Harmony: ESA's 10th Earth Explorer Mission

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esa
harmony
TO RESOLVE STRESS
IN THE EARTH SYSTEM
ESA's dynamic surfaces mission

ESA-DEVELOPED EARTH OBSERVATION SAR MISSIONS

2010
2015
2020
2025
2030

Heritage
Flying
Upcoming

ERS-1
ERS-2
Envisat
Sentinel-1A
Sentinel-1B
Sentinel-1C
Sentinel-1D
Biomass
Harmony
ROSE-L-A
ROSE-L-B
Sentinel-1
Sentinel Next Generation Missions

Science
Copernicus
European Union

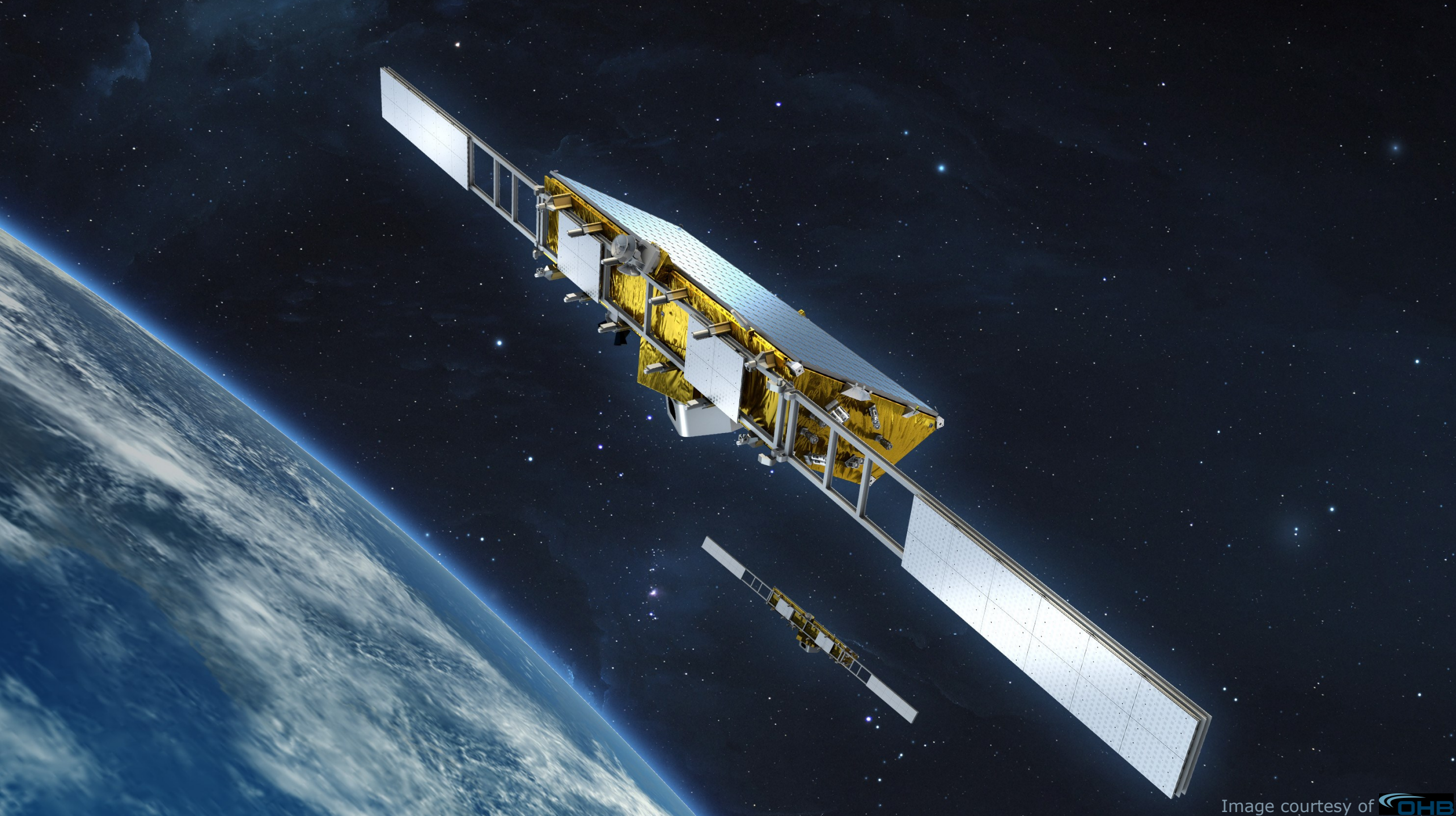
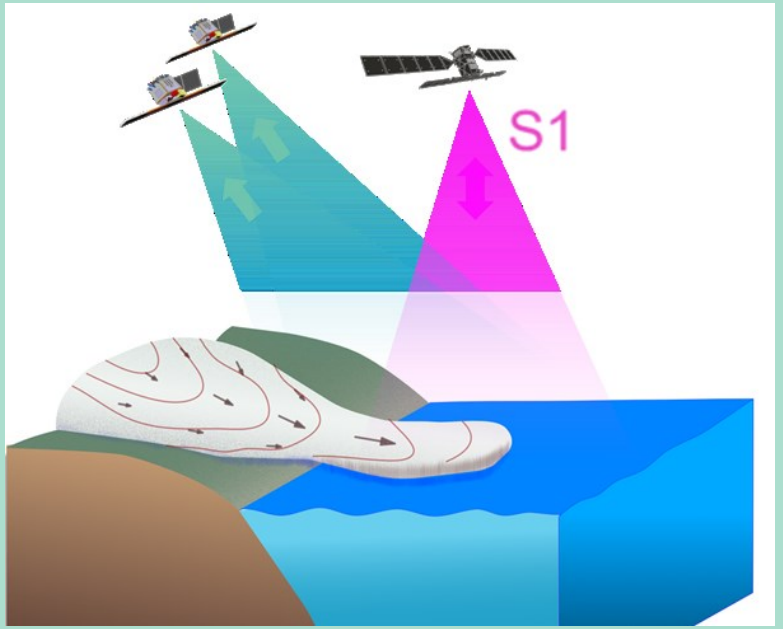


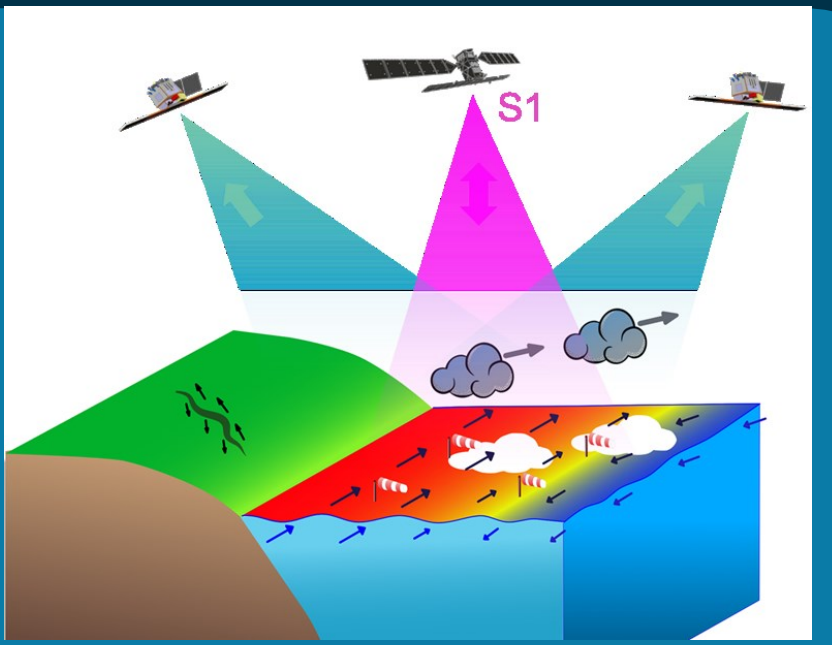
Image courtesy of OHB

Harmony in a nutshell

Harmony is ESA's Earth Explorer 10 mission, comprised of two companion satellites in a loose convoy with Sentinel-1D (along-track separation ~350 km)
Its payload suite consists of a passive SAR and a multi-view TIR instrument



Cross-track Interferometric phase covering land applications like glaciers, permafrost, volcanoes.



Stereo phase covering 3-D surface deformation ocean applications: surface motion, surface winds, sea surface temperature, cloud motion.

Year 1 | Year 2 | Year 3 | Year 4 | Year 5

Harmony – a multi-domain “Earth System” mission

Upper oceans and ocean-atmosphere interactions

Land ice and sea ice

Tectonic strain and volcanic processes

Bringing Harmony to a dynamic world

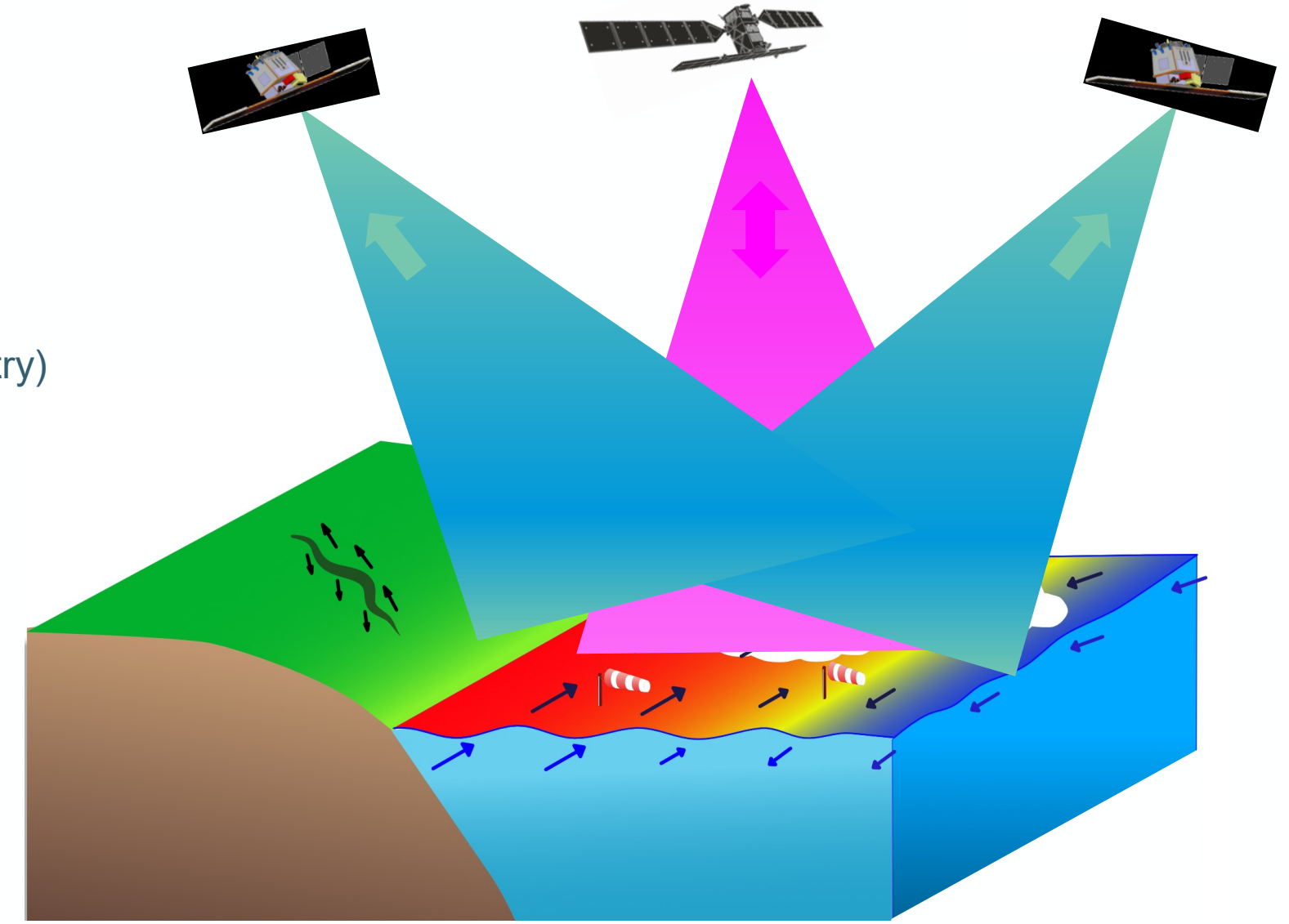
Harmony will resolve (sub) kilometer scale motion vectors and topography changes associated to dynamic Earth System processes:

- heat, gas and momentum exchanges at the air-sea interface;
- the inner structure of ocean-atmosphere extremes;
- gradual and dynamic volume changes of global mountain and polar glaciers;
- instantaneous sea-ice motions to characterise sea-ice dynamics;
- 3-D deformation vectors associated to tectonic strain;
- topographic change at active volcanoes worldwide.

Mission overview and observables

Line-of-sight diversity for high resolution

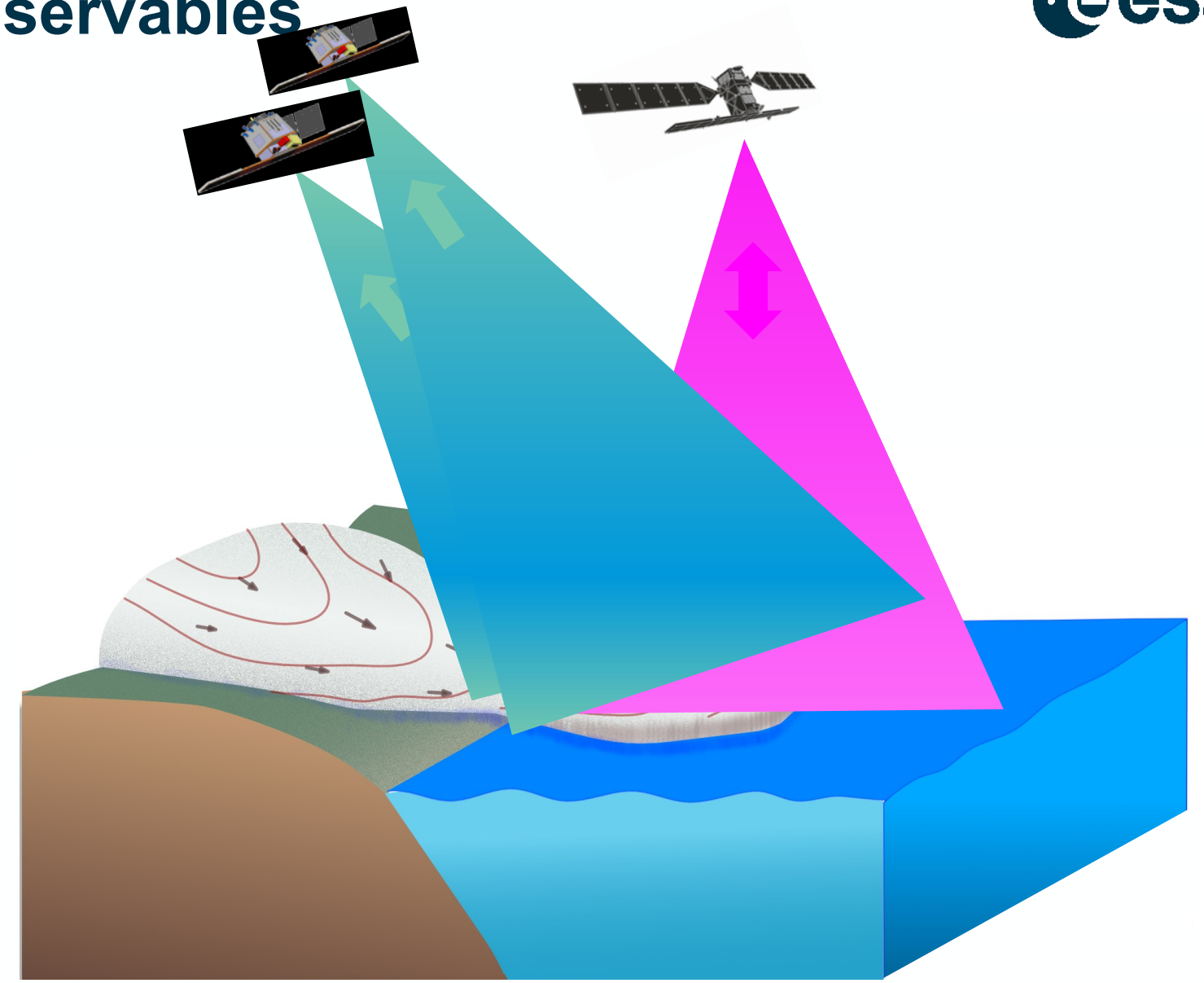
- Slow (DInSAR) and fast (Doppler) surface motion vectors.
- Directional roughness (→wind scatterometry)
- Improved directional surface wave spectra
- Sea Surface (skin) temperature
- Cloud-top motion vectors (TIR time-lapse) and height (TIR parallax)



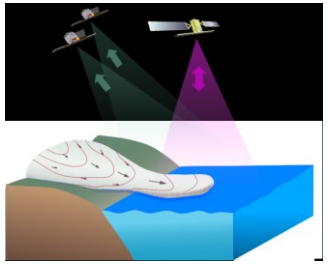
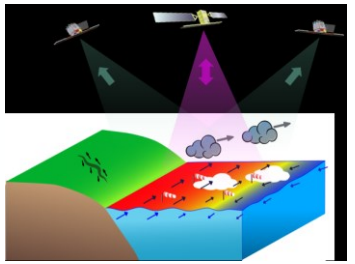
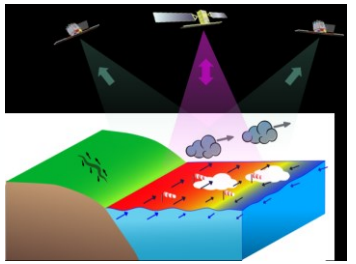
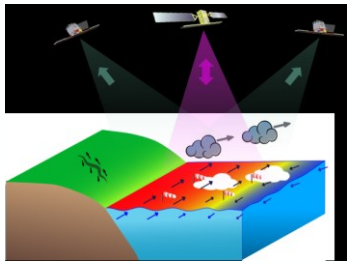
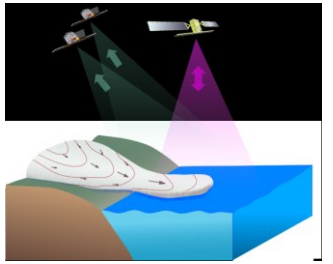
Mission overview and observables

Single-pass cross-track interferometer

- 3-D surface deformation (as in Stereo)
- **Surface elevation time-series**
    - **Glaciers**, permafrost, icebergs
    - Volcanoes

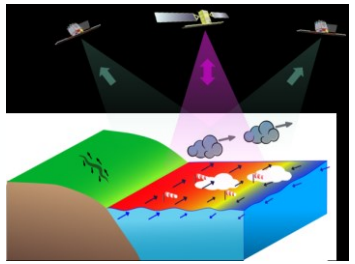


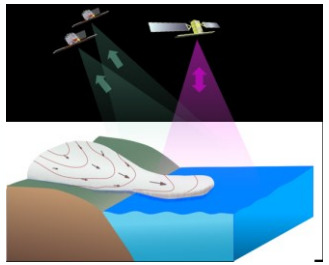
Mission Phases Timeline

Y1	Y2	Y3	Y4	Y5
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

Harmony in brief





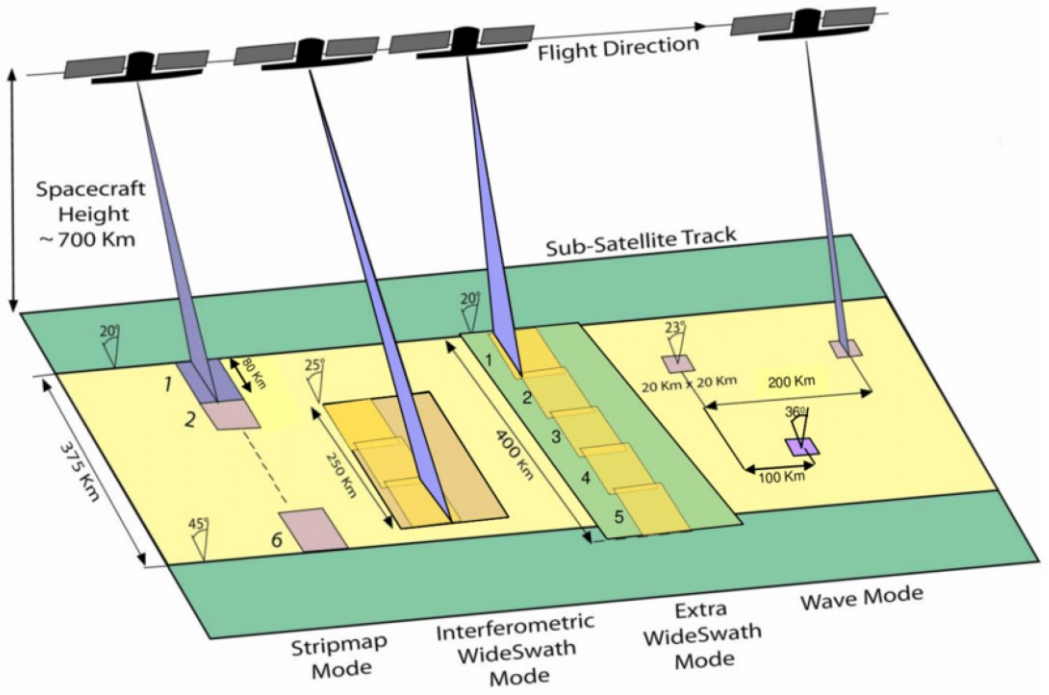
Simultaneous,
O(1 km) scale

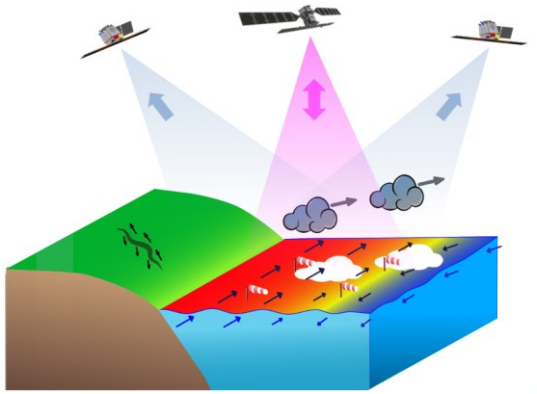
- SST
- Cloud-top Motion
- Directional roughness
- Directional Doppler
- C-band = all weather
- 3-D repeat pass InSAR
- Dense DSM time-series

Simultaneous,
O(50m) scale

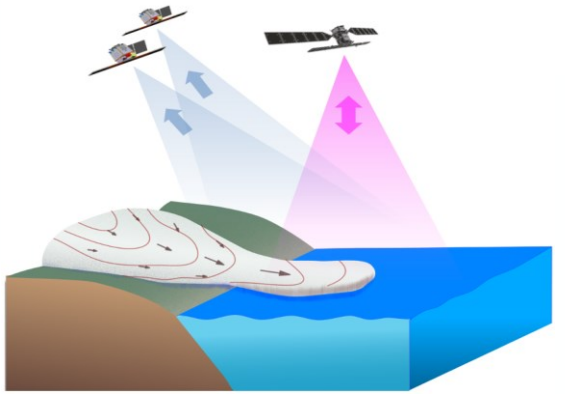
- Data driven ocean-atmosphere couplings and statistical. characterization of vertical fluxes in ESM 2.0.
- Understanding of air-sea interactions within extremes.
- Sea-ice dynamics.
- Global strain maps.
- Understand cycles of topographic change at volcanoes.
- Global and temporally consistent map of ice volume change (loss).
- Improved understanding of glacier dynamics.

SAR architecture and driving requirements





Stereo

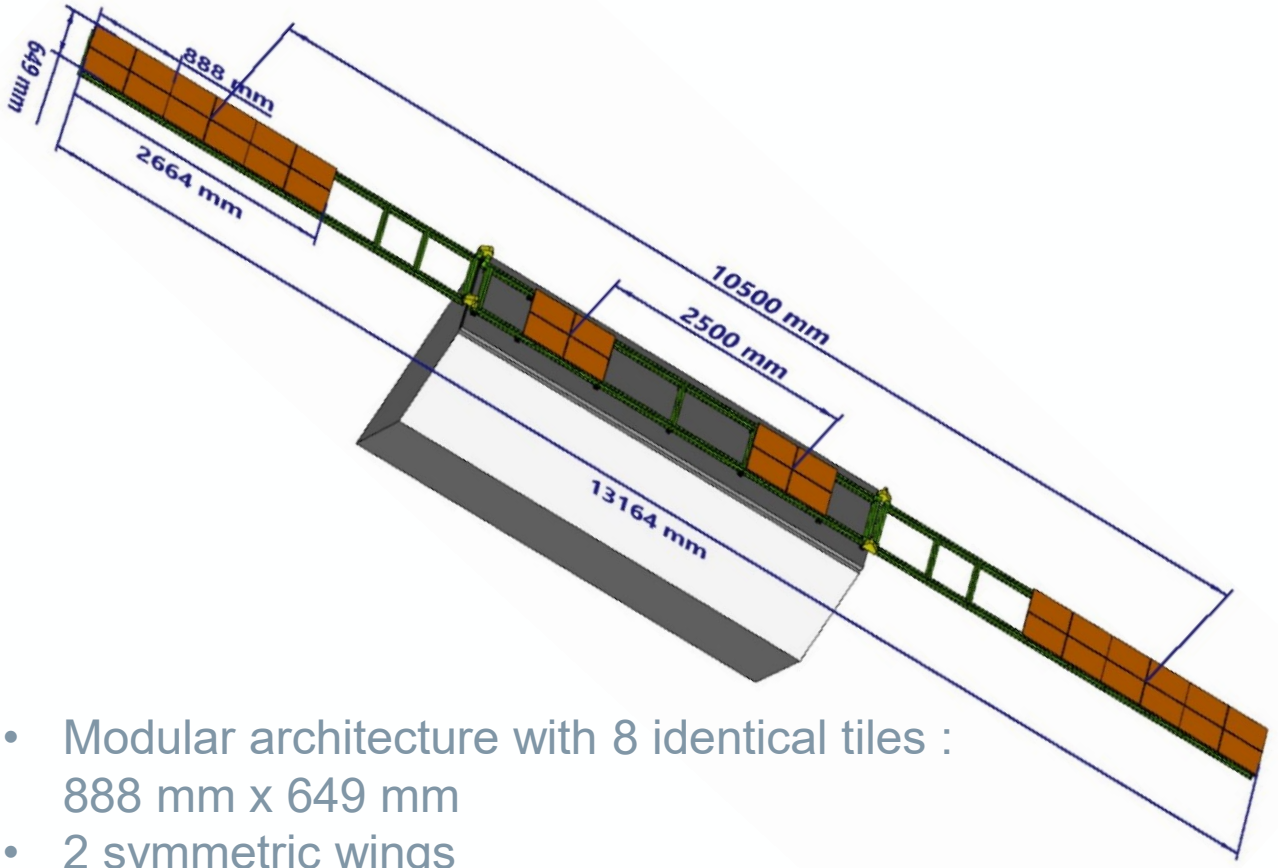


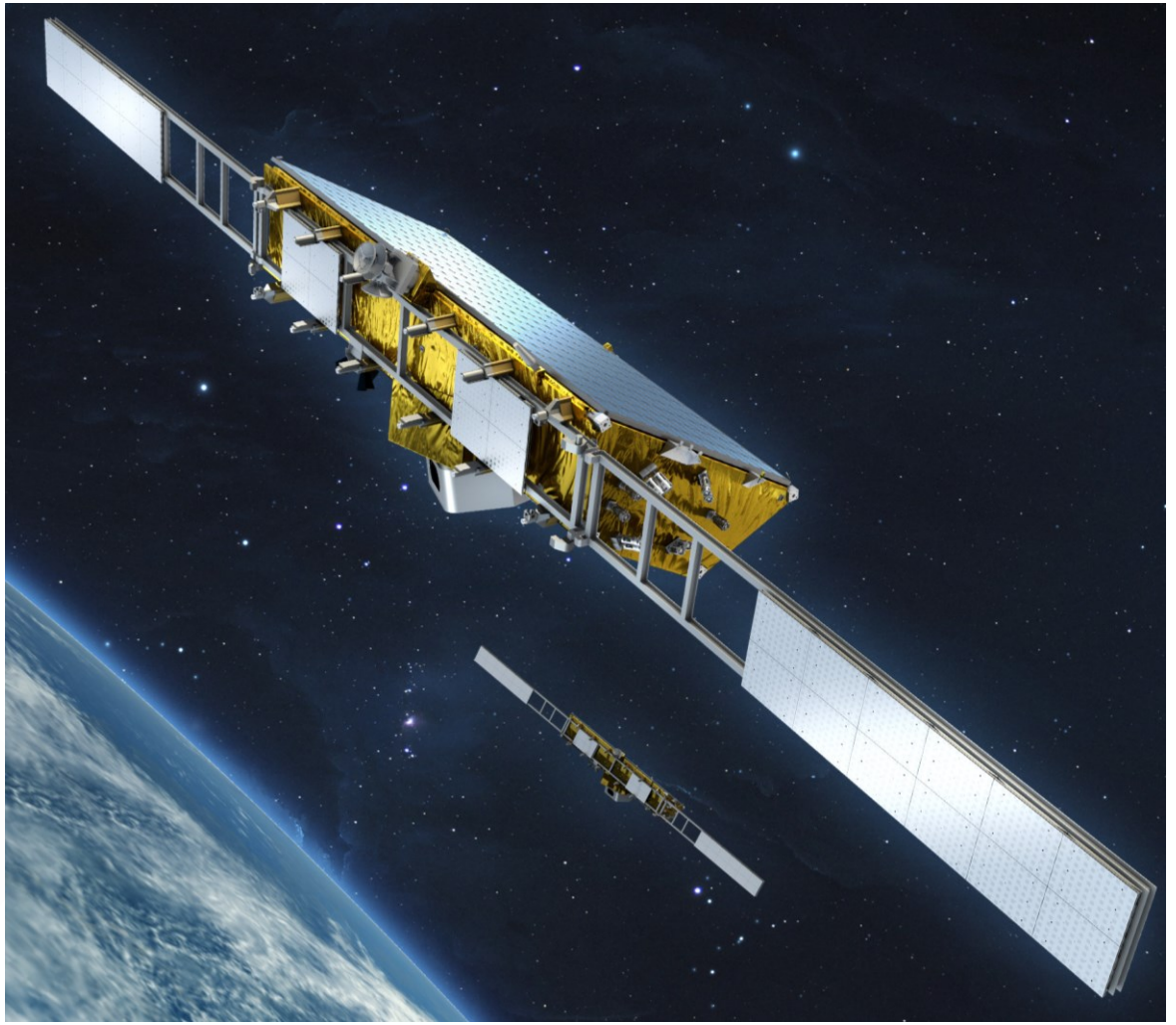
XTI

Requirement	Value
NESZ	-20 dB
DTAR	-17 dB
Radiometric Accuracy (1σ)	0.6 dB
Radiometric Stability (1σ)	0.3 dB
Polarimetric Phase Error (3σ)	5 deg
RPE (mid-wind scenario and 2x2 m^2 resolution)	0.2 m/s
System contribution XTI phase error variation	1 deg across-swath 3 deg within 500 km along-track

- Harmony has been designed to be **fully compatible** with all Sentinel-1 SAR modes and to cover **all** sub-swaths

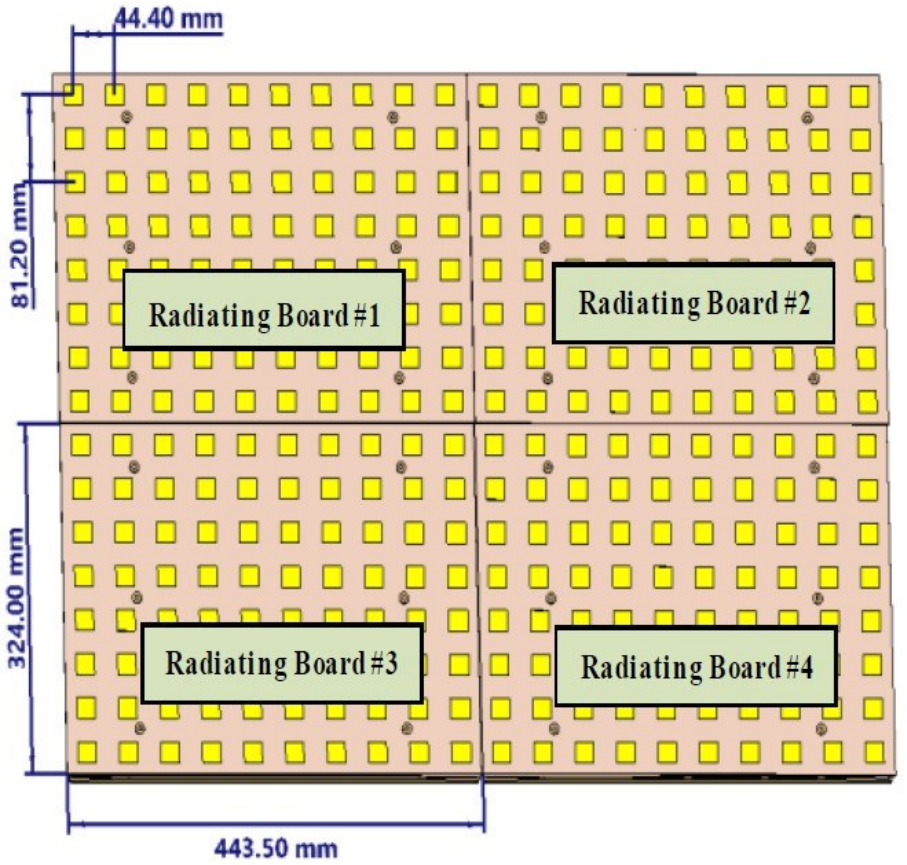
Harmony Antenna Subsystem (SAS)

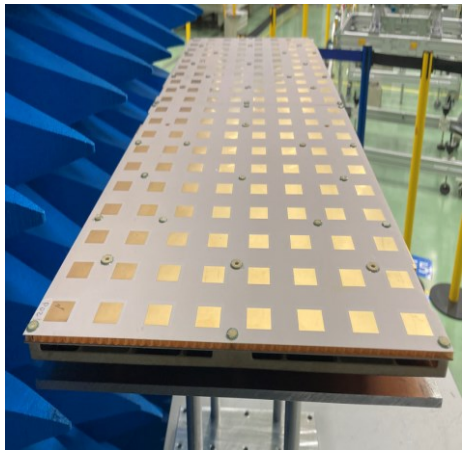


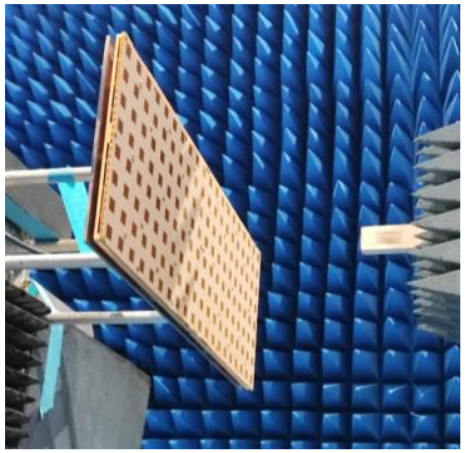


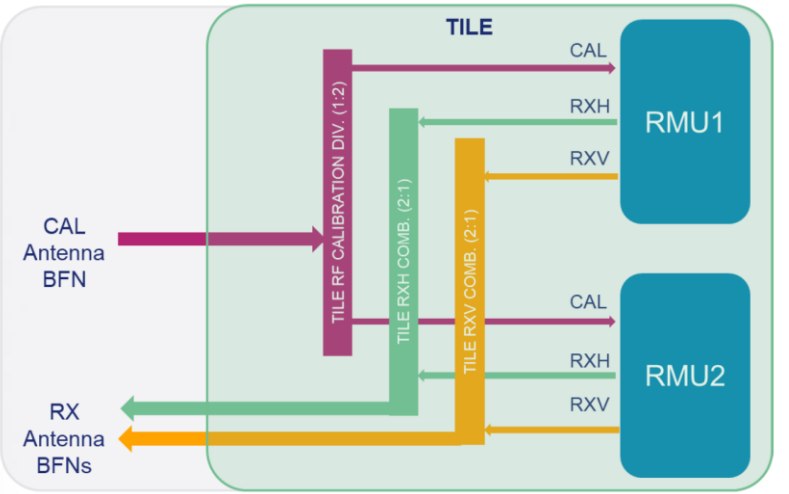
- Modular architecture with 8 identical tiles : 888 mm x 649 mm
- 2 symmetric wings
- 10.5 m baseline ATI baseline
- Total length : 13.164 m
- Design fully compatible with Sentinel-1 First Generation (S-1C/D)

Harmony Antenna Tile

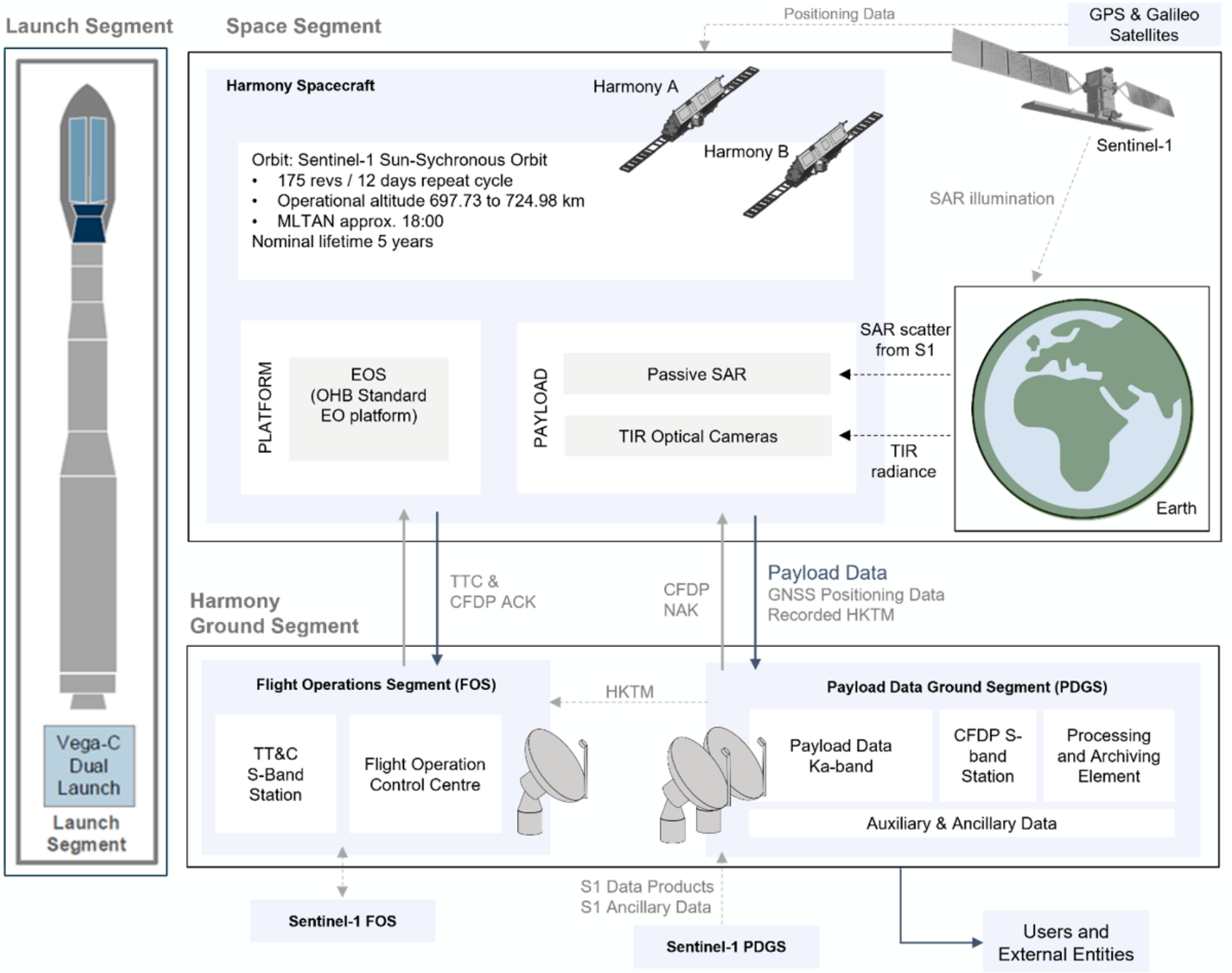






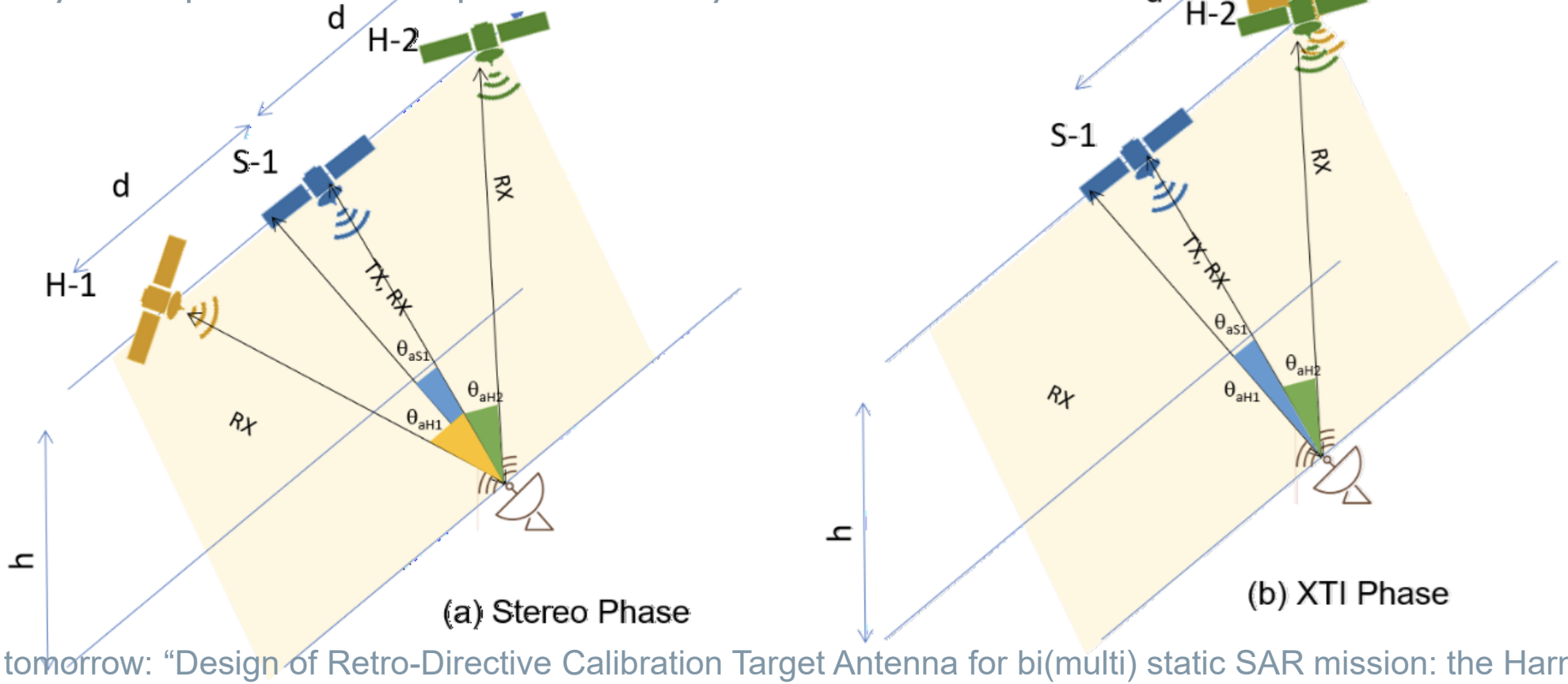


The Antenna Tile is the elemental modular component of the SAS assembly



Harmony Calibration Transponder: preliminary findings

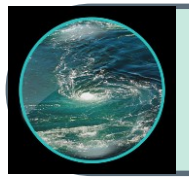
- Due to the strongly bistatic geometry of Harmony (d = 350 km), its polarisation basis is aligned neither to the one of the transmitter nor to the ground-referenced H-V polarisation
- Current technology development activity is based on a retro-directive antenna design
- Backend compatible with either single antenna with electronic steering or 3 separate antennas (each serving a single satellite)
- Harmony transponder development activity to be initiated



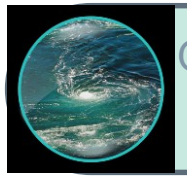
Poster tomorrow: “Design of Retro-Directive Calibration Target Antenna for bi(multi) static SAR mission: the Harmony case”

Level-2 validation: goal ocean science requirements

U_{10s} vector	
🎯	1 m/s or 7.5% U
↔	< 1 km^2



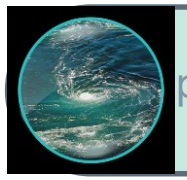
Capture MABL coherent structures associated with 3-D turbulence and vertical transport



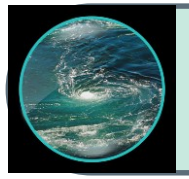
Observe sub-mesoscale upper oceans at resolutions comparable to state-of-the-art models and current gradients O(10^{-4}/s)

rTSC vector	
🎯	<0.2 m/s
↔	< 2x2 km^2

CMV vector + CTH	
🎯	3 m/s
↔	< 1.5x1.5 km^2
↕	500 m



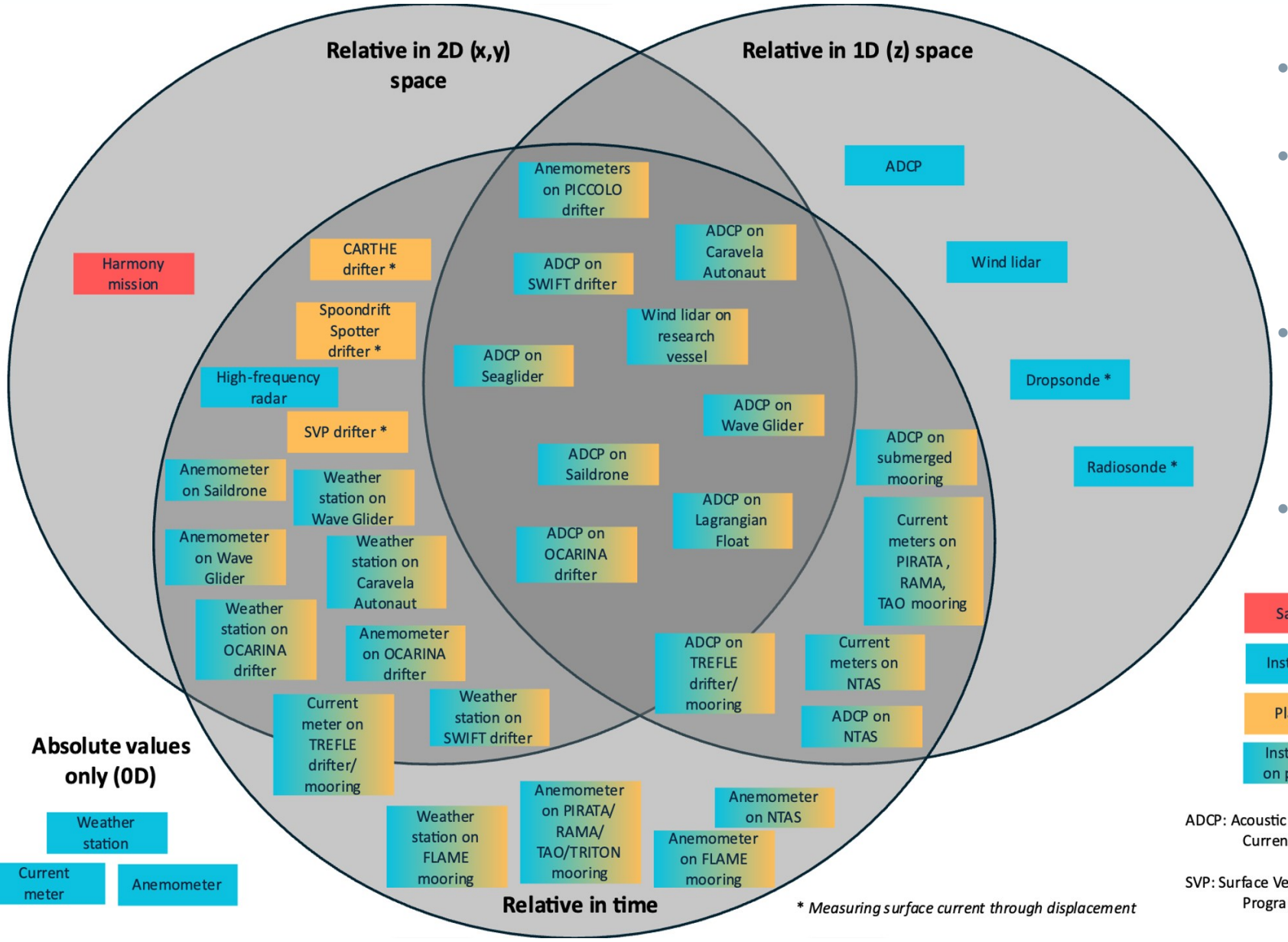
Quantify the contribution of small scale cloud dynamical processes O(1 km) to the vertical fluxes of water, momentum and heat (OBJ-O14).



Observe SST variations associated to submesoscales

Relative SST	
🎯	0.25
↔	1 km^2

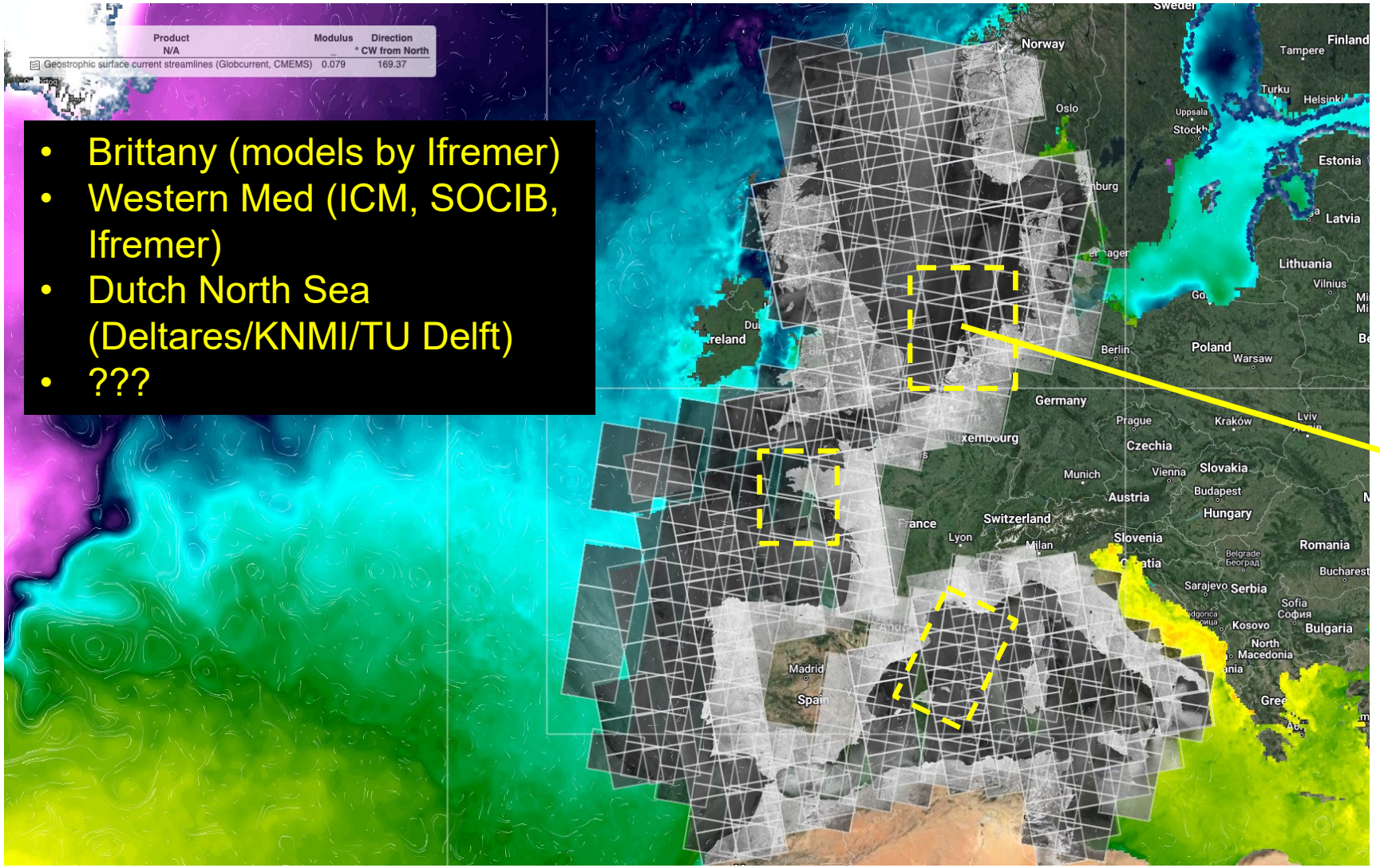
Ocean validation: The Challenge



- Spaceborne SAR provides snapshots covering large areas
- Most in-situ instantaneously measure small area/ point measurement
  - ➢ time/space scaling mismatch
- Ocean sub-mesoscale (order 1 km) to mesoscale (>30 km) features have lifetimes, O(hours to 10´s of days)
- Develop high-resolution SAR ocean product validation approaches
  - ➢ Designation of coordinated super-sites?

Figure courtesy of Jacotte Monroe (2024)

Potential ocean cal/val sites for Harmony L2 products



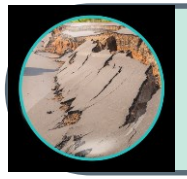
- Brittany (models by Ifremer)
- Western Med (ICM, SOCIB, Ifremer)
- Dutch North Sea (Deltares/KNMI/TU Delft)
- ???

Level-2 validation: goal land science requirements

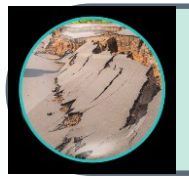
3D deformation	
🎯	< 5% of velocity
↔	< 100 x 100 m²
□	seasonal

Quantify multi-year average elevation change for most glaciers and ice sheet outlets, with a high spatial resolution of at least 100m, and sub-meter accuracy (OBJ-C11).

Observe 3D surface motion and deformation of glaciers and ice streams (OBJ-C22) and support of OBJ-C21



Constrain stain rate to detect variability down to 10 nanostrain per year (1mm/year/100km) (OBJ-G11)



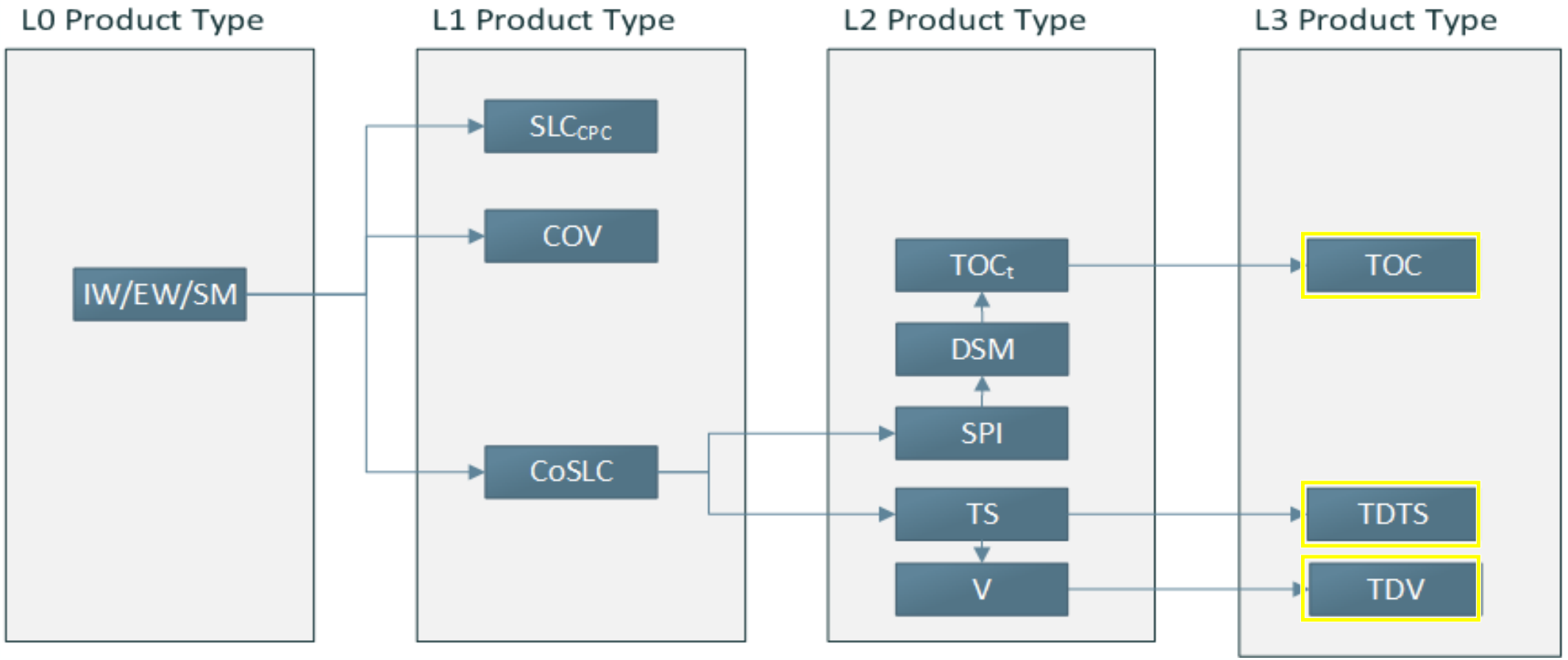
Provide measurements of topographic change at active volcanoes with a spatial resolution of 30 x 30 m2 (OBJ-G21).

Land Ice TOC	
🎯	< 0.2 m/yr
↔	< 100 x 100 m²
□	5 year

3D deformation	
🎯	1 mm/year
↔	100 x 100 m²
□	5 year

Solid Earth TOC	
🎯	< 1 m
↔	< 30 x 30 m²

Land validation: main products



TOC: Topography Change Product → Changes in topographic height over timescales between observations

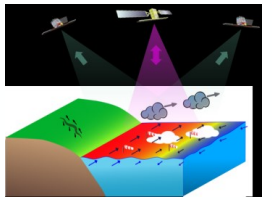
TDTS: Three-Dimensional Time Series → Time-series of three-dimensional deformation vectors

TDV: Three-Dimensional Velocity → Three-Dimensional deformation velocity vector

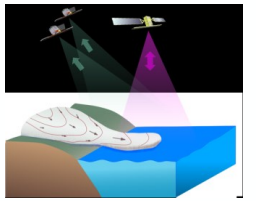
Summary

- Harmony is currently in Phase B2 → launch end of 2029

- Added lines-of-sight of Harmony enable additional products whilst not affecting the main Sentinel-1 mission operations
  - Reconfigurability of Harmony satellites
  - Enabling non-zero baselines



- Novel products require updated/new validation strategies
  - Dedicated activity planned for early 2025
  - Need for coordinated supersites



SARCALNET to include SAR higher level product validation?