Products, Processing Algorithms and End-to-End Simulations for Land Applications in the Harmony Mission

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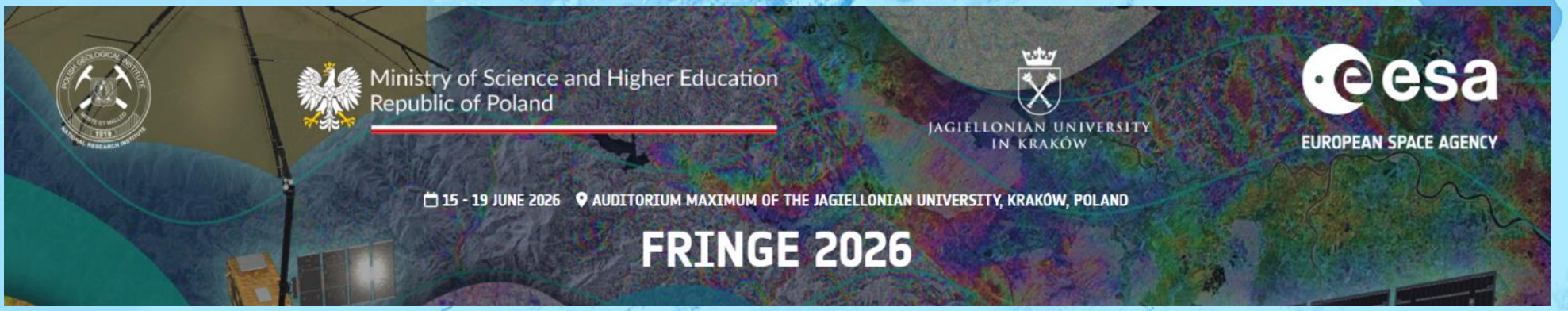


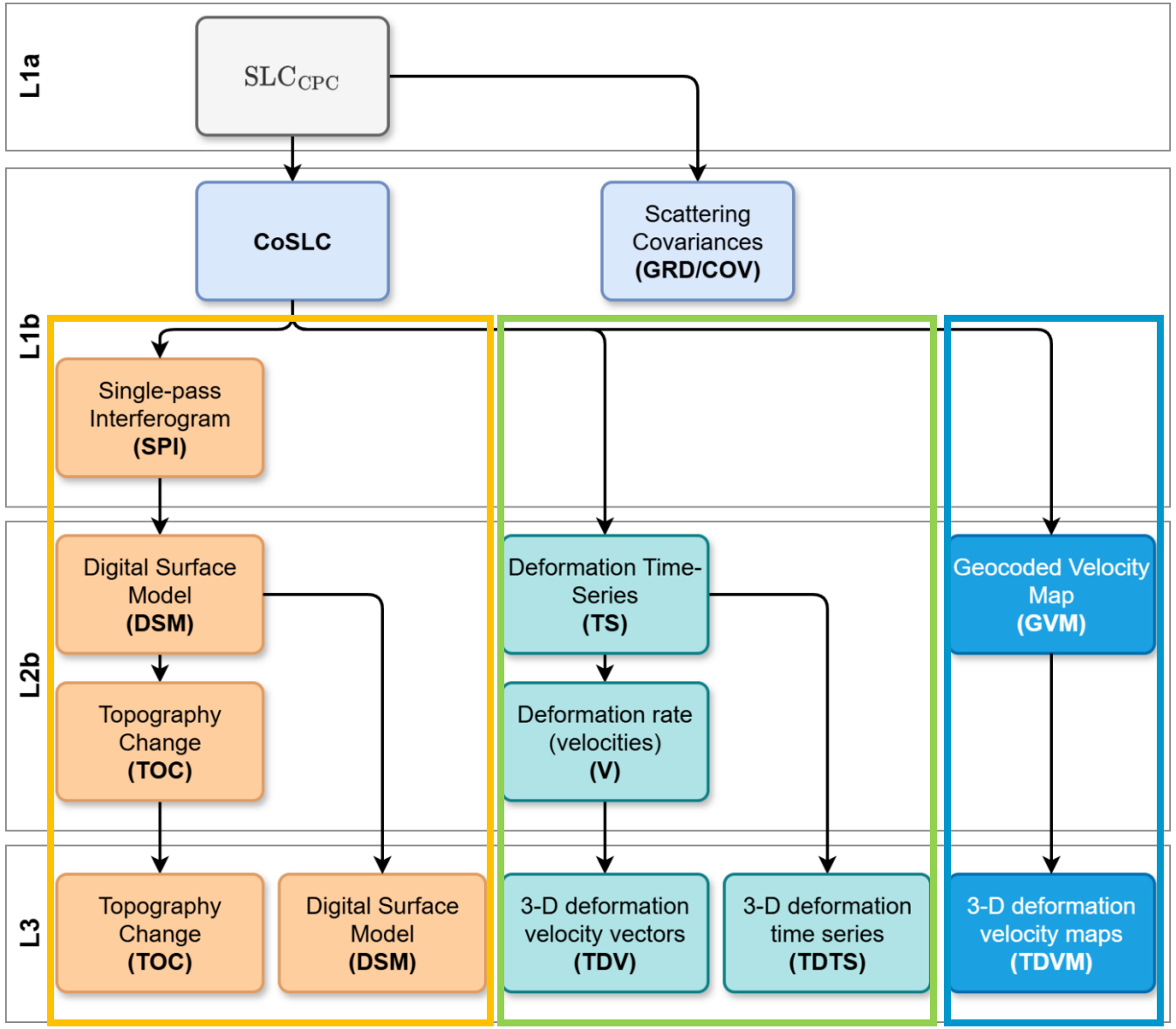
DLR

Scope of the Science Study on Land Applications

- System CDR (Q1 2027)
  - Further development of E2E and execution of performance campaign to demonstrate SRL-6
  - Consolidation of processing algorithms (ATBDs)
  - Implementation of breadboard processors (L1, L2 and L3)

- Challenges in the frame of processing/calibration and information retrieval
  - System calibration: clock synchronization, XTI and ATI baseline calibration
  - Calibration of L2/L3 products (removal of geophysical biases)
  - Efficient simulation of raw products including more representative instrument characterization and scenes generation
  - Efficient SAR image formation under large squints and bistatic angles

Product Tree for Land Products



Time Series

- Exploitation of PS/DS
- Slow-rate deformation areas (strain)
- Both XTI and STEREO phases

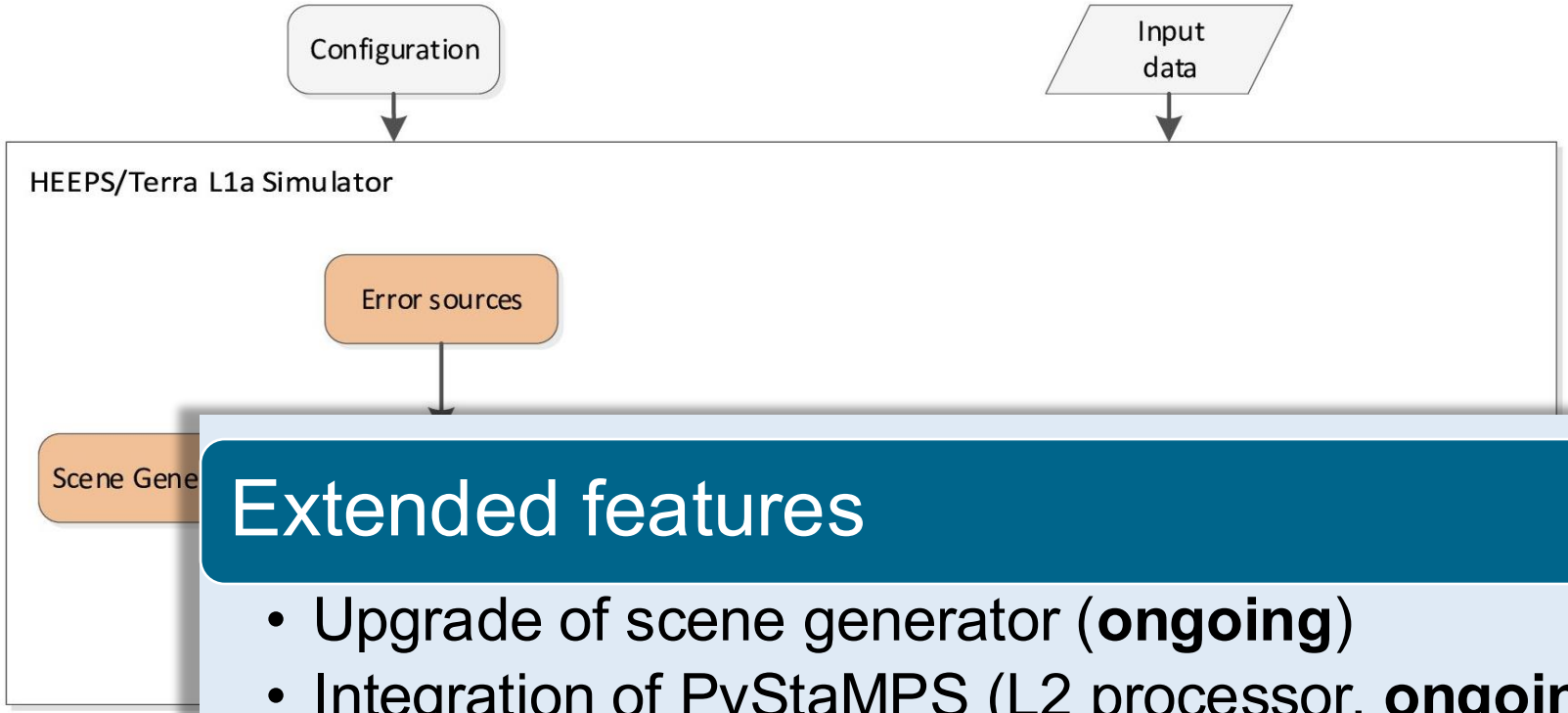
Fast deformation

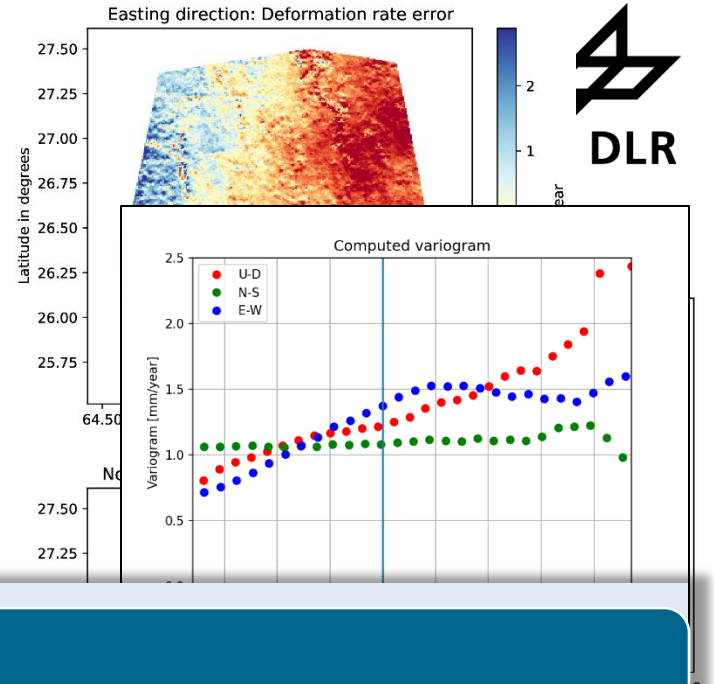
- Land ice deformation
- Typically exploitation of individual pairs
- Both XTI and STEREO phases

DEM and TOC

- Only during the XTI phase (close formation)

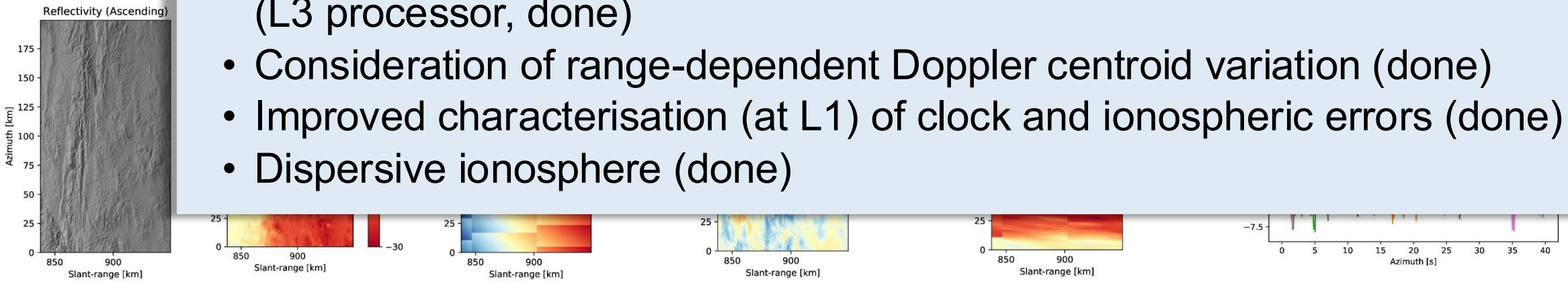
Status on Simulation Tools – The L1a Simulator





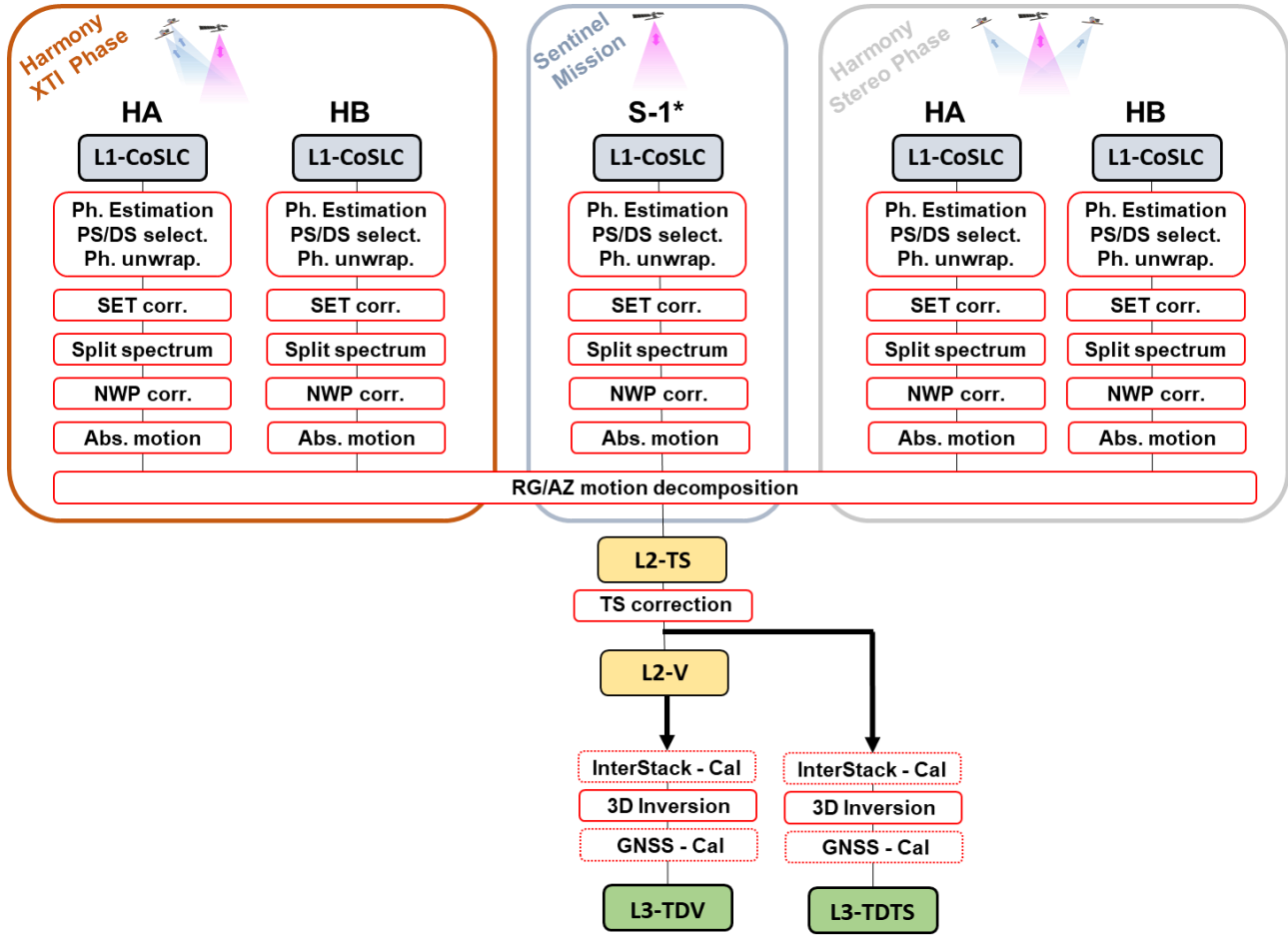
Extended features

- Upgrade of scene generator (**ongoing**)
- Integration of PyStaMPS (L2 processor, **ongoing**) and 3-D inversion tool (L3 processor, done)
- Consideration of range-dependent Doppler centroid variation (done)
- Improved characterisation (at L1) of clock and ionospheric errors (done)
- Dispersive ionosphere (done)



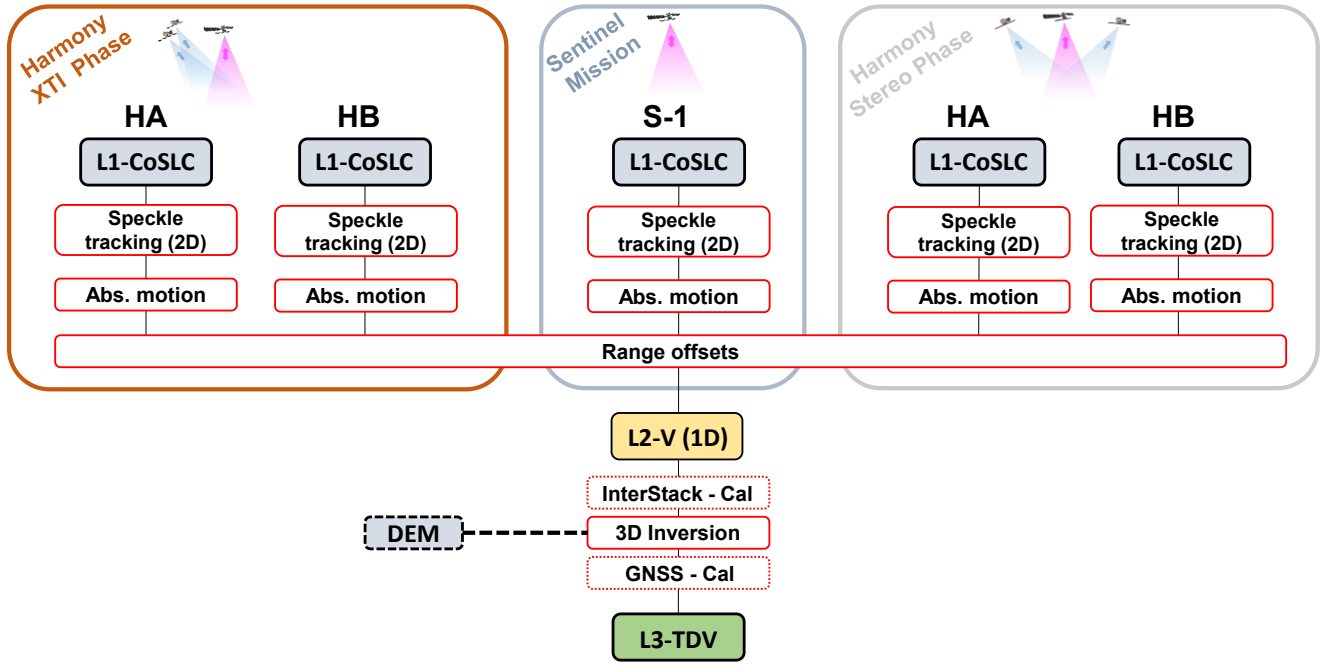
Status on Processing Algorithms –TDV for Solid Earth

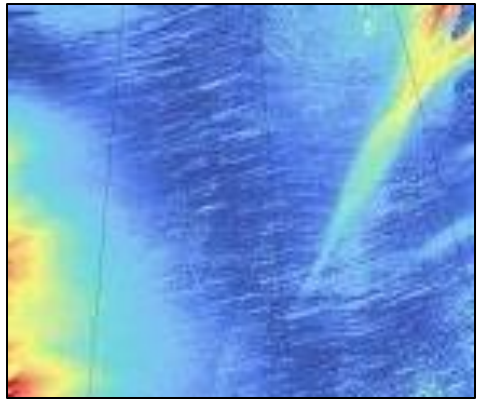
- ATBD consolidated (lead by DLR-IMF, Pi Space and delta phi)
  - PSI (full resolution) as baseline, DSI optional (phase linking or similar needed)
  - Interim releases of TDTS/TDV products (e.g., after 1 and 3 years)
  - Phase unwrapping: classical approach (1D temporal (arcs) and 2D spatial)
  - Temporal 1D phase unwrapping: parametric vs non-parametric
  - Corrections based on ETAD
- StaMPS selected as PSI breadboard processor
  - Extensively used since 15+ years by the EO community
  - **Pythonisation** and **integration** in end-to-end chain **ongoing**
  - Two parallel developments: **PyStaMPS** (KorrAI) and **Stampy** (Pi Space)

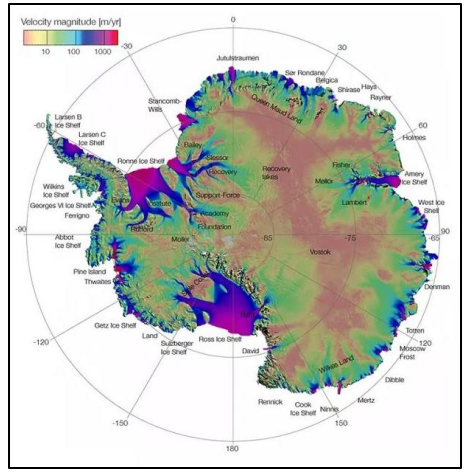


Status on Processing Algorithms –TDV for Land Ice

- Baseline processing approach based on state of the art, extended to exploit the angular diversity of Harmony
- Combination of range measurements obtained with cross-correlation and DInSAR:
  - Fast-moving regions
    - Usage of range measurements only
    - Note: Azimuth measurements based on cross-correlation very sensitive to ionosphere-induced azimuth shifts (biases, see image on bottom left)
  - Slow-moving regions
    - Exploitation of interferometric phase

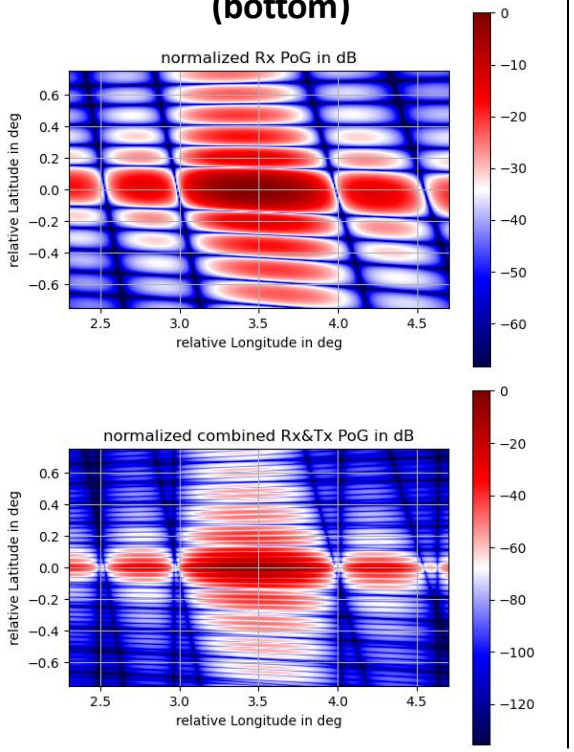




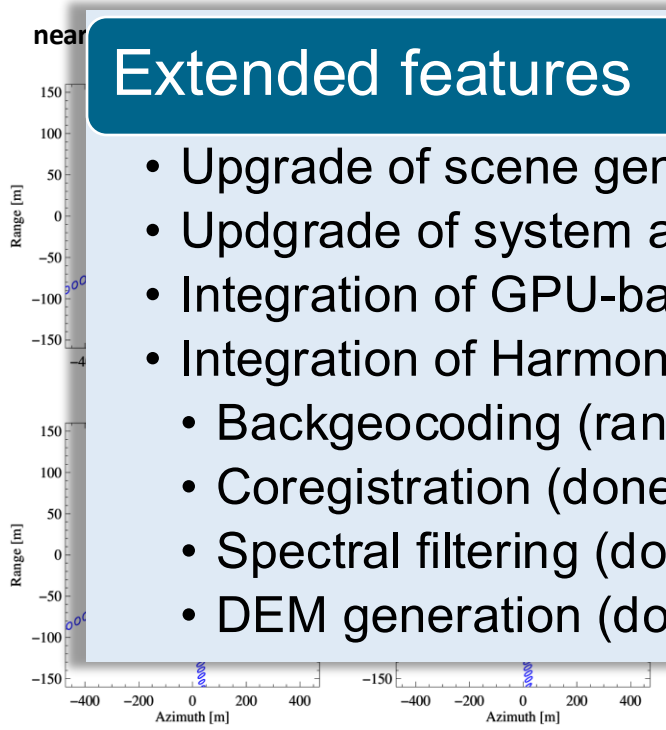


Status on Simulation Tools – The Bistatic End-to-End

Normalized antenna patterns: Rx single channel (top), Rx&Tx (bottom)



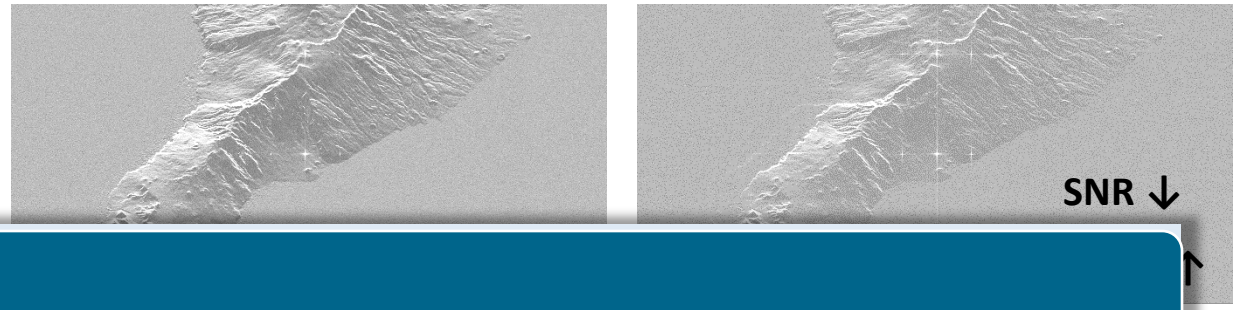
Point target responses within the simulated TOPS burst

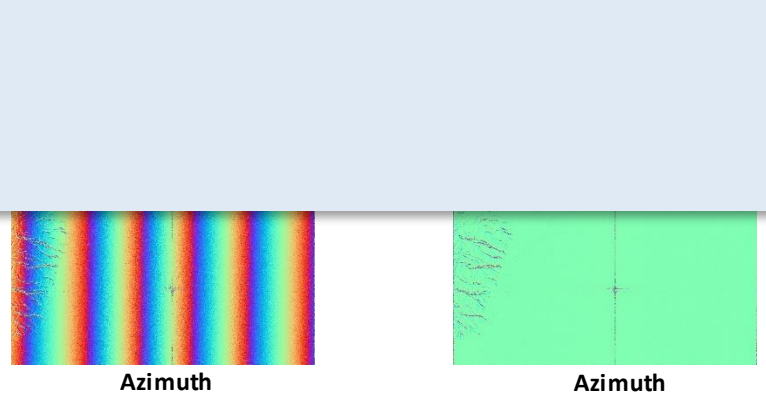


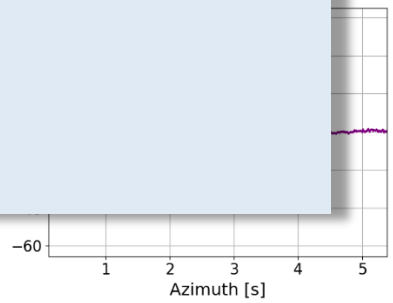
Effect of the antenna pattern on ambiguities:

Monostatic Sentinel-1

Bistatic Sentinel-1 / Harmony (center + wing)





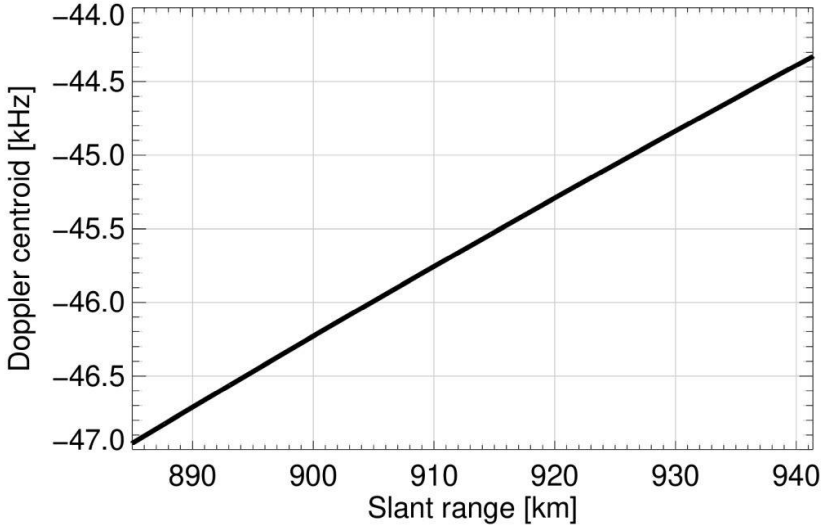


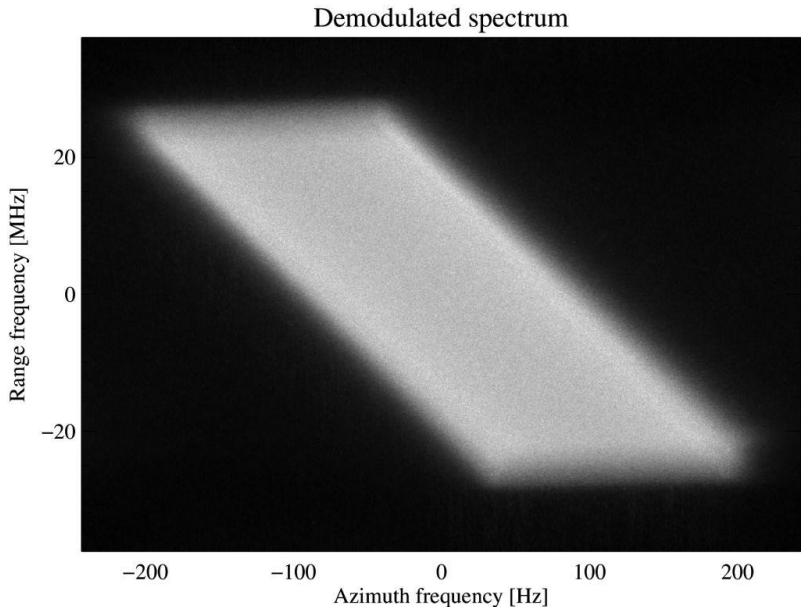
Extended features

- Upgrade of scene generator (**ongoing**)
- Updgrade of system and instrument characterisation (**ongoing**)
- Integration of GPU-based time-domain backprojection (done)
- Integration of Harmony-adapted InSAR chain (**ongoing**):
  - Backgeocoding (range-dependent Doppler) (done)
  - Coregistration (done)
  - Spectral filtering (done)
  - DEM generation (done)

Status on Processing Algorithms – L1 and InSAR

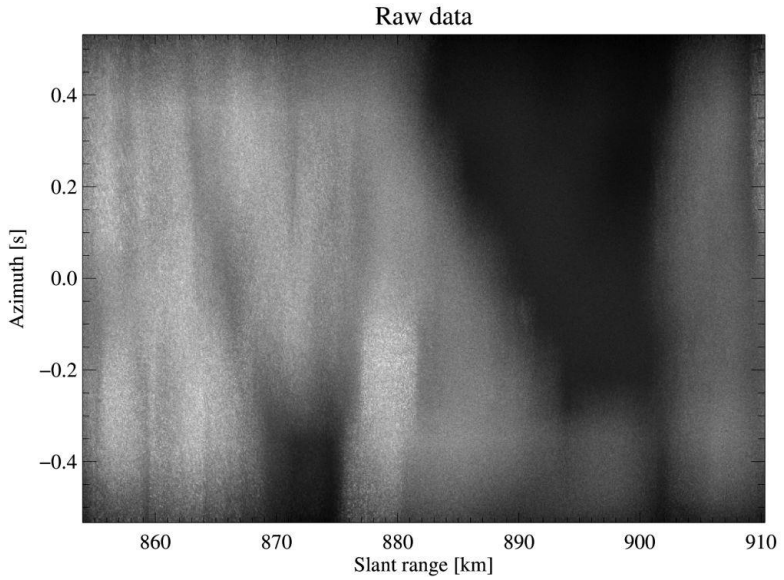
- Challenges
  - Handling of range-dependent Doppler centroid (~3 kHz variation through sub-swath)
    - Output grid in range-dependent beam-center geometry to minimize range spectral shift
  - Handling of dependency of Doppler centroid with wavelength → focusing, azimuth spectral filter, sub-looks generation
  - Data-based clock synchronisation

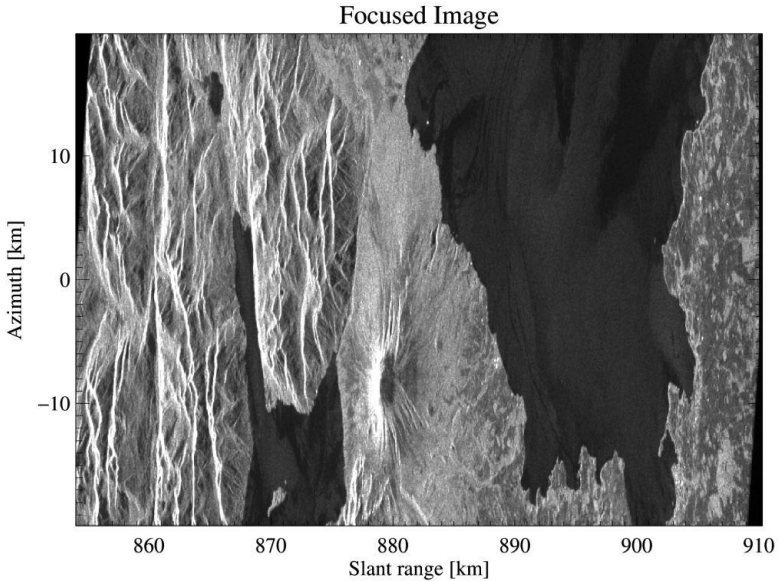




L1 Processing

- Current baseline (for the bistatic end-to-end):
  - GPU* implementation of time-domain back-projection:
    - Processing of one burst in less than 20 seconds, including topography accommodation and antenna pattern compensation
    - Configurable output pixel spacing and arbitrary output geometry. Current setting for Harmony:
      - 850 Hz azimuth sampling frequency (~8 m sampling) to accommodate skew of 2D spectrum
      - Output geometry: Range-dependent beam-center
    - Inherent accommodation of spectral support
- TODO:
  - Integration of Fourier-based GAFA processor



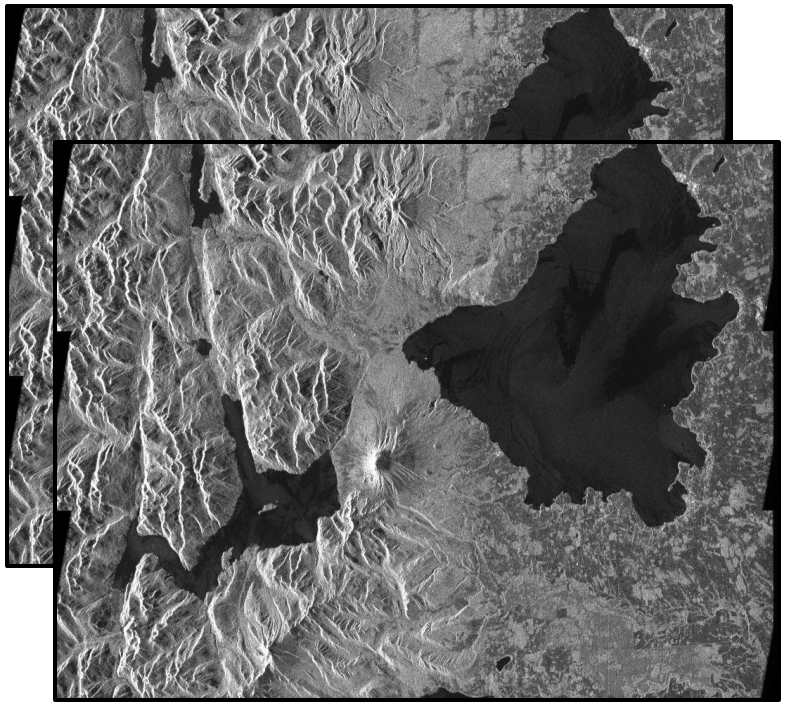


GPU specification: NVIDIA® HGX™ A100 4-GPU 40GB SXM4 GPU

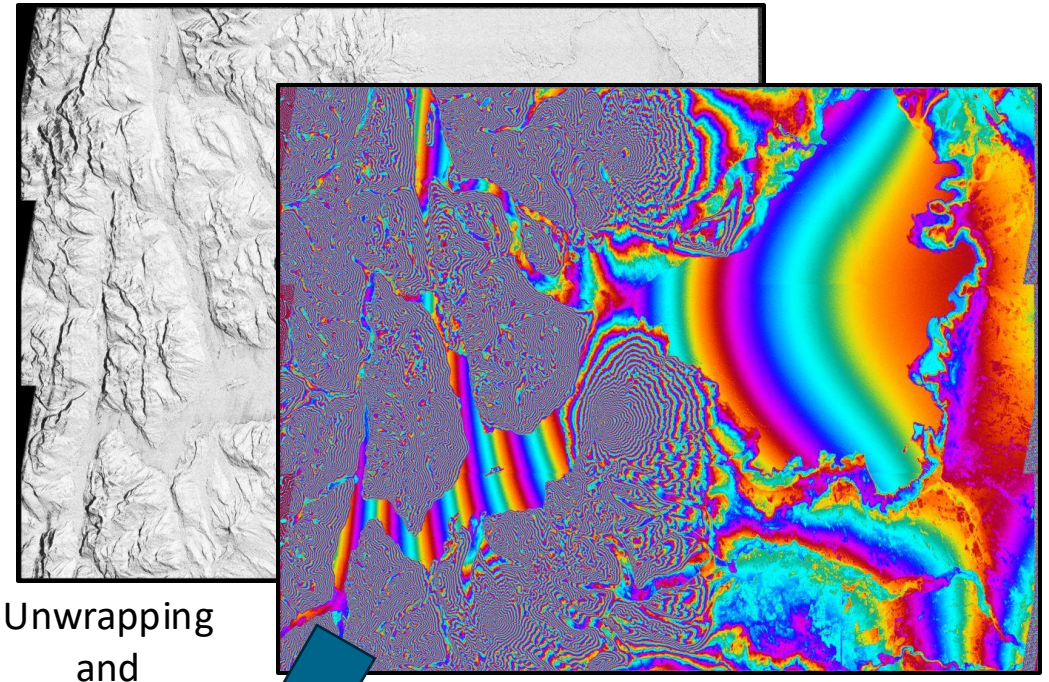
DEM Chain

- Interferometric bistatic chain for Harmony. Key steps:
  - Backgeocoding of external DEM information (using bistatic Doppler equations)
  - Coregistration (generation of CoSLC product)
  - Spectral filtering: proper consideration of spectral shape
  - DEM generation (using, again, the bistatic Doppler equations)
- InSAR breadboard processor shall be based on the EO-Tools (https://github.com/odhondt/eo_tools by Olivier D'Hondt)
  - Open source code (MIT license)
  - Extension to bistatic case finalized and being tested

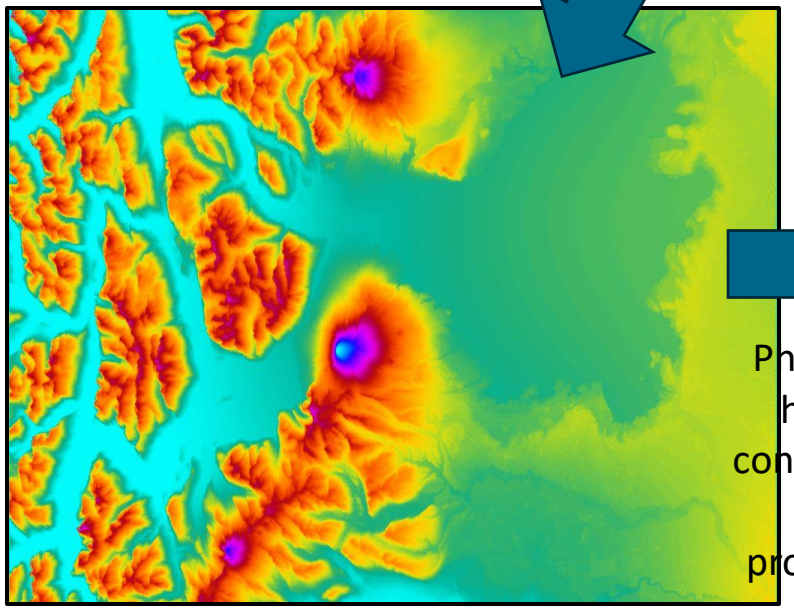
DEM Chain



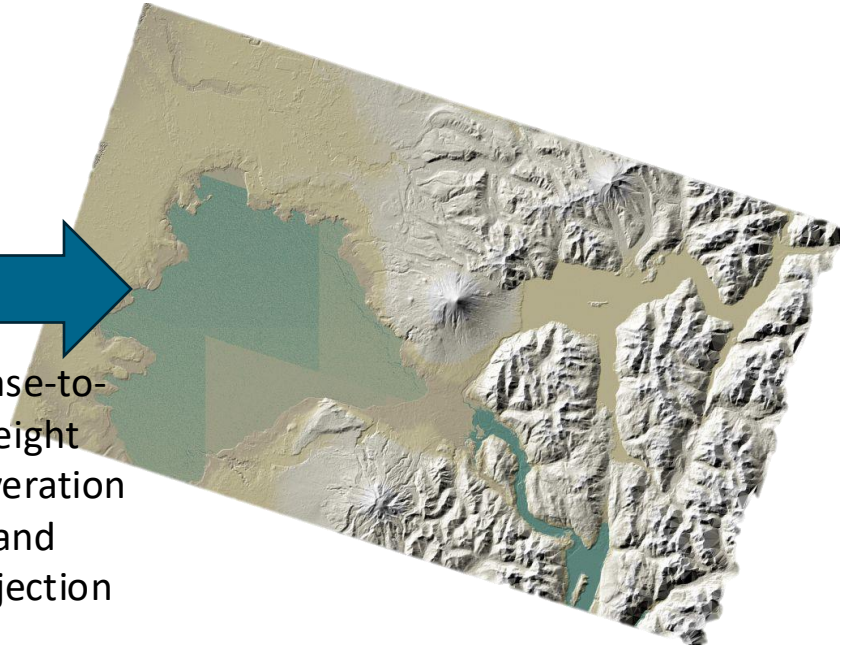
InSAR processing



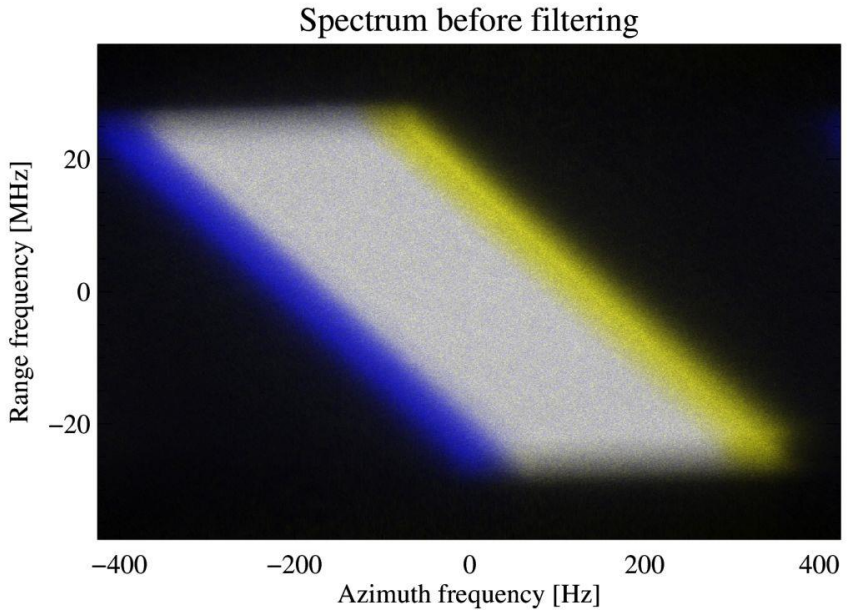
Unwrapping and calibration



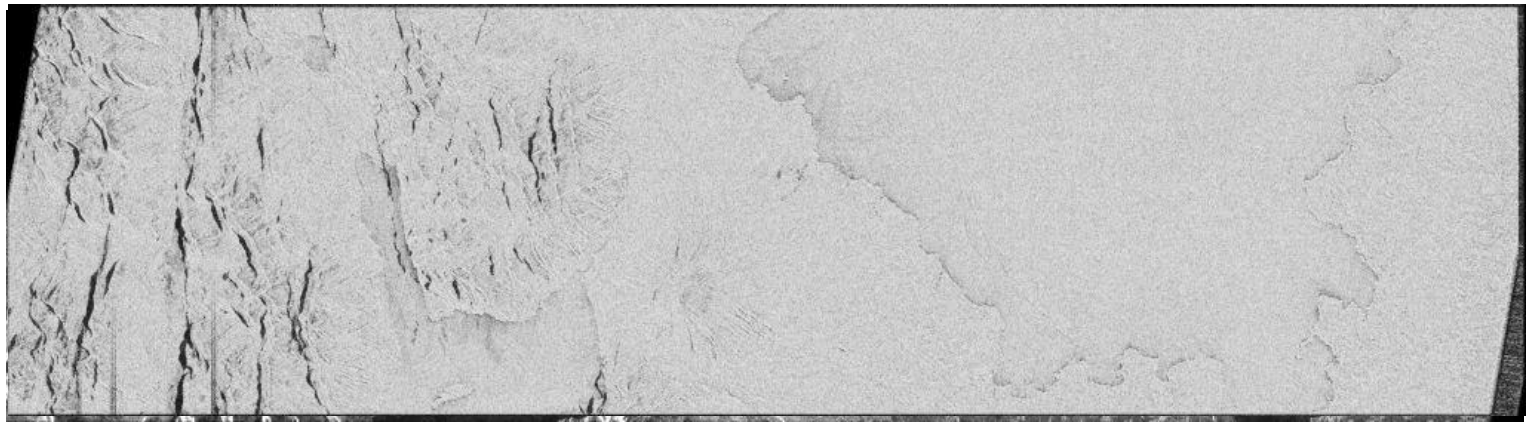
Phase-to-height converation and projection

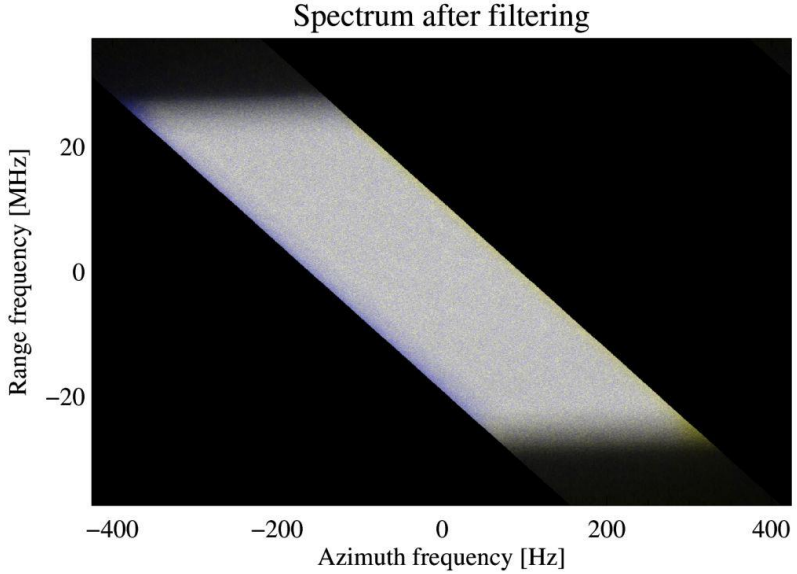


InSAR Processing – Azimuth Spectral Filter



Interferometric coherence before filtering

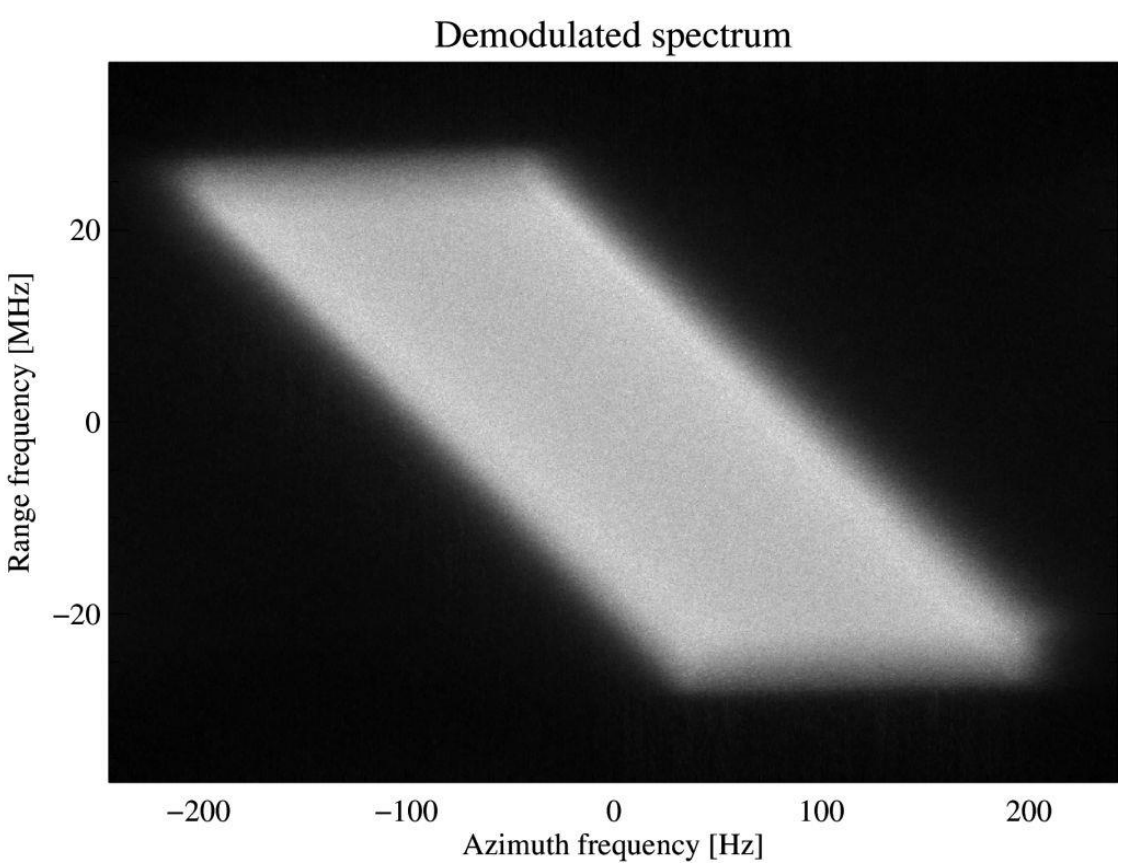


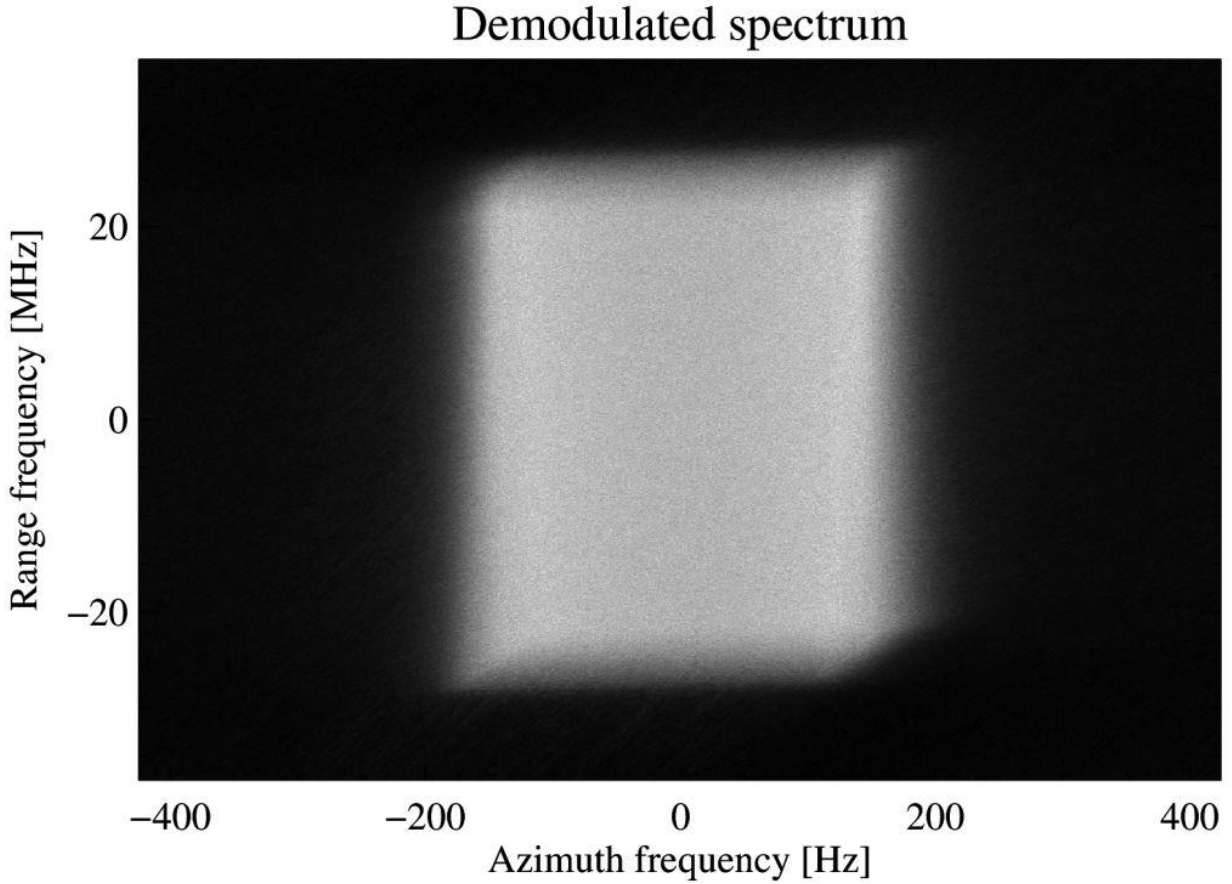


Interferometric coherence after filtering

InSAR Processing – Azimuth Spectral Filter

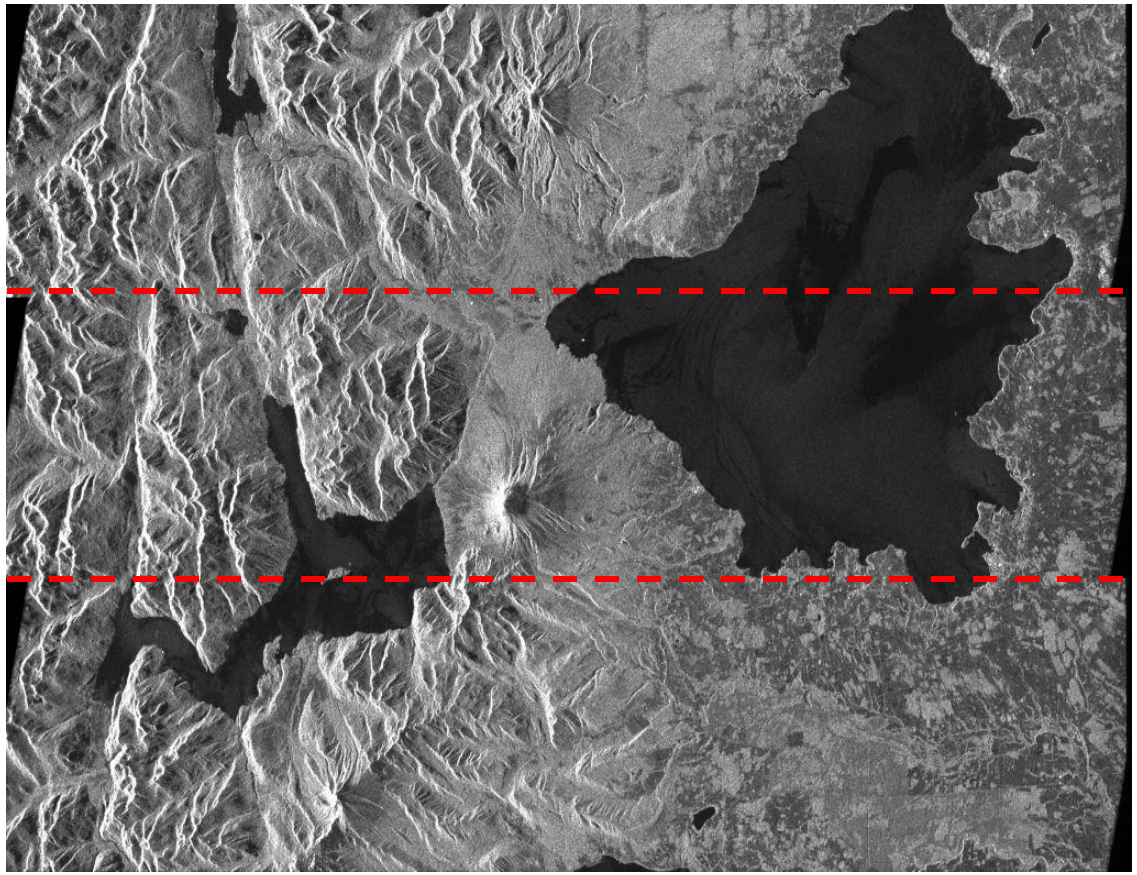
- Investigations on optimal output grid for spectral filtering / sublooks generation **ongoing**:

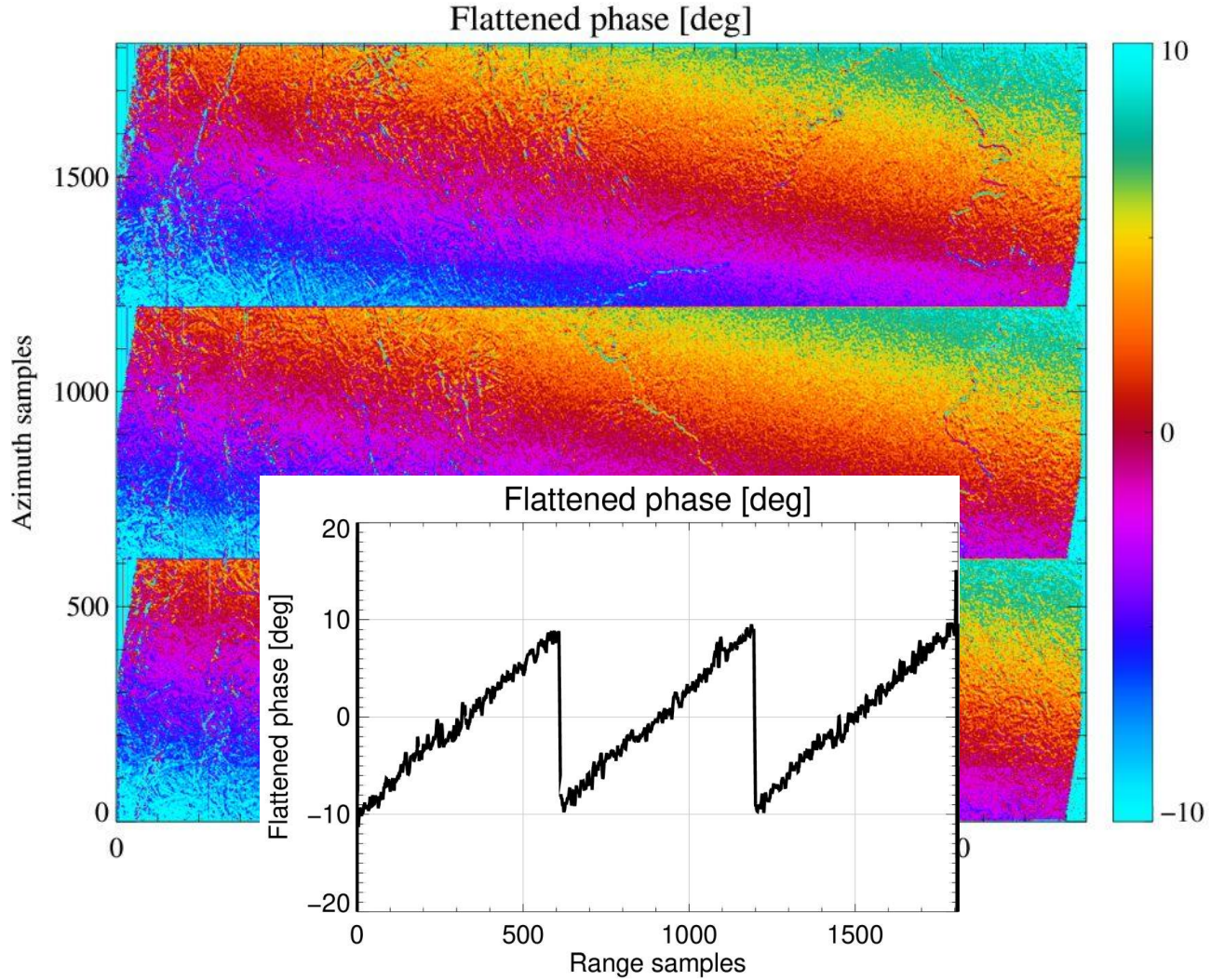




InSAR Processing – Enhanced Spectral Diversity

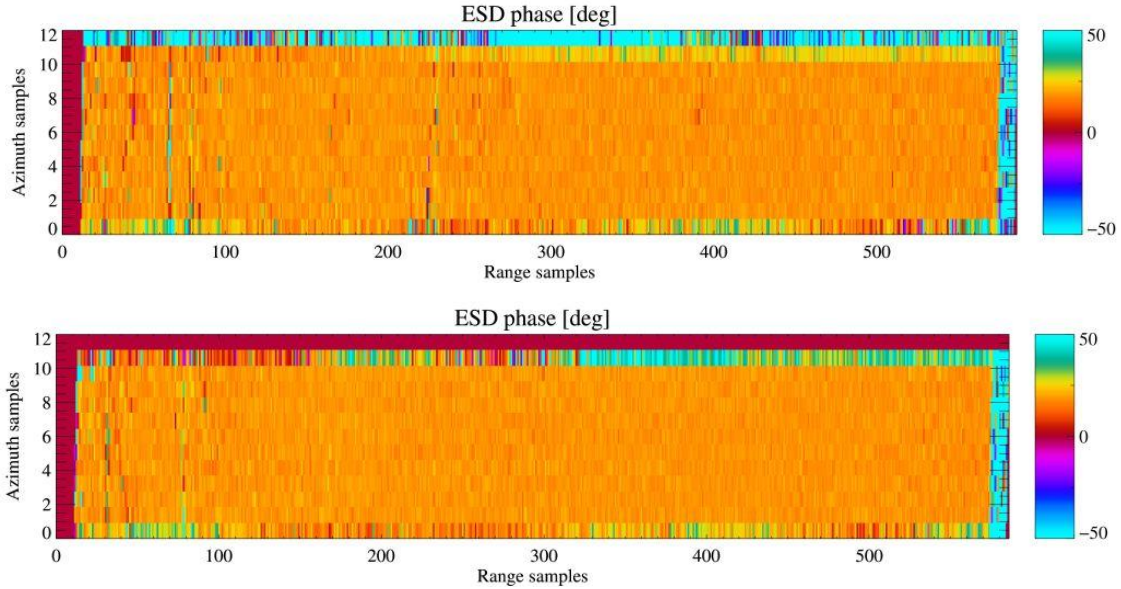
- Artificial injection of a 10 cm azimuth error $\rightarrow \phi_{err} = 2\pi \cdot f_{DC}(r,a) \cdot \Delta t_{coreg}$
- Azimuth phase ramp due to **azimuth-dependent** Doppler centroid in TOPS
- Range phase ramp due to **range-dependency** of Doppler centroid due to output geometry





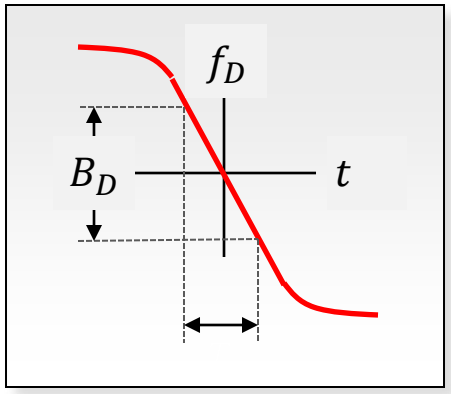
InSAR Processing – Enhanced Spectral Diversity

- ESD measurement at the 2 overlap areas:

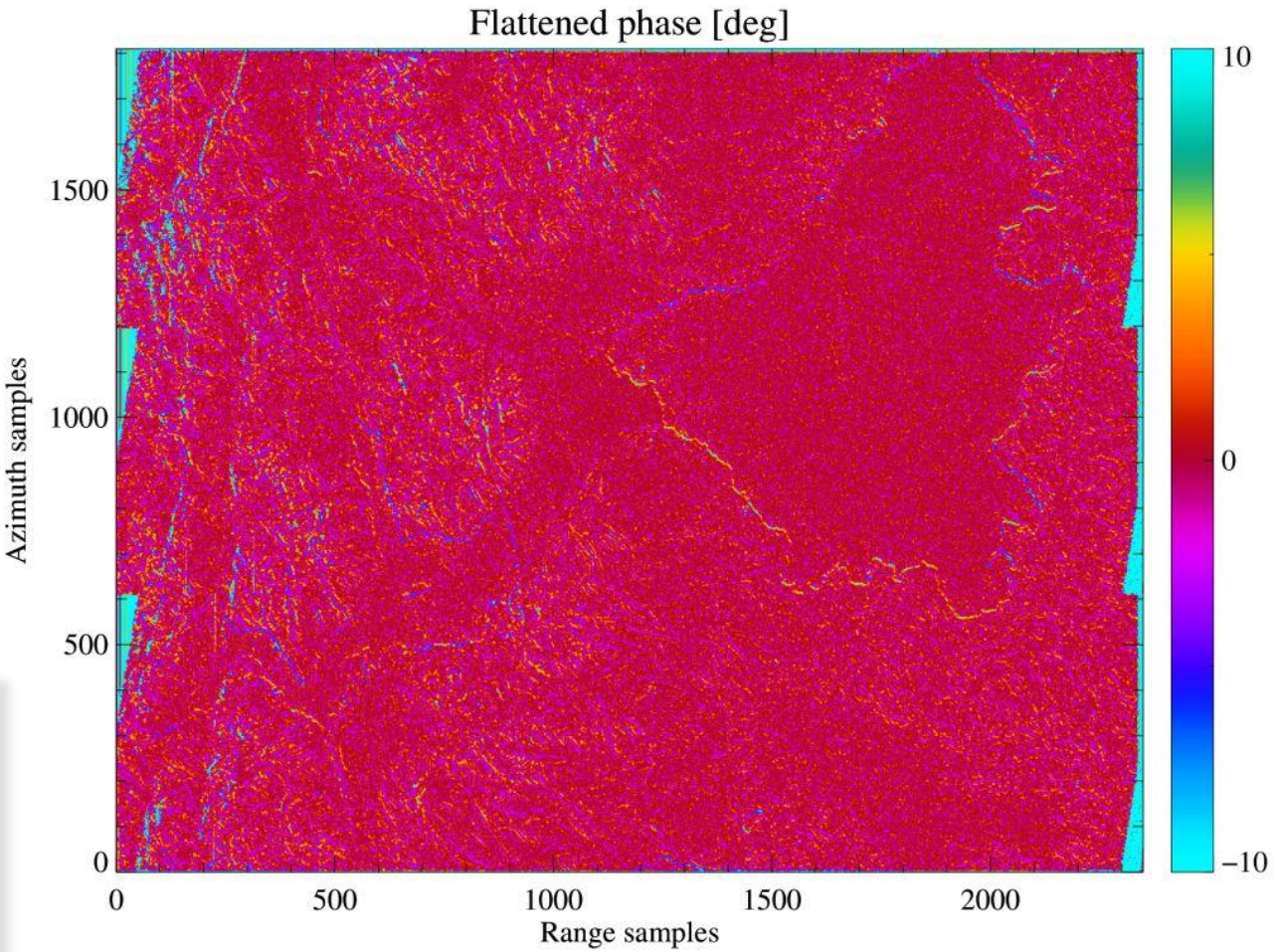


- ESD phase around 18º, which matches well with the injected azimuth shift of 10 cm

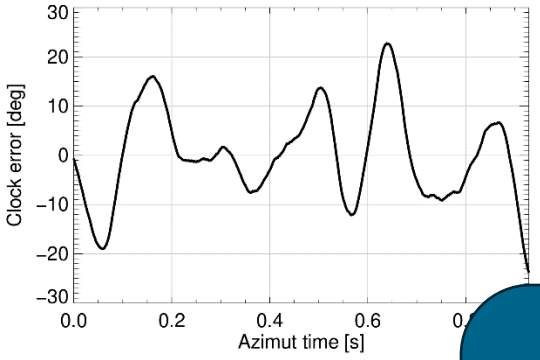
- **Interesting observation**: The spectral separation at the overlap area is smaller than for Sentinel-1 (around 10% smaller) due to the reduction of Doppler bandwidth with squint for the same observation time

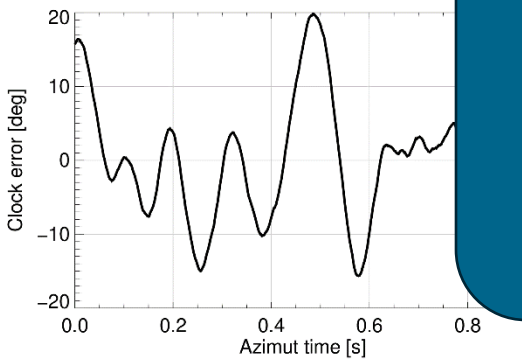


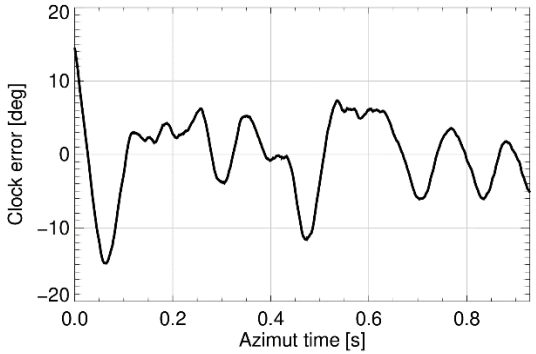
After correction

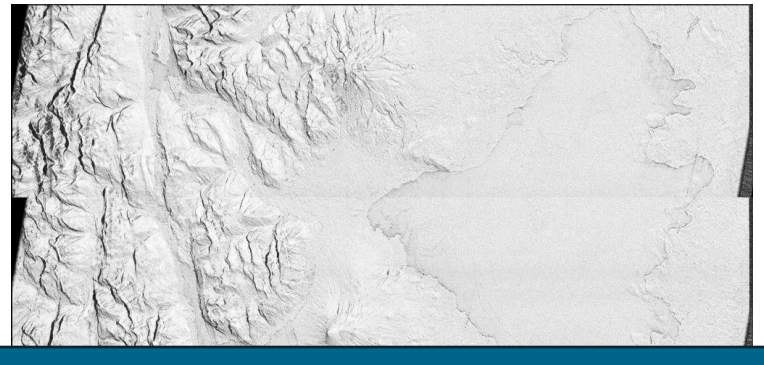


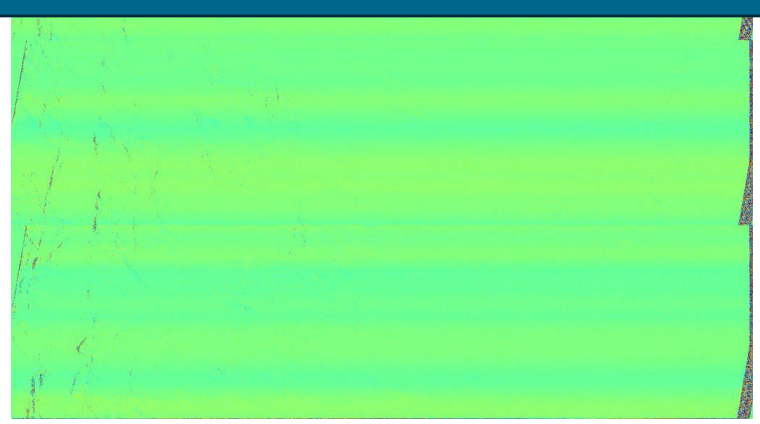
Clock Synchronisation

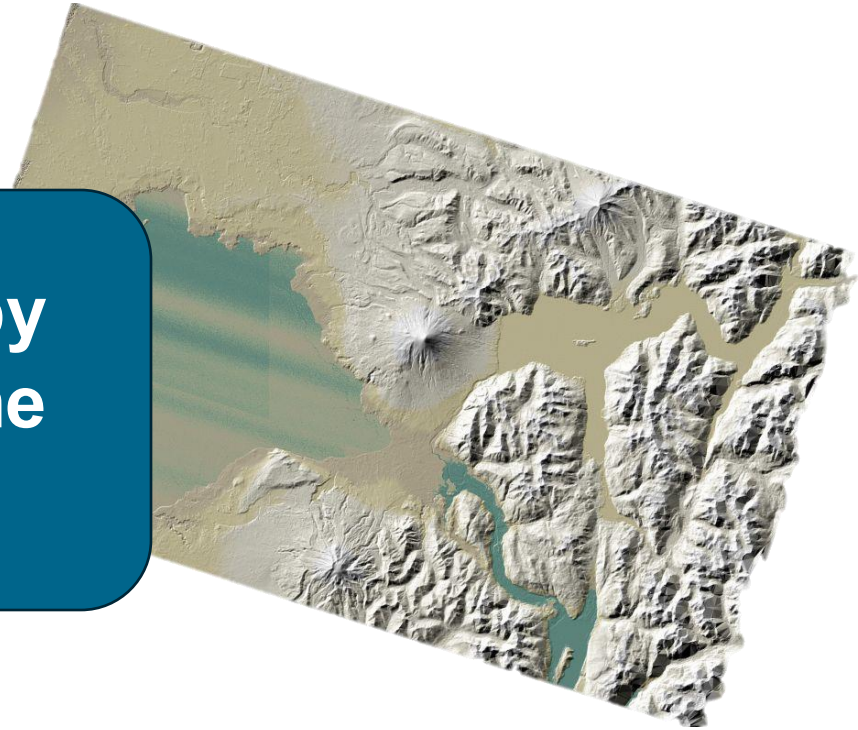






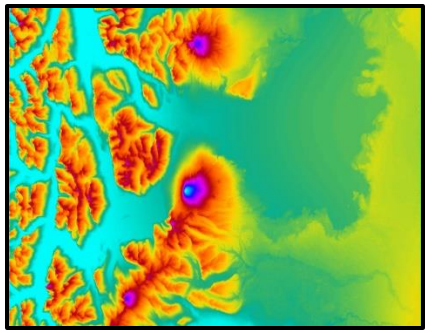






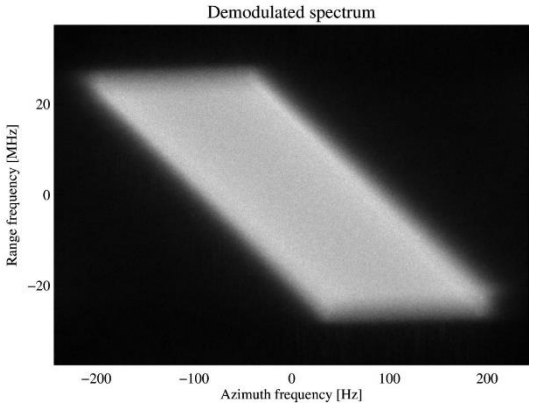
Don’t miss the presentation by Marc Rodriguez-Cassola at the end of this sesion!

Way Forward for Land Applications



HEEPS/Terra: End-to-End Simulation

- Continue system characterization (instrument, antenna, orbit, attitude)
- Improve forward models (snow/ice, dispersive ionosphere)
- Accurate reverse processing kernel for raw data generation of extended scenes (topography, antenna)



L1/L2/L3 Algorithms

- Finalize implementation, testing, and integration of breadboard processors: L1 (TDBP&GAFA), L2 (InSAR chain, DEM retrieval chain), L2 (PyStaMPS/Stampy PSI chain), L3 (TOC, 3-D inversion)