# Towards understanding the impact of declining sea ice on tides

A.N. Vasulkar[@,*,†] M. Verlaan[*,†] C. Slobbe[‡]

[@]A.N.Vasulkar@tudelft.nl, [*]Delft Institute of Applied Mathematics, TU Delft, [†]Deltares, The Netherlands, [‡]Civil Engineering and Geo Sciences

## Background

The impact of Arctic sea ice decline on future global tides and storm surges is unknown. Regional studies, Overeem et al. (2011), Kowalik (1981), Kagan & Sofina (2010), have shown that the impact can be substantial (eg: increased erosion). Further, as the Arctic tides and surges impact North Sea water levels, the impact will also be noticed in the Dutch coastal waters and the Wadden Sea. The project titled, 'Forecast Arctic Surges and Tides for the Netherlands' (**FAST4NL**), focuses on evaluating this impact on the tides and surges over the entire Arctic ocean. The project overview is shown in figure 1.

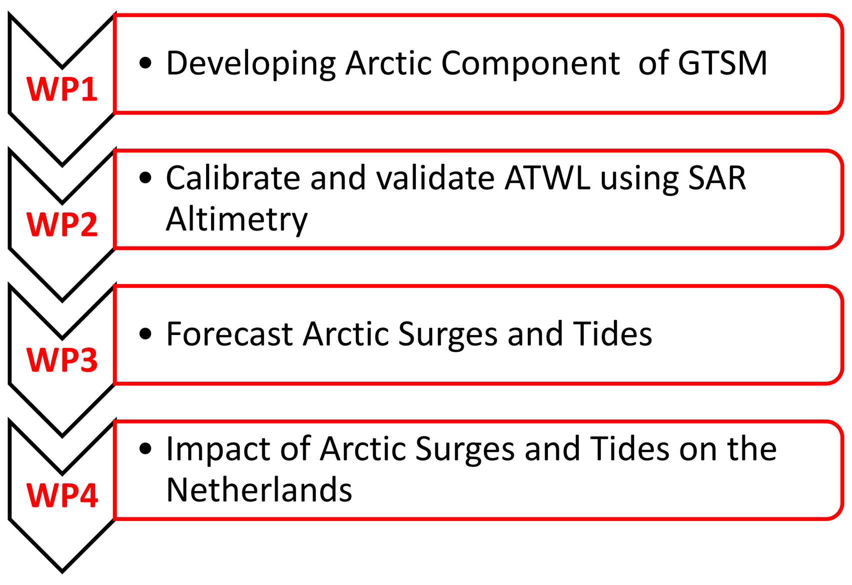


*Figure 1: Project milestones in terms of the work packages (WP)*

The project aims at developing a model referred to as the Arctic total water level (**ATWL**) to assess this impact by assimilating the observations from Sentinel-3 and CryoSat-2 along with the limited tide gauge data over the Arctic.

## Problem Description

The ATWL model will be developed as an extension of the Global Tide and Surge Model (**GTSM**), Verlaan et al. (2015), which is built upon the Delft3D-FM unstructured mesh code. Currently, the GTSM does not incorporate the effect of sea ice cover on tides. The graphic (2) illustrates the air-ice-ocean interactions.

*Figure 2: Graphic showing the forces in play for an air-ice-ocean model.*

Graphic 2 shows that the presence of ice adds a dissipative frictional force to the ocean. Thus, the governing equations of the GTSM should have this additional force.

$$\frac{\partial h}{\partial t} + \nabla\cdot(hu) = 0, \tag{1}$$

$$\frac{\partial u}{\partial t} + f \times u + \frac{1}{h}(\nabla\cdot(huu) - u\nabla\cdot(hu)) = -g\nabla(\zeta) + \nabla\cdot(\nu(\nabla u + \nabla u^T)) + \frac{\tau_b}{h} + \frac{\tau_{IT}}{h} + \frac{\tau_a}{h} + \frac{\lambda\tau_{iw}}{h}, \tag{2}$$

where $\tau_{iw} = \rho_i R_i||u_i - u||(u_i - u)$. The aim is to have a **rough estimate** of the impact of $\tau_{iw}$ on M2 tides due to the presence of *landfast* ice ($u_i = 0$). This will enable to judge the significance of the term and it's use in further modelling of the ATWL.

## Approach

The GTSM is extended by adding the dissipative term ($\tau_{iw}$) under following assumptions as per Cancet et al., 2016:

- The coefficient of friction ($R_i$) is assumed to be equal to $1.65 \times 10^{-3}$. This is the same as the bottom friction coefficient.
- Two configurations of ice cover are considered,
  - **Winter configuration**, based on median extent of March, 2014.
  - **Summer configuration**, based on median extent of September 2014.

Under the above assumptions, we perform our first experiment to see the potential effect.

## Results & Discussion

The results from the original GTSM (without ice) and the extended version are compared by computing the differences in amplitudes of the M2 tidal wave.

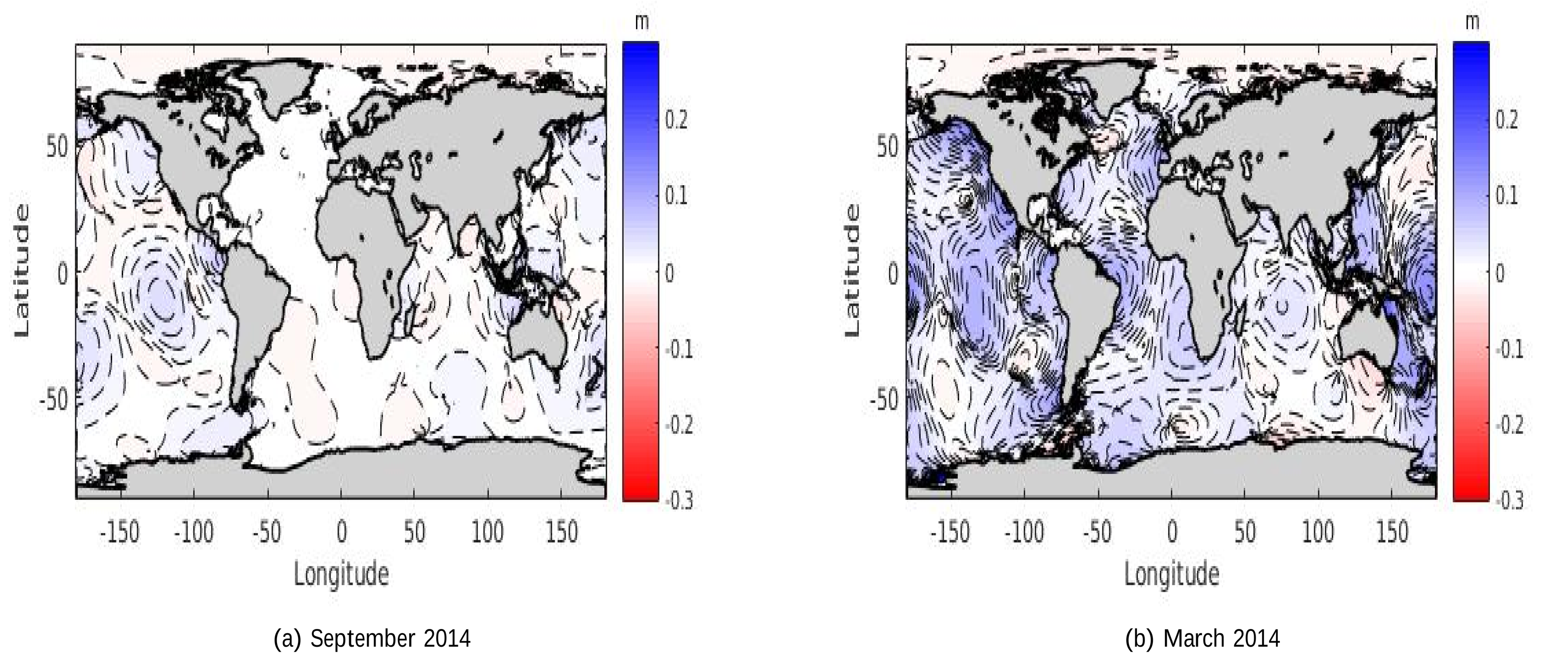


*Figure 3: Contour plot of the differences in the amplitude of M2 tide due to the additional dissipative ice-water friction term.*

Figure 3 shows that the effect of the ice cover on tides is distributed over the world with certain regions having significant effects ( **50cm**). The differences are larger in the winter than in the summer implying that a larger ice cover has more effect on tides. This shows that dissipative term $\tau_{iw}$ indeed has an effect on tides.

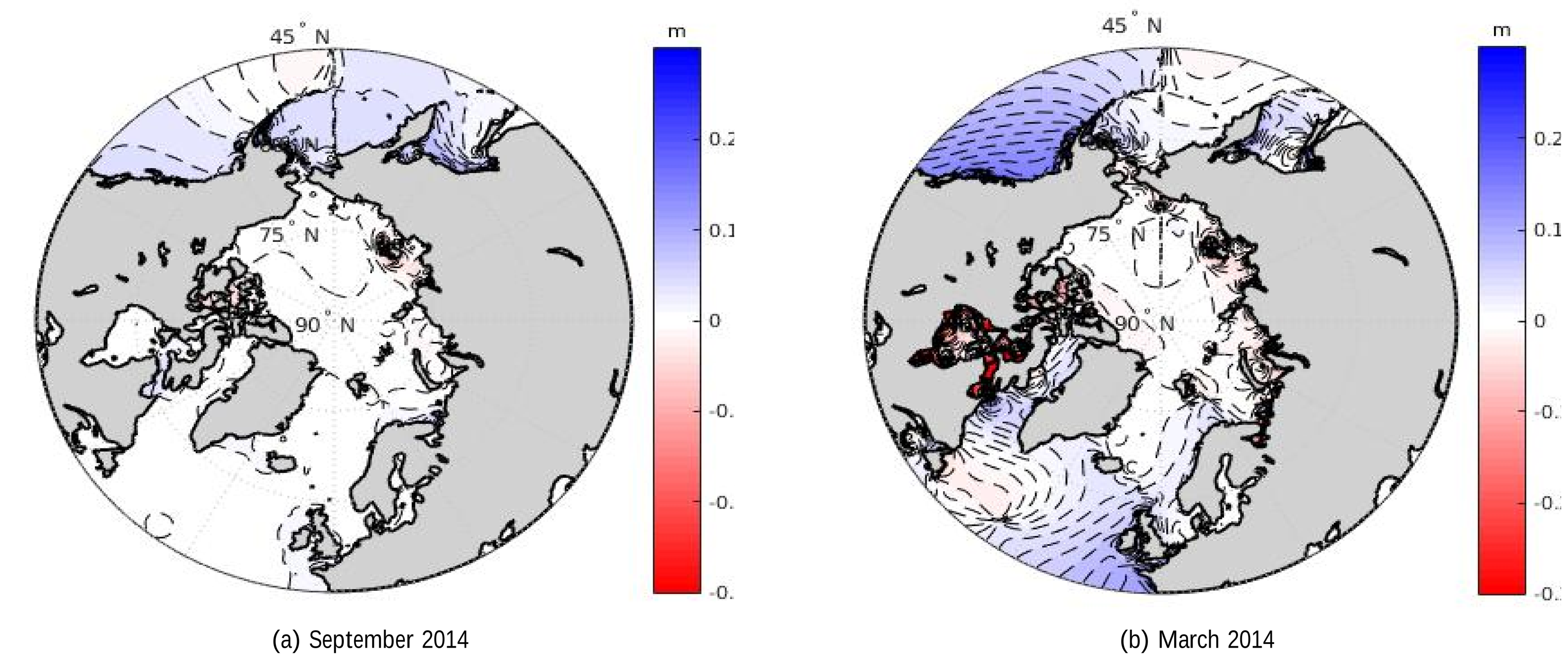


*Figure 4: Polar contour plot of the differences in the amplitude of M2 tide due to the additional dissipative ice-water friction term.*

Figure 4 is a polar plot which shows that the term has a significant effect in some regions over the Arctic, like the Canadian Archipelago, Siberian shelf and east of Japan. Further, the winter configuration shows that the North Sea tidal amplitudes show a difference of around **10cm** which corroborates the importance of the use of the dissipative term $\tau_{iw}$ in the modelling of ATWL.

## Conclusion & Future Work

The above results are highly dependent on the coefficient of friction $R_i$. So, even though the above experiment shows a significant impact of the dissipative term on the tides, the analysis is **preliminary** as we have considered a constant value of the friction coefficient $R_i$. In reality, this coefficient varies in space and time with some places having much lower or higher value. In future, towards achieving a more realistic tidal simulation we would like to proceed with the following.

- A **better estimate** of the ice-water friction coefficient ($R_i$). Preferably, a real time estimate with the changing sea ice cover.
- A treatment for **drifting ice** ($u_i \neq 0$) and the incorporation of the same in the ice-water friction term ($\tau_{iw}$).

These steps will help towards completing the first work package of the FAST4NL project; developing the ATWL model for further calibration using the SAR altimetry data.

### Acknowledgement

This work is part of the research programme FAST4NL with project number (ALWPP.2017.001), which is (partly) financed by the Dutch Research Council (NWO).

### References

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