ESA report on In-Situ observations Copernicus Programme

Philippe Goryl, ESA EOP-GMQ

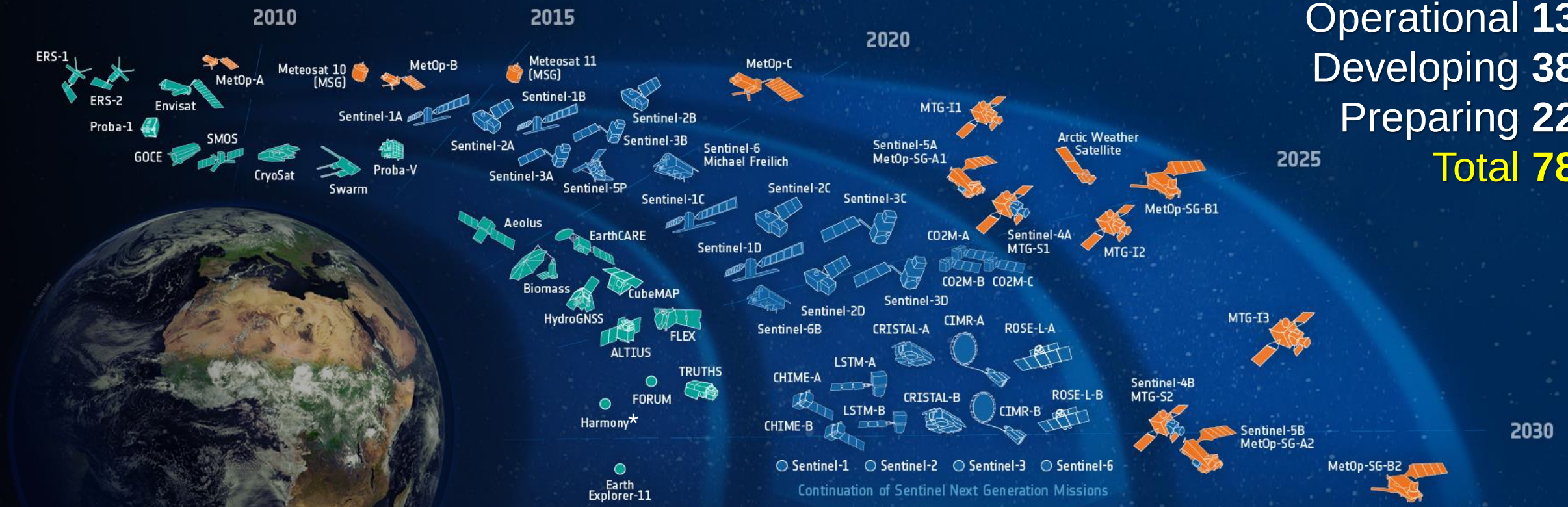
EEA, 25-26 October 2023

ESA UNCLASSIFIED – For ESA Official Use Only

ESA's Earth Observation Mission

Develop world-class Earth Observation systems with European and global partners to address scientific & societal challenges

Satellites
Heritage **05**
Operational **13**
Developing **38**
Preparing **22**
Total **78**



Science

Copernicus

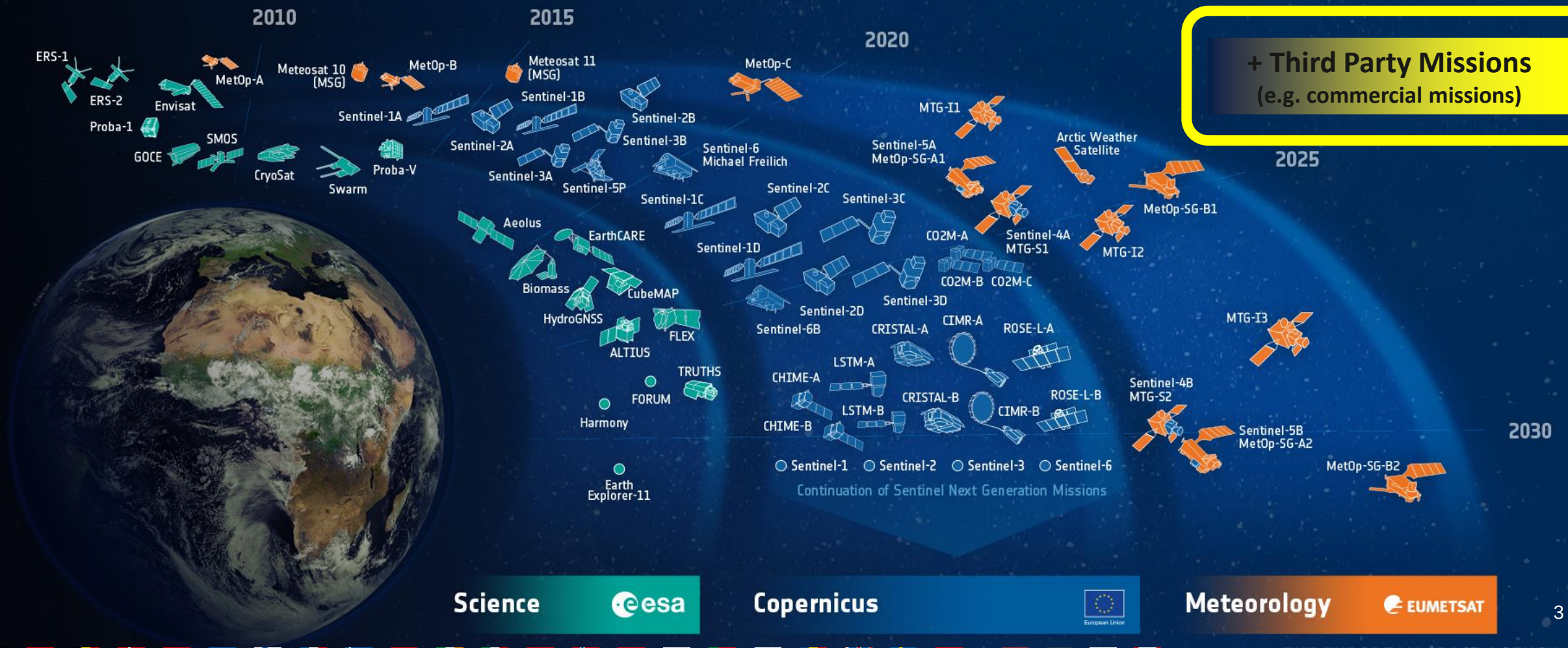
Meteorology

*Pending final mission selection

→ THE EUROPEAN SPACE AGENCY

ESA's Earth Observation Missions

Develop world-class Earth Observation systems with European and global partners to address scientific & societal challenges



+ Third Party Missions
(e.g. commercial missions)

Science | **Copernicus** | **Meteorology** EUMETSAT

ESA EO (data) customer role

ESA enables user access to EO data generated by commercial companies (including New Space companies) within two programmes:

ESA Earthnet programme paves the way towards the utilization of the commercial data for operational services

Earthnet Third Party Missions

Data for R&D and science needs

Initial data assessment
(e.g. for New Space data)

Copernicus Contributing Missions

Data (and associated delivery services) for operational public needs

Operational data delivery

EO commercial data

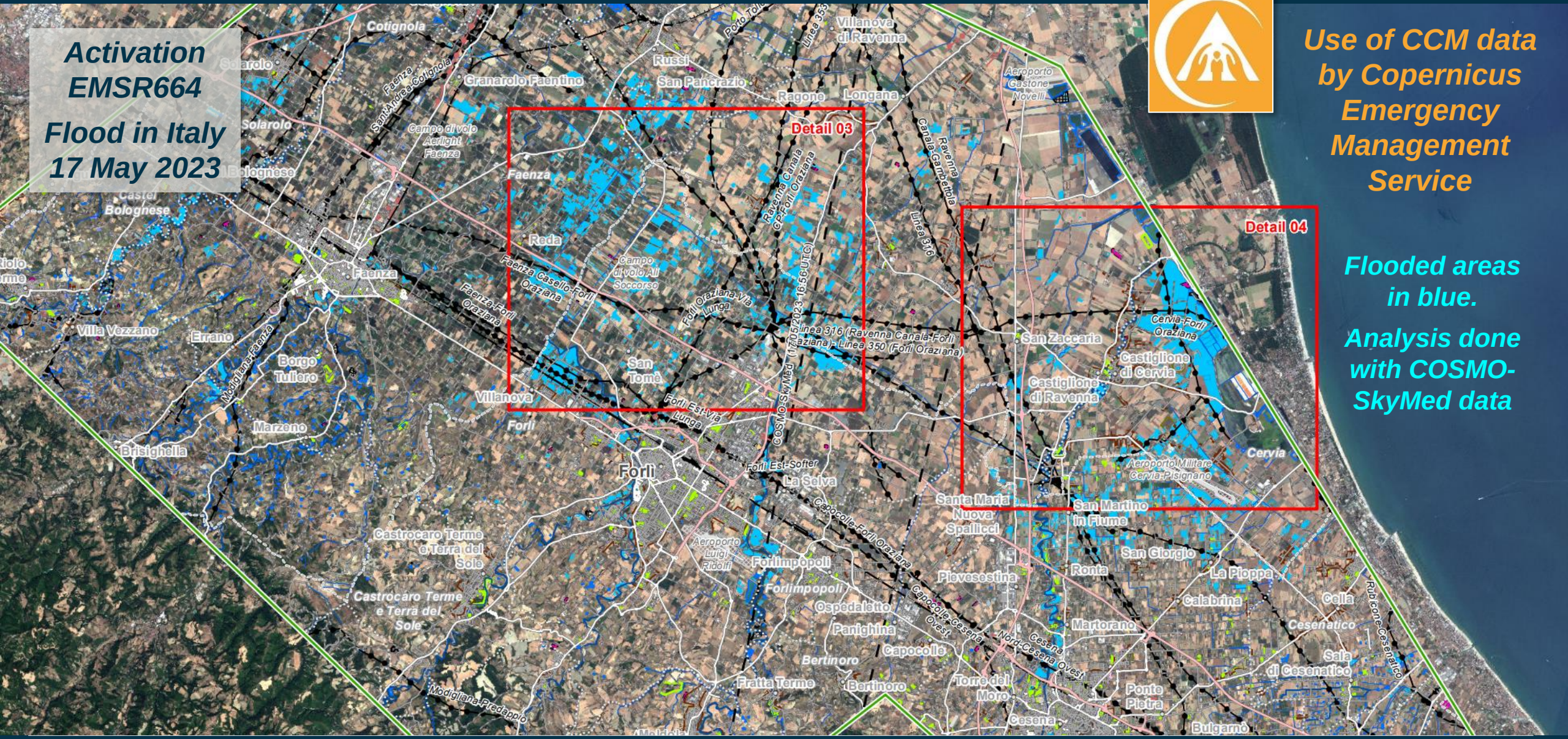
Airbus Pleiades Neo
(7 September 2022)



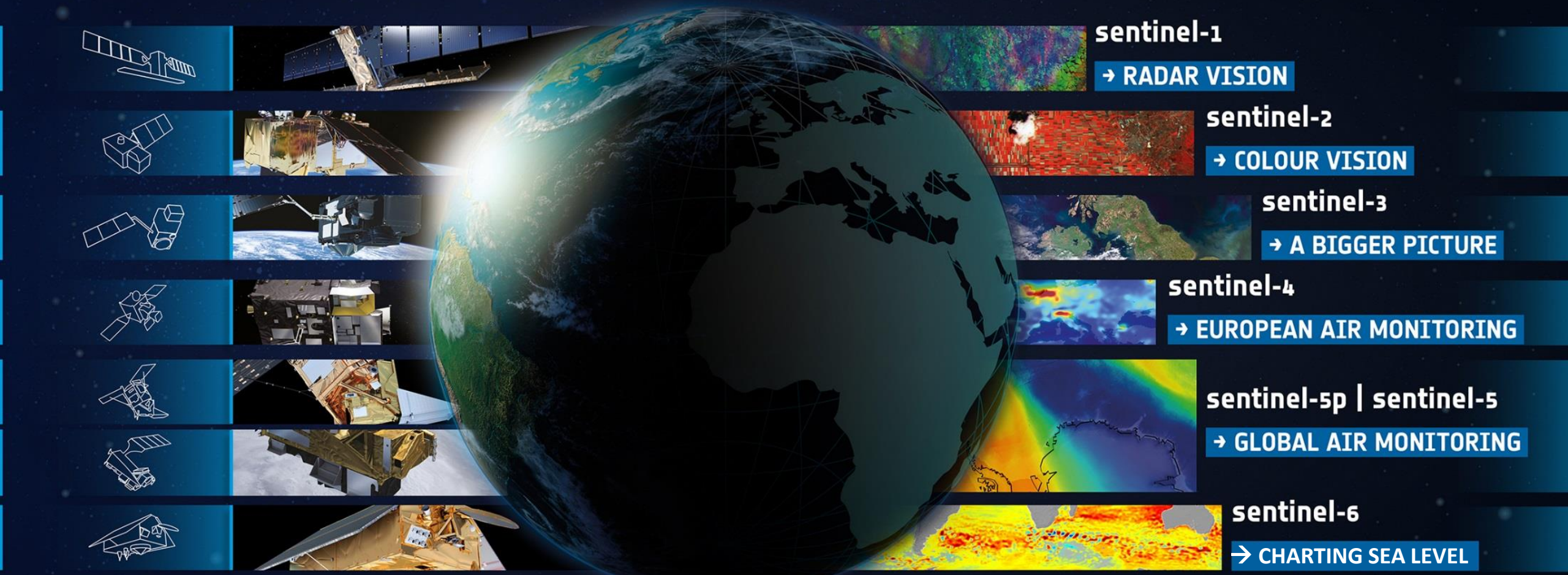
Very High Resolution EO data are provided by commercial companies.

These data are particularly relevant for some Copernicus services, e.g. Copernicus Emergency Management

Copernicus Contributing Missions (CCM)



Copernicus Sentinels (First Generation)



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PROGRAMME OF THE EUROPEAN UNION

Copernicus
Europe's eyes on Earth

co-funded with esa

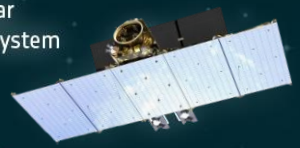
Sentinel Expansion missions to strengthen Copernicus



CHIME
Copernicus Hyperspectral Imaging Mission for the Environment

soil properties
crop health
raw materials
biodiversity
water quality

ROSE-L
L-band Radar Observing System



geohazards
polar ice
forest management
food security
maritime surveillance



LSTM
Land Surface Temperature Monitoring

sustainable agriculture
water resources management
drought
urban heat islands

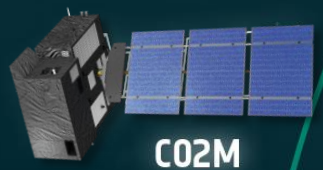
Food Security and Water Management

Monitoring Land and Natural Resources

sea-ice concentration
sea-surface temperature
polar maritime security
global ocean and cryosphere
soil moisture and vegetation

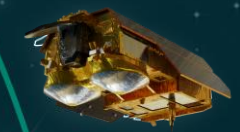


CIMR
Copernicus Imaging Microwave Radiometer



CO2M
Copernicus Anthropogenic Carbon Dioxide Monitoring

carbon dioxide and methane from human activity



CRISTAL
Copernicus Polar Ice and Snow Topography Altimeter

sea-ice thickness
ice sheets and glaciers
snow
polar oceanography
coastal and inland waters



Combatting Climate Change

Copernicus Sentinel Expansion Missions

Safeguarding the Arctic

Fiducial Reference Measurements

FRM project	Parameter	Missions	Status
Current FRM Project			
FRM4SM	Soil Moisture	SMOS / CIMR	Started 2020 – ccn for 2023
FRM4STS	SST	SLSTR / CIMR	CCN planned for Q2 2023
St3TART	Water surface height, land and sea ice thickness	Sentinel 3 (CRISTAL)	Started 07/2021 – end 04/2023
FRM4RADAR	Cloud products	EarthCARE	Started 15/05/2018 – 15/08/2020 and CCN still on-going
DIVA	Aerosol, Ozone, Water Vapour, other atmospheric composition gases from Lidar, Photometer, PANDORA and the GRASP inversion algorithm	S3, S5p, ADM-Aeolus, EarthCARE, S4, S5, MERLIN, GOME-2c, 3MI.	Phase I started 2017 Phase II started 2019 Phase III Q2 2023
EVE	Vertical and slant aerosol profiles from high quality multi-wavelength / multi-polarisation Lidar	Mainly for Aeolus and EarthCare (lidar) missions. Aerosol products useful for any atmospheric composition missions	
FRM4DOAS	Tropospheric & stratospheric NO2 vertical profiles, total O3 column, tropospheric HCHO profile Under development: aerosol product; advanced urban tropospheric NO2 product	S5P / S5 /S4	&D: First project 2016 - 2020 Second project started 2021 – 2025. Project on-going, current focus on urban NO2.
FRM4GHG	CO, CH4 Characterisation and comparison of small portable FTIR instruments products with established TCCON: CO2	S5P, S5, CO2M	R&D: First project 2016 - 2020 Second project started 2021 – 2025. Project on going. Travel standard is very successful, being deployed after the development.
COCCON	CO, CO2, CH4 Operational instruments support (processing, calibration)	S5P, S5, CO2M	Operational and R&D (ESA funded): Preops: 2017 – 2023 Operational: 2023 – 2027. Pre-operation is on going. Routine deployment of Coccon stations are on going. Data are routinely sent to EVDC (Match Up Data Base)
FRM4AQ	Total and tropospheric column: O3, NO2,	S5P, S4, S5	R&D – FRM4AQ (ESA budget): First project: 2018 – 2022 Second project: 2023 – 2026
PGN (Pandonia Global Network)	SO2, HCHCO, H2O Under development: CHOCHO, NO3, HONO		PGN workshop is planned on 3-5 October 2023. WV as test product has been introduced and is currently used. Operational (EC budget): POp : 2018 - 2022 POp 2.0 : 2022 - 2027
SIN'XS	Sea ice thickness, snow depth on sea ice	Multi-mission (CryoSat, SMOS, S3, AltiKa)	Started xx/05/2022 – 3-year contract
FRM4Veg	Surface reflectance FAPAR	Sentinel-2, Sentinel-3	FRM4Veg-Phase 2 had KO on 11-12/02/2020 – CCN for postponing end of activities to 2023, due to the Covid outbreak in 2020-2021. FRM4Veg-Phase 3 foreseen.
FRM planned			
FRM4BIOMASS	Evolve the protocols and tools to estimate plot level forest biomass estimates from tree-by-tree forest census observations, capitalising on the Biomass R package developed under the ESA Forest Observation system contract.	BIOMASS, ROSE-L	KO planned for October 2023.
FRM4DOAS FAST	Operational central processing of FRM4DOAS products	S5P, …	ITT Q1-Q2 2023
TCCON FAST	TCCON data products in timely availability <= 3 months	S5P, …	ITT Q1-Q2 2023
FRM4FLEX	Fluorescence	FLEX (S5P)	ITT Q3 2023 - Start: Q2 2024
St3TART Follow On	Water surface height, land and sea ice thickness	Sentinel 3 (CRISTAL)	Follow on : ITT Q2/Q3 2023
FRM4Veg	Surface reflectance FAPAR	Sentinel-2, Sentinel-3	FRM4Veg-Phase 3 foreseen for Q1 2024
FRM4ROSEL Ocean	Total HS, wind speed, surface velocity	ROSEL/Harmony/S1	ITT Q3 2024 - Start: Q2 2025
FRM4ROSEL Forest	Forest height, AGB	ROSEL/BIOMASS	ITT Q3 2024 - Start: Q2 2025
FRM4O3PROFILE	O3 profile	S5P, Altius	To be defined – start ca 2025
Future Ideas			
FRM4CRISTAL	Surface elevation, Sea-ice thickness, snow depth	CRISTAL, CIMR, Sentine-3, Sentinel-6, CryoSat	To be defined – start ca 2026
FRM4CIMR	Sea Ice characteristics, Snow Depth on Sea Ice, Ocean Surface Wind Speed, Terrestrial Snow, Lake Ice Cover, Soil Moisture, Vegetation Indicators, Land Surface Temperature	CIMR, CRISTAL, SMOS	To be defined – start ca 2026

FRM (Fiducial Reference Measurement) :
is the suite of independent ground measurements that provide **independent validation results** and satellite measurement **uncertainty estimation**, over the entire **end-to-end duration of a satellite mission**.

→ **ESA started/prepares a number of projects aiming at improving the Calibration/Validation measurements**

FRM4Veg

FRM4VEG is an ESA-founded project aiming at **applying the FRM concept to in-situ measurements of the several land products ESA distributes** (surface reflectance, the fraction of absorbed photosynthetically active radiation (FAPAR), canopy chlorophyll content, etc.).

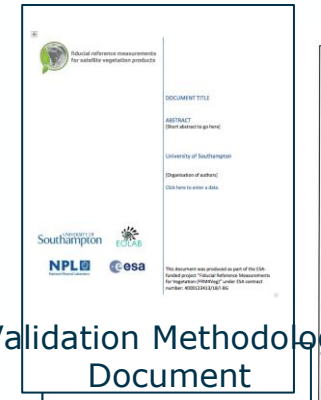
- ✓ Definition of **methodology and protocols** for validation;
- ✓ Provision of **SI traceability**;
- ✓ Estimation of **full uncertainty budget;**
- ✓ Building on **existing capacity.**

https://frm4veg.org/

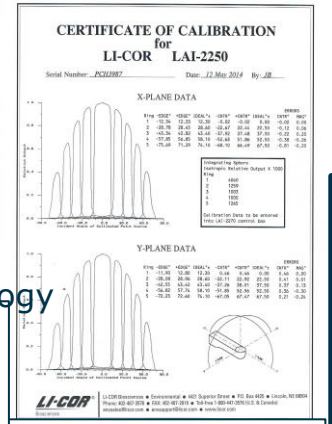
SENTINEL 2 SENTINEL 3 CHIME proba-v flex

SRIX4Veg – Surface Reflectance Intercomparison Exercise - is a joint effort to ensure consensus on surface reflectance validation protocols using drones, with CEOS endorsement

Instrument Calibration history and certificates



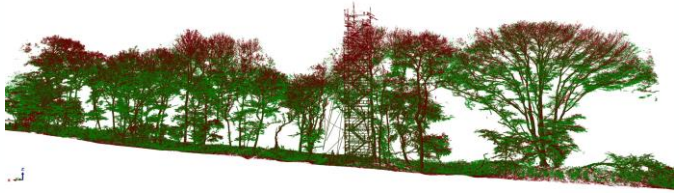
Validation Methodology Document





FRM Protocols and Procedures Document



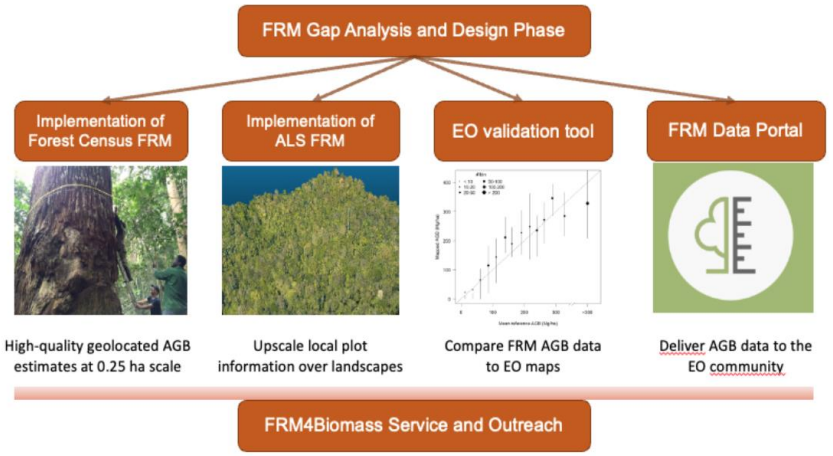








FRM4biomass Structure



- Project team: **CNRS, IRD, GFZ, IIASA**

FRM4biomass Highlights

- FRM4Biomass KO in November 2023, 26 months contract (until January 2025)
- Strong ties to the CCI biomass project (through common tools and study team).
- Additional leverage through the GEO-TREES initiative (an international collaboration to collect ground data)
- CCI contributes with an additional WP to support the integration of GEO-TREES data (CCN to be implemented)

FRM4SM Objectives

OBJ-1: Evolve the biomass R package to convert tree-by-tree forest census measurements to plot level AGB estimates and implement the changes (protocols and software tools).

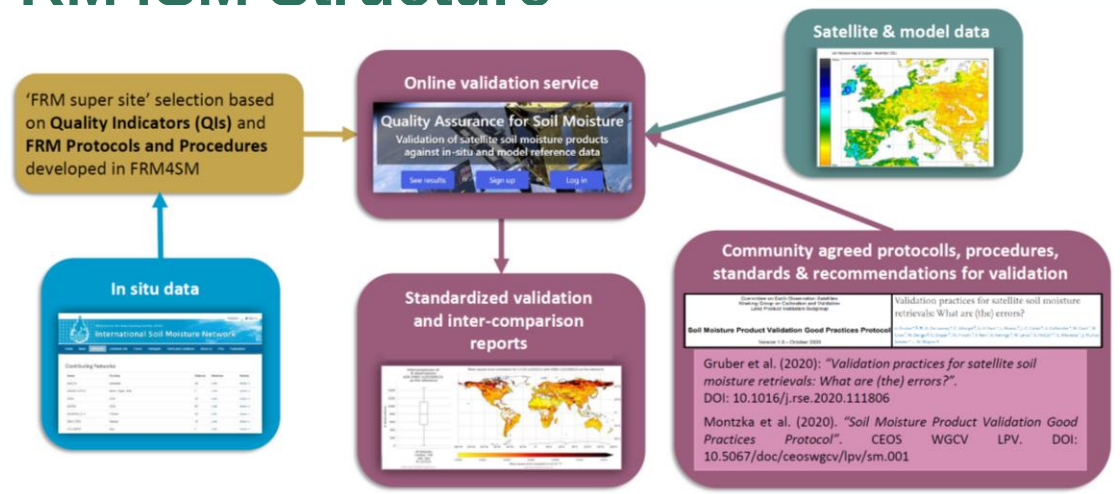
OBJ-2: Design and implement a processing pipeline (protocols and tools) to estimate plot level canopy height and AGB from Airborne Lidar Scanning measurements.

OBJ-3: Evolve the plot2map toolkit (a CCI biomass predevelopment) for the validation of biomass products and implement it on the Biomass MAAP. The tool shall allow the autonomous generation of validation reports for AGB and FH products following recommendations defined in the CEOS biomass cal/val protocol.

OBJ-4: Implement and maintain a data portal and ensure open, free and fair sharing of the forest census and ALS FRMs.

OBJ-5: Systematically integrate data collected in the GEO-TREES initiative in the FRM4biomass data portal (funded through CCI).

FRM4SM Structure



- Project team: AWST, TU Wien, CESBIO

FRM4SM Highlights

- **FRM4SM Phase 1 was completed in June 2023, project extension until December 2024**
- **Project outcomes are reported on [FRM4SM: Fiducial Reference Measurements for Soil Moisture - Earth Online (esa.int)]**
- **QA4SM Validation platform updated (V2) and used by CCI**
- **Phase-2 (-> 2025) under definition (*in cooperation with CCI?)***
  - *Strong ties to the CCI soil moisture project (through study teams and common tools).*

FRM4SM Objectives

New quality indicators (QI) will be tested and, if deemed useful, implemented into next QA4SM in June 2024 *(relevant for CCI)*

- Spatial Scale Qis: describing sub-pixel heterogeneity of land cover, soil texture, biomass, organic carbon content, water body fraction
- Temporal scale-related QIs: describing data gap characteristics (quasi-randomly, intermittently, prolonged, …)
- Temporally-dynamic Qis: describing seasonal changes in measurement uncertainty

FRM protocols and procedures will be further developed

- Guidelines for FRM-compliant network installation, calibration, and maintenance will be developed in collaboration with relevant community experts, Efforts toward traceable uncertainty budgets for ISMN networks will be continued

Assessment and development of temporal stability metrics *(relevant for CCI)*

- Common GCOS definitions and thresholds for temporal product stability will be critically revisited
- Alternative metrics to assess temporal product stability will be tested e.g., converting L1 sensor drifts to soil moisture space vs. FRM-based stability assessments.

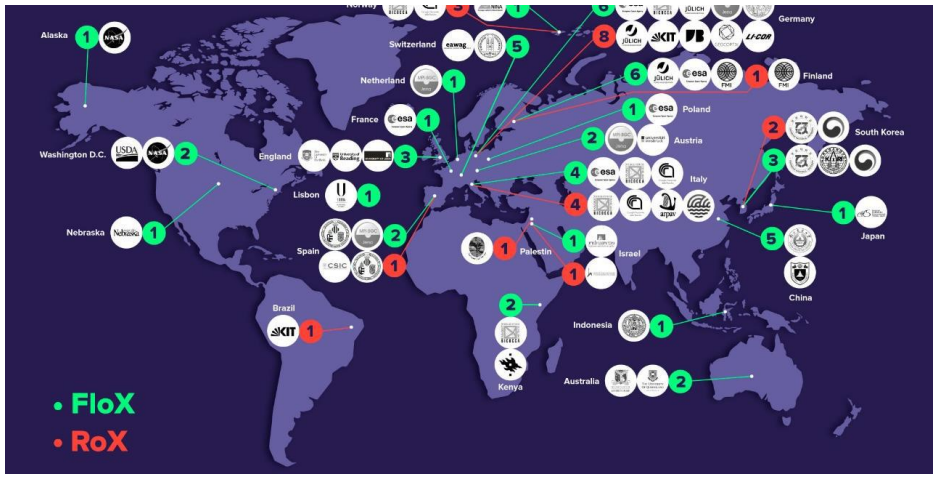
FRM4FLEX

- Project planned to start Q2/Q3 2024 with an initial duration of 2 years
- **Main goal**: provide a ground network for FLEX validation prior launch
- **Activities** centred around the FLOX system
  - establish a full uncertainty propagation protocol for all FLOX instruments
  - define a calibration strategy for the instruments deployed in the field
  - Building the network – create a FLEX reference validation database using data from all the available FLOX systems (50+ instruments spread around the world) with a consolidated unique and centralized data processing and calibration
- Potential to use the network for validating other Fluorescence products in the context of SIF as ECV

FLuorescence boX (FLOX)



OPTIC	Spec1	Spec2
Wavelength range	~ 650–800 nm;	~ 400–950 mn
Spectral Sampling Interval (SSI)	~ 0.17 nm	~ 0.65 nm
Spectral resolution (FWHM)	~ 0.3 nm	~ 1.5 nm
Signal to Noise Ratio (SNR)	~ 1000	~ 250
Field Of View (FOV)	Dual FOV. Upwelling radiance ~25°. Downwelling radiance 180°	



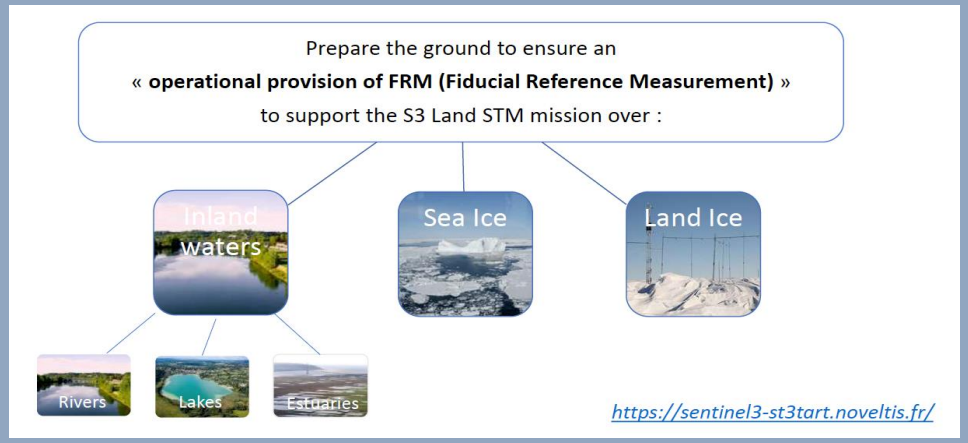
(Credits T. Jullita)

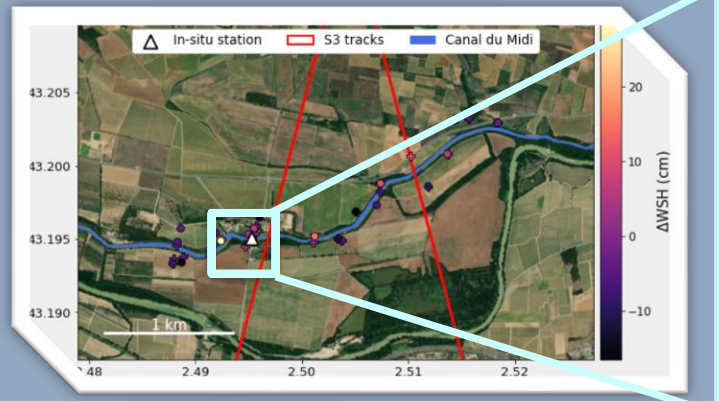
S-3 Altimetry – St3TART project

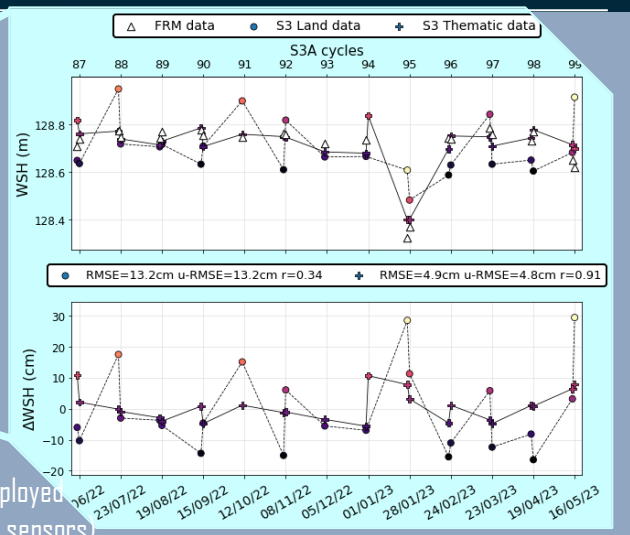
PROGRAMME OF THE EUROPEAN UNION

NEW FIDUCIAL REFERENCE MEASUREMENTS (FRM) FOR S-3 OVER SEA ICE, LAND ICE & INLAND

St3TART (S-3 Topography mission Assessment through Reference Techniques) main objective:





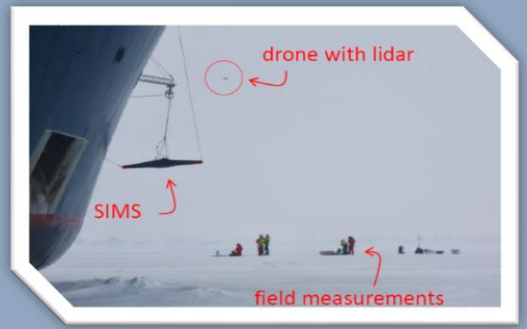




In numbers:

- 12 micro stations deployed over EU (7 pressure sensors) for inland waters
- 20 in-situ campaigns performed
- 250 km of drone flights over sea ice and inland waters









Main project outcomes:

- FRM protocols and procedures definition
- Roadmap and Strategy for FRM operational provision

- St3TART FO for FRM operational provision
  ➔ **ITT issue in Q1 2024**

More info: https://sentinel3-st3tart.noveltis.fr/
Success Story on Sentinel Online

S-3 Altimetry – St3TART project

PROGRAMME OF THE EUROPEAN UNION

Copernicus Europe's eyes on Earth

esa

1

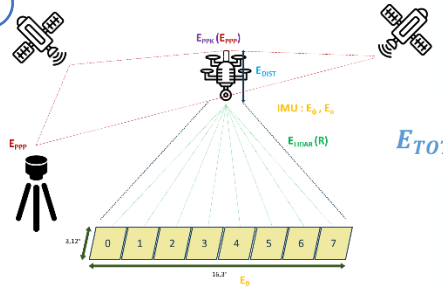
Correction	Average order of STD
Geoid height	Negligible impact if a sensor is +/- 1 km to the actual ground track
Pole tide, Solid Earth tide and Loading tide	Few milimeters
Orbit determination	< 1 cm
Ionosphere correction from models	< 1 cm
Dry tropospheric correction from models	< 1 cm
Wet tropospheric correction from models	~ 1.5 cm
Range estimation	Several cms or decimeters

2 4





5



$$E_{TOT} = \sqrt{E_{PPK}^2 + E_{DIST}^2 + E_{AD_{TOT}}^2}$$

1 Identification of the measurand to focus on, reviewing altimetry measurement uncertainties

2 Review of in-situ sensors performance and adequacy to FRM needs

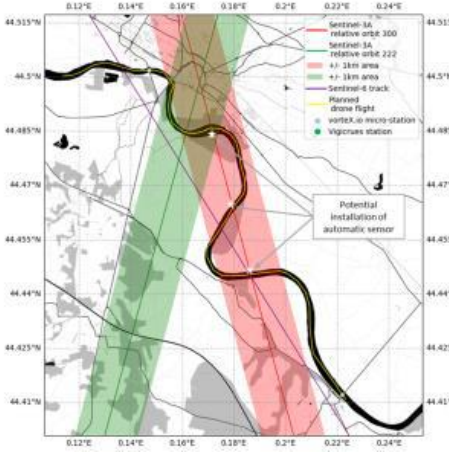
3 Identification of super sites to deploy sensors

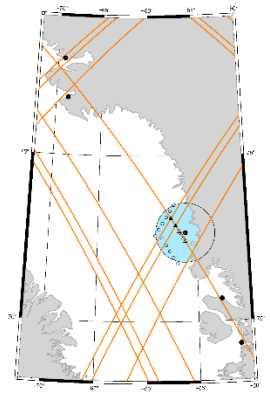
4 Deployment on the field (not over land ice)

5 Comparison of measures with S3 data (1st level of analysis) + analyse of uncertainties

6 Definition of the roadmap for FRM provisionning

3



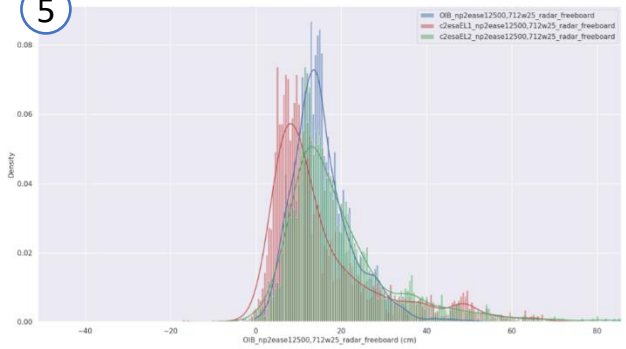


2 4





5



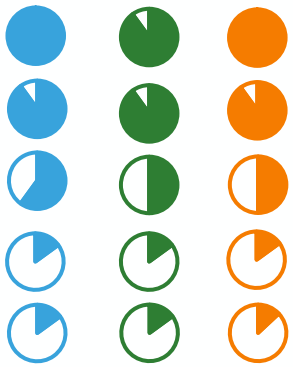
S-3 Altimetry – St3TART project

PROGRAMME OF THE EUROPEAN UNION

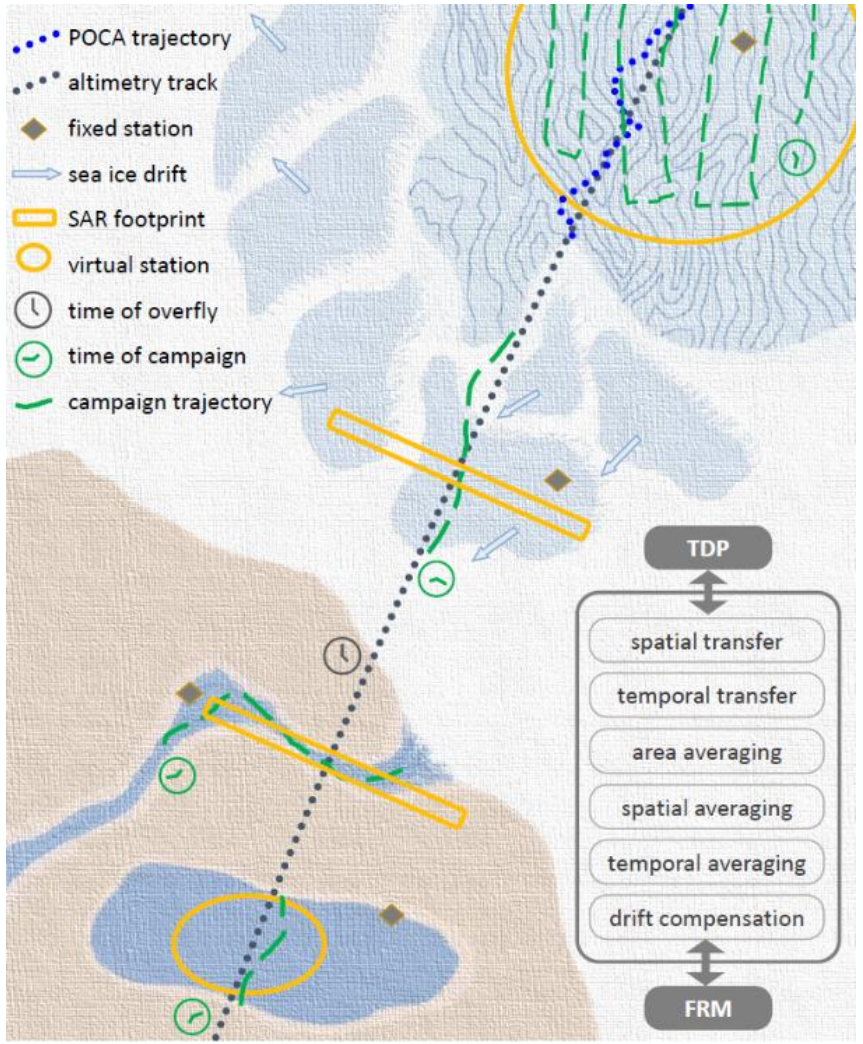
Focus on metrology – Analysis of uncertainties

MEASURAND 01 | TRACEABILITY 02 | UNCERTAINTY 03 | CALCULATE 04 | Document 05

1. Define the measurand and the measurement model
2. Establish traceability with a diagram
3. Evaluate sources of uncertainty and establish effects tables
4. Calculate the FRM and its associated uncertainty
5. Document/provide uncertainties for different purposes



➔ Work to be completed within St3TART FO



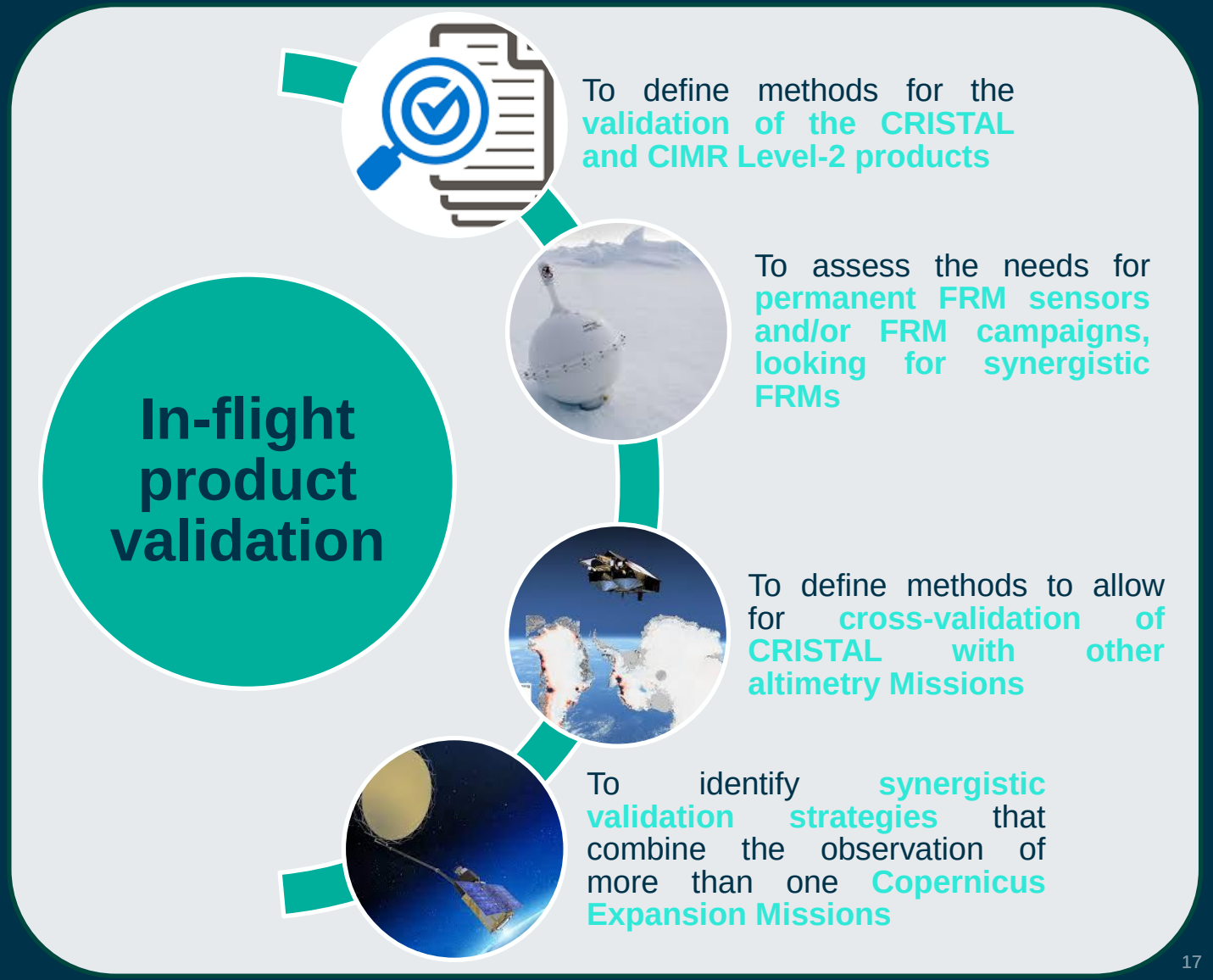
Product Validation Plan for CRISTAL and CIMR

Objectives of the activity for CRISTAL and CIMR missions:

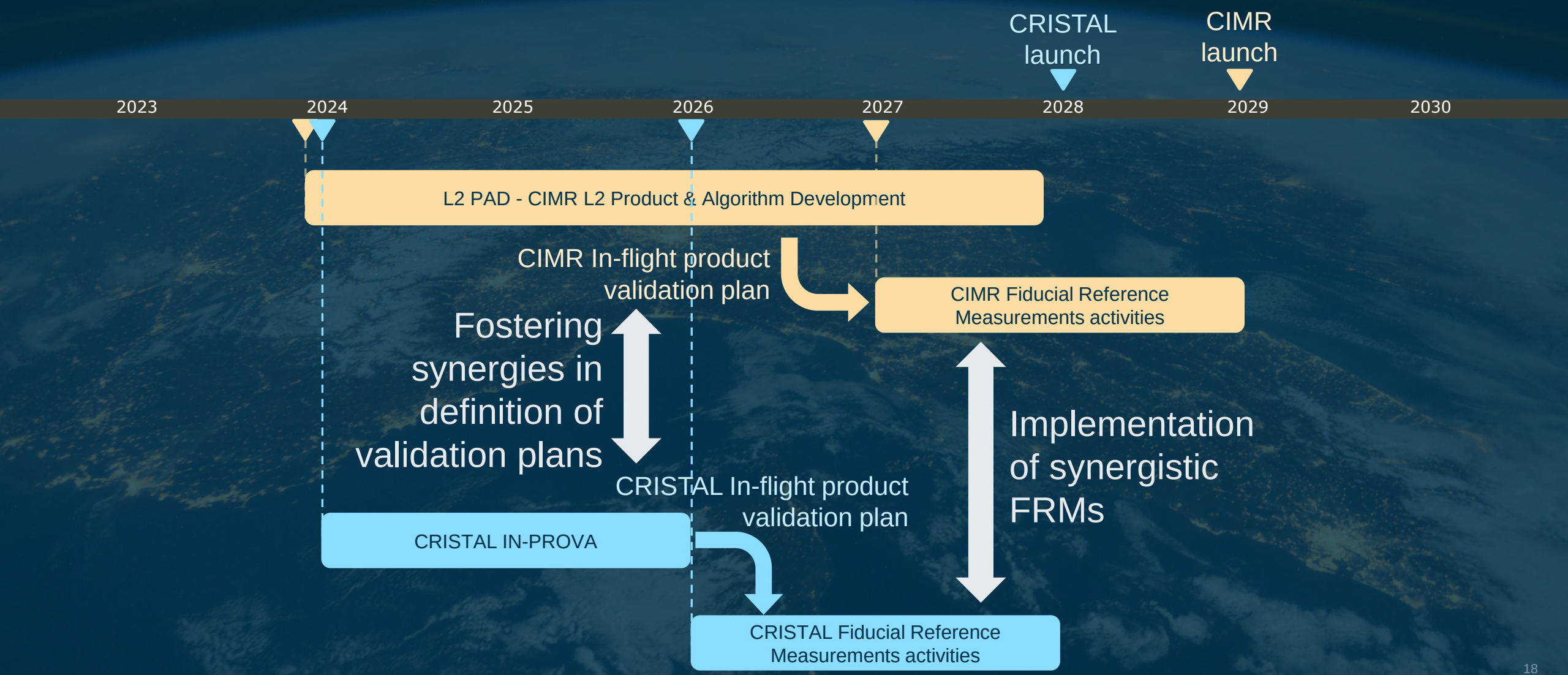
Define the methods, protocols and associated measurement data for the validation of the ESA Level-2 products versus FRM measurements, other missions and/or models

Main output:

- *CRISTAL In-flight Level-2 Product Validation Plan*
- *CIMR In-flight Level-2 Product Validation Plan*



Product Validation Plan for CRISTAL and CIMR



Product Validation Plan for ROSE-L (I)

- ROSE-L is the Copernicus Sentinel Expansion Mission for SAR.
- As an L-band SAR mission, it will bring complementary information w.r.t Sentinel-1 C-band observations.
- Mission will support the generation of various geophysical products from SAR, including:
    - **Ocean** (continuity with Sentinel-1);
    - **Forest** (synergy with ESA and non-ESA SAR missions);

  both will be developed as potential ESA core products!
- Fiducial Reference Measurements are needed for:
    - Calibration and validation of **L1 SAR** products
        - *(Passive) corner reflectors:*
            - Used for geometric calibration and radiometric monitoring (and potentially calibration);
            - Big potential to profit from *existing corner reflector sites* (e.g., put in place for other L-band missions);
            - **Need to be sure, information is reliable and complete** (should feature in **SARCalNet**);

ROSE-L FRM (II)

- Fiducial Reference Measurements are needed for (cont.):
  - Calibration and validation of **L1 SAR** products (cont.):
    - *(Active) transponders:* need for **dedicated targets**, essential for absolute radiometric calibration!
      - Planning will start soon in cooperation with S-1 project and synergy with IoC use.
  - Calibration and validation of **L2 geophysical** products**:**
    - *Forest:*
      - Need FRM for Above Ground Biomass (AGB), forest coverage and forest change;
      - Largely profiting from synergy with activities for BIOMASS cal/val and FRM4BIOMASS
    - *Ocean:*
      - Need measurements (and ideally FRM) for Surface Wind Speed, Surface Wind Direction, Sea State and Significant Wave Height;
      - Building on from S1 experience, extending use of in-situ measurements (e.g., buoys, drifters, etc) and decreasing dependency with models for validation.

FRM activities for definition of cal/val methods, surveying procedures and FRM requirements

→ ITT issue intended in Q2/Q3 2024 **(for Ocean and Forest)**

Product Validation Plan for LSTM

TIRCALNet Context

As per CNES WGCV presentation last year:

- Several TIR missions operational: ECOSTRESS, ASTER, LANDSAT-8&9, MODIS, VIIRS, SLSTR, SEVIRI…
- TIR future missions with higher resolution: TRISHNA, LSTM, SBG
- More and more demanding LST accuracy requirements better than 0.1 K for climate studies
- Importance of vicarious calibration for the validation of on-board calibration systems (black bodies) or direct calibration
- L2 products (temperature & emissivity) validation need

In addition, numerous new space TIR companies are about to launch: ConstellR, Ororatech, Aistech,…

Product Validation Plan for LSTM

TIRCALNet Objectives

- To collect surface temperature and emissivity, and atmospheric data necessary for the simulation of observations by TIR optical sensors and thus verify their radiometric calibration
- To increase the number of matchups between in-situ measurements and space sensor observations and reduce the overall uncertainties, and reduce the efforts of individual agencies
- To ensure traceability of the space sensor radiometry to the “Système International” (SI)
- To support the establishment of the Global Earth Observation System of Systems by providing measurements to verify the radiometric consistency between EO space sensors
- To build on success and experience return from RadCalNet network dedicated to VNIR-SWIR optical sensors cal/val

Product Validation Plan for LSTM

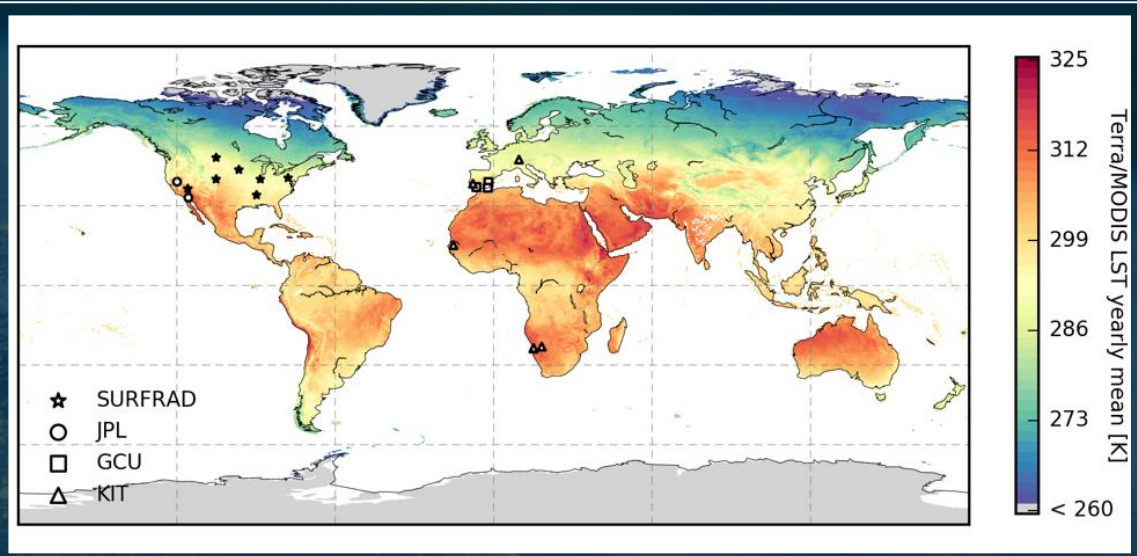
Site Study Objectives

- TRISHNA, LSTM, SBG
- Existing network for LST
- Need for a denser network
  - that provides L_{TOA}
  - with evaluated uncertainty for each site
  - with a demanding requirement on TOA radiance (0.5K)

- Impact of uncertainty sources ?
  - Atmosphere
  - Emissivity
  - Temperature (retrieved from radiometer measurements)

→ Study on LaCrau site

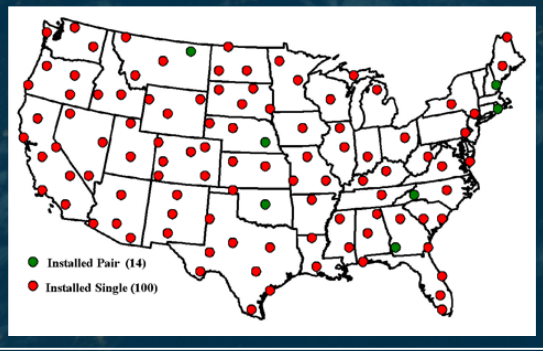
JPL TIR radiometer installed in LaCrau



SURFRAD: Surface Radiation, NOAA JPL network

GCU: Global Change Unit, University of Valencia KIT (Karlsruhe Institute of Technology) stations

Location of ground observational networks currently used to validate standard LST products derived from US and European spaceborne instruments.



USCRN: US Climate Reference network

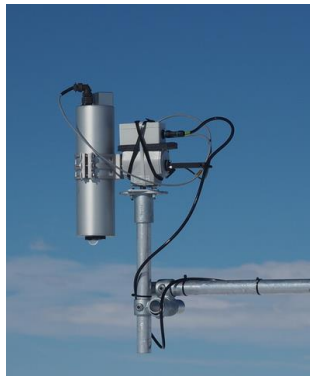
HYPERNET

INSTRUMENTS

Automated hyperspectral measurements



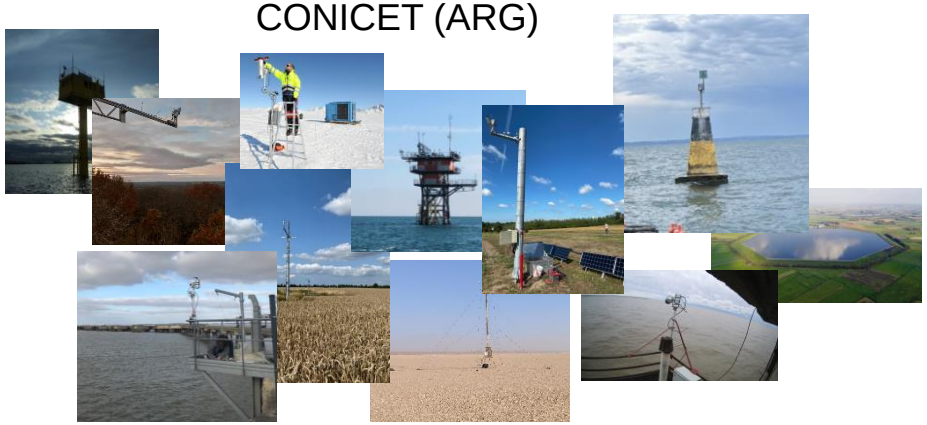
PANTHYR system
[Vansteenwegen et al, 2019]
400-900nm, 10nm FWHM



HYPSTAR® system
[https://hypstar.eu/]
380-1700nm, 3-10nm FWHM

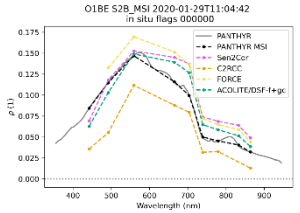
NETWORK

RBINS (BE, coordinator)
+ VLIZ (BE), CNR (IT), LOV (FR),
NPL (UK), GFZ (D), TARTU (ES),
CONICET (ARG)

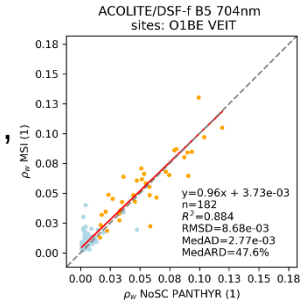


12 water and 12 land sites by Dec 2022
Many international requests to join in 2023 ...

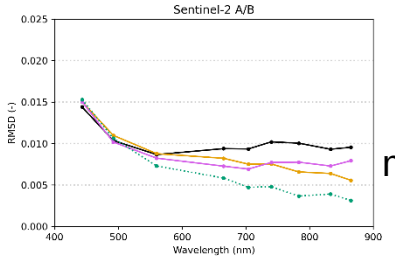
DATA PROCESSING and ANALYSIS



e.g. one matchup



one band (S2/704nm),
many matchups



spectral stats,
many matchups

Prototype network has provided validation data and information to:

Sentinel-2A&B, Sentinel-3A&B/OLCI, Landsat-8&9, Planetscope Doves, PRISMA, Pléiades, ENMAP, ...

in progress for:

MODIS-A&T, VIIRS-1&2, ...

and preparing for:

MTG, CHIME, PACE, GLIMR, SBG, PROBAV-CC, various Newspace, ...

OBJECTIVE: To validate all VIS/NIR spectral bands (400-1700nm, @3nm FWHM) for all satellite missions measuring water or land surface reflectance

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Thank you !