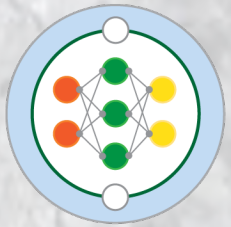


A machine learning correction model for the warm bias over Arctic sea ice in atmospheric reanalyses

Lorenzo Zampieri[1,*], Gabriele Arduini[2], Marika Holland[1], Sarah Keeley[2], Kristian Mogensen[2], and Steffen Tietsche[2]

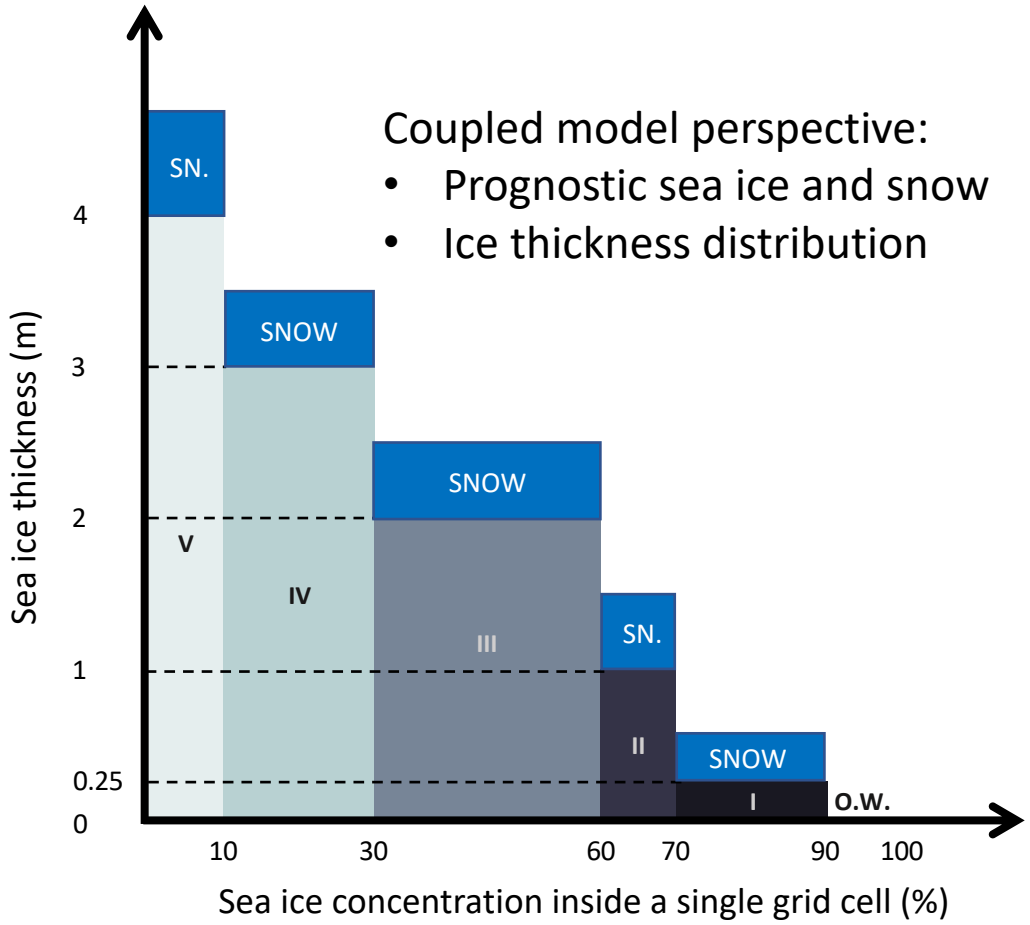
[1]National Center for Atmospheric Research

[2]European Centre for Medium-Range Weather Forecasts

zampieri@ucar.edu

https://m2lines.github.io/

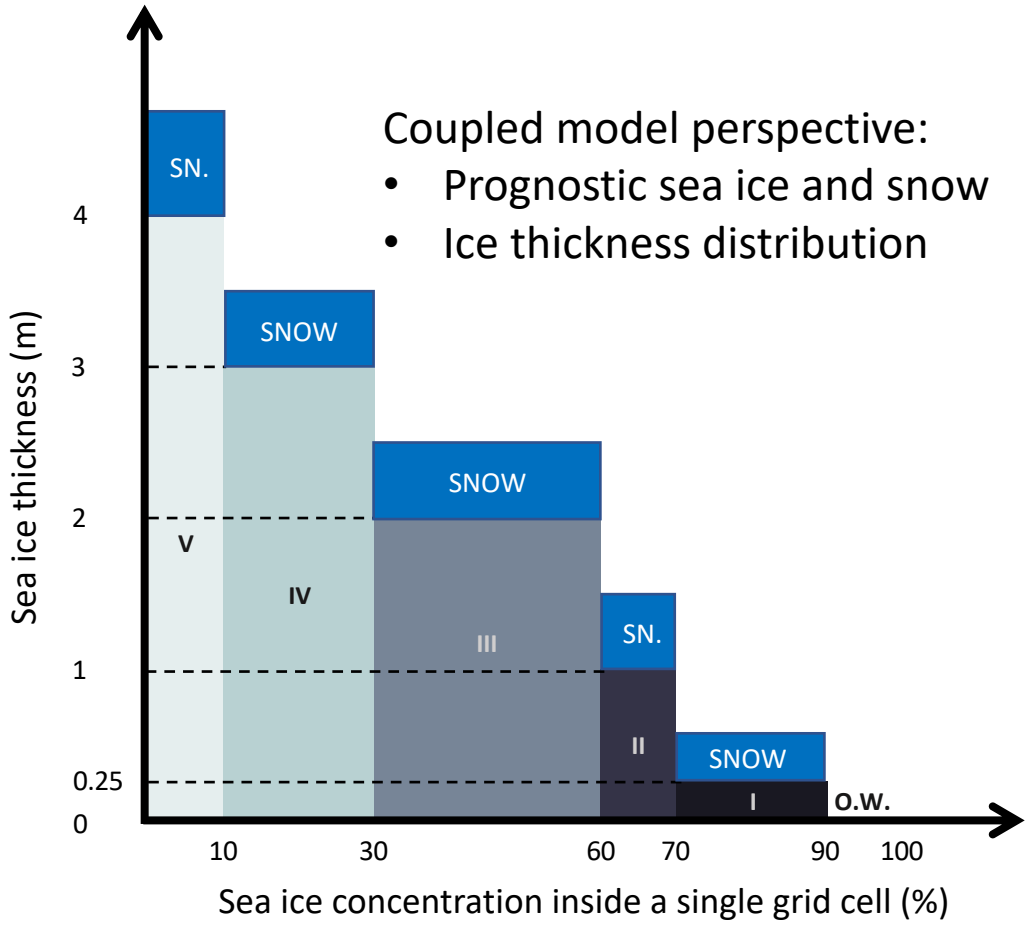
Sea ice and snow description in an atmospheric reanalysis model



Coupled model perspective:

- Prognostic sea ice and snow
- Ice thickness distribution

Sea ice and snow description in an atmospheric reanalysis model



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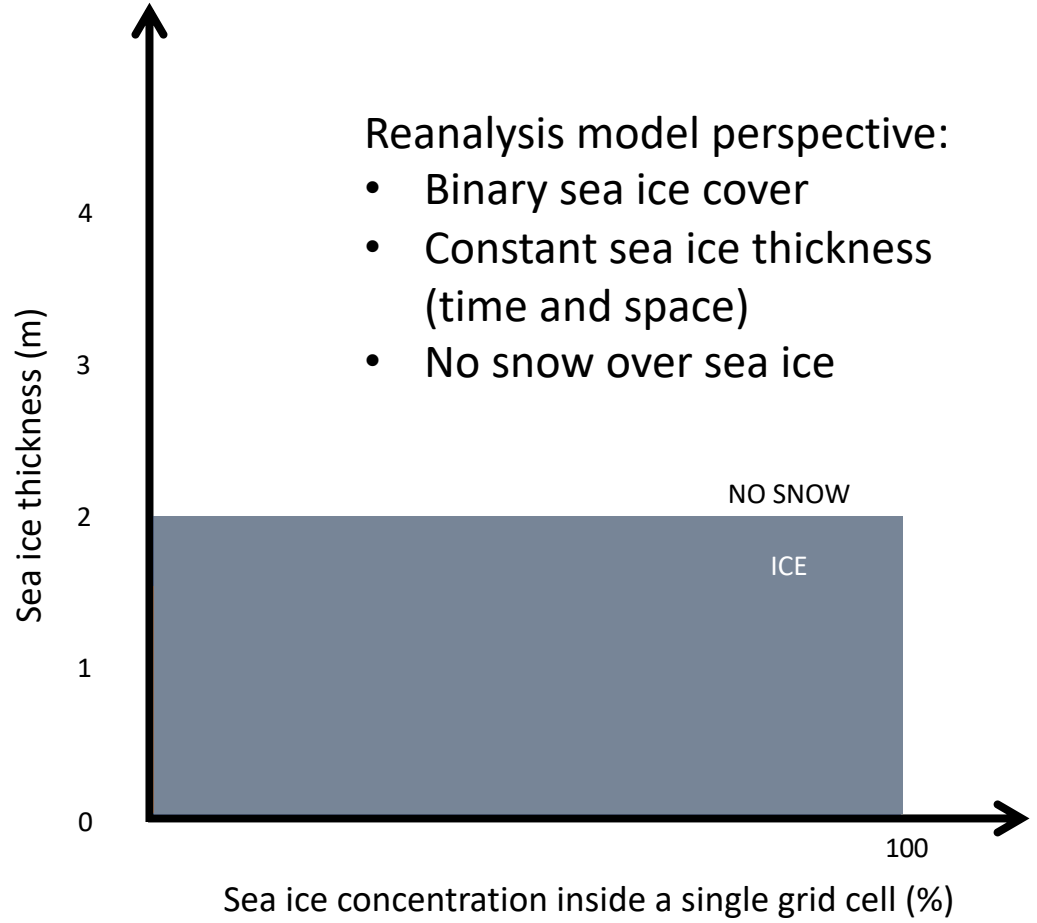
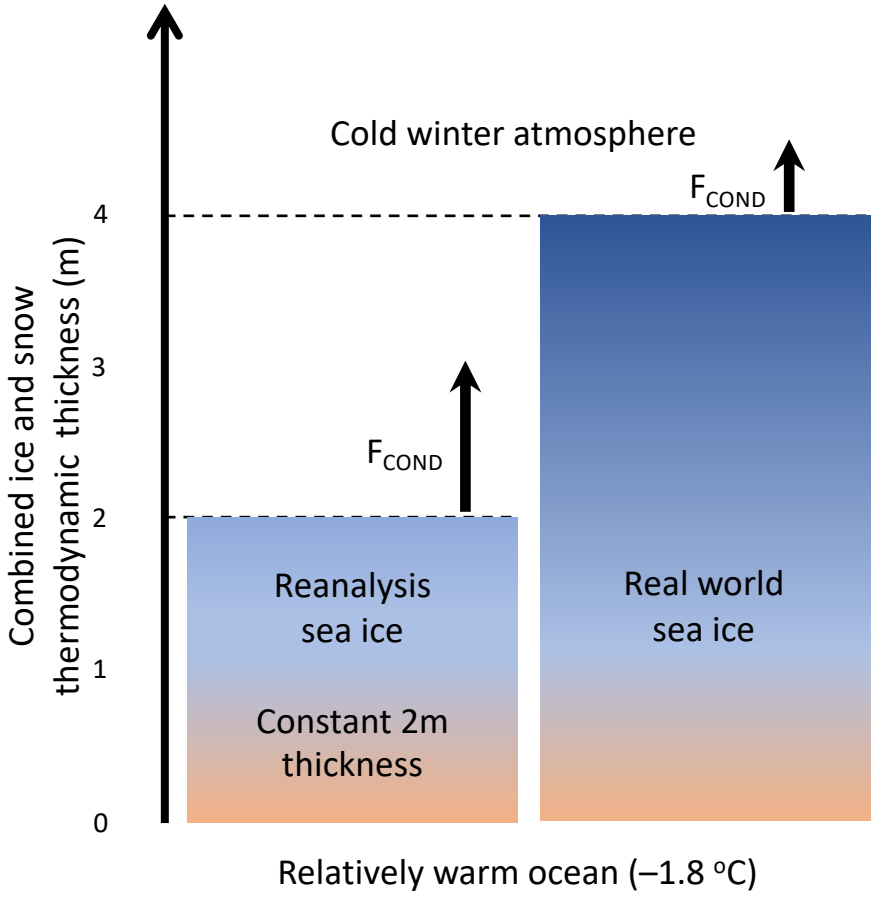


Reanalysis model perspective:

- Binary sea ice cover
- Constant sea ice thickness (time and space)
- No snow over sea ice

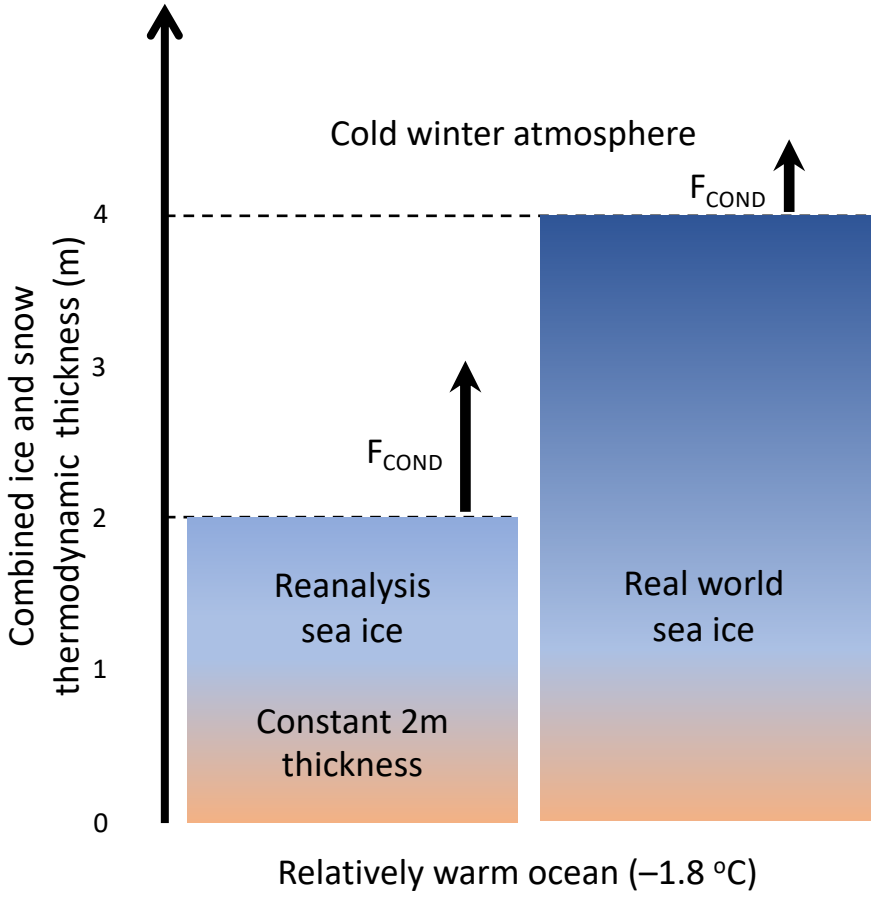
Batrak, Y., Müller, M. On the warm bias in atmospheric reanalyses induced by the missing snow over Arctic sea-ice. *Nat Commun* **10,** 4170 (2019).

Misrepresentation of conduction through sea ice and snow leads to surface temperature biases



Reanalysis has a **POSITIVE** surface temperature bias

Misrepresentation of conduction through sea ice and snow leads to surface temperature biases



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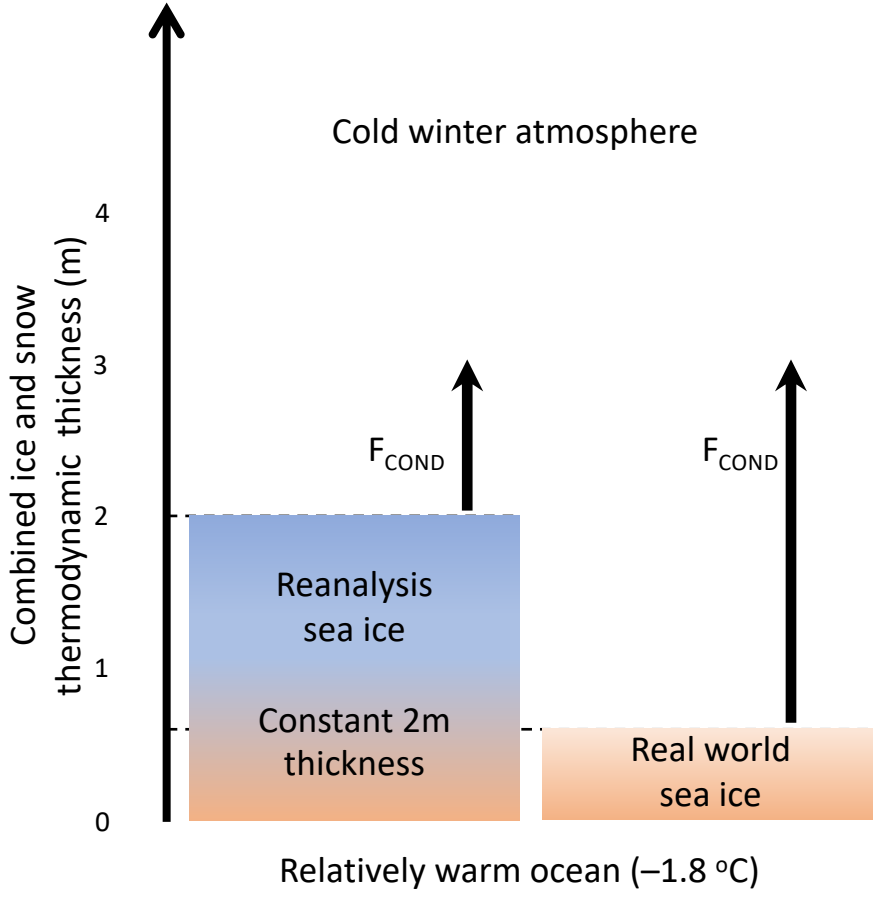
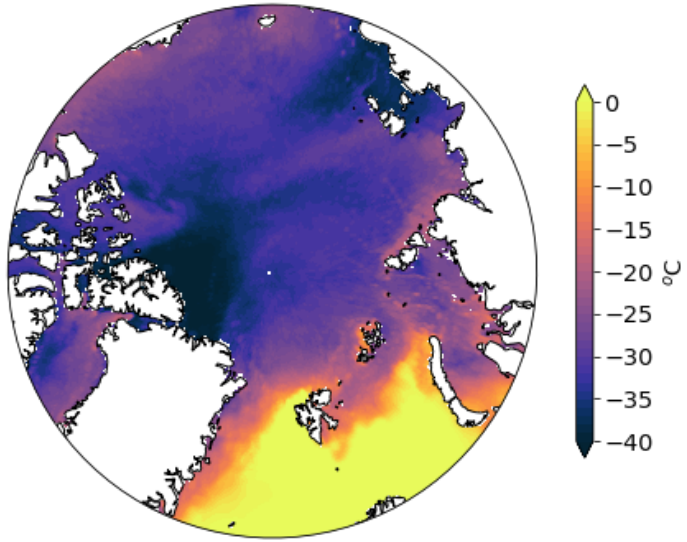


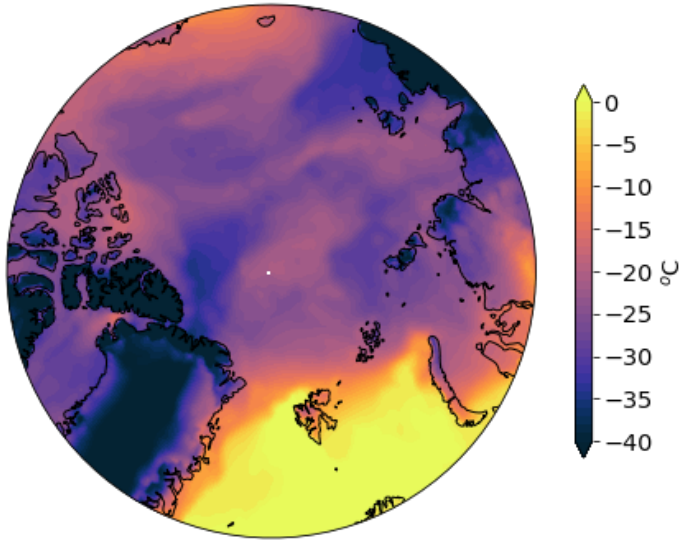
Reanalysis has a **NEGATIVE** surface temperature bias

An illustration of the surface temperature bias in reanalysis

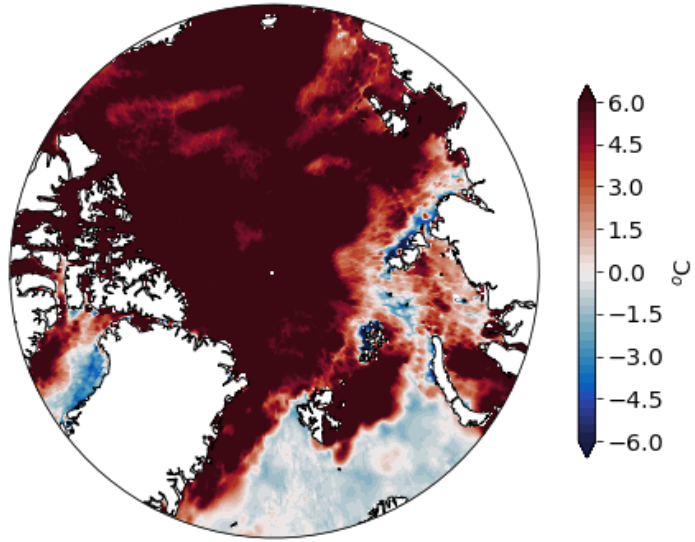
Observed Skin Temperature
2015-03-01 daily mean



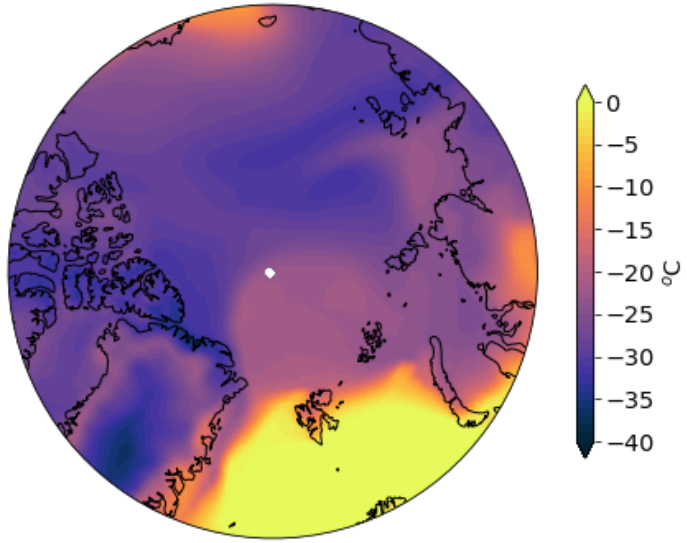
ERA5 Skin Temperature
2015-03-01 12:00



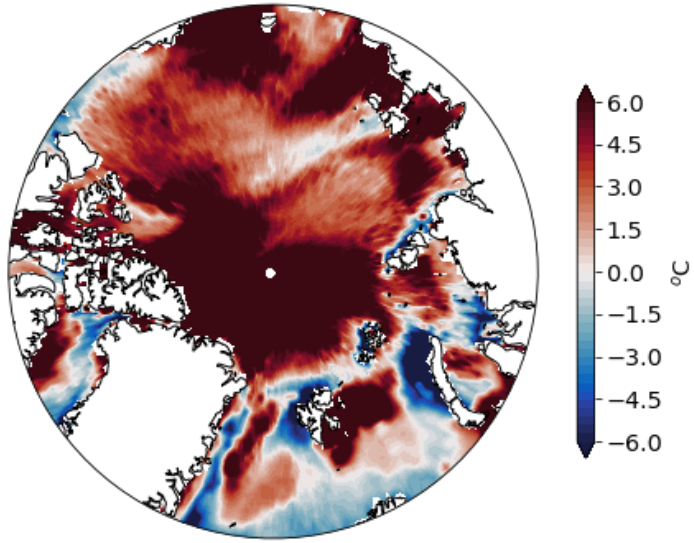
ERA5 Skin Temperature Bias
2015-03-01 12:00



JRA-55 Skin Temperature
2015-03-01 12:00

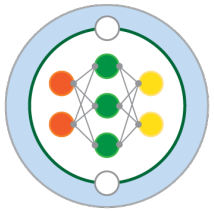


JRA-55 Skin Temperature Bias
2015-03-01 12:00



Observations from passive infrared sensors such as those collected by the **Advanced Very High-Resolution Radiometer** onboard the MetOp-A satellite and processed by the **Danish Meteorological Institute**

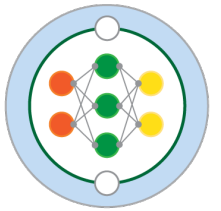
Formulating an effective bias correction strategy



These biases are state dependent and they manifest themselves in particular under **CLEAR SKY CONDITIONS**. The correction should therefore be **STATE DEPENDENT**!

Observations are not available all the time.
We cannot rely on them to correct long reanalysis records

Formulating an effective bias correction strategy



These biases are state dependent and they manifest themselves in particular under **CLEAR SKY CONDITIONS**. The correction should therefore be **STATE DEPENDENT**!

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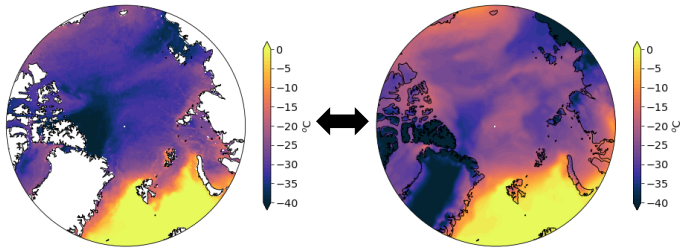
Temperature Bias Quantification



Observations Reanalysis

Identification of Temp. Bias Predictors

ATMOSPHERIC PREDICTORS

- Surface Temperature from reanalysis
- Downward Longwave Radiation from reanalysis

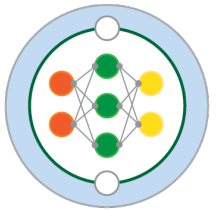
SEA ICE PREDICTORS

- Sea ice thickness from PIOMAS reanalysis
- Snow thickness over sea ice from SnowModel-LG reanalysis

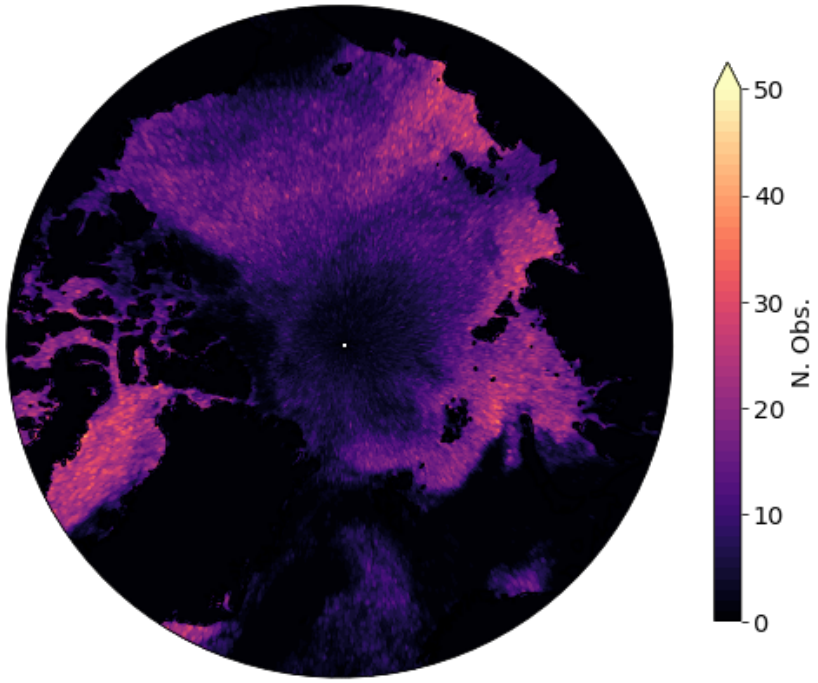
Learning the Relation between Predictors and Bias

Training a ML model (fully connected neural network) that can link the predictors to the a space and time dependent correction factor that reduces the bias

The cloud state is relevant for the observations and the bias



Number of Observations 2015-03-01



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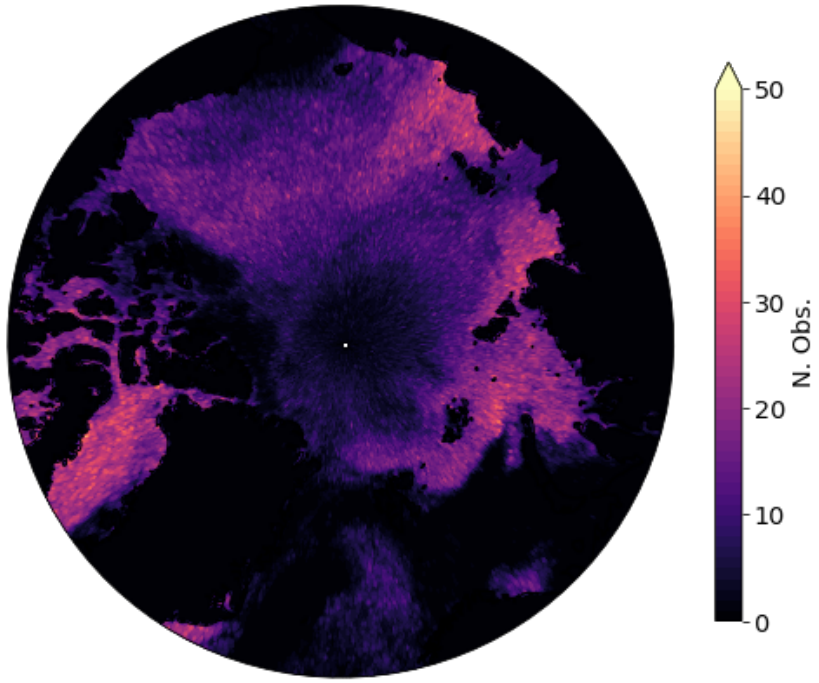
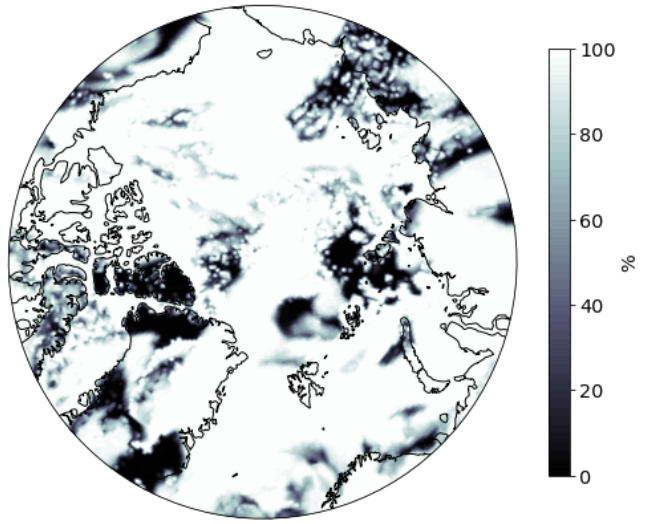
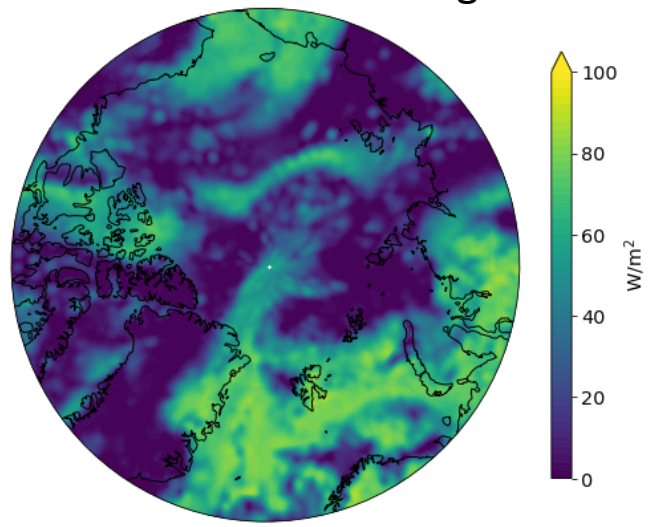


ERA5 2015-03-01 12:00

Total Cloud Cover

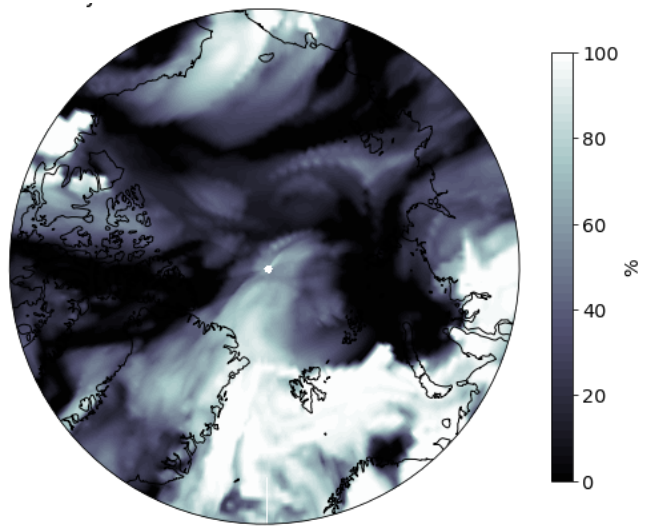


Cloud contribution to longwave

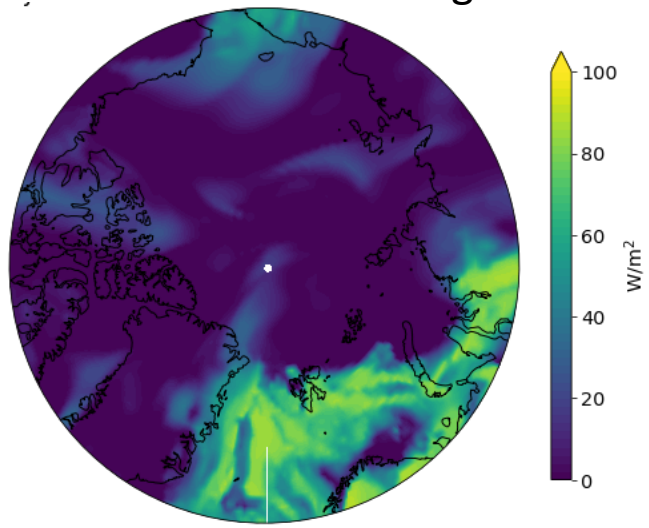


JRA-55 2015-03-01 12:00

Total Cloud Cover



Cloud contribution to longwave

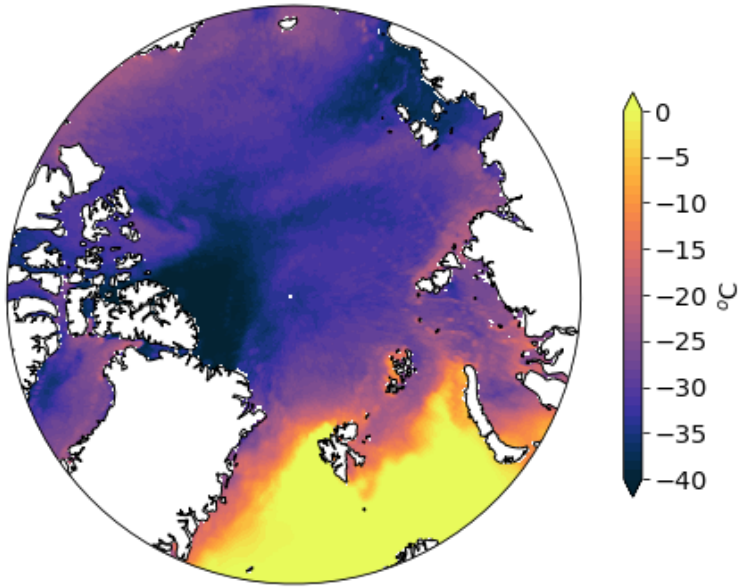


The cloud state is relevant for the observations and the bias

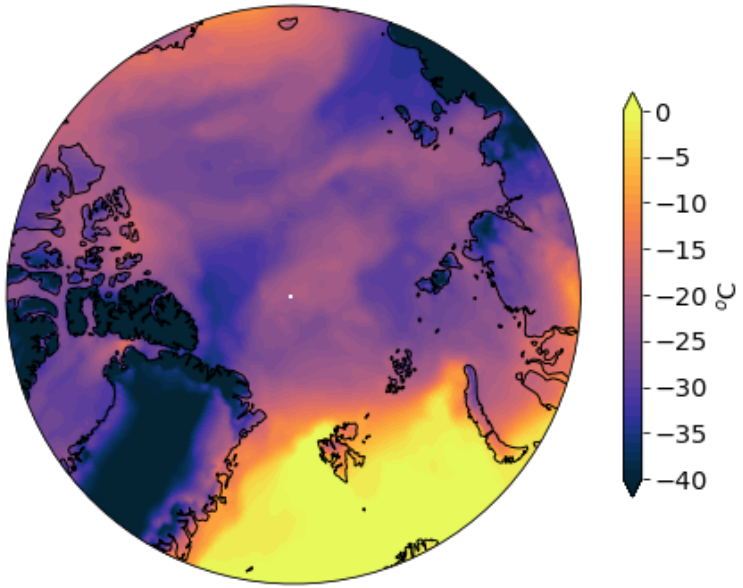
Surface temperature observations are reliable only in clear-sky conditions

The surface temperature bias is larger under clear sky conditions

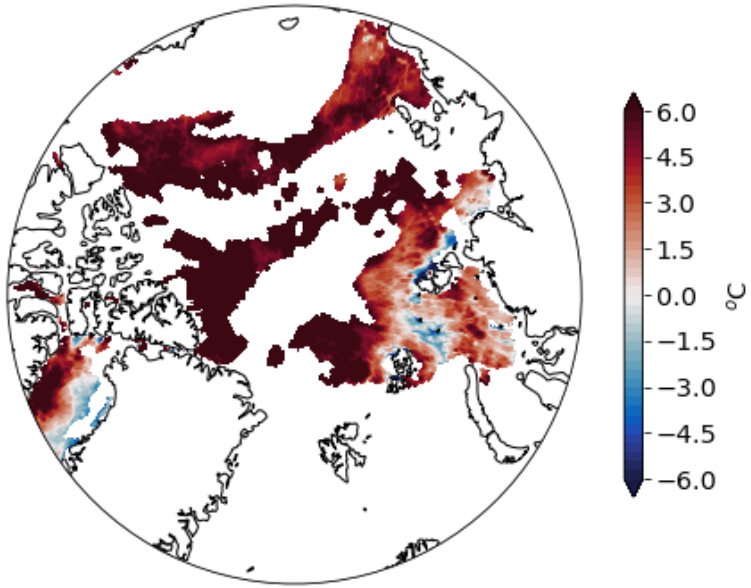
Observed Skin Temperature
2015-03-01



Original ERA5 Skin Temperature
2015-03-01 12:00

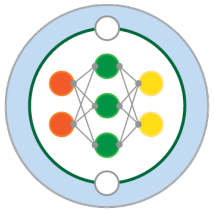


Original ERA5 Skin Temperature Bias
2015-03-01 12:00

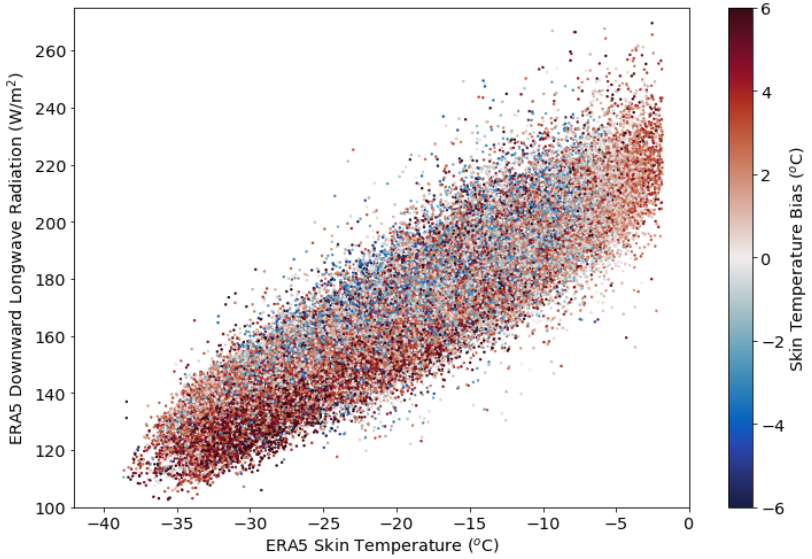


Only cloud free
regions displayed

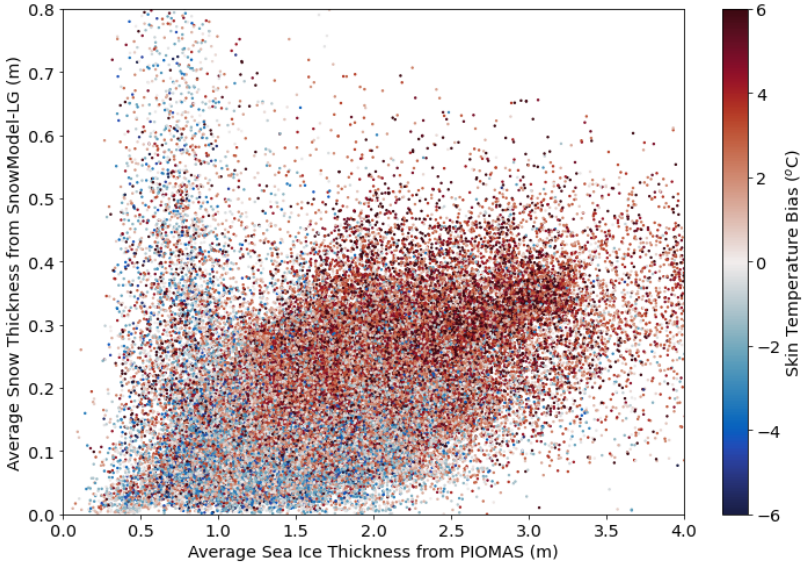
Temperature Bias, Predictors, and Correction



(a) Reanalysis temperature bias before correction (AI1, AI2)



(c) Reanalysis temperature bias before correction (II1, II2)



Temperature Bias, Predictors, and Correction

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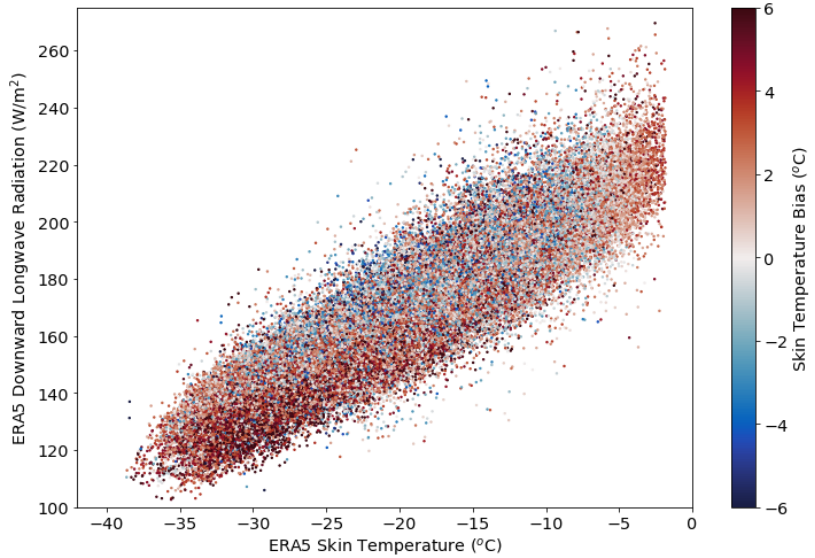
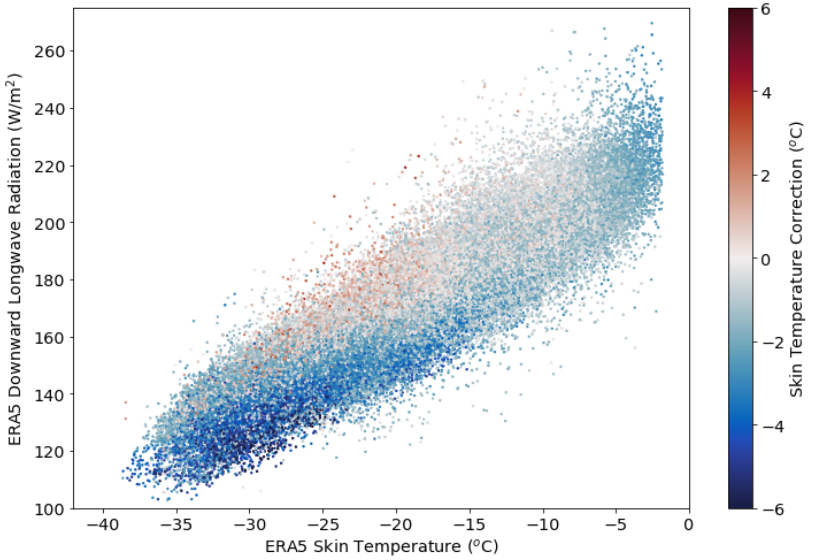


(b) Predicted reanalysis temperature correction (AI1, AI2)



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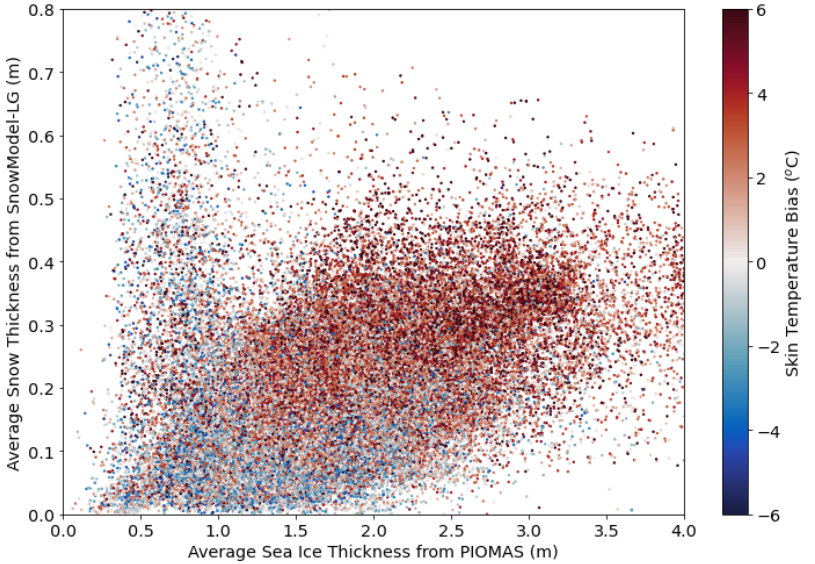
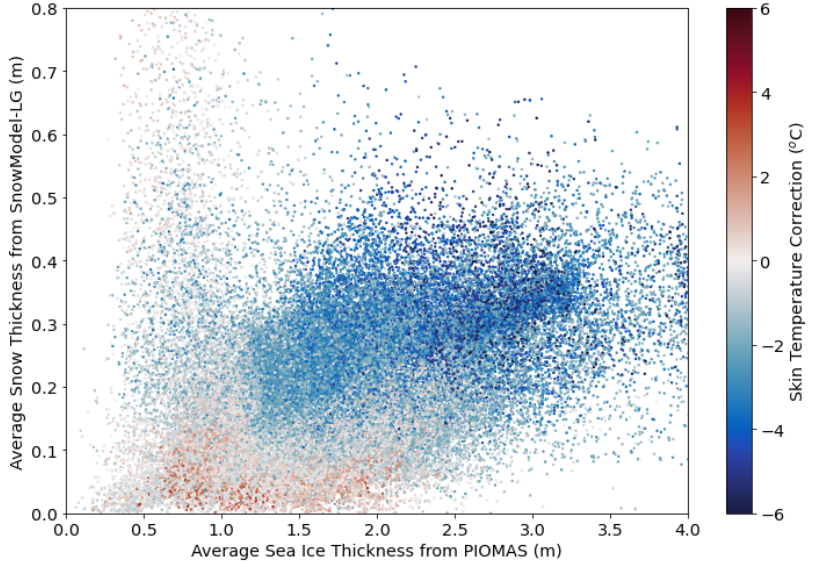
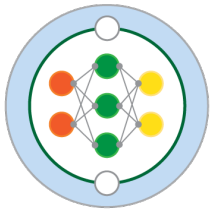


(d) Predicted reanalysis temperature correction (II1, II2)



Corrective skill of the atmospheric and ice predictors

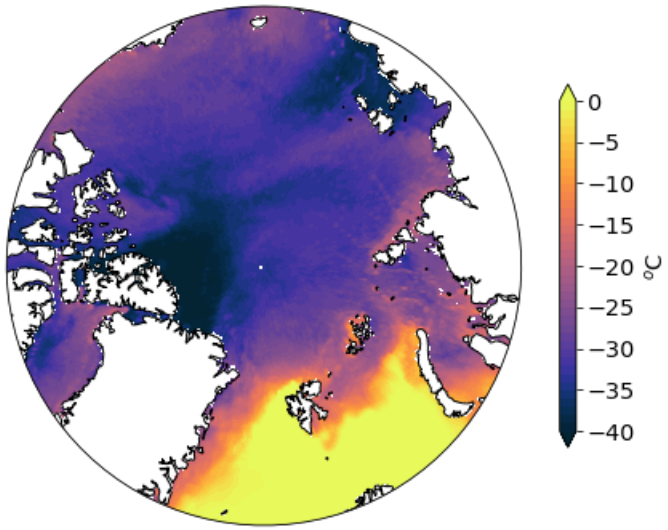


Correction Predictors	MSE	RMSE	MAE	r
before correction	11.46 $^oC^2$	3.38 ^oC	2.71 ^oC	0.93
AI1, AI2	8.06 $^oC^2$	2.83 ^oC	2.22 ^oC	0.94
II1, II2	7.74 $^oC^2$	2.78 ^oC	2.17 ^oC	0.94
AI1, AI2, II1, II2	6.52 $^oC^2$	2.55 ^oC	1.96 ^oC	0.96

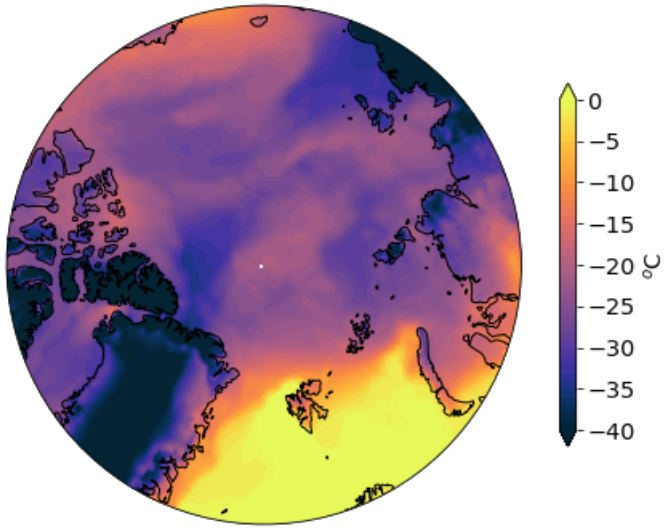
- The best correction model can be obtained by combining the atmospheric and ice predictors
- A portion of the information provided by the ice and atmospheric predictors is redundant
- The Ice predictors are (surprisingly) slightly more skillful than the atmospheric ones

Surface Temperature Correction – Single Timestep

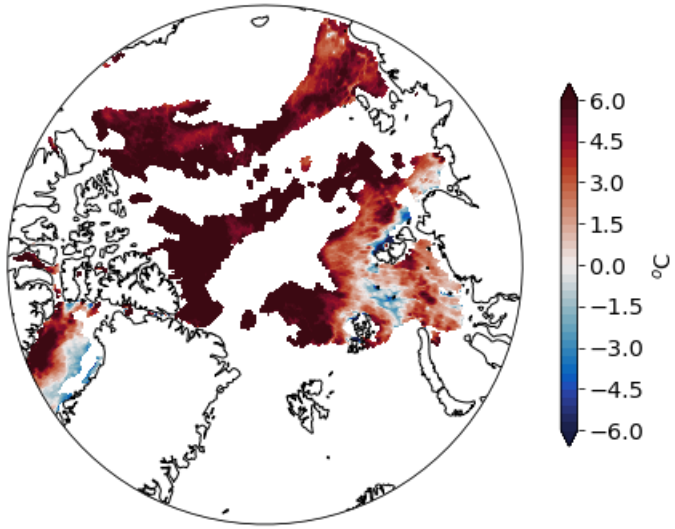
Observed Skin Temperature
2015-03-01



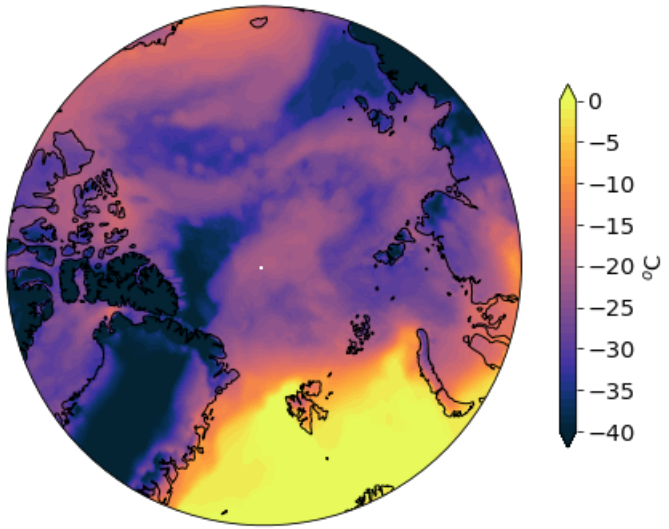
Original ERA5 Skin Temperature
2015-03-01 12:00



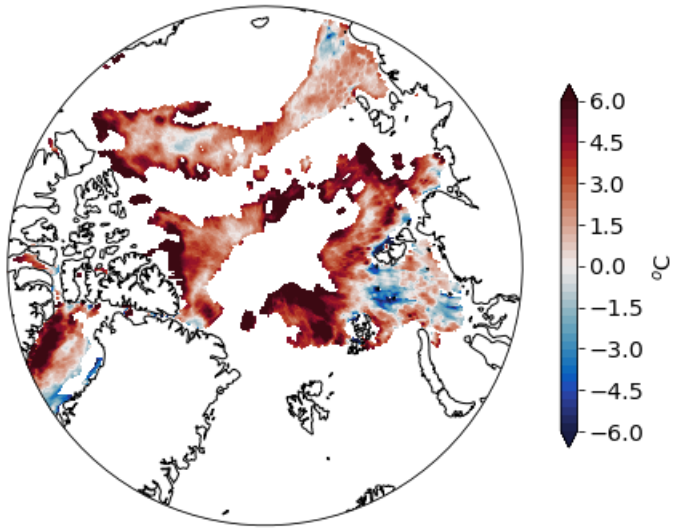
Original ERA5 Skin Temperature Bias
2015-03-01 12:00



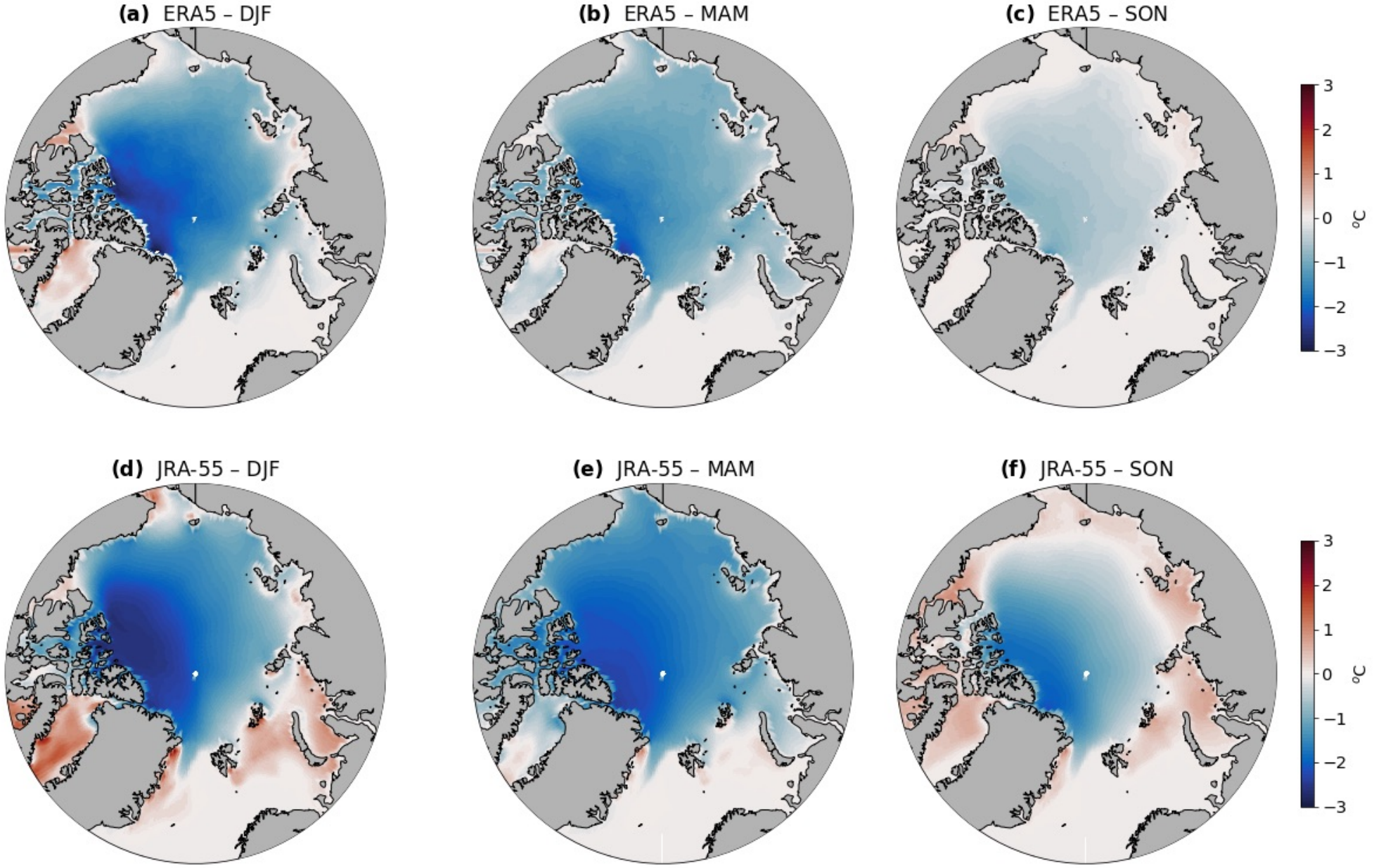
Corrected ERA5 Skin Temperature
2015-03-01 12:00



Corrected ERA5 Skin Temperature Bias
2015-03-01 12:00

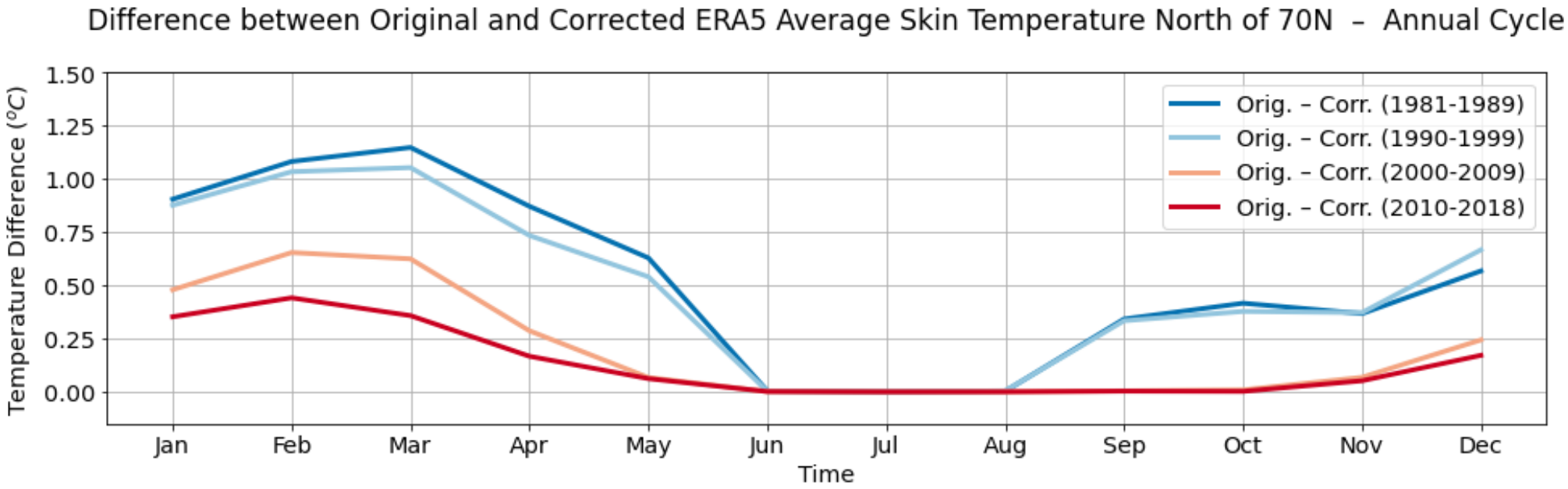


Surface Temperature Correction – 1981 to 2018 Average

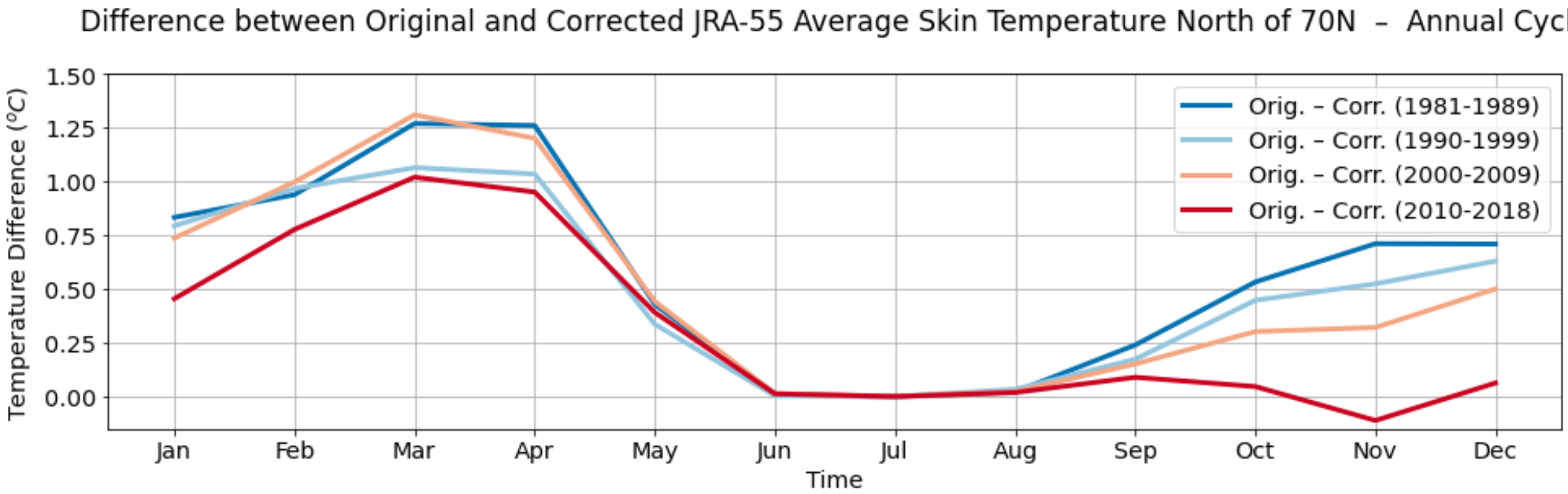


Seasonality of the temperature correction

ERA5

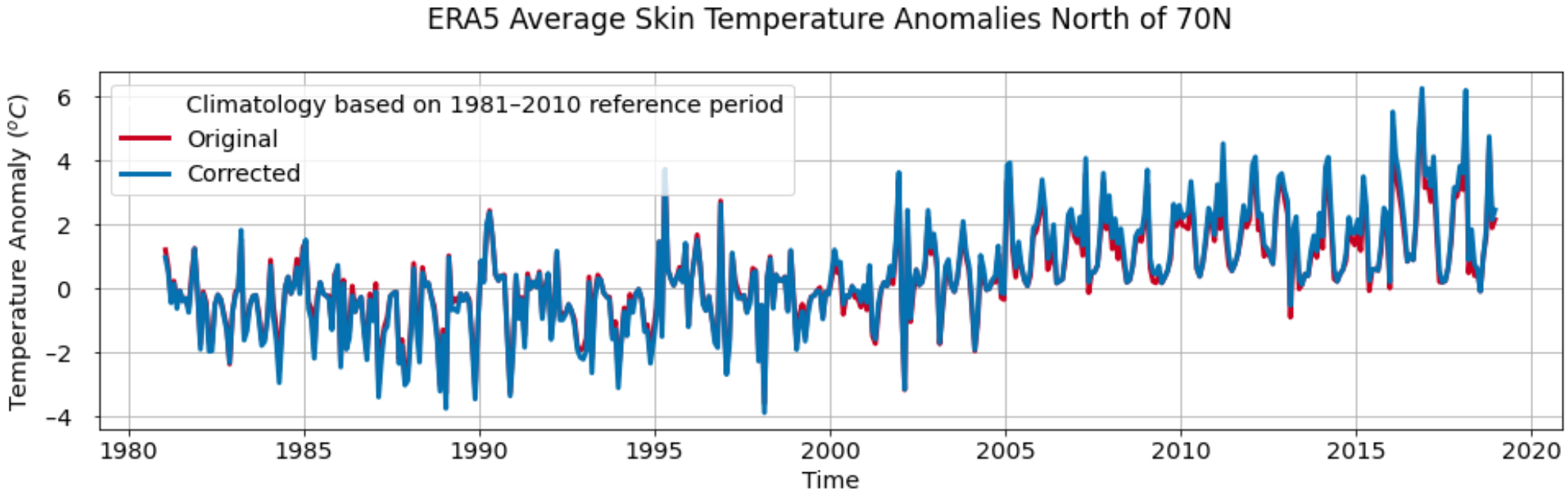


JRA-55



Trend of the temperature correction

ERA5



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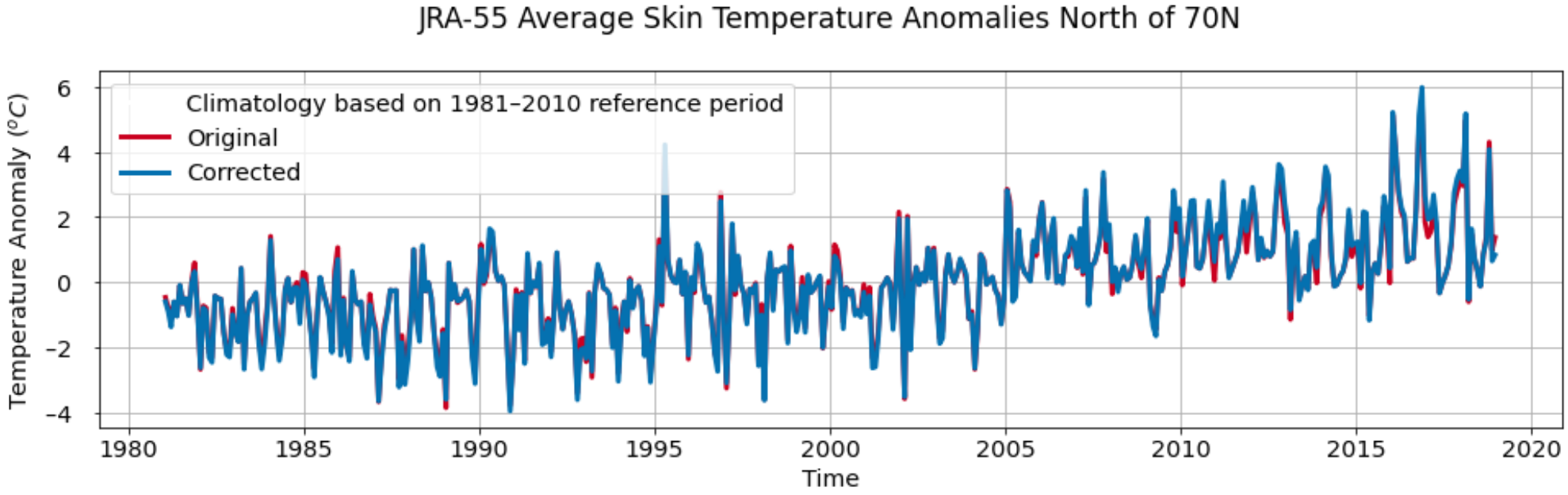
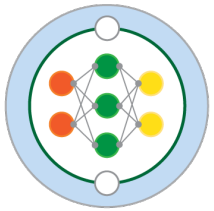


Summary



- The correction is state-dependent, meaning that it is coherent with the observed sea ice conditions and with the local weather. It favors clear-sky events, in agreement with the observation-based characterization of the reanalysis bias

- The predictors can be associated with the physical mechanism causing the bias in the first place, which is the misrepresentation of the conductive heat flux through the snow and sea ice

- Even though the reanalysis bias in the Arctic is on average warm, our model is able to correct also less common occurrences of cold biases occurring on thin ice, mostly at the beginning of the freezing season

- A self-emerging property of the correction is its interannual trend, which is compatible with our physical understanding of the bias and with the mutating sea ice conditions in the Arctic due to global warming

Thank you! Questions?