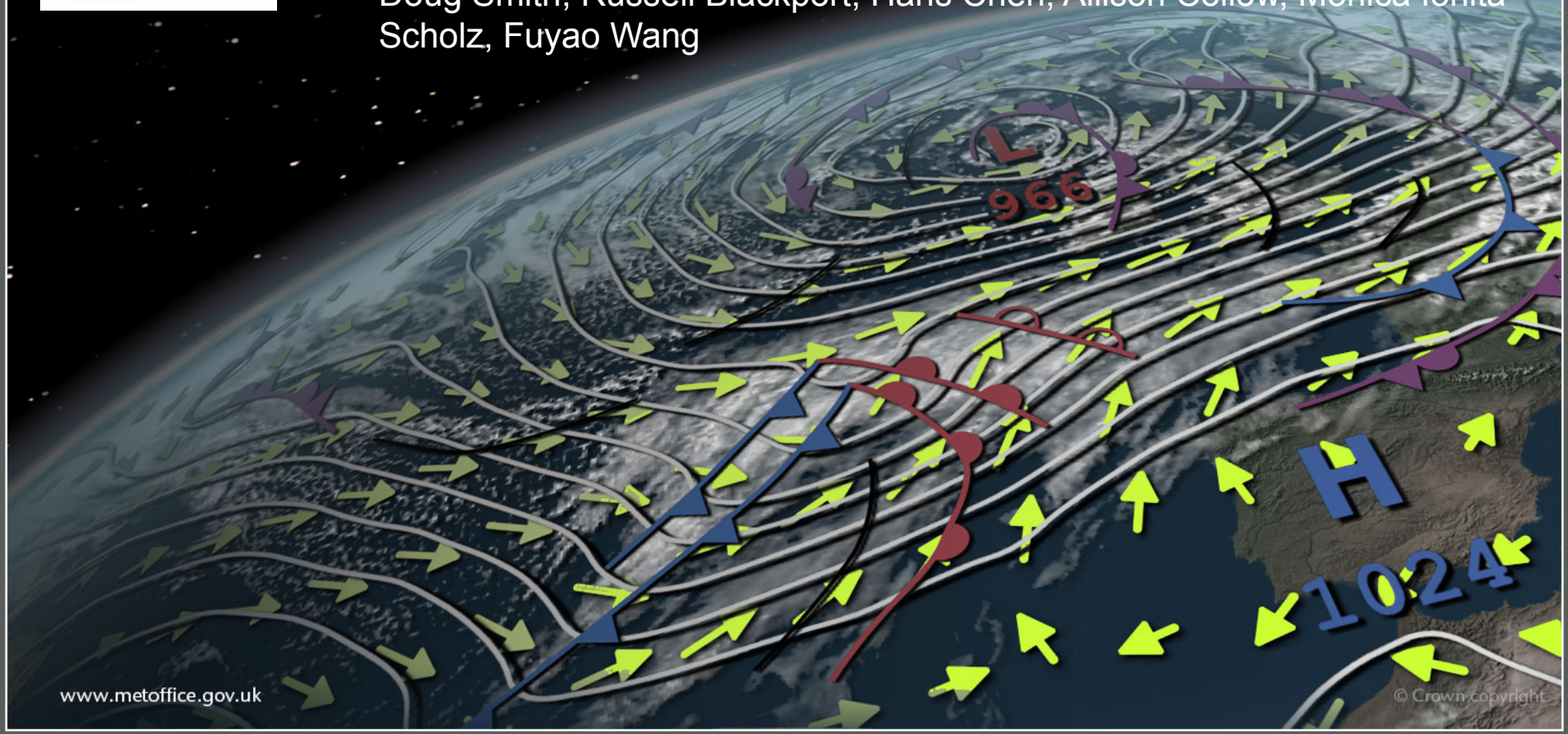
Met Office
Hadley Centre

SPECS
Seasonal-to-decadal climate Prediction for the improvement of European Climate Services

Overview of recent modelling studies of atmospheric response to varying sea ice: **Why do some studies produce a robust response and others do not?**

Doug Smith, Russell Blackport, Hans Chen, Allison Collow, Monica Ionita-Scholz, Fuyao Wang



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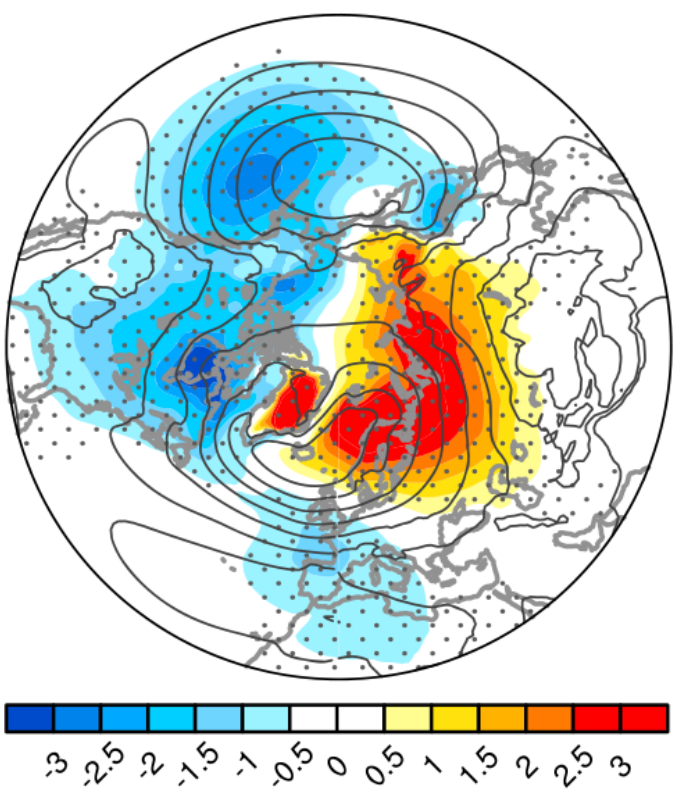
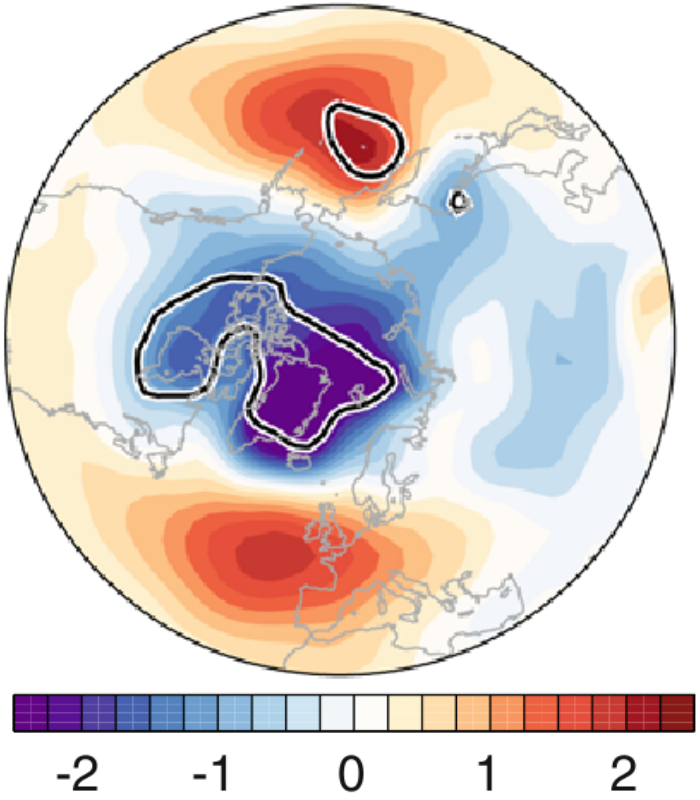
Non-robust response: full range of NAO responses have been reported





• **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; Peings and Magnusdottir 2014; Nakamura et al 2015 …

• **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 …

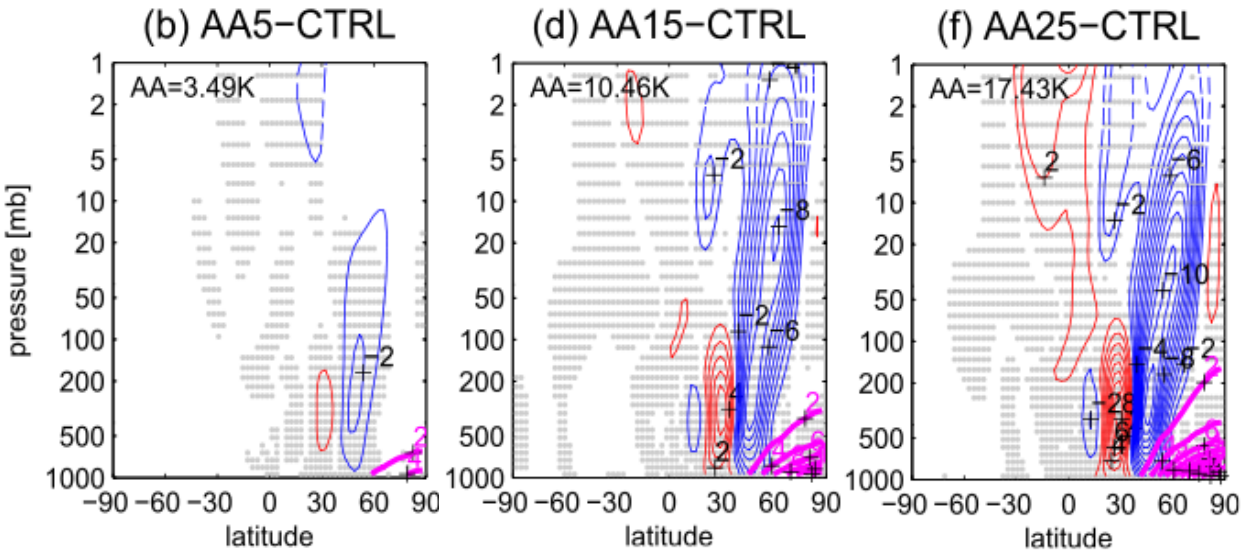
• **Little NAO response**

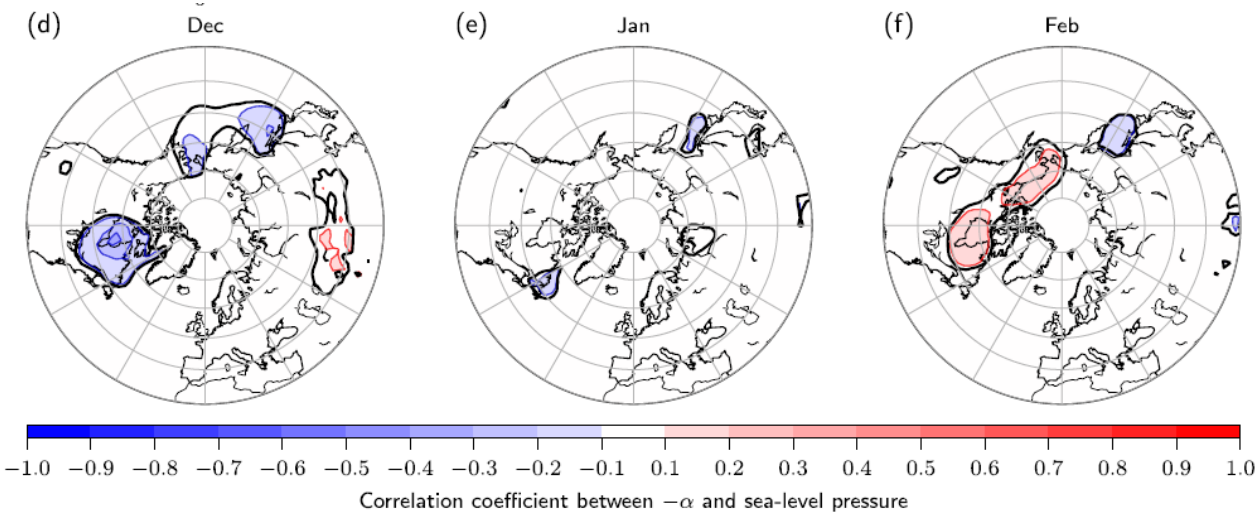
• Screen et al. 2013; Petrie et al 2015; Blackport and Kushner 2016 …

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

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

Magnitude of the forcing



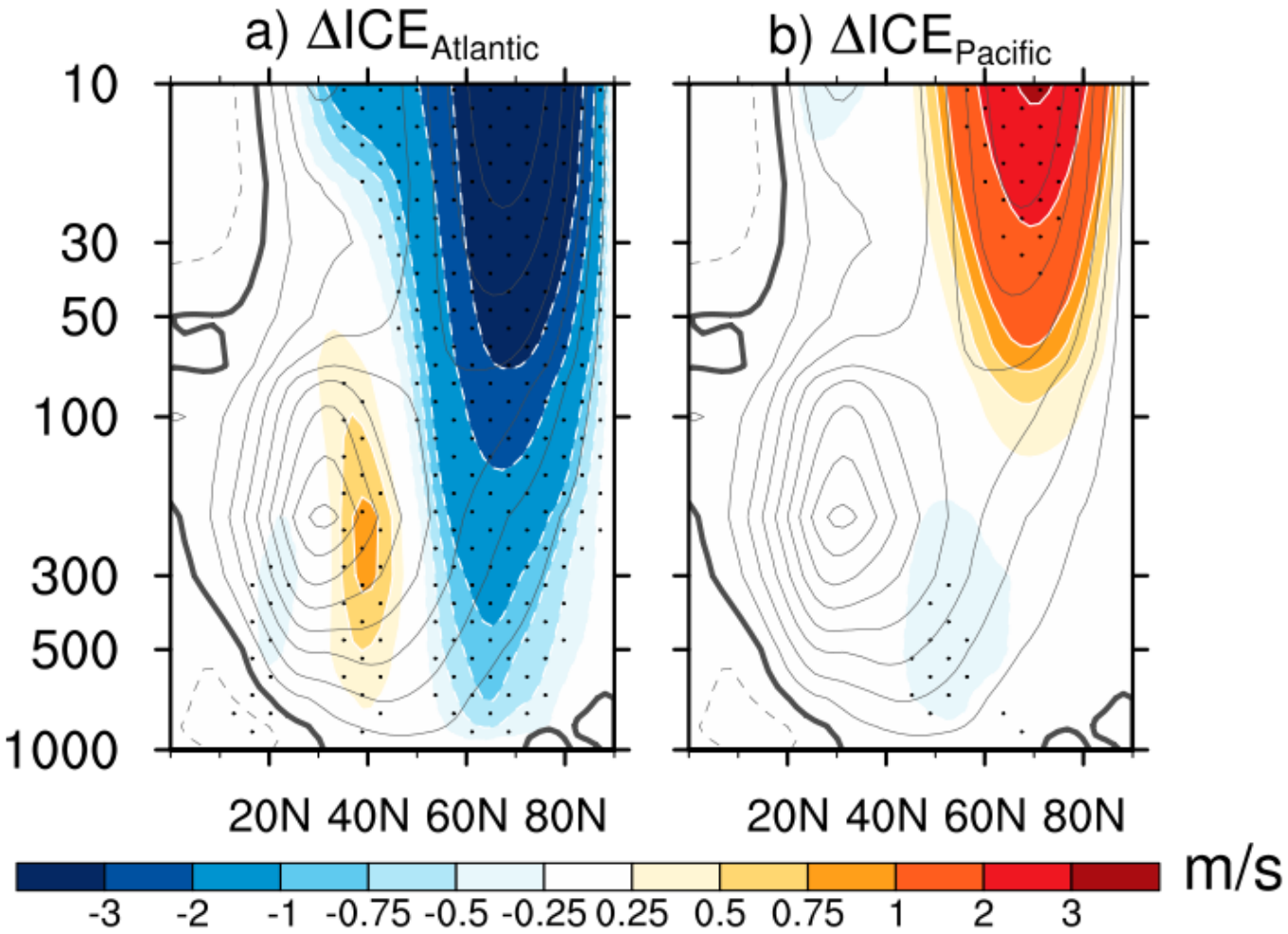


- Wu and Smith 2016:
- Zonal wind response scales with the magnitude of the applied forcing

- Chen et al 2016:
- No correlation between sea level pressure response and applied forcing
- Non-linear response?

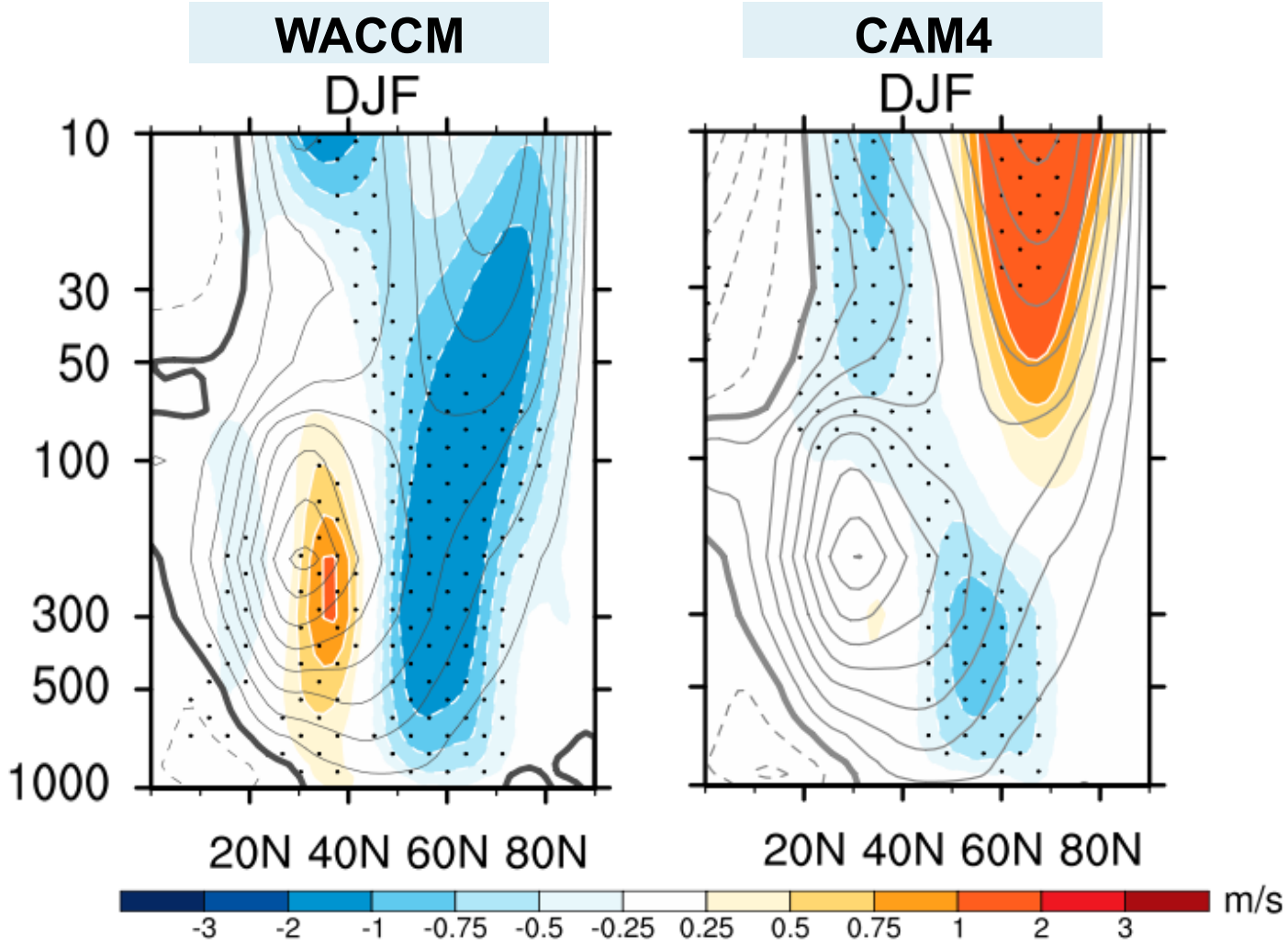
(Petoukhov and Semenov 2010; Semenov and Latif 2015)

Pattern of forcing



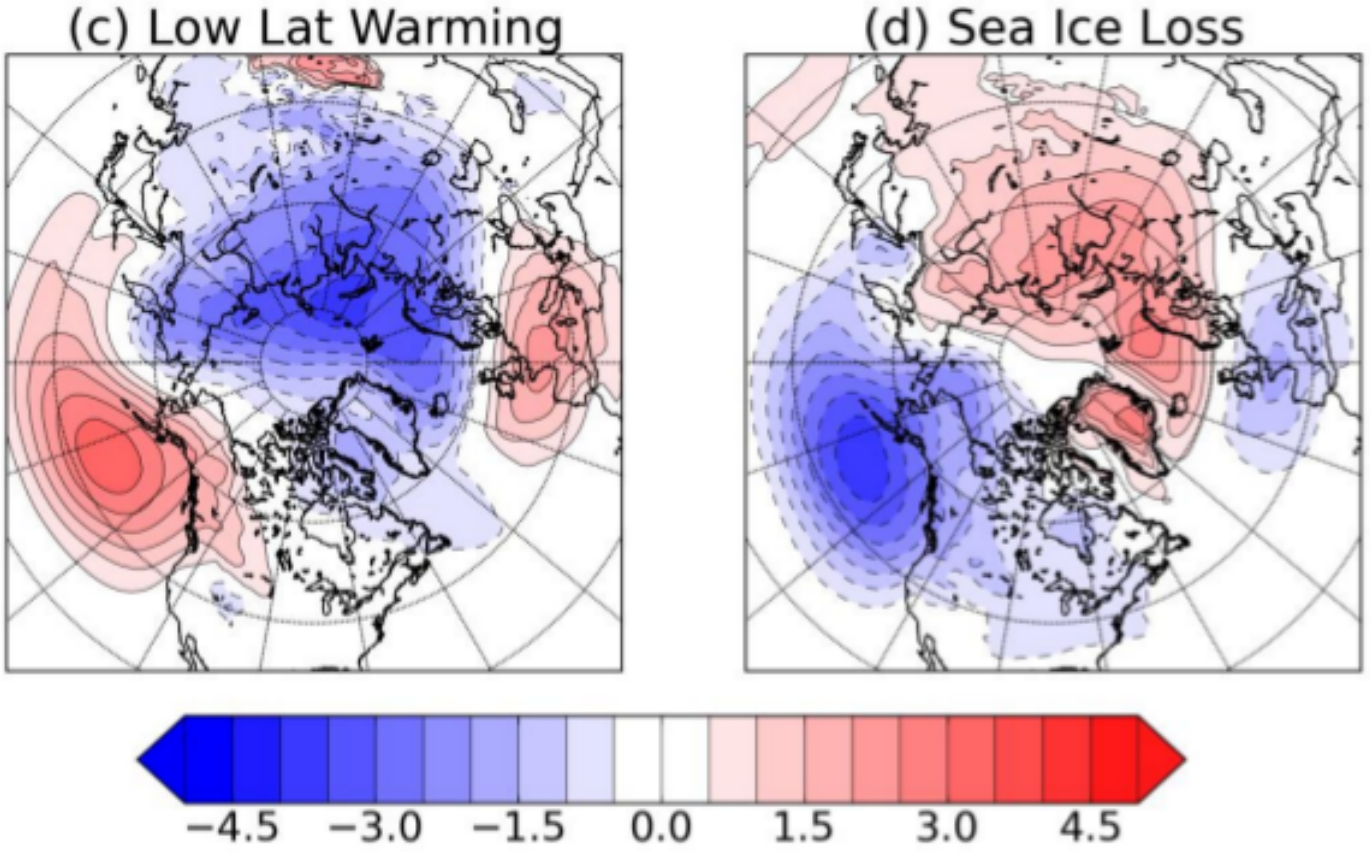
- Opposite response if forcing is applied in Atlantic and Pacific sectors separately
- Sun et al 2015; Alexander et al 2004; Peings and Magnusdottir 2014; Screen 2017

Model



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

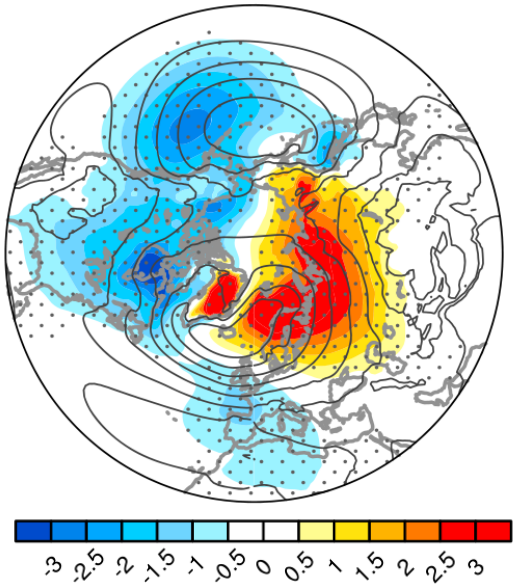
Other forcings

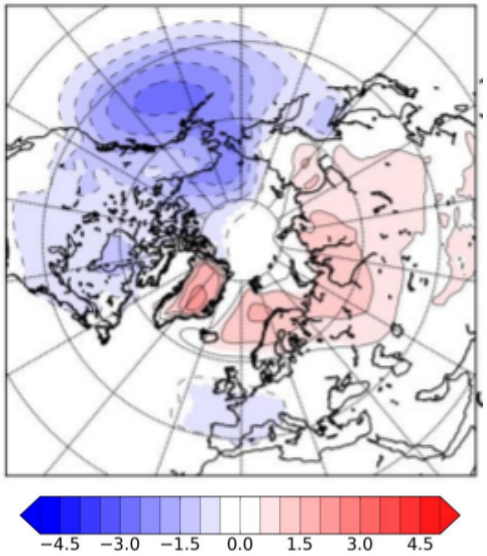


- Opposite pressure response to low latitude warming (e.g. greenhouse gases) and sea ice loss
- **Key challenge: what is their relative importance?**
- Blackport and Kushner 2017

How the forcing is imposed

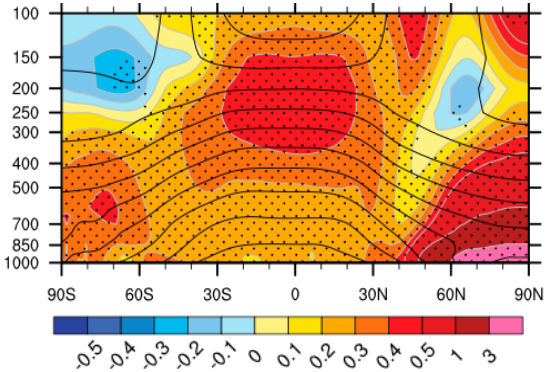
Sea level pressure

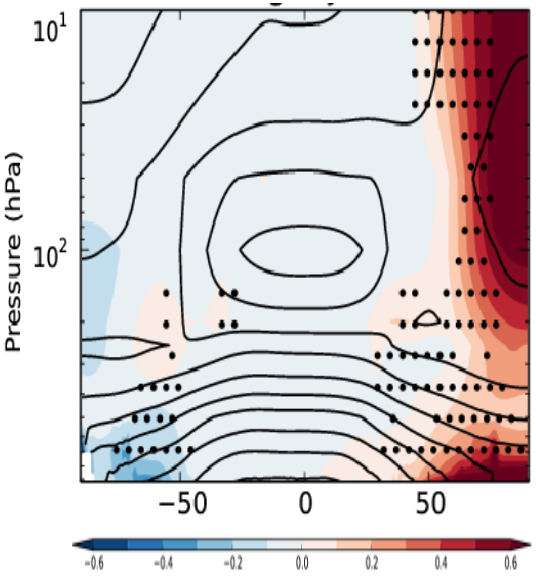




- Longwave flux (left, Deser et al 2015)
- Albedo (right, Blackport and Kushner 2017)
- Same model
- Similar sea level pressure response…

Zonal mean temp

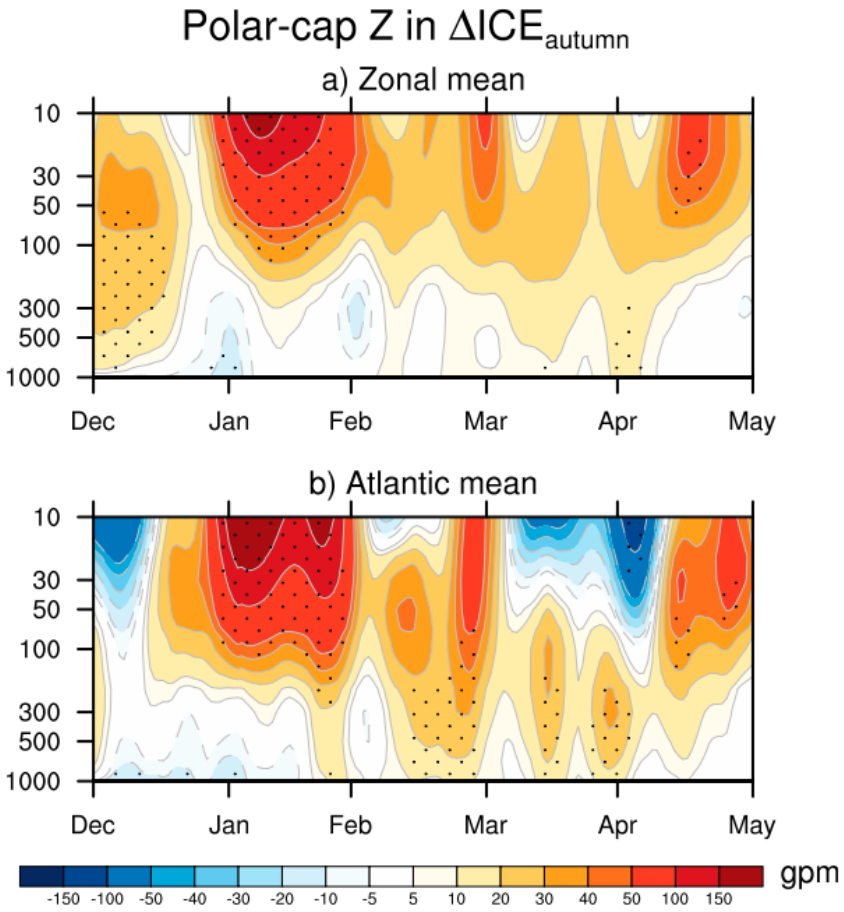


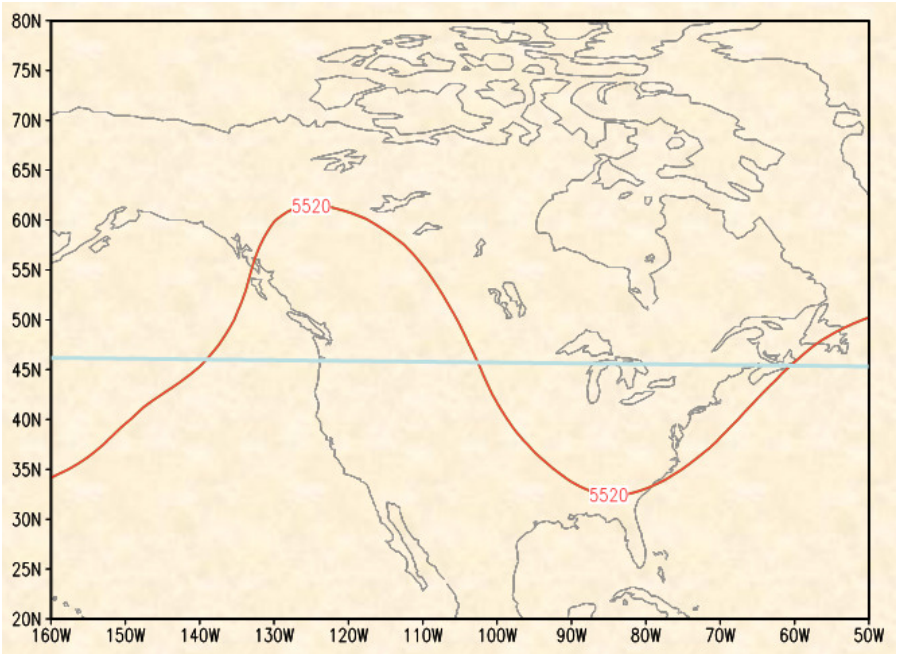


- Low latitude warming simulated in response to longwave forcing (left, Deser et al 2015)
- …but not in study using relaxation to impose sea ice (right, Smith et al submitted)

- 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”?

Analysis

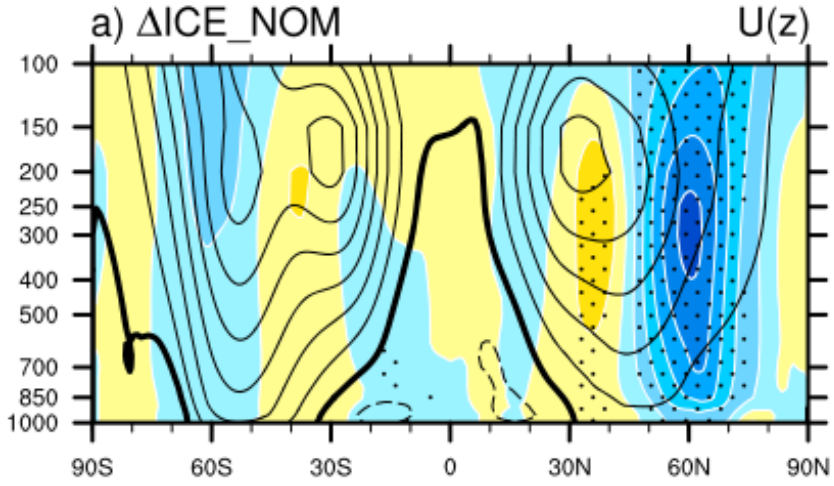




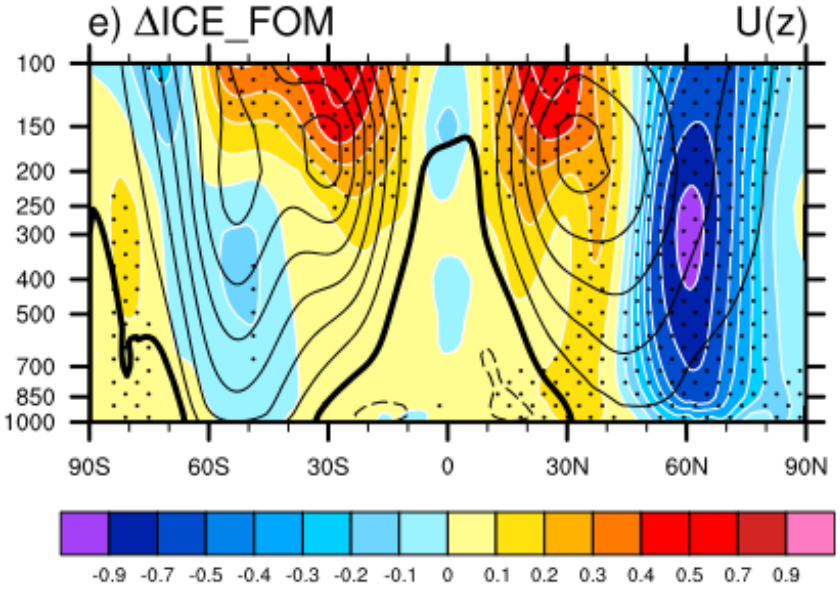
- Zonal averaging may mask significant responses (left, Sun et al 2015)
- Consider additional metrics such as “sinuosity” (right, Cattiaux et al 2016, Vavrus et al 2017), blocking frequency, …

Atmosphere vs coupled models

Atmosphere only model



Fully coupled model

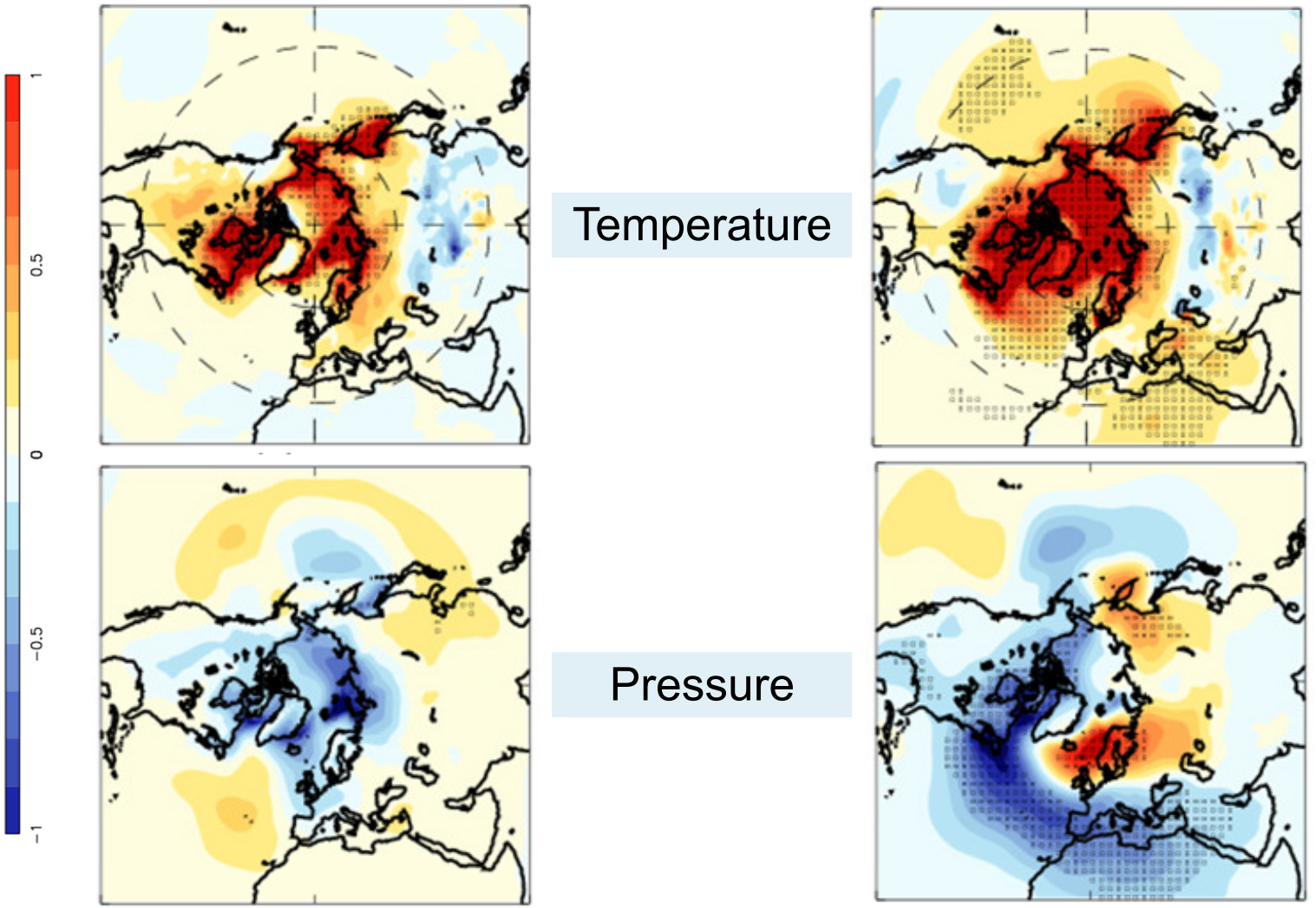


- Stronger response with coupled model
- DJF zonal mean wind
- Deser et al 2016

Atmosphere vs coupled models

Atmosphere only model

Fully coupled model

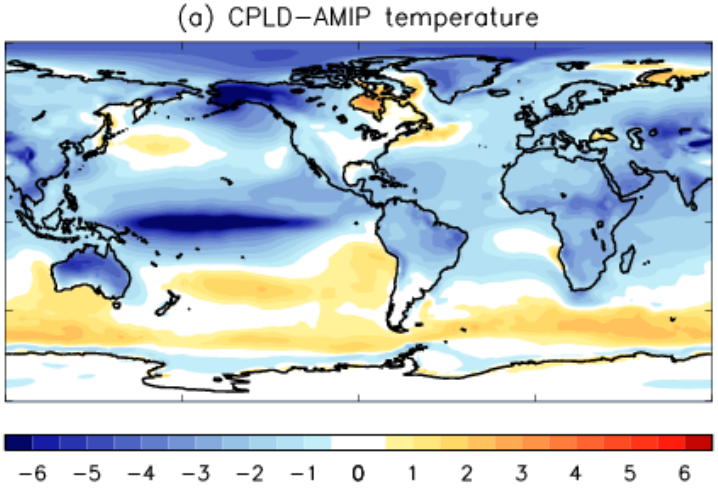


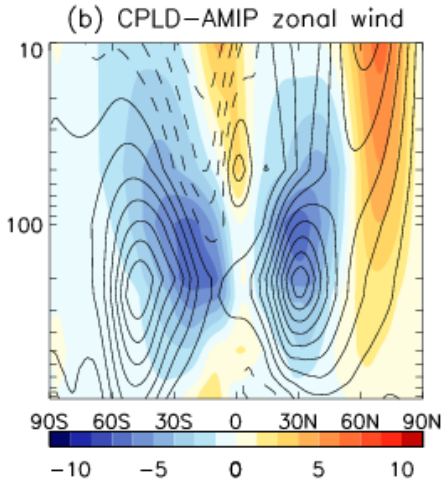
• Opposite sign of NAO response in atmosphere only and coupled model

Smith et al submitted

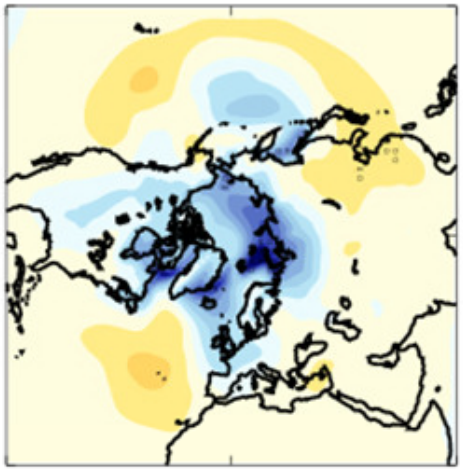
Dependence on background state

Coupled model biases

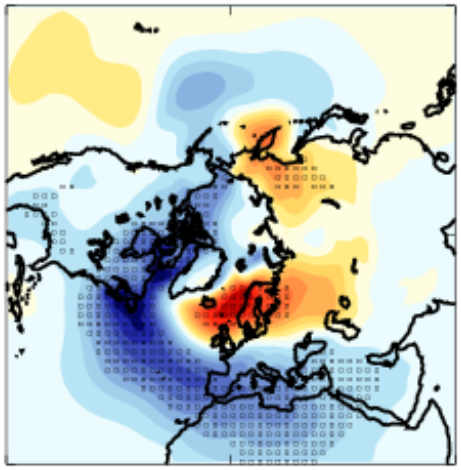




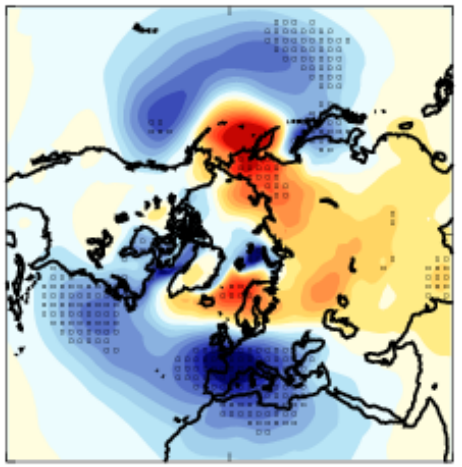
Atmosphere model



Coupled model



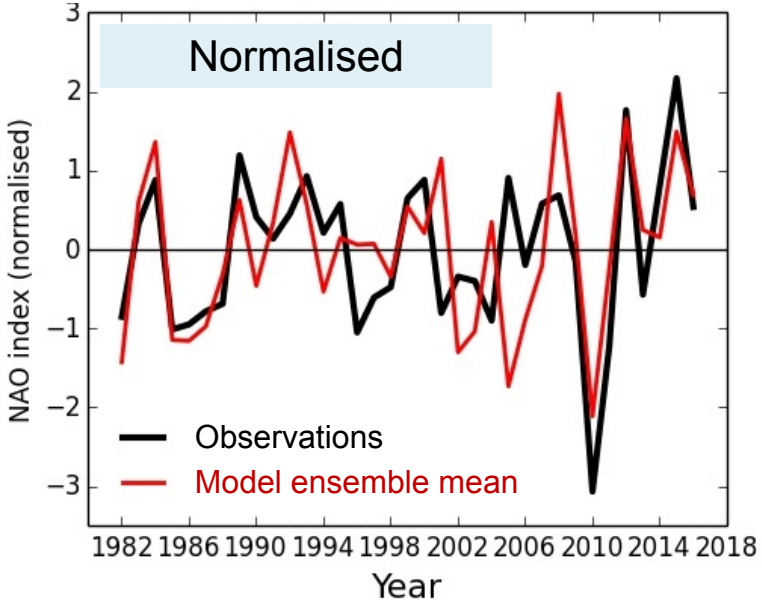
AMIP_CPLD

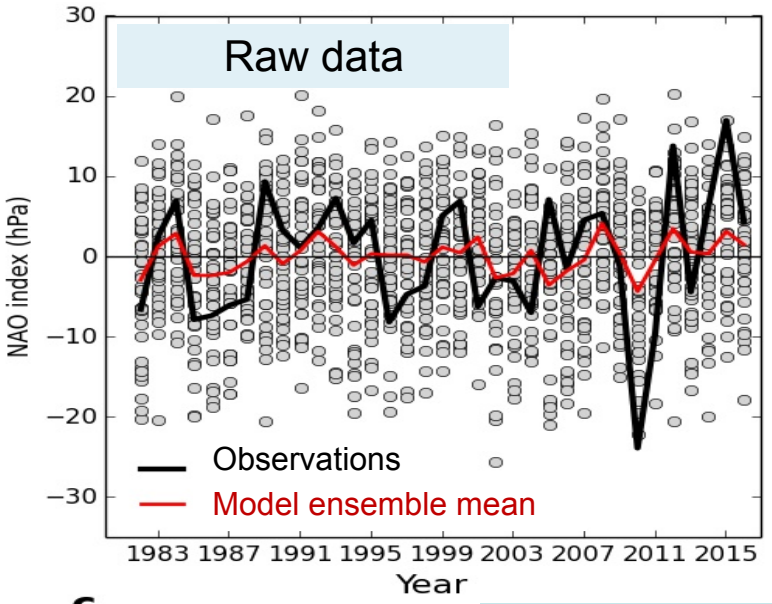


- **Different response could be caused by coupling or background state (model bias)**
- **Test by repeating atmosphere model but imposing COUPLED SST bias → AMIP_CPLD**
- **Reproduces COUPLED response → background state is key**

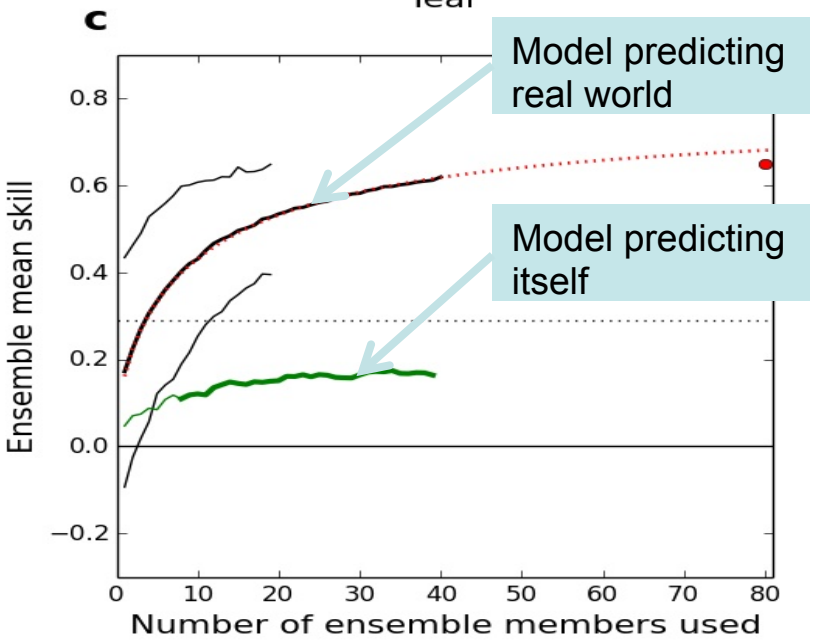
Smith et al submitted

Signal to noise issues



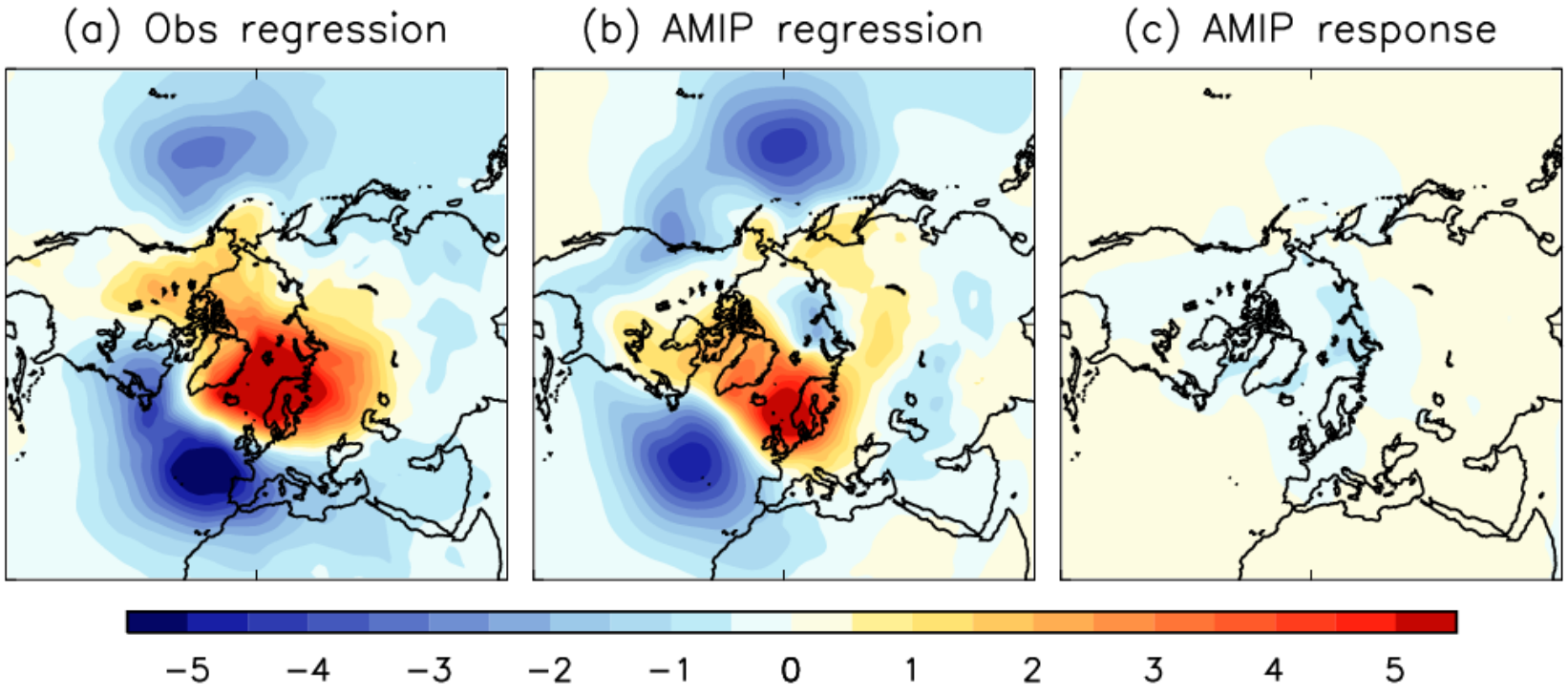


- Skill (anomaly correlation) of seasonal forecasts of the NAO (DJF from Nov)
- High skill of ensemble mean, but variance much too low
- Model ensemble mean predicts the real world better than individual model members!
- Signal to noise ratio is too small in models
- **Need a very large ensemble to get 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

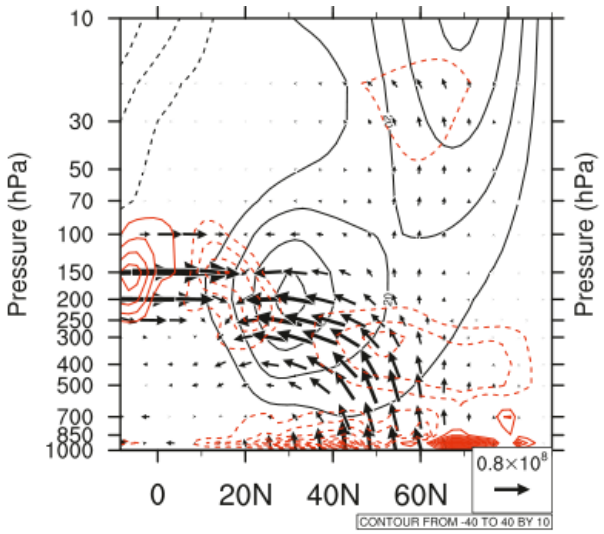
Real world response? *Cannot be diagnosed from regression*

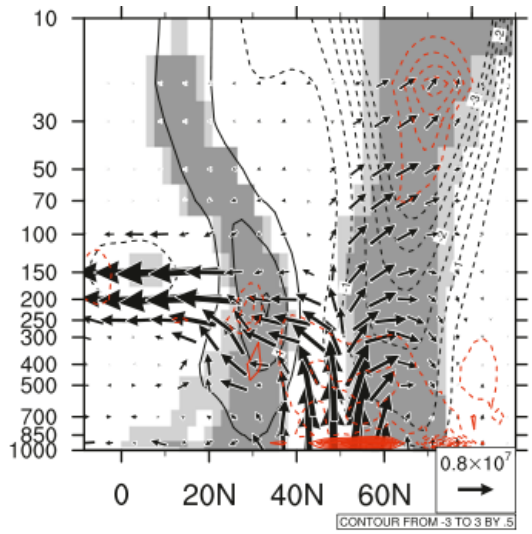


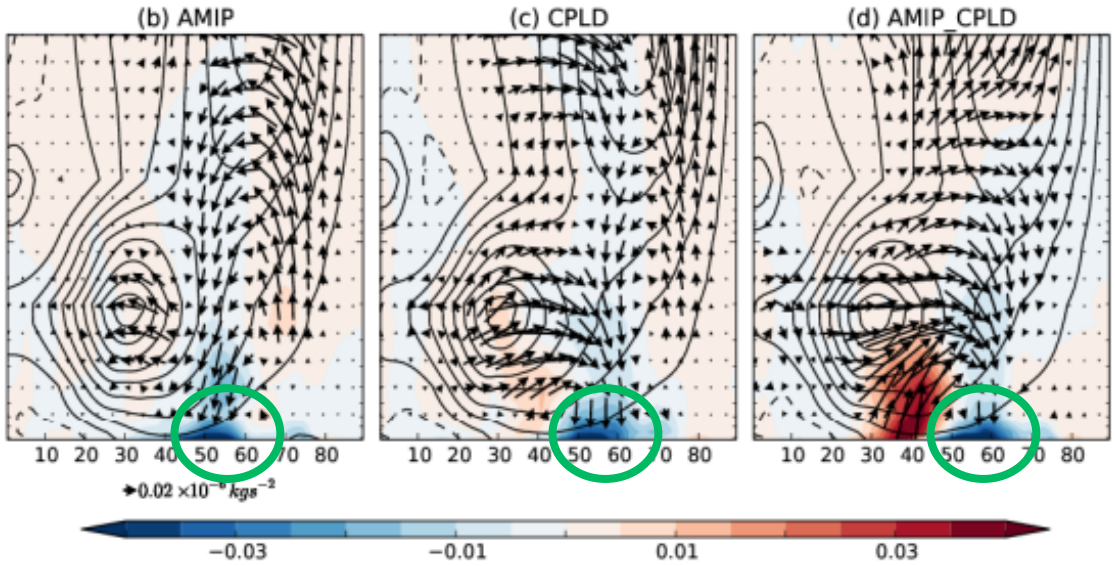
- **Regression between autumn (SON) sea ice extent and winter (DJF) sea level pressure (sign reversed)**
- **Obs and AMIP agree**
- **BUT AMIP response forced by reduced ice in model experiments sea ice is completely different**
- **The pattern is forced by SSTs rather than sea ice**

Smith et al submitted

Planetary waves







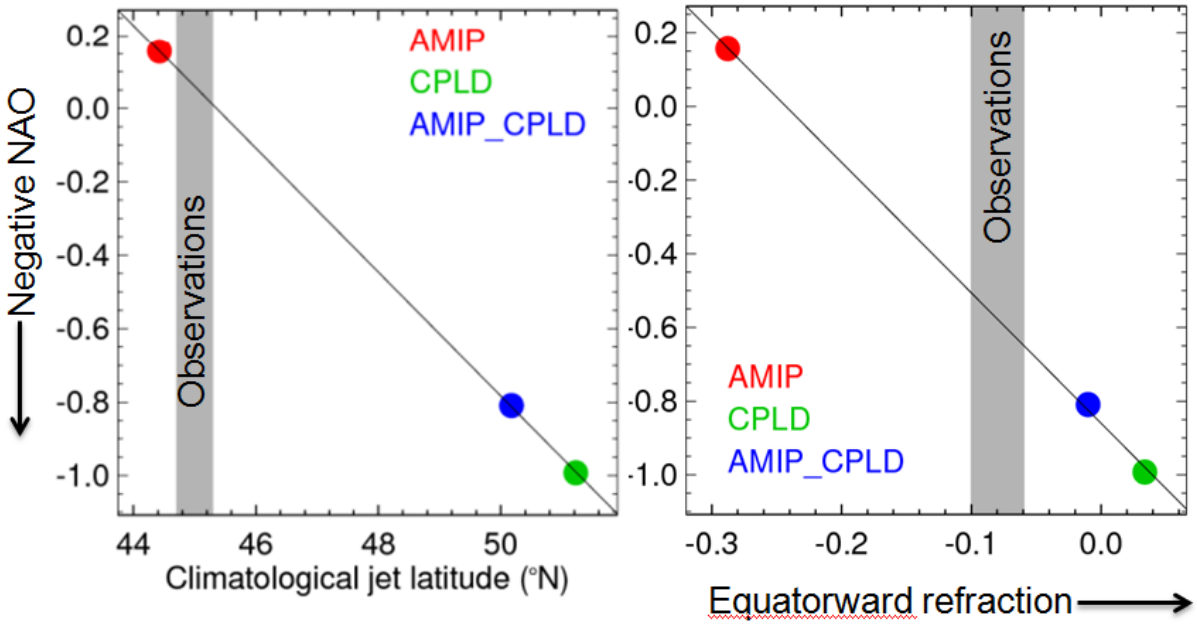
- **Increased** upward planetary waves in response to reduced Arctic sea ice
- Jaiser et al. 2013; Kim et al. 2014; Peings and Magnusdottir 2014; Feldstein and Lee 2014; Sun et al. 2015; Nakamura et al. 2015; Overland et al. 2016

- **Decreased** upward planetary waves in response to reduced Arctic sea ice
- Seierstad and Bader 2009, Smith and Scott 2016, Smith et al submitted
- Reduced Equator to pole temperature gradient, reduced baroclinicity

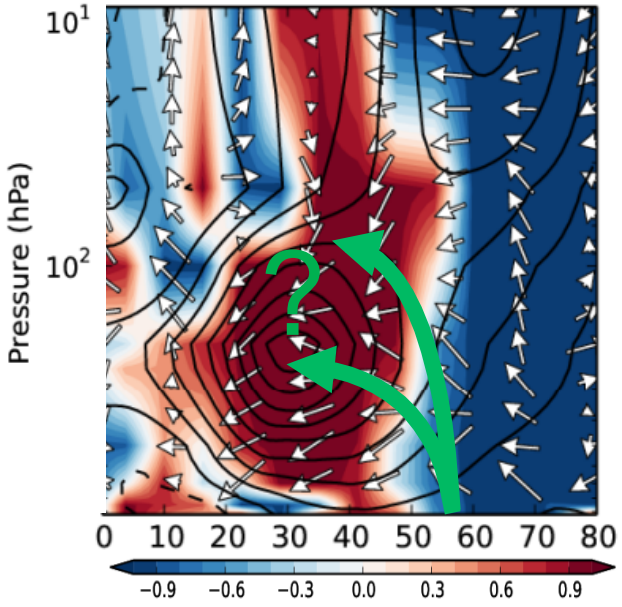
- **Planetary waves likely to be important in dynamical response, but no consensus on sign of response!**

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 submitted

Summary

- 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
- Cannot diagnose real world response from regression
- Signal to noise ratio too small in models
- Emergent constraint might be possible
- **Need coordinated multi-model experiments…**