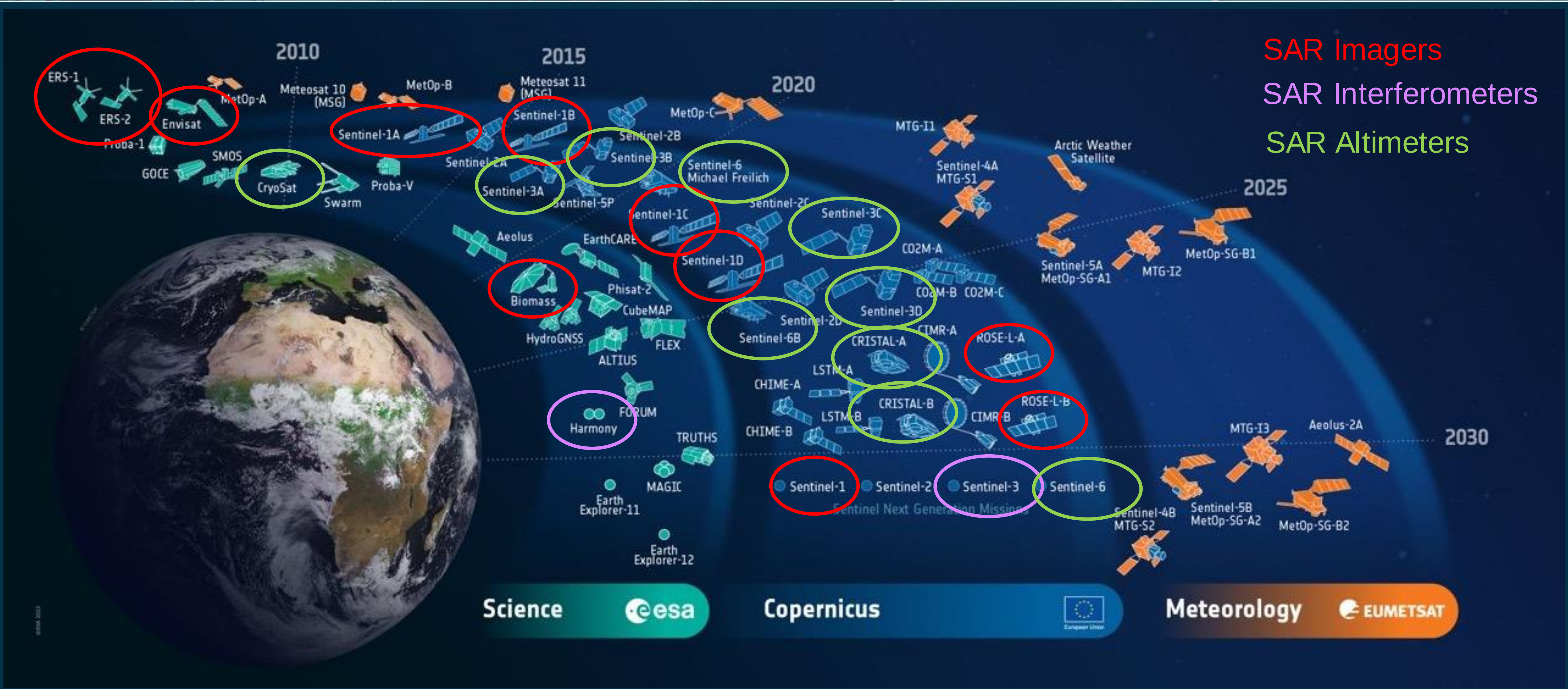
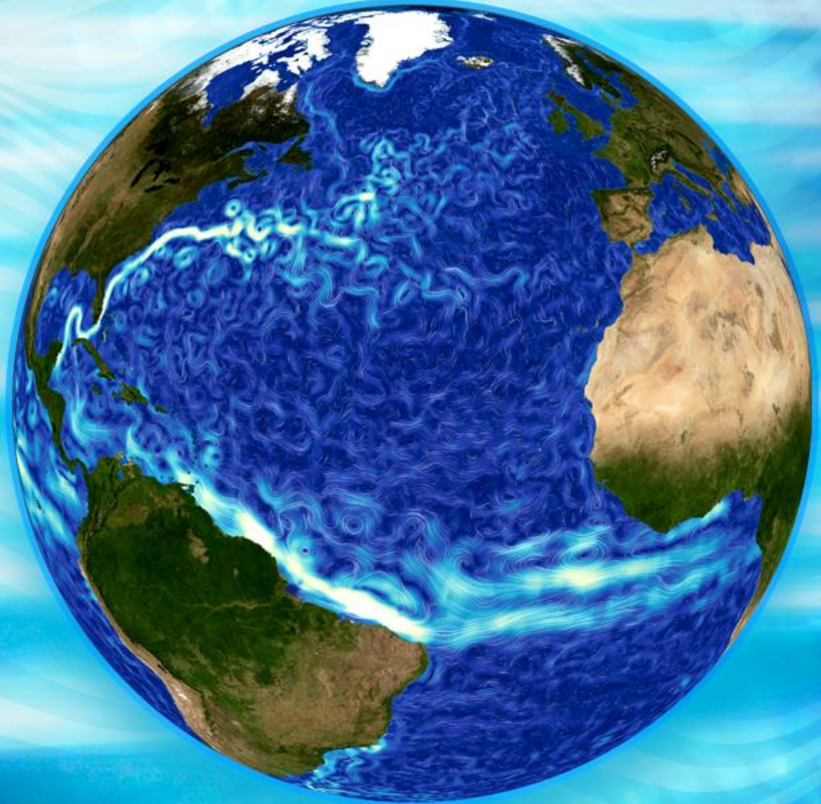
Theme 8 Future Missions

Craig Donlon, Alejandro Egido, Christine Gommenginger, Adrien Martin, the SeaSTAR team, Cathleen Jones, Marcel Kleinherenbrink, Paco Lopez-Dekker, B. Rommen, Fabrice Collard, Rob Cullen, Luisella Giulicchi, Martin Suess, Tom Rune Lauknes, Agnar Sivertsen, Temesgen Gebrie Yitayew, Line Rouyet, Charles Werner, Michael Jenning, Dirk Plettemeyer, Shridhar D. Jawak, Tom Rune Lauknes, Line Rouyet, Agnar Sivertsen, Fu Jiayu, Li Yuanhao, Chen Zhiyang, Hu Cheng, P. Dubois, J. Kubanek, M. Davidson, L. Iannini, D. Geudtner, R. Furnell, C. Albinet, M. Pinheiro, A. Valentino

ID	Title Submission Type / Conference Track · Uploaded	Author(s) Submitting Author
103	**Enhanced Sea Ice Performances from CRISTAL Mission** Extended Abstracts 1st file Enhanced Sea Ice Performances from CRISTAL Mission.pdf (10th Feb 2023, 04:45:57pm CEST)	**Garcia-Mondéjar, Albert; Freer, Bryony; López-Zaragoza, Juan Pedro; McKeown, Charlie; Gibert, Ferran; Mank, Enrico; Recchia, Lisa; Hendricks, Stefan; Scagliola...** Garcia-Mondéjar, Albert isardSAT
104	**Airborne SAR Sensor in Svalbard; User Perspective on Mission Requirements and Observational Needs** Extended Abstracts 1st file SeaSAR extended abstract Final.pdf (5th Jan 2023, 11:50:43am CEST)	**Jawak, Shridhar; Lauknes, Tom Rune; Rouyet, Line; Sivertsen, Agnar** Jawak, Dr Shridhar Svalbard Integrated Arctic Earth Observing System (SIOS)
114	**A New Distributed ATI SAR System: GEO-LEO SAR ATI Concept** Extended Abstracts 1st file A NEW DISTRIBUTED ATI SAR SYSTEM: GEO-LEO SAR ATI CONCEPT .pdf (23rd Jan 2023, 05:13:33pm CEST)	**Fu, Jiayu; Li, Yuanhao; Chen, Zhiyang; Hu, Cheng** Jiayu, Fu Beijing institute of technology
115	**The Harmony SAR Instrument** Extended Abstracts 1st file The Harmony SAR Instrument.pdf (25th Jan 2023, 11:07:14am CEST)	**Suess, Martin; de Witte, Erik; Rommen, Björn** Sues ESA/ A NEW DISTRIBUTED ATI SAR SYSTEM: GEO-LEO SAR ATI
123	**Development of a Dual-Frequency Airborne SAR Sensor in Svalbard** Extended Abstracts 1st file Abstract SeaSAR 2023-Lauknes-final.pdf (25th Jan 2023, 10:45:03am CEST)	**Lauknes, Tom Rune; Sivertsen, Agnar; Gebrie Yitayew, Temesgen; Rouyet, Line; Werner, Charles; Jenning, Michael; Plettemeier, Dirk; D. Jawak, Shridhar** Lauknes, Dr Tom Rune NORCE Norwegian Research Centre
131	**Future Missions at the European Space Agency** Extended Abstracts 1st file Future Missions at the European Space Agency.pdf (26th Jan 2023, 10:49:26am CEST)	**Donlon, Craig** Donlon, Dr Craig European Space Agency
136	**SEASTAR - Earth Explorer 11 Mission Candidate: Imaging Small-Scale Ocean Dynamics** Extended Abstracts 1st file SEASAR23 Abstract SEASTAR.pdf (27th Jan 2023, 11:29:28am CEST)	**Gommenginger, Christine; Martin, Adrien; Nagamine, Katia; Gracheva, Valeria; Egido, Alejandro; Hall, Kevin; Casal, Tania; Martin-Iglesias, Petronilo** Egido, Dr Alejandro European Space Agency
157	**Multistatic High-Resolution Observations of the Ocean with the Harmony Mission: Science, Products, and Expected Performances** Extended Abstracts 1st file SeaSAR2023 HarmonyOveview.pdf (12th Feb 2023, 08:19:27pm CEST)	**Lopez Dekker, Paco; Chapron, Bertrand; Pasquero, Claudia; Stoffelen, Ad; Buongiorno Nardelli, Bruno; Masina, Simona; Kleinherenbrink, Marcel; Theodosiou, Andreas; Rommen...** Lopez Dekker, Dr Paco TU Delft
162	**Harmony End-o-End Performance Simulator: Evaluating The Performance Of A Bi-static ATI SAR Mission For Ocean Observations** Extended Abstracts 1st file Dubois et al-Harmony E2E Simulator Performance SeaSAR23 Abstract.pdf (10th Feb 2023, 05:02:50pm CEST)	**Dubois, P.; Monnier, G.; Lopez-Dekker, P.; Yitayew, T. G.; Armstrong, T.; Gombert, B.; Soulat, F.; Hellouvry, Y.-H.; Camus, B.; Grydeland, T.; Lajas, D.; Rommen, B.; De...** Soulat, Dr François CLS
164	**WaddenSAR campaign: first results** Extended Abstracts	**Lopez Dekker, Paco; Kleinherenbrink, Marcel; Theodosiou, Andreas; Eleveld, Marieke; Zijl, Firmijn; Macedo, Karlus; Luiz, Thiago; Kubanek, Julia** Lopez Dekker, Dr Paco TU Delft

ESA-developed Earth observation missions





skim

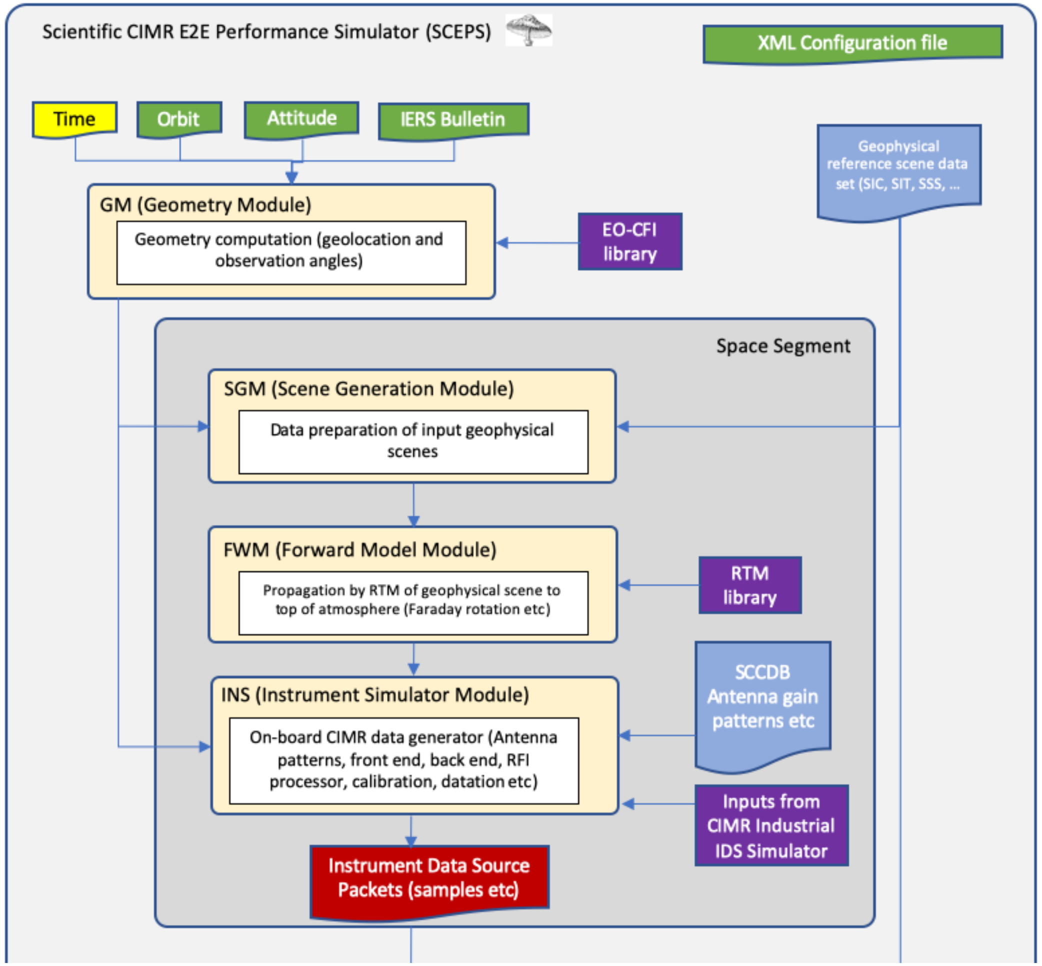
→ UNDERSTANDING OCEAN SURFACE MOTION

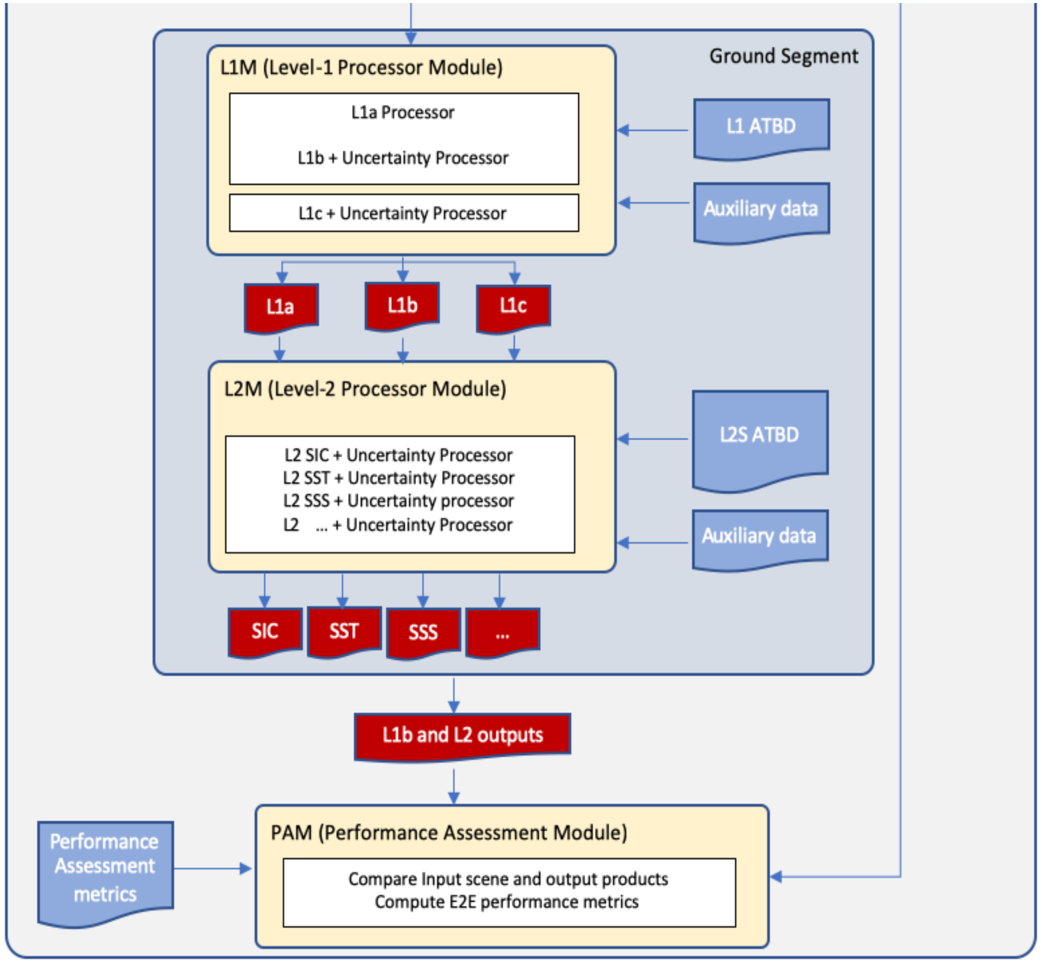
Scientific Presentation II

EARTH EXPLORER 9 USER CONSULTATION MEETING

Cambridge, UK, 16-17 July 2019

Simulation…is a key tool but also a creative scientific process

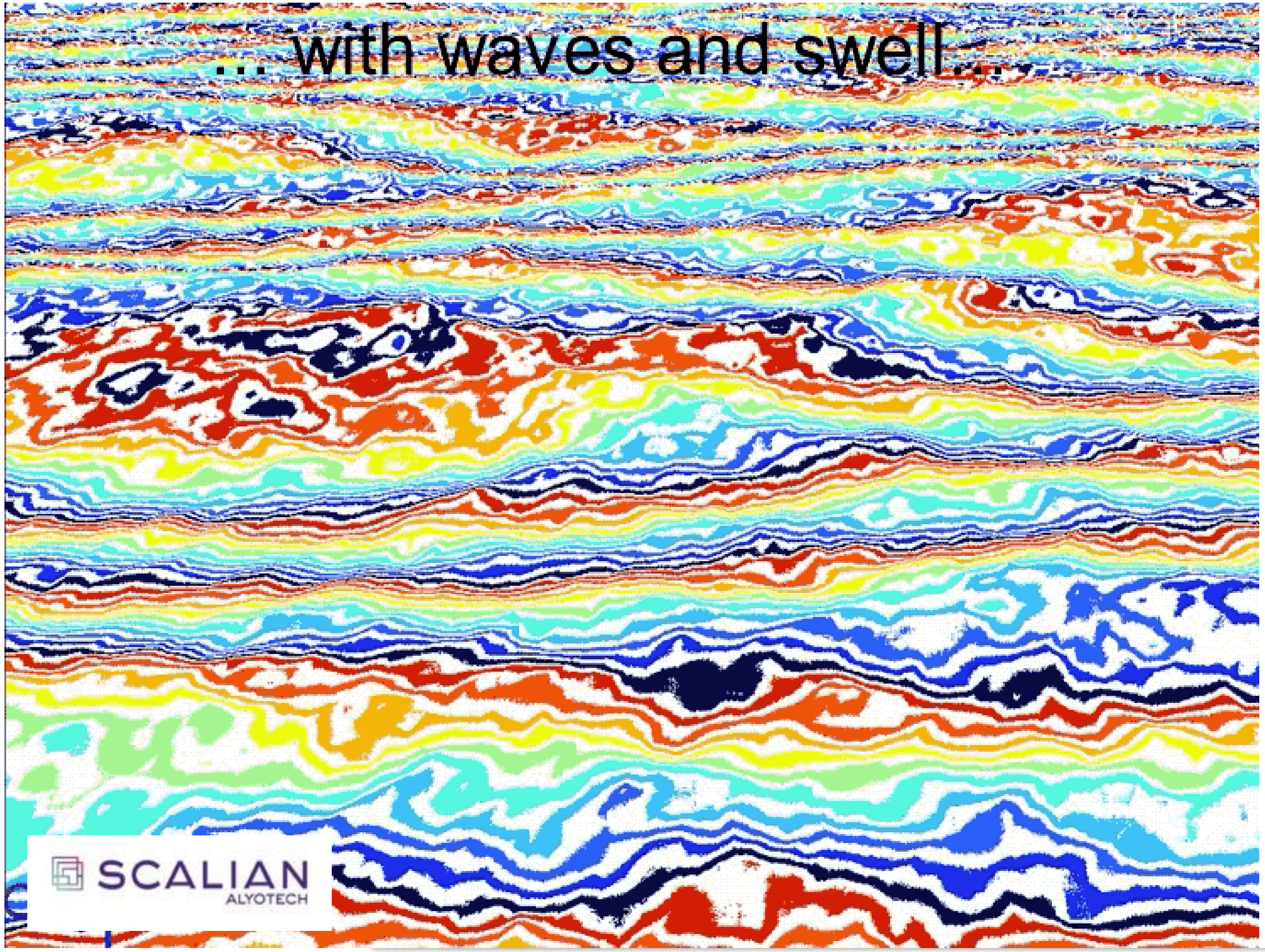


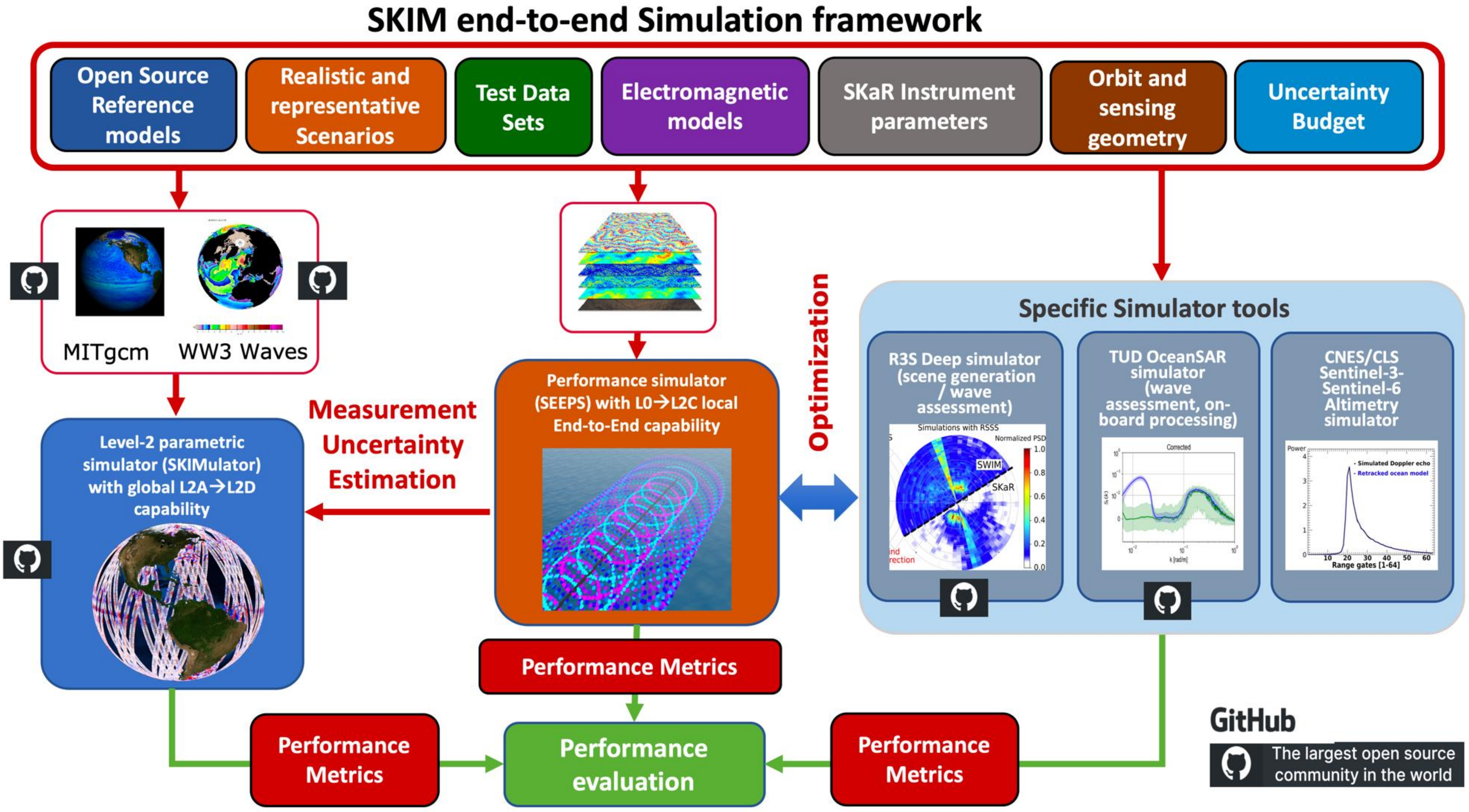


SEEPS SKIM Test Scene Generation

To accurately simulated signal

From Roughness...




SKIM end-to-end Simulation framework
Open Source Reference models
Realistic and representative Scenarios
Test Data Sets
Electromagnetic models
SKaR Instrument parameters
Orbit and sensing geometry
Uncertainty Budget
MITgcm
WW3 Waves
Level-2 parametric simulator (SKIMulator) with global L2A→L2D capability
Measurement Uncertainty Estimation
Performance simulator (SEEPS) with L0→L2C local End-to-End capability
Optimization
Specific Simulator tools
R3S Deep simulator (scene generation / wave assessment)
Simulations with RSSS
Normalized PSD
SWIM
SKaR
TUD OceanSAR simulator (wave assessment, on-board processing)
Corrected
CNES/CLS Sentinel-3-Sentinel-6 Altimetry simulator
Power
Simulated Doppler echo
Retracked ocean model
Range gates [1-64]
Performance Metrics
Performance Metrics
Performance evaluation
Performance Metrics
GitHub
The largest open source community in the world


forum
→ UNDERSTANDING HOW EARTH IS LOSING ITS COOL
skim
→ UNDERSTANDING OCEAN SURFACE MOTION

ESA/PB-EO(2019)43
Att: ESA/ACEO(2019)01
Paris, 09 September 2019
(Original: English)

EUROPEAN SPACE AGENCY

EARTH OBSERVATION PROGRAMME BOARD

Earth Observation Envelope Programme

The Evaluation of the Two Candidate Earth Explorer 9 'Fast Track' Missions

The Report of the Advisory Committee for Earth Observation

Summary

This paper contains the detailed evaluation of the two Earth Explorer 9 Candidate Missions, FORUM and SKIM by the Advisory Committee for Earth Observation (ACEO) following the Earth Explorer 9 (EE9) User Consultation Meeting (UCM) held on 16-17 July 2019 at Robinson College, University of Cambridge, UK.

Taking account of the detailed points made in the attached report, ACEO recommends that FORUM be selected for implementation as the 9th Earth Explorer Mission.

For the SKIM mission that is not recommended for selection as 9th Earth Explorer Mission, ACEO recommends that other ways and means be sought to implement the SKIM mission concept.

Theme 8 Future Missions

The EE11 SeaSTAR mission candidate

Alejandro Egido, Christine Gommenginger, Adrien Martin
& the SeaSTAR team

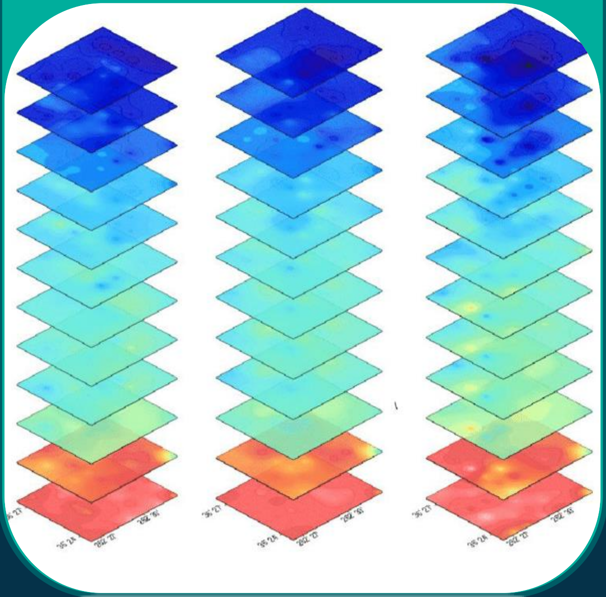
26/04/2023

FutureEO-1 Segment 2 – Research Missions - EE11 …

CAIRT

Understanding the links between CC and atmospheric chemistry and dynamics at 5 to 120 km

First limb-sounder with imaging Fourier-transform infrared technology in space



Nitrosat

Understanding the links between CC and the natural carbon and nitrogen cycles

Measurement of nitrogen dioxide and ammonia, two important reactive nitrogen compounds in the atmosphere

WIVERN

Improving the prediction of high-impact weather and hazard warnings

Dual-polarisation, conically scanning 94 GHz Doppler radar for measuring wind in clouds and delivering profiles of rain, snow and ice water

Seastar

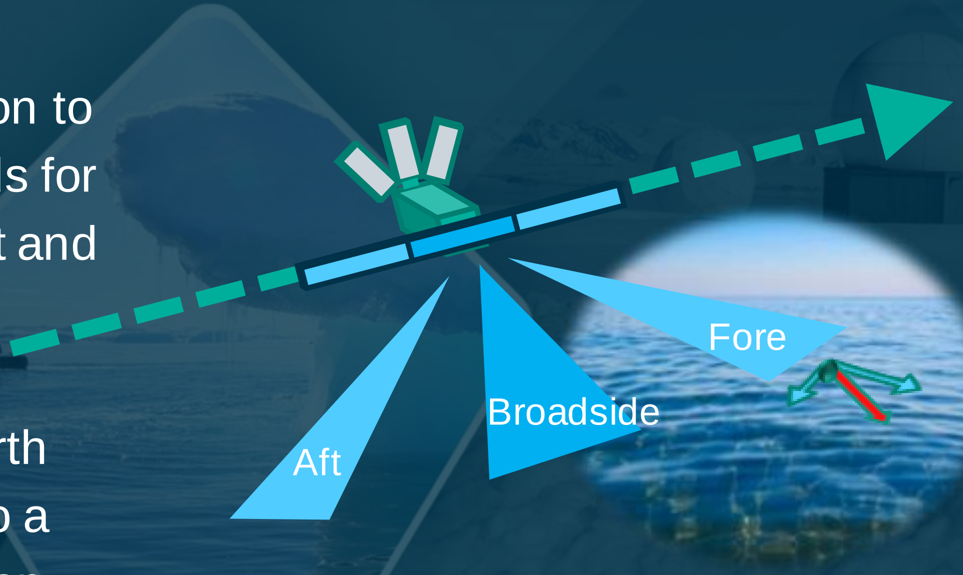
Understanding air–sea interactions using two-antenna along-track interferometry radar

Providing ocean surface current & wind vectors at 1 km resolution for all the coastal ocean, shelf seas and marginal ice zones

SEASTAR Summary

SEASTAR is a dedicated ocean mission to address well-articulated scientific needs for new synoptic imaging of ocean current and wind vectors at 1km resolution.

Its focus on key interfaces of the Earth system makes SEASTAR relevant to a large and growing community of ocean, atmosphere, cryosphere, coastal and climate scientists and operators.



https://projects.noc.ac.uk/seastar/

A ‘quantum leap in knowledge’ for Earth Observation and Earth Science

The first mission of its kind, with some ambitious elements, that builds on high levels of scientific and technological readiness in Europe.

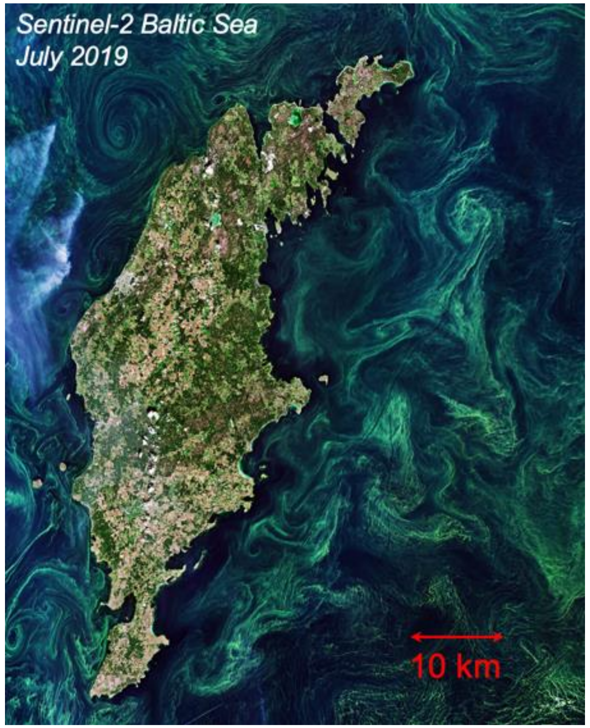
EE11 SeaSTAR Key objectives

One of four candidates to Earth Explorer 11, currently in Phase 0 (Phase A Decision: Oct/Nov'23)

Focus on small-scale ocean surface dynamics in coastal & shelf seas and Marginal Ice Zones

Primary Objectives

1. Measure 2D images of Total Surface Current Vectors and Ocean Surface Vector Winds at **1 km resolution with high accuracy**
2. Quantify the magnitude, spatial distribution and temporal variability on **daily, seasonal and multi-annual time scales**
3. Deliver **high-order derivative products** like gradients, divergence, vorticity and strain
4. Investigate relations between small-scale **dynamics and marine productivity using synergy** with in situ data and other satellite sensors
5. **Validate high-resolution and coupled models** and support the development of **new parameterisations** to improve operational forecasts and reduce uncertainties in climate projections



SeaSTAR Primary Products (Level 2)
Total Surface Current Vector (L2-TSCV)
One continuous swath ≥ 100-150 km
Horizontal posting (resolution) ≤ 1 km
TSCV Uncertainty @ 1km ≤ 0.1 m/s or 10%
Ocean Surface Vector Wind (L2-OSVW)
Same swath as TSCV
Same horizontal posting as TSCV
OSVW Uncertainty @ 5km ≤ 1 m/s or 10%

EE11 SeaSTAR Innovations

First squinted Along-track Interferometric SAR in space

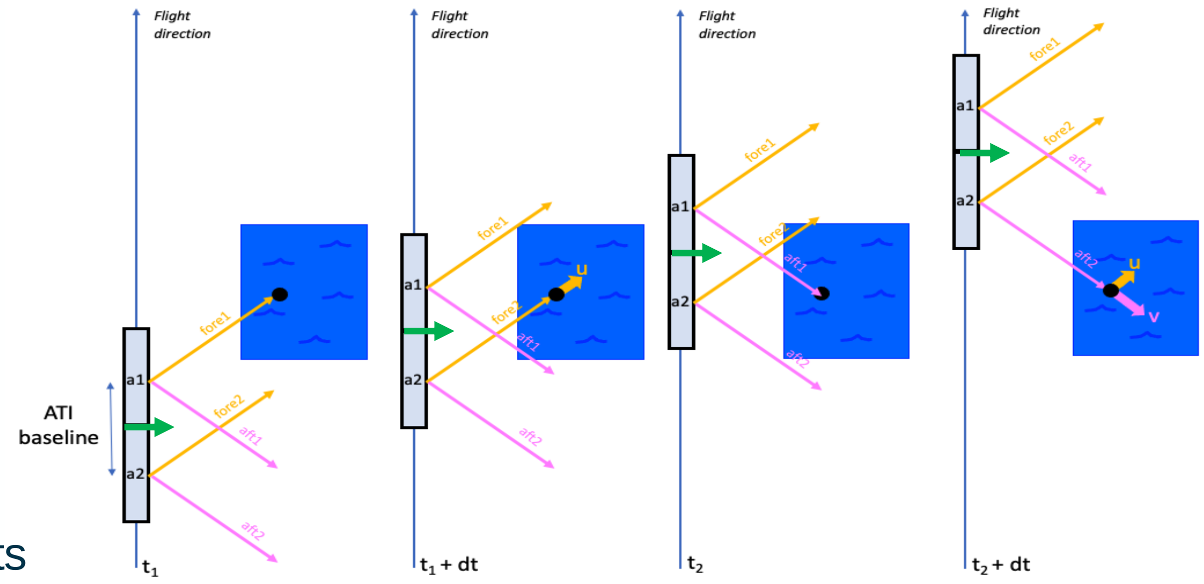
- Ku-band
- Physical baseline ~ 15 metres (dt ~ 1ms)

Three azimuth directions in ASCAT-type configuration

- One ATI pair pointing 45º forward
- One ATI pair pointing 45º backward
- One DCA or ATI pointing broadside

Moderate incidence angles: 20-50 deg

- High incidence angles = greater sensitivity to currents (horizontal) and lower Doppler wave velocity



Doppler and NRCS data in 3 directions enables retrieval of TSCV and OSVW in a single-pass

Directional swell spectrum (broadside)*

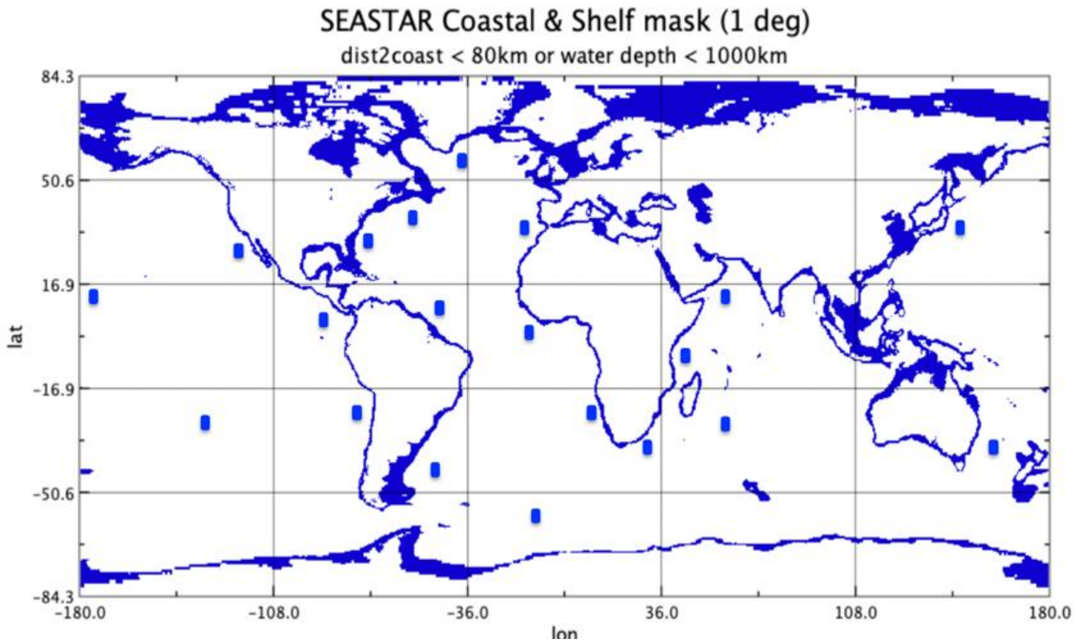
HH/VV polarisation (broadside)*

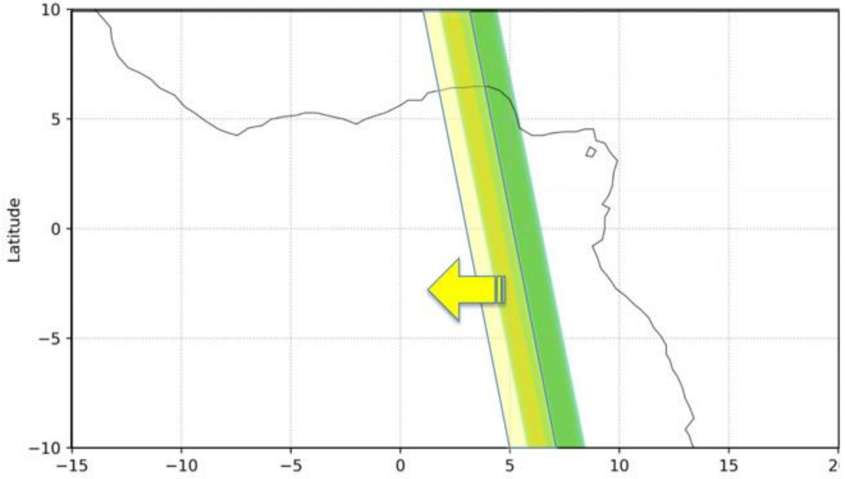
Directional wave spectrum (squinted beams)**

* Subject to EE11 cost cap
** Subject to SRL

EE11 SeaSTAR Innovations

- The first squinted along-track SAR interferometer in space dedicated to small-scale ocean surface dynamics
    - A stand-alone satellite with a single payload
    - first spaceborne Ku-band SAR
- Coincident collocated total current vectors, wind vectors and directional wave spectra
- Unprecedented performance at 1km spatial resolution
    - 2D images of high-order derivatives
    - SeaSTAR will resolve sub-pixel variability to improve data from other missions e.g. SAR, scatterometers, XTI
- Flexible temporal sampling to sample fast-varying processes
    - Daily, seasonally, multi-annual, for 5 years (goal: 7 years)
    - Hourly (high latitudes)
- SeaSTAR's airborne demonstrator: OSCAR
    - available now for scientific campaigns

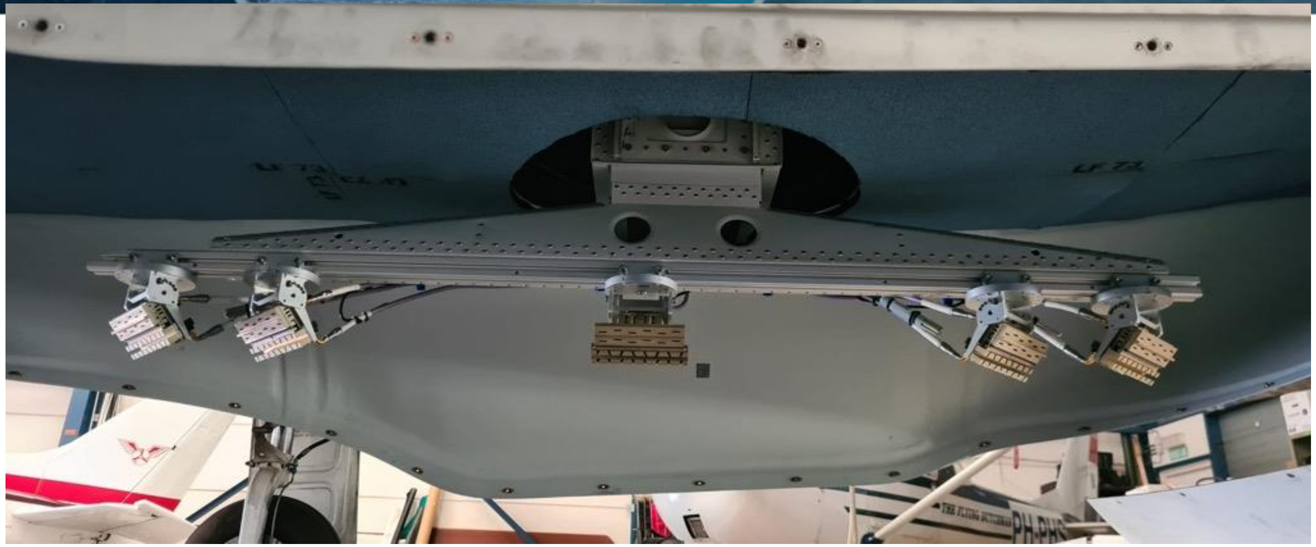




EE11 SeaSTAR OSCAR airborne demonstrator

- OSCAR = Ocean Surface Current Airborne Radar
- SeaSTAR airborne demonstrator
- Ku-Band, VV polarisation
- Three looks
  - Two ATI channels squinted ± 45º
  - Zero-doppler broadside channel
- 5km swath, 8m pixels

[redacted]



SEASTARex airborne campaign, May 2022

OSCAR airborne campaign in May 2022 over Iroise Sea, West of Brest, France

Areas of strong tidal currents (Ouessant) and homogenous zones for validation

Validation with ADCP, HF radar, X-band radar, satellite SAR and high-resolution models

National Oceanography Centre

NOVELTIS

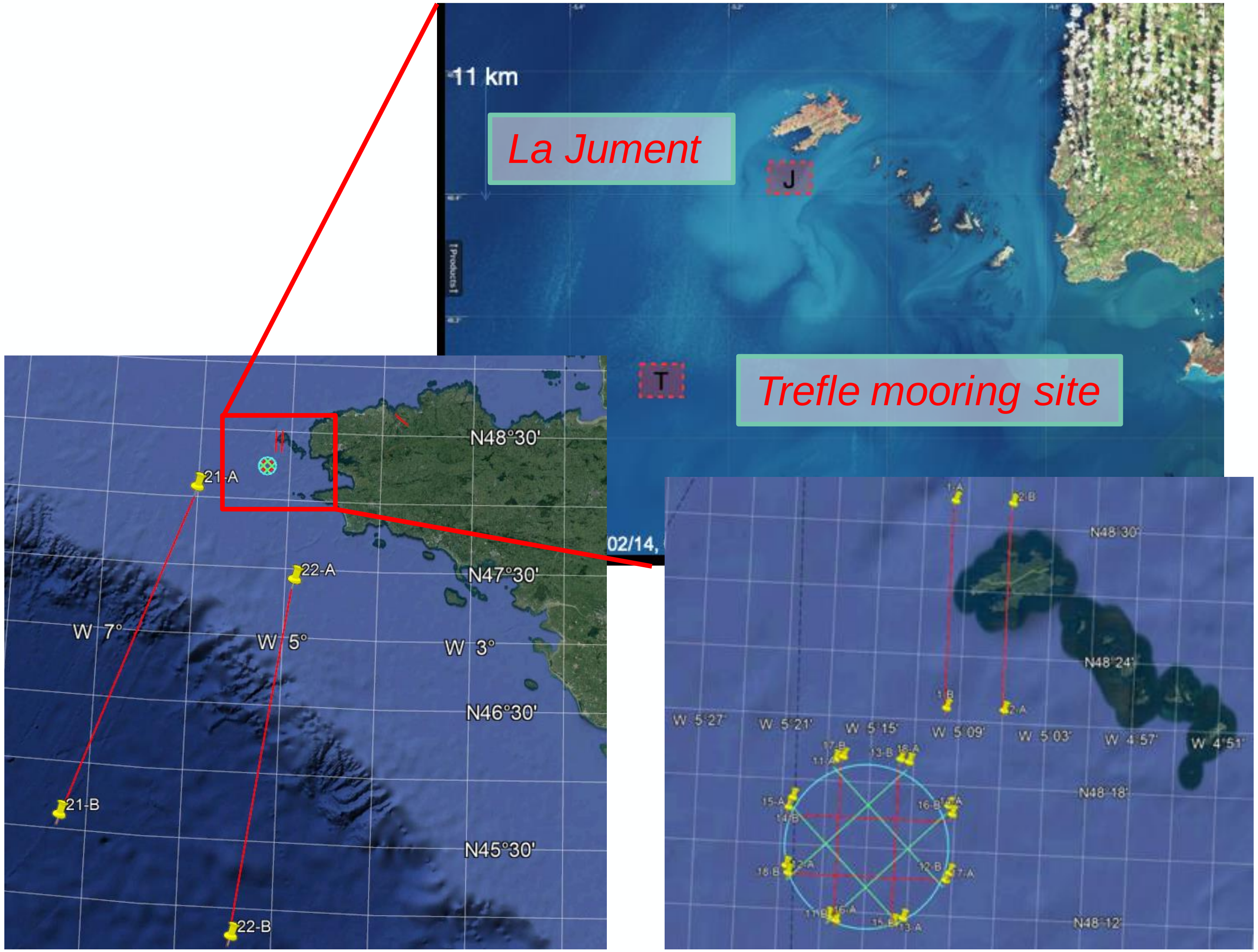
Ifremer

Radarmetrics
Seeing through.

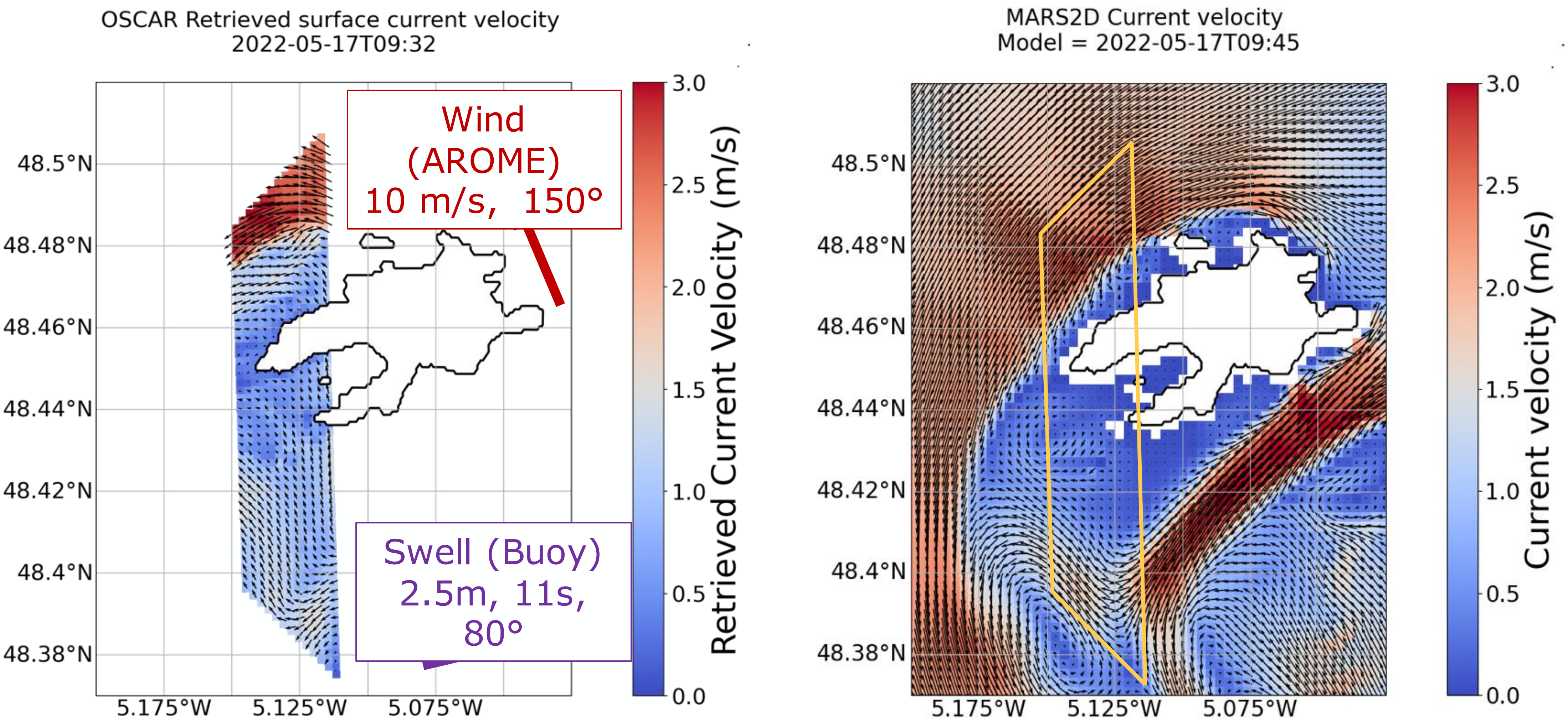
Helmholtz-Zentrum hereon

[redacted]

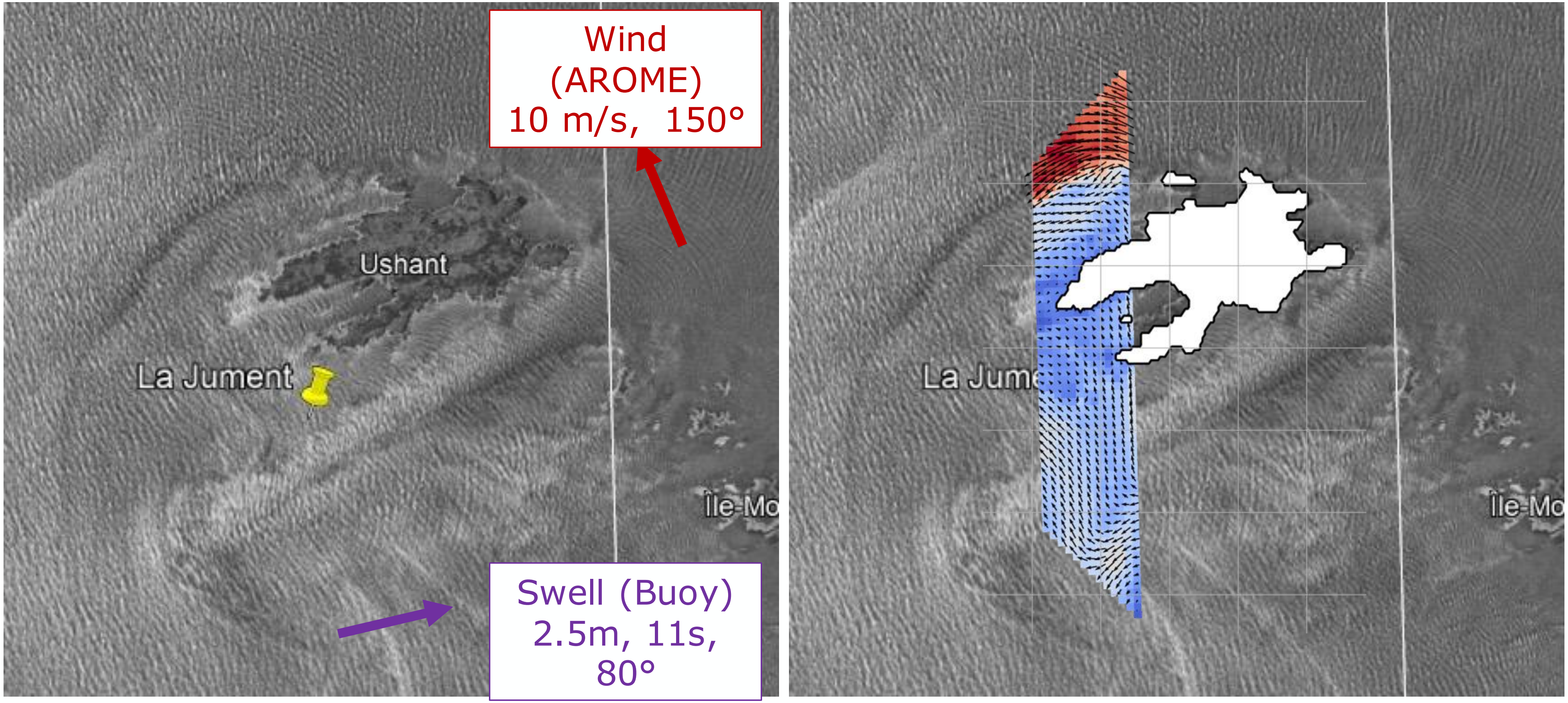
ICM Institut de Ciències del Mar



SEASTARex results – TSCV comparison with MARS2D

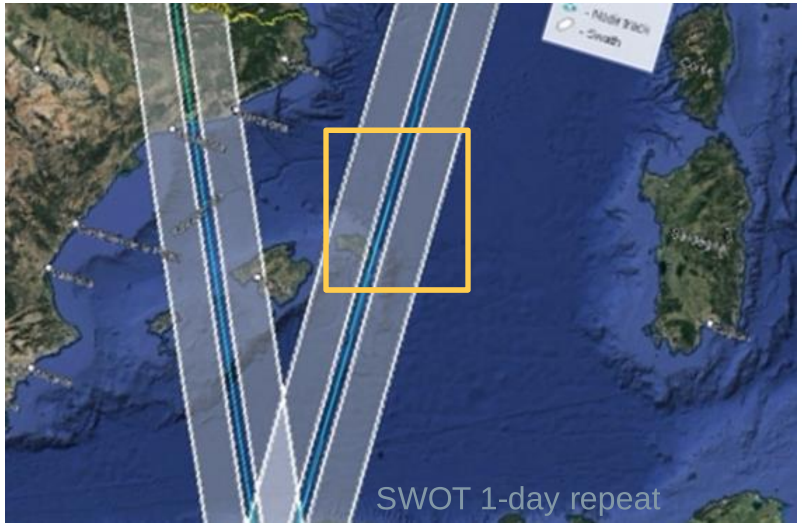


SEASTARex results – Visual comparison with NOVASAR

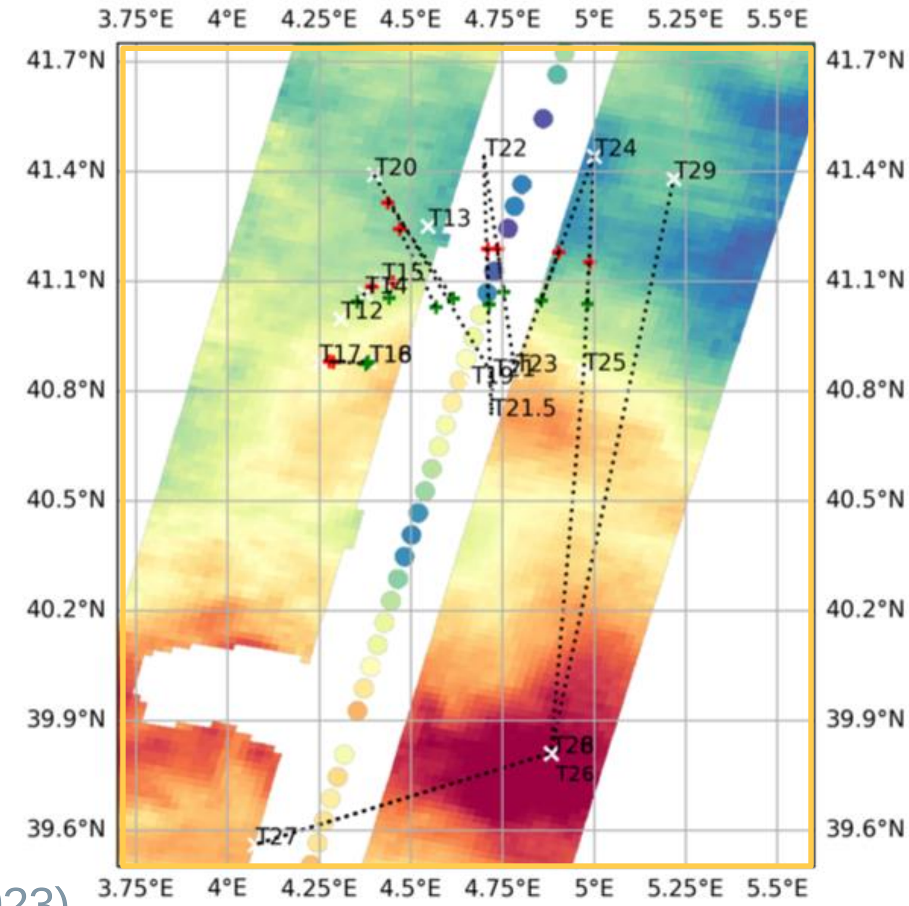


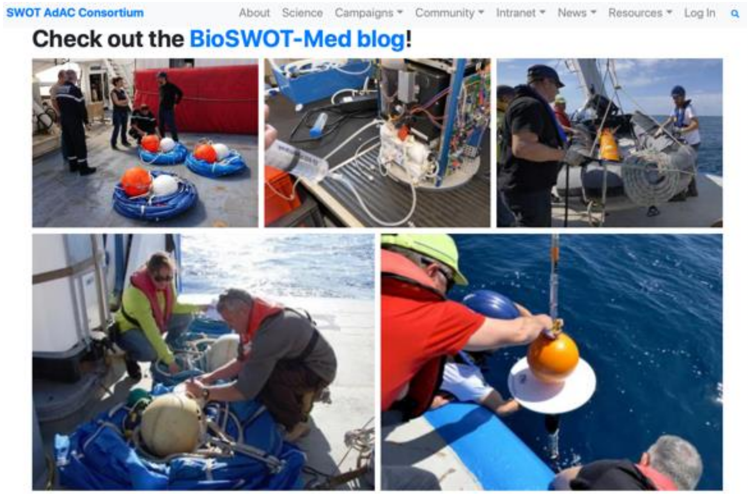
SEASTAREx SWOT-Med campaign, May 2023

Happening THIS week!



Airborne team in Menorca (03 May 2023)





BioSWOT team

Remaining knowledge gaps and deficiencies

- Radial Velocities calibration
    - Using land to remove residual errors linked to platform and antenna mispointing. Is it good enough ?
    - Is high-performance telemetry necessary to remove residual biases?
- NRCS calibration
    - How easily can ASCAT-type calibration be applied to SAR and SeaSTAR high-resolution data ?

- L2 inversion
    - Simultaneous, iterative, sequential ?
- Choice of GMF
    - Wind-wave Artefact Surface Velocity (WASV aka Wave Doppler)
    - Ku-band NRCS GMF

- Validation
    - TSCV: fiducial reference for 'surface' currents ? Differences between sensors ? Variation with depth ?
    - OSVW: validation data for fine-scale wind variability ?

Outlook and recommendations

- **Recommendation**: ESA should select SeaSTAR for EE11 (obviously!)
  - EE11 launch in 2031/32 timeframe

- SeaSTAR and HARMONY
  - HARMONY launch ~2029 => HARMONY and SeaSTAR in orbit together for a few years
  - **Recommendation:** recognise why we want both!

- Synergy with Odysea and S3-NG Topo
  - Odysea = US/France mission candidate, global daily medium-res Doppler scatterometry (~2031 launch)
  - **Recommendation**: joint projects between ESA, NASA, CNES to promote collaboration between HARMONY, SeaSTAR, OdySea and S3-NG Topo

- **Recommendation**: initiate international programmes to observe currents, winds and waves and validate spaceborne Doppler missions in different parts of the globe
  - e.g. SPURS, S-MODE type campaigns
  - long term validation sites

Harmony Mission

Paco Lopez-Dekker and Martin Suess

03/04/2023

Science objectives in a nutshell

Harmony will resolve (sub)kilometer scale motion vectors and topography changes associated with :

- Vertical transport/mixing of heat, gasses and momentum in the lower marine atmosphere, the upper ocean, and the interface between;
- the inner structure and evolution of ocean-atmosphere extremes;
- gradual and dynamic volume changes of global mountain and polar glaciers.
- instantaneous sea-ice motions to characterize sea-ice dynamics
- 3-D deformation vectors associated to tectonic strain;
- topographic change at active volcanoes worldwide;

Contributing to data-driven Earth System Modeling

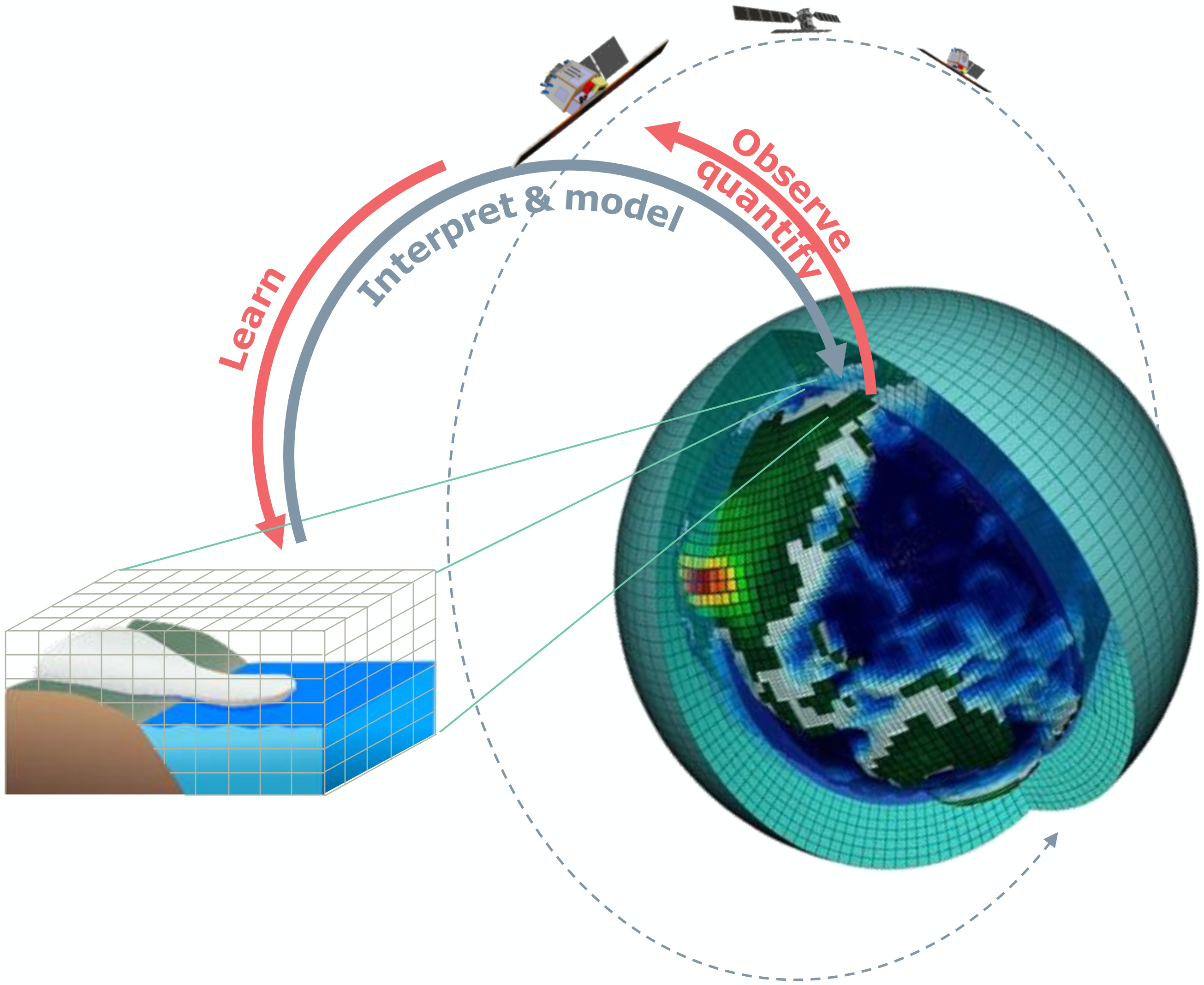
Earth System is highly non-linear → complex couplings and feedbacks between processes at different scales.

⇩

Unresolved O(≲ 1km) processes and couplings in Earth System Models (ESMs) represent major contribution to model uncertainties.

⇧

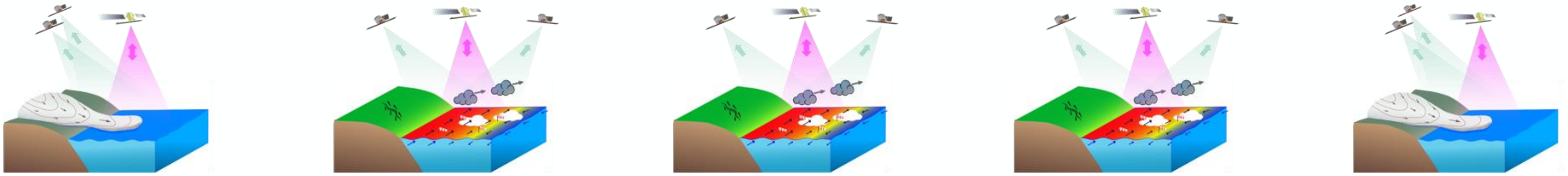
Harmony is set to provide observations needed to develop/train/validate next generations of fully coupled ESMs and Digital Twins Earth (DTEs).



Harmony's mission objectives / Ocean

Air-Sea Interactions (H-O1)	
Extend the knowledge of the 2D co-spectra of surface stress, ocean surface wind vector, surface current vectors, and SST from the scatterometer scale (25km) down to O(1km) scales, covering all relevant conditions at the sea surface and in the MABL.	P
Quantify the contribution of small scale processes (down to O(1 km) scales) to the air-sea fluxes of gas (CO_2, H_2O), momentum, and heat.	P
Quantify the vertical fluxes (momentum and buoyancy) within the MABL at 1km horizontal scale.	P
Quantify the contribution of small scale cloud dynamical processes O(1 km) to the vertical fluxes of water, momentum and heat.	P
Marine-Atmosphere Extremes (H-O2)	
Measure surface stress equivalent wind vectors at 1 km scale in extreme wind conditions, to estimate inflow convergence toward the low pressure center and vorticity perturbations embedded in the cyclonic flow.	P
Retrieve directional wave spectra and simultaneous near inertial currents at 5-10 km resolution, during all phases (ahead, during, and in the wake) of the passage of the extreme weather event.	P
Small-scale upper ocean dynamics (H-O3)	
Extend the knowledge of the ocean surface motion power spectrum from currently resolved mesoscales (O(50km)) down to submesoscales (O(1-5km)), capturing the regional variability and the seasonal cycle.	P
Quantify the vorticity and flow divergence in the upper ocean at O(1km) horizontal scale, to estimate the vertical transport of nutrients, heat and, gas across the ocean boundary layer.	P

Mission Phases Timeline



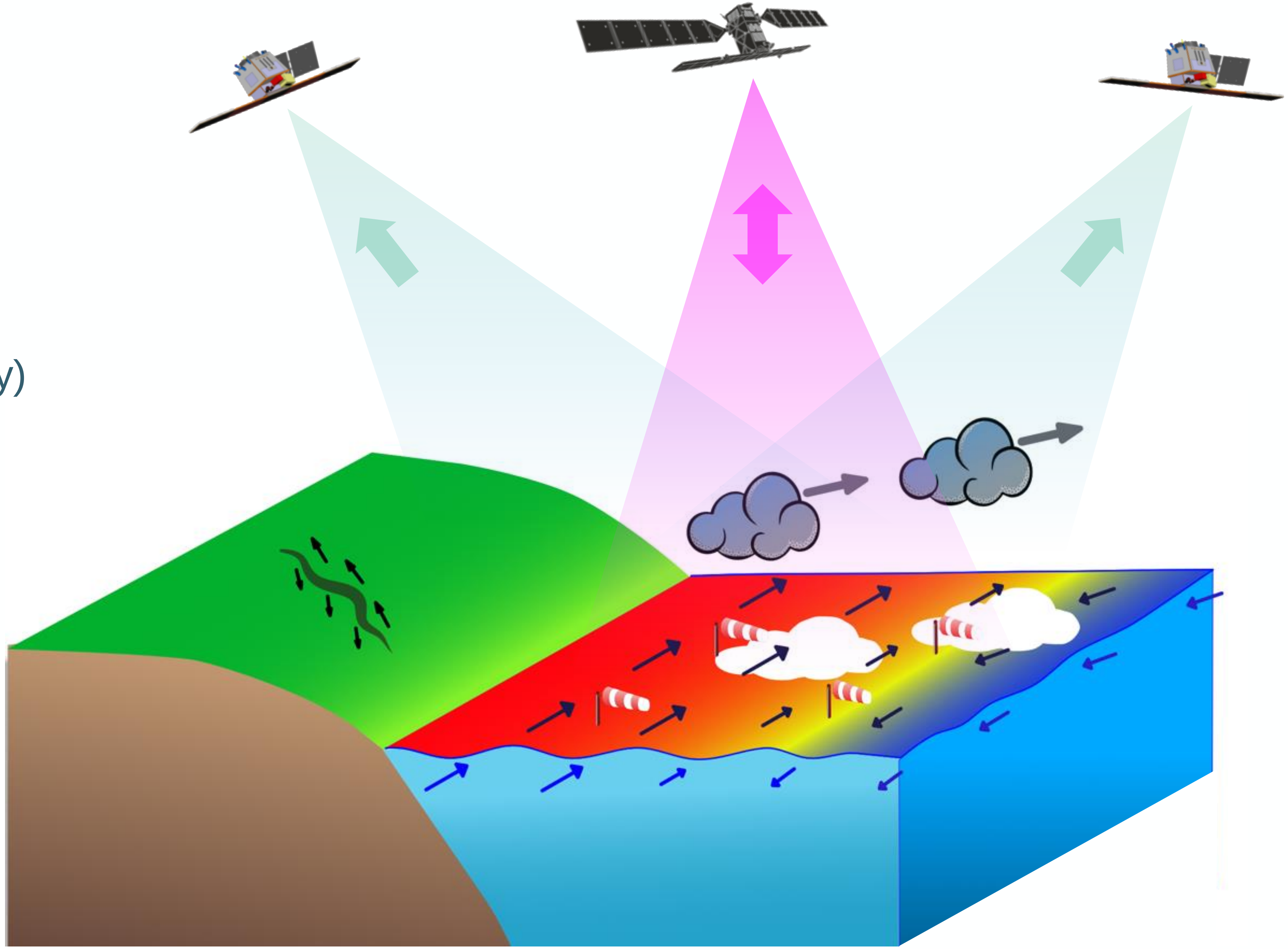
Y1	Y2	Y3	Y4	Y5
XTI Phase		Stereo Phase		XTI Phase

XTI Phase	Stereo Phase	XTI Phase
Ice Volume change		**Ice Volume change**
Glacier dynamics		**Glacier dynamics**
	3-D Ice surface motion	
	Air-sea interactions	
Ocean topography **(experimental)**	**Atmosphere-ocean-extemes (Tropical Cyclones, Polar lows, etc)**	Ocean topography **(experimental)**
	Upper ocean dynamics	
	Tectonic Strain (3-D deformation)	
Vol. change (volcanoes)		Vol. change (volcanoes)
Iceberg volume	Sea-ice instantaneous motion/deformation	Iceberg volume

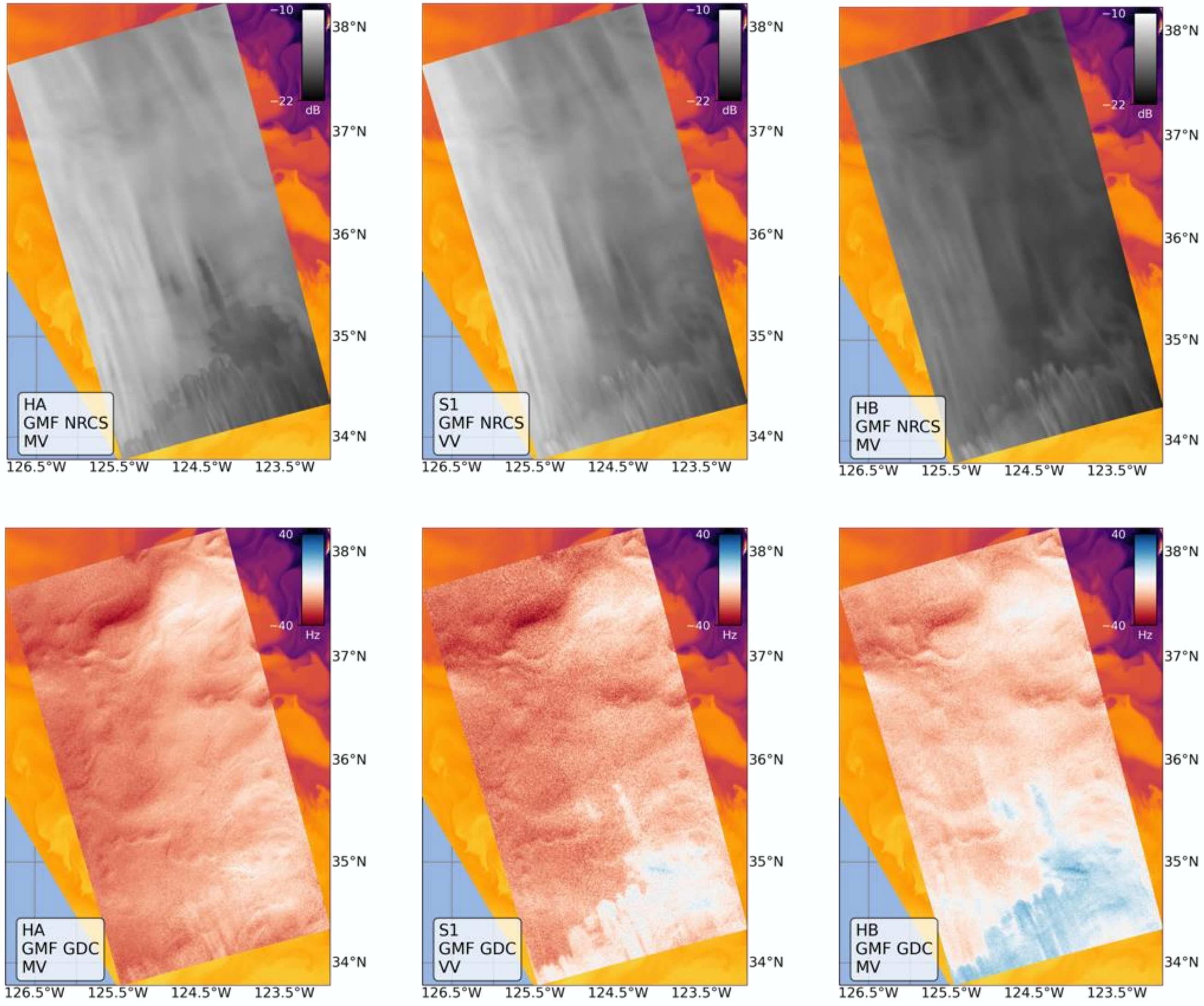
Stereo phase observables

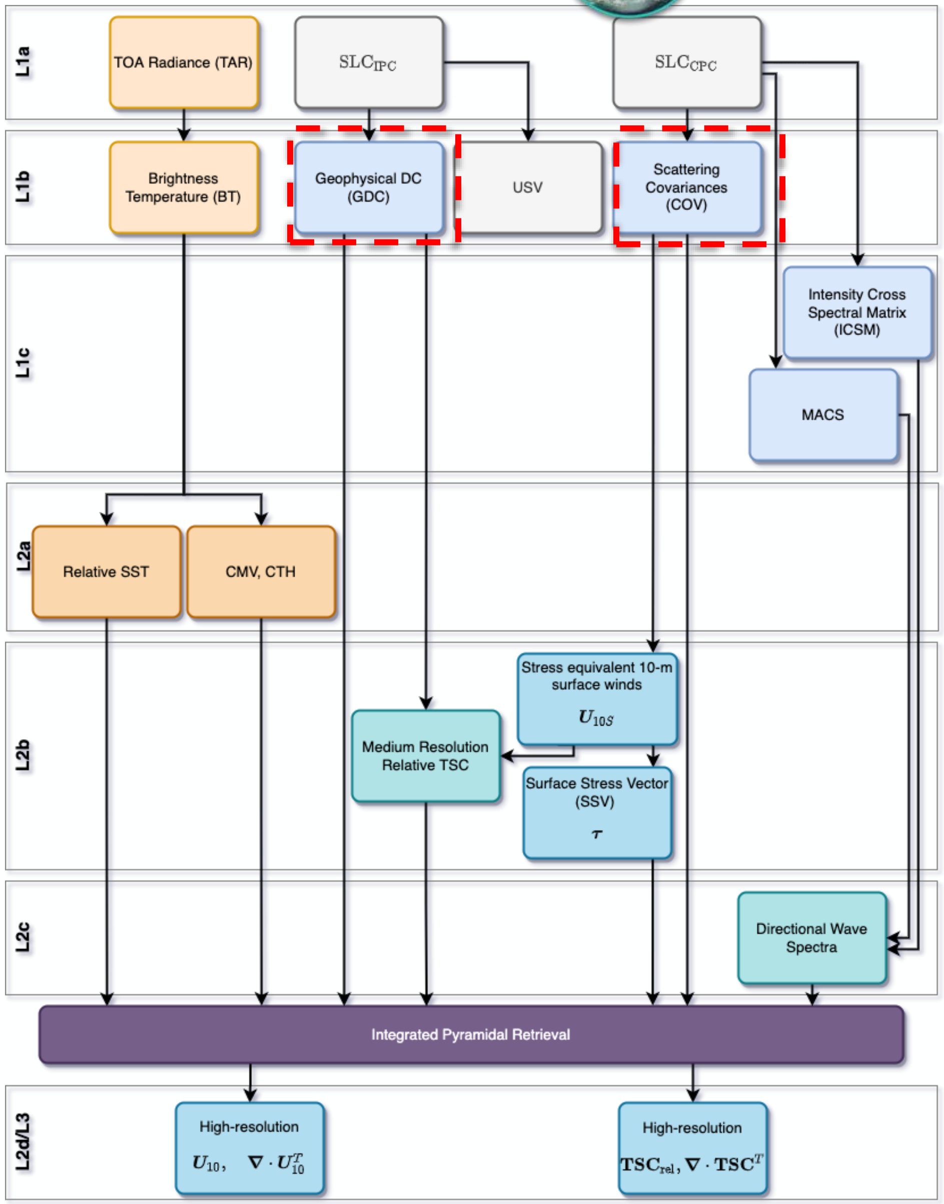
Line-of-sight diversity for high resolution

- Slow (DInSAR) **and fast (Doppler) surface motion vectors**.
- Directional roughness (→wind scatterometry)
- Improved directional surface wave spectra
- Sea Surface (skin) temperature
- Cloud-top motion vectors (TIR time-lapse) and height (TIR parallax)

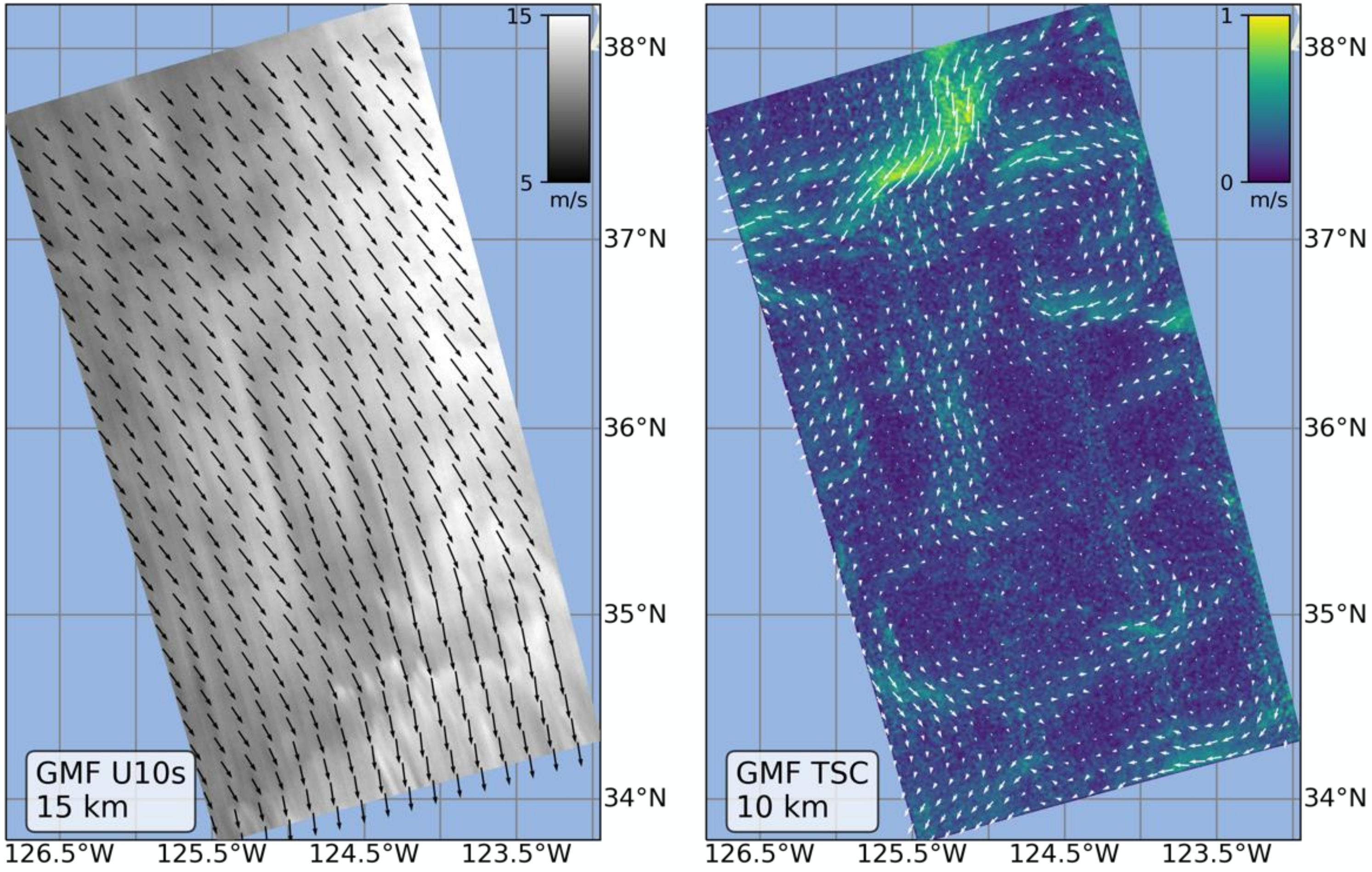


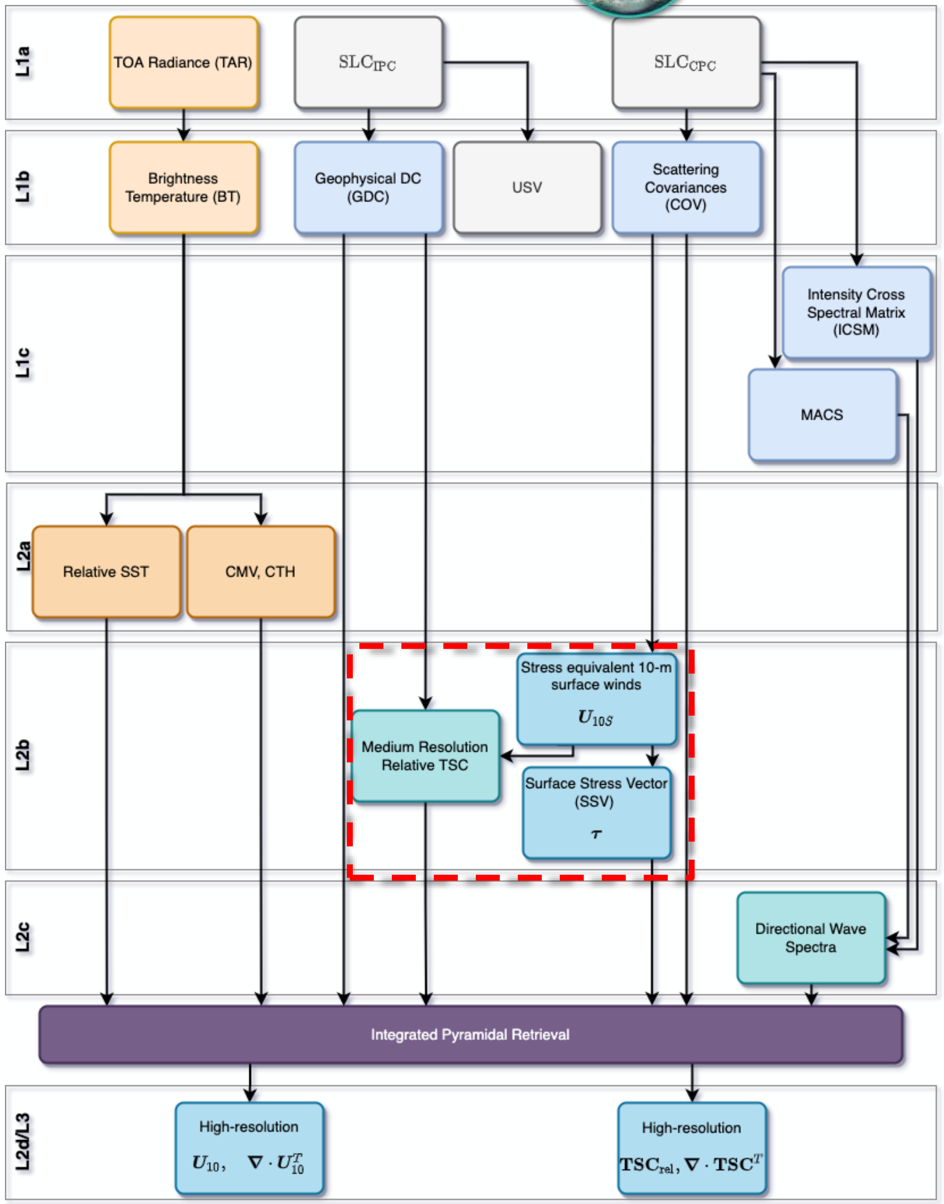
L1b: NRCS (COV) & Geophysical Doppler



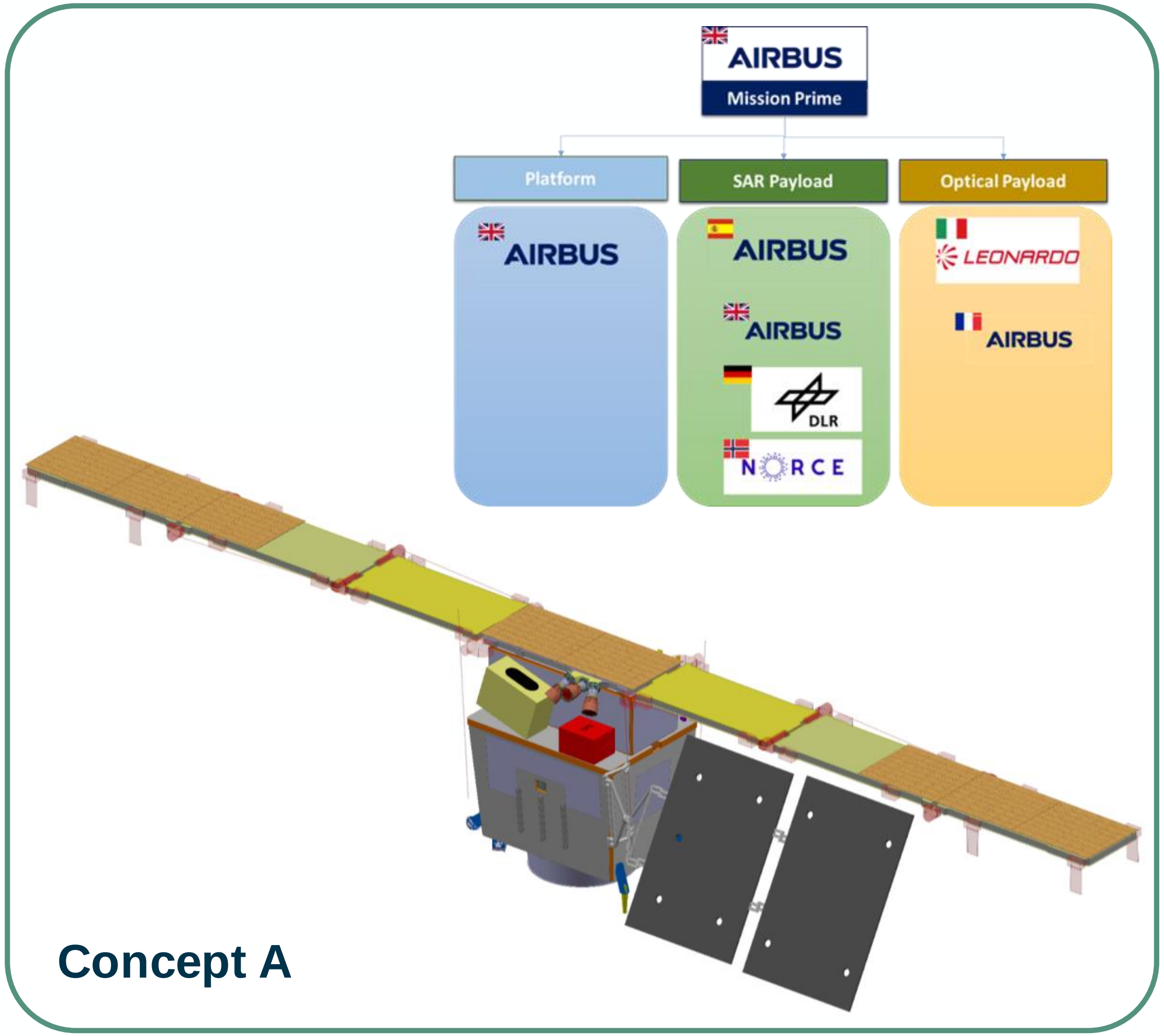


L2b: Stress equiv. surface wind (U_{10s}) & relative surface current (TSC)

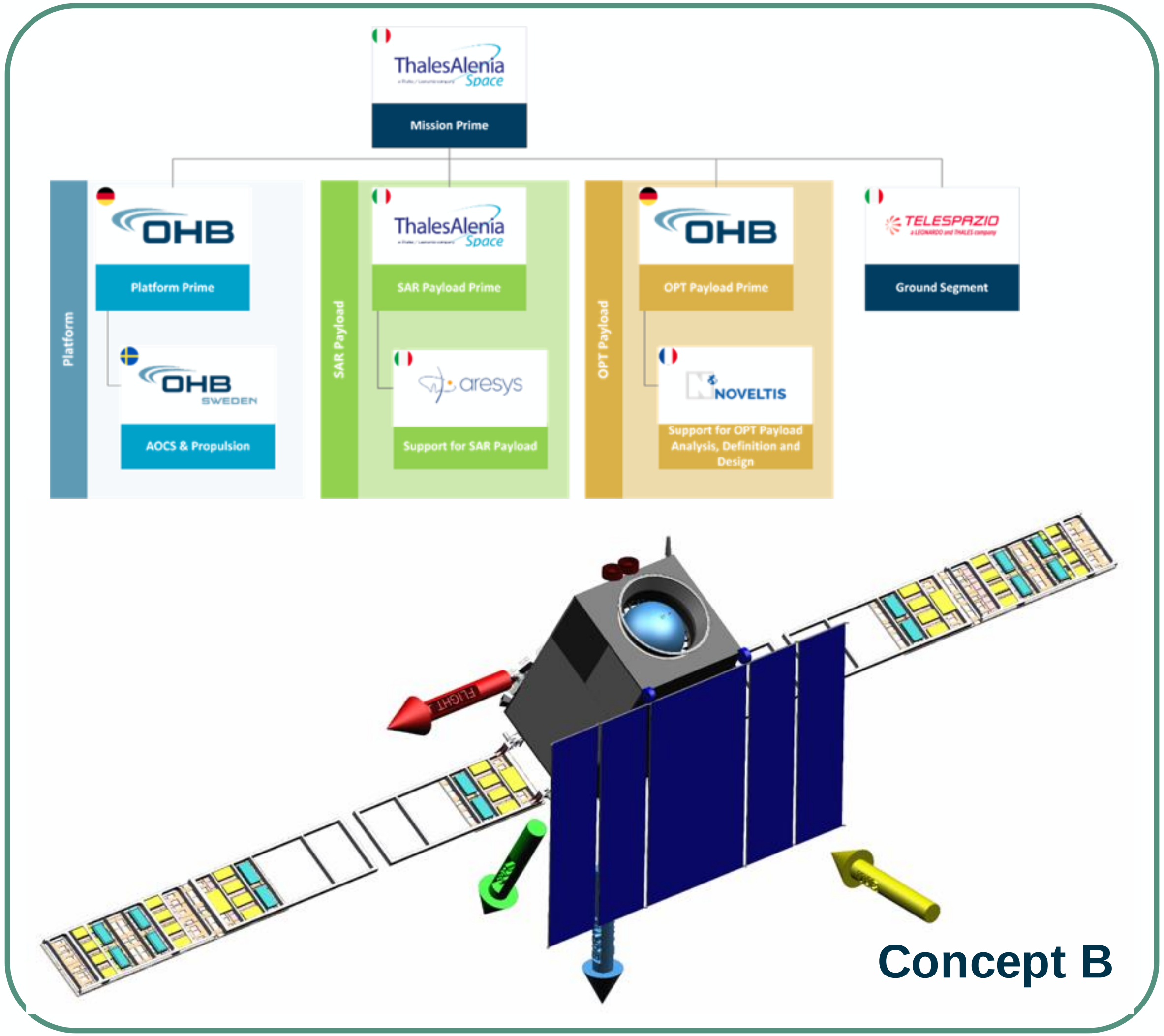




Harmony Parallel Phase 0/A studies

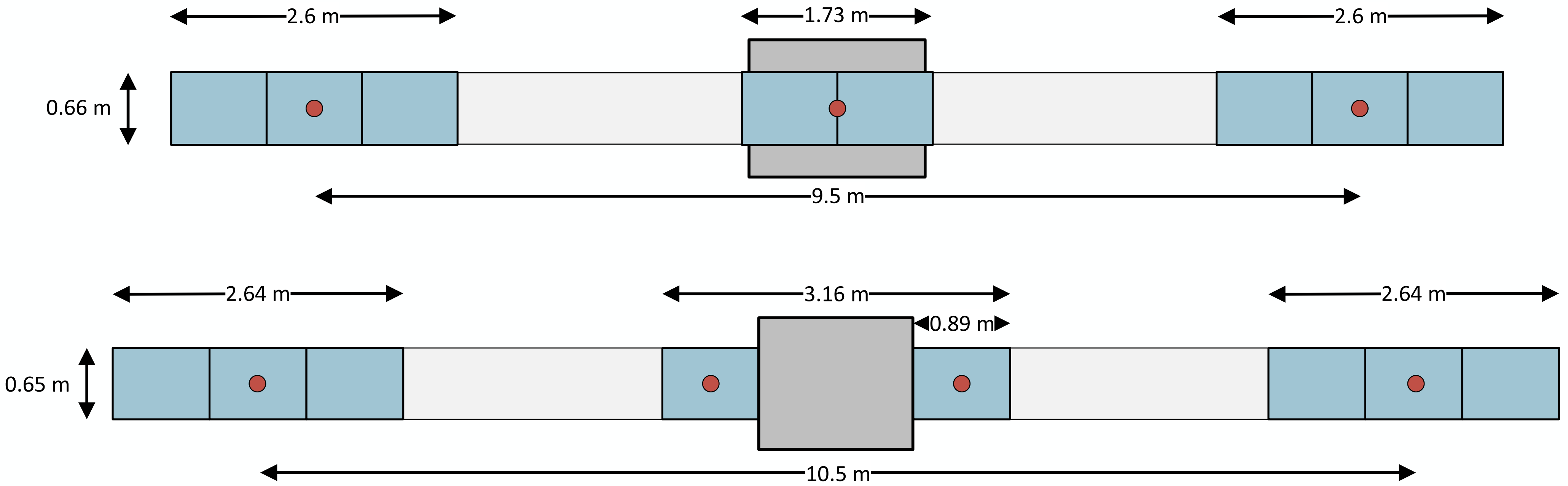


Concept A



Concept B

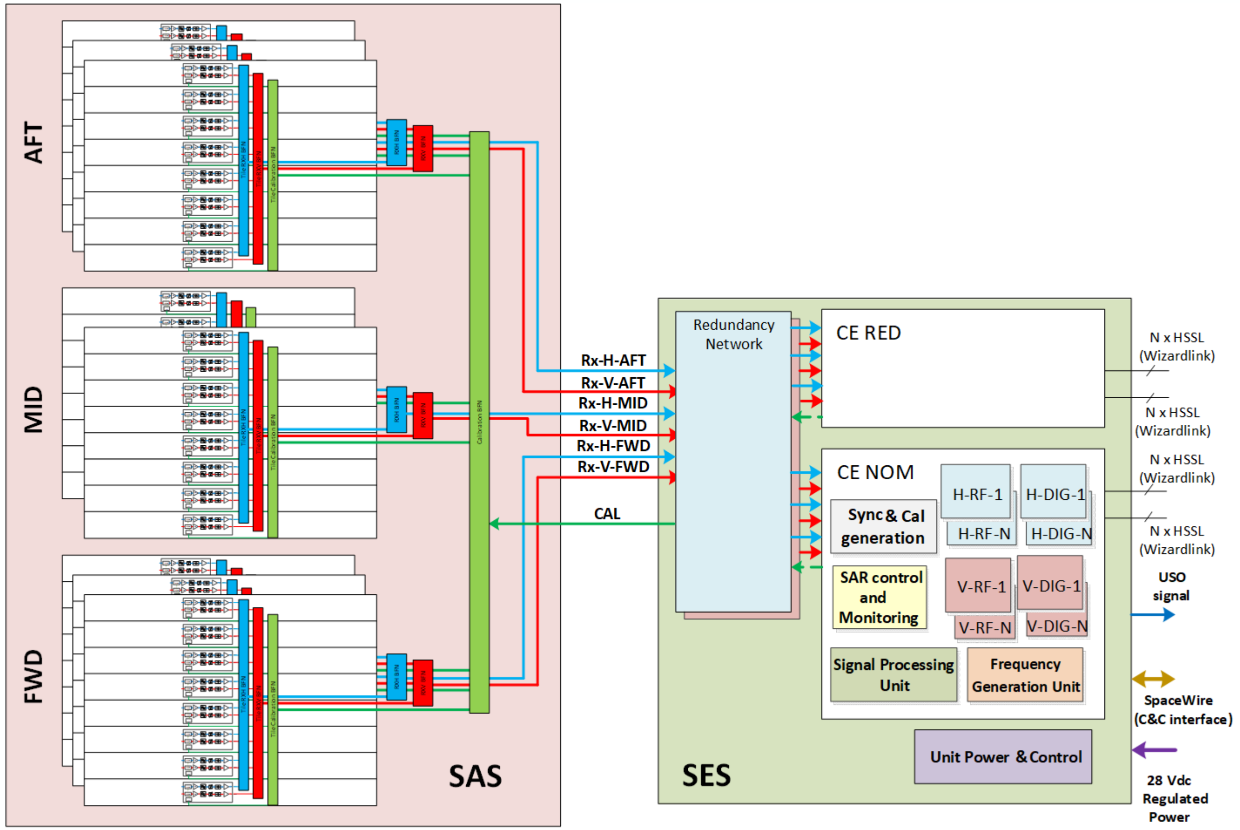
SAR Antenna Configuration



- Both SAR antennas converged to very similar solutions for both concepts.
- They make optimum use of available hardware resources.

Parameter	Concept A	Concept B
Antenna Surface	4.61 m²	4.62 m²
Overall antenna length	12.1 m	13.1 m
Number of sub-apertures	3	3
Number of antenna tiles	8	8
Number of single polarization receive modules	128	128

SAR Instrument Architecture

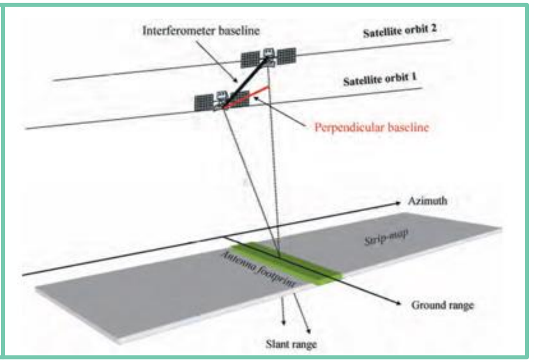


The SAR instrument comprises of the SAR Antenna Subsystem (SAS) and the SAR Electronics Subsystem (SES)

Full Antenna Level 1 Performance

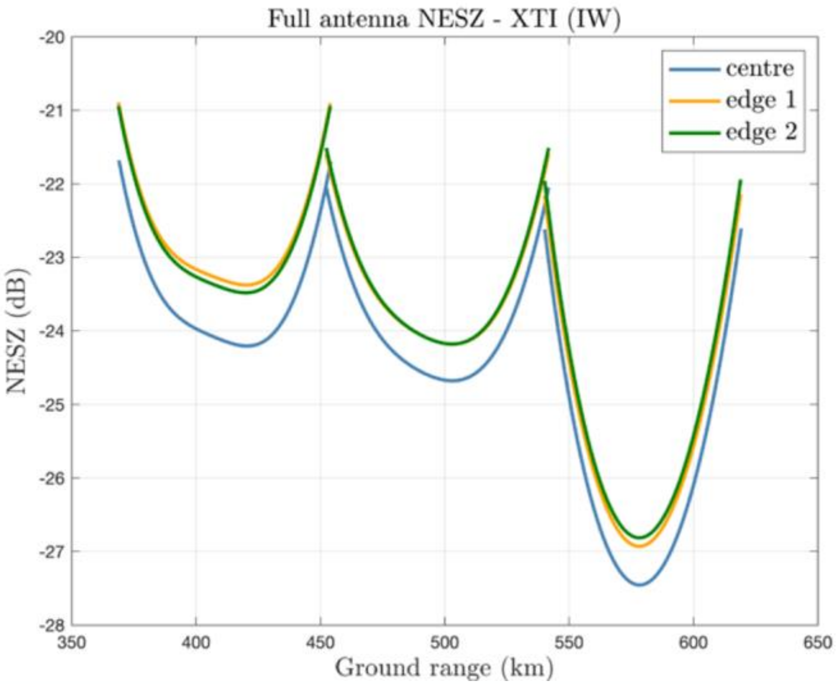
Observe topography changes

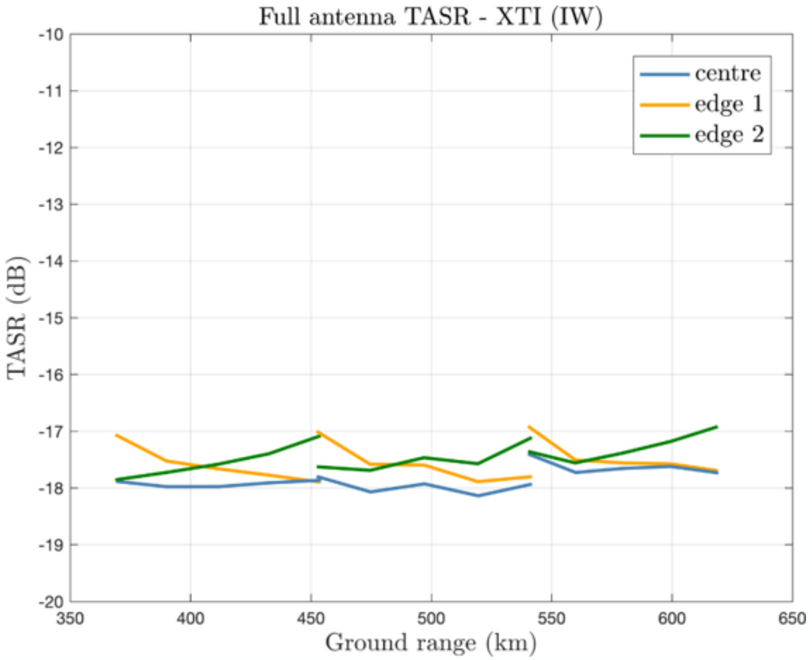
- XTI configuration
- Sensitivity of radar instrument (NESZ<-20dB)



Mission designed for 2x 1yr XTI mode
+ 3 XTI reconfigurations in between

NESZ < -20 dB
DTAR < -17dB

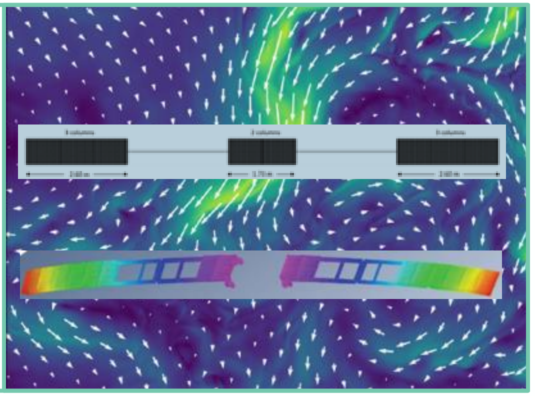




Ocean Surface Velocity Performance

Ocean surface velocities

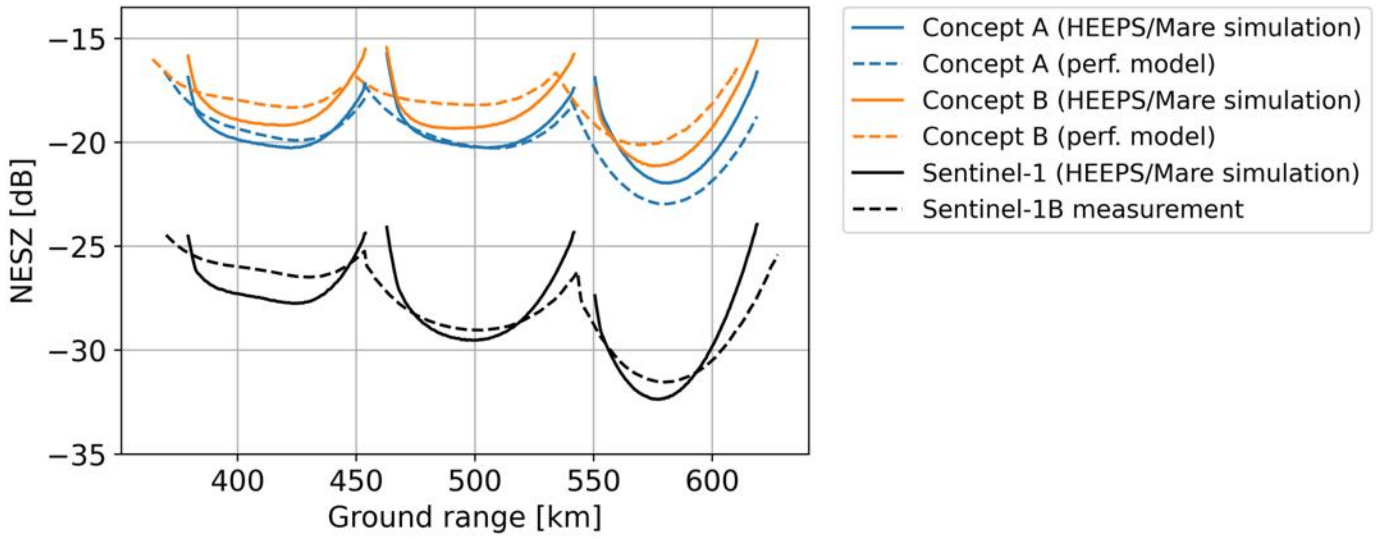
- Relative error < 20 cm/s @ 2km
- Mean error < 20 cm/s @ 10 km

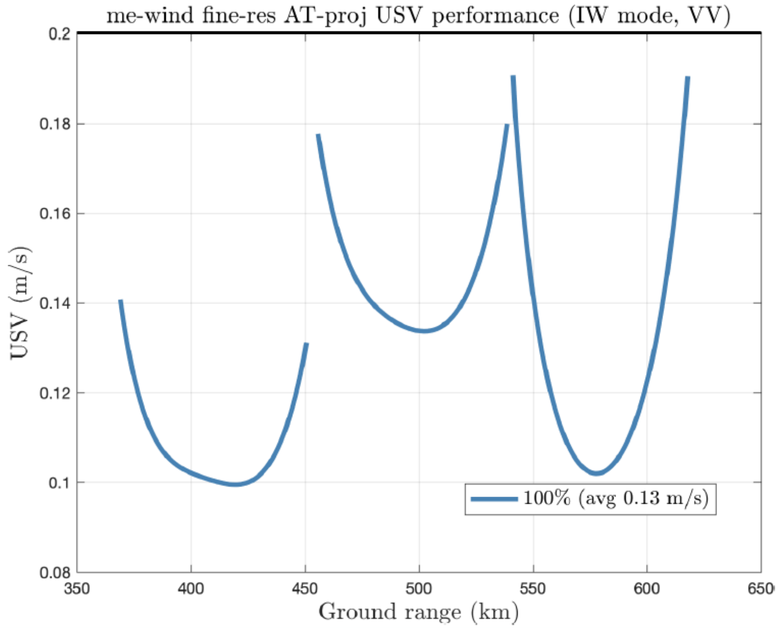


Relative Performance Error < 20 cm/s

Mean Performance Error < 20 cm/s

Validation of performance analysis tools
With end-to-end simulations



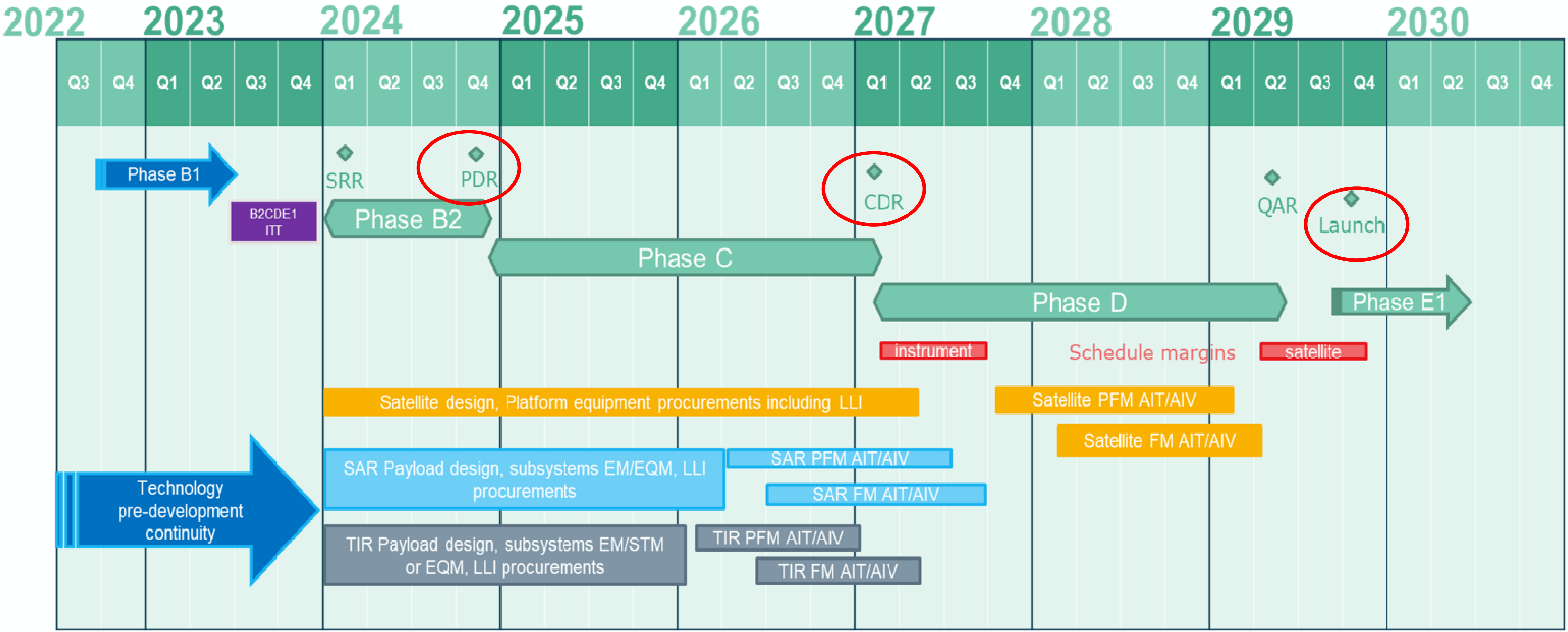


Harmony performance study : technical and scientific challenges in E2E framework (P.Dubois)

- Underlying physics to be considered in modeled ocean surface
  - What parameters & what correlation to consider (not too much, not too less)?
  - Data-driven approach / phenomenology : how to learn from the obs. ?
  - Mesh-gridded approach for simulation: how to deal wisely with this softaware separation scale not driven by EM nor geophysics ?

- On the design & use of E2E tools for future missions
  - How to set the priorities during dev. phase ? eg what progressive level of complexity in the observing system representativity along Phases 0/A/B ?
  - Processing of levels 1 & 2 : what feedback loop between ATBDs and results from implementation ?
  - What inter-dependency to other tools ("scientific" simulators, "manufacturers" simulators, ...) ?

Harmony development schedule key dates



A New Distributed ATI SAR System: GEO-LEO SAR ATI Concept

Fu Jiayu, Li Yuanhao, Chen Zhiyang, Hu Cheng
Beijing Institute of Technology

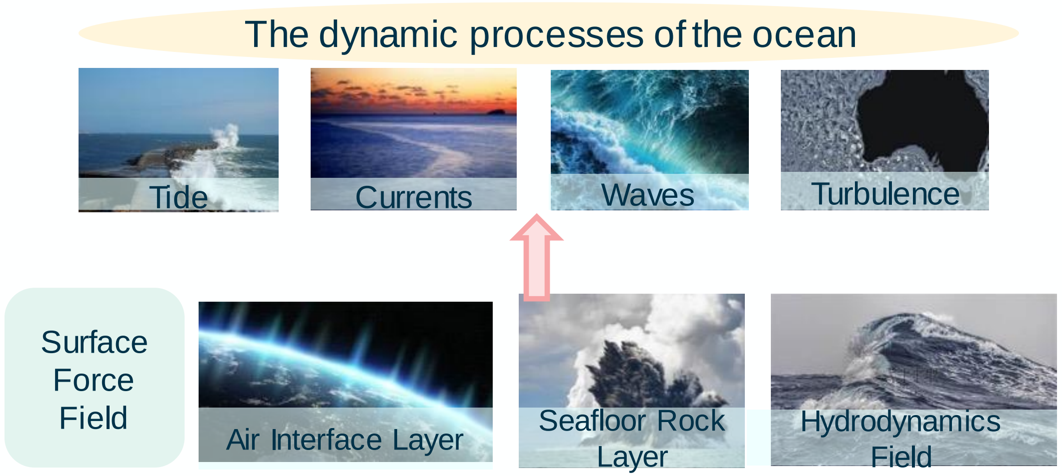
04/05/2023

Key Objectives

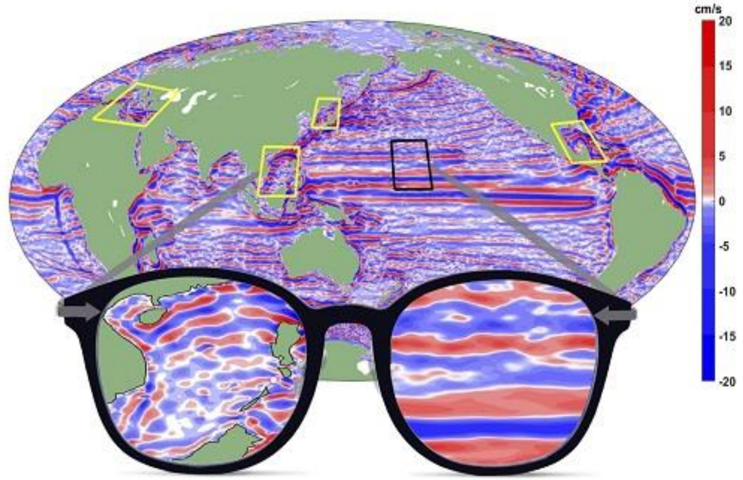
- The Acquisition of Retrieval Total Surface Currents Velocity Vectors(TSCV)
  - The main measurement elements
    - Velocity
    - Direction
    - Geographical Distribution

Key Objective

Complete Current Vectors	Multiple Geographical Scales



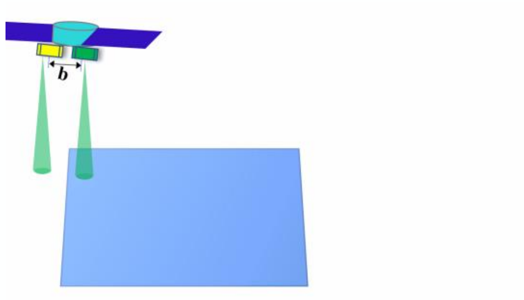
The Mechanical Causes of Ocean Currents



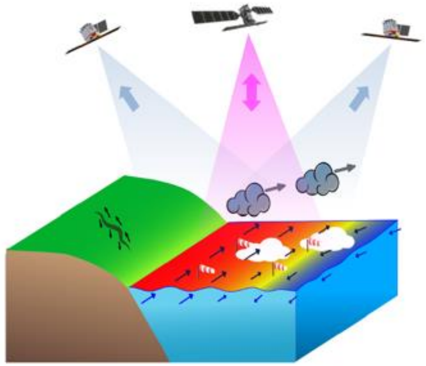
Multiple Scales of Ocean Current observation

Key Objectives

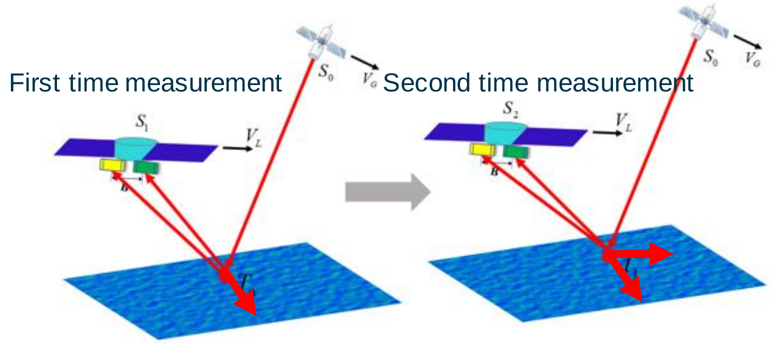
- Along-track Interferometry(ATI) SAR System
  - A mainstream method in ocean SAR field, offering LOS velocity of the surface
  - Development Trend:
    - Traditional ATI: Based on single SAR platform
    - Distributed ATI SAR System: eg. Harmony
    - **GEO-LEO SAR ATI System**: China's GEO SAR will be launched soon, which could be used as a stable illumination source for distributed SAR system in the future.



Traditional ATI SAR System



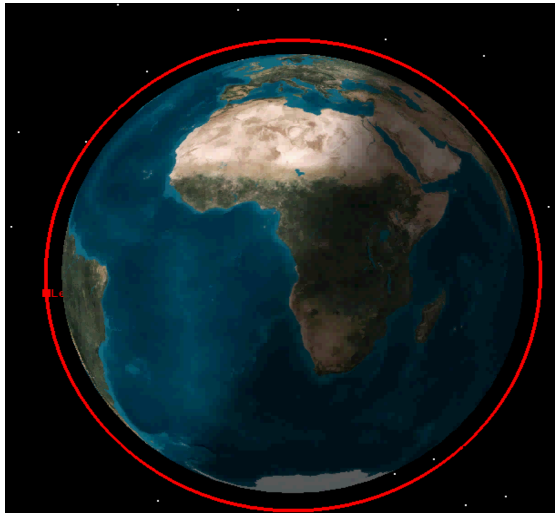
Harmony:
A distributed ATI SAR System



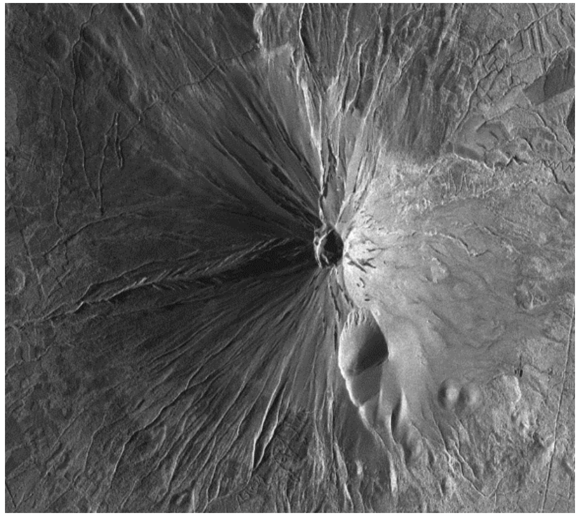
GEO-LEO ATI SAR:
A distributed ATI SAR System

Key Objectives

- GEO SAR System: Geosynchronous SAR System
  - LEO SAR → GEO SAR
    - Orbit height: <1000km
    - Small swath width(10~100km), long revisit time (days)
    - Slow response to emergencies: earthquake, flooding, etc.



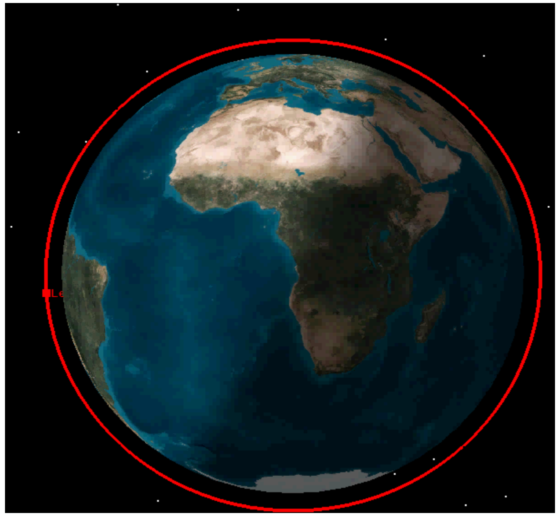
LEO SAR



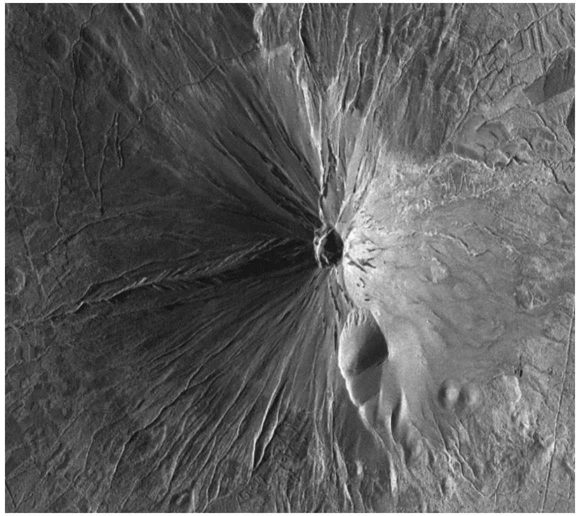
LEO SAR Image

Key Objectives

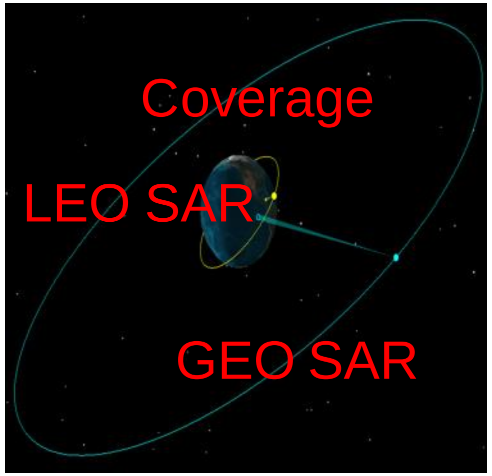
- GEO SAR System: Geosynchronous SAR System
  - LEO SAR → GEO SAR
    - Orbit height: ~36000km, non-stationary orbit
    - Wide swath: >1000km
    - Short revisit time: ~hours



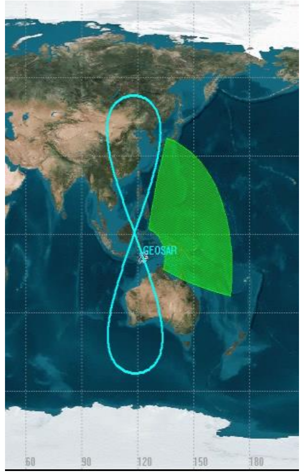
LEO SAR



LEO SAR Image



Geometry of GEO SAR and LEO SAR



Beamfoot coverage of GEO SAR

Key Objectives

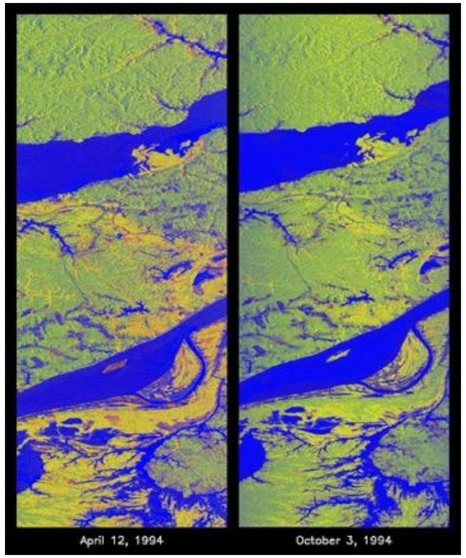
GEO SAR System: Geosynchronous SAR System

GEO SAR Applications

- Wide coverage imaging & continuous observation
- Emergency management (flood, earthquake, debris flow, etc.)

Main debris flow area of China

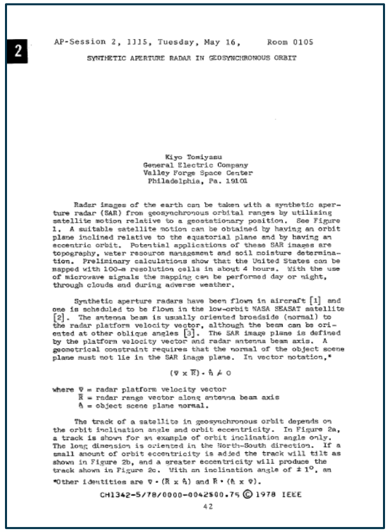
Seismic active region of China



Water change detection

Key Objectives

- GEO SAR System: Geosynchronous SAR System
  - GEO SAR History:
    - First proposed by Prof.Tomiyasu, 1978



2

AP-Session 2, 1115, Tuesday, May 16, Room 0105

SYNTHETIC APERTURE RADAR IN GEOSYNCHRONOUS ORBIT

Kiyo Tomiyasu
General Electric Company
Valley Forge Space Center
Philadelphia, Pa. 19101

Radar images of the earth can be taken with a synthetic aperture radar (SAR) from geosynchronous orbital ranges by utilizing satellite motion relative to a geostationary position. See Figure 1. A suitable satellite motion can be obtained by having an orbit plane inclined relative to the equatorial plane and by having an eccentric orbit. Potential applications of these SAR images are topography, water resource management and soil moisture determination. Preliminary calculations show that the United States can be mapped with 100-m resolution cells in about 4 hours. With the use of microwave signals the mapping can be performed day or night, through clouds and during adverse weather.

Synthetic aperture radars have been flown in aircraft [1] and one is scheduled to be flown in the low-orbit NASA SEASAT satellite [2]. The antenna beam is usually oriented broadside (normal) to the radar platform velocity vector, although the beam can be oriented at other oblique angles [3]. The SAR image plane is defined by the platform velocity vector and radar antenna beam axis. A geometrical constraint requires that the normal of the object scene plane must not lie in the SAR image plane. In vector notation,*

$$(\bar{V} \times \bar{R}) \cdot \hat{n} \neq 0$$

where $\bar{V}$ = radar platform velocity vector
$\bar{R}$ = radar range vector along antenna beam axis
$\hat{n}$ = object scene plane normal.

The track of a satellite in geosynchronous orbit depends on the orbit inclination angle and orbit eccentricity. In Figure 2a, a track is shown for an example of orbit inclination angle only. The long dimension is oriented in the North-South direction. If a small amount of orbit eccentricity is added the track will tilt as shown in Figure 2b, and a greater eccentricity will produce the track shown in Figure 2c. With an inclination angle of $\pm 1^{o}$, an

*Other identities are $\bar{V} \cdot (\bar{R} \times \hat{n})$ and $\bar{R} \cdot (\hat{n} \times \bar{V})$.

CH1342-5/78/0000-0042$00.75 © 1978 IEEE

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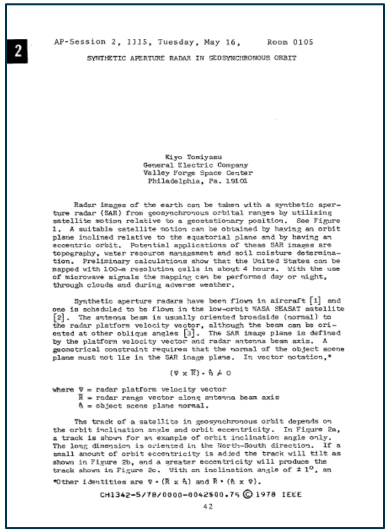
Paper: *Synthetic aperture radar in geosynchronous orbit*
From: International Symposium on Antennas and Propagation, 1978

Prof. Tomiyasu
(IGARSS 2010, Hawaii)

Key Objectives

GEO SAR System: Geosynchronous SAR System

- GEO SAR History:
  - First proposed by Prof.Tomiyasu, 1978



2

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CH1342-5/78/0000-0042$00.75 © 1978 IEEE

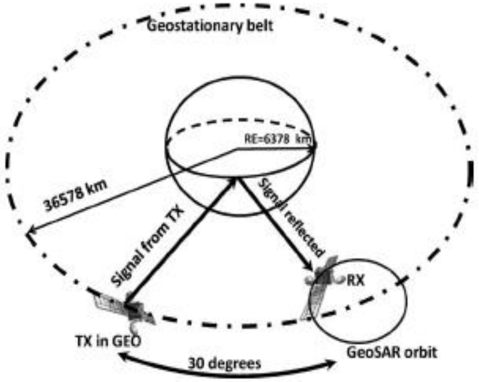
42

Paper: *Synthetic aperture radar in geosynchronous orbit*
From: International Symposium on Antennas and Propagation, 1978

Prof. Tomiyasu
(IGARSS 2010, Hawaii)

- Bistatic Parasitic GEO SAR:
- L-band broadcast satellites or others: transmitter
- Only geosynchronous receivers: small payload

Paper: *Passive Geosynchronous SAR System Reusing Backscattered Digital Audio Broadcasting Signals*
From: IEEE TGRS, 1998
Polytechnic University of Milan



Sketchmap of Bistatic configuration

Key Objectives

- GEO SAR System: Geosynchronous SAR System
  - GEO SAR History:
    - GESS System: Global Earthquake Monitoring System, 2003
    - SIMO Parasitic GEO SAR system, 2006 UK
    - GEO SAR swarm: Bistatic or MIMO, 2012 Italy&Spain
    - More research works engaging in China:

Year	Project	Funding organization
2008	GEO SAR Initial research	China Academy of Space Technology Beijing Institute of Technology
2010	Theory and key technologies research on GEO SAR	National Natural Science Foundation of China
2012	Demonstration Research on GEO SAR satellite system	China Academy of Space Technology
2013	Research on GEO D-InSAR and deformation monitoring	National Natural Science Foundation of China
2014	GEO SAR: First scientific research satellite	Medium and long term development plan of national civil space infrastructure in China
Currently	GEO SAR satellite	Under development

Will be soon launched!

Key Objectives

Research on BIT

- Main research:

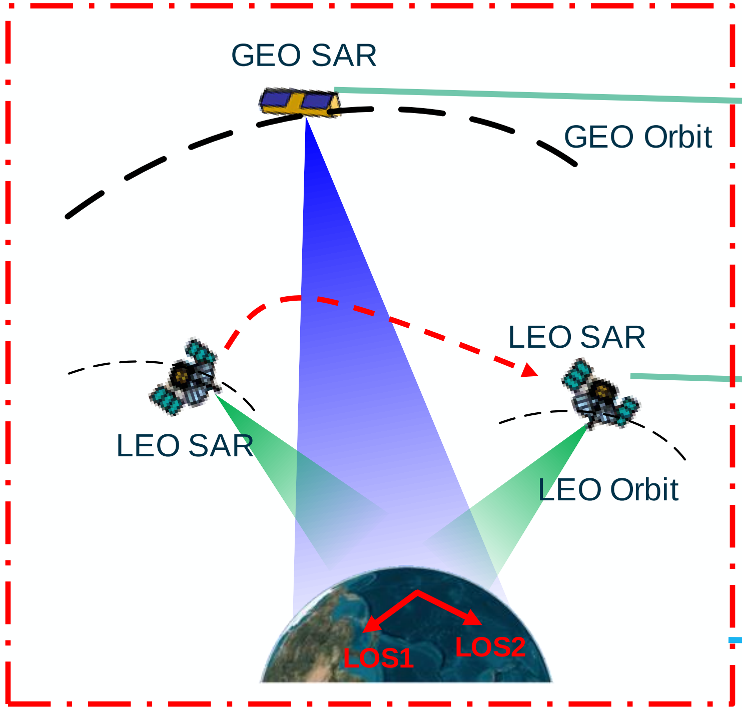
Research Aspects	Innovations and Solutions
System Design	Resolution analysis: Gradient theory + Projection theory
Imaging Algorithm	Accurate Signal Model + 2D NCS algorithm
Ionosphere Analysis and Compensations	Time-space varying TEC Model
	Scintillation sampling model
D-InSAR / TomoSAR	Optimal data acquisition method

Experiment Validation: Bistatic imaging experiment
Ionosphere monitoring experiment
Deformation / TomoSAR measurement experiment

Innovation(New findings and Achievements)

A New Distributed SAR System: GEO-LEO SAR

- The acquisition of complete current vectors: ATI SAR technology
- **GEO SAR** as a Stable Irradiation Source, **LEO SAR** as a Passive Receiver



Distributed GEO-LEO SAR System

- Advantages:
  - ✓ Large Irradiation Area
  - ✓ Slow & Steady Motion
- Shortcomings:
  - × Long Integration Time→Bad Coherence for ATI
  - × Poor Resolution

- Advantages:
  - ✓ Short Integration Time Demand→Satisfying Coherence for ATI
  - ✓ Good Resolution
- Shortcomings:
  - × Only One LOS Direction for ATI measurement
  - × Cost High for Applying on Distributed LEO SAR System

- **Advantages:**
  - ✓ **Multiple Observing Angle Directions at A Time**
  - ✓ **At least 2 LOS Velocities when Applying ATI when using time division measurement**

Innovation(New findings and Achievements)

esa

A New Distributed SAR System: GEO-LEO SAR

- Difficulty1: Configuration, a distributed SAR configuration optimization method is proposed
- Difficulty2: Processing methods, an ATI processing algorithm for Bi-SAR(this mode) in multi-view observation is proposed

Difficulty1

- Much DOF
- Multiple target parameter
- Large difference of geometry

Configuration Parameter	Target Parameter
	Imaging Performance
GEO SAR Look Angle $\theta_G/°$	d_{gr}/m
	d_{ga}/m
LEO SAR Look Angle $\theta_L/°$	Resolution angle $\Omega/°$
	NESZ $NE\sigma_0$/dB
LEO SAR Squint Angle $\vartheta_L/°$	ATI Performance
Bistatic Angle $\phi/°$	$\frac{\Delta v_{ATI}}{\Delta \phi}$

NSGA-III

- **Mathematical modeling of problem:**
  - ✓ Multi-objective non-convex optimization

Configuration Optimization Method

Difficulty2

- Phase model failure
- Multi-view data fusion
- Multiple error sources interfere

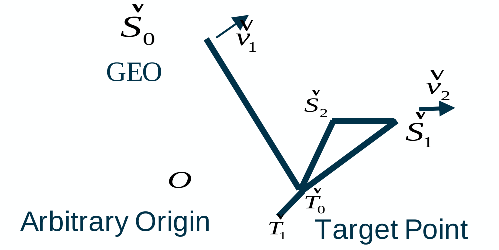
Derivation of ATI Phase

$$|v_r| = \varphi_{ATI} \cdot \frac{\|v_{LEO}\|}{B} \cdot \frac{\lambda}{2\pi} + \frac{\vec{n}_{GEO}}{\|\vec{n}_{GEO}\|} \cdot \vec{v}_{GEO}$$

Error term to be compensated

$$\vec{u}_r = \frac{\vec{n}_{LEO} + \vec{n}_{GEO}}{\|\vec{n}_{LEO} + \vec{n}_{GEO}\|}$$

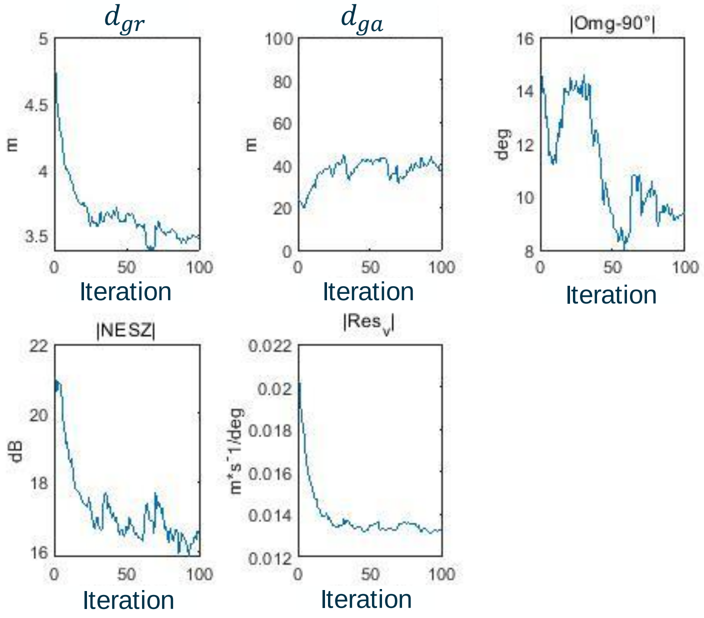
New LOS direction



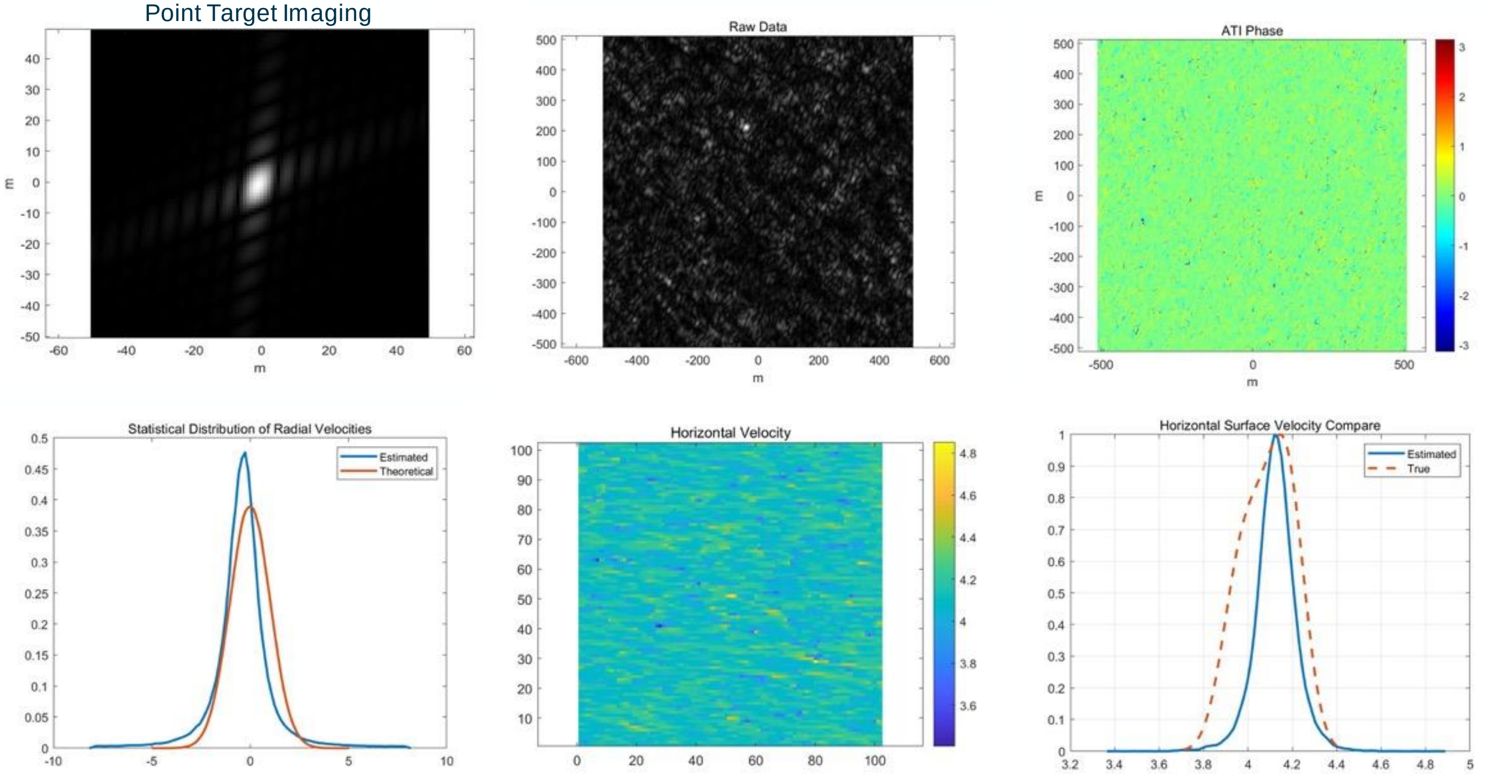
ATI Algorithm Design

A New Distributed SAR System: GEO-LEO SAR

Some Simulation Results



Genetic Algorithm as Optimal Configuration Solution

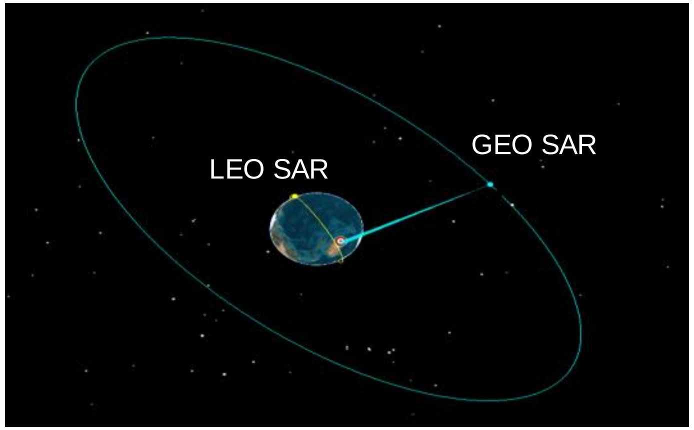


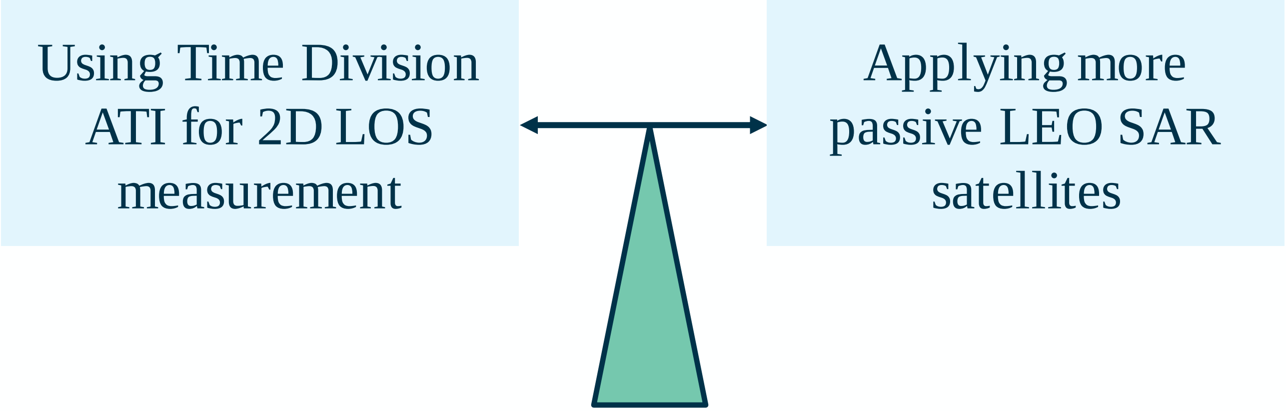
Verification of Configuration and ATI Processing

Remaining Knowledge Gaps and Deficiencies

A New Distributed SAR System: GEO-LEO SAR

- High precision 2-D ocean current field inversion algorithm needs to be studied
  - How to acquire complete TSCV by using GEO-LEO ATI system is still a problem
    - ✓ Take two ATI measurements in a short period of time (Suppose that the velocity of the current is constant for a short period of time)
    - ✓ Applying two or more LEO SARs offering two LOS at a time



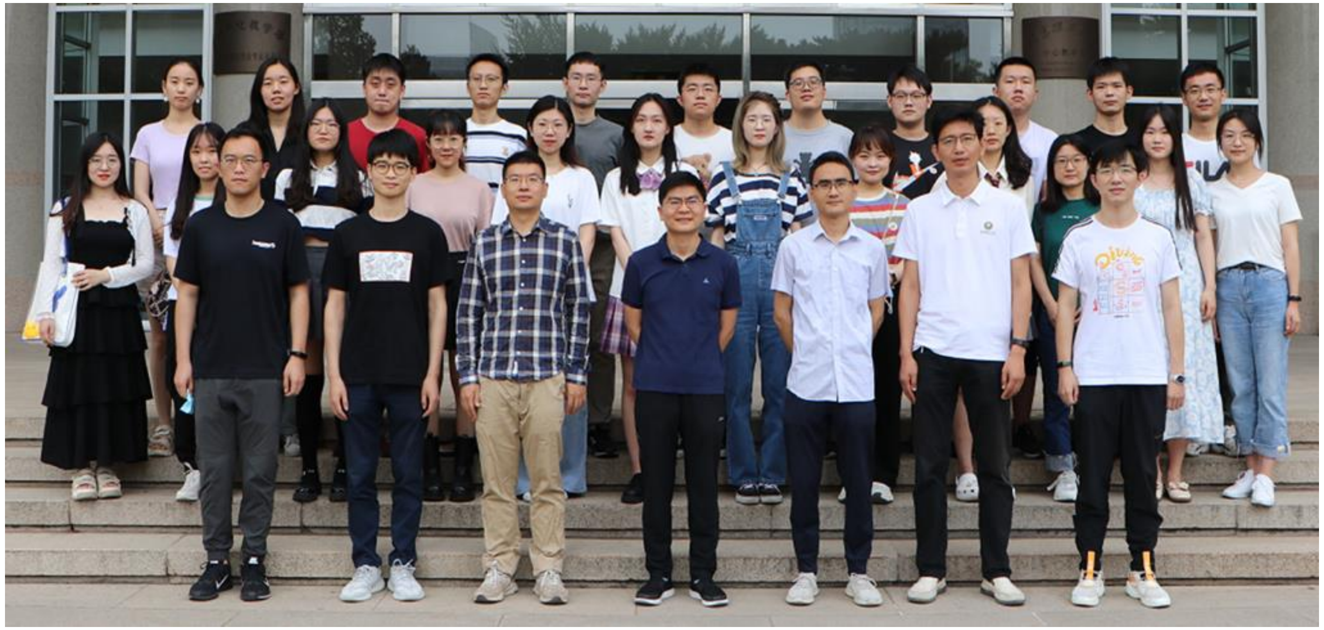


Outlook and Recommendation

- As an alternative concept for Harmony to retrieve Ocean currents vectors and other dynamic or static parameters
  - The technical feasibility of using this distributed system to measure other dynamic and static parameters of the ocean remains to be studied, eg. Sea surface wind vectors(SWV), Sea surface stress vectors(SSV) and so on
- GEO SAR as a stable irradiation source can be used in many other potential tasks
  - It may reduce the cost of distributed systems for various passive SAR can be used to perform many kinds of tasks
  - As China's GEO SAR is about to be launched, various future distributed SAR missions that may using GEO orbit or transmit & receive separate systems will be validated with it

Outlook and Recommendation

Our Teams in China!



- If you are interested in or have more questions, please contact us:
- Prof. Li Yuanhao
- Contact Email : lyh.900101@163.com

Radar Research Laboratory

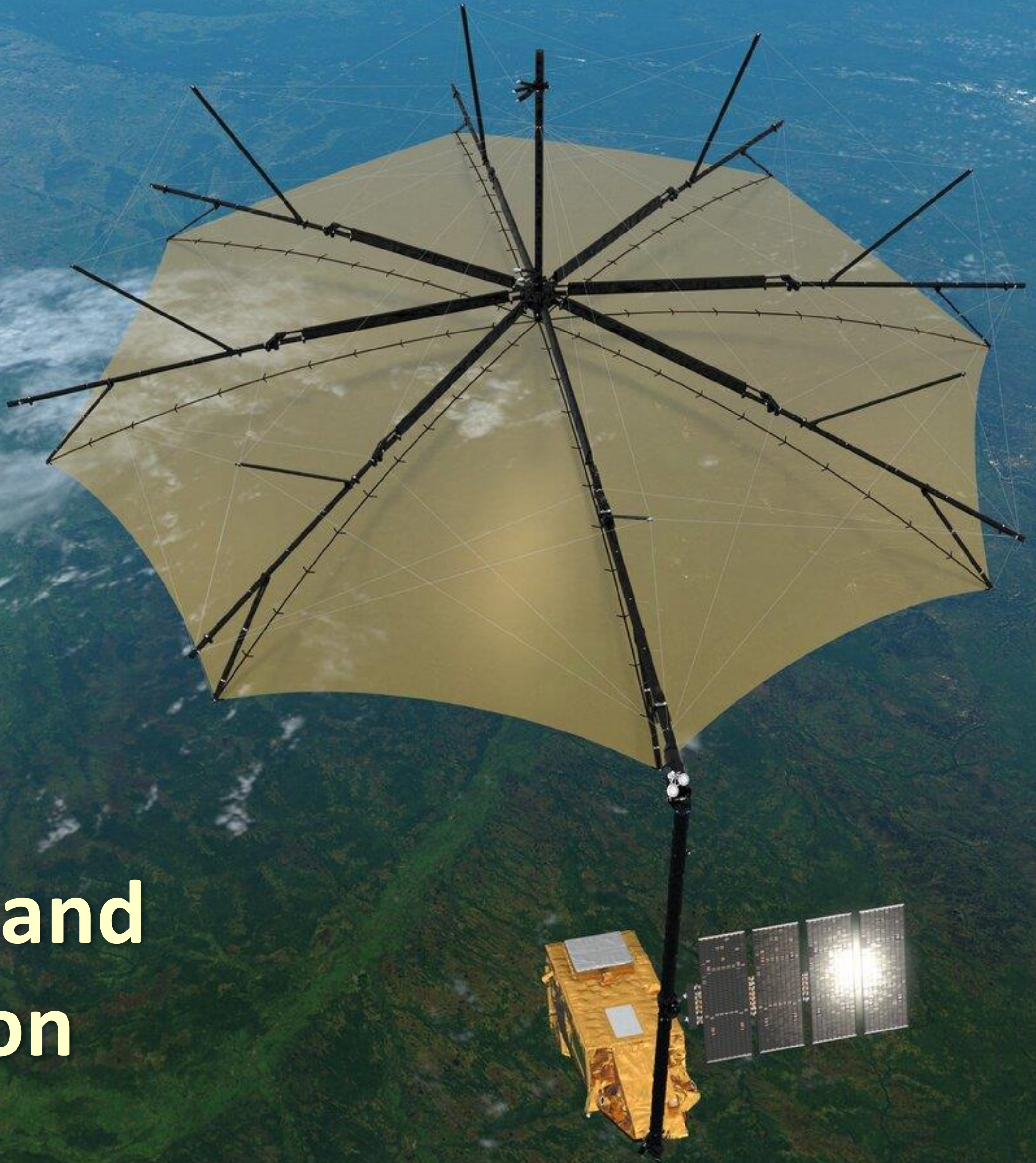
of

Beijing Institute of Technology

Unit Address: No.5 Zhongguancun South Street, Haidian District, Beijing

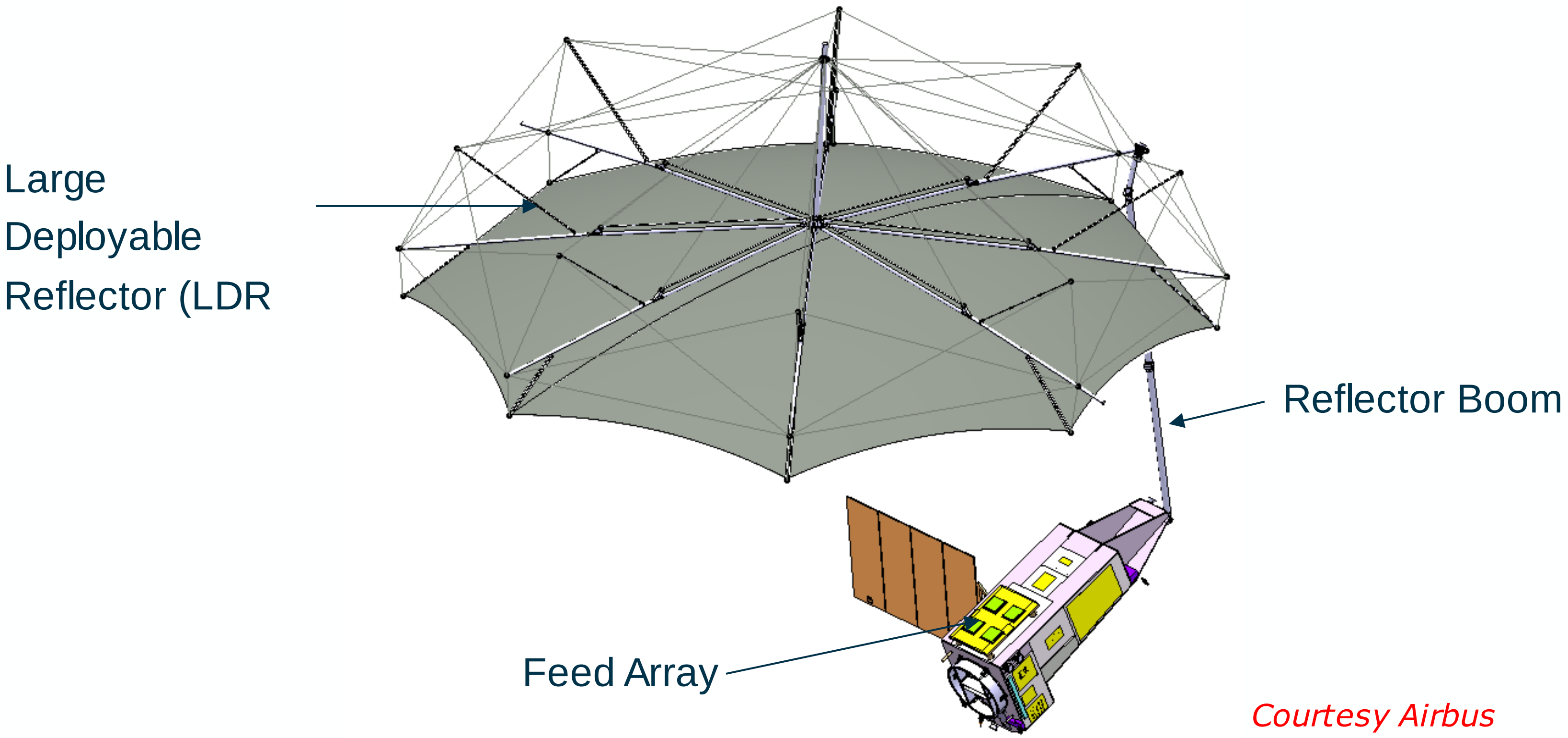
BIOMASS:

P-band SAR
Reducing uncertainties in land use change carbon flux

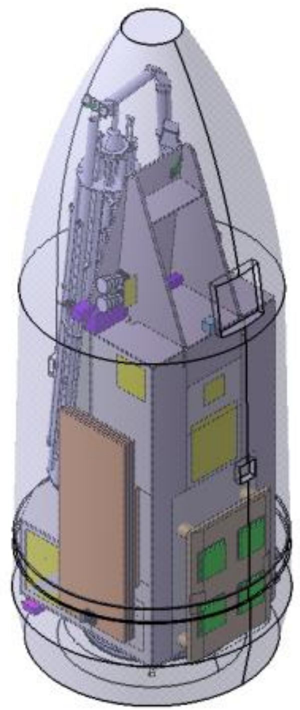


Biomass spacecraft design and status (1/2)

P-band / 435 MHz (with 6 MHz bandwidth) / ~ 70 cm wavelength



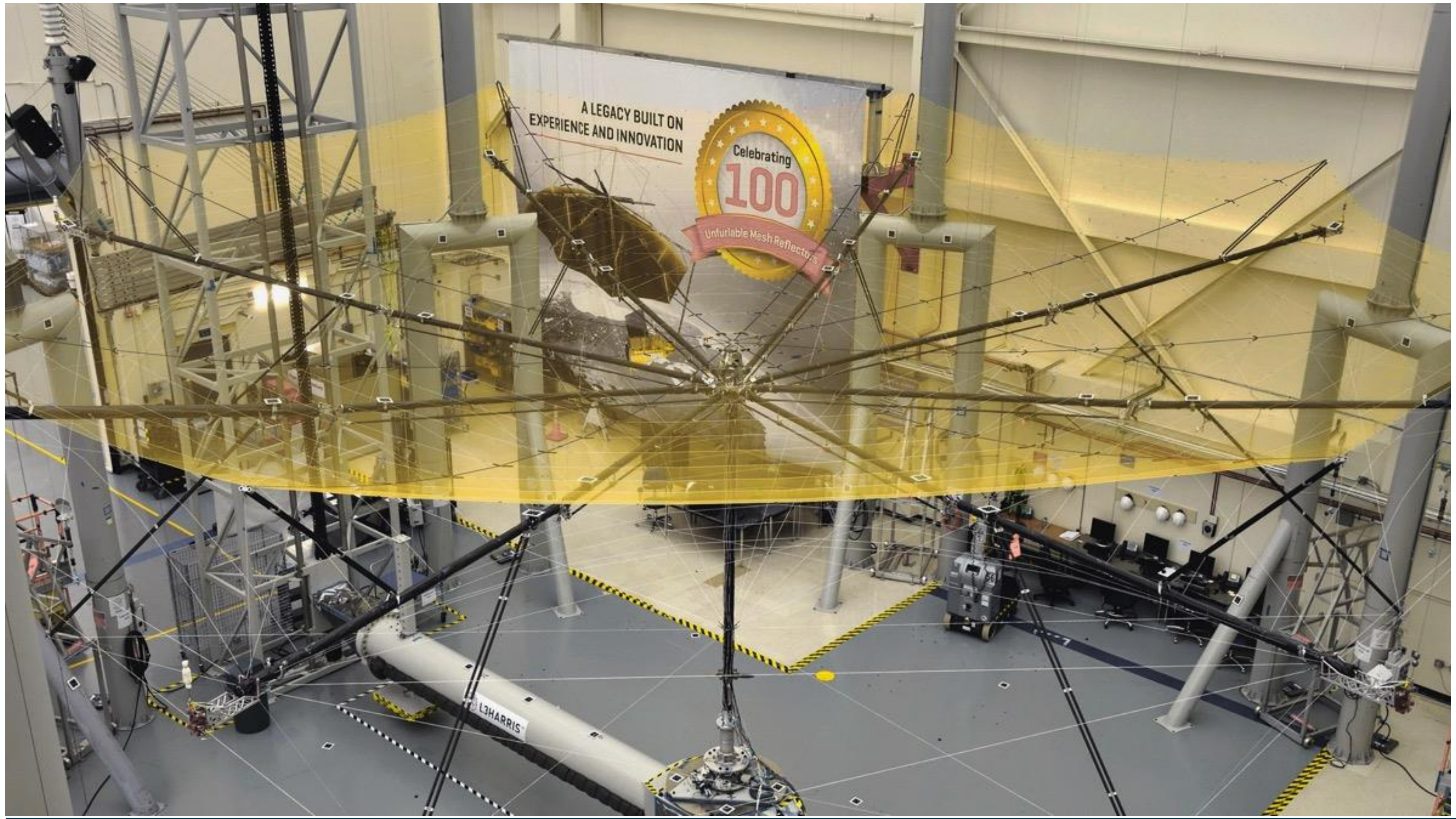
Courtesy Airbus

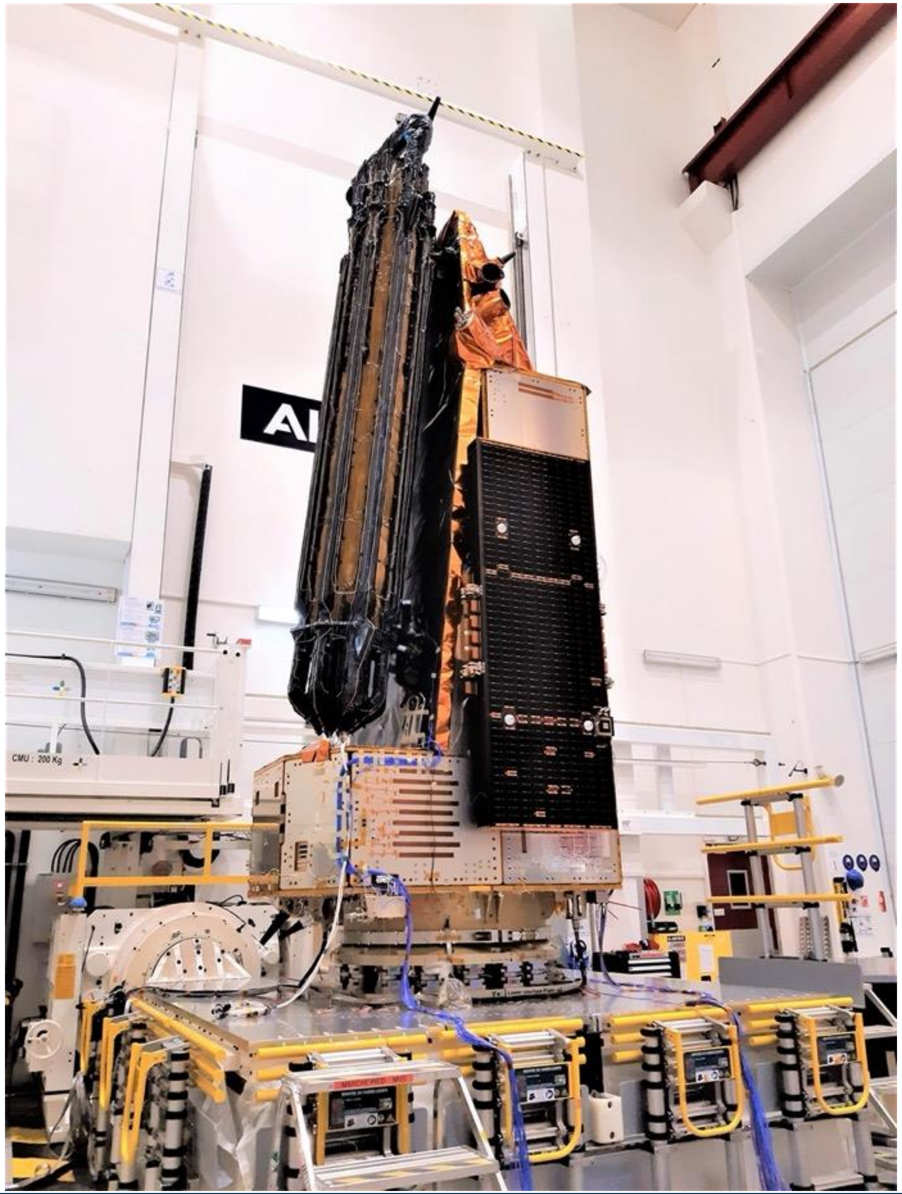


- offset feed-reflector antenna system with a 12 metres aperture deployable reflector
- satellite avionics based on the Airbus AS250 platform, including power, command and data handling, payload data handling, Attitude and Orbit Control Systems (AOCS) and telemetry and telecommand subsystems.
- The AOCS architecture provides zero-Doppler steering and roll steering to ensure compatibility with deployable reflector and to meet the SAR mission performance needs

Biomass spacecraft design and status (2/2)

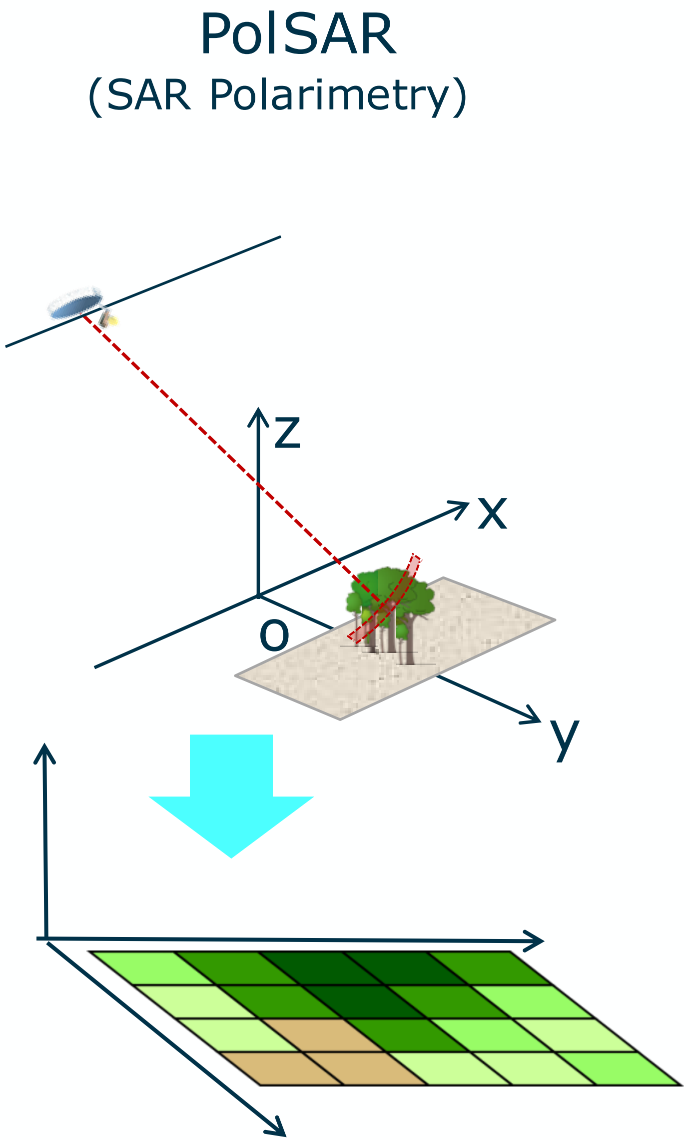
- Biomass is currently in integrated system validation and testing phase. The reflector has been shipped back to Florida (L3Harris) for final on-ground deployment tests
- Launch foreseen (Vega) Q3-2024

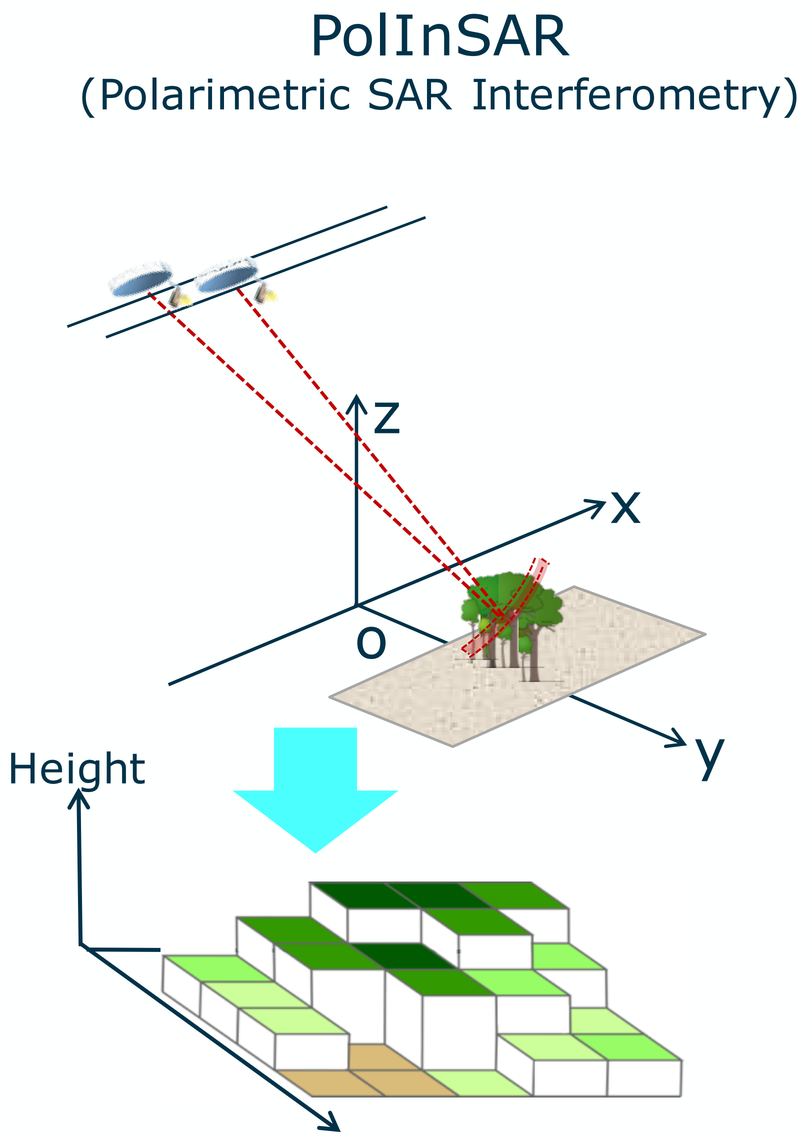


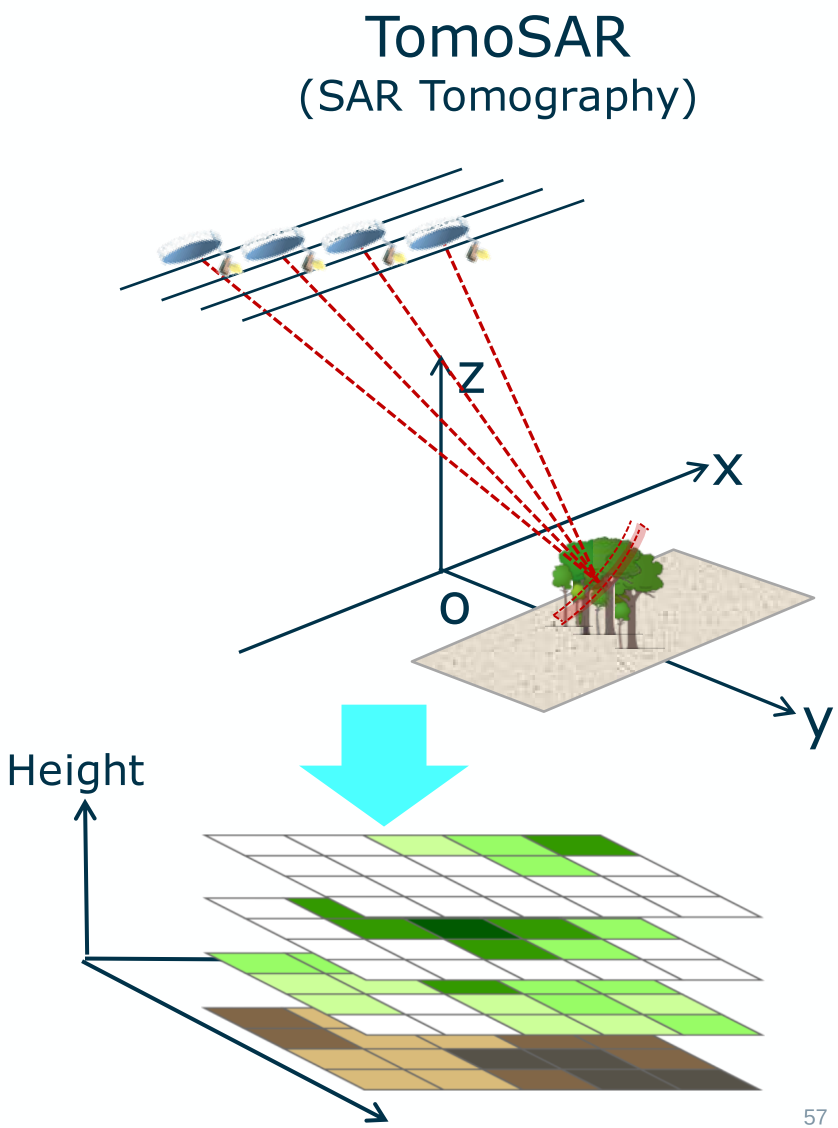


Biomass SAR observation capability

50% duty cycle (50 min in any 100 min window)







BIOMASS COVERAGE

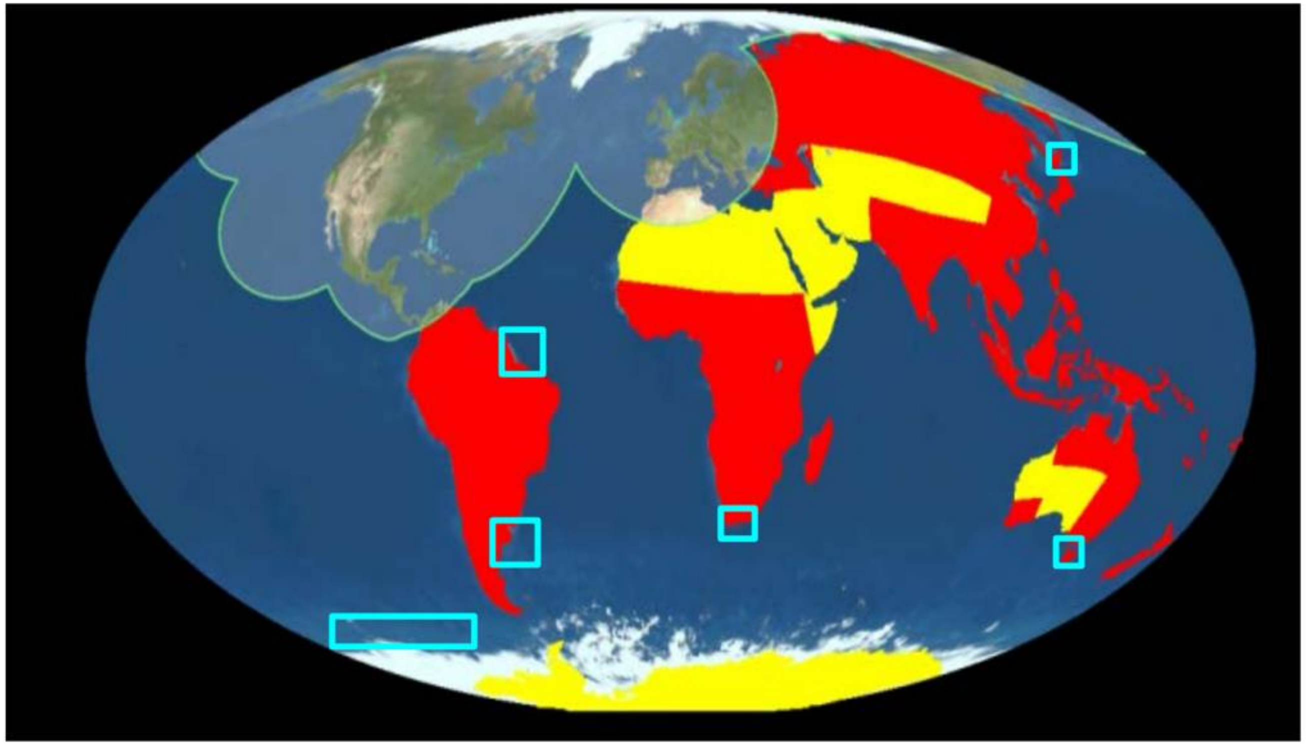
1. Acquisition mask restricted by US Space Objects Tracking Radar (SOTR)

2. Systematic Acquisitions for forested

land (red area) in both ascending and

descending passes.

3. Best effort acquisitions for non forested areas (yellow + ocean/sea ice ROIs)

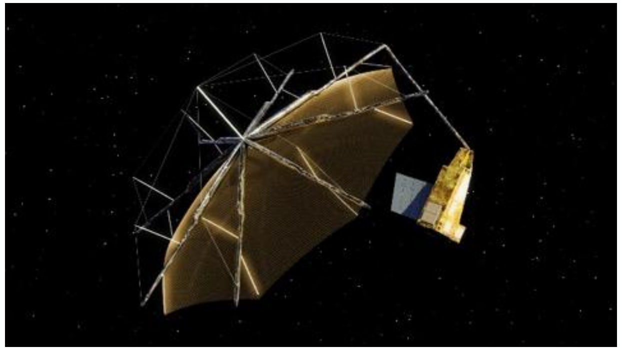


(Red = Primary objective coverage mask, Yellow = Secondary objective coverage mask)

BIOMASS MISSION (P-band ~ 70 cm wavelength)

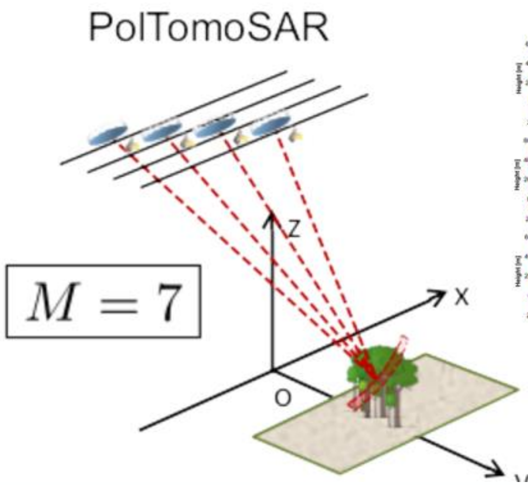
Primary Objectives

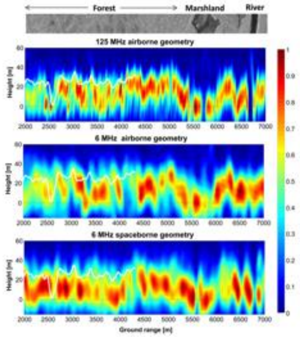
- **Above ground Biomass → Reduce uncertainties on Carbon flux from tropical region**



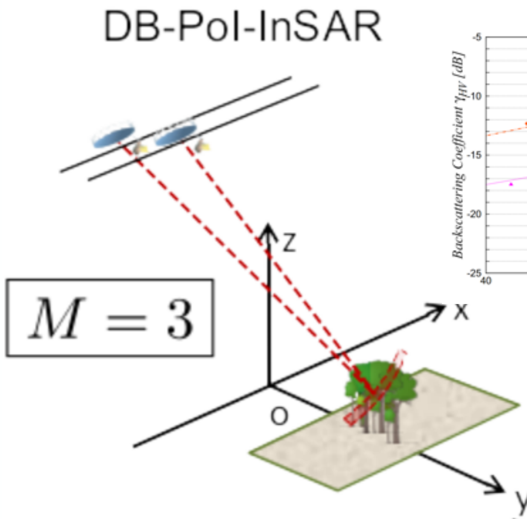
Biomass mission. Copyright: Airbus Defence and Space

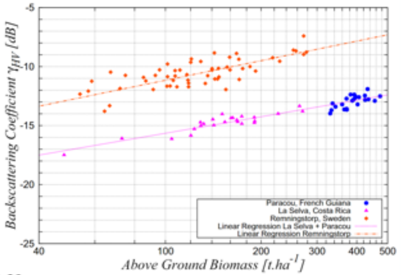
Tomographic Phase:
7 x 3-day repeat
15 months for global coverage





Interferometric Phase:
3 x 3-day repeat; **7 months revisit**
≈ 4 years time series





2024 (assumed) | 11/2024 | 02/2026 | 11/2029

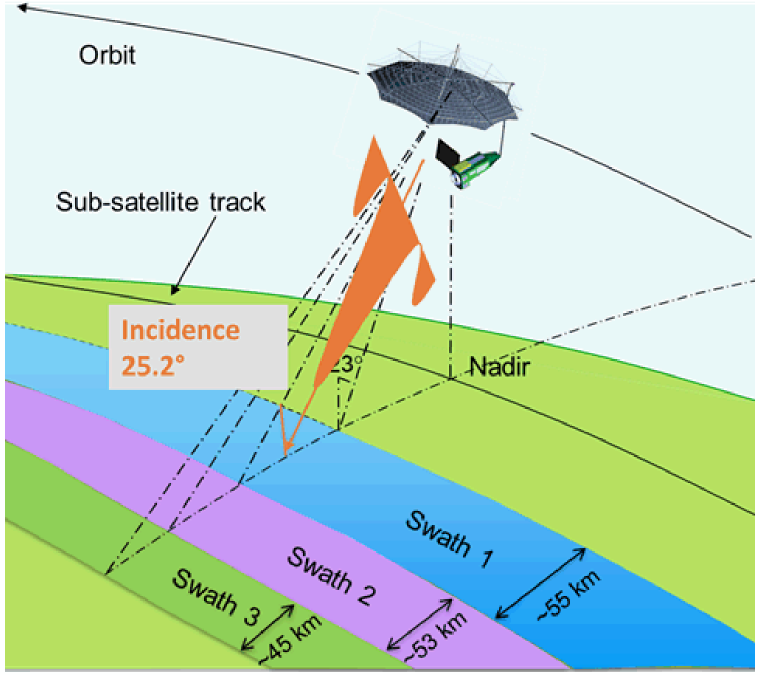
COM ~ 6 months

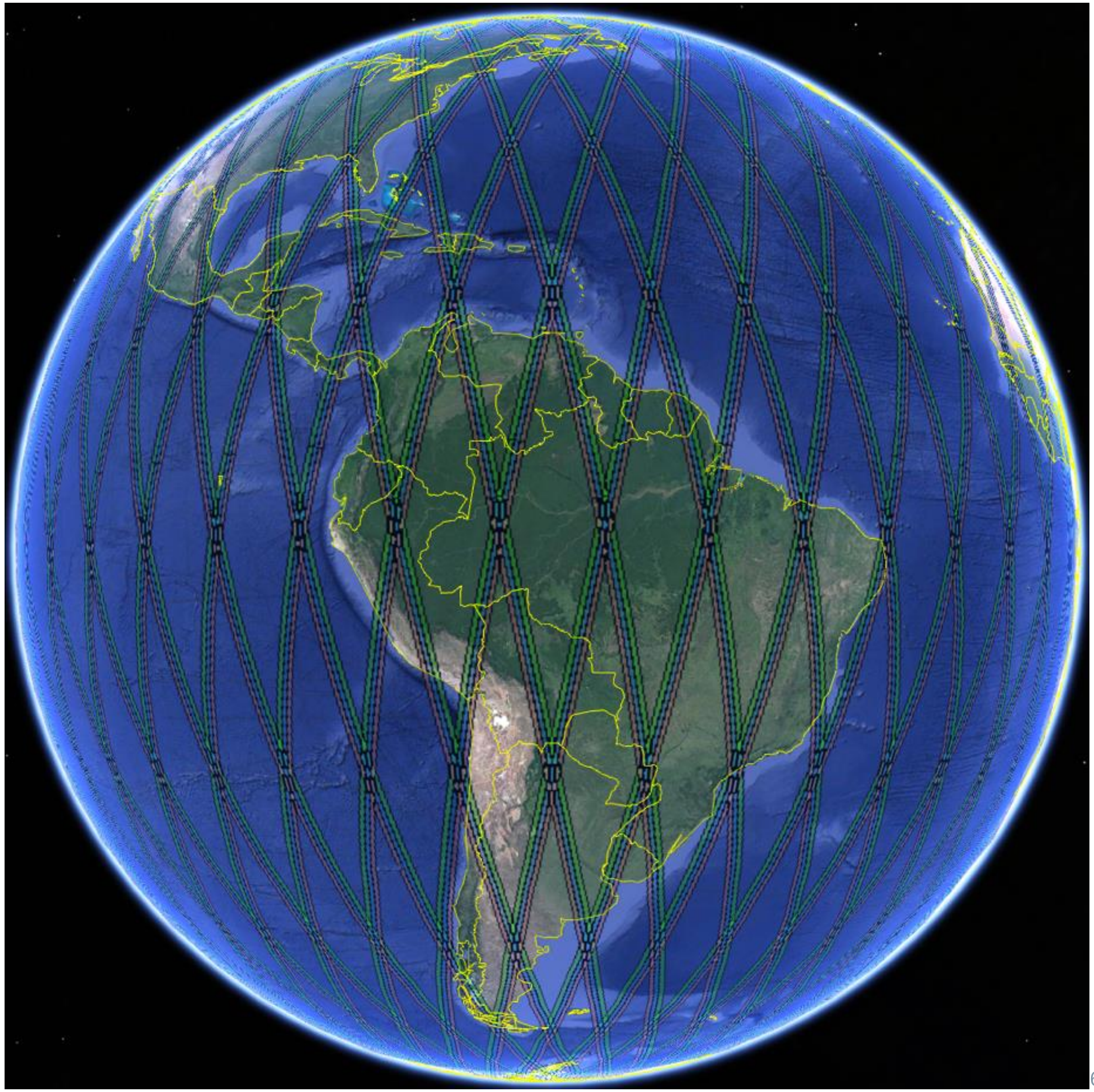
TOM ~ 15 months
1 global cycle

INT ~ 45 months
6 global cycles

Biomass orbit & swath considerations [1/2]

- → Sun-synchronous 666 km dawn-dusk orbit
- → 3-day repeat / 44 orbits
- → Small East-West drift to implement baselines
- → Stripmap mode operation @6MHz bandwidth
- → Satellite roll for swath access (**left-looking**)
- → Satellite repositioning manoeuvre after each "major cycle"





Mission operations concept

During the **TOMographic** phase:

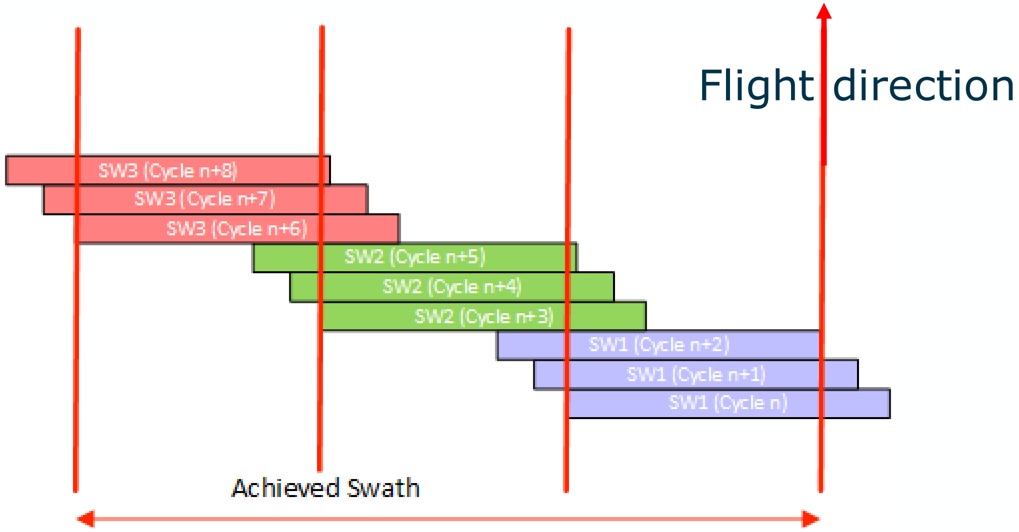
- each swath is imaged 7 times before rolling the satellite and covering the next swath
- The revisit being 3 days, it means that a target on ground will be imaged 7 times each being separated by 3 days. The global coverage is achieved in less than 17 months.

During the **INTerferometric** phase:

- each swath is imaged 3 times before rolling the satellite and covering the next swath.
- The revisit being 3 days, it means that a target on ground will be imaged 3 times each being separated by 3 days. The global coverage is achieved in less than 9 months.

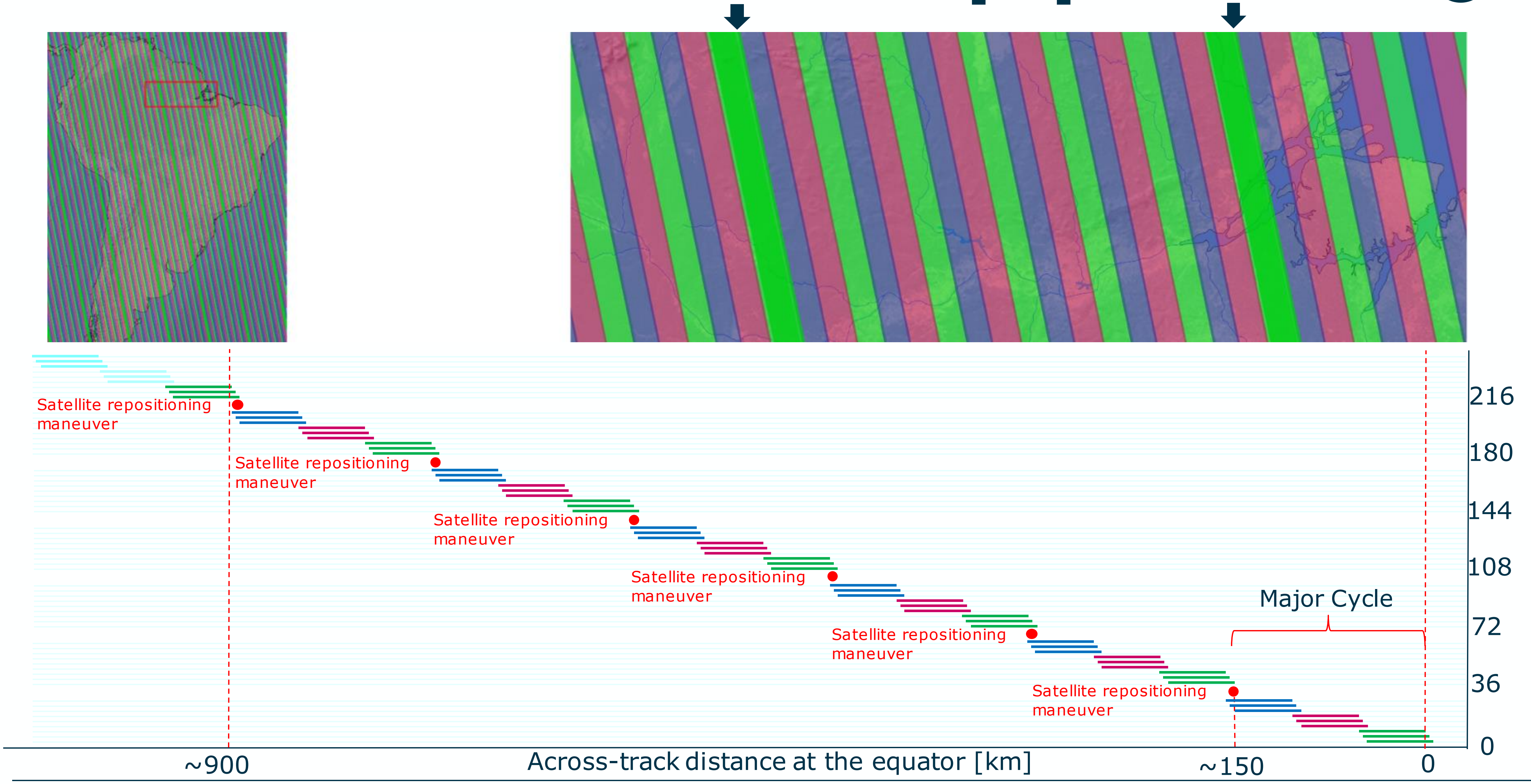
- The imaging cycle duration is fixed for both the tomographic phase (63 days) and the interferometric phase (27 days) by the repeat cycle, number of swaths to be imaged and the number of baselines

- Global coverage is built up over a sequence of "major cycles", each of which generate a total swath of approximately 150 km at the equator

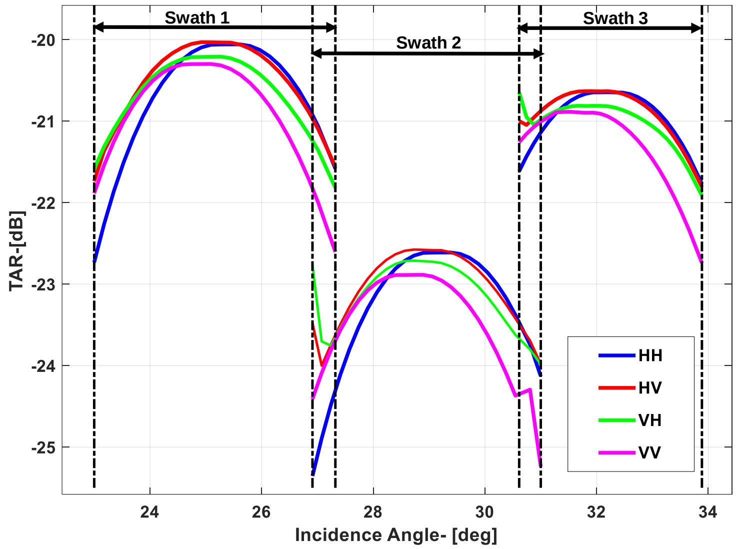


Example of Biomass overlapping swaths for the interferometric stack build-up

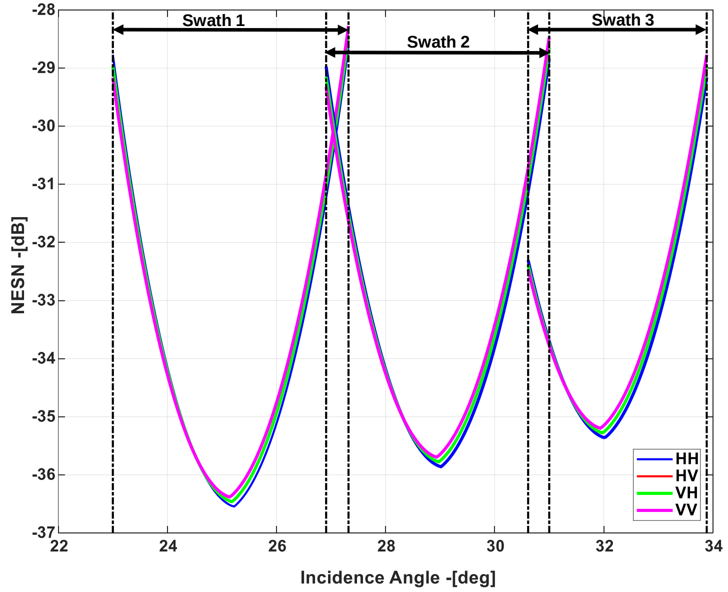
Biomass orbit & swath considerations [2/2]



Biomass estimated mission performance



Example of the achieved TAR for the three swaths

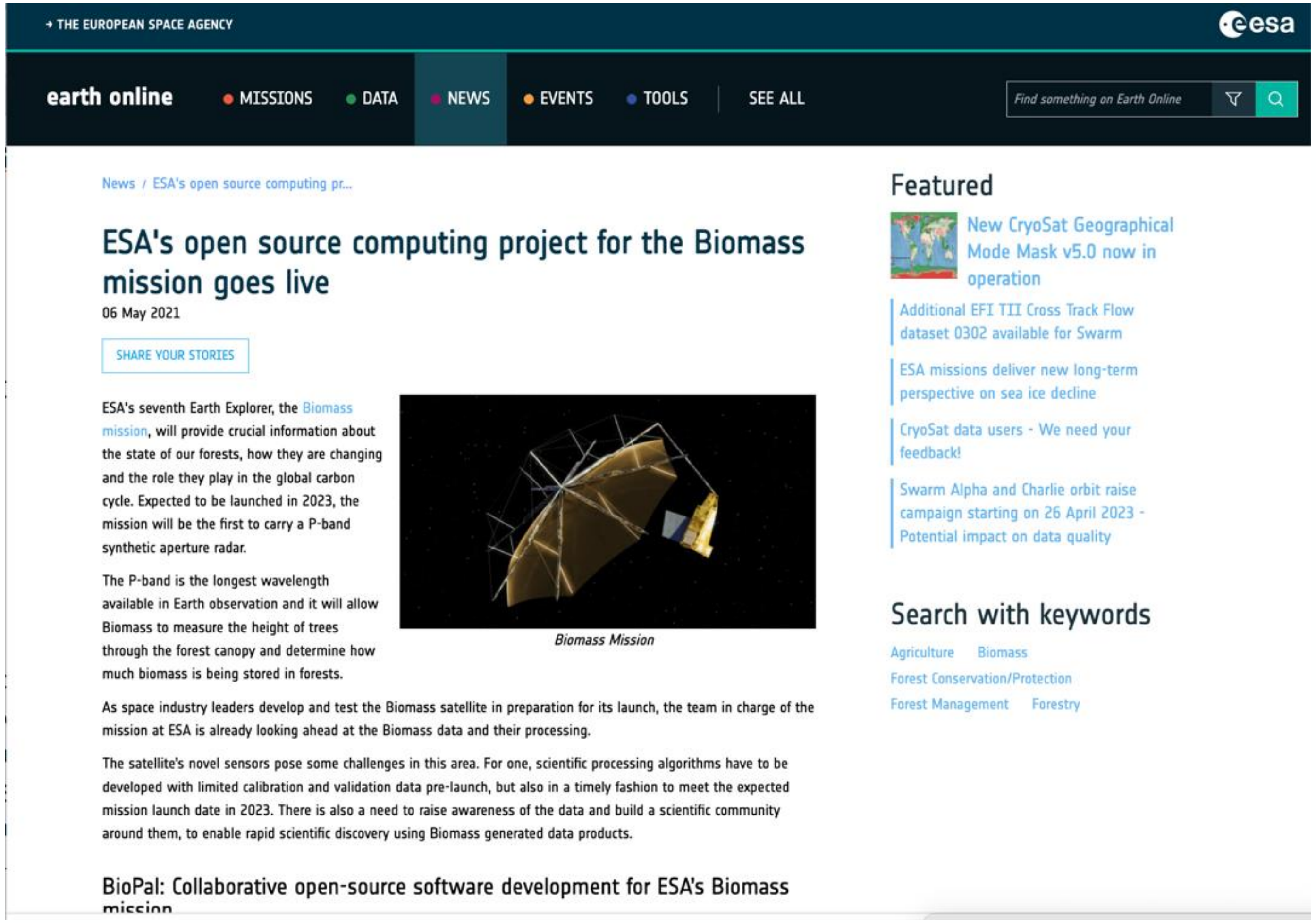


Example of achieved NESN for the three swaths

Key Parameters	
Sensitivity (NESZ)	≤ -27 dB
Total Ambiguity Ratio	≤ -18 dB
SLC resolution	≤ 60m x 8m
Dynamic Range	35 dB
Radiometric Stability	≤ 0.5 dB [1σ]
Radiometric Bias	≤ 0.3 dB [1σ]
Crosstalk	≤ -30 dB

Acquisitions over Ocean (best effort over selected windows) → Please recommend!!!

- Open Science, Open software, Open Data a focal point is the Mission Algorithm and Analysis Platform (MAAP) – Plus BioPAL GitHub repository
- The BIOMASS SAR will have a high operational orbital duty cycle,
- Acquisitions initially focused on the land masses.
- There is an interest in ice shelves.
- Opportunities to acquire over over ocean targets (P-band / 435 MHz (with 6 MHz bandwidth) / ~ 70 cm wavelength)
- Very short temporal coverage (3-days) for a short time (to build up the stack) then next revisit is 9 months later (for same asc/desc).



→ THE EUROPEAN SPACE AGENCY

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News / ESA's open source computing pr...

ESA's open source computing project for the Biomass mission goes live

06 May 2021

SHARE YOUR STORIES

ESA's seventh Earth Explorer, the Biomass mission, will provide crucial information about the state of our forests, how they are changing and the role they play in the global carbon cycle. Expected to be launched in 2023, the mission will be the first to carry a P-band synthetic aperture radar.

The P-band is the longest wavelength available in Earth observation and it will allow Biomass to measure the height of trees through the forest canopy and determine how much biomass is being stored in forests.

Biomass Mission

As space industry leaders develop and test the Biomass satellite in preparation for its launch, the team in charge of the mission at ESA is already looking ahead at the Biomass data and their processing.

The satellite's novel sensors pose some challenges in this area. For one, scientific processing algorithms have to be developed with limited calibration and validation data pre-launch, but also in a timely fashion to meet the expected mission launch date in 2023. There is also a need to raise awareness of the data and build a scientific community around them, to enable rapid scientific discovery using Biomass generated data products.

BioPal: Collaborative open-source software development for ESA's Biomass mission

Featured

New CryoSat Geographical Mode Mask v5.0 now in operation

Additional EFI TII Cross Track Flow dataset 0302 available for Swarm

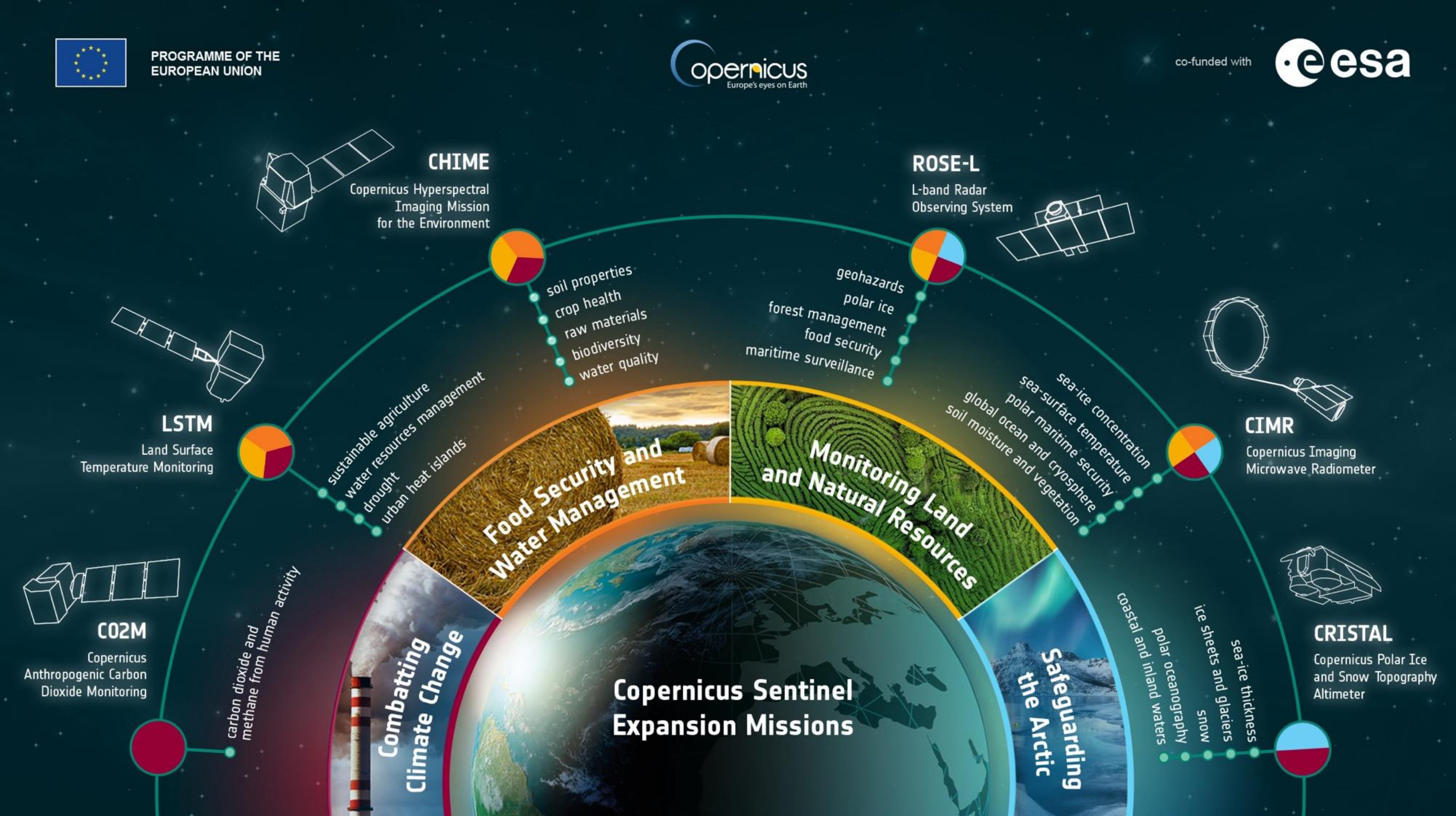
ESA missions deliver new long-term perspective on sea ice decline

CryoSat data users - We need your feedback!

Swarm Alpha and Charlie orbit raise campaign starting on 26 April 2023 - Potential impact on data quality

Search with keywords

Agriculture · Biomass · Forest Conservation/Protection · Forest Management · Forestry



PROGRAMME OF THE EUROPEAN UNION
Copernicus
Europe's eyes on Earth
co-funded with
esa
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
CIMR
Copernicus Imaging Microwave Radiometer
sea-ice concentration
sea-surface temperature
polar maritime security
global ocean and cryosphere
soil moisture and vegetation
CO2M
Copernicus Anthropogenic Carbon Dioxide Monitoring
carbon dioxide and methane from human activity
CRISTAL
Copernicus Polar Ice and Snow Topography Altimeter
coastal and inland waters
polar oceanography
ice sheets and glaciers
snow
sea-ice thickness
Food Security and Water Management
Monitoring Land and Natural Resources
Combatting Climate Change
Safeguarding the Arctic
Copernicus Sentinel Expansion Missions

Theme 8 Future Missions

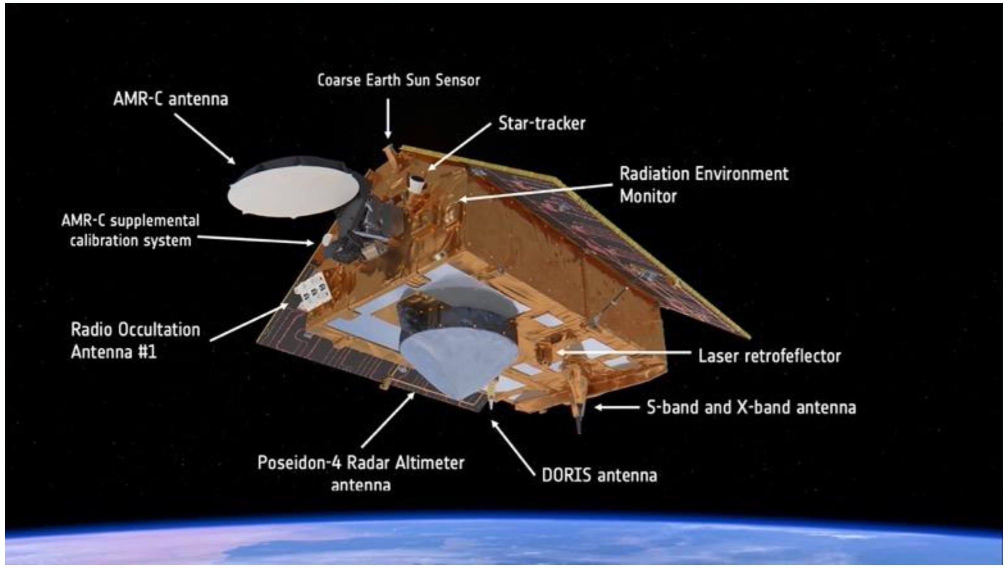
SAR Altimetry

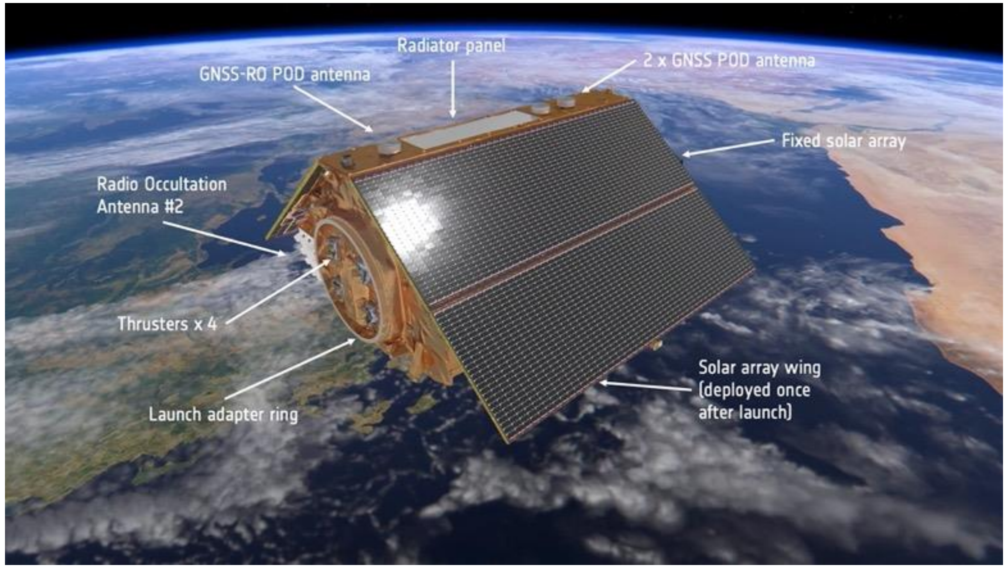
C Donlon

26/04/2023

Sentinel-6 - dedicated to Sea Level Rise

Sentinel-6 Main Features

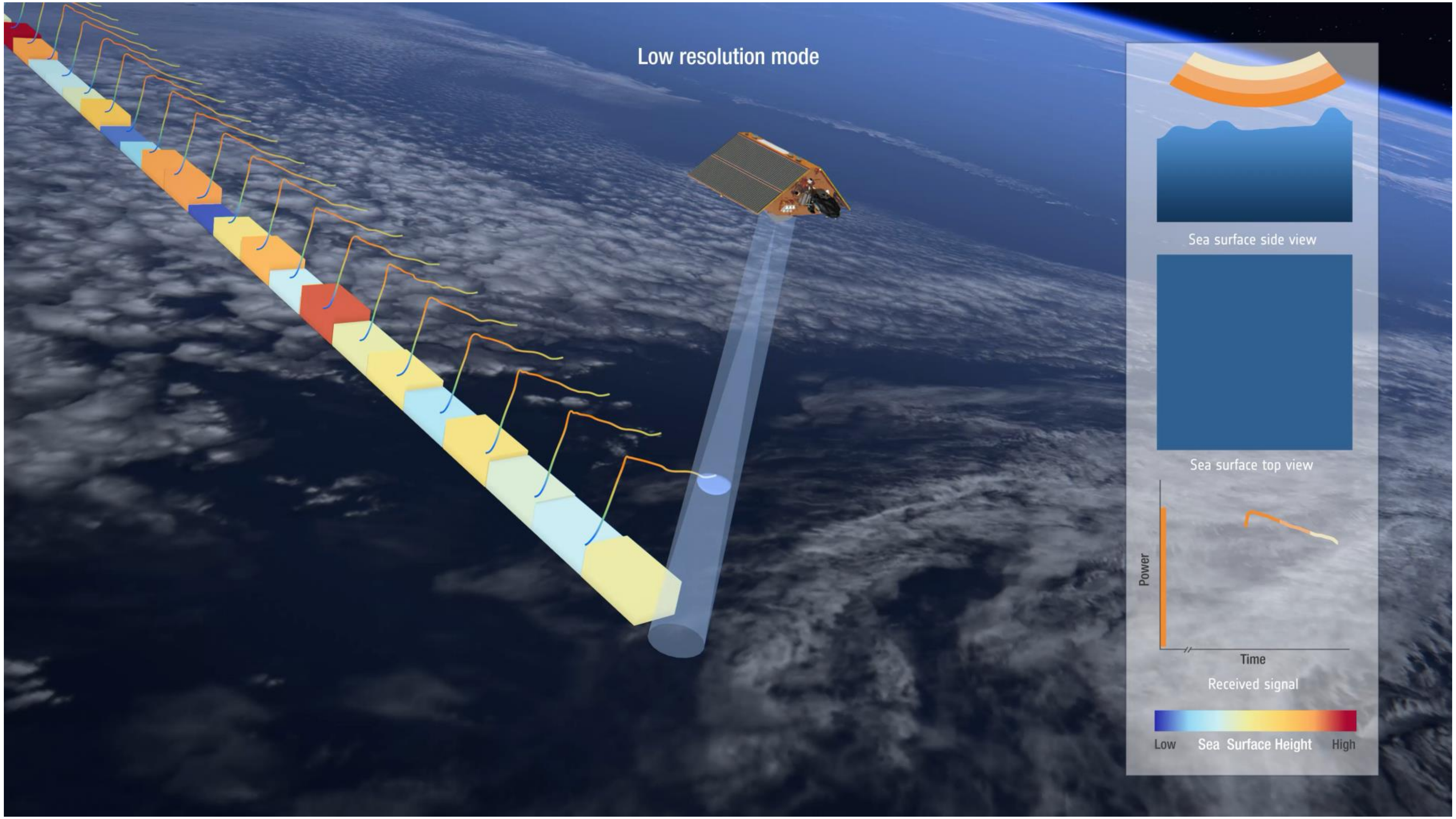


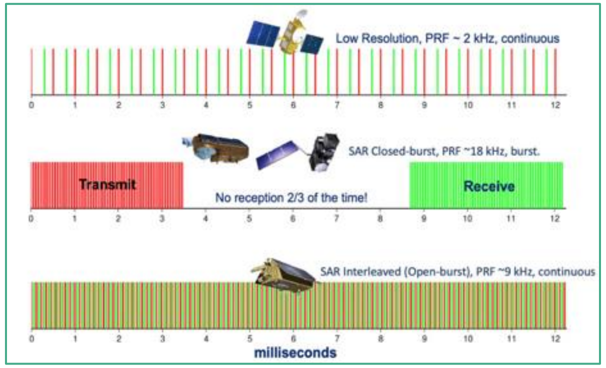


Sentinel-6 Michael Freilich satellite during tests at IAGB facilities, Germany

Sentinel-6 Poseidon-4 altimeter

Video at https://www.youtube.com/watch?v=OXf4Mf4TQeI



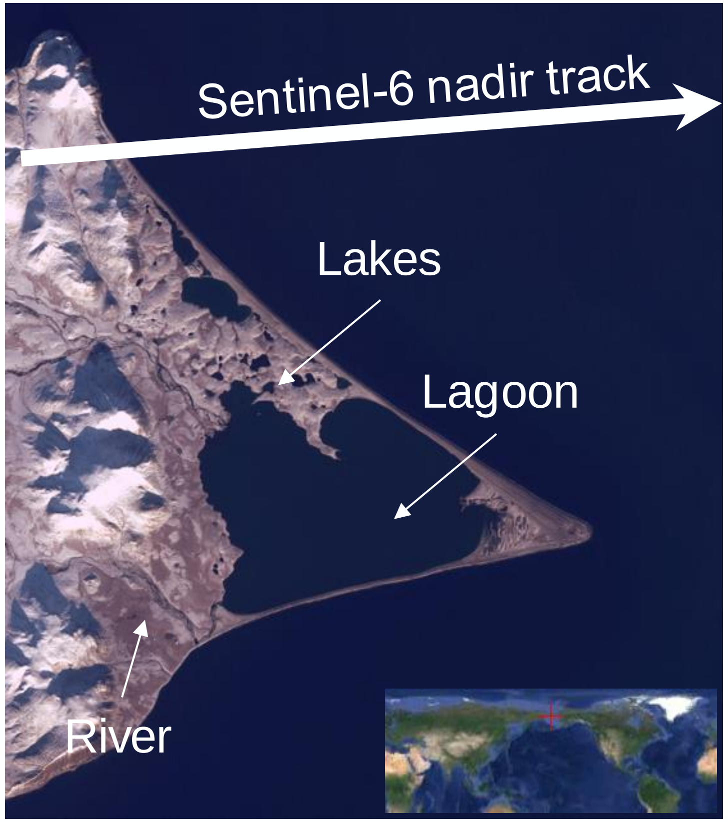


Poseidon-4 uses a new interleaved chronogram allowing simultaneous LRM and SAR acquisition

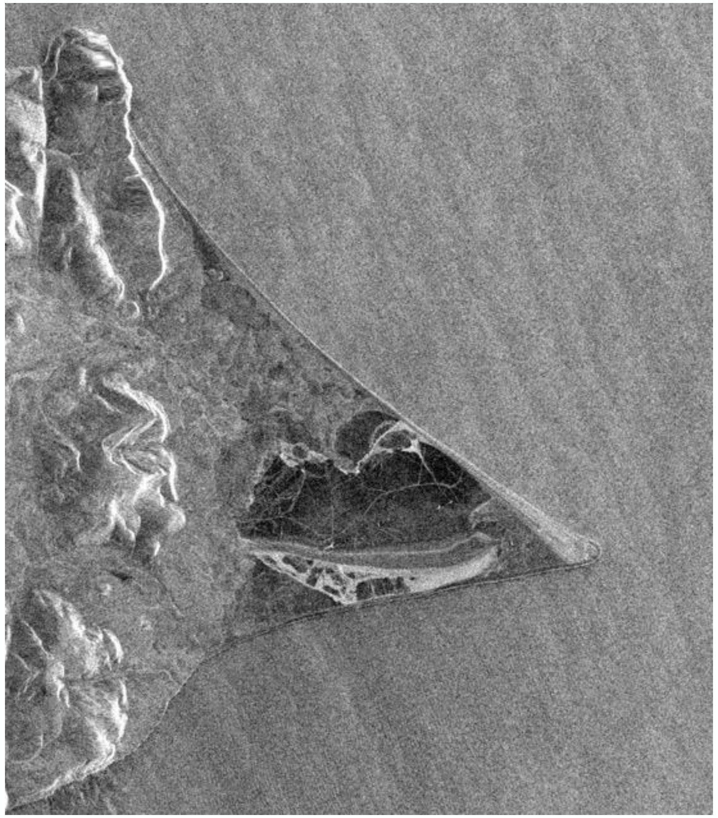
On-board Processing implements Range Migration Compression and significantly reduces data rates

The Beauty of Copernicus: First S6 Cross Track SAR Range Image with Copernicus SAR and Optical data

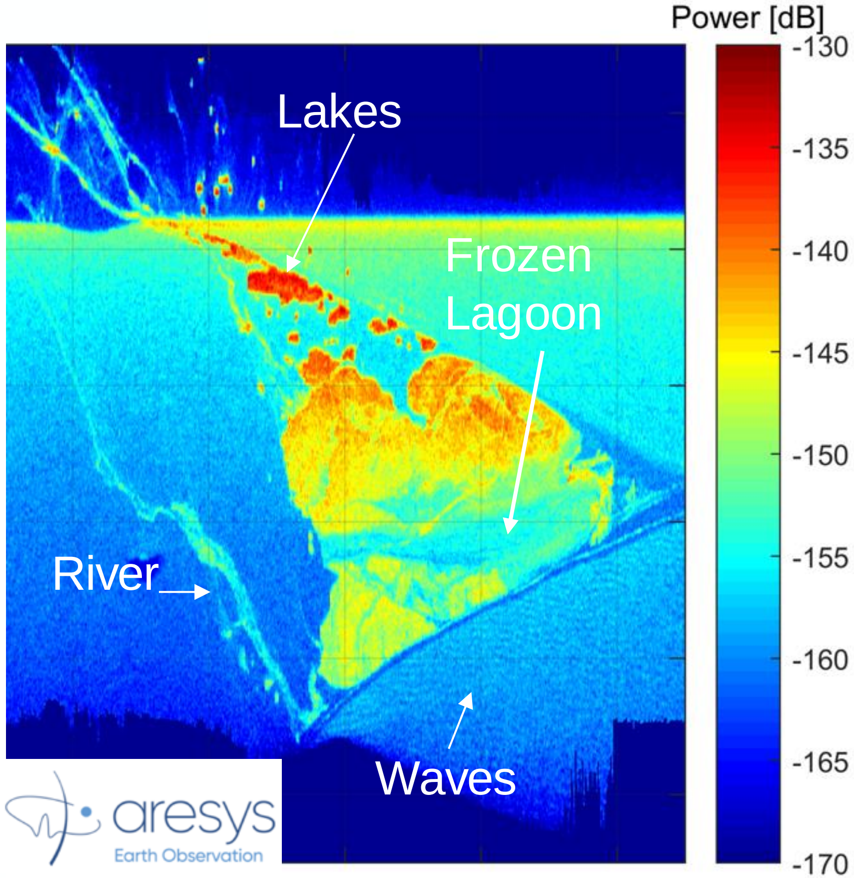
S6-MF Poseidon-4 altimeter reveals unprecedented detail in the Ozero Nayval lagoon and surrounding river areas. Fully focussed synthetic aperture radar **processing highlights the low noise performance of new digital instrument** architecture.



Sentinel-2B (10m) Ozero Nayvak peninsular, Russia, 15 August 2020



Sentinel-1B Interferometric Wide Swath, 29 Nov 2020



Sentinel-6MF (a) LRM (b) Fully Focussed SAR Range image, 30 Nov 2020

SAR altimetry spectra

- Intensity modulation resulting from swell waves are visible in waveform tails.
- By normalization and reprojection on the ground it is possible to compute SAR spectra.
- Dominant mechanisms are velocity and range bunching.
- Only possible to retrieve swell in low to moderate sea states (SWH < 6 m).
- ‘Cut-off’ estimation (velocity variance) and swell retrieval might become essential to constrain the sea-state bias.

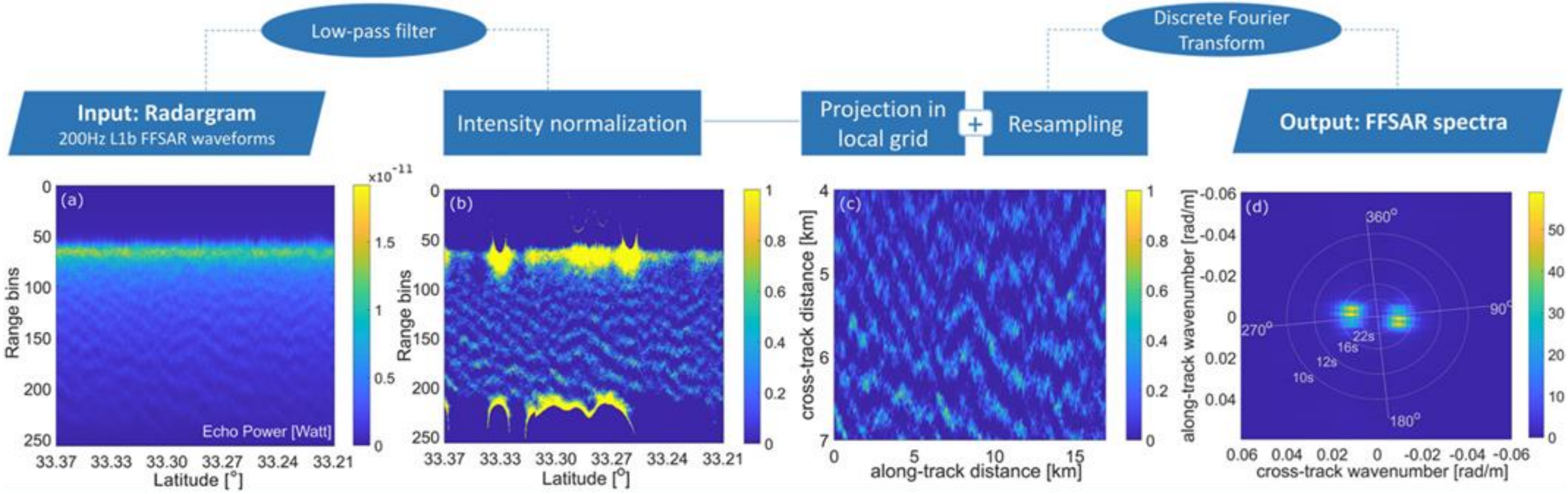
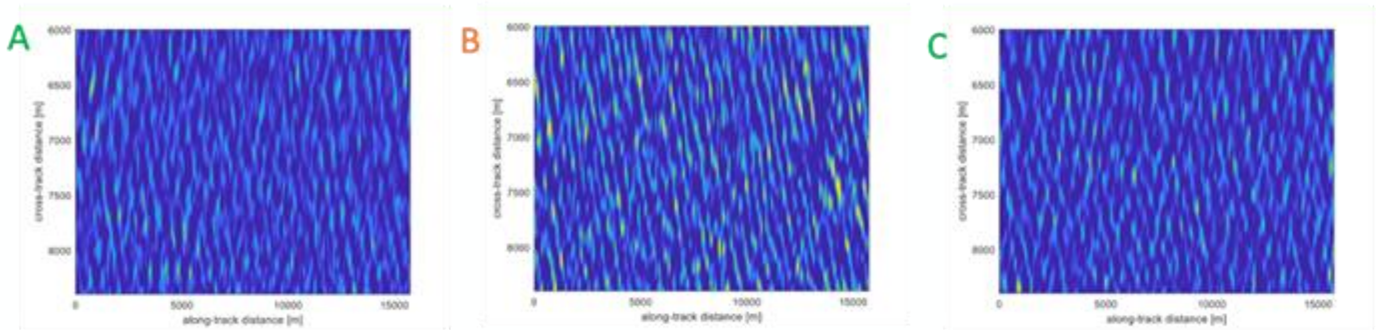


Figure from Altiparmaki et al. (2022)

SAR altimetry spectra

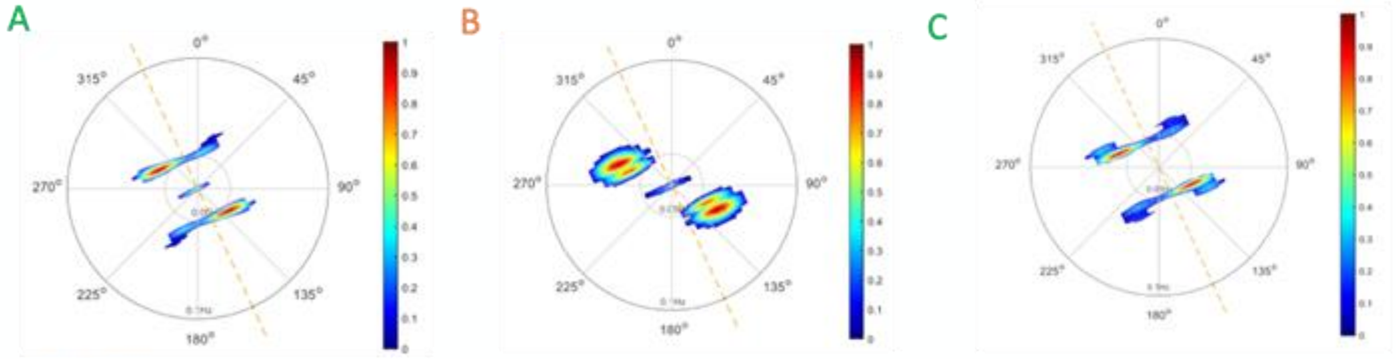
Rania Altiparmaki, Claire Maraldi, Samira Amraoui

PROJECTED/NORMALIZED RADAGRAM



ERA5 SWELL SPECTRUM

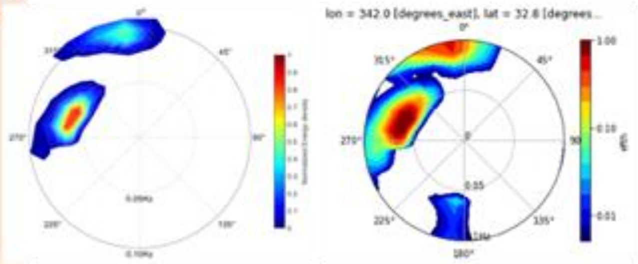
SAR SPECTRA



A: Tp =17.0 sec
Dp = 293 deg

B: Tp =15.1 sec
Dp = 293 deg

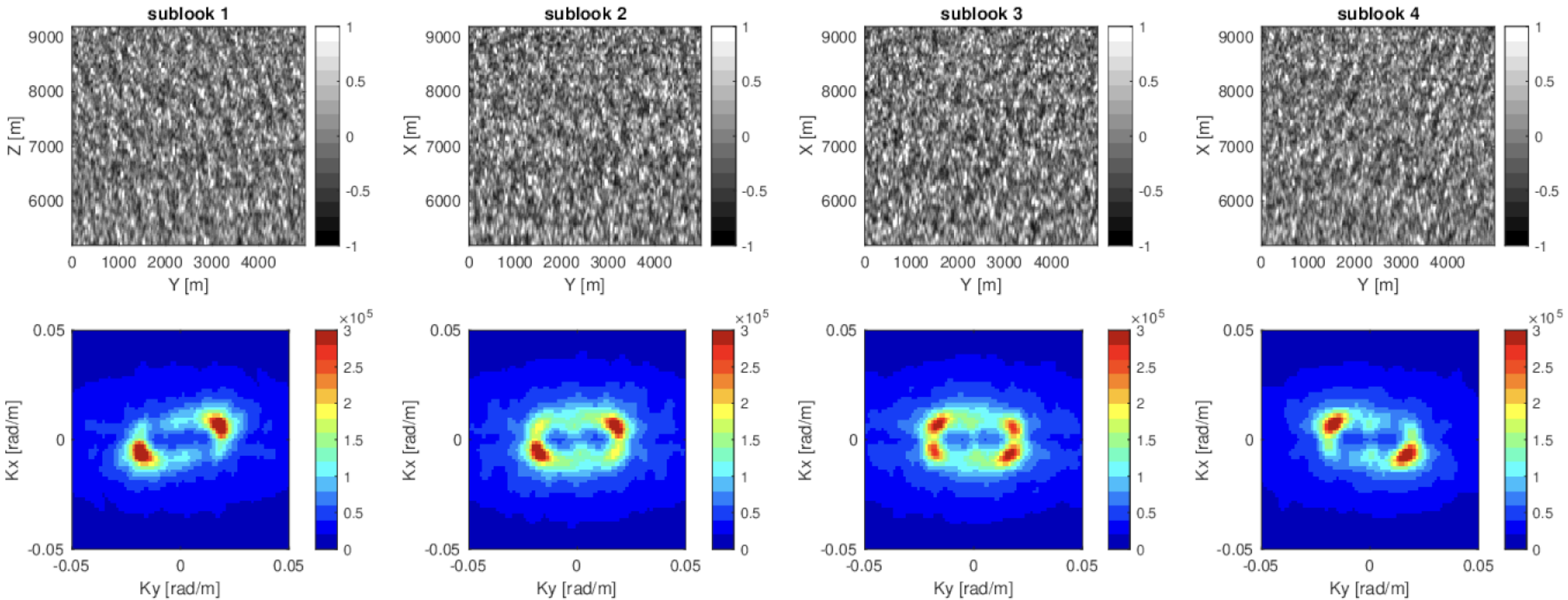
C: Tp =17.6 sec
Dp = 290 deg



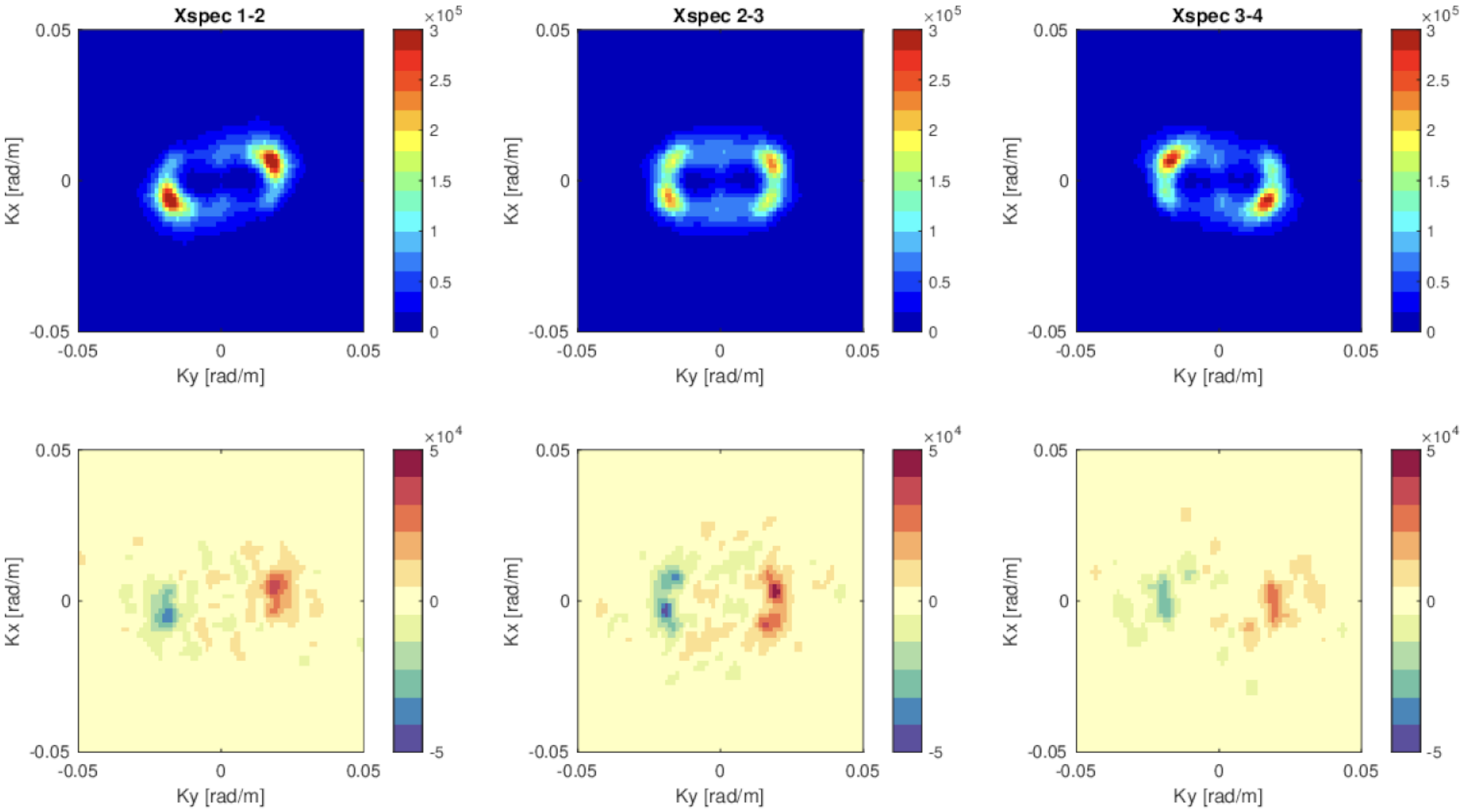
Tp = 15.8 sec
Dp = 292.5 deg

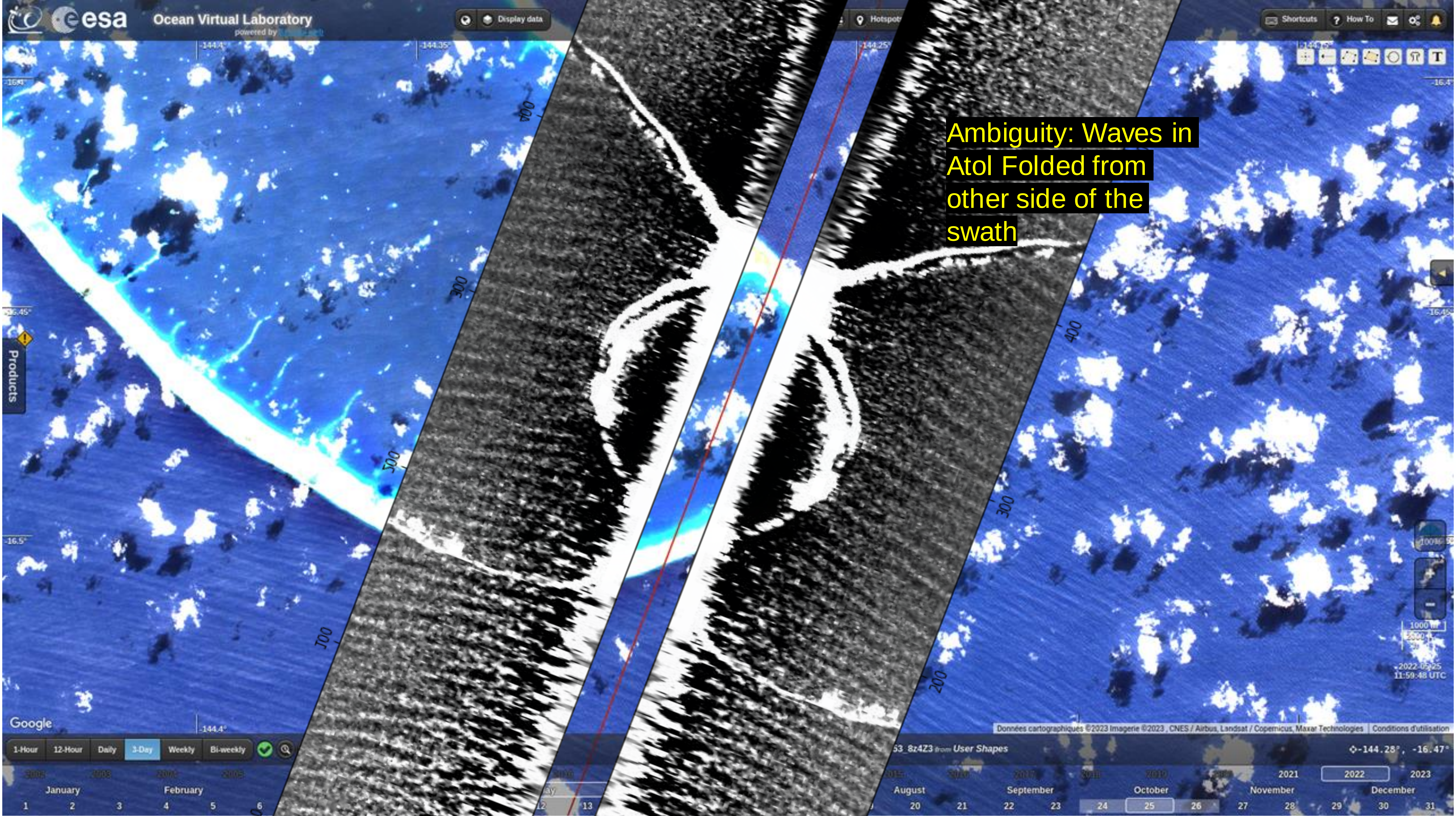
Projected radargram and Wave Spectra from Sentinel-6

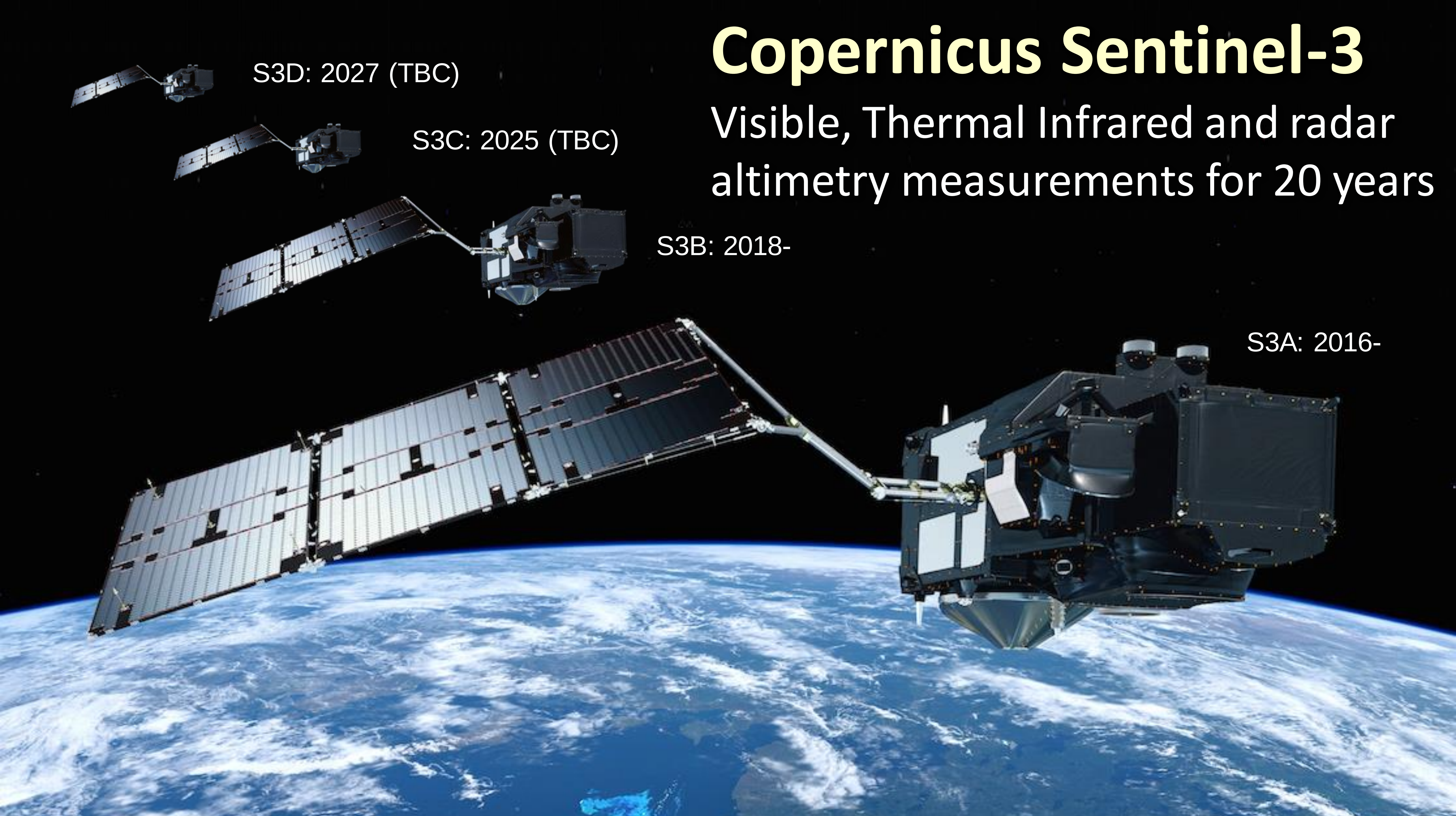
Nadir altimetry brings azimuth diversity within a full aperture



Cross Spectra between looks: wave propagation direction




Ambiguity: Waves in Atol Folded from other side of the swath
Ocean Virtual Laboratory
Display data
Shortcuts
How To
Products
Google
1-Hour
12-Hour
Daily
3-Day
Weekly
Bi-weekly
User Shapes
January
February
August
September
October
November
December
2021
2022
2023
2022-05-25 11:59:48 UTC


Copernicus Sentinel-3
Visible, Thermal Infrared and radar altimetry measurements for 20 years
S3D: 2027 (TBC)
S3C: 2025 (TBC)
S3B: 2018-
S3A: 2016-

Swell in the sea ice (Arctalas)

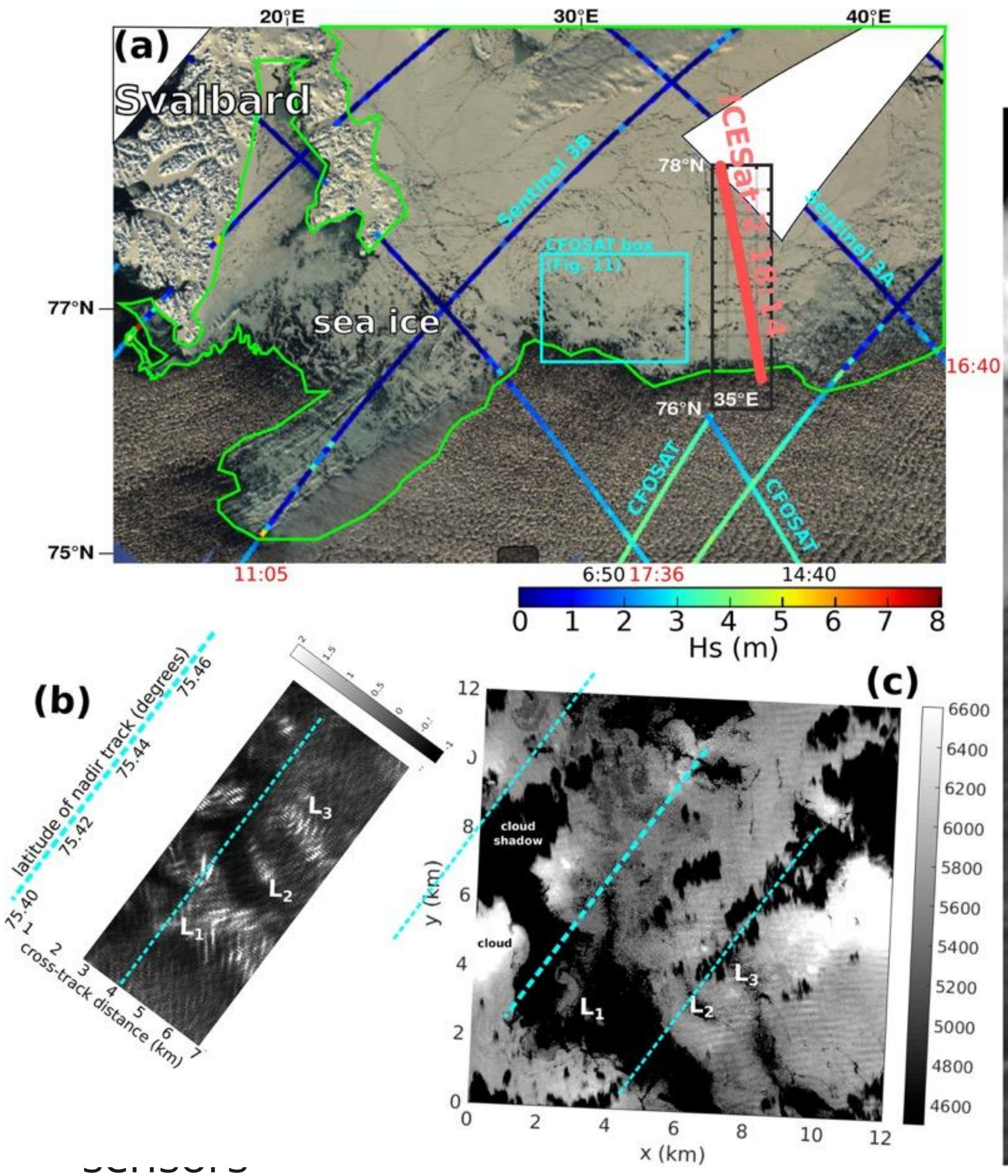
JGR Oceans

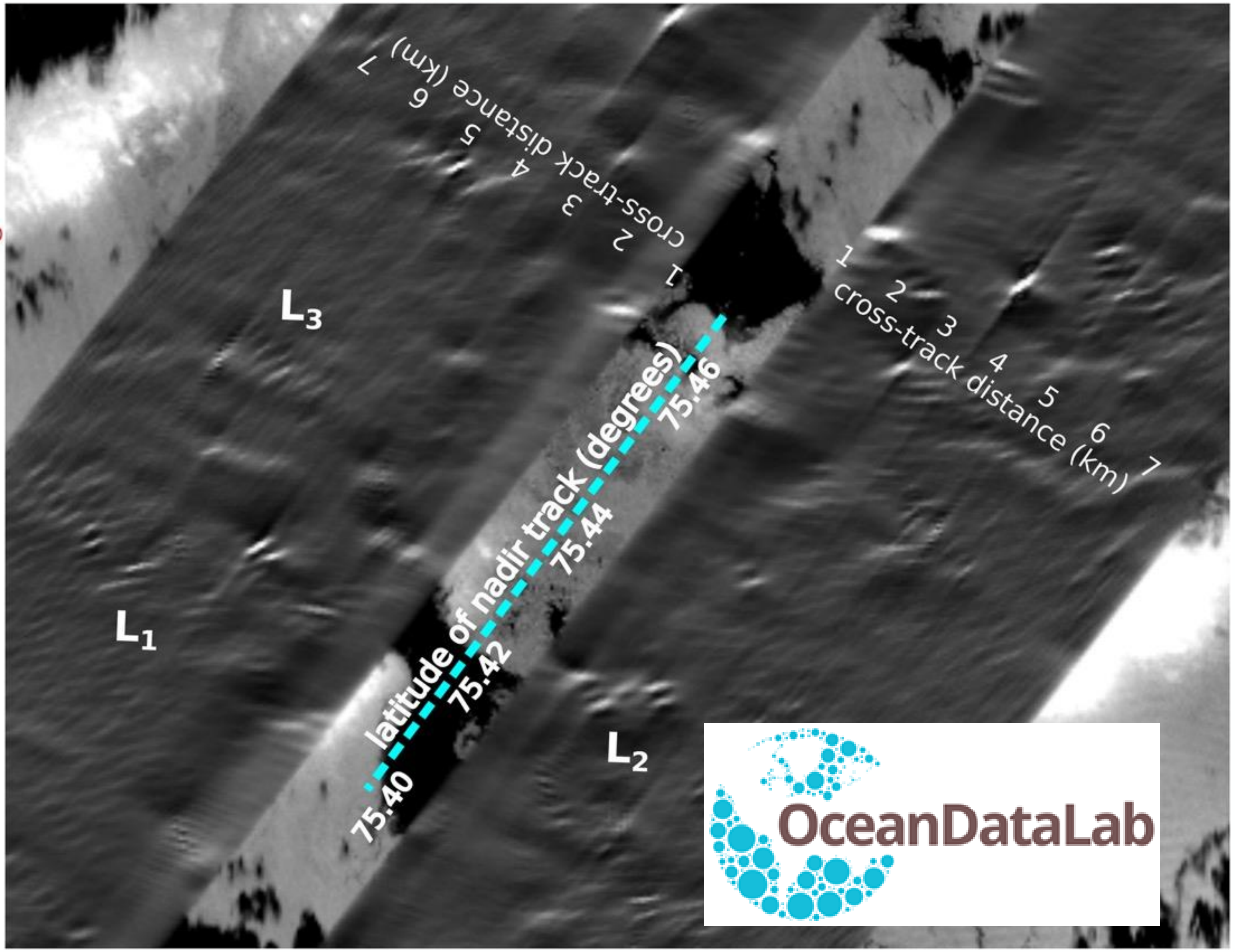
Research Article | Full Access

Wind-Wave Attenuation in Arctic Sea Ice: A Discussion of Remote Sensing Capabilities

Fabrice Collard, Louis Marié, Frédéric Nouguier, Marcel Kleinherenbrink, Frithjof Ehlers, Fabrice Ardhuin

First published: 12 June 2022 | https://doi.org/10.1029/2022JC018654



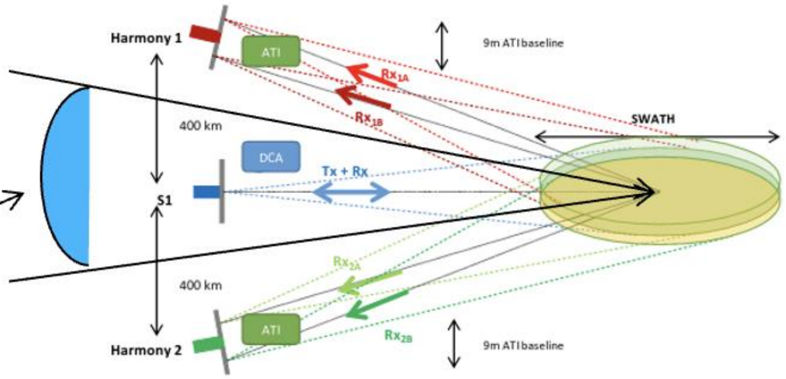


Future Harmony measurement involves SAR surface roughness at high resolution with azimuth diversity between fore and aft “beams”.

What can we anticipate?

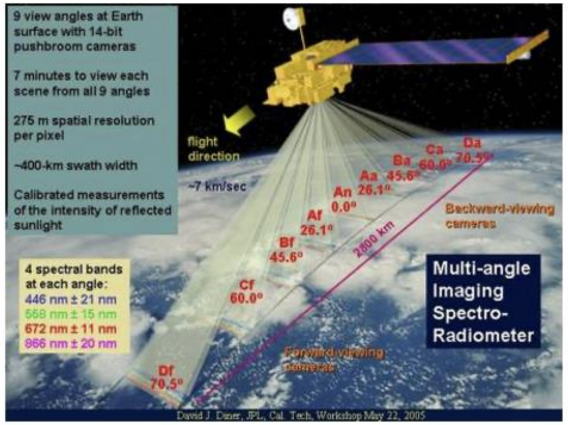
Harmony in Stereo Config. viewing geometry:

C-band roughness
S1 incidence angles: [20° 45°]
Harmony incidence angles [32° 48°]
Harmony azimuth difference [54° 27°]
Time delay 0 sec

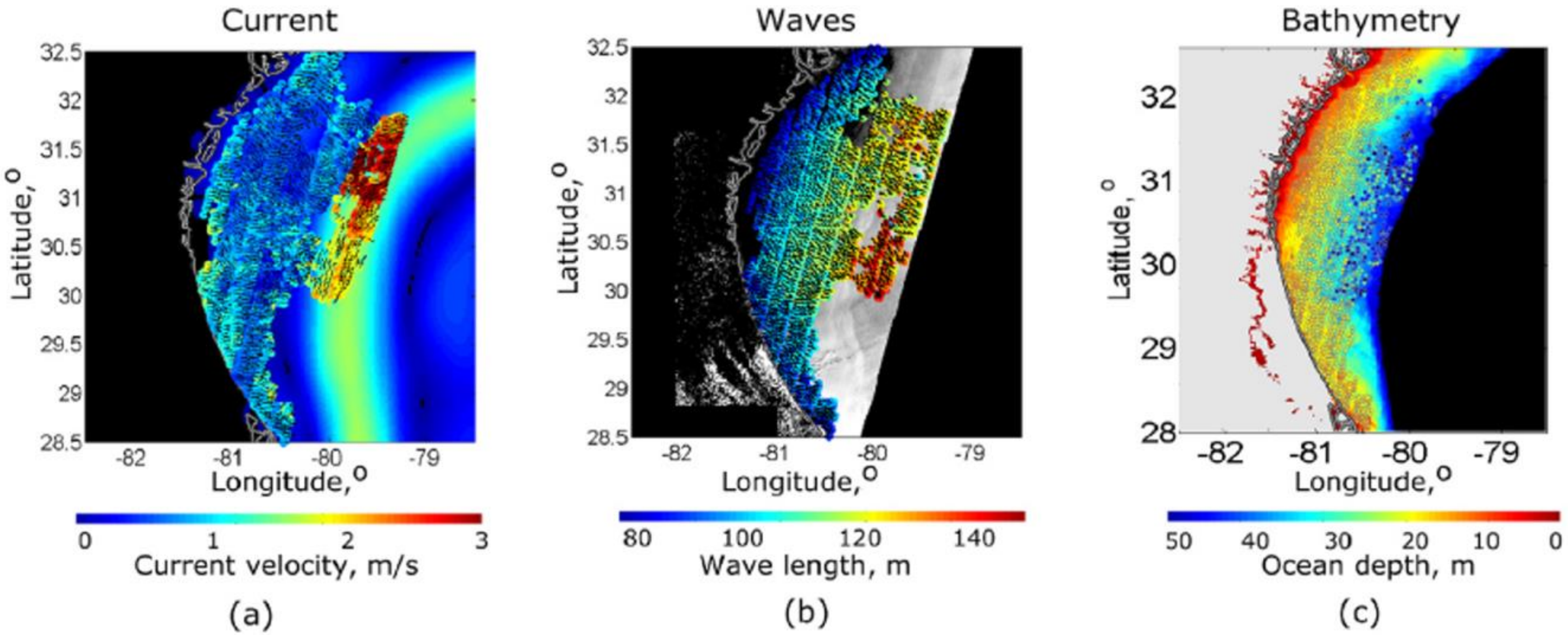


MISR sunglint:

Optical roughness
Incidence angles [0° 22°]
Azimuth difference [15° 165°]
Time delay 45 sec < T < 7 min



Current and bathymetry retrieval using sunglint optical images



Gulf Stream current + bathymetry (Yurovskaya et al 2019)

Remote Sensing of Environment 234 (2019) 111468

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

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Ocean surface current retrieval from space: The Sentinel-2 multispectral capabilities

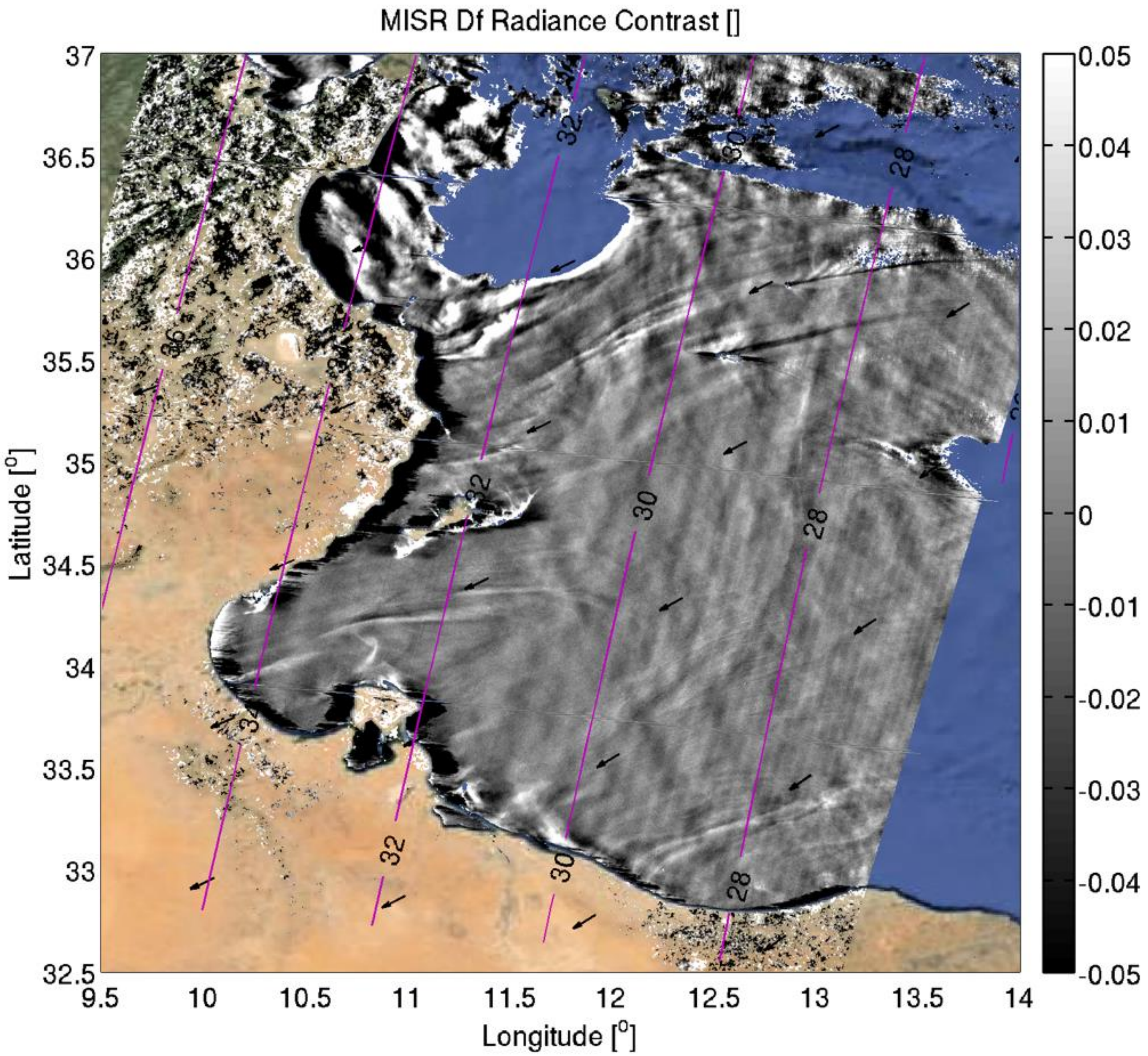
Maria Yurovskaya[a,b,*], Vladimir Kudryavtsev[a,b], Bertrand Chapron[b,c], Fabrice Collard[d]

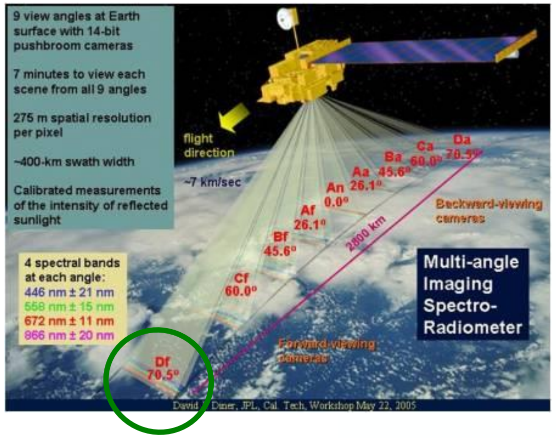
[a] Marine Hydrophysical Institute of RAS, Sevastopol, Russia
[b] Satellite Oceanography Laboratory, Russian State Hydrometeorological University, Saint Petersburg, Russia
[c] Institut Français de Recherche pour l'Exploitation de la Mer, Plouzané, France
[d] OceanDataLab, Déolen, France

8 /45

science of ocean glitter

Surface roughness from sun glint at multiple view angles: example at medium resolution (250m)





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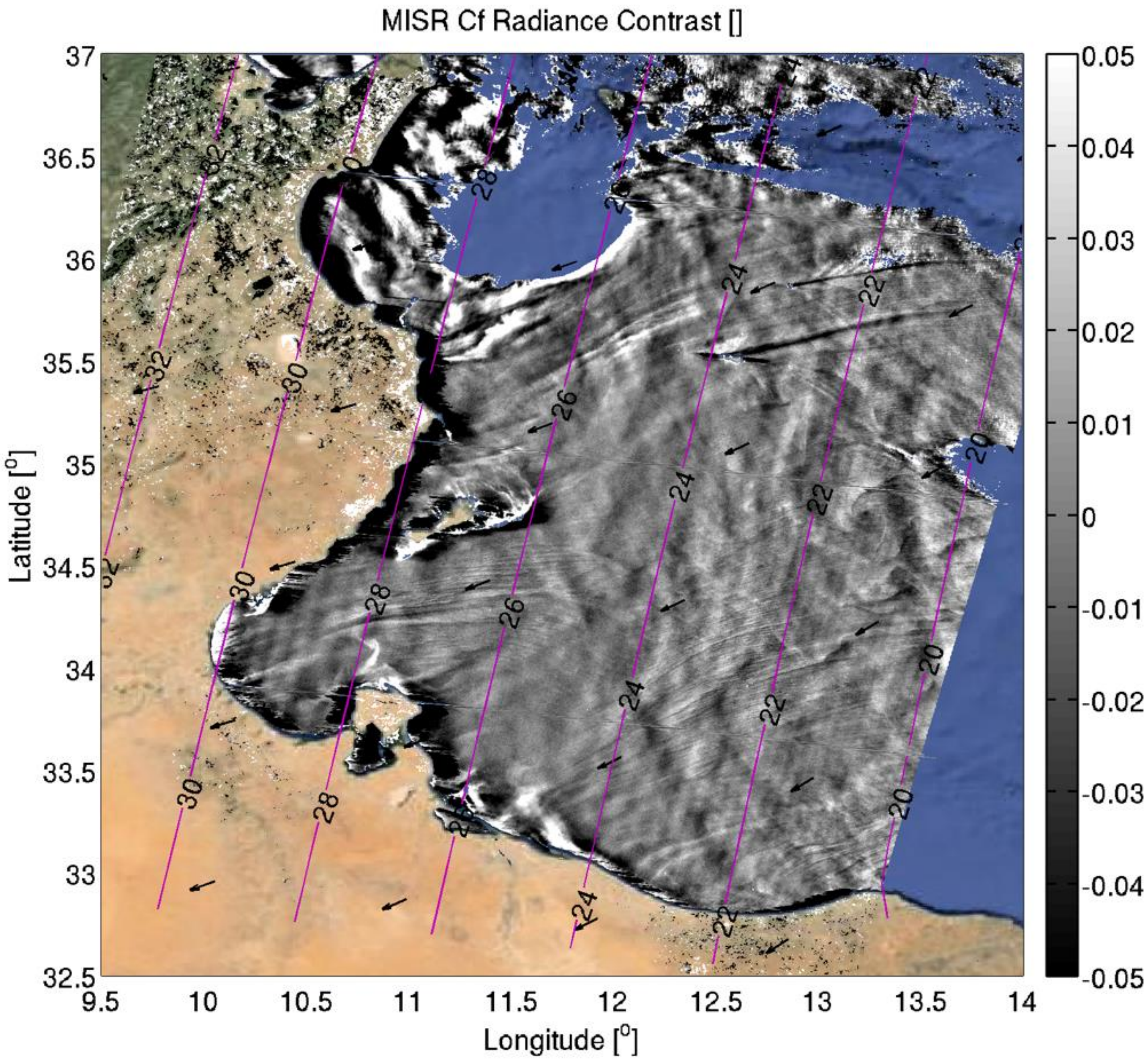

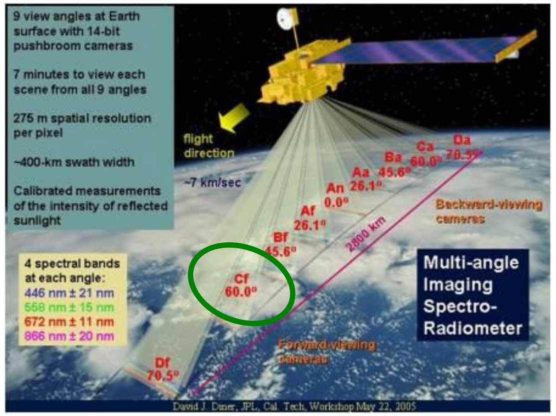

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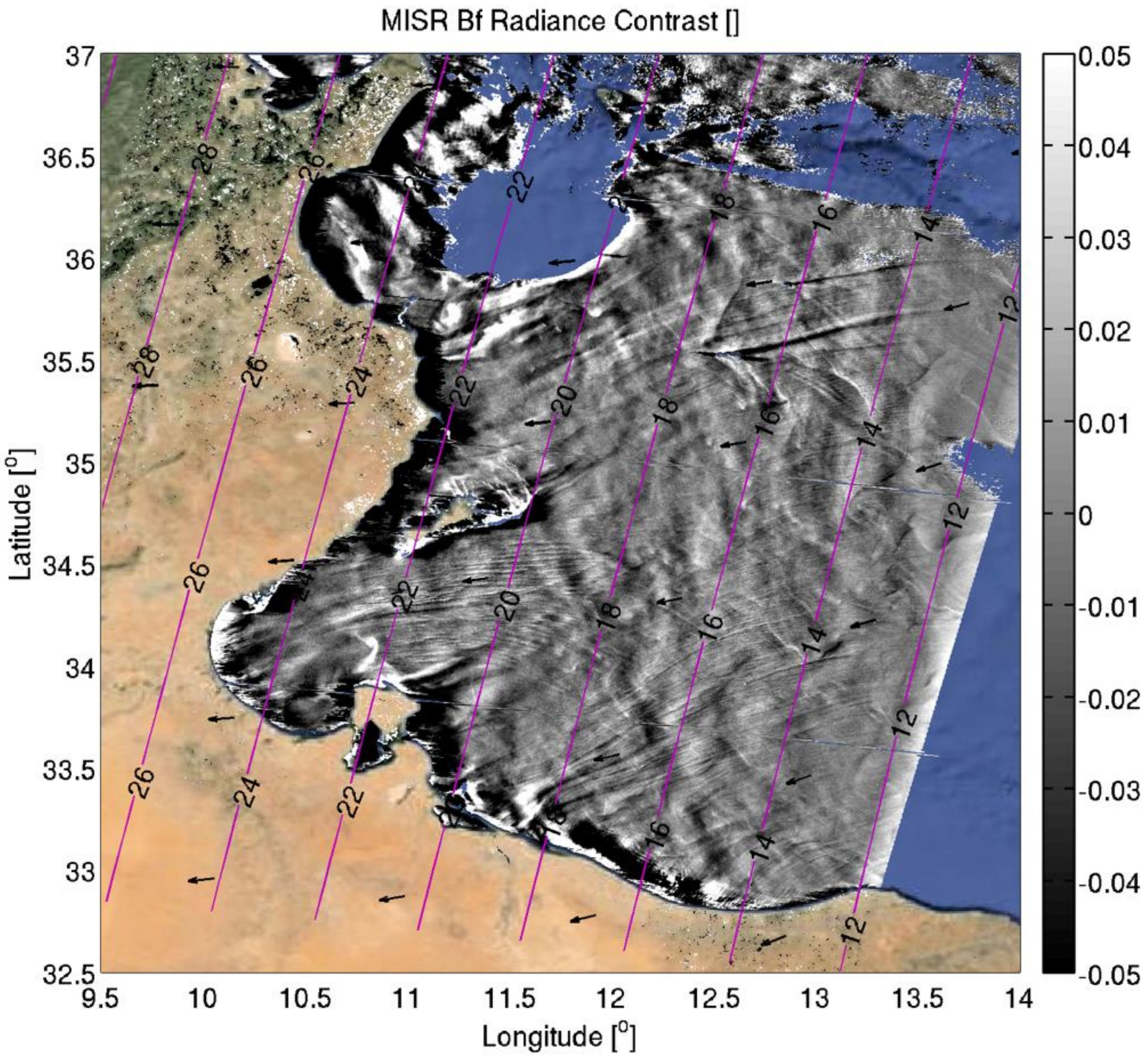

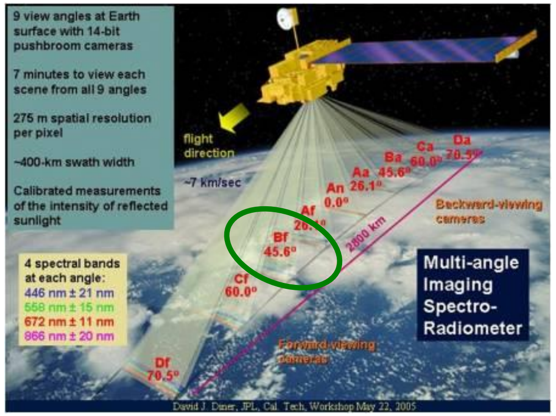

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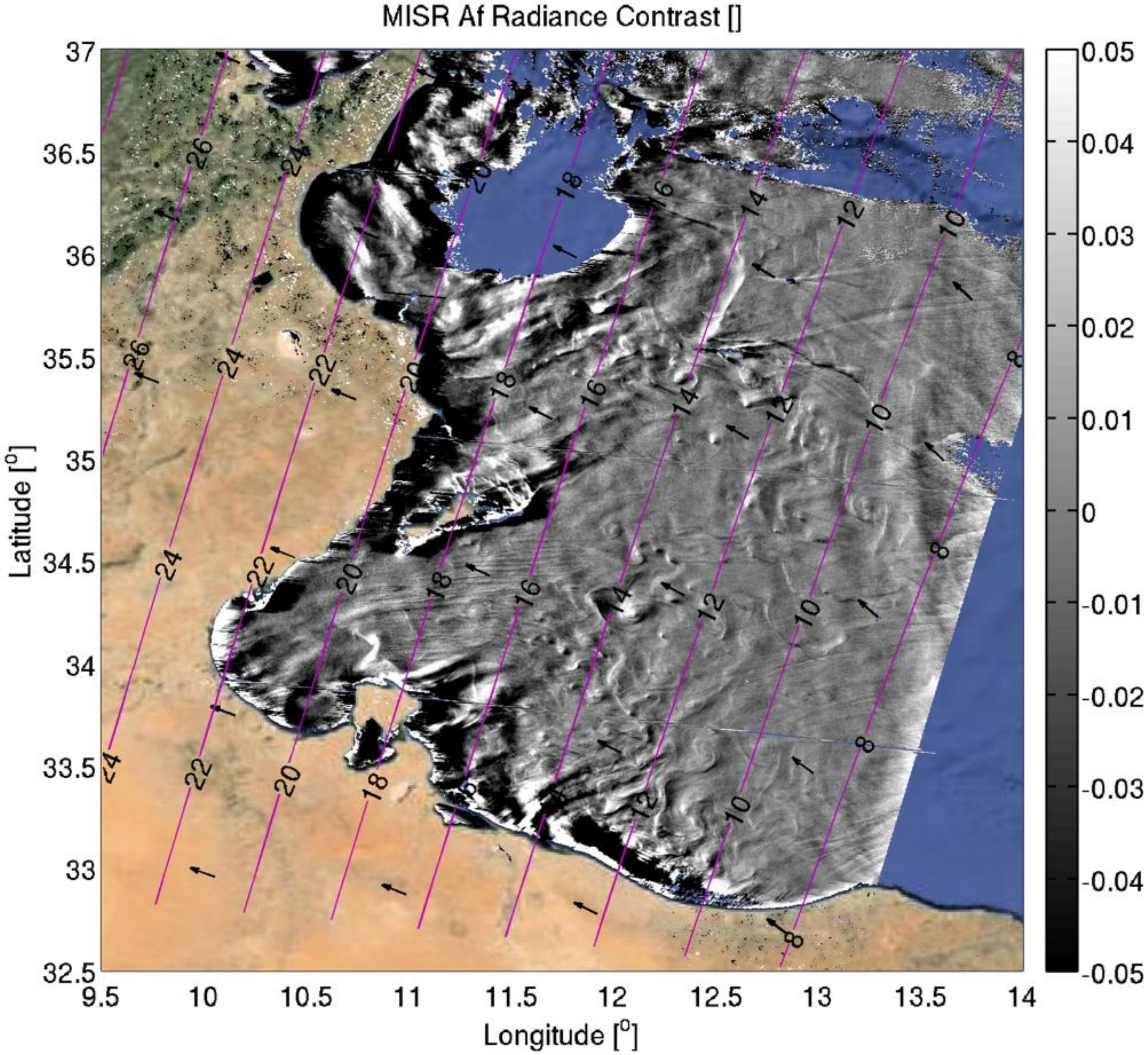

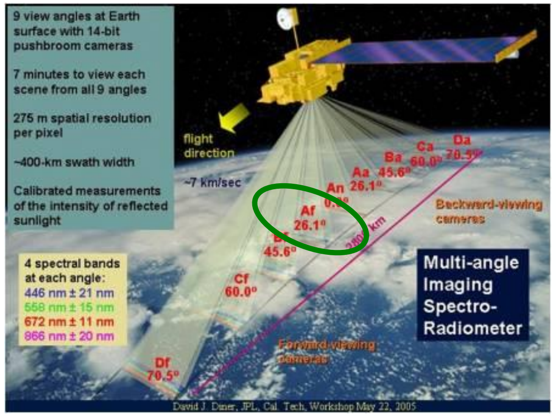

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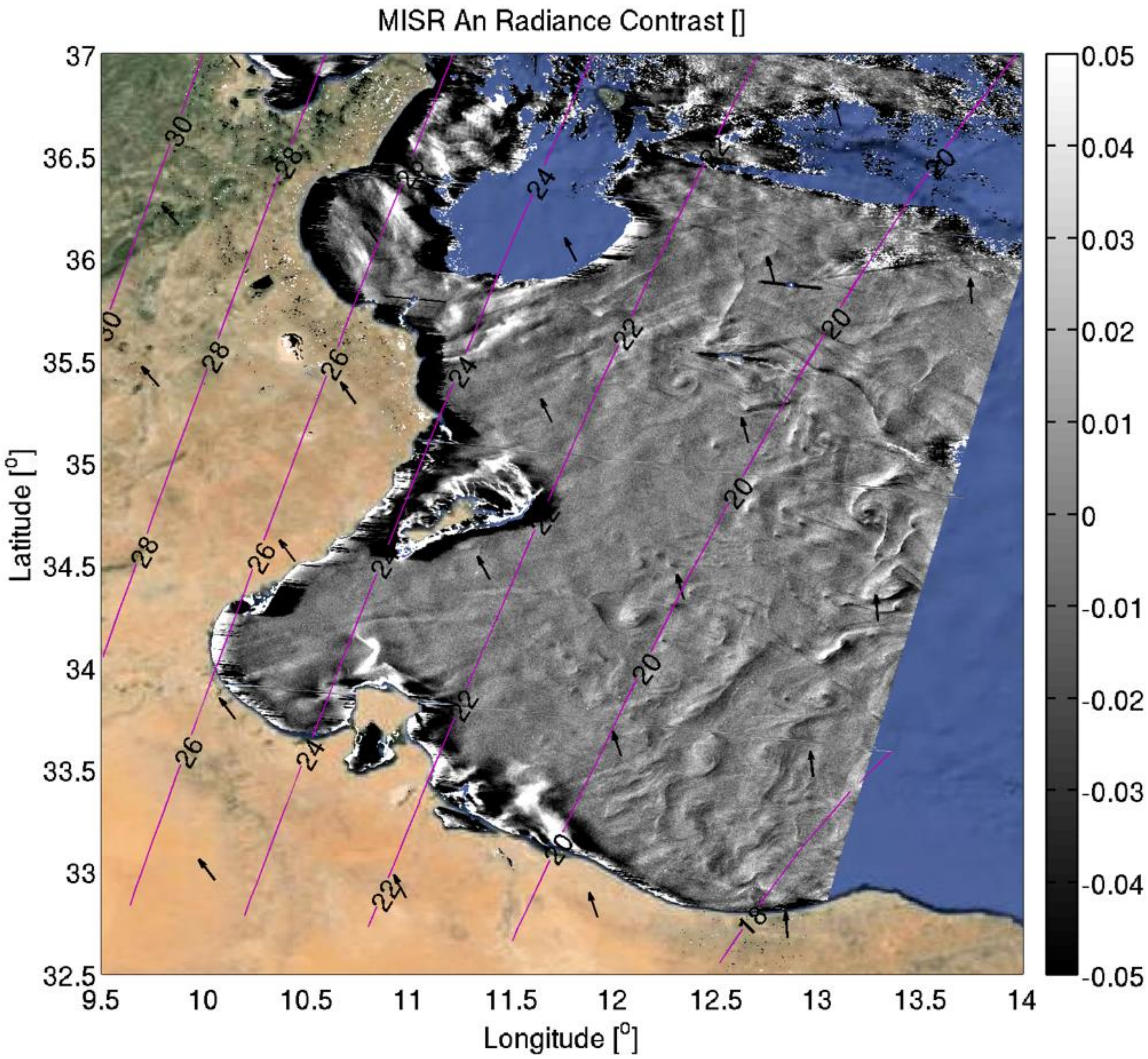
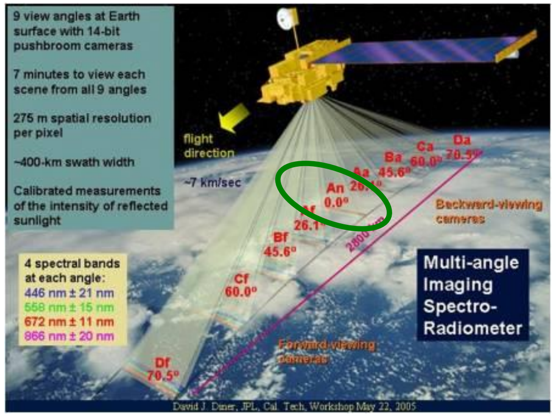
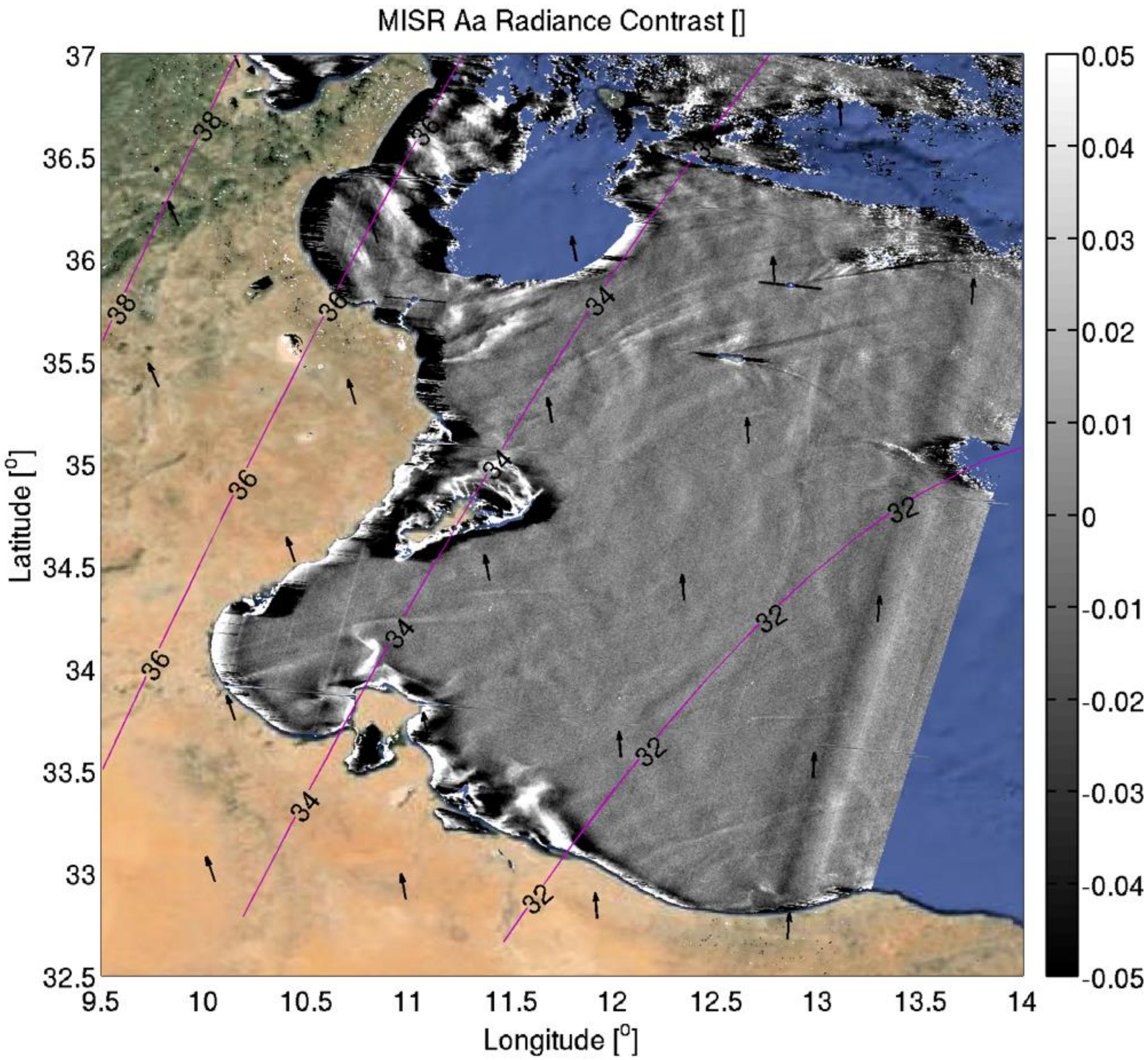
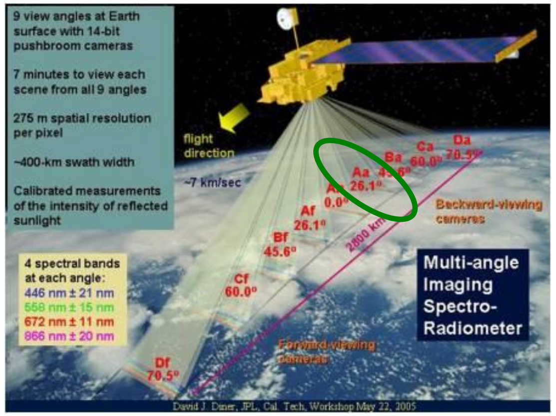




Surface roughness from sun glint at multiple view angles: example at medium resolution (250m)





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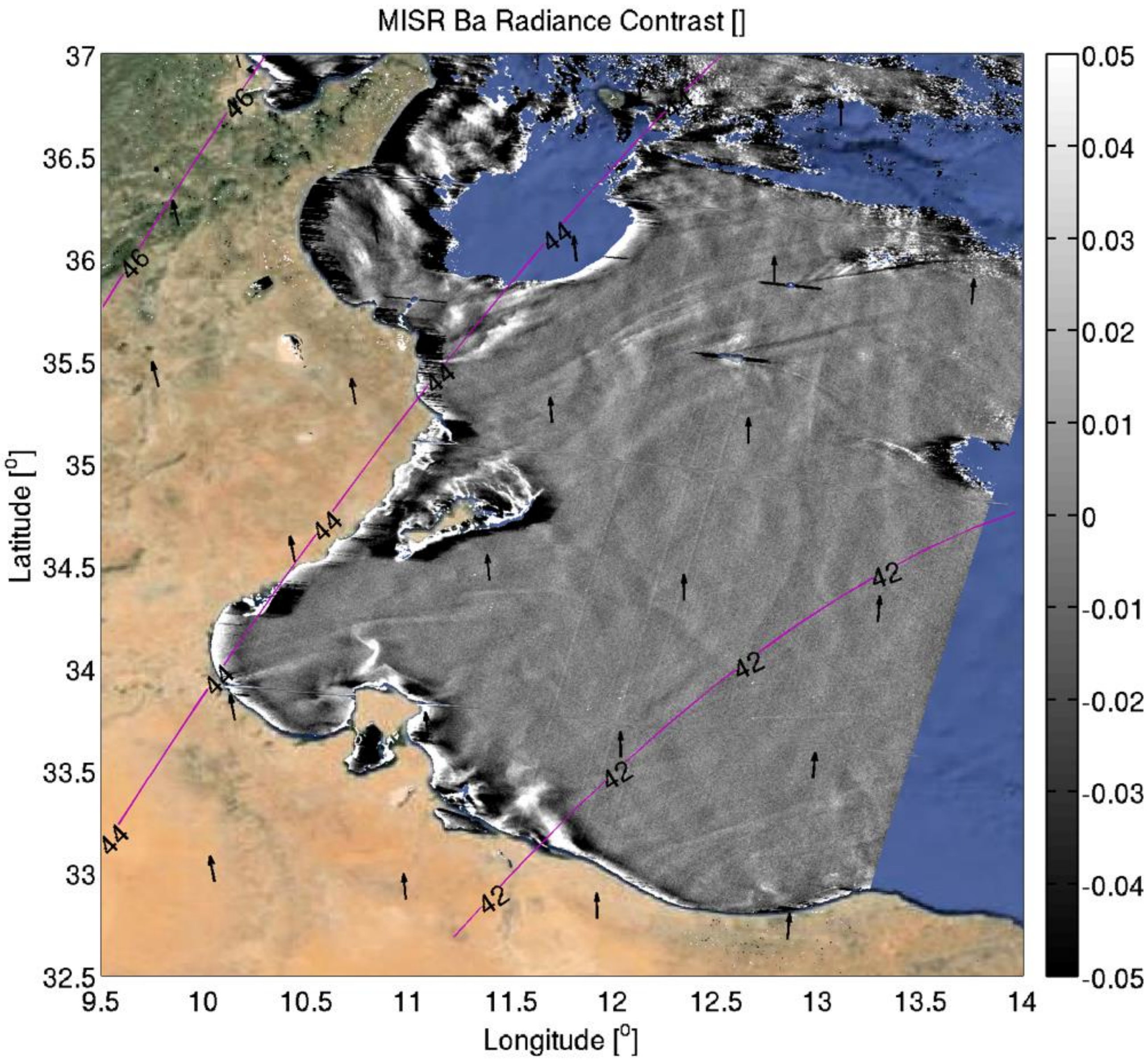

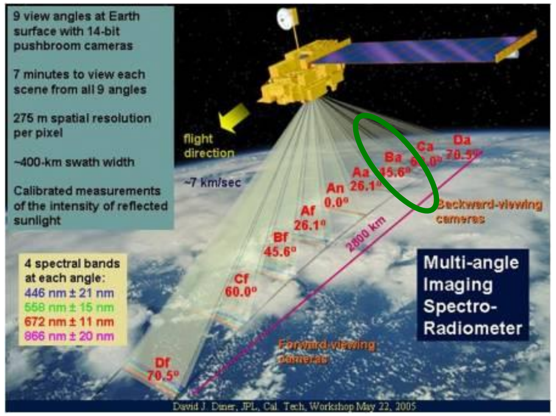

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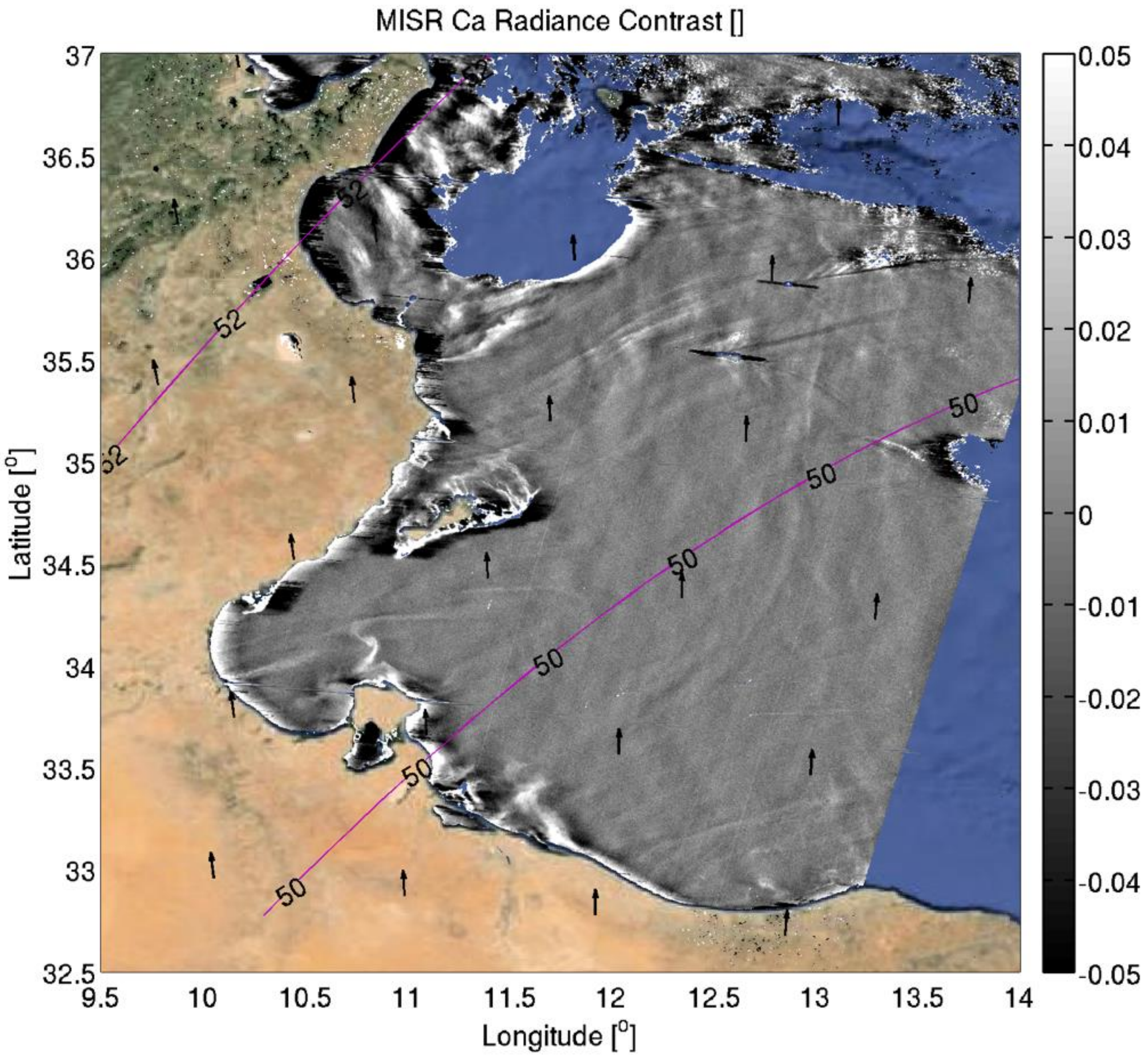

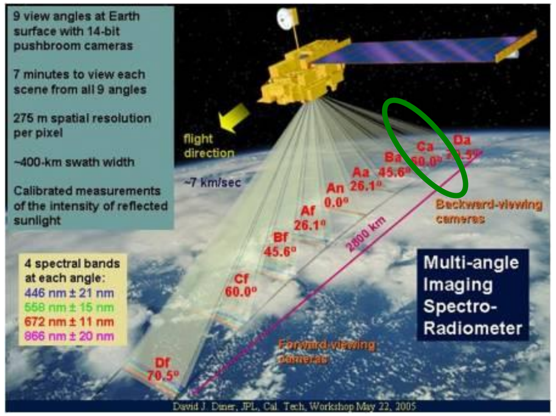

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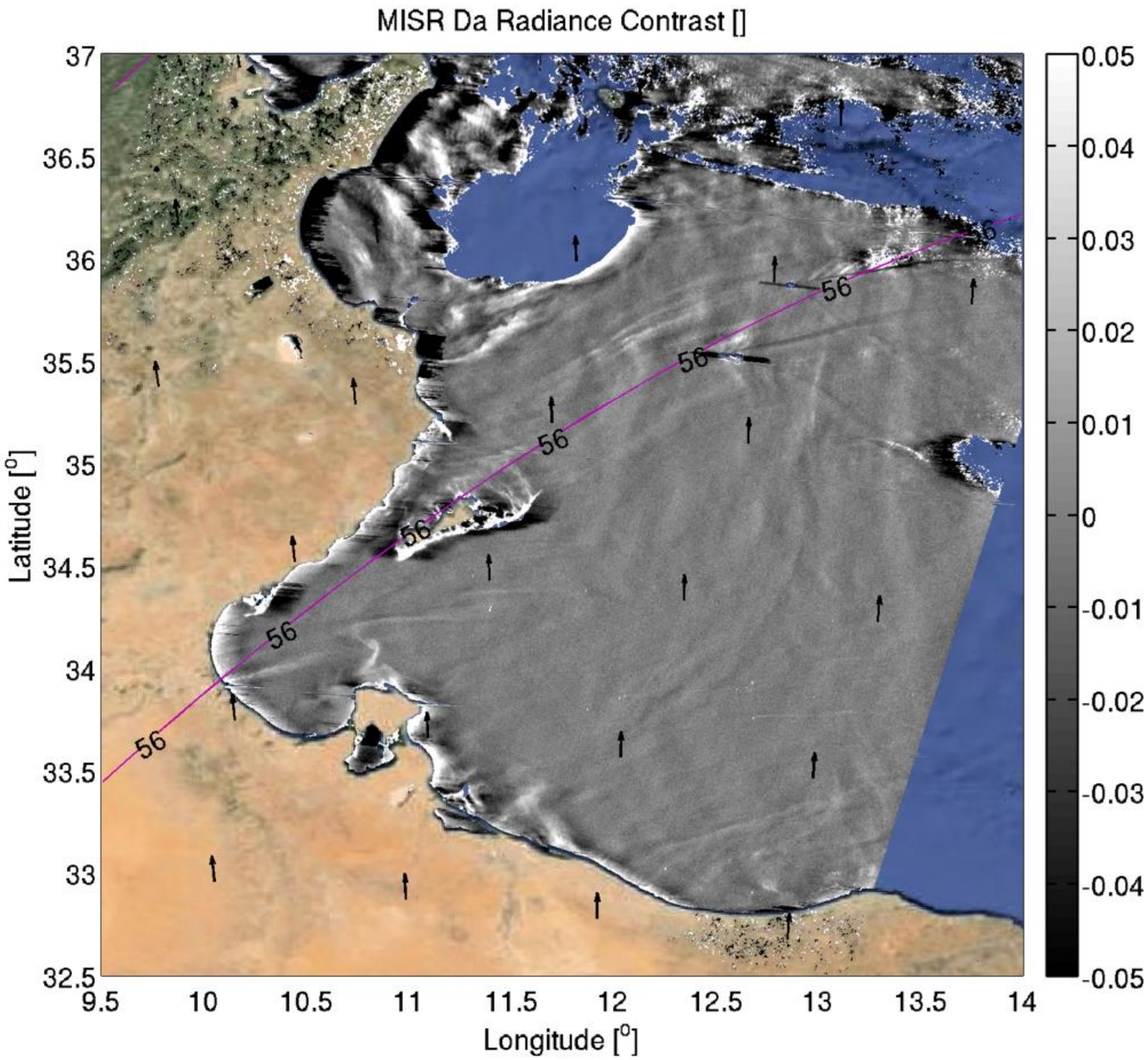
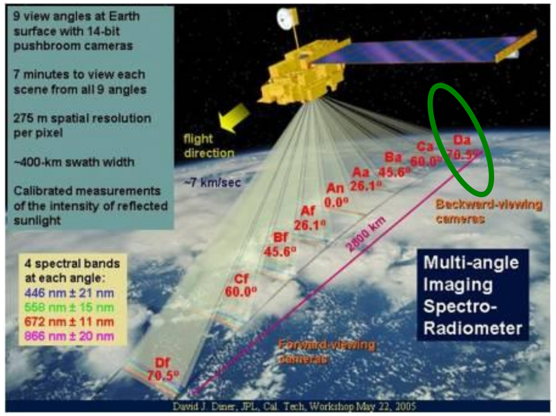
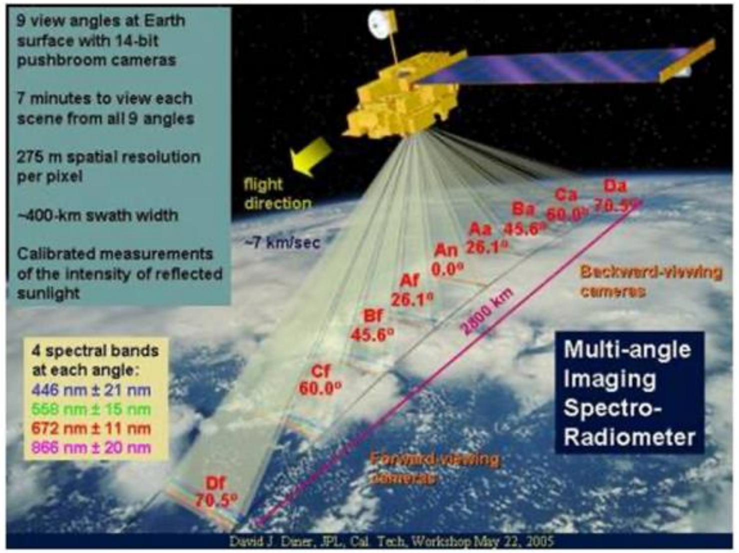
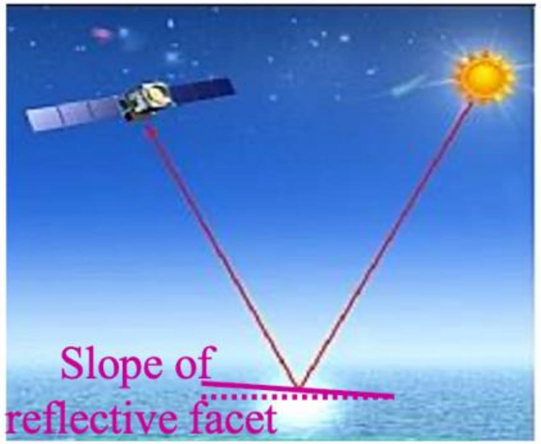


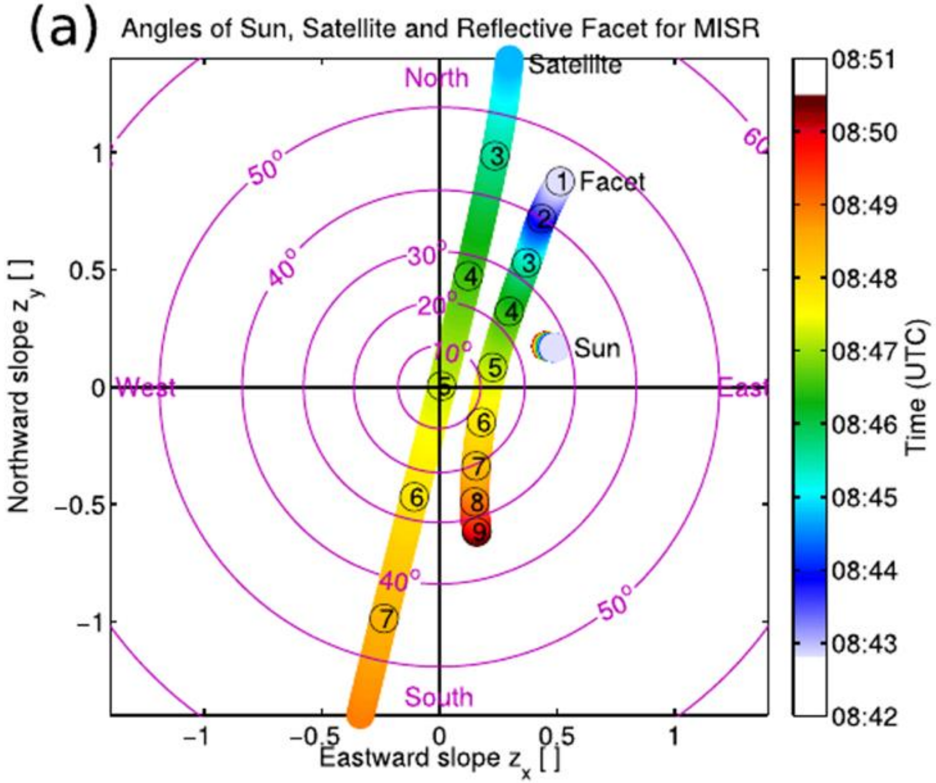


Proposition of a viewing geometry dedicated to wind, waves, current and bathymetry

Example of MISR multi-look sensor (onboard Terra)



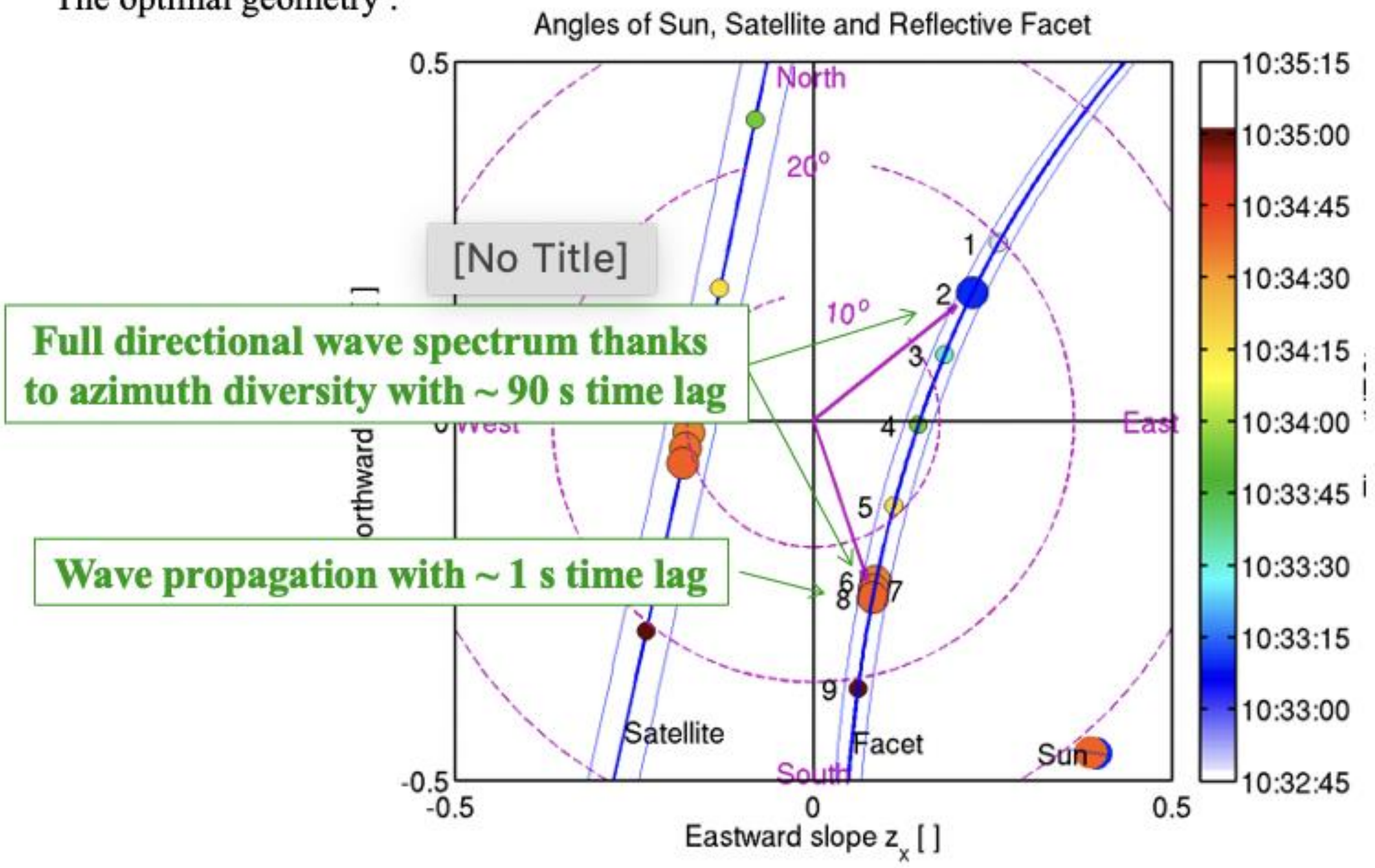




sarong
science of ocean glitter

Proposition of a viewing geometry dedicated to wind, waves, current and bathymetry

The optimal geometry :



sarong
science of ocean glitter


CRISTAL
Polar Ice and Snow
Topographic Mission
esa
Mapping polar sea ice thickness and land ice elevation with overlaying snow depth
Expected launch A 2028 / B 2030
→ THE EUROPEAN SPACE AGENCY

CRISTAL Mission Heritage

CryoSat-2

- 18KHz Closed-burst SAR
- 2 Rx Channel mode
- 88º orbit
- Repeat time 369 days

Sentinel-6

- 9KHz Open-burst SAR
- Orbit 66°
- Repeat time 9.92 days
- AMR-HRMR

Sentinel-3

- 18KHz Closed-burst SAR
- OLTC
- 82° Orbit
- Repeat time 27 days

AltiKA

- 4KHz Open Burst
- 82° Orbit
- Ka Band

CRISTAL Mission Heritage

CryoSat-2

- **18KHz Closed-burst SAR**
- **2 Rx Channel mode**
- **88º orbit**
- **Repeat time 369 days**

Sentinel-3

- **18KHz Closed-burst SAR**
- **OLTC**
- 82° Orbit
- Repeat time 27 days

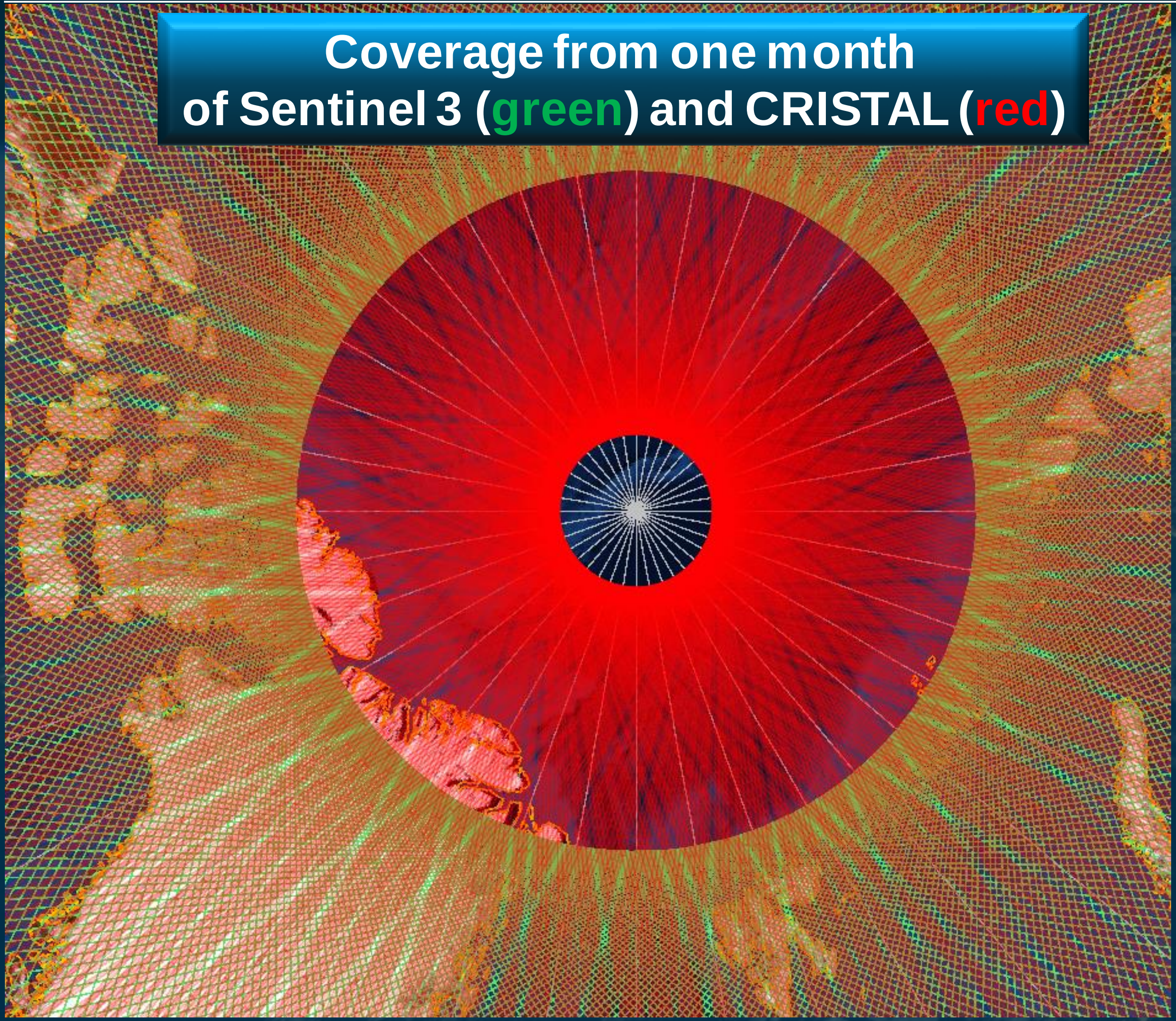
Sentinel-6

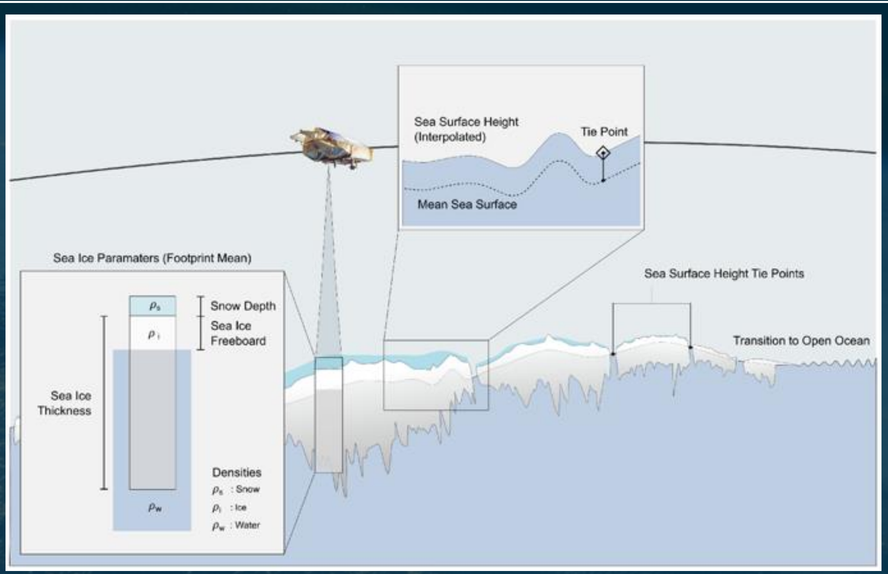
- 9KHz **Open-burst SAR**
- Orbit 66°
- Repeat time 9.92 days
- **AMR-HRMR**

AltiKA

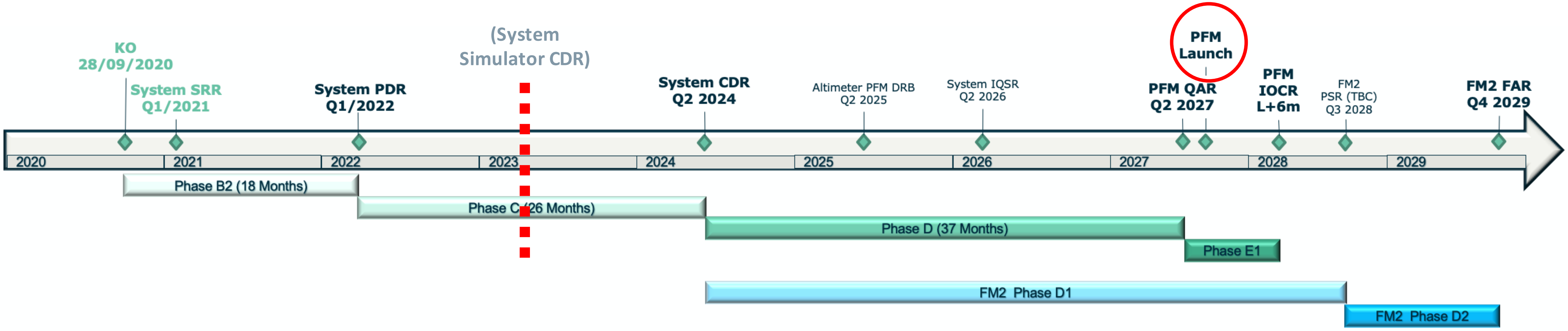
- 4KHz Open Burst
- 82° Orbit
- **Ka Band**

Dense Polar altimetry coverage





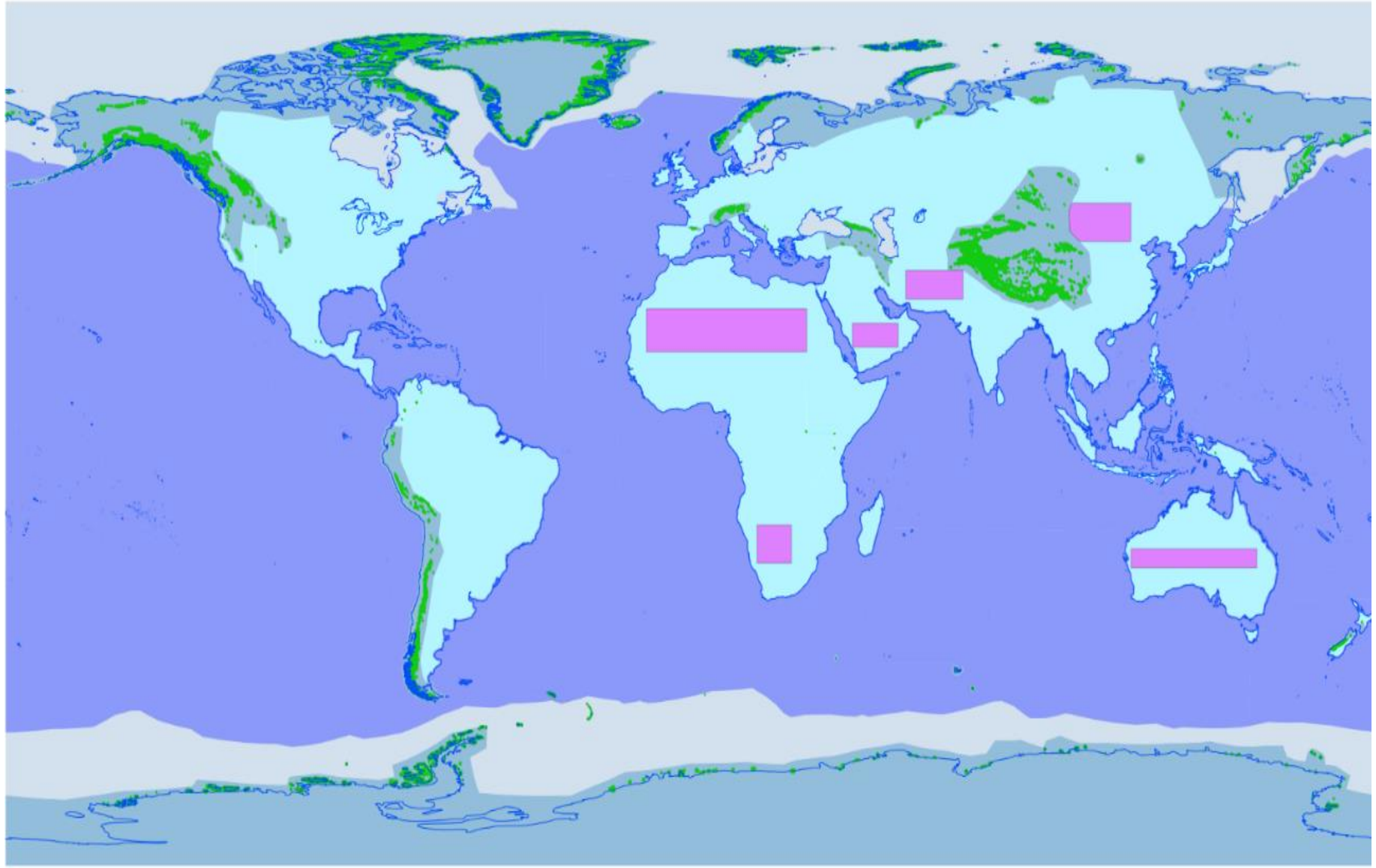
CRISTAL: where we are now



	KO	SRR	PDR	CDR	PFM QAR	FM2 FAR
Satellite	28/09/20 ✓	Feb-Mar’21 ✓	Feb-Mar’22 ✓	May’24	Jun’27	Oct’29
Altimeter	28/09/20	Feb-Mar’21	Feb-Mar’22	Apr’24	May’25	Jan’26

CRISTAL-A on track for launch in late 2027
Followed (towards EOL) by CRISTAL-B

CRISTAL Mode Mask (preliminary)



- Sea Ice **SARin Open Burst**
- Land Ice **SARin Closed Burst**
- Glaciers **SARin Closed Burst**
- Ocean **SAR Closed Burst**
- Inland Water **SAR Closed Burst**
- Calibration

Data rates: SAR RMC CB 22 Mbps, SARin CB 255 Mbps, SARin OB 198 Mbps

Exploitation of FF-SAR processing over sea ice

Identify co-located S6 and CS2 passes

30 April 2022 – 2 June 2022

Credit: Michel ☺

CRISTAL: S6 and CS2 observations

Exploitation of FF-SAR processing over sea ice

Visual identification of surface features, comparing to optical imagery

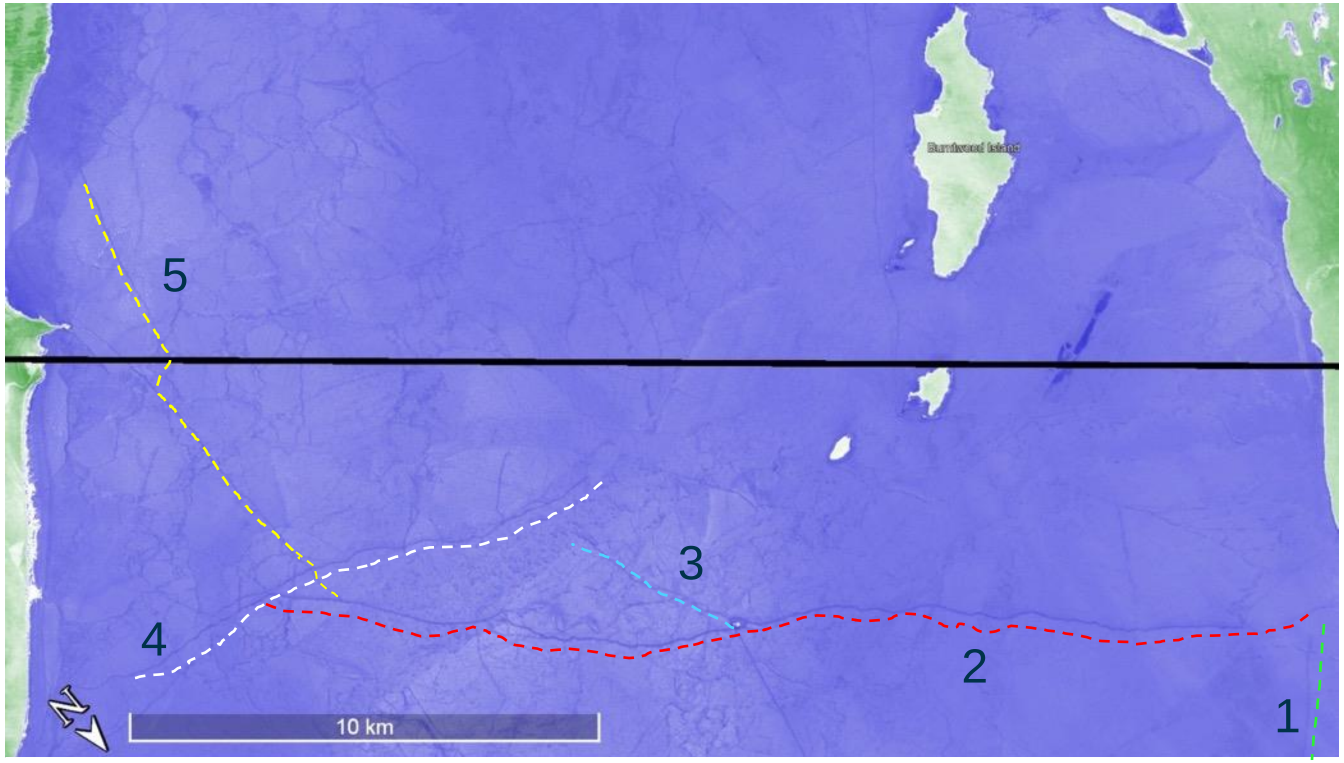
Shoreline

Leads

Sentinel-6
(Pass 178)
04-05-2022

Islands

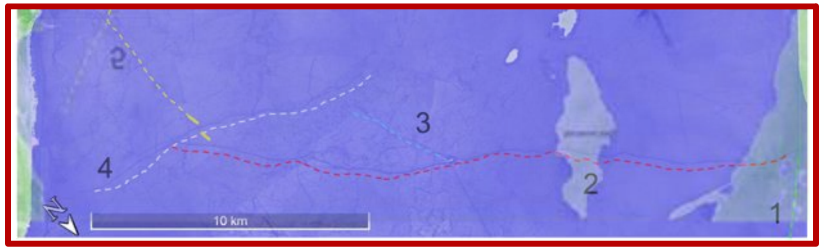
Onshore
lakes



CRISTAL: S6 and CS2 observations

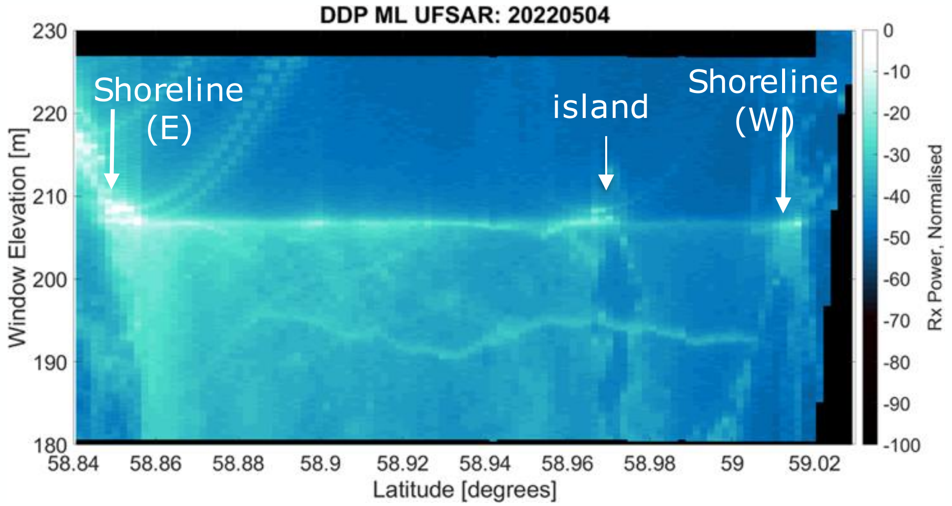
Exploitation of FF-SAR processing over sea ice

Compare UF and FF processing of S6 to identify surface features in 2D radargrams

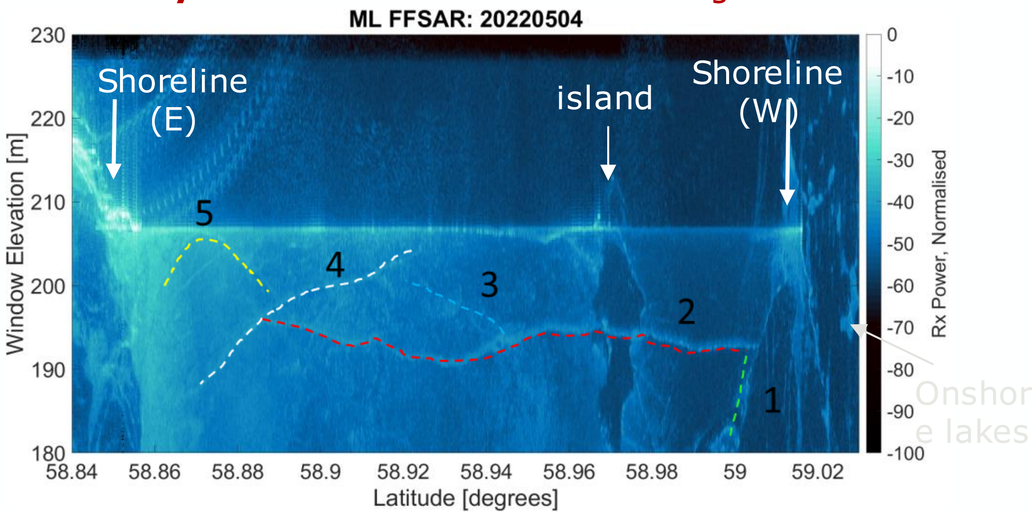


Note: Signals from L and R of the S6 pass are 'folded' in the radargram – complicates interpretation

Unfocused: 300m resolution along-track



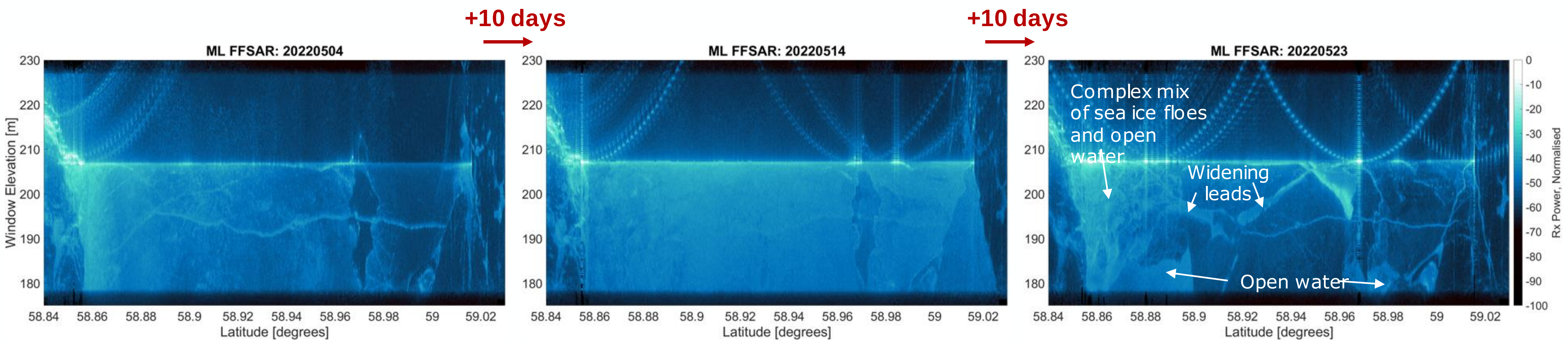
Fully-Focused: 20m resolution along-track



CRISTAL: S6 and CS2 observations

Exploitation of FF-SAR processing over sea ice

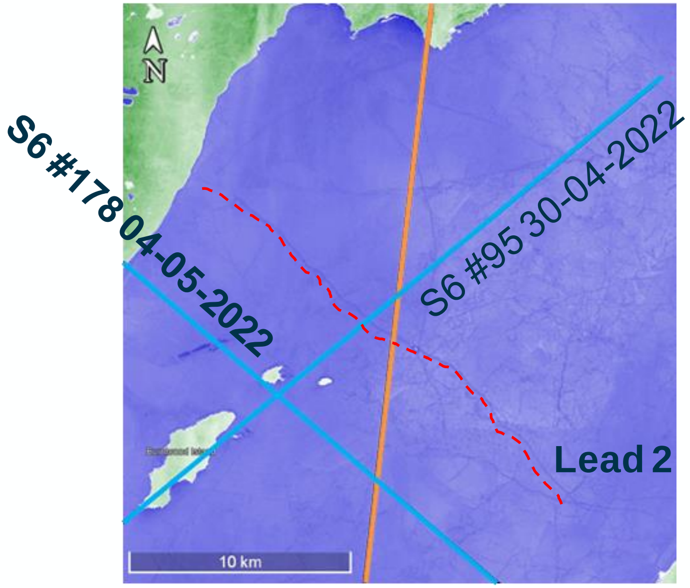
Compare time-series of FF radargrams to observe changes in sea ice conditions.



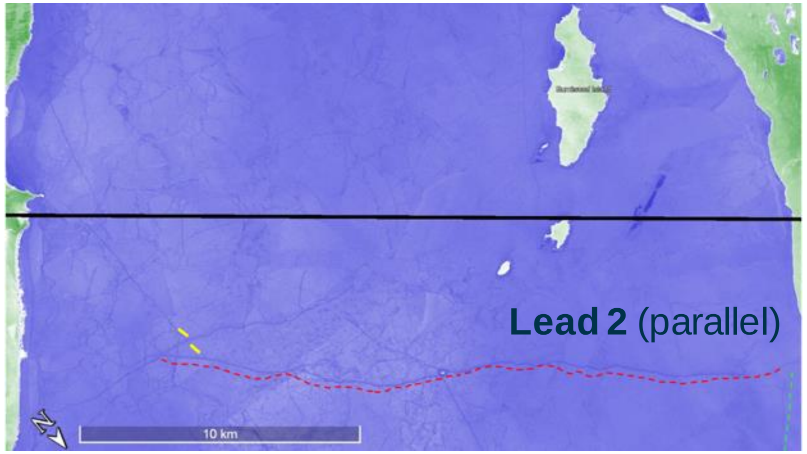
CRISTAL: S6 and CS2 observations

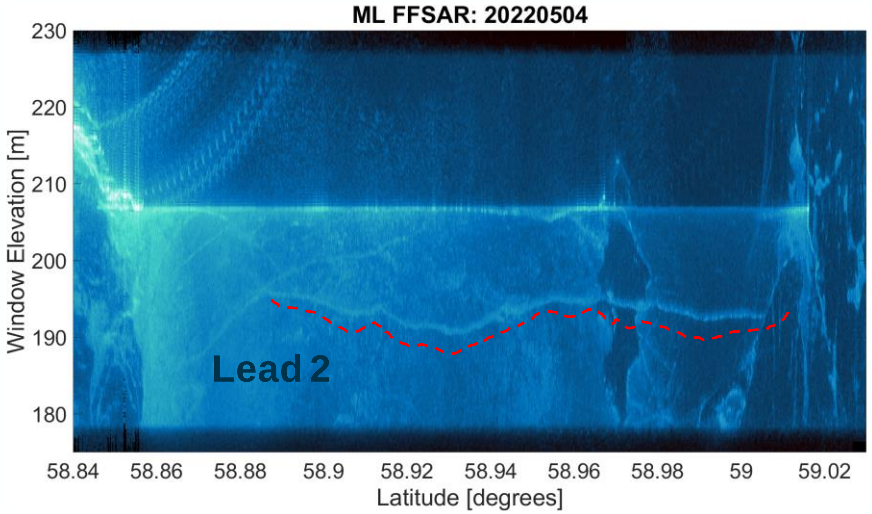
Exploitation of FF-SAR processing over sea ice

Compare FF-SAR from S6 with the interferometric capabilities of CS2



S6 Pass 178
04-05-2022

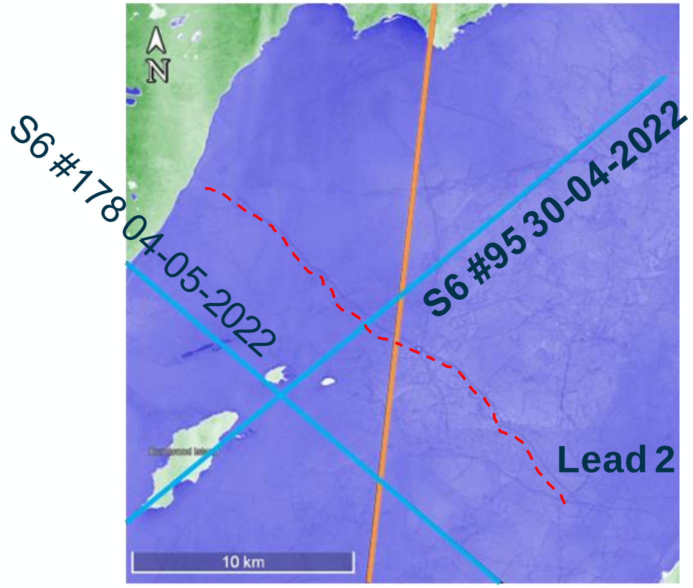




CRISTAL: S6 and CS2 observations

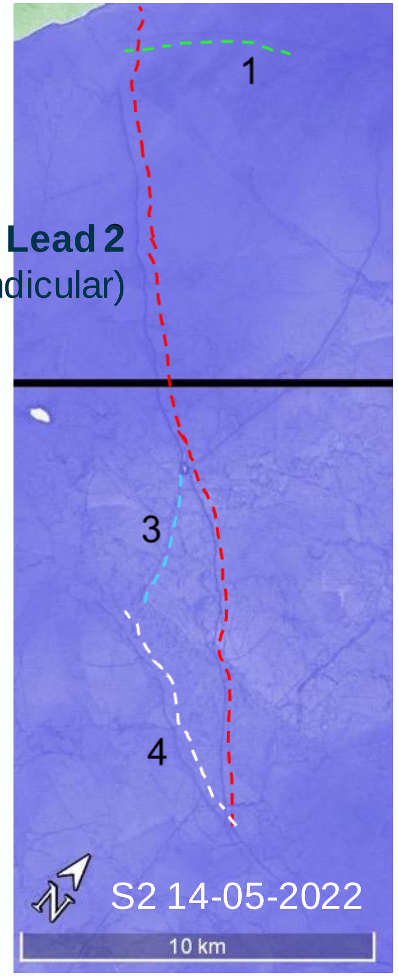
Exploitation of FF-SAR processing over sea ice

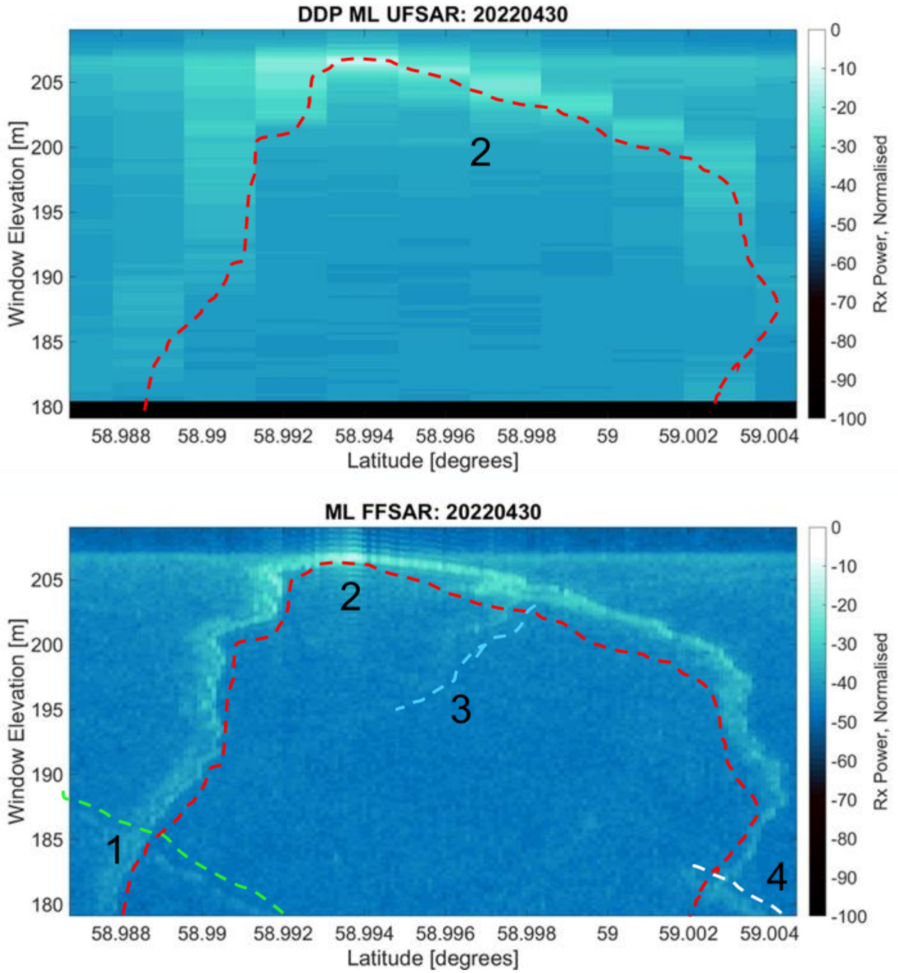
Compare FF-SAR from S6 with the interferometric capabilities of CS2



Lead 2 (perpendicular)

S6 Pass 95
30-04-2022

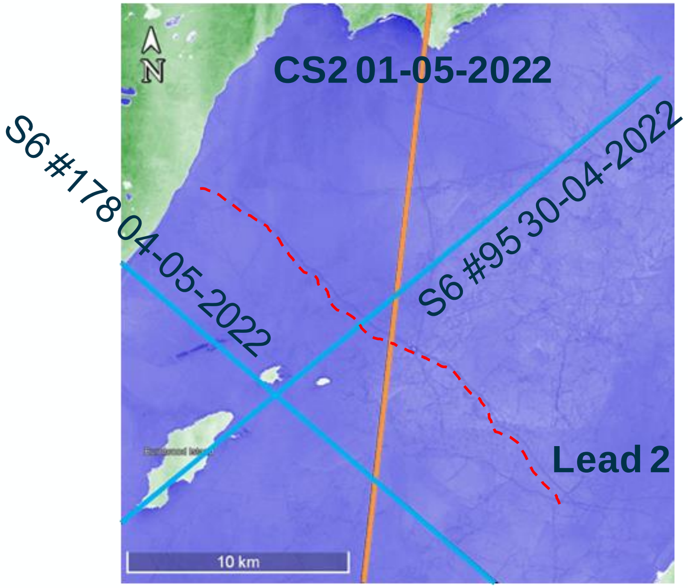


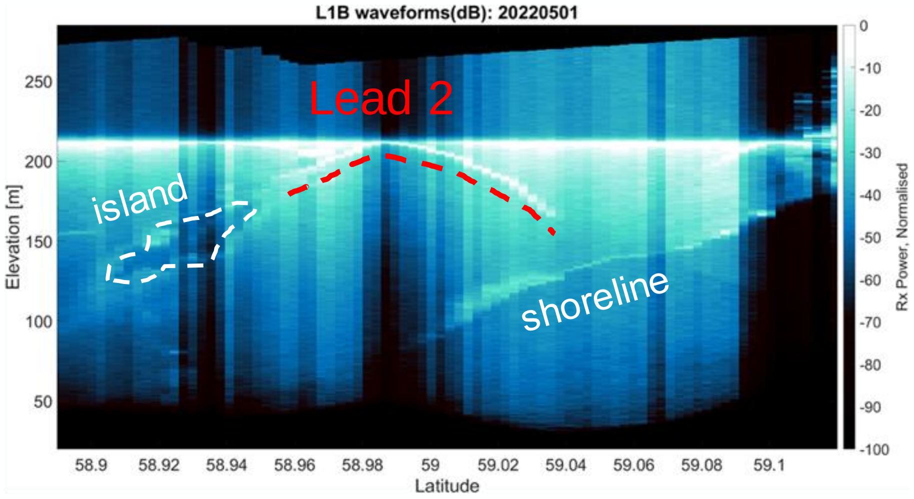


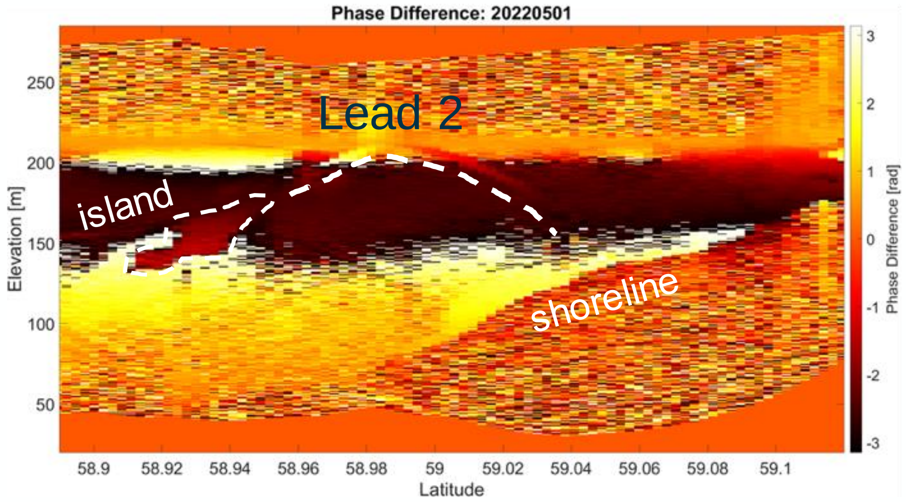
CRISTAL: S6 and CS2 observations

Exploitation of FF-SAR processing over sea ice

Compare FF-SAR from S6 with the interferometric capabilities of CS2







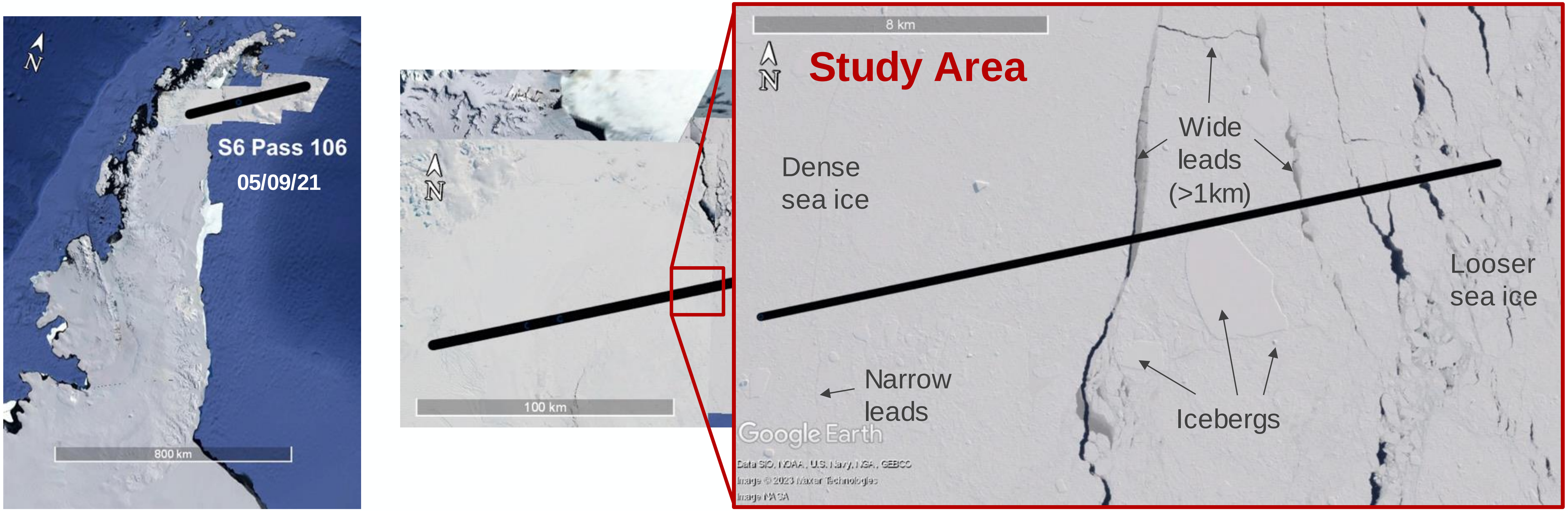
+ve φ :
signal from R

-ve φ :
signal from L

CRISTAL: S6 and CS2 observations

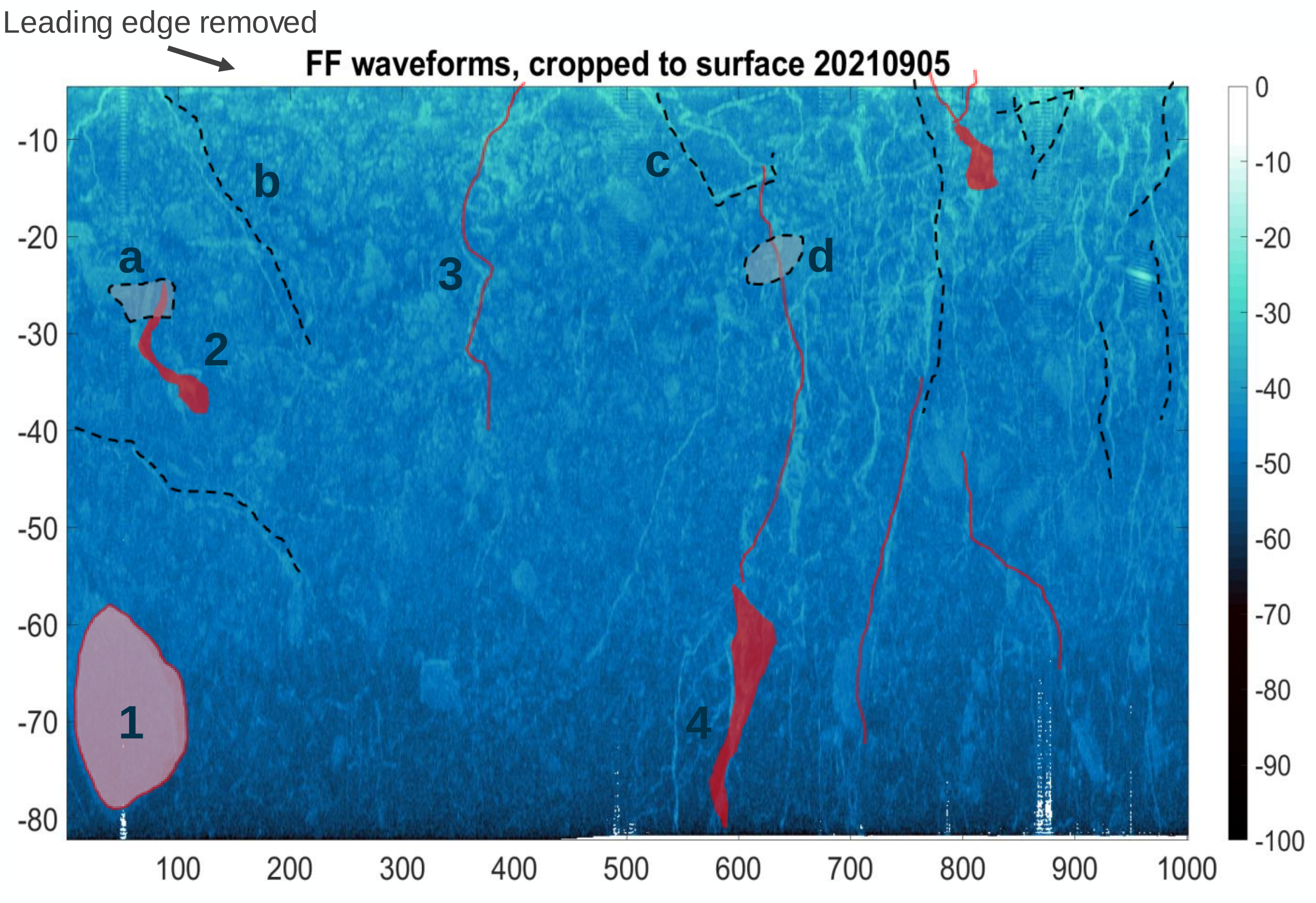
Improving lead detection over sea ice

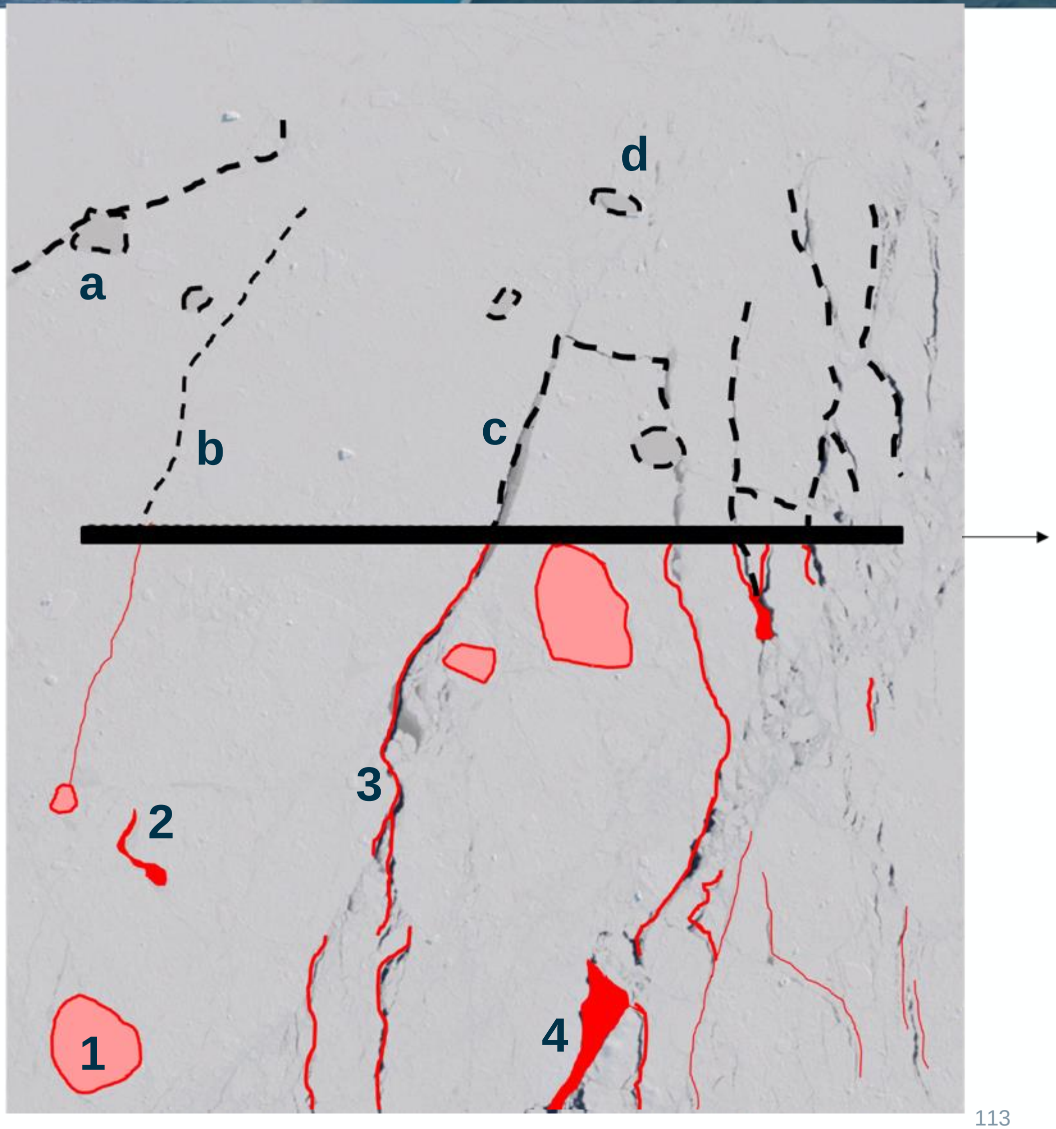
Applied to Antarctica (greater density of leads)



CRISTAL: S6 and CS2 observations

Improving lead detection over sea ice



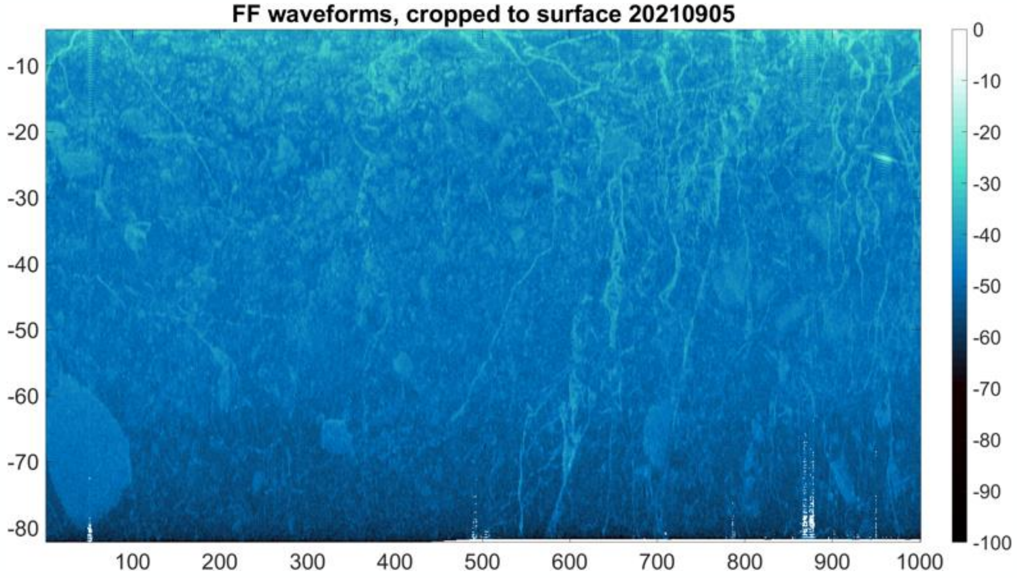


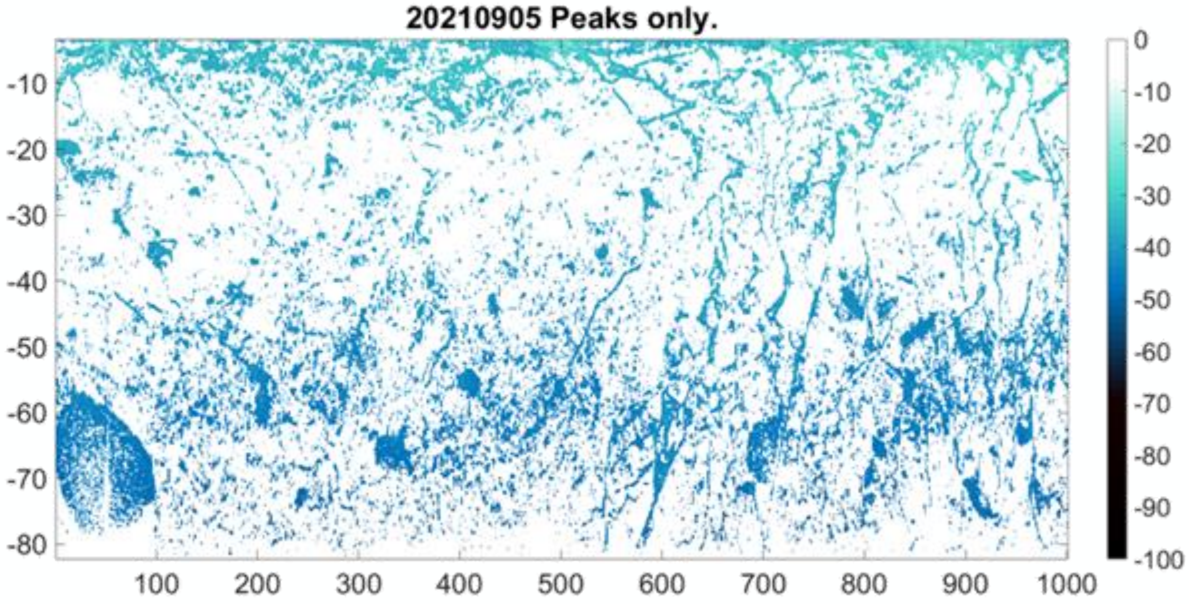
CRISTAL: S6 and CS2 observations

Surface type discrimination – open ocean, floes and leads

Challenges: Range folding and translation from %cover in radargram to %cover when projected

Thresholding approach



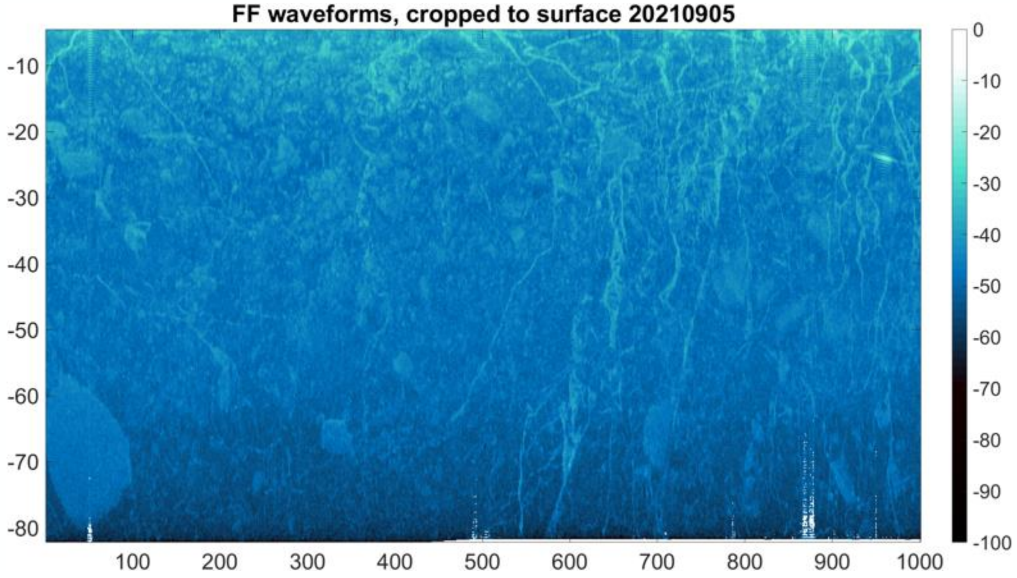


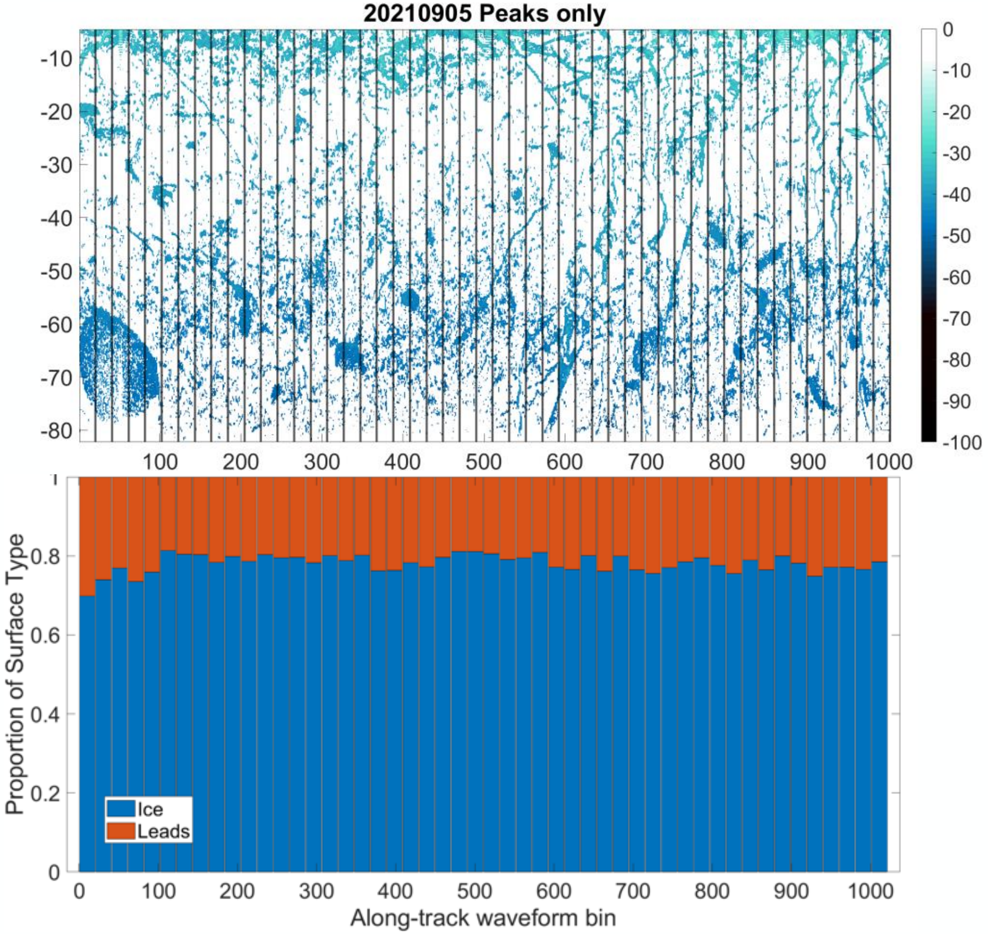
21.9% Leads/Ocean/Icebergs
78.1% Sea Ice

CRISTAL: S6 and CS2 observations

Surface type discrimination – open ocean, floes and leads

Thresholding approach



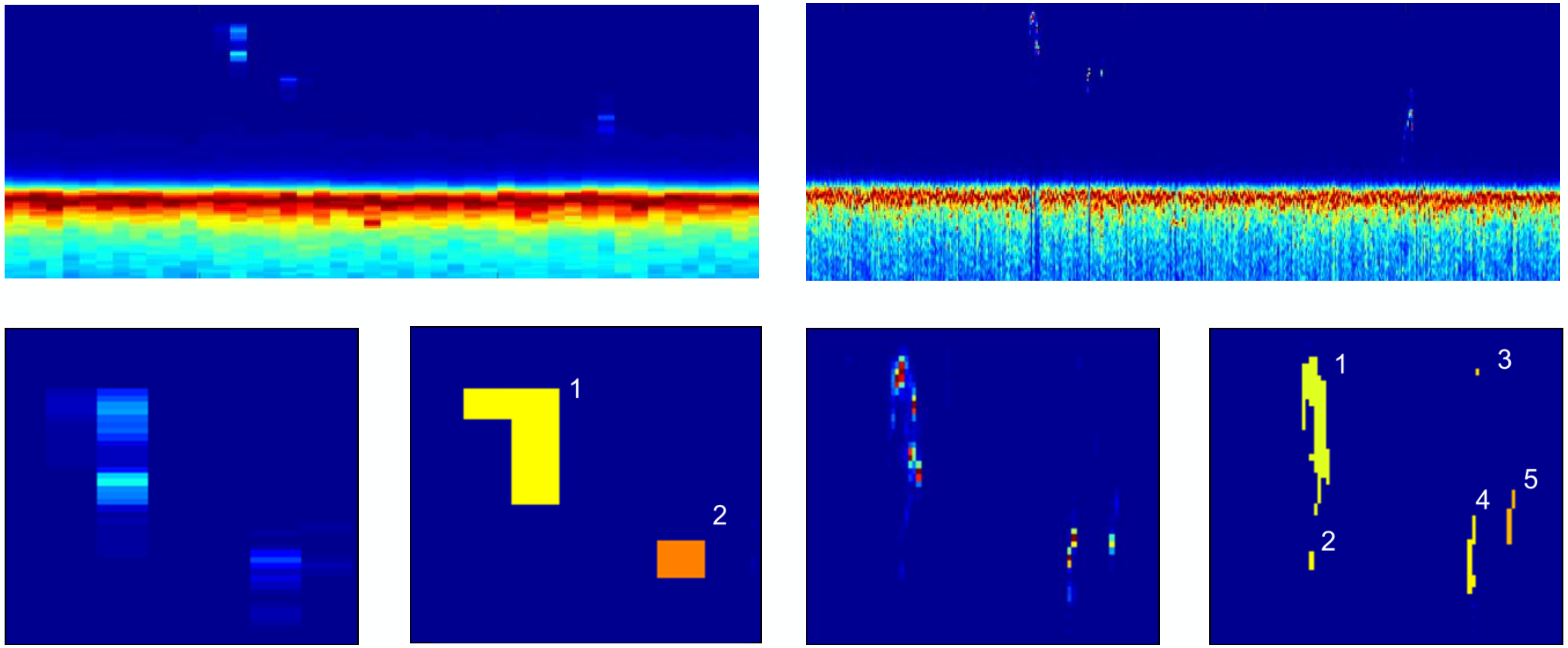


Iceberg location and shape

Applying methods already working with CS2 unfocussed data.

Unfocused: 300m resolution along-track

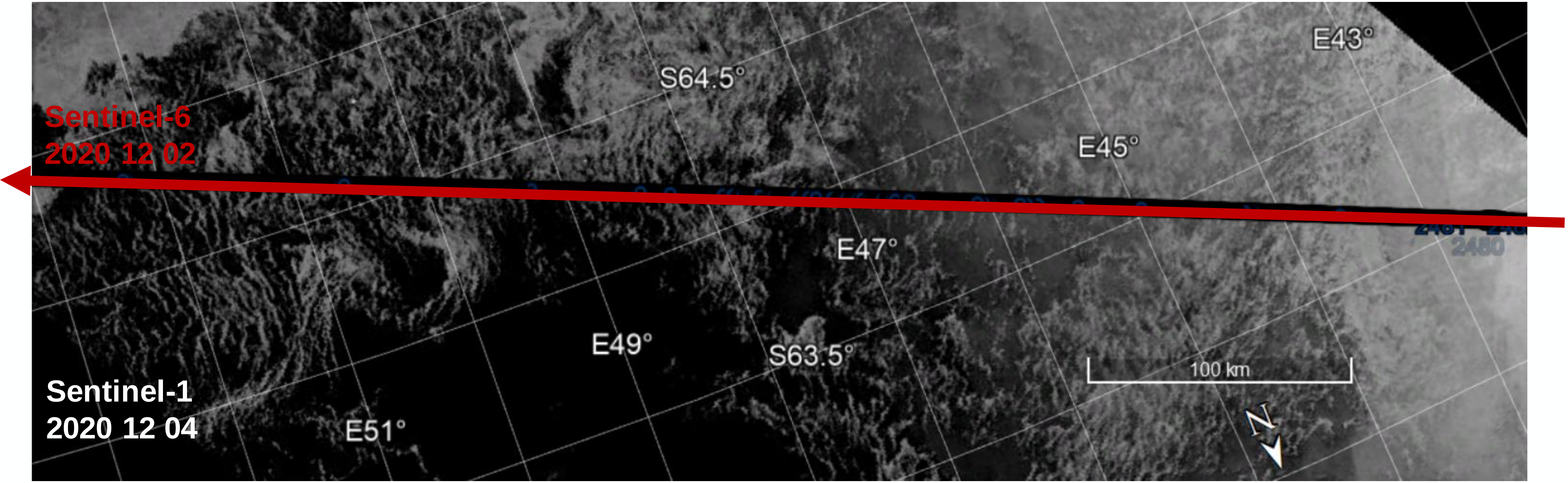
Fully-Focused: 20m resolution along-track

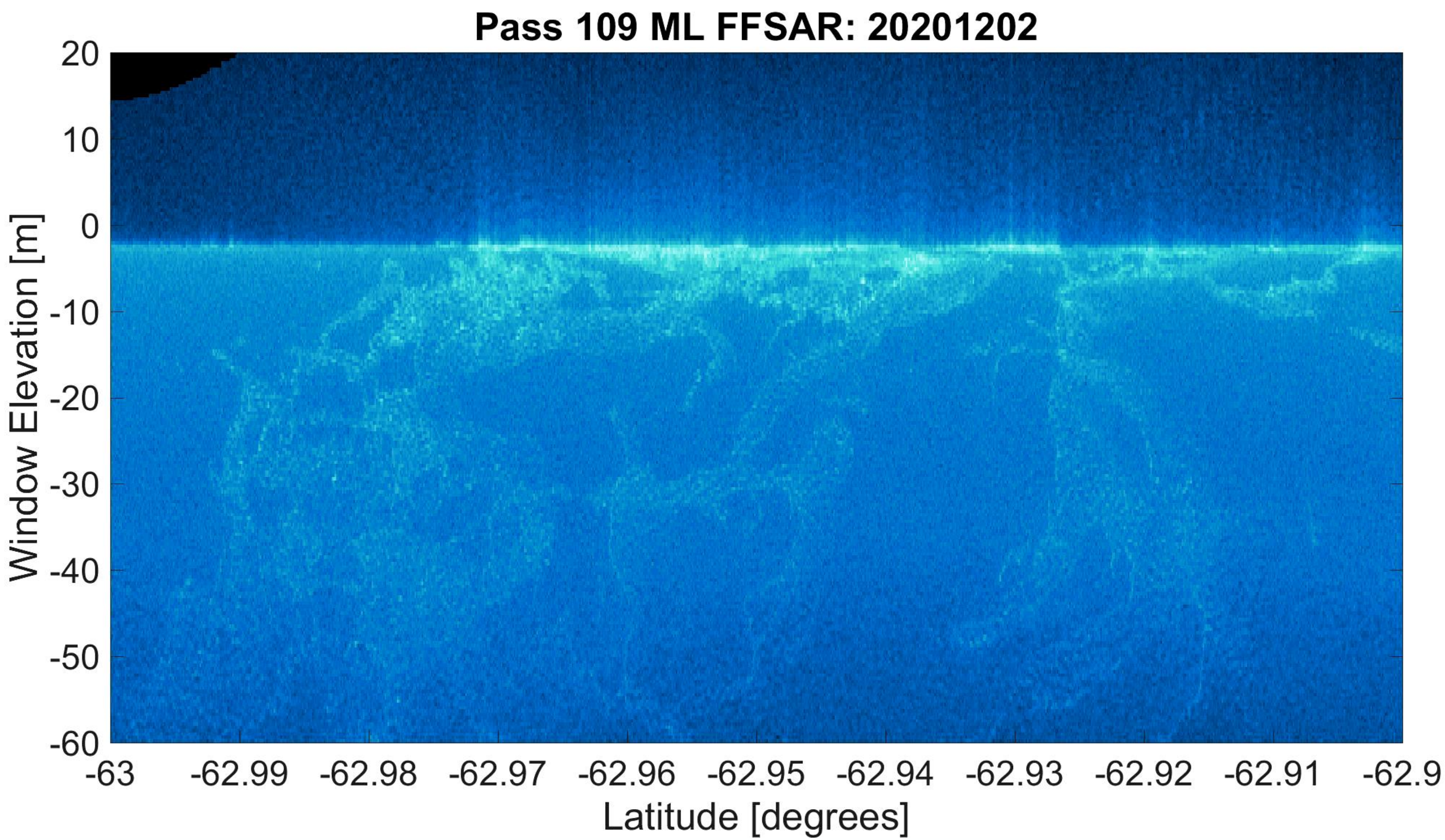


Discussion points

Discussion points for breakout session

- Mispointing on CRISTAL
  - CryoSat-2 has a 0.1º roll that helps the interferometric handling ambiguities in flat surfaces
- Ka&Ku interfaces: penetration uncertainty, snow density
  - MoSAIC expedition, simulated data, theoretical assessment
- Open Burst everywhere?:
  - Fully Focussed over Ocean, Inland Water targets and small glaciers will benefit from it.
  - First altimetry mission enabling FF-SAR for Ka.


Sentinel-6
2020 12 02
S64.5°
E43°
E45°
E47°
E49°
S63.5°
E51°
100 km
N
2480
Sentinel-1
2020 12 04


Pass 109 ML FFSAR: 20201202
Window Elevation [m]
20
10
0
-10
-20
-30
-40
-50
-60
-63
-62.99
-62.98
-62.97
-62.96
-62.95
-62.94
-62.93
-62.92
-62.91
-62.9
Latitude [degrees]

Video link

Copernicus Sentinel-1

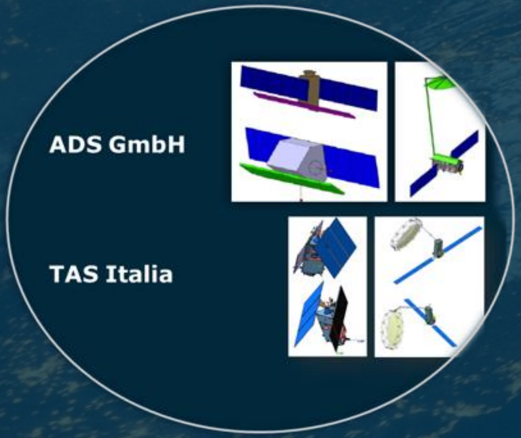
High resolution C-band SAR imagery for 20 years

Operational monitoring of sea ice/icebergs, glaciers, ocean wind and waves, oil spills, land deformation/earthquakes..

Sentinel-1 NG Highlights

OBJECTIVES

- *Ensure continuity* and expansion of services and applications relying on Sentinel-1
- *Enhance* existing services and applications
- *Enable* new application developments building on improved performance and observation gaps (e.g. resolution, revisit and others)



MISSION AND SYSTEM REQUIREMENTS

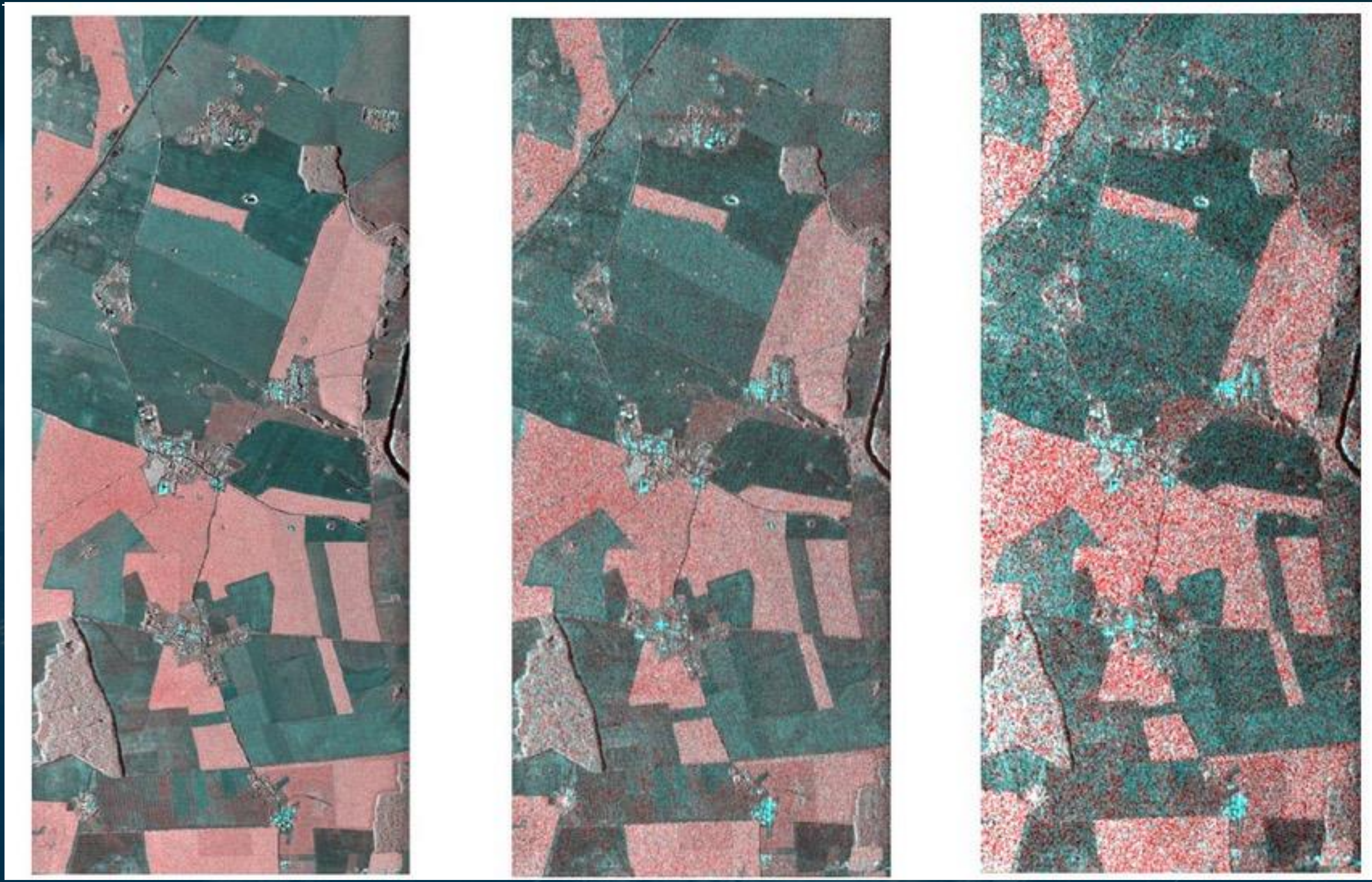
- Performance shall be equal or better than Sentinel-1 FG
- Revisit: 3 days Global, 0.5 days Arctic and sea ice
- Resolution ≤ 25 m^2
- NESZ ≤ -26 dB
- Full continuity in Dual-Pol and Quad-Pol capability
- Use of a dedicated Mission Mode to cover the North Pole region
- **Same orbit of S1FG / ROSE-L in constellation of two satellites**

Sentinel-1 NG Requirements

Performance Requirements	Sentinel-1 NG	Sentinel-1
Latitude coverage	**-80 to +90 deg**	North-pole gap
Revisit	Goal: **3 days** Global Goal: **0.5 days** Arctic and Sea Ice	Up to 12 days
Latency	**10 min** European Waters **120 min** Global	10 min RT, 1 h NRT emergency, > 3 h Global
Repeat pass InSAR	**6 / 12 days** (S1 & ROSE-L orbit)	6 / 12 days
Incidence angle access	**Better than 20 – 45 deg**	20 – 45 deg
Swath width	**Larger than 400 km**	250 IW – 400 EW
Resolution	**25 m2**	~100m2 IW - ~800m2 EW
NESZ	**-26 dB**	-22 dB
Polarization capability	**SP, DP and QP**	SP and DP
Duty cycle	**43% (˜43 min/orbit) with 53min any orbit**	25min/orbit

Other Mission Requirements
Enhanced operations through the **potential integration of additional satellites**
Automatic Identification System (AIS) payload to augment maritime services
Over open oceans the mission shall support the generation of **wave mode products**

Next Generation Imaging



E-SAR standard (8 looks) S1 SM [~S1-NG] (4 looks) S1 IWS (4 looks)

Lower NESZ (-26 dB)

will further enhance mapping and characterization of weak scatterers (benefits in soil moisture, oil spills, sea ice mapping, etc…)

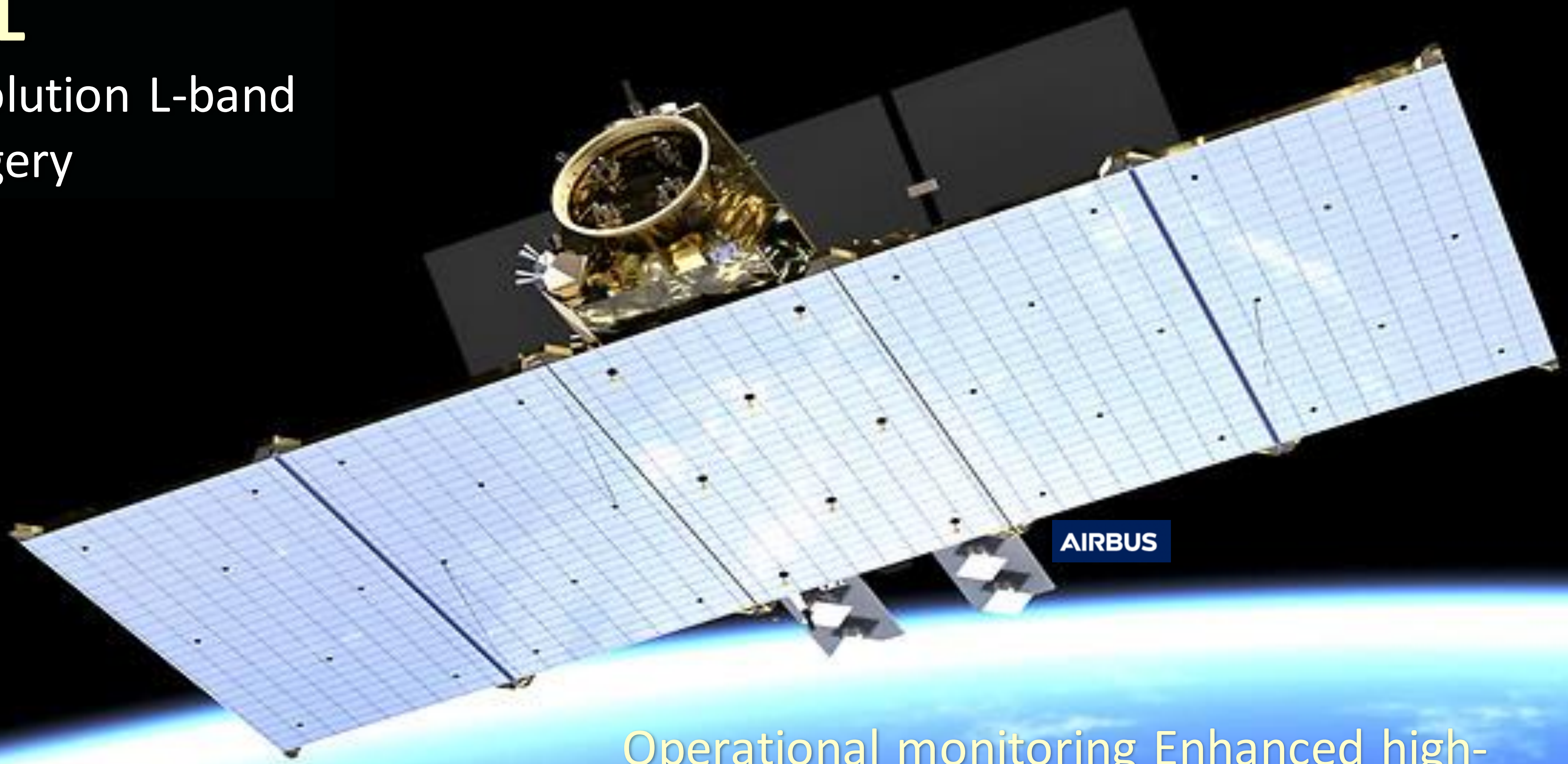
E-SAR data for ESA AgriSAR campaign with Sentinel-1 simulation in stripmap and IWS mode. Color coding is RGB: HV-HH-HH. Stripmap resolution is the same as S1-NG, although with higher NESZ (DLR)

S1NG Status

- Sentinel-1 First Generation has enabled the development of new operational applications
- Sentinel-1 Next Generation at C-band to
  - *ensure continuity* and expansion of services and applications relying on Sentinel-1
  - *enhance* existing services and applications
  - *enable* new application developments building on improved performance and observation gaps (e.g. resolution, revisit and others)
- Sentinel-1 NG will bring new and enhanced capabilities
  - Higher resolution (25m2 for S1NG)
  - Low NESZ (-26 dB for Sentinel-1 NG)
  - Wide swath and frequent revisit capability and greatly enhanced duty cycle
- Sentinel-1, ROSE-L and Sentinel-1 NG are addressed as a system (not in isolation).
- Phase 0 (Mission Identification) carried out in 2019-2020
- Phase A/B1 in two years 2021-2023
  - PRR carried out to be concluded in Q2 2023 for both consortia
- ITT for Development Phase (Phase B2/C/D) expected in second half 2023
- Expected launch > 2032

ROSE-L

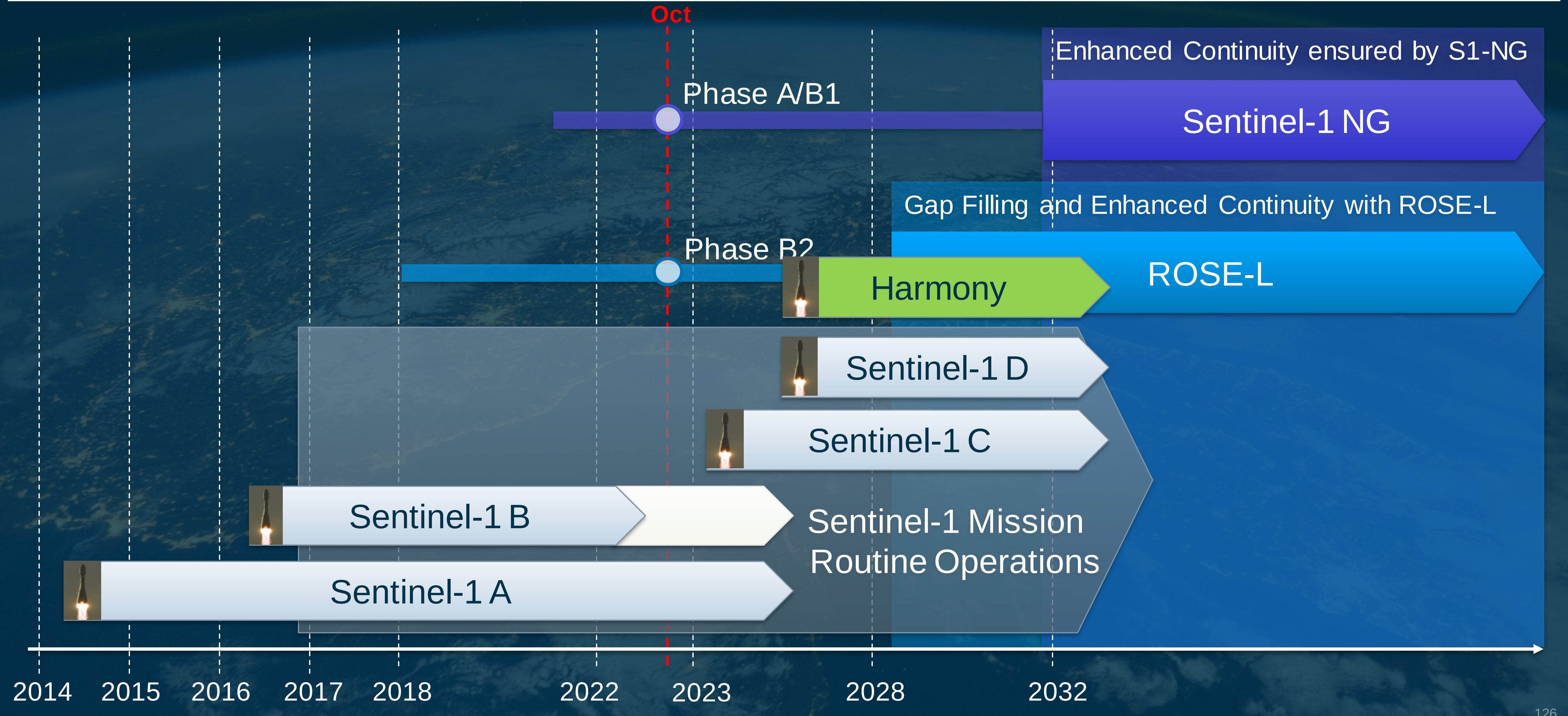
High resolution L-band SAR imagery



Operational monitoring Enhanced high-resolution sea ice information Snow Water Equivalent, maritime monitoring (Iceberg, Oil Spills and Vessel Detection and Mapping)

Launch anticipated in 2028+

Copernicus Timeline – Current and Future SAR Missions



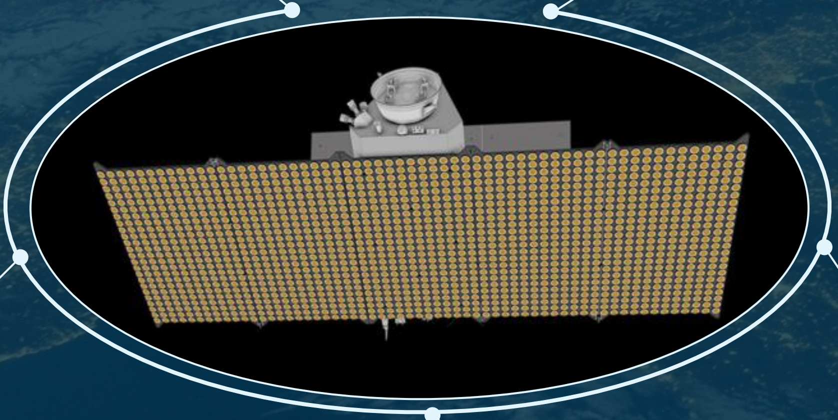
ROSE-L Mission in Brief

GENERAL

- Constellation of 2 satellites (PFM & FM2) + options under study
- Consortium led by Thales Alenia Space Italy (TAS-I), involving 29 companies from 15 countries
- Service continuity with Sentinel-1 FG and NG

IMAGING

- L-Band – 85 MHz ITU allocated band (1.215-1.300 GHz)
- Dual-Pol and Quad-Pol modes
- Wave mode capability
- Resolution < 50 m2 (Dual-Pol)
- NESZ < -28 dB
- DTAR < -23 dB
- Swath width > 250 km



COVERAGE

- Coverage of Global Land (excl. Antarctica) and Arctic
- Revisit with 2 satellites :
  - 6 days Global Land
  - 3 days Europe
  - 1 day Arctic
- Repeat cycle of 6 days over Global Land (2 satellites)

PROGRAMMATICS

- Currently reaching end of Phase B2
- Science Plan activities start in 2022
- Launch of PFM expected in 2028
- FM2 delivery expected in 2030

SYSTEM

- Synergic acquisitions with Sentinel-1: co-located swaths and support to convoy configuration
- Low latency
  - 10 min Europe coastal waters
  - 200 min Global
- Enable companion for single-pass Interferometry

ROSE-L Objectives and Services

CLMS
C3S
CMEMS
EMS
Security
Meteorology and Hydrology Services
National and Local Authorities

Geohazards Monitoring

- Deformation
- Landslides
- Urban subsidence
- Flooding

EU-GMS

Land Use, Agriculture and Forestry

- Forest biomass and structure
- Land over and land cover change
- Agriculture

Soil Moisture

- High-resolution soil moisture

METEO

Cryosphere and Arctic

- Sea ice characterization
- Ice sheets and glacier velocity
- Grounding line
- Snow water equivalent
- Permafrost thawing and extent

METEO

Marine Monitoring

- Ocean surface wind vectors
- Swell properties

METEO

Maritime Monitoring

- Iceberg location, size and drift
- Vessel location, size and velocity
- Oil spill location and morphology

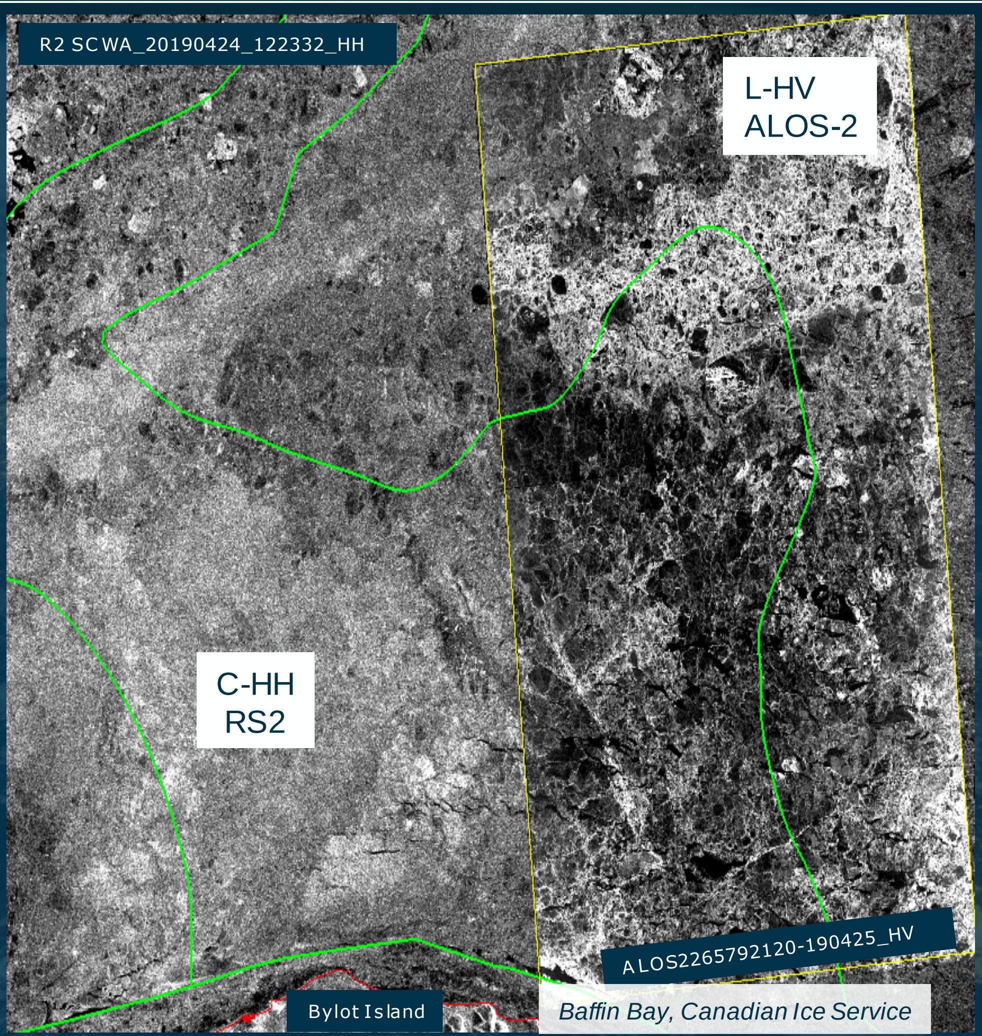
EMSA
FRONTEX

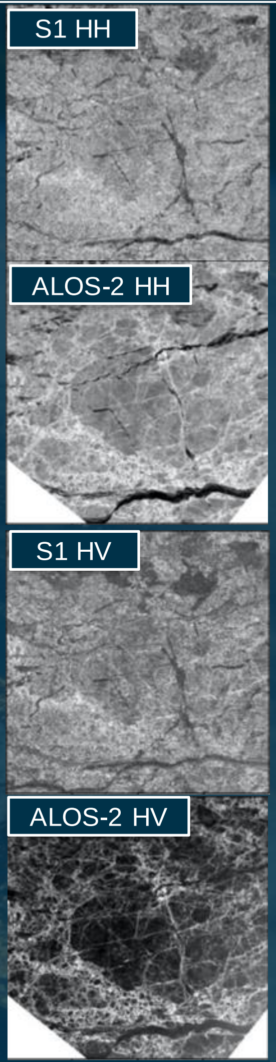
Sea Ice Monitoring

- **Daily high-resolution information on hazardous sea-ice and icebergs** for navigation and weather/climate services
- **Enhanced mapping of sea-ice type and concentration,** adding to C-band the L-band sensitivity to large ice structures (e.g. fractures and ridges)
- **Improved mapping of sea-ice drift** by flying in a close formation with Sentinel-1

REQUIREMENTS

- Revisit (1 day Arctic, 3 days Europe, 6 days Global)
- Low noise level (NESZ, ambiguities)
- High-resolution and wide swath
- Simultaneous acquisitions with Sentinel-1 for sea ice mapping





Sentinel-1 Extra Wide Swath and ALOS-2 PALSAR-2 Wide Beam images acquired at HH- and HV polarization over Fram Strait, on Dec. 9, 2019. The PALSAR-2 images were aligned to the Sentinel images. By courtesy of Johannes Lohse, UiT. From Dierking et al., 2022, IGARSS

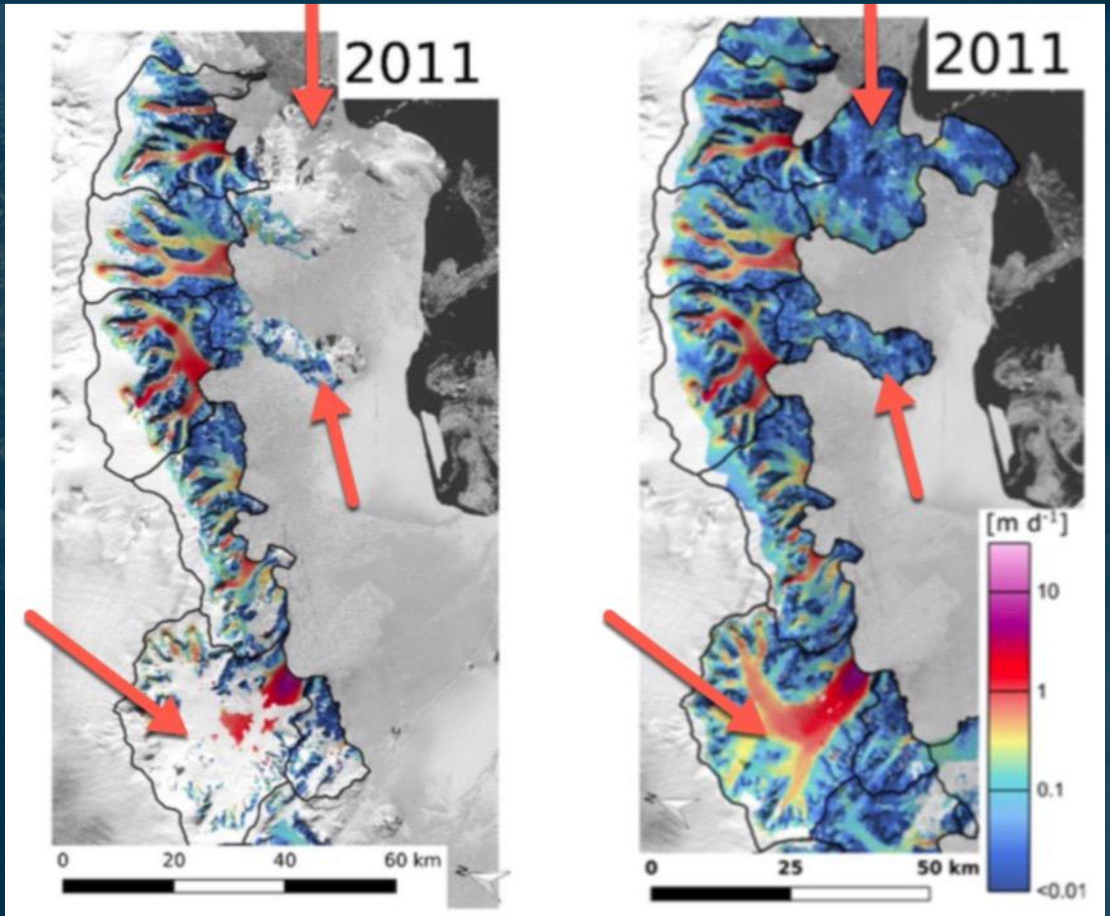
Land Ice and Seasonal Snow

- **Enhanced ice velocity retrieval (ice sheets and glaciers)** thanks to a deeper and more stable signal
- **New seasonal snow modeling capability** through retrieval of **Snow Water Equivalent (SWE)**, enabled by to penetration till the ground in dry snow

REQUIREMENTS

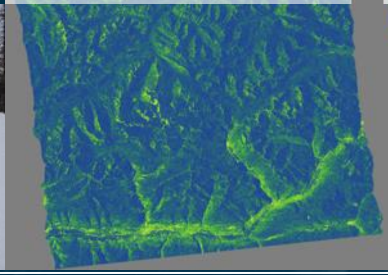
- 6 days repeat pass for ice velocity and SWE
- Low noise level (NESZ and ambiguities)
- High-resolution and wide swath
- Close acquisition to Sentinel-1 for wet snow detection

Maps of ice velocity on glaciers of Larsen-A embayment. Left: derived from TerraSAR-X repeat-pass SAR data by offset tracking. Right: Gaps in TerraSAR-X velocity map filled by means of PALSAR (L-band) velocity data. Note the areas indicated by the red arrows where L-band SAR has contributed and filled gaps with ice velocity information.

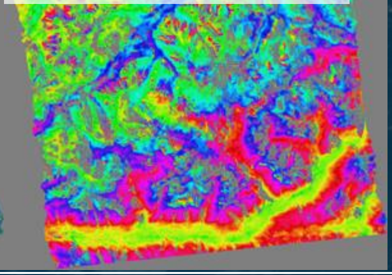


Ongoing assessment of SWE in Engadin (CH), Eastern Alps. By ENVEO

InSAR Frame 910 17/12/2019 – 31/12/2019
Coherence

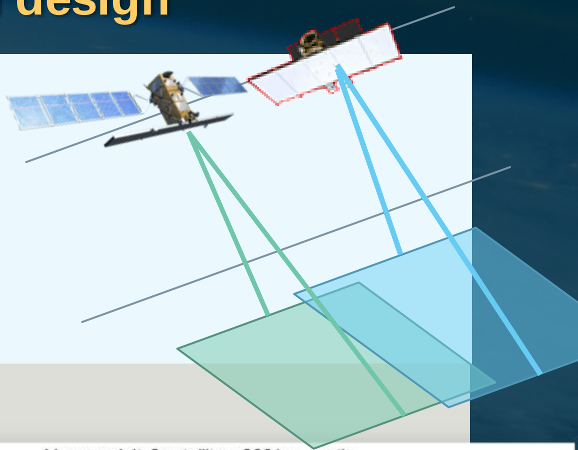


InSAR Frame 910 17/12/2019 – 31/12/2019
InSAR phase



ROSE-L Mission Design Highlights

ROSE-L will augment Sentinel-1 by means of a **synergic acquisition plan and mission design**

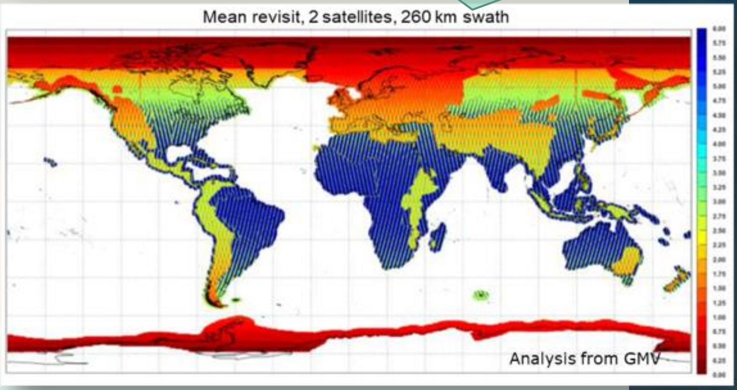


Collocation with Sentinel-1

- Same orbit configuration of Sentinel-1.
- Phasing of the orbital plane adjusted to follow the **same ground track of Sentinel-1**
- Mission design supports option for optimized revisit or convoy with Sentinel-1 (within 1min)

Extensive Global coverage and consistent long-term archive

- Coverage of Global land (except for South pole). **~ 38 min/orbit duty cycle**
- Consistent acquisitions through years for **long-term coherent data stacks**



Performant Imaging

- Low NESZ (-28 dB)
- Dual-pol and Quad-pol capabilities

Free, full and open data policy

Moving towards a **System of Systems concept** and enhanced information products

ROSE-L SAR Imaging and Systematic Acquisitions

SAR Instrument provides ***three (3) SAR modes*** with different resolution and coverage

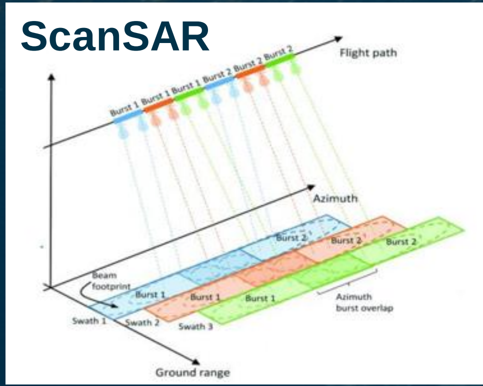
SAR Mode Overview – Key Parameters			
	Dual-pol (nominal)	**Quad-pol**	**Wave mode (single pol)**
Access	25^{0} – 46^{0}	1 fixed swath within 25^{0} – 46^{0} e.g. 25^{0} – 42.3^{0}	variabel
Swath/ coverage	260 km	260 km	20 km x 20 km (separation of center 100 km)
Resolution (single look)	50 m²	100 m²	50 m²
DTAR	< -23 dB	< -23 dB	< -23 dB
PTAR	< -25 dB	< -25 dB	< -25 dB
NESZ	< -28 dB	< -28 dB	< -28 dB

ROSE-L satellite sizing:

a) "Always on" over ***Europe***, ***Arctic***, ***coastal Antarctica*** and ***global Tectonic areas*** in dual or quad-pol SAR mode

b) Full coverage of ***remaining landmass*** (not included in a)) within *12-day* revisit time , i.e. *6-day* revisit time for entire *constellation* in dual or quad-pol SAR mode

c) Wave mode over ***Open Ocean***

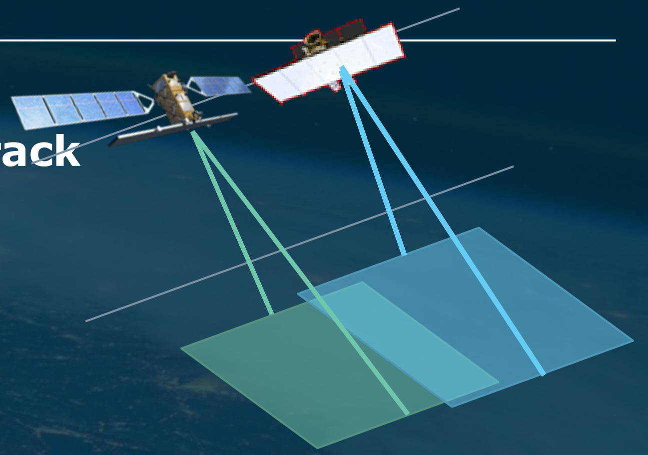


ROSE-L *continuous operations* capability per sliding orbit time window:

- 35 min in ***dual- pol SAR mode*** or
- 20 min in ***quad-pol SAR mode***, and
- for the remaining time in ***Wave Mode***

Colocation of ROSE-L and Sentinel-1 Acquisitions

- **ROSE-L is flying in the orbit configuration (orbital hight) of Sentinel-1**
- Phasing of the orbital plane will be adjusted to allow ROSE-L to follow the **ground track of Sentinel-1**
- Same acquisition geometry as Sentinel-1 (IW) will provide an **operational dual-frequency system of satellites** and **enhanced information products**



ROSE-L Dual-Pol (RIWS):
ScanSAR
Swath width = 260 km
- Incident Angle range: $\eta_{Near} = 25°$, $\eta_{Far} = 46°$
- Single look resolution: $\delta_{Range} = 5\ m$, $\delta_{Azimuth} = 10\ m$

Near Swath (1-3)
- Incident angles: $\eta_{Near} = 25°$, $\eta_{Far} = 42.25°$

Far Swath (2-4)
- Incident angles: $\eta_{Near} = 31.33°$, $\eta_{Far} = 46.77°$

S-1 Interferometric Wide Swath (IW):
Dual Pol TOPS Mode
Swath width = 250 km
- Single look resolution: $\delta_{Range} = 5\ m$, $\delta_{Azimuth} = 20\ m$
- Incident angles: $\eta_{Near} = 30.8°$ (29 °), $\eta_{Far} = 46°$
- Operation include roll steering maneuver to reduce electrical beam steering
- Constant PRF for each sub-swath around orbit

=> Selection of same incidence angle range enables matching of ROSE-L and Sentinel-1 ground-tracks while providing flexibility for choice of time lapse (e.g. 1min, 10min etc)

Moving to RTC

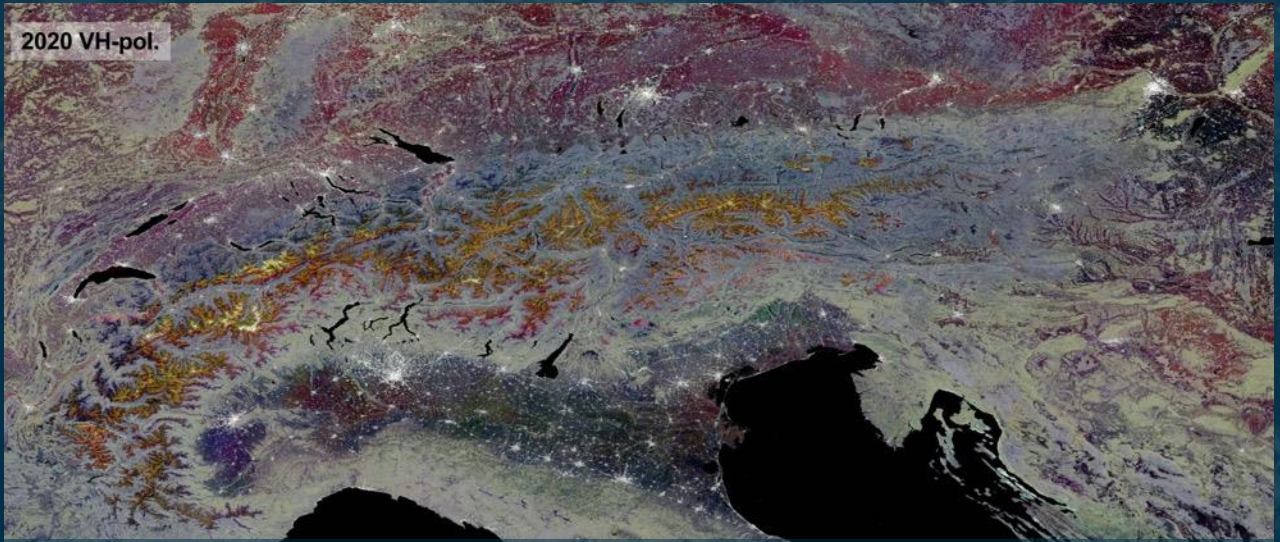
In order to broaden user community on the use of dense time-series

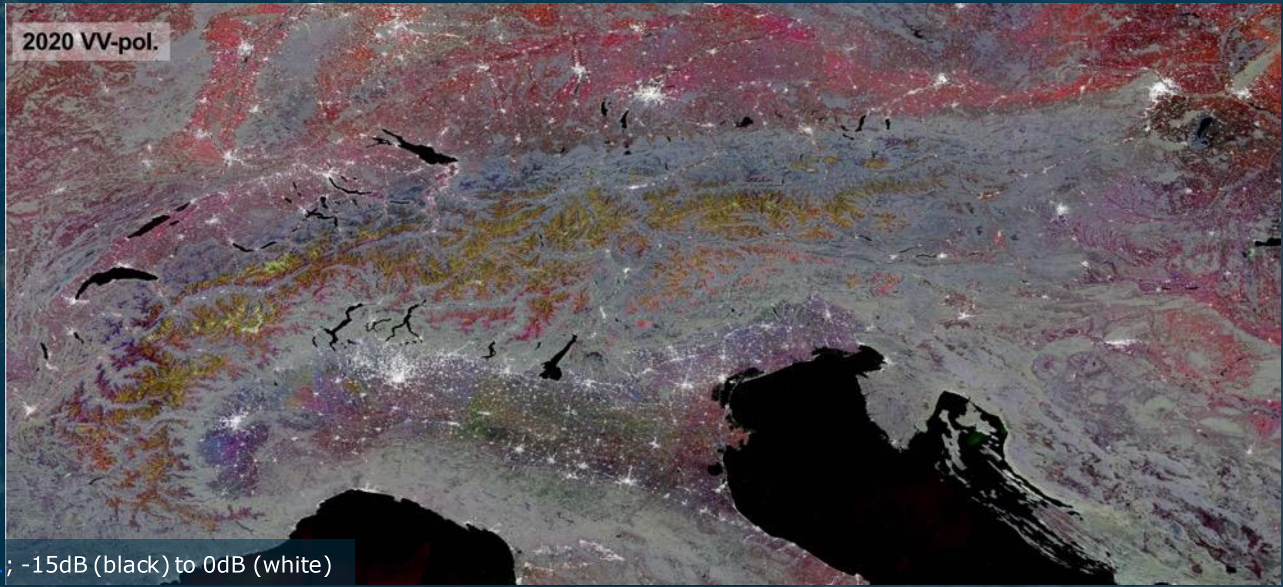
- Provide data products that do not require expert knowledge
- Move from radar geometry (slant & ground range) to map coordinates

GRD product likely to be replaced in the HPCM / Next Gen mission processors by ARD data, including for instance the RTC product (Radiometric Terrain Correction).

RTC: Product family specification of Normalized Radar Backscatter (NRB) is formulated by the CEOS-ARD initiative (https://ceos.org/ard/)

- Backscatter normalized using local scattering area, not incident angle
- Facilitates multi-sensor data integration





From David Small (UZH). Sentinel-1 IW Backscatter Composites 2020: Feb 6-17, Mar 31-Apr 11, Apr 30-May 11; -15dB (black) to 0dB (white)

ROSE-L status

ESA with industry and together with EC preparing "expansion" of Copernicus SAR missions

- ROSE-L Mission at L-band as a Copernicus Expansion mission *to address information gaps* and provide new information not yet available through current Sentinel missions

ROSE-L bring new and enhanced capabilities

- High resolution ($50m^2$ for ROSE-L)
- Low NESZ e.g. -28 dB for ROSE-L
- Wide swath and frequent revisit capability

Sentinel-1, ROSE-L and Sentinel-1 NG are addressed as a system (not in isolation)

- ROSE-L same orbit, swath and acquisition geometry as Sentinel-1 (IWS) providing an operational dual-frequency system
- Synergies between C- and L-band expected to lead to enhanced and new information beyond what can be achieved for each mission taken in isolation
- Synergies with other missions such as Earth Explorer Biomass @P-band also need to be further investigated

Work still required to prepare for uptake of ROSE-L by user community (e.g. ionospheric correction, interferometric error budgets, C- and L-band synergies)

… on the current S1 mission

- **Sentinel-1 Quality Working Group** restarting soon!

- Next meeting will be planned after the summer break at ESRIN (September, TBC) with focus on L2 users

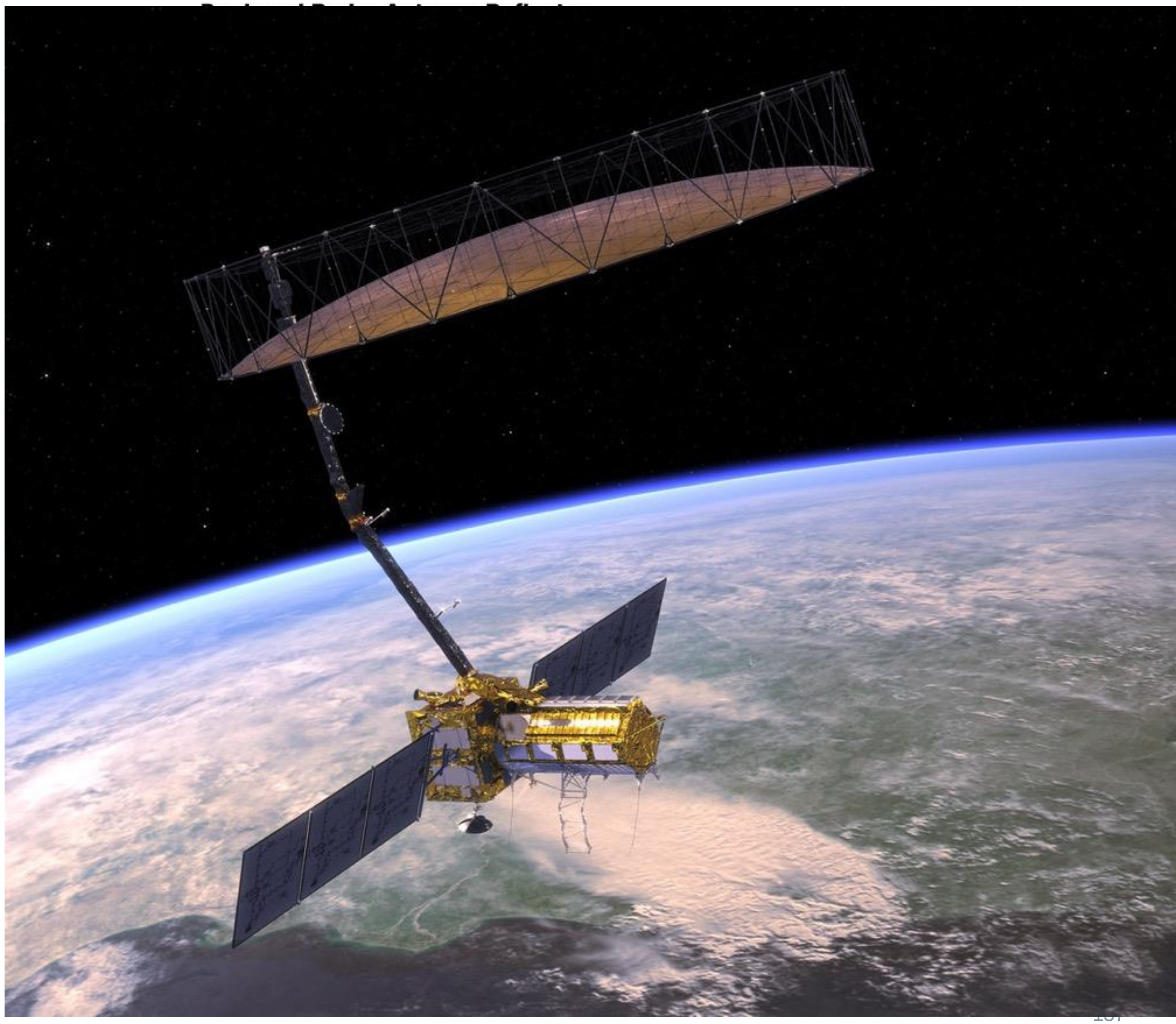
- The goal is to receive further user feedback on S1 L1 and L2 products (quality, content, format, dissemination, etc.), and to discuss needs regarding products and algorithms

- This QWG should also give us a forum to start discussions on L2 ROSE-L products to be possibly generated by ESA

- **You are kindly invited to participate!** More information will be made available soon and you can also contact Muriel.Pinheiro@esa.int if you would like to join

The NASA-ISRO SAR (NISAR) Mission will measure Earth's changing ecosystems, dynamic surfaces, and ice masses providing information about biomass, natural hazards, sea level rise, and groundwater, and will support a host of other applications.

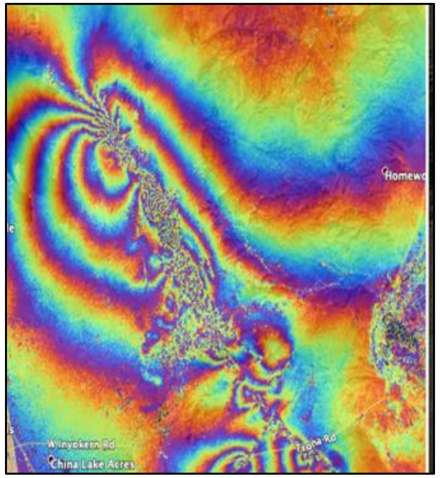
The NISAR spacecraft will accommodate two fully capable synthetic aperture radar instruments (24 cm wavelength L-SAR and 10 cm wavelength S-SAR), each designed as array-fed reflectors to work as SweepSAR scan-on-receive wide swath mapping systems. The spacecraft will launch on an ISRO GSLV-II launch vehicle into a polar sun-synchronous dawn dusk orbit.



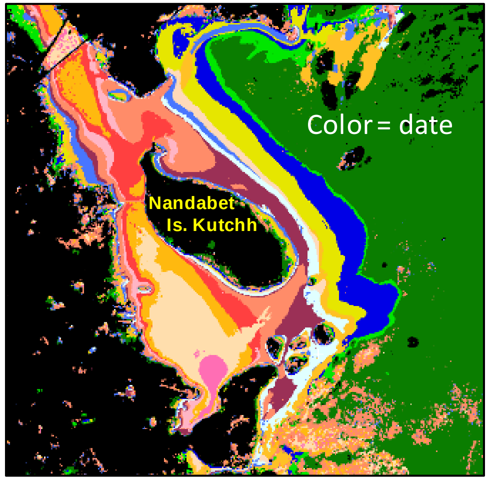
NISAR – NASA ISRO SAR Mission

- **Collaboration of NASA and the Indian Space Research Organization (ISRO)**
- **Launch in Jan. 2024**
- **Two radars**
  - L-band (24 cm) global land + sea ice – higher coherence than C-band
  - S-band (10 cm) India's AOIs
- **12 day orbit repeat interval**
- **Product delivered in ~24 hours**
  - 5 hours for disaster response
- **Data is free and open to all**
  - Hosted at the Alaska Satellite Facility

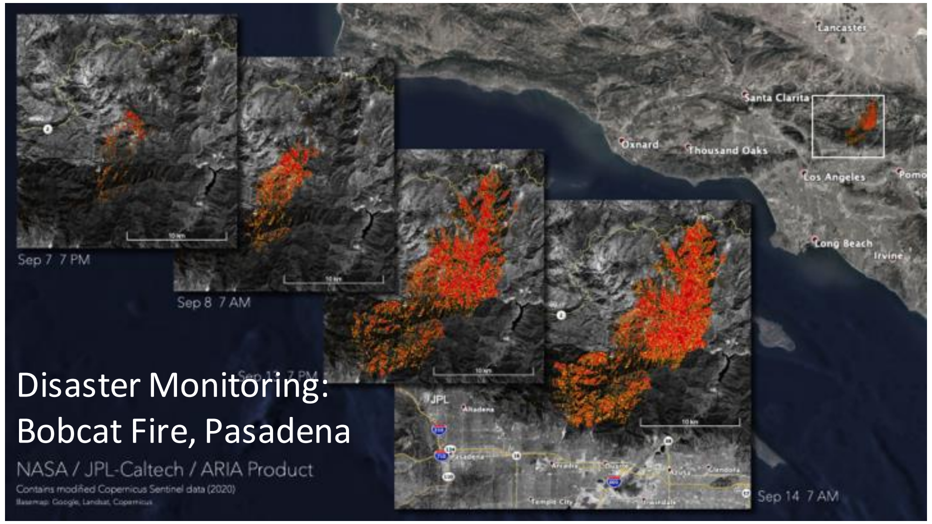
Flight Configuration of NISAR



Earthquake Dynamics, Ridgecrest



Wetland Inundation, India



Disaster Monitoring: Bobcat Fire, Pasadena

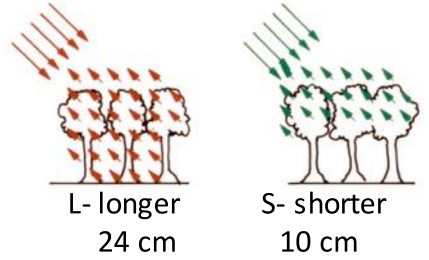
Hazard Response

- **Dynamics of Ice: Ice sheets, Glaciers, and Sea Level**
  - *Will there be catastrophic collapse of the major ice sheets, including Greenland and West Antarctic and, if so, how rapidly will this occur?*
  - *What will be the resulting time patterns of sea-level rise?*
  - *How are alpine glaciers changing in relation to climate?*
- **Ecosystems and Biomass Change**
  - *How do changing climate and land use in forests, wetlands, and agricultural regions affect the carbon cycle and species habitats?*
  - *What are the effects of disturbance on ecosystem functions and services?*
- **Solid Earth Deformation**
  - *Which major fault systems are nearing release of stress via strong earthquakes?*
  - *Can we predict future eruptions of volcanoes?*
  - *What are optimal remote sensing strategies to mitigate disasters and monitor/manage water and hydrocarbon extraction and use?*
  - *Where is subsidence occurring, by how much, and due to what processes?*
- **Coastal Processes**
  - *What is the state of important mangroves?*
  - *How are Indian coastlines changing?*
  - *What is the shallow bathymetry around India?*
  - *What is the variation of winds in India's coastal waters?*

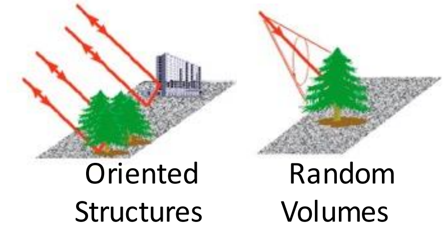
NISAR instrument Characteristics

NISAR Characteristic:	Enables:
L-band (24 cm wavelength)	*Low temporal decorrelation and foliage penetration*
S-band (9 cm wavelength)	*Sensitivity to lighter vegetation*
SweepSAR technique with ***Imaging Swath > 240 km***	*Global data collection*
*Polarimetry (Single/****Dual****/Quad)*	*Surface characterization and biomass estimation*
12-day exact repeat	*Rapid Sampling/time series*
3 – 10 meters mode-dependent SAR resolution	*Small-scale observations*
Pointing control < 273 arcseconds	*Deformation interferometry*
Orbit control < 500 meters	*Deformation interferometry*
L*/S-band >* ***50****/10% observation duty cycle*	*Complete land/ice coverage*
Left-Looking	*Uninterrupted time series; More Antarctic coverage*

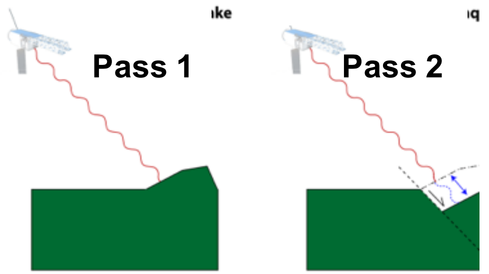
L- and S-band Wavelength



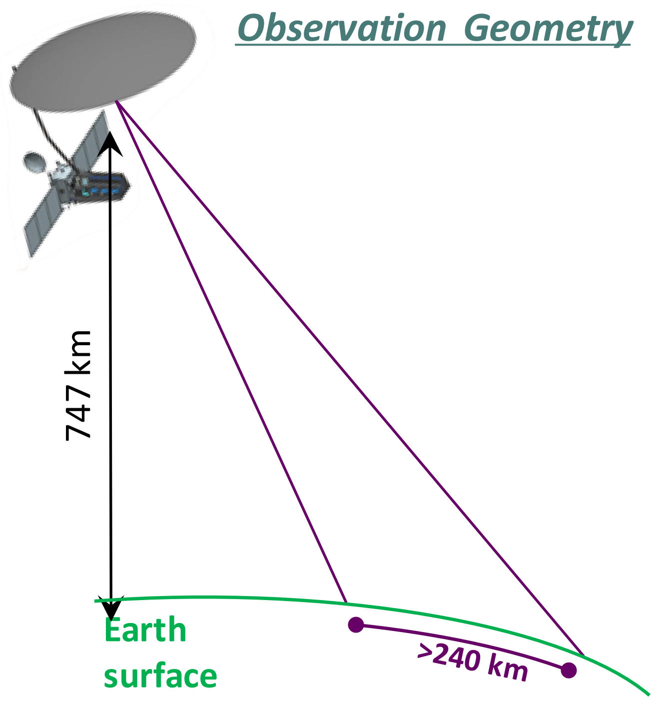
Polarimetry



Repeat Pass InSAR

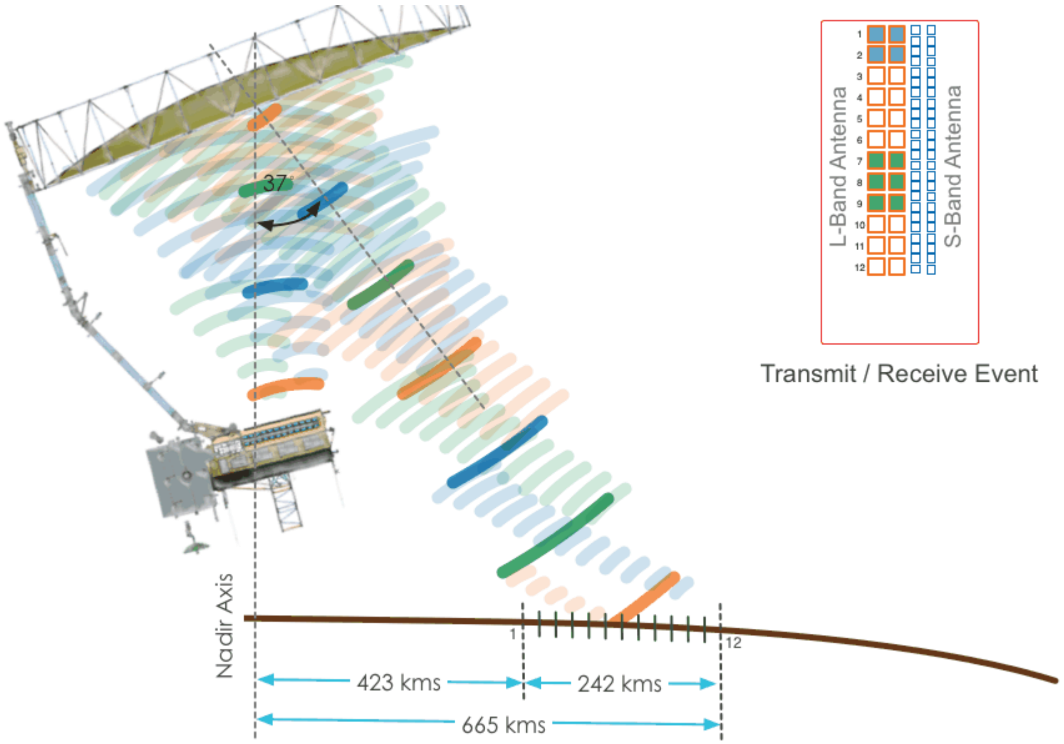


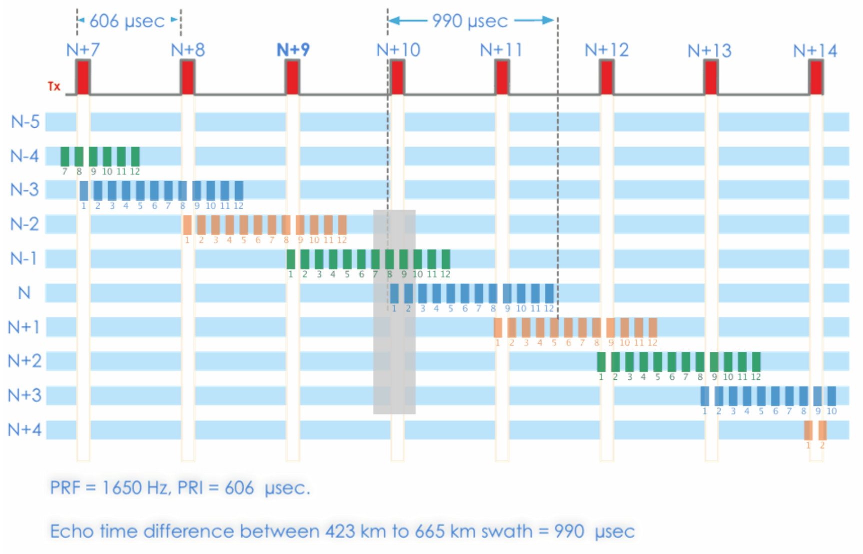
6 AM / 6 PM Orbit
98.5° inclination
Arctic Polar Hole: 77.5 Lat
Antarctic Polar Hole: -87.5 Lat



Measurement Technique
SweepSAR

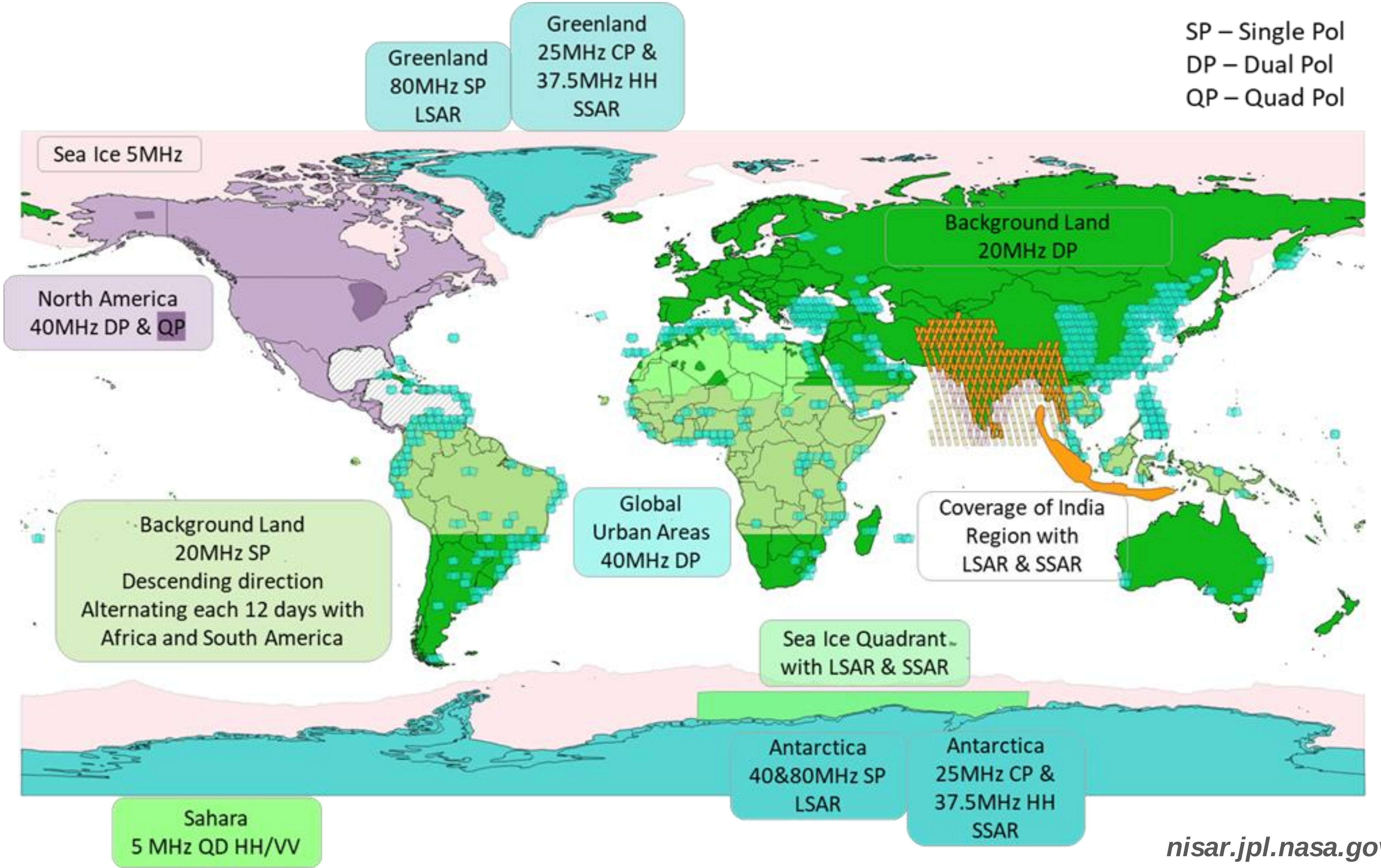
- **SweepSAR**
  - On Transmit, illuminate the entire swath of interest
  - On Receive, steer the beam in fast time to follow the angle of the echo coming back to maximize the SNR of the signal and reject range ambiguities
  - Allows echo to span more than 1 Inter-Pulse Period (IPP)
- **Consequences**
  - 4 echoes can be simultaneously returning to the radar from 4 different angles in 4 different groups of antenna beams
  - Each echo needs to be sampled, filtered, beam-formed, further filtered, and compressed
  - On-board processing is not reversible – Requires on-board calibration before data is combined to achieve optimum performance





Current Observation Plan

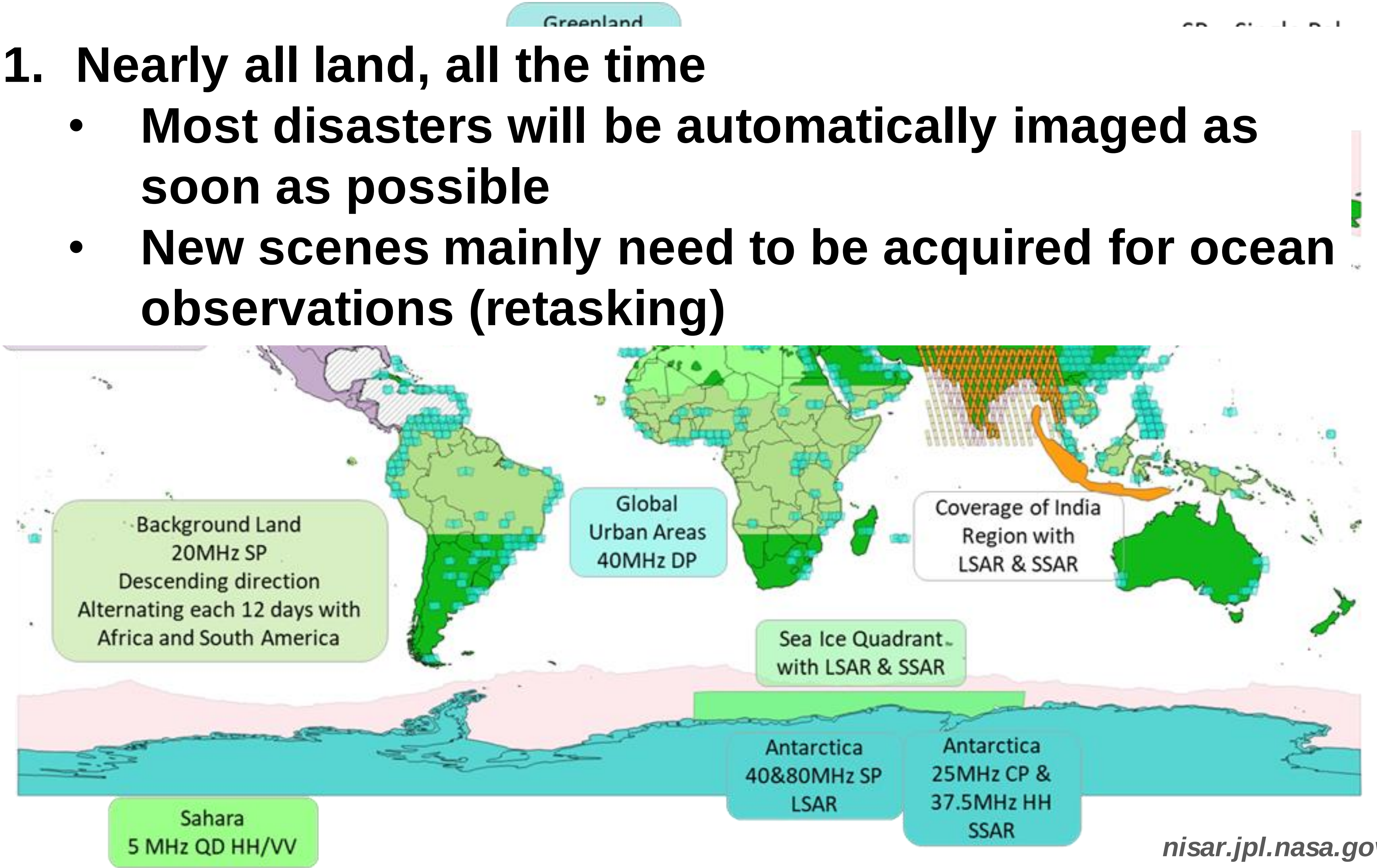
SP – Single Pol
DP – Dual Pol
QP – Quad Pol



nisar.jpl.nasa.gov

Current Observation Plan

1. Nearly all land, all the time
   - Most disasters will be automatically imaged as soon as possible
   - New scenes mainly need to be acquired for ocean observations (retasking)



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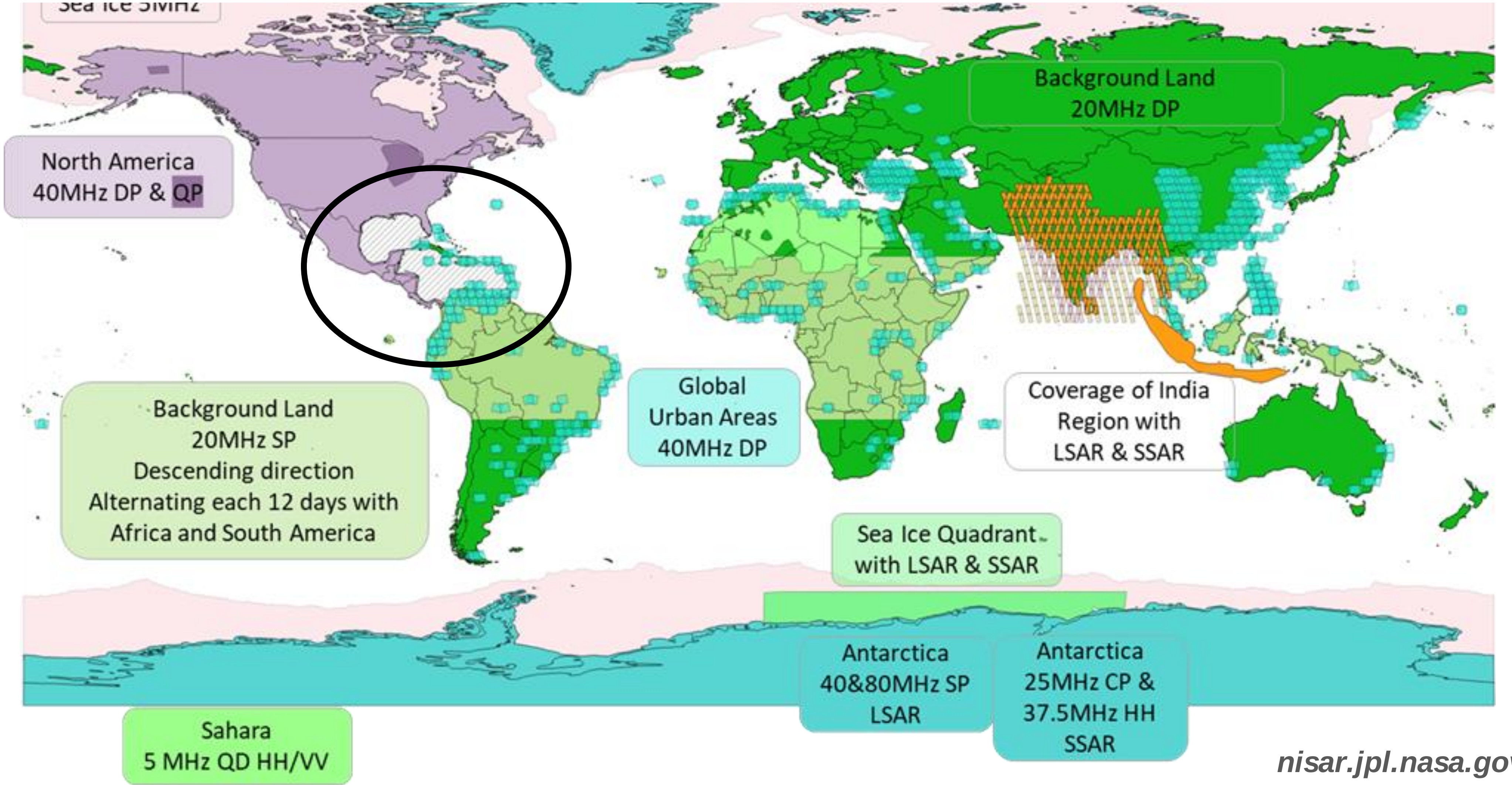
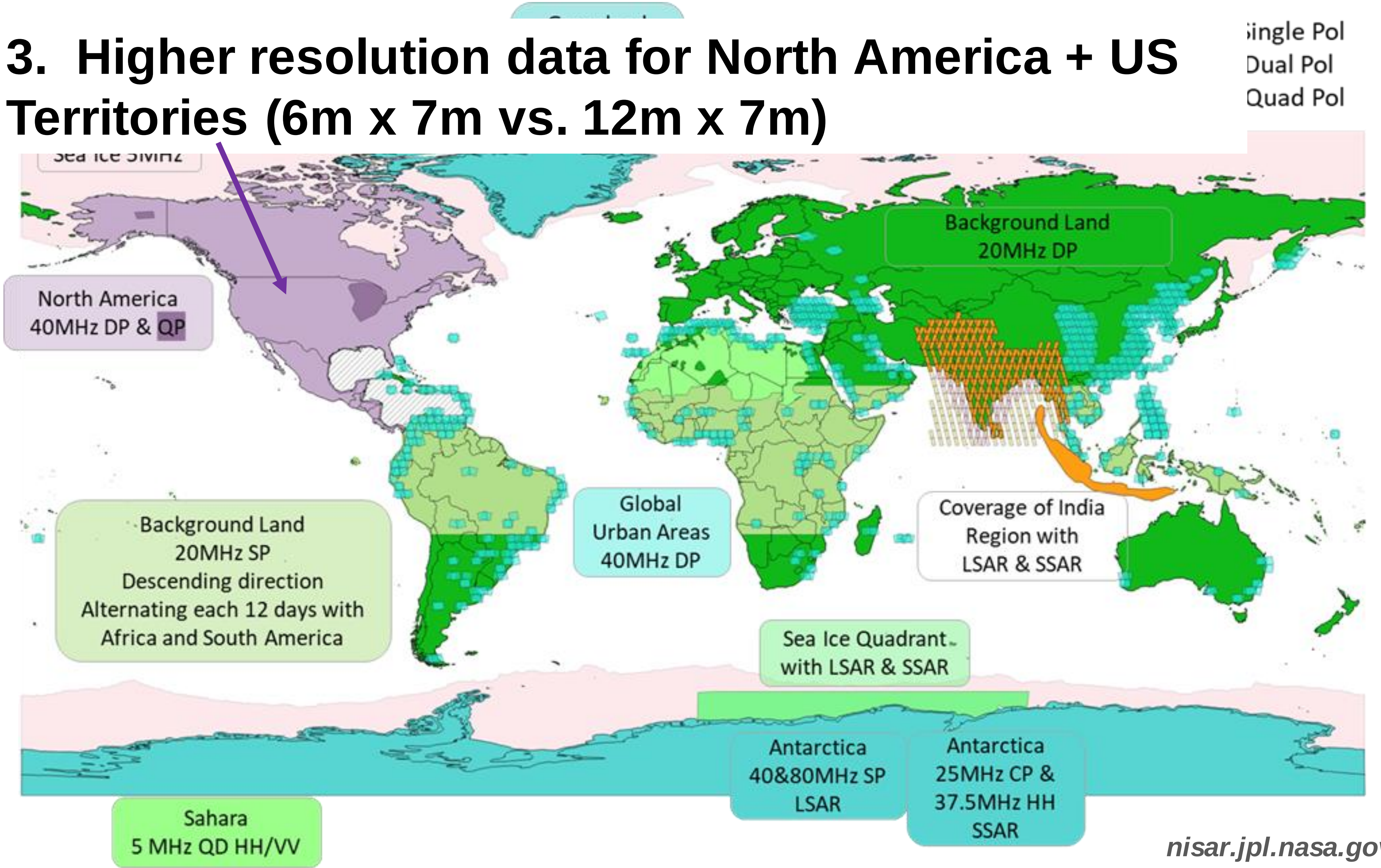
Current Observation Plan

2. Added Gulf of Mexico & Caribbean Sea to Standard Plan



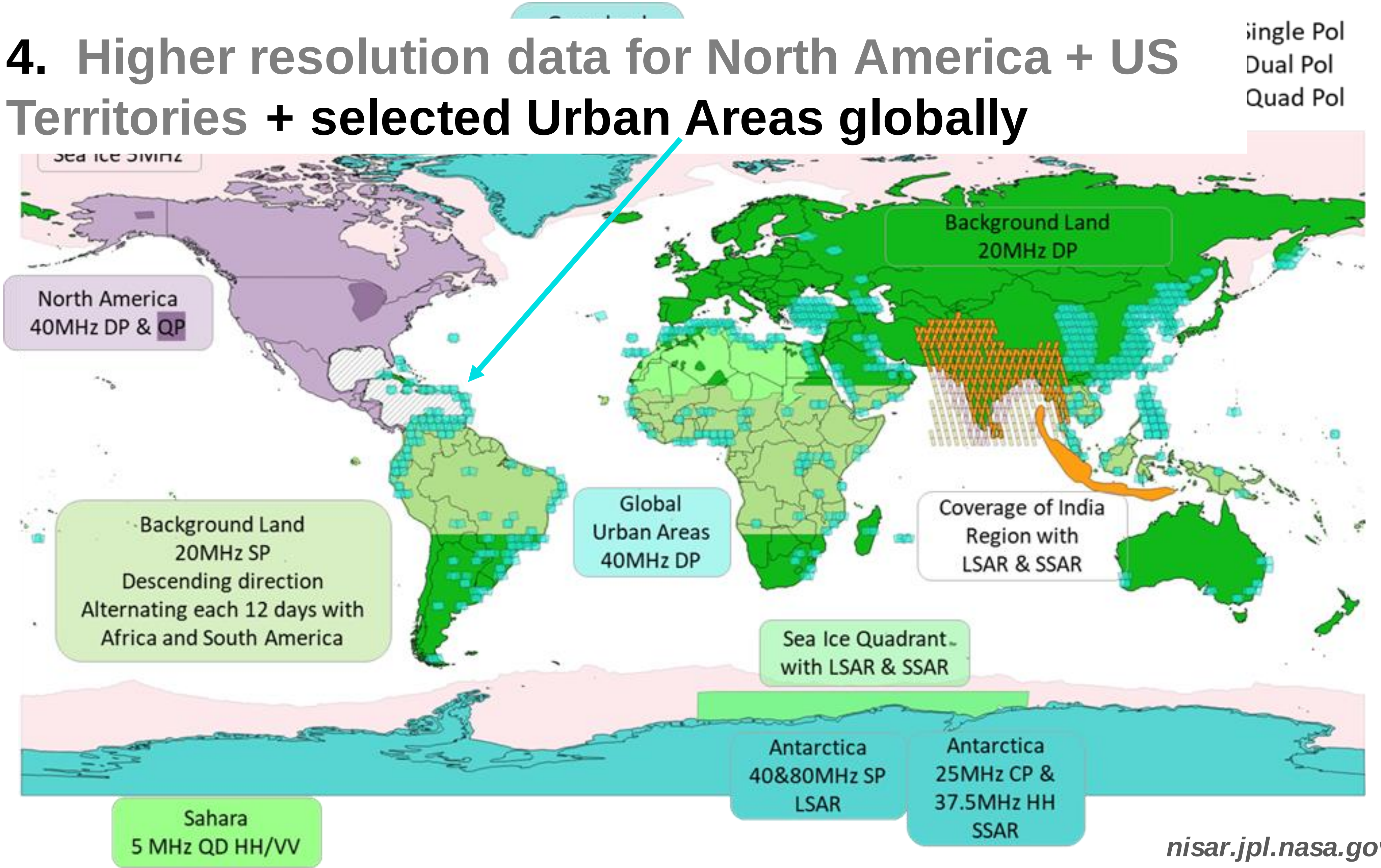
Current Observation Plan

3. Higher resolution data for North America + US Territories (6m x 7m vs. 12m x 7m)



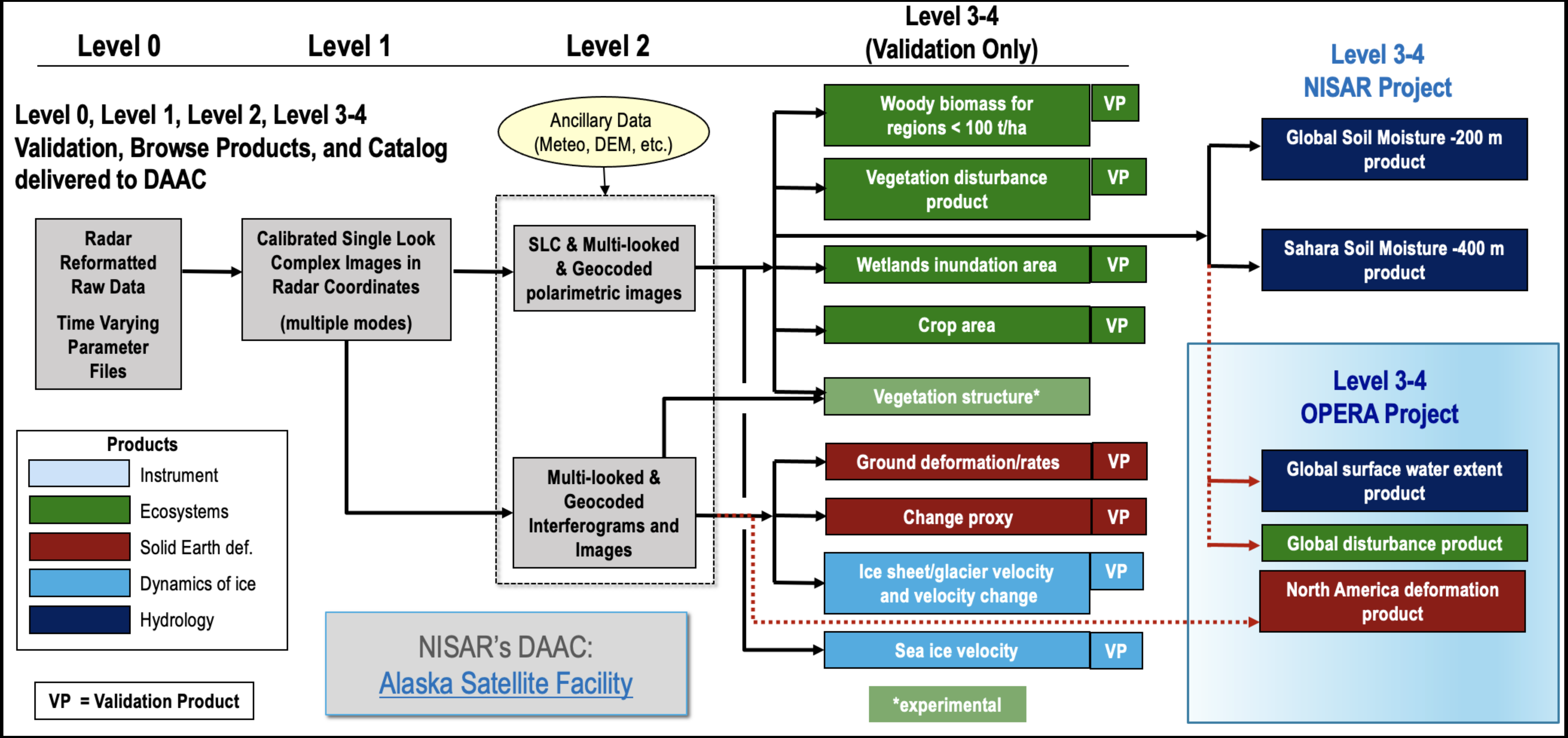
Current Observation Plan

4. Higher resolution data for North America + US Territories + selected Urban Areas globally



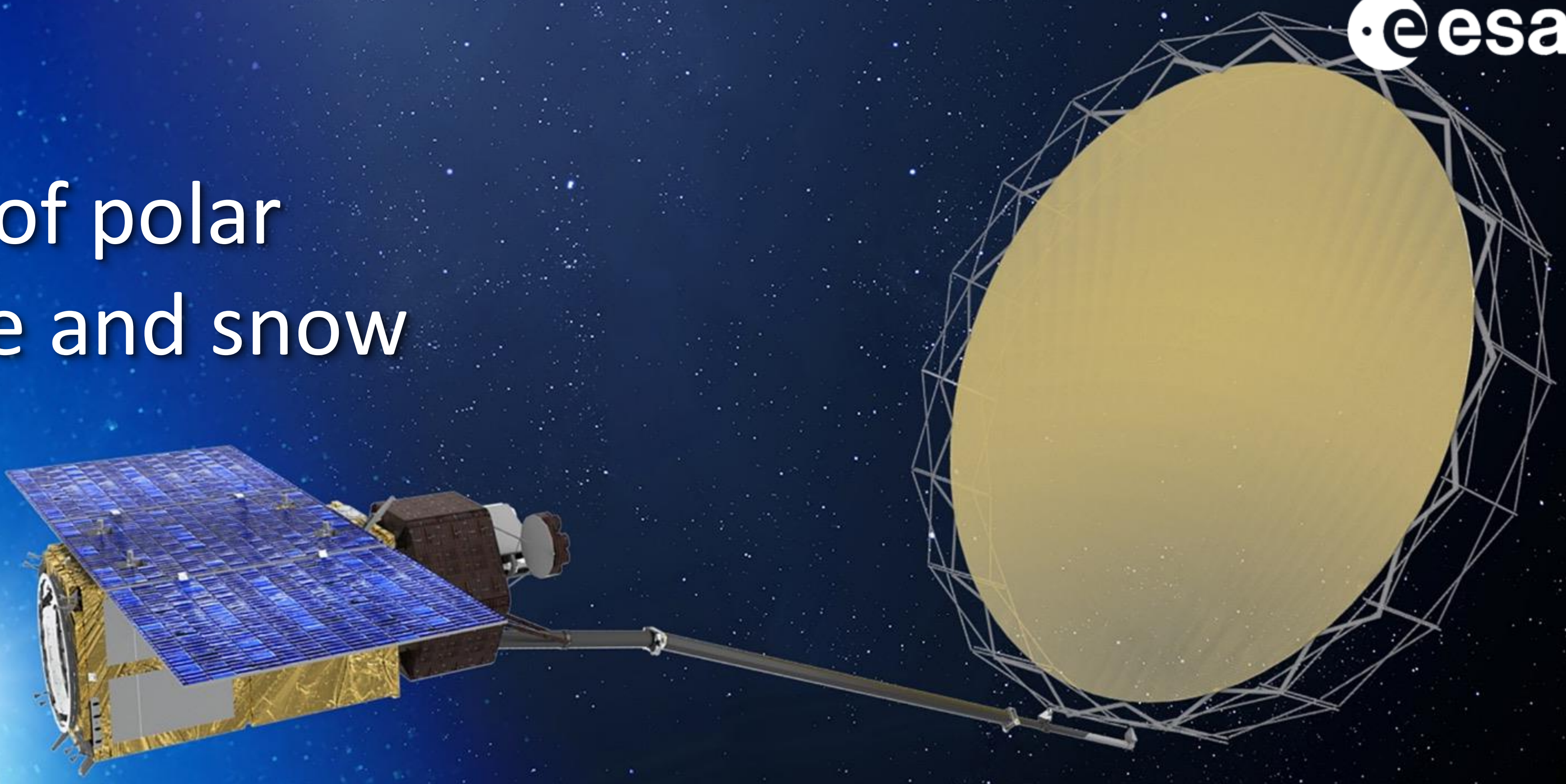
nisar.jpl.nasa.gov

L-band L0 - L3/L4 Products



CIMR

Daily imaging of polar oceans, sea ice and snow

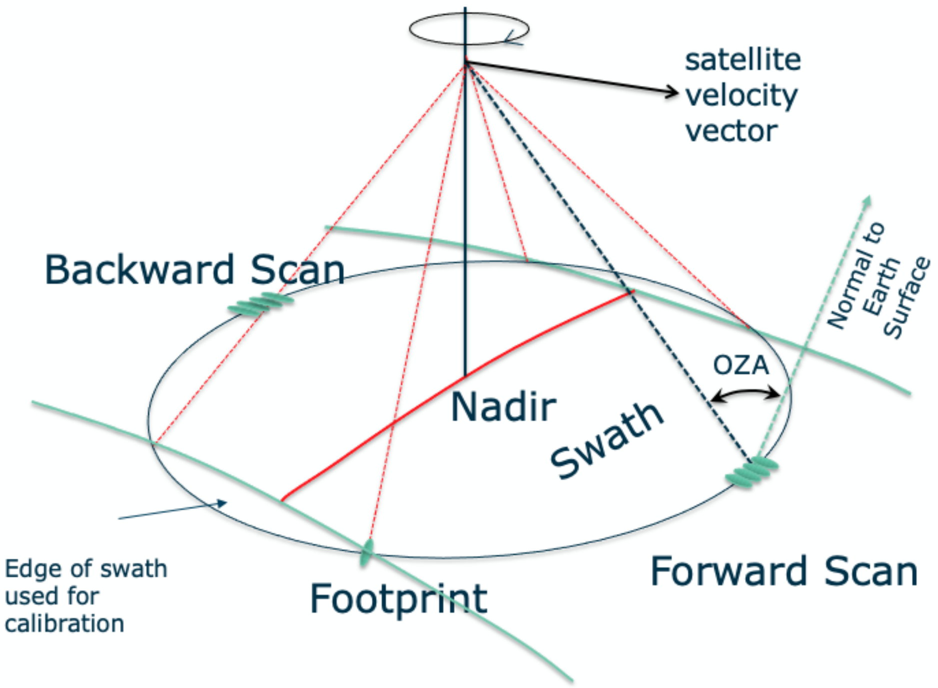


Understanding the polar oceans and their impact on our changing climate

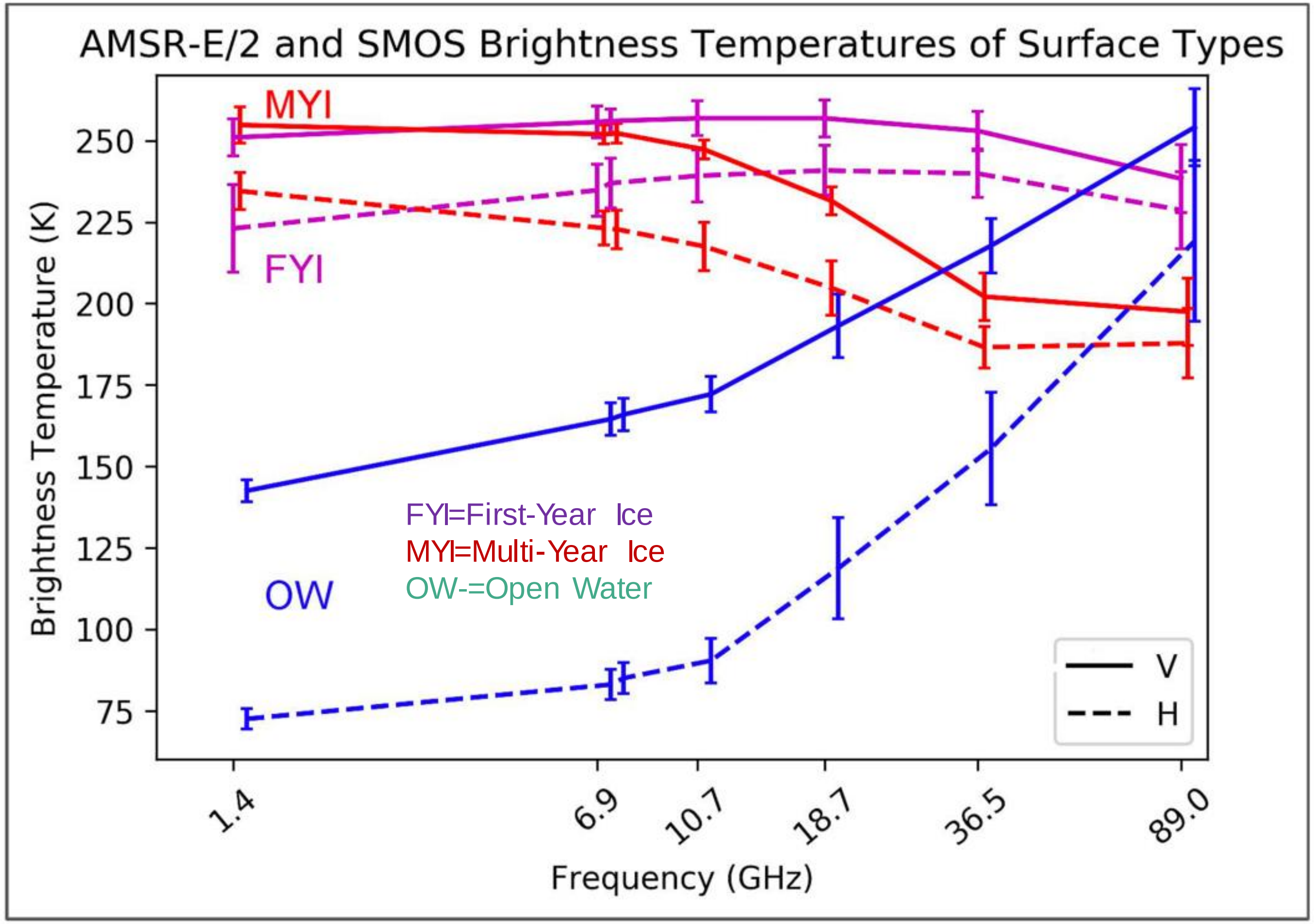
Expected launch A 2029 / B 2036

→ THE EUROPEAN SPACE AGENCY

CIMR conically Scanning, L-, C/X, K/Ka-bands (H,V, 3rd Stokes)



Donlon, Craig; Vanin, Felice (2019): Scanning Geometry of the CIMR instrument. Figshare https://doi.org/10.6084/m9.figshare.7749398.v1



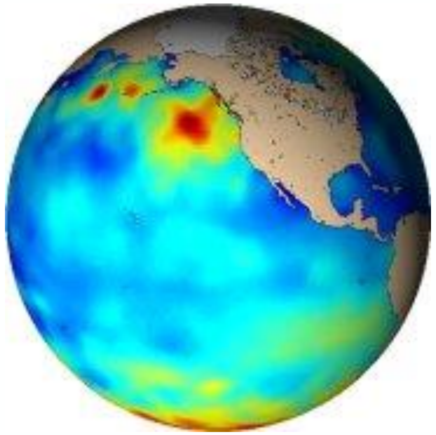
Lu, J. and Heygster, G.: AMSR-E/2 and SMOS Brightness Temperatures of Surface Types, , doi:10.6084/m9.figshare.7370261.v2, 2018.

Sentinel-3 Next Generation Topography Mission (S3NG-T)

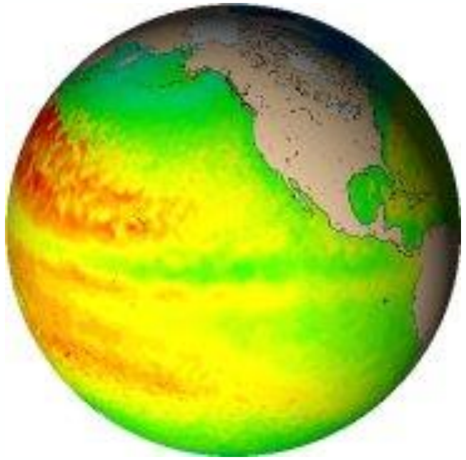
A.Egido

Global ocean Altimetry from S3 up to 81.5N&S

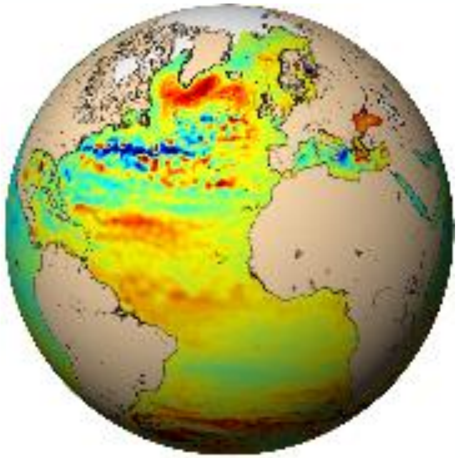
Wind and Waves

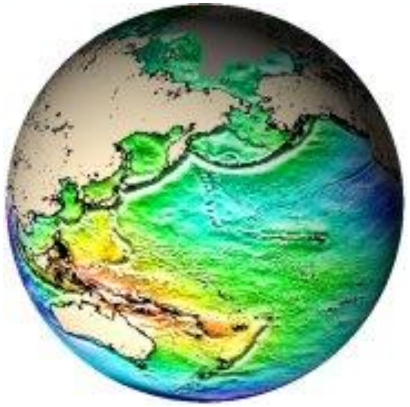


Sea Surface Height

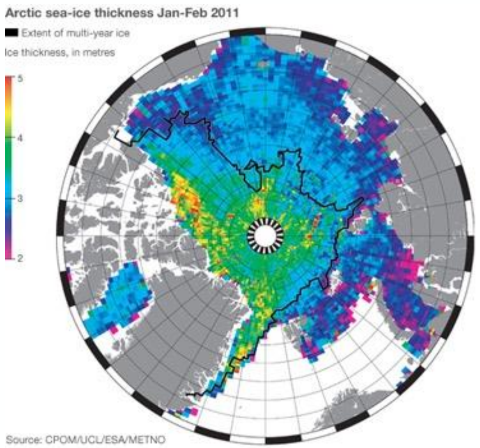


Sea level rise

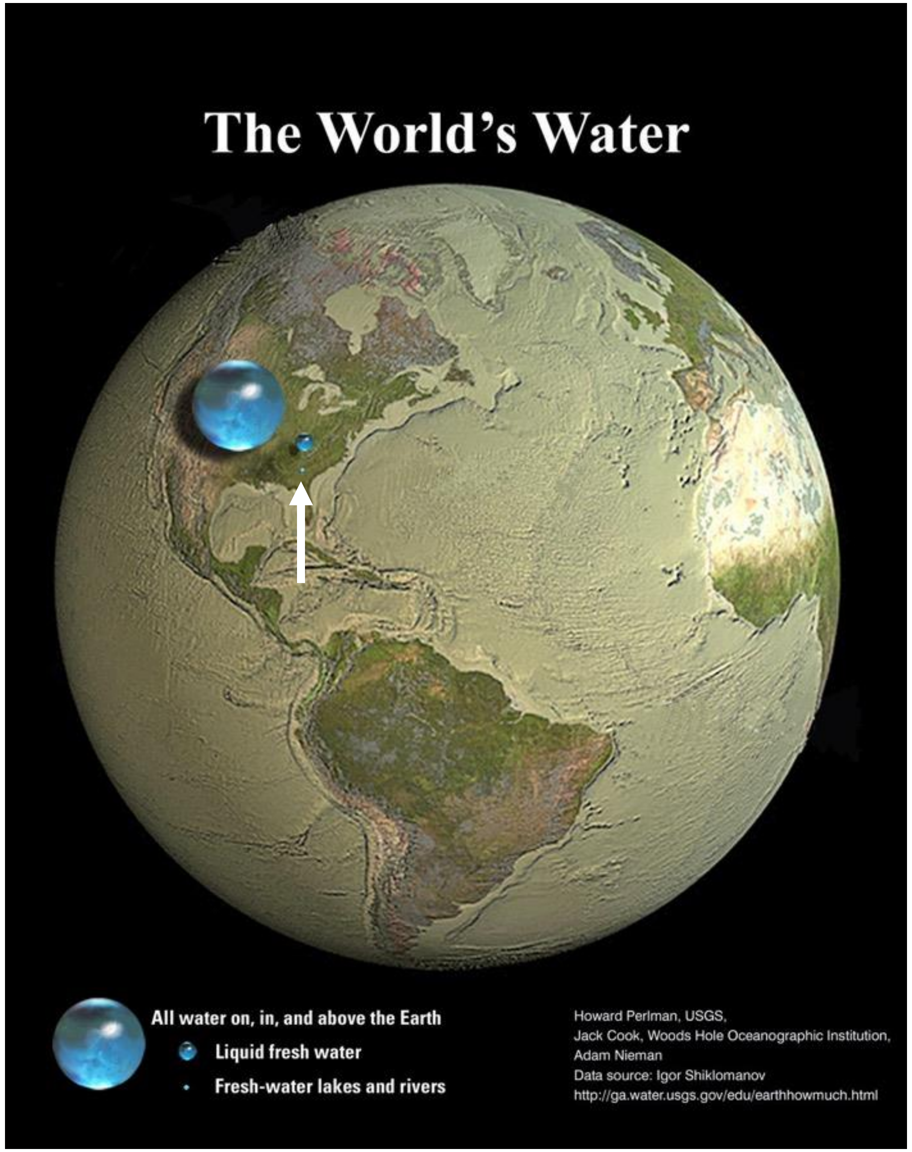




DEM, Tides, Hydrology, MSS …



Sea ice and Ice sheets



Copernicus User Needs

- **User Needs are sourced from Official European Commission Documents**
  - Wide ranging needs that, at high time and space resolution, cannot always be met
- Nevertheless, we can see strong and clear User Needs **for Topography** (**i.e. SSH, Hs, winds, River and lakes, sea level,** continuity of the altimeter reference mission, 2D-wave spectra, Ice sheet elevation and dynamics, sea ice thickness, Surface ocean currents (TSCV for marine plastic debris etc)…)
- **ESA Analysis of User Needs provided by the European Commission provides the justification and traceability for a S3NG-T mission**

S3NG-T Mission Aim and Objectives

- Mission aim and Objectives stem from the analysis of User needs and LTS
- Target is to **guarantee the continuity of S3 today**
  - For **ALL** topography variables SSH, Hs, U10, Sigma0, sea ice, land ice, river and lakes…
- **Then, to enhance S3** and address:
  - **Sampling and coverage → time AND space sampling (#1 User Need – for everyone working with altimetry)**
  - **Hydrology** sampling and performance (now primary Objective by EC request)
  - Provide **new products** to meet evolving Copernicus User Needs.

ESA UNCLASSIFIED – For ESA Official Use Only

4 S3NG-T MISSION AIMS AND OBJECTIVES

4.1 S3NG-T Mission Aim

Considering the User needs expressed by the European Commission and concisely articulated in the previous sections, the **aim** of the Copernicus Next Generation Sentinel-3 Topography (S3NG-T) Mission is:

> ***To ensure continuity of Sentinel-3 in flight performance topography capability in the 2030-2050 timeframe.***

4.2 S3NG-T Objectives

Mission requirements are then derived from mission Objectives.

The primary objectives of the S3NG-T mission are to:

PRI-OBJ-1. **Guarantee continuity of Sentinel-3 topography measurements** for the 2030-2050 time frame **with performance at least equivalent to Sentinel-3 in-flight performance** as defined in Table 2.4-1 ('baseline mission').

PRI-OBJ-2. Respond to evolving user requirements and **improve sampling, coverage and revisit** of the Copernicus Next Generation Topography Constellation (S3NG-T and Sentinel-6NG) to ≤50 km and ≤5 days (CMEMS, 2017) in support of Copernicus User Needs.

PRI-OBJ-3. **Enhance sampling coverage, revisit and performance for Hydrology Water Surface Elevation** measurements in support of Copernicus Services.

PRI-OBJ-4. Respond to evolving user requirements and **enhance topography Level-2 product measurement performance**.

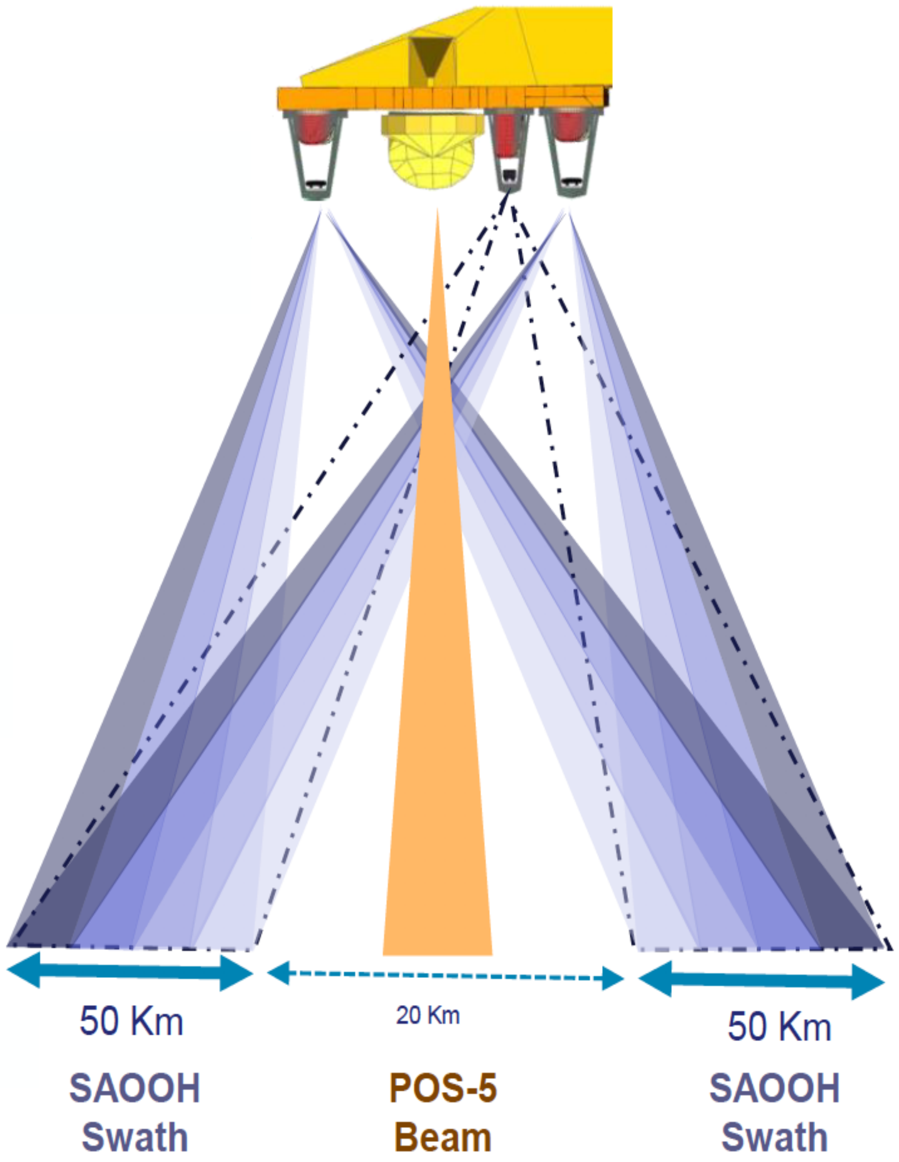
The **secondary objectives**[9] of the S3NG-T mission are to:

SEC-OBJ-1. Provide directional wave spectrum products that address evolving Copernicus user needs.

SEC-OBJ-2. Provide new products[10] that address evolving Copernicus user needs.

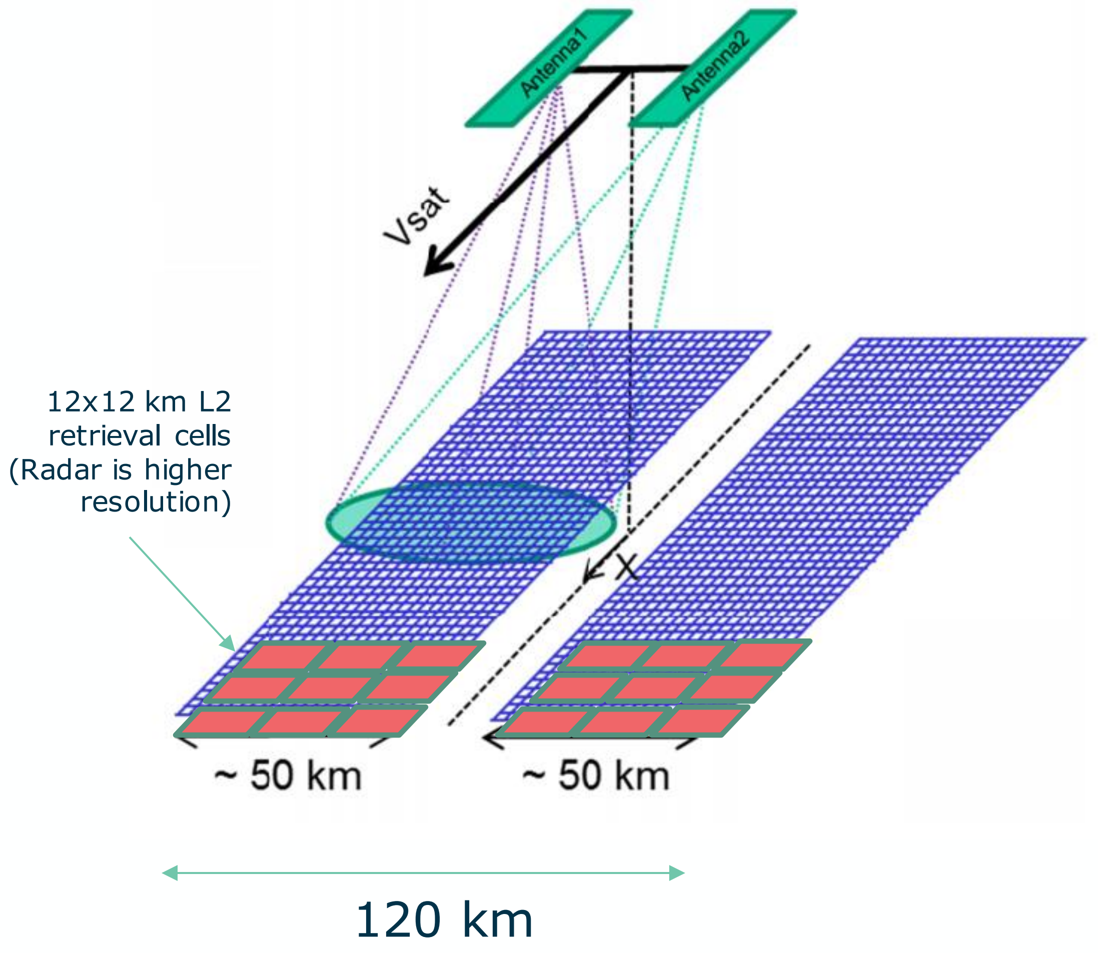
Sentinel-3 NG-TOPO

- Based on the PCR outcome (July 2022) and programmatic assessment, it is envisaged to continue the Phase A/B1 studies to implement the Sentinel-3 NG-TOPO mission as:
  - two dedicated large-satellites carrying Wide-Swath and Nadir altimeters, together with radiometer and POD instruments.



S3NG-T ESA Phase A/B1: baseline focus on radar interferometry

Constellation of 2 **European swath altimeter satellites**



Sentinel-3 baseline continuity performance/coverage/revisit (ocean, ice, inland water) from Nadir altimetry

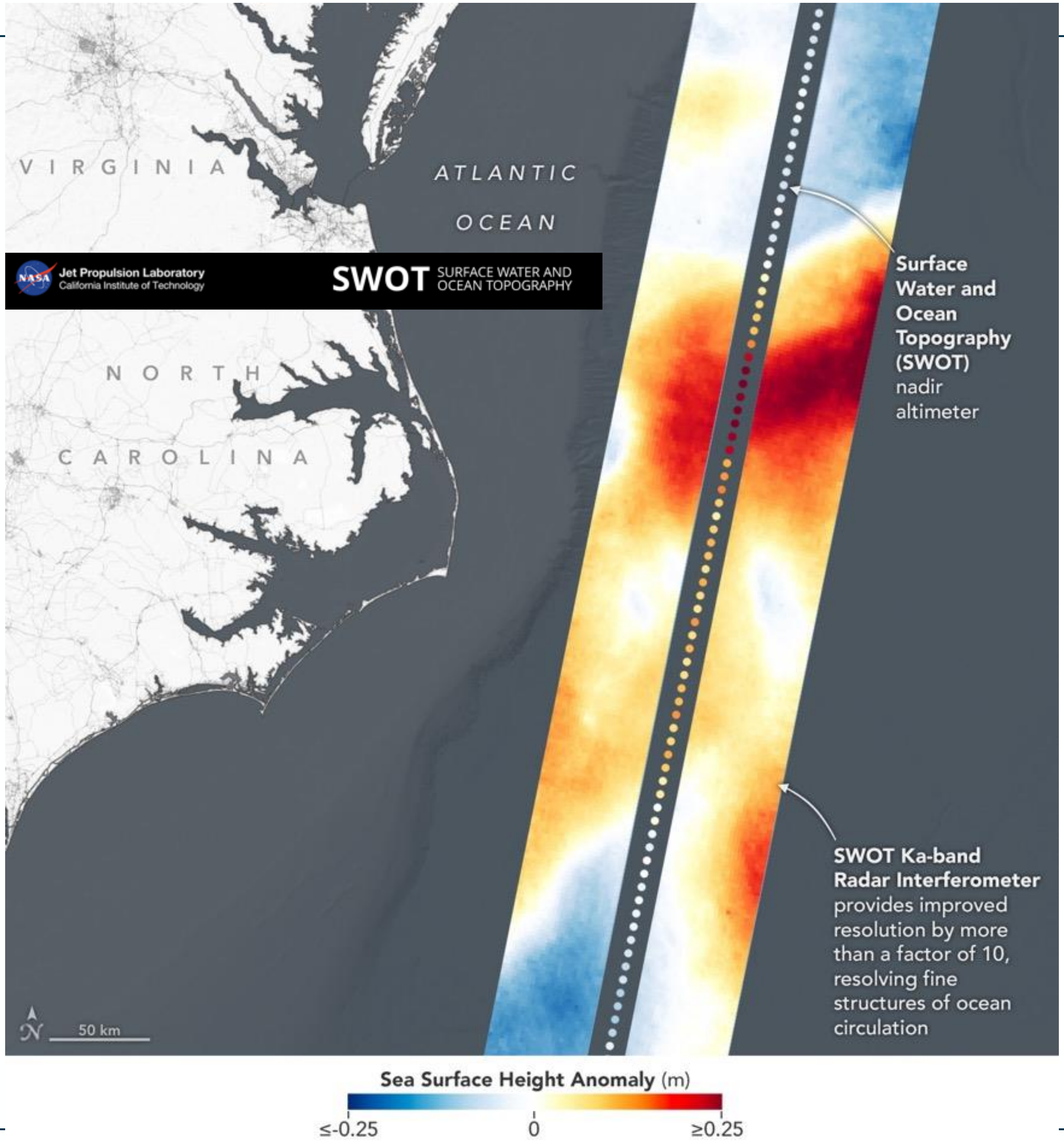
Then we add New Technologies to enhance the nadir measurements (NASA/CNES SWOT R&D mission will be the first demonstration in 2023+)

←L2 @ ~ 12km ka-band (SAOO) for ocean surfaces (higher native posting)
←Ku-band Nadir altimeter required at centre of swath for Hs and long wavelength roll error.
←Enhanced hydrology and ocean height gradient measurement
•2 operation modes LR and HR for ocean and hydro/sea ice.
- 250 (LR) – 35 (HR) metres resolution along-track,
- 70 (far range) – 10 (near range) metres resolution across-track
- Continuous wave mode over ocean providing 2D directional spectra

← **Major implementation of on-board processing since data rates are enourmous**

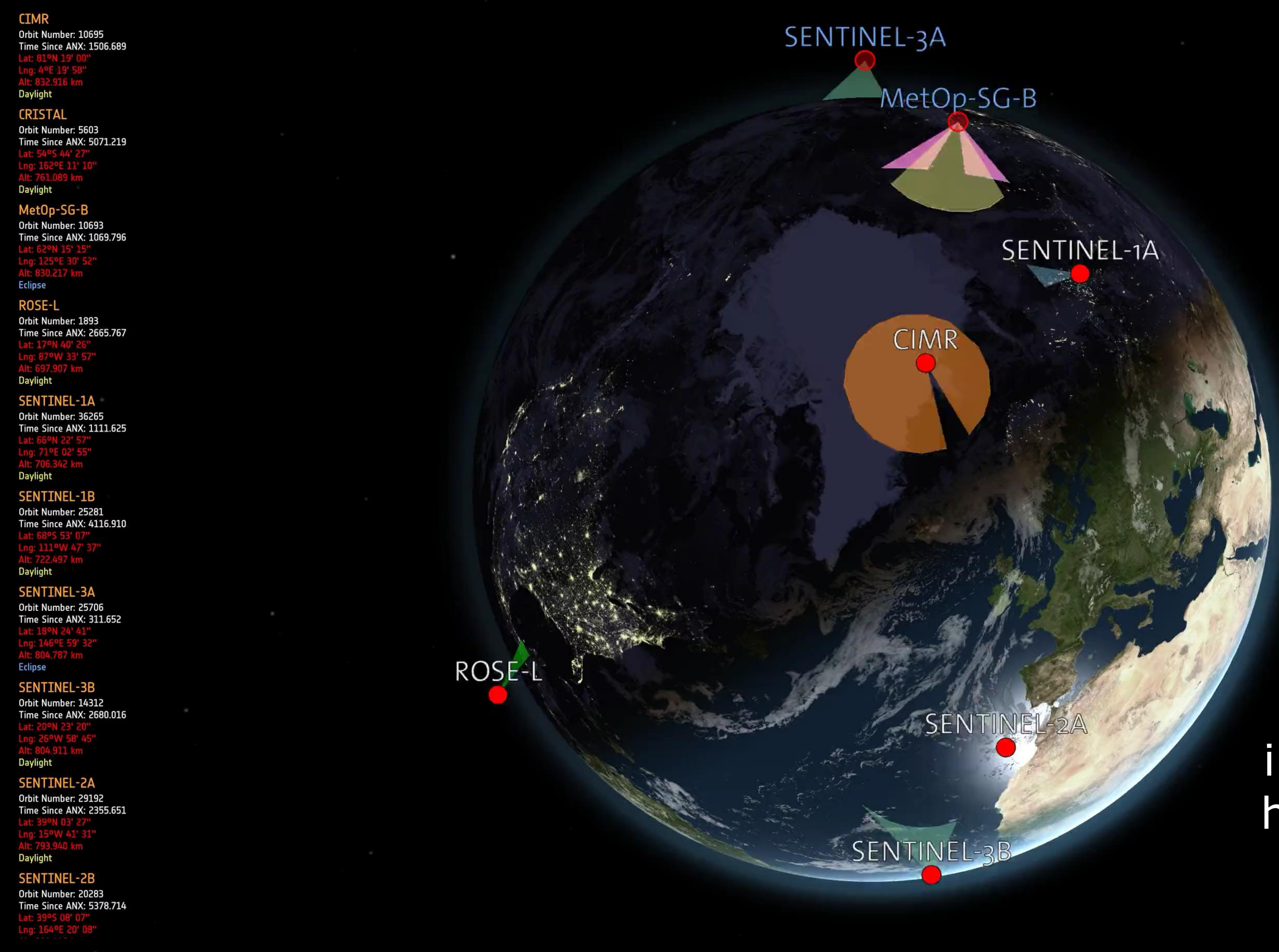
← **There will be a gate review @SWOT launch+14 months to confirm the performance of SWOT @L2 to proceed with the swath altimeter design**

SWOT first results look promising…



Expect to explore a range of new retreivals over ocean, sea ice and land

Sea ice will be particularly interesting



Copernicus
Europe's eyes on Earth

esa

UTC 2021-01-23 12:00:40.000
Speed: 1000x

Synergy between Missions is important as we will have unprecedented coverage of Our Earth

Copernicus Big-Data Revolution with First Generation Sentinels

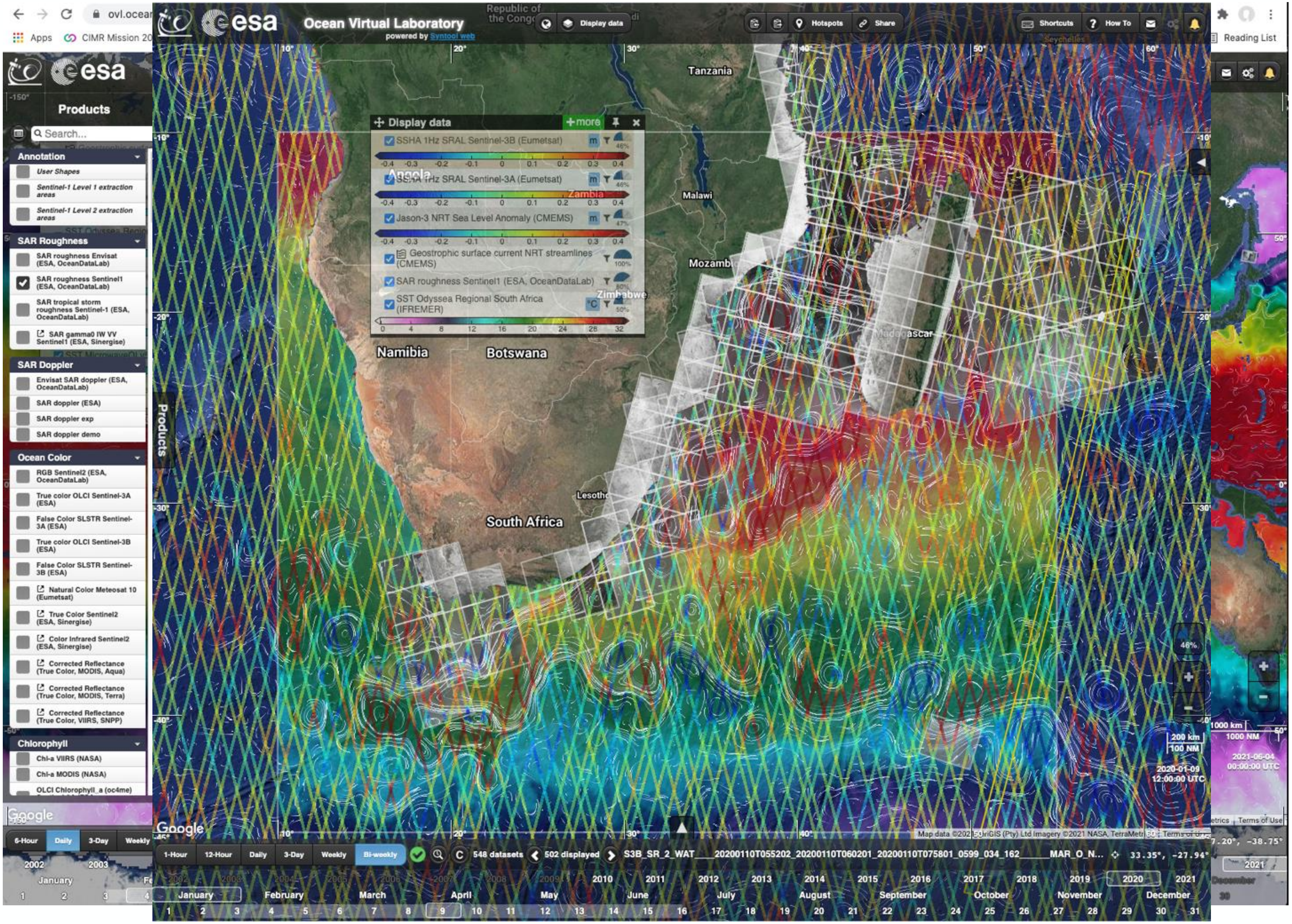
esa

Copernicus is the largest producer of EO data in the world

All global landmass is observed every 5 days at 10m resolution

25 TB of Daily Data Production by Sentinels

250 TB of Daily Sentinel Products Disseminated for Services to Society



OceanDataLab

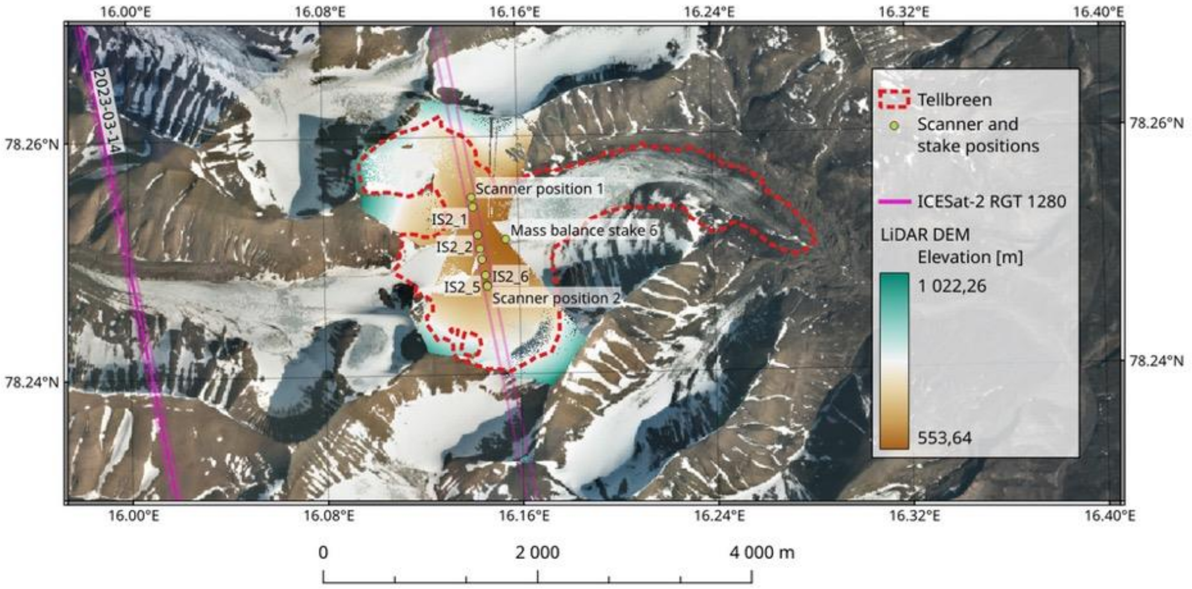
https://ovl.oceandatalab.com/

To keep “in touch” with the data, new abstraction Tools enable data interpretation from the local to the global scale have become necessary

Svalbard Sustainable Climate Reference Observatory

- Effort to utilise Svalbard as an in-situ supersite
  - In-situ measurements of ECV's as well as sensor relevant parameters
  - Easy access to glaciers and sea ice
  - Student workforce!

- Pilot phase spring 2023:
  - Snow thickness under ICESat-2
  - Laser scanning under ICESat-2 & Cryosat
  - GPR under CryoSat-2



- Plans for 2024-2025:
  - Start tackling Ku / Ka radar penetration!
  - Target CRISTAL, CIMR and ROSE-L relevant knowledge gaps!

Conclusion

- **We have been part of two decades of profound change in Earth Observation**
- **Many of our dreams from SeaSar 2003 have materialised**
- **Observation Observation Evidence Base** that is supporting an enormous and growing number of applications across **all domains**
- **Fundamental challenges remain to exploit satellite measurements in synergy** from the local process-driven perspective to the global climate challenges.
- **We have an extremely rich and growing data archive for reanalyses and climate activities that provides an unparalleled scientific evidence base**
- **These are critical for effective decision making and Policy implementation – and of course our next generation of forecasting and prediction systems**
- **Bring on the next Decade!!!**

Theme 8 Future Missions summary

☺ Large number of planned and proposed missions with SAR capability in ESA and Copernicus programmes

- Also national and commercial missions e.g RCM, COSMO-SkyMed, Capella, etc.

☺ Rapid diversification of technology, frequencies and techniques

- X-band, C-band, P-band, L-band, Ka-band, Ku-band
- SAR imagers, SAR ATI, SAR XTI, SAR altimeters
- New polarimetric capability

☺ Relevant to emerging focus on air-sea coupling and wind/wave/current interactions – synergy with other missions (e.g. optical glitter, scatterometry, radiometry, model data..)

☺ New capabilities for nadir pointing SAR altimeters – note Sentinel-3A has 80Hz data in Level-1a products but very poor user uptake – why?

☺ We have a lot of data and we need to gat back to looking at the image data – new tools such as the OVL are helping

☺ Recommend us of Jupyter notebooks tuned to users for each product (open and display data "put your code here")

Theme 8 Future Missions summary

😕 Orbits still mostly SSO 6am/6pm

- How can we observe diurnal processes ?

😕 Large community, mostly working in parallel, on individual missions, creating knowledge silos

😕 Uptake of SAR ocean data still limited

How can we improve engagement with broader geoscience and modelling community?

Large international science-driven multi-sensor projects and campaigns might help

Thank you Any Questions?

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