Reducing the Parallax Effect in Sentinel-2 Data Through Enhanced Atmospheric Correction with Per-Pixel Angular Input

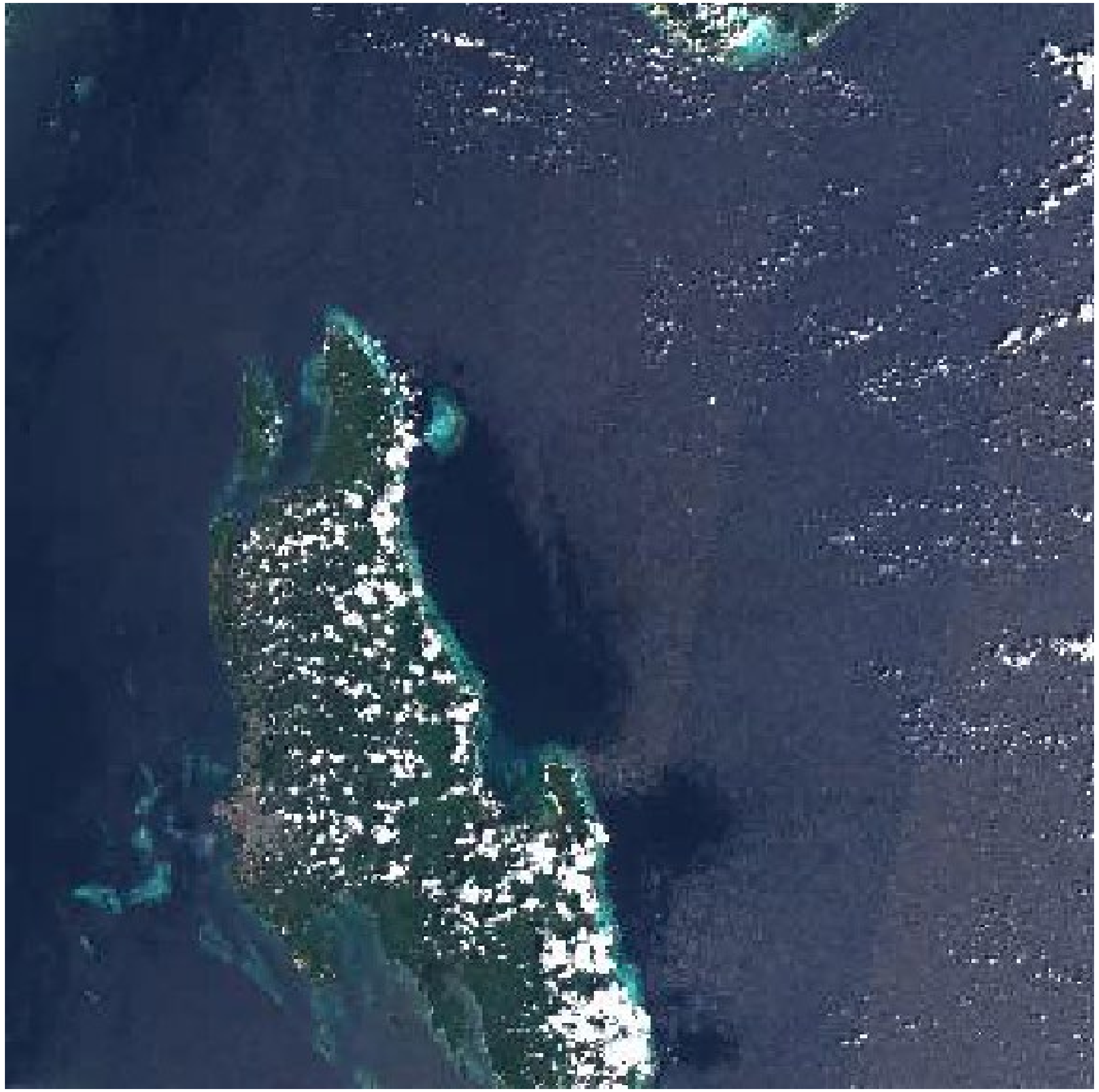
Celina Riegel (Department Imaging Spectroscopy / EOC / DLR)
Contact: Celina.Riegel@dlr.de

7th Sentinel-2 Validation Team Meeting 13 – 15 October 2025 @ ESA-ESRIN

DLR

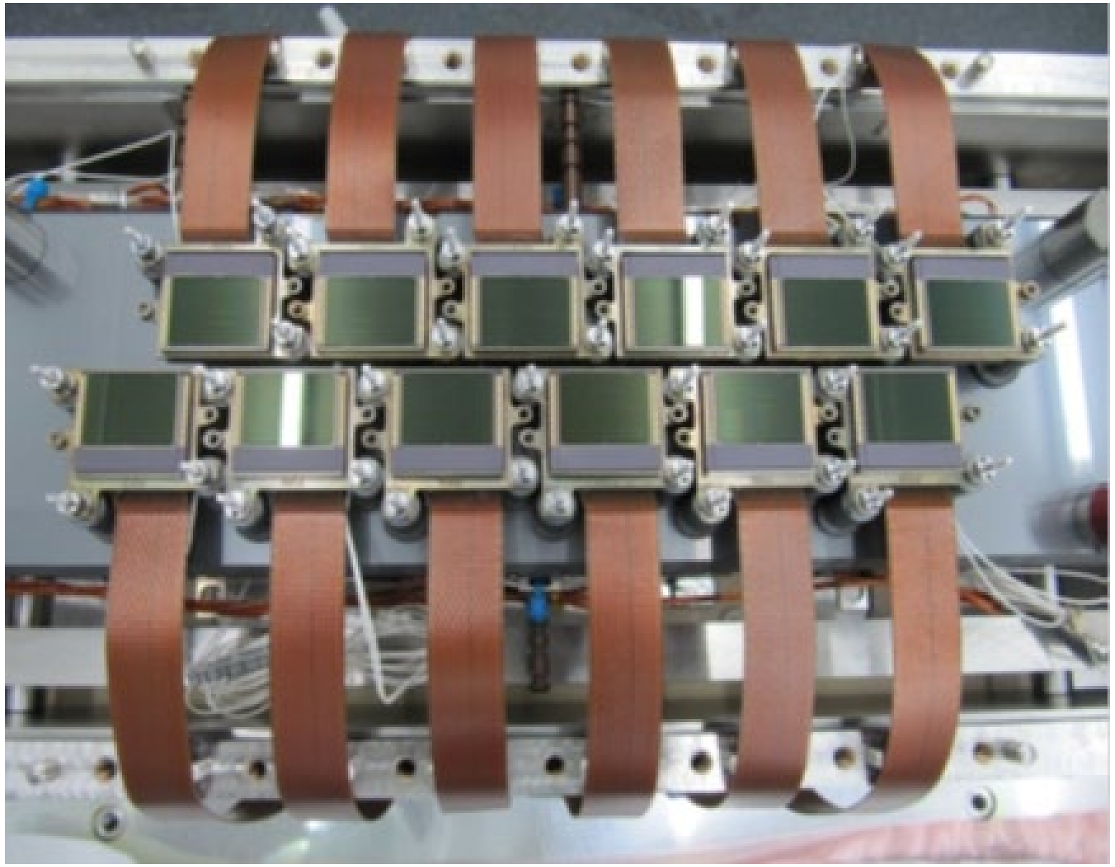
Striping Artifacts in Sentinel-2 Scenes

- Sentinel-2: key mission for aquatic remote sensing
- Aquatic surfaces → low reflectance, high sensitivity
- Atmospheric correction crucial for reliable BOA reflectance
- Problem: striping artifacts in L2A products
- Especially strong in sunglint areas



The Parallax Effect in Sentinel-2

- Two-row detector layout → alternating viewing geometries
- Causes subtle angular differences between detectors



https://sentiwiki.copernicus.eu/web/s2-mission

The Parallax Effect in Sentinel-2

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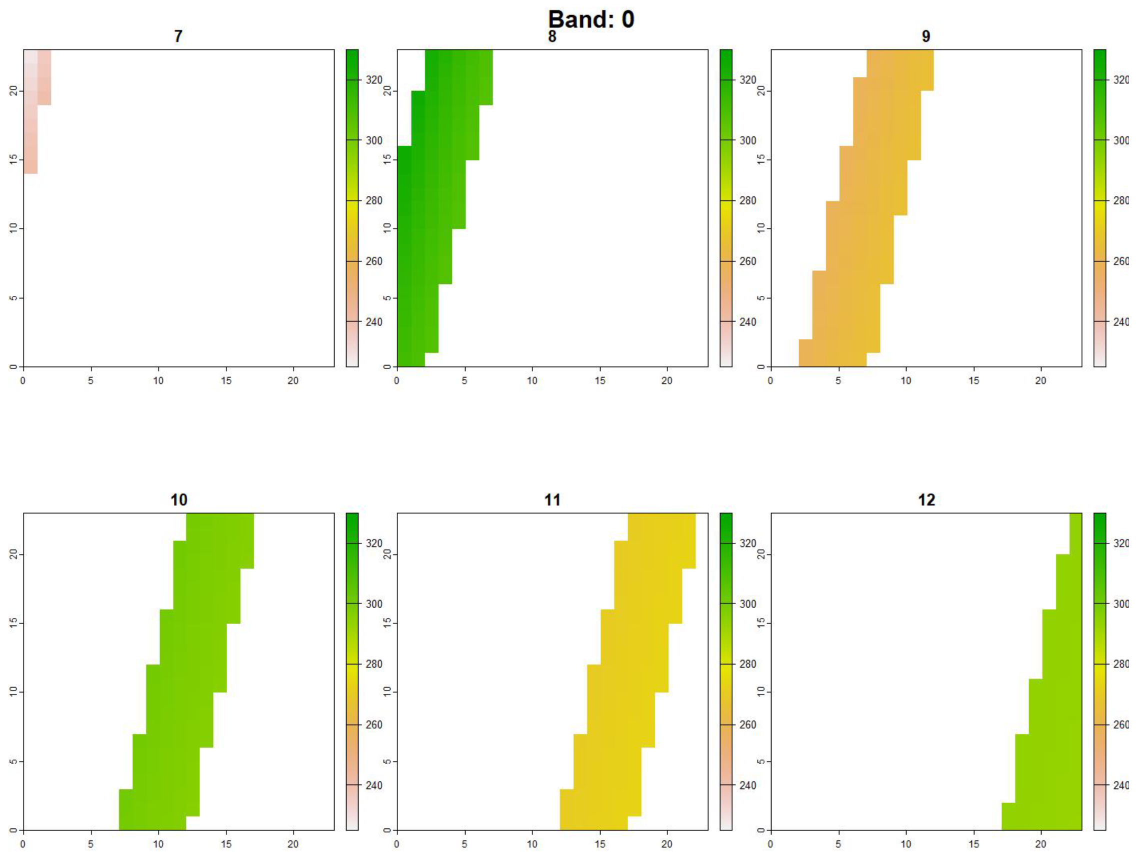
- Causes subtle angular differences between detectors
- Striping correlates with viewing azimuth angles (vaa)

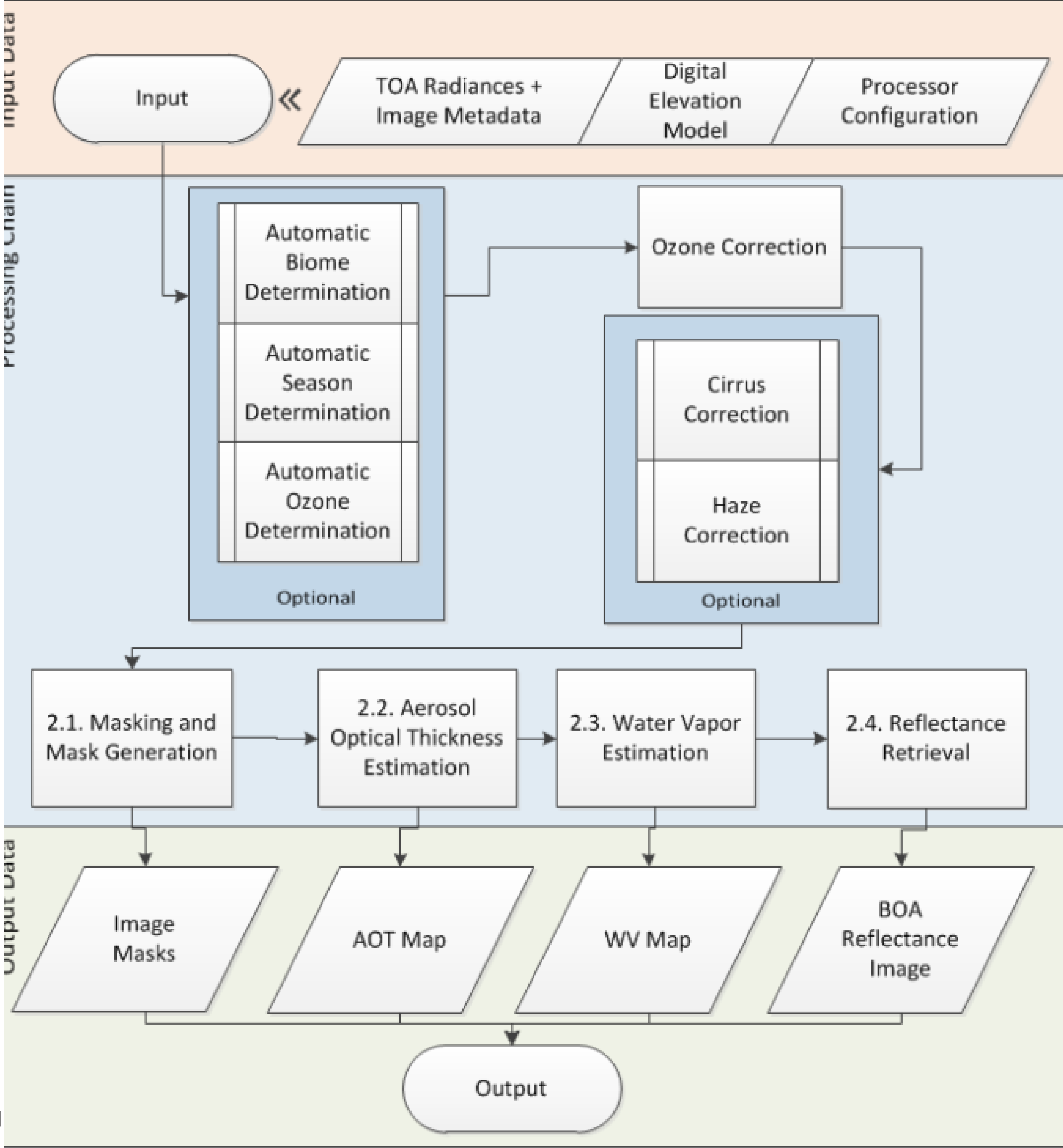


Atmospheric Correction with PACO

- Internal data model storing all relevant parametrization:
  - L1B (sensor geometry)
  - L1C (ortho-rectified)
  - DEM (Digital Elevation Model) (rugged-terrain)
- Output product:
  - **BOA reflectance**
  - Masks: (clouds, haze, land, water,..)
  - Aerosol Optical Thickness (AOT) map
  - Water Vapor (WV) map
  - …….
- Atmospheric correction functionalities
  - Masking -> masks
  - AOT estimation (DDV based) -> AOT
  - WV estimation -> WV
  - Rugged / Flat-terrain AC -> BOA reflectance
- Additional (user options):
  - De-cirrus
  - De-haze

- Smile-aware AC possible
- Per scene, single scene processing

Source: de Los Reyes, R., Langheinrich, M., Schwind, P., Richter, R., Pflug, B., Bachmann, M., ... & Reinartz, P. (2020). **PACO: Python-based atmospheric correction**. *Sensors*, *20*(5), 1428.



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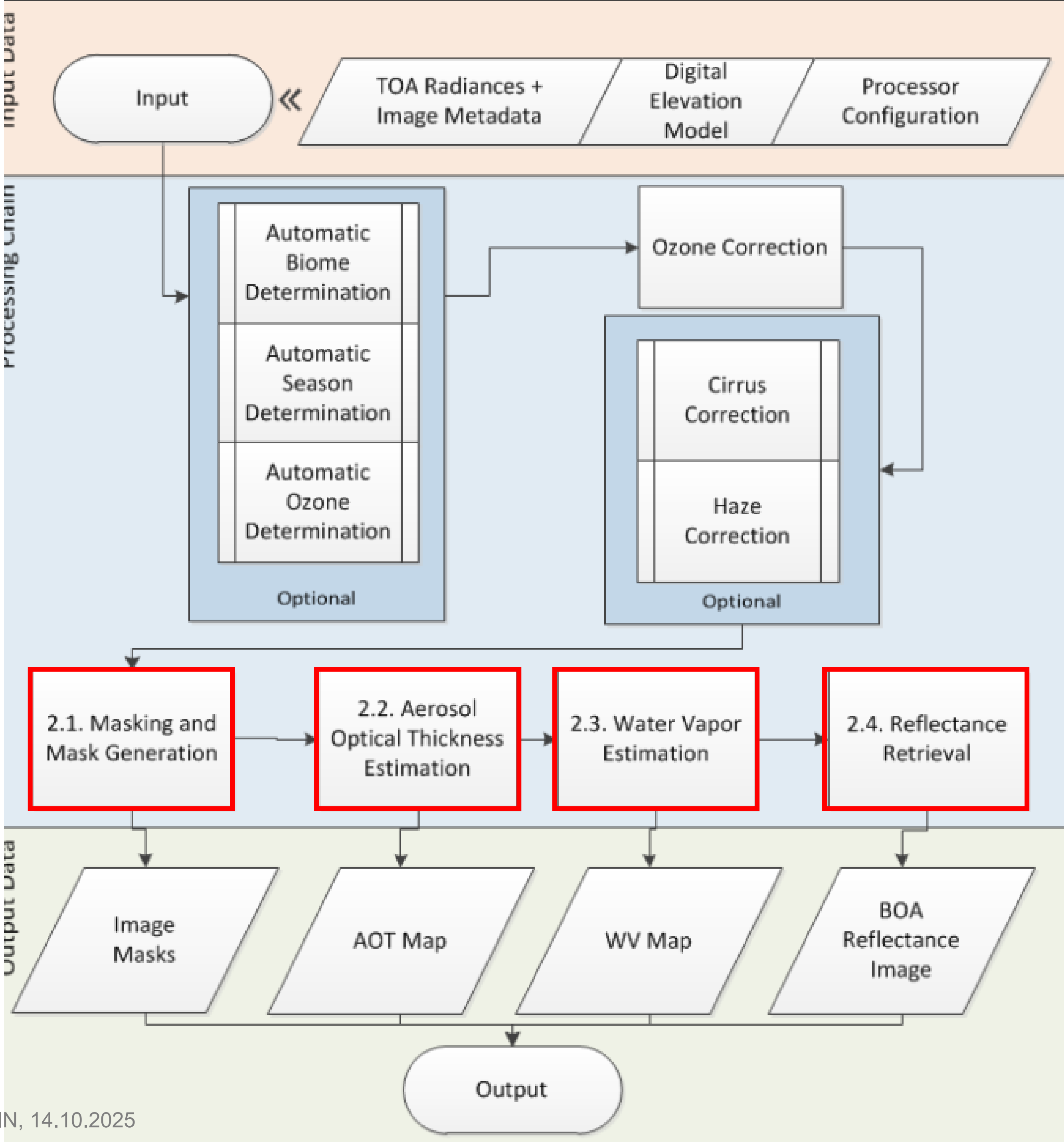

Atmospheric Correction with PACO

Atmospheric Look-up table (LUT)

Parameter / Bin	1	2	3	4	5	6	7	8
VIS [km]	5	7	10	15	23	40	80	120
SZA [deg]	0	10	20	30	40	50	60	70
RAA [def]	0	30	60	90	120	150	180	
ELE [km]	0	0.7	1.5	2.5	4.0			
VZA [def]	0	10	20	30	40			
WVC [cm] summer	0.4	1.0	2.0	2.9	4.0	5.0		
WVC [cm] winter	0.2	0.4	0.8	1.1				

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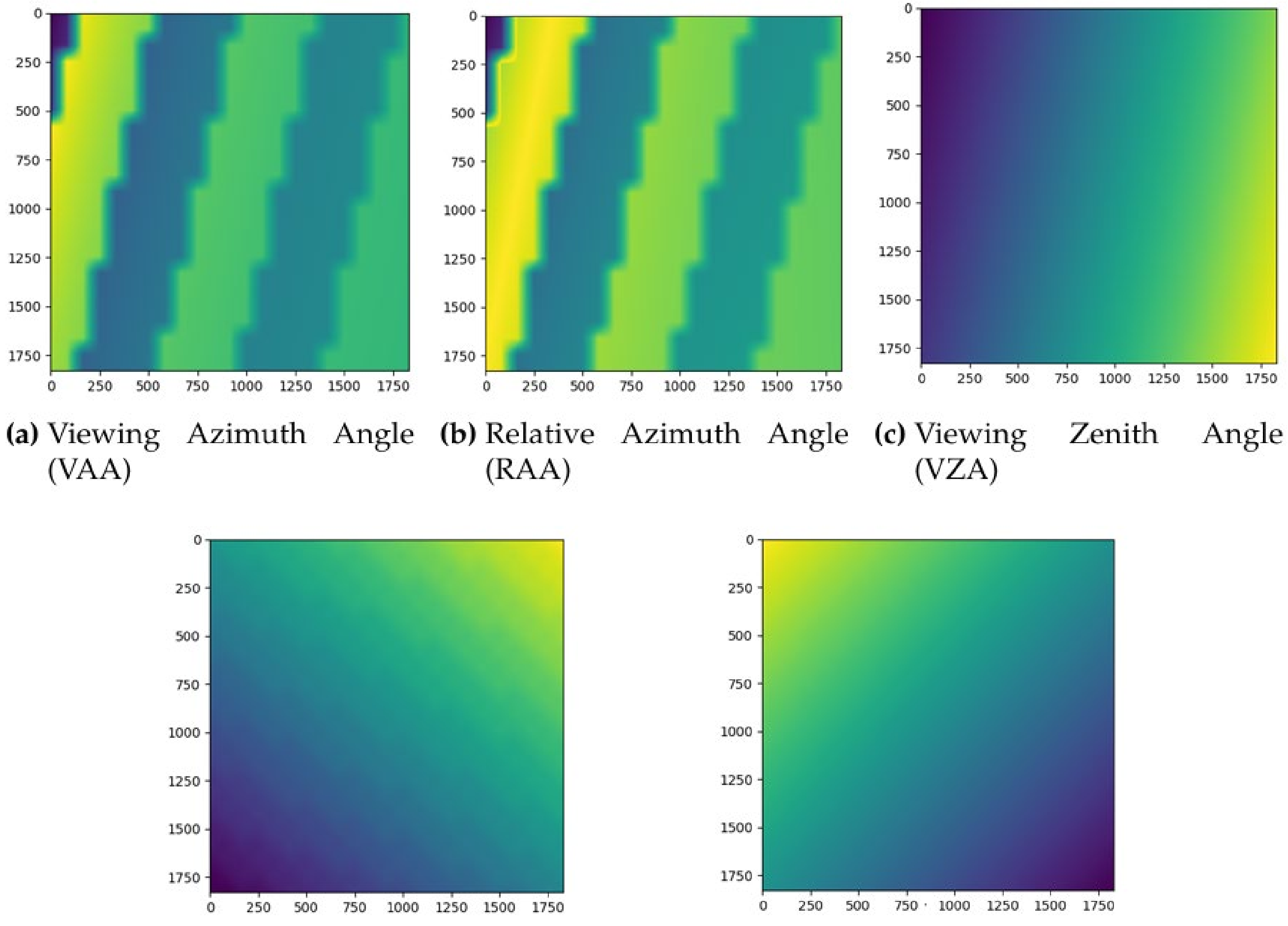
Previous Handling of Viewing Angles in PACO

Out of the box angle information implemented with certain limitations:

- Step-like artifacts visible in the VAA and RAA geometry
- AC up to now was only using mean scene angles for LUT interpolation

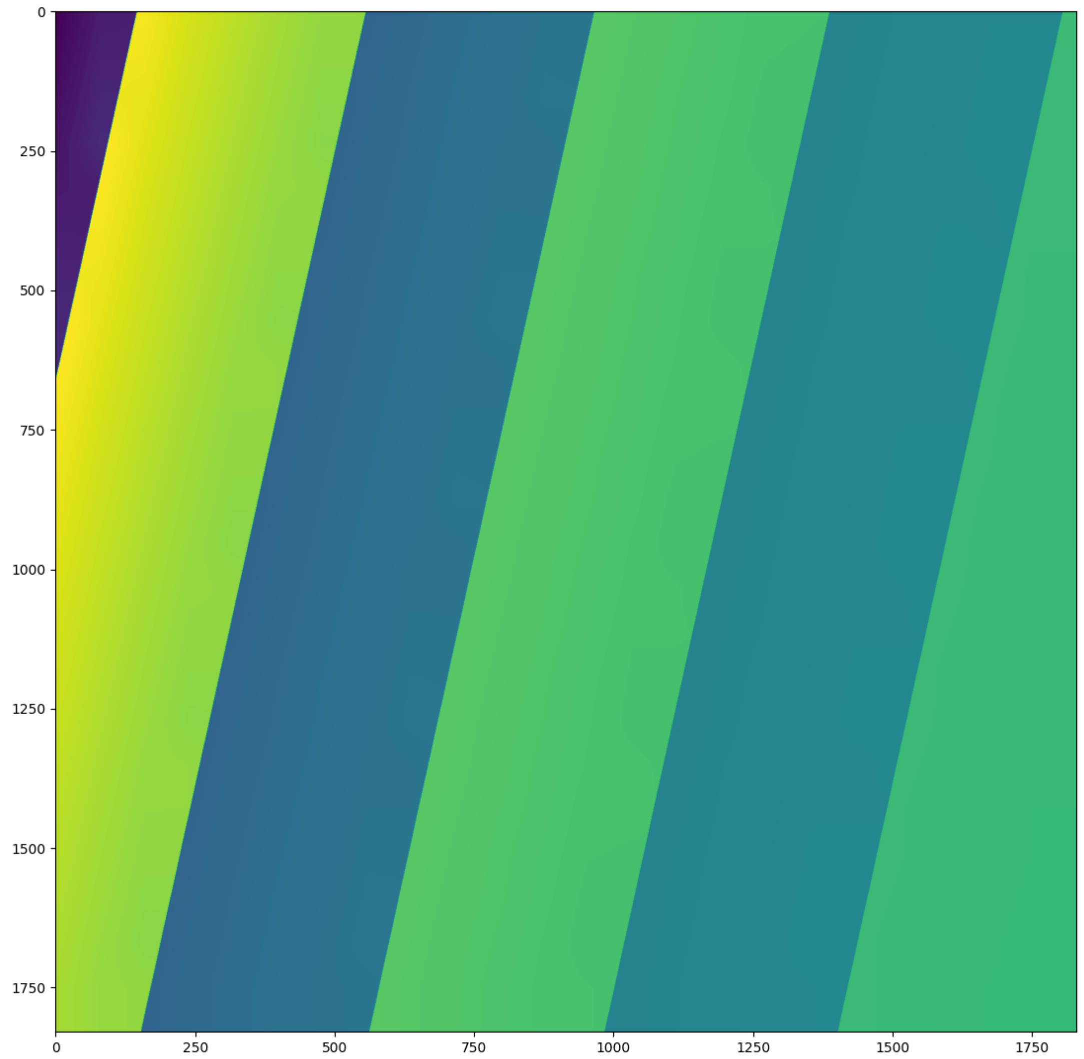


(a) Viewing Azimuth Angle (VAA) **(b)** Relative Azimuth Angle (RAA) **(c)** Viewing Zenith Angle (VZA)

(d) Solar Azimuth Angle (SAA) **(e)** Solar Zenith Angle (SZA)

Receiving the per-pixel angle values

1. Scale coarse angular metadata to band resolution
2. Map viewing angles to correct pixels based on detector map
3. Create high-resolution angle dataset



Method as provided in:

Alexis Deru et al. *"Sentinel-2 MSI Level-1 Radiometric Uncertainty Tool, status and application to tandem analysis. Presented at the session: Recent progress on uncertainty analysis for Earth Observation measurements – PART 1"*, Living Planet Symposium 2025. Hall N1/N2, Vienna, Austria, 27 June 2025.

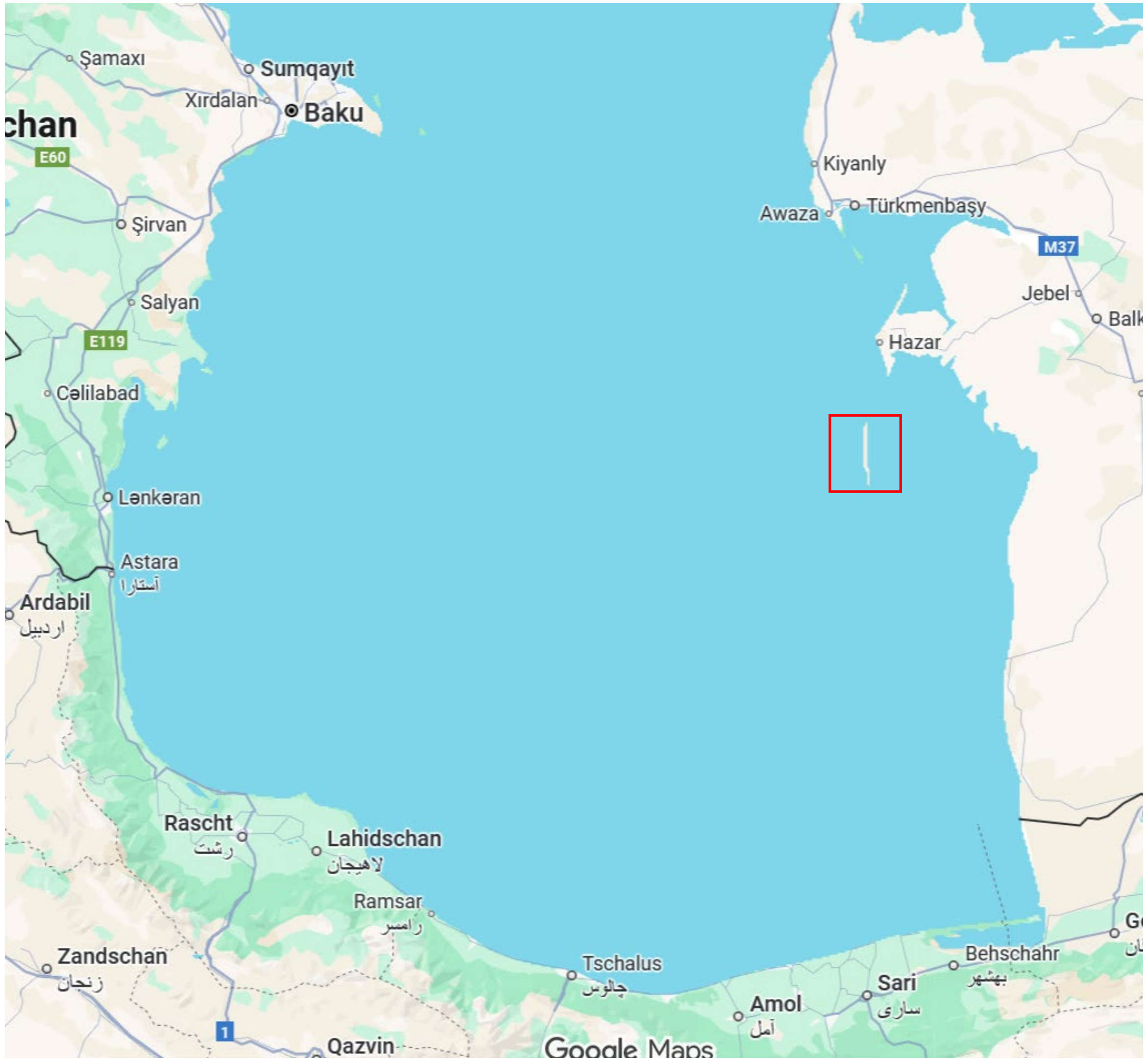
Validation of per-pixel angle processing

- Example:

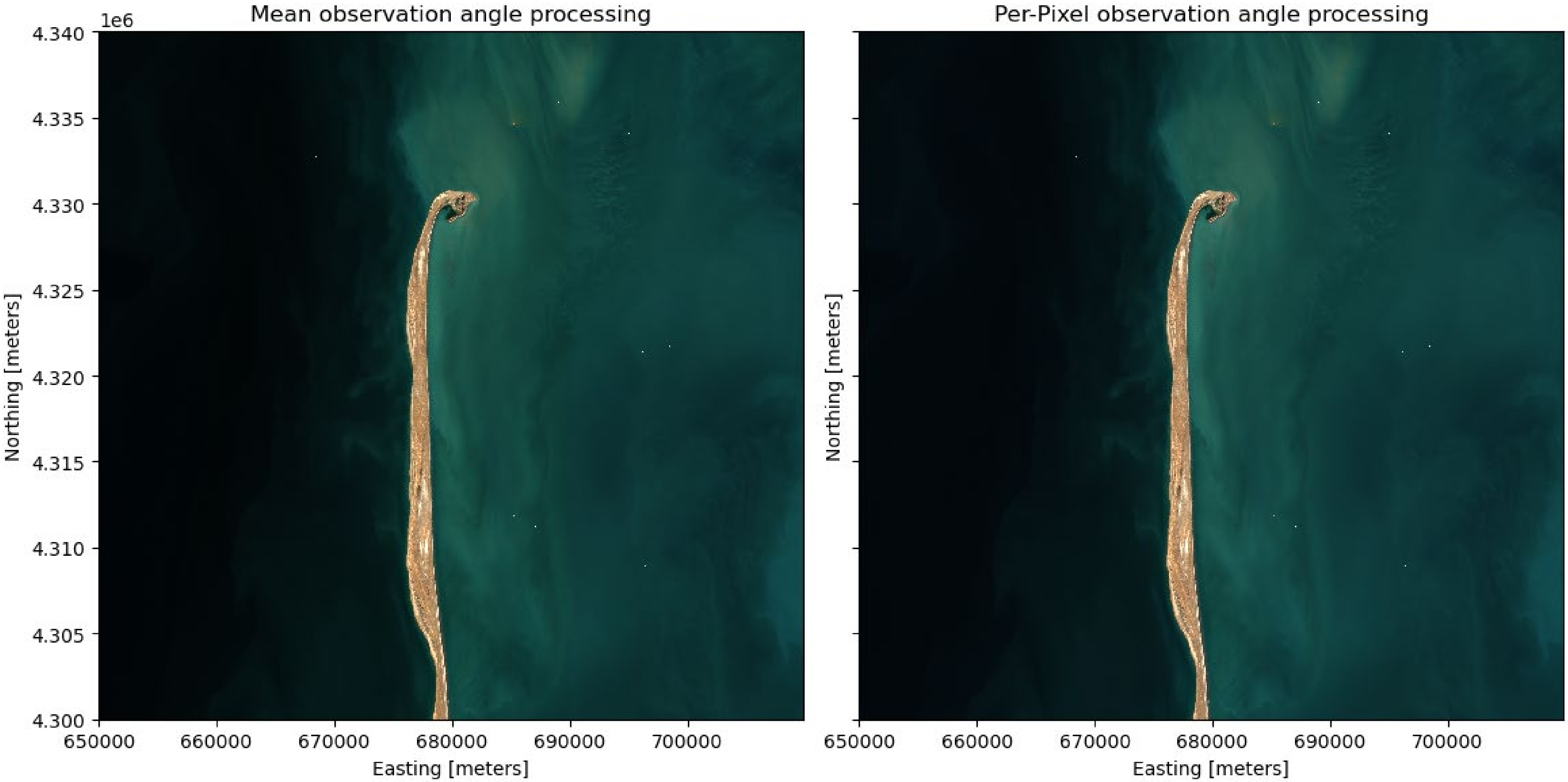
  Sentinel-2B scene
  East Caspian Sea 30 Oct 2018

  (S2B_MSIL1C_20181030T072019
  _N0500_R006_T39SXD)

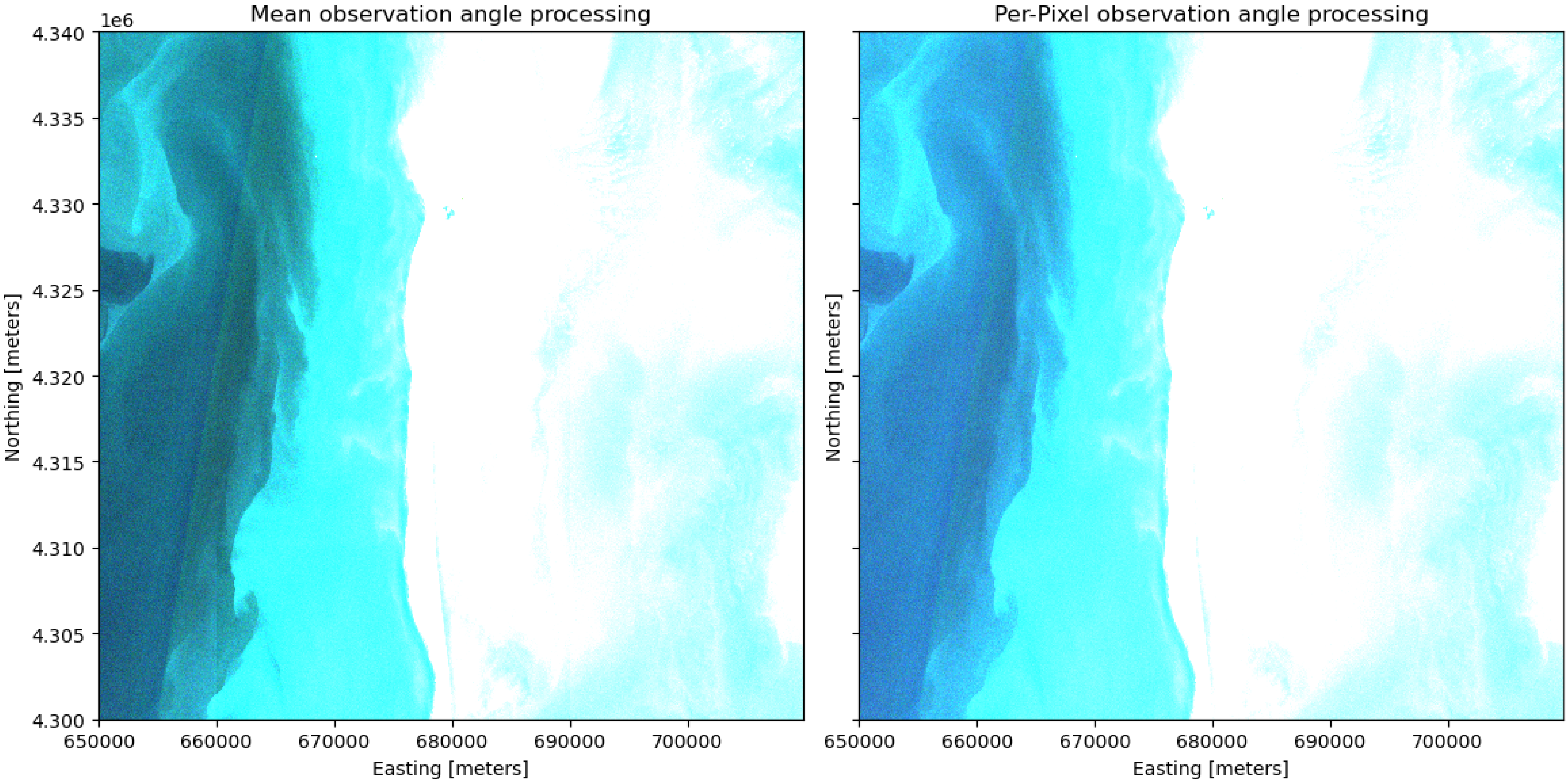
- Clear viewing conditions, no sun glint pollution



S2B L2A BOA reflectances



Validation: S2B L2A BOA reflectances



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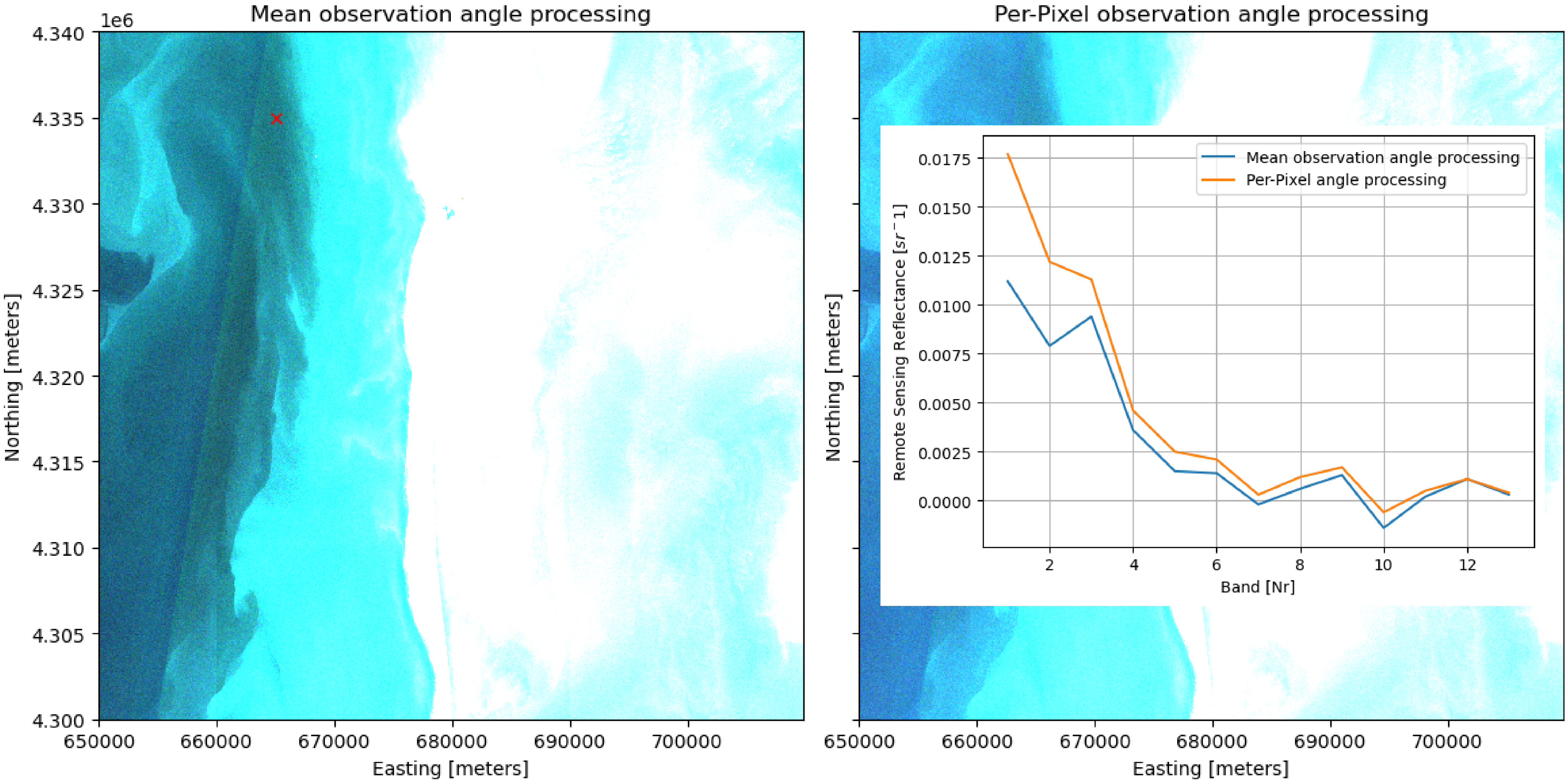


Validation of per-pixel processing on derived products

Two derived products were generated to evaluate the effect of the per-pixel observation geometry:

- Satellite derived bathymetry:

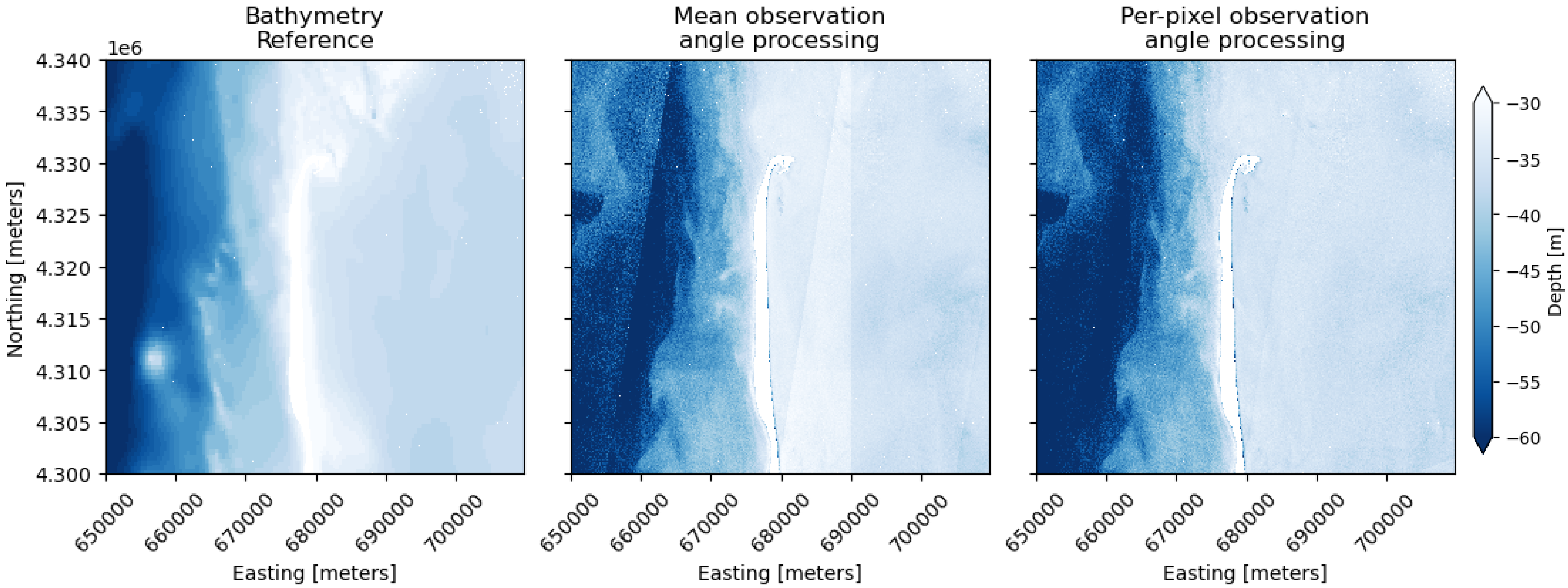
  David R. Lyzenga. “*Shallow-water bathymetry using combined lidar and passive multispectral scanner data*”. In: International Journal of Remote Sensing 6.1 (1985), pp. 115–125. DOI: 10 . 1080 / 01431168508948498.

  N. Thomas et al. “*Space-Borne Cloud-Native Satellite-Derived Bathymetry (SDB) Models Using ICESat-2 And Sentinel-2*”. In: Geophysical Research Letters 48 (2021), e2020GL092170. DOI: 10.1029/2020GL092170. URL: https: //doi.org/10.1029/2020GL092170

- Random Forest Classification (of seagrass):

  Alina Blume et al. “*Bahamian seagrass extent and blue carbon accounting using Earth Observation*”. In: Frontiers in Marine Science 10 (2023), p. 1058460. DOI: 10.3389/fmars.2023.1058460. URL: https://doi.org/10.3389/ fmars.2023.1058460

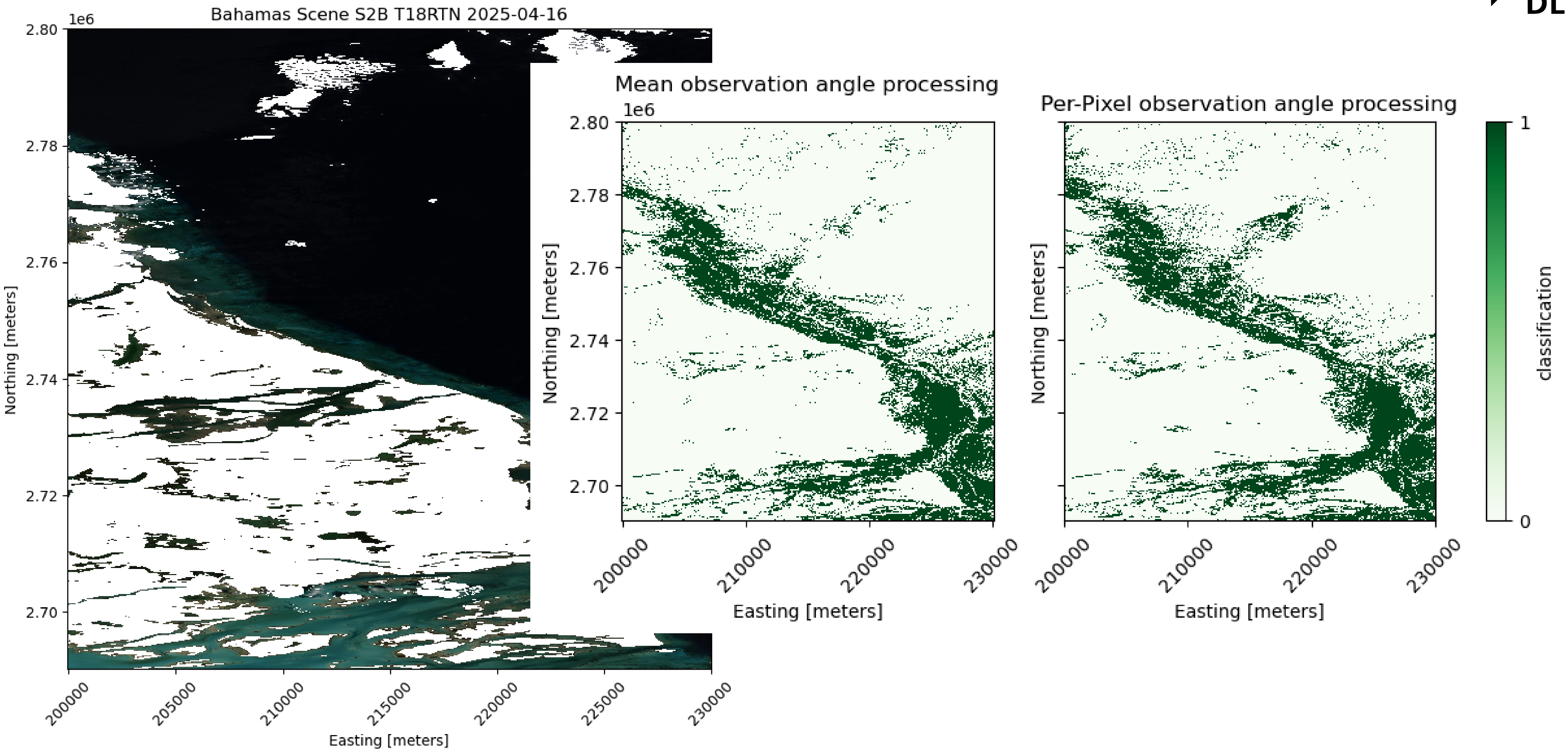
Validation: Satellite-Derived Bathymetry Results



Validation: Satellite-Derived Bathymetry Results

Scene	RMSE		MAE		R^2	
	before	after	before	after	before	after
S2A_T18RTN_20250314	2.07	2.06	1.16	1.15	0.588	0.591
S2B_T18RTN_20250416	1.99	1.99	1.22	1.21	0.559	0.563
S2A_T54LYN_20241015	4.43	4.43	3.56	3.52	0.611	0.623
S2B_T17TLK_20240406	3.37	3.35	2.72	2.68	0.726	0.730
S2B_T17TLK_20241020	3.62	3.74	2.92	3.00	0.66	0.636
S2B_T31SBD_20231226	4.17	4.12	3.26	3.18	0.715	0.728
S2B_T37MEP_20230617	5.72	5.61	4.76	4.67	0.236	0.242
S2A_T39SXD_20230809	3.14	3.09	2.51	2.43	0.732	0.742
S2B_T39SXD_20230730	2.86	2.79	2.28	2.17	0.773	0.784

Validation: Seagrass classification



Validation: Seagrass Classification

Scene	OA		K		PA		UA	
	before	after	before	after	before	after	before	after
S2A_T18RTN_20250314	0.905	0.901	0.635	0.617	0.736	0.729	0.652	0.629
S2B_T18RTN_20250416	0.906	0.903	0.627	0.619	0.758	0.737	0.618	0.624
S2A_T54LYN_20241015	0.999	0.999	0.400	0.666	1.000	1.000	0.250	0.500
S2B_T30UWU_20230625	0.930	0.937	0.531	0.608	0.700	0.703	0.477	0.591
S2B_T31SBD_20231226	0.980	0.981	0.419	0.465	0.636	0.643	0.280	0.375
S2B_T37MEP_20230617	0.993	0.992	0.368	0.354	0.833	0.714	0.238	0.238

Conclusions

Conclusions:

- Thought small, improvements regarding the parallax effect of S2 data can be seen after applying per-pixel observation angles during radiative transfer calculations.
- Bathymetry: Relies mainly on water colour (of clear water), therefore improvements to the retrieved reflectance (in particular blue wavlengths) improve depth estimation.
- Seagrass classification: No improvement detectable. Features learned by RF most likely do not rely as strongly on the improvements in the blue wavelengths.

Outlook

Outlook:

- Quantitative validation ongoing:
  - Analysis on results regarding sunglint correction (WASI)
- Applicable to other sensors:
  - PACO is a multi-sensor algorithms that uses common AC modules for processing.
  - i.e. Implementation in CHIME L2 OSL for hyperspectral processing (Presentation @ WHISPERS 2025 in Barcelona)

Thank you for your attention!
(from Botswana!)