Sentinel-1 instruments status, product performance and evolutions

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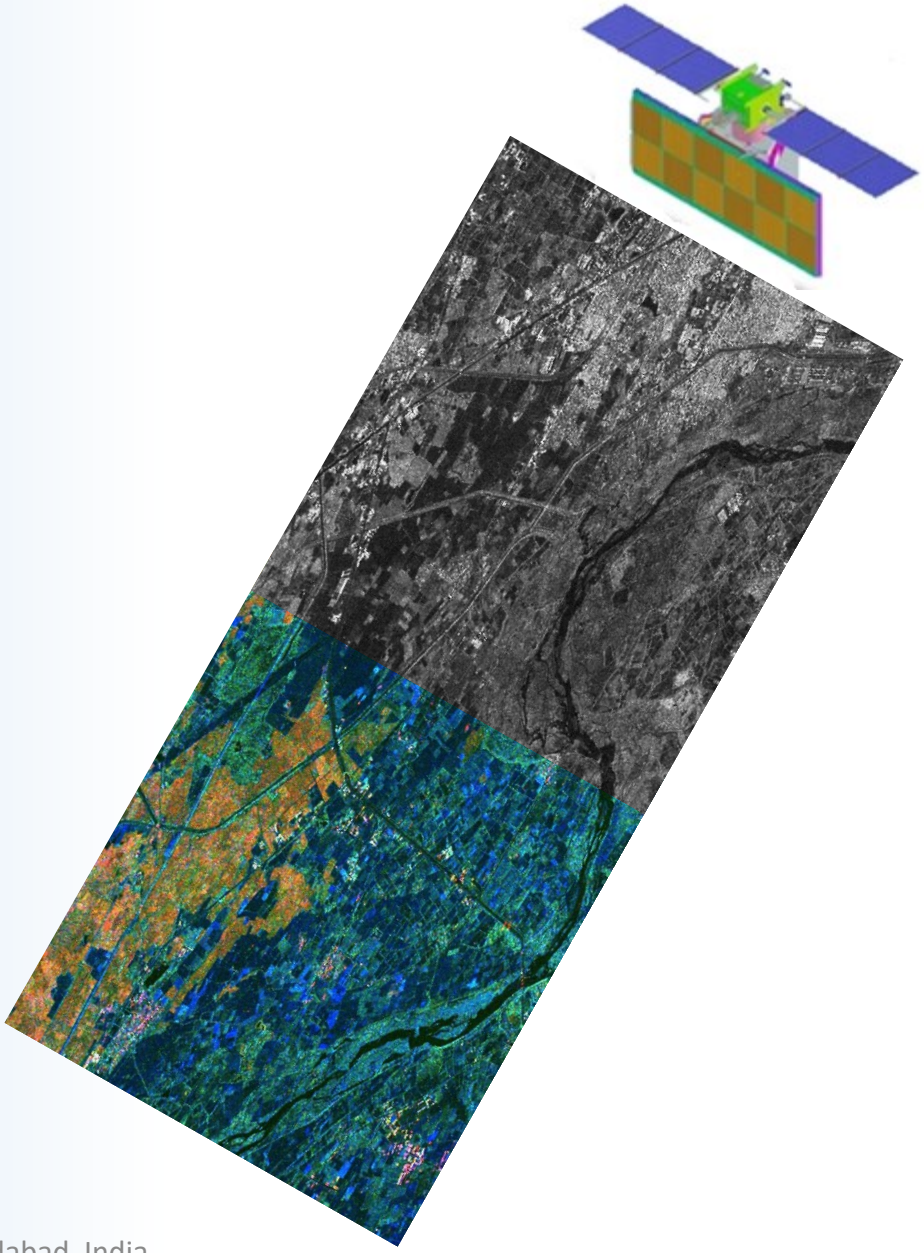
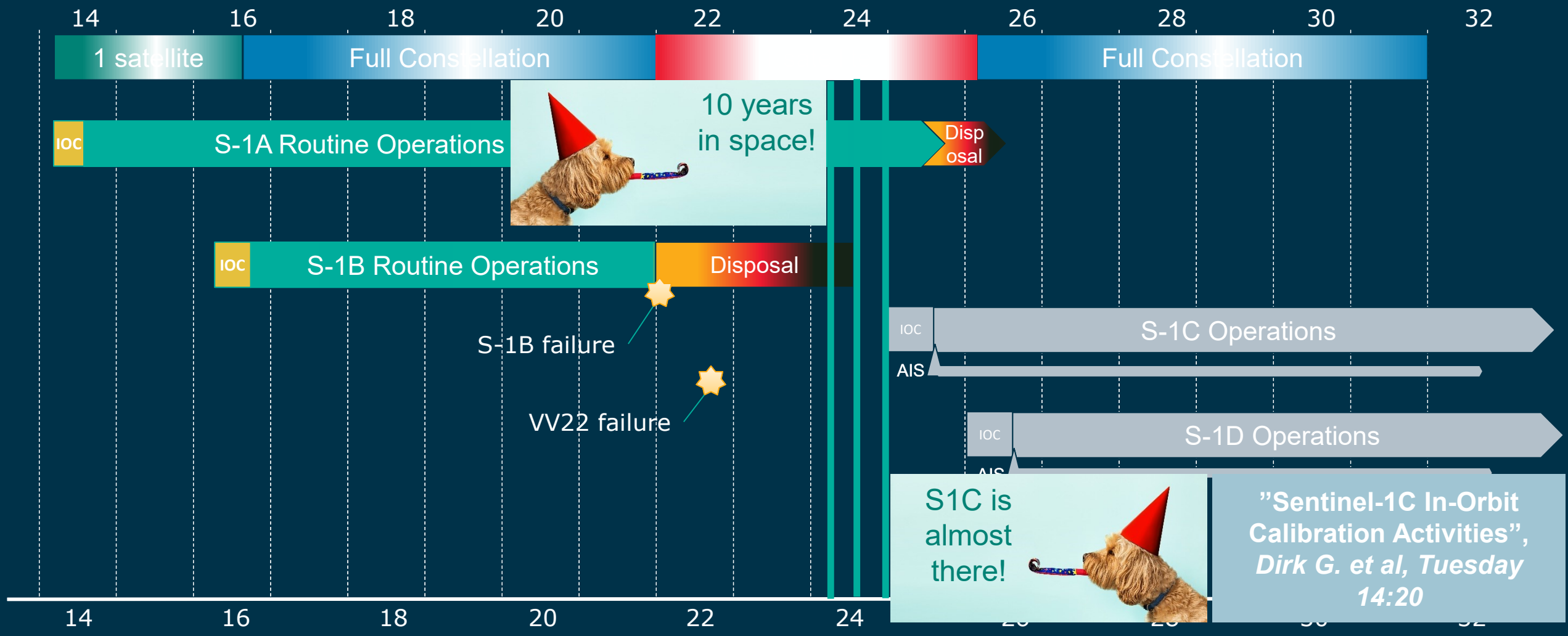


Overview

- Brief overview of mission timeline
  - *Timeline*
- Instrument performance monitoring
  - *Orbital tube change, TRM failure and Doppler monitoring*
- L1 quality and product evolution
  - *ETAD*
- L2 quality and product evolution
  - *Tropical Cyclones, L2 & Machine Learning*

Sentinel-1 Mission timeline



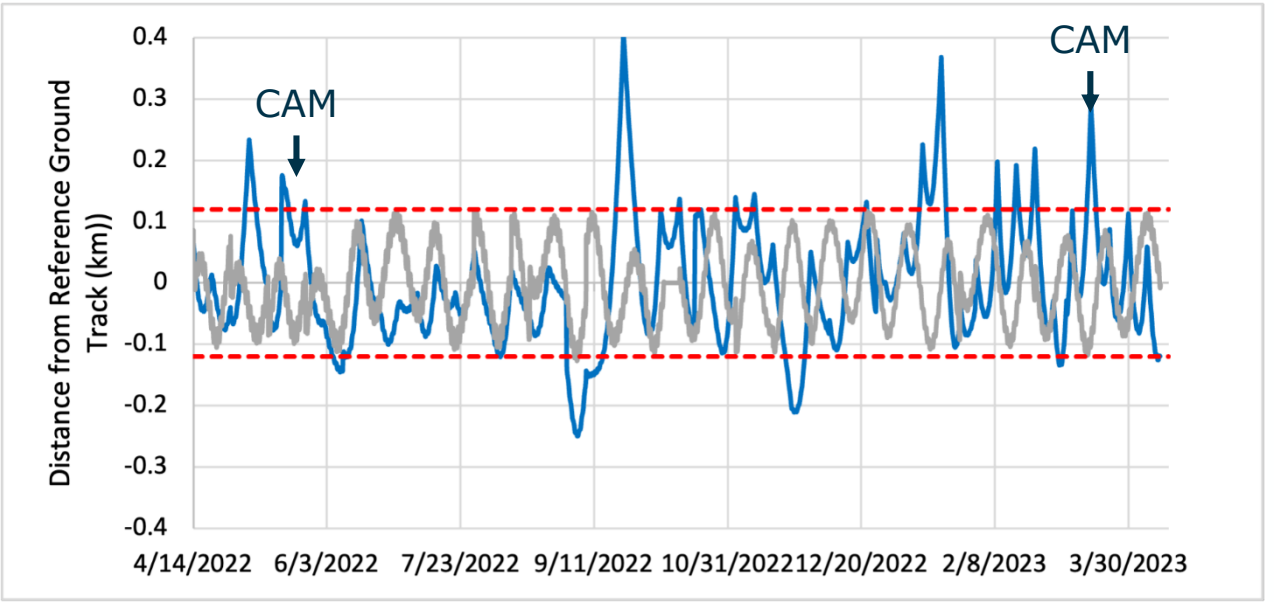
S1-A Orbital Tube Control Change

The ground track control is implemented with:

- **In-Plane OCMs:** 65 /year (approx. 1-4 per week)
  - IP OCMs to control the ground-track deviation at the Equator crossings and the evolution of the Eccentricity Vector / Semi Major Axis
- **Out-of-Plane OCMs:** 11 /year (approx. 1 every 4 to 5 weeks)
  - OOP OCMs to control the orbit inclination and the ground-track deviation at northern and southern most latitude

Since S1-A IOC, orbital tube has been nominally kept within a 200 m (RMS)

Nominal Orbital Control
(dead-band of +/-120m around a reference ground-track controlled at Equator crossing and Maximum latitudes)



S1-A Orbital Tube Control Change

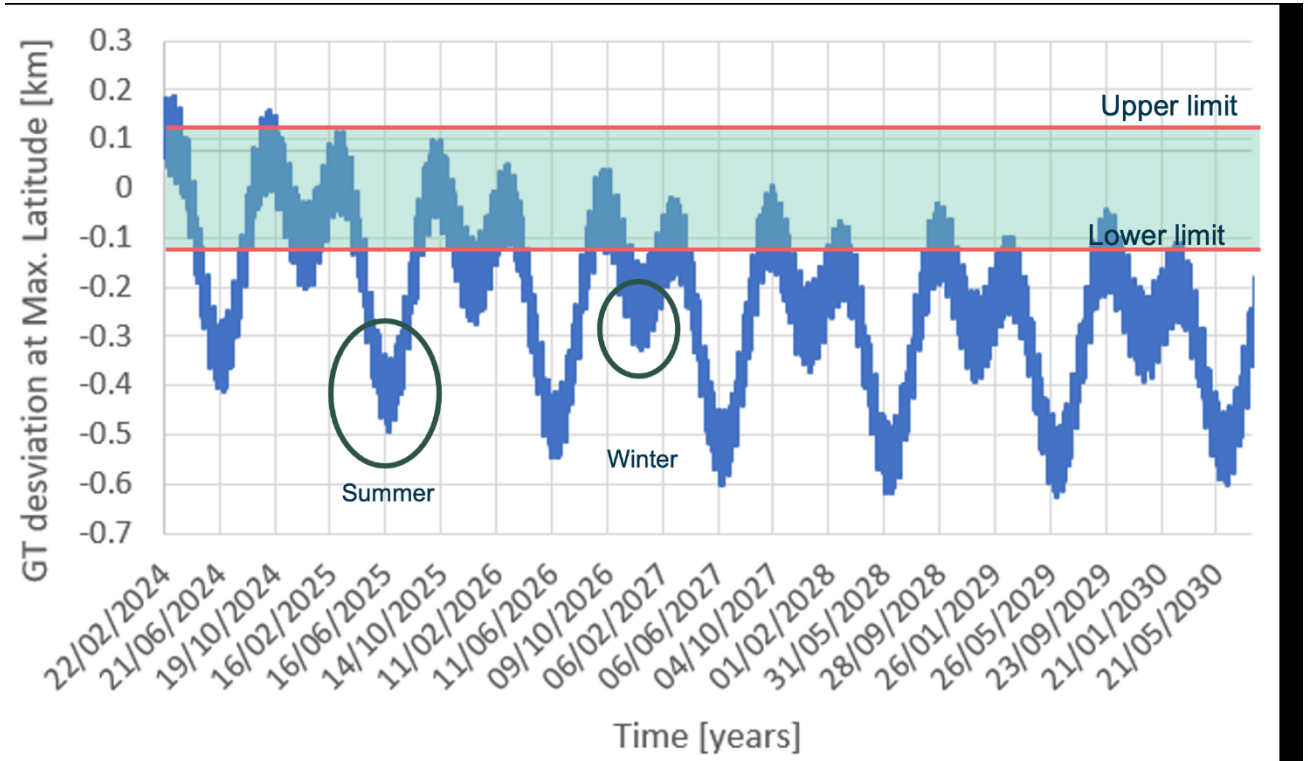
On October 2022, S1-A propulsion system underwent a **major** anomaly requiring to switch to the redundant branch (B-branch)

On Feburary 2024, the thruster RCT-3B, in charge of the Out-Of-Plane (OOP) Manoeuvre presented issues. **To ensure safety of S/C, it has been decided with the EC to stop OOP OCM**

Stopping OOP OCMs will **degrade the ground track deviation** (hence the baseline) as function of the latitude. **The higher the latitude the worst the degradation**.

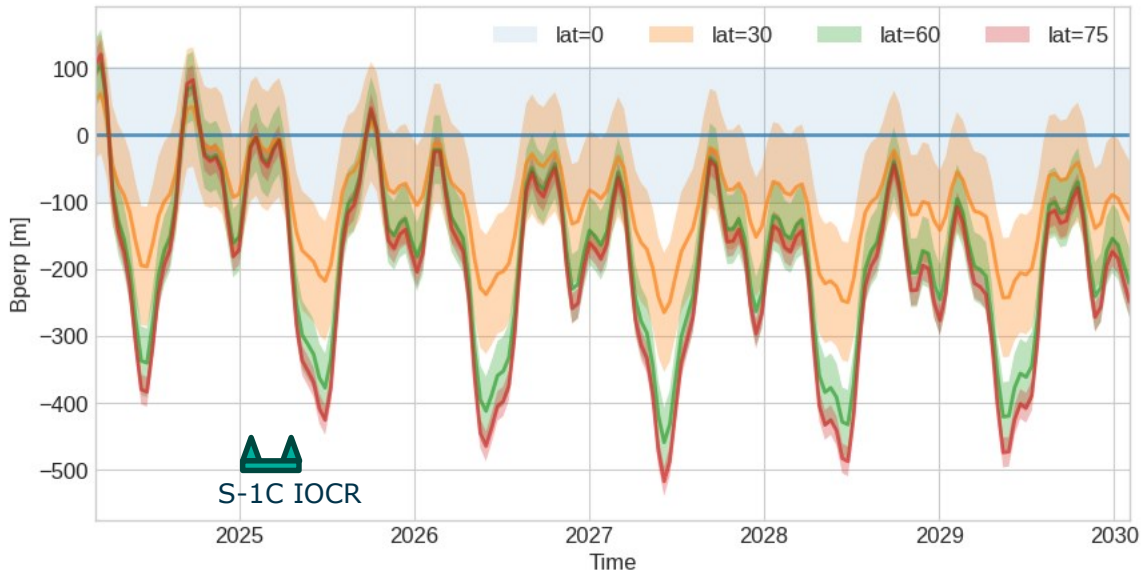
According to the prediction Sentinel-1A will exit the current orbital tube in April/May 2024

Modified Orbital Control
(degraded GT deviation due to stop of OOP)



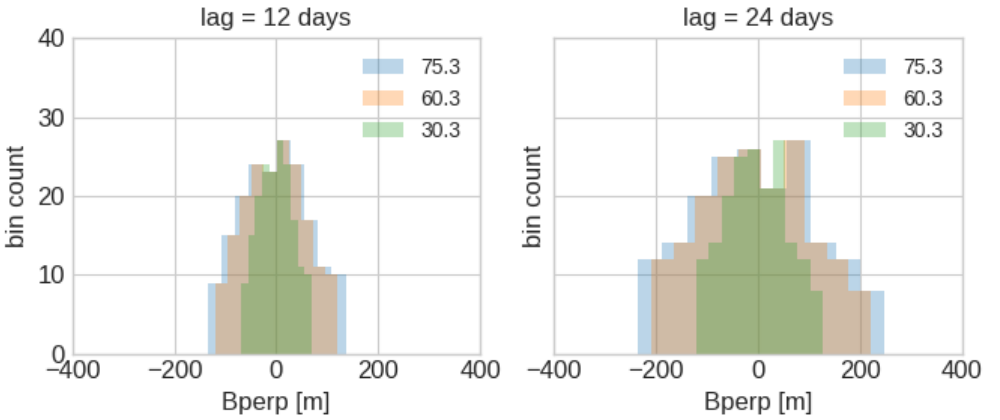
S1-A Orbital Tube Control Change: impact in InSAR

Bperp Evolution in Time

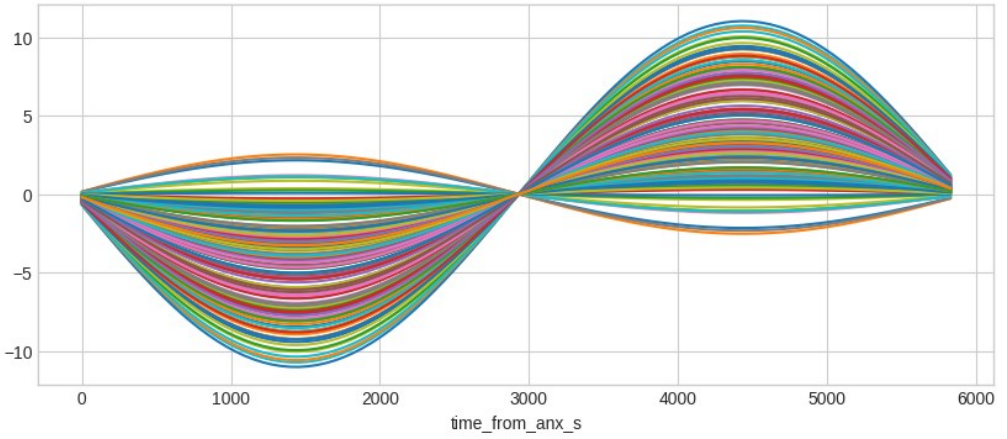


- Increased Bperp (< 10% of Bc worst case)
- Short time InSAR (one unit)
  - Bperp remains < 250 m
  - HoA can reach ~25 m for 36 days pair at high latitude
- Spectral shift due to crossing orbits < 10Hz worst case
- Burst sync at beginning of datatake mostly secured by IP OCM but some dependency with inclination is observed. Variation within datatake 2x worse in worst case

Pairwise B-perp



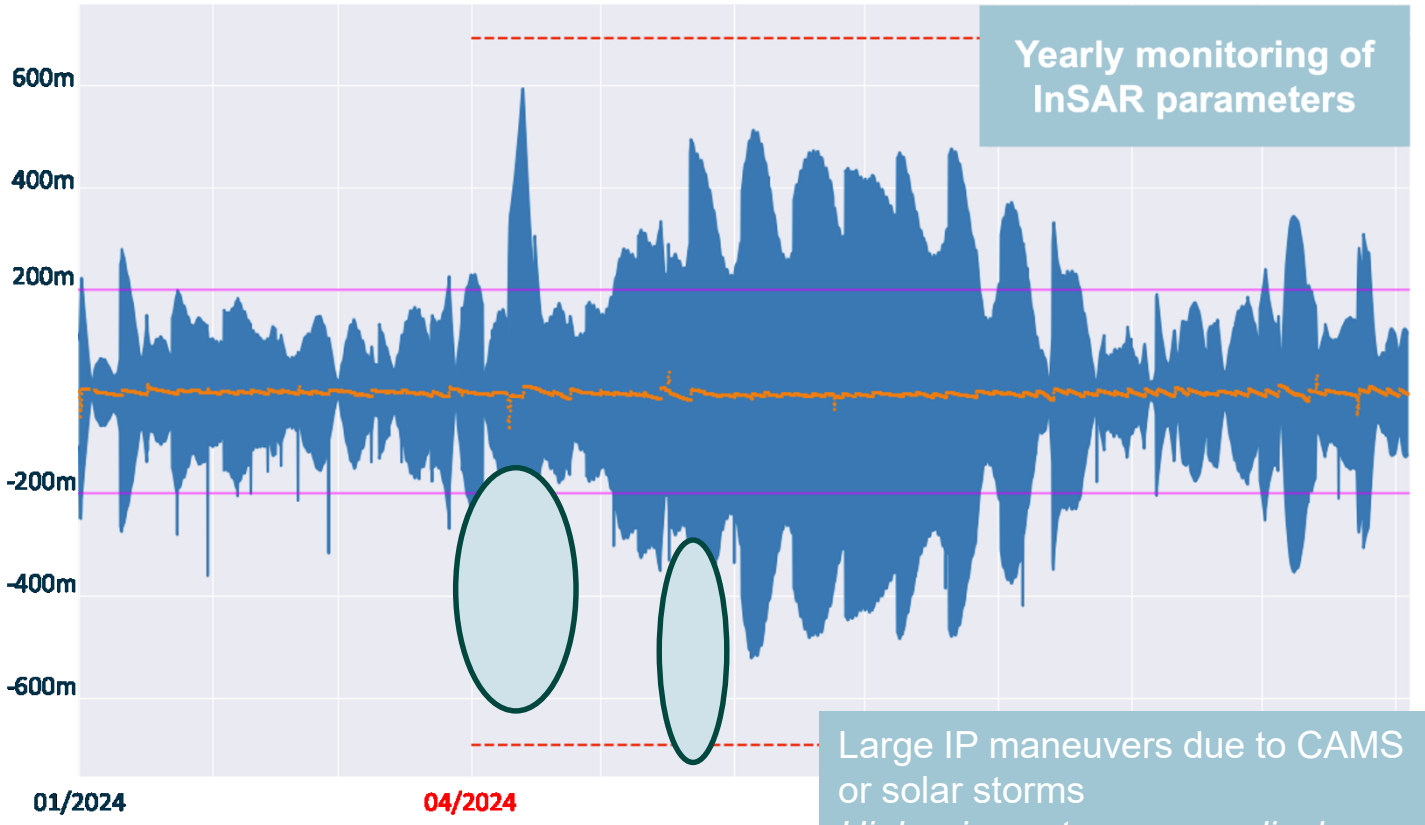
Azimuth Spectral Shift [1]



[1] Role of the Orbital Tube in Interferometric Spaceborne SAR Missions, *Pau Prats et al*

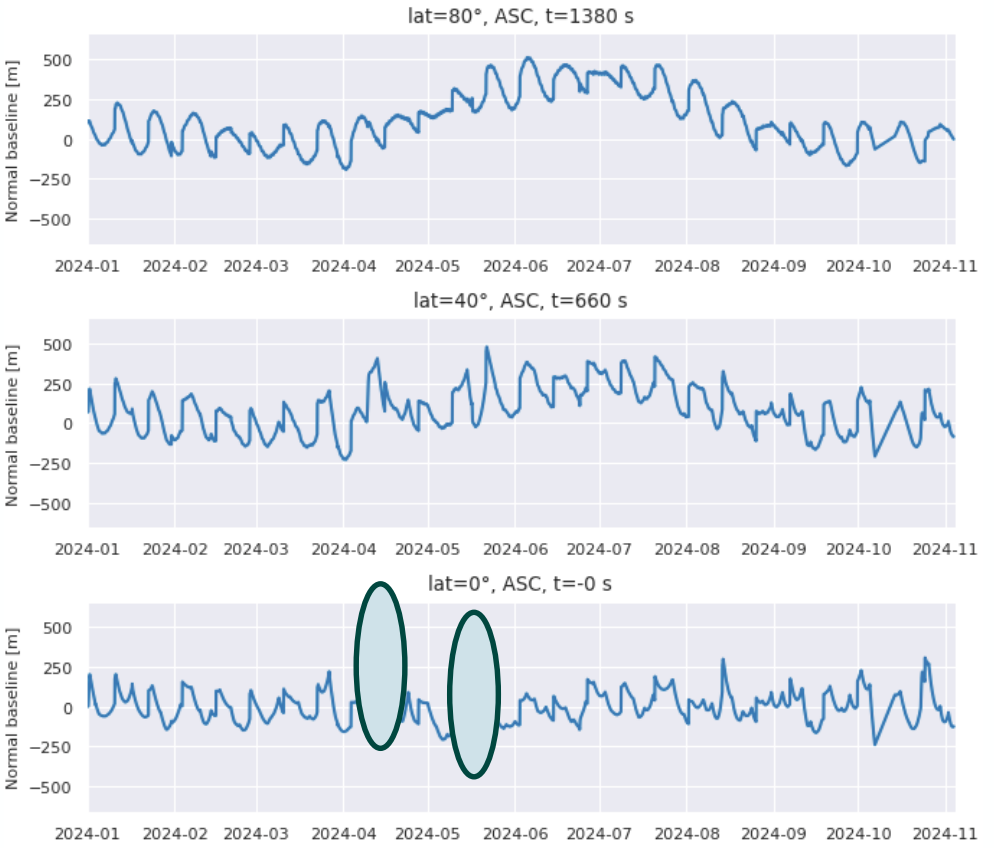
S1-A Orbital Tube Control Change: monitoring

InSAR Perpendicular Baseline over time

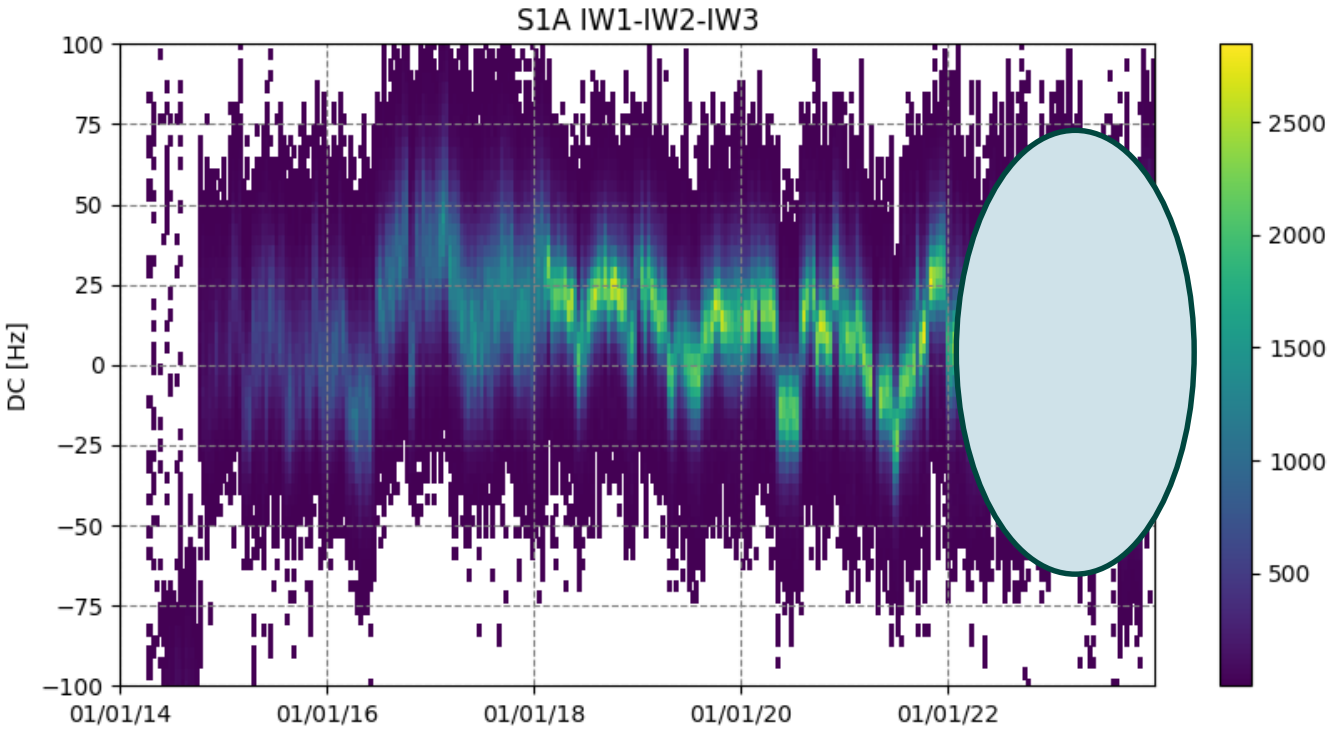


Large IP maneuvers due to CAMS or solar storms
Higher impact on perpendicular baseline

InSAR Perpendicular Baseline over latitude



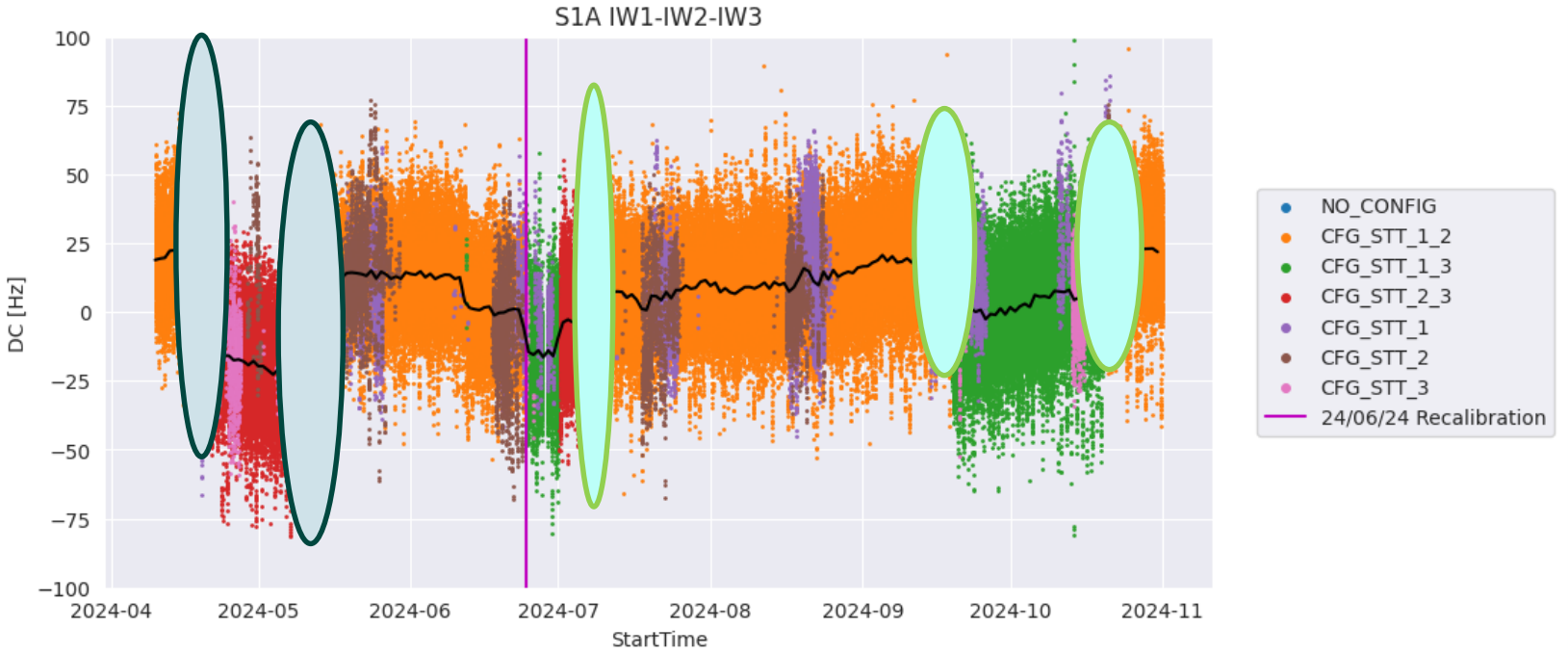
Doppler monitoring STT alignment



- Instrument health is checked via different monitoring:
  - Baselines and Burst Sync
  - Error matrices (Antenna Status)
  - Instrument Noise
  - Instrument Temperature
  - PG gain and phase
  - **Doppler**
- S-1A Doppler pointing has shown jumps of ~30Hz since mission start.
- In 2024 jumps of about 50Hz are being observed when moving from between specific STTs configuration

STT realignment campaign was carried out to minimize InSAR impact (more relevant due combined effect with *no OOP in InSAR coherence*)

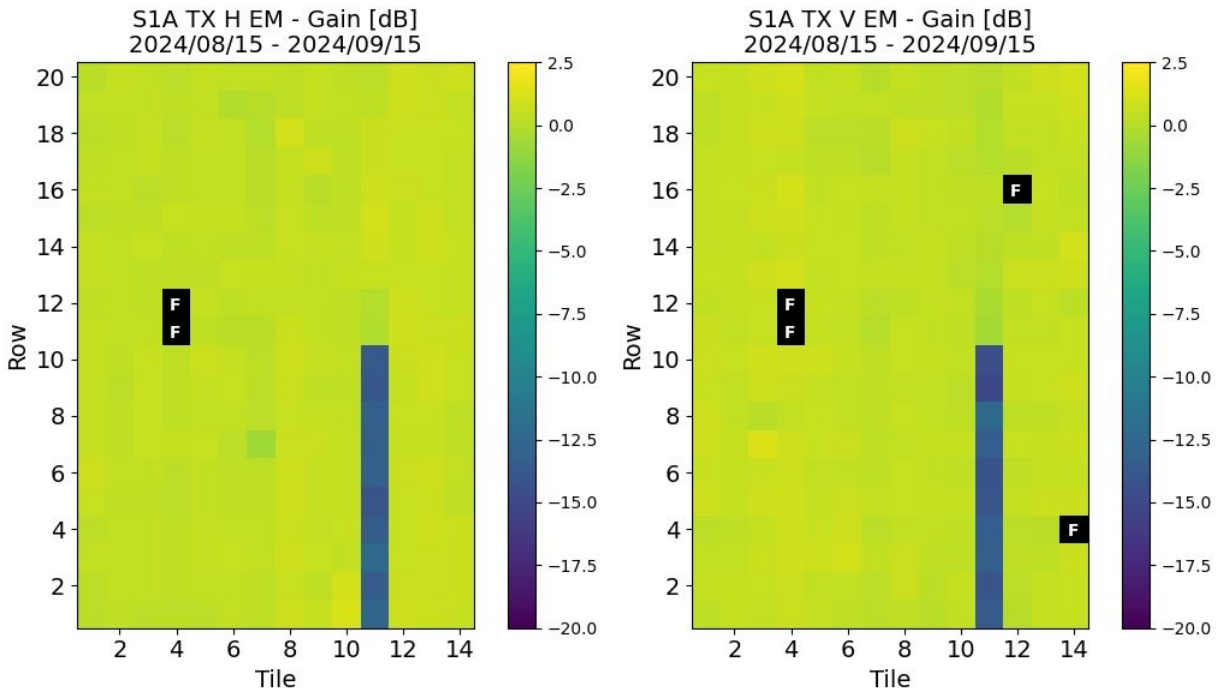
Doppler monitoring STT alignment



Jumps reduced w.r.t initial observations in 2024, in any case not completely removed (but consistent with S1A history).

Antenna monitoring and latest TRM failure

Monthly Average Antenna Error Matrix



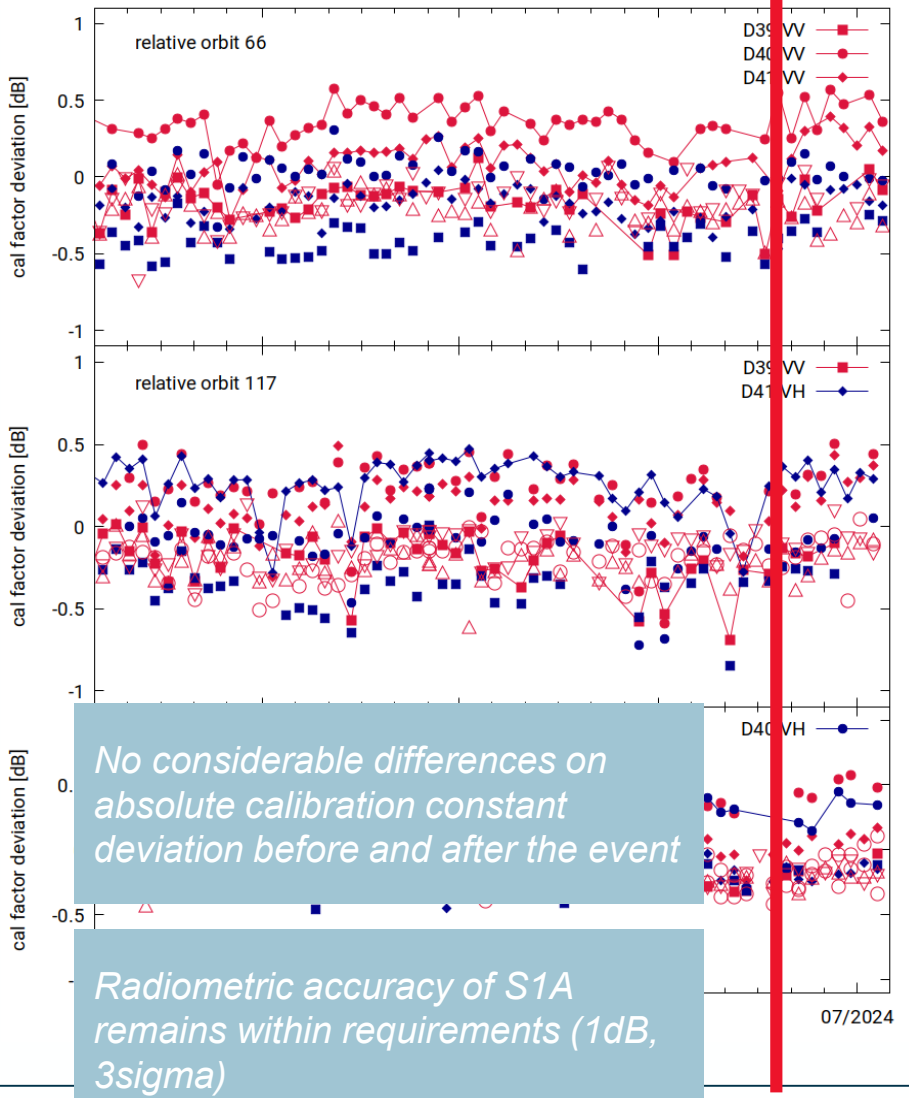
Major antenna events

Date	Tile	Row	Mode	Notes
05/05/14	4	11,12	TX H TX V RX V	Failures related to the same Electronic Front End element
09/06/14	4	12	RX H	
29/04/15	4	11	RX H	
18/05/15	12	16	TX V RX V	Intermittent failures since 16/04/15
18/10/14 22/07/15	5	1-20	RX H RX V	Intermittent failures of tile 5. Switch to redundancy solved the problem
27/06/16	11	1-10	TX H TX V	Reduced TX power for half tile 11 to avoid instrument switch-off
17/10/17	11	1-10	TX H TX V	Update of tile 11 configuration to improve antenna electronic status
04/01/21	7	7	TX H RX H	Small gain reduction and phase jump
14/04/24	**14**	**4**	**TX V**	**TRM failure**

TRM failure: impact analysis

- Failure of single TRM is not expected to cause significant performance degradation
- In any case, analysis follows to verify this assumption and discard/confirm need of calibration of parameters and need for quality disclaimer
  - Analysis of product at time of failure
  - PG trend
  - Antenna model
  - Radiometry: gamma profiles and calibration constant analysis
  - Glocalization analysis
- Full analysis to be included in annual performance report

Radiometric analysis over transponders



No considerable differences on absolute calibration constant deviation before and after the event

Radiometric accuracy of S1A remains within requirements (1dB, 3sigma)

TRM failure: impact analysis

- Failure of single TRM is not expected to cause significant performance degradation
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  - Analysis of product at time of failure
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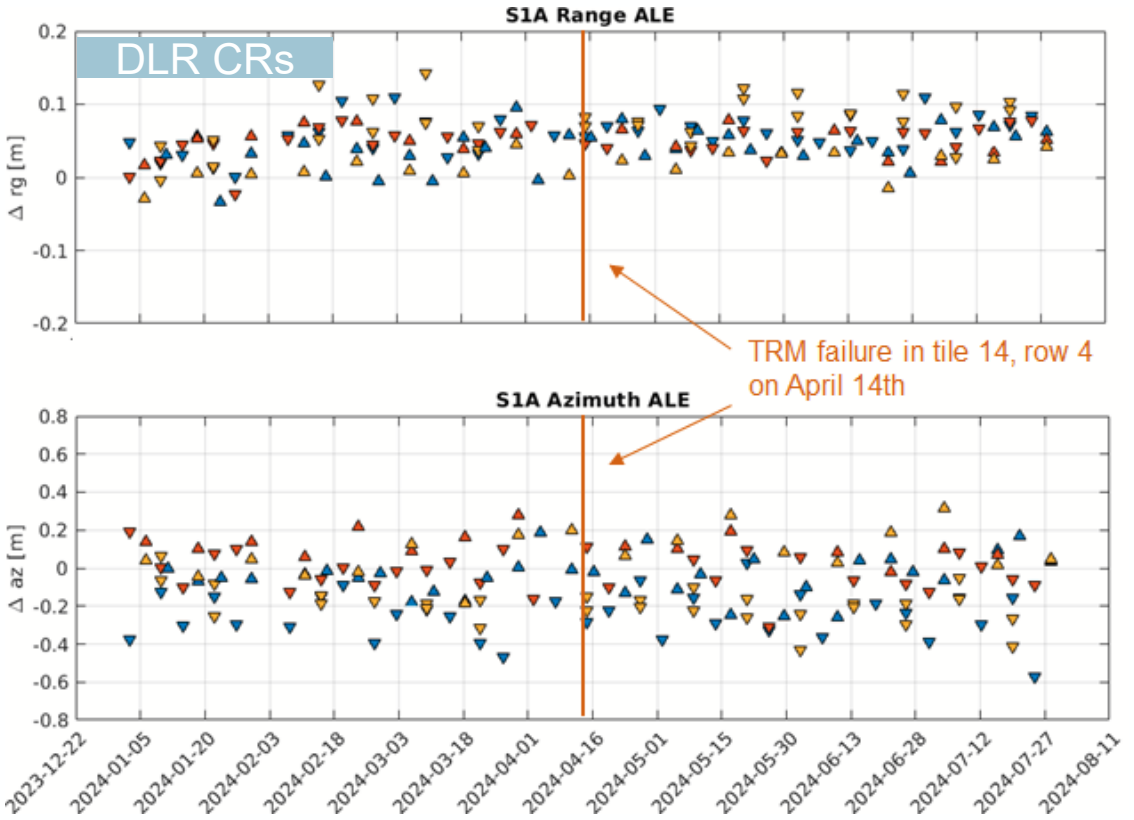
Geolocation analysis over corner reflectors



No noticeable differences on geolocation error deviation before and after the event

Geolocation accuracy of S1A remains well within requirements

TRM failure: impact analysis

- Failure of single TRM is not expected to cause significant performance degradation
- In any case, analysis follows to verify this assumption and discard/confirm need of calibration of parameters and need for quality disclaimer
  - Analysis of product at time of failure
  - PG trend
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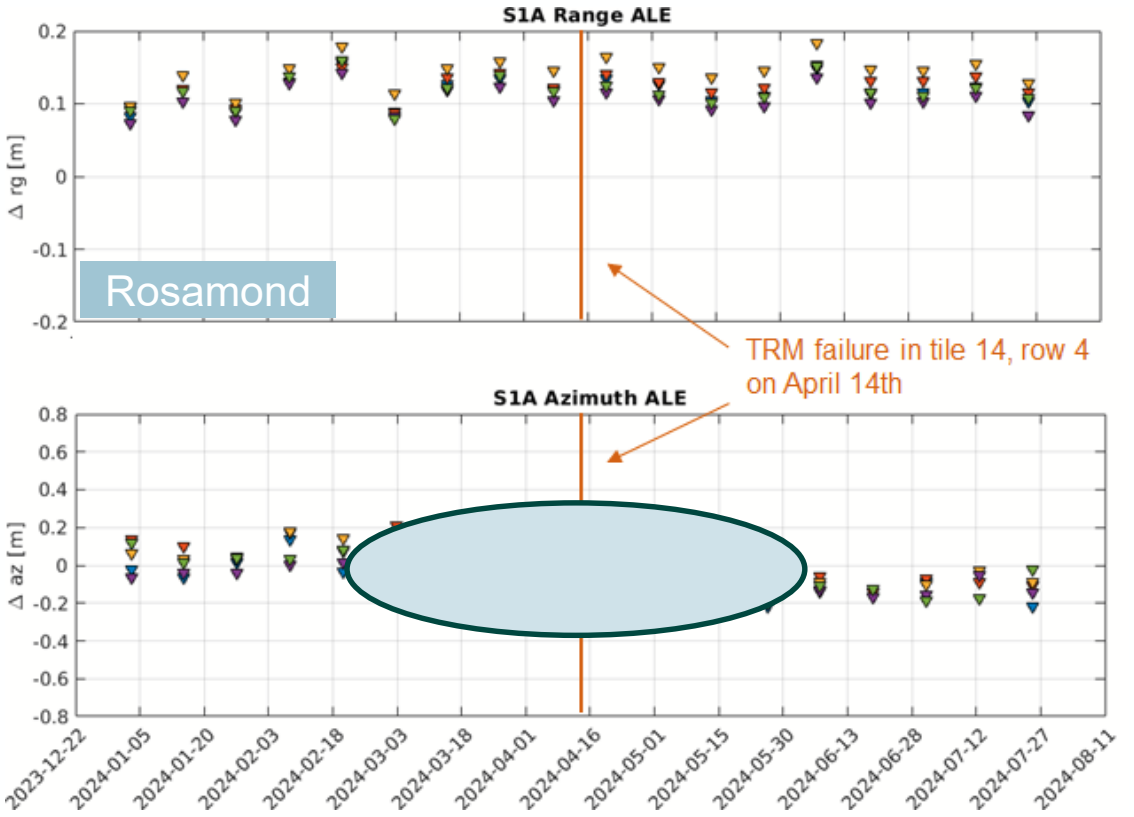
Geolocation analysis over corner reflectors



… the story with bigger CRs is slightly different. Azimuth shift might be there

AM does predict an error, but smaller (<10cm). Monitoring to be continued and eventual recalibration need TBD

S-1A L1 Evolution

Extended **T**iming **A**nnotation **D**ataset for S-1 SAR data

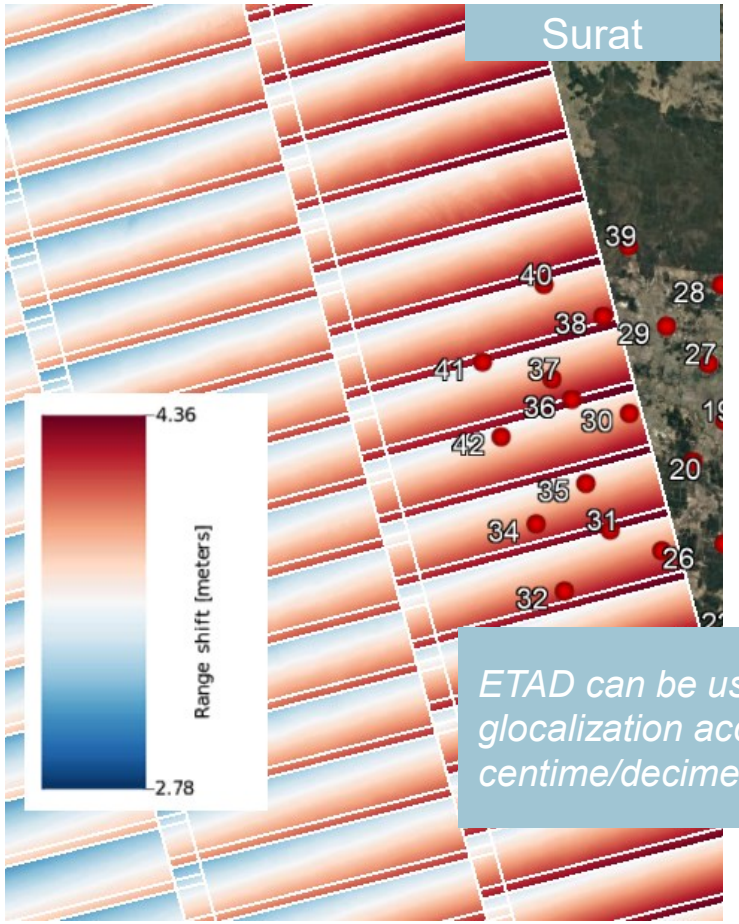
Gridded corrections (~200m) in SAR slant range and azimuth

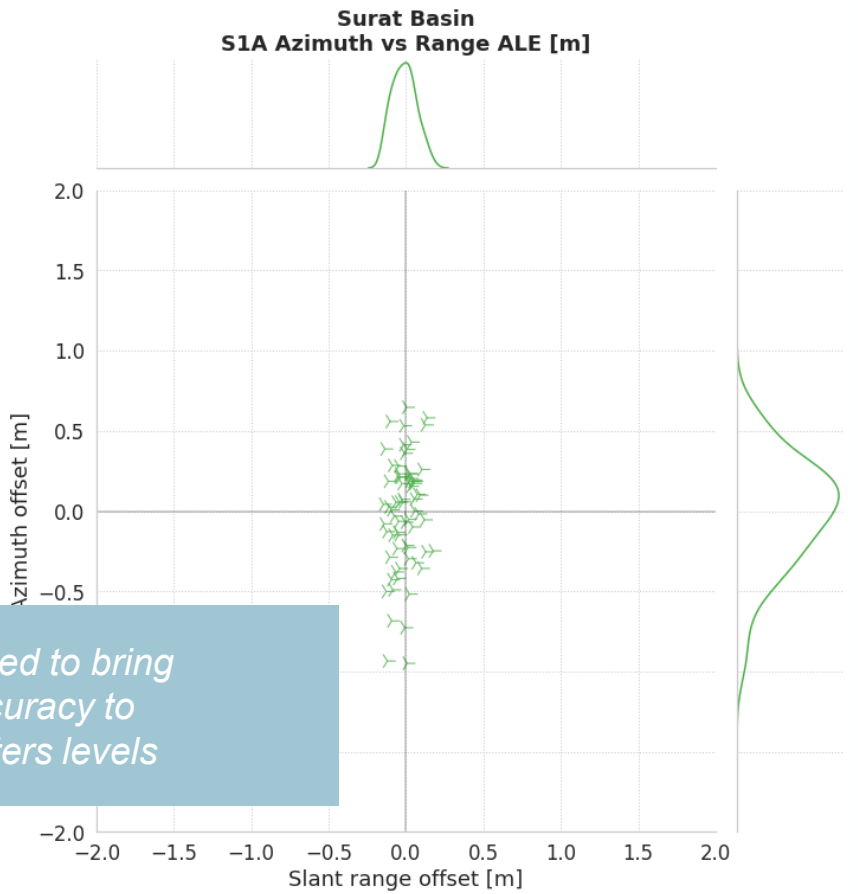
- **Tropospheric path delay**
- **Ionospheric path delay**
- **Solid Earth tides**
- **S-1 system corrections**

ETAD products available in CDSE (starting from July 2023)

Can be used to improve geolocation of SLC products and support InSAR

Decimeter Geolocation Error after correction with ETAD layers





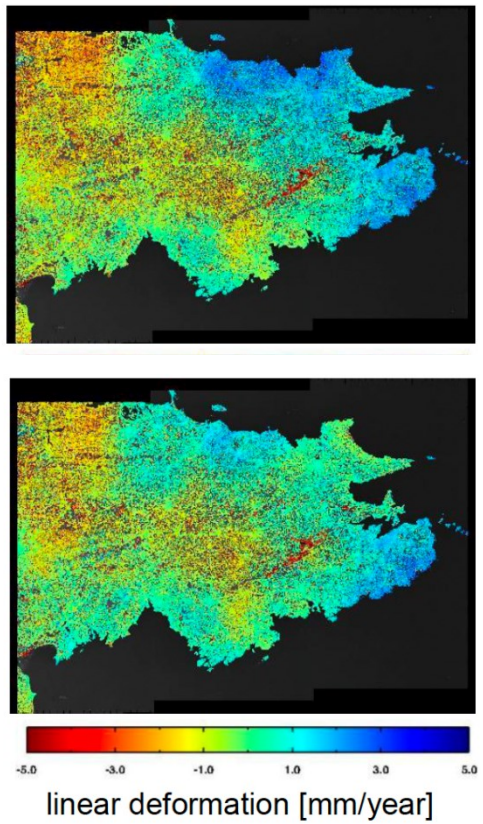
ETAD can be used to bring glocalization accuracy to centime/decimeters levels

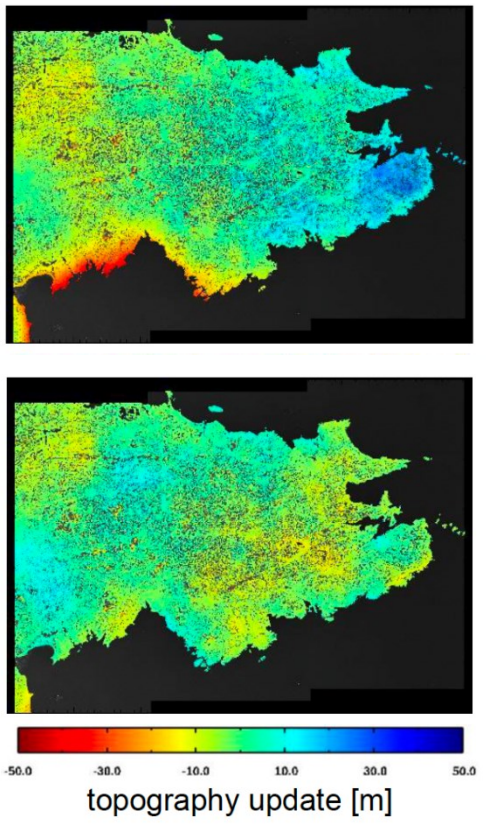
S-1A L1 Quality and Product Evolution

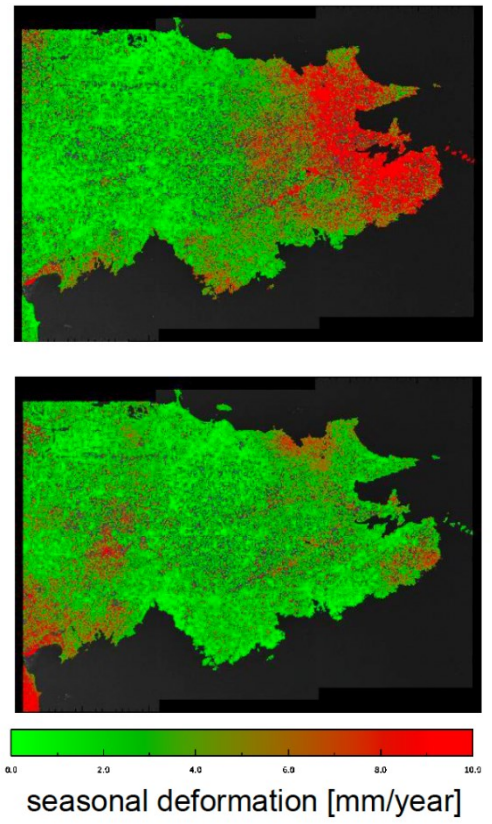
Upcoming: Tropospheric gradient and **ocean tidal loading** layers to further support InSAR (Q2 2024, TBC)

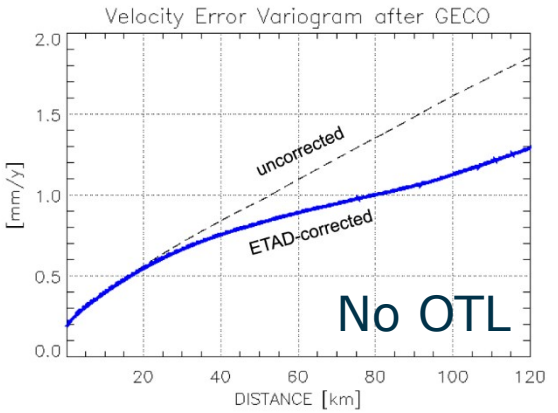
No Correction

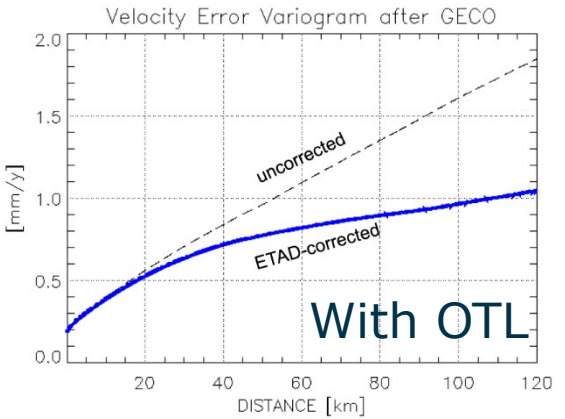
ETAD + OTL











S-1A L2 Quality and Product Evolution: TC

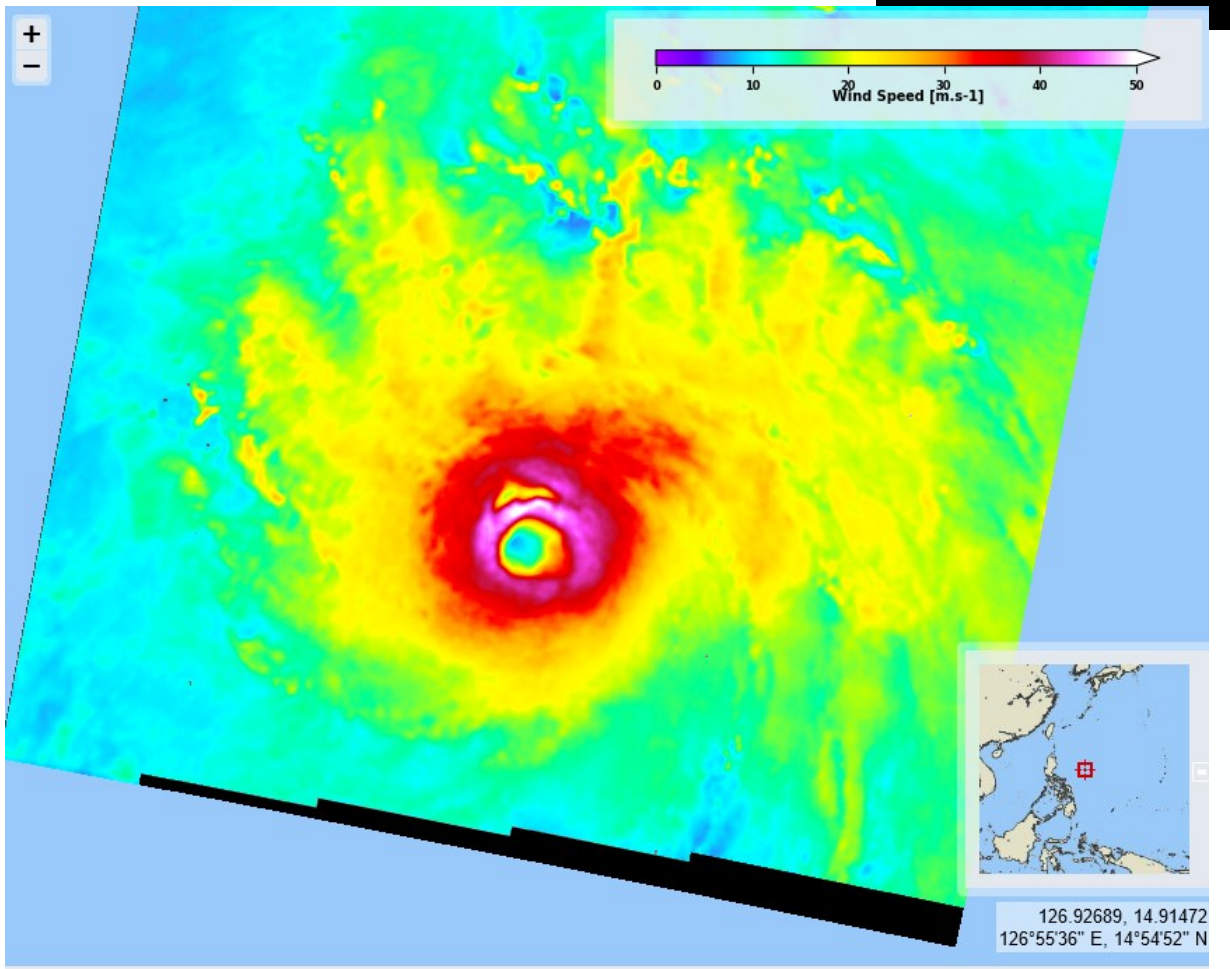
Consolidation of Strategy of acquisition over tropical Cyclone in 2023

Process has been automatized with the support of L2 ESL for prediction and Mission Planner for the tasking
ECMWF prediction is used and following criteria are considered:

- Crit.1 - S1 acquisitions over sea surfaces
- Crit.2 - Min. Delay: Enough time to plan the S1 acquisitions
- Crit.3 - Max. Delay: Not long after TC track generation
- Crit.4 - Min. TC Cat.: Not considering less energetic TCs
- Crit.5 - Spatial Collocation: S1 acquisition is within a certain distance from the TC track (220 km form mid-swath)

Improvement from 35% to 80% of partial hits and 24% to 48% full hits. Criteria threshold can be further optimized when S1C/D are flying

Wind speed product processed with dedicated TC chain/ format and distributed in https://www.esa-cyms.org/data-access/.

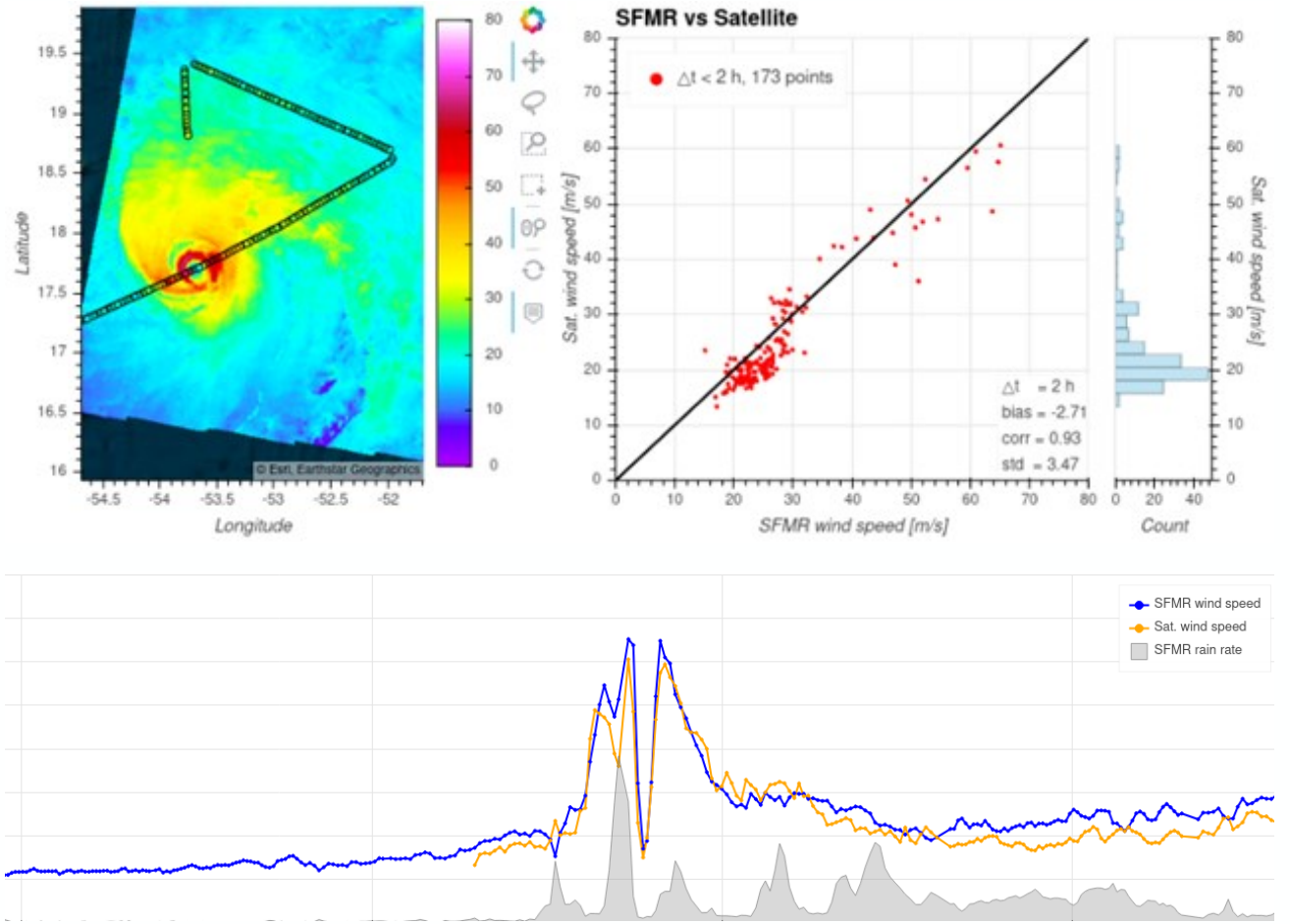


Typhon Yinxing, east of Philippines, 2024/11/04. Maximum sustained wind speed of about 50m/s as derived from SAR

S-1A L2 Quality and Product Evolution: TC

- Tropical cyclone activities include:
  - Processing of recently acquired acquisition
  - Tunning of GMF and dedicated TC processing chain
  - Reprocessing of archive
    - Full archive available in: https://cyclobs.ifremer.fr/static/cyclobs/data/coloc/sat_sat/product
  - Validation of SAR measurement w.r.t.
    - Spaceborne radiometers (SMOS, SMAP) https://cyclobs.ifremer.fr/static/cyclobs/data/coloc/sat_sat/product
    - Airborne radiometers (SFRM) https://cyclobs.ifremer.fr/static/cyclobs/data/coloc/sfmr

Lee TC, September 2023: S1A and Airborne



S-1A L2 Quality and Product Evolution: ML

- Machine Learning (ML) becomes more and more present in SAR applications

- The L2 OCN retrieval already considers ML algorithms
  - OSW total HS (in L2 IPF)
  - OSW quality flag (in L2 IPF)
  - OSW HS wind sea (under development)
  - OWI rain rate (developed, pending integration in IPF)

  …. and, certainly, more to come

- This poses new challenges to operations, requiring
  - Flexibility to deploy and update models independent of (less flexible) IPF deployment schedule
  - Clear understanding of impact of instrument and processor changes
  - Clear definition of training dataset
  - Clear definition of re-training approach
  - Actual processing capacity for retraining outside Processing Center

AUX_ML2 introduced in IPF 3.8 (June 2024)

```
File/Folder Name
MMM_AUX_ML2_VYYYYMMDDTHHMMSS_GYYYYMMDDTHHMMSS.SAFE
├── manifest.safe
├── data
│   ├── qf-models
│   │   ├── mmm-sss-hs-best-model-gyyyymmdd.ubj
│   │   ├── mmm-sss-phi-best-model-gyyyymmdd.ubj
│   │   ├── mmm-sss-wl-best-model-gyyyymmdd.ubj
│   │   └── mmm-ss-regression-model-thresholds4QF_gyyyymmdd.pkl
│   ├── mmm-aux-ml2.json
│   └── ths_models
│       └── mmm-ss-heteroskedastic-gyyyymmdd.h5
└── support
    ├── mm-aux-ml2.xsd
    └── test
        ├── qf-models
        │   ├── test_ipf520.npy
        │   └── test-ipf520.py
        └── ths-models
            ├── mmm-sss-ocn-test.nc
            └── test-ipf503.py
```

Includes python test script and sample to ensure L2 is able to run a model update without requiring new SW version

... and to finish: S1 Quality online