EE-12 Proposal (LOI01-EE12-Irena-Hajnsek)

SKaDI

Ka-band Interferometric Radar for Cold Environments

Science Team

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Industry Team: **AIRBUS and OHB**

Primary Mission Objectives …

- **Permafrost landscape topography** and its dynamic evolution for studying active layer trends across large regions as well as thermokarst, major mass movements, and coastal erosion at local scale.
- **Snow topographic changes** to observe the snow mass accumulation for accurately quantifying & predicting snowmelt runoff and water availability.
- **Glaciers, ice caps, ice-clad volcanos** to observe their **mass balance** and its temporal change & to assess their dynamic response to changing boundary conditions.

1. Measure **gradual but widespread regional** topographic changes using repeat elevations with **high vertical accuracy over multi-year periods**.

Gradual landscape scale subsidence through ground ice loss

2. Measure abrupt **strong local** topographic changes using repeat elevations with **seasonal and high spatial resolution**.

4. Measure **canopy height variability** for the estimation of vegetation structure, productivity and change

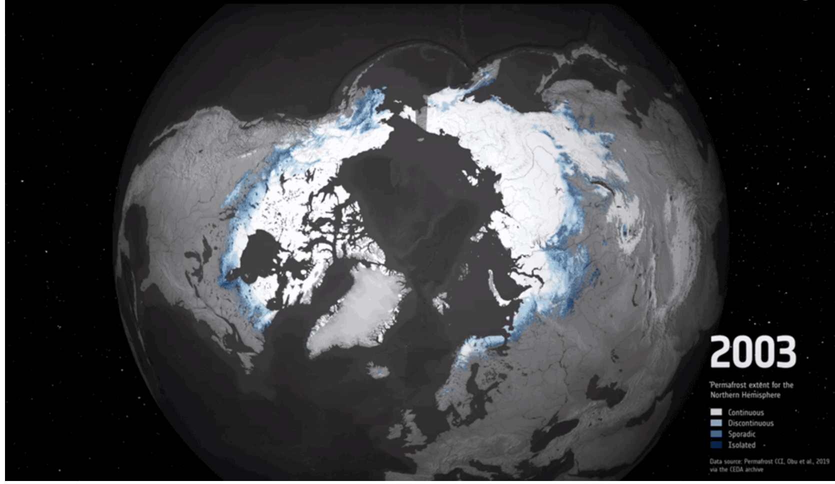
3. Measure **snow thickness distribution** as key driver of permafrost distribution and thermal state.

Science Rationale…

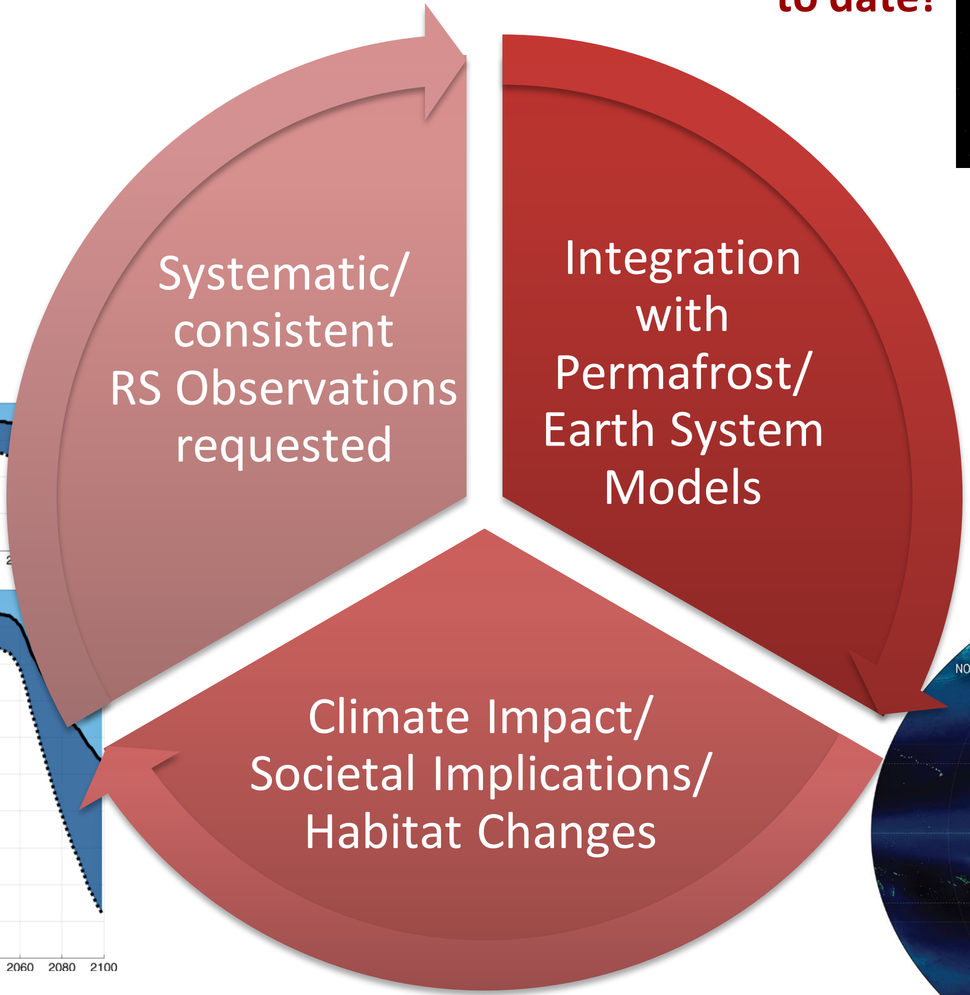
Dramatic changes in Arctic permafrost are emerging and are projected to increase – with strong impacts on climate, ecosystems, the Arctic economy, and local societies. Permafrost is a GCOS/WMO ECV!

Observations today…

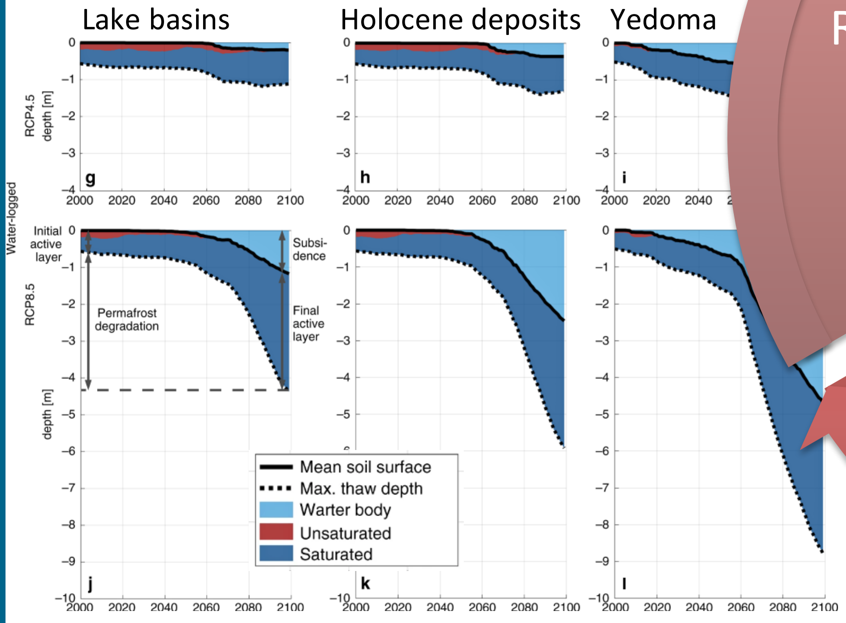
No dedicated permafrost satellite mission targeting the 22% of northern hemisphere land surface with permafrost to date!



Permafrost is a subsurface phenomenon. Reliable detection and understanding of changes requires an **integrated observing system with remotely sensed boundary conditions** as a key input.

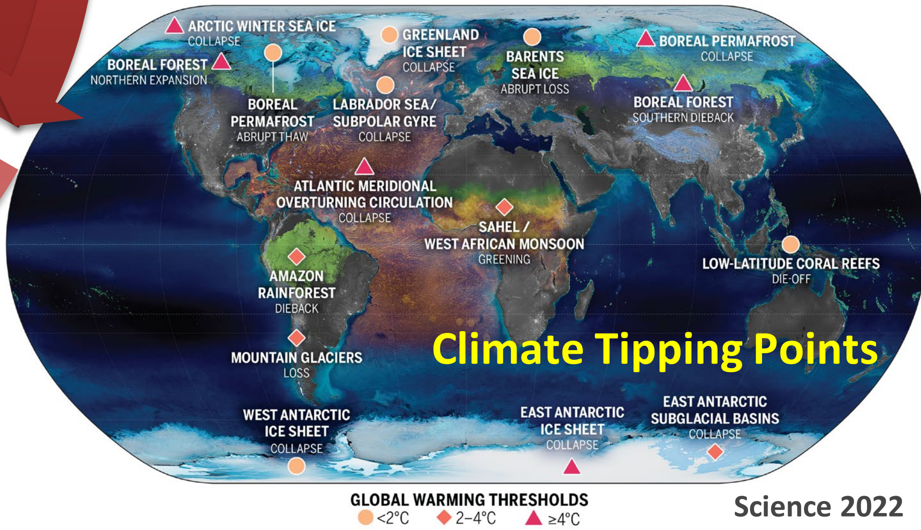


Predictions…



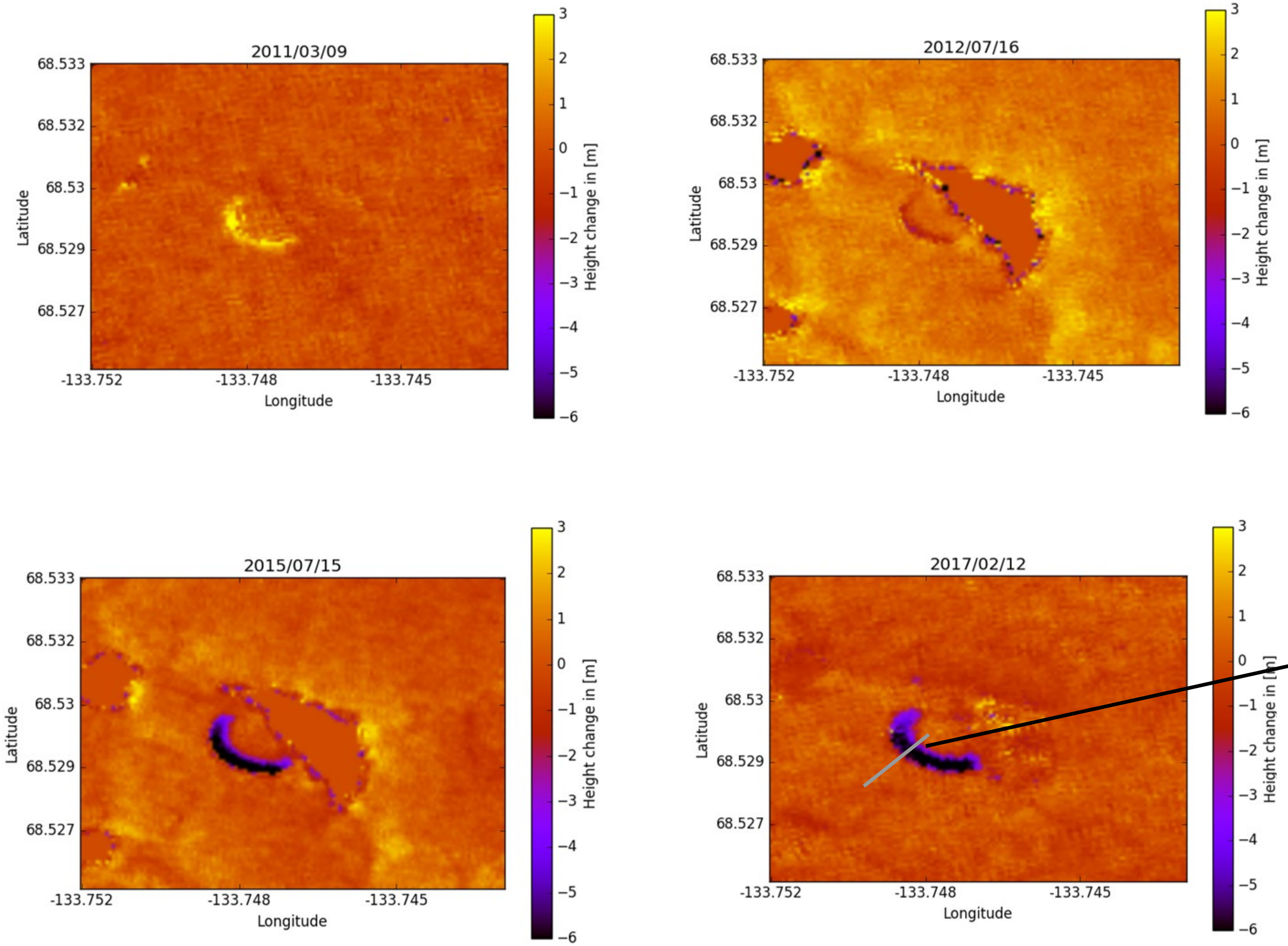
Drastic permafrost degradation

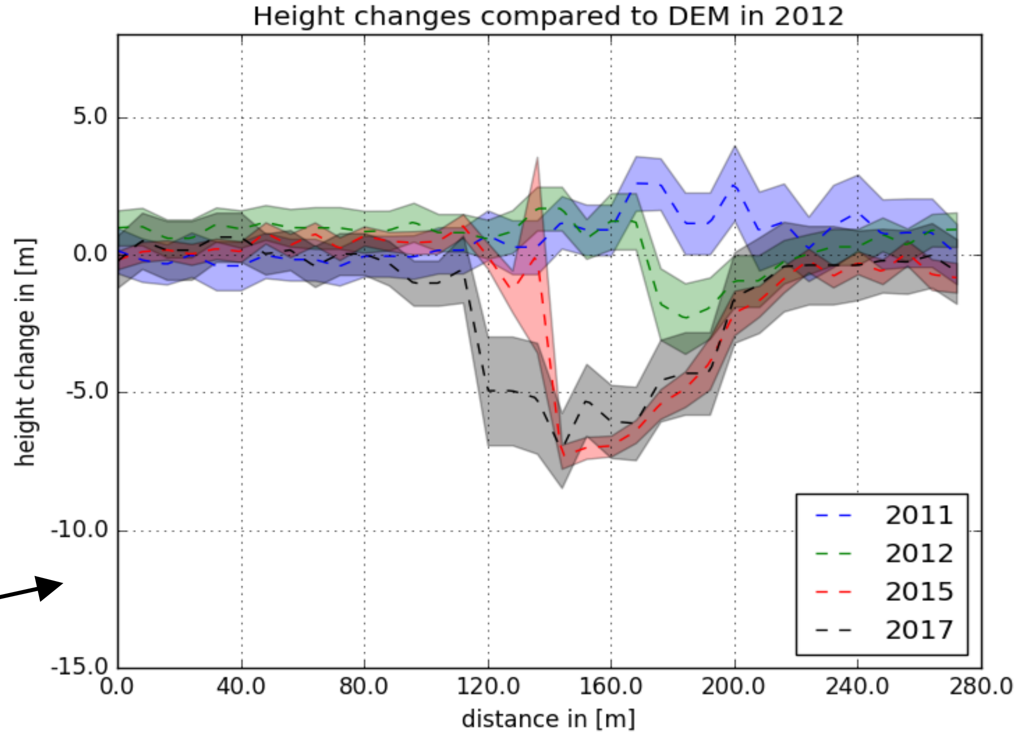
Nature Communications 2020



Science 2022

DEM Differencing over an (RTS) Retrogressive Thaw Slumps using TanDEM-X

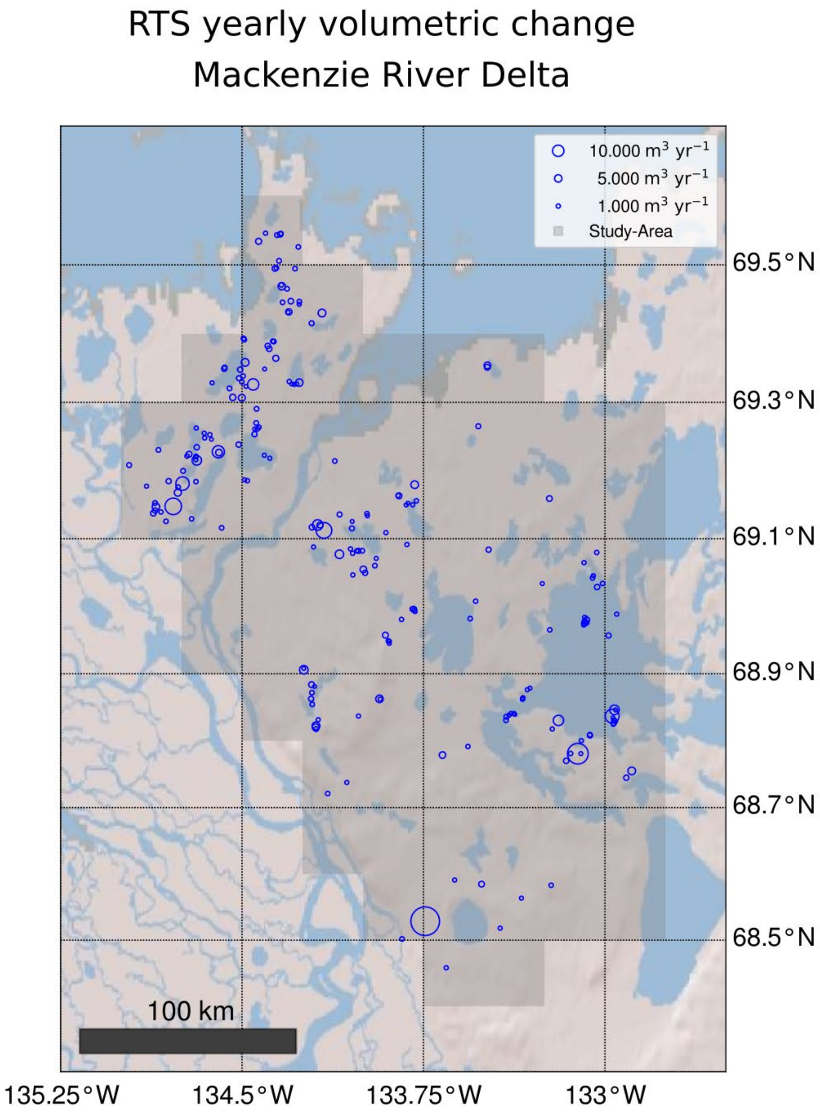


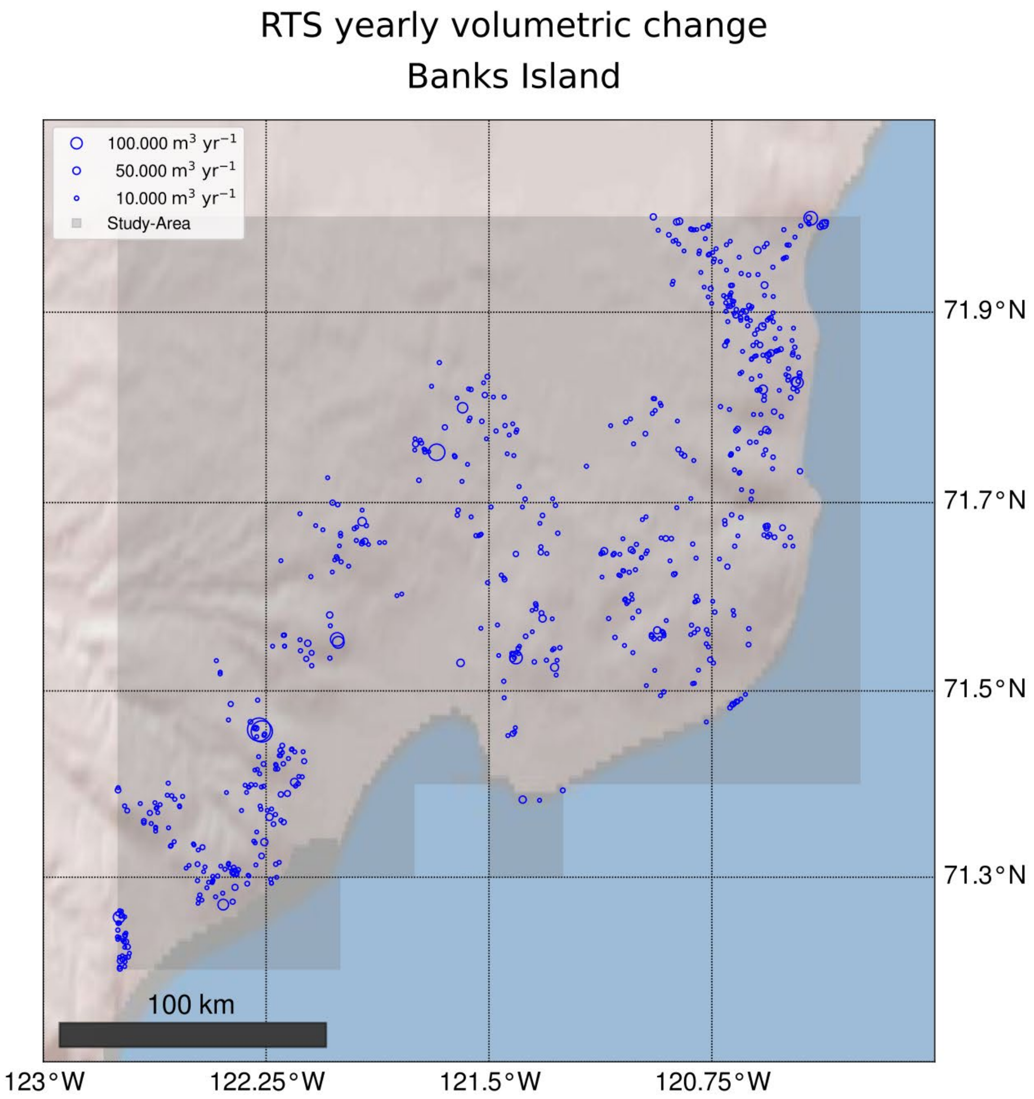


P. Bernhard, S. Zwieback, S. Leinss and I. Hajnsek, "Mapping Retrogressive Thaw Slumps Using Single-Pass TanDEM-X Observations," in *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, vol. 13, pp. 3263-3280, 2020, doi: 10.1109/JSTARS.2020.3000648.

POSTER FRINGE 2023:
Assessing TanDEM-X-Derived Digital Elevation Models for Monitoring Rapid Permafrost Thaw: A Case Study in the Mackenzie River Delta
Kathrin Maier et al.

From Height Differences to Volumetric Changes



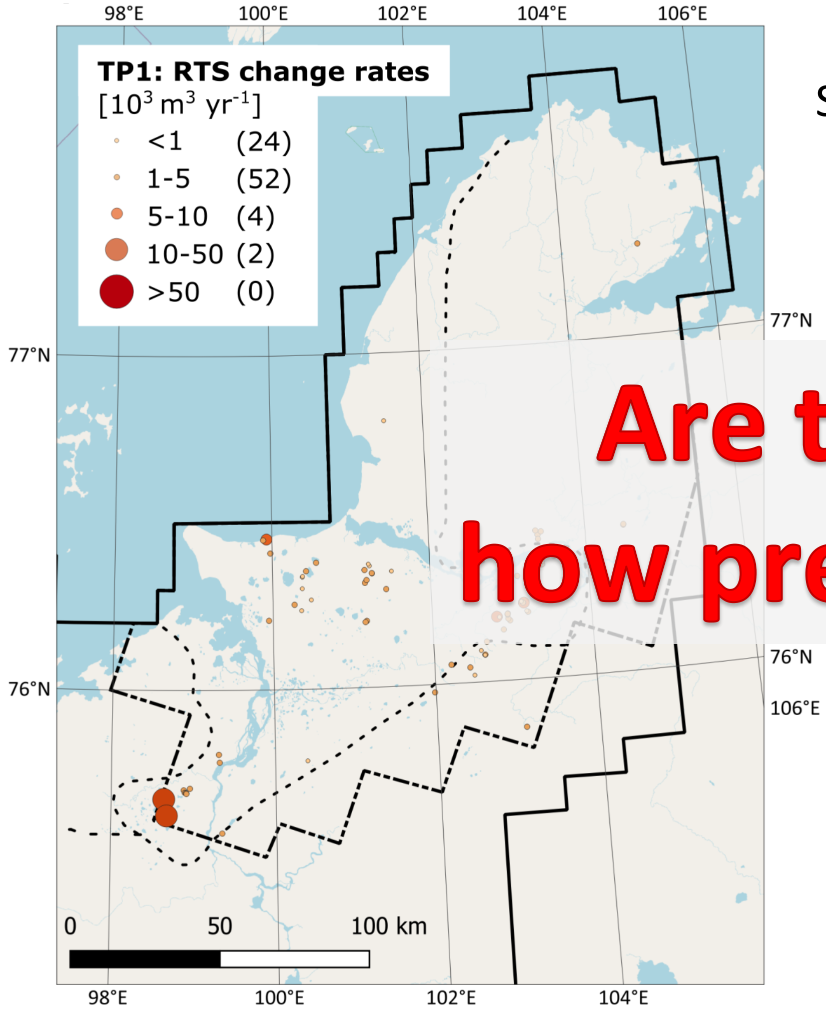


Using a power law relation developed for Landslides

Bernhard, P., Zwieback, S., Bergner, N., and Hajnsek, I.: Assessing volumetric change distributions and scaling relations of retrogressive thaw slumps across the Arctic, The Cryosphere, 16, 1–15, https://doi.org/10.5194/tc-16-1-2022, 2022.

Strong increase due to climate warming!

TP1: 2010/11/12 to 2016/17

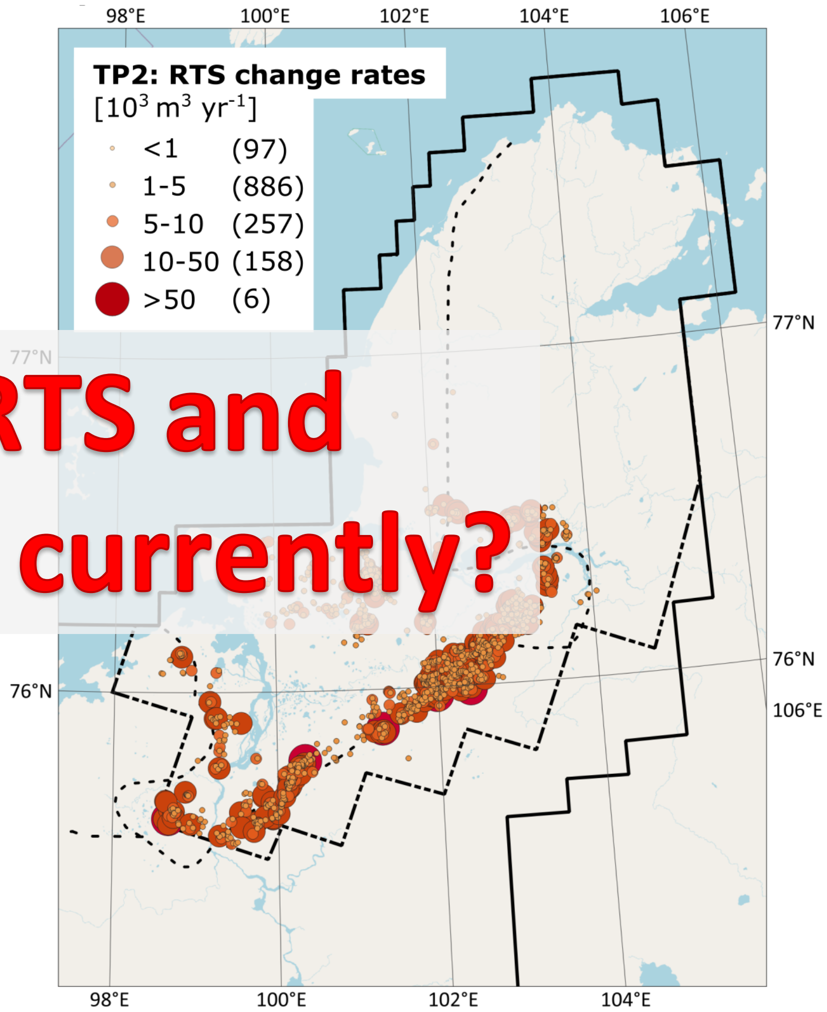


Strong increase in RTS activity:
82 RTSs → 1404 RTSs

42-fold increase in volumetric change rates

area change rates

TP2: 2018/19 to 2020/21



Are there more RTS and how precise are we currently?

Bernhard, P., Zwieback, S., and Hajnsek, I.: Accelerated mobilization of organic carbon from retrogressive thaw slumps on the northern Taymyr Peninsula, The Cryosphere, 16, 2819–2835, https://doi.org/10.5194/tc-16-2819-2022, 2022.

Science Requirements and SRL

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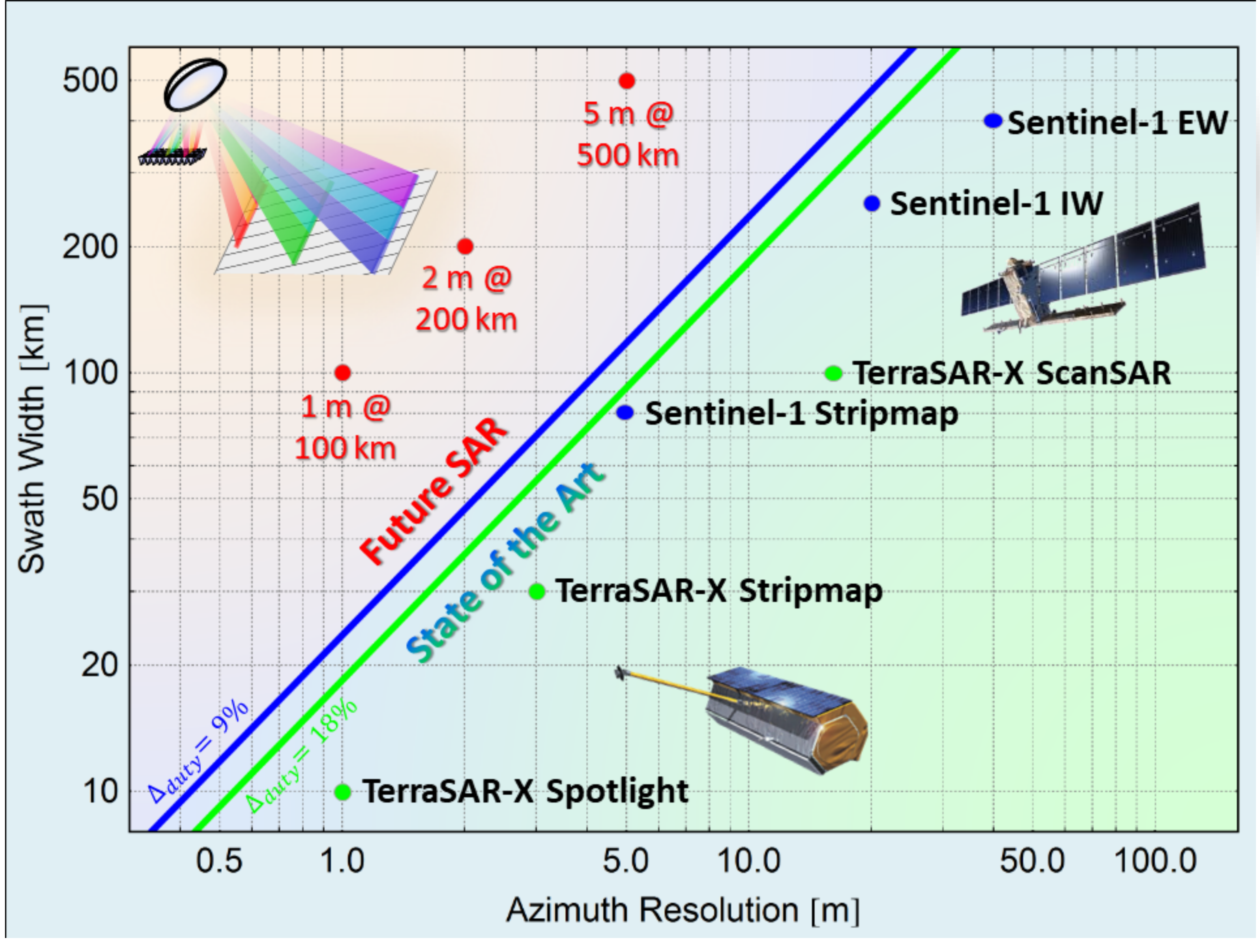
Parameter Link to Objective Nr.	Spatial Sampling	Temporal Sampling	Coverage	Accuracy (relative std. dev.)	SRL	Comments
Primary Parameter						
Topography change in permafrost regions lowland and mountain (Gradual Thaw)	100 m (T) 50 m (G)	1 seasonal (T) 1 monthly (G) (summer)	Regional scale – entire permafrost regions	0.2 m (T) 0.1 m (G) (vertical)	4	Relative change in elevation
Topography changes in local permafrost areas (Abrupt/Rapid Thaw)	20 m (T) 10 m (G)	1 monthly (T) bi-monthly (G) (summer)	Local scale, regions with high to moderately high ice content and the Arctic coastline	0.5 m (T) 0.2 m (G) (vertical)	4	Selected areas, relative change in elevation
Snow height change	100 m (T) 30 m (G)	1 month (T) 1 week (G) (winter)	Snow covered regions during winter, gridded sampling	0.3 m (T) 0.1 m (G) (vertical)	4	Relative change in elevation / compact mode
Surface elevation change (SEC) glaciers & ice caps	50 m (T) 30 m (G)	3 yr (T) ~1 yr (G)	Mountains and mid- to high-latitude lowlands, ice caps, outlet glaciers	1.0 m (T) 0.3 m (G) (vertical)	4	Relative change in elevation
Secondary Parameter						
Vegetation structure	100 m (T) 50 m (G)	2 yr (T) 1 yr (G)	Entire permafrost and tropical forest sampling	horizontal and vertical structure	2-3	Relative change in elevation and structure from interferometric phase & coherence, experimental
Sea ice topography/roughness and fresh water topography	20 m (T) 10 m (G)	1 month (T) 7 days (G) (winter)	Artic sea ice, gridded sampling	0.5 m (T) 0.2 m (G) (vertical)	3	Relative change in elevation, experimental
Geohazards (landslides, rockfalls, mining, landfill, volcanic activities, seismic events)	100 m (T) 50 m (G)	½ yr (T) 10 days (G)*	Cold environment, sampling on demand	2 m (T) 0.3 m (G) (vertical)	4	Relative change in elevation, *depending on activity of phenomena
Topography of land surfaces	100 m (T) 50 m (G)	5 yr (T) 1 yr (G)	All land surfaces	5 m (T) 0.5 m (G) (vertical)	4	Basic DEM update

Mission Requirements

Basic Requirements:

- **Swath width**: min. 50 km (preferable more)
- **Spatial resolution**: ~1.5 m
- **Repeat time**: as frequent as possible (preferable weekly)
- **Imaging mode**: single-pass SAR-Interferometry

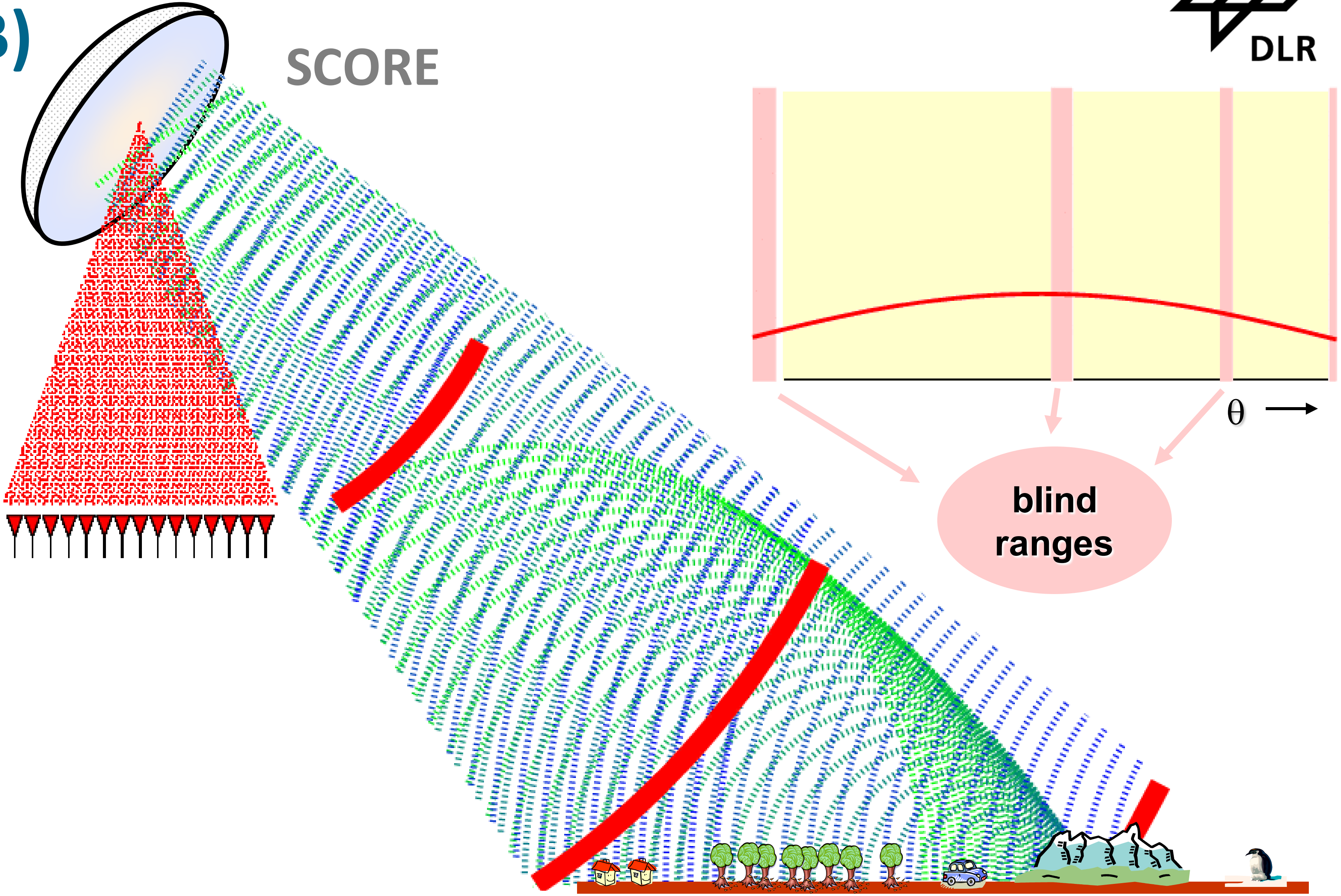


Challenging requirements with conventional imaging modes in Ka-band

Two Industry Consortia (AIRBUS and OHB)

Discussed Instrument Concepts:

- Score-on-receive (SCORE)
- Staggered SAR
- Frequency SCAN for Time-of-Echo Compression (f-STEC)
- Photonic Beamforming



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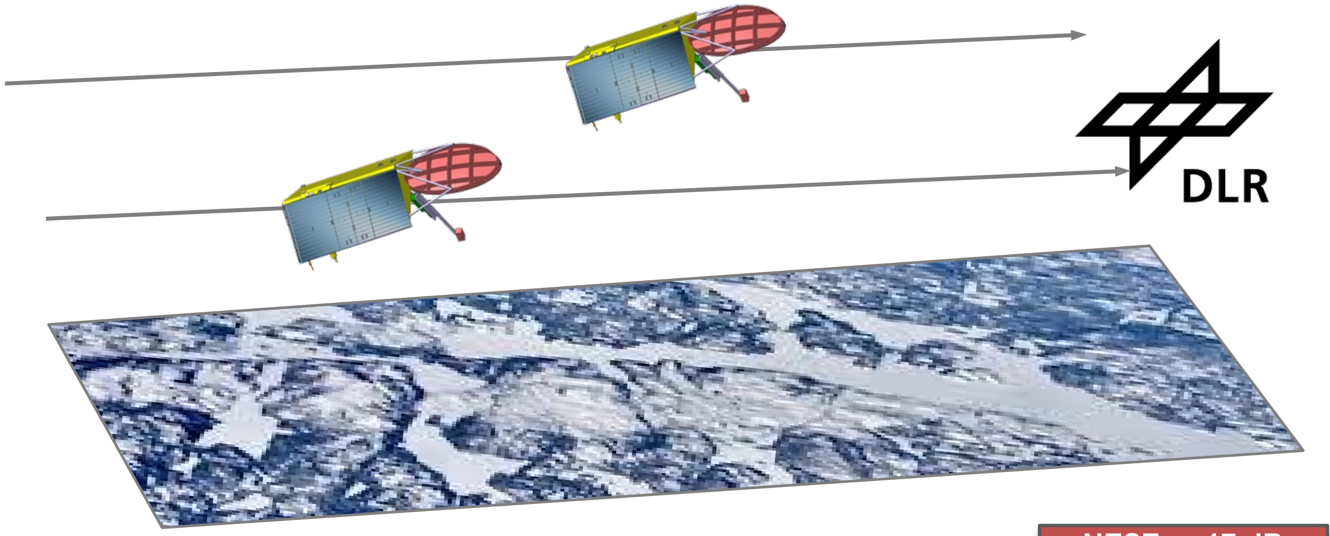
Mission Characteristics

- Mission for cold environment (Arctic and high alpine)
- **Single-Pass Interferometer** in Ka-band (two satellites)
  - Single HoA (30 m) and dual HoA (15 m)
- **Polarimetric** capabilities (dual/quad pol)
- **SAR specification:**
  - Spatial high resolution (tbd ~1.5 m)
  - Decimetric height accuracies (~10 cm)
  - Global DEM over the mission time
- **Products:**
  - Δ DEMs
  - Vegetation topography and structure
  - Density/Grain size of snow (polarimetric scattering)
  - Penetration bias of snow and ice

DLR



Performance Analysis (dual baseline)

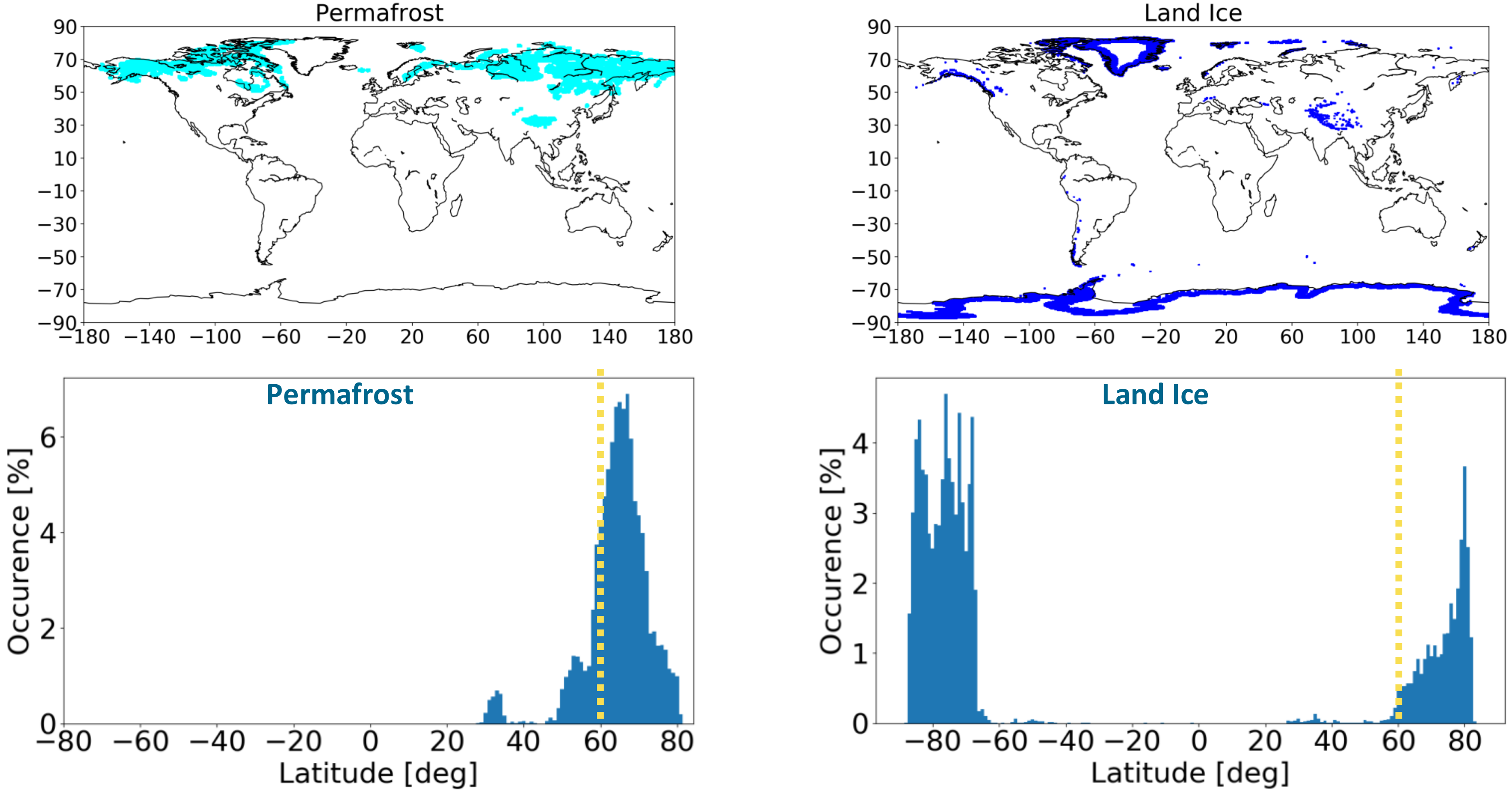
NESZ = -17 dB
Slope = 0%
dp = 0.5 m

Parameter Link to Objective Nr.	Spatial Sampling	Accuracy (std. dev.)	Brg = 150 MHz HOA = 15 m	
Primary			Wet Snow	Dry Snow
Topography change in permafrost regions	20 m (T) 10 m (G)	0.5 m (T) 0.2 m (G)	0.22 0.46	0.12 0.25
Snow height change (SEC)	100 m (T) 30 m (G)	0.3 m (T) 0.1 m (G)	0.04 0.15	0.02 0.08
Surface elevation change (SEC) glaciers & ice caps	50 x 50 (T) 30 x 30 (G)	1.0 m (T) 0.3 m (G)	0.09 0.15	0.05 0.08
Secondary				
Sea ice topography/ roughness and fresh wáter topography	20 x 20 (T) 10 x 10 (G)	0.5 m (T) 0.2 m (G)	0.22 0.46	0.12 0.25
Geohazards (landslides, rockfalls, mining, landfill, volcanic activities, seismic events)	100 m (T) 50 m (G)	2 m (T) 0.3 m (G)	Bare soil: 0.03 0.06	
Topography of land surfaces	100 m (T) 50 m (G)	5 m (T) 0.5 m (G)		

From Application to Mission Requirements

- **Temporal sampling:**
  - 1 month (G) over permafrost regions (topography change): **driving requirement**
  - 1 week (G) over snow regions (topography change)
  - 1 year (G) global surface acquisition (for global DEM change, glaciers and ice caps): no criticalities

- **RoI Masks and latitudes of interest**



Mission Concept, Phases and Orbit Selection

Key Mission Parameters

- Orbit Height = 519 km (reference orbit)
- Swath Width = 50 km
- Incident Angle = 30° (mid swath)
- NESZ ≤ 17 dB
- 2D resolution ≤ 10 m^2
- HoA ~15 m

Mission Phase 1: Permafrost (May - October)

- **29 days repeat@ 519 km** (518.7 km), n. revs = 439
  - track separation at the equator: 91 km
  - full coverage with 50 km swath at 56.78° lat
- 1st month: Inc. angle (27.67° - 32.32°)
- 2nd month: Inc. angle (32° - 36.3°)
- Swath Overlap: 3.62 km

Mission Phase 1: Permafrost (May - October)

- **65 days repeat@ 519 km** (518.5 km), n. revs = 984
  - track separation at the equator: 41 km
  - Inc. angle (27.67° - 32.32°)

Mission Phase 2: Snow (November - April)

- 7 days repeat @ 517 km, n. revs = 106

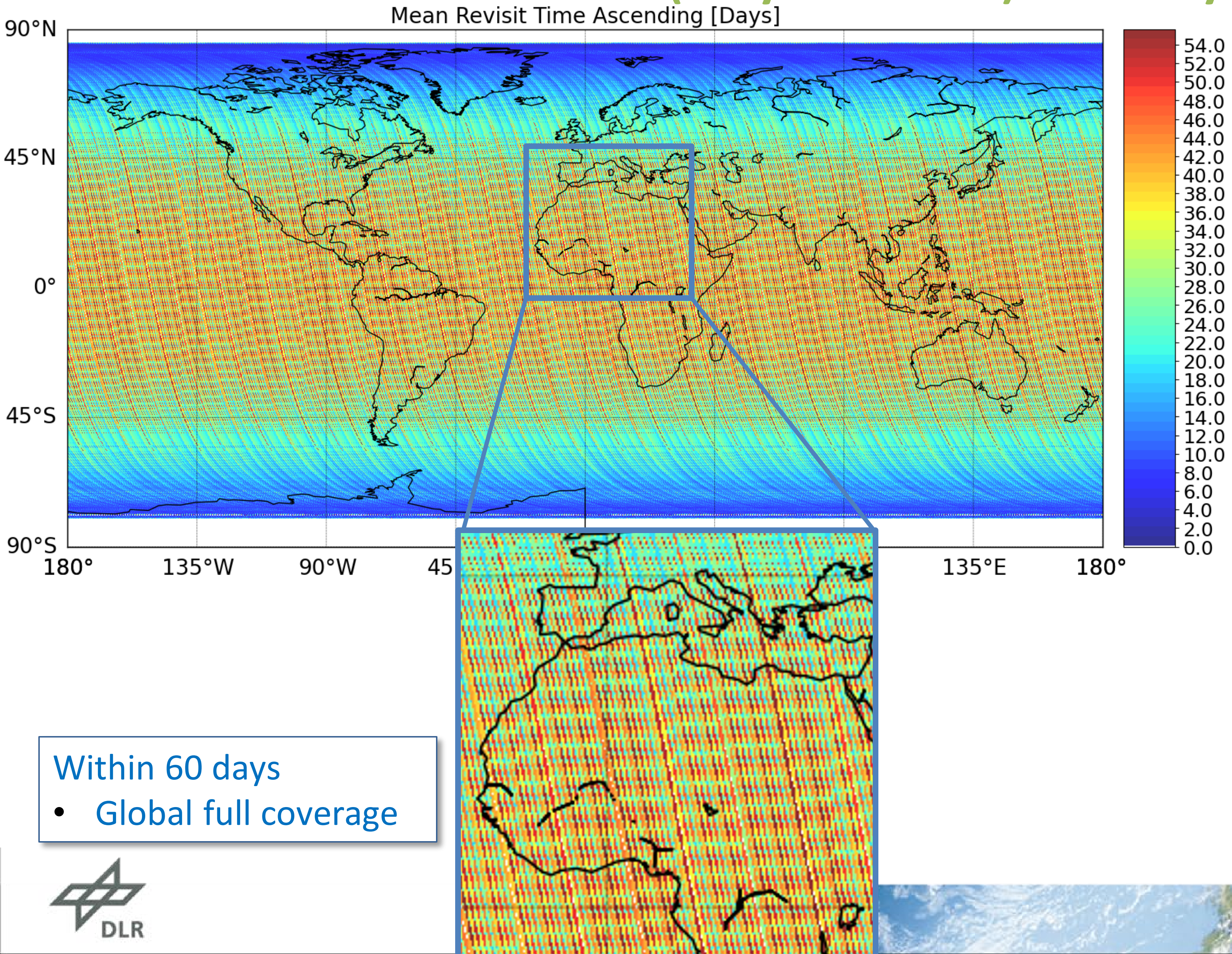
Mission Phase 3: Global DEM

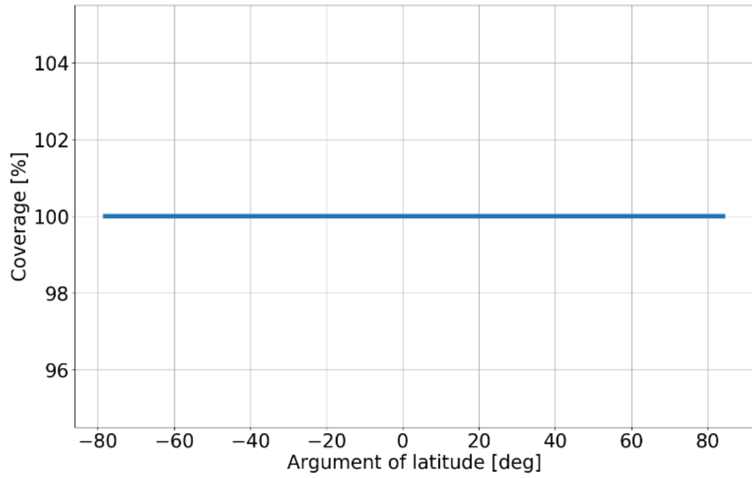
- Same orbit as for phase 1, or
- Longer Orbit repeat

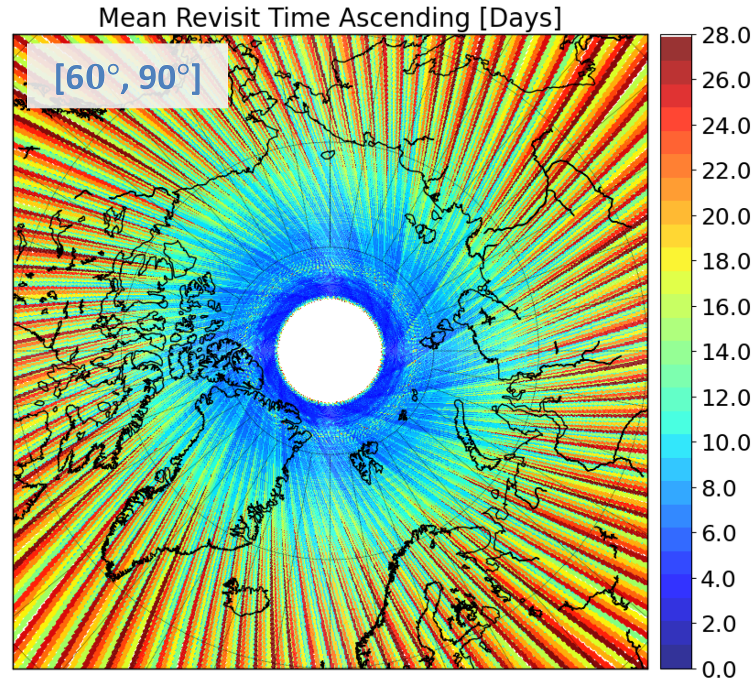
Mission Phase 1: Permafrost (May - October) - 29-Days Orbit

Swath Width = **50 km**

1st Month: (27.7° - 32.3°) and 2nd Month: (32° - 36.3°)







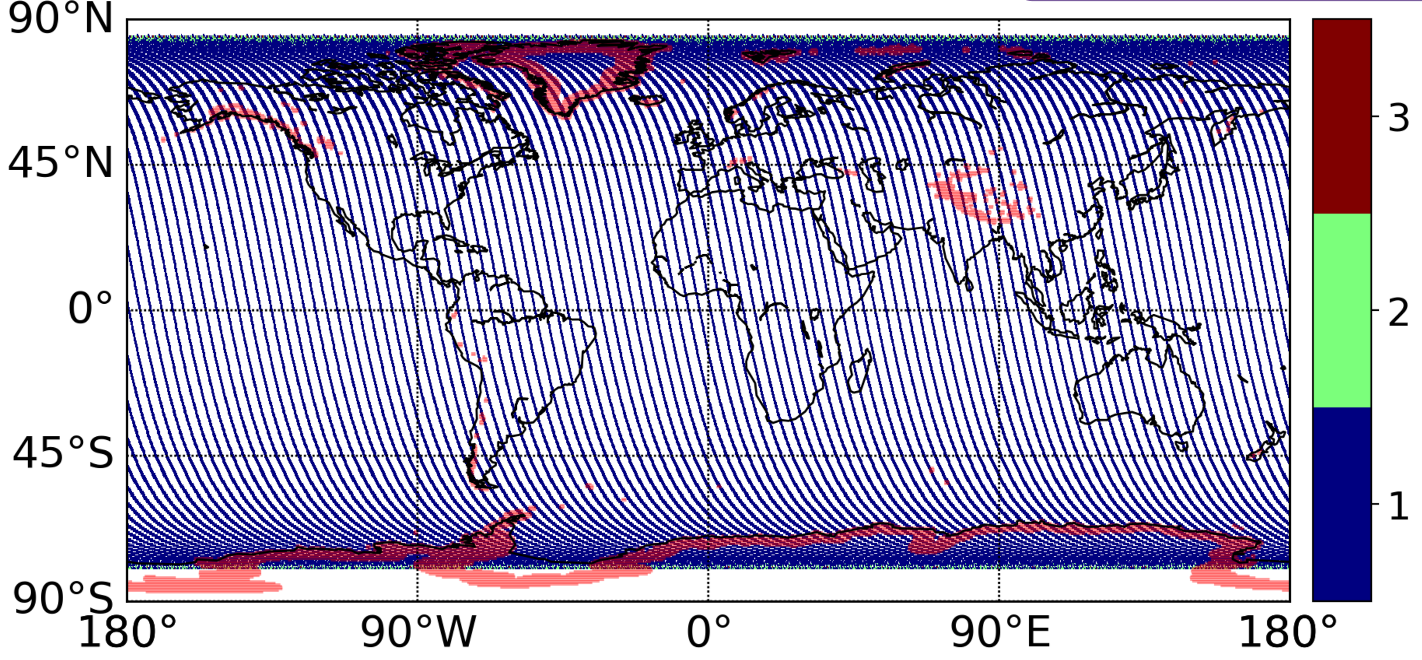
Within 60 days

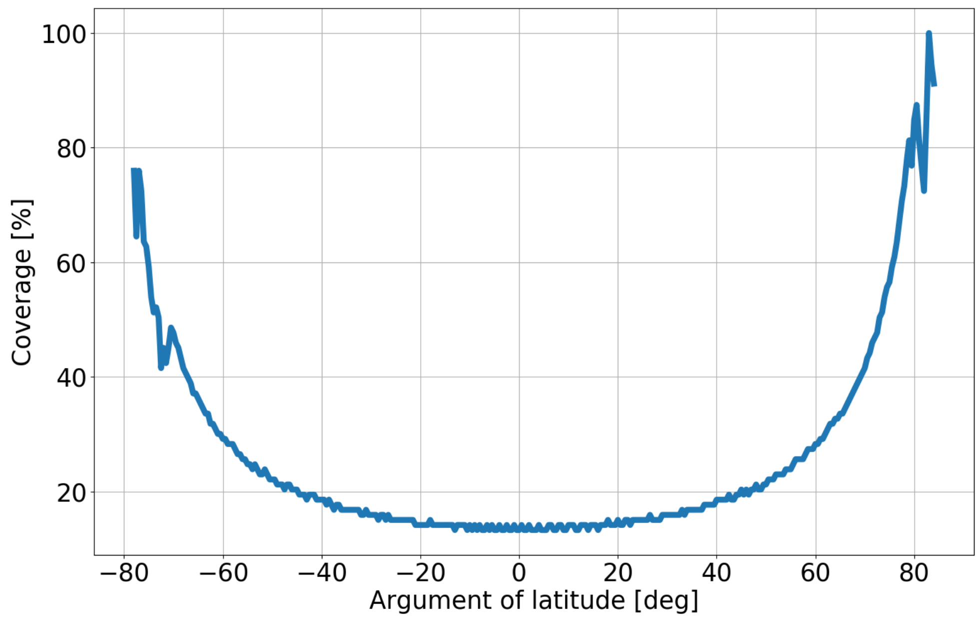
- Global full coverage

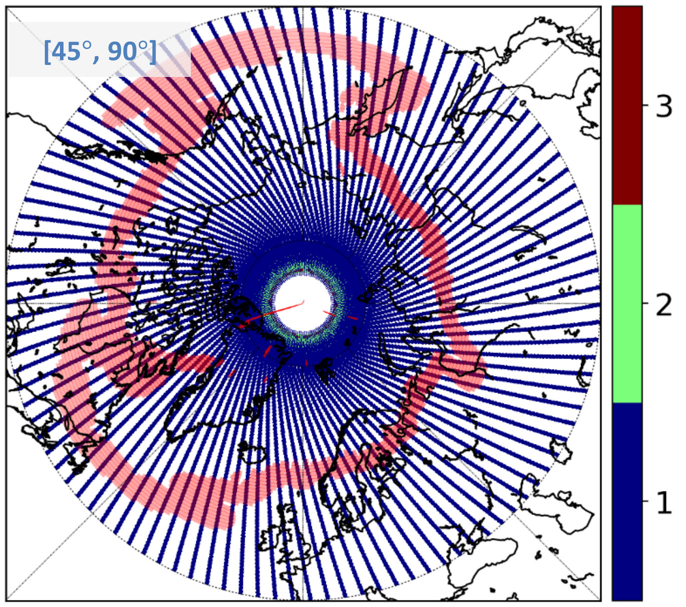
DLR

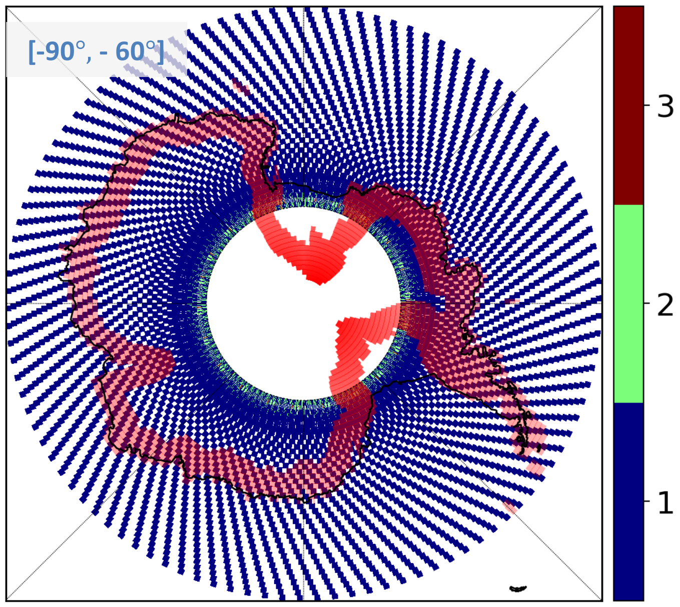
Mission Phase 2

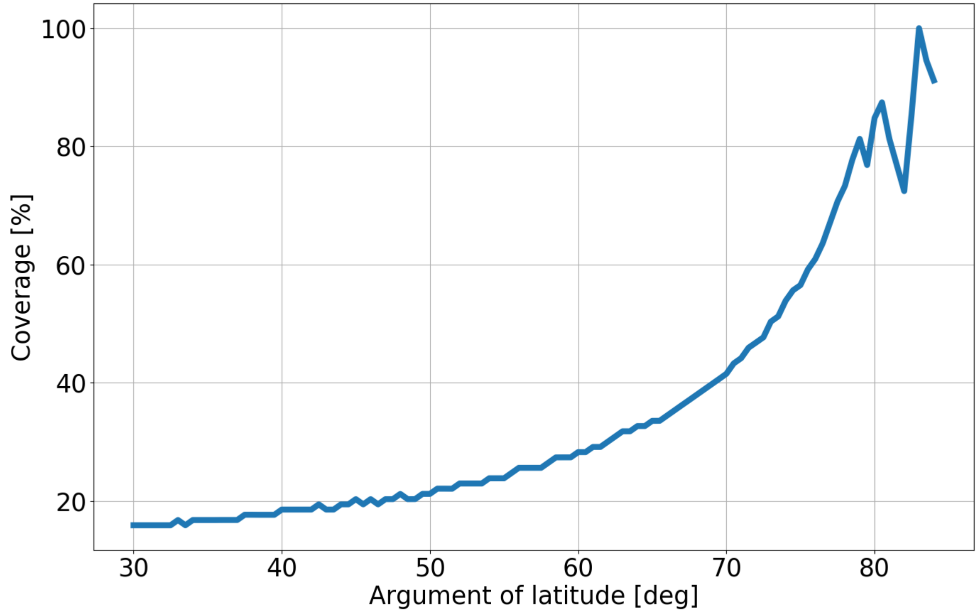
7-days orbit: ascending only
Inc. Angle: (27.7° - 32.3°)











Programmatic Elements

SKADI addresses

- **Three Key Scientific Challenges** of ESA's Living Planet Programme for the Cryosphere, Solid Earth and Land Surface.
- **Societal Issues** of ESA's Living Planet Programme (climate, biodiversity, food and water, natural energy, hazards).

Uniqueness, Complementarity and Synergies

- **Small penetration** - of very few cm - in the media of interest (ice, snow, permafrost and vegetation).
- **Synergies/complementarities** between a Ka-band mission and **other existing missions** in ESA's Copernicus and Earth Explorer programs (e.g., Sentinel-1/2/3, Biomass, CryoSat, CRISTAL, Rose-L, Harmony,…)
  - differential single-pass measurements
  - sensitivity to very small structures

Need, Usefulness, Excellence

- SKADI will collect unique data that are urgently needed to answer pressing science and societal questions, supported by highly qualified experts. (ECVs, Earth system tipping elements)

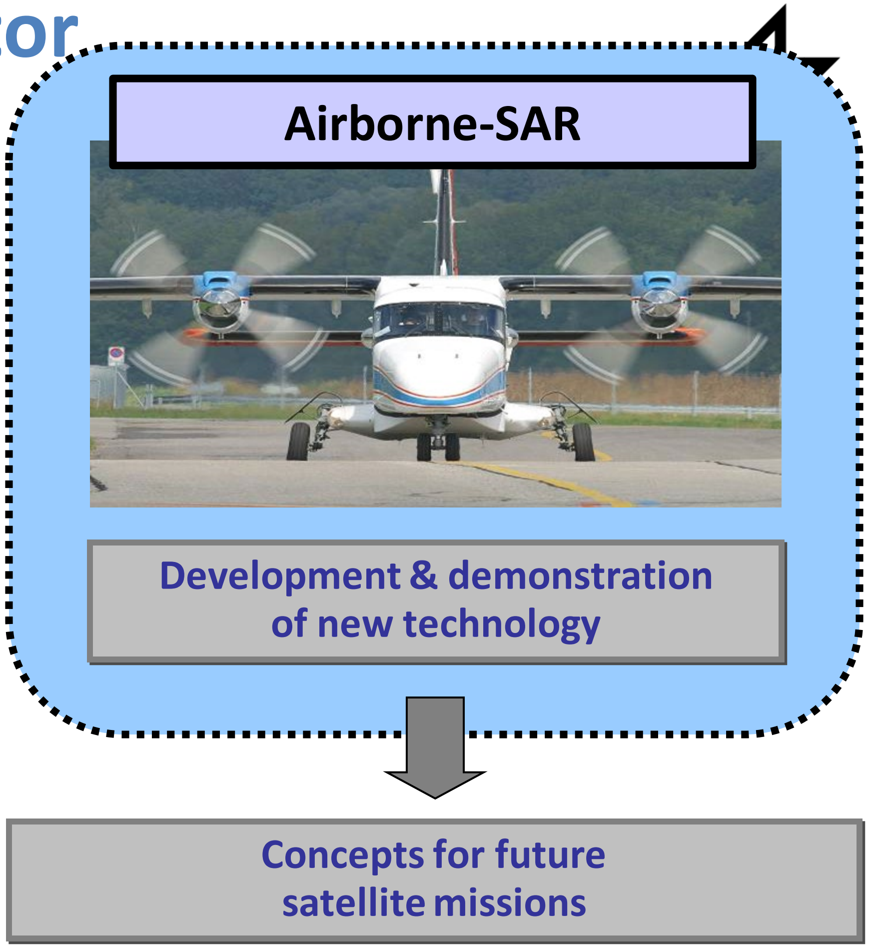
Feasibility and Level of Maturity

- Benefits from ESA's **strong heritage and innovative programmatic element** due to its many science and mission concepts as well as instrument design studies.
- Instrument design: Strong heritage and innovative implementation concepts (TRL 5-6 at end of phase B1).

Recommendation and Next Steps

- There is a need of more studies related to innovative imaging techniques/frequencies!
- Lack of Ka-band data - support of Ka-band **airborne campaigns**
- **Ground based sensors**: Evaluation of WBSCAT (Gamma Remote Sensing) acquired data over a snow season.
- **Proposal submission to the ESA's EE-12 call.**

Outlook DLR's Ka-Band PolInSAR Demonstrator



Goals:

- Add-on for the DBFSAR/F-SAR System in form of a Ka-band segment with multi-baseline PolInSAR capabilities
- Research of Ka-Band applications and techniques (polarimetric and interferometric)
- Operation together with X- and L-band segments of F-SAR

Radar specification:

- 35.75 GHz
- 500 MHz bandwidth
- +59 dBm transmit power (typ.)
- PRF up to 15 kHz
- 8 simultaneous receive channels
- +2km swath width expected

Antenna specification:

- Dual-polar transmit and receive antennas (single-polar in 1st generation) in slotted waveguide technology
- 4 across-track antenna positions (3 baselines)
- Possibility for ping-pong (full-baseline) modes
- 1 along-track baseline as future option

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