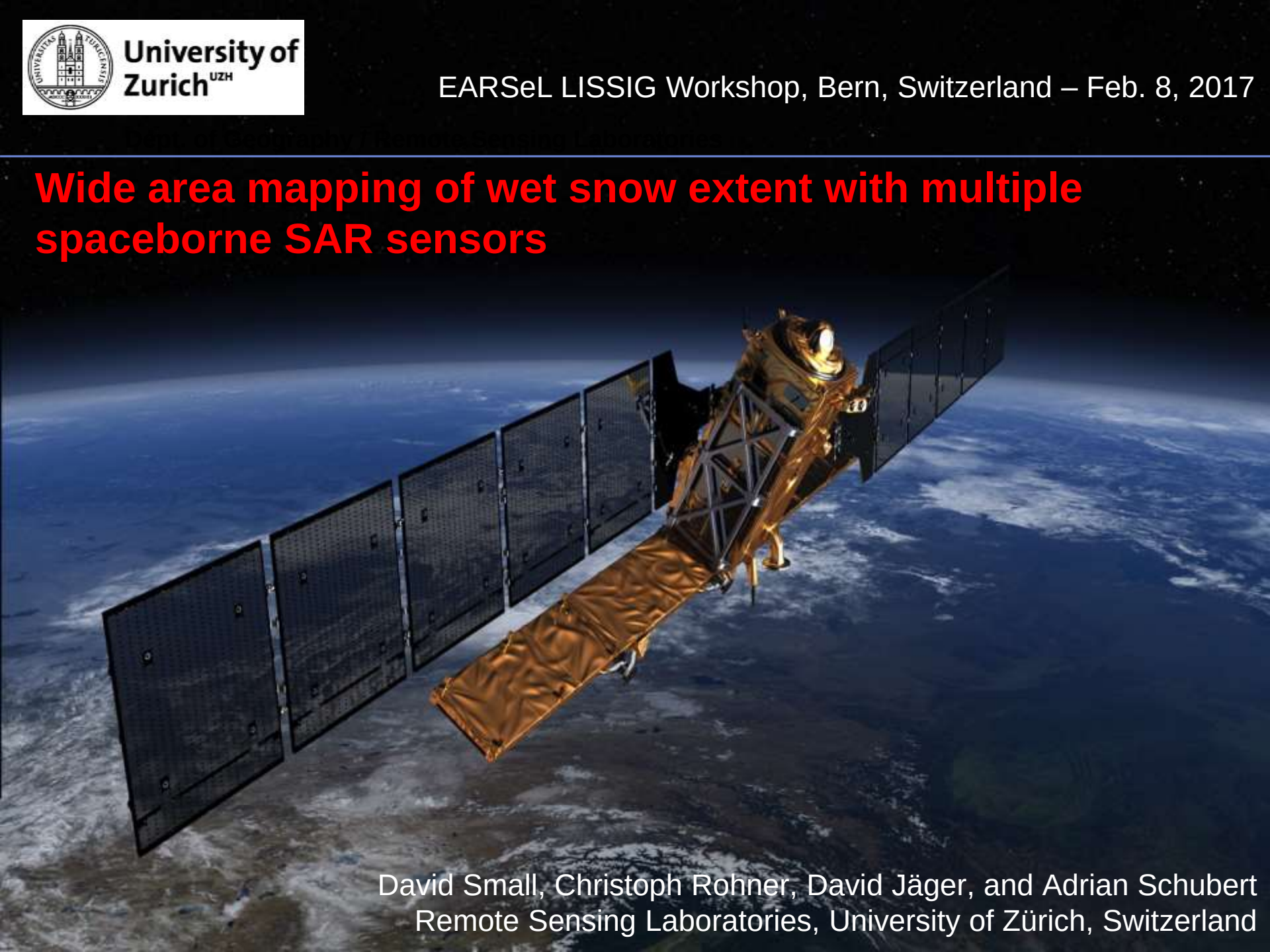
University of Zurich[UZH]

EARSeL LISSIG Workshop, Bern, Switzerland – Feb. 8, 2017

Dept. of Geography / Remote Sensing Laboratories

Wide area mapping of wet snow extent with multiple spaceborne SAR sensors



David Small, Christoph Rohner, David Jäger, and Adrian Schubert
Remote Sensing Laboratories, University of Zürich, Switzerland

Outline

- Radiometric Terrain Corrections
- Backscatter Compositing
- Test Sites
  - Coastal British Columbia
  - European Alps
    - Wet snow maps
  - Ellesmere Island – Nunavut, Canada
    - Improved temporal resolution from first Sentinel-1/Radarsat-2 Hybrid backscatter composites
- Conclusions

Terrain-flattened Gamma Nought

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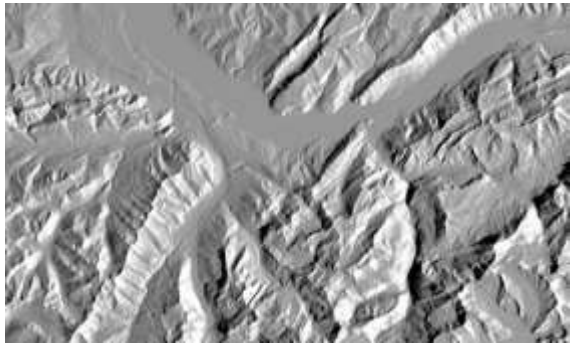
Interlaken, Switzerland
Sentinel-1A IW GRDH VH-pol.
May 26, 2015

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



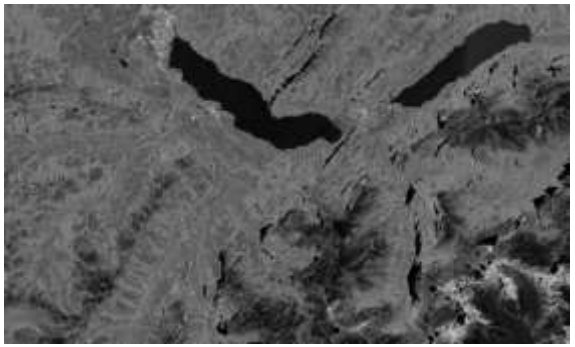
β^0 GTC



A_γ / A_β

-26dB -1dB

g_T^0 =



RTC

$$g_T^0 = b^0 \times \frac{A_b}{A_g}$$

University of Zurich[UZH]

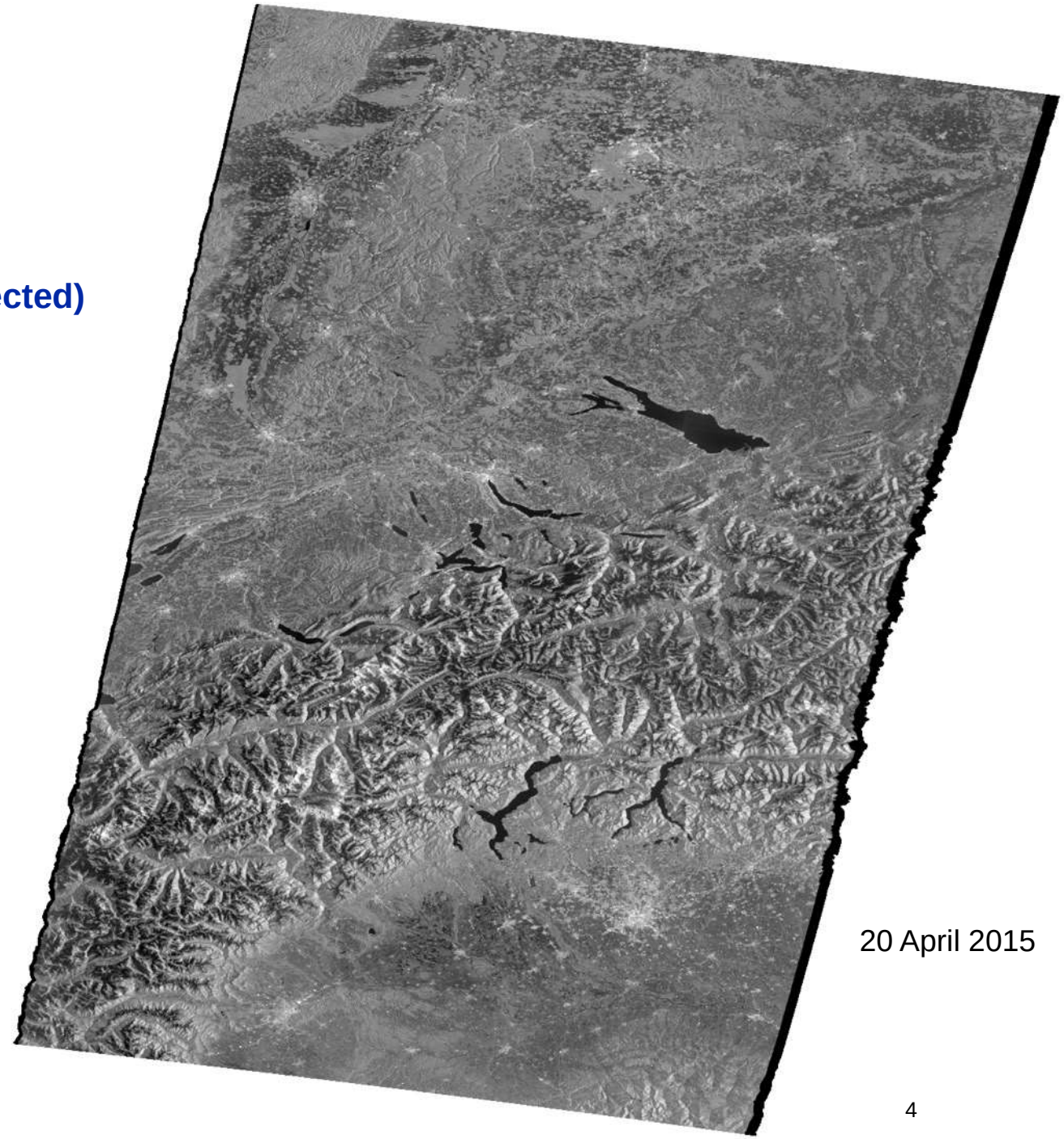
Dept. of Geography / R

Sentinel-1A: GTC

(Geometrically Terrain Corrected)

g_E^0

-26dB -1dB



Generated automatically from 3 IW GRDH products using SRTM3

20 April 2015

Copernicus Sentinel data (2015)

University of Zurich[UZH]

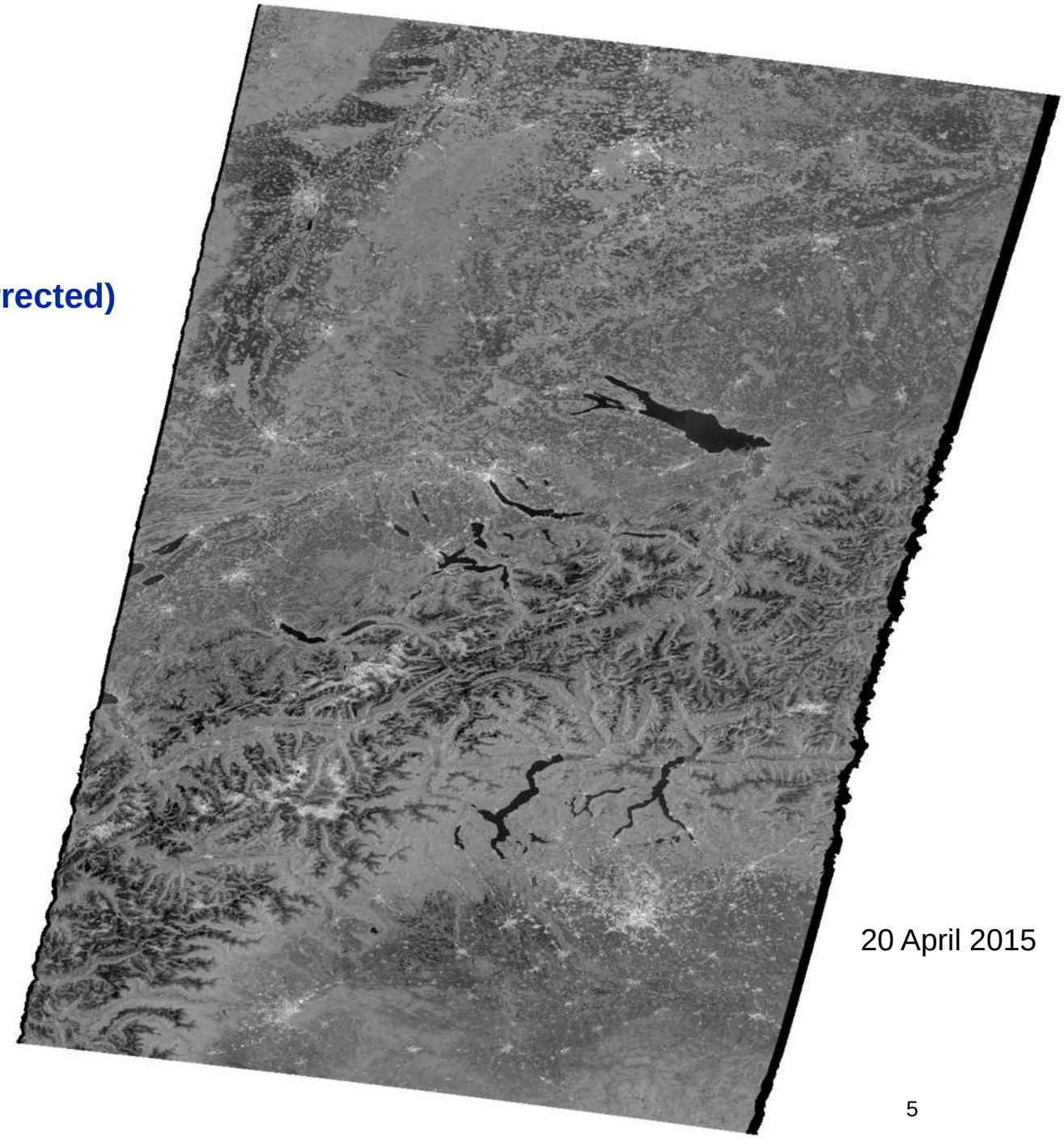
Dept. of Geography / R

Sentinel-1A: RTC

(Radiometrically Terrain Corrected)

g_T^0

-26dB -1dB



Generated automatically from 3 IW GRDH products using SRTM3

20 April 2015

Contains modified Copernicus Sentinel data (2015)

University of Zurich[UZH]

Sentinel-1A: GTC
(Geometrically Terrain Corrected)

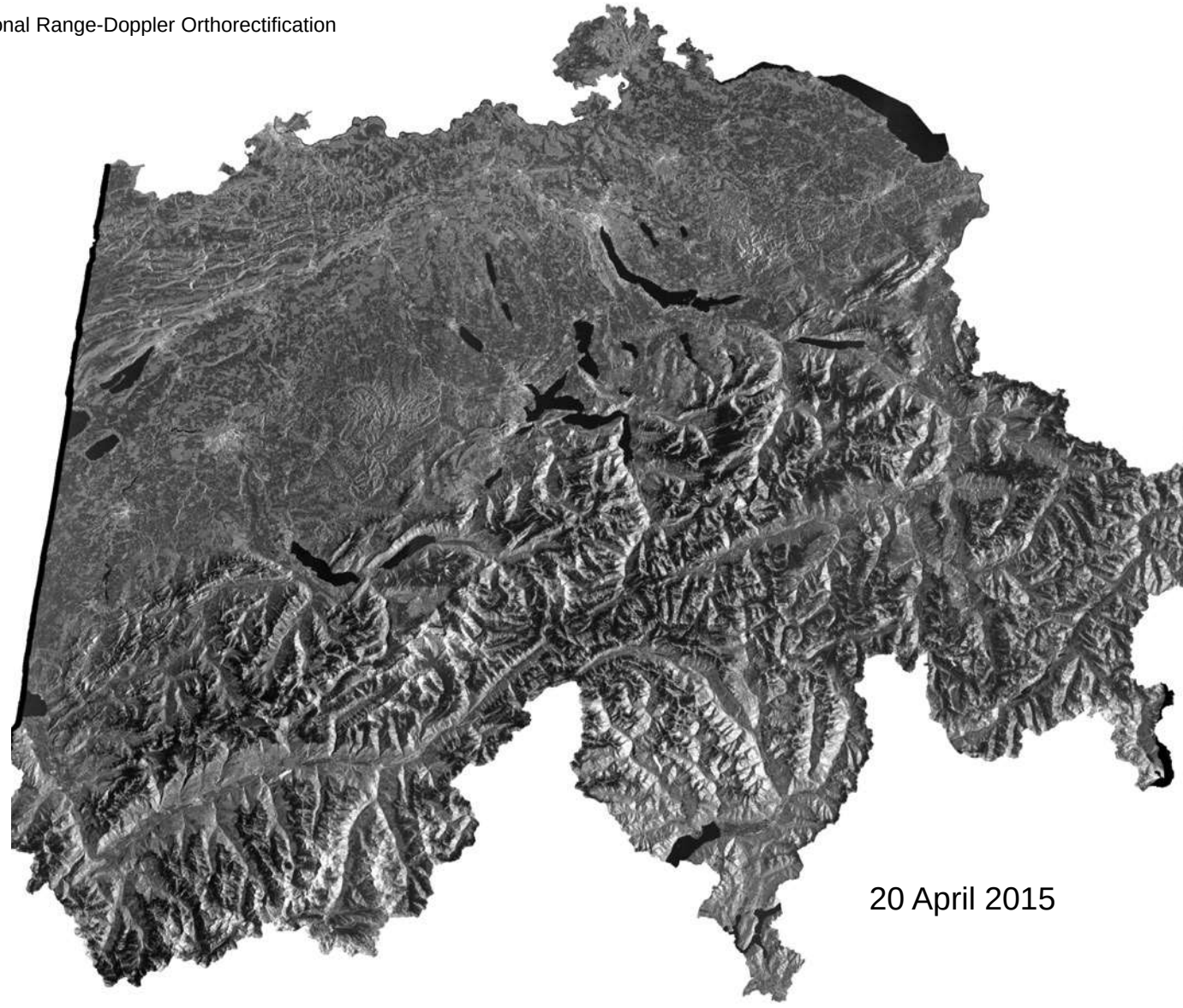
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Conventional Range-Doppler Orthorectification

Switzerland

g_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)

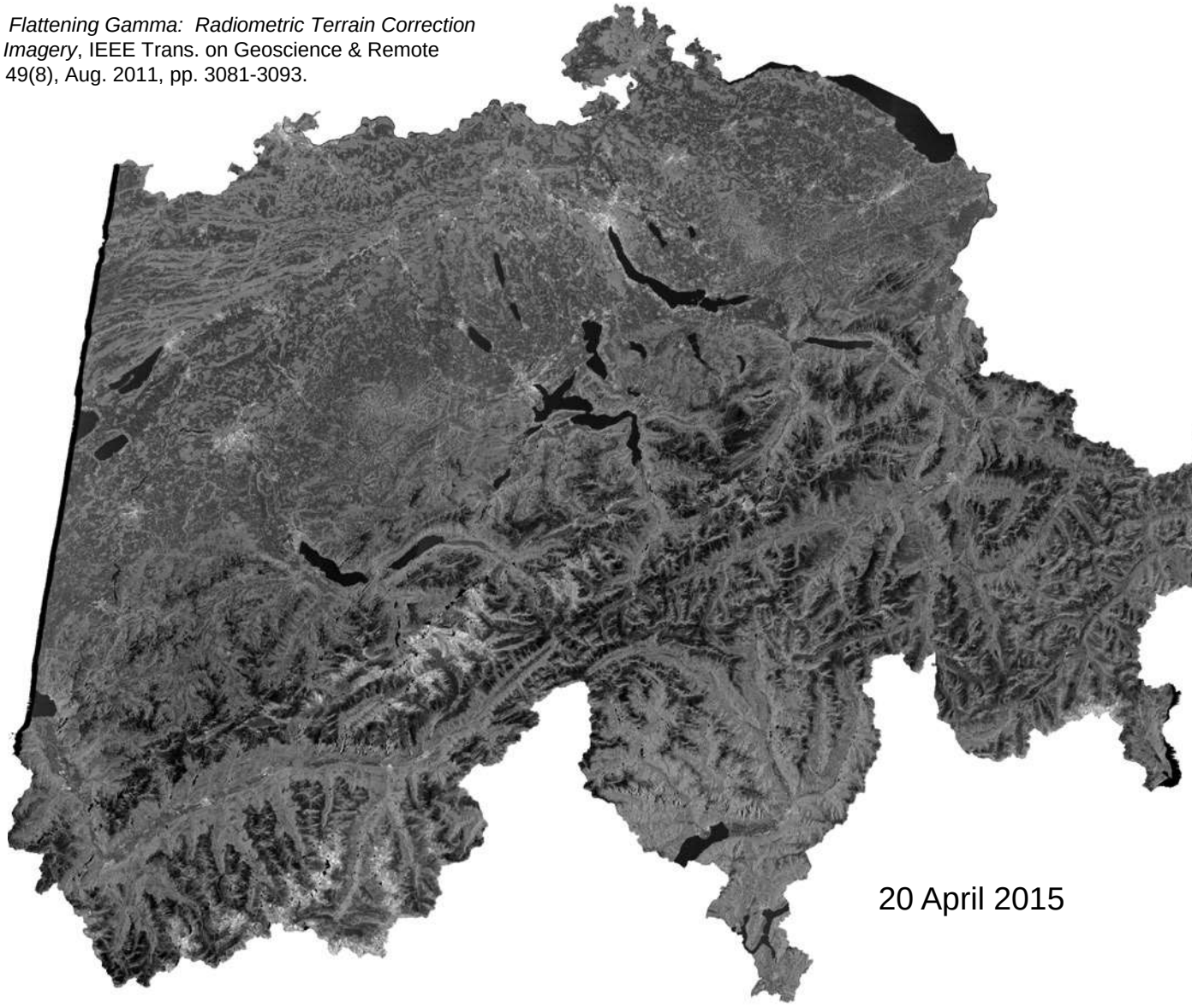
Dept. of Geography / Remote Sensing Laboratories

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

Switzerland

g_T^0 VH-pol.

-26dB -1dB



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

Contains modified Copernicus Sentinel data (2015)

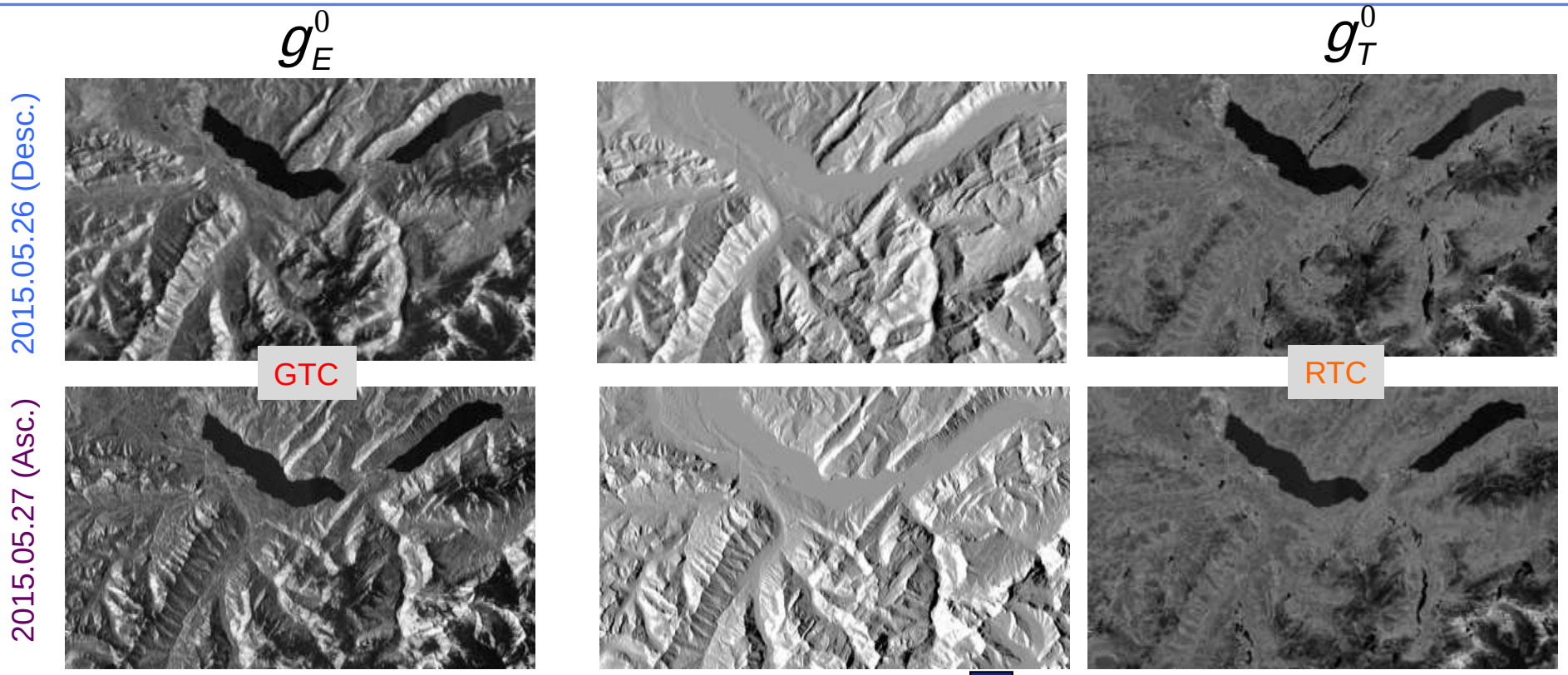
20 April 2015

Backscatter Composites

Backscatter Composites

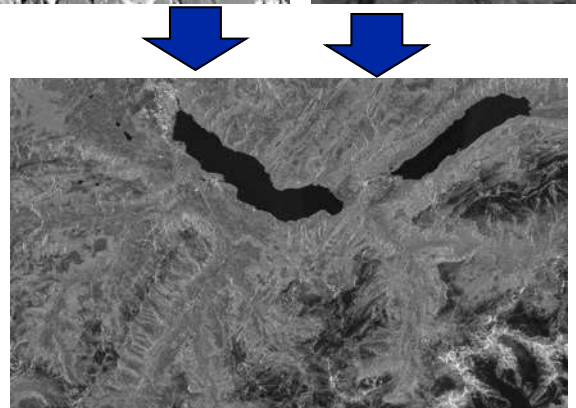
-26dB -1dB

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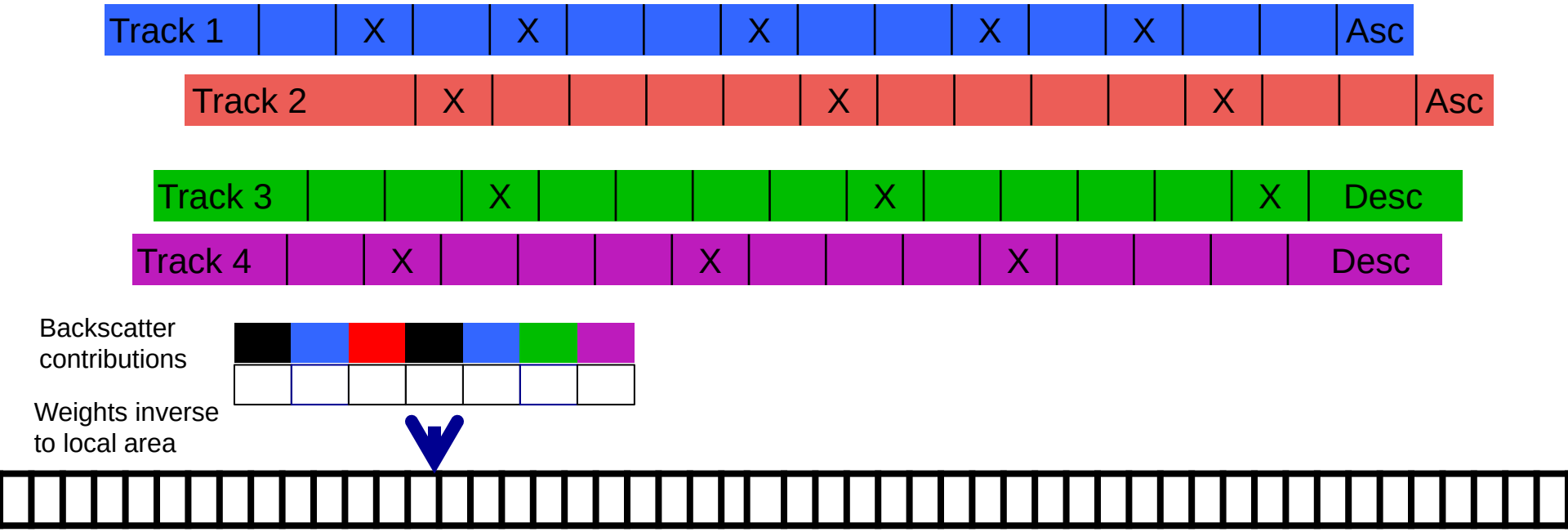
- Combine asc. & desc. observations to generate **composite** with improved local resolution
- Less shadow than single RTC, lower noise

Interlaken, Switzerland



Composite

Revisit Interval: Breaking the tyranny of exact repeat passes



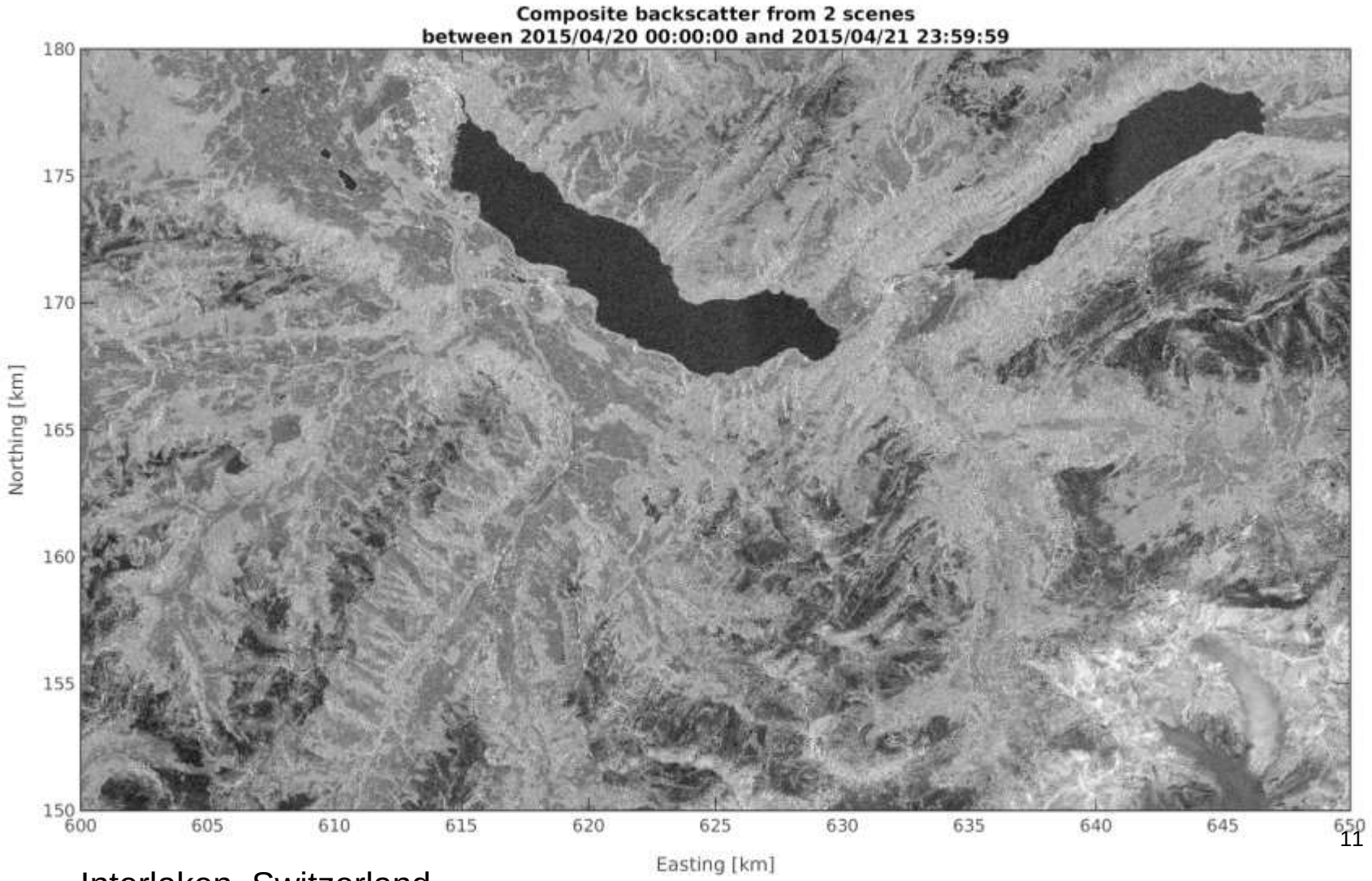
For *Regular Intervals* with temporal resolution better than repeat-pass interval

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

Composites in Time Series Movie

-26dB -1dB

Jan – May 2015



Contains modified Copernicus Sentinel data (2015)

Interlaken, Switzerland

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.

Uni
Zuri

Dep

Coastal British Columbia Backscatter Composites

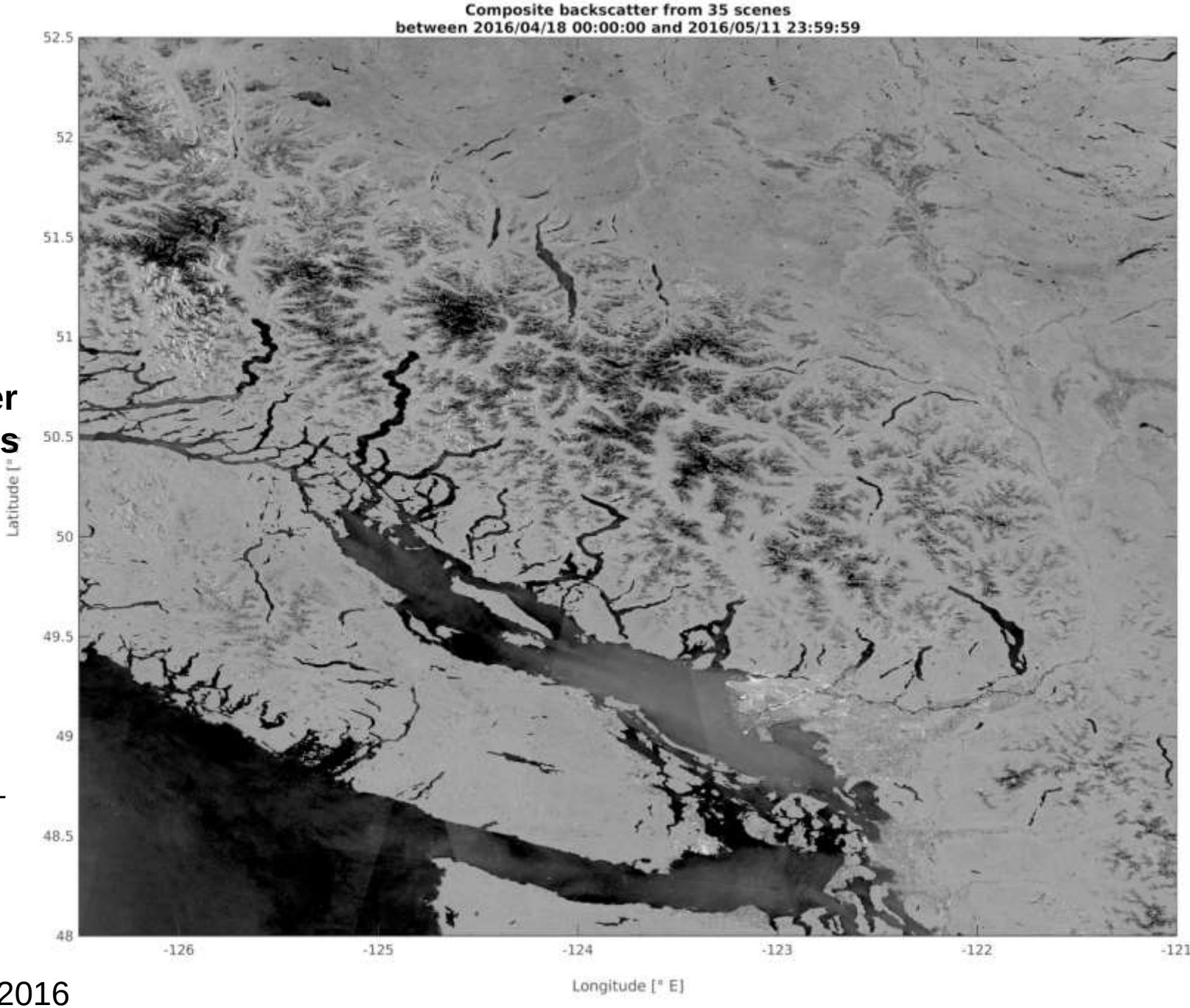
S1A IW VV

12 day delta

24 day window

N.B.

Increased dual-pol VV/VH acquisitions in last months)



Jan. – Dec. 2016

Contains modified Copernicus Sentinel data (2016)

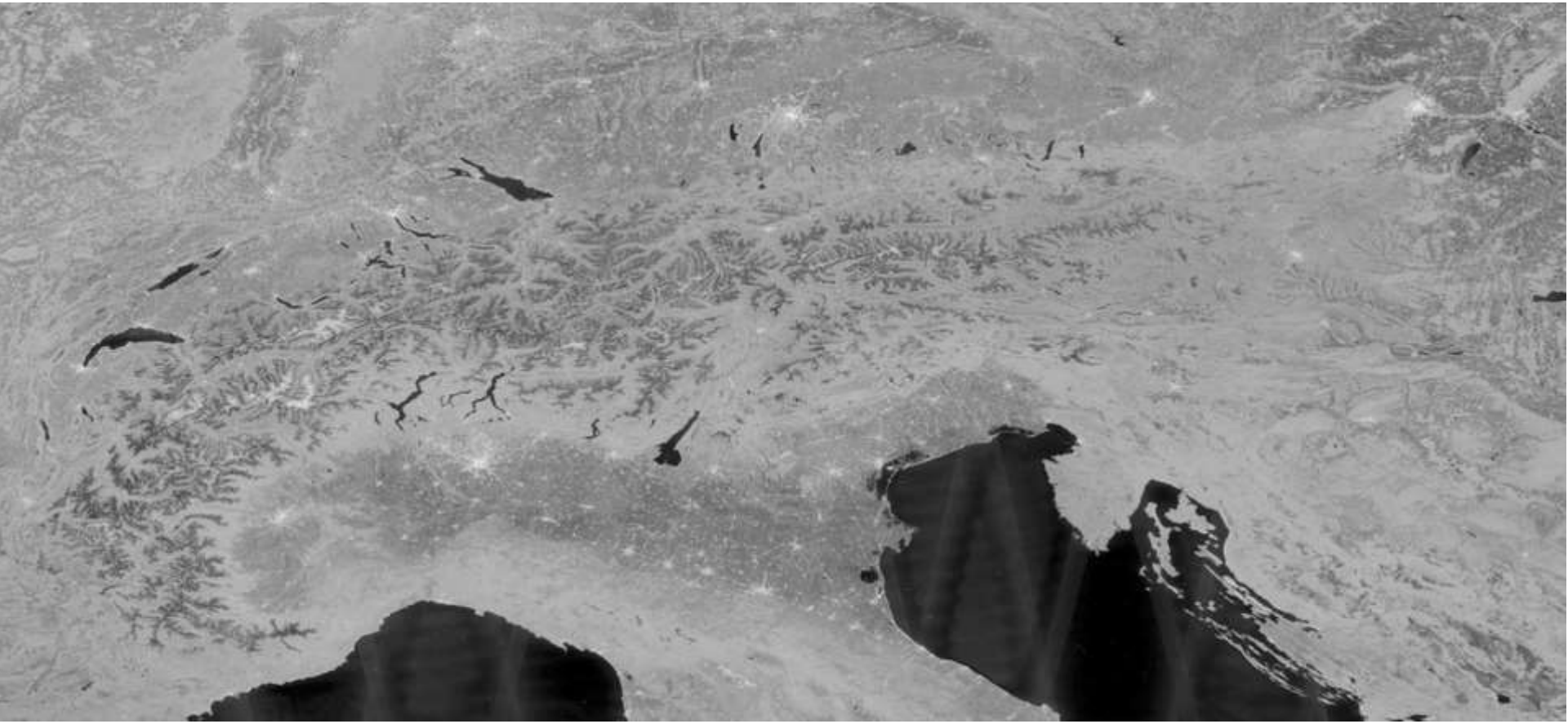
University of Zurich[UZH]

Sentinel-1 Alps Backscatter Mosaic

Dept. of Geography / Remote Sensing Laboratories

Contains modified Copernicus Sentinel data (2015-2016)

S1A IW VH & VV-pol. Oct. 2014 – Jan. 2017: 16-day time windows
Nov. 2015 – Dec. 2016 VH-pol. looped here:

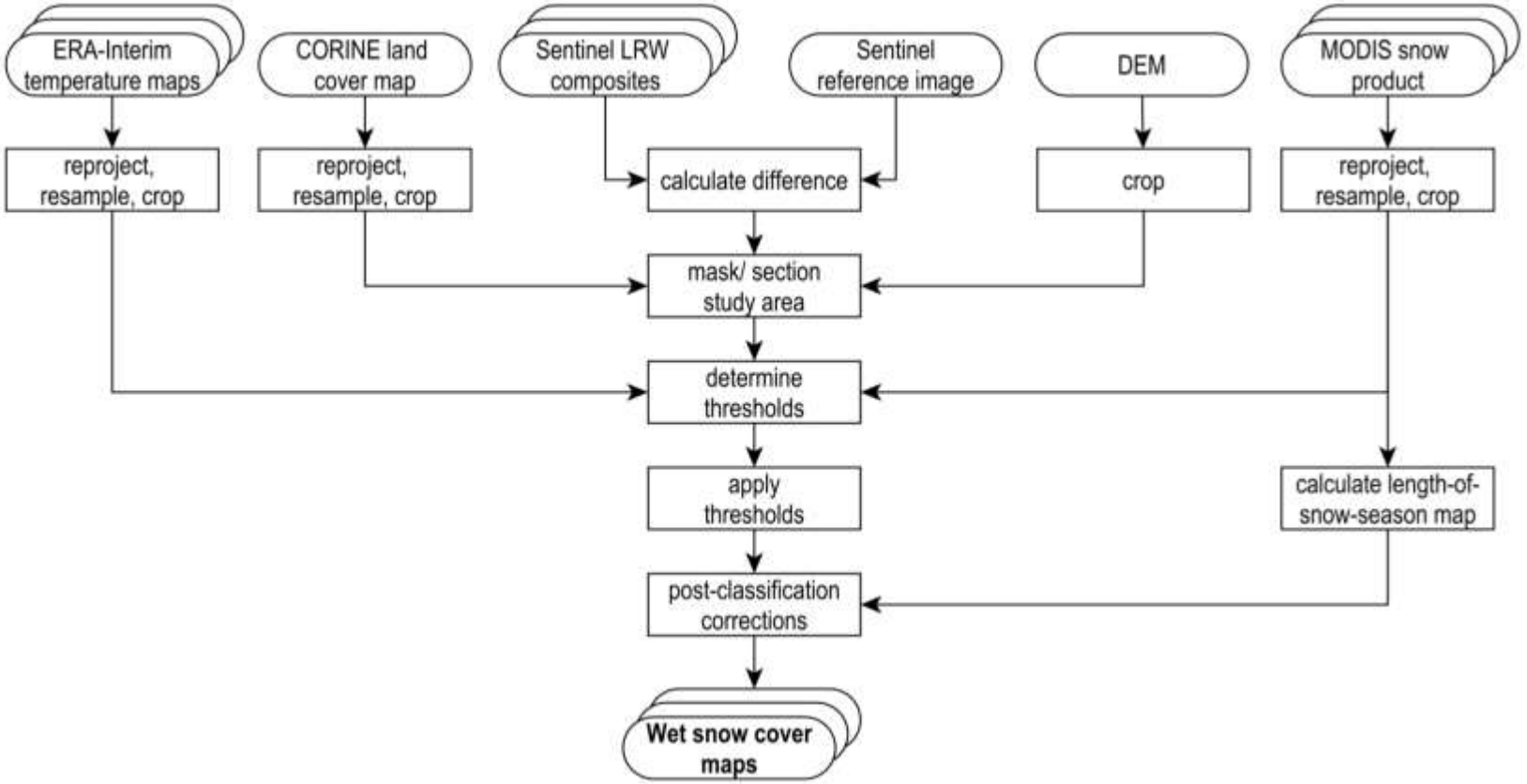


SRTM used for geometric and radiometric corrections

Sentinel-1 Wet Snow Mapping

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Contains modified Copernicus Sentinel data (2015)



University of Zurich[UZH]

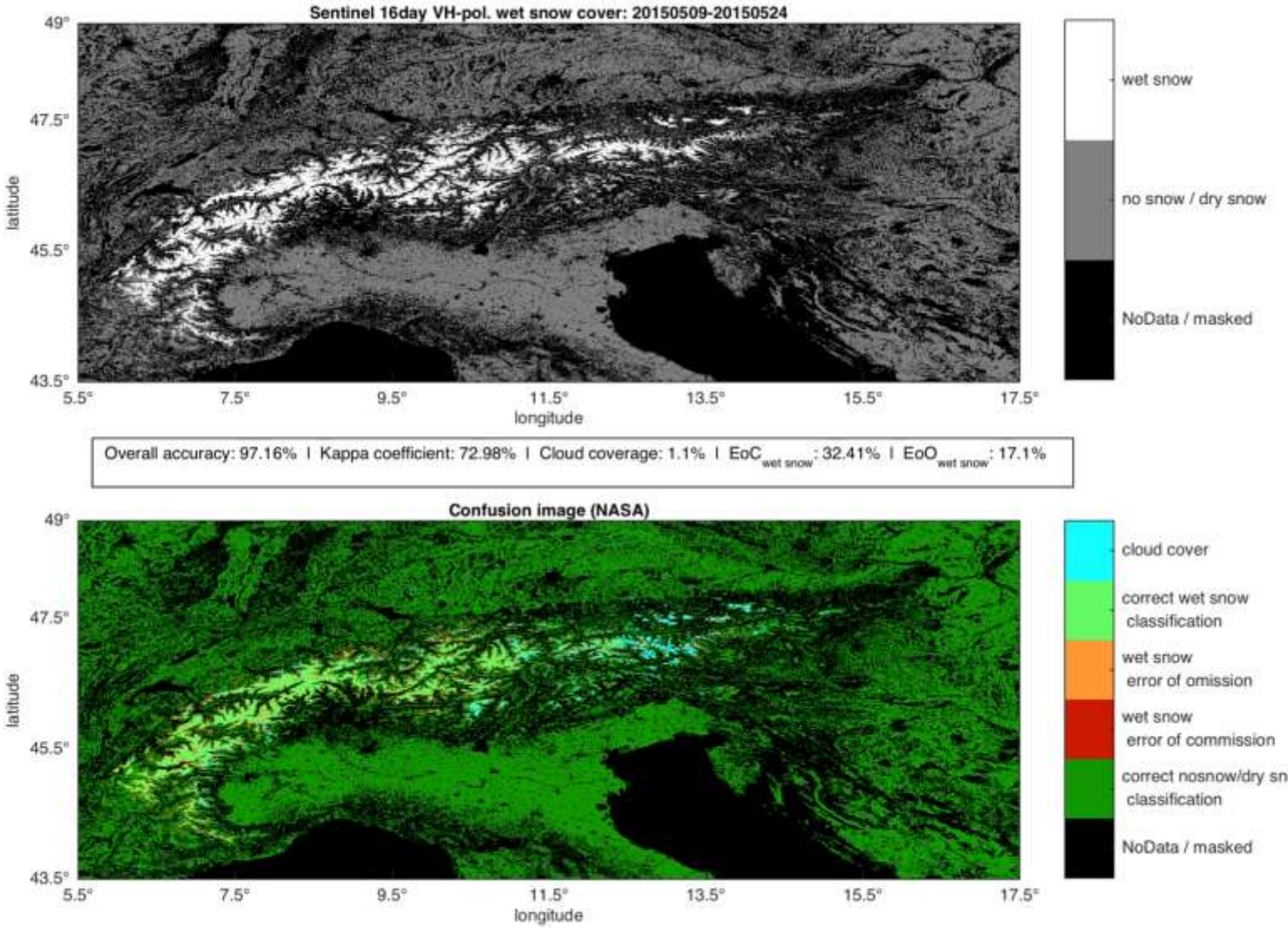
S1A Alps Wet Snow Maps

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Contains modified Copernicus Sentinel data (2015)

S1A IW 2015
VH & VV-pol.

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

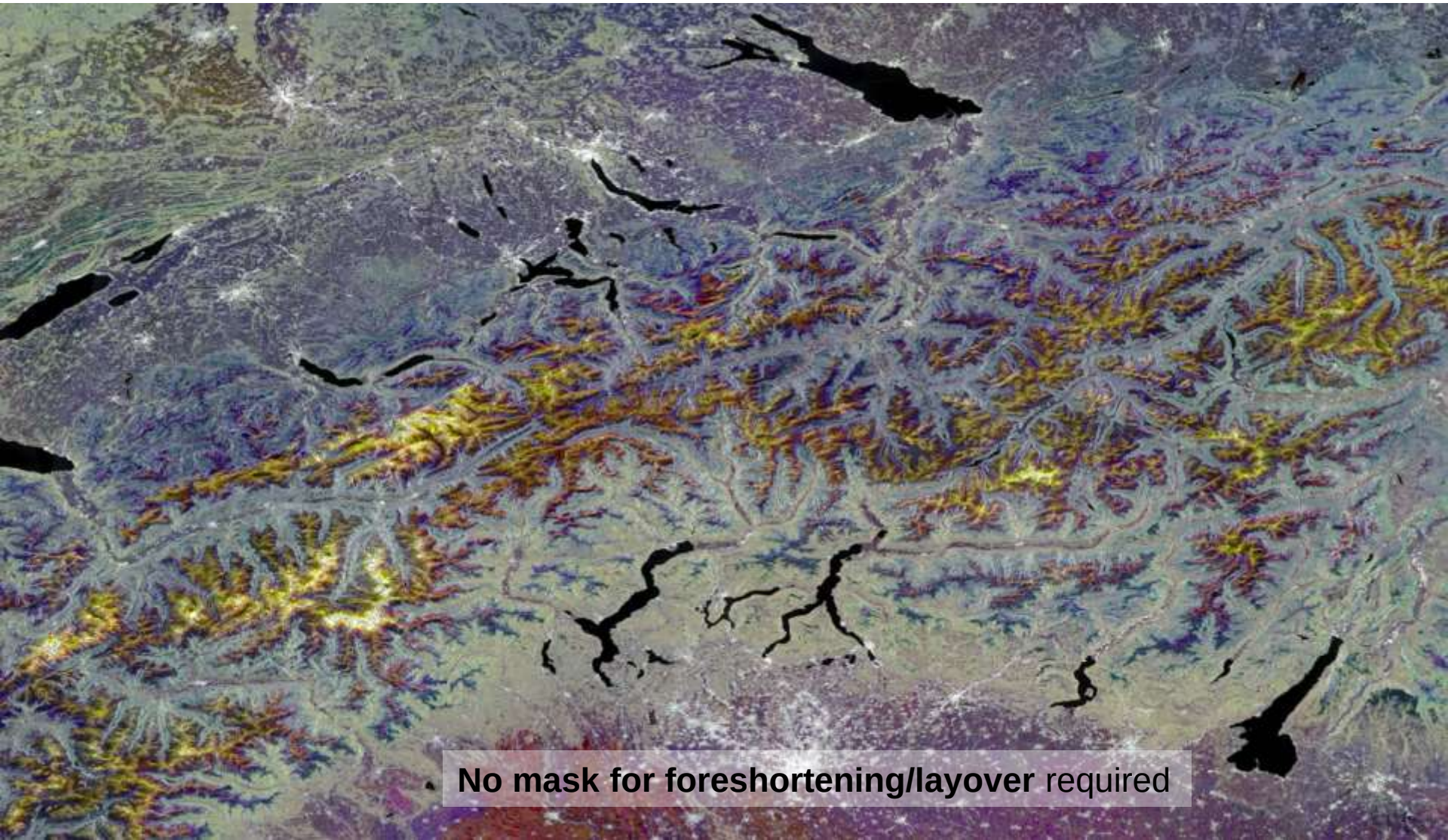


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Contains modified Copernicus Sentinel data (2015)

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Sentinel-1 IW 16d Composites 2015 VH: March 14-29, April 7-22, May 25-June 9; -23dB (black) to -6dB (white)



Methods for Wet Snow Retrieval

	Single Mode/Geometry	Composite from time window
Time covered	Single point in time	Narrow time window (e.g. 3 or 7 days)
Temporal resolution for backscatter comparisons	S1A+S1B: 6 days RS2: 24 days	Narrowest time window providing full coverage, e.g. at temperate latitudes: S1 ~6 days x2; Arctic: ~2 days x2
Sensitivity to data dropout (missing acquisition)	Strong	Less sensitive
Noise	System level	Lowered with averaging
Spatial resolution on mountains	Poor on foreslopes, high on back-slopes	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

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Dept.

Data provision organised through WMO Polar Space Task Group (CSA & MDA)

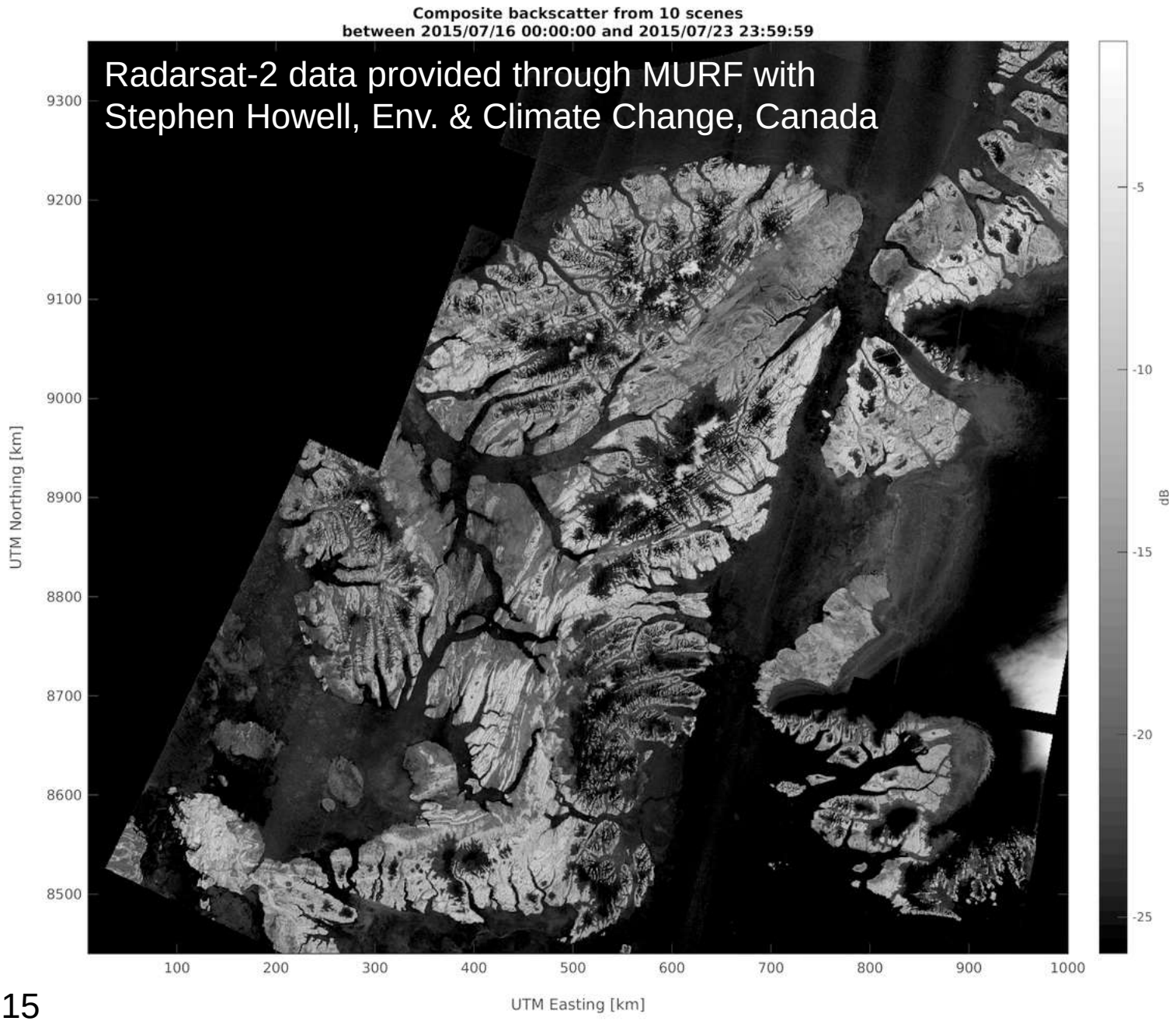
Ellesmere Island Backscatter Composites

RS2 SCWA HV

4 day delta

8 day window

N.B.
8 bit radiometry
CDEM



May – Aug. 2015

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Ellesmere Island Backscatter Composites

S1A EW HV

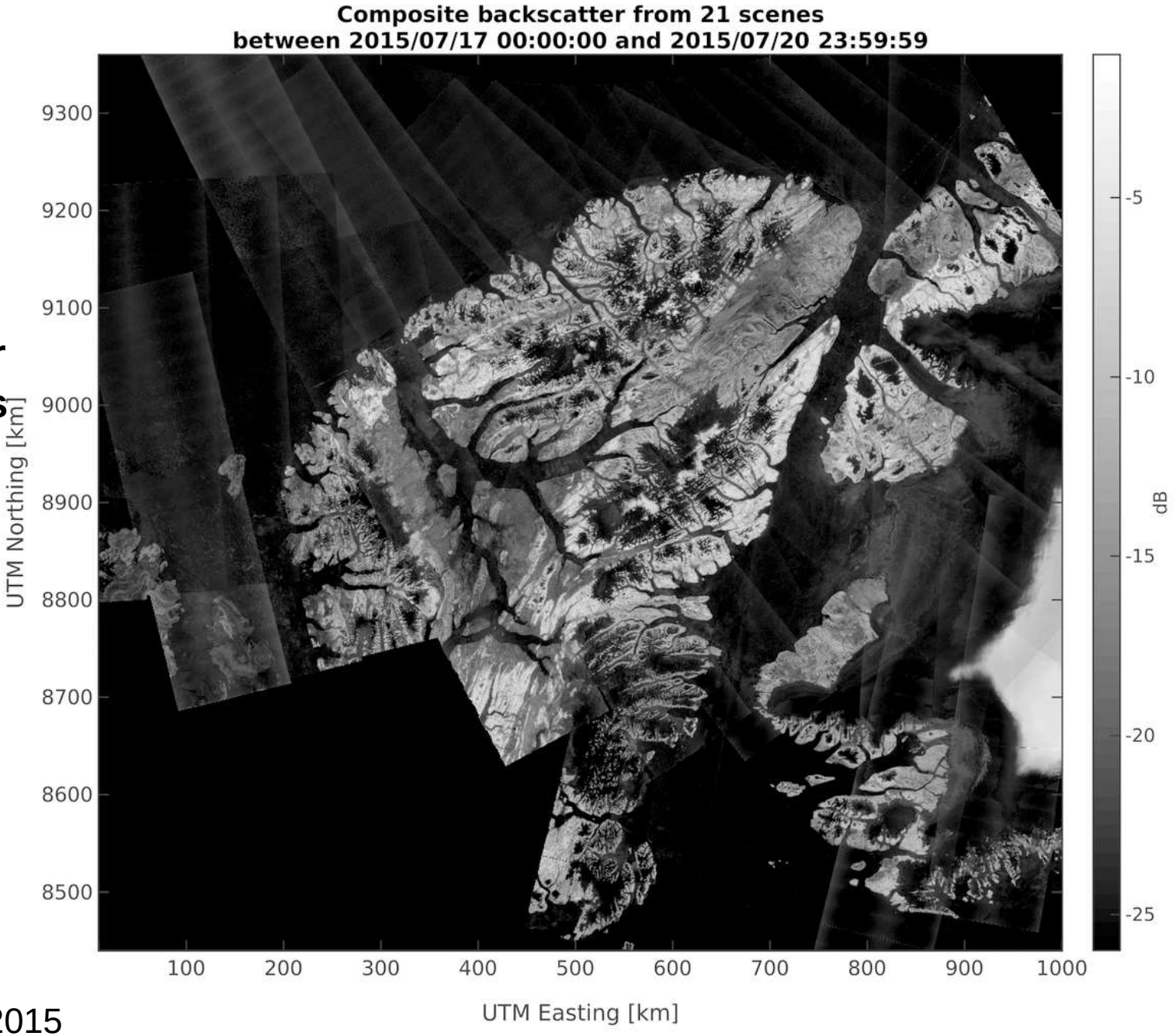
2 day delta

4 day window

N.B.

HH also available

CDEM



May – Sept. 2015

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Ellesmere Island *Hybrid* Backscatter Composites

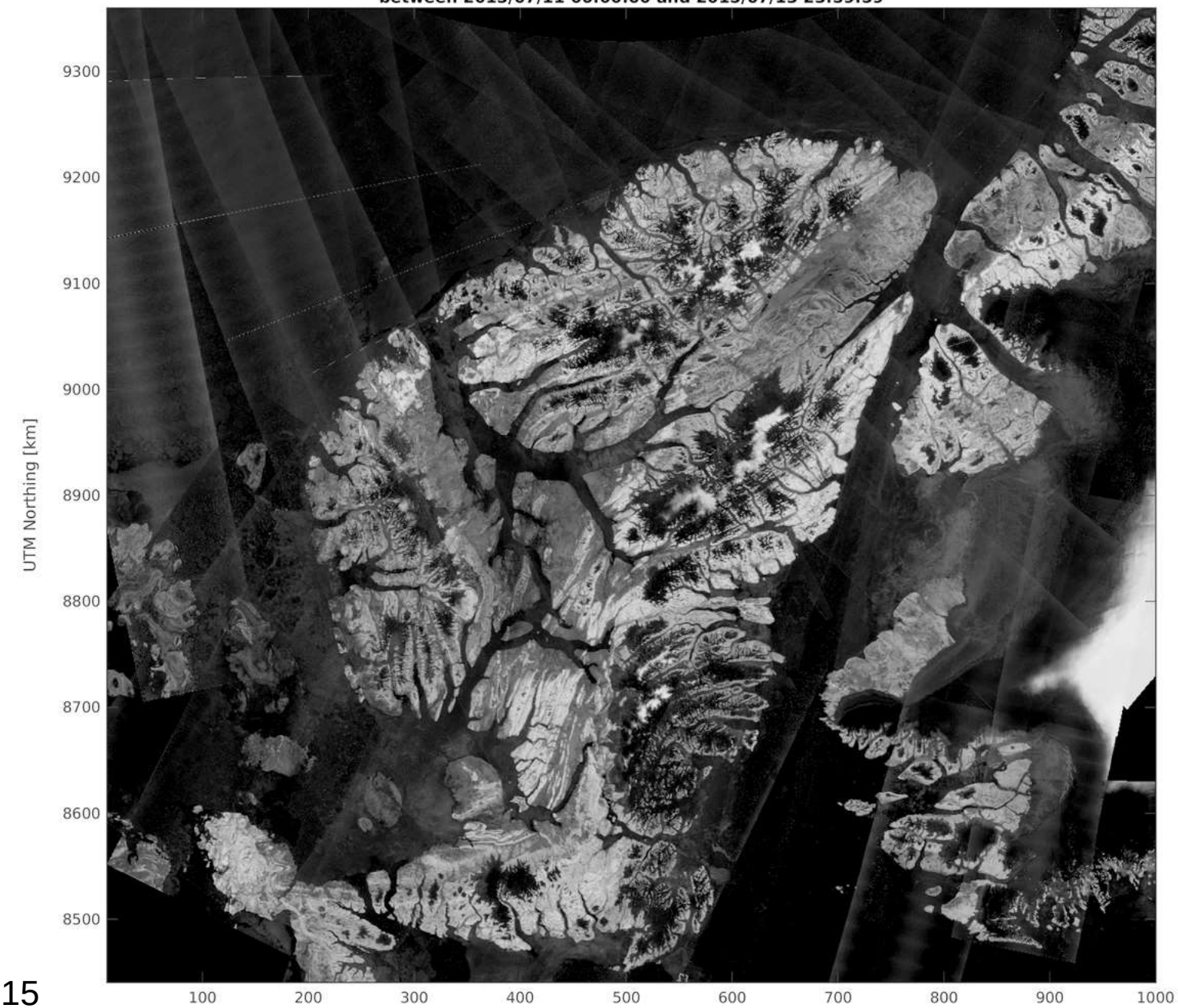
S1A **+** ***RS2***

HV

1 day delta

3 day window

CDEM



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Ellesmere Island *Hybrid* Backscatter Composites

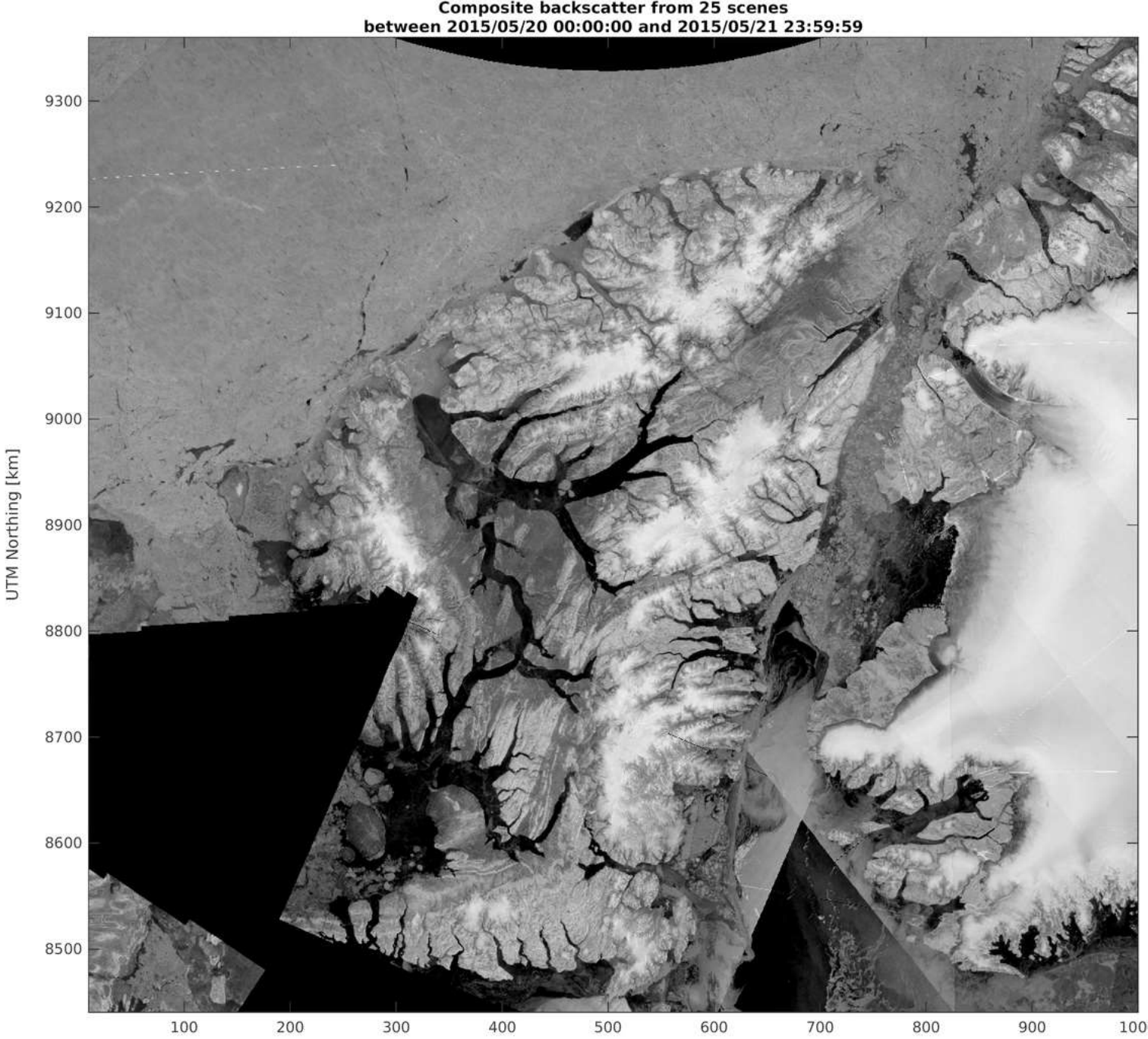
S1A* + *RS2

HH

1 day delta

2 day window

CDEM



May – Aug. 2015

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Ellesmere Island Backscatter Composites

S1A/S1B HV

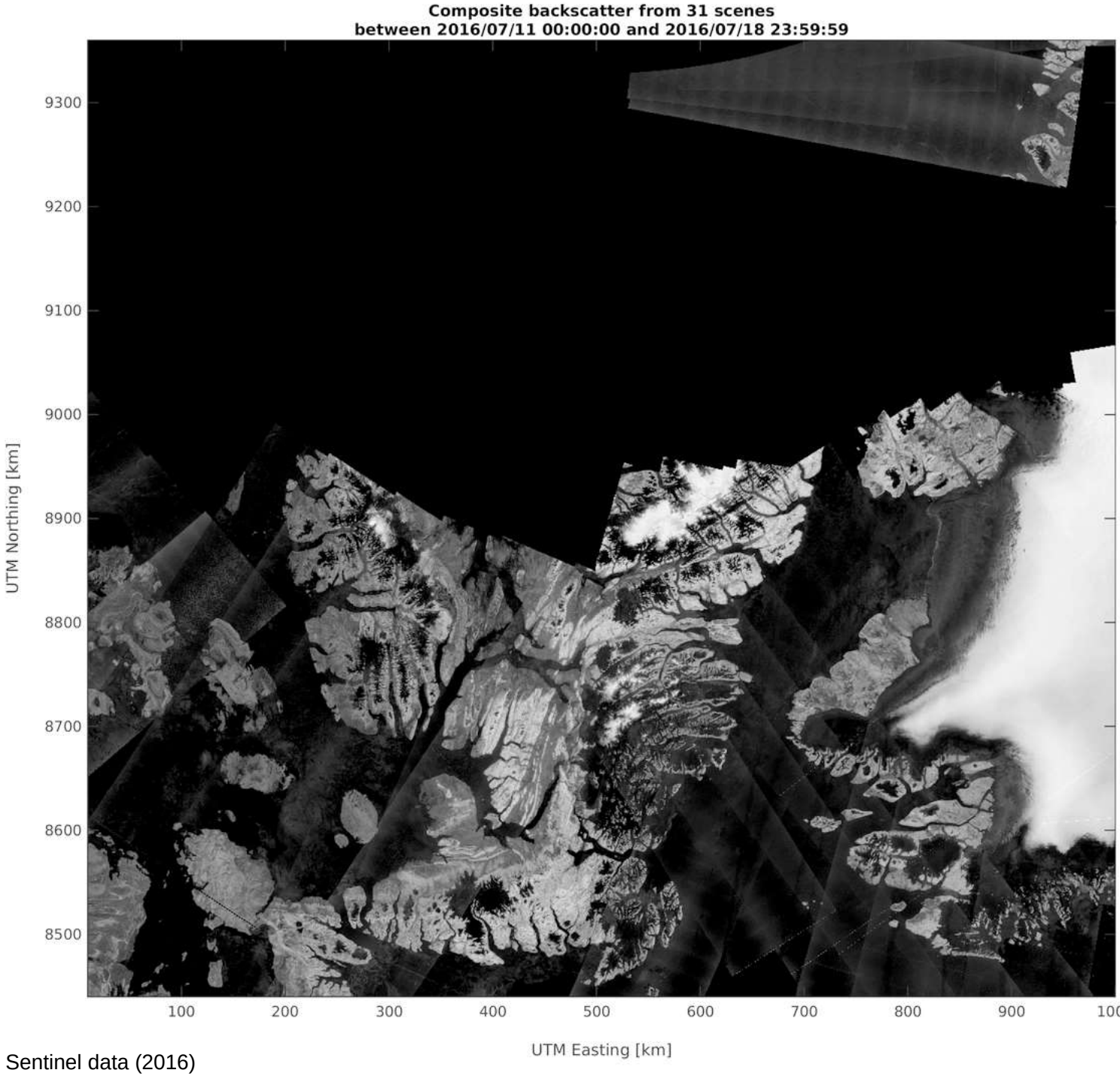
4 day delta

8 day window

S1B contributing from late Sept. 2016

CDEM

May 2016 – Jan. 2017



Contains modified Copernicus Sentinel data (2016)

University Zurich[UZH]

Dept. of Ge

Ellesmere Island Backscatter Composites

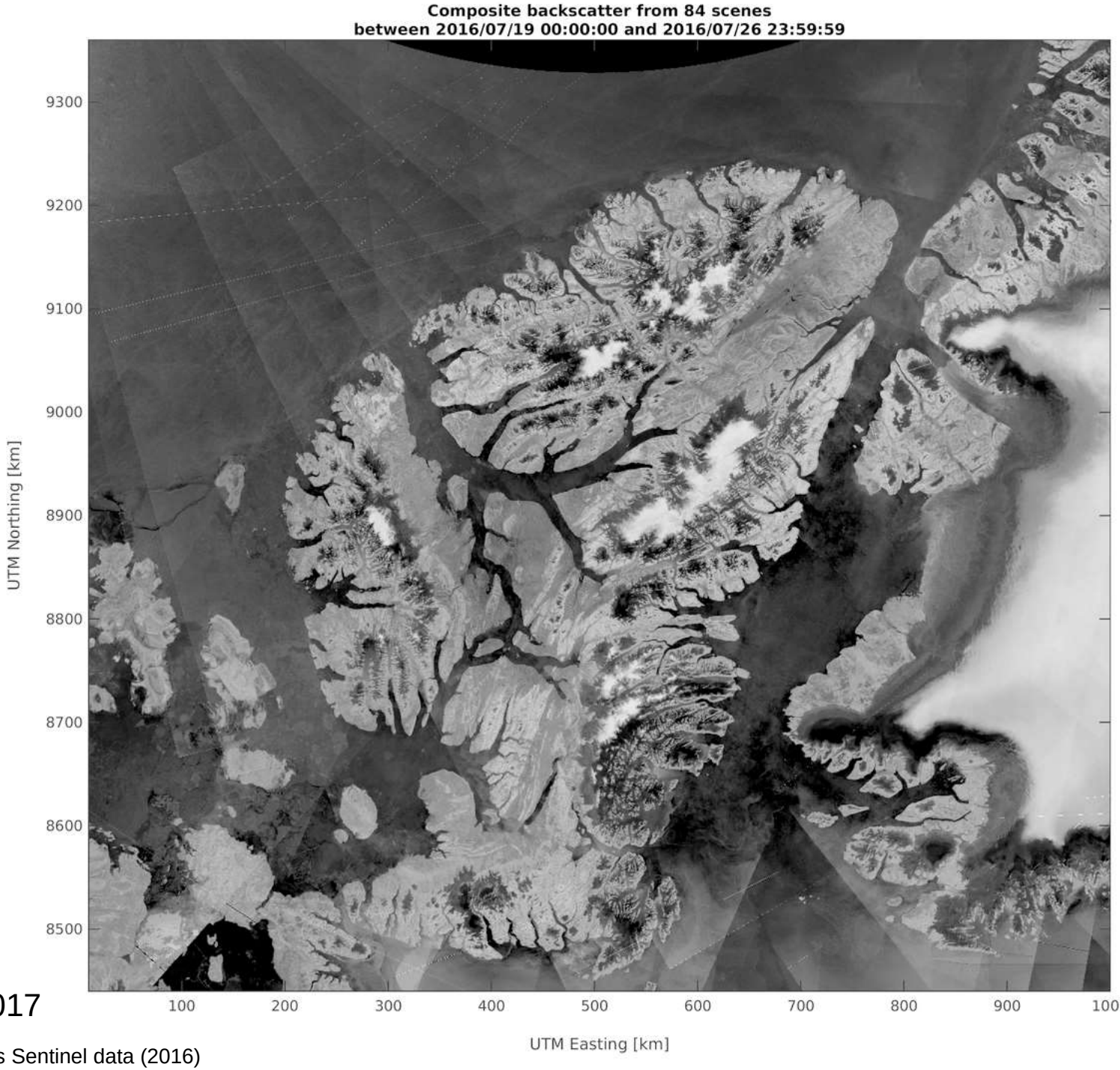
S1A/S1B HH

4 day delta

8 day window

S1B contributing from late Sept. 2016

CDEM



May 2016 – Jan. 2017

Contains modified Copernicus Sentinel data (2016)

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Ellesmere Island Backscatter Composites

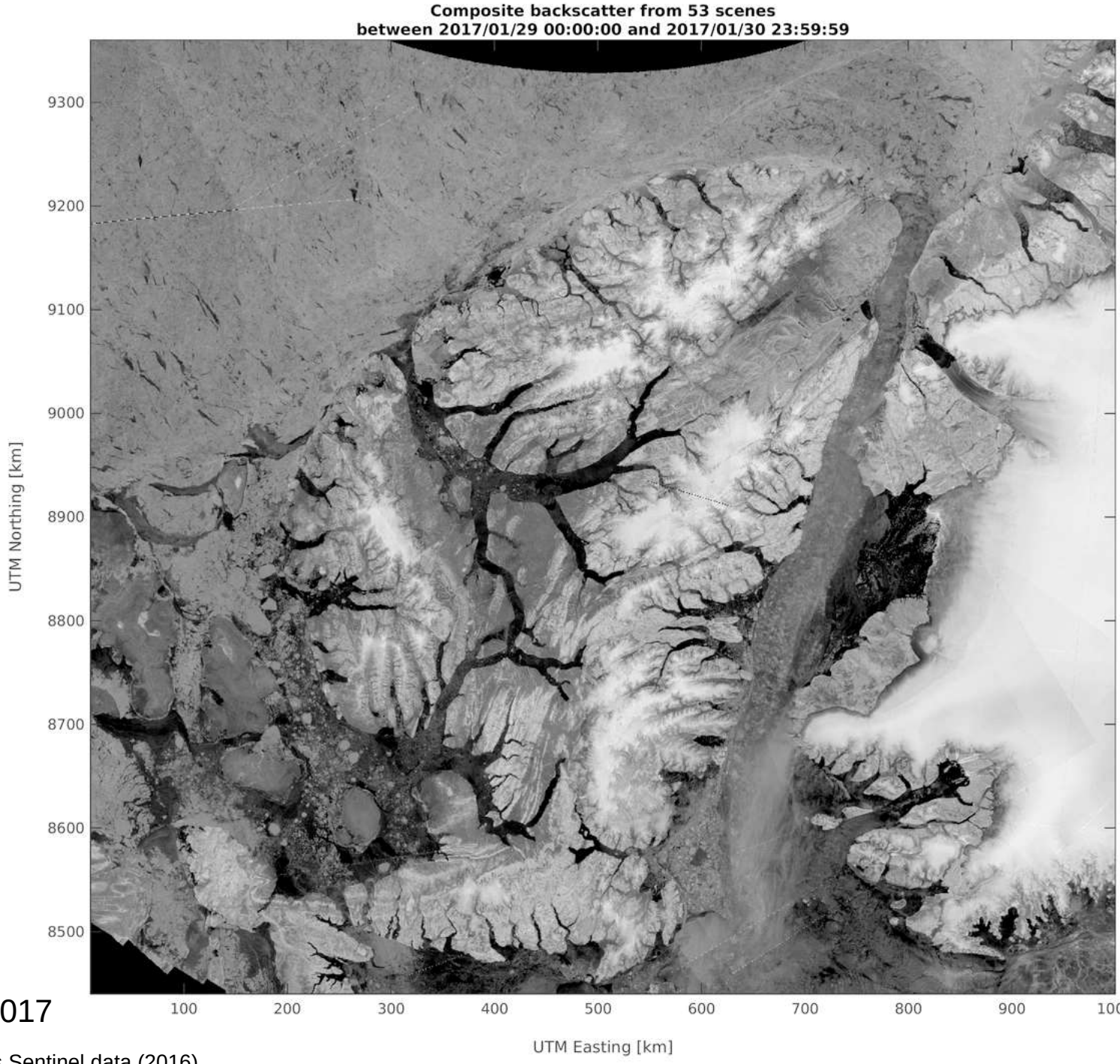
S1A/S1B HH

1 day delta

2 day window

S1B contributing from late Sept. 2016

CDEM



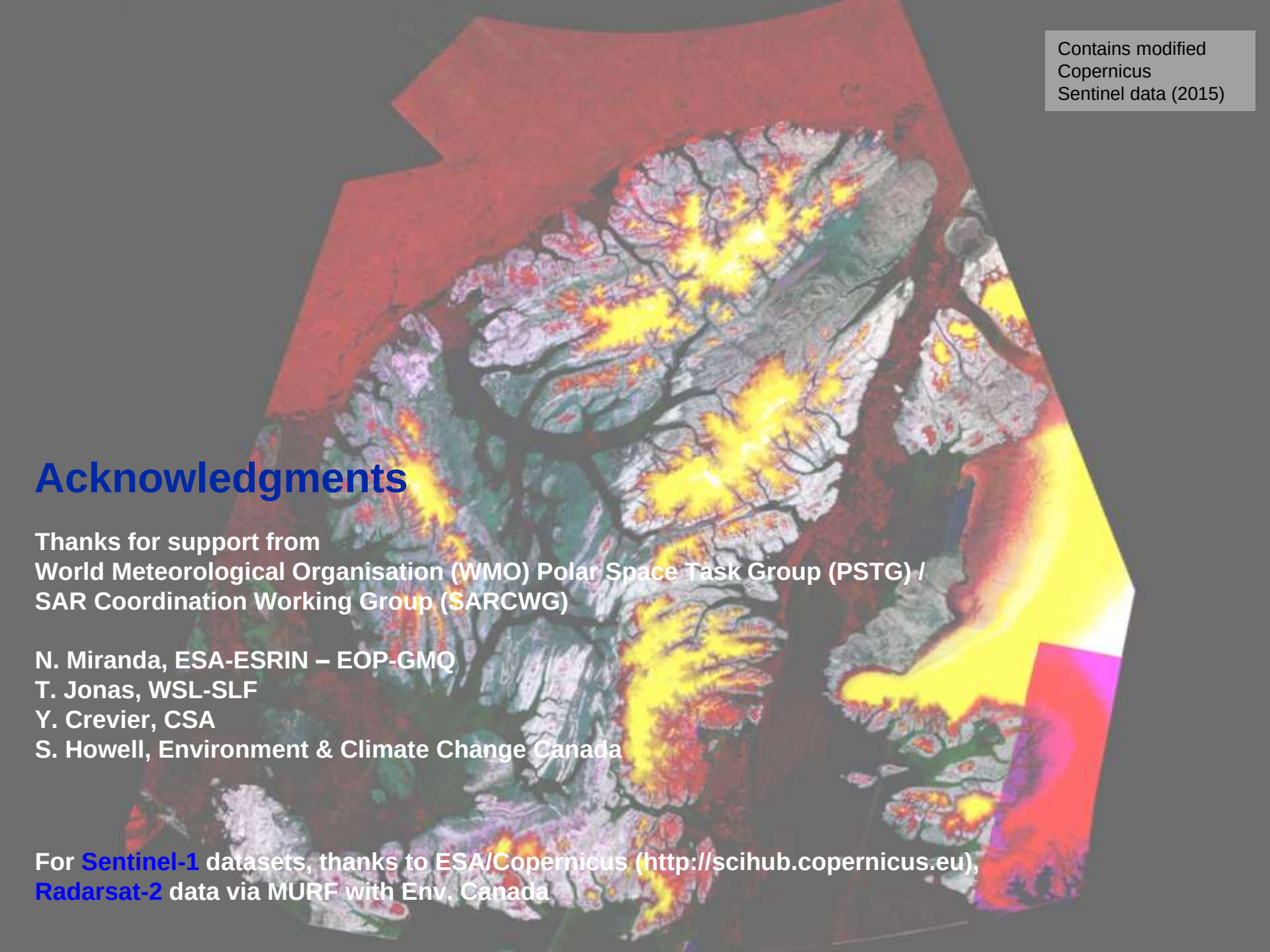
Sept. 2016 – Jan. 2017

Contains modified Copernicus Sentinel data (2016)

Backscatter Composites

- **Demonstration of *hybrid backscatter maps* from Sentinel-1 & Radarsat-2**
  - Dependent on robust geometric and radiometric corrections for effects of topography
  - Specific effects of mode, track strongly mitigated
  - Temporal window window improved from ~8 or 4 days to 3 days (HV), 2 days for HH
  - Composites provide wide area coverage
    - Effects of layover/shadow/foreshortening strongly mitigated

- **With composites, we can benefit from harnessing multi-sensor synergies**:
  - Width of time window can be *narrowed* simultaneously improving spatial coverage
    - 2017: S1A+S1B+RS2 (3 satellites)
    - 2018: launch of **RCM-1, -2, -3** (6 satellites)
    - Shortly afterward: S1C & S1D, …



Contains modified Copernicus Sentinel data (2015)

Acknowledgments

Thanks for support from
World Meteorological Organisation (WMO) Polar Space Task Group (PSTG) / SAR Coordination Working Group (SARCWG)

N. Miranda, ESA-ESRIN – EOP-GMQ
T. Jonas, WSL-SLF
Y. Crevier, CSA
S. Howell, Environment & Climate Change Canada

For Sentinel-1 datasets, thanks to ESA/Copernicus (http://scihub.copernicus.eu), Radarsat-2 data via MURF with Env. Canada