Cryosphere Applications

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Application Showcases: Motivation

	Application		Motivation
Cryosphere	Land ice extinction (internal structure)	Internal	Glacier mass balance changes Indicator for climate change
	Snow water equivalent	Internal	Ground water recharge Indicator of climate change
	Sea ice: observation	Internal	Distinction of different sea ice features; Ship routing Indicator for climate change
	Sea ice: thematic mapping	External External	
	Sea ice thickness	External	
	Permafrost observation	External	Land-surface-atmosphere fluxes Climate change imapct Hazard: costal degradation, road destruction, deformation, ect.

Application Showcases: Methodology

	Application	Methods and used frequency (P/L/C/X)	Polarisation	Frequency
Cryosphere	Land ice extinction (internal structure)	Pol-InSAR decomposition and inversion (P/L)	Quad pol	Preferred: P/L
	Snow water equivalent	PolSAR decomposition and inversion (C/X)	Quad pol (dual pol)	Preferred: X/Ku
	Sea ice: observation	PolSAR observables and decompositions (L)	Quad pol (dual pol)	Wide swath needed
	Sea ice: thematic mapping	Statistical image segmentation based on PolSAR descriptors (C)	Quad pol	Wide swath needed
		Wishart classification applied to PolSAR entropy/alpha decomposition (L/C)		
	Sea ice thickness	PolSAR decompositions, segmentation and empirical models (X)	Quad pol (dual pol)	Wide swath needed @ X
	Permafrost observation	Based on a PolSAR two-layer scattering model (L)	Quad pol (dual pol)	Preferred: P/L

DLR

Application Showcases: Testsites

	Application	Location	Data Origin	Sensor	Airborne /Spaceborne	Band	Polarisation
Cryosphere	Land ice extinction (internal structure)	Svalbard	IceSAR	E-SAR	airborne	L/P	Pol-InSAR
	Snow water equivalent	Sodankylae	TerraSAR-X	TerraSAR-X	spaceborne	X	dual/quad pol
	Sea ice: observation	Barentsea, Storfjord	IceSAR	E-SAR	airborne	L	quad-pol
	Sea ice: thematic mapping	Svalbard Bay of Bothnia	Arctic Campaign	RadarSAT-2/ ALOS	spaceborne	C/L	quad-pol
	Sea ice thickness	Bellingshausen Sea	Antartic Campaign	TerraSAR-X	spaceborne	X	dual pol
	Permafrost observation	Alaska	Permafrost Campaign	ALOS	spaceborne	L	quad pol

Ice Extinction Estimation Using PolInSAR

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Motivation

What is ice extinction?

- It indicates how fast a radiation extinguishes when propagating through an ice mass (usually expressed in dB/m)

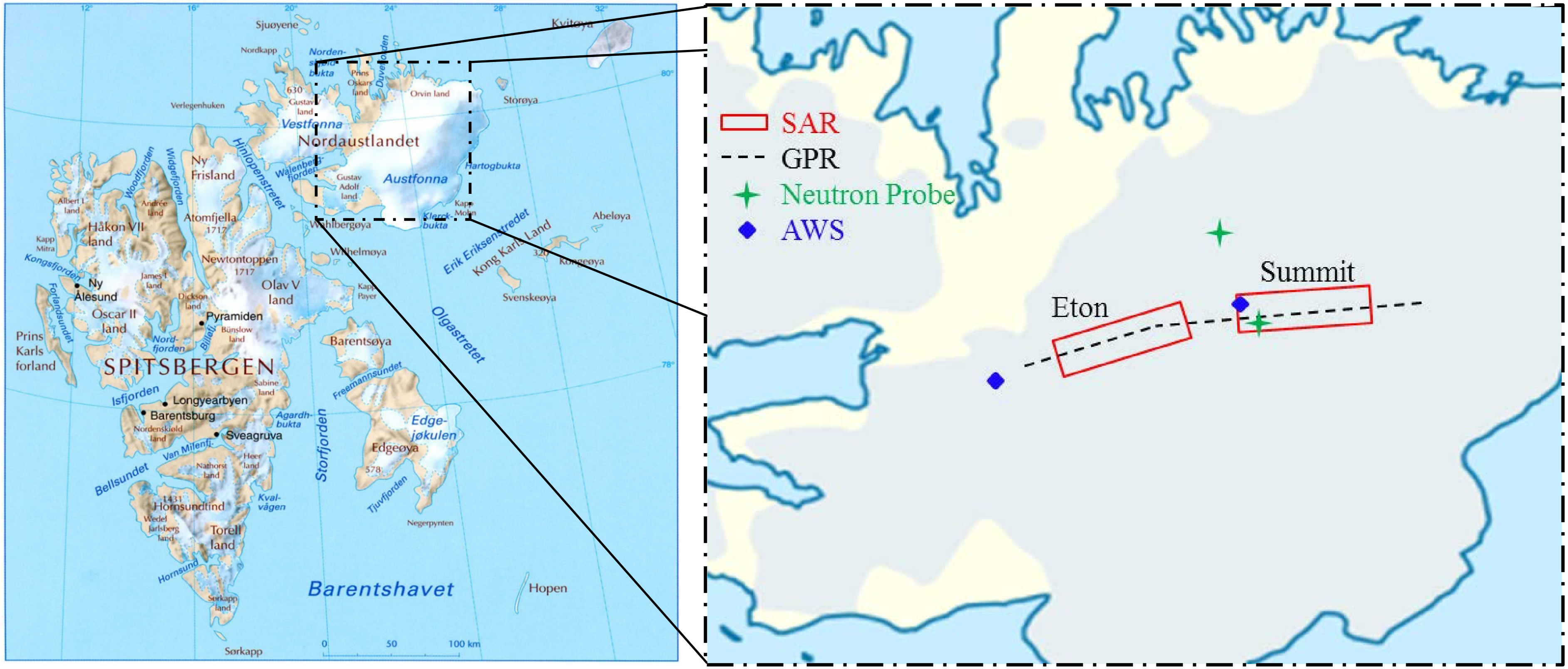
Why to care about ice extinction?

- Ice extinction is related to ice internal structure through physical parameters (e.g. density)
- Knowledge of extinction is needed to characterize glacier subsurface layers and support mass balance estimation
- Ice extinction could help in correcting penetration bias in InSAR and altimetry products

What is the benefit of using SAR polarimetry?

- Polarimetry allows a better understanding of the scattering mechanisms
  - Possibility to isolate the scattering from the ice volume and to estimate its physical properties using polarimetric scattering models

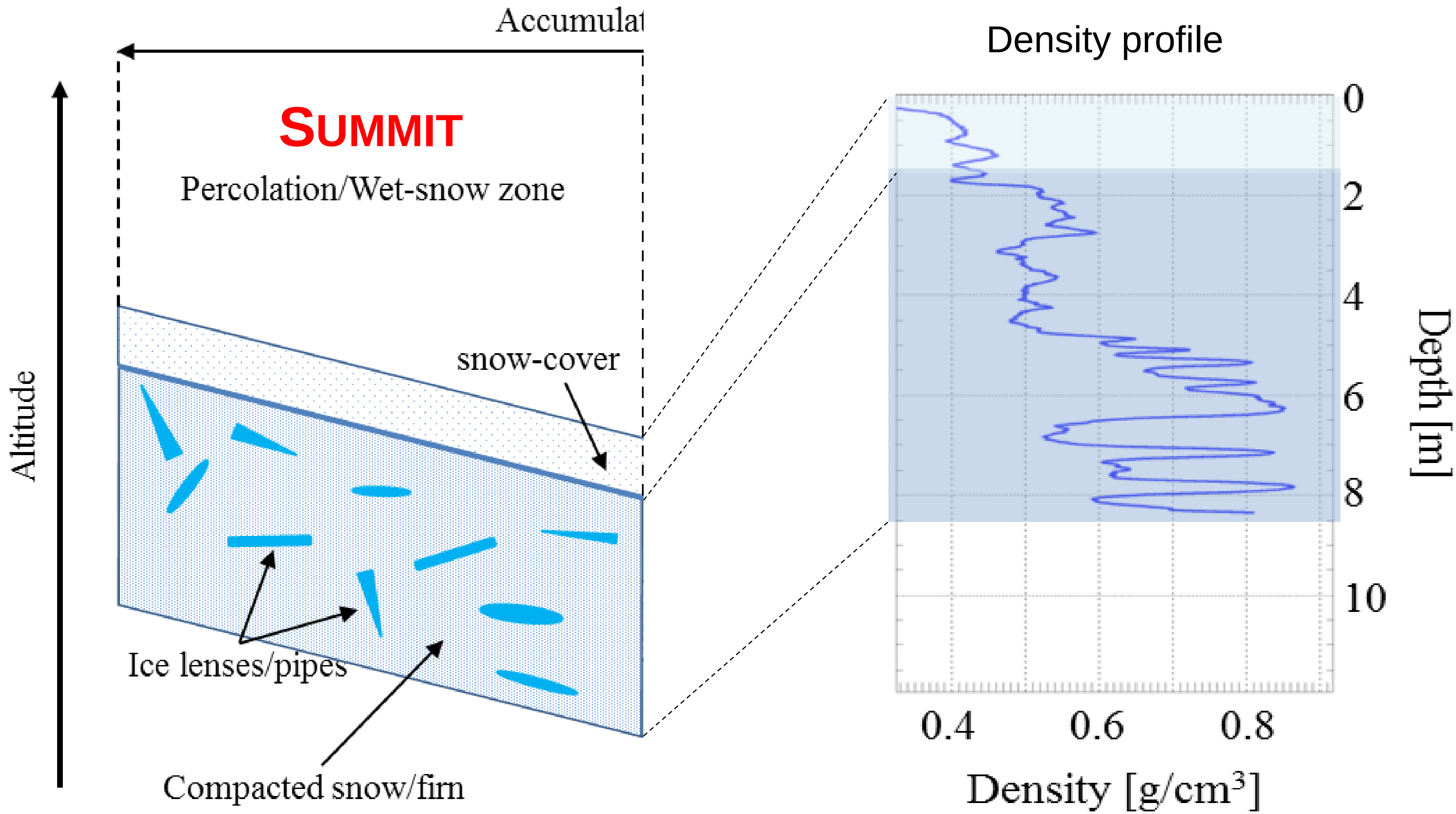
Test sites and data sets



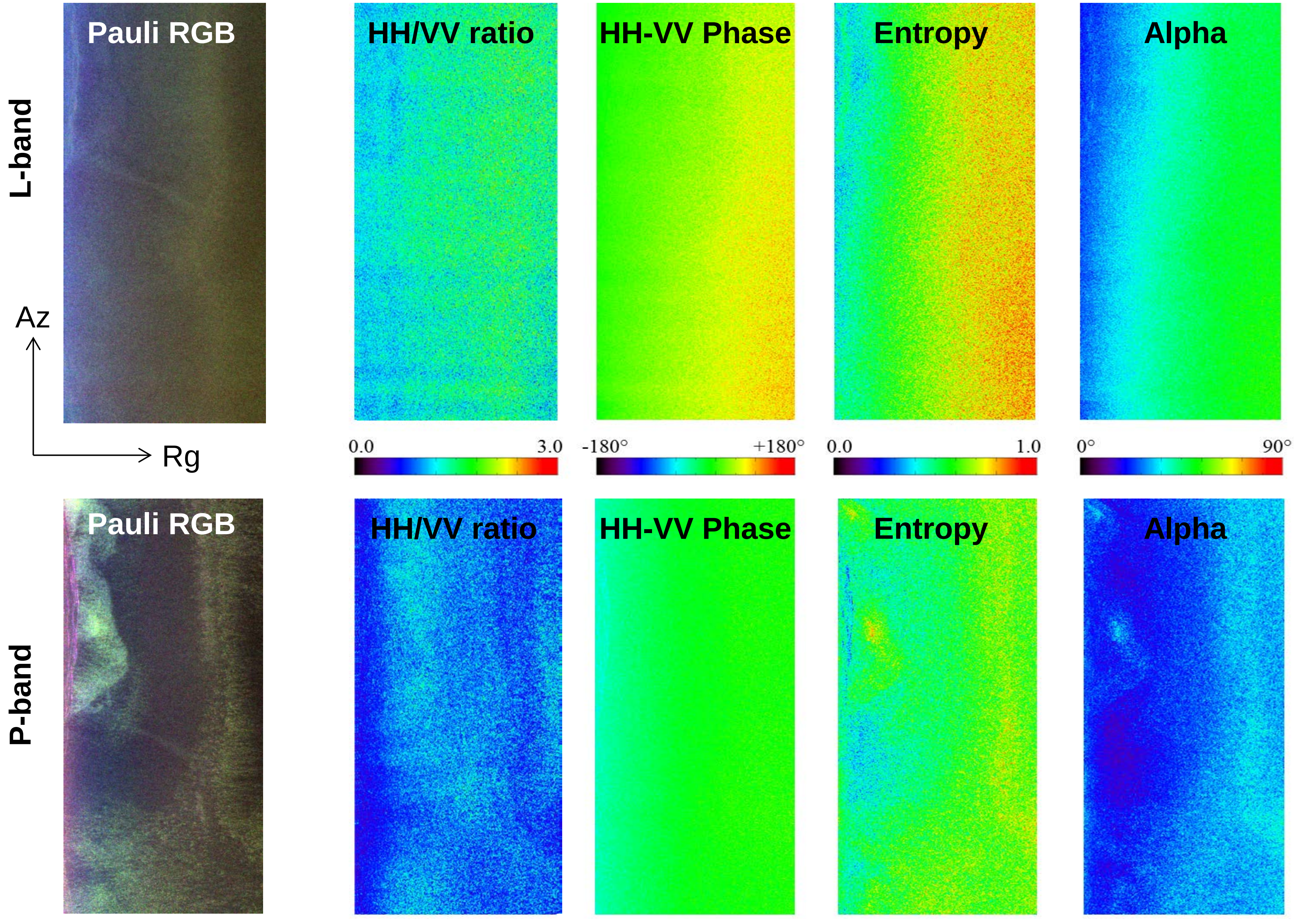
E-SAR data @ L- (1.3 GHz) and P- band (0.35 GHz) - IceSAR2007 Campaign

GPR profiles @ L-band (0.8 GHz), Density profiles (neutron probe)

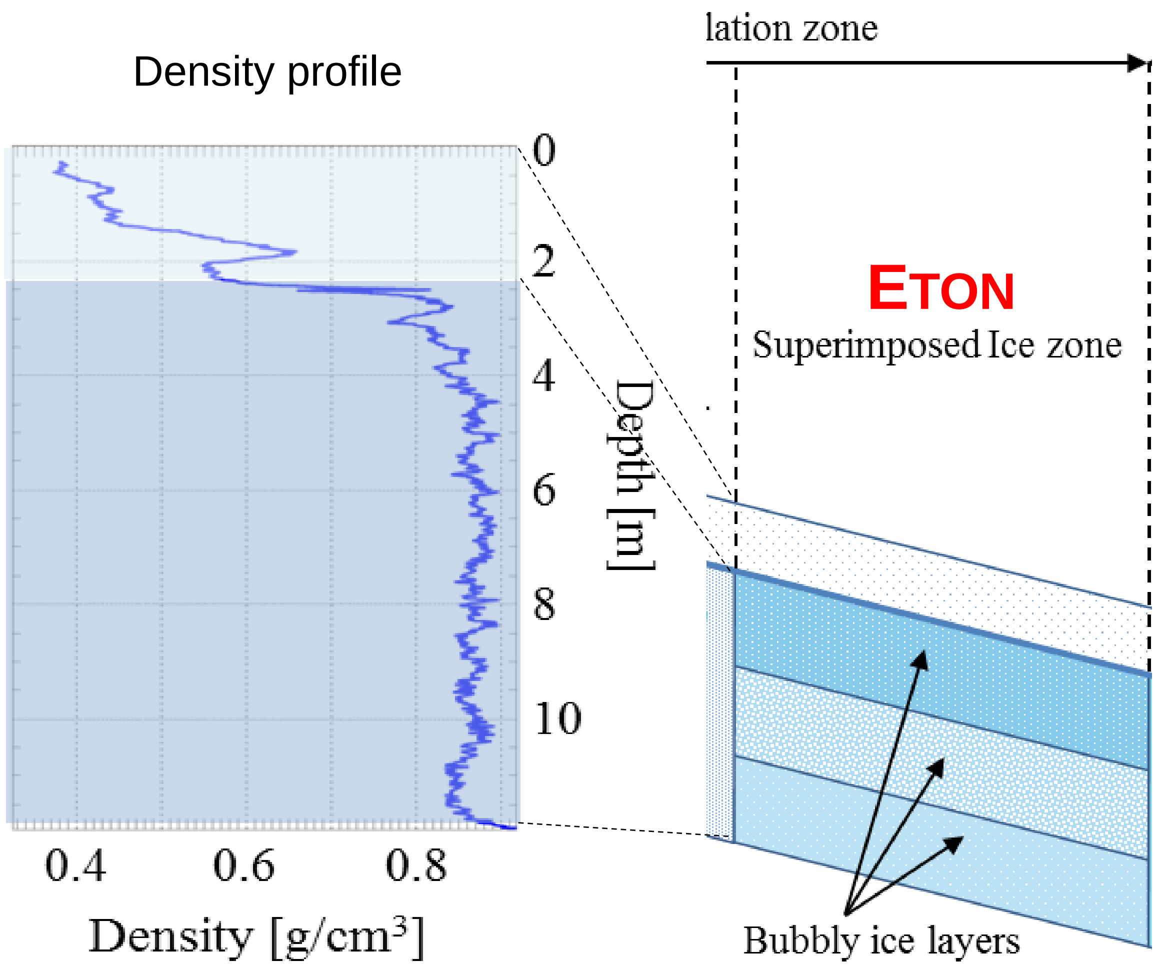
Summit: Test site characteristics



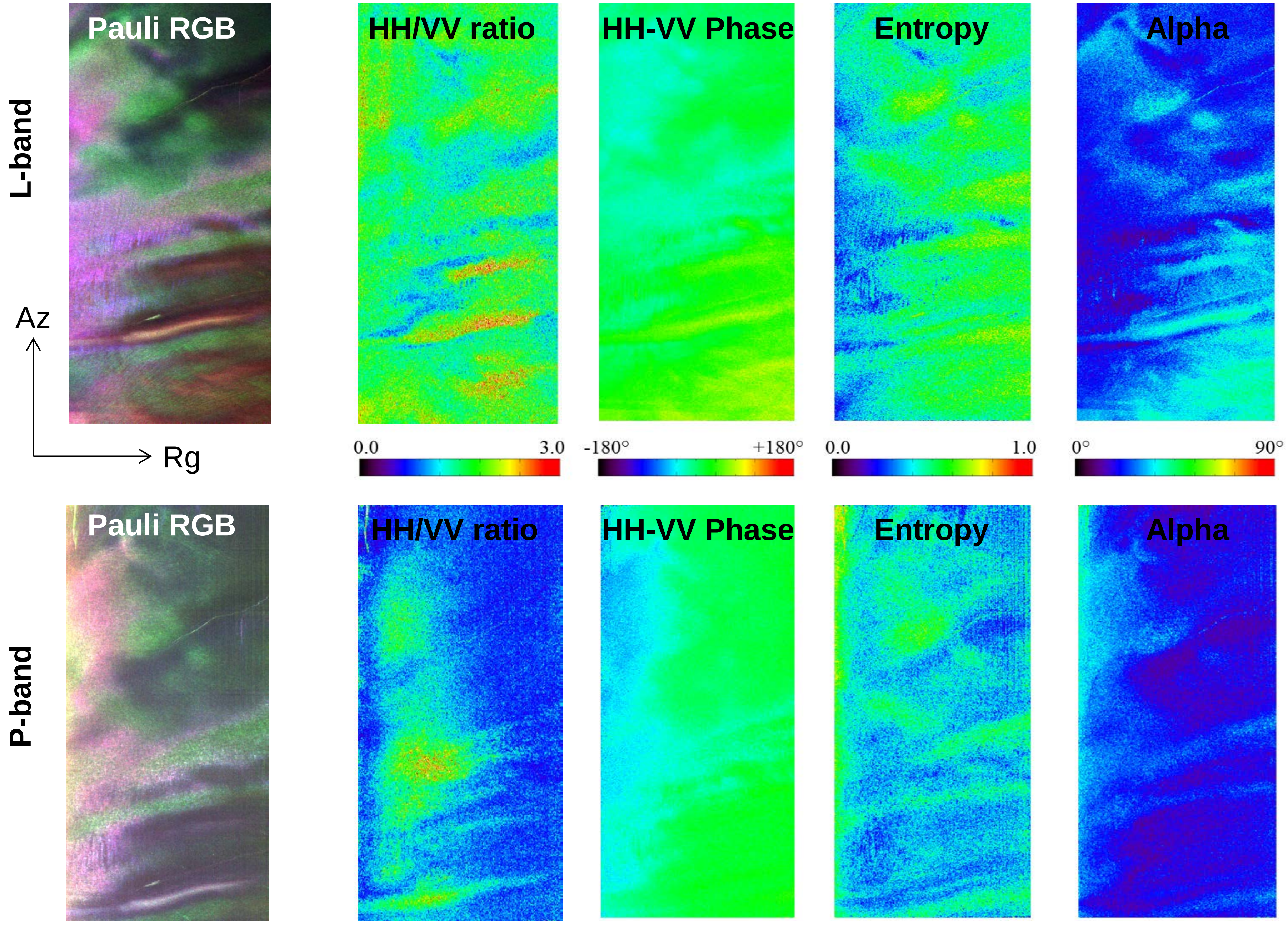
Summit: Polarimetric signatures



Eton: Test site characteristics



Eton: Polarimetric signatures



Ice extinction estimation: Methodology

Master acquisition (fully polarimetric)

Slave acquisition (fully polarimetric)

Model-based polarimetric decomposition
$C = C_{surface} + C_{volume}$

Pol-InSAR coherence
γ_z

Surf-to-Vol ratios
m_{HH}, m_{VV}, m_{HV}

Invert for *Ke*

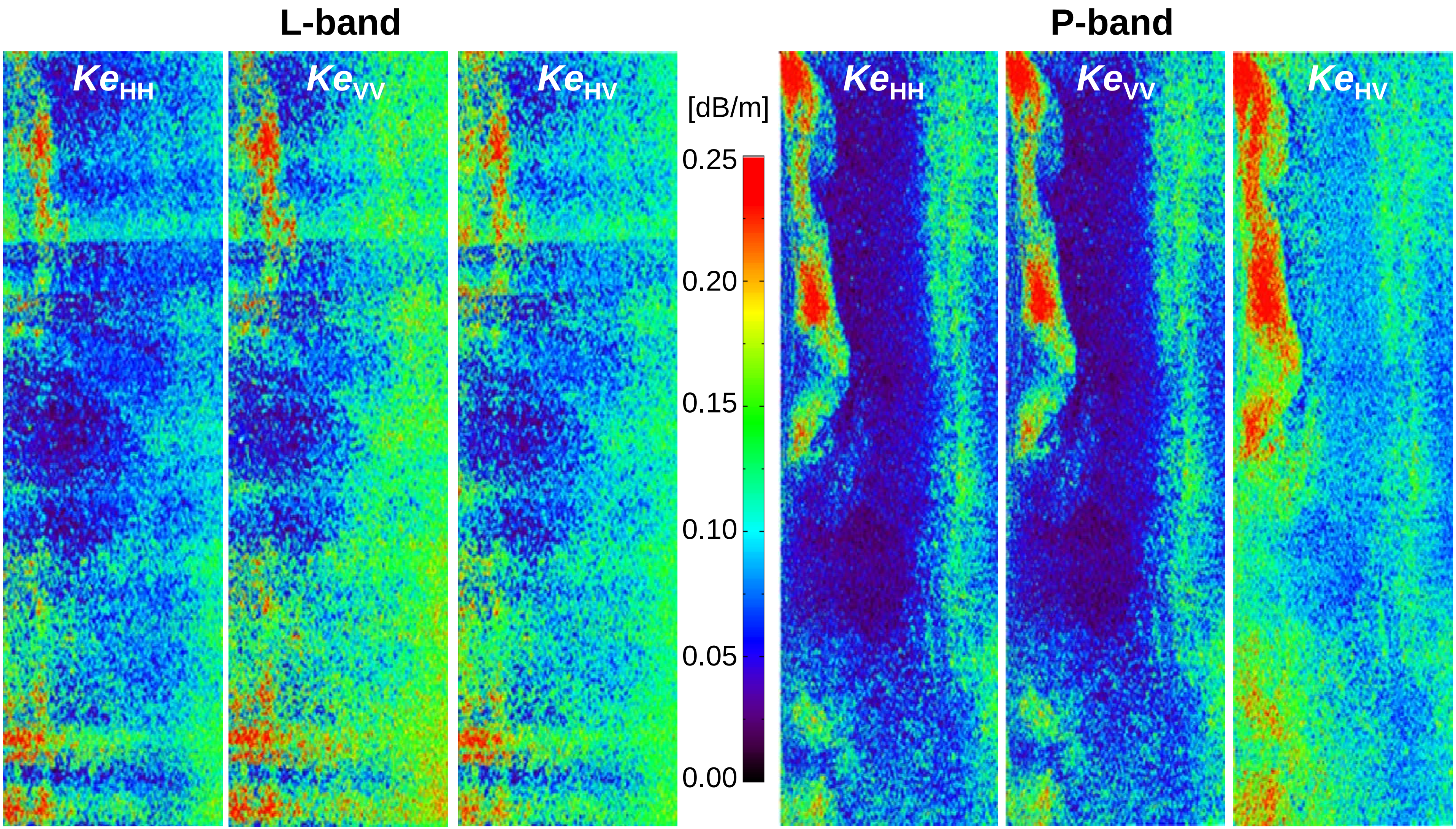
$$|\gamma_z| = \left| \frac{\gamma_{vol}(k_e) + m}{1 + m} \right|$$

Hypothesis: Infinite uniform ice volume under the surface

Ice extinction estimates:
$Ke_{HH}, Ke_{VV}, Ke_{HV}$

Sharma J.J., "Estimation of Glacier Ice Extinction Using Long-Wavelength Airborne Pol-InSAR", IEEE TGRSS, vol. 51, no. 6, pp. 3715-3732, Jun. 2013.

Results: Estimated Ice Extinction (Summit)



Validation

- As expected, extinction is **higher at higher frequency** (L-band)
  - This fits with the lower penetration depth expected for L-band, compared to P-band
- Regions of higher extinction are likely related to higher concentration of melt-features
- Obtained values are in rough agreement with **laboratory measurements**[1] performed on pure ice
- Exhaustive validation is complicated by a number of factors:
  1. Extinction is very **site-dependent**
  2. Values measured in laboratory appreciably depend on the method and the instruments used
  3. Comparison with other remote sensing techniques (e.g. GPRs and sounders) is limited by the **different geometry of acquisition**

[1] Sharma J.J., "Estimation of Glacier Ice Extinction Coefficients using Long-Wavelength Polarimetric Interferometric Synthetic Aperture Radar", Ph.D. Dissertation, Karlsruher Institut fuer Technologie (KIT), Germany, 2010.

Comparison with Single- and Dual-Pol

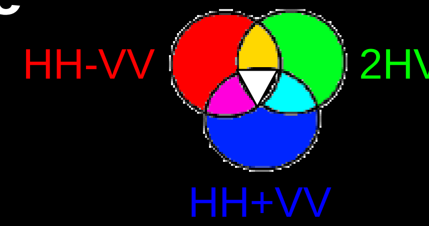
- **No other SAR studies** (including single- or dual-pol) about ice extinction does exist in literature
- **Single/dual pol data** do not allow polarimetric decomposition
  - Impossible to isolate volume scattering component
  - **Additional complexity** to model eventual surface and other scattering components

- Only polarimetric observations can provide information about:
  - Types of **scattering mechanisms** in the scene (entropy and alpha angle)
  - Presence of **oriented volumes** (polarization ratios, phase differences)
  - Scatterers **shape and orientation** (entropy and pol-ratios)

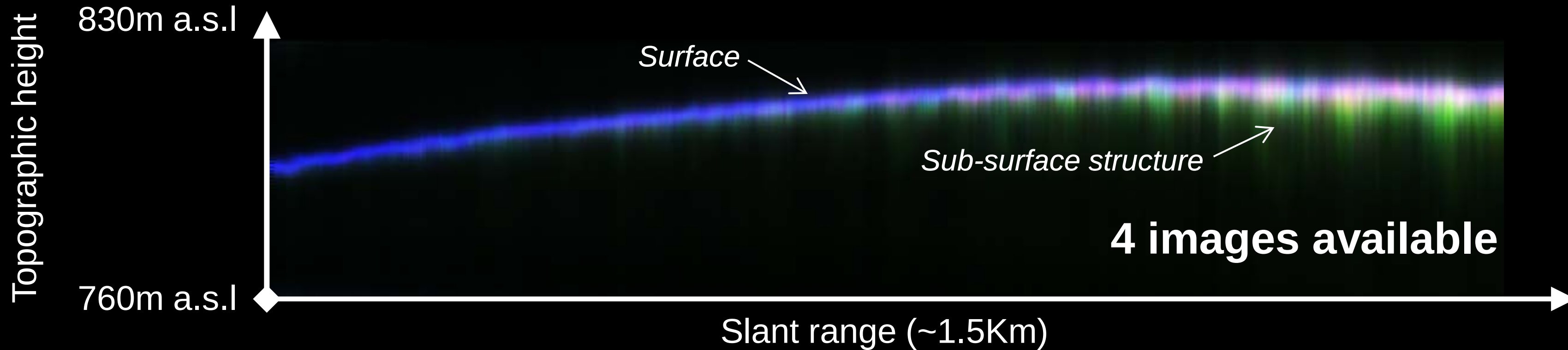
Conclusions

- Polarimetry is fundamental for characterizing glacier internal structure
- **Polarimetric decomposition** techniques can be used to extract and interpret volume scattering from the glacier subsurface
- After estimating the surface-to-volume scattering ratio using the polarimetric decomposition, ice extinction can be inverted from **interferometric coherences**
- The presented method provides **realistic estimates** (compared to laboratory studies)
- **Low frequencies**, e.g. L- and P-band are strongly recommended for their penetration capabilities

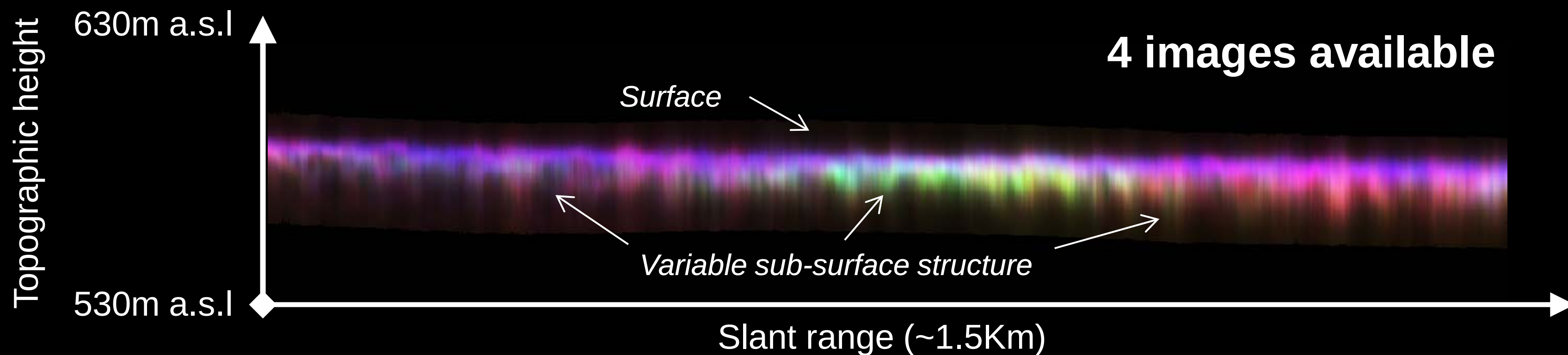
Outlook: Polarimetric SAR Tomography in Ice



- Site: Summit, Svalbard, DLR IceSAR 2007 experiment (L)



- Site: Etonbreen, Svalbard, DLR IceSAR 2007 experiment (L)



Snow Water Equivalent Retrieval

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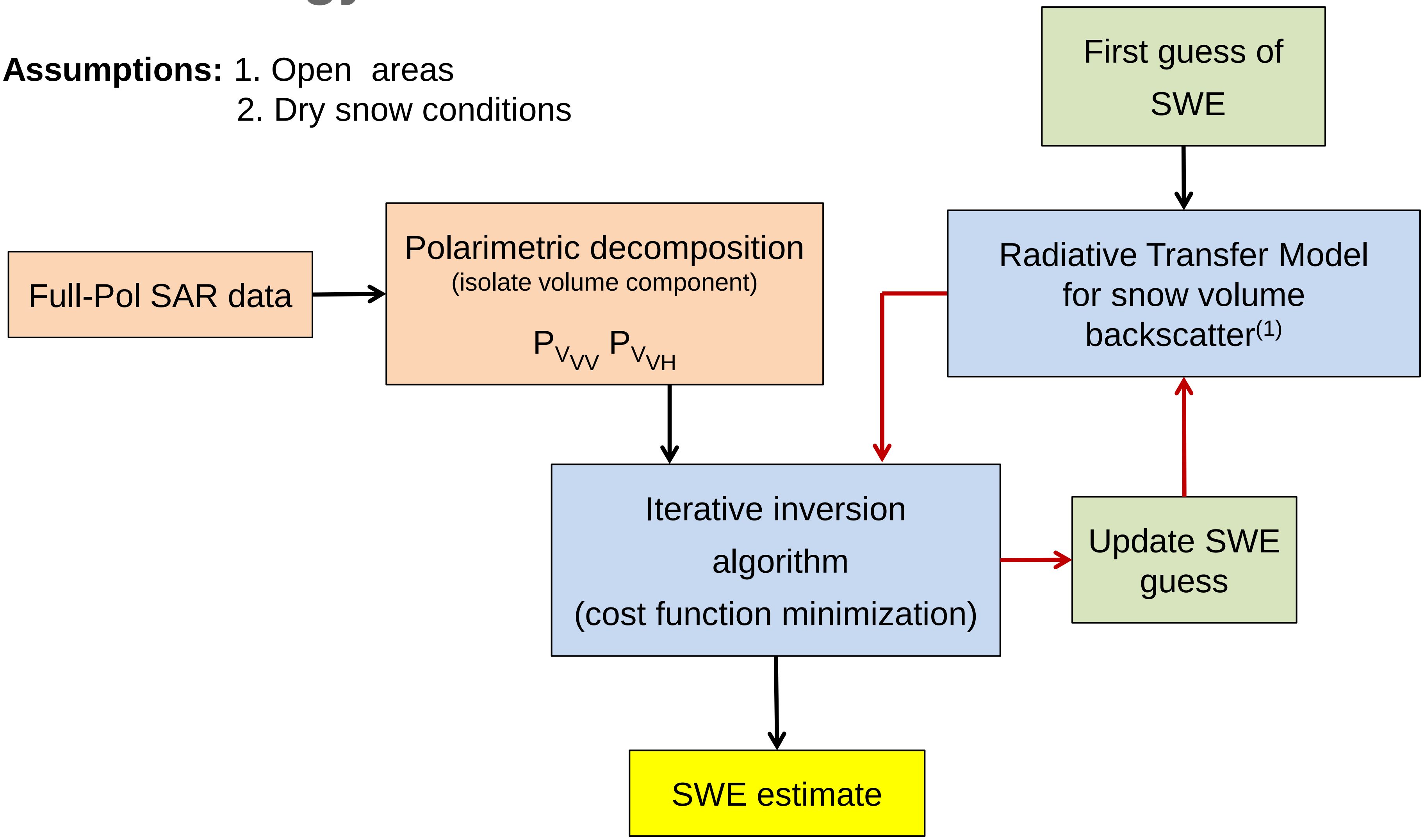
ETH

Motivation

- Snow is a key component of the **global water cycle** and climate system
- About one sixth of Earth’s population relies on seasonal snow cover and glacier for water supply
- Knowledge of snow properties is needed on large scale
  - To understand **climate change**
  - To develop global hydrological model for **water management**
- Many studies based on SAR using single/dual polarization data. They mainly aim to model backscattering coefficients from snow covered areas
- **Polarimetry** can help to model SAR backscattering from snow isolating the contribution of the snowpack from the underlying ground

Methodology

Assumptions: 1. Open areas
2. Dry snow conditions



[1] Nagler T. et al., “Development of snow retrieval algorithms for CoReH2O”, ESA-report n. 22830/09/NL/JC, August 2011.

Test sites and data sets

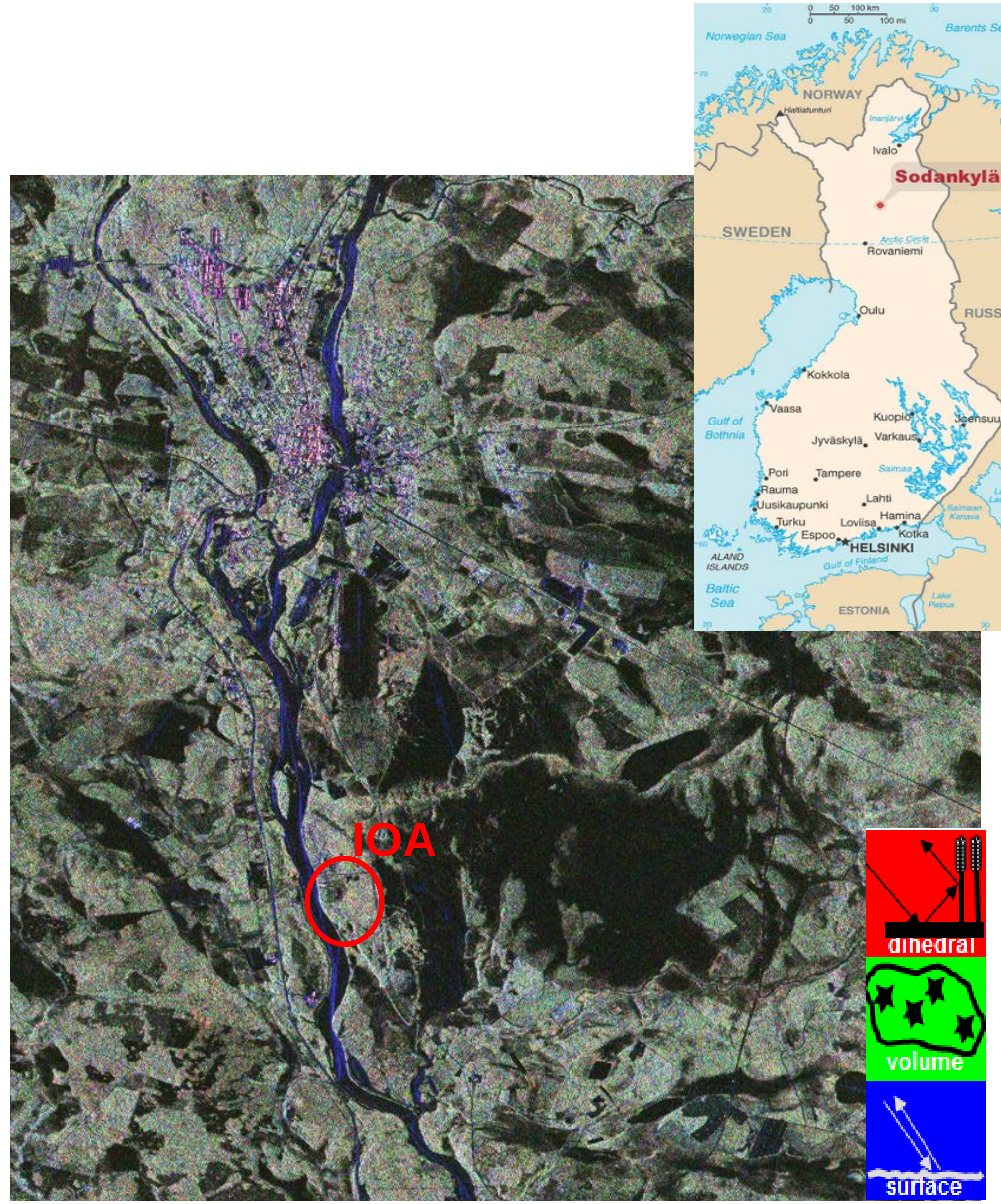
- The test site is around the city of Sodankylä (~67˚N, 26˚E), in Lapland, Finland

- Intensive Observation Area (IOA), open area in the boreal forest, selected as test site for Phase A studies of the CoReH2O EE7 Candidate Mission

- **Ground Measurements:**

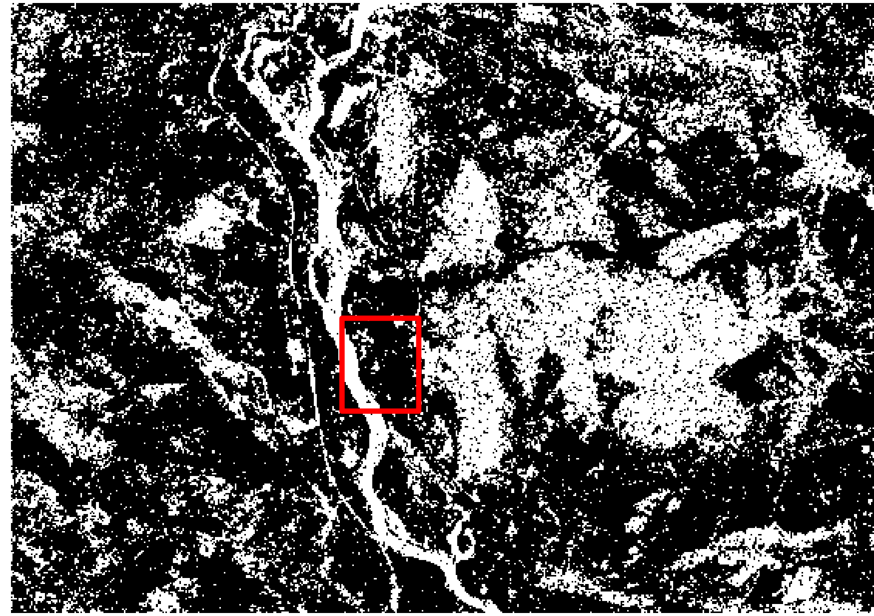
  NoSREx campaign (winter 2009/10) including SWE, snow depth and density

- **TerraSAR-X** fully polarimetric acquisitions
  - 11th April 2010
  - 22nd April 2010
  - 3rd May 2010



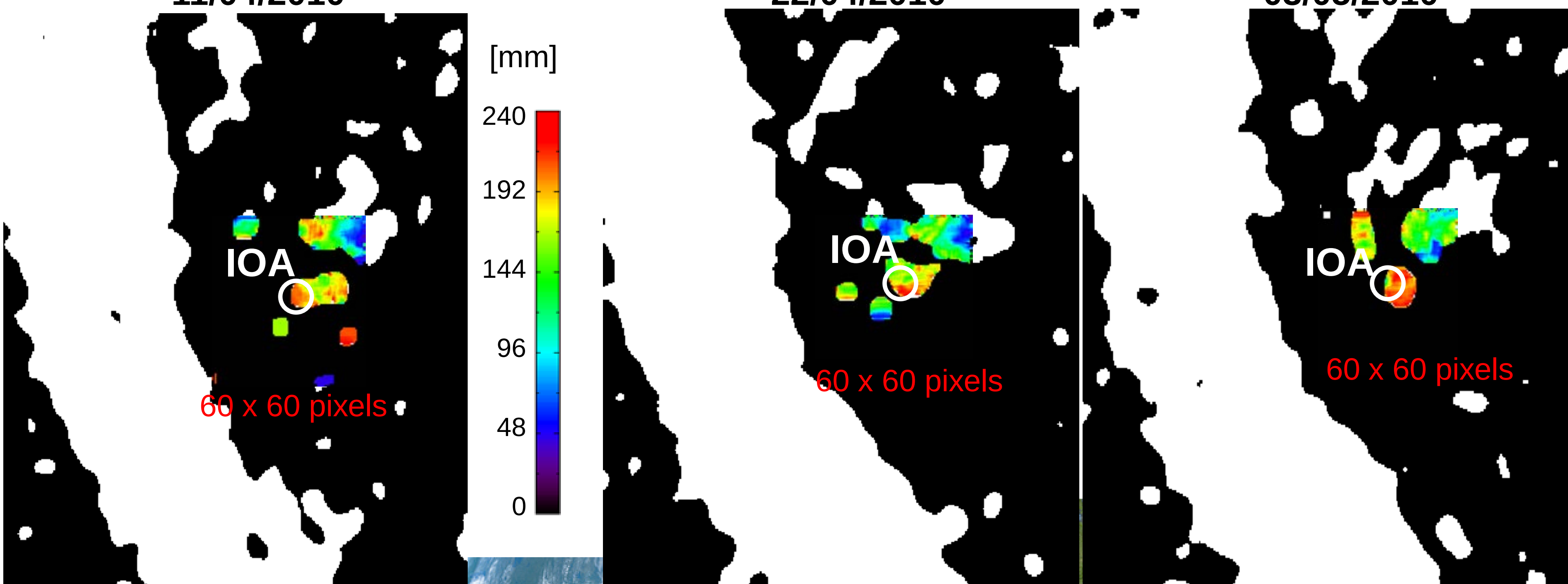
$R : 1/2<|HH-VV|^2>$, $G : 2<|XX|^2>$, $B : 1/2<|HH+VV|^2>$

Results and Validation (1/2)



- Entropy-based mask to extract open areas
- Estimated SWE in IOA
  - 205mm on 11th April 2010
  - 191mm on 22nd April 2010
  - 164mm on 3rd May 2010

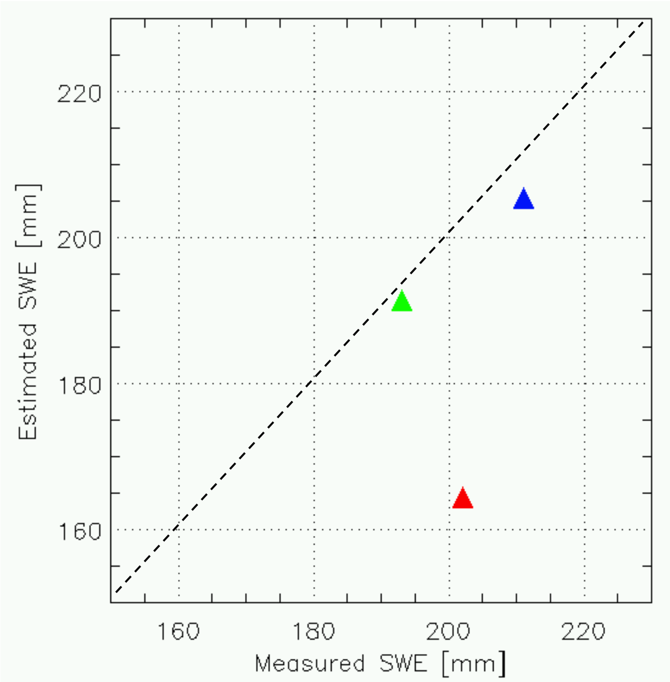
11/04/2010 **22/04/2010** **03/05/2010**



Results and Validation (1/2)

- Validation by comparison of SWE estimated from polarimetric X-band SAR data with ground measurements

Date	Measured SWE [mm] (NoSREx)	Estimated SWE [mm]
11/04/2010	211	205
22/04/2010	193	191
03/05/2010	202	164

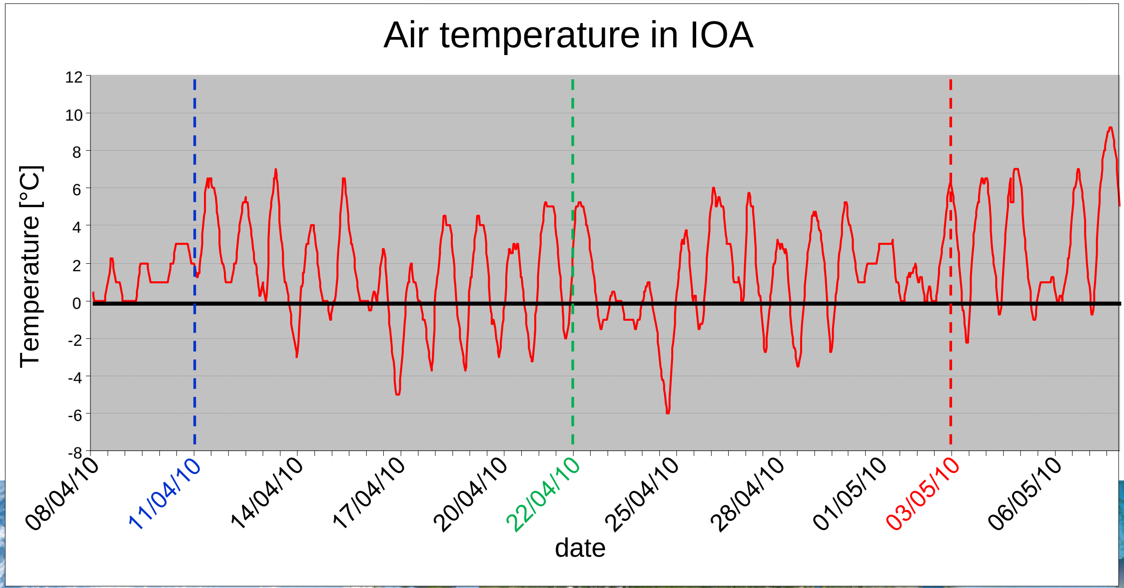


Alternating **freezing** and **thawing** cycles

Change in snowpack structure (merging of snow particles)

Temperature constantly above 0˚C from 30th of April

Wet snow on 3rd of May



Comparison with Single- and Dual-Pol

- A dual-frequency **dual-pol** SWE estimation algorithm was proposed for the CoReH2O EE7 Candidate Mission
  - Based on a radiative transfer model: simulation of a ground and a snow volume scattering component
    - Needs *a-priori* information about soil and snowpack conditions
    - The choice of the **surface scattering model** significantly influences SWE inversion

- **Fully polarimetric** data allow applying polarimetric decomposition
  - Isolate snowpack scattering contribution
  - **No need** to invert scattering model for soil contribution
    - **Reduced amount** of needed *a-priori* information
    - SWE inversion procedure results significantly **simplified**

Sea Ice observation

Armando Marino and Irena Hajnsek

Institute of Environmental Engineering, ETH Zurich, Switzerland

Motivation

- ✓ Understanding the backscattering from sea ice is **very challenging**
  - ✓ It is a **multi-layer medium** and its behaviour is strongly influenced by many parameters as **temperature**, **water content**, **salinity**, **surface roughness**, conditions in **ice formation**, presence of **ridges** or **frost flowers**, **etc**

- ✓ Polarimetry is expected to provide two main advantages:
  1) **To have a better understanding of the scattering process.**
     a) To separate different scattering mechanisms
     b) To evaluate surface/volume parameters
  2) **To correct for possible errors/ambiguities**
     a) To alleviate noise effects
     b) To remove ambiguities (in single-pol) due e.g. to target orientation

Methodology

- ✓ The most of the work so far was focused at considering special combinations of polarimetric channels (i.e. **observables**) that allow an easier extraction of the polarimetric information.

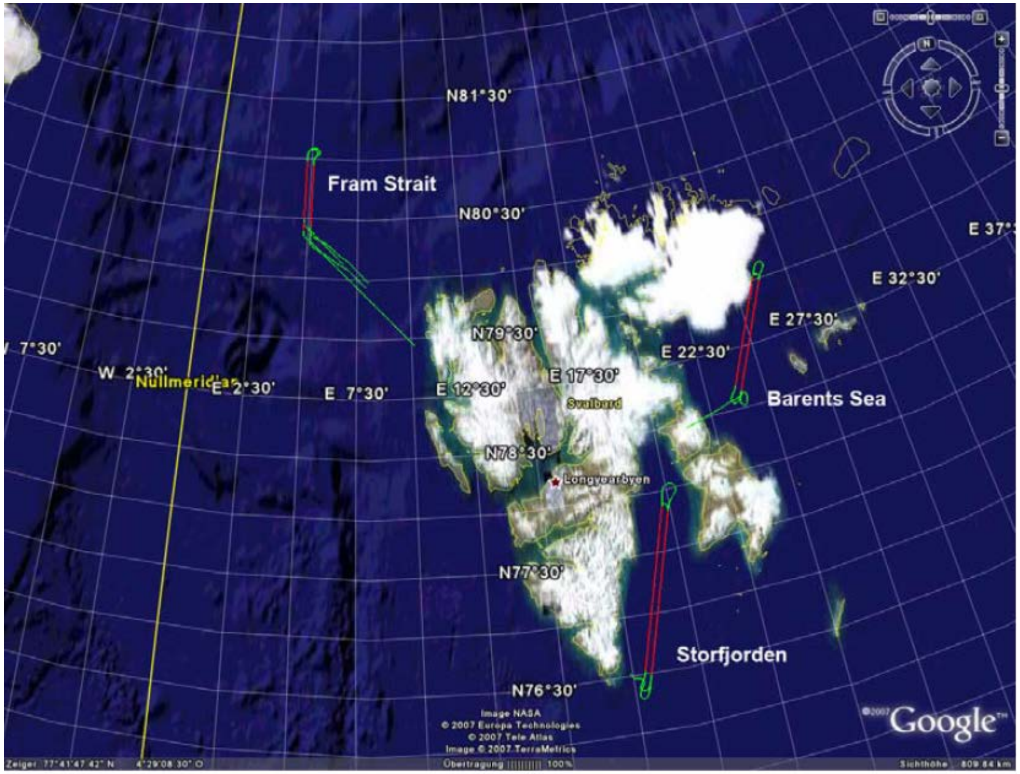
- ✓ Three main categories of observables are commonly exploited:
  1) **Backscattering** at different polarisation channels.
  2) **Ratios** of intensity for polarisation channels.
  3) **Coherences** between polarisation channels: defined as normalised cross-correlations.

ETH

Test sites and data sets: ICESAR 2007 campaign

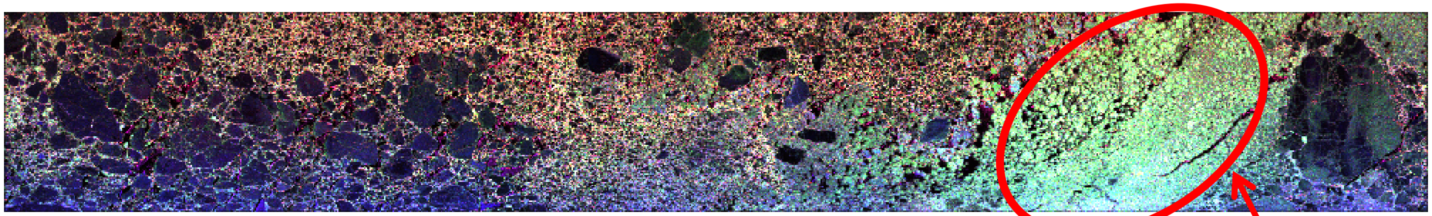
✓ The data exploited in this analysis are from the **ESA ICESAR** campaign (**2007 in Svalbard**):
- Sensor: **E-SAR** (DLR)
- Frequencies: **L**-, **C**- and **X**-band
- Polarimetry: L-band quad-polarimetric; C- and X- dual-polarimetric

✓ Three tests sites were selected for the sea ice observation:
- **Barents Sea**
- **Fram Strait**
- **Storfjorden**



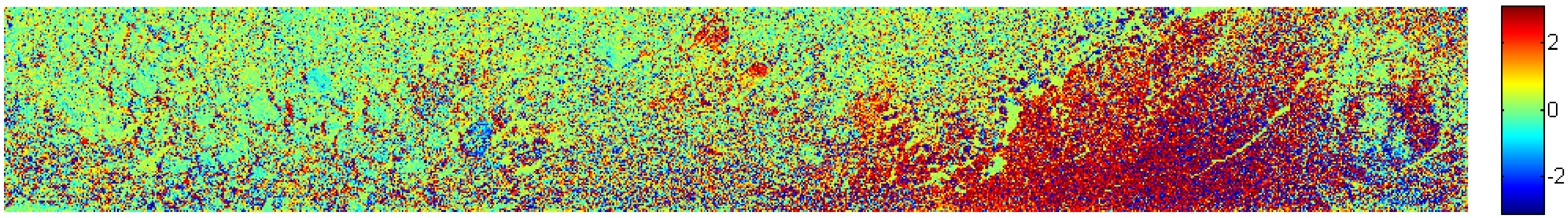
The following images are represented in Pauli RGB: Red: HH-VV; Green: 2*HV; Blue: HH+VV
Area: ~3.5 X 13 km; boxcar 7X28 pixels, ENL=86; NESZ -30dB to -35dB; Incidence angle from 26° to 65°

Results: Avoiding misclassification in Storfjorden



In the Pauli RGB, the Green stands for **HV**, that is generally associated to volume scattering.

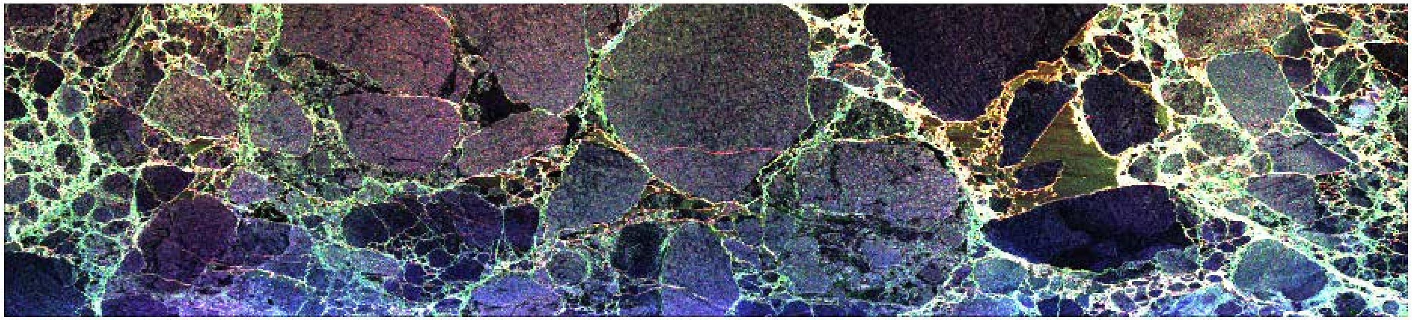
Therefore, one may think that this is **thick Multi Year Ice.**



- ✓ However, if the phase of the **Circular Co-polarisations Coherence** is checked, it can be observed that the strong HV is only due to target **orientations** (and not volume scattering).
- ✓ A ground survey confirmed that there was **only First Year Ice** in the scene.

Results: where is the open water, in Barents Sea?

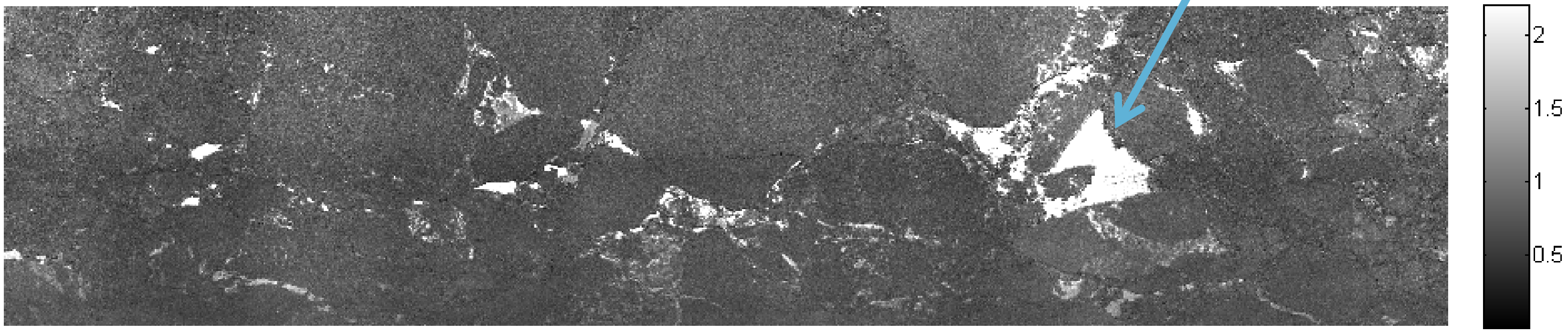
RGB Pauli: boxcar



Detecting **open water** areas is an important task. It is hard to locate the water pool in this scene, looking only at the backscattering.

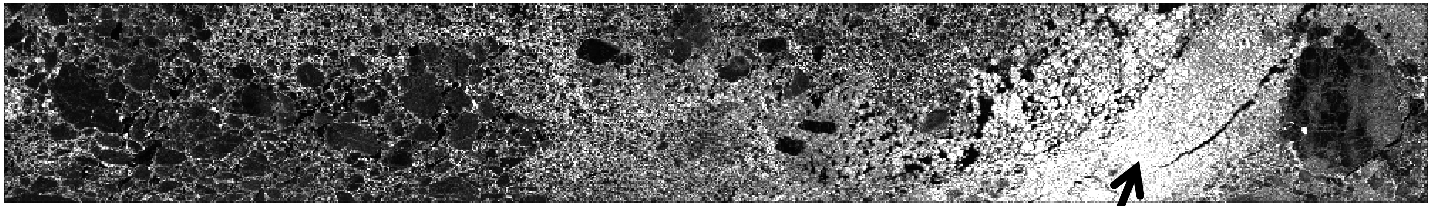
Consider the **Co-polarisations Ratio**, the open water areas appear very clearly in the image.

CoPolarisations Ratio



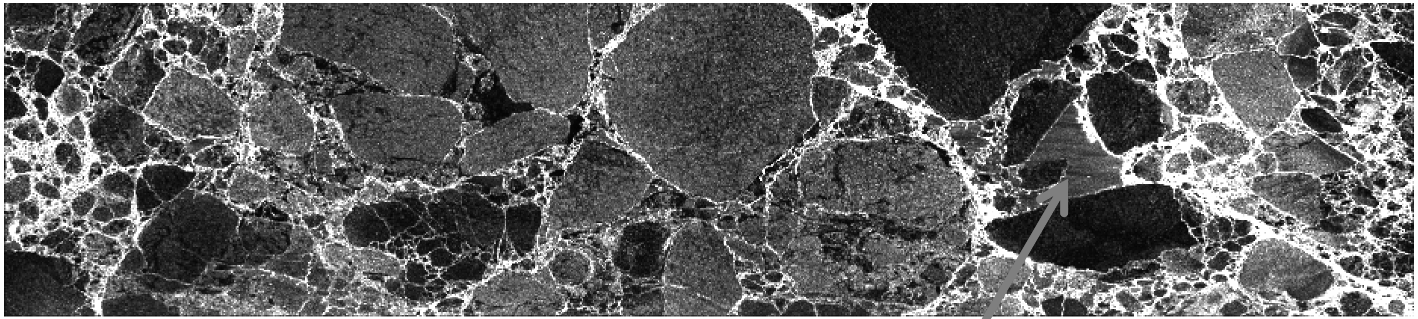
Comparison: can we do it with single pol?

Intensity of HV: Storfjorden



The HV channel is very bright in this area. If only this image would be used, it could be **mistaken for Multi Year Ice**

Intensity of HV: Barents Sea



The open water area is very hard to detect and its **backscattering** value is **comparable to** the one of many **other floes**.

Conclusions

✓ Polarimetry is important to extract information from sea ice

✓ Two **examples** were showed where polarimetry can help to:

1) **Reduce misclassification** (also for automatic algorithms)
2) **Detect special features** as open water (that may be very hardly visible exploiting only one image)

✓ In the next future several **satellites** will be able to acquire polarimetry data exploiting **large swaths** (which are very beneficial for sea ice monitoring):

- **Sentinel**
- **ALOS-2**
- **RADARSAT Constellation Mission**
- **Tandem-L**

Cryosphere Applications

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Summary: Application Showcases

	Application	Contributors	Methods and used frequency (P/L/C/X)	Radar data preference / requirements / comments
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	Snow water equivalent	G. Parrella, I. Hajnsek	PolSAR decomposition and inversion (C/X)	Preferred frequencies: X/Ku Dual-pol may suffice
	Sea ice: observation	A. Marino, I. Hajnsek	PolSAR observables and decompositions (L)	Wide swath needed
	Sea ice: thematic mapping	T. Eltoft	Statistical image segmentation based on PolSAR descriptors (C)	Wide swath needed
		L. Eriksson	Wishart classification applied to PolSAR entropy/alpha decomposition (L/C)	
	Sea ice thickness	M. Necsoiu	PolSAR decompositions, segmentation and empirical models (X)	Wide swath needed At X-band, dual-pol may suffice
	Permafrost observation	M. Watanabe	Based on a PolSAR two-layer scattering model (L)	Wide swath needed