Thematic Area 1 – Session
Polarimetric and Multi-frequency SAR Applications

Ake Rosenqvist (JAXA) & Magdalena Fitrzyk (ESA)

TA1 topics

- Forest & Biomass (Paul Siqueira, UMass) [*Virtual]
- Wetlands (Ake Rosenqvist, JAXA)
- Agriculture & Crop monitoring (Heather McNairn, NRCan) [** by Ake]
- Soil Moisture (Laura Frulla, CONAE) [*Virtual]
- Sea Ice (Malin Johansson, Univ. Tromsø)

Forest & Biomass

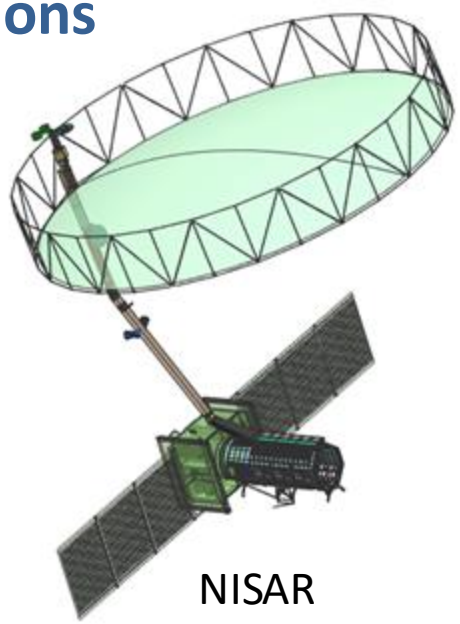
Paul Siqueira (UMass, USA)
Maurizio Santoro (Gamma RS, CH)
Ake Rosenqvist (JAXA, Japan)

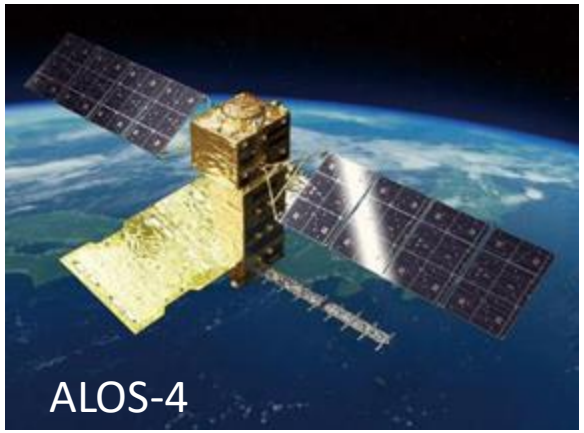
Suggestions for current and near future SAR missions

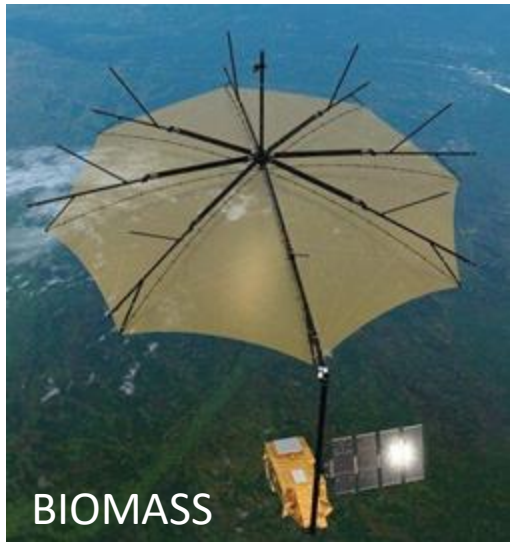
- Current and near-future mission complementarity
  - **ALOS/ALOS-2/SAOCOM:** Critical historical L-band archive → Make data public open
  - **ALOS-4:** Adding wide-swath Quad-pol capacity
  - **NISAR:** Dual-pol weekly observations
  - **Sentinel-1**: Critical historical C-band archive

- High resolution SAR, over multiple observing modalities is an immediate opportunity.

- The immediate challenge is in learning how to cope with the enormous data volumes and instrument peculiarities and learning on how to make best use of these observing systems
  - Data fusion (polarimetry, interferometry, multi-frequency, etc.)
  - Bringing algorithms to the data rather than data to the algorithms (cloud computing)
  - Harnessing machine learning

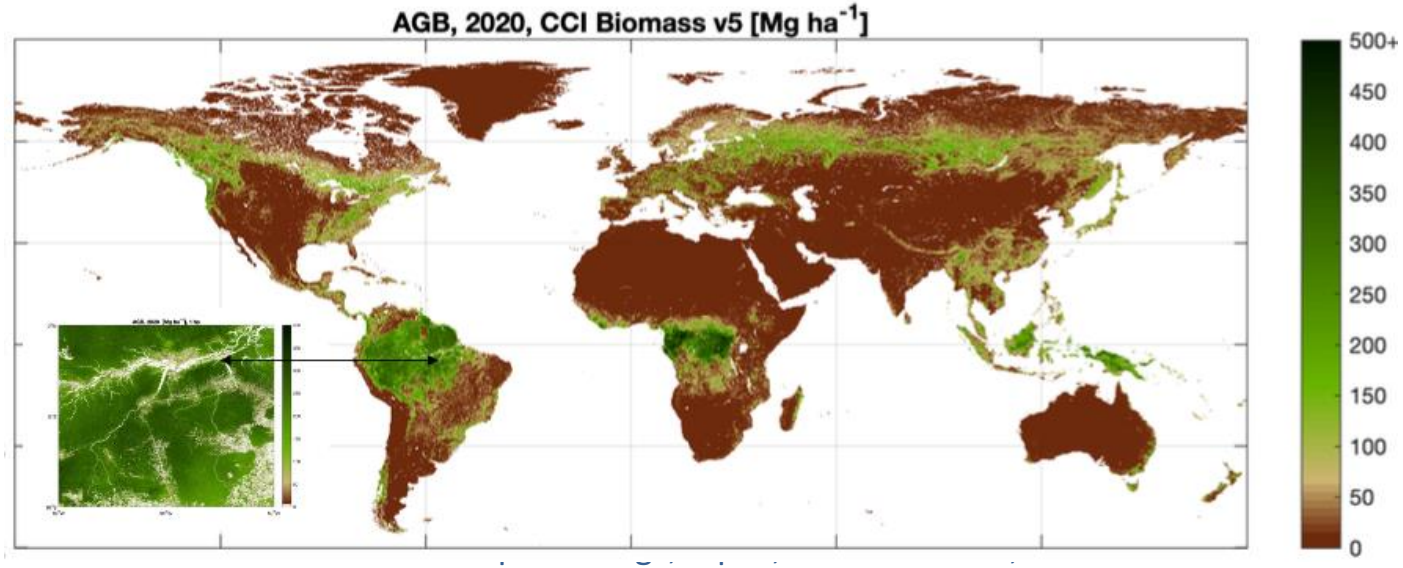

NISAR





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

- ESA's ROSE-L and Sentinel-1 series, combined with BIOMASS and other such missions, will serve as a base of SAR data collections for building new and innovative systems for the future
- NASA currently has two relevant missions mentioned in the last decadal survey
  - Surface Deformation and Change (**SDC**) meant to be the follow-on mission for NISAR. Despite the name, an Ecosystems component is an essential part of the mission.
  - Surface Topography and Vegetation (**STV**) – intended to estimate vegetation vertical density profiles, likely using a combination of TomoSAR and Lidar
- Begin planning for a follow-on P-band mission
- Coordination with JAXA, CONAE, DLR, ISRO, to leverage resources and improve frequency of observations (e.g. 3-day repeat to capture weather variations.
- Keeping consistent time series over decades is fundamental, building on the 3-decade L-band data record by JERS-1, ALOS and ALOS-2.



[Santoro et al. 2024]

Wetlands

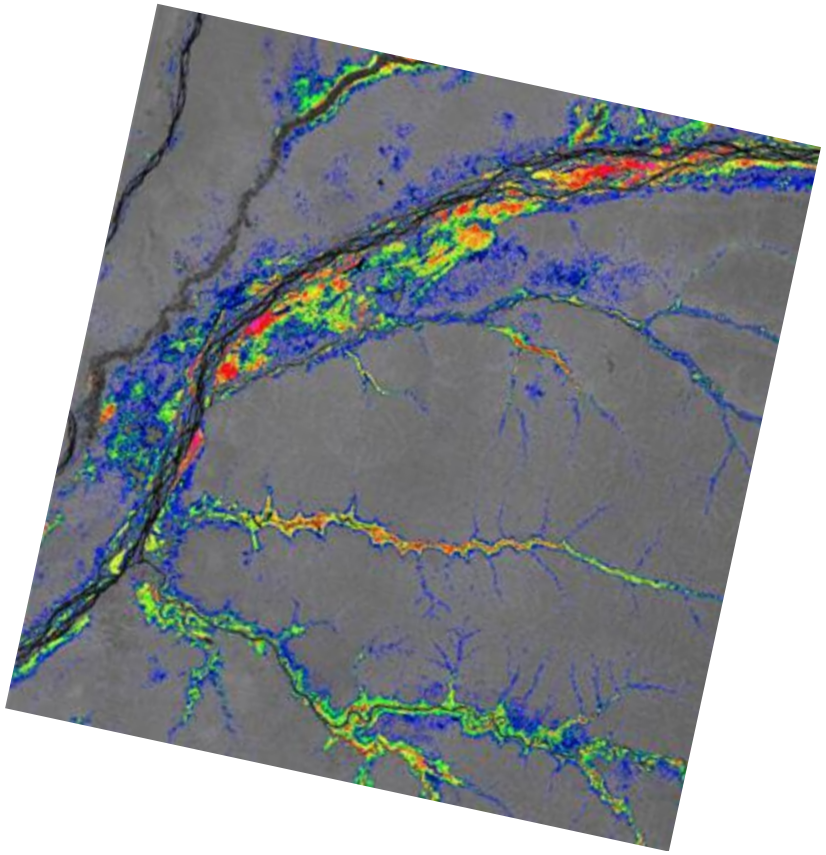
Ake Rosenqvist (JAXA, Japan)
Laura Hess (UCSB, USA)

Recommendations for current and near future SAR missions

- Continued uninterrupted systematic L-band wide-swath time-series observations (DP or QP) over the world's wetlands. L-band critical, but all frequencies are useful
- Wetlands are highly dynamic. Lost observations result in voids in time series → minimise acquisition gaps!!
- Spatial resolution of current missions (10-25 m) is adequate
- Temporal resolution: ~ Weekly (no less than monthly)
- L-band mission complementarity
  - ALOS-2: Continue ScanSAR data record until EOL
  - ALOS-4: Continue ALOS/ALOS-2 ScanSAR data record + Quad-pol multi-seasonal observations
  - NISAR Dual-pol weekly observations (current mission plan adequate)
  - Access to SAOCOM-1A/B systematic archive
- Sentinel-1/RCM: Access to systematic C-band HH+HV data over key wetlands (superior to VV+VH)

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

- Future SAR missions to consider wetlands as part of mission objectives
- Continuity of systematic time-series observations over the world's wetlands at all SAR frequencies
- Temporal revisit: ~weekly
- Spatial resolution: 10-25 m
- Frequency: L-band critical, but all frequencies useful
- Polarisation: HH+HV critical (also for C- and S-band)
- Quad-pol – at least dual-season annually



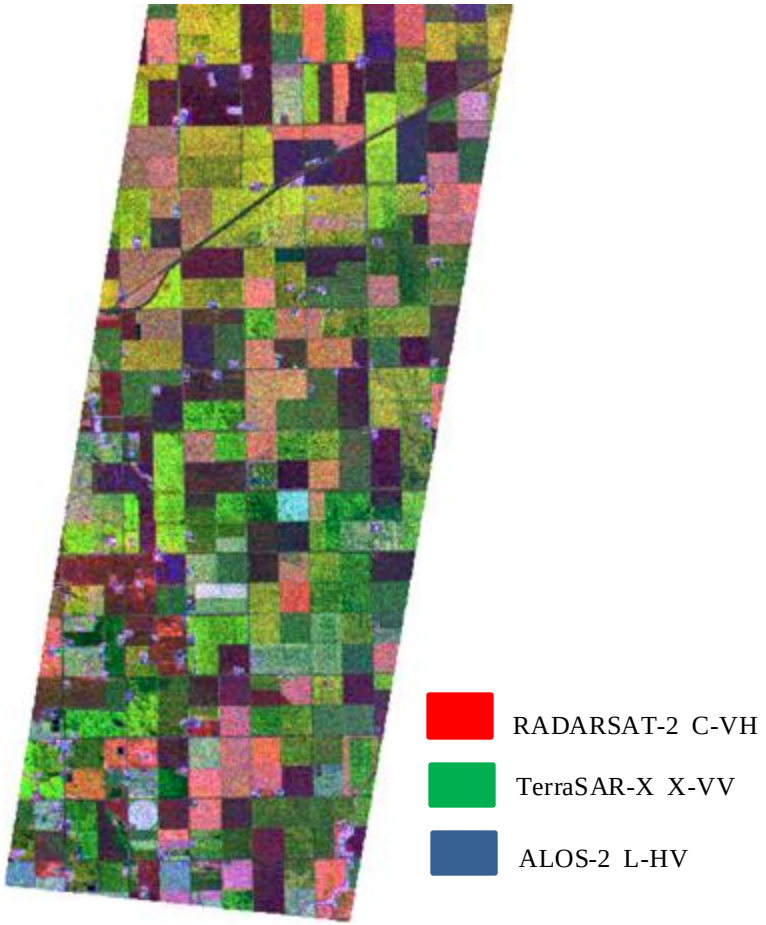
[Rosenqvist et al. 2009]

Agriculture & Crop Monitoring

Heather McNairn (Agriculture Canada)

Recommendations for current and near future SAR missions

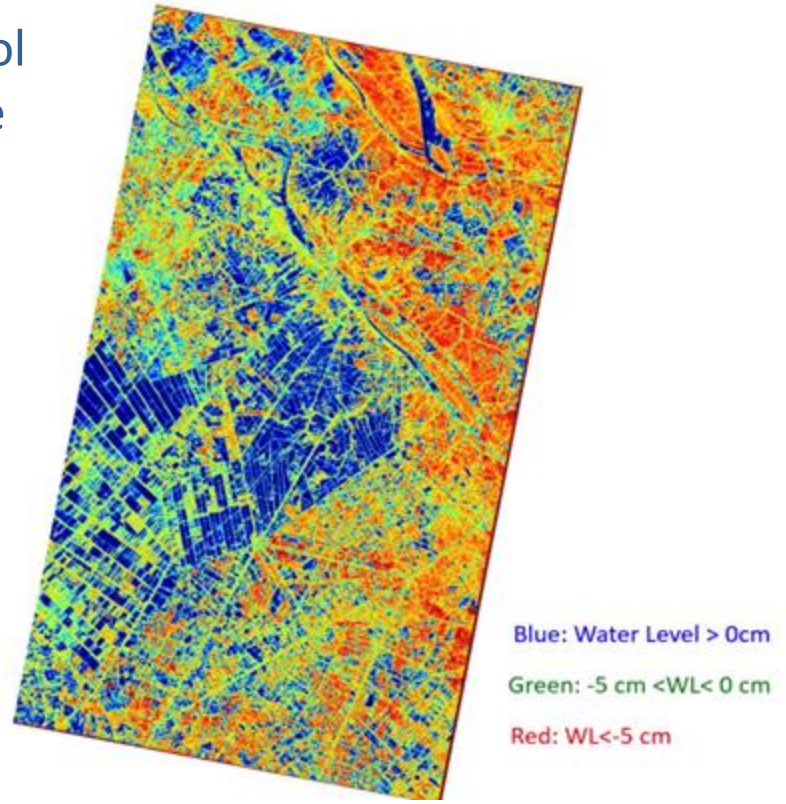
- Coordination of virtual constellations to improve temporal coverages and access to multi-frequency datasets beyond research sites and localized monitoring. Uptake in operations requires coverages that are predictable, repeatable and dependable.
- Consider use of Compact Polarization modes on current and near future missions.



[Courtesy of H. McNairn]

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

- Multi-frequency with improved polarisation diversity beyond dual-pol (e.g. Compact Polarimetry). Ideally multiple frequencies on the same satellite. No single polarization is best.
- We need to fill the gap for X-band large area coverage.
- Temporal domain is key to success and requires that data sets are available as a dense time series over large geographies.
- There is no exact temporal repeat recommendation as this varies depending on application (crop mapping versus crop condition monitoring). In research, observations >3 days apart considered likely to be different due to changing crop structures.



[Arai et al. 2022]

Soil Moisture

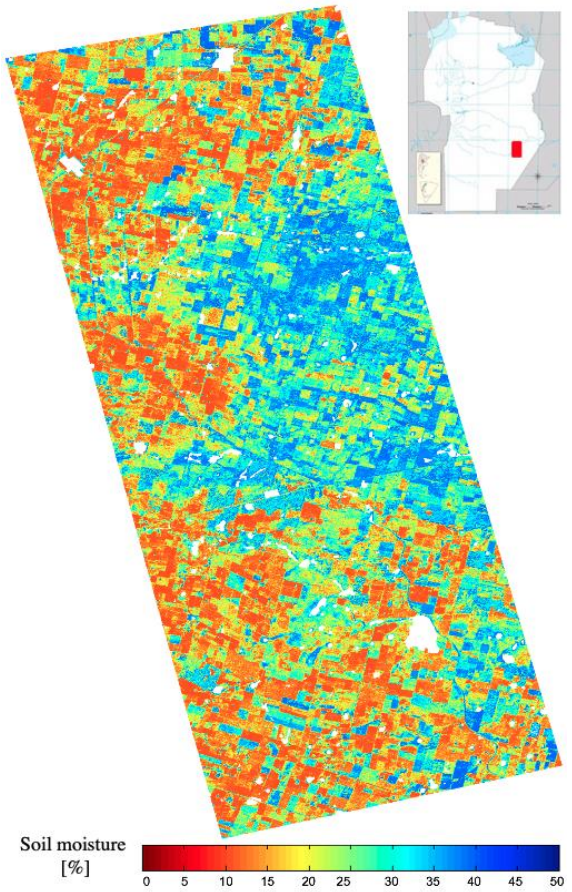
Laura Frulla (CONAE)

Recommendations for current and near future SAR missions

- Improve algorithms and software for faster and more accurate SAR data processing
- Improve algorithms to better reduce radio frequency interference
- Increase the frequency of SAR data acquisitions, and combine acquisitions from different SAR sensors, to reach higher temporal resolution
- Coordinate L-, C- and X-band acquisitions to improve worldwide soil moisture estimates:
  - L-band over areas with vegetation and dense vegetation, C-band over areas with sparse to no vegetation and X-band over areas with no vegetation,
- Coordinate in-situ measurements simultaneously with SAR acquisitions in different parts of the world for better validation
- Develop more affordable SAR technologies, including small satellites
- Increase the spatial resolution of the data sets.

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

- Satellite constellation (by one or more agencies)
  - four full polarimetric SAR satellites operating at L band
  - not less than 3 or 4 days of repeat cycle
  - spatial resolution ~ 5 to 10 m
- At least two satellites can have a passive companion satellite to provide:
  - estimates of subsidence in agricultural areas
  - detailed information on vegetation structure and identification of subsurface features by using SAR tomography and 3D profiling



Soil moisture from SAOCOM
[Courtesy of L.Frulla]

Sea Ice

Malin Johansson (U. Tromsø)

Recommendations for current and near future SAR missions

- Multi-frequency and polarimetric SAR data can help to overcome these ambiguities:
  - L-band SAR coverage essential during early melt season -> separation of rough and deformed ice from smooth level ice
  - L-band data preferable for deformation
  - High temporal resolution data during the melt season can address some of these shortcomings.

- Data with temporal gaps of 10s of minutes – to hours is difficult for drifting sea ice → Solution: Tandem constellations consisting of L- and C- or X-band satellites

- NISAR will offer simultaneous S- and L-band SAR over Beaufort Sea → showcase the usefulness of multi-frequency SAR without the need to drift-correct the data.

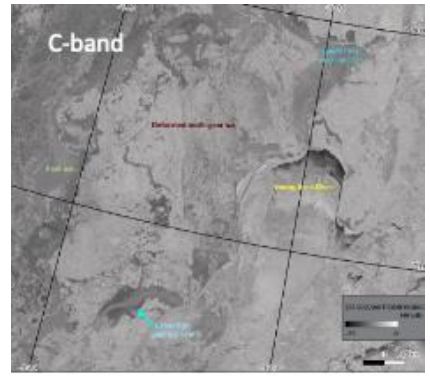
- High temporal resolution -> improved ice motion, deformation (convergence/divergence)

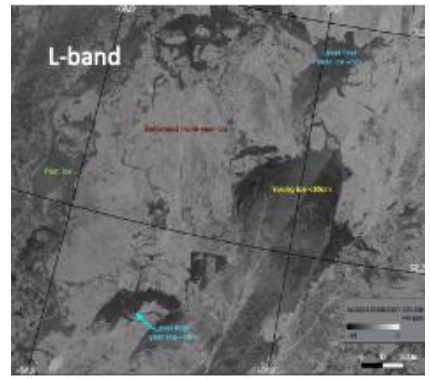
- Multi-frequency data can help overcome issues with snow retrievals → in particular for X- and C-band

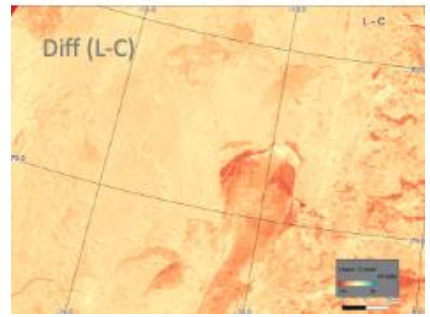
- Use RCM HH+VV mode in summer over the Arctic
  - Better for melt ponded time period
  - "Avoids" the low return signal issue

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

- L-band SAR constellation mission
- Nearly simultaneous C- and L-band observations
  - Tandem flight pattern for ROSE-L and Sentinel-1
  - Braver -> one satellite platform with C- and L-band
- Combine two SARs with different observation modes (narrow swath/fine res + wide swath/coarse res) modes for increased detection of icebergs. Convoy of sensors possible easier option, fly in parallel and cover adjacent swath
- Use RCM HH+VV mode in summer over the Arctic
  - Better for melt ponded time period
  - "Avoids" the low return signal issue
- Low noise floor
- Derive instantaneous surface motion from Doppler shift -> Done using simulated Harmony data (Kleinherenbrink et al. (2021)) –> SNR not good enough
- Coordination also with passive microwave, altimeter, optical sensors







2022 TA-1/2 Survey

Magdalena Fitrzyk (ESA)
Ake Rosenqvist (JAXA)
Cathleen Jones (JPL)

Main recommendations from ICGS-SAR Survey 2022 (1/2)

- **Enhanced Observation Plans for existing and future SAR missions**

  Sub-daily and daily acquisition capabilities, availability of continuous observations (similar to that of the Sentinel series for C-band SAR)

- **Increased Access to Multi-Frequency Data**

  Consistent satellite coverages at multiple frequencies; provision of open access to the data and to open operational cloud environment for data processing

- **Development of Innovative Missions**

  Development of missions focusing on a multi-frequency tomographic approach or dual-frequency combinations (like L-band with C-band)

Main recommendations from ICGS-SAR Survey 2022 (2/2)

- **Use of Advanced Technologies**

  Integration of AI and advanced onboard processing

- **Collaboration and common investment of countries/Agencies**

  in fully-polarimetric, low-frequency, and multi-frequency missions.

- **Systematic Monitoring Frameworks**

  Establishment of systematic and effective monitoring frameworks that include various sensor types (optical, IR, and multifrequency radar) for real-time data acquisition and analysis.

- **Open Data Policies**

  Sharing data openly would drive research and innovation.

Observation requirement matrix (TENTATIVE)

TA1 theme	SAR band	Main Polarisation(s)	QP/CP	Spatial res	Temporal res	Coverage (gap free!!!)	Latency	Relevant Missions	Others
Forest (AGB)	L (C, P)	HH+VV (ideally QP)	Yes	10-25m	~ Monthly	Global	Not critical	NISAR, ALOS-4, BIOMASS, SAOCOM	Gap-free time-series & Open access data policies for public missions!!
Forest (Deforestation)	L	HH+HV	No	10-25m	< Weekly	Regional	1 day (?)	NISAR, ALOS-4	
Wetlands (Inundation)	L (C, S)	HH+HV	No	10-25m	Weekly	Regional/global	Not critical	NISAR, ALOS-4, Sentinel-1, R2/RCM	
Wetlands (Peatlands)	L (C, S)	QP	YES!!!	10-25m	Weekly	Regional/global	Not critical	ALOS-4, SAOCOM	
Agriculture (Crop monitoring)	L, C, S, X	Multi f / multi-pol	YES (CP)	5-10m	~ 3 days	Local/regional	1 day (?)	ALL + X-band	
Agriculture (Irrigated rice)	C, L	HH+HV	Yes	5-10m	~ 3 days	Local/regional	1 day (?)	NISAR, ALOS-4, Sentinel-1	
Soil Moisture	L (C, X)	QP	YES!!!	5-10m	< 3 days	Local/regional	1 day (?)	SAOCOM, ALOS-4 (NISAR, ROSE-L)	
Sea Ice + icebergs	L + C (X)	HH+VV (ideally QP)	QP	5-25m	Daily	Regional	Near-Real Time	Sentinel-1, ALOS-4, RADARSAT, NISAR	

https://docs.google.com/document/d/1fESJZ7OZ0zIsKH_zqrZASjsugWWIY9AJvyBBU_EgT_g/edit?tab=t.0