Atmospheric response to sea ice: the importance of coupling and the background state

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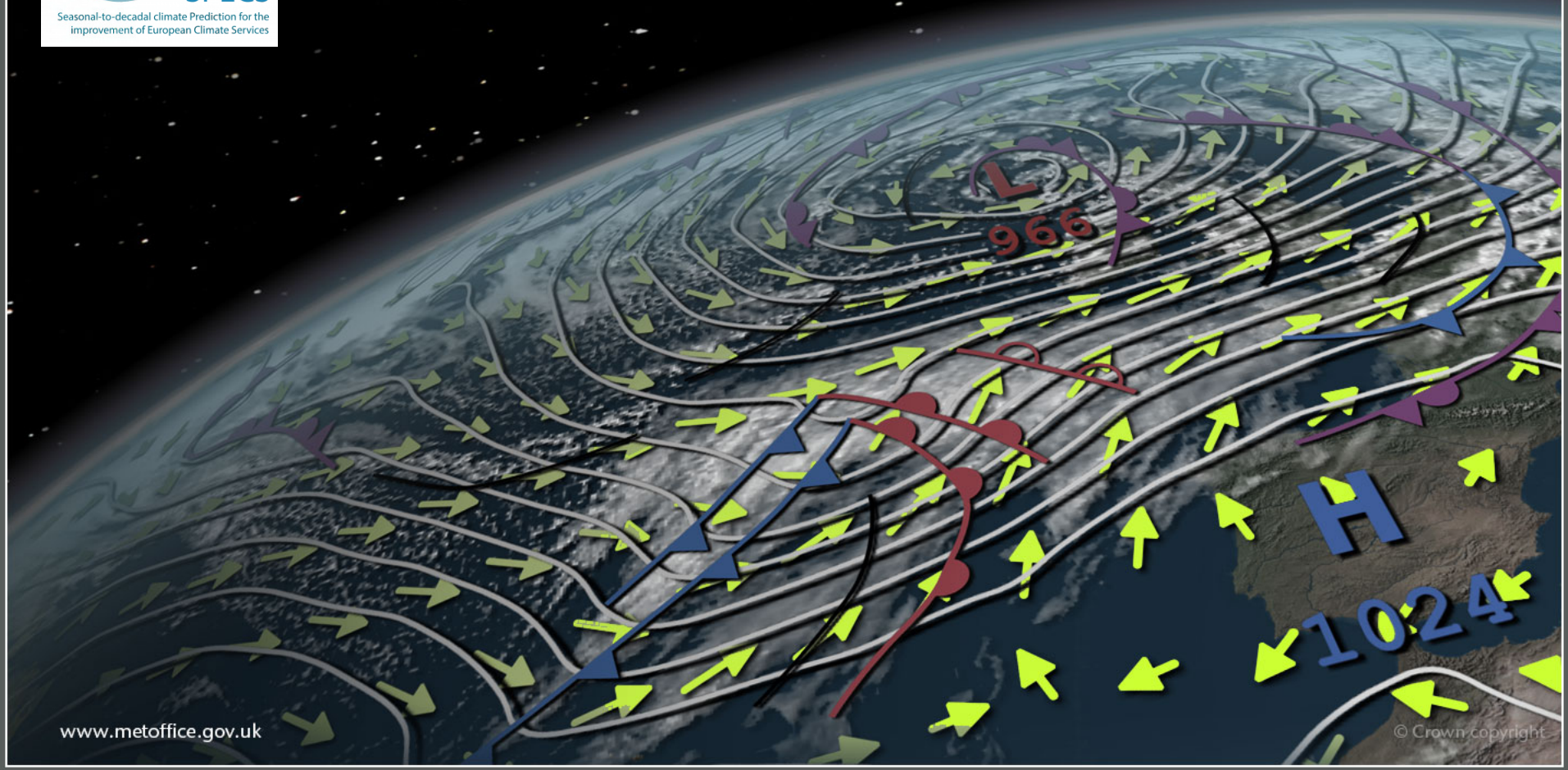
SPECS
Seasonal-to-decadal climate Prediction for the improvement of European Climate Services



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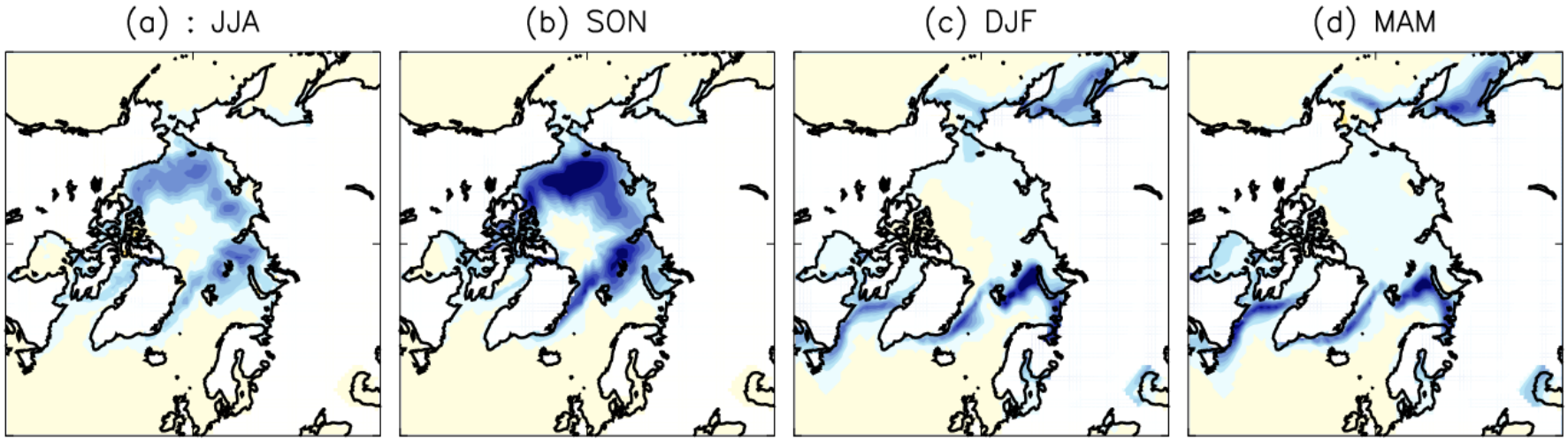
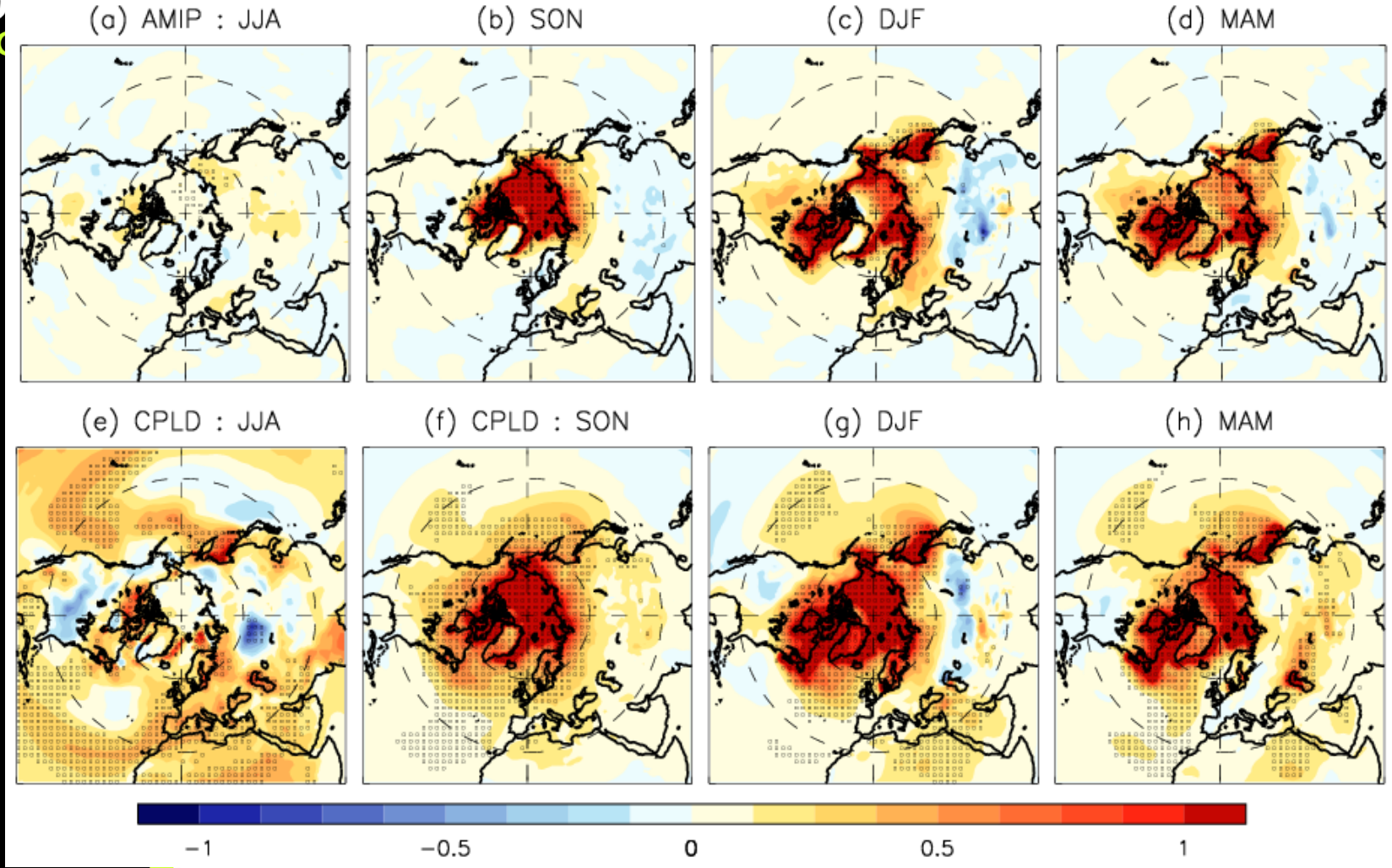
Experiments

Imposed Arctic sea ice change



- 30 year period Dec 1979 to Nov 2009
- CONTROL: observed sea ice (monthly mean)
- PERTURBED: reduced sea ice, obtained by projecting recent 15 year trends
- HADGEM3, GA3, ~150 km resolution, 85 levels
- 10 ensemble members
- AMIP, observed SST, set to 0°C where sea ice has disappeared
- Also COUPLED (1° ocean resolution, 75 levels):
  - same sea ice as AMIP
  - upper 200m ocean is free to respond
  - constrained below 200m to prevent spurious circulations

Surface temperature response



- Warming where sea ice reduced
- Bigger in COUPLED model, and extends to surrounding ocean

Remote response in CPLD (JJA)

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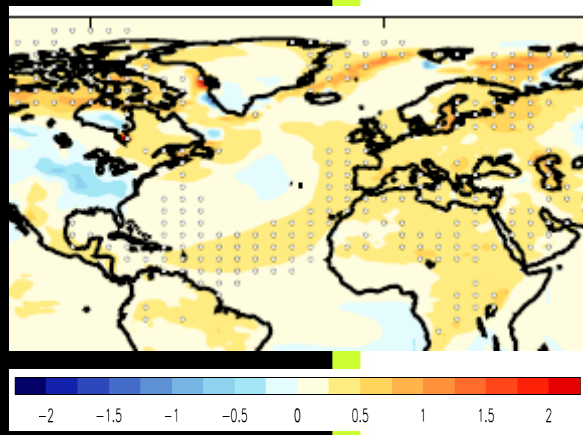
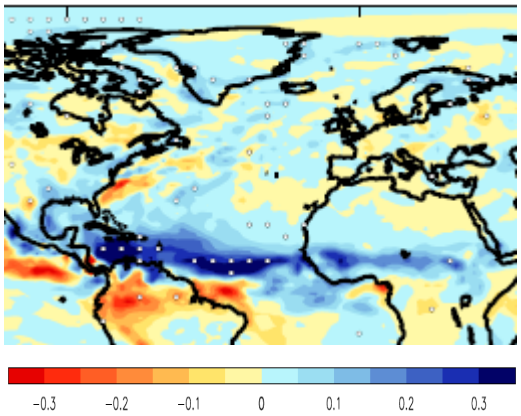
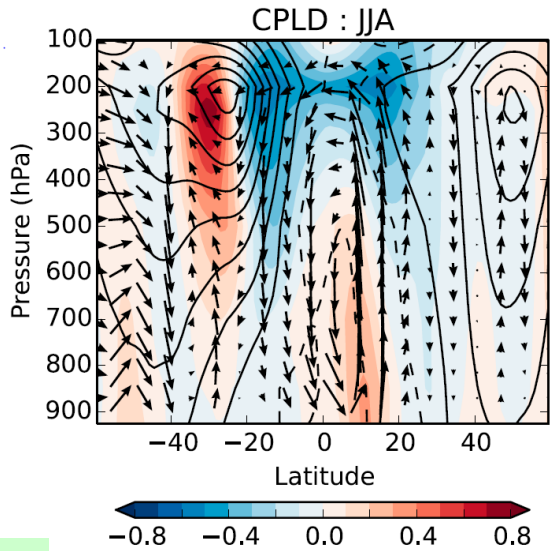
Temperature



Rainfall

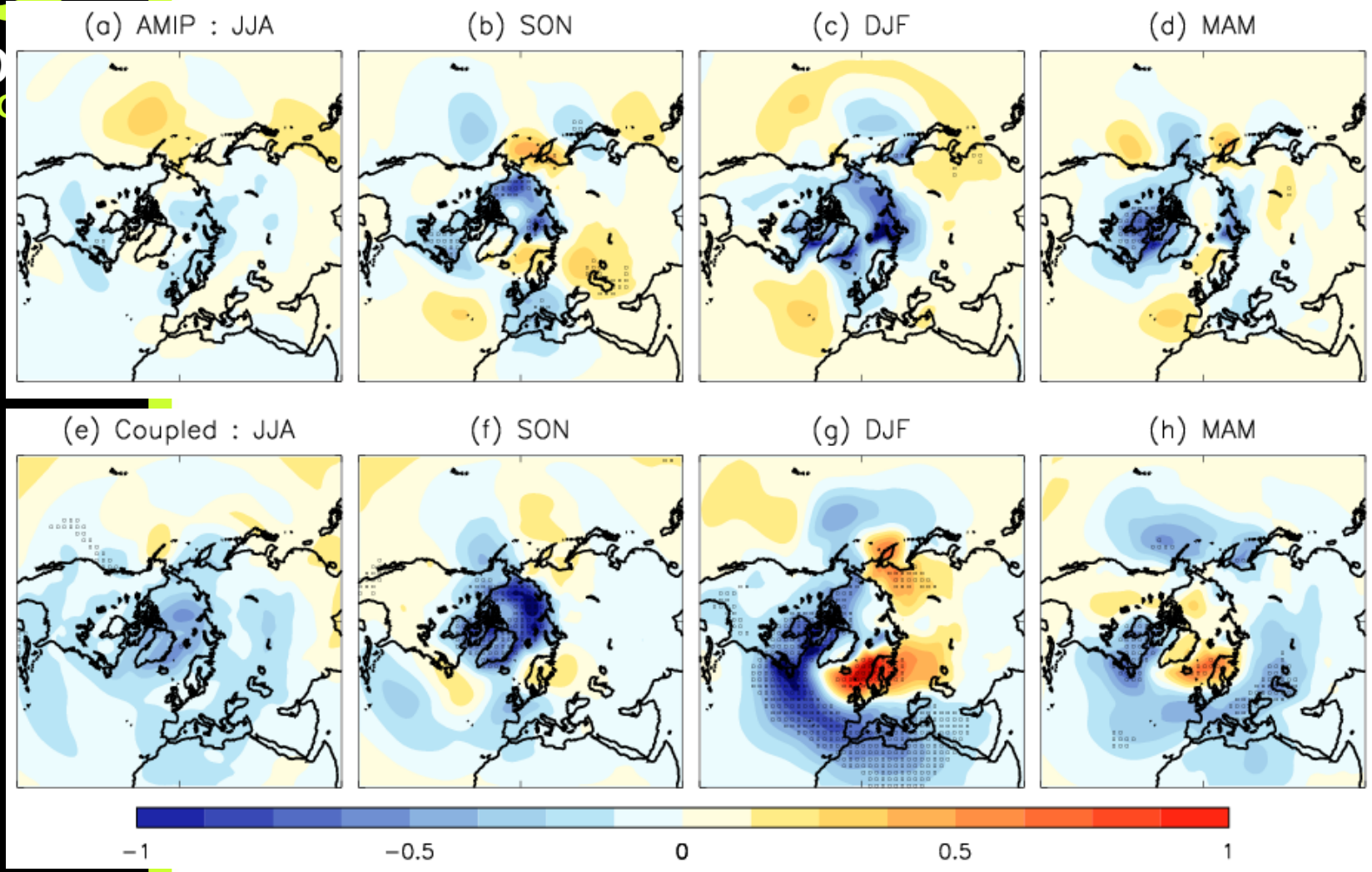


Zonal wind: Atlantic (90W to 0E)



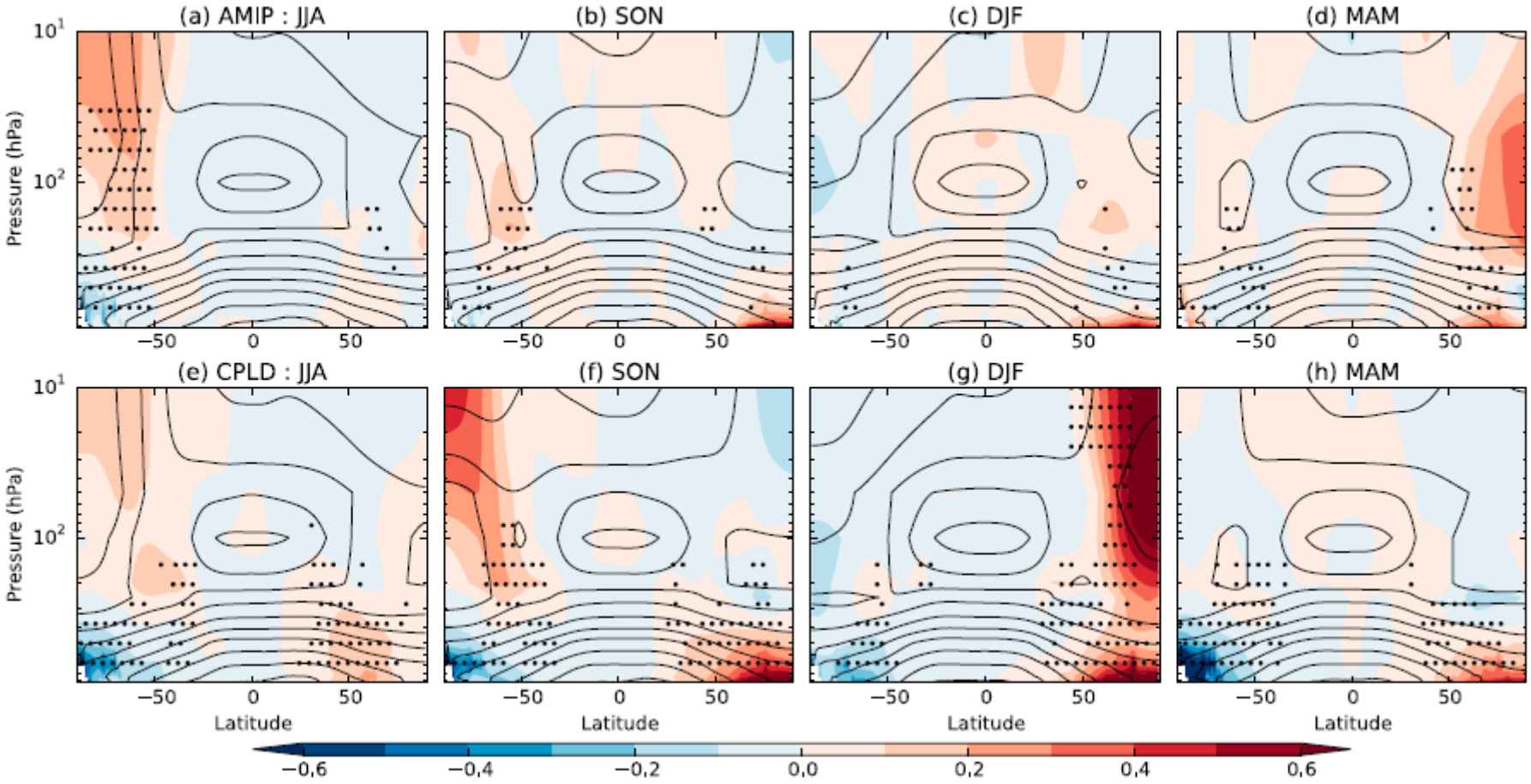
- Warm tropical Atlantic (only in coupled simulations)
- Anomalous Hadley circulation northward shift of ITCZ
  - ➢ increased rainfall (including Sahel)
  - ➢ Increased ascent and reduced zonal wind shear → more hurricanes
- See also Chang and Bitz 2005

Sea level pressure response



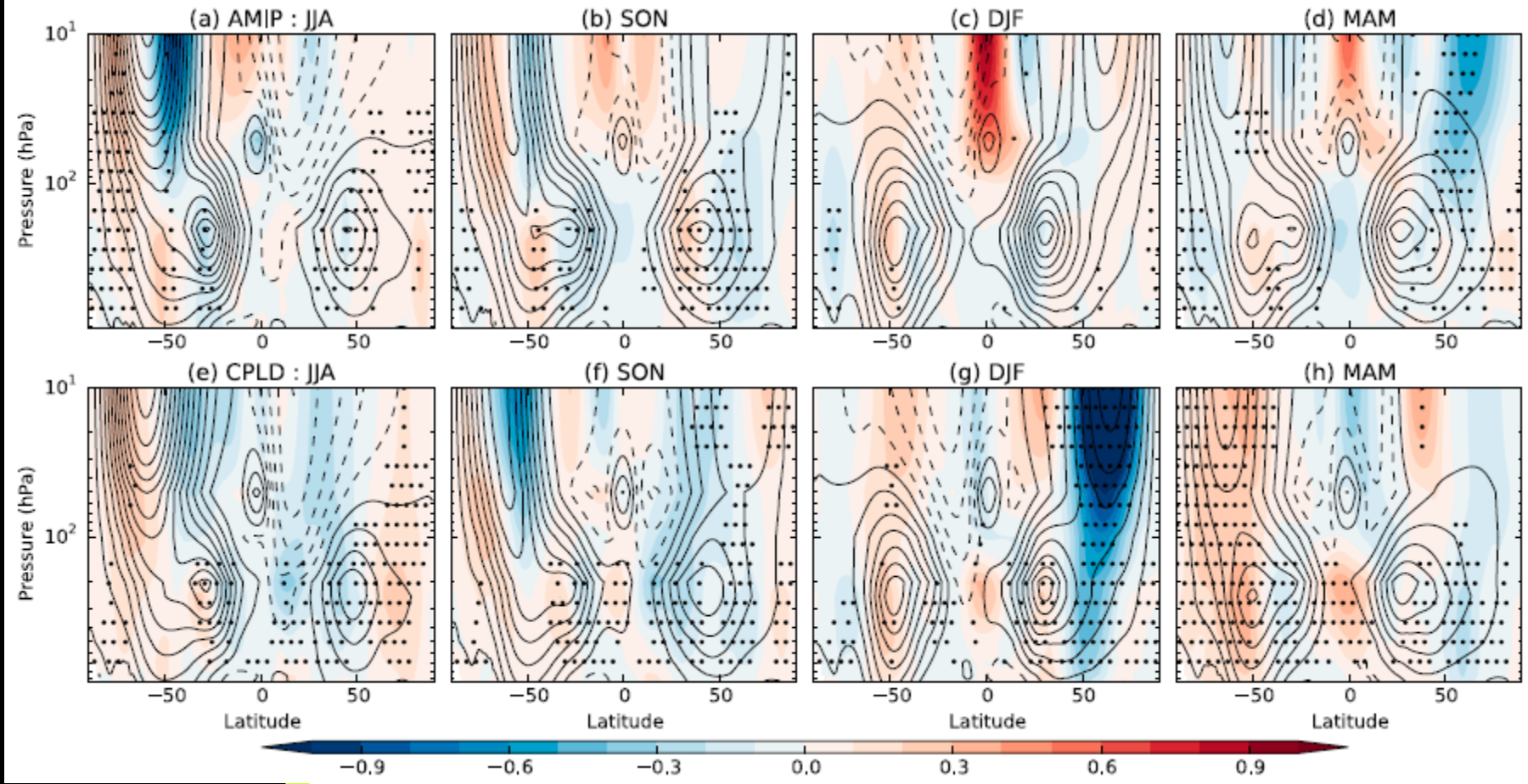
- AMIP: "heat low" in all seasons → projects onto +ve NAO
- COUPLED: similar in JJA and SON though larger signal
- Opposite signal (-ve NAO) in DJF and MAM

Zonal mean temperature response



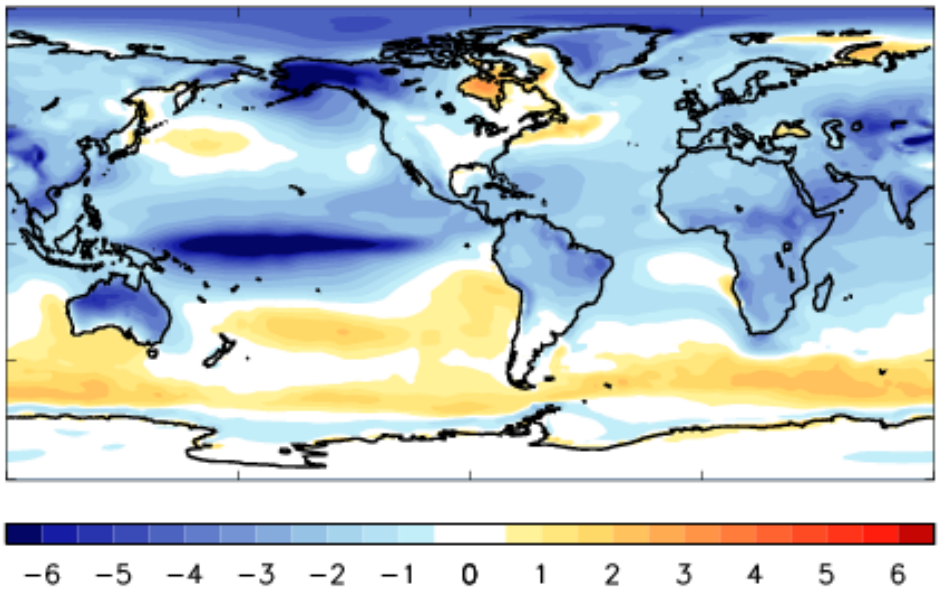
- **AMIP: Arctic warming confined to boundary layer (except MAM)**
- **COUPLED: Arctic warming throughout atmosphere**

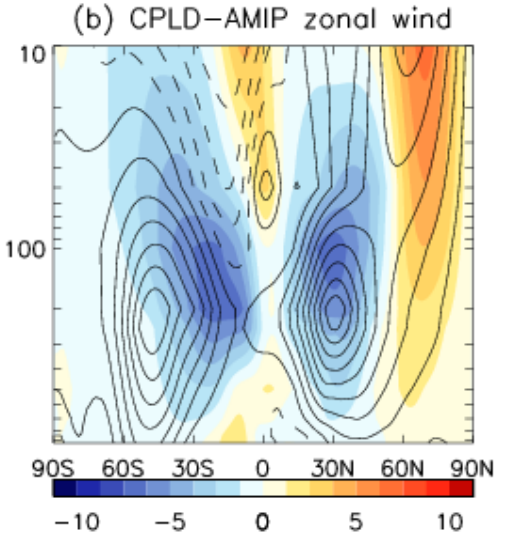
Zonal mean wind response

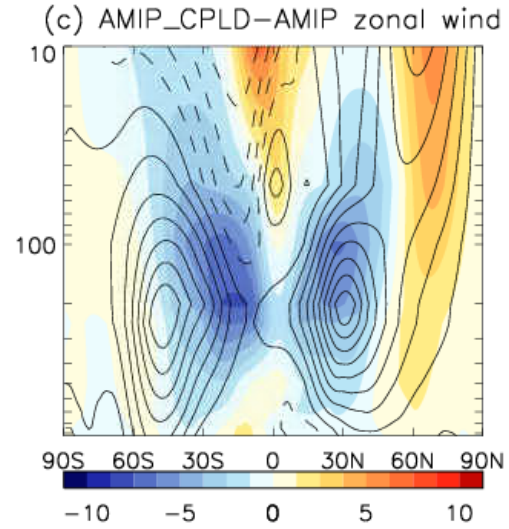


- **AMIP: Little response in DJF**
- **COUPLED: Barotropic response, weakening and Equatorward shift of the jet**

COUPLED model biases







- Different response could be caused by coupling or background state (model bias)
- Test by repeating AMIP but imposing COUPLED SST bias → AMIP_CPLD
- Reproduces zonal wind biases

Sea level pressure response depends on background state

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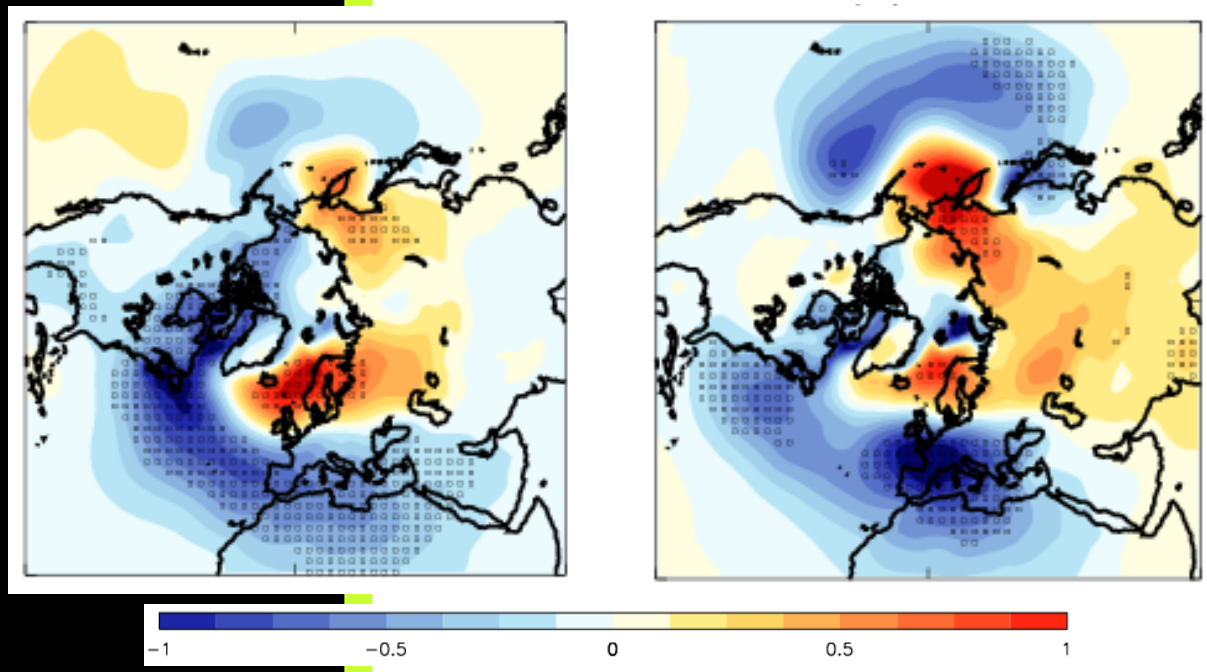
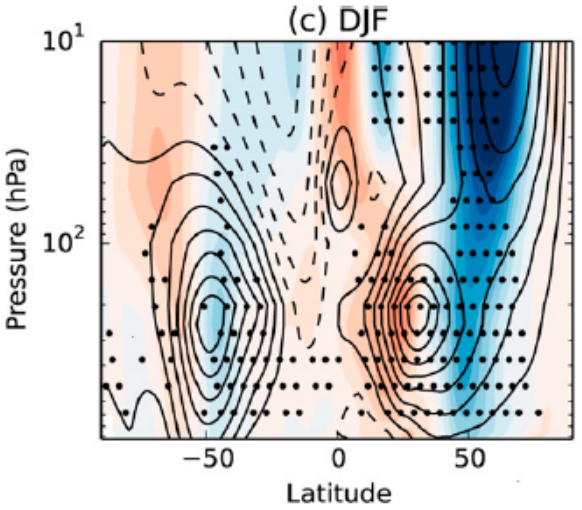
COUPLED

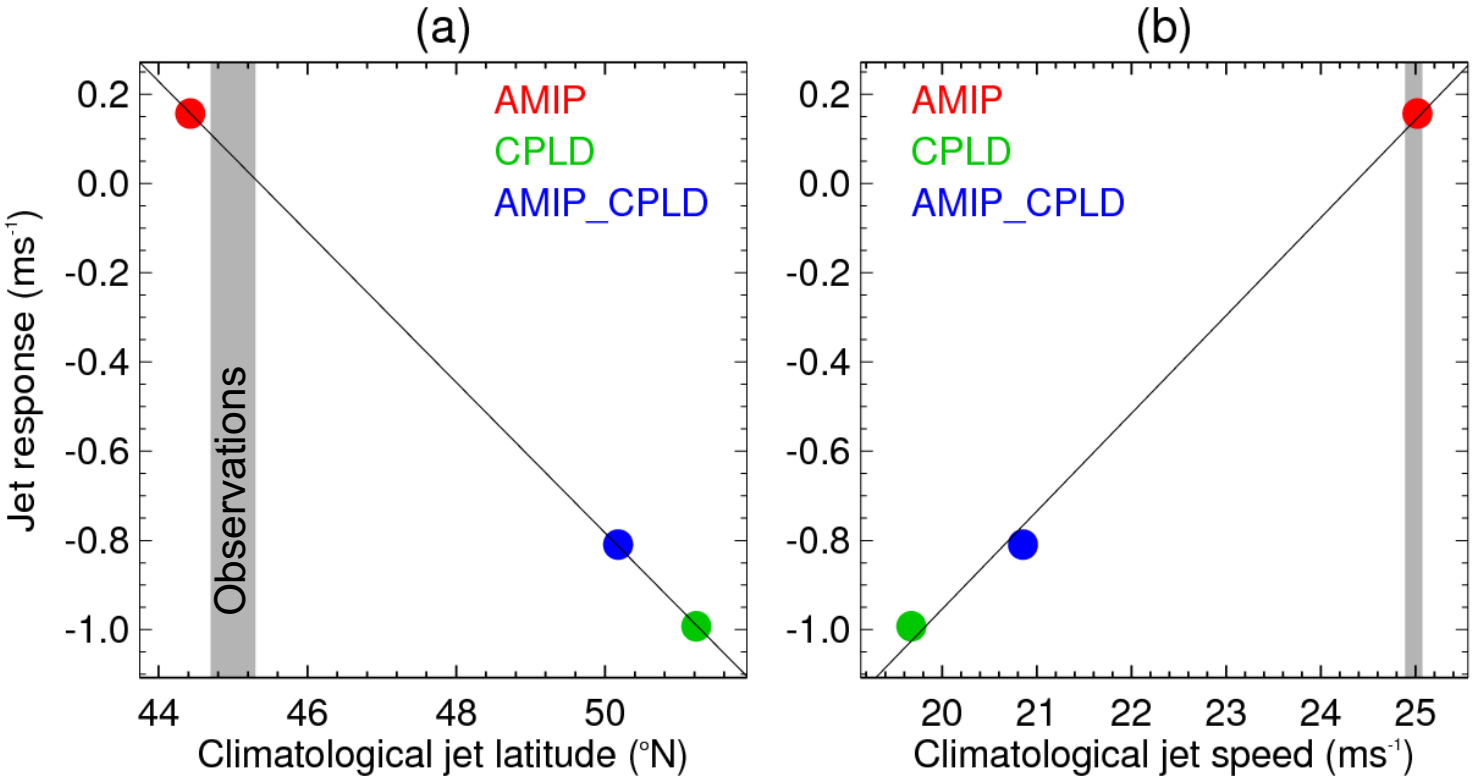
AMIP_CPLD





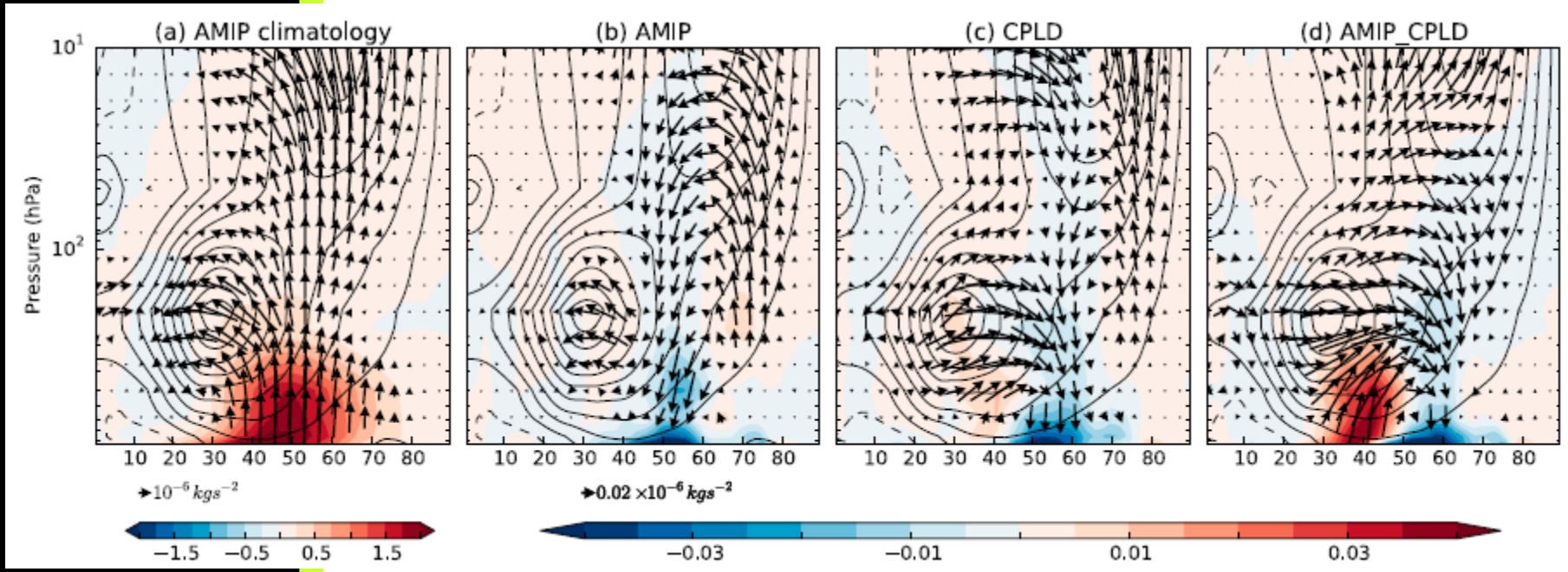
- COUPLED model response reproduced by AMIP_CPLD
- Background state is key

Response depends on Atlantic jet?



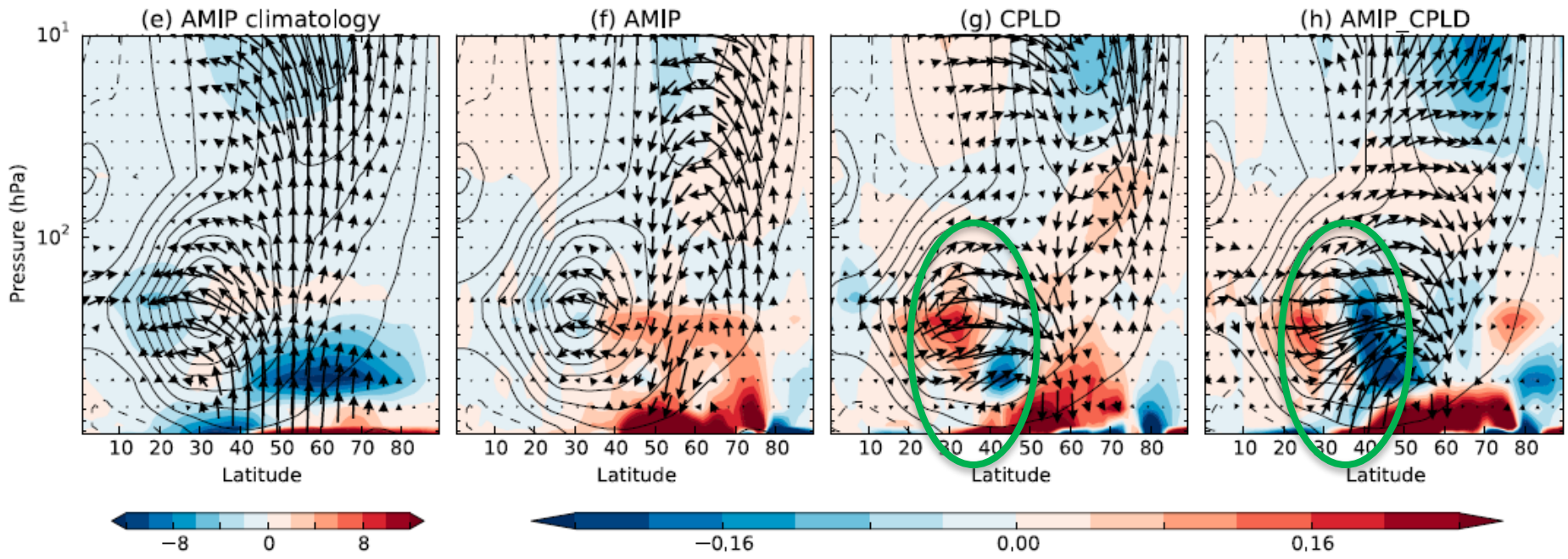
- Stronger weakening of jet if jet is more poleward
- …or weaker
- AMIP is closest to observations (grey shading)

EP flux response (upward)



- Reduced upward EP flux in all experiments (in contrast to many studies)
- Consistent with reduced Equator to pole temperature gradient

EP flux response (divergence)



- CPLD and AMIP_CPLD: EP flux divergence (convergence) on equatorward (poleward) flank of jet
- Southward shift, -ve NAO

Role of refractive index

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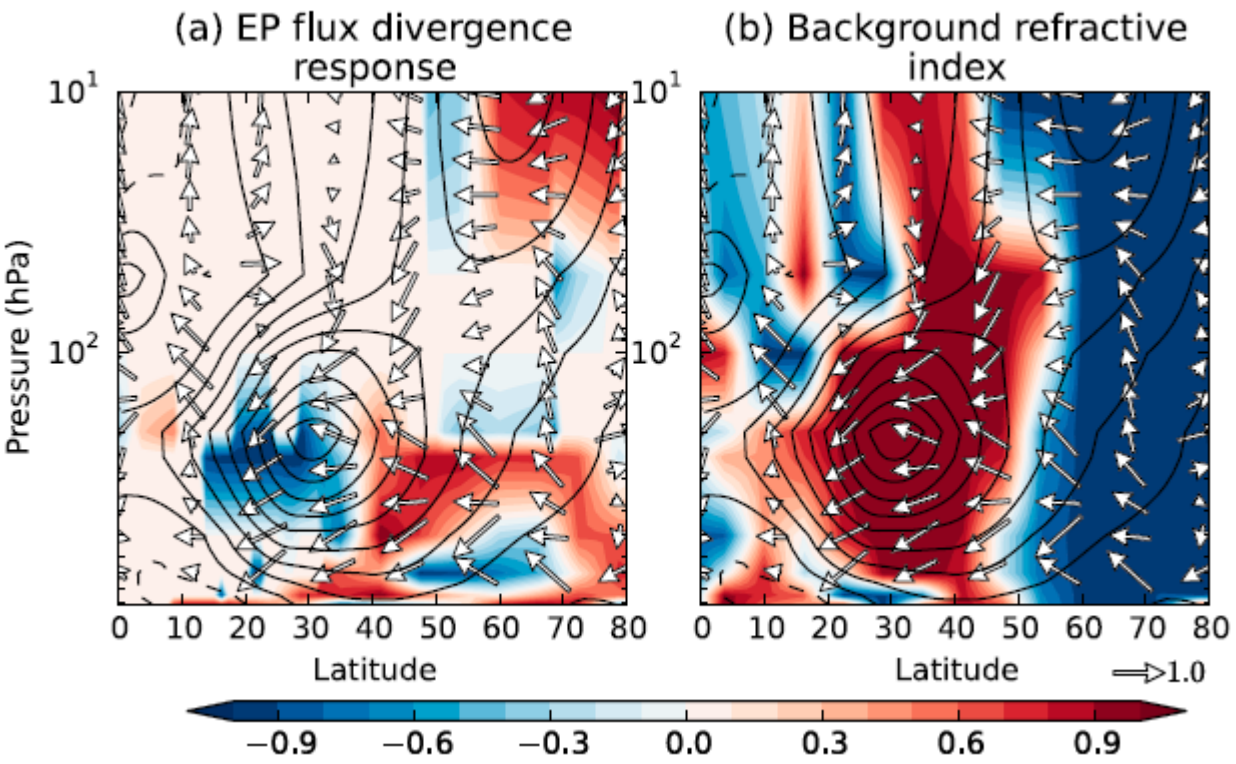
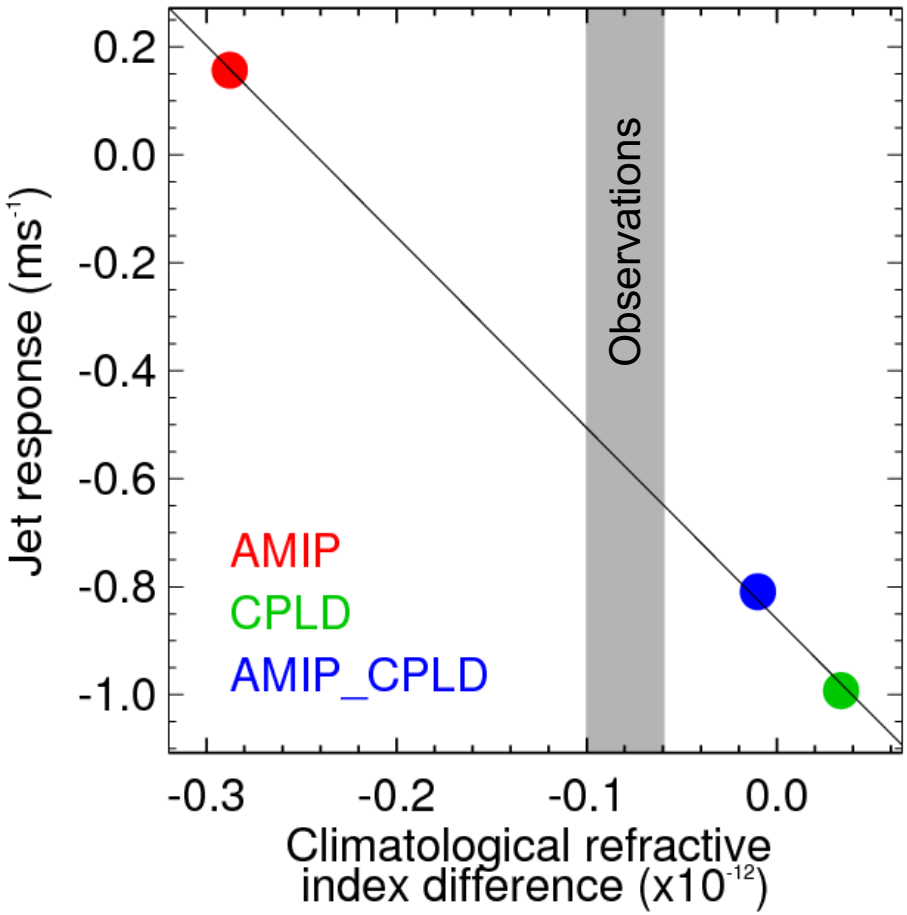
Correlation across AMIP, CPLD and AMIP_CPLD of jet response to *increased* sea ice



Easier to visualise response to *increased* se ice

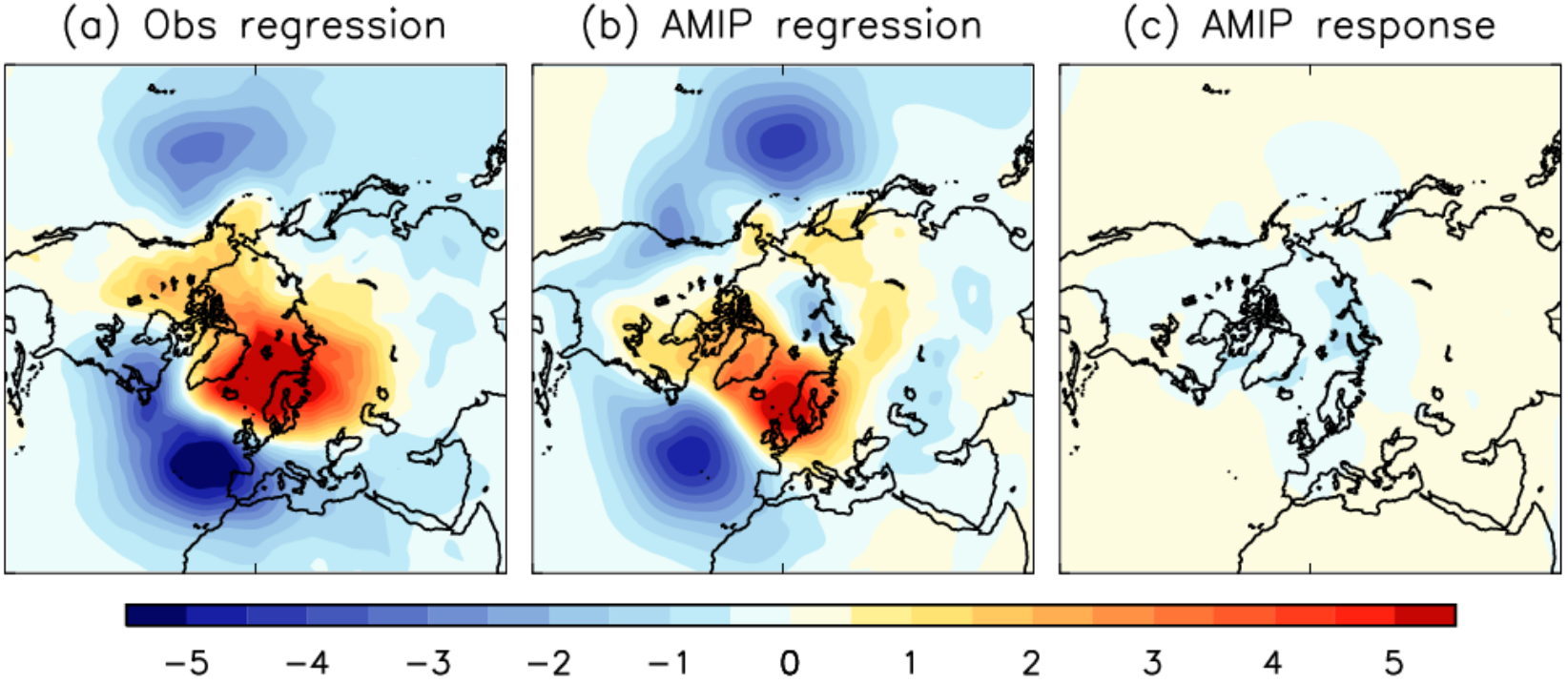
- **Increased wave flux**
- **Propagation depends on climatological refractive index**
- **EP flux divergence (convergence) on poleward (equatorward) flank of jet**
- **Poleward shift of jet, +ve NAO**

Constraint based on refractive index



- Response depends on wave propagation, and hence refractive index (difference between mid (25-35°N) and high (60-80°N) latitudes at 200 hPa
- Observations (grey shading) closer to CPLD than AMIP, supporting –ve NAO response
- Need more models → coordinated multi-model experiments (PA-MIP)

Caution: response cannot be diagnosed by regression



- Regression between autumn (SON) sea ice extent and winter (DJF) sea level pressure (sign reversed)
- Obs and AMIP agree
- BUT AMIP response to reduced sea ice is completely different

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Summary

- Coupling enables remote SST response → Atlantic ITCZ and **Sahel rainfall, hurricanes**
- Sign of NAO response to Arctic sea ice depends on the climatological background (e.g. **model bias**)
- Reduced sea ice results in **reduced upward wave flux** (in contrast to several other studies)
- Response depends of the background **refractive index** (difference between mid and high latitudes in upper troposphere)
- Constraint based on refractive index supports –ve NAO
- But more models needed (**PA-MIP**)
- CAUTION: response cannot be diagnosed from regression (and hence from observations alone)