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Multi-sensor Wide-area Level-3 Radar Backscatter Time Series

CEOS WGCV SAR Cal/Val Workshop
ESA-ESRIN, Frascati, Italy, Nov. 18-22, 2019

David Small, Christoph Rohner (UZH)
Nuno Miranda (ESA)
Stephen Howell (ECCC)
Yves Crevier (CSA)

REMOTE SENSING LABORATORIES RSL
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CEOS SAR Calibration/Validation Workshop

Local Incidence Angle Considered Harmful

David Small[1], Nuno Miranda[2], Erich Meier[1]

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david.small@geo.uzh.ch

[2]: European Space Agency, Frascati, Italy

Pasadena, California, USA -- Nov. 17-19, 2009

SAR Constellations

- Sentinel-1A and Sentinel-1B acquiring >12TB per day
- Radarsat-2 a commercial enterprise
- RCM just came out of commissioning

- Sentinel-1 and RCM satellites have same central frequency
  - But they are in differing orbits: systematic *InSAR combinations unviable*
- Combining the backscatter amplitudes will still be possible, assuming acquisitions modes are selected to ensure *common polarisations*

- **Multisource Composite Backscatter maps**
  - Optical constellation composite products the norm, e.g. for MODIS cloud clearing
  - Systematic composites from radar constellations: benefits

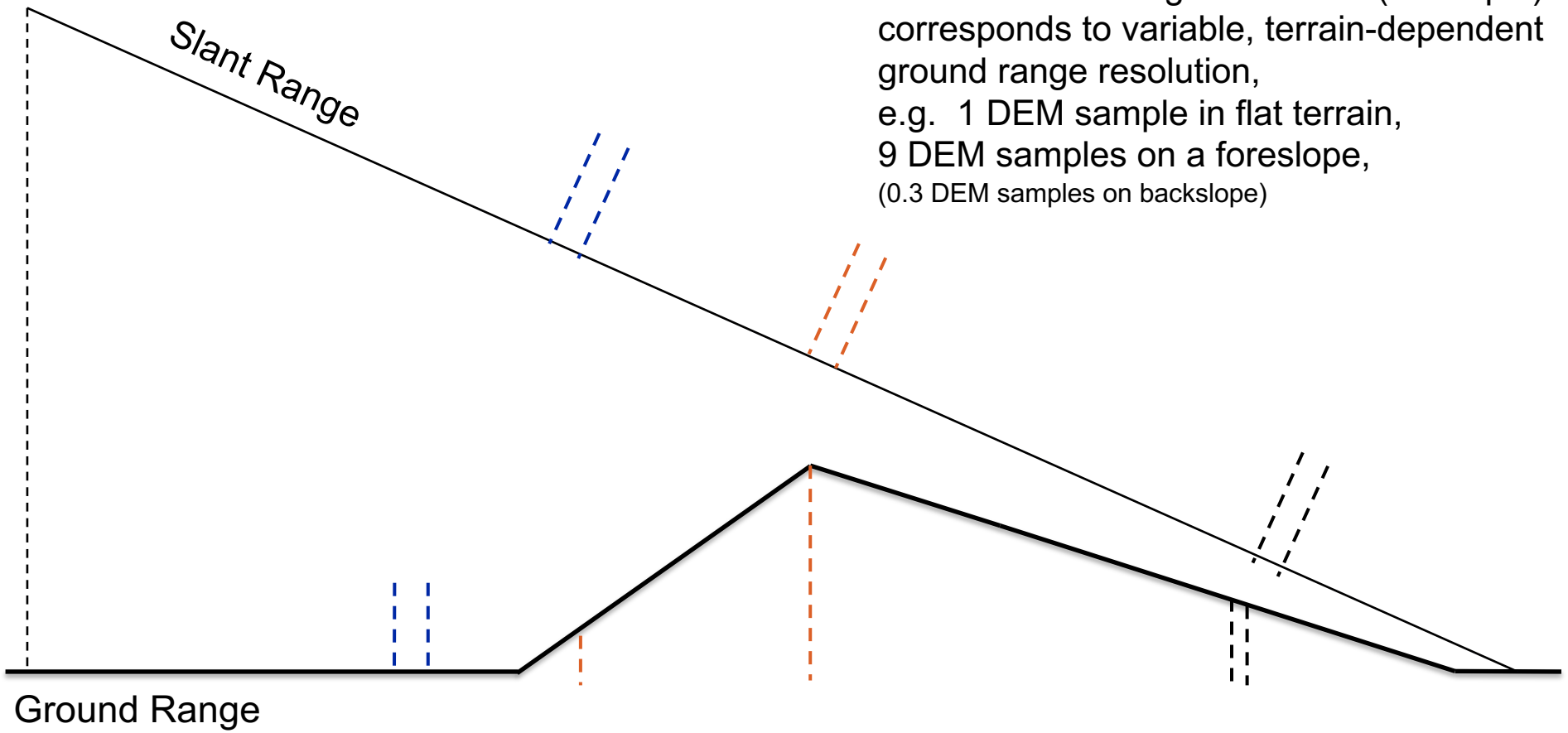
Radar terrain corrections

- Geometric Terrain Correction (**GTC**)
- Radiometric Terrain Correction (**RTC**)
- Wide area backscatter *composites* from Local Resolution Weighting (**LRW**)
- LRW backscatter *composite* time series are ***Analysis Ready Data*** **(ARD)**
  - *2D image time-series:*
    - *Applicable over wide area*
    - *Lowers barrier to entry for analysis*

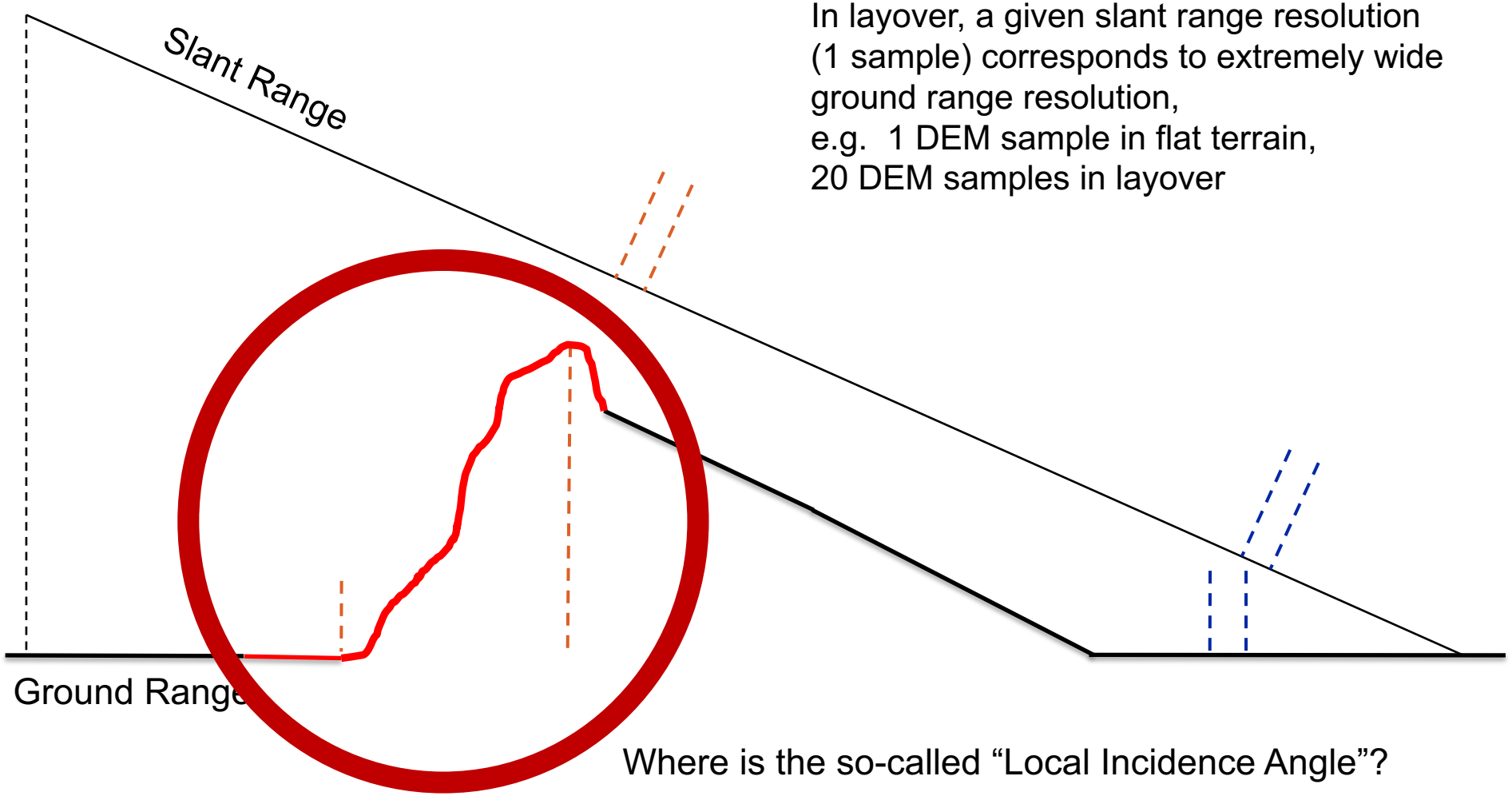
- **CEOS CARD4L** Analysis Ready Data for Land Processes
  - Define standards for ARD backscatter products
    - RTC (L1): Terrain-flattening – Normalised Radar Backscatter (NRB)
    - LRW (L3): Wide-area **Analysis Ready Data**

Foreshortening a non-local phenomenon

Constant slant range resolution (1 sample) corresponds to variable, terrain-dependent ground range resolution,
e.g. 1 DEM sample in flat terrain,
9 DEM samples on a foreslope,
(0.3 DEM samples on backslope)



Layover a non-local phenomenon



In layover, a given slant range resolution (1 sample) corresponds to extremely wide ground range resolution,
e.g. 1 DEM sample in flat terrain,
20 DEM samples in layover

Where is the so-called “Local Incidence Angle”?

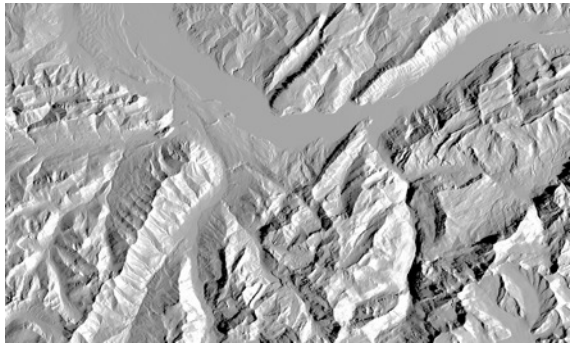
Terrain-flattened Gamma Nought

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

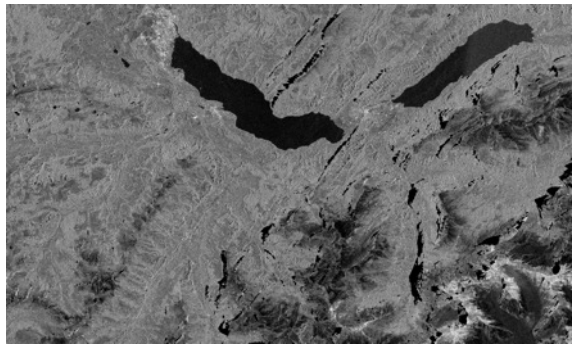
β^0 GTC



A_γ / A_β

-26dB -1dB

γ_T^0 =



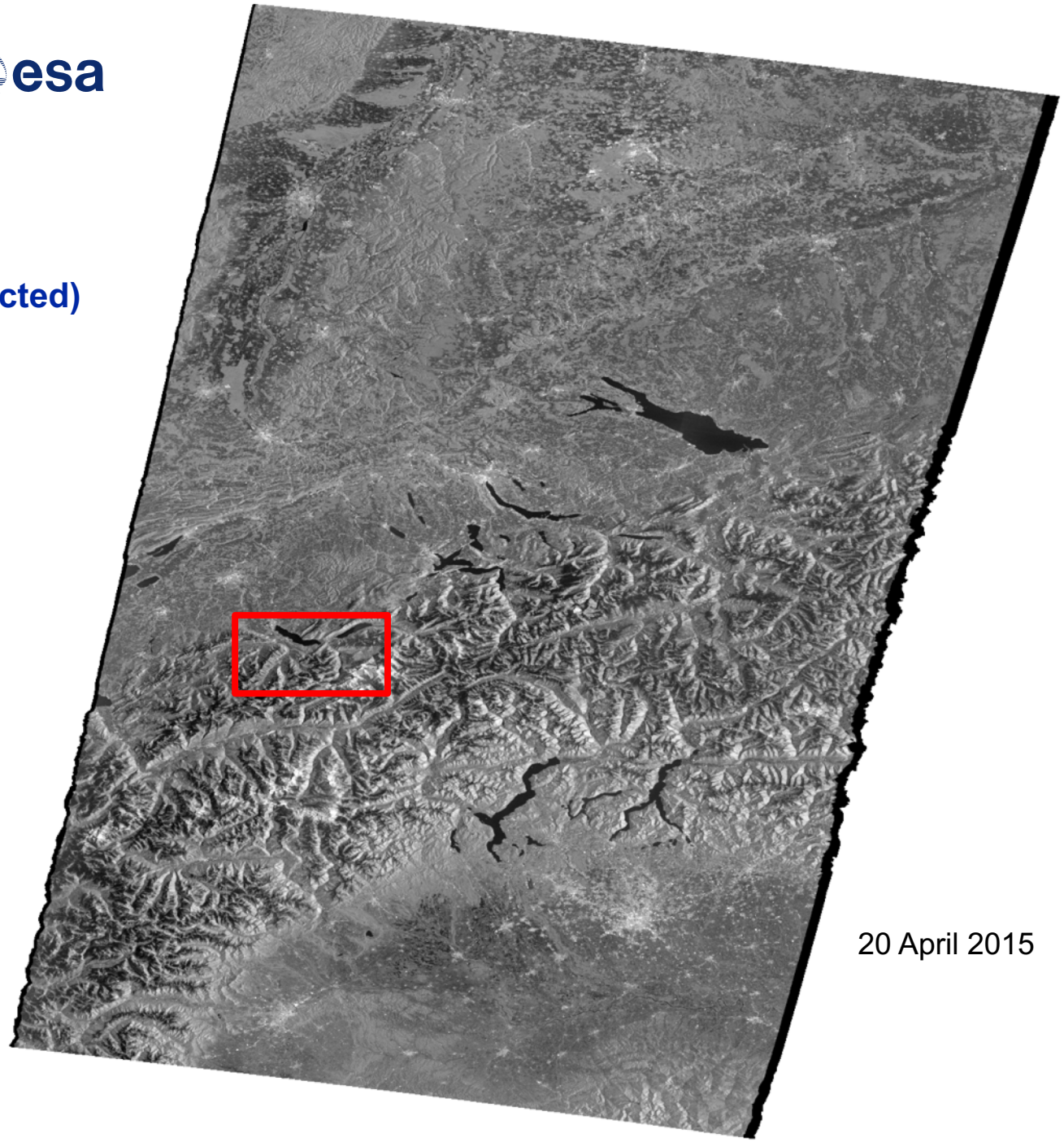
RTC

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

Sentinel-1A: GTC
(Geometrically Terrain Corrected)

$$\gamma^0_E$$

-26dB -1dB



Generated automatically from 3 IW GRDH products using SRTM3

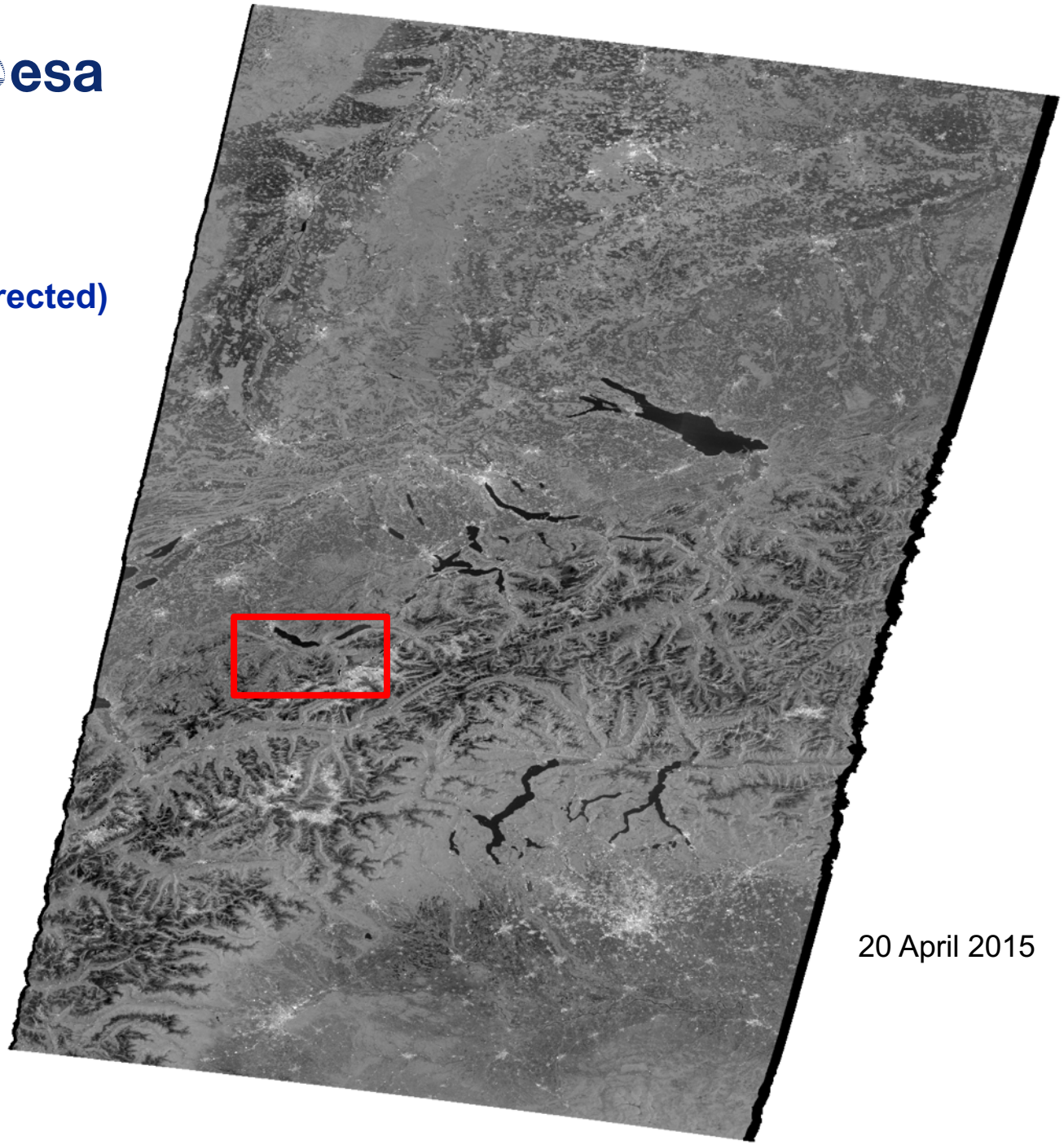
20 April 2015

Copernicus Sentinel data (2015)

Sentinel-1A: RTC
(Radiometrically Terrain Corrected)

$$\gamma_T^0$$

-26dB -1dB



20 April 2015

Generated automatically from 3 IW GRDH products using SRTM3

Contains modified Copernicus Sentinel data (2015)

Backscatter Composites

-26dB -1dB

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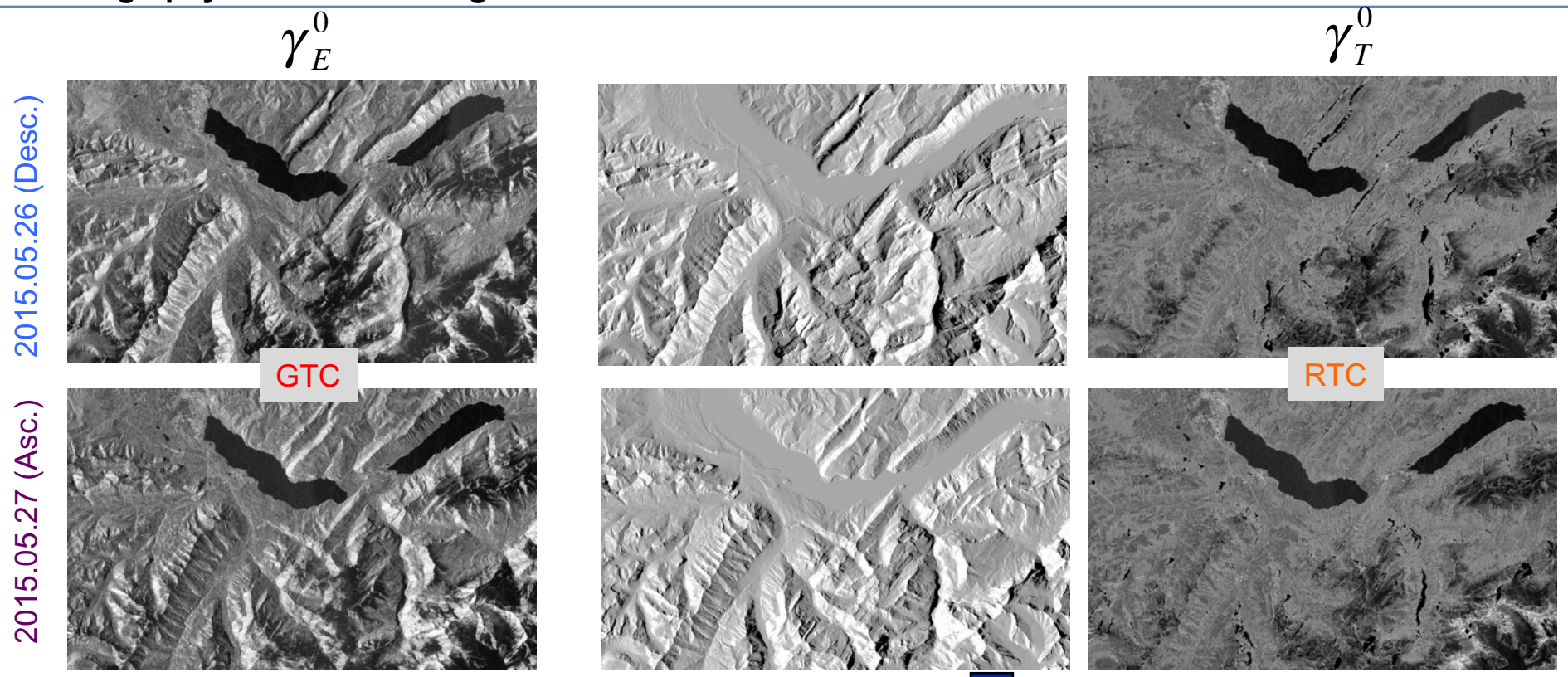
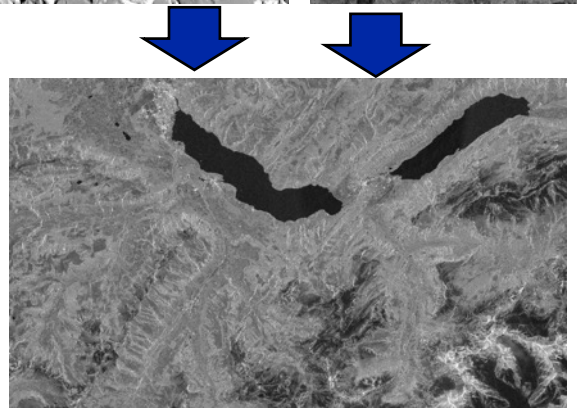


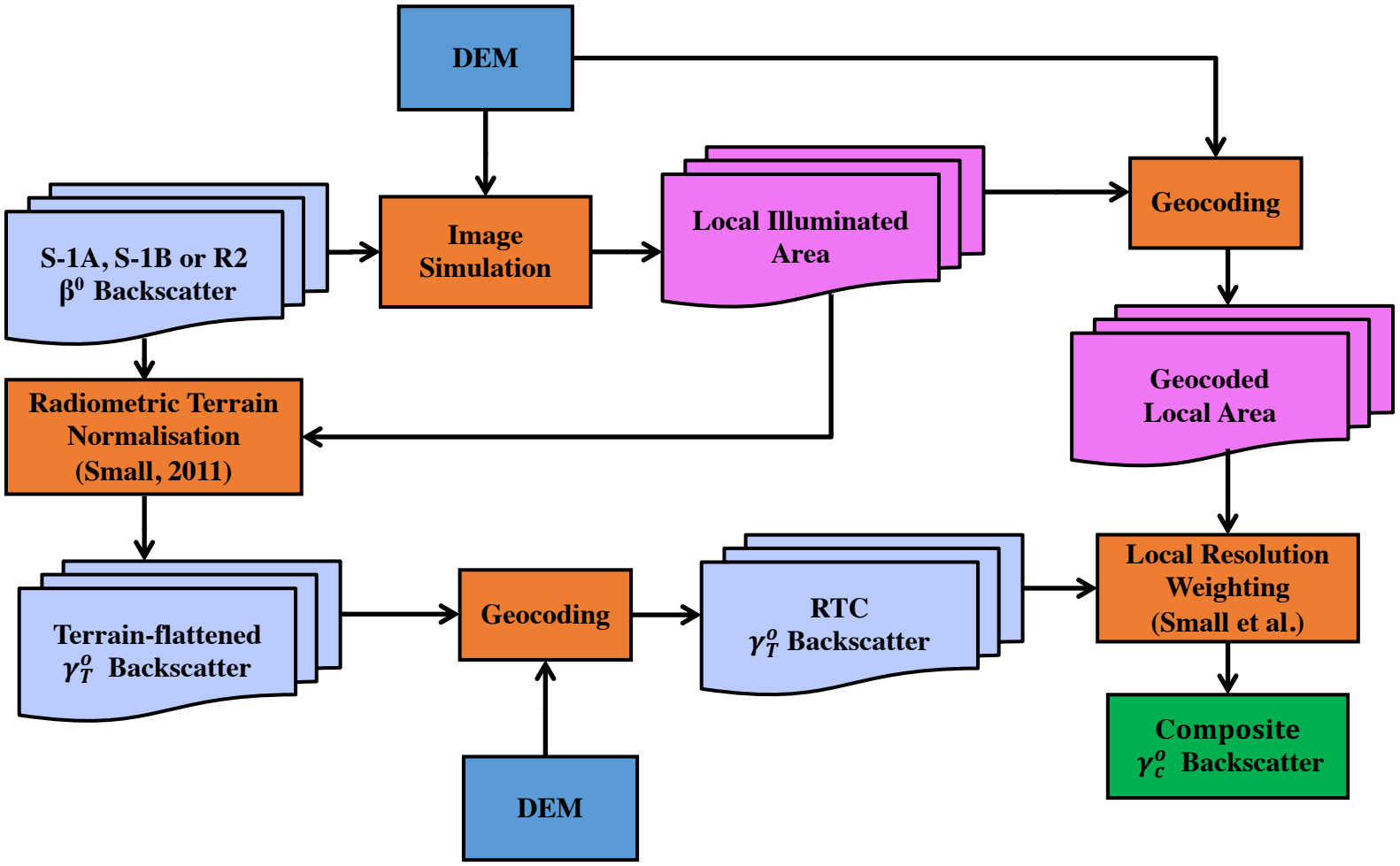
- Combine asc. & desc. observations to generate **composite** with improved local resolution
- Less shadow than single RTC, lower noise

Interlaken, Switzerland



Composite

Local Resolution Weighting

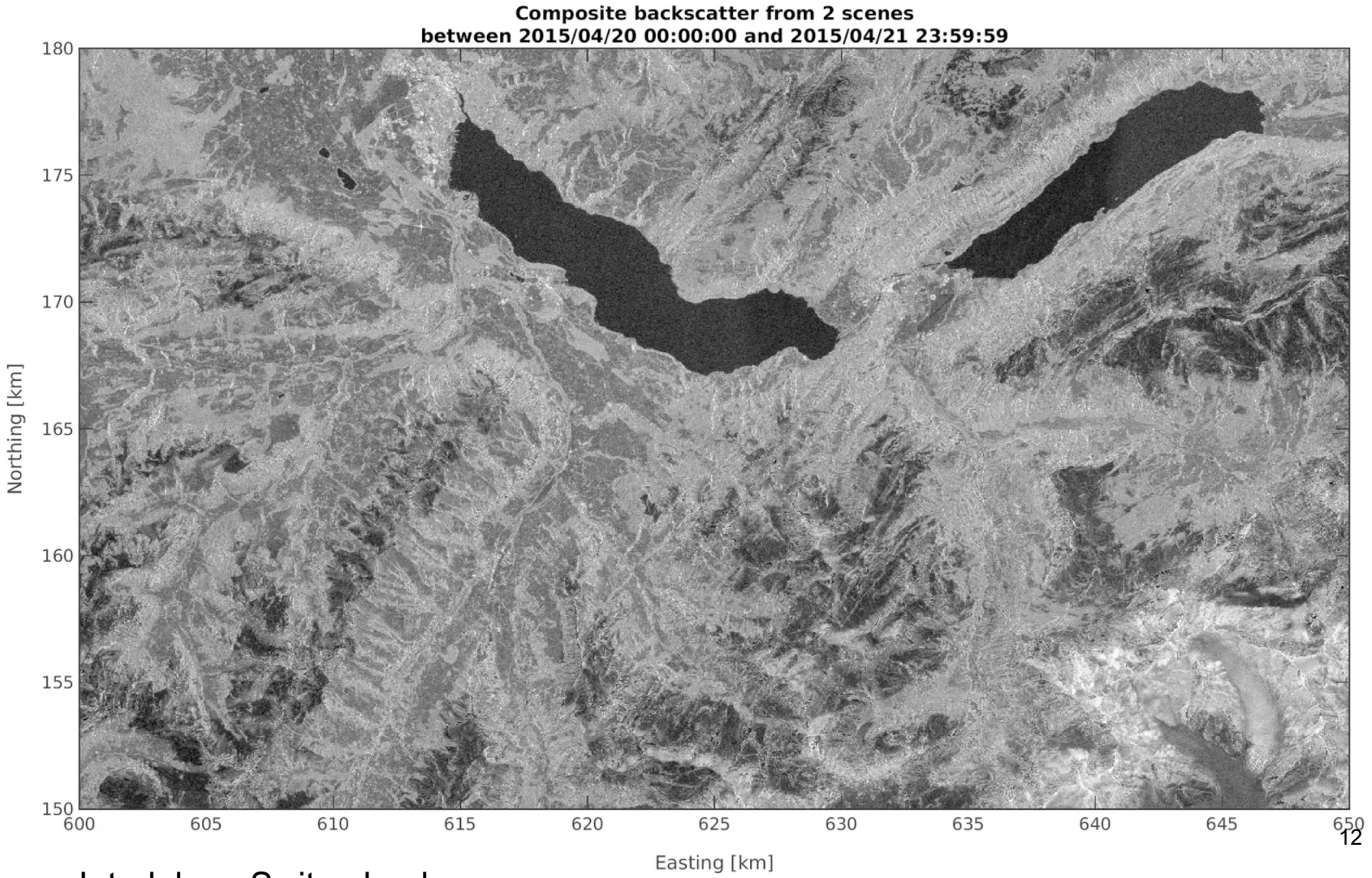


Small et al.,
"**Wide-area Analysis Ready Radar Backscatter Composites**"
In Review.

Composites in Time Series Movie

-26dB -1dB

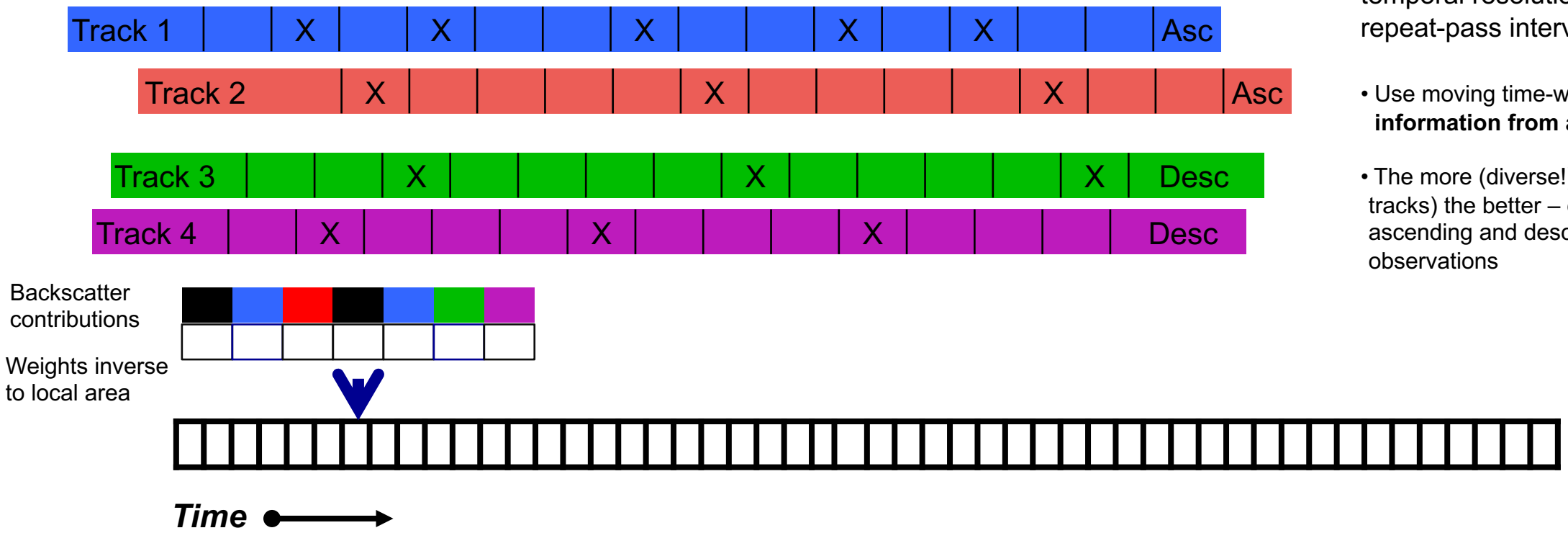
Jan – May 2015



Contains modified Copernicus Sentinel data (2015)

Interlaken, Switzerland

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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Sentinel-1 Alpine Springtime Backscatter Time-Series

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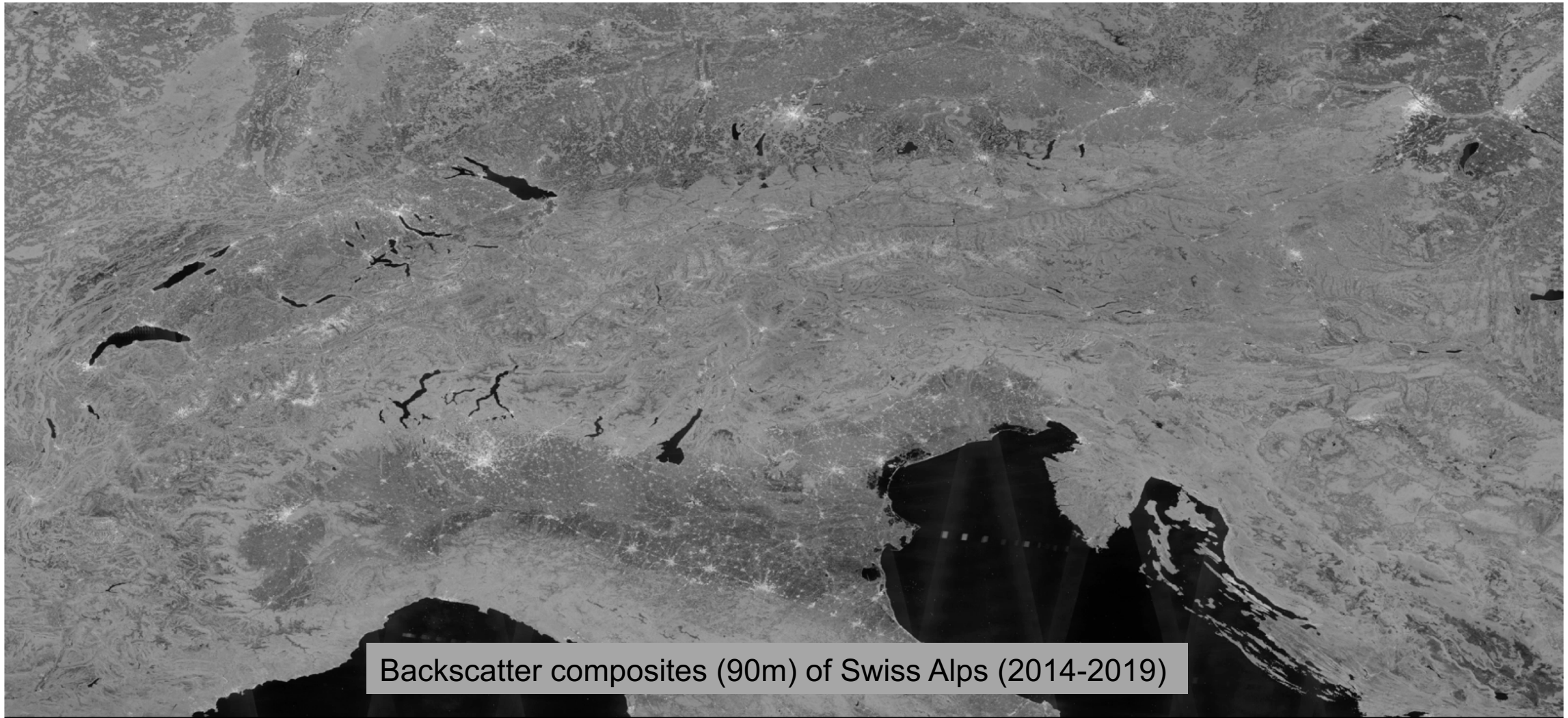
S-1A + S-1B IW VH-pol. **Feb. - June 2019**: 12 day windows



Backscatter composites (90m) of Swiss Alps (2014-2019)

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Contains modified Copernicus Sentinel data (2018)

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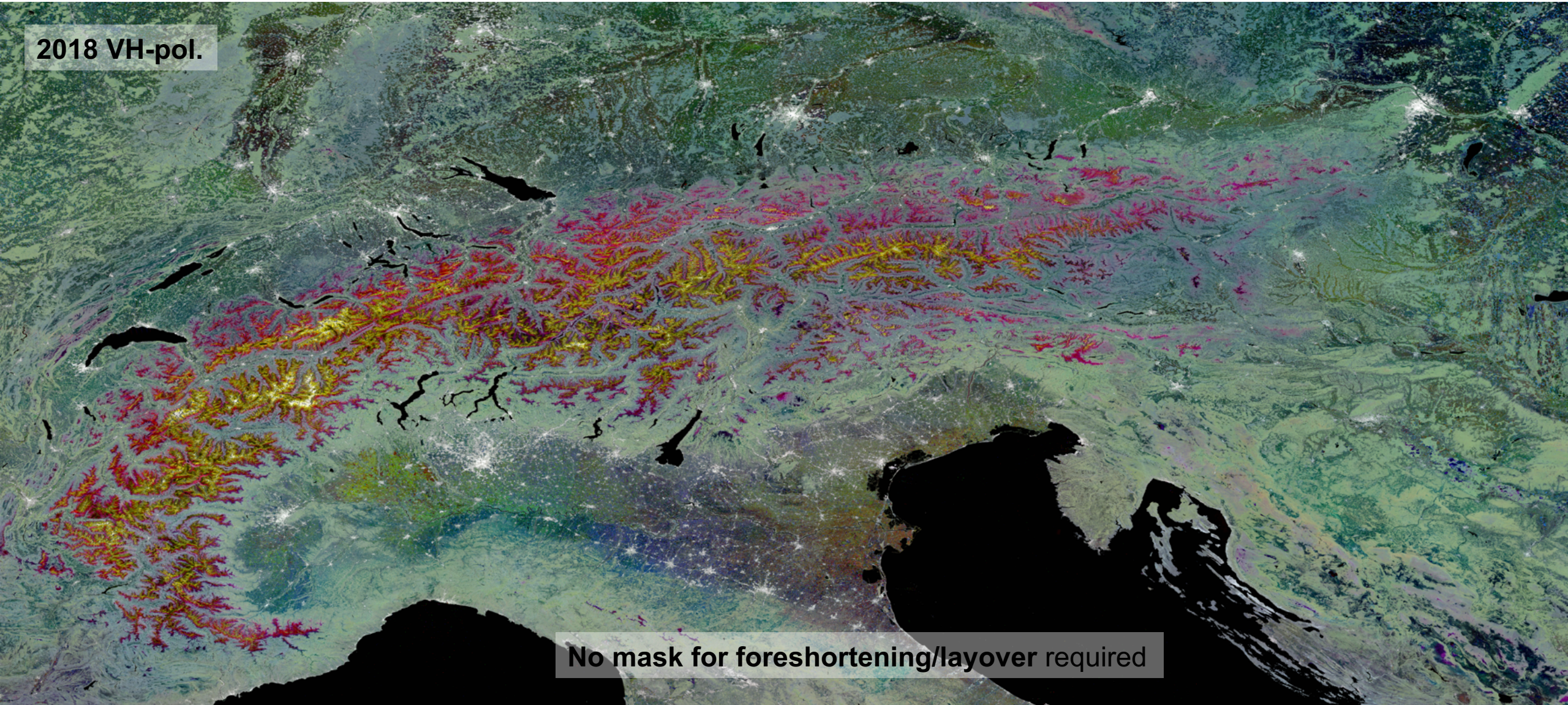
Sentinel-1 IW Backscatter Composites 2018 VH: Feb 24-Mar 7, April 1-12, May 1-12; -23dB (black) to -6dB (white)



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Contains modified Copernicus Sentinel data (2019)

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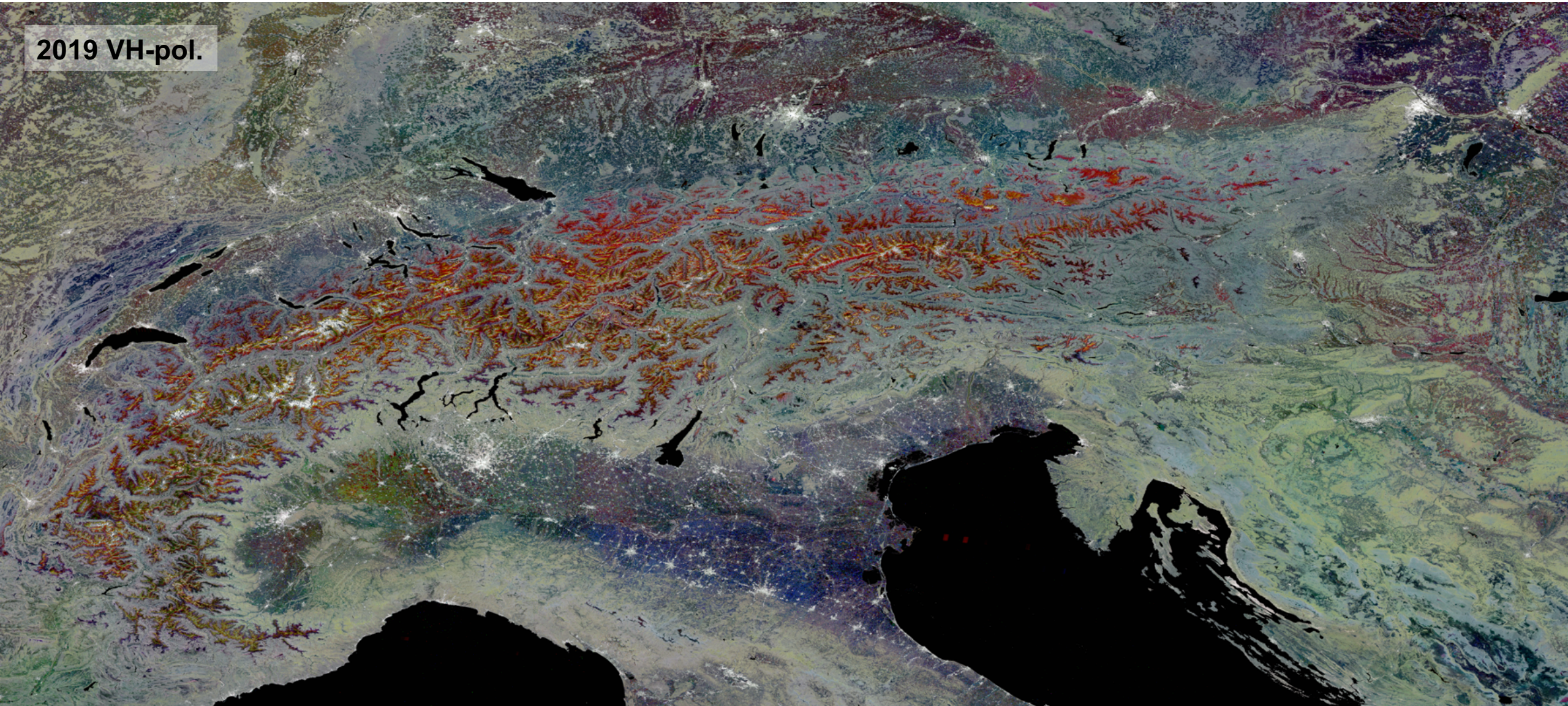
Sentinel-1 IW Backscatter Composites 2019 **VH**: Feb 6-17, April 1-12, May 1-12; -23dB (black) to -6dB (white)



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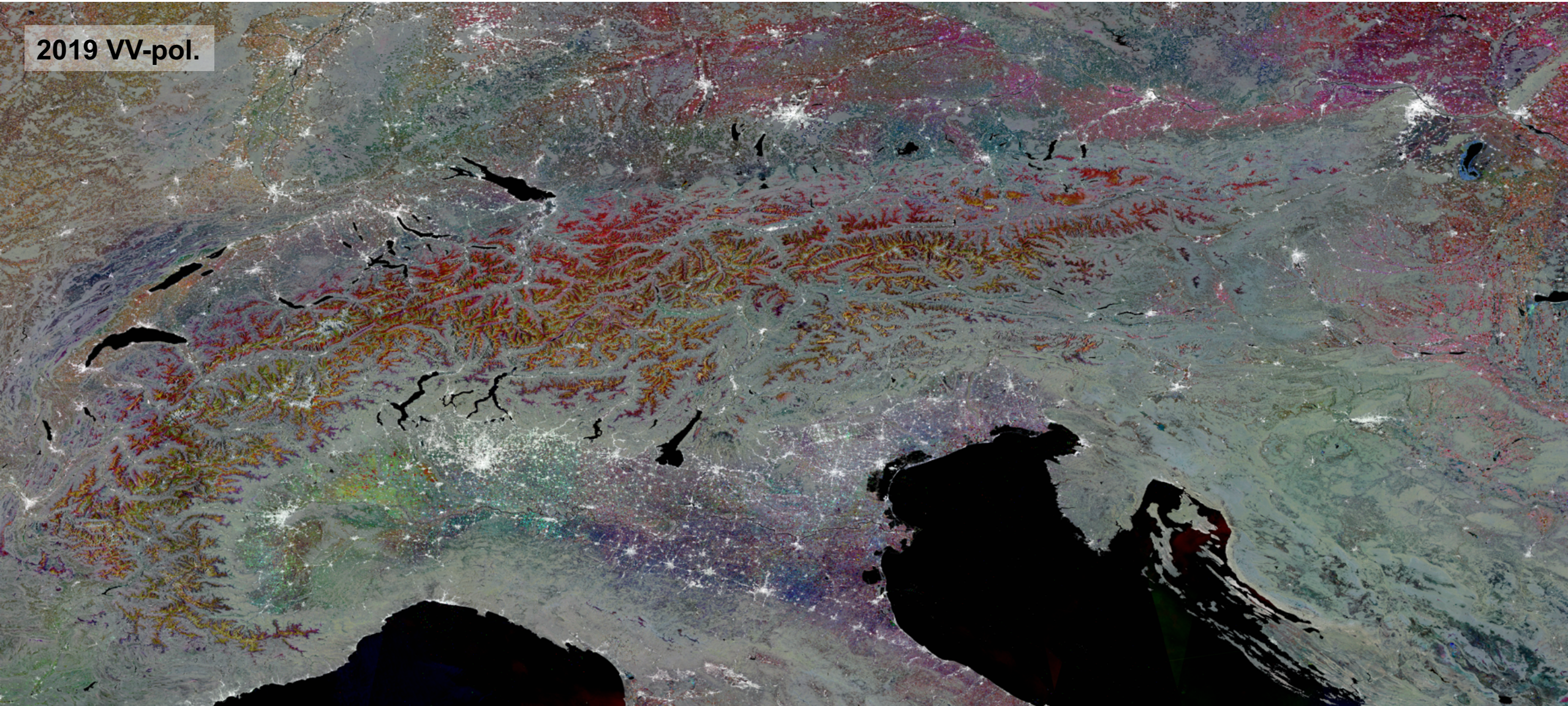
Sentinel-1 IW Backscatter Composites 2019 **VV**: Feb 6-17, April 1-12, May 1-12; -23dB (black) to -6dB (white)



Radar products in map geometry

Correction(s) Applied	GTC	RTC	LRW (ARD)
Geometry (position)	✔	✔	✔
Radiometry (contributing area)		✔	✔
Spatial Resolution homogeneity			✔
Seamless wide-area coverage			✔
Time series from multi-sensor inputs			✔
Temporal resolution can be < repeat			✔

Ellesmere Island, Nunavut, Canada

Image Kyle Odonoghue, 2013.

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Ellesmere Island Backscatter Composites

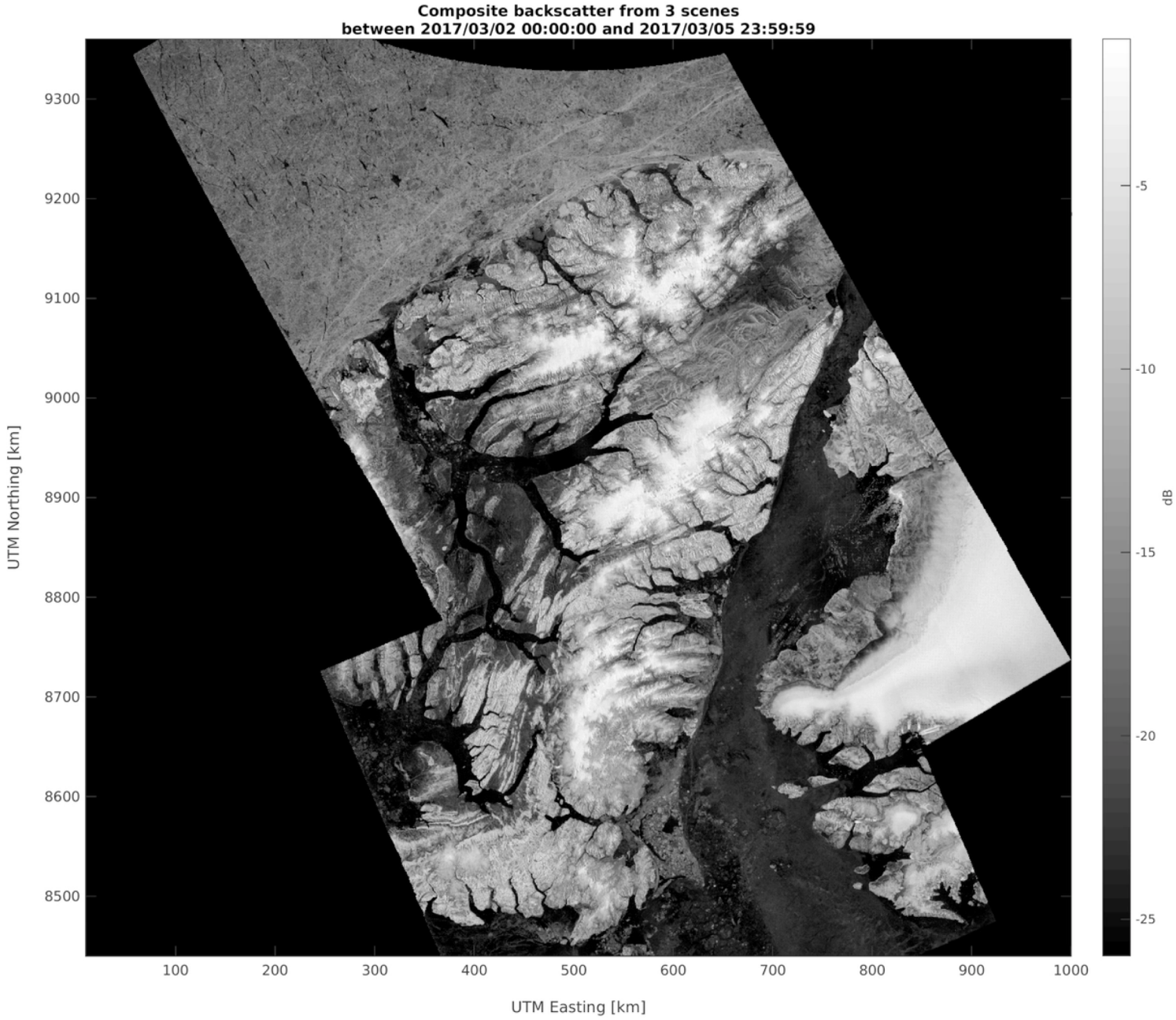
RS2 SCWA HV

2 day delta

4 day window

N.B. CDEM

Mar – Aug. 2017



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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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Contains modified Copernicus Sentinel data (2017)

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Ellesmere Island Backscatter Composites

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

+RS2 SCWA

1 day delta
1 day window

N.B. CDEM

Apr. – Aug. 2017

- **Comparisons with Passive Microwave & ASCAT:**
- **Sea ice melt onset detection** (Howell, Small, et al., Rem. Sens. Env., 2019)

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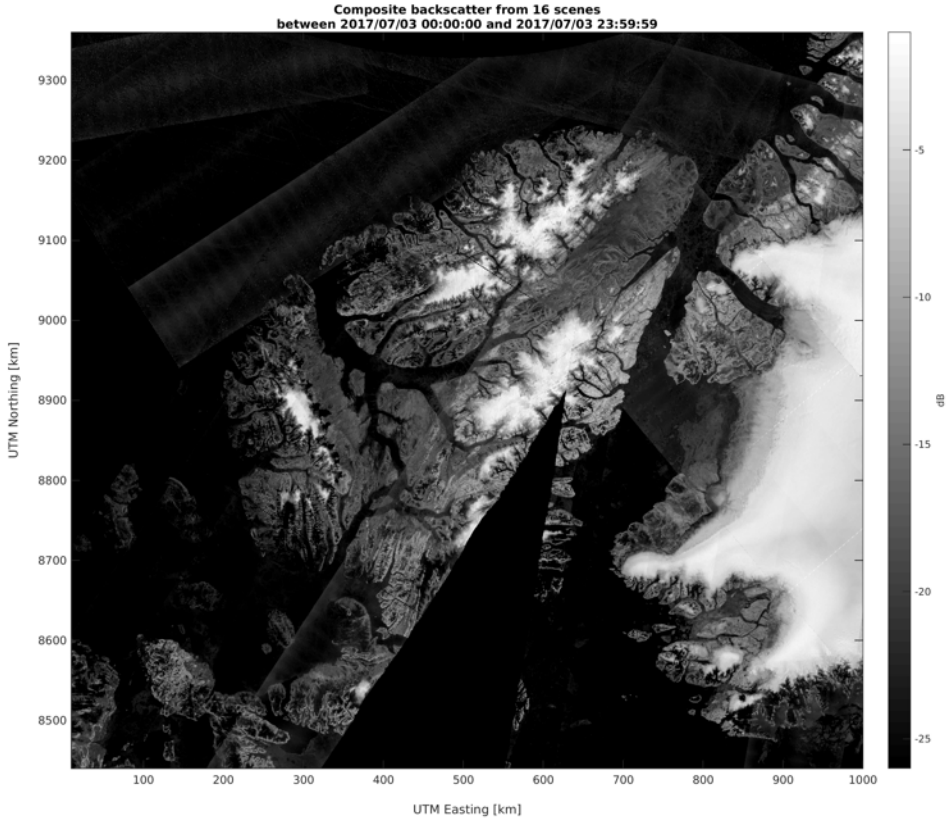
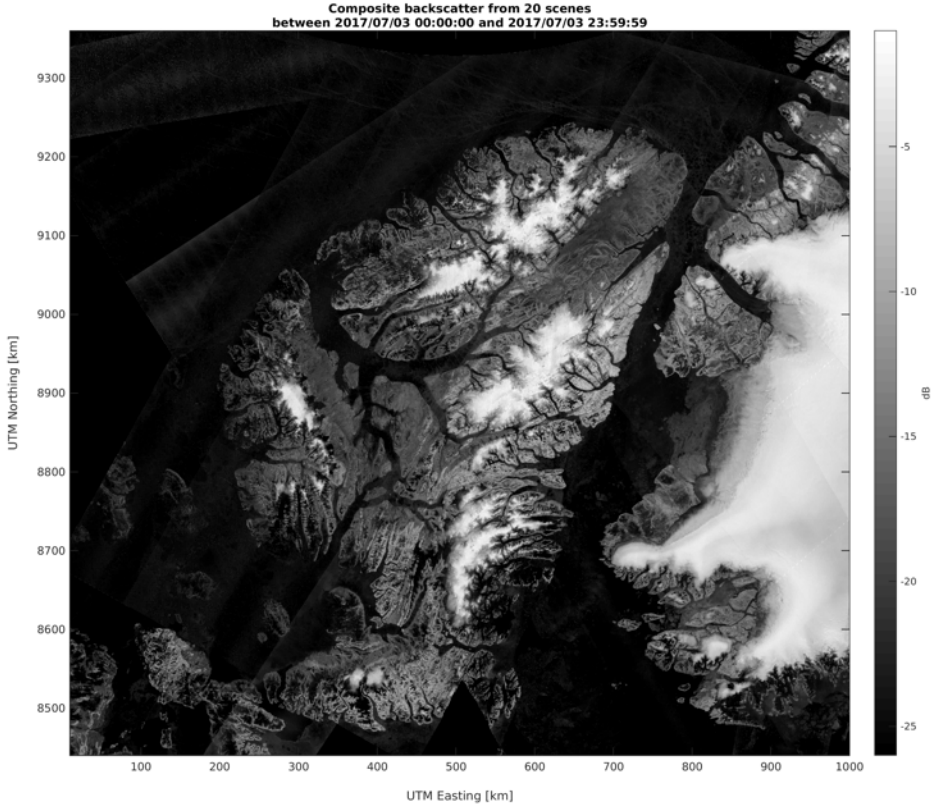
Ellesmere Island Backscatter HV-pol. Composites – July 3, 2017

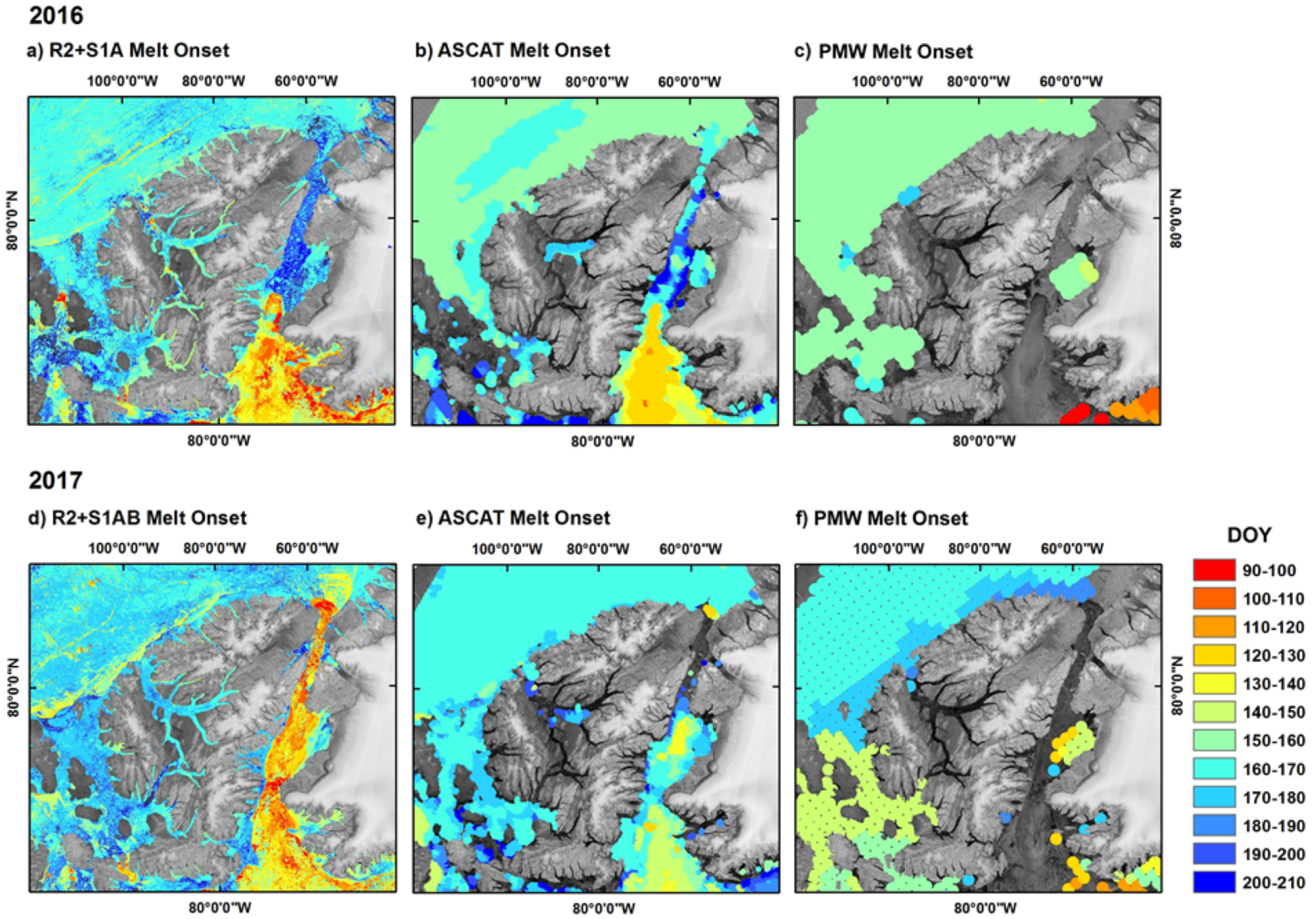
S-1A+S-1B



S-1A+S-1B+ RS2



Contains modified Copernicus Sentinel data (2017)

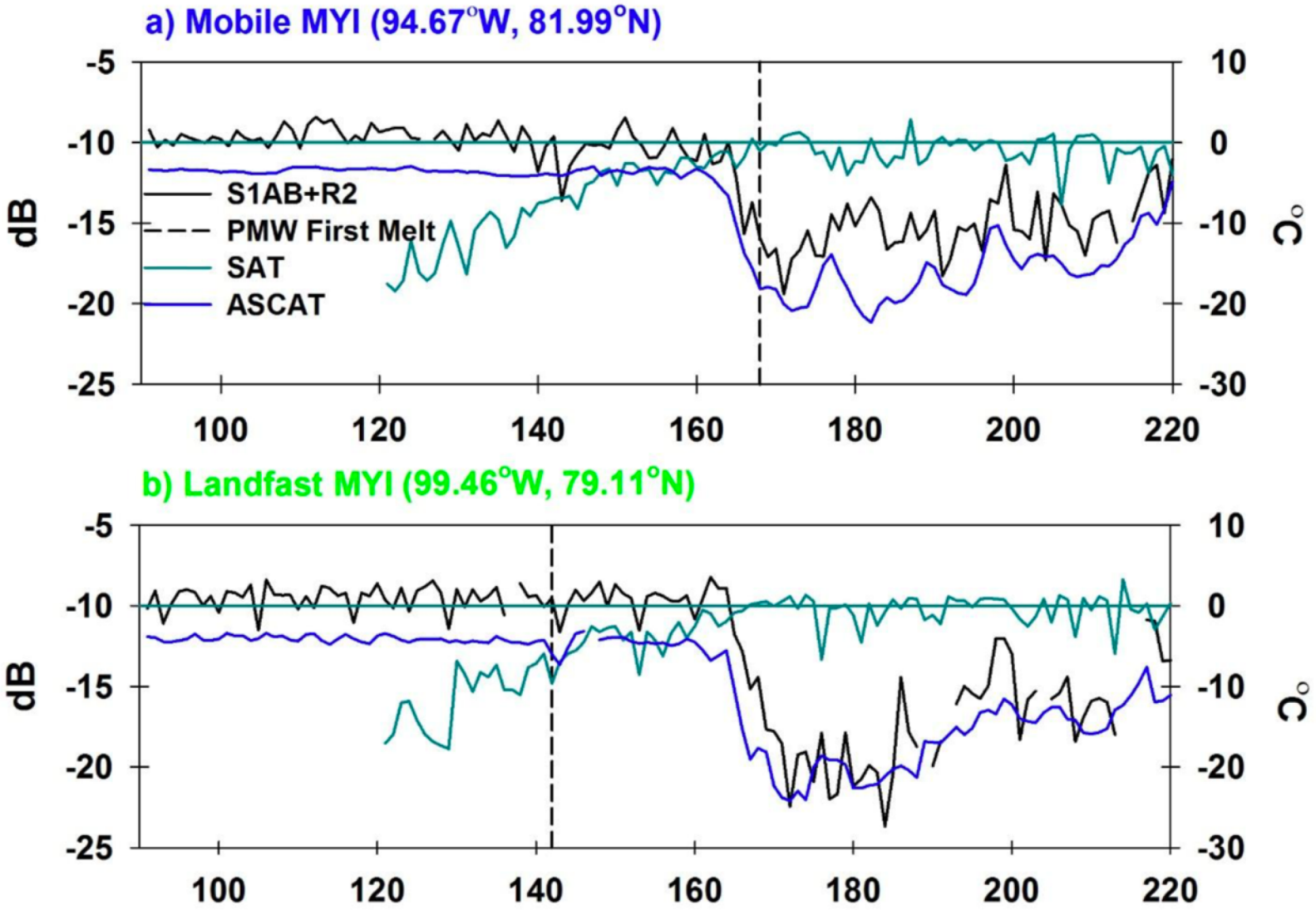


Ellesmere Island

- **R2+S-1**
- **ASCAT**
- **Passive microwave**

SAR *greatly improves spatial resolution* compared to conventional sensors, *now at competitive temporal resolution*

Howell S., D. Small, C. Rohner et al.,
Estimating melt onset over Arctic sea ice from time series multi- sensor Sentinel-1 and RADARSAT-2 backscatter, RSE, 2019.



Ellesmere Island

- **R2+S-1**
- **ASCAT**
- **Passive microwave**

PM misjudges melt onset due to mixed pixel contaminations

- *ASCAT & SAR more consistent*

Howell S., D. Small, C. Rohner et al.,
Estimating melt onset over Arctic sea ice from time series multi- sensor Sentinel-1 and RADARSAT-2 backscatter, RSE, 2019.

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Ellesmere Island Backscatter Composites

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

+RS2 SCWA

1 day delta
1 day window

May – Aug. 2018

Contains modified
Copernicus Sentinel data (2018)

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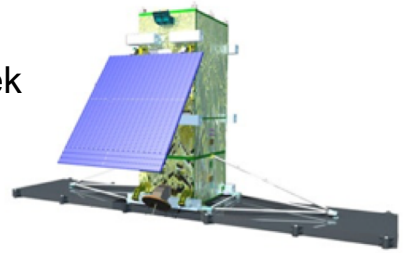
Radarsat Constellation Mission:

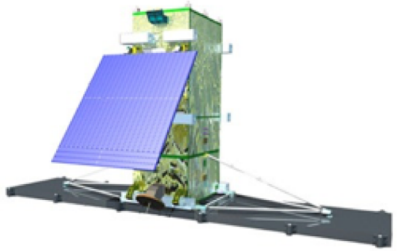
3 new C-band Satellites launched in 2019

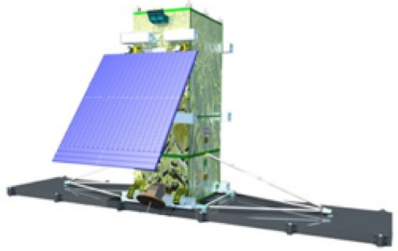
➢RCM (Canadian Space Agency)

- ➢ Government-owned; open-data policy planned
- ➢ **Six active C-band satellites: S-1A, S-1B, RS2, RCM1-3**
  - Harmonisation of acquisition patterns between agencies

- **Polar Space Task Group** SAR Coordination Working Group
  - Possible coordination of acquisition patterns
  - Meeting at UZH Zürich, Switzerland Wed. - Thu next week







WMO PSTG 2014 White Paper

PSTG Terrestrial Snow: SAR Acquisition Planning	Issue: 0.9 Date: 18 Aug 2014 Page 1 / 15 Ref: PSTG-SARCWG-SNOW-001

Coordinated SAR Acquisition Planning for Terrestrial Snow Monitoring

A recommendation to the Polar Space Task Group (PSTG)

PSTG-SARCWG-SNOW-001

DRAFT Issue 0.9 – 18 Aug 2014

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(A list of supporters and contributing authors is provided in the Appendix)

Context

The Polar Space Task Group (PSTG) is succeeding the IPY as the coordinating body of international space agencies for cryosphere applications and issues. The PSTG SAR Coordination Working Group was created to address the issue of SAR data acquisitions in the cryosphere. This document covers the SAR data requirements for observing snow melt events. A summary of its findings was presented at the EARSeL LIS-SIG workshop in Bern, Switzerland in Feb. 2014. Further details were presented at the IGARSS 2014 session on "Multi-sensor Remote Sensing of Terrestrial Snow". Both general and sensor-specific recommendations are incorporated. The sensor-specific recommendations summarised in the Appendices will form the basis for on-going discussions of the SAR Coordination Working Group.

Conclusions

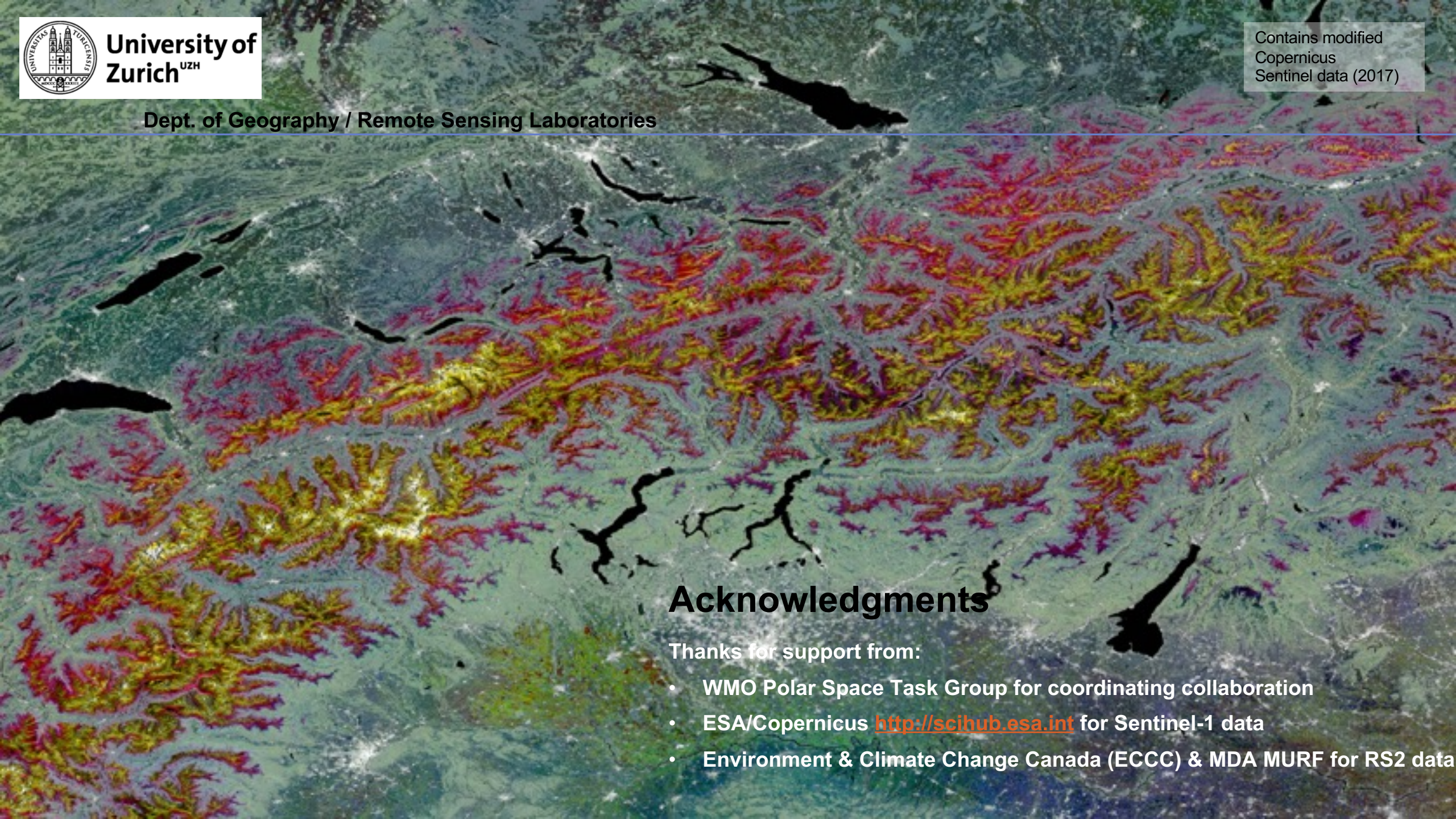
Composite backscatter from **multi-sensor** constellations

- Relies on high standard of level 1 geometric and radiometric calibration
- Best given acquisitions with consistent backscatter regime (e.g. 30° < θ < 40° S-1 IW / RS2 SCNB); ascending + descending
- Share the coverage load, *improve temporal resolution*, ***lower costs***!

Multi-Sensor Backscatter composites ***Analysis Ready***

- Wider coverage, less noise and higher mean resolution than single-scene RTC products
- Selected References:
  - Small D., **Flattening Gamma: Radiometric Terrain Correction for SAR Imagery**, TGRS, 2011.
  - Small D. et al., **Wide-area Analysis Ready Radar Backscatter Composites**, In Review, 2019.
  - Jäger D., **Wide-area wet snow mapping of the Alps based on Sentinel-1 multi-track radar backscatter composites**, M.Sc. Thesis, UZH, 2016.
  - Rüetschi M., M. Schaepman, D. Small, **Using Multitemporal Sentinel-1 C-band Backscatter to Monitor Phenology and Classify Deciduous and Coniferous Forests in Northern Switzerland,** Remote Sens., 10(55), 2018.
  - Rüetschi M., D. Small, L. Waser, **Rapid Detection of Windthrows Using Sentinel-1 C-Band SAR Data,** Remote Sens., 11(2), 2019.
  - Howell S. et al., **Estimating melt onset over Arctic sea ice from time series multi-sensor Sentinel-1 and RADARSAT-2 backscatter**, RSE, 2019.

- **Realising the full potential of SAR satellites is achievable with multi-agency coordination**



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Acknowledgments

Thanks for support from:

- WMO Polar Space Task Group for coordinating collaboration
- ESA/Copernicus http://scihub.esa.int for Sentinel-1 data
- Environment & Climate Change Canada (ECCC) & MDA MURF for RS2 data