Seasonal Variability of Global Internal Tides

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Research Questions

- Which areas in the global ocean have high seasonal variability in total (stationary + non-stationary) M_2 internal tides?

- How does seasonal variability in HYCOM compare with altimeter data?

- What factors (time variability in tidal forcing, mesoscale currents, and stratification) can be responsible for the seasonal variability of total internal tides?

Model

- Steric sea surface height (SSSH) from Hybrid Coordinate Ocean Model (HYCOM) simulation Expt 18.5 is used in this study

  - ➢ Forward simulation

  - ➢ 8-km horizontal resolution and 32 layers

  - ➢ Atmospheric forcing from FNMOC NOGAPS

  - ➢ Forced with M_2, S_2, N_2, K_2, K_1, O_1, P_1, Q_1 tidal constituents and SAL correction

  - ➢ 6-year simulation; data output every hour

Tripolar Grid

Schopf 2005 after Murray 1996
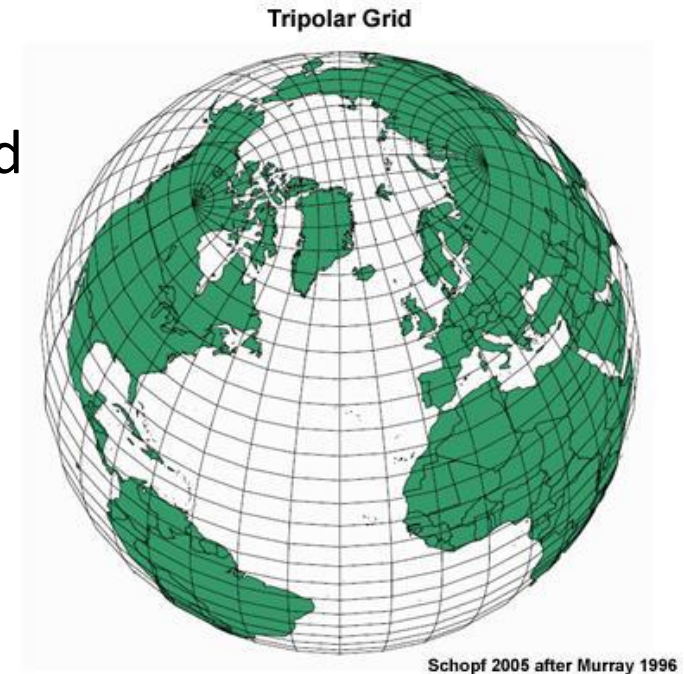
Data Analysis

- Six-year time series is divided into one-month segments (72 segments)

- For each one-month segment (m), harmonic analysis is done to extract M_2 amplitude and phase

$$\eta_m(t) = A_m\cos(\omega_{M_2}t - \varphi_m) = a_m\cos(\omega_{M_2}t) + b_m\,\sin(\omega_{M_2}t)$$

- This is considered as total internal tide

- Stationary tide is computed by averaging over harmonic constants (a and b) over all months (all Jan., all Feb., etc.) for the four seasons
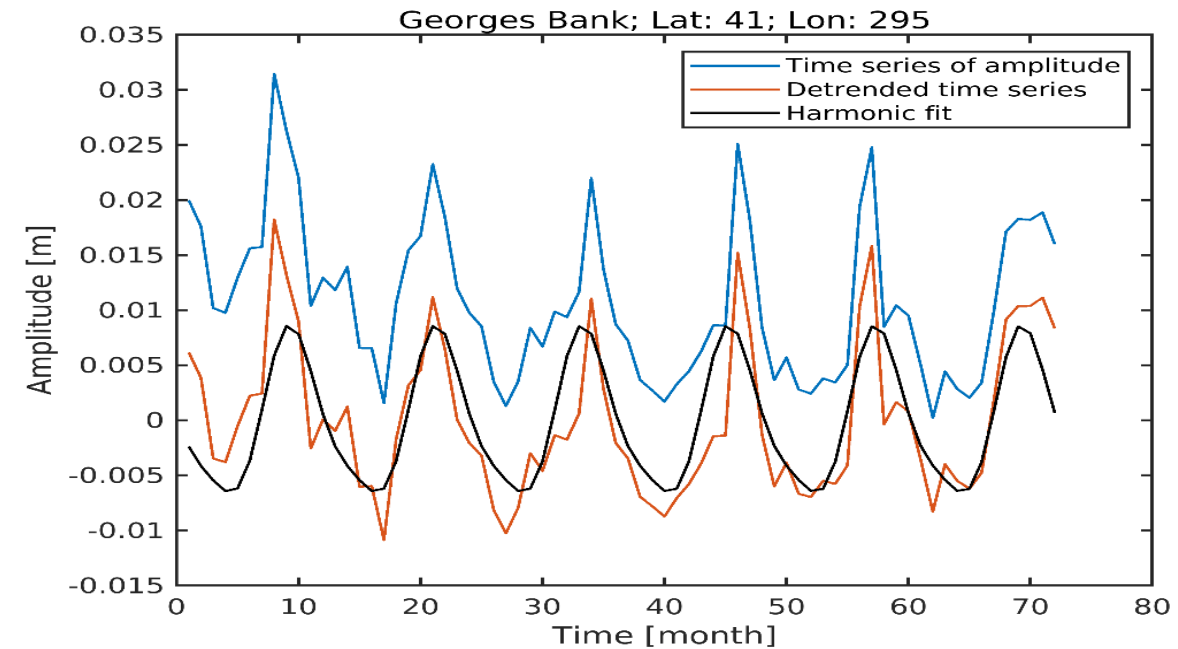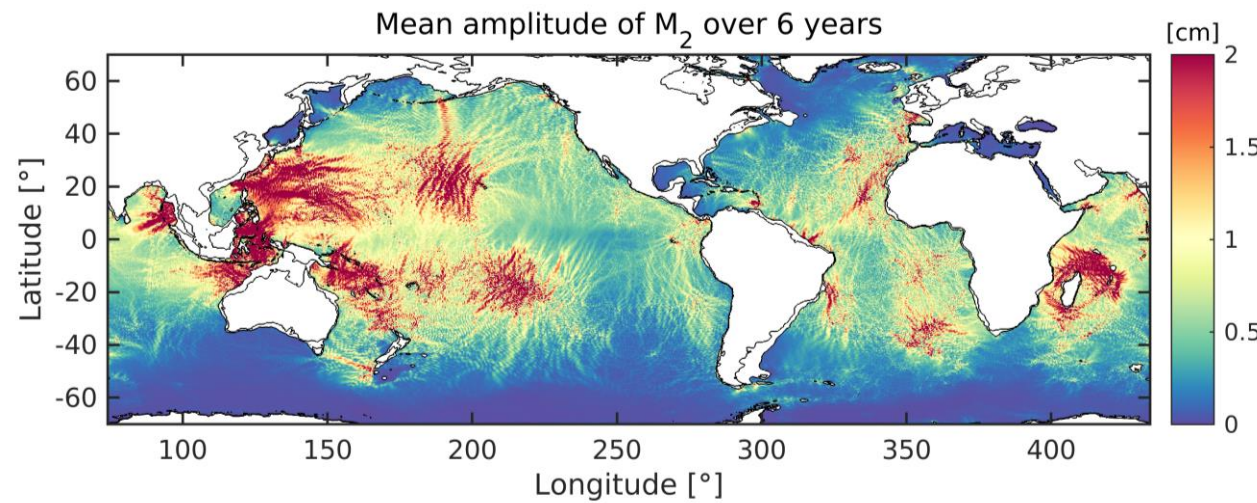

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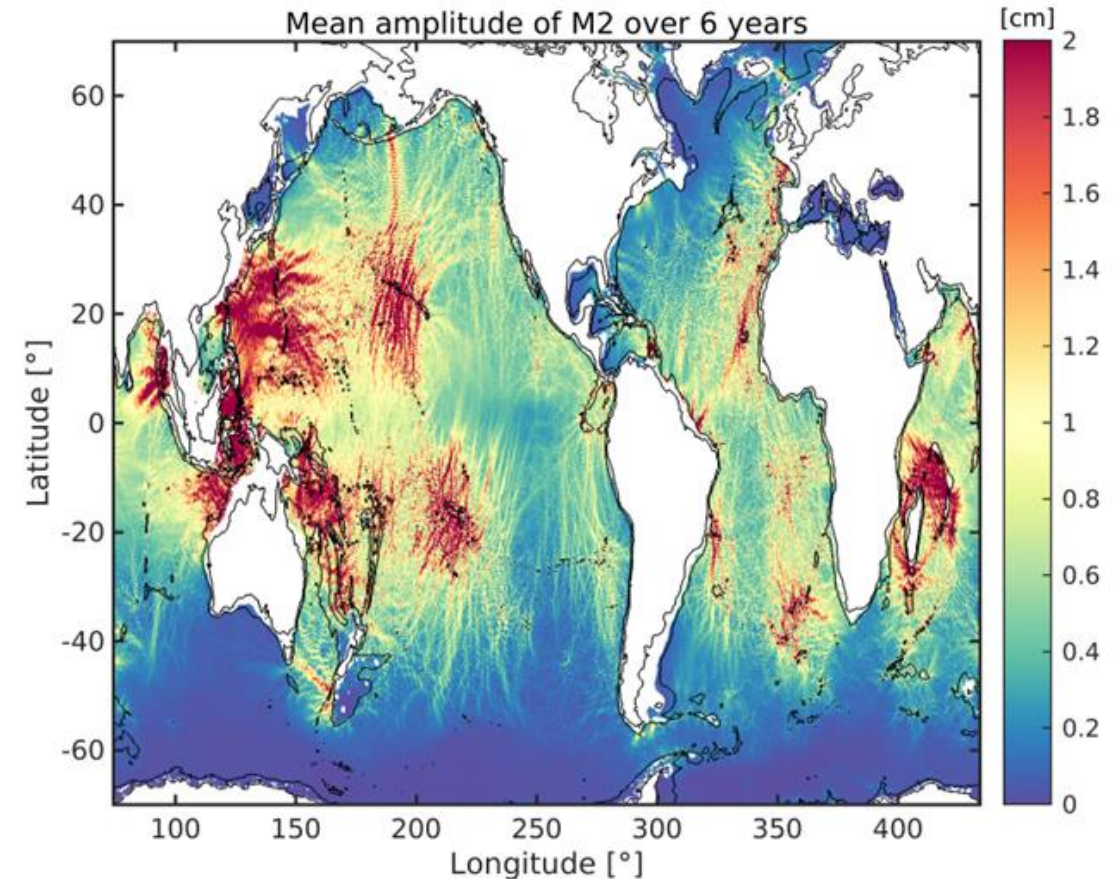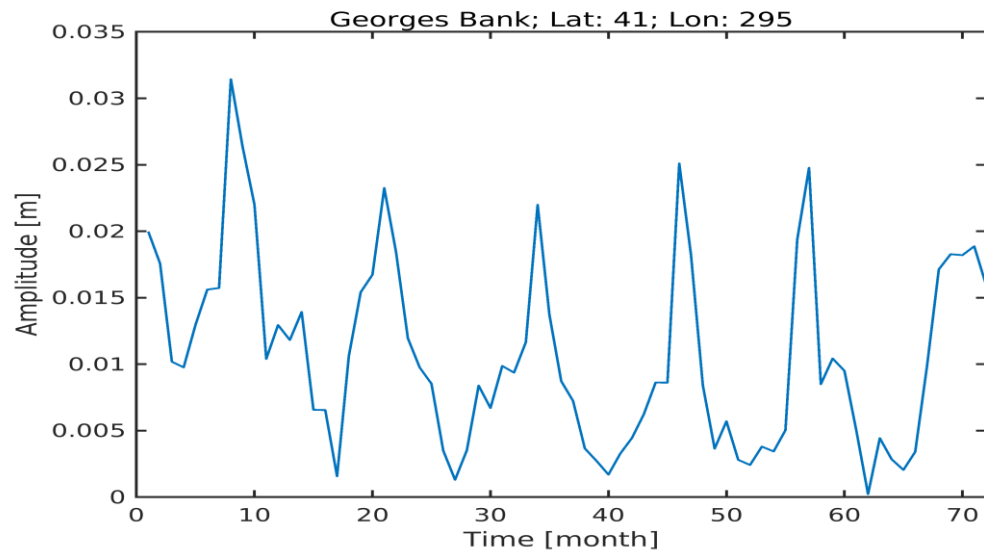
Seasonal Variability in Total Internal Tides

To study the seasonal variation in monthly amplitude for semidiurnal M$_2$ SSSH:

1) Linear trend is removed : $A_{wt}(t) = A(t) - bt$,

2) Annual and semiannual seasonal signals are fitted using the least-squares method :

$$A_{wt}(t) = A_0 + \underbrace{A_a \cos(\omega_a t + \varphi_a)}_{Annual} + \underbrace{A_{sa} \cos(\omega_{sa} t + \varphi_{sa})}_{Semiannual} + \varepsilon$$

Georges Bank; Lat: 41; Lon: 295

Mean amplitude of M$_2$ over 6 years

Seasonal Variability in Total M$_2$ Internal Tides

- The internal tides generated in coastal areas are showing high seasonal variability - Georges Bank, Amazon shelf, and Arabian Sea

- Internal tides in the equatorial region also show large seasonal variability

- The Northern and Southern Hemispheres are out of phase which indicates the seasonal variation due to changes in stratification
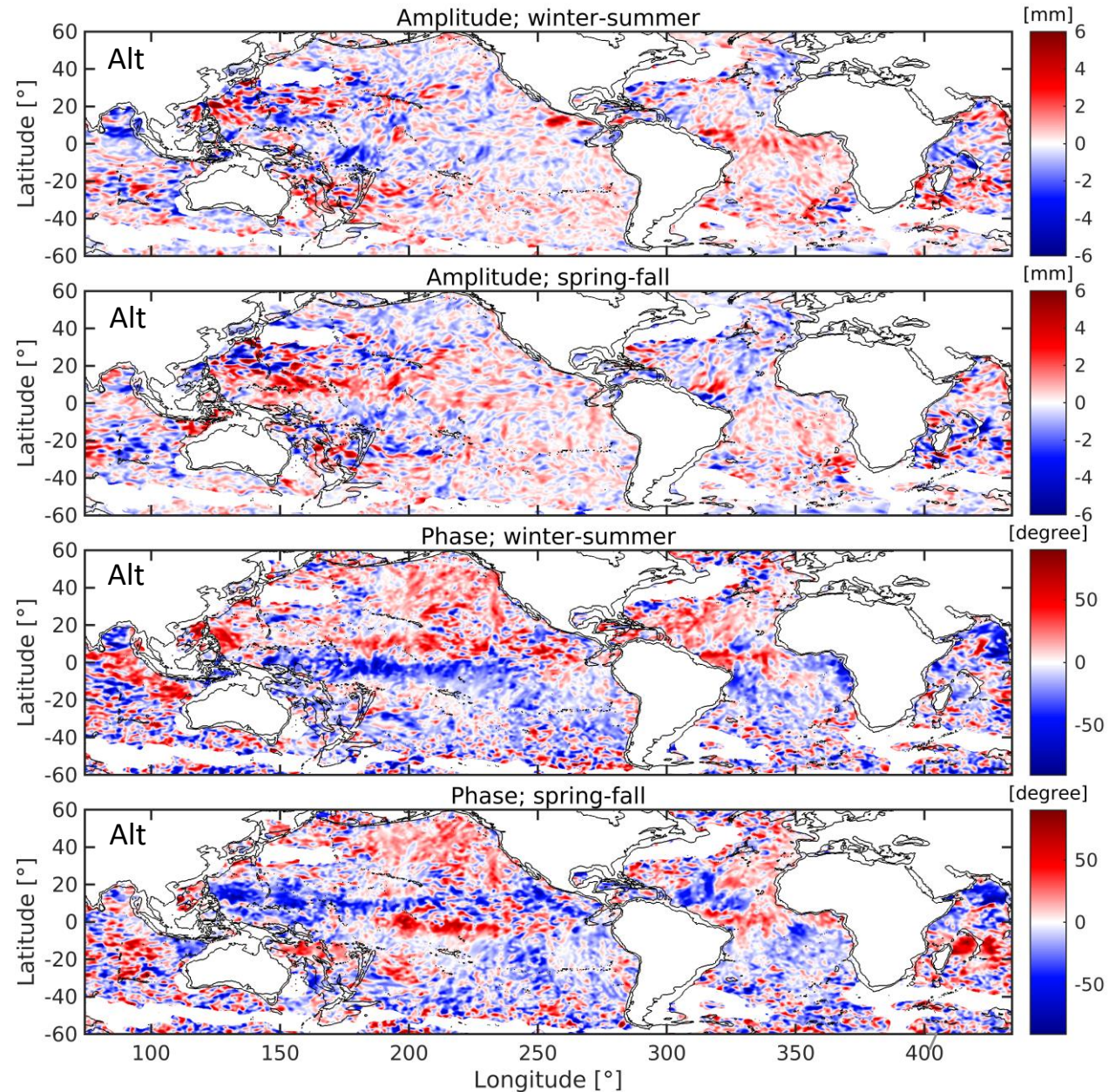
Normalized Amplitude (Annual Cycle)

Phase (Annual Cycle)

R^2
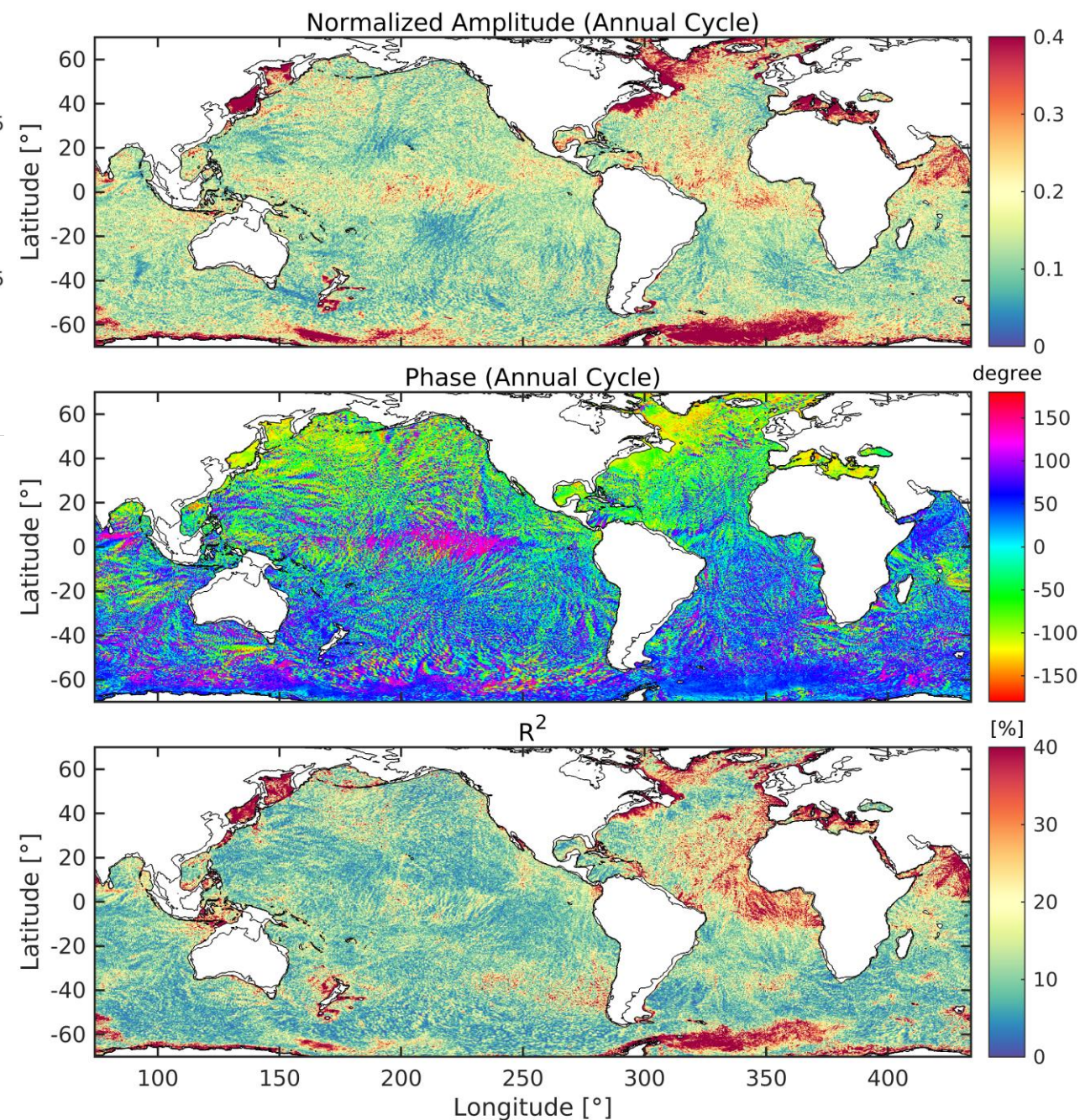
Comparison with altimeter data
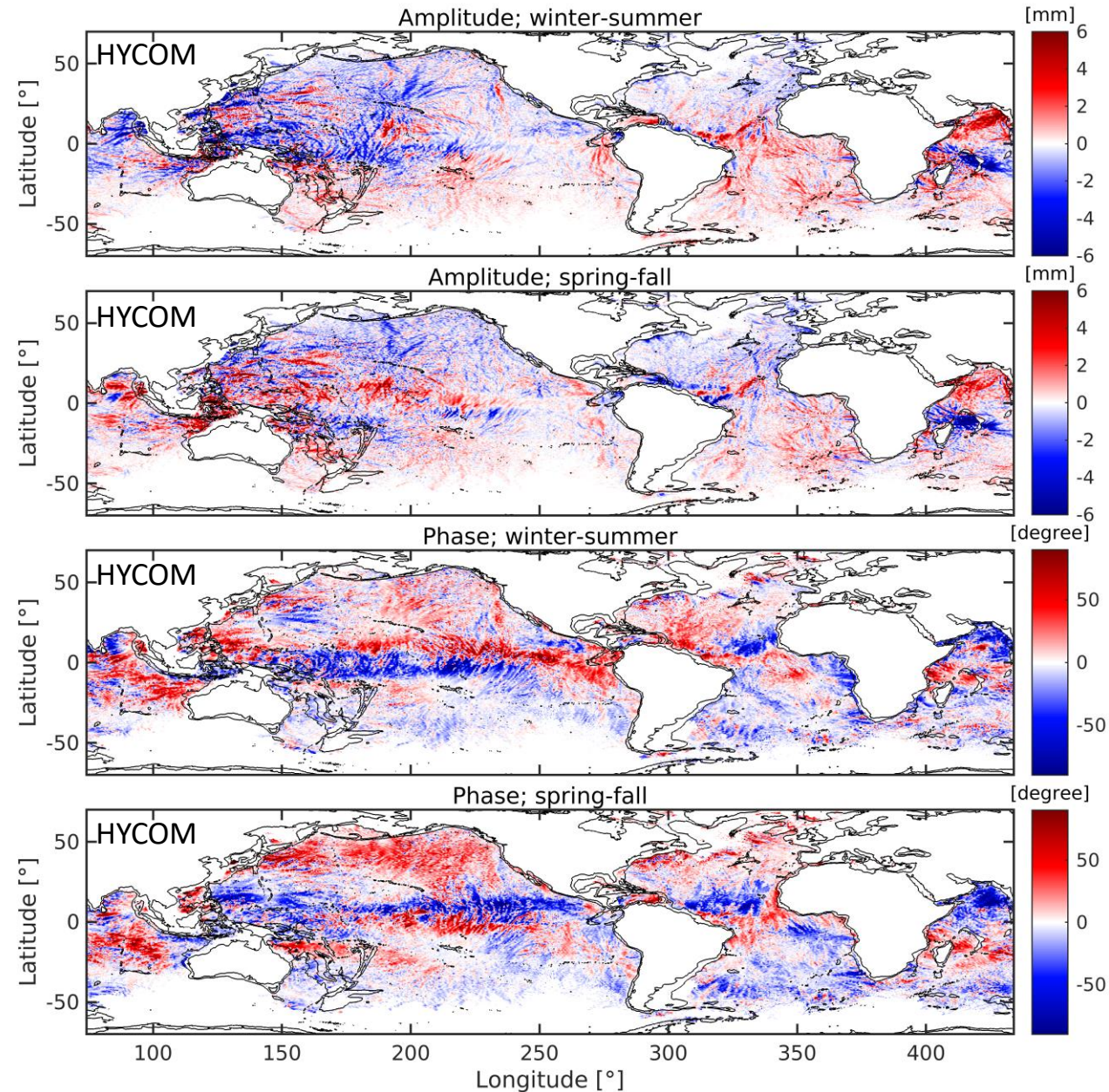
Resolution : 1/12.5°   Resolution : 0.2°   Zhao (2021)

Factors causing seasonal variability

- Generation - barotropic tides and stratification variability (Buijsman et al. (2012))

$$C = Wp'(z = -h)$$

C : depth-integrated barotropic to baroclinic energy conversion

W : vertical barotropic velocity

$p'(z = -h)$: perturbation pressure at the bottom

- Propagation – stratification and mesoscale currents variability (Zaron and Egbert (2014))

$$\frac{\delta c_p}{c_p} \approx \frac{1}{2}\frac{\delta c_1^2}{c_1^2} + \frac{|\overline{u}|}{c_p} + \frac{1}{2}\frac{f^2}{\omega^2}\text{Ro}$$
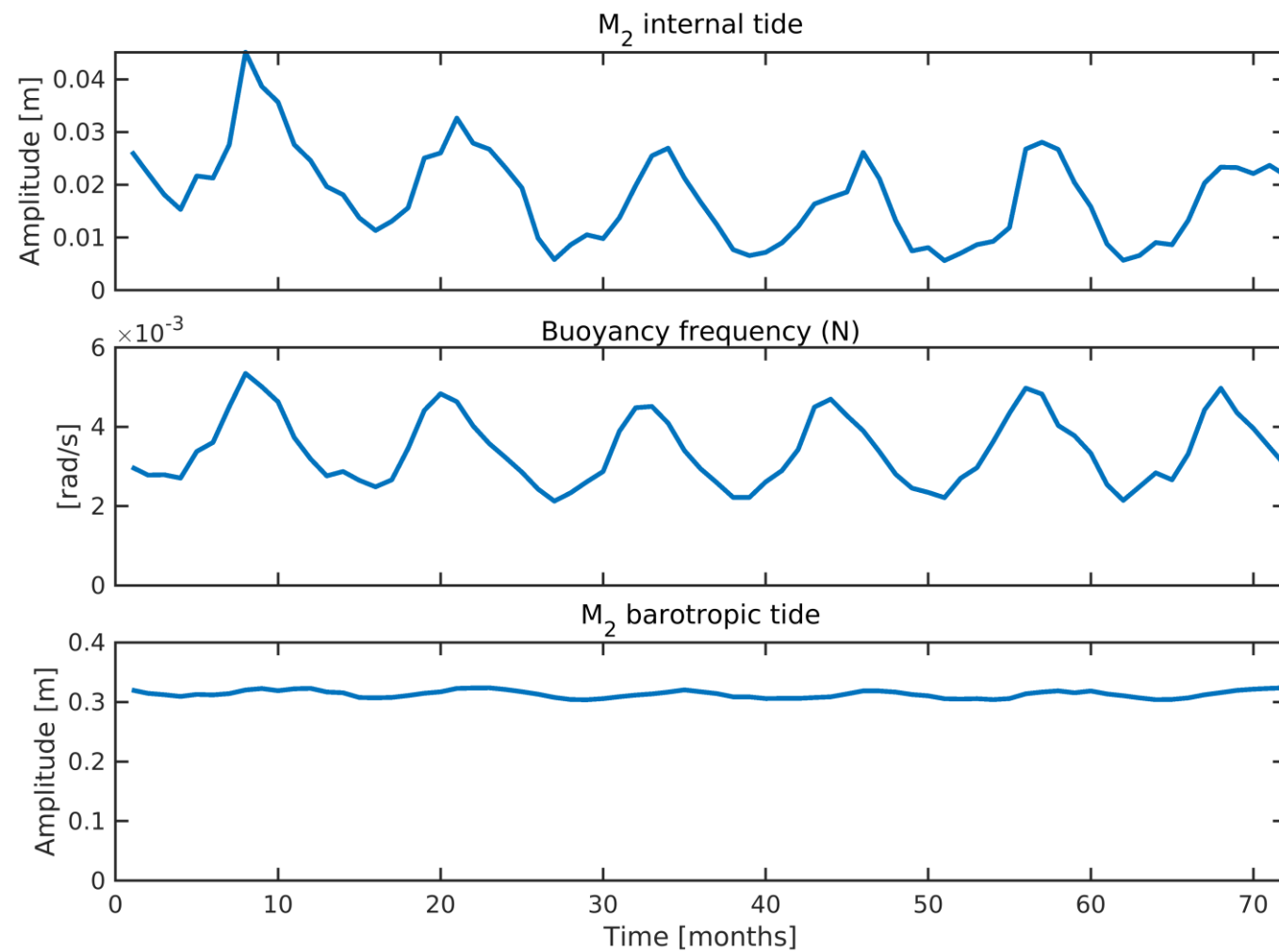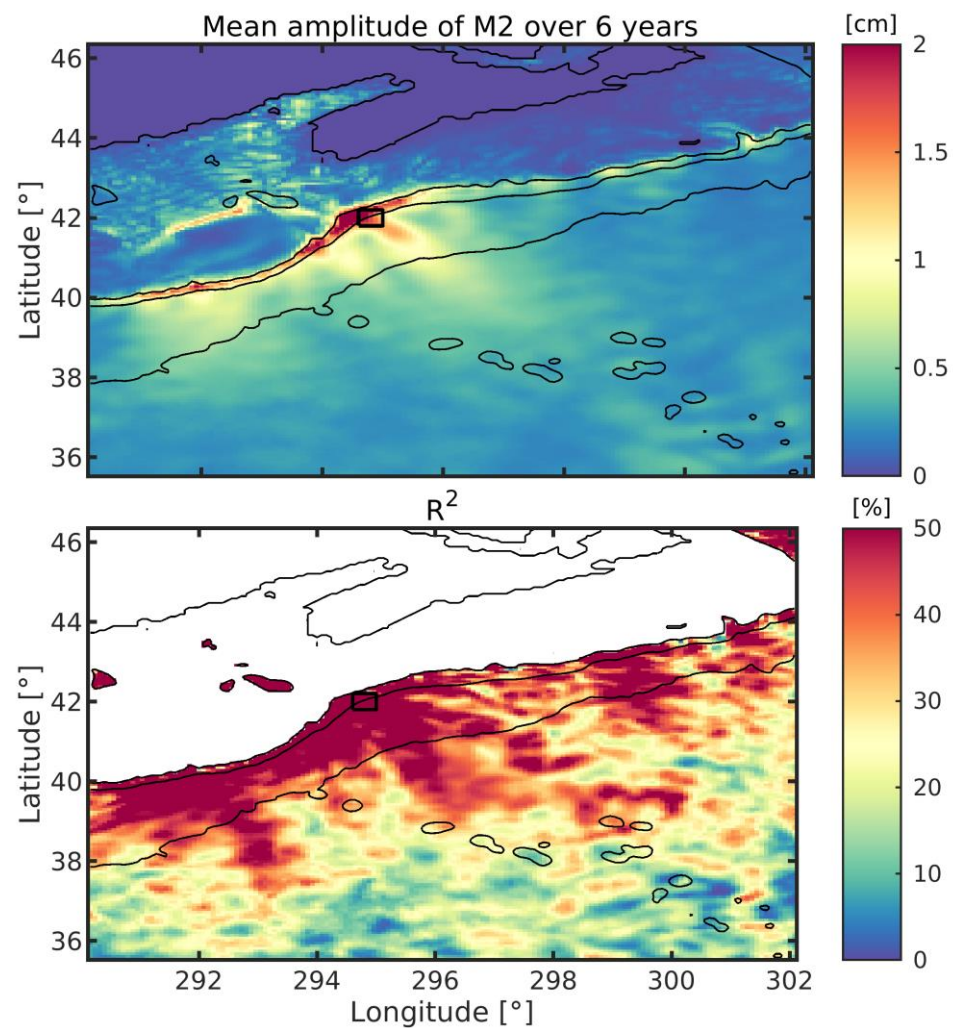
$\frac{\delta c_p}{c_p}$: relative changes in mode 1 phase speed

$\frac{1}{2}\frac{\delta c_1^2}{c_1^2}$: refraction due to background stratification

$\frac{|\overline{u}|}{c_p}$: advection by the subtidal current

$\frac{1}{2}\frac{f^2}{\omega^2}\text{Ro}$: refraction due to background relative vorticity

Generation - Georges Bank

Propagation – Stratification and Mesoscale current

- For stratification, strong seasonal variations are present in the equatorial region and along some shelf areas

- For advection, strong seasonal variations occur in equatorial regions , western boundary currents, and Antarctic Circumpolar Current

- Stratification is the dominant factor affecting variability in the internal tide

Stratification

Seasonal variability in M_2 internal tide (R^2)

Advection
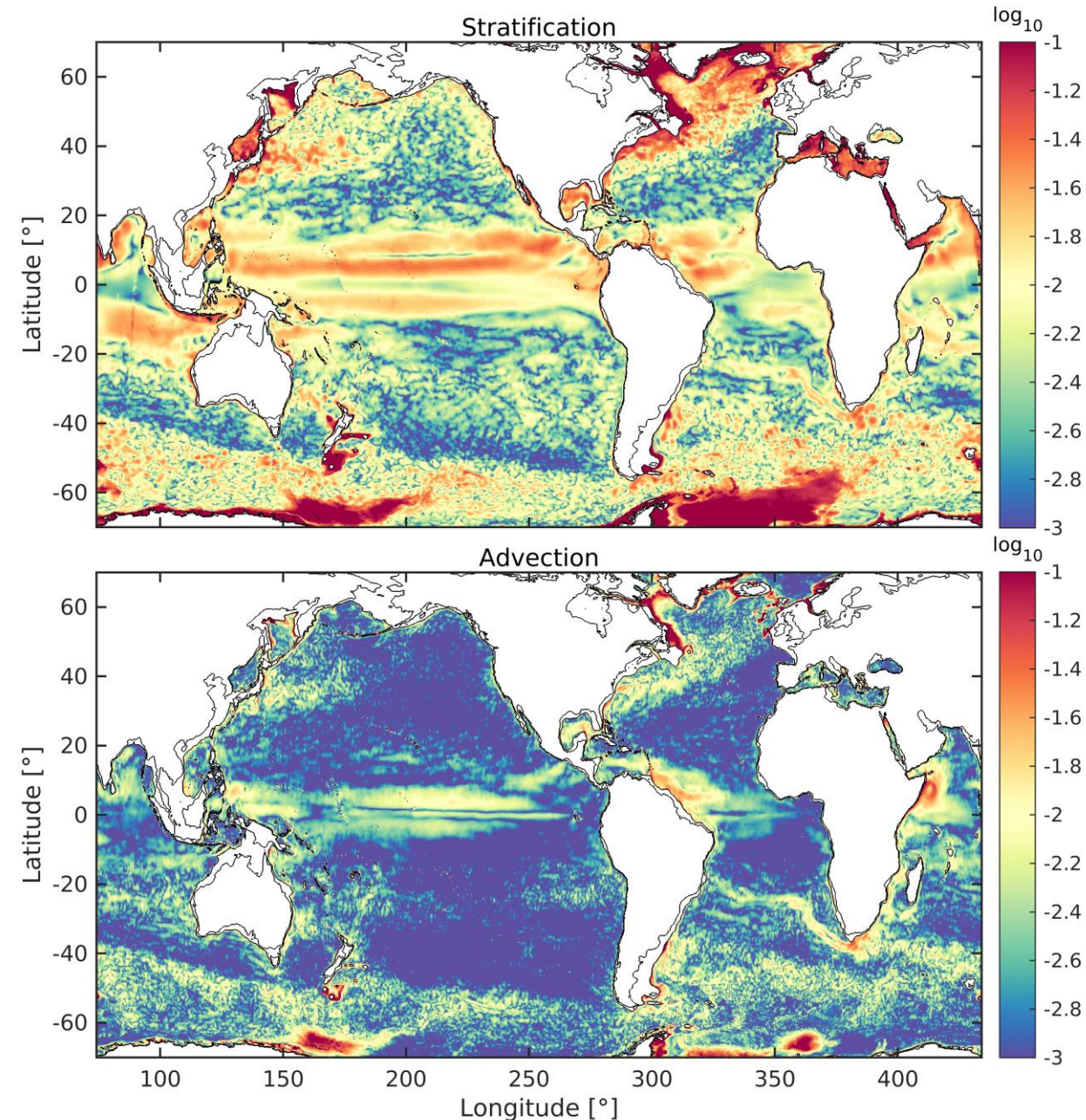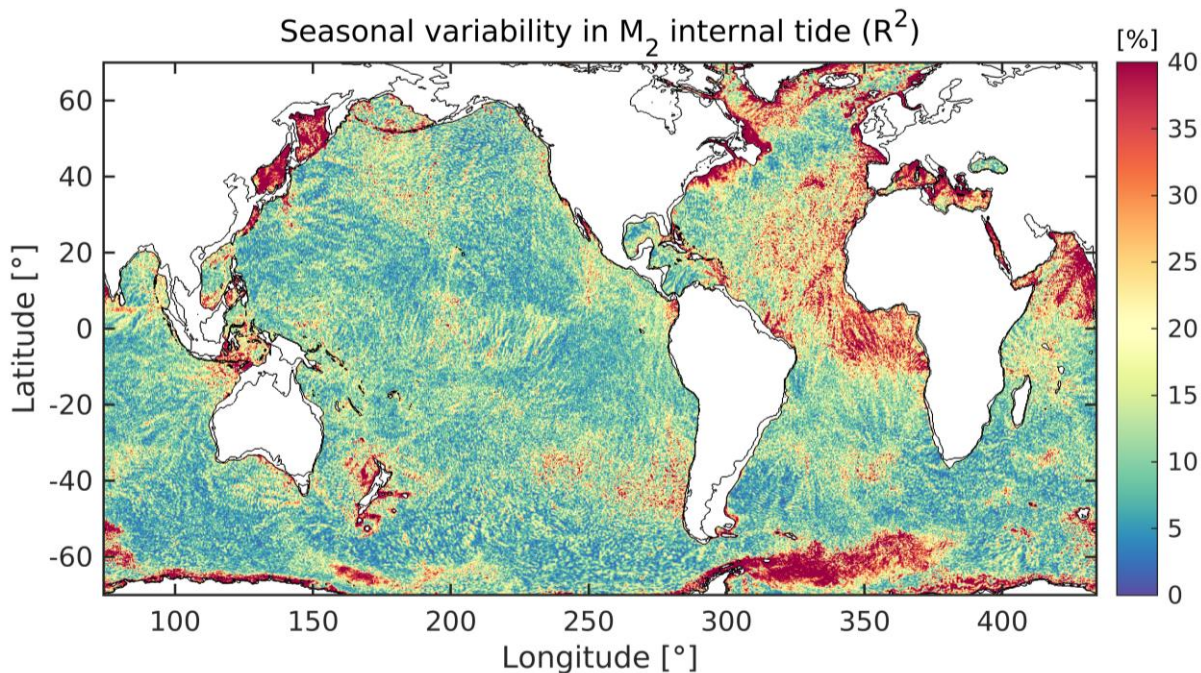
Summary

- Internal tides generated in the coastal regions, such as Georges Bank, Arabian Sea, and Amazon Shelf, show high seasonal variability in M_2 amplitude

- Our results show a good agreement in patterns with altimetry data for seasonal variability in stationary M_2 tides

- For the Georges Bank, seasonal variability is present at generation, and it is due to seasonality in stratification

- It is observed that seasonality in stratification is the dominant factor affecting seasonality in the propagating internal tide

Future work

- Further explore mechanisms responsible for seasonal variability in the generation and propagation of internal tides