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

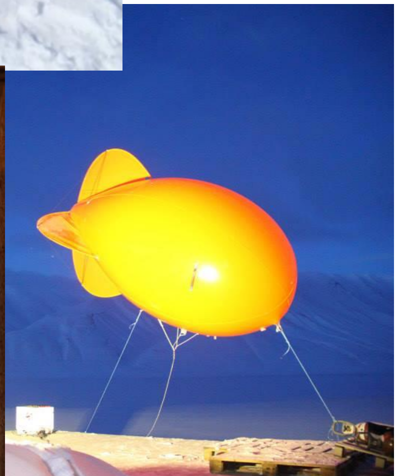
Photo: Amory Ross

Introducing myself..

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

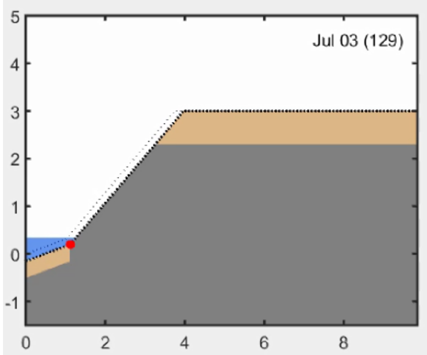
MSc: U. Hamburg, Max Planck Institute for Meteorology (2014)

- 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



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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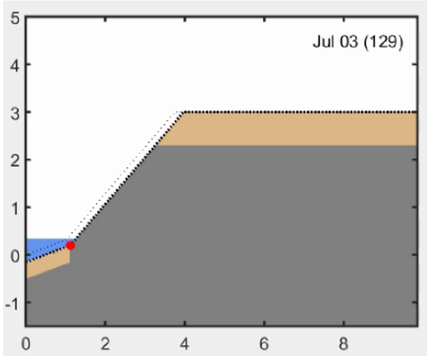
Talk outline

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



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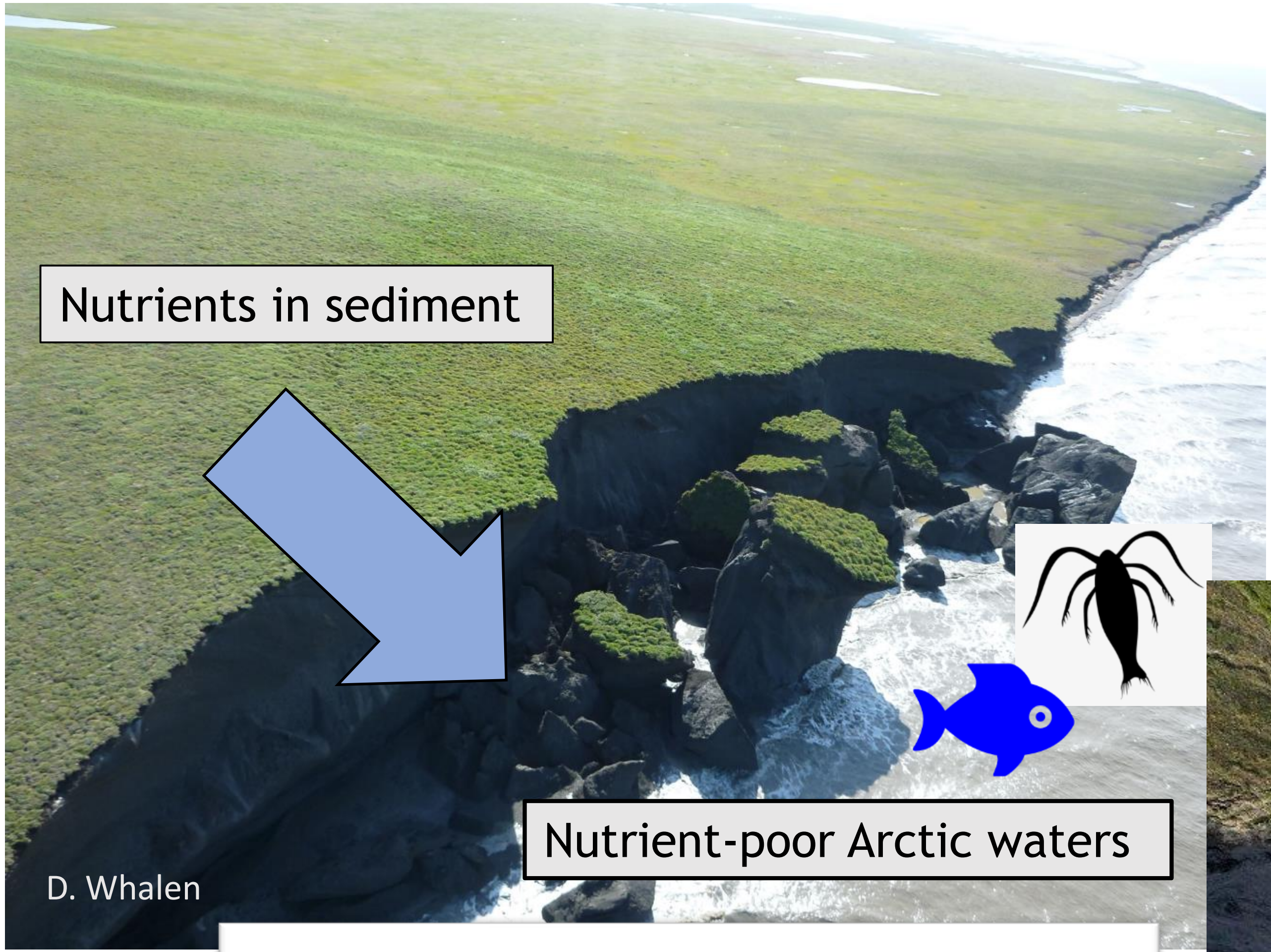
Why model erosion in the Arctic?



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

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

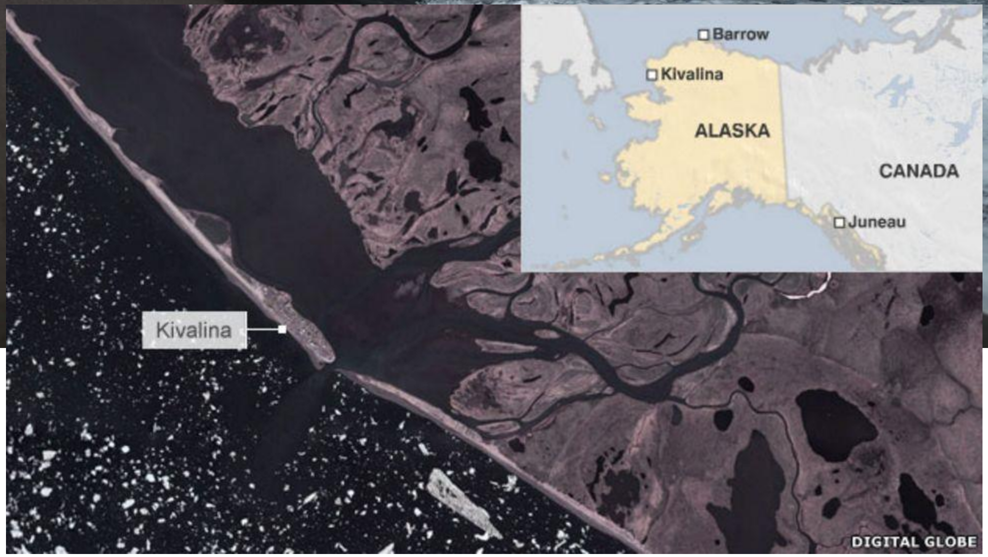
September 2019 Storm.
Photo: Jemeyson

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**

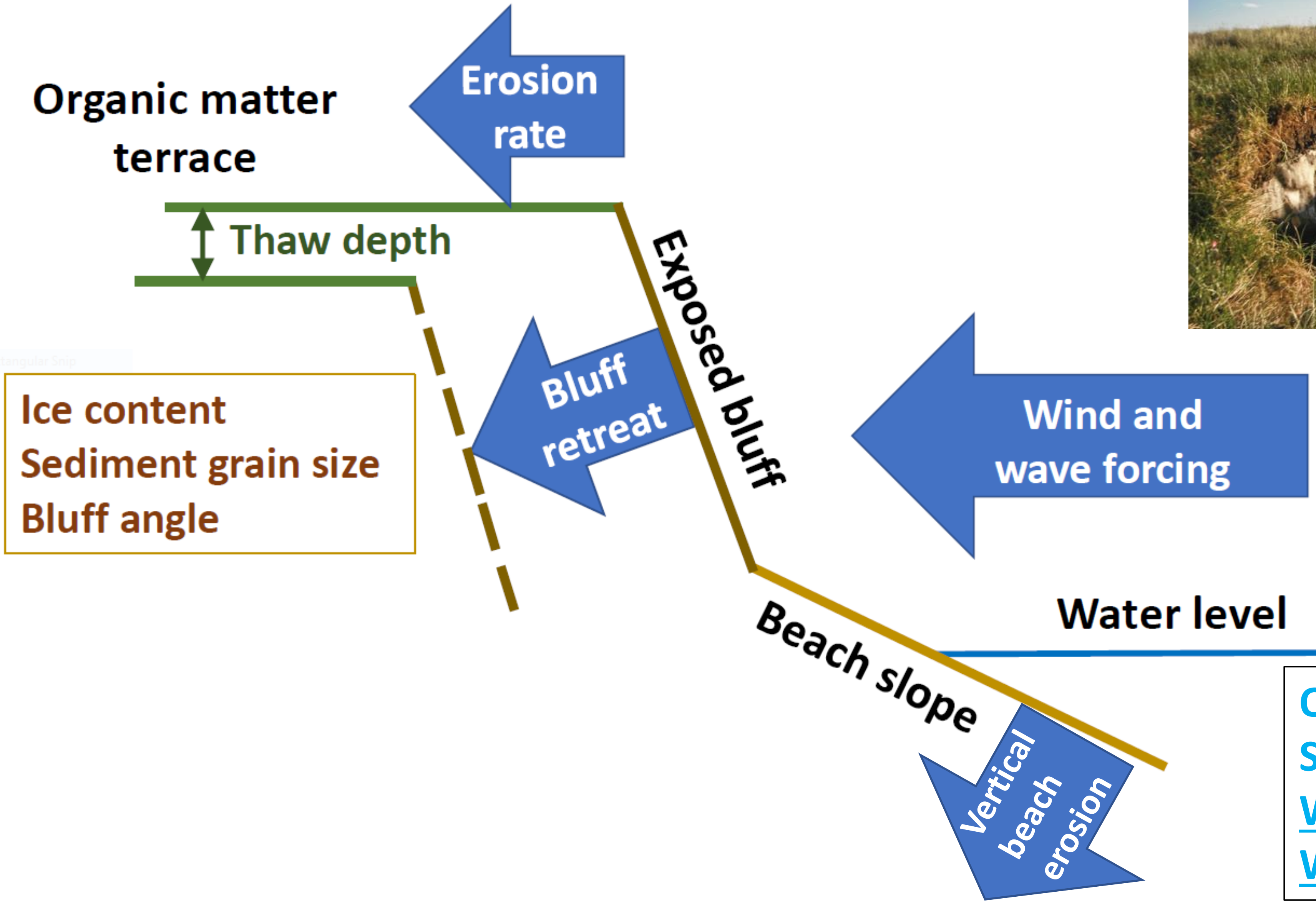
pan-arctic

- ~~Site-specific~~ erosion modelling

globally available

- Require initialization data ~~unique to certain coastlines~~

Model sketch (Kobayashi et al., 1999)

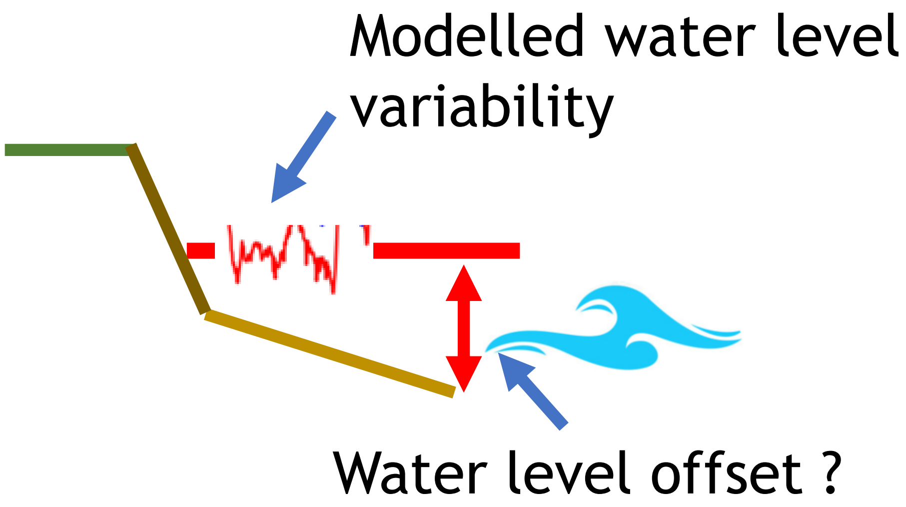


Providing water levels

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

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

Freeman, Baer, and Jung (1957)

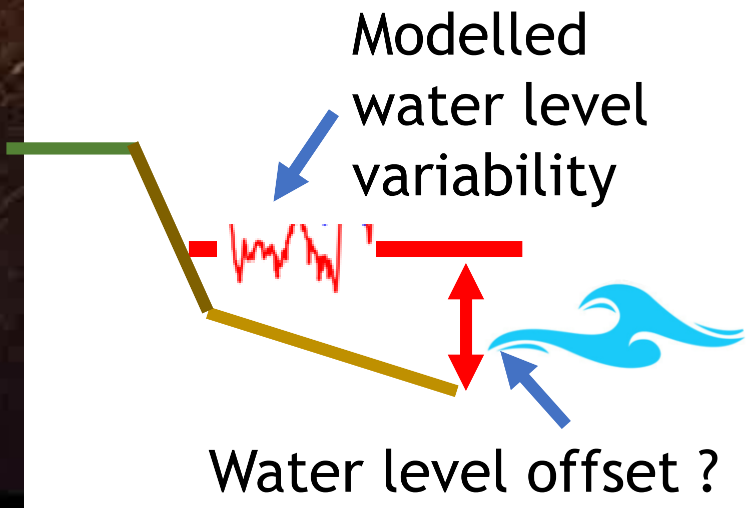


- ➢**Gives water levels as function of changing wind stress** → **Reanalysis winds**
- ➢Neglects onshore flow
- ➢Solved using finite difference

Footage of general conditions at Drew Point

Need to calibrate water level model to a certain baseline

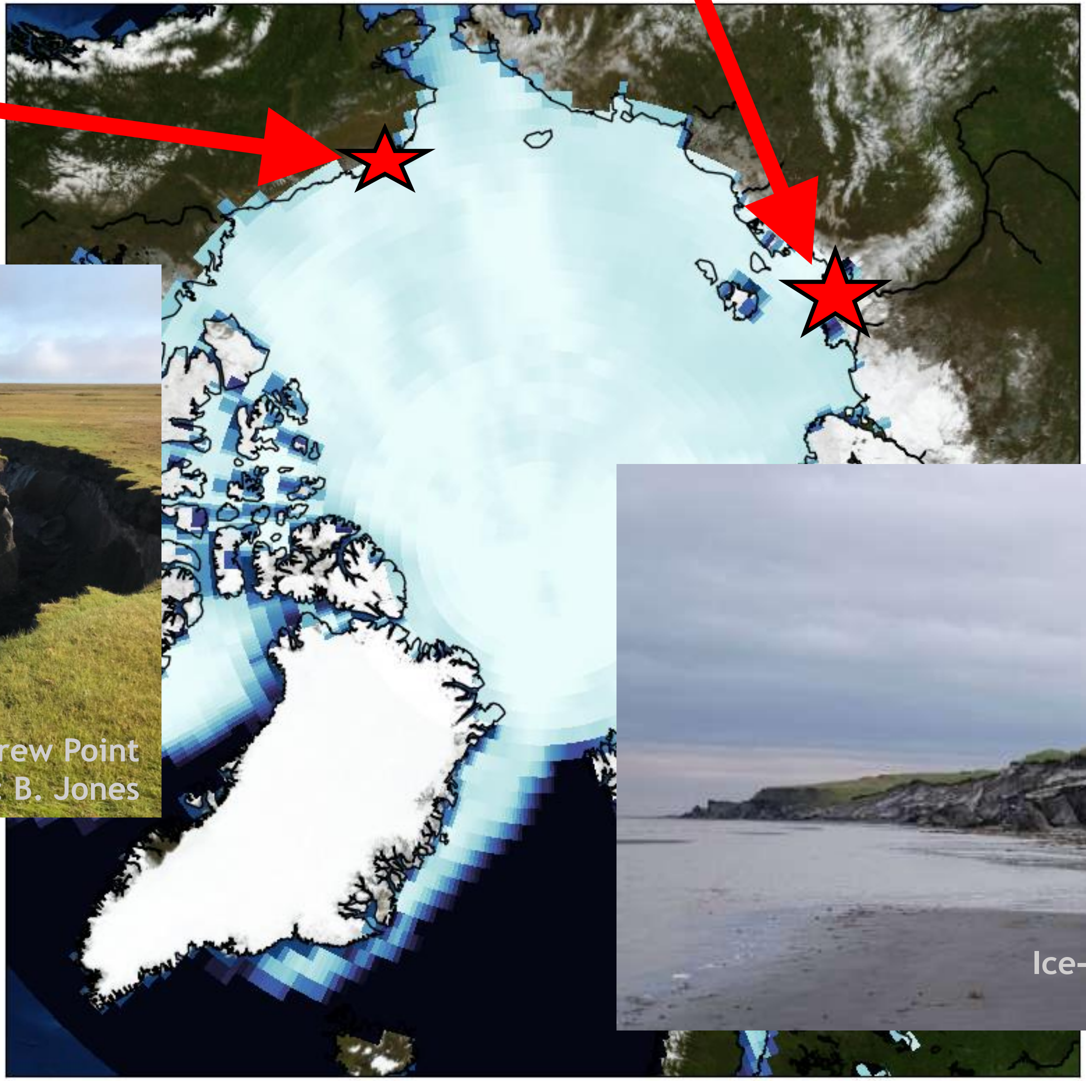
Video: Ben Jones



Case study sites

Mamontovy Khayata, Bykovsky Peninsula

Drew Point,
Alaska

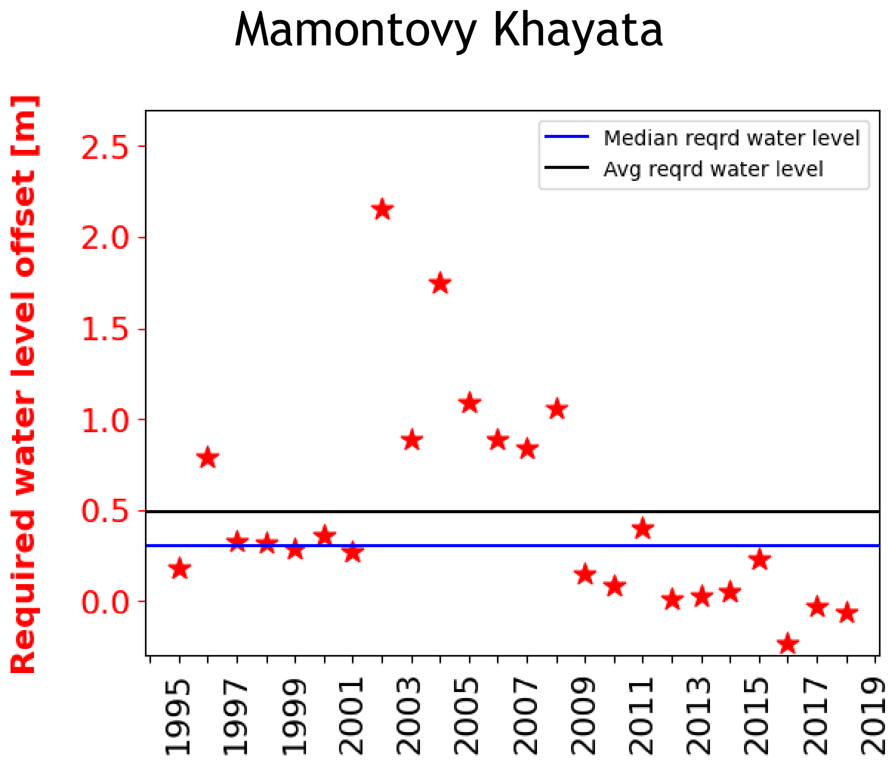


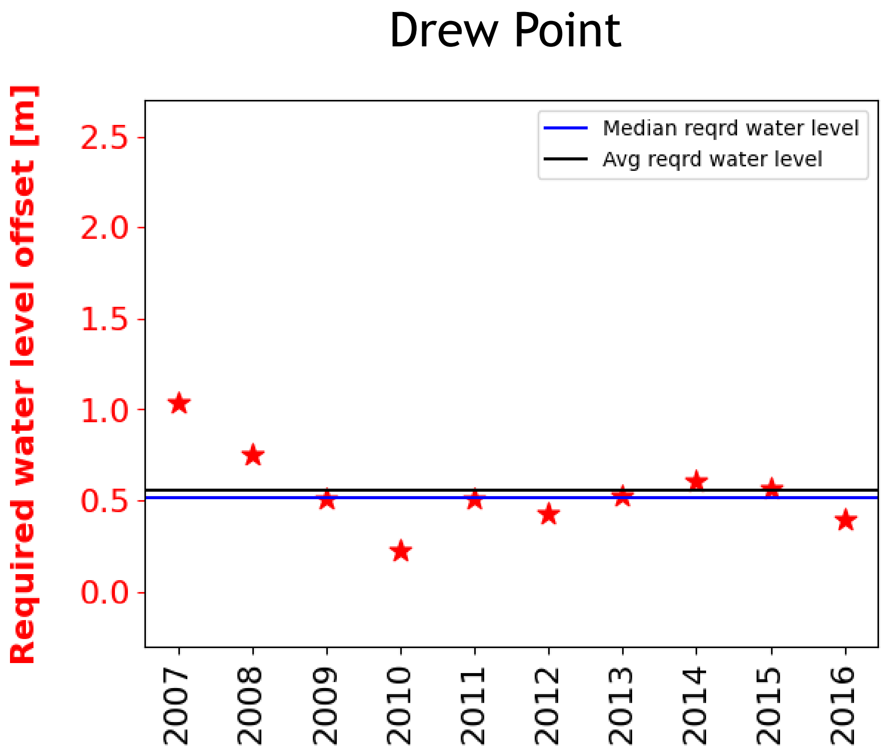
Drew Point
Photo: B. Jones

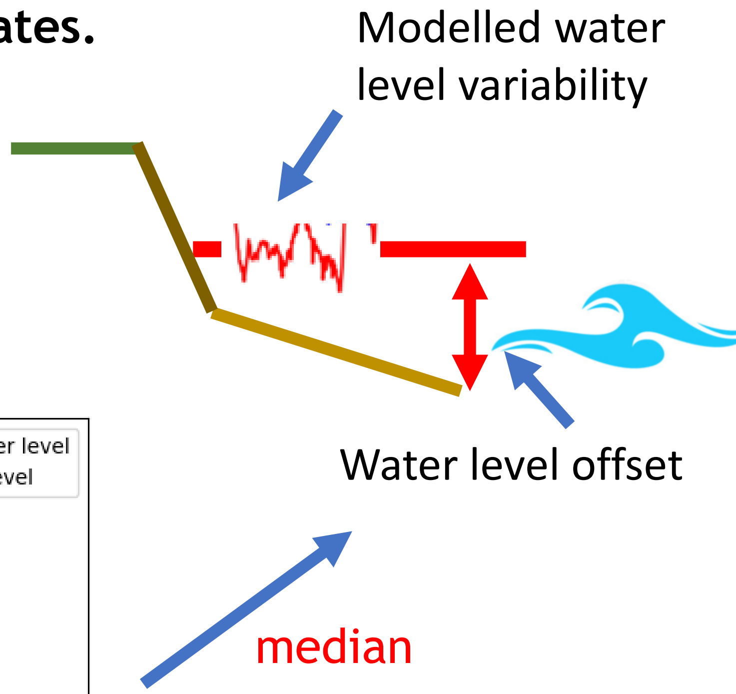
Ice-rich coasts of Bykovsky Peninsula
Photo: P. Overduin, 2017

Water level offset: calibrated to observed retreat

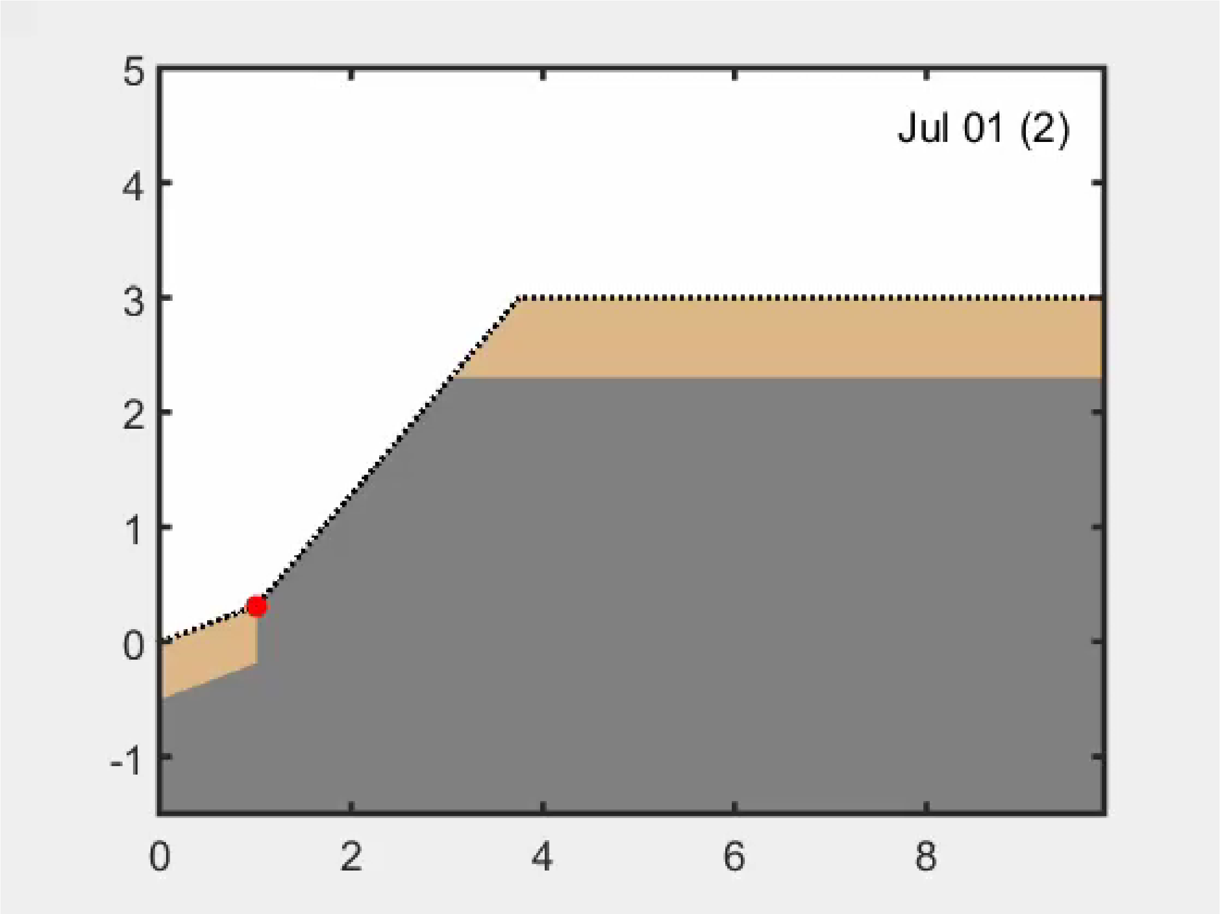
- I found the water level offset required to reproduce the observed retreat rates.







Example output for 1 open water season



Distance [m]

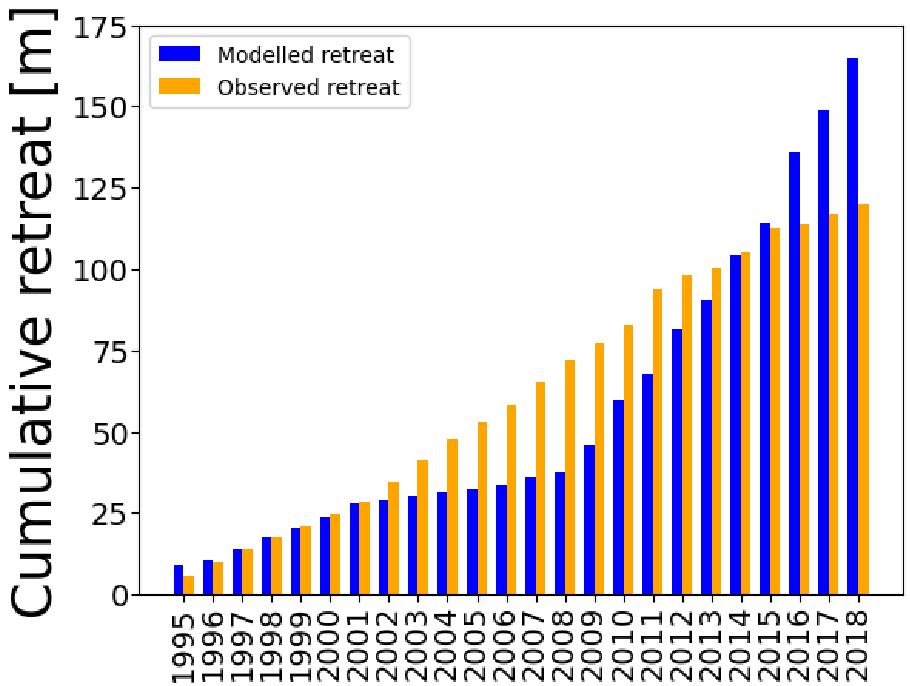
Distance [m]

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

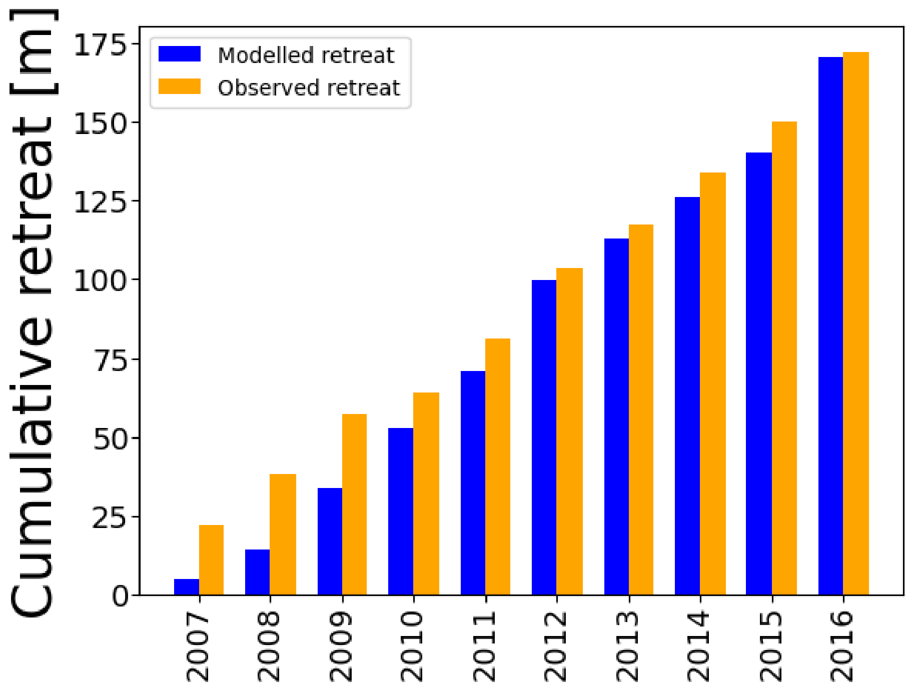
Animation: Paul Overduin (AWI)

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

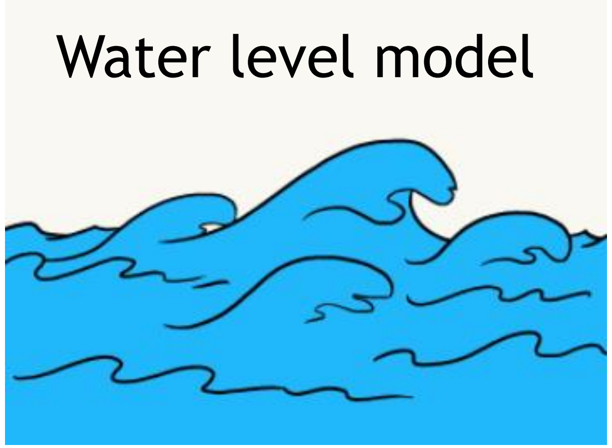
How does erosion rate change when you …

- 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

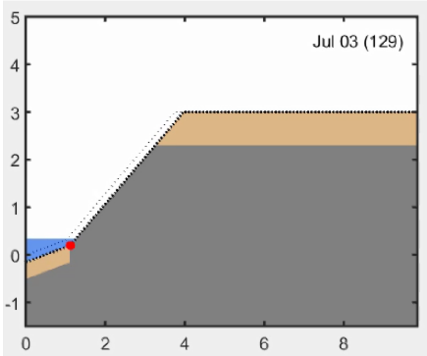
&

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

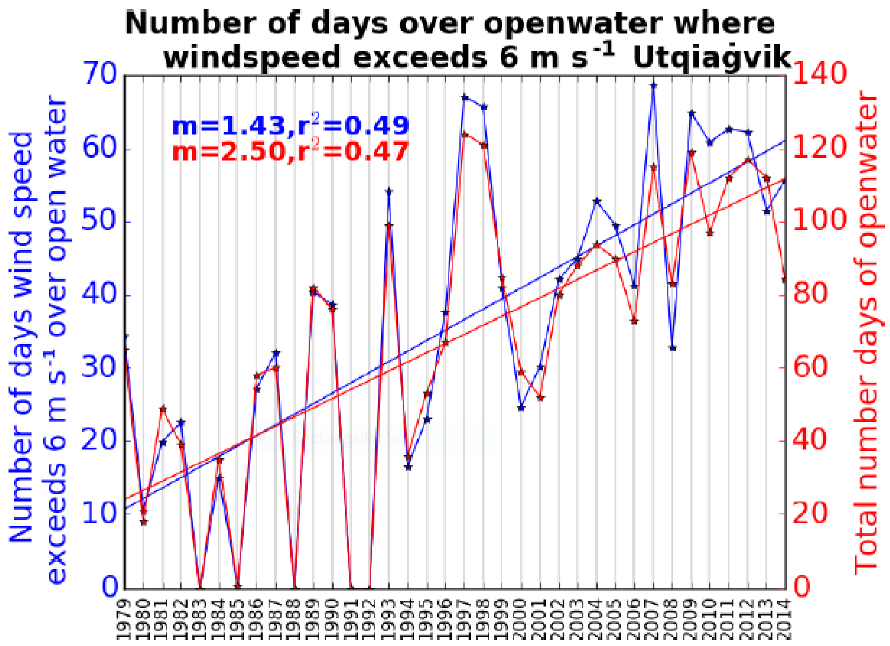
Can we quantify the social impact of ocean variables?

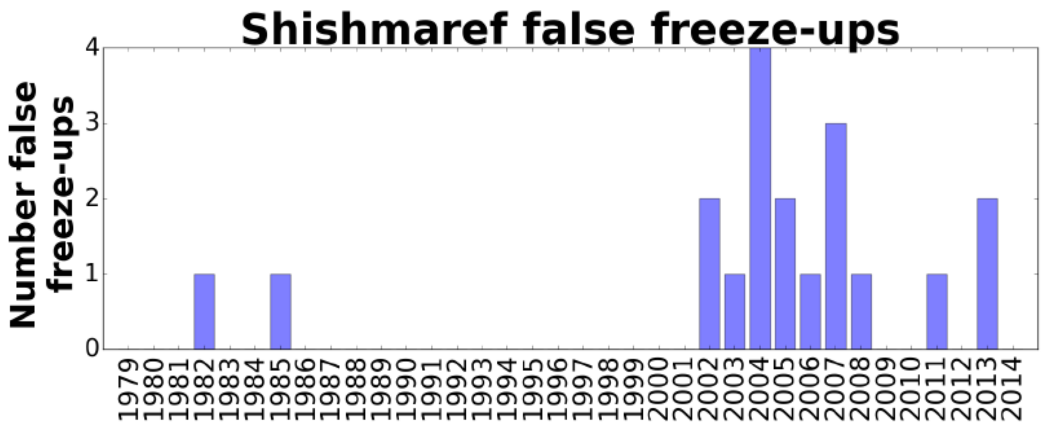
Night-time polar bear watch at Utqiagvik in Spring
Photo: Yuyan

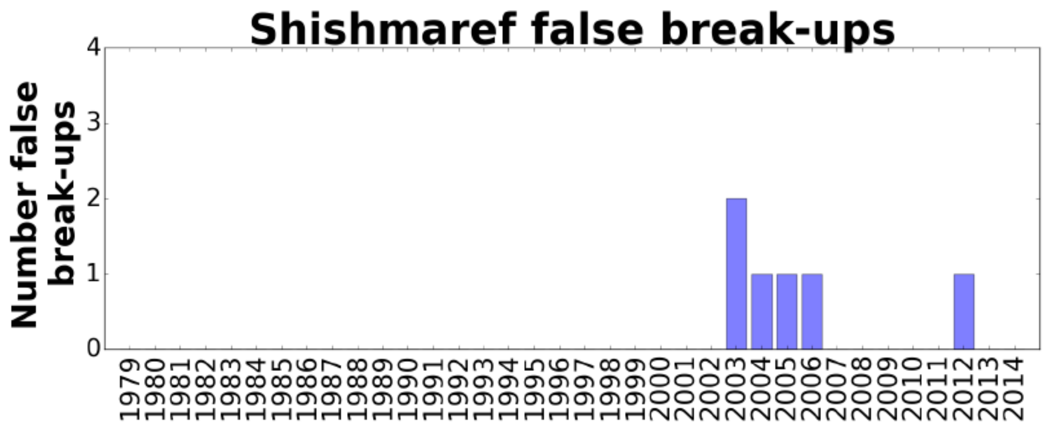
Point Hope, AK
J. Mishler

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

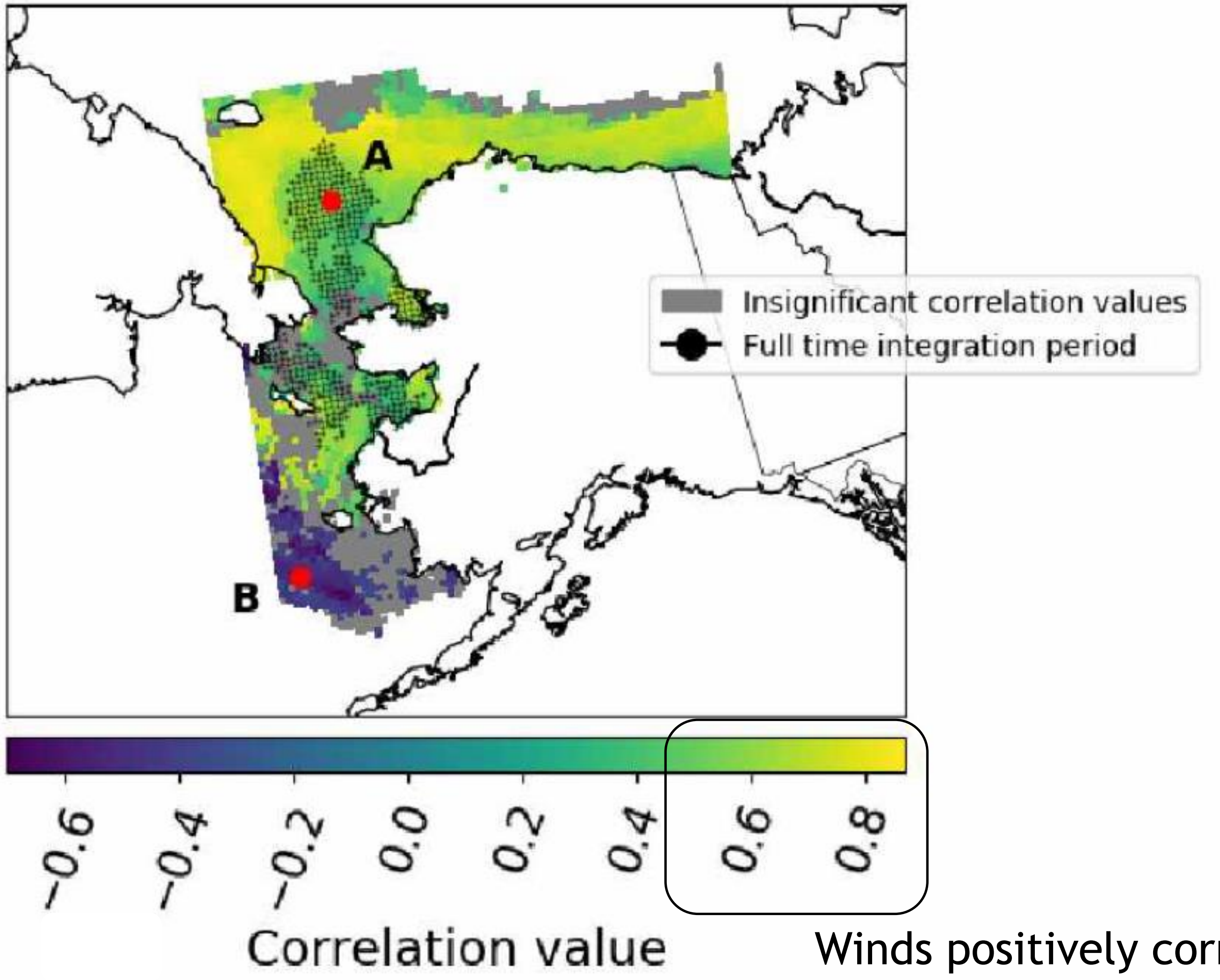






Rolph et al. (2018) *The Cryosphere*

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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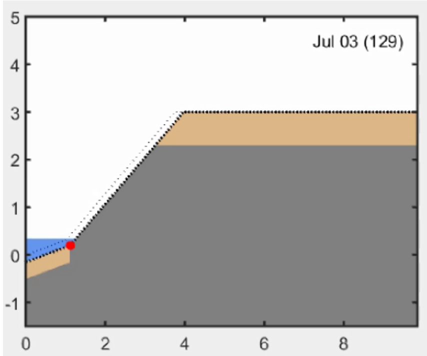

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Media attention for sea state products

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

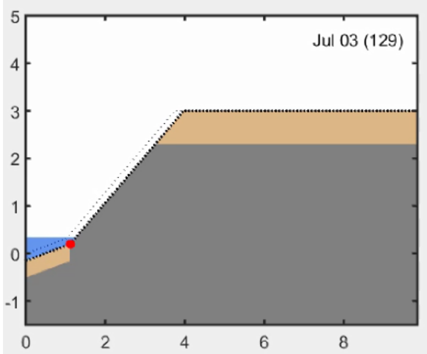
- SWH (“we don’t go there if SWH > X m”)

- 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



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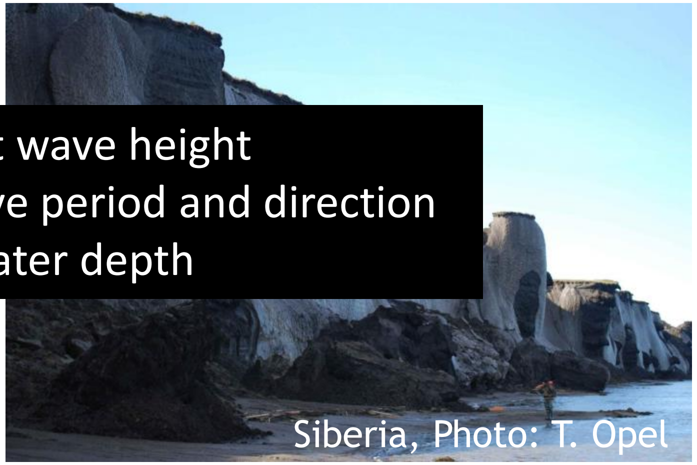

Siberia, Photo: T. Opel

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

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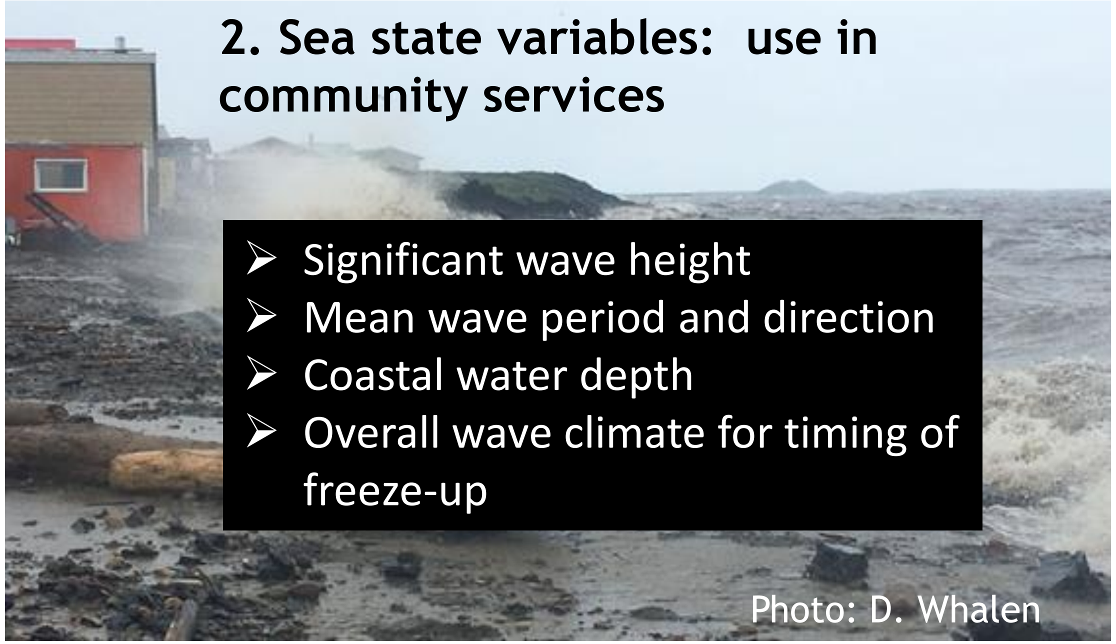
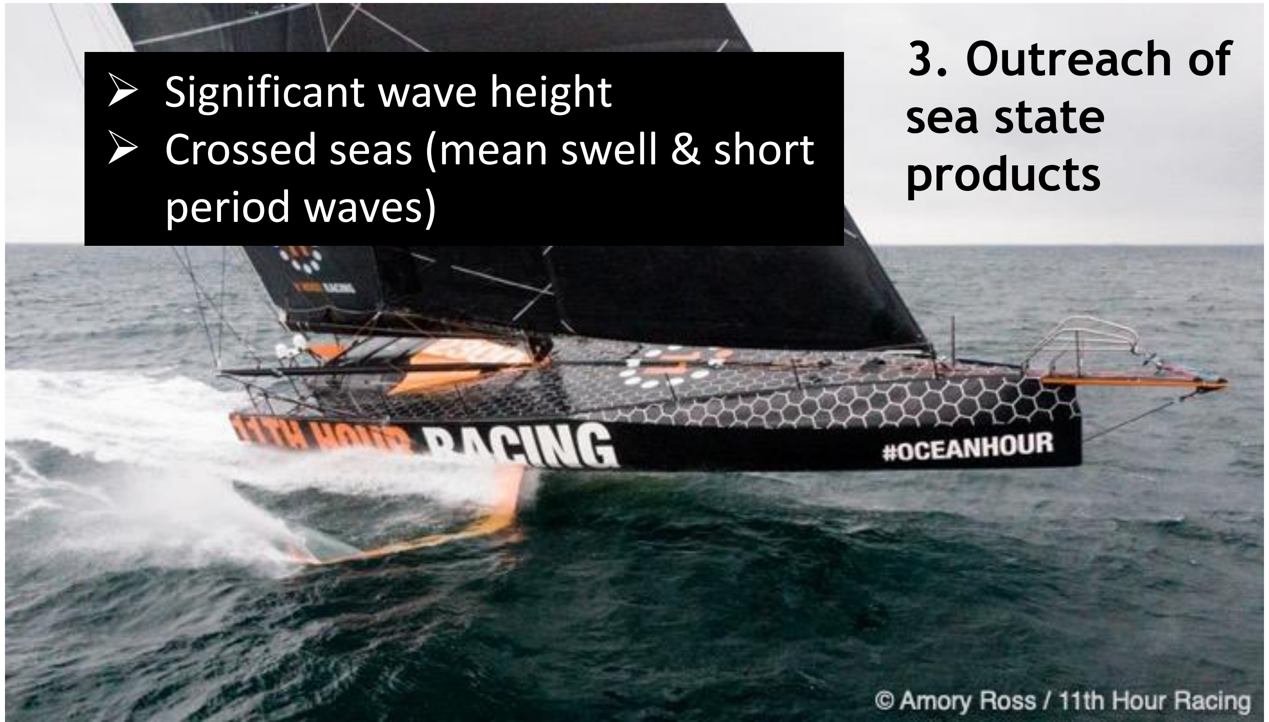


- Significant wave height
- Mean wave period and direction
- Coastal water depth
- Overall wave climate for timing of freeze-up

Photo: D. Whalen

3. Outreach of sea state products



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

Thank you! rebecca.rolph@awi.de

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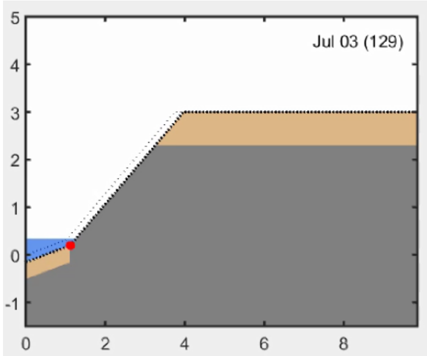

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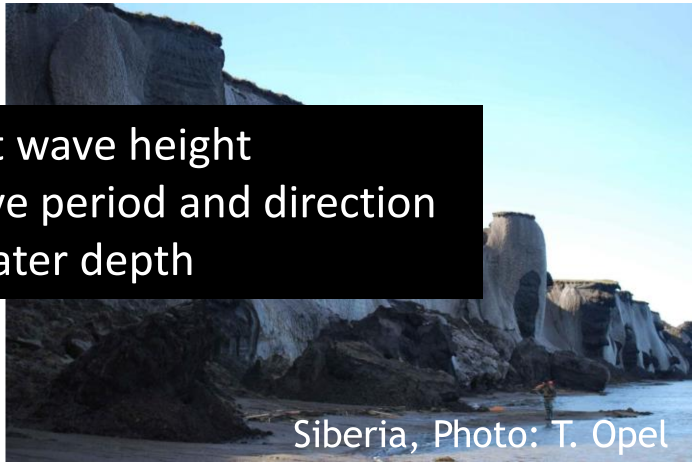

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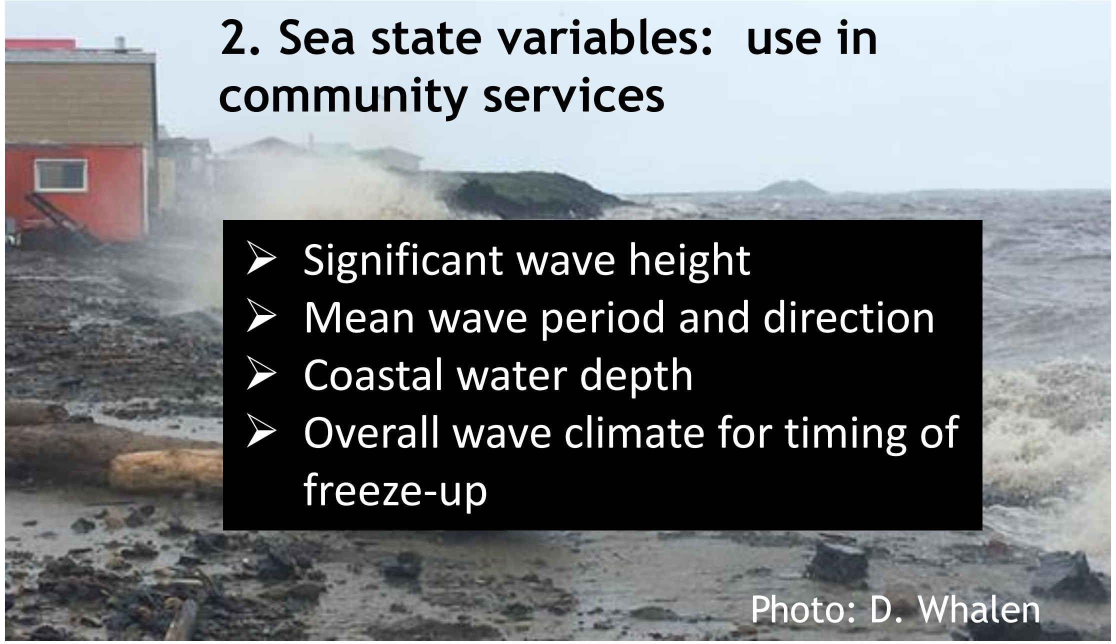

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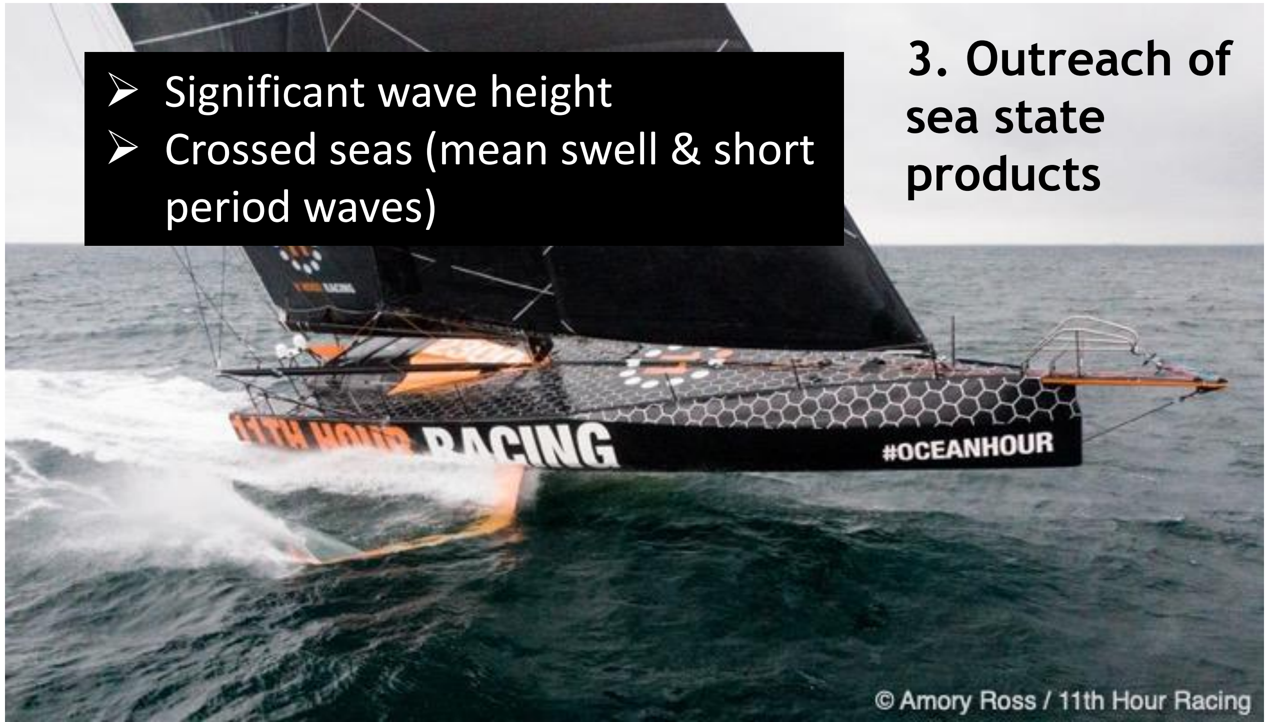

- Significant wave height
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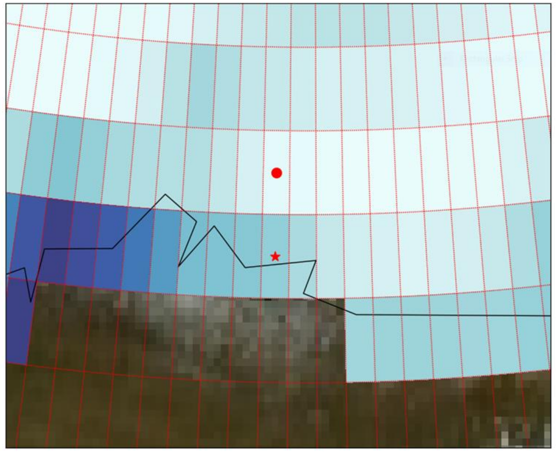
Supplementary slides

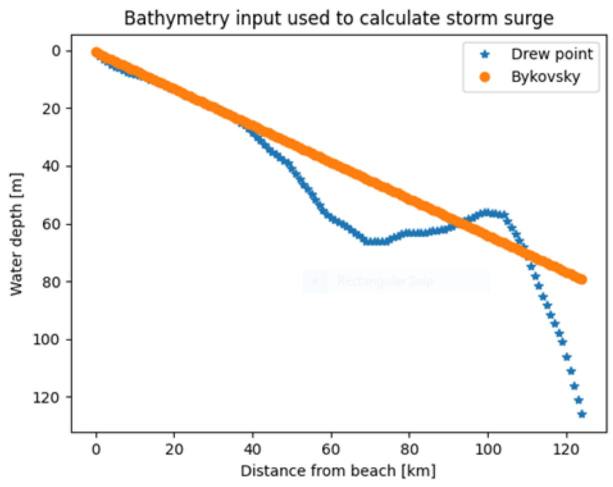
Forcing for the storm surge model



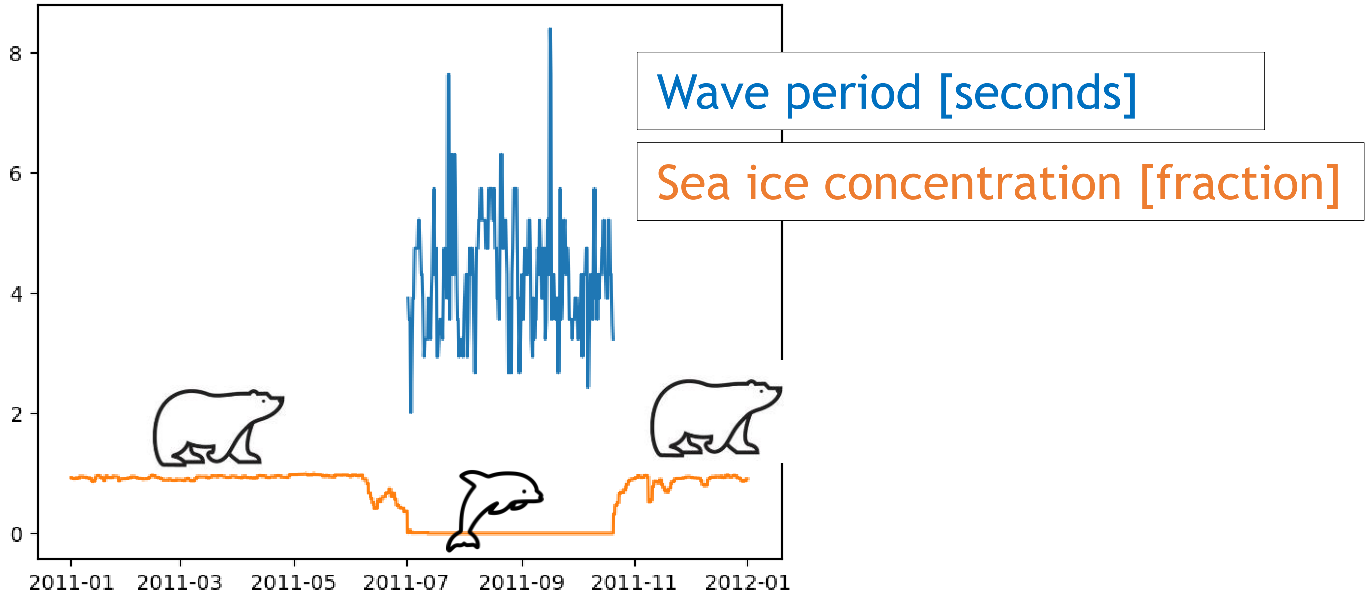
ERA-Interim reanalysis data:

- 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

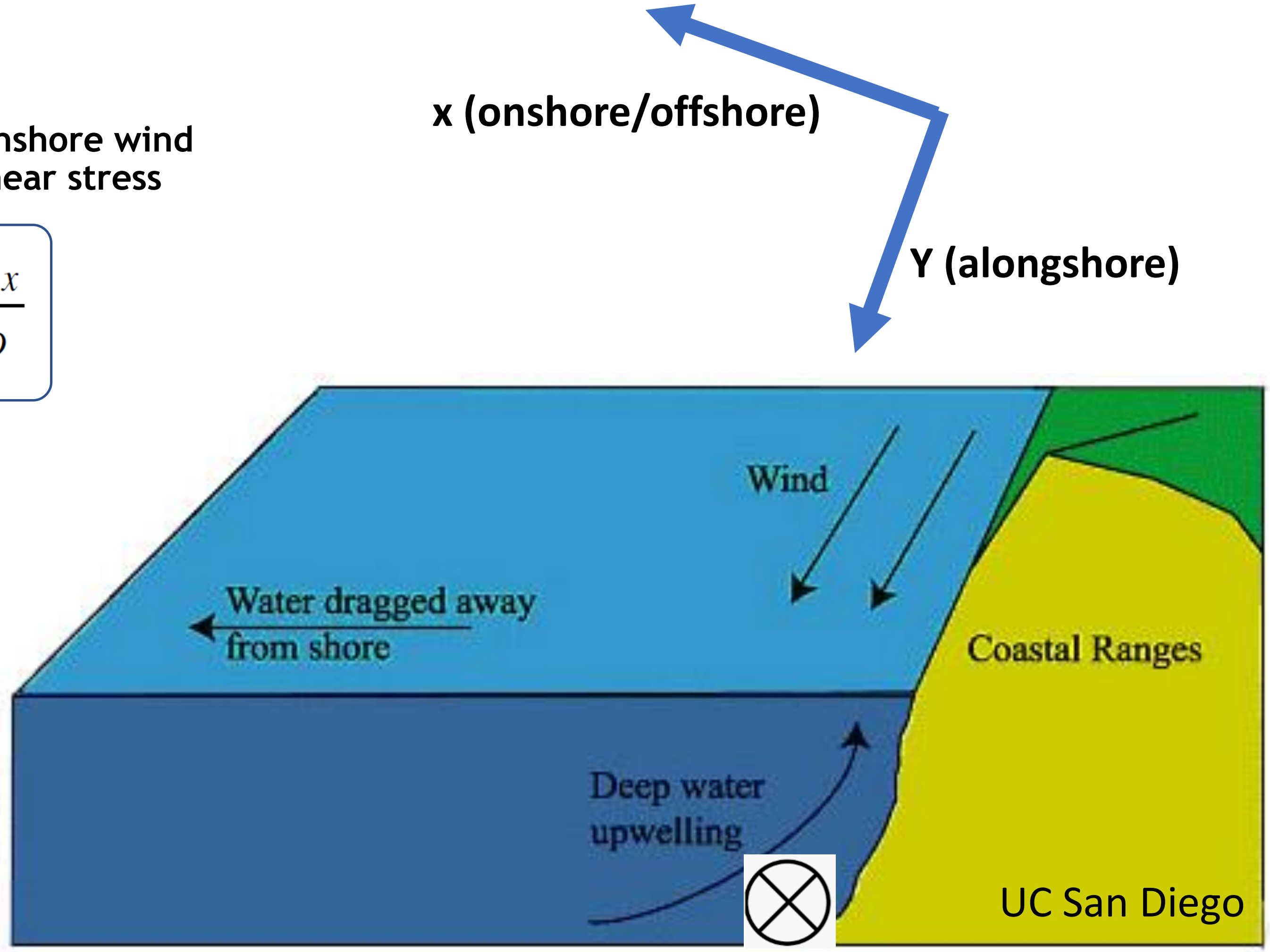
Onshore wind shear stress

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

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

Change in alongshore flow

Alongshore surface and bottom shear stresses



- **<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