# Polar Amplification MIP (PA-MIP)

**Objective:** to investigate the causes and consequences of polar amplification

**Co-chairs:**

Doug Smith (Met Office), James Screen (University of Exeter),

Clara Deser (NCAR)

**Team:**

Judah Cohen (AER), John Fyfe (CCCma),

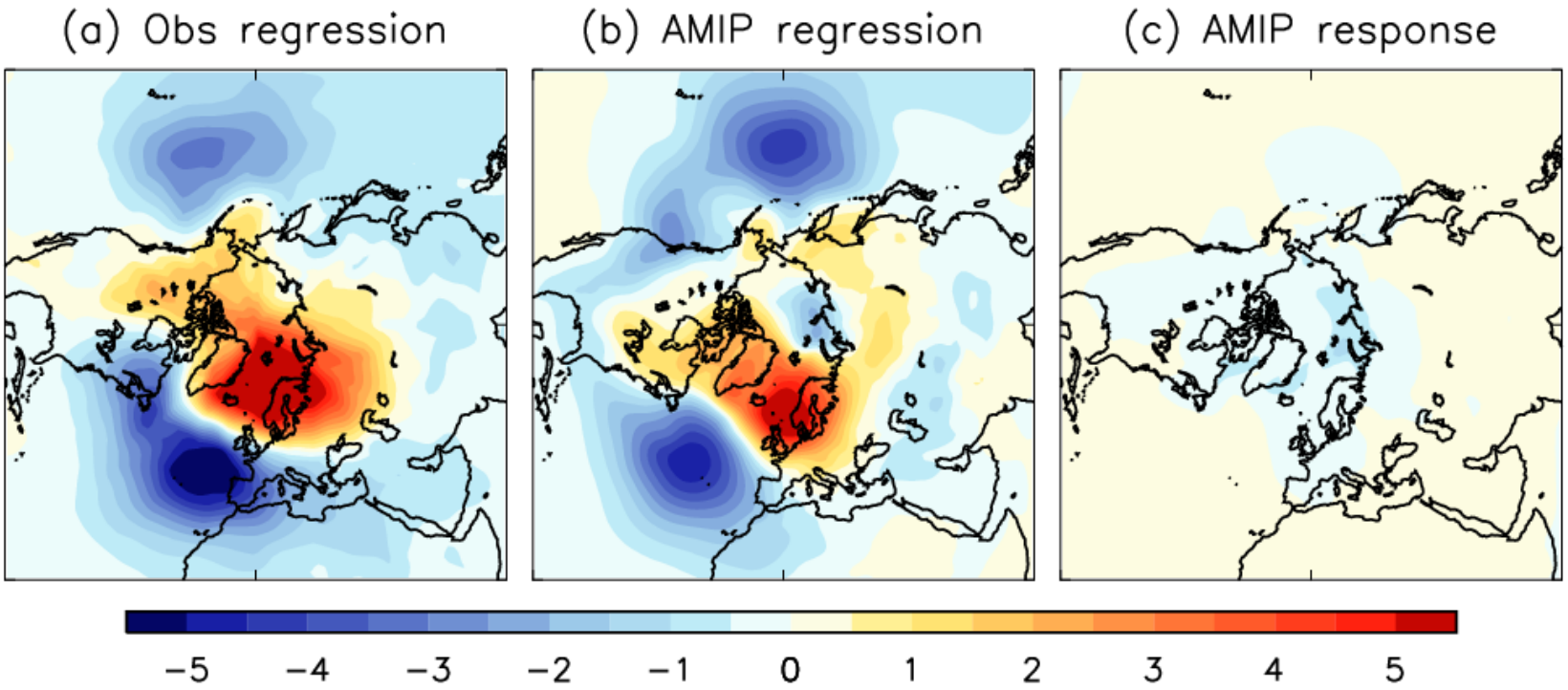
Javier García-Serrano (BSC), Thomas Jung (AWI),

Daniela Matei (MPI), Rym Msadek (CERFACS),

Yannick Peings (University of California), Jinro Ukita (Niigata University),

Jin-Ho Yoon (GIST), Xiangdong Zhang (University of Alaska)

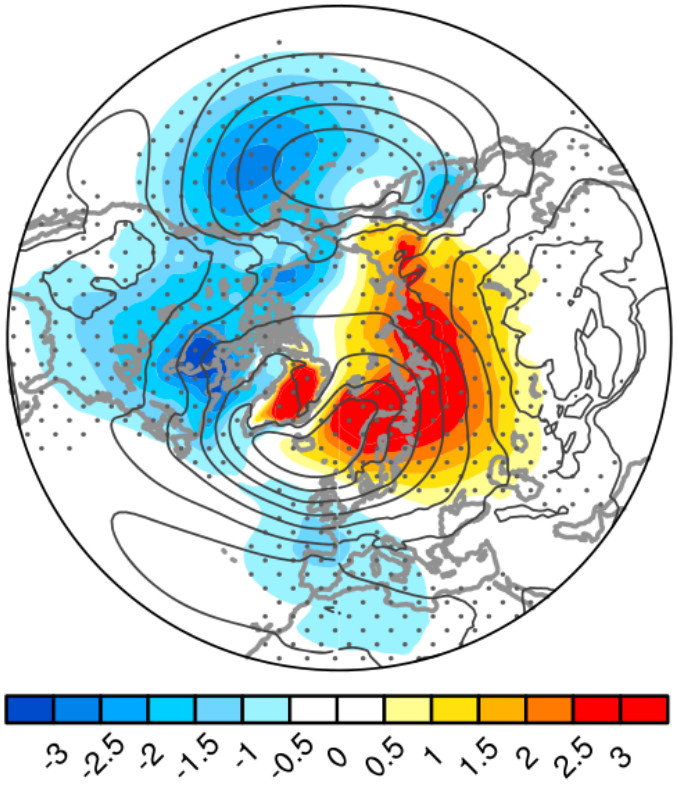
# Real world response? *Cannot be diagnosed from regression*

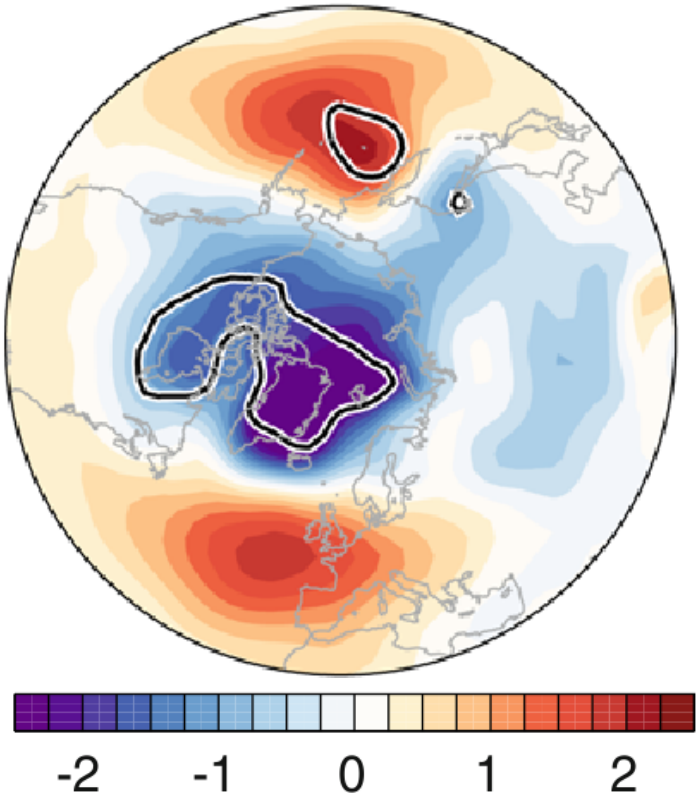



- **Regression between autumn (SON) sea ice extent and winter (DJF) sea level pressure (sign reversed)**
- **Obs and AMIP agree**
- **BUT AMIP response forced by reduced ice in model experiments sea ice is completely different**
- **The pattern is forced by SSTs rather than sea ice**

Smith et al 2017

# Non-robust response: full range of NAO responses have been reported




• **Negative NAO** (DJF, mslp, hPa)

• Deser et al 2016; Honda et al 2009; Seierstad and Bader 2009; Mori et al 2014; Kim et al 2014; Nakamura et al 2015 …

• **Little NAO response**

• Screen et al. 2013; Petrie et al 2015; Blackport and Kushner 2016 …

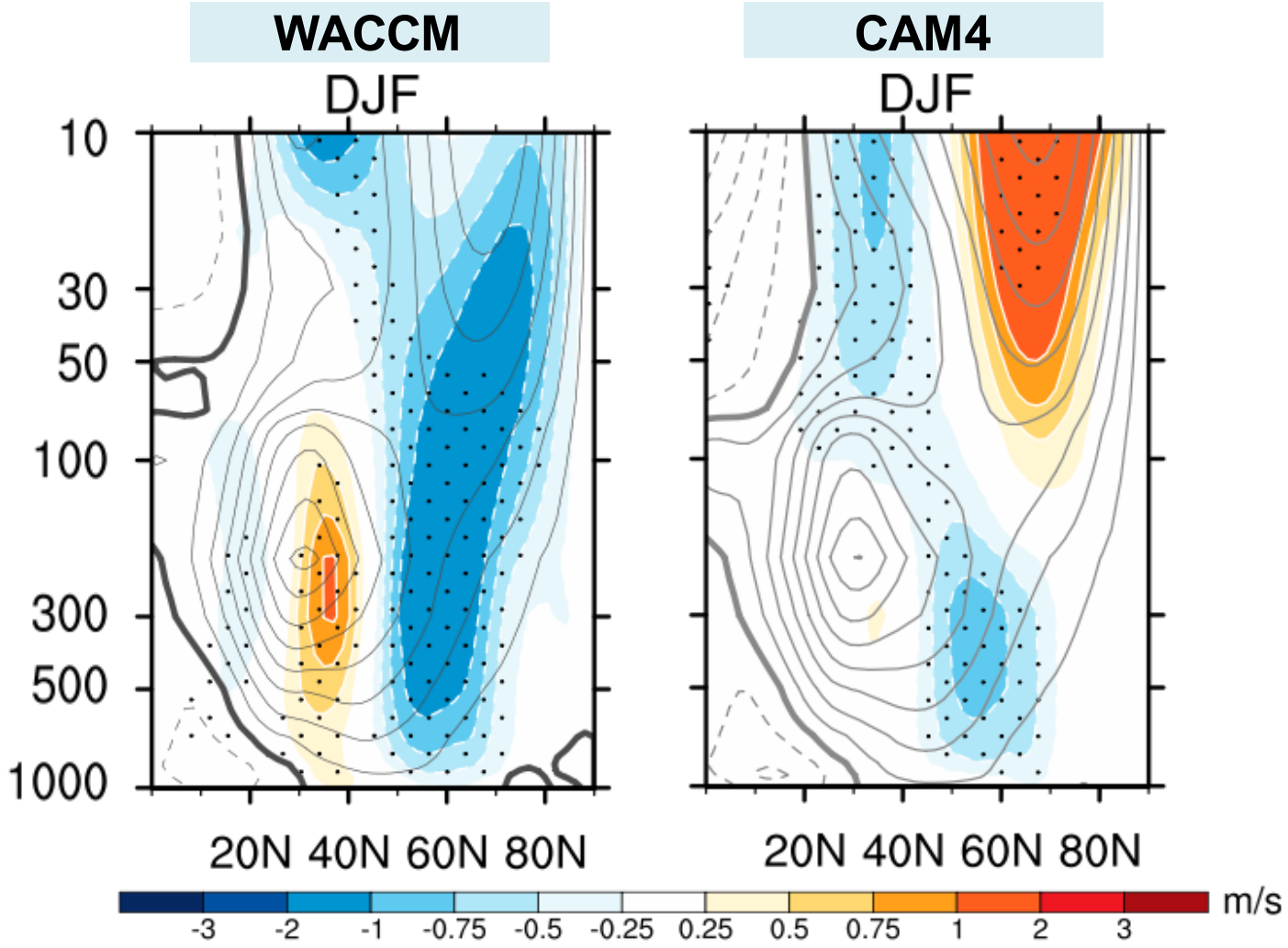
• **Positive NAO**

• Screen et al 2014; Singarayer et al 2006; Strey et al 2010; Orsolini et al 2012; Rinke et al 2013; Cassano et al 2014 …

• **NAO response that depends on the forcing**

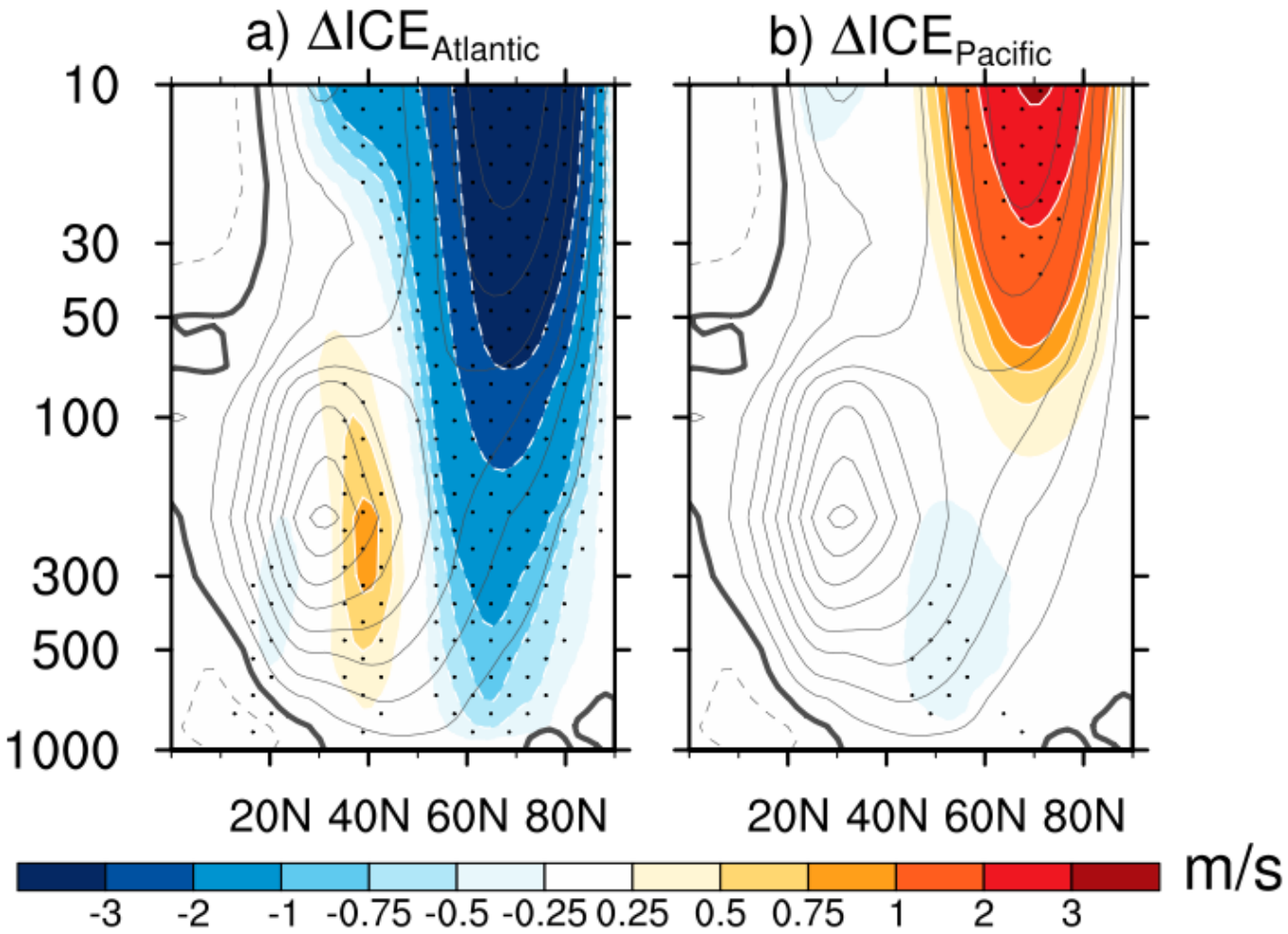
• Alexander et al 2004; Petoukhov and Semenov 2010; Peings and Magnusdottir 2014; Sun et al. 2015; Pedersen et al 2016; Chen et al 2016 ...

# Model




- Opposite responses in WACCM and CAM4 (in stratosphere)
- DJF zonal mean wind, same forcing
- Sun et al 2015

# Pattern of forcing

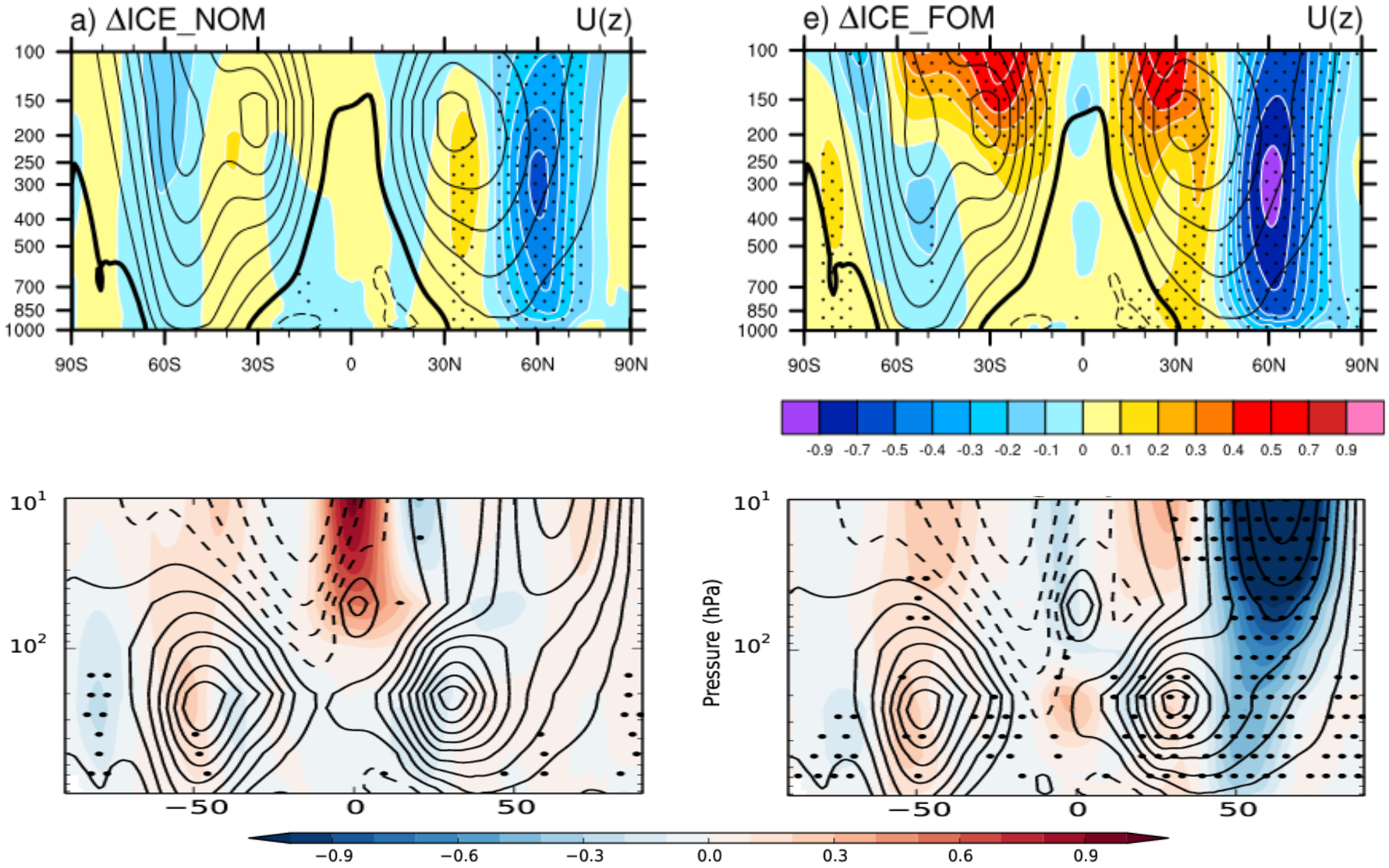



- Opposite response if forcing is applied in Atlantic and Pacific sectors separately
- Sun et al 2015; Alexander et al 2004; Peings and Magnusdottir 2014; Screen 2017

# Atmosphere vs coupled models

Atmosphere only model

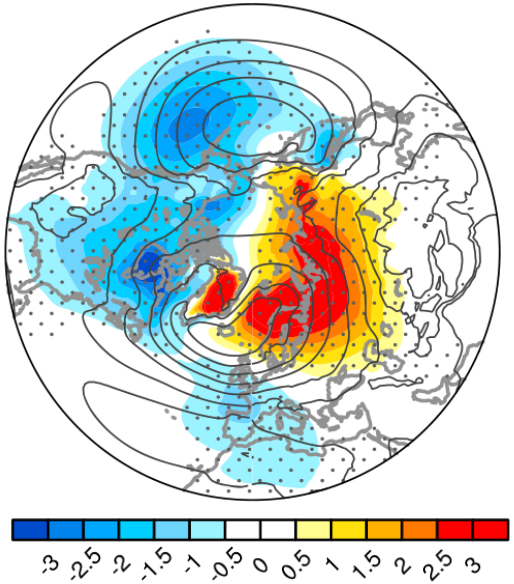
Fully coupled model

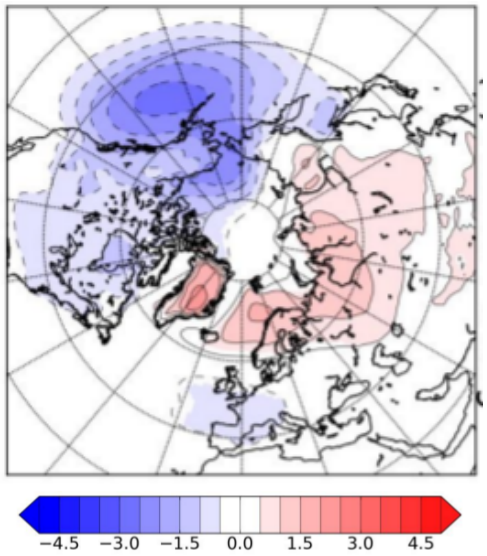



Deser et al 2016; Smith et al 2017

# How the forcing is imposed

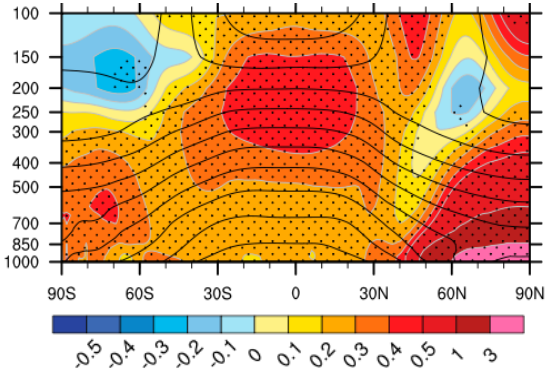
Sea level pressure

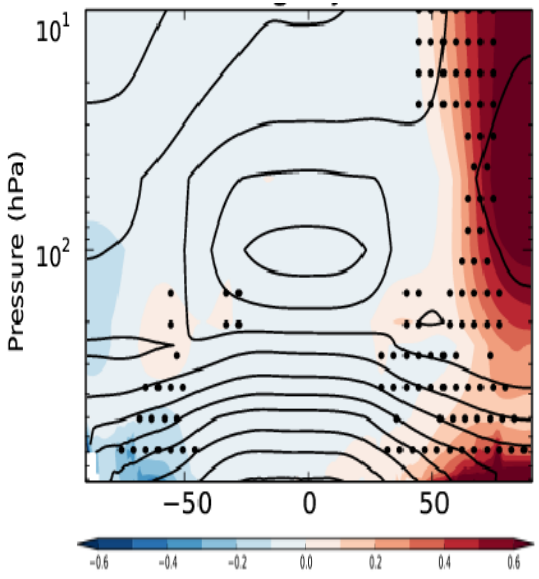



- Longwave flux (left, Deser et al 2015)
- Albedo (right, Blackport and Kushner 2017)
- Same model
- Similar sea level pressure response…

Zonal mean temp



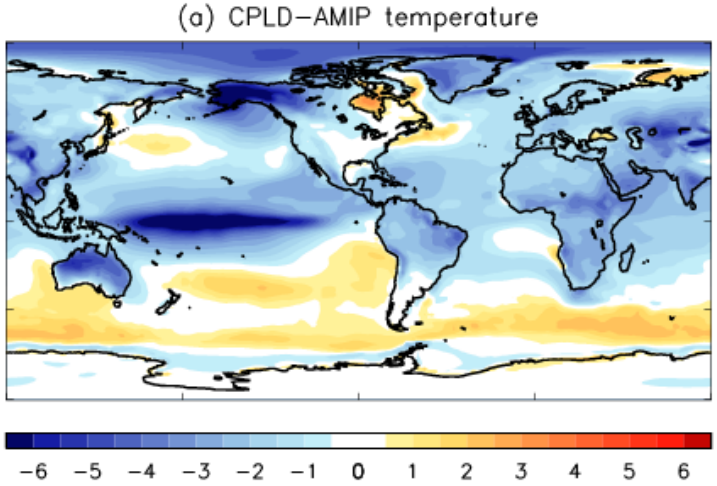



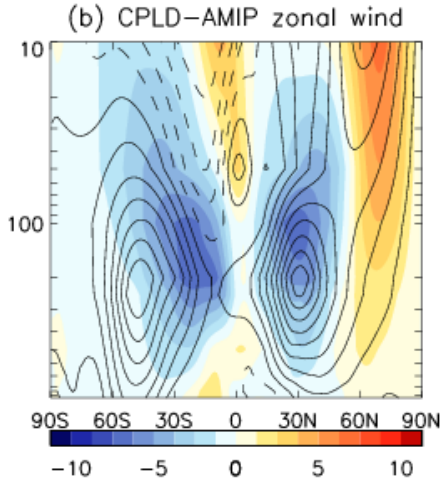

- Low latitude warming simulated in response to longwave forcing (left, Deser et al 2015)
- …but not in study using relaxation to impose sea ice (right, Smith et al 2017)

- Longwave/albedo forcing artificially perturbs the energy balance?
- Relaxation does not allow feedbacks from the tropics to the Arctic (e.g. low lat warming, maybe also from rainfall, Baggett et al 2016)
- Which is “best”?

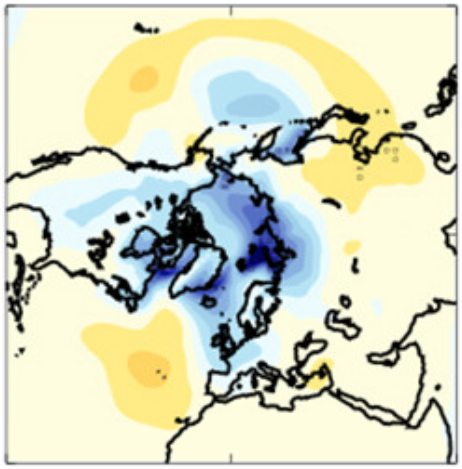
# Dependence on background state

Coupled model biases

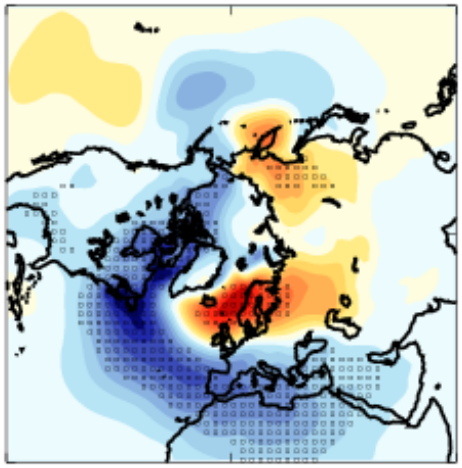


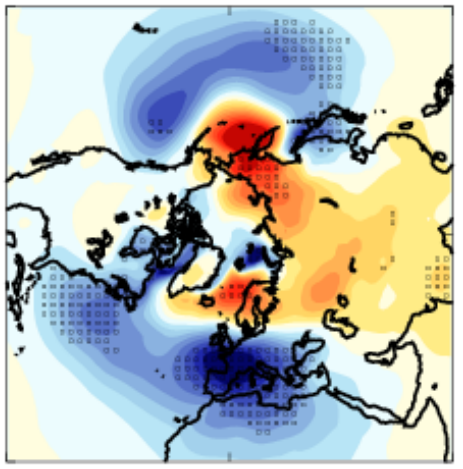

Atmosphere model



Coupled model



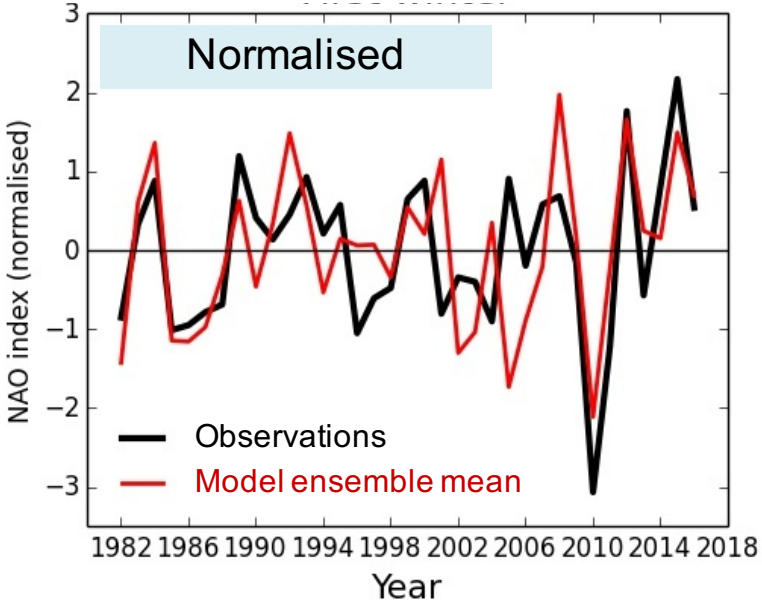
AMIP_CPLD

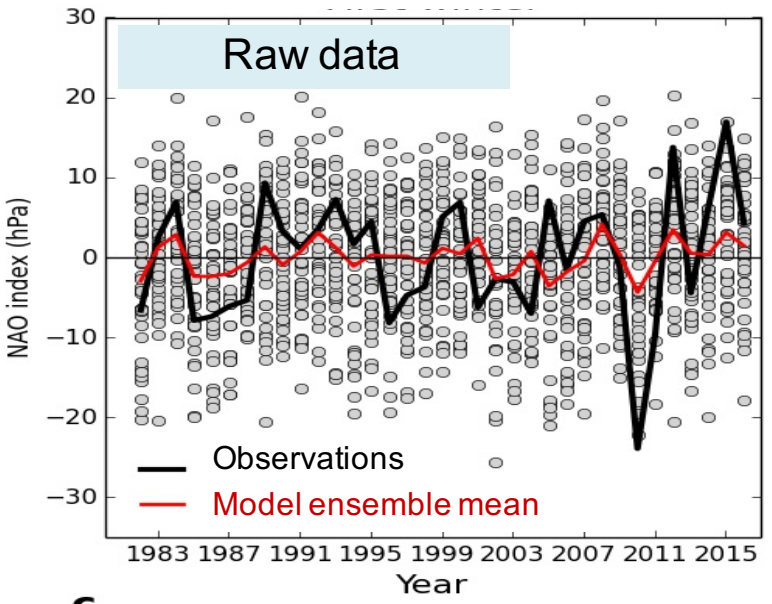


- **Different response could be caused by coupling or background state (model bias)**
- **Test by repeating atmosphere model but imposing COUPLED SST bias → AMIP_CPLD**
- **Reproduces COUPLED response → background state is key**

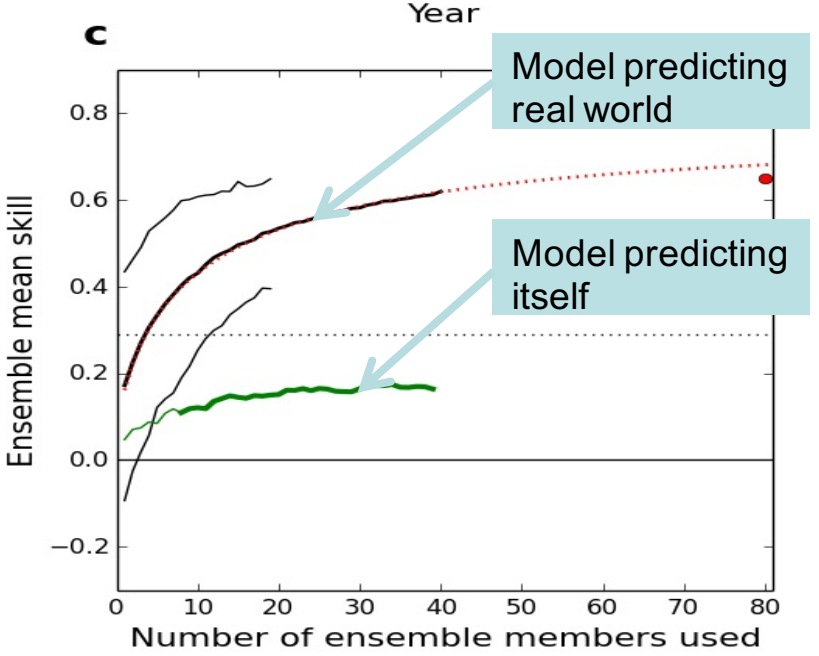
Smith et al 2017

# Signal to noise issues



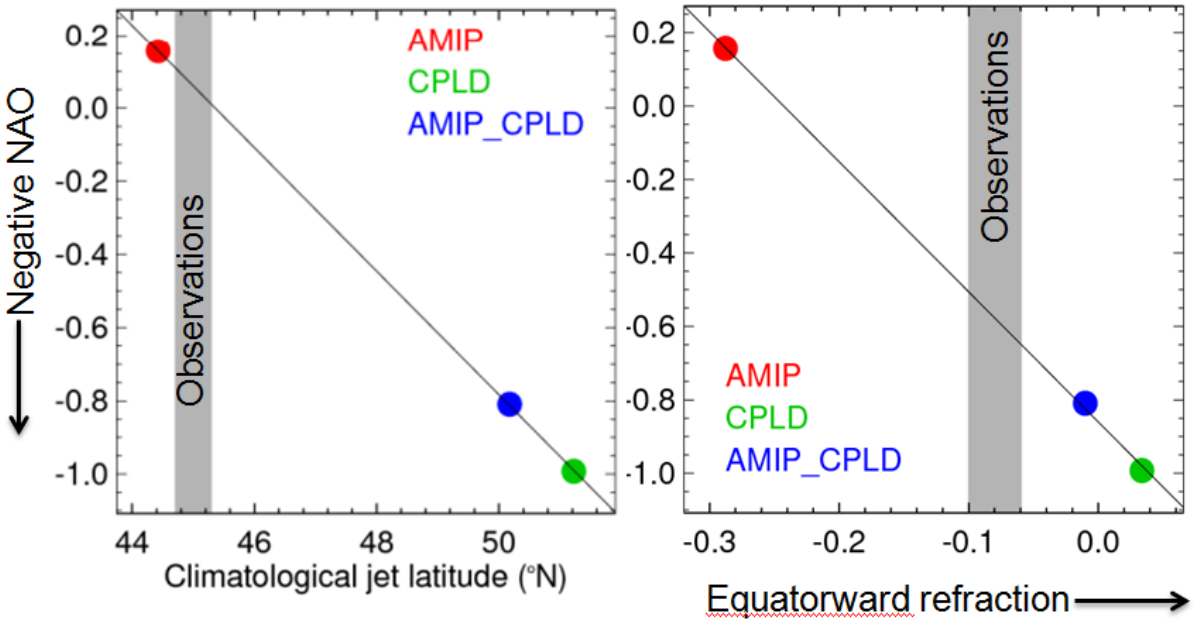

- High skill of ensemble mean, but variance much too low
- Model ensemble mean predicts the real world better than individual model members!
- Signal to noise ratio is too small in models
- **Need a very large ensemble to get robust results**
- **Cannot trust the magnitude of the model response to sea ice**



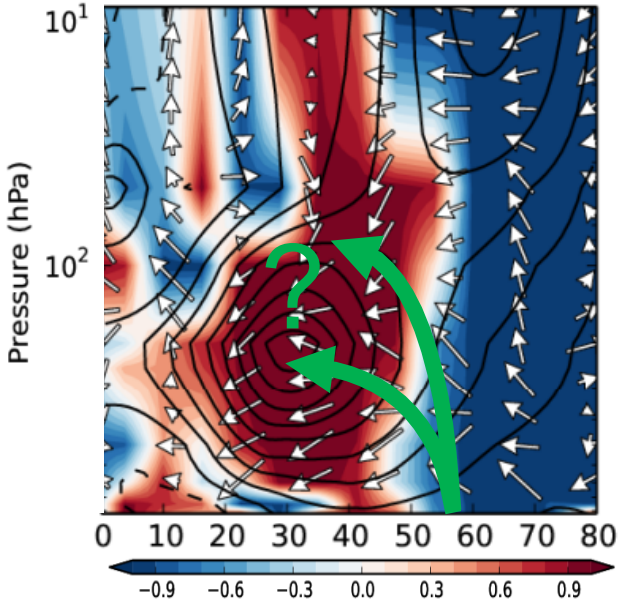

Eade et al 2014, Scaife et al 2014, Dunstone et al 2016

# Emergent constraint?

## Response in Atlantic jet




Correlation of jet response with EP flux response and background refractive index (NB for *increased* sea ice)




- **Response is correlated with jet latitude**
- **Possibility of "emergent constraint"?**
- **But response depends on wave propagation, and hence background refractive index**
- **Need constraint to be based on underlying physics**
- **Need more models → coordinated multi-model experiments**

Smith et al 2017

# Summary

- Cannot diagnose real world response from regression
- Full range of NAO responses reported in the literature
- Several potential reasons, including:
  - magnitude of forcing and how it is applied
  - pattern of forcing
  - background state
- Planetary waves are important, but no consensus even on sign of response
- Signal to noise ratio too small in models
- Emergent constraint might be possible
- **Need coordinated multi-model experiments…**

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# Experiments (1)

| No. | Experiment name | Description | Notes | Tier | Number of years | Minimum ensemble size |
|---|---|---|---|---|---|---|
| **1. Atmosphere-only time slice experiments** | | | | | | |
| 1.1 | amip-control | AMIP simulations forced by climatological monthly mean sea surface temperature (SST) and sea ice concentration (SIC) for the present day[1,2] | | 1 | 1 | 100 |
| 1.2 | amip-piSST | Repeat 1.1 but with pre-industrial SST | Investigate the role of SSTs in polar amplification | 1 | 1 | 100 |
| 1.3 | amip-2degSST | Repeat 1.1 but with future SST representing 2 degree global warming | | 2 | 1 | 100 |
| 1.4 | amip-piSIC-Arctic | Repeat 1.1 but with pre-industrial Arctic SIC[3] | Investigate the impacts of present day and future Arctic sea ice, and the role of Arctic SIC in polar amplification | 1 | 1 | 100 |
| 1.5 | amip-2degSIC-Arctic | Repeat 1.1 but with future Arctic SIC[3] | | 1 | 1 | 100 |
| 1.6 | amip-piSIC-Antarctic | Repeat 1.1 but with pre-industrial Antarctic SIC[3] | Investigate the impacts of present day and future Antarctic sea ice, and the role of Antarctic SIC in polar amplification | 2 | 1 | 100 |
| 1.7 | amip-2degSIC-Antarctic | Repeat 1.1 but with future Antarctic SIC[3] | | 2 | 1 | 100 |
| **2. Coupled time slice experiments** | | | | | | |
| 2.1 | cpld-control | Coupled model simulation constrained by climatological monthly mean sea ice concentration for the present day[2,4] | | 2 | 1 | 100 |
| 2.2 | cpld-piSIC-Arctic | Repeat 2.1 but with pre-industrial Arctic SIC[3] | As 1.4 and 1.5 but with coupled model | 2 | 1 | 100 |
| 2.3 | cpld-2degSIC-Arctic | Repeat 2.1 but with future Arctic SIC[3] | | 2 | 1 | 100 |
| 2.4 | cpld-piSIC-Antarctic | Repeat 2.1 but with pre-industrial Antarctic SIC[3] | As 1.6 and 1.7 but with coupled model | 3 | 1 | 100 |
| 2.5 | cpld-2degSIC-Antarctic | Repeat 2.1 but with future Antarctic SIC[3] | | 3 | 1 | 100 |

**Notes:**

[1] All necessary SST and sea ice fields will be provided to participants.

[2] Time slice simulations to begin on 1st April (?) and run for one year (or do we need an extra month or 2?)

[3] Past and future sea ice will be computed from the ensemble of CMIP5 projections as described below. SST where sea ice has reduced will be provided.

[4] Sea ice concentration to be nudged into coupled model with a relaxation time-scale of 6 hours (?)

# Experiments (2)

| | | | | | | |
|---|---|---|---|---|---|---|
| | Antarctic | | | | | |
| **3. Atmosphere-only time slice experiments to investigate regional forcing** | | | | | | |
| 3.1 | amip-2degSIC-Arctic-Pacific | Repeat 1.5 but with future Arctic SIC only in the Pacific sector (or just Sea of Okhotsk?) | Investigate how the response depends on the pattern of Arctic sea ice forcing | 3 | 1 | 100 |
| 3.2 | amip-2degSIC-Arctic-Atlantic | Repeat 1.5 but with future Arctic SIC only in the Atlantic sector (or just Barents/Kara Seas?) | | 3 | 1 | 100 |
| **4. Atmosphere-only time slice experiments to investigate the role of the background state** | | | | | | |
| 4.1 | amip-control-cpldSST | Repeat 1.1 but with climatological SST from 2.1 rather than observations | Isolate the effects of the background state from the effects of coupling | 3 | 1 | 100 |
| 4.2 | amip-2degSIC - Arctic-cpldSST | Repeat 4.1 but with future Arctic SIC[3] | | 3 | 1 | 100 |
| **5. Atmosphere-only transient experiments** | | | | | | |
| 5.1 | amip-climSST-transientSIC | Repeat CMIP6 AMIP (1979-2014) but with climatological monthly mean SST | Use CMIP6 AMIP as the control. Investigate transient response and individual years | 3 | 36 | 3 |
| 5.2 | amip-transientSST-climSIC | Repeat CMIP6 AMIP (1979-2014) but with climatological monthly mean SIC | | 3 | 36 | 3 |
| **6. Coupled transient experiments** | | | | | | |
| 6.1 | cpld-control-transient | Coupled model control simulation of present day sea ice | Experiments to investigate the decadal and longer impacts of Arctic sea ice on the ocean. **Not sure how to do this!** | 3 | 100 | 1 |
| 6.2 | cpld-2degSIC-Arctic-transient | Coupled model simulation but with reduced Arctic sea ice | | 3 | 100 | 1 |

**Notes:**

[1] All necessary SST and sea ice fields will be provided to participants.

[2] Time slice simulations to begin on 1st April (?) and run for one year (or do we need an extra month or 2?)

[3] Past and future sea ice will be computed from the ensemble of CMIP5 projections as described below. SST where sea ice has reduced will be provided.

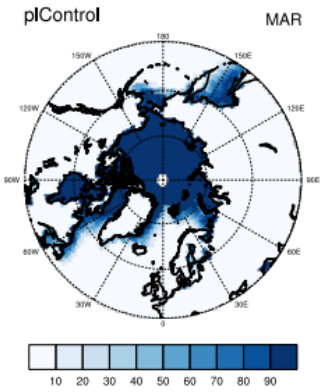
[4] Sea ice concentration to be nudged into coupled model with a relaxation time-scale of 6 hours (?)

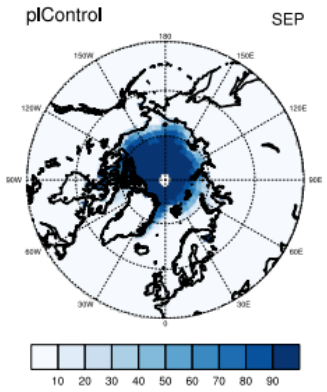
# Forcing fields

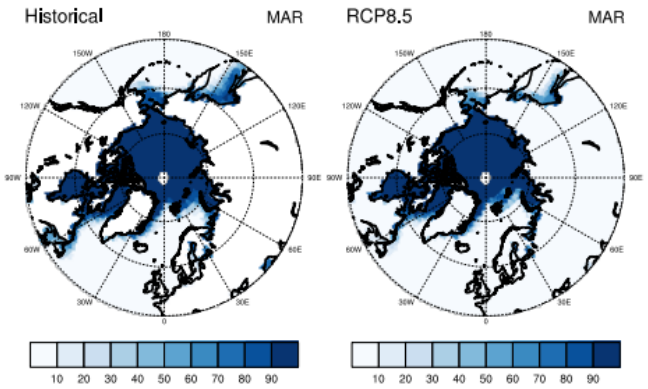
Monthly mean fields of SIC and SST are required for the present day, pre-industrial and future periods. Present day fields are obtained from the observations (define which ones). Future and pre-industrial fields are obtained from the ensemble of CMIP5 historical and RCP8.5 simulations but using present day observations as an "emergent constraint" as follows:

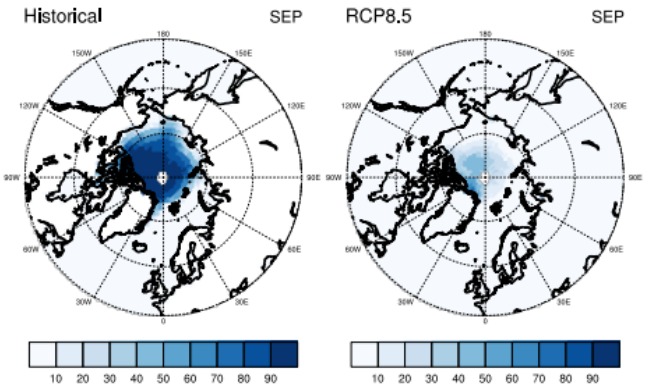
- Since some responses could depend on absolute temperatures rather than anomalies, we define absolute global mean temperatures representing pre-industrial (13.66$^{o}$C ), present day (14.24$^{o}$C) and future (2 degree warming, 15.66$^{o}$C) periods.
- For each model, find the periods when the 30 year mean global temperature equals the above values and compute the 30-year averaged fields.
- At each grid point, use the observed present day value to constrain the model simulations of future and pre-industrial conditions. This is achieved by computing a linear regression between future (or pre-industrial) and present day values simulated by the model ensemble, and taking the required future (or pre-industrial) estimate as the point where this regression relationship intersects the observed present day value. We use quantile regression based on the upper quartile rather than least squares regression to reduce the impact of outliers and hence provide a sharper ice edge.

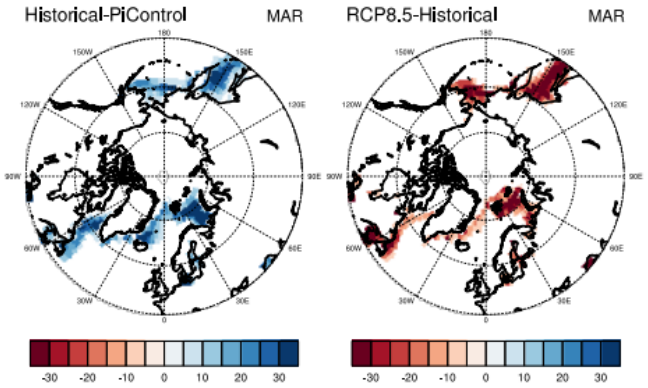
# Forcing fields: SIC

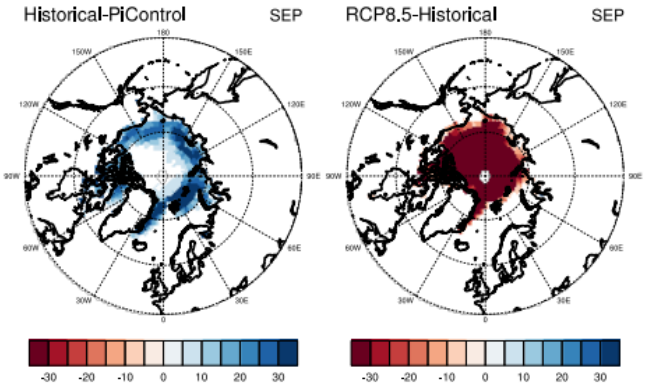


# Forcing fields: SST