The impact of sea state: from coastal erosion to sailing

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Collaborators:
M. Langer, P. Overduin, H. Lantuit, T. Ravens

Photo: P. Overduin
Bykovsky, Siberia

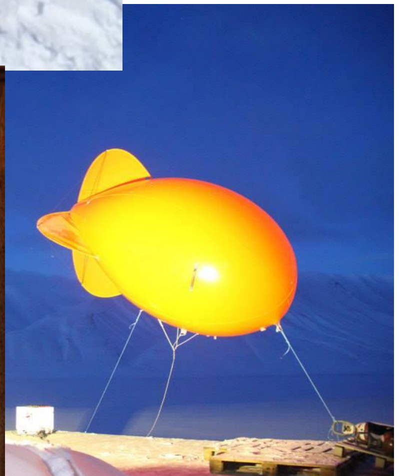
Photo: Amory Ross

Introducing myself..

PhD Geophysics
Sea ice group,
Fairbanks, Alaska (2018)

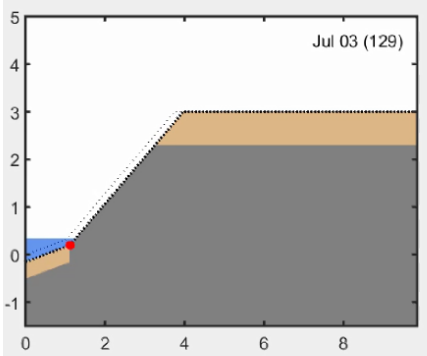
MSc: U. Hamburg, Max Planck Institute for Meteorology (2014)

- Earth system modelling
- Model development:
  - Sea ice
  - Arctic erosion



Sea state variables can be used in a variety of ways

1. Modelling the erosion of frozen coastlines → in a way to couple to ESMs

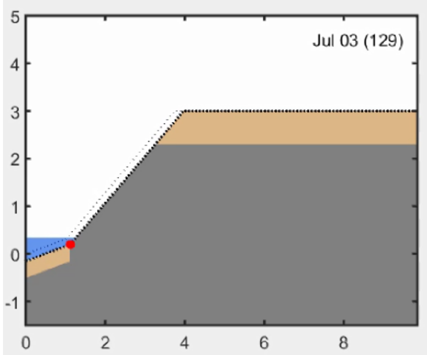


2. Sea state variables: use in community services

3. Outreach of sea state products

Talk outline

1. Modelling the erosion of frozen coastlines → in a way to couple to ESMs




Alaska, Photo: USGS

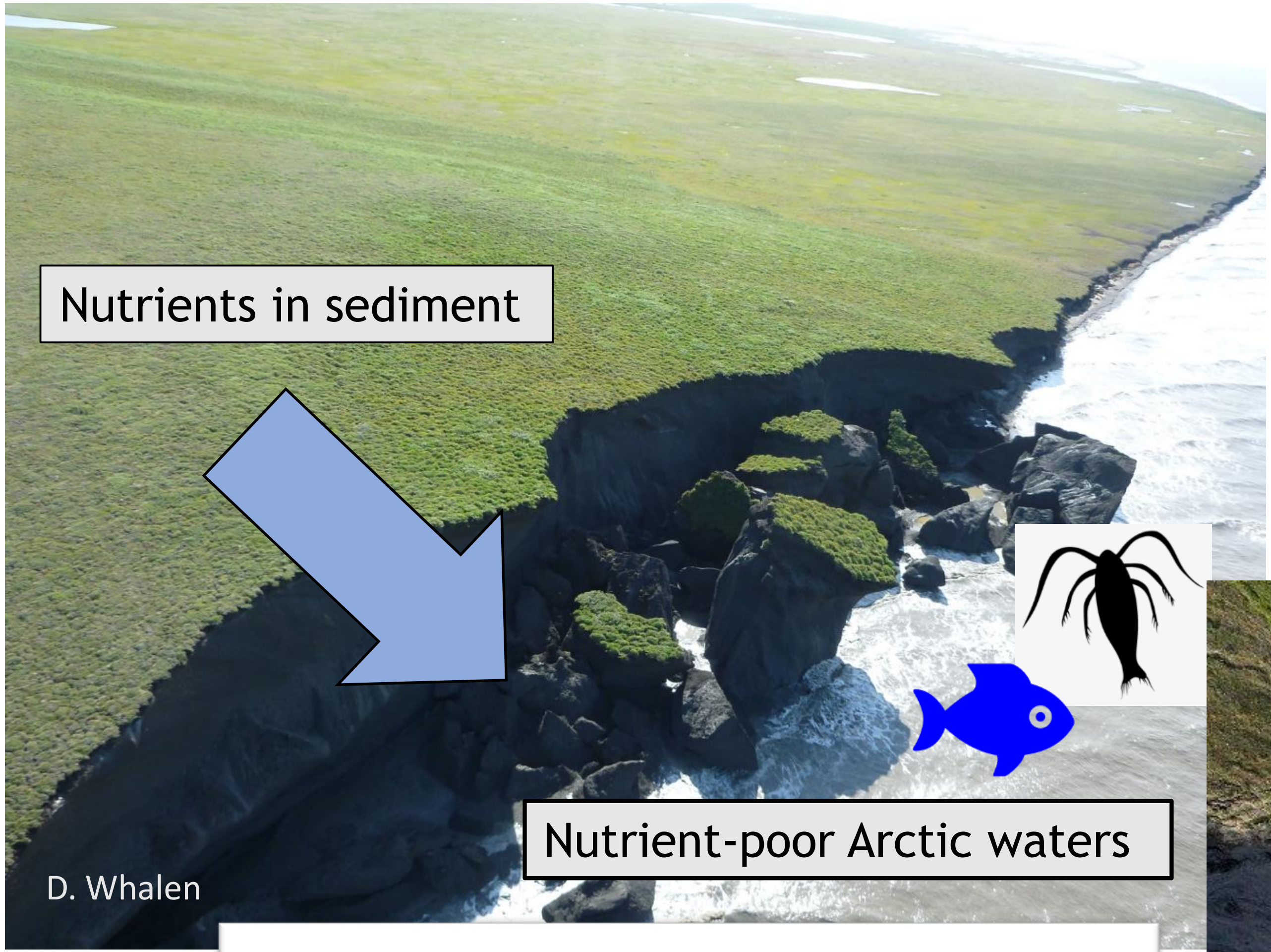

Siberia, Photo: T. Opel

2. Sea state variables: use in community services


Photo: D. Whalen

3. Outreach of sea state products

Why model erosion in the Arctic?



D. Whalen

Geophysical Research Letters

Research Letter | Open Access

Rapid CO_2 Release From Eroding Permafrost in Seawater

G. Tanski, D. Wagner, C. Knoblauch, M. Fritz, T. Sachs, H. Lantuit


Shishmaref, Alaska. USGS


J. Kirby

Impacts of erosion on Arctic communities

- Houses, schools, waste sites lost to sea
- Cannot afford relocation
- Cemeteries being washed away, fear of viruses
- Ice cellars inundated with floodwaters

Evacuation from storms - Arctic village of Kivalina

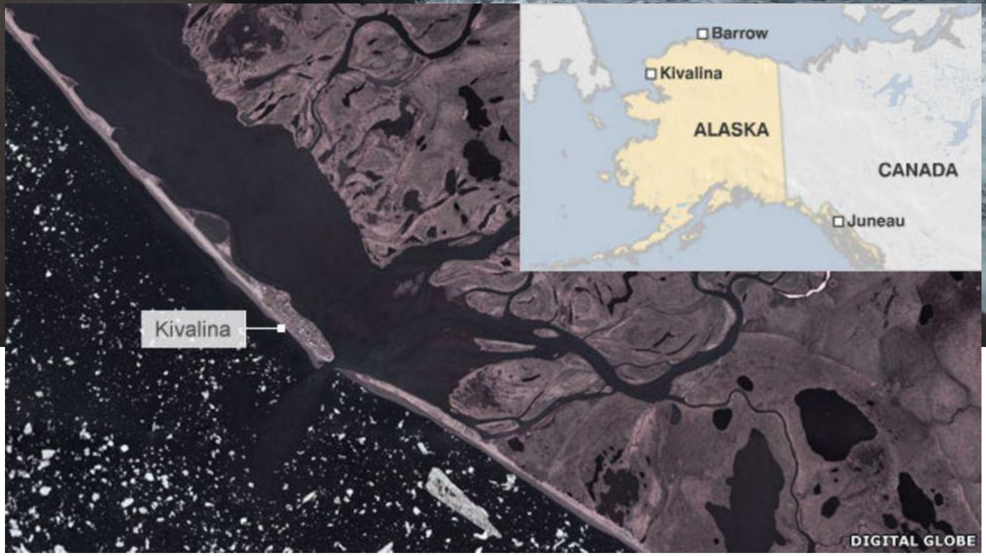
September 2019 Storm.
Photo: Jemeyson

Bulldozers brought in by barge

Photo: Raedle 2019

Escape route for storms

Raedle 2019



- ➢ Expected to be submerged by 2025

What can we contribute in terms of Arctic erosion model development?

What has been done:

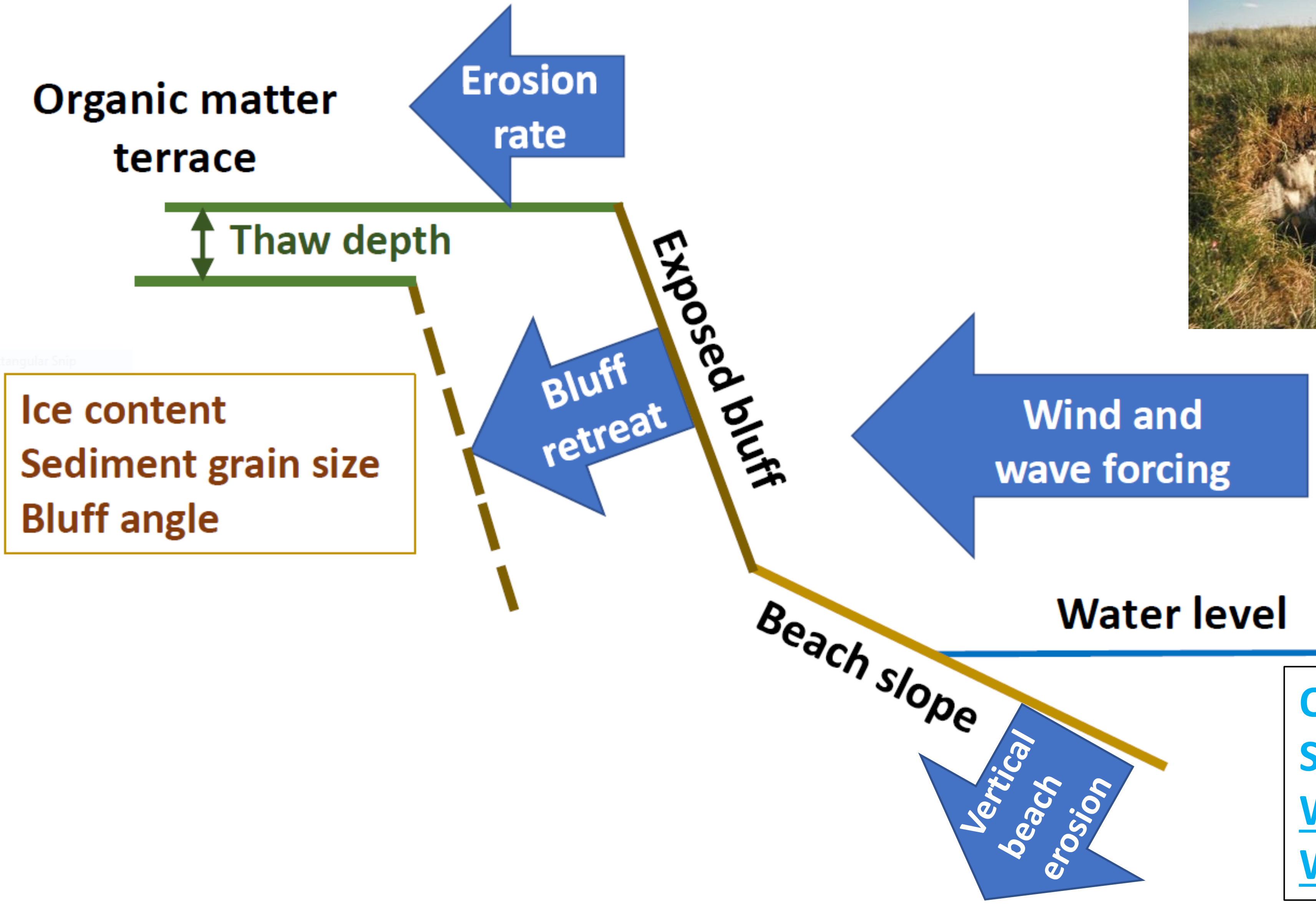
Our project:

Erosion is not yet included in global climate models …

→ **Needs to be fast and simple for coupling**

- ~~Site-specific~~ **pan-arctic** erosion modelling
- Require initialization data ~~unique to certain coastlines~~ **globally available**

Model sketch (Kobayashi et al., 1999)

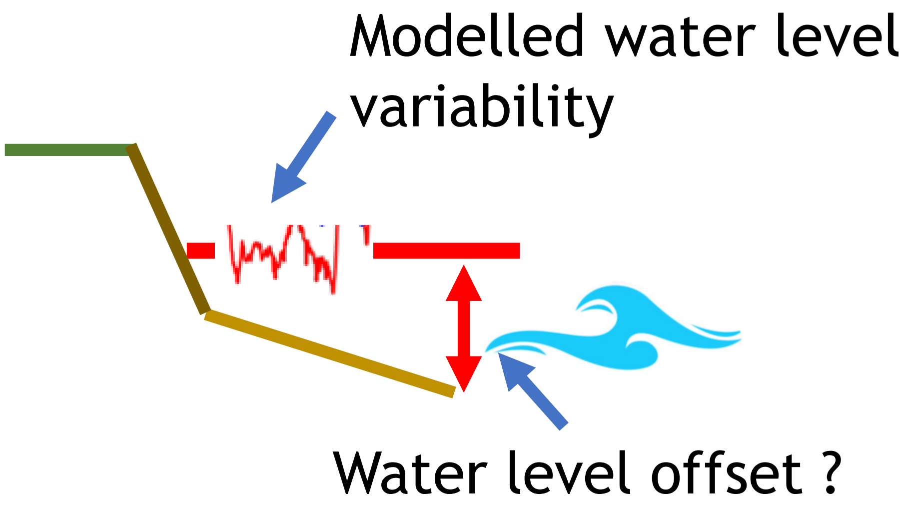


Providing water levels

$$g(h+\eta)\frac{\partial \eta}{\partial x} = (h+\eta)fV + \frac{\tau_{sx}}{\rho}$$

$$\frac{\partial V}{\partial t} = \frac{\tau_{sy} - \tau_{by}}{\rho(h+\eta)},$$

Freeman, Baer, and Jung (1957)



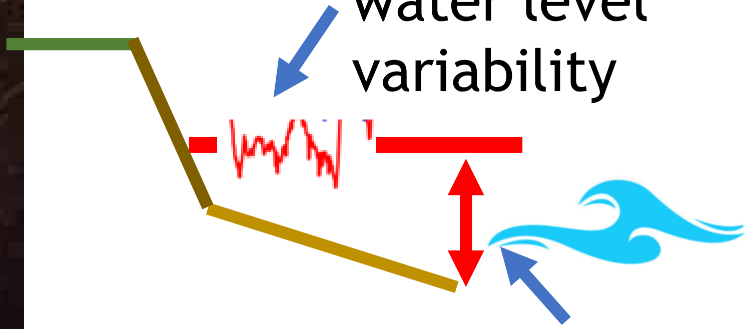
- **Gives water levels as function of changing wind stress → Reanalysis winds**
- Neglects onshore flow
- Solved using finite difference

Footage of general conditions at Drew Point

Need to calibrate water level model to a certain baseline

Video: Ben Jones

Modelled water level variability

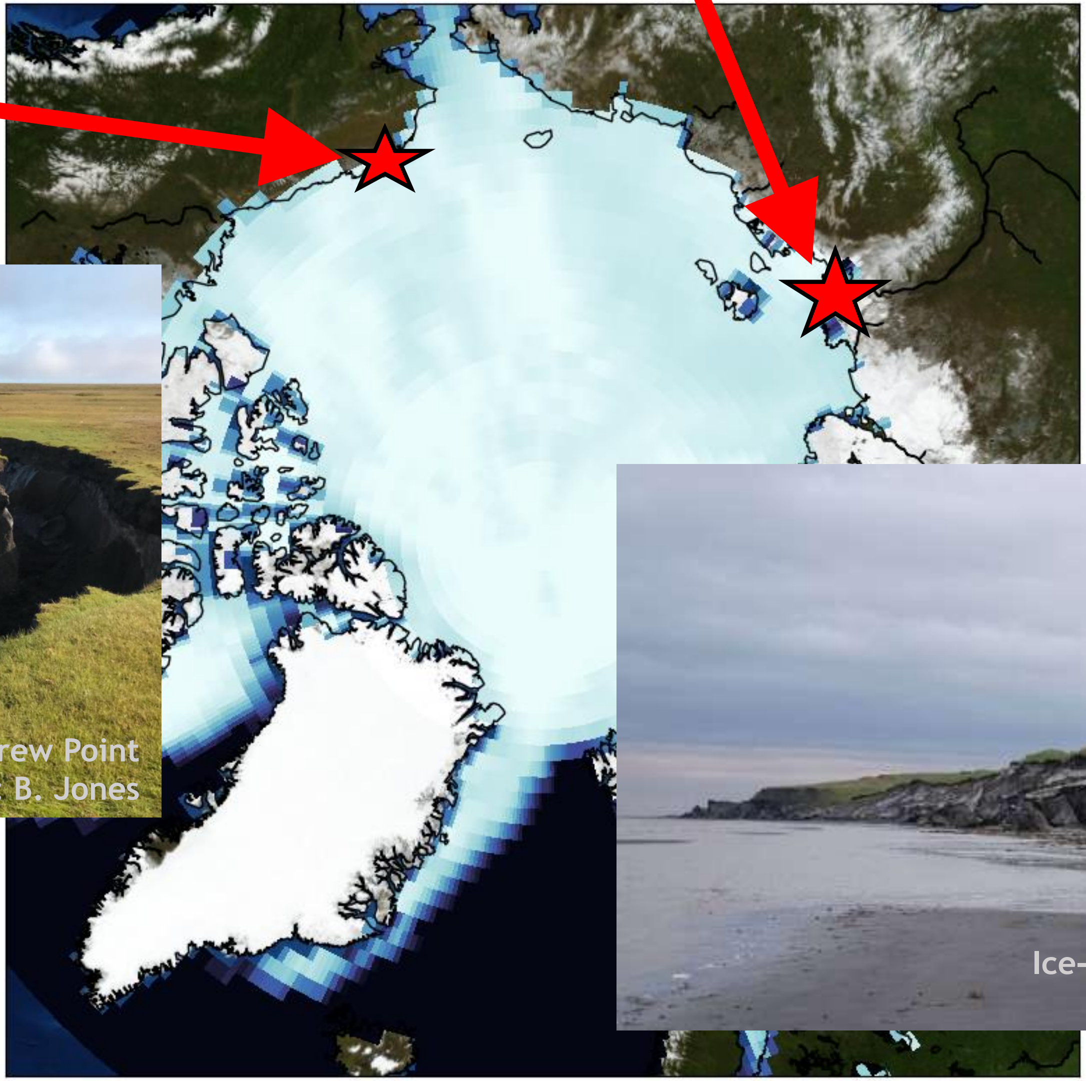


Water level offset ?

Case study sites

Mamontovy Khayata, Bykovsky Peninsula

Drew Point,
Alaska



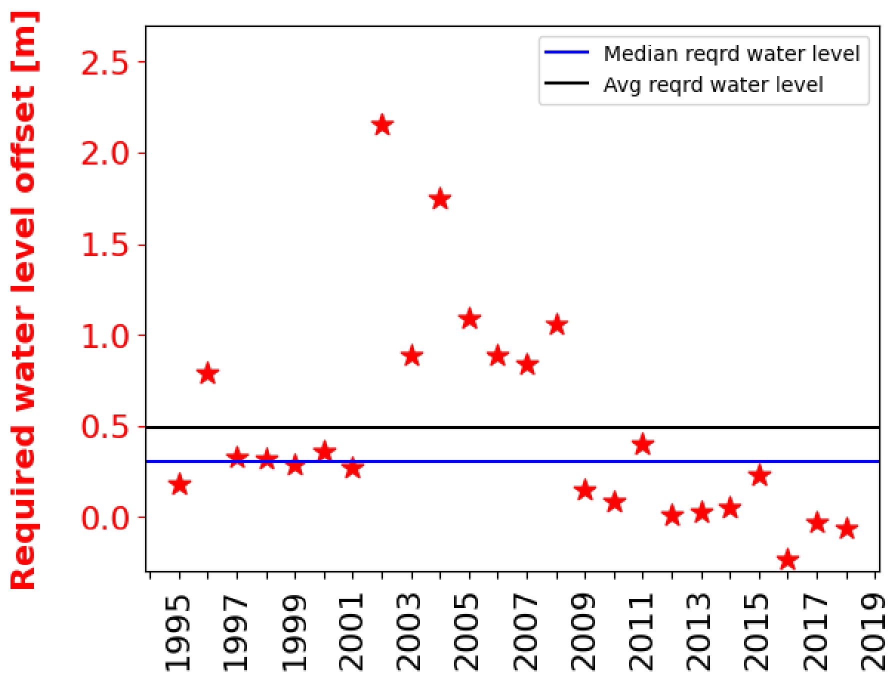
Drew Point
Photo: B. Jones

Ice-rich coasts of Bykovsky Peninsula
Photo: P. Overduin, 2017

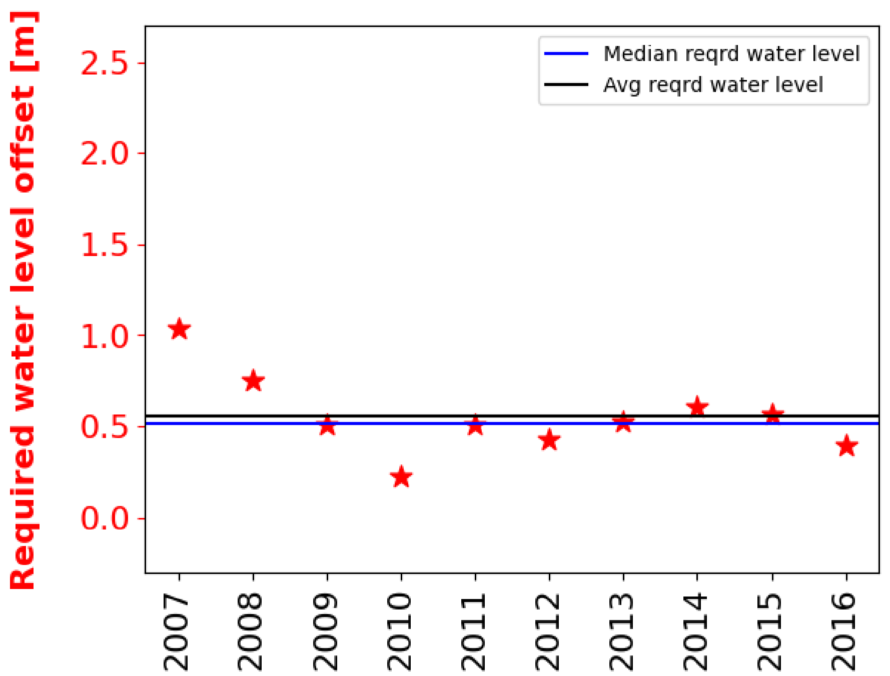
Water level offset: calibrated to observed retreat

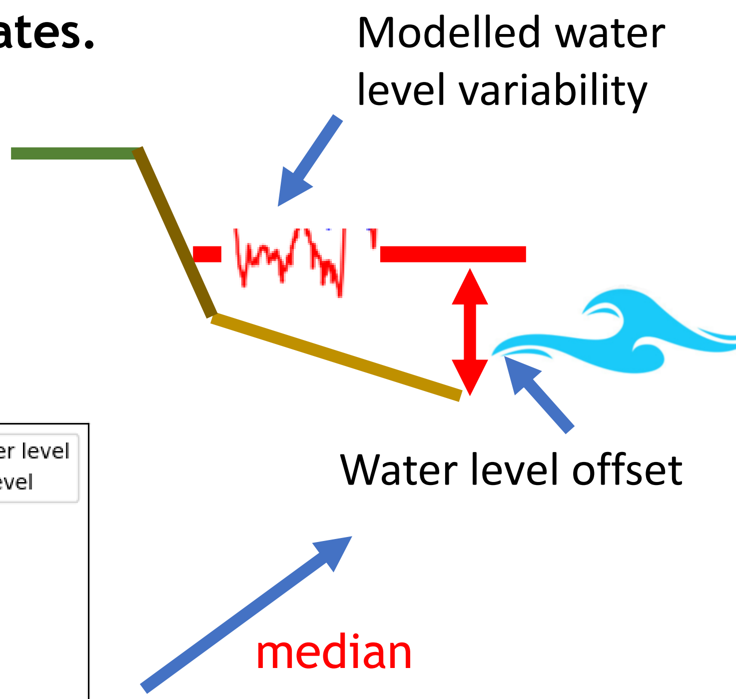
- I found the water level offset required to reproduce the observed retreat rates.

Mamontovy Khayata

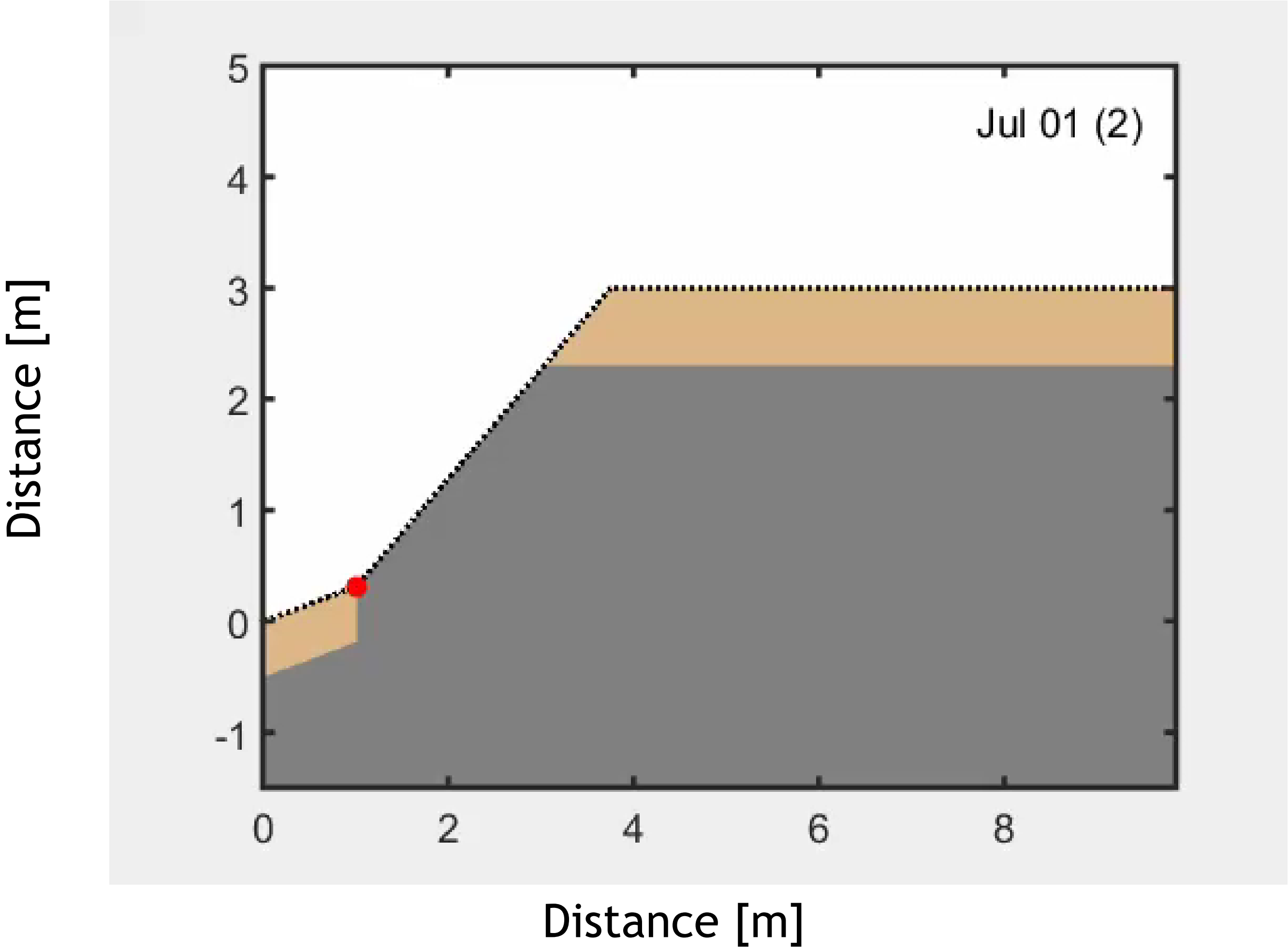


Drew Point





Example output for 1 open water season

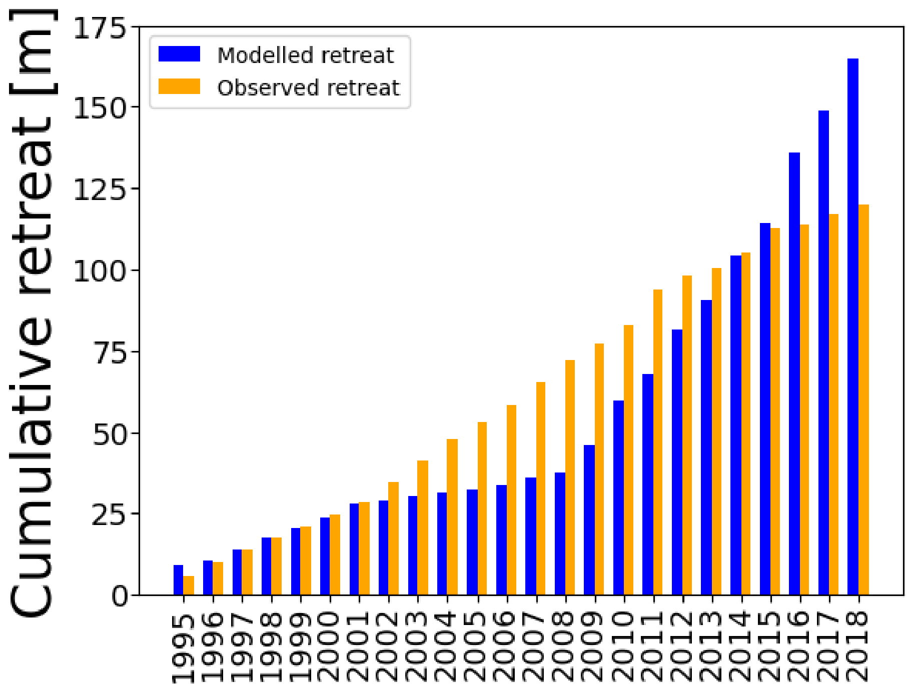


[This is an animation…. You can click it…….]

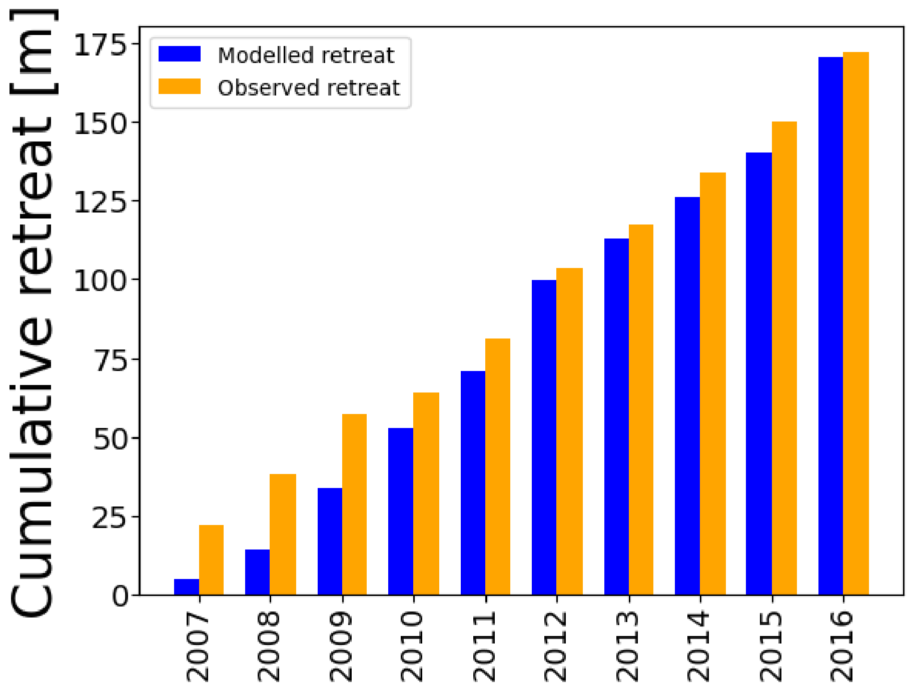
Animation: Paul Overduin (AWI)

How well does model match observed retreat?

Siberia
Mamontovy Khayata



Alaska
Drew Point



- Using the median (calibrated) water level offset
  + reanalysis-forced Freeman (1957) model
- Masked during times of sea ice cover
- Retreat rates are the right order of magnitude

Monte Carlo sensitivity studies

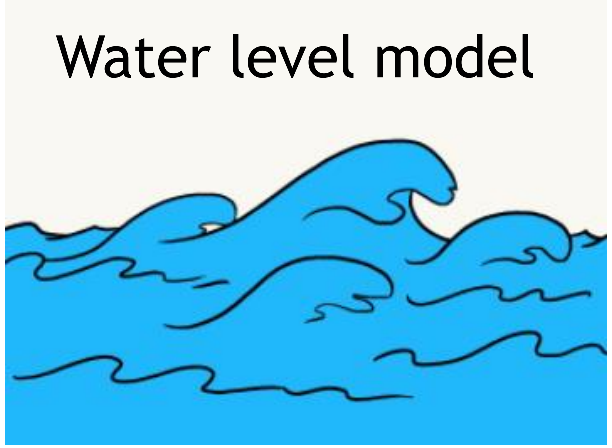
How does erosion rate change when you ...

- Change the amount of ice in the cliff?
- Change cliff angle ?
- Change thaw depth ?
- ...

Parameter	Low	Typical	High	Reference
Initial unfrozen beach sediment thickness [m]	0.5	1	2	Kobayashi et al. (1999)
Cliff height [m]	5 (MK), 1 (DP)	10 (MK), 3 (DP)	20 (MK), 10 (DP)	Overduin et al. (2007), Jones et al. (2018)
Cliff angle [degrees]	45	60	90	Overduin et al. (2007), Jones et al. (2018)
Initial unfrozen cliff sediment thickness [m]	0.1	0.2	0.5	Günther et al. (2015)
Coarse sediment volume per unit volume unfrozen cliff sediment [%]	5	10	20	Kobayashi et al. (1999), Overduin et al. (2014)
Ice volume per unit volume frozen cliff sediment [%]	60	80	90	Overduin et al. (2007), Kanevskiy et al. (2013)

Table 1. Parameter values used in the Monte-Carlo sensitivity studies to initialize the erosion model.

Erosion modelling summary



+

= Cliff retreat rates

- Model forced by globally available data

- We can apply it pan-Arctic --- as long as we have (even one or rough) historical retreat rates for calibration

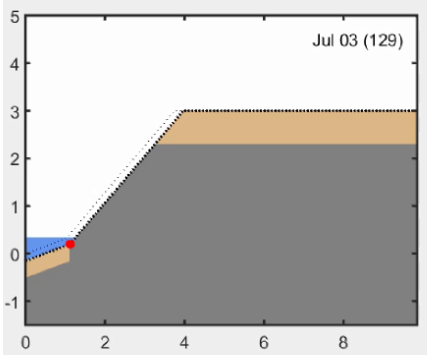
  - These datasets are available
    - Lantuit et al. (2012)

  → Current work… not just 2 proof-of-concept sites, but whole Arctic coastline & Erosion forecasting using projected winds

- Apply for quantification of carbon and nutrient input into ocean due to Arctic erosion

Talk outline

1. Modelling the erosion of frozen coastlines → in a way to couple to ESMs



Alaska, Photo: USGS

Siberia, Photo: T. Opel

2. Sea state variables: use in community services

Photo: D. Whalen

3. Outreach of sea state products

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Wave conditions impact subsistence hunting

- More open water ≠ more time to hunt by boat
- Snowmachine ⟷ boat

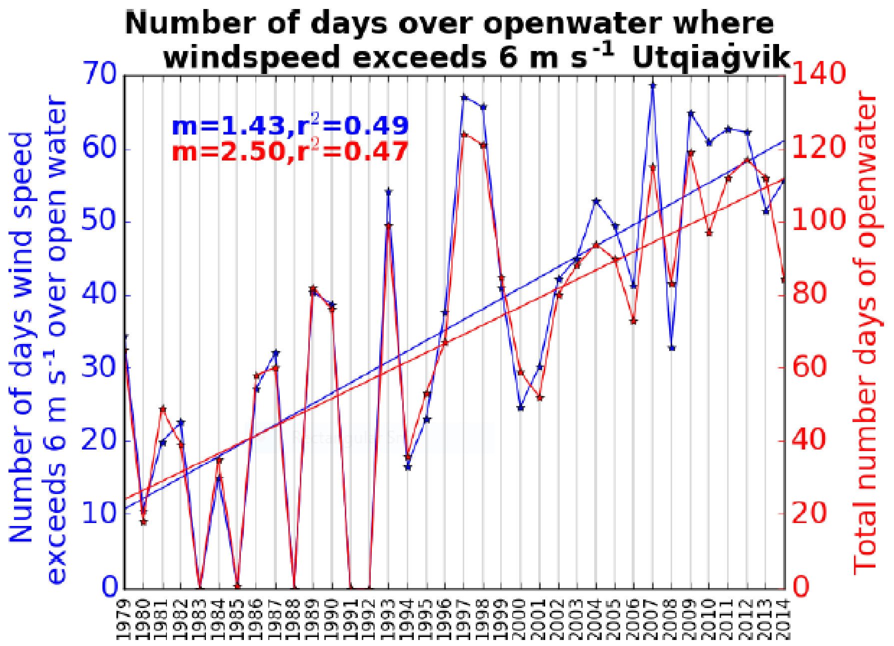
Can we quantify the social impact of ocean variables?

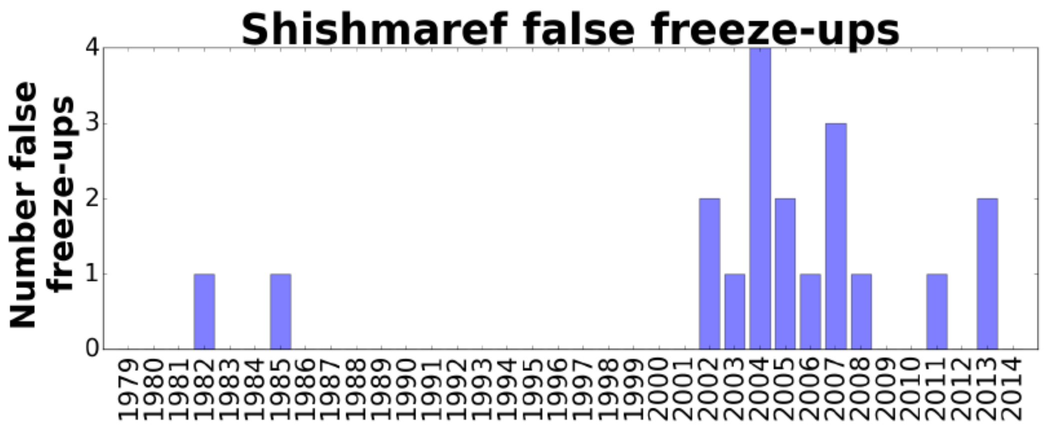
Point Hope, AK
J. Mishler

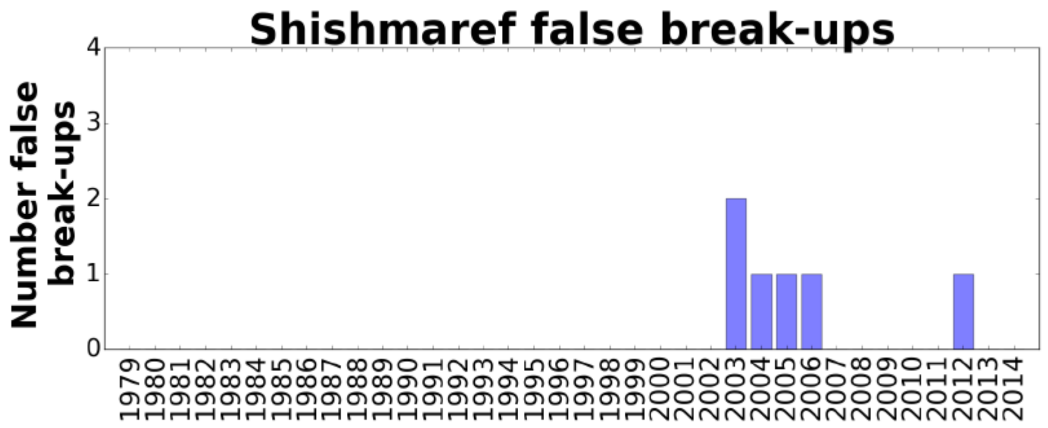
Night-time polar bear watch at Utqiagvik in Spring
Photo: Yuyan

Developing socially-relevant indices from climate datasets

- Directly use ocean variables to inform native communities
  - Thresholds
  - Interviews
- Hunters said higher than 6 m/s winds make it too difficult to hunt by boat
  - Wind speed threshold
- Number of times a switch is likely between boat and snow machine
  - Sea ice concentration threshold

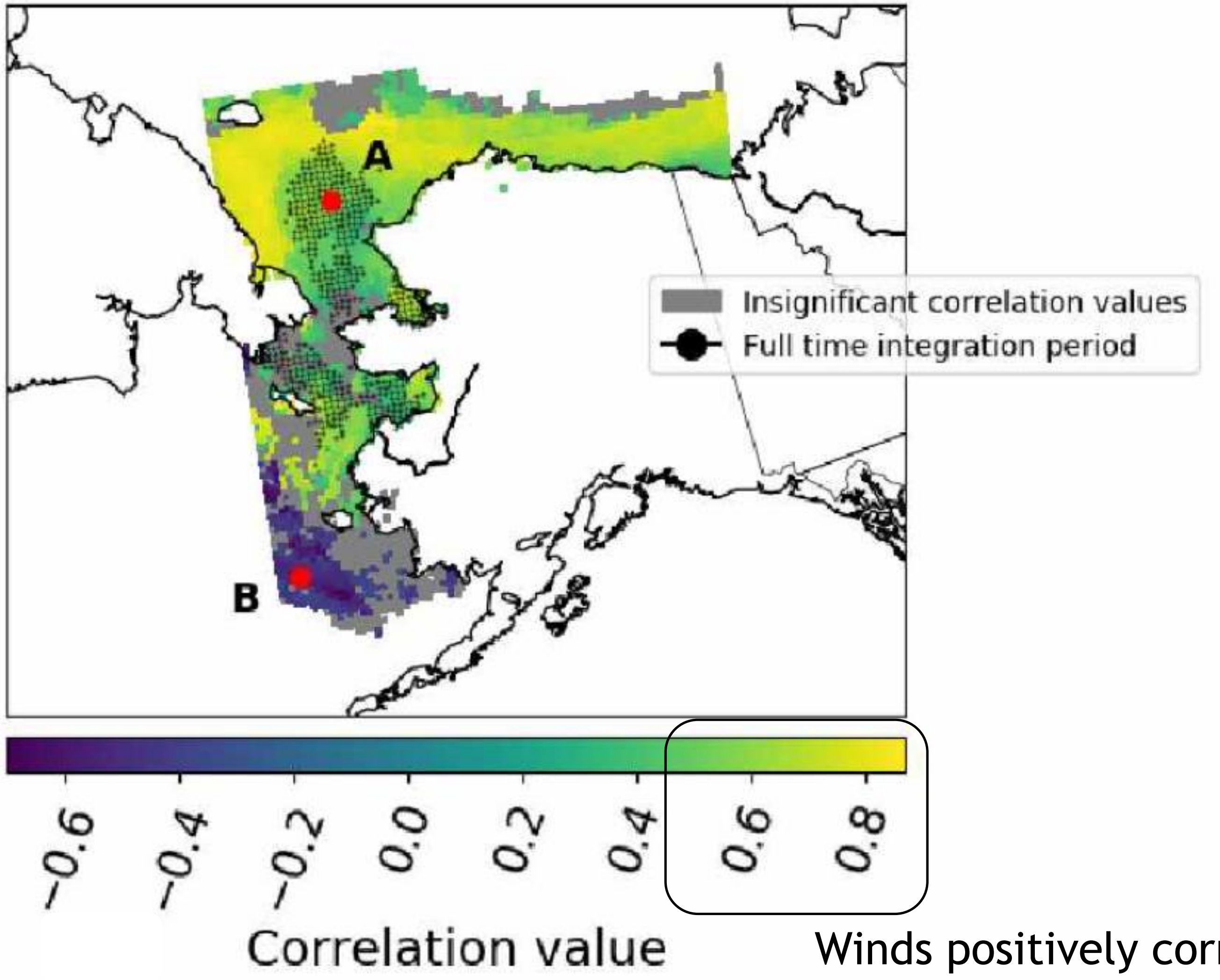






Rolph et al. (2018) *The Cryosphere*

Storms and upper ocean heat loss



Winds positively correlated with delayed freeze-up

- Correlations between:
  - cumulative wind energy input
  - freeze-up timing
- Chukchi:
  - Mixed layer deepening results in greater water volume to be cooled prior to freeze-up
  - more stormy season -> later freeze-up
- Bering:
  - Ice advection & shorter timescales
  - Storms promote freeze-up

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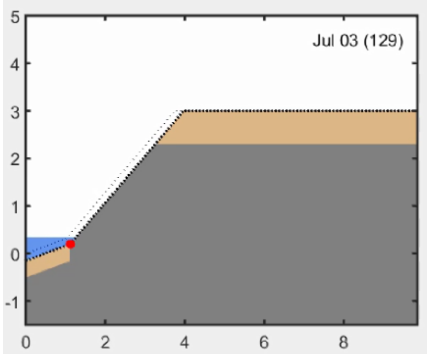

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Media attention for sea state products

Breakout 3 – Ocean and climate: How can data visualisation help us to tell a meaningful and tangible story?

Contributions from: Ana Agostinho, Anne-Cécile Turner, Charlie Cope, Dorina Seitaj, Eugenia Manzanas, Jo Finon, Lewis Blaustein, Peter Landschützer, Rebecca Rolph, Russell Stevens, Sunshine Menezes, Susan Glenny, Tania Mendes.

Merging sports and climate communication

- 2.5 million viewers 2017/18, 1.2 million followers on Facebook
- Don't forget sports as a means for outreach

Crossed seas

- Foilers boats
- Quiver charts:
  mean swell/long period wave direction

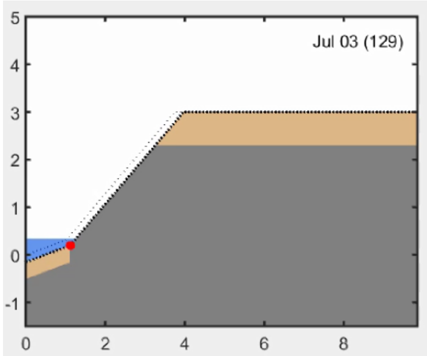
  overlaid on

  sea/short period wave direction
- Qualitative, to avoid large and crossed seas
- SWH (“we don’t go there if SWH > X m”)
- Boat ‘polar’ calculates potential boat speed
  - wave height and direction

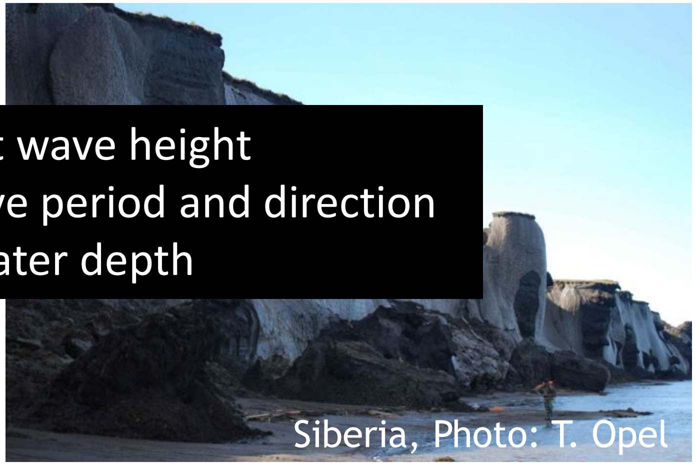
    e.g. reduce 10% boat speed if waves are head on

Summary

1. Modelling the erosion of frozen coastlines → in a way to couple to ESMs




Alaska, Photo: USGS


Siberia, Photo: T. Opel

- Significant wave height
- Mean wave period and direction
- Coastal water depth

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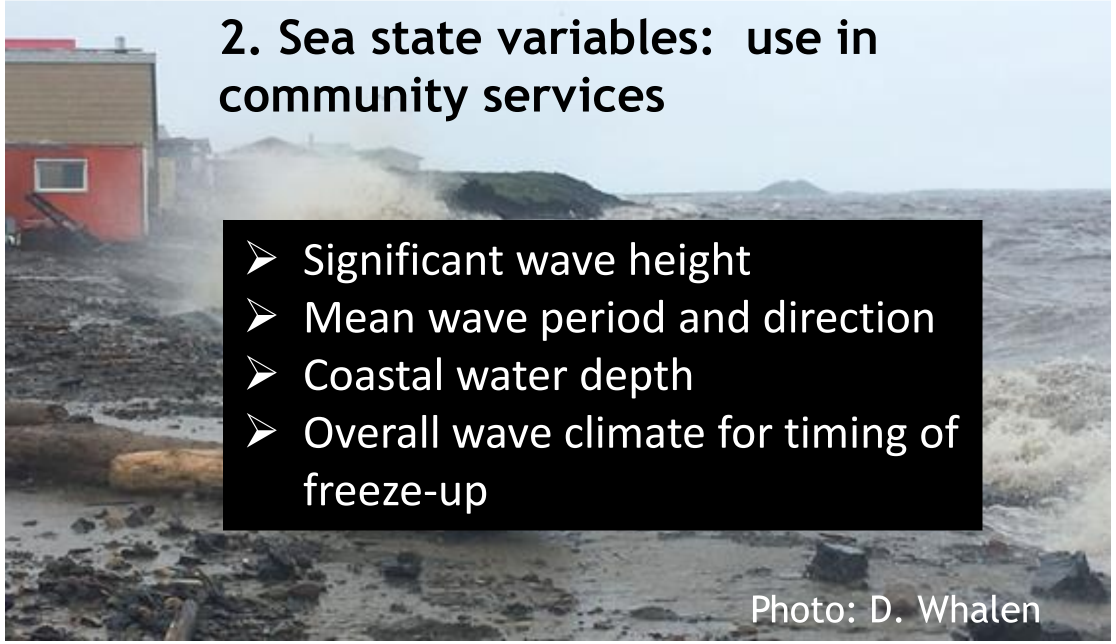
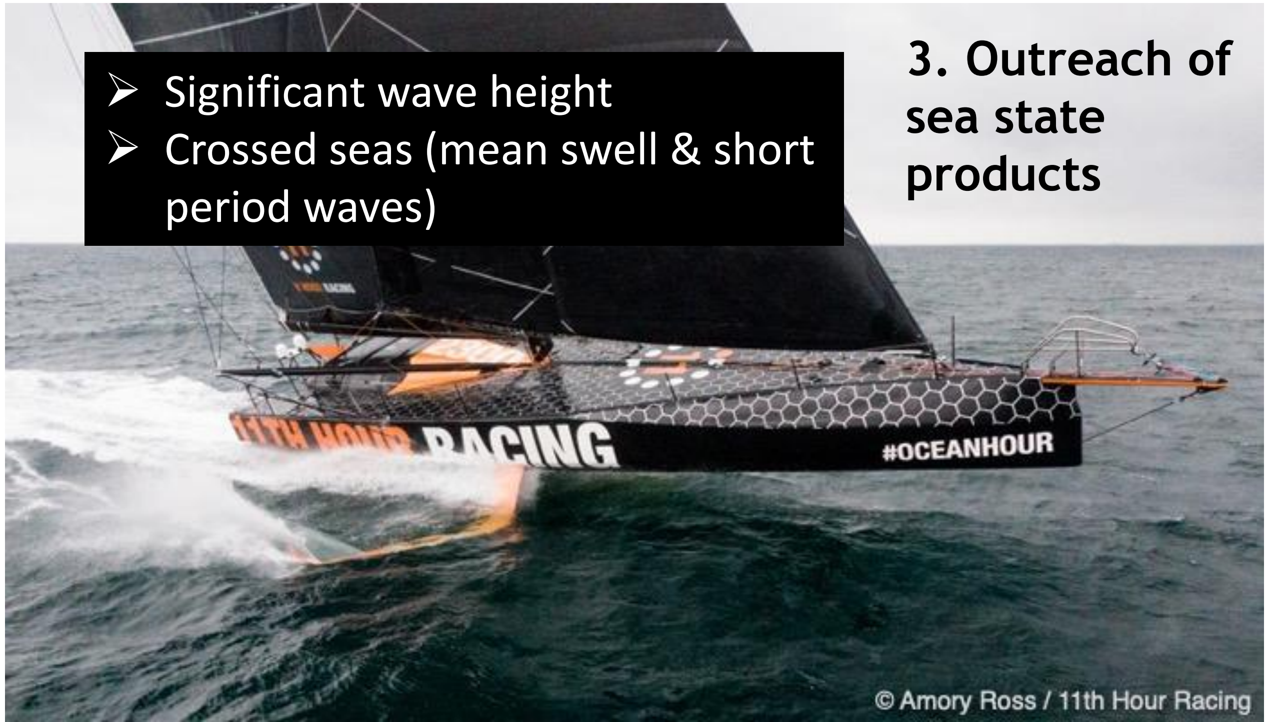


Photo: D. Whalen

- Significant wave height
- Mean wave period and direction
- Coastal water depth
- Overall wave climate for timing of freeze-up

3. Outreach of sea state products



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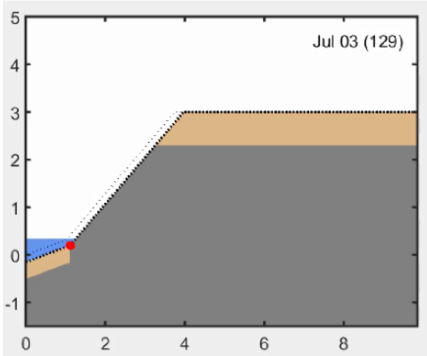
- Significant wave height
- Crossed seas (mean swell & short period waves)

Thank you! rebecca.rolph@awi.de

1. Modelling the erosion of frozen coastlines → in a way to couple to ESMs

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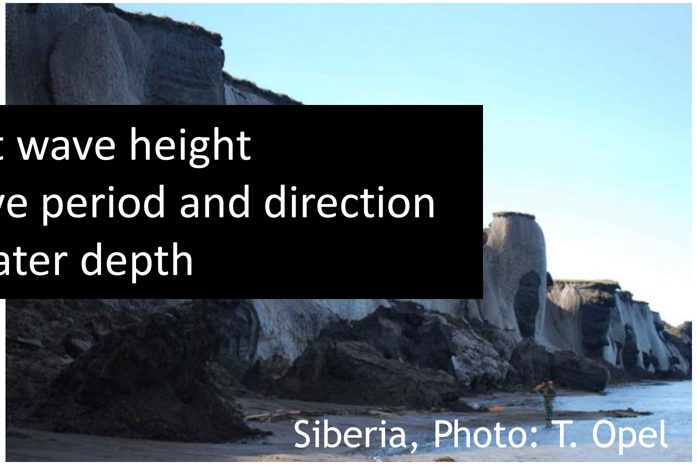
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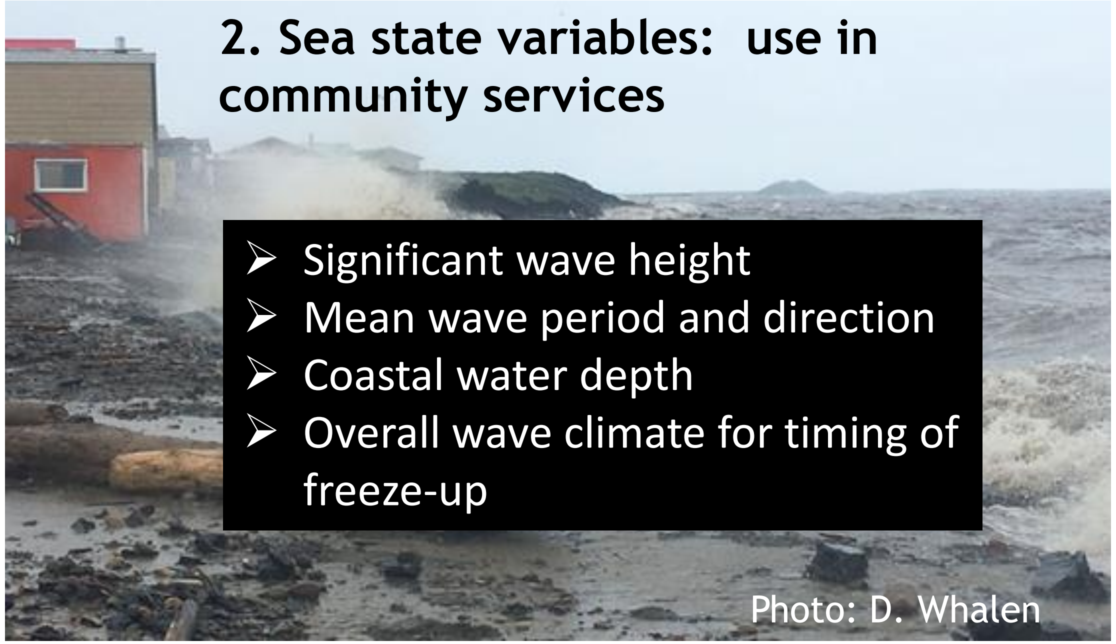

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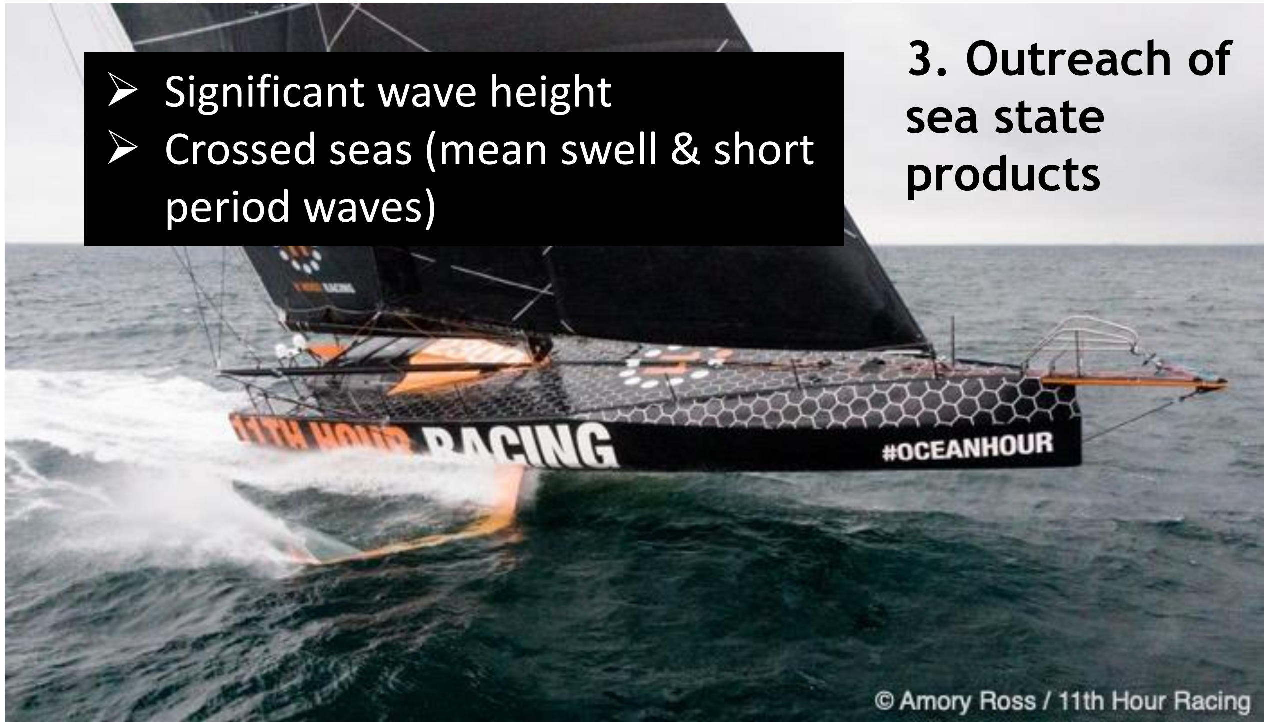

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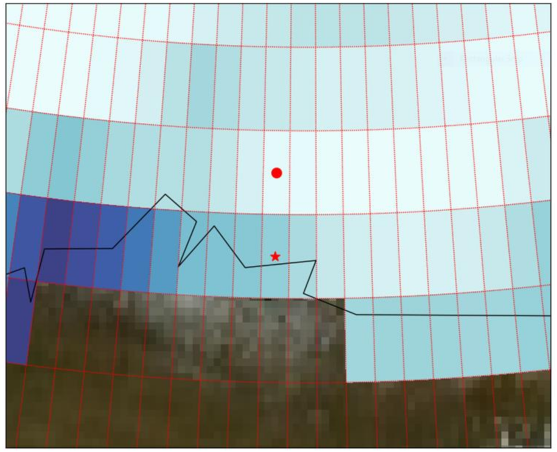
Supplementary slides

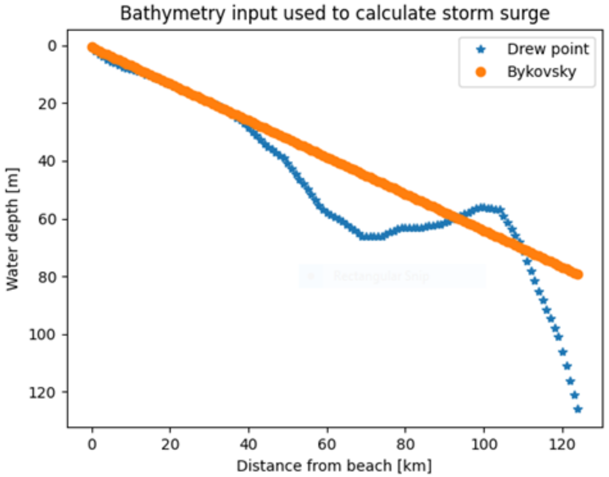
Forcing for the storm surge model



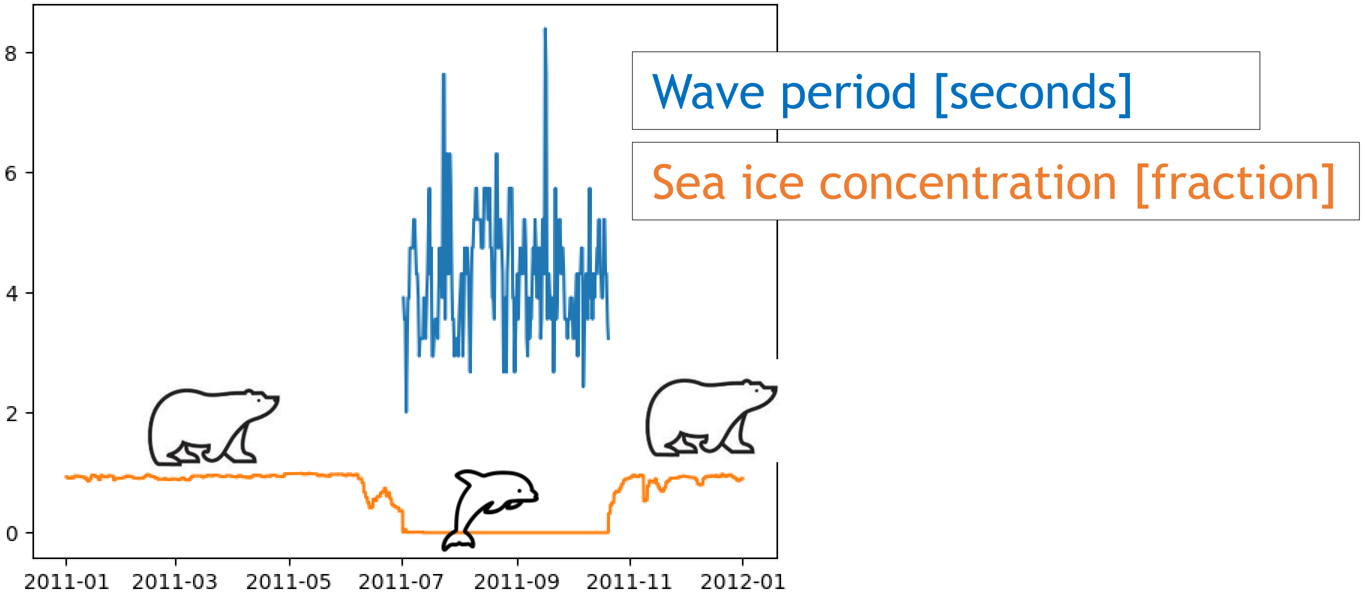
ERA-Interim reanalysis data:

- Wind speed
- Wind direction
- Wave height (for erosion model)
- Wave period (for erosion model)

Bathymetry



Masked at timesteps with sea ice cover



Storm surge model

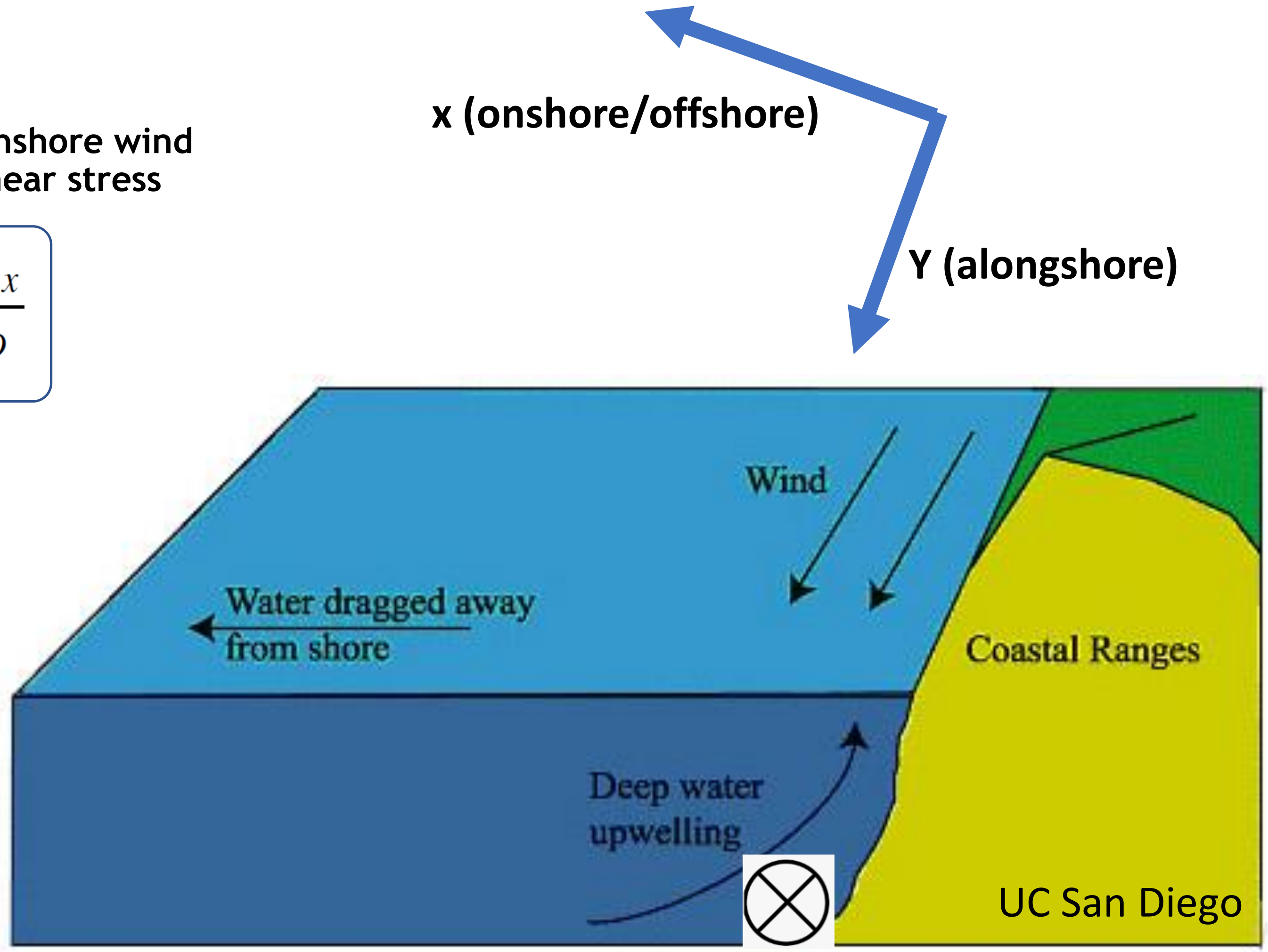
Freeman, Baer, and Jung (1957)

Hydrostatic forces from changing water level | Coriolis force induced by alongshore flow | Onshore wind shear stress

$$g(h+\eta)\frac{\partial \eta}{\partial x} = (h+\eta) f V + \frac{\tau_{sx}}{\rho}$$

Change in alongshore flow | Alongshore surface and bottom shear stresses

$$\frac{\partial V}{\partial t} = \frac{\tau_{sy} - \tau_{by}}{\rho(h+\eta)},$$



- <u>**Gives water levels as function of changing wind stress**</u>
- Neglects onshore flow
- Solved using finite difference

Cumulative wind energy input calculation

$$\frac{\delta E}{\delta t} = \rho m C_d u^3$$

where p = 1 . 2 is air density,
m = 10-3 is an efficiency factor
Cd = 10-3 is a drag coefficient,
u is wind speed at 10 m above sea level