SWOT Science Team Working Group on Tides and High-frequency motions

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2024 Chapel Hill Meeting

Is SWOT meeting requirements, pre-launch expectations?

- SWOT sees barotropic tides, internal tides, and solitons
- The SWOT 1-day and 21-day orbits were designed to optimize tidal sampling as much as feasible

New results being revealed

- Two-dimensional images are really helpful for understanding propagation of internal tides and solitons
- SWOT is revealing new information about barotropic tides in shelves
- SWOT will reveal new information about high-latitude tides
- Analysis of internal tides in SWOT 1-day data in the Amazon region reveals strong incoherence, in accordance with prior predictions – Tchilibou
- HYCOM can be used on top of HRET for more effective internal tide prediction

Lightning talks by PIs

New barotropic ocean tide models

EOT20	(1/8)°	– 17 constituents
DTU23	(1/16)°	– 10 constituents
TPXO10.1	(1/6)°	– 25 constituents
nested	(1/30)°	– 15 constituents
GOT5.5	(1/8)°	– 16 constituents (+ RE14 for long-period)
GOT5.6.	(1/8)°.	– ditto + 4 degree-3 tides
FES2022	(1/30)°	– see slide from Loren Carrere

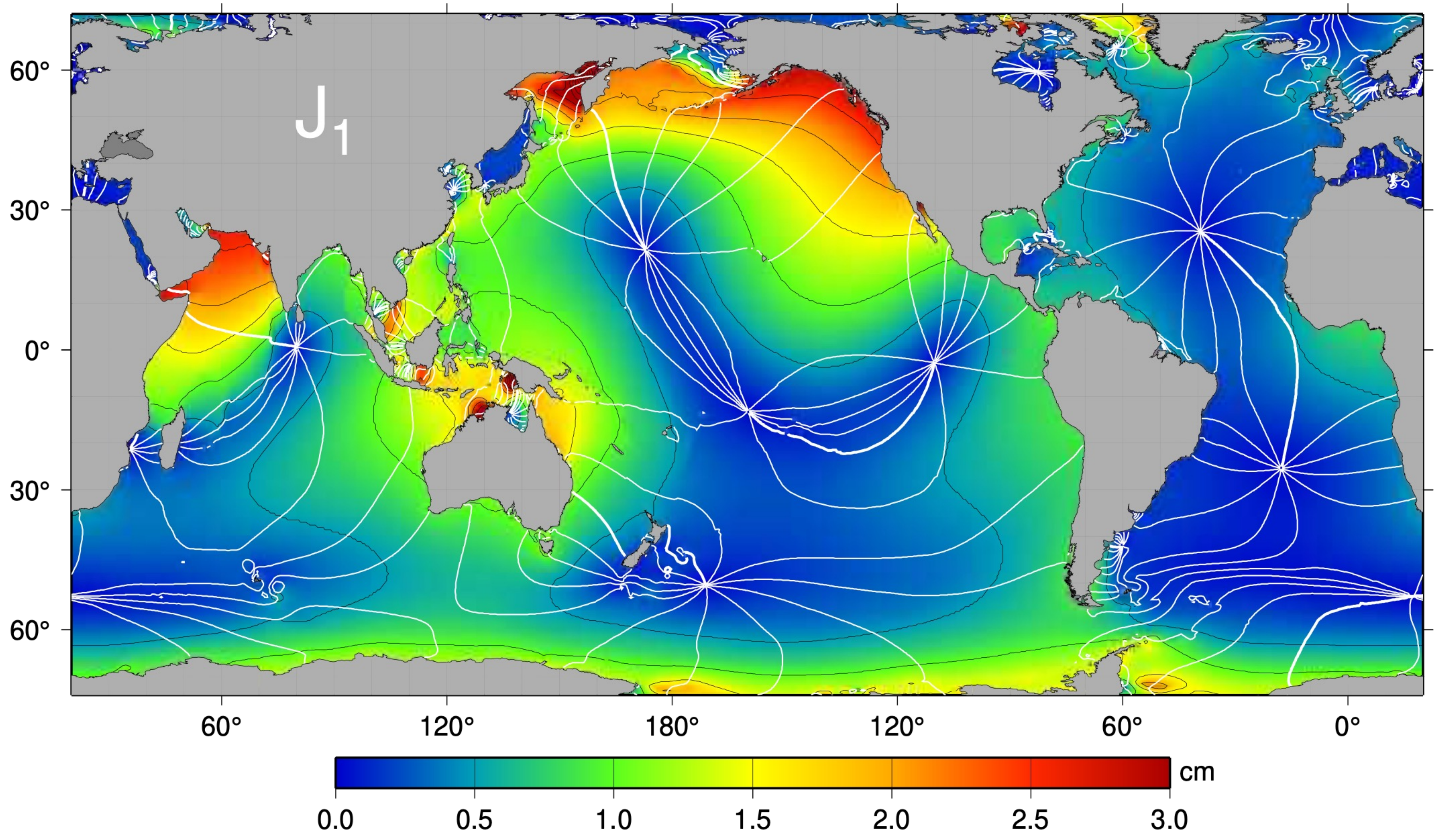
General prediction software

(multi-format, multi-constituent)

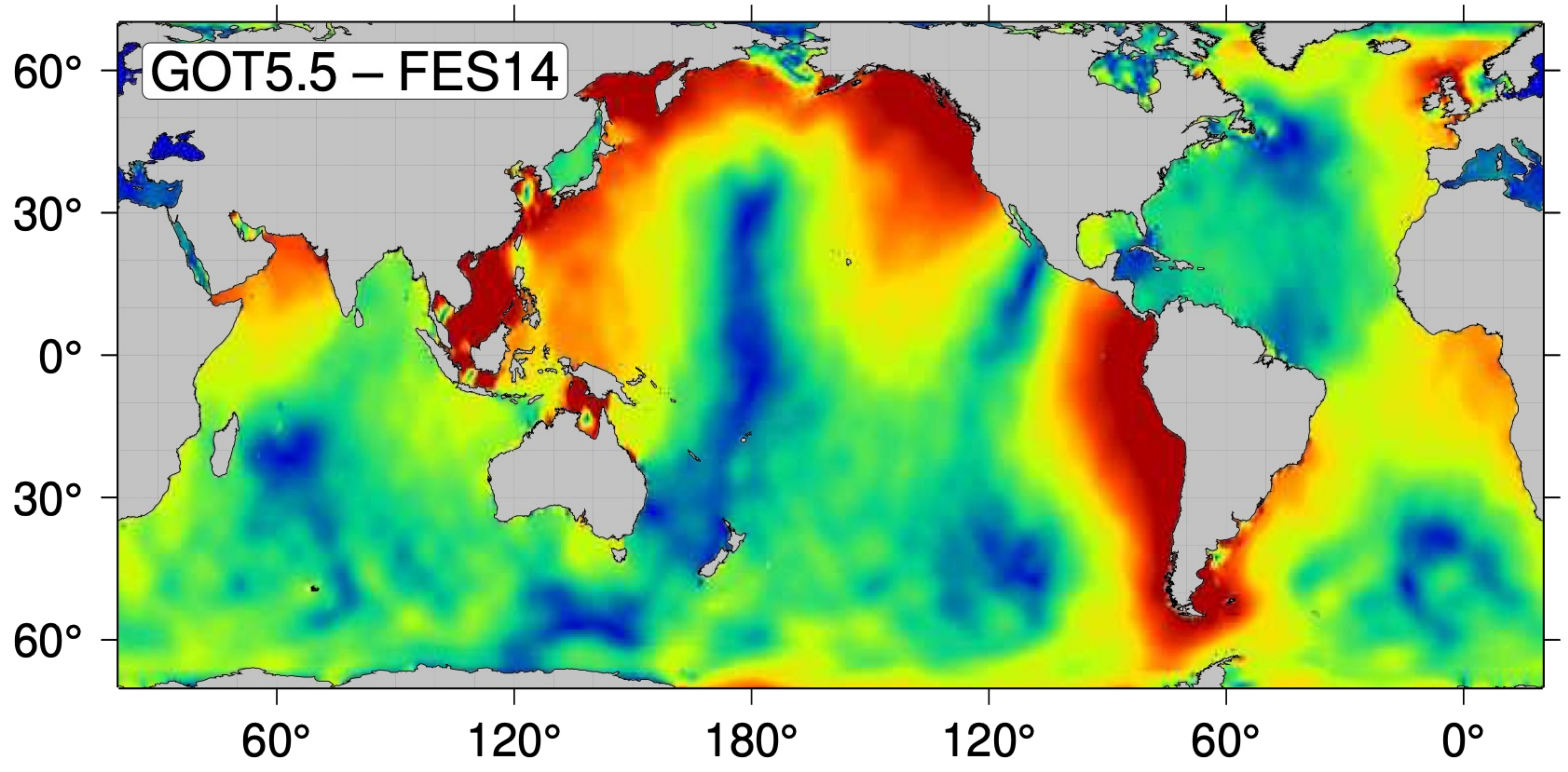
perth5 (fortran2003) – R. Ray

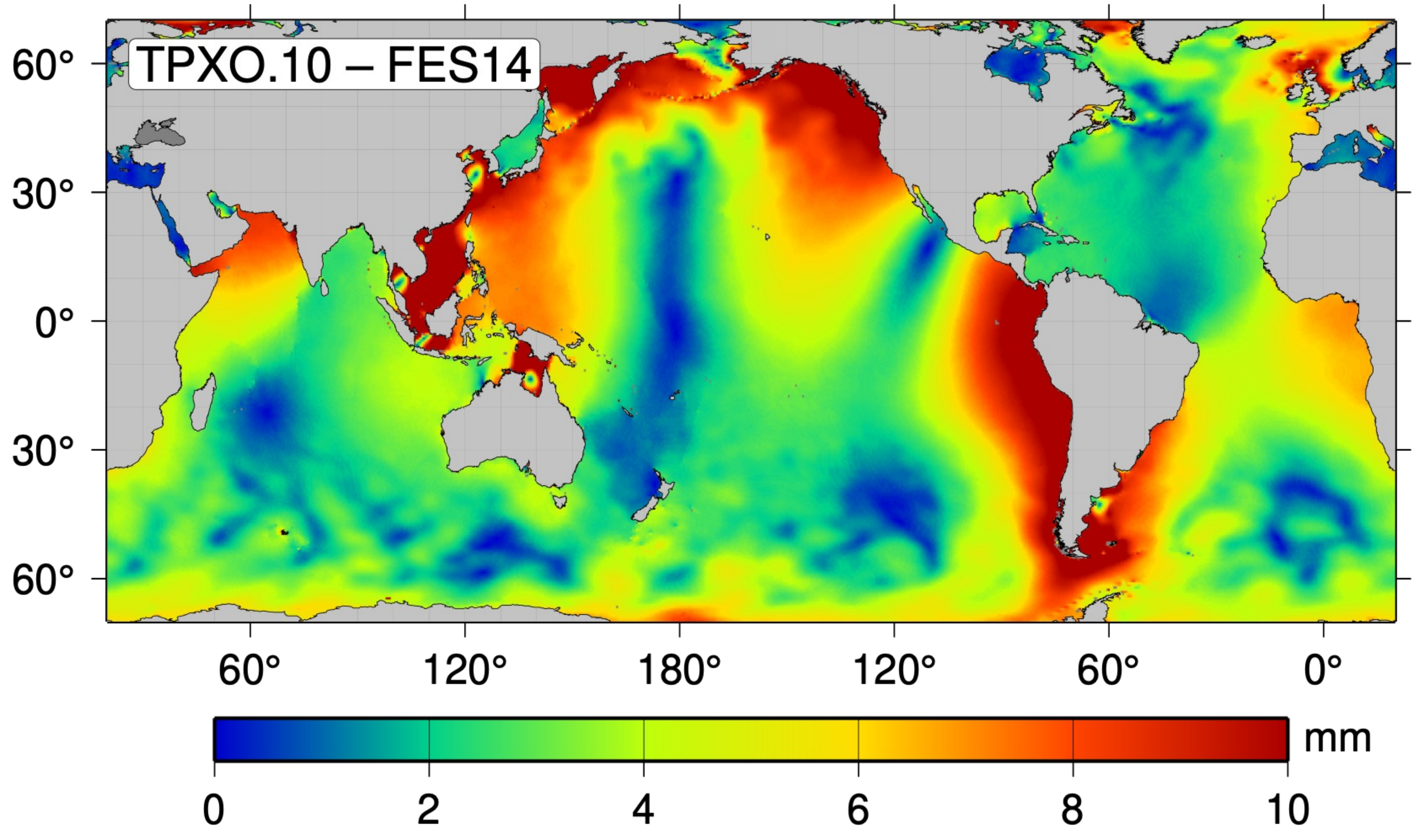
pyTMD (python) – T. Sutterley

Example: J1



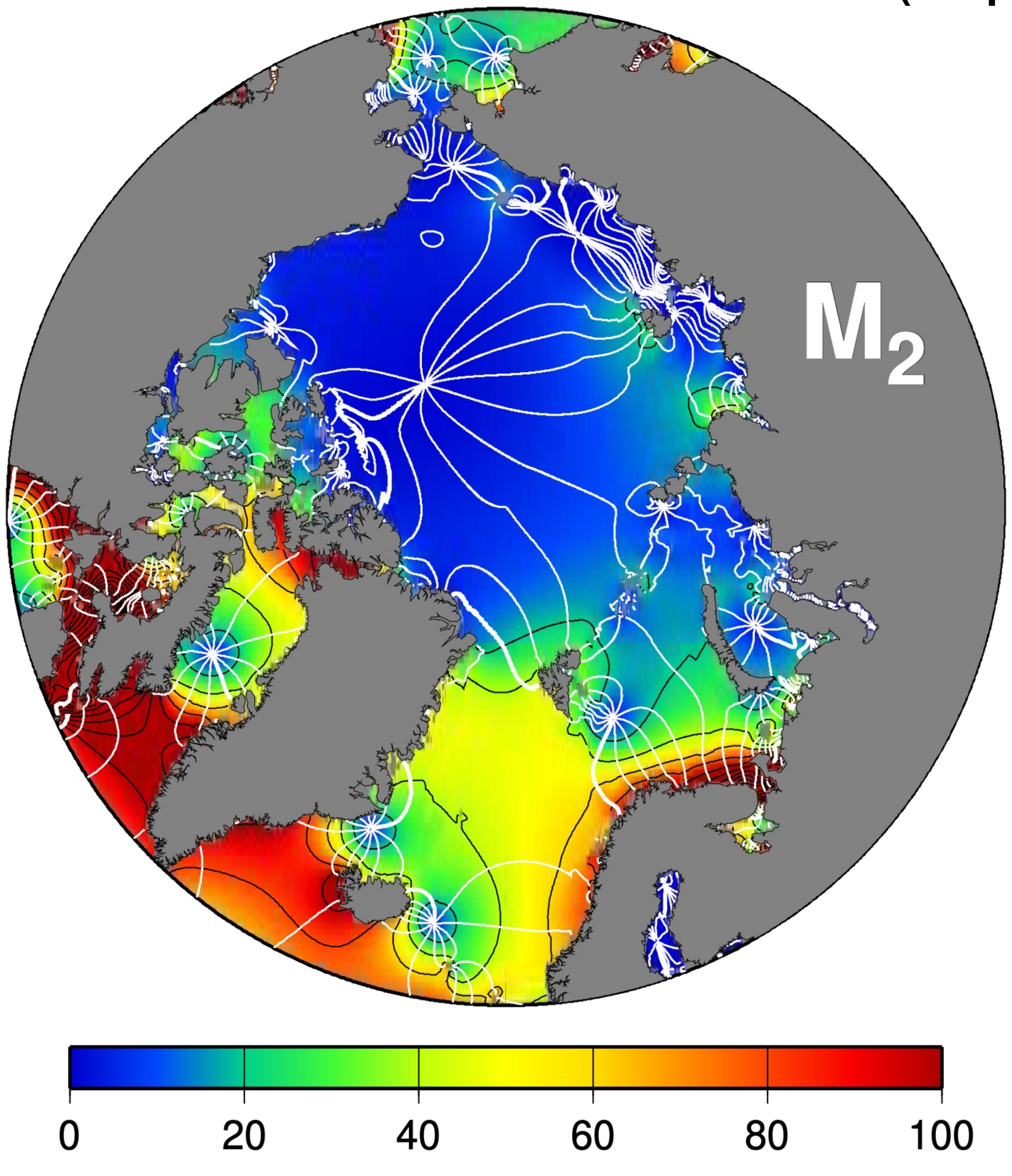
consistent differences with FES2014

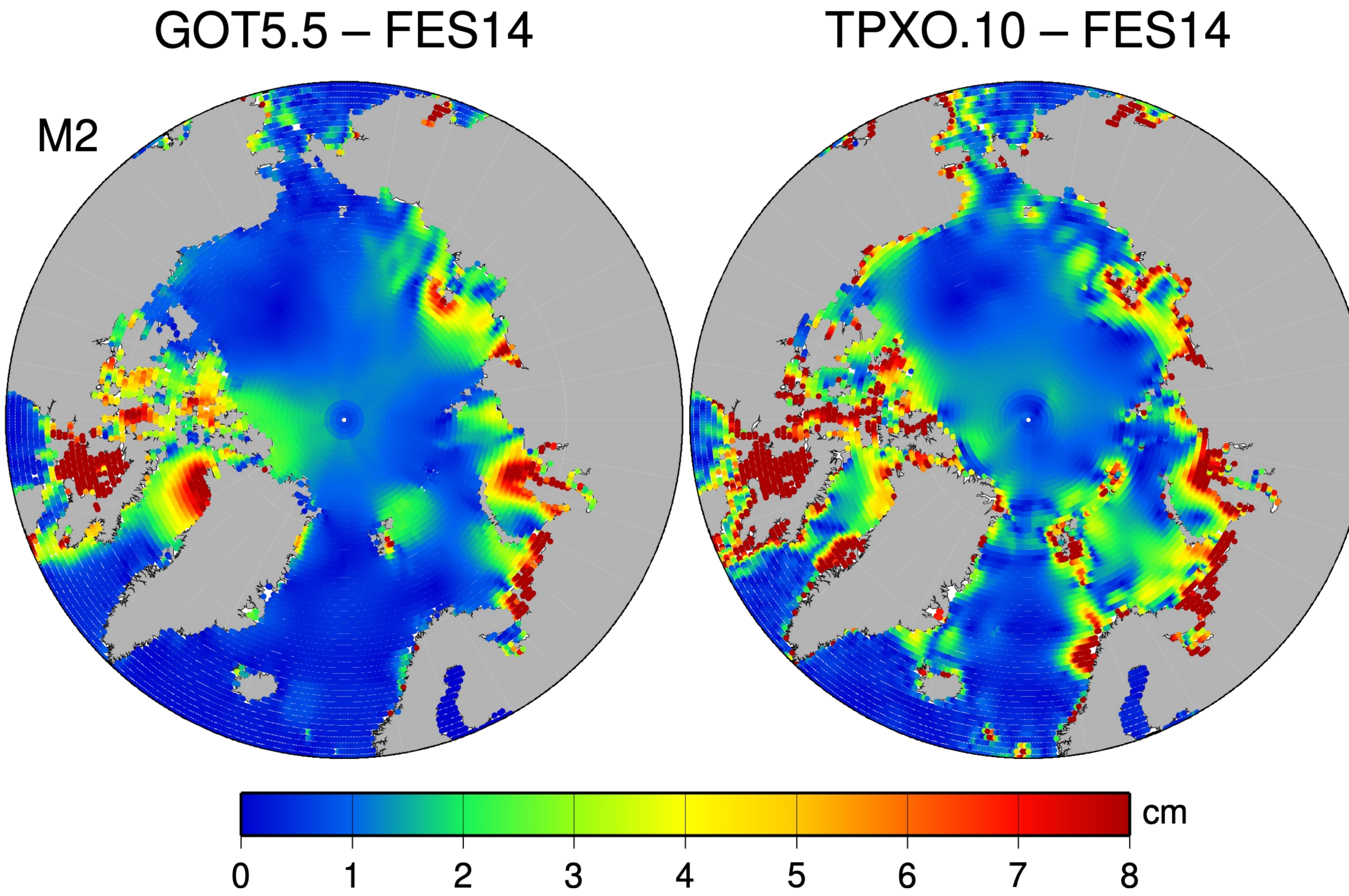




Arctic Ocean improvements

(especially thanks to CryoSat-2)





But still large differences!

FES2022 Status

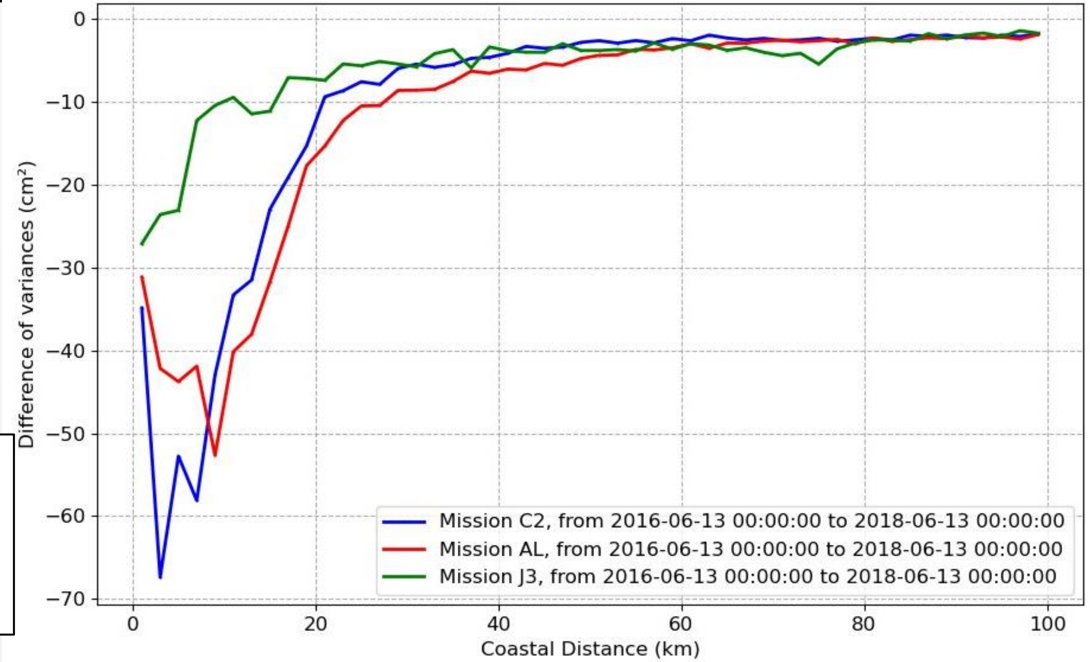
- FES2022B version is finalized : contains ocean tide elevations and loading tide

- **Official diffusion on AVISO website is planned by <u>end of june 2024 :</u>** **<u>https://www.aviso.altimetry.fr/en/data/products/auxiliary-products/global-tide-fes.html</u>**

- **34 waves included in FES2022 tidal spectrum :**
  - 19 Main Tides: 2N2, Eps2, J1, K1, K2, L2, Lambda2, M2, M3, Mu2, N2, Nu2, O1, P1, Q1, R2, S1, S2, T2
  - 6 Long Period Tides: Mf, Mm, MSqm, Mtm, Sa, Ssa
  - 9 Non linear Tides: M4, M6, M8, MKS2, MN4, MS4, Msf, N4, S4

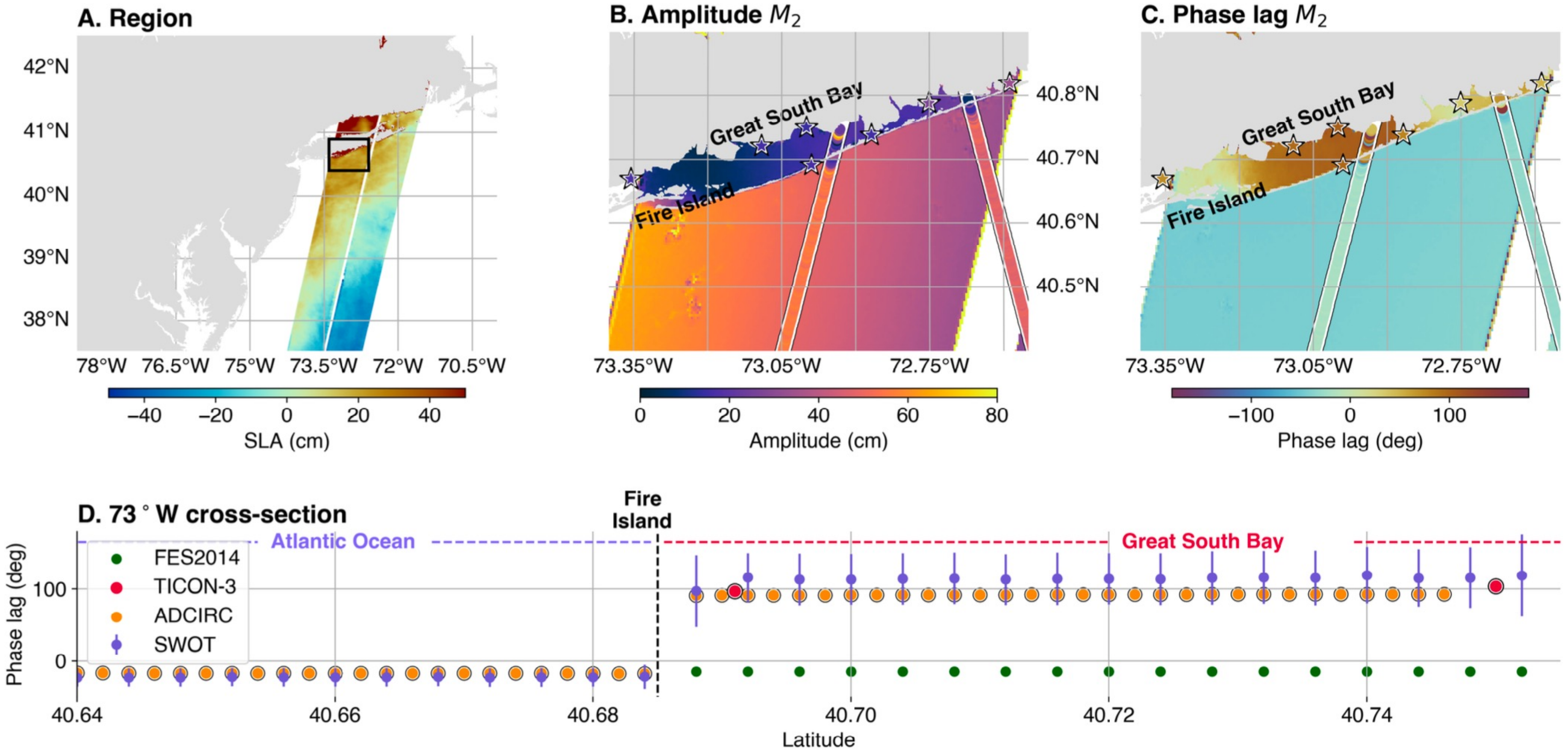
- **Tidal prediction software will be available also**

- **Reference paper to come soon:**
  - Lyard, F. H., Carrere, L., Fouchet, E., Cancet, M., Greenberg, Dibarboure, G. and Picot, N.: “FES2022 a step towards a compliant tidal correction”, in preparation, to be



SLA variance difference when using FES2022b tide model instead of FES2014b as a function of coastal distance, for 3 altimeter missions, in cm^2. The variance reduction when using FES2022b model is very significant when we get closer to the coast (distance < 60km).

SWOT measures near-coastal tides (even behind a barrier island!)



SWOT estimates M2 amp/phase behind Fire Island, NY

Fire Island dampens and lags the open-ocean tide

Transect at 73°W

Global tide models cannot capture this high resolution

Hart-Davis, Andersen, Ray, Zaron, et al., “Tides in complex coastal regions: early SWOT results,” (under review).

SWOT also provides a test for ocean forecast models: **HYCOM** removes additional 18.5% internal tide SSH variance

- Yadidya et al. (2024; GRL) demonstrated that US Navy ocean forecasts with HYCOM showed skill in removing internal tide sea surface height (SSH) variance from nadir altimetry comparable to that of HRET, the current state-of-the-art internal tide correction model (Figure 1).

- HYCOM is particularly skilled at removing the 'incoherent' internal tide SSH which is caused by interactions of other oceanic processes that the HYCOM forecast model predicts on timescales that are not captured by HRET.

- Following this work, we found that using HRET + HYCOM removed more variance from SWOT one-day repeat than HRET alone (Figure 2).

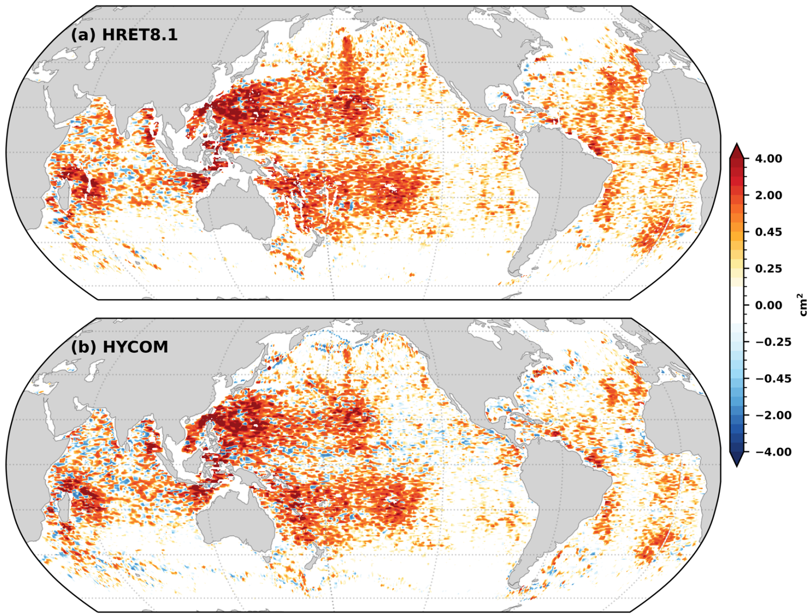


Fig. 1. Variance removed from Nadir Altimetry from empirical HRET model and US Navy HYCOM model [Yadidya et al. (2024) - GRL]

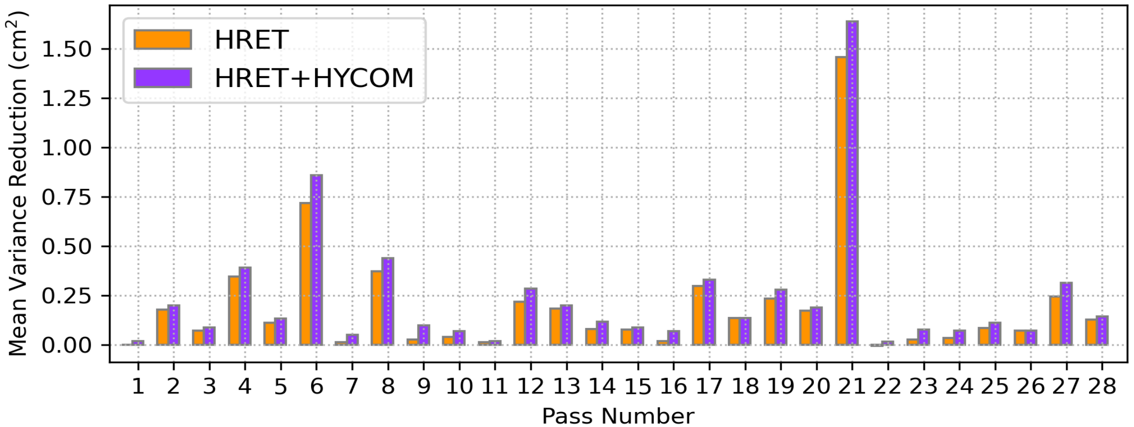


Fig. 2. Mean Variance Reduction for each pass during SWOT one-day repeat by HRET and HRET+ HYCOM

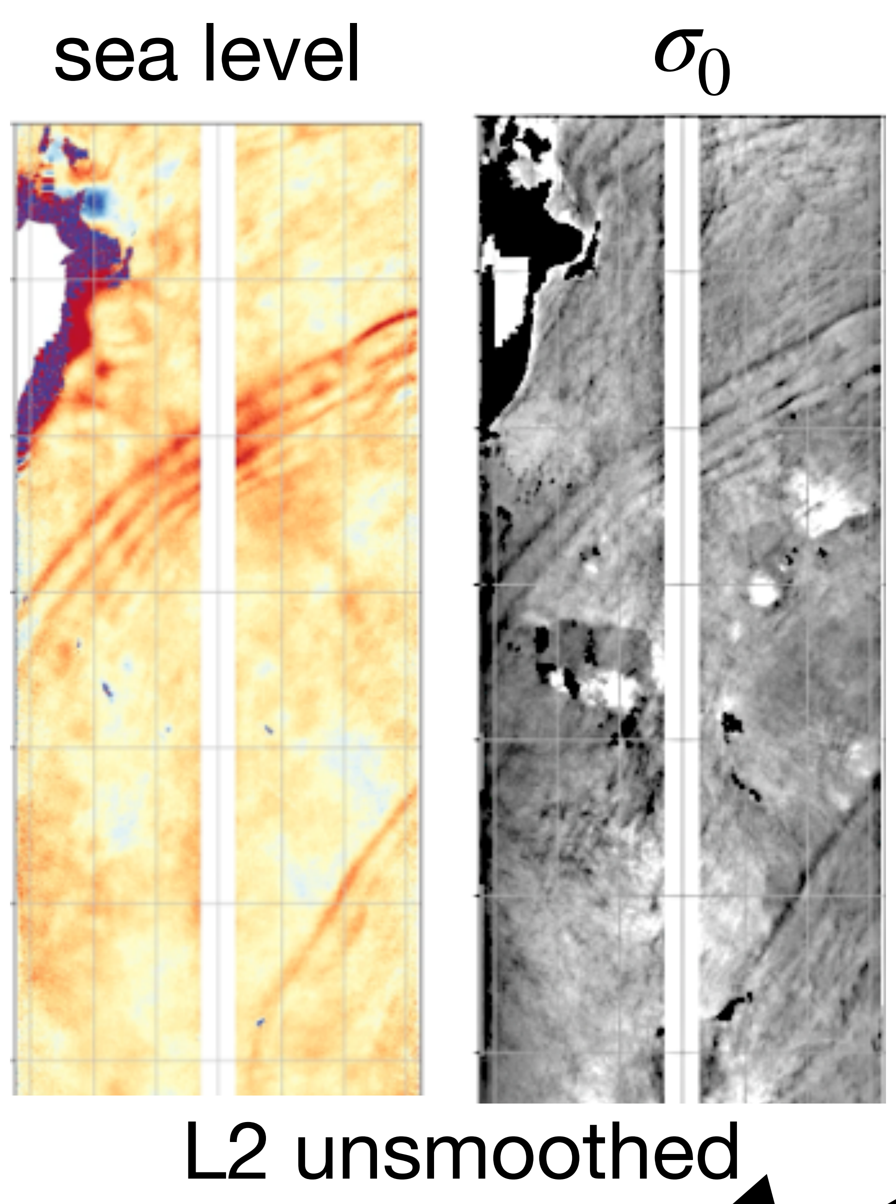
Yadidya Badarvada (yadidya@umich.edu),
Brian Arbic (arbic@umich.edu), and other authors of Yadidya et al. (2024)

Tidally generated nonlinear internal waves: Maluku's case study

Combining novel observations of nonlinear internal waves with dynamical models and remote sensing physics

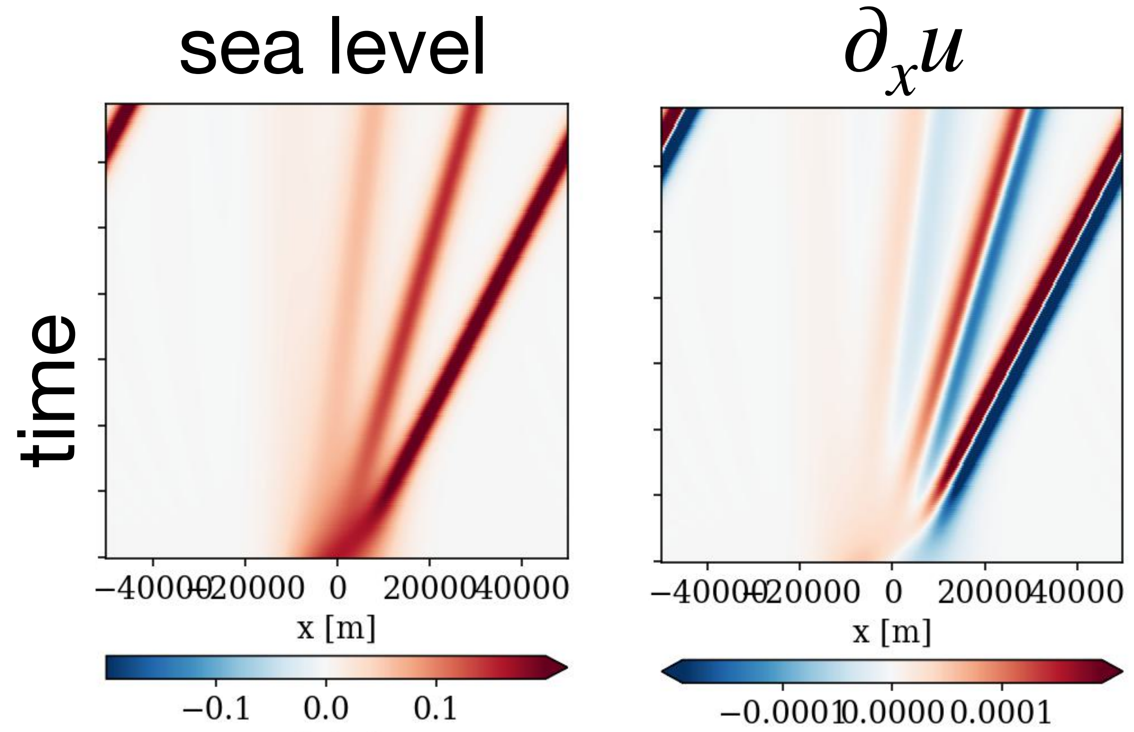
SWOT observations

2 to 20 cm sea level amplitude
2 to 10 km peak width
low noise environment
sea level - σ_0: occurrences & relationship
wave propagation characteristics



Non-linear internal wave dynamics / model

rationalization
synthetic data generation
parameter space exploration
expected sea level - current relationship



Remote sensing physics / modeling

sea surface roughness modeling
robustness of σ_0 - current deformation properties
SWOT imaging process simulation

Systematic effect of unresolved nonlinear internal waves on SWOT sea level ?
Potential synergy with NWA CalVal campaign

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Solitons in the Western Equatorial Indian Ocean

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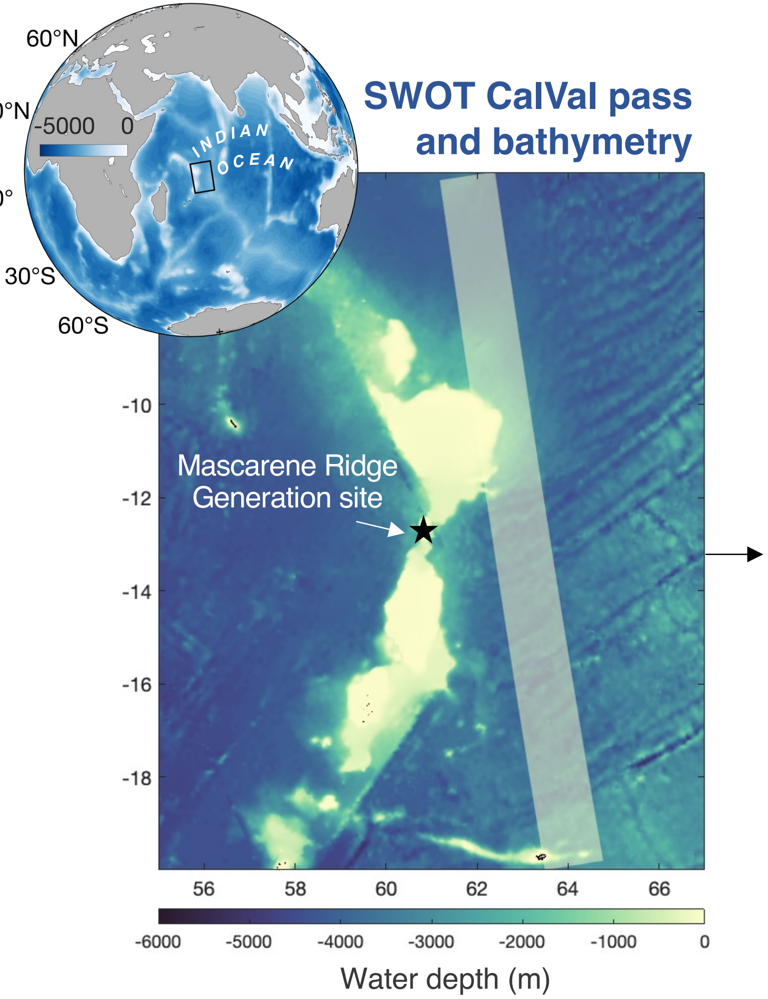
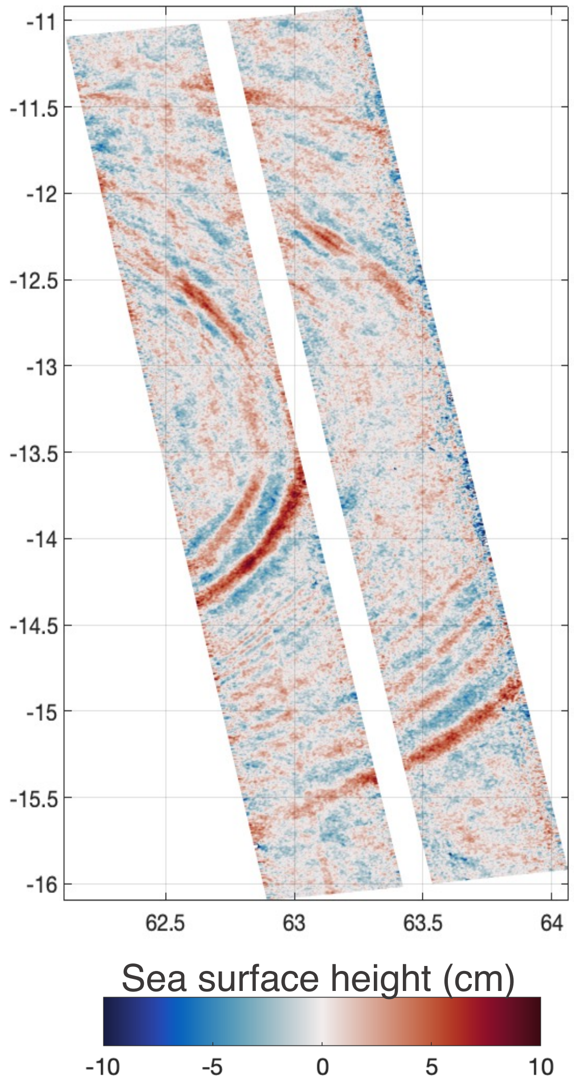
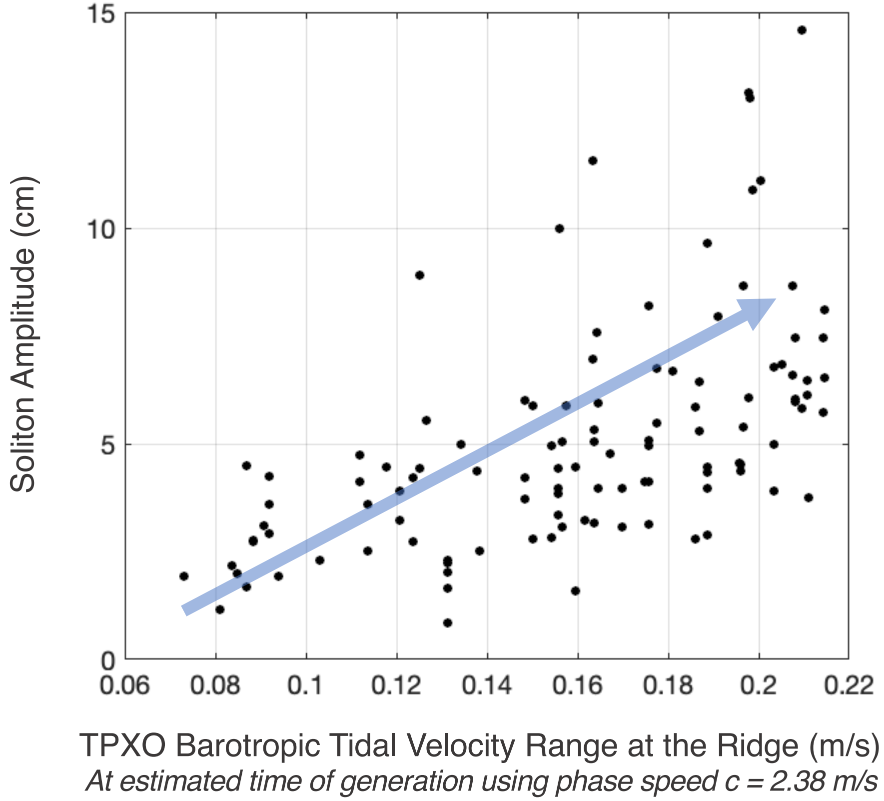
SWOT CalVal pass and bathymetry



Sea surface height
(*band-passed 2–50-km*)
example from one pass



Stronger tides generate larger solitons



Observed soliton variability in the Amazon basin is well-predicted with HYCOM with DA

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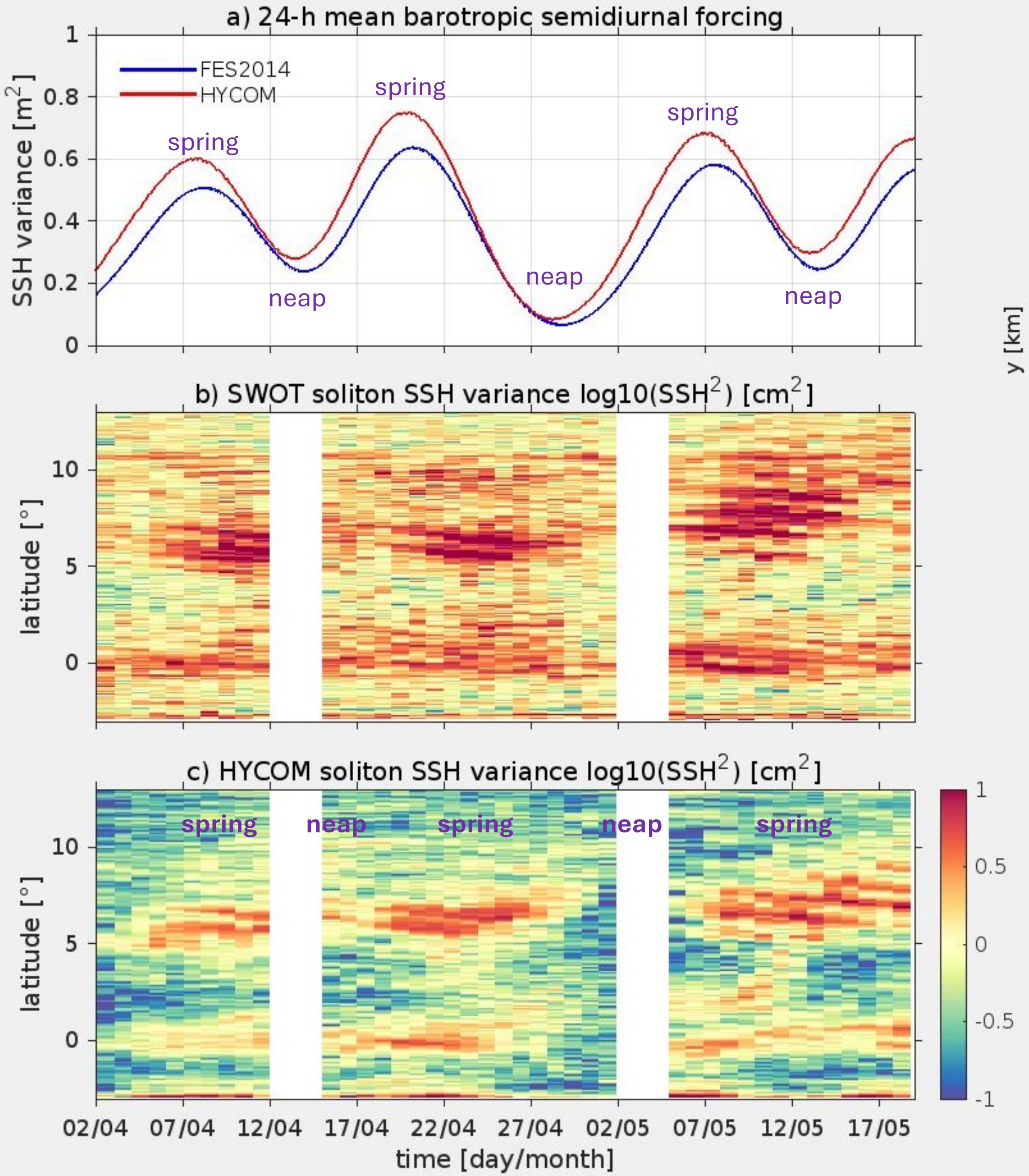
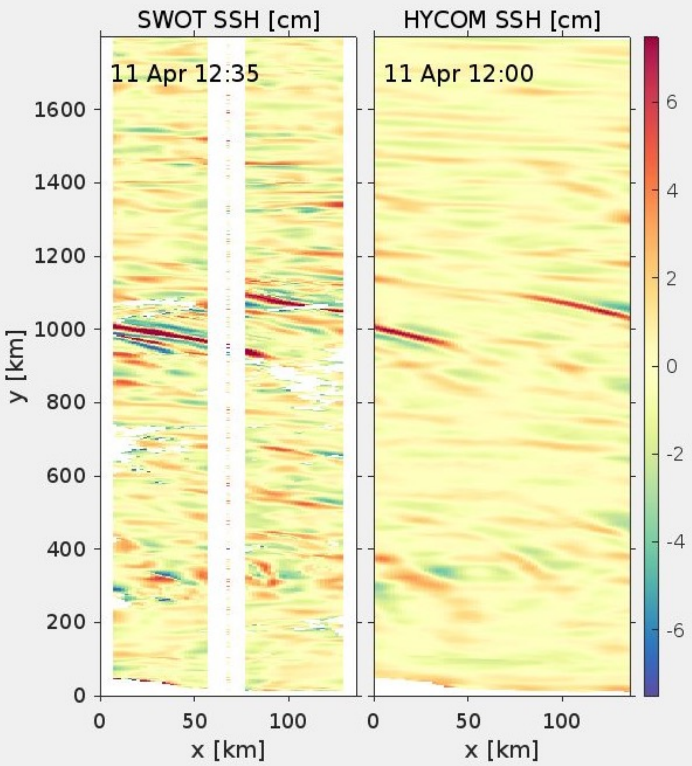
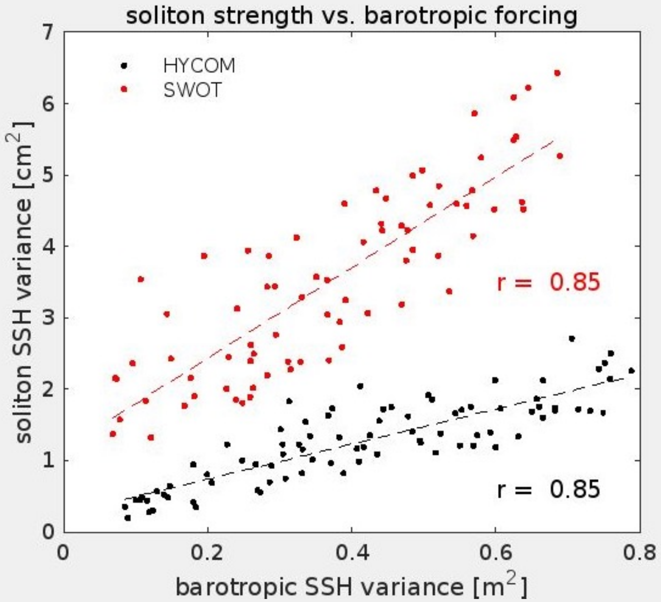




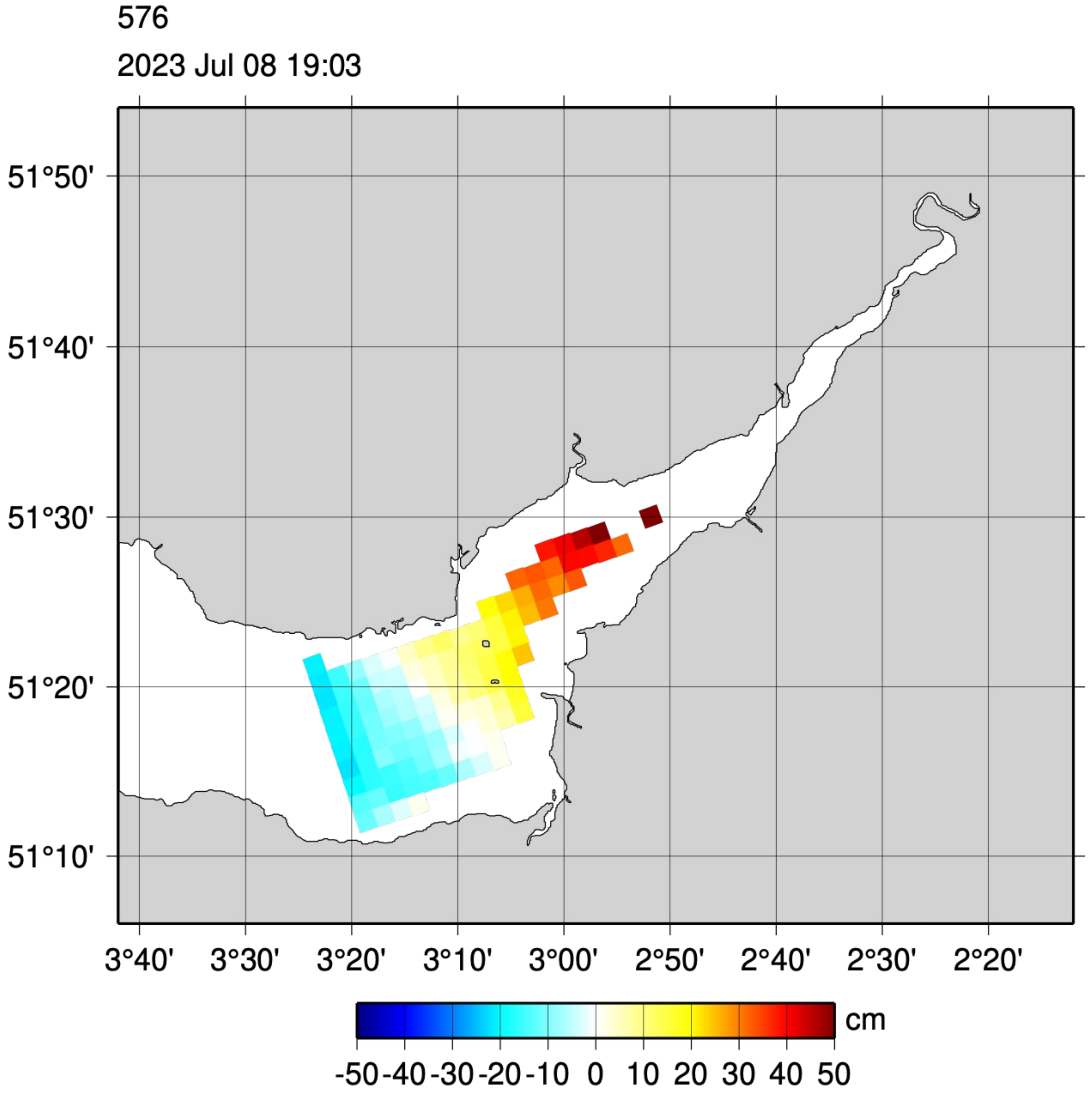


- The variability in time and space of **solitons** (scales < 40 km) in the Amazon basin observed in SWOT are well predicted by 4-km HYCOM with data assimilation (DA)
- Soliton strength is mainly determined by the semidiurnal spring-neap cycle in the barotropic forcing at the Amazon shelf:
  large (small) soliton SSH variance is observed at $\sim 6°$ N ($y \approx 1000$ km) about 4 days after the spring (neap) tide at the shelf due to travel time
- SWOT features larger variance at small scales than HYCOM, demanding the application of nested high-resolution nonhydrostatic simulations

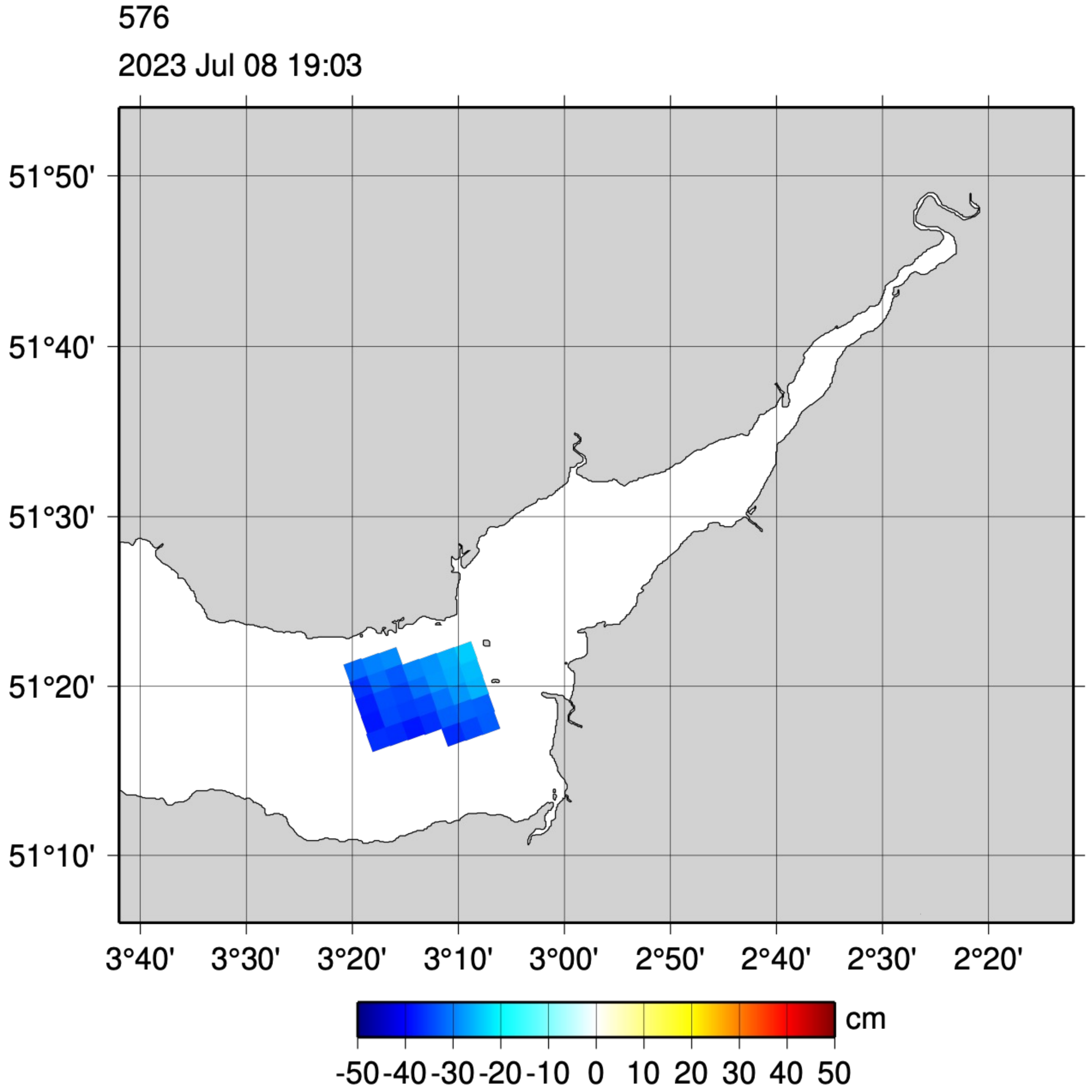
Problems and challenges

Dropped coverage of LR (2-km) data near coasts

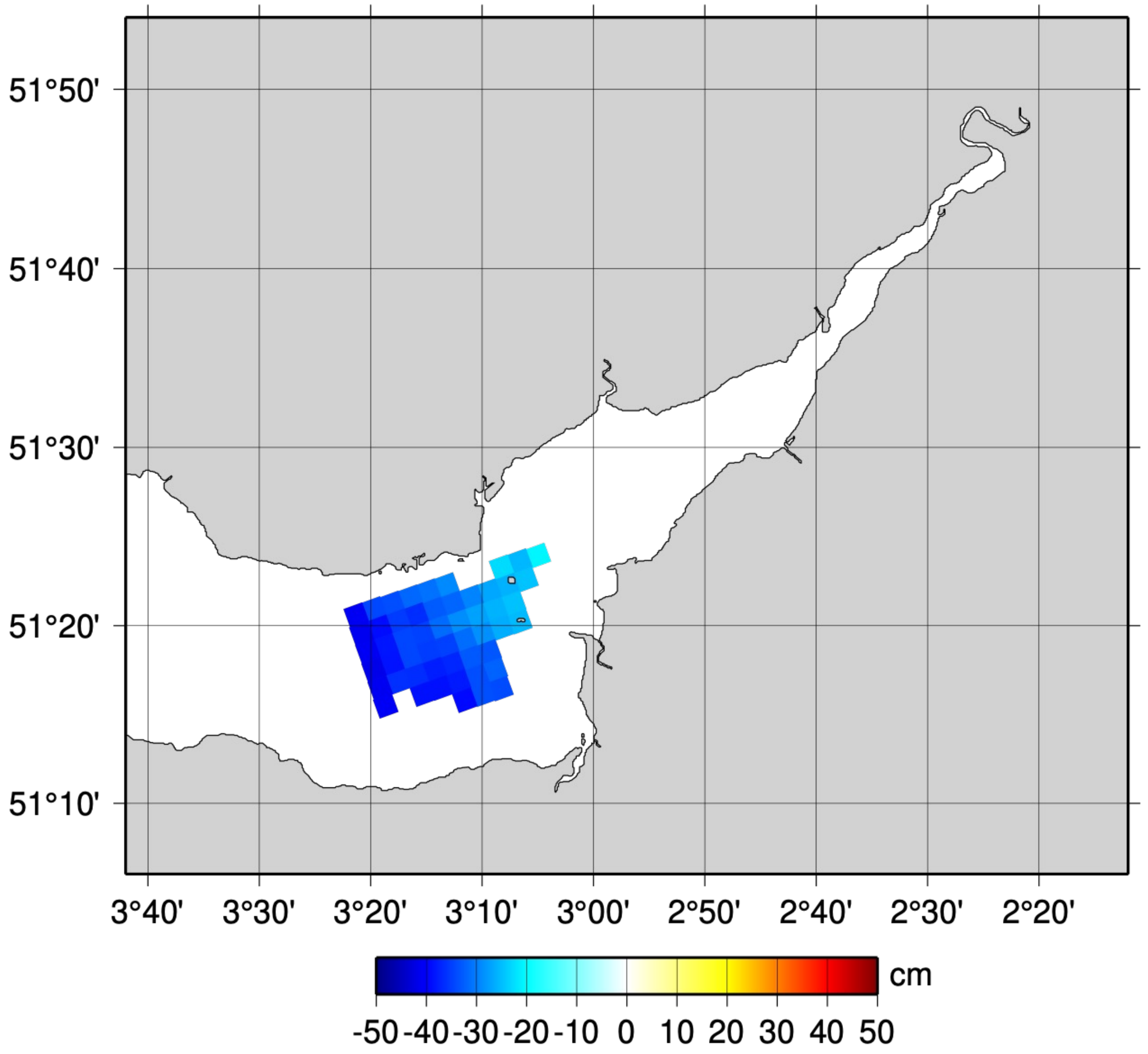
v0.2



v0.3



v1.0



SWOT_L3_LR_SSH_Basic_576_016_20230708T185252_20230708T194358_v0.2.nc
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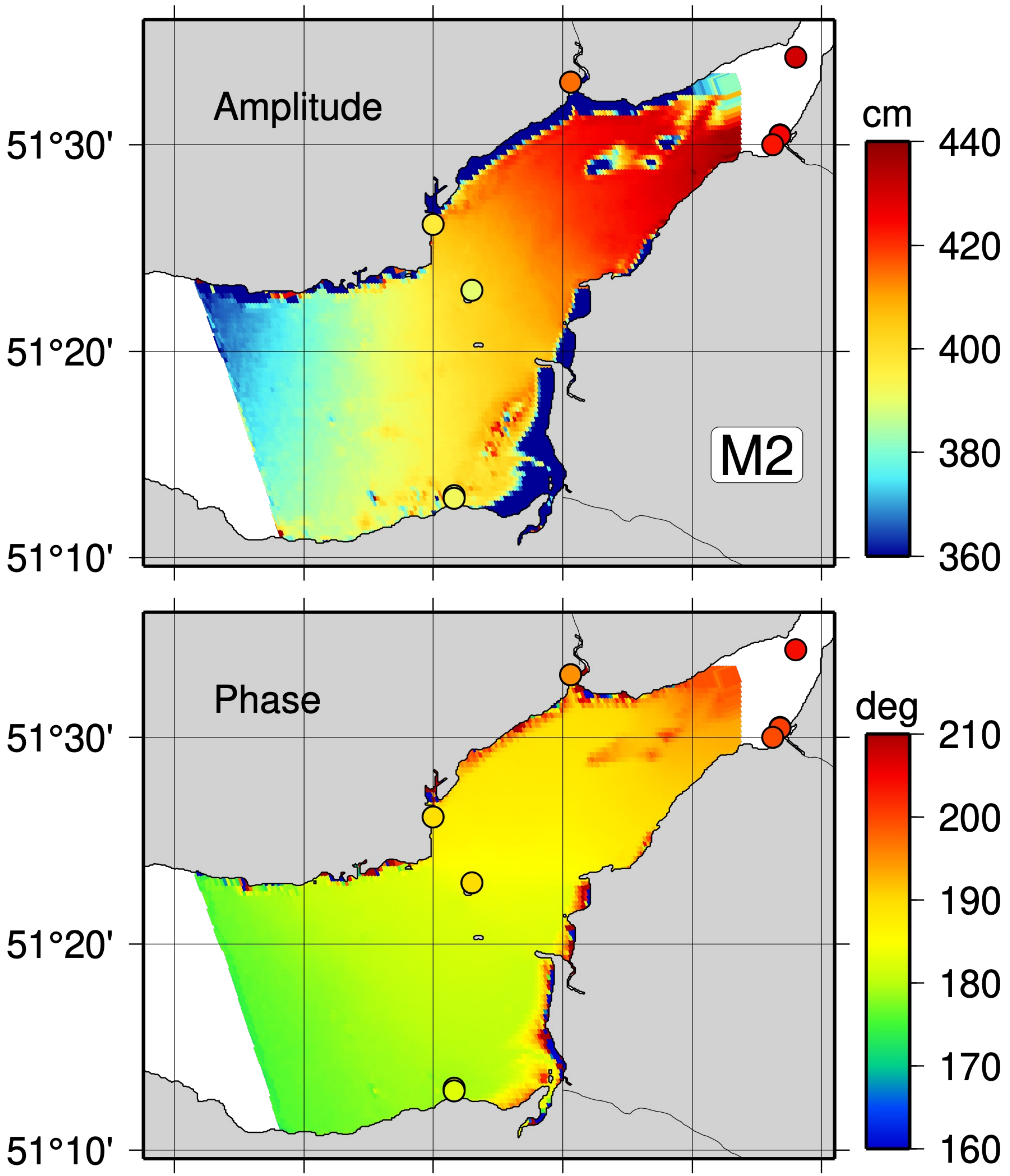
SWOT_L3_LR_SSH_Basic_576_016_20230708T185252_20230708T194357_v1.0.nc

Is this the MSS problem?



Bristol Channel tides
from
SWOT 1-day 250-m data

(see poster by Mike Hart-Davis et al.)

Central gauge is from a 1980 series (1-yr) from Evans & Pugh

Monthly tide estimates

Flat Holm, Severn Estuary

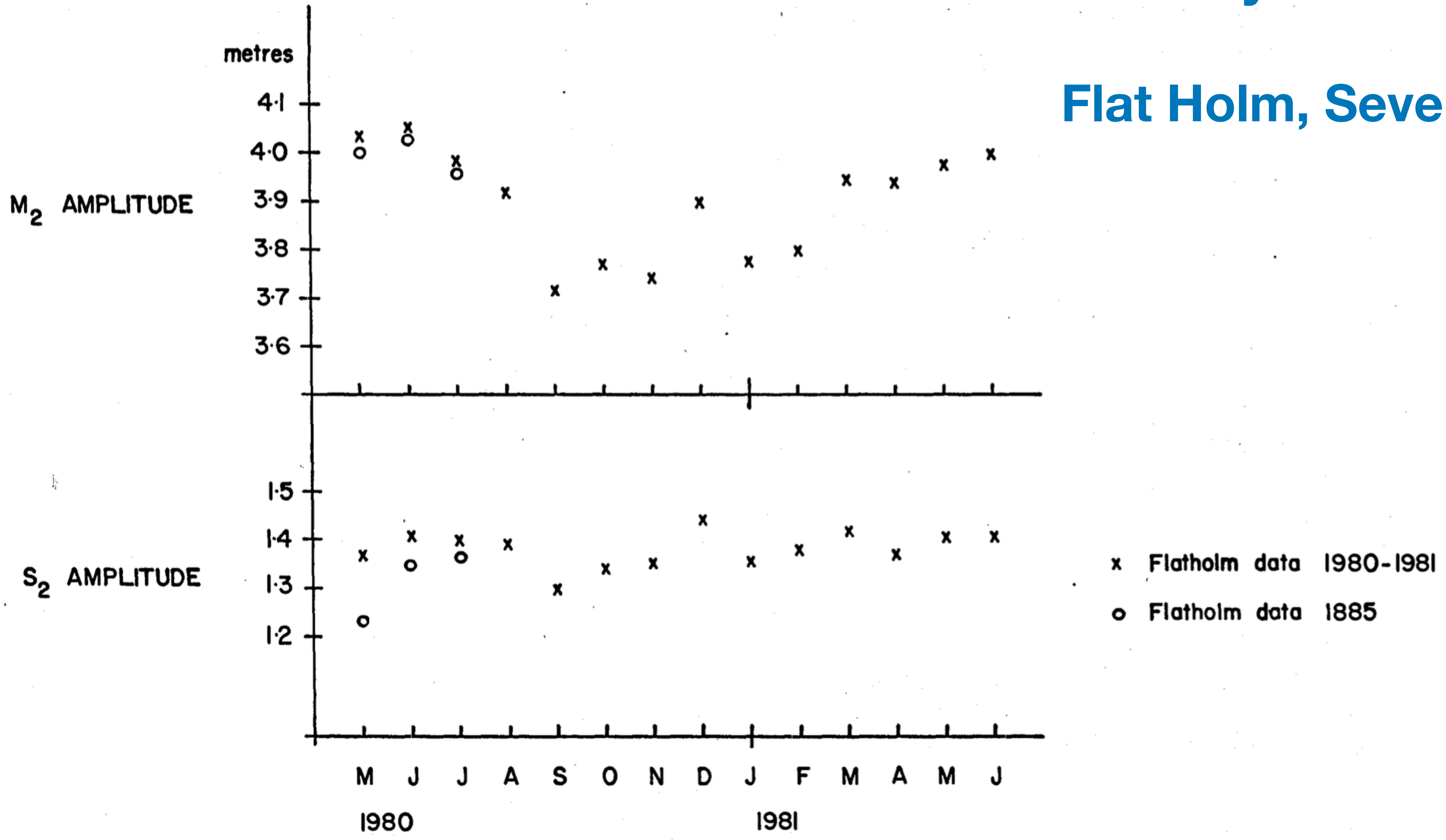
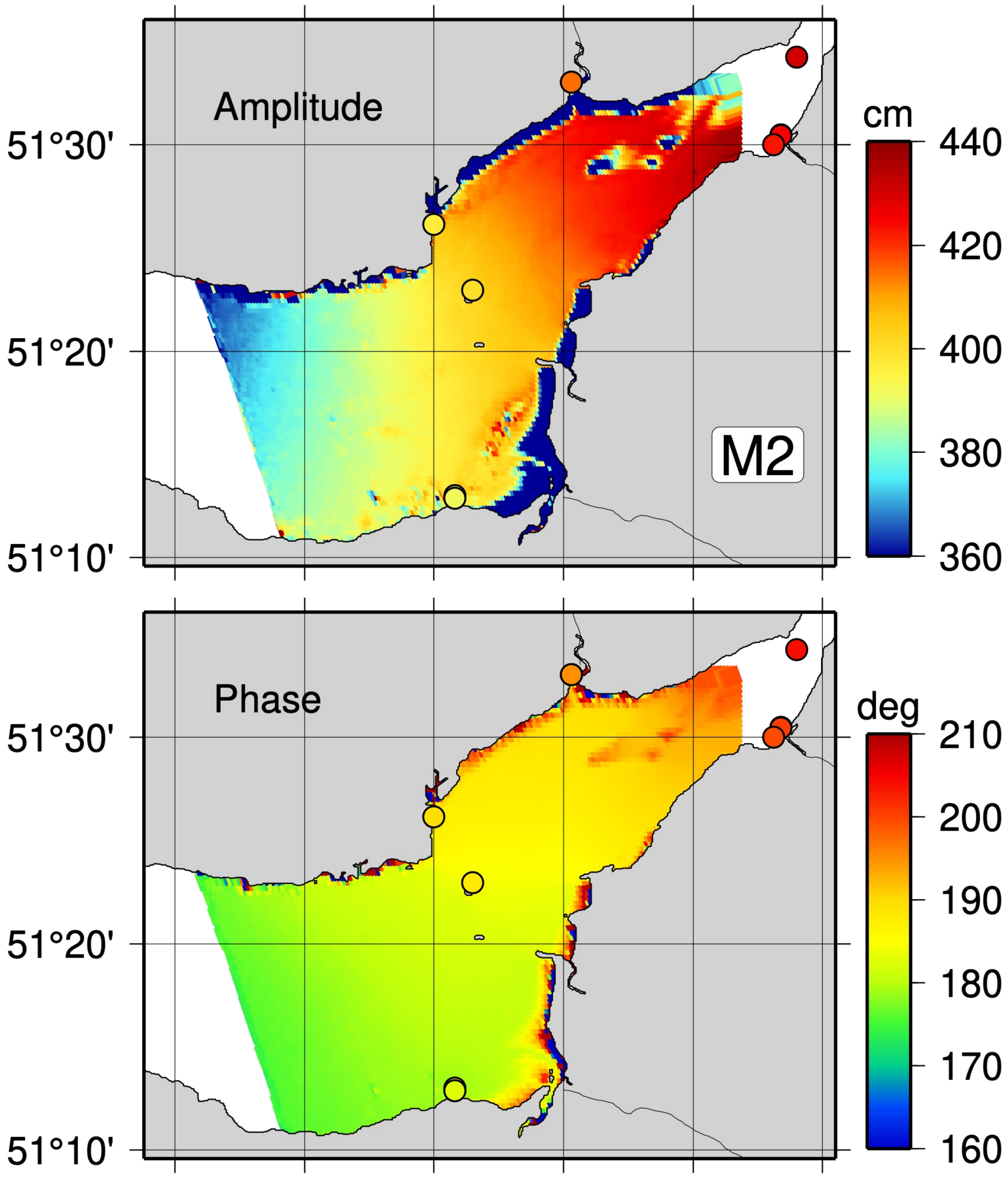


Figure 2

Evans & Pugh, I.O.S. report, 1981

Annual modulations (seasonality)
Semiannual modulations ($2MKS_2$)



Better agreement with gauge
in channel, using April-June only

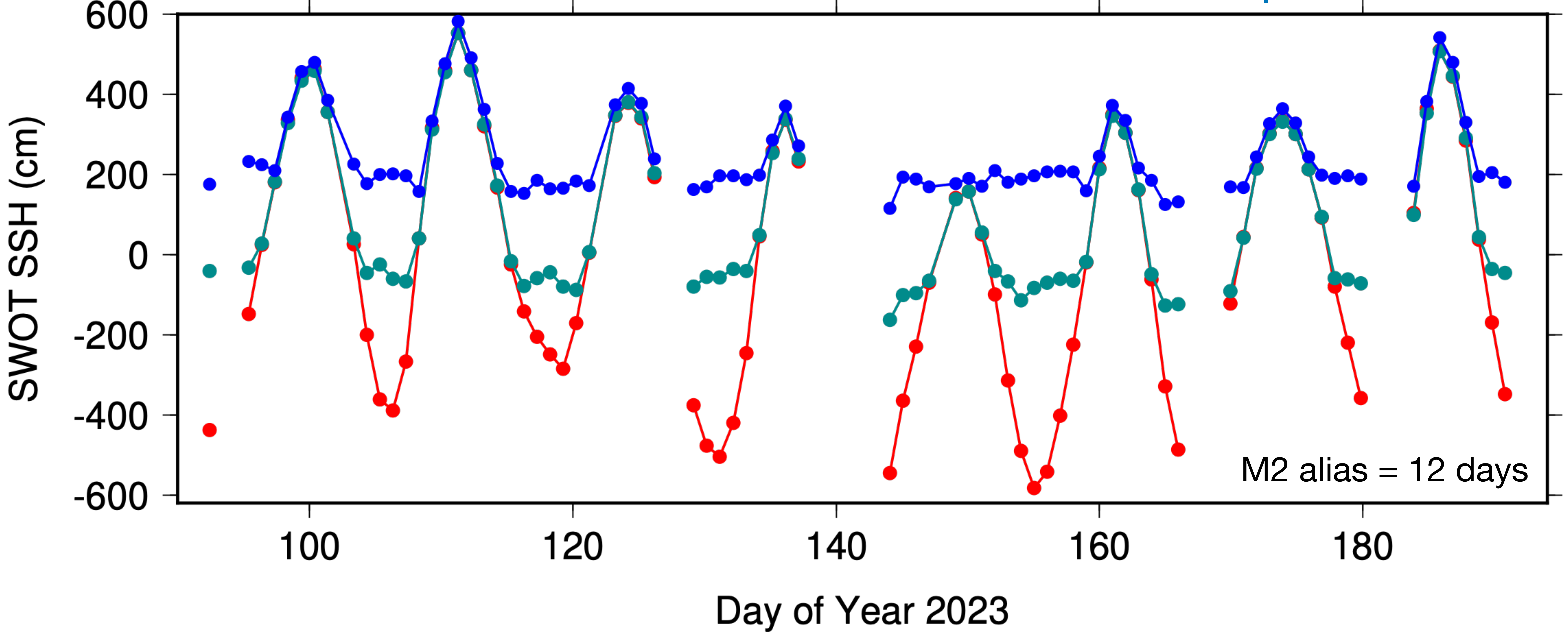
Reminder:
Estimated SWOT tides are
April–June only! (1-d data)

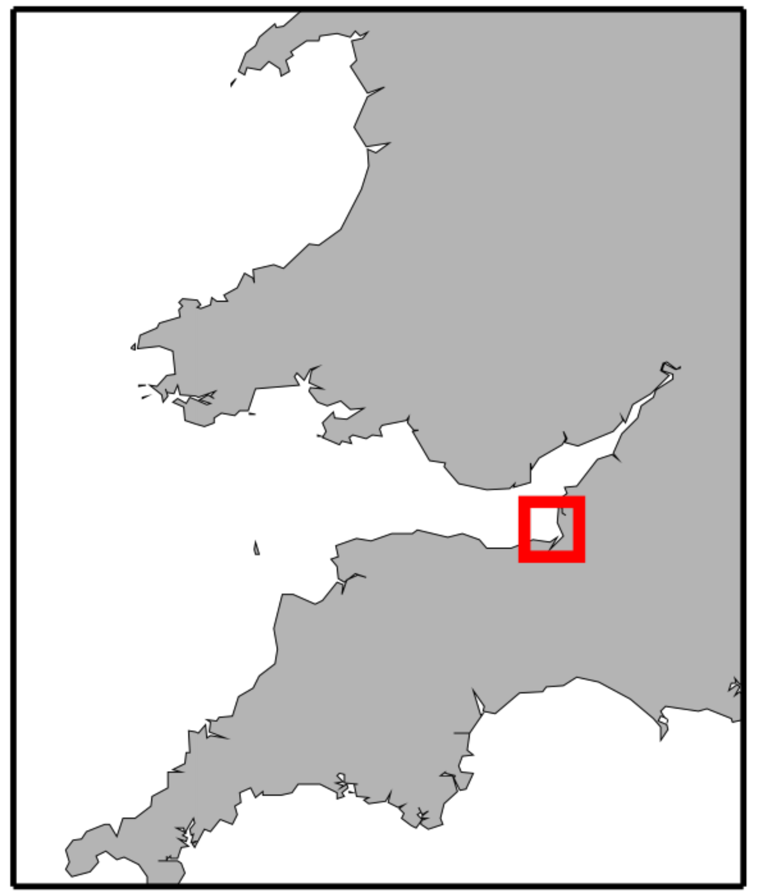
Bristol Channel Tides – from SWOT 1-day data

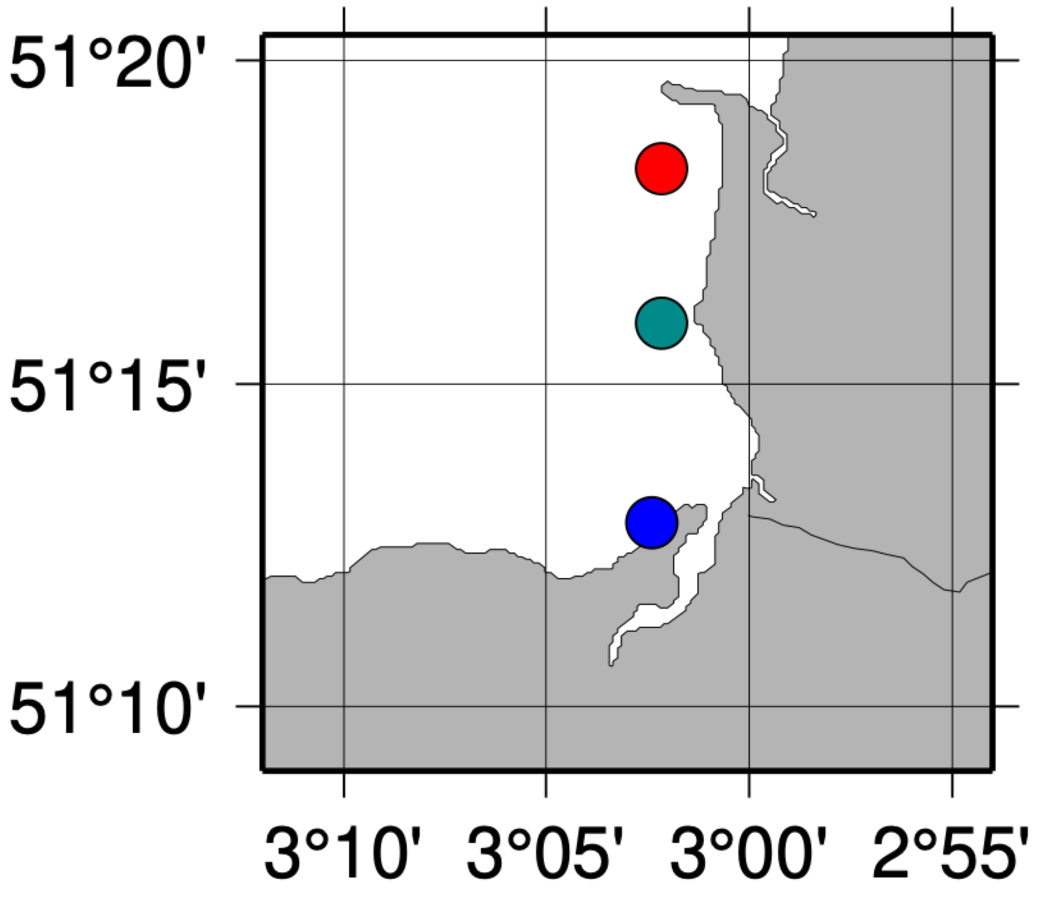
Solutions also for 2N2, N2, nu2, M4

Can we identify tidal flats while estimating tides?

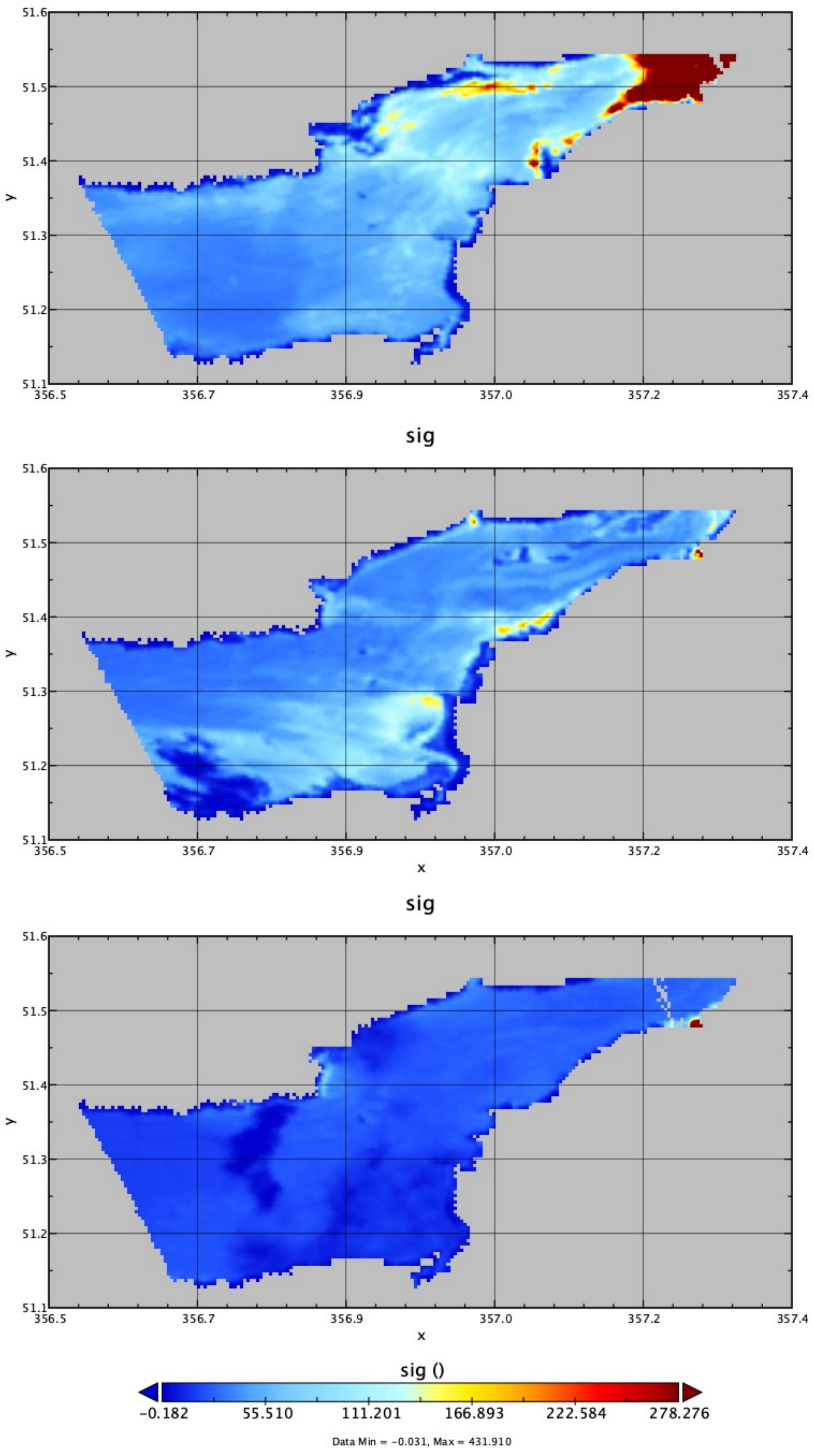
Tide “bottoms out” along Bristol Channel shoreline
SWOT returns SSH over mud; estimated “amp” → 0.







sigma0 alone not conclusive



Air tide leakage in DAC

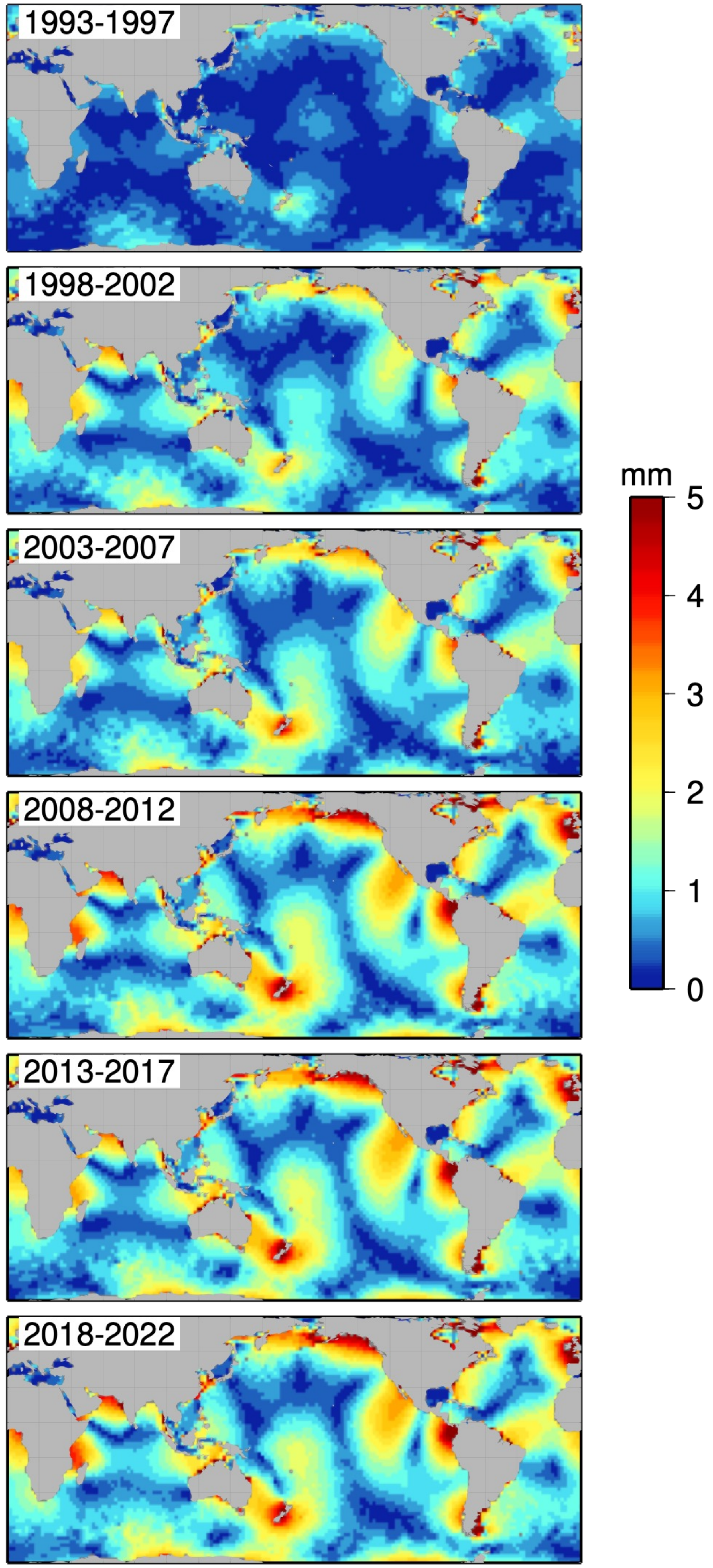
(an issue for OSTST)

M2

in

DAC

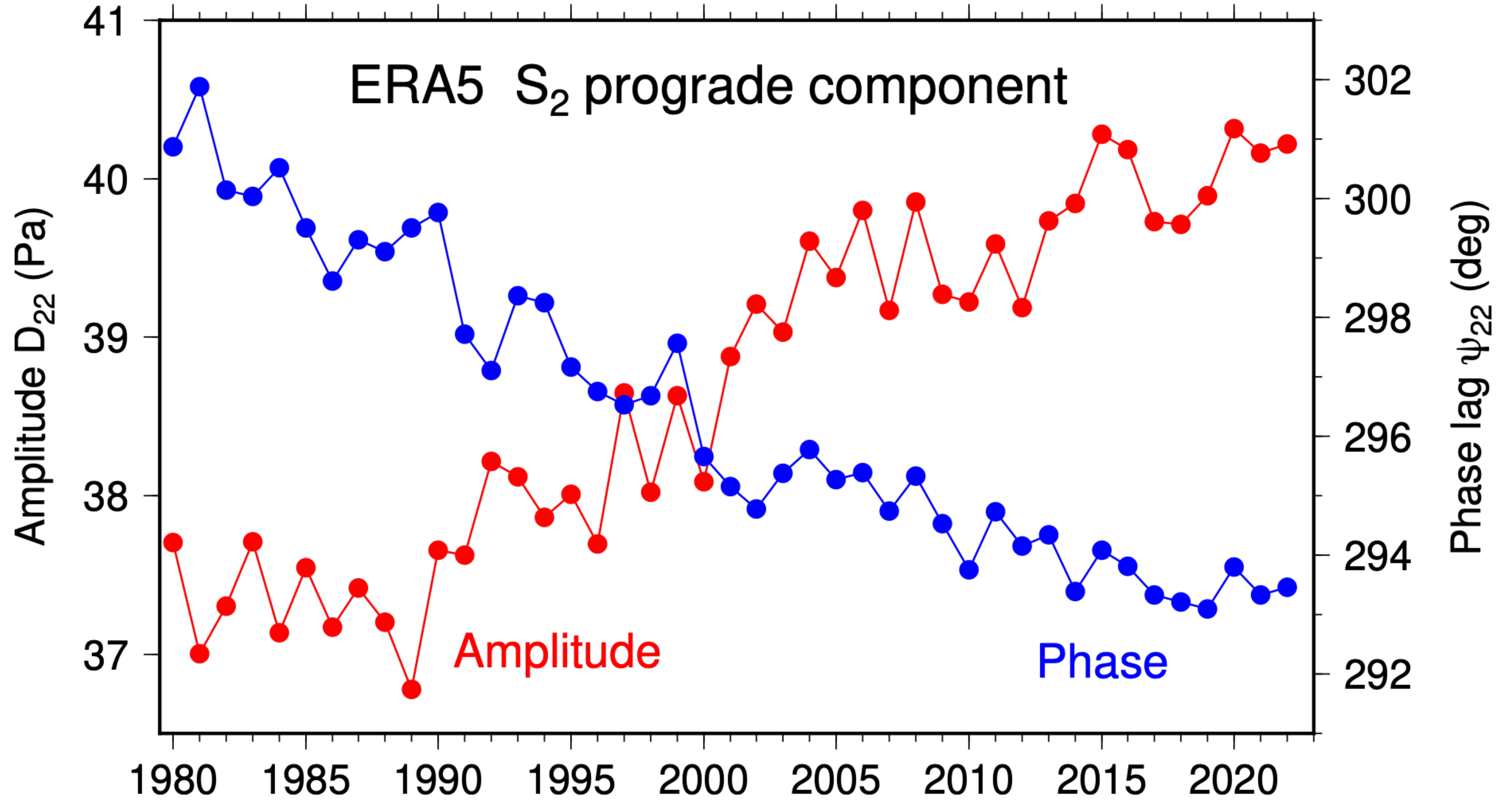
getting worse!



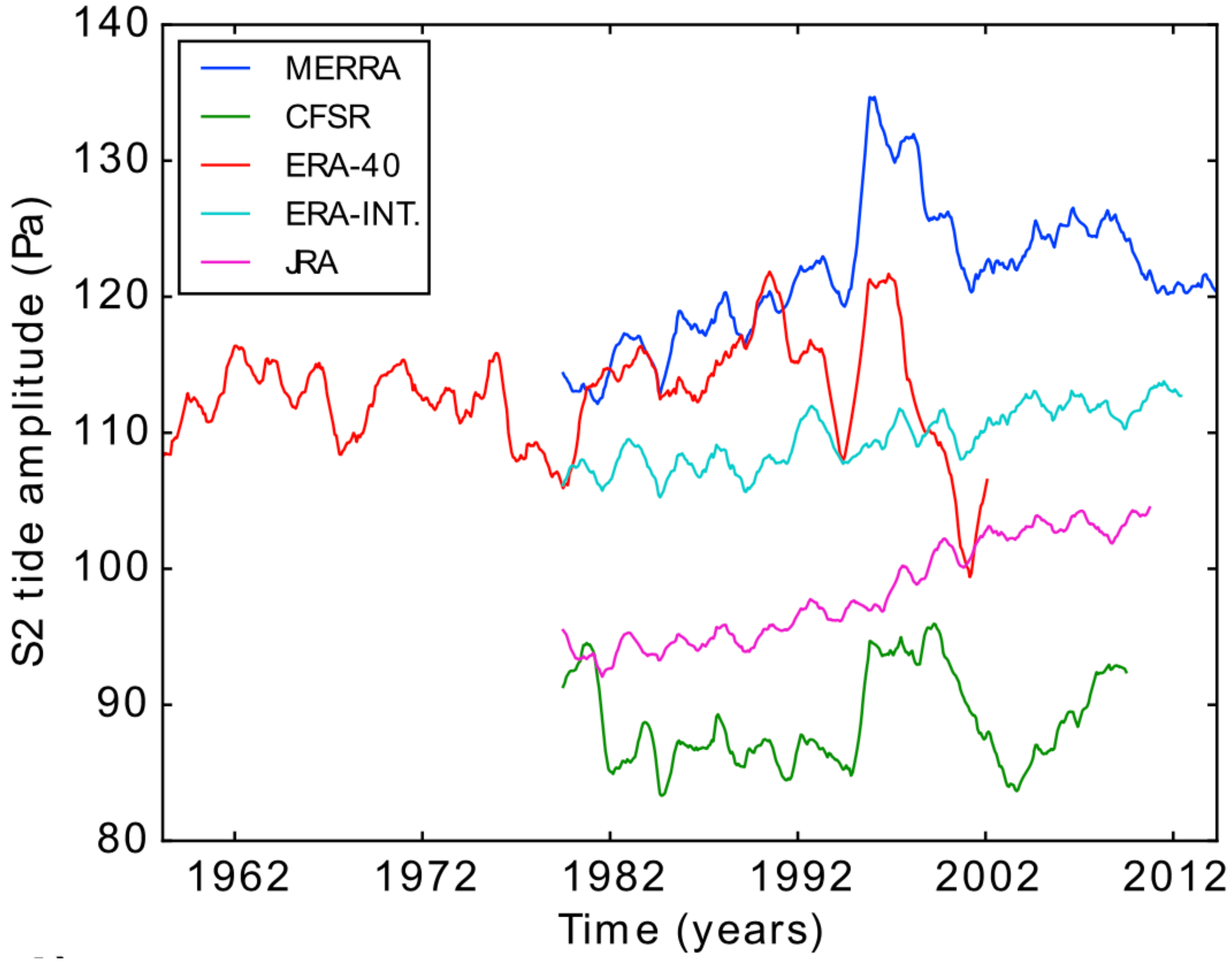
Similar leakage from S1, S2 air tides

Cause: spurious ECMWF air tides

Spurious trends in ERA5



Erratic air tides in ALL reanalyses



Diaz-Argandona et al., JGR, 2016

Further challenges and opportunites

Tides in estuaries and rivers—synergies with other working groups

Prediction of incoherent internal tides

How much of the high-wavenumber spectrum in SWOT is due to the internal gravity wave continuum, rather than internal tides?

Others?