Monitoring snowmelt area by means of Sentinel-1 Interferometric Wide Swath SAR

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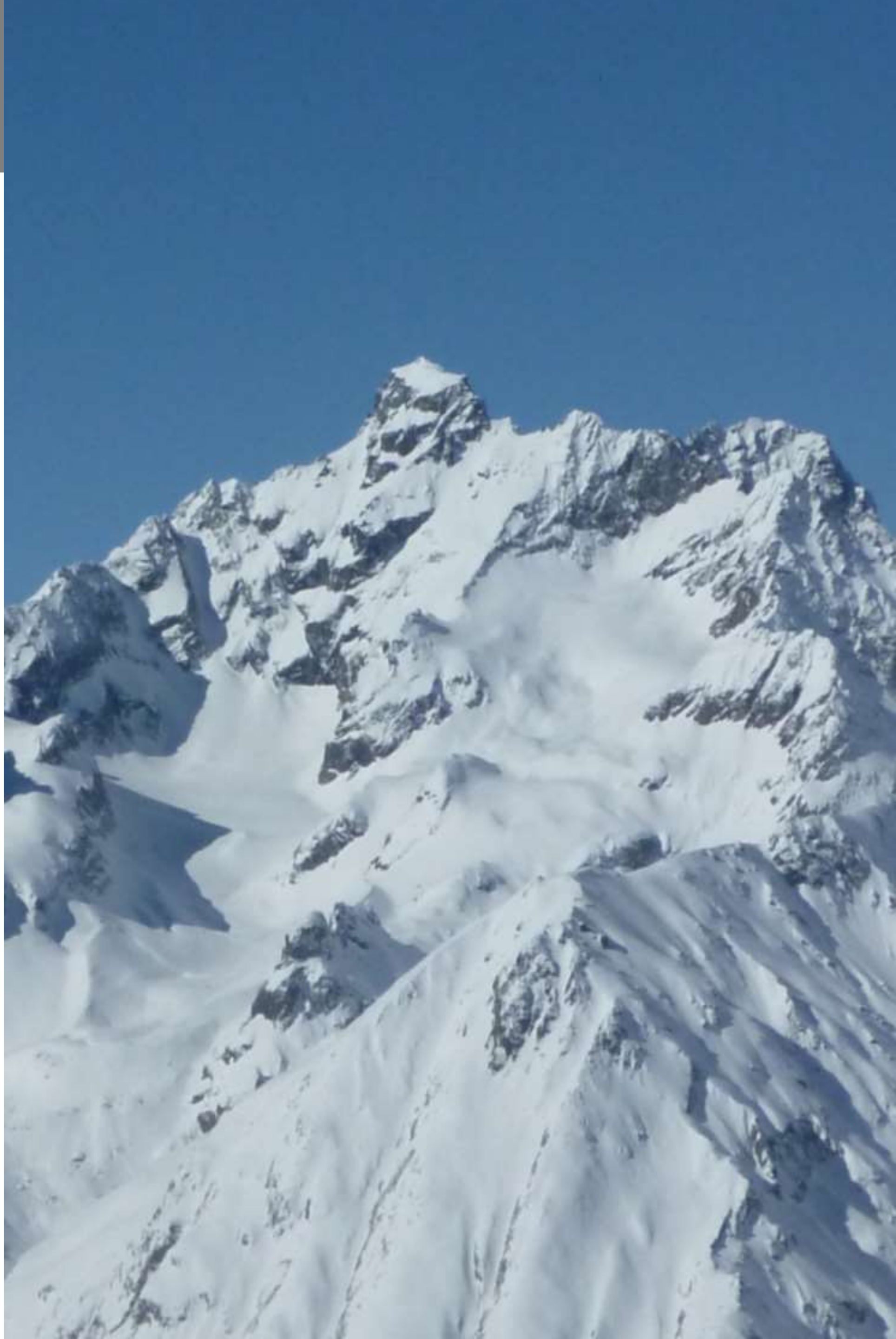
Outlook

- Algorithm for Snow Mapping by Sentinel-1 SAR IW mode data
- Examples and Validation of Algorithm in Alps and Northern Latitudes
- Prototype snow extent algorithm for Sentinel-3 optical sensors
- Combination of S1 and S3 snow products
- Conclusions



Observational Requirements and SAR Products

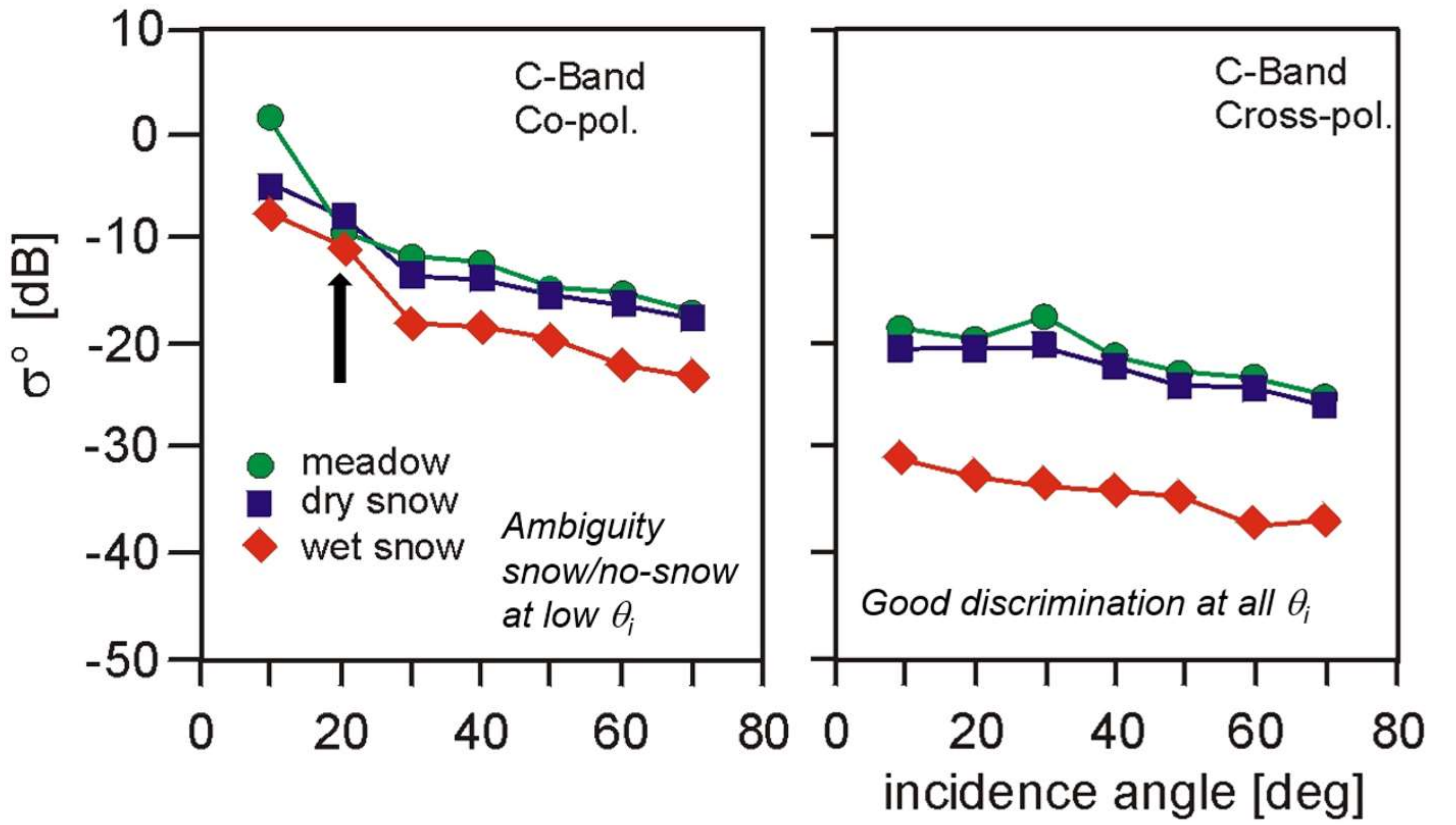
Observational requirements for satellite-based snow extent products for operational hydrology and climate research (*IGOS Cryosphere Theme Report*):

- Spatial resolution: 100 m
- Revisit time: 1 day (during melting period)

Product type of the current satellite-based C-band SAR Systems:

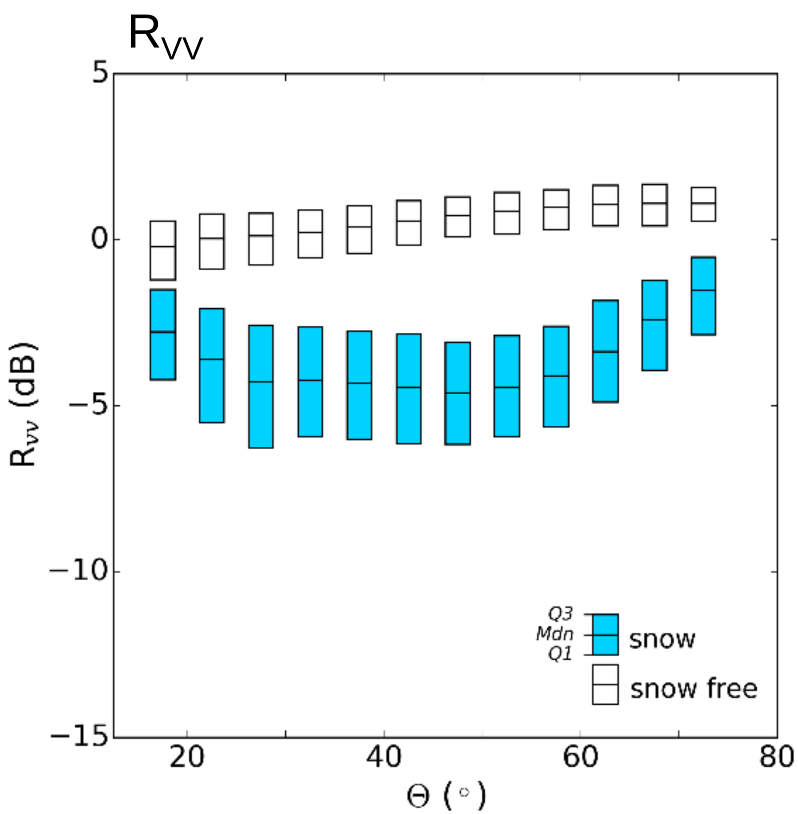
- **Extent of snow melt area** → based on backscatter sensitivity to wet snow
- C-band SAR backscatter is not suitable for operational monitoring of **dry snow areas** → very limited sensitivity to dry snow.

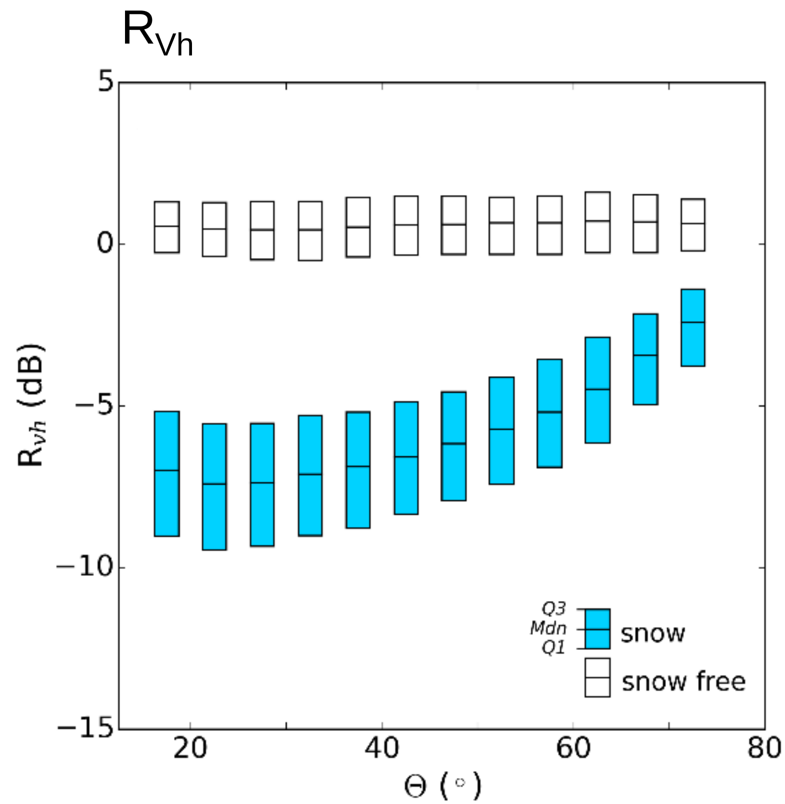
Groundbased Backscatter Signatures – Leutasch/Alps



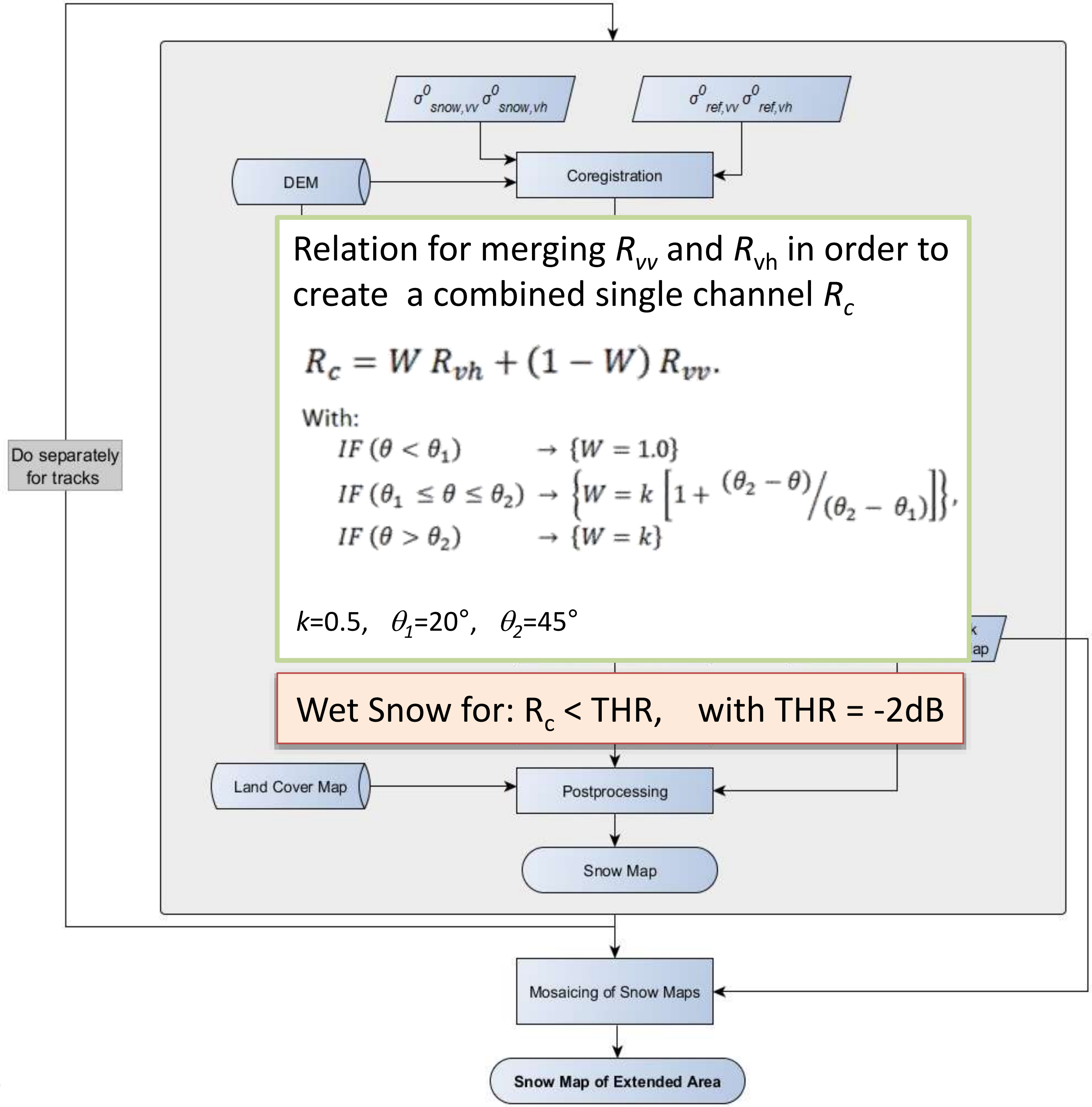
Sentinel-1 Backscatter Ratios
High Alpine Test site Ötztal

Backscatter ratio (median, Mdn, 1st and 3rd quartile) for Sentinel-1 *VV*- and *VH*- polarized channels in dependence of the local incidence angle, θ, for test area Ötztal.





Sentinel-1 Dual Pol Wet Snow Mapping Method



Relation for merging R_{vv} and R_{vh} in order to create a combined single channel R_c

$$R_c = W\,R_{vh} + (1 - W)\,R_{vv}.$$

With:

$$IF\ (\theta < \theta_1) \rightarrow \{W = 1.0\}$$
$$IF\ (\theta_1 \le \theta \le \theta_2) \rightarrow \left\{W = k\left[1 + {(\theta_2 - \theta)}/{(\theta_2 - \theta_1)}\right]\right\},$$
$$IF\ (\theta > \theta_2) \rightarrow \{W = k\}$$

k=0.5, θ_1=20°, θ_2=45°

Wet Snow for: R_c < THR, with THR = -2dB

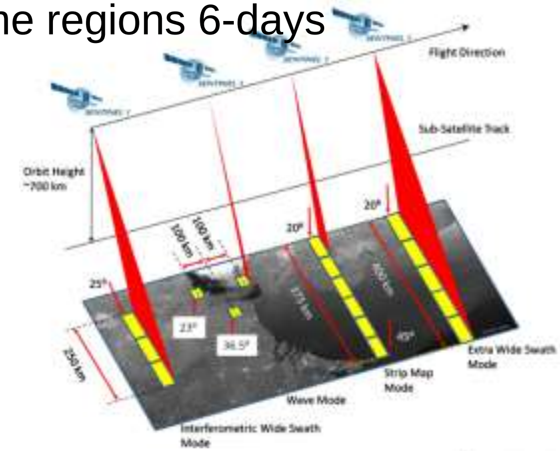
(Nagler et al. 2016; Rem. Sens., 2016, 8(4), 348, doi:10.3390/rs8040348)

Sentinel-1 and Sentinel-3 Sensor Overview

S1 SAR IW Mode

Polarisation	Dual (HH + HV, VV + VH)
Access (incidence angles)	31°–46°
Azimuth resolution	<20 m
Ground range resolution	<5 m
Azimuth and range looks	Single
Swath	>250 km
Maximum NESZ	−22 dB
Radiometric stability	0.5 dB (3σ)
Radiometric accuracy	1 dB (3σ)

<u>Global Land (Status):</u> 12 days repeat coverage wit IW mode; some regions 6-days



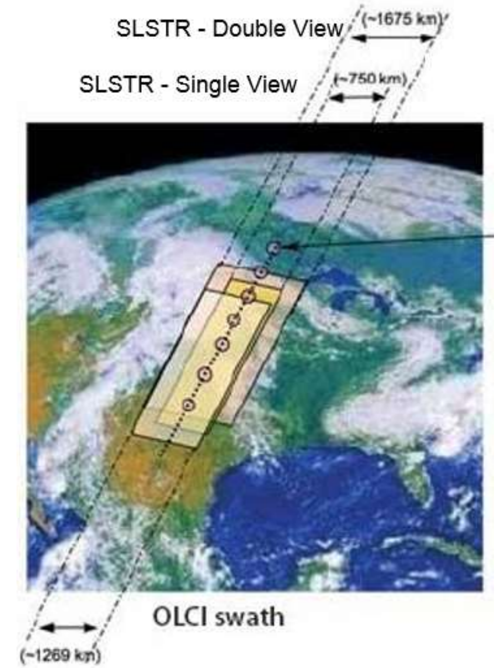
OLCI (Ocean and Land Colour Instrument)

- Swath width: 1270 km, with 5 tilted cameras
- Spatial sampling: 300 m @ SSP
- Spectrum: 21 bands [0.4-1.02] µm

esa

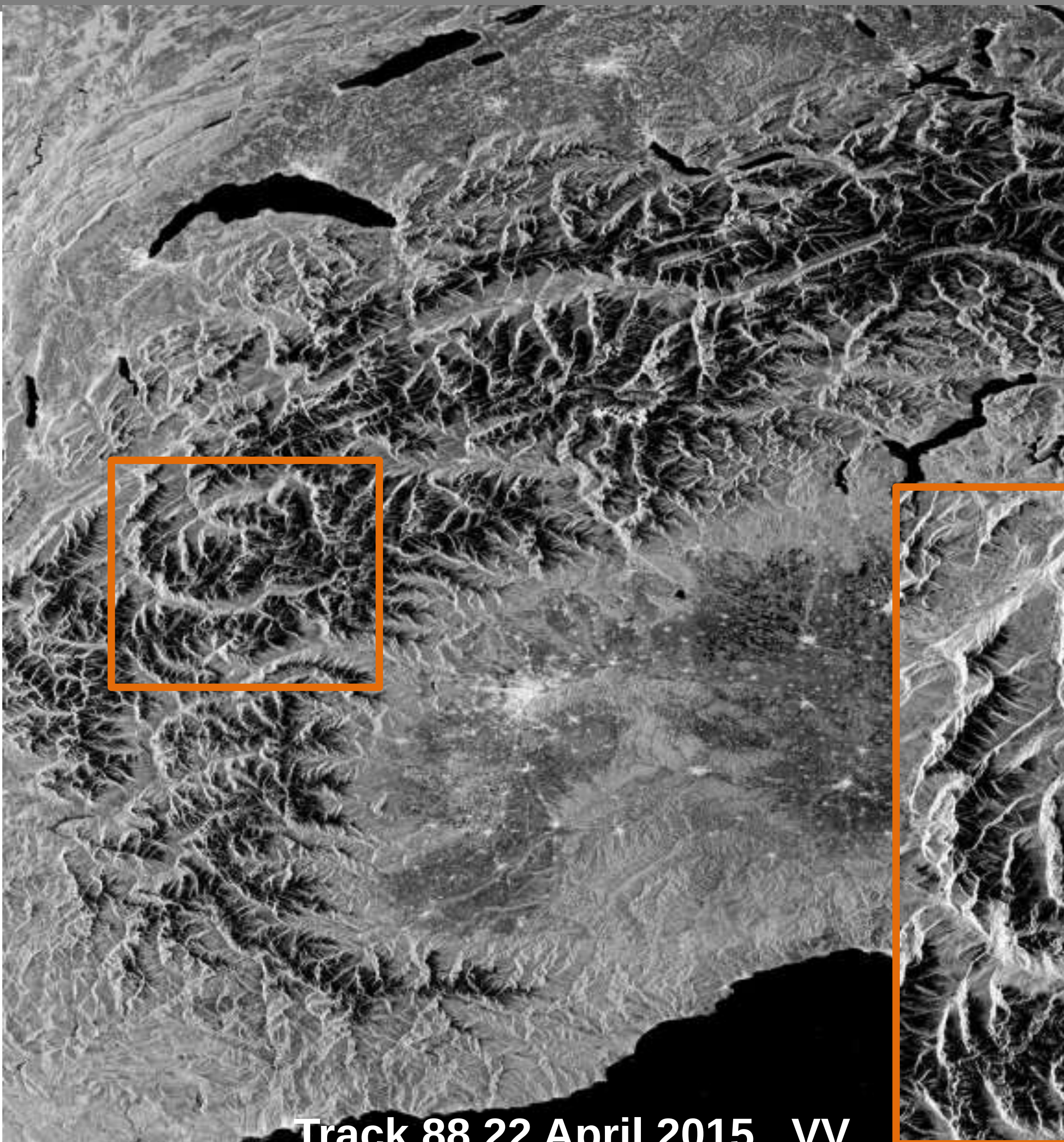
SLST (Sea and Land Surface Temperature)

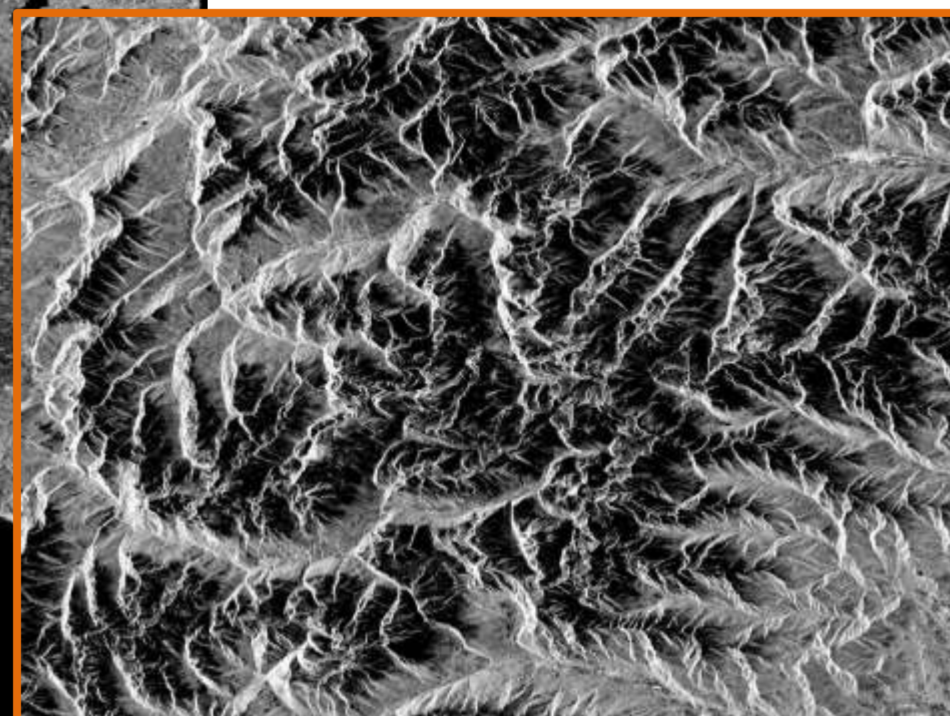
- Swath width: dual view scan, 1675 km (nadir) / 750 Km (backwards)
- Spatial sampling: 500 m (VIS, SWIR), 1 km (MWIR, TIR)
- Spectrum: 9 bands [0.55-12] µm



Optionally for S3: Metop- SG VII

Sentinel-1 IW Swath Product





Example of S1 Snow Melt and Landsat TM Snow Extent – Ötztal Alps

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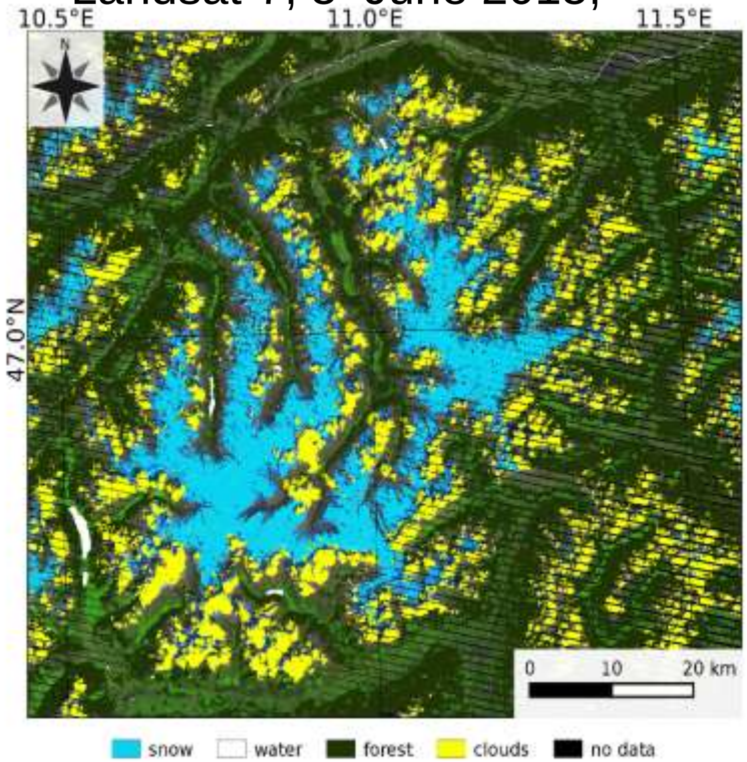
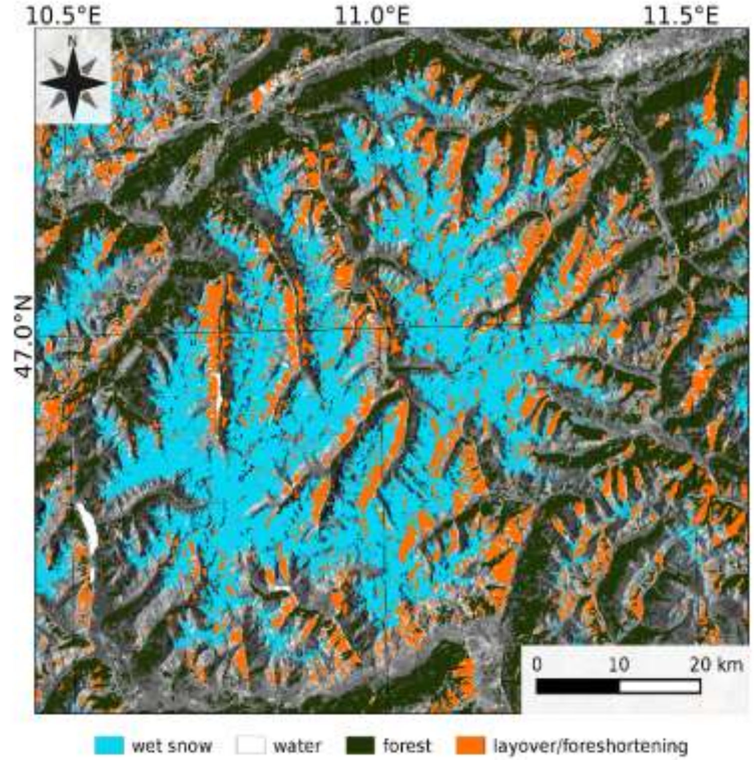
Landsat-7, 5 June 2015;



Sentinel-1, 2 June 2015;

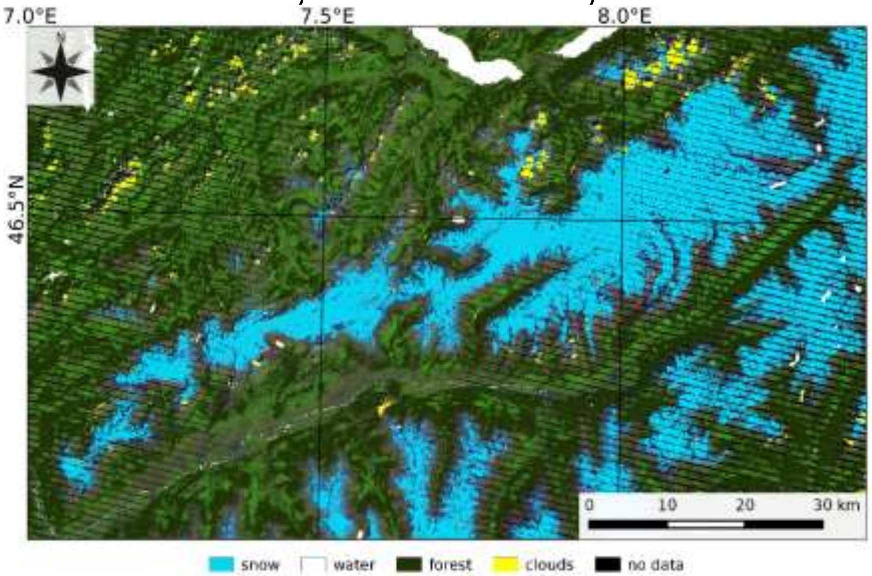


	R_{vv}			R_{vh}			R_c		
	S1-S	**S1-F**	AR	**S1-S**	**S1-F**	AR	**S1-S**	**S1-F**	AR
LS-S	80.7	19.3		94.5	6.4		94.7	5.3	
LS-F	4.2	95.8		5.3	94.7		3.2	97.8	
			0.882			0.946			0.962

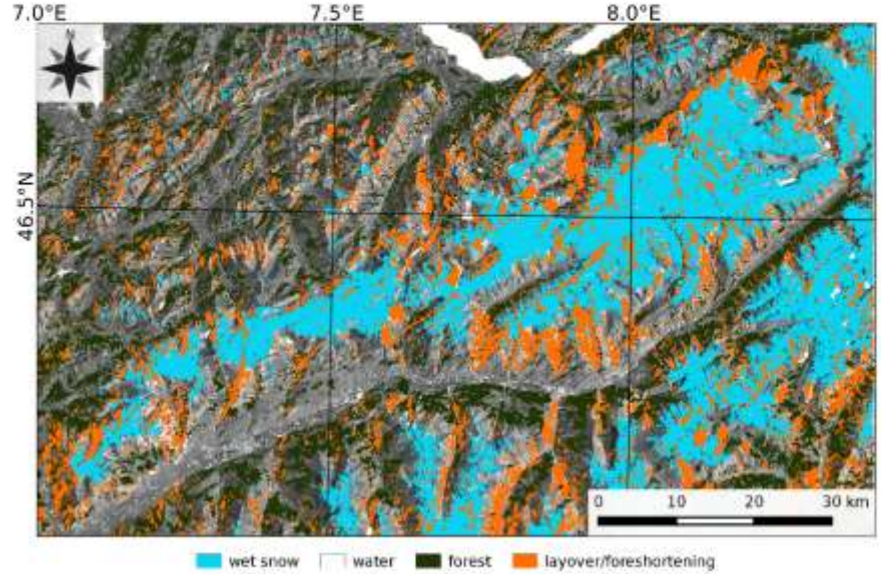
Confusion matrix for the classes snow (S) and snow-free (F) in Ötztal test site, for snow classification based on Landsat (LS) and Sentinel-1 (S1) data. AR — overall agreement rate ($0.0 \leq AR \leq 1.0$).

Validation site for S1 Snow melt product
Swiss Alps

Landsat-7, 3 June 2015;



Sentinel-1, 7 June 2015;



Confusion matrix for the classes snow (S) and snow-free, for snow classification based on Landsat (LS) and Sentinel-1 (S1) data. AR — overall agreement rate ($0.0 \leq AR \leq 1.0$).

	R_{vv}			R_{vh}			R_c		
	S1-S	S1-F	*AR*	S1-S	S1-F	*AR*	S1-S	S1-F	*AR*
LS-S	80.7	19.3		94.5	6.4		94.7	5.3	
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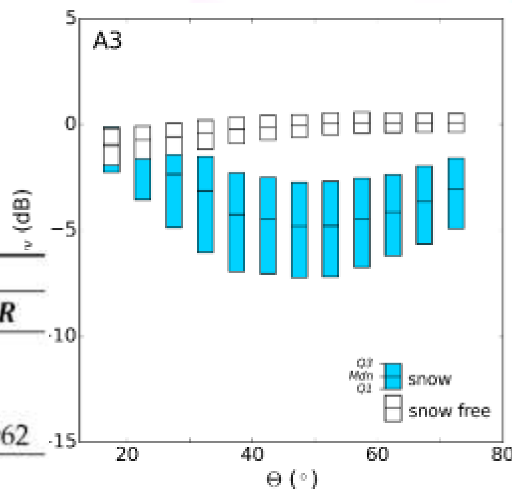
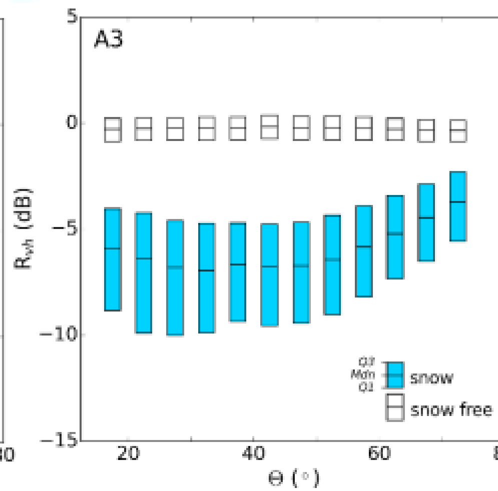
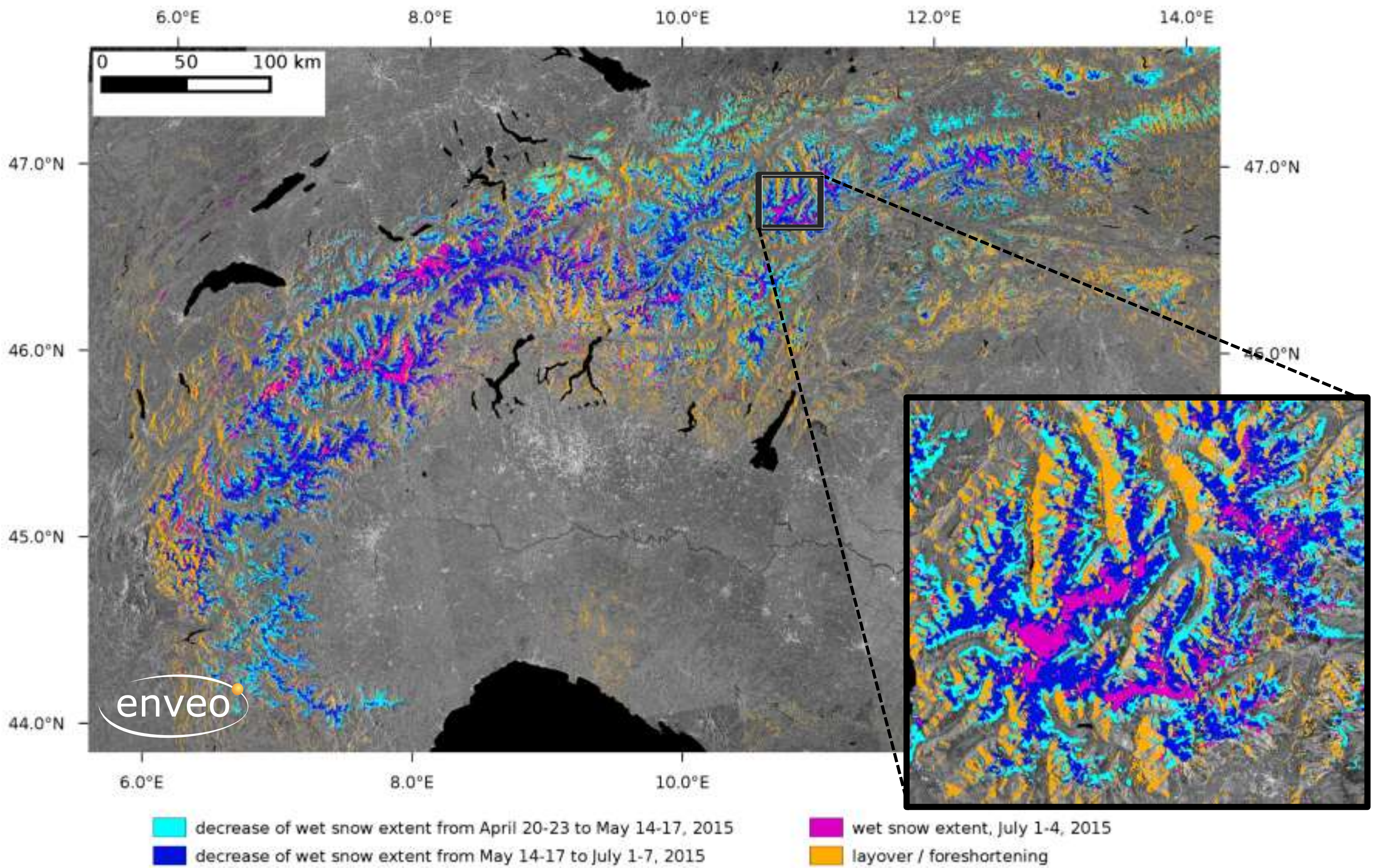




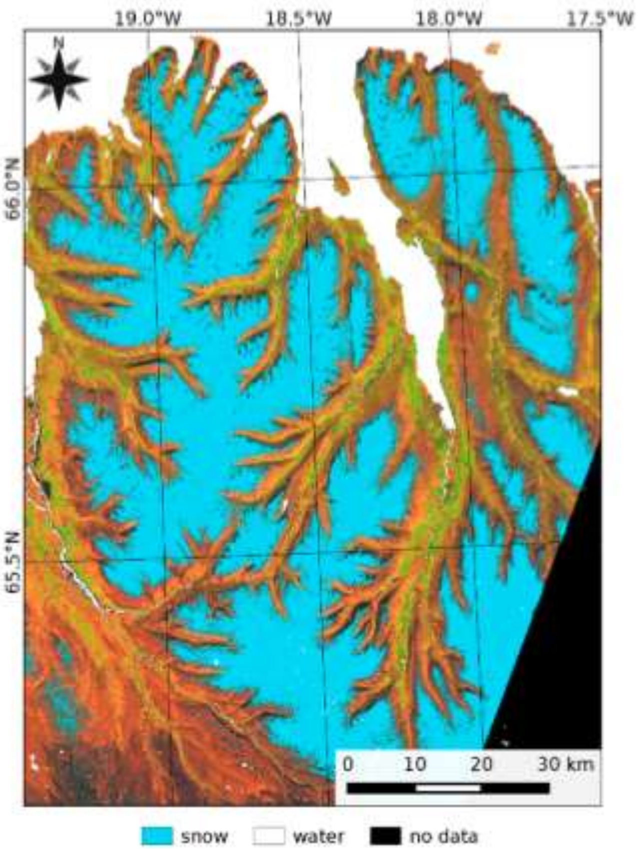
Sentinel-1A Wet Snow Maps - Dual Pol Algorithm



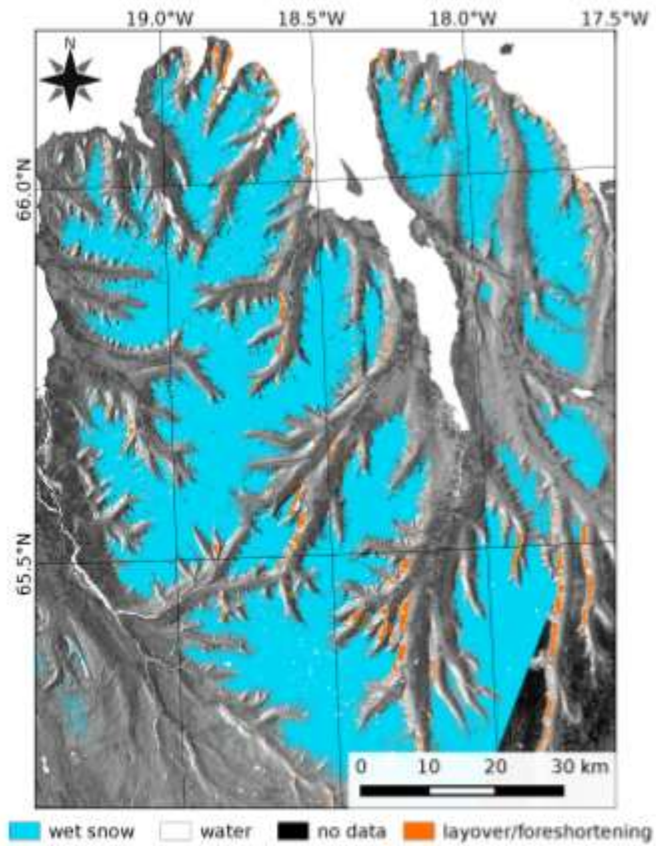
Derived from 4 tracks

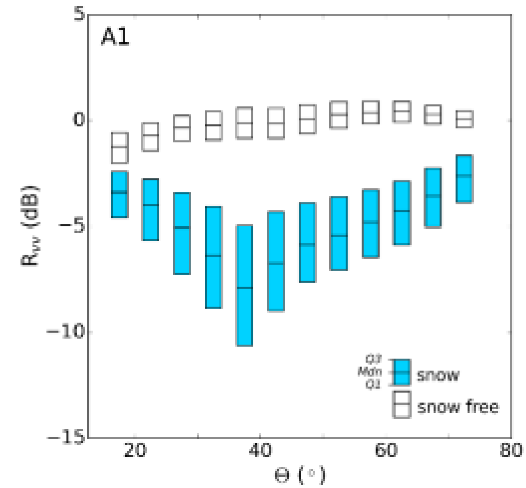
Validation Site for S1 Snow Melt and Landsat TM Snow Extent – Tröllaskagi Peninsula, Iceland

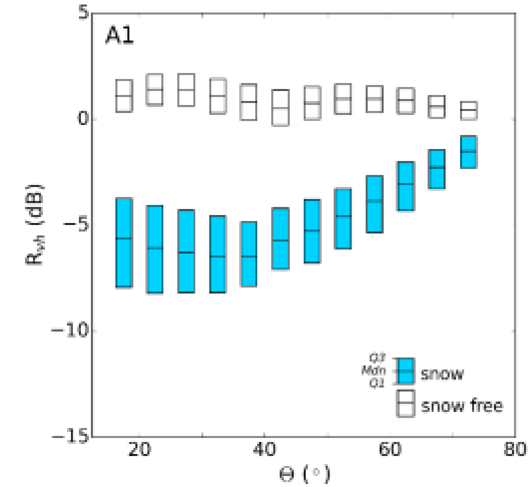
Landsat-8, 27 June 2015;



Sentinel-1, 26 June 2015;



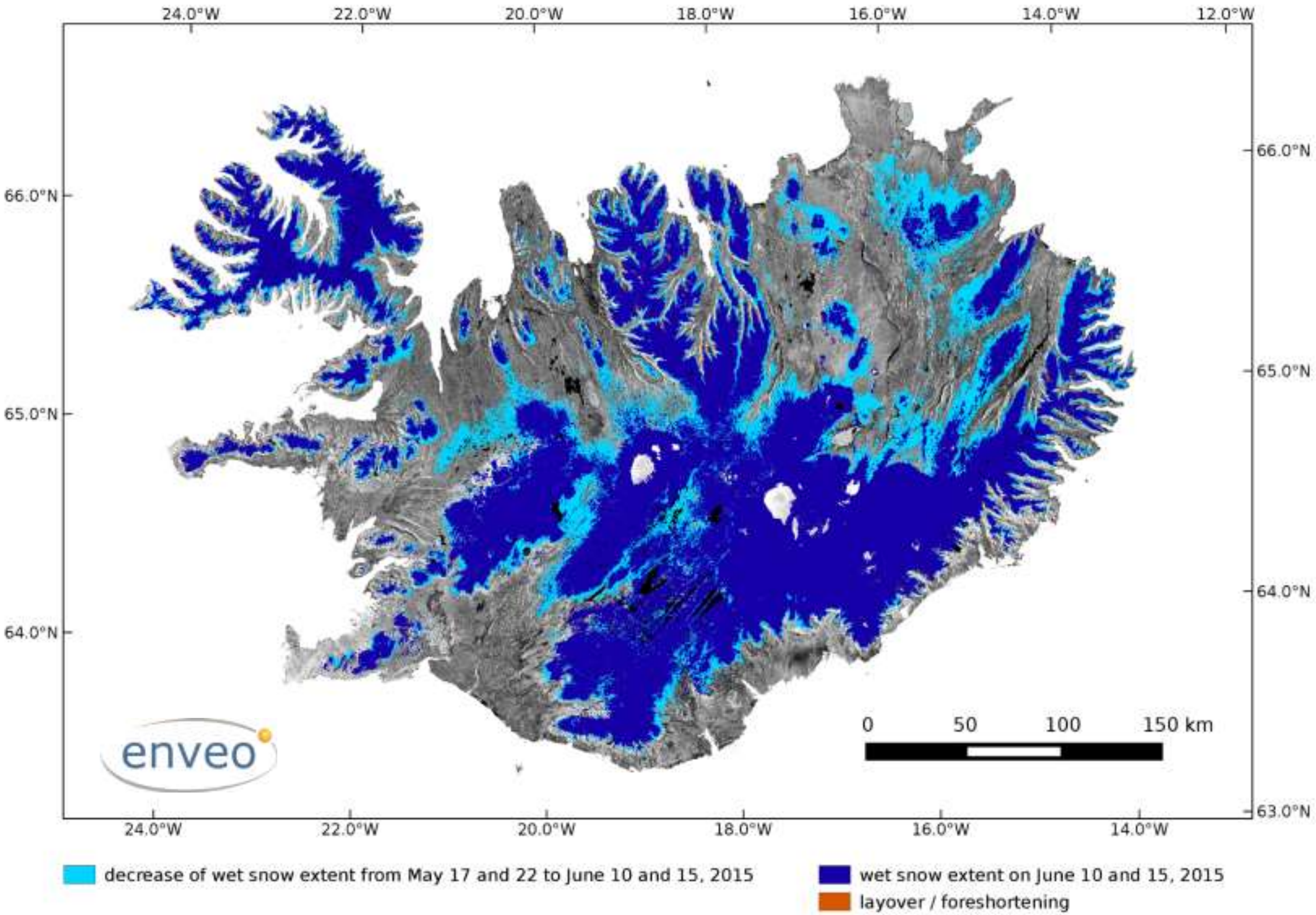




	R_{vv}			R_{vh}			R_c		
	S1-S	S1-F	*AR*	S1-S	S1-F	*AR*	S1-S	S1-F	*AR*
LS-S	92.8	7.2		92.6	7.4		94.6	5.4	
LS-F	2.0	98.0		0.2	99.8		0.2	99.8	
			0.954			0.962			0.972

Confusion matrix for the classes snow (S) and snow-free, for snow classification based on Landsat (LS) and Sentinel-1 (S1) data. AR — overall agreement rate ($0.0 \leq AR \leq 1.0$).

Monitoring melting snow using Sentinel-1 SAR



Nagler et al., Remote Sensing, 2016

Concept for SENTINEL-3 Snow Mapping using SLSTR and OLCI

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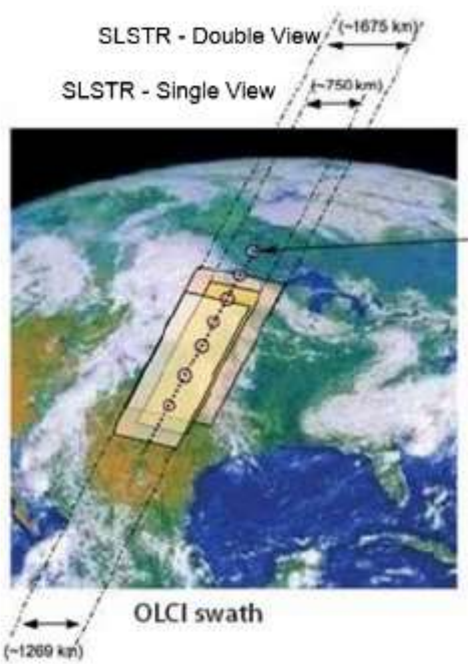
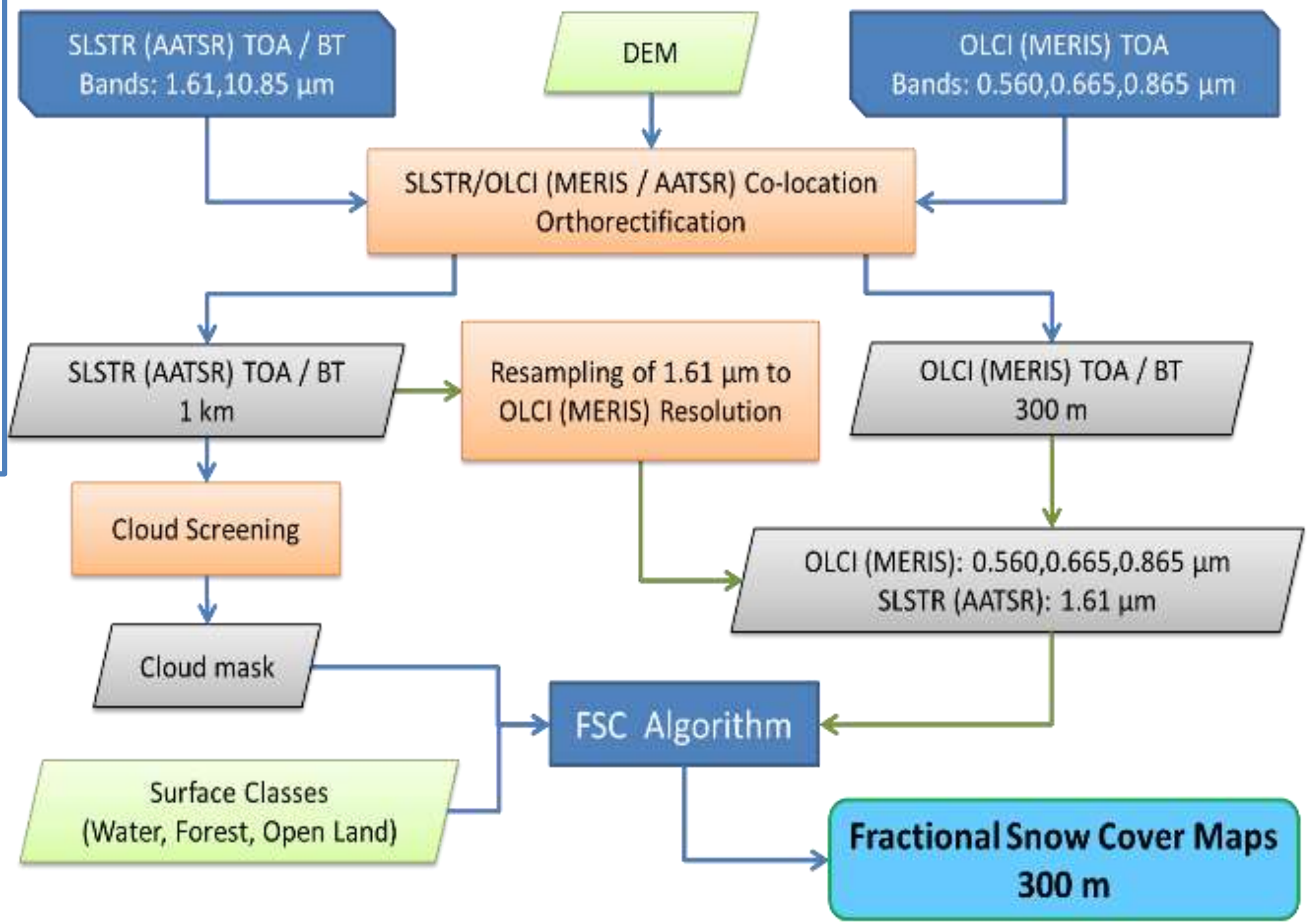
Sentinel-3:

SLSTR (follow on of AATSR):
0.5 – 1.6, -3.7 µm + TIR
500 m / 1 km

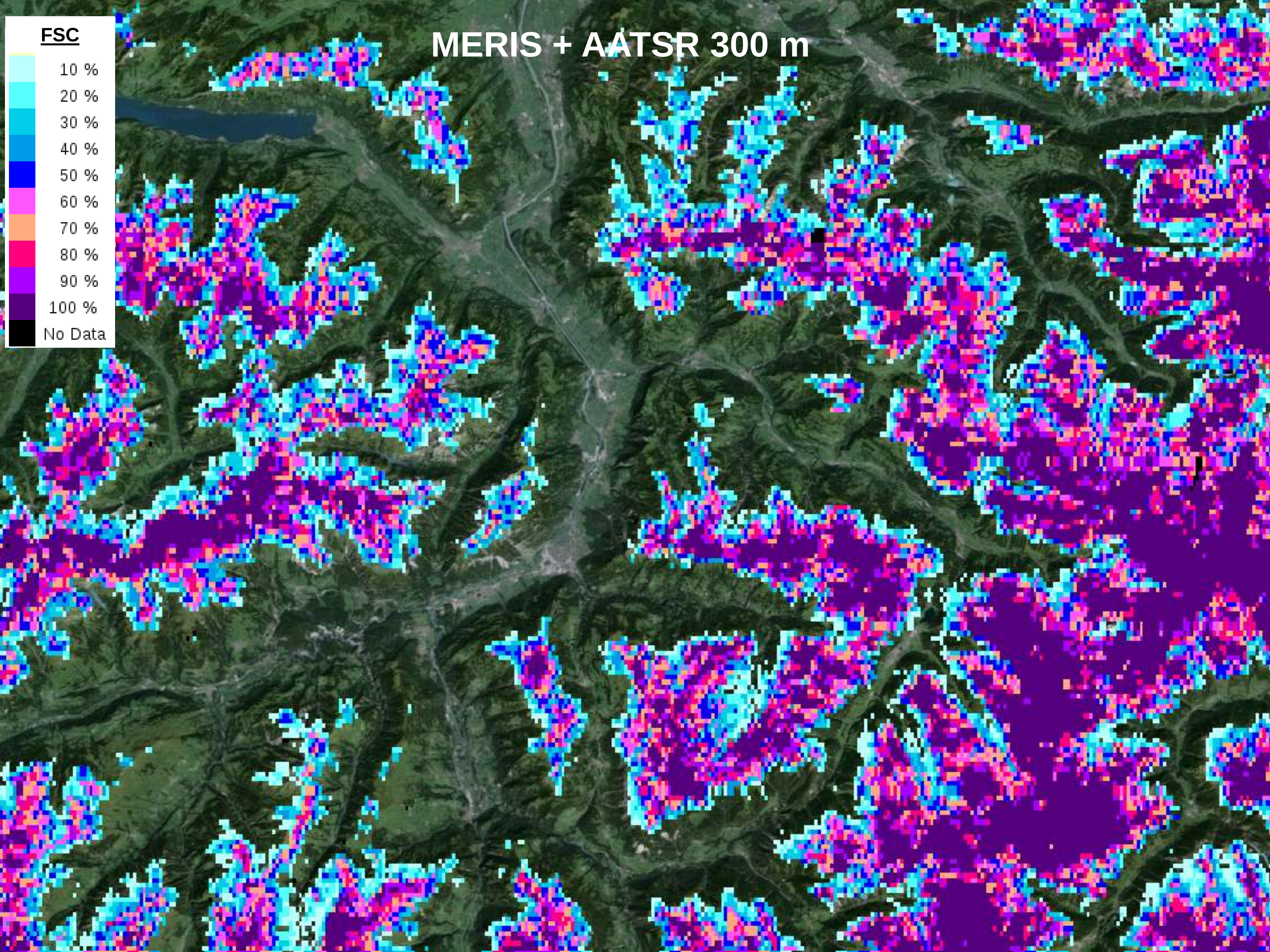
OLCI (follow on of MERIS):
0.4.-1.2 µm; 300 m

Daily Global Coverage

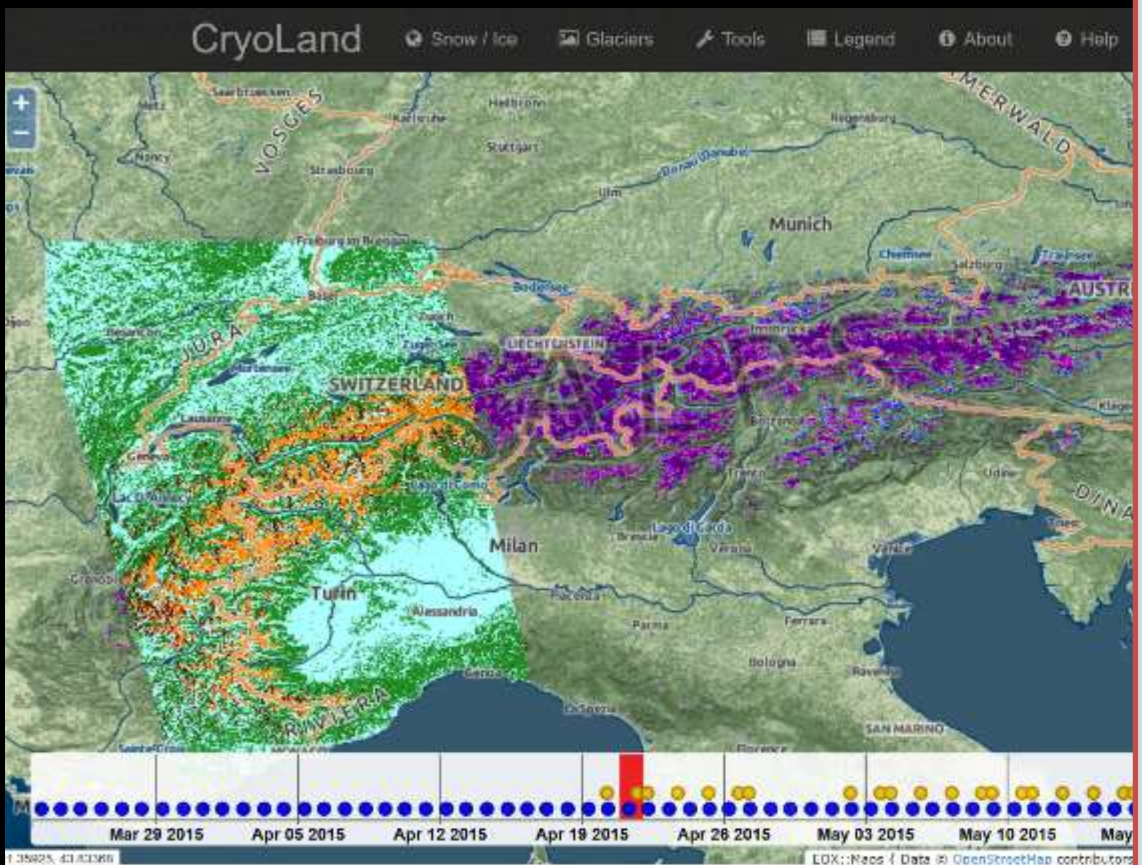


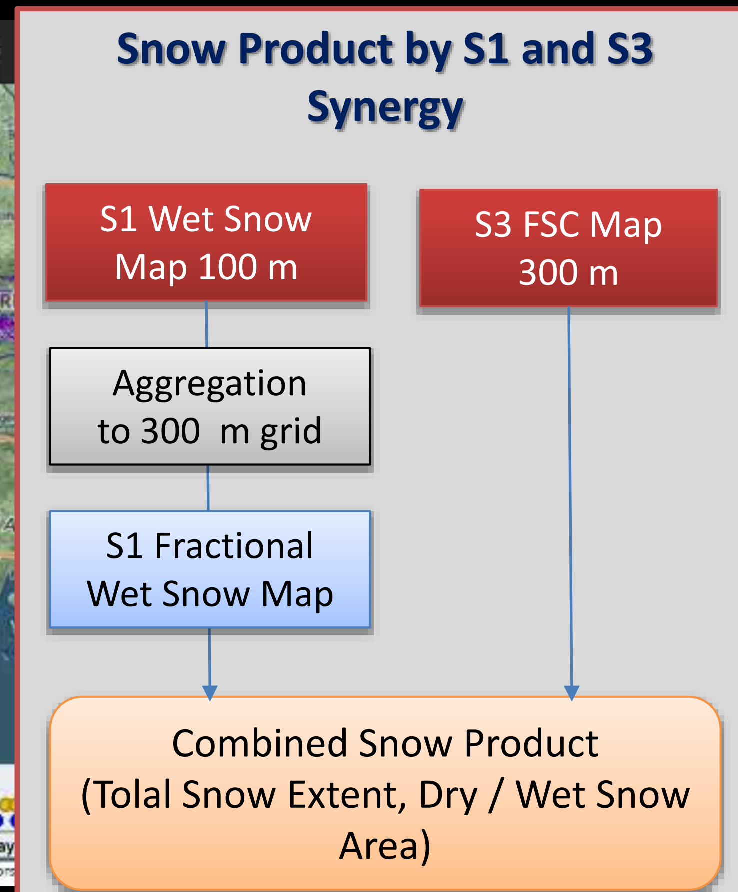


Fractional Snow Extent estimated using multi-spectral algorithm


MERIS + AATSR 300 m
FSC
10 %
20 %
30 %
40 %
50 %
60 %
70 %
80 %
90 %
100 %
No Data

Combining fractional snow extent maps with melting snow area maps





Conclusions

- A dual pol (Co-, Cross) Snow Melt Algorithm for Sentinel-1 IW was developed and validated in Alps and Northern Latitudes, shows a very high agreement with snow maps from high resolution optical data.
- Due to the high spatial resolution and frequent repeat coverage, Sentinel-1A & 1B time series of snowmelt area are of great interest for applications in hydrology and water management.
- Synergy of Sentinel-1 and -3 sensors is a powerful approach for comprehensive snow monitoring in terms of repeat coverage and snow pack state.

S1-4SCI SNOW - DEVELOPMENT OF PAN-EUROPEAN MULTI-SENSOR SNOW MAPPING METHODS EXPLOITING S1

ESA SEOM Study - Dec 2016 – Nov 2018

PRIMARY OBJECTIVES

- Develop, implement and validate methods for generating maps of snowmelt area based on SAR data of the S-1 mission
- Combination of S-1 wet snow products with snow products from optical sensors of S-2 and S-3
- Use developed algorithm to generate pan-European snow maps from S-1 and S-3

CONSORTIUM

ENVEO IT GmbH, Innsbruck, Austria (Principle Investigator)

Finnish Meteorological Institute, Helsinki, Finland

University of Zurich, Zurich, Switzerland

Finnish Environment Institute, Helsinki, Finland

Norut, Tromsö, Norway