ESA's Extended Timing Annotation Dataset (ETAD) for Sentinel-1 Product Status and Case Studies

Living Planet Symposium 2022

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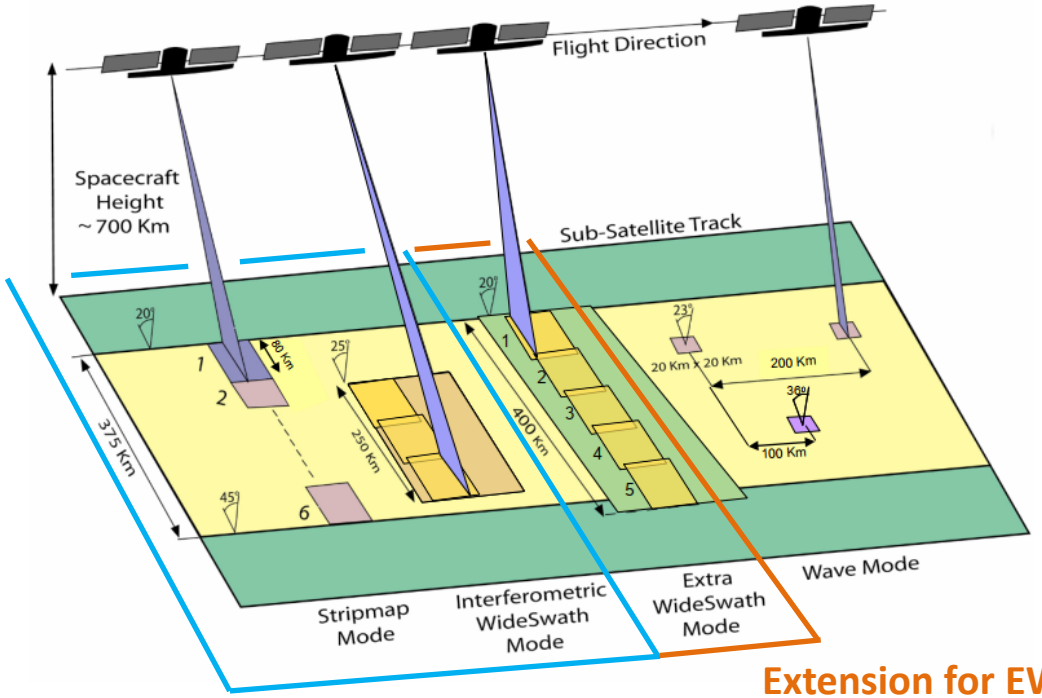
Motivation and Purpose of ETAD for Sentinel-1

- Comprehensive product to **provide timing corrections**
  - **Atmospheric path delays** (troposphere & ionosphere)
  - **Solid Earth tides** caused by Sun and Moon
  - **Sentinel-1 system specific effects** related to the SAR-IPF
- **Sentinel-1 level 1 SLC geometric product specification (NRT)** *[1]*
  - SM products: **2.5m**
  - IW TOPS product: **7m**
  - EW TOPS product: **N/A**
- **ETAD geometric product specification (1 sigma)**
  - Non-TOPS ETAD: **0.2m (rg)** and **0.1m (az)**
  - TOPS ETAD: **0.2m (rg)** and **0.1m (az)**



Operational ETAD generation for every Sentinel-1 L1- SSC-Product in SM and IW

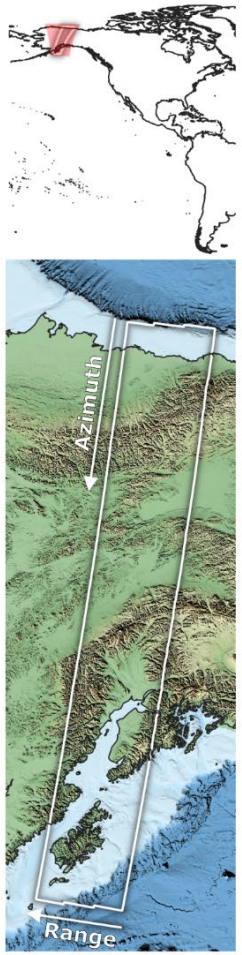
Extension for EW already foreseen by design

[1] S1-RS-MDA-52-7440, Sentinel-1 Product Definition, issue 2, rev. 7, 25/03/2016

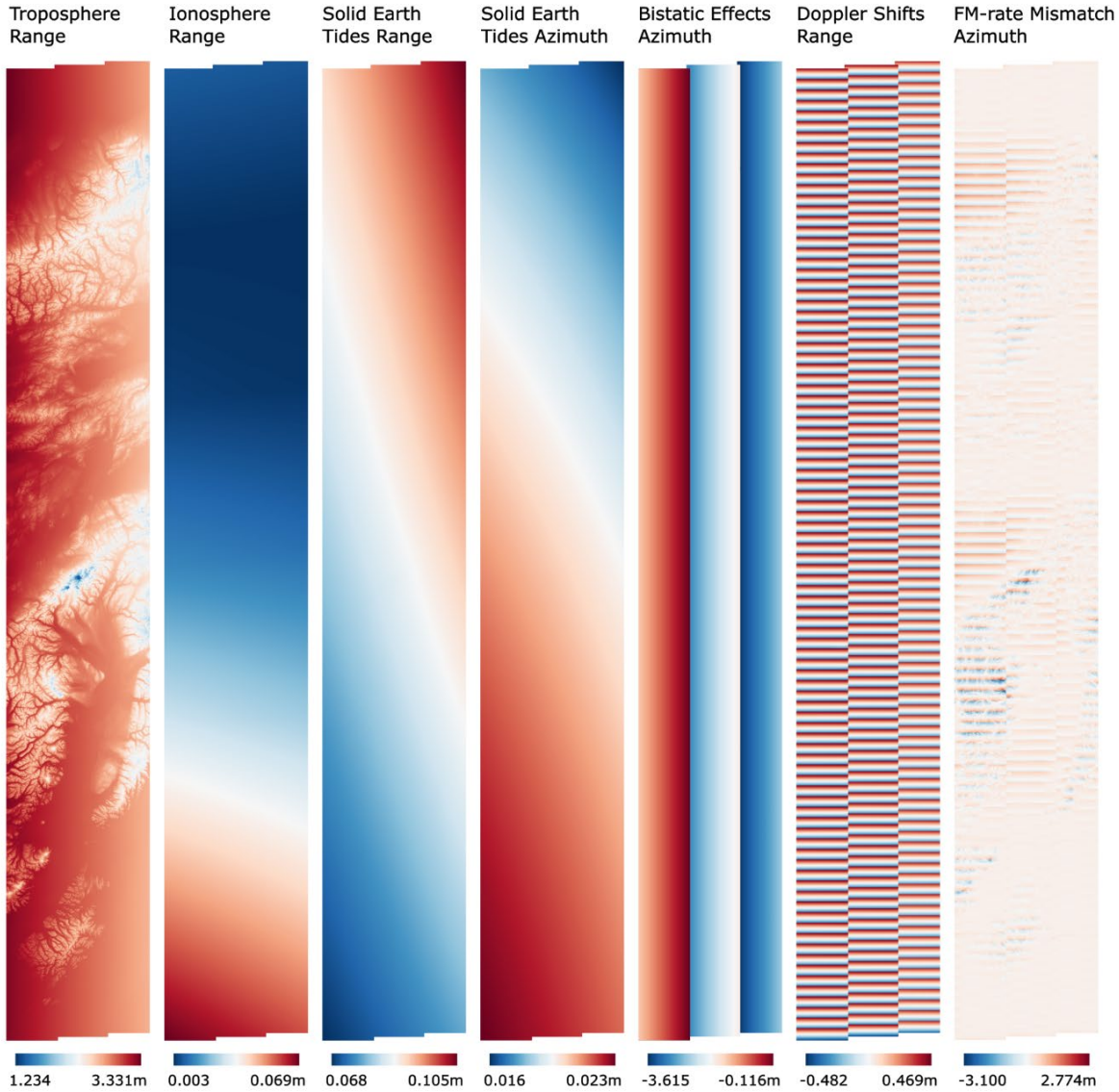
Product Overview

- **ETAD product key features**
  - Coverage of **S-1 data-takes**
  - Regularly sampled **grids in slant range and azimuth (~200m)**
  - **NetCDF data format** distributed as **SAFE containers**
  - **Applicable to** SM & IW **SLC products**
  - Includes the S-1 **precise orbit solution for data-take**
  - Product **timeliness of 21 days***

Sentinel-1 **E**xtended **T**iming **A**nnotation **P**rocessor



Sentinel-1A data-take over Alaska, USA 2020-01-28 16:26:52 UTC



* Poster in B1.06: A. Valentino et al., Towards NRT Sentinel-1 ARD products

SETAP IPF Processor and Algorithms

- **Efficient operational s/w processor with cloud support**

External Data Providers

PDGS Internal Resources

ECMWF Operational Analysis
IFS data: T, P_S, P_{MSL}, q, W

IGS INTERNATIONAL GNSS SERVICE Global Ionospheric Maps:
Total Electron Content

Copernicus POD Service:
Precise Orbit Ephemerides

S-1 PDGS: L1 SLC
annotations of data-takes

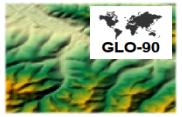
S-1 PDGS Archiving System

management layer

management layer

Static Processor Resources

direct access



Copernicus Global
90m DEM: h_{DEM}(lat,lon)

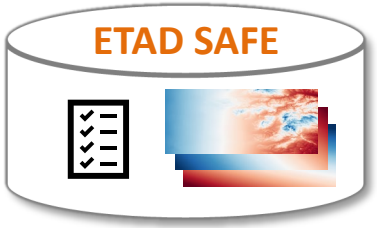
NASA Jet Propulsion Laboratory California Institute of Technology JPL Planetary
Ephemerides: DE421

SETAP IPF

docker

Troposphere	▸ Direct Integration of NWM Data
Ionosphere	▸ Single Layer TEC Mapping
Earth Tides	▸ Conventional Geodynamic Model
S-1 System	Bistatic Shifts in Azimuth Doppler-induced Range Shifts Azimuth Shifts due to FM-rate Mismatch

[1] [2] [3]



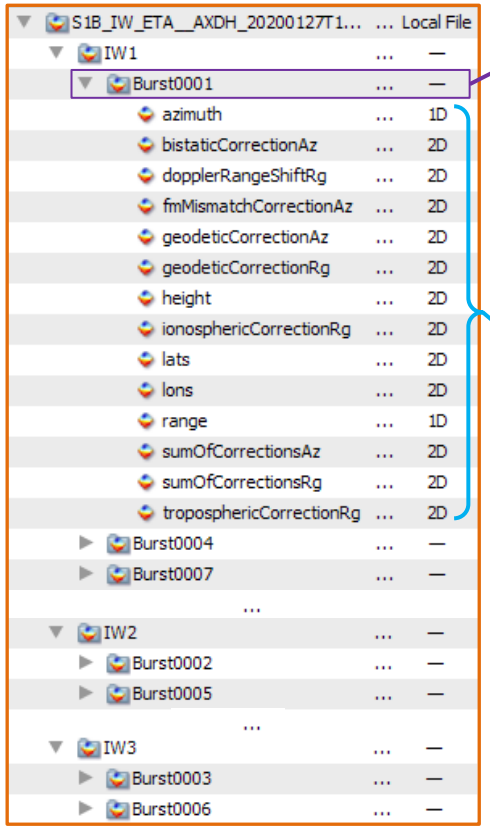
Throughput with 32 cores @ 3 GHz:
~ 65s / IW Slice (~ 1.2 Mio points)

[1] **Cong et al. 2018**, *Mitigation of Tropospheric Delay in SAR and InSAR Using NWP Data,* Remote Sensing
[2] **Gisinger et al. 2020**, *In-Depth Verification of Sentinel-1 and TerraSAR-X Geolocation …, IEEE TGRS*
[3] **Petit and Luzum (eds.) 2010**, *IERS Conventions 2010*, Online: www.iers.org

ETAD NetCDF Contents and Usage

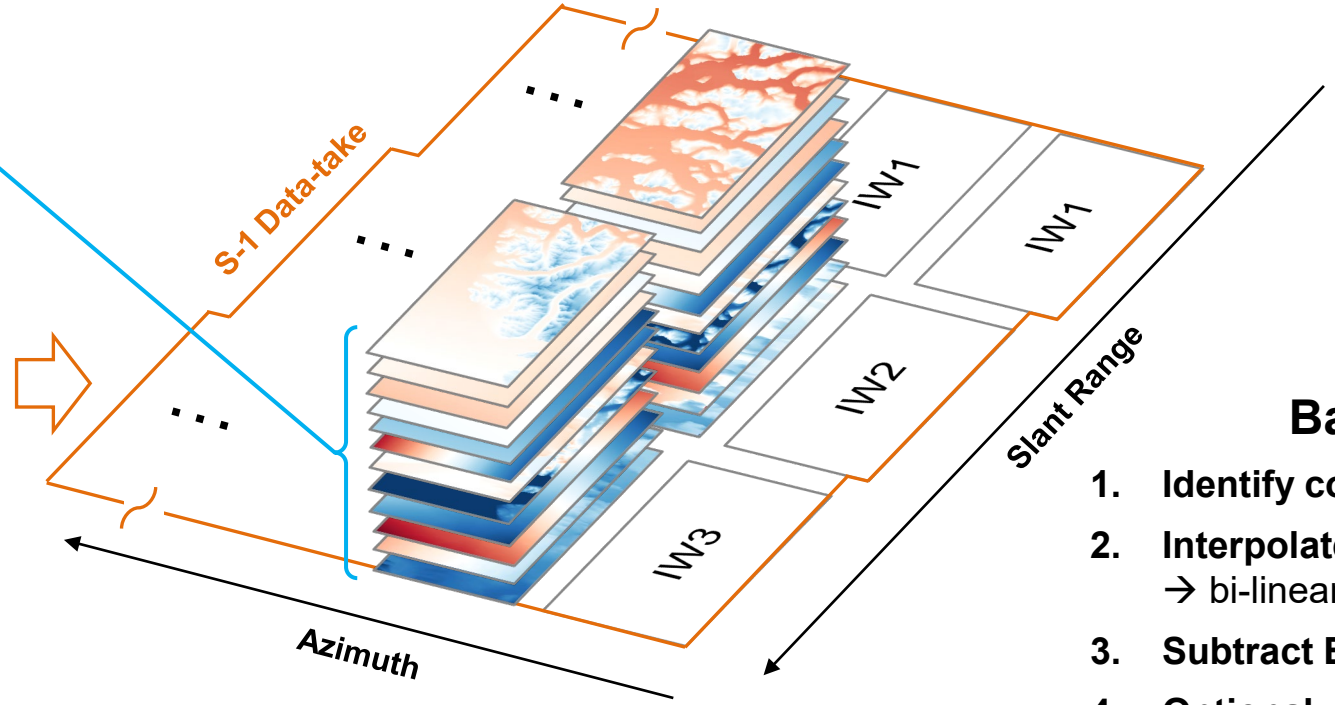
Precise orbit

ETAD NetCDF



Attributes at Burst Level

- **instrumentTimingCalibrationRange**
- **instrumentTimingCalibrationAzimuth**
- **…**



ETAD layers

Δ_i (range, azimuth) [**seconds**]

Select your layers

Basic usage[1] (Python API)

1. **Identify corresponding** SLC and ETAD **bursts**
2. **Interpolate** ETAD layers **to SLC resolution**
   → bi-linear interpolation
3. **Subtract ETAD** from SLC timing annotations
4. **Optional: Resample the SLC**

[1] **Python API by ESA: https://gitlab.com/s1-etad/**

Product Validation at CR Calibration Sites – IW Data

- Validation of **ETAD accuracy at calibration sites** applying **S-1A/B SAR geolocation analysis**

2x 1.5m CR Wettzell (GER)

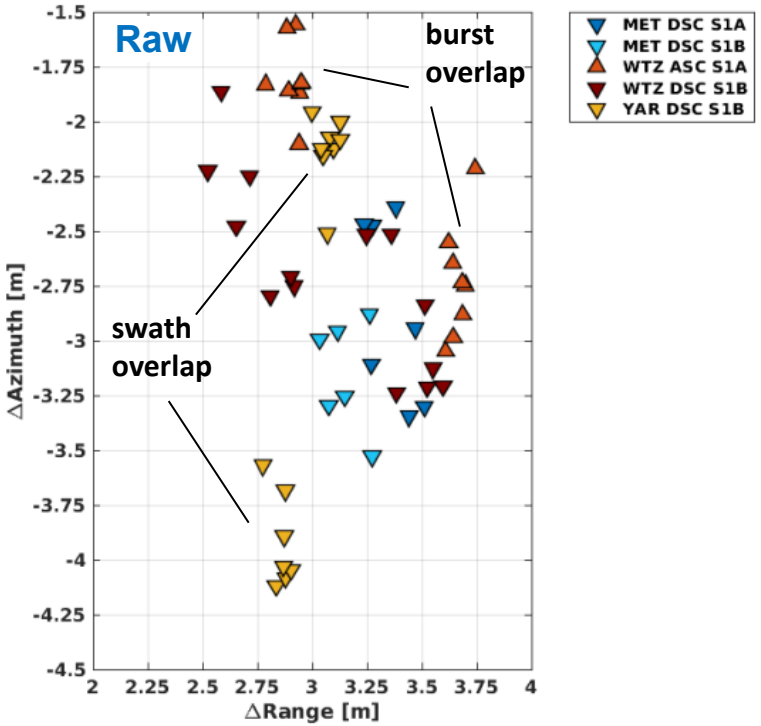
1.5m CR Metsähovi (FIN)

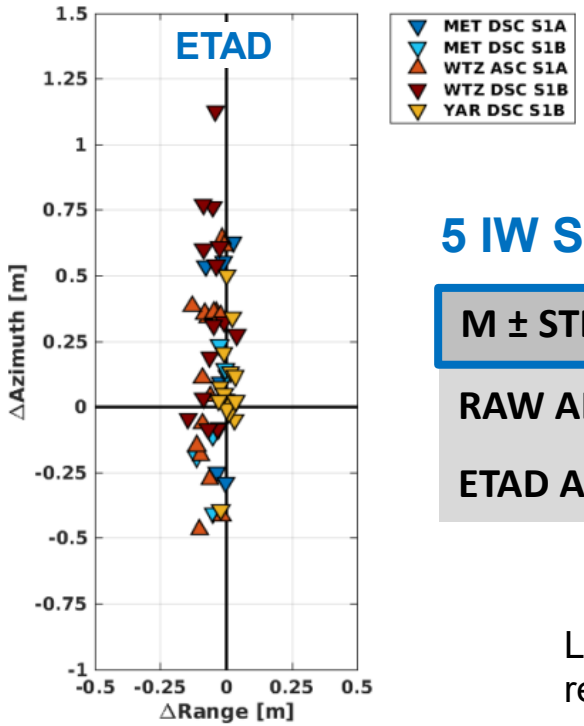
1.5m CR Yarragadee (AUS)

$$\Delta rg = (\tau_{SAR} - \tau_{REF} - \Delta\tau_{SumETAD}) \cdot c_{light}/2$$

$$\Delta az = (t_{SAR} - t_{REF} - t_{SumETAD}) \cdot v_{Beam}$$

⇨ **A**bsolute **L**ocation **E**rror (**ALE**) residuals **with & without ETAD**





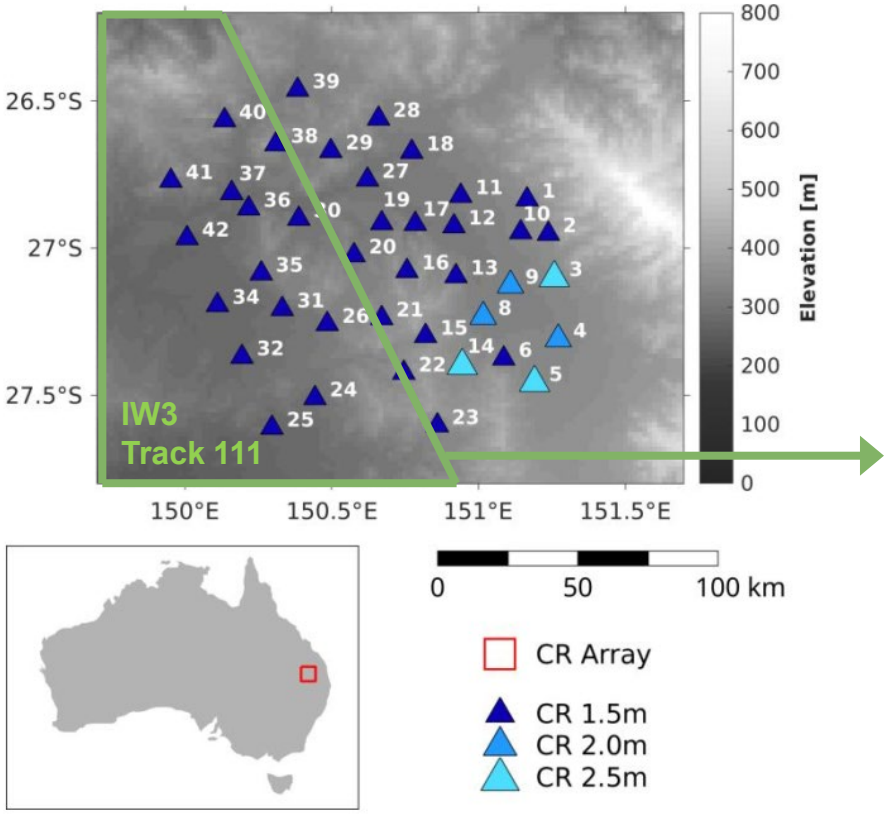
5 IW Stacks: S1A/B, Asc. & Desc.

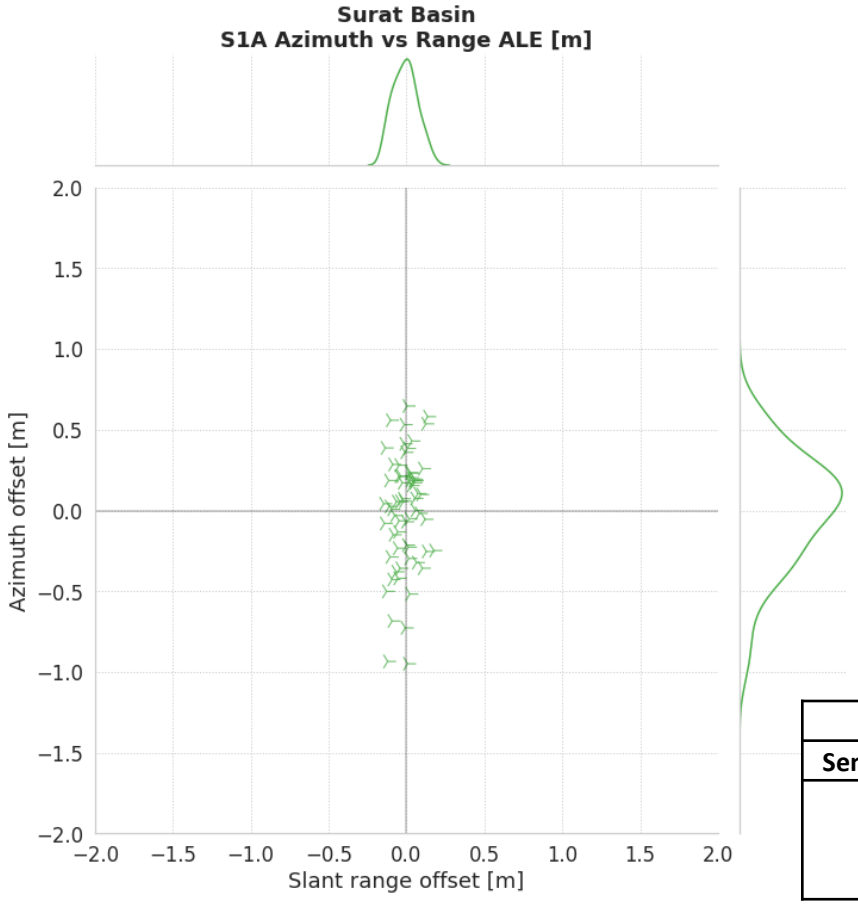
M ± STD [m]	Range	Azimuth
RAW ALE	3.150 ± 0.320	-2.736 ± 0.687
ETAD ALE	-0.036 ± 0.045	0.159 ± 0.334

Limited by 20m TOPS azimuth resolution / target SCR

Validation of ETAD Pre-Operation: IW Data at Australian CR Site

- Validation of **ETAD accuracy at calibration sites** applying **S-1A/B SAR geolocation analysis**





SAR-MPC

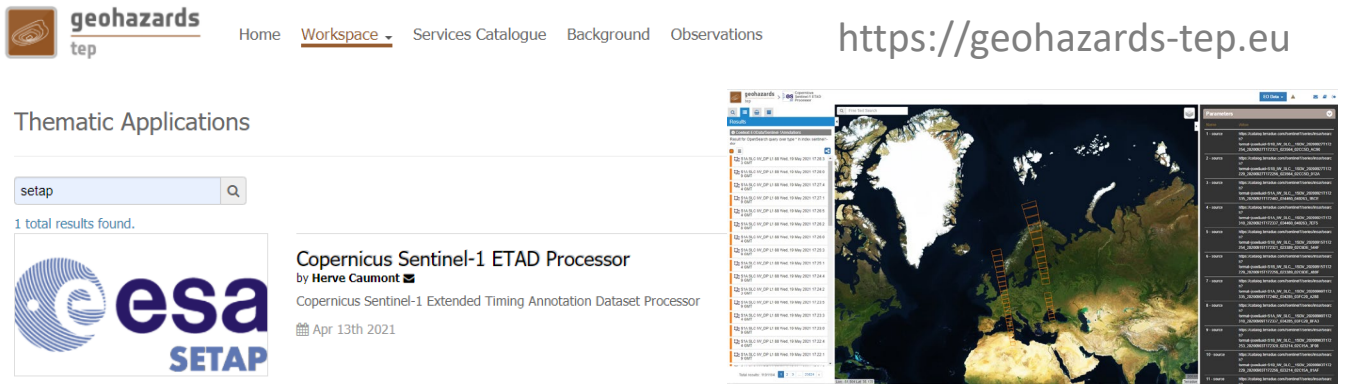
02/22 - 04/22:
5 S1A acquisitions / ETAD Products
14 reference CRs

Swath
IW1
IW2
IW3
Orbit direction + Polarization
ASCENDING H/H
ASCENDING V/V
DESCENDING H/H
DESCENDING V/V

	Range ALE [m]	Azimuth ALE [m]
Sentinel-1A	**-0.009 +/- 0.076**	**-0.004 +/- 0.350**
IW-1	/	/
IW-2	/	/
IW-3	-0.009 +/- 0.076	-0.004 +/- 0.350

ETAD Pilot Studies

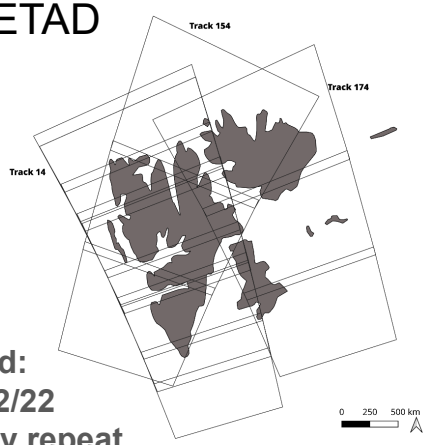
- Processor integrated to **Geohazard Thematic Exploitation Platform** for user pilot studies
  - Accessible to registered users until August 2022
  - Send request to: *s1-etad@esa.int*



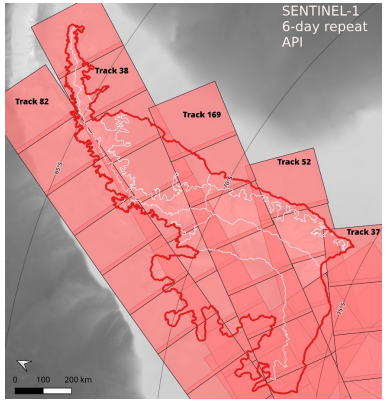
Offset Tracking for Ice Velocity

enveo

39 & 69 ETAD products



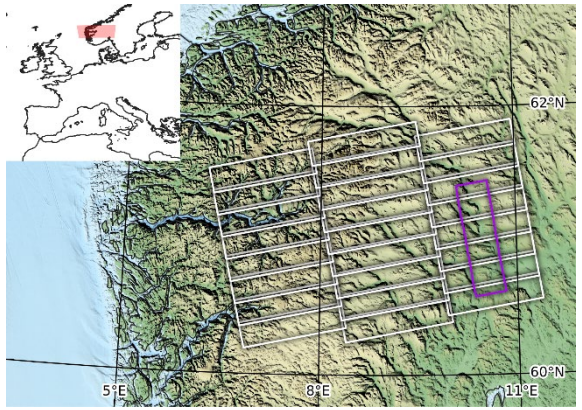
S-1 Svalbard:
- **12/21 – 02/22**
- **6 & 12 day repeat**



S-1 Antarctic Peninsula:
- **06/21 – 09/21**
- **6 day repeat**

First Evaluation for InSAR

PPO.Labs



12 ETAD products

Southern Norway:
- **07/19 – 09/19**
- **Track 44, 6 day repeat**

More Study Results involving ETAD:

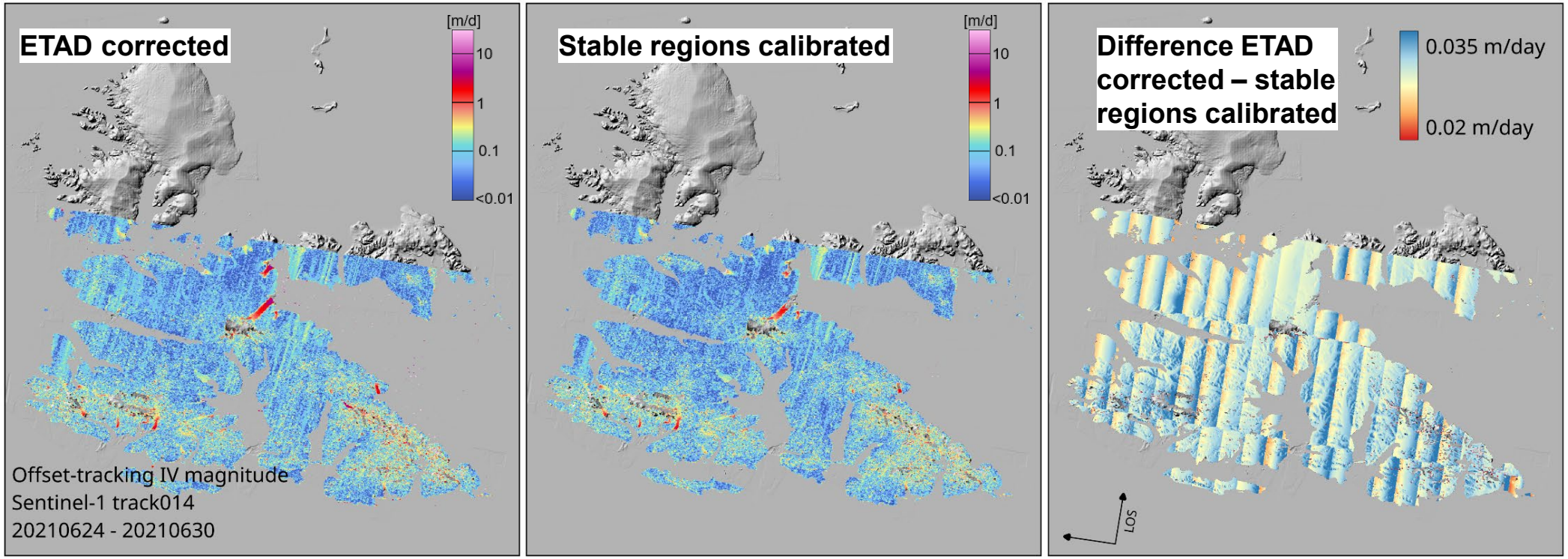
Poster in B1.06: M. Avian et al.: SAR meets atmosphere

DLR esa

Pilot Study by ENVEO – Offset Tracking for Ice Velocity

- **Correcting biases with ETAD** in offset-tracking **to avoid calibration** against stable/slow-moving regions

Svalbard: Track 014 Pair 20210624 - 20210630



Same processing line **BUT:**

- ETAD corrections at **burst level**
- Calibration at **de-bursted level**

→ Difference shows intra-burst trends captured with ETAD

Further evaluation and validation ongoing for single pairs, track stacks and merged products

Pilot Study by ENVEO – Offset Tracking for Ice Velocity

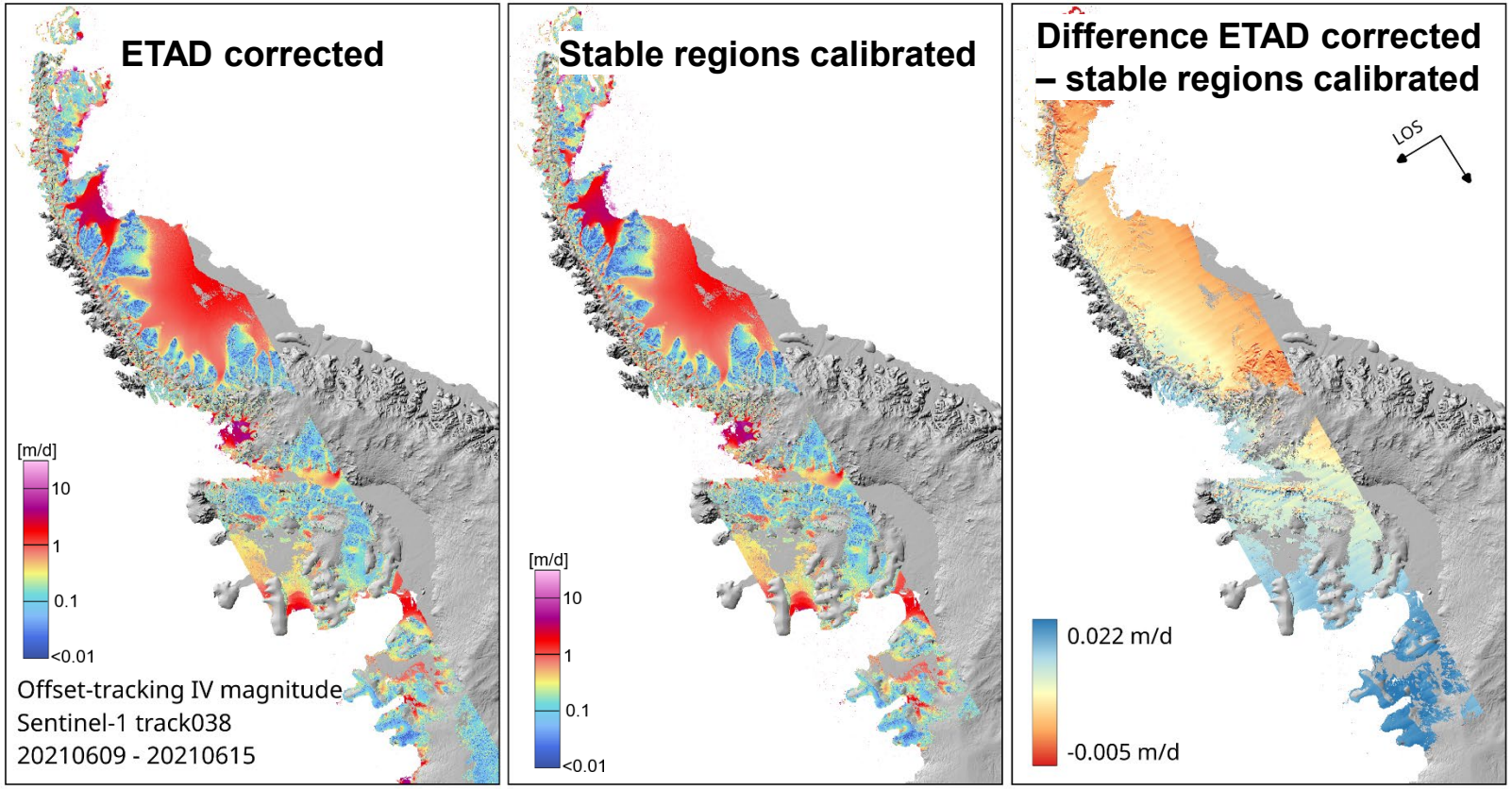
- **Correcting biases with ETAD** in offset-tracking **to avoid calibration** against stable/slow-moving regions

Antarctic Peninsula:
Track 038
Pair 20210609 - 20210615

Same processing line **BUT:**

- ETAD corrections at **burst level**
- Calibration at **de-bursted level**

→ Difference shows long-scale trends

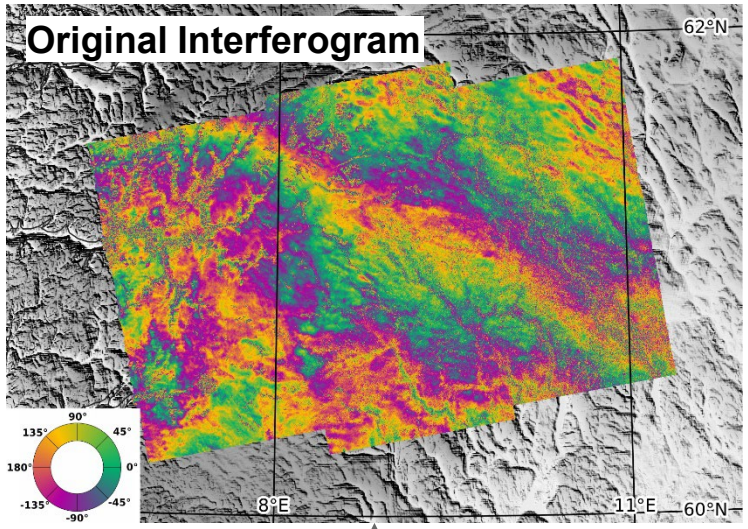


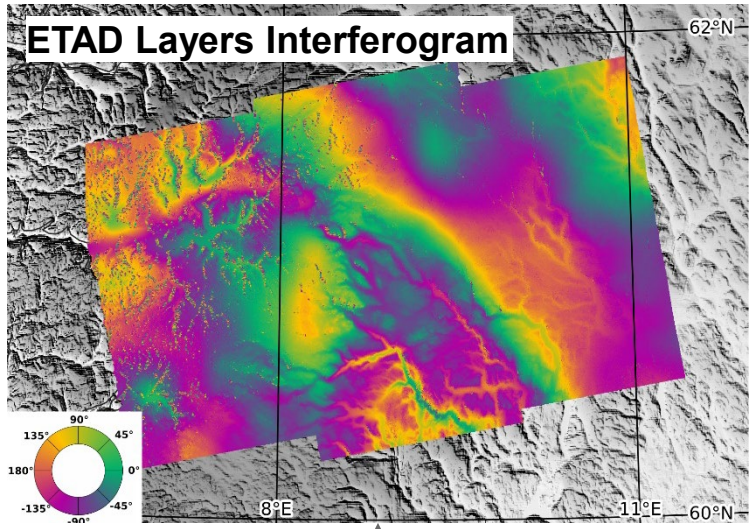
Further evaluation and validation ongoing for single pairs, track stacks and merged products

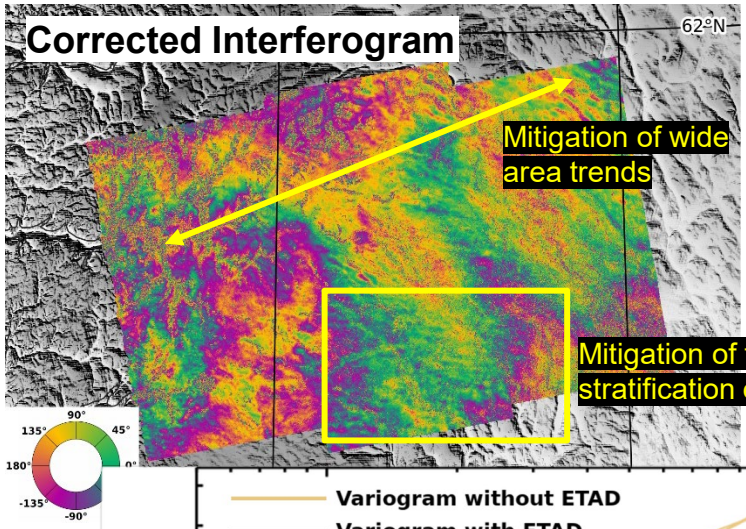
Pilot Study by PPO.labs – First Evaluation for InSAR

- Generation of **differential phase corrections** using the ETAD layers **to correct interferograms**

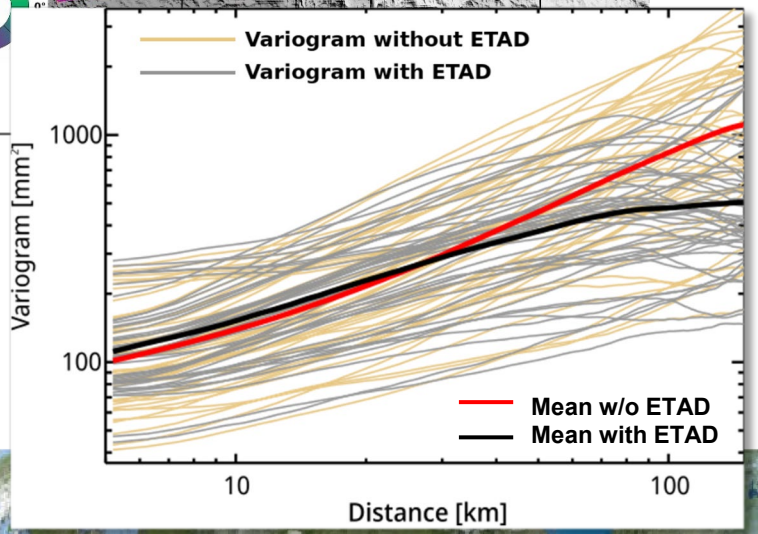
Southern Norway: Track 044, Example 20190708 - 20190906







12 scenes / ETADs → P(12, 2) = 66 interferograms ⇨ **Variogram analysis[1]**



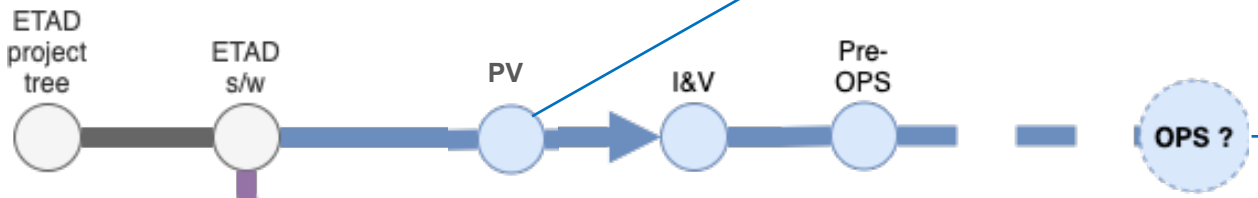
[1] **Parizzi et al. 2021**, *InSAR Performance for Large-Scale Deformation Measurement, IEEE TGRS*

Conclusions

- **The ETAD product is the result of more than two years of intensive development by DLR and ESA**
  - **Atmospheric delays, solid Earth tides,** and **SAR system effects corrections** for **Sentinel-1 SM & IW data**
  - **User-friendly package** with all information in a **self-contained NetCDF** and **distribution of precise orbits**
- **Product validation at CR reference sites → formal specification** (1 sigma): **0.2m (rg)** and **0.1m (az)**
  - ETAD **fulfills formal specifications** and geolocation **results are in line with** earlier **S-1 MPC assessments**
  - IW & SM results show **attainable geolocation accuracy of 5 cm range & 5 cm azimuth** when applying ETAD
- **ETAD pilot studies supported by GEP**
  - Example by ENVEO – **Offset Tracking for Ice Velocity**
    - → ETAD corrections reduce the need for velocity calibration, especially for 6-day pairs
    - → Corrections address long-scale trends and burst-scale effects
    - → Impact assessment on merged results at Svalbard and Antarctic Peninsula ongoing
  - Example by PPO.labs – **First Evaluation for InSAR**
    - → ETAD can reduce stratification signals and wide area trends above ~25 km spatial distance
    - → Analysis with larger stacks and deformation time series ongoing

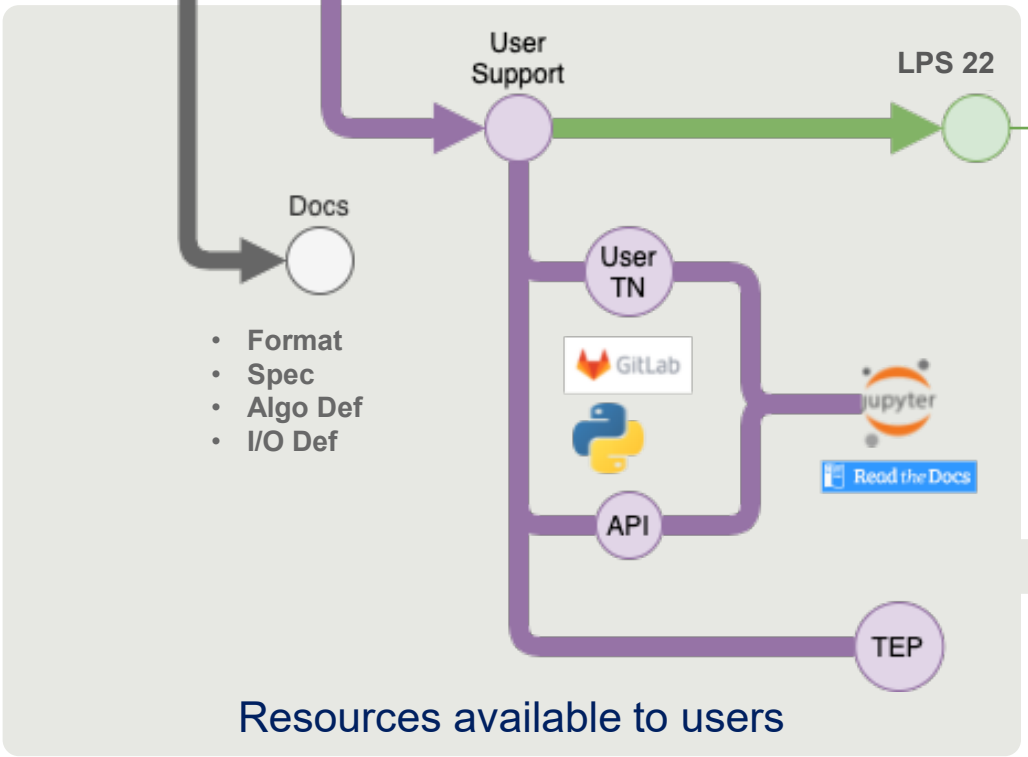
ESA Roadmap for ETAD

IEEE TGRS Paper: *The ETAD for Sentinel-1 – Product Description and First Evaluation Results*; reviewed, in revision

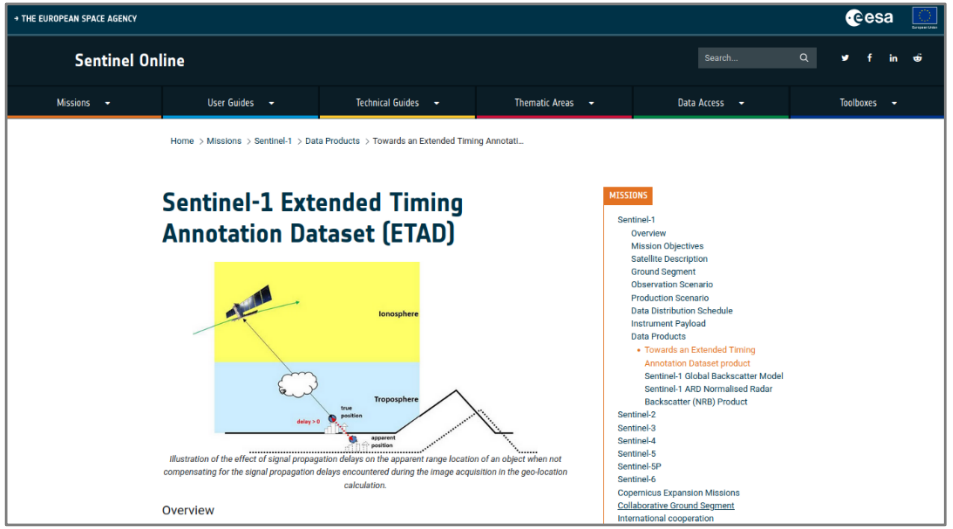


→ **I&V and pre-operations** (not open to user) complete

→ Ramp up of **routine operations** (routine generation of the product) **planned for Q4 2022**



ETAD accessible to users through pilot studies



https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-1/data-products/etad-dataset

Acknowledgement

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