

Thoughts regarding tides and the reference orbit

Richard Ray
Crofton, Maryland

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What will be lost with a new orbit?

A system capable of monitoring the ocean in (almost) exactly the same way over multiple decades.

This is the best way to monitor changes in the ocean while minimizing changes in (possibly unknown) systematic error.

This includes changes in oceanic tides (a very small signal).

My current conclusions

Our ability to detect changes in ocean tides will be severely impacted.

- Granted, tide changes are mostly tiny, and therefore barely impact accuracy of tidal predictions.
- But tide changes are a manifestation of a changing ocean & climate, so therefore of general interest.

Recent work

Trends in M_2 Ocean Tides

from T/P, Jason-1,2,3, Sentinel-6A
strictly on the **primary** ground track

- At each location, solve for mean tide + trends in in-phase/quad components
- Philosophy: Hold data sampling fixed over 30 years (to the extent possible).
- Thus, avoid new data at new locations $\Rightarrow$ uncertain tradeoff between mean & trend.

Recent papers:

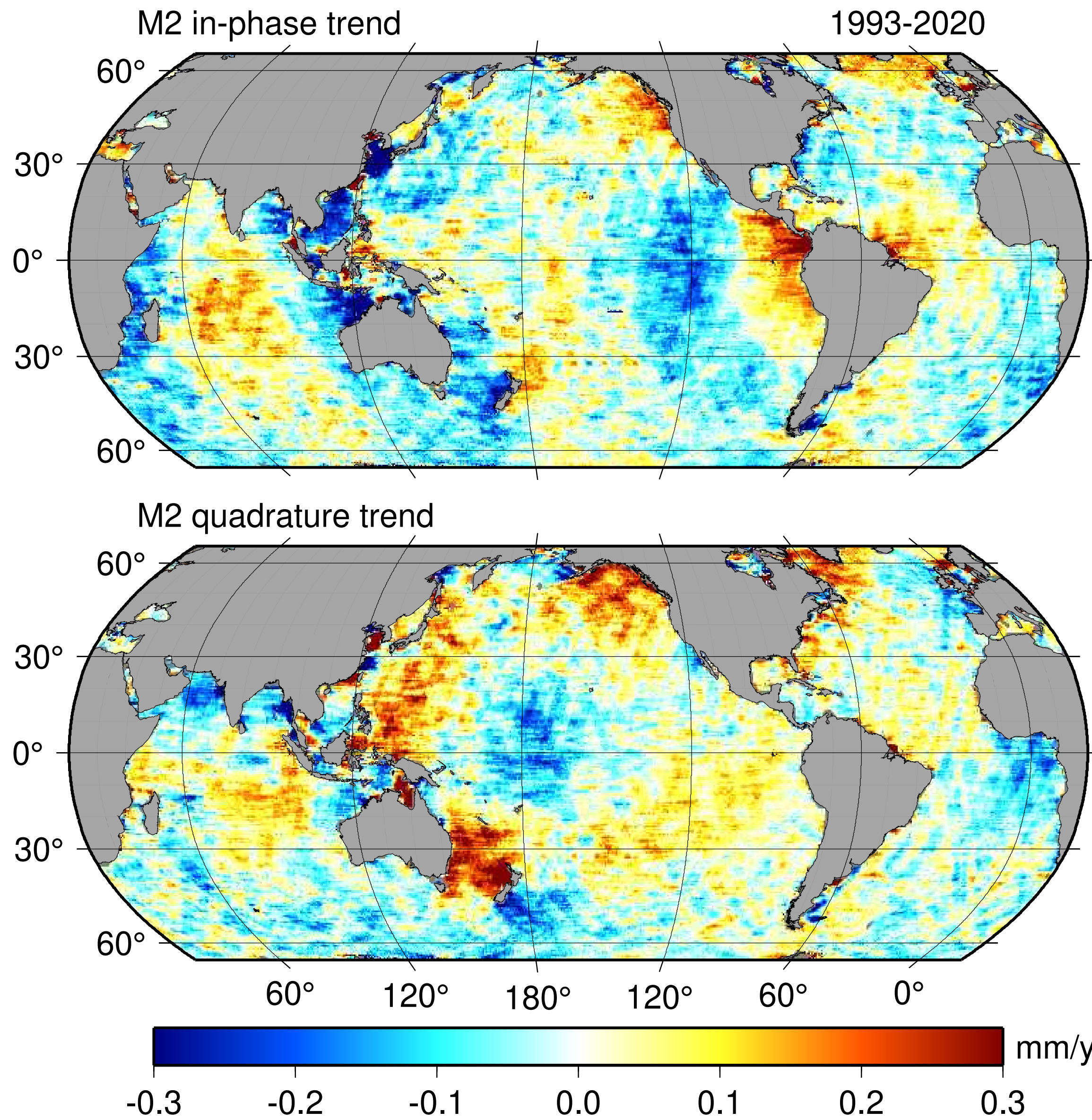
Bij de Vaate, Slobbe, Verlaan, *JGR-Oceans*, 2022.

Opel, Schindelegger, Ray, *Commun. Earth Environ*, 2024.

Ray & Schindelegger, *J. Geodesy*, 2025.

M₂ Trends
1993–2020

T/P-J1-J2-J3

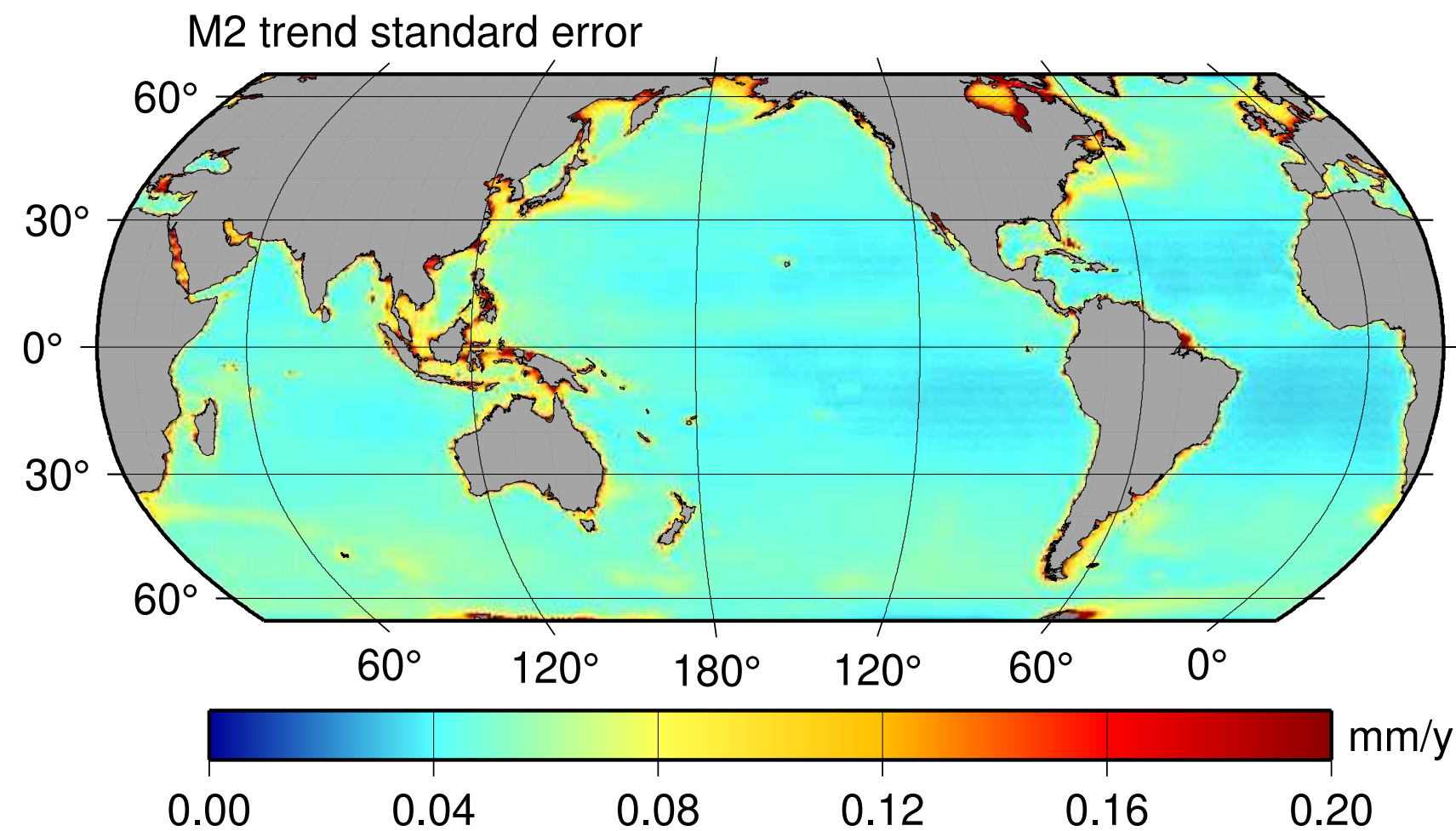
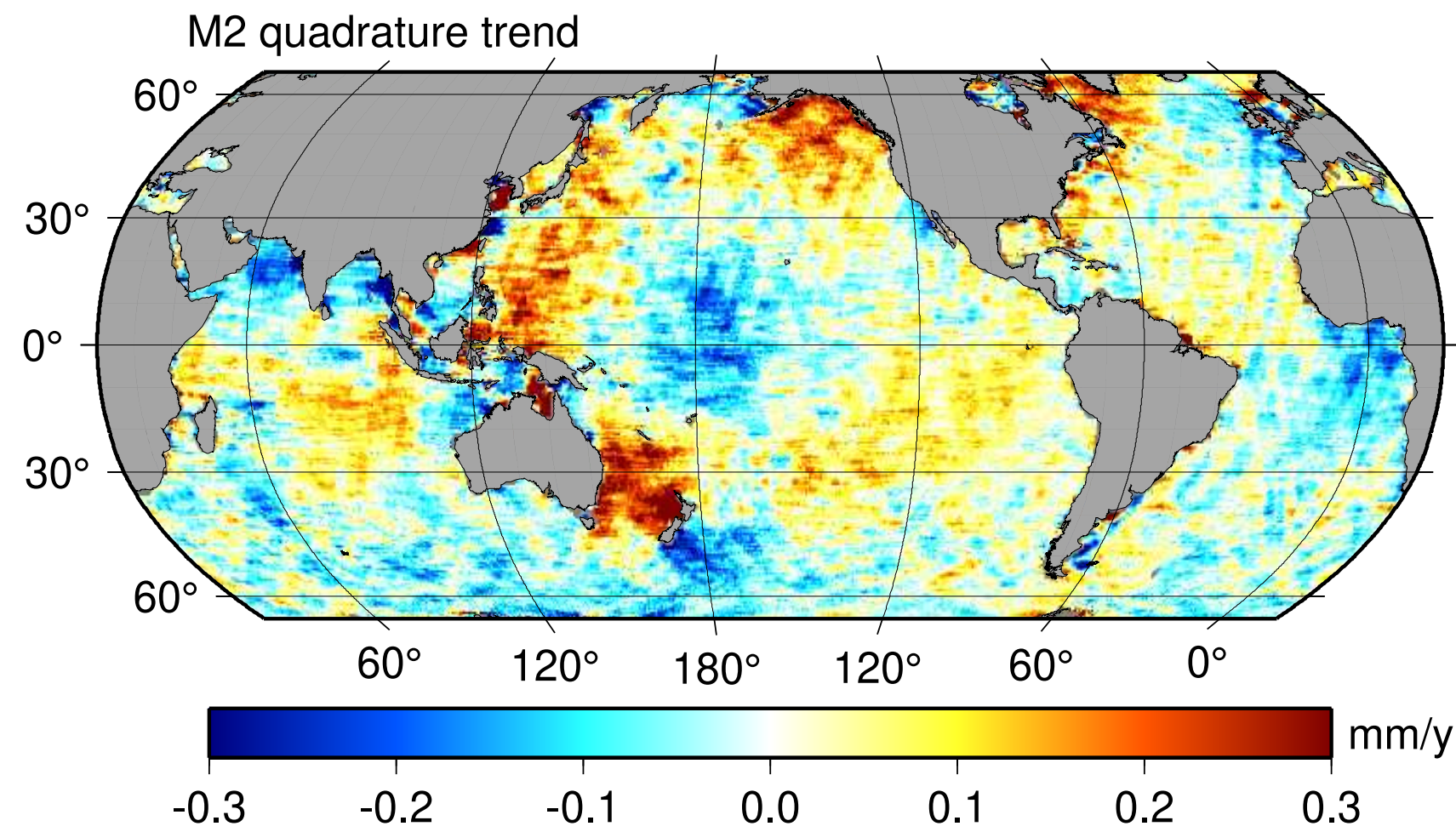
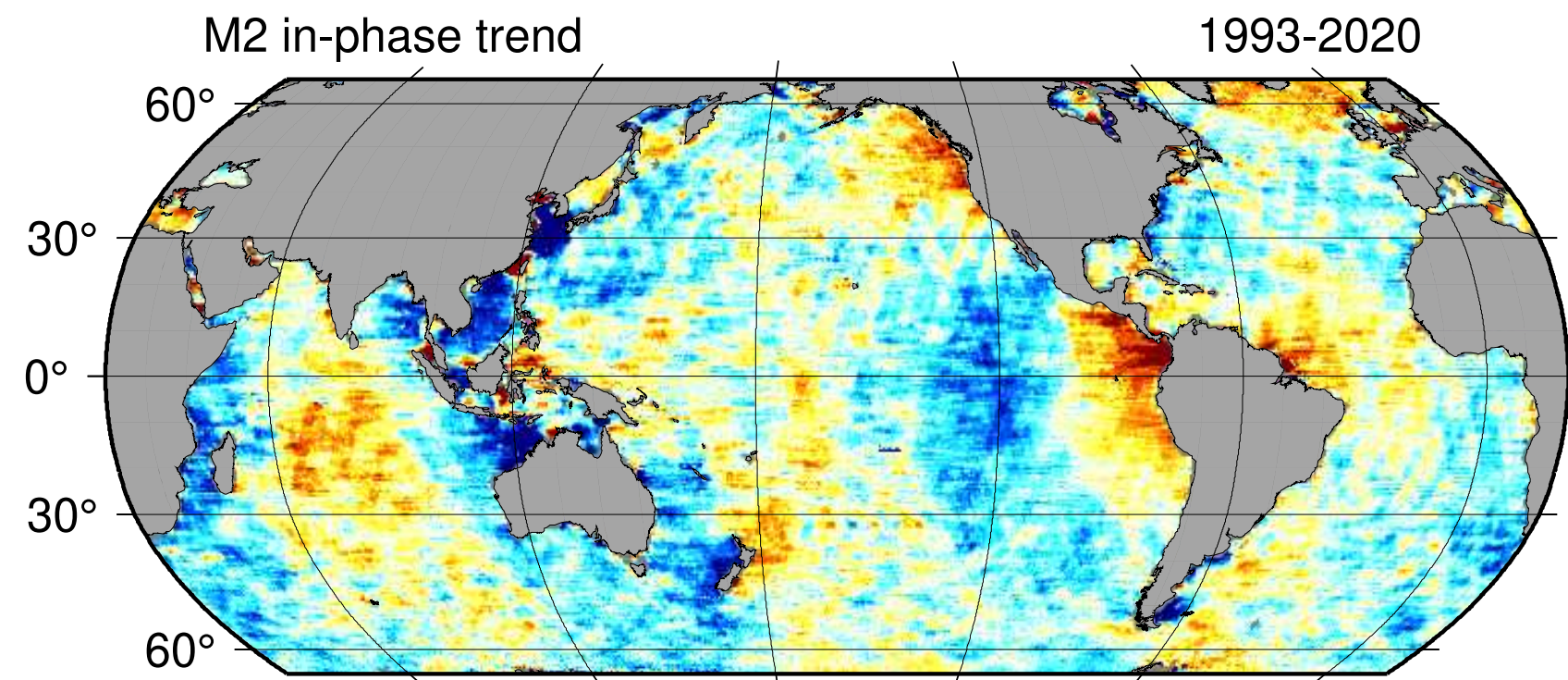


Noisy,
But broad patterns of
~ 0.1 to 0.2 mm/y
Larger in shallows

(Diurnal tide trends appear
to be mostly noise.)

M₂ Trends 1993–2020

T/P-J1-J2-J3



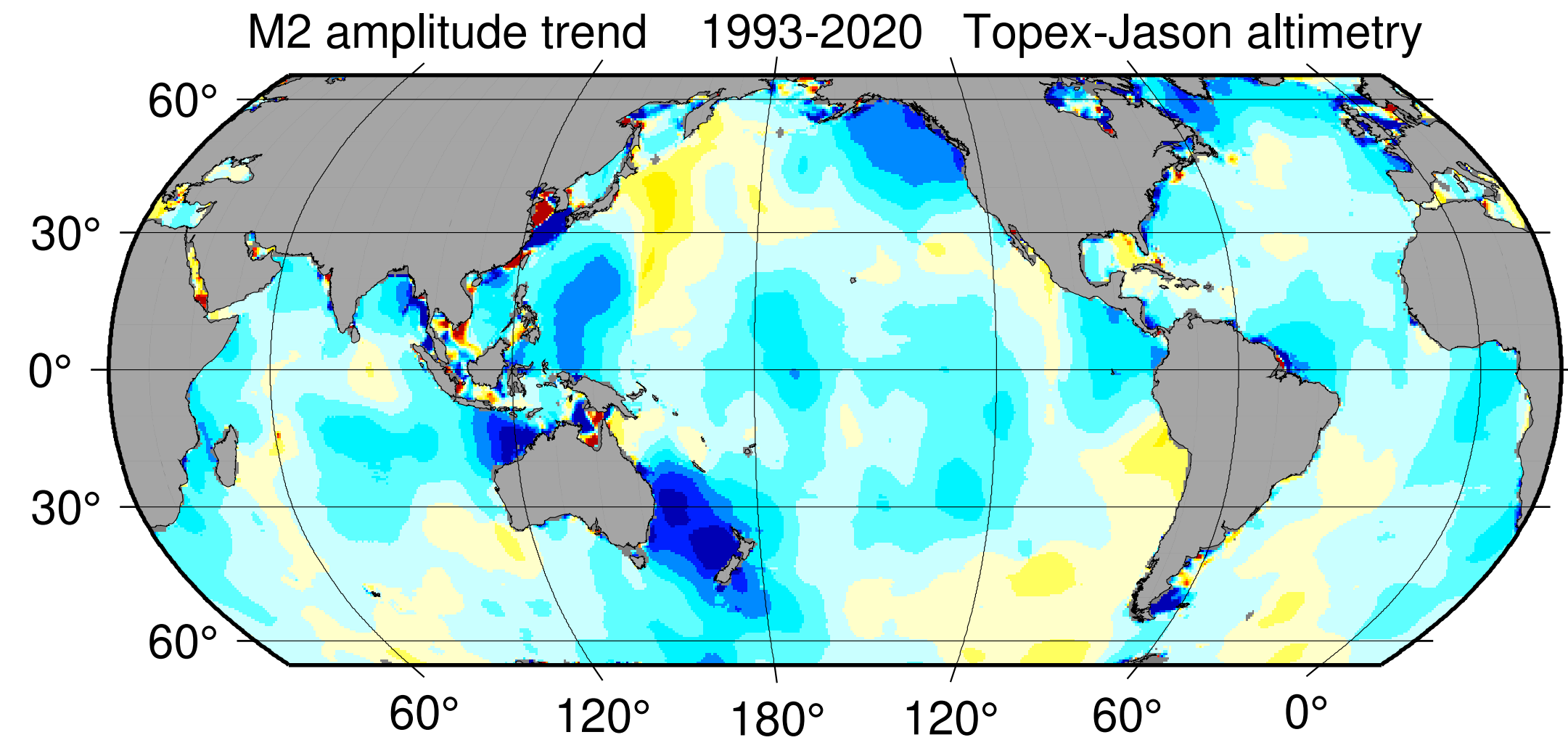
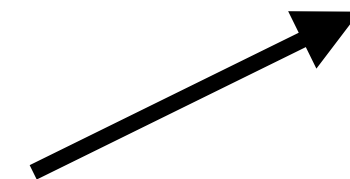
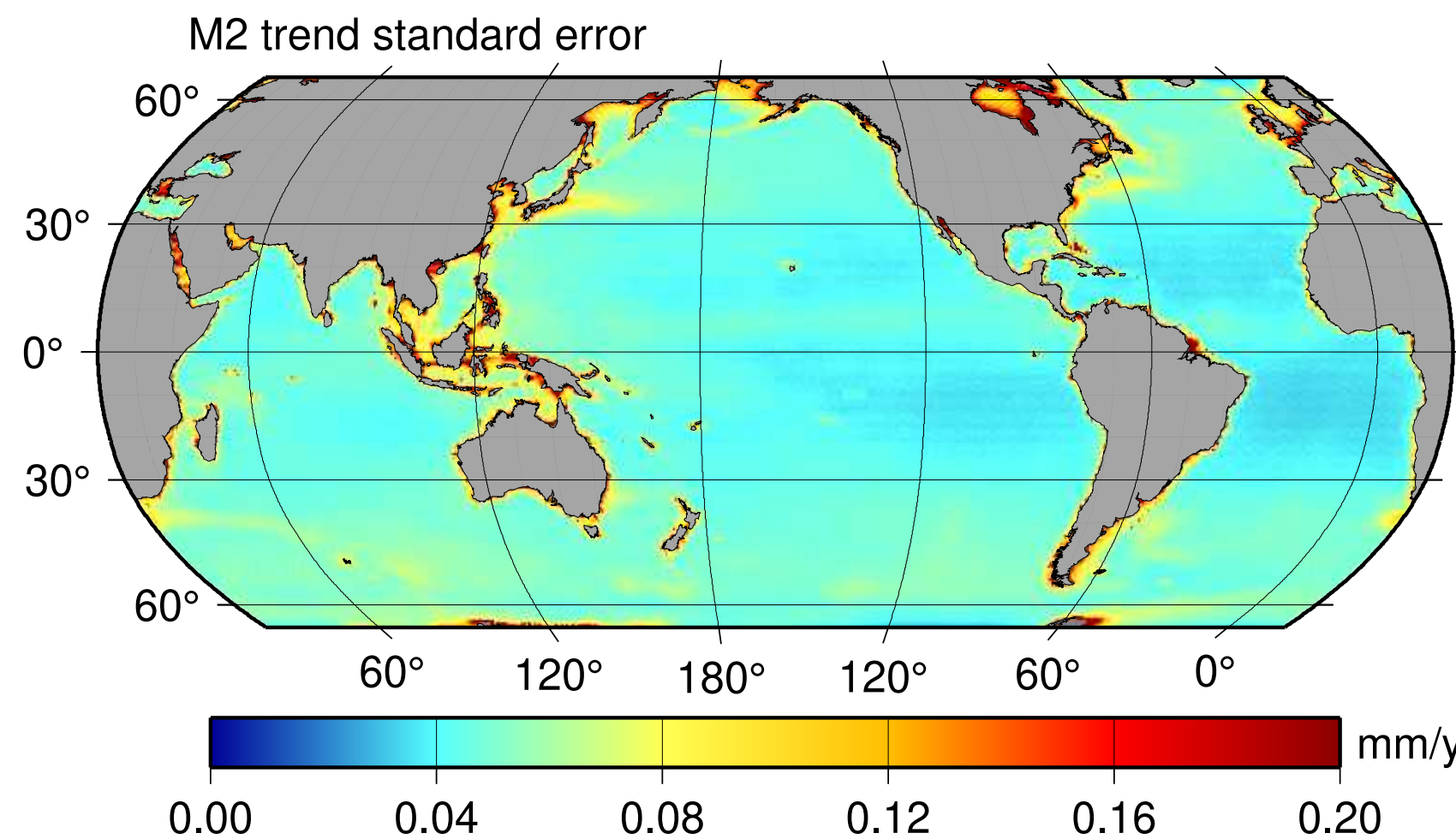
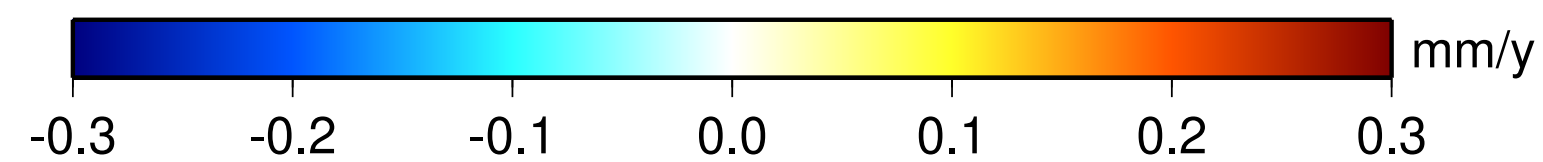
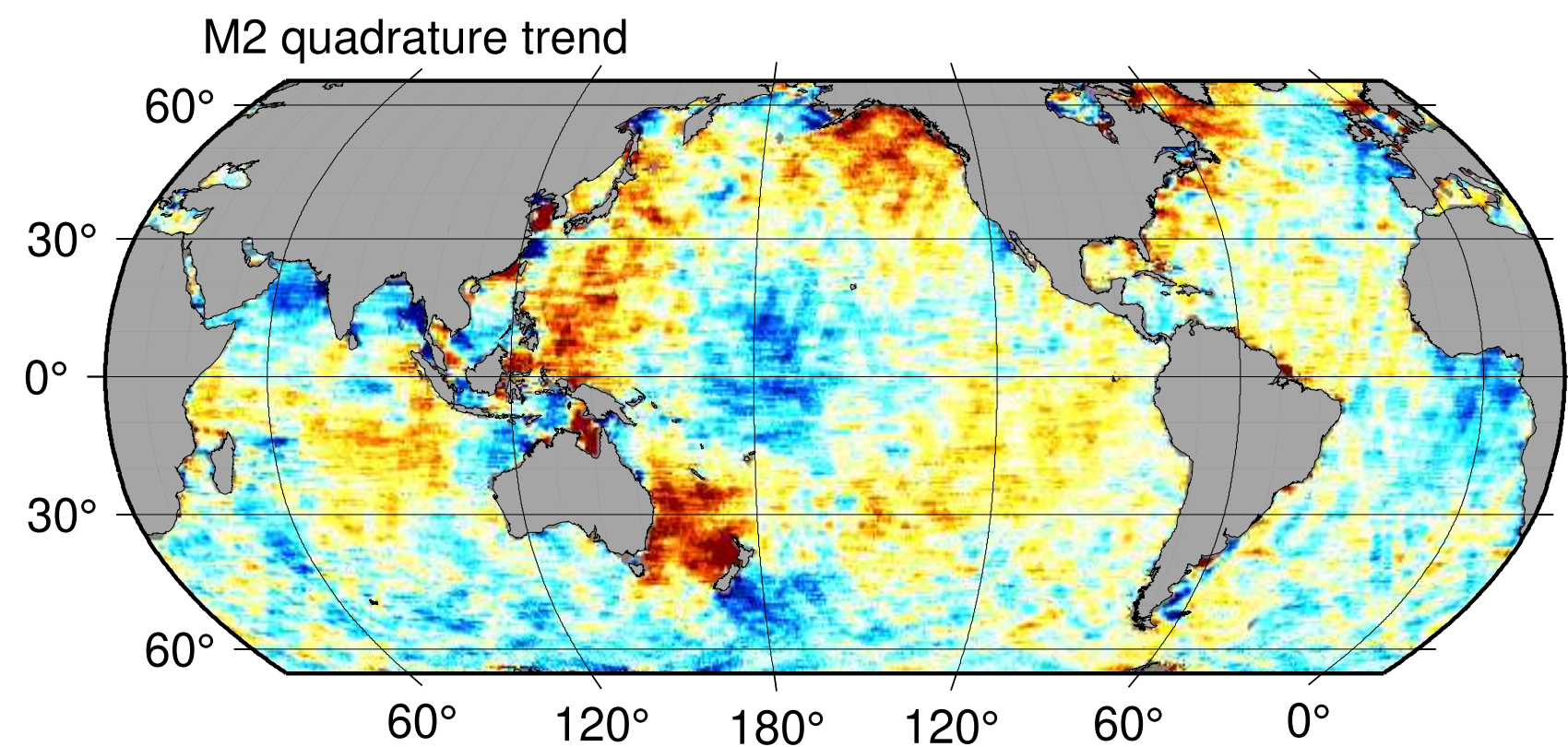
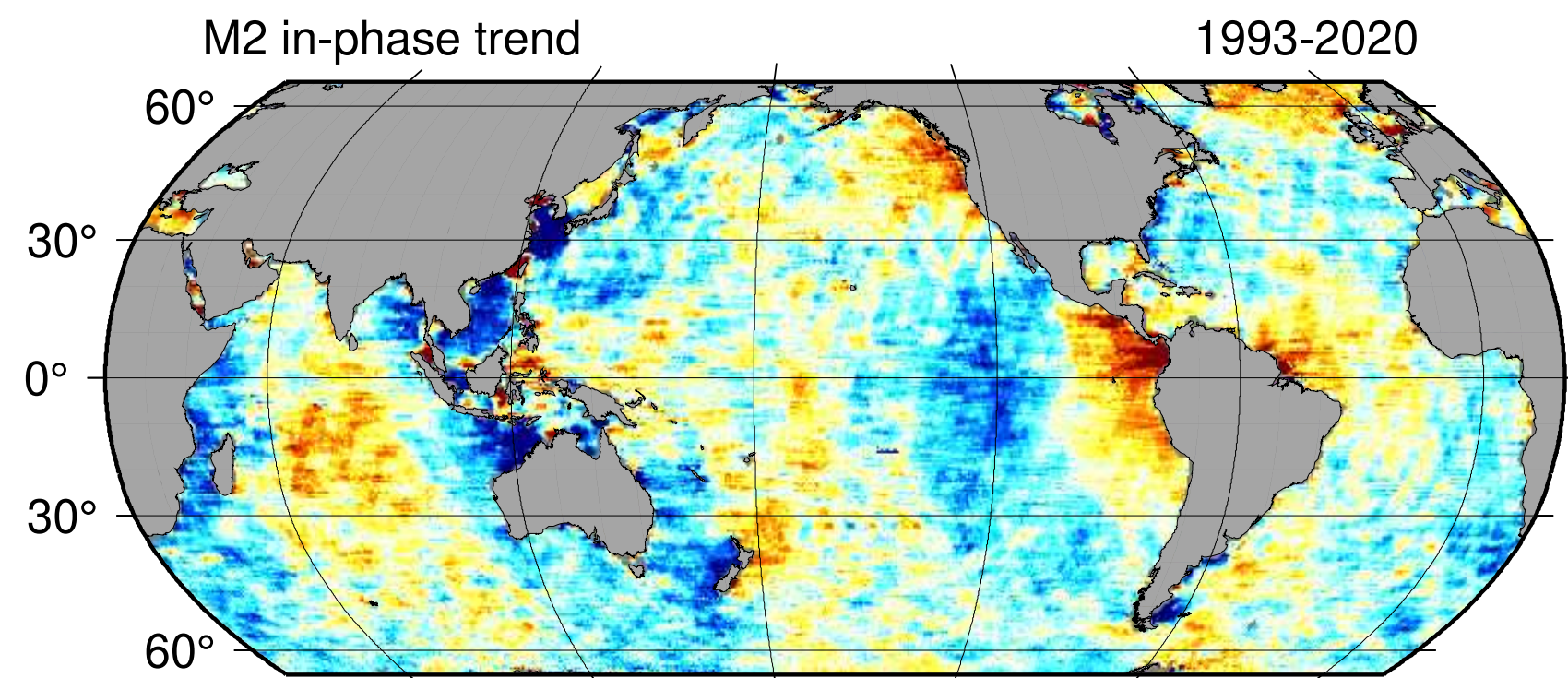
Noisy,
But broad patterns of
~ 0.1 to 0.2 mm/y
Larger in shallows

$\sigma \sim 0.05$ mm/y in open ocean
larger in shallows

Opel, Schindelegger, Ray (2024)

M₂ Trends 1993–2020

T/P-J1-J2-J3



$$A = \sqrt{(X^2 + Y^2)}$$

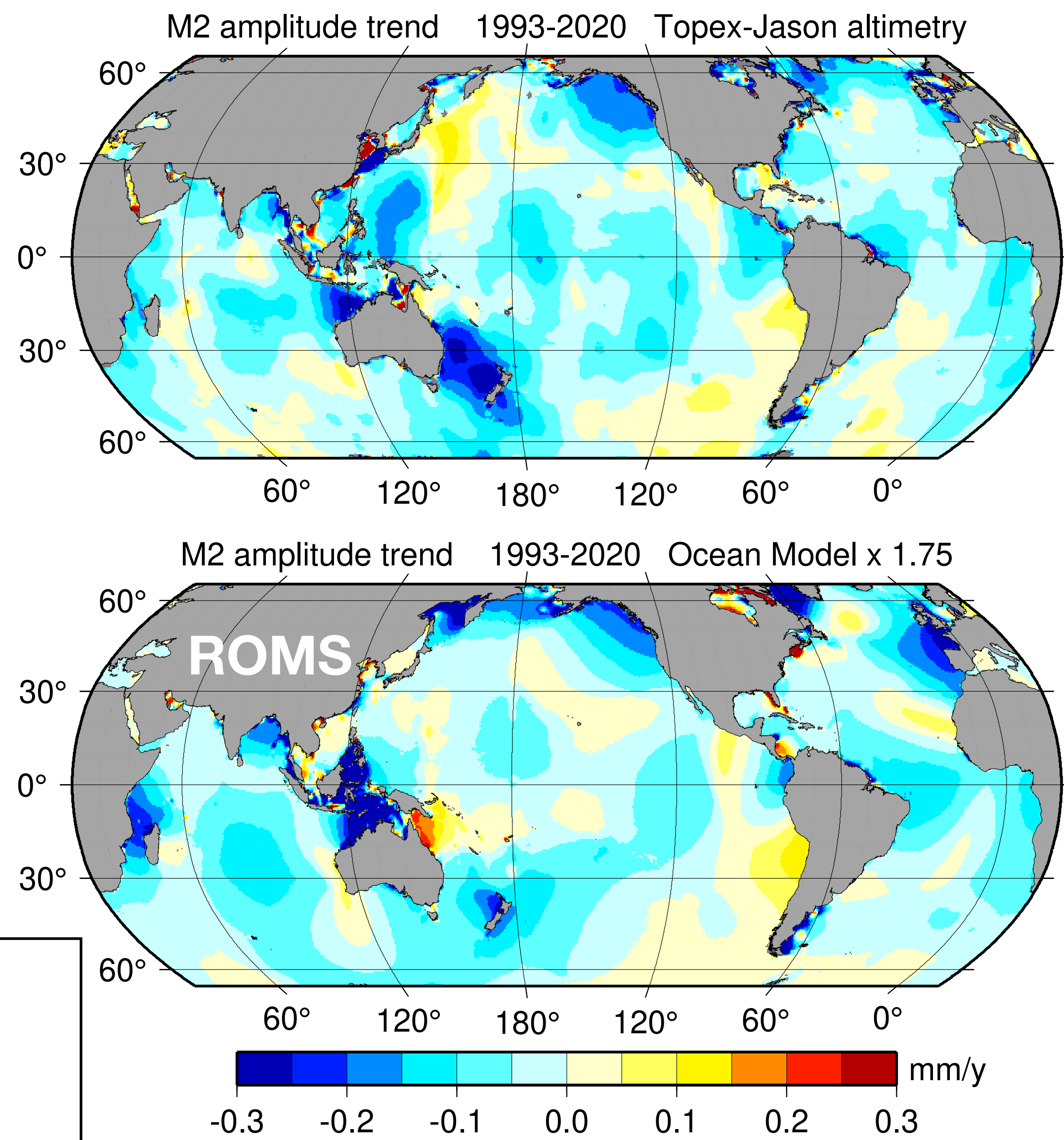
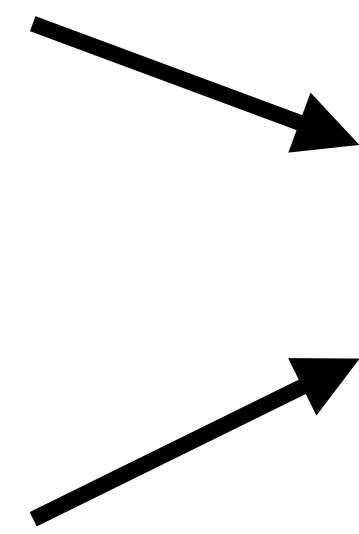
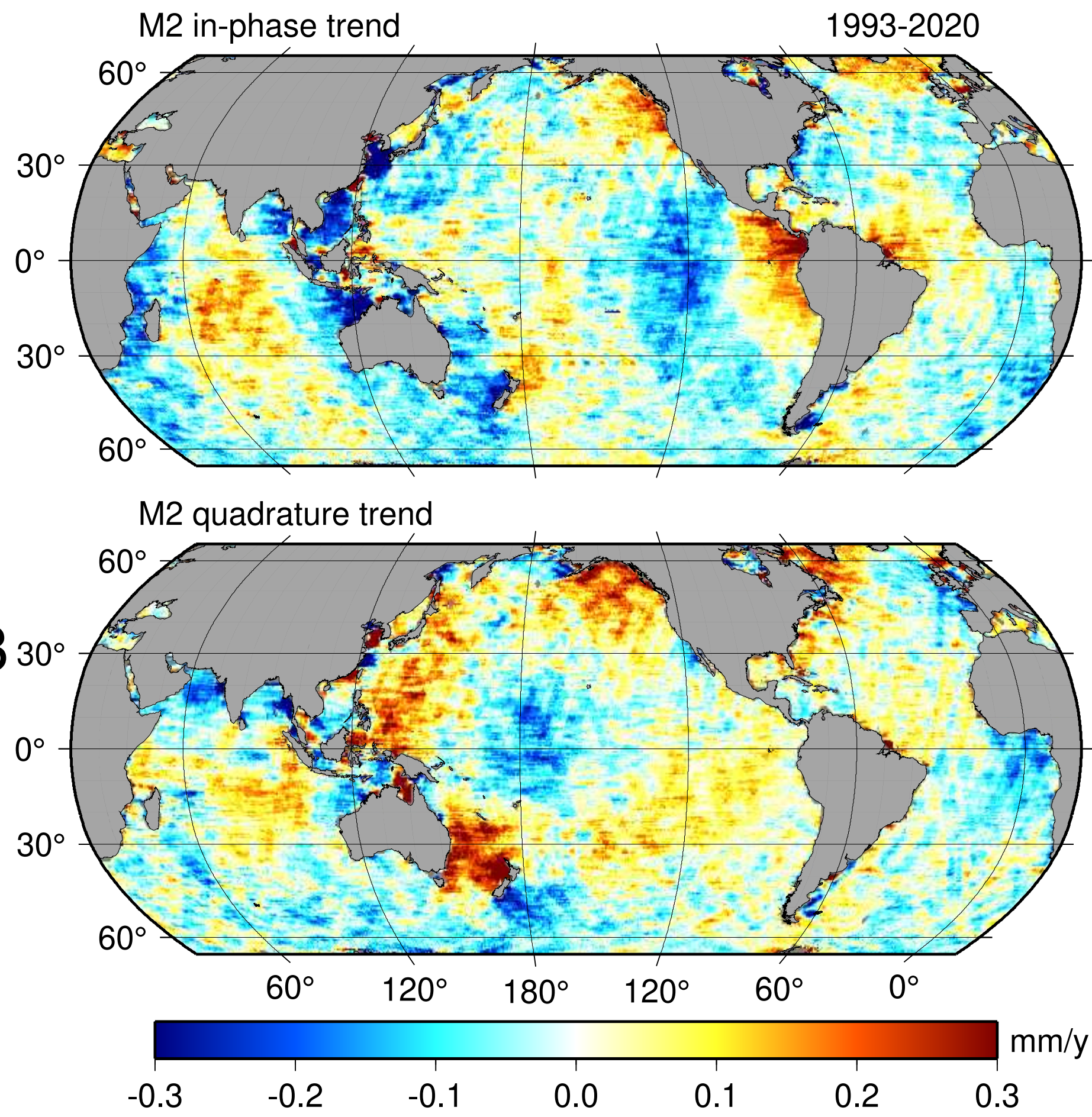
$$\dot{A} = (X\dot{X} + Y\dot{Y})/A$$

Amp trends mostly negative.

Opel, Schindelegger, Ray (2024)

M₂ Trends 1993–2020

T/P-J1-J2-J3

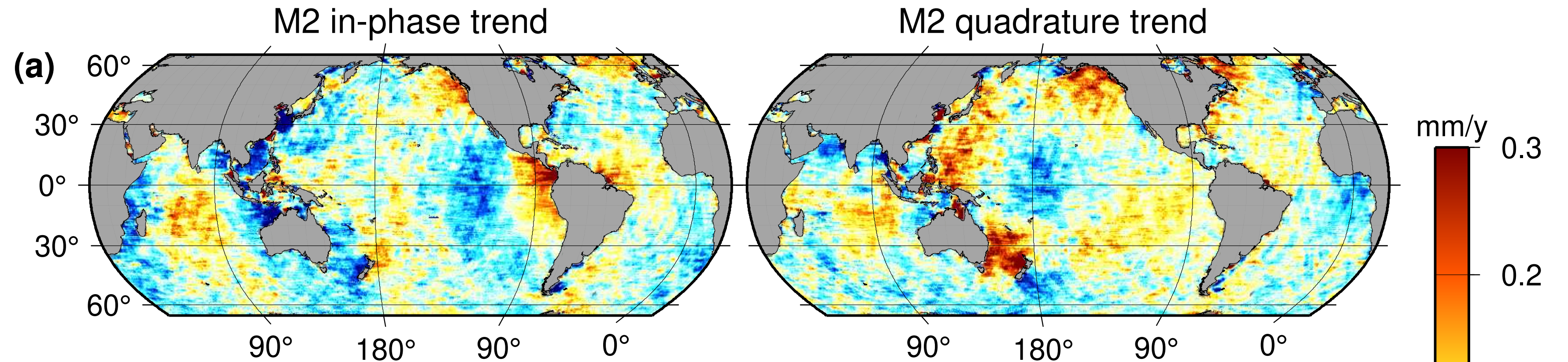


ROMS ocean modeling
Stratification from GLORYS12
Increasing stratification over 30 yrs
leads to increasing barotropic-baroclinic
conversion, decreasing barotropic tide

Opel, Schindelegger, Ray (2024)

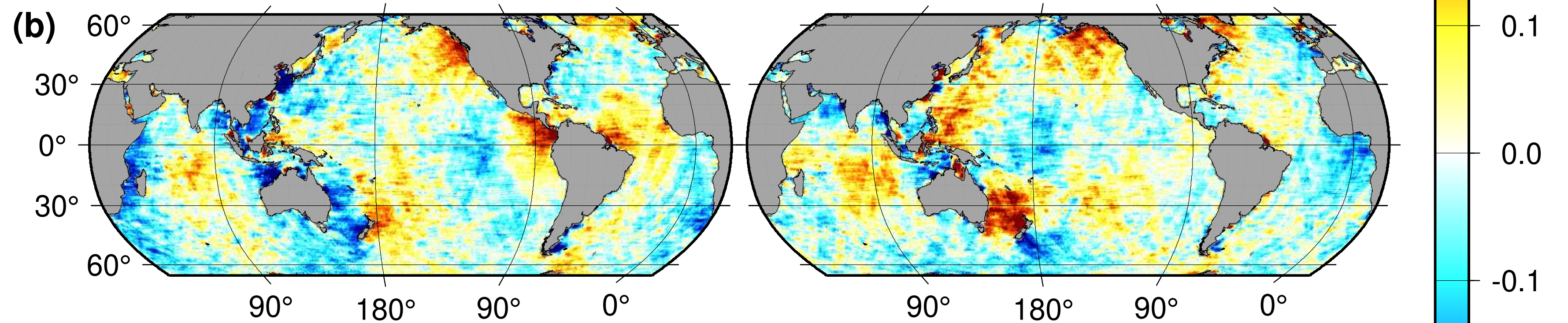
Signal is tiny. Systematic errors are large.

(a) from Opel et al (2024)



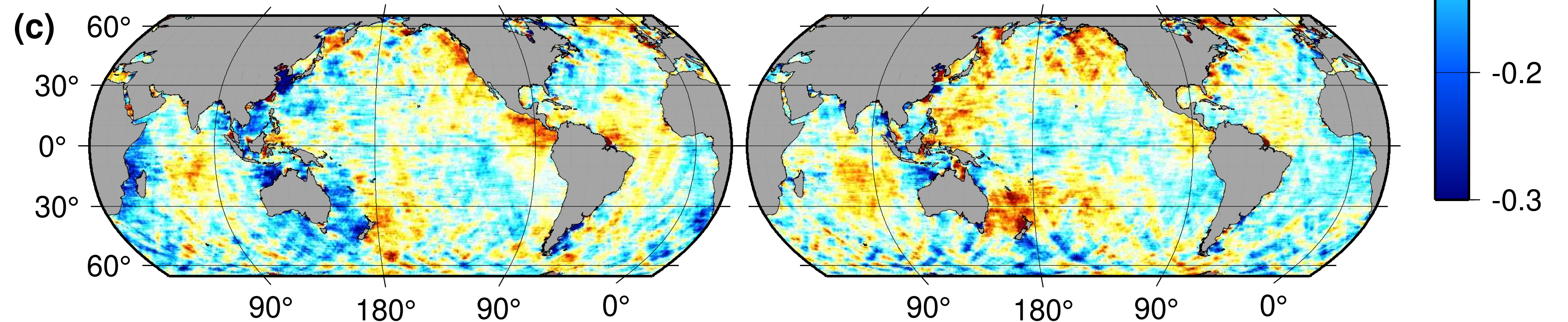
(b) from Ray et al (2025)

Different orbits
Longer timespan



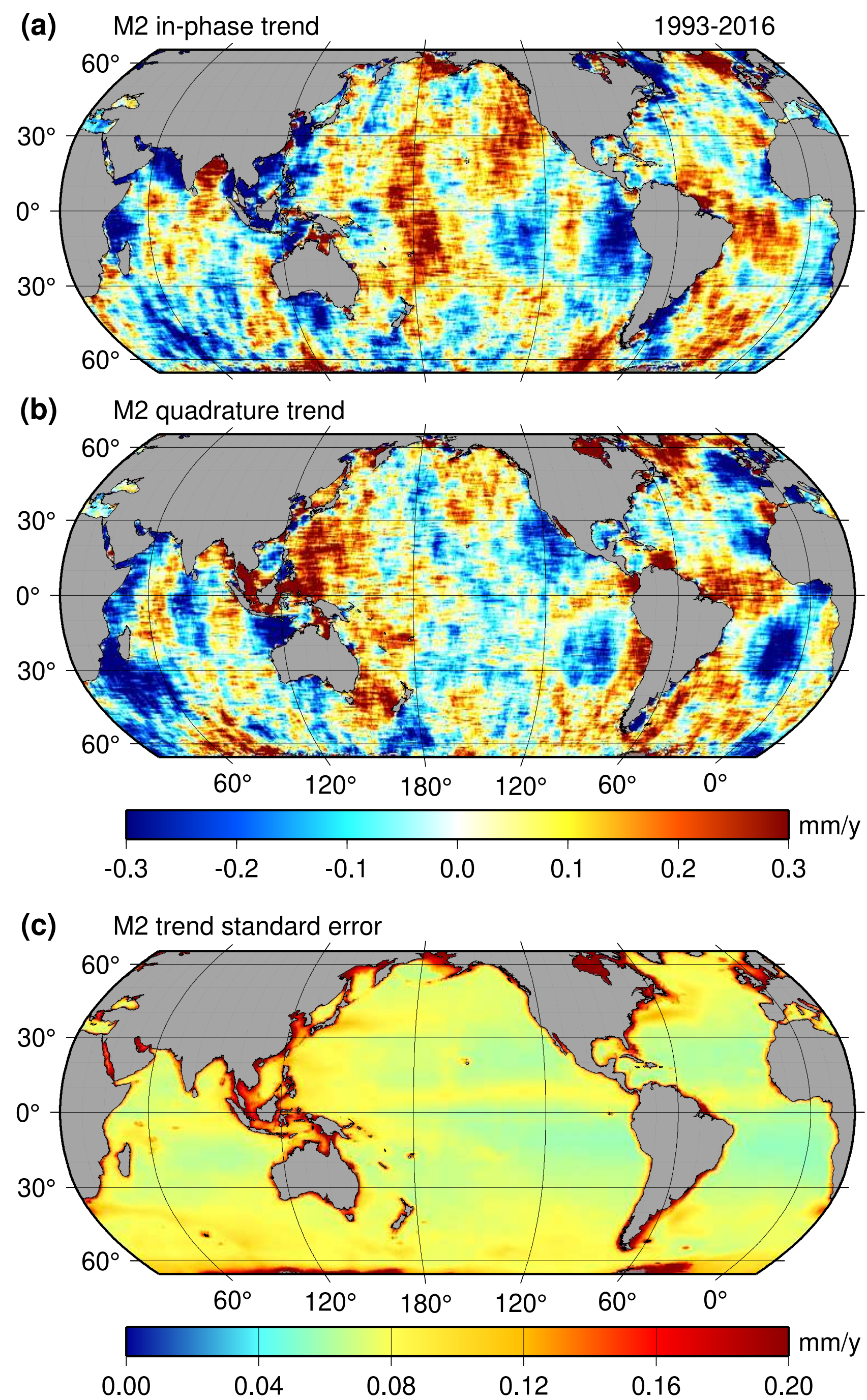
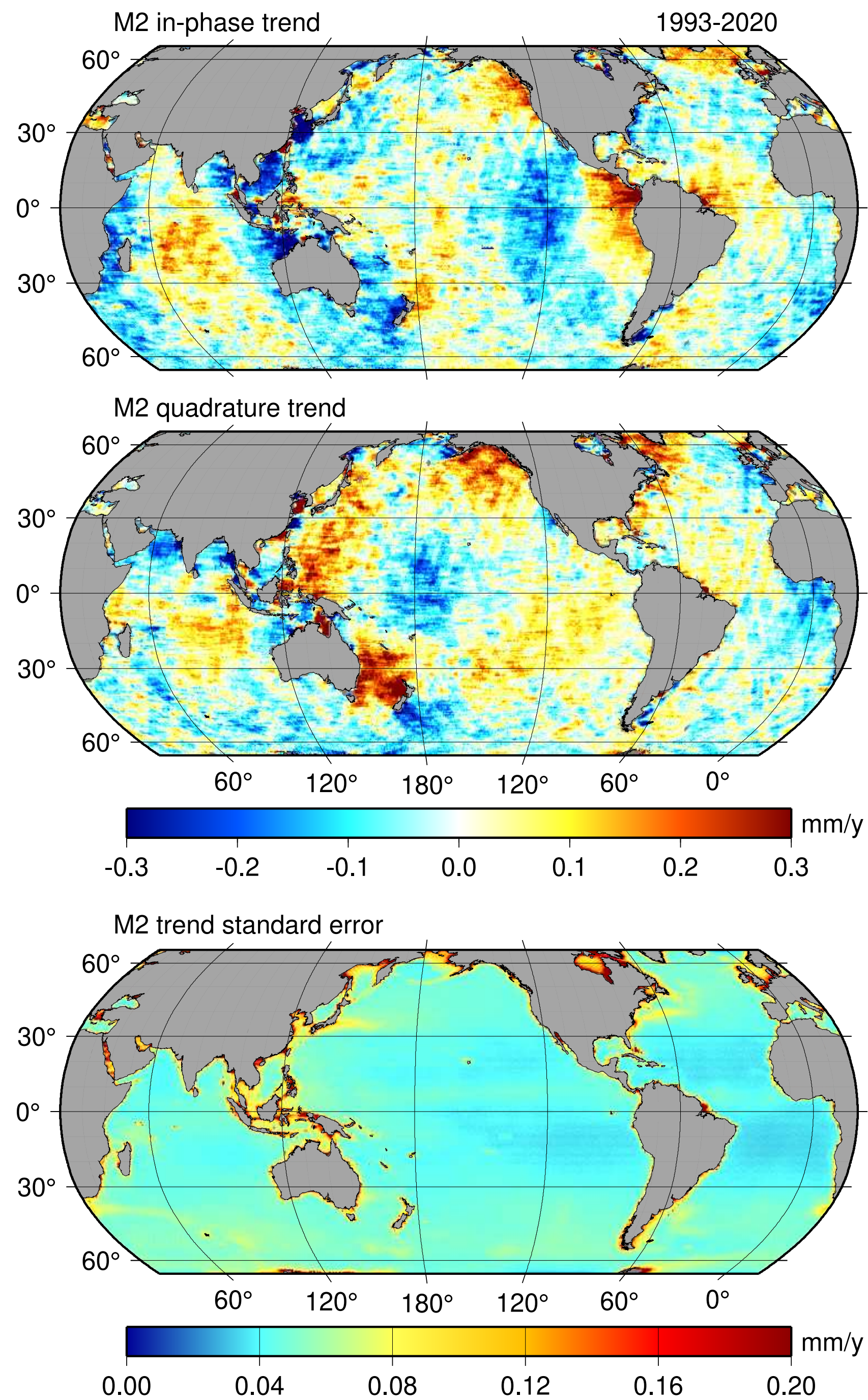
(c) unpublished

Different orbits
Longer timespan
Modified DAC; more noise



Can this be done without T/P, Jason, Sentinel-6A??

T/P
Jason-1
Jason-2
Jason-3
1993–2020



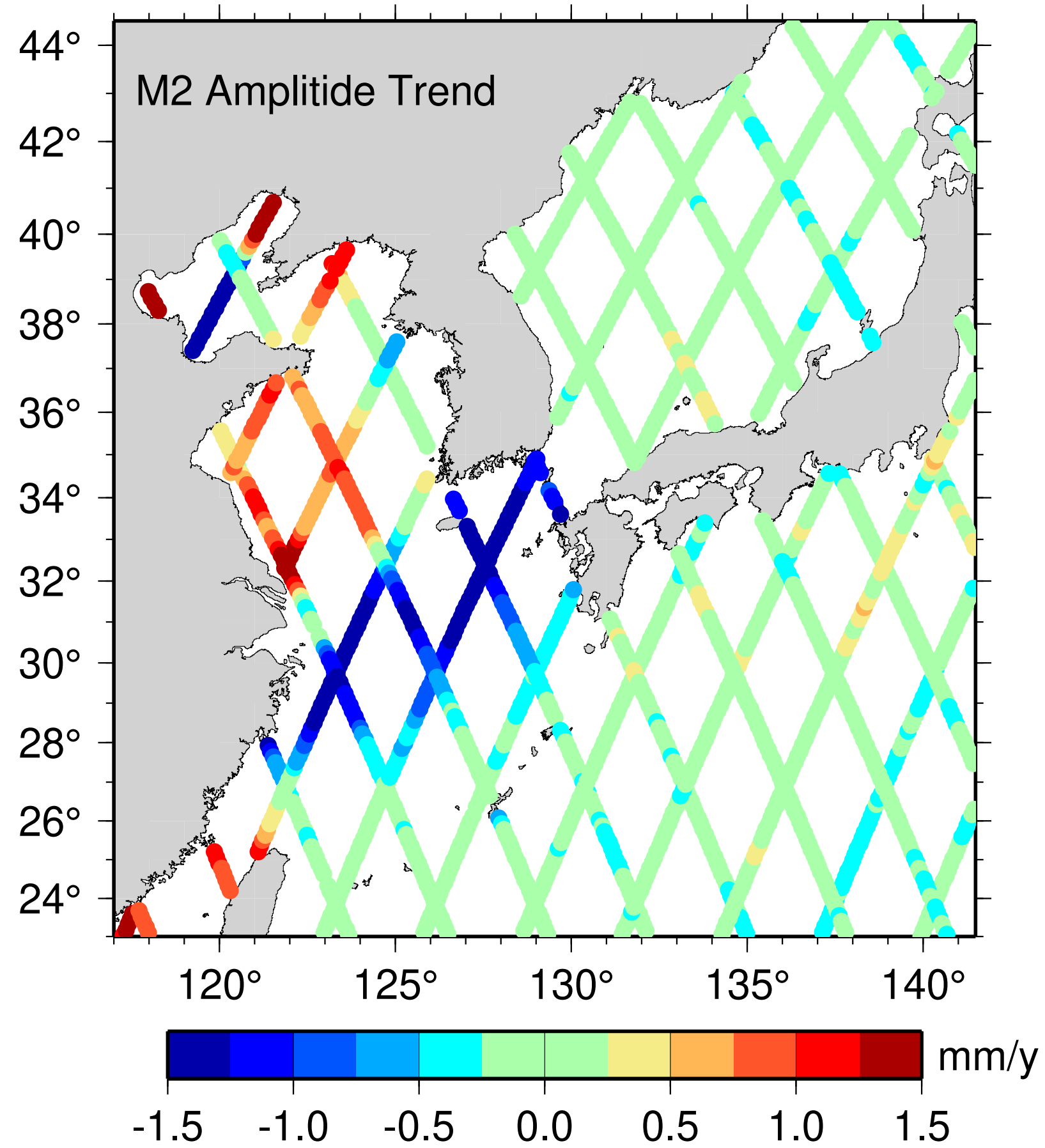
ERS-1
ERS-2
Envisat
SARAL
1993–2016

Not too
encouraging

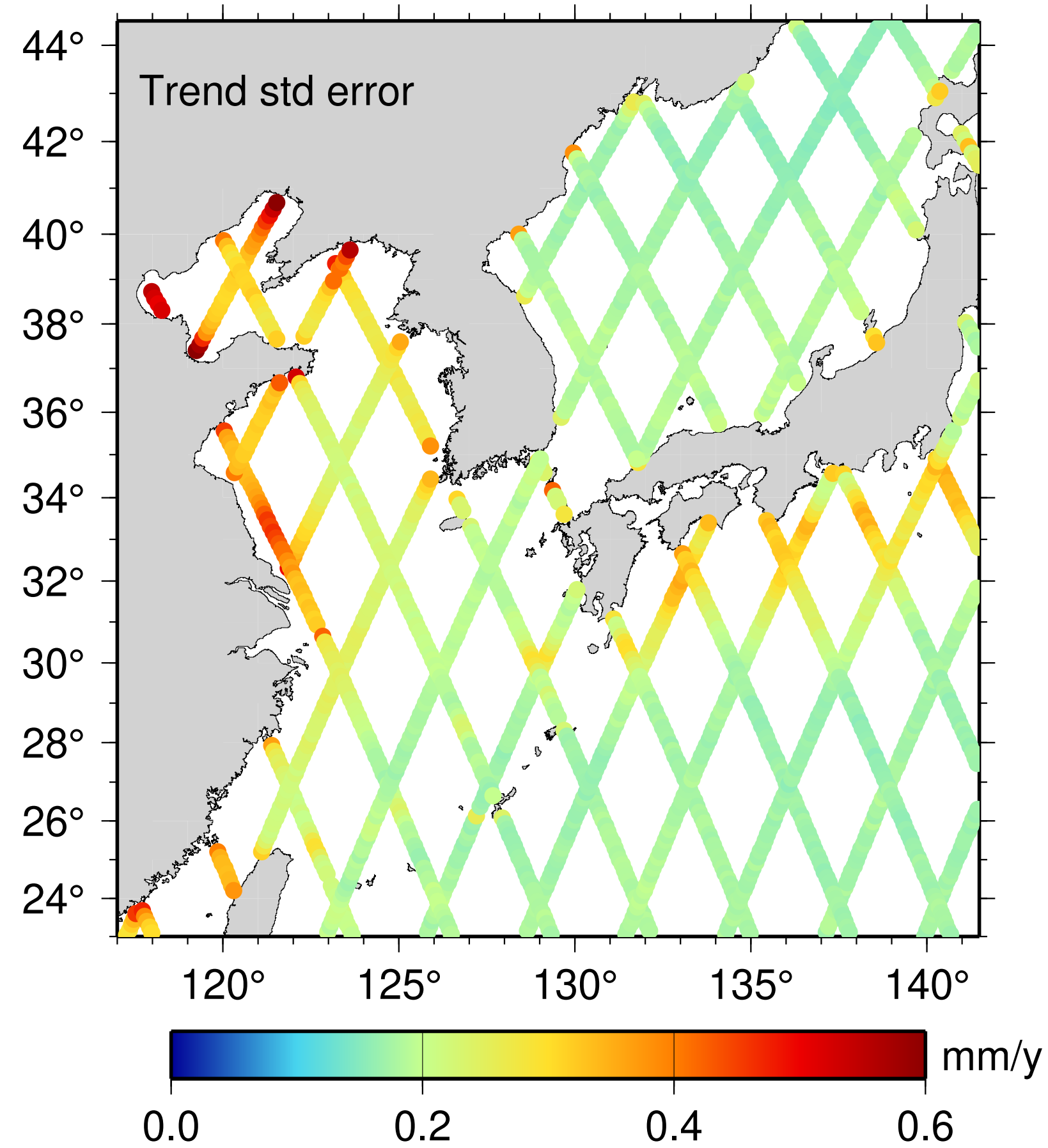
Can it be done without T/P, Jason, Sentinel-6A
in the **Yellow Sea**, where signals are 10 times larger??

M₂ amplitude trends in Yellow / East China Seas

Along-track estimates from T/P, Jason, S-6A

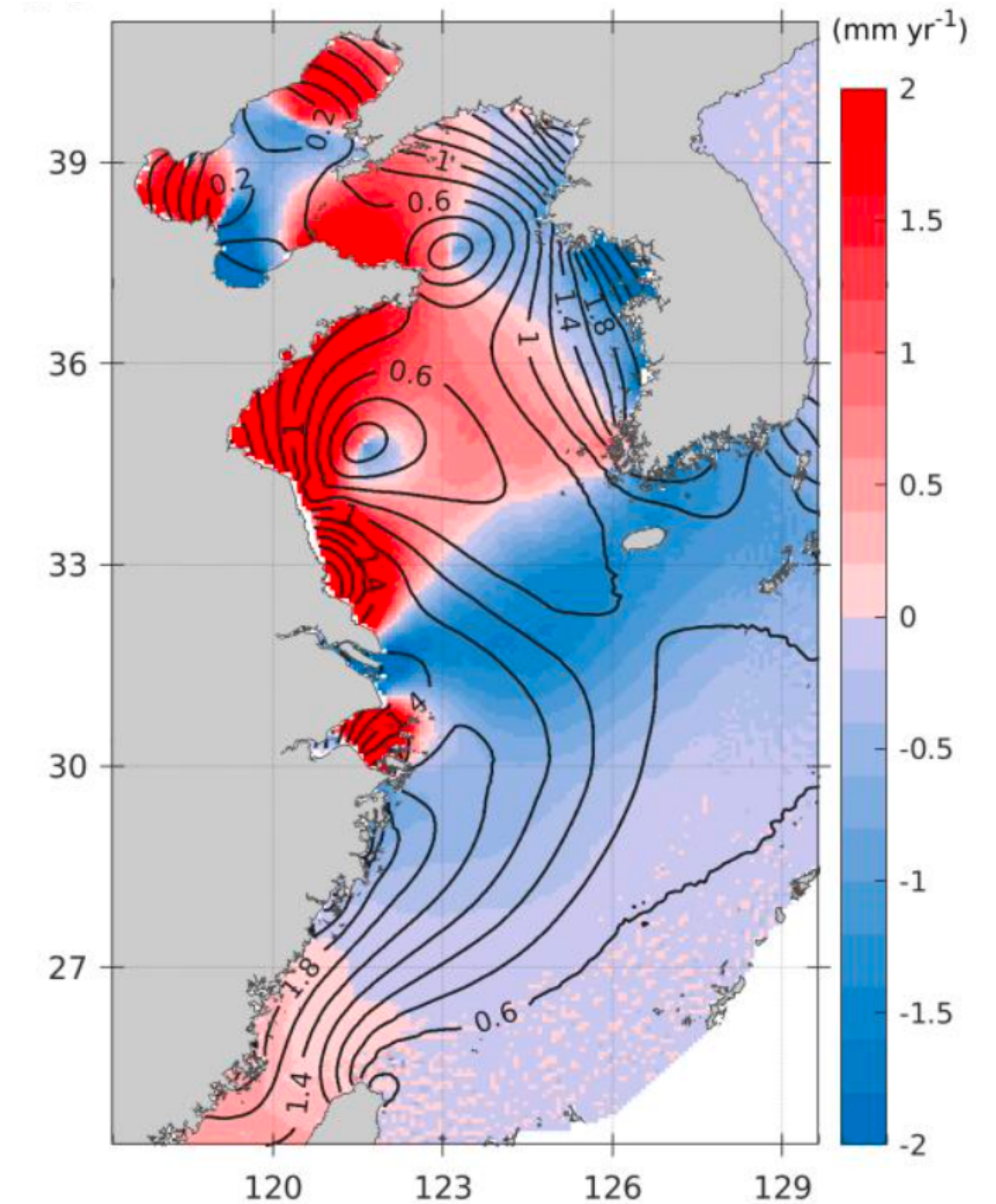


1140 repeat cycles
1993–2023



2-layer ocean model

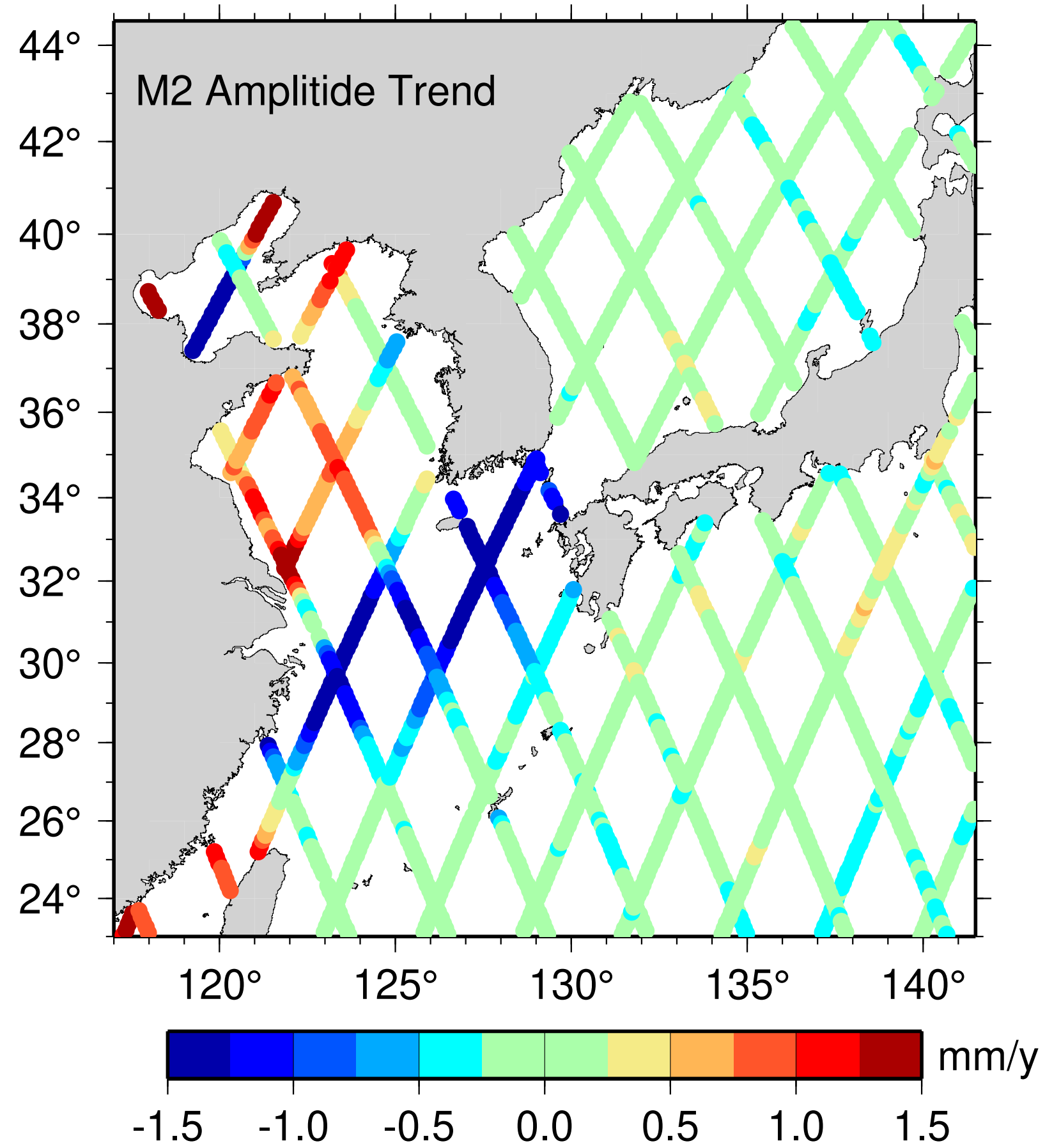
land reclamation, stratification, SLR



From Sok-Kuh Kang's group, SNU
Kim et al., submitted

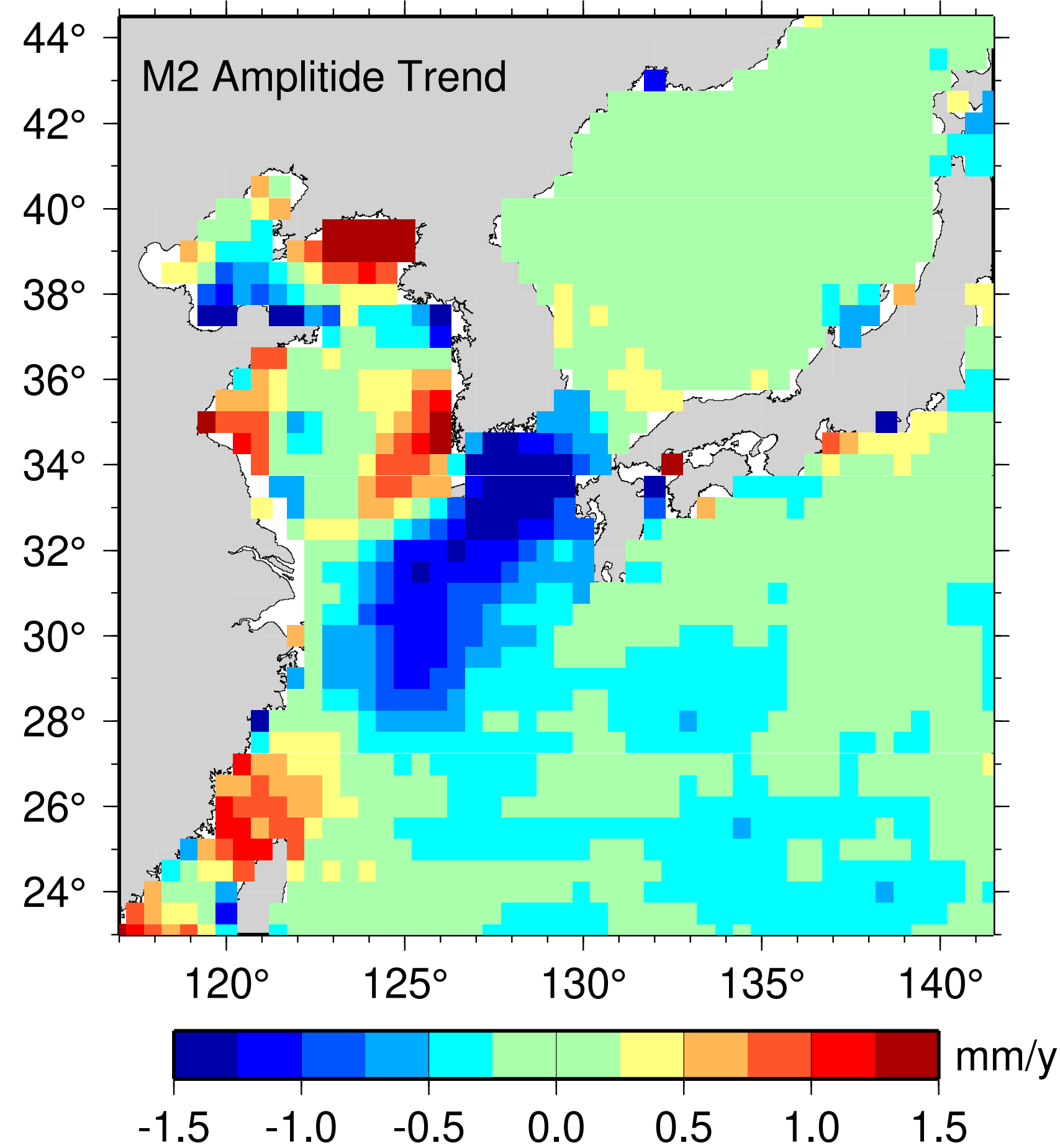
M₂ amplitude trends in Yellow / East China Seas

T/P, Jason, S-6A

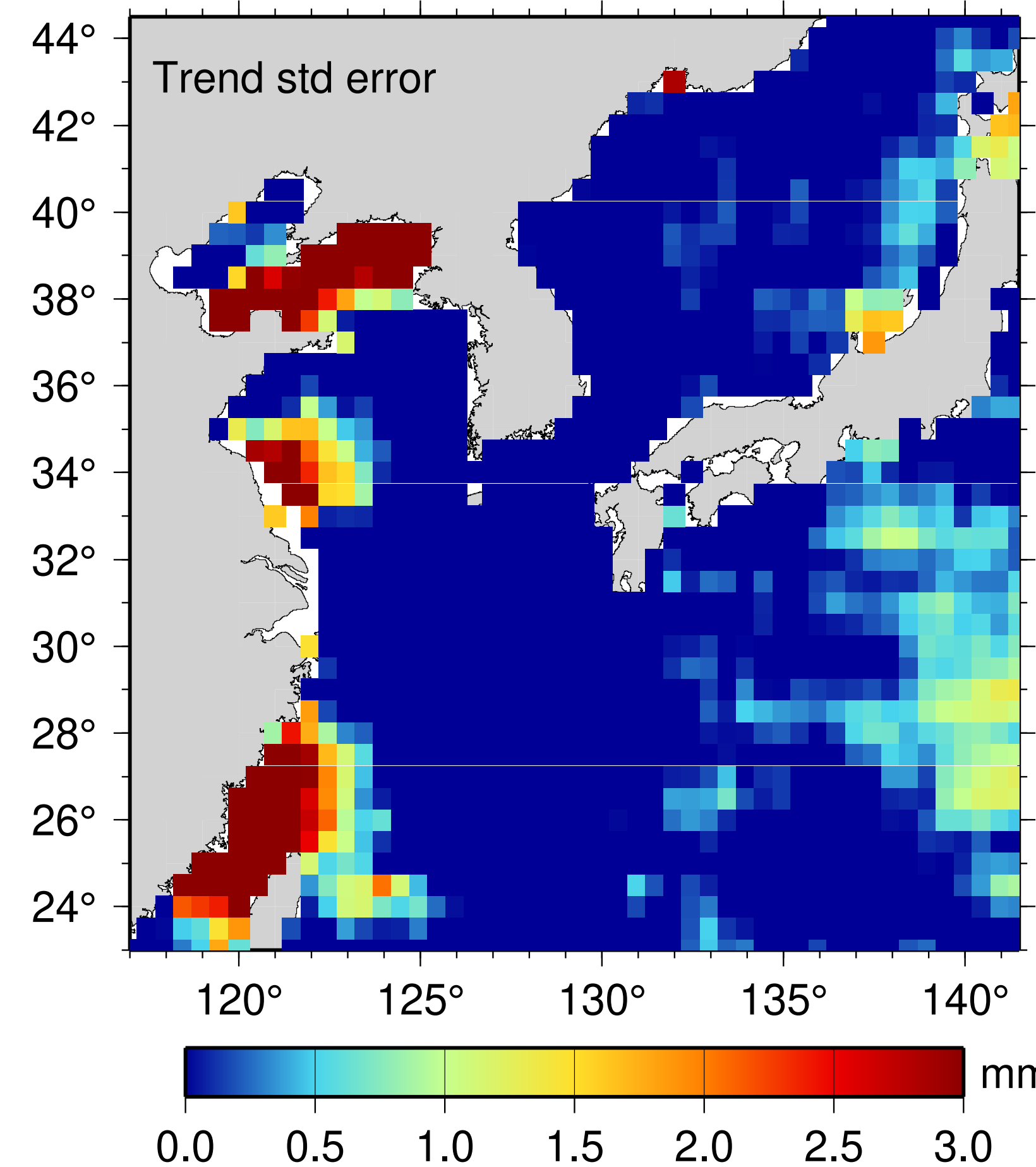


1140 repeat cycles
1993–2023

Results from ERS-1/2, Envisat, SARAL

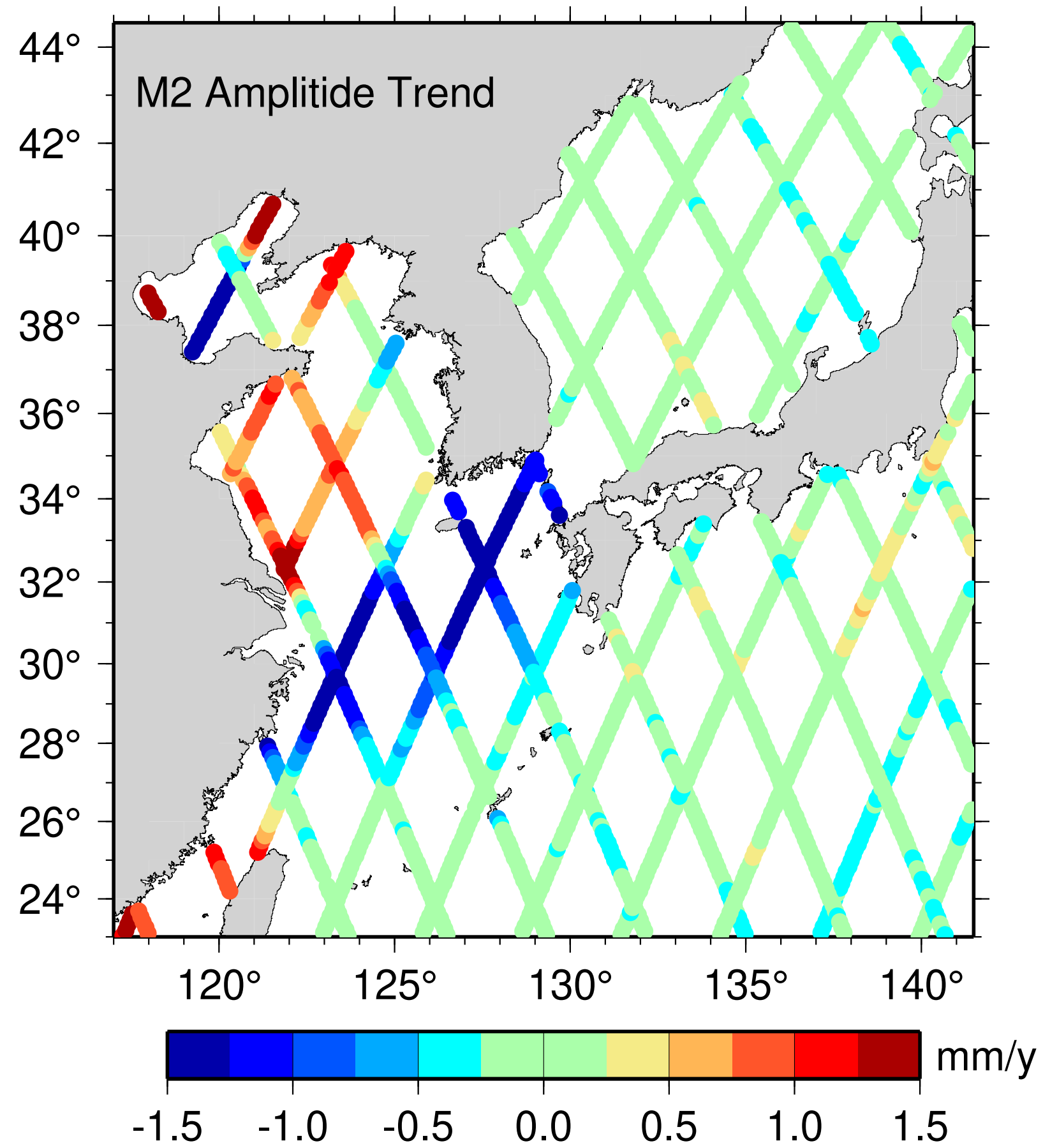


More encouraging than the global results!

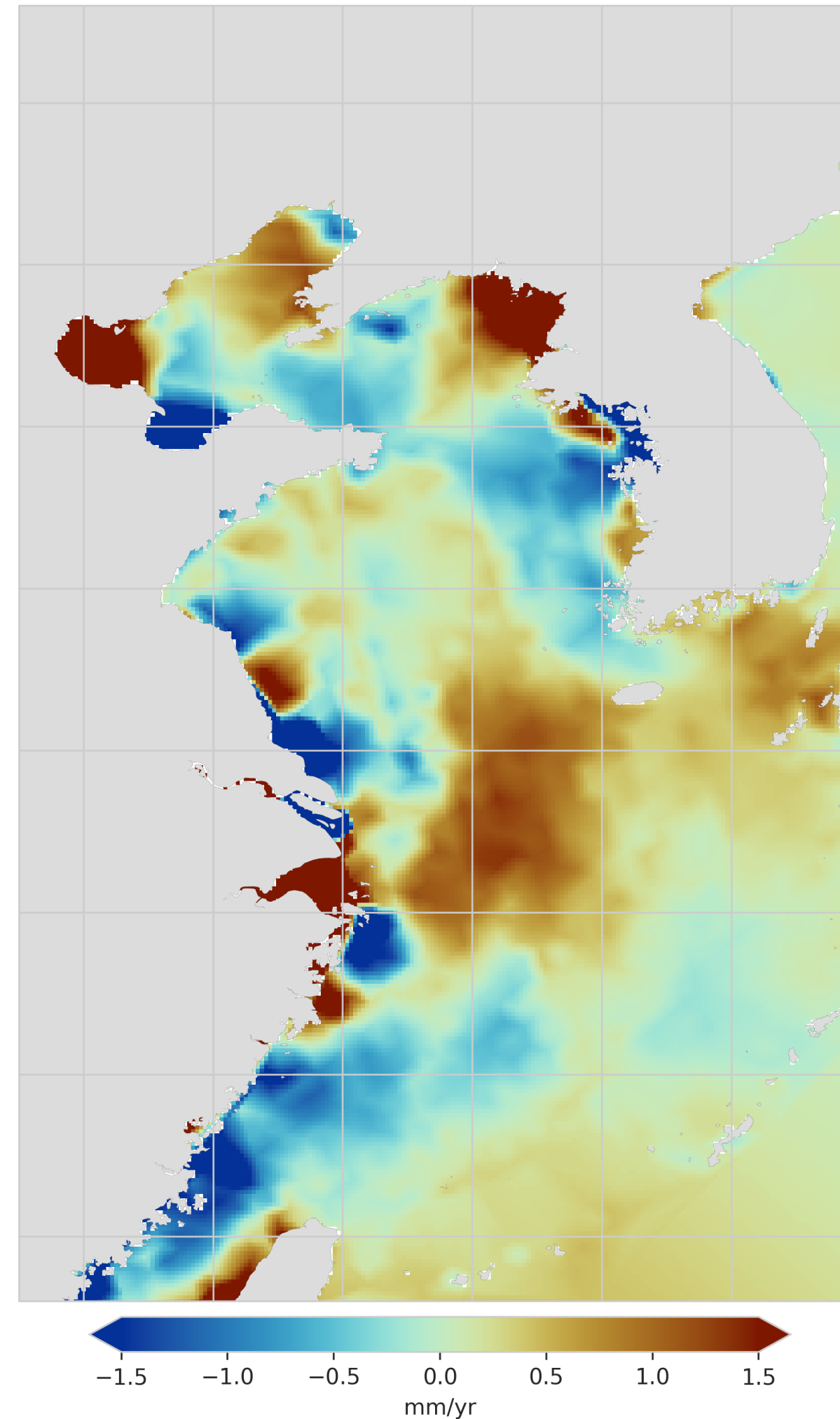


M₂ amplitude trends in Yellow / East China Seas

T/P, Jason, S-6A



1140 repeat cycles
1993–2023



All available ERM altimeters
(1993-2025)

Thanks to Mike Hart-Davis
for computing this.

Trends disagree a lot
(but agree in Bohai Sea).
Note that EOT25 mean tide
estimates are very accurate.

SUMMARY

- M_2 trends in the open ocean are tiny, of order 0.2 mm/y or less, evidently caused by the ocean's increasing stratification.
- M_2 trends in Yellow Sea are important, of order 2 mm/y, caused mostly by land reclamation, secondarily by stratification & SLR.
- Open-ocean tide trends are difficult to map, even with T/P-J-S6.
- Mapping results based on non-T/P-J-S6 data are not encouraging.
- If S6NG is in a different orbit, it will be challenging to extract new trend information that can build on the current T/P-J-S6 time series.
- Work needed: experiment with different ways to combine Envisat/SARAL and Sentinel-3 with current T/P-J data. Can it be done?