

GFDL seminar series (remotely)
21-22 October 2021

Various aspects of seasonal sea ice forecasting

An EU perspective

François Massonnet

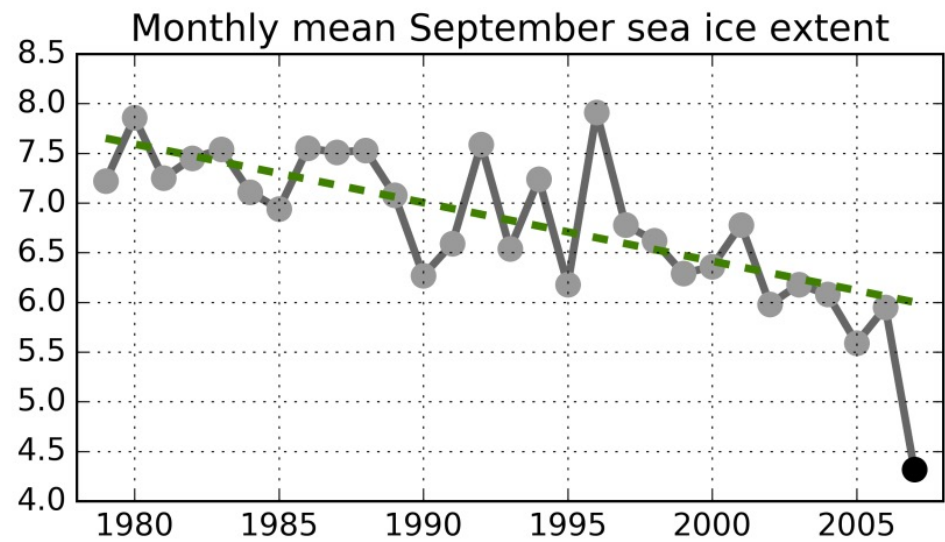
francois.massonnet@uclouvain.be

www.climate.be/u/fmasson

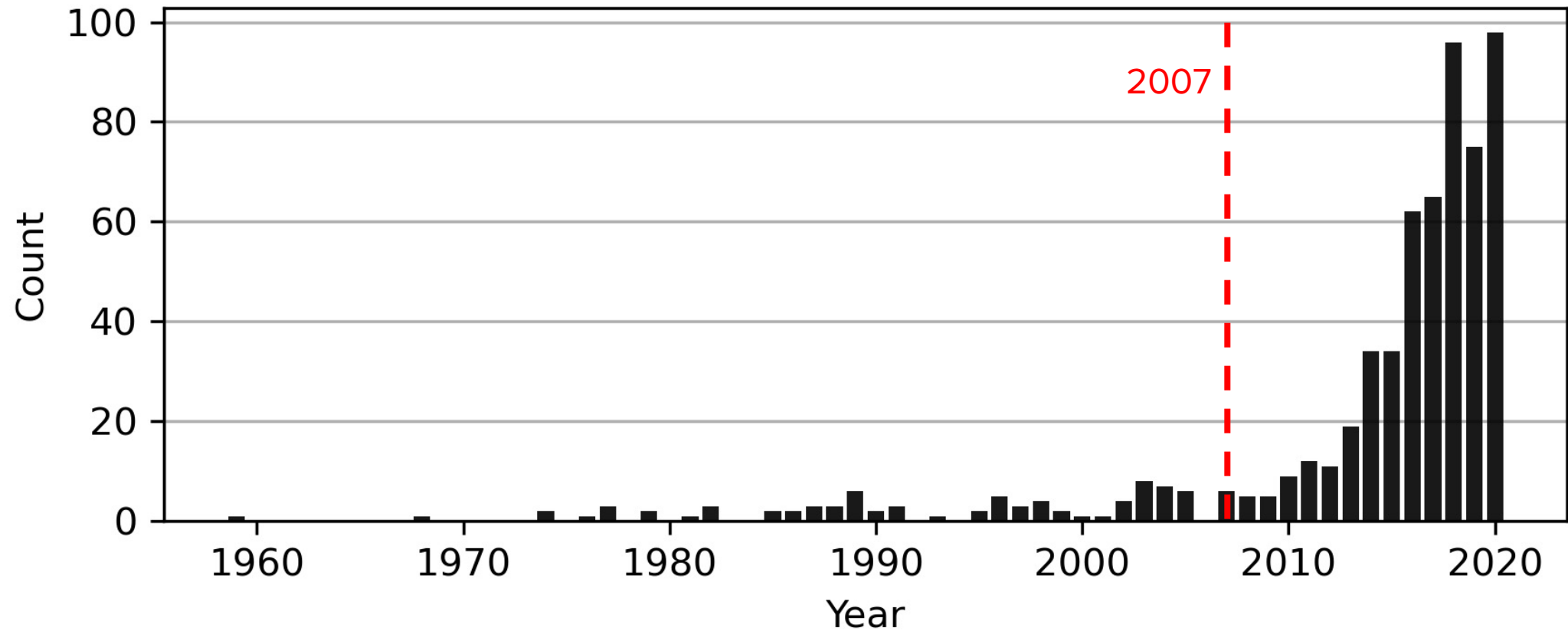
 @FMassonnet

With thanks to S. Delhayé, T. Fichefet, H. Goosse, P. V. Huot, X. Lin, C. Pelletier, L. Ponsoni, J. Sterlin, G. Van Achter, D. Verfaillie

September 2007



Number of publications with "Polar/Arctic/Antarctic/Southern Ocean prediction"



Publication count done with

<https://app.dimensions.ai/discover/publication>

1. Seasonal sea ice predictions

Testing the feasibility of sea ice freeboard assimilation in a coupled model

Freeboard on
May 1, 2012

Observations, CryoSat-2 (CS2)

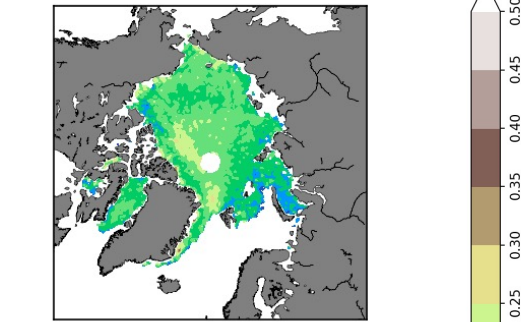
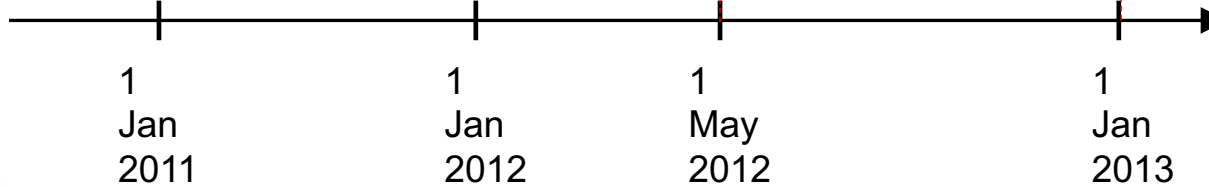
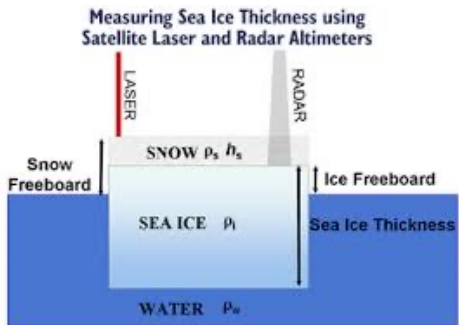
Coupled EC-Earth3 run,
historical forcing
No assimilation

50-member ensemble (10^{-4} K random
SST initial perturbations added to 1 Jan
2011 restarts), historical forcing

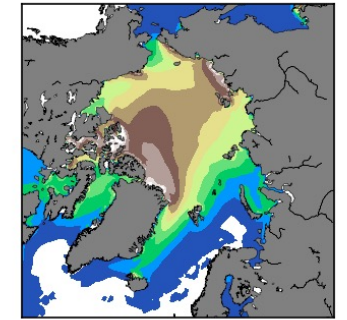
Uninitialised predictions
(continued from previous
ensemble)

50-member ensemble with
assimilation of Arctic sea ice
freeboard, or thickness, or
concentration and freeboard

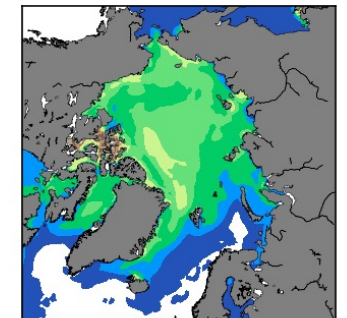
Initialised predictions



Model, nothing assimilated



Model, CS2 freeboard assimilated



Key ideas of EnKF:

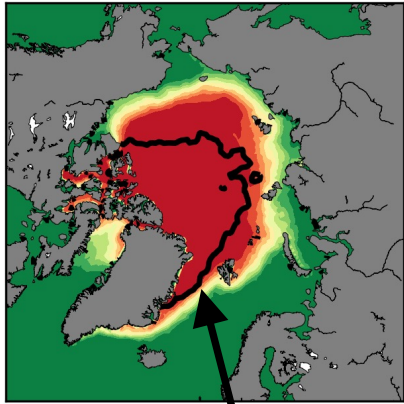
- The filter updates the fields that are not observed, incl. ocean ones, by exploiting covariances in the model forecast ensemble. However, here, atmospheric fields are not updated
- Under assumptions (unbiasedness, gaussianity of errors), the analyzed ensemble has lower bias compared to observations, and lower variance, than the forecast ensemble

Assimilation method: Deterministic Ensemble Kalman Filter (DEnKF, Sakov et al. 2008), NERSC implementation adapted to EC-Earth3. See Massonnet et al. 2015

The uninitialised ensemble is biased high for sea ice concentration. The ensemble overstates the probability of finding ice in many parts of the basin

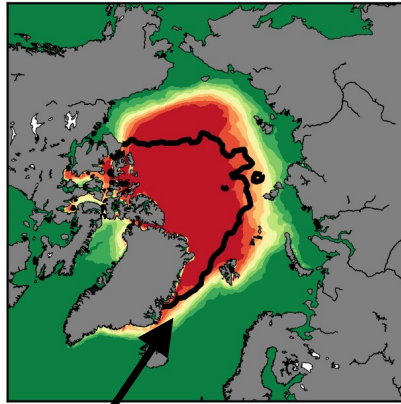


Uninitialised

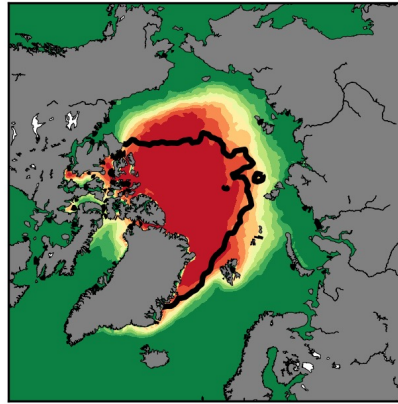


Observed ice edge

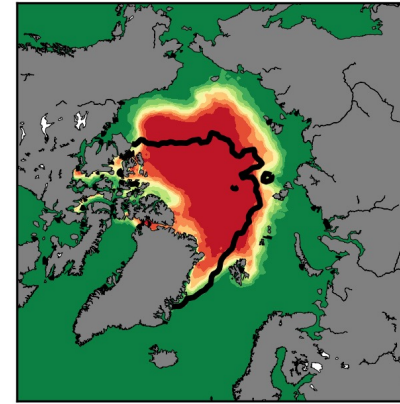
Freeboard



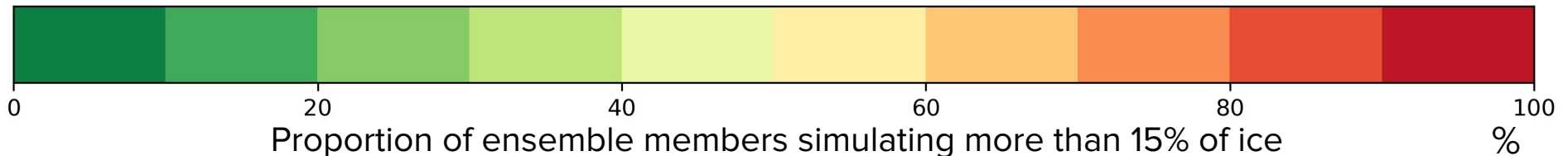
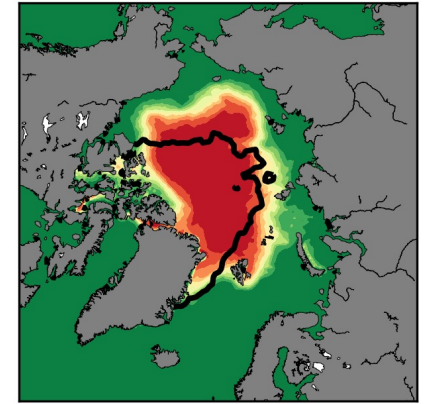
Thickness



Concentration



Freeboard + Concentration



Assimilation reduces, but does not eliminate, the biases in the Chukchi-Beaufort-East Siberian Seas by prescribing thinner ice (see previous slide).

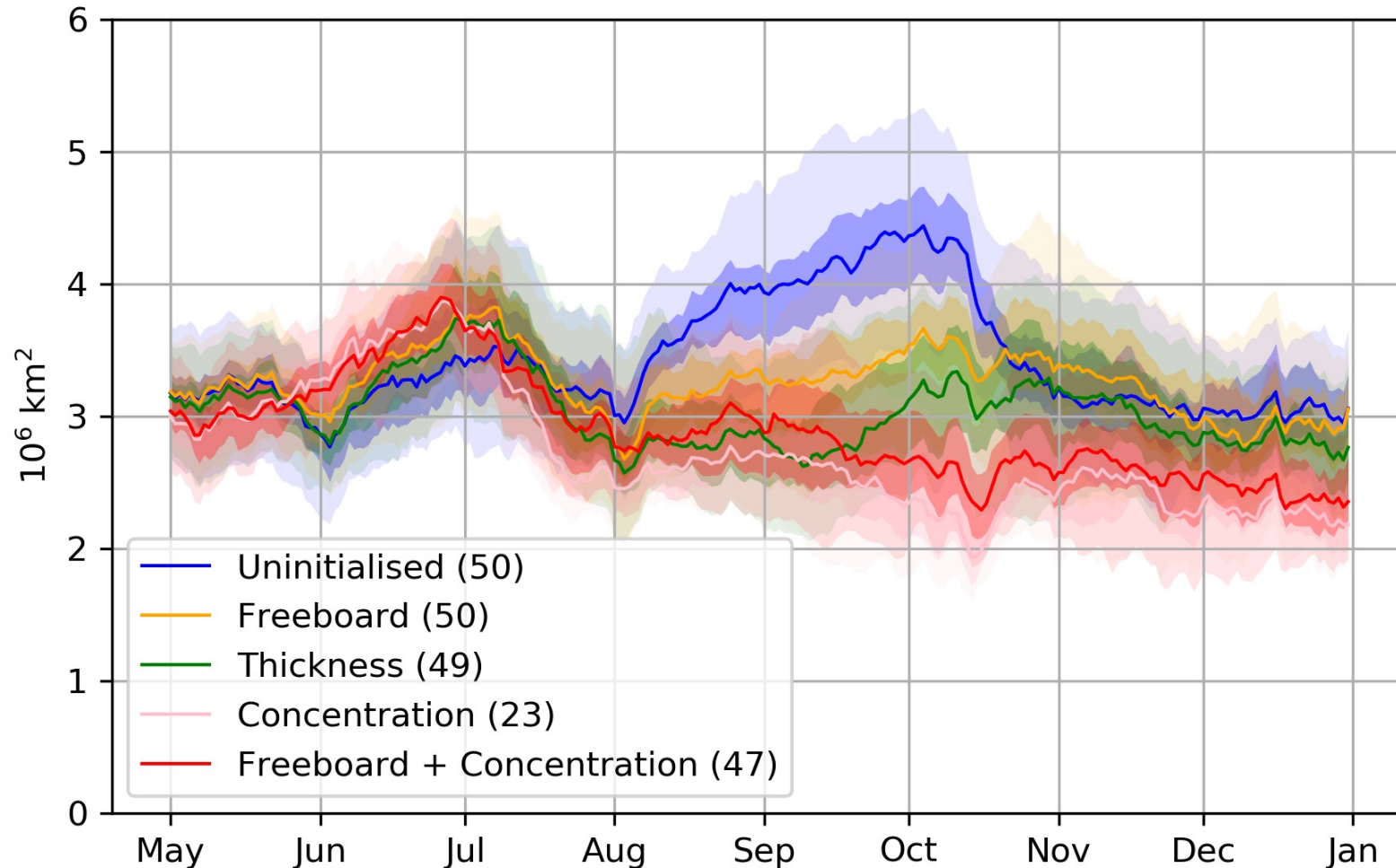
Interestingly, the constraint on concentration alone seems to be as efficient as the constraint on freeboard/thickness alone



Probability of sea ice presence on 2012-09-15

Note: the observed 2012 September sea ice conditions were affected by the « great » cyclone of early August 2012. The occurrence of this event is not predictable, but an ensemble of forecasts should be such that the observed ice edge lies in between the 0 and 100 % sea ice probability presence contours derived from the forecast ensemble

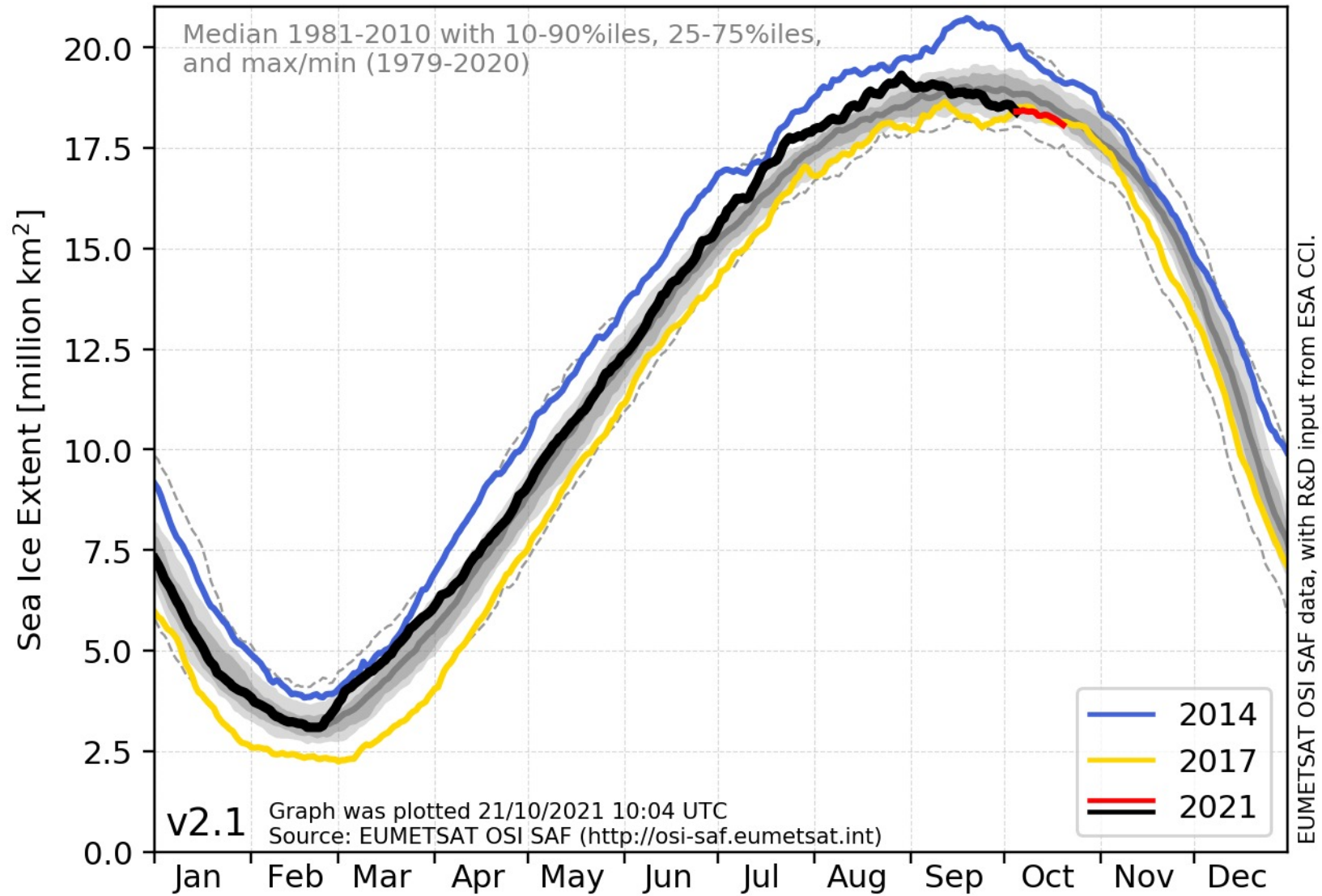
Integrated Ice Edge Error: cumulative area of grid cells where the forecasts and the verification data disagree on the event « sea ice concentration is above 15% »



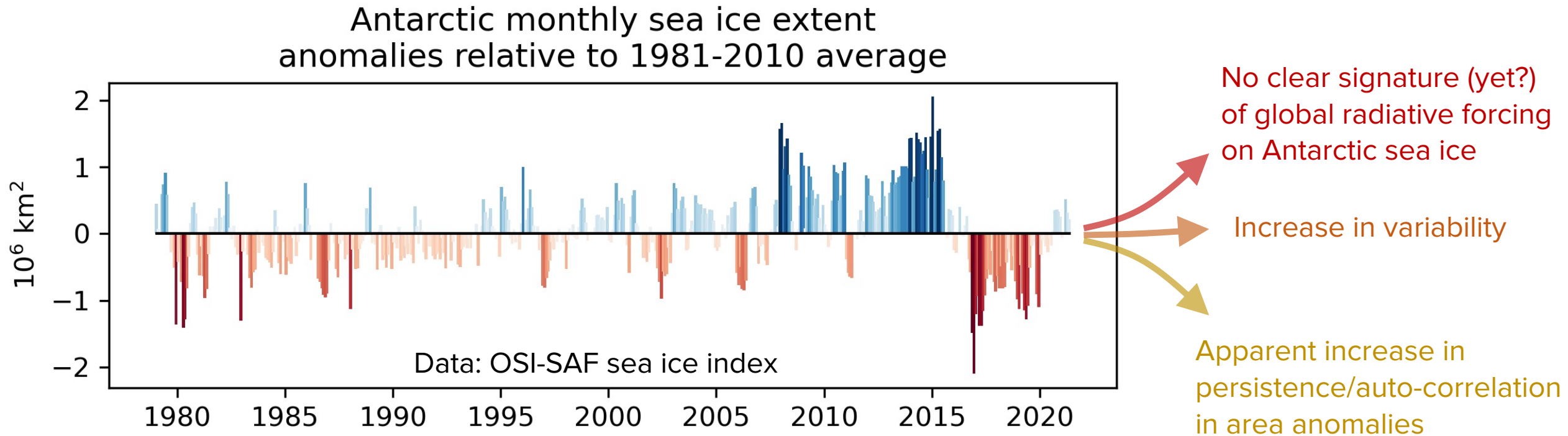
Results so far suggest:

- That assimilation is always beneficial for summer sea ice prediction
- That assimilation of thickness yields slightly better results compared to assimilation of freeboard
- That assimilation of concentration yields good skill throughout the summer season → evidence for spring-to-fall reemergence of sea ice area anomalies?

Antarctic Sea Ice Extent



Antarctica, are you trying to tell us something?





The Sea Ice Prediction Network South (SIPN South) has three main goals:

- 1) Identify existing efforts in Southern Ocean seasonal sea ice forecasting (currently scattered) and build an international network;
- 2) Coordinate realistic prediction test cases and evaluate the skill of current forecast systems;
- 3) Lay the foundations for systematic evaluation of forecasts in the coming years.

1 AUGUST 2021

BUSHUK ET AL.

Seasonal Prediction and Predictability of Regional Antarctic Sea Ice

MITCHELL BUSHUK,^{a,b} MICHAEL WINTON,^a F. ALEXANDER HAUMANN,^c THOMAS DELWORTH,^a FEIYU YONGFEI ZHANG,^{a,c} LIWEI JIA,^{a,b} LIPING ZHANG,^{a,b} WILLIAM COOKE,^a MATTHEW HARRISON,^a BILL H. NATHANIEL C. JOHNSON,^a SARAH B. KAPNICK,^a COLLEEN MCHUGH,^{a,d} HIROYUKI MURAKAMI,^a ANTHONY ROSATI,^{a,b} KAI-CHIH TSENG,^{a,c} ANDREW T. WITTENBERG,^a XIAOSONG YANG,^a AND FANRONG ZENG^a

^a National Oceanic and Atmospheric Administration/Geophysical Fluid Dynamics Laboratory, Princeton, New Jersey

^b University Corporation for Atmospheric Research, Boulder, Colorado

^c Atmospheric and Oceanic Sciences Program, Princeton University

^d SAIC, Science Applications International Corporation

Climate Dynamics
<https://doi.org/10.1007/s00382-018-4292-2>



Reemergence of Antarctic sea ice predictability and its link to deep ocean mixing in global climate models

Sylvain Marchi¹ · Thierry Fichefet¹ · Hugues Goosse¹ · Violette Zunz² · Steffen Tietsche³ · Jonathan J. Day³ · Ed Hawkins⁴

Processes Controlling Arctic and Antarctic Sea Ice Predictability in the Community Earth System Model

ANA C. ORDOÑEZ, CECILIA M. BITZ, AND EDWARD BLANCHARD-WRIGGLESWORTH

Department of Atmospheric Sciences, University of Washington, Seattle, Washington

(Manuscript received 31 May 2018, in final form 25 September 2018)

ABSTRACT

Initial-value predictability of Antarctic sea ice in the Community Climate System Model 3

Marika M. Holland,¹ Edward Blanchard-Wrigglesworth,² Jennifer Kay,¹ and Steven Vavrus³

Geophysical Research Letters

RESEARCH LETTER

10.1029/2019GL084096

Special Section:

Bridging Weather and Climate:
Subseasonal-to-Seasonal (S2S)
Prediction

Key Points:

Predictability of Antarctic Sea Ice Edge on Subseasonal Time Scales

Lorenzo Zampieri¹ · Helge F. Goessling¹ · and Thomas Jung^{1,2}

¹Alfred-Wegener-Institut, Helmholtz-Zentrum für Polar- und Meeresforschung, Bremerhaven, Germany, ²Faculty of Physics and Electrical Engineering, University of Bremen, Bremen, Germany

ARTICLE

DOI: 10.1038/s41467-017-00820-0

OPEN

Springtime winds drive Ross Sea ice variability and change in the following autumn

Marika M. Holland¹, Laura Landrum¹ · Marilyn Raphael² · & Sharon Stammerjohn³

- Antarctic sea ice is potentially predictable at seasonal time scales
- Mechanism at play: ice area anomalies → mixed layer depth heat content anomalies → reemergence
- GCM biases may lead to an over/under estimation of predictability estimates
- Skill of prediction systems exceeds benchmarks such as persistence forecast

	2017-2018	2018-2019	2019-2020	2020-2021
Number of groups contributing	13	12	11	14
Total number of forecasts received	160	199	191	243

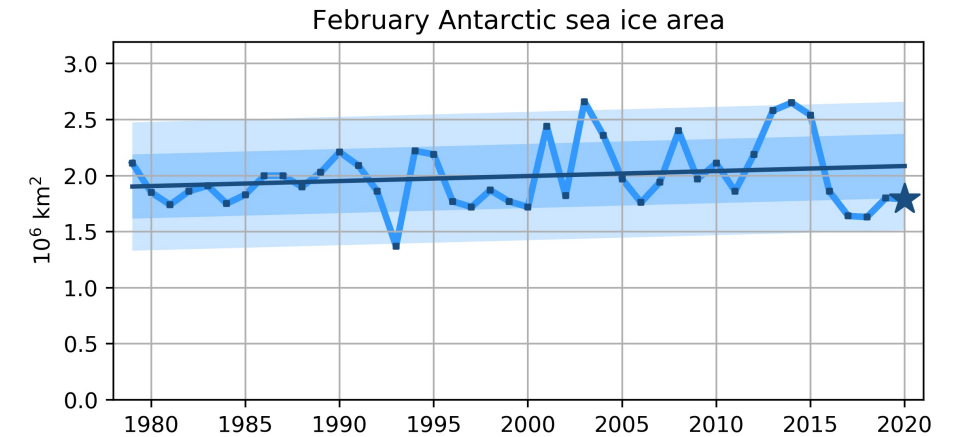
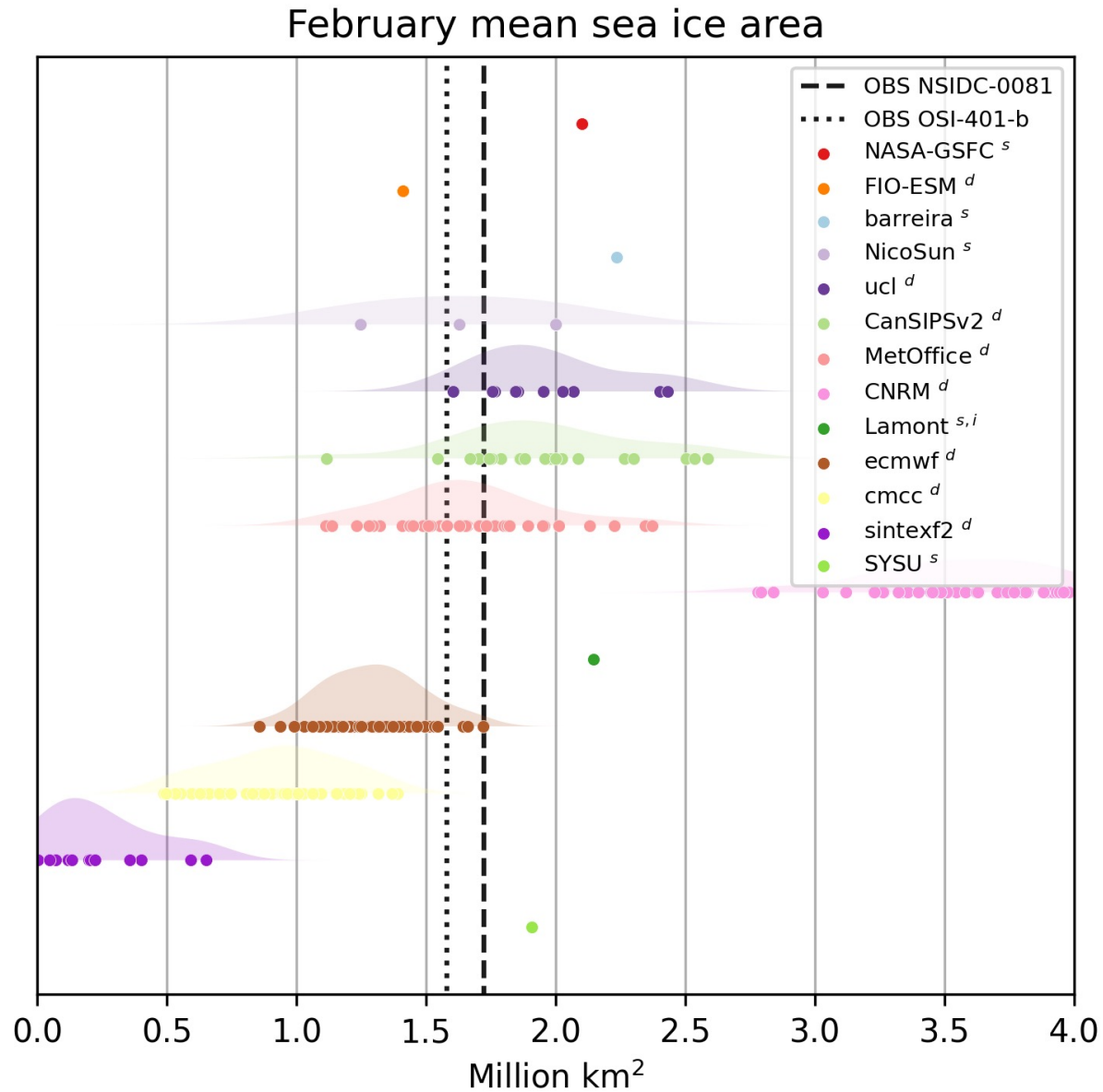
The 2020-2021 Southern Ocean summer sea ice forecasts

	<i>Contributor name</i>	<i>Short name (in figures)</i>	<i>Forecasting method</i>	<i>Nb. of forecasts</i>	<i>Init. date</i>	<i>Diagnostics provided</i>
1	Nico Sun	NicoSun	Statistical model	3	Nov. 30 th	SIA+SIC+SIV
2	FIO-ESM	FIO-ESM	Coupled dynamical model	1	Nov. 1 st	SIA
3	Barreira	barreira	Statistical model	1	Dec. 1 st	SIA+SIC
4	NASA-GSFC (Alek Petty)	NASA-GSFC	Statistical model	1	Nov. 30 th	SIA
5	Met Office	MetOffice	Coupled Dynamical Model	42	Dec. 1st	SIA+rSIA+SIC
6	CanSIPsv2	CanSIPsv2	Coupled Dynamical Model	20	Nov. 30	SIA+rSIA
7	CNRM	CNRM	Coupled Dynamical Model	51	Nov. 30	SIA+rSIA+SIC+SIV
8	Lamont Sea Ice Group	Lamont	Statistical model	1	Nov. 31 st	SIA+rSIA+SIC
9	CMCC	CMCC	Coupled Dynamical Model	50	Oct. 31 st	SIA+rSIA+SIC
10	ECMWF	ecmwf	Coupled Dynamical Model	51	Nov. 30 th	SIA + rSIA
11	Sintexf2 (JAMSTEC)	sintexf2	Coupled Dynamical Model	12	Nov. 30 th	SIA+rSIA
12	AWI	AWI-SDAP	Statistical model	1	Nov. 30 th	SIP**
13	UCLouvain	ucl	Ocean—Sea Ice Model	10	Nov. 1 st	SIA+rSIA+SIC+SIV

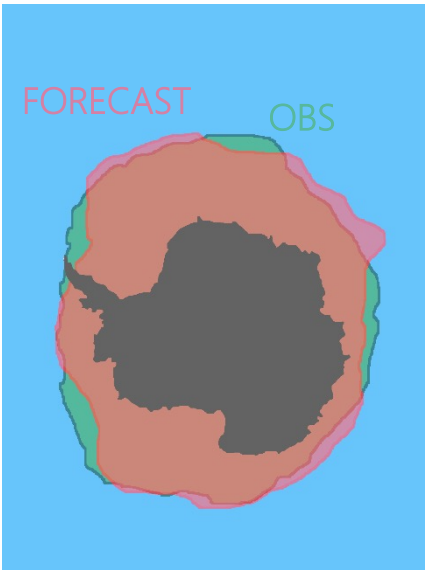
*received as monthly data, interpolated daily

** received as Sea Ice Probability

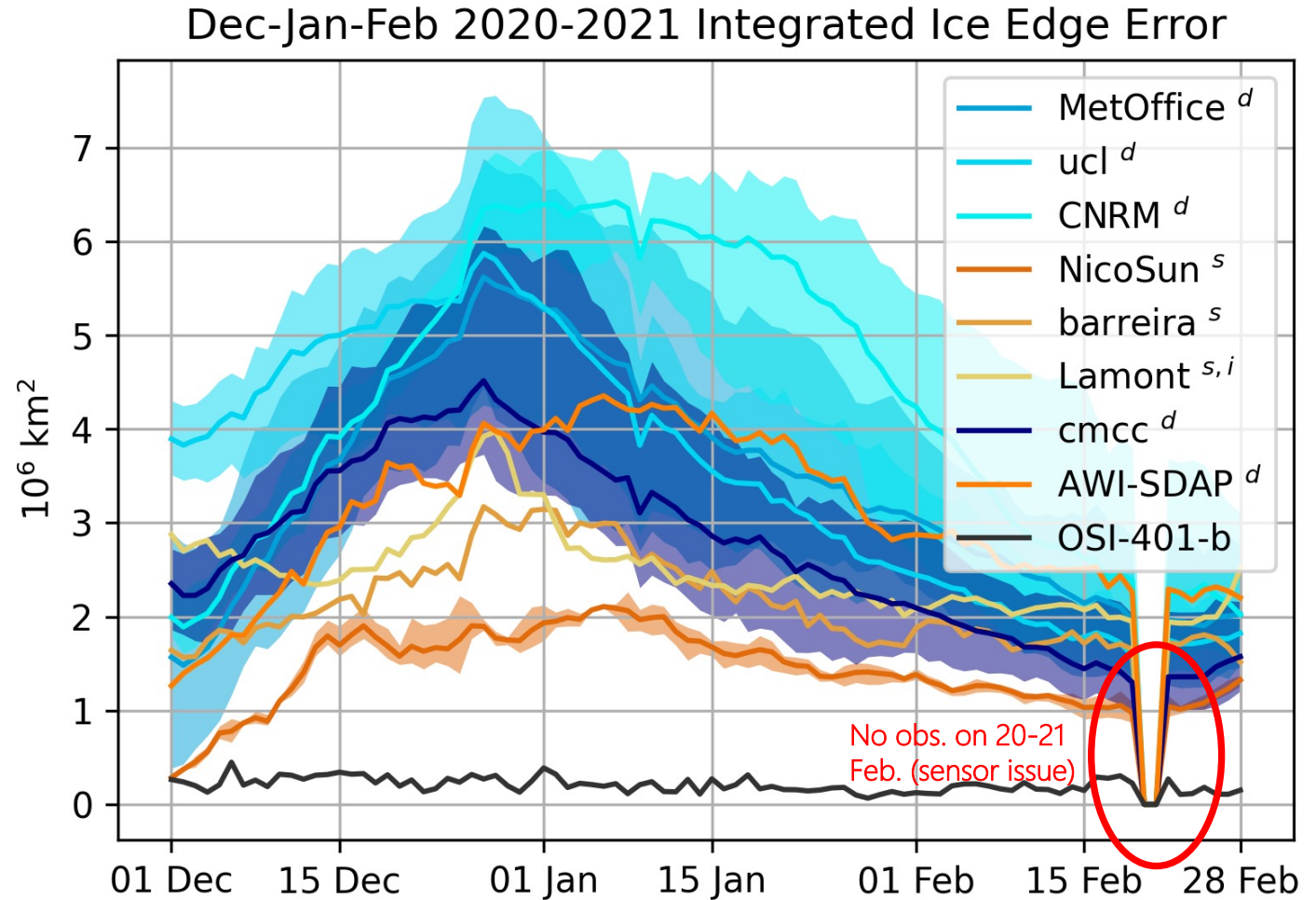
SIPN South predictions and verifying observations



Integrated Ice Edge Error: quantification of spatial errors in forecasted sea ice concentration



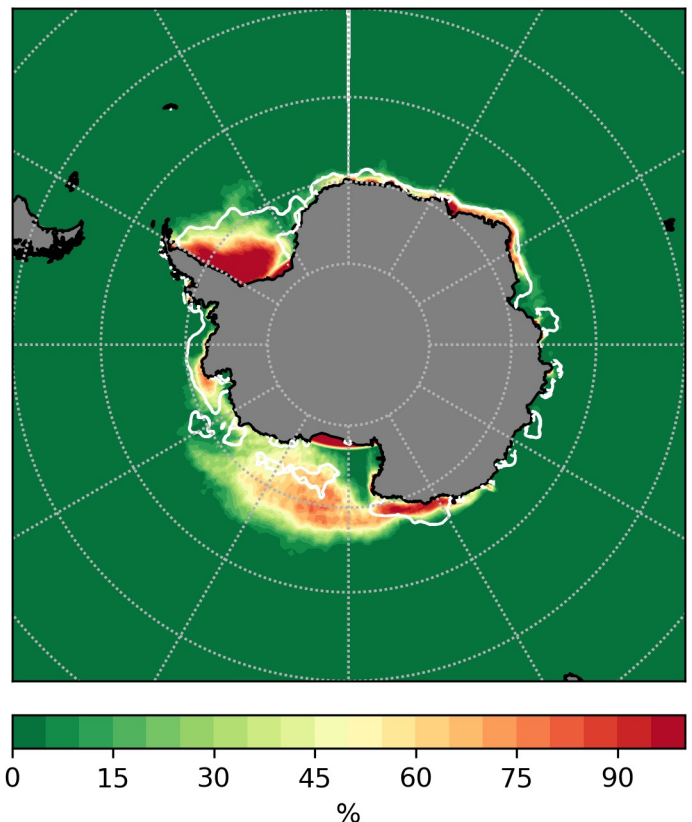
Integrated Ice Edge Error =
Area of overestimation
+
Area of underestimation



Probability of sea ice presence

Dynamical model (42 forecasts)

MetOffice | prob > 15% | 15 February 2021

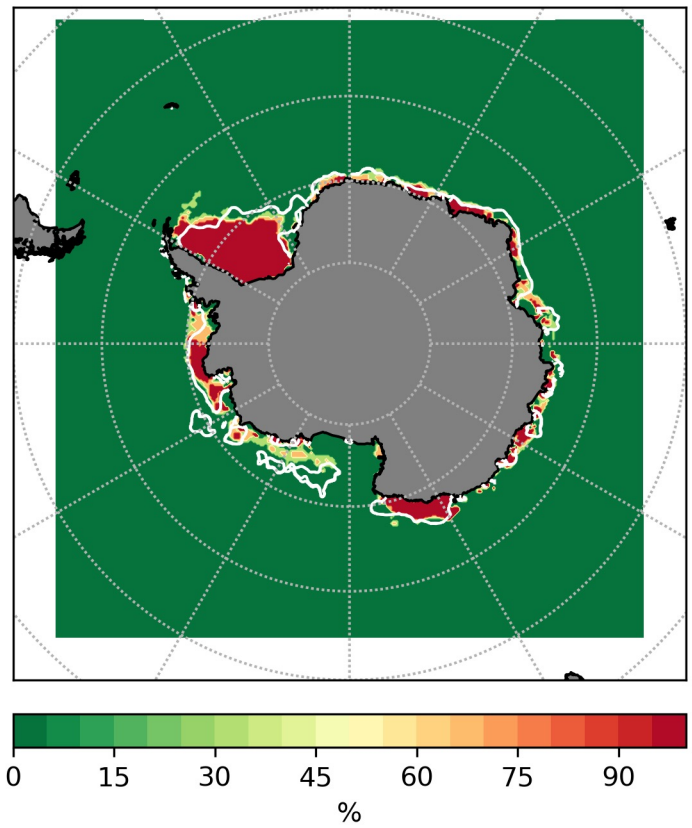


Spread but with a bias



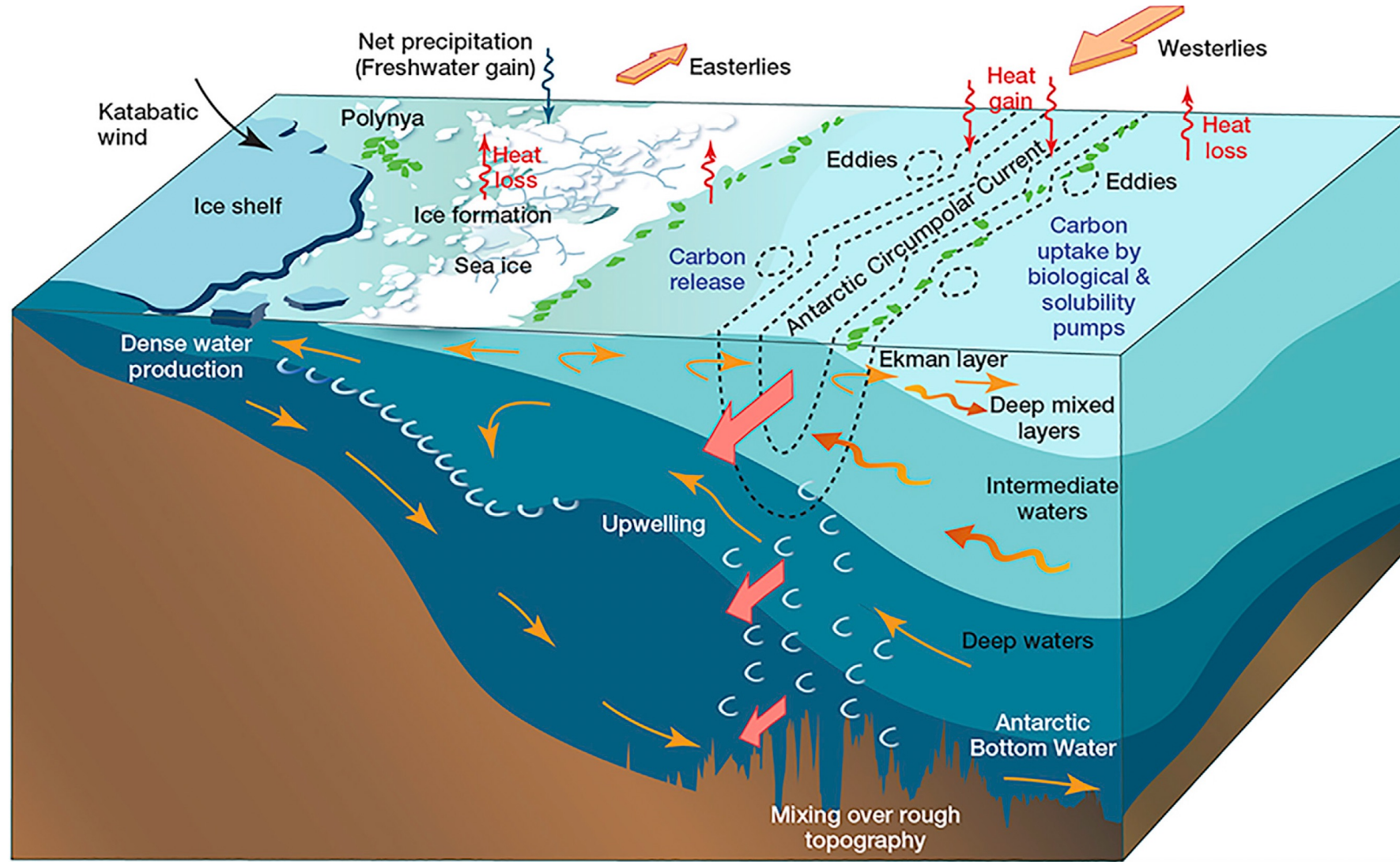
Statistical model (3 forecasts)

NicoSun | prob > 15% | 15 February 2021



(Too?) sharp but not so far from observations

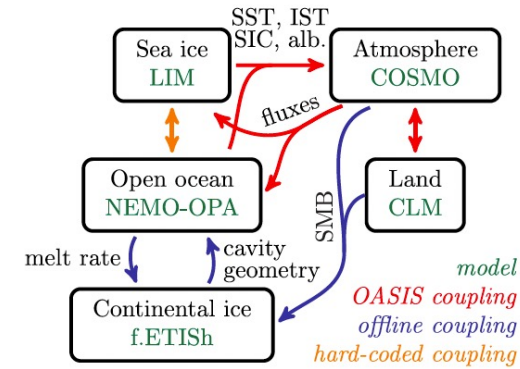
2. Atmosphere – sea ice – ocean –
ice shelves interactions



Kennicutt, M. C., Bromwich, D., Liggett, D., Njåstad, B., Peck, L., Rintoul, S. R., Ritz, C., Siegert, M. J., Aitken, A., Brooks, C. M., Cassano, J., Chaturvedi, S., Chen, D., Dodds, K., Golledge, N. R., Le Bohec, C., Leppe, M., Murray, A., Nath, P. C., ... Chown, S. L. (2019). Sustained Antarctic Research: A 21st Century Imperative. *One Earth*, 1(1), 95–113. <https://doi.org/10.1016/j.oneear.2019.08.014>

PARASO, a circum-Antarctic fully-coupled ice-sheet - ocean - sea-ice - atmosphere - land model involving f.ETISH1.7, NEMO3.6, LIM3.6, COSMO5.0 and CLM4.5

Charles Pelletier¹, Thierry Fichefet¹, Hugues Goosse¹, Konstanze Haubner², Samuel Helsen³, Pierre-Vincent Huot¹, Christoph Kittel⁴, François Klein¹, Sébastien Le clec'h⁵, Nicole P. M. van Lipzig³, Sylvain Marchi³, François Massonnet¹, Pierre Mathiot^{6,7}, Ehsan Moravveji^{3,8}, Eduardo Moreno-Chamarro⁹, Pablo Ortega⁹, Frank Pattyn², Niels Souverijns^{3,10}, Guillian Van Achter¹, Sam Vanden Broucke³, Alexander Vanhulle⁵, Deborah Verfaillie¹, and Lars Zipf²



Peri-Antarctic (>30°S) coupled ocean-sea ice-atmosphere-ice sheet configuration (1/4°)

PARAMOUR

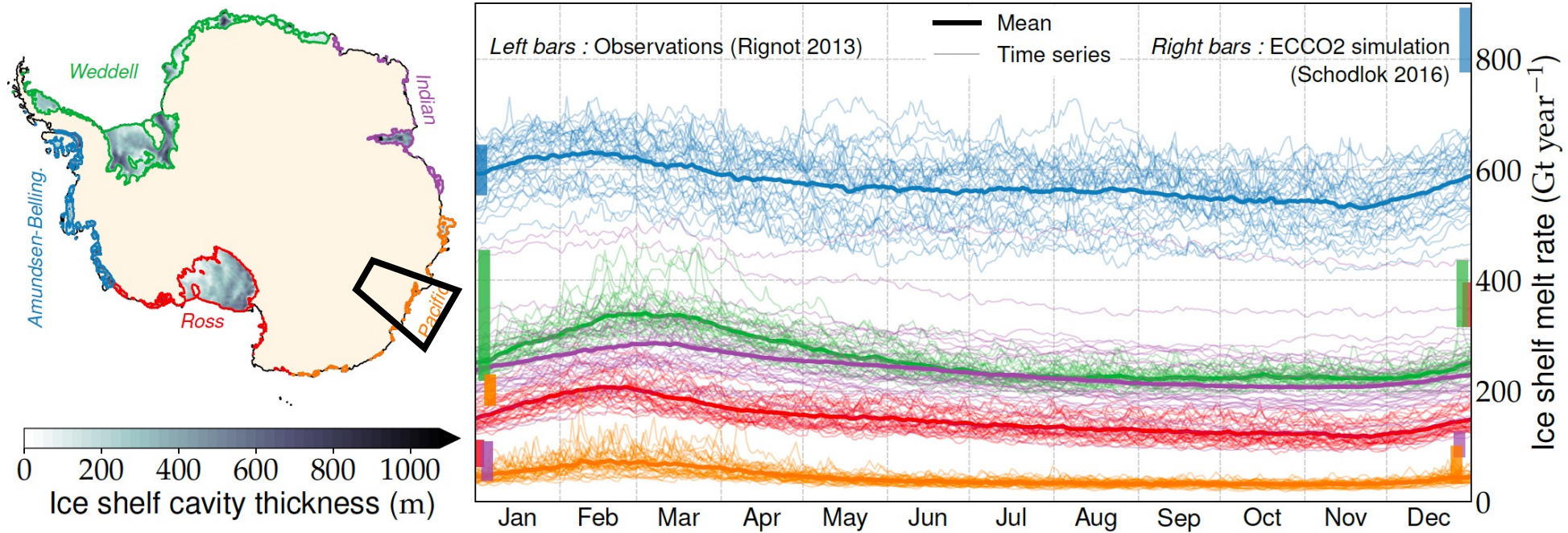
Decadal predictability and variability of polar climate:
the role of atmosphere-ocean-cryosphere multiscale interactions

<https://www.climate.be/paramour>

Contact: Hugues Goosse (hugues.goosse@uclouvain.be)

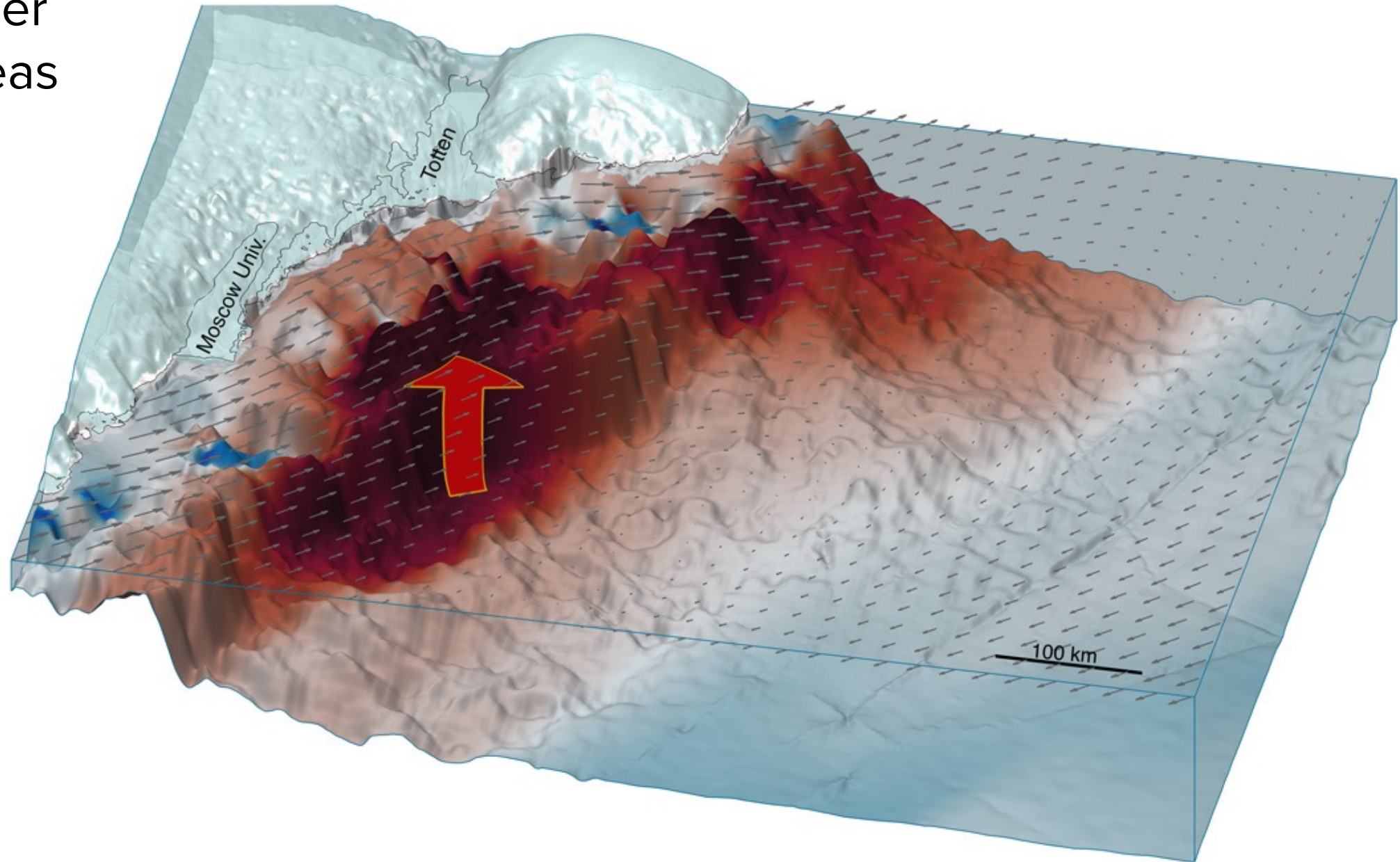
A model reconstruction of the spatio-temporal variability of ice-shelf basal melt rates, 1985-1995 (being extended)

→ Key input for GCMs



Pelletier, C., Fichet, T., Goosse, H., Haubner, K., Helsen, S., Huot, P.-V., Kittel, C., Klein, F., Le clec'h, S., van Lipzig, N. P. M., Marchi, S., Massonnet, F., Mathiot, P., Moravveji, E., Moreno-Chamarro, E., Ortega, P., Pattyn, F., Souverijns, N., Van Achter, G., ... Zipf, L. (2021). PARASO, a circum-Antarctic fully-coupled ice-sheet—Ocean—Sea-ice—Atmosphere—Land model involving f.ETISH1.7, NEMO3.6, LIM3.6, COSMO5.0 and CLM4.5. *Geoscientific Model Development Discussions*, 1–59. <https://doi.org/10.5194/gmd-2021-315>

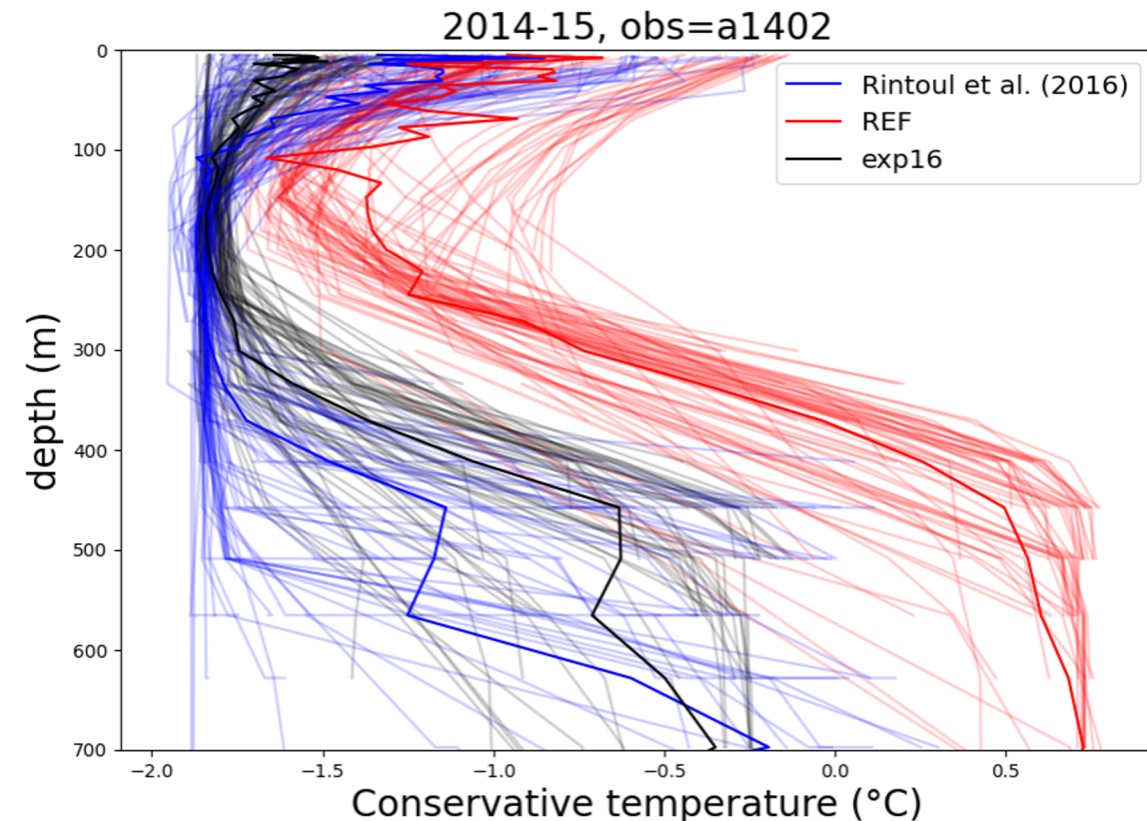
The Totten glacier and ice shelf areas



Greene, C. A., Blankenship, D. D., Gwyther, D. E., Silvano, A., & van Wijk, E. (n.d.). Wind causes Totten Ice Shelf melt and acceleration. *Science Advances*, 3(11), e1701681. <https://doi.org/10.1126/sciadv.1701681>

How to improve the simulated ocean temperature in front of the Totten ice shelf ?

- Our NEMO-LIM ocean – sea ice configuration over the Totten Glacier area is warmer by more than 1°C in front of the Totten cavity (red) compared to observations (blue).
- 0.5 – 0.7°C bias [0 – 300 m] : not enough sea ice production, shallower simulated mixed water depth (mld).
=> increase of the mld coefficient
=> increase the air – ice and ice – water drag coefficients
- 0.5 – 1°C bias [300 – 700m] : warmer simulated mixed circumpolar deep water compared to observations.
=> change of the ocean lateral boundary conditions
- It results in a new simulation (black) with simulated ocean temperature closer to the observations.

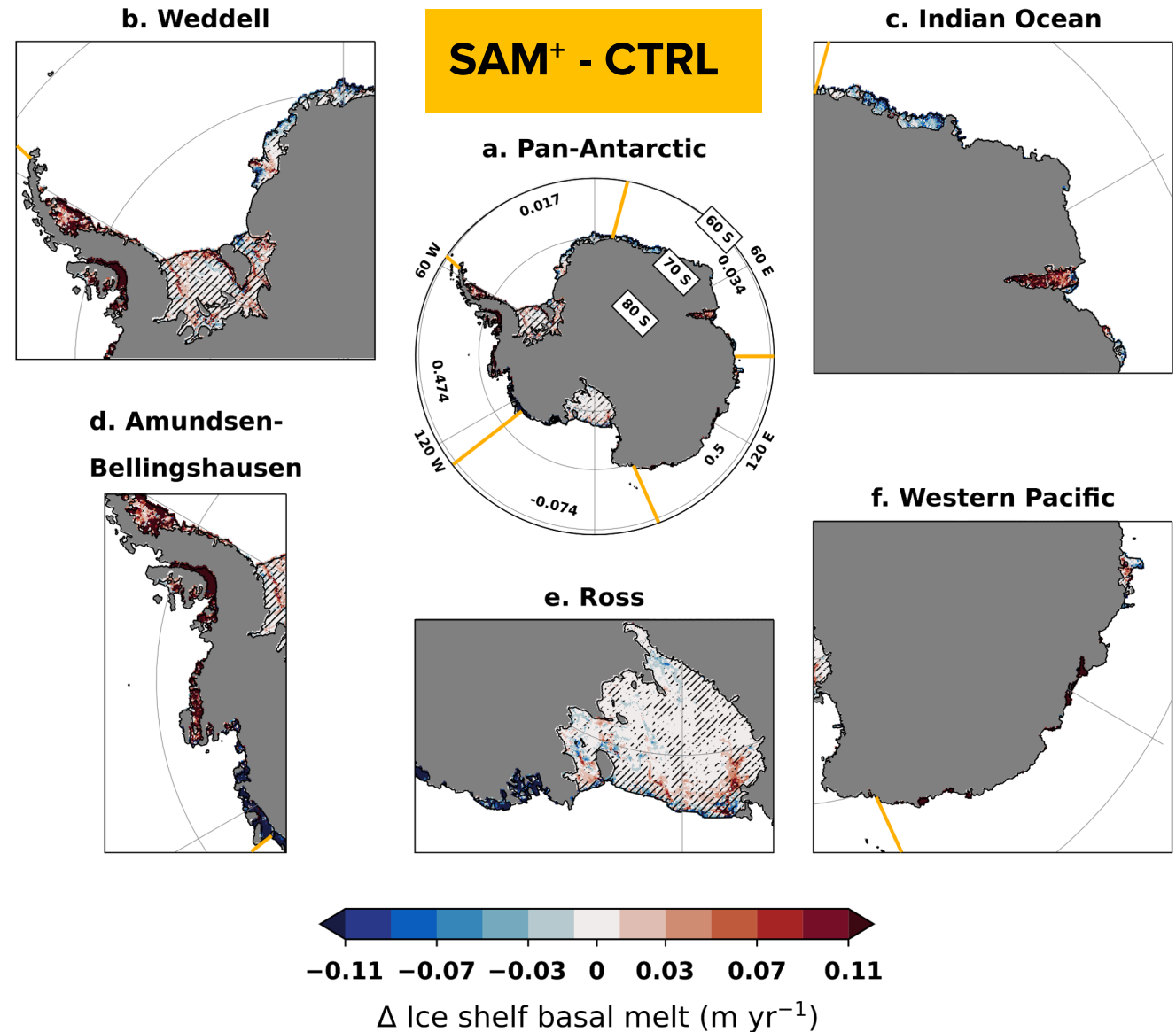


Impact of the Southern Annular Mode on ice-shelf basal melt in Antarctica

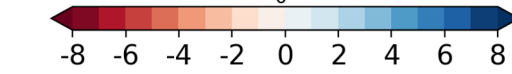
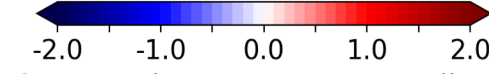
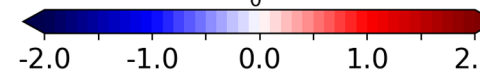
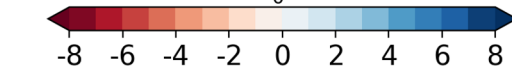
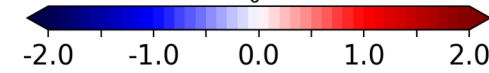
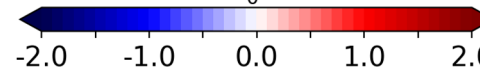
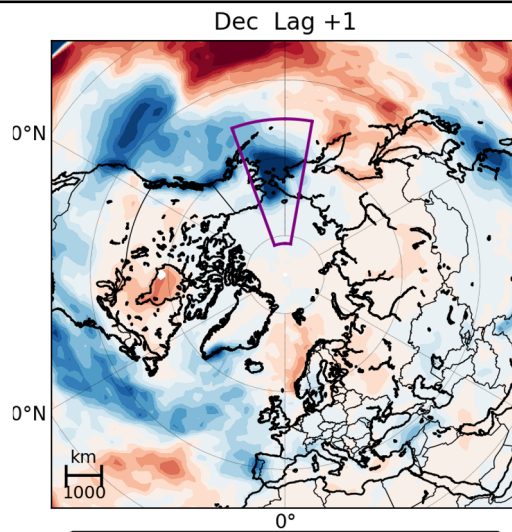
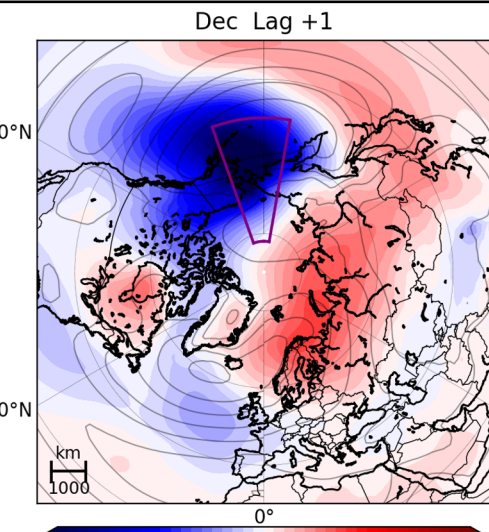
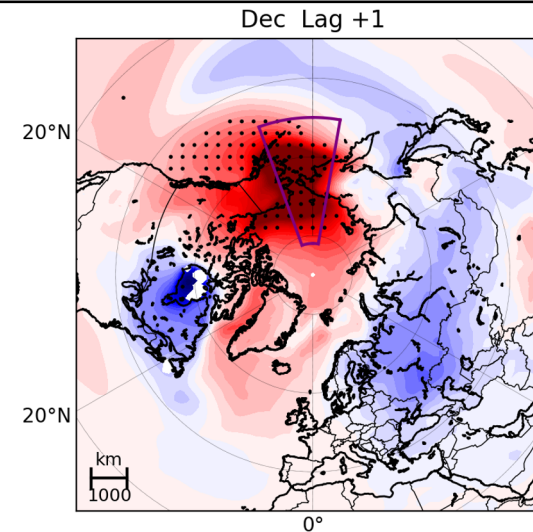
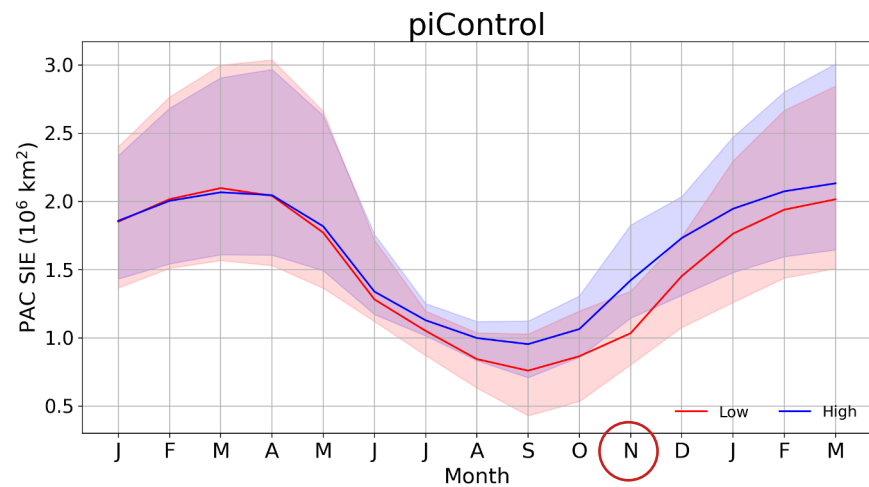
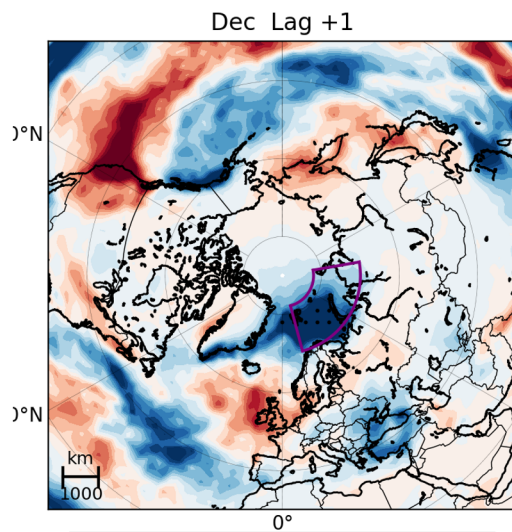
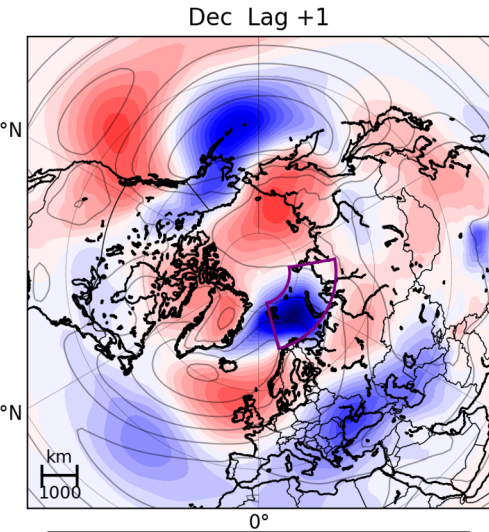
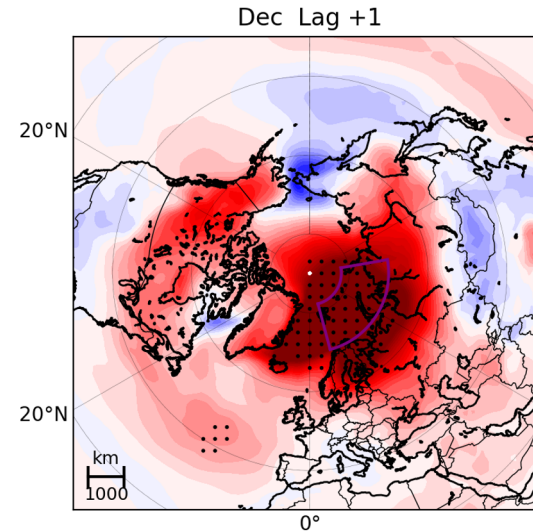
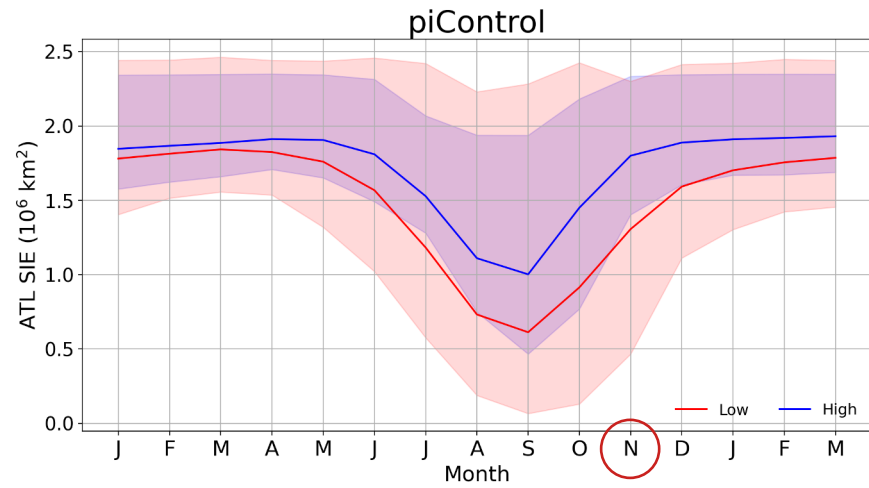
NEMO-LIM3.6, 0.25° , forced by ERA5

- **CTRL** run: **repeat-year forcing** from ERA5 (30 years)
- **SAM⁺** run = CTRL run + 1σ SAM on all forcing variables (20 years)

- Ice-shelf basal melt **increase**: **+40.3 Gt yr⁻¹**
- Due to more **upwelling** of **warmer** and **saltier** waters
- **Ross** response is **opposite**
→ **ASL/SAM** interaction, more **vertical mixing** and/or less upwelling due to **stronger slope current?**



26 CMIP6 models (piControl)



Surface Temperature

Low - High ($^{\circ} \text{C}$)

Sea Level Pressure Low - High (hPa)

Precipitation Low - High (mm)

3. Observing system design

APPLICATE in a nutshell

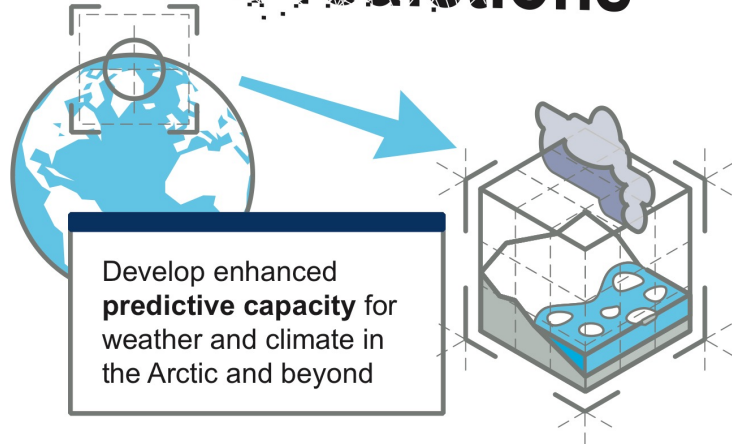
Advanced Prediction in Polar regions and beyond:
modelling, observing system design and Linkages
associated with a Changing Arctic climaTE

Horizon 2020 EU project
15 partners from 8 countries
8 million EUR
Coordinator T. Jung

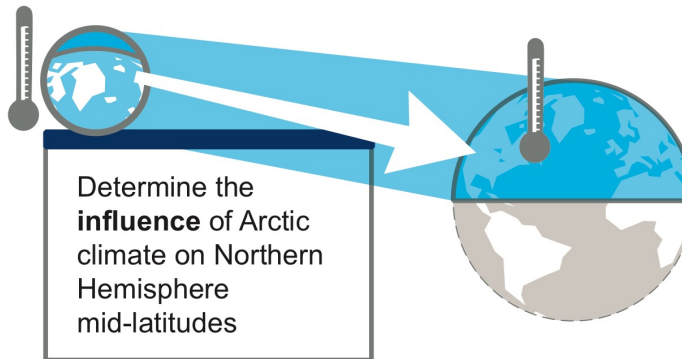
2016-2021 (finished)
www.applycate-h2020.eu

MISSION

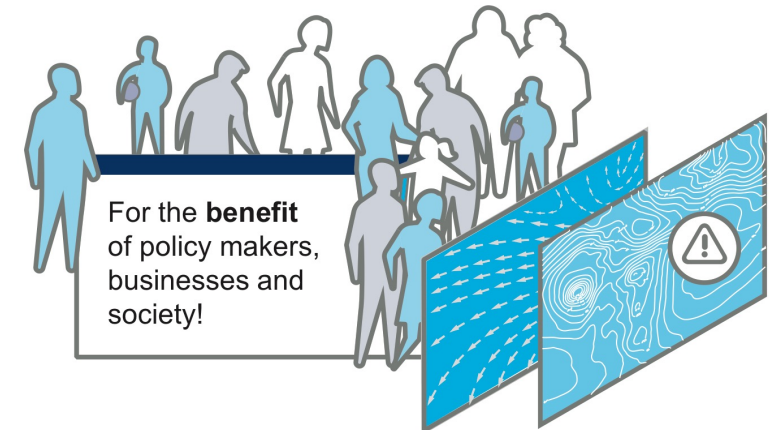
Predictions



Remote influence



Benefits



Observational challenges in the Arctic

The nature of the problem

- The Arctic is **data-sparse** in conventional observations but **data-rich** in satellite observations
- A lot of observations are either not used, underused, or misused in current numerical prediction systems (NPS; including NWP and climate models)
- Polar prediction skill is limited in NPS

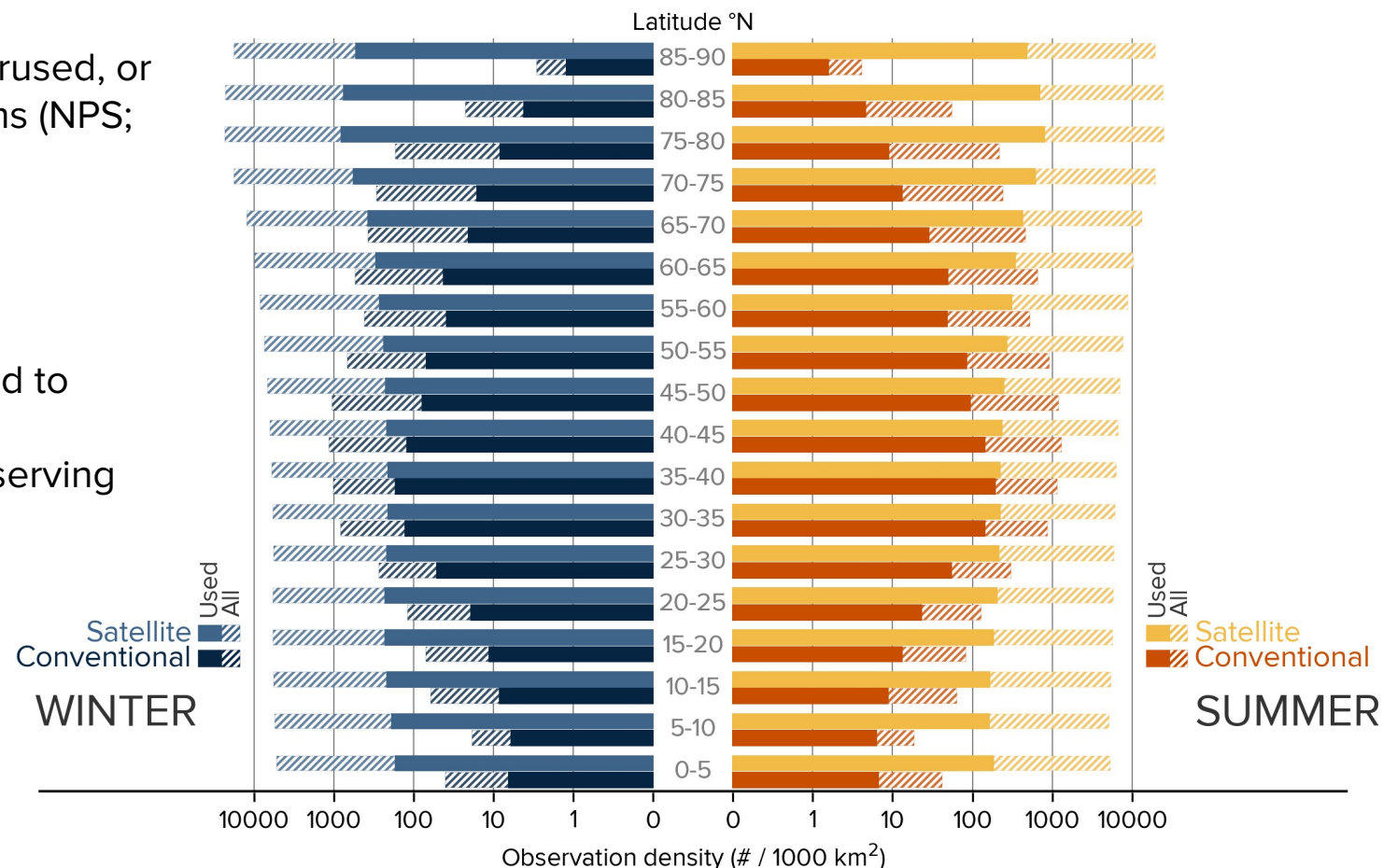
Hypotheses

- Better uptake of observations in NPS could lead to increased predictive skill
- In turn, use of NPS could inform on optimal observing system usage and design

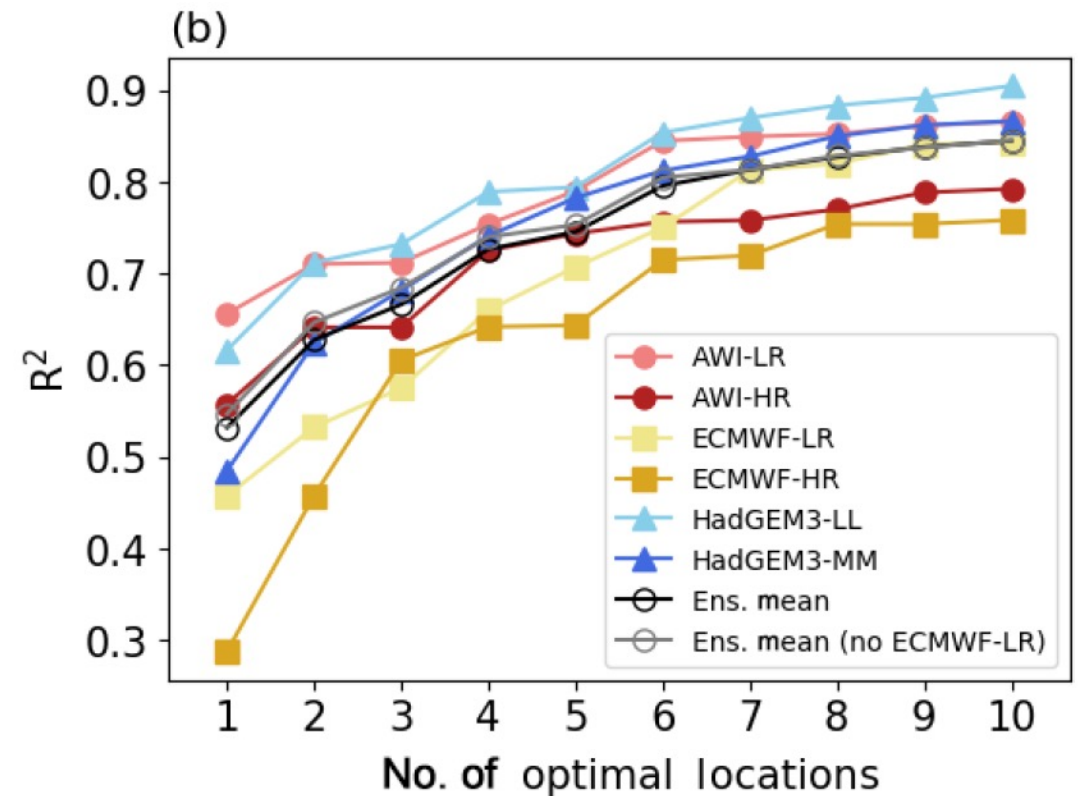
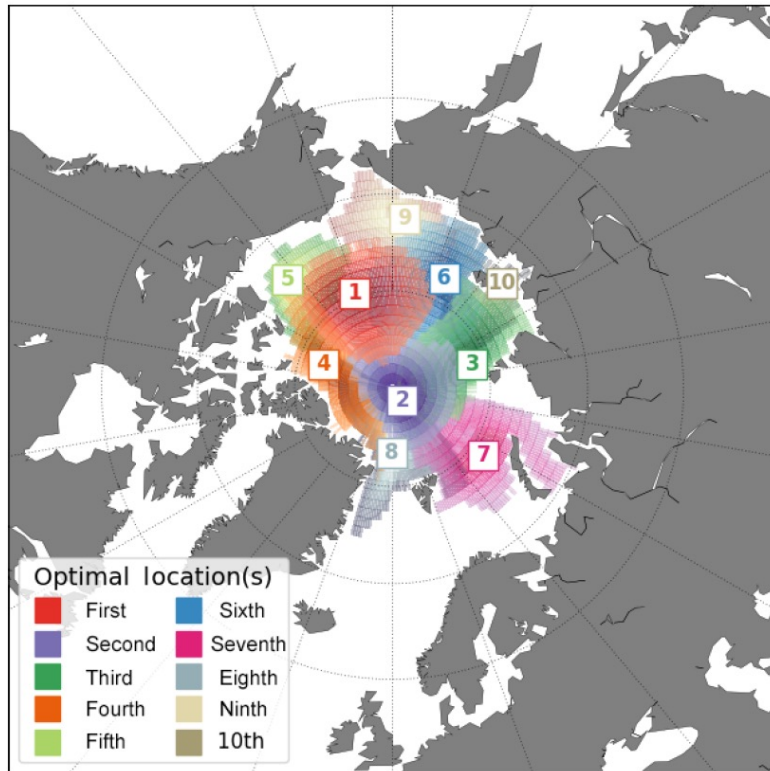
Objectives

Derive recommendations for the design of the future observing systems in the Arctic

Number of observations available and assimilated in the ECMWF forecasting system (2019)



The knowledge of sea ice thickness at a handful of discrete locations can be used to partially reconstruct sea ice volume anomalies (according to numerical models)



Climate Models as Guidance for the Design of Observing Systems: the Case of Polar Climate and Sea Ice Prediction

François Massonnet¹ 



Science blog

New insights into polar observing systems using numerical models

8 January 2021
Irina Sandu
François Massonnet



Irina Sandu, ECMWF Physical Processes Team Leader, and François Massonnet, F.R.S.-FNRS Research Associate at the Université Catholique de Louvain (UCLouvain), Belgium

Recent posts

Extreme precipitation and large-scale flow patterns in the Mediterranean

New insights into polar observing systems using numerical models

2020 – a crazy year (for satellite navigation data and NWP!)

<https://www.ecmwf.int/en/about/media-centre/science-blog/2021/new-insights-polar-observing-systems-using-numerical-models>

Quarterly Journal of the Royal Meteorological Society



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Impact of Polar Observations on Predictive Skill

Special Collections | First published: 16 October 2020 | Last updated: 26 October 2020

This special collection gathers a series of studies highlighting the impact of polar observations on predictive skill in polar regions and beyond, from weather to climate time scales. Some of these studies rely on the extensive numerical experimentation performed in the framework of the **Year of Polar Prediction (YOPP)** of the World Meteorological Organization and of the H2020 project **APPLICATE**. This coordinated effort aimed to understand how to increase the uptake of existing polar observations in numerical weather prediction and climate prediction systems, and to guide the design of future observing systems in polar regions. It relied on so-called Observing System Experiments (OSEs) in which certain observations are withdrawn (denied) from the data assimilation system used to create initial conditions for weather forecasts. As part of this effort, coordinated OSEs in which observations were denied in polar regions, were performed for the first time at several operational weather centres, including ECMWF, Environment and Climate Change Canada, DWD and Met Norway. The results were analysed to understand the impact of observations on short and medium-range forecast skill. These OSEs covered the Special Observing Periods of YOPP in both the Arctic and the Antarctic. This special issue also welcomes OSEs studies covering longer time scales (e.g., those analyzing the impact of degrading initial oceanic and/or sea ice initial conditions on the predictive skill at sub-seasonal to seasonal time scales), as well as studies that use numerical experimentation to explore the possible added value of recently available or hypothetical observations (for which instruments are not deployed yet) on predictive skill.

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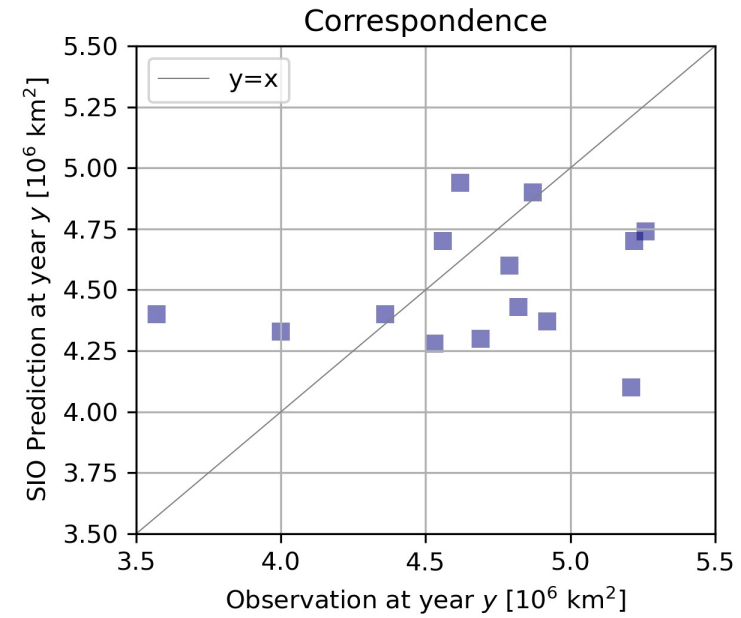
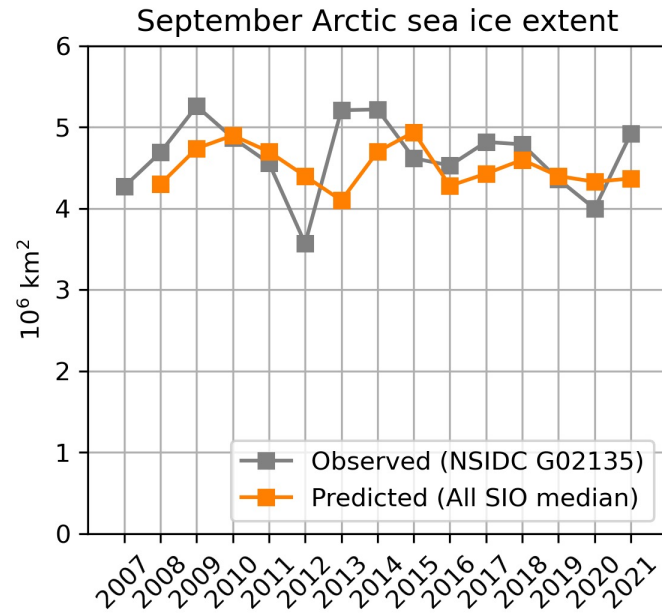
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4. Forecast verification / model evaluation

All contributions



Prediction of 2022 June SIO median (all):
4.65 +/- 0.23 million km²

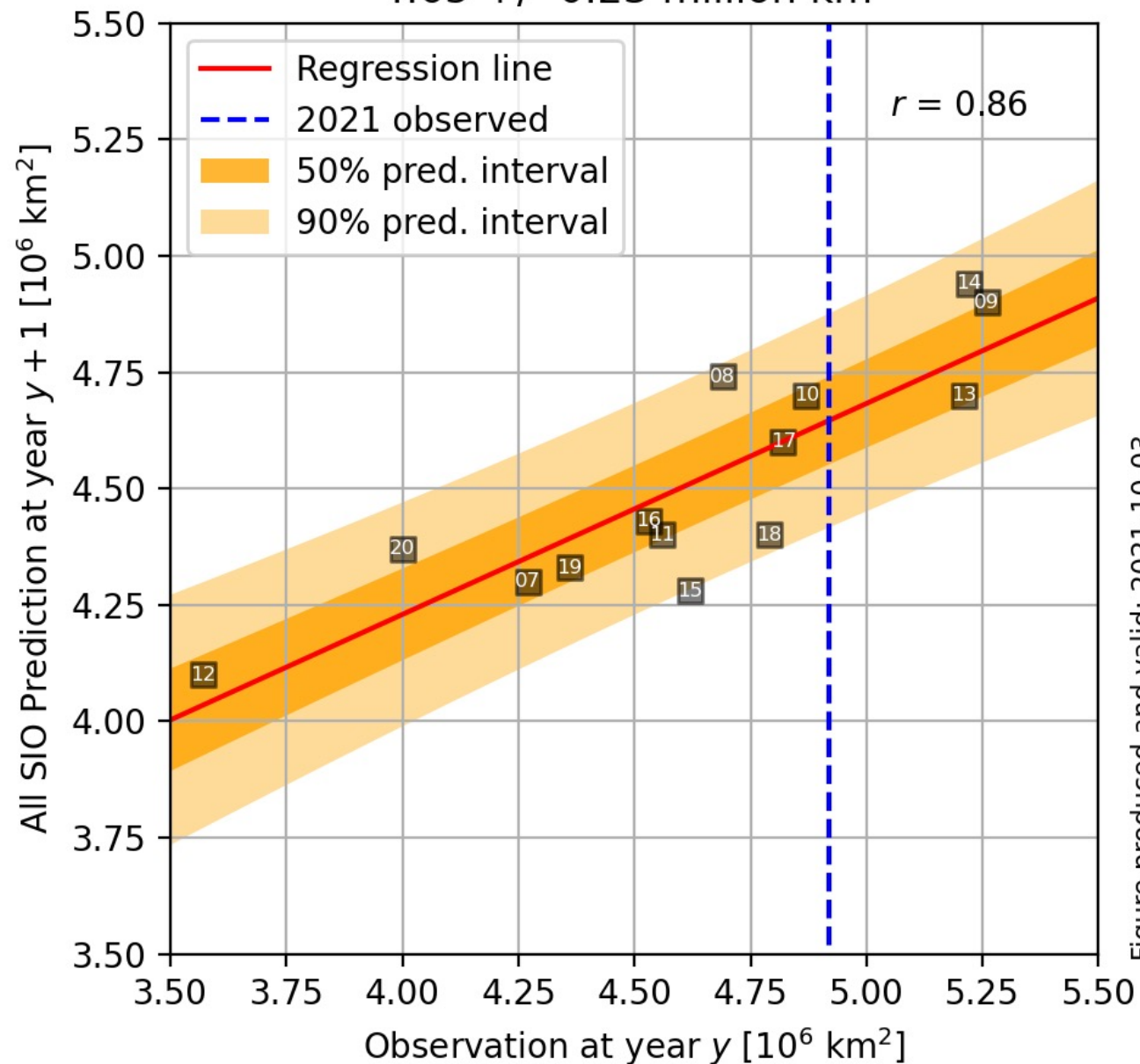


Figure produced and valid: 2021-10-03



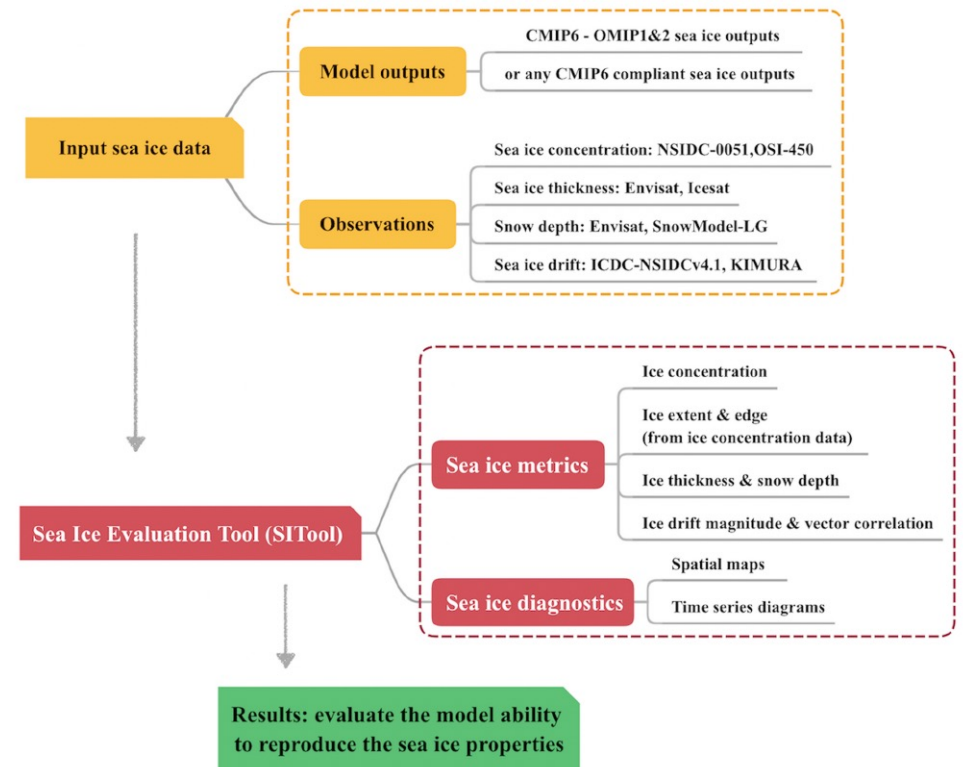
SITool (v1.0) – a new evaluation tool for large-scale sea ice simulations: application to CMIP6 OMIP

Xia Lin^{1,2}, François Massonnet¹, Thierry Fichefet¹, and Martin Vancoppenolle³

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²Southern Marine Science and Engineering Guangdong Laboratory (Zhuhai), Zhuhai, 519000, China

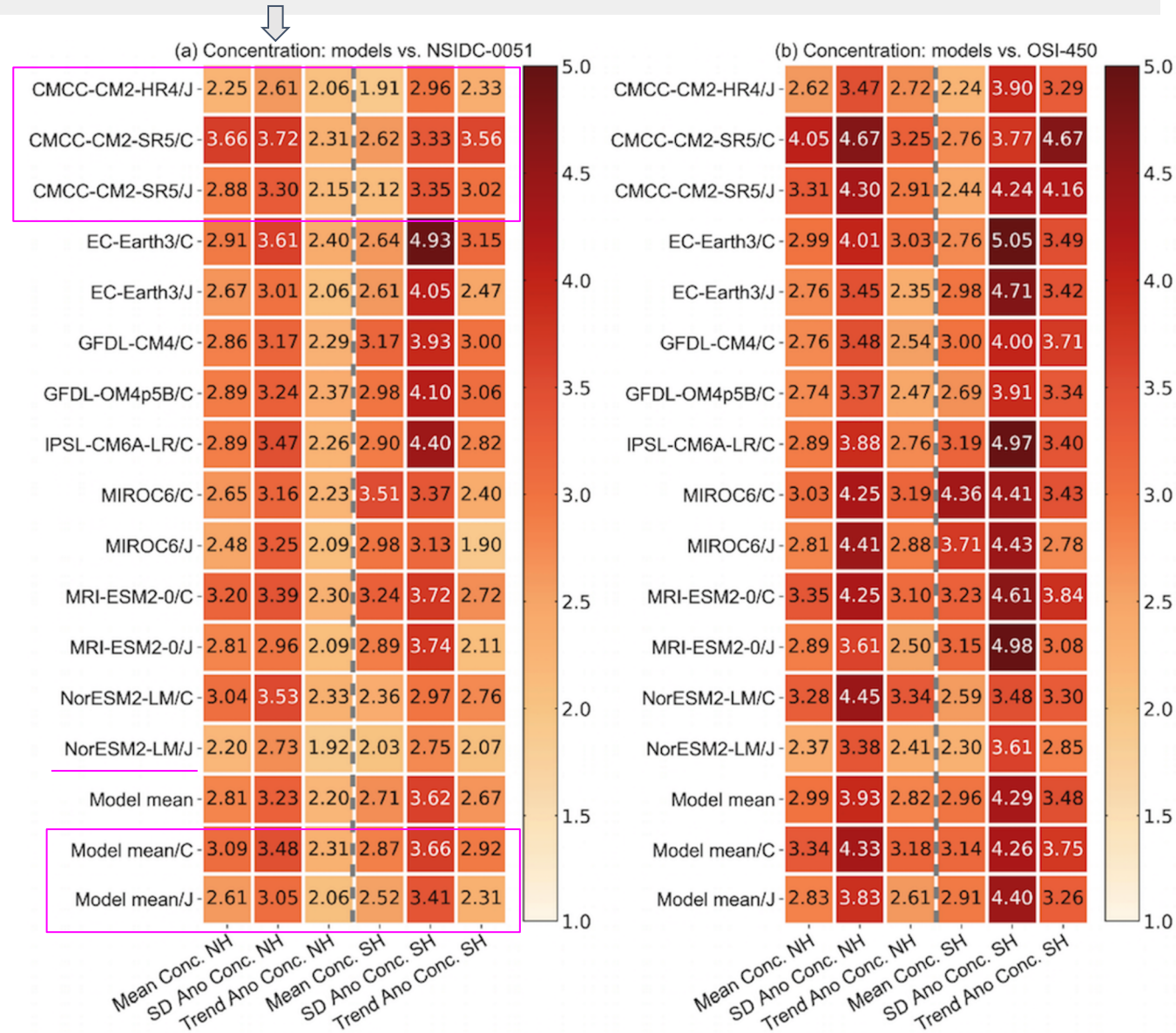
³Laboratoire d’Océanographie et du Climat, CNRS/IRD/MNHN, Sorbonne Université, 75252, Paris, France



Lin, X., Massonnet, F., Fichefet, T., & Vancoppenolle, M. (2021). SITool (v1.0) – a new evaluation tool for large-scale sea ice simulations: Application to CMIP6 OMIP. *Geoscientific Model Development*, 14(10), 6331–6354.

<https://doi.org/10.5194/gmd-14-6331-2021>

1. Ice concentration metrics



General approach:

compute scaled absolute errors

1) 1980-2007 At each grid cell

Mean: -> monthly mean over 12 months

Interannual variability/trend: monthly anomalies -> standard deviation/linear regression

-> absolute difference

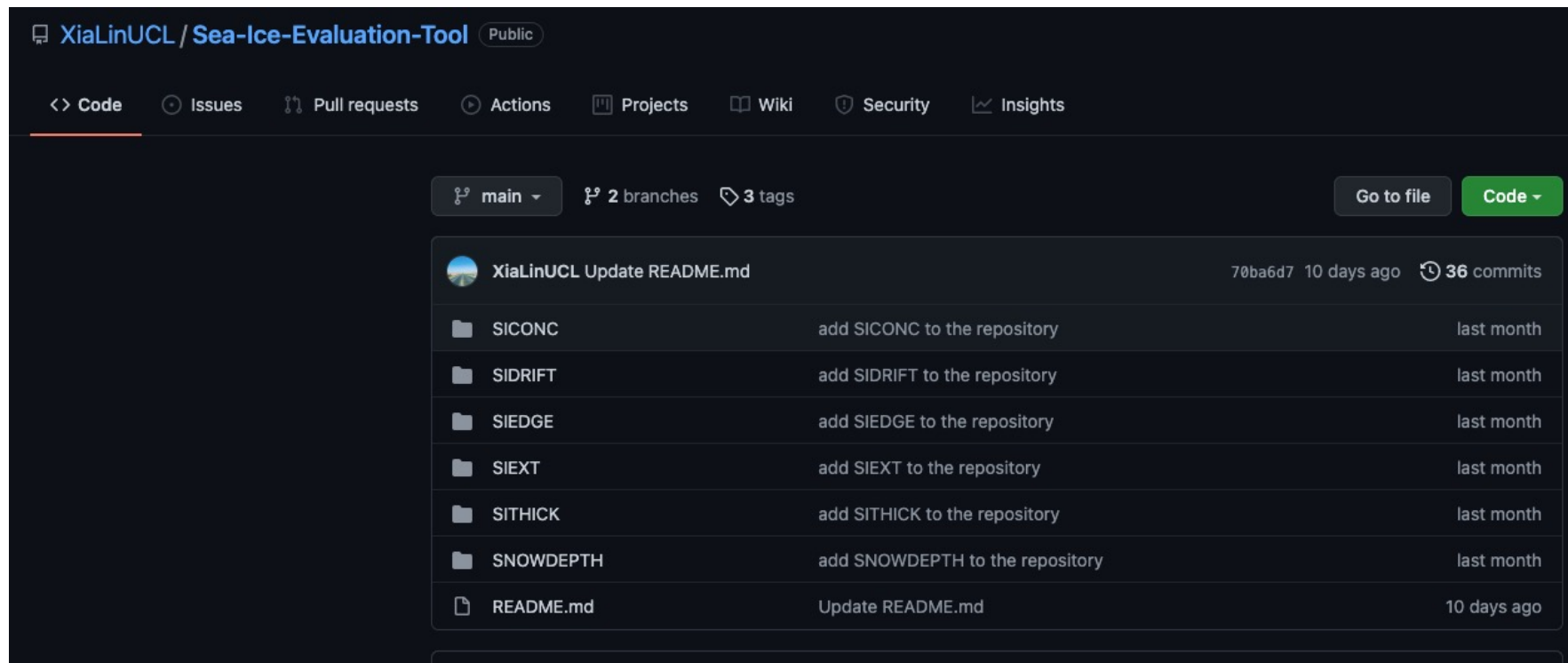
2) Average spatially weighted by grid cell areas

3) Scaled by typical errors (absolute difference between two observations)

Lower values -> better skill

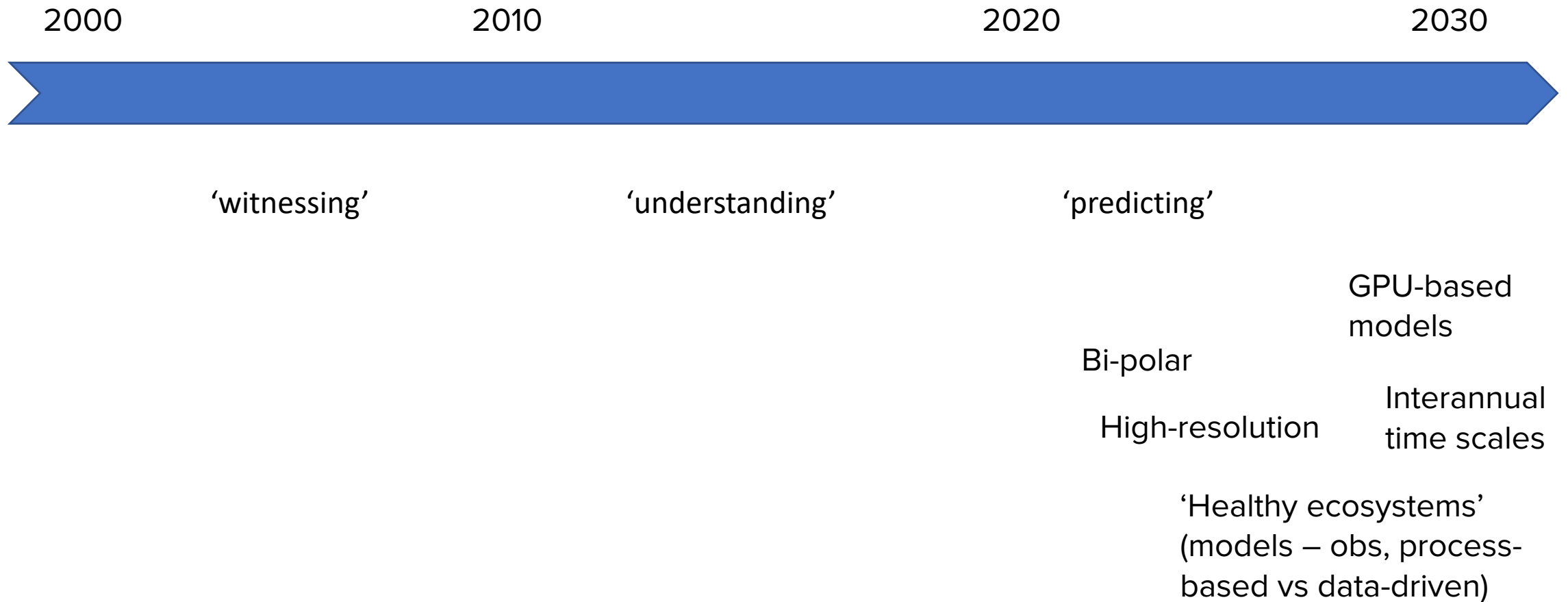
- ❖ model errors >> observational uncertainty (close to NSIDC-0051)
- ❖ improved simulations under OMIP2 & increased model spatial resolution
- ❖ lower skill on the simulation of ice concentration variability

The SITool (v1.0) code is publicly available on Github for use and reuse. It is CMIP6 output-compliant.



<https://github.com/XiaLinUCL/Sea-Ice-Evaluation-Tool>

And now?



Thank you



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Abstract

Starting from essentially nowhere in the mid 2000s, the field of sea ice prediction has made several breakthroughs in hardly 15 years. This spectacular progress, sparked by the dramatic retreats of Arctic sea ice in 2007 and 2012, has been made possible by the advent of new observational products and modeling tools, but also by considerable advances in our theoretical understanding of predictability mechanisms. In this seminar, I will review recent EU-coordinated efforts on these topics, with particular emphasis on modeling, data assimilation and forecast verification / model evaluation efforts. I will outline the added value of spring sea ice freeboard and concentration assimilation for summer Arctic sea ice prediction, present recent developments in the modeling of the cryosphere-ocean-atmosphere coupled system around Antarctica, introduce a recently developed model evaluation tool for sea ice simulations and present evidence that numerical climate models hold some potential to (re-)think the polar observing system for the next decade. All welcome!