RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

cnes
CENTRE NATIONAL D'ÉTUDES SPATIALES

ALL-IN-ONE SWOT LAKE APPROACH

VOLUMES, BATHYMETRY AND UNCERTAINTY ESTIMATION

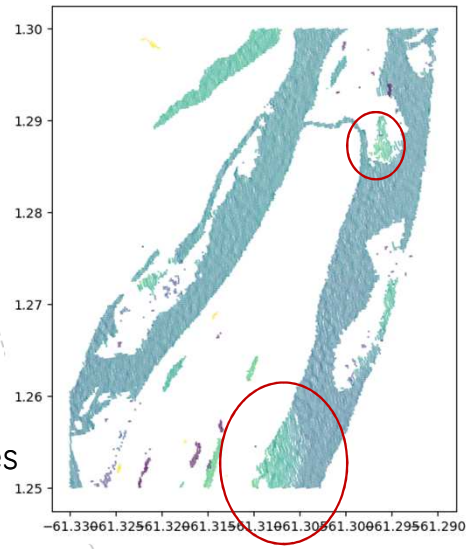
SWOT SCIENCE TEAM MEETING

14-17 OCTOBER 2025

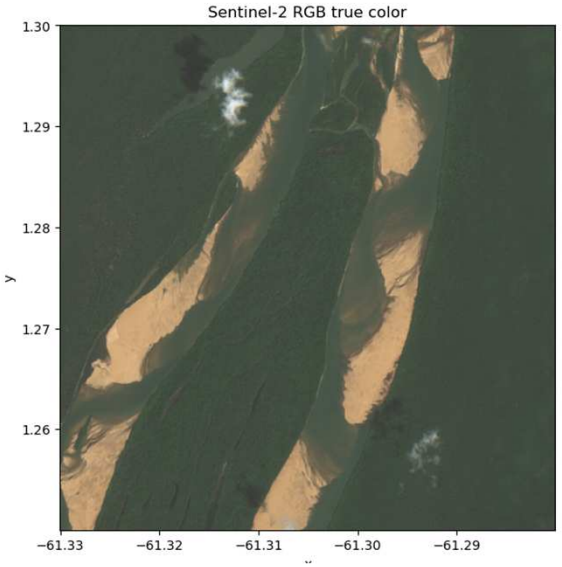
Santiago PENA LUQUE (CNES)
Dawa DERKSEN
Nicolas GASNIER
Laetitia LALLA (CS-Soprasteria)
Benjamin TARDY

CONTEXT - PIXEL CLOUD OBSERVATIONS

- Evidence
  - SWOT PIXC shows over estimation of WATER class in Sandbanks
    - Water AREA/WIDTH estimation might be Wrong
- Opportunity
  - Actually, flat and smooth sandbanks may offer good geolocation/wse (high coherence and SNR) –(E.Salameh et al, 2024)



SWOT PIXC WSE from Water Classes (3,4)



Rio Branco Sentinel2

- Questions
  - How could we use WSE from sandbanks?
  - How to reclassify water areas ?
  - Do we take Land pixels as well?
  - How to automate it?

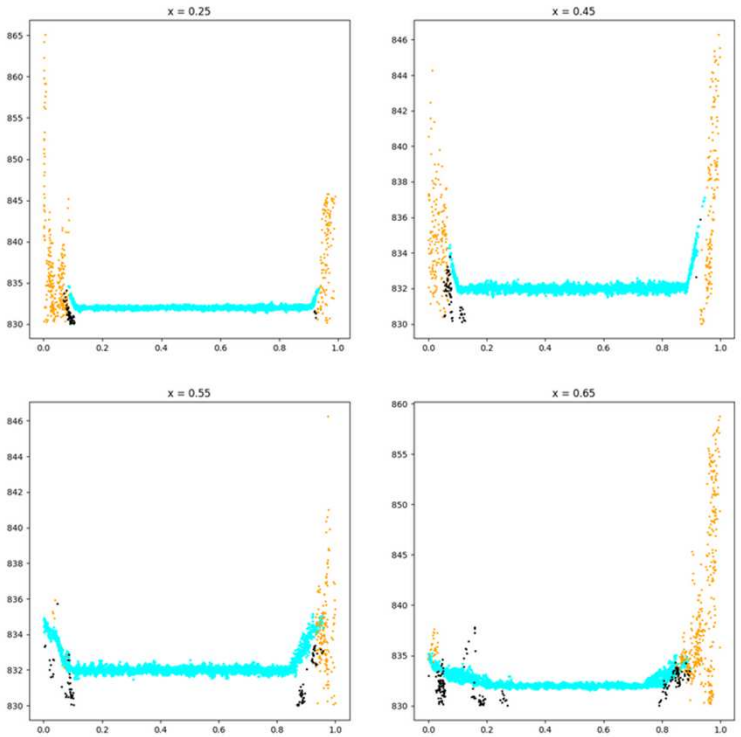
- Wrong Classification but useful WSE for bathymetry estimation

IMPLICIT NEURAL REPRESENTATION - LAKES

INPUT

4D SWOT Point Cloud

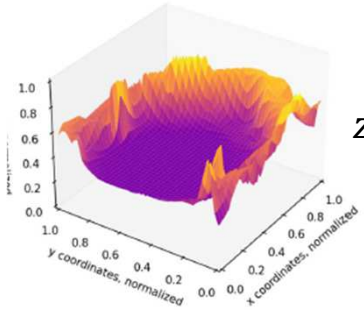
$\{x_i, y_i, z_i, t_i\}, i \in [1 \dots N]$



2 branches model:

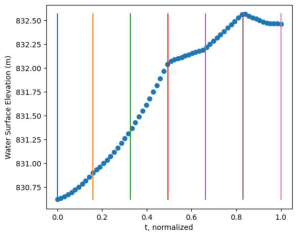
- Static : Ground/Bathy (x,y)
- Dynamic : Water level (t)

Implicit representation of Ground DSM/Bathymetry



z_g

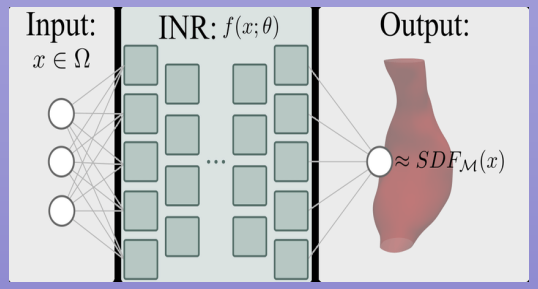
Water level timeseries



z_w

Max or softmax

Implicit neural representation



Example of 3D volumes (inspired by NERF)

IMPLICIT-LAKE : INVERSE PROBLEM

Uncertainty assesment

Forward rendering / simulation

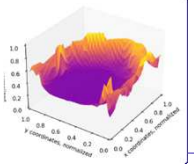
$\hat{z}(x, y, t) = max(z_g, z_w)$

Iterative process to fit the implicit model to the data

SWOT PIXC Data

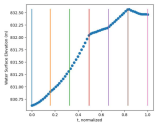
$\{x_i, y_i, z_i, t_i\}, i \in [1 \dots N]$

2-branch MLP parameters « θ »

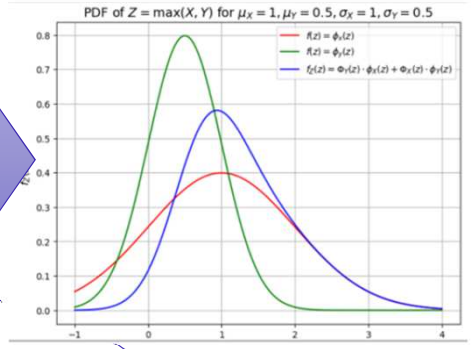


$z_g(x, y)$

$z_w(t)$



Probabilistic distributions



Output variables

Water presence
Surface
Volume

$phase\_noise\_std$

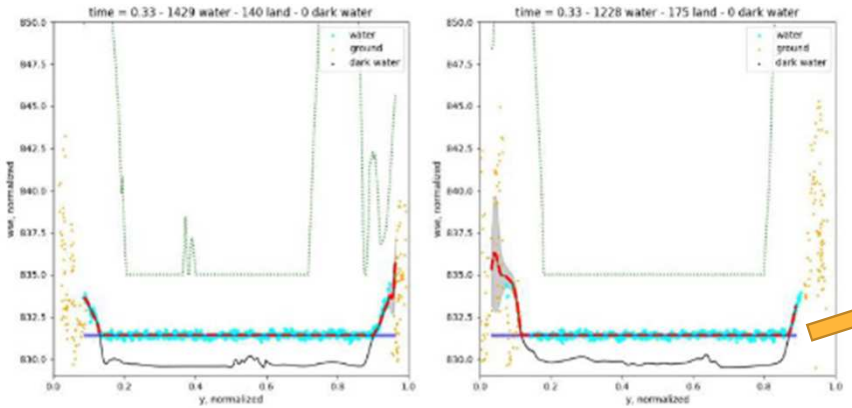
Cost function
« Data fidelity »

$\nabla_\theta(\hat{z}(x_i, y_i, t_i) - z_i)^2$

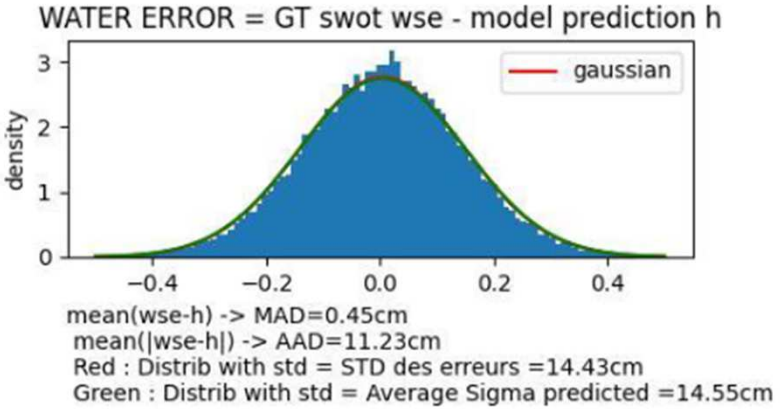
Physical priors :

- The DEM/Bathymetry does not change through time
- The water has the same elevation everywhere on the ROI : lake area
- The observed elevation is the max of ground and water elevations

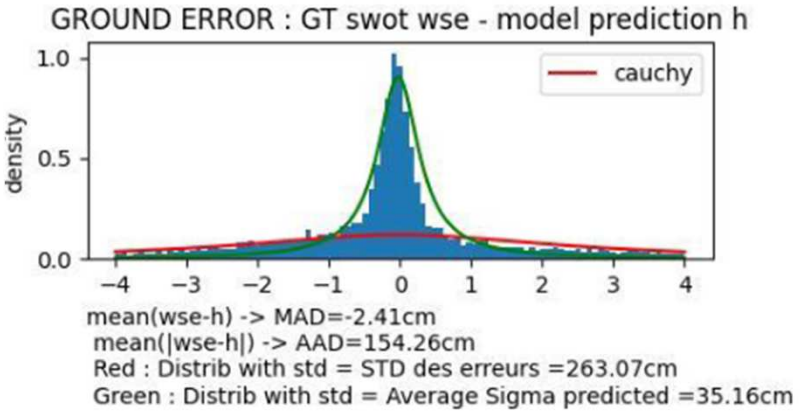
RESULTING DISTRIBUTIONS



Water Distribution F(t)



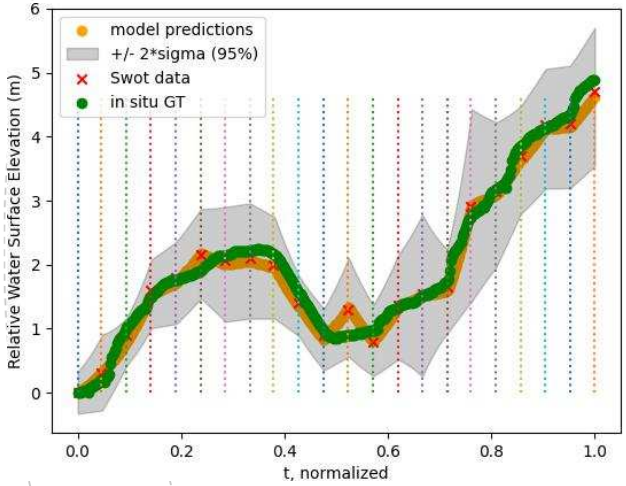
Ground distribution F(x,y)

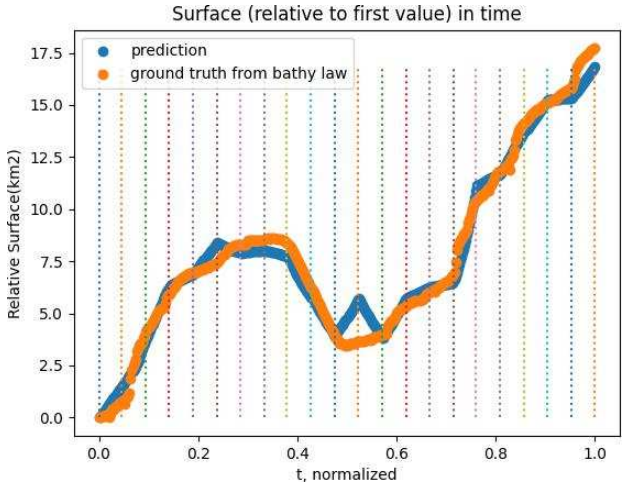


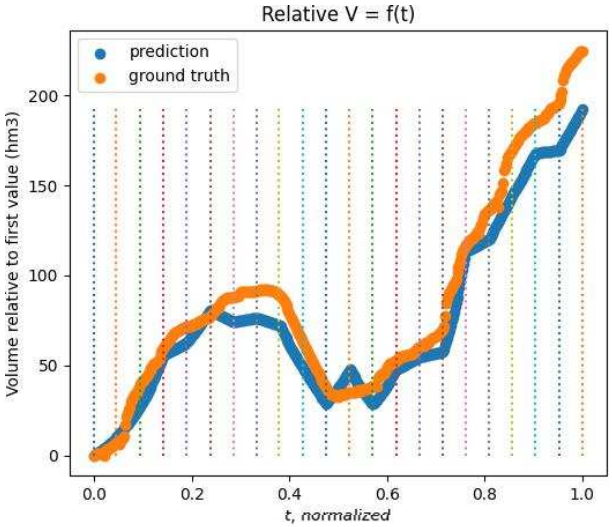
PLS2

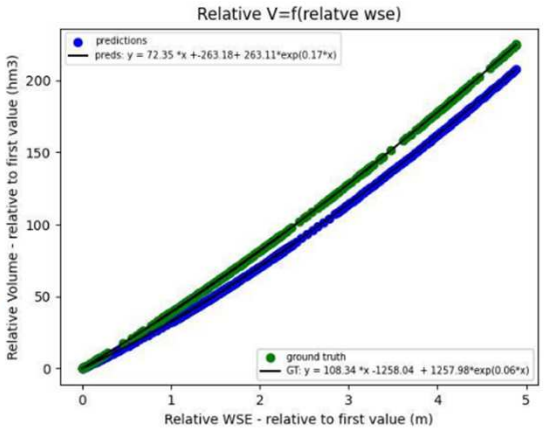
RESULTS – EBRO RESERVOIR (SPAIN)

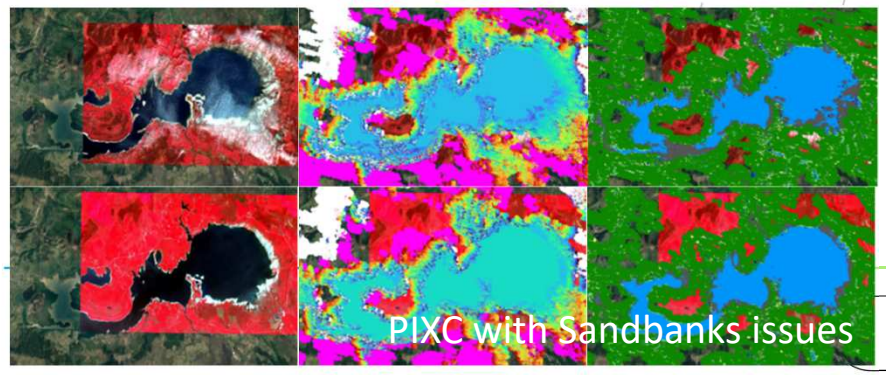
Implicit Lake : Reservoir Stock Monitoring from Multitemporal SWOT Pixel Cloud (D.Derksen, N.Gasnier, S.Pena, L.Lalla) [on going]











RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

cnes

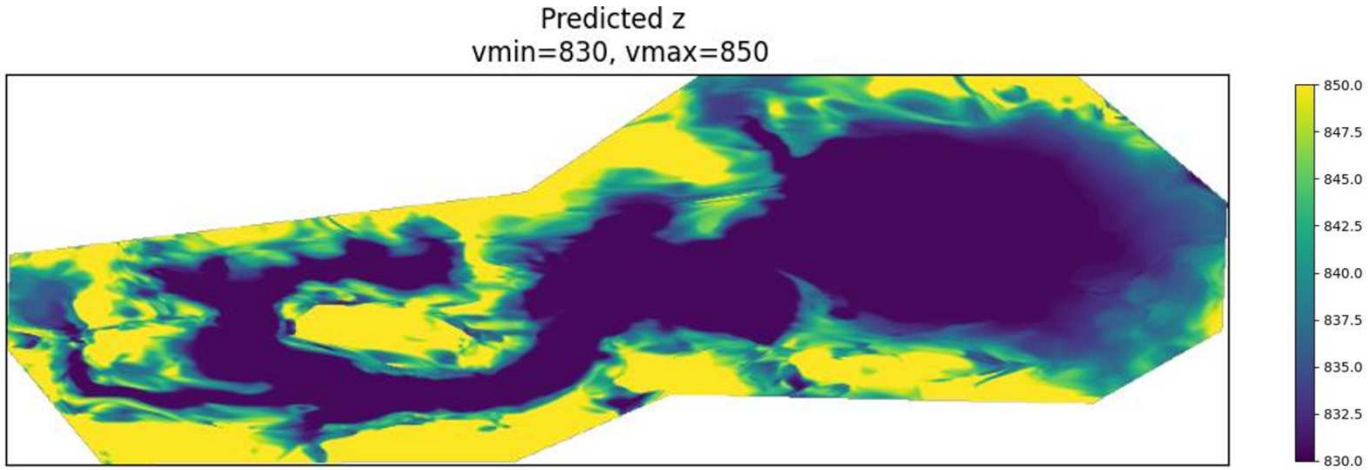
Diapositive 6

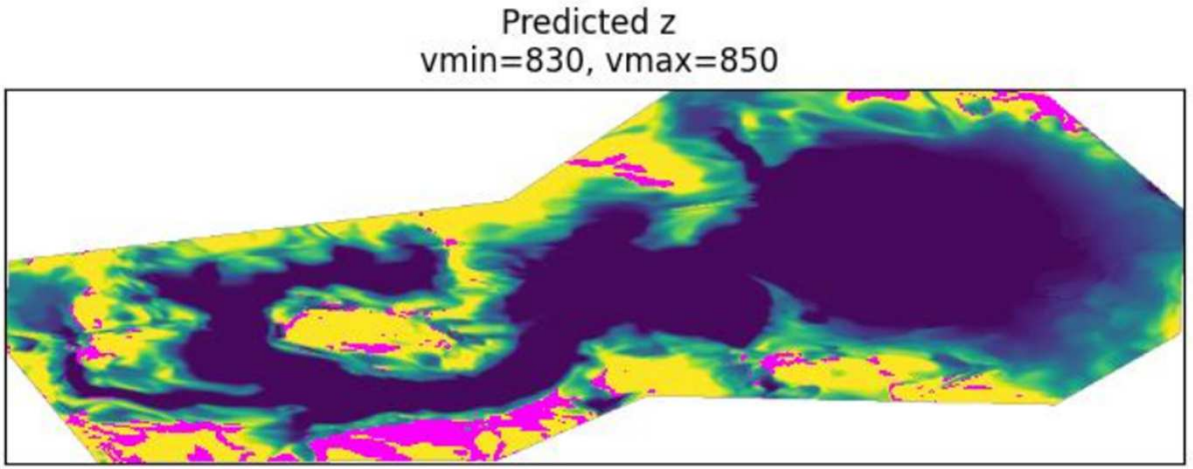
PLS2 Pena Luque Santiago; 14/10/2025

RESULTS – EBRO RESERVOIR (SPAIN)

Spatialized & Probabilistic Results

- Ground DSM: Most probable solution
- Evaluation - Pléiades DSM on wet bathymetry
  - 0.7m RMSE

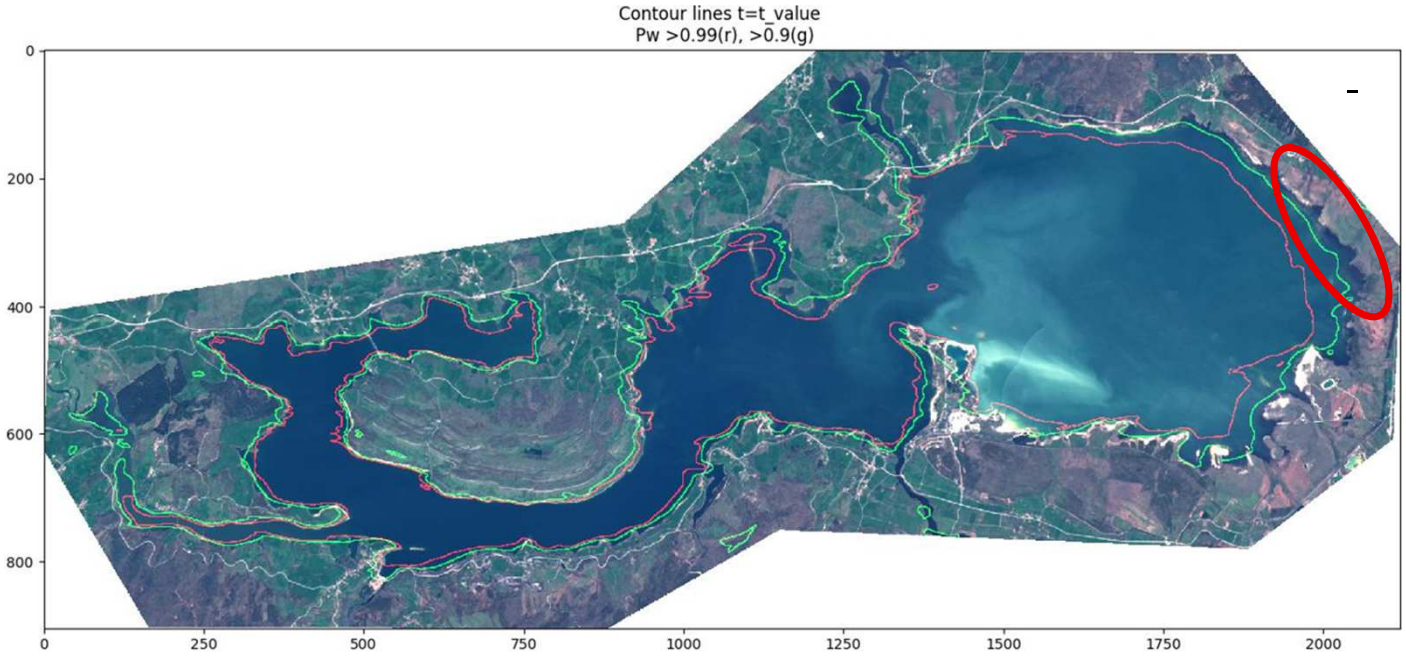




- Pink = High uncertainty (high predicted STD)

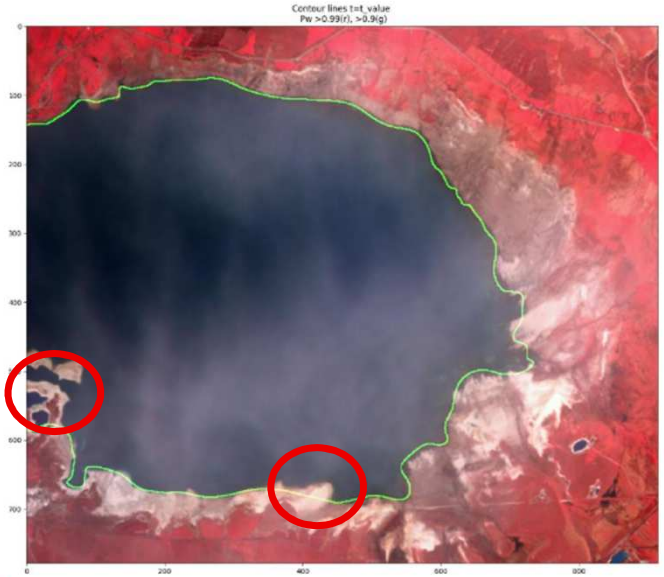
RESULTS – EBRO RESERVOIR (SPAIN)

Spatialized & Probabilistic Results



- Predicted Water Extent (SWOT) compared to simultaneous Sentinel 2

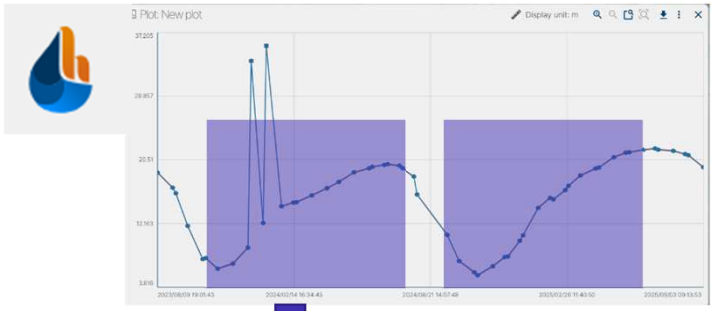
- Prone to area smoothing



- Smoothness of results

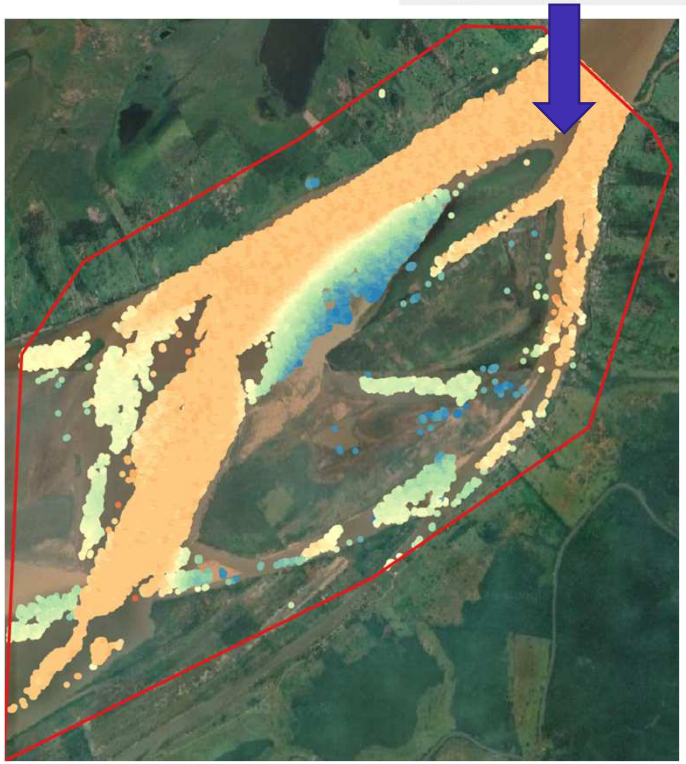
FLOOD PLAIN DEM / RIVERS

RiverSP – Drought periods 2023 & 24



Amazon – Manaos

Manaos –Solimoes River

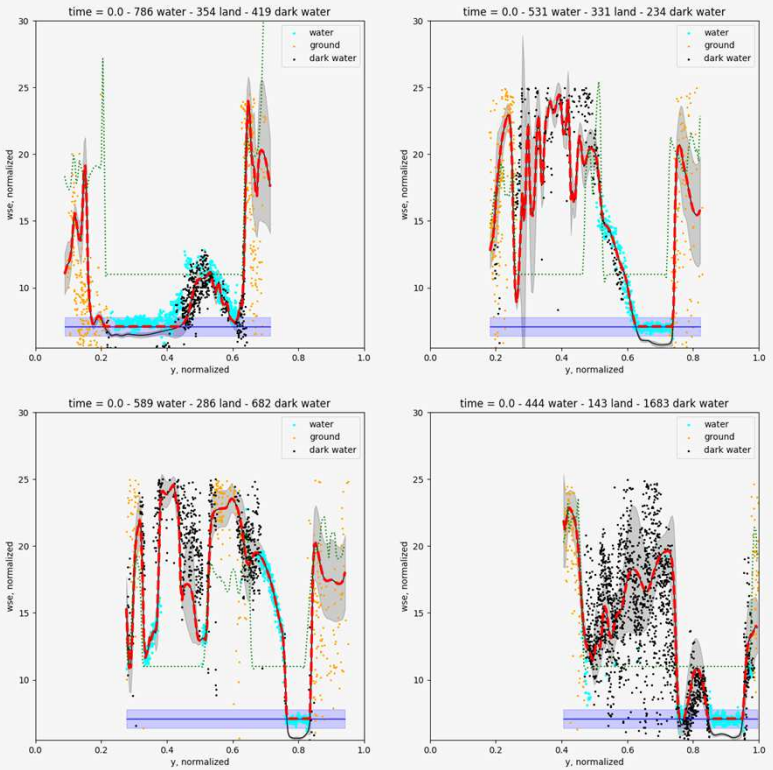


SWOT PIXC « Water » pixels - WSE

Hypothesis:
Similar WSE in ROI
<
SWOT RMSE (10, 15cm)

IMPLICIT RIVER

Preliminary Results from Implicit river :
Water levels and wet bathymetry



Estimation of
DEM+ Wet bathymetry

Copernicus 30m

Estimation DEM – 149L

Estimation DEM – 160L

Estimation DEM – ALL

CONCLUSION

- Automatic approach with just SWOT PIXC (independent from PIXC Classification)
- Management of Probability Distribution functions to handle Uncertainty

→ Candidate for « FloodPlainDEM » Estimation on SWOT Expertise Center (HAWK) – Coordination with D.Desroches/R.Fjortoft

- Limitations:
  - Only one Water body (WSE) to be processed in ROI
  - Hyperparameters sensitivity
  - Static DSM/Bathymetry hypothesis >> Pay attention to Bathymetry changes/ Seasons

Perspective:

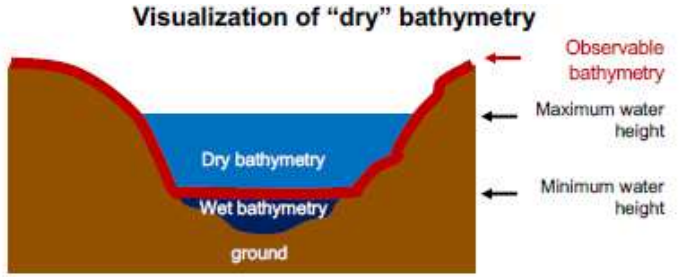
- Ready to be applied on Rivers and therefore, capabilities on Flood Plain DEM generation
- Better **Hyperparameters** management
- Analysis on Observation angles and complementarity of different orbits.
- Multiple water bodies to be segmented in ROI areas (nearby lakes, multiple water bodies reservoirs, etc)

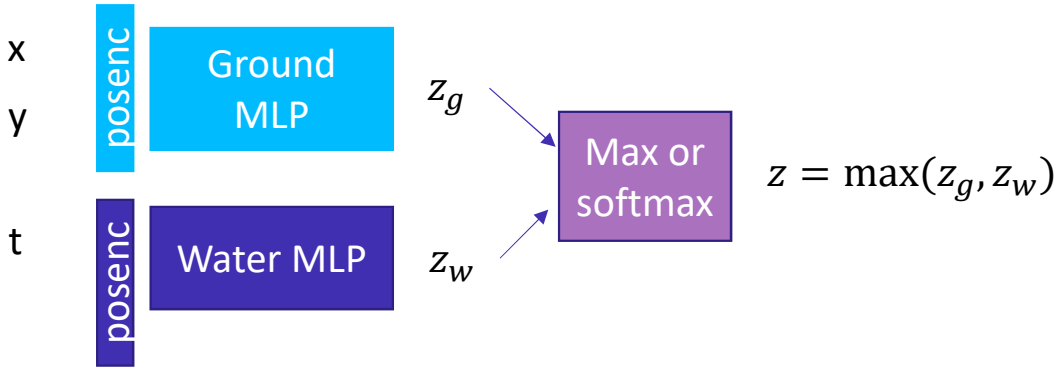
THANKS

FOR YOUR ATTENTION

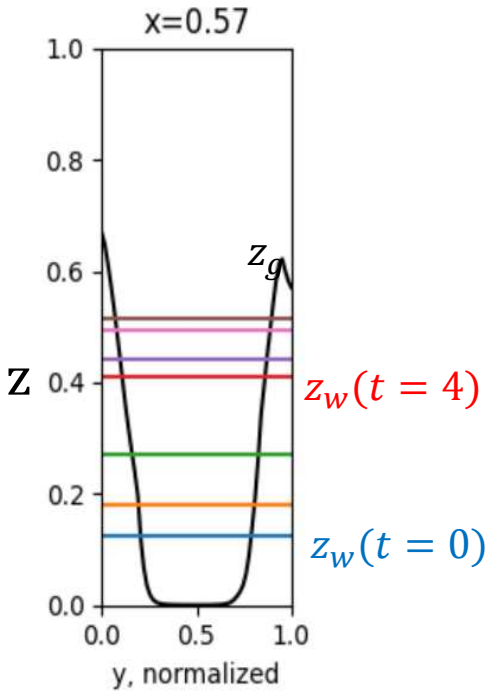
santiago.penaluque@cnes.fr

IMPLICIT NEURAL REPRESENTATION





$$\tilde{z} = [z_g, z_w] \times softmax(\lambda, [z_g, z_w])^T$$

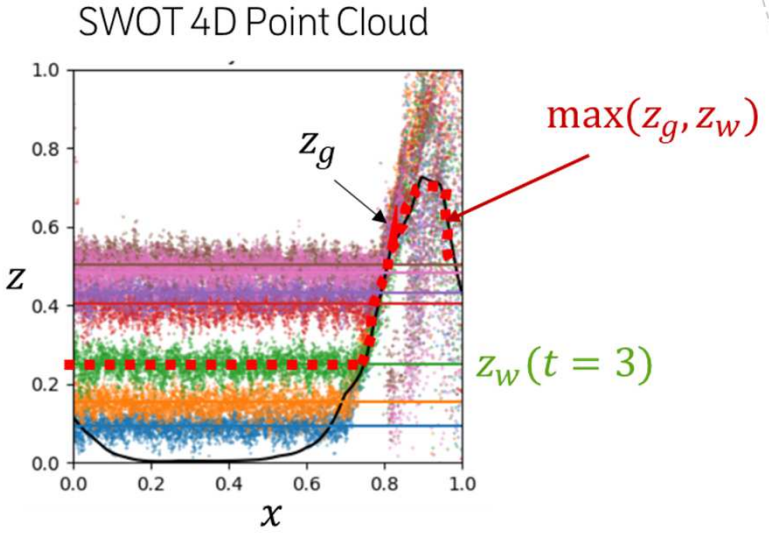


IMPLICIT LAKE – PROBABILITY FUNCTIONS

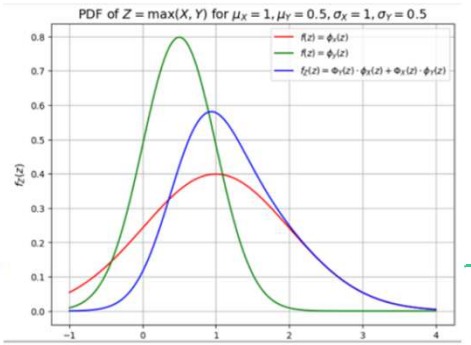
Implicit model

- Digital Elevation Model
  $$f : (x, y) \rightarrow z_g$$
- Water elevation
  $$f : (t) \rightarrow z_w$$
- Observed elevation
  $$f: (x, y, t) \rightarrow z = \max(z_g, z_w)$$

Results :



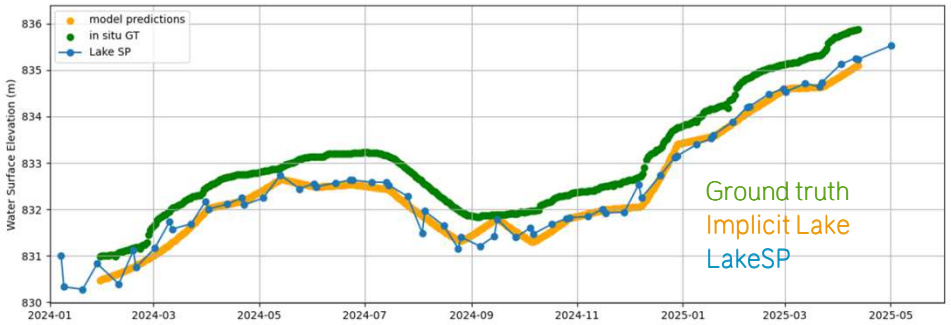
Probabilistic distributions



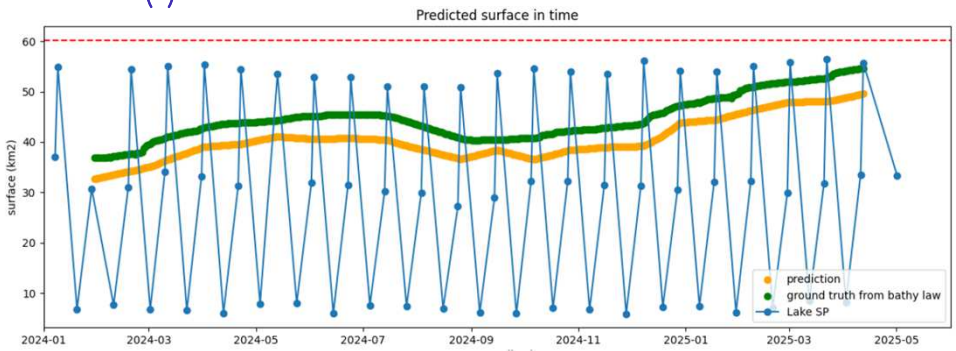
Uncertainty assesment

COMPARISON OF VOLUME ESTIMATIONS

WSE (t)

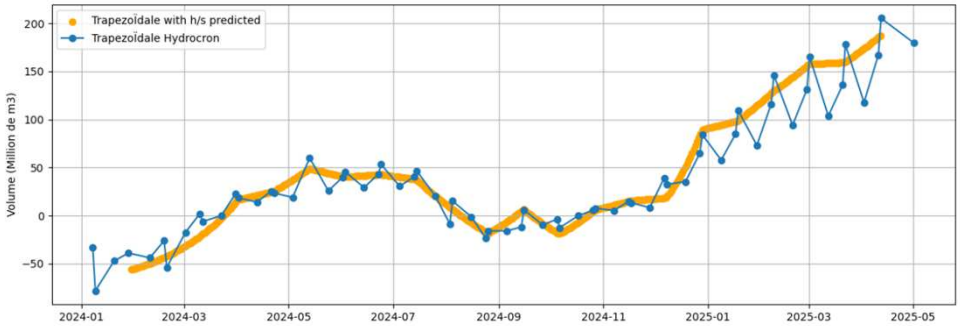


Area(t)



* Warning: Lake SP includes partial views

Volume change (t) – Trapezoidal approach



Improvement on Volume estimations compared to Lake SP estimations