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Arctic Climate Change: Scenarios and Consequences

ECRA
European Climate Research Alliance

Arctic ECRA
Strategy and Work Plan

"Advancing European Arctic climate research for the benefit of society"

www.ecra-climate.eu

1. Why is Arctic summer sea ice disappearing so rapidly?
2. What are the local and remote consequences?
3. Can we project and predict it?

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\+ Implications of different emission pathways for the Arctic

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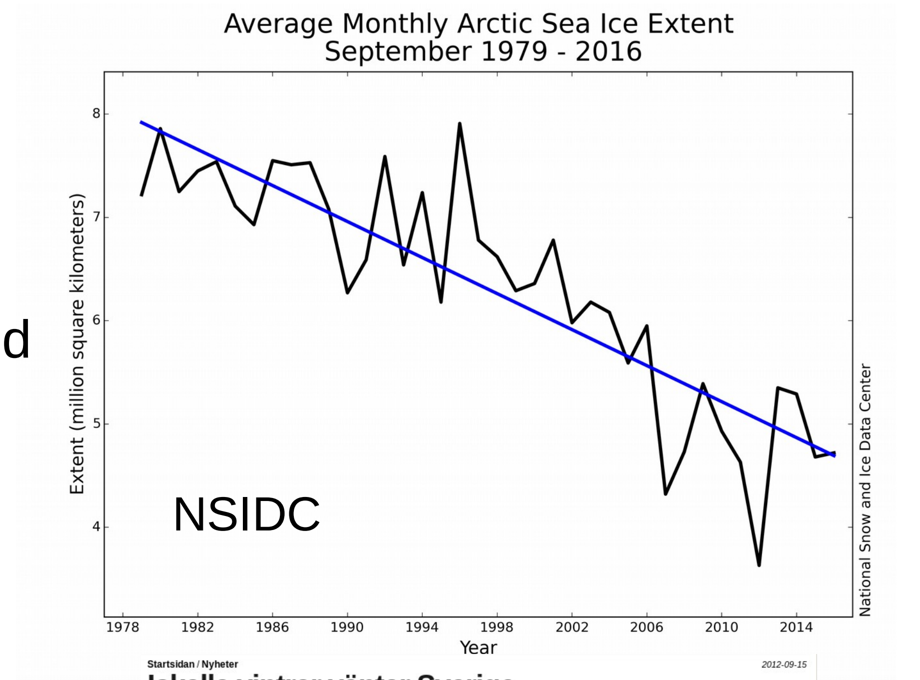
Reasons for recent sea ice decline

In a nutshell:

- Cumulative CO_2 emissions
- Arctic amplification (albedo, temperature and other feedbacks)
- Thinning and rejuvenating
- Increased sea ice drift (Tara vs Fram)
- Melting from the top/below
- Influence of ocean heat transport
- Changed patterns of atm. advection (heat and moisture transport)




Startsidan / Nyheter

2012-09-15

Iskalla vintrar väntar Sverige

Smältande istäcken på Arktis riskerar ge väderkaos i Europa

Detta klipp finns inte längre på aftonbladet.se, men prova gärna **Aftonbladet TV**.

Polarisen smälter - framför ögonen på oss

Aftonbladet på plats på klimatkrisens ground zero

(The Polar ice is melting in front of us)

Reviews: e.g. Döscher et al. 2014, Serreze and Stroeve 2015

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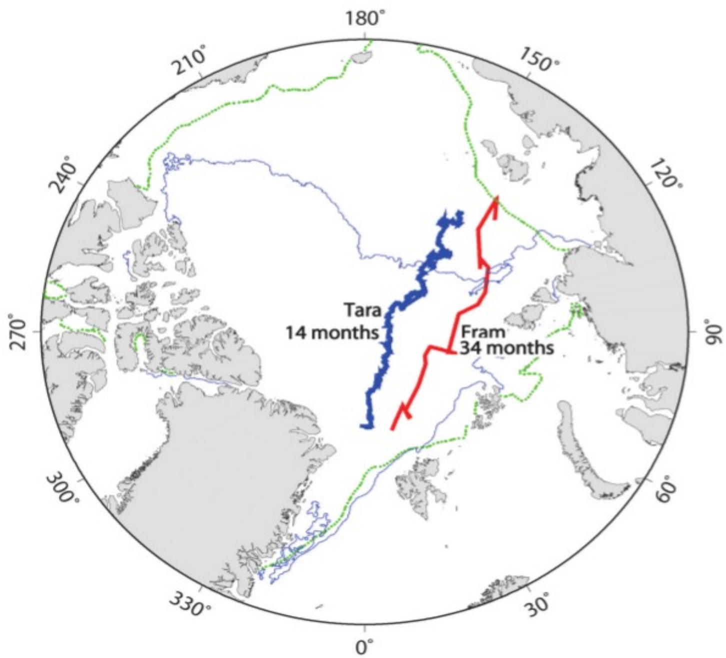

Figure 2. Drift trajectories of the vessels *Tara* (blue, November 2006–January 2008) and *Fram* (red, October 1893–August 1896). The sea ice edges are displayed for September 2007 (blue) and for the September mean 1979–1983 (green). Döscher et al. (2014)

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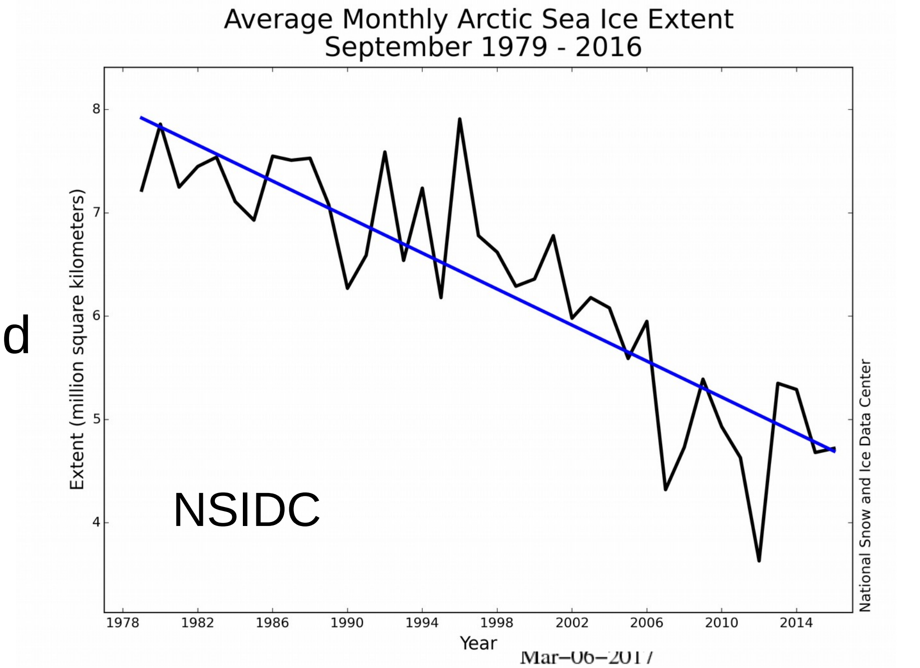

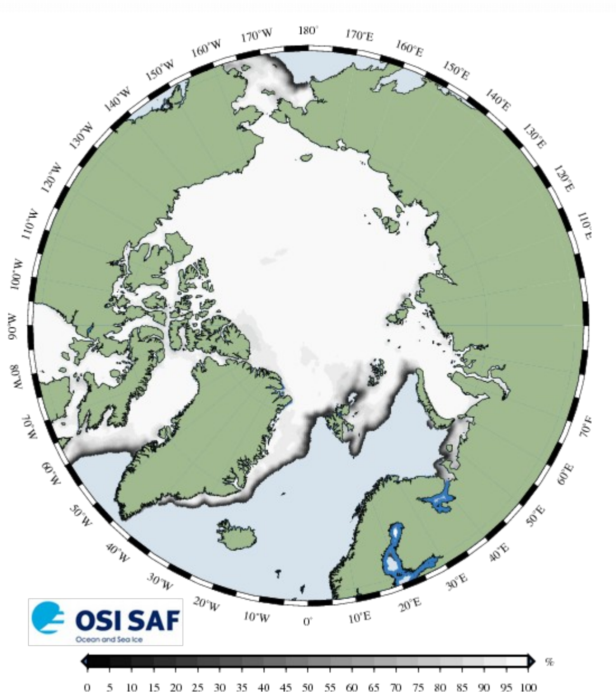

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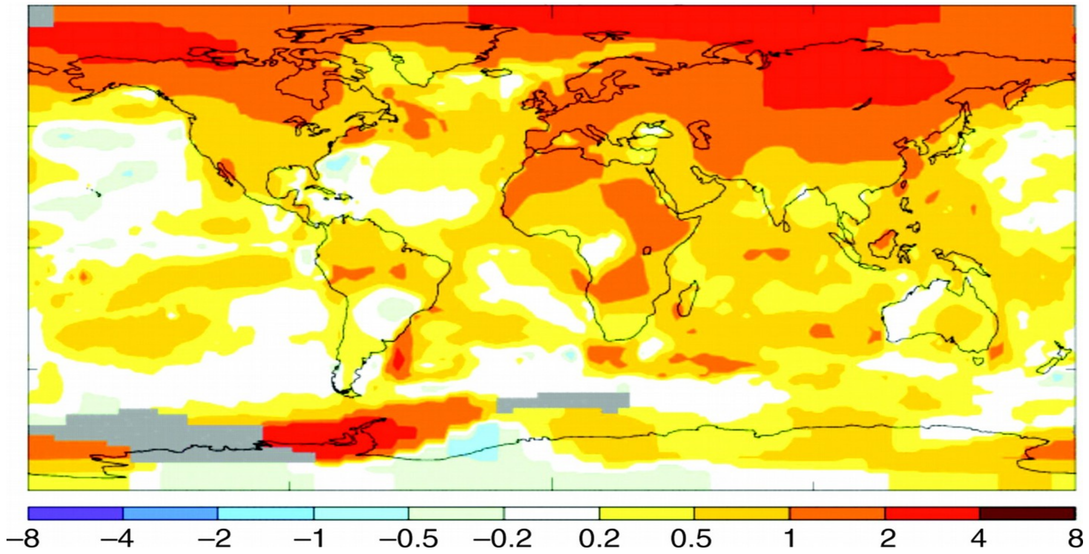
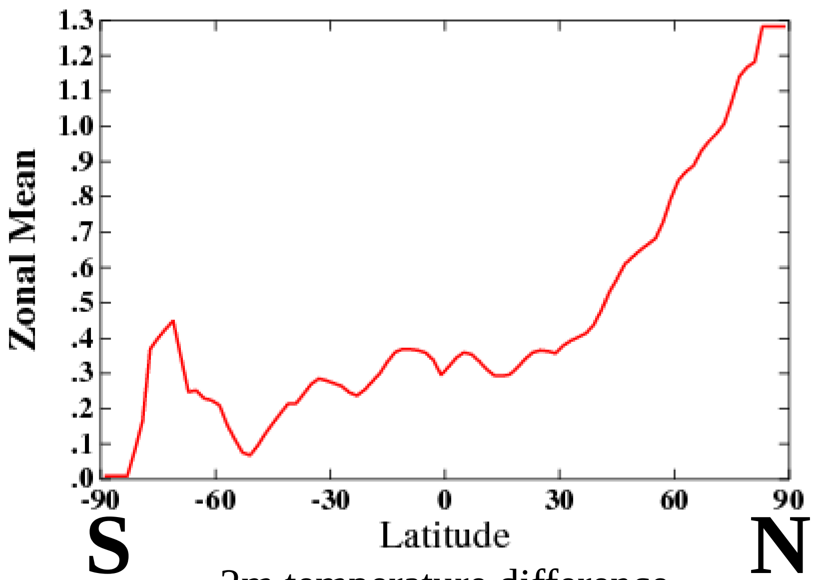
Arctic Amplification



Arctic amplification of recent temperature trends as captured by a map of the change in annual surface temperature from 1958 to 2008 (data and mapping algorithm from NASA Goddard Institute for Space Studies).

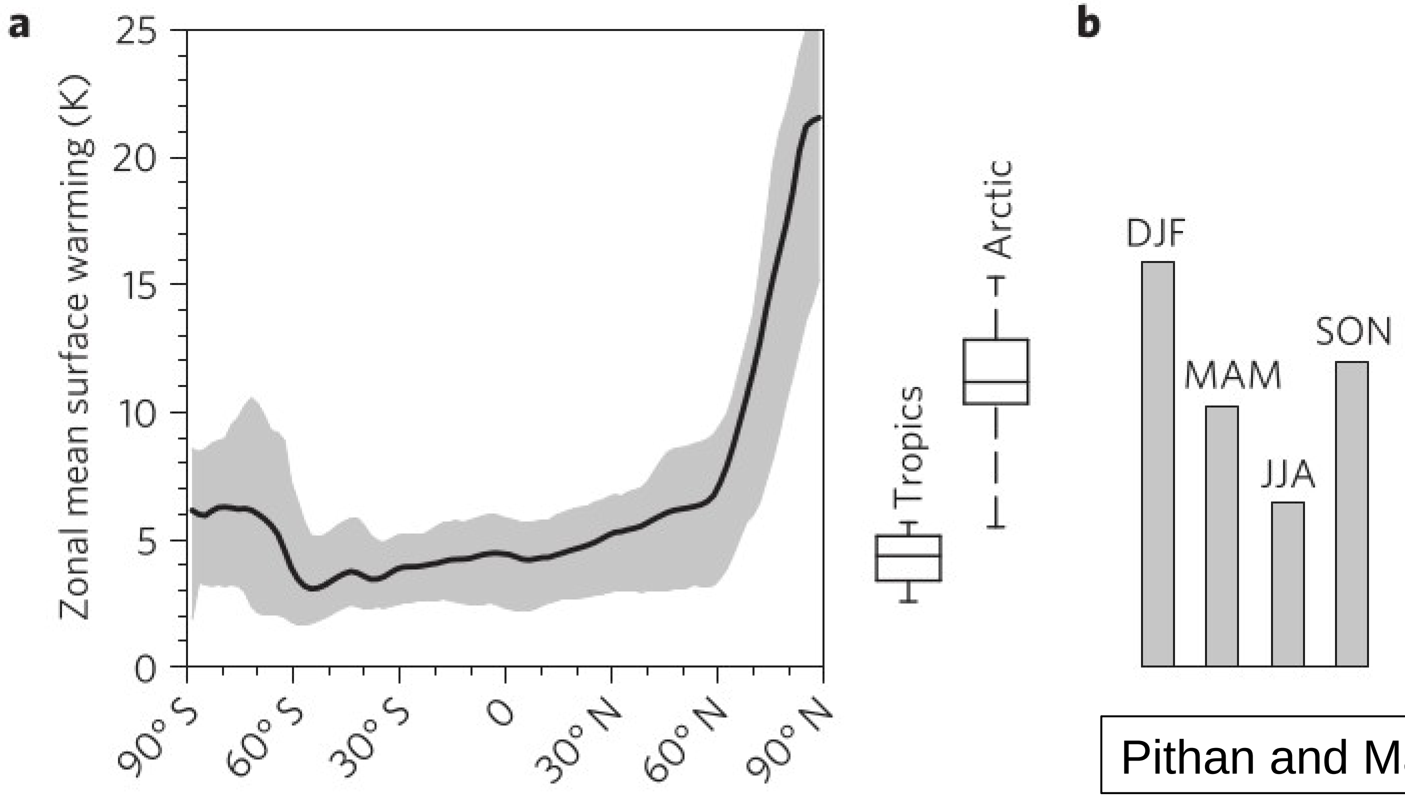


2m temperature difference
(1991-2010) vs (1951-1990)

After 1970: +0.4 K/10y (Arctic) vs. +0.2 K/10y (global)

=> The Arctic is warming faster,
with contributions by sea ice-albedo feedback,
cloud and water vapor feedback, lapse-rate, Planck feedback and
atmospheric circulation feedbacks.

Do we have an Arctic amplification in climate models ?



Pithan and Mauritsen (2014)

Zonal mean surface temperature change for the last 30 years of the CMIP5 4 × CO2 experiment compared with the last 30 years of the control run.

Yes, we have, here shown in CMIP5 models

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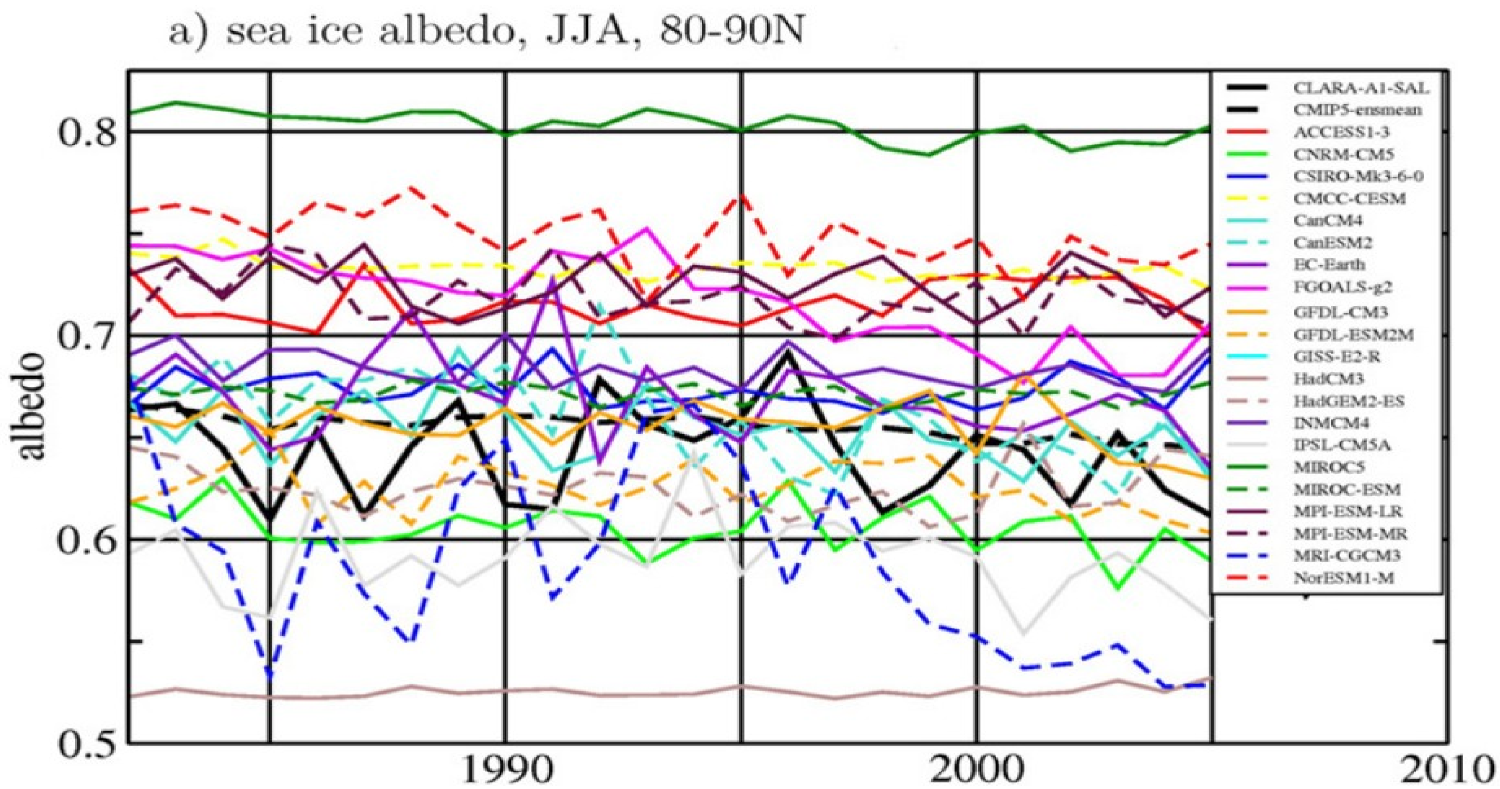
How realistic is the Arctic albedo in CMIP5 models ?



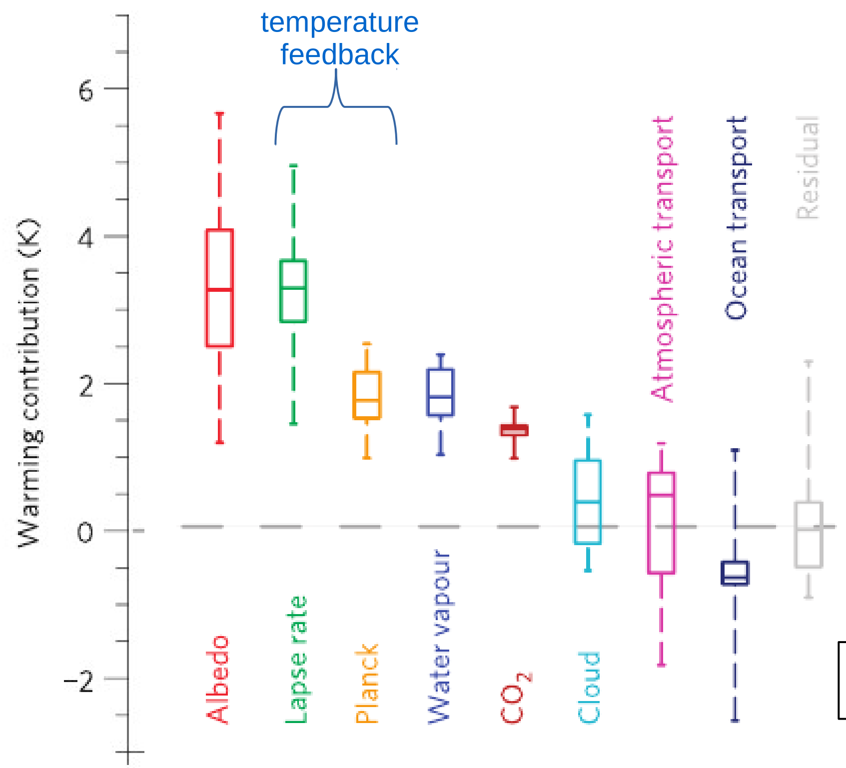
Summer months show a large spread of ice albedo among models;

=> The CMIP5 ensemble mean agrees relatively well in the <u>central Arctic</u>.

Additional info: In most models, the ice albedo is <u>spatially too uniform</u>ly distributed. The summer surface net solar radiation of the ice-covered Arctic areas is highly related to the ice albedo in the CMIP5 models. However, the <u>impact of the ice albedo on the sea ice conditions</u> in the CMIP5 models is <u>not clearly visible</u>. This indicates the importance of other Arctic and large-scale processes for the sea ice conditions.

Koenigk, Devasthale, Karlsson (2014), SMHI

Arctic amplification: Quantification of different feedbacks



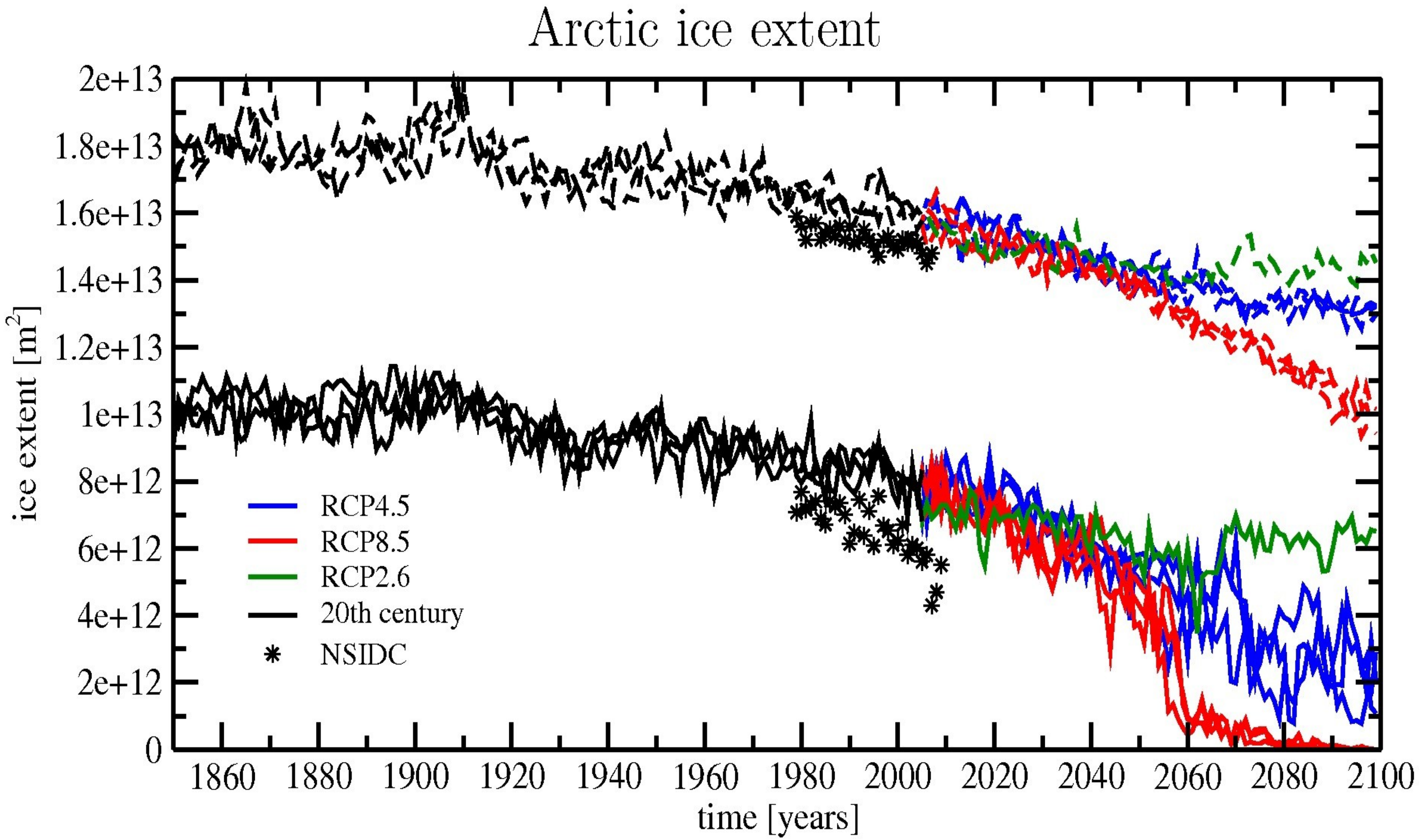
Pithan and Mauritsen (2014)

In **CMIP5** models: **the largest contribution to Arctic amplification** comes from **temperature feedbacks** (Lapse rate and Planck): as the surface warms, more energy is radiated back to space in low latitudes, compared with the Arctic.

This effect can be attributed to both the different vertical structure of the warming in high and low latitudes, and a smaller increase in emitted blackbody radiation per unit warming at colder temperatures.

The **surface albedo feedback is the second main contributor** to Arctic amplification

Climate scenarios for the Arctic



data from CMIP5, upcoming: CMIP6

Koenigk et al. 2013, Clim Dyn

Constraining sea ice scenarios: selecting models

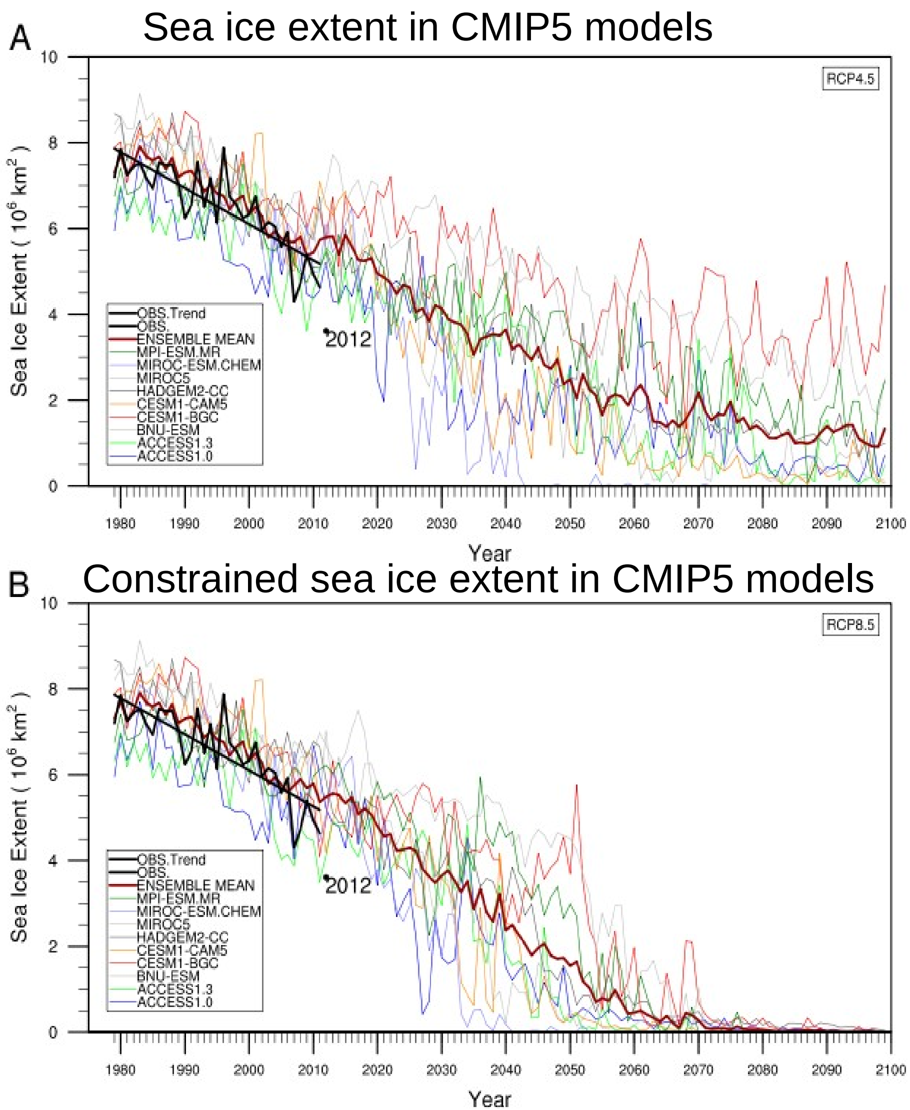


Fig. 3. Time-series of the simulated (colored lines) September sea ice extent from 1979 to 2100 for the nine selected models under the (*A*) RCP4.5 and (*B*) RCP8.5. The thick black line is the observations, the thick red line is the ensemble mean of the nine models, and the black circle is September sea ice extent in 2012.

Liu et al.

Liu et al. (2013)

Approach

- Retain the models with the simulated September sea ice extent falling within 20% of the observations
- Retain those models with simulated September sea ice extent trend falling within 30% of the observations
- This leaves us with 9 out of 30 projections

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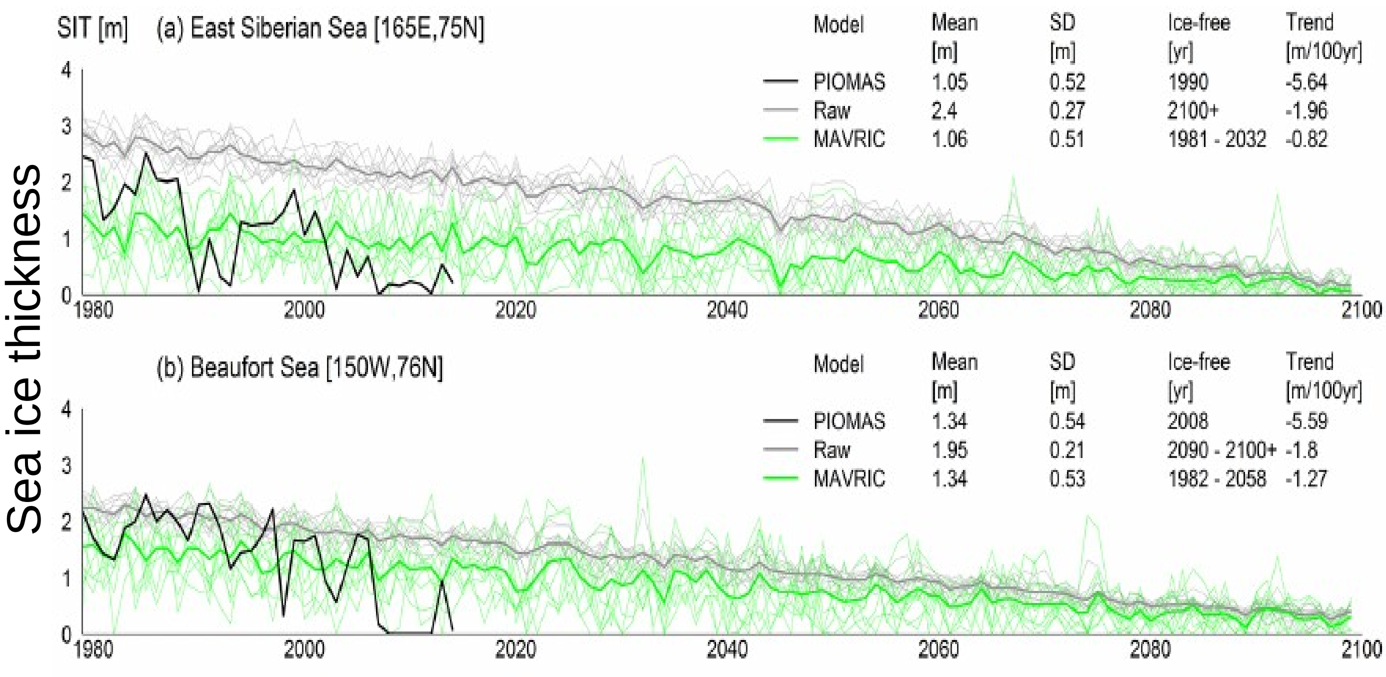
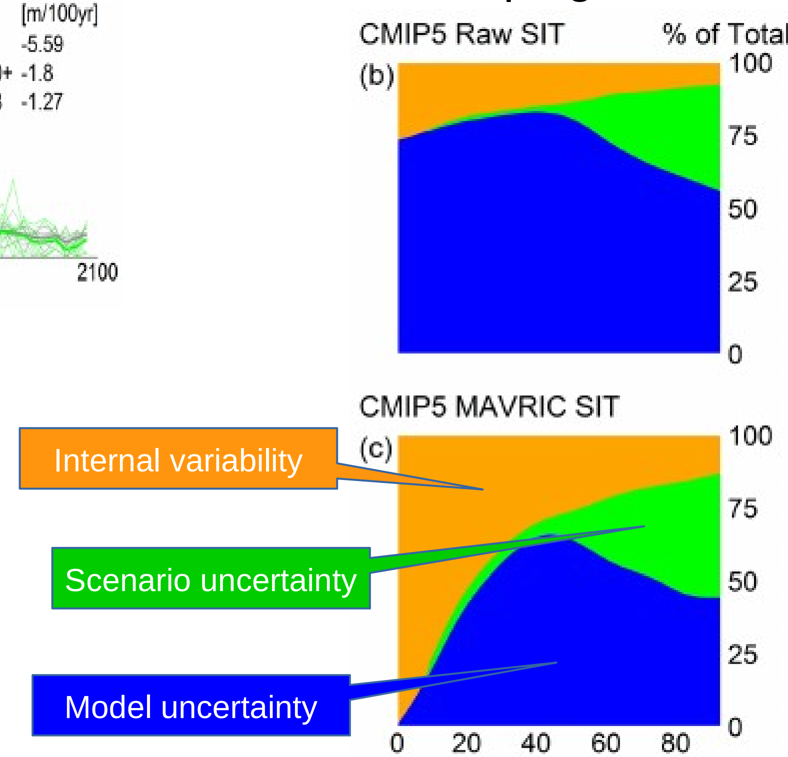
Constraining sea ice scenarios for regions: bias correction of sea ice thickness

Constraining CMIP5 simulations with an ice thickness reanalysis (PIOMAS) by means of the mean and variance correction technique.



Total uncertainty in projections of SIT can be reduced.

Sources of uncertainty developing in time



<u>Correcting both mean and variance</u> of models is found to be critical for improving the robustness of the projections, and is necessary for feedback and impact studies

Melia et al. 2015

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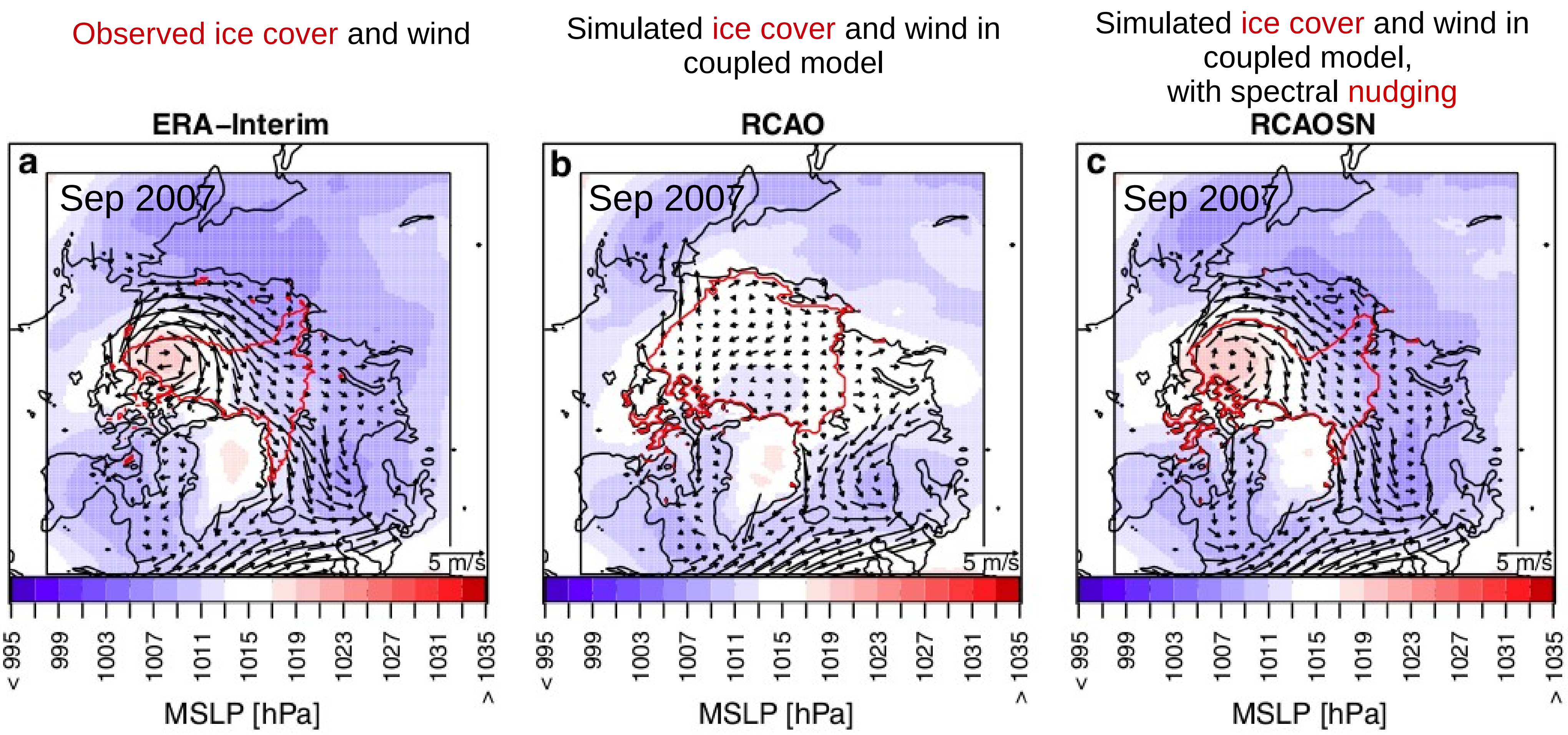
What is causing internal variability of sea ice ?

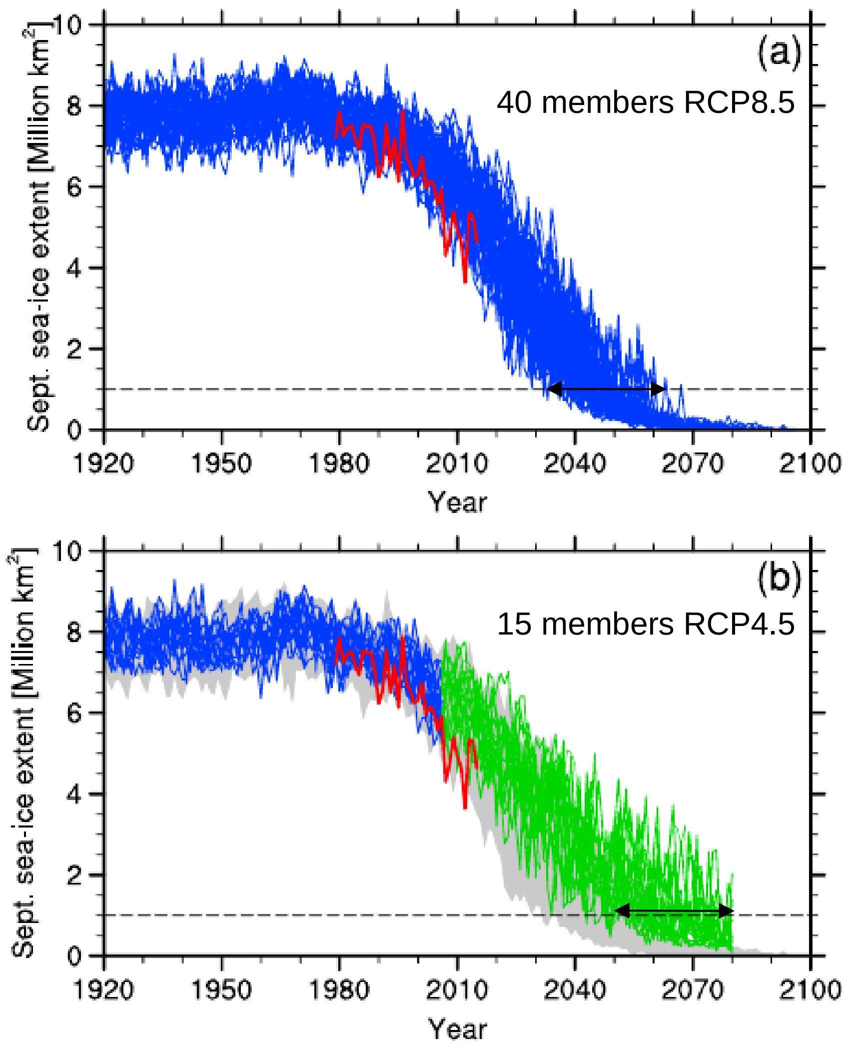
The role of wind forcing



=> Internal wind variability can prevent coupled models from simulating realistic sea ice cover in specific years

Berg, Döscher, Koenigk (2015), SMHI

Is constraining of sea ice scenarios possible at all?



September sea ice extent from the (a) 40-member CESM LE for RCP8.5 and the (b) 15-member CESM ME for RCP4.5 (see supporting information Figure S3 for individual plots for all CESM LE ensemble members to see the details of their evolution). The ensemble spread of the CESM LE is shown in Figure 1b under the CESM ME as grey shading, to allow a direct comparison of the two ensembles.

<u>Internal variability</u> alone leads to a prediction uncertainty of about <u>two decades</u>

<u>Scenario uncertainty</u> between RCP8.5 and RCP4.5 forcing scenarios <u>adds 5 years</u>

<u>Using performance of the past and present mean sea ice state</u> (such as ice extent, volume, and thickness as well as global mean temperatures) <u>do not allow a reduction of the prediction uncertainty from internal variability.</u>

=> empirical correction (based on past and present climate observations)

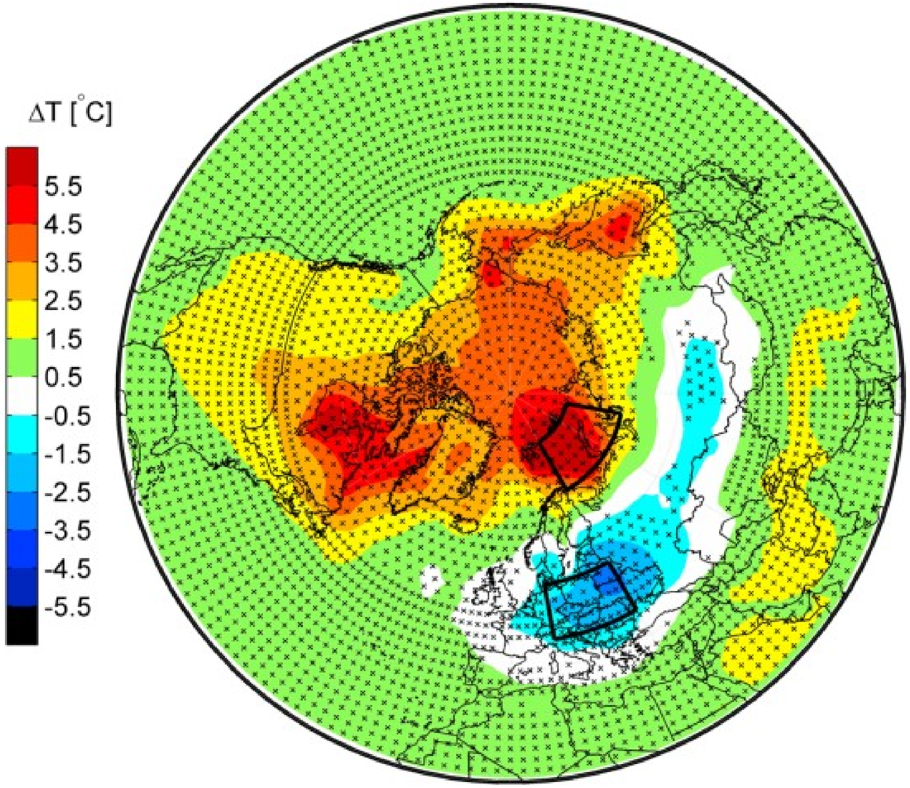
- *might reduce the model uncertainty,*
- *but cannot reduce the uncertainty due to internal variability.*

Jahn et al. (2016)

Arctic – low latitude linkages

colder winters or changed weather patterns as a response to reduced sea ice in the Arctic ?

CMIP5 climate models: ensemble mean of composites of SAT anomalies for European cold Januaries 2006-2050 as projected in scenarios RCP8.5.



Yang and Christensen (2012)

Examples of additional studies:
Petoukov and Semenov (2010), Liu et al. (2012), Jaiser et al. (2012), Koenigk et al. (2015), ...

Consensus view from Barcelona workshop on Arctic climate prediction (Jung et al., 2014):

- The **Arctic** has the **potential to modify mid-latitude variability**; the relative importance of different possible mechanisms, however, remains to be explored. **Linkages with midlatitude extreme weather events are possible, and they are regional and episodic,** and vary with season.
- A **research focus on surface fluxes and shifts in** atmospheric dynamic **patterns** will provide improved insights and potential extended range forecast potential.

Robustness of Arctic Sea Ice – Mid Latitude Links

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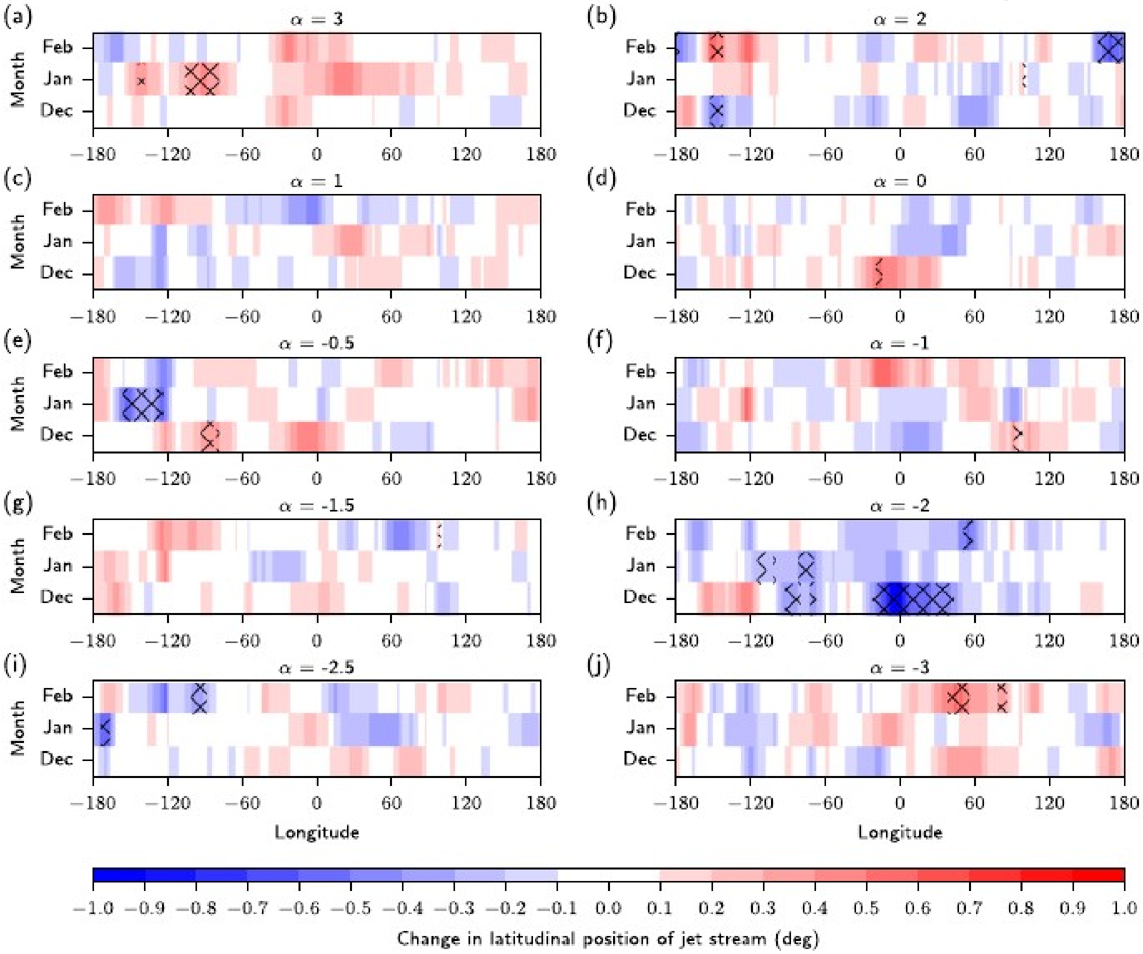
Large ensemble of 550 simulations, prescribed Arctic sea ice anomalies in 10 different ways



Deviations in the ensemble mean jet stream position for 10 sea ice scenarios. Cross hatching indicates significant differences from the mean position.

Chen et al. 2016

- Statistically **significant changes** for certain features of the midlatitude circulation but not for others.
- Midlatitude circulation **changes do not scale linearly with the sea ice anomalies** ..., indicating that... response... can be statistically significant under certain conditions but is **generally non-robust**.
- This suggests **interactions between variability and persistence** in the coupled system, which may contribute to the lack of convergence among studies of Arctic influences on midlatitude circulation.

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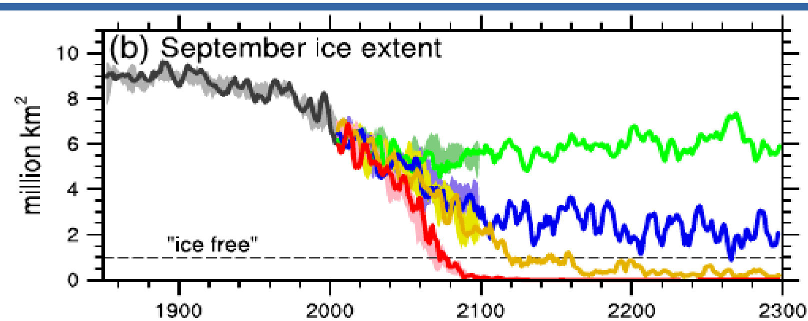
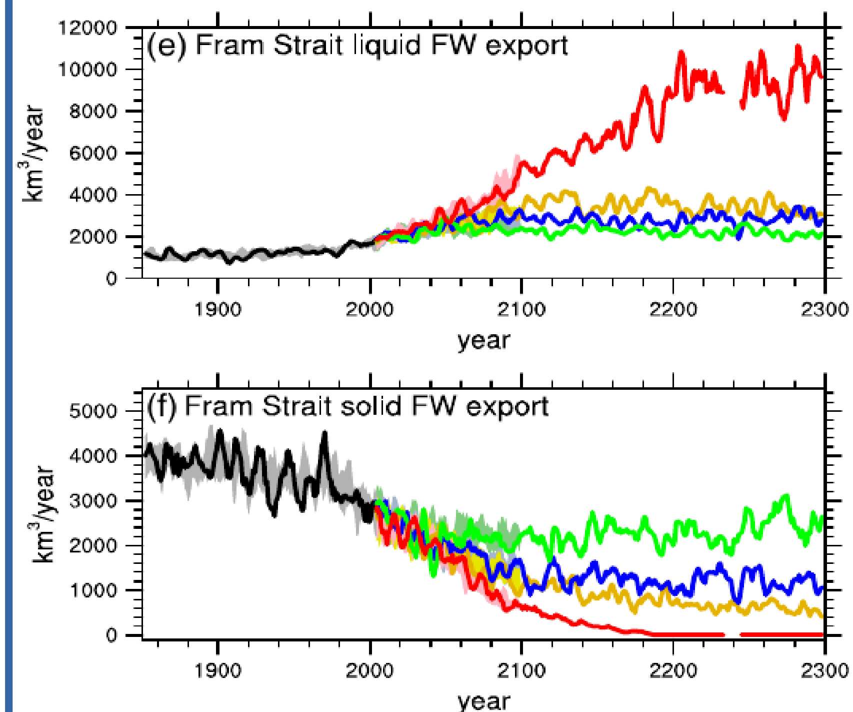
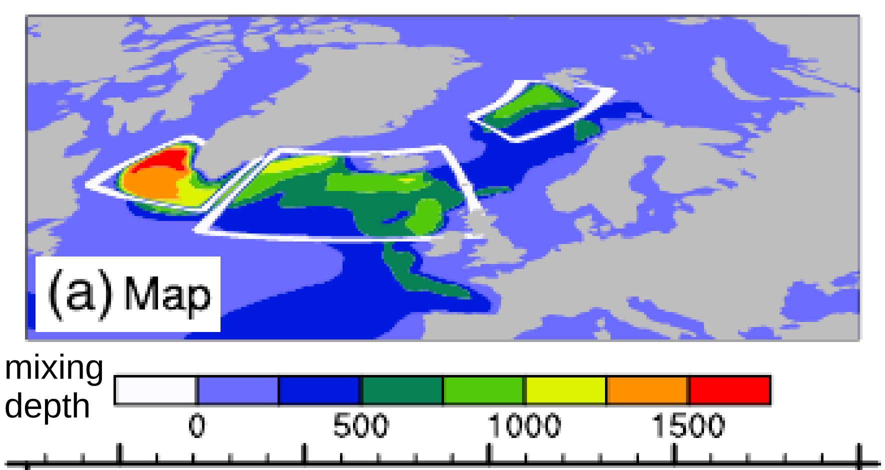
Global consequences of Sea ice reduction: deepwater formation

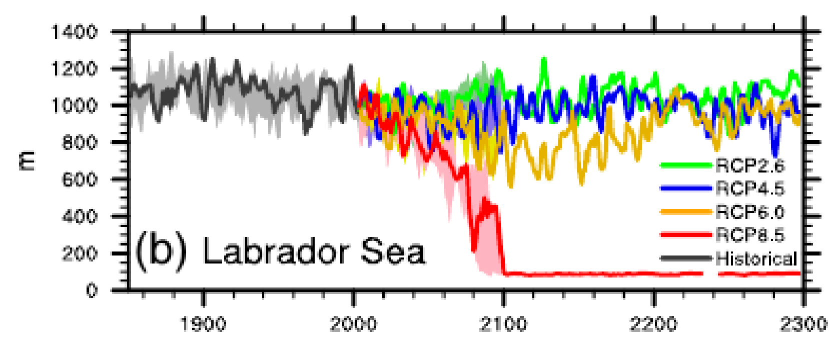


Knowledge of Arctic ocean influences on North Atlantic is more mature than that for atmospheric linkages



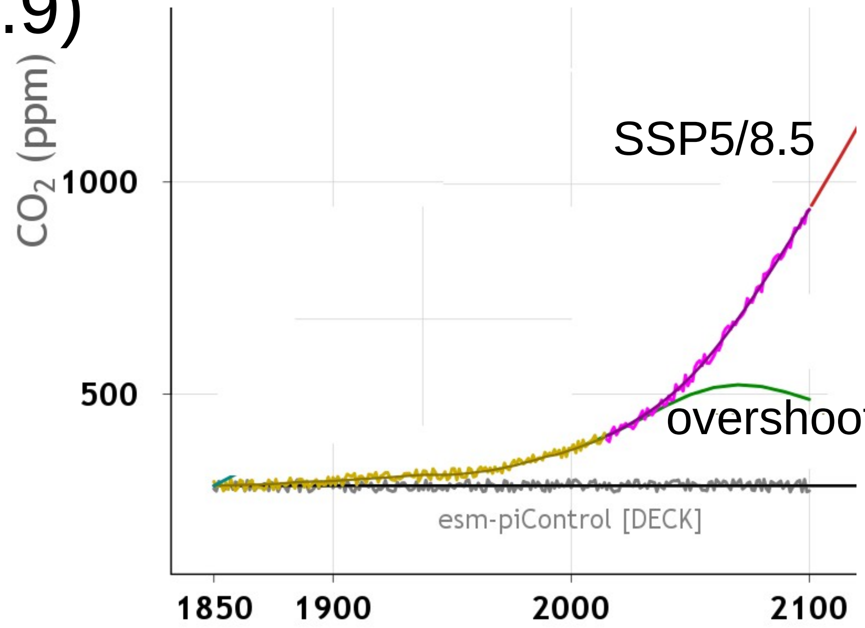
Jahn and Holland (2013)





The Arctic and the Paris agreement

- 4^0 instead of 2^0 because of Arctic amplification?
- What is the response of the Arctic in
  - a Paris scenario (SSP1/1.9)
  - an overshoot scenario?



- Reversibility
- Ocean: physical, regionally and ecosystem
- Interaction with the rest of the globe?

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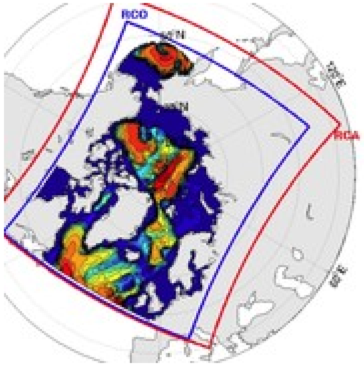

Combined feedbacks can simulate Arctic Amplification well

- Interplay of mechanisms need to be better verified to increase simulation capability.

The question ”when will the sea ice disappear” is notoriously difficult

- Correction methods can only attempted to correct the model error, not the larger error due to internal variability

Remote consequences of Arctic sea ice reduction are expected (= statistically significant but generally not robust), but difficult to project

- Potential to modify mid-latitude weather, variability and ocean deep convection
- Linkages with extreme midlatitude weather events are possible; statistically significant under certain conditions but are generally non-robust, i.e. effects are to be expected, but difficult to project and predict.
- Better verification needed for the roles of air-sea interactions and stratosphere-troposphere coupling.

Consequences of different choices of emission pathways (Paris agreement and others) for Arctic climate need to be explored.

- Arctic temperatures increase by more than 2 degrees, even if we live up to the Paris agreement; feedbacks with repect to physics and greenhouse gases.

The End