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PERFORMANCE ANALYSIS OF THE HARMONY MISSION FOR LAND APPLICATIONS: RESULTS FROM THE PHASE A STUDY

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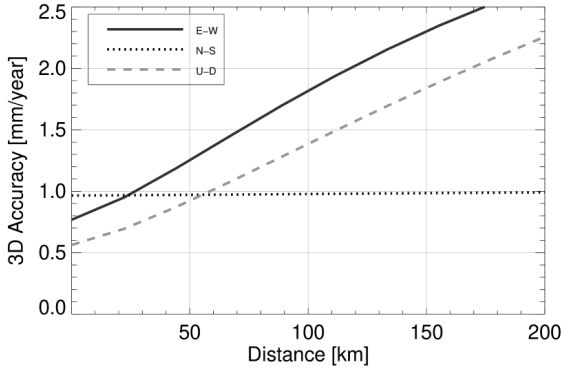
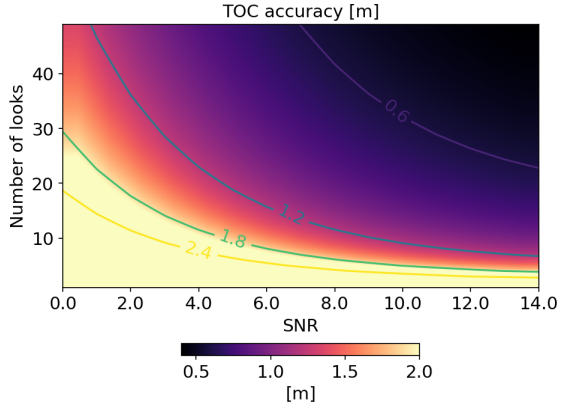
Performance Evaluation for Harmony Land

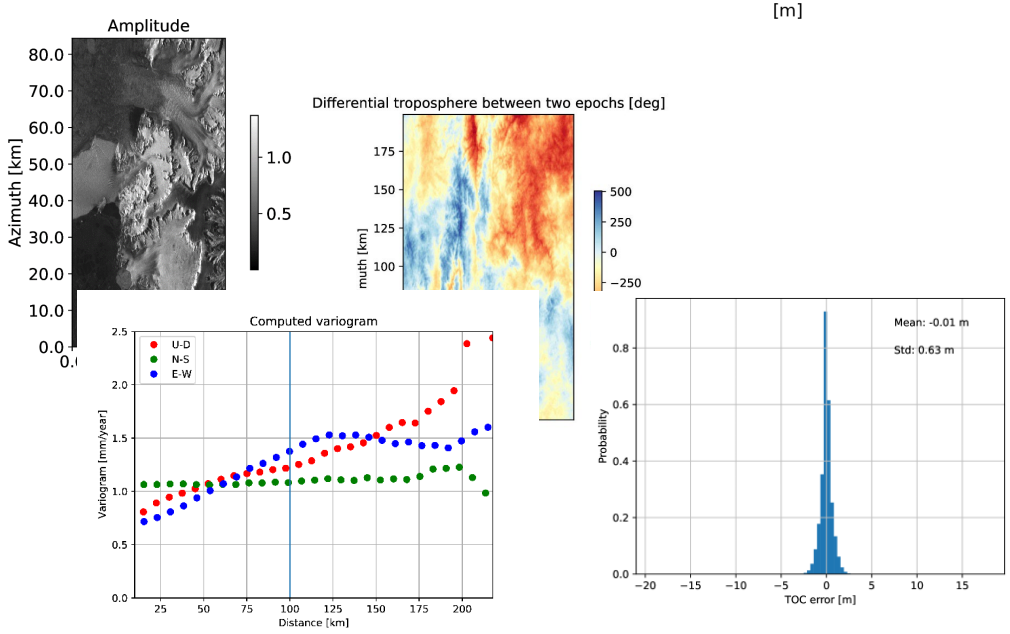
- Goal: evaluate the performance for the TVD (3-D deformation) and TOC (topography change) products for both solid Earth and land ice

- Analytical performance models to compute the asymptotic performance (mostly based on existing literature)

- Numerical end-to-end simulations using as realistic as possible forward models, partially using real data (S1 reflectivity, covariance, atmospheric data, real clock realizations, etc.) including up to L2/L3 processing





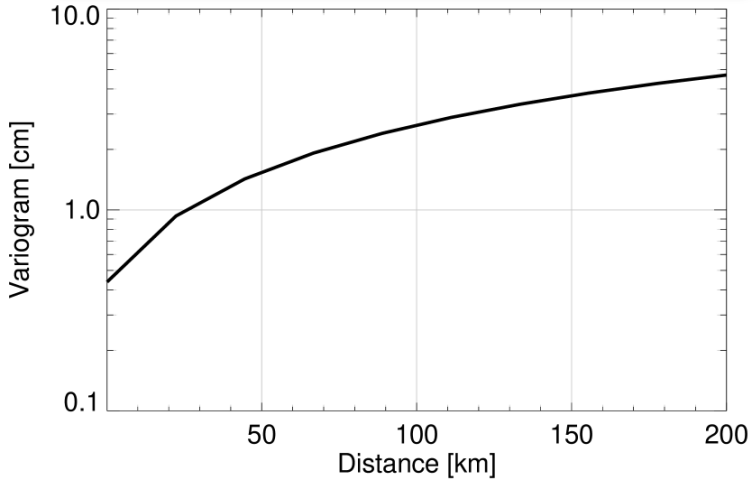


Analytical Performance Models

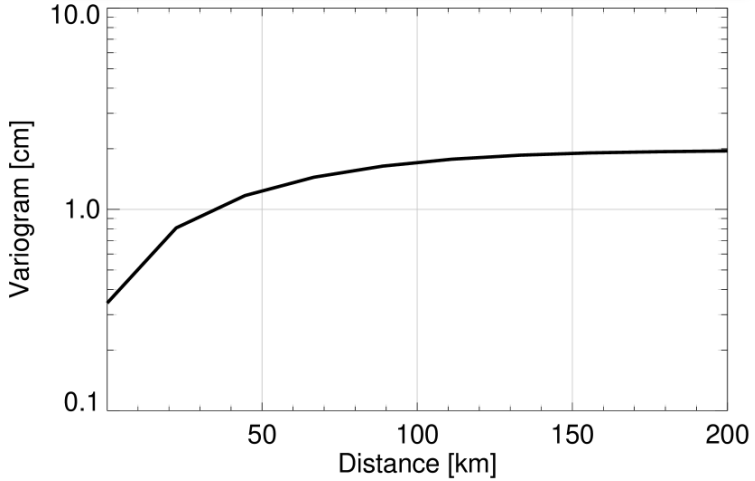
Analytical Product Performance Evaluation

- TVD (3-D Deformation) product performance based on literature [1] and updated to include 3 lines of sight + additional error sources (ionosphere, clock errors, baseline errors), as well as the different mission phases
- Usage of data-based model for troposphere (variograms)

Troposphere variogram w/o model-based corrections



Troposphere variogram with model-based corrections



[1] Prats-Iraola, P., Lopez-Dekker, P., De Zan, F., Yagüe-Martínez, N., Zonno, M., & Rodriguez-Cassola, M. (2017). Performance of 3-D surface deformation estimation for simultaneous squinted SAR acquisitions. IEEE Transactions on Geoscience and Remote Sensing, 56(4), 2147-2158.

Analytical Product Performance Evaluation

Test Case	Description	Comment
Scenario #1	5 years Stereo	Ideal (for reference)
Scenario #2	Asc&Desc with Harmony (1 year XTI + 3 years STEREO + 1 year XTI)	Best N-S performance
Scenario #3	Only one configuration with Harmony	Worse N-S performance than scenario #2
Scenario #4	Asc&Desc with Harmony + 5 extra years Sentinel-1	Improved performance for E-W and vertical components

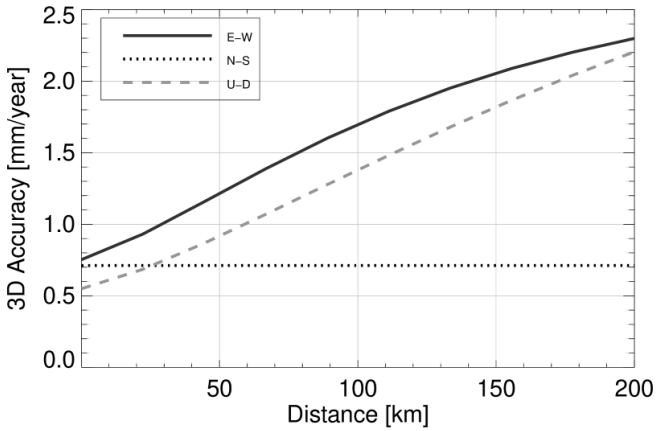
Relevant simulation parameters:

- Harmony-S1 along-track baseline: 350 km
- Temporal decorrelation: exponential model (τ = 40 days, $\gamma_\infty = 0.2$)
- Orbit inclination: 12º
- Product resolution: 100 m x 100 m

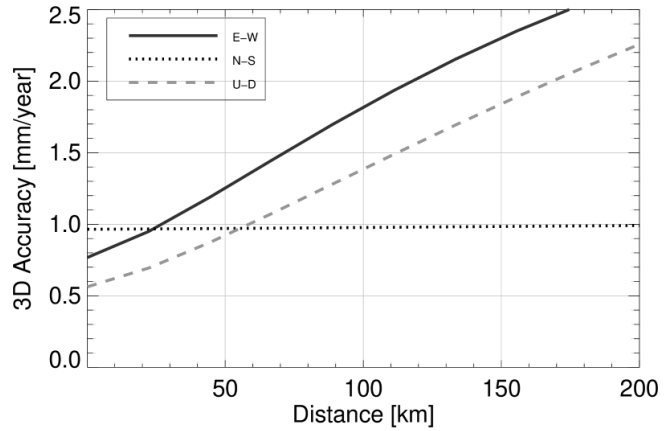
Analytical Product Performance Evaluation

DLR

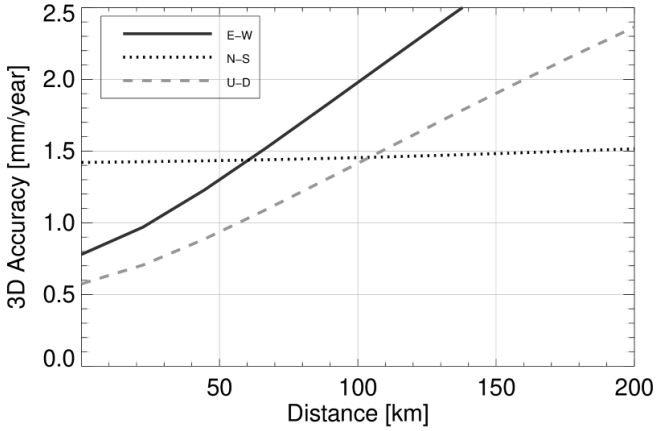
Scenario #1



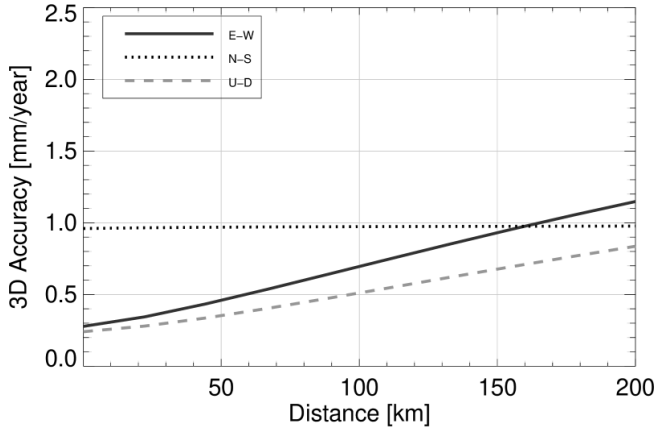
Scenario #2



Scenario #3



Scenario #4

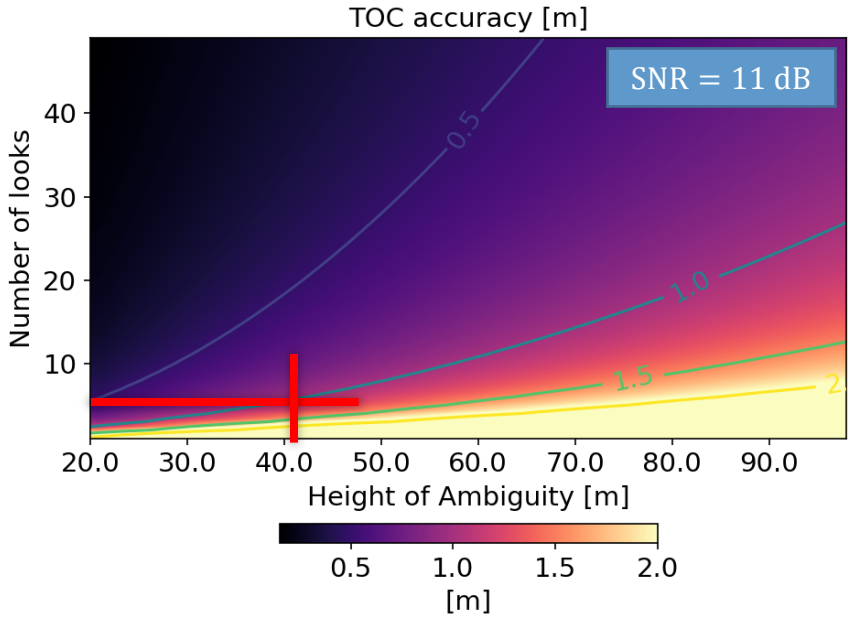


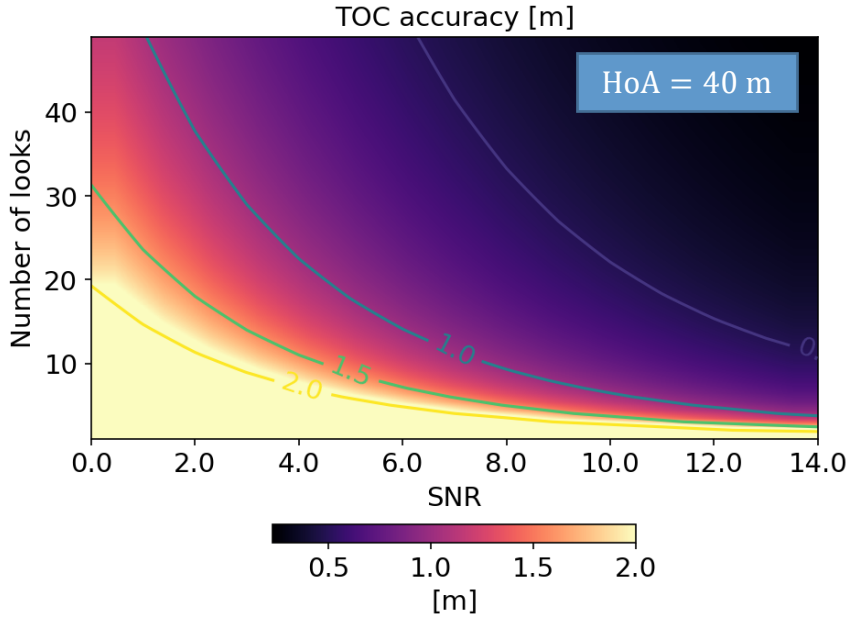
Observations:

- N-S deformation almost independent of distance to reference point (high correlation of tropospheric signal among lines of sight)
- E-W and vertical performance can be improved by extending the time series with pre-Harmony Sentinel-1 acquisitions.
- Goal requirement (1 mm/yr @100 km) achieved in Scenario #4
- Threshold requirement (2 mm/yr @100 km) achieved in all scenarios

Analytical Performance Evaluation

- TOC (Topography Change) product performance based on well-known InSAR performance equations [2]





Observations:

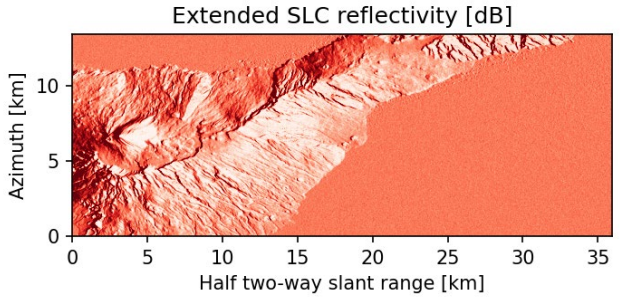
- Goal requirements of 1 m TOC acuracy at 30 m x 30 m (solid Earth) and 0.2 m/yr at 50 m x 50 m (land ice) are challenging
- Large baselines result in a more challenging phase unwrapping
- Averaging of consecutive DEMs might need to be assessed for each particular scenario

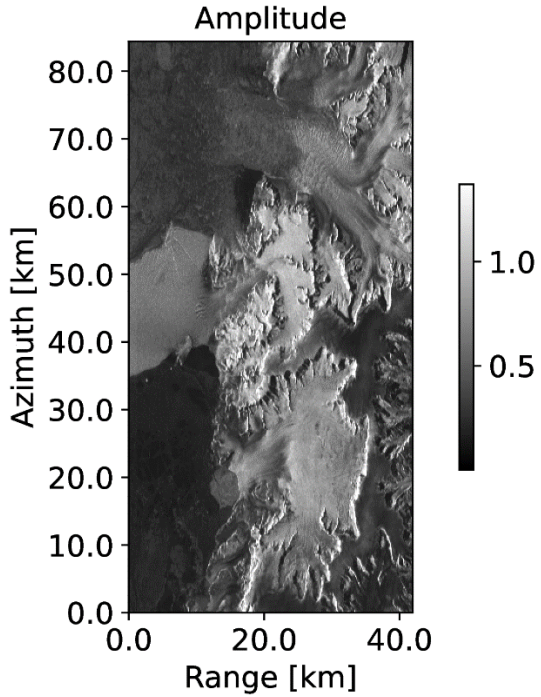
[2] Krieger, G., Moreira, A., Fiedler, H., Hajnsek, I., Werner, M., Younis, M., & Zink, M. (2007). TanDEM-X: A satellite formation for high-resolution SAR interferometry. IEEE Transactions on Geoscience and Remote Sensing, 45(11), 3317-3341.

End-to-End Simulations

HEEPS/Terra – Overview

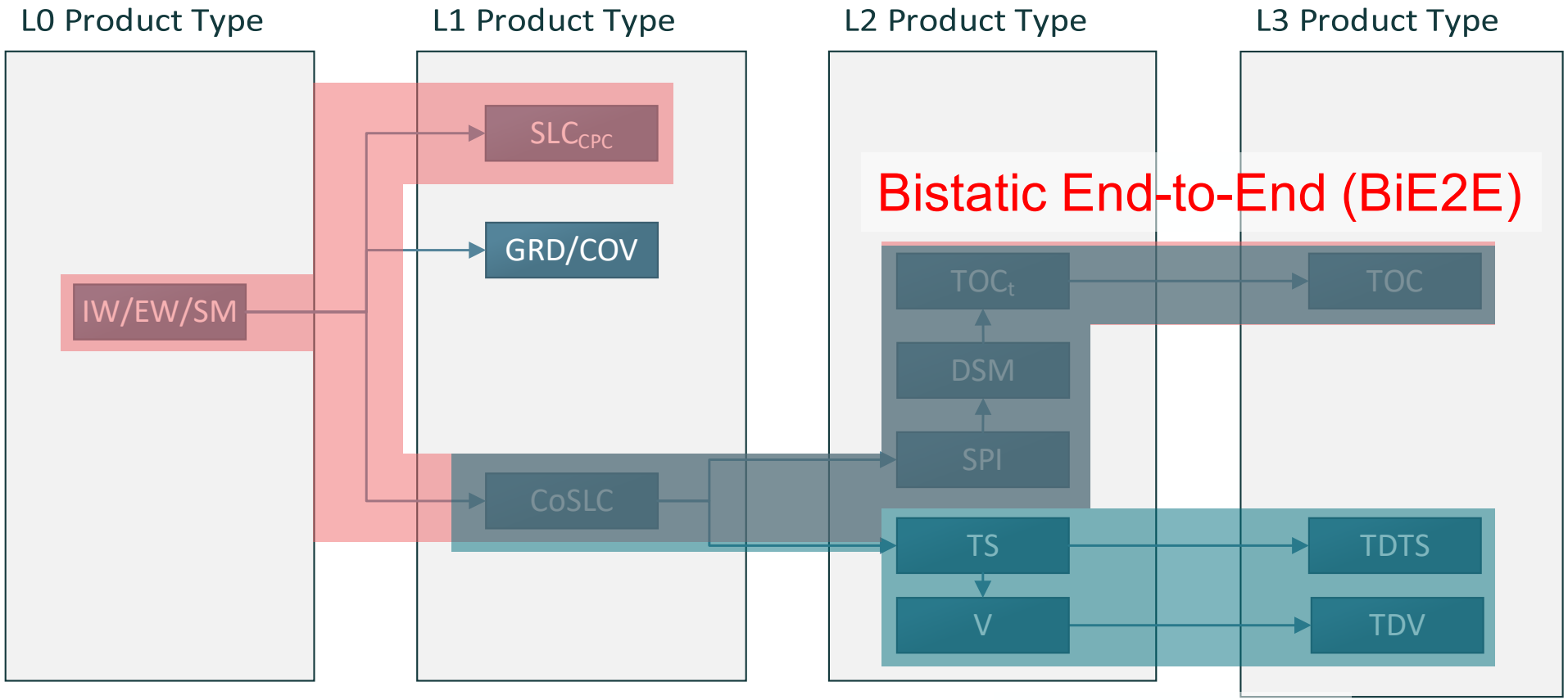
- HEEPS = Harmony End-to-End Performance Simulator
- Bistatic End-to-End (BiE2E) simulator
  - Builds on previous developments under ESA contract
  - Generates raw data
  - Includes L1&L2 processing
  - Simulation of XTI phase
- L1a Simulator
  - Extension of simulator developed during Phase 0
  - Generates L1a (single-look complex) images
  - Includes L2/L3 processing
  - Simulation of XTI and Stereo phases





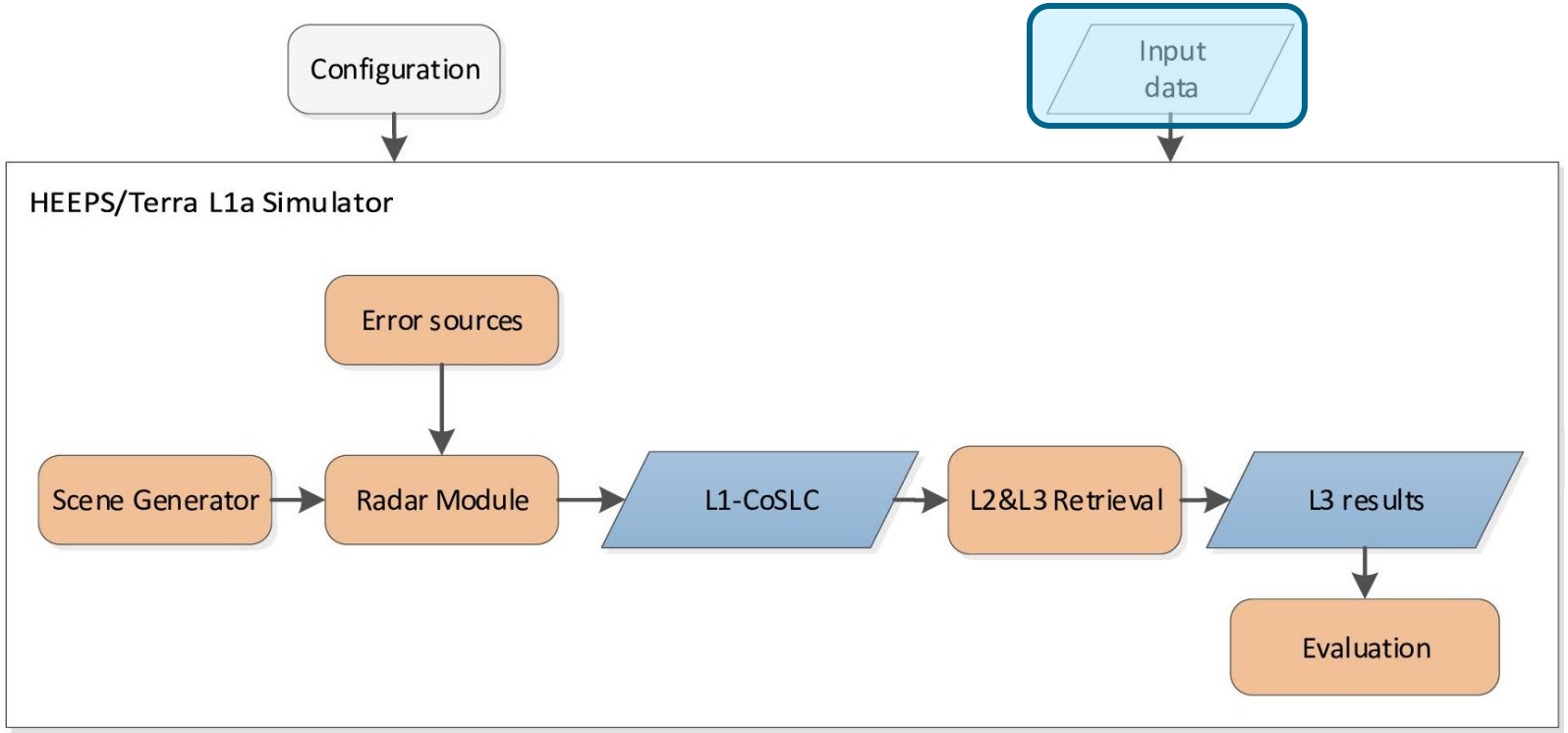
HEEPS/Terra – Overview

Product tree for land applications

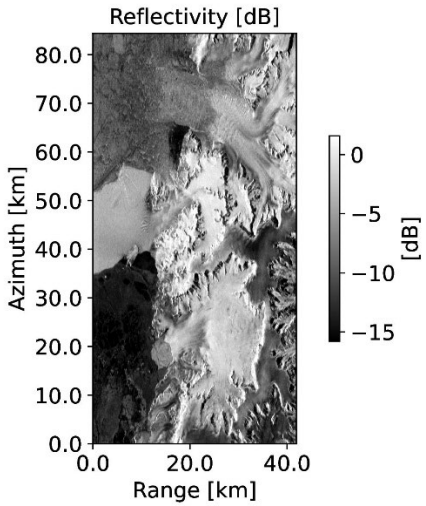


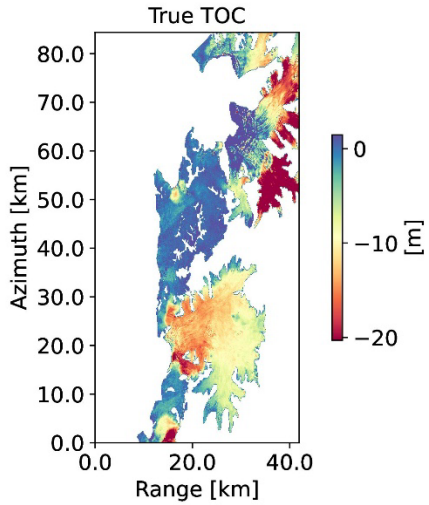
DSM: Digital Surface Model
TOC: Topography Change
TDV: 3-D Velocity Vectors
TDTS: 3-D Time Series

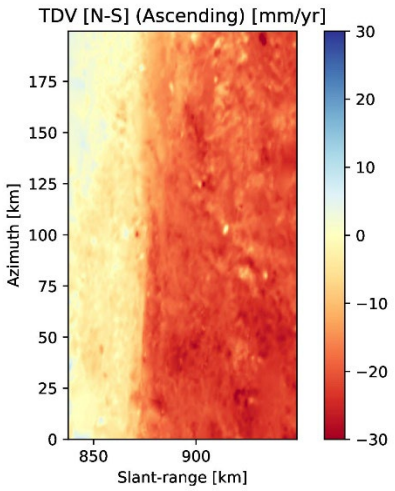
HEEPS/Terra L1a Simulator – Architecture

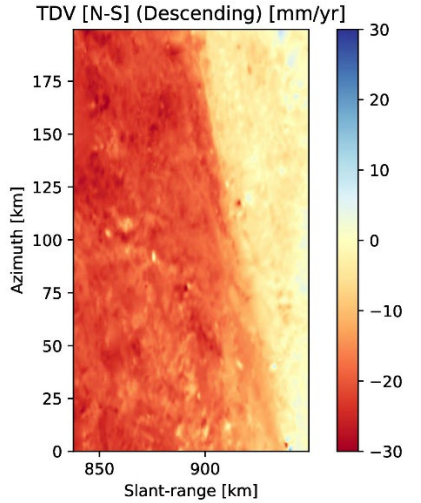


Sentinel-1 reflectivity image

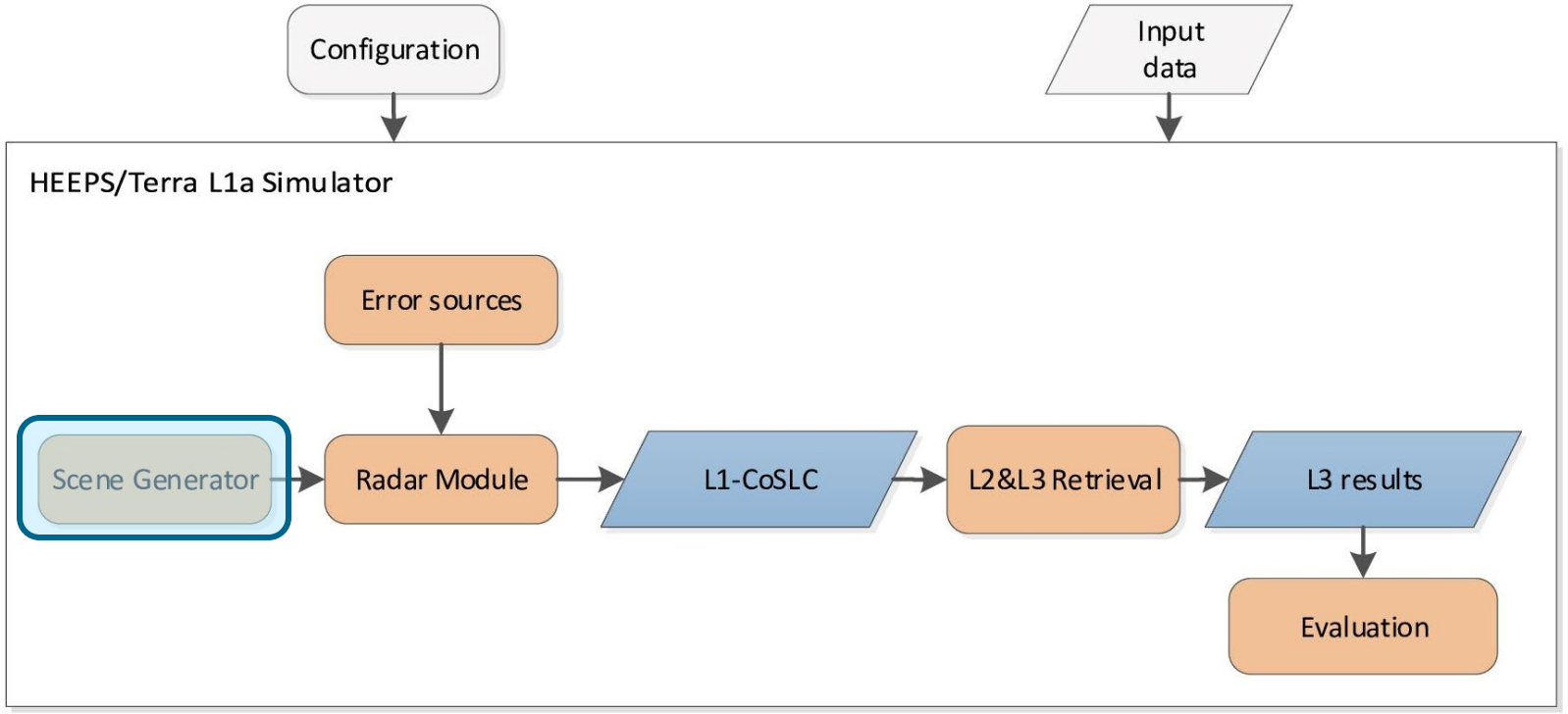


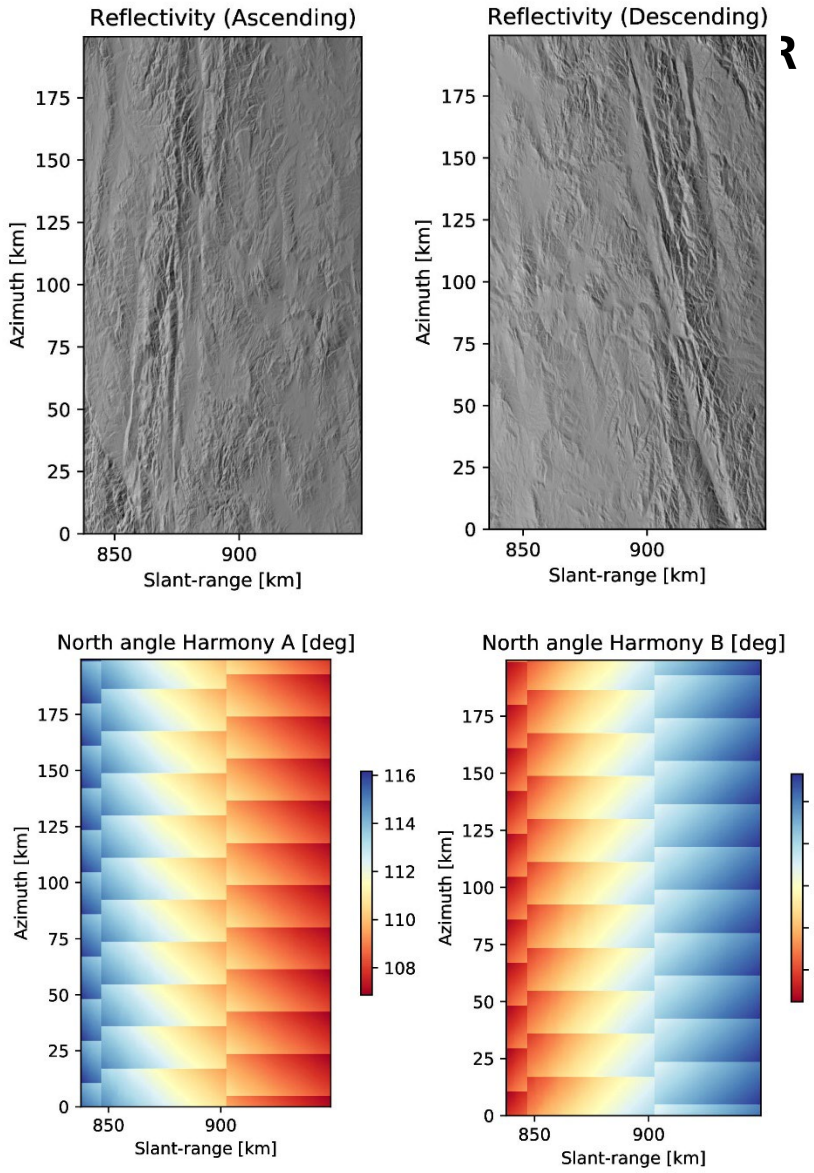






HEEPS/Terra L1a Simulator – Architecture





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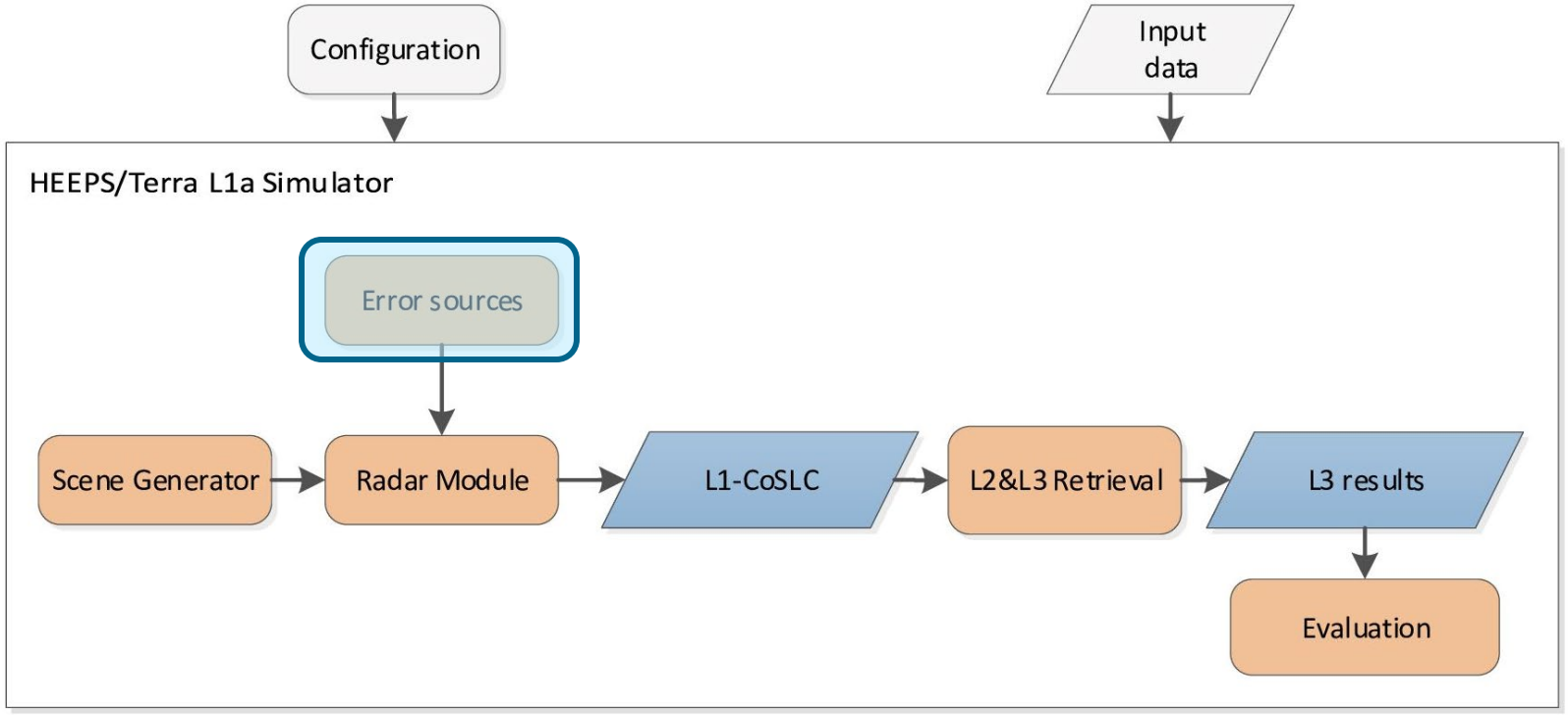
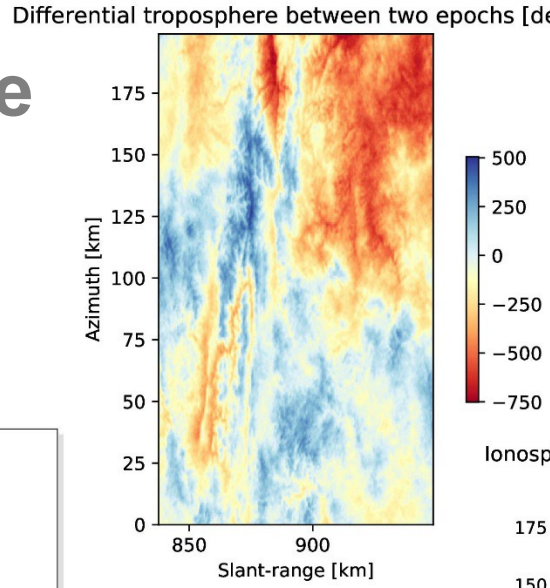
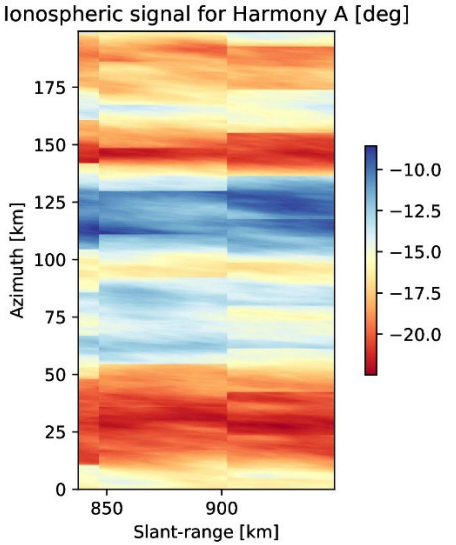
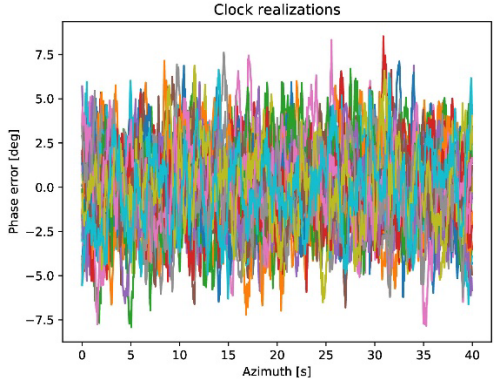
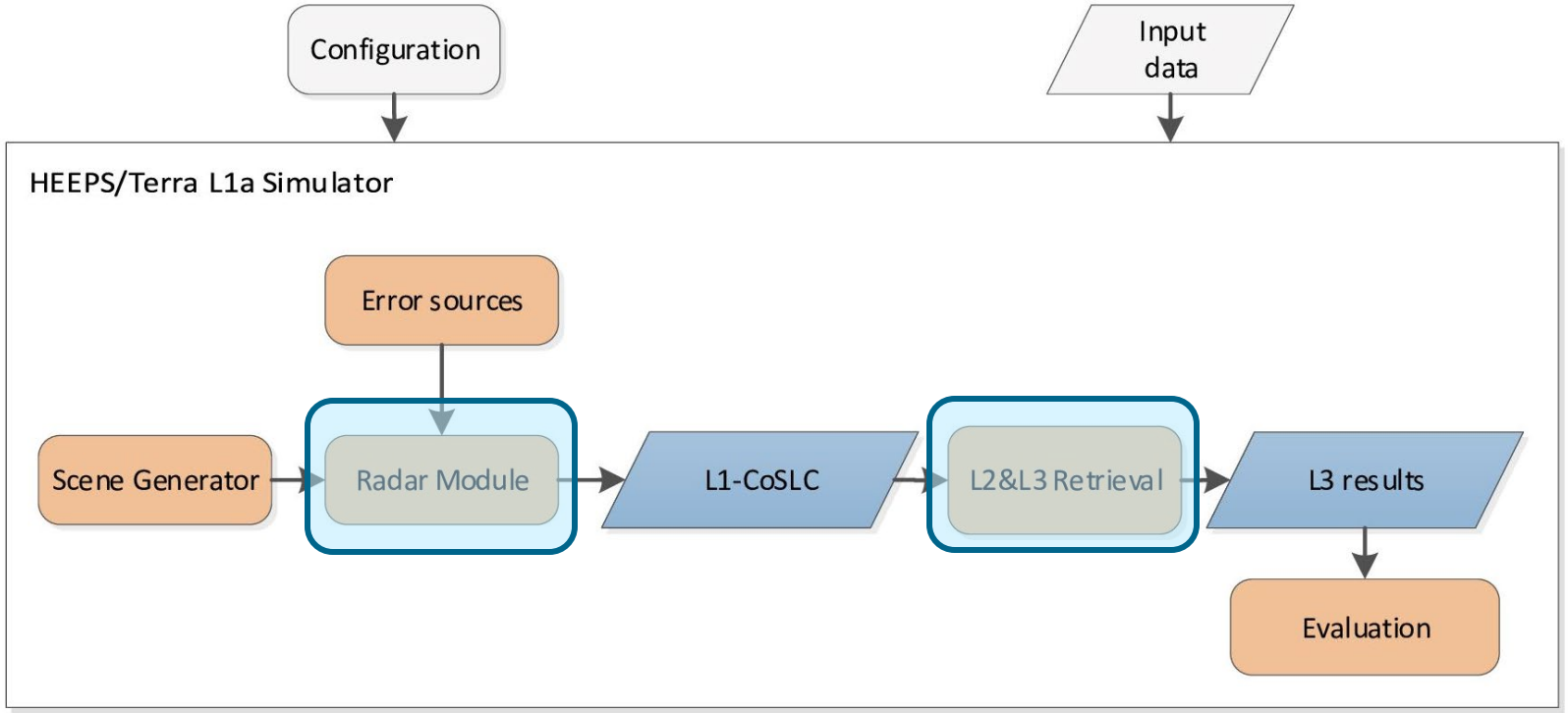


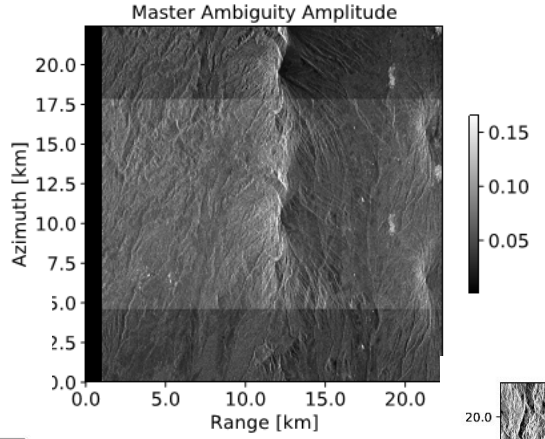


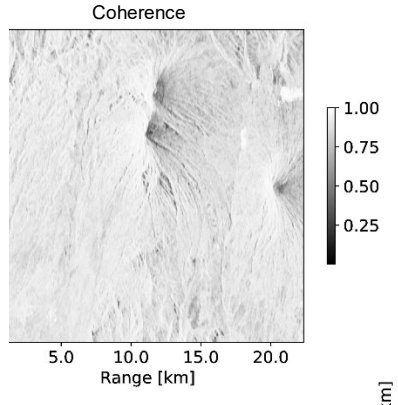


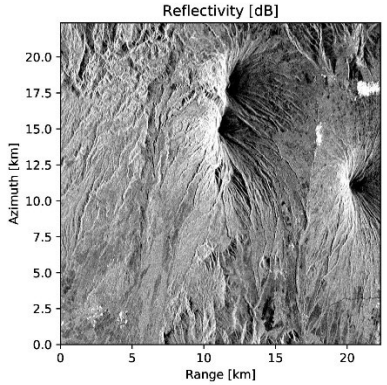


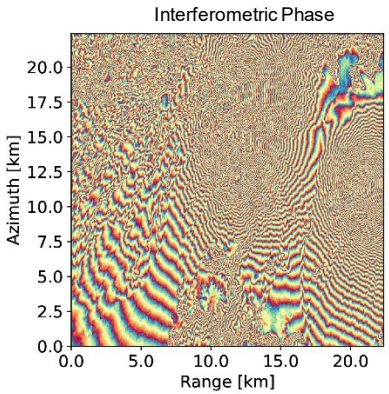
HEEPS/Terra L1a Simulator – Architecture

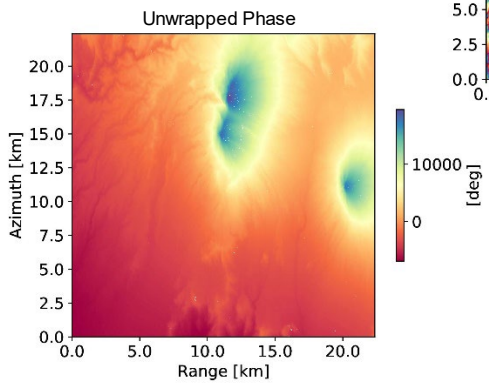






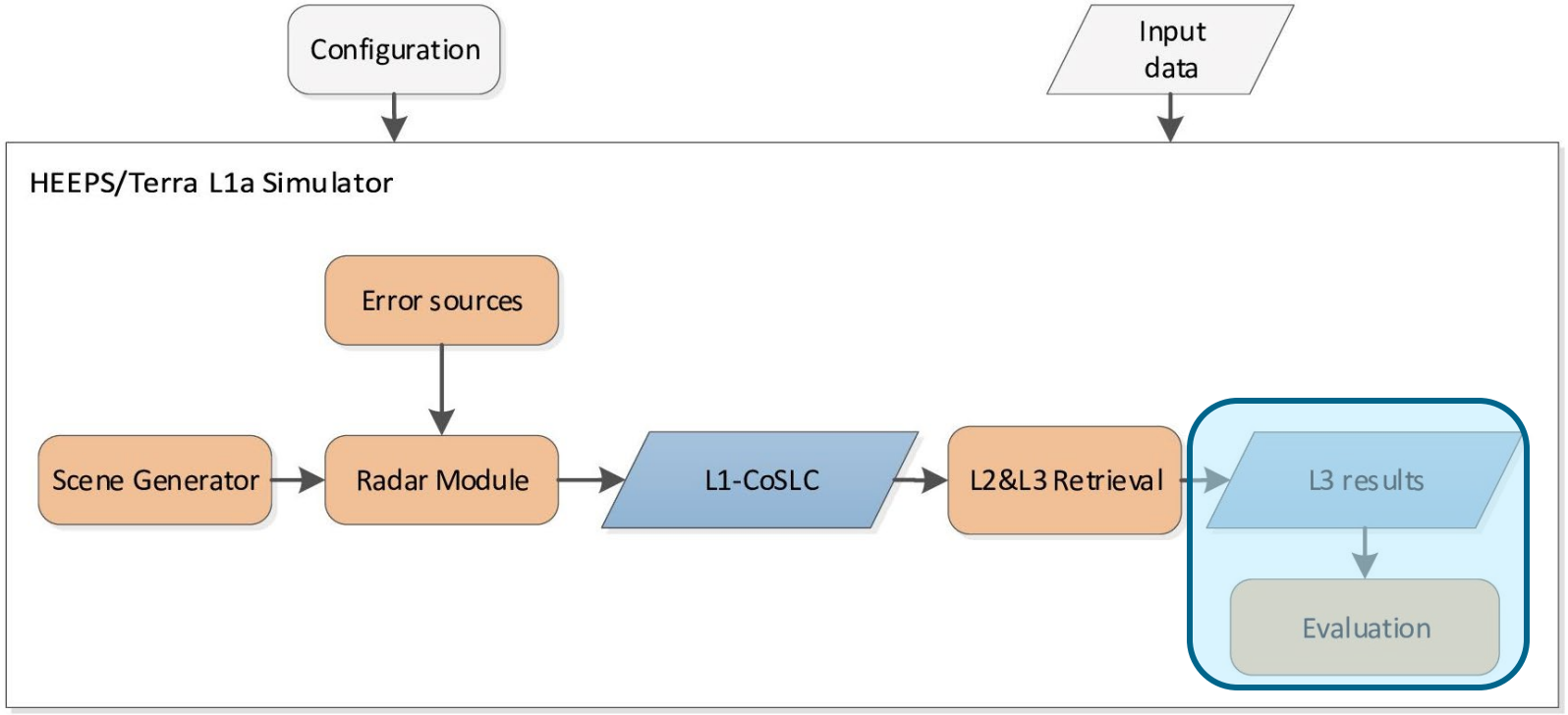


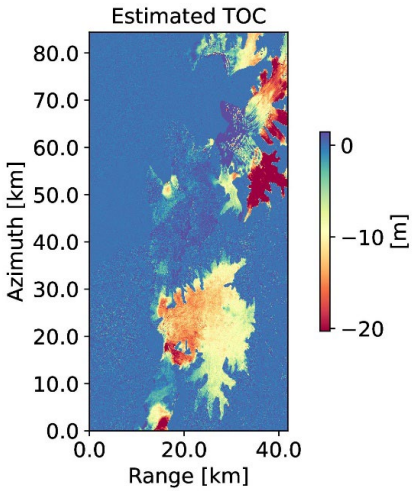


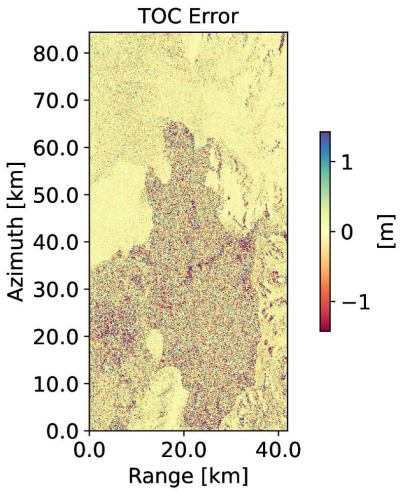


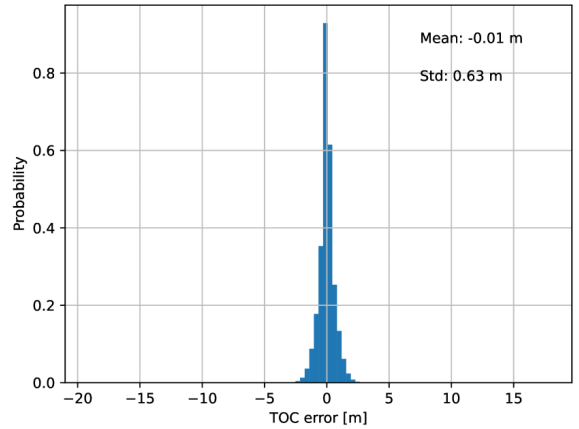
- Simulation of large stacks (~900 images for 5 years) for 3-D Velocity Vectors (TDV)

HEEPS/Terra L1a Simulator – Architecture





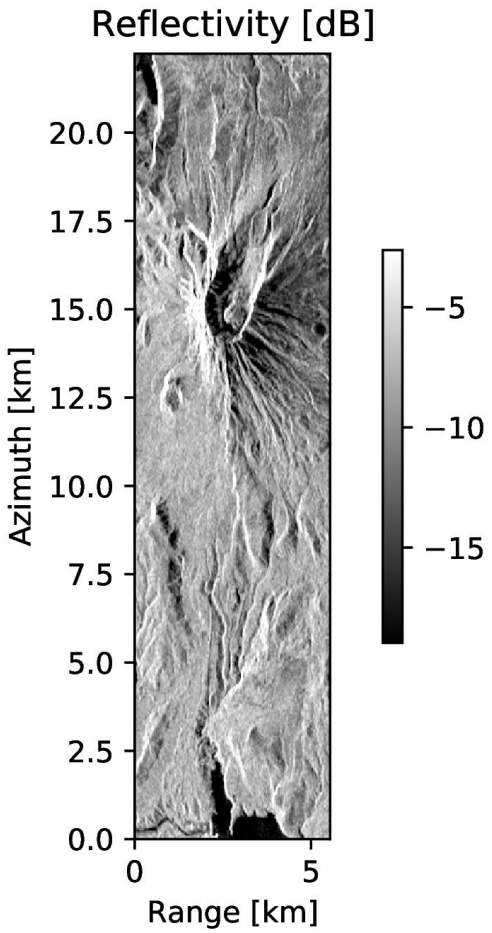




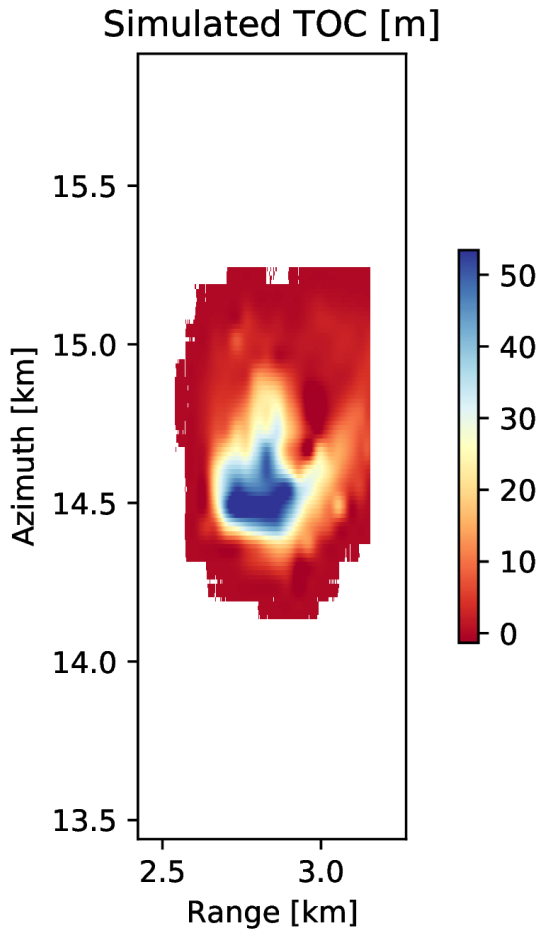
HEEPS/Terra L1a Simulator — L2/L3: TOC Solid Earth

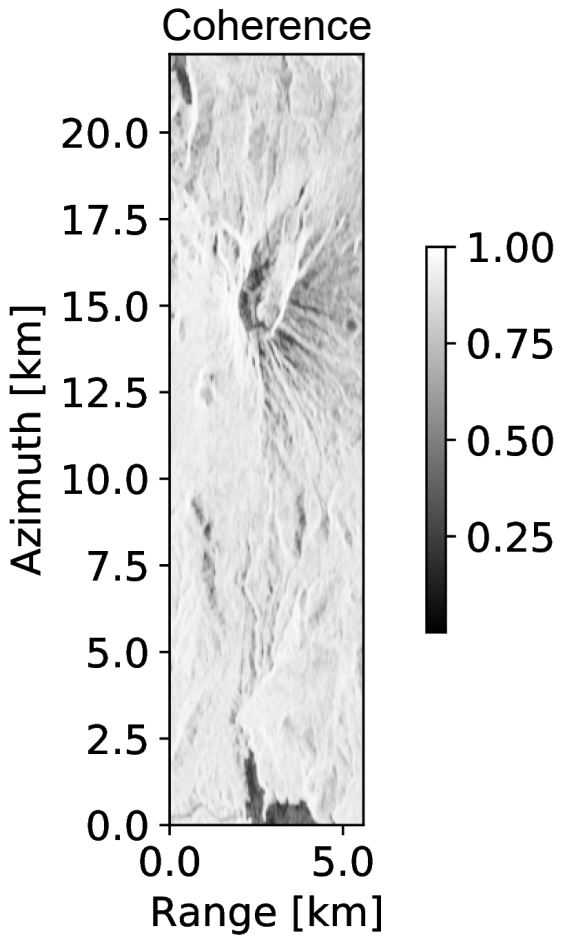
- Mount St. Helens (volcanic dome growth)
- Height of ambiguity: 40 m
- Product resolution: 30 m x 30 m

Sentinel-1 reflectivity image

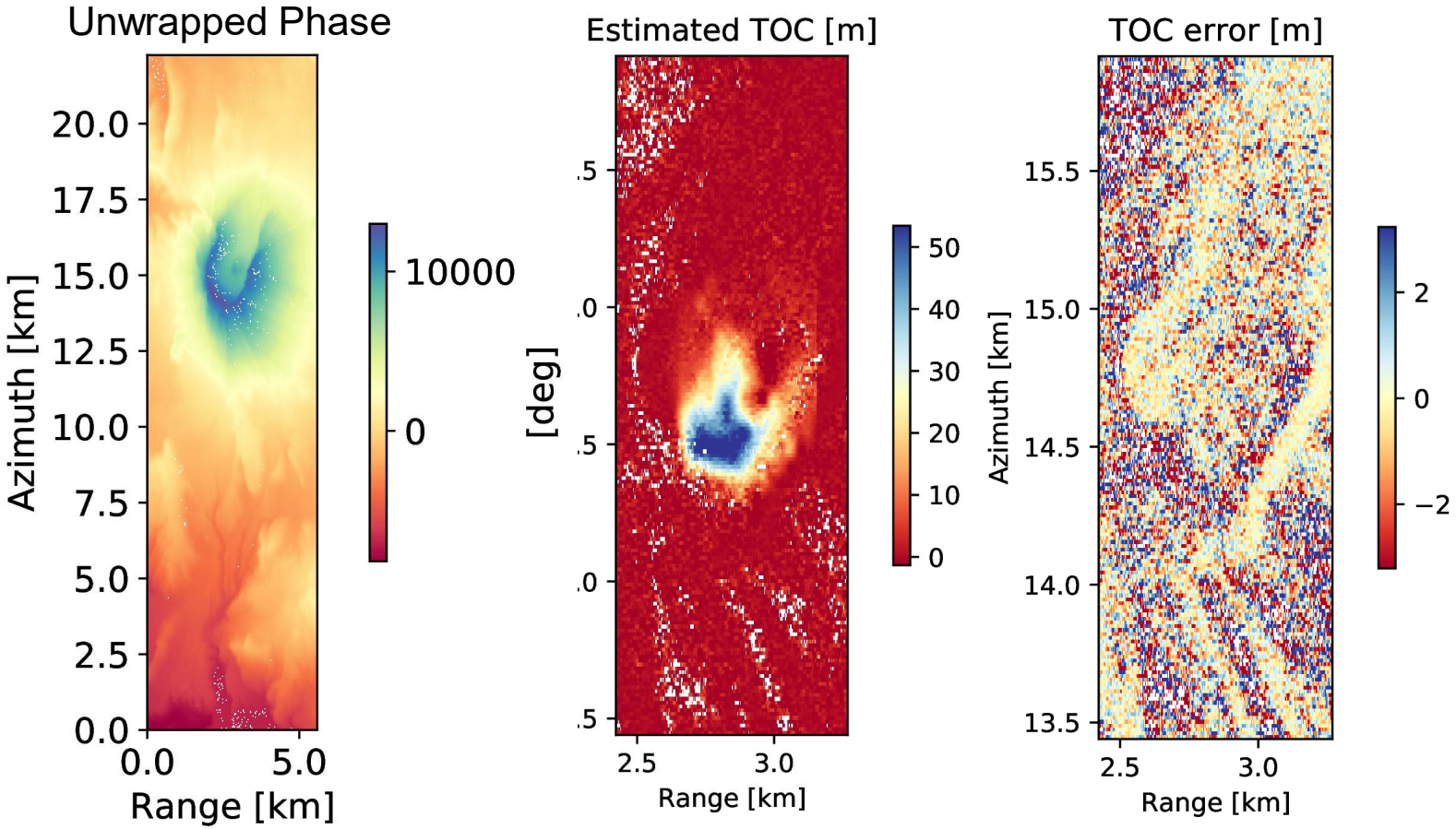


TOC derived from lidar data

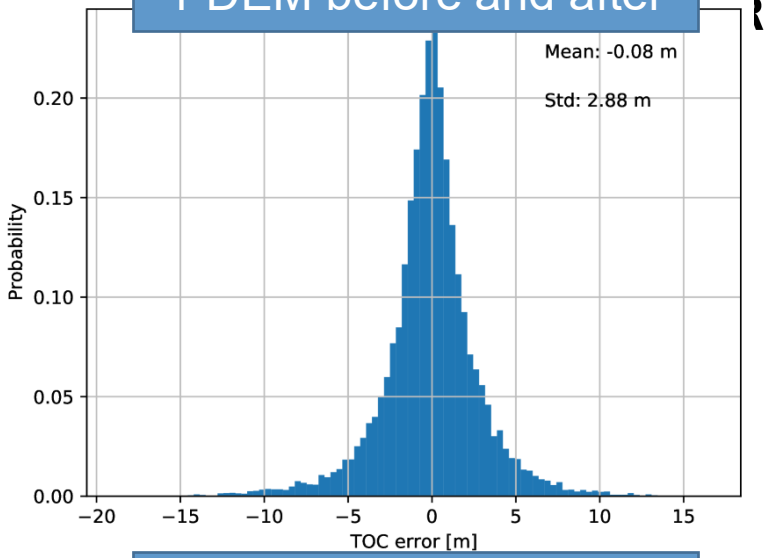




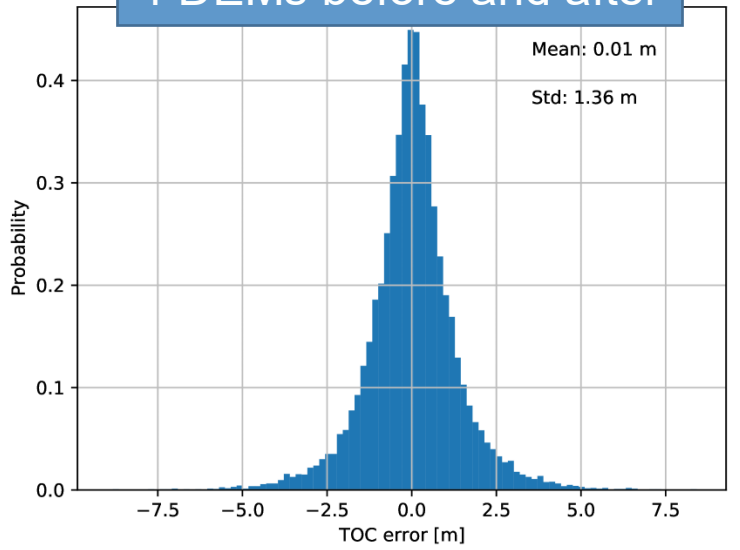
HEEPS/Terra L1a Simulator — L2/L3: TOC Solid Earth



1 DEM before and after



4 DEMs before and after

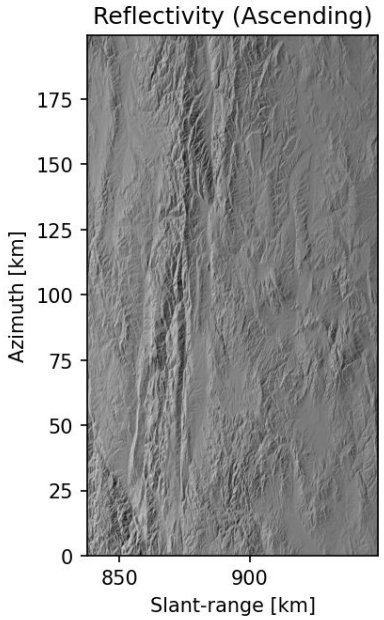


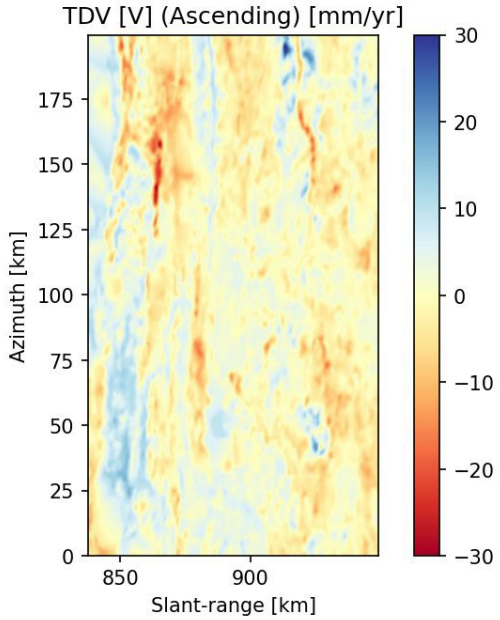
Performance within requirement for large baselines (height of ambiguity ≤ 30 m), or by averaging consecutive DEMs:

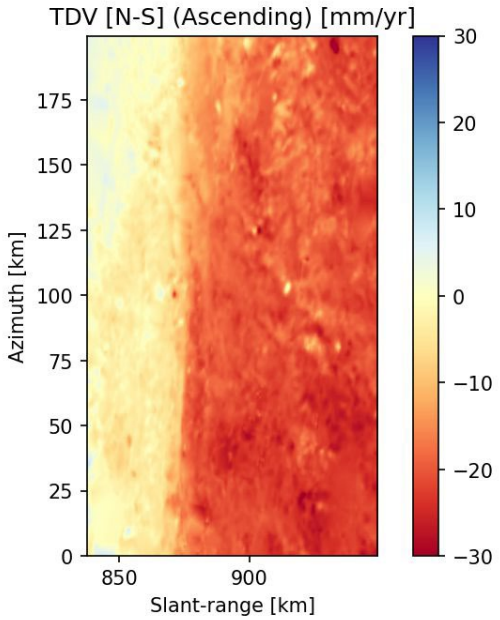
1 m at 30 m x 30 m resolution

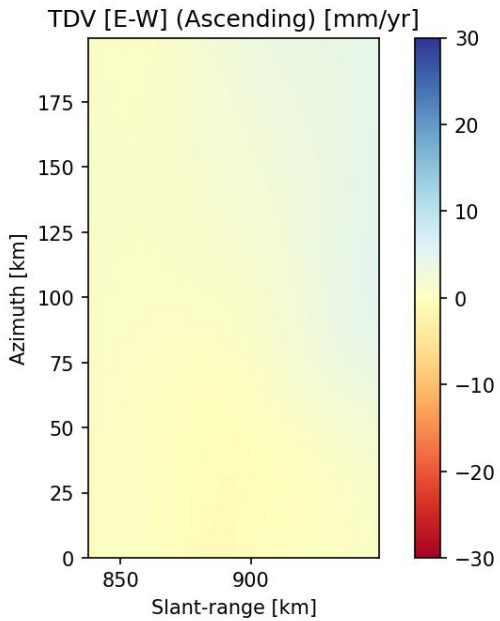
HEEPS/Terra L1a Simulator — L3: TDV Solid Earth

Test Case	Description	Comment	Test Data Set
Scenario #1	5 years Stereo	Ideal (for reference)	Rotated North Anatolian fault deformation derived from Sentinel-1 time series
Scenario #2	Asc&Desc with Harmony	Best N-S performance	
Scenario #3	Only one configuration with Harmony	Worse N-S performance than scenario #2	
Scenario #4	Asc&Desc with Harmony + 5 extra years Sentinel-1	Improved performance for E-W and vertical components	



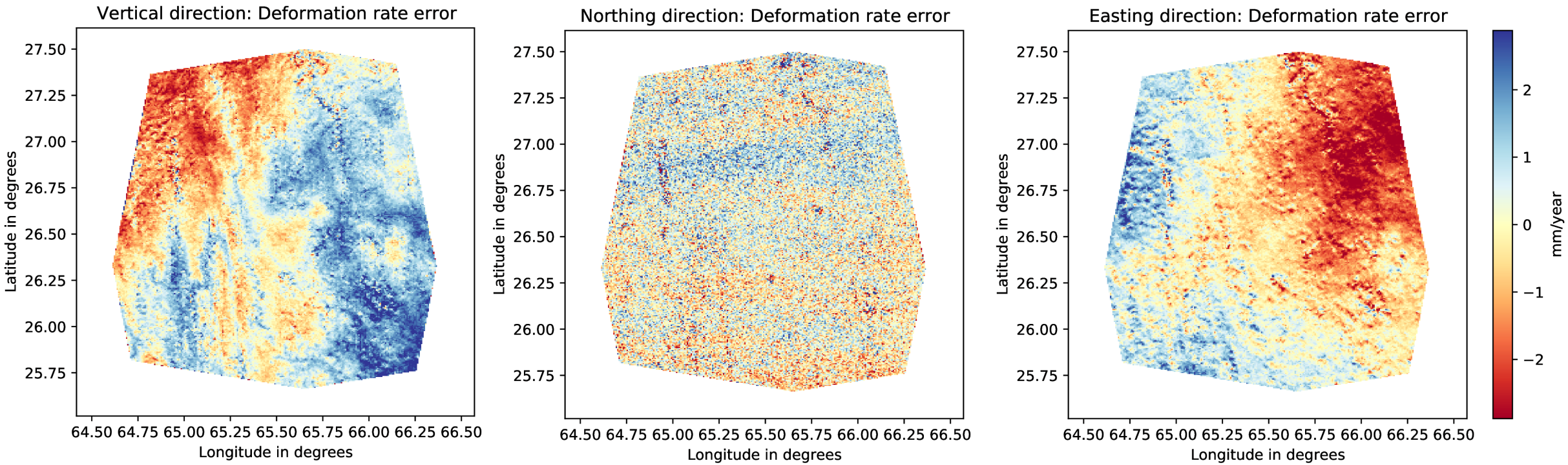






Rotated North Anatolian Fault — Scenario #2

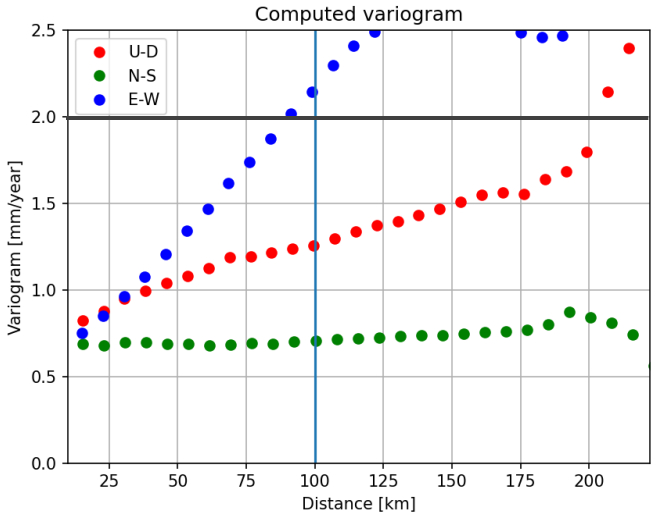
L3 product: 3-D Velocity Vectors

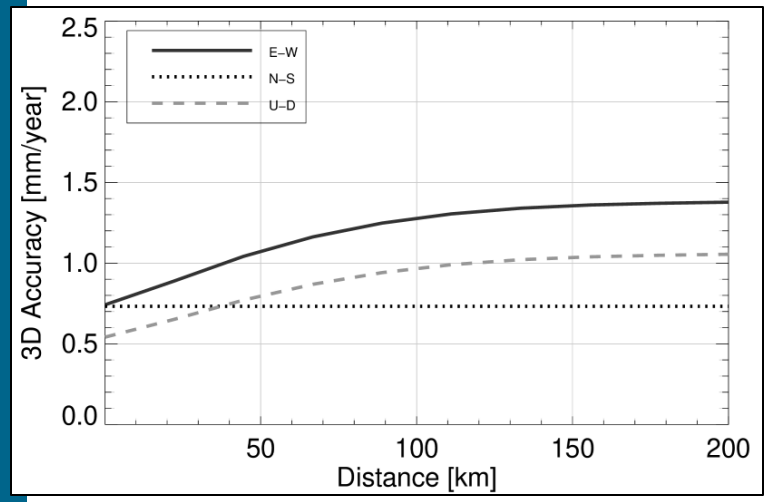


Rotated North Anatolian Fault — Simulated Scenarios

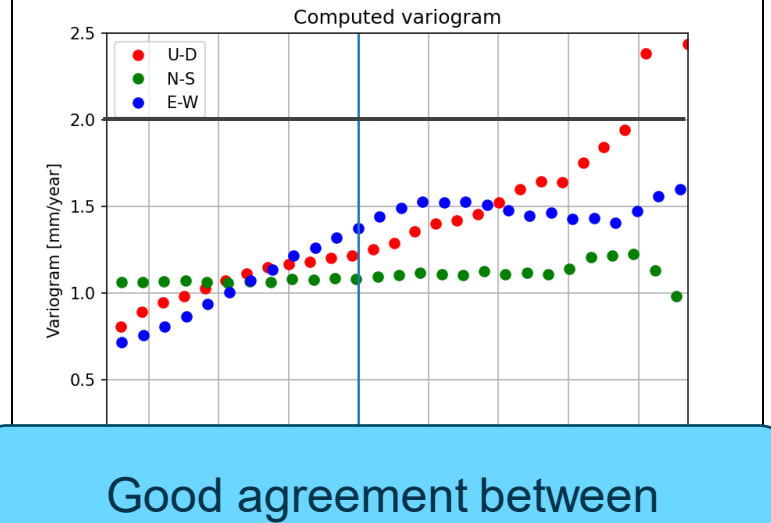
DLR

Scenario #1

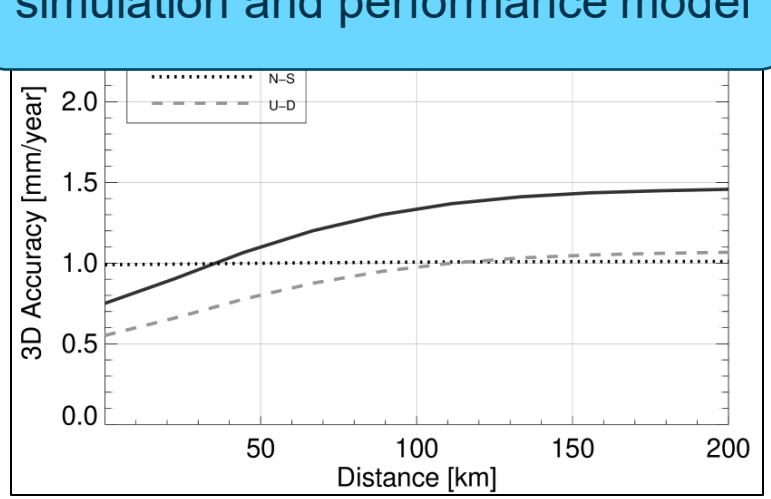




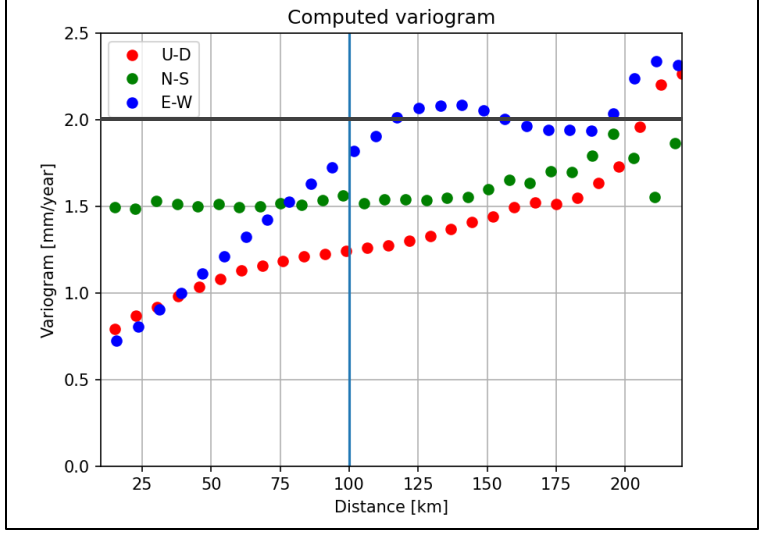
Scenario #2

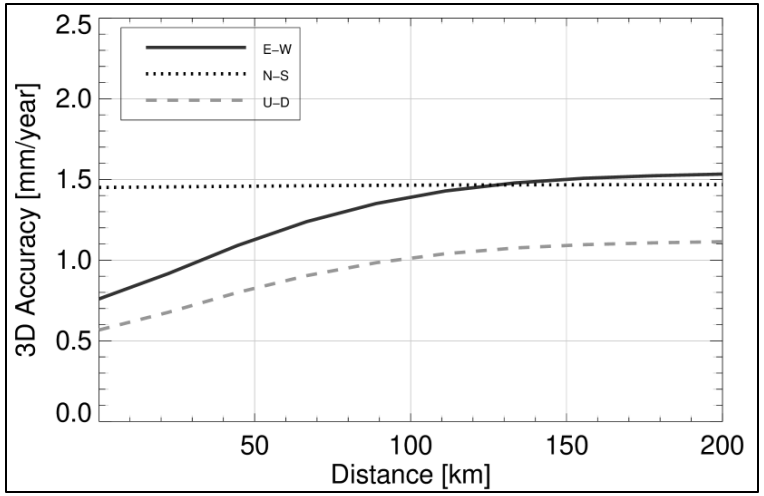


Good agreement between simulation and performance model



Scenario #3

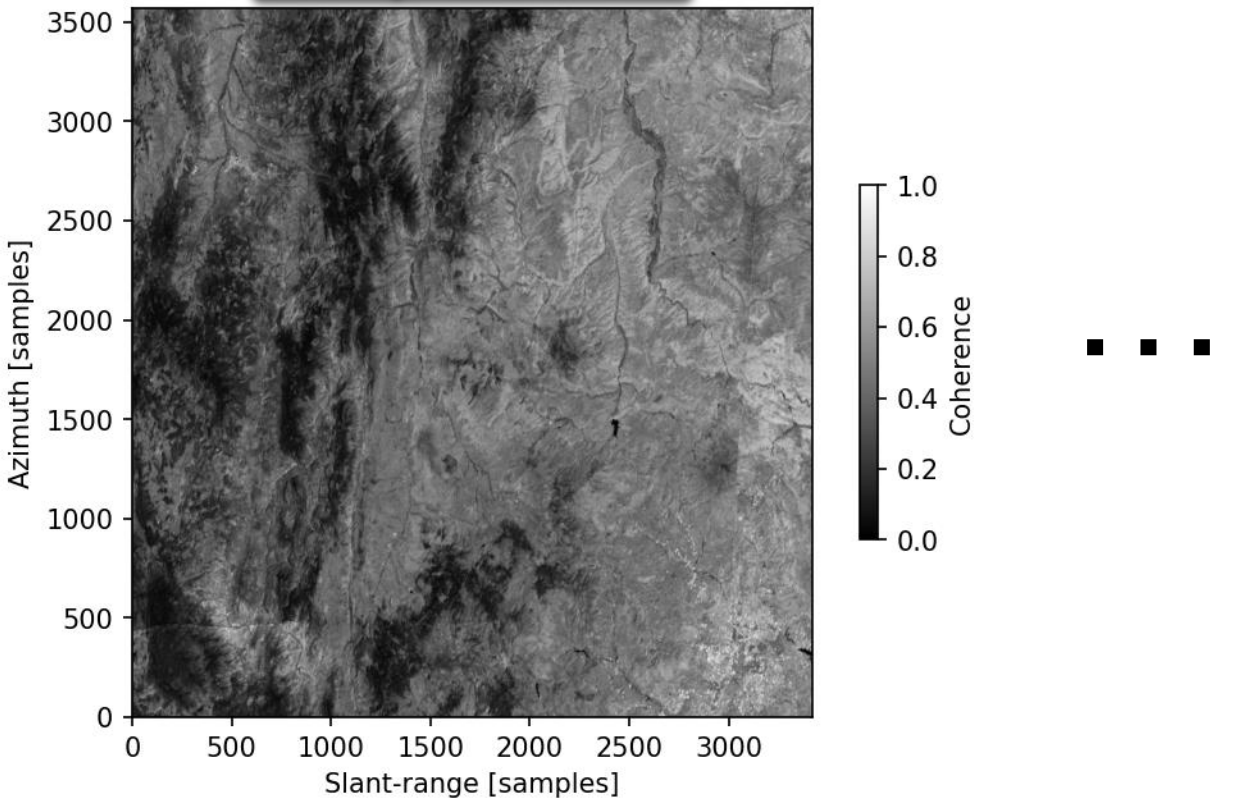




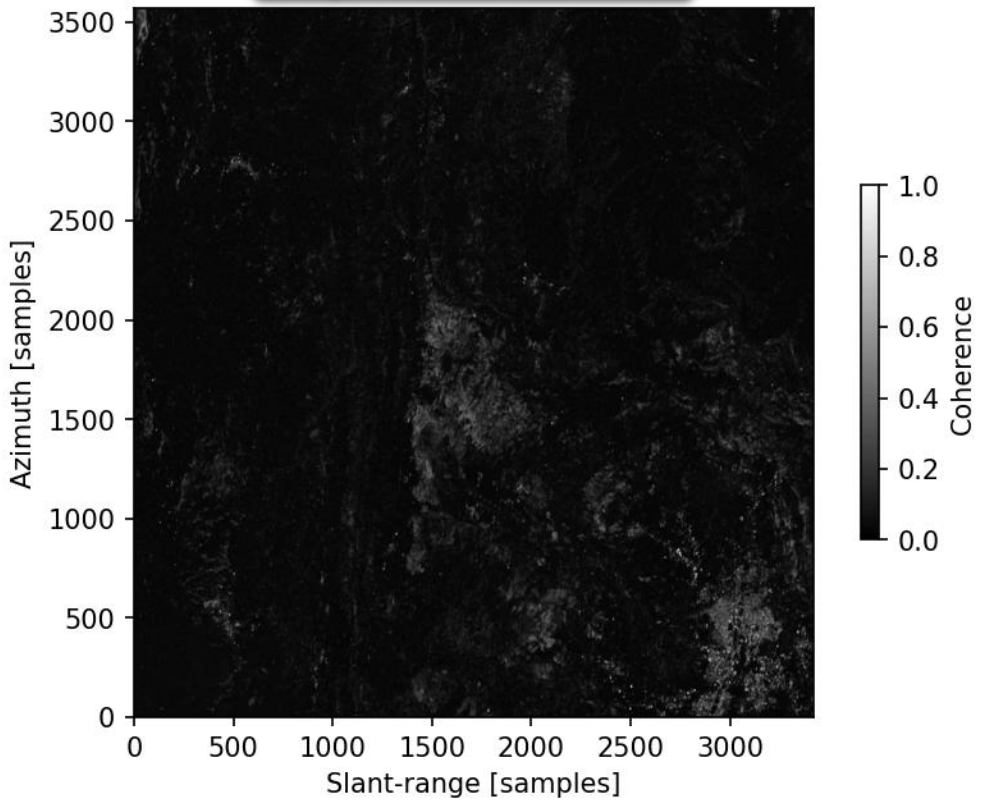
Rotated North Anatolian Fault — S1 Real Covariance

DLR

6-day coherence



5-year coherence

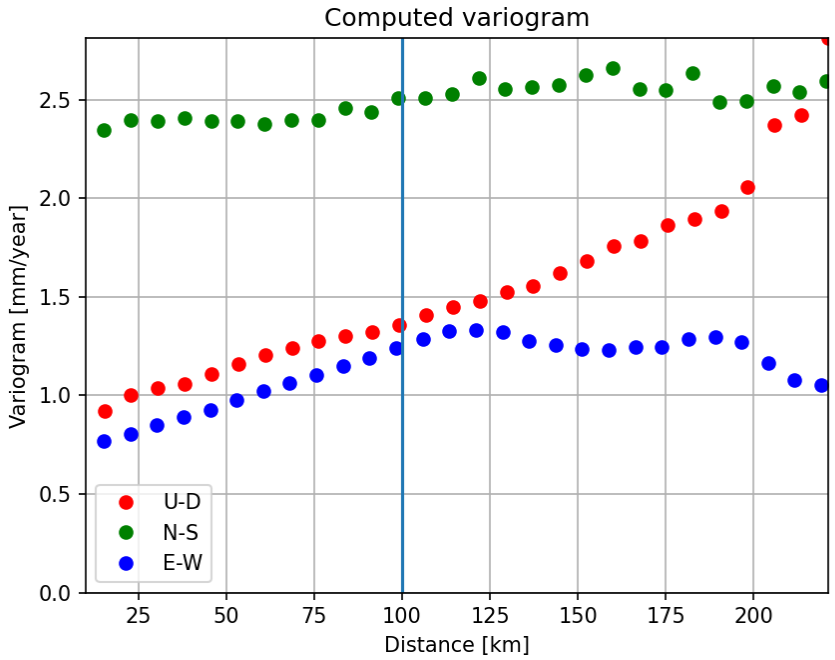


Time

Rotated North Anatolian Fault — S1 Real Covariance

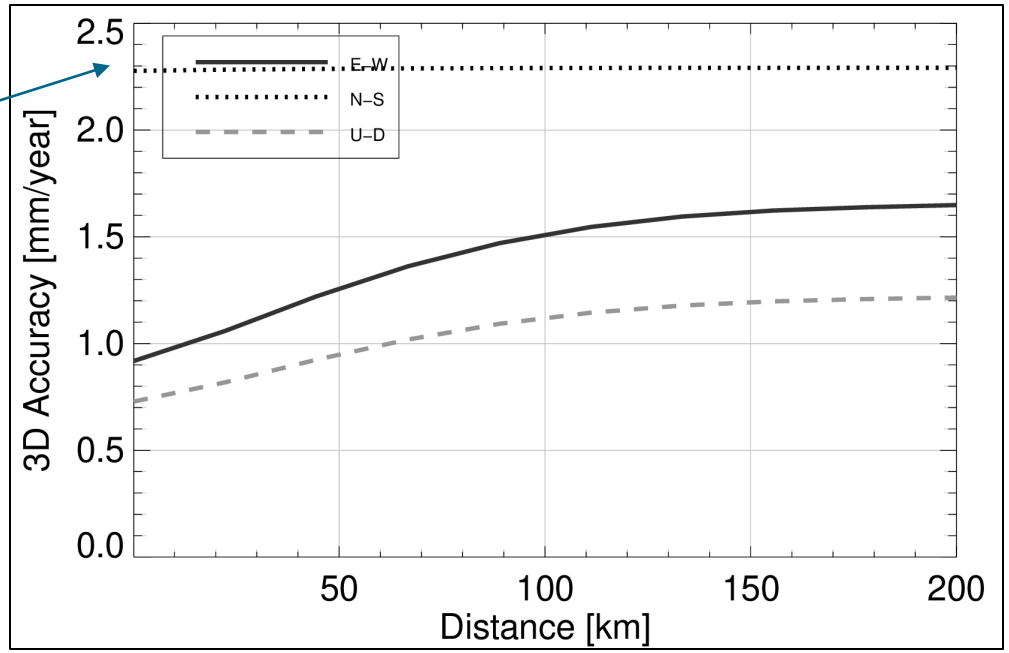
Time

End-to-End Simulation



Larger “noise” scaling for the N-S

Analytical Performance Model



Summary and Way Forward

- Good agreement between analytical performance models and end-to-end simulations
- Goal requirements are met. On the other hand:
  - Assumptions
  - Challenging in some scenarios
- HEEPS/Terra Simulator(s) to be further extended during the next phases of the Harmony mission in order to improve the performance prediction and consolidate the L1/L2/L3 processing and calibration algorithms

Additional Information

- More details on HEEPS/Terra can be found at the User Consultation Meeting portal (Report for Mission Selection and UCM slides)

https://atpi.eventsair.com/ucm-2022/ucm-doc