

Towards the inclusion of sea-ice into a global tidal model

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Background

To study the effect of declining sea ice on tides, it is important to have accurate tidal models in the polar regions. Hydrodynamic global tidal models face challenges in the polar regions ($\pm 66^\circ$) (5). Interaction between sea ice and tides is one of the major sources of model errors. Most of the existing tidal models either ignore the presence of sea ice or assume stationary mean ice concentration fields (2). This approximation is not so accurate. Some tidal models are coupled to sea ice models to include the effect of sea ice on tides (eg. STORMTIDE; (3)). But for the case of global tidal models such a coupling significantly increases computation costs and complexity. Our aim is to include the effect of sea ice in our global hydrodynamic tidal model (Global tide and Storm Surge Model (GTSM) (7)). It is not possible to couple GTSM to a sea ice model, hence, we focus on studying the sea ice and tide interaction to model a more accurate influence of sea ice on tides.

Sea ice in a tidal model

Sea ice forms a layer between the ocean and atmosphere. This layer exerts a drag on the ocean surface (τ_{iw}) as seen in the graphic (Fig. 1). The drag essentially replaces the wind drag on the ocean. This physical interaction should be included in the governing hydrodynamic equations of GTSM.

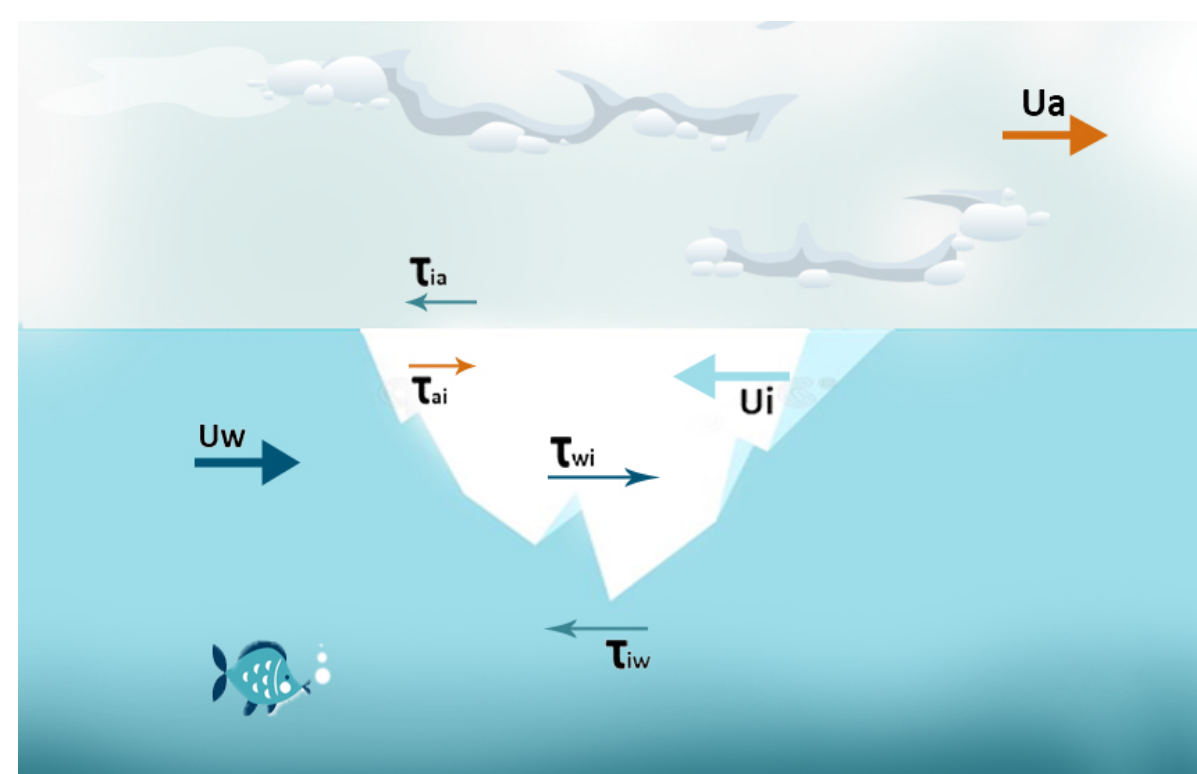


Figure 1: Graphic showing the forces in play for an air-ice-ocean model.

The equation for the drag between sea ice and ocean is given by:

$$\tau_{iw} = \rho_w C_w (\mathbf{u}_i - \mathbf{u}_w) |\mathbf{u}_i - \mathbf{u}_w|, \quad (1)$$

where ρ_w is the density of water, C_w is the ice-water drag coefficient, $\mathbf{u}_i$ is the sea ice velocity and $\mathbf{u}_w$ is the water velocity.

There is no readily available dataset which provides sea ice velocities on a tidal time scale to easily model this term in GTSM. The interaction between sea ice and tides is studied

to accurately model this term. We divide the sea ice cover into different regimes (landfast ice, free drift ice and ice drifting under strong internal stresses) and study the interaction of each regime separately. In this poster, the studies of only free drift sea ice and landfast ice are discussed.

Free drift sea ice

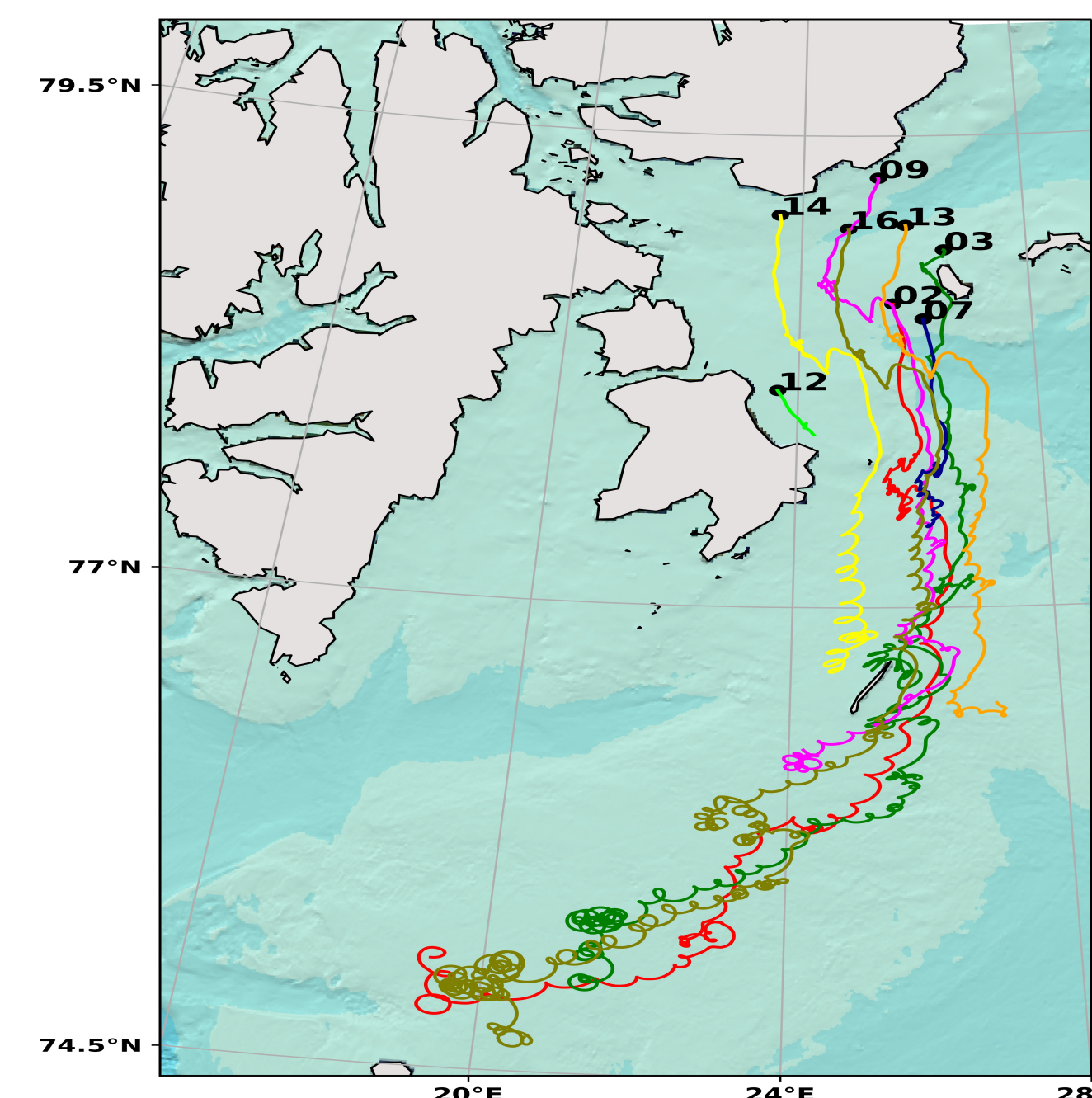


Figure 2: The trajectories of 8 buoys starting from March 16, 2014 with different end dates. The longest buoy was buoy 16 which transmitted data until May 15, 2014.

The interaction between free drifting sea ice and tides is studied with the help of drifting sea ice buoy dataset from an experiment conducted in the Barents Sea region (Fig.2). The buoys were on thin ice drifting freely and showed strong tidal and inertial oscillations while passing through the Spitsbergen shelf.

The velocities of these oscillations are seen to highly correlate with the tidal velocities (from GTSM) along the buoy trajectories (Fig. 3). The high correlation insinuates that the tides and sea ice tends to move together in this region.

Thus, it can be said that the dissipation between free drift sea ice and tides is not large and can be neglected while modelling the sea ice tidal drag in Equation (1). A publication of further detailed analysis is under process.

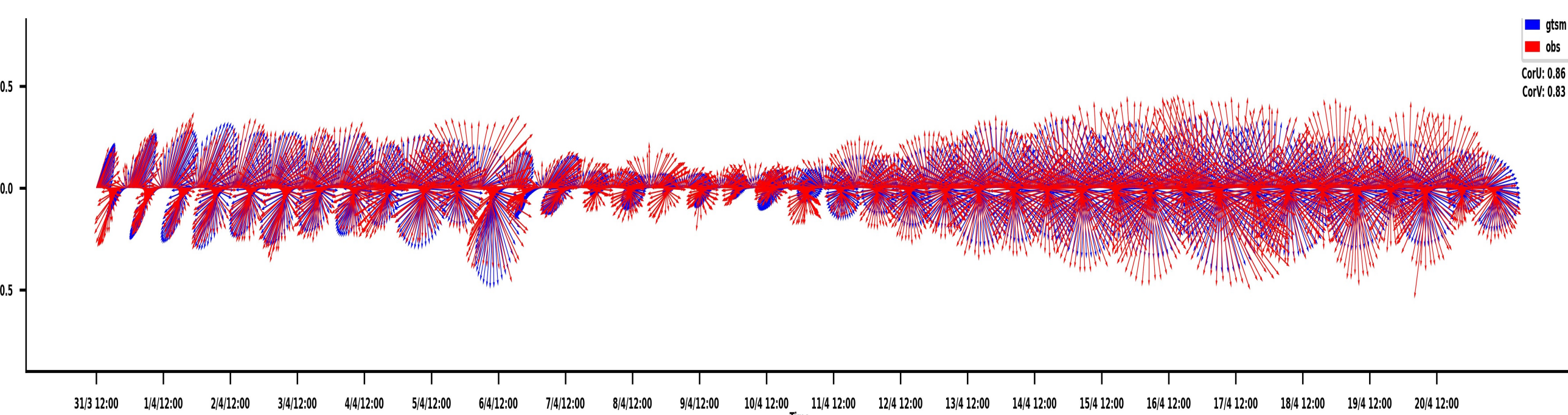


Figure 3: Velocity vector plots of a part of the time series of sea ice oscillations (observations) (red) and gtms derived velocities along the trajectory (blue) for buoy 16.

Landfast sea ice

For landfast sea ice, the sea ice velocity ($\mathbf{u}_i = 0$) and hence, the drag term (1) is straightforward. In a 2D model (like GTSM), this term is similar to frictional stress from the ocean bed but with a different drag coefficient. We implement this term in GTSM for a landfast ice cover for the year 2013. The year was chosen as it had the largest mean landfast ice

cover in the period from 2010-2019 (1). The simulations were performed and we computed the dominant M_2 amplitude and phase for the Arctic region and compared to the FES2014 dataset.

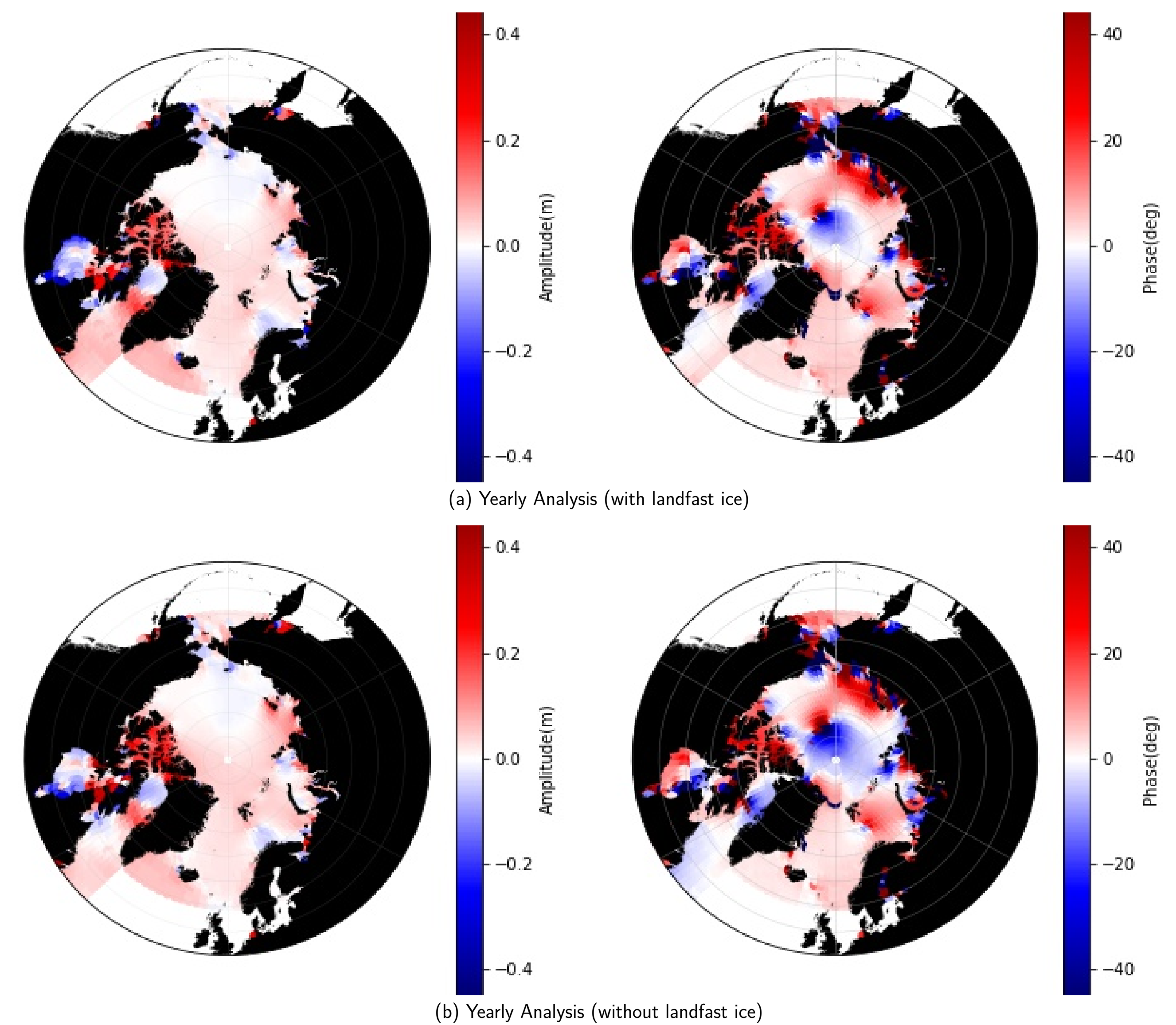


Figure 4: Plot of differences between the M_2 tidal amplitude and phase between model simulations and FES2014 for the Arctic region. A zero indicates no difference while a red (positive) indicates the model values are larger than FES2014. Vice versa for blue. The drag coefficient (C_w) was 2.5×10^{-3}

Figure 4 shows the differences in the M_2 amplitude and phase obtained from the model runs of GTSM with landfast ice (Fig. 4a) and without any ice (Fig.4b) compared to the FES2014 dataset. The tidal analysis to compute the amplitude and phases is done for the entire year of 2013 with monthly median landfast ice configurations obtained from (4). The landfast ice cover is majorly in the Canadian Archipelago and from the figures it is seen that including the landfast ice makes the model results less red (white indicates zero difference) in this region. The RMSE with respect to FES2014 results improves from 15.56cm to 14.28cm. A further analysis was done on the sensitivity towards drag coefficients.

Simulation	RMSE (cm)
Standard GTSM (without ice)	15.56
GTSM ($C_b=1.67e-03$; $C_w=5.5e-03$)	15.05
GTSM ($C_b=2.5e-03$; $C_w=2.5e-03$)	14.28

Figure 5: Graphic showing the forces in play for an air-ice-ocean model.

The two important parameters of simulation (C_b the drag coefficient of ocean bed frictional stress and the ice-water drag coefficient (C_w)) are studied for their sensitivity towards model results. The simulations using two different coefficients of drag (Fig. 5) show that the model results are sensitive to these parameters. To improve the model results further a calibration can be performed using data assimilation.

Future Work

The next step is to study the interaction between sea ice drifting under strong internal stresses and tides. Such a type of sea ice is moving hence, $\mathbf{u}_i \neq 0$ but, it is not clear if it moves with tides or not. This is because the internal stresses between sea ice floes are large which could cause a resistance to the sea ice movement with tides. So the interaction between such a sea ice and tides needs to be studied.

As a first step, we would follow the approach used by some models where such ice drifting under strong internal stresses is modelled as landfast ice only. Then, we will work our way up to find a more accurate solution by considering the underlying physics and momentum equation of sea ice.

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