ARKTALAS Science Workshop

Impact of the sea ice on the ocean tides in the Arctic Ocean

Mathilde Cancet (Noveltis), Florent Lyard (LEGOS), Ergane Fouchet (Noveltis)

Status of paper 6

UNIS, Longyearbyen, Spitsbergen

Wednesday 27 April 2022

Context

- **Aim of the study**
  - › **Decreasing / thinning of the sea ice cover in the Arctic Ocean over the years**

    → **Modification of the friction at the top of the water column**

  - › **Analyze the interaction between the tides and the sea ice cover using hydrodynamic simulations.**

    - Sensitivity study of the parameterization of the sea ice cover friction at the top of the water column.
    - Before testing the parameterization of the sea ice cover friction, some improvements to the "no-ice" model configuration

Model configuration

TUGO-m 2D hydrodynamic model, developed at LEGOS

- Model used to produce the FES2004, FES2014 and soon-to-come FES2022 global tidal atlases

- **Spectral mode:** solves each tidal component in the frequency domain
- **Time-stepping mode:** simulation of the water elevation + tidal harmonic analysis of the time series

- **Ice friction – several possibilities:**
  - Multiplying factor of the BF value in polygons/raster map (*New!*) defining the ice extent
  - Friction proportional to the sea ice concentration (*New!*)

Regional modelling

- **Model configuration**
  - **Validation datasets (no-ice configuration)**
    - **Tide gauge** tidal harmonic constituents (amplitude and phase lag):
      - Computed from time series over different periods (from the 1940 to the 2020s), depending on availability
      - Extracted from databases/publications (time series generally not available at high frequency)
    - **CryoSat-2** tidal harmonic constituents computed:
      - From GOP Baseline C products (LRM, SAR and SARin modes)
      - In bins of 1° x 1°
      - Over 2010-2020

Regional modelling

• Model configuration

› Starting from the Arctide2017 configuration (Cancet et al., 2018)

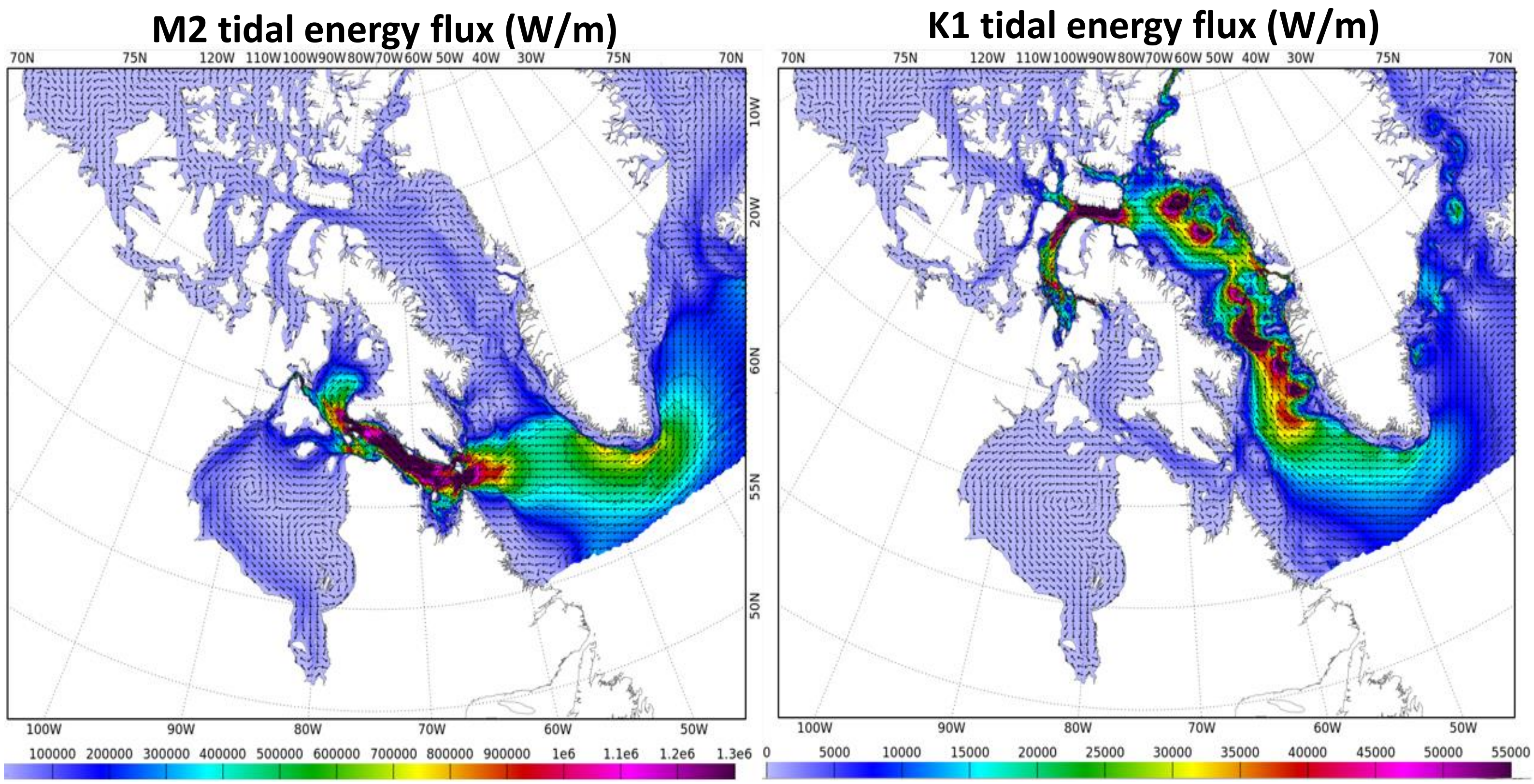
- **High resolution unstructured grid** in the Arctic Ocean
  - Coast: 4 - 7 km with higher resolution locally
  - Offshore: 8 - 30 km

- **Mesh improvements:**
  - **Integration of the Hudson Bay in the model domain:** strong improvement of the ocean tide solution in the Baffin Bay
  - **Extension of the model domain:** South of Iceland and in the Bering Strait (including the Anchorage Bay), to avoid model instabilities over steep bathymetry gradients

- **Bathymetry improvements:** integration of more recent datasets and local patches (BedMachine, GEBCO-2020, NOAA data,…)

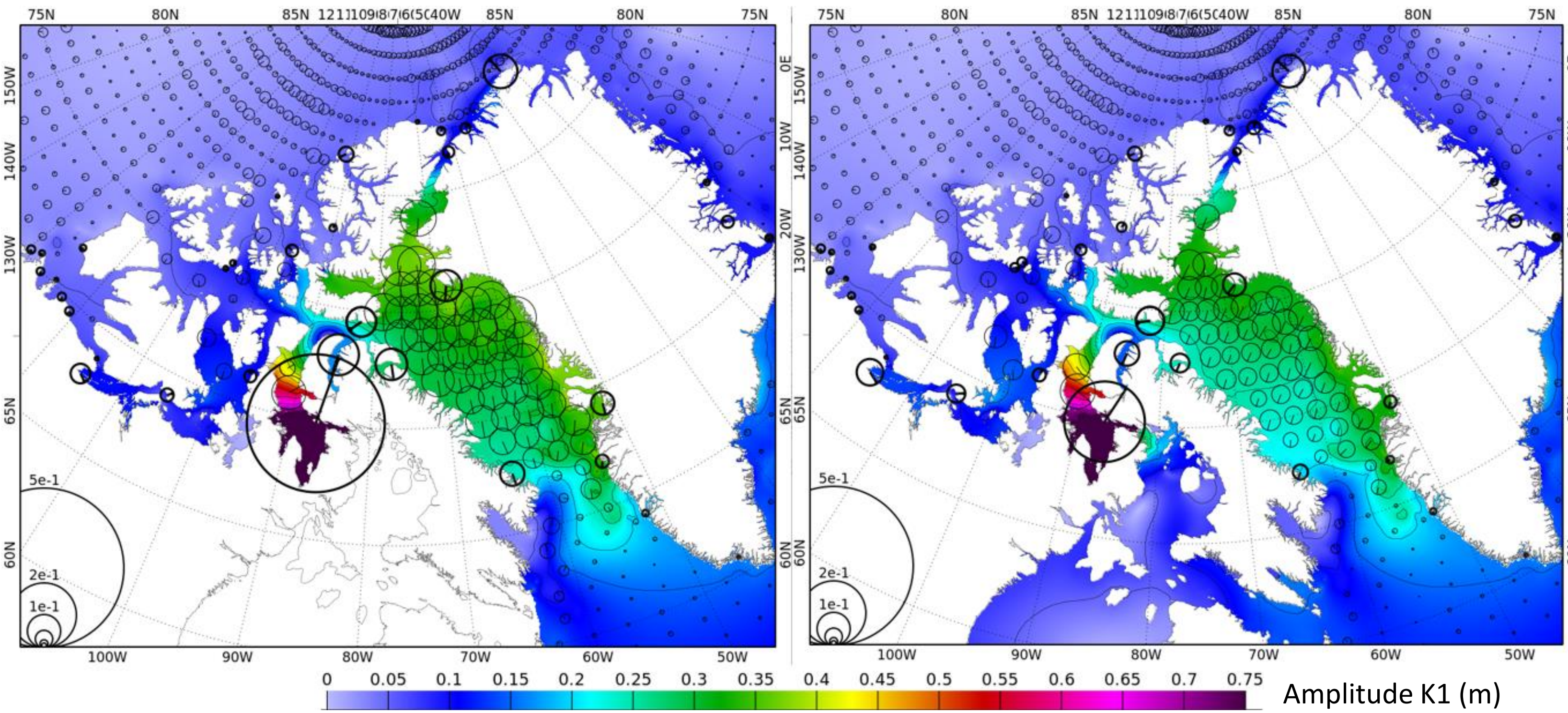
• Model configuration

› **Integration of the Hudson Bay in the model extent**



Regional modelling

- **Model configuration**
  - **Integration of the Hudson Bay in the model extent:** major positive impact on the solution, especially on the diurnal waves (K1).
    - Reduction of the K1 error by 20% relative to CryoSat-2 altimetry data
    - Reduction of the K1 error by 30% relative to Arctic tide gauges



Regional modelling

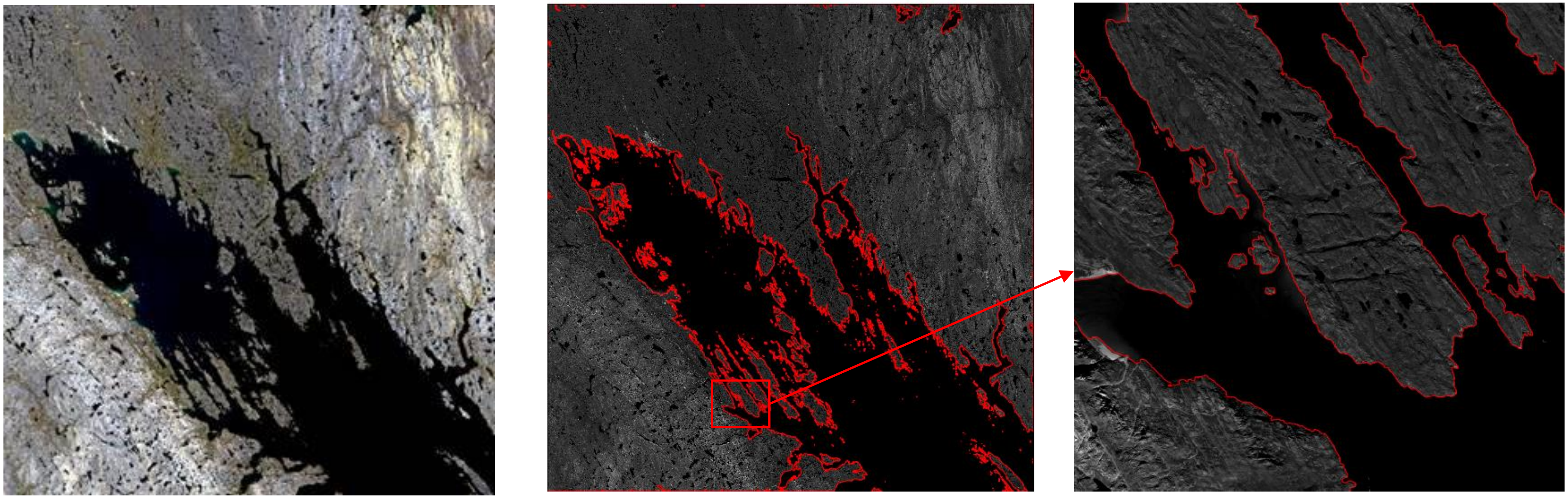
- ## Model configuration
  - **Starting from the Arctide2017 configuration (Cancet et al., 2018)**
    - **Coastline local improvements:** some local shifts of several 100s of meters (up to 1-2 km) detected in the GSHHS-v3.2.7 coastline, used as mesh limit

• Model configuration

› **Starting from the Arctide2017 configuration (Cancet et al., 2018)**

- **Coastline local improvements:** some shifts of several 100s meters (up to 1-2 km) detected in the GSHHS-v3.2.7 coastline, used as mesh limit

→ Use of Sentinel-2 images to determine a more accurate coastline information (need to have information about tidal elevation at the time of the S2 images)



Regional modelling

- Sea ice friction
    - In general, the bottom and sea ice frictions depend of the velocity

$$\text{Friction} = f(\langle U \rangle \times U)$$

    - In spectral mode

$$\text{Friction(wave)} = f(\langle U(\text{all waves}) \rangle \times U(\text{wave}))$$

In most regions, M2 dominates:

$$\text{Friction(M2)} = f(\langle U(\text{M2}) \rangle \times U(\text{M2}))$$

$$\text{Friction(K1)} = f(\langle U(\text{M2}) \rangle \times U(\text{K1}))$$

→ M2 more sensitive to the friction tuning (varies in U^2) than the other waves (linear)

Sea ice friction

› **Multiplying factor of the BF value in polygons defining the sea ice extent**

- 1980-2010 median sea ice cover extent from NSIDC, for March and September
- Sensitivity study considering various multiplying coefficient values (2, 3, 4, and 5)

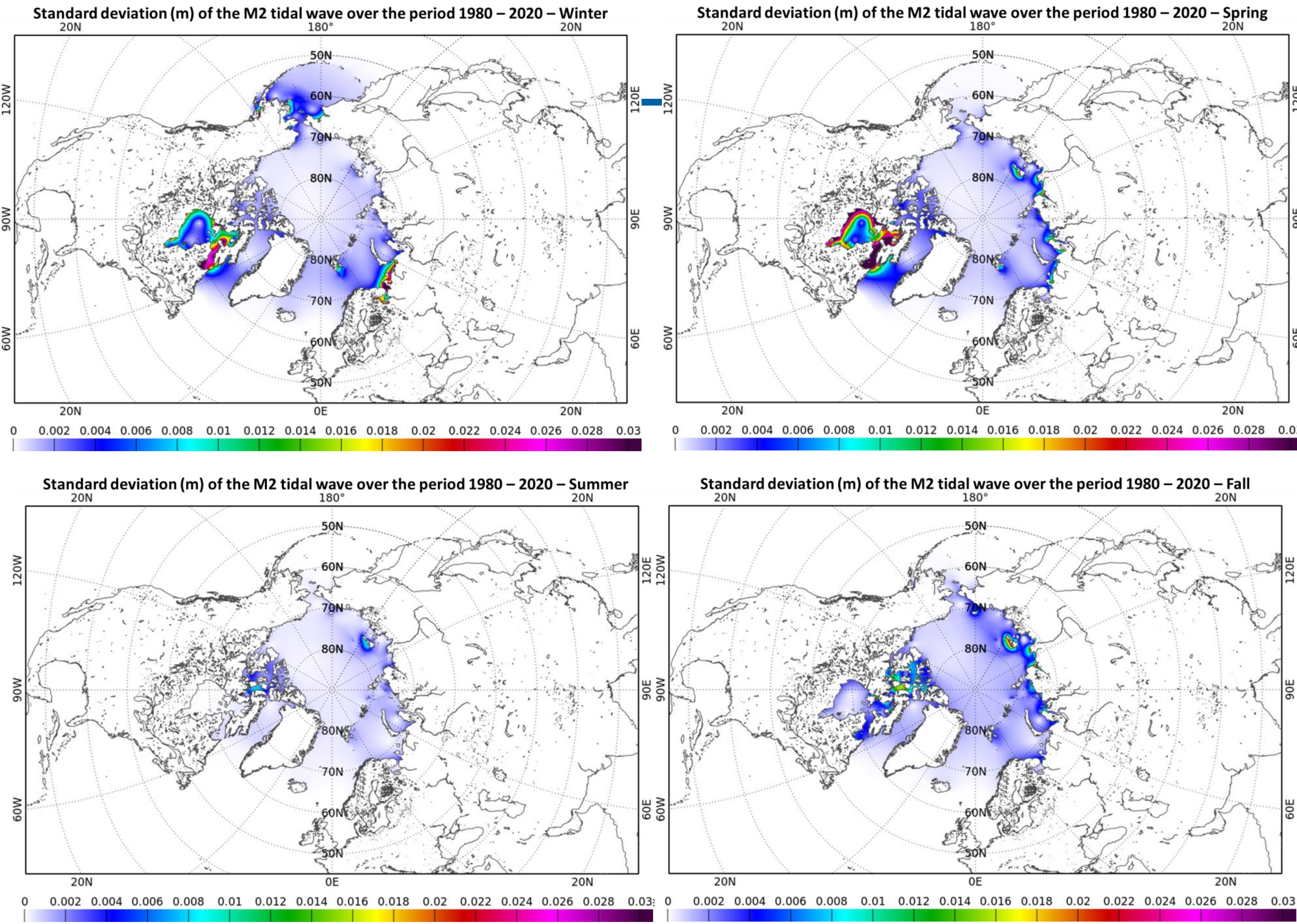
› **Friction proportional to the sea ice concentration**

- Seasonal sea ice cover based on NSIDC monthly sea ice concentration
- Threshold set to 70% of sea ice concentration

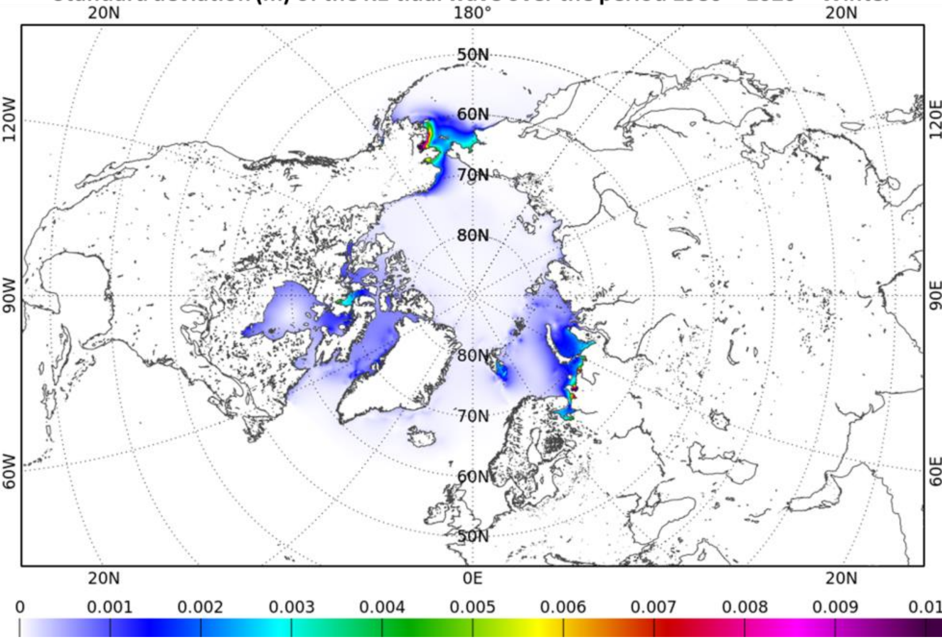
→***Assumption:*** *if sea ice is dense to a certain point, it can be considered fixed, and thus induces friction, contrary to less dense ice that moves with the tides.*

- Simulations every year over 1980-2020, for each season

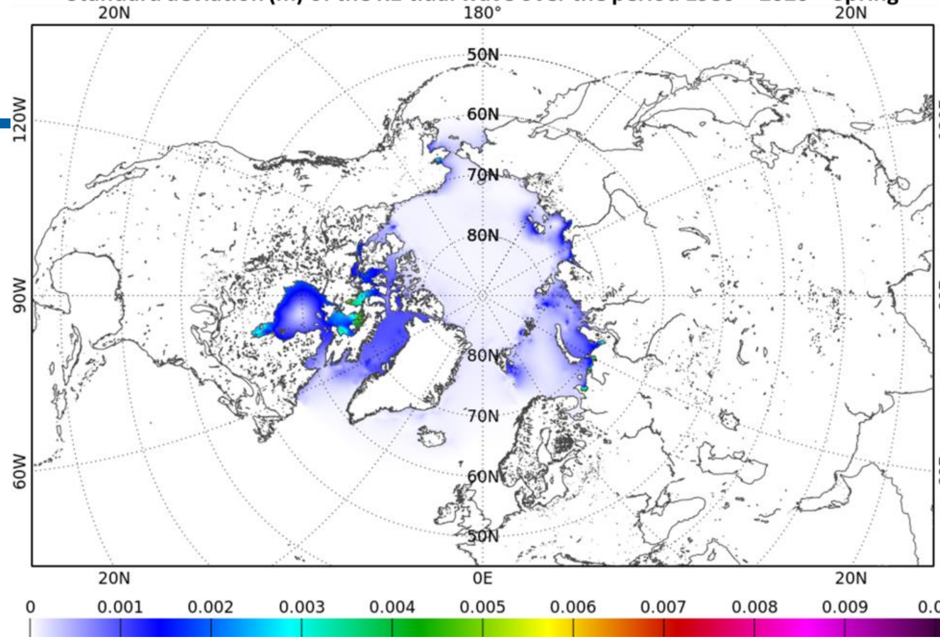
➔ **Standard deviation of the M2 and K1 waves for each season over 40 years**


Standard deviation (m) of the M2 tidal wave over the period 1980 – 2020 – Winter
Standard deviation (m) of the M2 tidal wave over the period 1980 – 2020 – Spring
Standard deviation (m) of the M2 tidal wave over the period 1980 – 2020 – Summer
Standard deviation (m) of the M2 tidal wave over the period 1980 – 2020 – Fall
180°
20N
0E
120W
90W
60W
120E
90E
60E
50N
60N
70N
80N
0 0.002 0.004 0.006 0.008 0.01 0.012 0.014 0.016 0.018 0.02 0.022 0.024 0.026 0.028 0.03

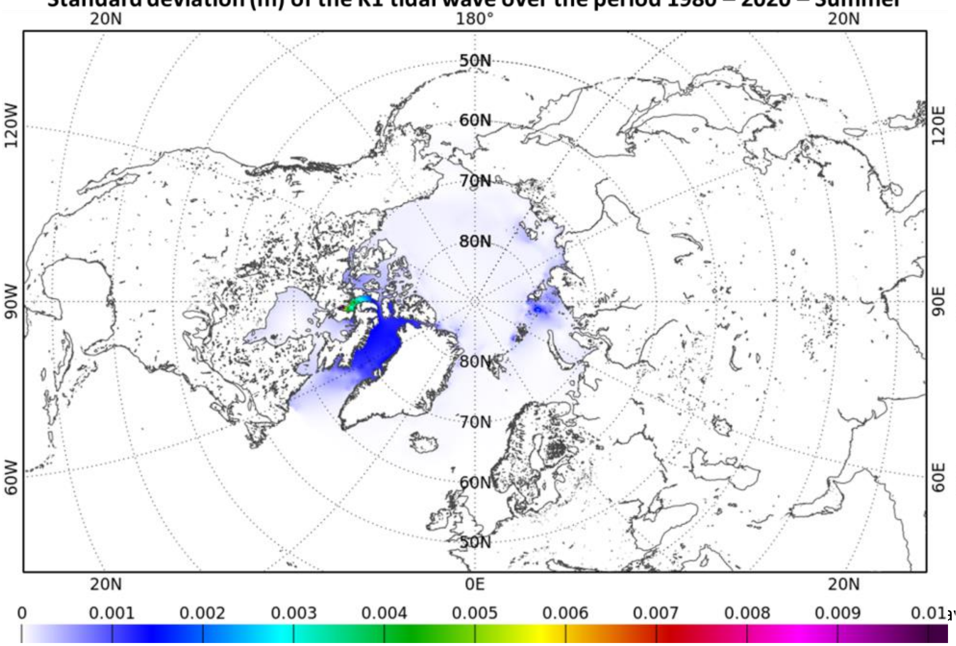
Standard deviation (m) of the K1 tidal wave over the period 1980 – 2020 – Winter



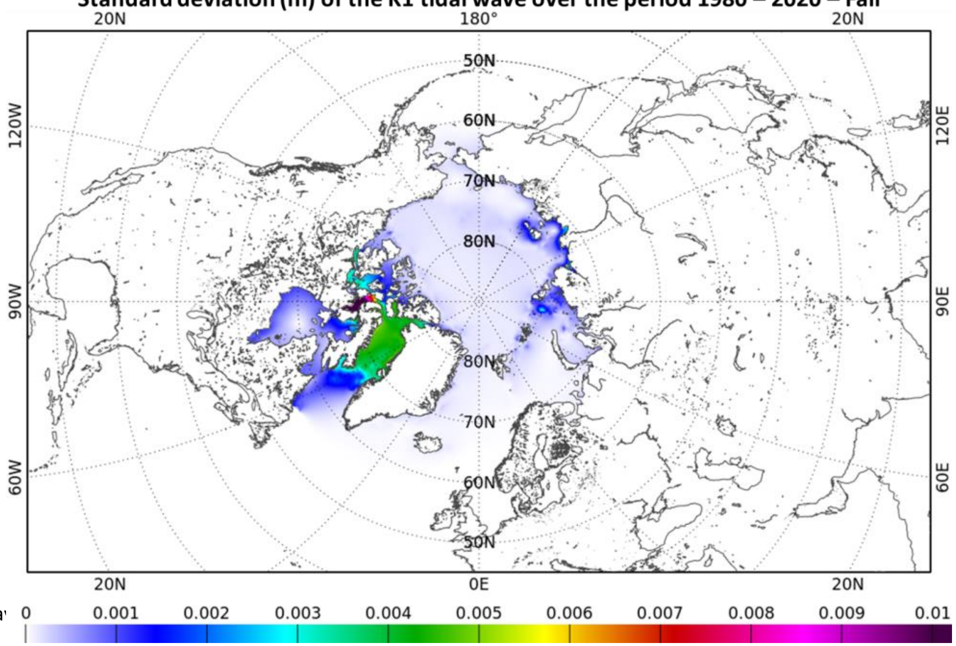
Standard deviation (m) of the K1 tidal wave over the period 1980 – 2020 – Spring



Standard deviation (m) of the K1 tidal wave over the period 1980 – 2020 – Summer



Standard deviation (m) of the K1 tidal wave over the period 1980 – 2020 – Fall



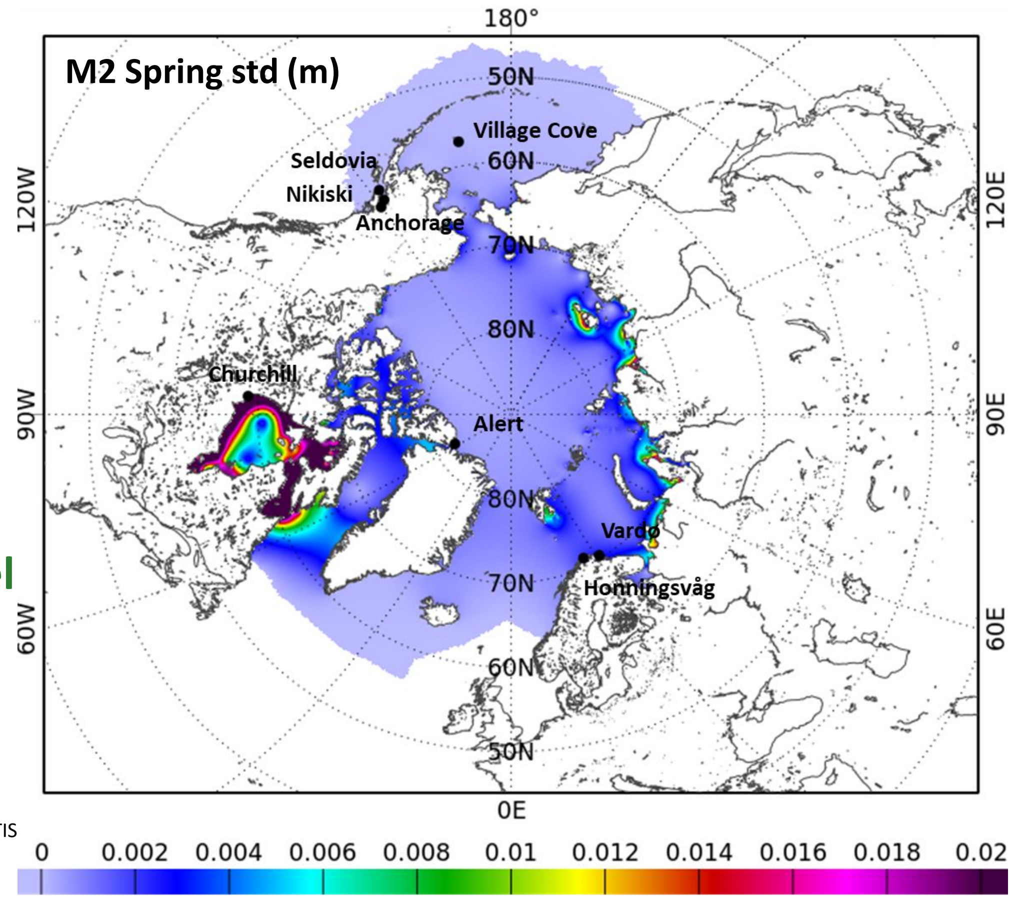
In situ observations

- **Selection of tide gauge stations**
  - Hourly data from GESLAv3 (released Nov. 2021) and UHSLC databases
  - Long time series covering 1980-2020 (quite rare)
  - Located in areas where the model shows some long-term variability

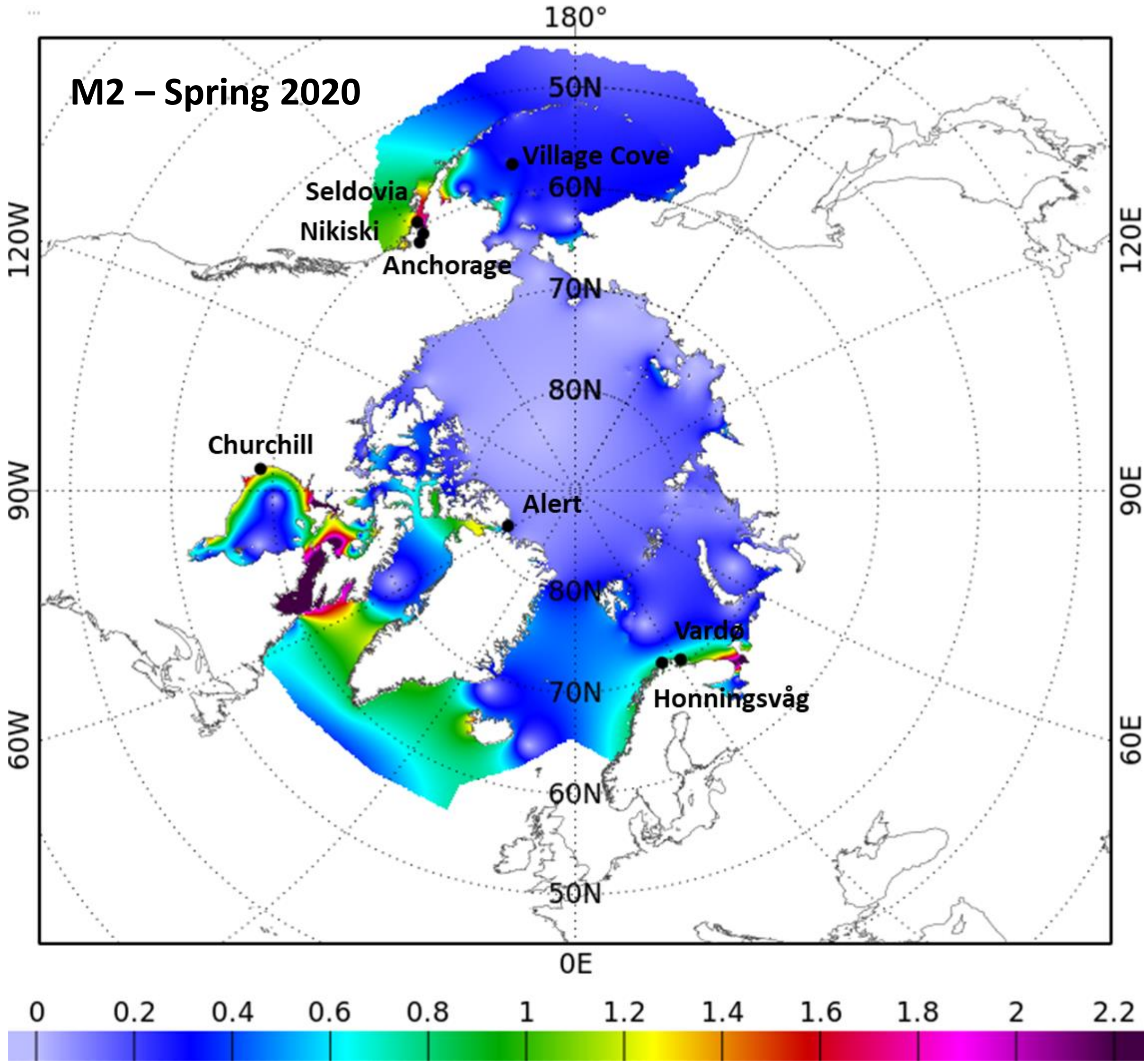
➔ **8 stations, some with gaps**

- **Data processing**
  - Split of the time series in 3-month subsets
  - Harmonic analysis on each subset to retrieve seasonal tidal estimates

➔ **Comparison with the model seasonal tidal estimates**

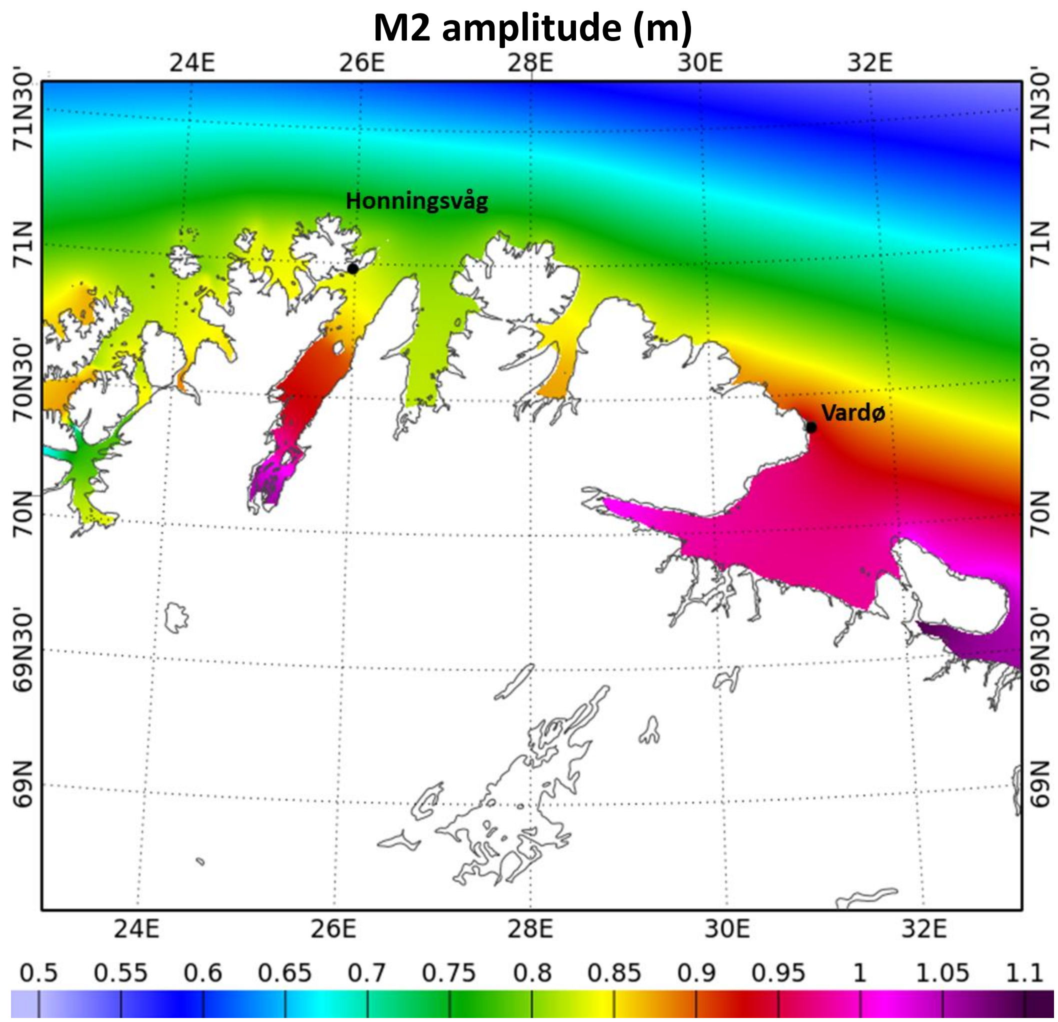


In situ observations



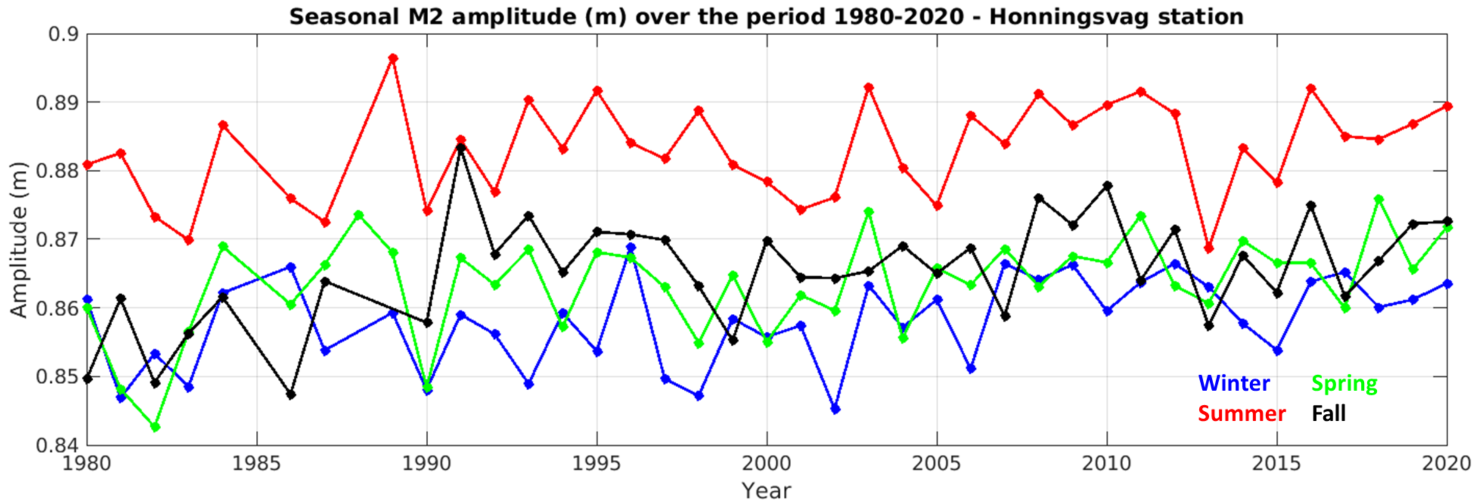
Comparisons model vs TG

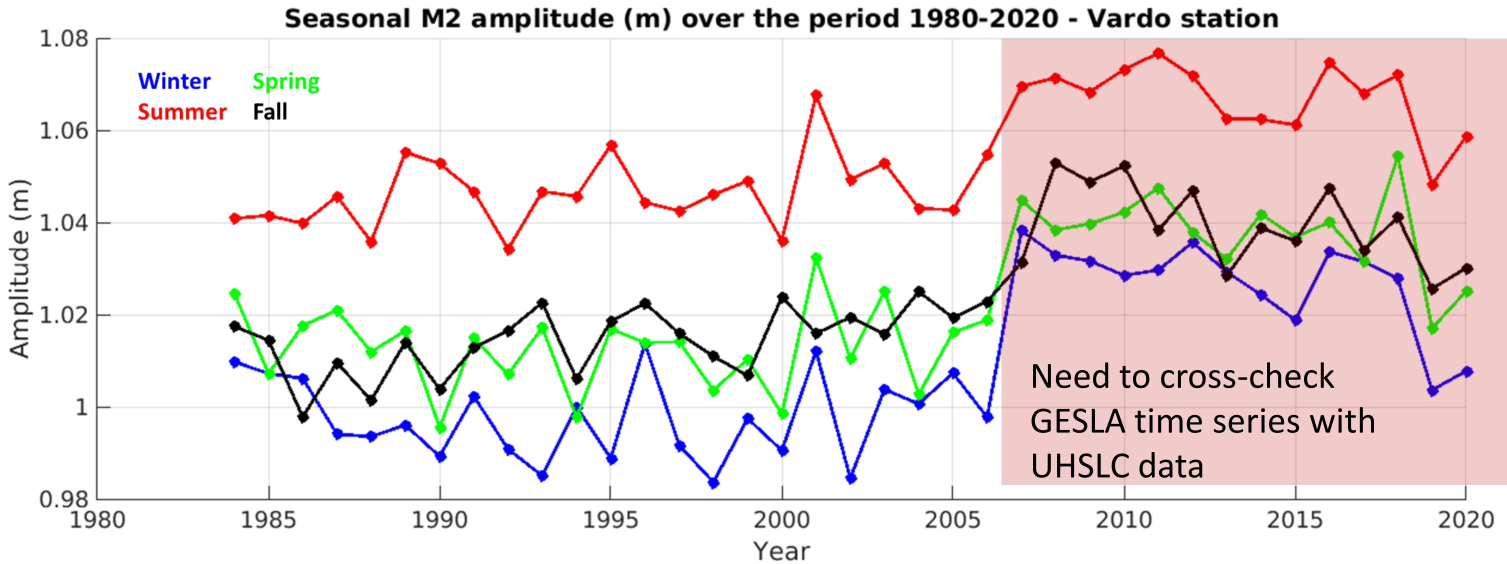
- **Northern Norway**
  - Two TG stations, relatively close
  - No sea ice



Comparisons model vs TG

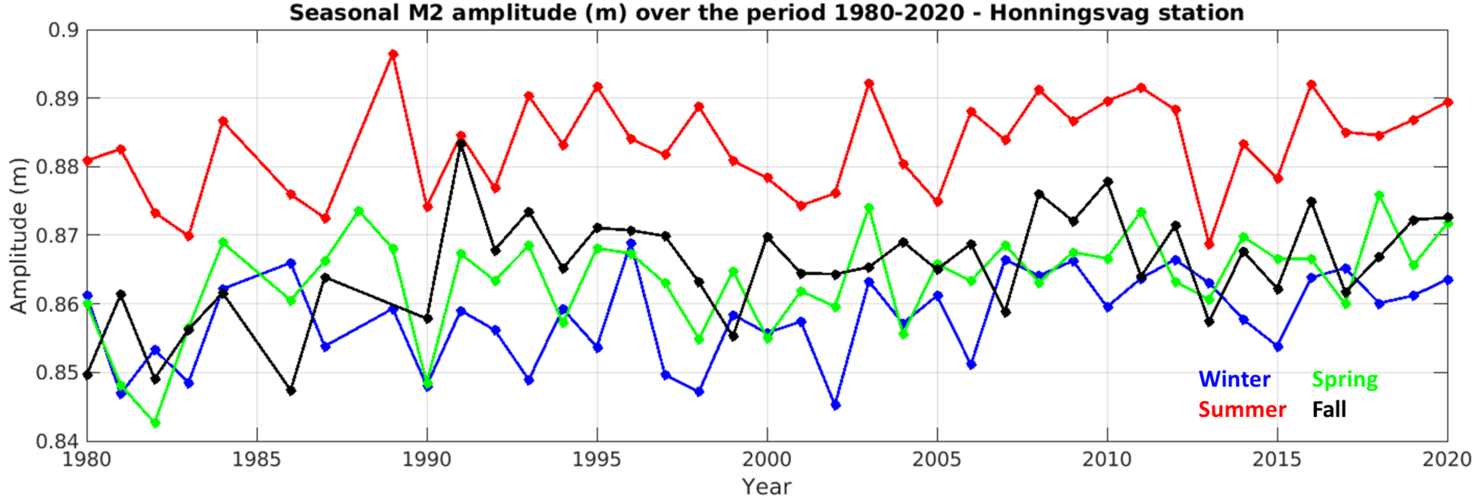
- **Northern Norway**

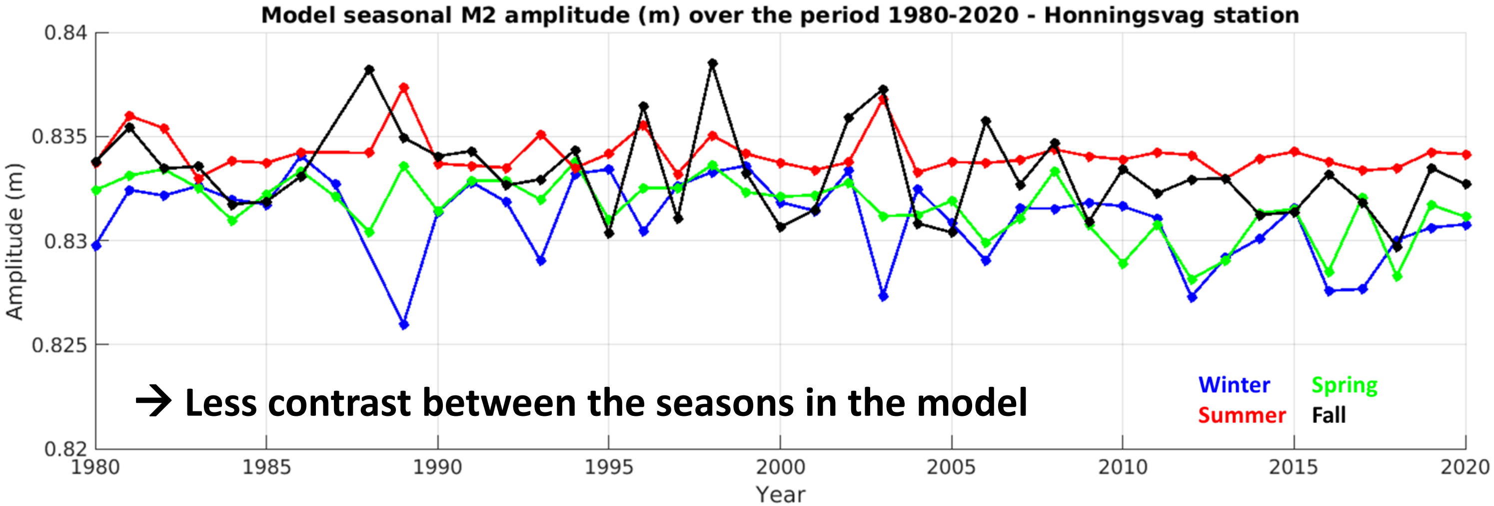




Comparisons model vs TG

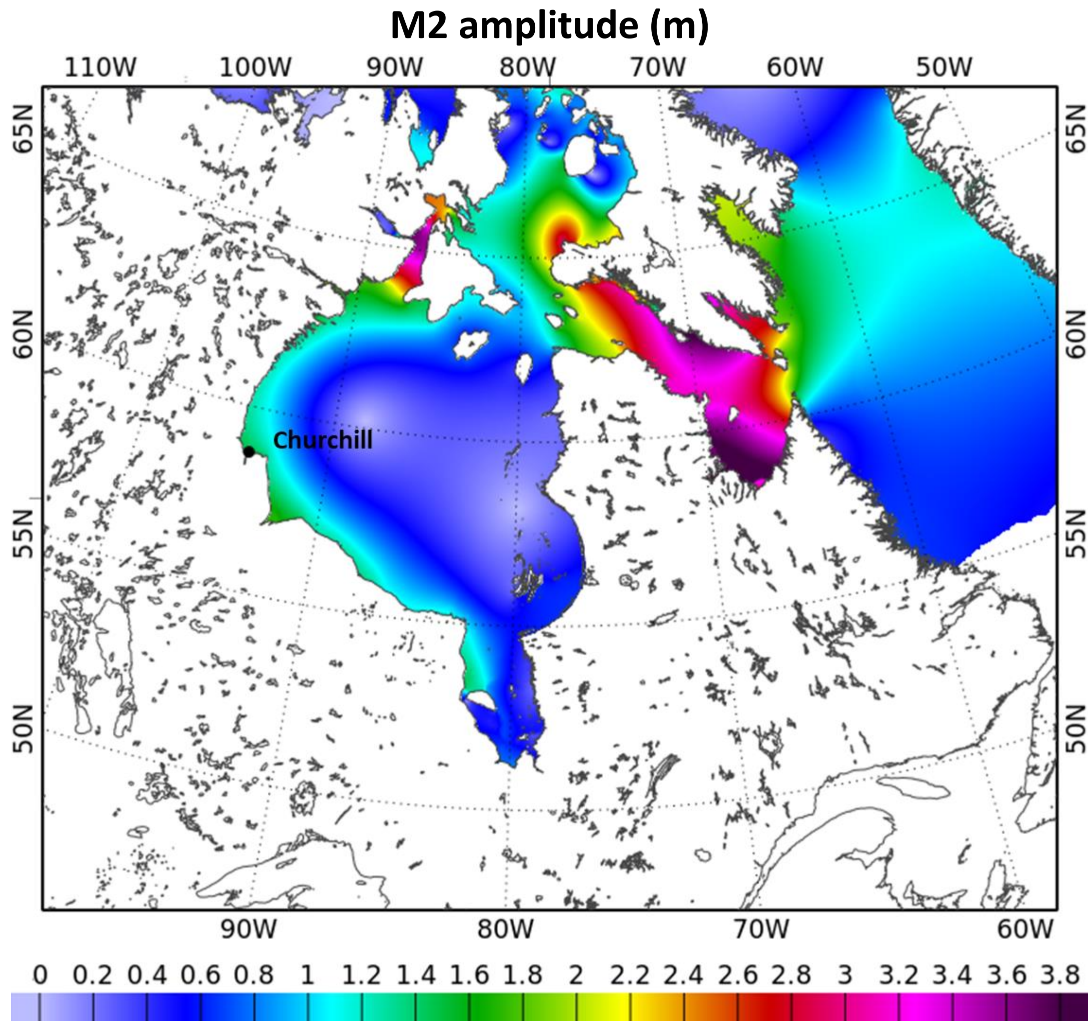
- **Northern Norway**





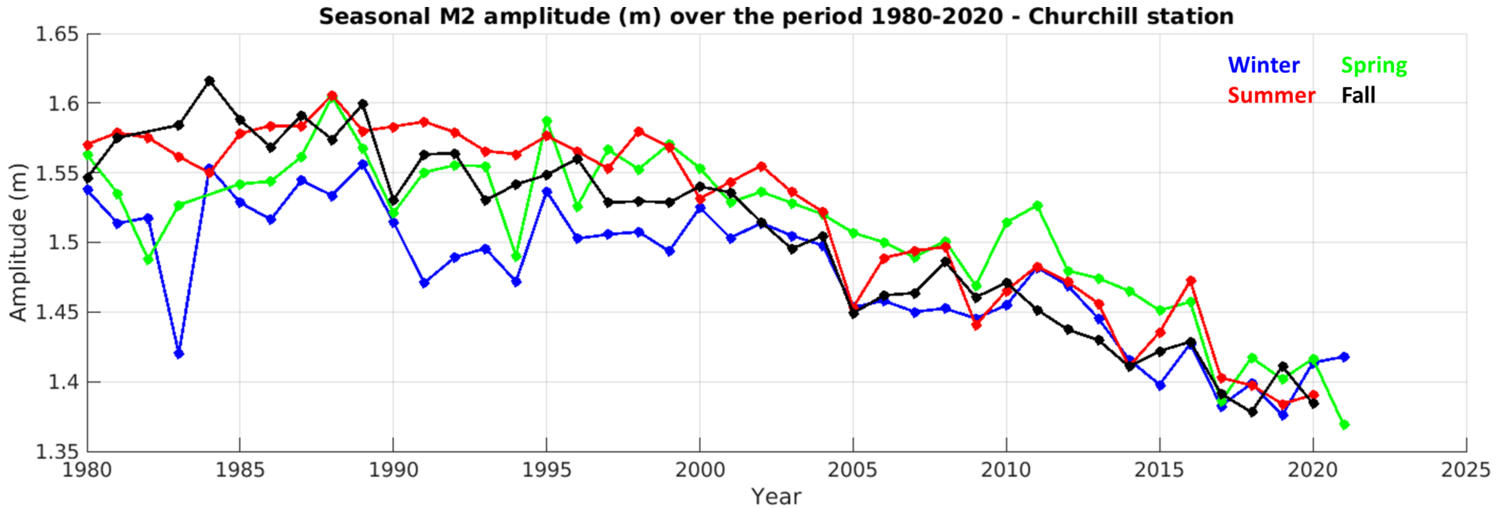
Comparisons model vs TG

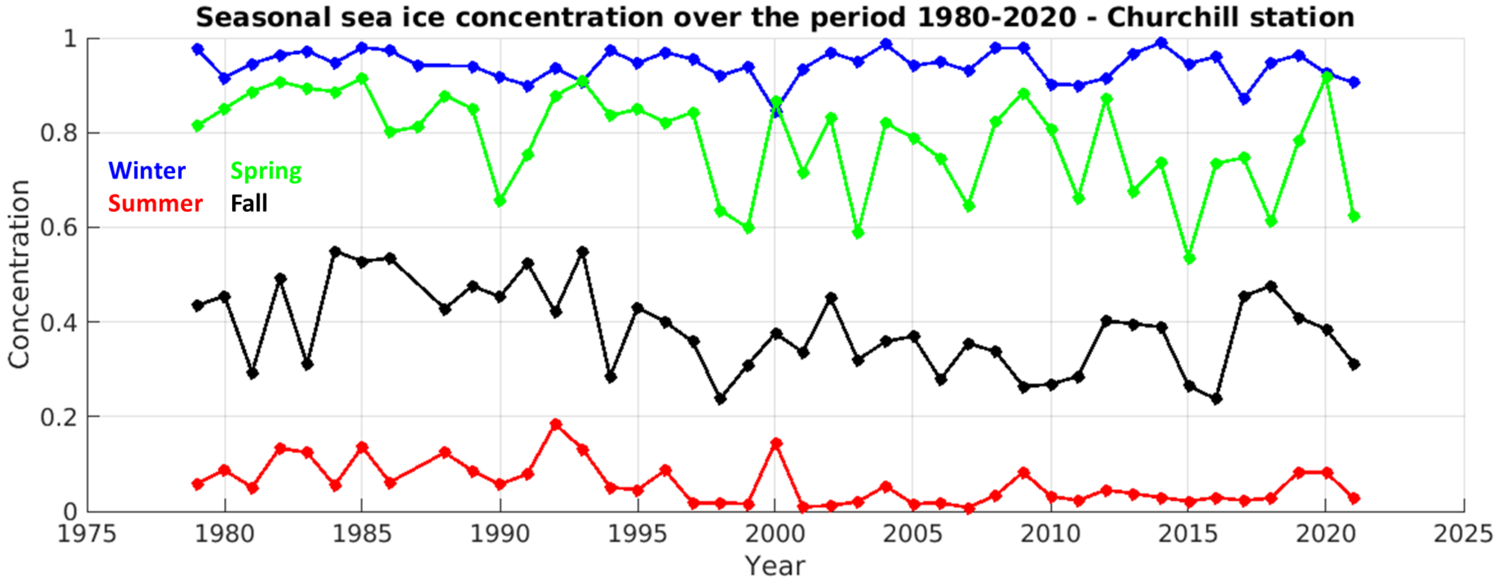
- **Hudson Bay**
  - Only 1 TG station with a long time series
  - Estuarine area
  - Seasonal presence of sea ice



Comparisons model vs TG

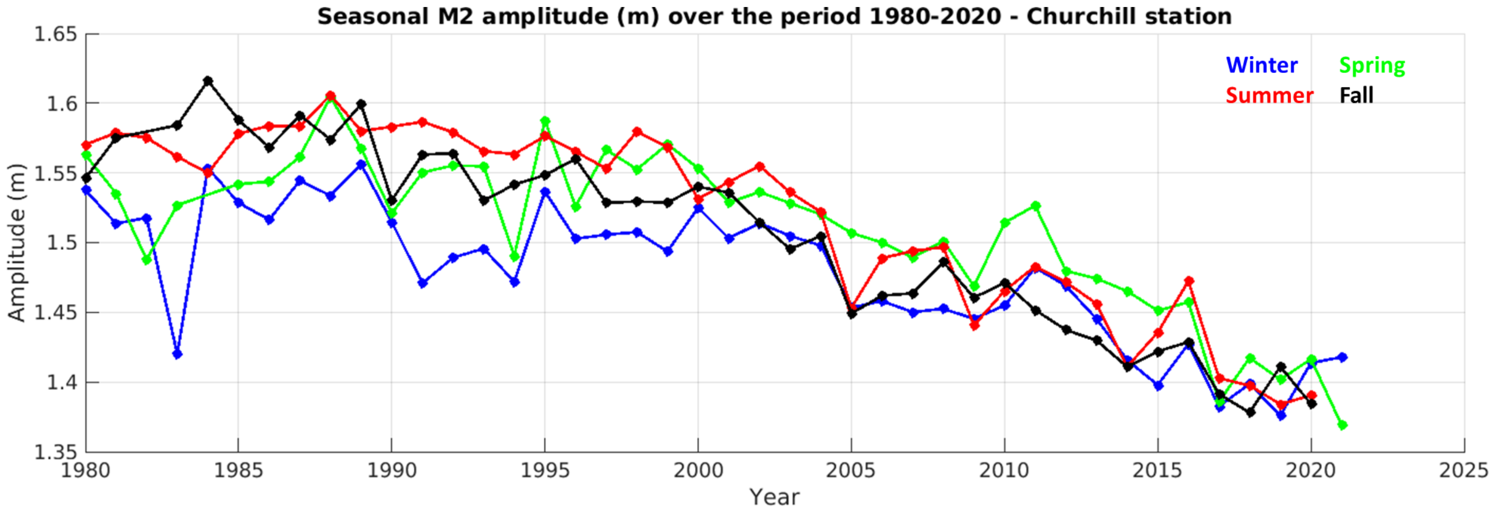
- **Hudson Bay**





Comparisons model vs TG

- **Hudson Bay**



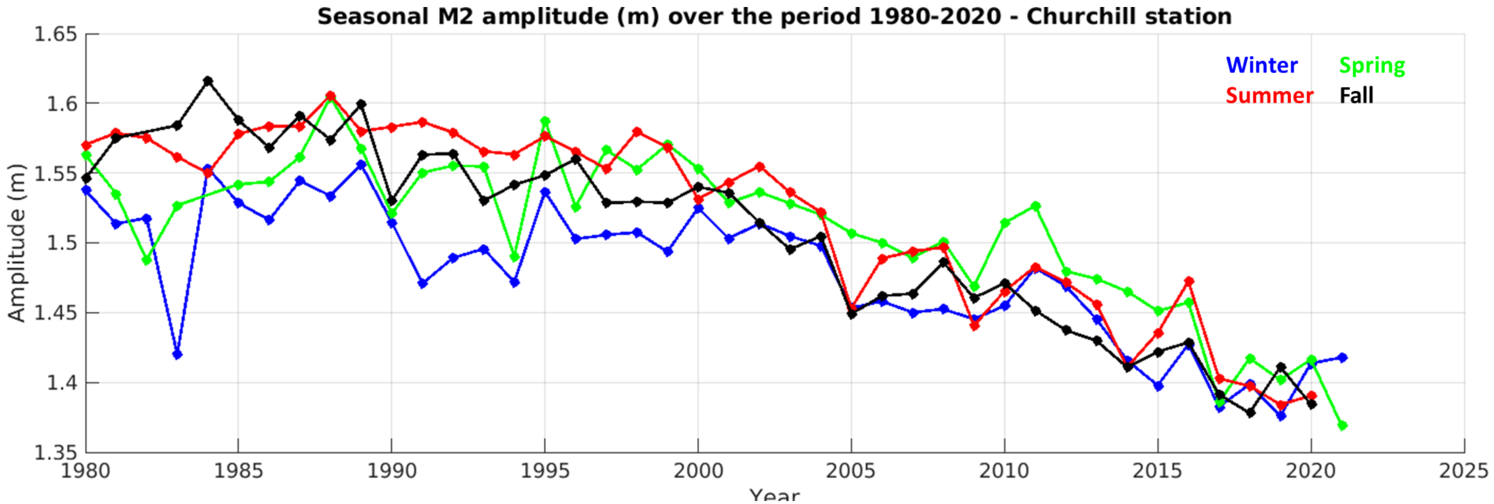
→ Such a long-term attenuation on M2 seems a bit strange.

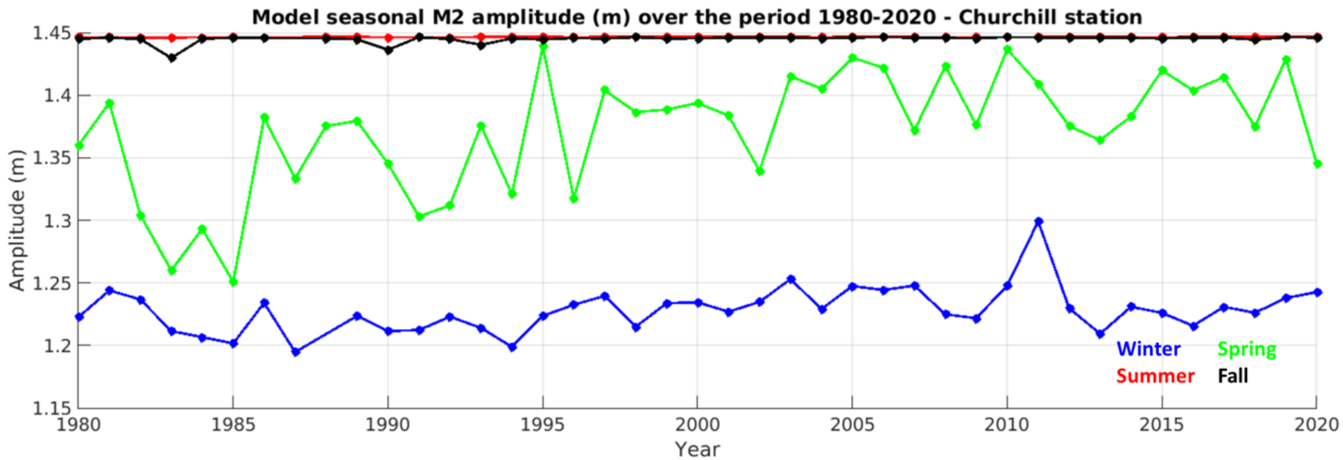
→ CryoSat-2 data (representative of the recent period) give an amplitude in the order of 1.5 m.

→ Siltation of the site? Issue with the tide gauge instrument? Something else?

Comparisons model vs TG

- **Hudson Bay**

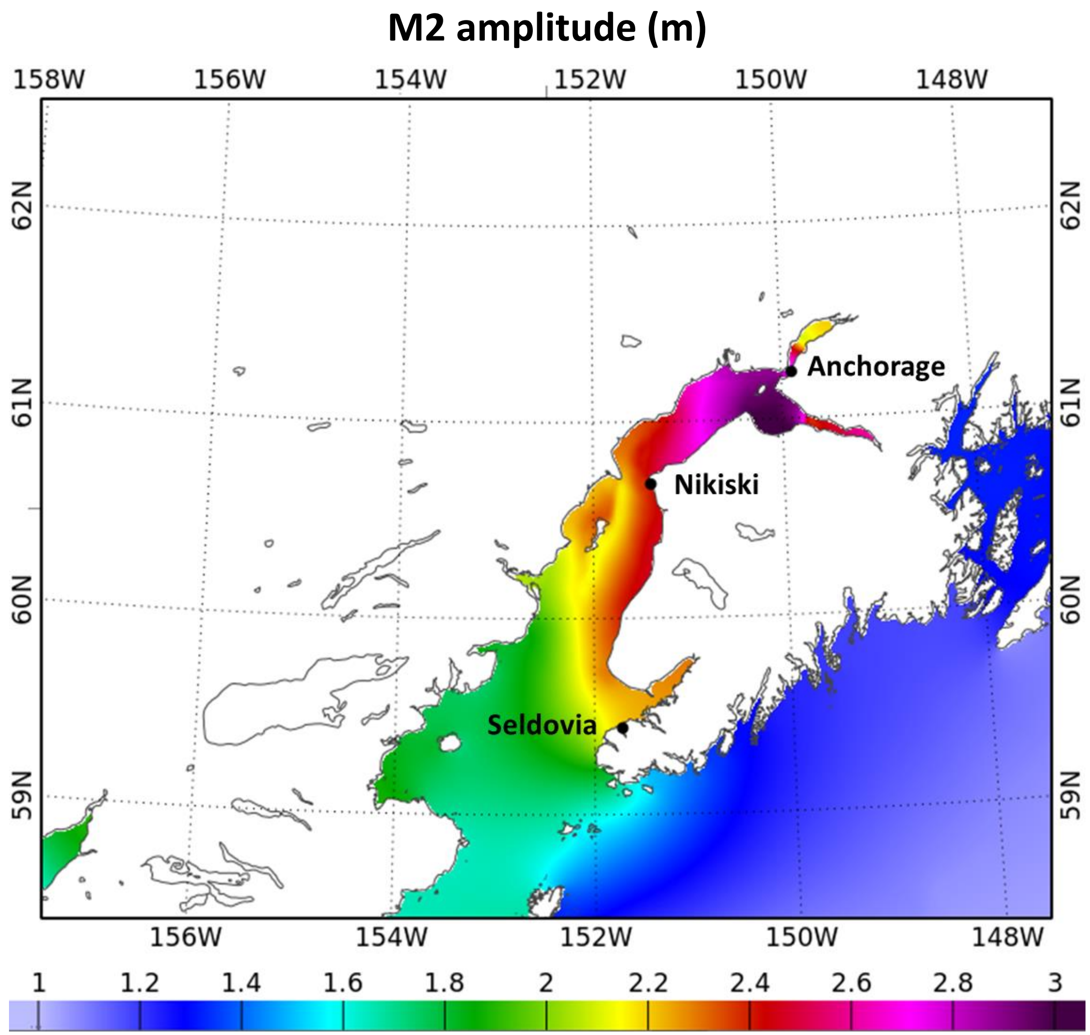




→ Time-stepping model simulation currently running with monthly sea ice concentration, to compare with the seasonal spectral simulations

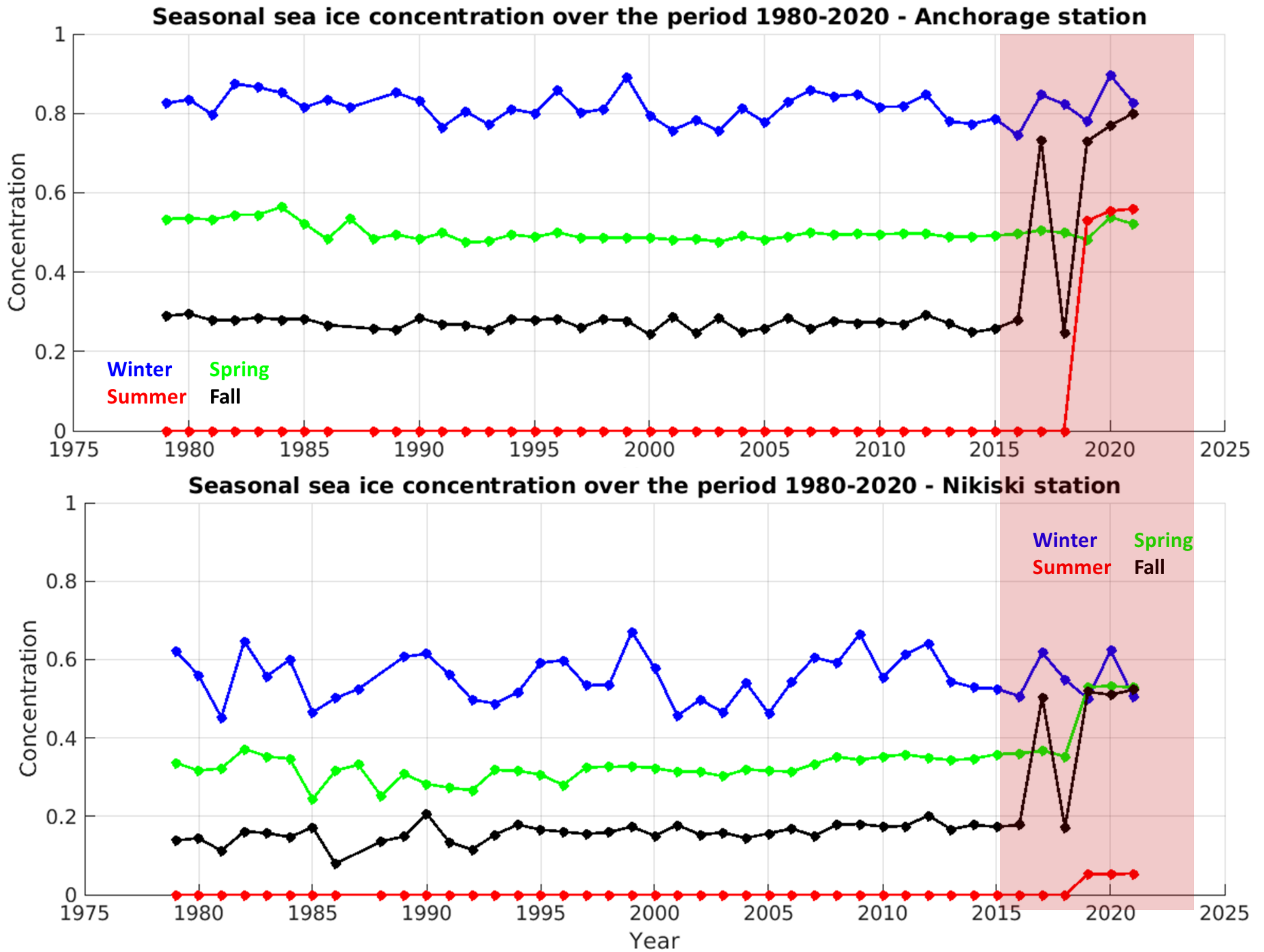
Comparisons model vs TG

- **Anchorage Bay**
  - 3 TG stations
  - Anchorage: estuary
  - Seasonal presence of sea ice



Comparisons model vs TG

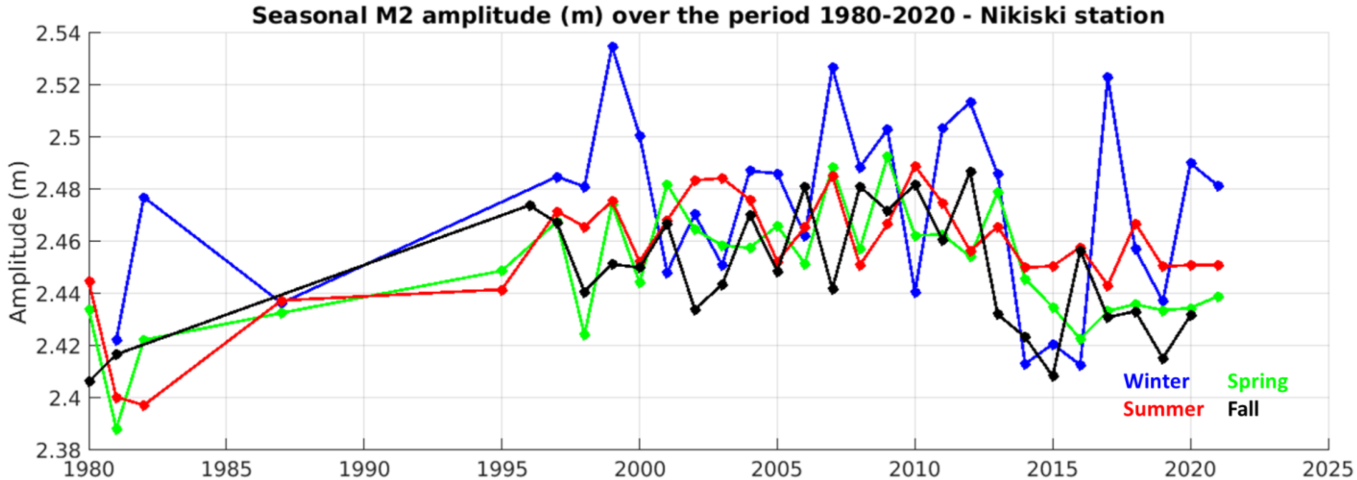
• Anchorage Bay

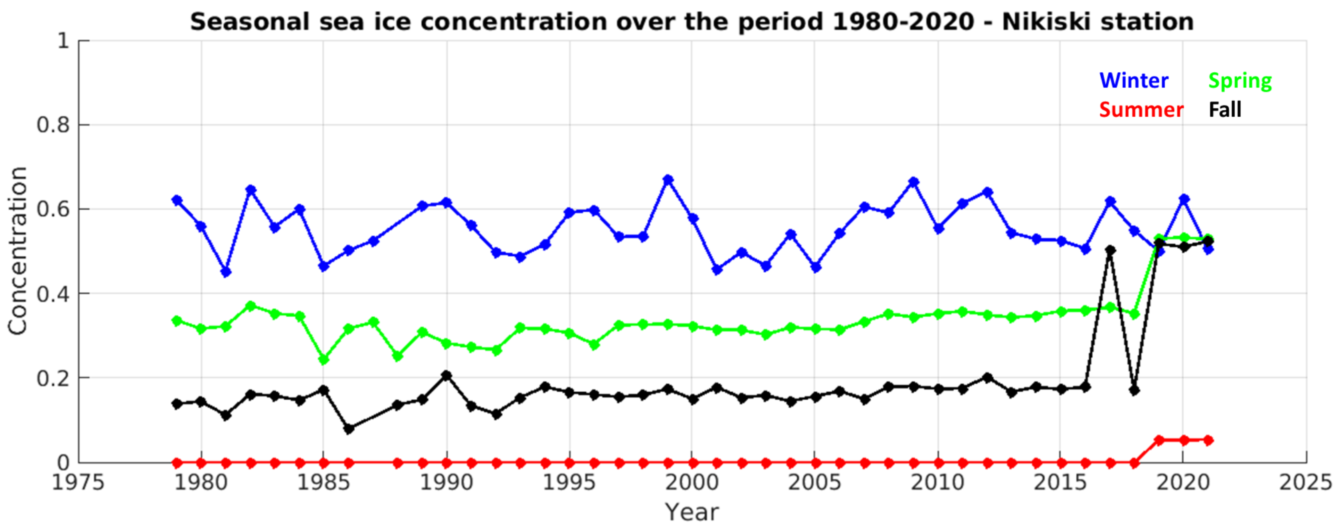


→ Some unexpected sea ice patterns in the Bay in Summer and Fall

Comparisons model vs TG

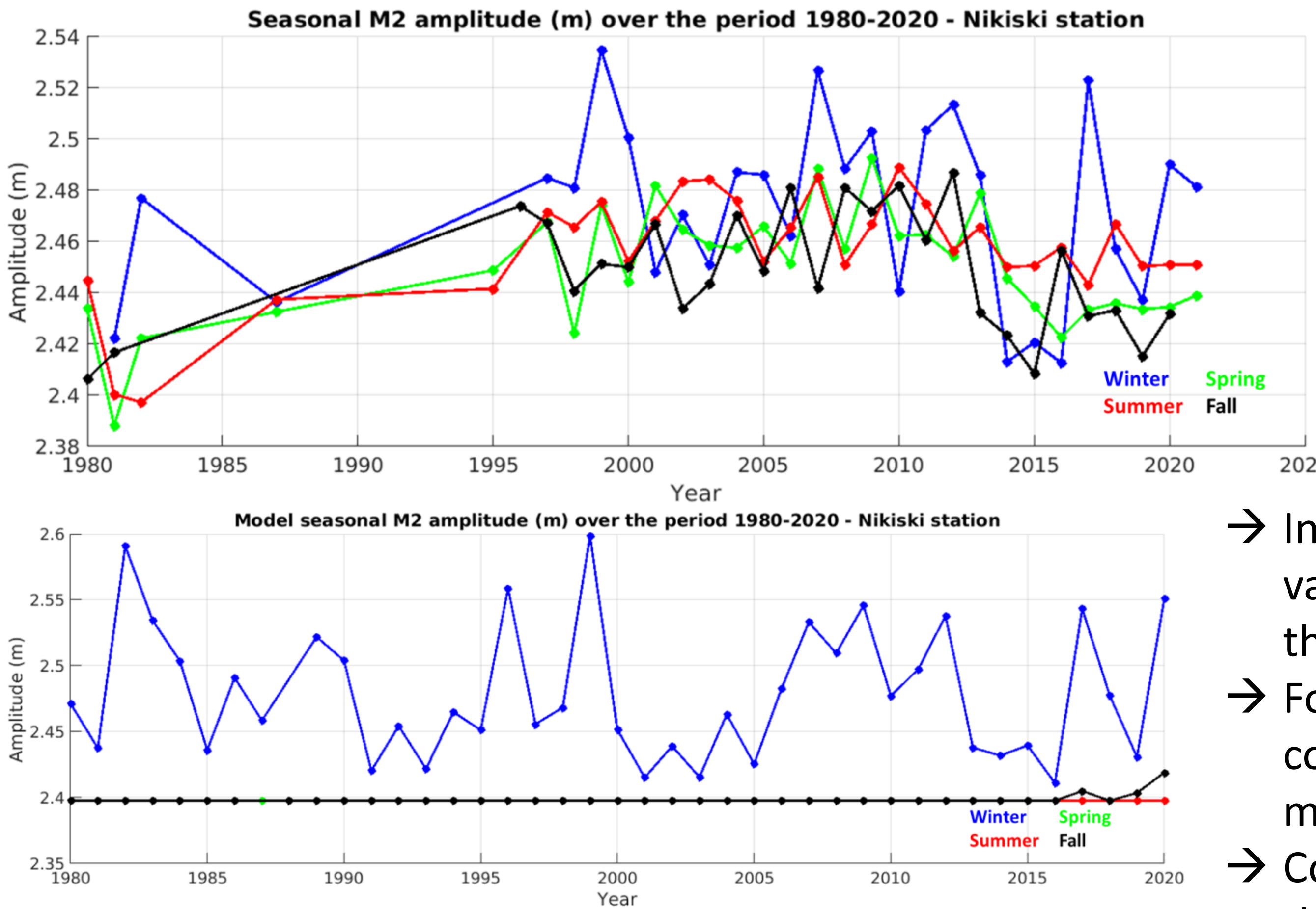
- **Anchorage Bay – Nikiski station**





Comparisons model vs TG

- **Anchorage Bay – Nikiski station**



→ In Winter, a bit more variability in the model than in the TG

→ For other seasons, no contrast in the spectral model

→ Consider a lower threshold on sea ice concentration in enclosed bays?

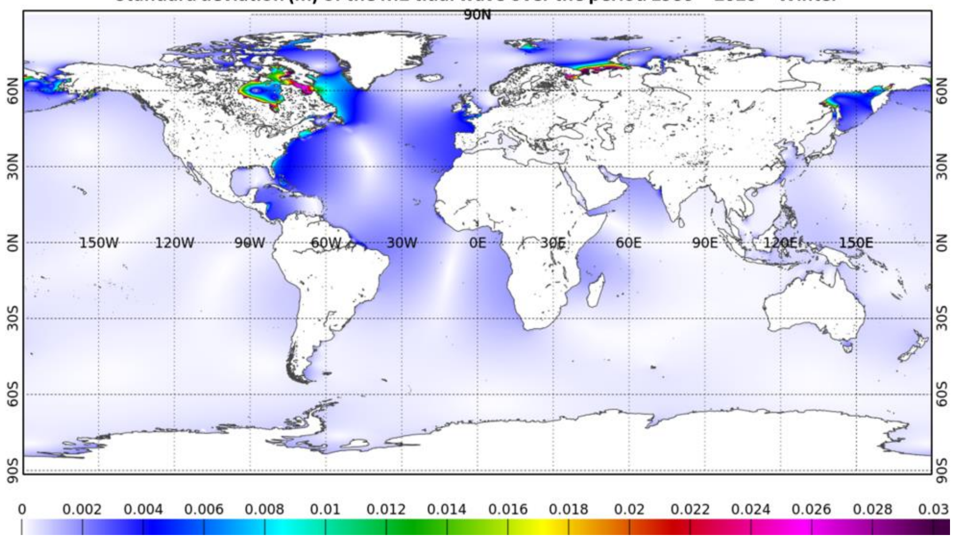
Global modelling

- **Global simulations**
  - FES2014 global configuration (mesh and bathymetry)
  - Every 5 years over 1980-2020, for each season (spectral mode)
  - Seasonal sea ice cover (NSIDC sea ice concentration) in the Arctic and in the Southern Ocean
  - Ice shelves cover in Antarctica

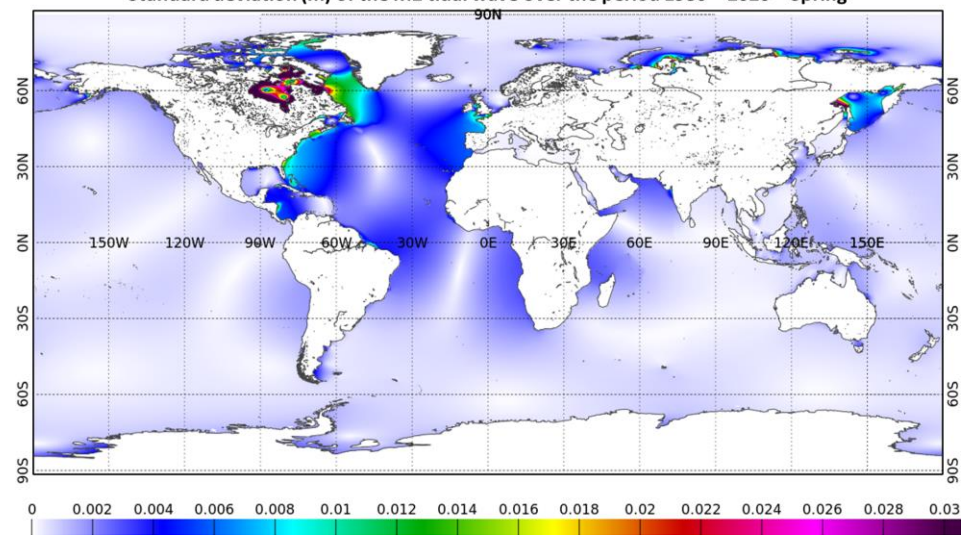
➔ **Standard deviation of the M2 and K1 waves for each season**

Global modelling

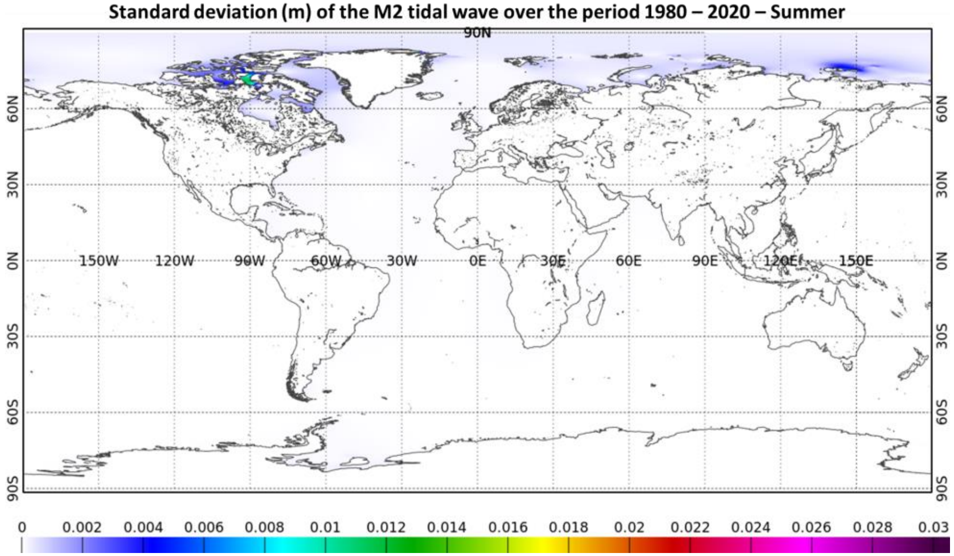
Standard deviation (m) of the M2 tidal wave over the period 1980 – 2020 – Winter



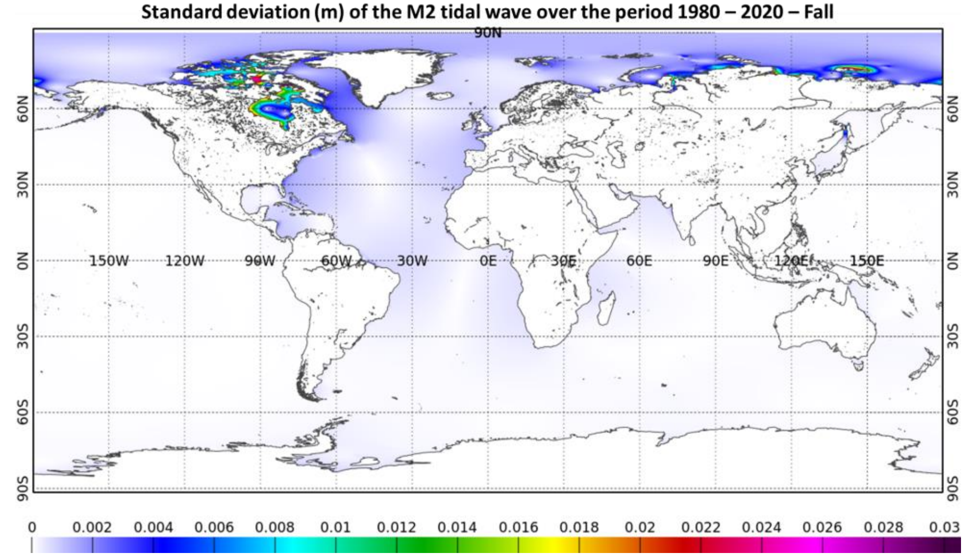
Standard deviation (m) of the M2 tidal wave over the period 1980 – 2020 – Spring



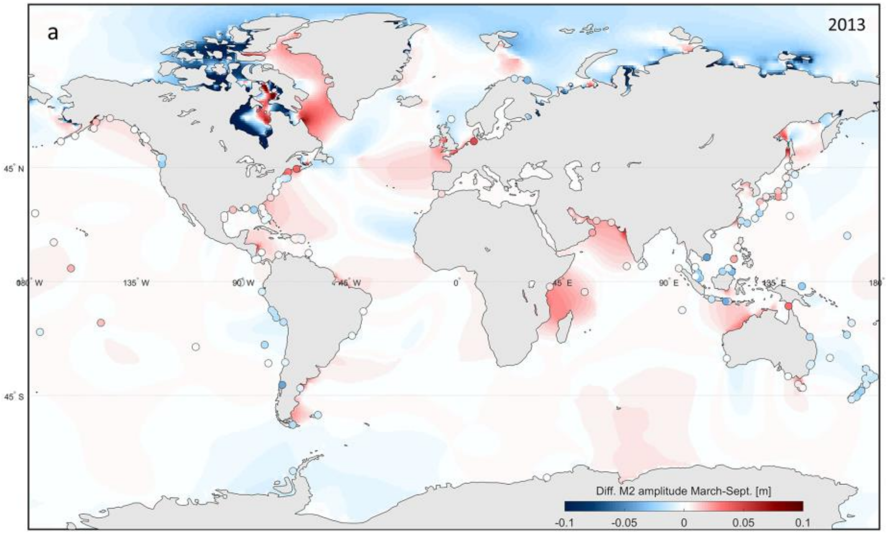
Standard deviation (m) of the M2 tidal wave over the period 1980 – 2020 – Summer

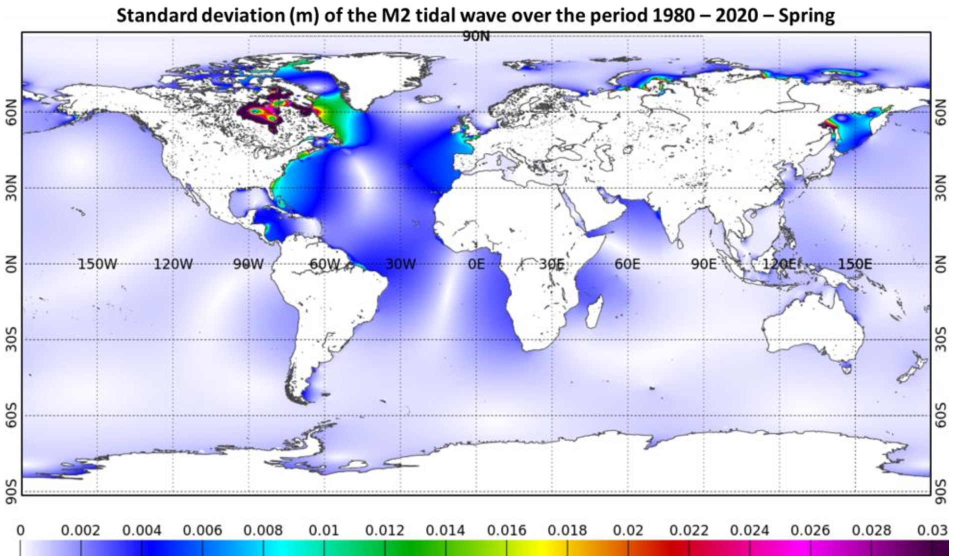


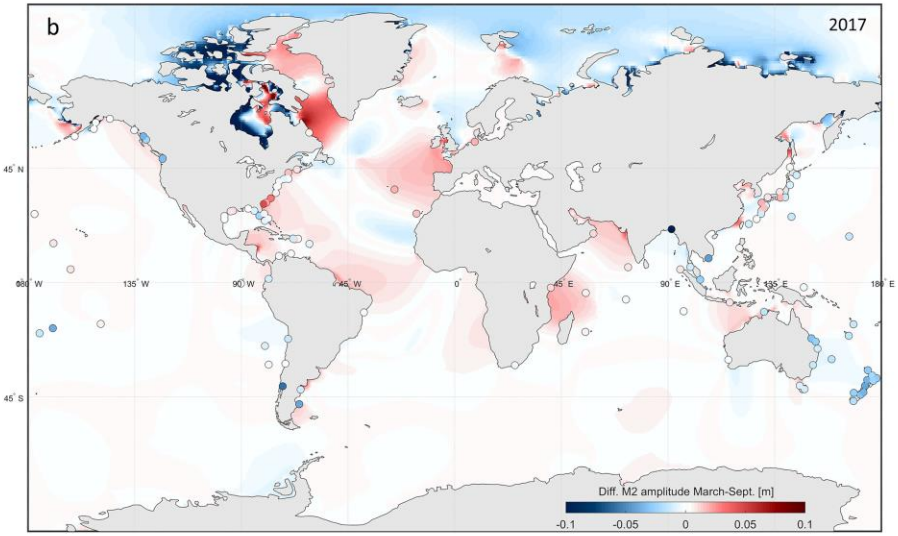
Standard deviation (m) of the M2 tidal wave over the period 1980 – 2020 – Fall



Global modelling







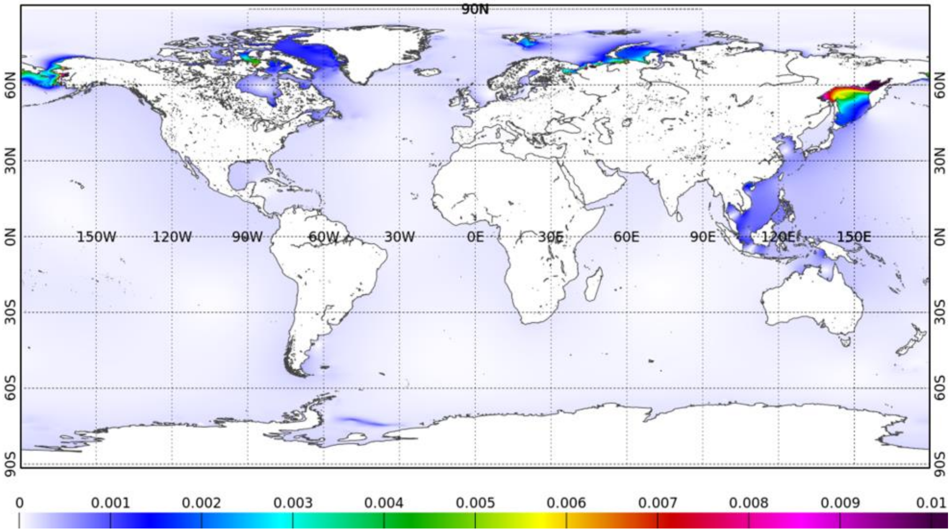
The Influence of Arctic Landfast Ice on Seasonal Modulation of the M2 Tide, Bij de Vaate et al., 2021

M2 differences between March and September in 2013 and 2017

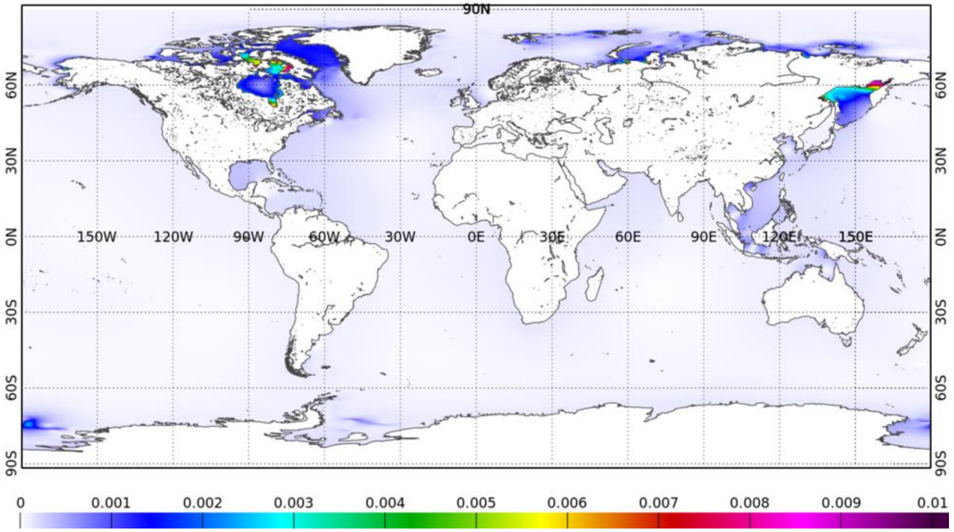
➔ Similar regions highlighted
➔ Long-distance influence of the Arctic sea-ice cover

Global modelling

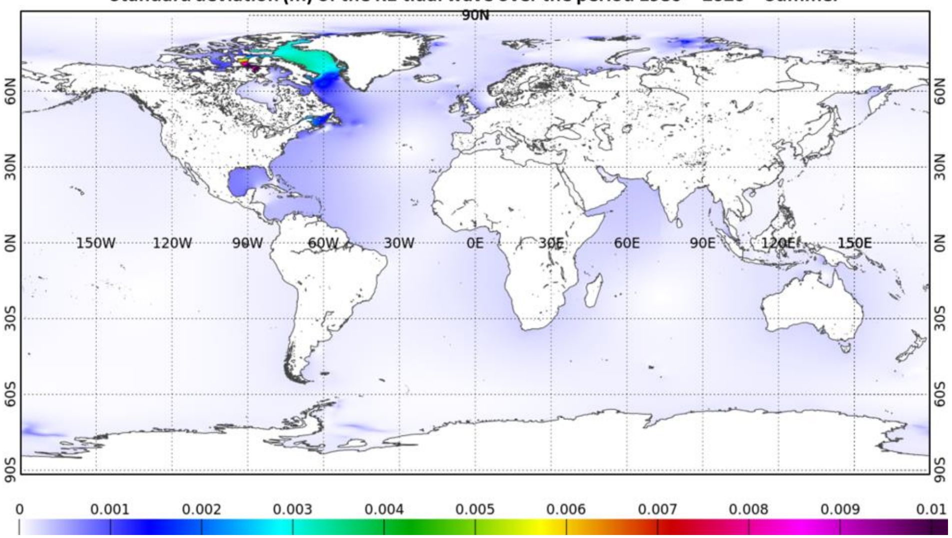
Standard deviation (m) of the K1 tidal wave over the period 1980 – 2020 – Winter



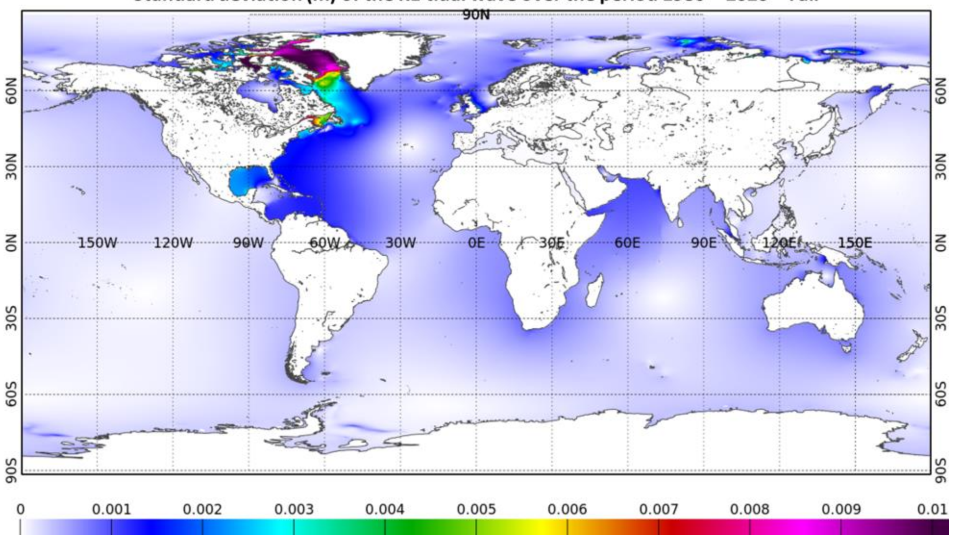
Standard deviation (m) of the K1 tidal wave over the period 1980 – 2020 – Spring



Standard deviation (m) of the K1 tidal wave over the period 1980 – 2020 – Summer



Standard deviation (m) of the K1 tidal wave over the period 1980 – 2020 – Fall



Conclusions

- **Summary**
  - **In general, difficult to accurately estimate the seasonal tidal variations over a long-term period in the Arctic Ocean**
    - High-frequency tide gauge data availability and quality
    - Altimetry data only for the most recent period
    - Difficulty to tune the model – high sensitivity to friction
    - Sometimes some issues also in the sea ice concentration products

→ Use of the most reliable tide gauge stations + altimetry to fine tune the model and then try to understand what happens elsewhere

  - **Some open points remain and are not in the model,** like the possible accumulation of sea ice in some channels with the wind, that can temporarily block the tidal circulation: how to identify and document such events?

  - **Paper to be finalized and submitted to Ocean Science**

- **A few more info about tidal models**
  - **FES2022 global tidal model** to be released in the coming months (CNES/CLS/LEGOS/NOVELTIS)
  - **ALBATROSS ESA project** (NOVELTIS/DTU/UCL/NPI)
    - Improve bathymetry knowledge in the Southern Ocean
    - Implement a new high-resolution tidal model in the Southern Ocean, including assimilation of CryoSat-2 reprocessed data.