The Arcachon Bay

A coastal laboratory for unlocking SWOT’s topographic potential

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The Arcachon Bay

A meso-tidal system

- A shallow, semi-confined lagoon located on the French Atlantic coast.

- The system is mesotidal, characterized by a semi-diurnal cycle with a wide amplitude, ranging from 0.8 m (neap) to 4.6 m (spring).

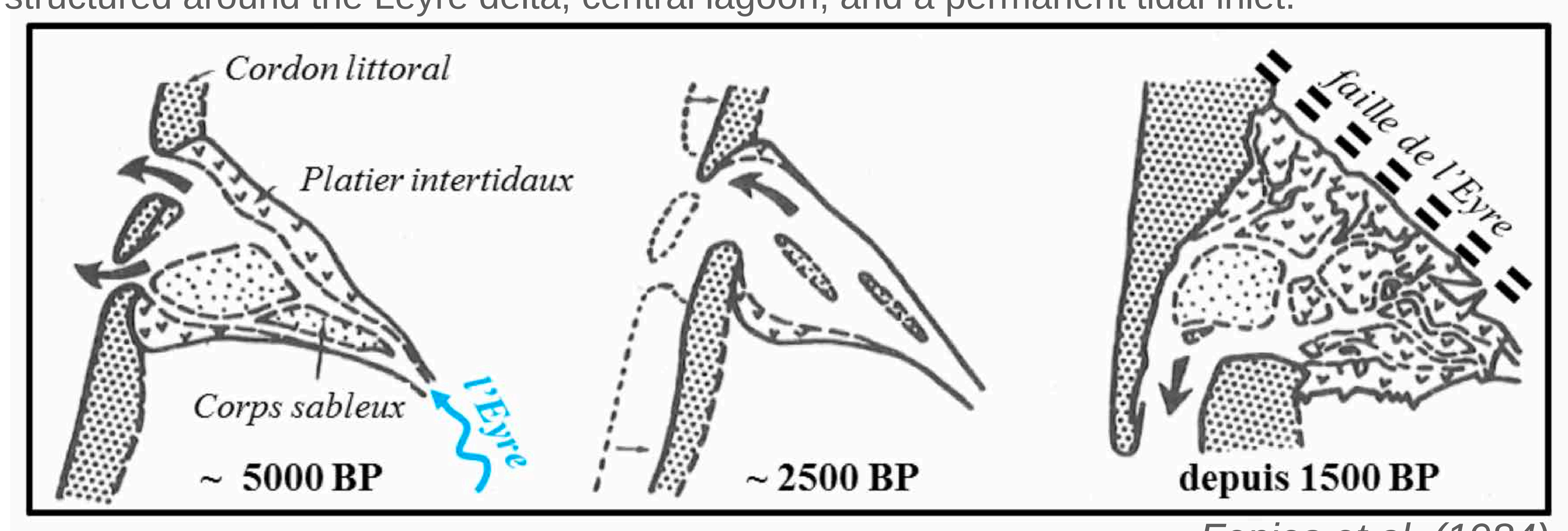
- Vast Intertidal Zone: approximately 65% of the total surface area (~117 km^2) emerges at low tide.

- The bay connects to the ocean via a highly dynamic, 3-km wide inlet, controlled by the Cap Ferret sand spit and a large ebb delta.

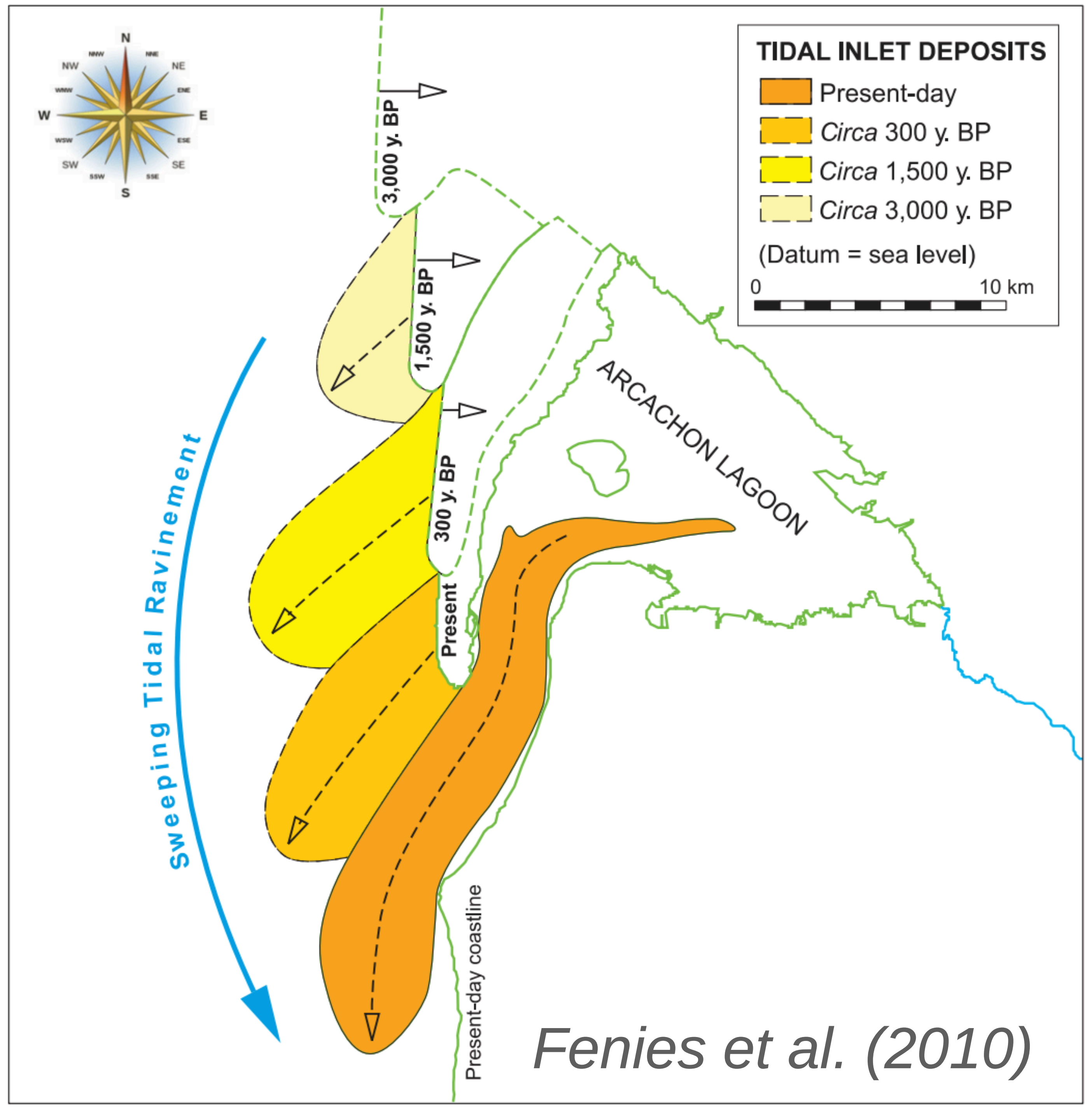
Geological Evolution

From incised valley to lagoon

- Origin: The basin began as the Leyre River estuary, carved into a northwest valley during a low sea level linked to regional tectonics.
- Marine Transgression: Rising seas then flooded the valley, forming an estuary.
- Cap Ferret Formation: About 3,000 years ago, as sea-level rise slowed, the Cap Ferret sand spit started developing on the estuary’s north bank.
- Modern Morphology: The spit’s growth and estuary infilling during the late Holocene shaped today’s meso-tidal lagoon.
- Inlet Perpetuity: Unlike nearby coastal lakes, the large valley and regional subsidence maintained strong tidal exchanges, keeping the inlet open.
- Current State: Arcachon Bay is now a wave-dominated estuary, barred by the Cap Ferret spit, and structured around the Leyre delta, central lagoon, and a permanent tidal inlet.



Fenies et al. (1984)



Fenies et al. (2010)

Current Situation

Current sedimentary dynamics and key geomorphic entities

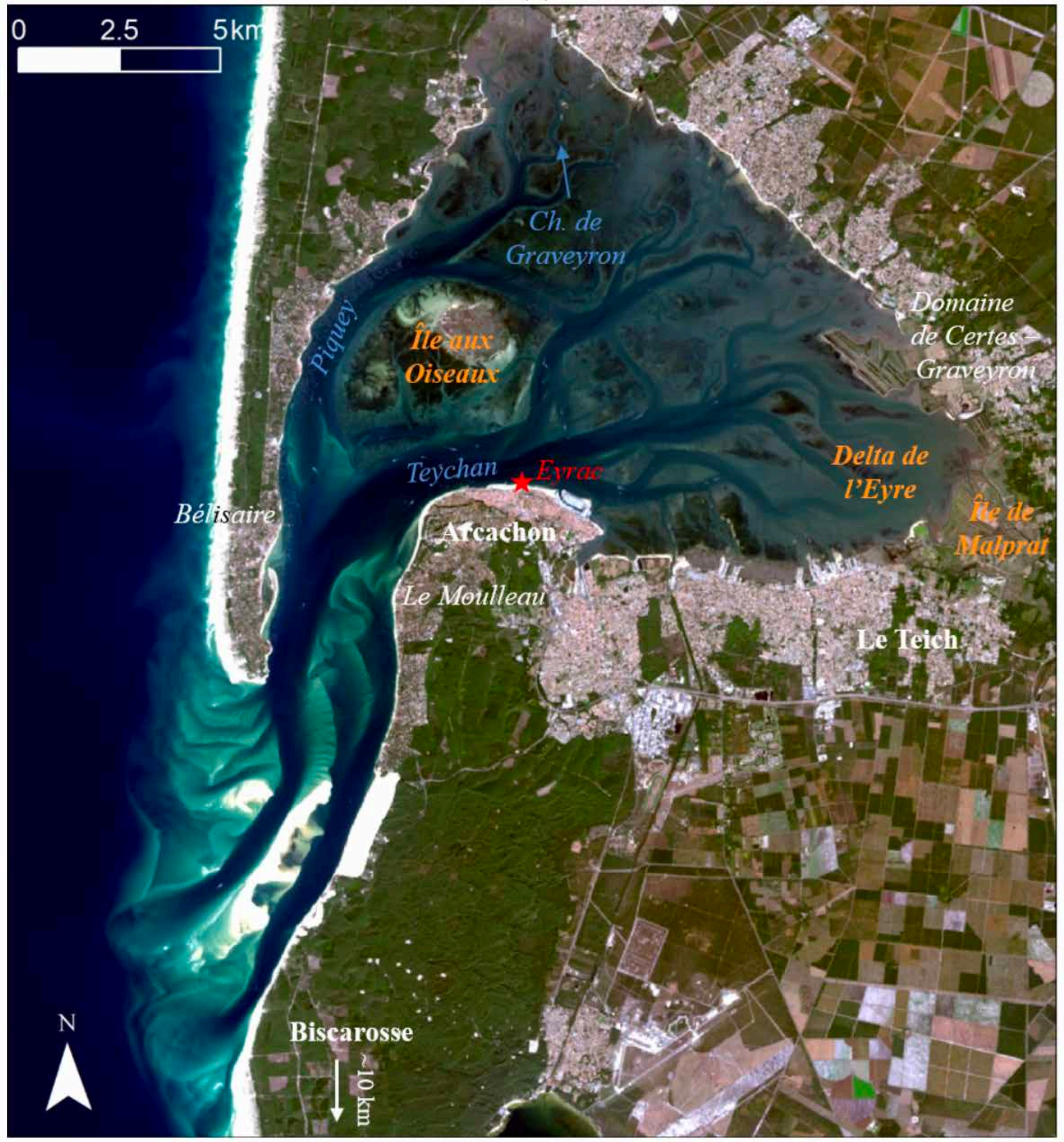
- Central Stability: The contours of the internal channels, including the two major axes (Piquey and Teychan) have remained largely stable over the last 200 years (since 1826).

- Key Geomorphic Features: The current morphology includes the accreting Eyre Delta and the Île aux Oiseaux.

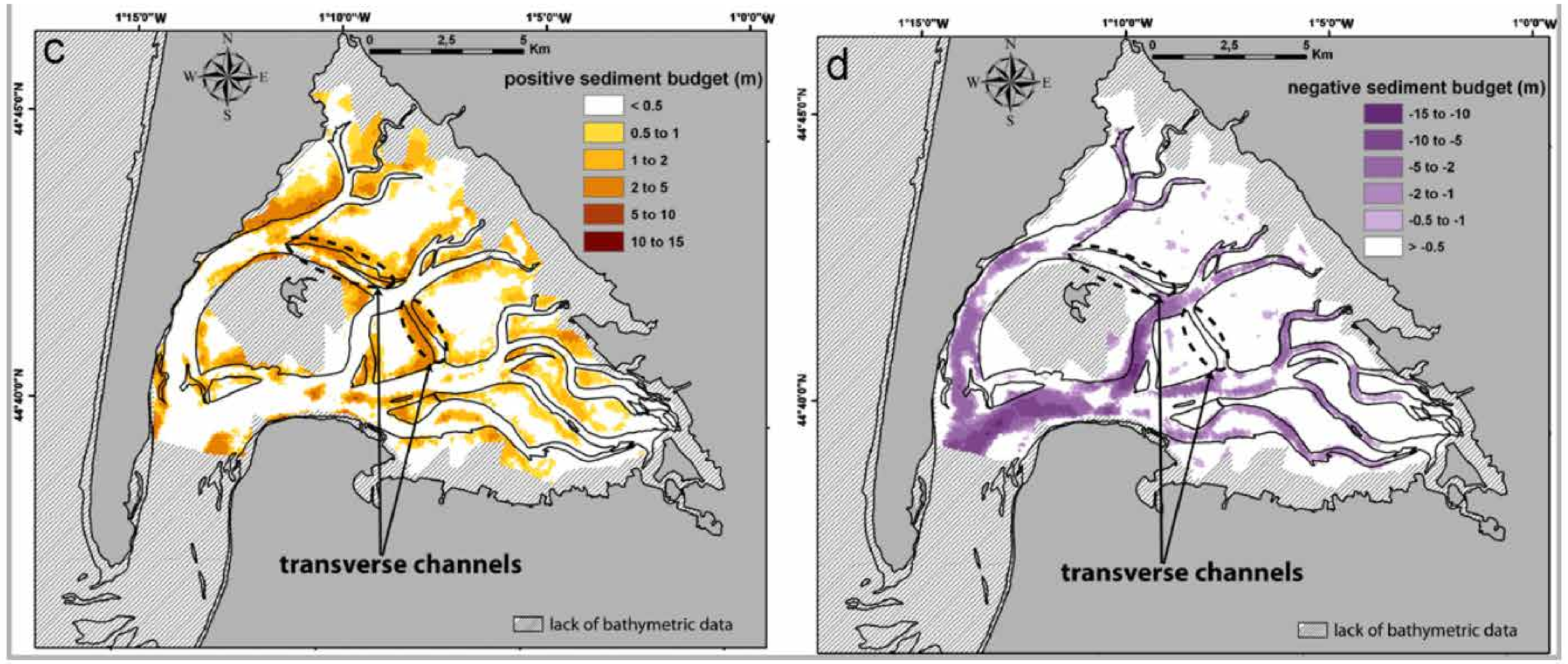
- Despite long-term stability, bathymetric analysis (1865–2001) shows a slight net sediment deficit (erosion of ≈9.9×10^6 m^3 over 136 years), suggesting the lagoon acts as a slight sediment source for the adjacent coast.

- This slight deficit results from a constant balance of processes: deep main channels (ebb-dominated) are eroding, while the wide intertidal flats and transverse channels are experiencing accretion (due to weak or flood-dominated currents).

- Morphological Trend: Over the past century, the internal channel network has gradually simplified, with transverse channels closing.



Nahon et al. (2018)

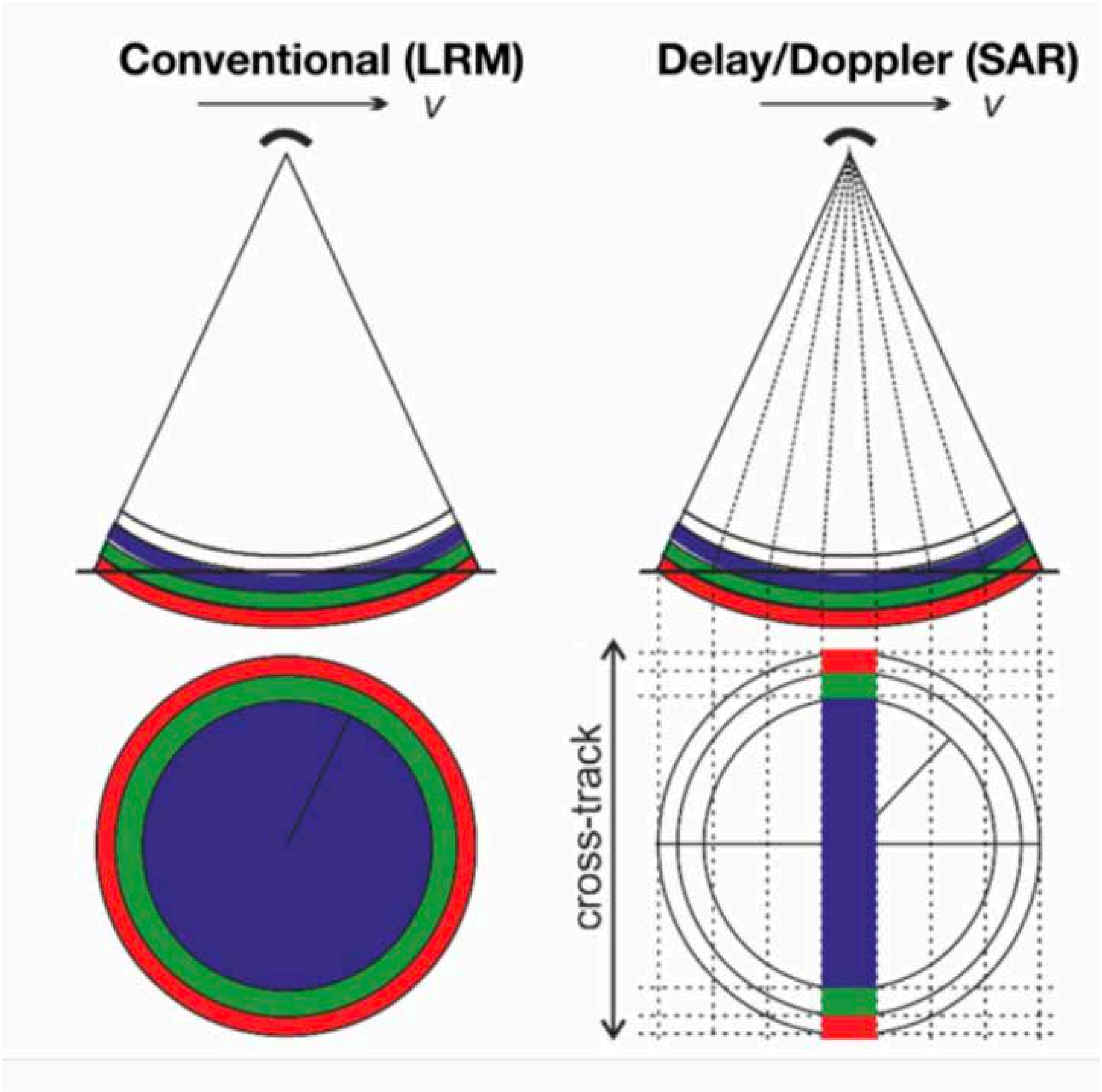


Allard et al. (2009)

Satellites: the only viable tool

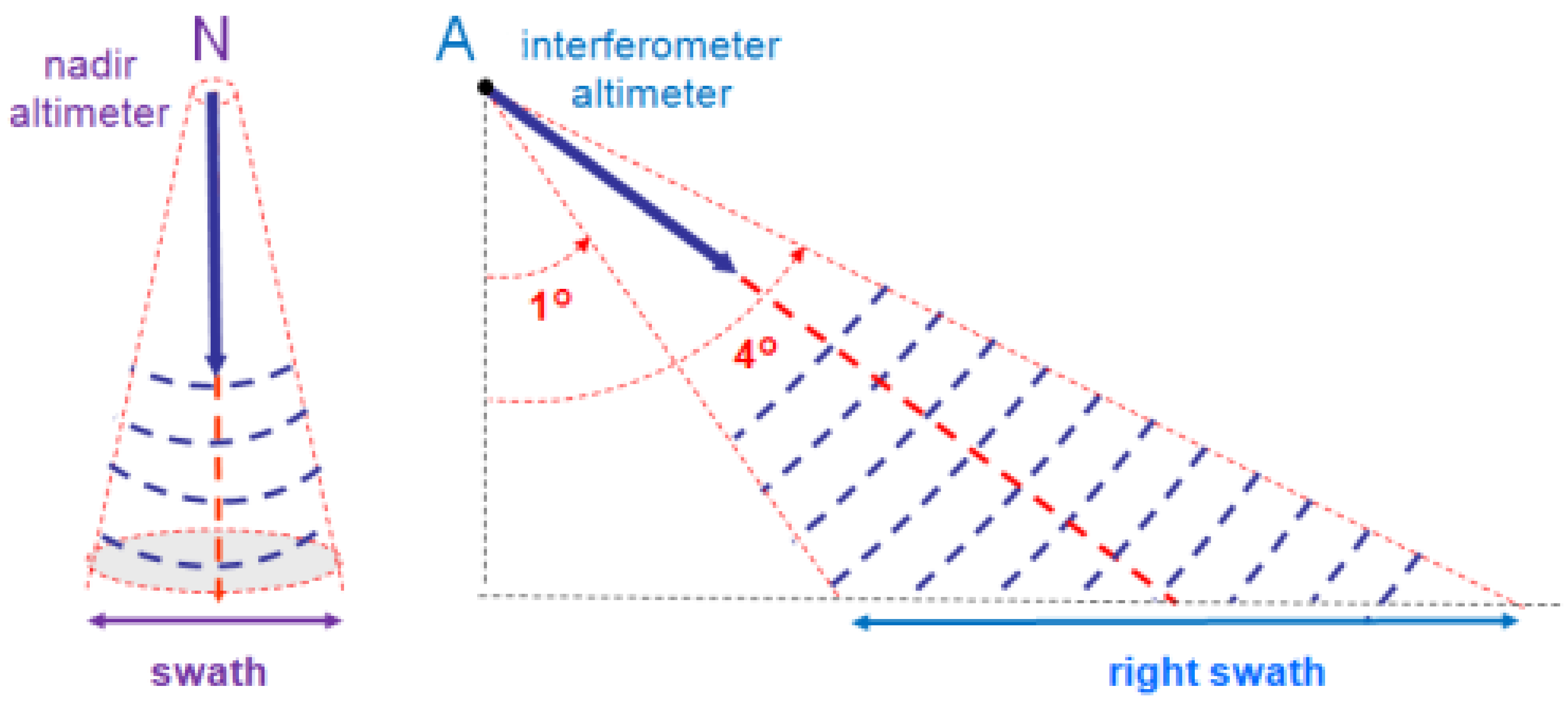
Overcoming logistical and temporal gaps in intertidal topography monitoring

- The scale and complexity of the Arcachon Basin make monitoring its dynamics impossible using conventional methods.
- Traditional ground, ship-borne, and airborne methods (LiDAR/echo sounders) are logistically complex and cost-prohibitive for a frequent mapping.
- Static DEMs rapidly become obsolete restricting the detection of volume changes (erosion/accretion).
- Successful monitoring requires a continuous, synoptic spaceborne solution.
- The most immediate approach was to adapt existing satellite **nadir radar altimetry**, an instrument of **direct elevation** observation, to prove the feasibility of measuring exposed terrain, laying the foundation for future **2D mapping missions like SWOT**.



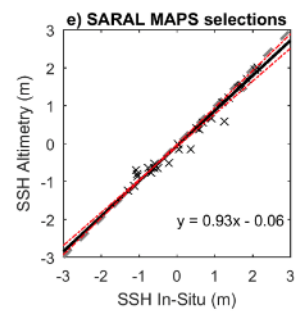
LRM (Low Resolution Mode): Early missions limited by large, contaminating footprints.

SAR Mode / Ka-band (InSAR): Later missions utilized specialized processing (SAR) and shorter wavelengths (Ka-band) to achieve a smaller measurement footprint and improve 1D data quality.

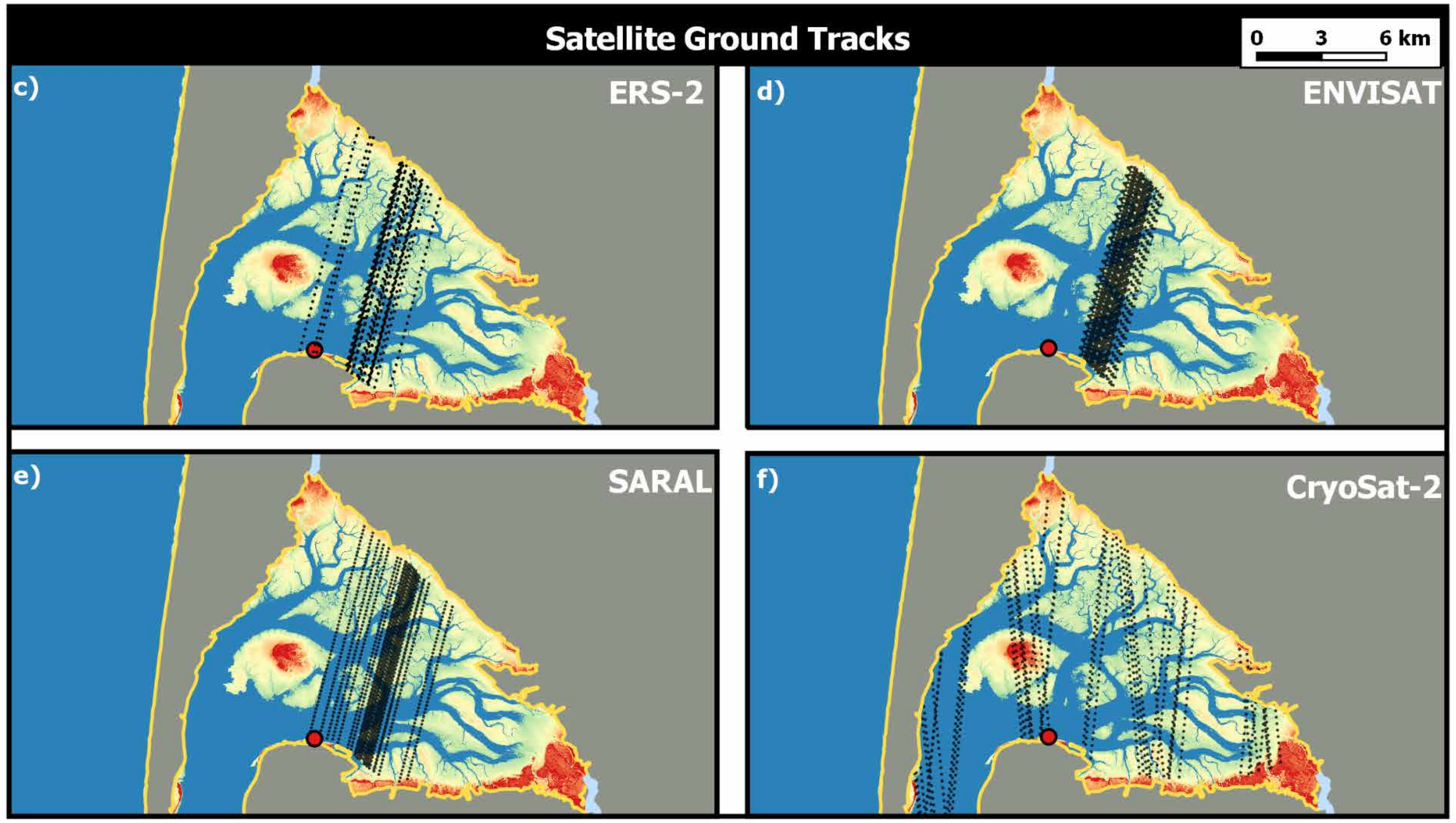


Extracting 1D Topography Profiles

Nadir radar altimetry



A first study conducted in Arcachon successfully demonstrated that nadir altimeters (SARAL, CryoSat-2) can retrieve intertidal bed elevation profiles, not just Sea Surface Height (SSH), during low tide cycles.



Salameh et al. (2018)

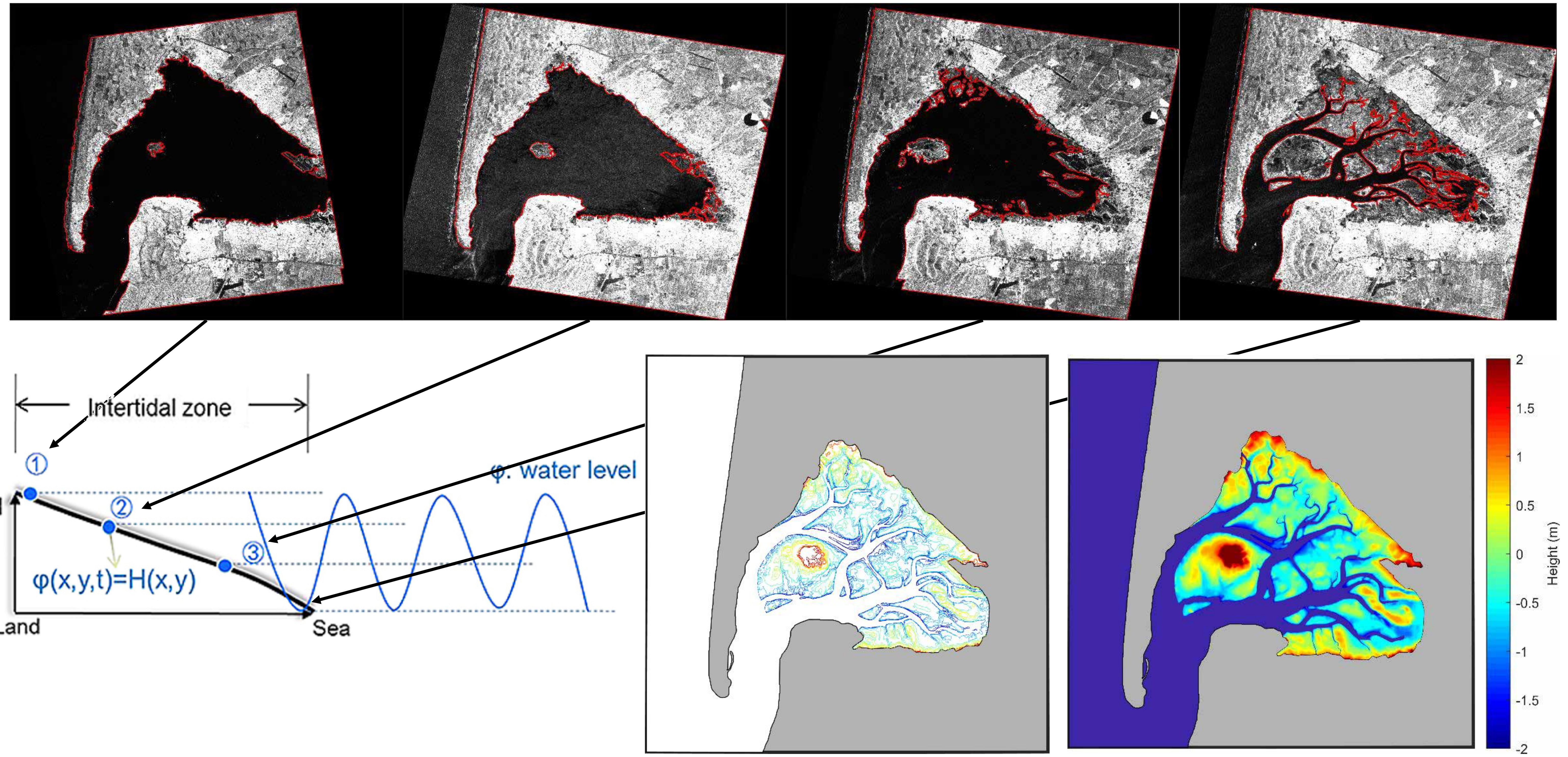
- The reduced footprint of the Ka-band (SARAL) and the enhanced processing of the SAR mode (CryoSat-2) improved measurement quality in coastal areas.
- Profiles were validated against local LiDAR surveys, achieving robust 1D vertical accuracy with RMSE <0.44 m and a high correlation (R≈0.79).

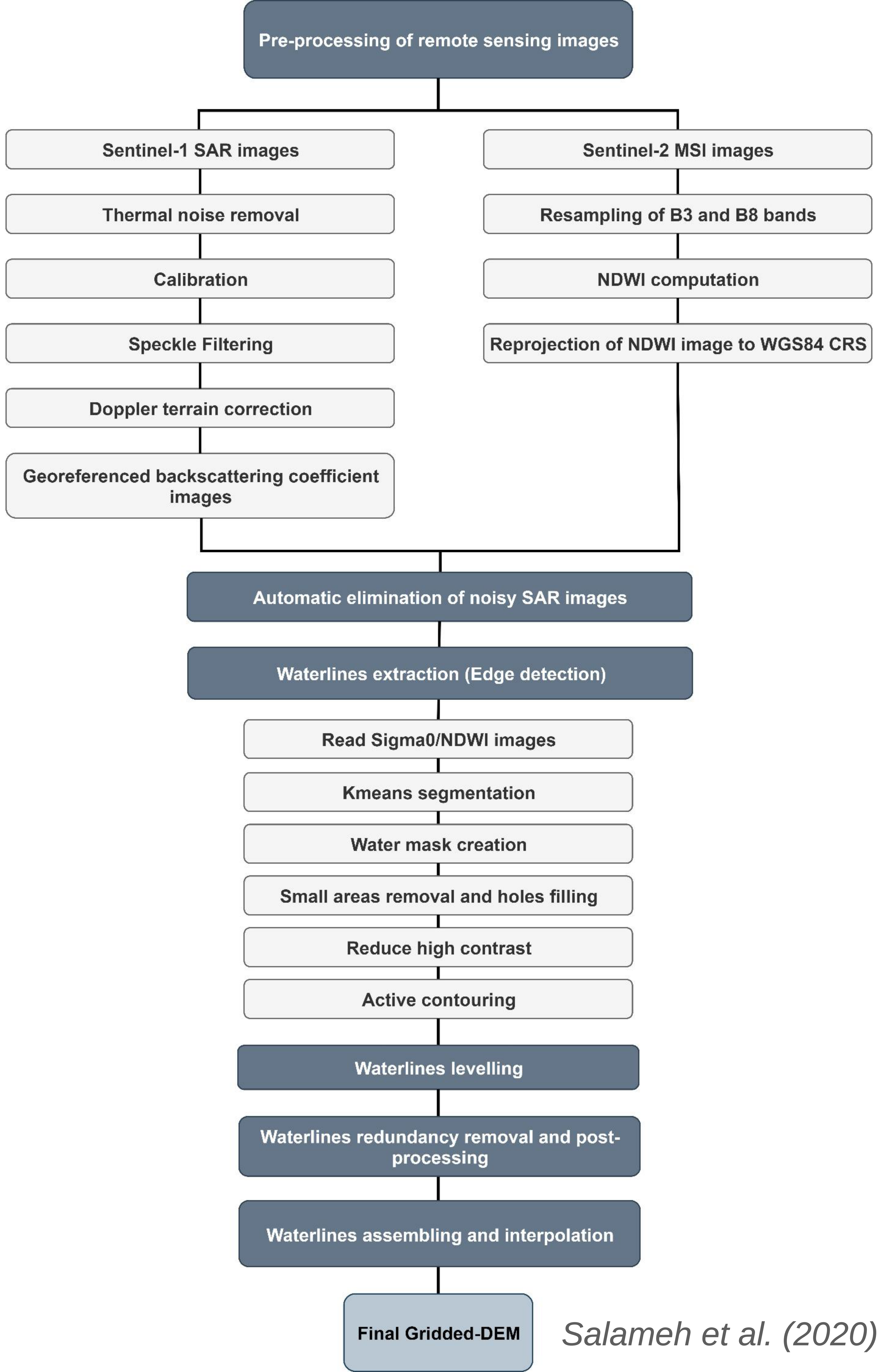
From 1D to 2D

Full 2D coverage

The waterline method from SAR and optical imagery

- Extracting waterlines from a series of images
- Assigning heights to waterlines using sea level information
- Assembling and interpolating the waterlines to form a gridded-DEM

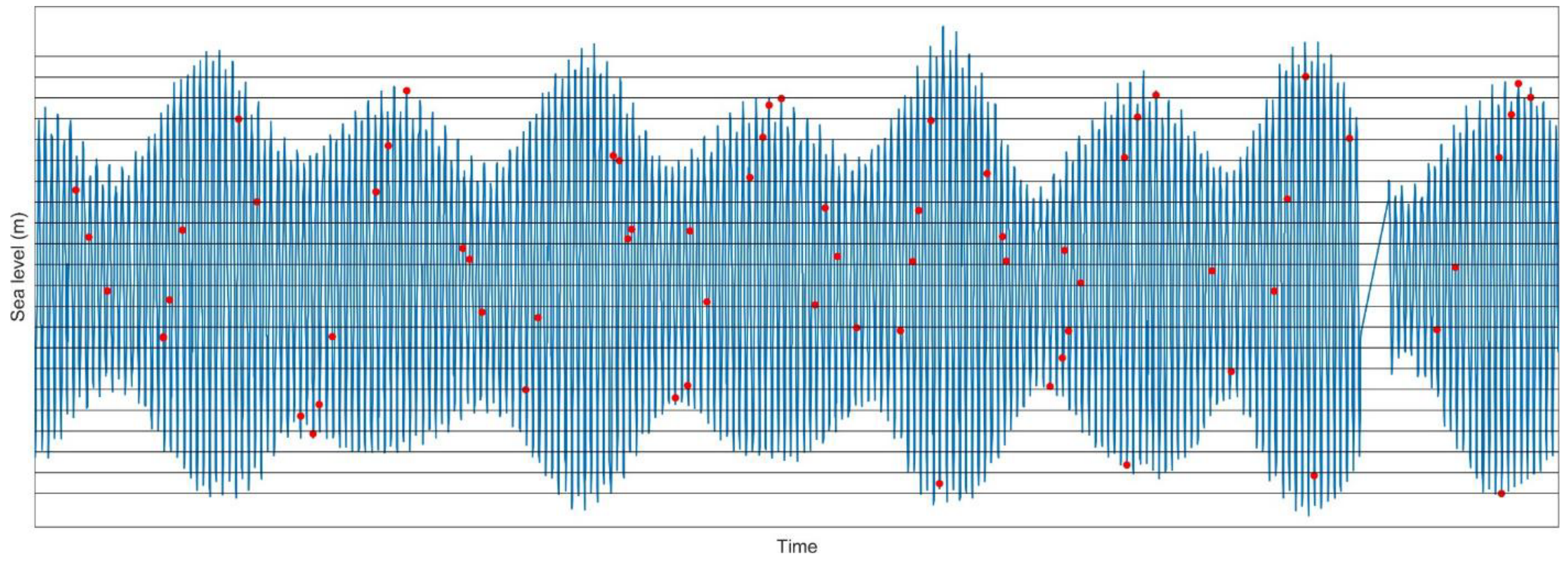




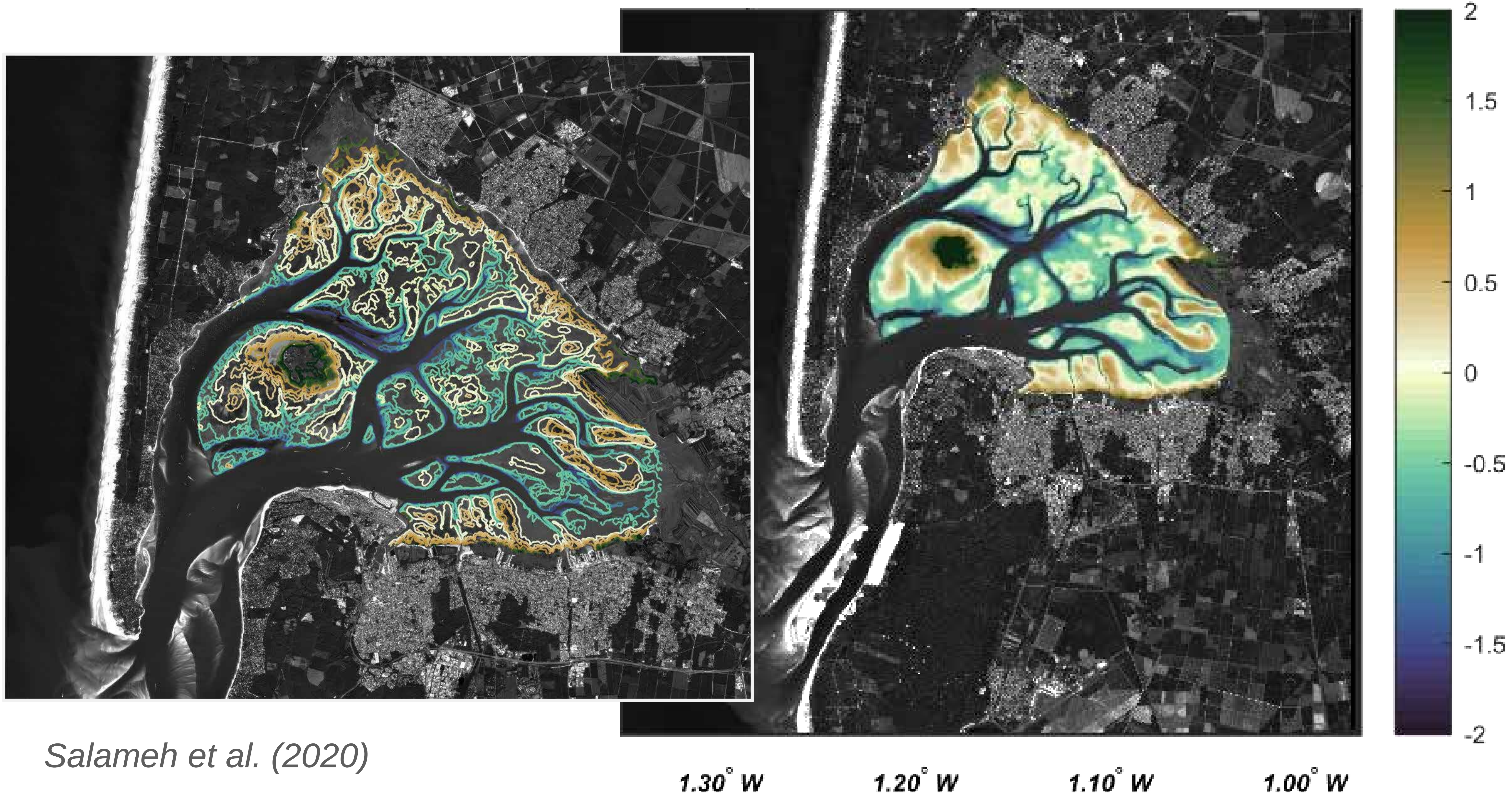
Salameh et al. (2020)

Waterline-derived DEMs

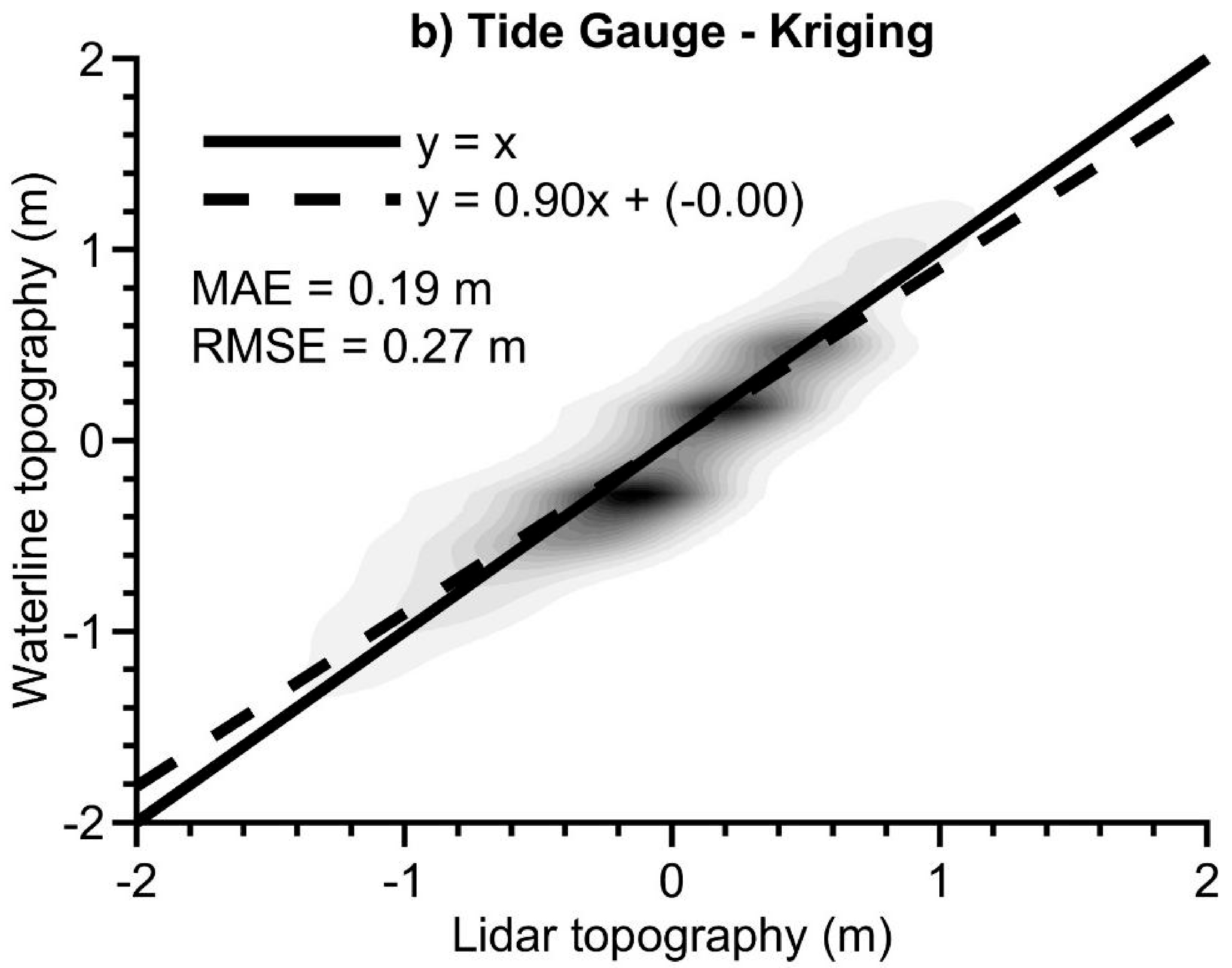
Combining and interpolating waterlines



The frequent, dense temporal sampling provided by the Sentinel-1 (SAR) and Sentinel-2 (Optical) constellations enabled the successful application of the waterline method over the Arcachon Bay with vertical accuracy of 19 cm (MAE).

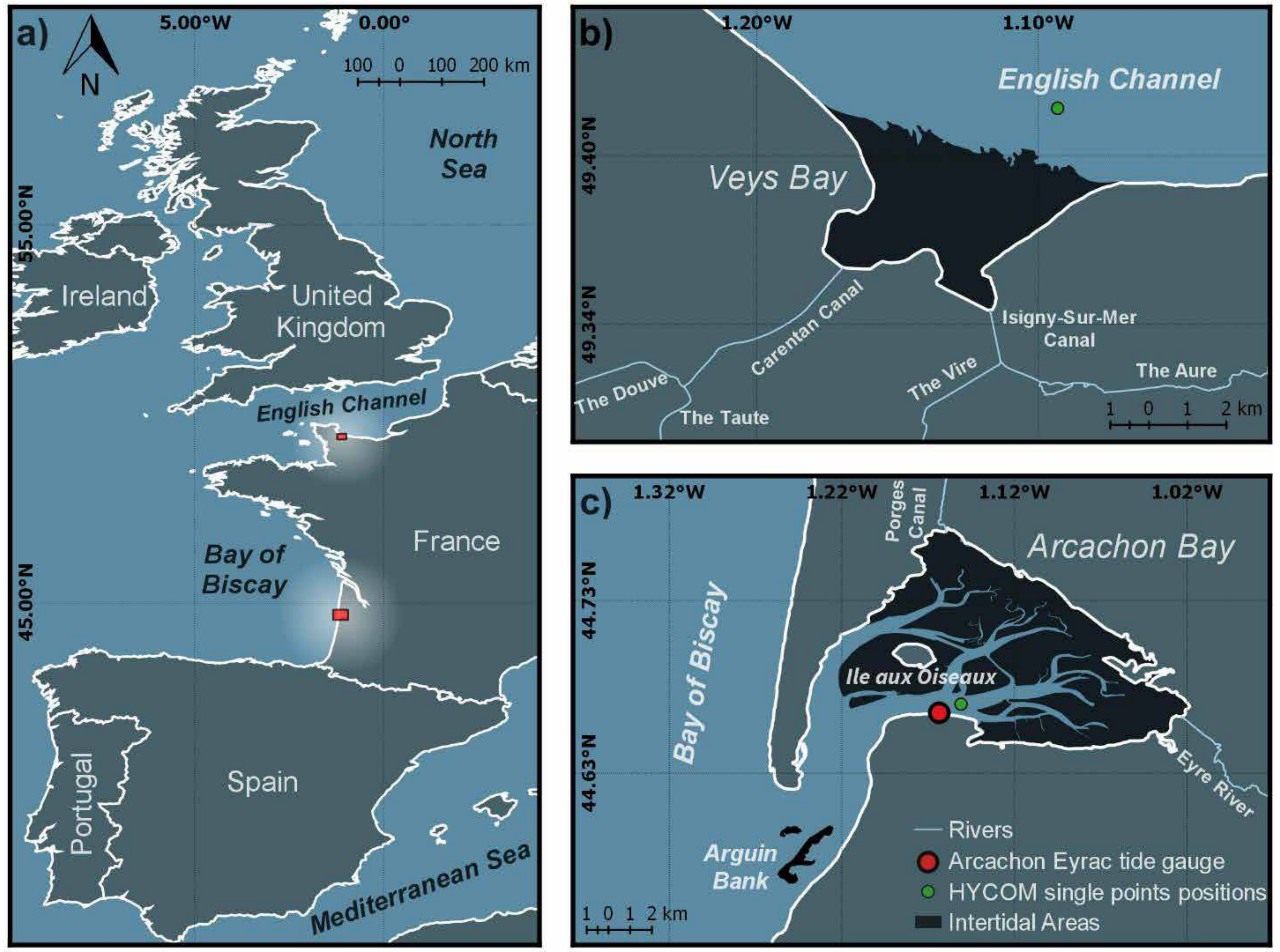


Salameh et al. (2020)

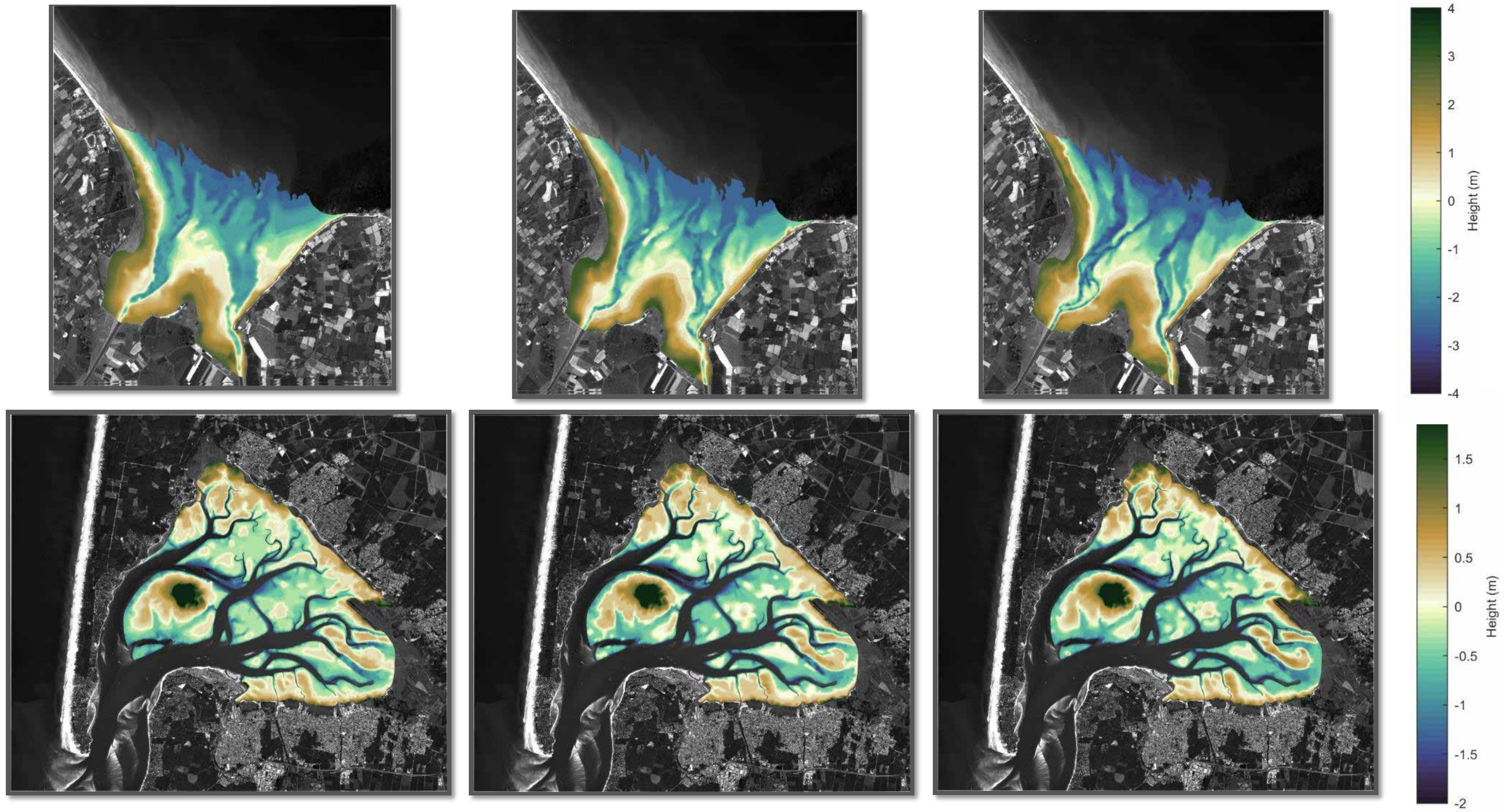


Intertidal DEMs

Arcachon Bay and Bay of Veys in France



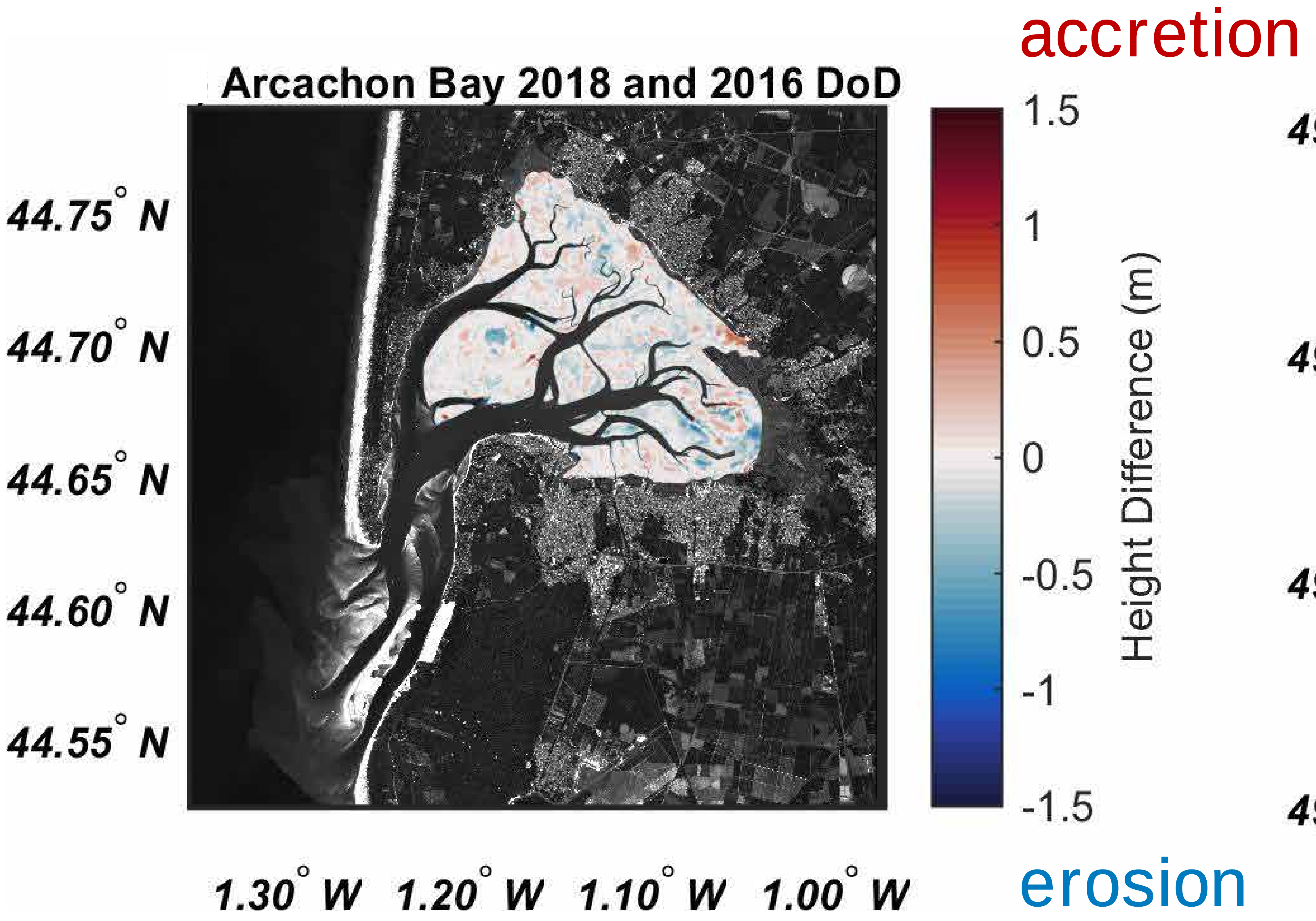
Arcachon	Veys
Mesotidal	Macrotidal
Muddy	Muddy/Sandy
Sheltered	Exposed
117 Km^2	38 km^2

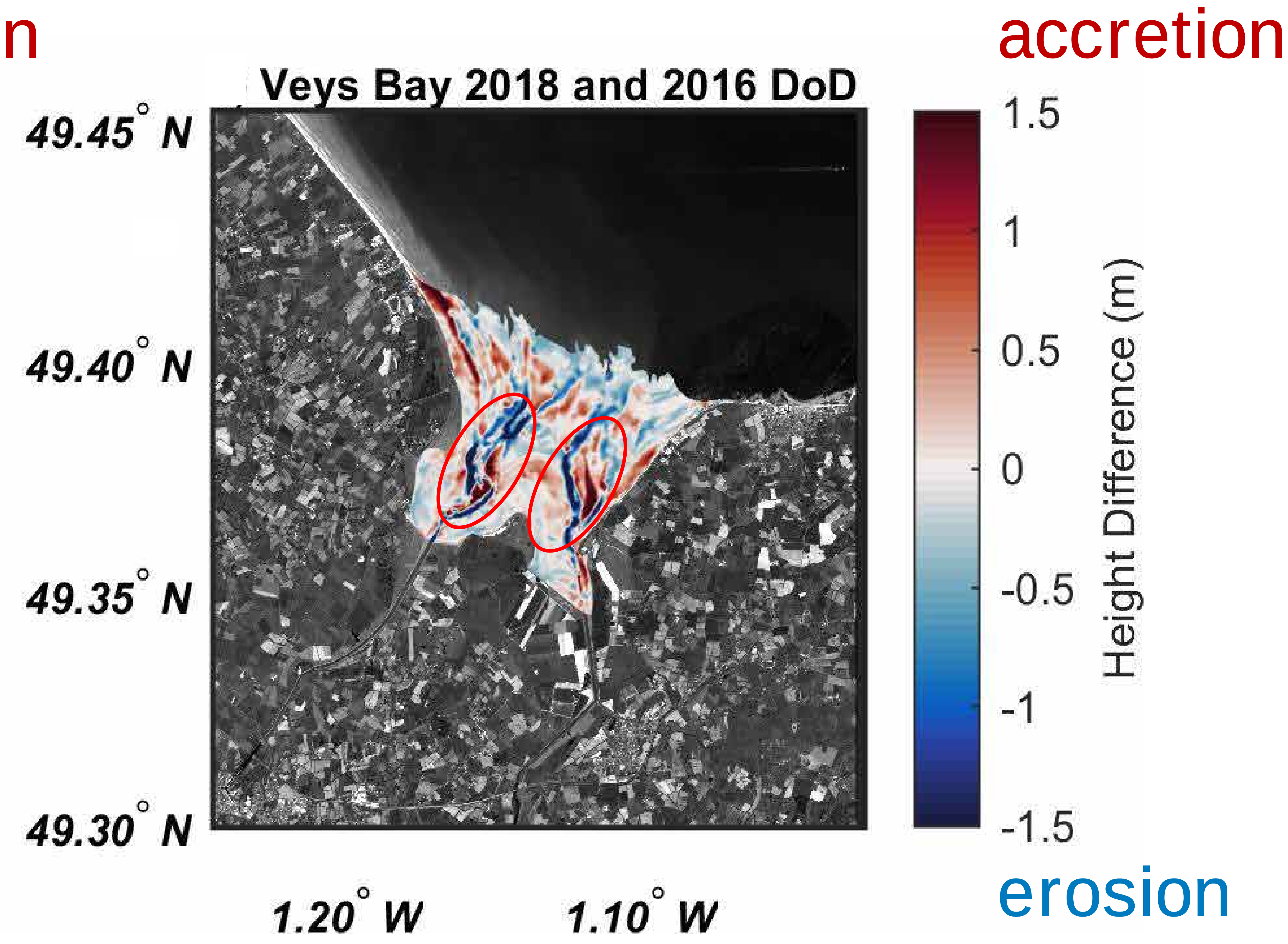


2016 2017 2018

Waterlines were extracted from Sentinel images acquired between June and September for each year.

Topography evolution and sediment budget





Study Site	Surface (km^2)			Volume (10^6 m^3)		
	Stable	Eroded	Deposited	Eroded	Deposited	Total
Arcachon	89.22 (96.00%)	2.93 (3.15%)	0.79 (0.85%)	-1.54±1.12	0.42±0.30	-1.12
Veys	17.42 (63.44%)	5.16 (18.79%)	4.88 (17.77%)	-4.23±1.75	3.53±1.66	-0.70

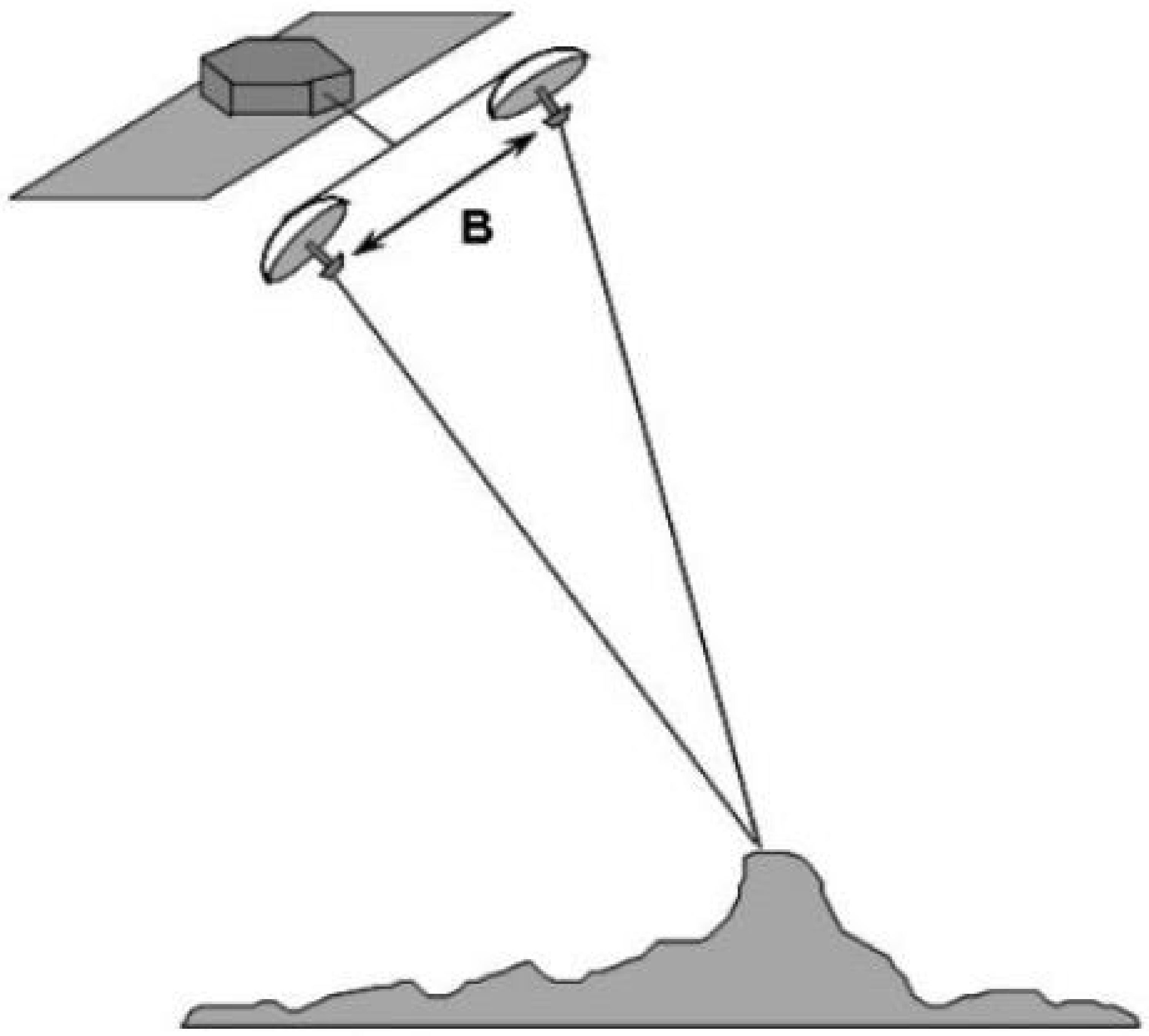
SWOT for intertidal topography

Two Approaches

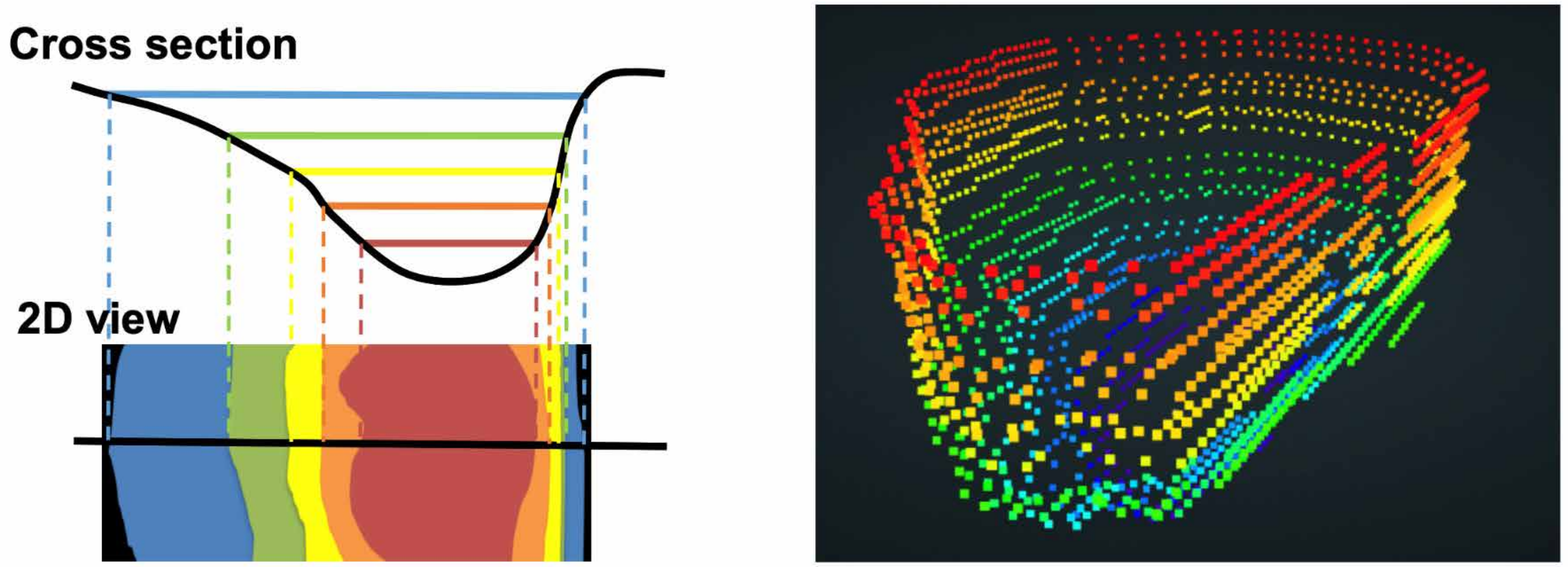
From 2D to 2D but with SWOT

Using the SWOT **interferometric** processing chain directly

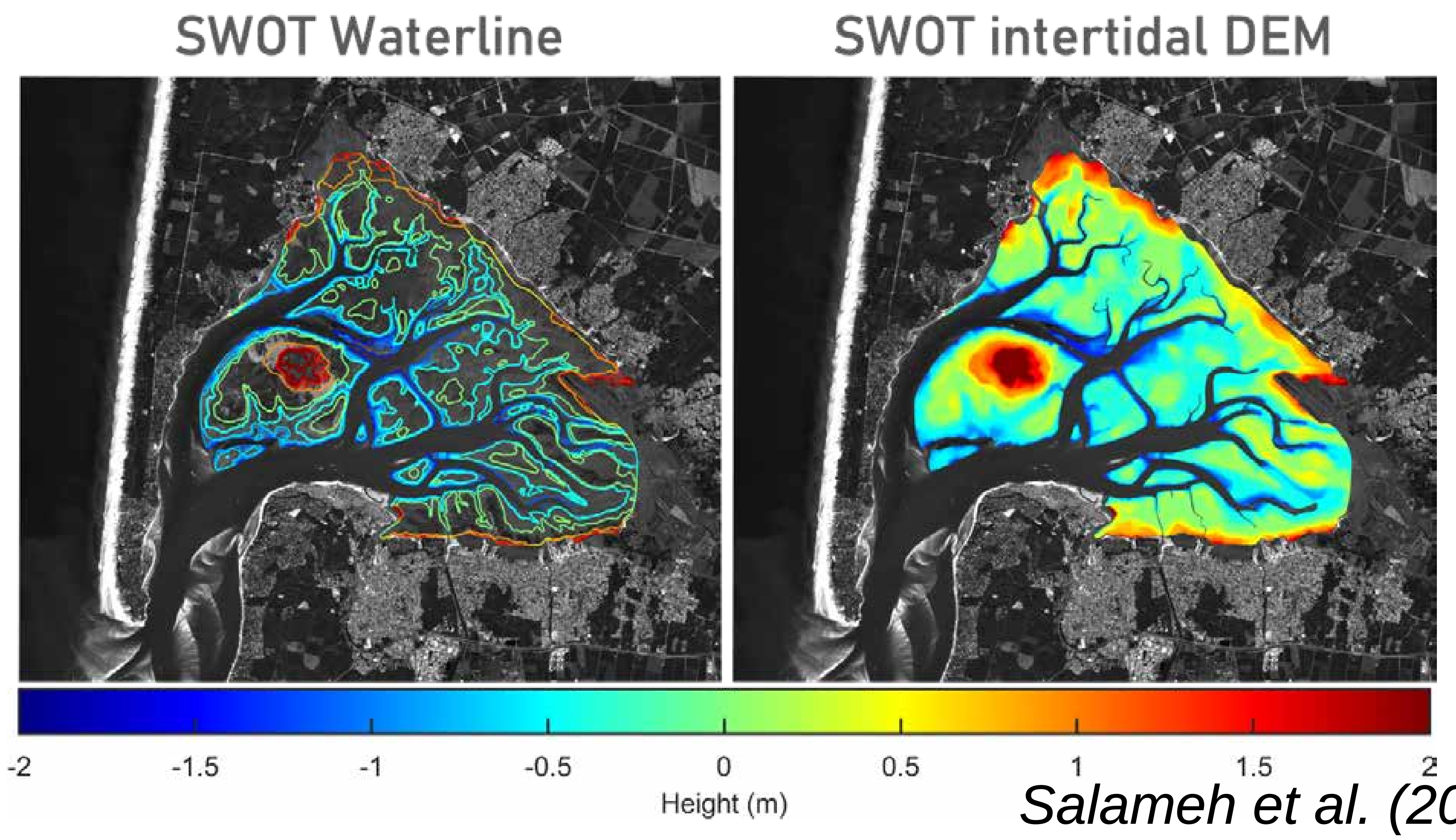
Direct Heights values from SWOT_HR_PIXC (pixel cloud) product over the flats at low tide



Using the **waterline method** (bathtub-ring method)



Williams and Desroches (2021, 2022)

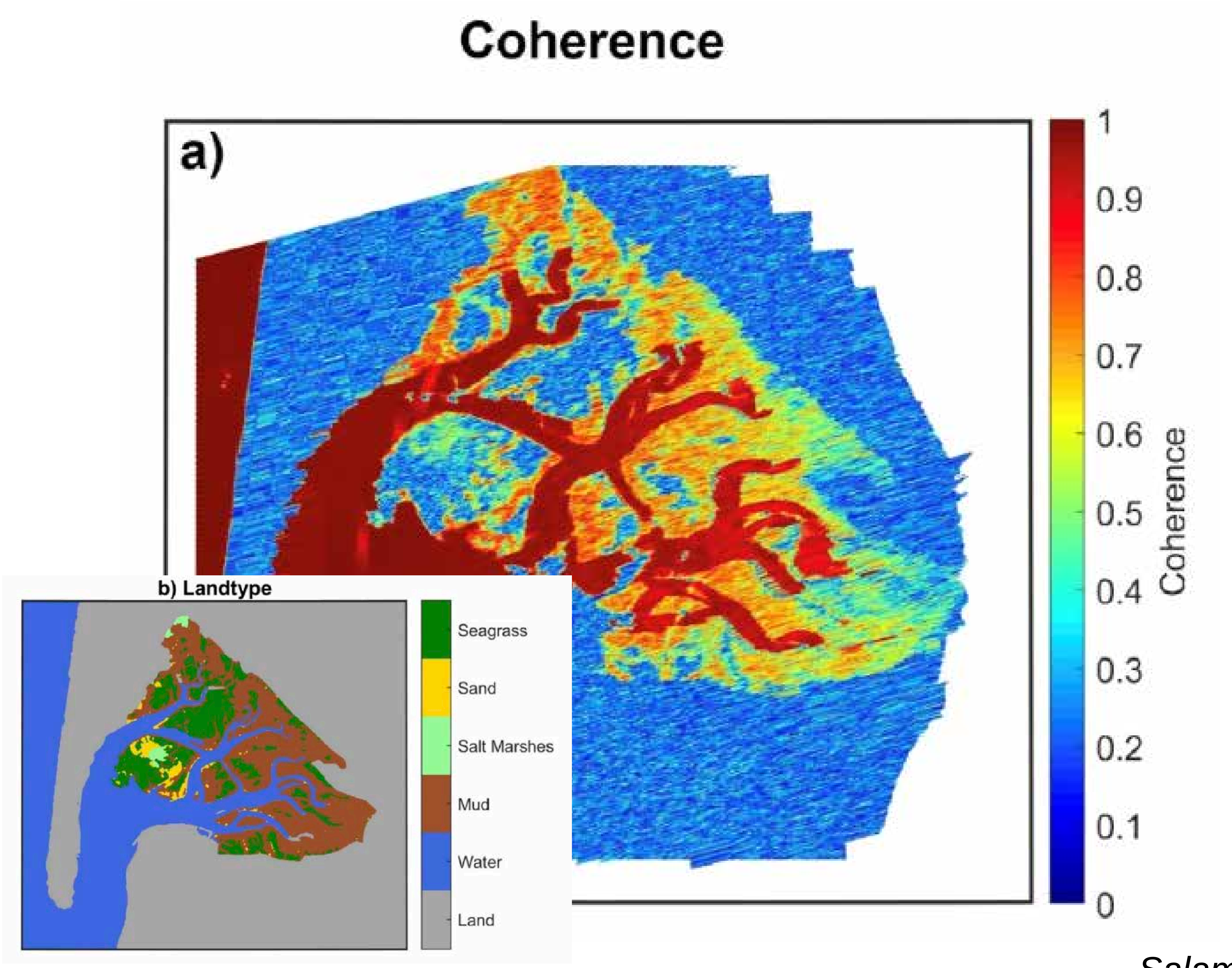


Salameh et al. (2021)

SWOT Simulations

Before Launch

Using the SWOT **interferometric** processing chain directly

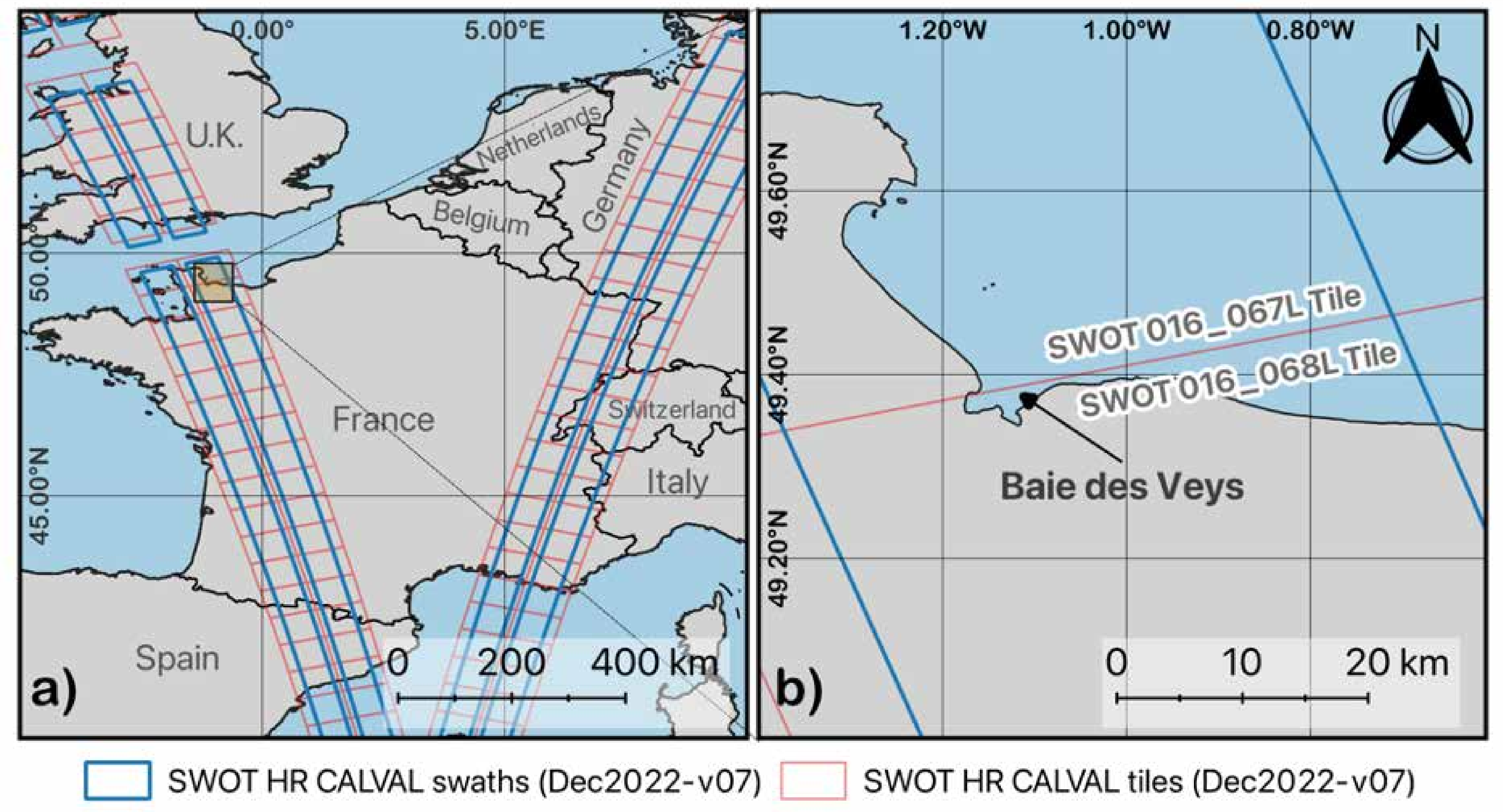


Using the **waterline method** (bathtub-ring method)

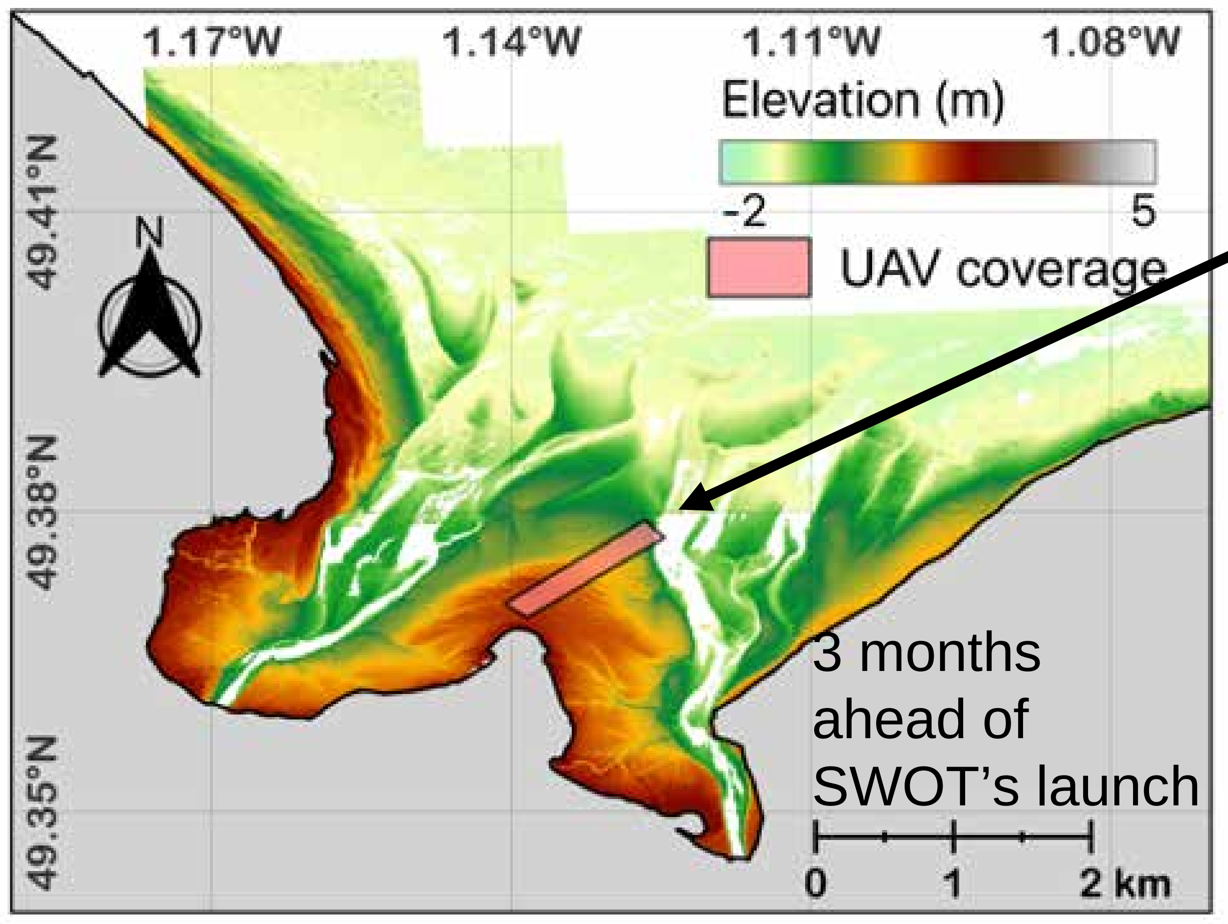
Salameh et al. (2021)

SWOT calval phase (1-day orbit)

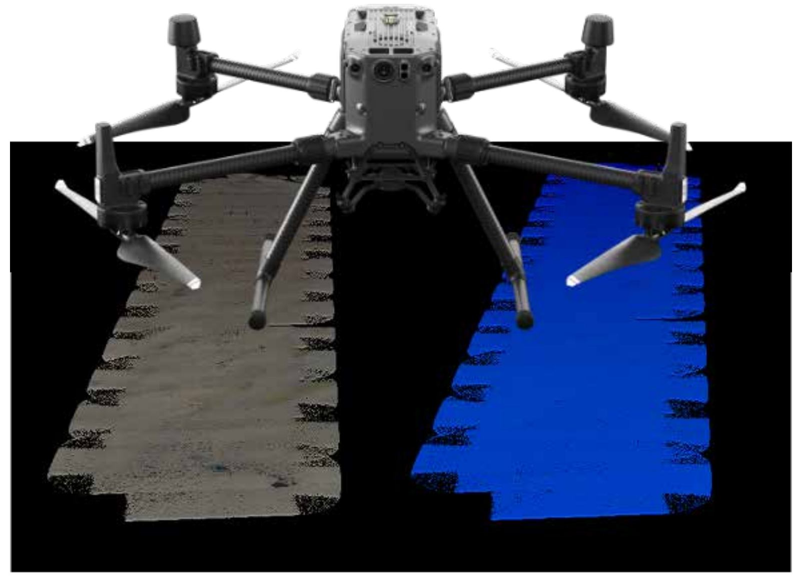
Bay of Veys : A Normandy validation site



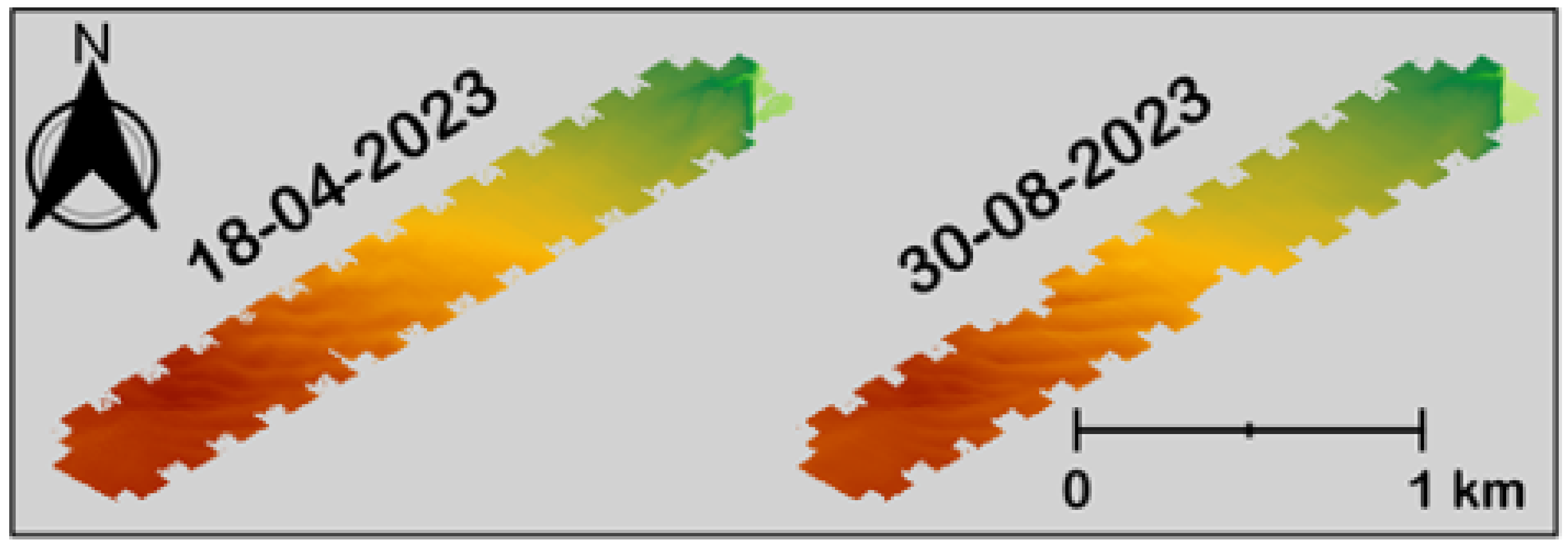
a) IGN LiDAR HD intertidal DEM



- Bay of Veys: a **validation site for SWOT intertidal topography mapping** under the 1-Day orbit.
- Two UAV LiDAR flights at 50 m altitude during low tide.
- An airborne LiDAR acquisition by the IGN (French national institute of geographic and forest information) 6 months ahead of the first fully exploitable HR cycle.



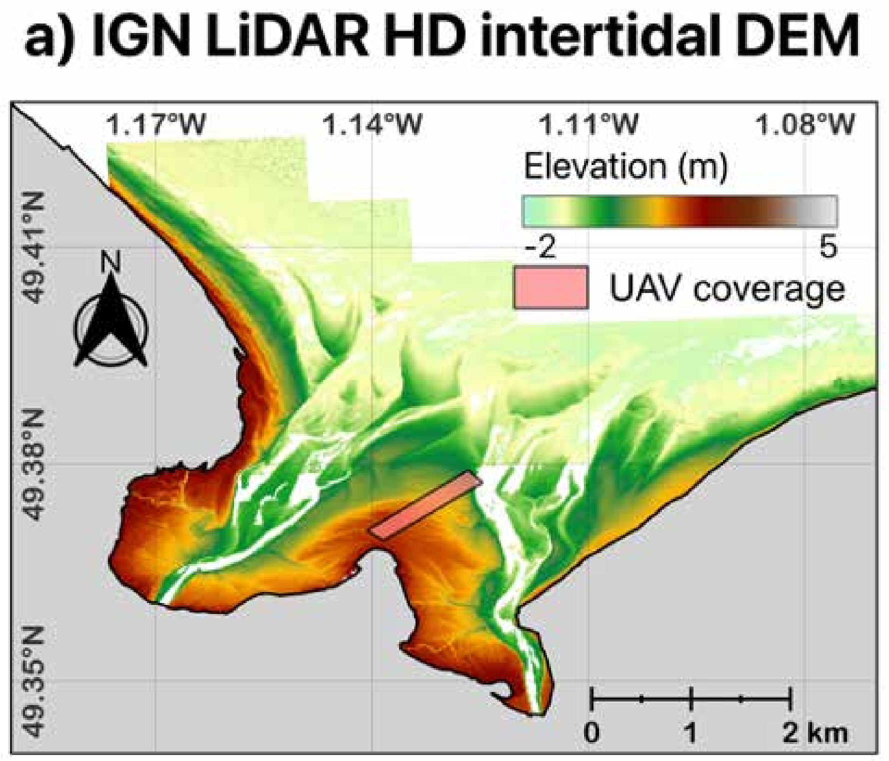
b) UAV LiDAR intertidal DEMs

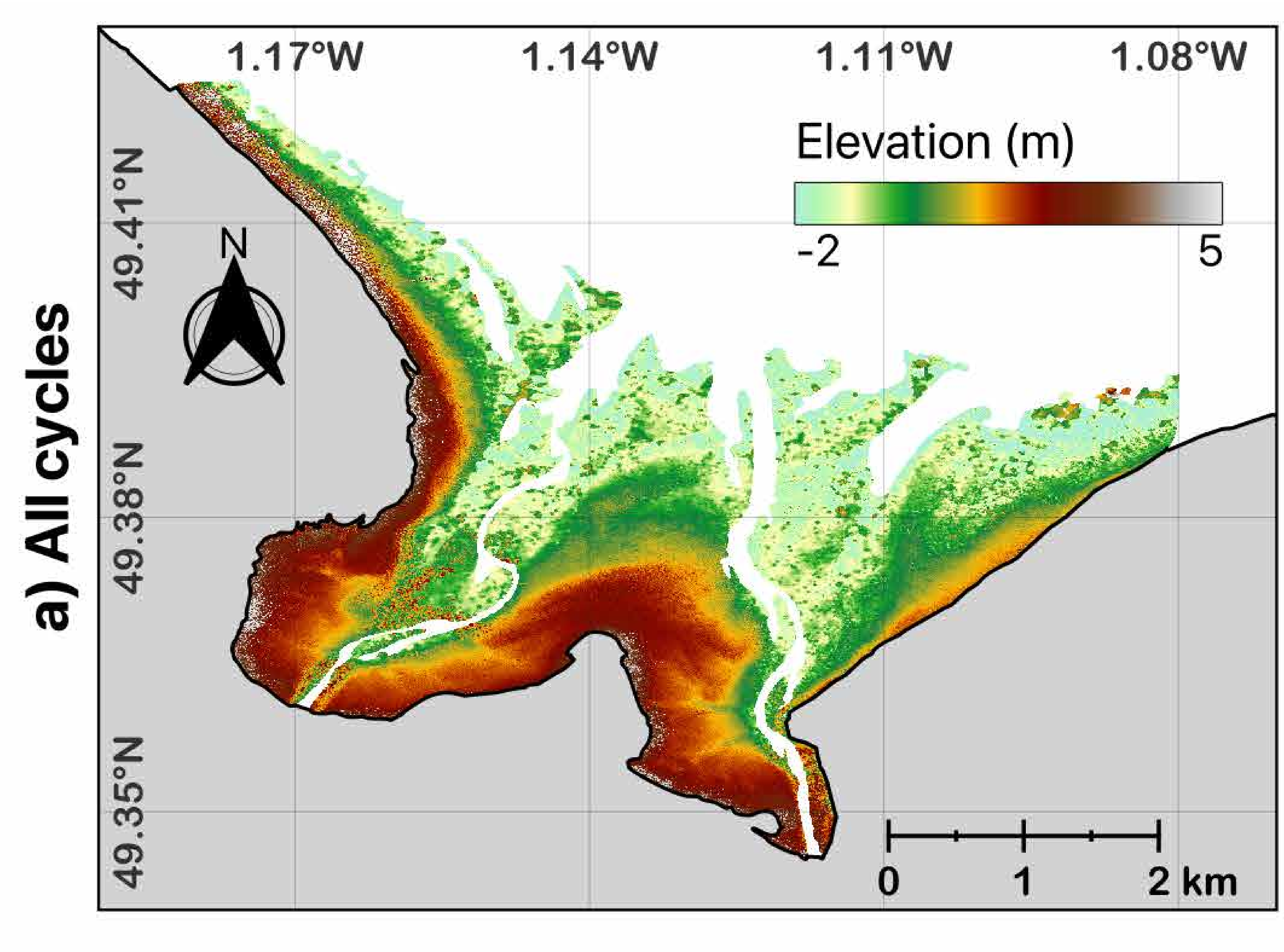


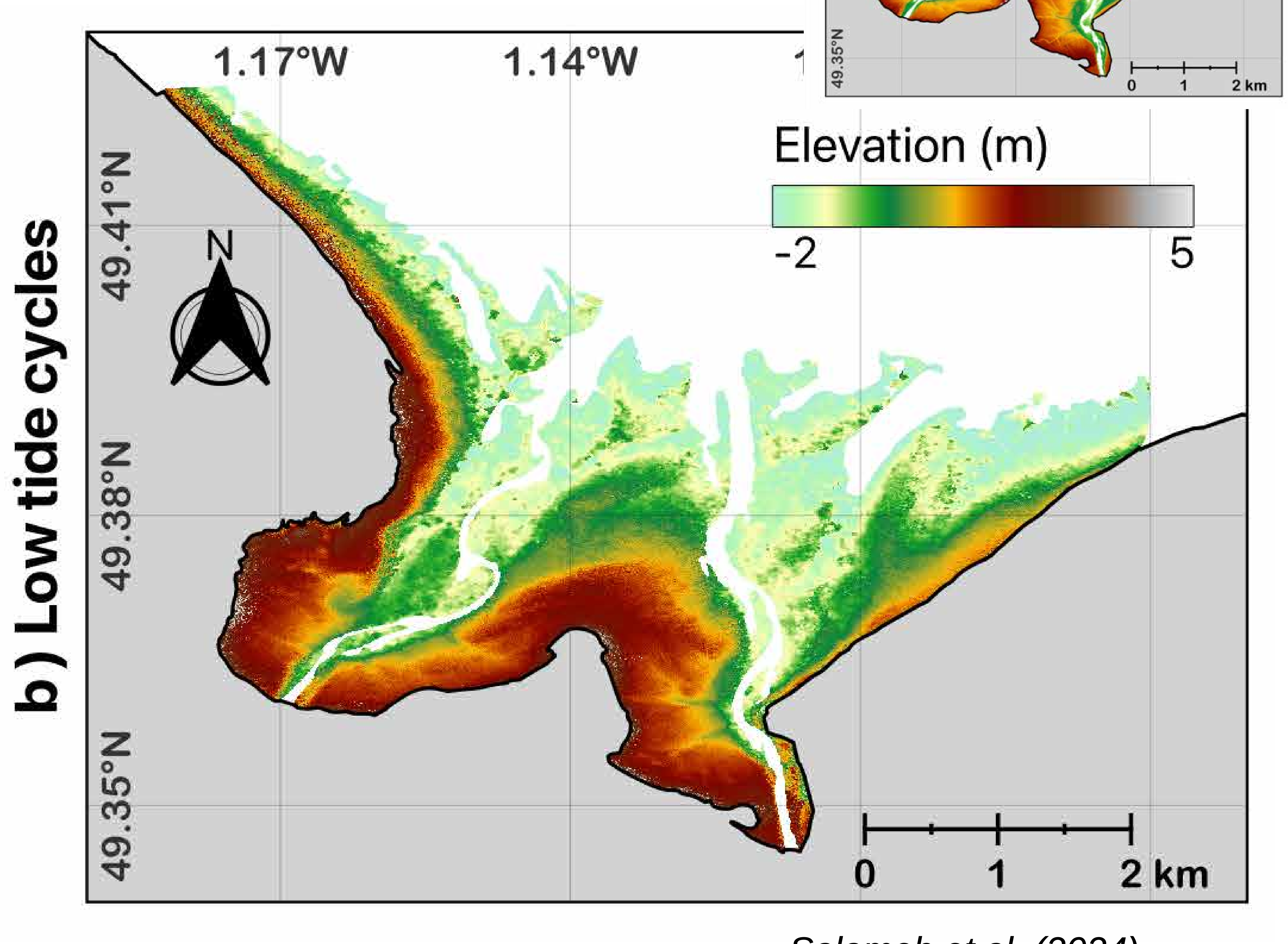
Validation datasets should be as close as possible in time to SWOT acquisitions because of the dynamic nature of these environments

SWOT-derived Intertidal topography

SWOT Aggregated Intertidal DEMs



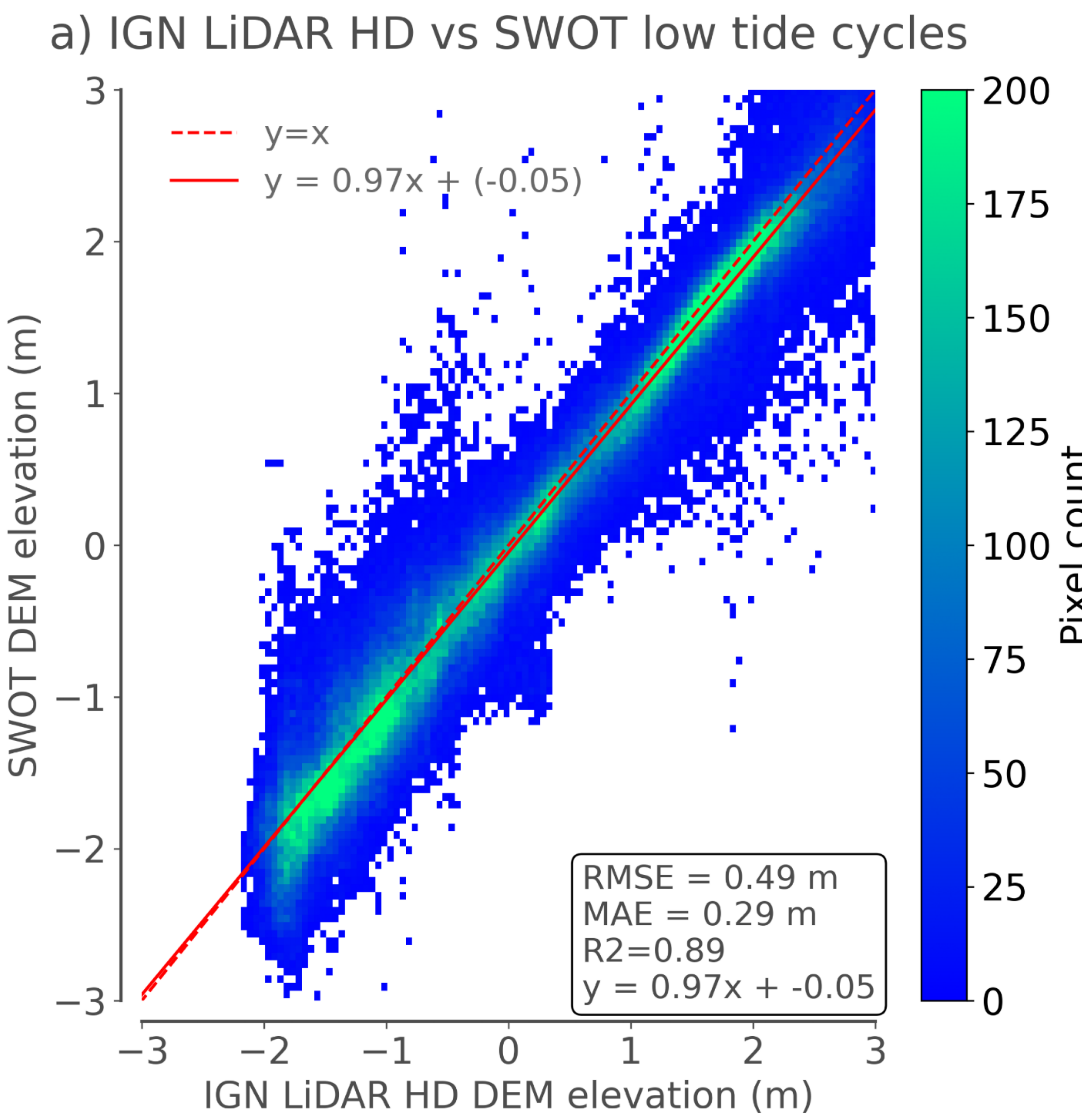


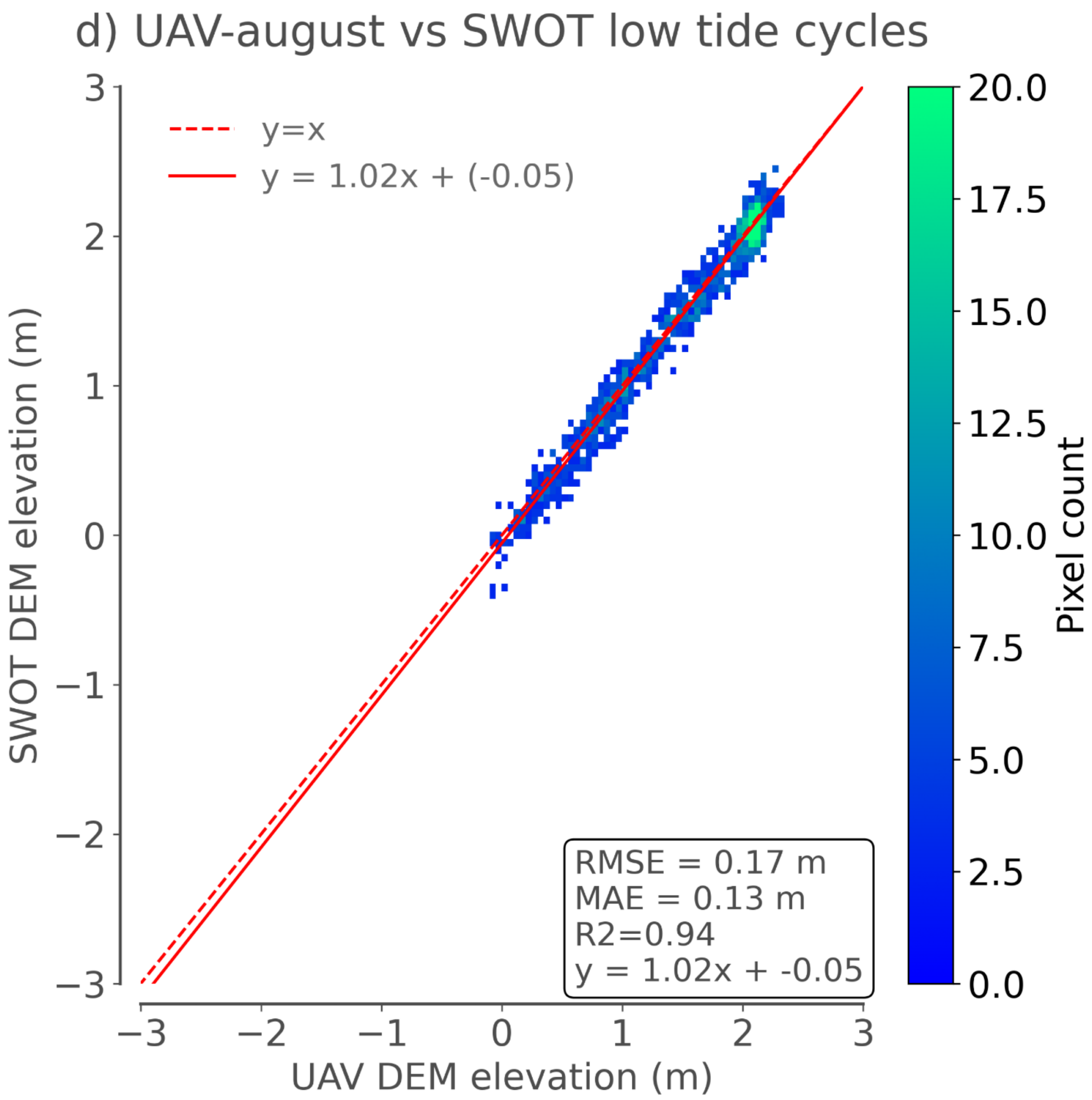


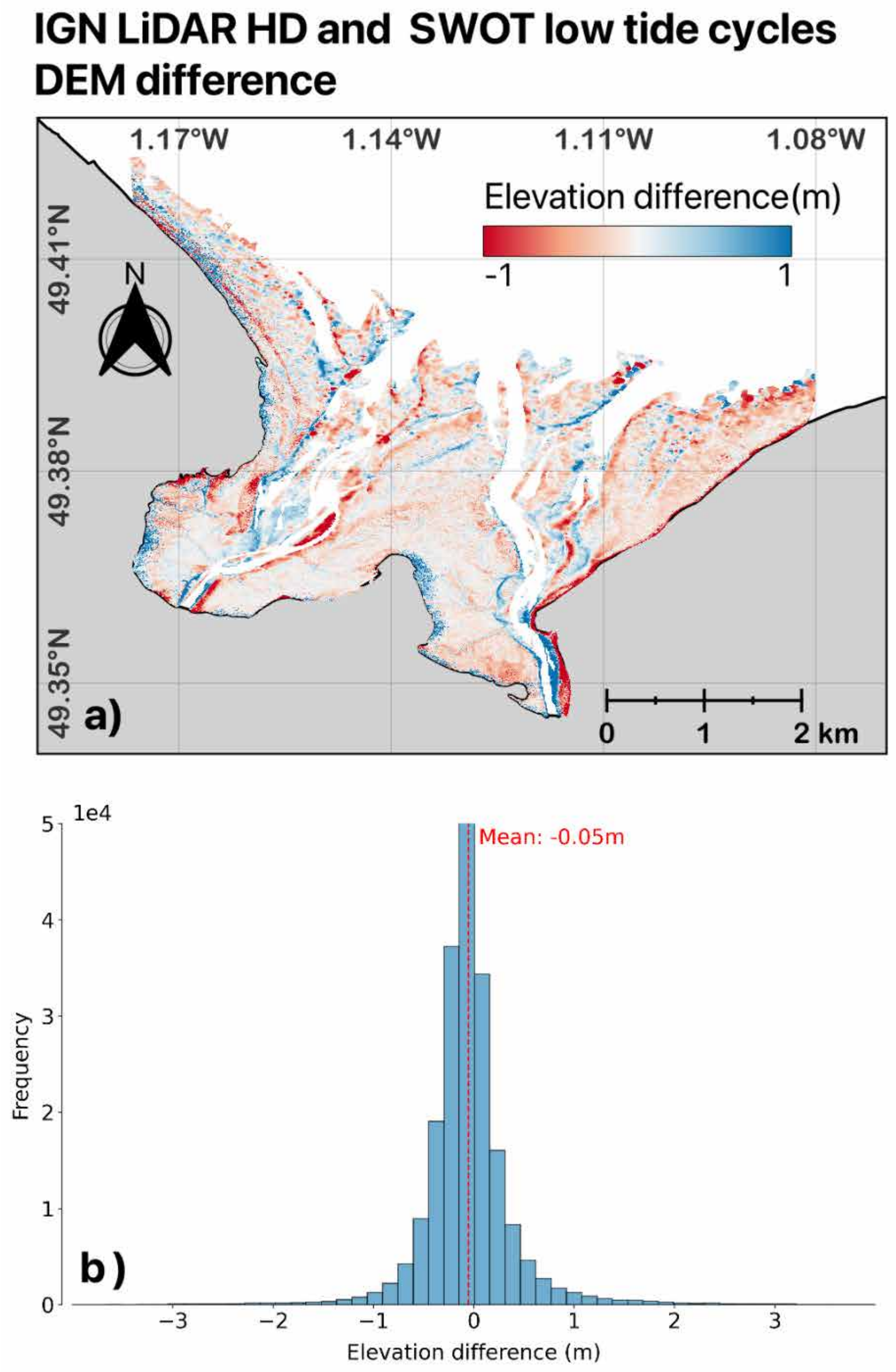
Salameh et al. (2024)

Validation

Comparing SWOT to LiDAR UAV and IGN DEMs



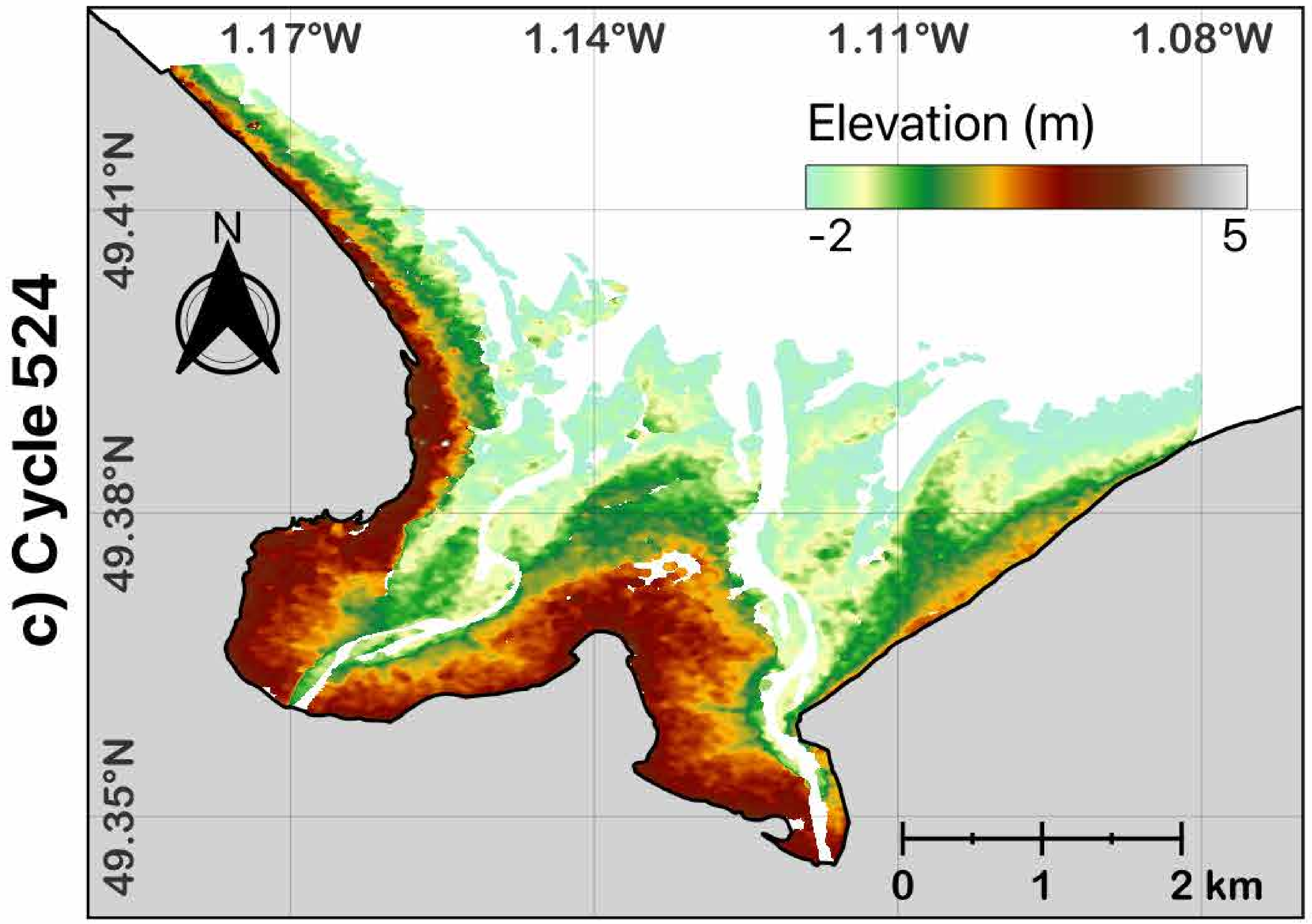


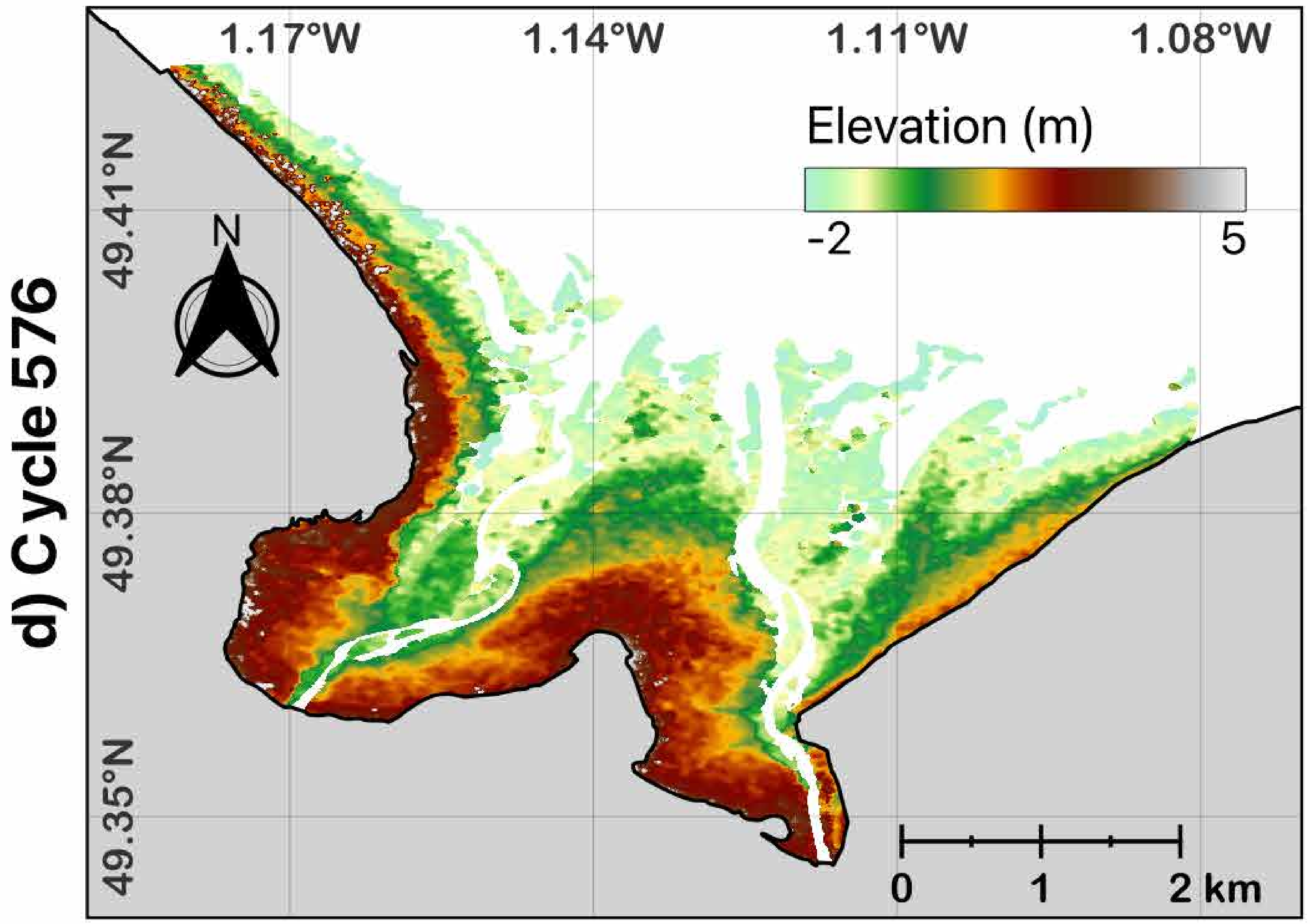


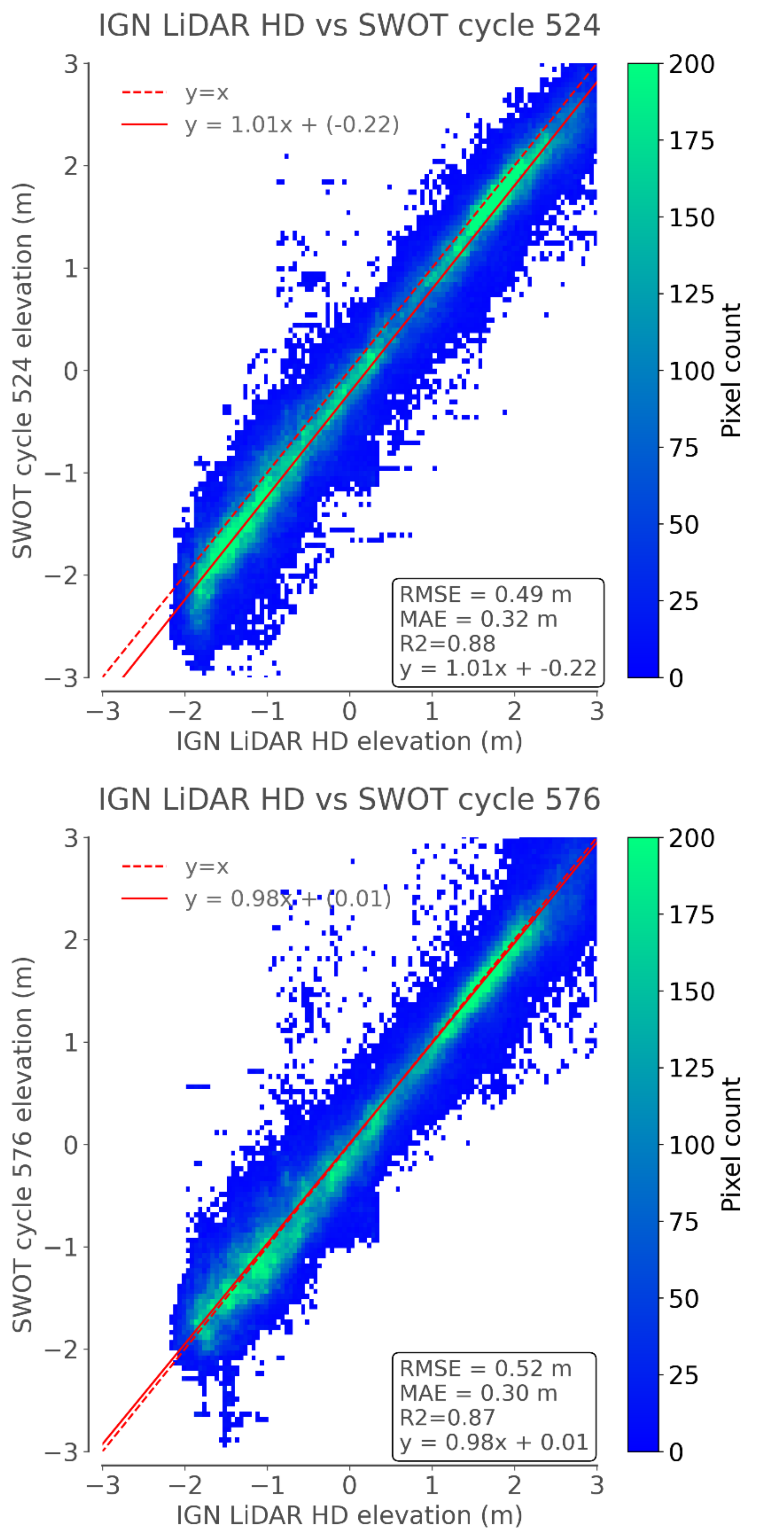
Salameh et al. (2024)

SWOT-derived Intertidal topography

Topography from single SWOT passes





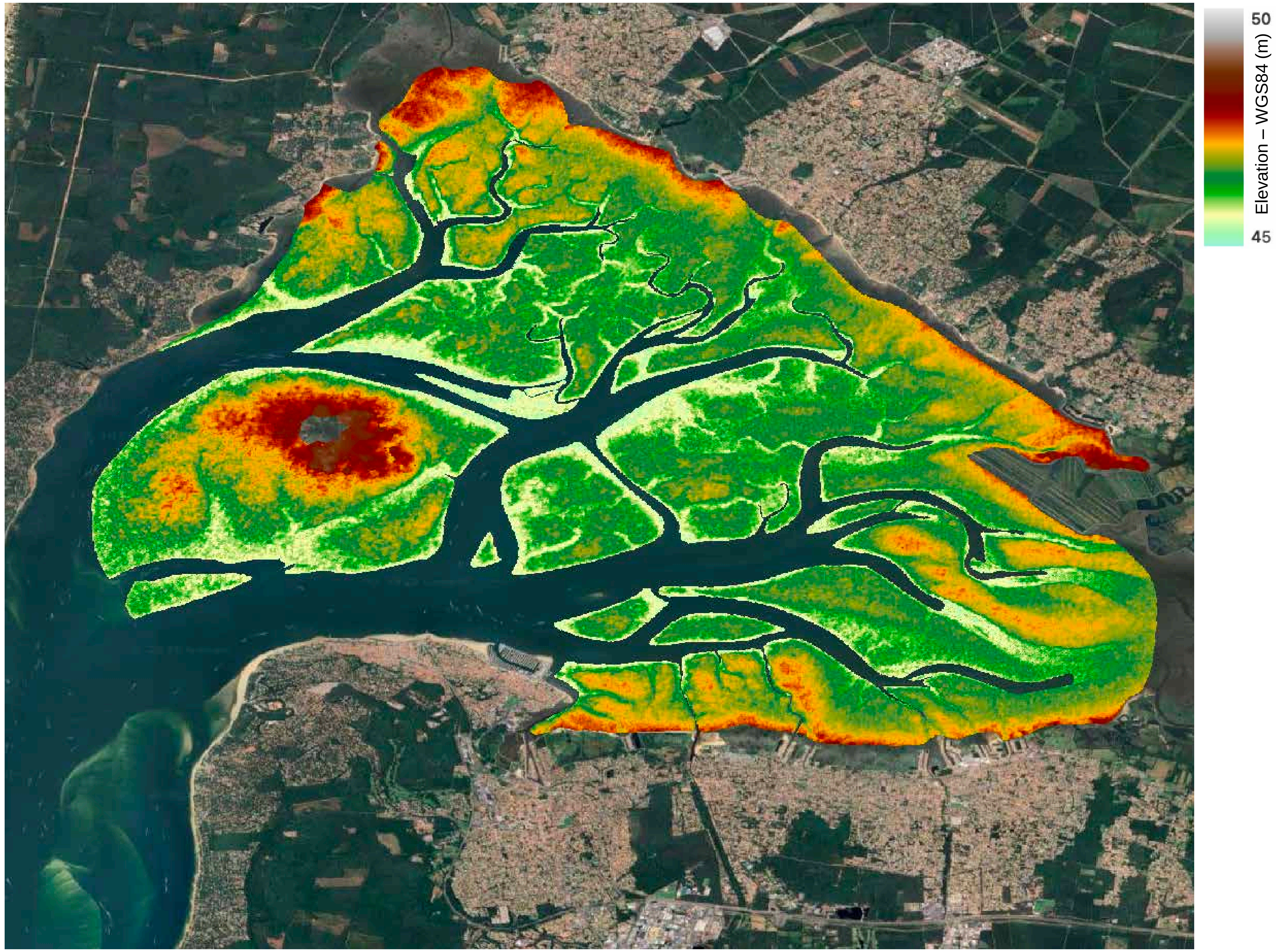


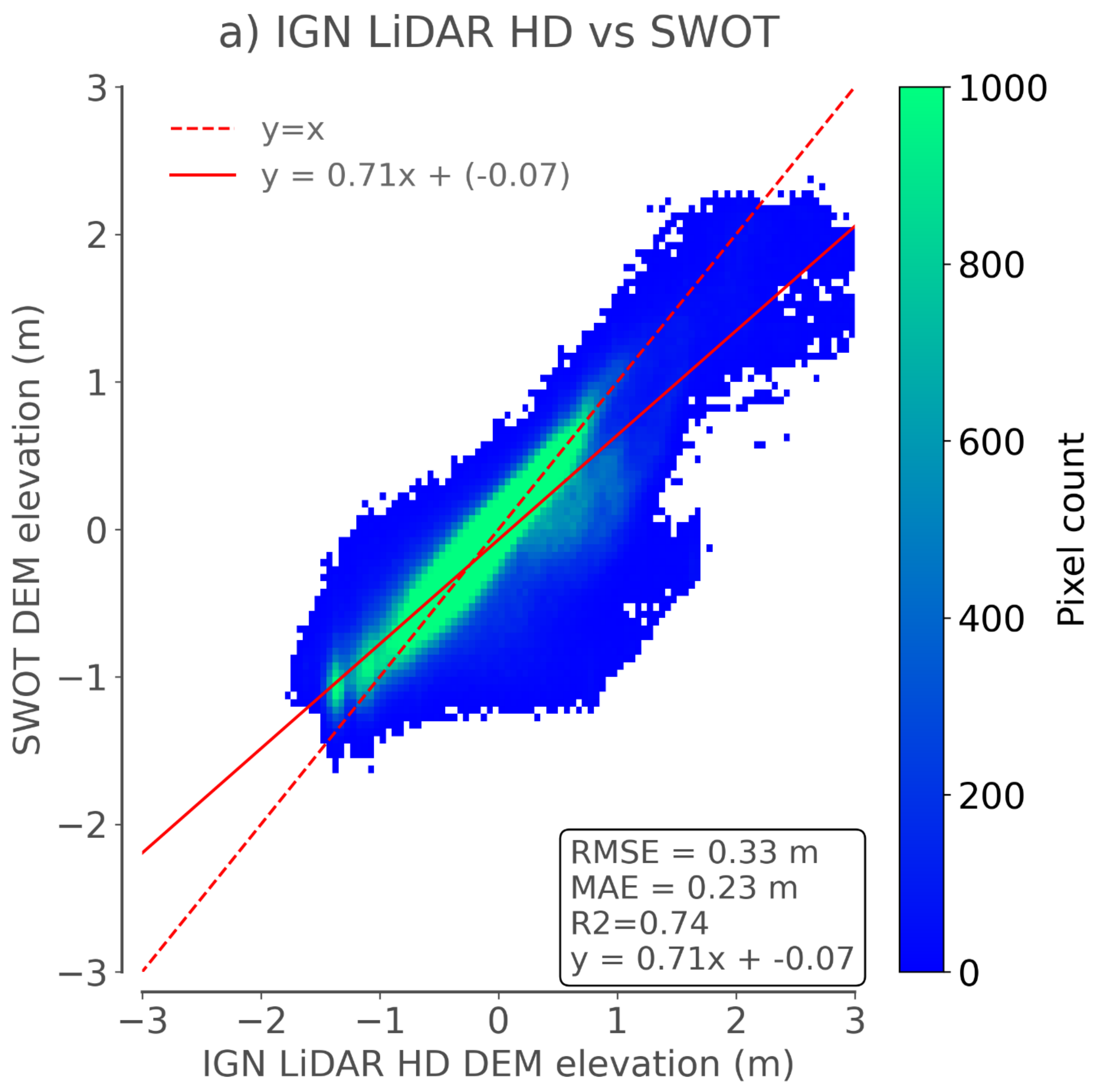
Salameh et al. (2024)

SWOT single-pass DEMs show a relatively good accuracy (and consistency)

SWOT Real data over Arcachon

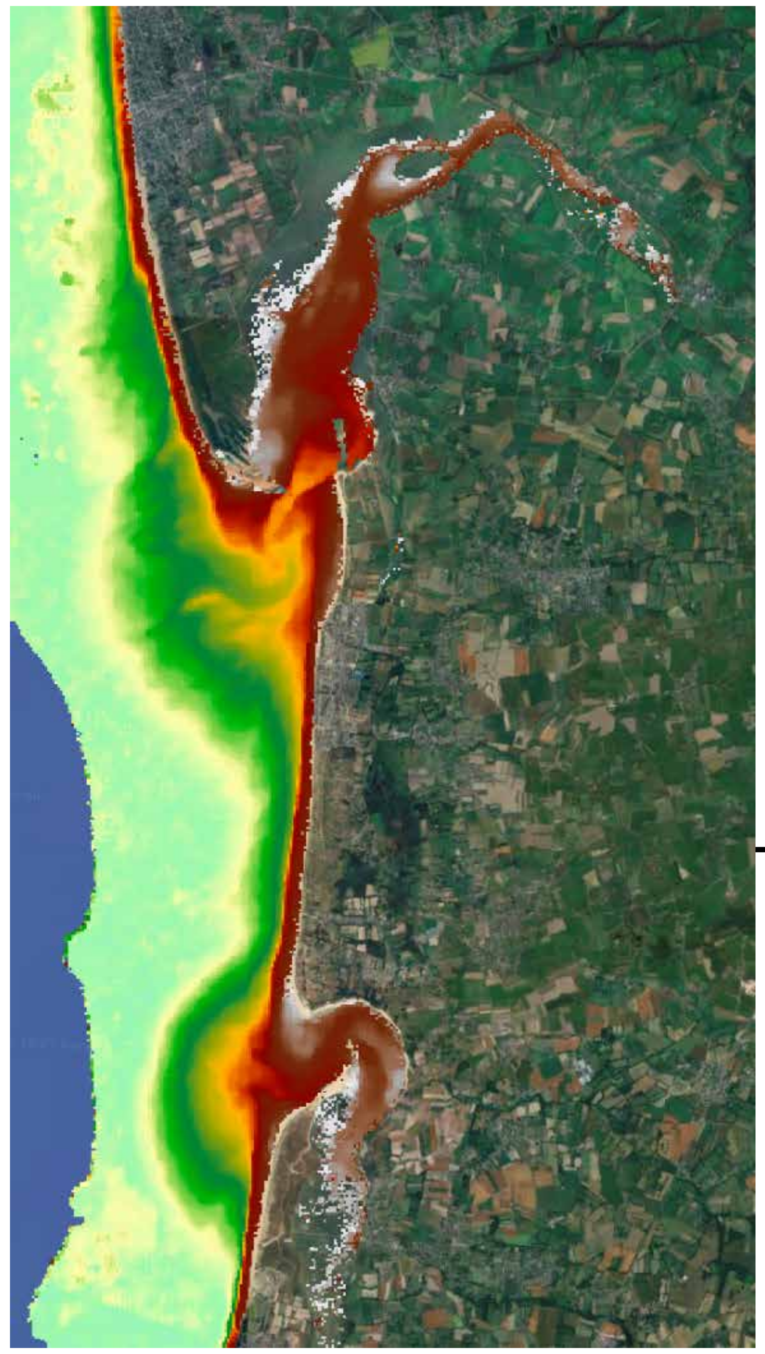
Intertidal topography from SWOT's nominal orbit

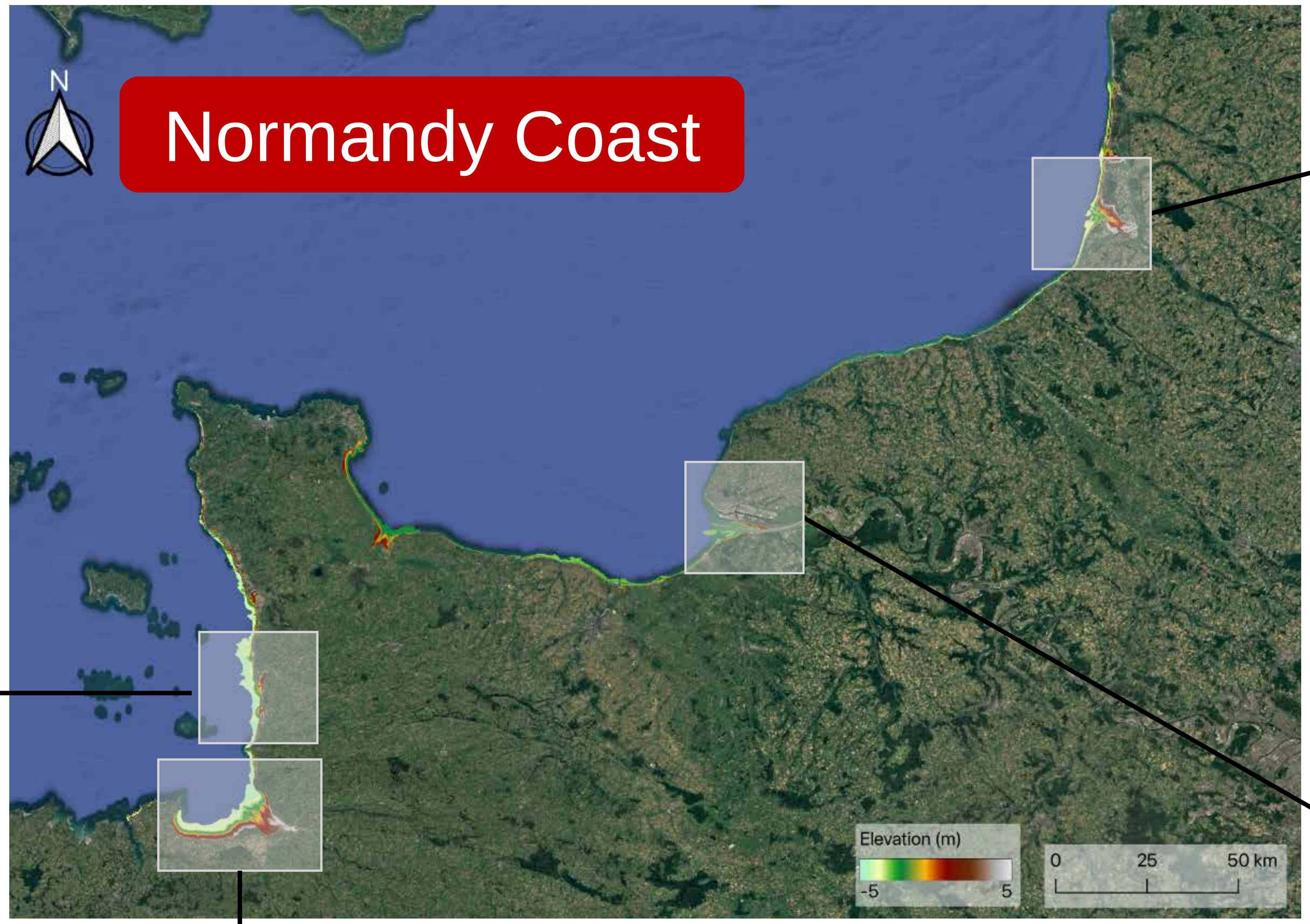


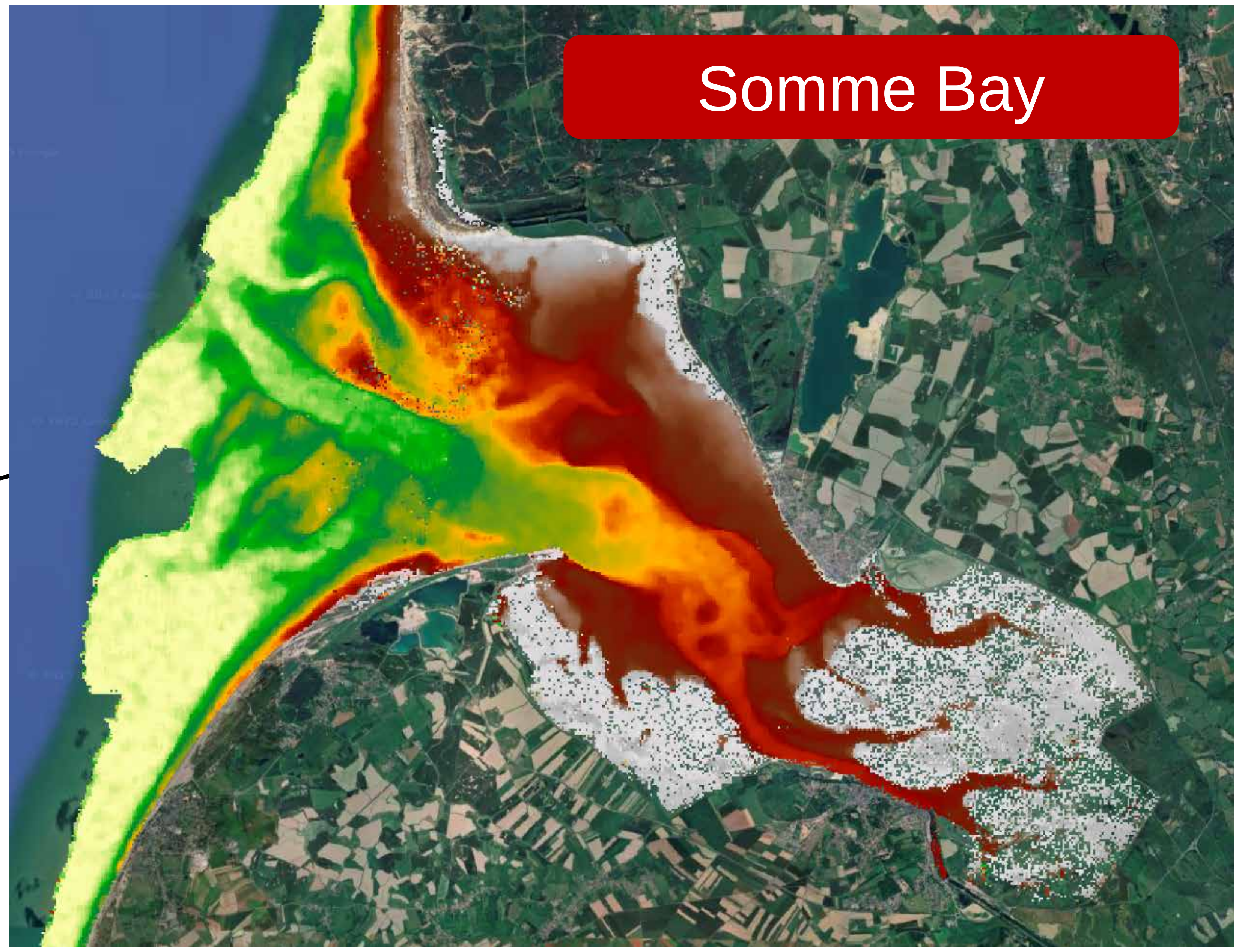


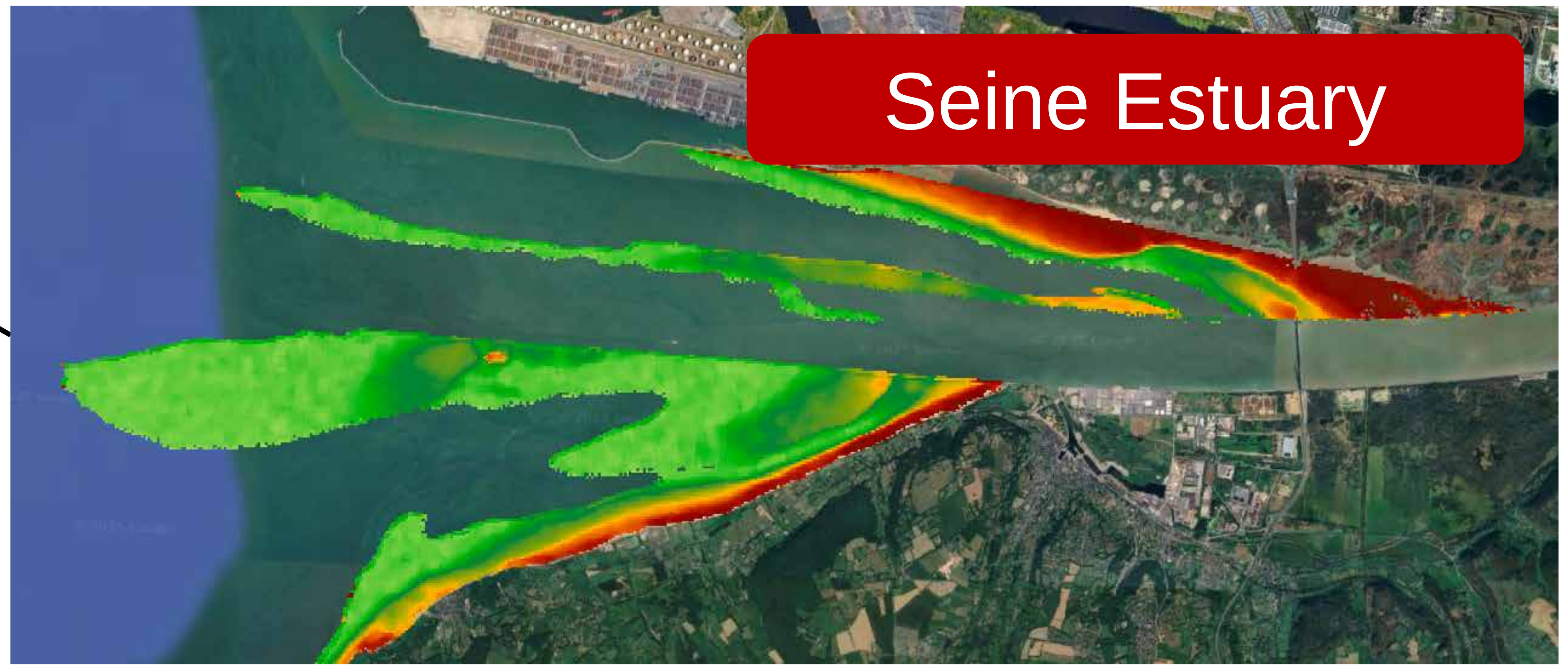
Regional Scalability

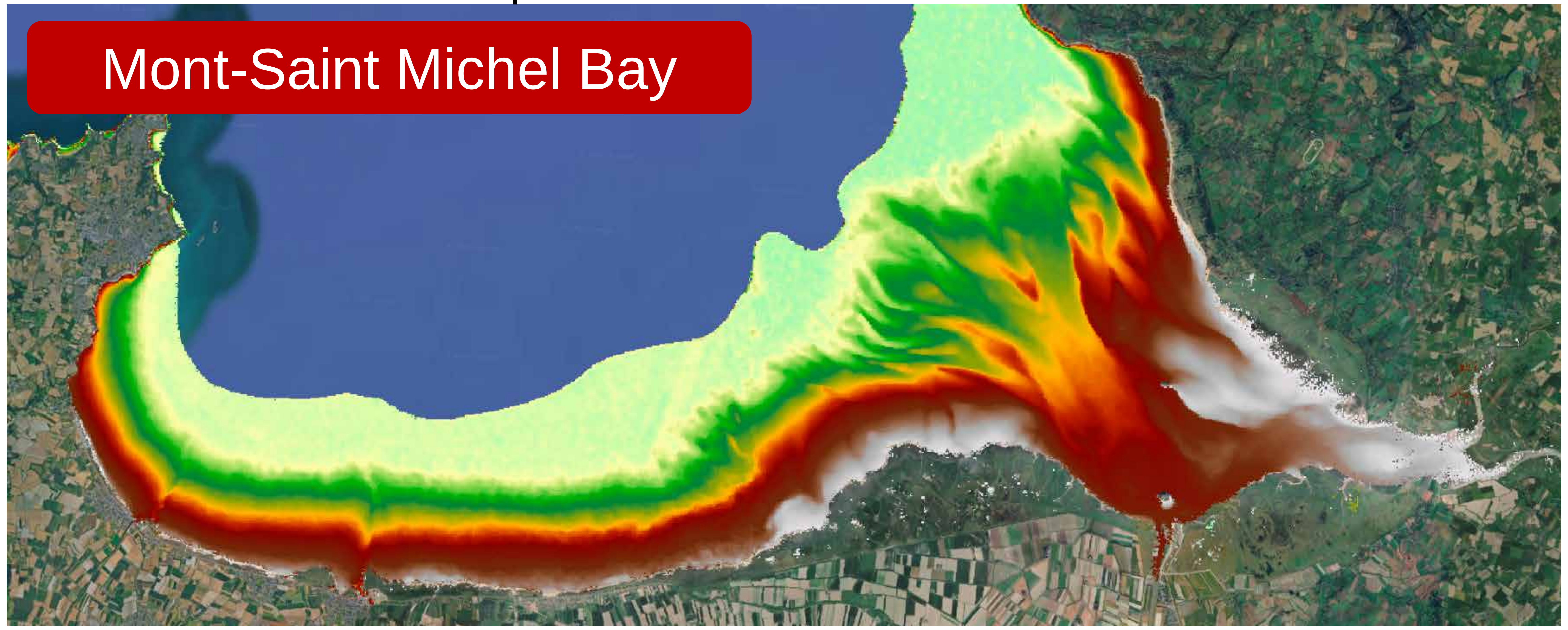
Mapping the Entire Normandy Coast

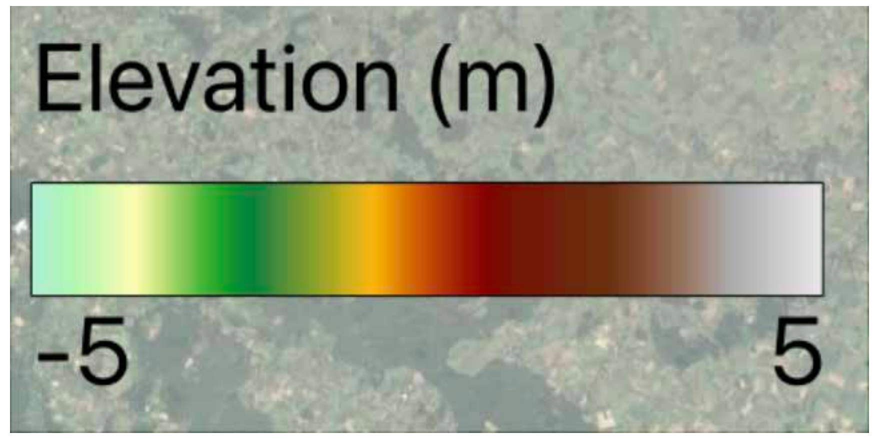








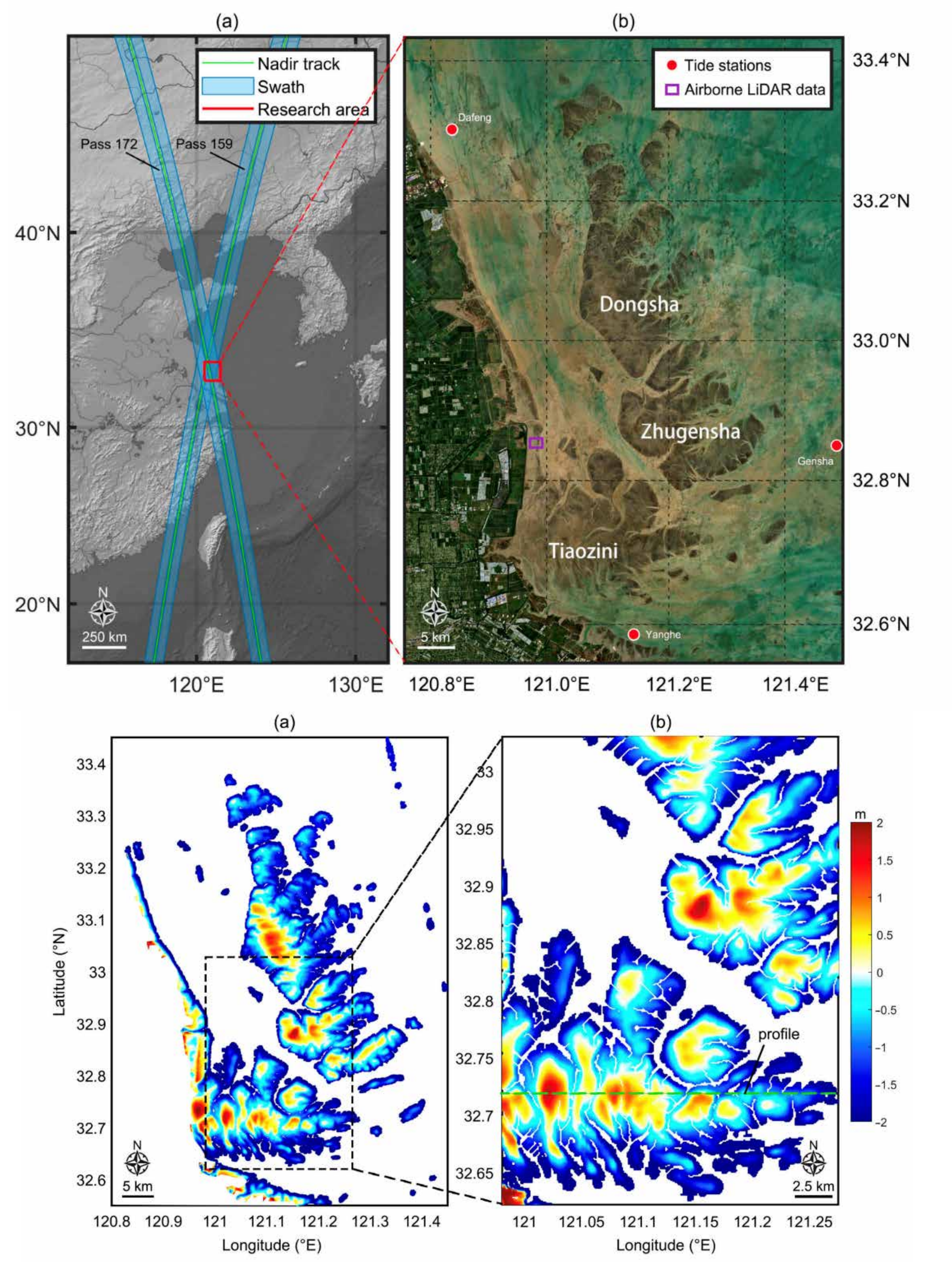




Other studies

Confirming SWOT intertidal mapping capabilities

The tidal flats of the **radial tidal sand ridges** in the coastal area off Central Jiangsu, **north of the Yangtze River Delta**

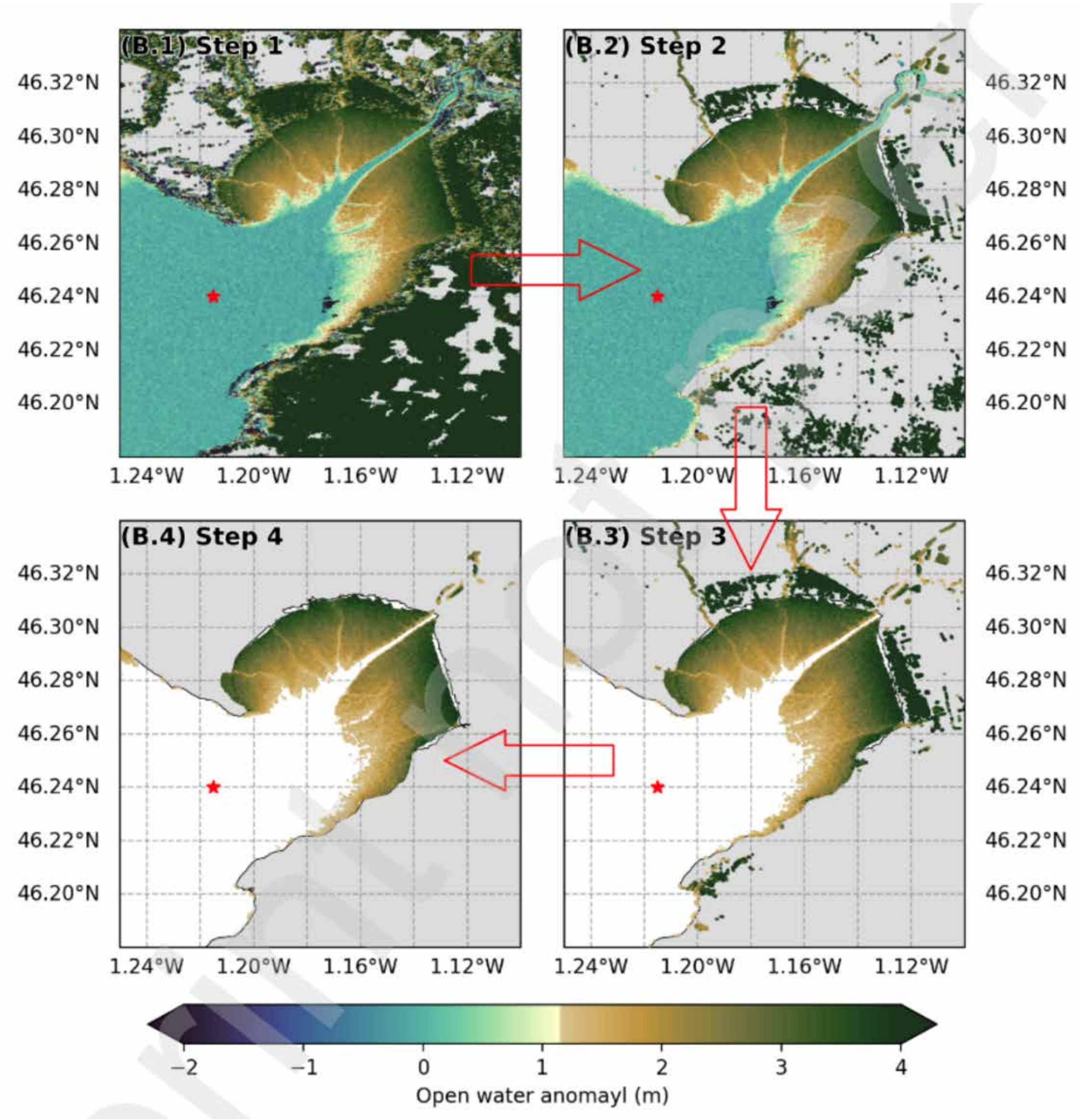


SWOT Level-2 (L2) Low Resolution (LR) unsmoothed data with a spatial resolution of 250 m.

Slope-based Method: This framework uses a neighborhood slope operator to create a topographic slope map. It then uses a histogram analysis of this map to determine a threshold for separating sea and land. An adaptive steepest descent algorithm is used to mask tidal channels. The method incorporates external tide gauge data as a reference.

Shi et al. (2025)

Pertuis Charentais, France, a macro-tidal region with complex geography and diverse bottom types (mud, sand, rock).



SWOT Level-2 (version C) High Resolution (HR) pixel cloud dataset. The HR product is a geolocated point cloud with a native resolution of ~15-25m cross-track and ~5-10m along-track.

This approach identifies intertidal pixels based on the probability distribution function (PDF) of sea surface height anomalies. It uses a phase noise threshold and a SWOT-derived water extent mask to filter out open water and land pixels.

Yeasmin et al. (preprint)

From Arcachon to the World

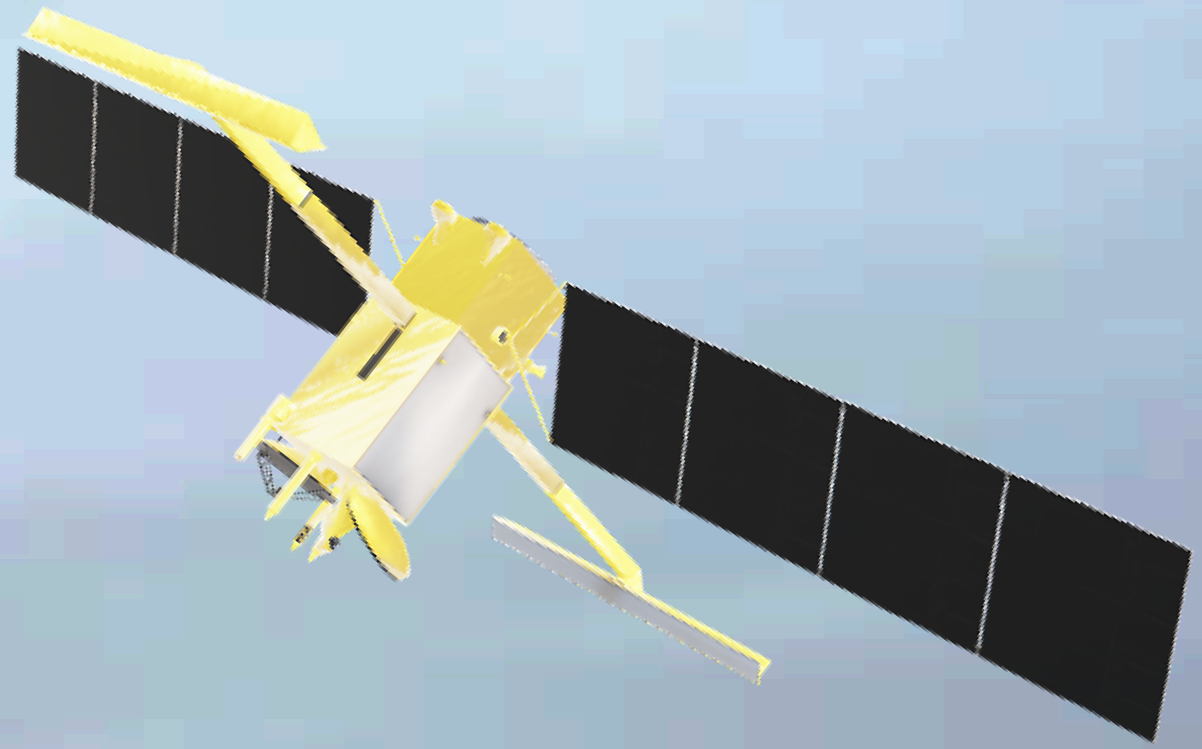
SWOT’s intertidal mapping

- From challenging 1D profile retrieval in Arcachon (RMSE<0.44 m) to routine, instantaneous 2D mapping (MAE≈0.13 m) using SWOT.

- The breakthrough lies in successfully exploiting SWOT's single-pass interferometry over exposed mudflats, providing a robust, instantaneous measurement that bypasses the limitations of multi-pass methods.

- This validated capability enables operational regional mapping and critical local studies, providing essential input for hydrodynamic models and managing coastal flood risk.

- SWOT has the potential to be a foundational component of the coastal observing system, providing the necessary spatiotemporal frequency to monitor seasonal and interannual morphological change globally.



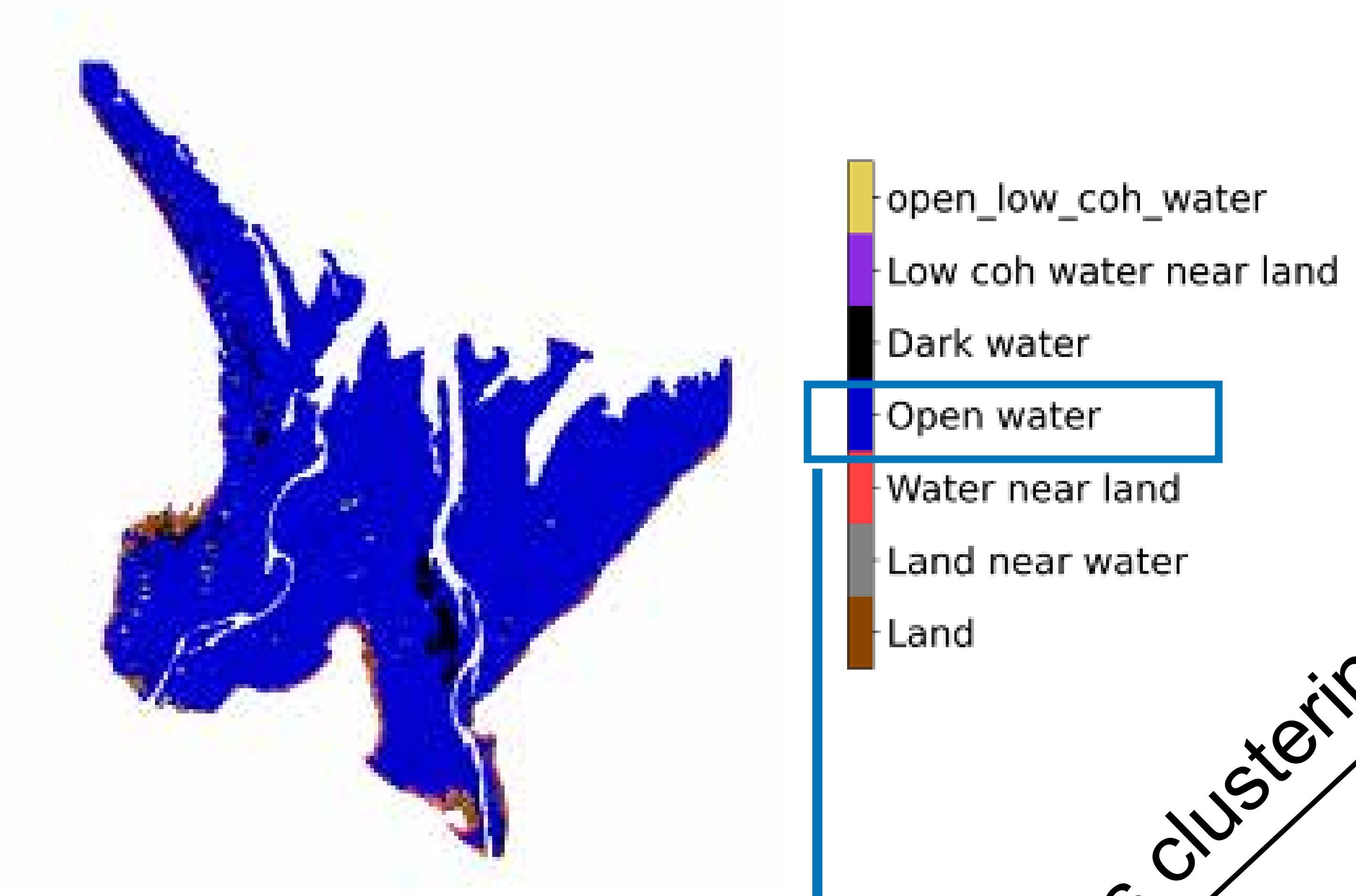
Thank you

Building SWOT DEM

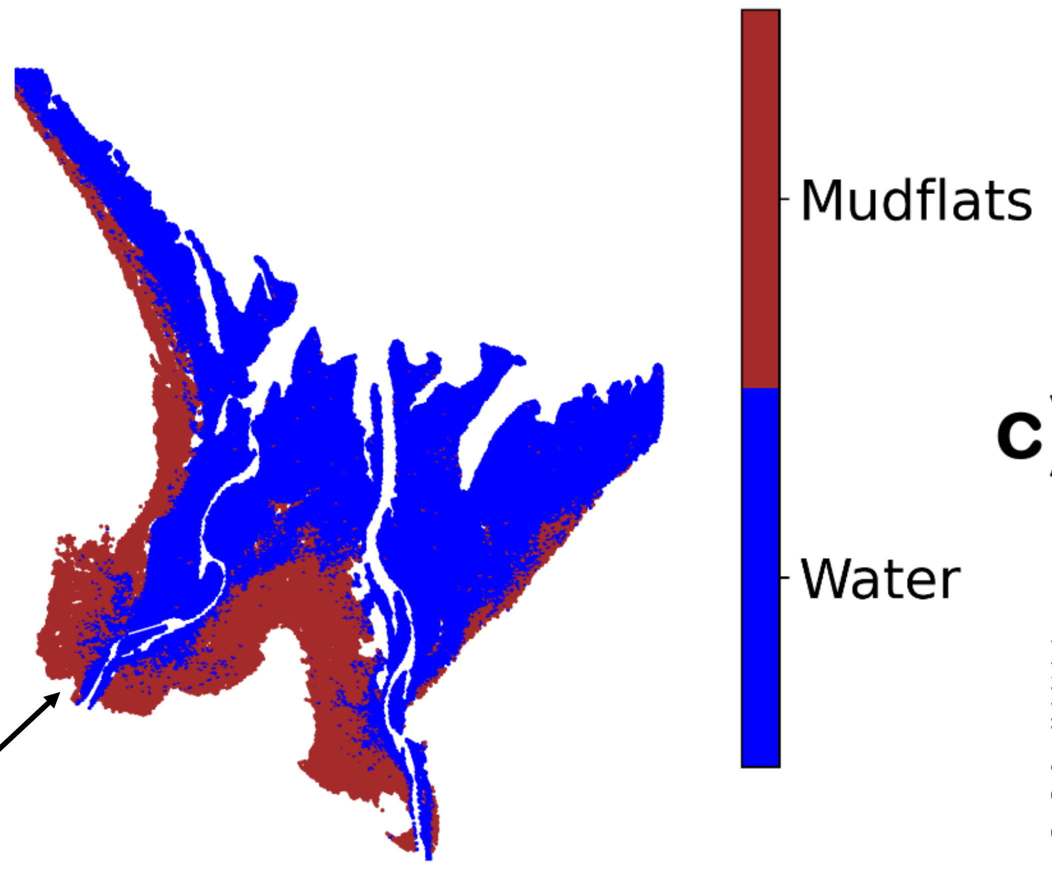
Separating uncovered mudflat pixels from water

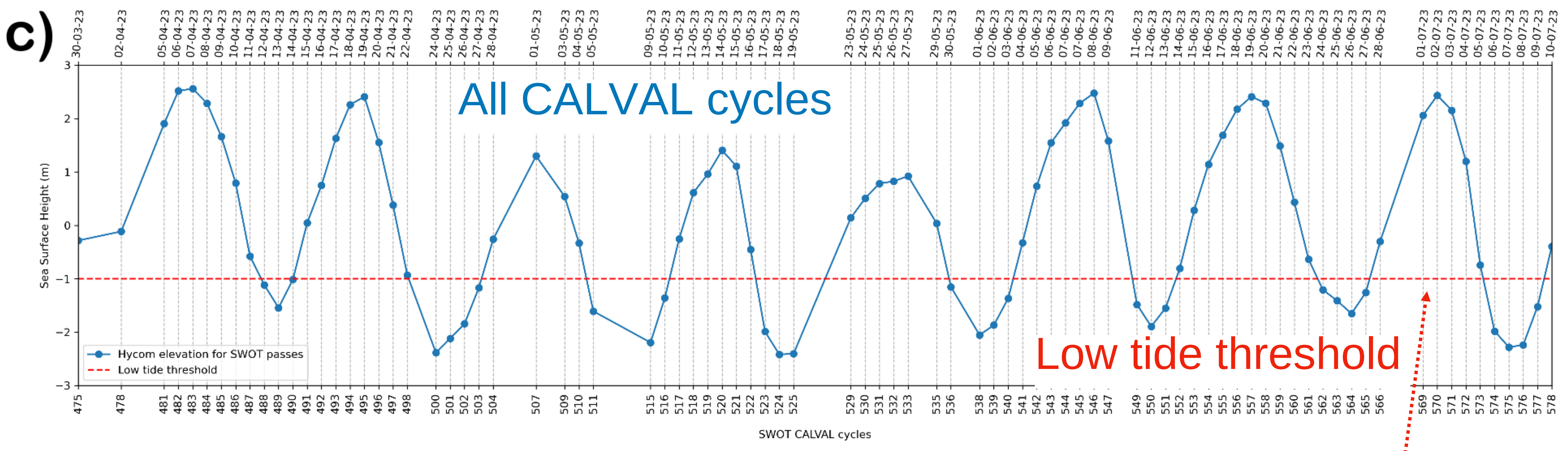
Extracting mudflat pixels by using a k-means clustering algorithm applied for pixels classified by SWOT as open water.

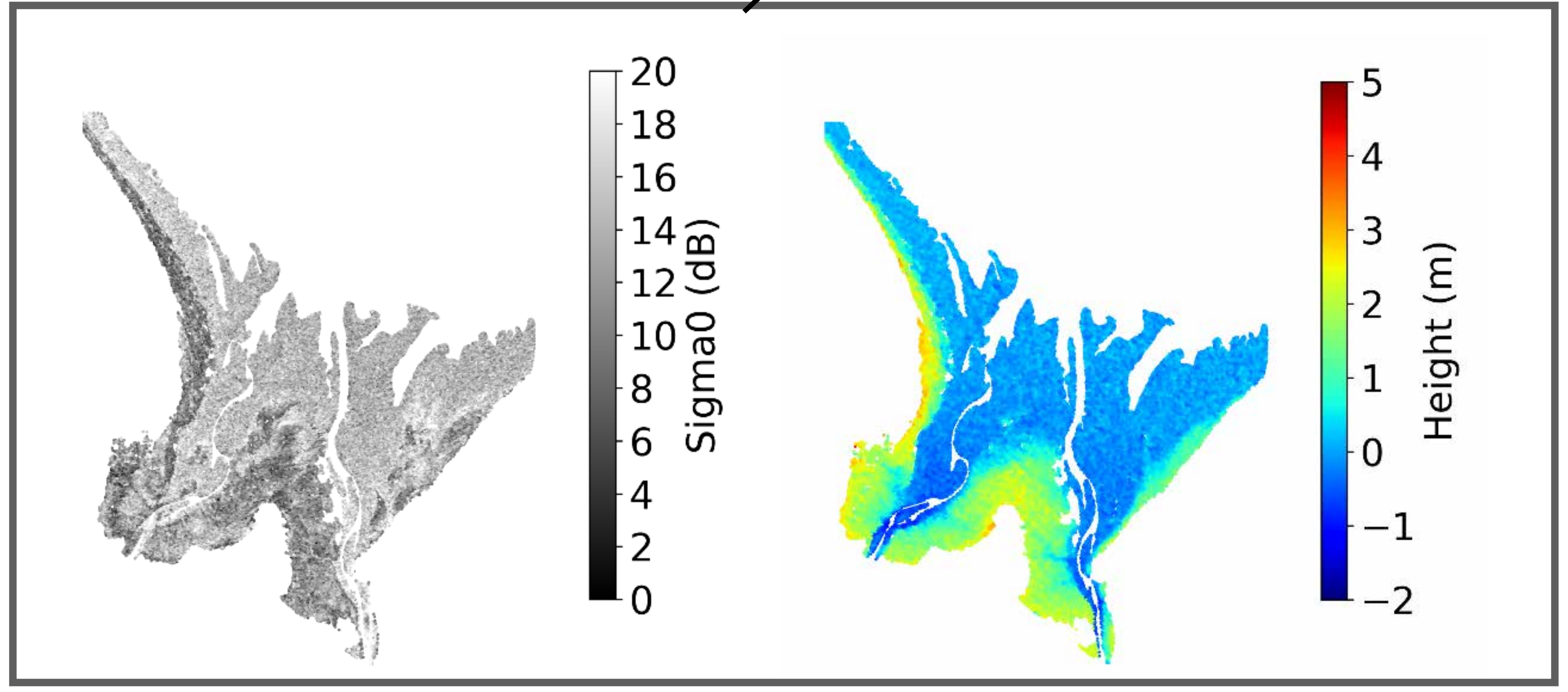
Two input parameters for k-means: Sigma0 and height



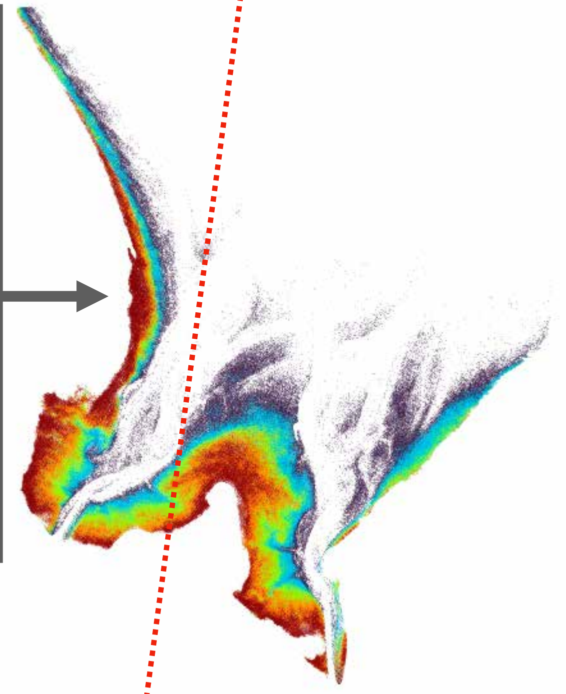
K-means clustering







- Extracting mudflat pixels from all CALVAL cycles
- Aggregating mudflat pixels height in a single point cloud
- Interpolation on a regular 10 m grid



DEM from all cycles

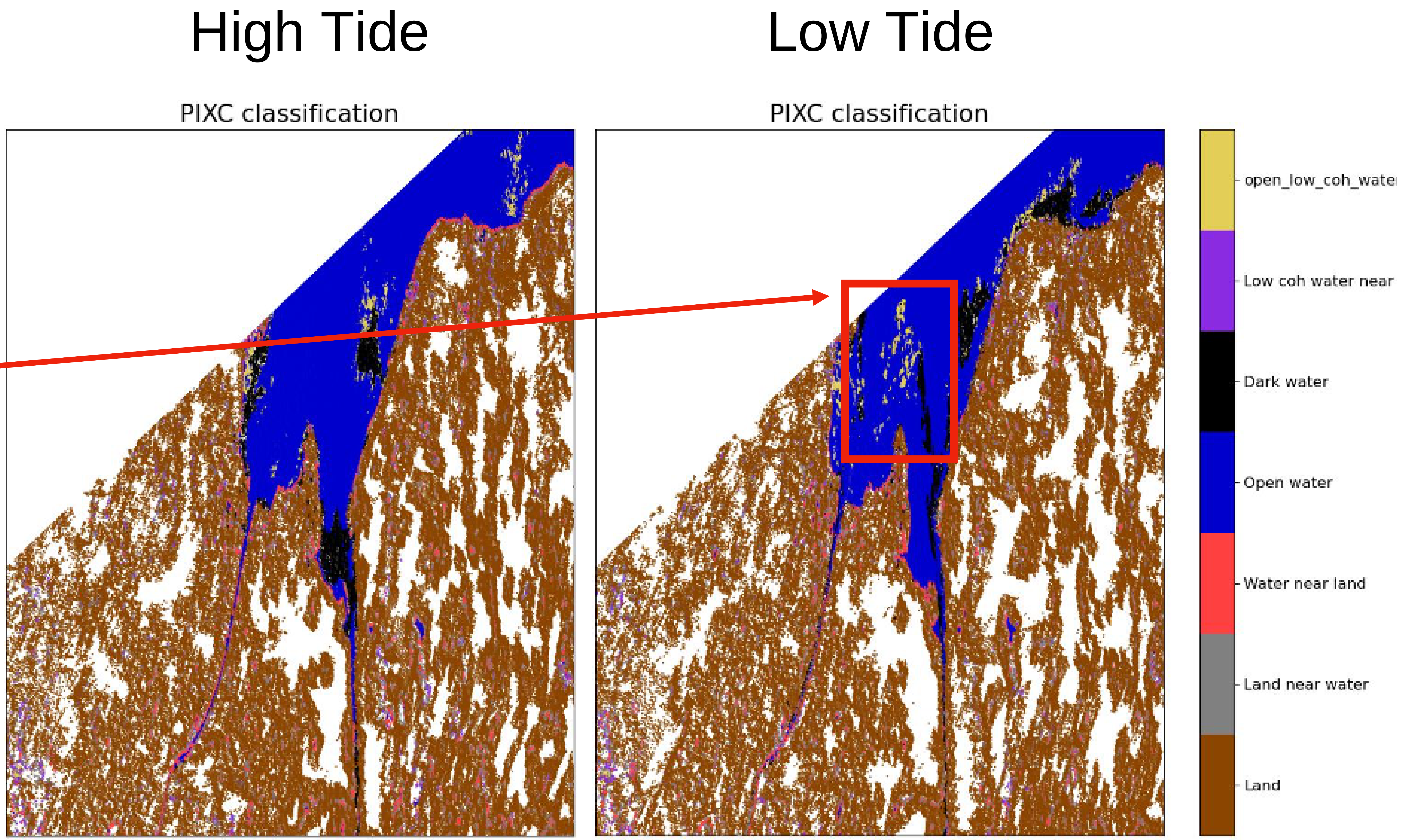
DEM from low tide cycles

SWOT HR DATA

A first look at the Pixel Cloud product

- SWOT_HR_PIXC **classification** at high tide and low tide.
- There is no dedicated class for mudflats
- At low tide, the emerged intertidal bed, is mostly classified as open water (due to the strong backscatter of these surfaces compared to dry land)

The waterline approach is not straightforward without an adequate classification

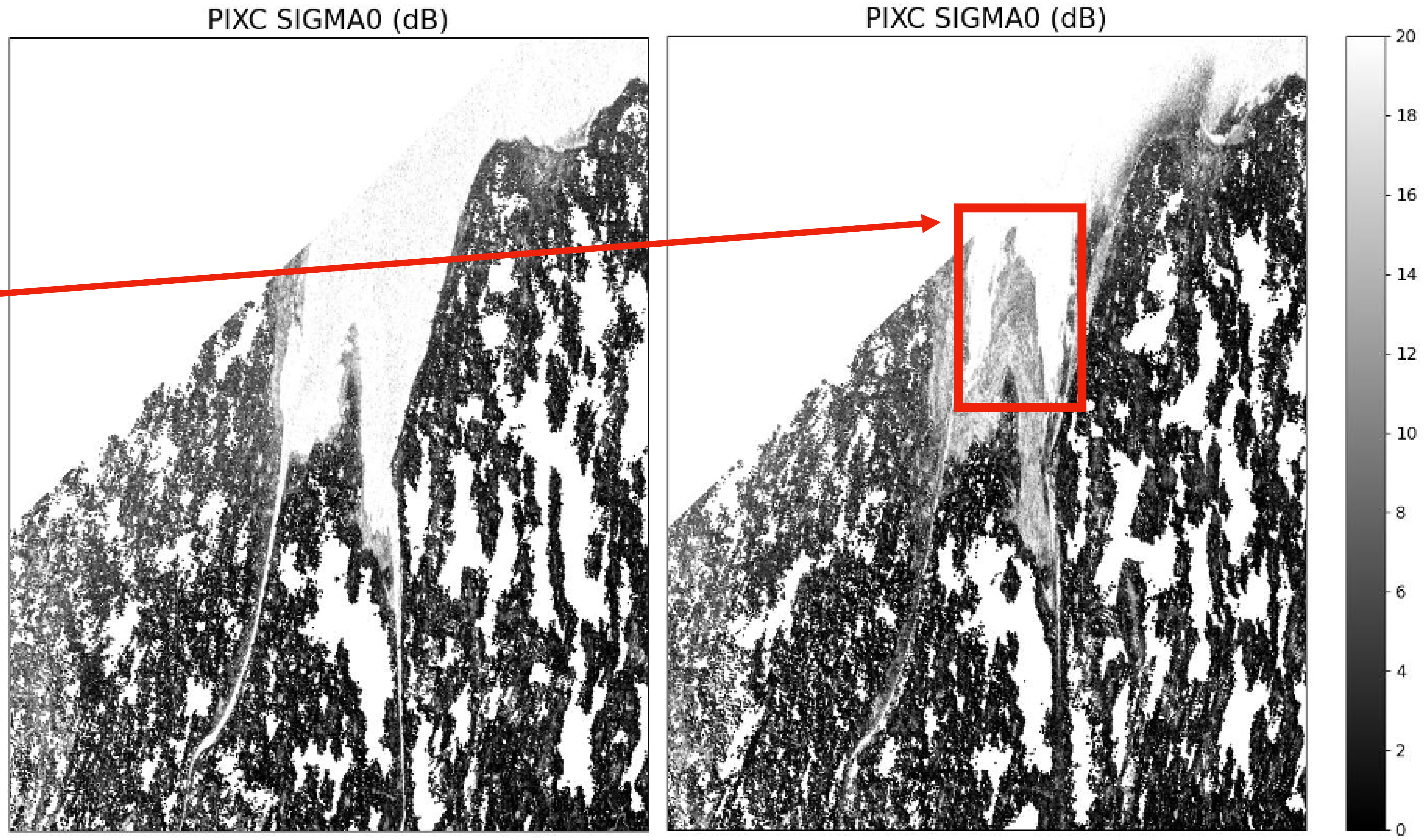


SWOT HR DATA

A first look at the Pixel Cloud product

High Tide Low Tide

- SWOT_HR_PIXC backscattering coefficient (**Sigma0**) at high tide and low tide.
- The high backscatter over the emerged intertidal bed, should allow for achieving adequate interferometric coherence, therefore, precise geolocated heights.



SWOT HR DATA

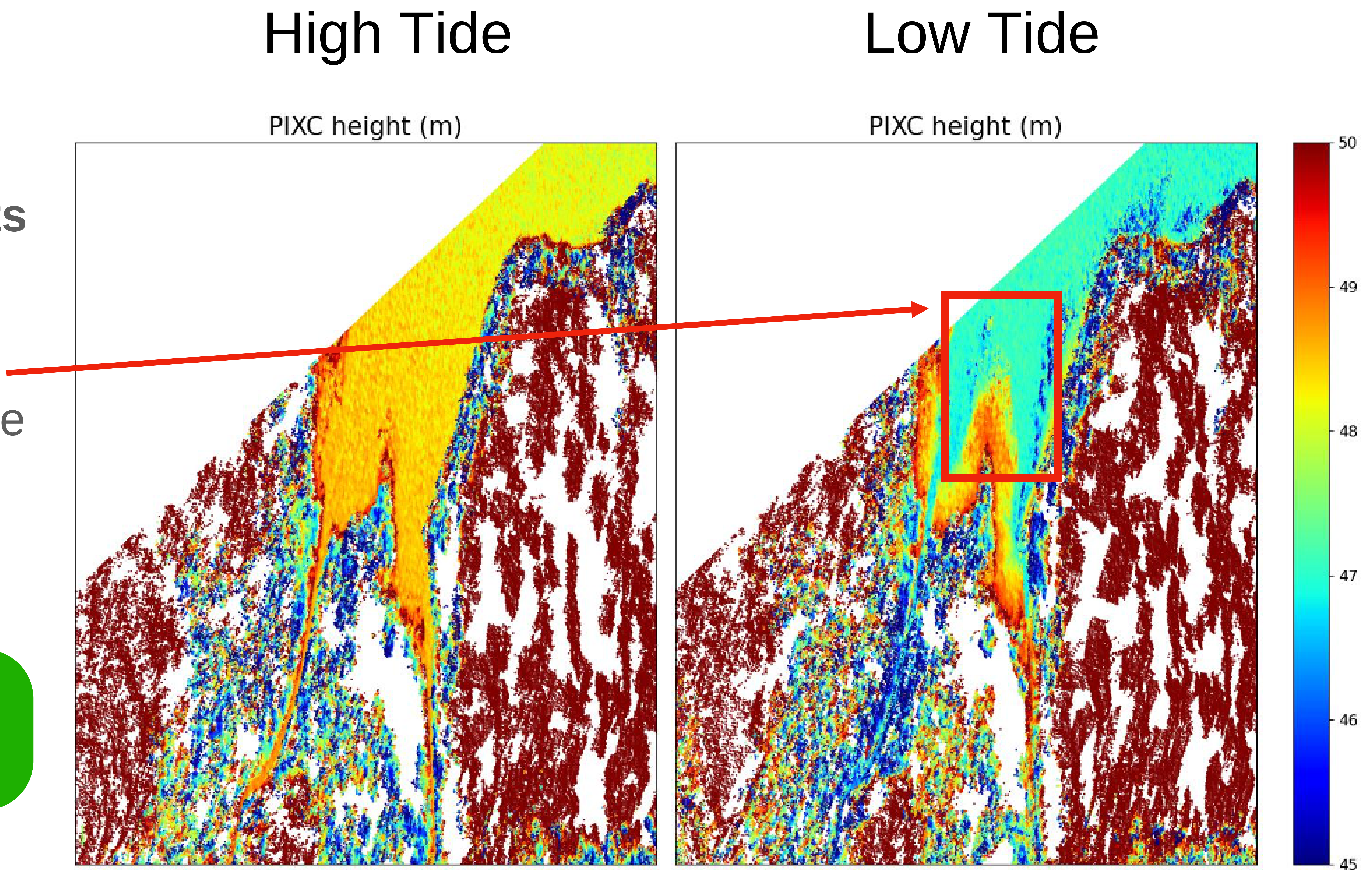
A first look at the Pixel Cloud product

- SWOT_HR_PIXC **heights** at high tide and low tide.

- At low tide, the emerged intertidal bed heights were close to the known intertidal topography

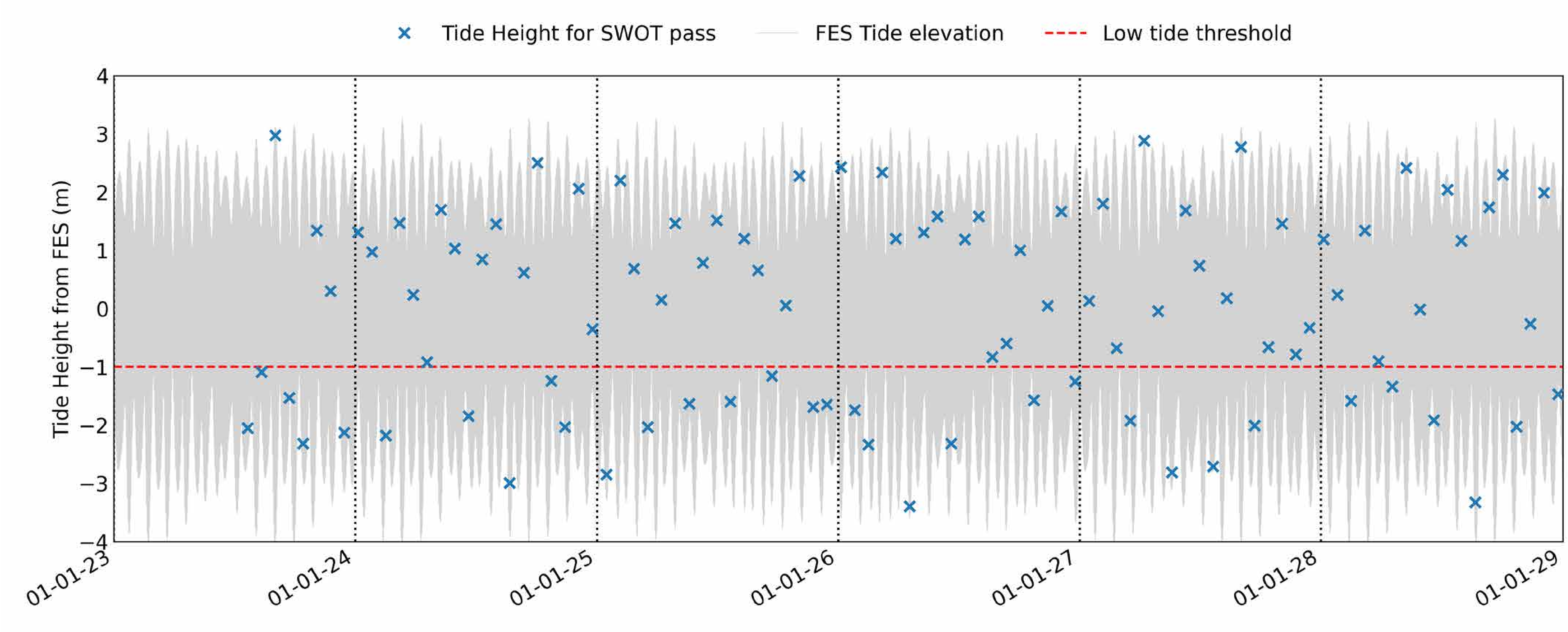
↓

An opportunity for accurate topography from interferometric heights



SWOT science orbit (21-day)

What can we expect?



- Expected SWOT passes over the Bay of Veys according to tidal height predicted from FES2014 for the next 5 years.
- 4 to 7 low tide acquisitions are expected from SWOT each year.
- These acquisitions span different seasons, allowing the eventual assessment of seasonal changes, particularly following highly energetic events that induce significant changes in the system.

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