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A Cloud-Based Solution for Sentinel-1 InSAR Processing with openEO in the Copernicus Data Space Ecosystem

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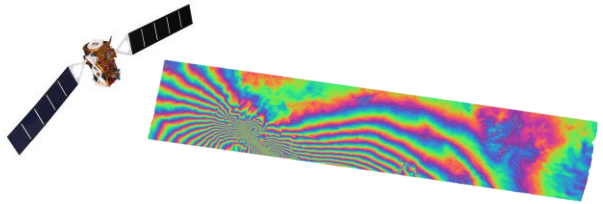
Motivations and project main objective

- **Sentinel-1 InSAR** processing requires **significant computing resources** and access to **large amount of data**
- The **Copernicus Dataspace Ecosystem (CDSE)** hosts the complete archive of **Sentinel-1 Single Look Complex (SLC)**
- **openEO** provides unified access to many satellite data types, but prior to **ClouDInSAR** it did not support **Sentinel-1 SLC** processing



CDSE COPERNICUS DATA SPACE ECOSYSTEM

open EO

The main aim of **ClouDInSAR** is to bring **Sentinel-1 SLC** processing capabilities with **openEO** in **CDSE**, enabling scalable and reproducible Sentinel-1 InSAR processing

Development framework

openEO as standardized EO API

Scalable pipelines with Common Workflow Language (CWL)

Docker container

CDSE COPERNICUS DATA SPACE ECOSYSTEM

Burst-level Sentinel-1 data access through CDSE

SNAP

SAR processing algorithm based on SNAP

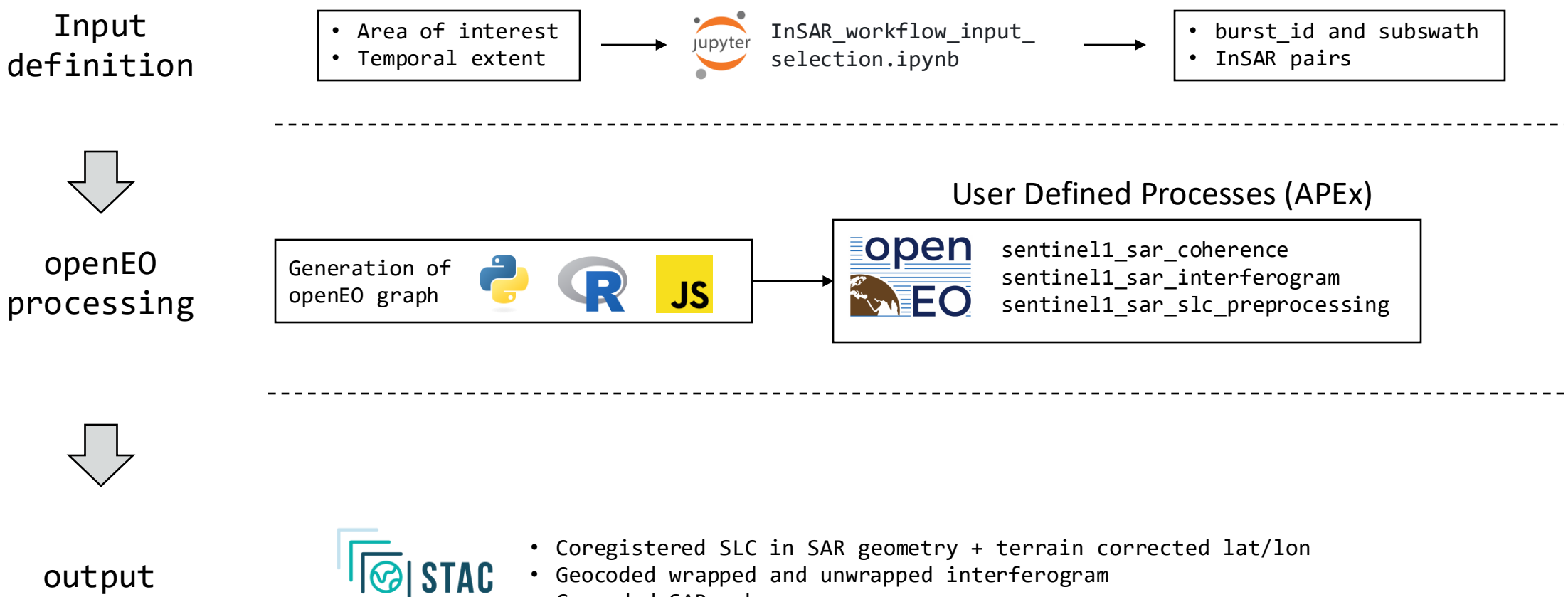
STAC

Output as STAC catalogue

GitHub

https://github.com/cloudinsar/s1-workflows

Implementation



Use cases

1. InSAR coherence time series for debris cover glacier detection
   - **Objective**: Detect debris-covered glacier areas using Sentinel-1 InSAR coherence
   - **openEO** process tested: **`sentinel1_sar_coherence`**
   - Generation of multi-temporal InSAR coherence mosaic to detect persistent decorrelation associated with glacier motion
   - Methodology based on established approaches for debris-covered glacier mapping (Barella et al., 2022, IEEE JSTARS) and validated with glacier inventory obtained with aerial ortophotos and LiDAR acquisitions

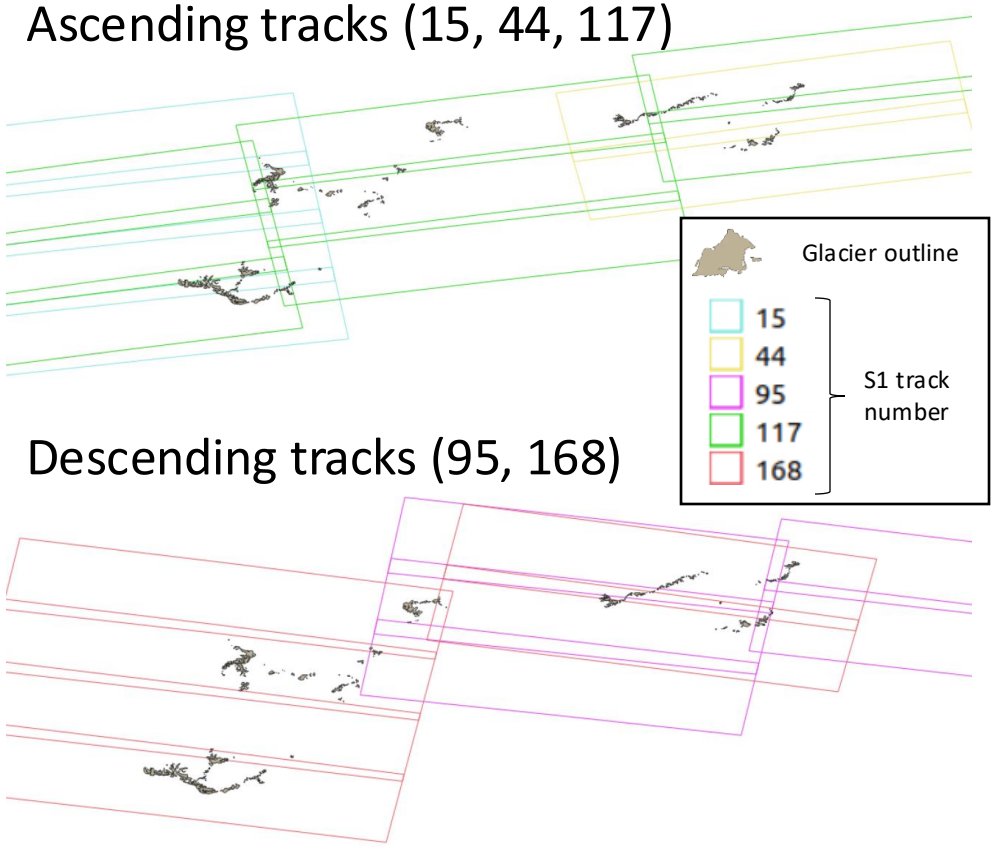
2. Surface deformation monitoring through multi-temporal interferometry
   - **Objective**: Validate cloud-native interferogram generation for deformation analysis
   - **openEO** process tested: **`sentinel1_sar_interferogram`**
   - Generation of Sentinel-1 interferogram time series in **openEO**
   - Test the ingestion of **openEO** generated interferogram into **Mintpy** for multi-temporal interferometry analysis
   - Comparison with validated reference products generated using the **ASF-HyP3** service

Use case 1: InSAR coherence time series

12days InSAR coherence time series over all the glaciers of South Tyrol from 1-Jul-2023 to 30-Sep-2023.
Application: Debris cover glacier detection (Barella et al., 2022, IEEE JSTARS)

Ascending tracks (15, 44, 117)

Descending tracks (95, 168)



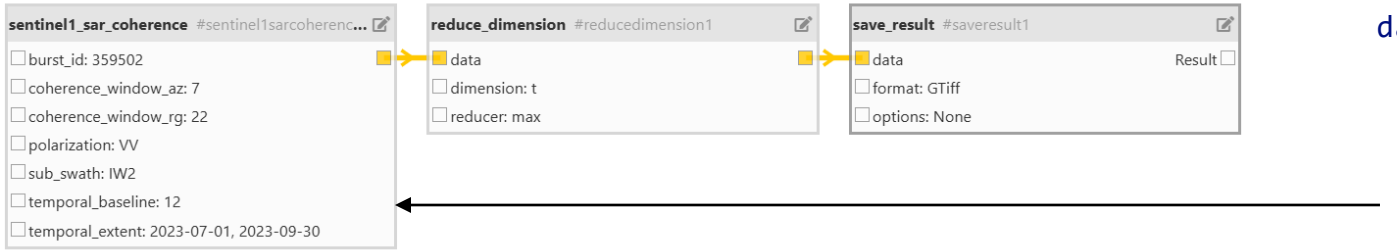
Total number of bursts:
25

Total number of 12-days InSAR pairs for 3 months (1-Jul – 30-Sep):

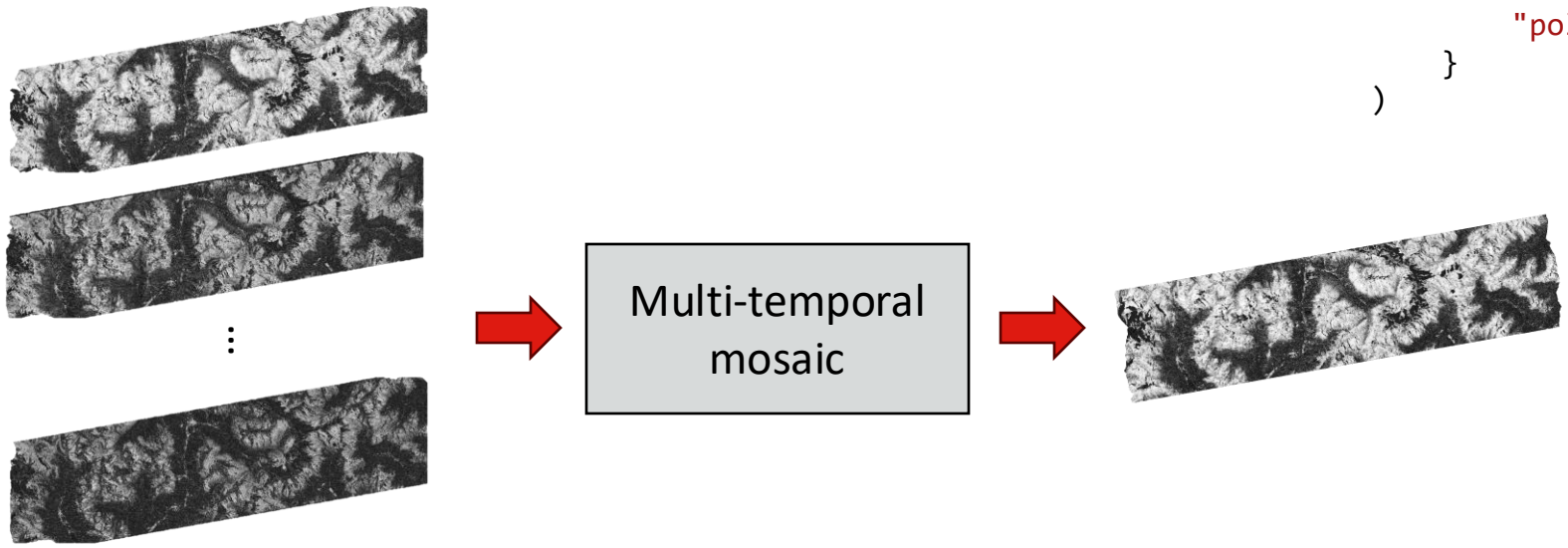
$$\frac{92}{12} \times 25 \approx 190$$

Use case 1: InSAR coherence time series

For each burst a multitemporal mosaic of InSAR coherence is computed with the following graph:

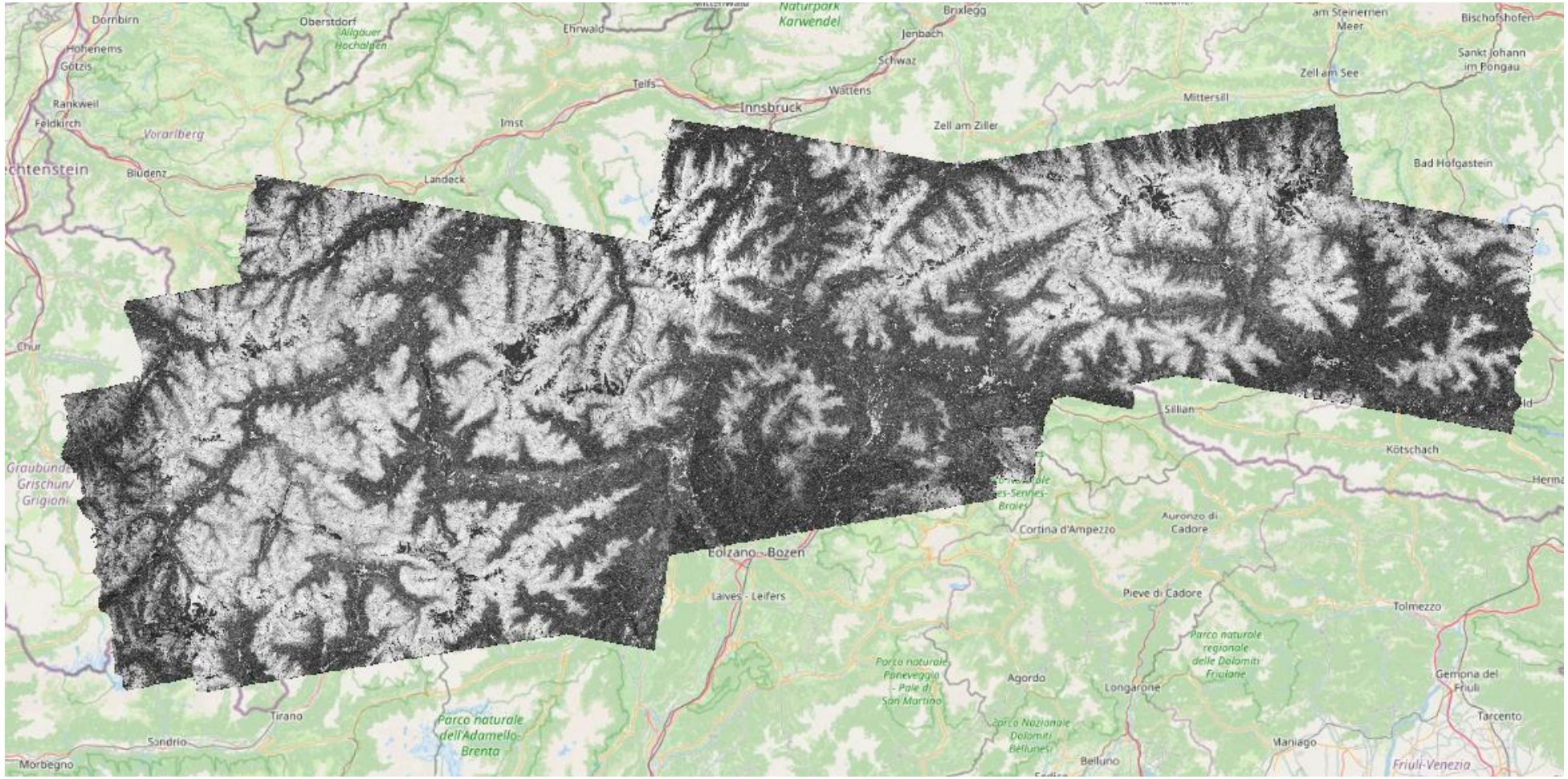



```
datacube = connection.datacube_from_process(
    "sentinel1_sar_coherence",
    namespace=sentinel1_sar_coherence_namespace
    **{
        "temporal_extent": ["2023-07-01", "2023-09-30"],
        "temporal_baseline": 12,
        "burst_id": 30345,
        "sub_swath": "IW3",
        "coherence_window_az": 7,
        "coherence_window_rg": 22,
        "polarization": "VV"
    }
)
```

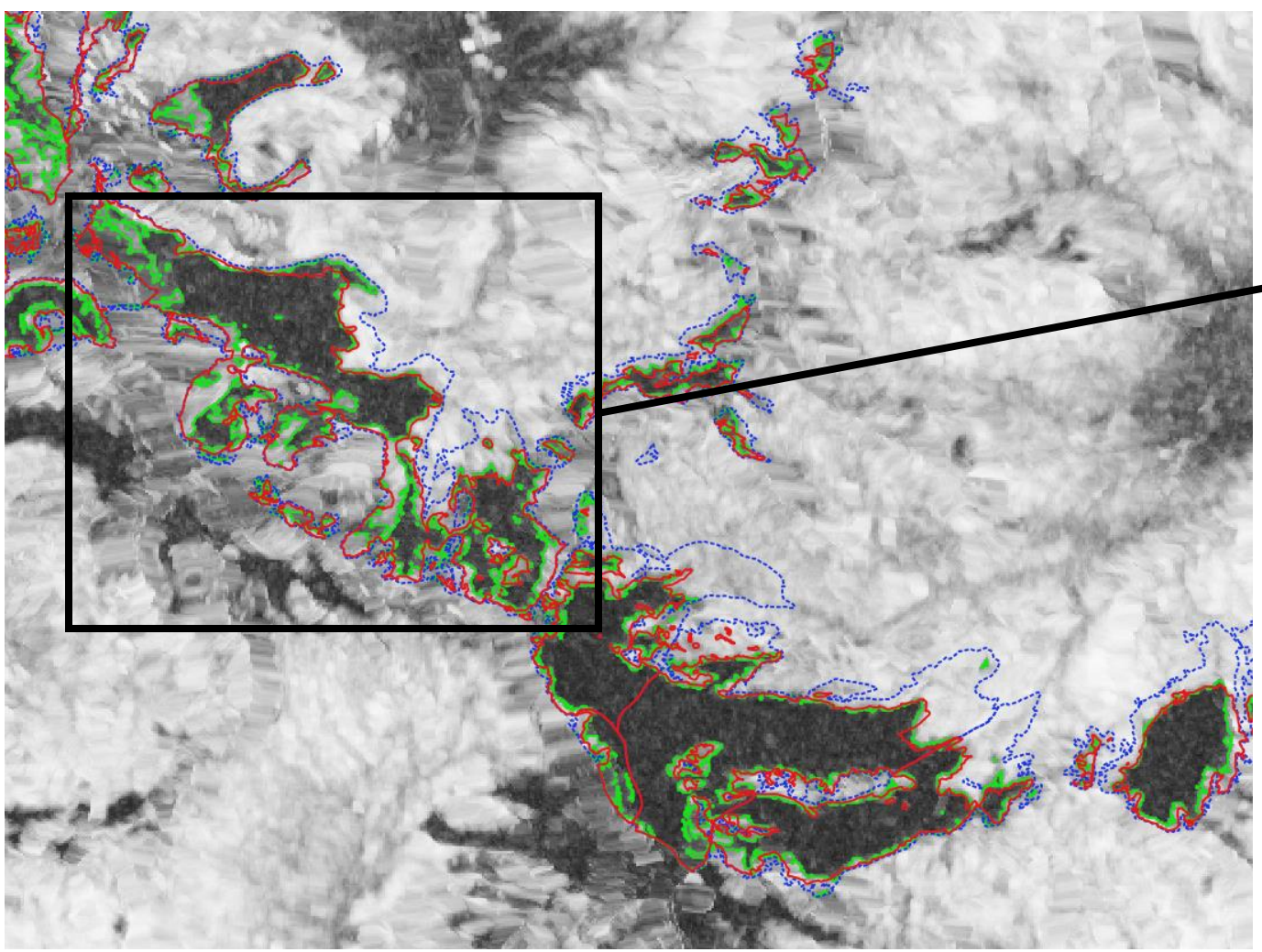


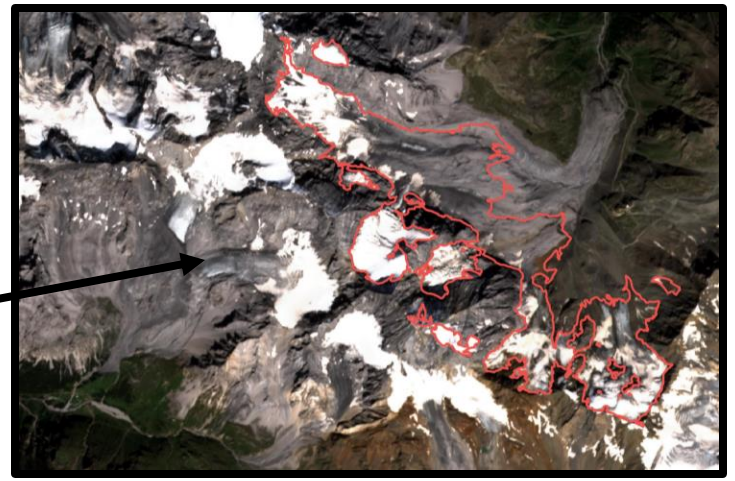
Use case 1: InSAR coherence time series

All the burst multi-temporal mosaics are then downloaded, merged, classified and vectorized



Use case 1: InSAR coherence time series





Background coherence mosaic 2023

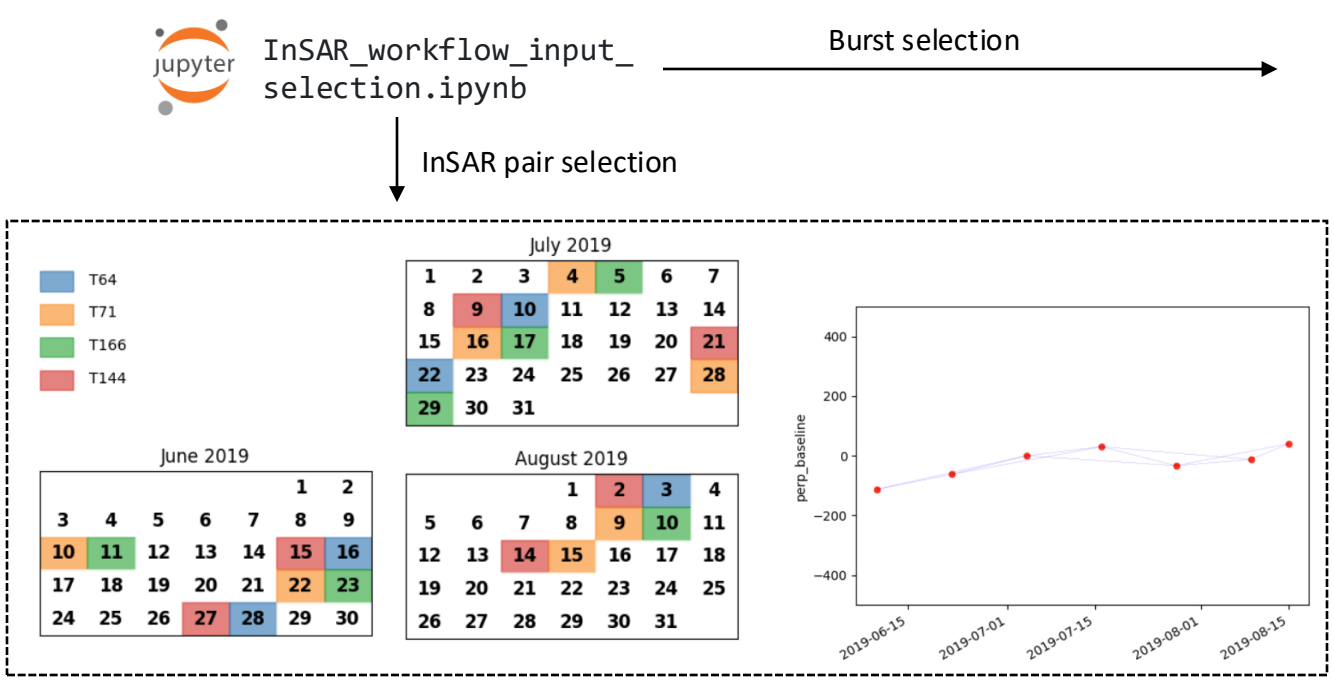
glacier outline 2023 from S1

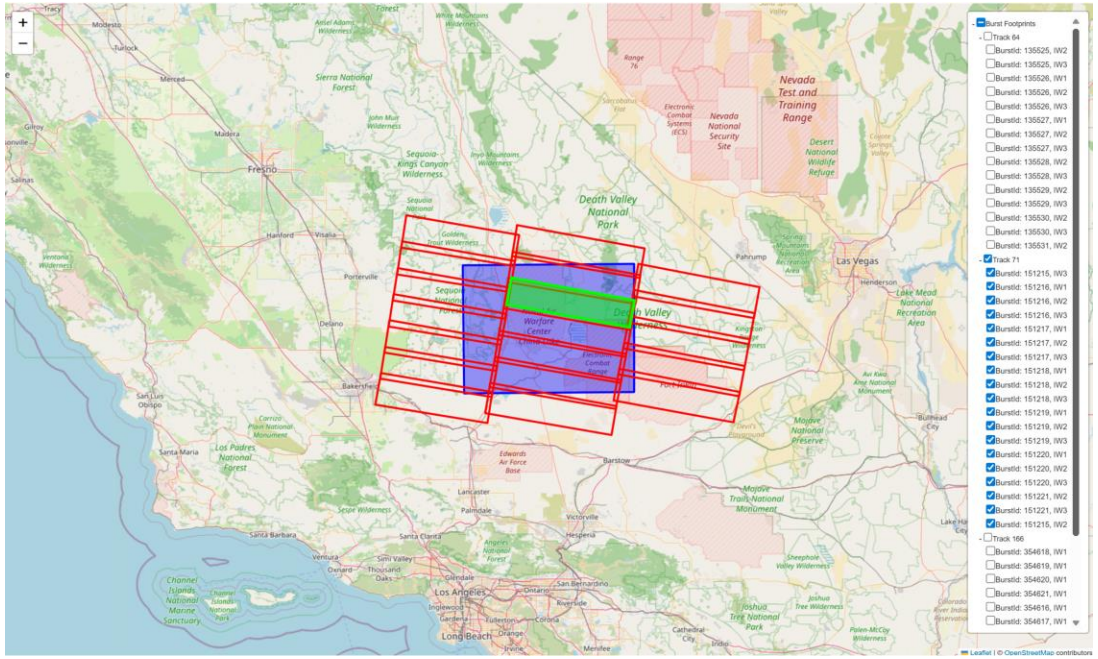
glacier inventory 2023 (validation)

glacier inventory 1997 (buffer)

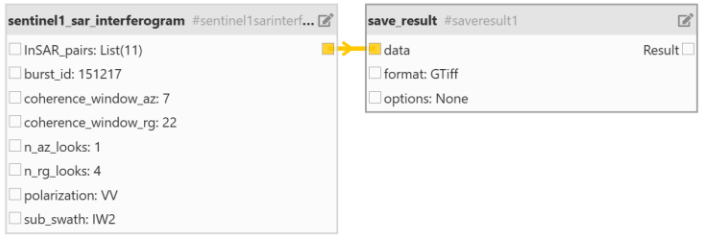
Use case 2: Multitemporal interferometry

- 6 July 2019 Ridgecrest earthquake (California) surface deformation monitoring
- 7 Sentinel-1 acquisitions (from 10 June 2019 to 15 August 2019); 11 interferograms
- Reference dataset distributed with MintPy was generated using the ASF HyP3 processing service → used as benchmark for comparison



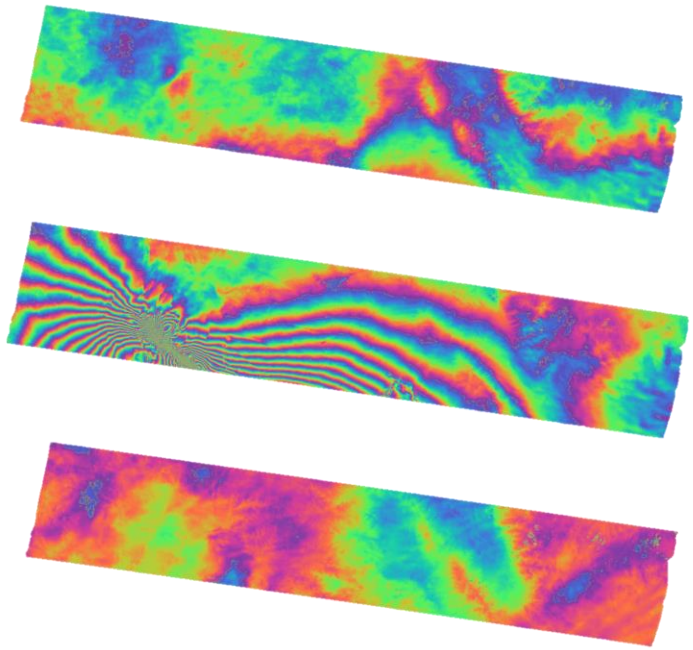


Use case 2: Multitemporal interferometry




```
datacube = connection.datacube_from_process(
    "sentinel1_sar_interferogram",
    namespace= sentinel1_sar_coherence_namespace,
    **{
        "InSAR_pairs": [
            ["2019-06-10", "2019-07-04"],
            ...
            ["2019-07-28", "2019-08-15"]
        ],
        "burst_id": 151217,
        "sub_swath": "IW2",
        "coherence_window_az": 7,
        "coherence_window_rg": 22,
        "n_az_looks": 1,
        "n_rg_looks": 4,
        "polarization": "VV"
    }
)
```

...



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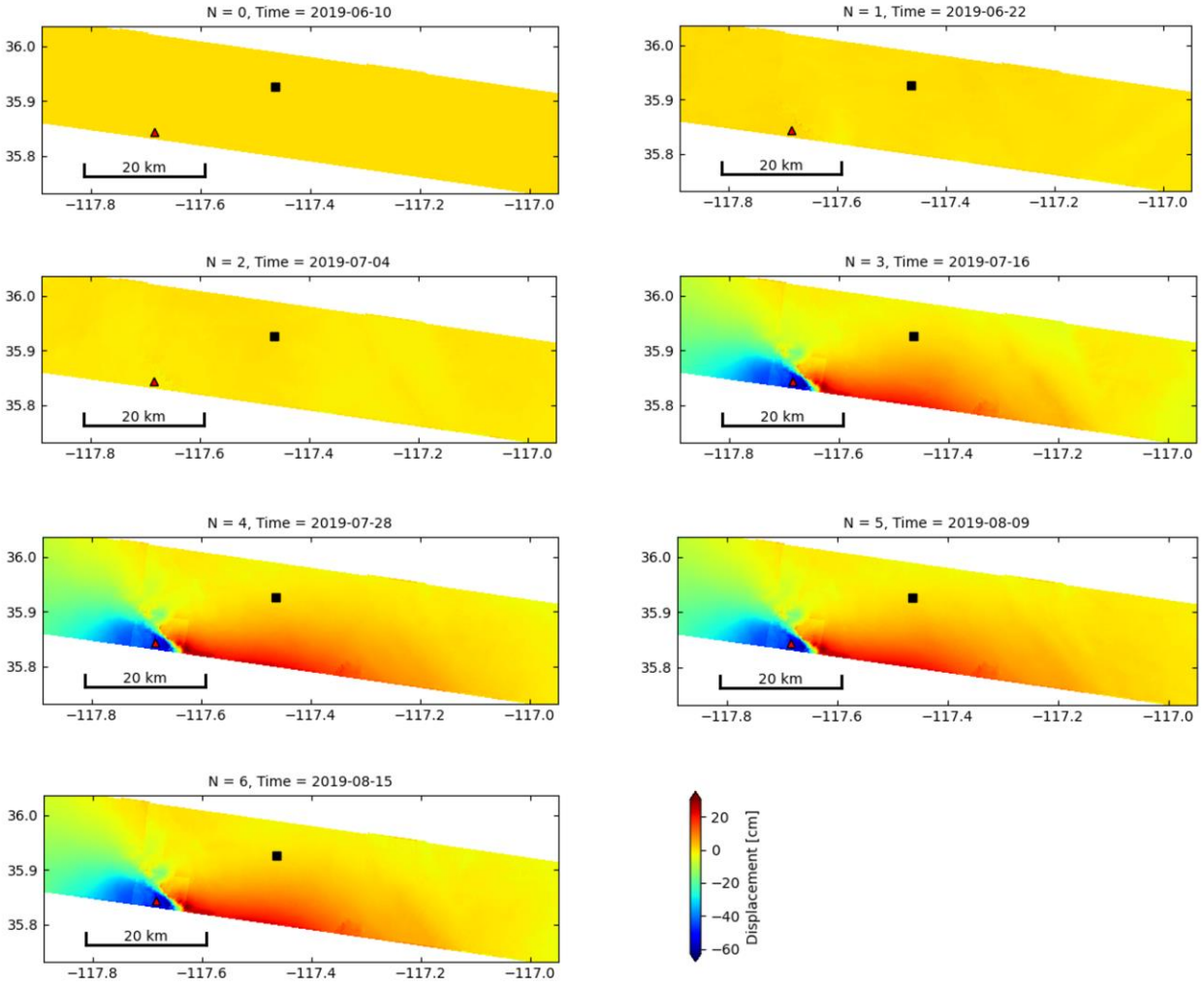
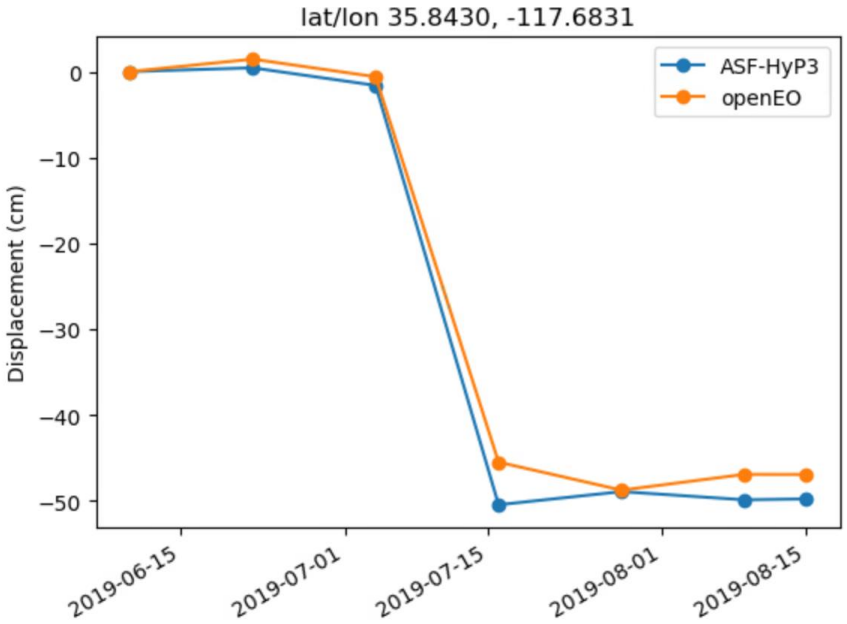
MintPy

Miami InSAR time-series software in Python

Use case 2: Multitemporal interferometry





Performance assessment

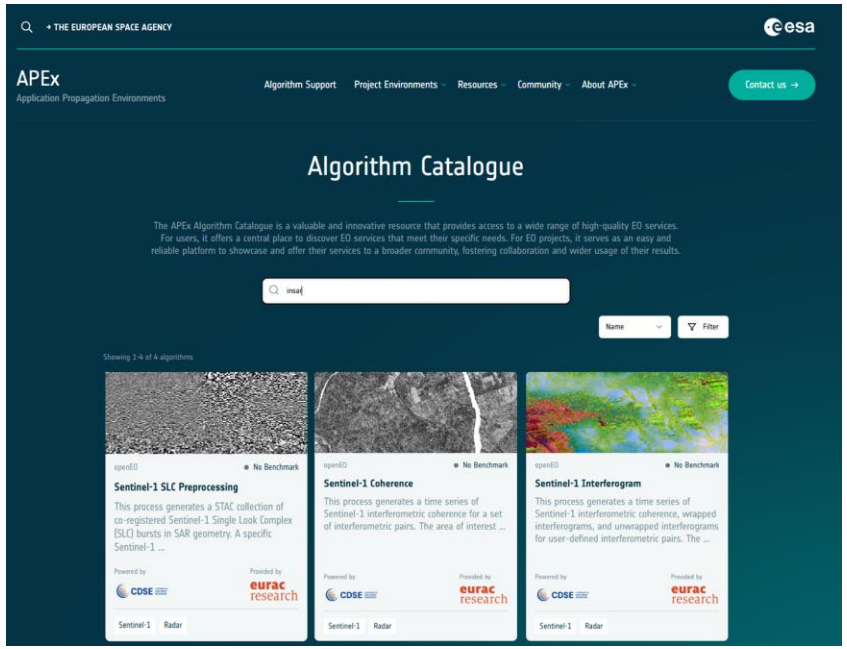
- **CDSE** works with a credit system. 10 000 free credits per months are available for each user

- **Sentinel-1 SAR Interferogram and coherence:**
  - 2 credits per pair with 7 credits base cost.
  - A single pair processing takes around 10min with 7Gb RAM
  - Some examples:
    - Whole of 2025 in a burst from the Andes: 90 credits, 43 pairs (2.1 credits/pair)
    - Whole of 2023 in a burst from Europe: 64 credits, 28 pairs (2.4 credits/pair)
    - Concurrent jobs for SAR coherence on 190 pairs over 25 different bursts takes around 2 hours

- **Sentinel-1 SAR SLC Preprocessing:**
  - Similar performances to SAR Interferogram and coherence

Conclusion

- The new openEO InSAR processes are available and ready to be tested by users through CDSE
- Documentation available in the [APEx Algorithm Catalogue]
- Check our [GitHub repository] and our [eo4society web story] for more details



GitHub