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FLOODPLAIN DEM

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Science Team Meeting, 2025, Arcachon

FPDEM SCIENCE REQUIREMENTS

2.6.4.a [Requirement] A DEM of land elevations near the boundary of water bodies shall be derived from water elevations and extent.

2.6.4.b [Requirement] This DEM shall be produced annually starting with the first year of data after the conclusion of the fast-sampling phase. The estimation of storage change for both rivers and lakes requires known bathymetry (i.e., topography) for the case when flooding is initiated across previously dry land (e.g., the first pulse of floodwaters across a floodplain or that of a rising lake level across a low slope shore). In addition, floodplain Digital Elevation Models (DEMs) are a key data set for understanding flood dynamics. Floodplain DEMs may be produced by using the varying river or lake stage and extent to contour the floodplain topography. The topography maps cannot be produced for each pass since they require the observation of the river stage history over the mission lifetime.

PROPOSAL

Open issues due to SWOT phenomenology (dark water, bright land areas…) make it difficult to produce a floodplain DEM everywhere in a robust way. However, SWOT's high performance, in particular the high signal level on wet land surfaces, means that several approaches to estimate bathymetry are possible.

Combining different approaches, depending on involved phenomenology, seems difficult to fully automatize in order to address the particular characteristics of each scene. In particular, the accuracy of SWOT classification (both water detection and dark water prediction) and flagging is not sufficient to perform a robust floodplain DEM extraction globally.

➔ **Global floodplain DEM extraction method will be too difficult to scale up in terms of:**

- **Algorithm development**
- **Cost/compute resources**
- **Validation/person time**

➔ **Global floodplain DEM will not be produced by the project.**

PROPOSAL

- Select sample floodplain DEM areas that cover a variety of water body topologies and SWOT phenomenology
- Propose several open source algorithms (scripts and notebook tutorials)
  - Allow the science community to process these test cases
  - Users adapt the proposed algorithms to their own case studies
  - Users can make collaborative improvement of these algorithms
- Some algorithms are adapted only for specific science fields (rivers, individual lakes, etc…)
  - We need input from science users to know if it is useful and worth to scale these methods
  - What framework? ST working groups, project?
- Introduce multi-sensor approaches
  - Water versus wetland detection is a critical point to address
  - Independent water masks could help a lot

AREAS STUDIED

- Barotse river (Zambia)
  - Lots of bright land with good interferometric phase
- Orient lake (France)
  - Reservoir lake with simple shape, featuring some typical issues
- Koshi river (Nepal)
  - Complex steep river with a lot of variations in extent
- Haditha lake (Iraq)
  - Big complex lake with over-prediction of dark water
- Intertidal areas: Mont Saint Michel and Oleron (France)
  - Areas with strong radiometric variations over wet sediments (brighter or darker than water)
  - Ongoing studies over other sites
- Congo and Niger basin
  - Large inundated areas with strong (and fast) dynamics
- Toshka lake (Egypt):
  - Very dry land falsely detected as water.
  - Some interesting agricultural field patterns detected by SWOT
- Lajeodo river (Brazil):
  - River with complex morphology: strong slope, a floodplain on the west side, and a lot of dark water for some cycles
  - Plenty of wet fields and small ponds with algae making the water/land categorization difficult

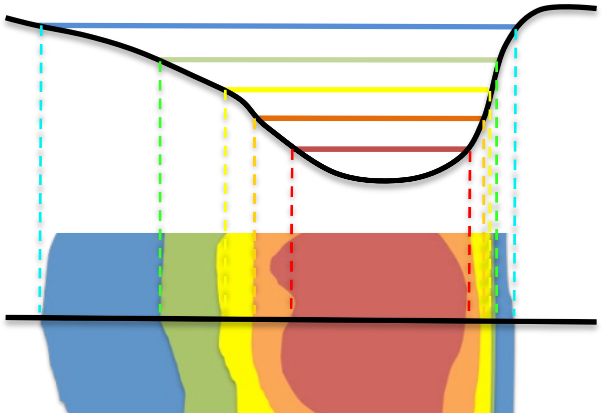
PROPOSED APPROACHES

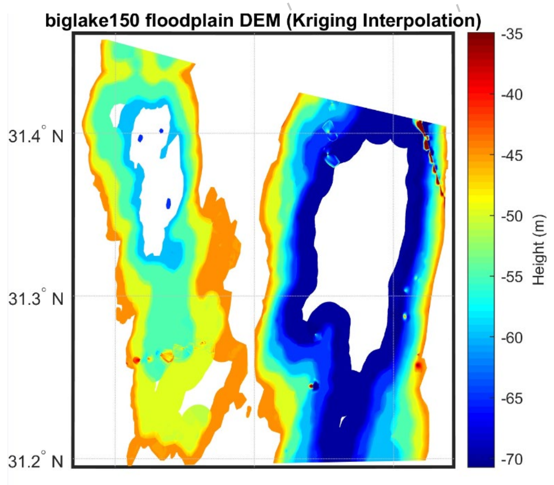
- Bathtub ring method
- Direct interferometric method
  - Based on PIXC product
  - Based on reprocessed PIXC with all pixels kept
- River Flood Plane DEM and Height Width Relationships
- Neural network-based alternative approach
- Combination of approaches

INITIAL APPROACH: BATHTUB RING

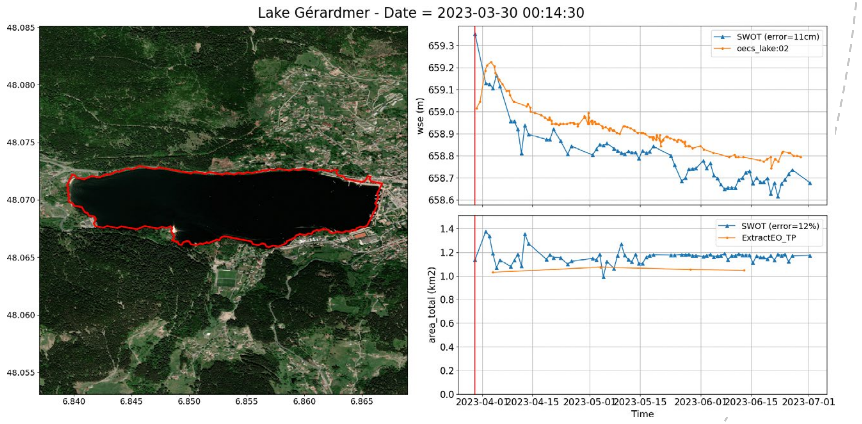
Principle and limitations

- Pre-launch plan was to use the waterbodies’ variations in elevation and extent to derive a partial bathymetry based on PIXC/PIXCVec products
  - For each date, the edge pixels of a detected water body form an (iso-) elevation curve (with slope for rivers and big lakes)
  - Between observed min and max water level only
  - Long time series needed (at least one year of data)
- Difficulties:
  - Errors and pseudo-random variations in elevation and extent (ex: Gerardmer lake where(true extent varies very little)
  - Fast dynamic (flooding event, etc…) have not sufficient number of different acquisitions to build a bathymetry
  - Very sensitive to dark water (and dark water flagging)
  - Bright land detected as water (crops, inundated areas, etc.) : Bathtub ring approach is not suitable and loses important contour lines
- Promising results obtained on some sites, but also many unsatisfactory cases.



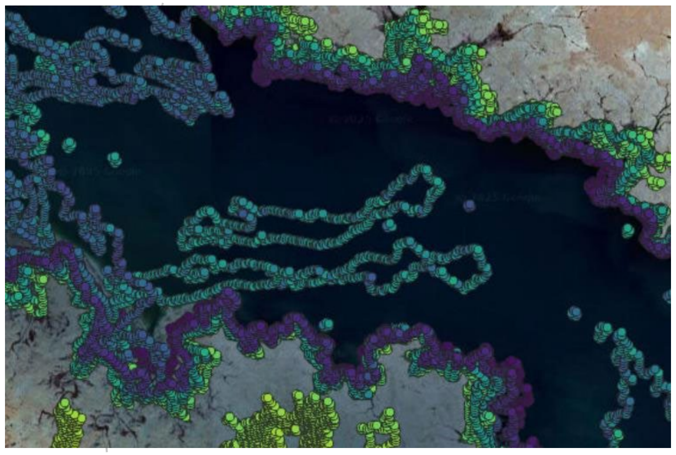


Example based on simulated data

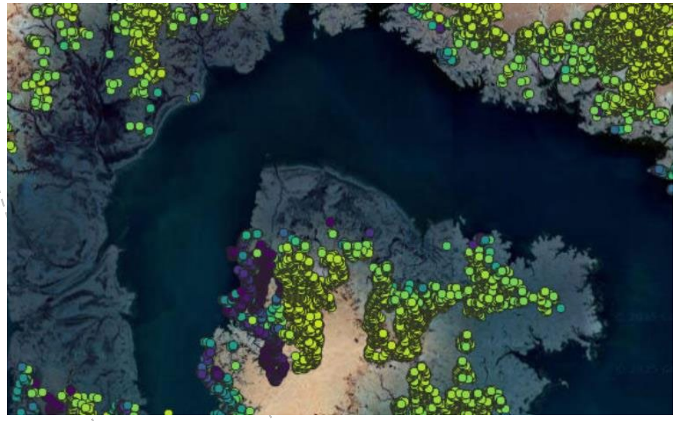


BATHTUB RING APPROACH

Example: Haditha Lake in Iraq ⇨ **Issues with dark water flagging**



Pixels correctly flagged as dark water but not used as water in FPDEM bathtub algorithm



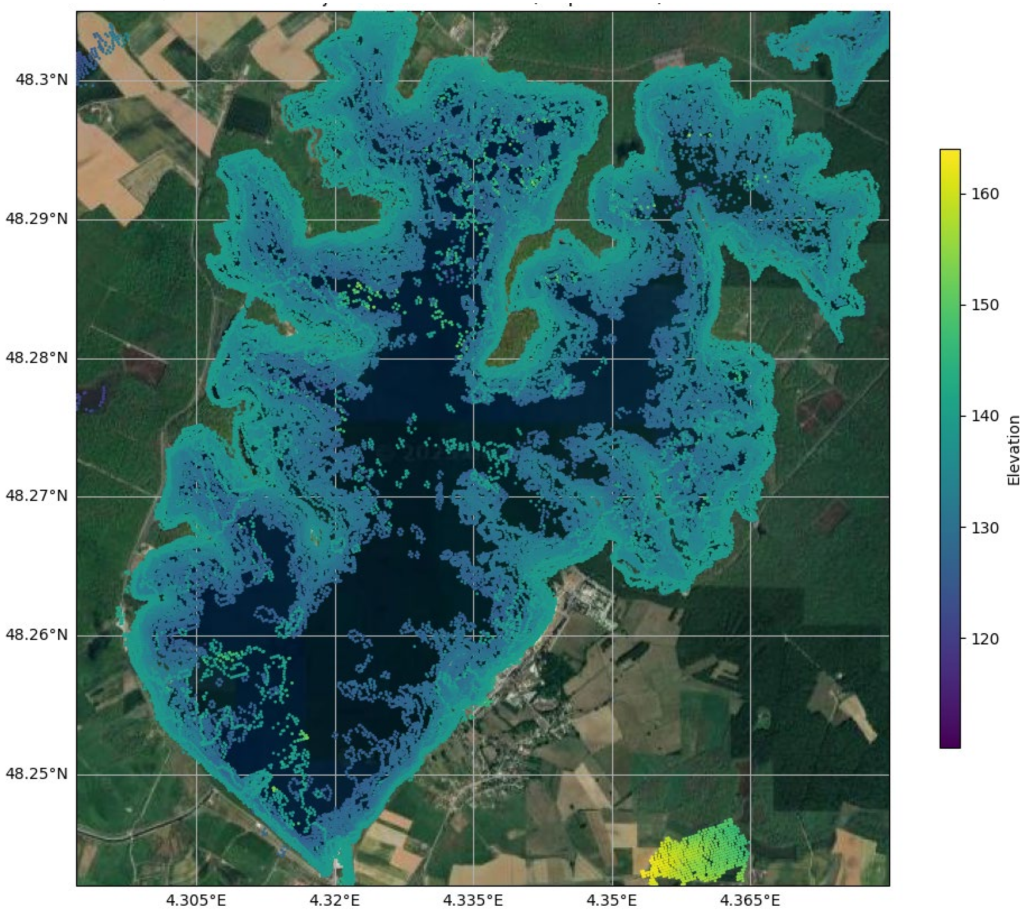
Pixels wrongly flagged as dark water and use as water in FPDEM bathtub algorithm

Difficult to automatically handle bad dark water prediction:

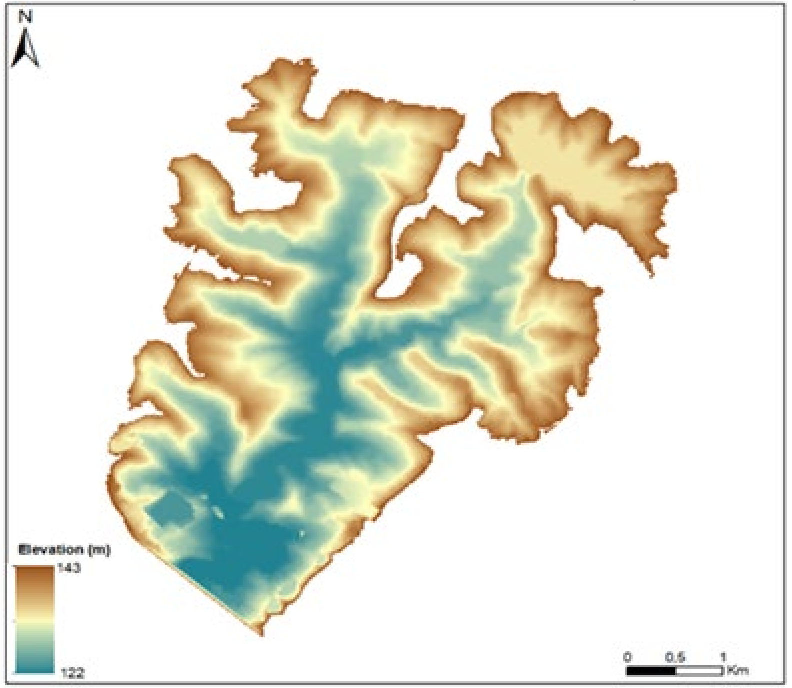
- Partial solution: use PEKEL 100% occurrence mask to only keep very plausible dark water pixels to avoid creating wrong boundaries
- Not sufficient to handle all cases, in particular when dark water occurs for low water level

BATHTUB RING APPROACH

Example: Orient Lake in France



Reference bathymetry based on in situ measurements
©Grands Lacs de Seine



Good overall agreement between SWOT-derived contour lines and in situ reference bathymetry (left), and partial bathymetry based on S2 images and gauge data (right), but with less detail for this SWOT time series (12 dates only), but with remaining artefacts that may be difficult to automatically handle

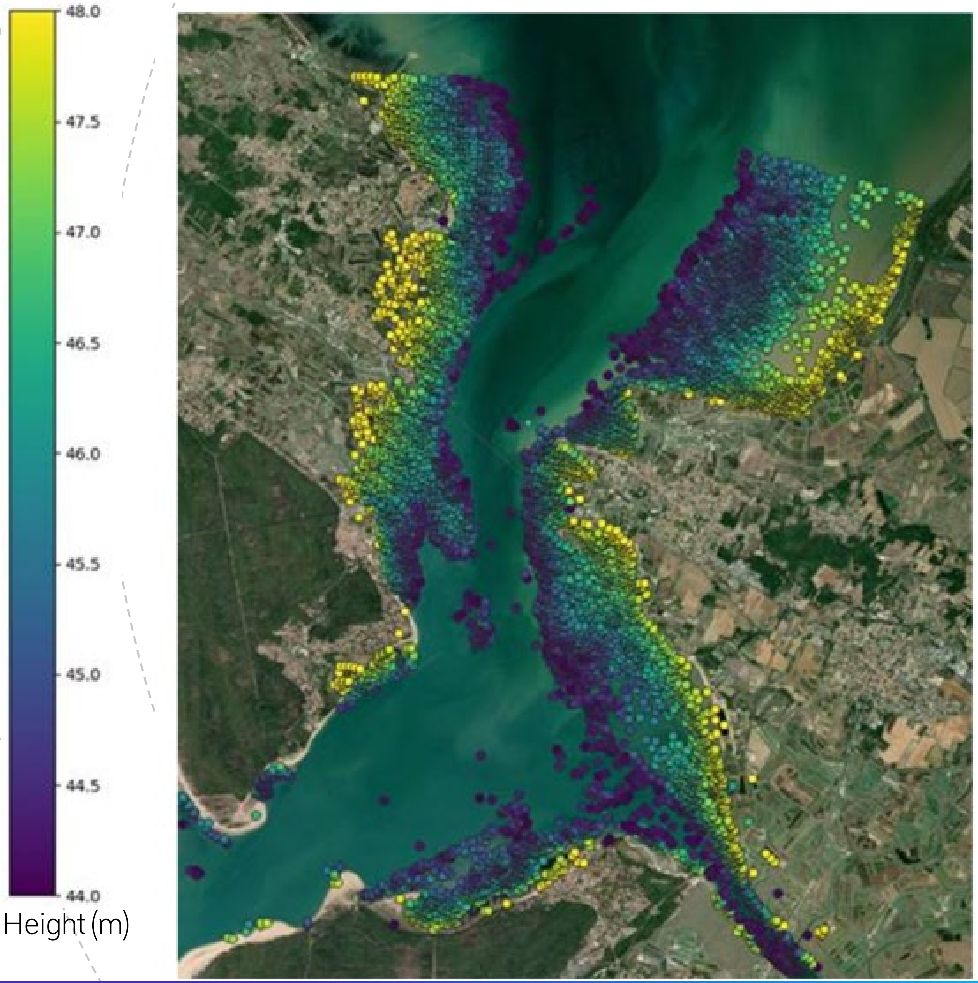
DIRECT HEIGHT EXTRACTION

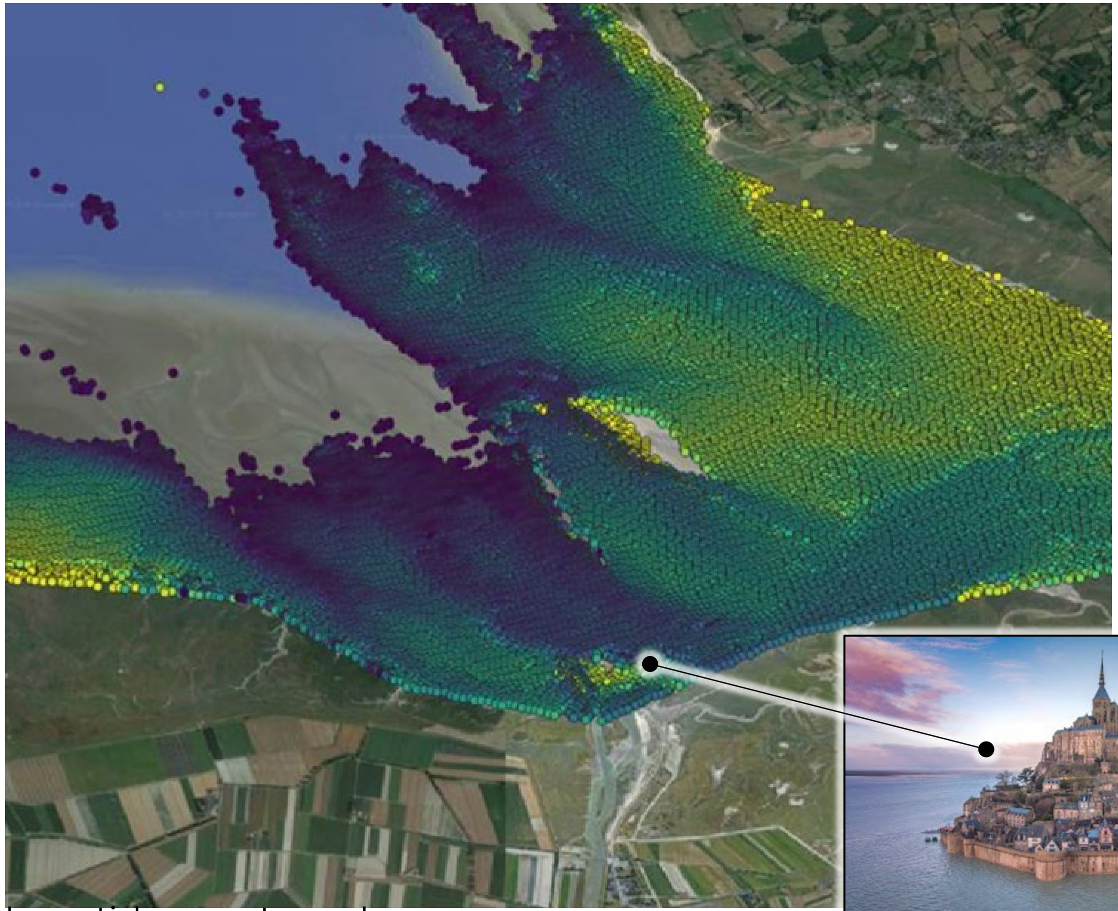
- Pre-launch hypothesis was that only water surfaces provide sufficient backscattering to perform interferometric height extraction based on SWOT HR data.
- However, some land surfaces including floodplains and intertidal coastal areas turn out to have sufficient signal to allow direct height extraction based on interferometry.
- With this approach, each acquisition (in favorable conditions) can provide a partial bathymetry, with the possibility to aggregate results over time.
- Limitations and challenges:
  - Layover may deteriorate DEM when the terrain slope exceed SWOT incidence (1°-4°)
  - Intertidal areas / floodplains not always detected as water (may be missing in PIXC product)
  - Water areas need to be distinguished and subtracted
- Not limited between observed min and max water level only (like with bathtub ring approach)
- Promising results obtained in coastal areas (wet sediments) and for certain floodplains (dry sediments)
- Main difficulty is to select only land pixels and remove water
- Could necessitate specific PIXC processing to keep relevant land pixels in the product

DIRECT HEIGHT EXTRACTION

Edward Salameh
University of Rouen

Example: Intertidal bathymetry in Moeze Oleron and Mont Saint-Michel Bay (France)

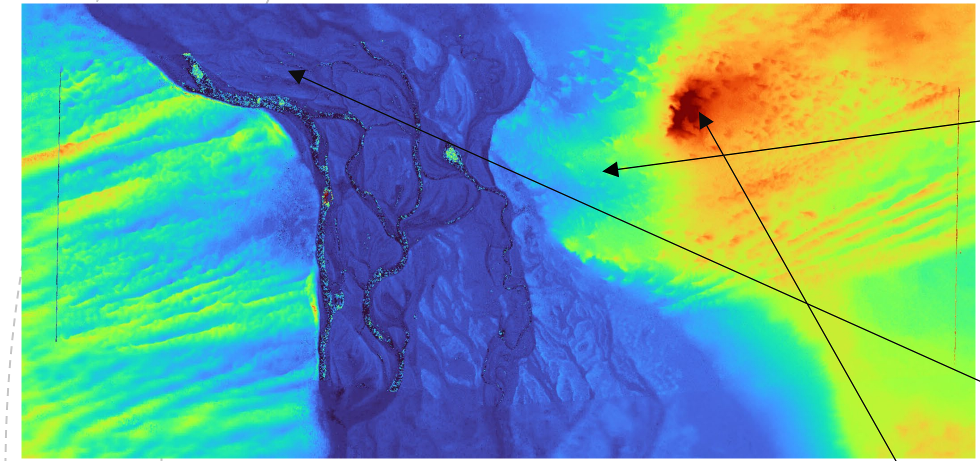




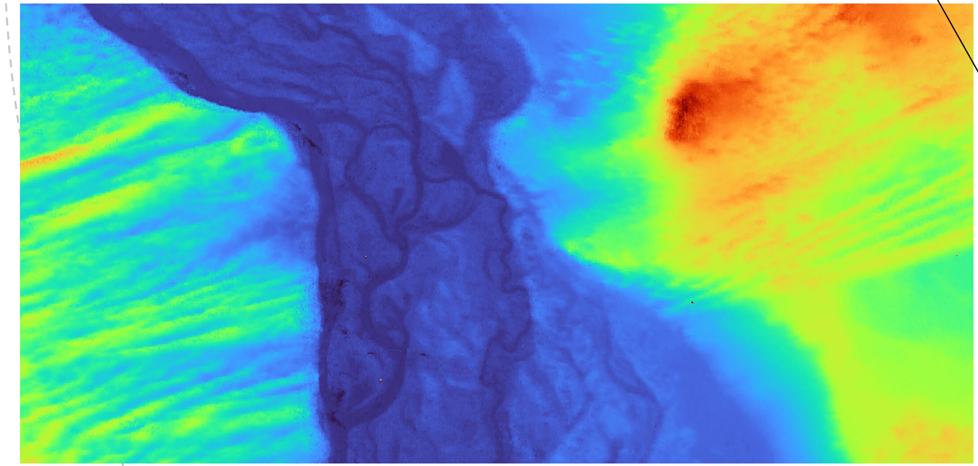
Low tides, wet sand

DIRECT HEIGHT EXTRACTION (WITH FULL DETECTION)

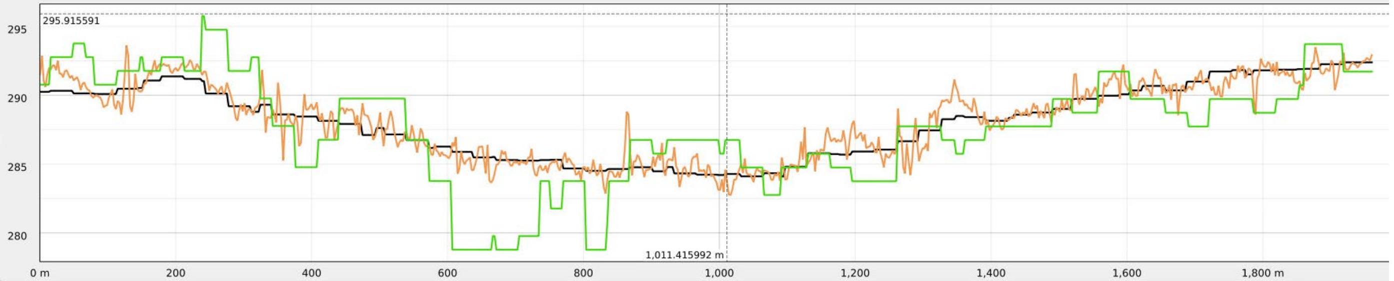
High resolution Pleiades DEM



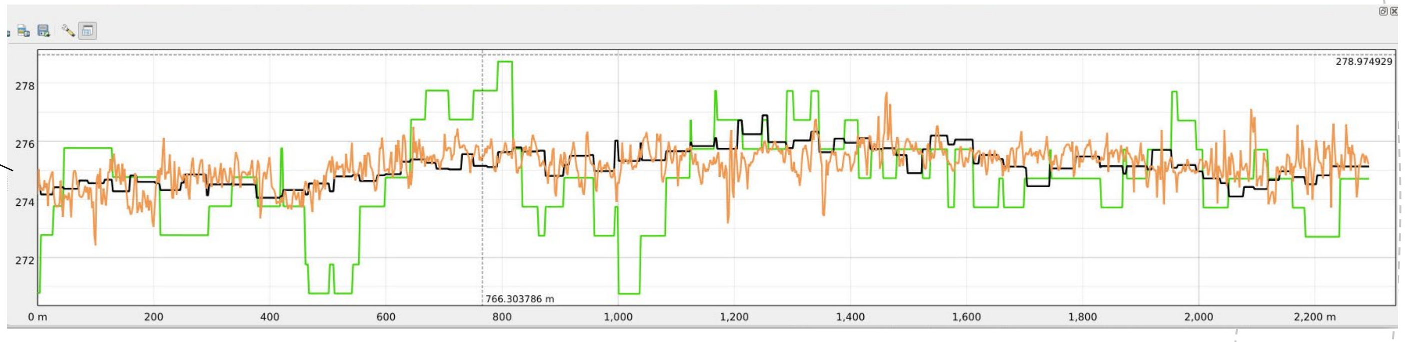
SWOT DEM (25 cycles, 2 passes, only summer cycle for central basin)



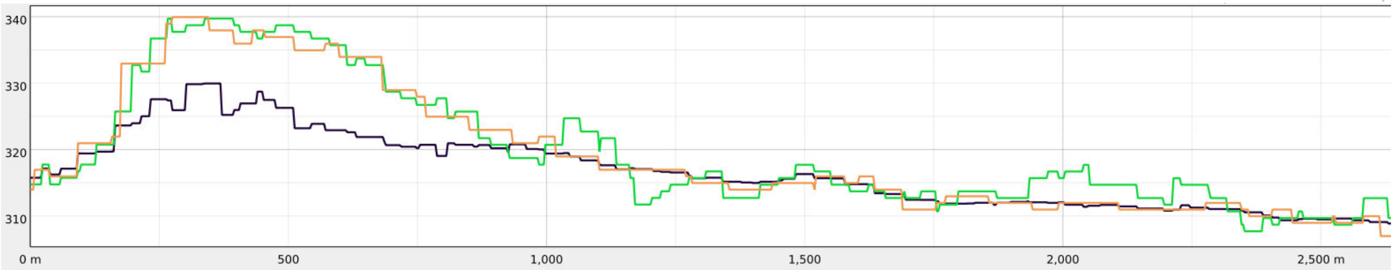
Sand dune area



Interior basin (fully flooded during winter)



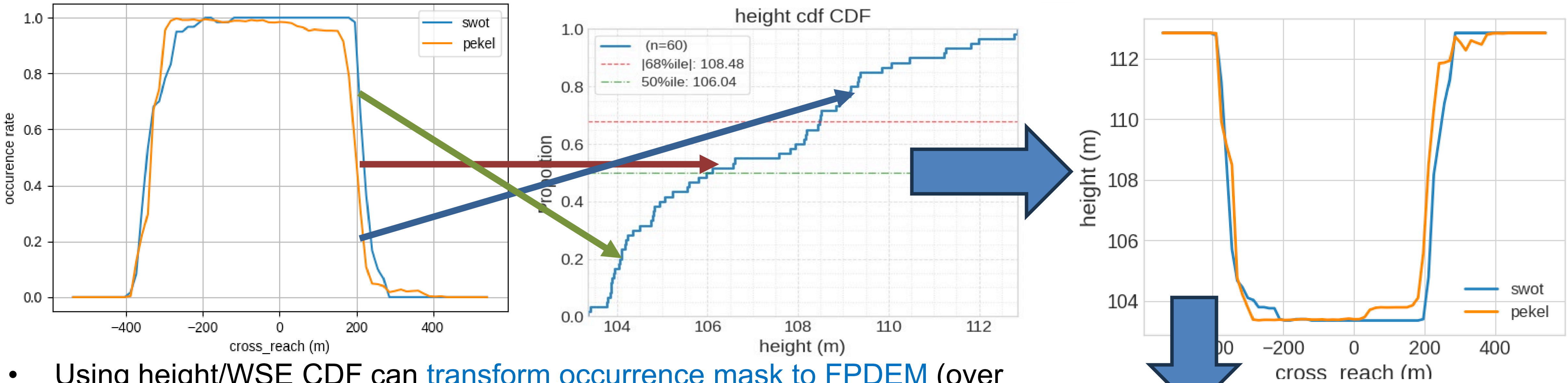
High slopes dunes (SWOT strong layover strongly degrade the DEM)



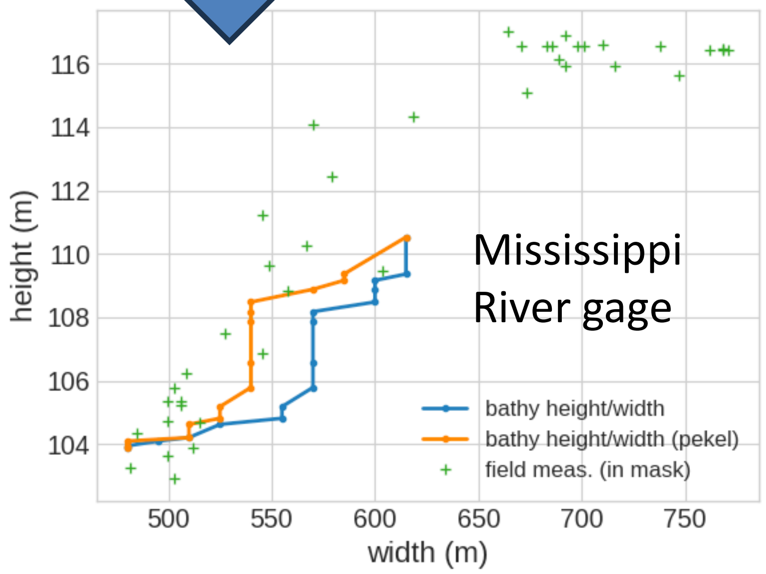
Green : SRTM reference DEM
Black: Averaged SWOT DEM
Orange : High resolution Pleaides DEM

Water detection deactivated (all pixels kept). Main limitation for SWOT DEM is layover

River Height/Width vs Height/Cross-reach



- Using height/WSE CDF can transform occurrence mask to FPDEM (over observed range of WSE)
  - Can use SWOT water occurrence, or Pekel, with SWOT node WSE CDF at any node globally
  - Other methods also possible that use WSE to measure riverbanks directly



- Height/width can be derived from the cross-reach DEM
  - Both SWOT- and Pekel-derived results are consistent with field measurements for this case

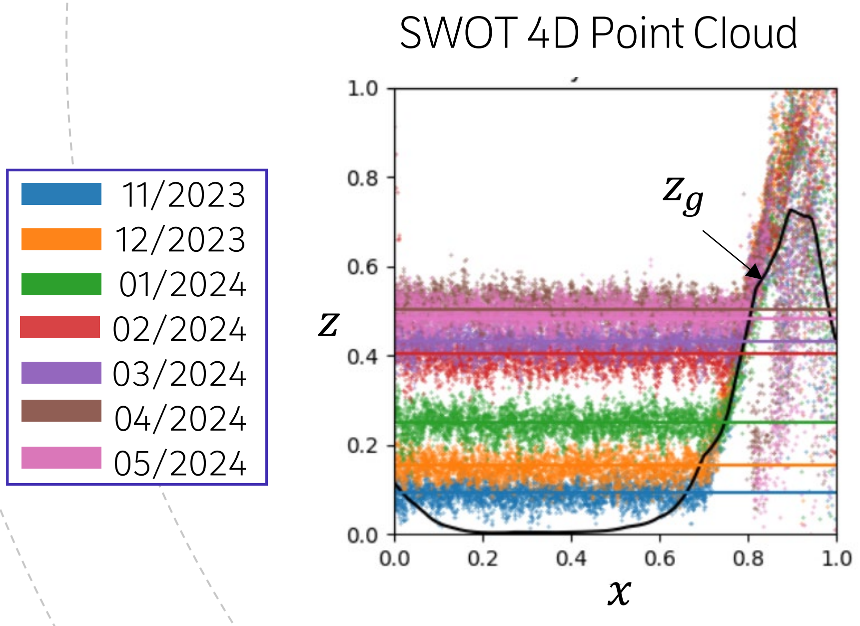
- This is a simple case, but there are cases where height vs cross-reach can encode much more information than height width (e.g., multichannel, or asymmetric banks)

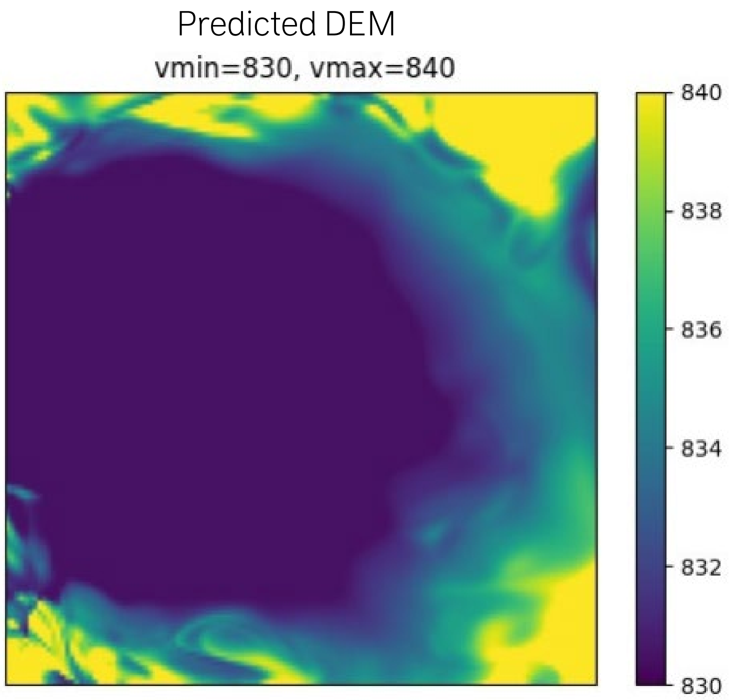
URS335953, CL#25-4193

ALTERNATIVE METHOD BASED ON NEURAL NETWORK

- Alternative approach studied by CNES downstream applications team
- Use the full pixel cloud and don't rely on the PIXC classification, only 4D coordinates
- Could be proposed for adapted areas (lakes, etc…)

Dawa Derksen (CNES)
Santiago Peña luque (CNES)
Laetitia lalla (CS-Group)
Benjamin Tardy (CS-Group)





More details in backup slides

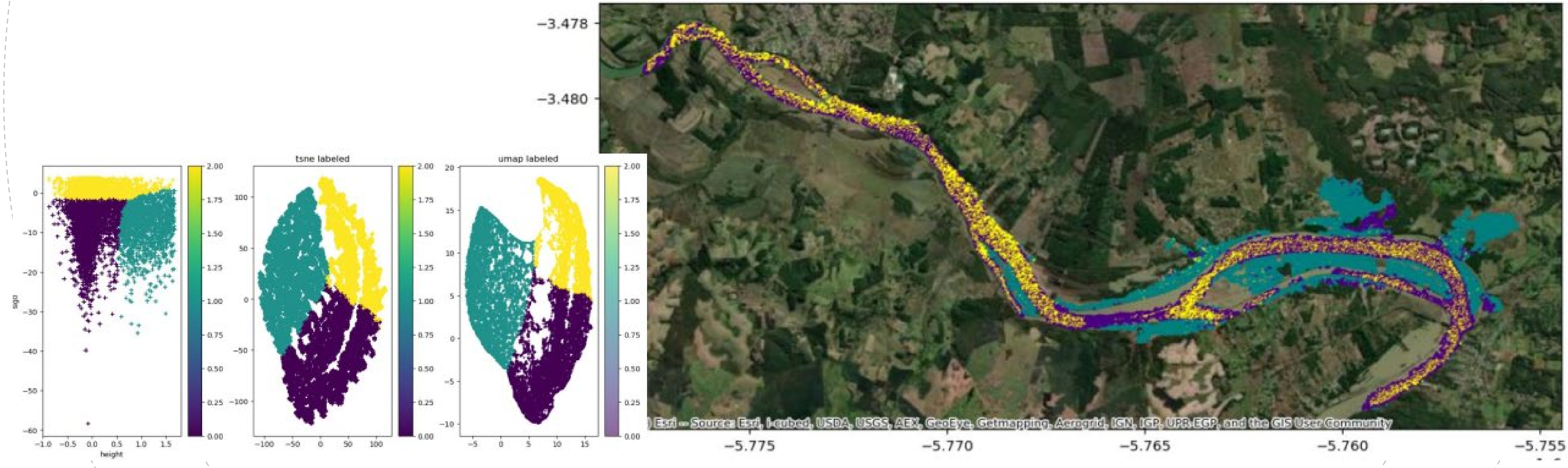
COMBINATION OF APPROACHES (BATHTUB RING + DIRECT METHOD)

- Identify which kind of surface we have for each water body
  - Water only ➔ Bathtub ring method
  - Land only ➔ Direct method
  - Mixed land and water ➔ Clustering and direct method for land, bathtub for water
- Identification based on both heights and sigma0 histograms
  - Need to select best indicator and combined method (p_value, skew, q_plot)
  - How to handle height variations (for rivers with strong slope, or water bodies with strong geoid variations)?
  - Use of auxiliary data (PEKEL, SWORD)? Rare drought or flooding events may not be correctly handled.

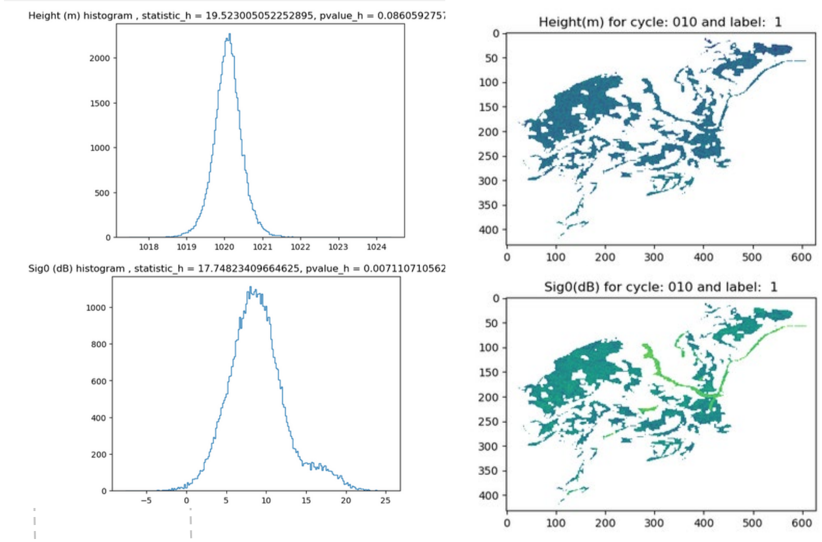
CLUSTERING OF MIXED LAND/WATER AREAS

Clustering method : zscore + kmeans

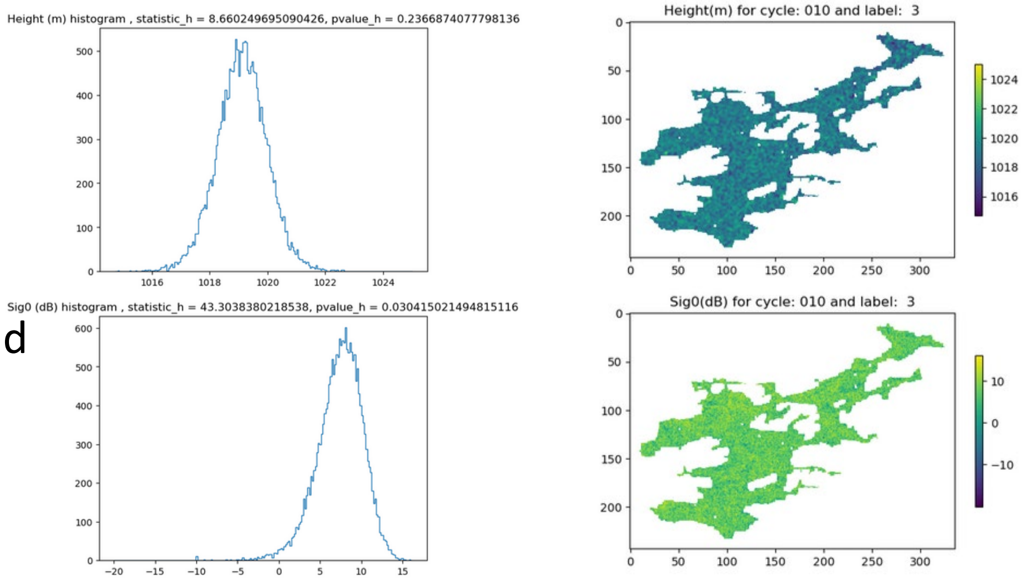
Height, sig0, longitude and latitude are used in the clustering algorithms.
Beforehand, the points are filtered using either 'zscore' or 'isolation forest' methods to exclude outliers in height and sig0.
River slope needs to be taken into account to improve robustness.



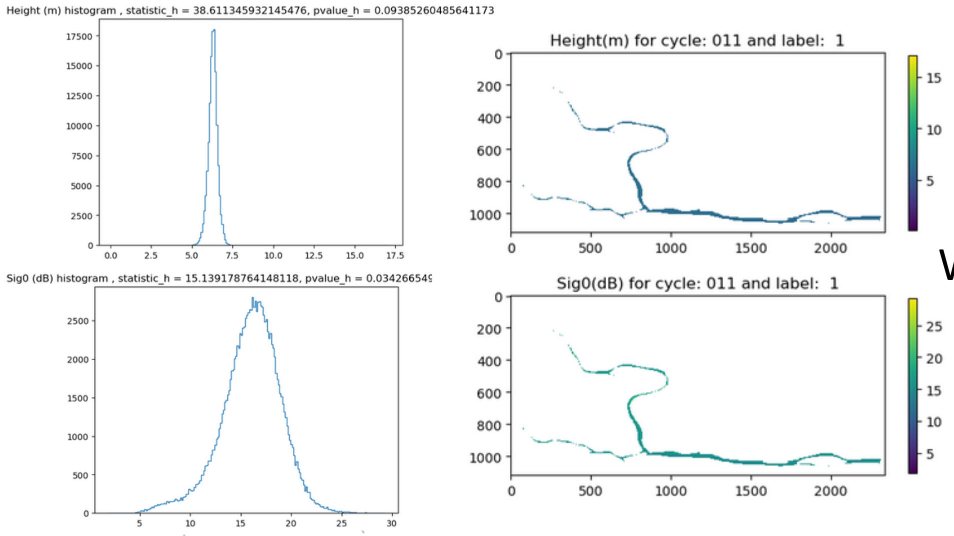
IDENTIFY STRUCTURES (LAND, WATER OR MIXED)



Water + land



Land



Water

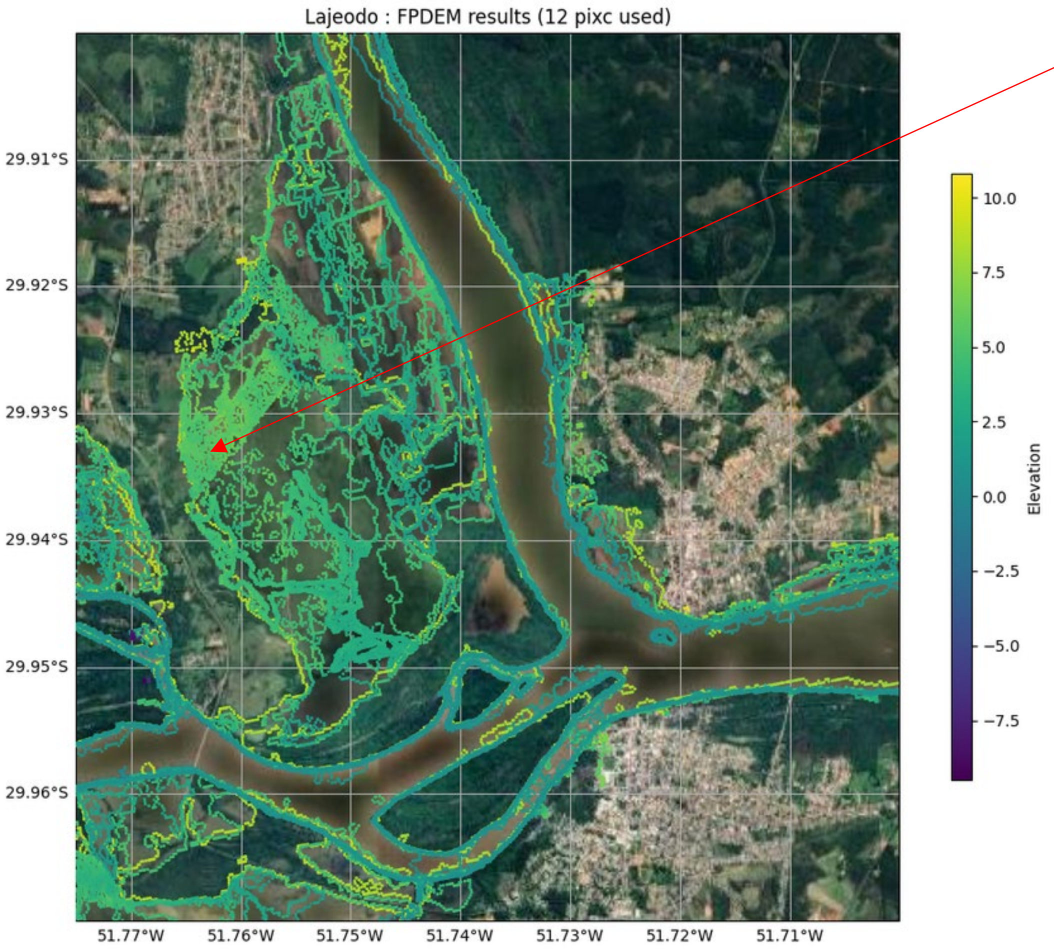
- Need for a large dataset with a lot of situations (lakes, river, flooding events, wet sand, vegetation, etc.…) to optimize identification criteria.
- May be to difficult to fully automatize due to natural variations ➔ manual tuning necessary for areas studied so far

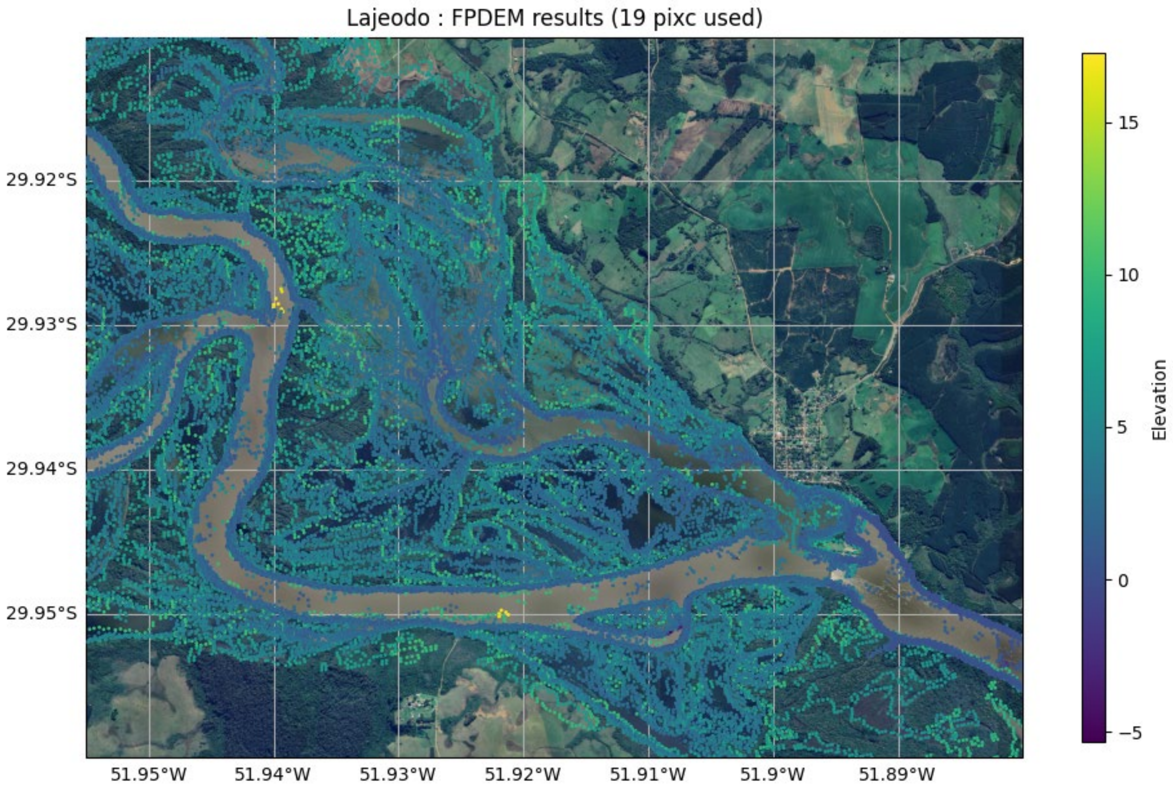
Skewness (for height/sigma0) ➔ mixed water/land
Skewness (only for height?) ➔ water with slope
Symmetry ➔ land or flat water
Mean/median sigma0
Width of the distribution can also be an indicator

RESULTS FOR LAJEODO FLOODING

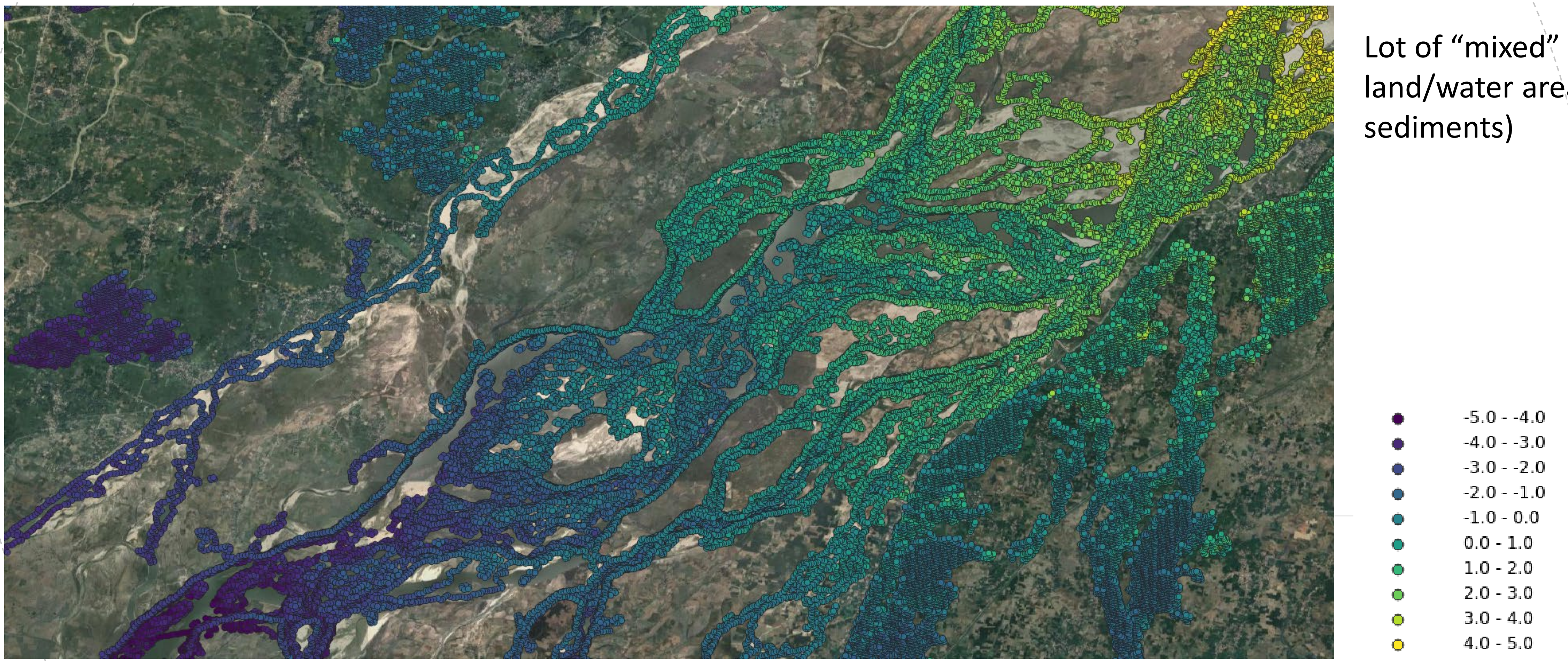
Mostly bathtub ring method (area identified as water)

Direct method (area identified as land)





RESULTS FOR KOSHI RIVER (NEPAL)



Lot of “mixed” land/water areas (wet sediments)

CONCLUSIONS

- Large variability of SWOT phenomenology for water surfaces and floodplains makes it difficult to extract floodplain bathymetry automatically at the global scale
- Main issue, whatever the method used, is to discriminate water from wet sediments and other land surfaces detected as water, especially when averaging multiple cycles and passes to reduce noise.
- Dark water (including misdetection due to clouds) also leads to errors because it create erroneous land/water boundaries that not represent bathymetry
- But high SNR, especially on wet soil, makes it possible to perform direct interferometric height extraction on some land areas, and obtain bathymetry of good quality

➔ Several approaches and algorithms, adapted to different scenes, will be proposed to science team

➔ Ongoing work on how to use quality flags to keep only relevant pixels

➔ Additional filtering may be necessary to handle outliers

PATH FORWARD

- We encourage you to test the different approaches on your test sites
  - To have high quality validation data to evaluate the extracted floodplain DEM
  - To address specific issues that have not been identified yet
  - To address if specific modification/addition needs to be done in processing chain to facilitate floodplain DEM reconstruction
  - To propose new methods and improvements to the currently available algorithms
- What level of involvement are we anticipating on the project side?
  - Validation is very time-consuming
  - Some methods and test cases may require specific PIXC reprocessing (disabling water detection), and we need to evaluate whether we can provide such data or tools to produce them
  - Do we continue to develop new approaches, or is it now a field for the science community?

River Path Forward

- FPDEM in the special context of rivers is potentially more scalable than a more general FPDEM

- What should be done by who and who will validate it?
  - Height/width relationships from RiverSP data at every node in SWORD
    - ADT not planning on developing nor validating
    - Science team well suited to do this (e.g., put it in future SWORD releases)
    - Developments can be used by ADT in future RiverSP algorithms
  - Height/cross-reach from Pekel occurrence and SWOT RiverSP node WSE CDF
    - This is likely also practical to do at scale, though more cumbersome
    - ADT not planning on developing nor validating
    - Science team could also develop and validate this, if desired
  - Height/cross-reach from SWOT PIXC/PIXCVec at large scale is less practical
    - ADT not planning on developing nor validating
    - Development could be done by science team (with guidance from ADT?) as well as validation
    - Unclear whether this is worth pursuing
      - What is the benefit to river science beyond the simpler approaches?
      - ADT could quantify the amount of effort, the accuracy, etc, but science team better suited to quantify the science benefit

- Is there a need for a FPDEM working group? Or is this better to coordinate more informally?