Joint WGSIP/WGNE meeting
Toulouse, 4-8 November 2024

Rapid sea ice changes: causes and consequences

François Massonnet

francois.massonnet@uclouvain.be

UCLouvain

fnrs FREEDOM TO RESEARCH

belspo

erc European Research Council Established by the European Commission

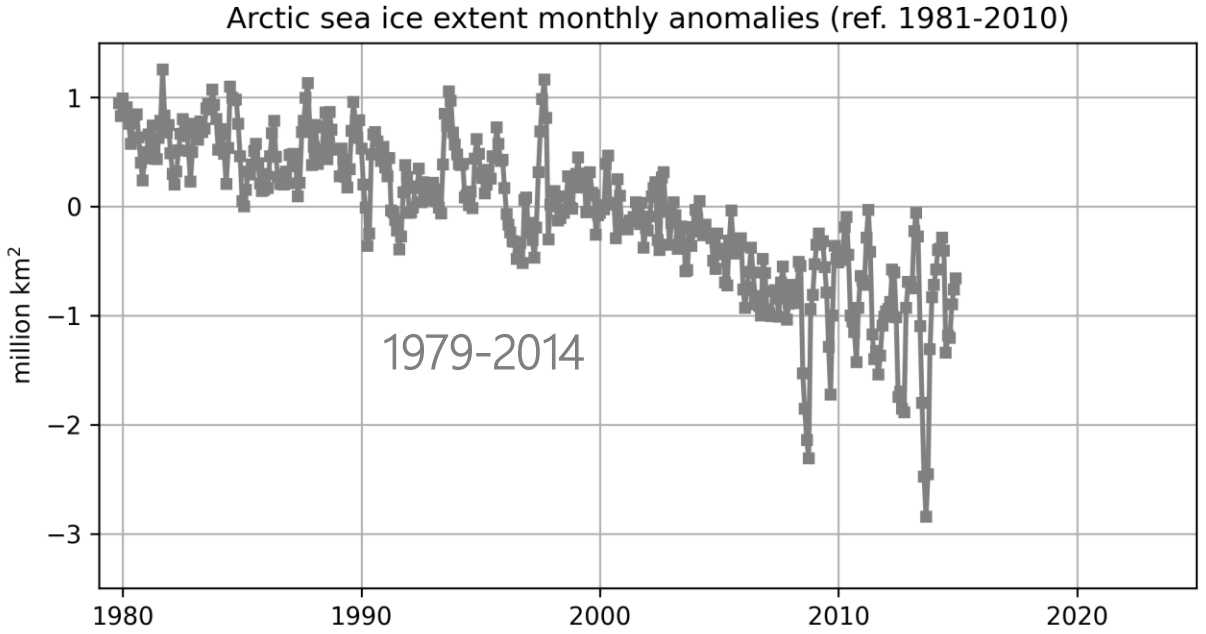
EARTH & LIFE INSTITUTE

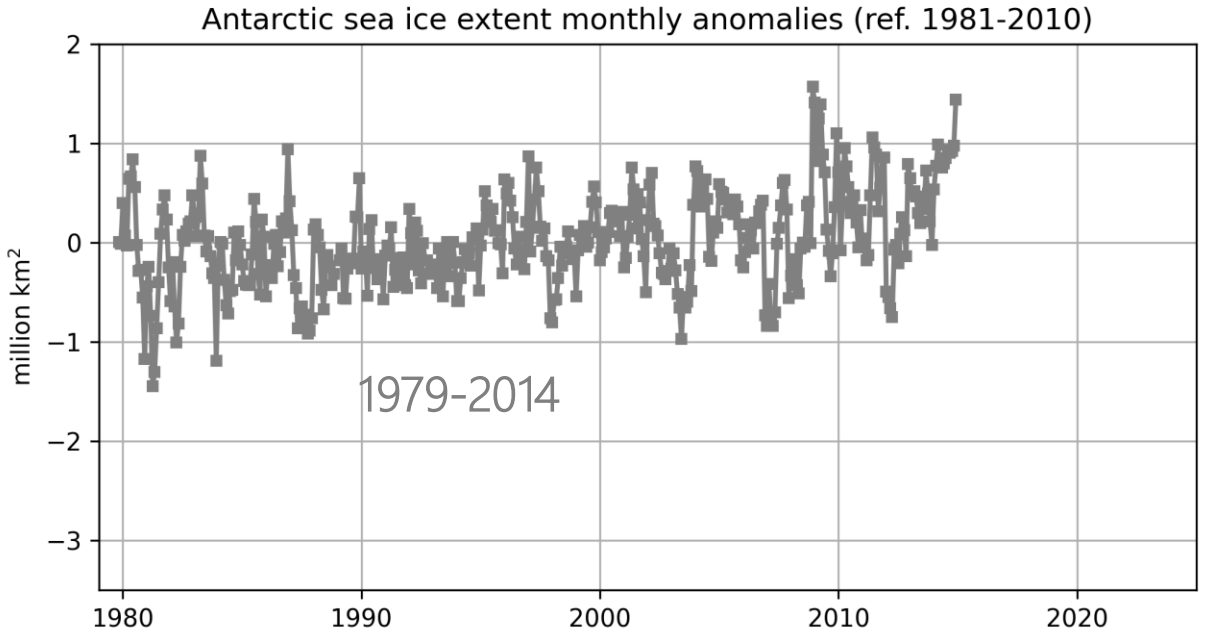
The Polar Research Group at UCLouvain: people

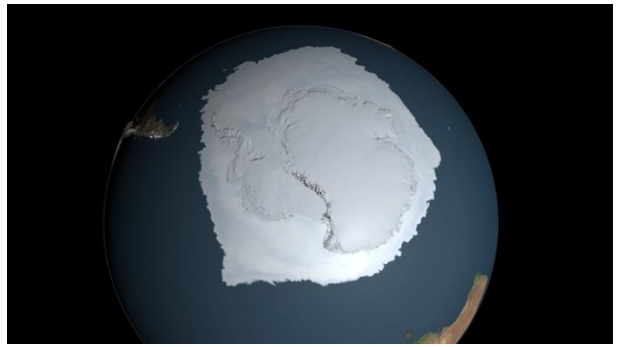
Currently 24 staff members

- 4 academics (François Massonnet, Thierry Fichefet, Hugues Goosse, Francesco Ragone)
- 10 PhD candidates (Annelies Sticker, Cécile Osy, Jerome Sauer, Noé Pirlet, Jinfei Wang, Emile Neimry, Alexandre Tytgat, Augustin Lambotte, Eva Lemaire, Huihong Xue)
- 8 Post-Doctoral researchers (Feba Francis, Dani Topal, Bianca Mezzina, Lauren Hoffman,, Benjamin Richaud, Patricia DeRepentigny, Alison Delhasse, Ting-Chen Chen)
- 2 technical and informatic supports (Pierre-Yves Barriat, Antoine Barthélemy)

UCLouvain

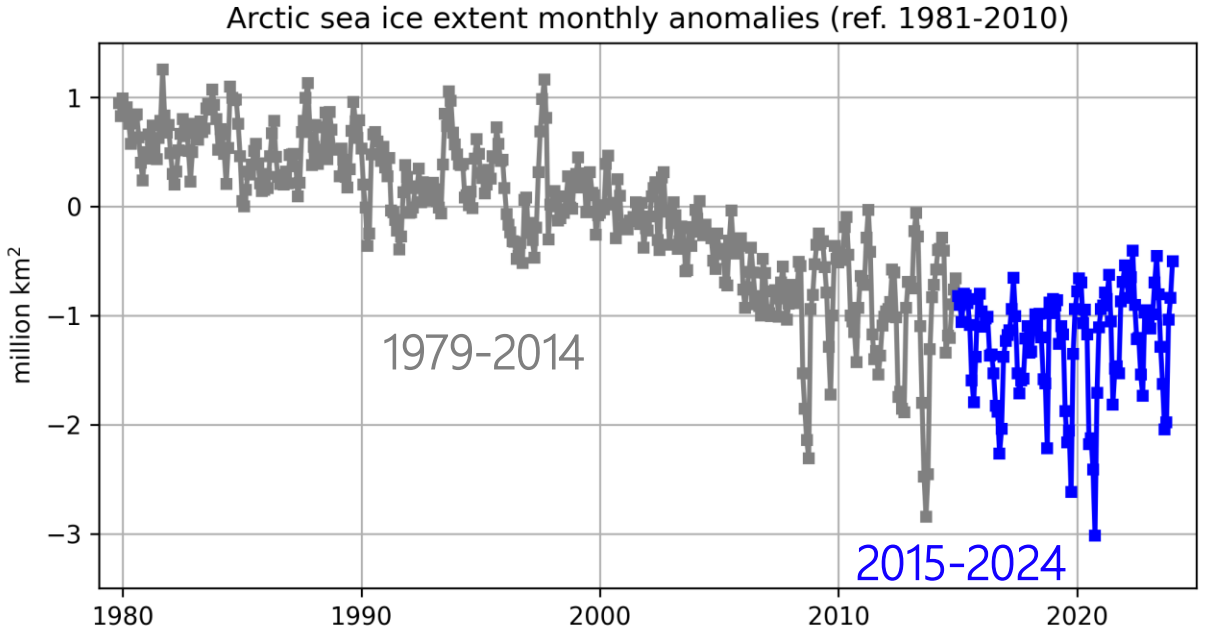


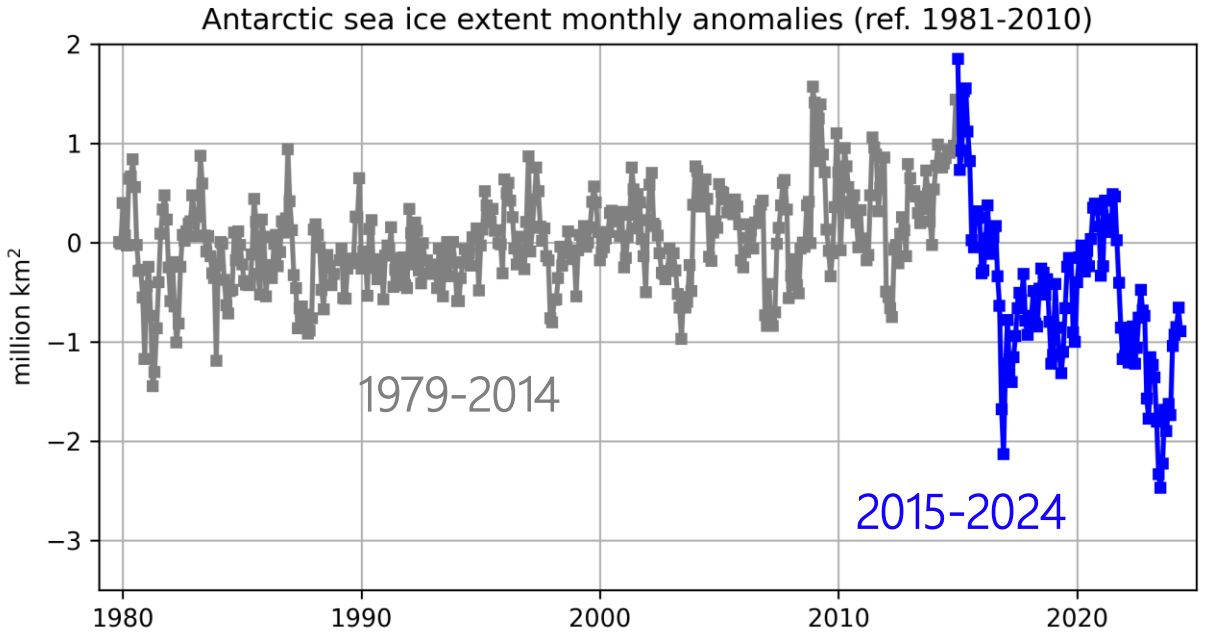


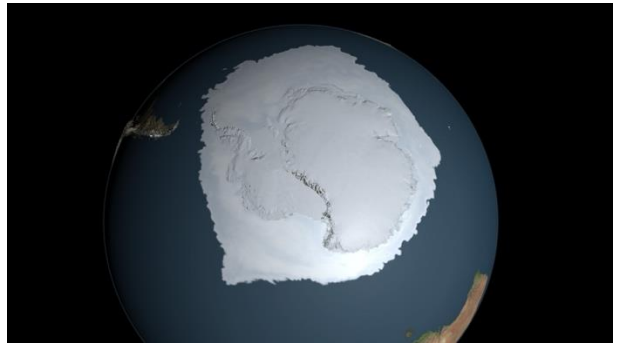


NSIDC sea ice index

Sea ice is never where you expect it to be







What happened to Antarctic sea ice recently?

How extreme can a sea ice extreme be, and why?

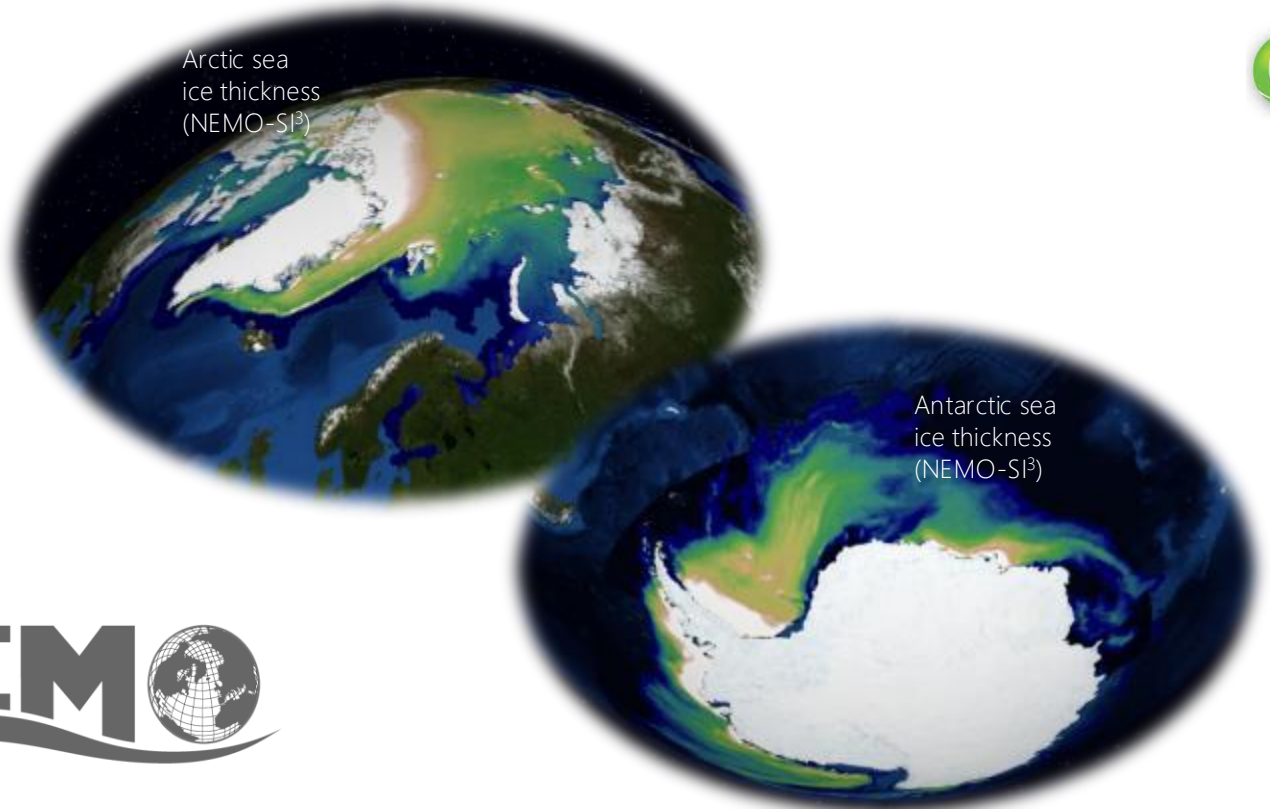
Are such sub-decadal fluctuations predicted by state-of-the-art climate models?

Are statistical / ML tools credible alternatives to dynamical models for prediction purposes?

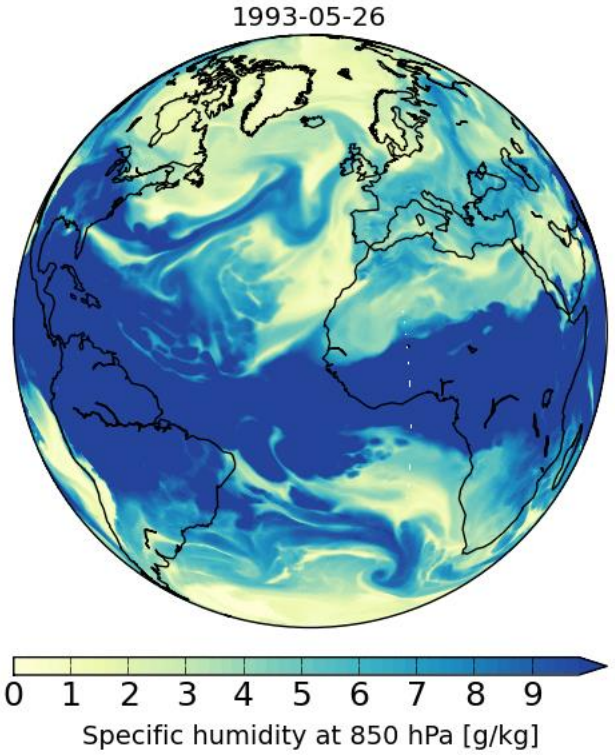
What's next?

The Polar Research Group at UCLouvain: tools

Ocean–sea ice model NEMO4-SI^3 (Nucleus for European Modelling of the Ocean – Sea Ice Modelling Integrated Initiative) run on a global or regional domain at different horizontal resolutions (namely, 1°, 1/4°, 1/12° and 1/24°).



EC-Earth ESM, data assimilation techniques, outputs from CMIP6 simulations, atmospheric and oceanic reanalyses, and in situ and satellite observational data.



What happened to Antarctic sea ice recently?

How extreme can a sea ice extreme be, and why?

Are such sub-decadal fluctuations predicted by state-of-the-art climate models?

Are statistical / ML tools credible alternatives to dynamical models for prediction purposes?

What's next?

What happened to Antarctic sea ice recently?

How extreme can a sea ice extreme be, and why?

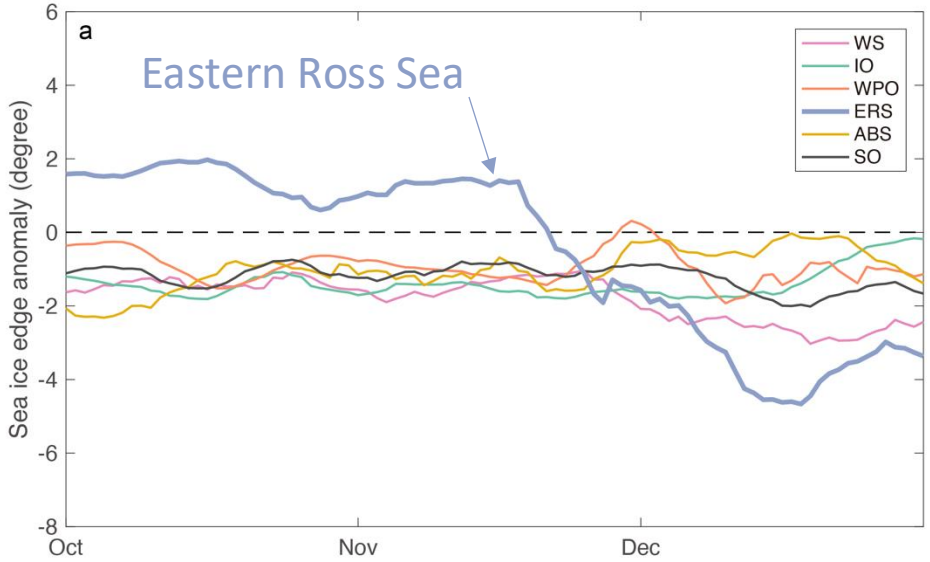
Are such sub-decadal fluctuations predicted by state-of-the-art climate models?

Are statistical / ML tools credible alternatives to dynamical models for prediction purposes?

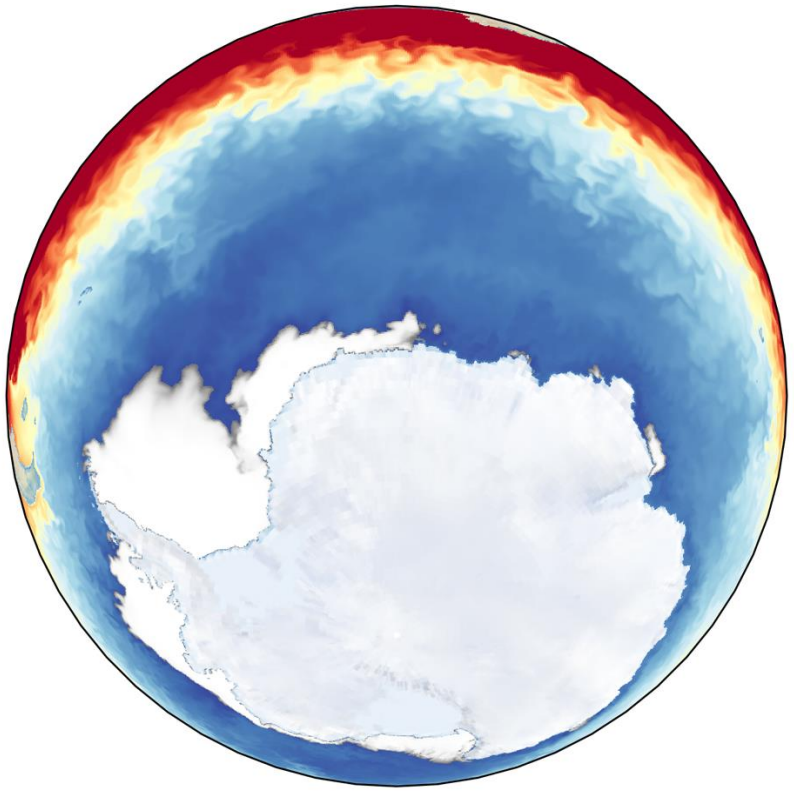
What's next?

Causes of the 2023 summer record low Antarctic sea ice

Sea ice edge anomalies (degrees latitude) during 2022-2023 (ref. 1981-2010) from NSIDC



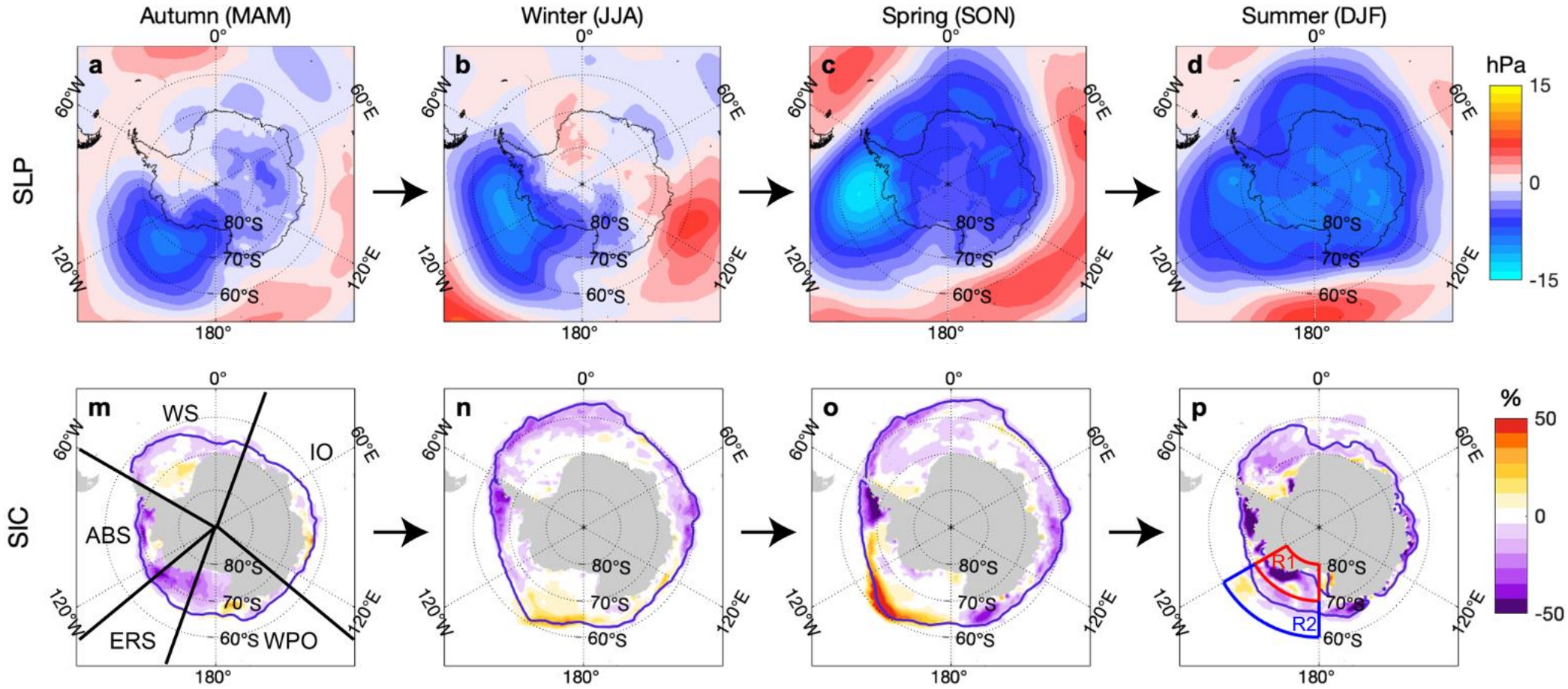
1/4° reconstruction of the ocean and sea ice states
www.climate.be/paramour



NEMO3.6-LIM3.6 ocean—sea ice model
Regional configuration, ORCA025 (1/4°), ERA5

Jinfei Wang (PhD Student)

2023 Antarctic sea ice record low: a 12-month retrospective case study



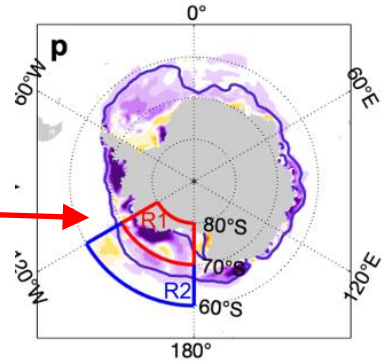
< March 2022: Preconditioning

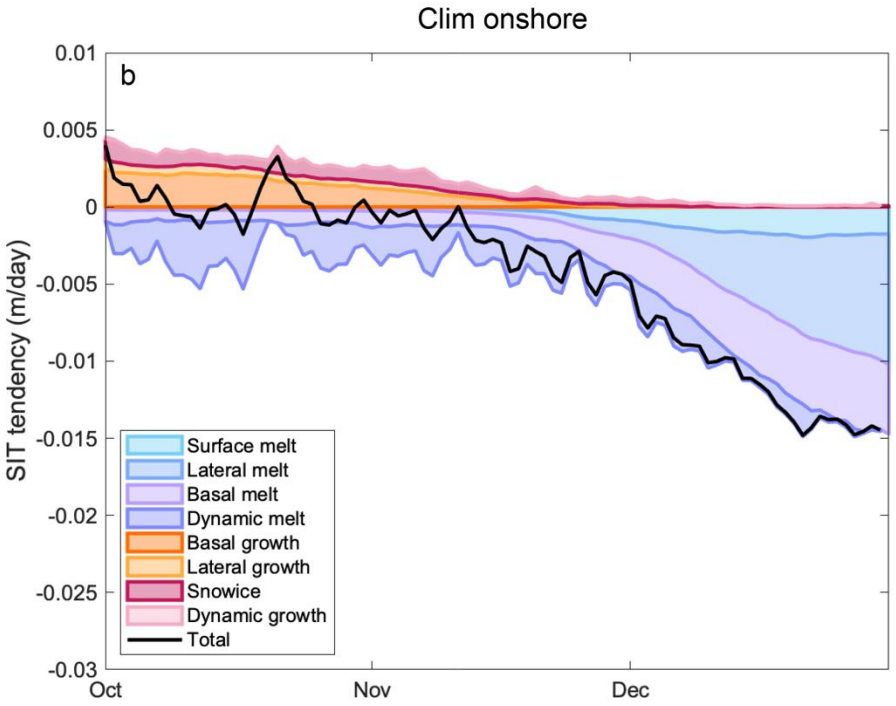
March 2022 → October 2022: Atmospheric processes

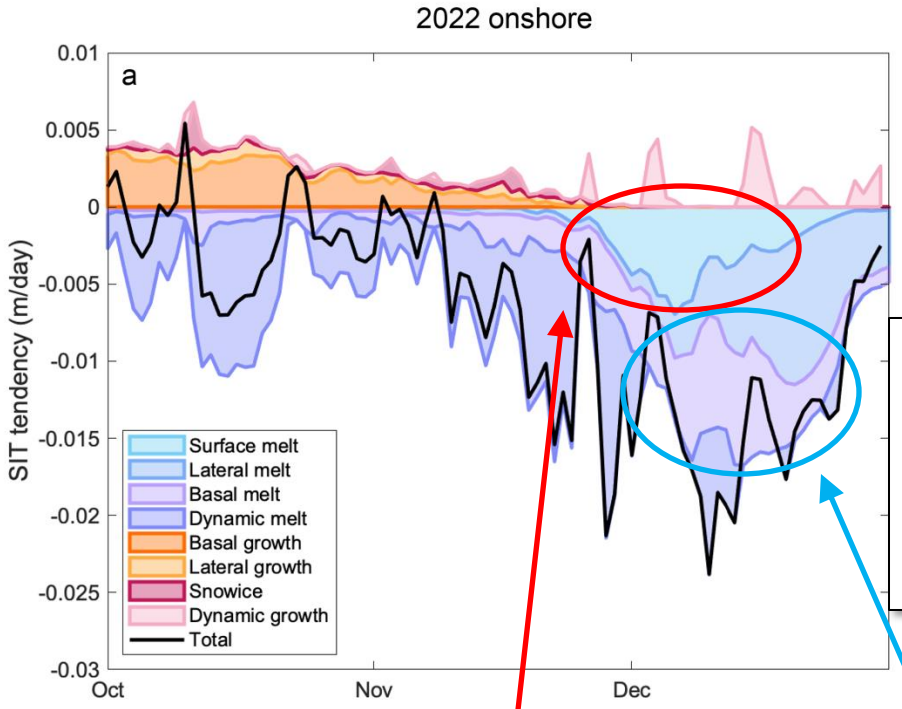
> November 2022: Ice-albedo feedback

Causes of the 2023 summer record low Antarctic sea ice

Sea ice thickness budgets from NEMO3.6-LIM3 in the red region

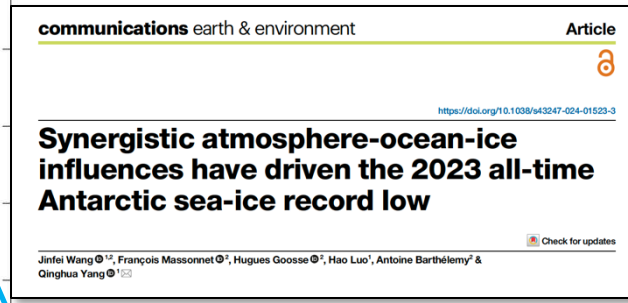






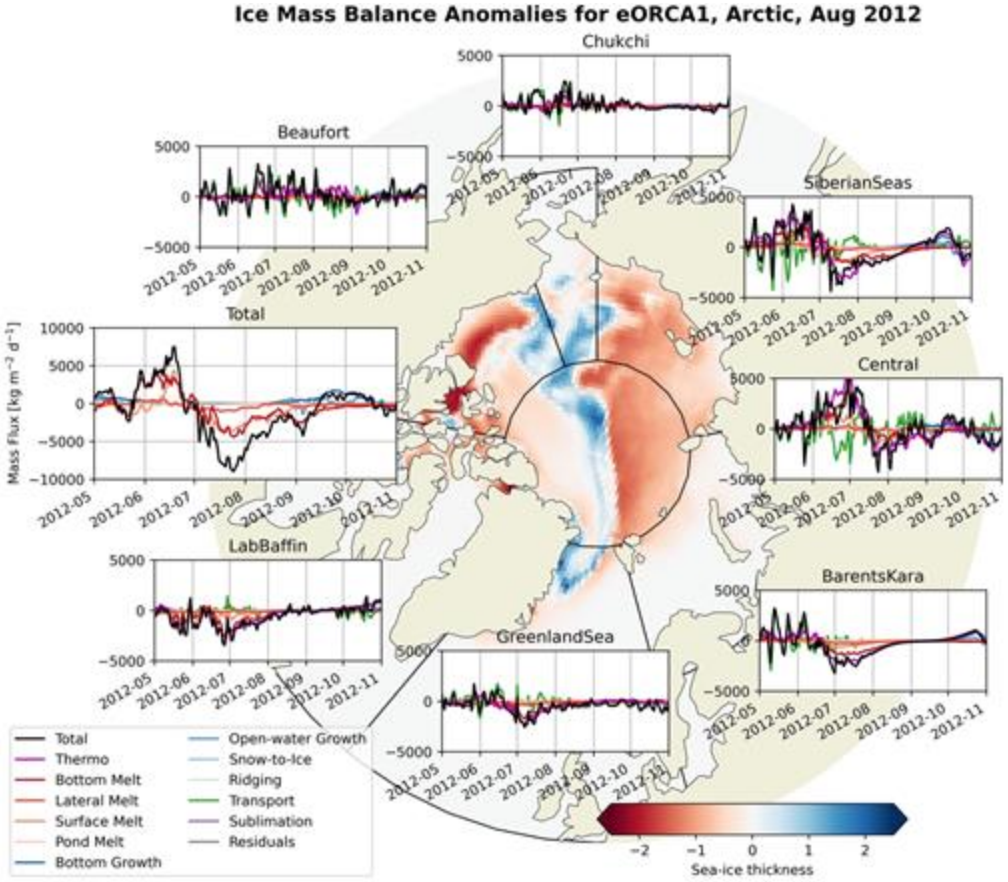
Anomalous surface melt…

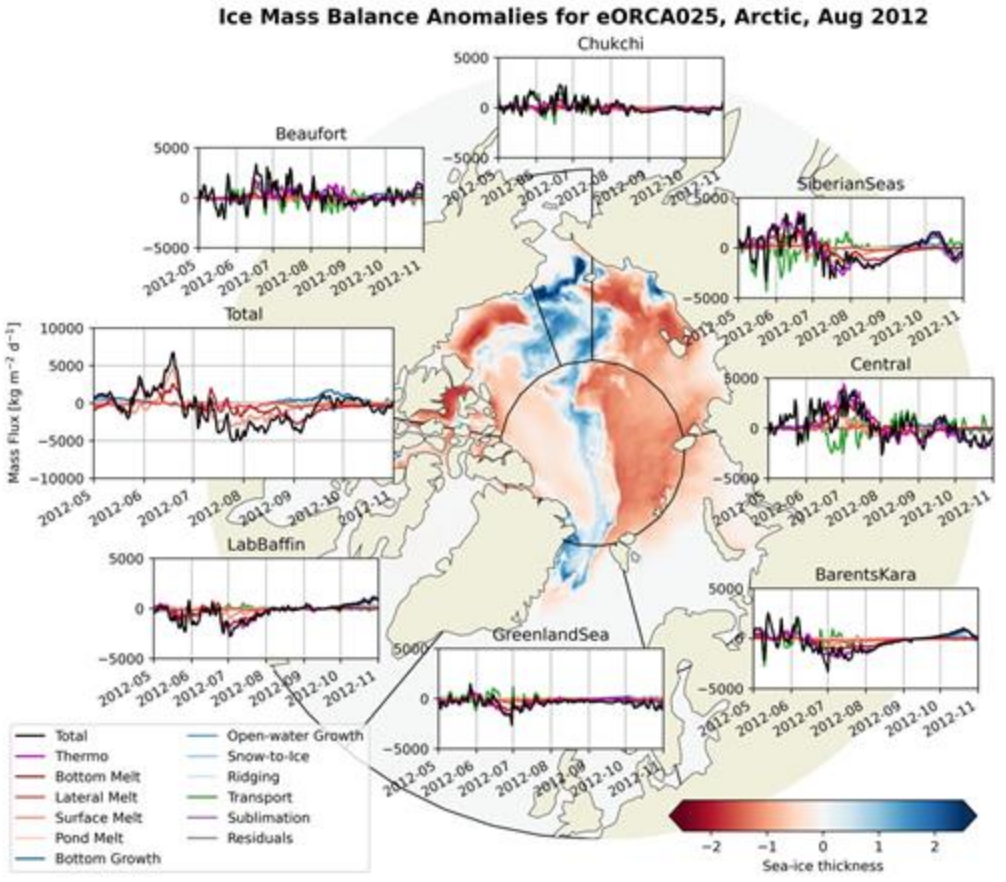
…followed by anomalous bottom melt



Jinfei Wang (PhD Student)

Simulated Arctic sea ice balance and the role of spatial resolution: 2012 as a case study



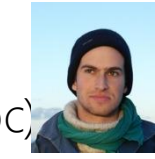


In ORCA1, bottom and surface melt contribute equally to the total anomaly

In ORCA025, surface melt anomaly dominates, mostly due to less bottom melt in Central Arctic and Siberian Seas.

https://resist-impuls.github.io/

RESIST



Benjamin Richaud (Post-Doc)

What happened to Antarctic sea ice recently?

How extreme can a sea ice extreme be, and why?

Are such sub-decadal fluctuations predicted by state-of-the-art climate models?

Are statistical / ML tools credible alternatives to dynamical models for prediction purposes?

What's next?

What happened to Antarctic sea ice recently?

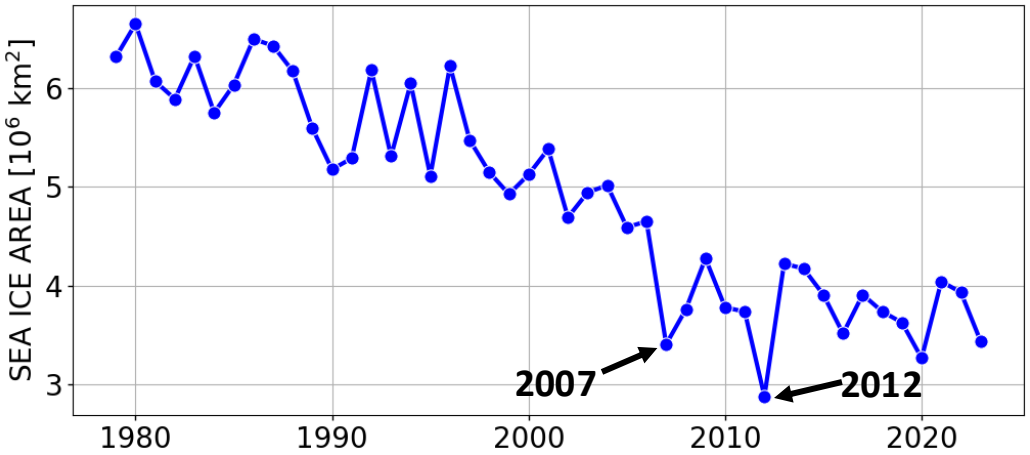
How extreme can a sea ice extreme be, and why?

Are such sub-decadal fluctuations predicted by state-of-the-art climate models?

Are statistical / ML tools credible alternatives to dynamical models for prediction purposes?

What's next?

Generating extreme reductions in the summer pan-Arctic sea ice area with the PLASIM T21-LSG climate model



September monthly mean pan-Arctic sea ice area [10^6 km^2]. OSI SAF 2023.

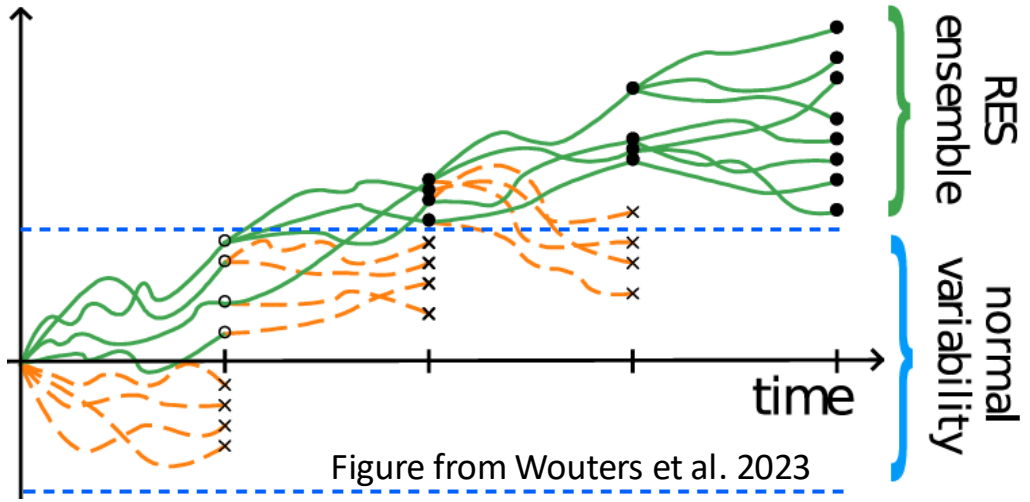
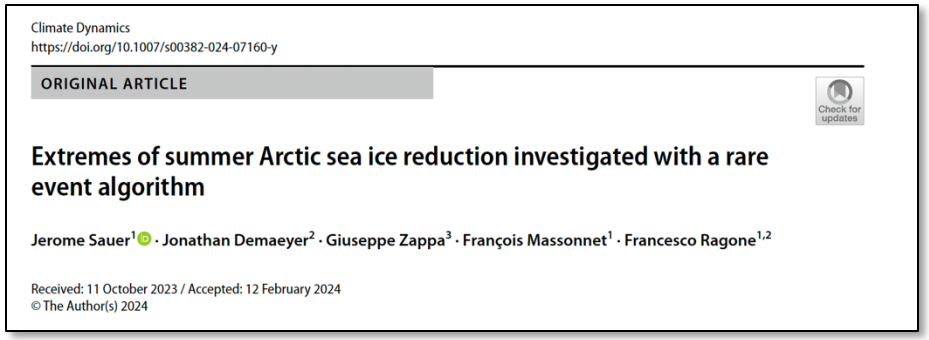


Figure from Wouters et al. 2023

- Problem: quantitative statistical and dynamical studies of climate extremes hindered by lack of data

→ From statistical physics: improve the sampling efficiency of extreme events with rare event algorithms



Climate Dynamics
https://doi.org/10.1007/s00382-024-07160-y

ORIGINAL ARTICLE

Extremes of summer Arctic sea ice reduction investigated with a rare event algorithm

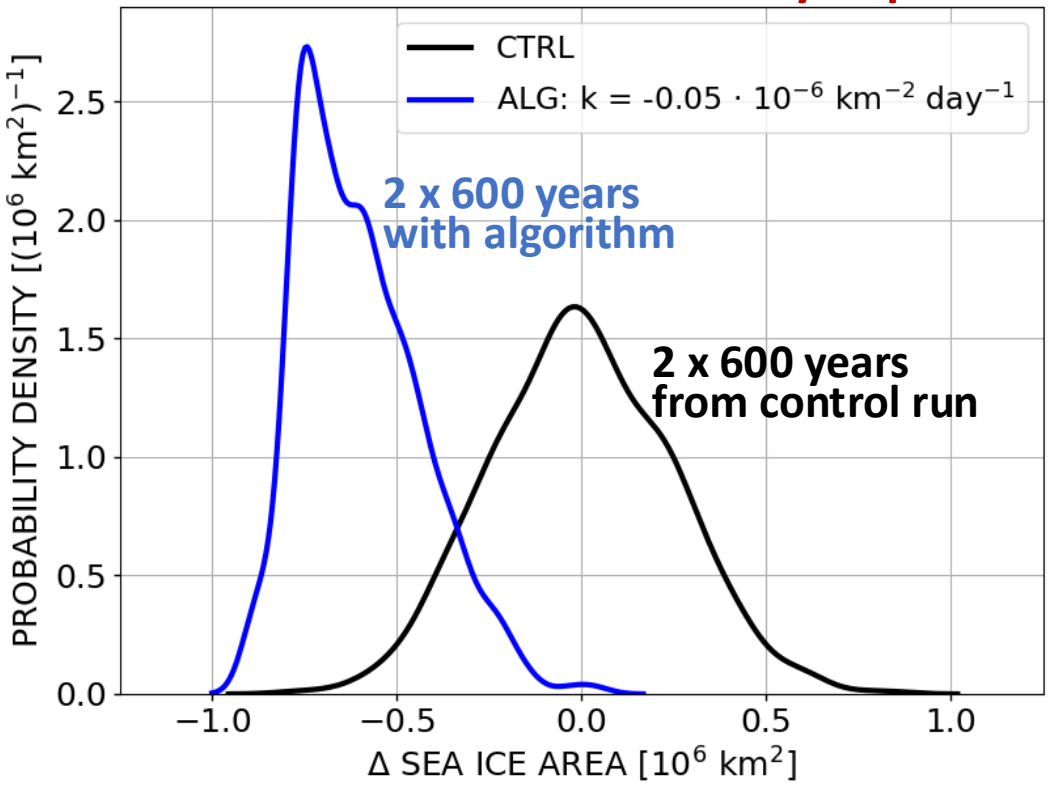
Jerome Sauer[1] · Jonathan Demaeyer[2] · Giuseppe Zappa[3] · François Massonnet[1] · Francesco Ragone[1,2]

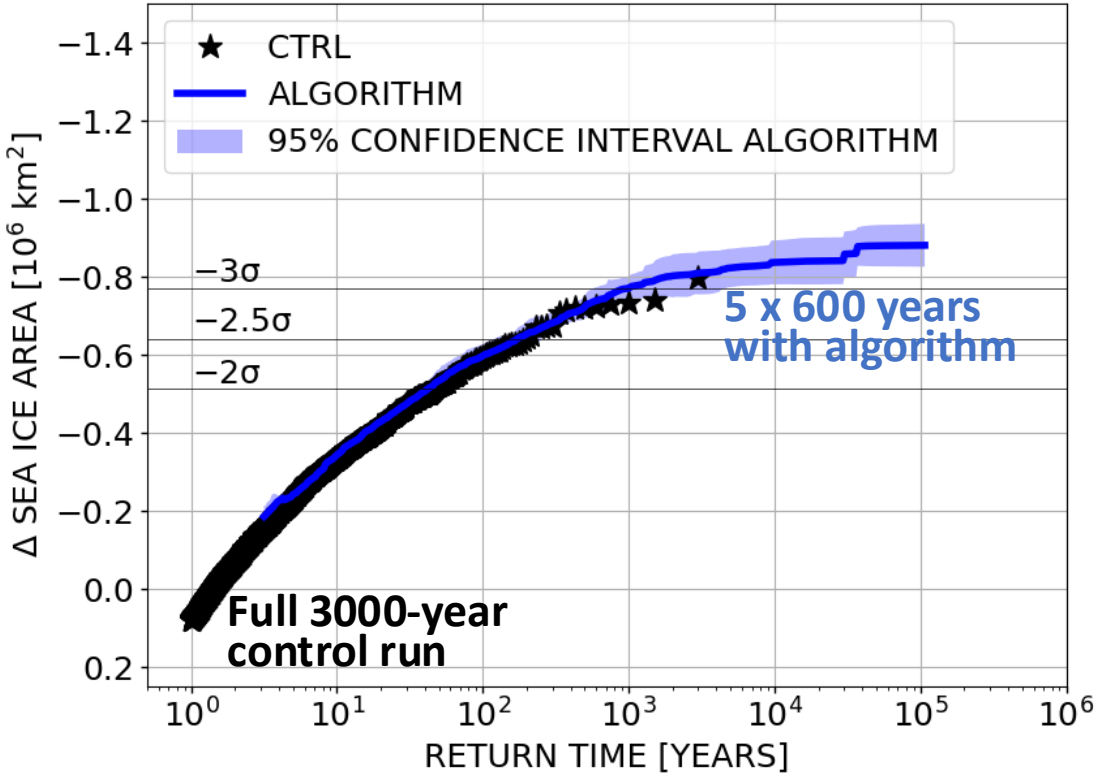
Received: 11 October 2023 / Accepted: 12 February 2024
© The Author(s) 2024

Jerome Sauer (PhD student)

Results: Application of the rare event algorithm to PlaSim-T21-LSG

February-September mean sea ice area anomalies





- Independent initial conditions sampled from long control run (stationary pre-industrial climate)
- Importance sampling of extreme negative February-September mean pan-Arctic sea ice area anomalies
- The algorithm allows to compute return times up to 10^5 years with computational cost of order 10^3 years

Jerome Sauer (PhD student)

What happened to Antarctic sea ice recently?

How extreme can a sea ice extreme be, and why?

Are such sub-decadal fluctuations predicted by state-of-the-art climate models?

Are statistical / ML tools credible alternatives to dynamical models for prediction purposes?

What's next?

What happened to Antarctic sea ice recently?

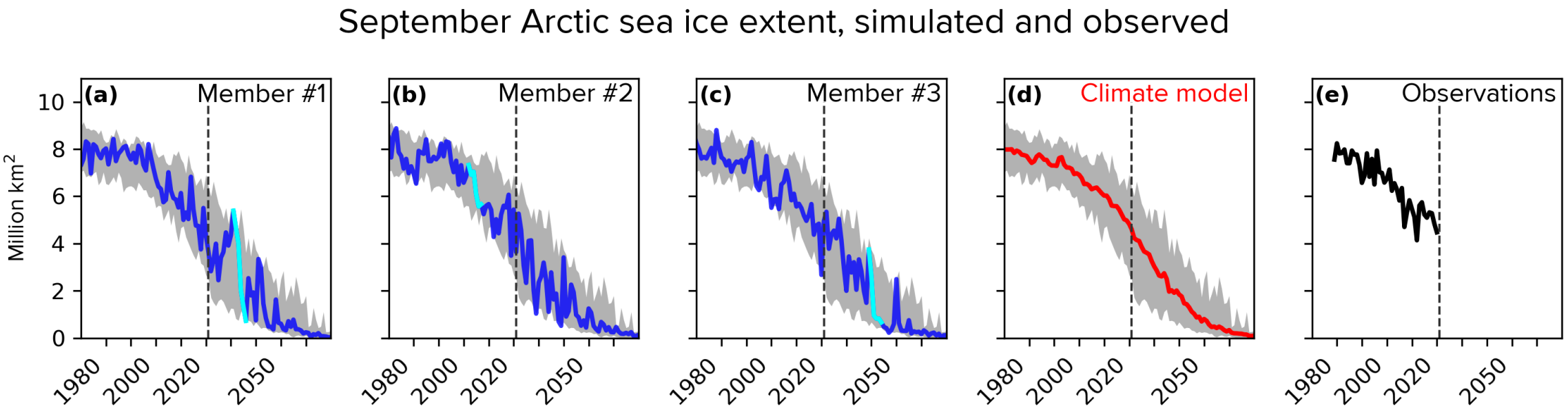
How extreme can a sea ice extreme be, and why?

Are such sub-decadal fluctuations predicted by state-of-the-art climate models?

Are statistical / ML tools credible alternatives to dynamical models for prediction purposes?

What's next?

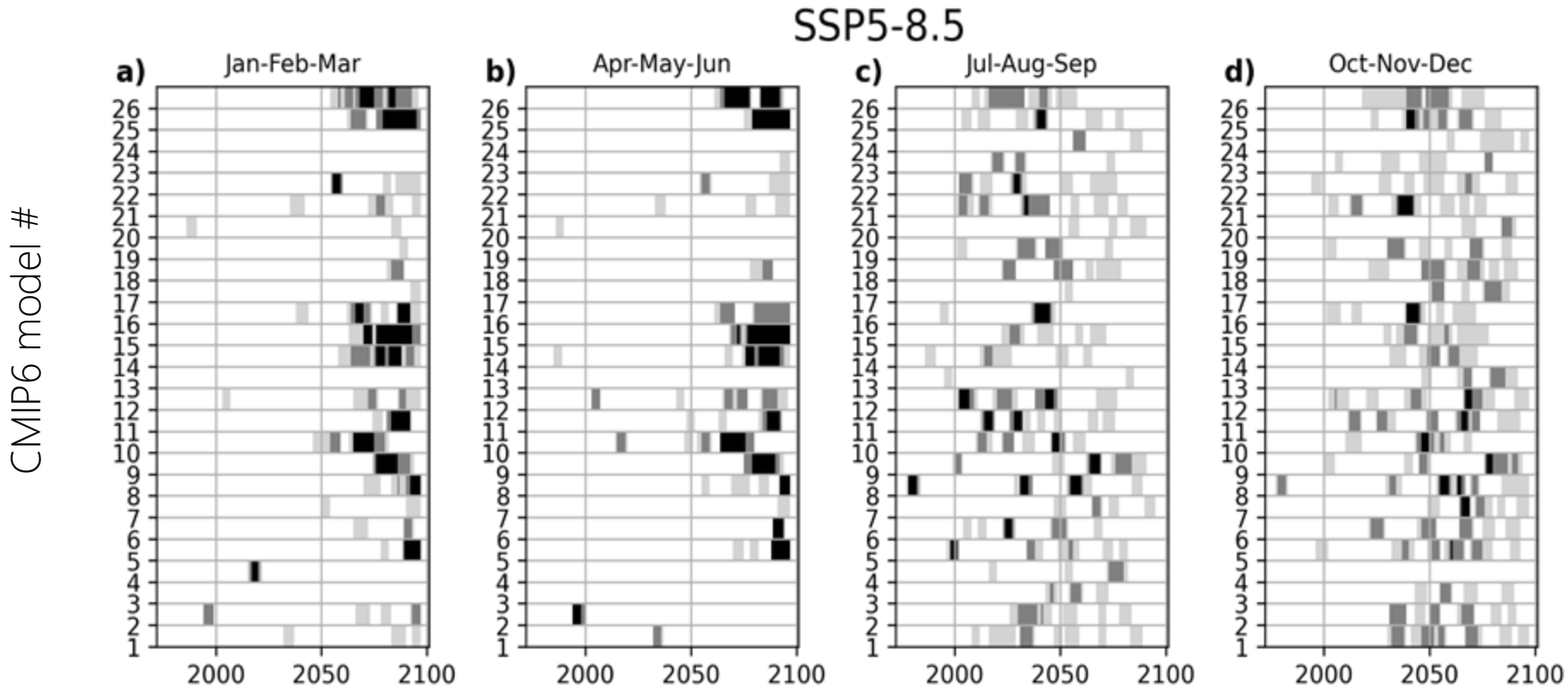
State-of-the-art climate models do predict fluctuations in sub-decadal sea ice extent trends



« Rapid ice loss event »: Sequence of at least 4 consecutive years for which the trend in the 5-yr smoothed SIE is less than -0.3 million km²/year (Auclair & Tremblay, 2018)

Rapid Ice Loss Events seasonally more consistent in winter, more randomly distributed in summer

Frequency of occurrence of RILEs in CMIP6, as a function of the season and the year



https://doi.org/10.5194/egusphere-2024-1873
Preprint. Discussion started: 1 July 2024

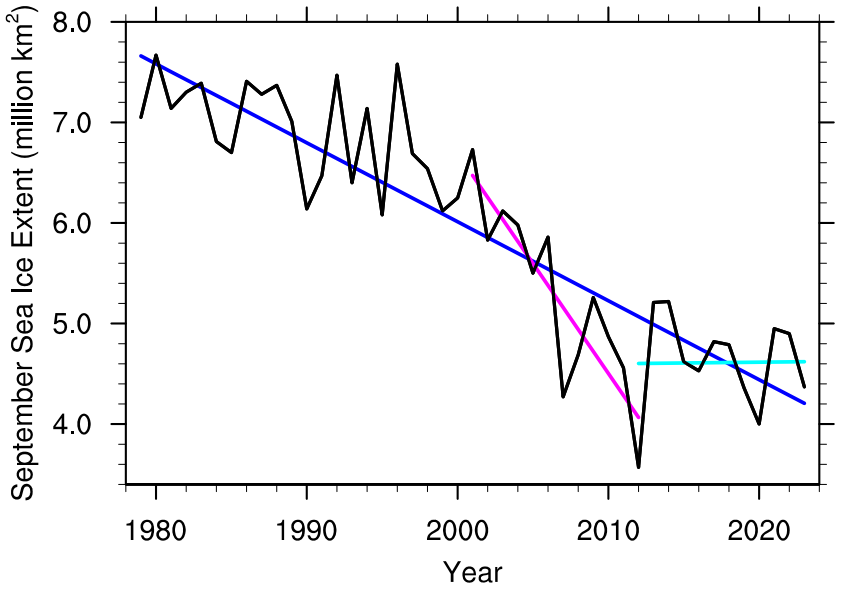
Seasonality and scenario dependence of rapid Arctic sea ice loss events in CMIP6 simulations

Annelies Sticker[1,*], François Massonnet[1], Thierry Fichefet[1], Patricia DeRepentigny[1], Alexandra Jahn[2,3], David Docquier[4], Christopher Wyburn-Powell[2,3], Daphne Quint[2], Erica Shivers[2], and Makayla Ortiz[2]

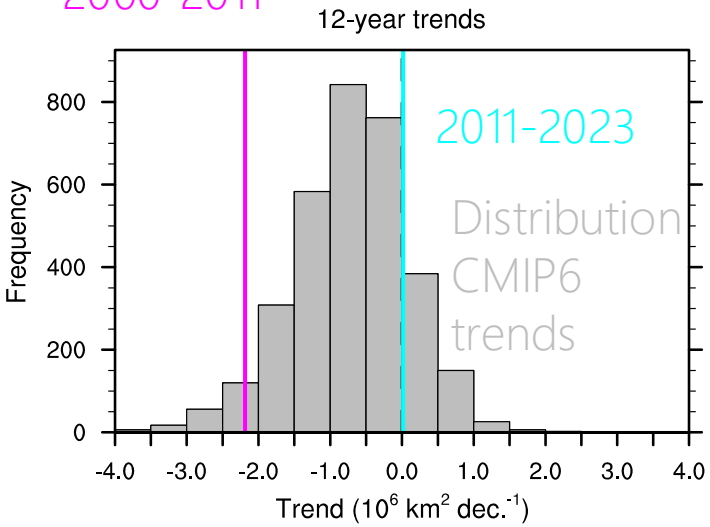
[1]Earth and Life Institute, Earth and Climate, UCLouvain, Louvain-la-Neuve, Belgium
[2]Department of Atmospheric and Oceanic Sciences, University of Colorado Boulder, Boulder, CO, USA
[3]Institute for Arctic and Alpine Research, University of Colorado Boulder, Boulder, CO, USA
[4]Royal Meteorological Institute of Belgium, Brussels, Belgium
[*]Corresponding author: Annelies Sticker (annelies.sticker@uclouvain.be)

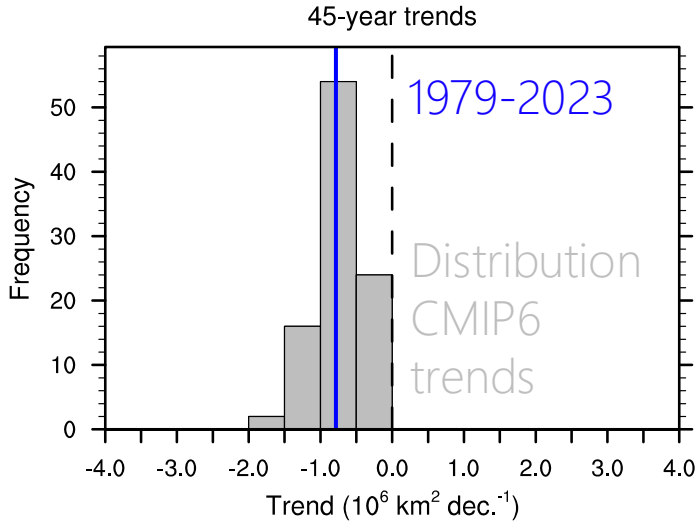
Annelies Sticker (PhD student)

Recently observed sub-decadal trends in Arctic sea ice extent are compatible with the models' natural variability

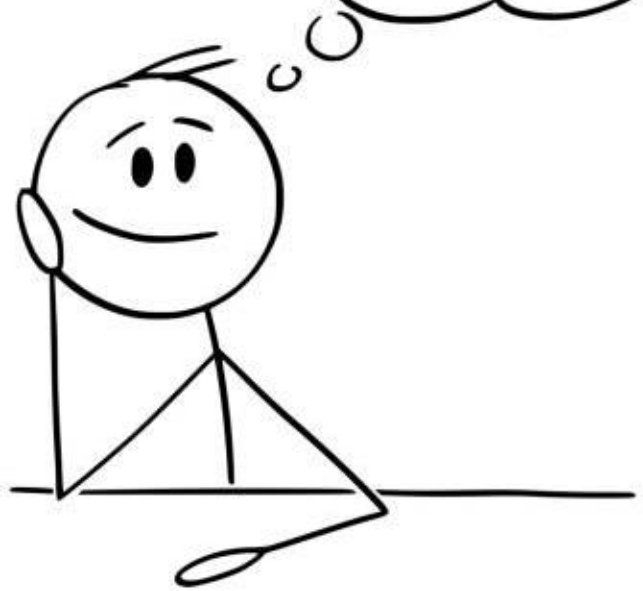


2000-2011





How predictable was the accelerated decline in sea ice during the 2000s and the relatively stable conditions that followed?



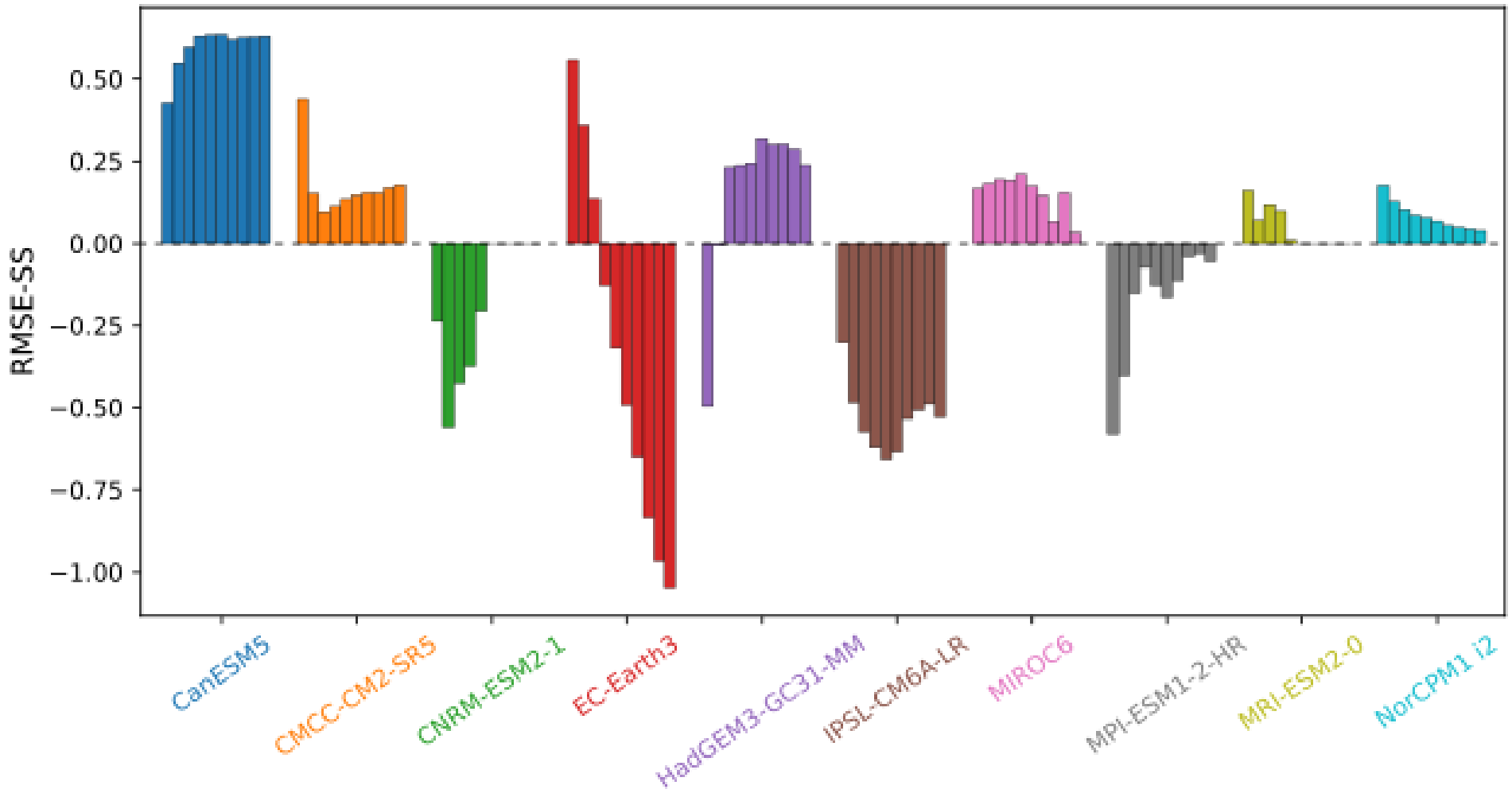
Patricia DeRepentigny (Post-Doc)

DCPP-hindcast simulations – Multi-model analysis (CMIP6)

Model	**Ensemble size**	**Initialization date**	**# of forecast years**	**Sea ice initialization method**
CanESM5	20	December 31	10	Full-field (via nudging)
CMCC-CM2-SR5	20	November 1	10	Full-field (via nudging)
CNRM-ESM2-1	10	November 1	5	?
EC-Earth3	10	November 1	10	Full-field (via nudging)
HadGEM3-GC31-MM	10	November 1	10	Full-field (via nudging)
IPSL-CM6A-LR	10	December 31	10	Anomaly (via nudging)
MIROC6	10	November 1	10	Full-field
MPI-ESM1-2-HR	5	November 1	10	Anomaly (via incremental analysis updates)
MRI-ESM2-0	10	November 1	5	Anomaly
NorCPM1	10	October 15	10	Anomaly

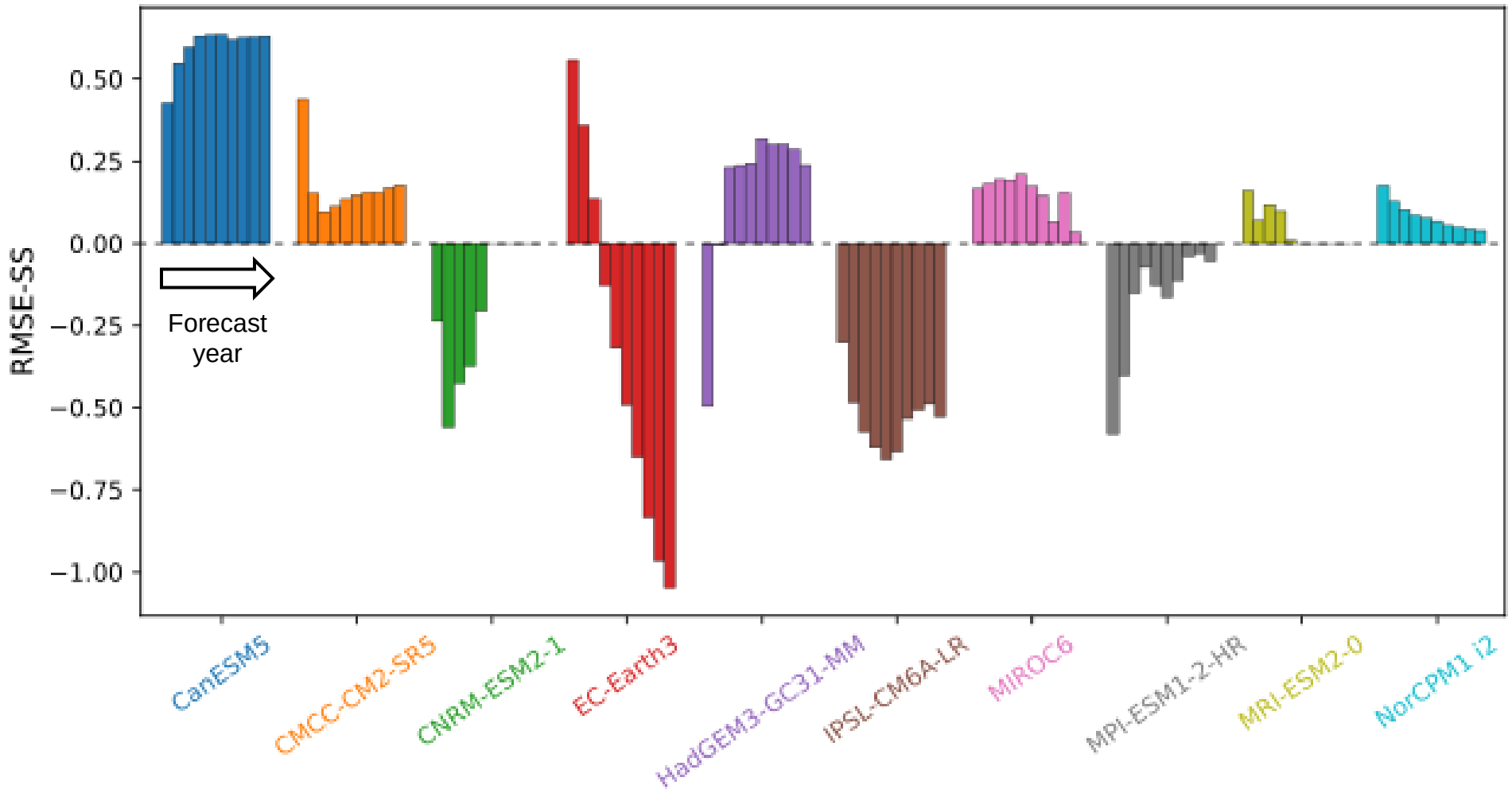
Do initialized runs show improvement over uninitialized runs?

$$RMSE\text{-}SS = \left(1 - \frac{RMSE_{forecast}}{RMSE_{reference}}\right) \qquad RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - y_i)^2}$$



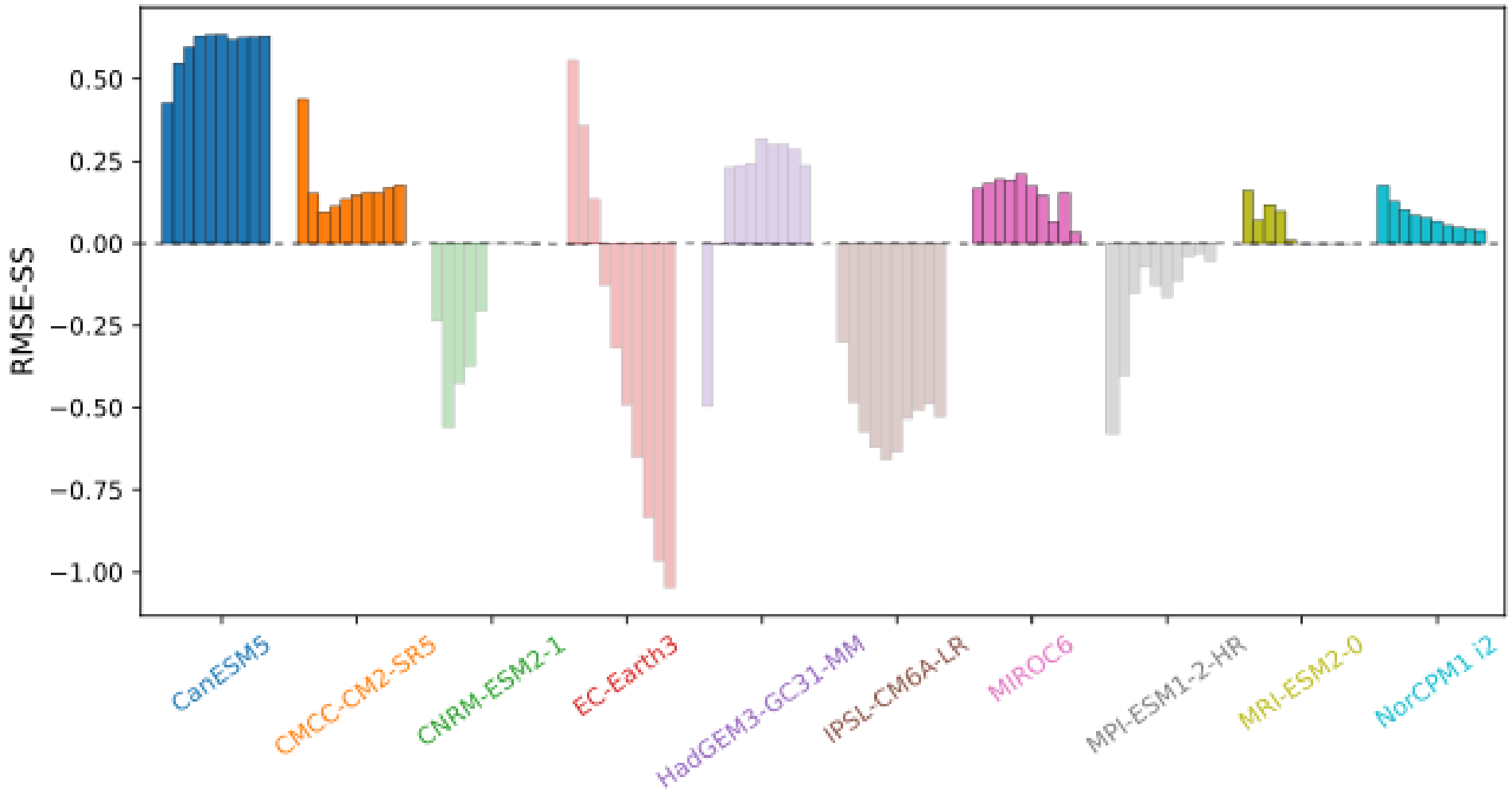
Do initialized runs show improvement over uninitialized runs?

$$RMSE\text{-}SS = \left(1 - \frac{RMSE_{forecast}}{RMSE_{reference}}\right) \qquad RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - y_i)^2}$$



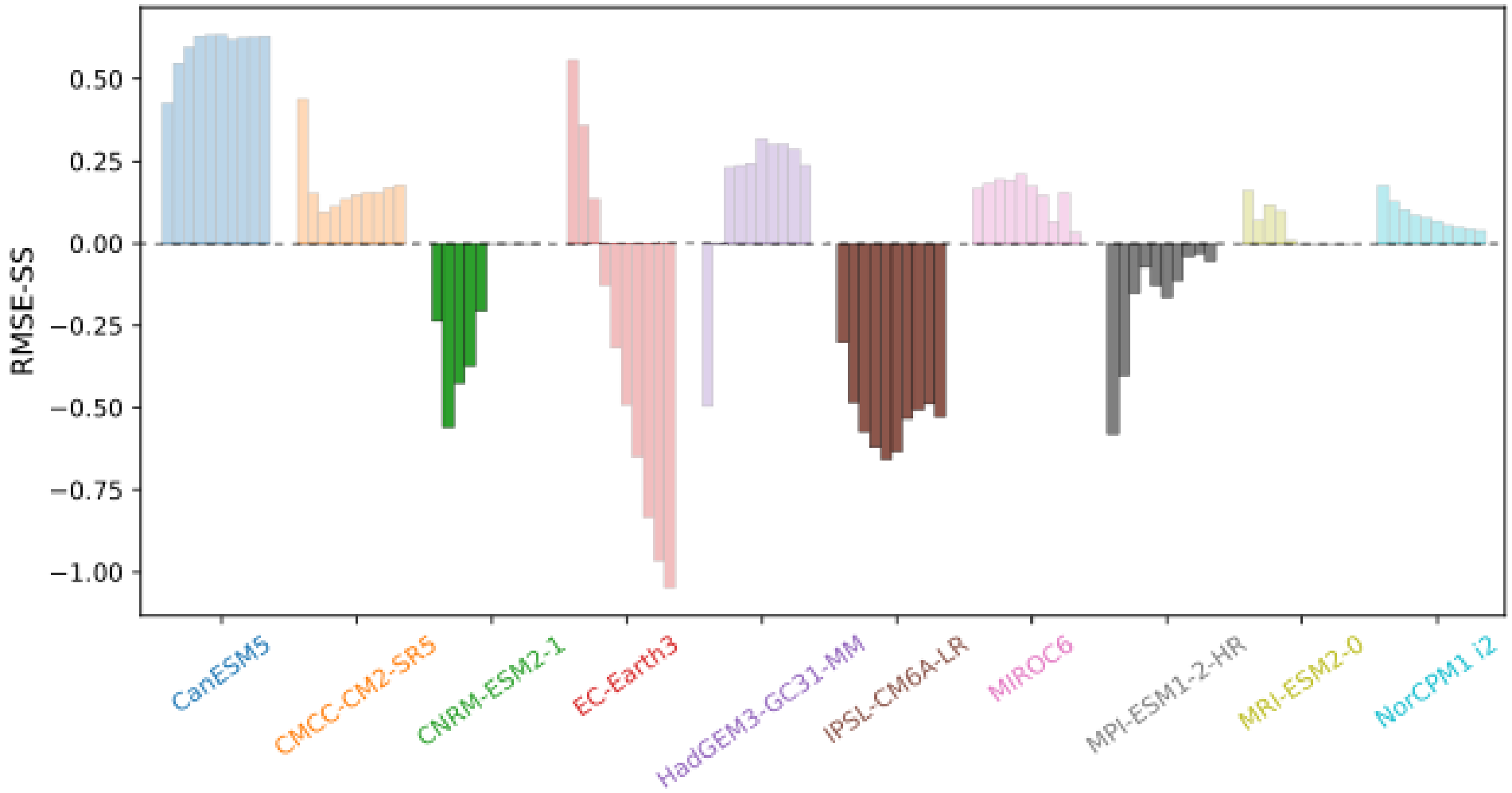
Do initialized runs show improvement over uninitialized runs?

$$RMSE\text{-}SS = \left(1 - \frac{RMSE_{forecast}}{RMSE_{reference}}\right) \qquad RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - y_i)^2}$$



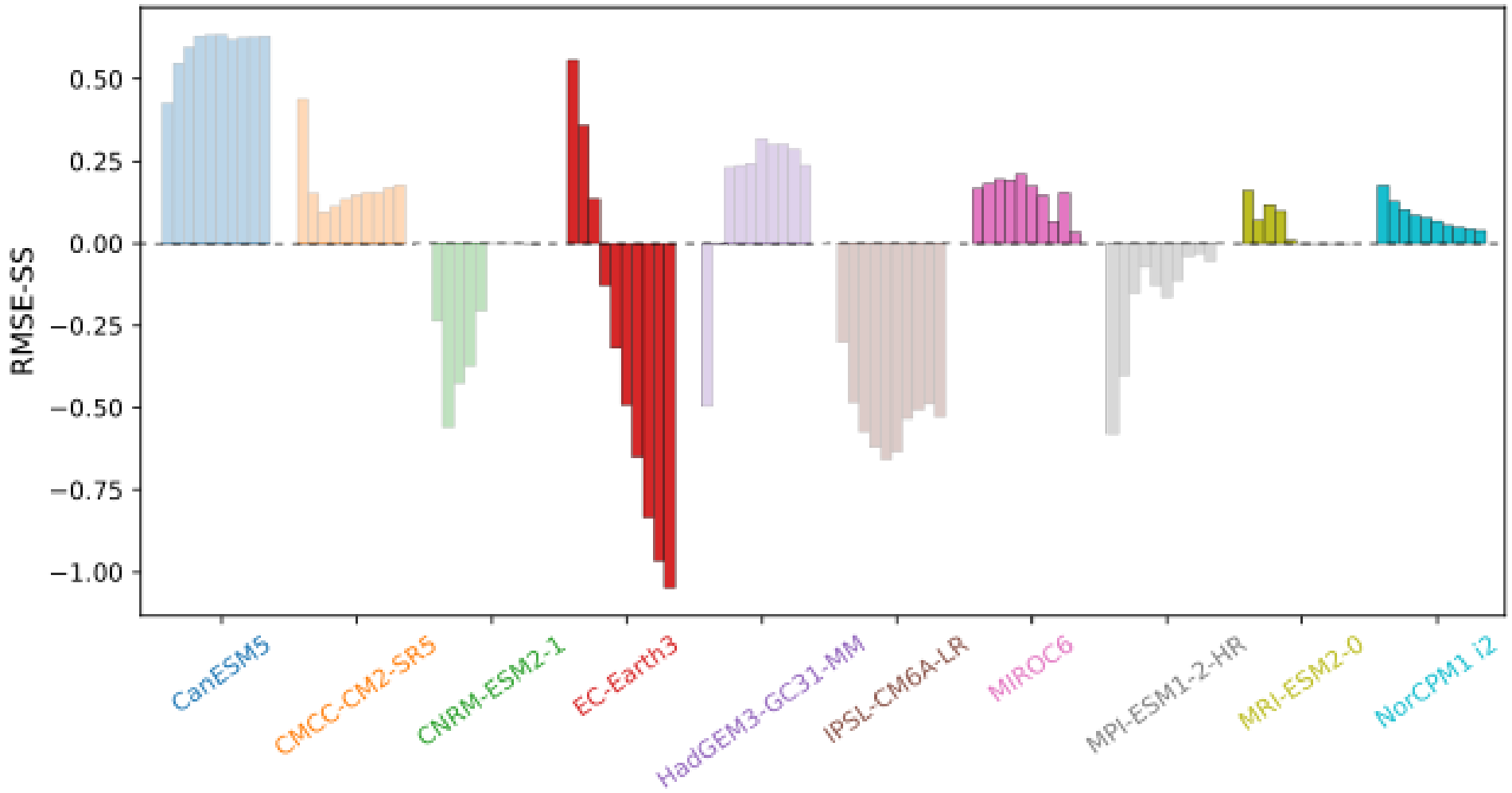
Do initialized runs show improvement over uninitialized runs?

$$RMSE\text{-}SS = \left(1 - \frac{RMSE_{forecast}}{RMSE_{reference}}\right) \qquad RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - y_i)^2}$$



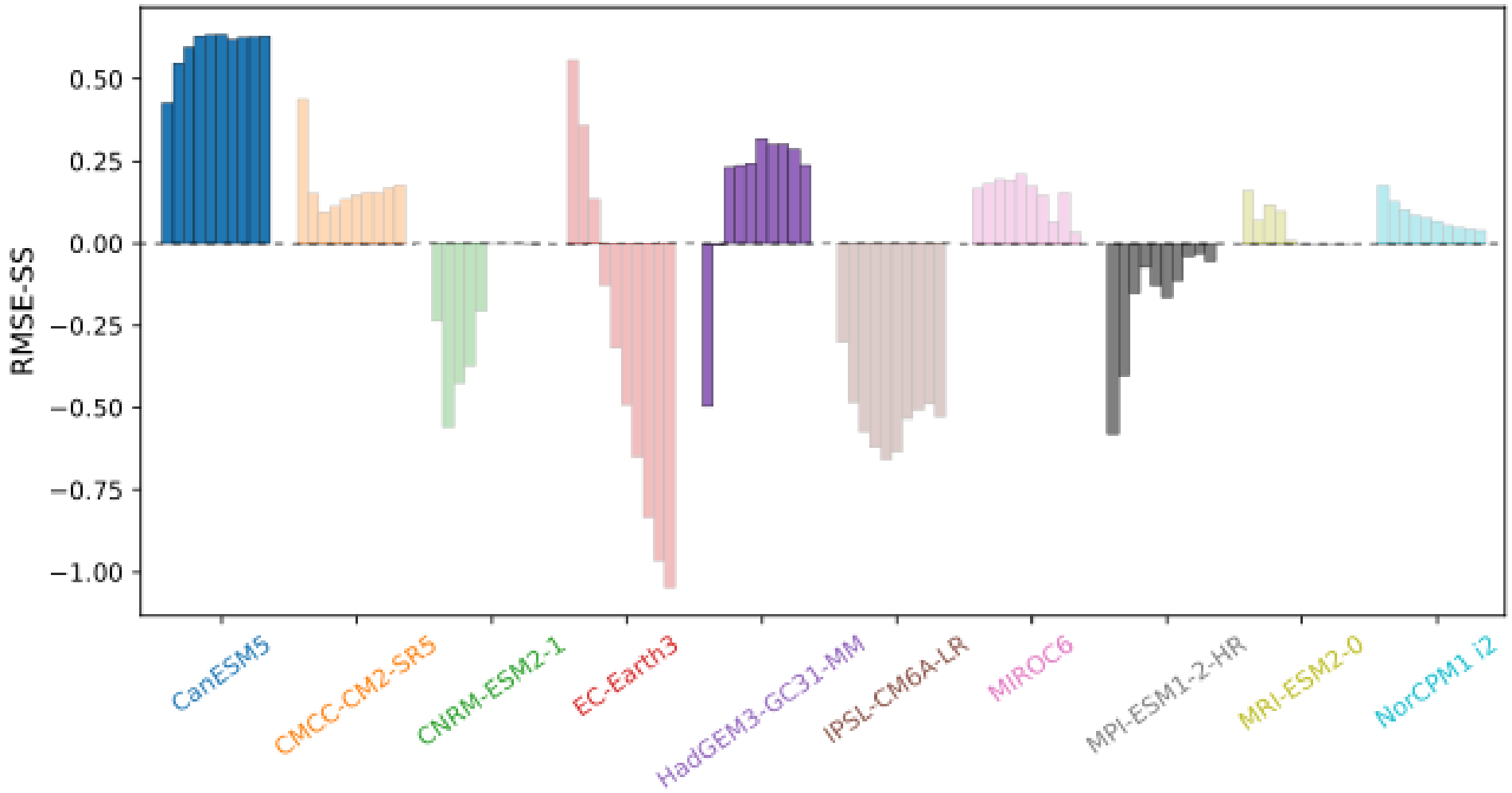
Do initialized runs show improvement over uninitialized runs?

$$RMSE\text{-}SS = \left(1 - \frac{RMSE_{forecast}}{RMSE_{reference}}\right) \qquad RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - y_i)^2}$$



Do initialized runs show improvement over uninitialized runs?

$$RMSE\text{-}SS = \left(1 - \frac{RMSE_{forecast}}{RMSE_{reference}}\right) \qquad RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - y_i)^2}$$



What happened to Antarctic sea ice recently?

How extreme can a sea ice extreme be, and why?

Are such sub-decadal fluctuations predicted by state-of-the-art climate models?

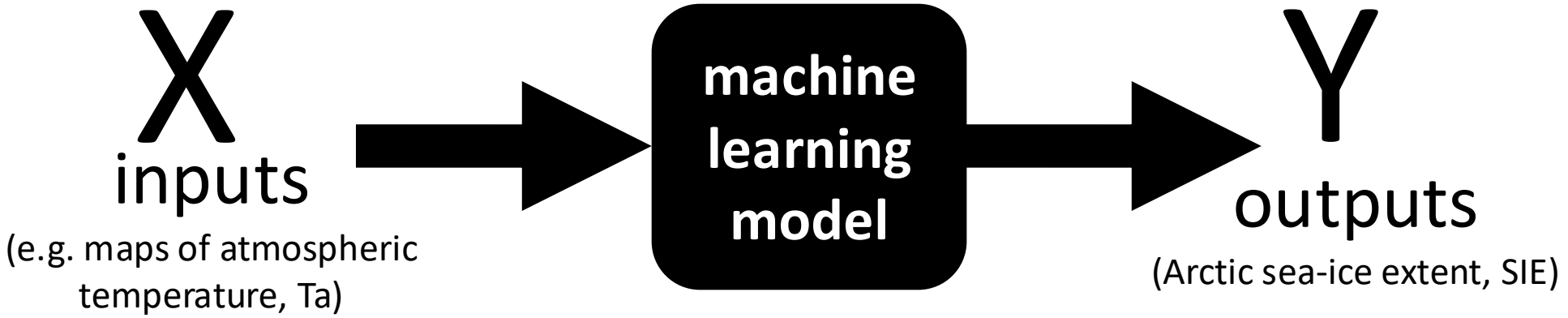
Are statistical / ML tools credible alternatives to dynamical models for prediction purposes?

What's next?

Is machine learning (ML) a useful tool to *predict* and *understand* rapid ice loss events in the Arctic on interannual to decadal timescales?

1. Predict:

Can we build a ML model that makes *skillful* predictions of sea-ice extent?

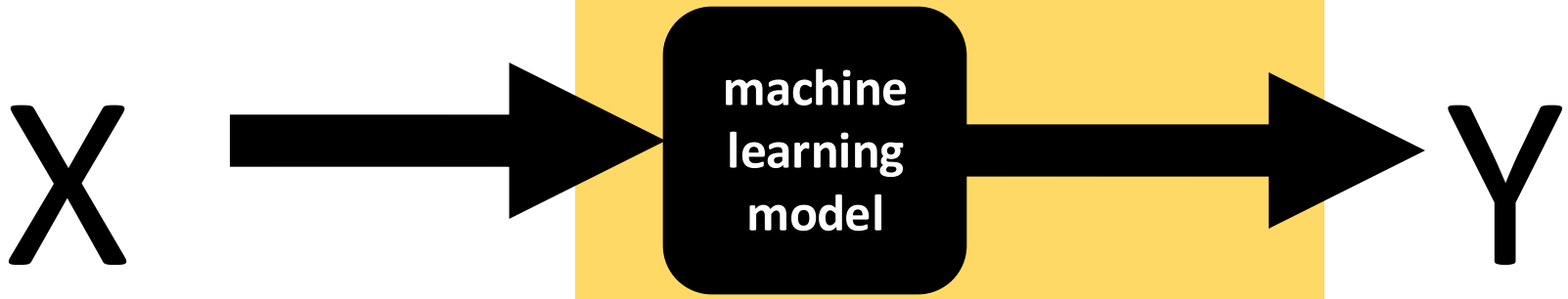


Lauren Hoffman (Post-Doc

1. Predict: We assess the skill of data-driven predictions of September sea-ice extent for various ***statistical models*** and ***predictive inputs***.

vary the statistical model:

- Persistence (benchmark)
- Transfer operator
- Neural network



inputs

vary the inputs:

- sea-ice extent
- sea-ice thickness
- sea-ice volume
- ocean heat content
- atmospheric temperature
- …

vary the time interval:

- time, t = 1 – N ; N = 0-10 years
  - yearly mean
  - September mean
  - DJF mean
  - JJ mean
  - March mean

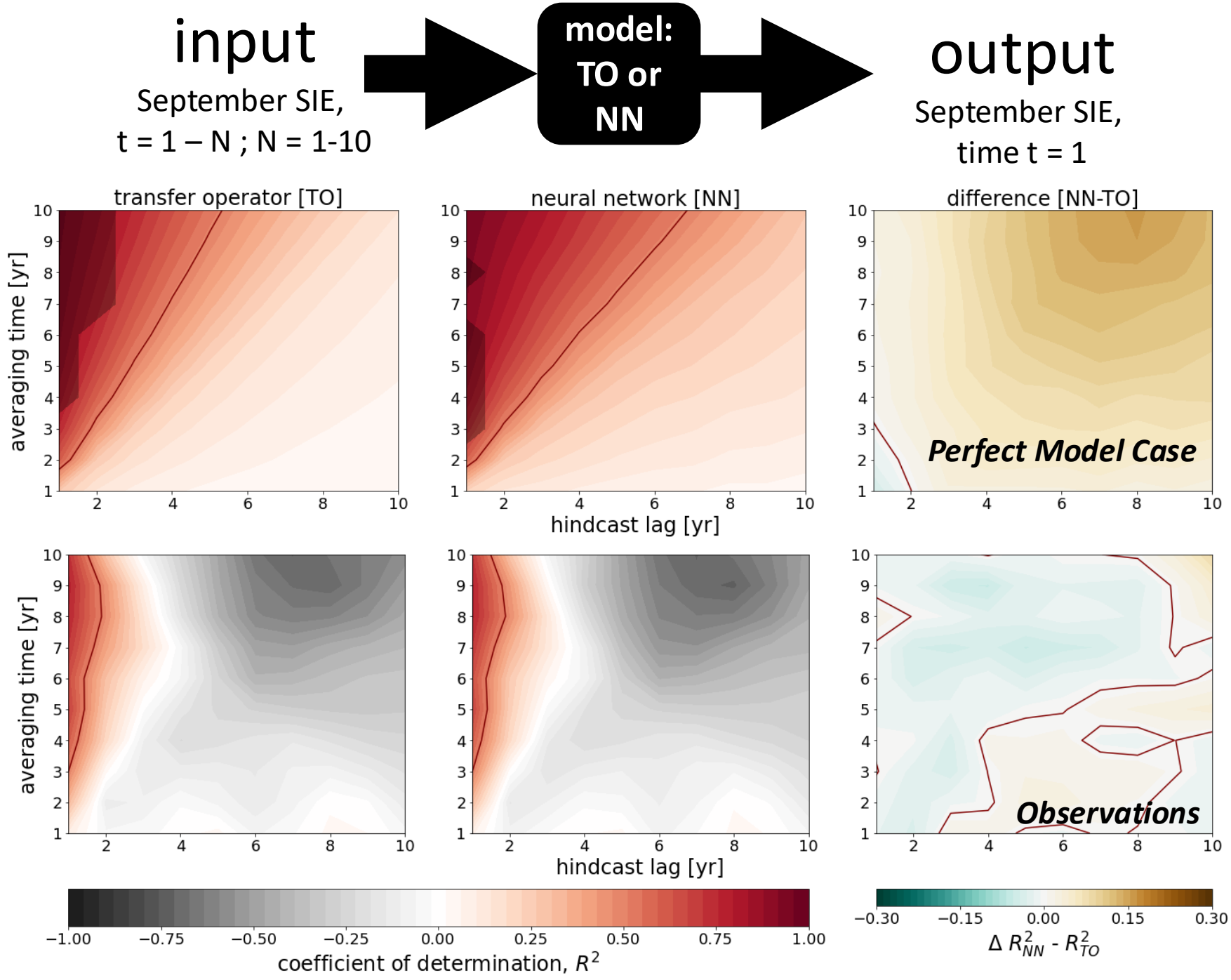
output

(September SIE, time t = 1)

Lauren Hoffman (Post-Doc

We compare the performance of a ***transfer operator (TO)*** and a ***neural network (NN)*** for predicting state transitions of September SIE.

Lauren Hoffman (Post-Doc)



What happened to Antarctic sea ice recently?

How extreme can a sea ice extreme be, and why?

Are such sub-decadal fluctuations predicted by state-of-the-art climate models?

Are statistical / ML tools credible alternatives to dynamical models for prediction purposes?

What's next?

What happened to Antarctic sea ice recently?

How extreme can a sea ice extreme be, and why?

Are such sub-decadal fluctuations predicted by state-of-the-art climate models?

Are statistical / ML tools credible alternatives to dynamical models for prediction purposes?

What's next?

Future plans

Seasonal predictability of Arctic landfast ice

Sea ice – icebergs interactions

Objective sea ice regime characterization

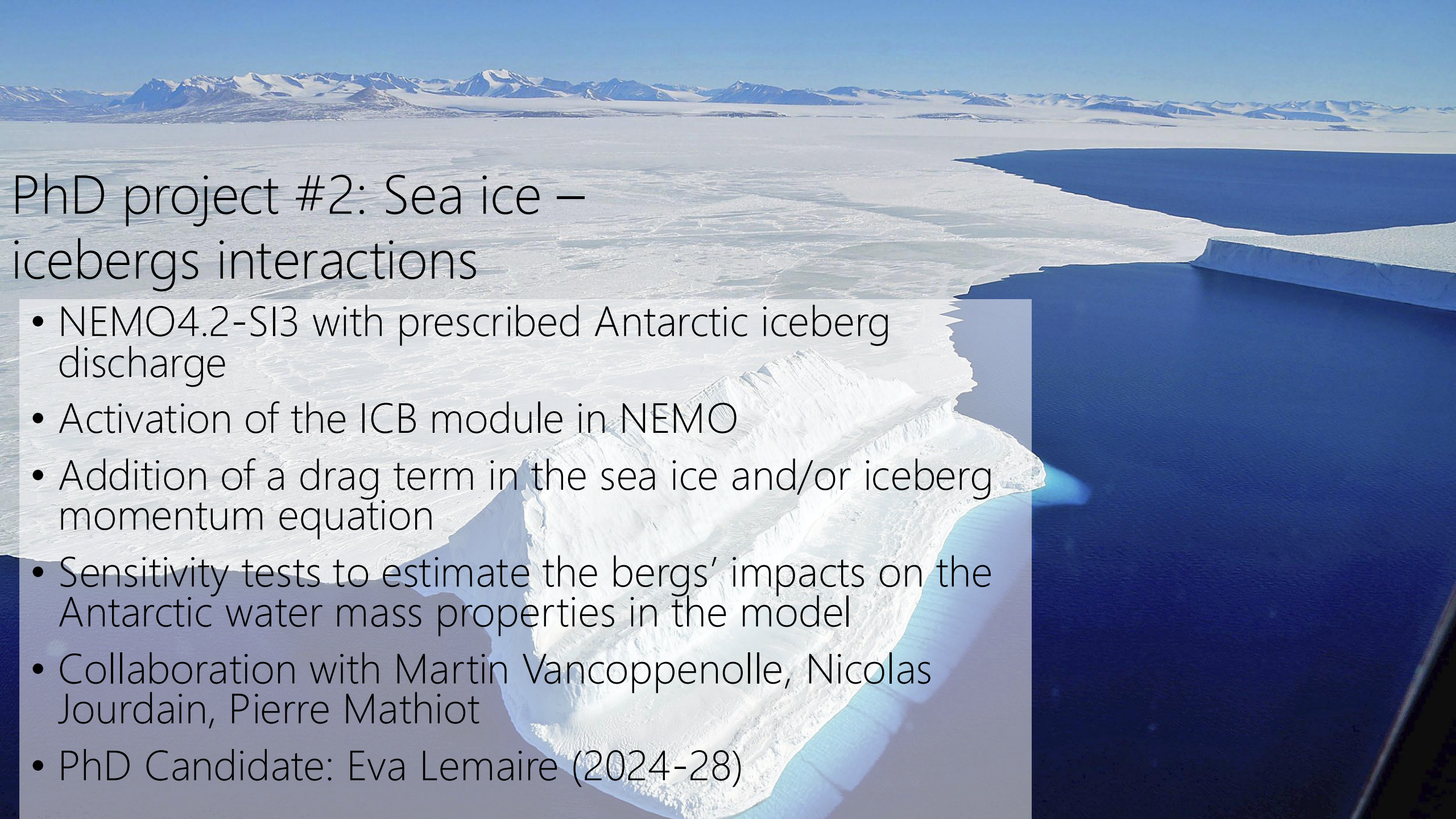
Sea Ice MIP (SIMIP)

PhD project: Seasonal Arctic landfast ice predictability

- NEMO4.2-SI3 ORCA025 with Lemieux et al. (2015,16) parameterizations (basal stress + tensile strength)
- Rheology? EVP definitely to be tested, but highly interested in testing the BBM rheology as well
- Coupled integrations to assess the initial-value predictability of landfast ice
- PhD Candidate: Augustin Lambotte (2024-28)

https://arctic.noaa.gov/report-card/report-card-2018/landfast-sea-ice-in-a-changing-arctic/

Augustin Lambotte, PhD candidate, 2024-2028

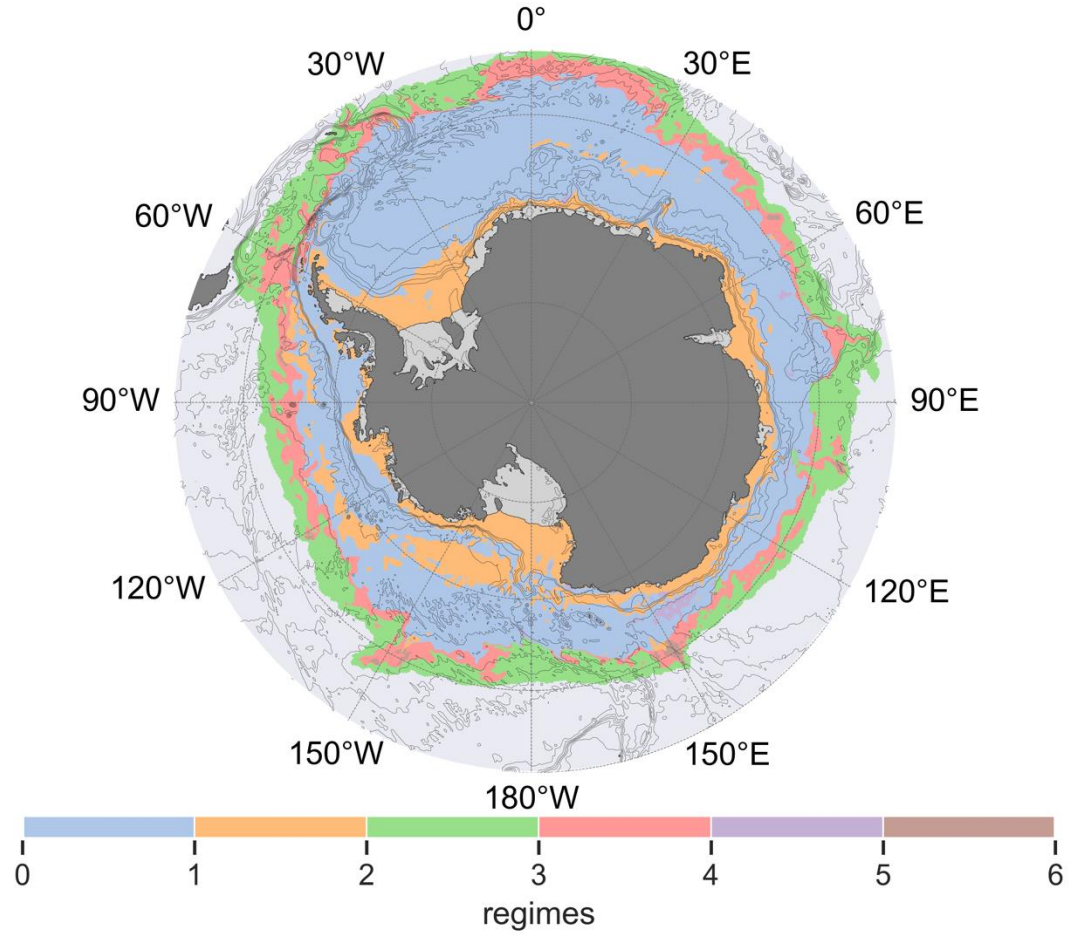


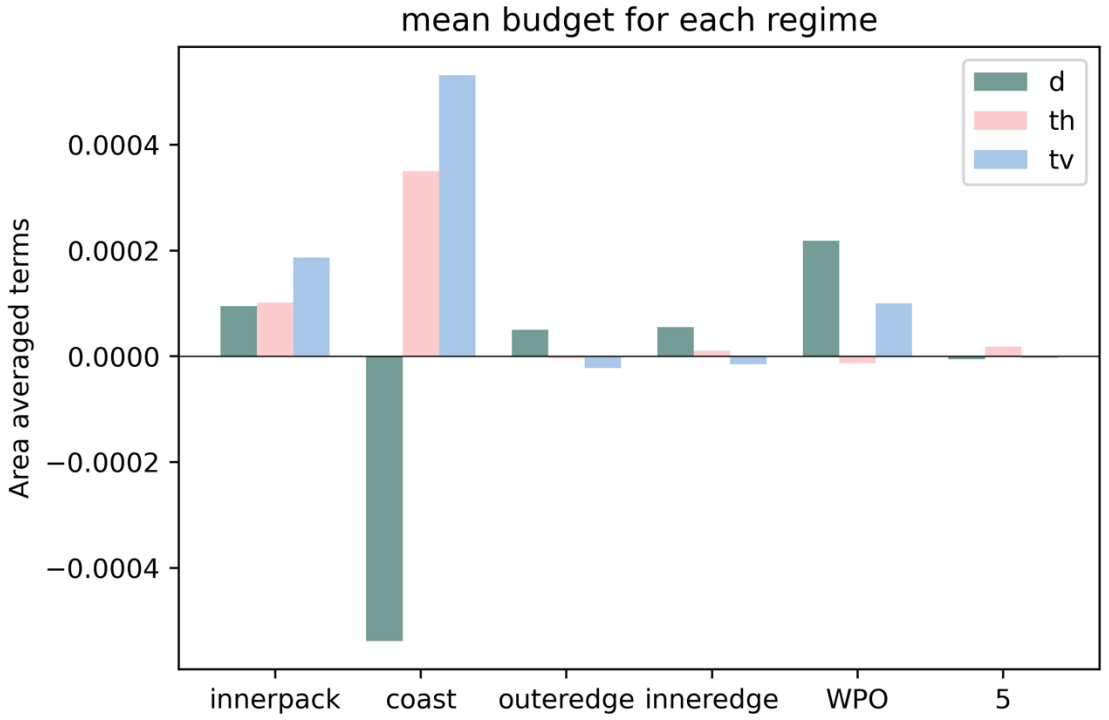
PhD project #2: Sea ice – icebergs interactions

- NEMO4.2-SI3 with prescribed Antarctic iceberg discharge
- Activation of the ICB module in NEMO
- Addition of a drag term in the sea ice and/or iceberg momentum equation
- Sensitivity tests to estimate the bergs' impacts on the Antarctic water mass properties in the model
- Collaboration with Martin Vancoppenolle, Nicolas Jourdain, Pierre Mathiot
- PhD Candidate: Eva Lemaire (2024-28)

Identifying Antarctic sea ice regimes by machine learning

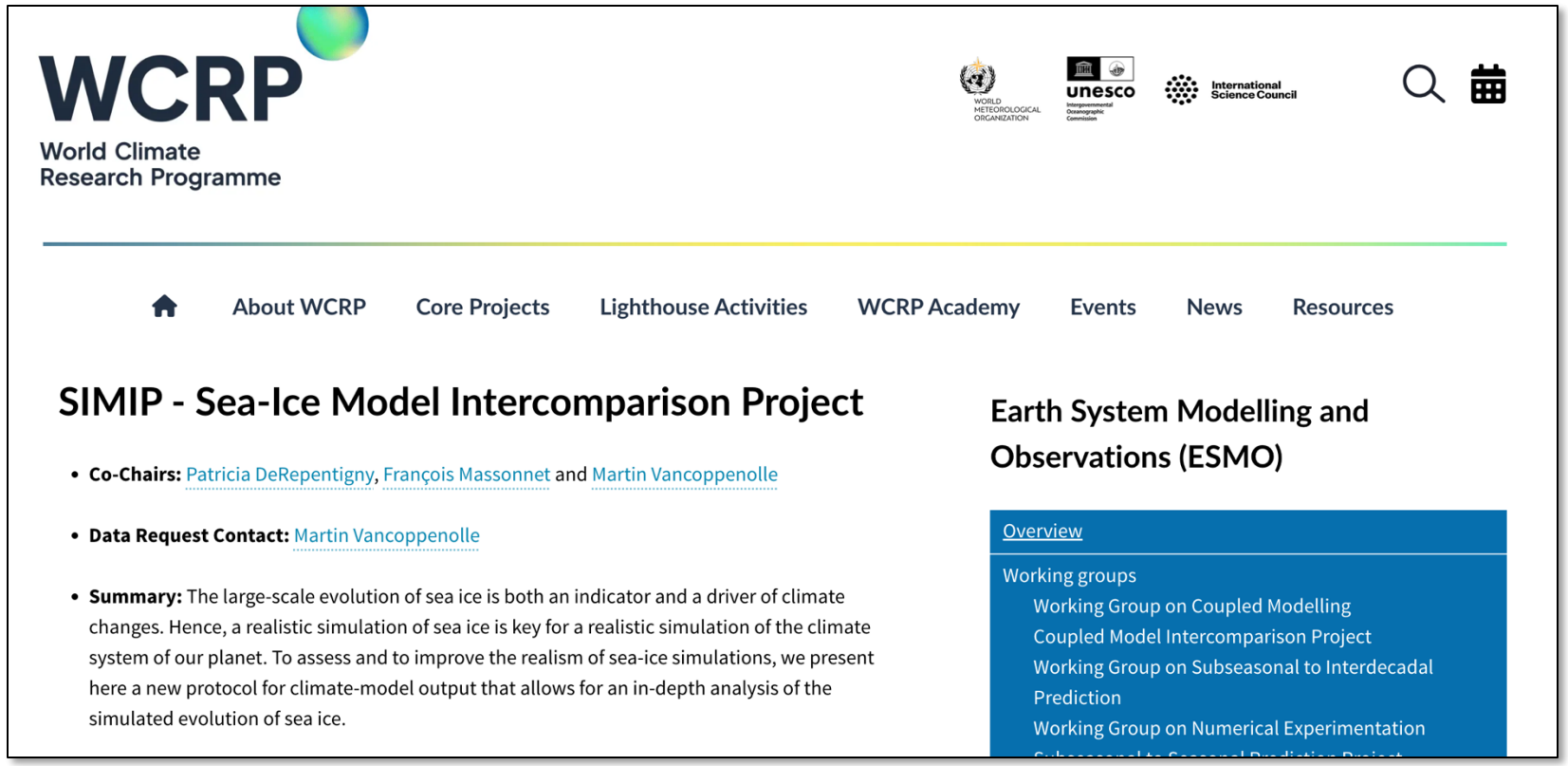
- Native Emergent Manifold Interrogation (NEMI) method (Sonnewald, 2023)
- Climatological sea ice mass budget terms (1981-2010) from NEMO4.2-SI3





Jinfei Wang, PhD student

The Sea Ice Model Intercomparison Project (SIMIP) for CMIP7 (2024-2030)



- ✓ CMIP7 data request coordination
- ✓ Sea ice workshop(s)
- ✓ Webinars
- ✓ Intercomparisons

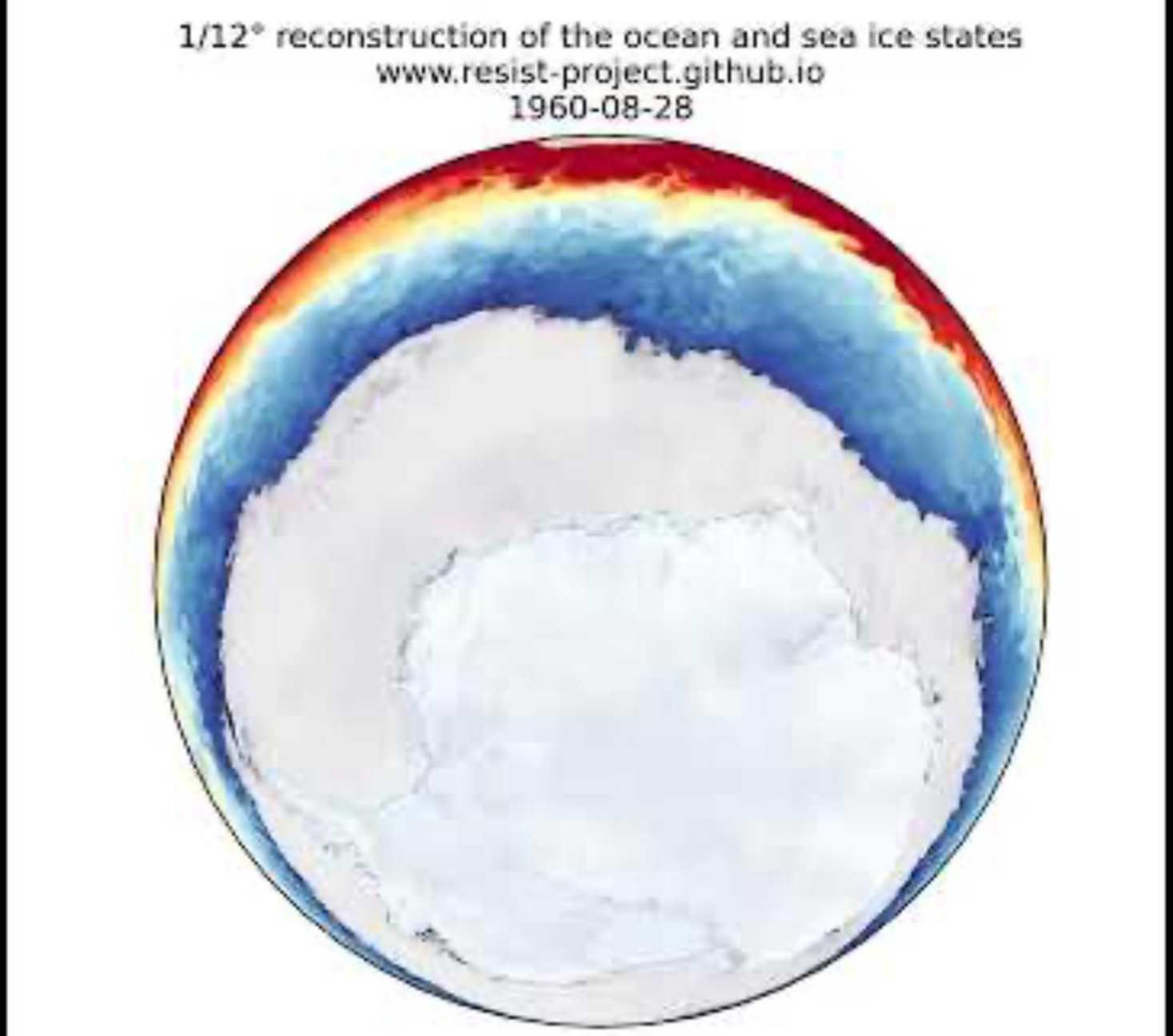
https://climate-cryosphere.org/simip-about/

Thank you

@FMassonnet

francois.massonnet@uclouvain.be

www.climate.be/u/fmasson



Spin-up of a 1/12° global ocean-sea ice reconstruction (NEMO4.2-SI3)