# TA2 Breakout Session topic

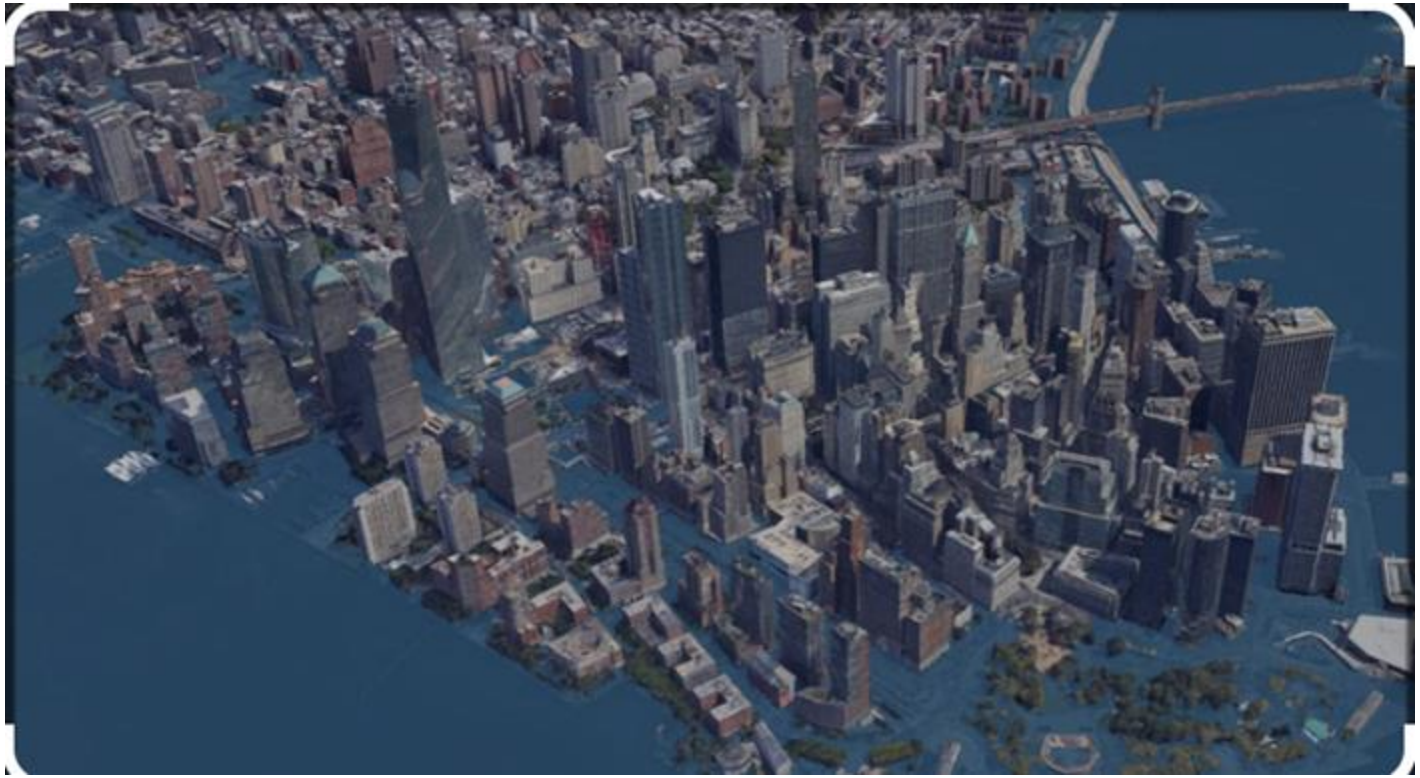
## TA2: InSAR applications

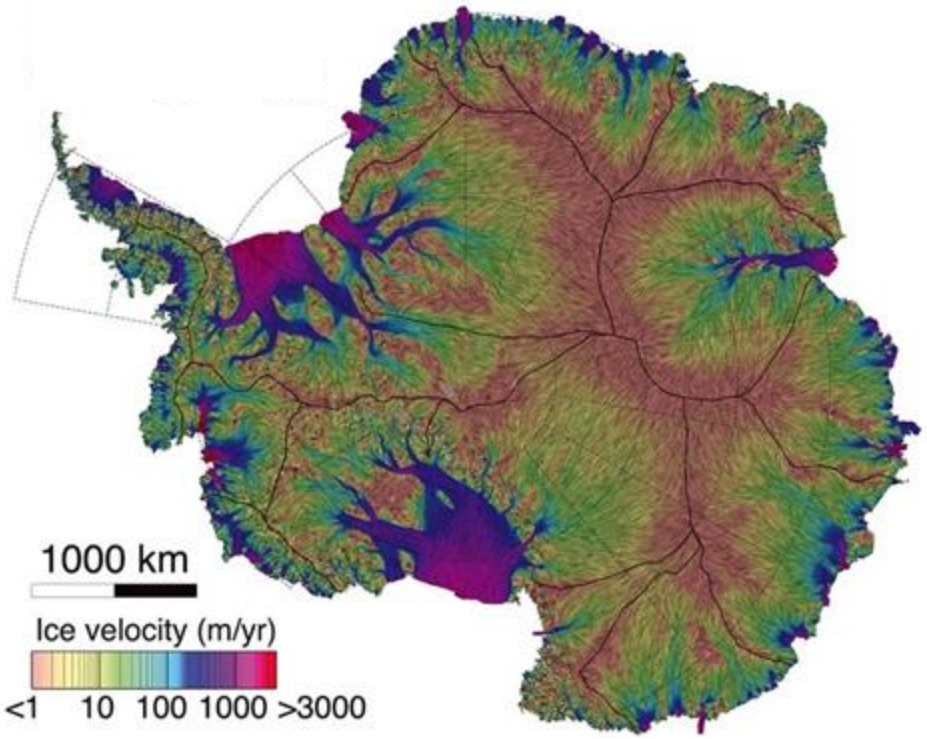
- Ice Sheets & Glaciers (Eric Rignot & Bernd Scheuchl)
- Hazards (Tomokazu Kobayashi and Cathleen Jones)
- Solid Earth Science (Yujie Zheng, Andy Hooper, Mark Simons)
- Permafrost (Line Rouyet & Annett Bartsch)
- Ocean Applications (Paco Lopez Dekker, Johnny Johanessen, Bjorn Rommen)
- Non-zero Baseline InSAR (Bjorn Rommen)

# Observation requirements for Ice Sheets and Glaciers

Eric Rignot (University of California Irvine and NASA's Jet Propulsion Laboratory, USA) & Bernd Scheuchl (UC Irvine, USA)
erignot@uci.edu ; bscheuch@uci.edu

Sea level rise worse than you think (1 to 2 m), "deep uncertainty" in rapid change, $T cost, new coastline w. pop. migration

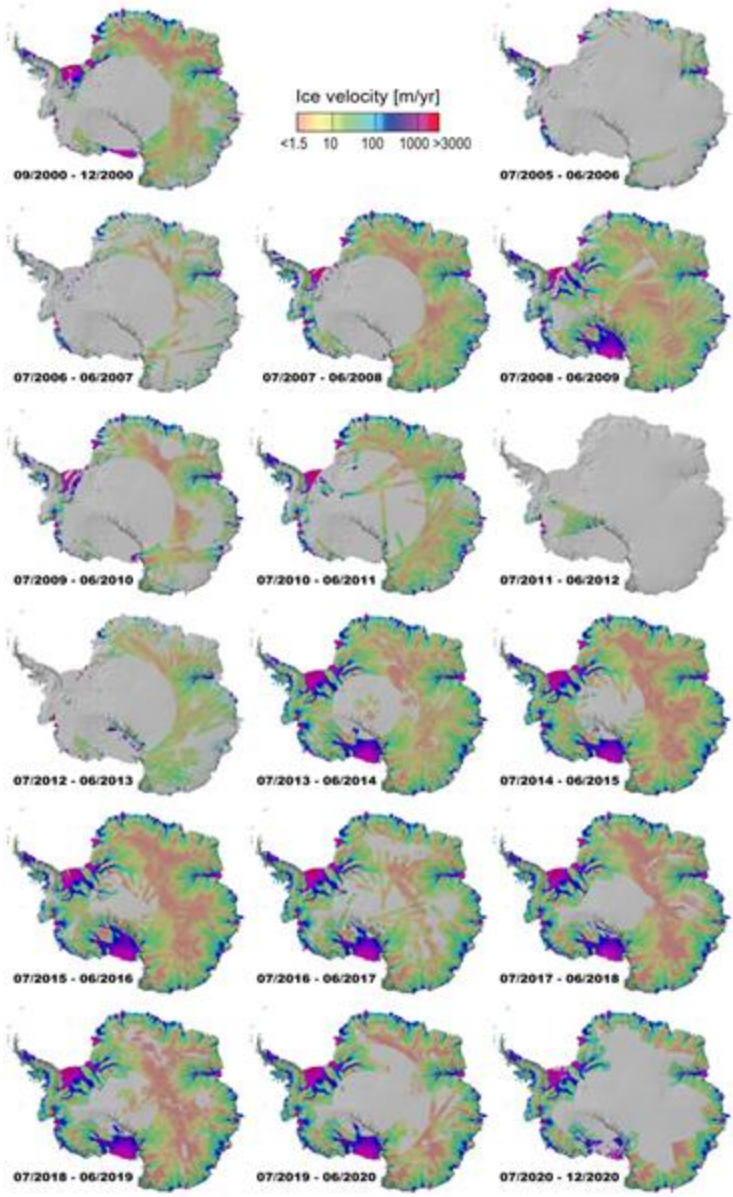




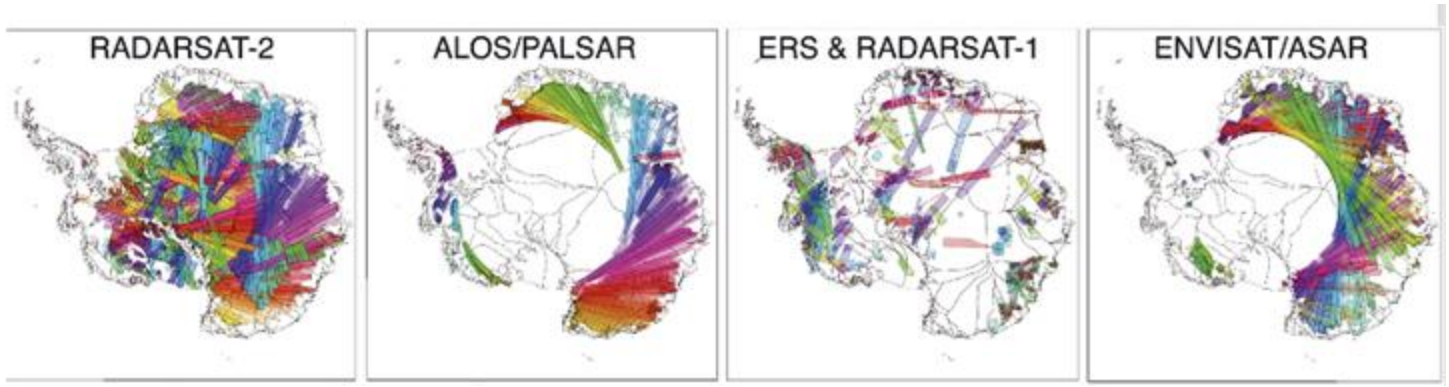
## State of the Art & Gap analysis 1/3

Interferometric SAR (InSAR) has revolutionised the study of ice sheets and glaciers since the 1990s: first comprehensive map of ice velocity and grounding line in Greenland and Antarctica. Results enabled ice sheet mass balance assessments, contributions to sea level, and identification of instabilities in West Antarctica. Projections of sea level rise by models heavily rely on these early discoveries and observations.

- **Strength:** From ERS-1, a virtual constellation of SAR missions assembled in the 2000s, grew, allowing annual and now monthly maps, but with incomplete coverage.
- **Coordination** between agencies via the Polar Space Task Group (PSTG) for IPY 2007. Focus on science ensured its success and agency buy-ins (NASA, ESA, CSA, JAXA).
- **Threat:** Limited access to observations will slow progress in ice sheet modelling and degrade science information for policy makers and city planners to guide “adaptation to” and “mitigation of” rapid sea level rise.
- **Opportunity:** Revive PSTG (or equivalent) for IPY 2032.
- **Goal:** Optimize use of space assets based on strength and availability to fulfil science requirements via a multiple agency organization (everyone).

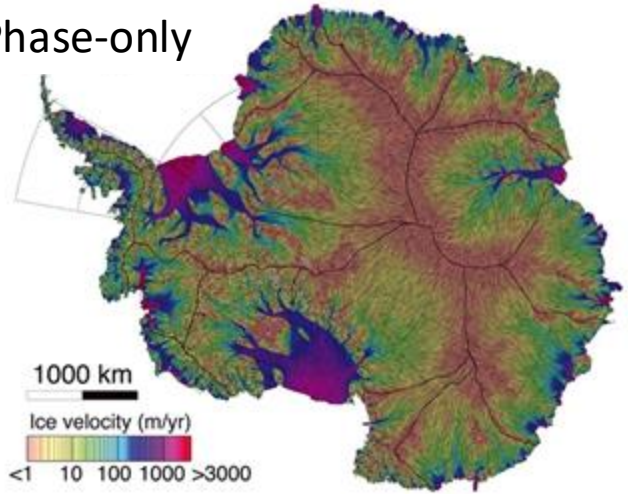


## State of the Art & Gap analysis 2/3

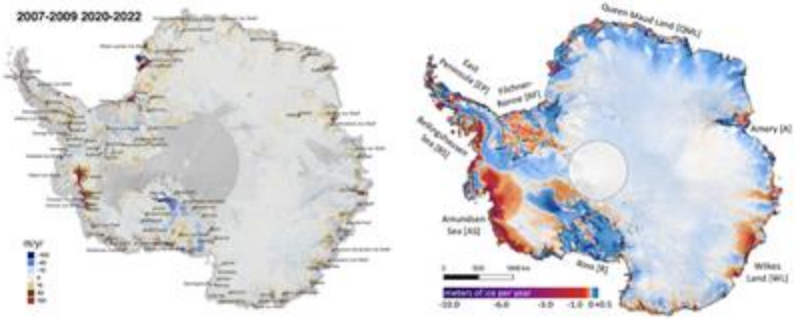



- Thanks to partner friends at ESA, CSA, JAXA and NASA much has been achieved with velocity and grounding line mapping since 1990s.
- Precision in speed improves from 2-5 m/yr (speckle tracking ST) to 20 cm/yr (phase only PO) w. 10 years of multi-agency phase-only data.
- Precision of ST annual time series is not sufficient to detect how fast/far coastal changes propagate inland (sliding law), but PO could do it.
- SAR repeat cycle is too long to observe seawater intrusions at grounding lines that have the potential to double (2 x) projections of mass loss.
- In 2023-2024, we monitor the grounding line of key Antarctic and Greenland glaciers using a commercial partner, ICEYE, which enables new science.
- Calving/rifting mechanisms at frontal margins require PO data + fast repeat.

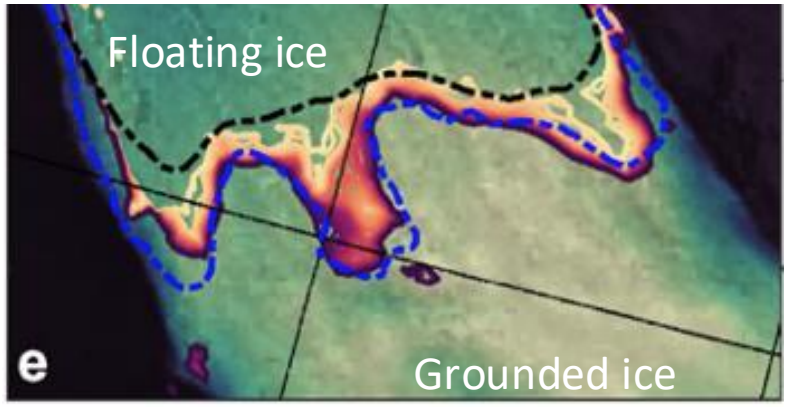
Phase-only




Achieved vs Desired




Km-scale seawater intrusion beneath Petermann Glacier, Greenland



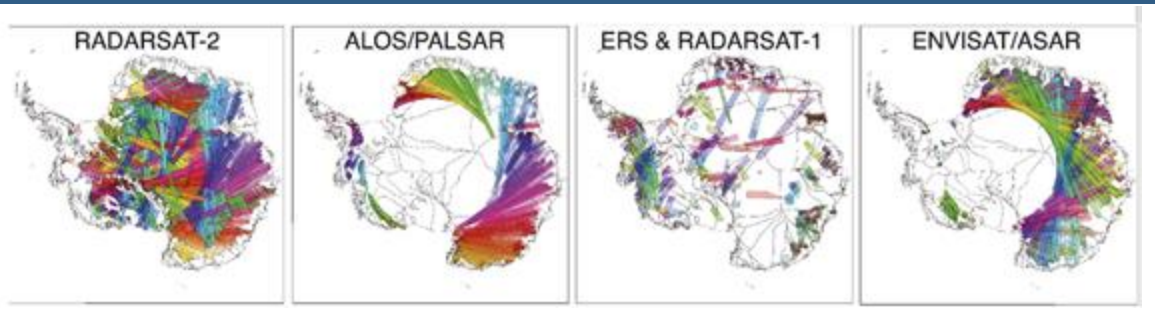
## State of the Art & Gap analysis 3/3

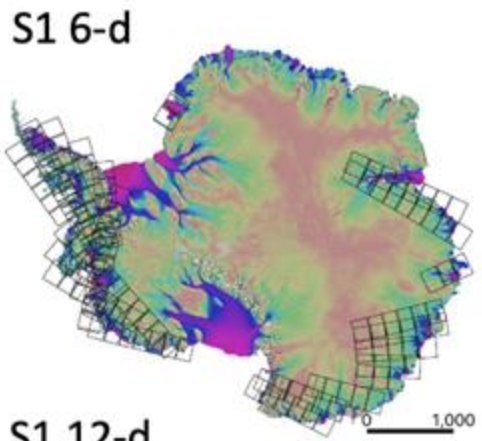
SAOCOM 8-d

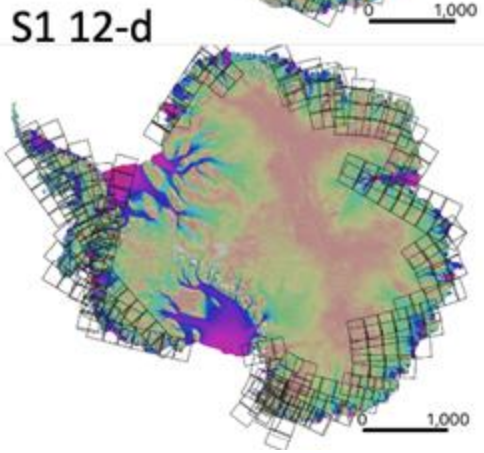
2016-2024

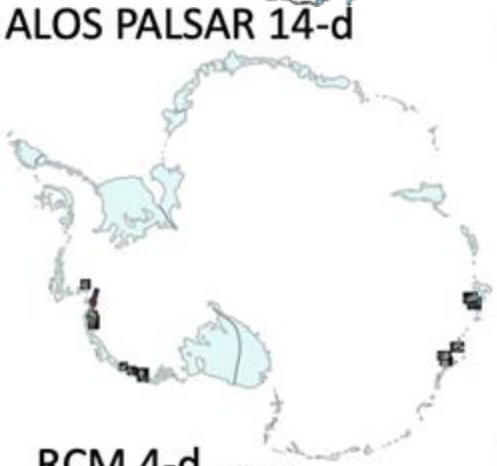
2007-2018

2025-IPY



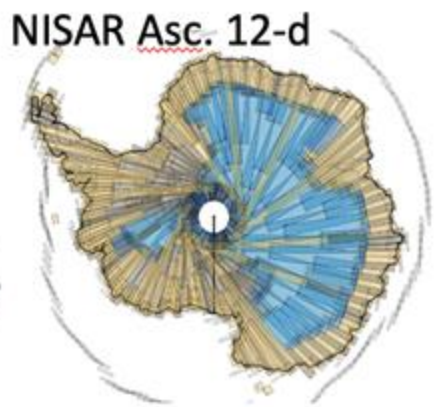



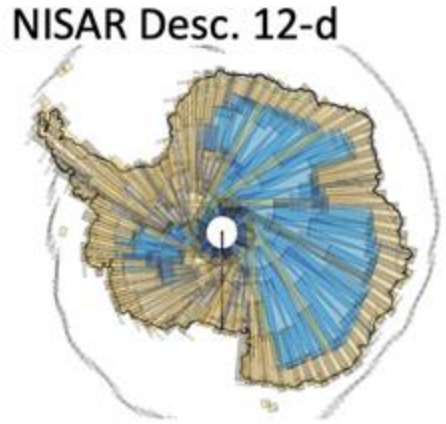










Present:

- InSAR is more frequent (S1) but coverage is less (partial S1+RADARSAT-2).
- Difficult to get coverage for RCM, ALOS-2 PALSAR-2, CSK2G, SAOCOM despite efforts.

Prior to IPY 2032:

- NISAR will do 3D mapping, detect changes over the continent, and map grounding lines.
- NISAR long repeat cycle will miss critical grounding lines, exclude North Greenland, and cannot do phase-only everywhere.
- Such limitations will impact Sea Level Rise science and protection of our population.

## Suggestions for current and near future SAR missions – C –Band

- **Sentinel-1 c-d (2024-2025) and NG (2032-)**
  - S1 long-term commitment (multi-generational) is a key aspect for long time series and stable data coverage.
  - Maintain (and improve) existing ongoing coverage for Antarctica and Greenland, esp. North Greenland.
  - Once the constellation is restored, revive 2-satellite coverage (6-day repeat).
  - Expand coverage to include ascending + descending tracks for 2D motion with phase.
  - With three satellites (a, c, d), reduce InSAR repeat to 4 days to cover key glaciers in West Antarctica (TBD).

- **Harmony and follow-on (2029-)**
  - Will enable 3D ice motion as S1 co-flyer but requires more S1 12-d acquisition in ascending and descending modes.

- **RADARSAT Constellation Mission (ongoing)**
  - Prioritize frames over the grounding line of fast-moving glaciers in Antarctica and provide sustained, consecutive 4-day repeat InSAR coverage for these regions.

## Suggestions for current and near future SAR missions – L-band (+ S-band)

- **NISAR**
  - Gaps in Northern Greenland and South Pole must be filled using other missions.
  - NISAR will not enable phase mapping of fast-moving glaciers in Antarctica and Greenland (long repeat), grounding lines in Greenland (coverage) and key fast-moving glaciers in Antarctica (long repeat)
  - Make S-band data collected accessible to the community to improve grounding line mapping in Antarctica
- **ALOS-2/ALOS-4**
  - Modify the BOS to improve InSAR repeat pass collections in coastal Antarctica with the shortest repeat orbit (12 d). Wider swath of ALOS-4 provides more overlap near the Poles. Will provide geometry diversity to NISAR. Reserve several tracks for InSAR collection with minimum impact on other BOS goals.
  - Use combined ALOS-2/ALOS-4 to collect 7-day InSAR data over critical fast glaciers with asc/desc coverage.
  - Provide InSAR coverage (asc/desc) in northern Greenland to fill NISAR gap.
  - Cover South Pole (south of 84S) in left looking mode (NISAR gap). Temporal baseline may be relaxed to weeks.
- **SAOCOM-1a/b**
  - Provide 8-day repeat InSAR coverage (asc/desc) over (5-10) regions of coastal Antarctica. Will provide geometry diversity to NISAR and ALOS-4 PALSAR-3.

# Suggestions for current and near future SAR missions – X –Band

## Agency missions & public private partnerships

- **TerraSAR-X / TanDEM-X**
  - Continue DEM mission to collect DEM time series in coastal Antarctica (essential for ice-ocean interactions)
  - Provide a third global DEM.
  - Make DEM products more readily available (instead of SLC) online.
- **COSMO SKYMED Second Generation**
  - Utilize the 1-day InSAR capability to maintain data collection at the grounding line of (30+) fast glaciers in Antarctica.
  - Make data available to the science community in larger quantity.

## Commercial missions

- **ICEYE**
  - Collect time series of 1-day asc/desc right/left looking InSAR over critical fast glaciers in Antarctica (10+) and Greenland (3). Critical capability not available from other SAR missions. Proven quality. Prospective of NASA contract.
- Other (Capella, Umbra, …)
  - Develop short-repeat InSAR capability.

## Suggestions for future missions in preparation for IPY 2032.

Ice velocity, grounding lines, ice fracturing are best observed with InSAR. The results have an enormous influence on the science of projecting sea level rise, but this requires daily (Antarctica) to sub-daily (Greenland) repeat with phase only and a diversity of viewing angles.

Scientific progress for rapid sea level rise will be limited by the availability of these observations (+ in situ ocean observations). “We cannot model what we cannot observe”:

Space agencies should work together to help polar science in preparation for IPY 2032. Advances and discoveries require a fast repeat, high resolution, multi-agency constellation striving to provide:

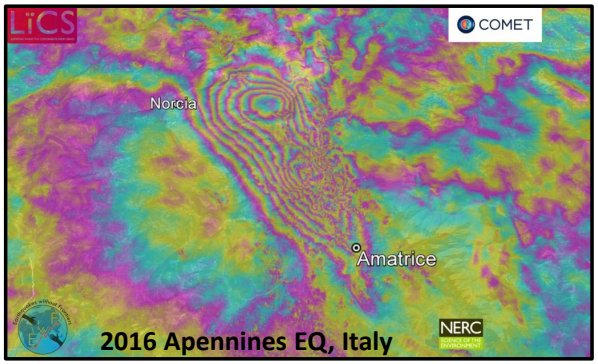
- Daily to sub-daily (2 hours (Greenland) to 6 hours (Antarctica)) along key coastal/fast sectors.
- Phase everywhere (multi-geometry w. diversity of short repeat cycles - Asc/Desc, Right/Left)
- Data openly available to the community, open software, advanced (L2-L3) products on the Cloud generated by experts, educational workshops, and growth of the user community.

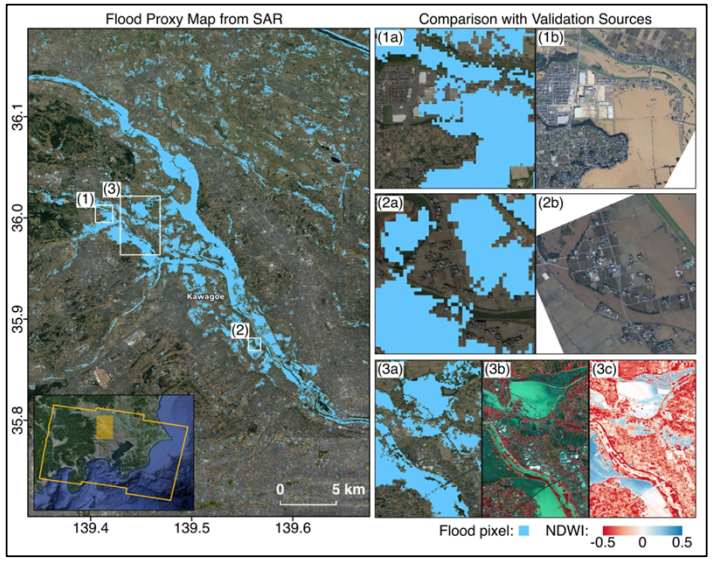
# Observation requirements for Hazards

*Tomokazu Kobayashi (Geospatial Information Authority of Japan)
Cathleen Jones (Jet Propulsion Laboratory, USA)

## State of the Art & Gap analysis – Pre-to-post Disaster Period

- During the short term pre-to-post disaster period, SAR is widely used for tropical storm winds and oil spills, and less so but increasingly used for flooding and geohazards.
- Optimal frequency and mode varies by disaster type, but generally any SAR is valuable. => SAR is widely used for hazard management.




*Tay et al., Scientific Data, 2020*

## Issues (needs) to be considered for hazard management

- **1st data acquisition** ASAP to **quickly** respond to hazard/disaster
- **Subsequent** observations with **short intervals** contribute to monitoring ongoing hazard
- The most significant impediment to SAR's operational adoption for disaster response is long **latency** in delivery of usable derived information to responders.
  - Latencies in tasking, downlink, processing, product generation and delivery all contribute
- **Regular** and **sustained observations** are required to know normal conditions
- Inconsistent access to data prior to activation of the International Charter can also be limiting

# Suggestions for current and near future SAR missions

1. **Regular observations** in InSAR-compatible modes for pre-to-post **change detection** (including New Space SARs if possible)
2. Fund and maintain **processing systems** providing **low latency** InSAR products, free of charge, for global disaster response
3. **Major space agencies commit** to providing **low latency** products (<=1 hr, L0 or higher)
4. **Coordinated disaster response effort among space agencies**, independent of Disasters Charter, to provide data for forewarned or smaller events prior to charter activation
   - Smart Tasking, i.e., automatic tasking (acquisition & downlink (if necessary)) and expedited processing
   - Include New Space SARs

# Partnership between GSI & JAXA

**Lesson from actual case**




Request

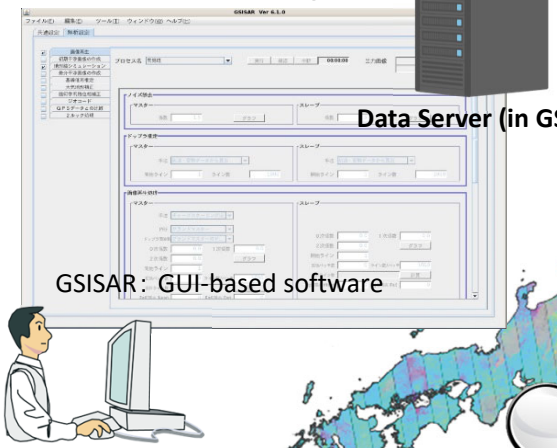
Agreement

Data

Disaster



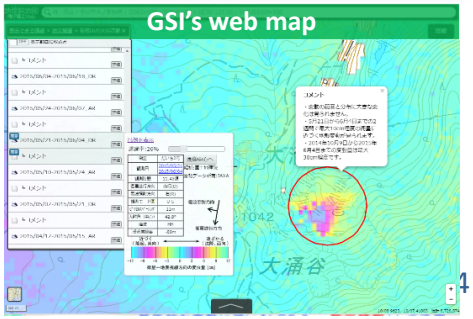

**SAR analysis**






**【 Expert committee 】**
**Evaluation/Discussion**
**(What's going on? / What happened?)**

- The Headquarters for Earthquake Research Promotion
- The Coordinating Committee for Earthquake Prediction, Japan
- The Coordinating Committee for Prediction of Volcanic Eruption




**Administrative agency**
[ Decision Making ]
- Alert level
- setting no-go area

**Response to Disaster**
Local governments
Ordinary people

**Academic study**
Researchers

**Survey**
Local governments
Survey companies

## Flow of disaster response by GSI & JAXA

### Lesson from【2015 Kuchinoerabu volcano eruption】

**Eruption**

**May 29 09:59 Eruption**



**Obs. Request**

**May 29 11:30**
**Request from GSI to JAXA**

**1 h before obs.**

**Observation**

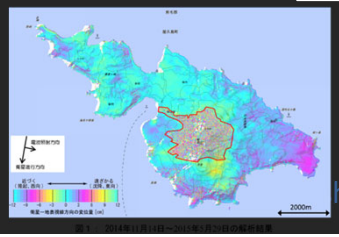


**May 29 12:53**

**1 after Obs.**

**Data distribution**

**May 29 14:00**



**InSAR analysis**

**May 29 16:00**

**It is important to allow observation requests to be made until just before the available observation time.**

**Acceptance of the observation request just before the observation time led to a quick disaster response.**

# Lesson from actual case

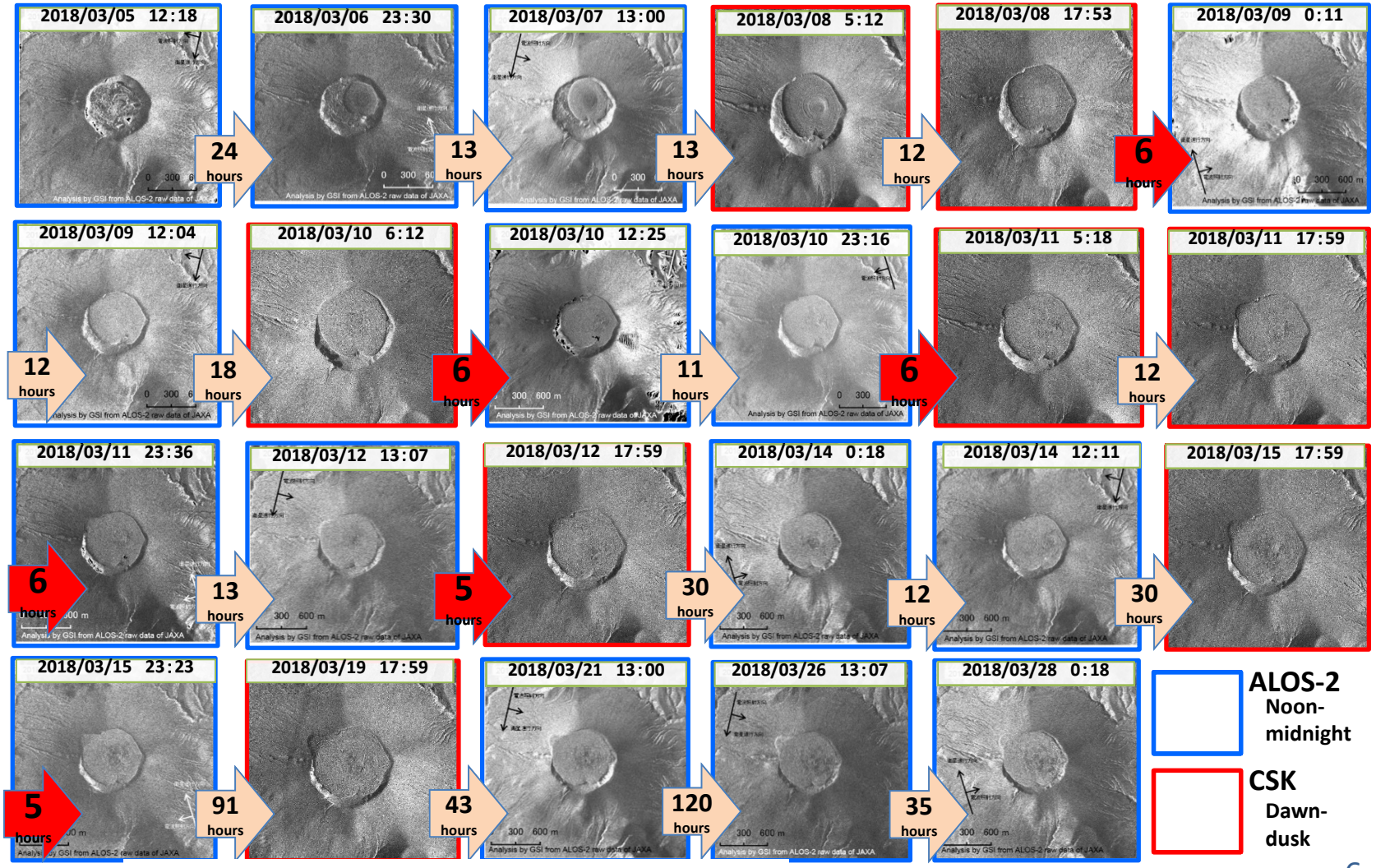
## 2018 Sinmoe-dake eruption






Japan Meteological Agency（JMA）

**International collaboration is very effective!**




COSMO-SkyMed Product - ©ASI –Agenzia Spaziale Italiana [2018]. All rights reserved

# A more efficient international constellation/collaboration is desirable to improve disaster response

## Reducing data distribution time is also important for disaster response

ALOS-2

| Obs. | Data Distribution | Latency |
|---|---|---|
| 2018.03.06 23:30 | 2018.03.07 00:00 | 0.5h |
| 2018.03.07 13:00 | 2018.03.07 14:06 | 1h |
| 2018.03.09 00:11 | 2018.03.09 00:38 | 0.5 h |
| 2018.03.09 12:04 | 2018.03.09 12:45 | 0.5 h |
| 2018.03.10 12:25 | 2018.03.10 12:44 | 0.5 h |
| 2018.03.10 23:16 | 2018.03.10 23:49 | 0.5h |
| 2018.03.11 23:36 | 2018.03.11 23:52 | 0.5h |
| 2018.03.12 13:07 | 2018.03.12 14:53 | 2h |
| 2018.03.14 00:18 | 2018.03.14 00:44 | 0.5h |
| 2018.03.14 12:11 | 2018.03.14 12:35 | 0.5h |
| 2018.03.15 23:23 | 2018.03.15 23:42 | 0.5h |
| 2018.03.21 13:00 | 2018.03.21 14:06 | 1h |
| 2018.03.26 13:07 | 2018.03.26 15:03 | 2h |
| 2018.03.28 00:18 | 2018.03.28 00:51 | 0.5h |

Average: ~45min

CSK

| Obs. | Data Distribution | Latency |
|---|---|---|
| 2018.03.07 20:12 | 2018.03.08 05:12 | 9h |
| 2018.03.08 17:53 | 2018.03.09 18:59 | 24h |
| 2018.03.10 06:12 | 2018.03.10 14:17 | 8 h |
| 2018.03.11 05:18 | 2018.03.11 08:58 | 3 h |
| 2018.03.11 17:59 | 2018.03.11 22:02 | 4 h |
| 2018.03.12 17:59 | 2018.03.13 00:13 | 6h |
| 2018.03.15 17:59 | 2018.03.15 21:35 | 3.5h |
| 2018.03.19 17:59 | 2018.03.19 22:03 | 4h |

Average: ~ 8h (479 min )

## Suggestions for brave mission solutions in the next decade (2030s)

- Coordinated, multi-InSAR, multi-mission disaster response system that supports both continual monitoring and imaging within hours of an event
- Interagency coordination of orbits and observation plans for new missions
  - Coordinate SAR coverage to distribute overpasses (not near-simultaneous imaging) to reduce time to image an area post-disaster
  - Reduce latency to InSAR repeat passes
  - Possibly focus coverage to known areas with geohazards, for example

# Observation requirements for Solid Earth Science

Yujie Zheng (UT Dallas, USA)
Andy Hooper (U. Leeds, UK)
Mark Simons (Caltech, USA)

# State of the Art & Gap analysis

- The expansion of the international constellation combined with a variety of imaging modes, have allowed an ever-expanding set of science targets.
  - Different phases of the seismic cycle (i.e., interseismic, coseismic, and postseismic, as well as aseismic creep)
  - Migration of magma
  - Shallow aquifer pressure variations
  - Slow-moving landslides
  - Variations of surface soil and vegetation moisture

Volcanic



Alaska National Park Service

Active



Soil/Vegetation Moisture



Photo By Diego Delso, CC BY-SA 3.0,

Landslide s



alos Verdes USG

Aquifer monitoring



## State of the Art & Gap analysis

- Current global repeat interval spans weeks
  - limits our ability to observe fast-evolving processes
  - Limits our ability to separate superposition of different geophysical processes
  - Daily repeat measurements (COSMO-SkyMed, commercial SAR) exist only over **selected** regions, faster **global routine** repeat imaging needed

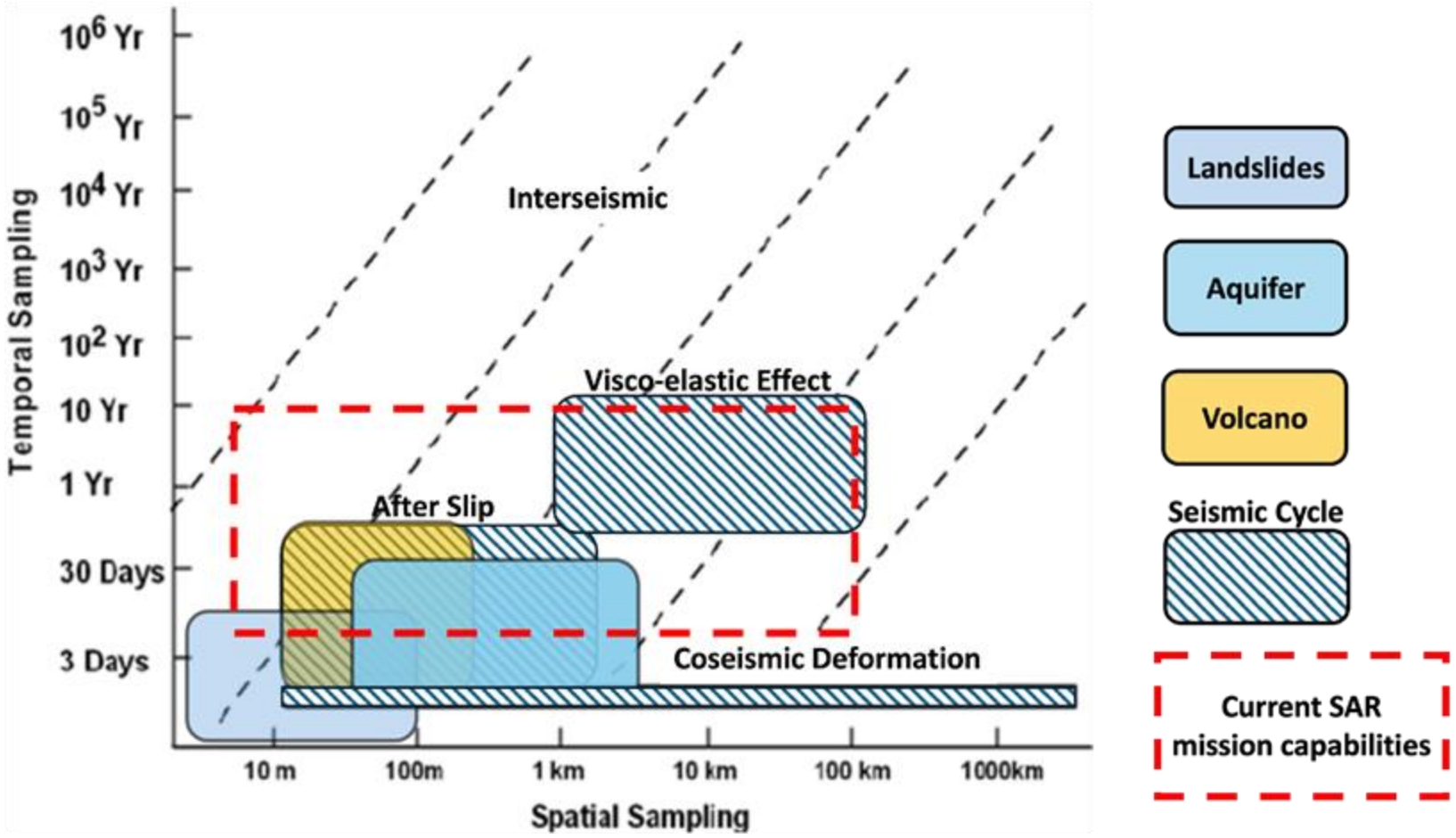



*Figure: The temporal and spatial sampling rate required for different Solid Earth Science targets.*

## State of the Art & Gap analysis

- Continuous monitoring
  - Key for distinguishing overlapping geophysical processes (e.g., co-seismic and post-seismic fault slip, hydrological and tectonic processes)
  - Overlap of different InSAR constellations essential.

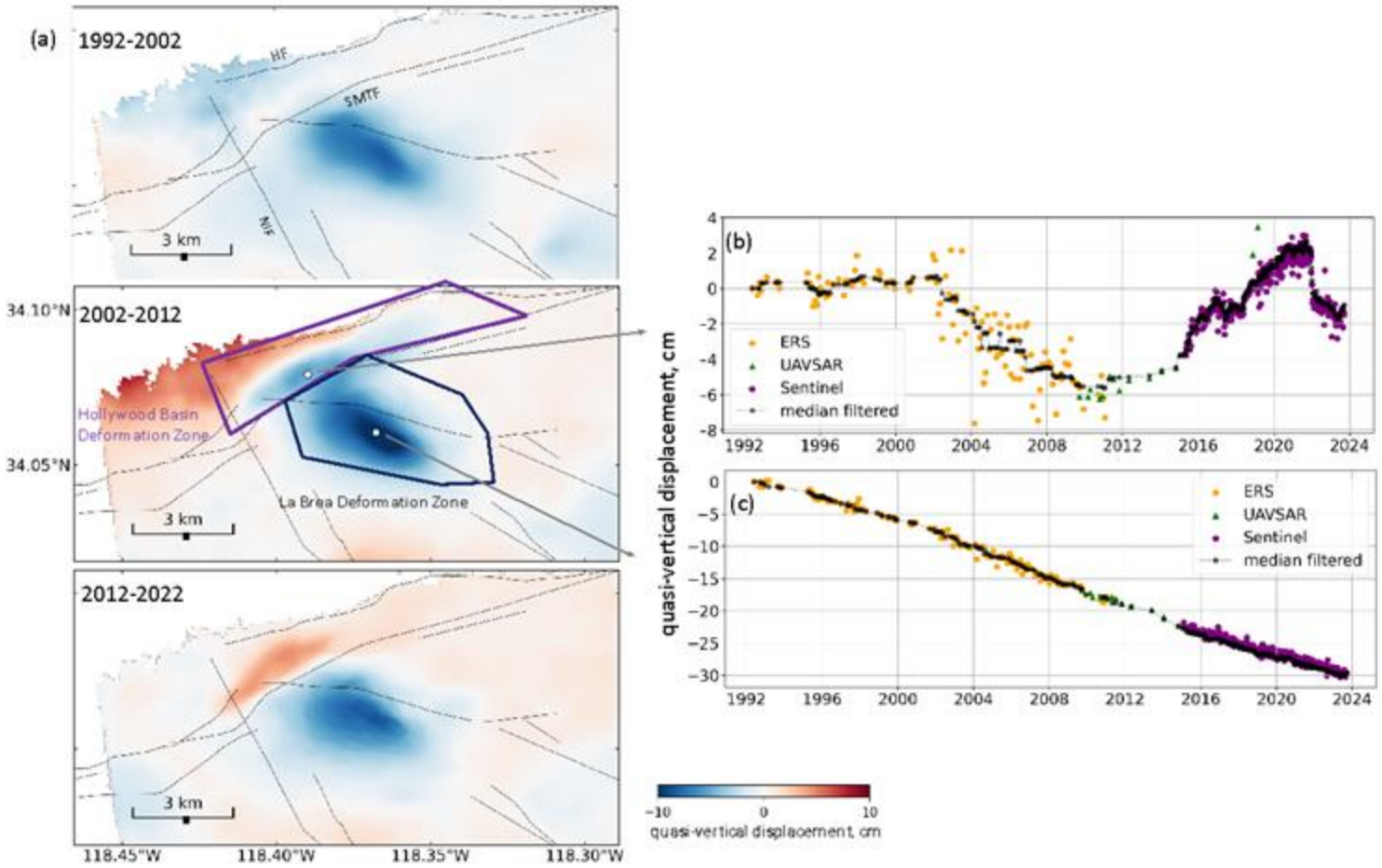



*Figure: Three decades of InSAR monitoring combining ERS, UAVSAR, and Sentinel-1 observations over North Los Angeles. From Zheng and Simons, 2024, preprint.*

## State of the Art & Gap analysis

- 3D velocity field observation
  - Essential for merging data from international InSAR constellations
  - **Current techniques**: Pixel offset tracking and Multi-Aperture SAR Interferometry improve InSAR's inherent insensitivity to along-track motion.
  - **Sentinel-1's TOPSAR mode** offers diverse squint angles within burst overlap areas but lacks continous mapping capability.

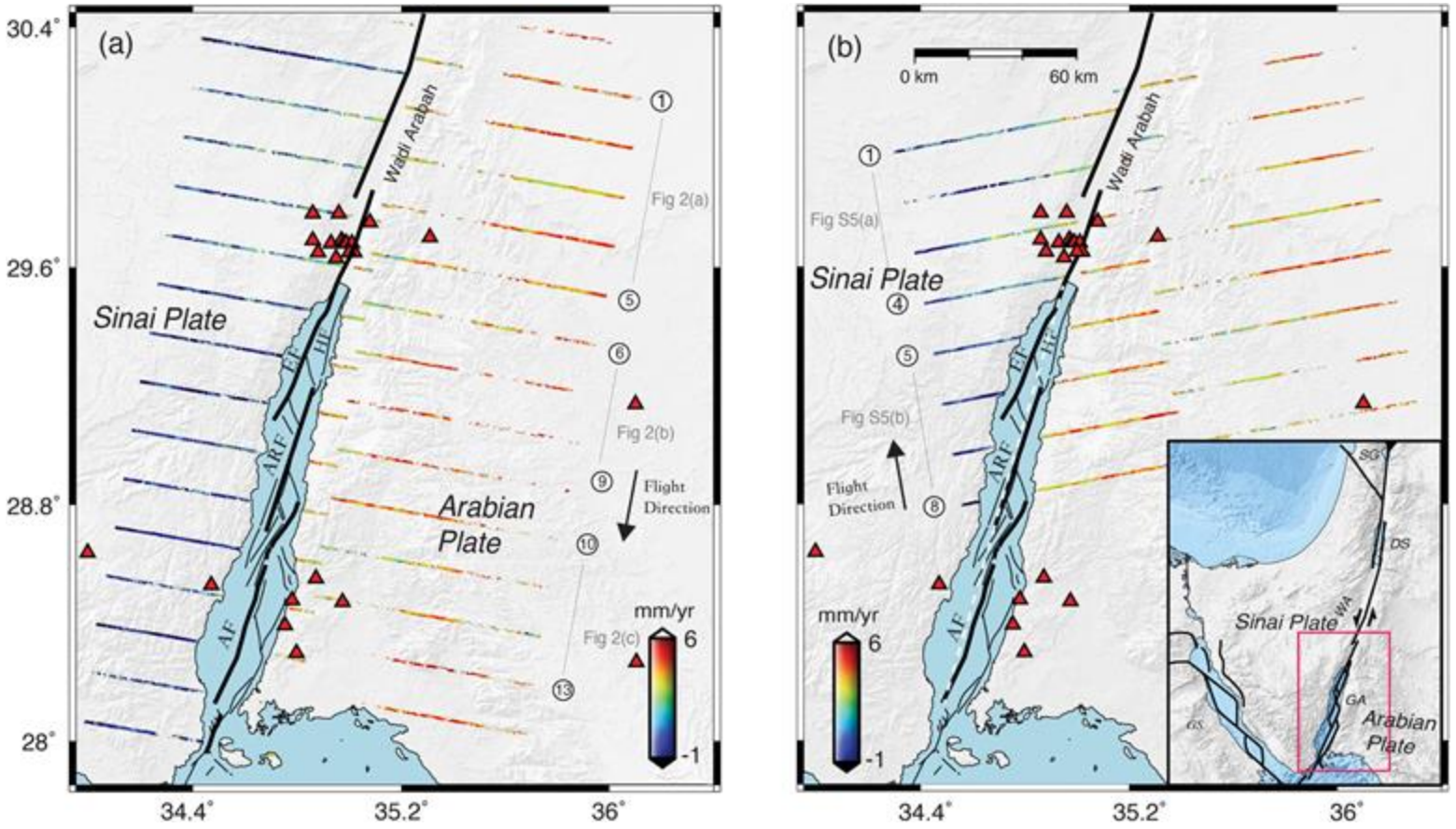



*Figure: Map of the southern Dead Sea transform fault showing the derived Sentinel-1 burst overlap interferometry along-track interseismic velocities. From Li et al., 2021, GRL*

## State of the Art & Gap analysis

- Resolving smaller signals
  - Crucial for detecting slow-evolving processes
  - **Limitations**: Decorrelation and various path delays
  - **Mitigation**: Short repeat intervals, longer wavelength radar, and techniques like split-band processing for ionospheric noise, weather model to account for stratified troposphere, and machine learning methods.

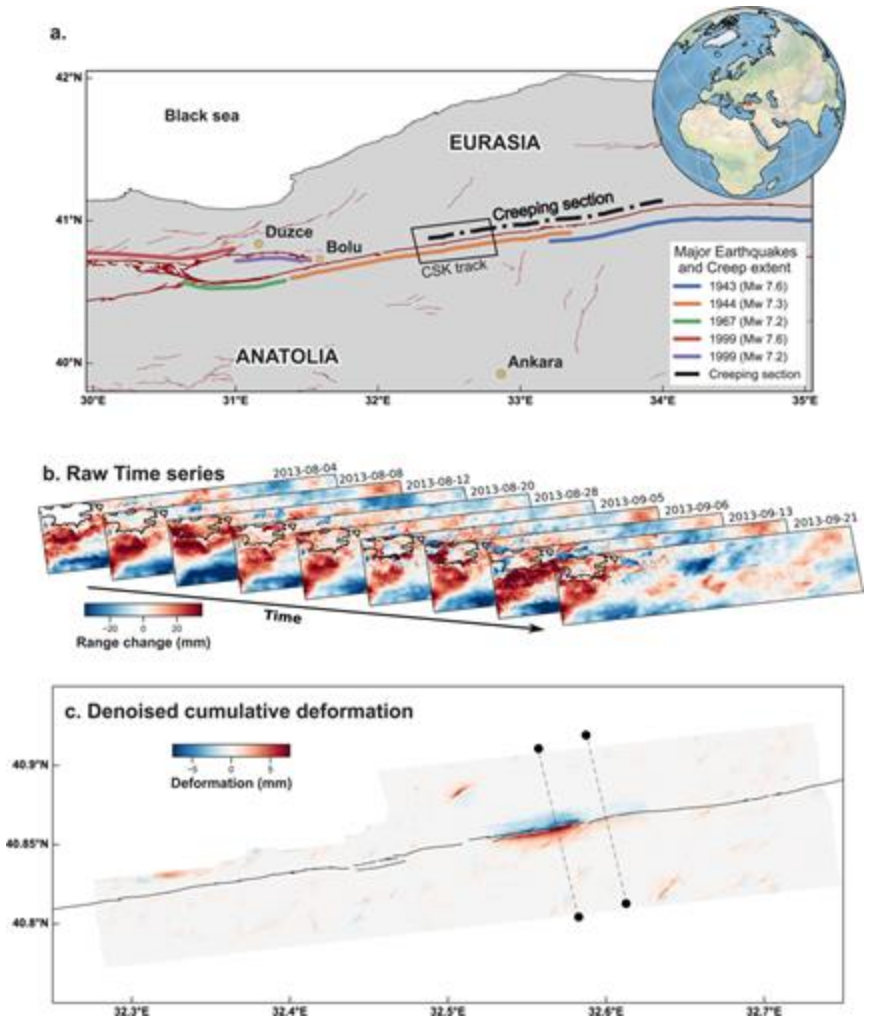



*Figure: Application of autonomous extraction of milimeter-scale deformation in InSAR time-series using deep learning to the North Anatolian Fault 2013 slow earthquake. From Rouet-Leduc et al., 2021, Nature Communications*

## Suggestions for current and near future SAR missions

- ALOS-2/ALOS-4, NISAR, SAOCOM-1a/B, Sentinel-1A/C, RADARSAT, EOS-04, TerraSAR-X, CSM,...
- Suggestions:
  1. **Increase temporal sampling:** Deploying companion satellites in the same orbit enhance temporal resolution of a single SAR mission
  2. **3D Deformation Reconstruction**: Use closely flying radar receivers to increase line-of-sight diversity (e.g., ESA's planned Harmony mission).
  3. **Achieve LOS diversity:** A combination of left- and right-looking observations from ascending and descending orbits, and potentially from highly squinted geometries.
  4. **Radar wavelengths diversity**: Utilize multiple radar bands (e.g., NISAR's L- and S-band) to improve data quality, especially in densely vegetated areas.
  5. **Continuous monitoring**: Plan missions with overlapping periods to maintain data continuity.

## Suggestions for brave mission solutions in the next decade (2030s)

- **Daily repeat sampling**:
  - Consistent geometry, radar wavelength from multiple satellites
  - Geostationary SAR offers daily sampling, though it sacrifices global coverage and faces issues like rotational decorrelation
- **Path delay correction and 3D deformation reconstruction**:
  - Requires simultaneous interferometry from multiple LOS directions.

# Observation requirements for Permafrost

Line Rouyet (NORCE, Norway)
Annett Bartsch (b.geos, Austria)

## State of the Art & Gap analysis I

- As a subground condition, permafrost is not directly observable from space, but several proxies and indicators can reflect its state and evolution.
- Three ECV associated parameters according to GCOS: Permafrost Temperature (**PT**), Active Layer Thickness (**ALT**) and Rock glacier Velocity (**RGV**).

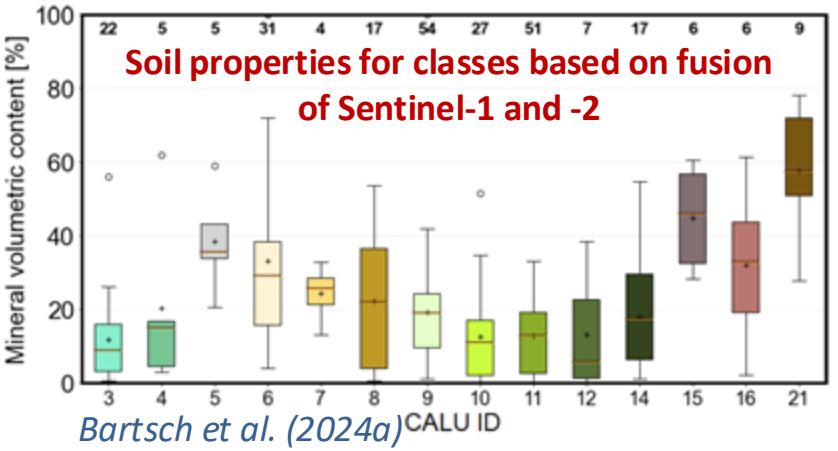
- **For modelling of PT and ALT:**
  - Most uncertainties related to parameterization of ground stratigraphy and snow.
  - SAR backscatter potential: **landcover (soil proxy)** and snow properties.
  - InSAR potential: soil proxies, specifically indicator of **ground ice content**.

  **Limitation:** Inconsistency of the pan-arctic spatial coverage and temporal resolution hinders our ability to generate systematic products of comparable quality at global scale.

- **For RGV monitoring:**
  - InSAR & SAR offset tracking for **interannual rock glacier velocity monitoring**.
  - InSAR decorrelation on fast-moving landforms, especially at X-/C-band.
  - SAR offset tracking requires high resolution imagery.

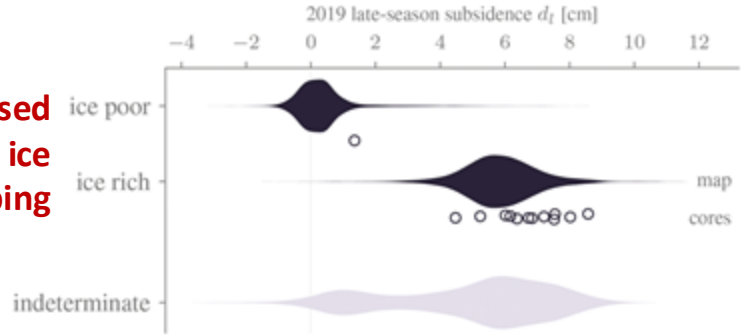
  **Limitation:** Weekly C-band acquisition at the limit of the max. velocity detection capability for fast-moving rock glaciers. Spatial resolution of most operational missions is too low for SAR offset tracking on small landforms.

**Soil properties for classes based on fusion of Sentinel-1 and -2**



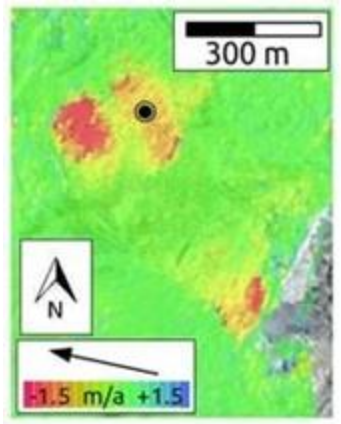

*Bartsch et al. (2024a)*

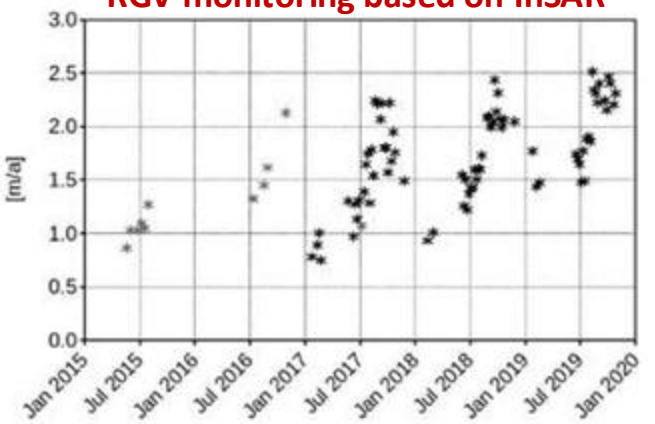
**InSAR-based ground ice mapping**




*Zwieback et al. (2021)*

**RGV monitoring based on InSAR**



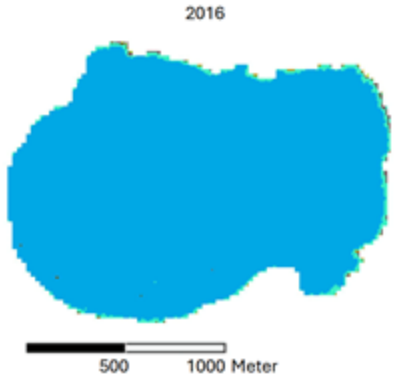




*Strozzi et al. (2020)*

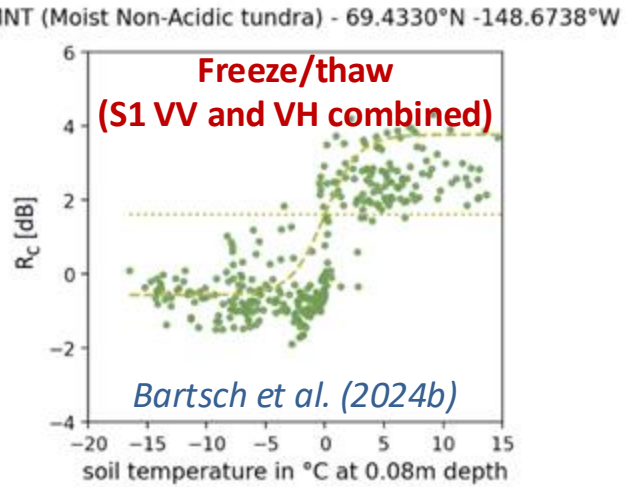
## State of the Art & Gap analysis II

- **Other proxies to be used as indicators of permafrost state and evolution:**
  - SAR backscatter to repeatedly map surface features reflecting permafrost degradation (e.g., **thermokarst lakes**, thaw slumps, coastal erosion).
  - SAR backscatter for monitoring the timing of **freeze and thaw**.
  - **Repeat-pass InSAR for slow surface movement** (e.g., thaw subsidence, frost heave and permafrost creep).
  - Single-pass InSAR for fast surface movement (e.g., thaw slumps, AL detachment slides).
- **Limitations:**
  - Applications have been demonstrated at local to regional scales only, due to **lack of acquisition consistency and high spatial resolution required for circumpolar implementation**.
  - Knowledge gap for unambiguously interpretation of SAR signal in permafrost regions: **need for SAR cal/val supersites and campaigns targeting permafrost monitoring**.

**Thaw lake basin evolution after drainage (S1/2 fusion)**

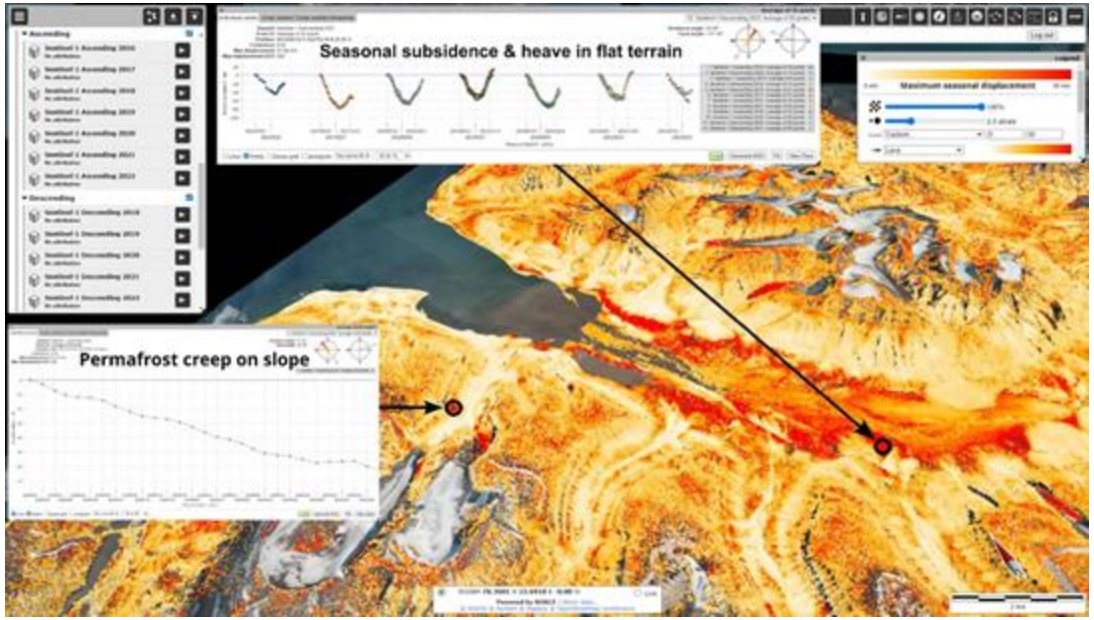



*v. Baeckmann et al. (2024)*




*Bartsch et al. (2024b)*

**Pilot product of the InSAR Svalbard GMS (S1)**




*Rouyet et al. (2024)*

## Summary and suggestions for current and near future SAR missions

- Permafrost monitoring from space requires:
  - ➢ the **combined use of a large set of parameters**.
  - ➢ the **integration of multiple proxies** and **advanced data fusion strategies** for assimilation into permafrost models.
- Utility of current missions for global assessment remains limited due to acquisition strategies which **disadvantage high-latitude permafrost regions**.
  - ➢ Need for **consistent acquisitions at pan-arctic coverage**.
- For several applications, C-band with a 12d repeat-pass is not enough.
  - ➢ Need for future missions with **shorter repeat-pass** and **lower SAR frequencies**.

## Suggestions for brave mission solutions in the next decade (2030s)

- Due to the diversity of the parameters studied by the permafrost community, **no single SAR system can address all the needs**.
- Permafrost monitoring requires a **combination of frequencies, polarizations, acquisition strategies and modes**.
- Efforts to **coordinate simultaneous acquisitions of complementary SAR missions** is mandatory.

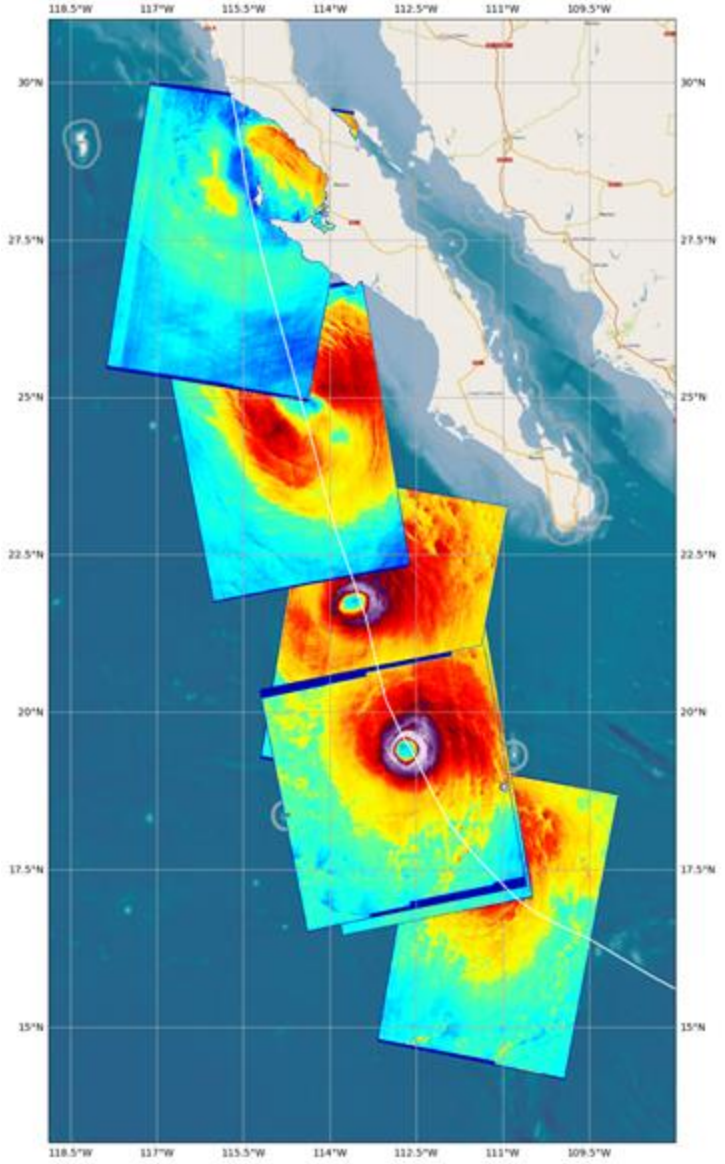
➢ **General need for SAR cal/val supersites and campaigns targeting permafrost applications**:
Fill the knowledge gap for unambiguously interpretation of SAR signal in permafrost regions.

➢ **Priority for lowland permafrost applications:**
Consistent acquisition and data delivery strategies over the whole circumpolar regions (incl. Siberia).

➢ **Priority for mountain permafrost applications:**
Consistent low frequency missions and high spatio-temporal resolution.

# Observation requirements for Ocean Science

Paco Lopez Dekker (Delft University of Technology, NL)
Johnny Johannessen (NERSC, NO)
Björn Rommen (ESA/ESTEC)



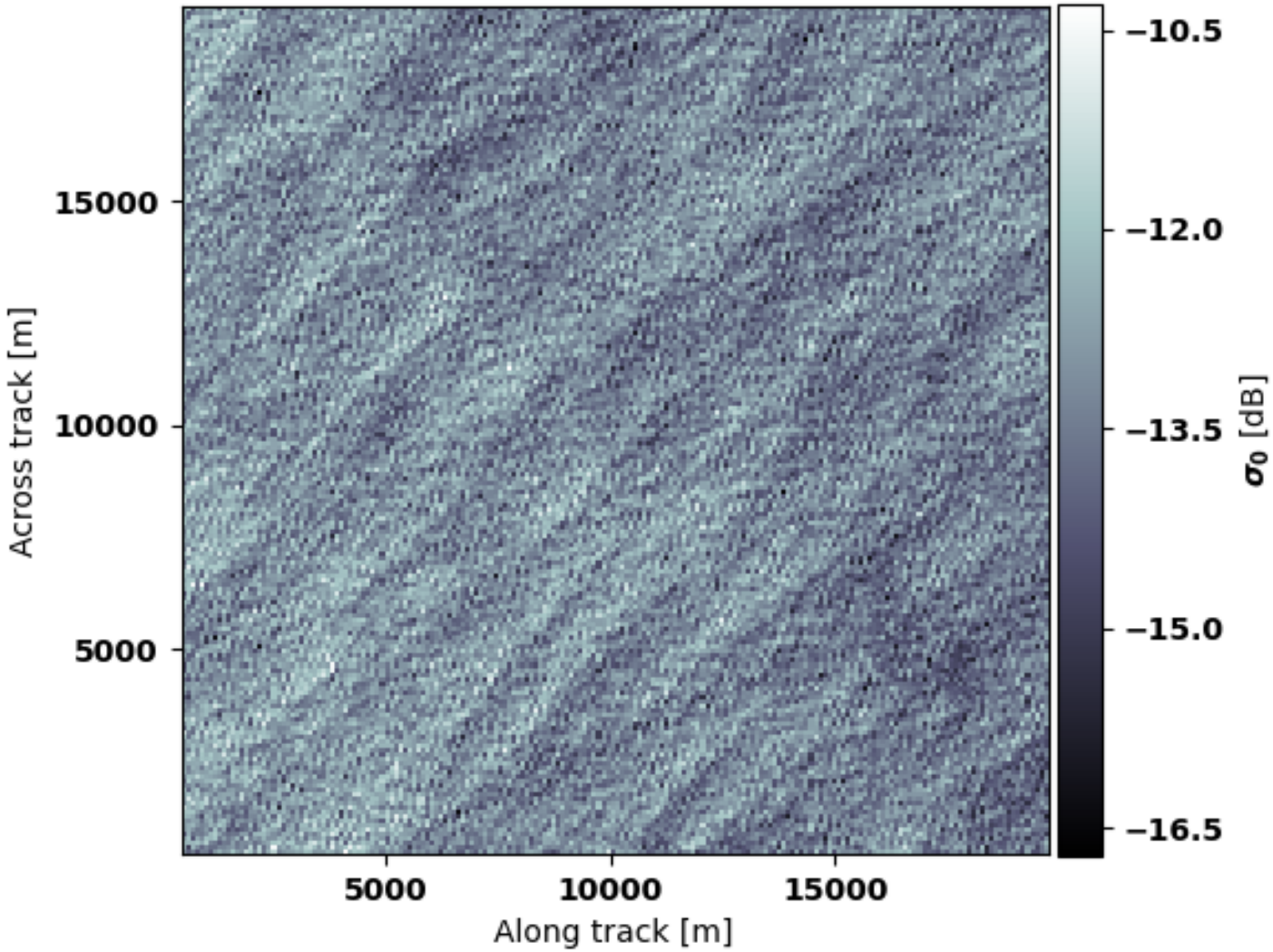

*Hilary, August 2023*

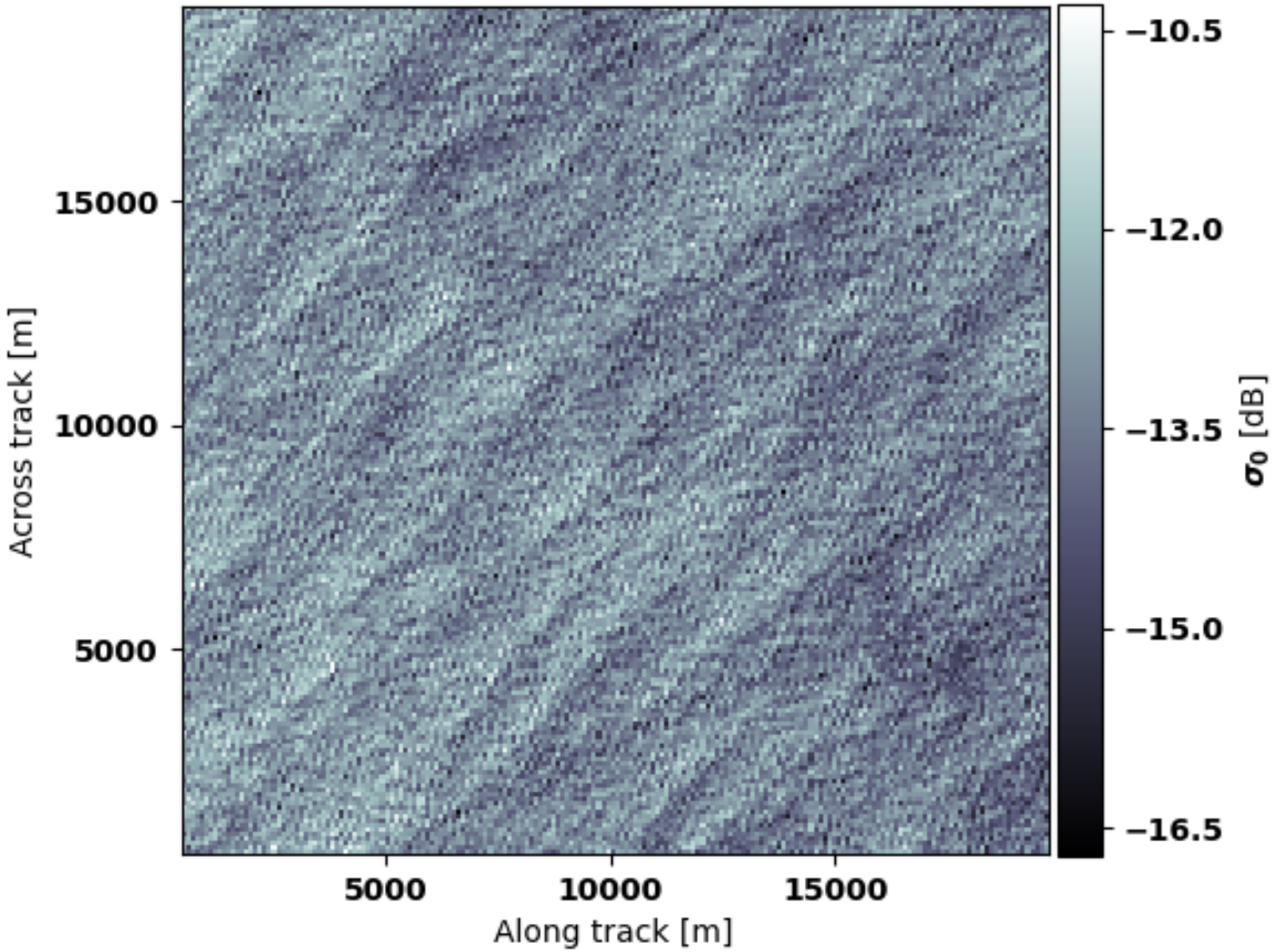
# State of the Art & Gap analysis

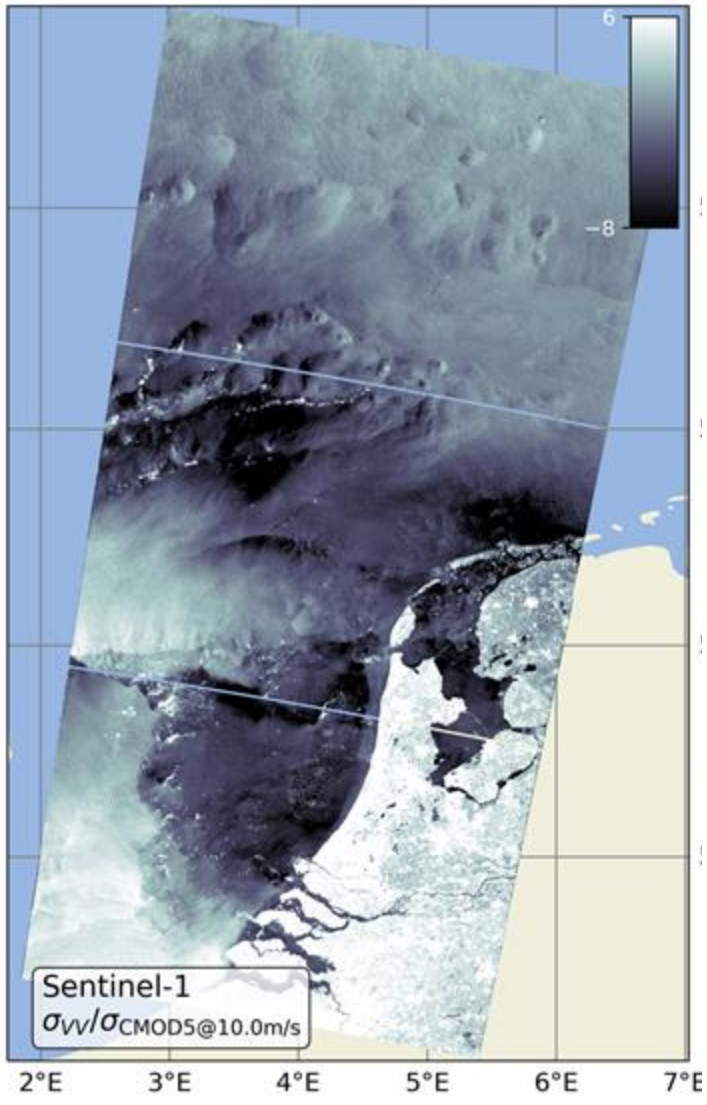
- **Recall:** SAR effective azimuth resolution over ocean is limited by wave motion
  - Velocity variance ($\sigma_v$) caused by surface waves results in an azimuth cut-off in the order of $\lambda_c \approx R \cdot \sigma_v / v_{orb}$
  - 50 – 400 m (sea-state dependent, frequency-independent) ⍰ *O*(100m)

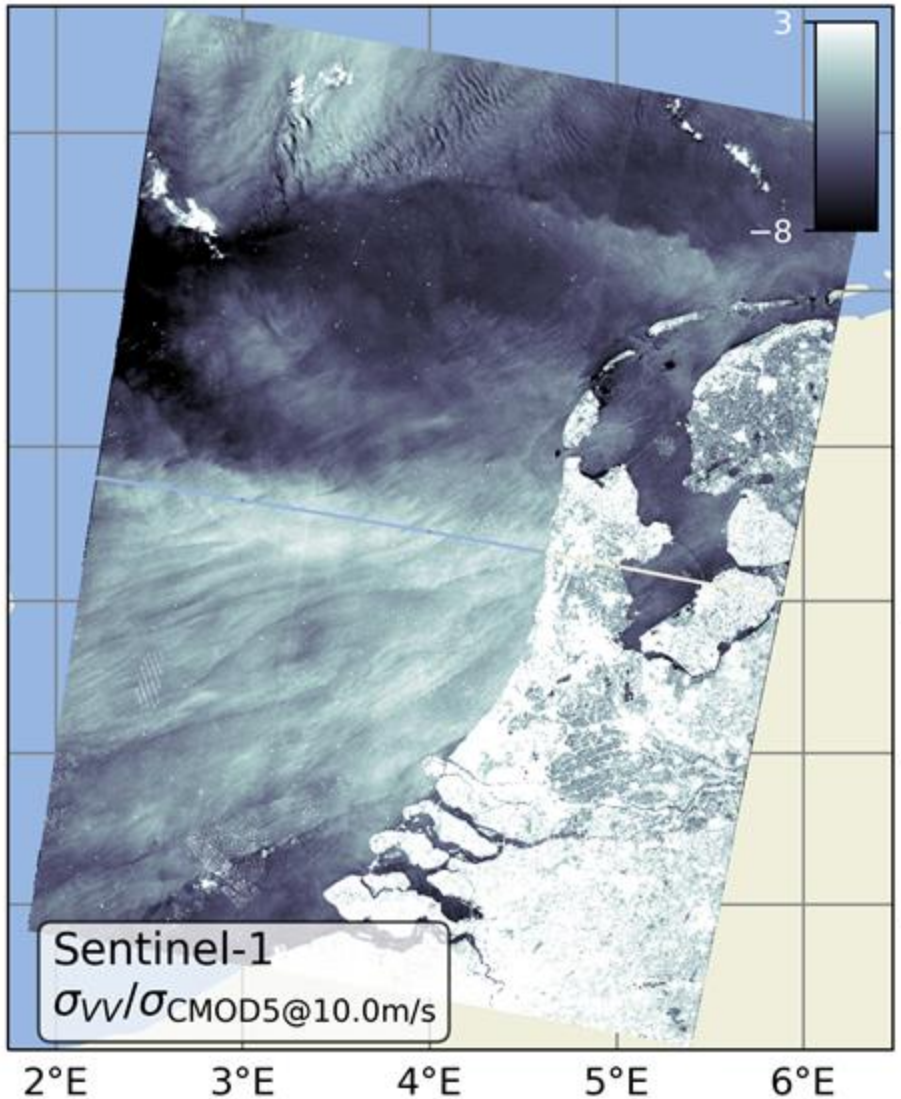
- **Current velocity** estimators exploit Doppler Centroid
  - Doppler Centroid Anomaly (DCA) needs to be corrected for systematic errors
  - Many of the limitations of the Doppler Centroid estimations are solved by the implementation of along-track-interferometric (ATI) modes
  - Removal of wave contribution to the Doppler necessary to recover range directed surface current

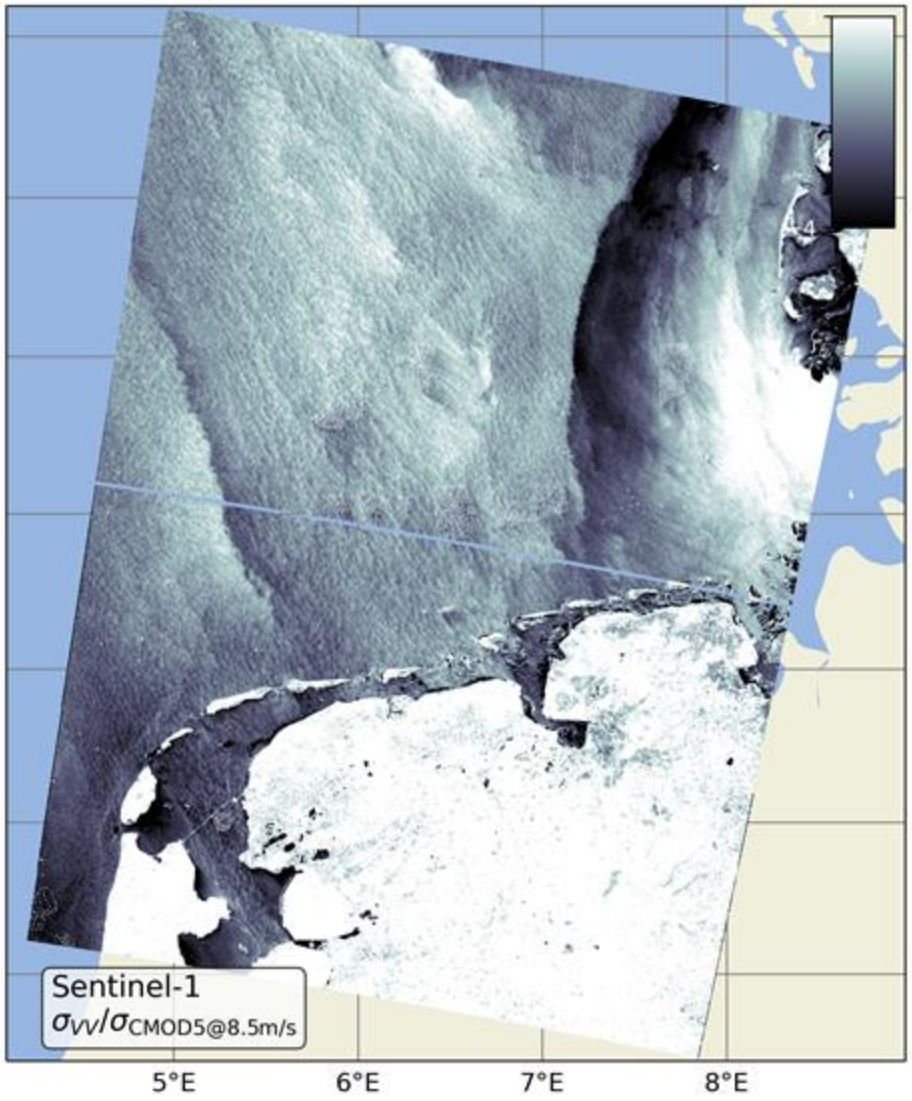
- **High-resolution wind scatterometry**
  - Wind vector estimation using single line-of-sight hampered by ambiguities:
    - Resolved by e.g. NWP re-analysis for single line-of-sight
    - Problematic within extremes (e.g. tropical cyclones, polar lows) or with addressing higher variability small-scale features


15000
10000
5000
Across track [m]
5000
10000
15000
Along track [m]
−10.5
−12.0
−13.5
−15.0
−16.5
σ0 [dB]


15000
10000
5000
Across track [m]
5000
10000
15000
Along track [m]
−10.5
−12.0
−13.5
−15.0
−16.5
σ0 [dB]


6
−8
Sentinel-1
$\sigma_{VV}/\sigma_{CMOD5@10.0m/s}$
2°E
3°E
4°E
5°E
6°E
7°E


3
−8
Sentinel-1
$\sigma_{VV}/\sigma_{CMOD5@10.0m/s}$
2°E
3°E
4°E
5°E
6°E


Sentinel-1
$\sigma_{VV}/\sigma_{CMOD5@8.5m/s}$
5°E
6°E
7°E
8°E

## Suggestions for current and near future SAR missions

- **HRWS-capable** SAR systems over the ocean to be operated in a narrow azimuth-beam mode, maximizing the antenna gain and exploit the available resources to either:
  - increase the range resolution
  - minimise the NESZ (in particular for cross-polarized channels)
  - to provide widely separated azimuth looks

- **ATI-capable** SAR systems by making use of:
  - Dedicated systems (Harmony, Seastar, …)
  - Exploitation of multiple ($\geqslant$2) phase centres in azimuth (e.g. Radarsat-2, TSX/TDX)

- Adding **directional diversity**, which is the key element in scatterometric wind retrieval
  - Including co- and cross-polarized channels

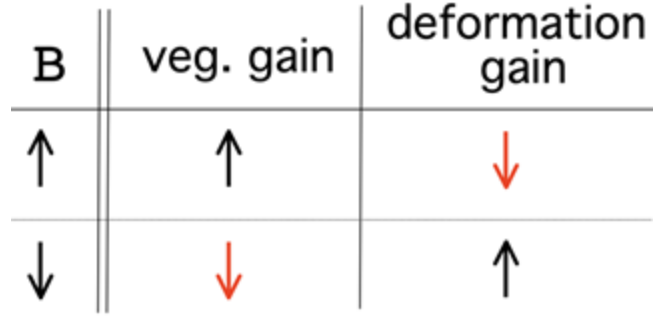
## Suggestions for brave mission solutions in the next decade (2030s)

- Ocean sub-mesoscale (order 1 km) to mesoscale (>30 km) features have lifetimes, *O*(hours to 10´s of days). Regular cover of the sub-mesoscale by the repeat visit of any spaceborne mission not feasible
  - Need for continued algorithm developments to support provision of analyses of globally sparsely sampled ocean data (using e.g. generative AI)

- Develop high-resolution SAR ocean product validation approaches
  - Designation of coordinated super-sites?

- Combining near-collocated directional diversity, including the use of co- and cross-polarized intensity and exploitation of Doppler signals

## Topography & Tomography




*P. Siqueira, 2003*

All “backbone” SAR missions at C- and L-band operate with ~ zero-baseline

- Largely benefiting surface deformation (reduction of volume/baseline decorrelation)
- Not optimised for height measurements (analogy: limited ‘parallax’) ⍰ height of ambiguity
- Dedicated missions in favour of SAR tomography or for increasing InSAR/PolInSAR height sensitivity:

1) multi-pass acquisition stack collection for a single mission with controlled across-track baselines (e.g. Biomass)
2) Tandem satellite operation (e.g. TerraSAR-X+Tandem-X)
3) Single-pass acquisition stack collection for a companion mission with controlled across-track baselines (e.g. Harmony)
4) Single-pass acquisition stack collection for interferometric cartwheel like concepts (dedicated transmitter)

Yesterday we have already seen some presentations for mission concepts being studied in this direction, e.g.

**CONAE:**

- SAOCOM-2 companion from 2030+

**NASA:**

- SDC L-band companion study

**ASI:**

- RODiO (four 12u X-band RX-only cubesats) flying with PLATiNO-1 (mid-size platform) when lowered in 425 km orbit (first phase PLATiNO in CSK orbit) – technology demonstrator mission

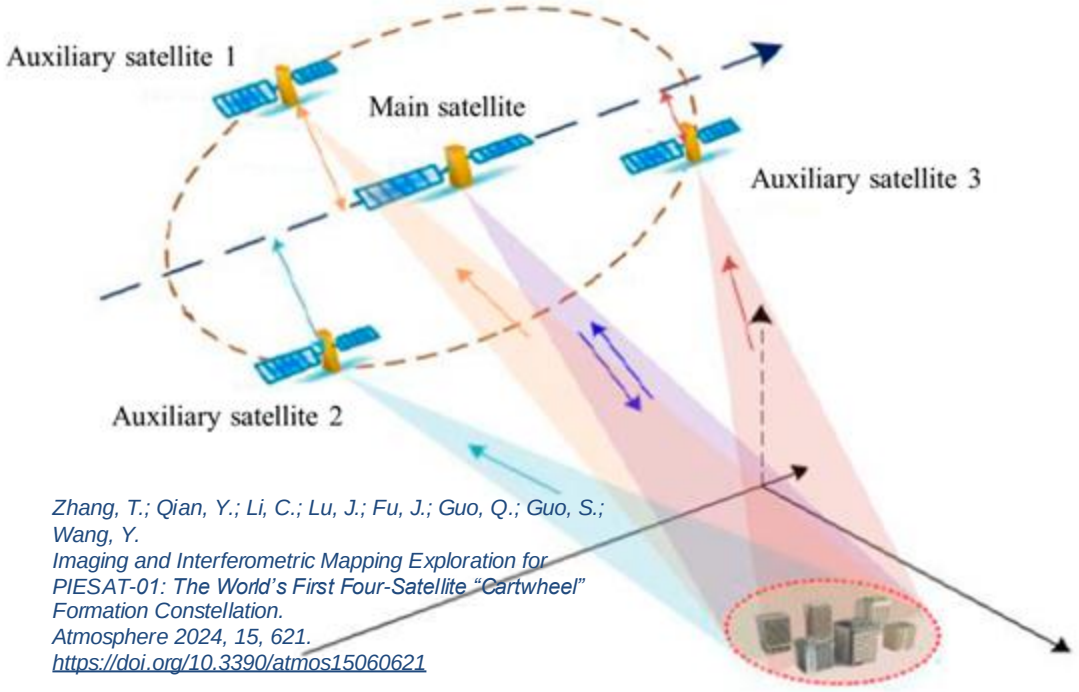
**ESA:**

- Harmony mission (C-band passive / 2 satellites / 1 tonne each / launch end of 2029);
- ROSE-L companion studies planned;
- 3DSAR (End of Phase 0 / C-band passive / 3 satellites / forest biomass)

**JAXA:**

- L-band companion proposed to be studied

# Hongtu-1: The first interferometric cartwheel in space




*Zhang, T.; Qian, Y.; Li, C.; Lu, J.; Fu, J.; Guo, Q.; Guo, S.; Wang, Y.*
*Imaging and Interferometric Mapping Exploration for PIESAT-01: The World's First Four-Satellite "Cartwheel" Formation Constellation.*
*Atmosphere 2024, 15, 621.*
*https://doi.org/10.3390/atmos15060621*

**Table 2.** Perpendicular component of interferometric baseline of investigated HT1 multi-static acquisition.

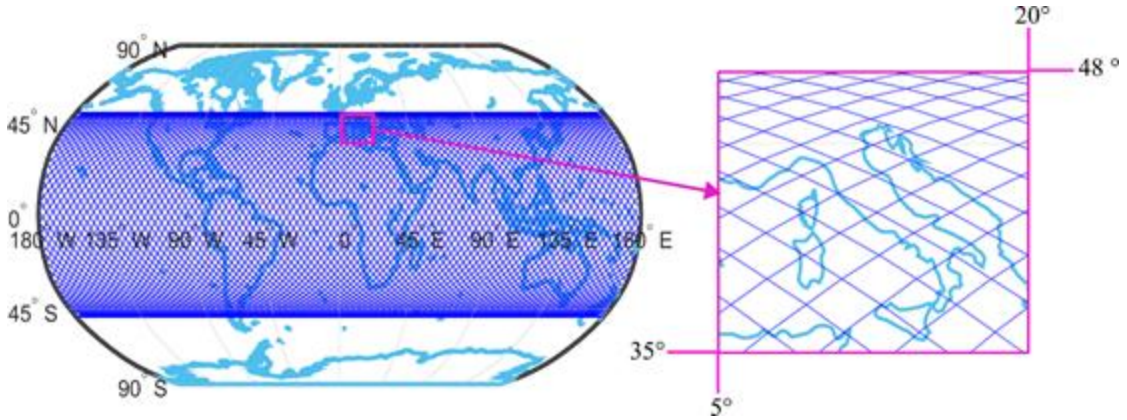
| Interferometric Pair | Perpendicular Baseline Component [m] |
|---|---|
| HT1-A–HT1-B | 275 m |
| HT1-A–HT1-C | −230 m |
| HT1-A–HT1-D | −64 m |
| HT1-B–HT1-C | −506 m |
| HT1-B–HT1-D | −339 m |
| HT1-C–HT1-D | 166 m |

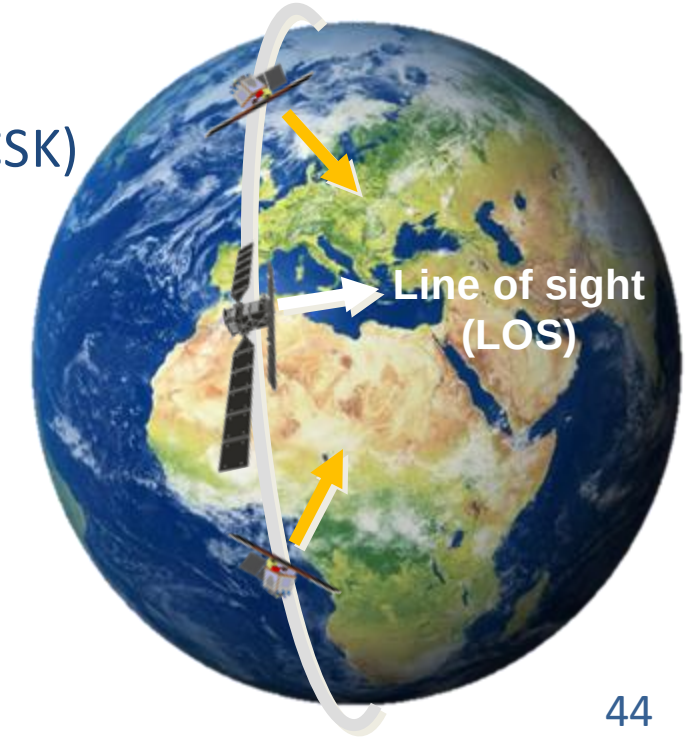
- Owned and operated by Chinese company PIESAT
- Also known as PIESAT-01 / launched on 30 March 2023
- Chinese X-band interferometric cartwheel (1 transmitter + 3 receiver satellites)
- 20-30 km swath / 3 m resolution
- DEMs, deformation and infrastructure monitoring
- master satellite weights approximately 320 kilograms and a single auxiliary satellite weights approximately 270 kilograms
- Recent assessment (27 September) published by Gamma-RS: https://www.mdpi.com/2072-4292/16/19/3600

# North-South sensitivity / 3D deformation

*Options (non-exhaustive):*

1) Exploiting ascending/descending + left-/right-looking geometries (e.g. ALOS-2/NISAR)
   - Disadvantage as toggling between left- and right-looking decreases the temporal resolution for each stack
     - ➢ could still be fine when implemented systematically
2) Exploiting burst-overlap region in TOPS modes (e.g. Sentinel-1)
   - only applicable in the limited overlap region
3) Mid-inclination orbits (e.g. NIMBUS IRIDE), combined with SSO SAR (e.g. CSK)
4) Dedicated companions with large along-track separation (e.g. Harmony)



# Recommendations from the last workshop
# TA2 - InSAR applications

## Now/Near-term needs

- Open data policy for archives of all agencies (encourage New Space to participate)
- Standardized / unified interface for tasking and data discovery / download
- New Space data access: Commercial data buys by the funding agencies for PI projects
- Reestablish Polar Space Task Group for an International Polar Decade

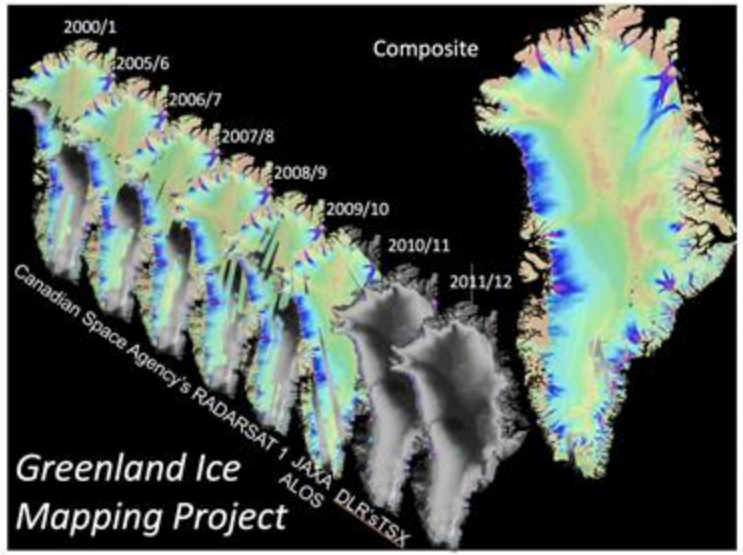
## 2030+ Timeframe recommendations

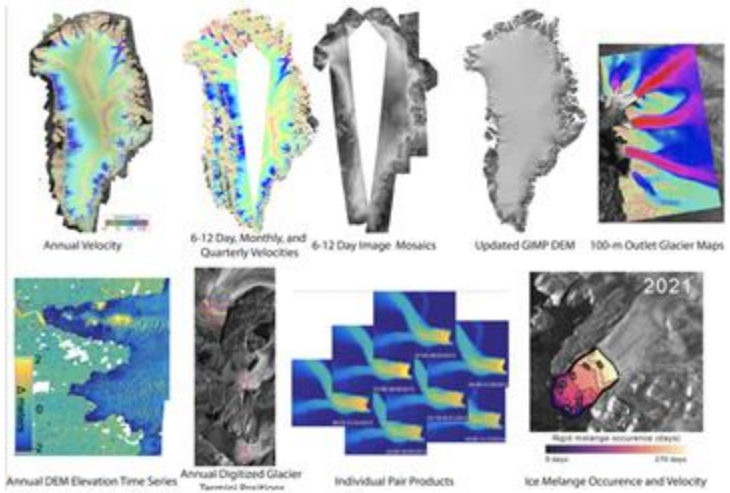
- Harmonized coordination of satellites sensors to give interferometric capability between different agencies' SARs
- High resolution, daily-to-subdaily interferometric observations
- Harmony-like companions for more missions

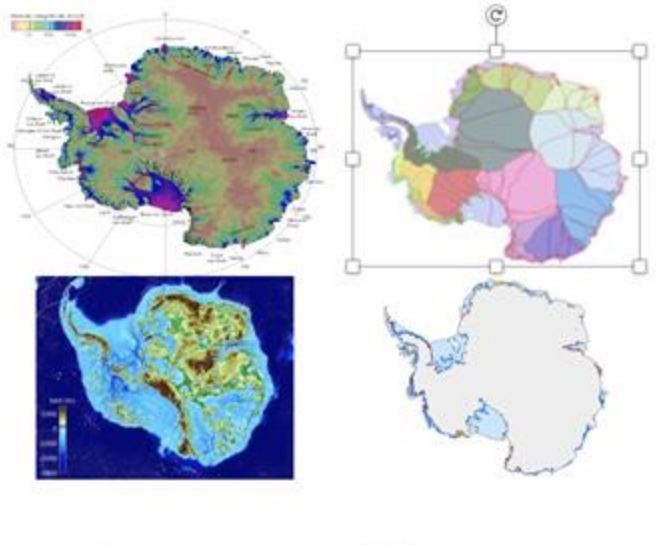
# Evolution of PSTG: Background and Rationale

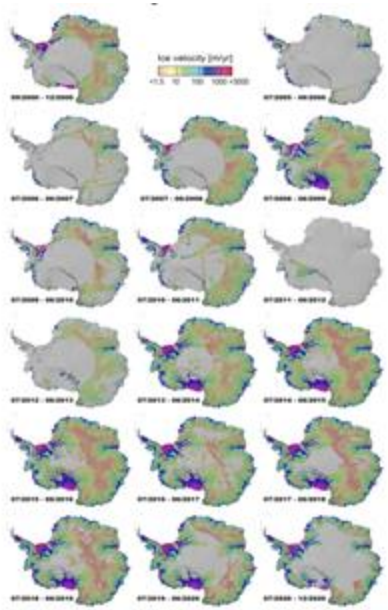
- The work of WMO's PSTG was seen to be very beneficial for engagement of space agencies in coordinating data acquisition and distribution over polar and high mountains
- For benefit of existing services and the cryosphere science community as a whole
- The International Coordination Group for Spaceborne Synthetic Aperture Radar (SAR) Missions (ICGS-SAR) has put out a recommendation on this topic in late 2022:
  *"Reestablish Polar Space Task Group for an International Polar Decade"*
- Whereas it is evident that SAR missions due to their limited orbital operational duty cycle would need coordination efforts to ensure appropriate acquisition planning over polar and high mountain areas, the work of PSTG has been more over-encompassing in terms of the remote sensing instruments it covered (e.g. inclusion of high-resolution optical imagery)
- WMO being one of the lead organisations for the 5$^{th}$ International Polar Year (2032-2033), the coordination work of such Group or Task Team will contribute to international research activities within the context of the 5$^{th}$ IPY (in the above called "*decade*" as the activities span a larger number of years, especially when considering data acquisition and timeseries analysis)
- WMO is uniquely positioned for hosting and enabling such Group or Task Team for successful coordination efforts for polar and high mountain areas globally

# Ice velocity mapping examples (Greenland & Antarctica)





- Past PSTG activities enabled the coordination of continuous mapping at continental scale
- Seen as a big success from the glaciological research community

# Evolution of PSTG: Timeline / Action Plan / Agreement

- Working to finalise Terms of Reference (ToR) – recent inputs have been provided; final review by early December;
- President of the WMO Infrastructure Commission has requested the chairs of the Advisory Group on the Global Cryosphere Watch (AG-GCW) and the Standing Committee on Earth Observing Systems and Monitoring Networks (SC-ON) to provide recommendations on the reporting structure for a new Team on Cryosphere and Polar Observations from Space (name tentative) by end 2024, between the two Commission Structures, and with a link to the WMO Executive Council Panel on Polar and High Mountain Observations, Research, and Services (PHORS). The proposal should address the engagement/interaction with the Expert Team on Space Systems and Utilization (ET-SSU);
- A call of representatives from those groups took take place on 6 November (yesterday);
- A decision of the President of INFCOM is expected by January 2025;
- Membership to be established in early 2025, to ensure that the team has the right composition to be effective;
- Expected to be able to communicate the outcome on structure and composition by April 2025 with a view of holding its first meeting mid 2025;
- The team composition would strive to avoid duplication and the links to observing requirements, gap analysis and WIGOS Vision, as well as GCOS, WCRP, etc. will be established through focal points in the team or invited experts, as agreed with each entity.