First examples of a Digital Twin Arctic

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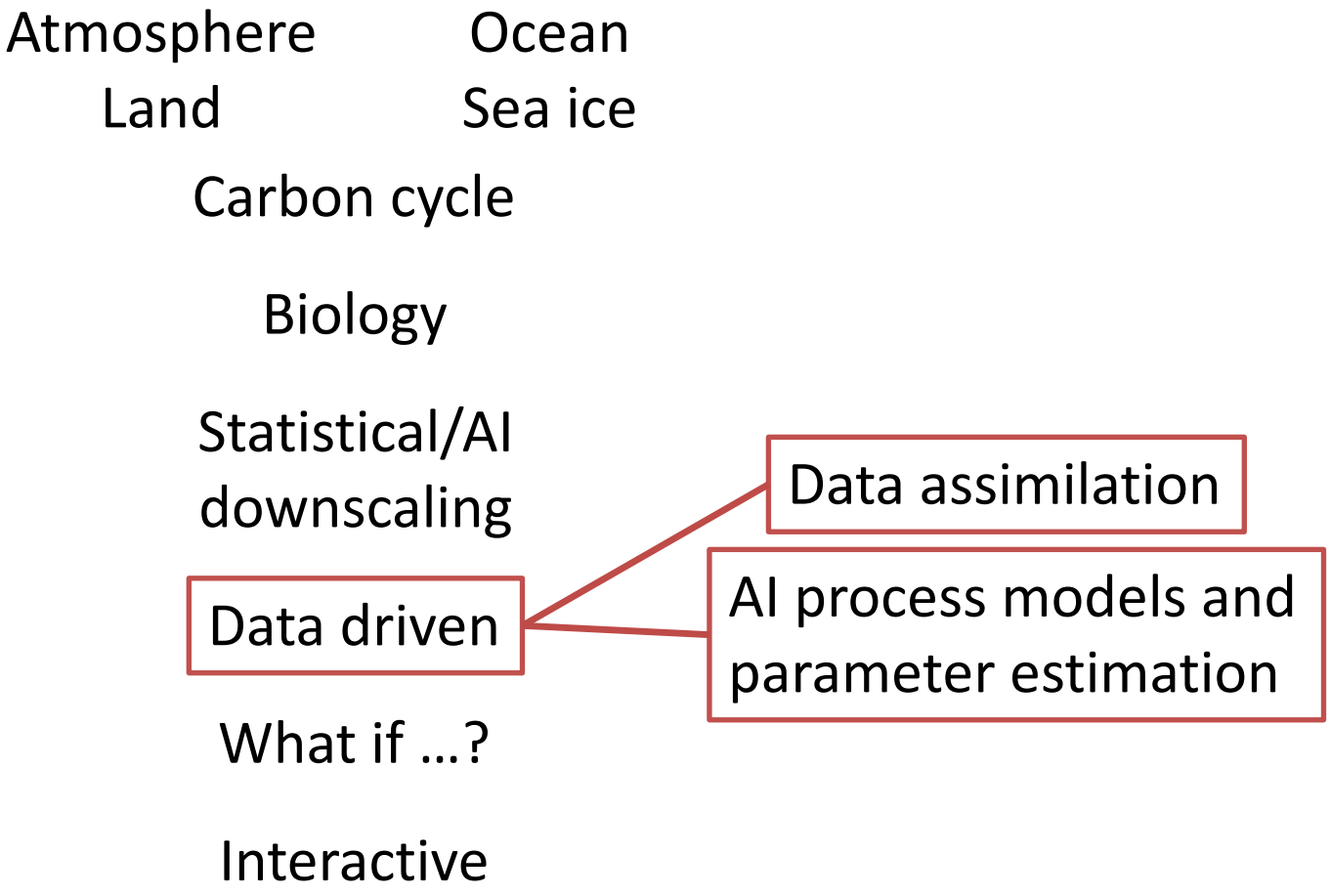
A Digital Twin of the Earth?

- A Digital Twin of the Earth should include
  - Earth System Model (components)
  - Be data driven through Artificial Intelligence
  - Support running what-if-scenarios
- It should support earth systems science
- It should support evidence based decision making
- It should be accessible to those that need it

A Digital Twin of the Earth?



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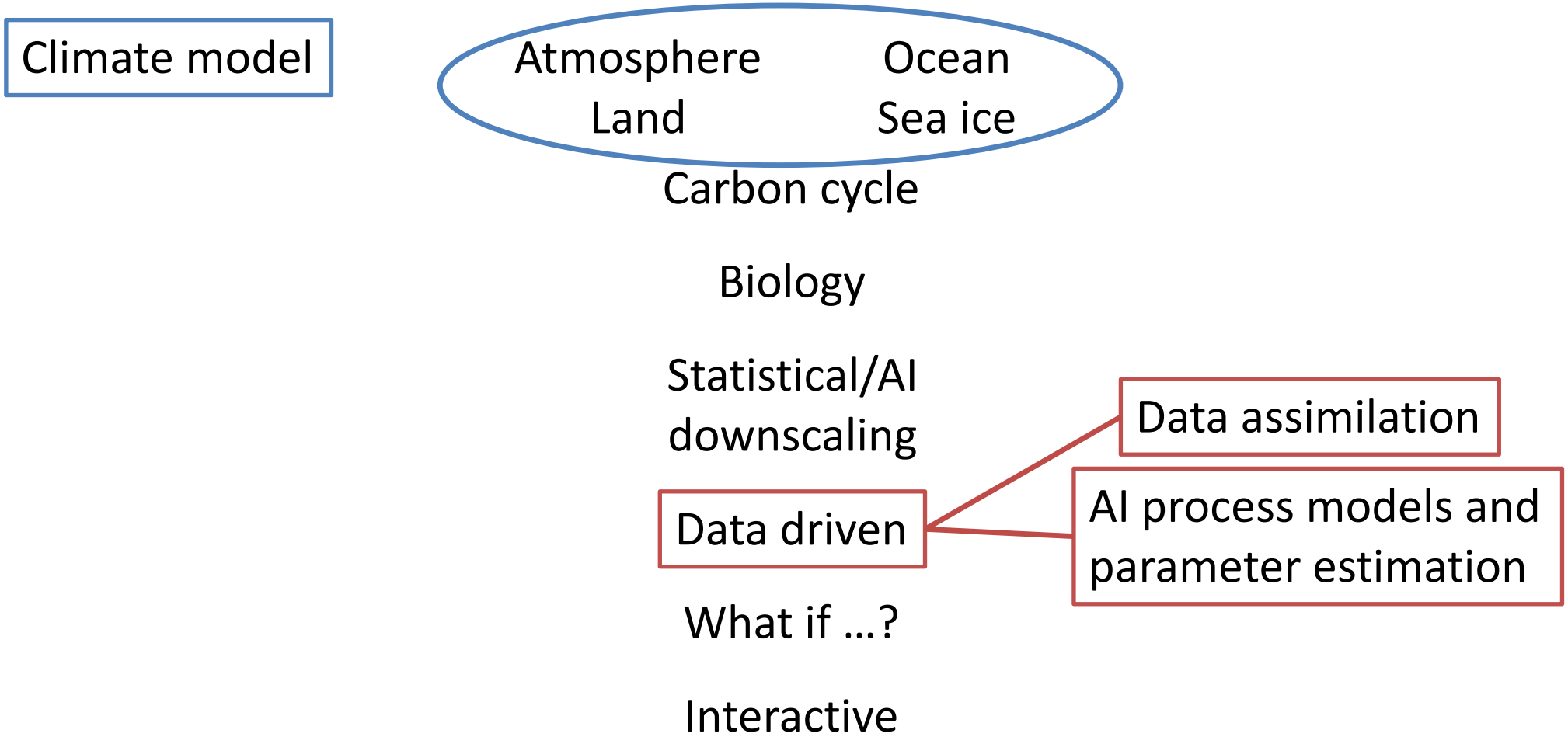

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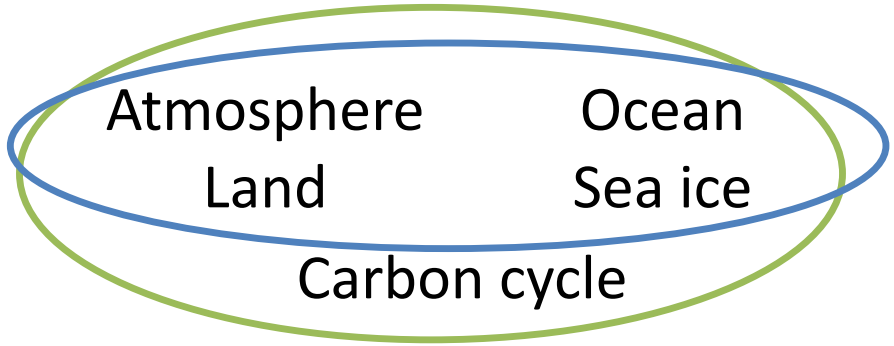


Climate model

Earth System Model

Biology

Statistical/AI downscaling

Data driven

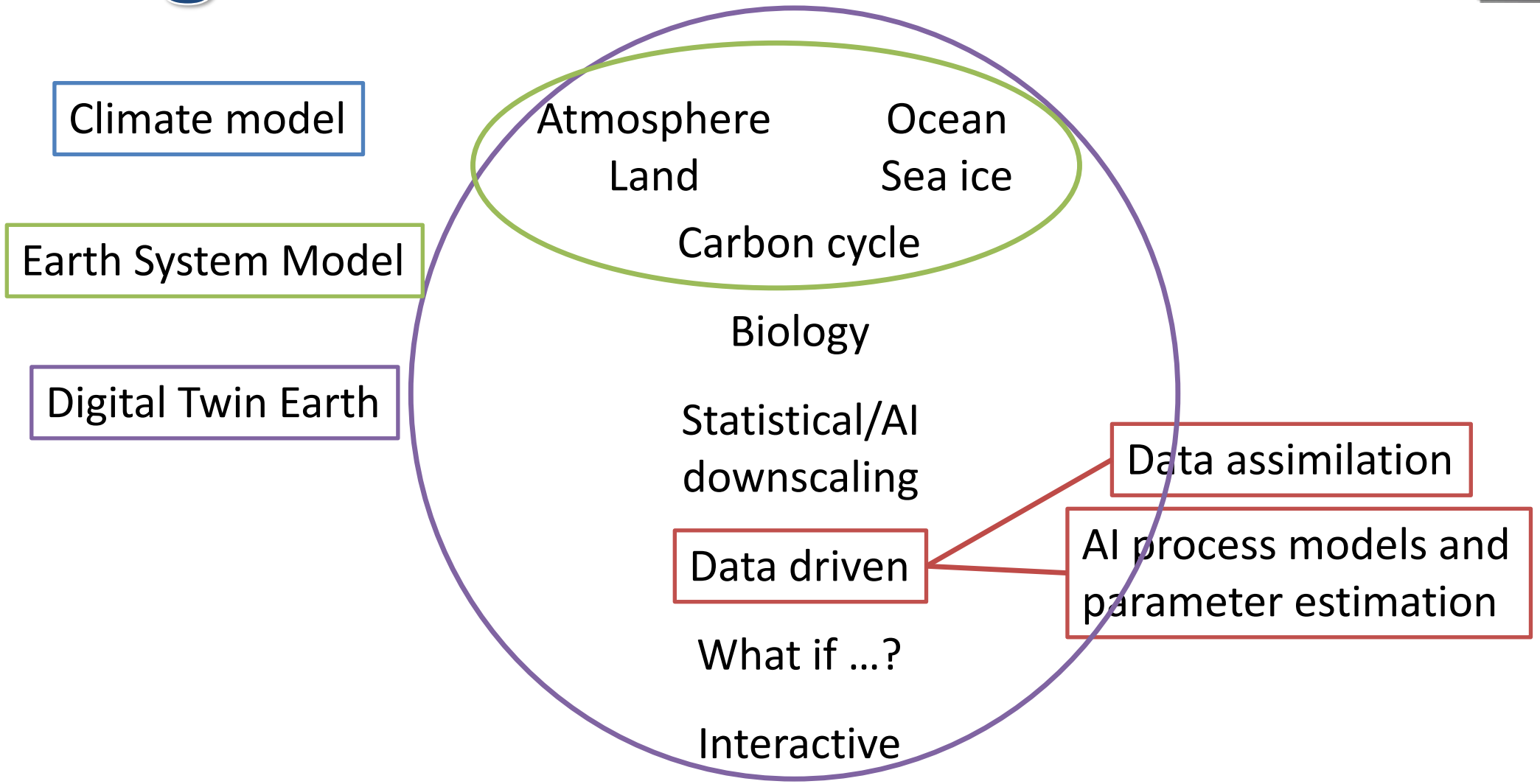
Data assimilation

AI process models and parameter estimation

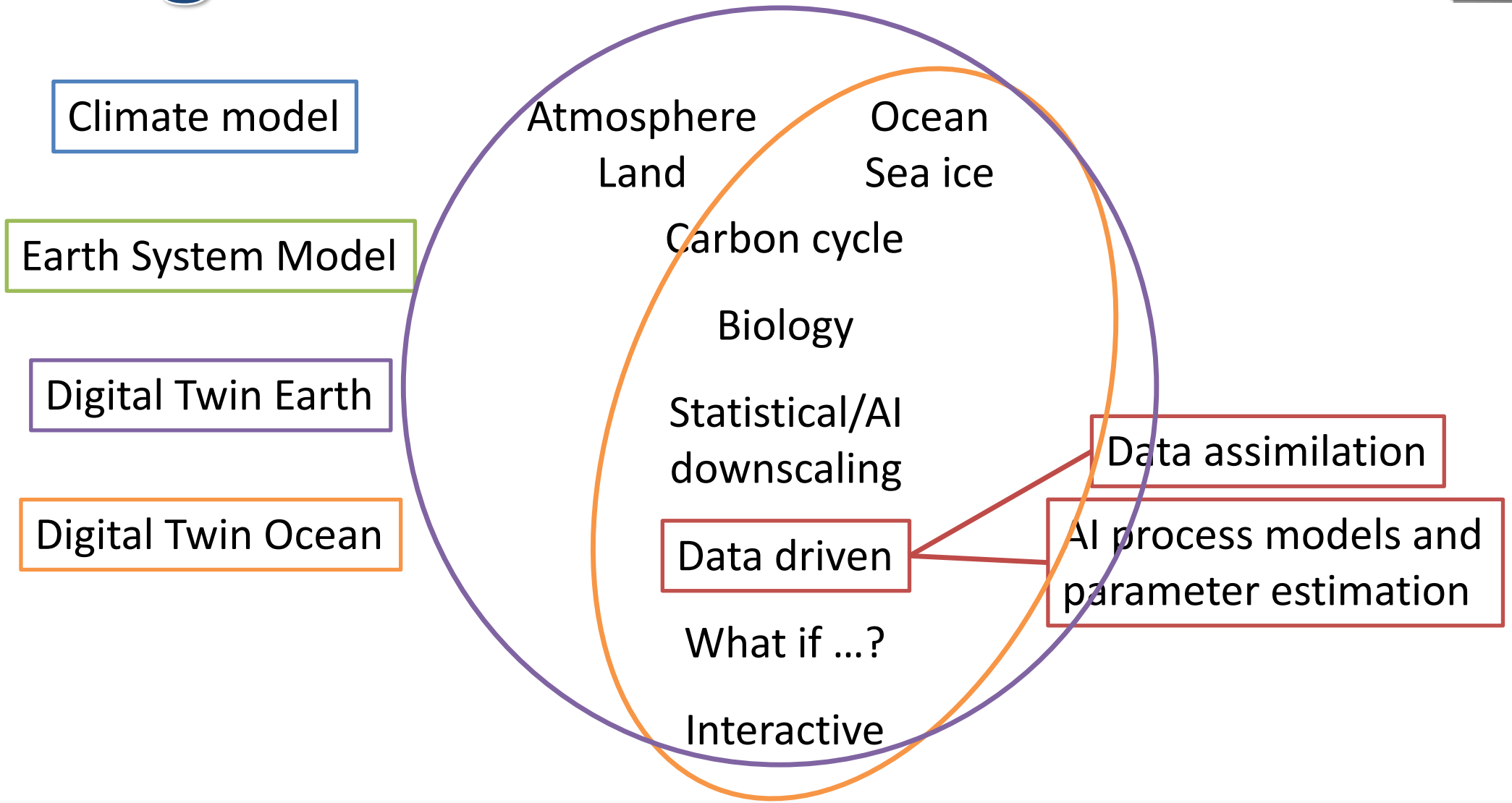
What if …?

Interactive

A Digital Twin of the Earth?



A Digital Twin of the Earth?



A Digital Twin of the Earth?

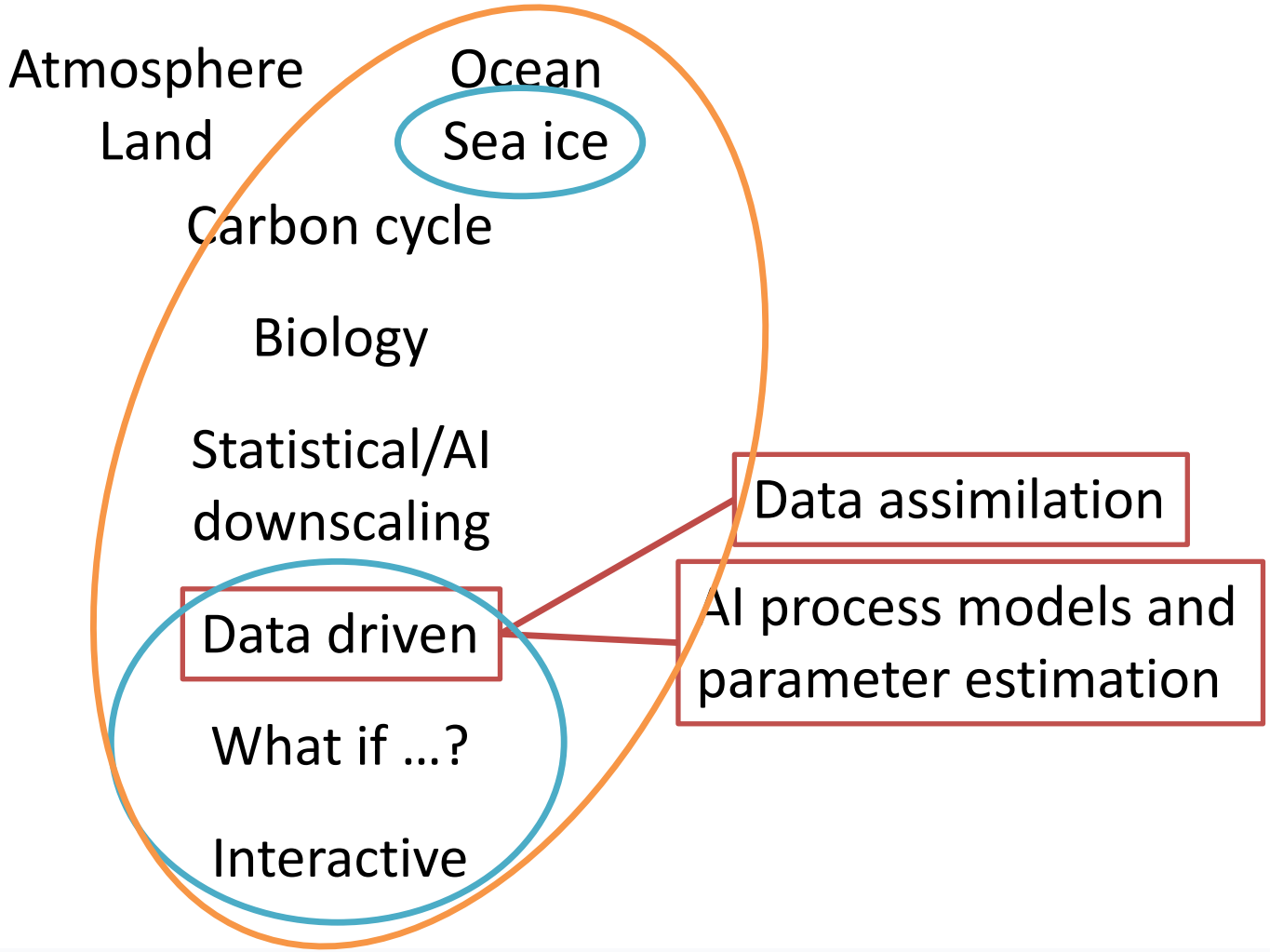
Climate model

Earth System Model

Digital Twin Earth

Digital Twin Ocean

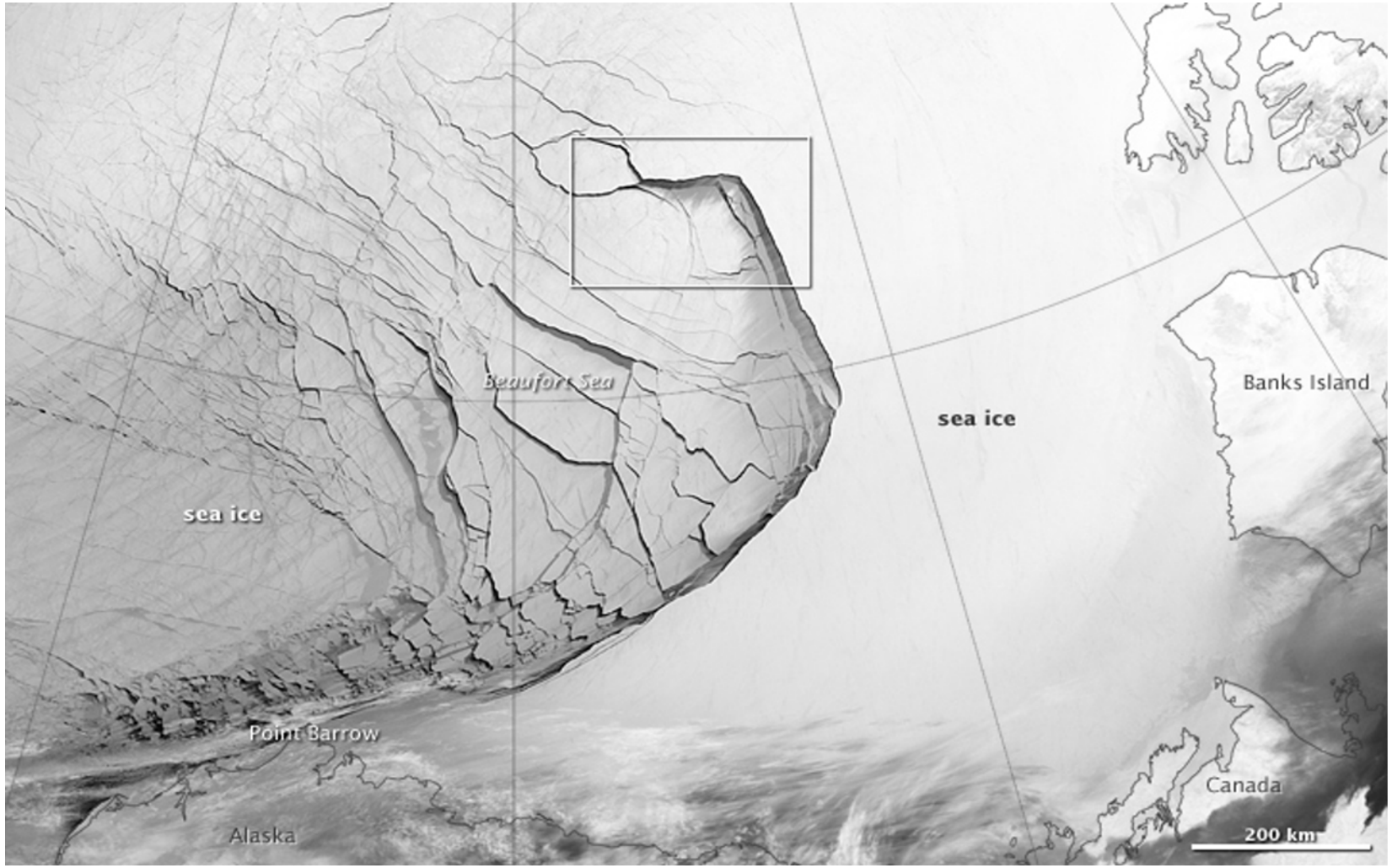
Digital Twin Arctic Precursor



The Digital Twin Arctic Precursor

1. Physical modelling of a ice breakup
2. ML methods to determine weak ice
3. Presentation and outreach

Sea-ice break-up in the Beaufort Sea in 2013



1. In 2013 an extreme break-up event occurred in the Beaufort Sea , mid-winter.
2. The event can be characterised by large arc-shaped fractures.
3. The break-up started in late January at Point Barrow off the Alaskan coast and gradually propagated east towards Banks Island.

Objective

Sea ice breakup events are striking and impossible to simulate without the advanced model and data combination that constitutes the DTE.

Breakup events drastically change the energy balance at the air–ice–ocean interface. Their presence may influence weather and climate in the Arctic and beyond. So far, this effect is not estimated.

Our goal

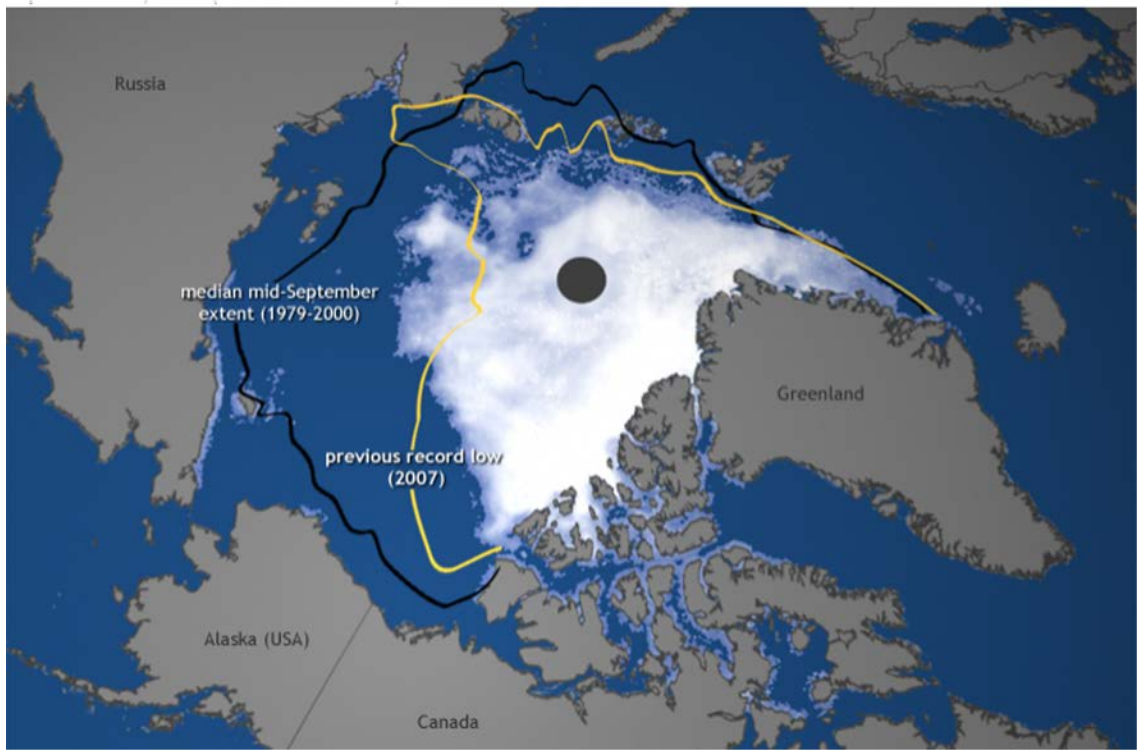
To illustrate reconstruction of Earth systems process by a satellite data driven model with focus on the ice-breakup and impact on sea ice-growth feedback.

The Digital Twin Arctic Precursor

1. Physical modelling of a ice breakup
2. ML methods to determine weak ice
3. Presentation and outreach

What factors influenced the break-up?

Record low sea ice extent

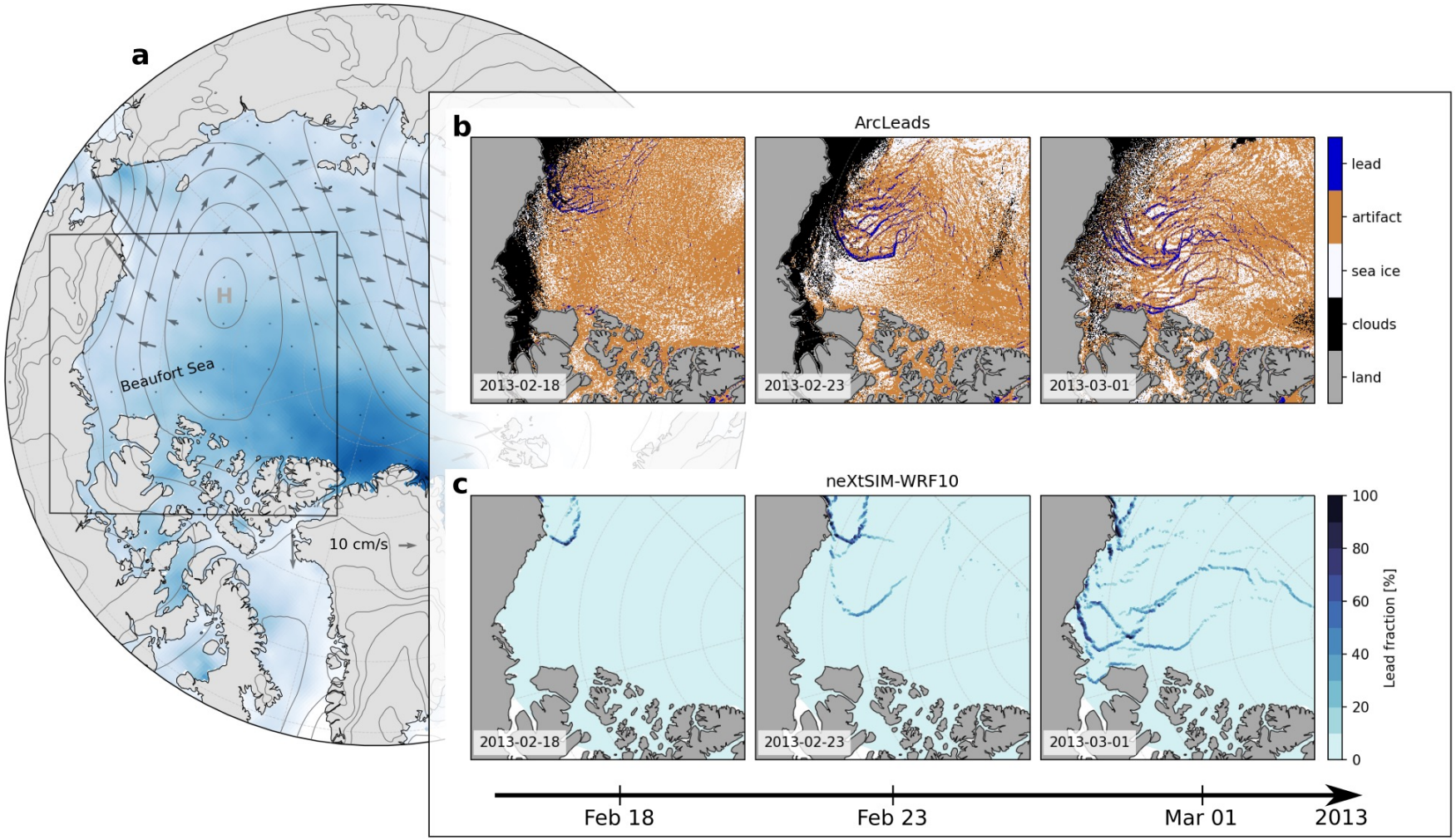


=> Record low sea-ice extent in fall 2012 leads to thin ice in the Beaufort Sea in 2013

Extreme Arctic storm event

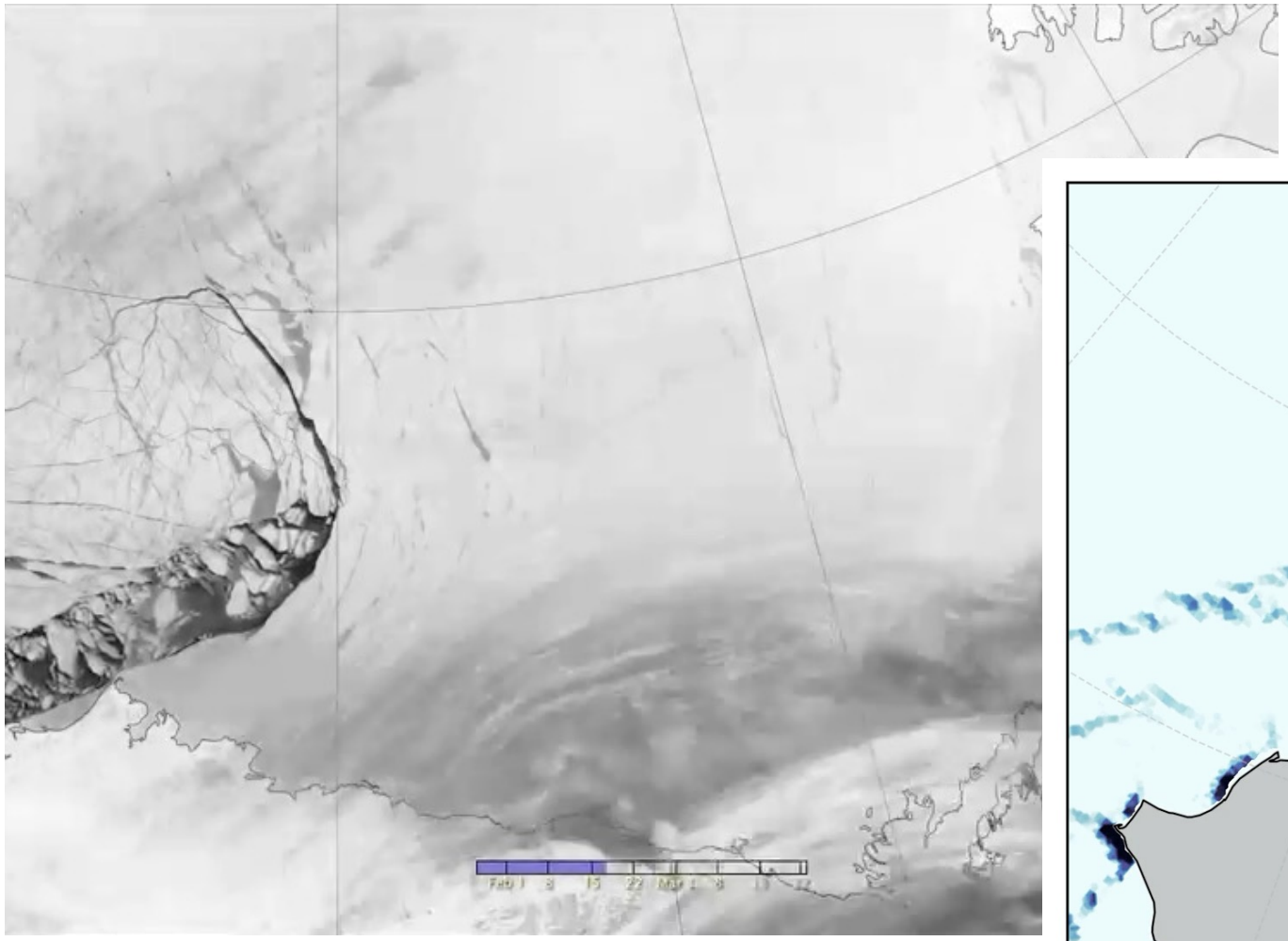
=> Strong winds associated with a persistent anti-cyclone over the Beaufort Sea in February—March

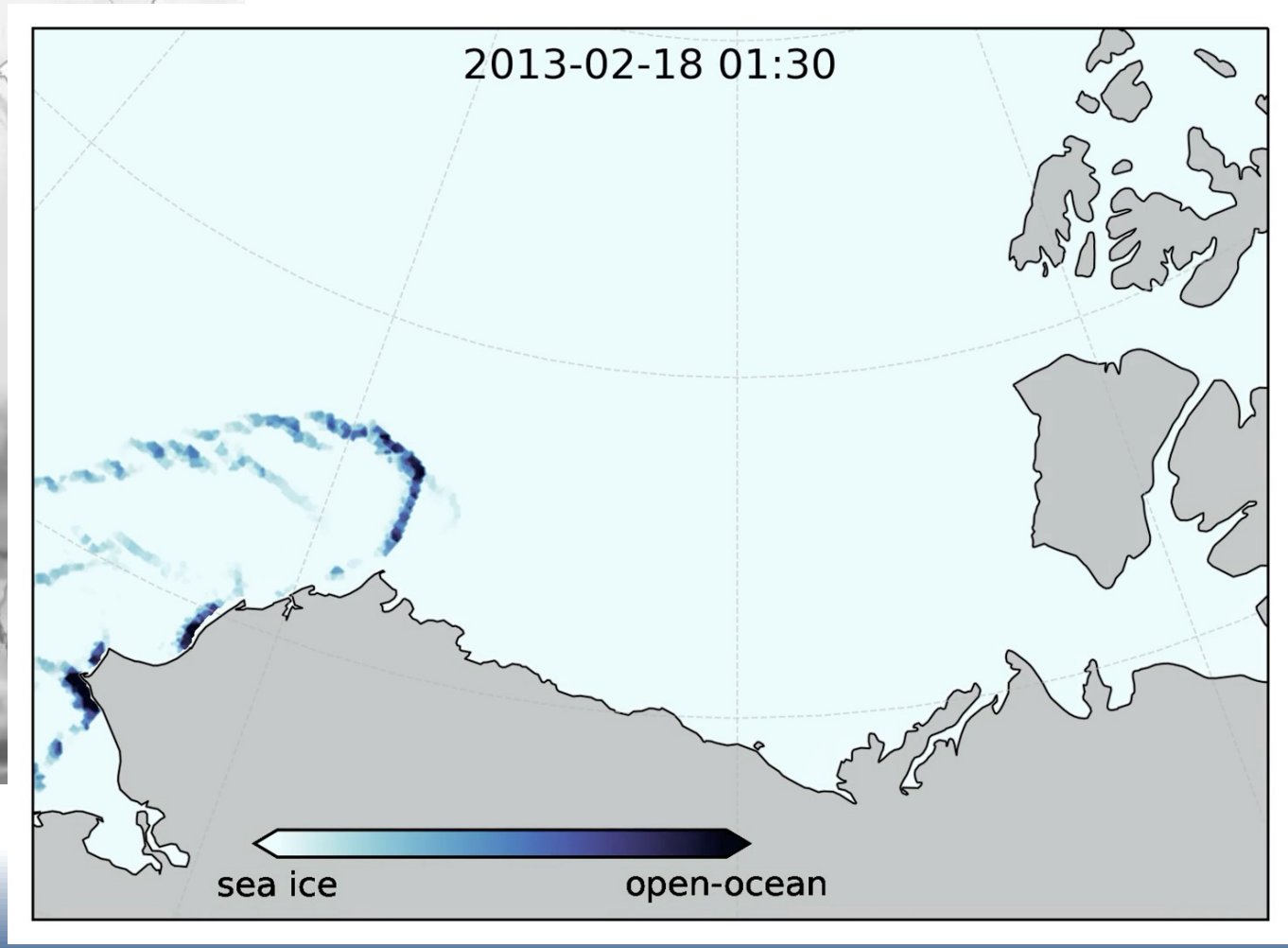
Observed and simulated lead formation



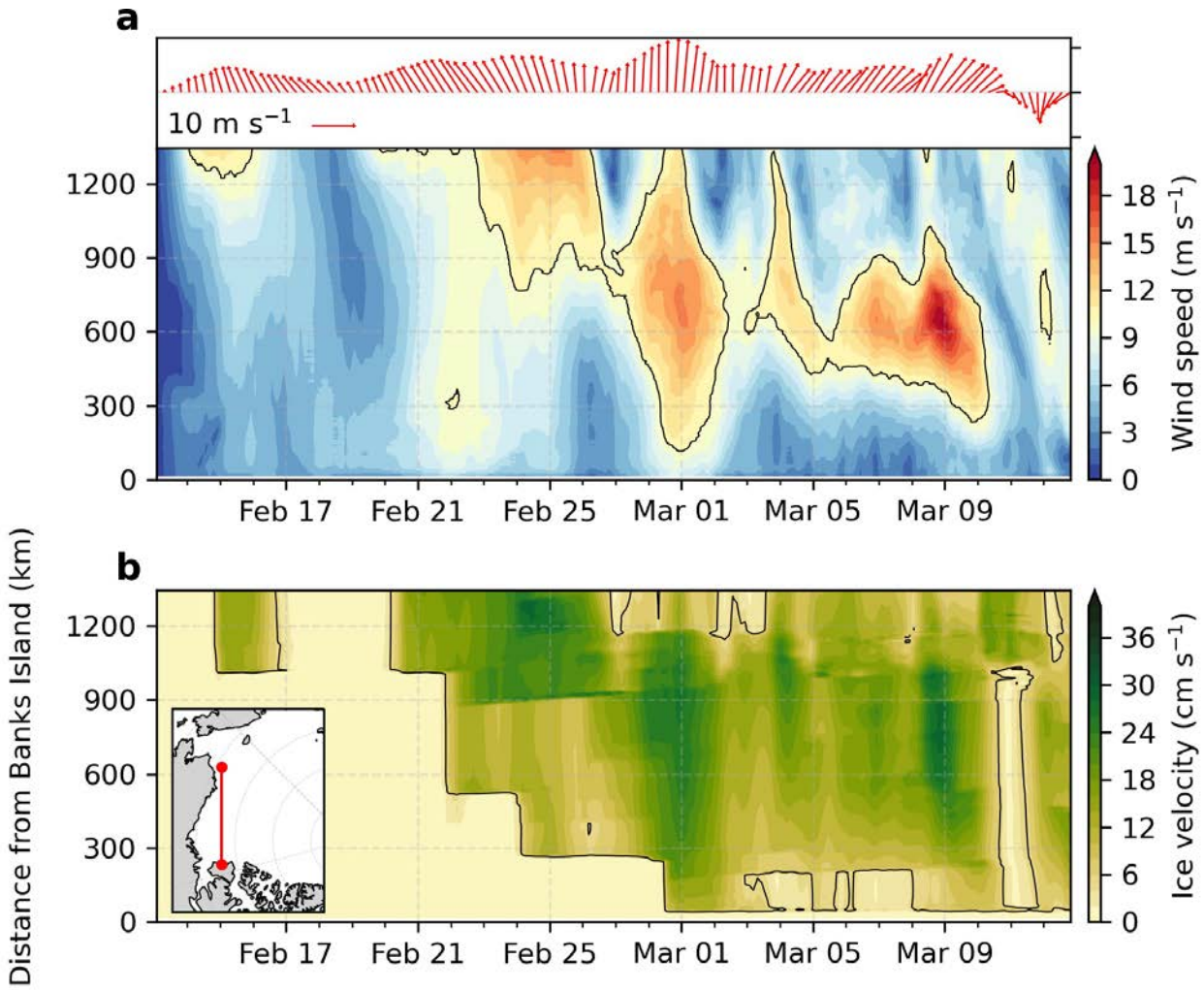
Qualitative comparison of observed and modelled lead fraction is very reasonable.

Observed and simulated lead formation



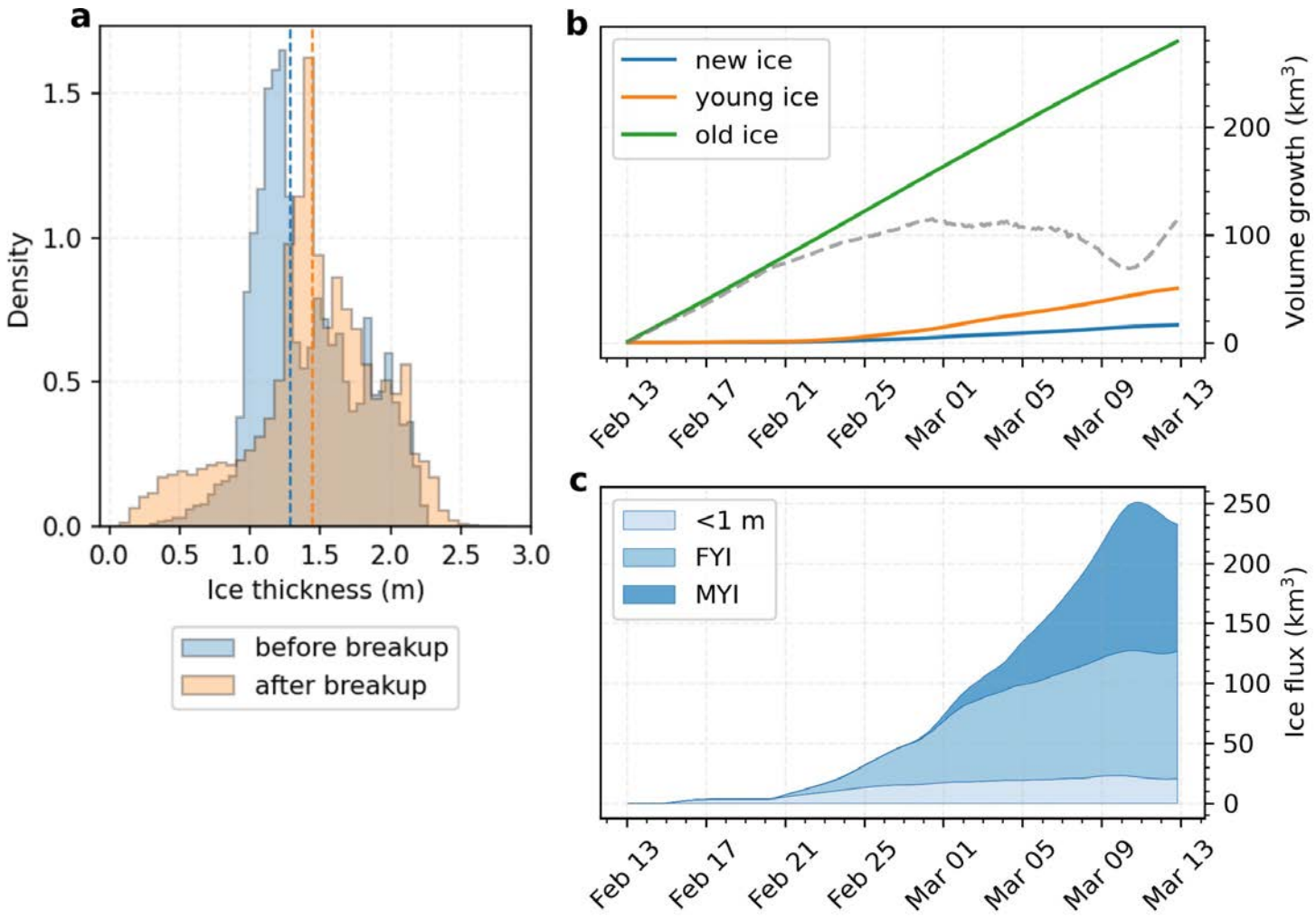


Strong winds break up the ice cover



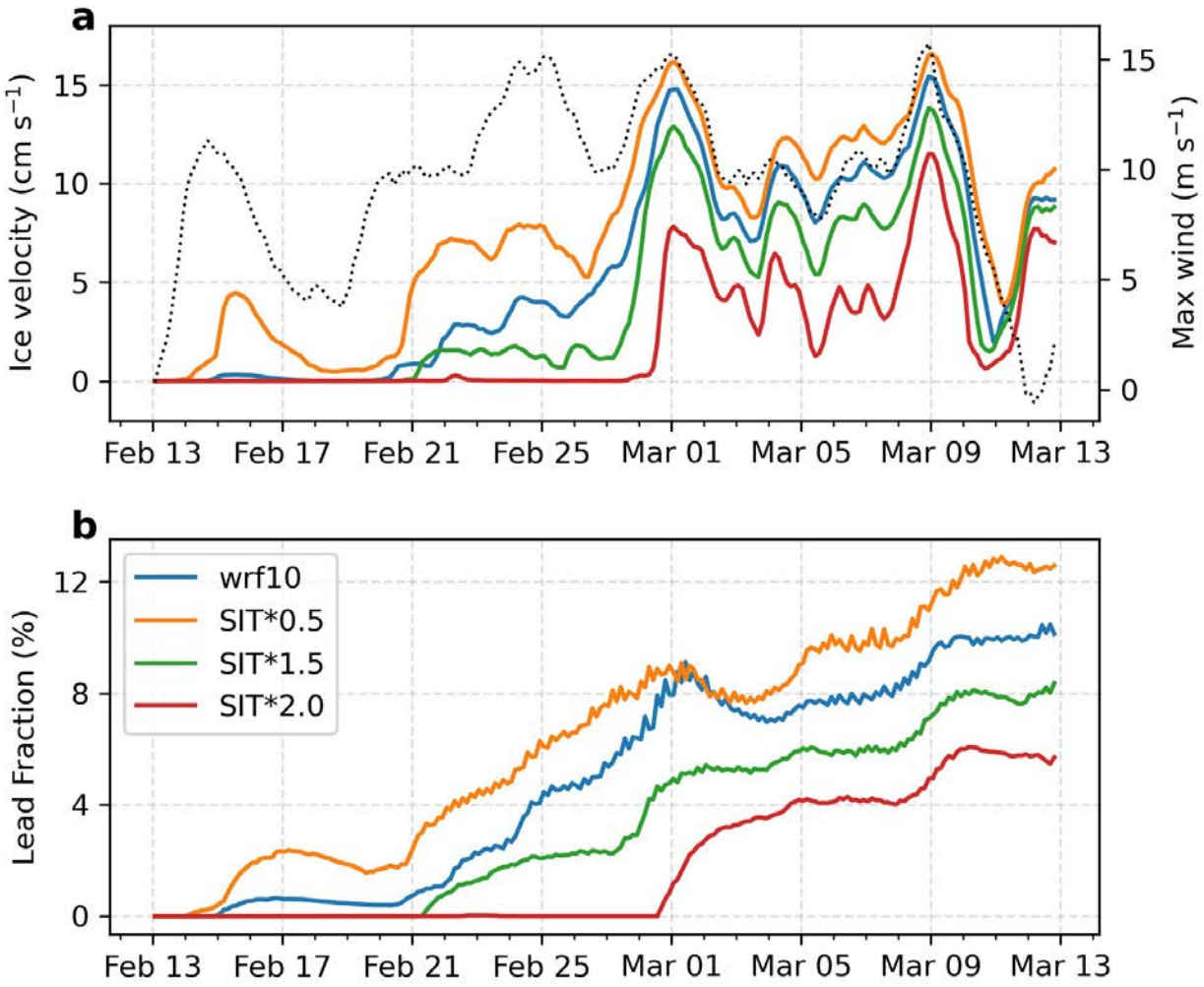
- Strong winds break up the ice — once a wind speed threshold is exceeded
- This results in a step-like behaviour in the break-up

Thin ice replaces thick



a. A large amount of thin ice is created in the leads
b. The total volume growth is still dominated by old-ice growth
c. A large amount of thick ice is exported from the region, to be replaced by thin ice.

What if … the ice was thicker/thinner?



- Thick ice (red) still breaks up – but the drift is slower and increase in lead fraction is lower
- Thin ice (orange) breaks up much more easily and the lead fraction is substantially higher
- The red and orange lines are representative of pre-industrial and future-climate scenarios

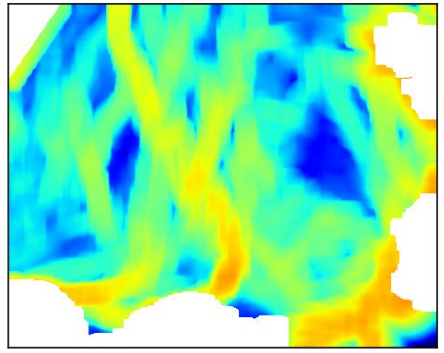
Precursor structure

1. Physical modelling of a breakup
2. ML methods to determine weak ice
3. Presentation and outreach

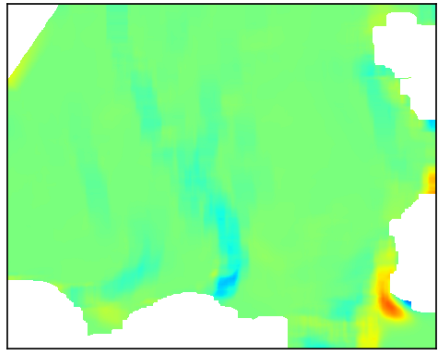
Super resolution of ice thickness

Low and medium resolution input

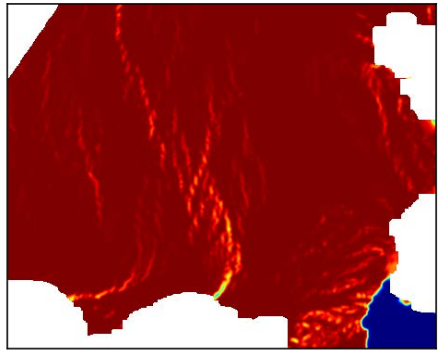
Shear



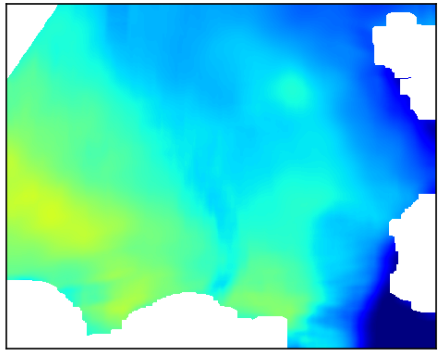
Divergence



Concentration



Thickness

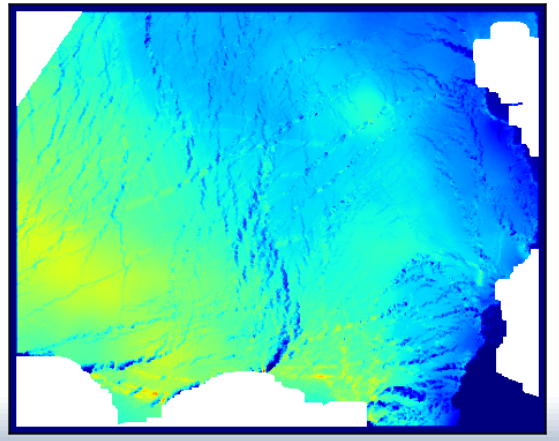


- Deformation alters concentration and thickness
- Use this to get higher resolution thickness from a low resolution source

⇒ Use neural network to deduce thin ice areas
  - Train with model results
  - Apply on observations

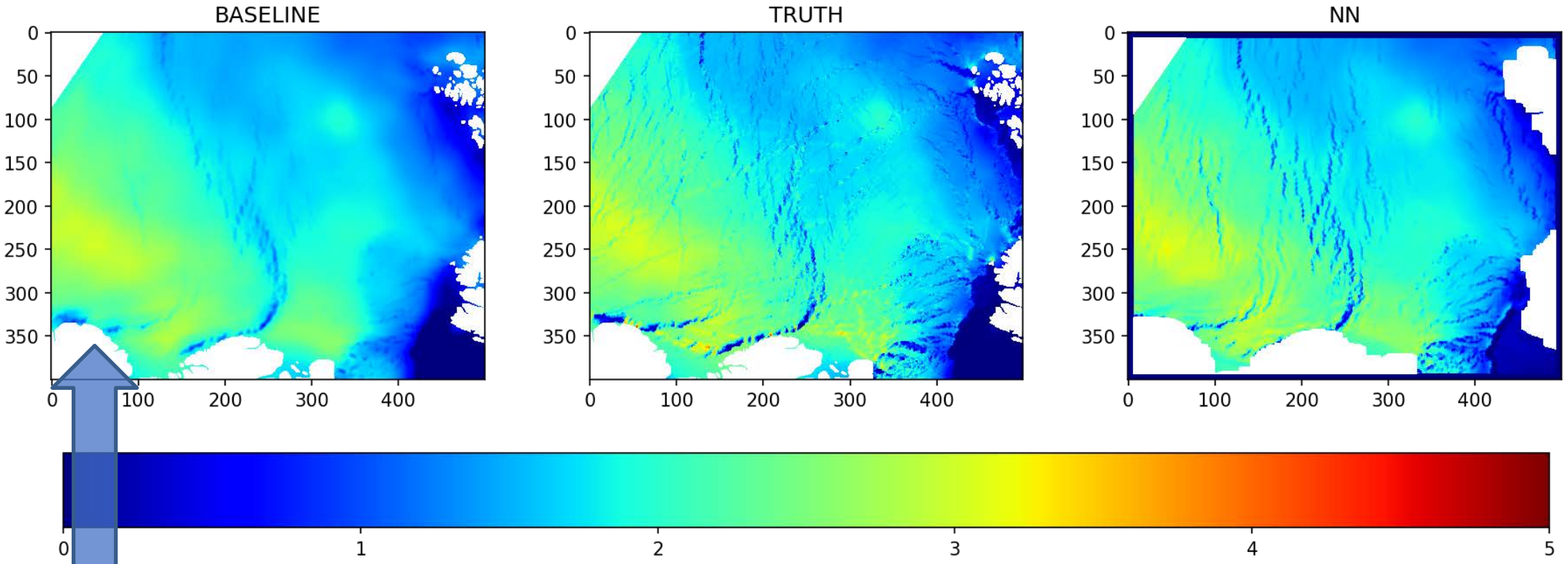
Neural Network

Thickness



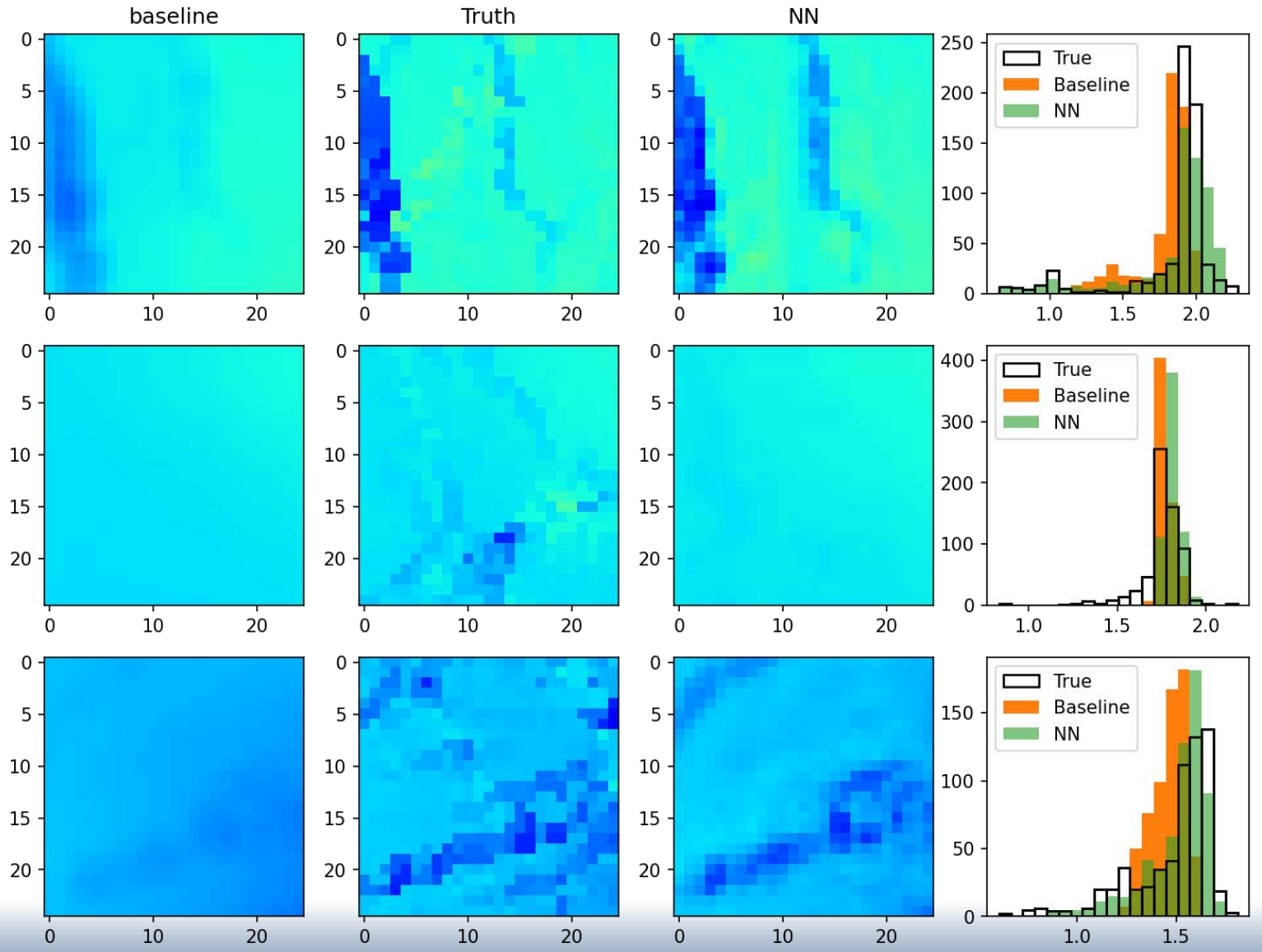
NN vs. a simple base line

Thickness



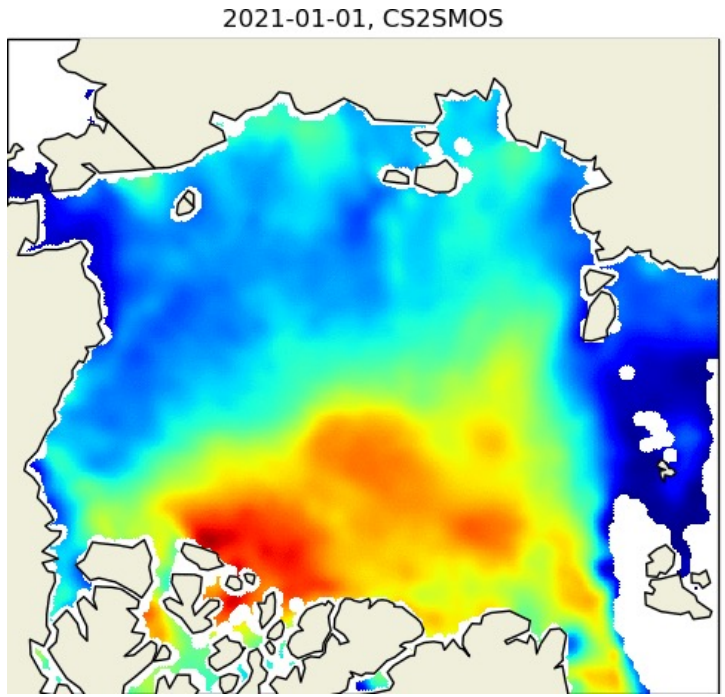
Baseline = Low resolution thickness x medium resolution concentration

Zoom at super-pixel resolution

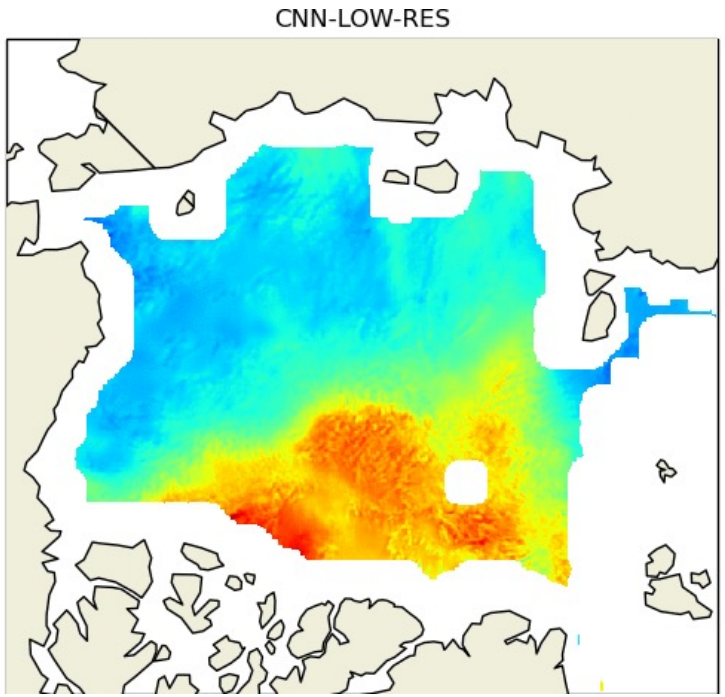


- The area here is equivalent to the size of a low-resolution pixel
- The NN can reproduce better the very high and low portions of the PDF

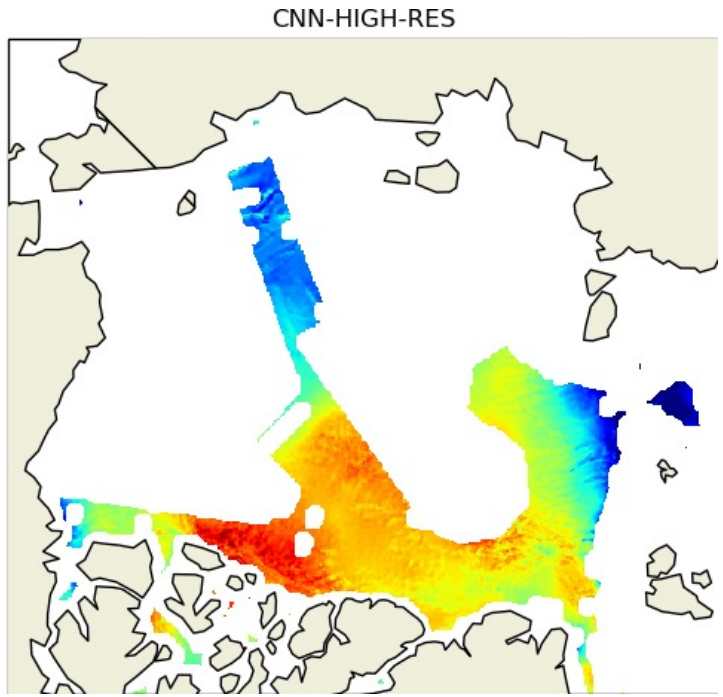
CNN applied to real satellite data



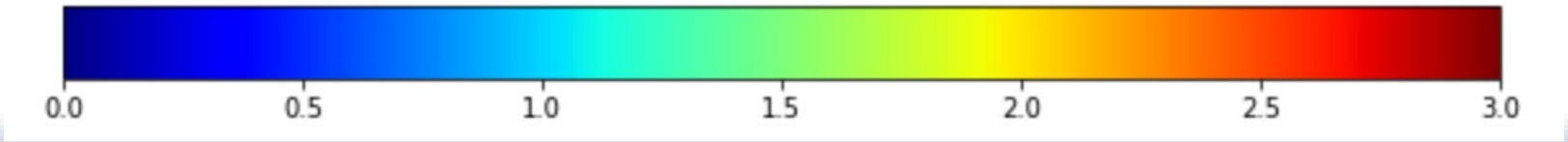
Input CS2SMOS



CNN for PMW ice drift



CNN for SAR ice drift

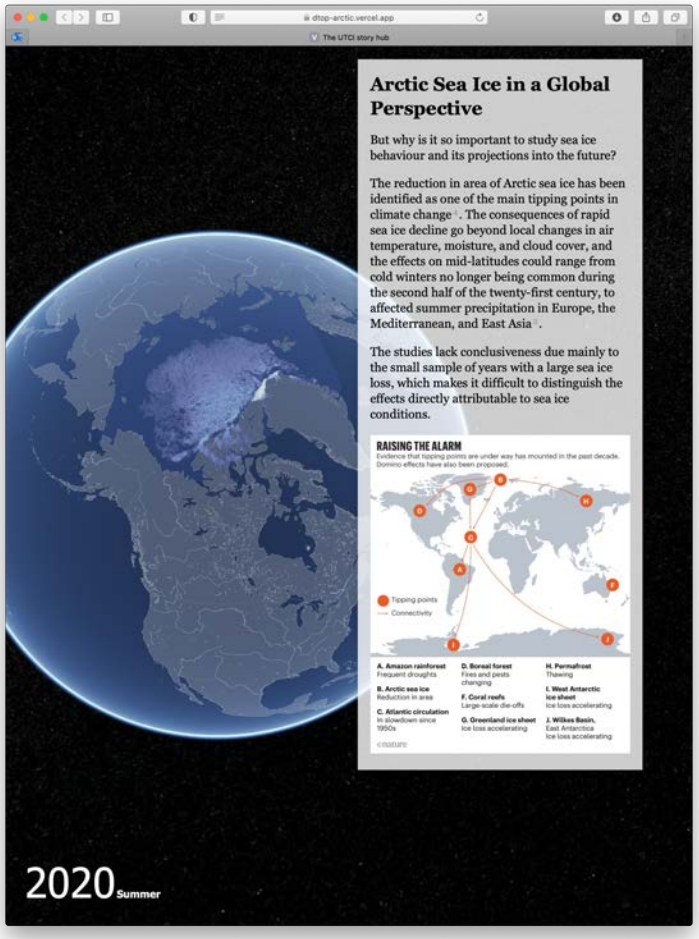


Precursor structure

1. Physical modelling of a breakup
2. ML methods to determine weak ice
3. Presentation and outreach

Traditional and popular science

- We are working on a paper on the physical modelling for a high-impact journal
- LobeliaEarth are creating a story about the break-up for popular outreach
- dtop-arctic.lobelia.earth



Summary

- We have shown the working pieces of a Digital Twin of the Arctic:
  - An advanced sea ice model
  - A what-if-scenario
  - AI powered data processing
  - Cutting edge visualisation and outreach
- All are examples of how to improve our understanding of the Arctic and to increase public engagement in our research

Steps towards a full Digital Twin

- For a full Digital Twin we need to connect the modelling, data processing, scenario building, and presentation
- Modelling should be extended to include ocean or regional climate model
- More data pre-processing is needed
- Model post-processing (e.g. AI powered down scaling) should be considered
- Interactive scenario construction is needed
- Interactive data presentation is needed