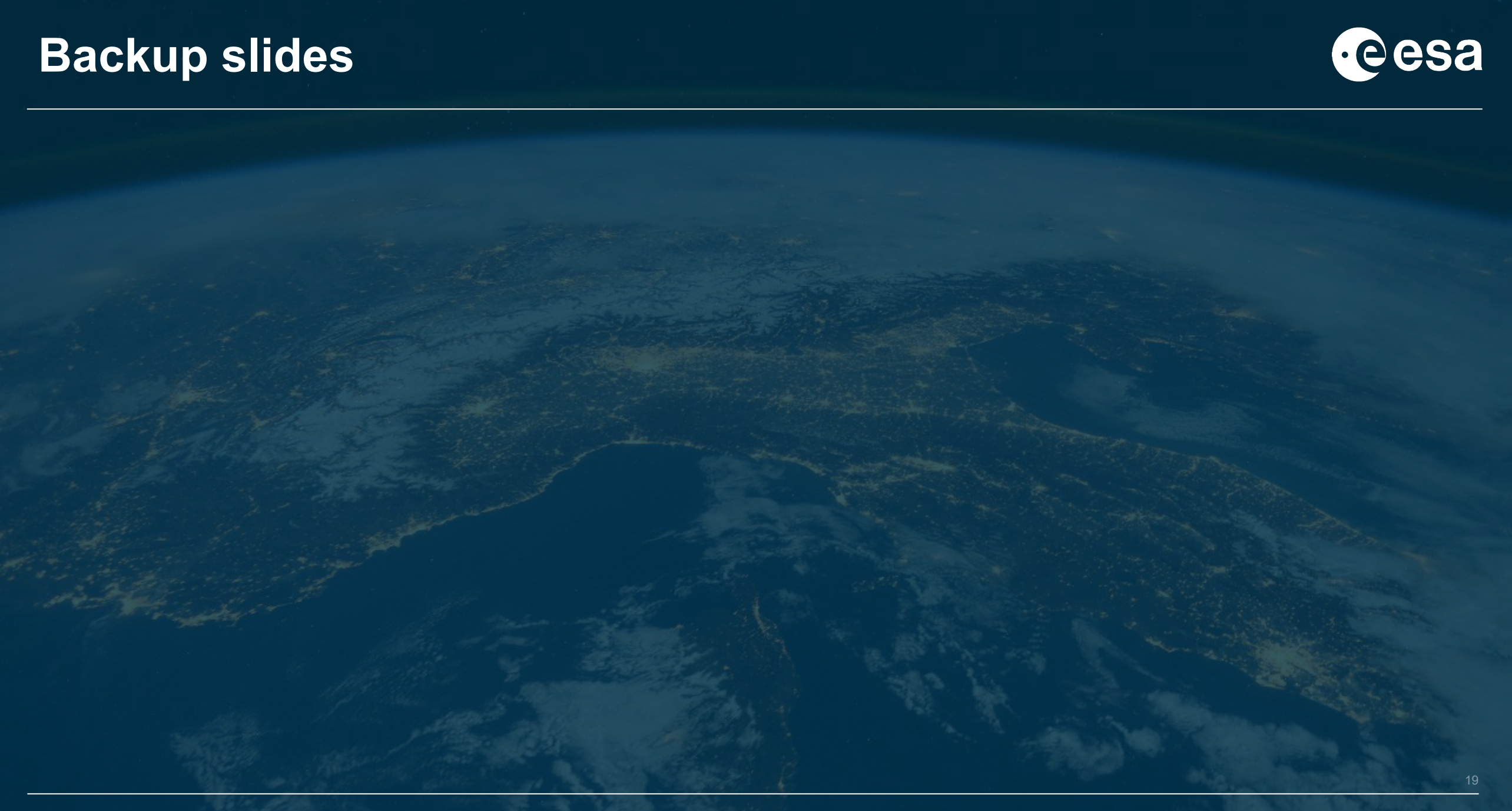
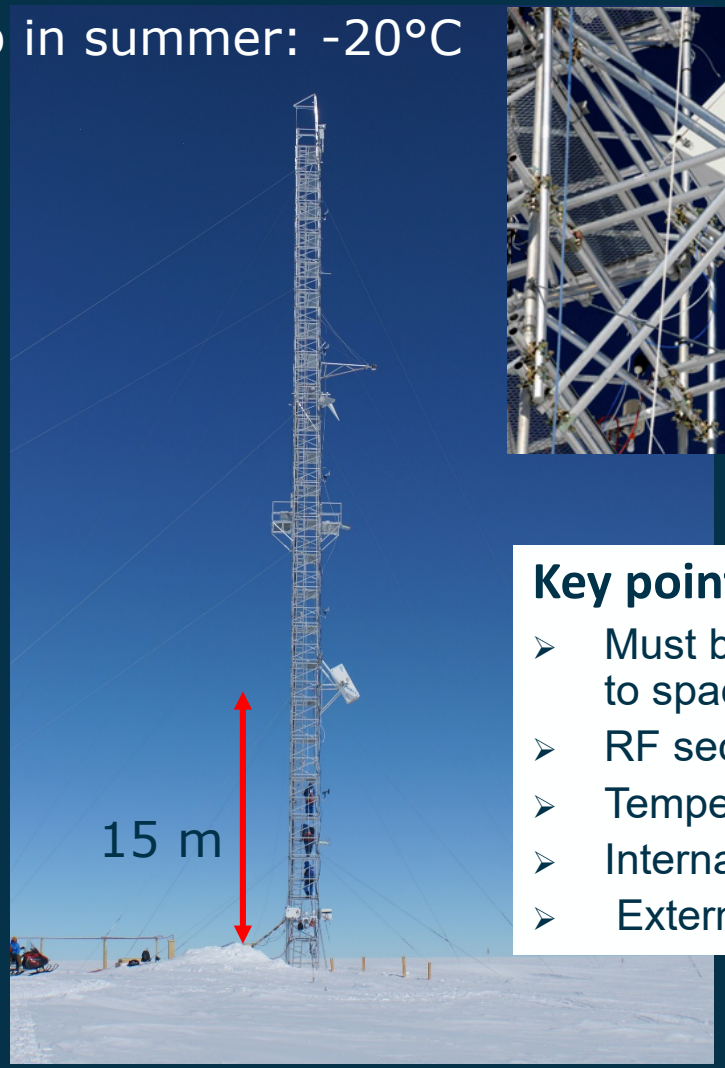
Backup slides



RADOMEX: L-band microwave radiometer

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



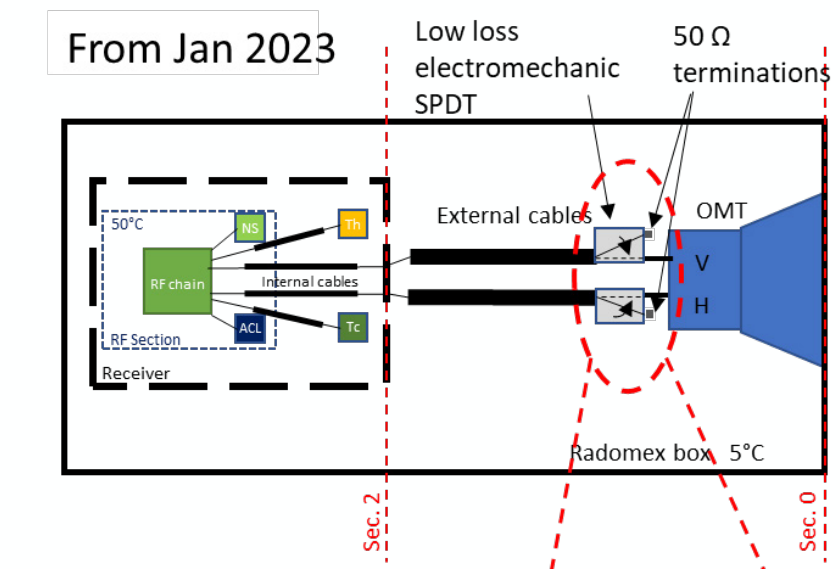
Frequency : 1413 MHz
Bandwidth: 27 MHz
Sensitivity = 0.2 K (Ti =2 sec)
Polarization: H and V
Antenna: Potter Antenna
HPBW: 20°
Active (PID) thermal control
Accuracy : 1 K

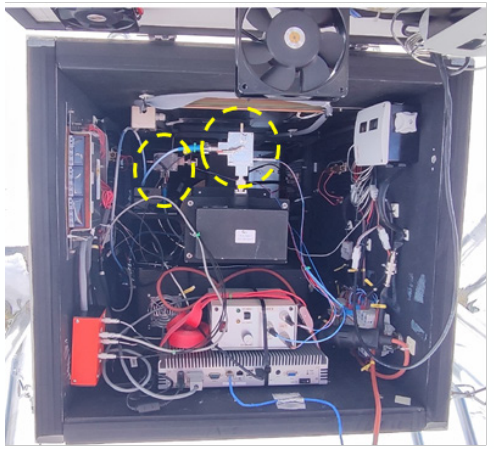
Key points:

- 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

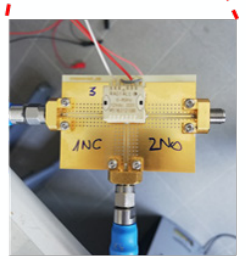
2023 Radomex Instrument Updates

To improve Absolute Calibration, an external Single Pole Double Throw switch switch (MEMS Radiall R51631210T) was connected at to the OrthoMode Transducer , it allows to connect the receiver to the antenna or to a 50 ohm termination



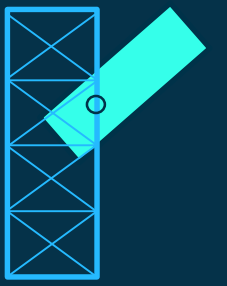


rear view

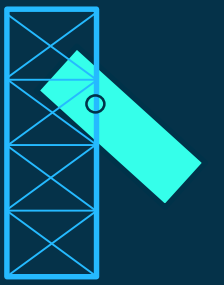


MEMS permanently installed on Radomex from January 2023

(1)
Sky acquisition 140 deg for 15 min



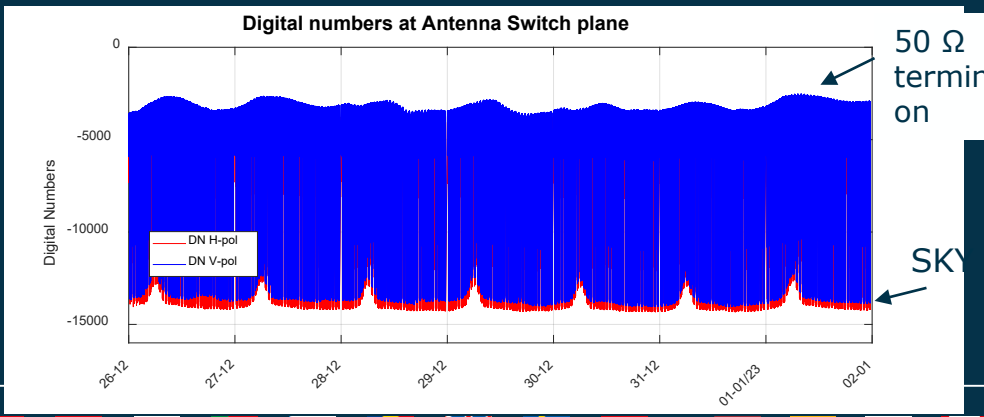
(2)
Ice sheet acquisition 42 deg for 15 min

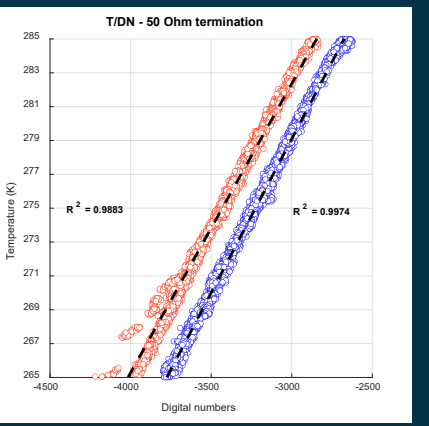


During each sky observation, external absolute calibration is computed using:

- clear sky as cold external reference (3.95 K)
- 50Ω Termination referred to the antenna plane as external hot reference
- Gain and Offset are derived and then applied to the consecutive snow observation at 42 deg.

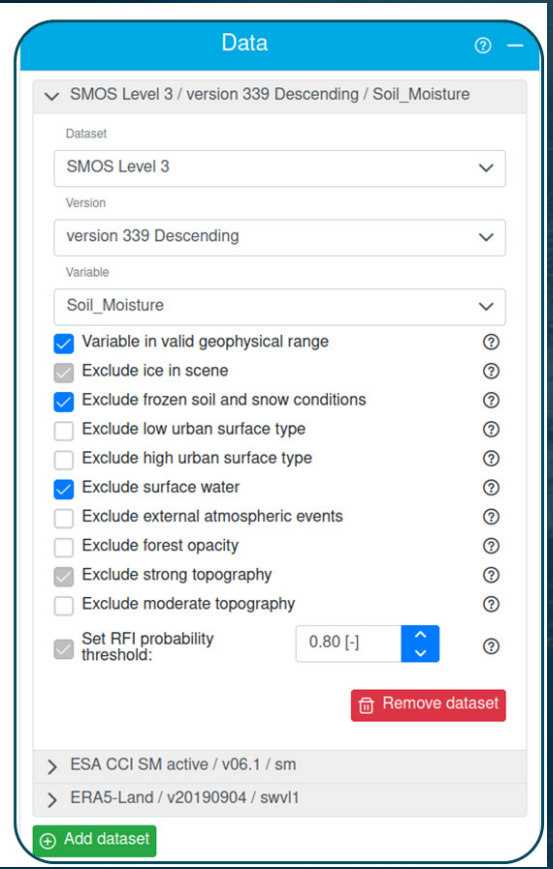
Preliminary results





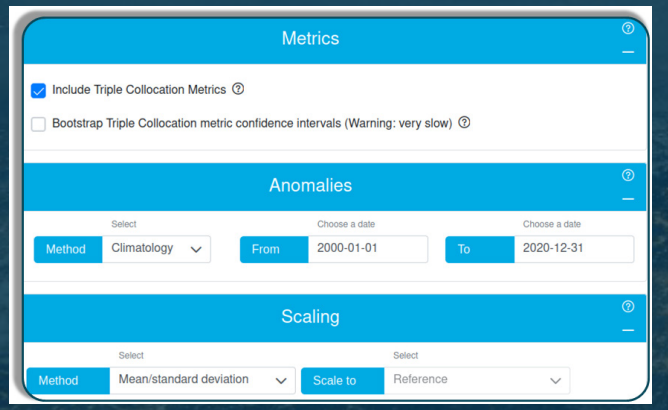
QA4SM Workflow https://qa4sm.eu

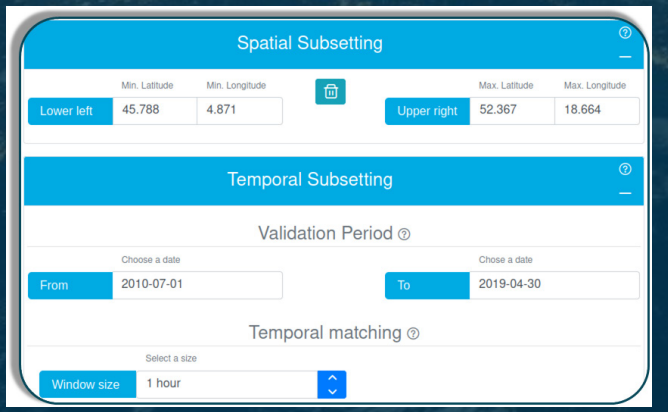
1) Data Selection



Up to 5 satellites + 1 reference

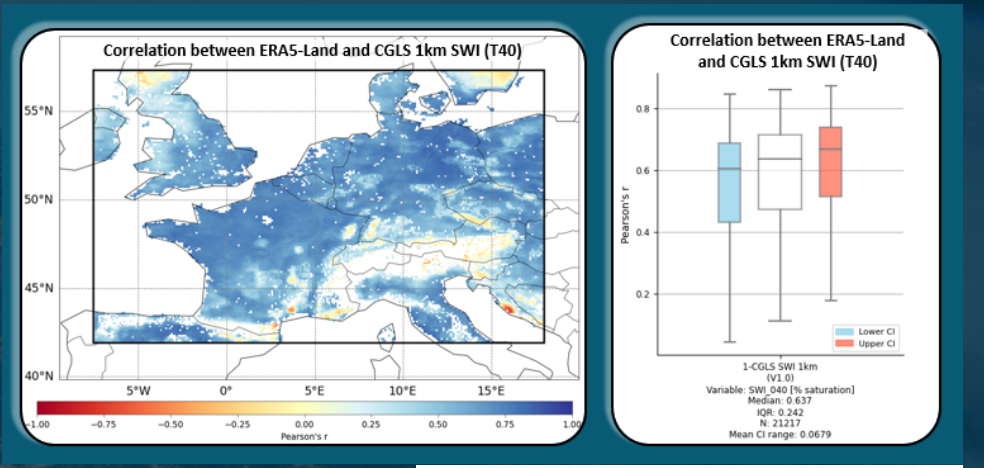
2) Customize Settings





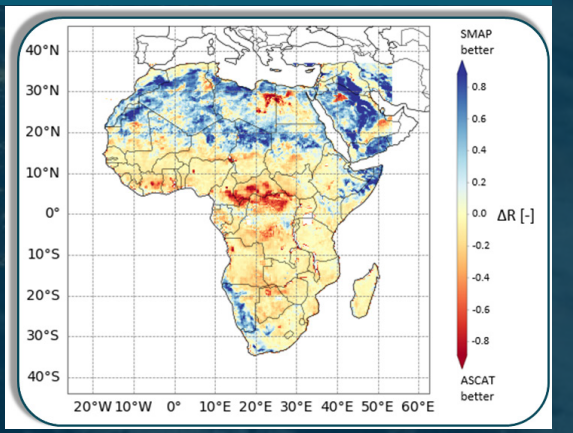
Temporal / spatial subsets, validation metrics + CIs, anomaly computation, ...

3) Process, visualize, share & download



Validation metrics ↑
tables, maps, box plots,...

Comparisons →
difference maps,
ISMN metadata based comparisons, ...



Public example: Published Validation of ESA CCI (C3S) Soil Moisture with ERA5 https://qa4sm.eu/ui/validation-result/e9a9d43a-deac-4ea5-bbcb-855065fbbeb8

TriHex features

- 3 hexagonal spacecraft rotate naturally around a reference centre at a radius of 5 m
- Spacecraft rotation plane has a roll angle of 30°; this enables avoiding Sun effects entirely
- Accurate relative navigation based on real-time carrier-based GNSS measurements
- Continuous electric propulsion maintains the formation accurately in place
- Optical links transfer raw data between spacecraft
- Syntonization and Synchronization achieved by Upper Side Band Syntonisation concept
- Body-mounted solar panels help in centre of mass stability and formation manoeuvrability
- Cold Sky calibration manoeuvres possible
- Breathing (change of inter-satellite distance) combined with repeat track for enhanced resolution possible
- Concept is scalable for further improvement in resolution

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

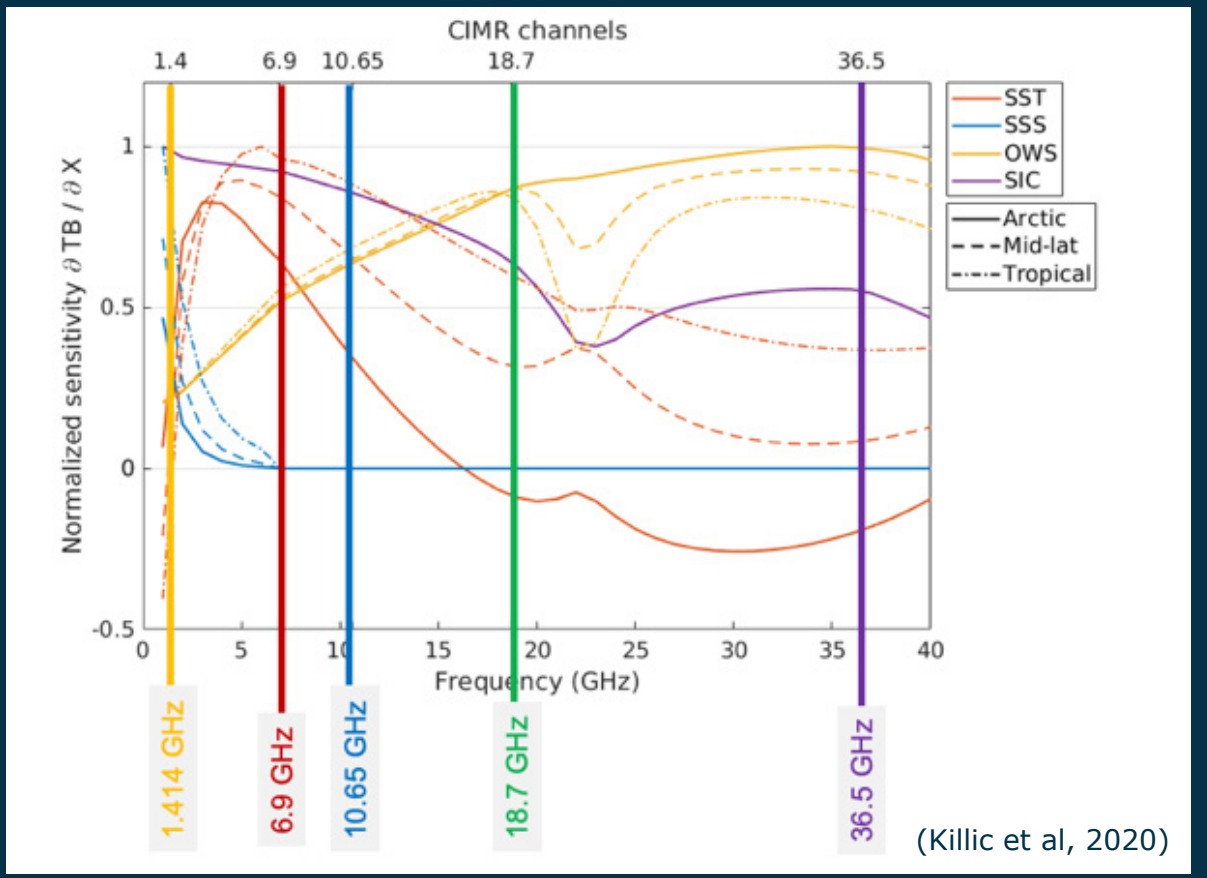
1.4135 GHz: SIT, SIC, SSS, WS, SM, SD

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



(Killic et al, 2020)

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 Level-1 and Level-2 Processing chain

The high level design for the CIMR Level-1 and Level-2 processing chain is presented here