
harmony
TO RESOLVE STRESS
IN THE EARTH SYSTEM
ESA's dynamic surfaces mission
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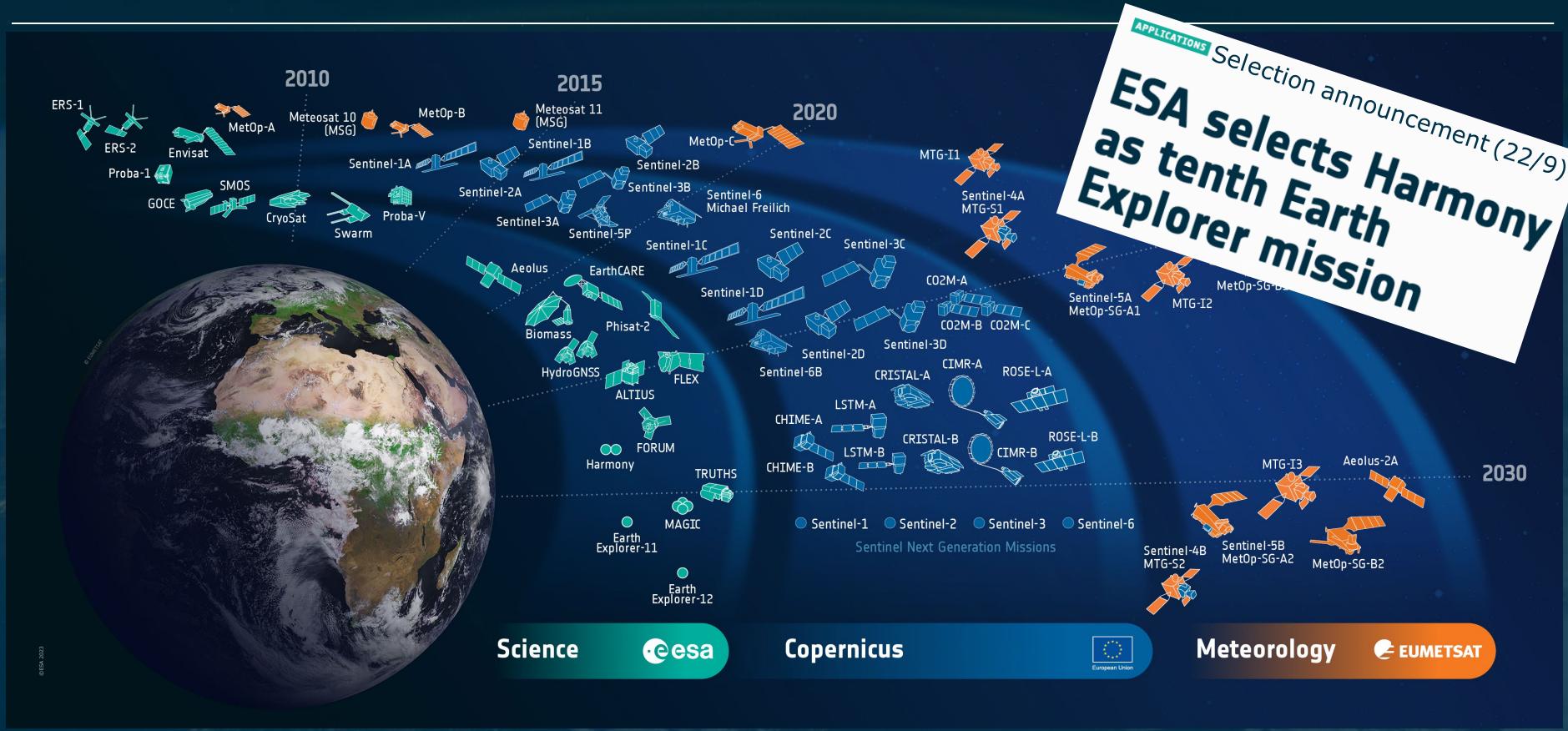
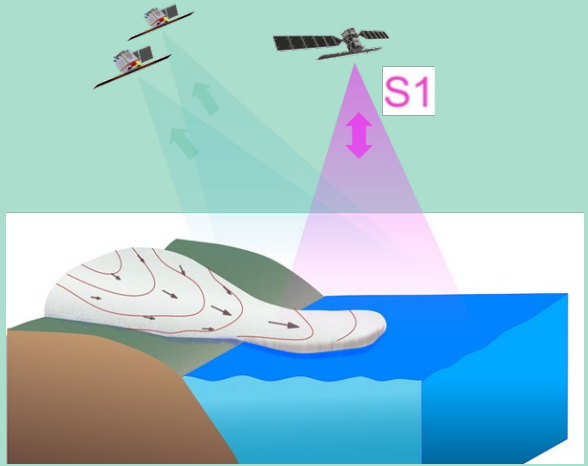
FRINGE 2023, Leeds, 11-15 September 2023

Harmony within ESA's EO missions landscape

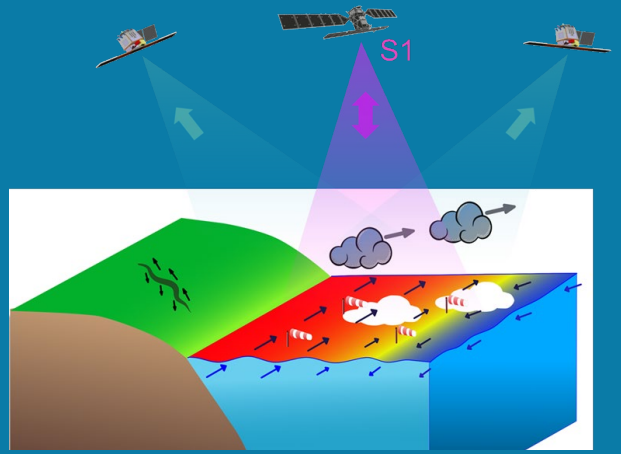


Harmony in a nutshell

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

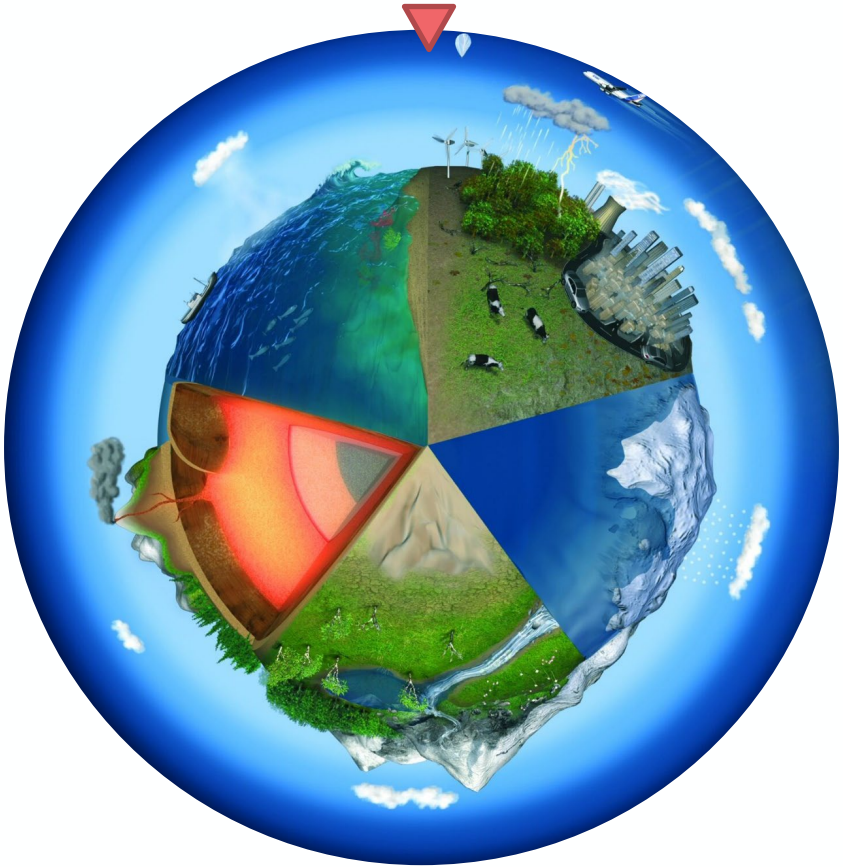
Harmony – a multi-domain “Earth System” mission

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:

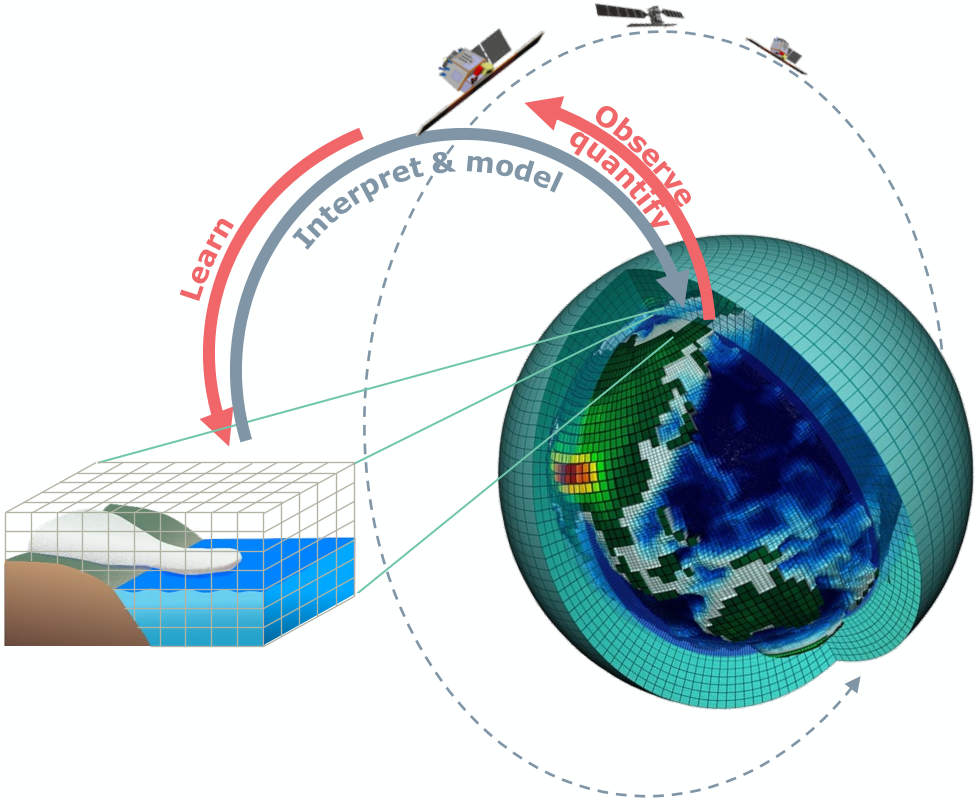
- heat, gas and momentum exchanges at the air-sea interface;
- the inner structure of ocean-atmosphere extremes;
- gradual and dynamic volume changes of global mountain and polar glaciers;
- instantaneous sea-ice motions to characterise sea-ice dynamics;
- 3-D deformation vectors associated to tectonic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

Contributing to data-driven Earth System Modeling

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

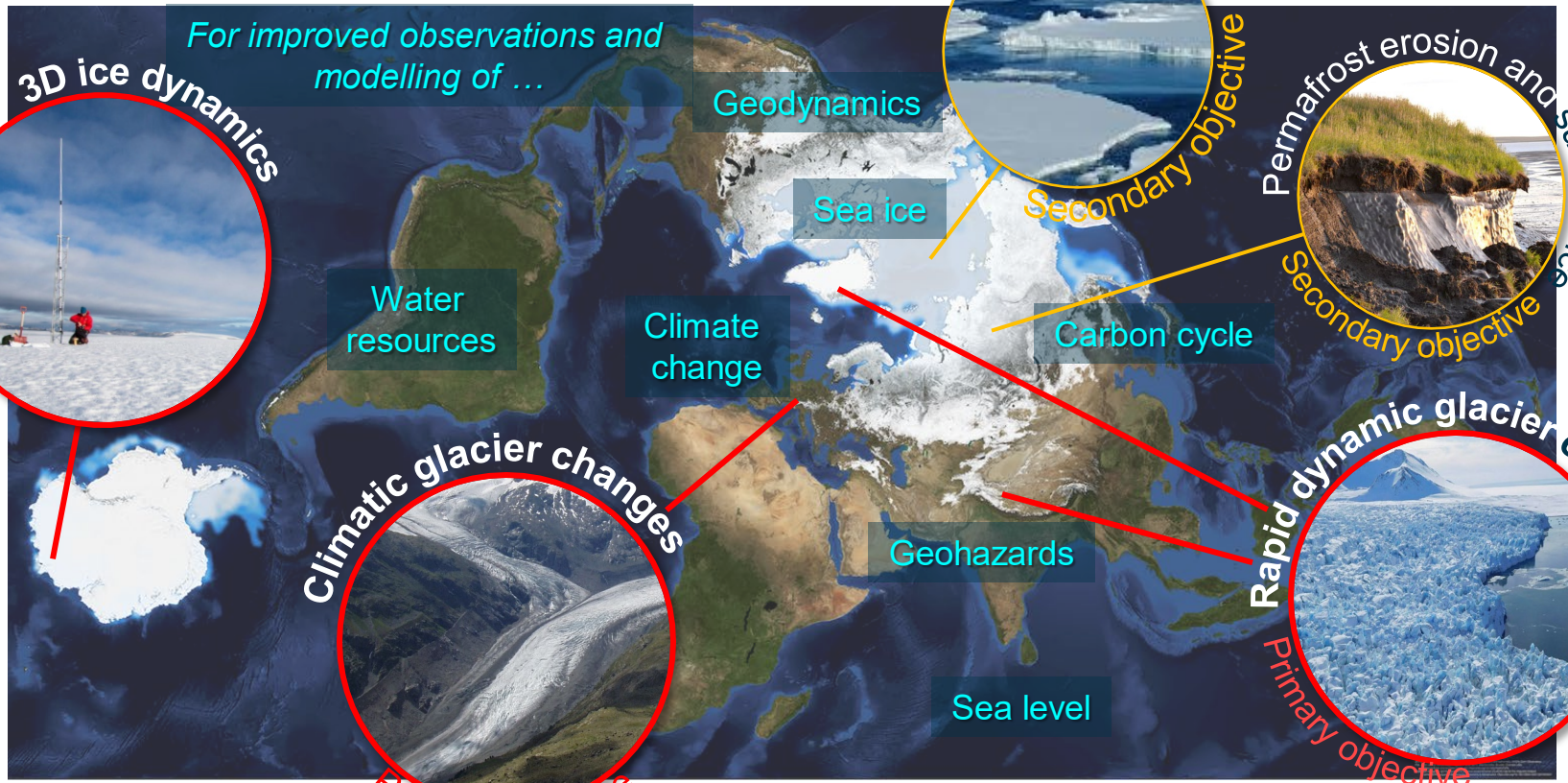
Unresolved O(≲ 1km) processes and couplings in Earth System Models represent major contribution to model uncertainties.

Harmony is set to provide observations needed to develop/train/validate next generations of fully coupled Earth System Models.



https://esamultimedia.esa.int/docs/EarthObservation/EE10_Harmony_Report-for-Selection_21June2022.pdf

Harmony: sensing the cryosphere

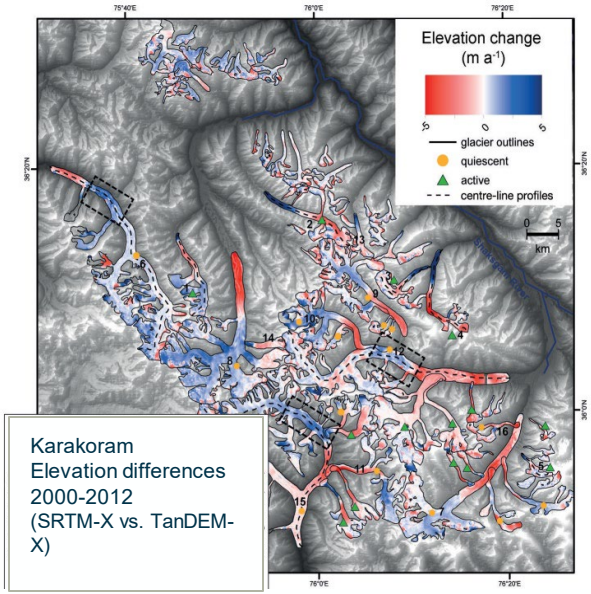


Harmony provides topographic changes …

Slow, gradual glacier changes
Typically climatic driven

Rapid glacier changes
Typically dynamic driven

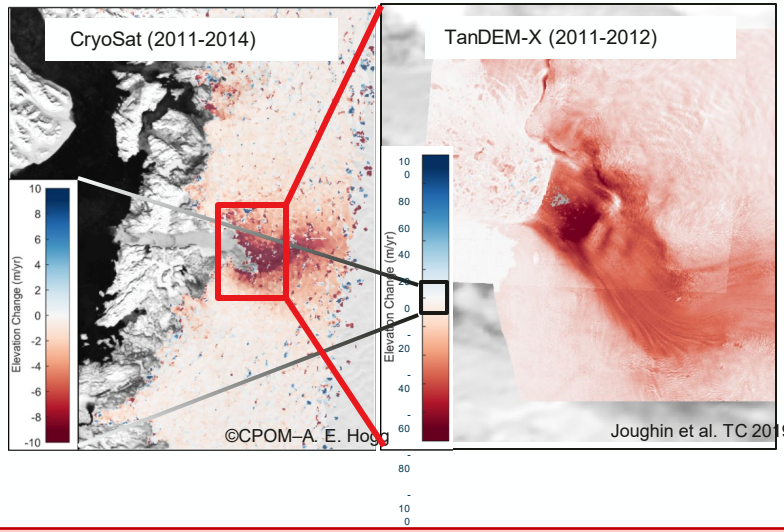
Global and temporally-consistent volume changes…



Karakoram
Elevation differences
2000-2012
(SRTM-X vs. TanDEM-X)

Low spatial res.

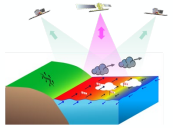
High spatial res.



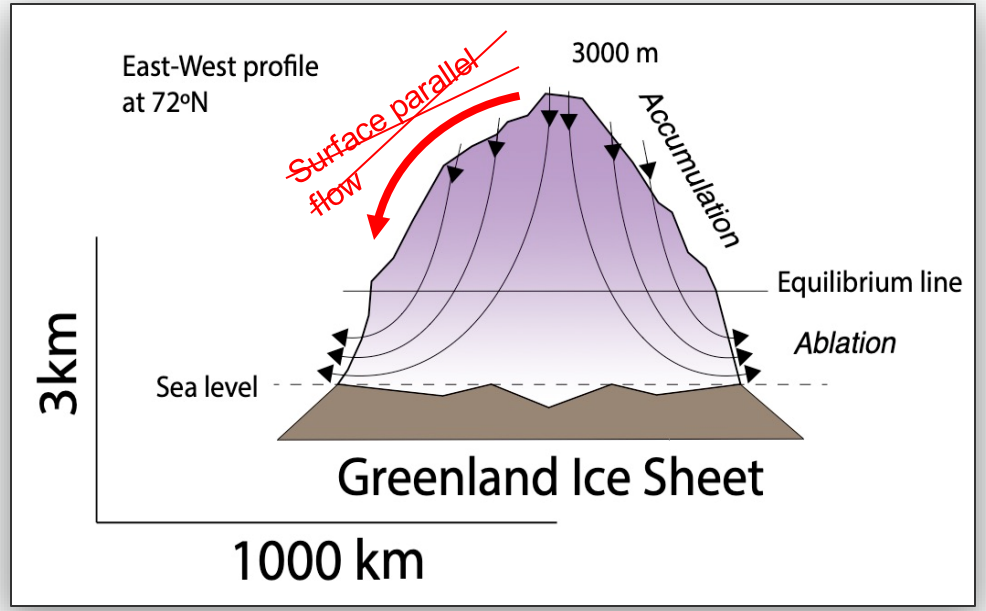
Glacier detachment and avalanche, Tibet, 2016

… simultaneous high-repeat topographic change *and* lateral ice motion.

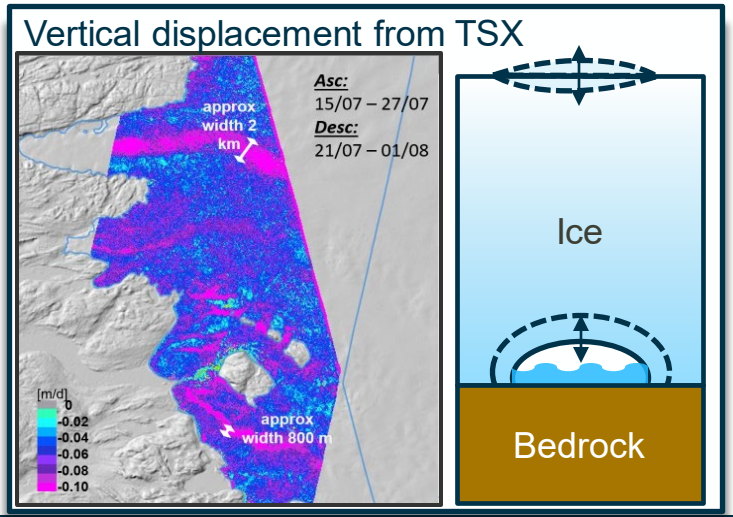
Harmony provides 3-D deformation vectors …



- Current observation get only 2 components
- 3rd component (**vertical**) assuming surface parallel flow.



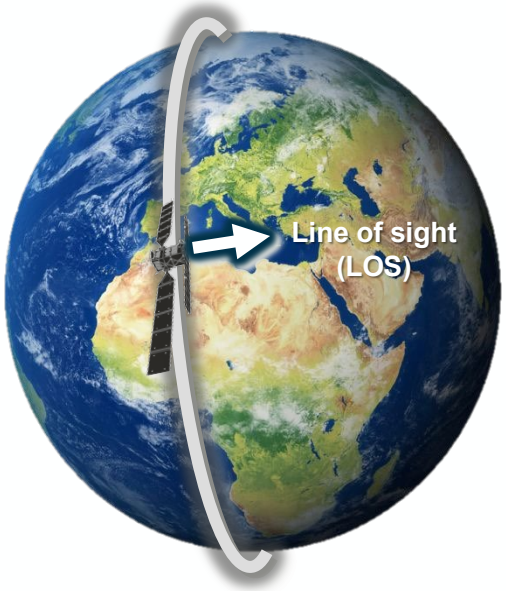
- Vertical component → ablation or accumulation
  - ➔ **First 3D structures of the ice sheets and glaciers**
  - ➔ **Evaluation of surface mass balance models**
- Expression on the surface of subglacial processes.
  - ➔ **Better understanding of the physical processes**



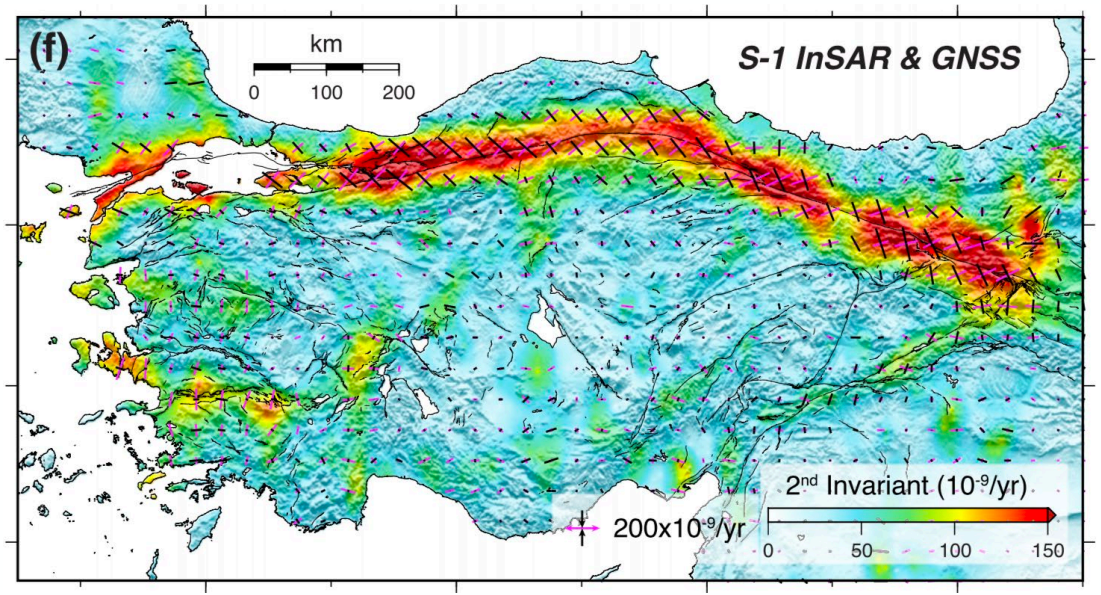
Harmony: Solid Earth

- Earthquakes and volcanoes shape the surface of the Earth.
- Understanding the processes involved requires measurements of deformation and elevation change.
- This is important to define global seismic hazard and forecast volcanic activity.

Solid Earth: E-W strain

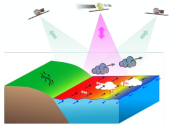


- Sentinel-1 produced a step change in our ability to measure strain.
- But: mostly sensitive to E-W motions

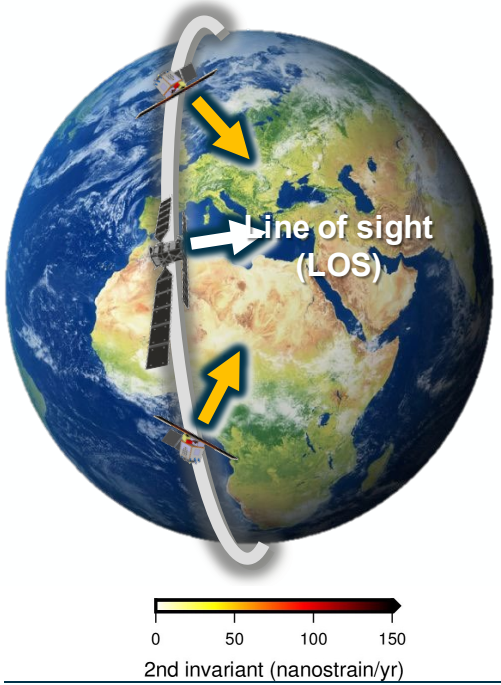


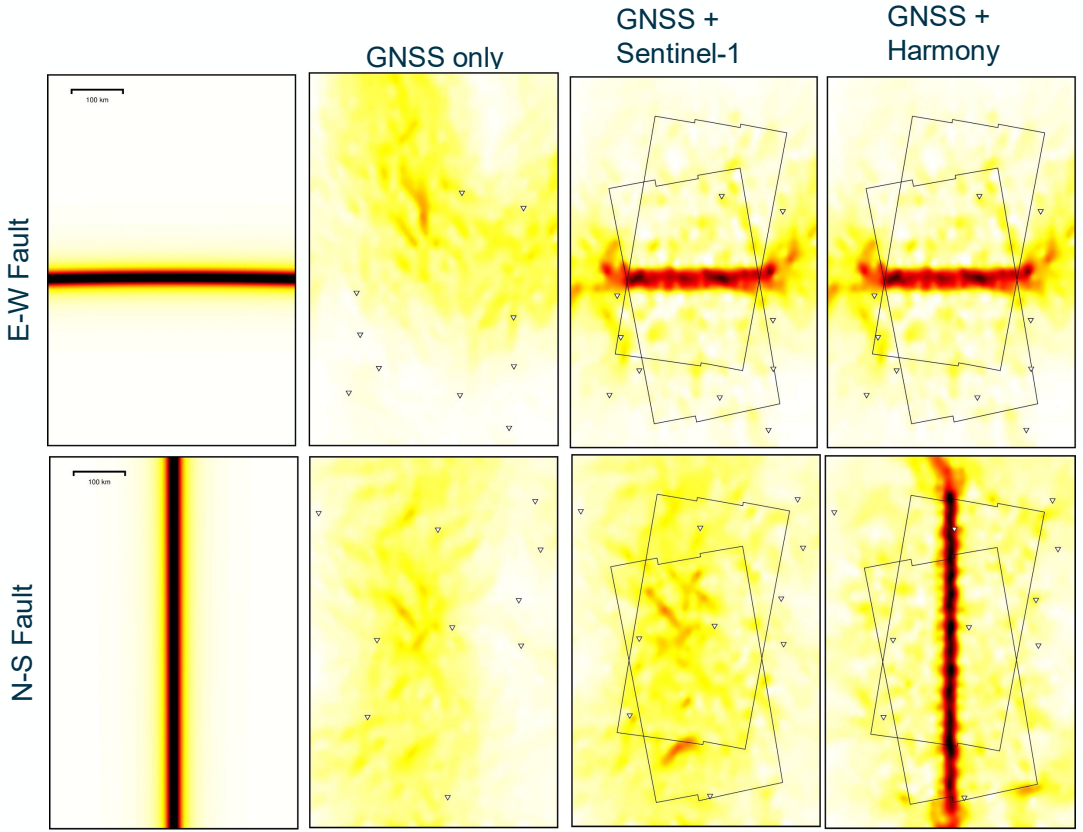
Strain rate for Anatolia from Sentinel-1 [Weiss et al, 2020]

Solid Earth: North-South Motion

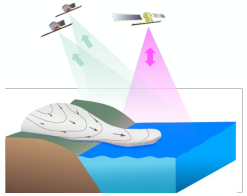
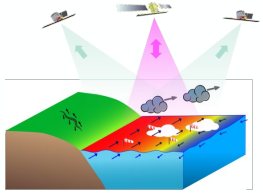
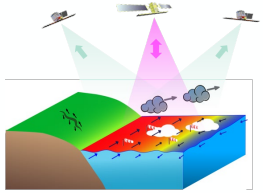
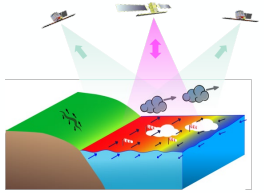
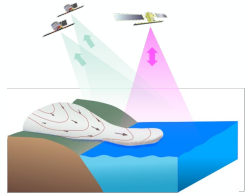


Harmony will be sensitive to all components of deformation, including North-South





Mission Phases Timeline

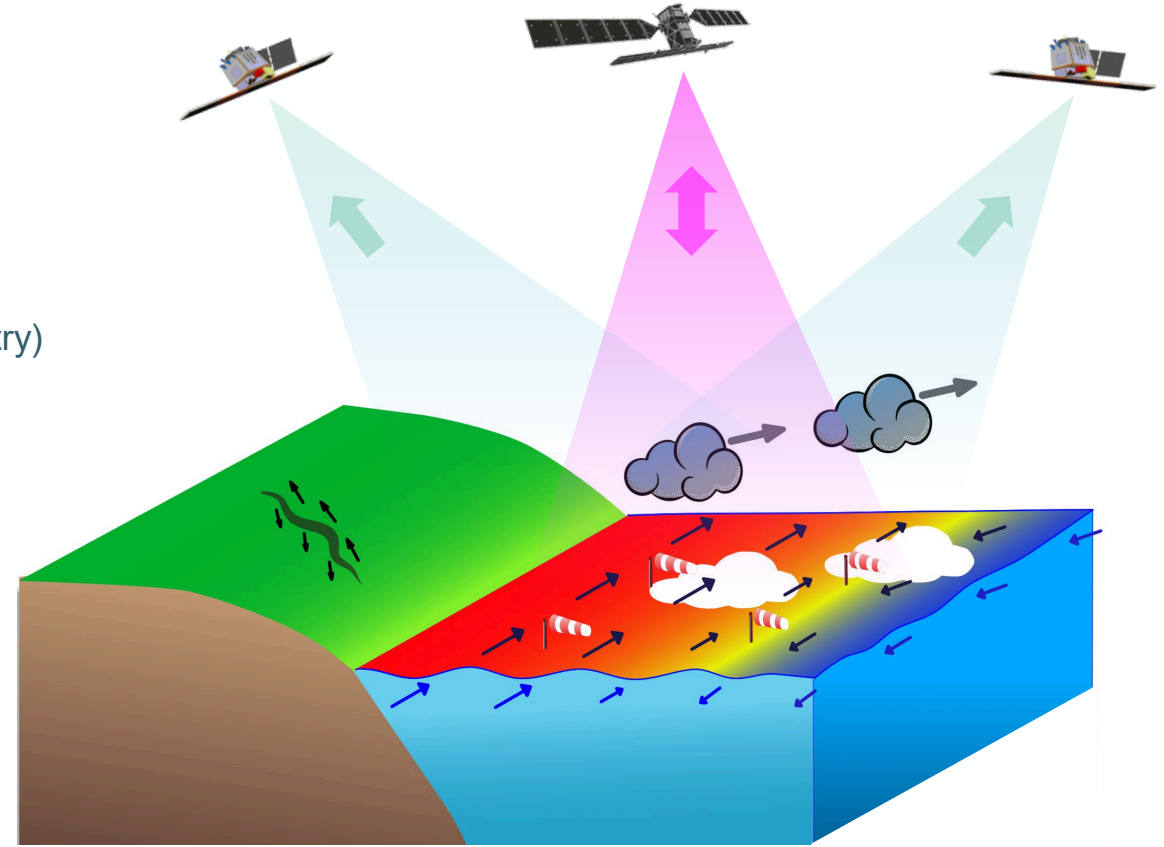






Y1	Y2	Y3	Y4	Y5
XTI Phase	Stereo Phase			XTI Phase
Ice Volume change				**Ice Volume change**
Glacier dynamics				**Glacier dynamics**
	3-D Ice surface motion			
	Air-sea interactions			
Ocean topography **(experimental)**	**Atmosphere-ocean-extemes (Tropical Cyclones, Polar lows, etc)**			Ocean topography **(experimental)**
	Upper ocean dynamics			
	Tectonic Strain (3-D deformation)			
Vol. change (volcanoes)				Vol. change (volcanoes)
Iceberg volume	Sea-ice instantaneous motion/deformation			Iceberg volume

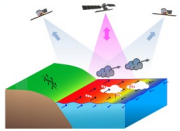
Mission overview and observables

Line-of-sight diversity for high resolution

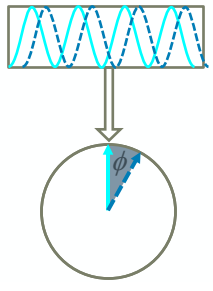
- Slow (DInSAR) and fast (Doppler) surface motion vectors.
- Directional roughness (→wind scatterometry)
- Improved directional surface wave spectra
- Sea Surface (skin) temperature
- Cloud-top motion vectors (TIR time-lapse) and height (TIR parallax)

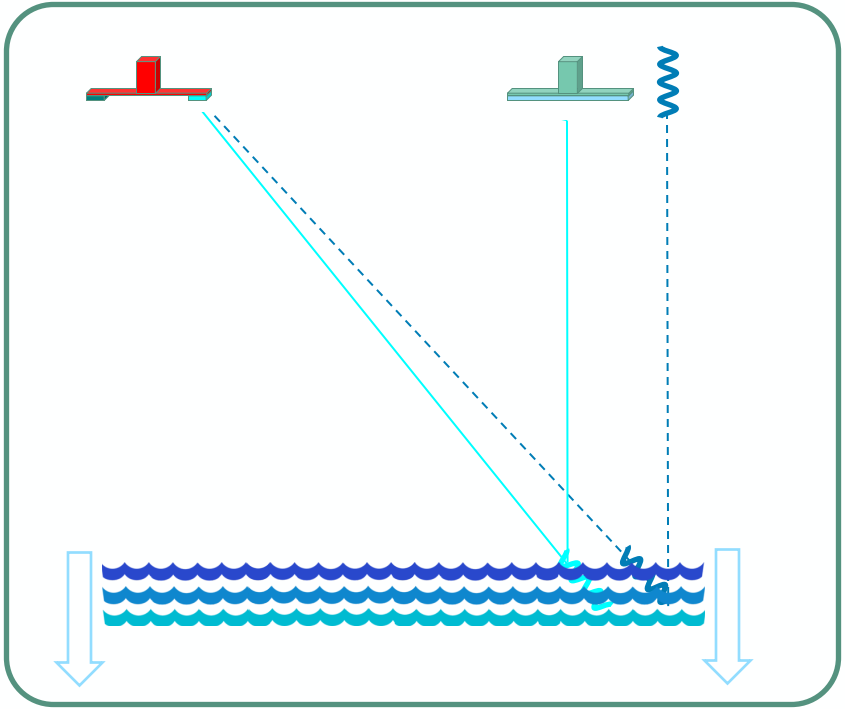


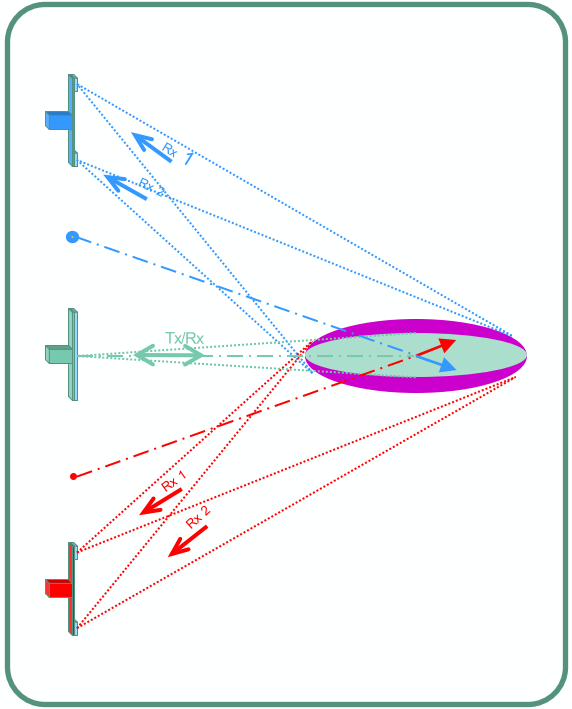
Observation Concept: Along-Track Interferometry (ATI)



STEREO

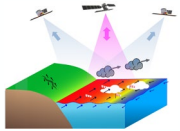






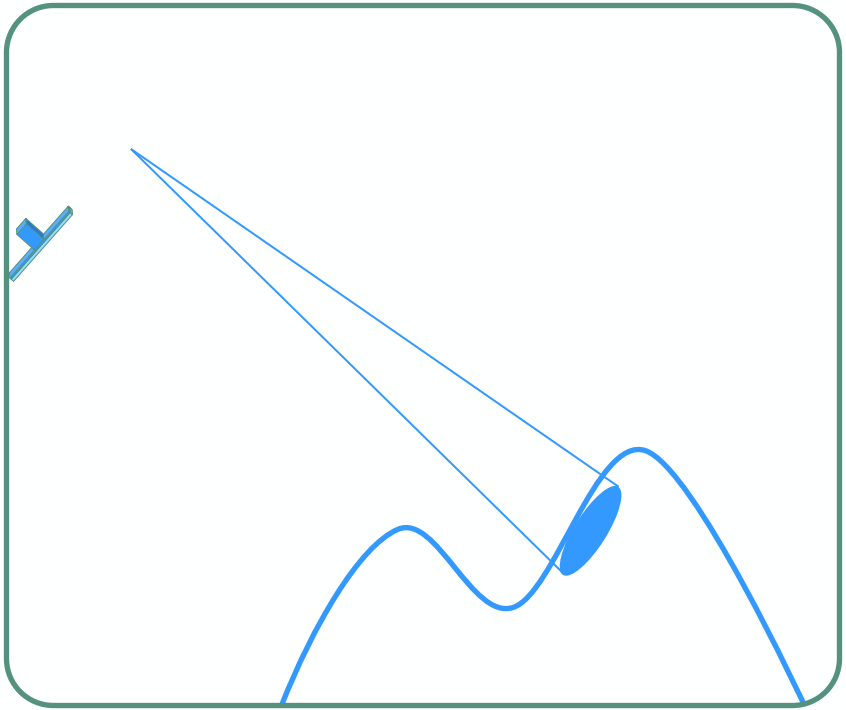
Harmony can observe instantaneous surface velocity vectors with Along-Track Interferometry (ATI).

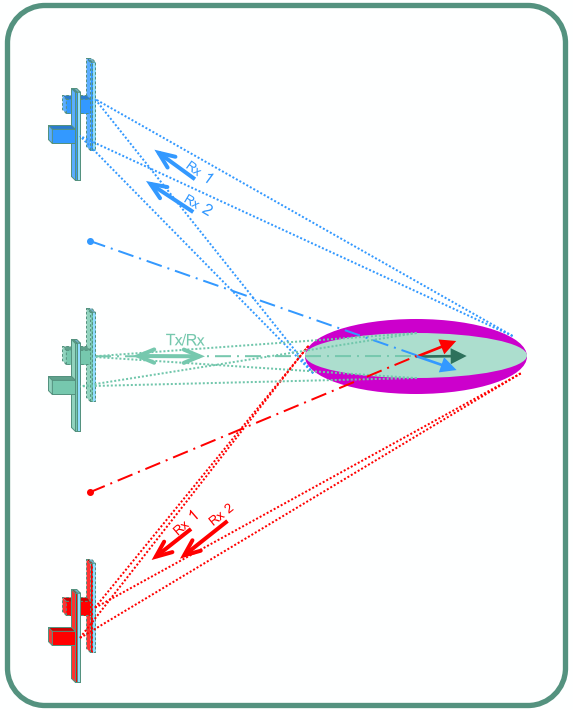
Observation Concept: Repeat-Pass Interferometry



STEREO

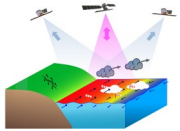
$$\Delta\phi = \frac{2\pi\Delta r}{\lambda}$$





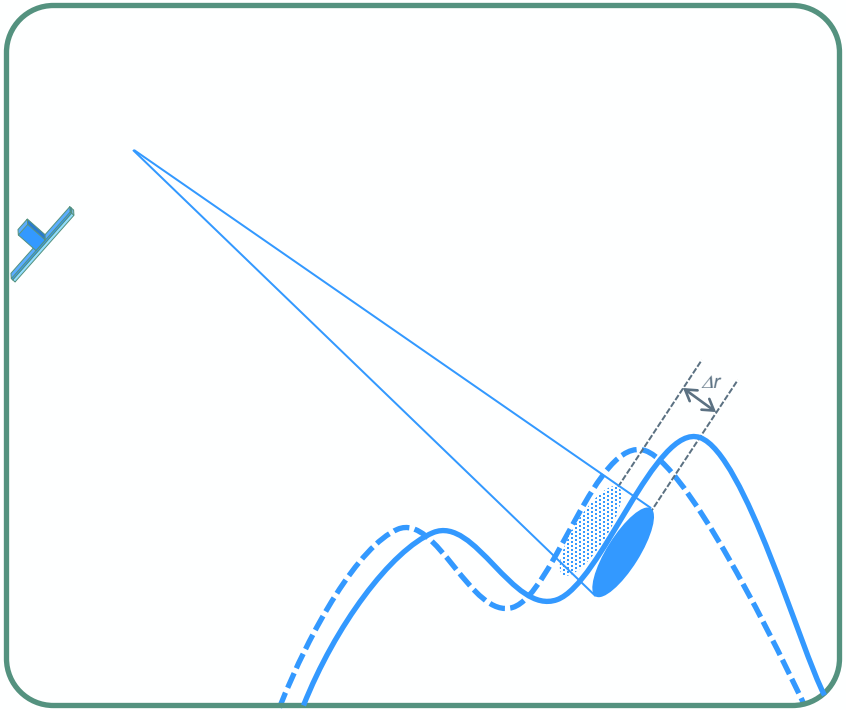
Harmony can observe slow movements in 3D with Repeat-Pass Interferometry.

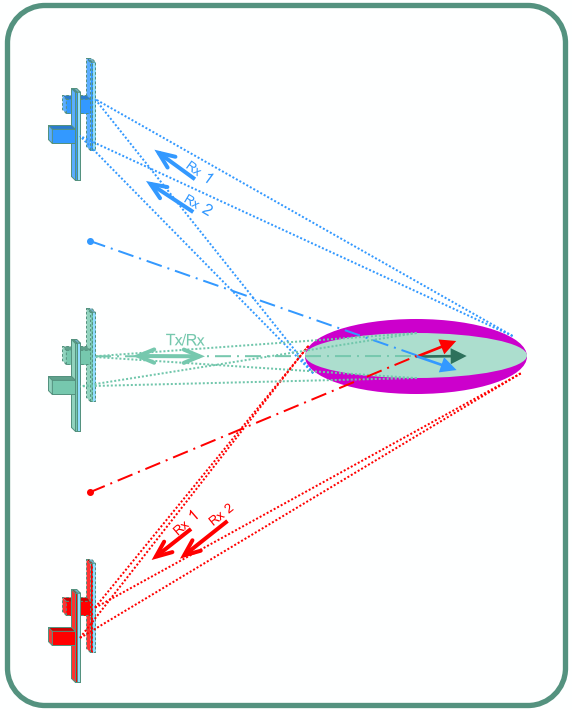
Observation Concept: Repeat-Pass Interferometry



STEREO

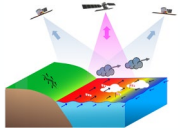
$$\Delta\phi = \frac{2\pi\Delta r}{\lambda}$$



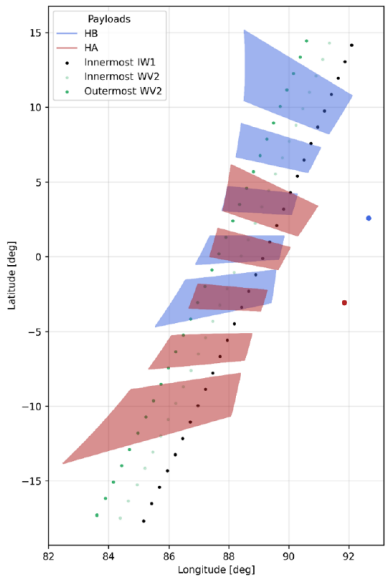


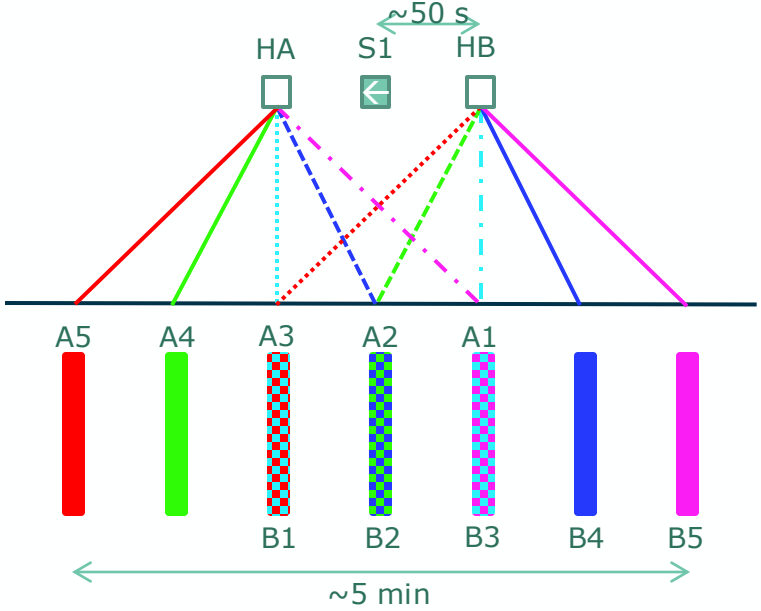
Harmony can observe slow movements in 3D with Repeat-Pass Interferometry.

Observation Concept: Thermal-Infrared



Band	Spectral Range
PAN	8.0-12.0 µm
CD-1	8.0-9.2 µm
TIR-1	10.4-11.3 µm
TIR-2	11.4-12.5 µm





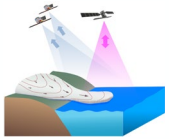
The Harmony TIR instrument is a multi-channel, multi-view instrument that can observe ocean and clouds whilst flying in the twilight of the dawn-dusk orbit.

Mission overview and observables

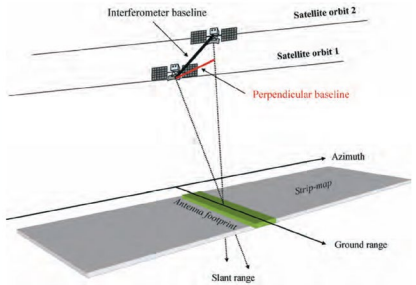
Single-pass cross-track interferometer

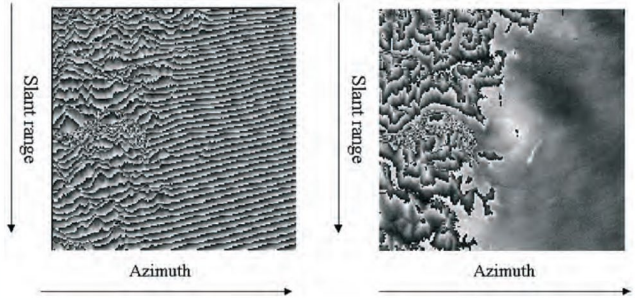
- 3-D surface deformation (as in Stereo)
- **Surface elevation time-series**
  - **Glaciers**, permafrost, icebergs
  - Volcanoes

Observation Concept: Across-Track Interferometry

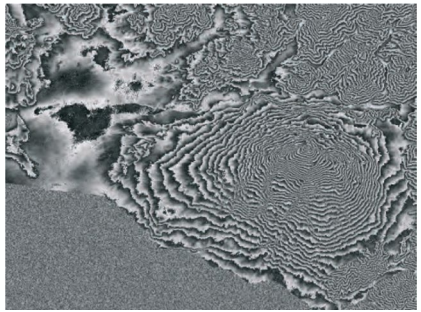


XTI





$$\Delta\phi = \frac{2\pi\Delta r}{\lambda}$$



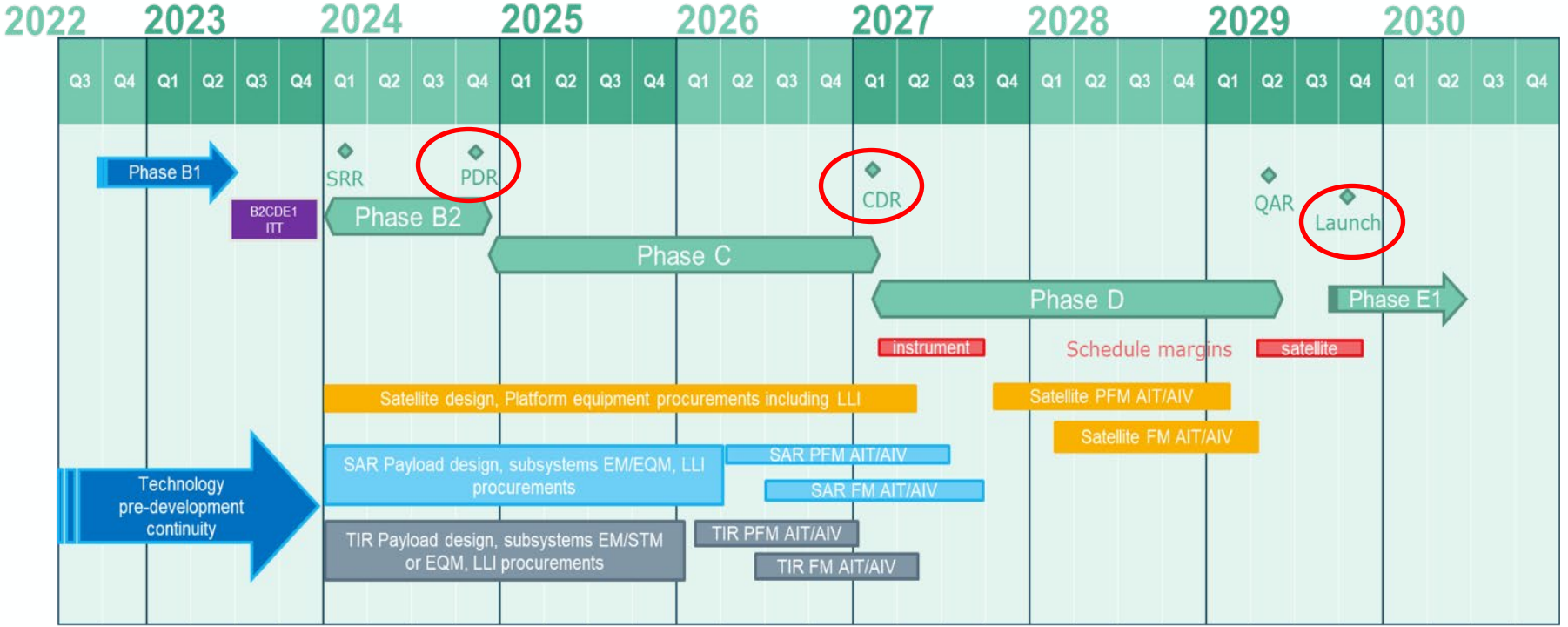
SOURCE: *InSAR Principles: Guidelines for SAR Interferometry Processing and Interpretation (TM-19, February 2007) ISBN: 92-9092-233-8*

Harmony can observe topography changes with Single-Pass Across-Track Interferometry (XTI).

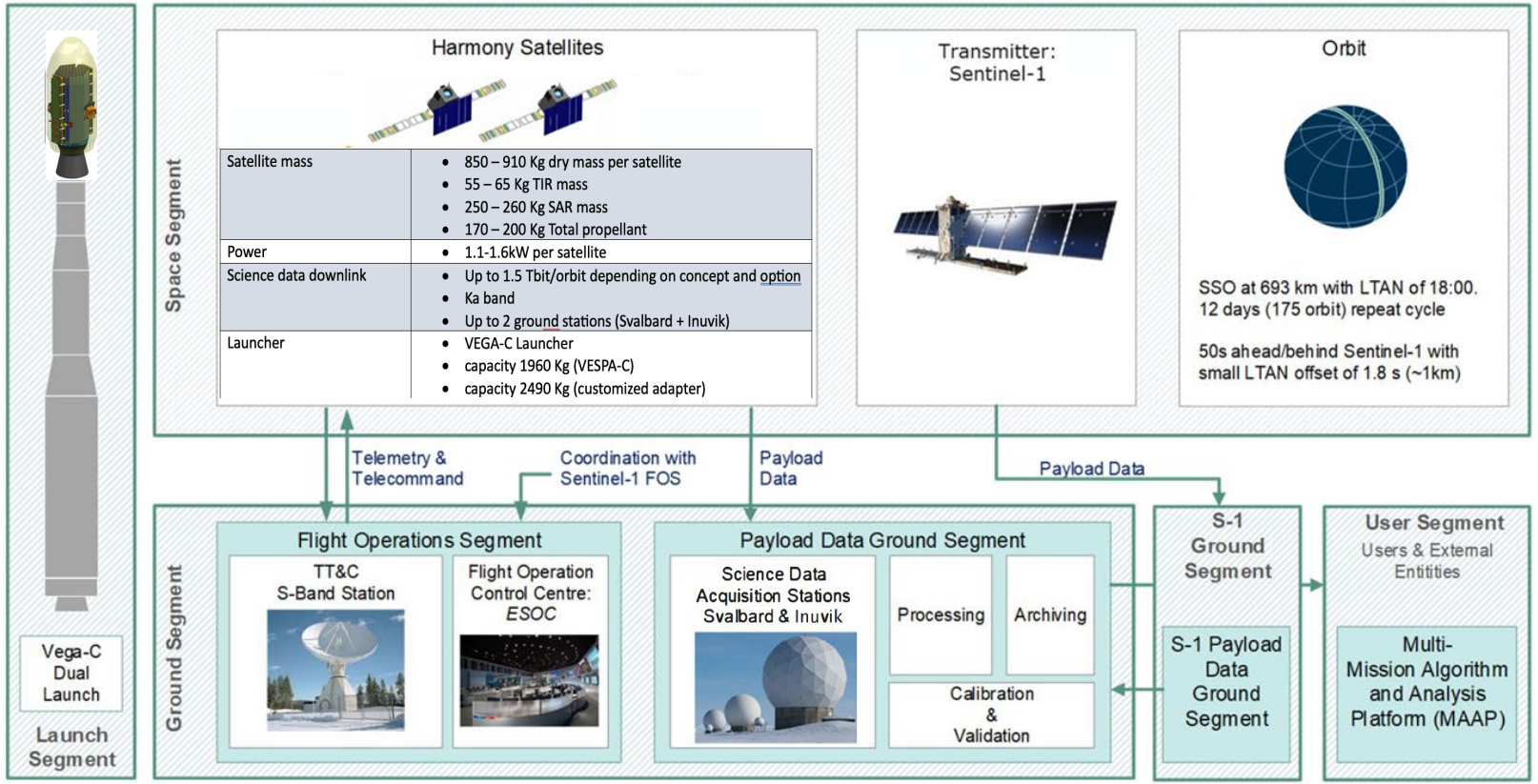
Science primary goals overview

Id	What	Techniques
H-O1	Air-sea interactions	High-resolution scatterometry, TIR, ATI-supported
H-O2	Air-oceans extremes	High-resolution scatterometry, ATI-supported, TIR-supported
H-O3	Upper oceans	High-resolution scatterometry, ATI (Doppler), TIR
H-C1	Glacier mass balance	XTI
H-C2	Glacier dynamics	XTI + DInSAR
H-G1	Tectonic strain	Multi-directional DInSAR

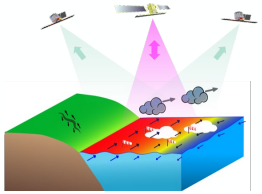
Harmony development schedule key dates

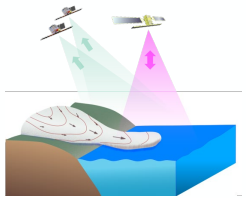


Mission Architecture Overview



Summary





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.

Key (driving) 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

Key (driving) science requirements

3D deformation	
	< 5% of velocity
↔	< 100 x 100 m^2
	seasonal

Solid Earth TOC	
	< 1 m
↔	< 30 x 30 m^2

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	
	< 0.5 m/yr
↔	< 100 x 100 m^2
	5 year

3D deformation	
	1 mm/year
↔	100 x 100 m^2
	5 year