Changes in extreme waves in the Arctic Ocean

Isabela de Souza Cabral

Ian Young

Alessandro Toffoli

Department of Infrastructure Engineering

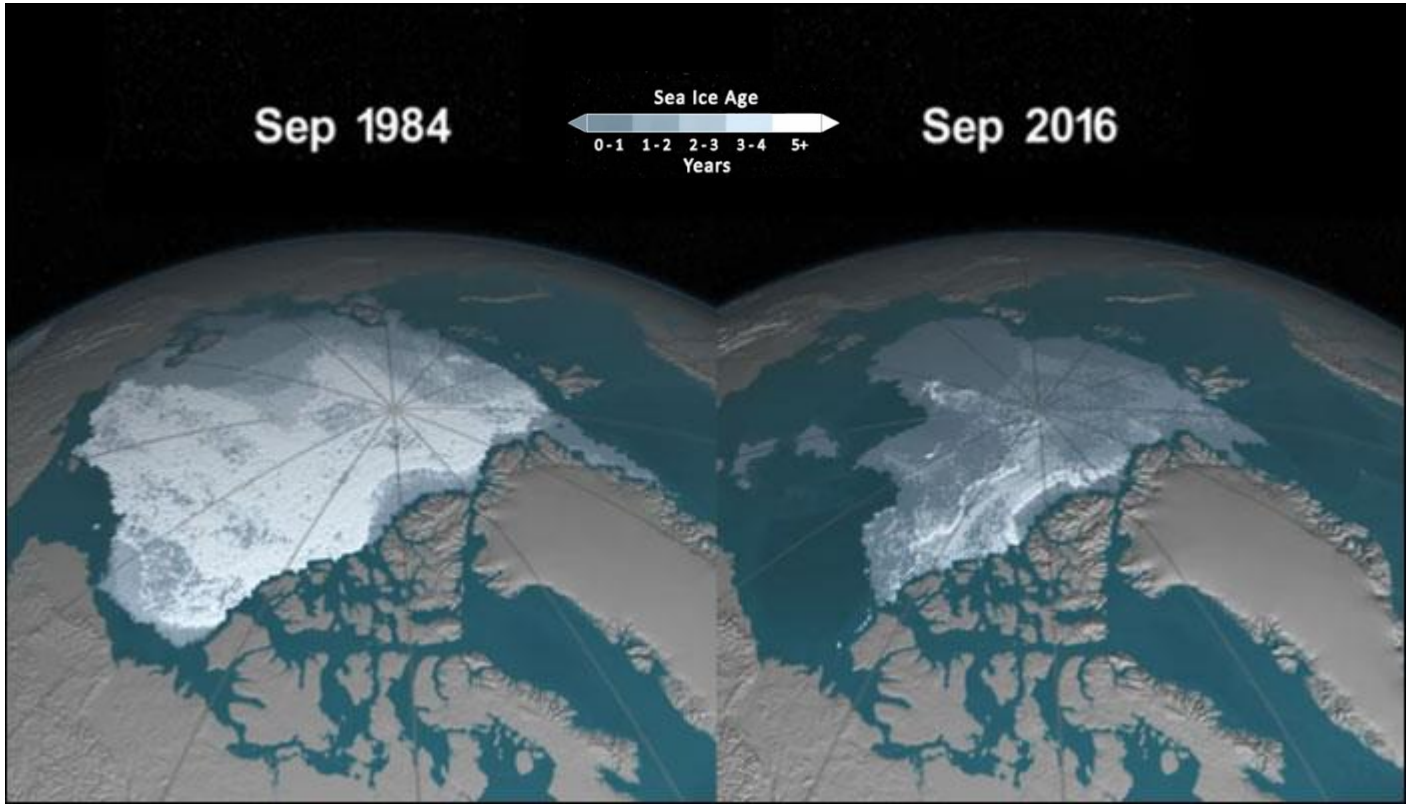
The University of Melbourne

Sea state changes in the Arctic

- Declining of sea ice extent
- Increasing fetches
- More energetic surface waves

Emerging Arctic Ocean

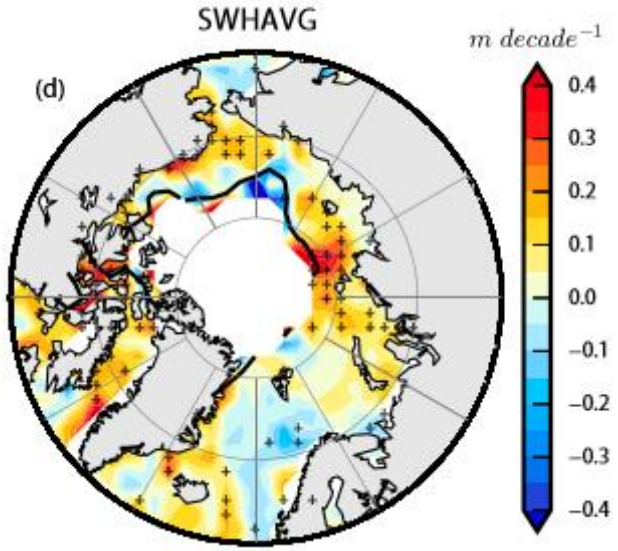
- Coastal morphological changes
- Supply of freshwater and terrestrial wildlife habitat
- Coastal infrastructures
- Eskimo villages need to relocate



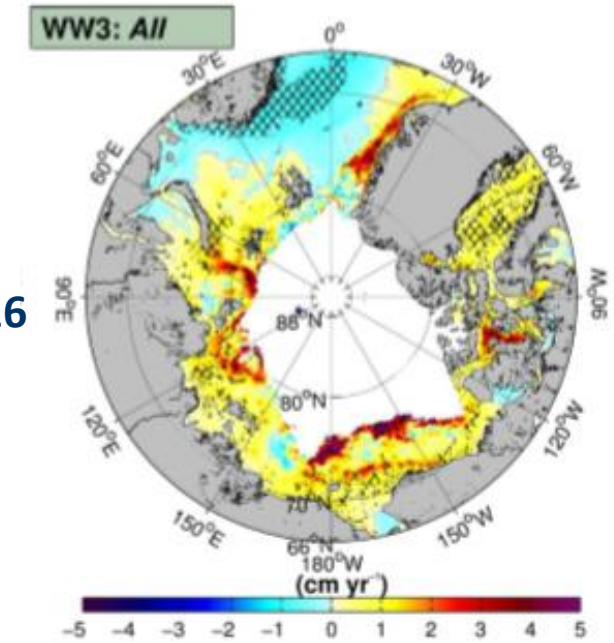
NASA, 2016

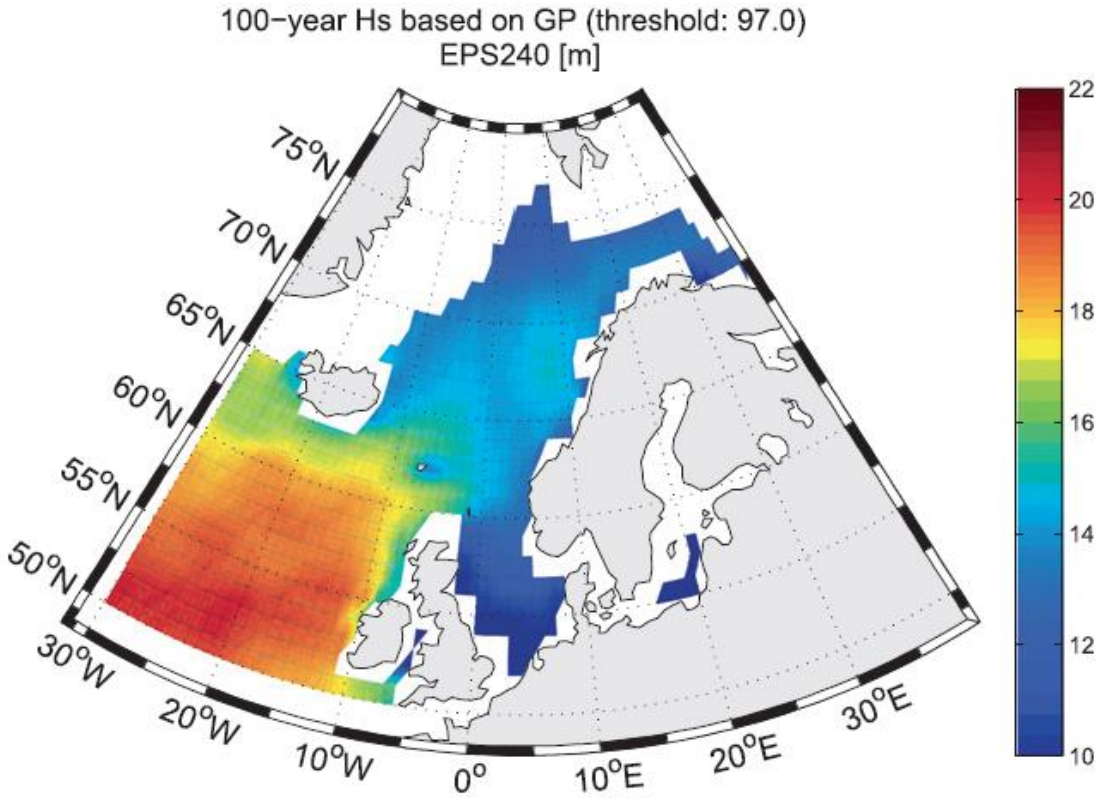
Sea state changes in the Arctic

Liu *et al.*, 2016



Stopa *et al.*, 2016



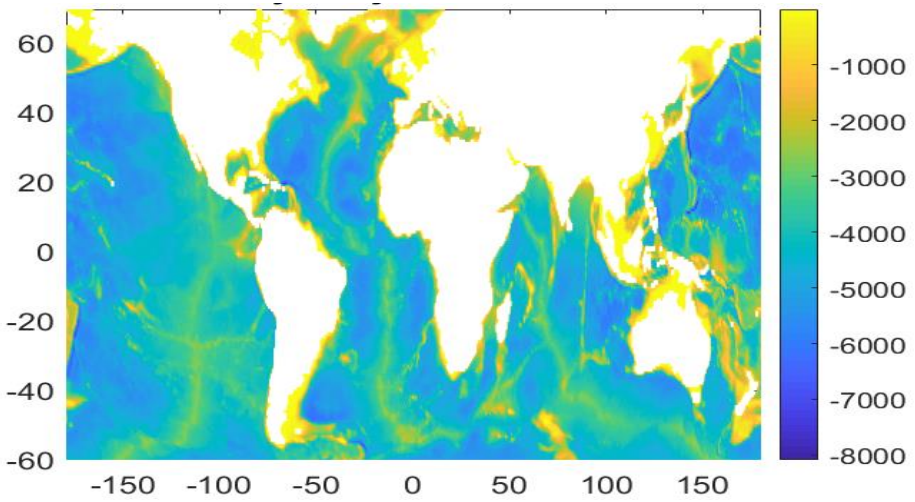


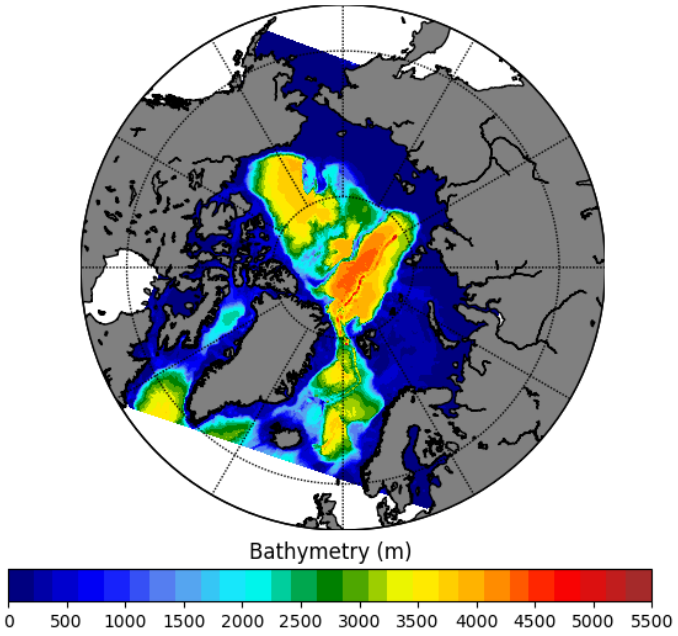
Breivik *et al.*, 2013

Aim

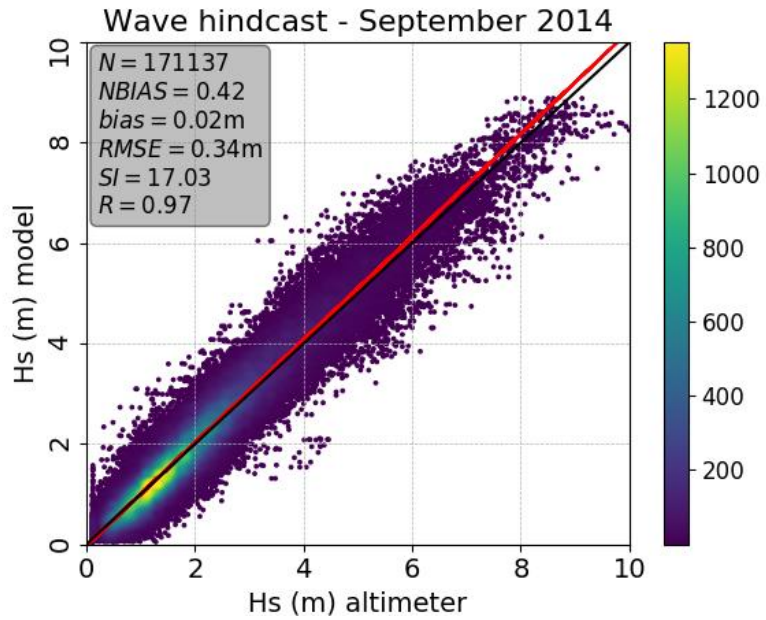
Assess the changes in extreme waves across the Arctic Ocean based on the results of a 28-year wave hindcast.

Model Setup

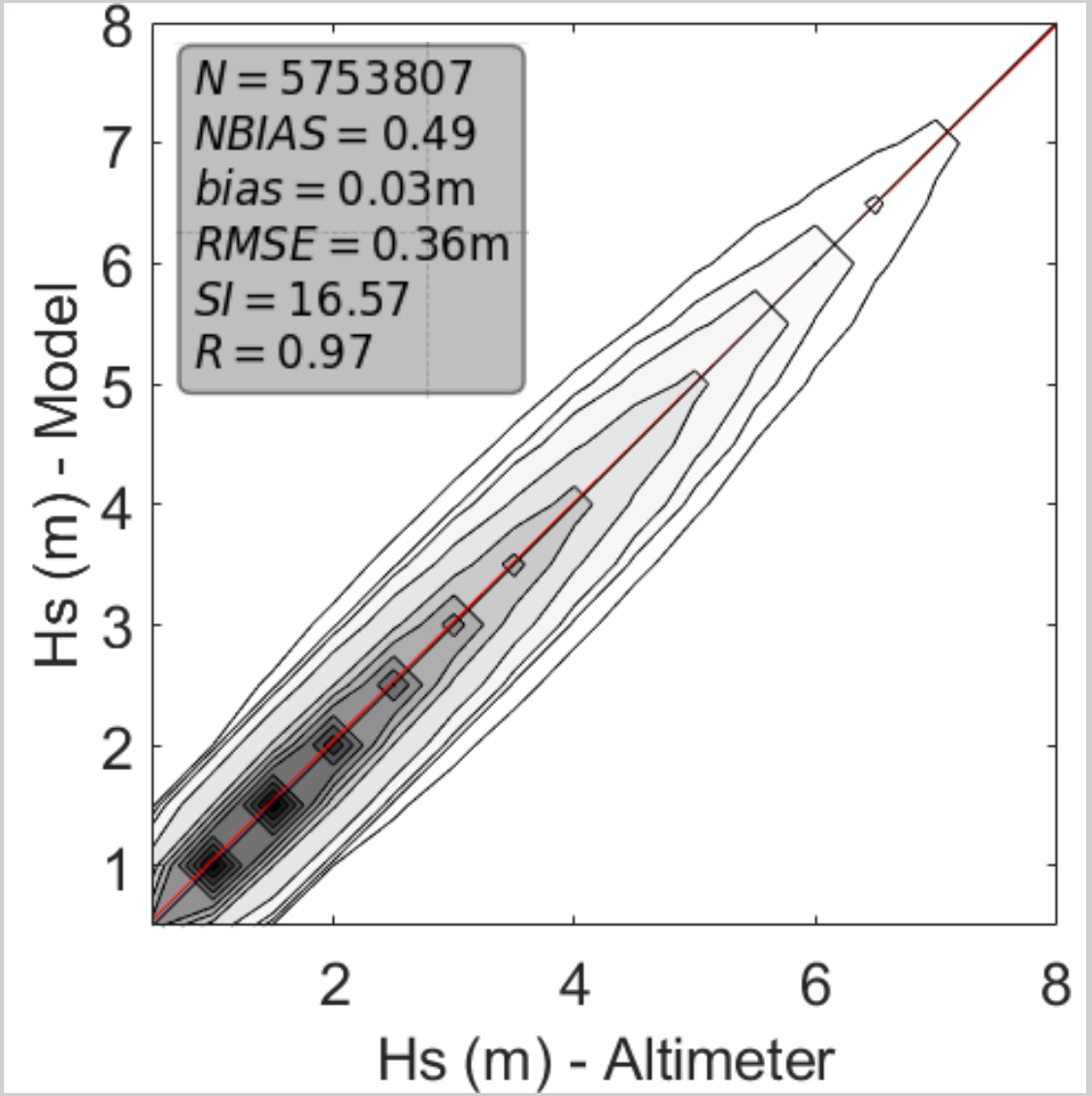




- **WaveWatch III version 6.07**
- **Atmospheric forcing**
  - **CFSR**
  - **ERA-Interim**
  - **ERA5**
- **Source and sink terms**
  - **ST4 (Ardhuin et al., 2010)**
  - **ST6 (Zieger et al., 2015)**
- **Sea ice concentration (land if >25%)**
  - **IFREMER/CERSAT**
  - **NSIDC/NOAA**
  - **GLORYSV4**
  - **ERA-Interim**
  - **ERA5**
- **Spatial resolution**
  - **9 to 22 km**
  - **6 to 16 km**
  - **4 to 13 km**



Validation



Hs hindcast versus co-located data from altimeters

Wave Hindcast: 1991-2018

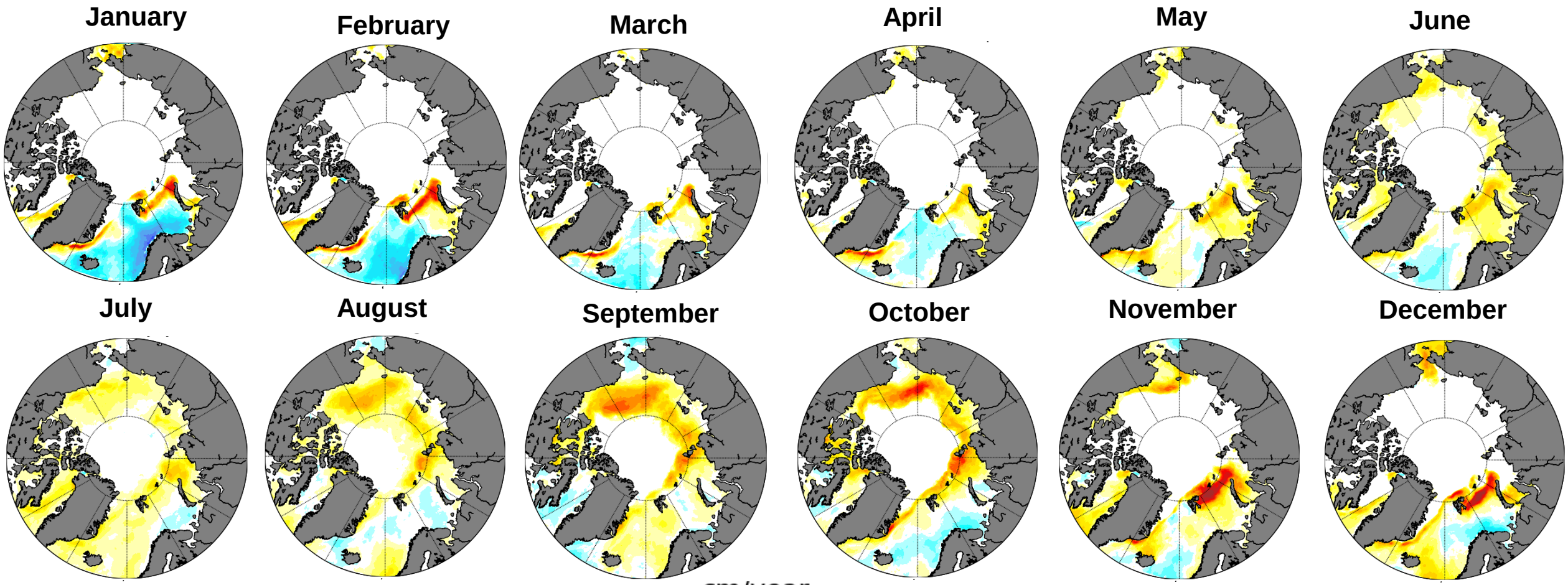
Model vs. Altimeters

(2012-2016)

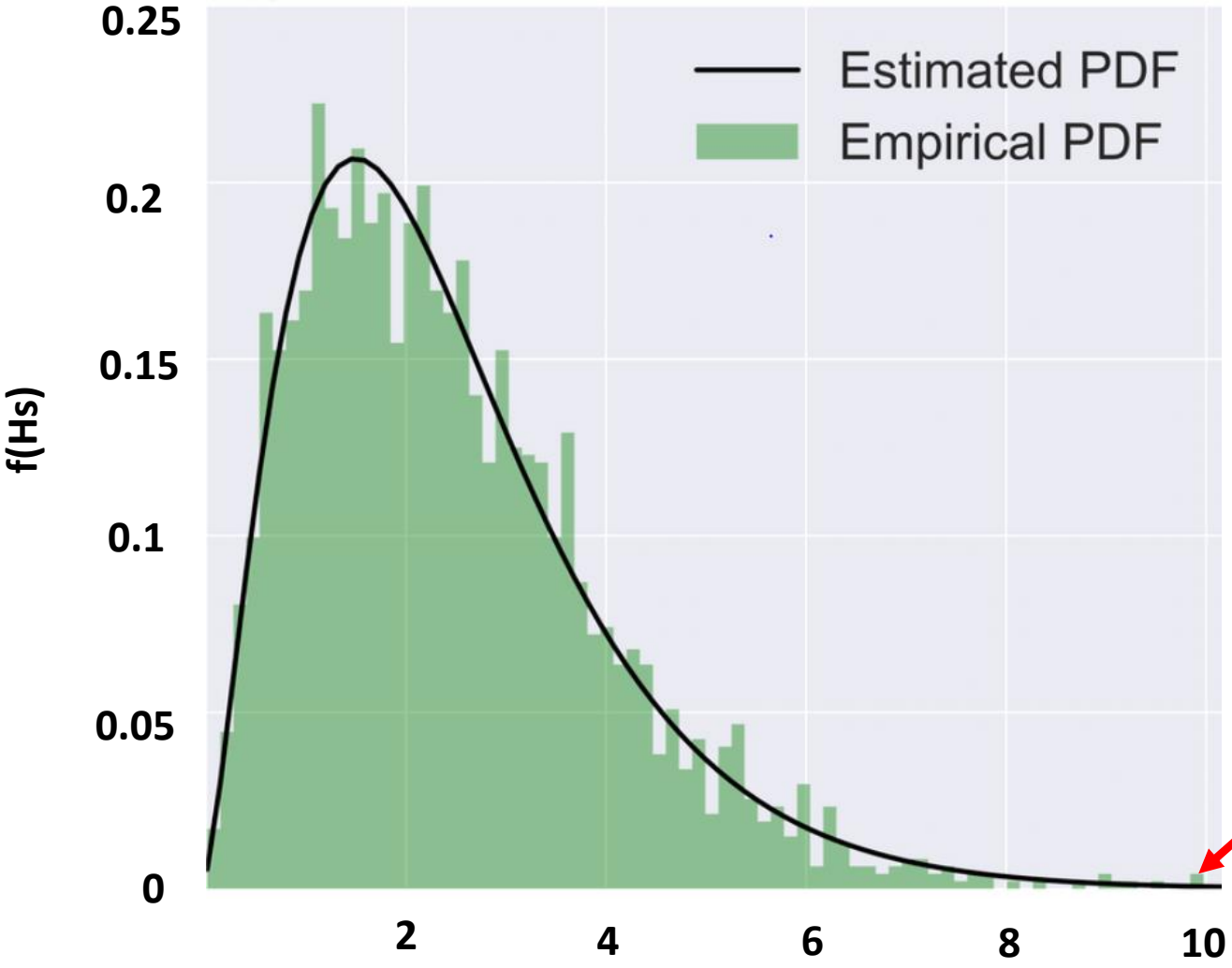
- **ERS1**
- **ERS2**
- **ENVISAT**
- **GFO**
- **CRYOSAT 2**
- **SARAL**

Wave Hindcast - Results

Mann Kendell trend
98th Percentile of Hs: 1991-2018



Estimates of extreme wave heights



Established EVA

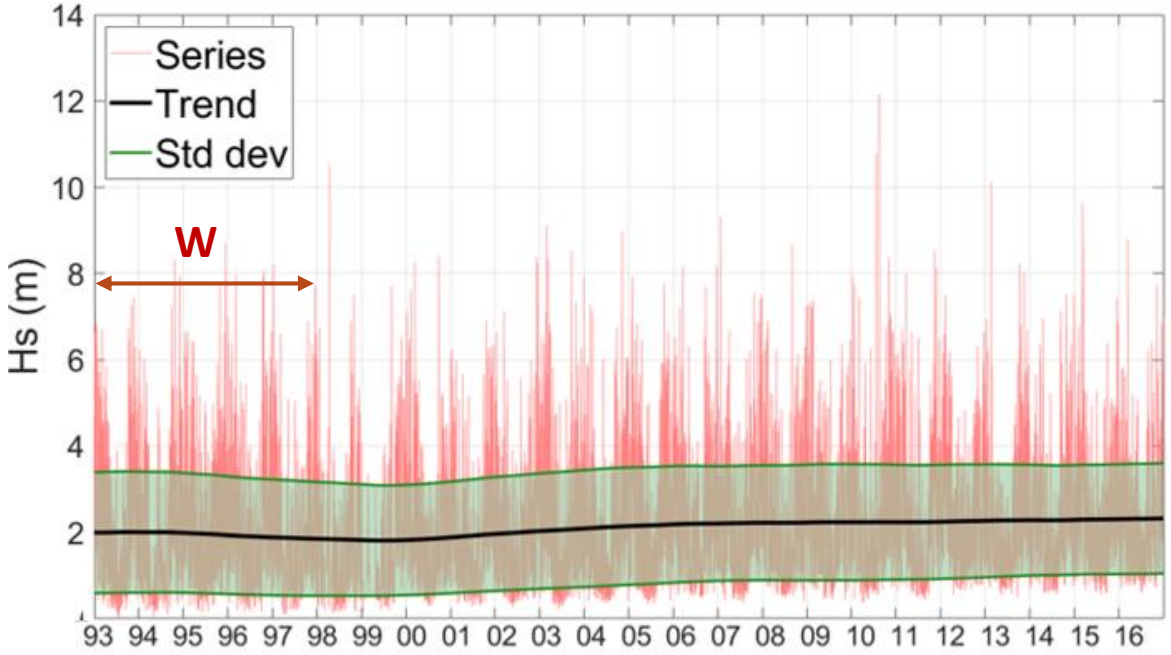
$$F(x) = 1 - \left[1 + k\left(\frac{x - A}{B}\right)^{-1/k}\right]$$

Interest in the tail of the PDF

Stationary approach

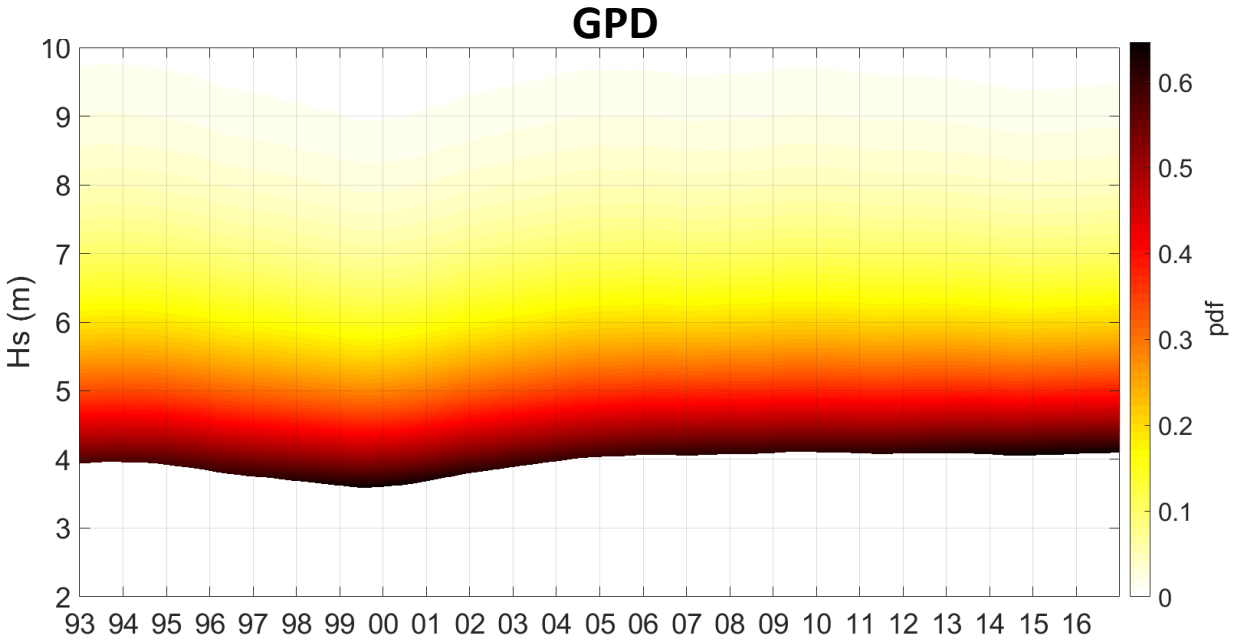
TS EVA – non-seasonal

Transformed stationary (TS) Method (Mentaschi *et al.*, 2016)



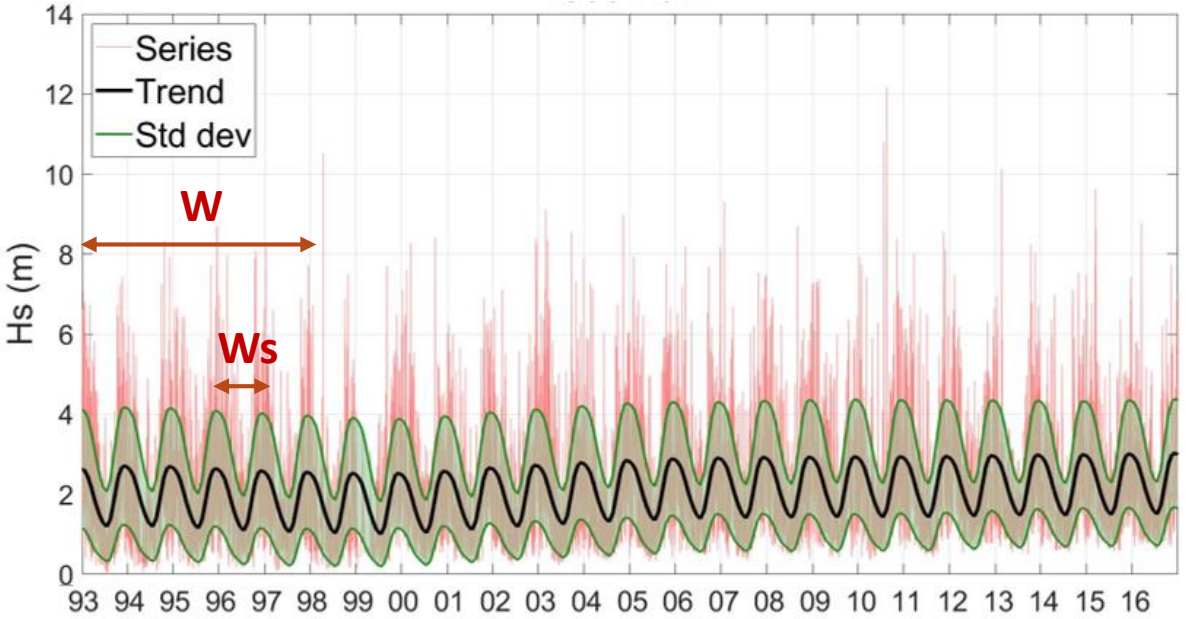
$$x(t) = f(y,t) = \frac{y(t) - T_y(t)}{S_y(t)}.$$

1. Transform the non-stationary time series y(t) into a stationary series x(t)
2. Performing a stationary EVA
3. Back-transforming the resulting extreme value distribution into a time-dependent one.



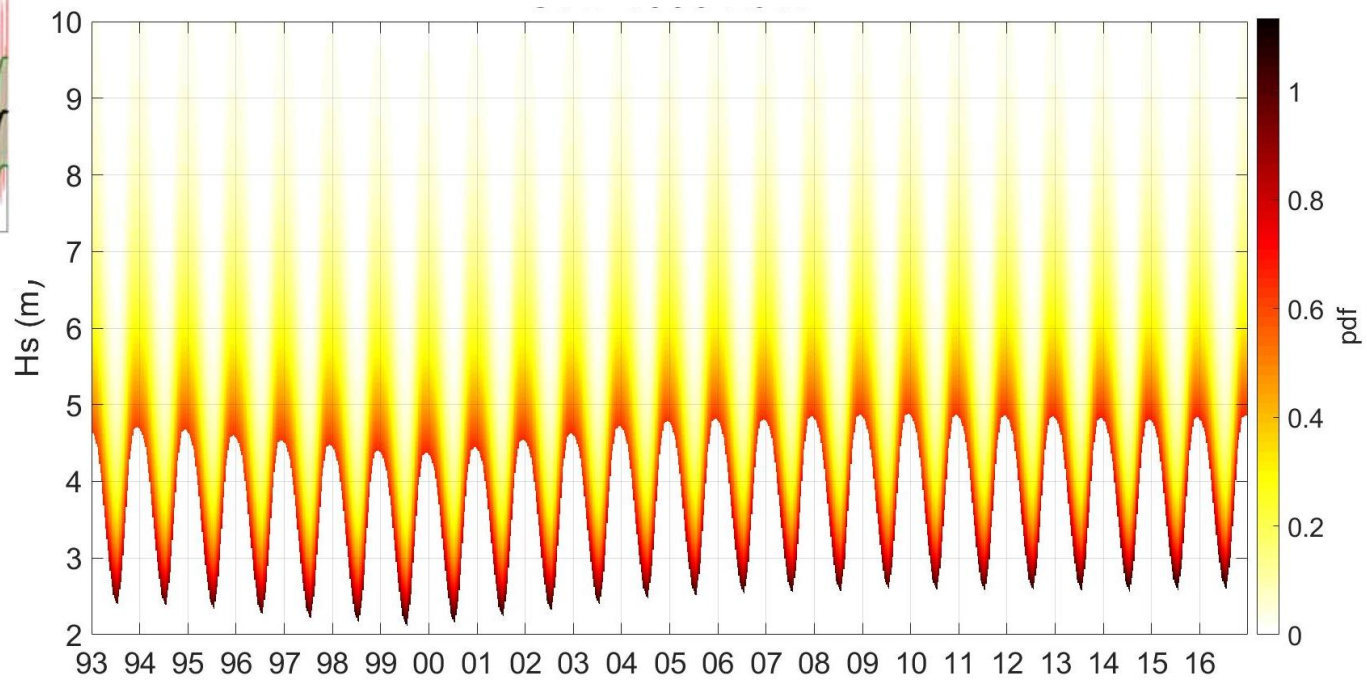
TS EVA – seasonal

Transformed stationary (TS) method (Mentaschi *et al.*, 2016)

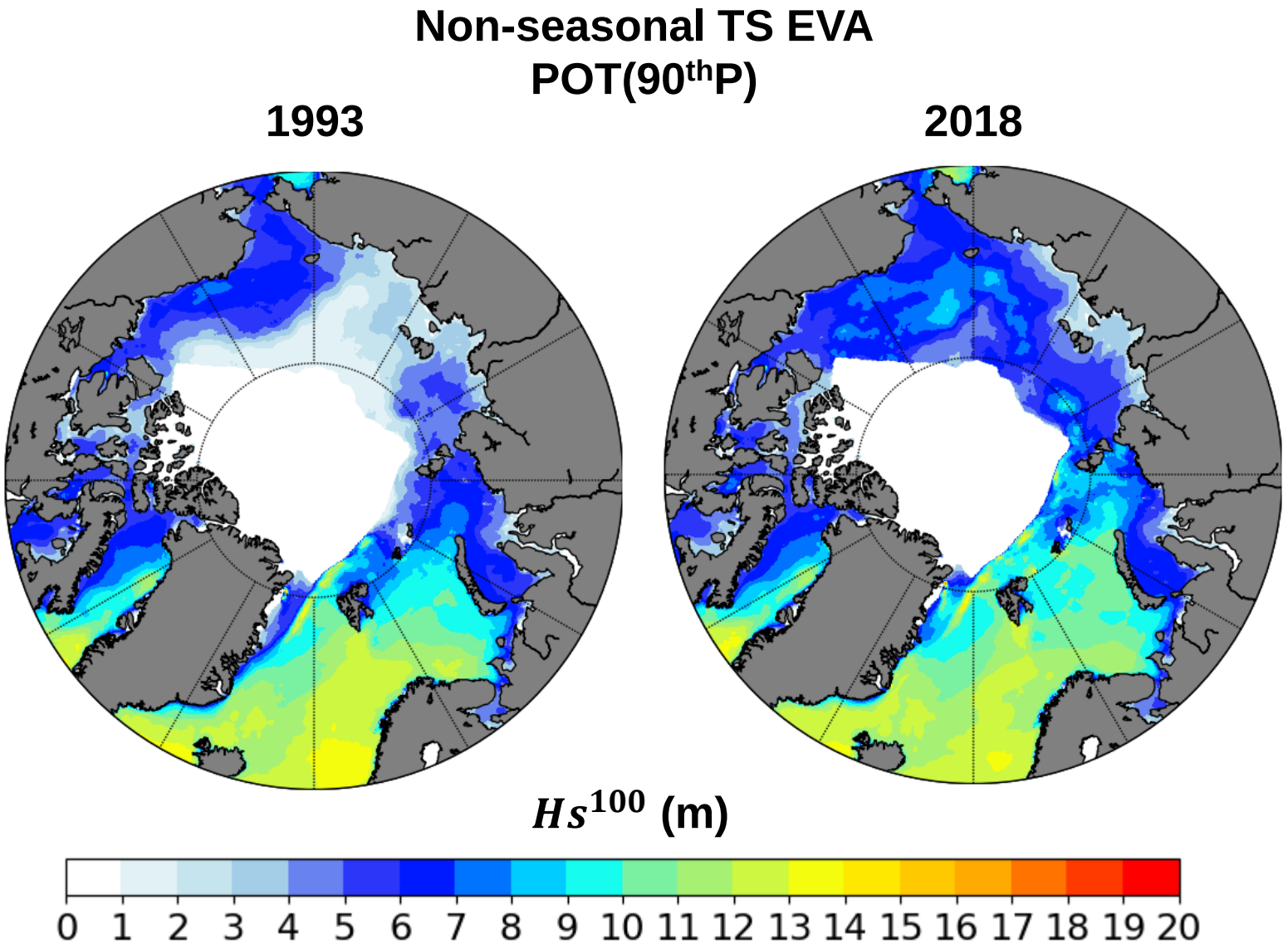


$$T_y(t) = T_{0y}(t) + s_{\mathrm{T}}(t),$$
$$S_y(t) = S_{0y}(t) \cdot s_{\mathrm{S}}(t),$$

GPD

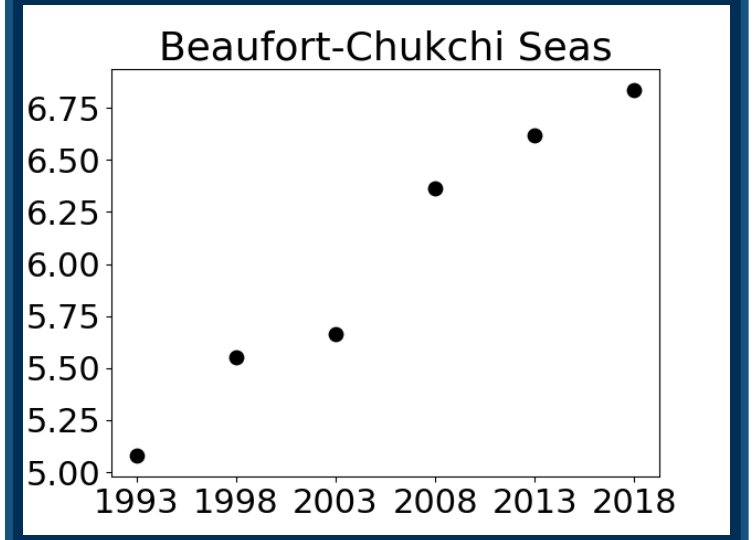


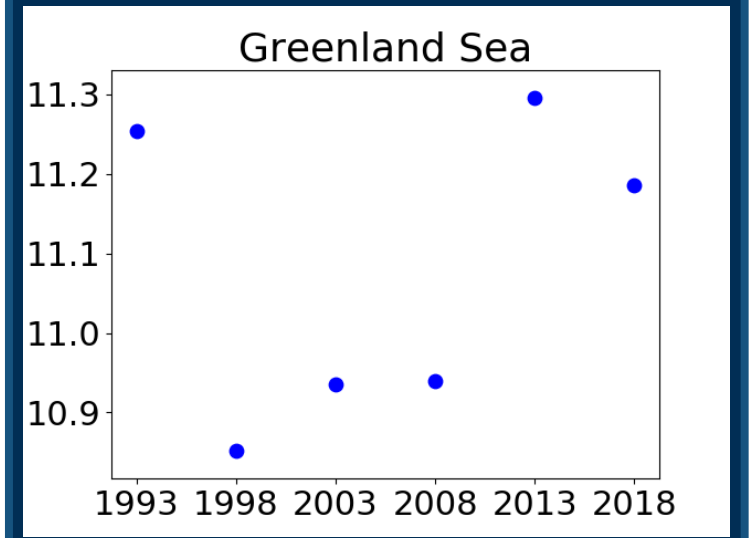
Non-seasonal TS EVA – Results



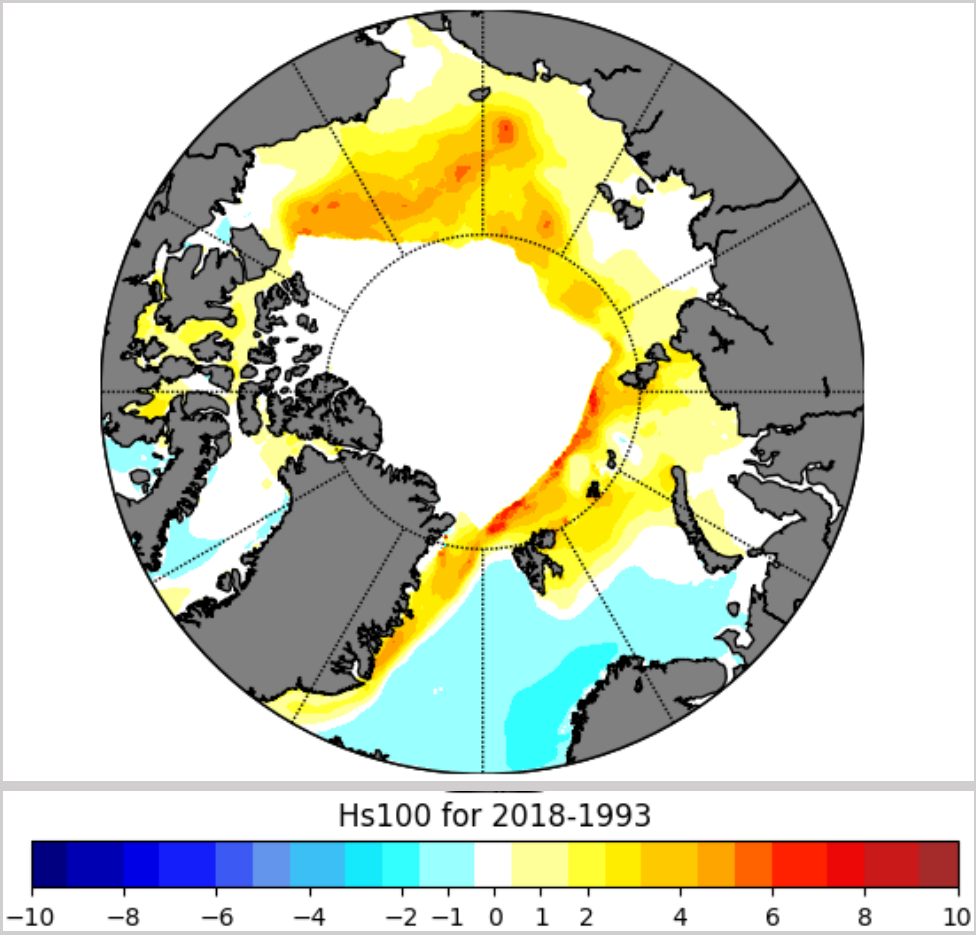
Non-seasonal TS EVA – Results

Hs100 areal-averages

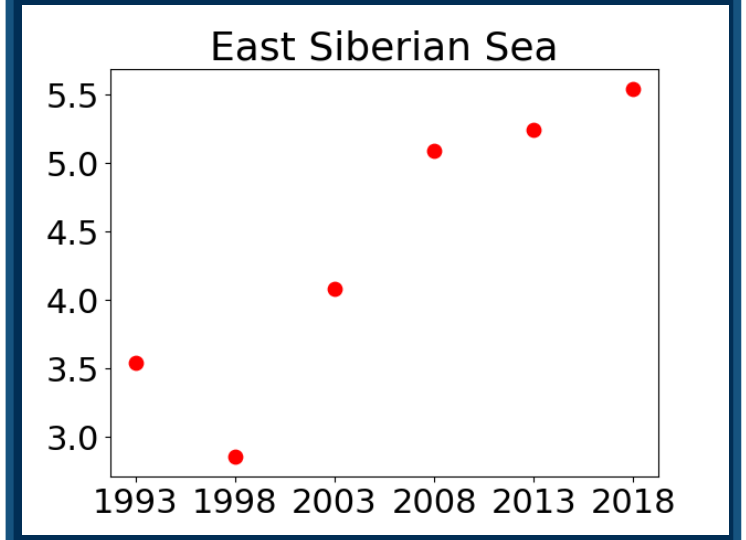


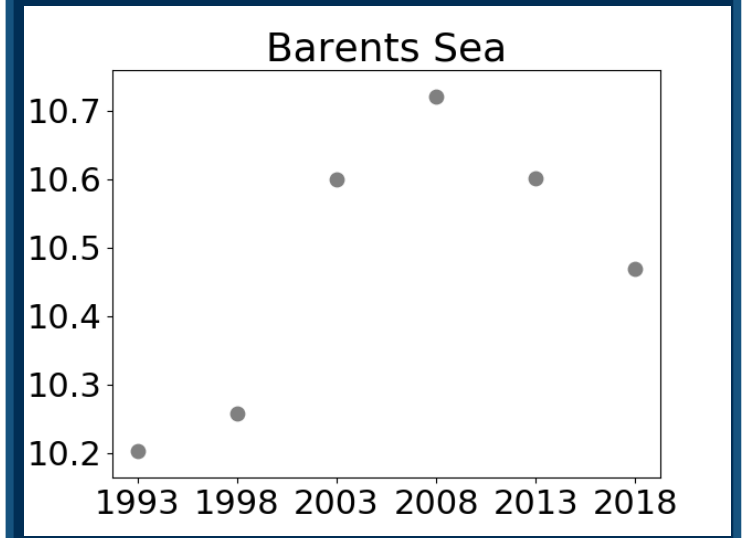


Comparison - 2018-1993



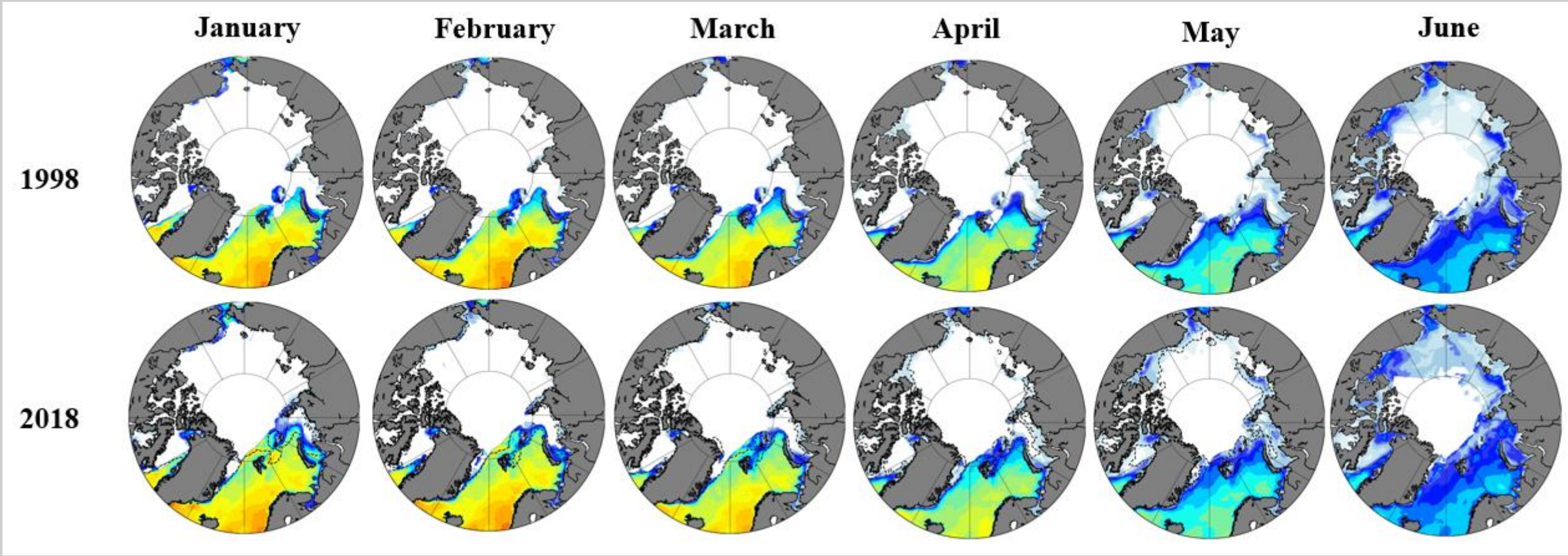
Hs100 areal-averages





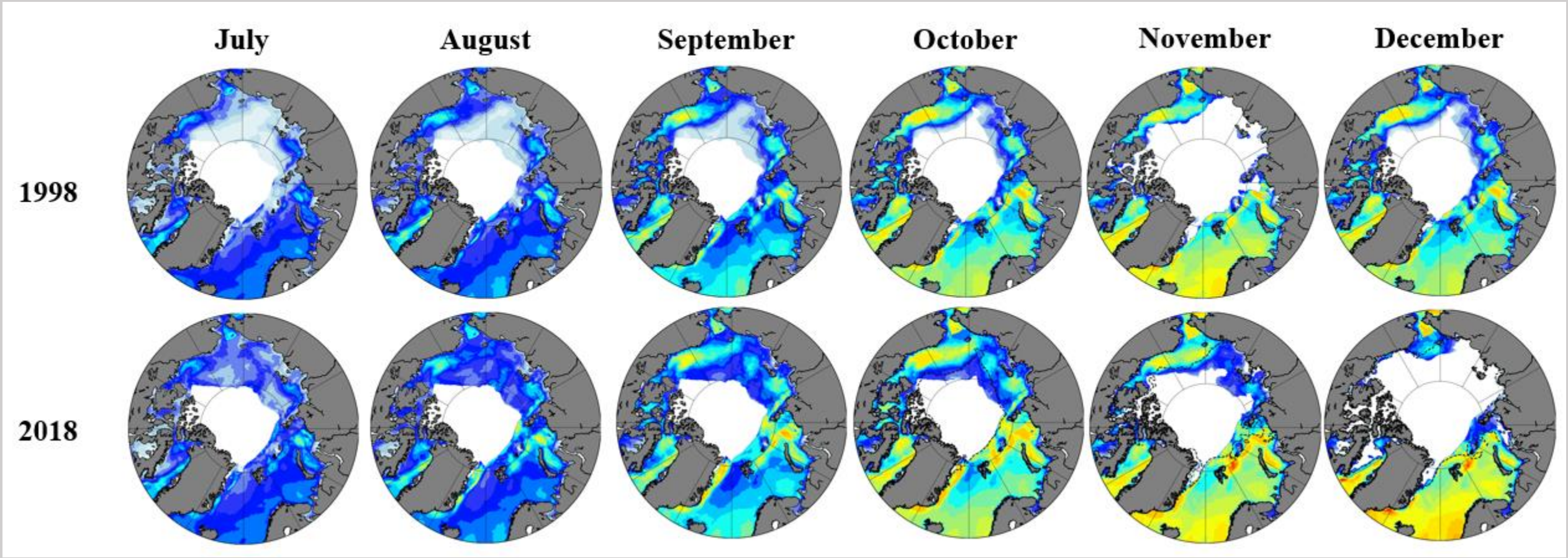
Seasonal TS EVA - results

POT(90thP)



Seasonal TS EVA - results

POT(90^{th}P)



Conclusions

- 28-year wave hindcast was performed and the validation against satellite data showed satisfactory agreement
- Monthly trends of 98th percentile of wave heights showed substantial seasonal differences. The results demonstrated a general increase in wave heights, with the exception of Greenland and Norwegian seas in some months.
- Non-stationary EVA was applied to evaluate the extreme waves across the Arctic, taking into account the long term trends and seasonality
- The non-seasonal approach showed an increase of the areal-average of the H_s^{100} of approximately 2 m across the Arctic Ocean, with the exception of the region closer to the North Atlantic Ocean.
- The EVA seasonal approach allowed a better understand of the regional changes in the extremes throughout the year and how much the extreme waves have increased over the past decades.