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Tides in the coastal region, insights gained from SWOT

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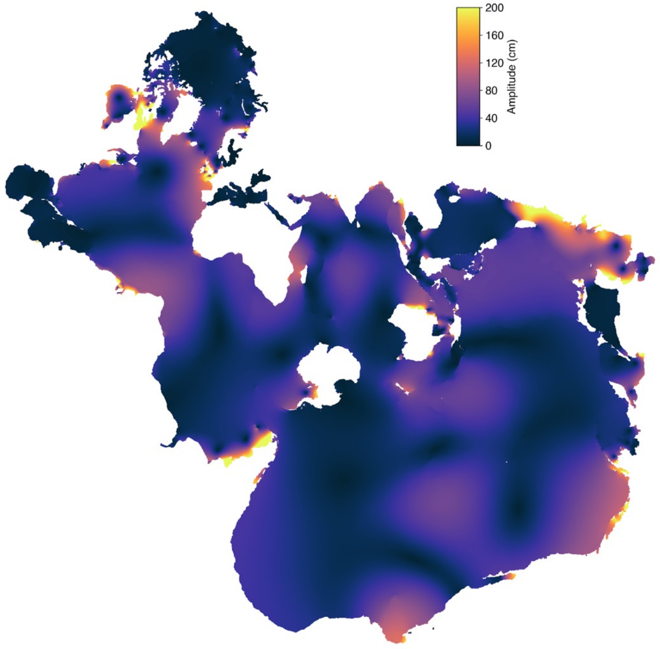
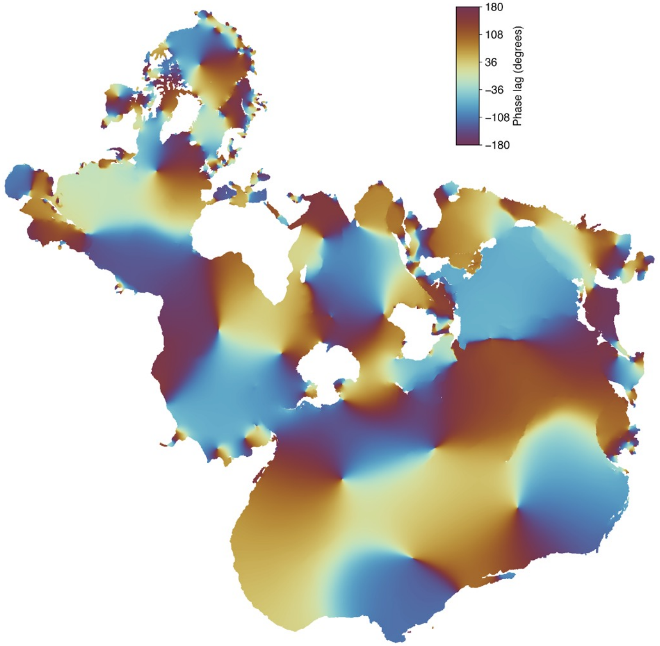




30 Years of Progress in Radar Altimetry Symposium
2-7 September 2024 | Montpellier, France

Global Tide Modelling Efforts

Shum et al (**1997**) → Stammer et al (**2014**)

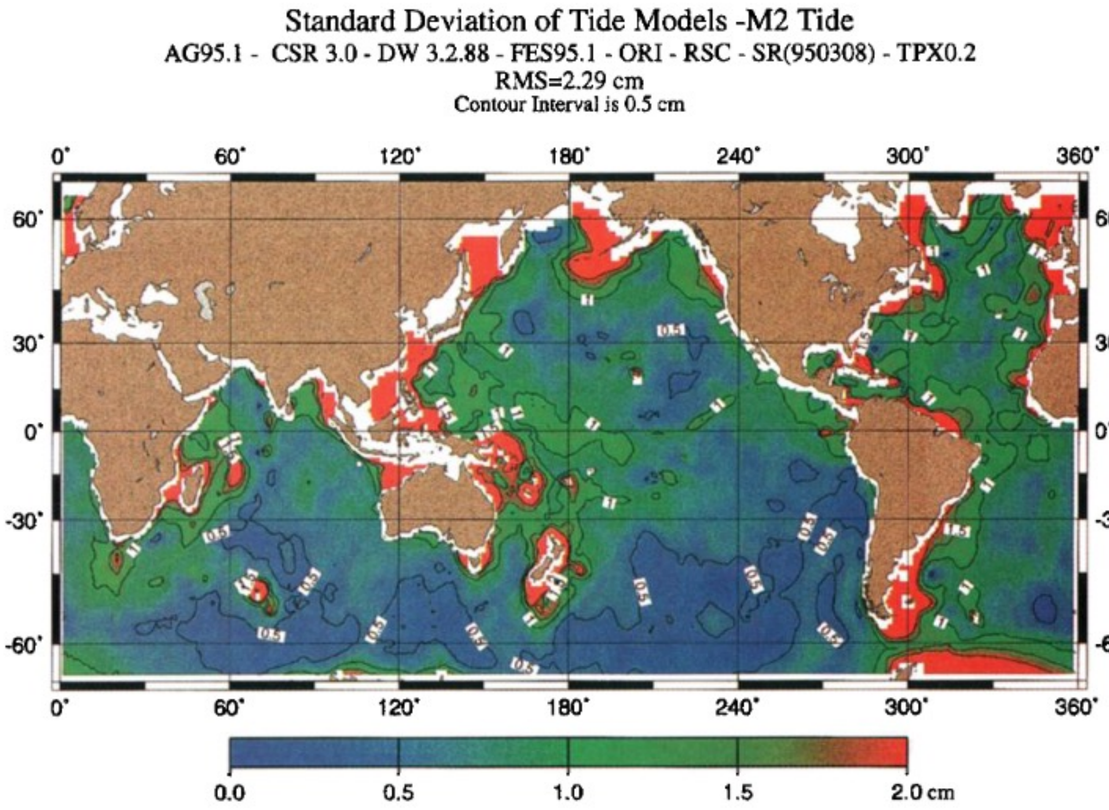
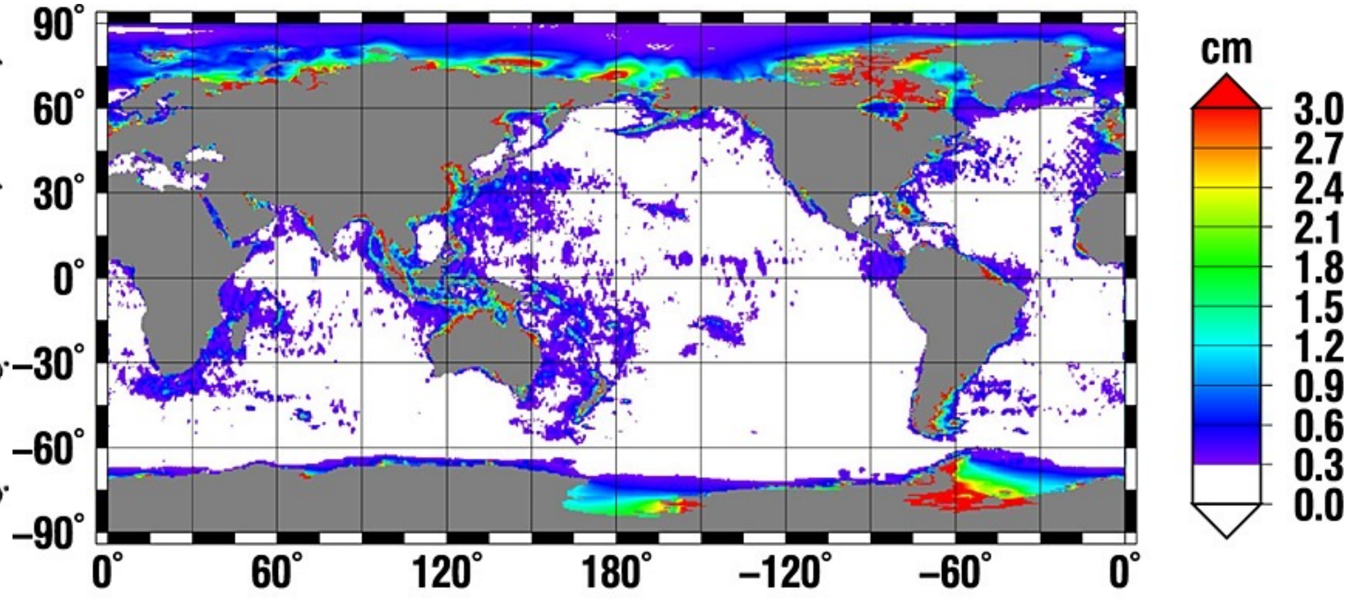


Plate 1. Standard deviations for M_2 from eight recent tide models.

GOT4.8, OSU12, DTU10, EOT11a, HAM12, FES12, TPXO8



Global Tide Modelling Efforts

This presentation (**2024)**

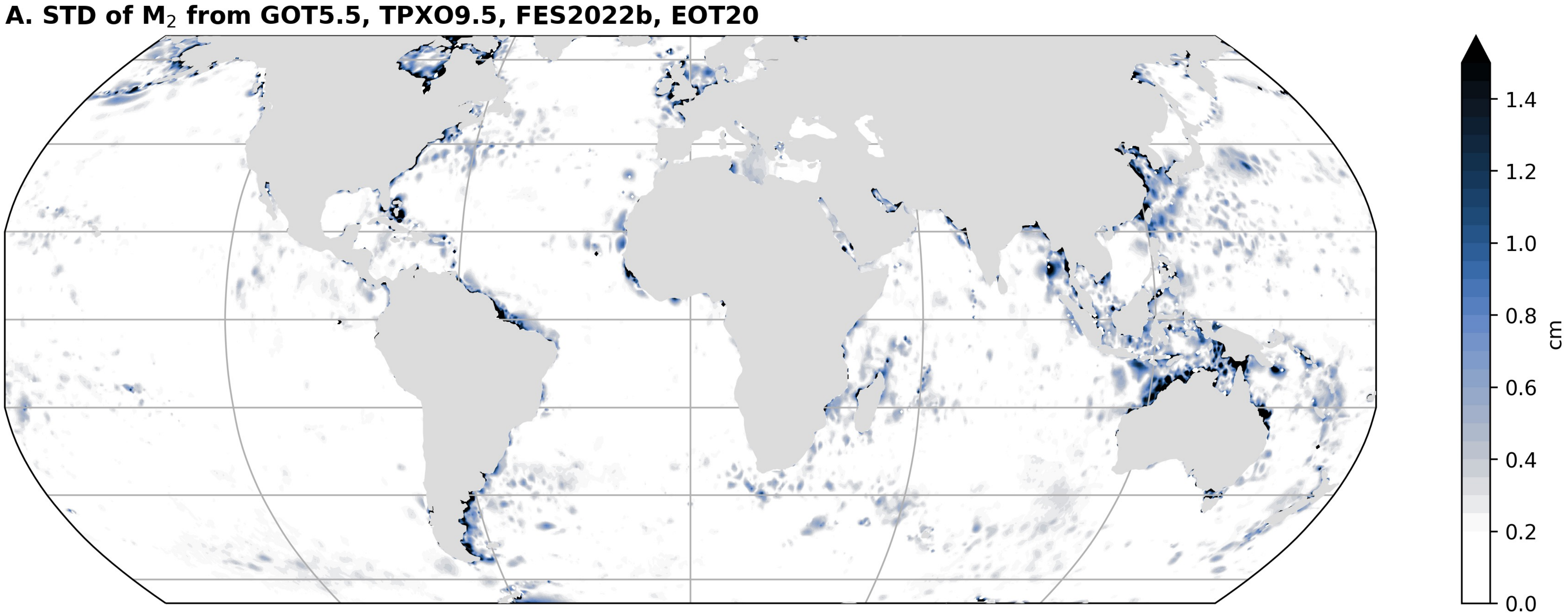
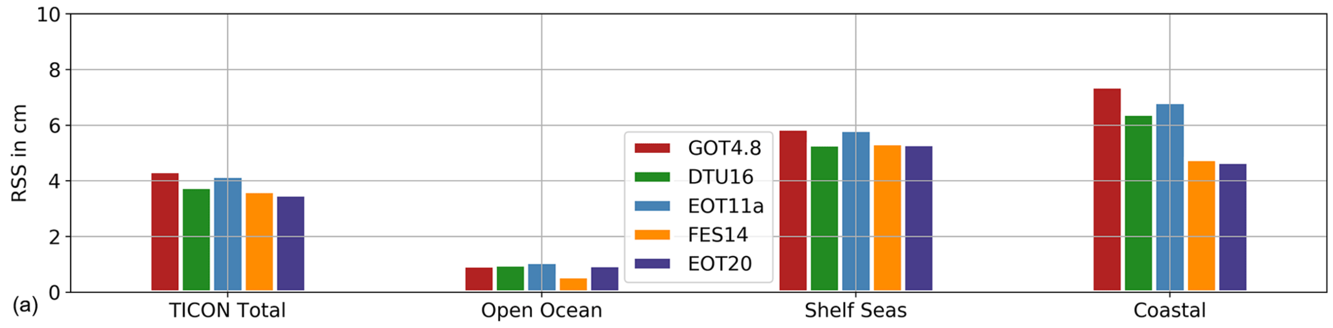
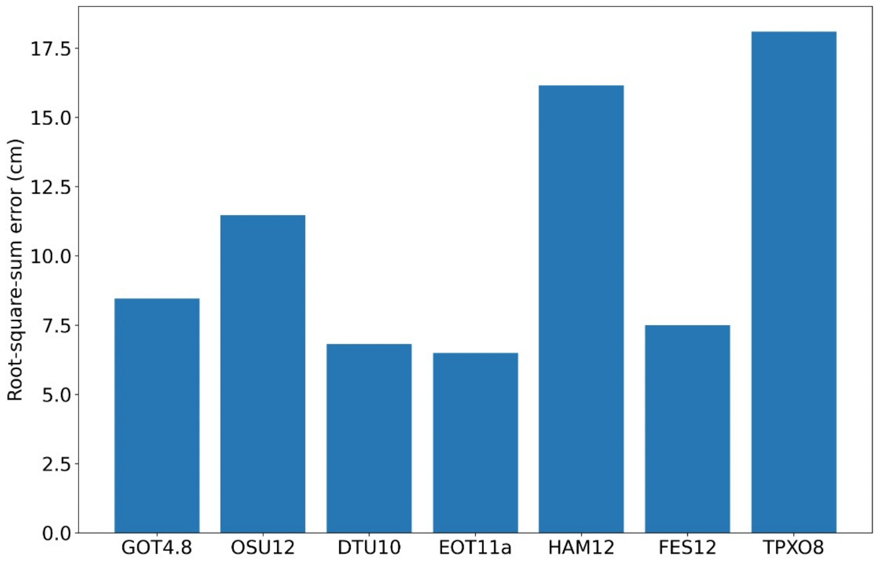


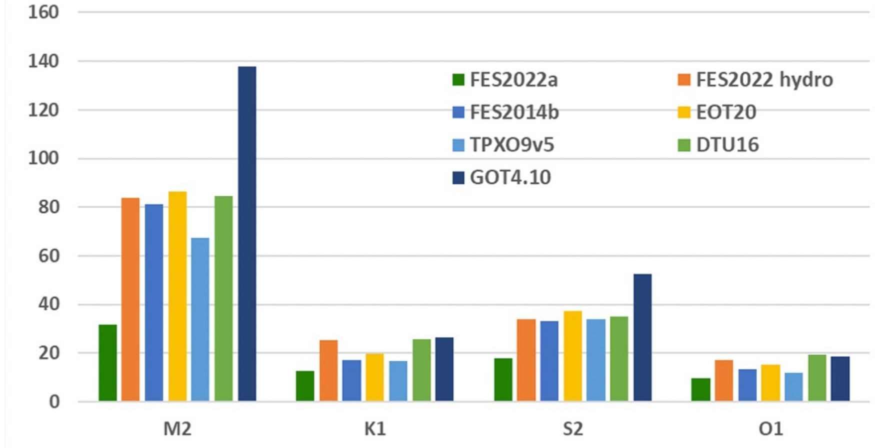
Fig. Standard deviation (in cm) of the M_2 tidal amplitude of five global tidal models. These models are EOT20, GOT5.5, FES2022b and TPXO9.5.

Global tide models in the coastal region



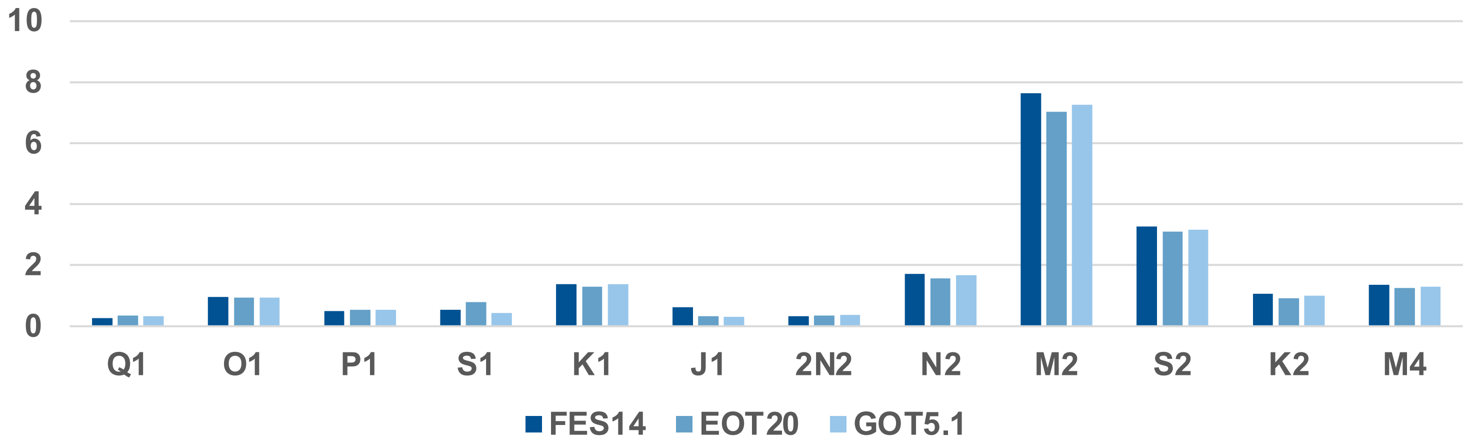
Stammer et al (**2014**)
Root Square of the eight major tides





Latest tide gauge analysis produced by:

- (**Top**) Hart-Davis et al (2021)
- (**Middle**) Carrere et al (OSTST 2023)
- (**Bottom**) Ray (OSTST 2022)



Since Stammer et al, models have improved by 2 cm root-square-sum (RSS) error in the coastal regions. Even more with the new FES2022!

Tides from SWOT

- In this presentation, we discuss ocean tides in complex coastal regions based on the following datasets from the Cal/Val phase:

  i. **Pixel cloud data:**
     - SWOT_L2_HR_PIXC_1.1

  ii. **250m product:**
     - SWOT_L2_KaRIn_SSH_Unsmoothed

  iii. **2km product:**
     - SWOT_L2_LR_SSH_Expert

- The geophysical corrections provided in the products are used. **Except the ocean tide.**

- Additionally, where available the roll correction is applied.

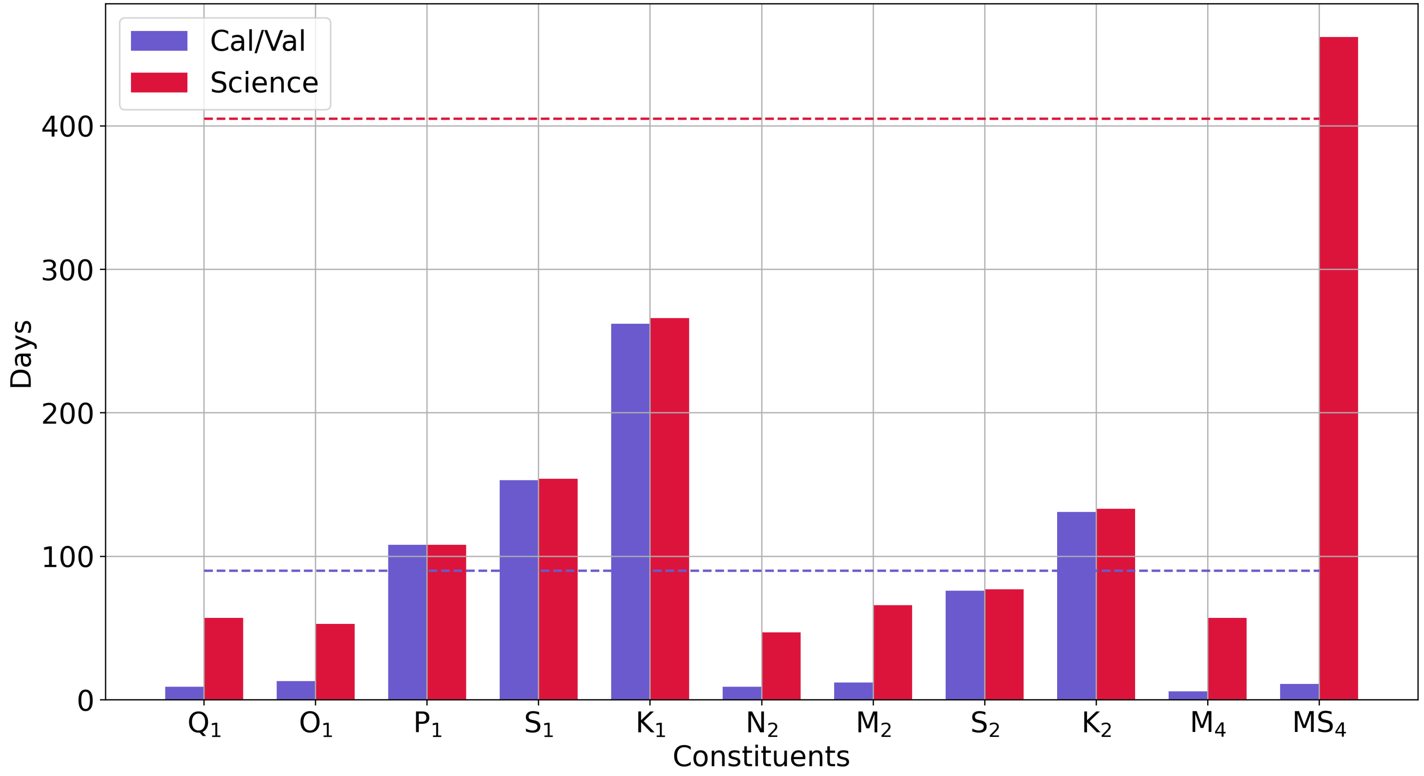


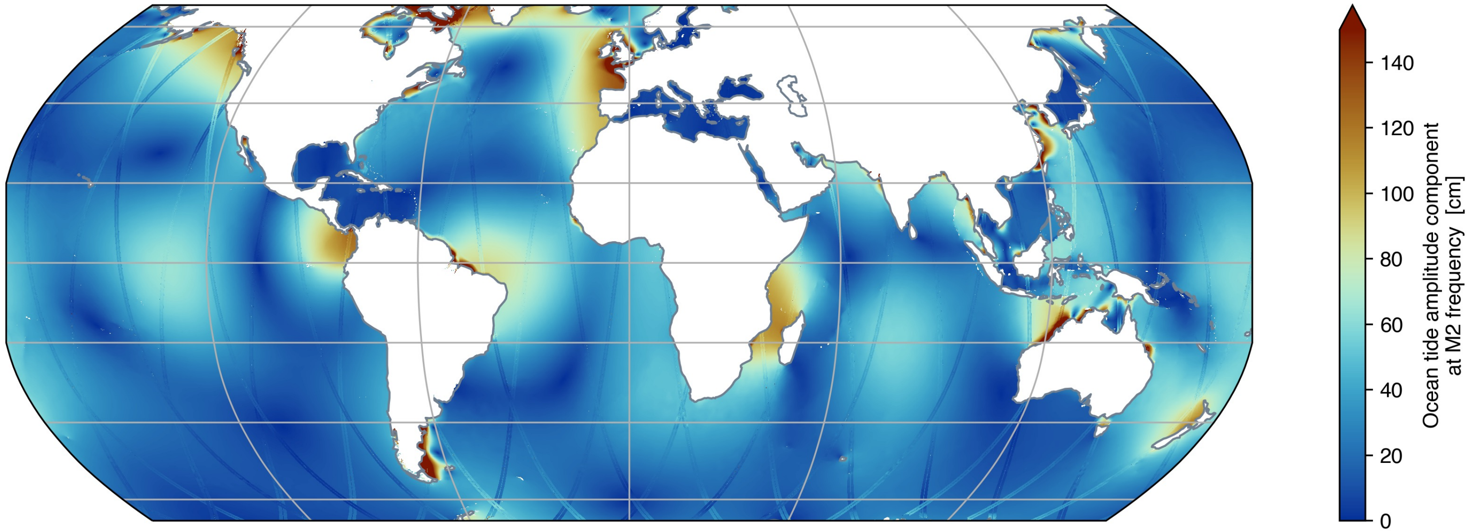
Figure. Aliasing period for several tidal constituents

- With the selected orbit of the Cal/Val phase, several major tidal constituents are derivable from SWOT.

- This presentation, focuses mainly on the **M_2 constituent** which is theoretically derivable after only **12 days.**

Global Tides from SWOT globally from Cal/Val Phase

A. SWOT overlaid onto EOT20



B. SWOT Cal/Val only

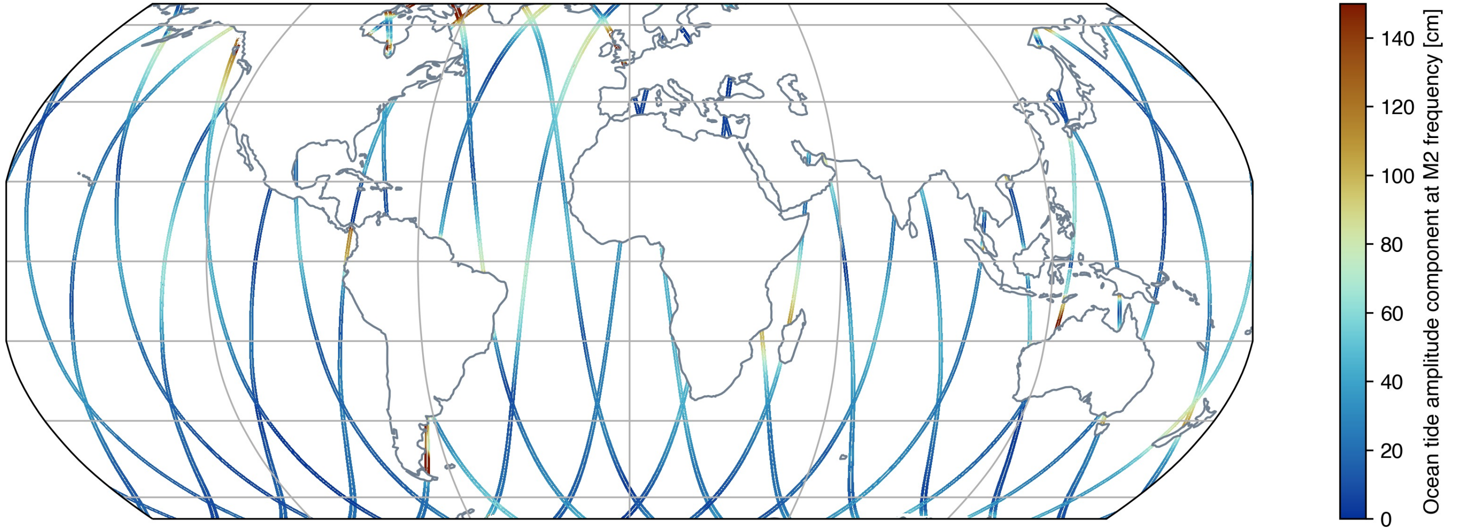


Figure. The full Cal/Val time-series has been used to derive the M_2 tide globally (bottom). Here, the amplitude is overlaid onto the EOT20 model (top)

- These estimations are purely empirical and are full estimations, i.e. are not a residual with respect to a model.
- Results match modelled estimations in the open ocean region and demonstrate a clear possibility for tides to be derivable from the KaRIn data.

Coastal uses of SWOT: Long Island Sound

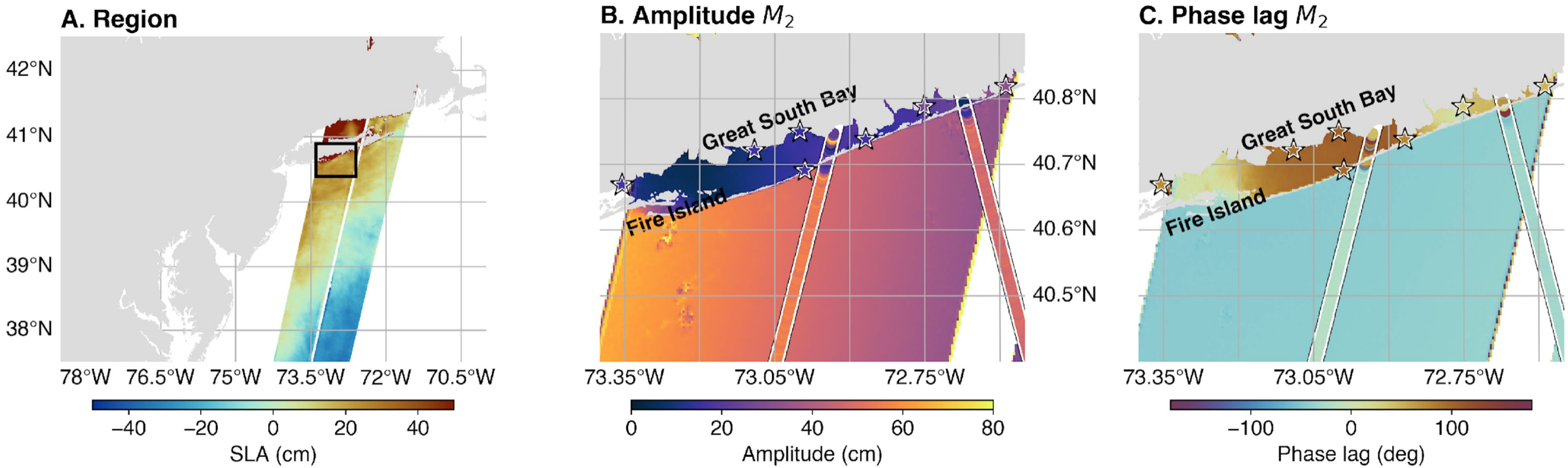


Fig. (A.) SLA from pass #009 and cycle #478 of SWOT across the east coast of the United States of America, with a box highlighting the region of interest. M_2 amplitude (B) and phase lag (C) derived in the Long Island region from the 250m product.

- The Great South Bay presents a challenge for present modelling efforts.
- **Fire Island serves as a barrier** between the Atlantic and the Bay.
- The tide gauges are found on the inside of the Bay, and thus this variability needs to be captured.
- The 250m product shows 1.75 cm amplitude and 3.36 degrees phase lag differences to these observations.

Coastal uses of SWOT: Long Island Sound

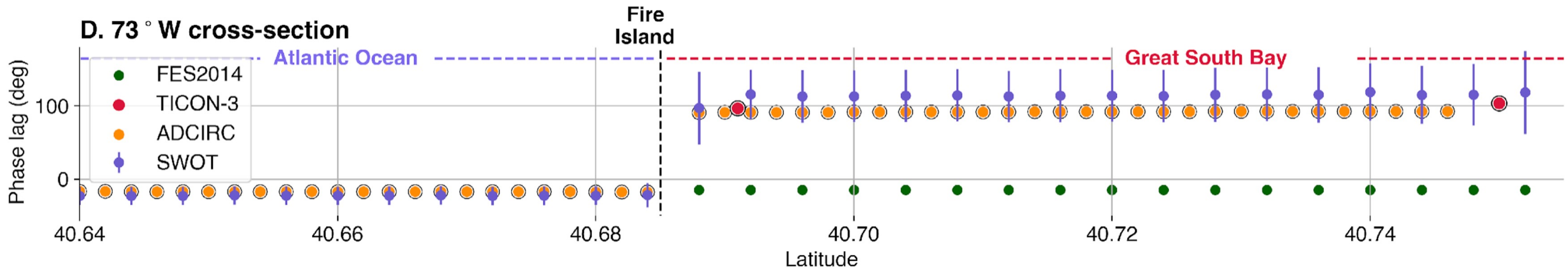


Fig. A cross-section of the resultant phase lag estimations at 73°W across the Great South Bay compared to available TICON-3 tide gauges and a global tide model (FES2014) and a regional tide model (ADCIRC; Szpilka et al., 2016).

- Modern day global models cannot resolve these fine scale variability as seen within the bay.
- SWOT shows that the validation of the global models with these tide gauge data could be inappropriate.
- A regional model, **ADCIRC**, can model the changes within the bay.
- EOT20 and FES2014 show average **amplitude errors exceeding 20 cm within this region**, and **phase lag errors exceeding 50 degrees**.
- For studies with SWOT, in regions such as this, the tidal corrections may be doing more harm than good!

Coastal uses of SWOT: Bristol Channel

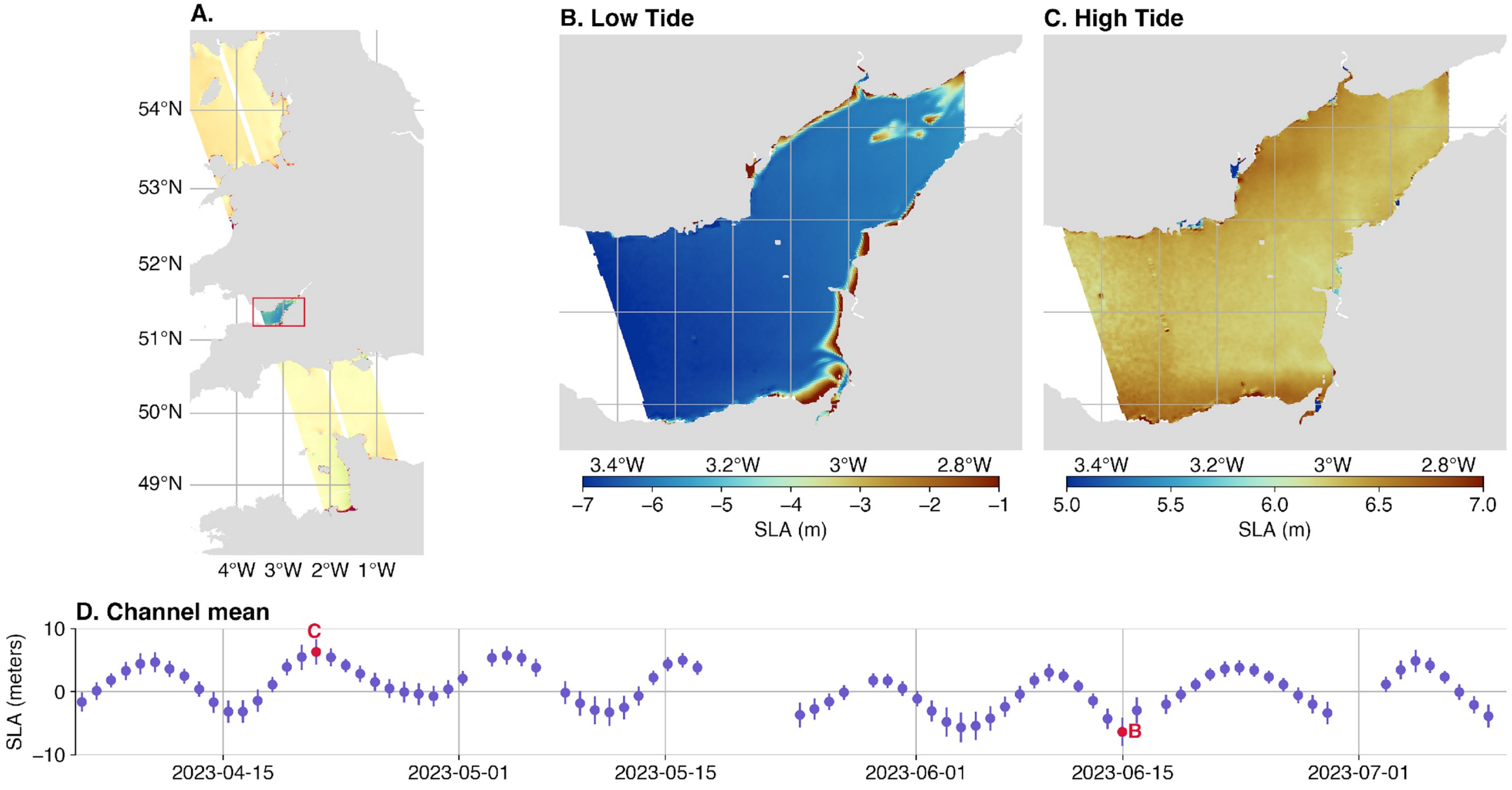


Fig. (**A**) The region of interested shown in the red square. Snapshots of SWOT SLA data taken on low (**B**) and high (**C**) tide periods. (**D**) is the across Channel SLA mean enclosed in a standard deviation envelope.

Coastal uses of SWOT: Bristol Channel

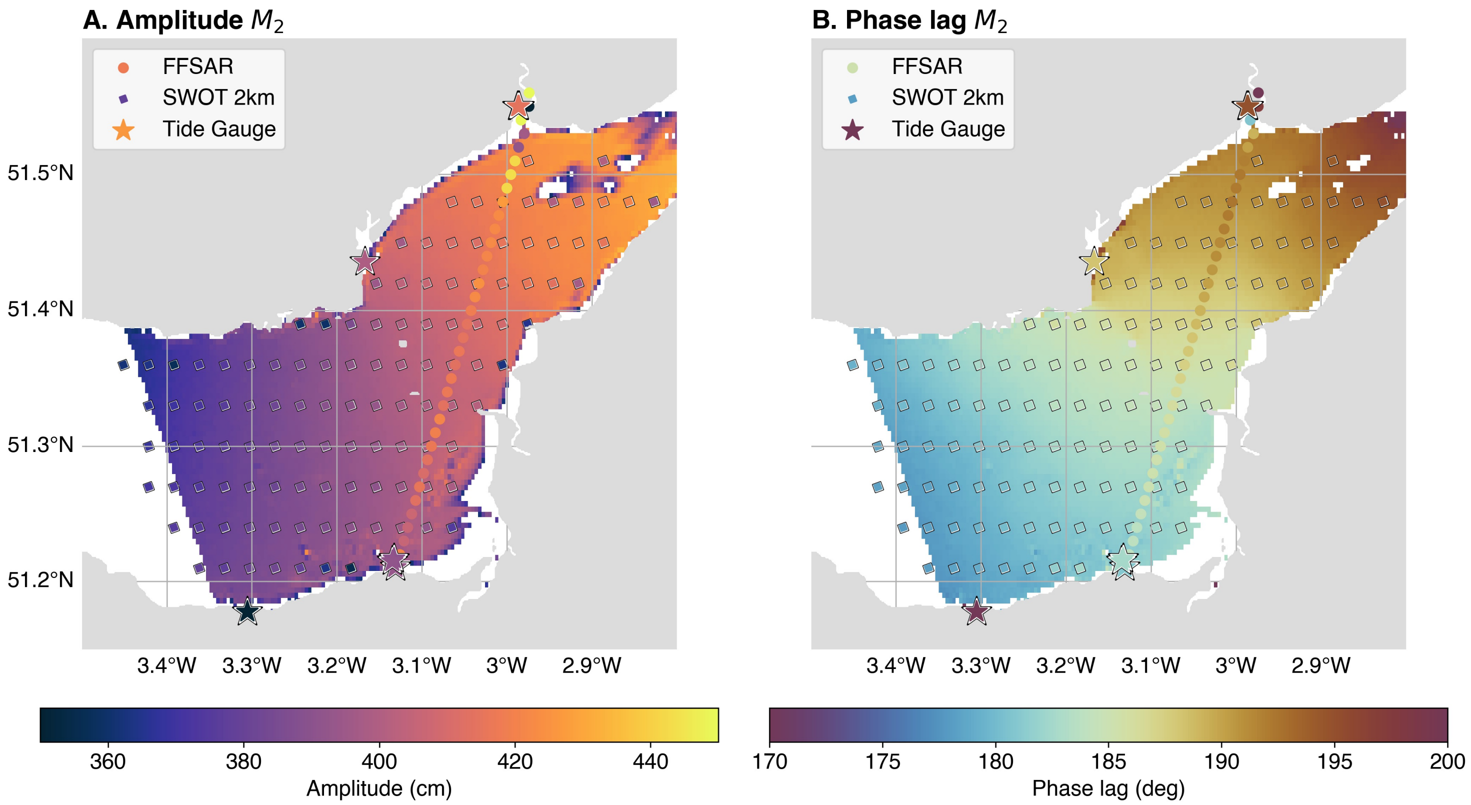


Fig. (**A** and **B**) Amplitude and phase lag of M_2 tidal constituent based on the 250m and 2km SWOT data within the Bristol Channel. The amplitude and phase lag of complementary Sentinel-3 FF-SAR pass are also shown. Stars are in-situ measurements from TICON-3 and Lichtman pers. comms.

- Tide gauges from TICON-3 (Hart-Davis et al 2021) and Lichtman pers. comms. were **used for validation**.
- The 2km product showed mean differences of **2.58 cm** and **2.72 degrees** for the amplitude and phase lag, respectively.
- For the 250m product, the differences were **2.72 cm** and **4.03 degrees**, respectively.
- The FFSAR pass was on average 5.89 cm for amplitude and 5.25 degrees for phase lag different at collocated SWOT positions.

Coastal uses of SWOT: Bristol Channel

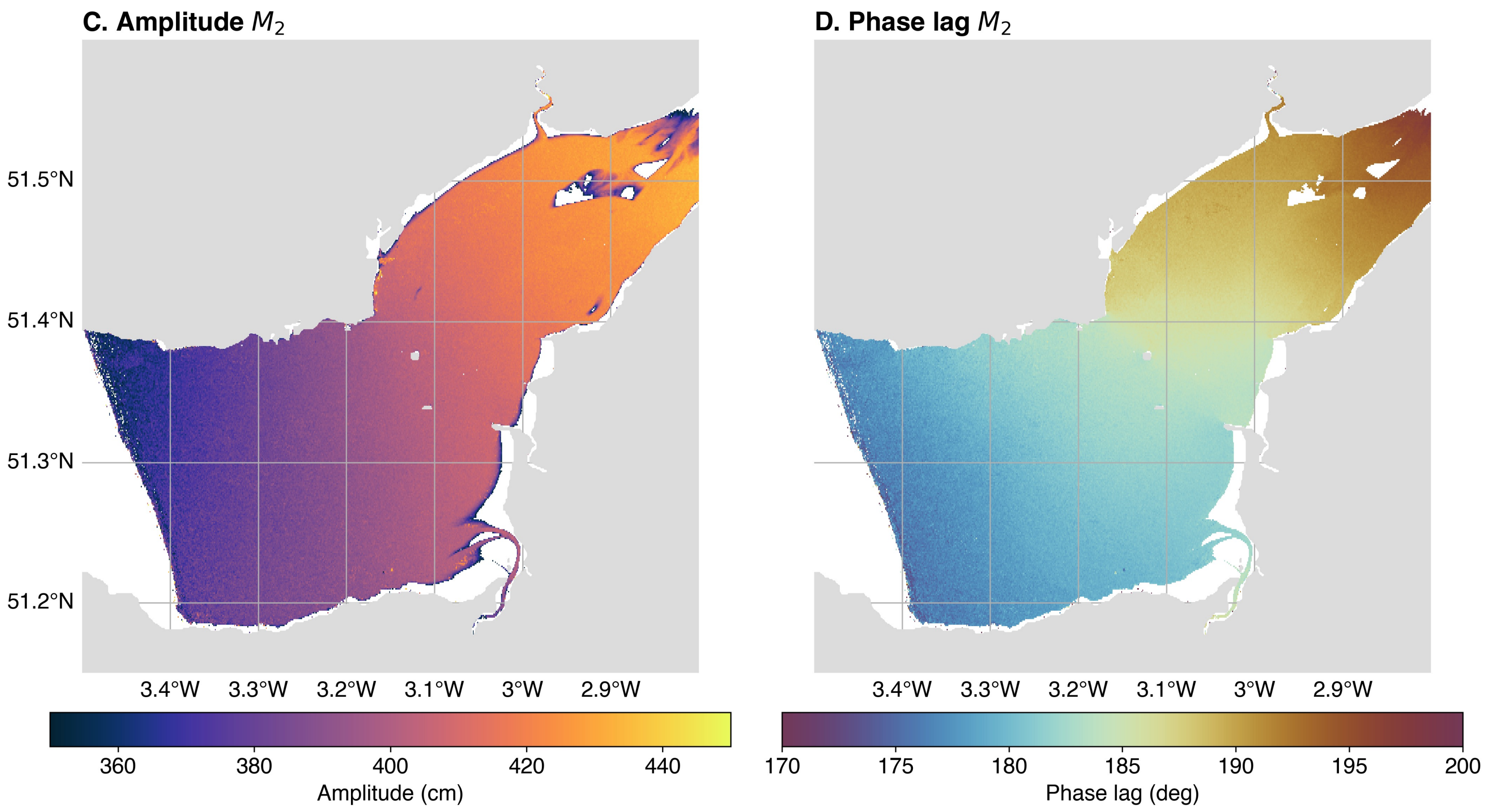
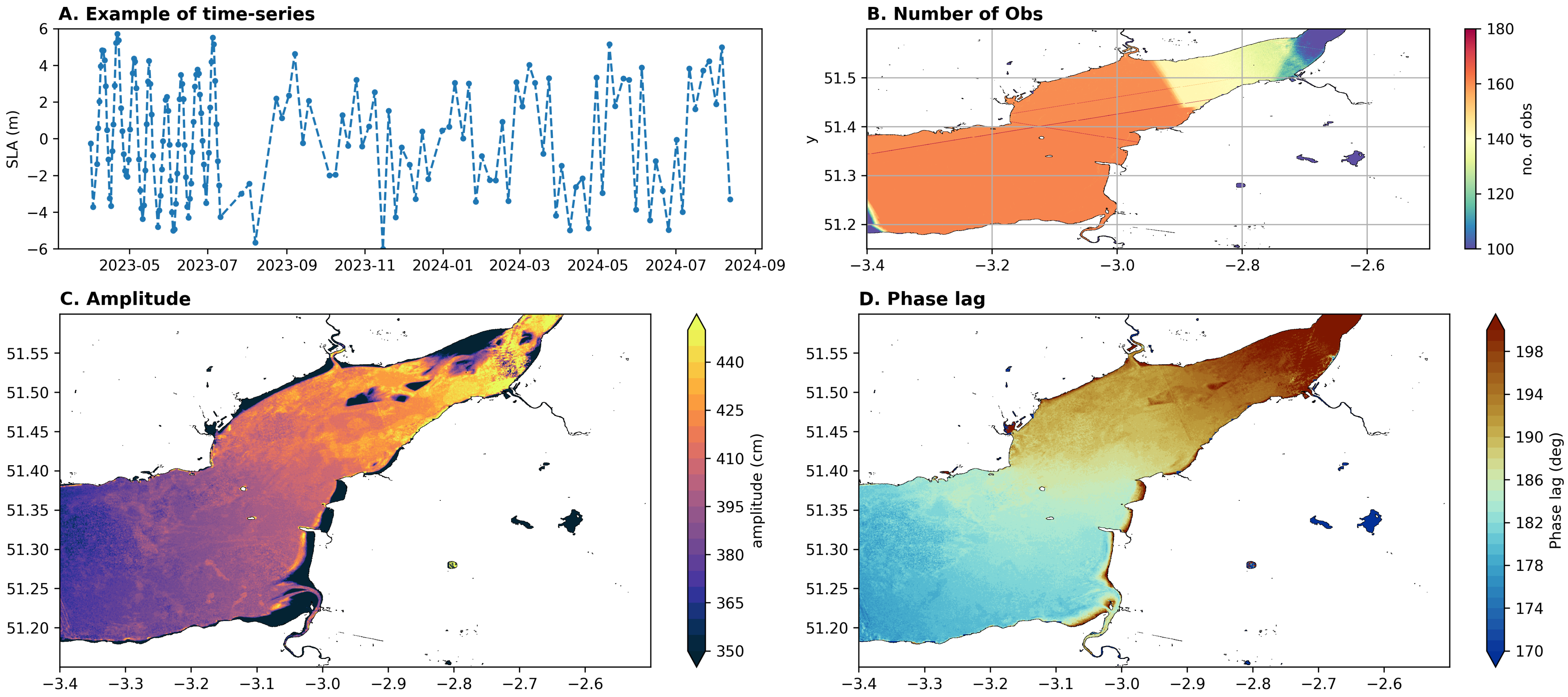


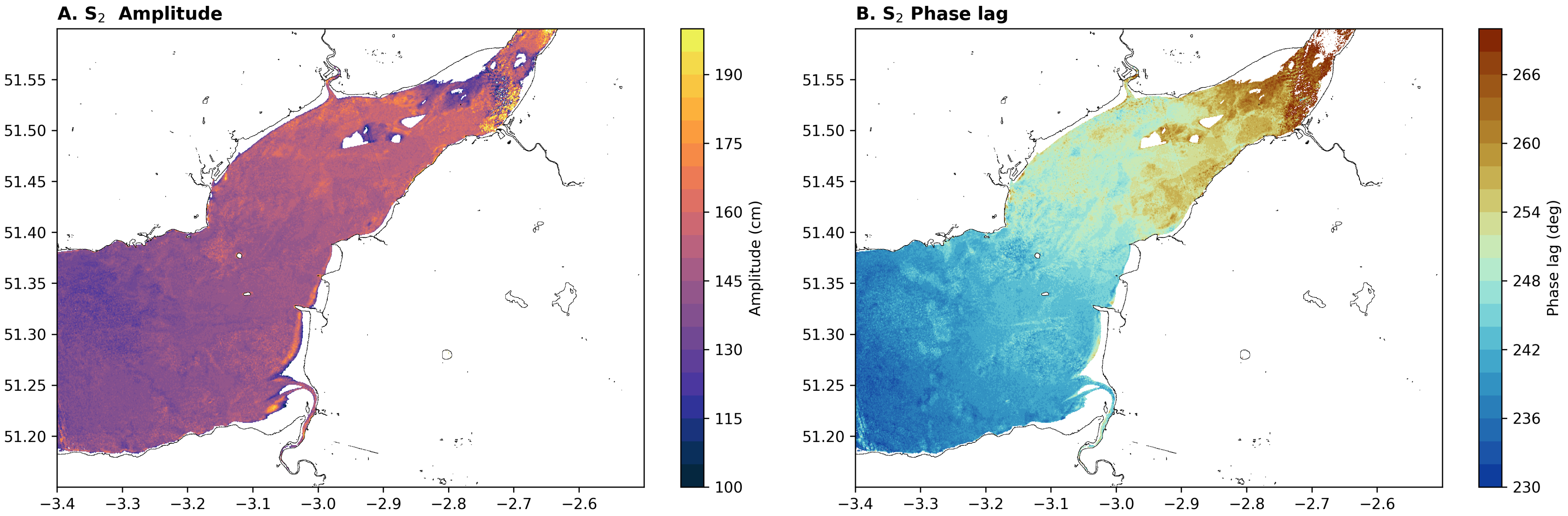
Fig. The amplitude (**C**) and phase lag (**D**) of the M_2 tidal constituent based on pixel cloud product

- The **hydrological product** from the Cal/Val phase is used here.
- These data are used here to derive the M_2 tide.
- The amplitude and phase estimations are clearly similar to those estimations made by the extended time series length 2km and 250m products.
- Influence of sand banks and erroneous data is clear.
- **Tides in rivers** is clearly possible!

Merging of Cal/Val + Science Orbits



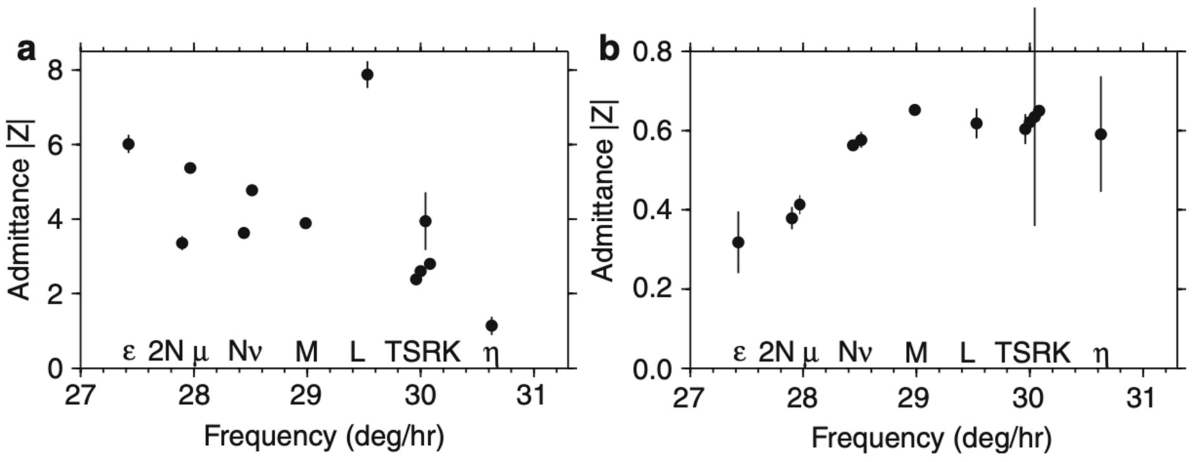
Importance of non-sun-synchronous orbit

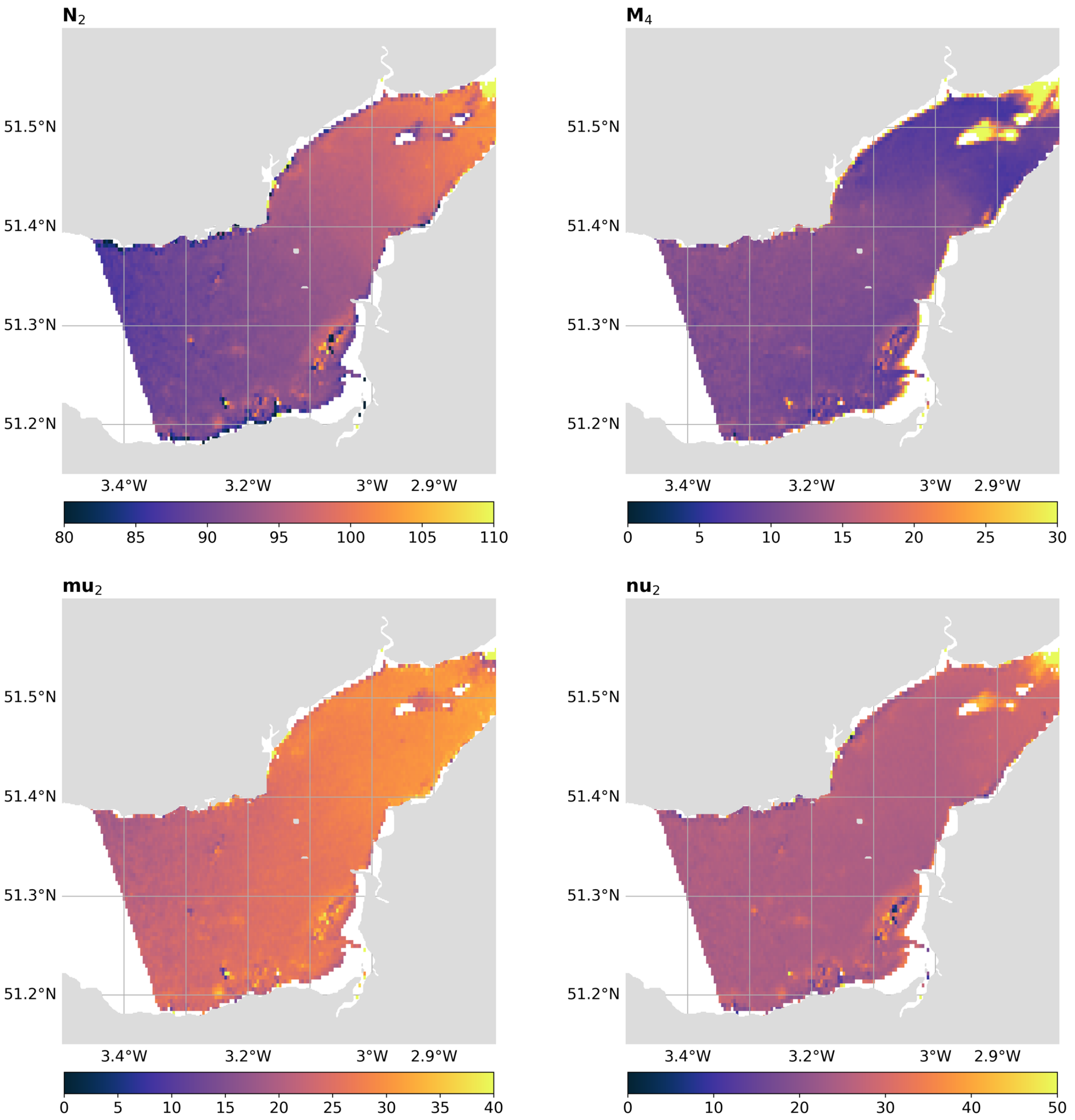


- ➢ The chosen orbits, both in Cal/Val and Science orbits are non-sun-synchronous, thankfully!
- ➢ This means we are able to derive the solar tidal constituents, which previously has only been possible from the TOPEX-Jason-Sentinel-6 series and Cryosat-2.

More Tides and Nonlinear Tides

Nonlinear Regime / Linear Regime





- ➢ Tidal constituents in nonlinear regimes (Bristol Channel) show clear influence from nonlinear tides.
- ➢ The one-day repeat in particular can be used to improve our understanding of these nonlinear affects (mu2).

SWOT for tides in fjords - Hortafjorden

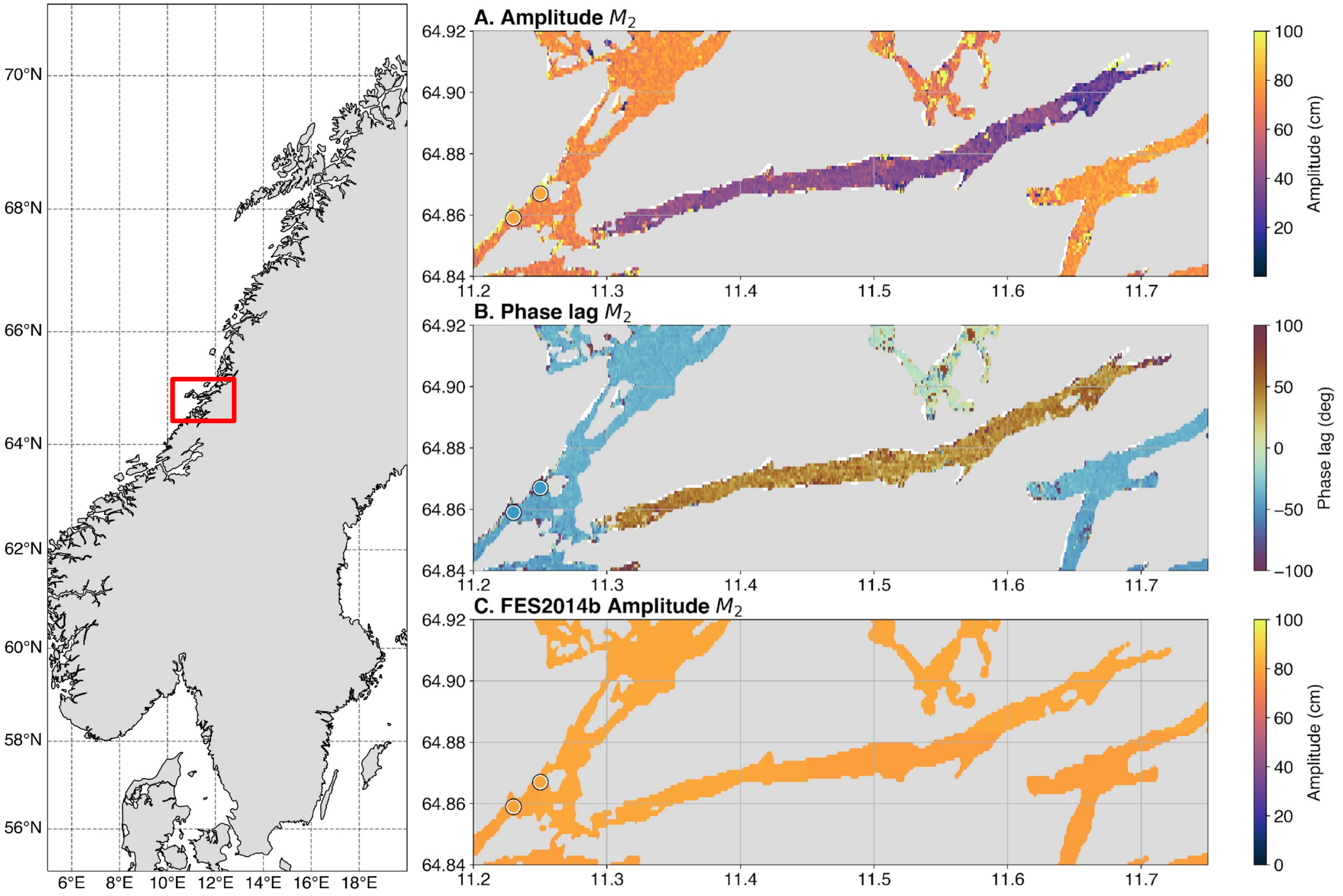


Fig. M_2 amplitudes (**A**) and phase lag (**B**) derived from the pixel cloud data within the Hortafjorden. (**C**) The FES2014b modelled amplitude in the region.

- A short look forward, towards **estimating tides in fjords.**
- Tides in fjords are only possible in very large fjords, but they do play important roles in the dynamics within fjords.
- The spatial characteristics of the fjord varies considerably compared to outside the fjord and to models.
- Due to limited observations in this fjord, the data matches well outside the fjord but it cannot be confirmed how well SWOT is doing within. More on this with more data!

SWOT for tides in fjords - Sognefjorden

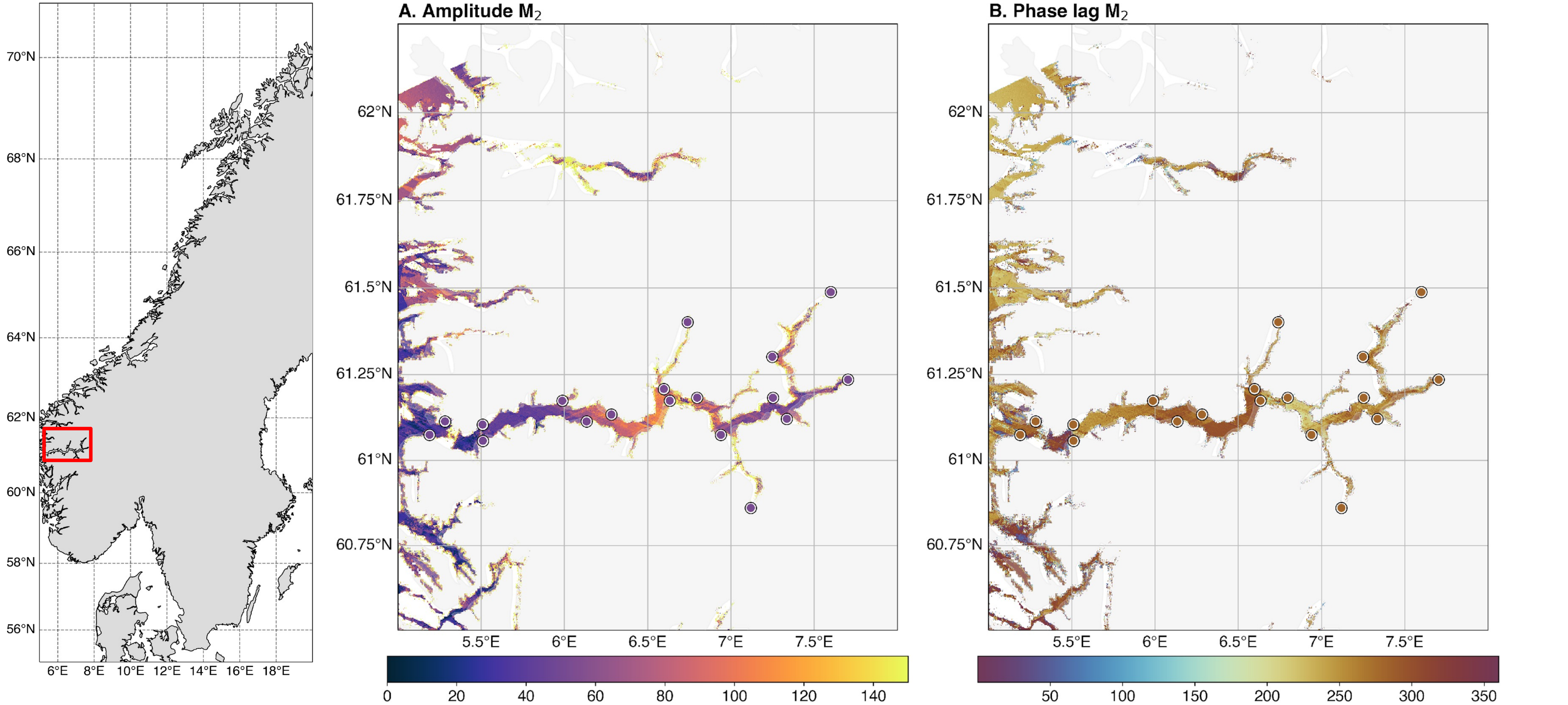
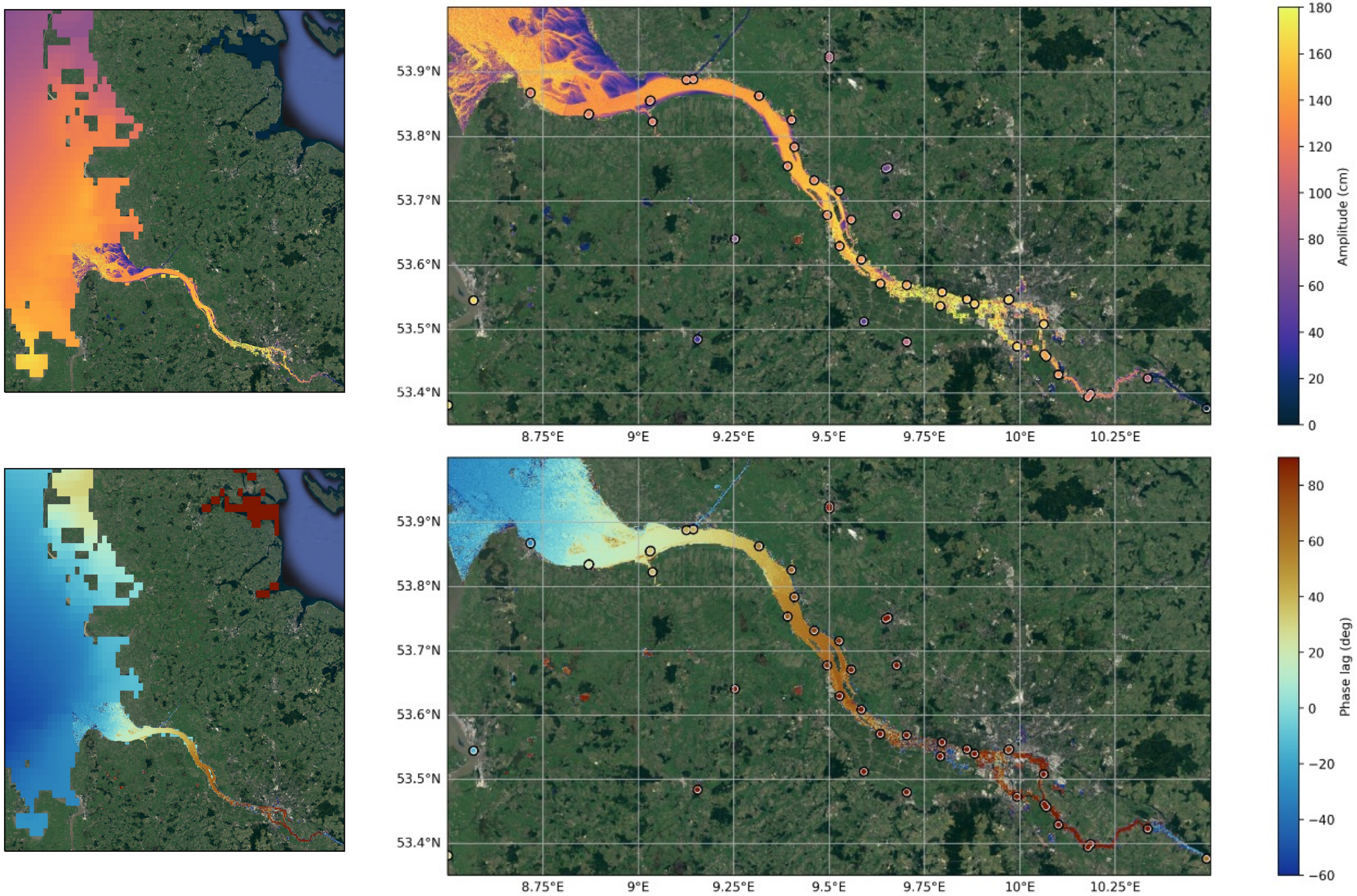


Fig. M_2 amplitudes (**A**) and phase lag (**B**) derived from the pixel cloud data within the Sognefjorden.

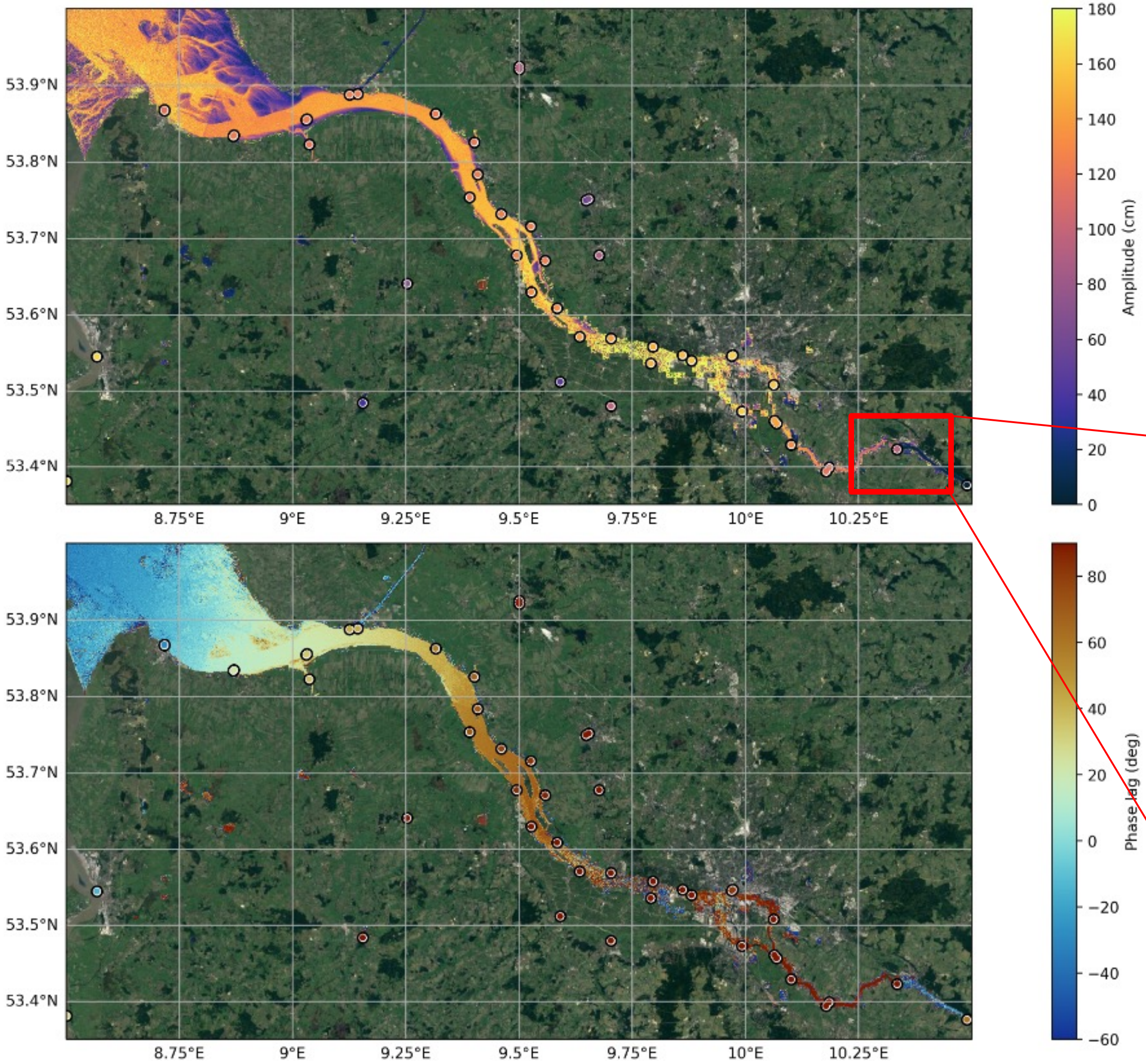
SWOT for tides in rivers and estuaries – Elbe River

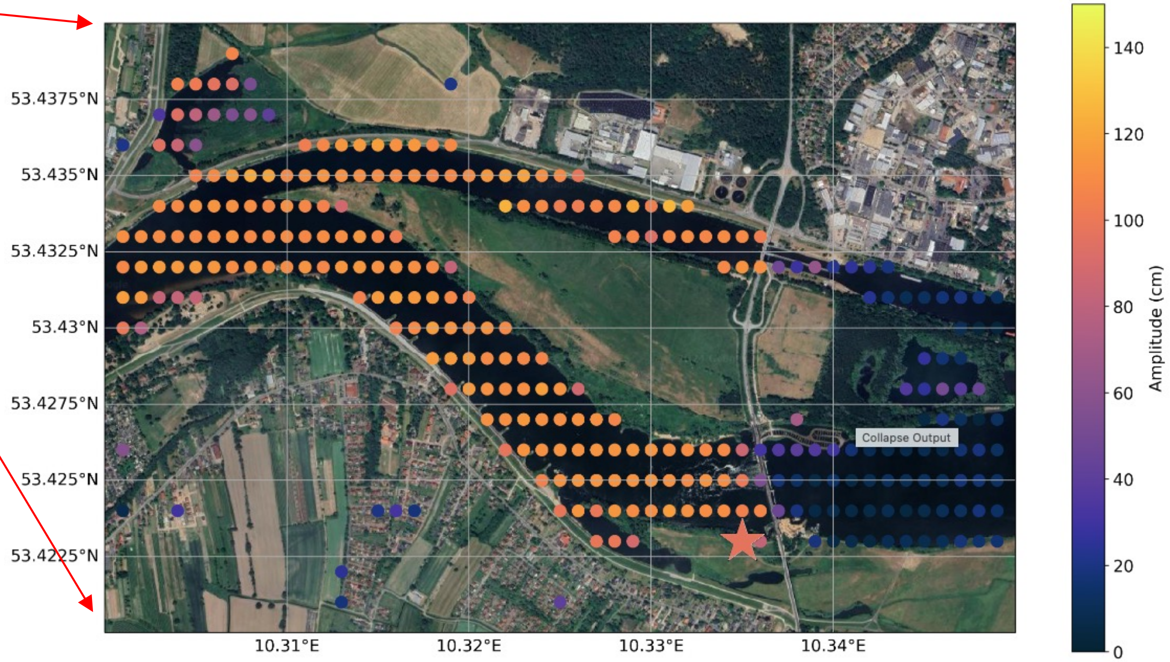


- SWOT from 21-day repeat and 1-day repeat are used here for the Elbe River.
- **The FES2022 model** is used to provide the amplitude and phase lag outside of the river mouth (left subplots).
- Validation with TICON-3 showed a mean difference of:

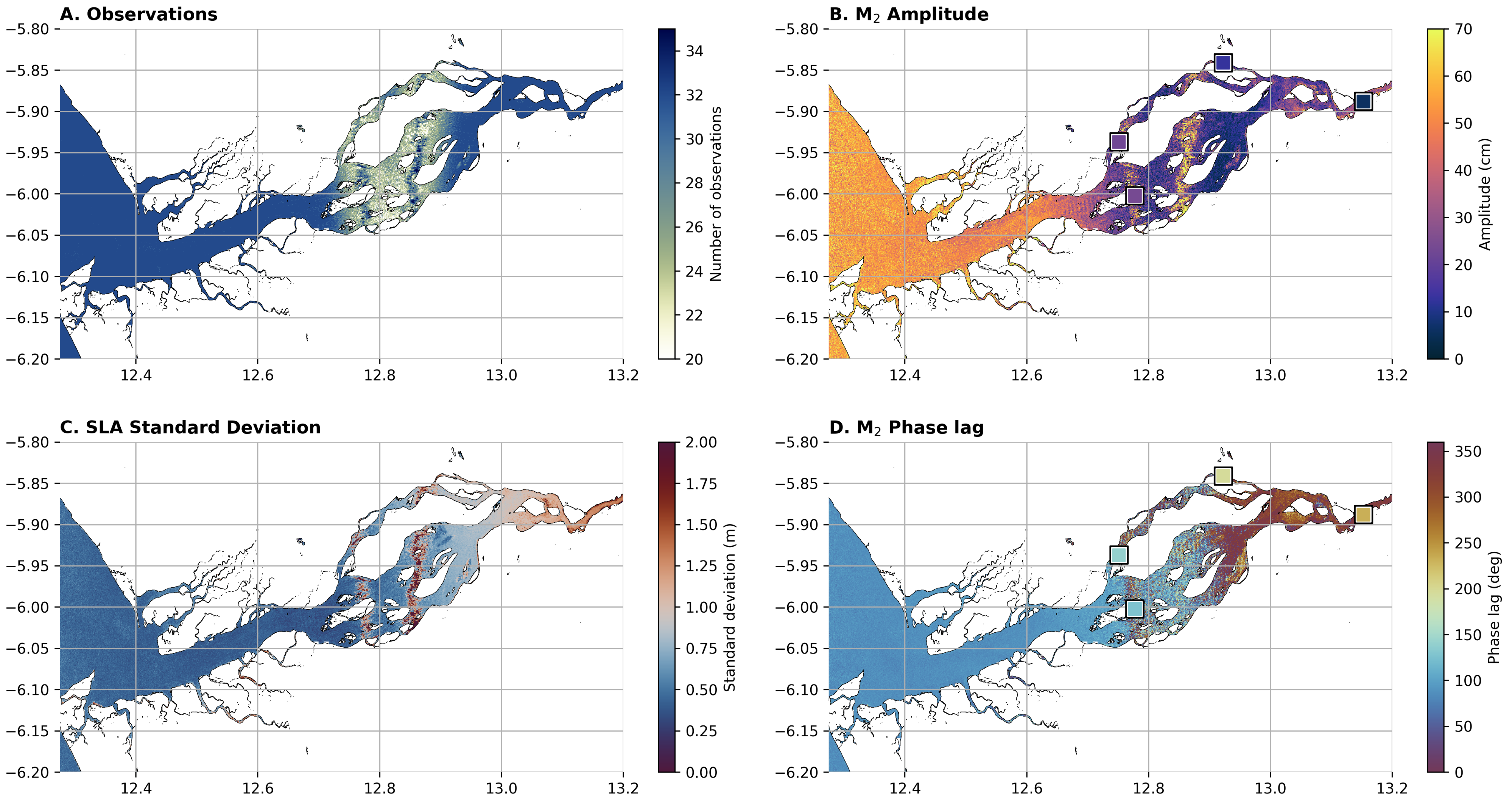
Amplitude: 2.61 cm
Phase lag: 37.81 degrees

SWOT for tides in rivers – Elbe River

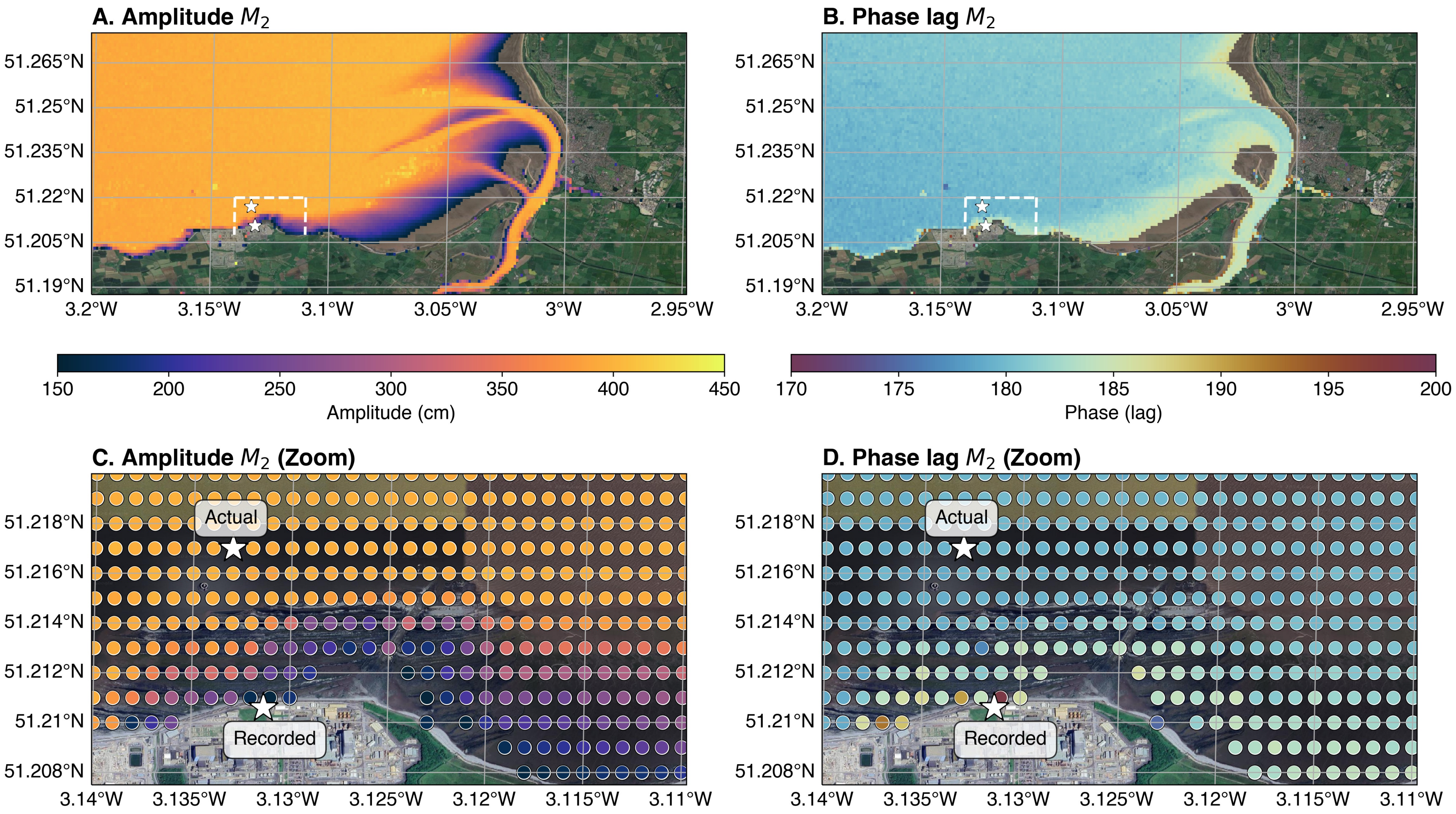




SWOT for tides in rivers and estuaries – Congo River

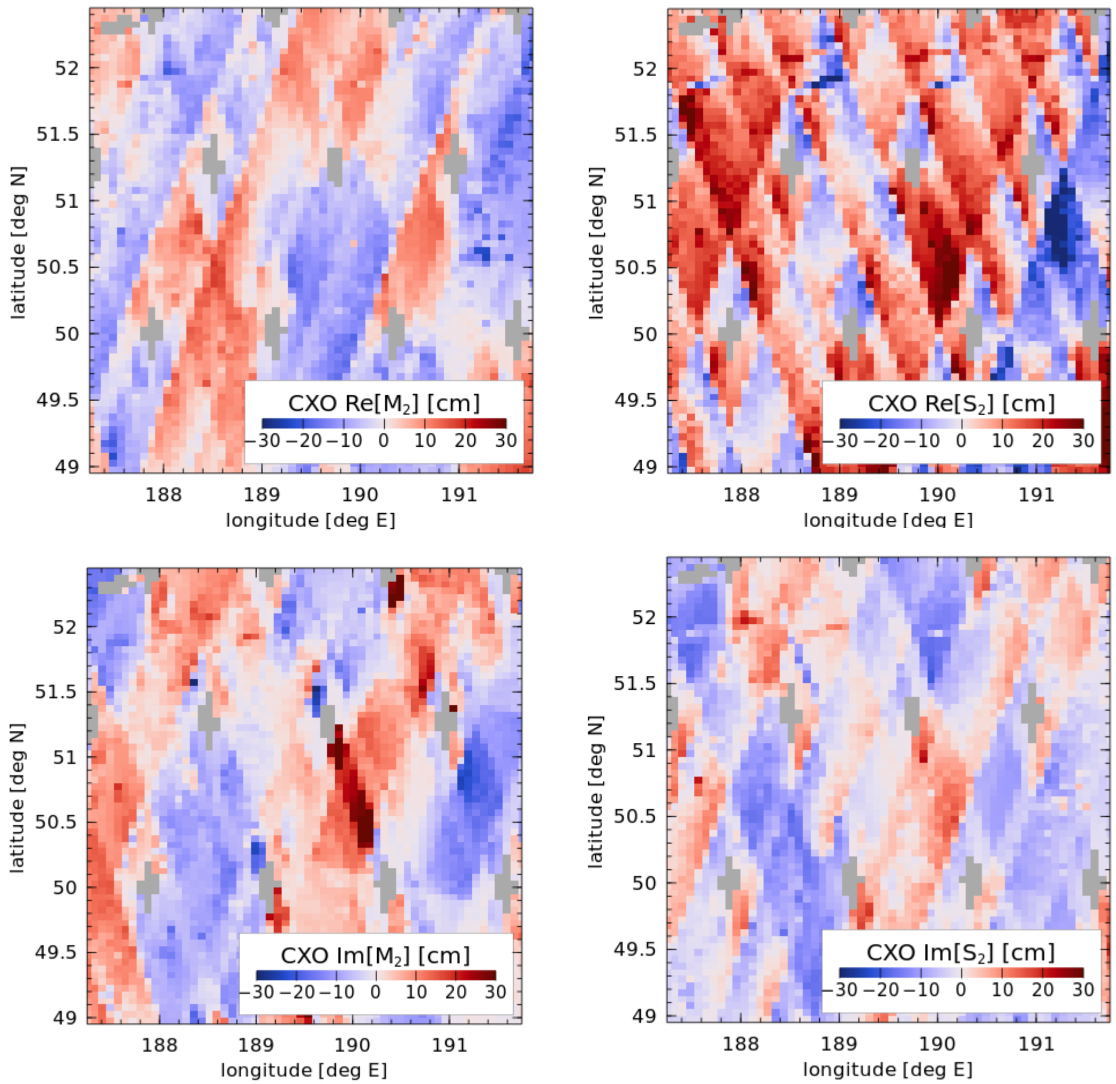


SWOT for improved validation of models

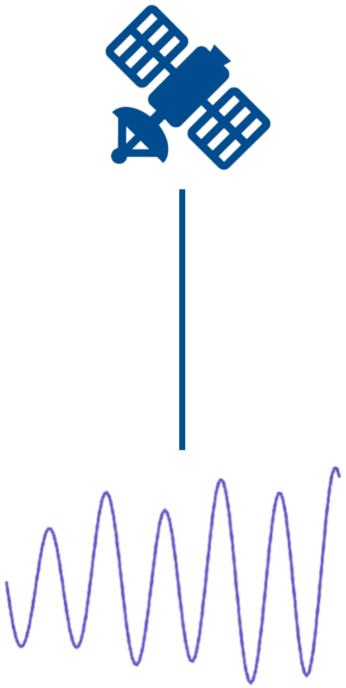


- In some cases, tide gauge locations are recorded at the computer location rather than the measurement position.
- Traditionally, model validation to modern tide models this difference doesn't have an influence.
- But when using the high resolution SWOT data, this starts to become important as amplitude differences can exceed 100s of cm (**Fig C)**.

Future prospects and outlook



- Our validation datasets can be improved with SWOT.
- The non-sun-synchronous orbit and the high resolution provided by the open ocean and coastal products will be critical for empirical models, particularly near the coast.
- New insights into tidal dynamics in estuarine and river systems is clearly feasible with sufficient data from SWOT.
- The influences of sandbanks on the SLA is a clear challenge for tidal research.
- The roll correction remains one of the key errors in tidal estimations from SWOT.
- For more information (Hart-Davis et al *in review*): https://essopenarchive.org/doi/full/10.22541/essoar.171770548.88858218



Thank you! Questions?

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