Theme: Sea ice
Topic: Multi-sensor synergy

Stefan Wiehle et al,
Johannes Lohse and Wolfgang Dierking
Malin Johansson et al.

Contributing work

Preliminary results of Sea Ice Classification using combined Sentinel-1 and Sentinel-3 data

By Stefan Wiehle, Dmitrii Murashkin, Anja Frost, Christine König, Thomas König

Combining C- and L-band SAR imagery for automated sea ice classification and segmentation

By: Johannes Lohse and Wolfgang Dierking

High resolution L- and C-band polarimetric variability during MOSAiC

By: Malin Johansson, S. Singha, G. Spreen, S. Howell

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Key objectives

Multi-sensor sea ice type classification, separation and characterization

- To develop new (fused) algorithms (combinations of methods or frequencies)
- Combine SAR + optical images (Sentinel-1 missions) for improved sea ice classification
- Investigate and quantify the benefits of combining C- and L-band SAR imagery for automatic sea ice type separation
- New polarimetric parameters for improved ice type characterization and separation
- Multi-frequency (X-, C- and L-band) aligned SAR imagery for ice type classification and iceberg detection

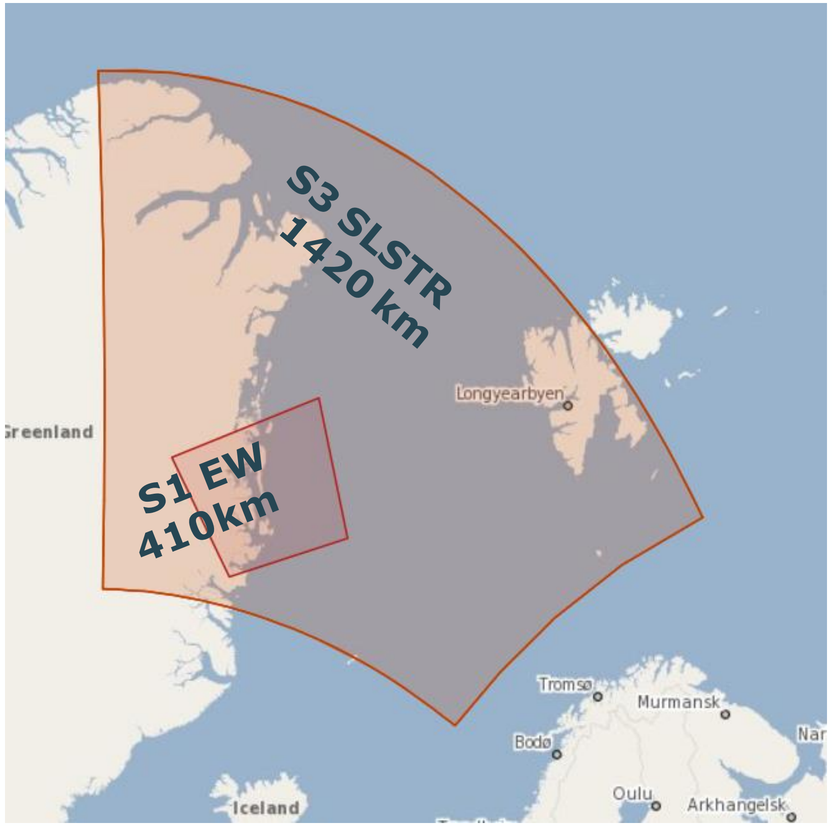
Application of multi-sensor algorithms

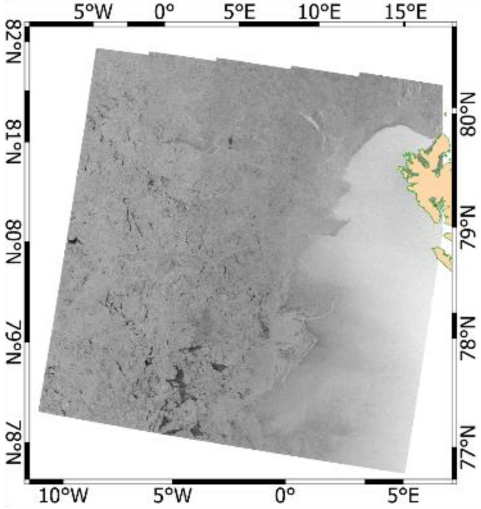
- Improve separation of ice types and ice-water
- Testing applicability of future missions (ALOS-4, NISAR, ROSE-L)
- Improve ship safety and reduce travel time by providing reliable and up-to-date sea ice information

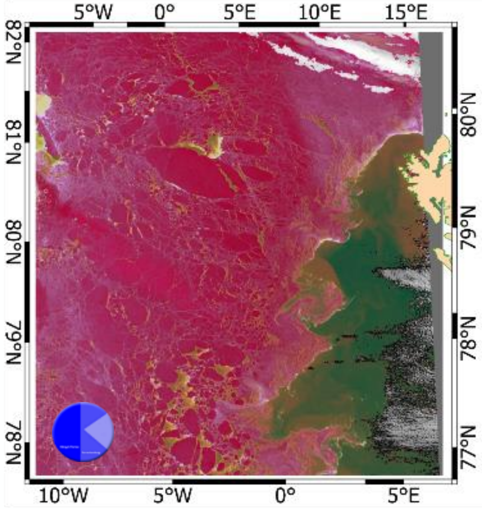
Innovations

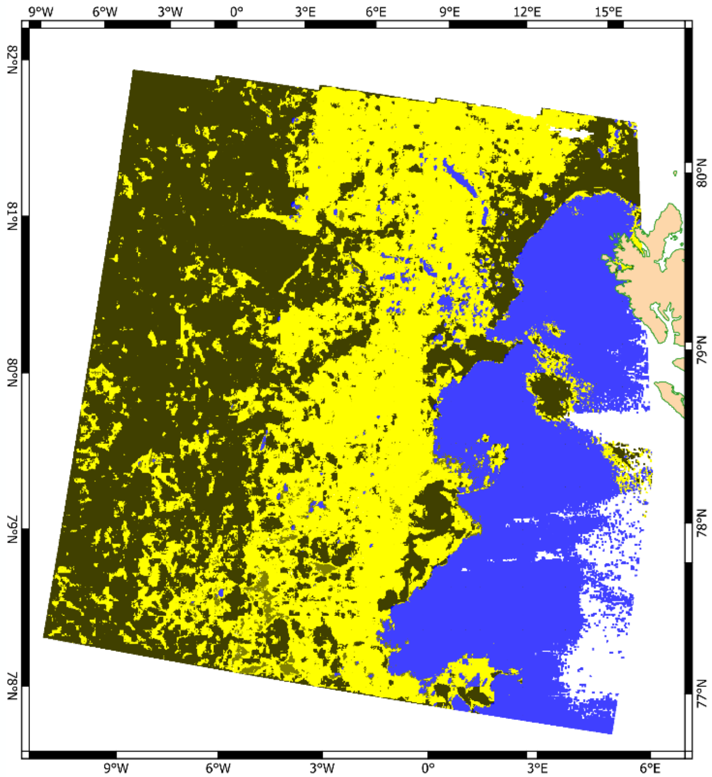
(Results)

Innovation (Wiehle et al.)









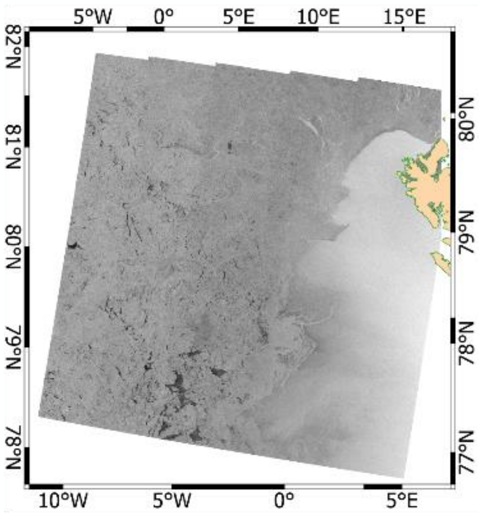
- CNN classification, 6 classes

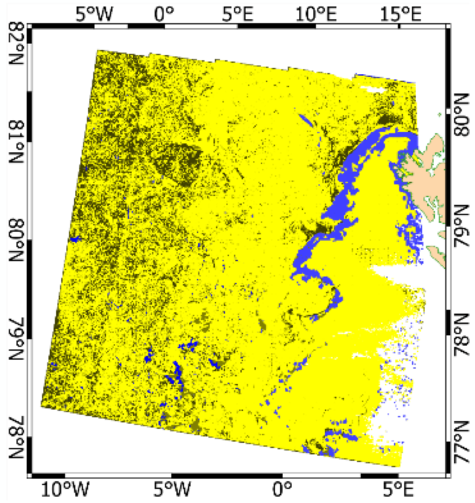
Multi-year ice	Open water, smooth
First-year ice	Open water, rough
Young ice	Rough ice

Innovation (Wiehle et al.)

- Open water challenging to classify in SAR
- High dependency on acquisition parameters
- Difficult to train

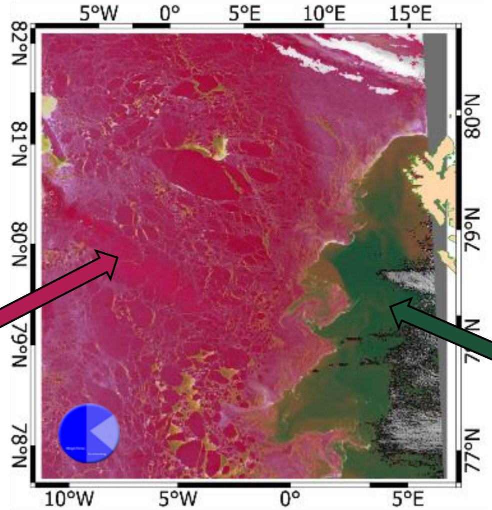
SAR only classification





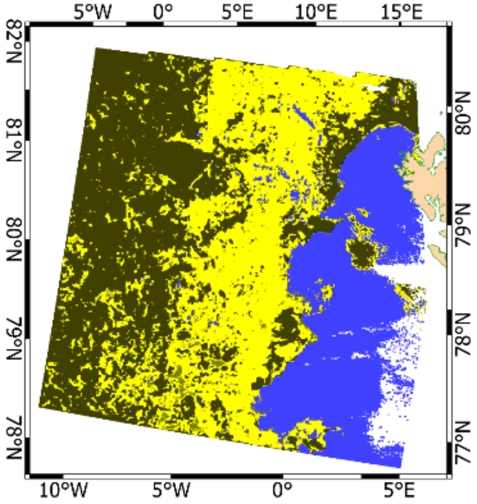
- Fusion: improved classification of open water

Ice with dry snow cover

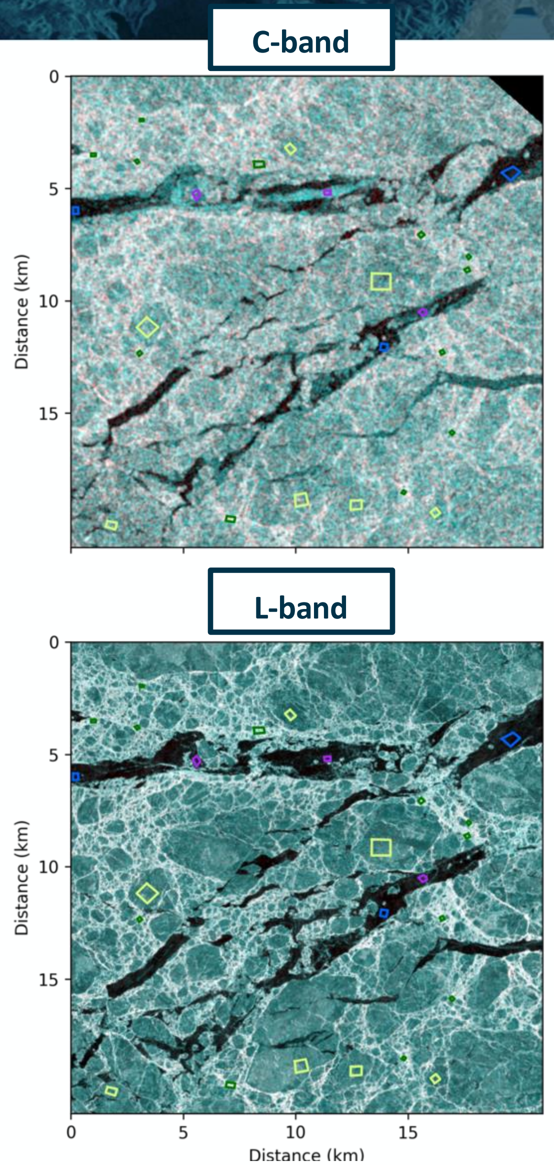


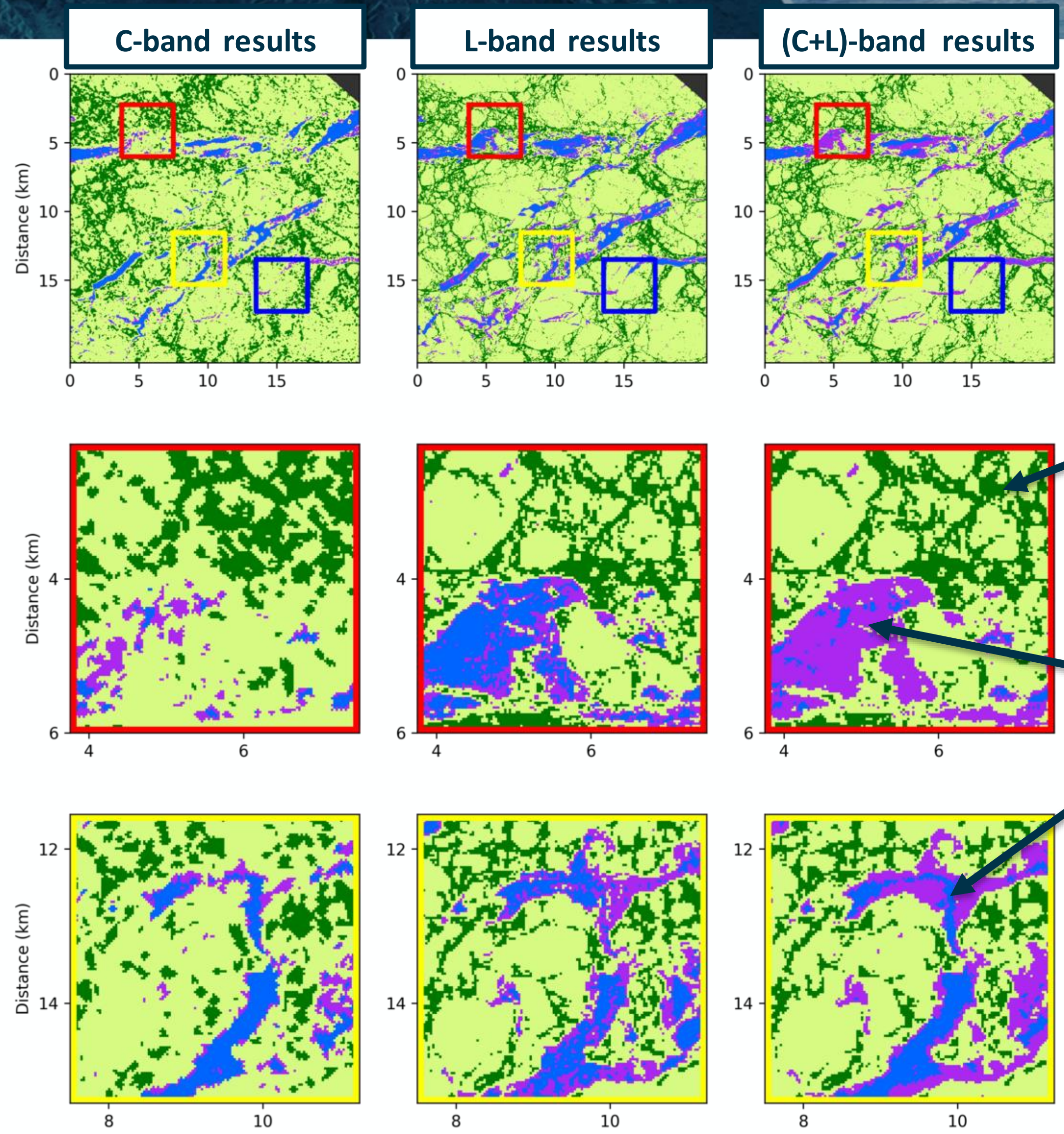
Open water

Fused classification



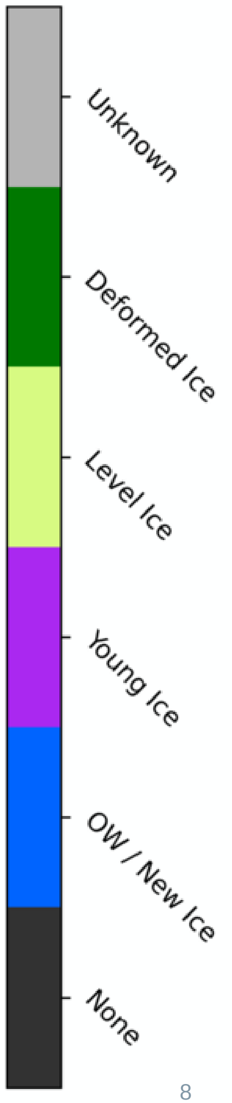
Innovation (Lohse and Dierking)





L-band or the combination of C- and L-band is clearly best at detecting *Deformed Ice*

Only the combination of C- and L-band captures *Young Ice* and *Open Water* within lead systems correctly

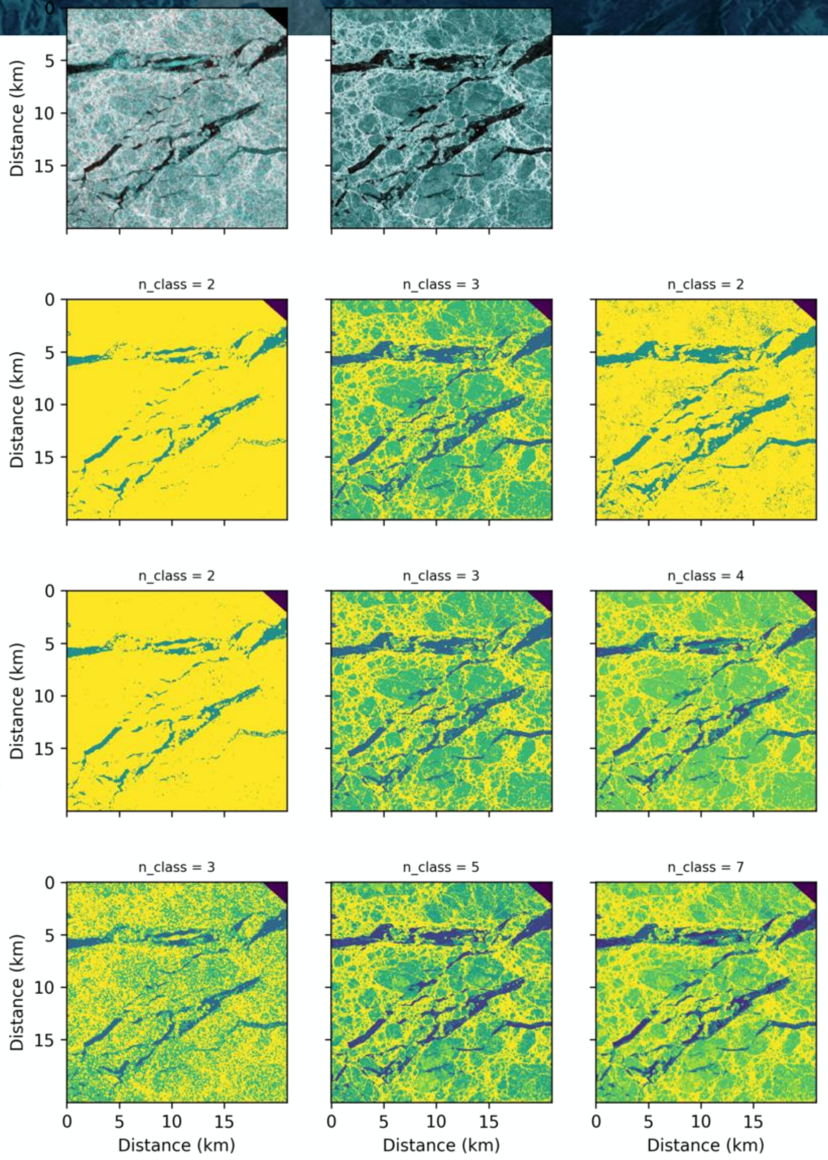


Innovation (Lohse and Dierking)

Increasing sensitivity

↓

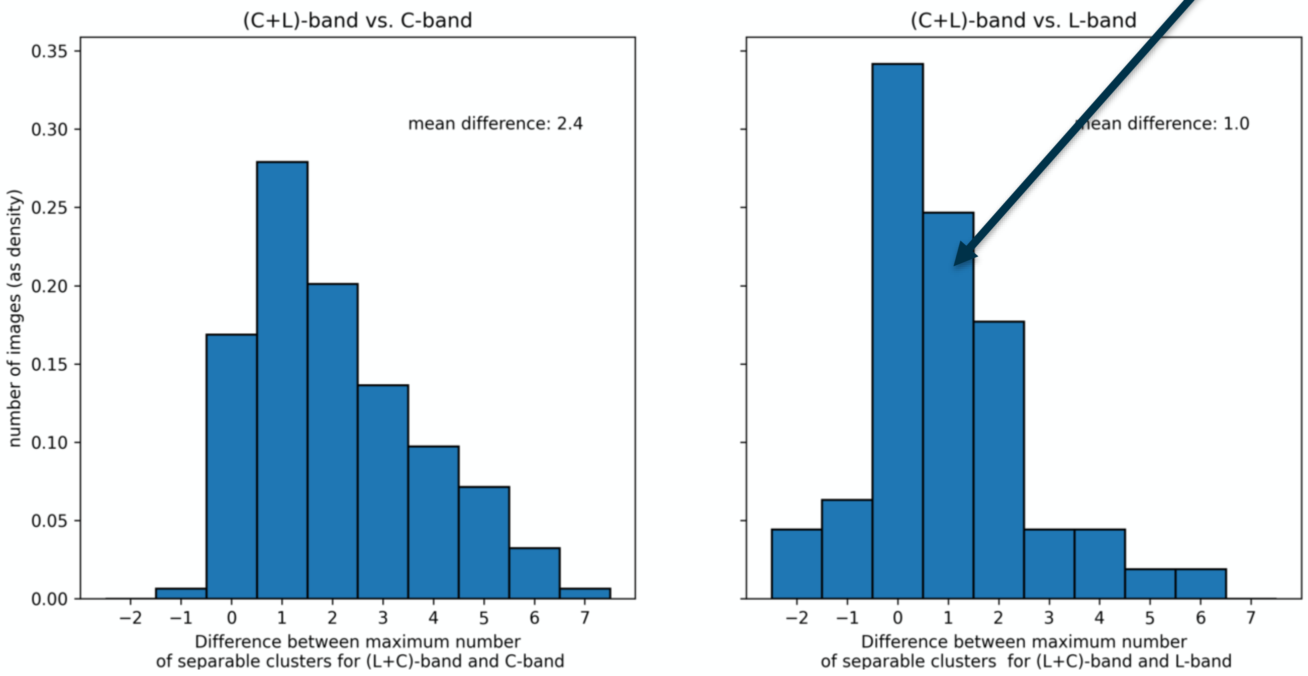
more clusters



Use distance measure to find maximum number of statistically separable clusters for:

- **C-band**
- **L-band**
- **(C+L)-band**

Number of image pairs for which (C+L)-band segmentation produces 1 more statistically significant cluster than L-band stand-alone segmentation



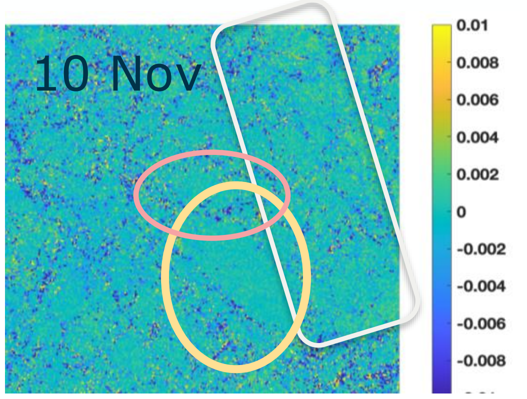
Innovation (Lohse and Dierking)

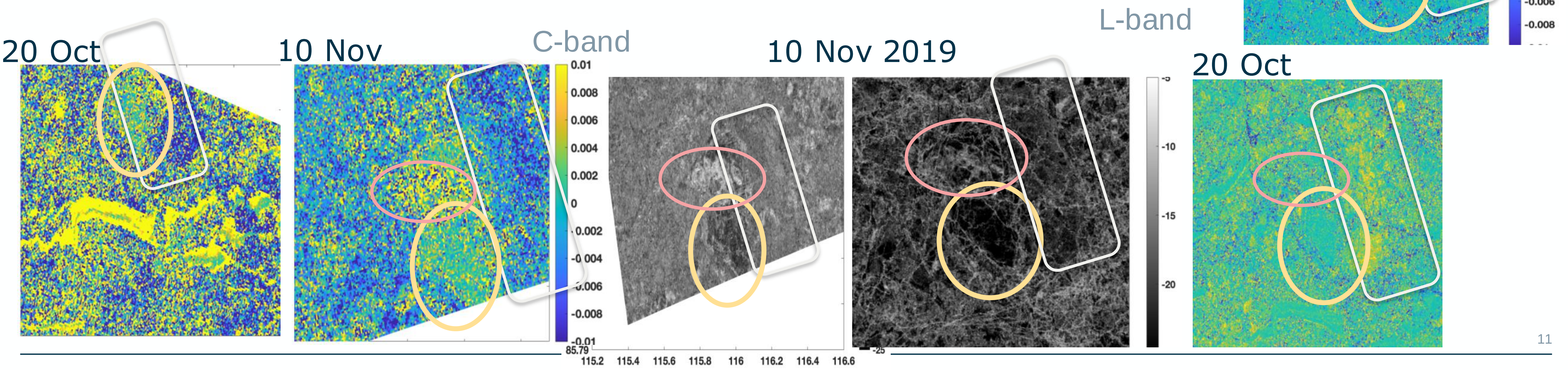
- L-band is always better at detecting *Deformed Ice* than C-band
  - Combination of C- and L-band is equally good or better
- Results for *Leads* and *Young Ice* are more variable:
  - Sometimes C-band is better, sometimes L-band is better (likely depending on small-scale roughness of YI)
  - Combination of C- and L-band is always best
- L-band maintains slightly better separation of *Level Ice* and *Deformed Ice* during melt onset
- Segmentation: (C+L) contains significantly more information than single-frequency approaches
  - On average 2.4 more clusters than C-band stand-alone and 1.0 more clusters than L-band stand-alone

Innovation (Johansson et al.)

Polarization difference (PD): VV-HH usefulness for sea ice type characterization -> separation of young ice

- Open water -> high PD
- Newly frozen sea ice -> high PD
- Young ice -> low PD
- Deformed ice -> large variability





Innovation (Johansson et al.)

L-band:

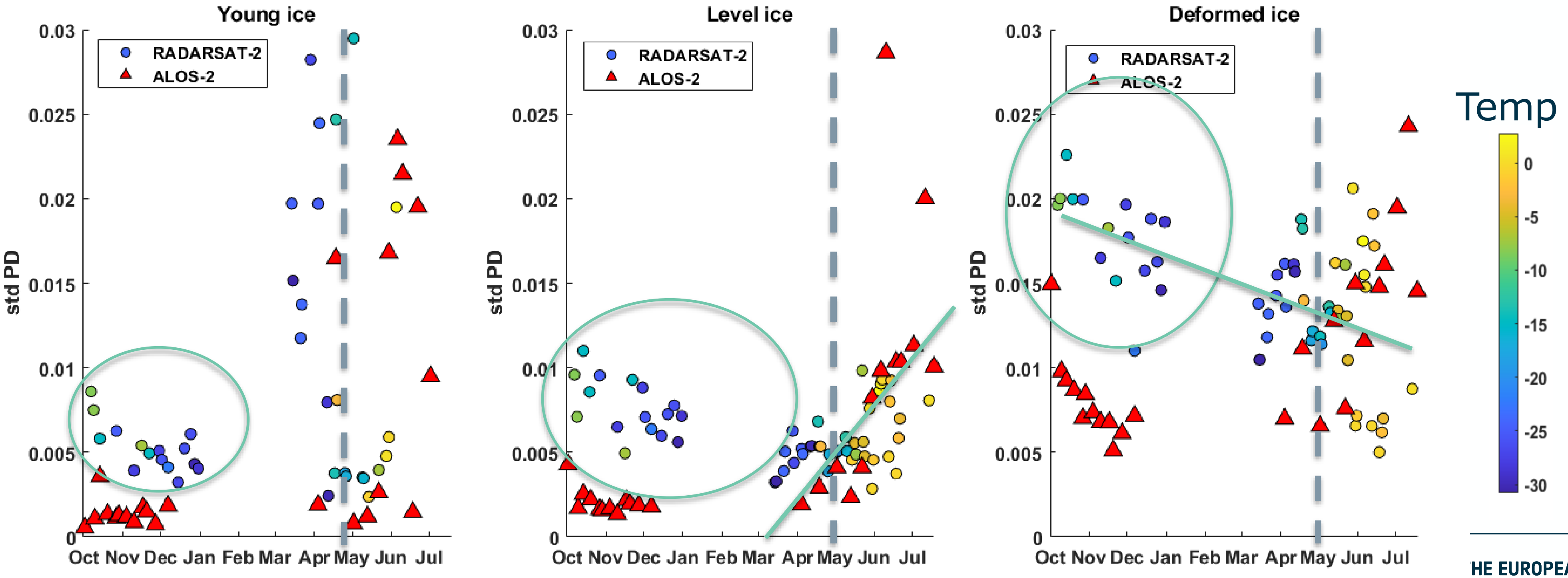
PD std small in freezing season

Larger std but same mean values in early melt season

Positive temp -> std and mean values increased

C-band:

- PD std large in freezing season
- High mean and lower std values for young ice regardless of low or high backscatter
- Level ice -> increased std with positive temp
- Deformed ice -> decrease std



Innovation (Johansson et al.)

Polarization difference

- Can be used separate young ice types from surrounding sea ice in both frequencies
  - L- and C-band have different dependencies on season and sea ice types
  - Reduced sensitive to incidence angle variations and noise
  - Possible from RCM, i.e. the HH+VV mode
  - The co-pol channels are also preferable for melt seasons for melt pond studies
  - Results transferable to data from, e.g., N-ICE2015 and CIRFA cruise 2022
    - Snow cover thicker during N-ICE2015

- Smaller L-band pixel spacing could aid the deformed sea ice extraction

Challenges and knowledge gaps

Multi-sensor synergy

- We have better coverage (temporal + spatial) when combining multiple sensors
- Several hours time delay between acquisitions
    - Critical especially for ocean applications with quickly changing parameters
    - Areas with high sea ice drift speeds (e.g. Fram Strait)
- Data alignment can produce good results, but multi-sensor data with temporal gaps are challenging
- SAR + optical satellite combination might be advantageous for multiple sea ice tasks
    – Clouds, fog and darkness

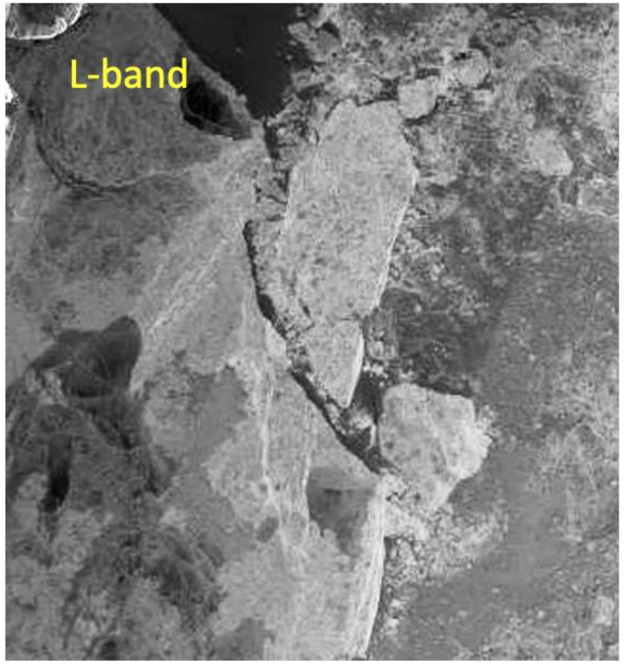
⇒ How to overcome the time separation?

Summer – melt season

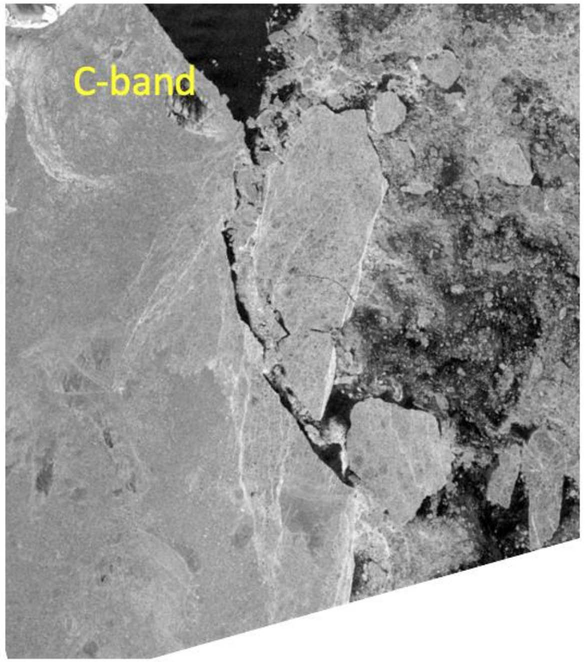
- The use of the two co-pol channels are preferable
    - Possible from RCM, i.e. the HH+VV mode, or compact pol missions
- Polarization difference can be used to separate young ice form thicker sea ice – RCM or compact pol data

Challenges and knowledge gaps

- How can we best assimilate different sensors and benefit from their strengths
  - IR thin vs thick ice -> heat fluxes
  - Optical -> open water, snow covered sea ice, ridges (with favourable illumination)
  - SAR -> penetrates (?) snow, can see the ice structure, ice water separation is challenging



PALSAR-2 WB HH-Pol. 20190708 14:27



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Example of multi-frequency SAR image combination

Belgica Bank (NE Greenland), melting phase: first-year ice (darker signature) easier to distinguish from multi-year ice (brighter areas) at L-band

Courtesy: Nick Hughes and Frank Amdal, Norwegian Ice Service

Outlook and recommendations

- Time separation between different SAR (satellite) sensors
  - ⇒ Tandem mission for ROSE-L is preferable (for automated ice type classification)
- Fleet of mixed micro-satellites (think Capella Space) might be an option when time delay <1h is ok
- Consider using RCM mode HH+VV over polar regions in summer
- Combine sea ice deformation and thermodynamics for sea ice classification/separation
- Operational L-band SAR constellation
  - Identify how L-band SAR can contribute for improved sea ice products
  - ALOS-2 has small pixel spacing – is this more important than resolution?
- Move towards integrated systems: (satellite) observations – assimilation – model
- Collaboration between different sensor acquisitions

Theme: Sea Ice

Topic: In situ data to support sea ice retrievals

Catherine Taelman et al,
Torbjørn Eltoft et al
Ekaterina Kim et al.

Contributing work

Tracking backscatter signatures of individual sea ice floes - Using in-situ drift observations

By Catherine Taelman, Johannes Lohse and Anthony P. Doulgeris

UiT The Arctic University of Norway

The CIRFA-2022 Cruise to the western Fram Strait: Objectives, Ground Measurements, and Preliminary Results

By: T. Eltoft, C. Taelman, M. Johansson, J. P. Lohse, S. Gerland, and W. Dierking

CIRFA - UiT the Arctic University of Norway

Quadruple Helix Framework for Sea Ice Monitoring: Next Steps

By: Ekaterina Kim. Roger Skjetne, Knut Høyland

NTNU

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Key objectives

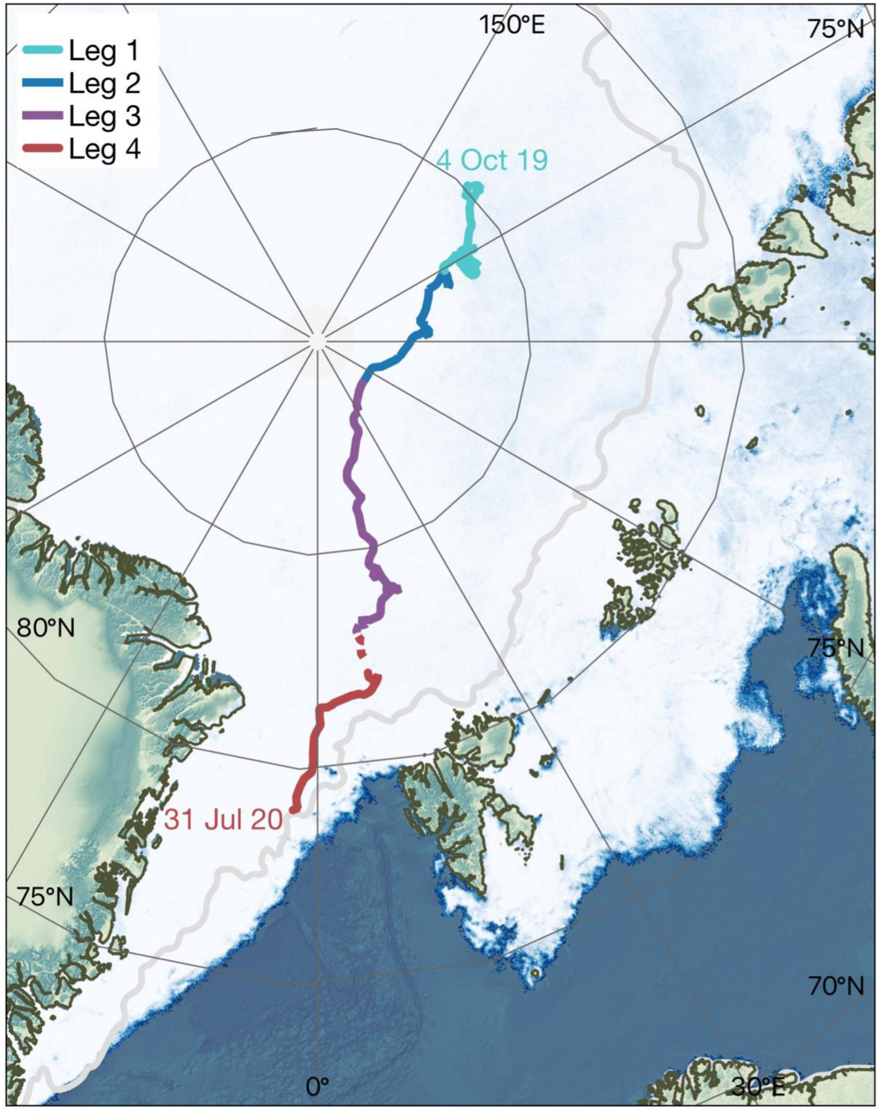
Collect In-situ data to aid remote sensing tool development

- Aid developments and validation of new sea ice algorithms
- Dedicated remote sensing validation campaigns
    - Temporal and spatial overlap
    - Instantaneous ice drift validation
    - Deployment of drifters on sea ice and icebergs
    - Tomographic radar measurements

To build a multiscale digital method and system that integrate remote sensing, numerical models and in-situ data

- Improved spatial and temporal resolution to achieve more precise forecasting of ice conditions in the Arctic
    - including better understanding of long-term variations in polar ice cover
    - Improve design and operation of offshore wind infrastructure

In-situ data campaigns



MOSAIC expedition Oct 2019 – Oct 2020

- Goal to continually monitor changes in the coupled ocean-ice-atmosphere system throughout the seasons

N-ICE 2015
NORWEGIAN YOUNG SEA ICE CRUISE

MOSAiC

the Nansen LEGACY

Icebird (2 yearly)

Photo by Sara Wang

Sea ice Environmental Research Facility (SERF), Uni Manitoba

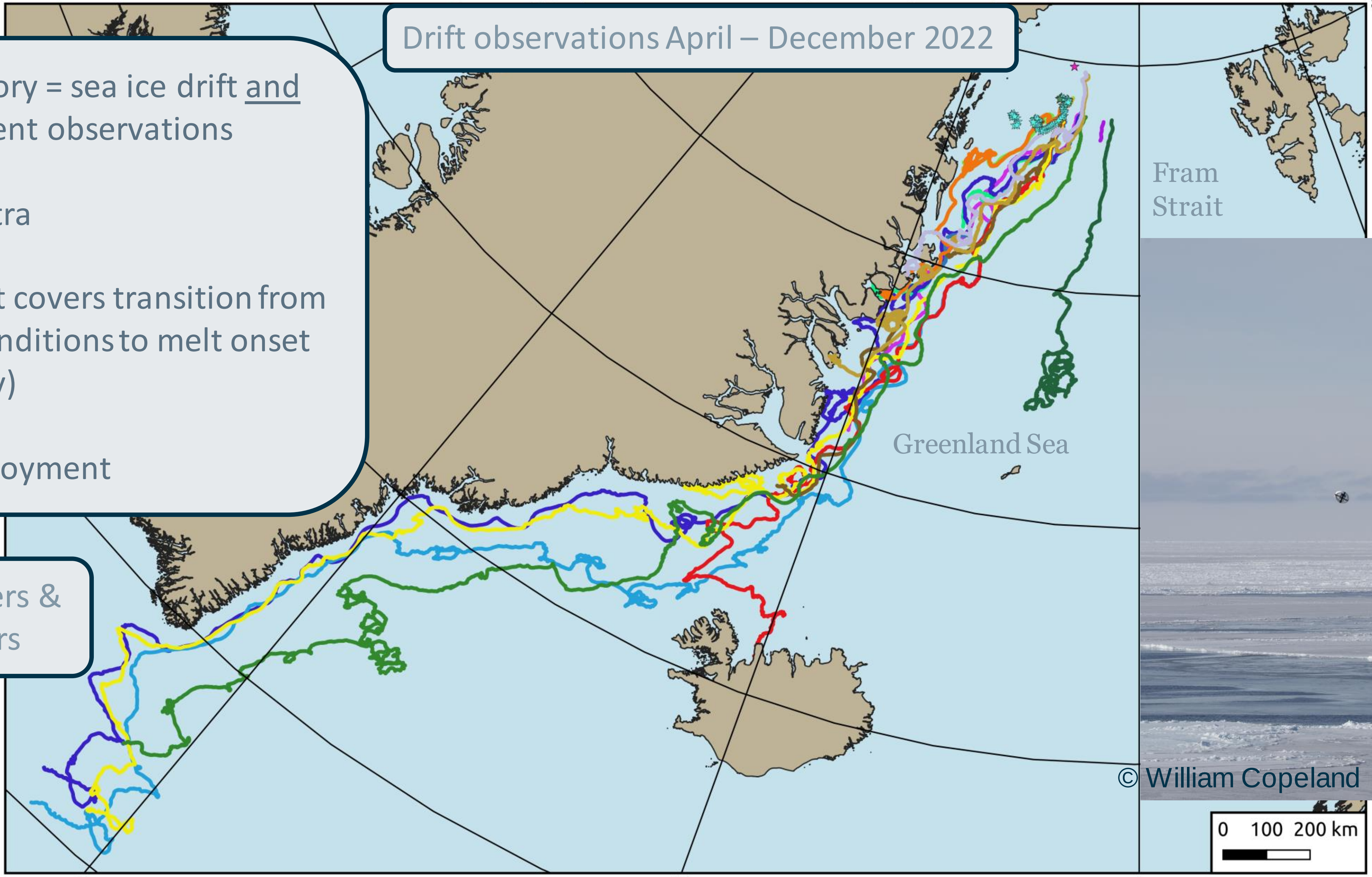
Innovations

(Results)

Innovation (Taelman et al.)

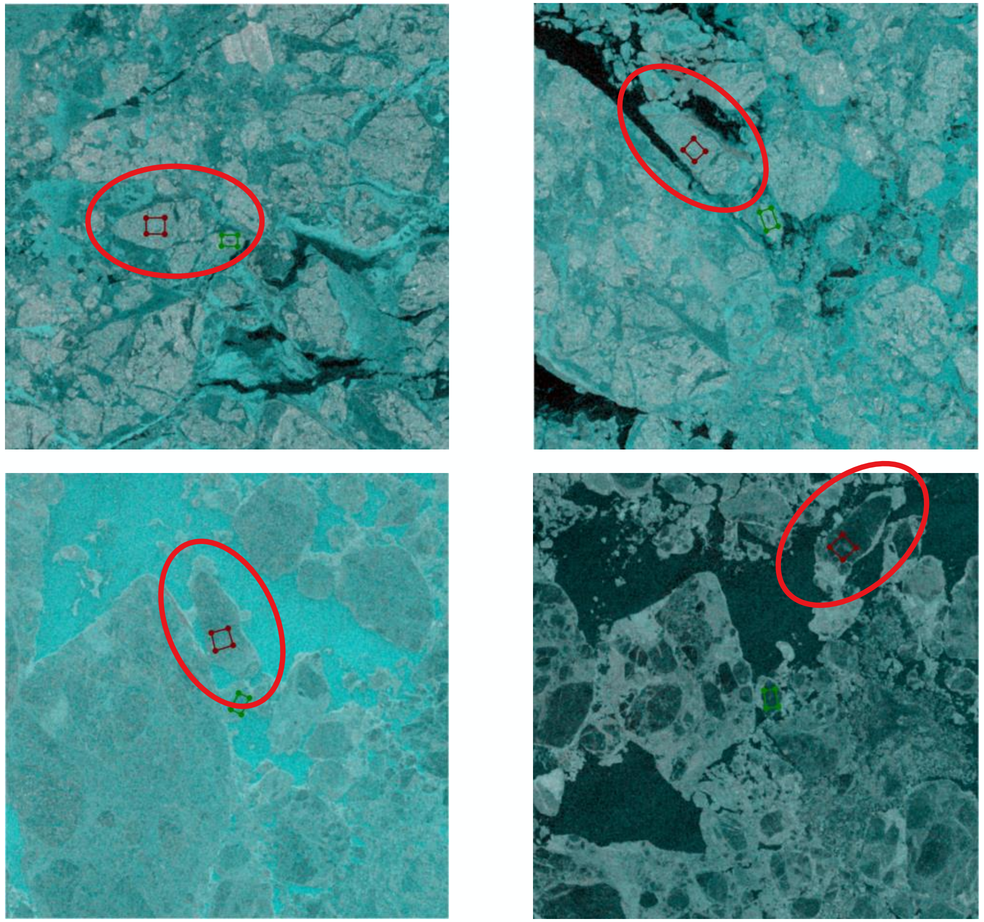
- Full trajectory = sea ice drift and ocean current observations
- Wave spectra
- Sea ice part covers transition from freezing conditions to melt onset (April – July)
- Drone deployment

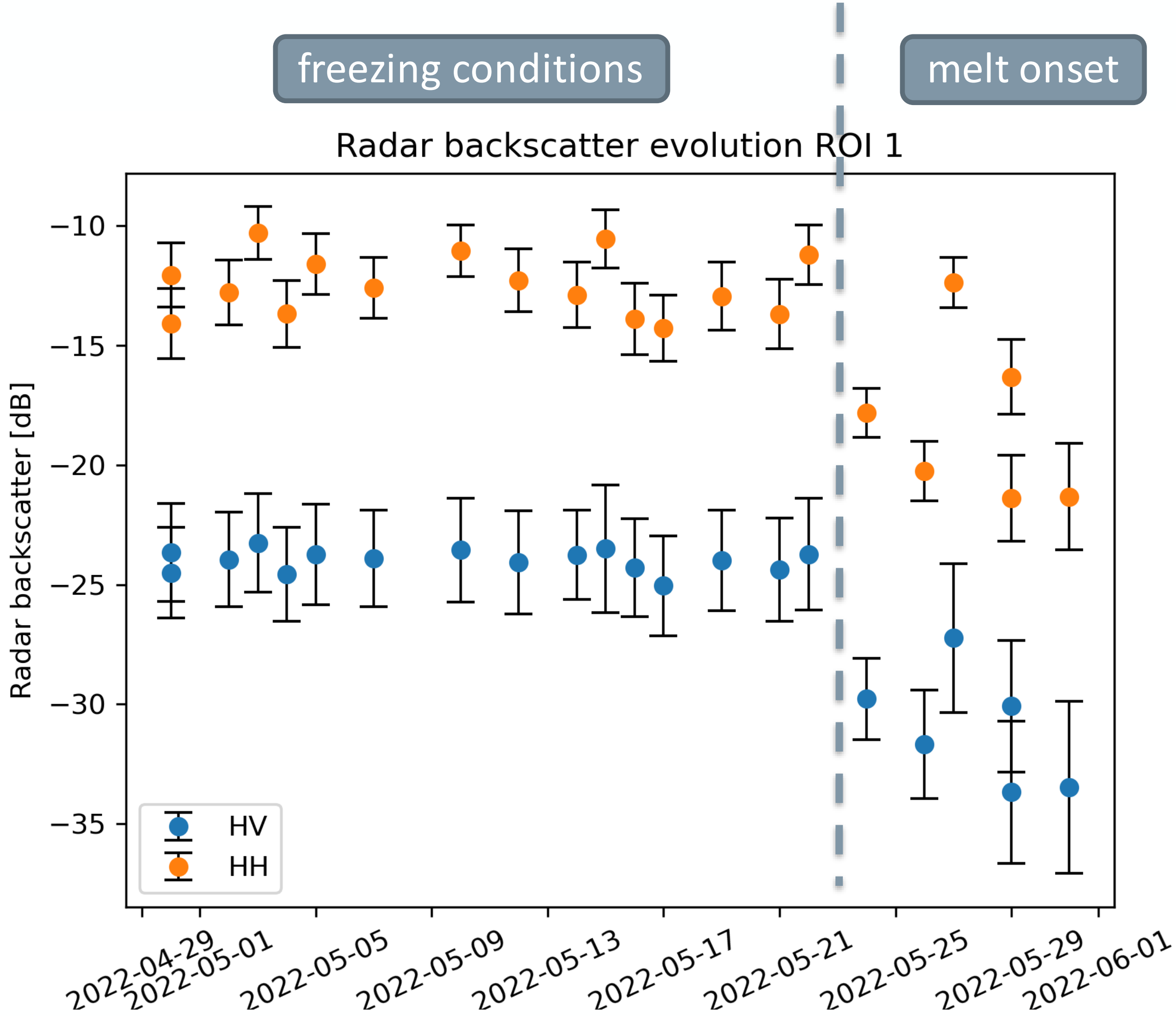
17 sea ice drifters &
3 iceberg drifters



Innovation (Taelman et al.)

- Expand the tracked area by manually identifying distinct ice structures in the vicinity of the drifter location

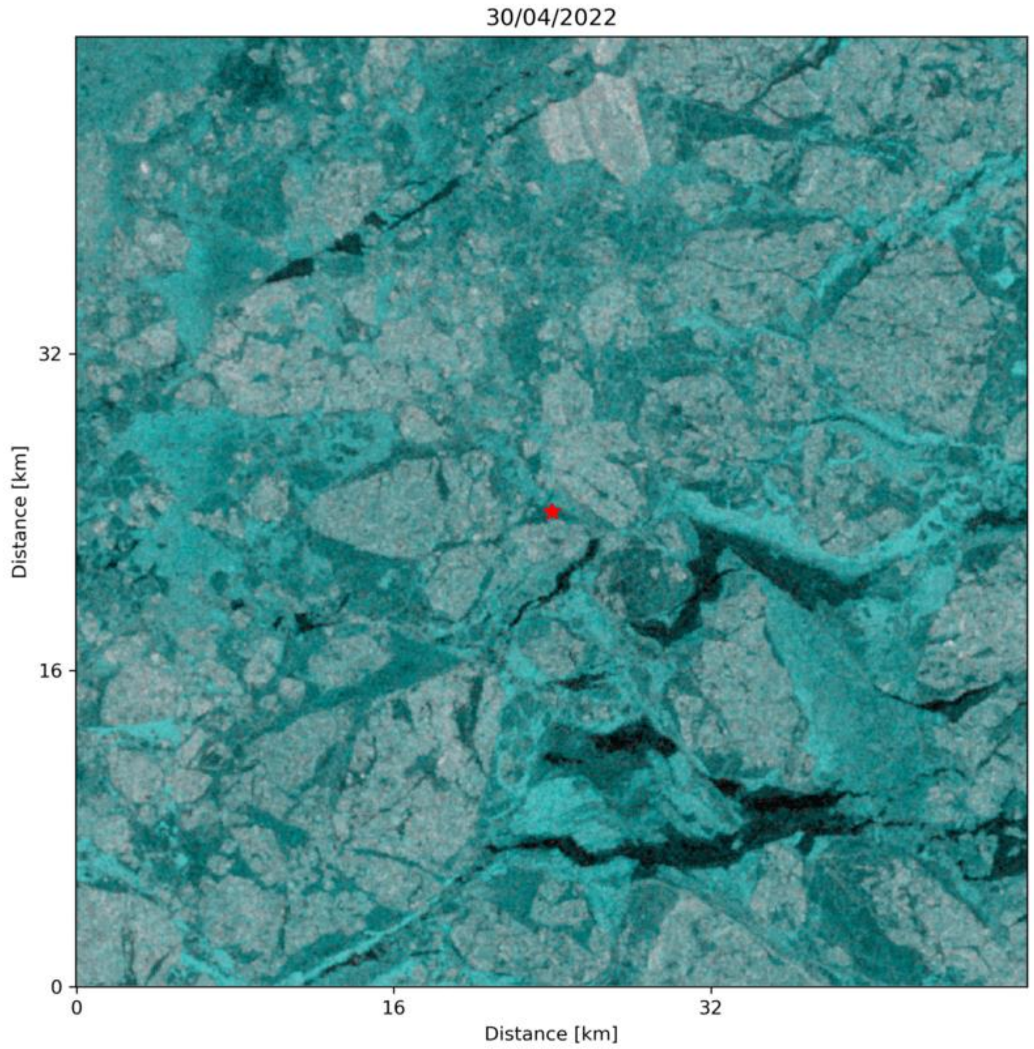




Innovation (Taelman et al.)

- Drones can be used to deploy drifters away from ships/land -> larger spread
- Larger number of drifters enables study of the temporal evolution and incident angle dependence of the radar backscatter for drifting ice floes, even in the melt season
- Preliminary results show that:
  - Freezing season: Radar backscatter variation is mostly due to incident angle
  - Melt season: Radar backscatter changes rapidly and the internal spread is larger. Difficult to attribute variations to either physical changes on the ice, or to incident angle.

Example SAR timeseries for 1 drifter (★)



Innovation (Eltoft et al.)

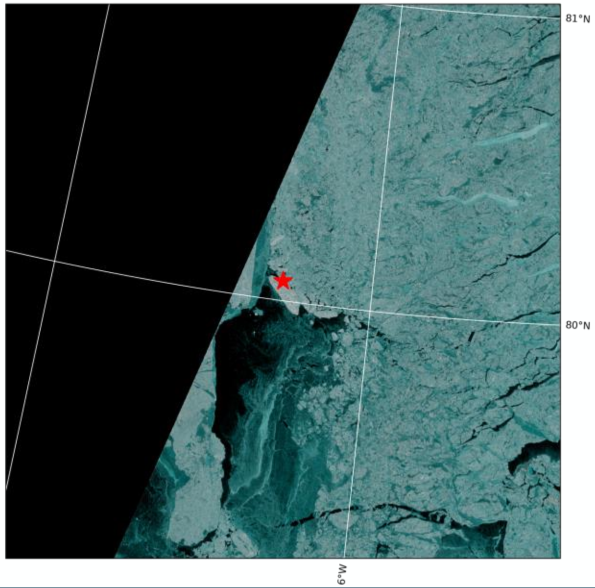
Near real time validation of ship-based sea ice observations with Classifier results.

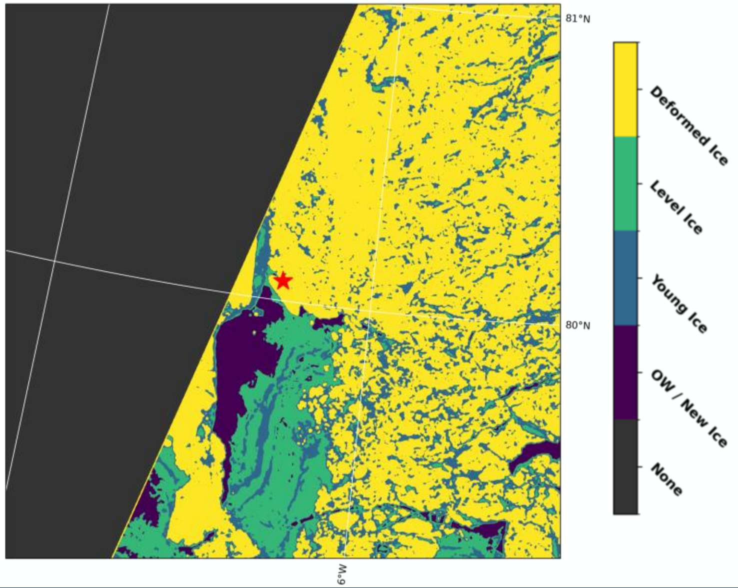
Sentinel-1: 2022/05/04 07:29 UTC

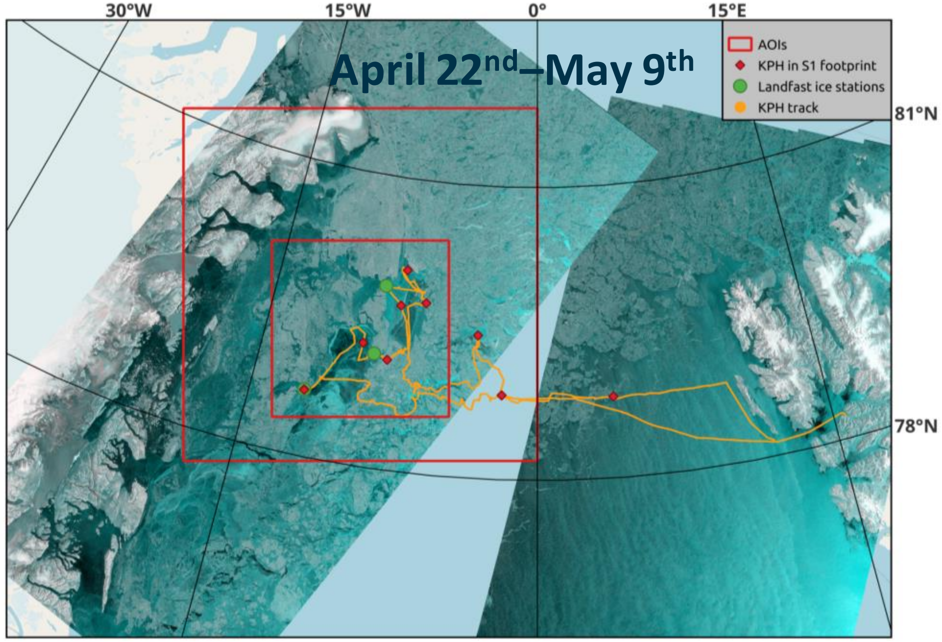
IceObs: Deformed Ice, small patches of Level Ice or Open Water

Classification: Deformed Ice

100x100km

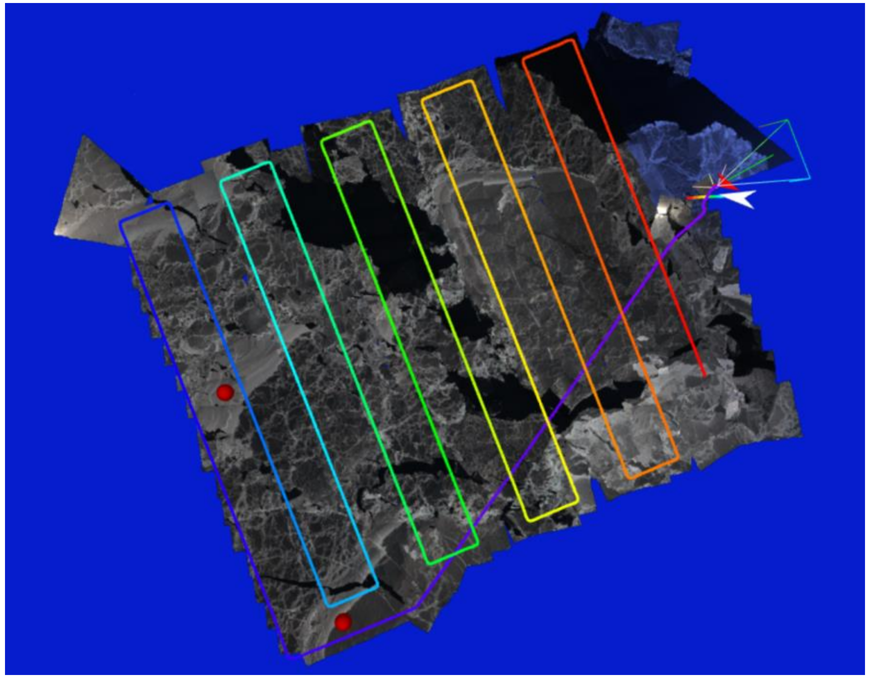


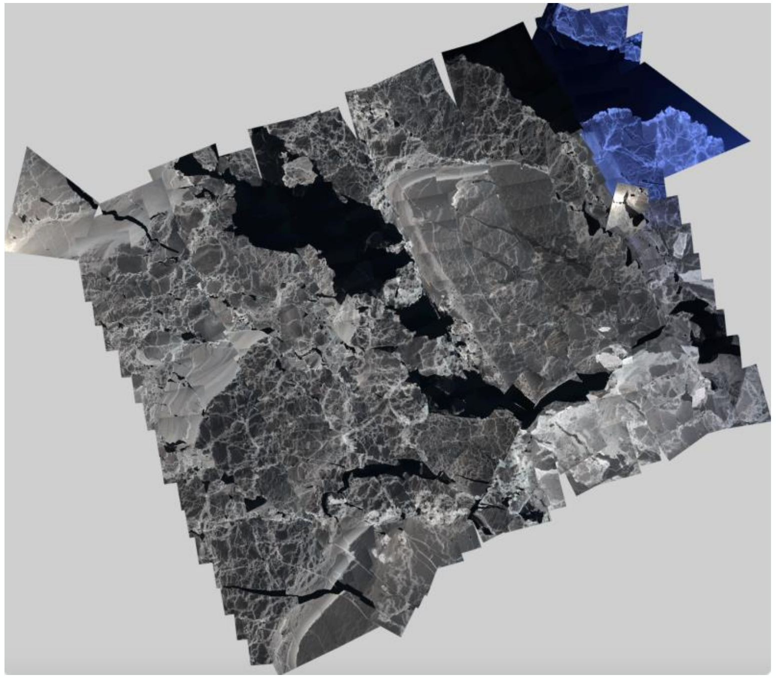




Innovation (Eltoft et al.)

- The VTOL drone could take-off and land on the heli-deck.
- Its long-distance flying capability allowed for km-meter wise optical mapping of sea ice with, 50 cm spatial resolution.
- Coinciding in time and place with SAR acquisitions
- Instantaneous sea ice drift estimates – Harmony mission



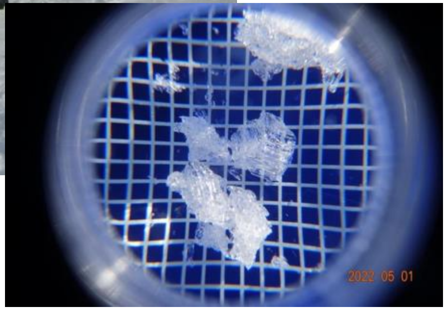


Innovation (Eltoft et al.)

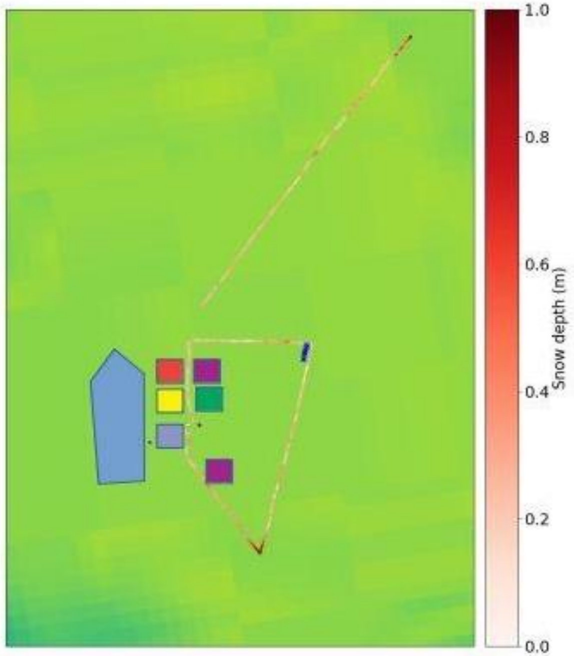
Multi-scale snow measurements

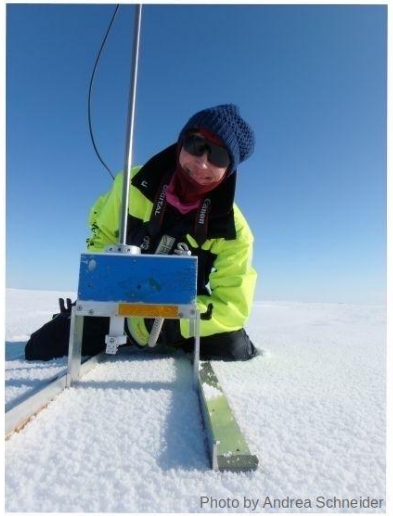
- Snow radar drone
- Snow depth (Magnaprobe)
- Snow hardness (Snow Micropenetrometer)
- Snow pits





Drone equipped with an UWB Snow radar

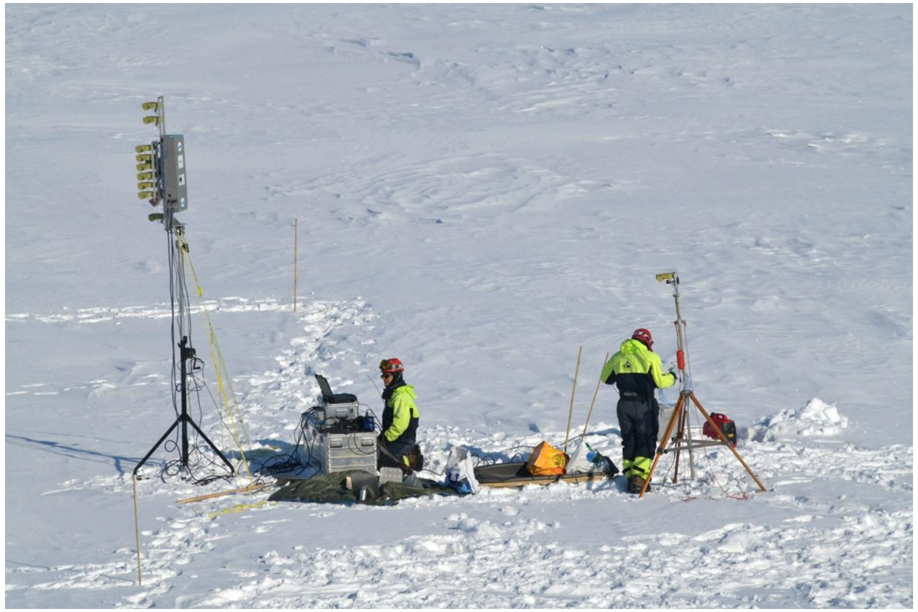


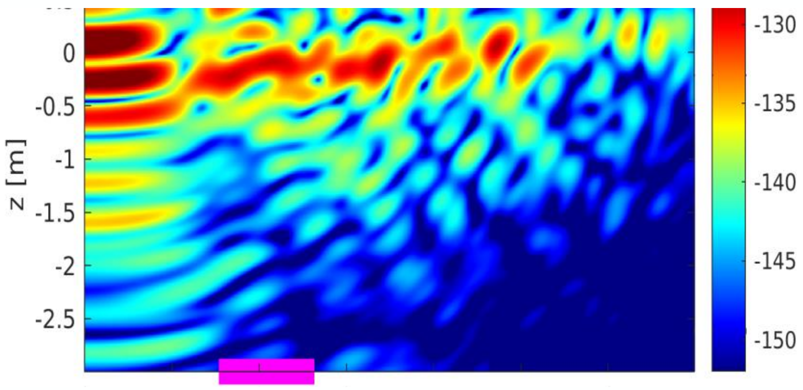


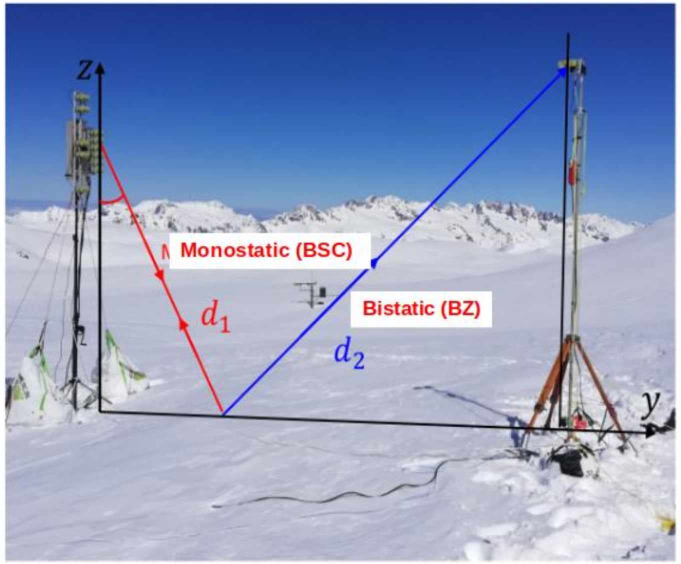
Snow Micropenetrometer

Innovation (Eltoft et al.)

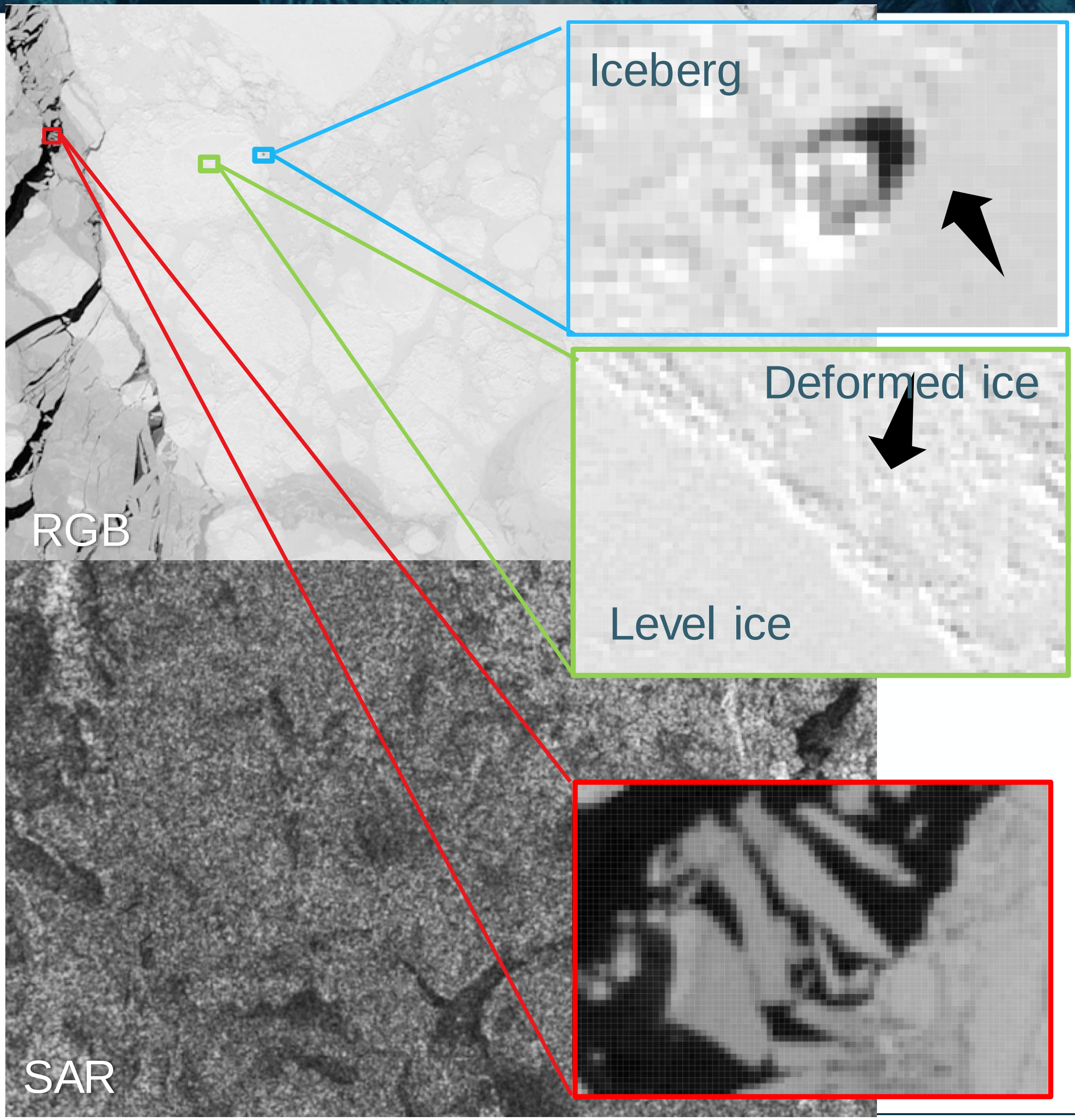
- **High-resolution ground-based radar** signatures to be compared to satellite data
- Discriminate sources of scattering within a *layered* medium consisting of snow on sea ice
- Testing assumptions associated with the radar response of sea-ice at C band





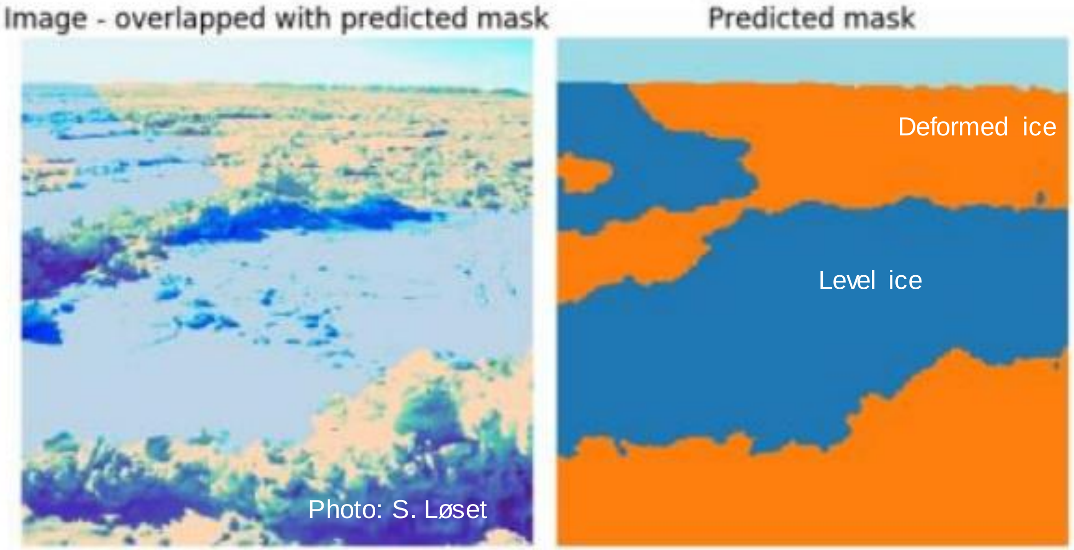


Innovation (Kim et al.)



- AI based segmentation of optical images from ships (Panchi et al, 2021)
- Retrieval of ice parameters
- Customized output

Detection of
Level ice
Deformed ice
Icebergs
Pancake ice
Brash ice
Ice floe
Melt ponds



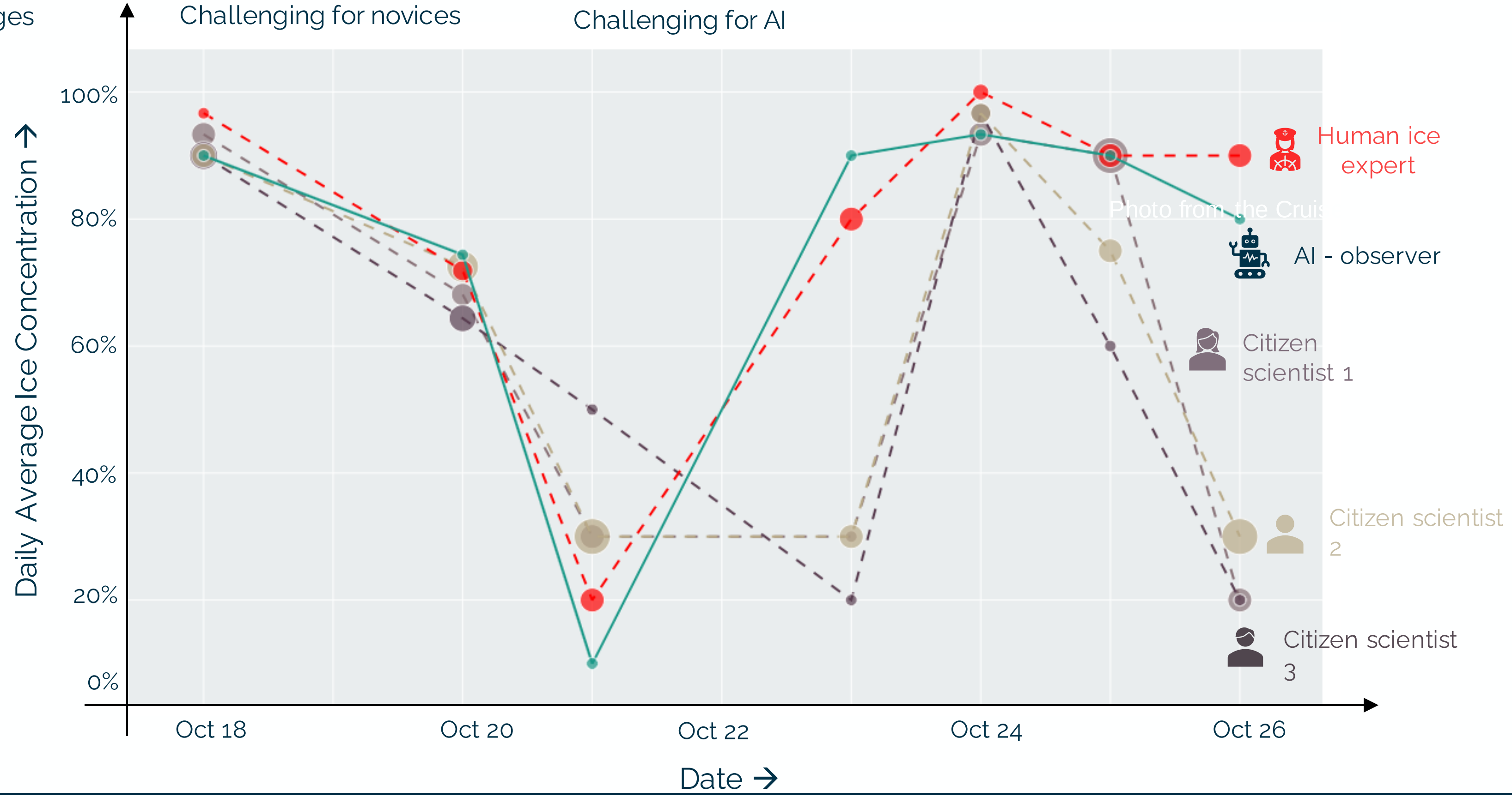
Innovation (Kim et al.)

Normal images

Challenging for novices

Challenging for AI

Tested during GoNorth-2022 (Panchi et al, 2023)



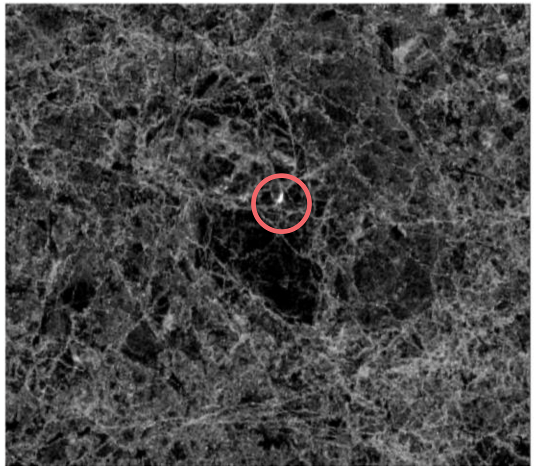
Challenges and knowledge gaps for in-situ data

esa

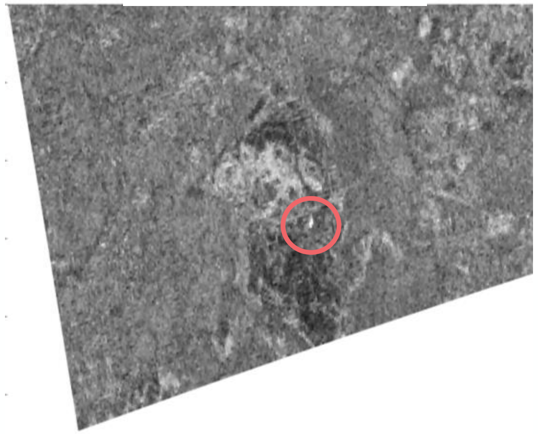
For drifting sea ice is temporal overlap between satellite images and in-situ data collection very important

- Time separation <u>without in-situ drift</u> make validation and training data extraction challenging
- Drift station data collection over time can help cover multiple seasons

PALSAR-2

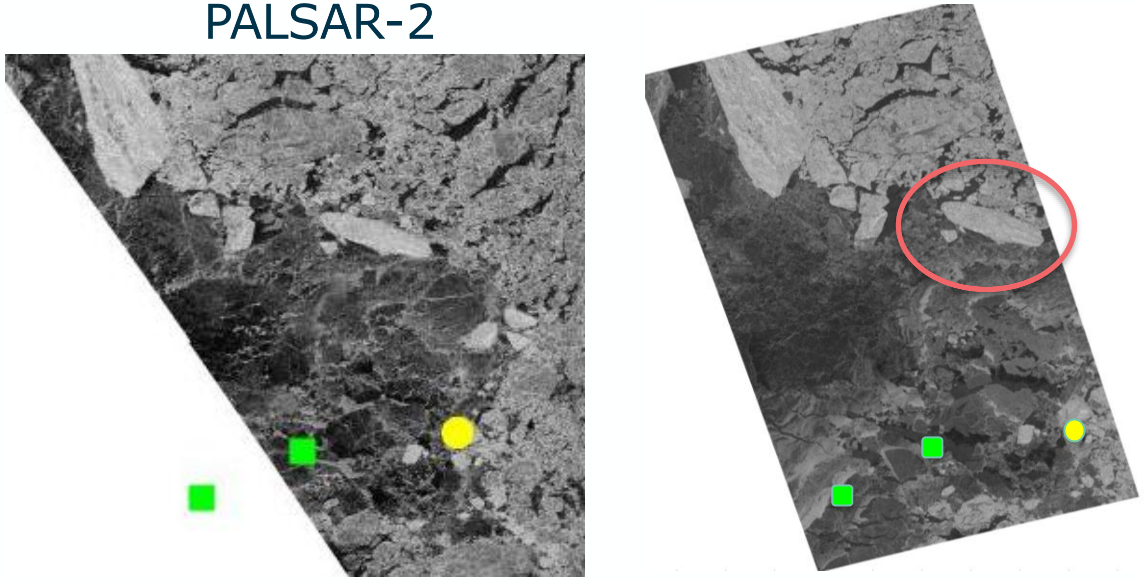


Radarsat-2



8 h time separation

PALSAR-2

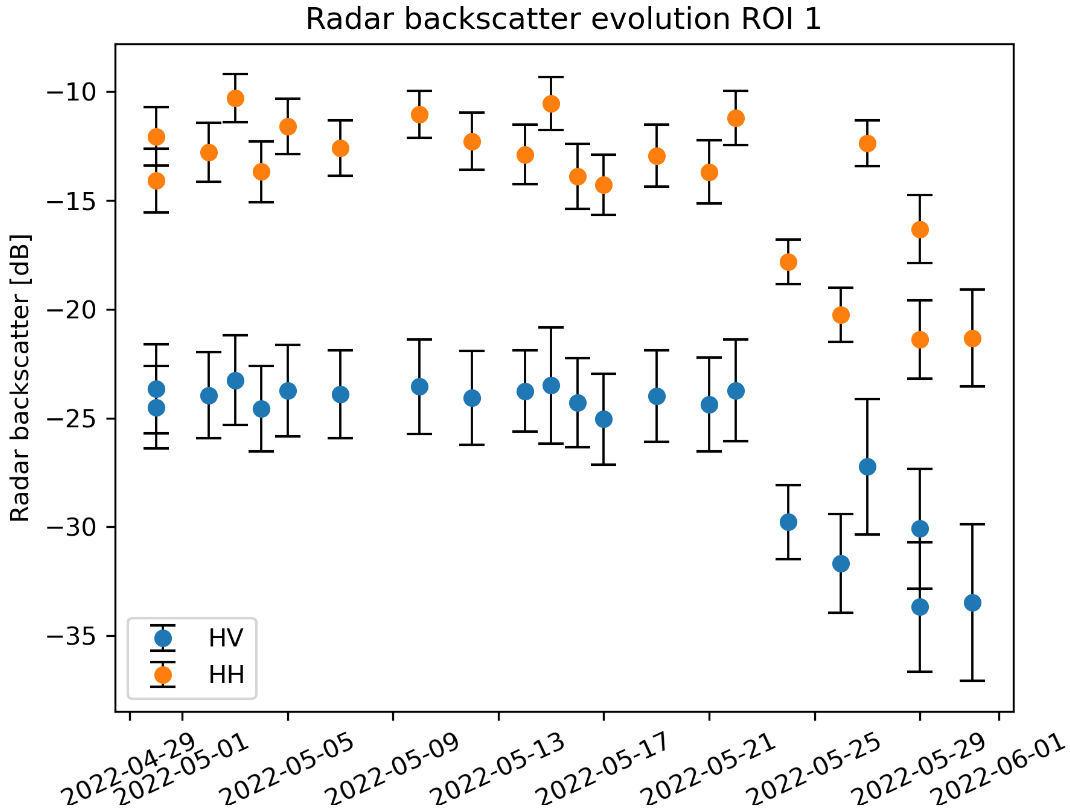


5 h time separation

Challenges and knowledge gaps for in-situ data

Rapid changing surfaces (melting in summer, ice drift year-round)

- Time separation between different satellite sensors and in-situ data collection
- High temporal cover during in-situ data campaigns – support from satellite service providers
    - JAXA-ESA LC-project



Challenges and knowledge gaps for in-situ data

Upscaling - downscaling

- Different modes (fine + coarse evolution) help with upscaling and downscaling
- How can we go from in-situ -> drones -> airborne -> satellites -> models?
- Large spatial possible cover over the site – help mitigate issues with overlapping drifting in-situ campaigns

Outlook and recommendations

Targeted in-situ data collection

- In-situ data campaigns targeting satellite data product validation
- Permanent stations overlapped with repeated satellite image overlaps
- In-situ collection should be adapted to solve the scientific question
- Connect ground radar observations -> drones -> SAR (other satellite images) for upscaling
- Consider overlaps in time and space for upscaling
    - SAR, Altimetry, PMW, IR, Optical sensors for satellites, drones and airborne sensors

Drone usage

- Increased use of georeferenced drone images for training and validation of satellite data products
- Plan drone flights to relate to the science and operational question
- Use drones for instantaneous sea ice drift retrieval - connect with SAR image observations (Harmony)
- Drones have long-distance capability allowed for km-meter wise optical and IR mapping
- Can fly below cloud cover and fly simultaneous with SAR (other satellite sensor) acquisitions

Outlook & remaining knowledge gaps

The role of snow must be better understood

- Snow metamorphism and the effect on the radar signature (perhaps) not fully understood
- Also under dry freezing conditions
- Wind compacted layers
- Rain on snow events
- Ice lenses within the snowpack and brine layer at the snow-ice interface, e.g., February N-ICE2015
- Might mostly relate to C- and X- band, L-band less affected

Summer season

Drifters

- Deploy more drifters on underrepresented sea ice
  - First year ice (thinner)
  - Fast drifting sea ice
- Data arrays, e.g., MOSAiC, NICE-2015 etc (drifting and deformation on a high-resolution scale)