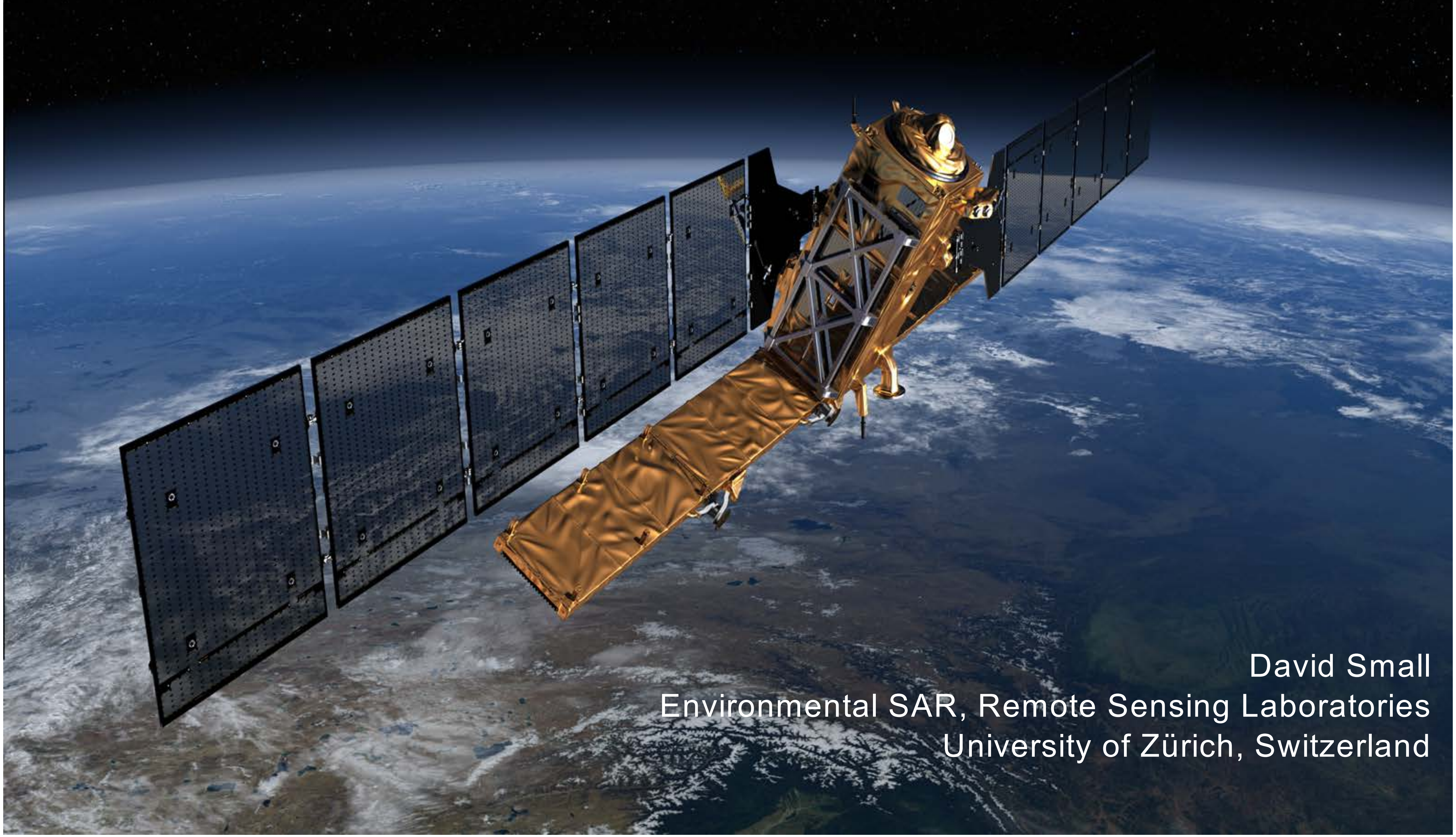
Snow Mapping Using SAR



David Small
Environmental SAR, Remote Sensing Laboratories
University of Zürich, Switzerland

Snow Mapping using SAR

- Motivation
- Geometric Calibration / Wet Snow Attenuation
- Backscatter Normalisation Conventions
- Radiometric Terrain Corrections
- Approaches for Wet Snow Mapping
  - Single-track dB differencing
  - Backscatter Compositing
- Conclusions

Remote Sensing of Snow: Motivation

Knowledge of snow parameterisation important for

- Mitigating large economic impacts of snowfall events
- Snow wetness: run-off modelling: measurements and future prognoses
- Snow wetness: Sudden melt events inducing flooding
- Snow wetness: Hydrology
- Snow distribution and season length – interactions with land cover
- Avalanche modelling
- Climate interactions

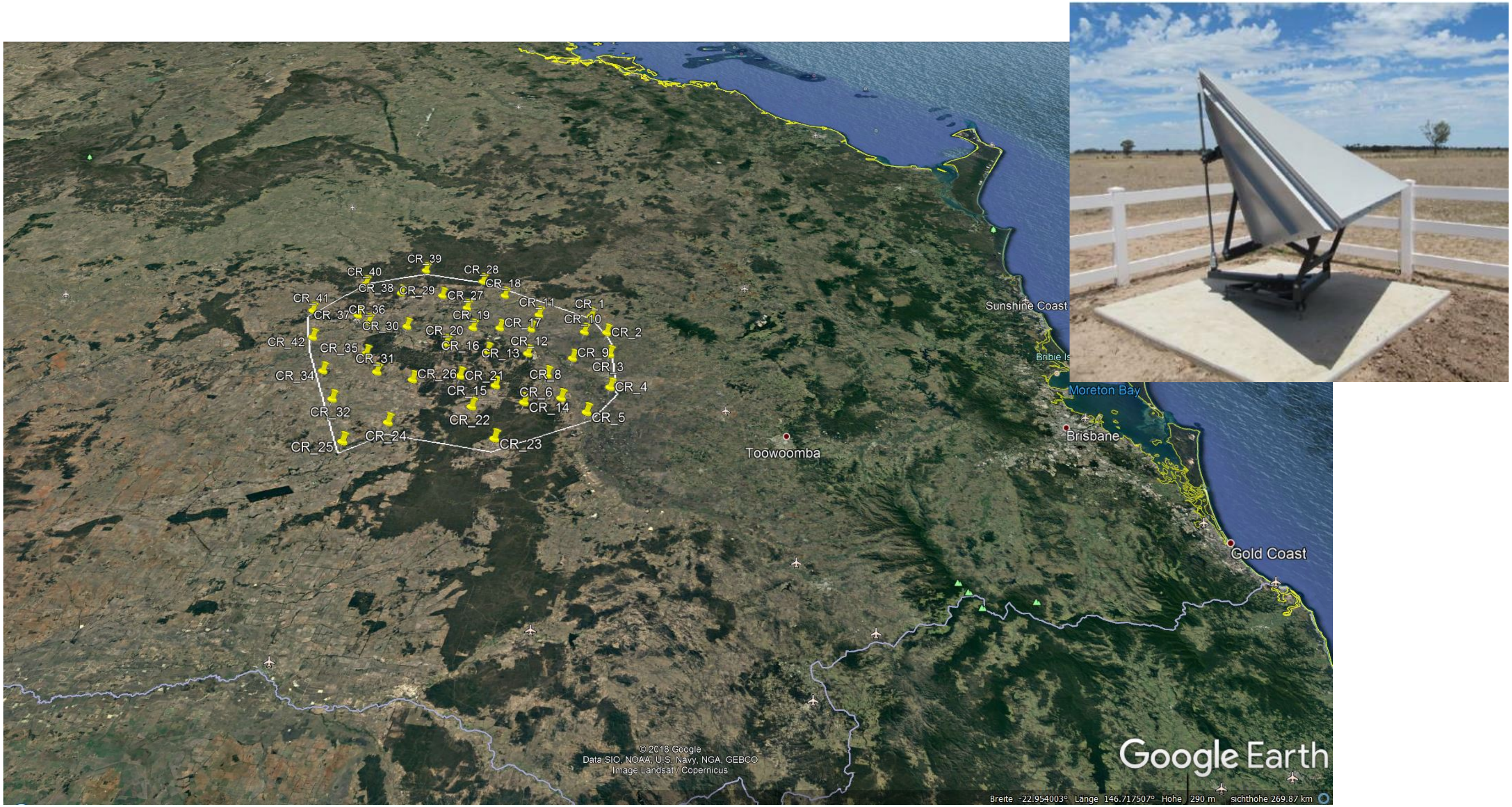
A. Dietz, C. Kuenzer, and S. Dech, "**Global SnowPack: a new set of snow cover parameters for studying status and dynamics of the planetary snow cover extent**," Remote Sens. Lett., 6(11), pp. 844–853, Sep. 2015.

D. R. DeWalle and A. Rango, **Principles of Snow Hydrology**. Cambridge, UK: Cambridge University Press, 2008.

Active Microwave: Synthetic Aperture Radar

Geometric Calibration: Test Site:

- *Surat* Basin, Australia (40 CRs)



Overview of geometric Corrections:

Reference target position:

- *Solid Earth Tides*
- *tectonics/ITRF geodetic frame shift*

Range timing:

- *atmospheric PD (troposphere & ionosphere)*
- *intra-burst-dependent range bias (TOPS mode: IW/EW) (1)*

Azimuth timing:

- *Bistatic residual correction*
- *Bistatic bulk bias correction*
- *Instrument Timing Correction (2)*
- *Topography-induced Doppler shift (2)*

[1] Rodriguez-Cassola M., Prats-Iraola P., De Zan F., Scheiber R., Reigber A., Geudtner D., Moreira A. Doppler-related distortions in TOPS SAR images. IEEE Trans. Geosci. Remote Sens. ***2015****, 53, 25–35.*
[2] Piantanida R., Recchia A., Fransceschi N., Velentino A., Miranda N., Schubert A., Small D., Accurate Geometric Calibration of Sentinel-1 Data, Proc. EUSAR 2018, 6p.

IW SLC ALE over Surat array using published method
(i.e. without division by 2π)

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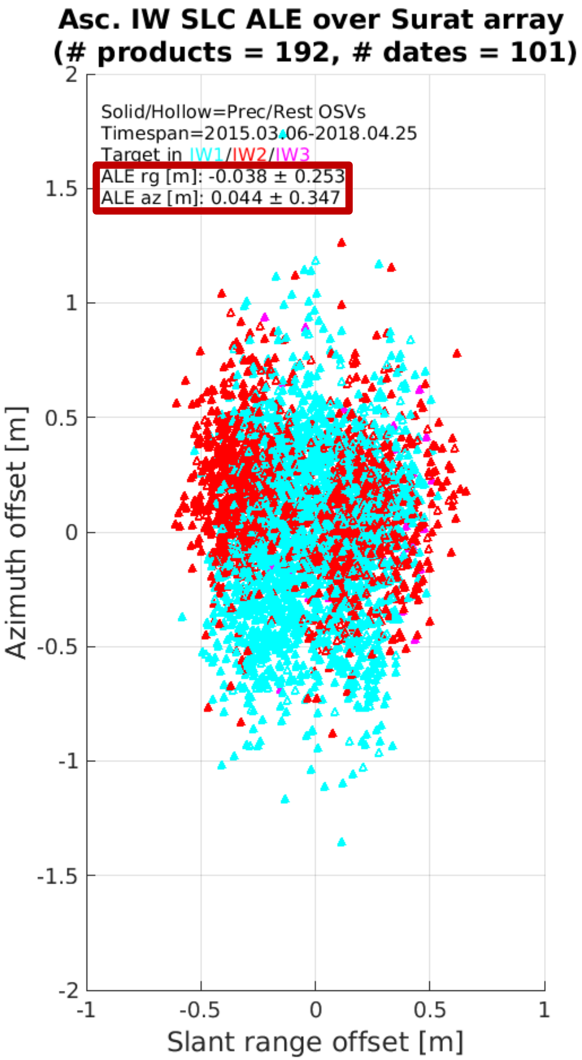
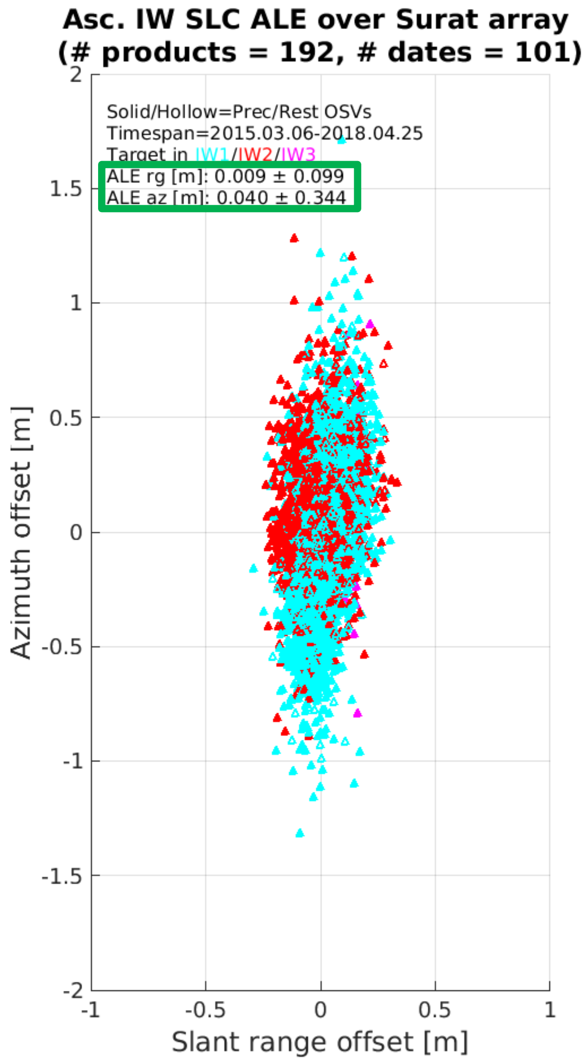
No intra-burst rg bias or terrain-induced DC corrections



Intra-burst rg bias and terrain-induced DC corrections



Attenuation in wet snow

Snow and Dielectric Constant

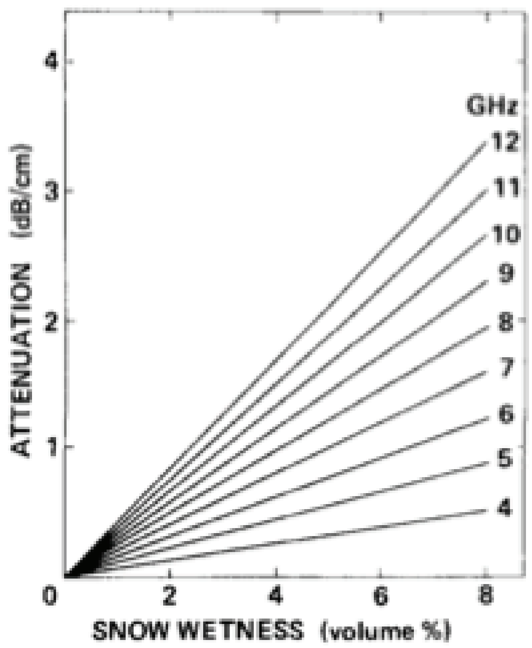
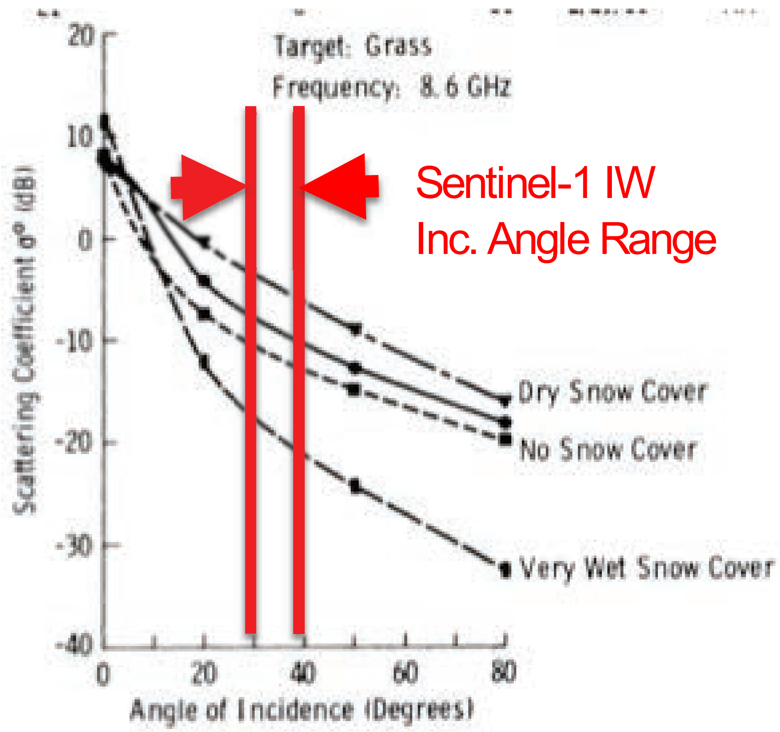


FIG. 5. Variation of attenuation with snow wetness at selected frequencies.



F. T. Ulaby, W. H. Stiles, and M. Abdelrazik, "**Snowcover Influence on Backscattering from Terrain**," IEEE Trans. Geosci. Remote Sens., vol. GE-22, no. 2, pp. 126–133, Mar. 1984.

W. I. Linlor, "**Permittivity and attenuation of wet snow between 4 and 12 GHz**," J. Appl. Phys., vol. 51, no. 5, pp. 2811–2816, May 1980.

SAR: Backscatter Normalisation Conventions

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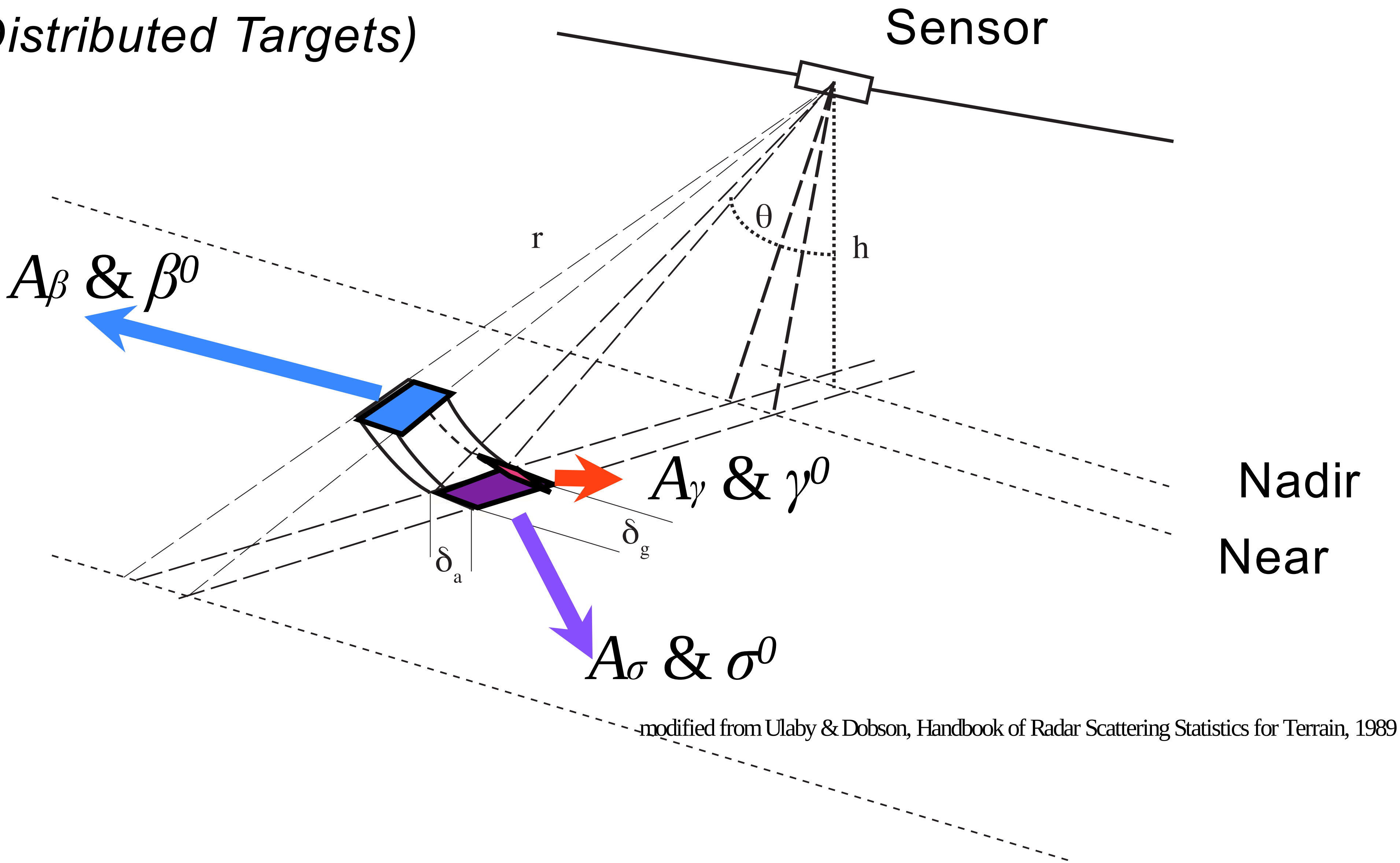
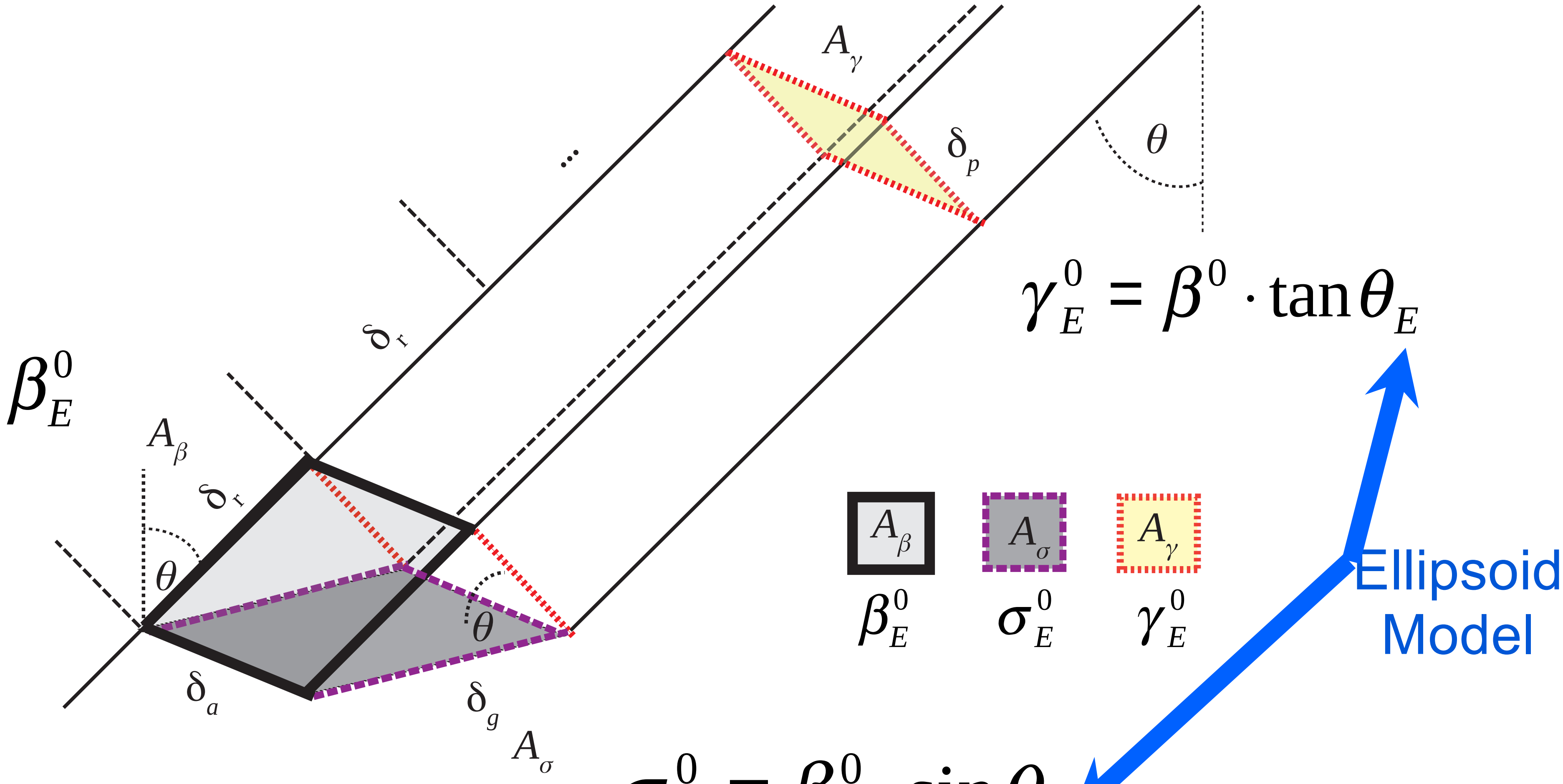
Standard Areas for Normalisation

(Distributed Targets)



modified from Ulaby & Dobson, Handbook of Radar Scattering Statistics for Terrain, 1989

Ground Illuminated Area



$$\gamma_E^0 = \beta^0 \cdot \tan\theta_E$$

$$\sigma_E^0 = \beta^0 \cdot \sin\theta_E$$

Backscatter coefficients are *relative* to *isotropic* scattering

An idealised **isotropic** scatterer will scatter *equally in all directions*

Real Imaged Objects

- can tend to scatter more **forward** than back to the sensor, focussing energy away from the measurement
  - are darker, generating **negative** *dB* values
- can focus energy **back** towards the sensor (e.g. through corner reflections), generating **positive** *dB* backscatter

$$(\gamma^0_{wet} - \gamma^0_{ref}) \ \ [\text{dB}]$$

When difference between candidate image backscatter and dry reference image is lower than -3dB, classify as wet snow

Developed using ERS-1 geometries, VV-pol.

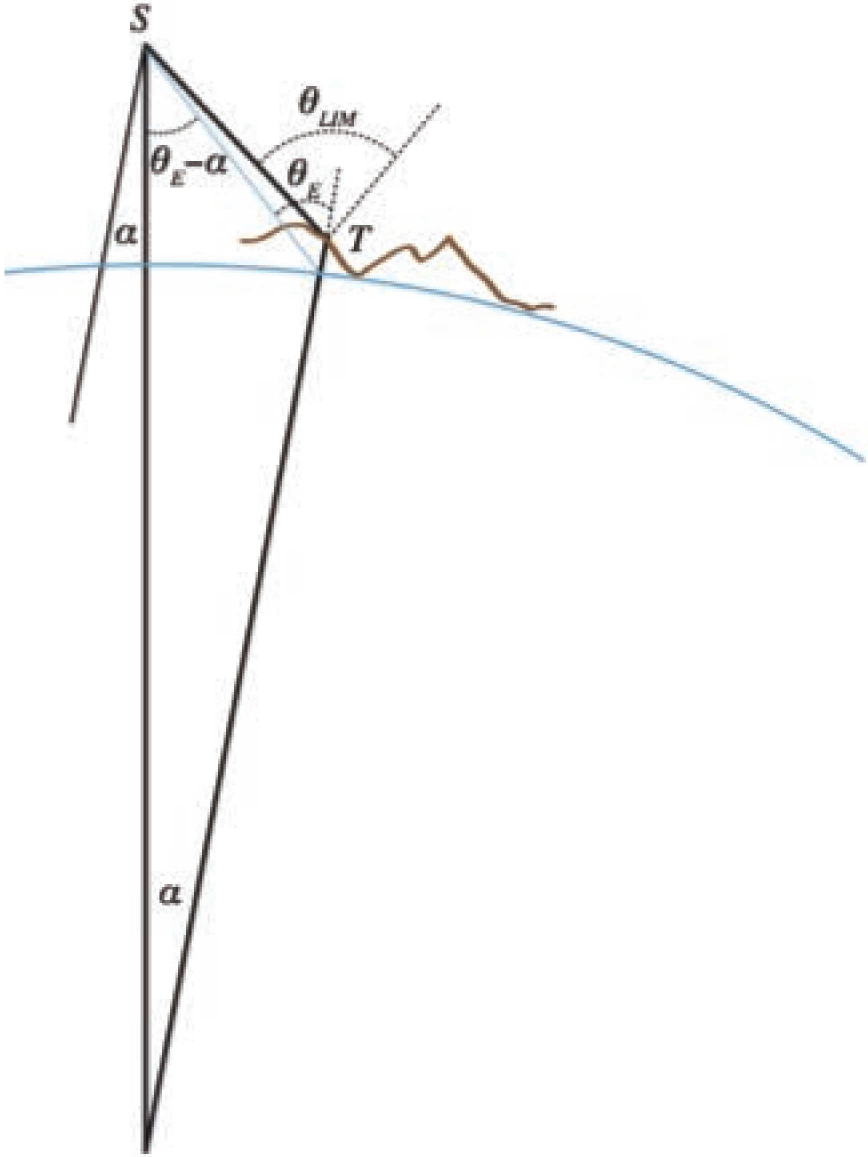
Relies on **exact repeat tracks** (e.g. 35-day ERS repeat) to avoid corruption e.g. by terrain-induced effects

N. Longépé, S. Allain, L. Ferro-Famil, E. Pottier, and Y. Durand, “**Snowpack Characterization in Mountainous Regions Using C-Band SAR Data and a Meteorological Model**,” IEEE Trans. Geosci. Remote Sens., vol. 47, no. 2, pp. 406–418, Feb. 2009.

T. Nagler and H. Rott, “**Retrieval of wet snow by means of multitemporal SAR data**,” IEEE Trans. Geosci. Remote Sens., vol. 38, no. 2, pp. 754–765, Mar. 2000.

N. Baghdadi, Y. Gauthier, and M. Bernier, “**Capability of Multitemporal ERS-1 SAR Data for Wet-Snow Mapping**,” Remote Sens. Environ., vol. 60, no. 2, pp. 174–186, May 1997.

Spaceborne Radar Geometry



Incident Angles:

1. Nominal, from **Ellipsoid**:

$$\theta_E$$

2. Local Incident Angle, from **height model**:

$$\theta_{LIM}$$

Normalising σ for *terrain*

$$\beta^0, \sigma_E^0, \gamma_E^0$$

are each usable and widely used to normalise the backscatter σ, but one main problem remains:

Each of β^0, σ^0, γ^0 vary with the local terrain situation (forest on a hill *foreslope* is brighter than forest on *flat* ground, which is brighter than forest on a hill *backslope*)

Local Incident-angle Mask (LIM)

The most common slope-normalisation methodology found in the literature is fails to account for **non-homomorphic** (one to many correspondence) nature of relationship between Earth coordinates (map geometry) & slant range geometry (native sensor acquisition process)

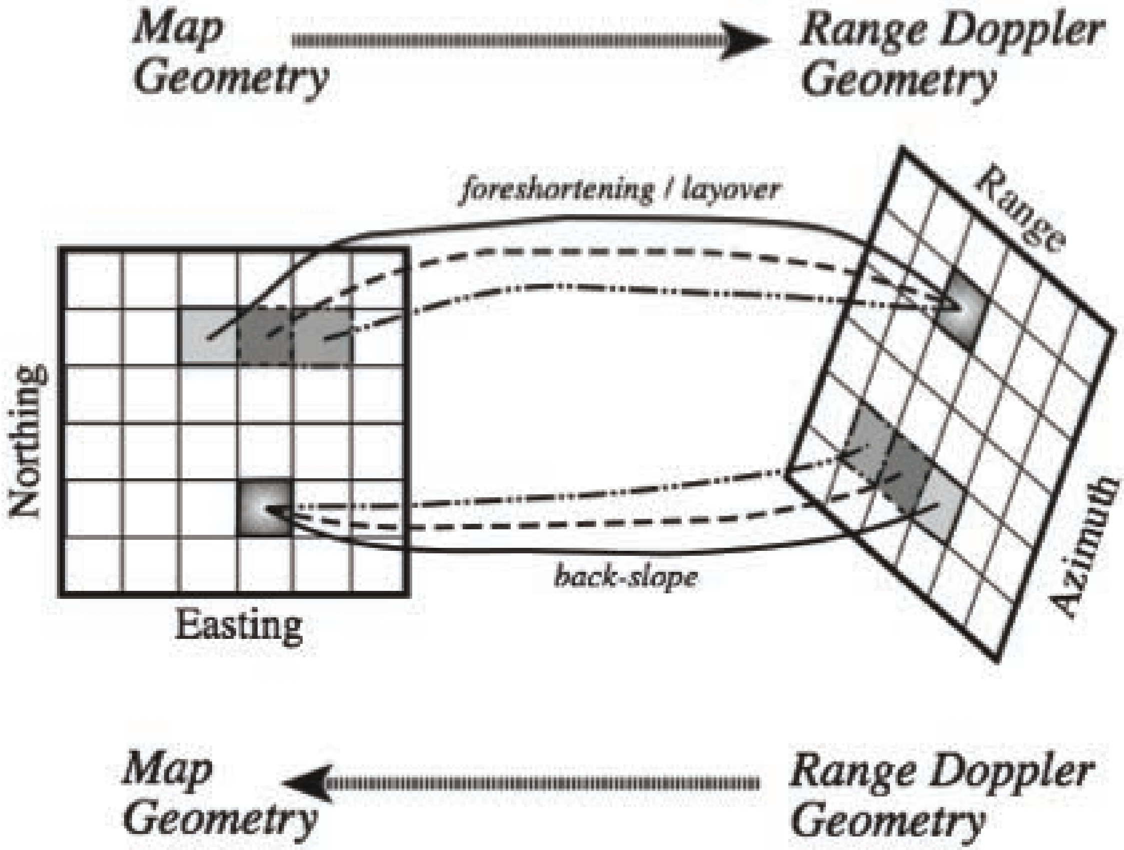
Normalisation for local variation of ground scattering area expressed in map geometry:

$$\sigma_T^0 \triangleq \sigma_{NORLIM}^0 = \sigma_E^0 \cdot \frac{\sin\theta_{LIM}}{\sin\theta_E}$$

e.g. Kellndorfer et al., *TGRS*, Sept. 1998.

Lack of Homomorphism

No one-to-one correspondence between slant range and map geometries on **fore-** and **back**-slopes



Radar Equation & Reference Area

Relating *received* to *transmitted* power:

$$\overline{P}_r = \frac{\lambda^2}{(4\pi)^3} \cdot \int_{\text{area illuminated}} \frac{P_t G^2}{R^4} \cdot \sigma^0 dA$$

Ulaby, Moore, Fung, 1982.

Standard equation of: $\sigma_E^0 = \beta^0 \cdot \sin\theta_E$

uses an ***ellipsoid Earth model*** approximation as a standard normalisation area - using ellipsoidal incidence angle θ_E as a **proxy for area**

- For radiometric terrain correction, we need to actually ***perform the integration*** on a DEM

Time to Leave Kansas!

The concept of a ***single*** *Local Incident Angle* determining the terrain's local normalisation area at a single pixel is **flawed**:

- old concept adapted from ellipsoidal incident angle for ocean, sea-ice, & *flatlands*
- fails to account for:
  - shadow
  - foreshortening
  - layover

Improve sensor model:

use local contributing ***area***, not angle!

and measure that area using the ***gamma*** convention

Radiometric Normalisation Conventions

Convention	1	2	3	4	5
	β^0	σ^0_E	γ^0_E	σ^0_T	γ^0_T
Earth Model	***None***	***Ellipsoid***		***Terrain***	
Reference Area	A_β	$\underline{A}_\sigma$	$\underline{A}_\gamma$	$\hat{A}_\sigma$	A_γ
Area Derivation	$\delta_r \cdot \delta_a$	$\underline{\delta}_g \cdot \delta_a$	$\underline{\delta}_p \cdot \delta_a$	$\delta_g \cdot \delta_a$	$\int_{DHM} \delta_p \cdot \delta_a$
Normalisation	$\beta^0 = \frac{\sigma}{A_\beta}$	$\beta^0 \cdot \frac{A_\beta}{\underline{A}_\sigma} = \beta^0 \cdot \sin\theta_E$	$\beta^0 \cdot \frac{A_\beta}{\underline{A}_\gamma} = \beta^0 \cdot \tan\theta_E$	$\sigma^0_E \cdot \frac{\hat{A}_\sigma}{A_\beta} = \sigma^0_E \cdot \frac{\sin\theta_{LIM}}{\sin\theta_E}$	$\frac{\beta^0 \cdot A_\beta}{A_\gamma}$
Product	***GTC***			***NORLIM***	***RTC***

Sentinel-1 Acquisition Modes

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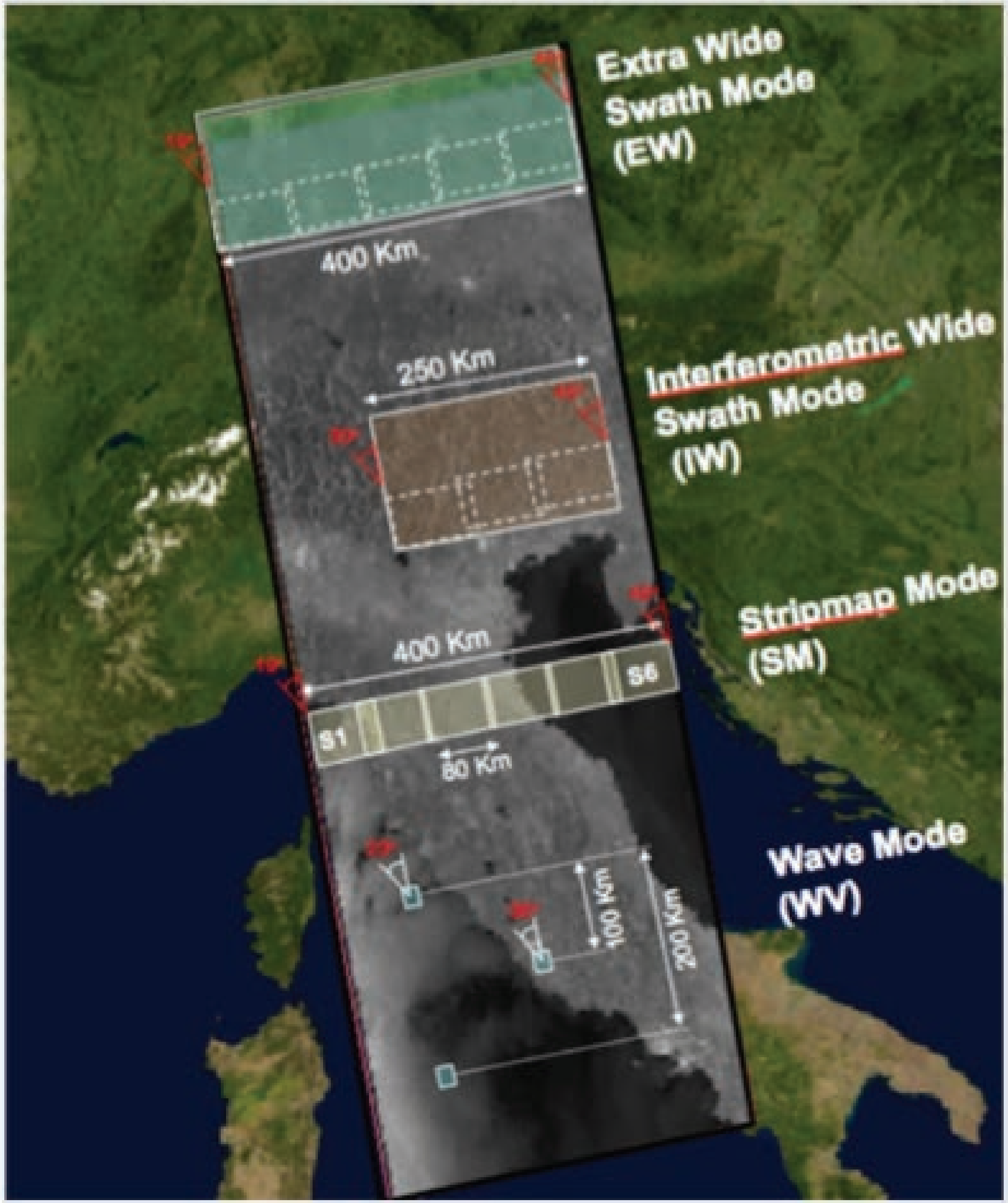

IW is main acquisition mode over land (>80%)

https://sentinel.esa.int/web/sentinel/user-guides/sentinel-1-sar/revisit-and-coverage

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Terrain-flattened Gamma Nought

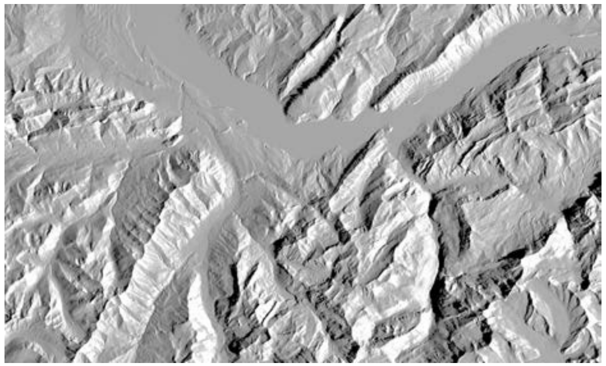
Interlaken, Switzerland
Sentinel-1A IW GRDH VH-pol.
May 26, 2015

Terrain-flattening: Small D. *Flattening Gamma: Radiometric Terrain Correction for SAR Imagery*, IEEE Trans. on Geoscience & Remote Sensing, 49(8), Aug. 2011, pp. 3081-3093.

Normalise β^0 **:** divide by simulated image

β^0 GTC

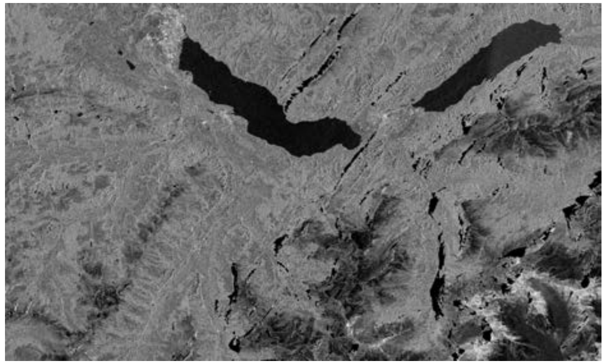
/



A_γ / A_β

-26dB -1dB

γ_T^0 =



RTC

$$\gamma_T^0 = \beta^0 \cdot \frac{A_\beta}{A_\gamma}$$

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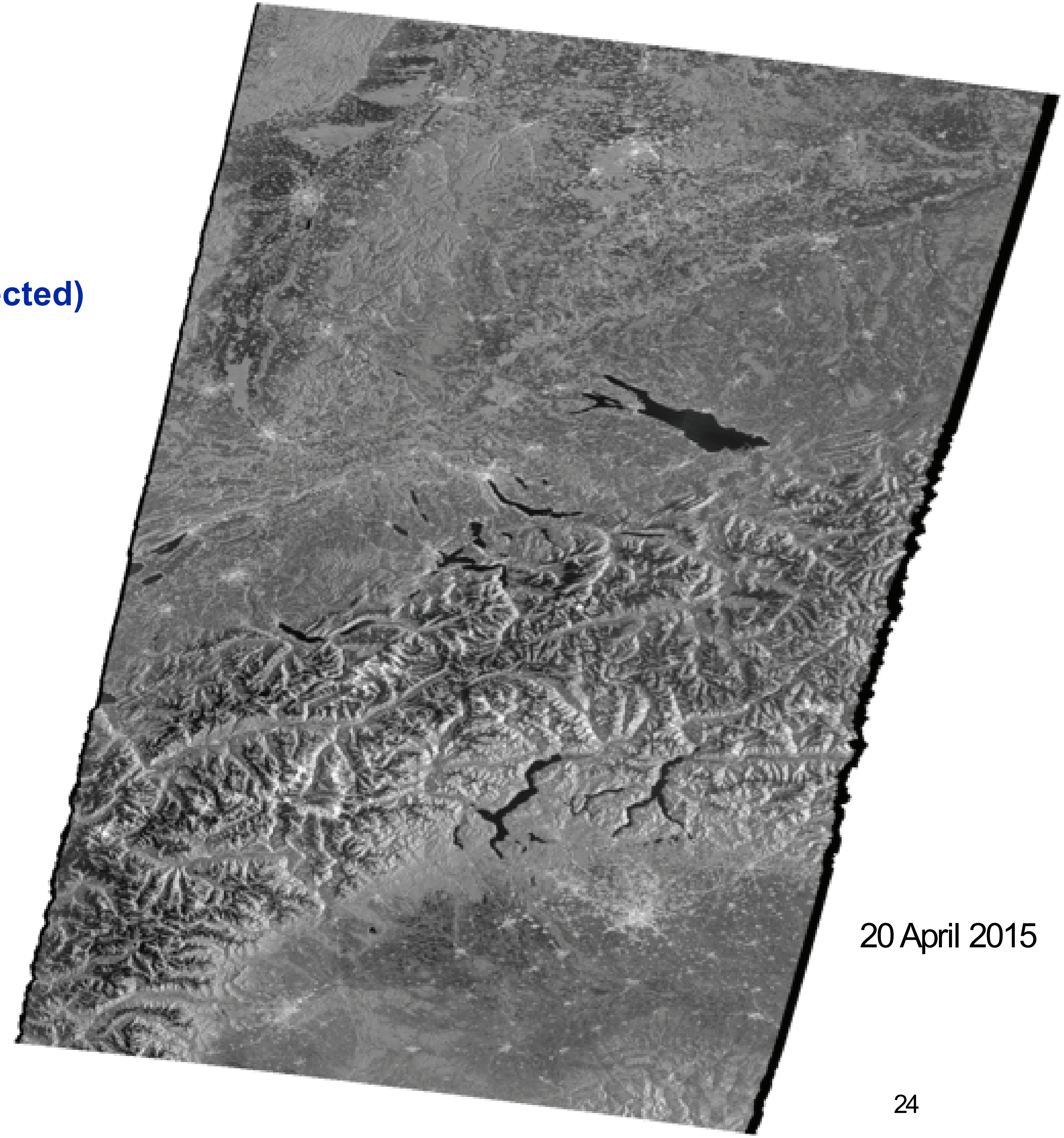
Sentinel-1A: GTC
(Geometrically Terrain Corrected)

$$\gamma_E^0$$

-26dB -1dB

Generated automatically from 3 IW GRDH products using SRTM3

Copernicus Sentinel data (2015)



20 April 2015

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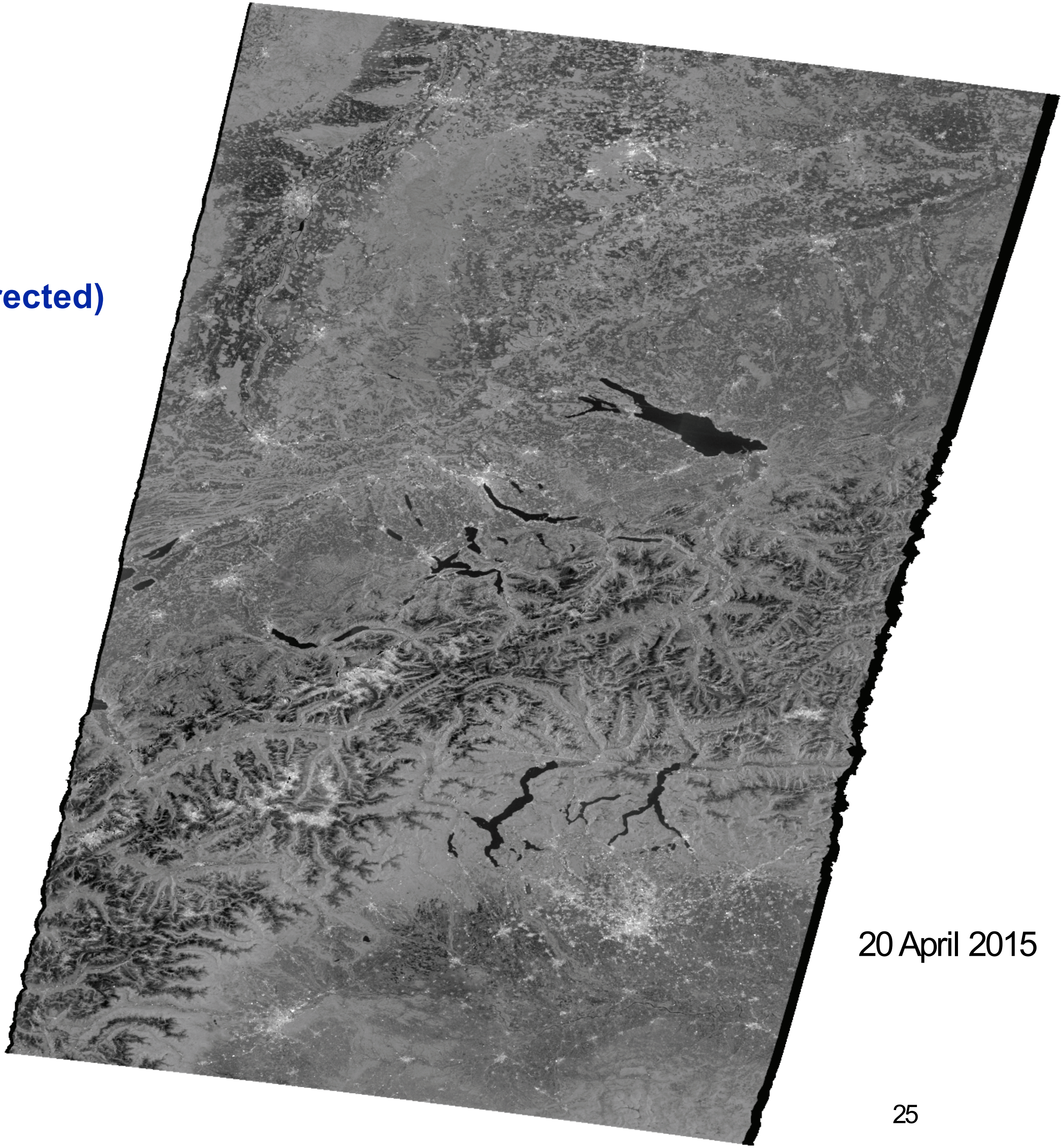
Sentinel-1A: RTC
(Radiometrically Terrain Corrected)

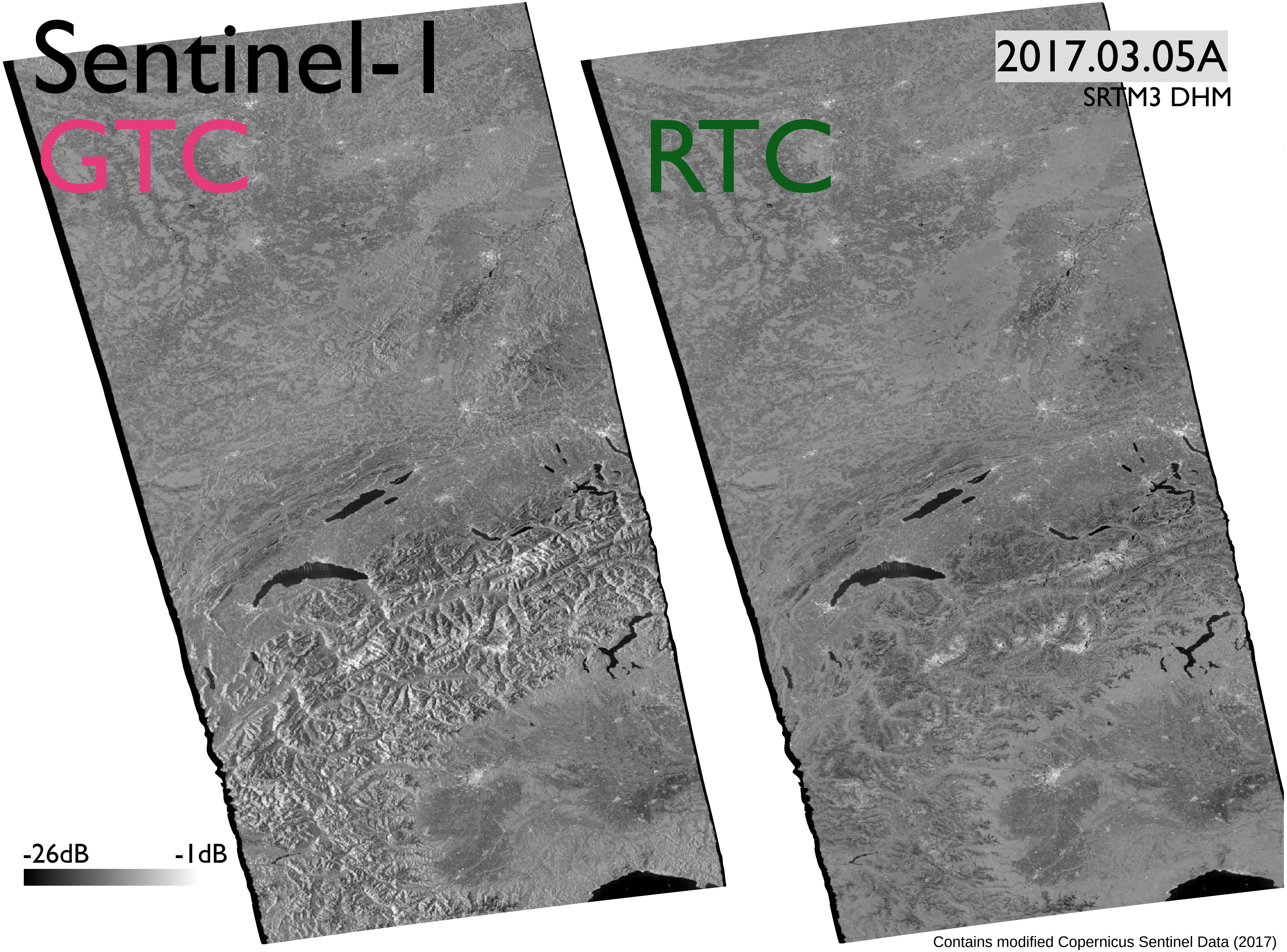
$$\gamma_T^0$$

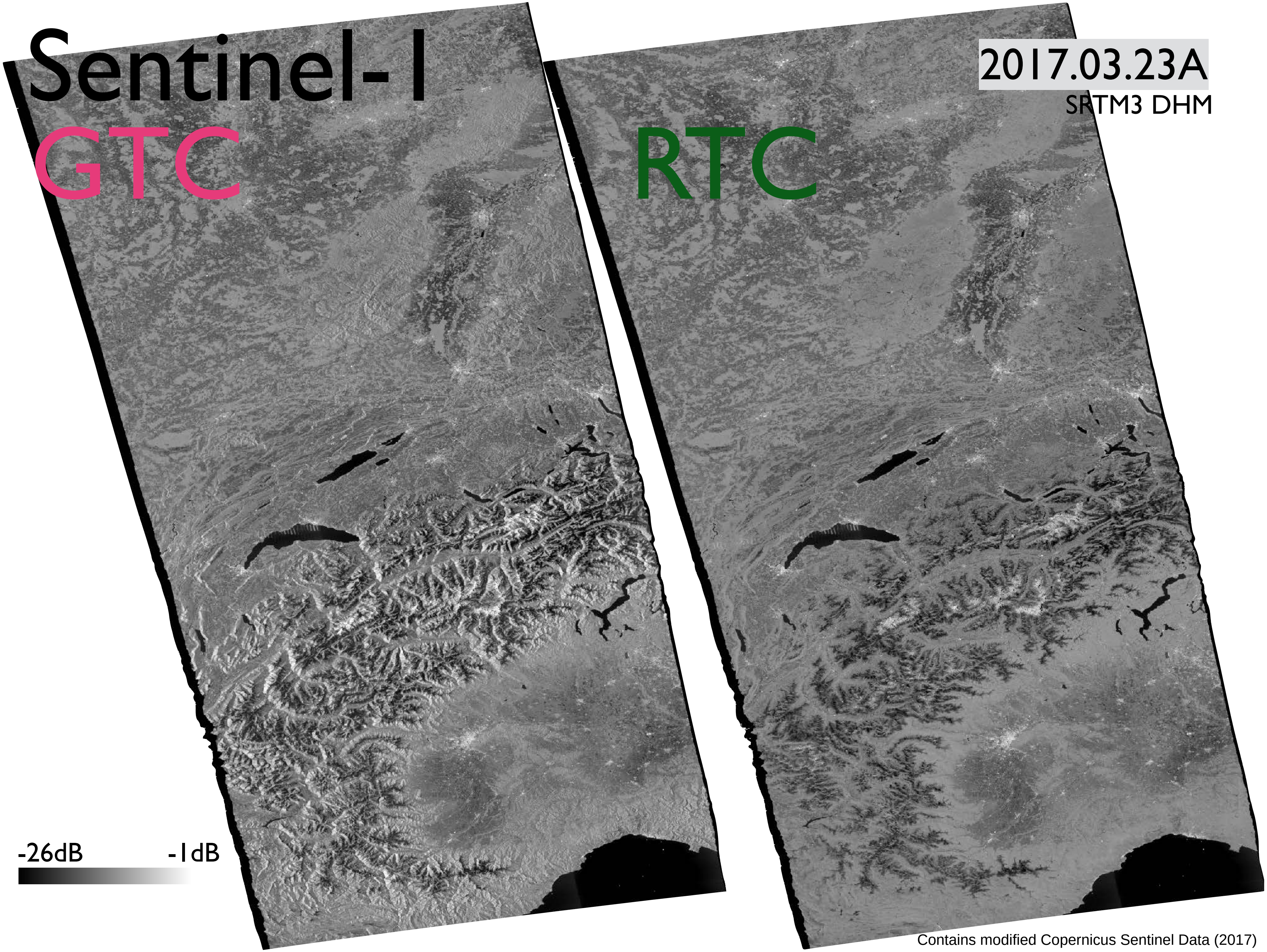
-26dB -1dB

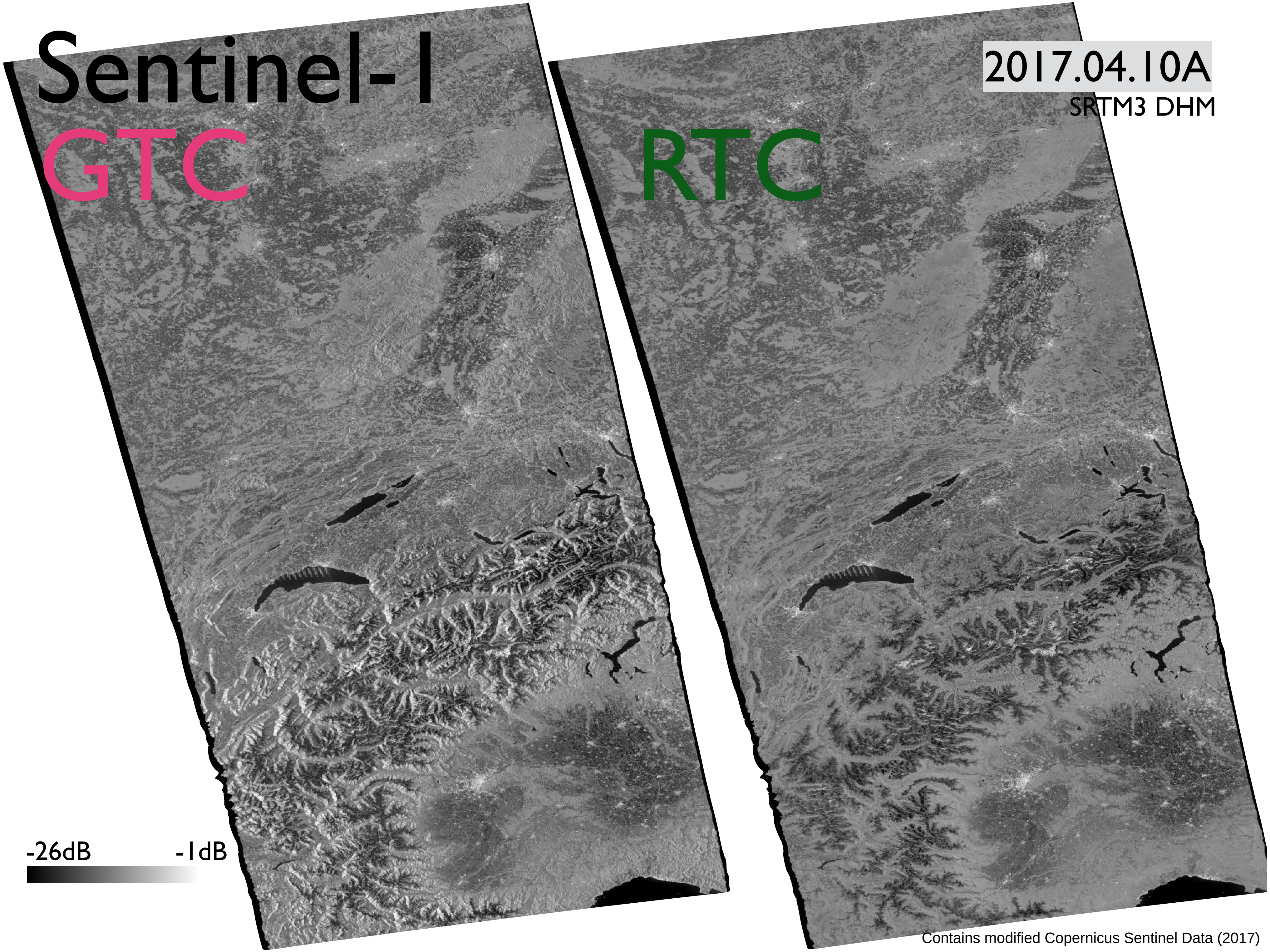


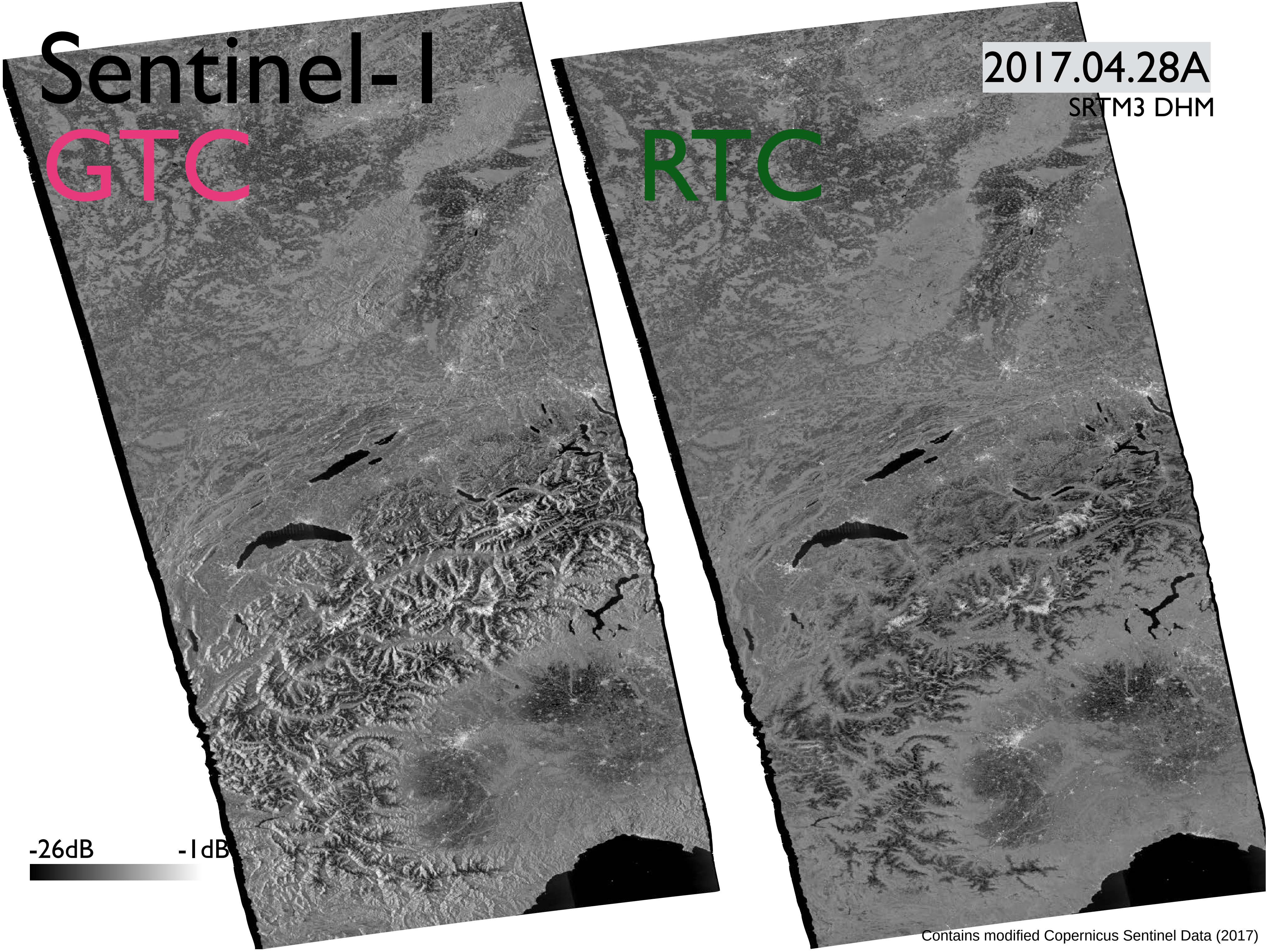
Generated automatically from 3 IW GRDH products using SRTM3

20 April 2015


Sentinel-1
GTC
RTC
2017.03.05A
SRTM3 DHM
-26dB
-1dB


Sentinel-1
GTC
RTC
2017.03.23A
SRTM3 DHM
-26dB
-1dB
Contains modified Copernicus Sentinel Data (2017)


Sentinel-1
GTC
RTC
2017.04.10A
SRTM3 DHM
-26dB
-1dB
Contains modified Copernicus Sentinel Data (2017)



Sentinel-1
GTC
RTC
2017.04.28A
SRTM3 DHM
-26dB
-1dB
Contains modified Copernicus Sentinel Data (2017)

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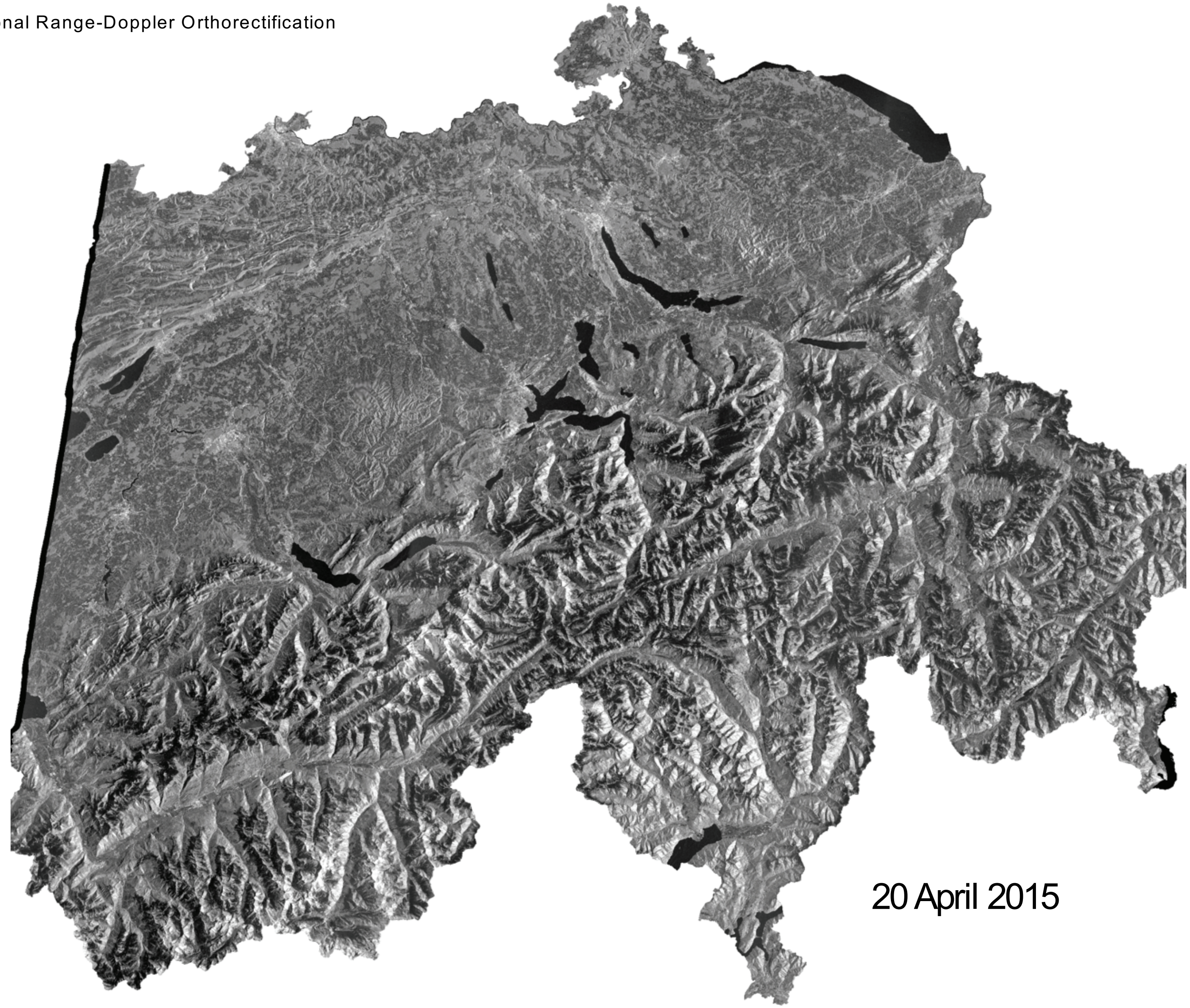
Sentinel-1A: GTC
(Geometrically Terrain Corrected)

Conventional Range-Doppler Orthorectification

Switzerland

γ_E^0 VH-pol.

-26dB -1dB



Generated from
3 IW GRDH products using
SwissALTI3D DEM (10m)

Copernicus Sentinel data
(2015)

20 April 2015

University of Zurich UZH

Sentinel-1A: RTC
(Radiometrically Terrain Corrected)

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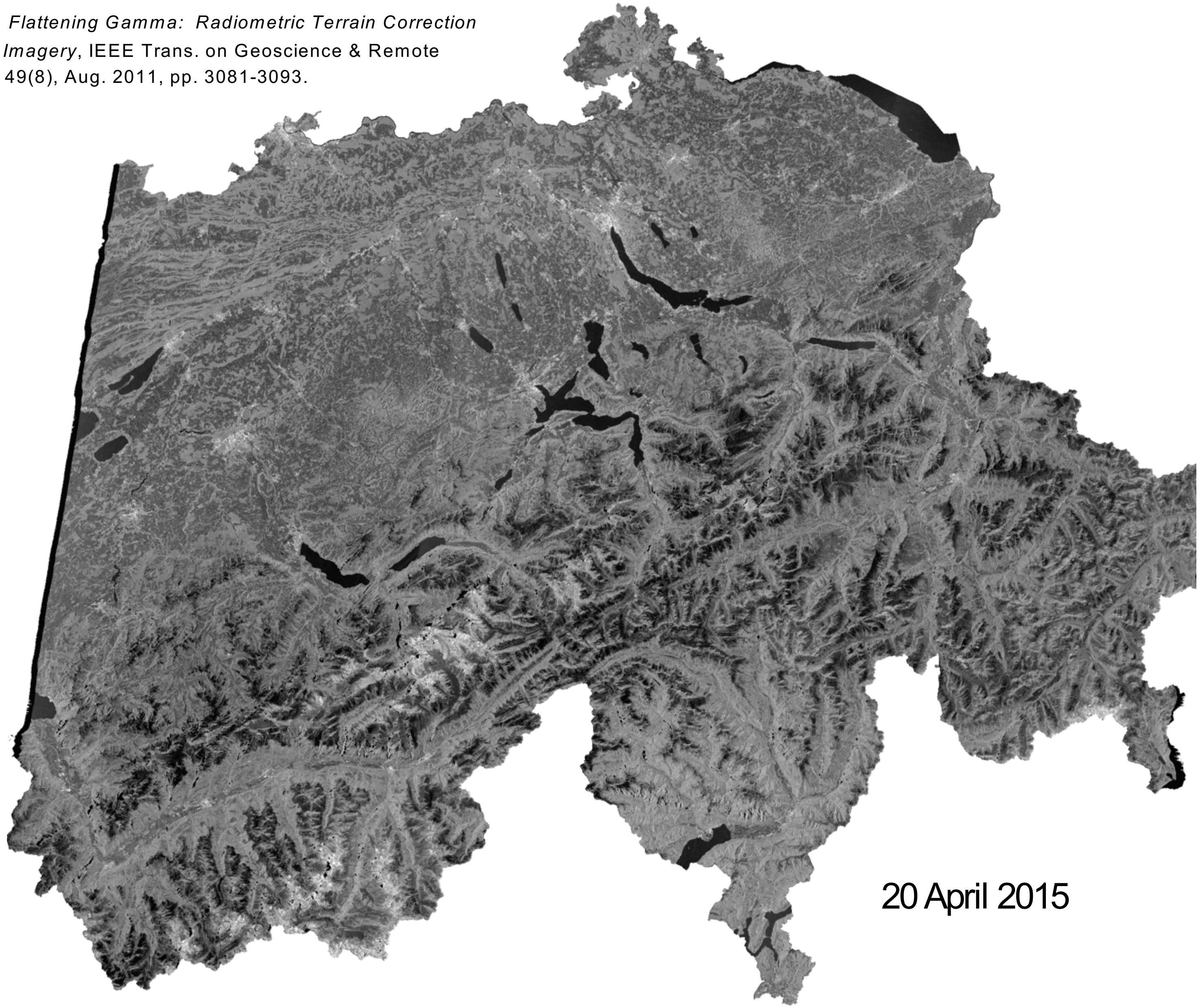
Small D. *Flattening Gamma: Radiometric Terrain Correction for SAR Imagery*, IEEE Trans. on Geoscience & Remote Sensing, 49(8), Aug. 2011, pp. 3081-3093.

Switzerland

γ_T^0 VH-pol.

-26dB -1dB



Generated from 3 IW GRDH products using SwissALTI3D DEM (10m)

Contains modified Copernicus Sentinel data (2015)

20 April 2015

Wet snow detection with dB thresholding

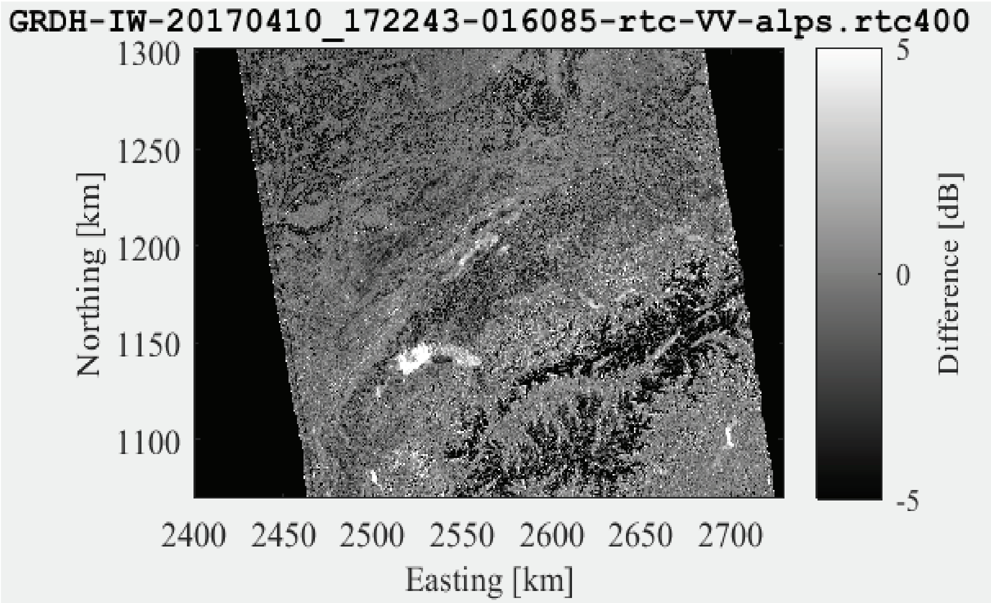
$$\Delta\gamma^0 = (\gamma^0_{wet} - \gamma^0_{ref}) \ [\mathrm{dB}]$$

When difference between candidate image backscatter and dry reference image is lower than a set threshold (e.g. -2 or -3dB), classify as wet snow

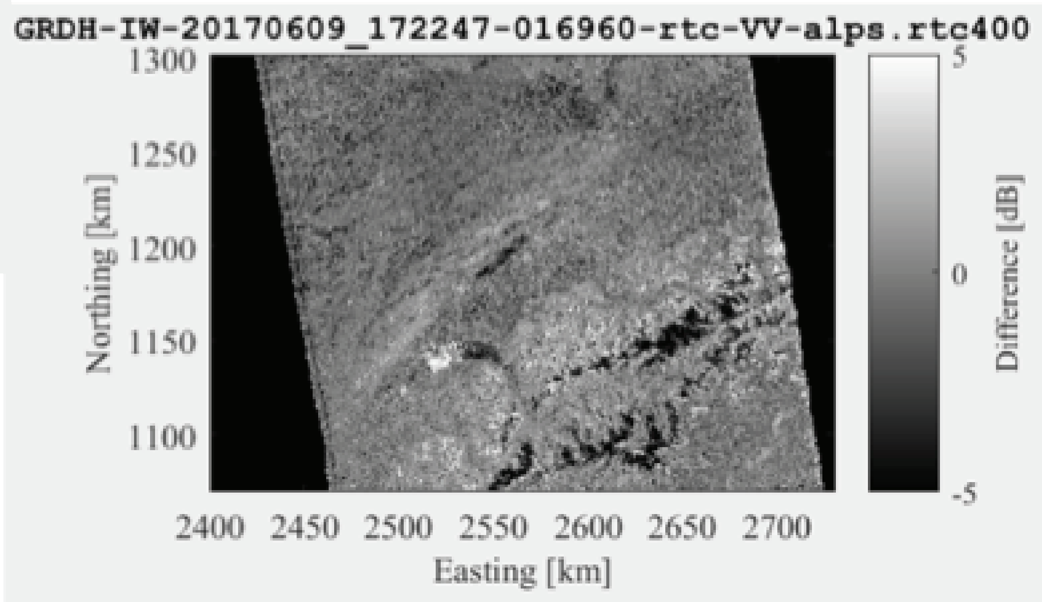
Relies on **exact repeat tracks** (e.g. 35-day ERS/ENVISAT or 24-day Radarsat-2 repeat) to avoid corruption e.g. by terrain-induced effects

Single-track (same rel. orbit) dB Differences: Apr-Mar vs. June-Mar

Apr



June



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Considerations when using a single track

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Single track/relative orbit	Advantages	Disadvantages
Response time	Quick (time-tag of single acquisition)	
Sensitivity to terrain normalization method	Low, as terrain is distorted similarly in all acquisitions from single-track	
Completeness		Shadow regions unobserved Foreshortened/layover regions observed with extremely poor local resolution
Adaptability to multiple modes/sensors		Poor: tied to individual tracks and acquisition modes & exact repeats
Consistency of reference images		Inconsistent: Reference images must be calculated separately for each relative orbit and acquisition mode

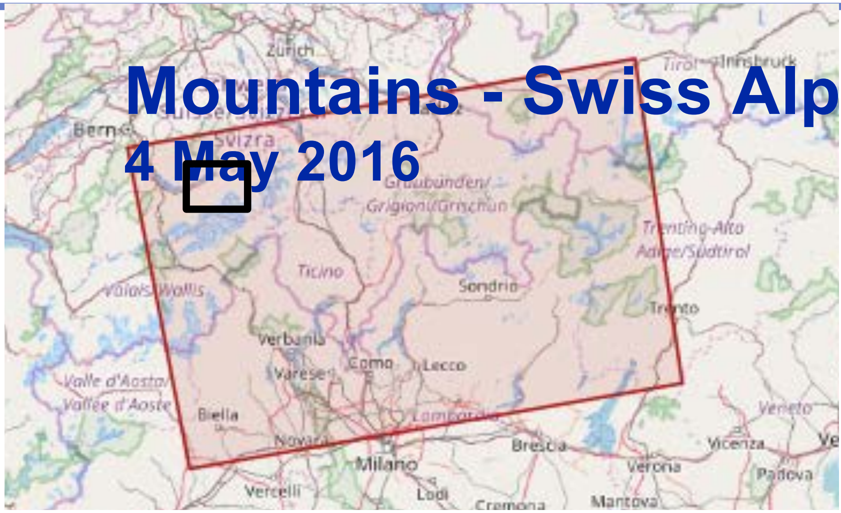
SEOM S1-4SCI SNOW

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

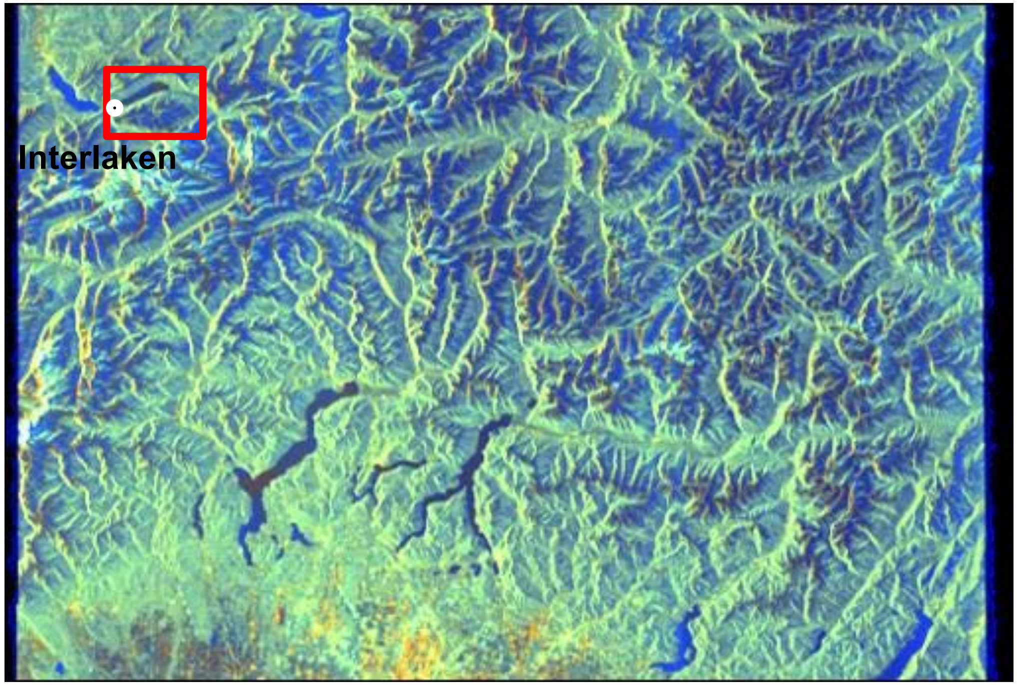
ROUND ROBIN EXPERIMENTS

enveo
FMI
Universität Zürich[UZH]
SYKE
norut NORTHERN RESEARCH INSTITUTE

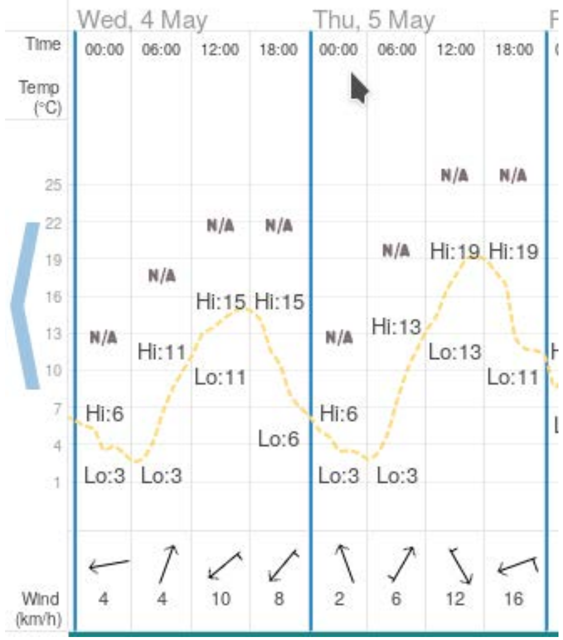
Mountains - Swiss Alps
4 May 2016



Sensor	Date
S1A (ASC)	2016-05-04T17:14:49.665Z – 2016-05-04T17:15:14.665Z
S2A (DESC)	2016-05-05T10:30:27.000Z



Interlaken 566 m.s.l.



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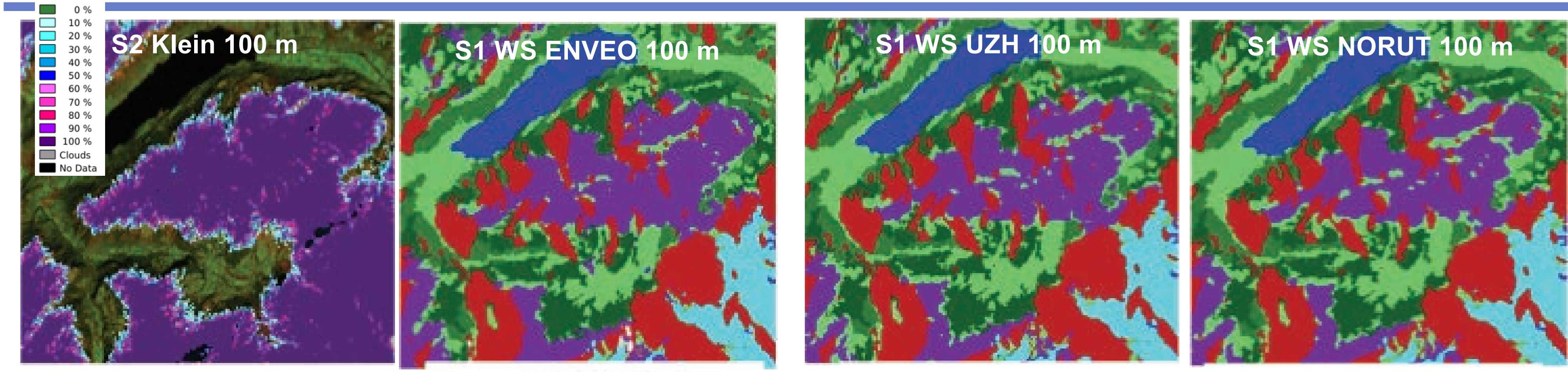
Mountains - Swiss Alps
4 May 2016



VALIDATION

KLEIN THR ≥ 90 %

SAR Wet Sow Map Enveo — Accuracy 91.56

OPT Snow Map KLEIN ≥ 90	SNOW	SNOW FREE
SNOW	TPR 92.18	FNR 7.82
SNOW FREE	FPR 9.21	TNR 90.79

SAR Wet Sow Map UZH — Accuracy 89.85

OPT Snow Map KLEIN ≥ 90	SNOW	SNOW FREE
SNOW	TPR 86.52	FNR 13.48
SNOW FREE	FPR 6.03	TNR 93.97

SAR Wet Sow Map Norut — Accuracy 87.82

OPT Snow Map KLEIN ≥ 90	SNOW	SNOW FREE
SNOW	TPR 81.91	FNR 18.09
SNOW FREE	FPR 4.85	TNR 95.15

SALOMONSON THR ≥ 90 %

SAR Wet Sow Map Enveo — Accuracy 91.18

OPT Snow Map SALOMONSON ≥ 90	SNOW	SNOW FREE
SNOW	TPR 93.45	FNR 6.55
SNOW FREE	FPR 11.41	TNR 88.59

SAR Wet Sow Map UZH — Accuracy 90.27

OPT Snow Map SALOMONSON ≥ 90	SNOW	SNOW FREE
SNOW	TPR 88.33	FNR 11.67
SNOW FREE	FPR 7.51	TNR 92.49

SAR Wet Sow Map Norut — Accuracy 88.39

OPT Snow Map SALOMONSON ≥ 90	SNOW	SNOW FREE
SNOW	TPR 83.67	FNR 16.33
SNOW FREE	FPR 6.23	TNR 93.77

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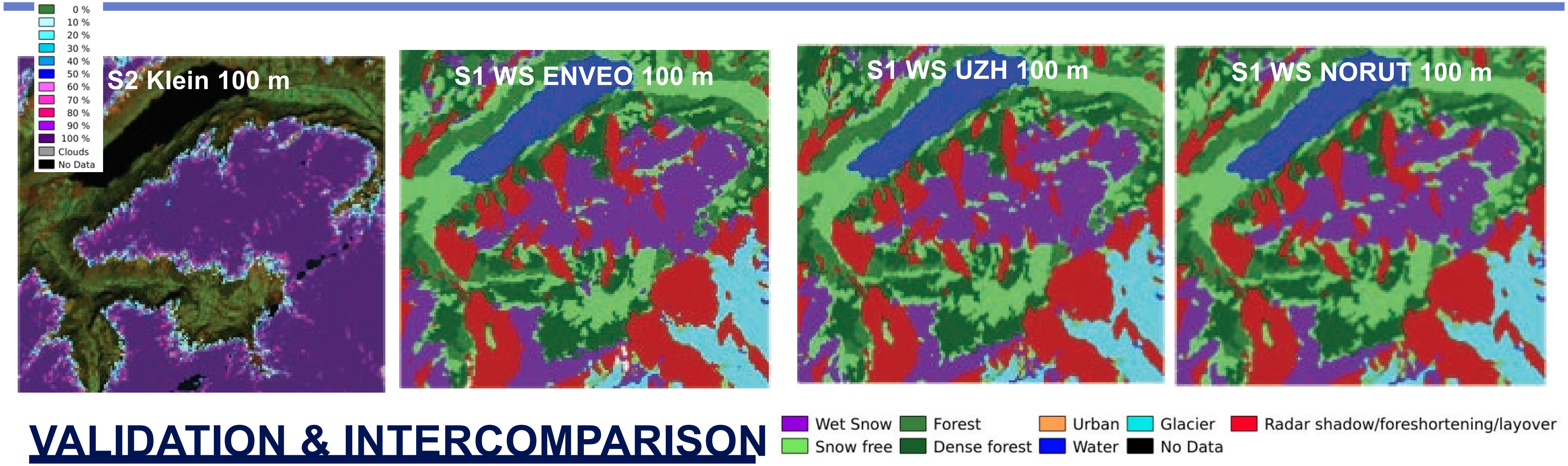
Mountains - Swiss Alps

4 May 2016



VALIDATION & INTERCOMPARISON

ACCURACY OPT ≥ 75%		S1 WS maps		
		ENVEO	UZH	NORUT
S2 OPT	Klein	92.17	89.90	87.55
	Salomonson	92.46	90.36	88.16
S1 WS maps	ENVEO		91.61	89.41
	UZH			92.97
	NORUT			

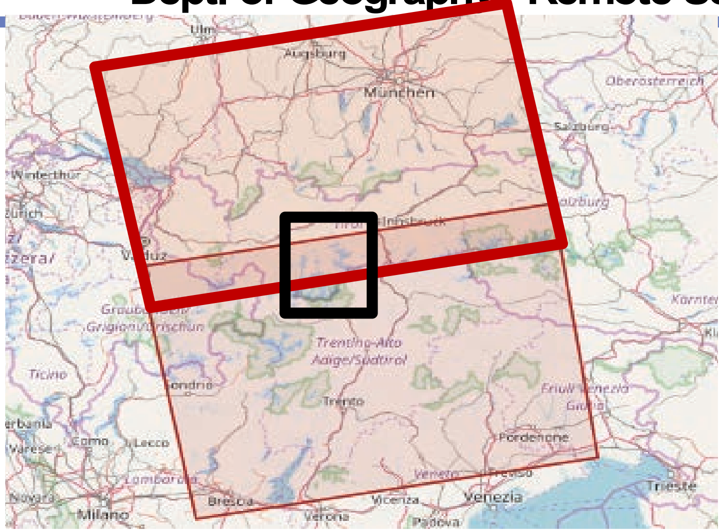
ACCURACY OPT ≥ 90%		S1 WS maps		
		ENVEO	UZH	NORUT
S2 OPT	Klein	91.56	89.85	87.82
	Salomonson	91.18	90.27	88.39
S1 WS maps	ENVEO		91.61	89.41
	UZH			92.97
	NORUT			

ACCURACY OPT = 100 %		S1 WS maps		
		ENVEO	UZH	NORUT
S2 OPT	Klein	90.03	89.17	87.56
	Salomonson	83.25	85.38	84.75
S1 WS maps	ENVEO		91.61	89.41
	UZH			92.97
	NORUT			

units in %

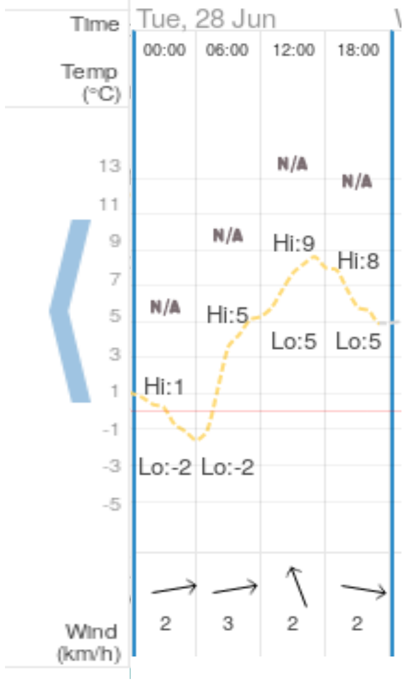
University of Zurich[UZH]
Dept. of Geography / Remote Sensing Laboratories

Mountains – Ötztaler Alps, Austria
28 June 2016



Sensor	Date
S1A (ASC)	2016-06-28T17:06:39.235Z – 2016-06-28T17:07:06.206Z & 2016-06-28T17:07:04.058Z – 2016-06-28T17:07:31.033Z
S2A (DESC)	2016-06-28T10:10:26.000Z

Obergurgl 1907 m.s.l.



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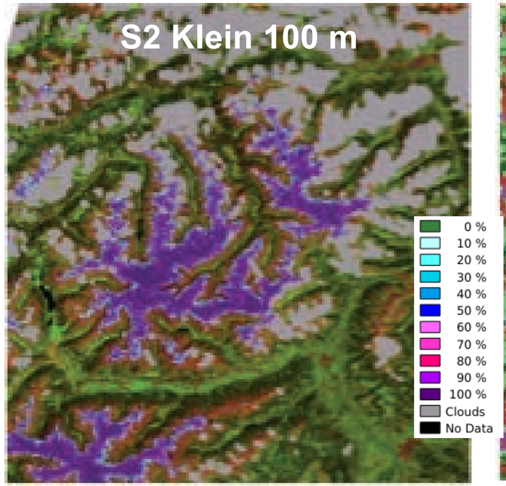
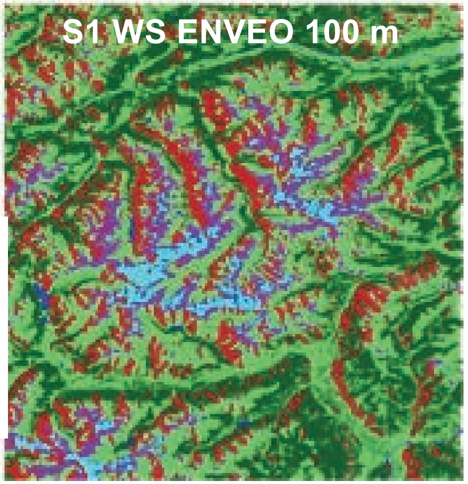
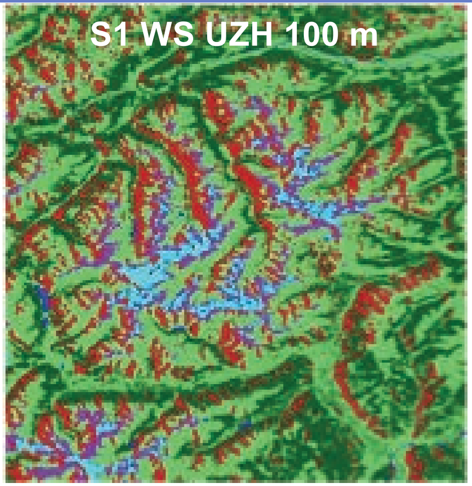
Mountains – Ötztaler Alps, Austria

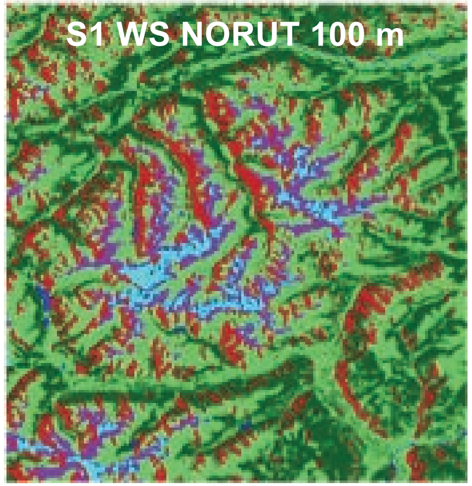
28 June 2016

Wet Snow | Forest | Urban | Glacier | Radar shadow/foreshortening/layover
Snow free | Dense forest | Water | No Data









VALIDATION

KLEIN THR ≥ 90 %

SAR Wet Sow Map Enveo — Accuracy 91.48

OPT Snow Map KLEIN ≥ 90	SNOW	SNOW FREE
SNOW	TPR 89.47	FNR 10.53
SNOW FREE	FPR 8.37	TNR 91.63

SAR Wet Sow Map UZH — Accuracy 94.77

OPT Snow Map KLEIN ≥ 90	SNOW	SNOW FREE
SNOW	TPR 85.32	FNR 14.68
SNOW FREE	FPR 4.55	TNR 95.45

SAR Wet Sow Map Norut — Accuracy 93.33

OPT Snow Map KLEIN ≥ 90	SNOW	SNOW FREE
SNOW	TPR 92.50	FNR 7.50
SNOW FREE	FPR 6.61	TNR 93.39

SALOMONSON THR ≥ 90 %

SAR Wet Sow Map Enveo — Accuracy 91.35

OPT Snow Map SALOMONSON ≥ 90	SNOW	SNOW FREE
SNOW	TPR 90.40	FNR 9.60
SNOW FREE	FPR 8.58	TNR 91.42

SAR Wet Sow Map UZH — Accuracy 94.72

OPT Snow Map SALOMONSON ≥ 90	SNOW	SNOW FREE
SNOW	TPR 86.66	FNR 13.34
SNOW FREE	FPR 4.74	TNR 95.26

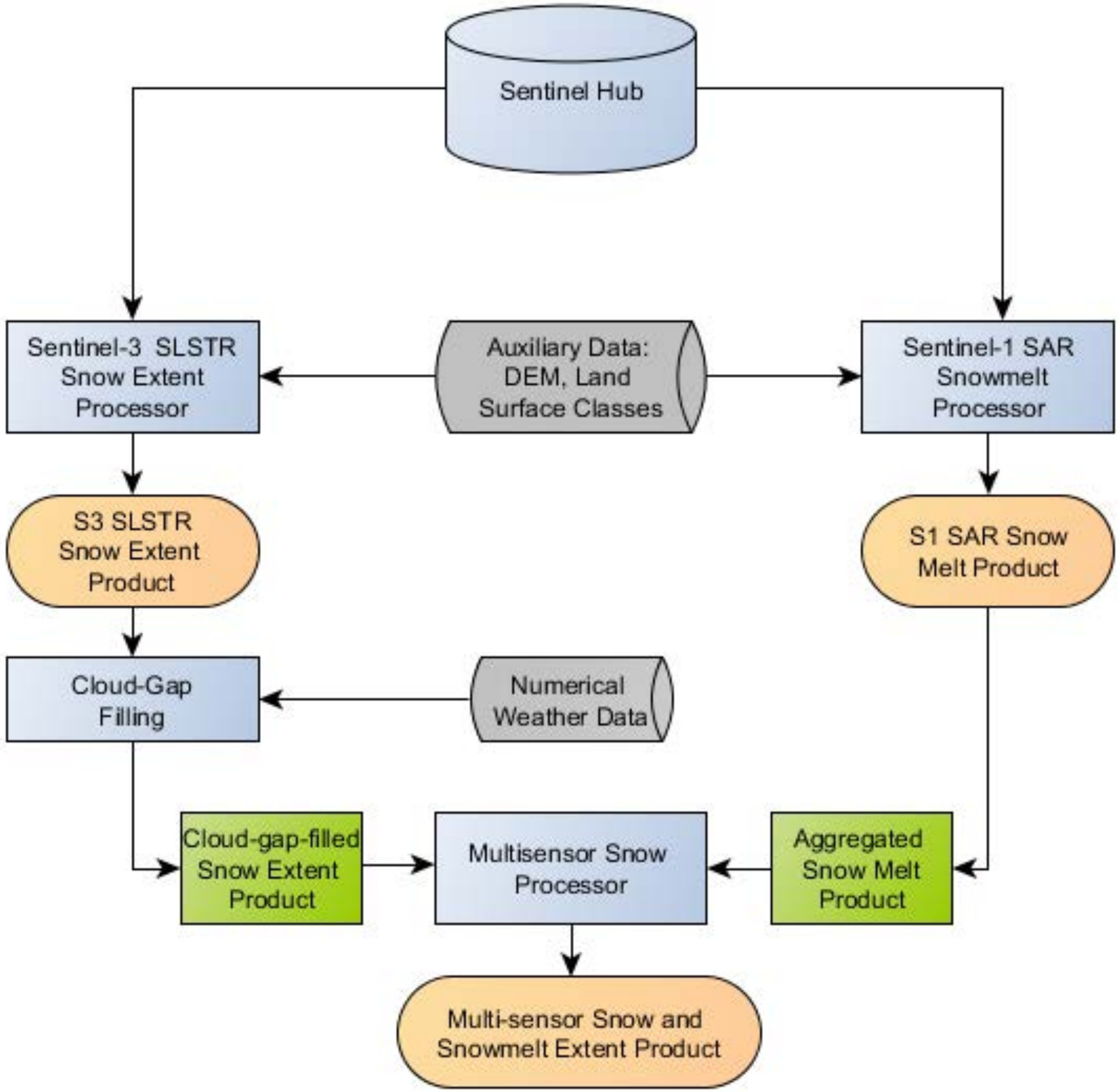
SAR Wet Sow Map Norut — Accuracy 93.17

OPT Snow Map SALOMONSON ≥ 90	SNOW	SNOW FREE
SNOW	TPR 93.31	FNR 6.69
SNOW FREE	FPR 6.84	TNR 93.16

Concept for Pan-European Wet Snow Product

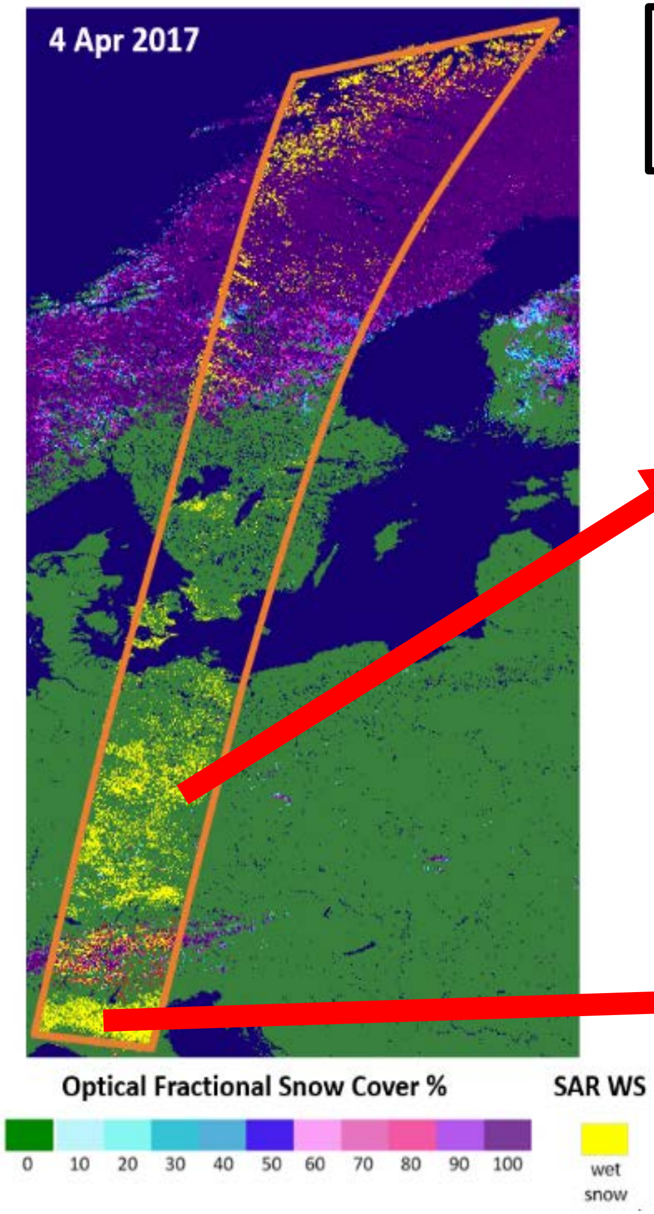
Modules for

- SAR Snowmelt Detection
- Optical Snow Mapping
- Cloud Clearing
- Multi-Sensor Snow processor



Track range – Pan European

Towards a MultiSensor Snow and Melt Extent product from Copernicus Satellite Data for the Pan-European Domain



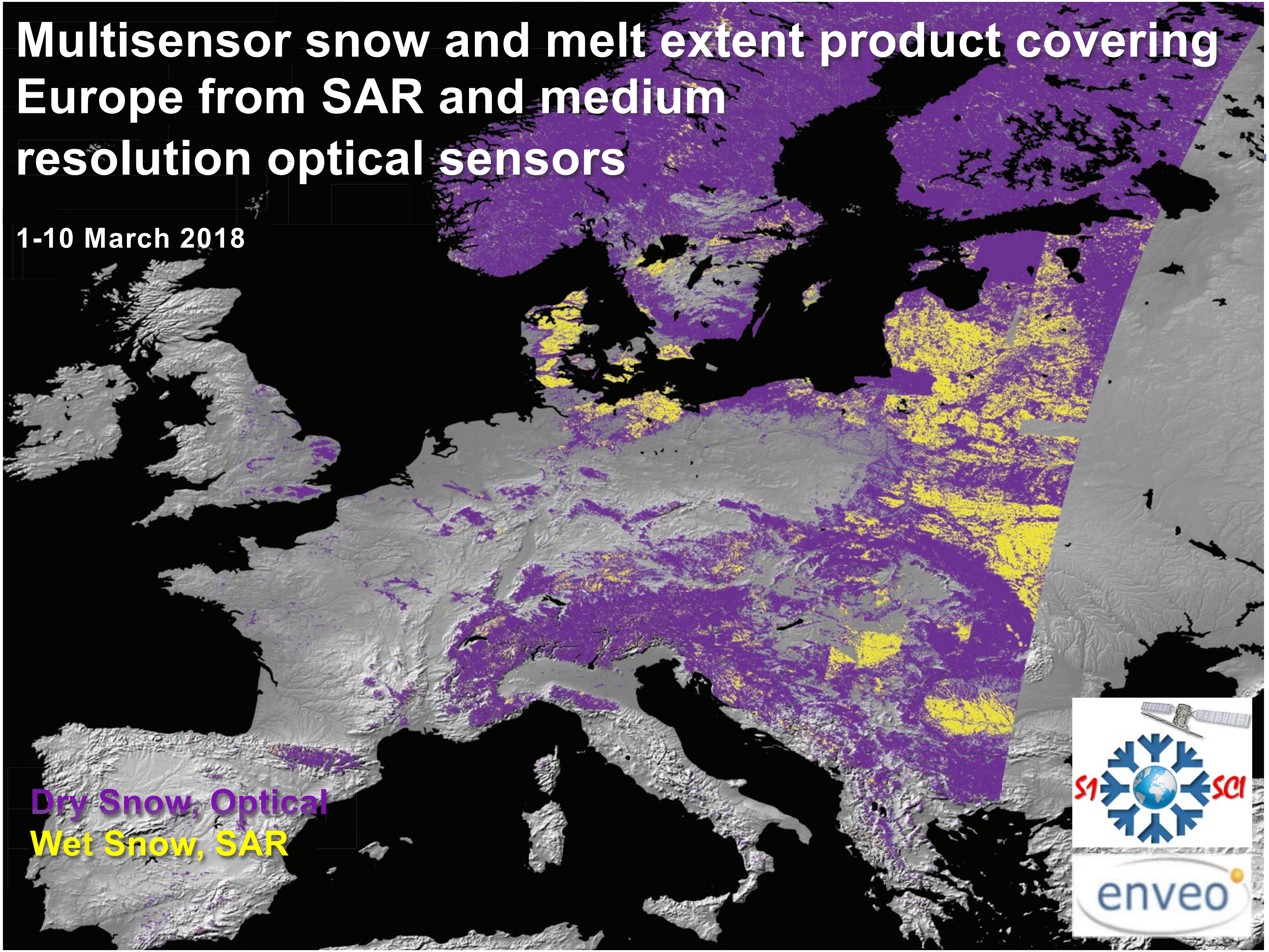
Problem: misclassification of snowmelt due to changes of backscatter caused by agricultural activities affecting especially long datatakes covering different environments and climate zones.

Agricultural fields Central Europe

Agricultural fields Po Valley

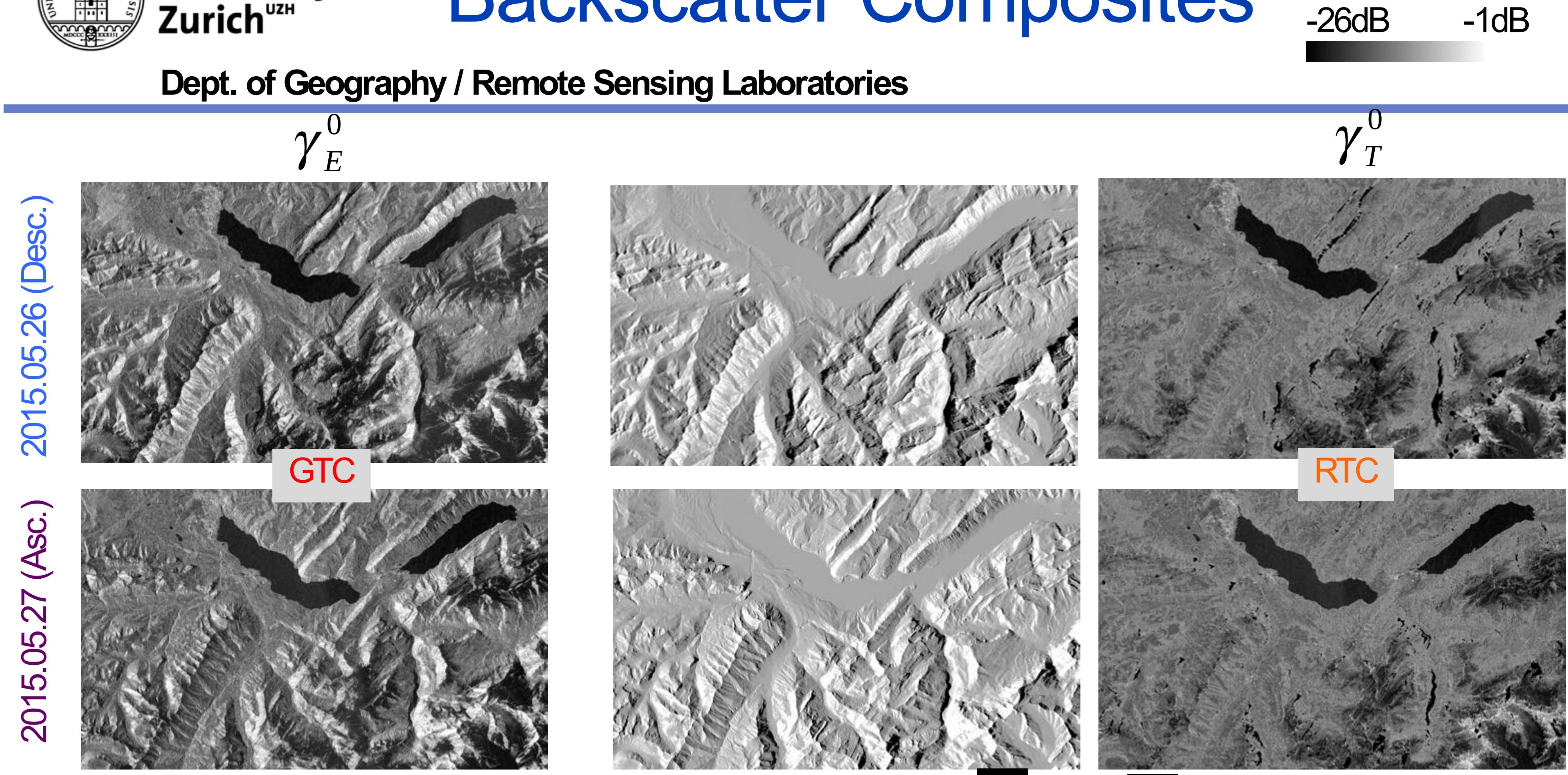
Multisensor snow and melt extent product covering Europe from SAR and medium resolution optical sensors

1-10 March 2018



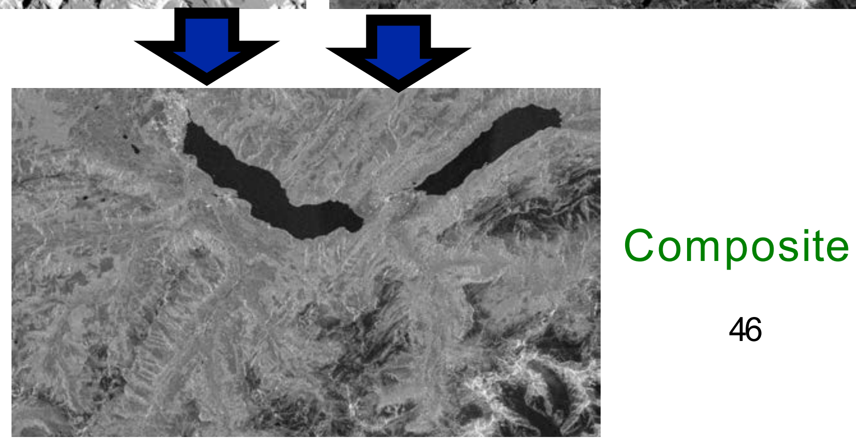
Wide area backscatter composites with local resolution weighting (LRW)

Backscatter Composites



- Combine asc. & desc. observations to generate **composite** with improved local resolution
- Less shadow than single RTC, lower noise

Interlaken, Switzerland



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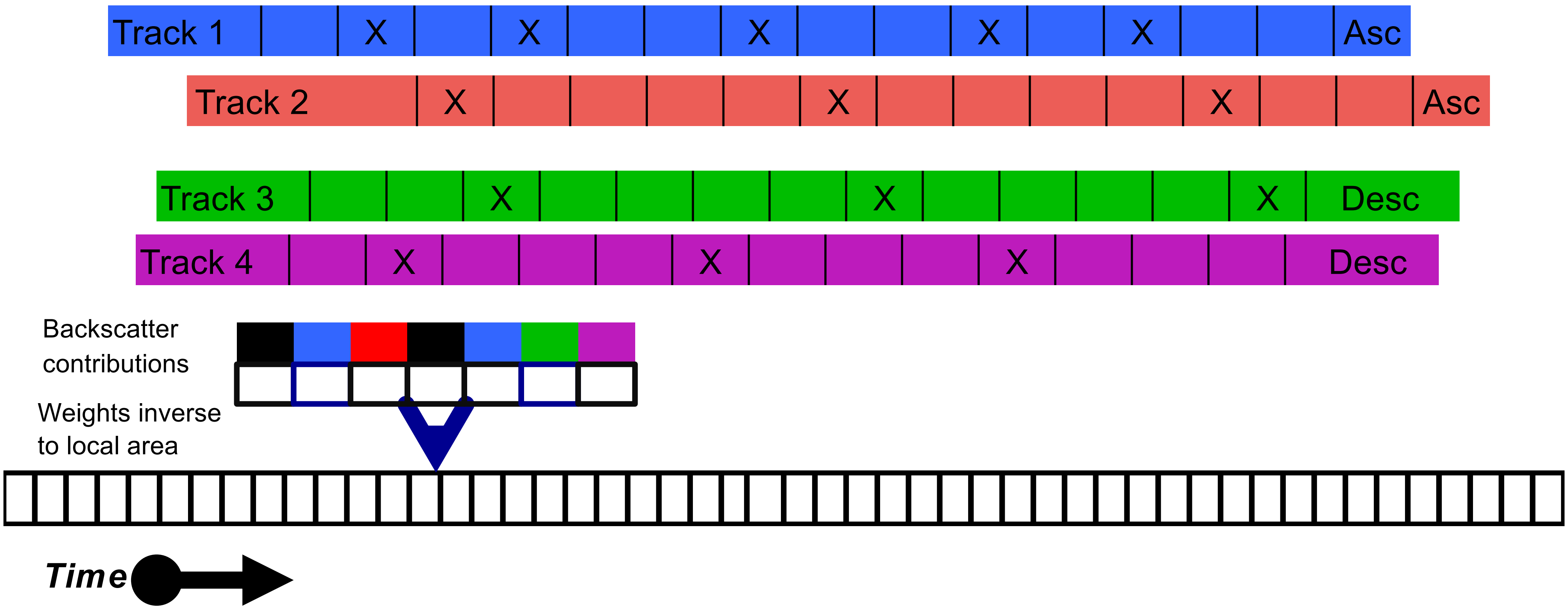
Revisit Interval: Breaking the tyranny of exact repeat passes



For *Regular Intervals* with temporal resolution better than repeat-pass interval

- Use moving time-window integrating information from all tracks
- The more (diverse!) data (and tracks) the better – esp. combine ascending and descending observations

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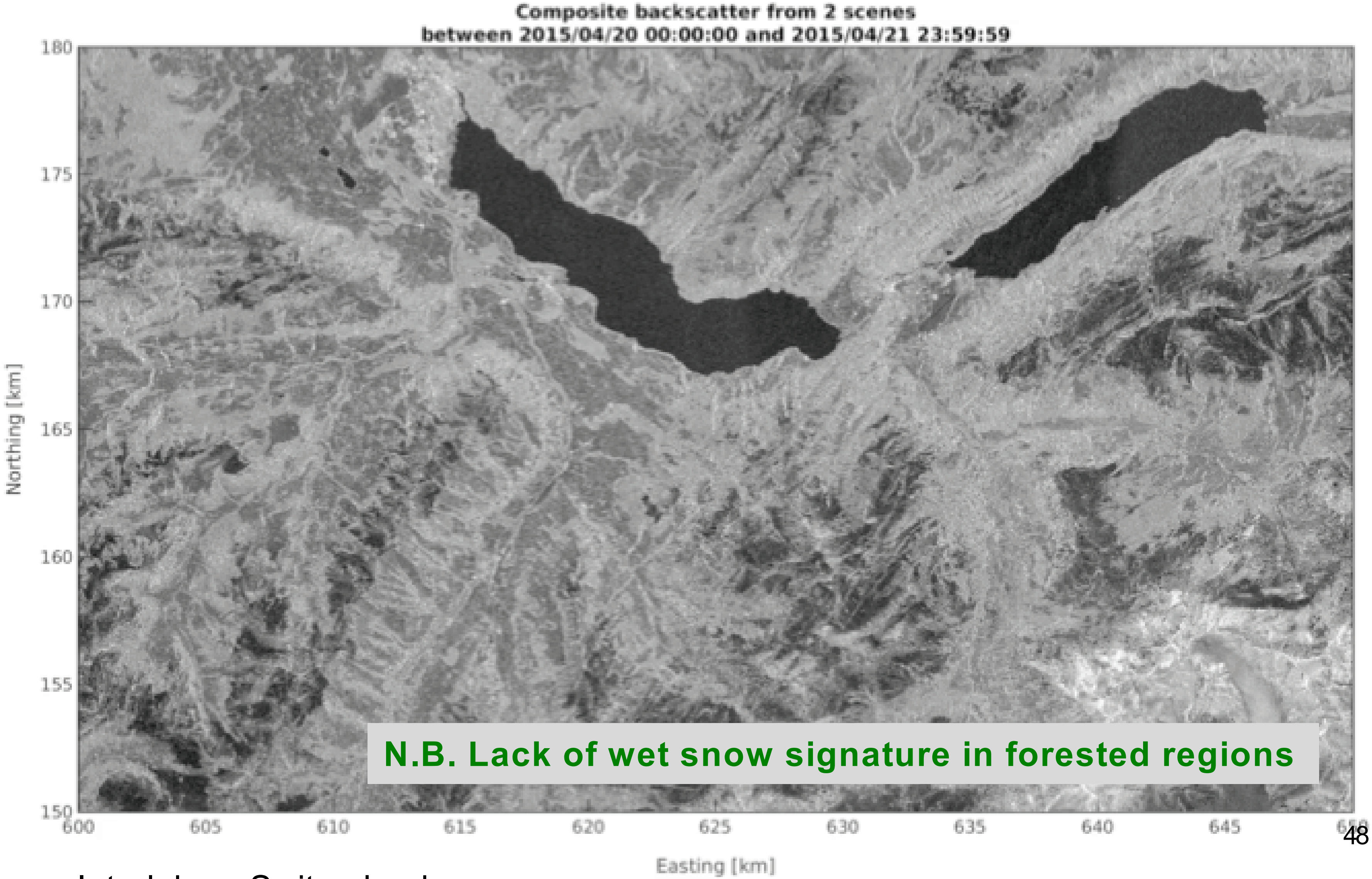
Composites in Time Series Movie

-26dB -1dB

Jan – May 2015



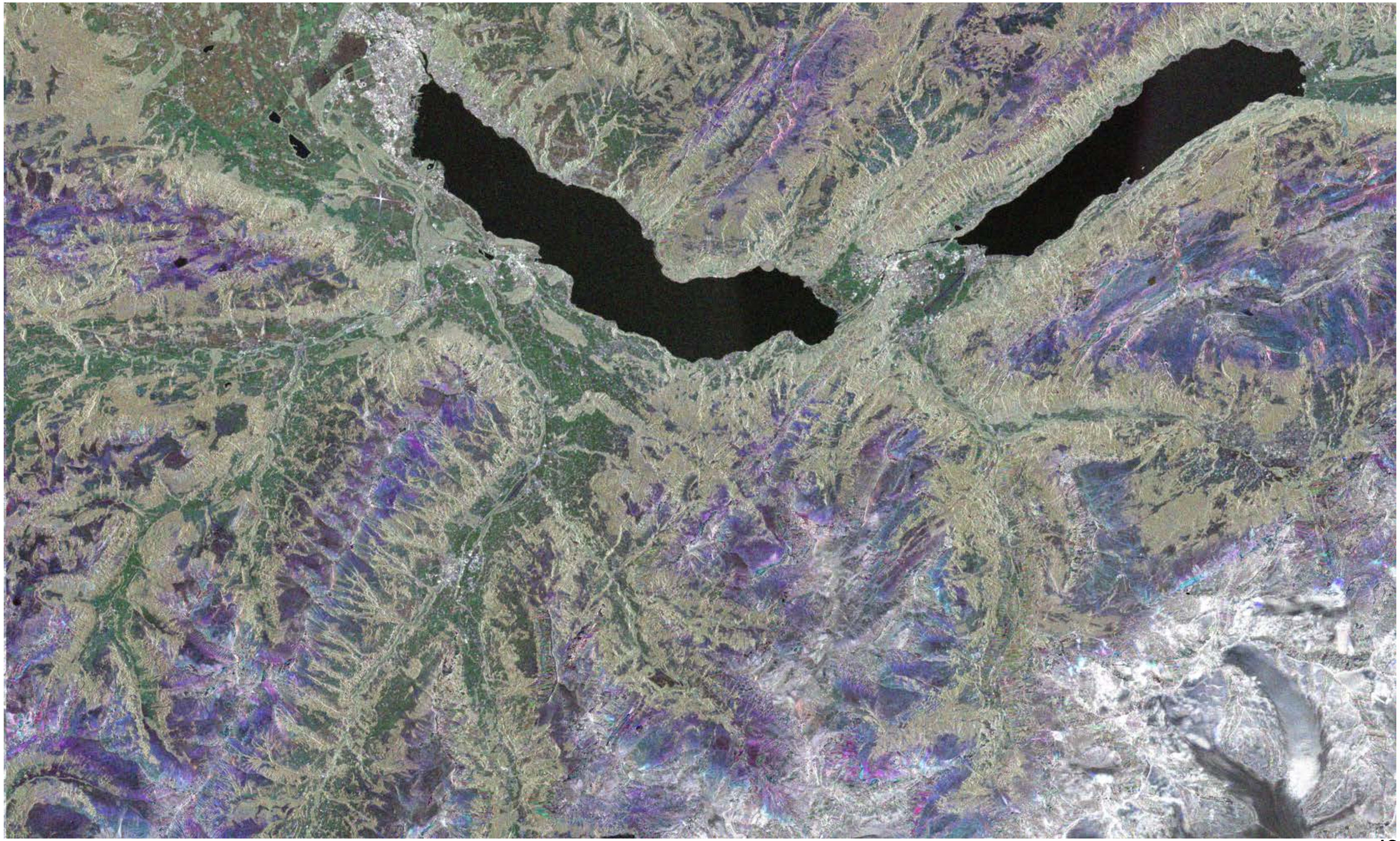
Interlaken, Switzerland

Contains modified Copernicus Sentinel data (2015)

Composites in RGB Time Series

-26dB -6dB

R=2015.01.02+03 / G=2015.01.14+15 / B=2015.02.07+08 ; (each Asc. + Desc.)



Contains modified Copernicus Sentinel data (2015)

Interlaken, Switzerland

Freezing: Higher backscatter in Feb. than Jan.: Blue

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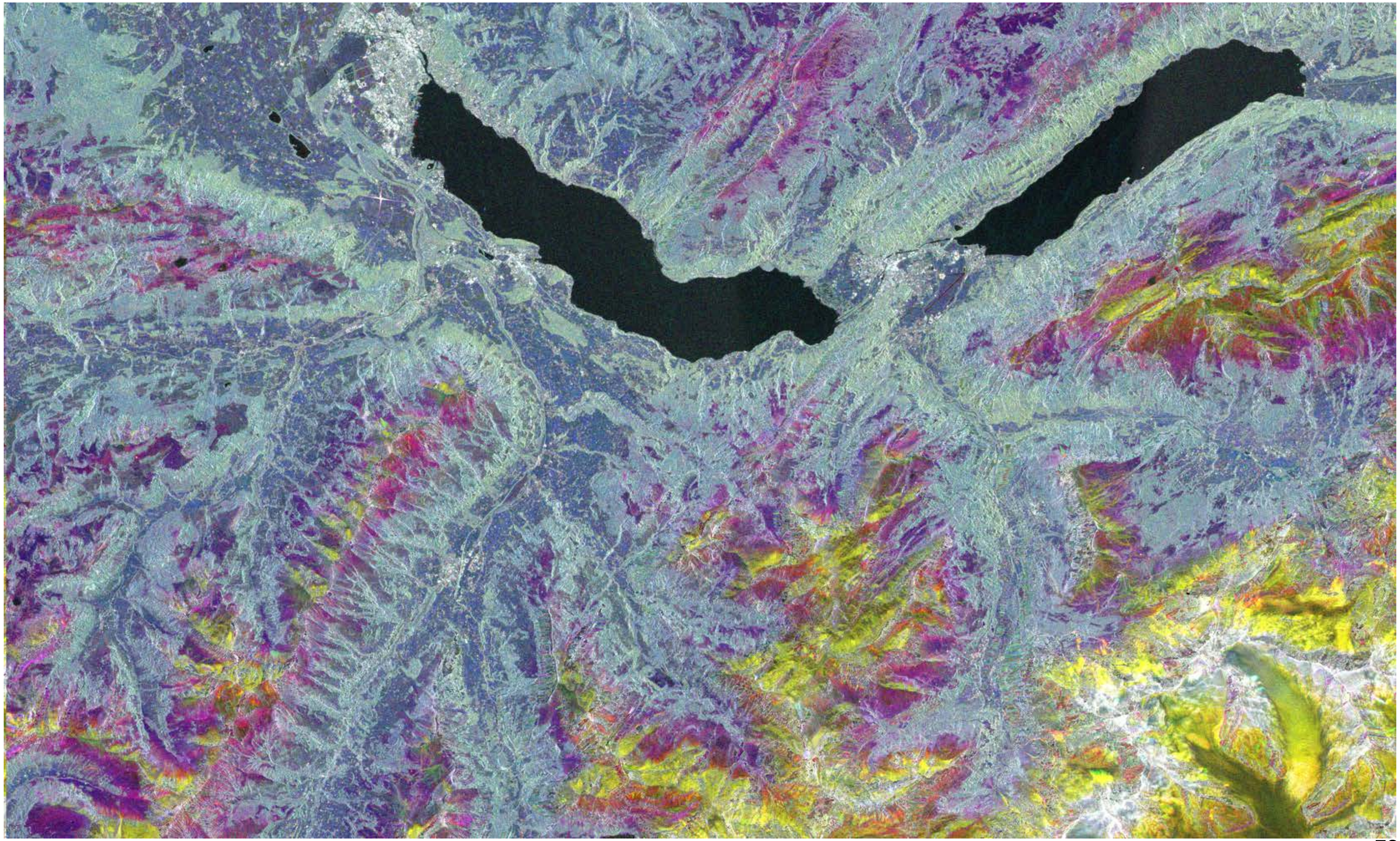
Composites in RGB Time Series

Dept. of Geography / Remote Sensing Laboratories

-26dB -6dB

R=2015.02.07+08 / G=2015.04.08+09 / B=2015.05.26+27 ; (each Asc. + Desc.)



Contains modified Copernicus Sentinel data (2015)

Interlaken, Switzerland

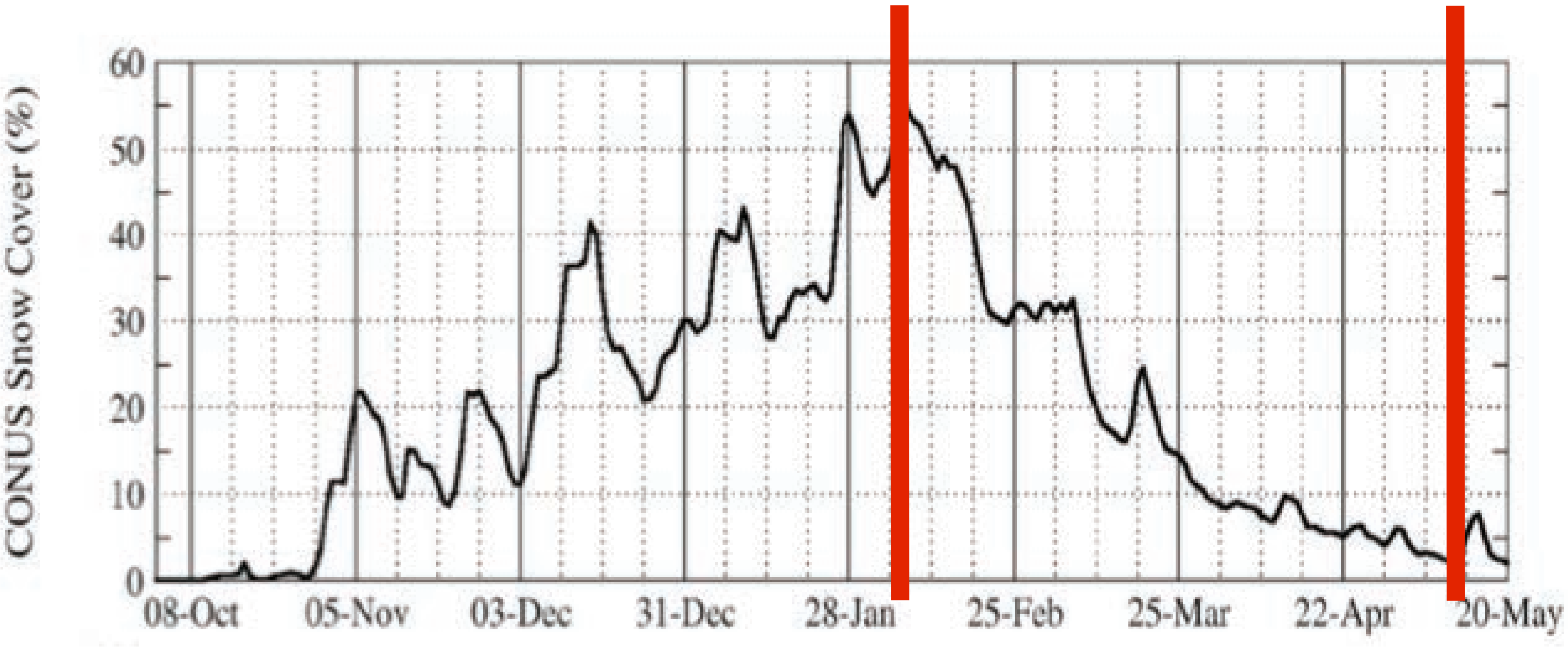
Melting: Lower backscatter in May than Feb/Apr.: Yellow

Seasonal prioritization of SAR observation windows

Evolution of Snow Cover in the US

[IGOS Cryosphere Theme Report, 2007]

Fig. 3.1. Percentage of snow-covered area within the conterminous U.S. during the 2003-2004 season with corresponding unique snow depths and SWE.



***WMO White Paper* on**
SAR Acquisition Planning for Terrestrial Snow Monitoring

Key General Recommendations

R1	**Use wide-swath modes** to enable wide area monitoring with high temporal resolution (i.e. RSAT2 SCN or SCW, Sentinel-1 IW or EW, TSX "SC Wide" & CSK "Huge Region" ScanSAR modes).
R2	Build combined **ascending/descending** coverage by default into acquisition plans covering mountainous regions. Favour asc./desc. acquisition sets acquired within a **tight time window** (1-3 days) to allow a narrow time-attribution to composites generated from these sets.
R3	Concentrate snowmelt acquisitions on the **seasonal window** when the majority of snow melting occurs (March through May at temperate northern latitudes). The *highest temporal resolution possible* is requested during this critical melting period. Although some further acquisitions are also requested *outside* of this seasonal window, lower temporal resolution at these less critical times is acceptable.
R4	Standardise dual-pol. mode acquisitions on **VV/VH** combination: a cross-platform consistent polarisation simplifies combination of datasets from multiple providers (e.g. S1/RSAT2/RCM or TSX/CSK).
R5	**Harmonise acquisition plans** of satellites with compatible calibrated backscatter values (e.g. S1/RSAT2/RCM or TSX/CSK). Utilise the available diversity of orbits to achieve the desired diversity of tracks – e.g. to achieve the fullest possible ascending/descending coverage.
R6	Assure **full coverage over land also in coastal regions** when other modes are by default programmed over ocean (e.g. favour Sentinel-1 IW or EW over WV).
R7	Maintain a **regular observation plan also during the winter** to assure frequent observations of other important snow parameters, and other phenomena related to the winter period such as avalanches and rain on snow events.

http://www.wmo.int/pages/prog/sat/meetings/documents/PSTG-4_Doc_08-01-01_Snow-SAR-DSmall-rev1.pdf

Science Requirements for wide area snowmelt monitoring

Spatial* resolution**: ***100m ✔

Variable	Extent	Spatial resolution	Temporal resolution	Sensor	Auxiliary Data
Snowmelt area	Regional	100m	1 to 5 days	Sentinel-1	Land cover, DEM
Snowmelt liquid water content	Regional	100m	1 to 5 days	Sentinel-1 dual polarisation	Land cover, DEM

[Malenovský, Z. et al. *Sentinels for science: Potential of Sentinel-1, -2, and -3 missions for scientific observations of ocean, cryosphere, and land*. Remote Sens. Environ. 120, 91–101 (2012)]

Temporal* resolution (target)**: ***1 day ✘

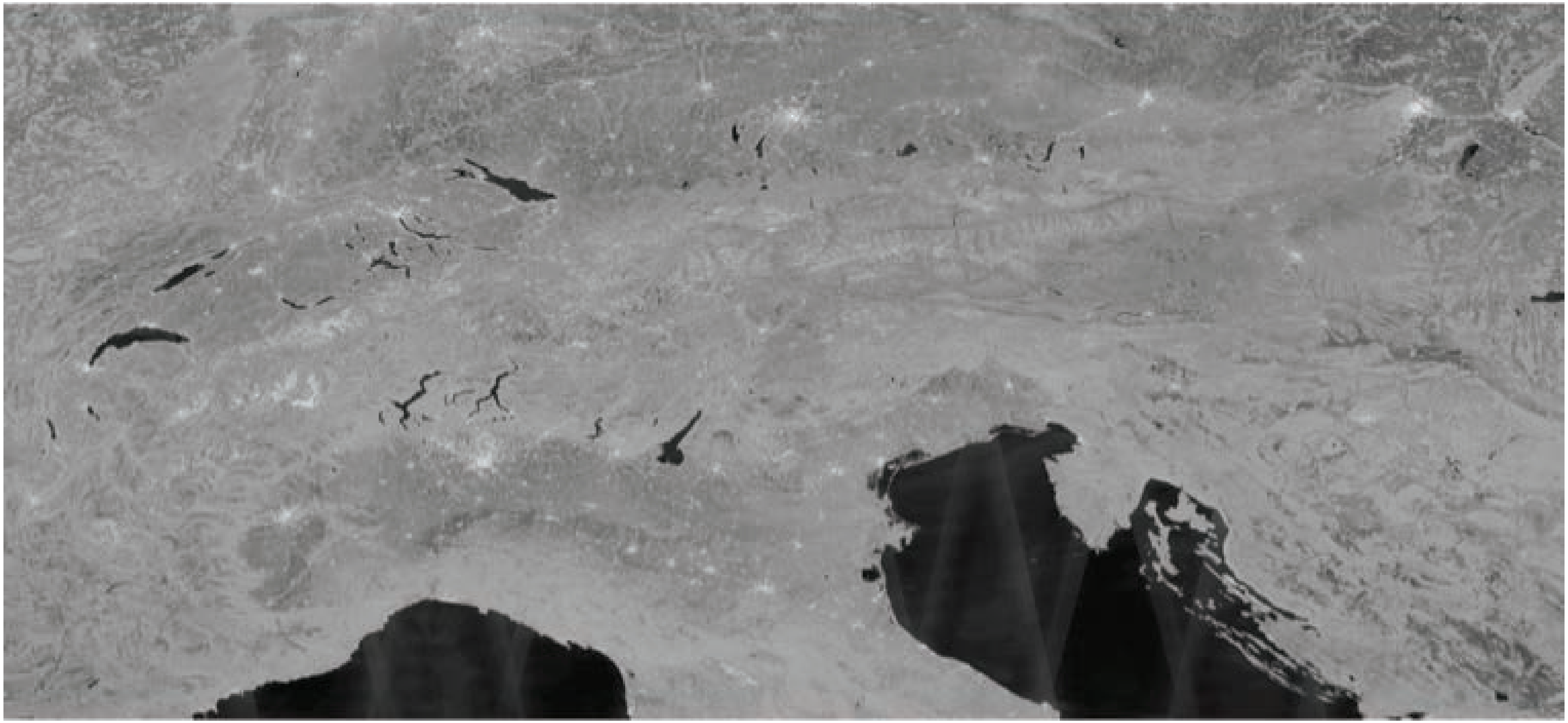
- "Observation of the ***daily*** *geographic extent of snow cover* is essential because it enables inference of several first order effects of snow on many Earth systems." [IGOS Cryosphere Theme Report, 2007]
- WMO PSTG report "Coordinated SAR Acquisition Planning for Terrestrial Snow Monitoring", PSTG-SARCWG-SNOW-001, Aug. 2014.

Data Collections

Region	DEM	Spatial sampling	Temporal resolution [days]	Sensors
Interlaken region, Switzerland	swissALTI3D (2m)	10 m	<6	S-1A/S-1B IW VV/VH
European Alps	SRTM3 (3s)	3s (~90m)	<6	S-1A/S-1B IW VV/VH
Coastal British Columbia, Canada	SRTM3 (3s)	3s (~90m)	<12	S-1A/S-1B IW VV
Ellesmere Island, Canada	CDEM[1]	400m	**1**	S-1A/S-1B EW + IW HH/HV RS2 SCWA HH/HV

[1]M. Santoro & T. Strozzi (2012): **Circumpolar digital elevation models > 55° N**
Canadian Digital Elevation Model Product Specifications, Edition 1.1, 2013-04-01, GeoGratis

Sentinel-1 IW VH-pol. **Feb. - June 2018**: 12 day windows



SRTM3 used for geometric and radiometric corrections

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Contains modified Copernicus Sentinel data (2018)

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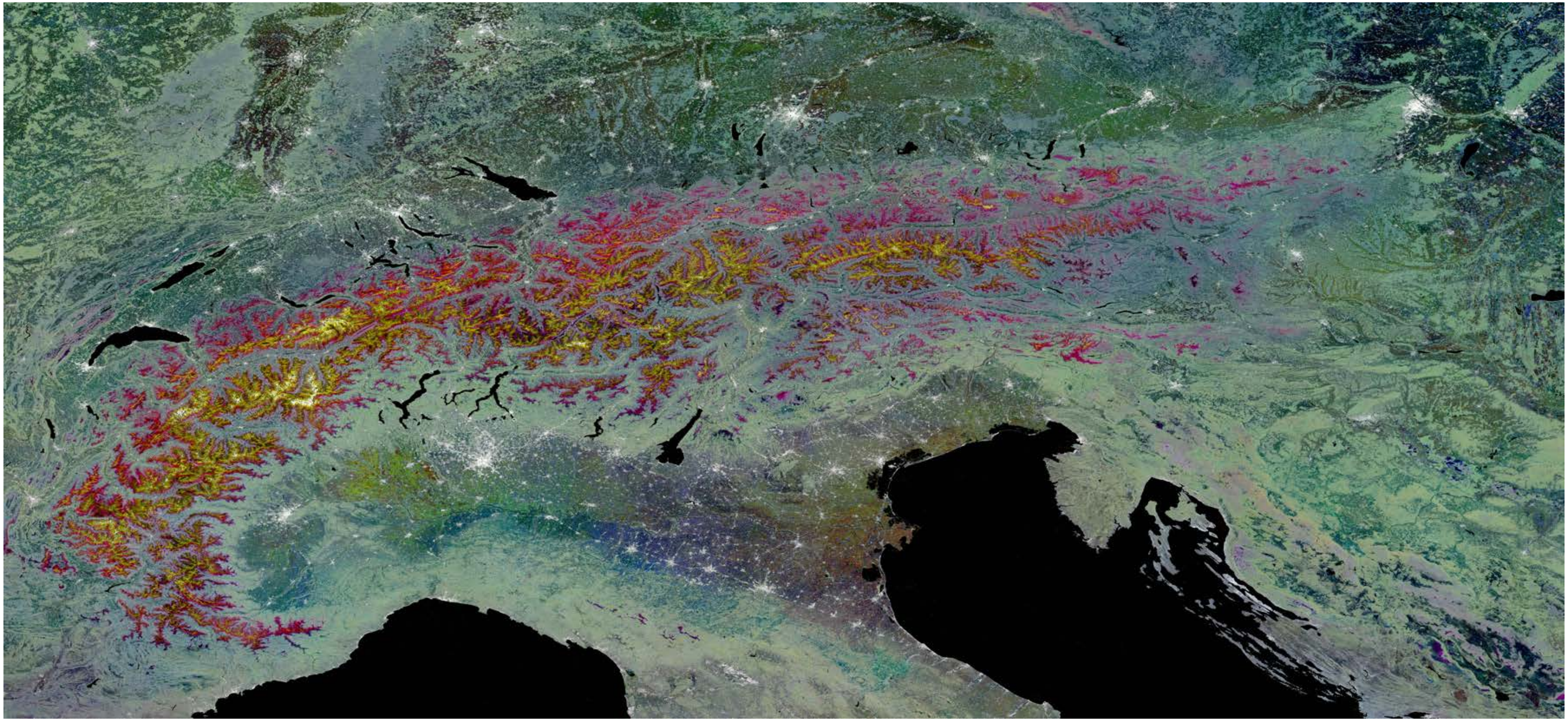
Sentinel-1 IW 12d Composites 2018 VH: Feb 24-Mar 7, April 1-12, May 1-12; -23dB (black) to -6dB (white)



No mask for foreshortening/layover required

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Sentinel-1 Western Alps Backscatter Movie

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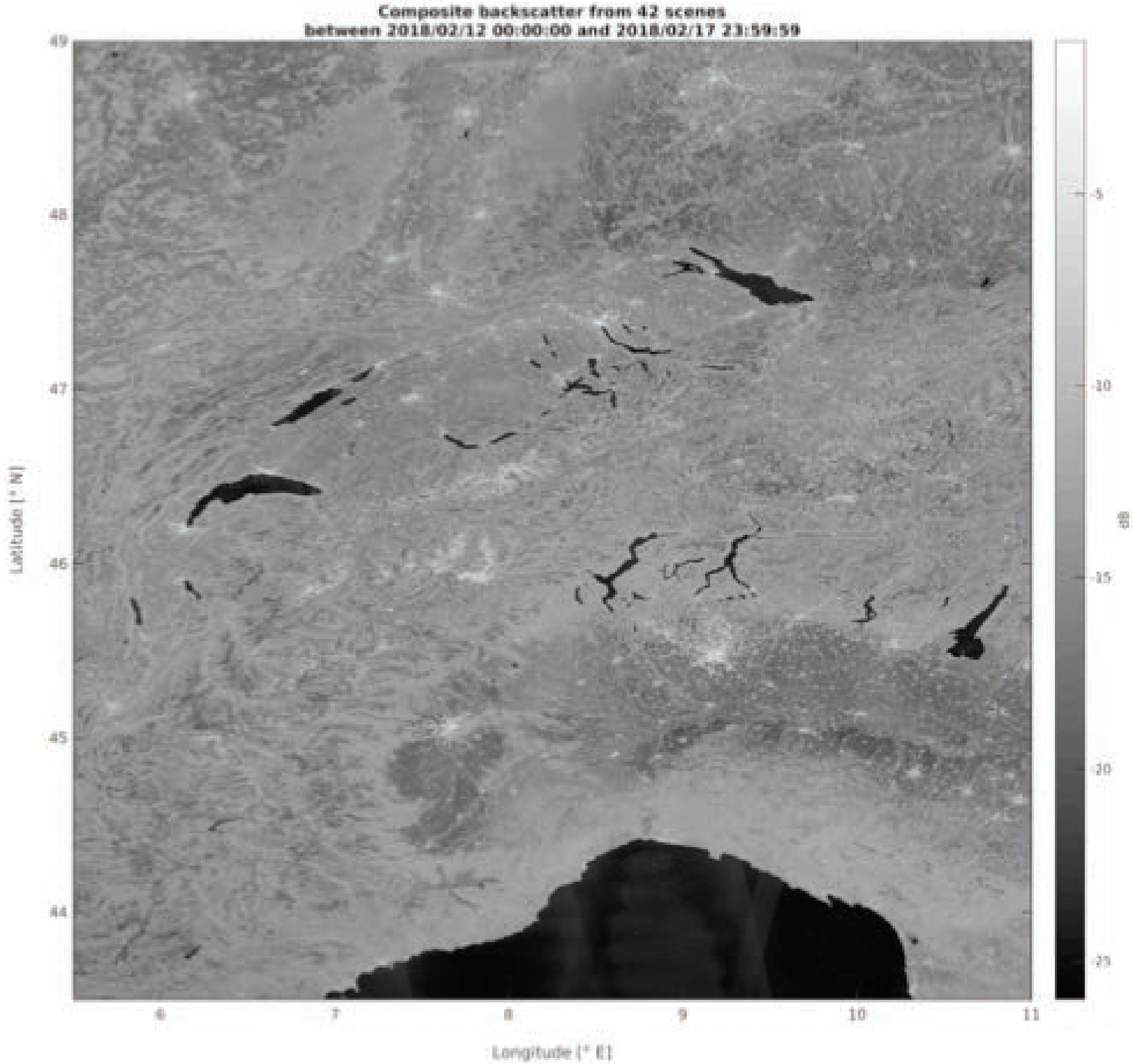
Sentinel-1 IW VH

Feb.- June 2018
6-day windows



SRTM3 used for geometric and radiometric corrections

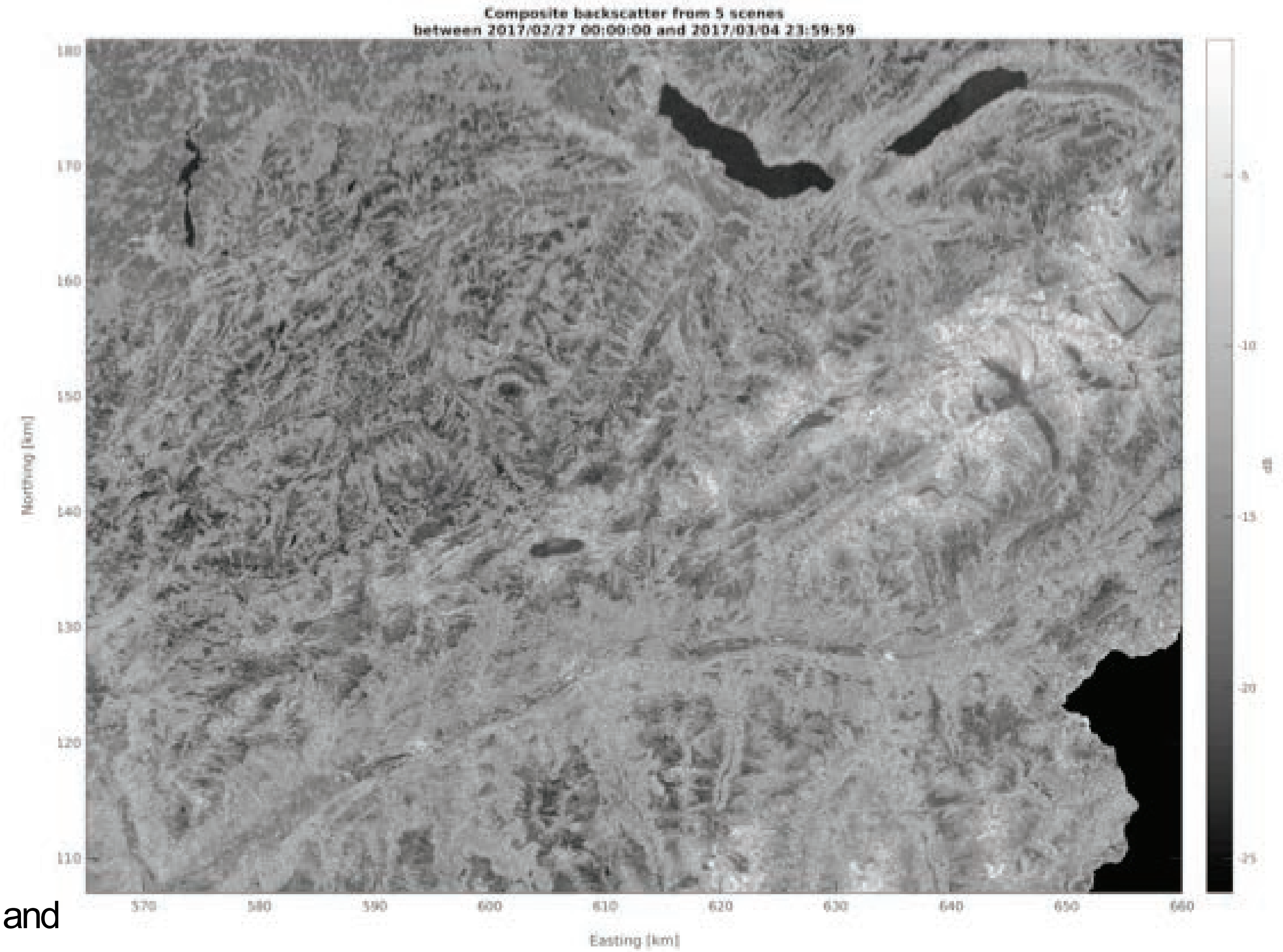
Sentinel-1 Bernese Oberland

University of Zurich[UZH]

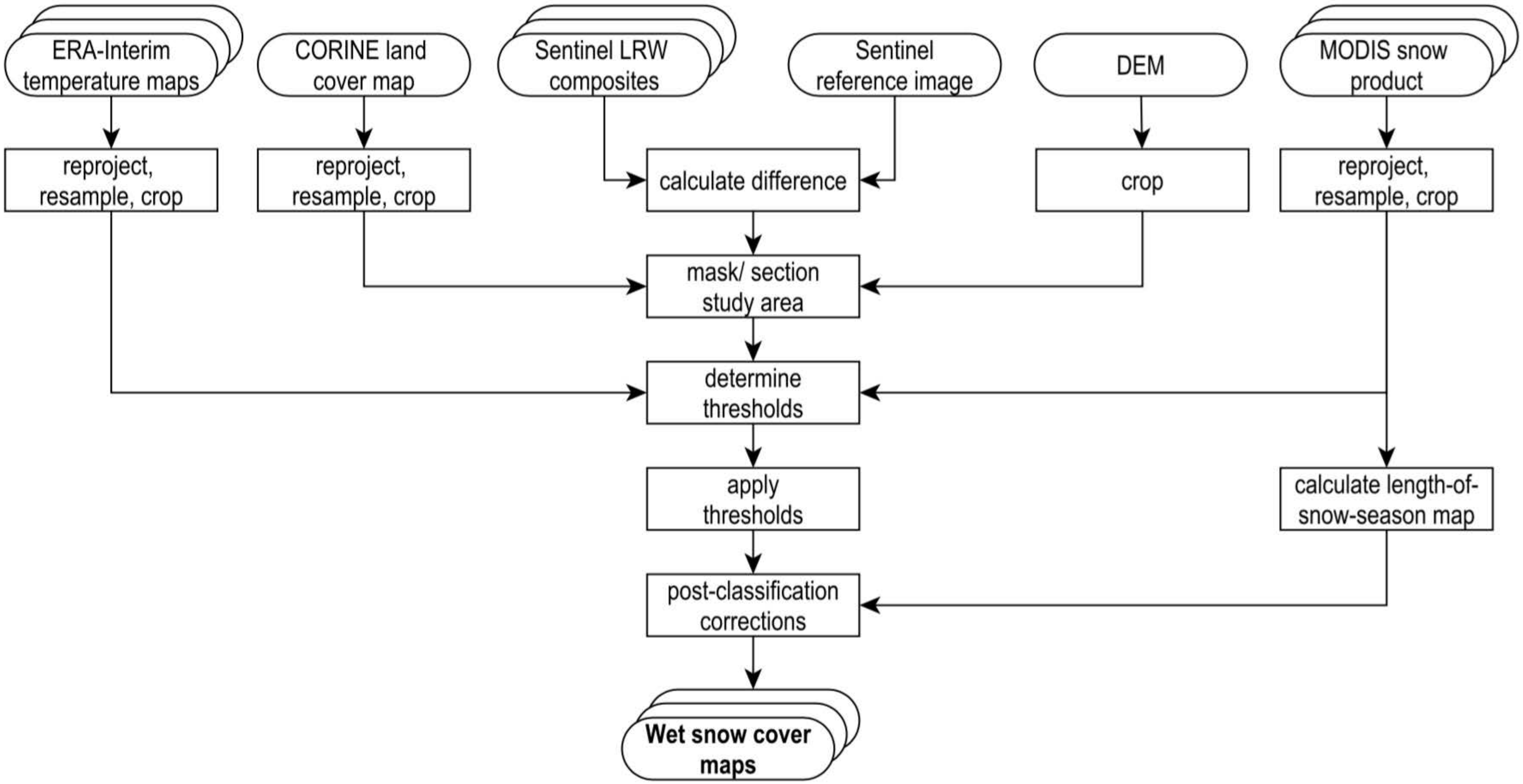
Dept. of Geography / Remote Sensing Laboratories

Sentinel-1 IW VH

Feb.- June 2017
6-day windows



SRTM3 used for geometric and radiometric corrections



D. Jäger, M.Sc. Thesis, UZH, 2016.

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Sentinel-1 Alpine Snow Melt Movie

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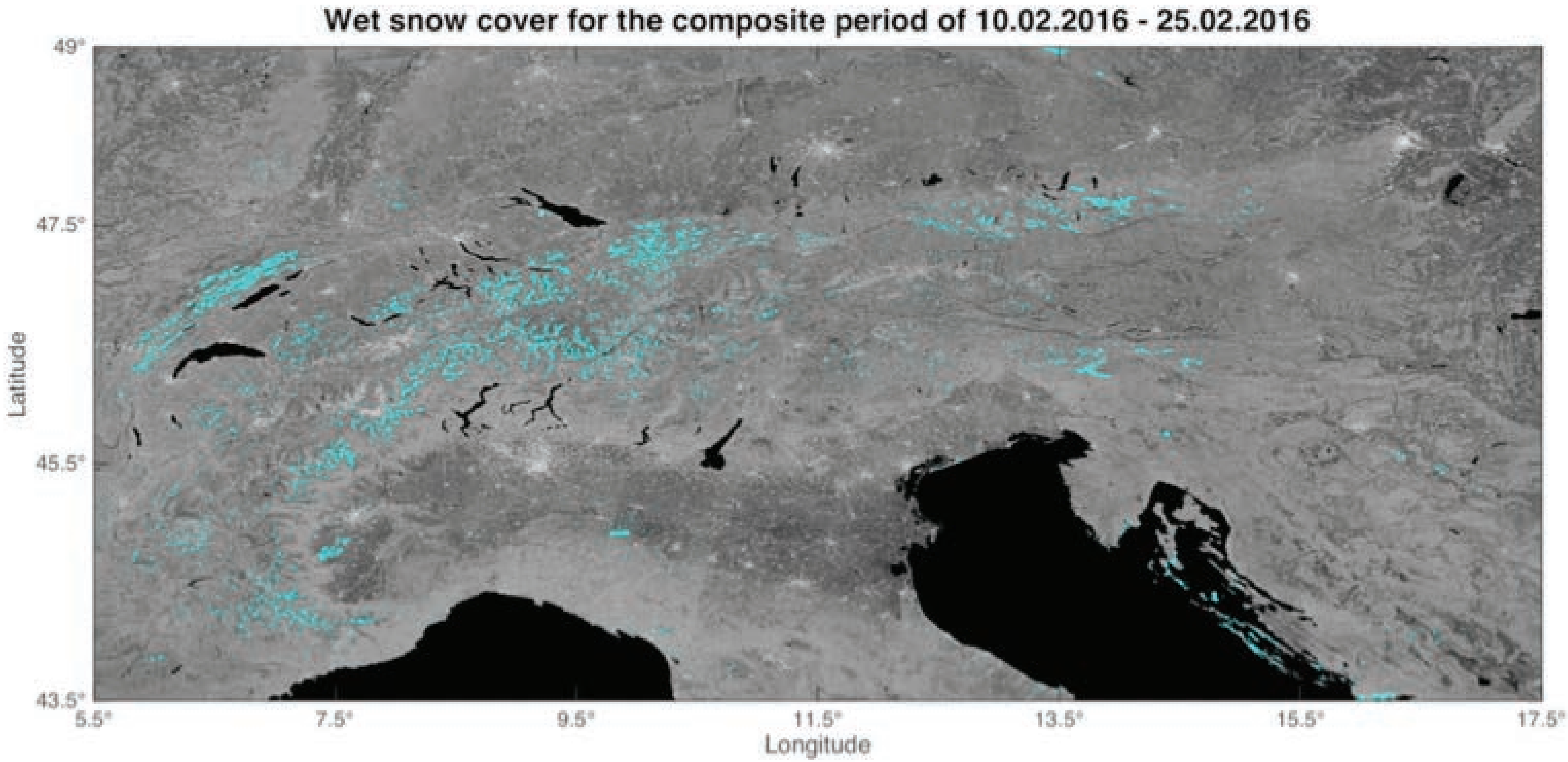
Sentinel-1 IW VH **Feb. – June 2016**, 16-day windows



SRTM3 used for geometric and radiometric corrections

D. Jäger, M.Sc. Thesis, UZH, 2016.

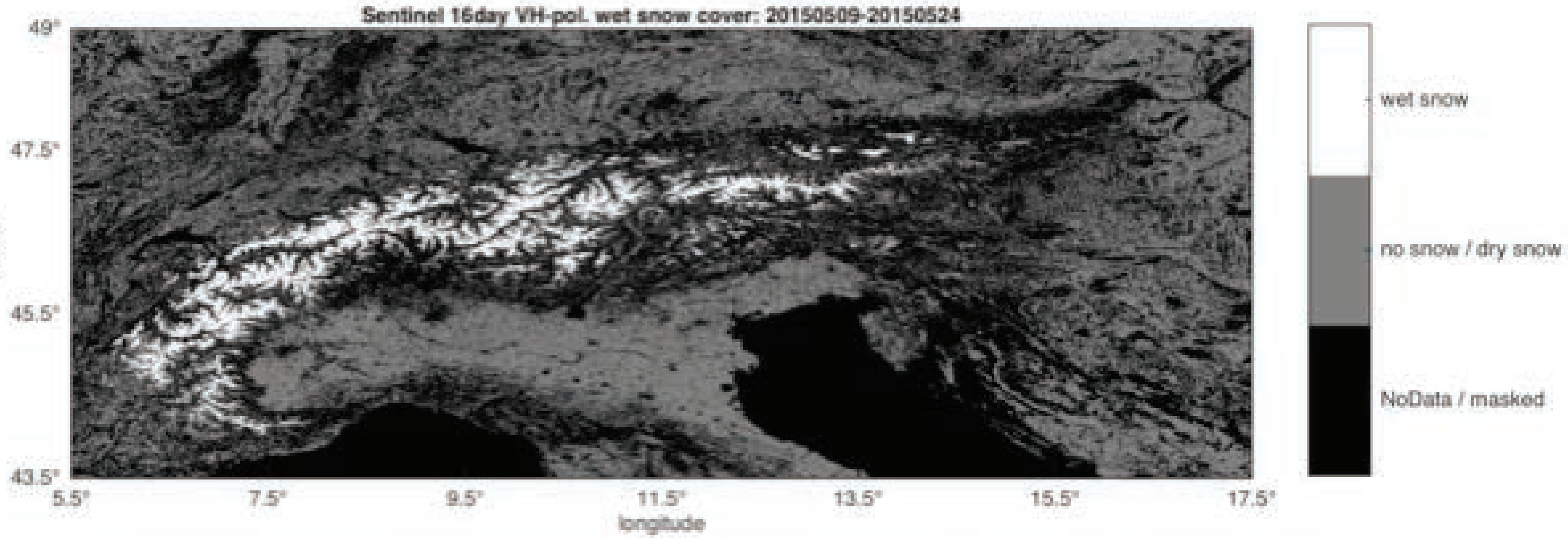
S1A Alps Wet Snow Maps

University of Zurich[UZH]

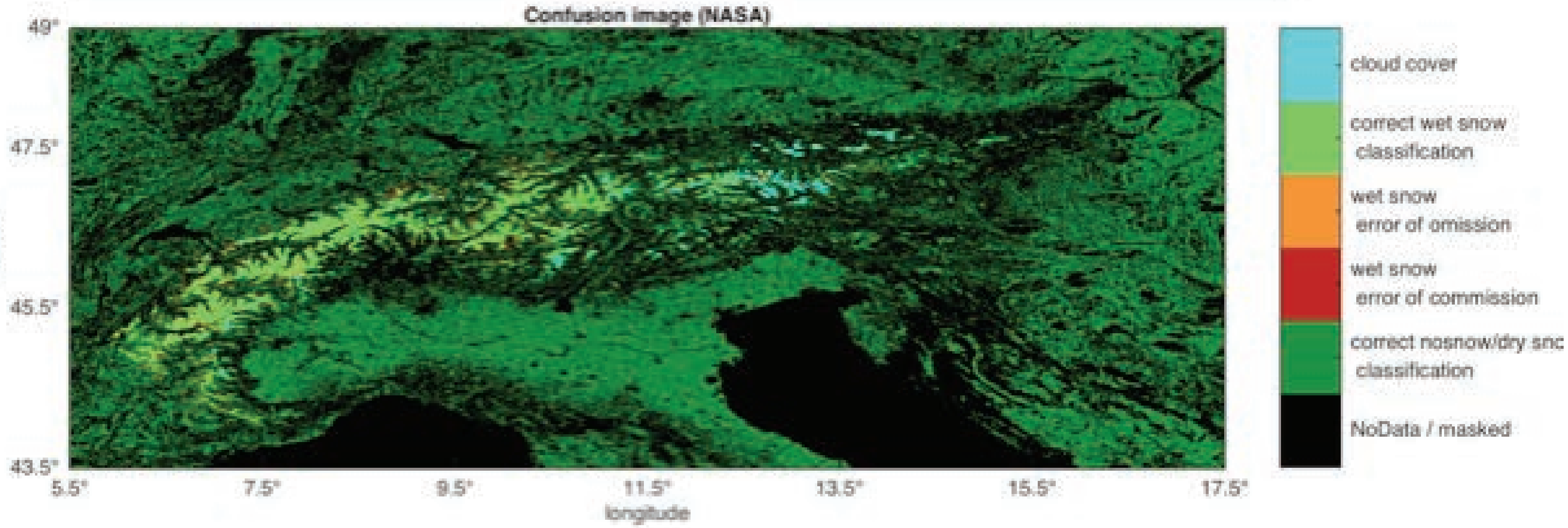
Dept. of Geography / Remote Sensing Laboratories

S1A IW 2015
VH & VV-pol.

S1-based
wet snow
classifications
compared with
NASA MODIS
snow products



Overall accuracy: 97.16% | Kappa coefficient: 72.98% | Cloud coverage: 1.1% | $EoC_{wet\ snow}$: 32.41% | $EoO_{wet\ snow}$: 17.1%



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Vancouver, Canada

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Coastal BC Backscatter Composites

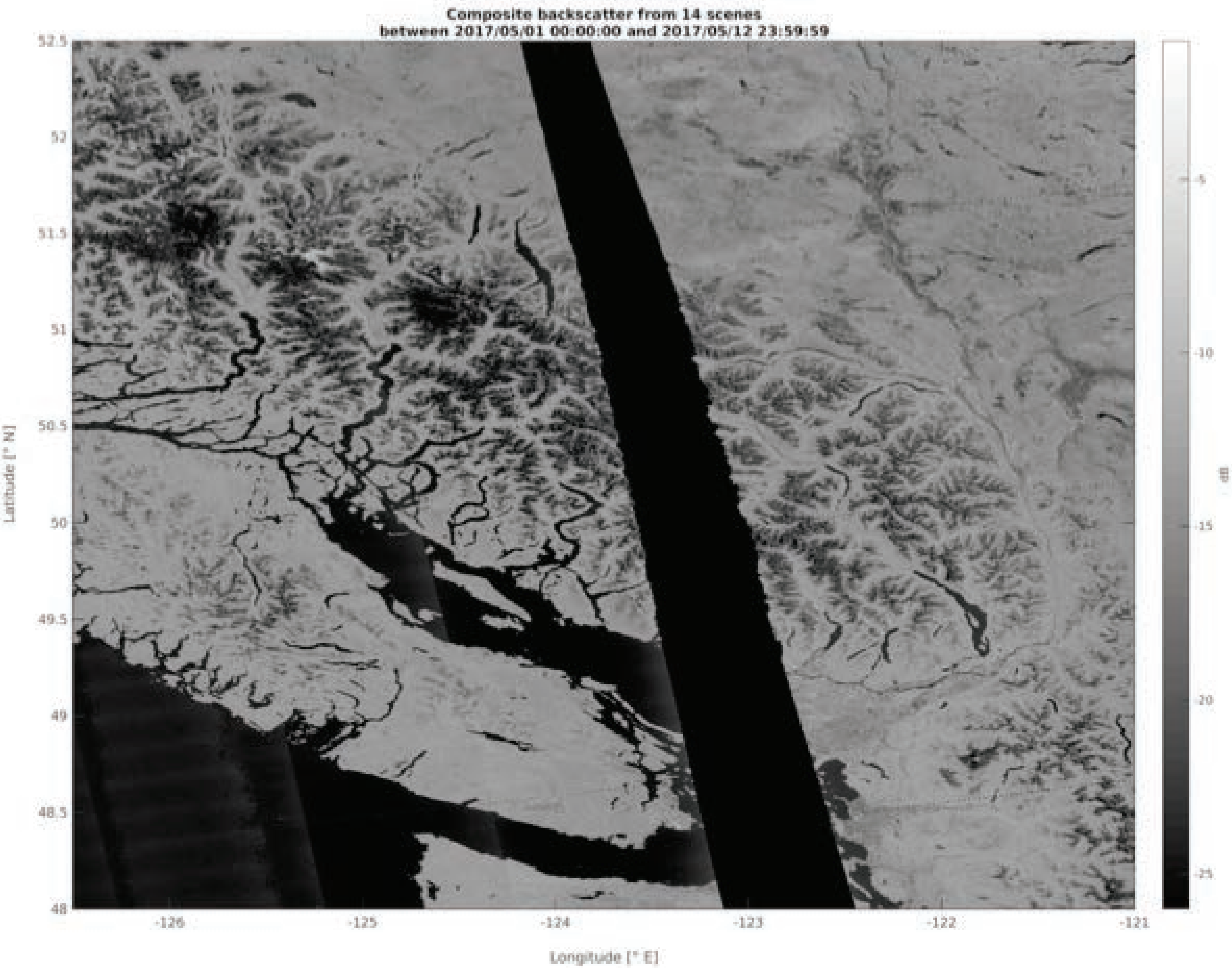
S-1A+S-1B
IW VH

6 day delta

12 day window

N.B.
SRTM DEM

May 2017
– Apr 2018



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Iceland

Backscatter Composites

S-1A+S-1B

IW VH

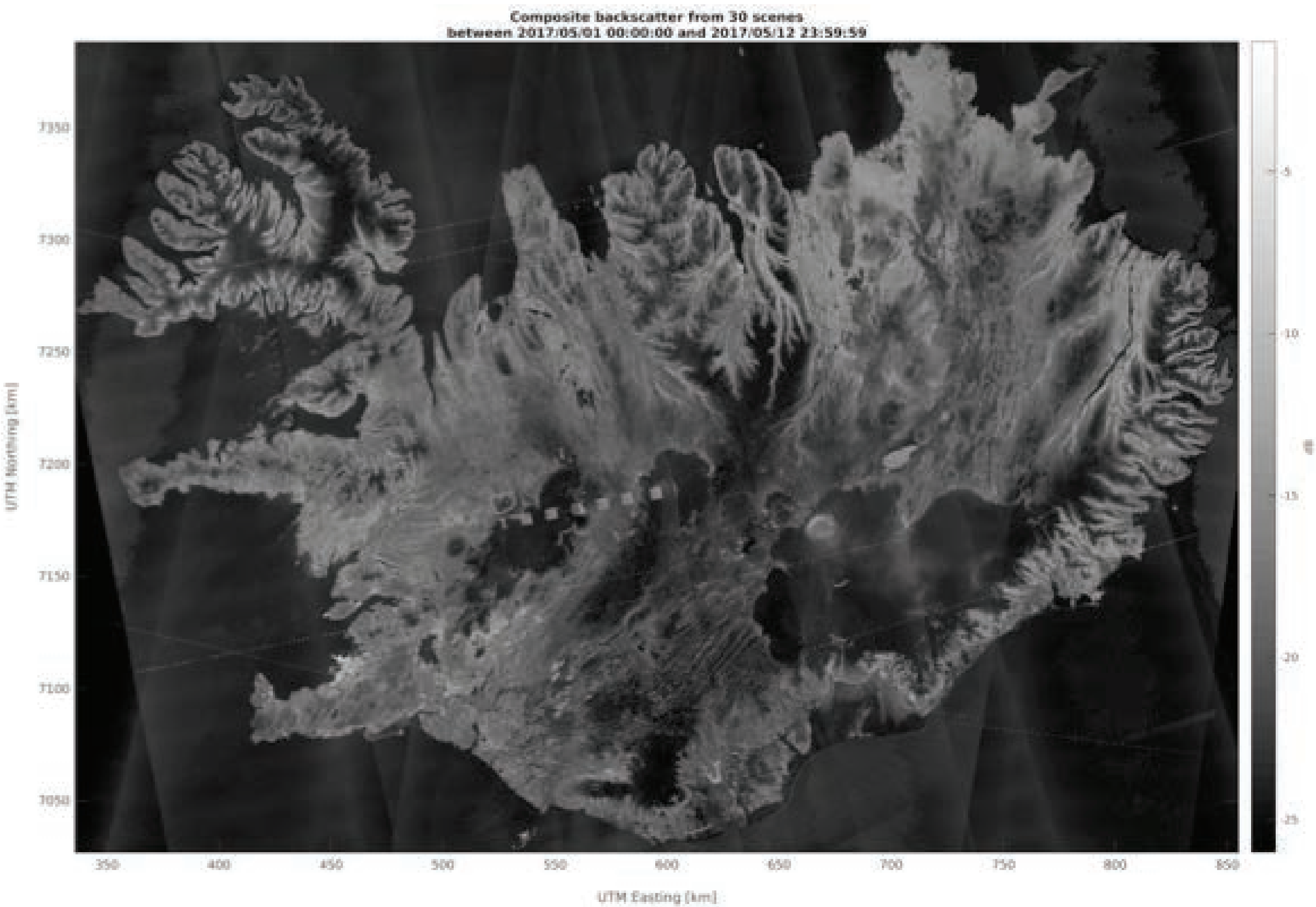
6 day delta

12 day window

N.B.

EU-DEM

May-Sept. 2017



Single Geometry vs. Composites

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	Single Mode/Geometry	Composite from time window
Time covered	Single point in time	Blurred time window (e.g. 1, 2, 3, or 6 days)
Temporal resolution	S1A+S1B: 6 days RS2: 24 days	Narrowest time window providing full coverage, e.g. at temperate latitudes: S1A+S1B: ~5 days; in high Arctic: ~1-2 days
Spatial resolution on mountains	Highly variable: Poor on foreslopes, high on back-slopes	More uniform: Able to **integrate ascending/descending** images for **best of both worlds**: higher spatial resolution than in any single acquisition
Scalability with availability of further sensors (e.g. S1+RCM)	Requires all sensors use same mode and orbit	Able to integrate diverse geometries from non-harmonised **S1+RCM** orbits or modes
Spatial extent	Single scene from given mode	Extendable to wide areas
Wide area interpretation	Complex	***Analysis Ready***

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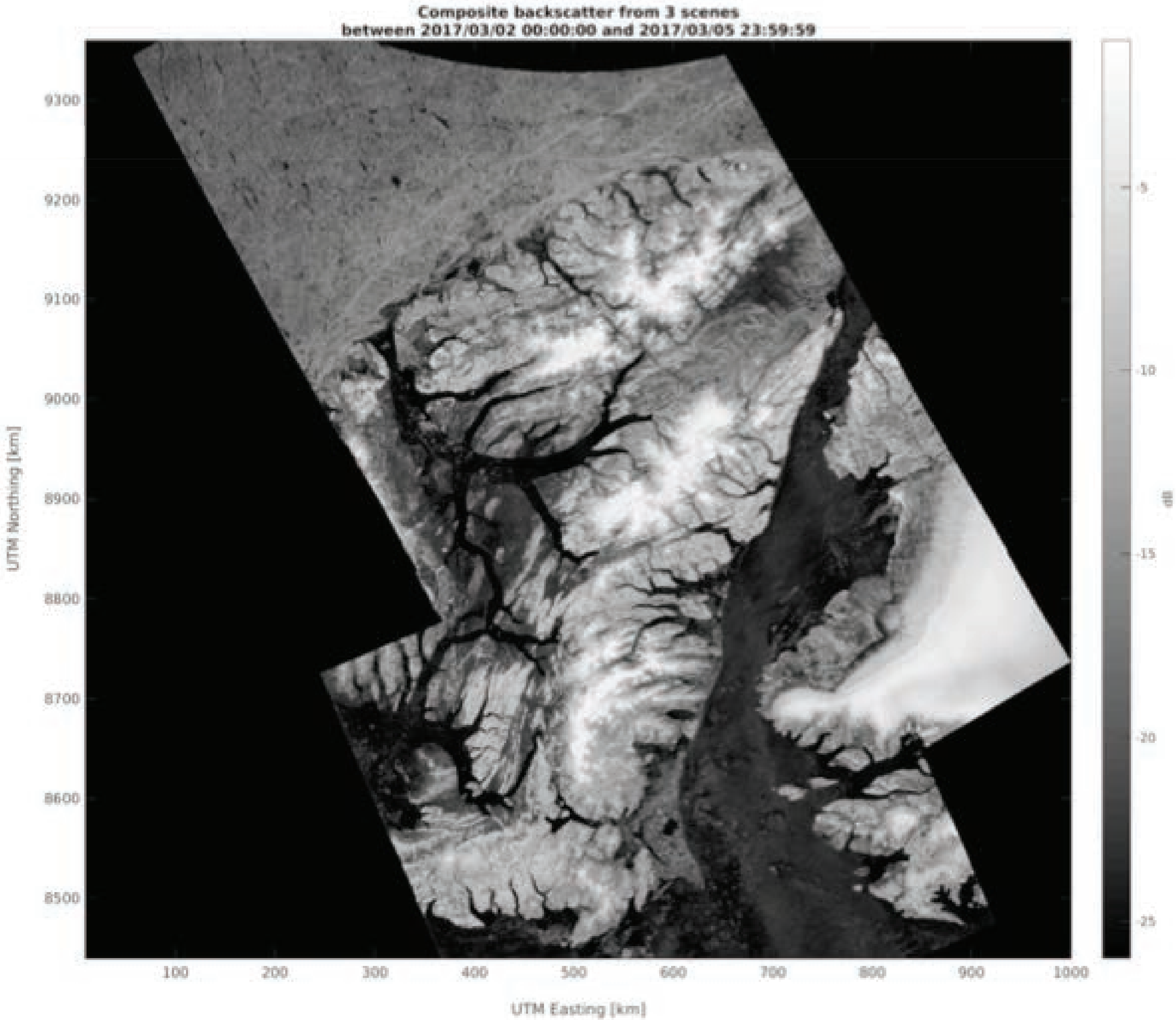
Ellesmere Island Backscatter Composites

RS2 SCWA HV

2 day delta

4 day window

N.B. CDEM



Mar – Aug. 2017

Unive
Zurich
Dept. o

Ellesmere Island Backscatter Composites

S-1A+S-1B EW+IW HV

1 day delta

2 day window

N.B. CDEM

Apr. – Aug. 2017

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Ellesmere Island Backscatter Composites

S-1A+S-1B EW+IW

+RS2 SCWA

HV

1 day delta

1 day window

N.B. CDEM

Apr. – Aug. 2017

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Ellesmere Island Backscatter Composites

S-1A+S-1B EW+IW

+RS2 SCWA

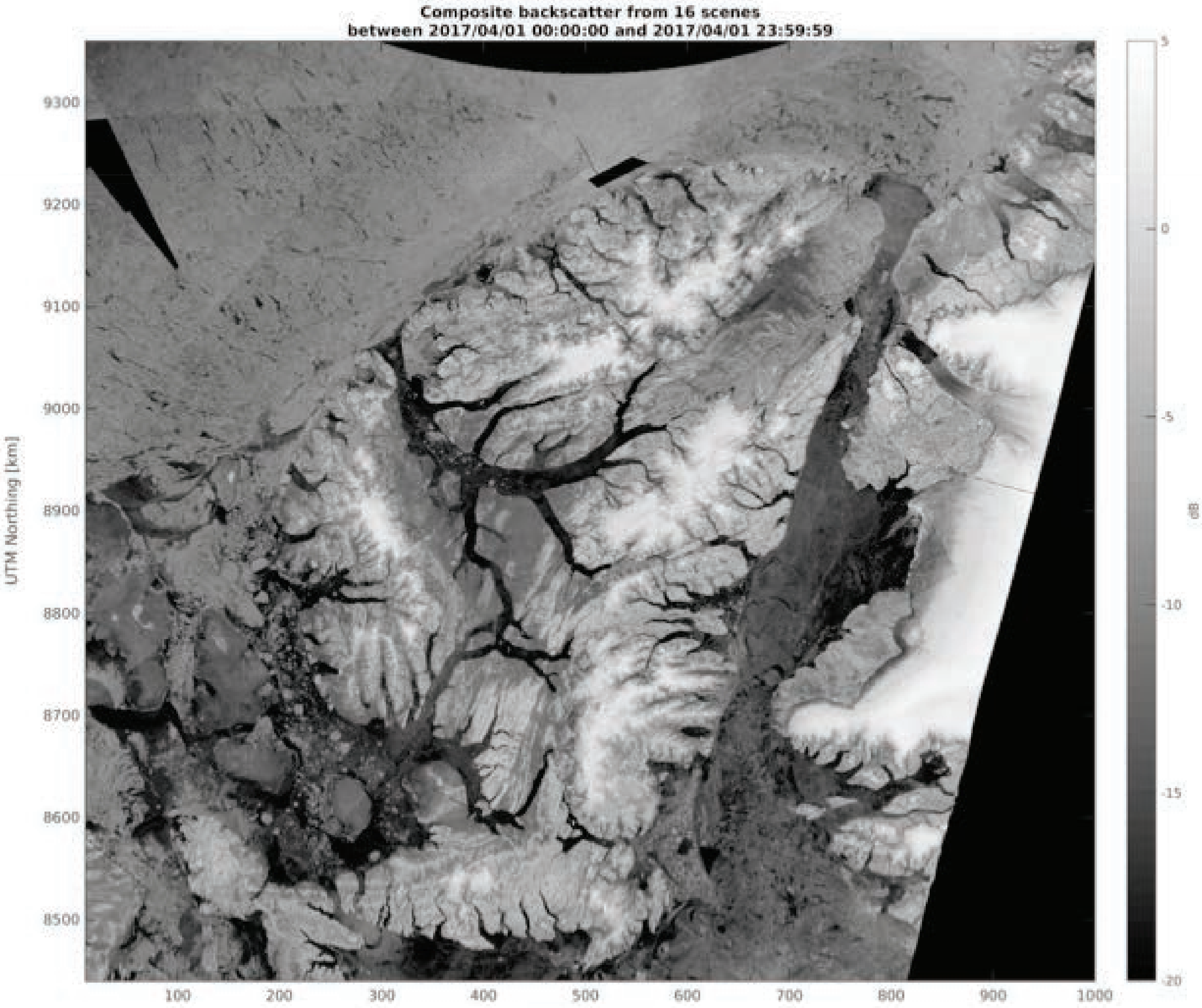
HH

1 day delta

1 day window

N.B. CDEM

Apr. – Aug. 2017



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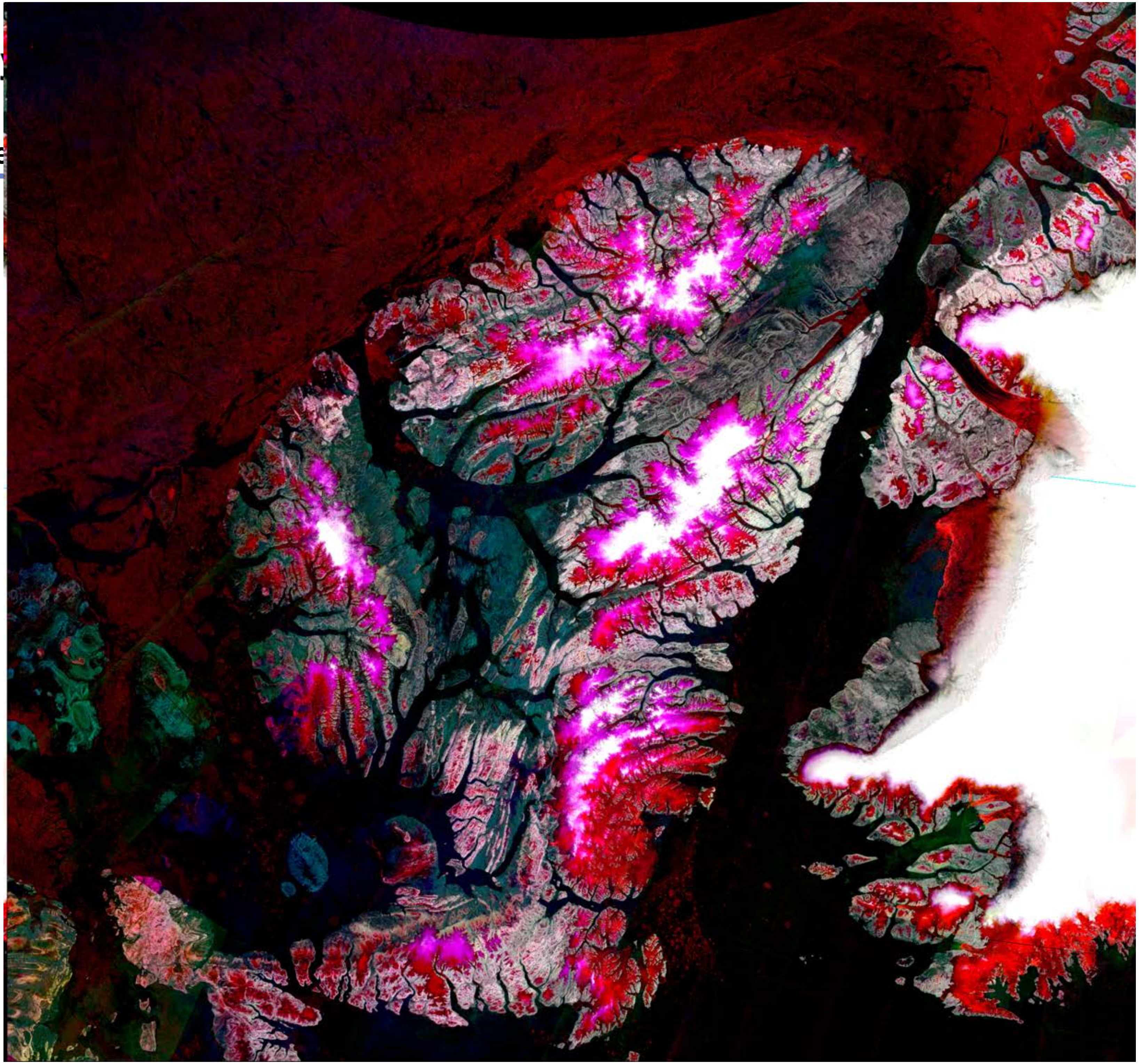
Ellesmere Island, Canada

Sentinel-1 EW+IW **2d** Composite
HV-pol.:

May 11-12,
July 8-9,
July 15-16

γ_T^0 HV-pol.

-23dB -6dB



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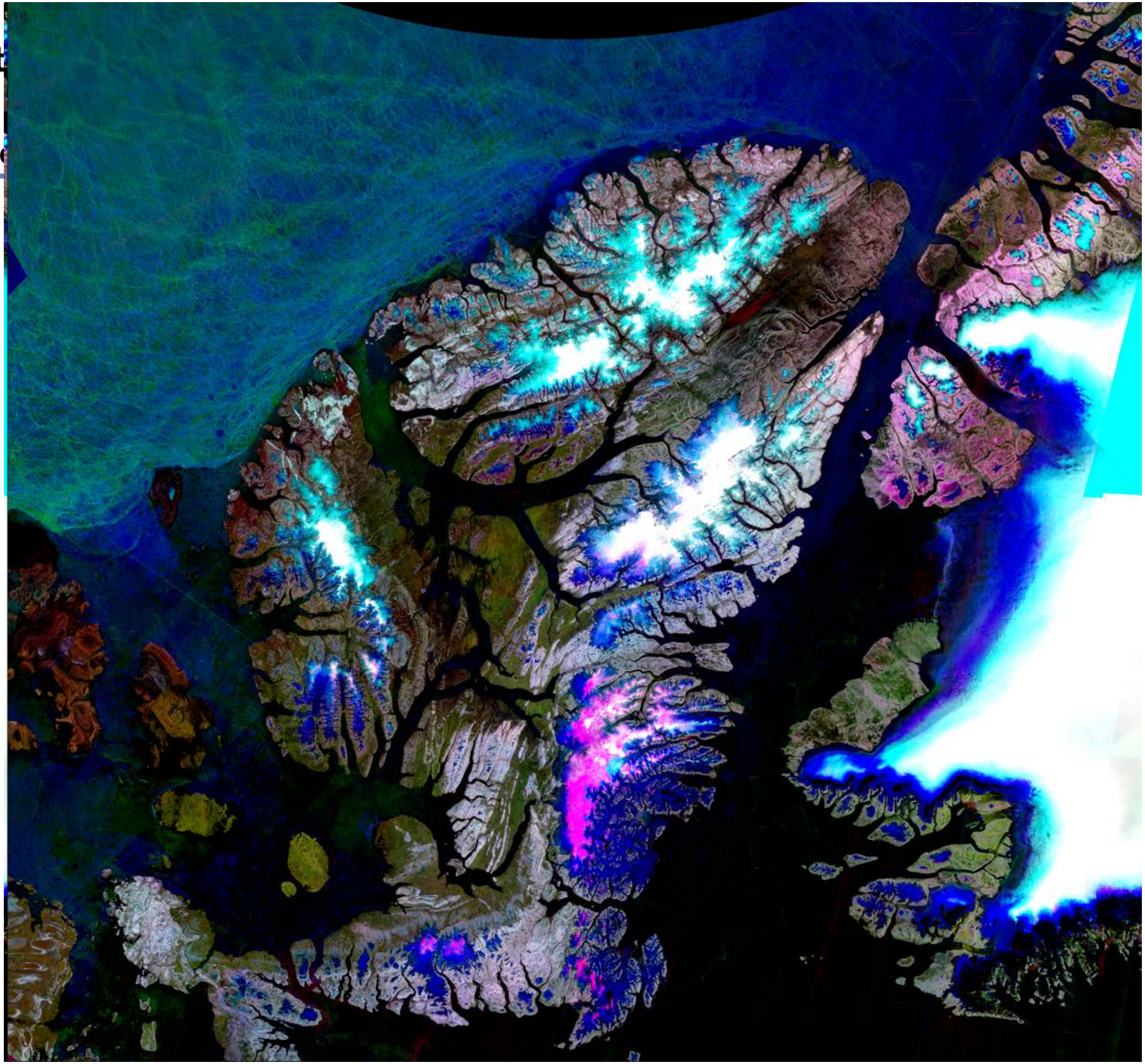
Ellesmere Island, Canada

Sentinel-1 EW+IW **2d** Composite
HV-pol.:

July 30-31,
Aug. 13-14,
Aug. 31-Sept. 1

γ_T^0 HV-pol.

-23dB -6dB



Future Radar Resources

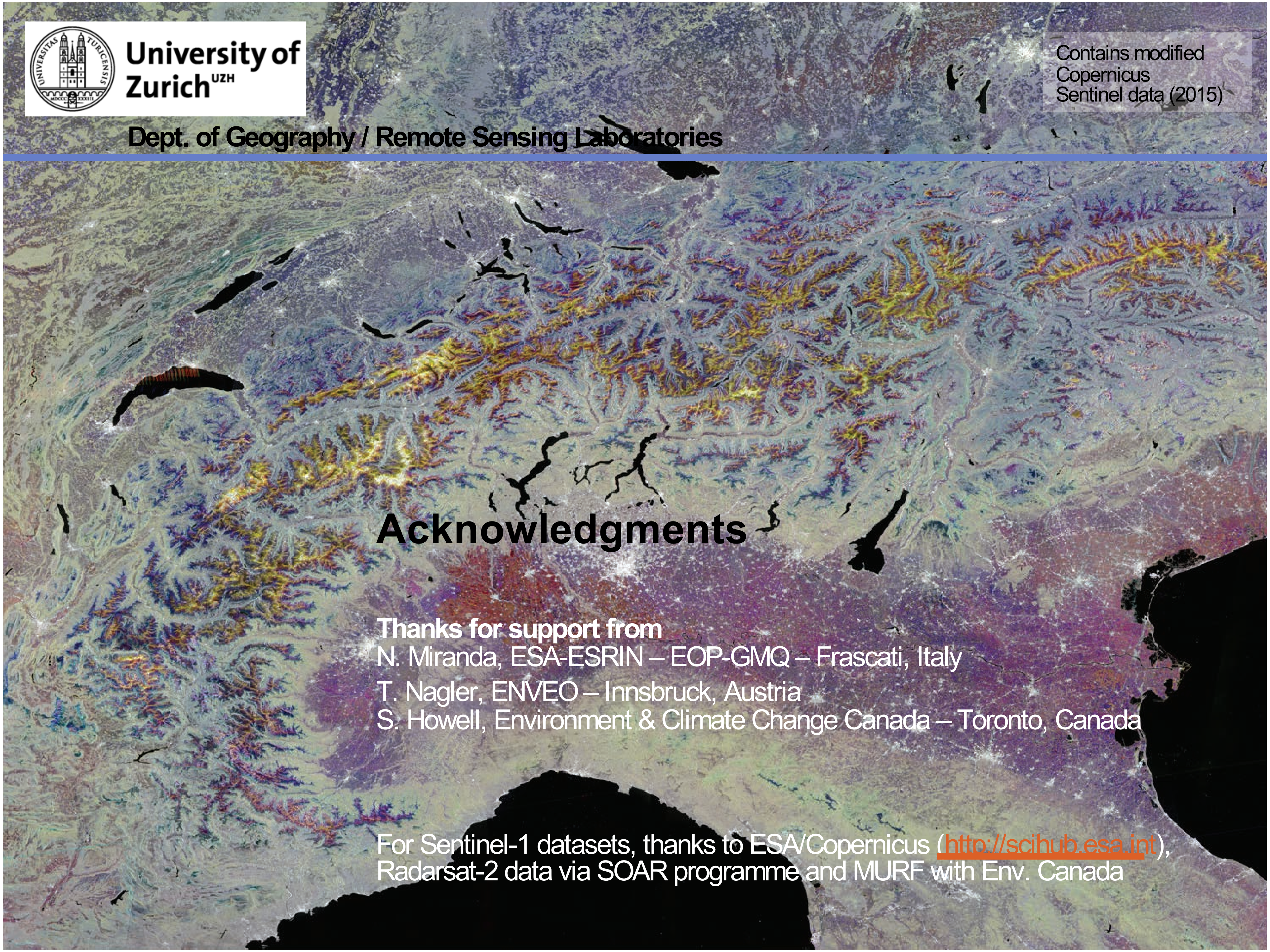
- **Radarsat Constellation Mission (Canadian Space Agency)**
- **Launch of 3 satellites planned for Nov. 2018**
  - C-band, same central frequency as Sentinel-1 and Radarsat-2
  - Non-commercial model, satellites owned by Canadian government
  - Six active C-band satellites:
    - S-1A, S-1B
    - RS2
    - RCM1-3
  - Harmonisation of acquisition patterns between ESA/EU and CSA will be helpful

Conclusions

- Snow wetness clear strong signal in C-band SAR imagery
- Snow depth and Snow Water Equivalent (SWE) currently not accessible in single-date C-band SAR data

- Backscatter composites would be more user-friendly than slant or ground range level 1 products for many users: ***Analysis Ready***
- Additional C-band satellites on the way:
  - Sentinel-1C / Sentinel-1D being built
  - Three satellites in Radarsat Constellation Mission (RCM) planned for 2018 launch

Daily temporal resolution achieved with multi-sensor / multi-agency data integration – in the future, also at more temperate latitudes?



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Contains modified Copernicus Sentinel data (2015)

Acknowledgments

Thanks for support from

N. Miranda, ESA-ESRIN – EOP-GMQ – Frascati, Italy

T. Nagler, ENVEO – Innsbruck, Austria

S. Howell, Environment & Climate Change Canada – Toronto, Canada

For Sentinel-1 datasets, thanks to ESA/Copernicus (http://scihub.esa.int), Radarsat-2 data via SOAR programme and MURF with Env. Canada