Impact of the atmospheric circulation on the Arctic snow cover and ice thickness variability

M. L. Athanase[1*], M. Schwager[1], J. Streffing[1,2], M. Andres-Martinez[1], S. Loza[1], H. F. Goessling[1]

1: Alfred Wegener Institute (AWI), Helmholtz Centre for Polar and Marine Research, Bremerhaven, Germany.
2: Jacobs University Bremen, Bremen, Germany.

* contact: marylou.athanase@awi.de

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Photo: Anika Happe

Motivation

Snow on sea ice → insulating barrier, driving sea-ice thickness variability

Accurate sea-ice (& plausibly snow) thickness initialization → crucial for skilful sea-ice forecasts

But

Snow depth scarcely measured

"Very limited predictive skill" according to the IPCC

Photo: Anika Happe

Spectral nudging technique

Free-running models

Random weather, determined by the initial state.

In consequence, specific weather events are not reproduced, and forecasting skills are limited by the "random weather" of the initial state.

VS.

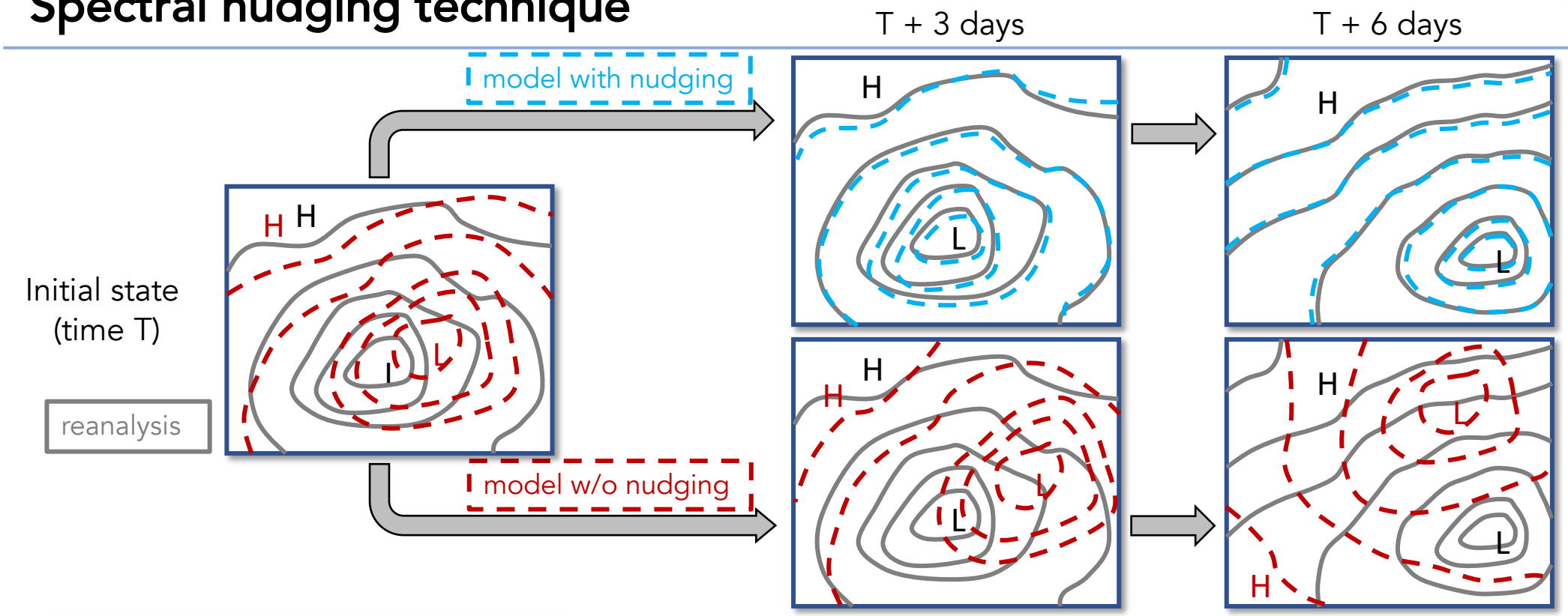
Spectrally nudged model

Atmosphere model no longer **free** but "nudged" towards observations (reanalysis). → At each time step, "nudging increment" added to **"push" the model parameter $\mathbf{X}$ towards the observed state $\mathbf{X}^{\mathbf{reana}}$.**

$$\frac{\partial X_n^m(\eta,t)}{\partial t} = \underbrace{F_n^m(\eta,t)}_{\text{Model forcing}} + \underbrace{G_n^m(\eta)\left[X_n^{m(\text{reana})}(\eta,t) - X_n^m(\eta,t)\right]}_{\text{Nudging increment}}$$

From Sánchez-Benítez et al. 2022

Spectral nudging technique



Graphics from
H. Gößling

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Model forcing — Nudging increment

From
Sánchez-Benítez et al. 2022

AWI-CM-3 spectral nudging experiments

Model Set-up

AWI-CM-3, new version of the AWI-Climate Model, global coupled model composed of:

OpenIFS (cycle 43r3)	+	FESOM2
Atmosphere component		Ocean component

Spectrally nudging OpenIFS winds (↔ constraining atmosphere dynamics) towards ERA5.

Observations vs. 1979-2020 experiments

Observations:

ERA5 Reanalysis data (SIC, T2M)
NSIDC snow thickness data
CS2-SMOS ice thickness data

Free run (Free):

No nudging

"Soft nudging" (SONU):

Relaxation time-scale: **24H**

Nudged wavenumbers below **T20**
(= only large-scale atmospheric patterns)

"Strong nudging" (STNU):

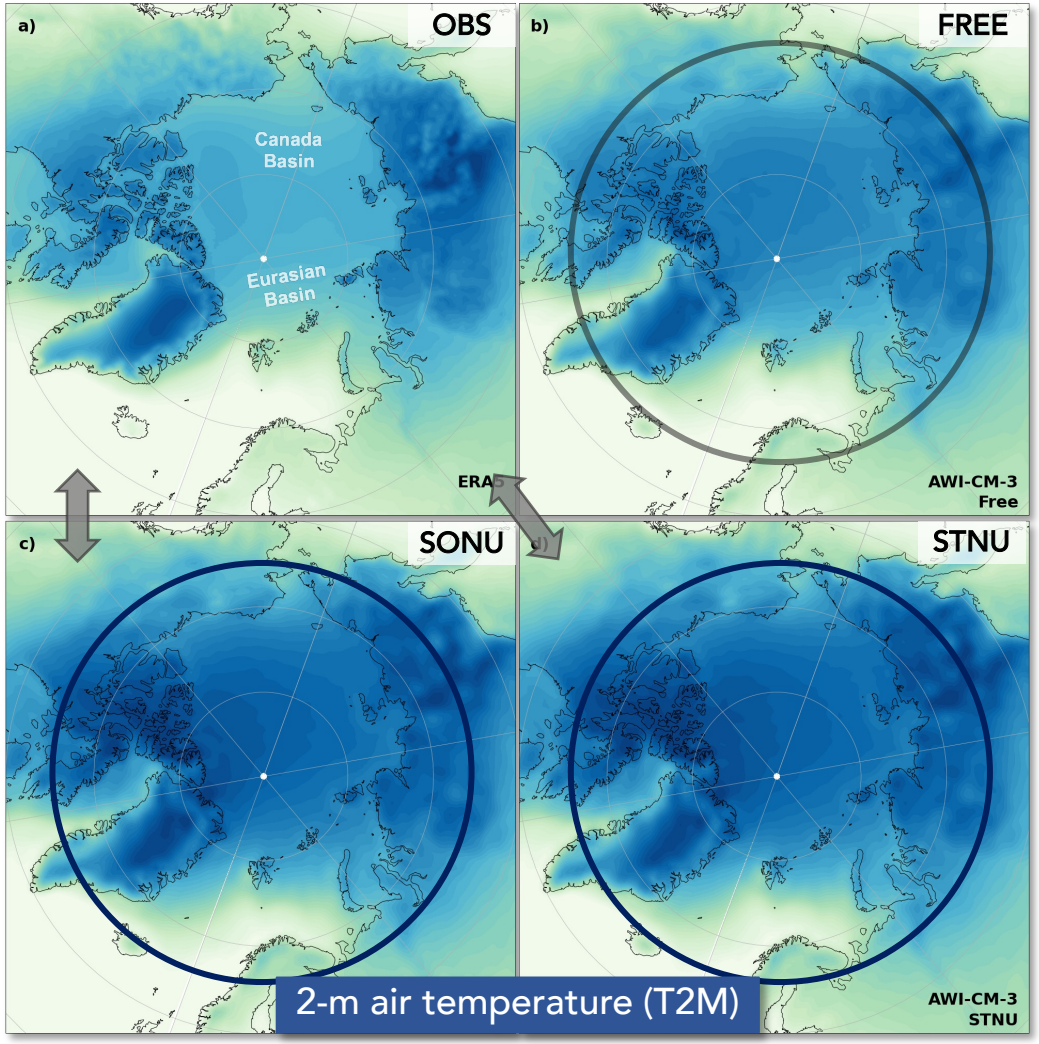
Relaxation time-scale: **1H**

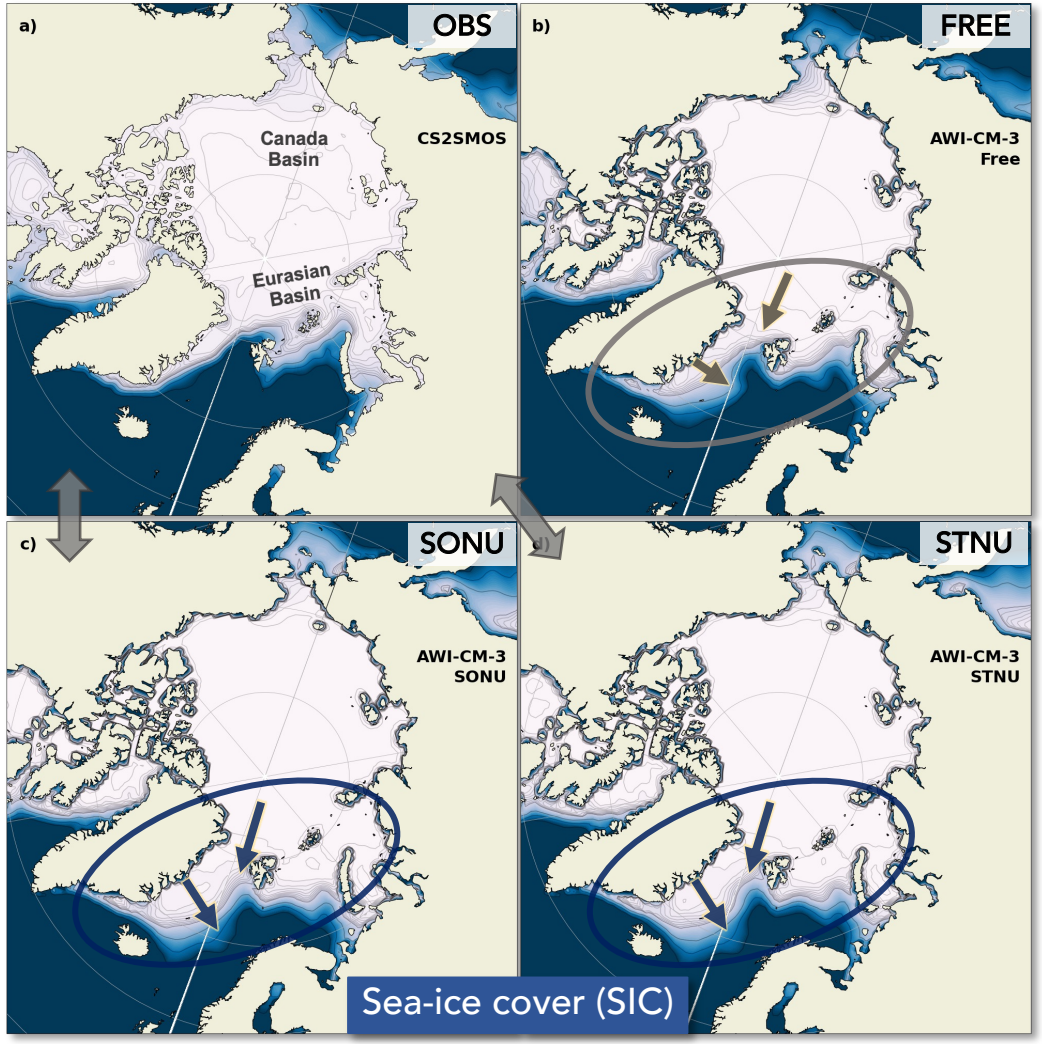
Nudged wavenumbers below **T159**
(= model resolution, all scales)

Nudged winds impact Arctic mean winter state

- **Free run:** Colder Arctic than in ERA5, slightly larger SI extent
- **Nudged run:** Even **colder Central Arctic**, larger SI extent

SONU: Soft nudging
STNU: Strong nudging

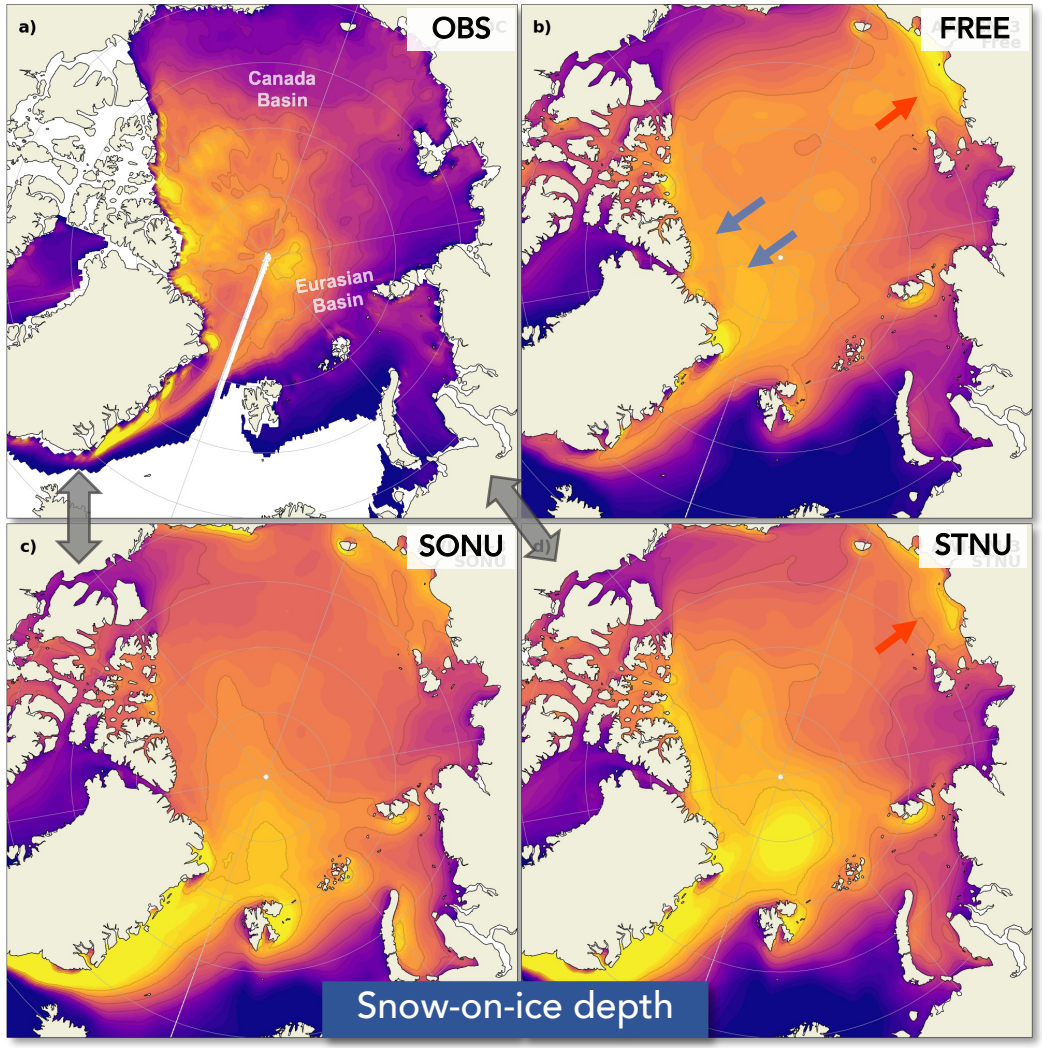


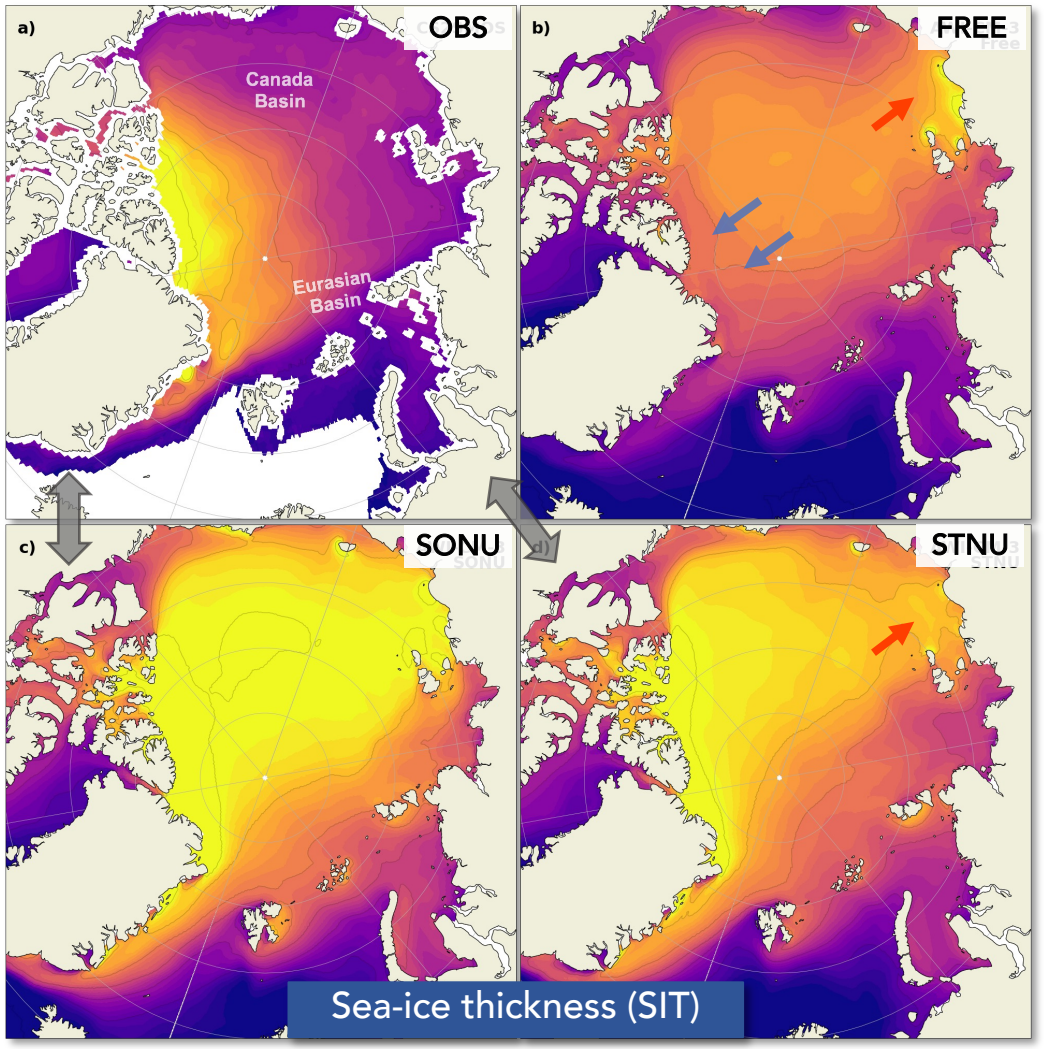


Nudged winds impact Arctic mean winter state

- **Free run:** Too thick snow and ice in Canadian Arctic ; **Inaccurate Greenland-Siberia gradients**
- **Nudged run:** **Better snow and ice thickness distribution** ; Biases in Canadian/Siberian Arctic remain

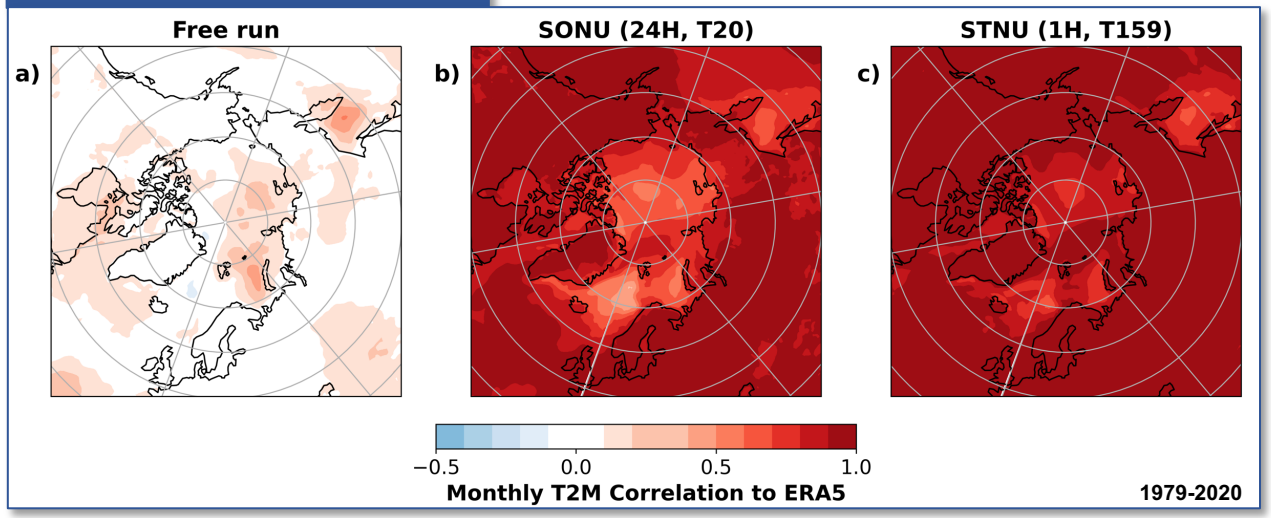
SONU: Soft nudging
STNU: Strong nudging





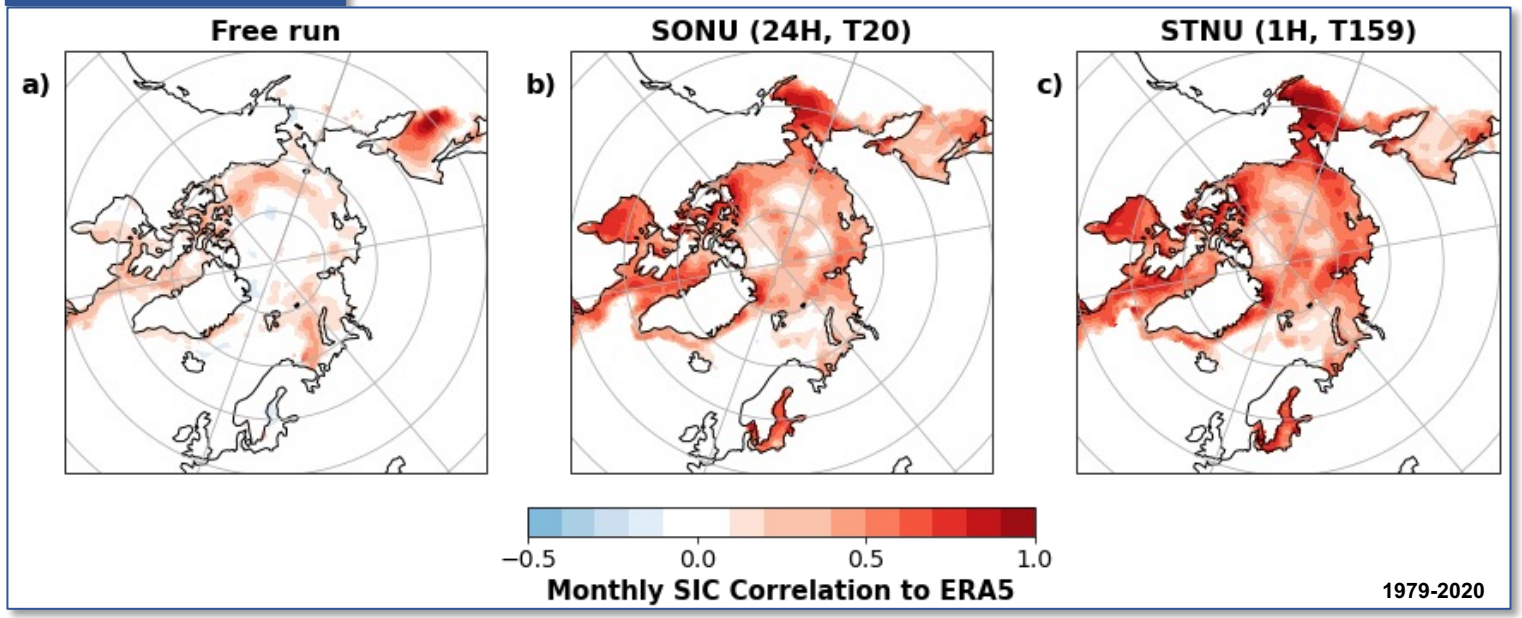
High correlations: good reproduction of observed variability

2-m air temperature (T2M)



Despite biases,
variations of T2M and SIC well captured
when nudging atmospheric circulation

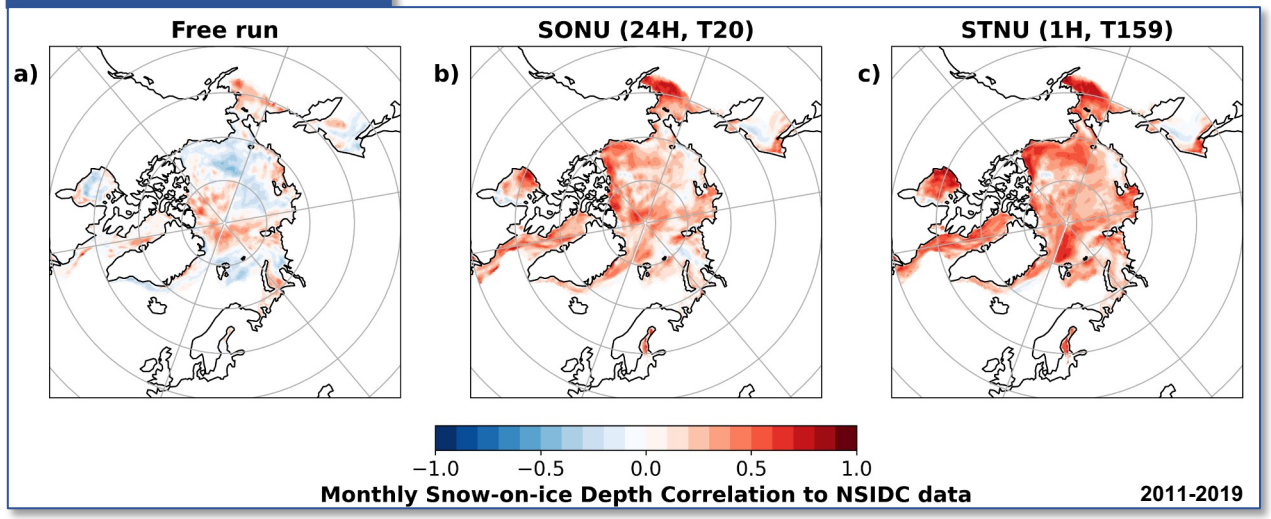
Sea-ice cover (SIC)



SONU: Soft nudging STNU: Strong nudging

High correlations: good reproduction of observed variability

Snow-on-ice depth



Stringent comparison: snow-on-ice depth variations depend on snowfall, wind advection and sea-ice motion

Well reproduced when nudging atmospheric circulation ($r = 0.4$ to 0.7 with nudging)

SONU: Soft nudging STNU: Strong nudging

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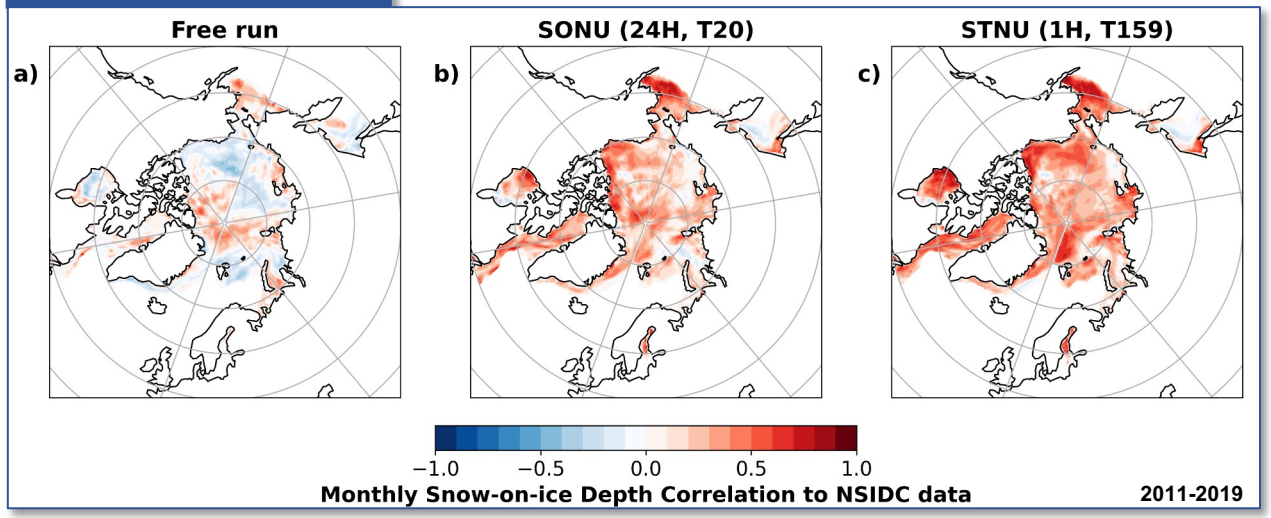
Snow-on-ice depth



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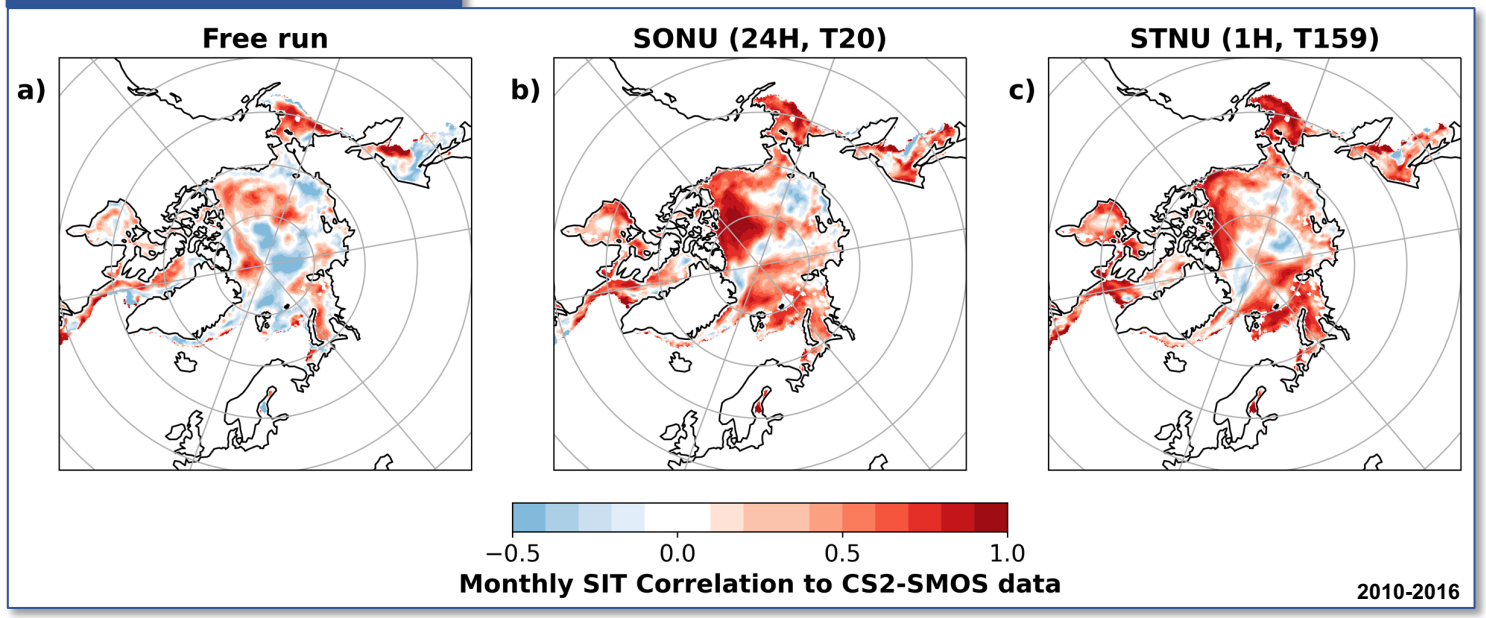
Sea-ice thickness (SIT)



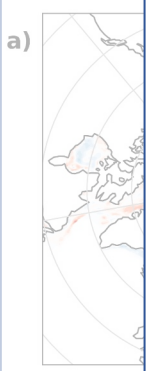
When nudging atmospheric circulation, **SIT variations reproduced in Eurasian Arctic and along continental margins**

SIT variations not captured in Siberian Sea and along the Transpolar drift: cause?

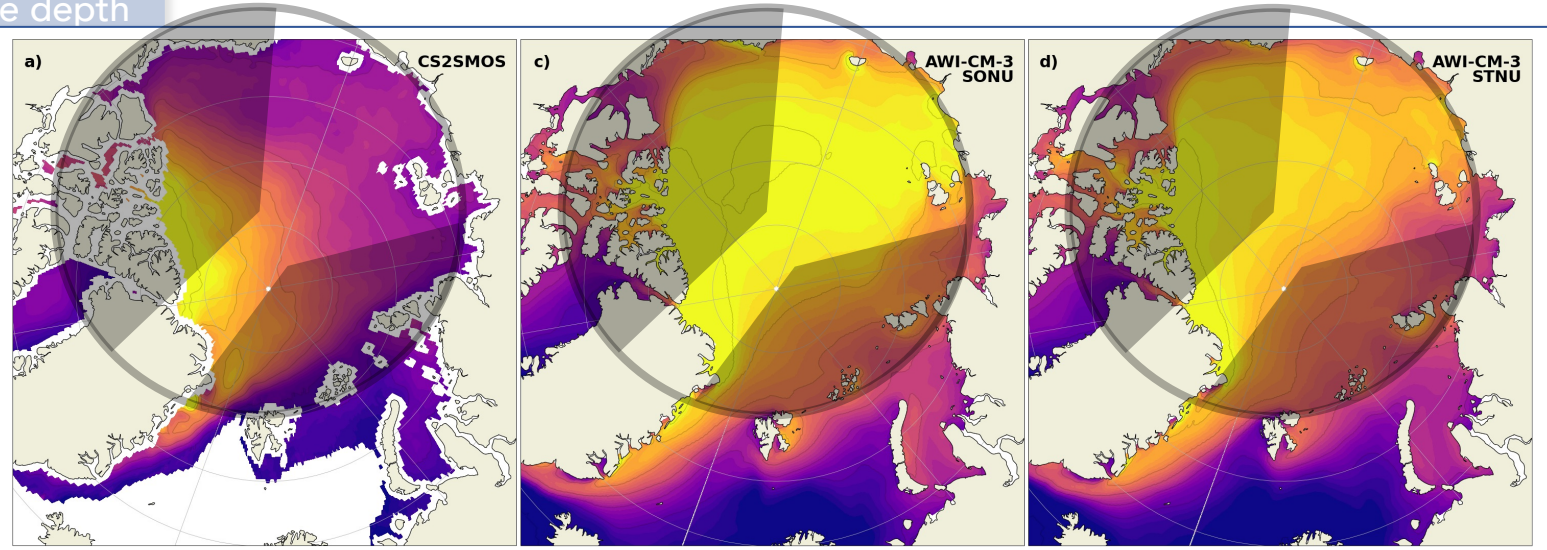
SONU: Soft nudging STNU: Strong nudging

High correlations: good reproduction of observed variability

Snow-on-ice depth

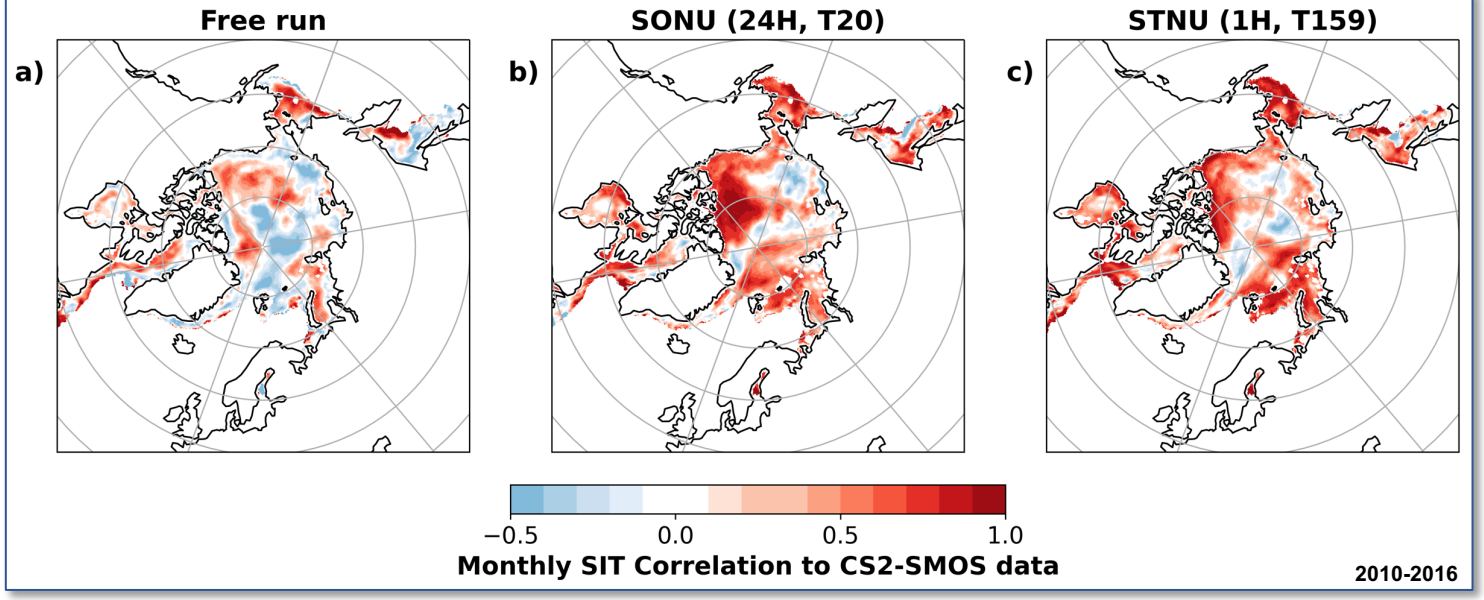


Sea-ice thickness (SIT) mean state



Remaining biases: **inaccurate SIT gradients in Central Arctic** (between shaded areas)

Sea-ice thickness (SIT)



When nudging atmospheric circulation, **SIT variations reproduced in Eurasian Arctic and along continental margins**

SIT variations not captured in Siberian Sea and along the Transpolar drift: due to **remaining model biases**

SONU: Soft nudging STNU: Strong nudging

Summary & Preliminary conclusions

1. Nudged winds impact the Arctic mean winter state:

Under investigation:
Arctic cold bias
leading to too much sea-ice.

Improved snow and ice thickness distributions
in the Eurasian Arctic.
In the Canadian Arctic, model biases remain.

2. Atmospheric circulation shapes sea-ice and snow variability:

Reproduction of observed variability of snow-on-ice, SIC and SIT
despite background model biases.

Spectral nudging has potential
to improve initial state
of snow & sea-ice thickness for forecast systems.

Ongoing work:

Find drivers of the cold Arctic bias.

Nudging impact on ensemble spread and forecasting skills.

SIT: Sea Ice Thickness SIC: Sea Ice Cover

Contact, questions: marylou.athanase@awi.de

Additional material

Climatology adjustment: sea ice drift

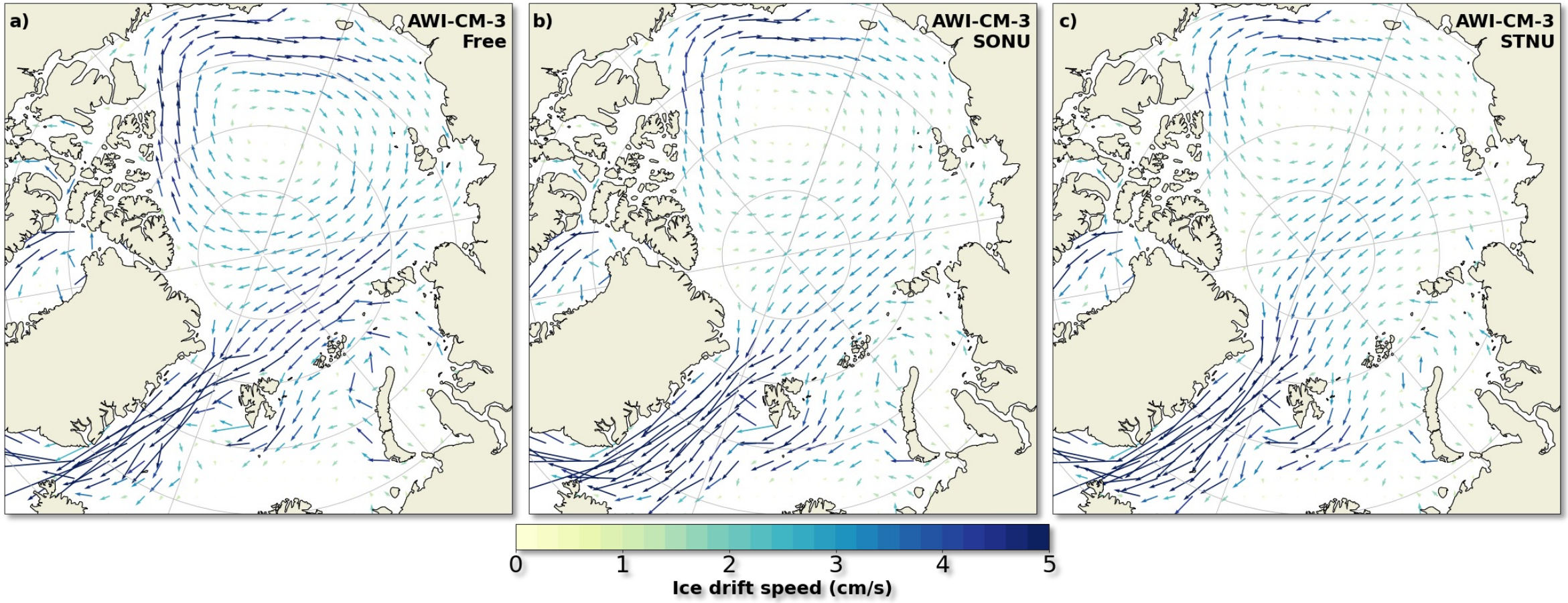
Free run:

Nudged run:

TPD too south, BG too large

Slower TPD, better BG

Realistic TPD and BG

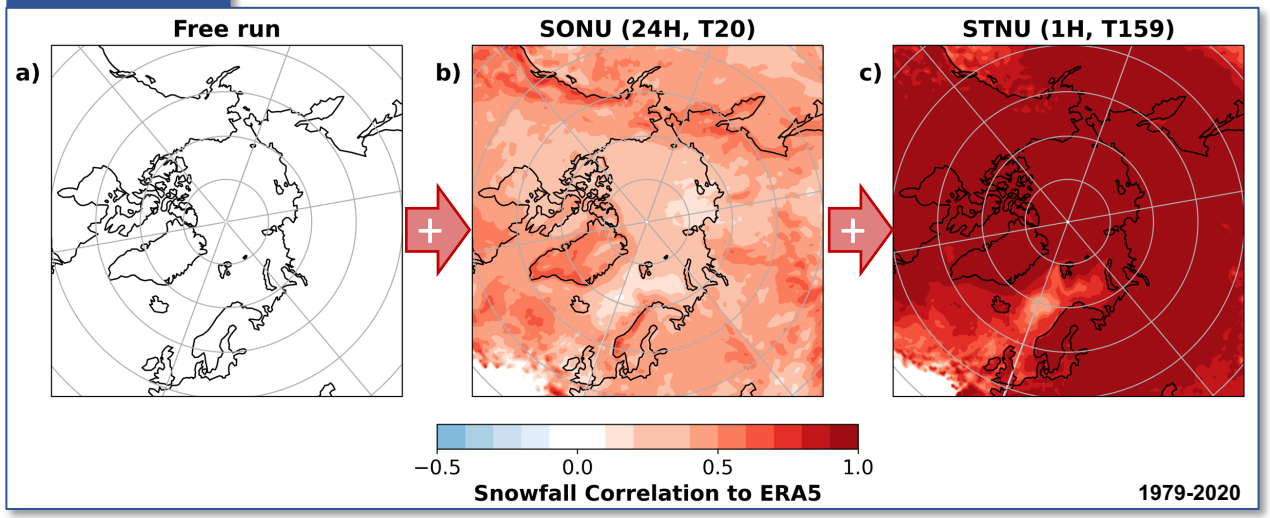


Free Run ice drift biases cannot explain unrealistic SIT distribution

Nudging improves the ice drift patterns

Precipitation(-dependant) parameters sensitive to nudging strength

Snowfall

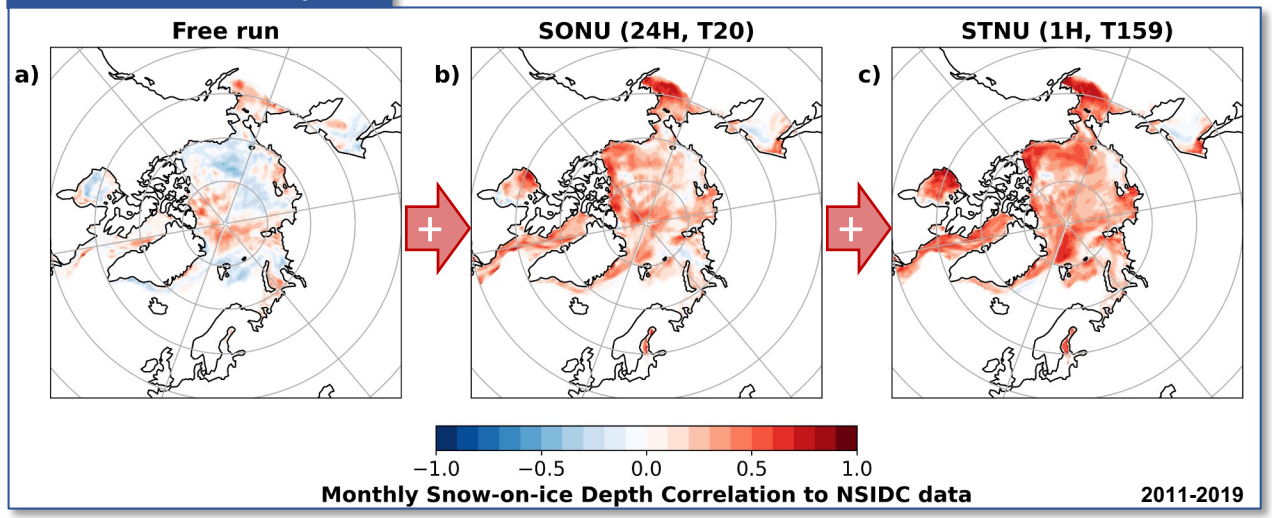


Sensitivity to nudging strength of precipitation(-dependant) parameters (e.g. snowfall and snow-on-ice).

SIT and SIC less sensitive.

Precipitations and snowfall also reproduced, very sensitive to nudging strength

Snow-on-ice depth



Stringent comparison: snow depth variations depend on snowfall, wind advection and sea-ice motion

Well reproduced when nudging atmospheric circulation
($r = 0.4$ to 0.7 with nudging)

+ Improved correlation = No improvement

SONU: Soft nudging STNU: Strong nudging