Open-source developments for processors and ARD products of ESA SAR missions

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12-15 November 2024

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1. Why is Open Science important?

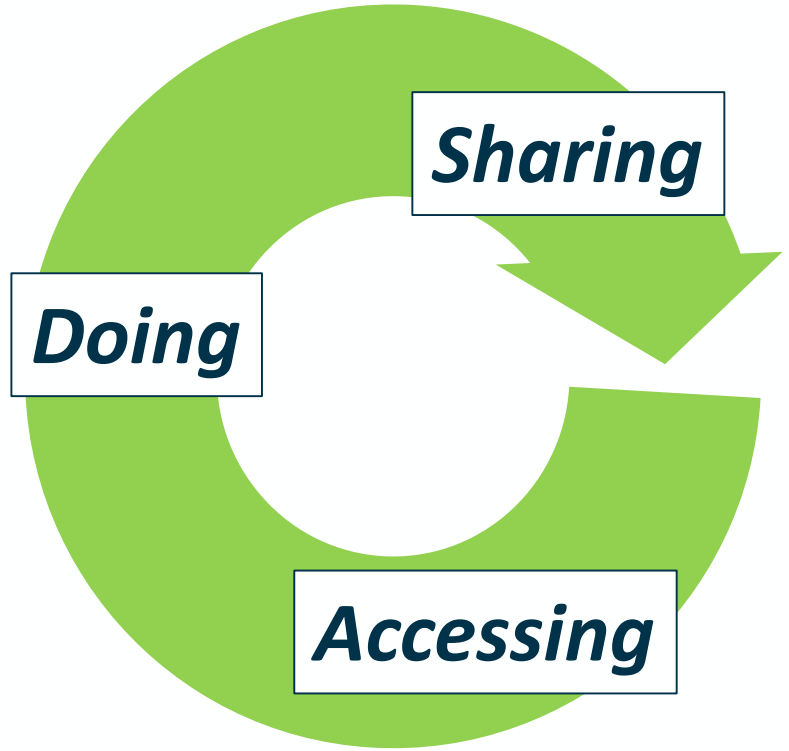
- Open science allows collaboration that creates beneficial synergies
- Encourages both higher quality work and community feedback on work
- Work has greater impact across the scientific community
- Open science creates new opportunities to leverage data, resources
- Encourages reuse of algorithms and computational workflows which lead to greater reproducibility

1. Open Source – driver of innovation

«Highly innovative SW organisations are enterprises that deeply integrate OS technologies, methods and culture into their daily business operations»

IDC Technology Spotlight 2019

- ***Innovation*** *– decentralised code contributions increase the likelihood for innovative code development compared to closed source communities.*
- ***Transparency*** *– visibility into source code and versioning history empowers users to expand and adapt the code or test for additional use cases and scenarios.*
- ***Lower Costs*** *– free to download, not free to produce and maintain.*
- ***Longevity*** *– less likely to be neglected or abandoned, community ensures continuity.*



1.a. Development of Open-Source SAR processors for ERS-1/2 & ENVISAT

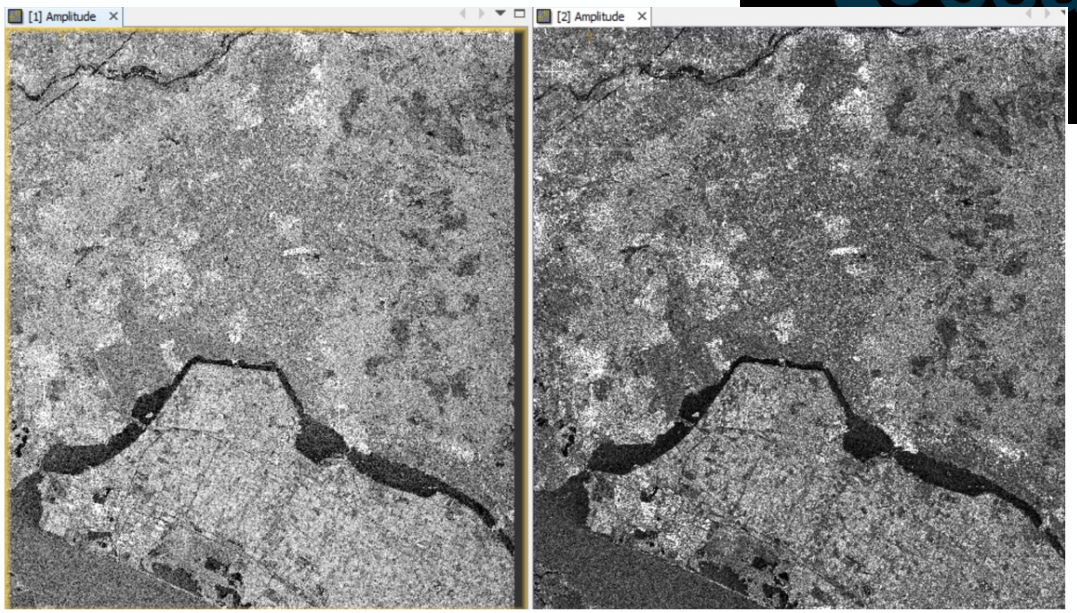
- The outcome of the ESA BULPP experimental project (https://github.com/cgi-estonia-space/ALUs), related to the GPU optimisation of SAR interferometric routines, has indicated the potential benefits of using the GPU technology applied to Satellite products generation.

- Objectives:
  - Port an operational processor into GPU technology, fulfilling all scientific and orchestrability requirements.
  - Obtain a new combined SAR/ASAR operational processor based on GPU to be used to step-up the possibilities for ESA service to its end users, both for On-The-Fly services, and to facilitate the execution of massive reprocessing campaigns.
  - Progress in the migration away from proprietary code.
  - Eliminate the dependencies from old legacy libraries.
  - Support the technology and security driven evolution of the code by adopting the latest Operative System release.

- Timeline:

1.a. Development of Open-Source SAR processors for ERS-1/2 & ENVISAT

- Goal ~2 seconds (for single instance):
  - For 16 seconds of Level-0 data.
  - Could be amplified by running multiple instances in parallel.
  - Does not differ per mode/product type:
    - Also do not foresee drop in performance when product correctness and metadata progresses.
  - Core calculations/compressions around 0.5 sec (on GPU).
  - Everything else is product reading, parsing, data transfer to/from GPU, product writing (on CPU):
    - Improving this part will be the focus on further performance optimizations.

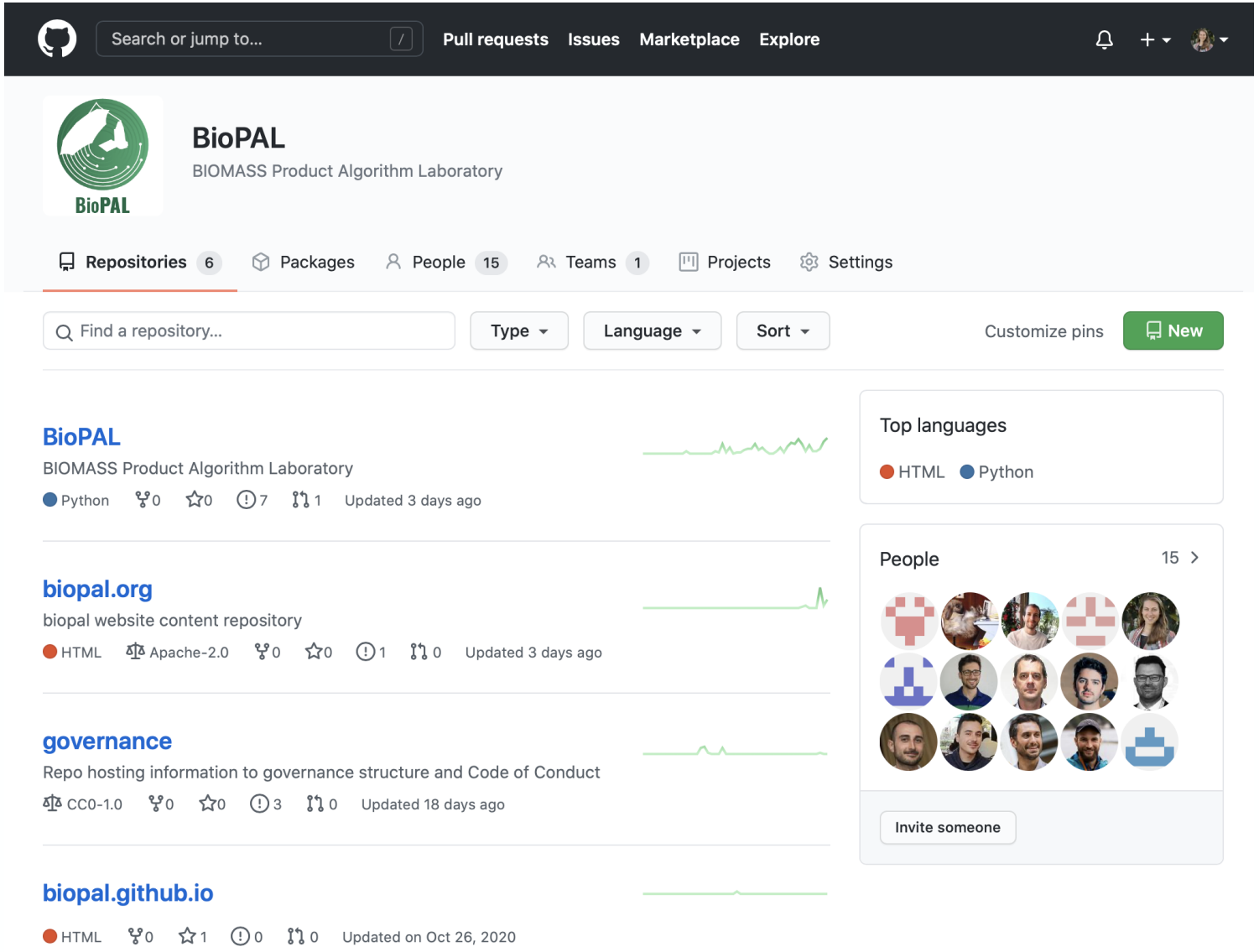


New GPU ASAR Edam Transponder response sections

Legacy CPU ASAR Edam Transponder response sections

- Current version of the source code available on GitHub (https://github.com/cgi-estonia-space/asar-focus).

1.c. Development of Open-Source SAR processors for BIOMASS



New concept at ESA!

Open source

Today:
Level-2 prototype algorithms

Tomorrow:
Level-1 (as much as possible), Level-2 and Level-3 operational algorithms, Data Quality tools, and other open-source algorithms (Tomo, DTM, etc.)

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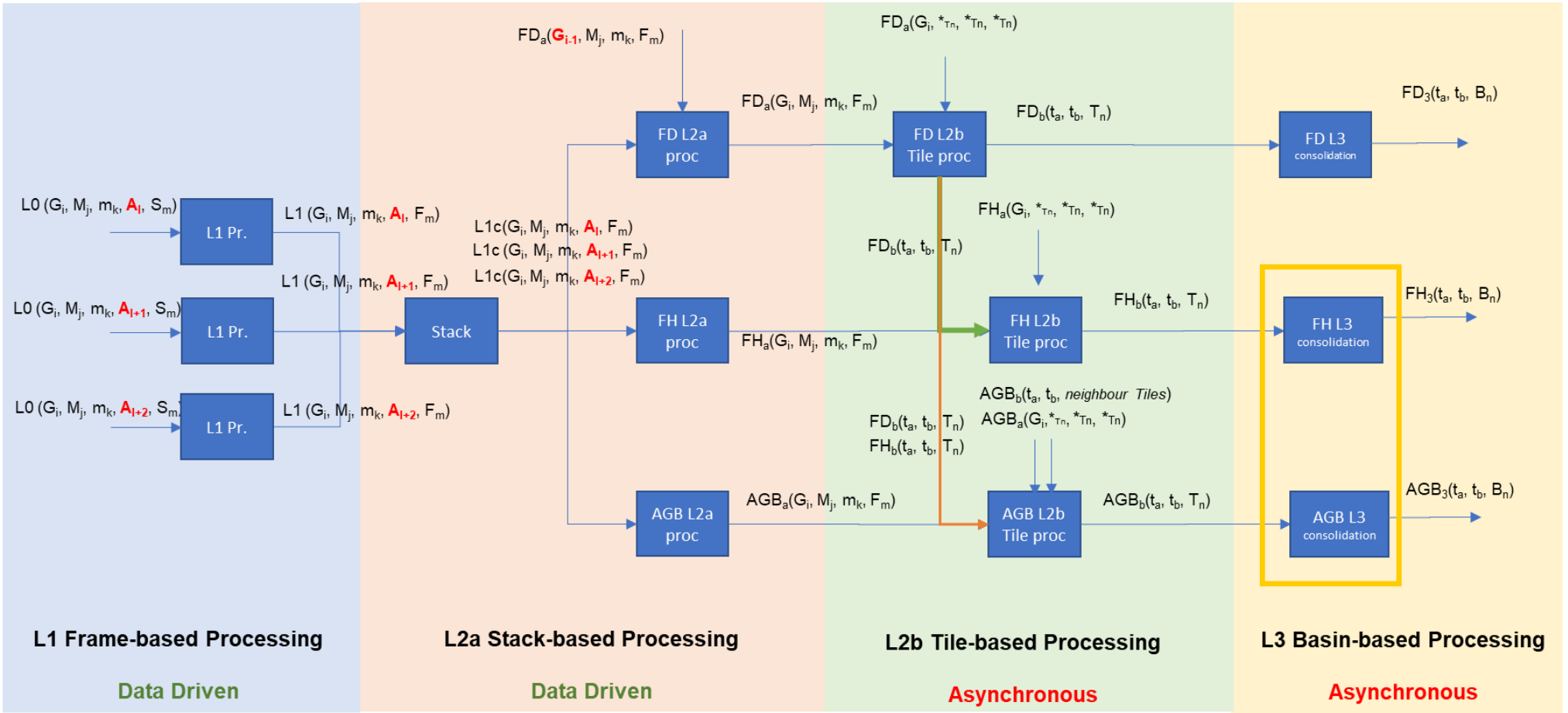
biopal.org
github.com/BioPAL

1.c. Development of Open-Source SAR processors for BIOMASS

Biomass Core Algorithm processor



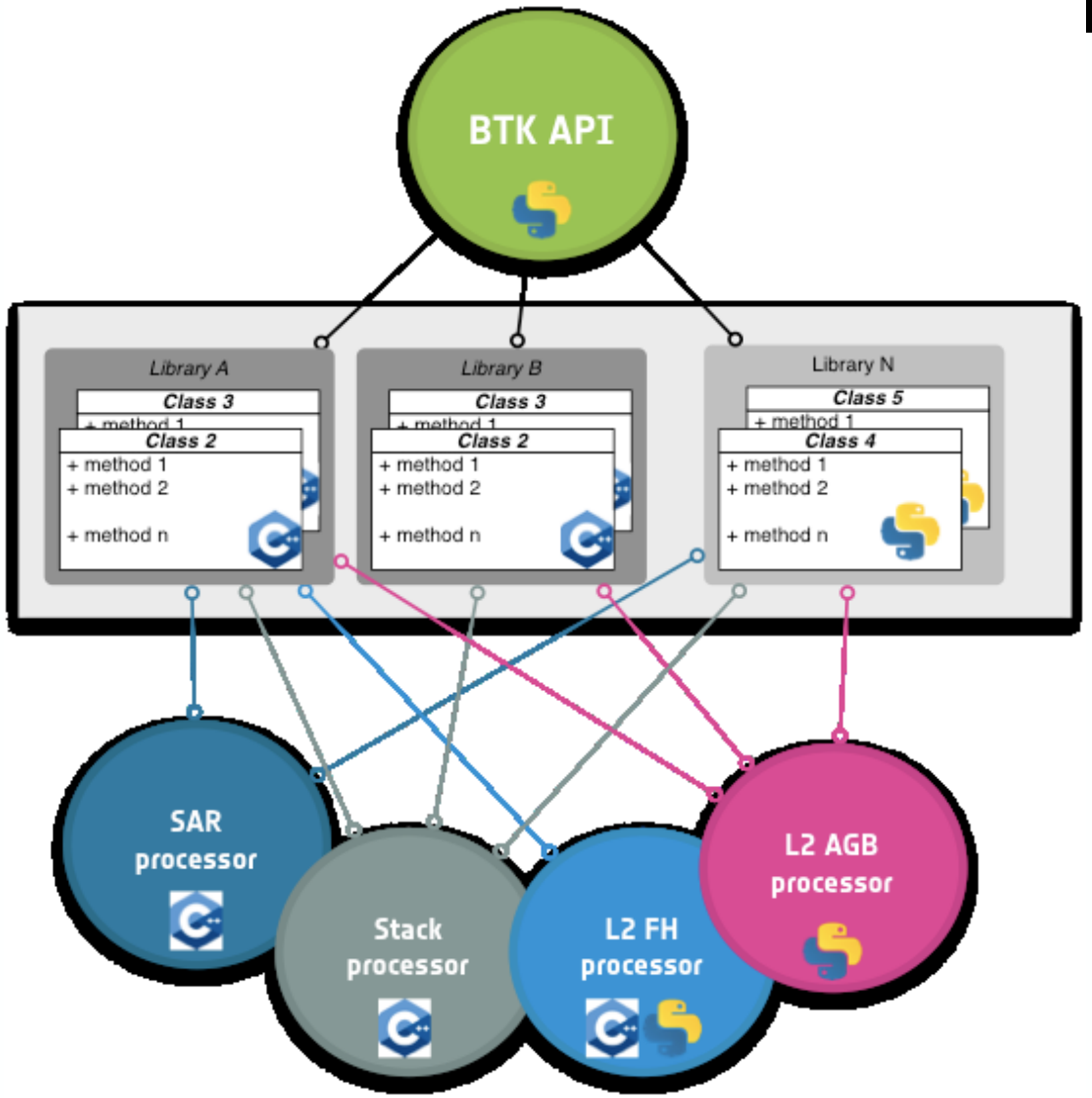
Systematic Processing "Data Driven"

At Global coverage completion

From the level 0, L1, L2a/L2b and L3 are produced

1.c. Development of Open-Source SAR processors for BIOMASS

- Expose BPS functionalities and allows the use of the BPS software in a customized way.
- Include quality tools to analyse BPS products.
- Aims at stimulating scientific contributions which could eventually help to evolve the BPS processor itself.
- Ease the product exploitation for the BIOMASS primary and secondary objectives or for educational purposes.
- Planned to be deployed in the MAAP and should be a component of the BioPAL.



2. What is an ARD product?

Definition CEOS Analysis Ready Data (ARD):

"[…] data that have been processed to a minimum set of requirements and organized into a form that allows **immediate analysis with a minimum of additional user effort** and **interoperability both through time and with other datasets**. (http://ceos.org/ard)

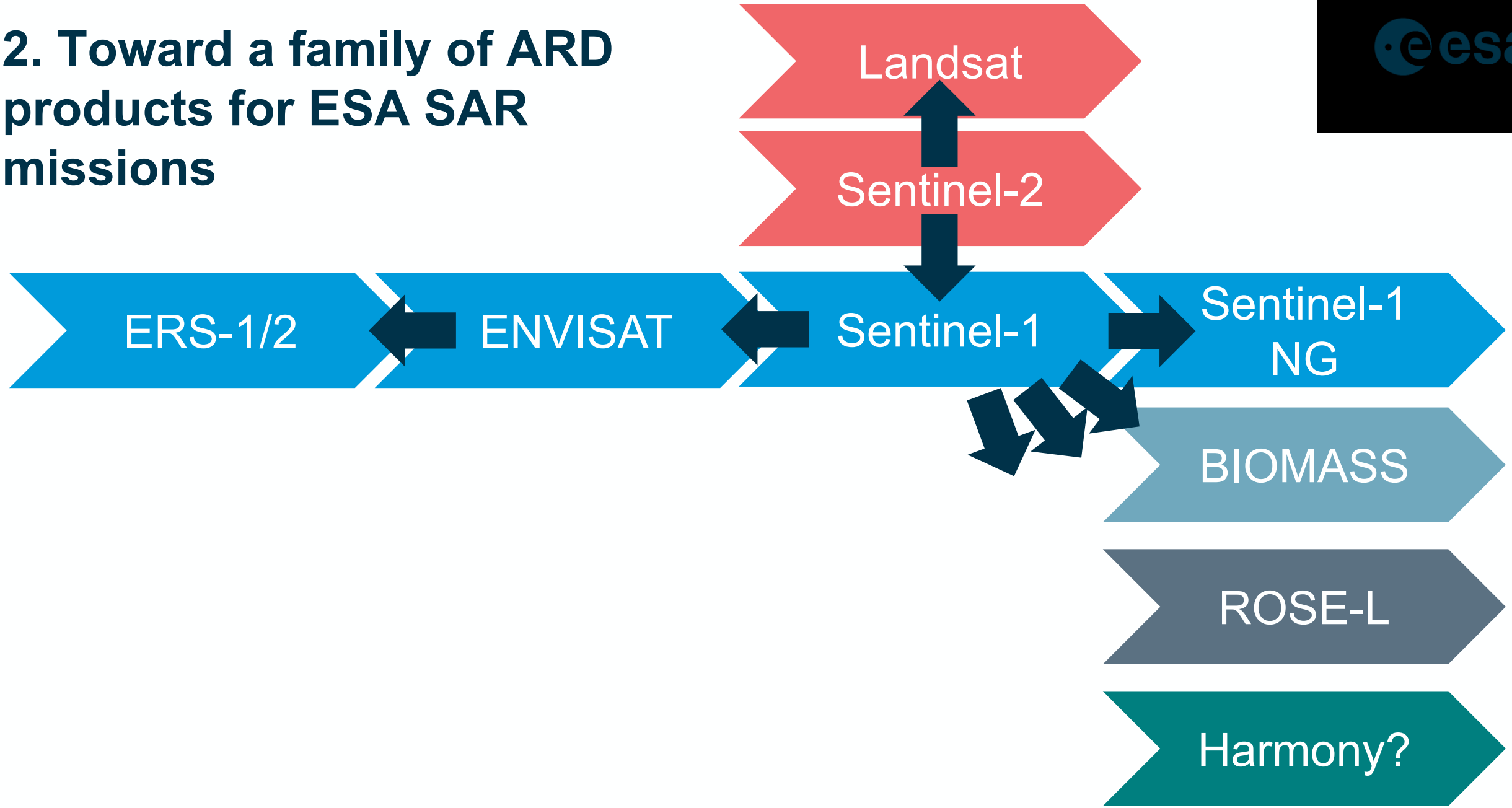
Main benefits of an ARD product:

- No need for larger data preprocessing by users
- Data already calibrated and projected
- Align gridding and projections of different datasets
- Considering requirements of users
- Compliant with modern data access approaches

SAR ARD currently defined:

- NRB: Normalised Radar Backscatter
- ORB: Ocean Radar Backscatter
- POL: Polarimetric Radar
- GSLC: Geocoded Single-Look Complex
- *InSAR (in preparation)*

2. Toward a family of ARD products for ESA SAR missions



2.a. Sentinel-1 NRB: Processing steps

Apply Timing Correction	Using ETAD files (under investigation)
Apply Orbit Files	Using available orbit file (precise or restituted)
Thermal Noise Removal	Using algorithm of ESA Spec or Park et al.
Apply Radiom. Calibration	Converting DN to radiometrically calibrated backscatter
Multi-Looking	Similar to current GRD HR product
Radiometric Terrain Flattening	Correct terrain-influenced radiometry (gamma naught)
Geometric Terrain Correction	Using Copernicus DEM (30 meters)

2.a. Sentinel-1 NRB: Prototype

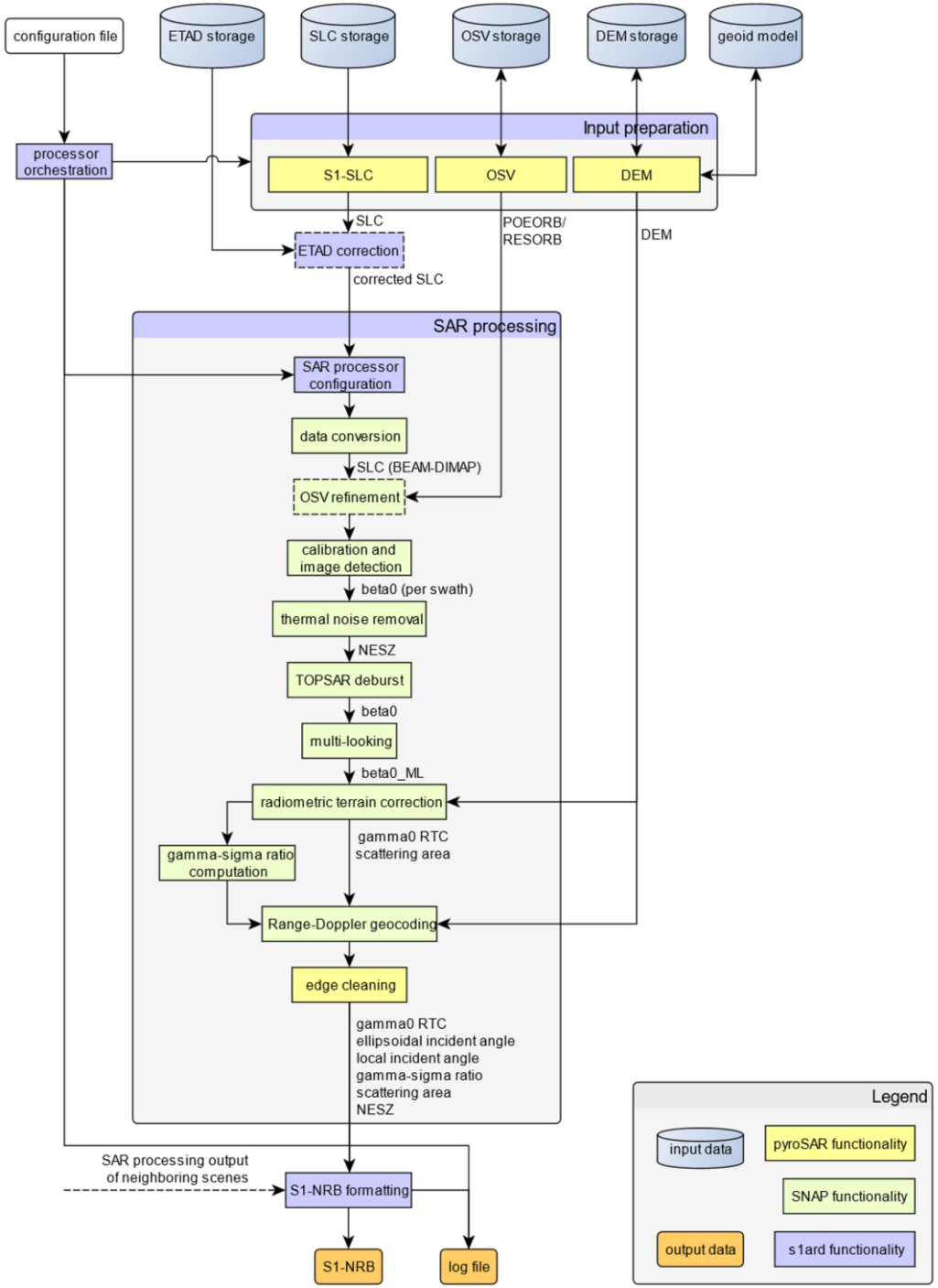
- Calibrated with RTC, denoised, projected over Copernicus DEM, geolocated ➔ *Immediate analysis!*
- Same gridding / tiling system, and DEM than Sentinel-2 (based on MGRS) ➔ *Interoperability!*
- Open-source processor (based on PyroSAR, GDAL, SNAP) ➔ *Open science compliant!*

- Prototype processor developed and validated through a test dataset over a few use cases.
- It can be found on GitHub:

  https://github.com/SAR-ARD/s1ard

➢ Prototype based on SNAP and PyroSAR.

➢ Prototype processor development achieved and available on-the-fly (C-TEP).

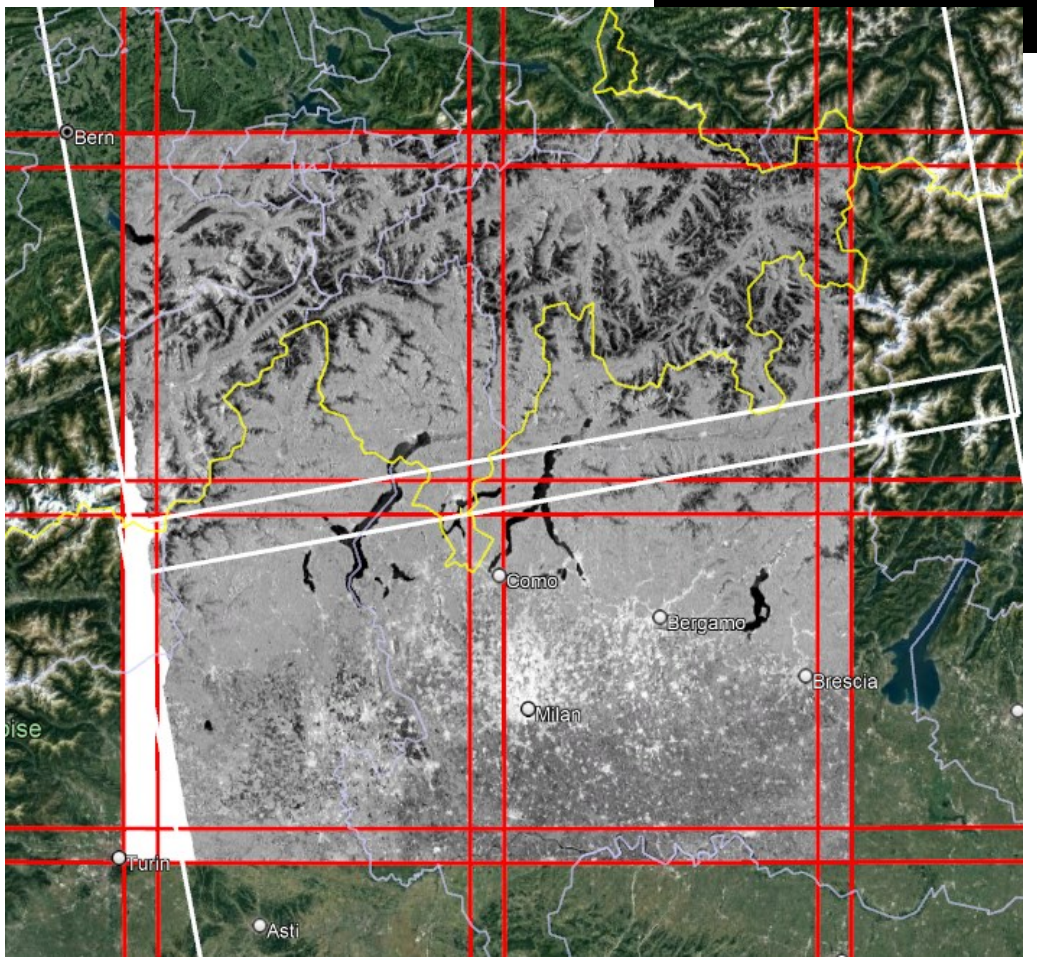


2.a. Sentinel-1 NRB: Operational processor

- Implementation on-going: ARD processor expected to be available by end of 2025:
  - Coded in Python
  - Open-source with a non-copy left type of open-source licence (Apache 2)

  Operational product corrections applied could diverge from the prototype.
- Further consolidation of this processor, and integration in the Sentinel-1 ground segment is targetted, with the objective to have a **systematic generation** of this product (TBC).

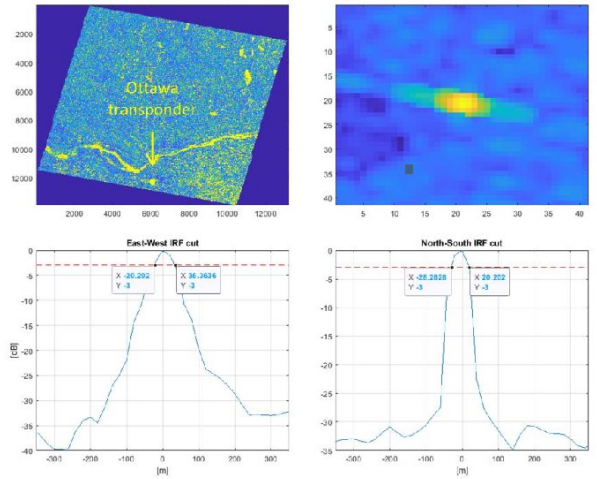
- A “backward processing” campaign could take place and linked to a potential re-processing campaign for the other Sentinel-1 products.
- Under design also CSLC and GSLC ARD operational processors.



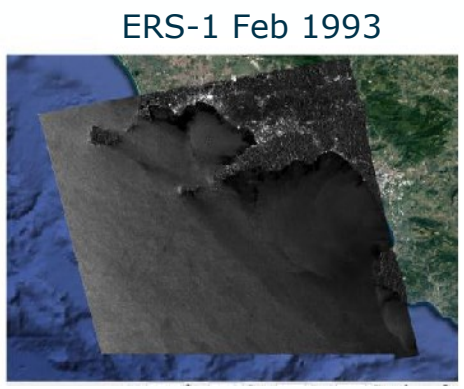
Example of four adjacent Sentinel-1 NRB products over the MGRS grid (red) and original SLC footprints (white).

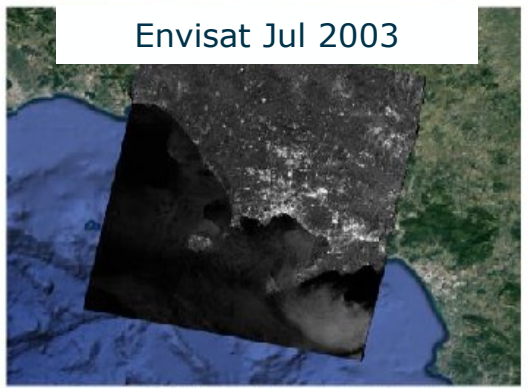
2.c. ERS-1/2 & ENVISAT (A)SAR NRB

- Project to align CEOS-ARD specs for ERS-1/2 & Envisat (A)SAR data (with a prototype processor) to the Sentinel-1 NRB product.
- **Processor v0.1.9 published on GitHub** with user and installation manual: https://github.com/SAR-ARD/ERS_NRB
- **The first subset of ERS and Envisat SAR NRB products was generated** and is aligned with the Sentinel-1 NRB prototype products:
  - Usage of the Copernicus 30 m DEM
  - Cloud Optimized GeoTIFF
  - MGRS gridding / tiling system



ASAR Ottawa transponder – 29 October 2006





2.c. ERS-1/2 & ENVISAT (A)SAR NRB

- Open-source, validated, optimised, and documented RTC implementation (from D. Small):
  - Works with Sentinel-1 data (and will be adapted later-on for ERS-1/2 and ENVISAT).
  - Further code optimizations (vector-area based local area estimation).
  - RTC validation guidelines (at CEOS level).
  - Available on GitHub (https://github.com/SAR-ARD/ERS_NRB)

- Next steps for ERS/ENVISAT:
  - To develop an operational NRB post processor starting from SLC or GRD (IMP, APP, WSM) and open-source, mainly in Python.
  - Processor and product aligned as much as possible with the Sentinel-1 NRB product:
    - Same RTC code
    - Same approach for the product format
  - Compatible with the current ERS/ENVISAT processor algorithm, the future GPU processor, and with On-The-Fly (OTF) capabilities.
  - Activity to be started in January 2025 for a completion in Q4 2025.

2.d. ROSE-L ARD prototyping

- L-band NRB and interferometric products will be developed for the ROSE-L mission (to be aligned with Sentinel-1):
  - Activity started in July 2024

B-Open

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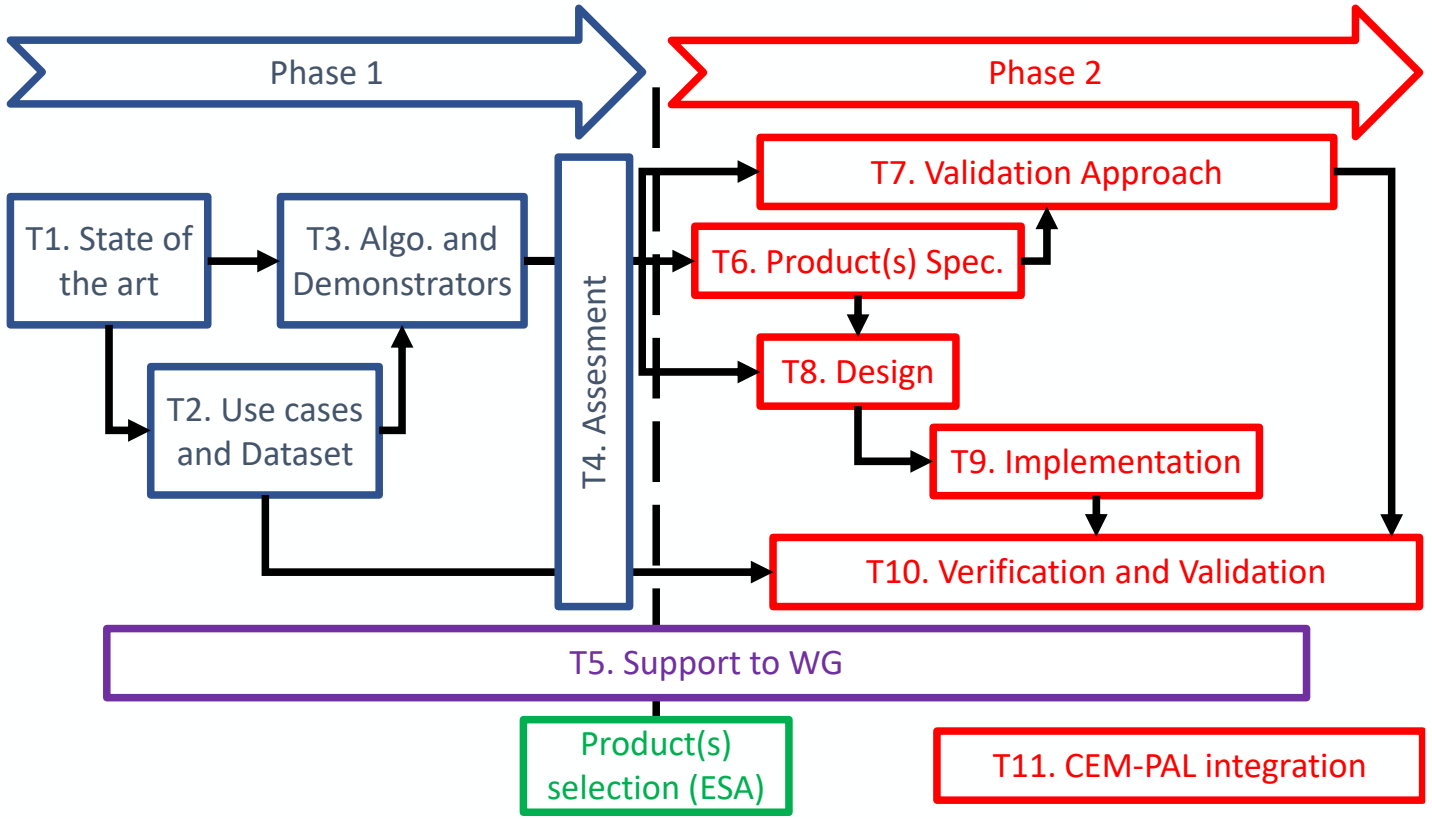
remote sensing

Universidad de Alicante

<u>Main objectives of the activity:</u>

- Identify ARD products that are relevant for the ROSE-L mission and joint use of ROSE-L and Sentinel-1.
- Develop an open-source SW prototype processor(s) to generate the identified ARD product(s) for ROSE-L and Sentinel-1.
- Define the validation strategy.
- Perform a preliminary assessment of the ARD products and methodologies for some identified use cases.



3. Long-term: Fundamental Data Record for SAR

- Fundamental Data Records: *« **Consistently reprocessed** record of **uncertainty-quantified sensor observations** that are **calibrated** to physical units and **located in time and space**, together with all ancillary and lower-level instrument data used to calibrate and locate the observations and to estimate uncertainty. »*
- 3 aspects:
  - Composite (Ascending/Descending)
  - Time series: between ERS-1/2 & ENVISAT, Sentinel-1, and the future Sentinel-1 NG.
    - ➢ Cross-calibration between instruments not overlapping in time (not easy…)
  - Cross-missions:
    - Concept of Virtual Constellation (like for Sentinel-2 and Landsat)
    - Between ERS-1/2 & ENVISAT and Radarsat-1/2
    - Between Sentinel-1 and RCM
    - Between ROSE-L and NISAR in the future?

➢ Activity with Univ. Of Zurich started in Q3 2024.

Universität Zürich[UZH]

➢ Definition of an appropriate CEOS-ARD product (Multisource Composite Backscatter - MCB)

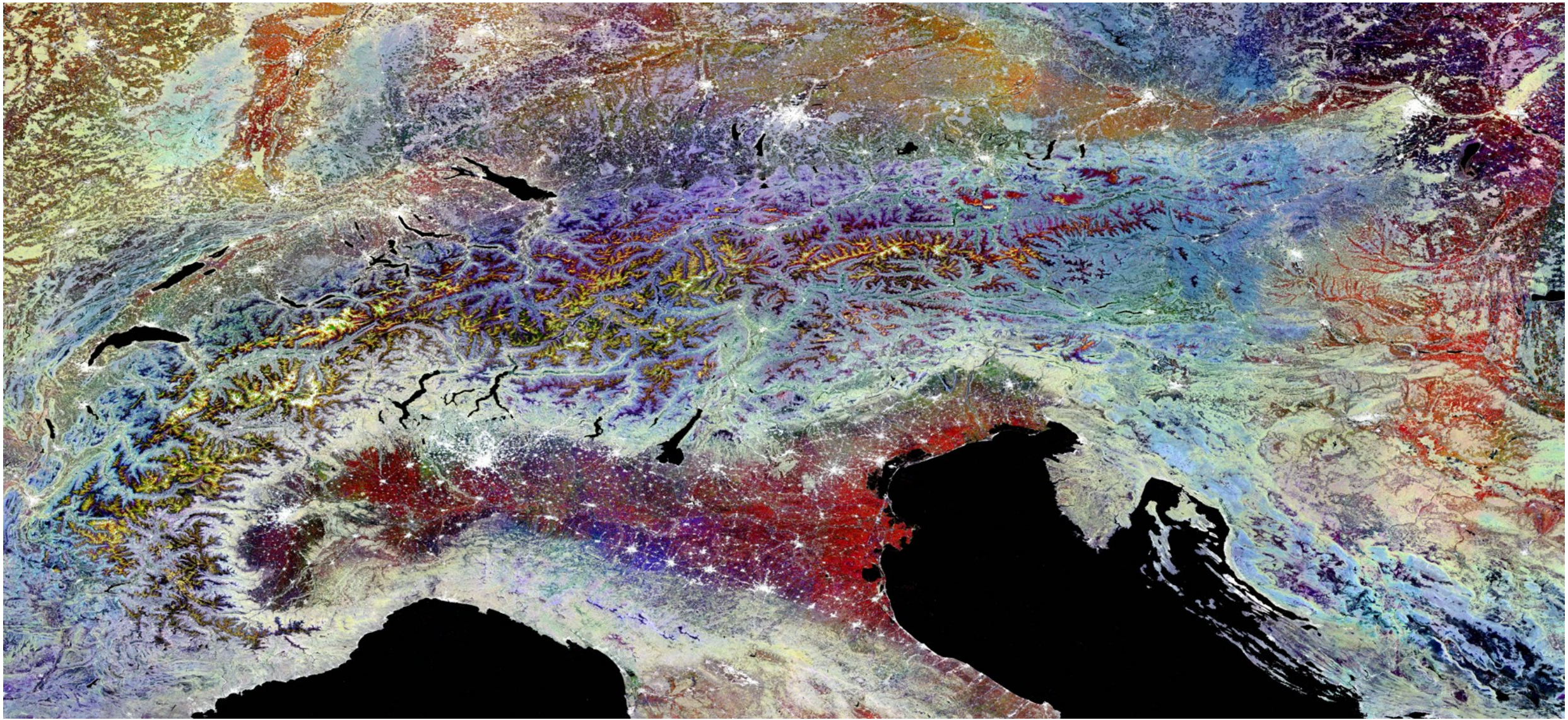
3. SAR backscatter composite: Example 1 with Sentinel-1

2022 VH-pol.

Courtesy of David Small (Univ. Of Zurich)

[Acknowledgment Copernicus/EU]

Sentinel-1A IW Backscatter Composites 2022 **VH**: Jan 1-12, Apr 1-12, May 1-12; Terrain-flattened Gamma-nought Backscatter: -19dB (black) to -11dB (white)



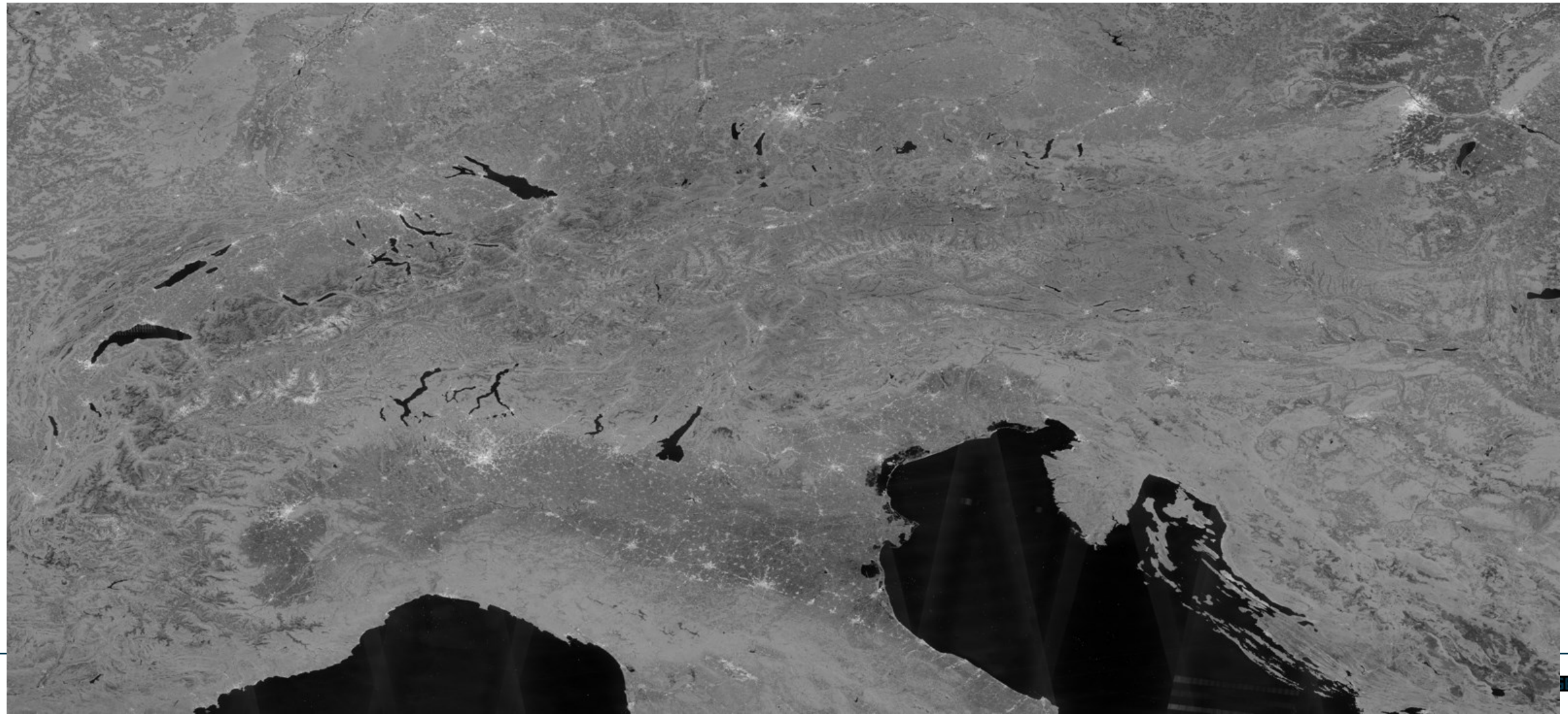
3. SAR backscatter composite: Example 2 with Sentinel-1

Courtesy of David Small (Univ. Of Zurich)

[Acknowledgment Copernicus/EU]

Backscatter composites (90m) of Swiss Alps (2014-2022)

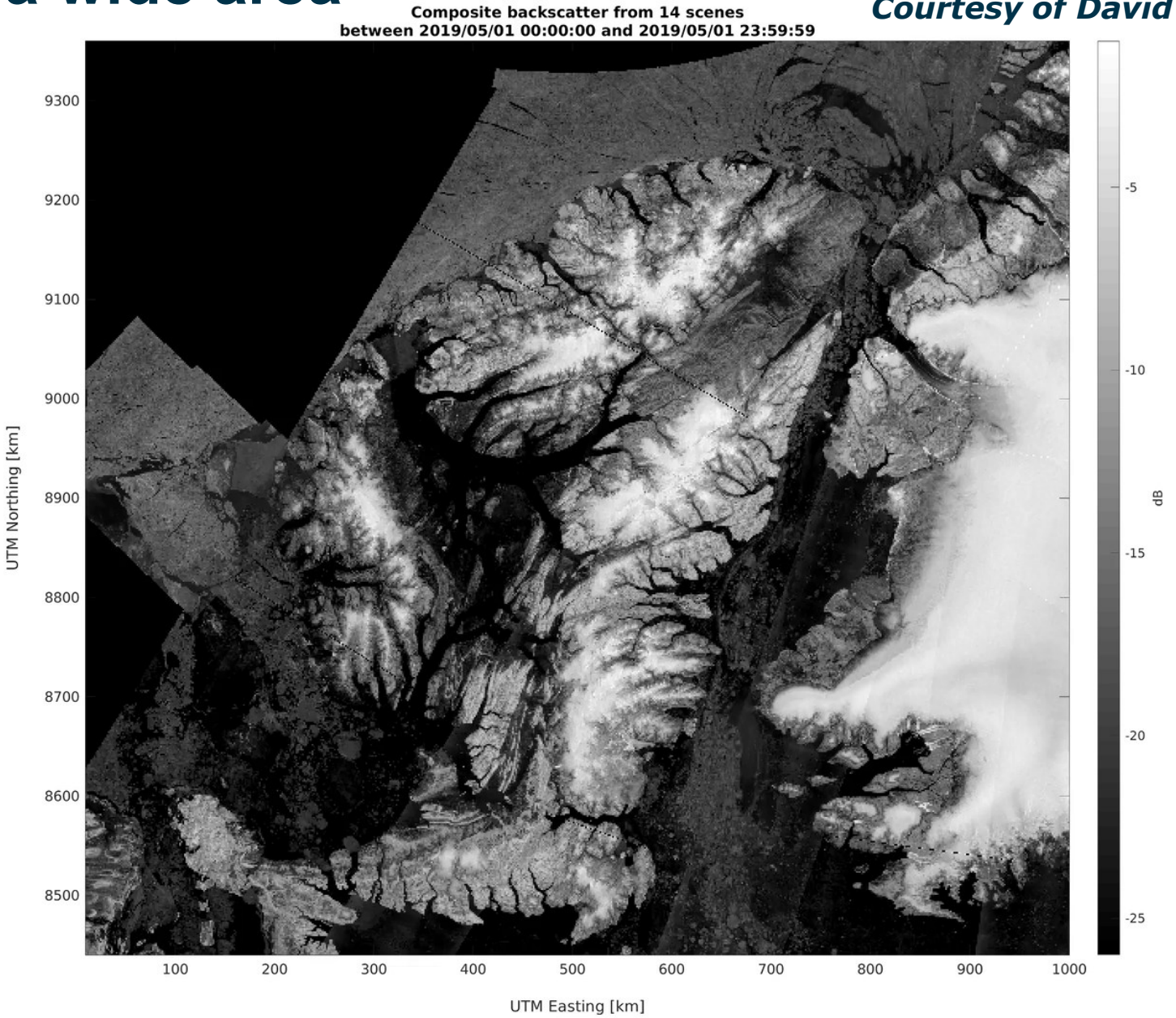
S-1A + S-1B IW VH-pol. ***Apr. – Aug. 2020****: 12 day windows*



3. Multi-source Composite Backscatter: Single-day temporal resolution over a wide area

Courtesy of David Small (Univ. Of Zurich)

- **Ellesmere Island (Canadian Arctic) & NW Greenland**
- **Backscatter composites from Sentinel-1A, Sentinel-1B, Radarsat-2**
- **Imaging modes: S1-IW, S1-EW, RS2-SCWA**
- **Temporal resolution: DAILY!**



May – Aug. 2019

[Acknowledgment: UZH, Copernicus/EU, MDA, Stephen Howell (ECCC Canada)]

Conclusion

- The proposed open-source SAR processors and family of ARD products will **ease data analysis and exploitation** by being « **cloud-computing compliant** », by **opening SAR data to new communities (non-experts)**, and by **enabling interoperability** between these products.

Way forward:

- Operationalisation of Sentinel-1 and ERS-1/2 & ENVISAT A(SAR) NRB processors.
- Definition of ARD products for ROSE-L and BIOMASS.

Objective & Challenge: Keep all these SAR processors and ARD products aligned!

To come:

- Many interactions with the user community
- Open-source → Plenty of opportunities for collaborations
- SAR ARD intercomparison exercises will be needed!