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Mapping estuarine tides based on in-situ and remotely-sensed data

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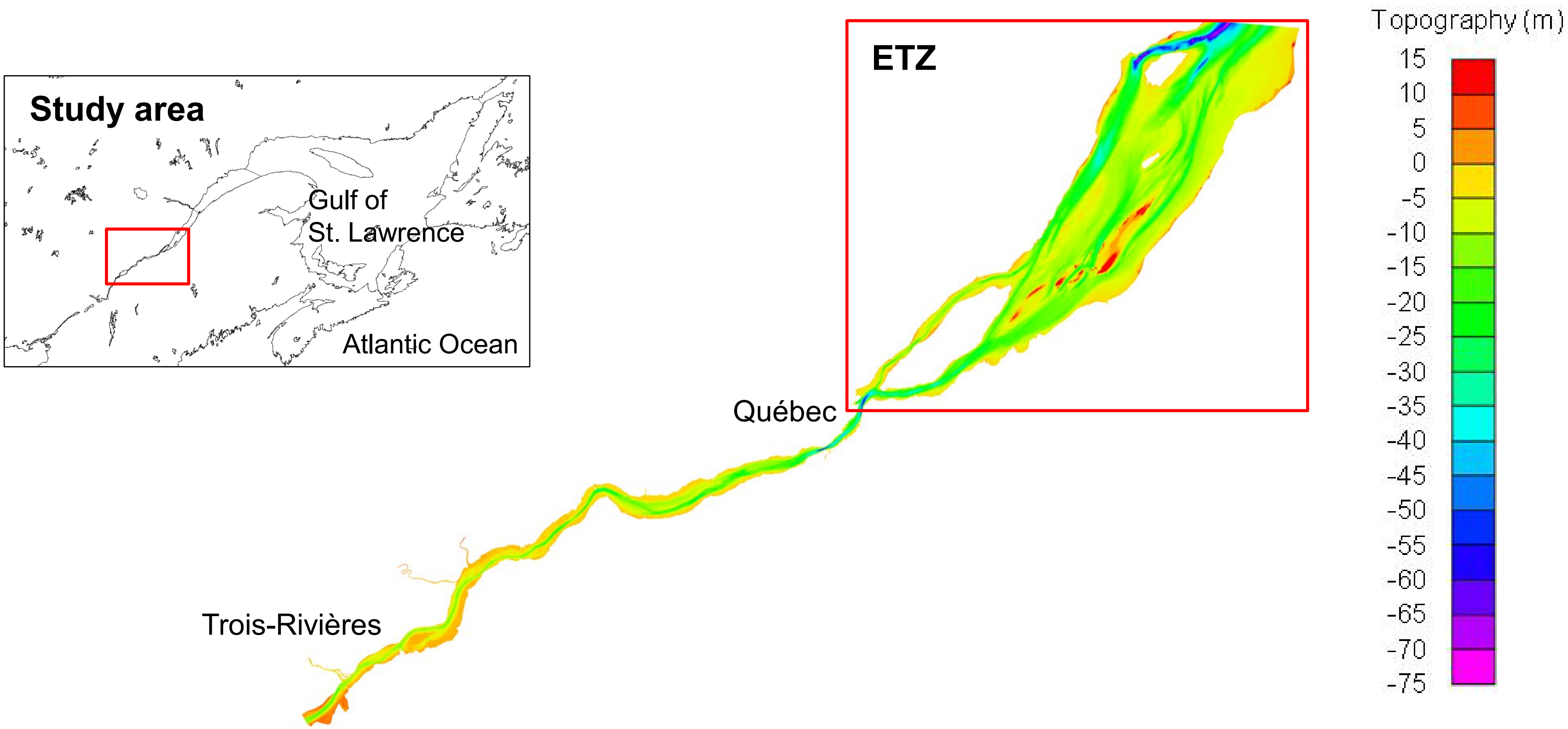
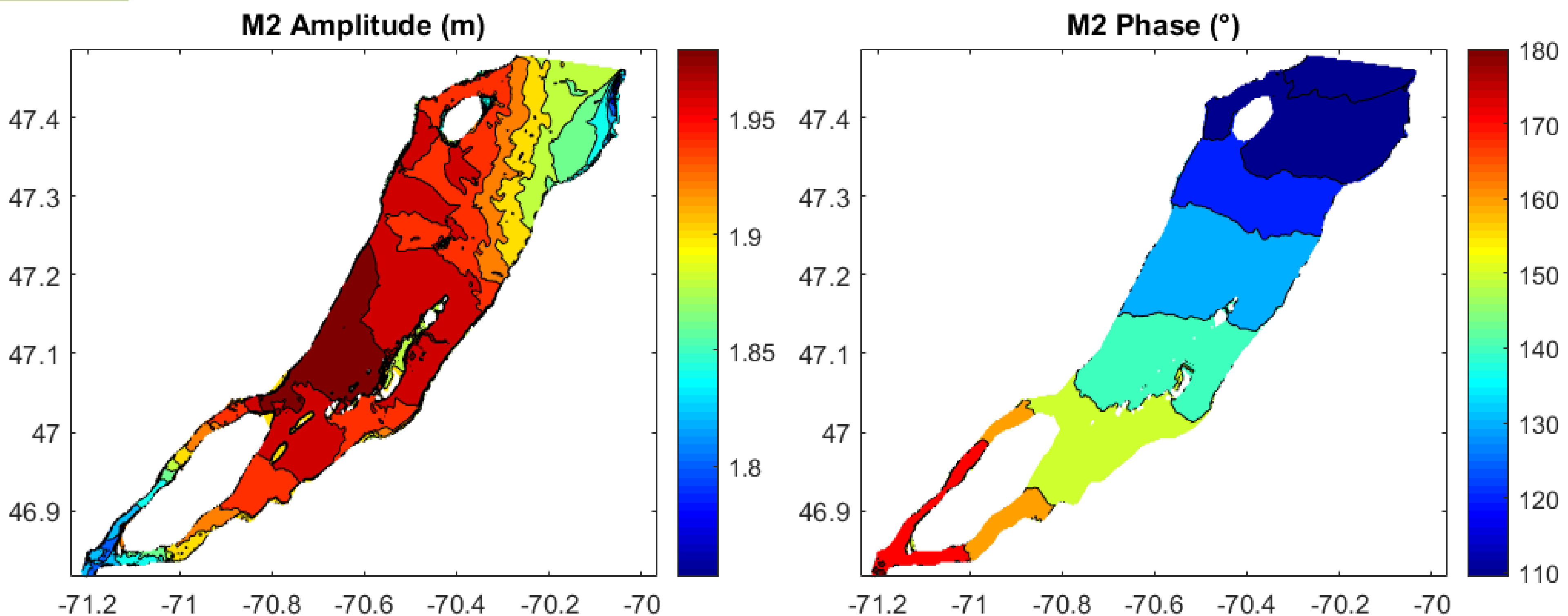
Objectives and Methods

- Evaluate the potential of the SWOT mission to map tides in estuaries
- Test bed: *St. Lawrence estuarine transition zone (ETZ)*



Objectives and Methods

- Develop a robust method for the recovery of tidal constituent properties
  - Robust to frequency of acquisition (no tidal aliasing)
  - Robust to record length (no limit in the number of constituents)
  - Independent of river geometry (no spatial function needed)



Classical Harmonic Analysis (HA)

- Classical harmonic model

$$y_c = c_0 + \sum_k C_k \cos(\sigma_k t - \Phi_k)$$

- Limitations of the least-square-fit approach
  - Data length required to resolve close frequencies (Rayleigh criterion)
  - Sensitive to frequency of acquisition (tidal aliasing)

- Hypotheses:
  - Tides are stationary and independent of time-varying riverine, oceanic and atmospheric influences
  - There is a fixed number of tidal constituents with discrete periodicities, phase angles and amplitudes
  - Tidal constituents are mutually independent

Method: Constrained Harmonic Analysis

- Constrained harmonic model

$$c_0 = (1 - d_0)a_0 + d_0 b_0$$

$$C_k = (1 - d_k)A_k + d_k B_k$$

$$\Phi_k = (1 - p_k)\alpha_k + p_k \beta_k$$

– The "virtual" distances d_k and p_k are determined by optimization for each tidal constituent, using partial data at station *c*

– The d_k and p_k are constrained to vary between 0 and 1 (typically), unless tidal amplification occurs

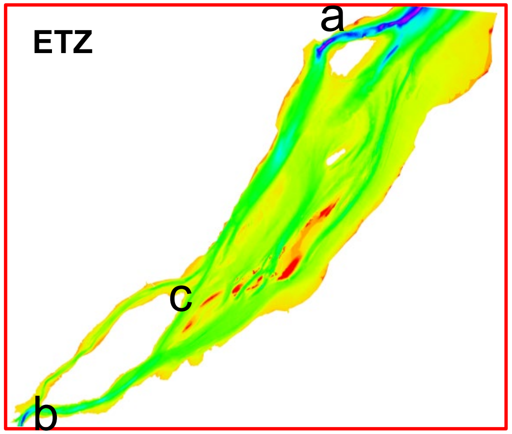
- Hypotheses:
  – Tides are spatially coherent
  – Amplitudes and phases vary non-linearly with distance

$$y_c = \boxed{c_0} + \sum_k \boxed{C_k} \cos(\sigma_k t - \boxed{\Phi_k})$$

Mean sea level c_0, constituent amplitudes C_k and phases Φ_k at location *c* are estimated from tidal properties at two boundary estuarine stations *a* and *b.*

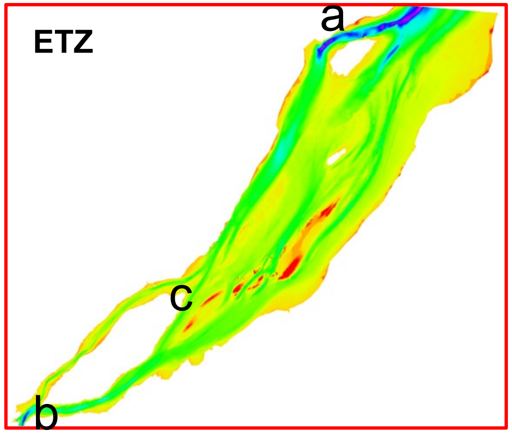
<u>Dowstream (*a*)</u>: $y_a = a_0 + \sum_k A_k \cos(\sigma_k t - \alpha_k)$

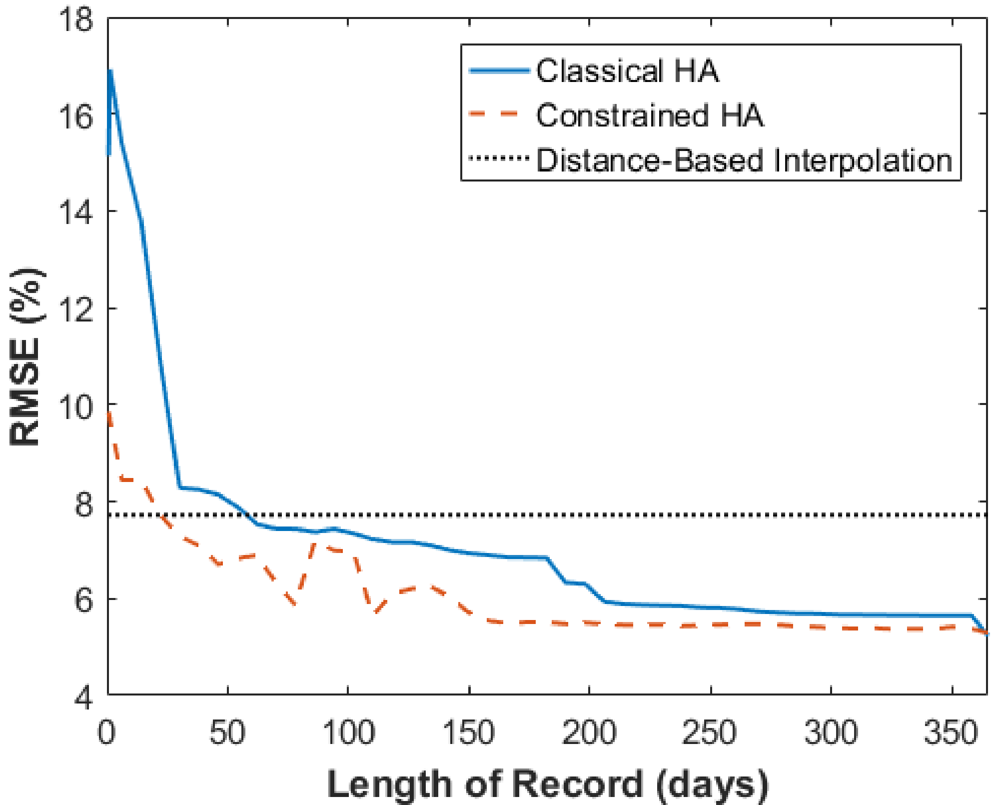
<u>Upstream (*b*)</u>: $y_b = b_0 + \sum_k B_k \cos(\sigma_k t - \beta_k)$

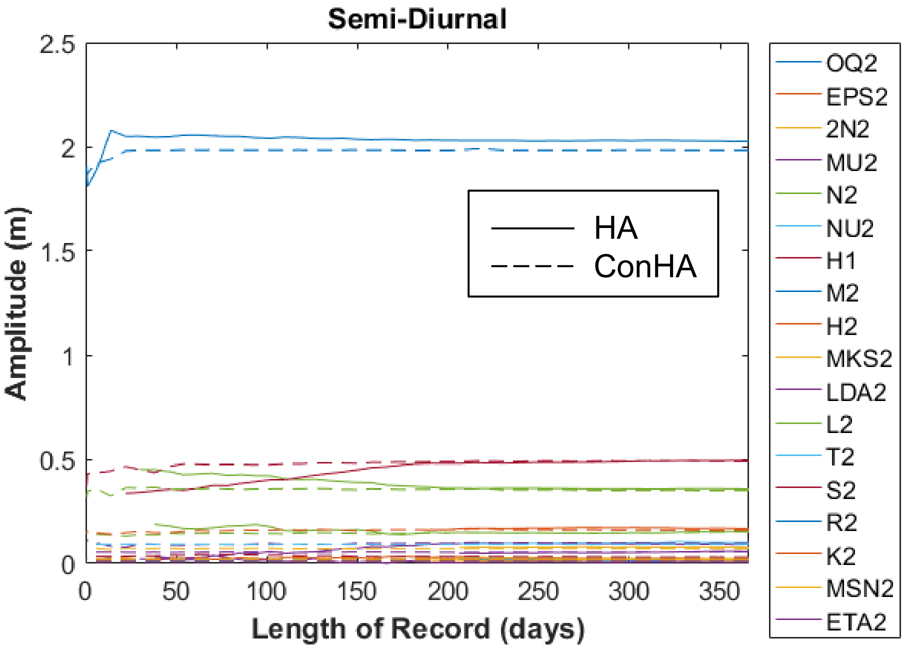


Sensitivity Analysis

- Sensitivity to length of record
  - Hourly-sampled data at station *c*
  - From 15-h to 1-year long records

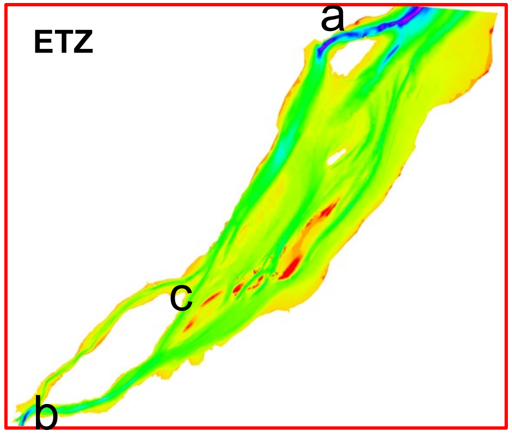


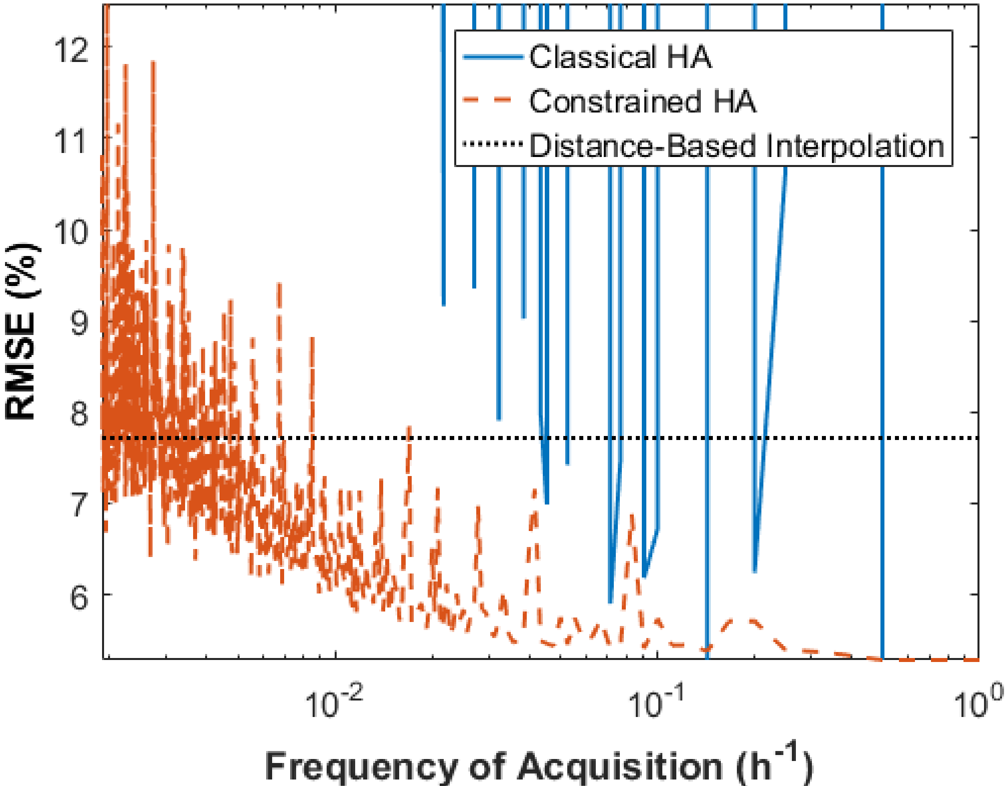


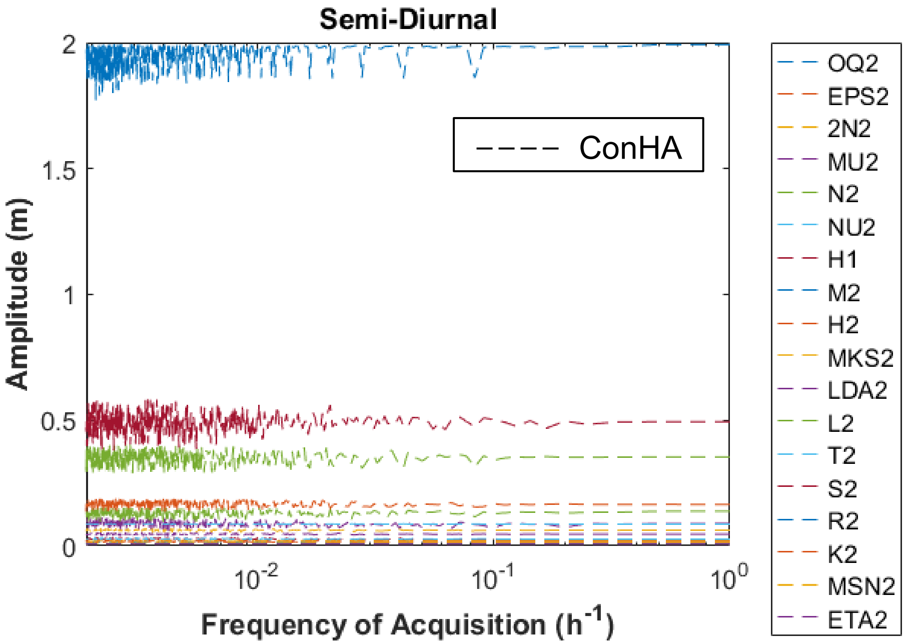


Sensitivity Analysis

- Sensitivity to frequency of acquisition
  - 1-year long record at station *c*
  - From hourly sampled to once every 21 days (regularly spaced)

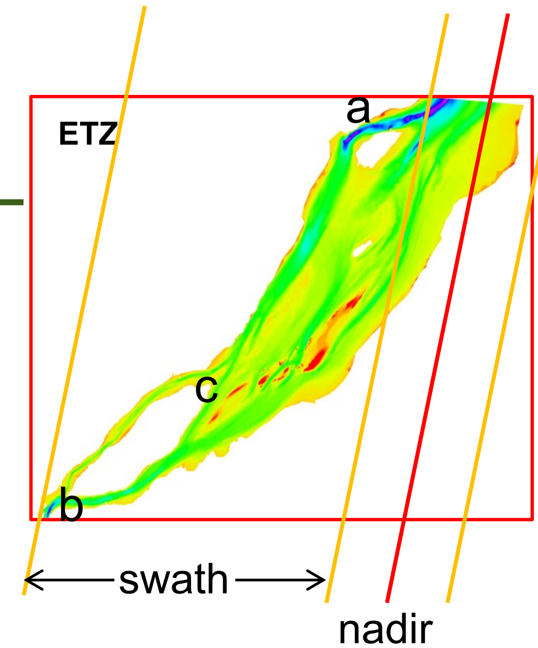


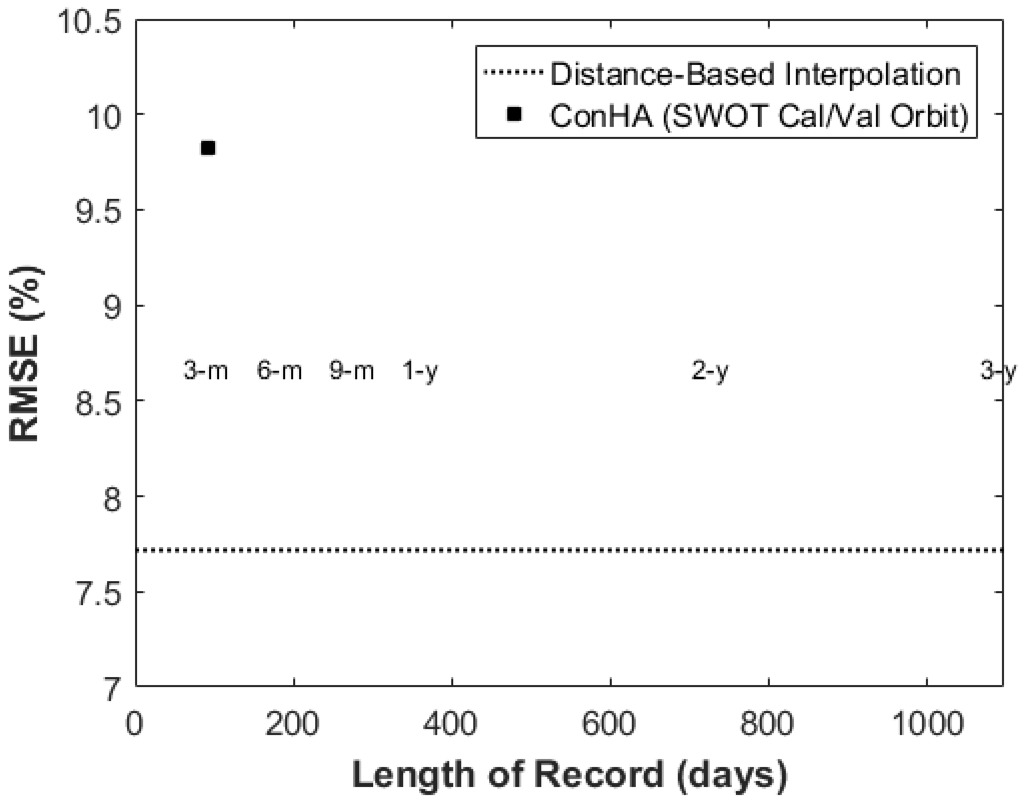




Sensitivity Analysis

- SWOT Cal/Val orbit
  - Daily-sampled data
  - 3-month long record





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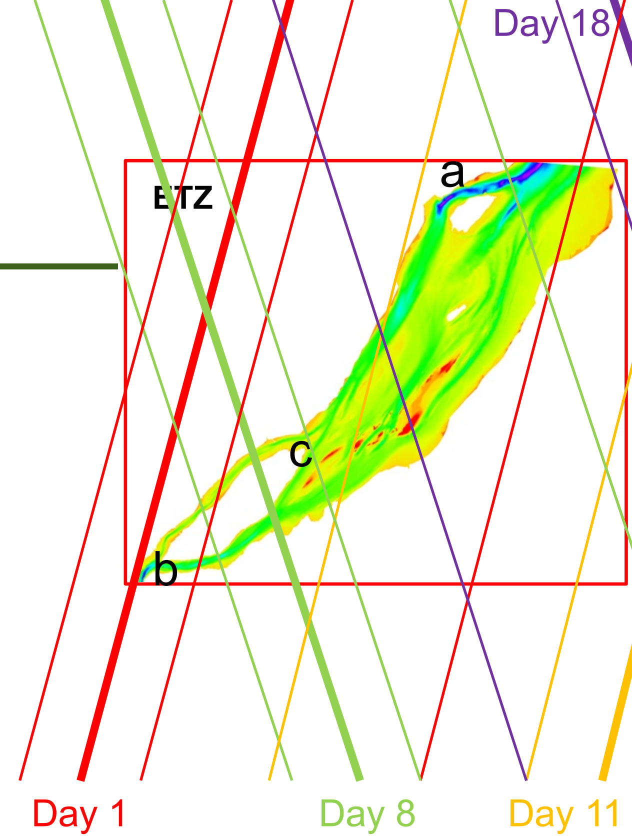
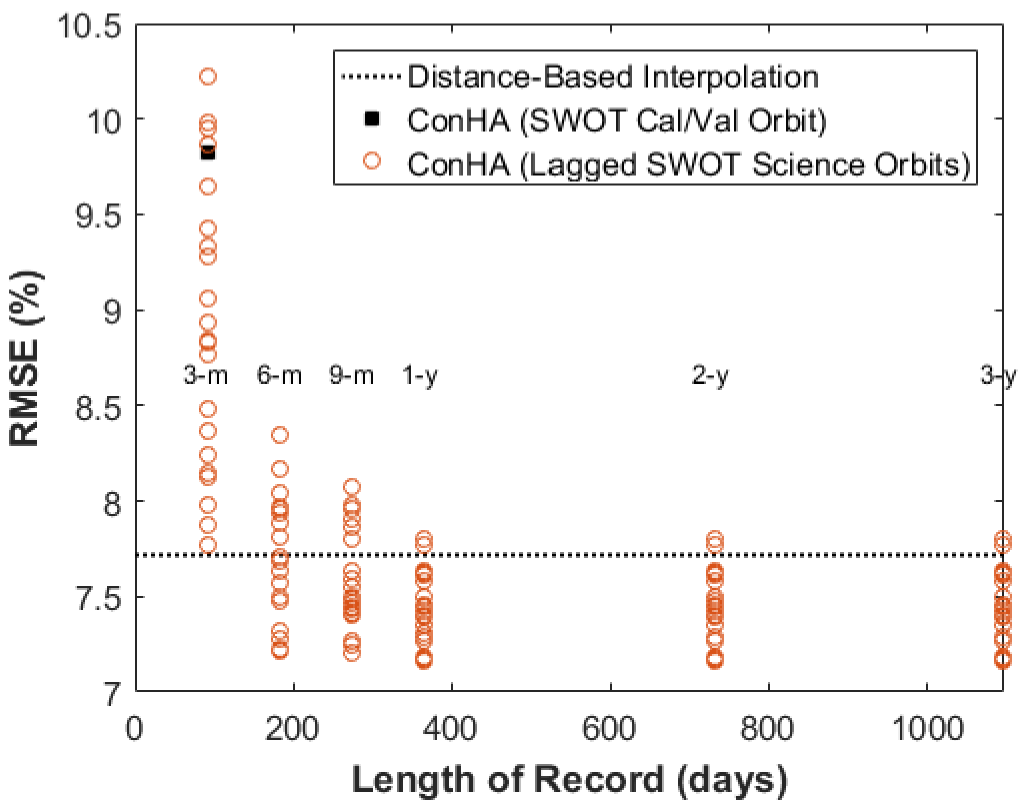
Sensitivity Analysis

- SWOT Science orbits
  - Days 1-8-11-18
  - Length of records: 3-m, 6-m, 9-m, 1-yr, 2-yr, 3-yr
  - Lag times from 1 to 21 days



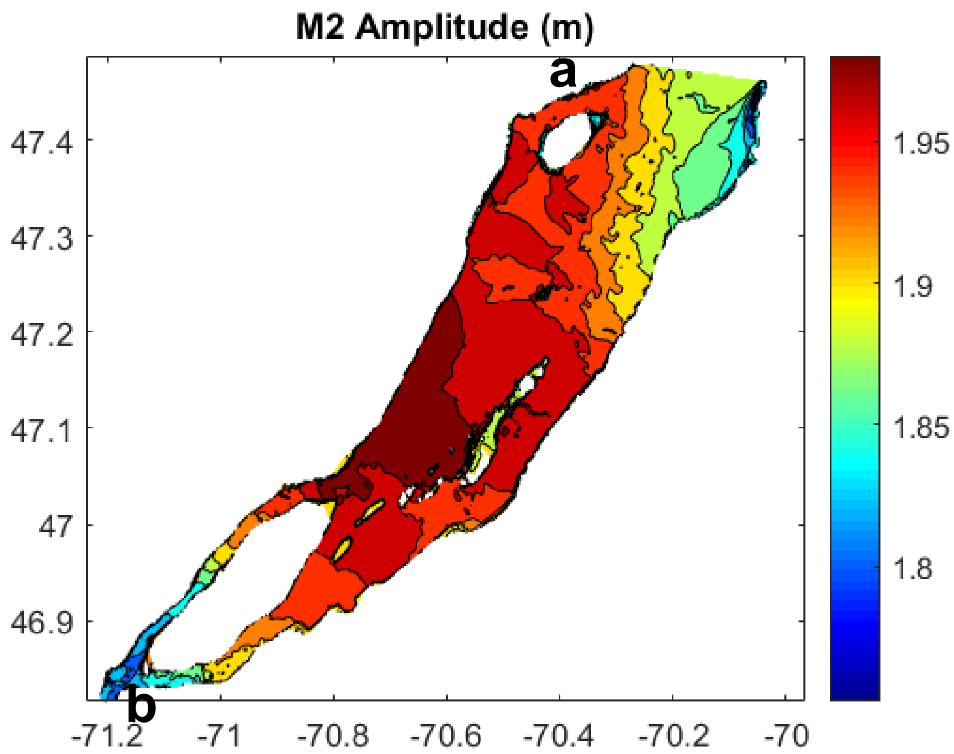


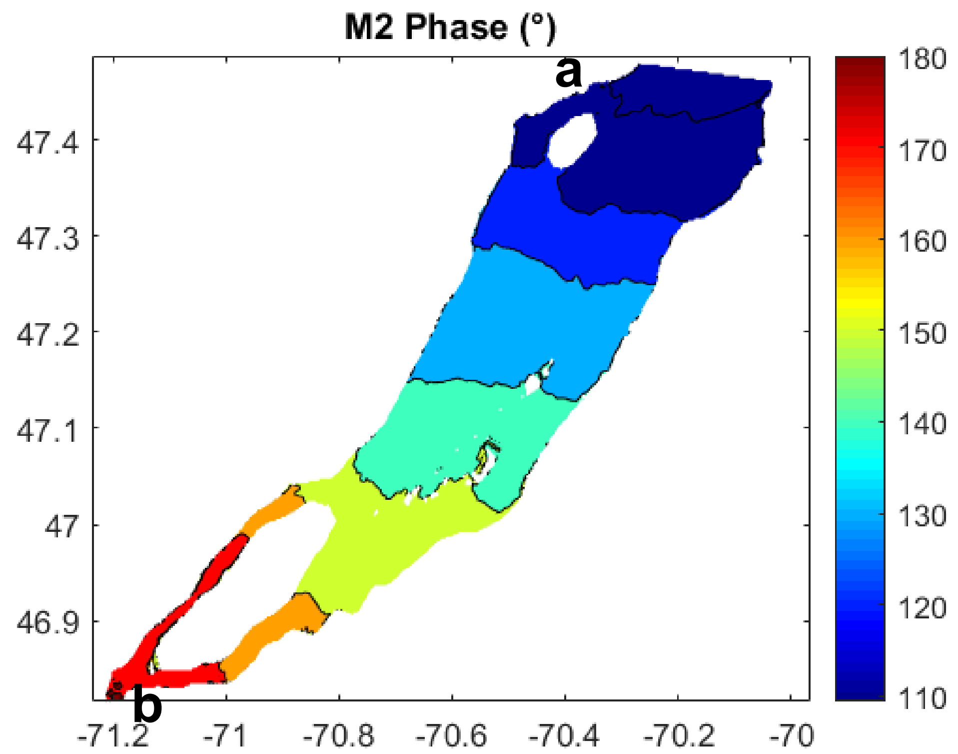
What's the added value?

- Captures lateral and longitudinal variability
- Spatial patterns in amplitude and phase differ between tidal constituents

2D Mapping

- Analysed 2D hydrodynamic results (using ConHA)
  - Hourly-sampled 2D water level fields
  - 3-month simulation (single case)
- Next step
  - Sensitivity analysis in 2D, including simulated satellite errors





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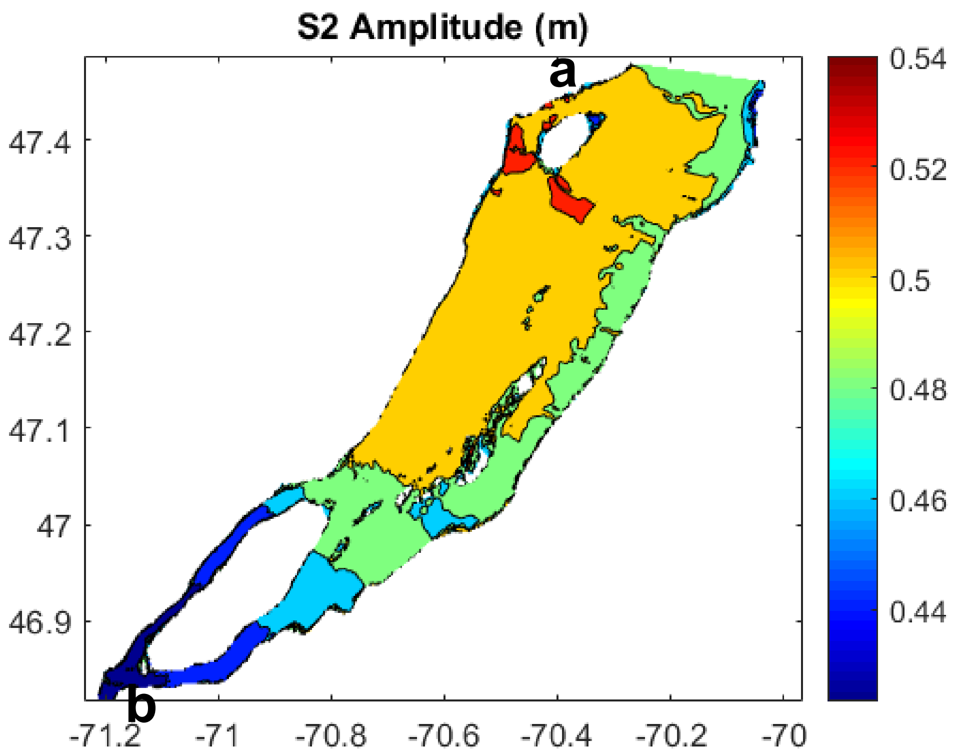

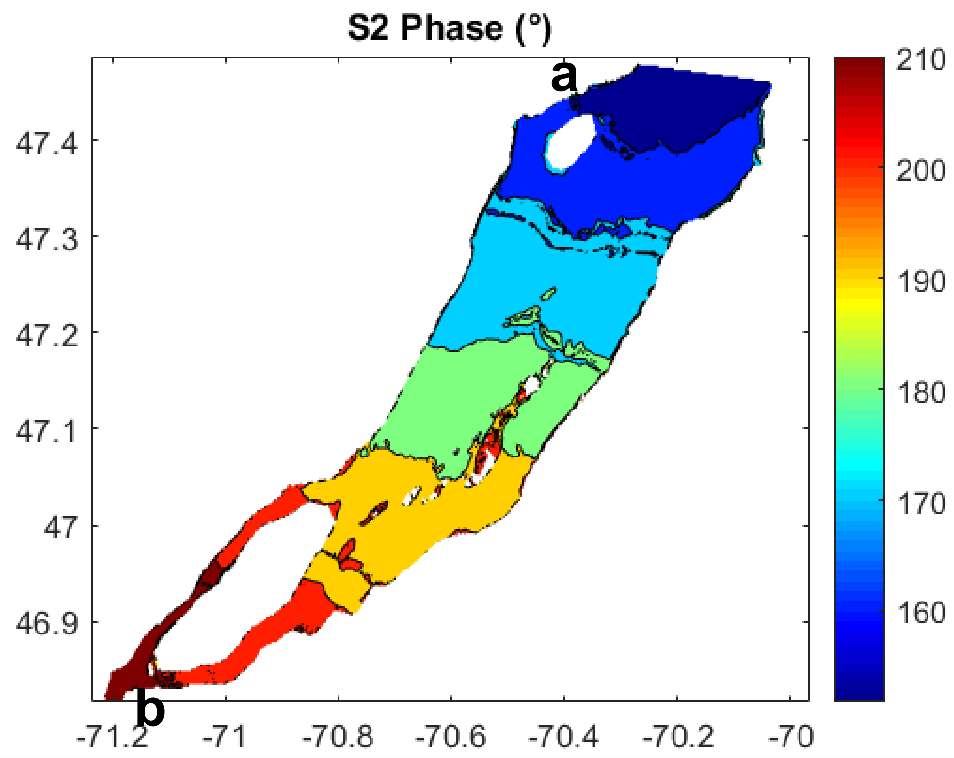

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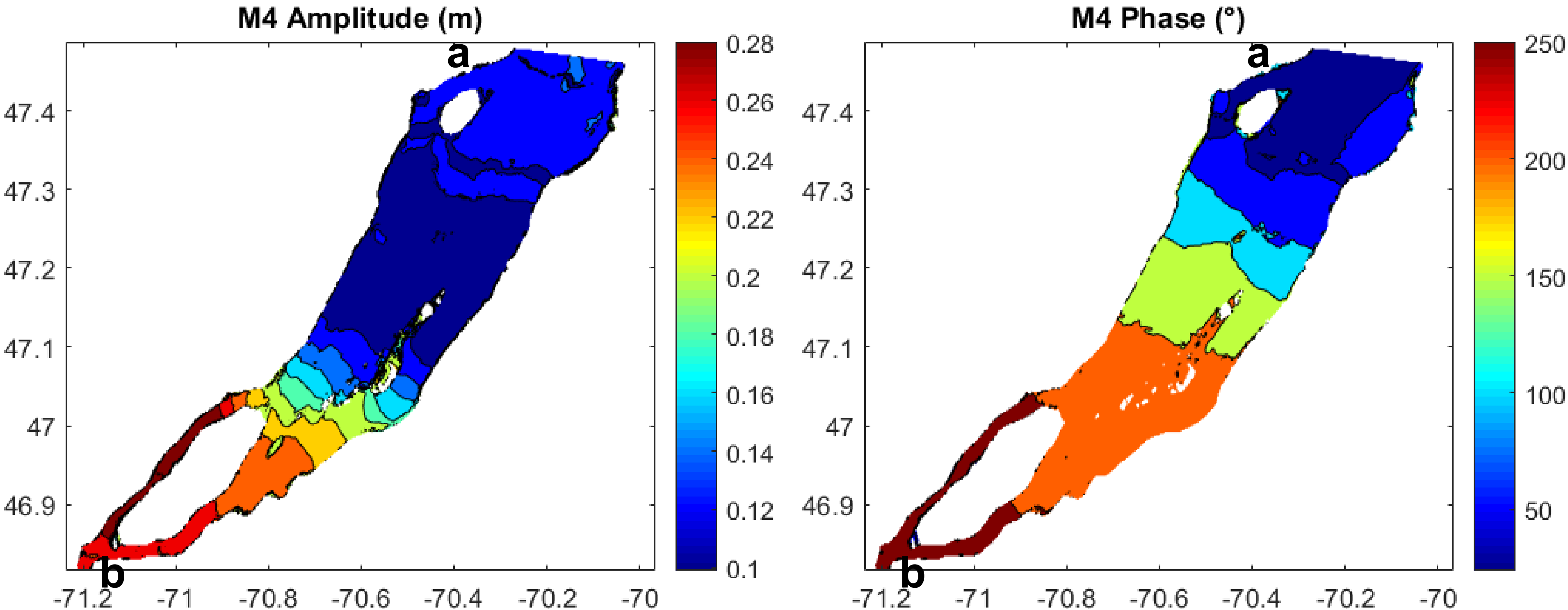

Conclusion

- Summary and highlights
  - Tidal spectrum is fully recovered by constrained optimization
    - Requires ≥1-yr records at boundary stations
    - Spatial coherence is maintained
  - Robust to downsampling and/or reduced record length
    - No tidal aliasing
    - Not limited by the Rayleigh criterion
  - Allows 2D mapping of nonlinear tides
    - No spatial function needed
  - Potential for SWOT
    - Accuracy <10% during Cal/Val
    - Stable accuracy (<8%) achieved after 1 yr of science mission
    - Sensitive to initial time

Conclusion

- Perspectives and applications
  - Work needed to address non-stationary signals (i.e. influenced by time-varying riverine, oceanic and/or atmospheric forcing)
  - Extend to coastal areas where tides are spatially coherent
  - Use in remote areas with limited field efforts
  - Infer bathymetry from 2D water levels
  - Model assimilation