Impact of regionally increased CO2 concentrations in coupled climate simulations

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Motivation

Everybody knows: **Arctic sea ice has been strongly declining** over the last 3 to 4 decades

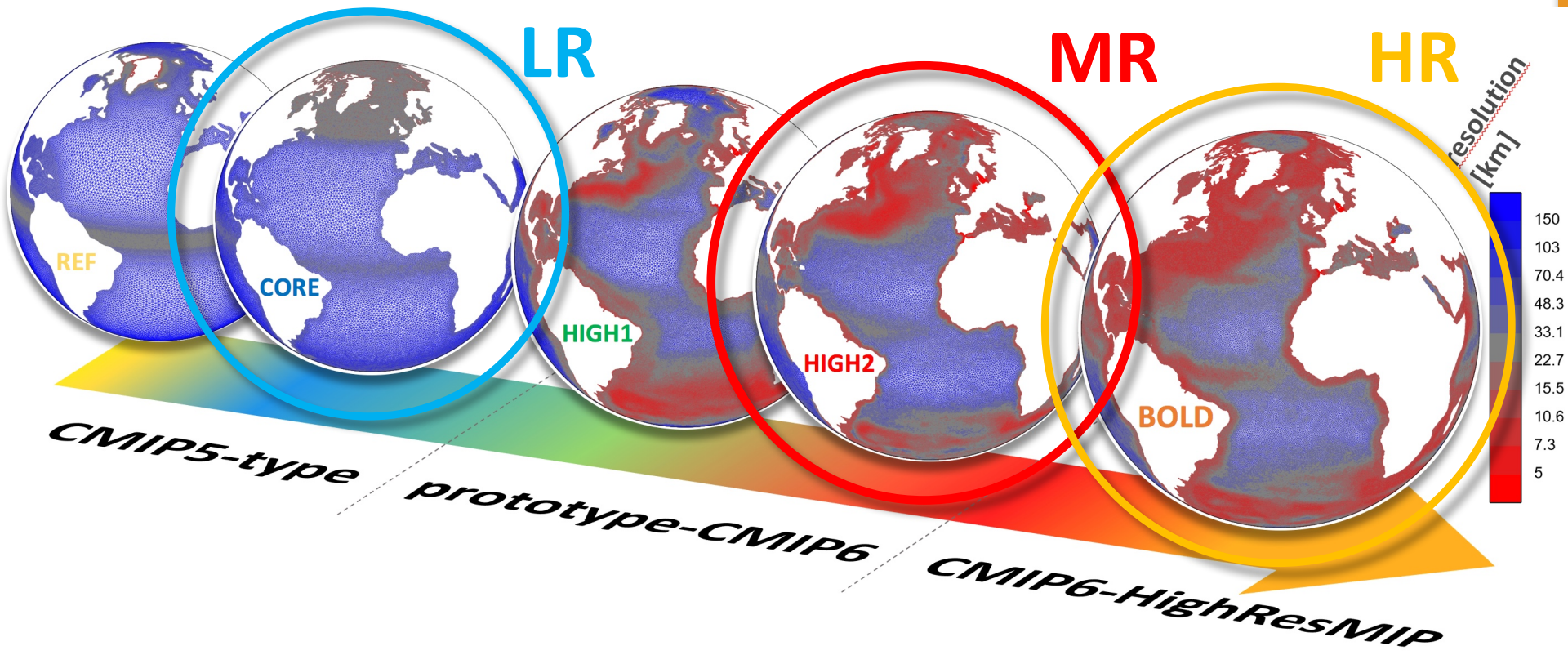
Many studies have investigated **the impact of such Arctic sea ice decline** on the Northern mid-latitudes

But which influence is stronger:
from the Arctic to the Northern mid-latitudes or the other direction?

Novel approach:
regionally prescribe 4*CO2 concentrations (recently applied by Stuecker et al., 2018)

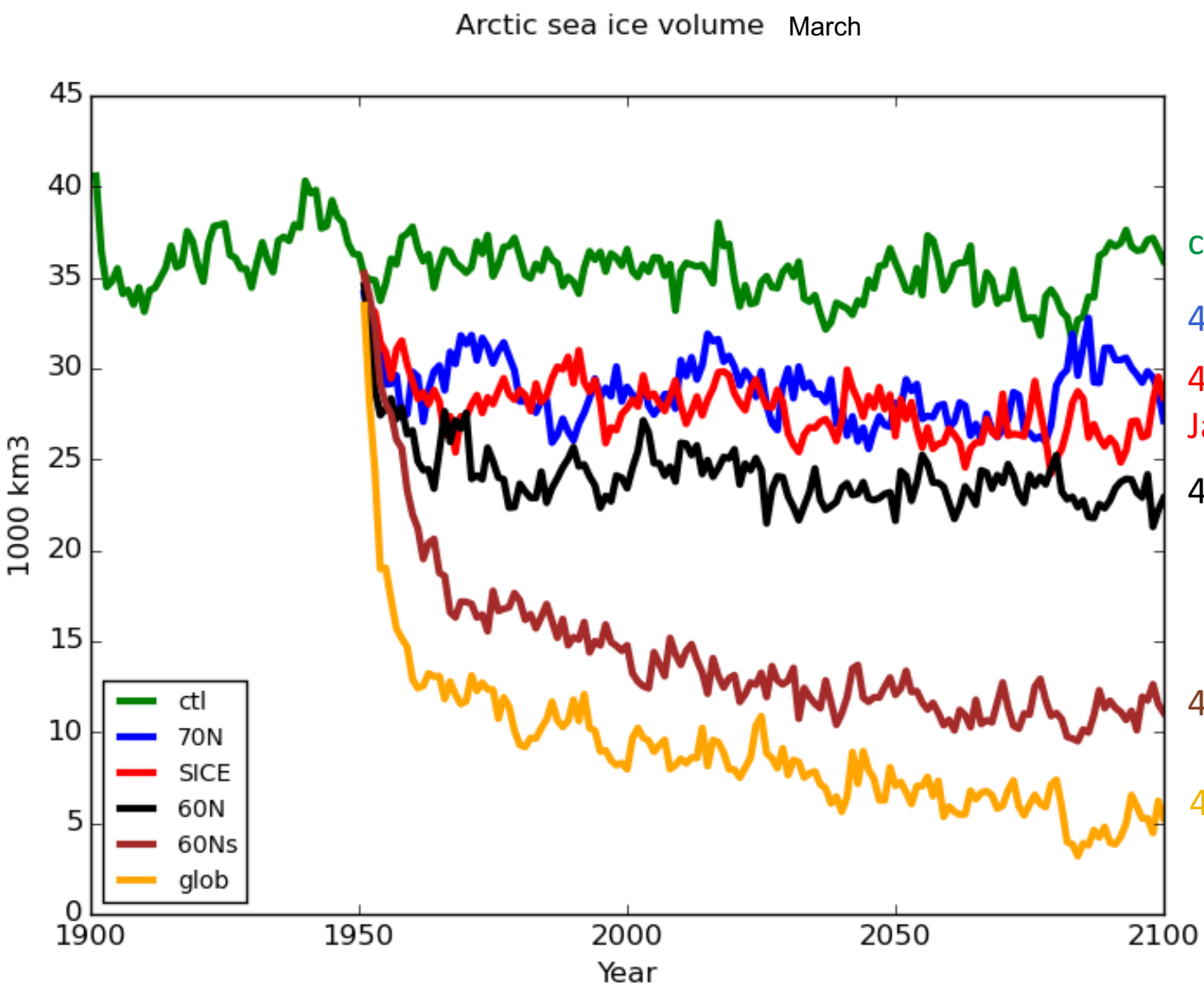
The tool: AWI-CM 1.1 (CMIP6 version)

- ECHAM 6.3 (from Max Planck Institute) coupled to FESOM 1.4 (AWI ocean model)
- Flexible mesh layout – examples:



Rackow et al. (2018)

Experiments



control

4*CO2 north of 70N

4*CO2 north of January ice edge

4*CO2 north of 60N

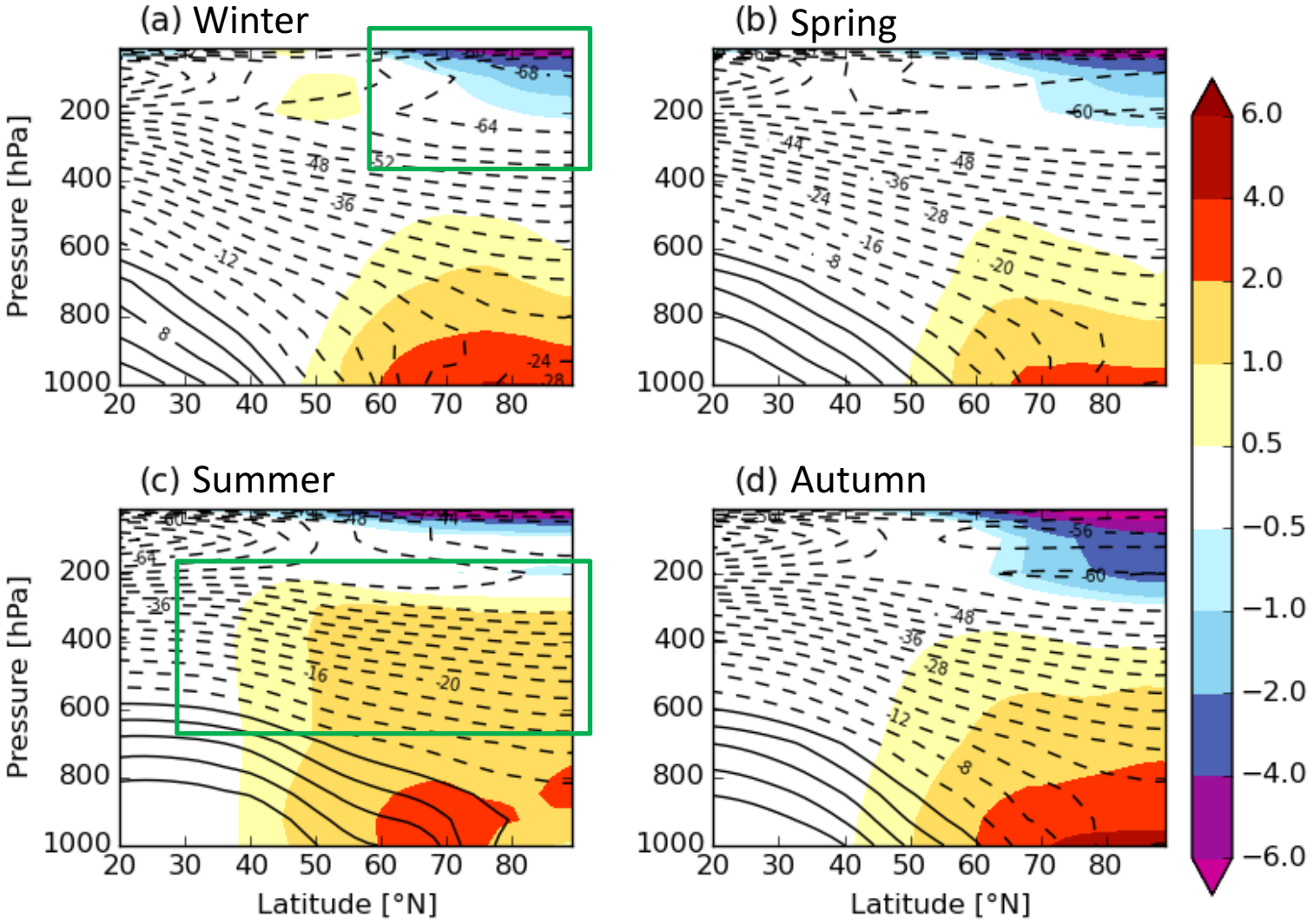
4*CO2 south of 60N

4*CO2 globally

Response in the temperature profile

4*CO2 north of 60 N for the first 30 years

Warming restricted to near-surface, except for summer



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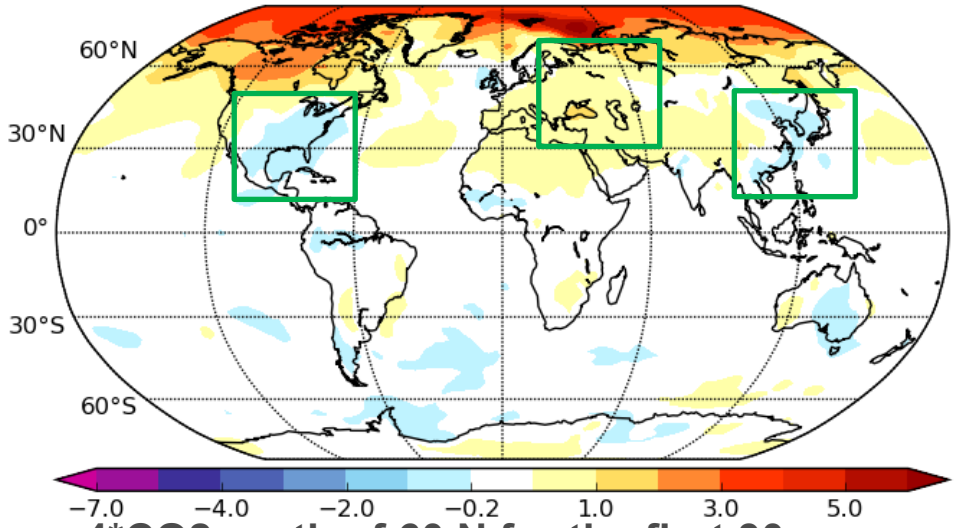
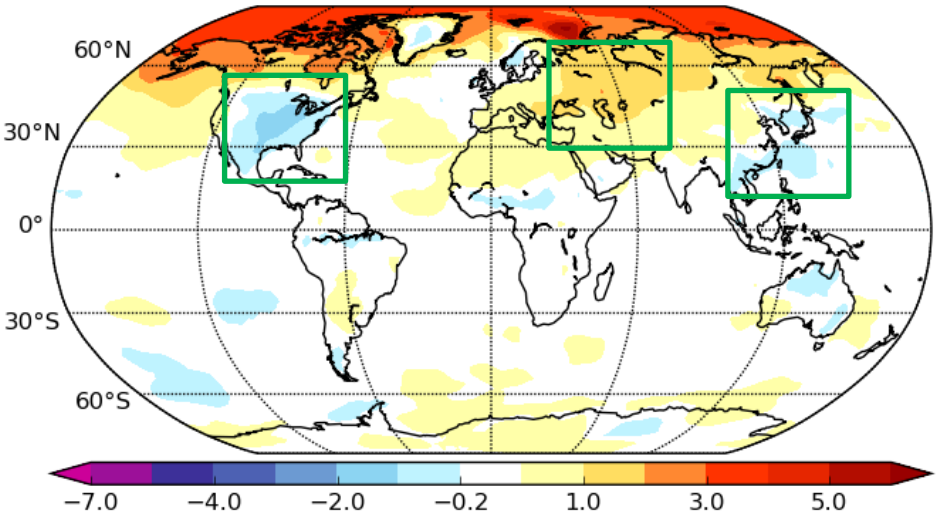
Winter 2 m temperature response (K)

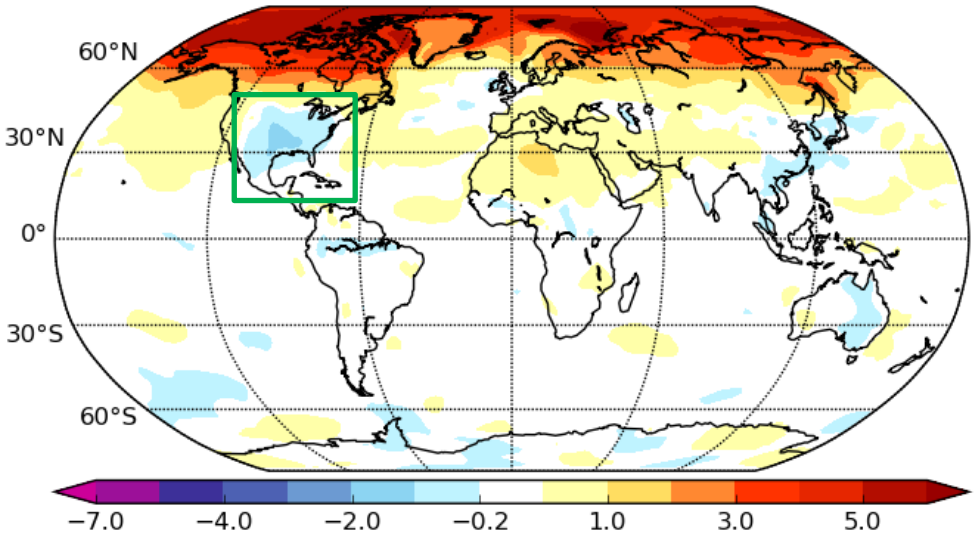
4*CO2 north of 70 N for the first 30 years



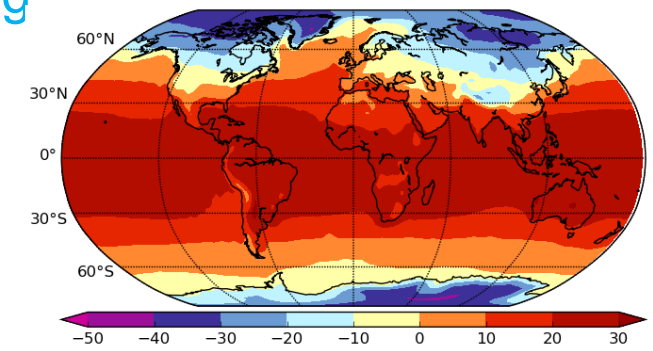
4*CO2 north ice edge for the first 30 years



4*CO2 north of 60 N for the first 30 years



North America and East Asia cooling without stratospheric warming



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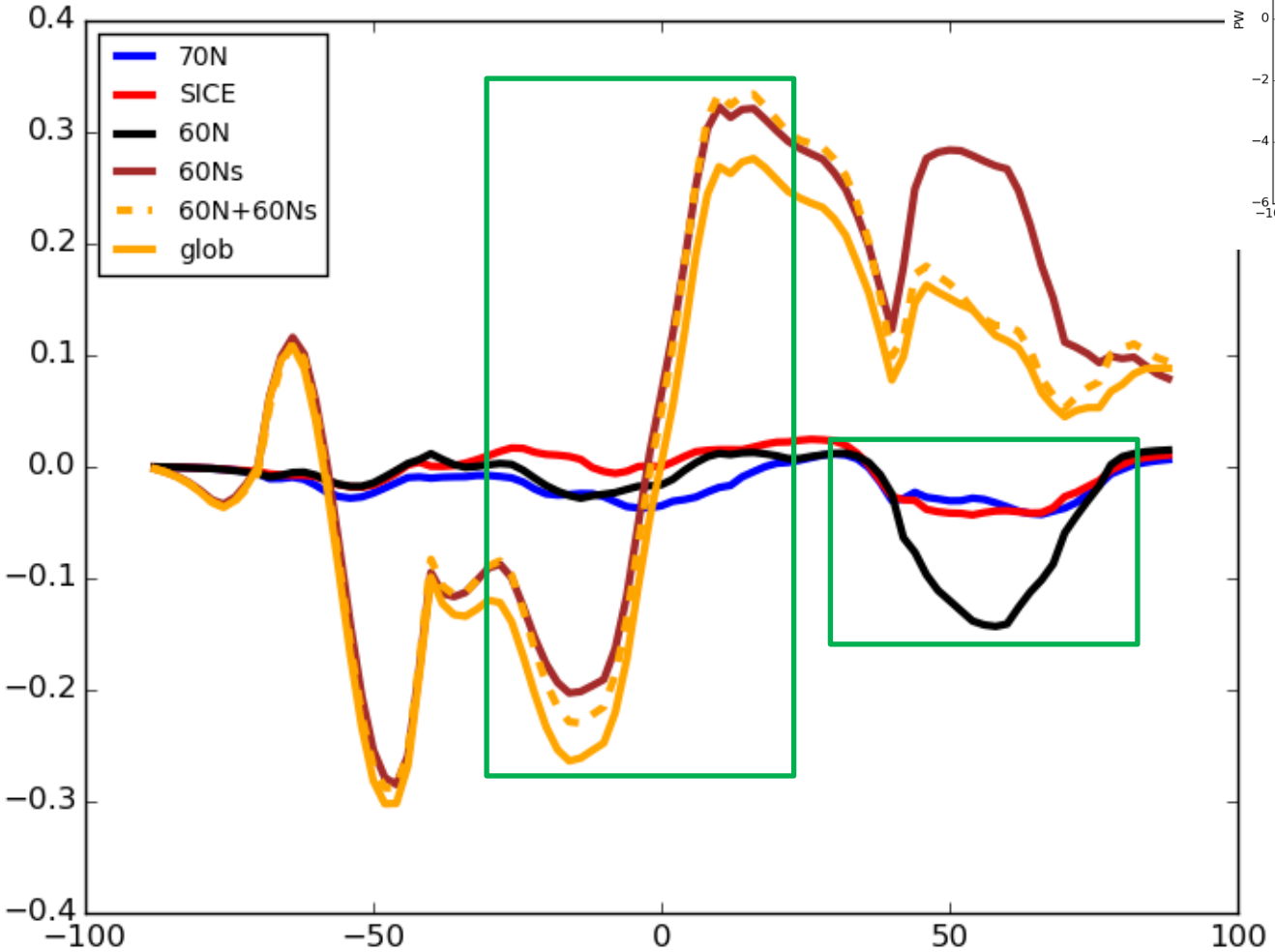
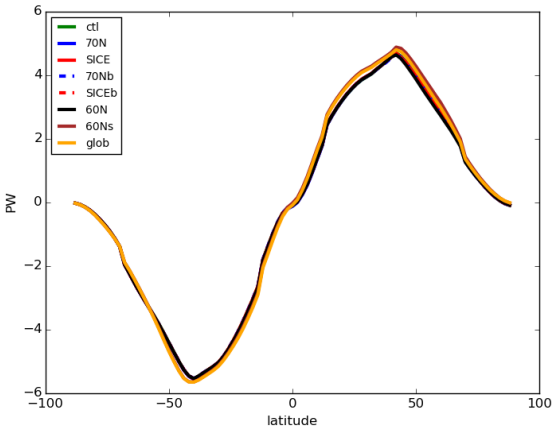
Meridional atm. energy transport (PW)

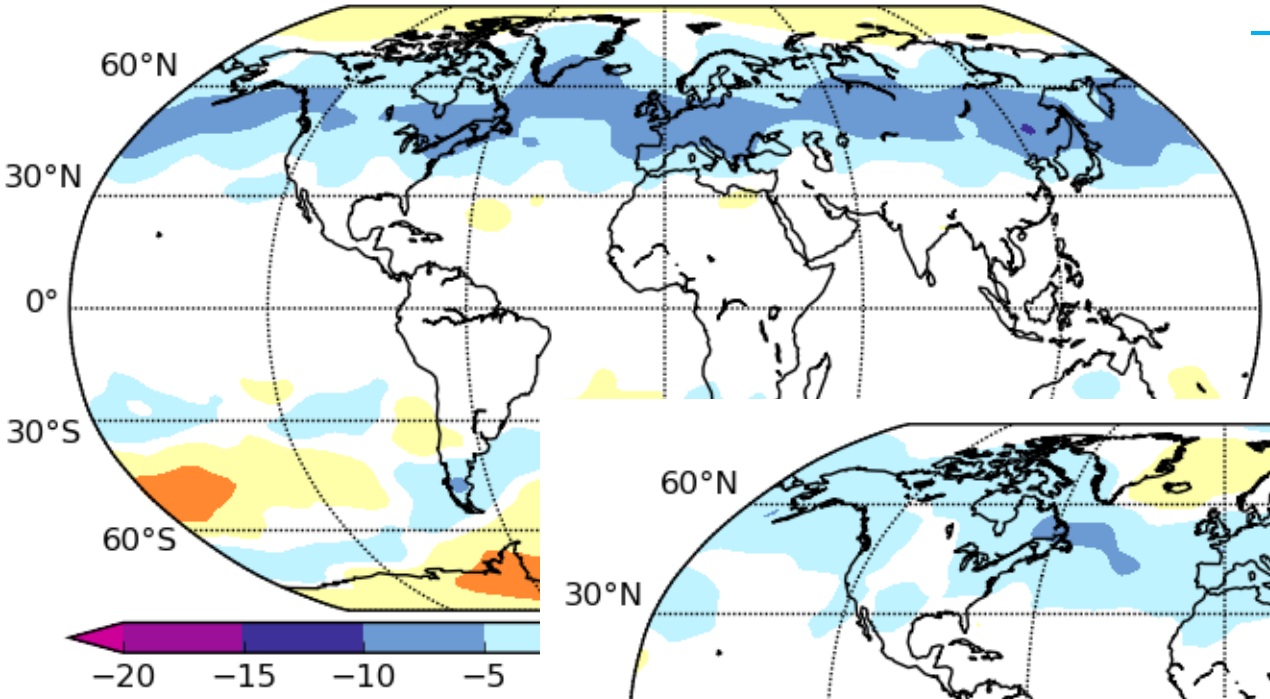
Difference to control simulation, first 30 years

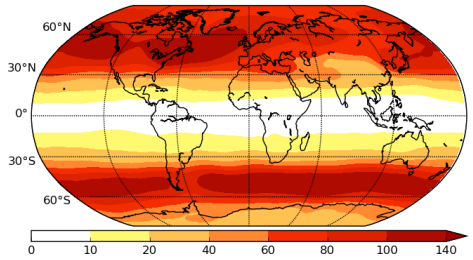




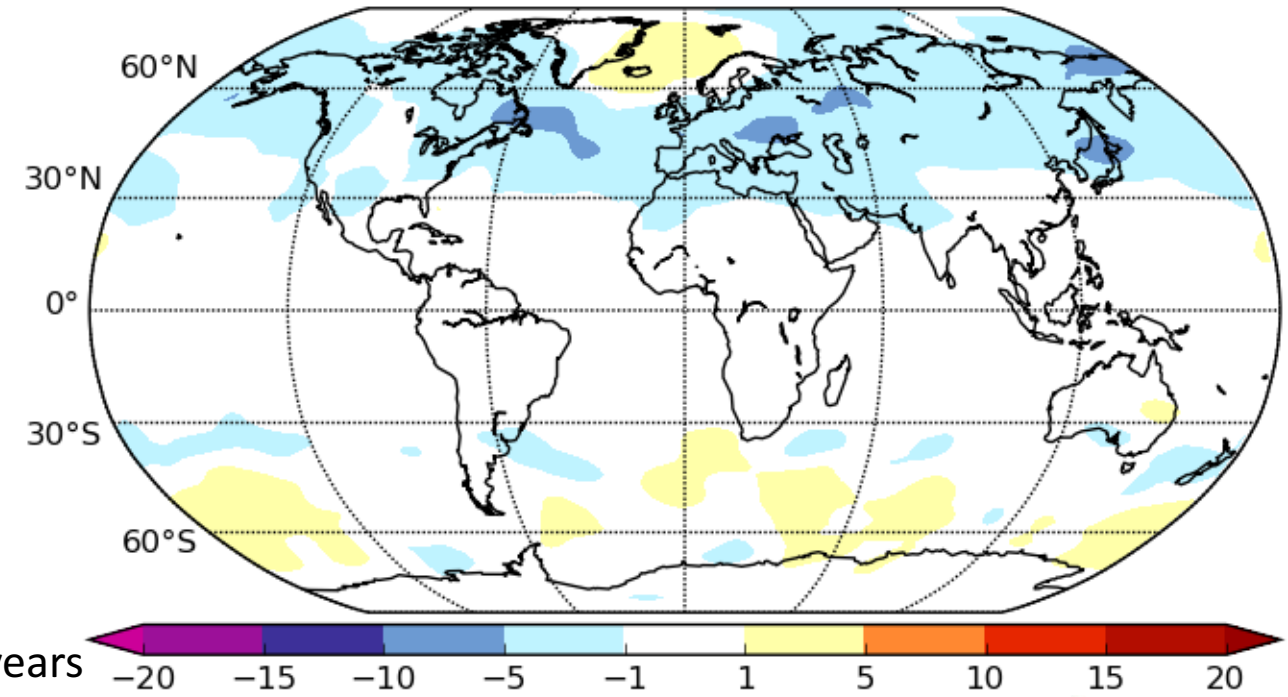
Synoptic activity 500 hPa (m)

4*CO2 north of 60 N, DJF





Last 120 years



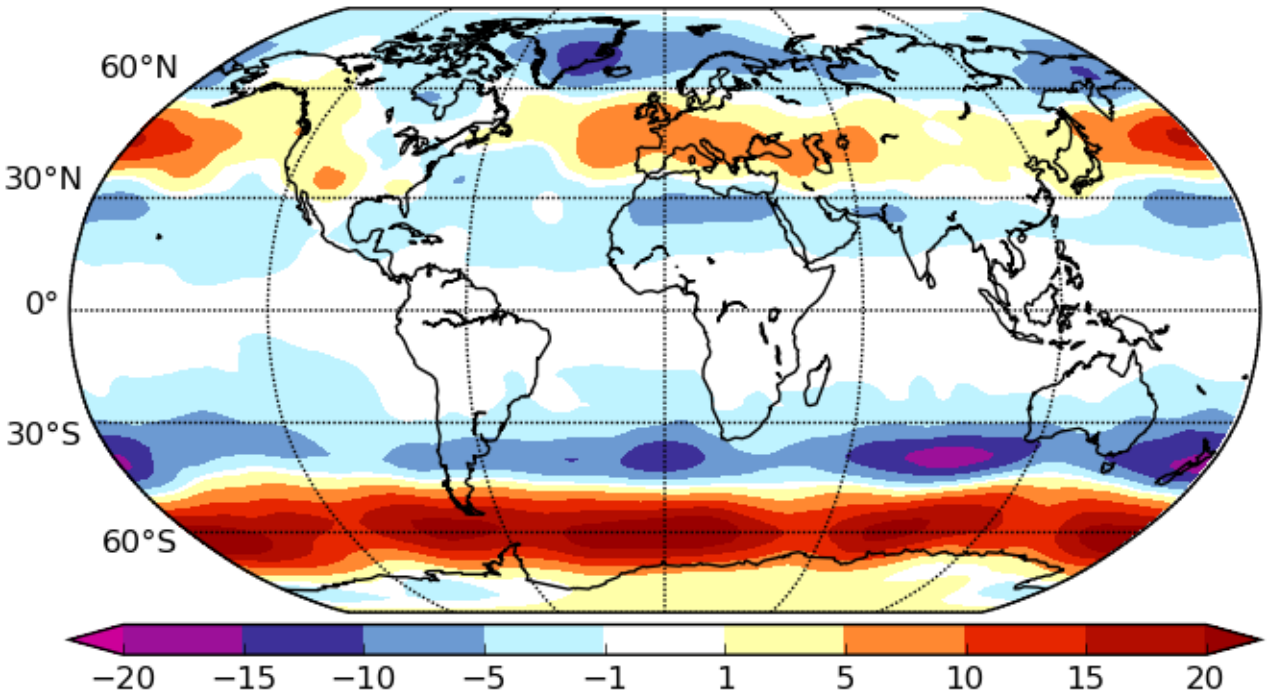
Less exchange Arctic – extra Arctic

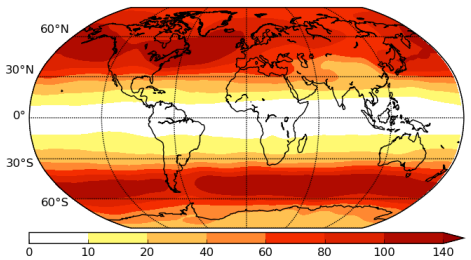
First 30 years

Synoptic activity 500 hPa (m)

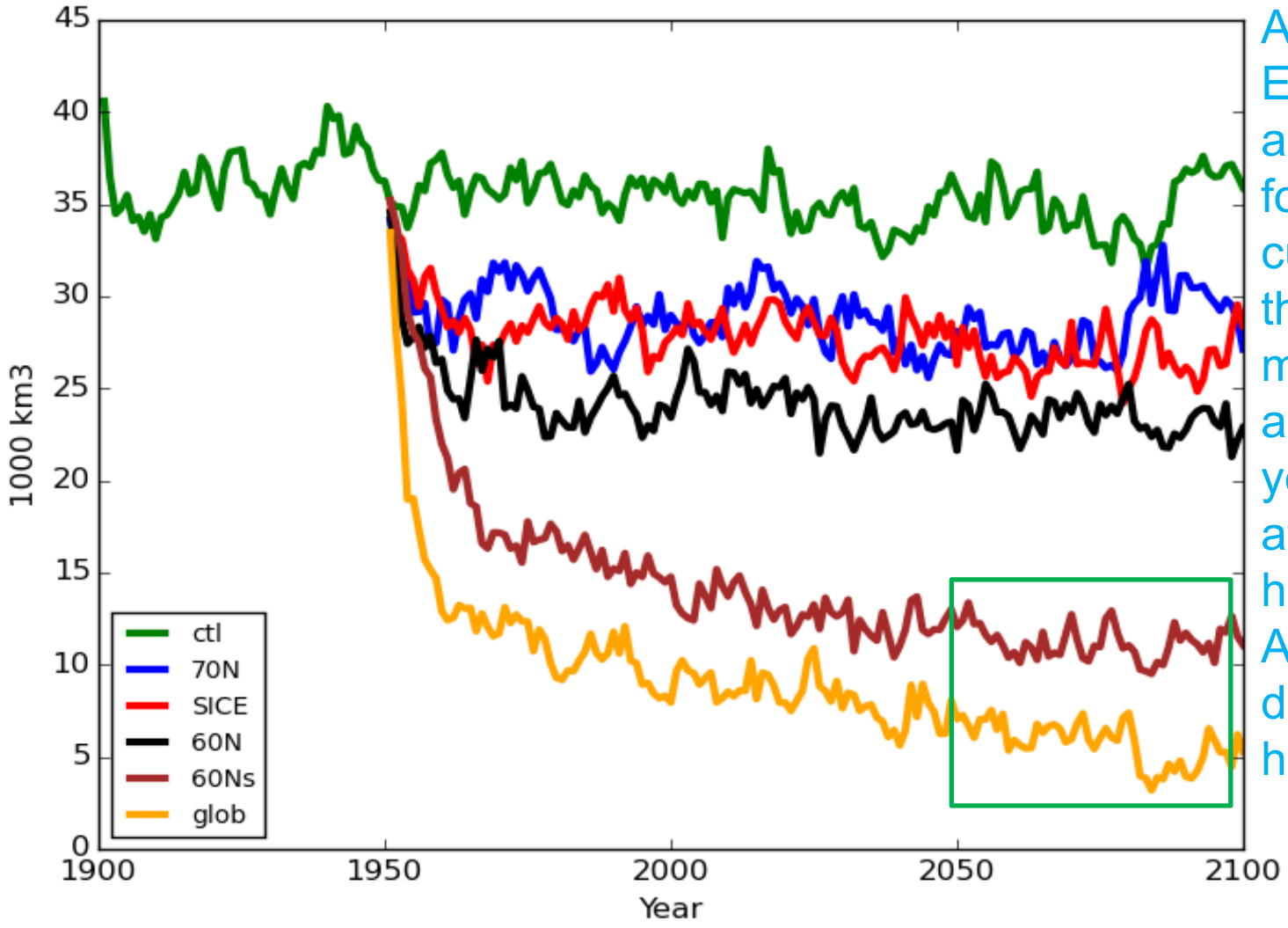
Redistribution of increase/decrease areas

First 30 years





Arctic sea ice volume in March



Strong extra-Arctic impact: Even without any Arctic forcing (brown curve) half of the sea ice is melted in around 15 years through atmospheric heat transport. Another sixth due to oceanic heat transport.

Energy fluxes 70°N

First 30 years	Surface	Meridional atmosphere	Meridional ocean
control	-11.7	102.9	13.8
60N	-10.5	98.6	14.6
60Ns	-10.6	106.8	17.8
glob	-9.7	101.1	18.8

Last 30 years	Surface	Meridional atmosphere	Meridional ocean
control	-13.0	101.6	15.2
60N	-12.7	96.3	16.2
60Ns	-14.8	103.9	20.0
glob	-13.2	98.5	19.1

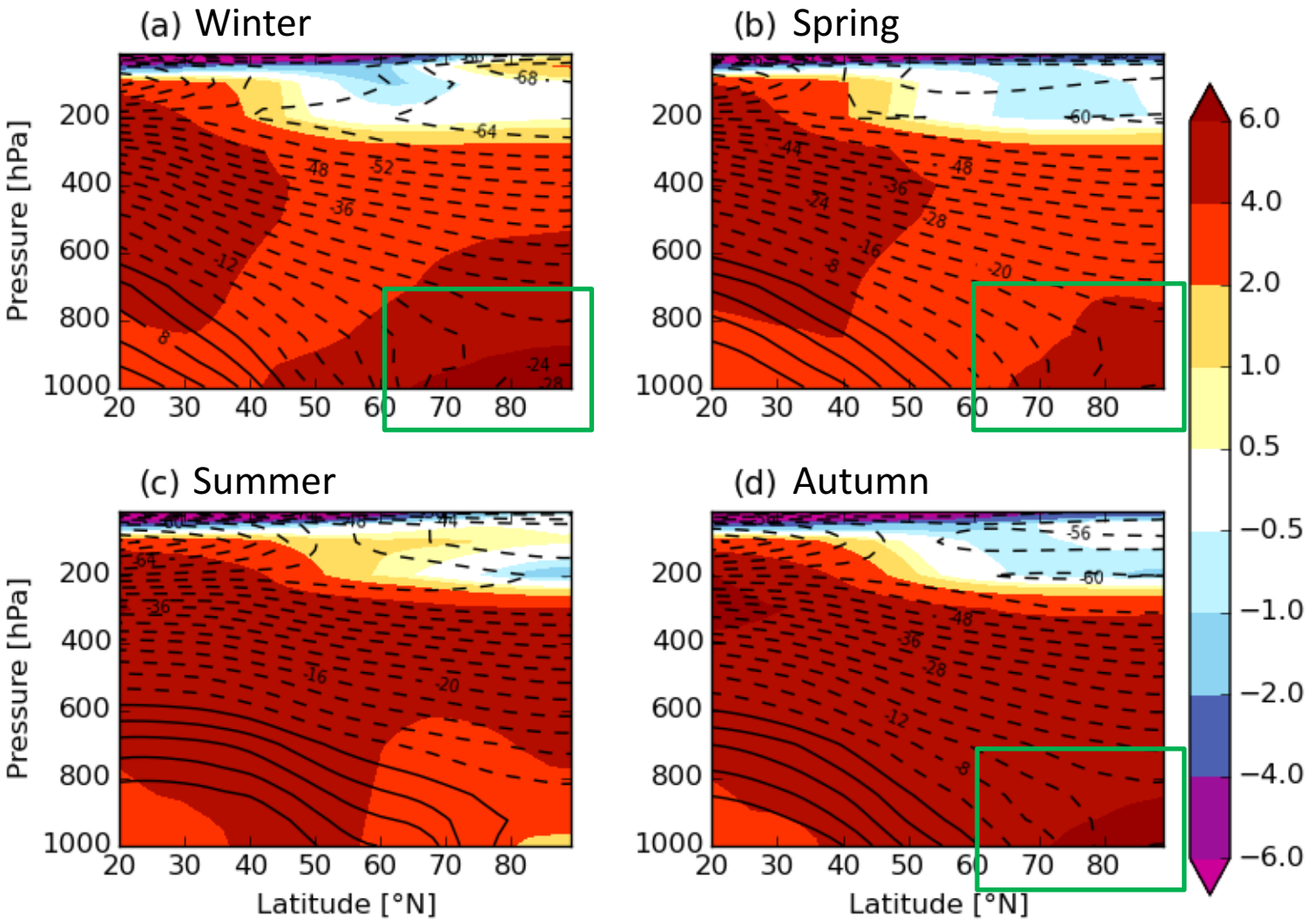
Meridional ocean transport small and meridional atmosphere transport large. However anomalies comparable.

Ocean plays important role in redistribution of energy when switching on extra-Arctic forcing

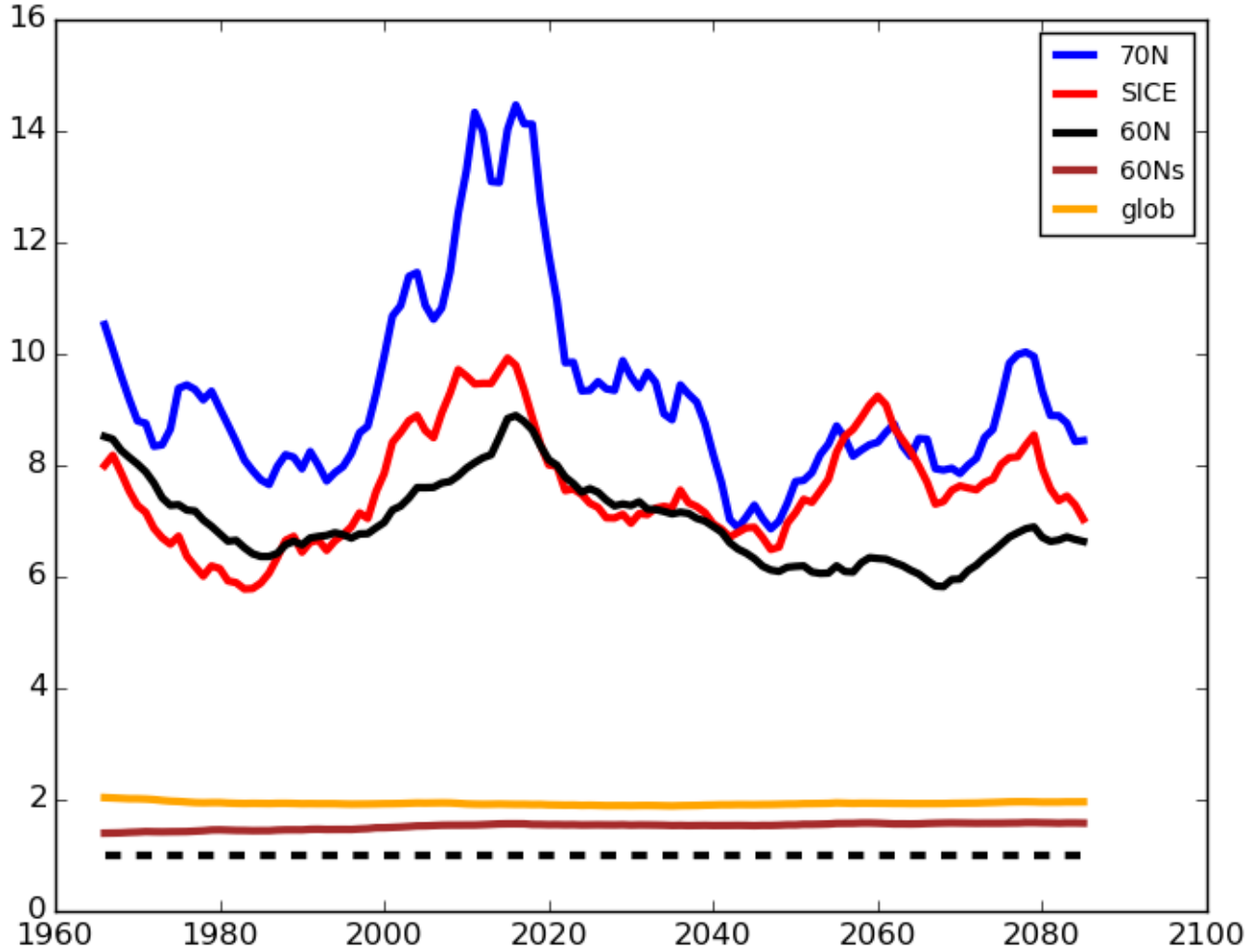
Response in the temperature profile

4*CO2 south of 60 N for the first 30 years

Arctic amplification without Arctic forcing except for summer!



Arctic Amplification Index (AAI)
(60°N Arctic temperature increase / global temperature increase)

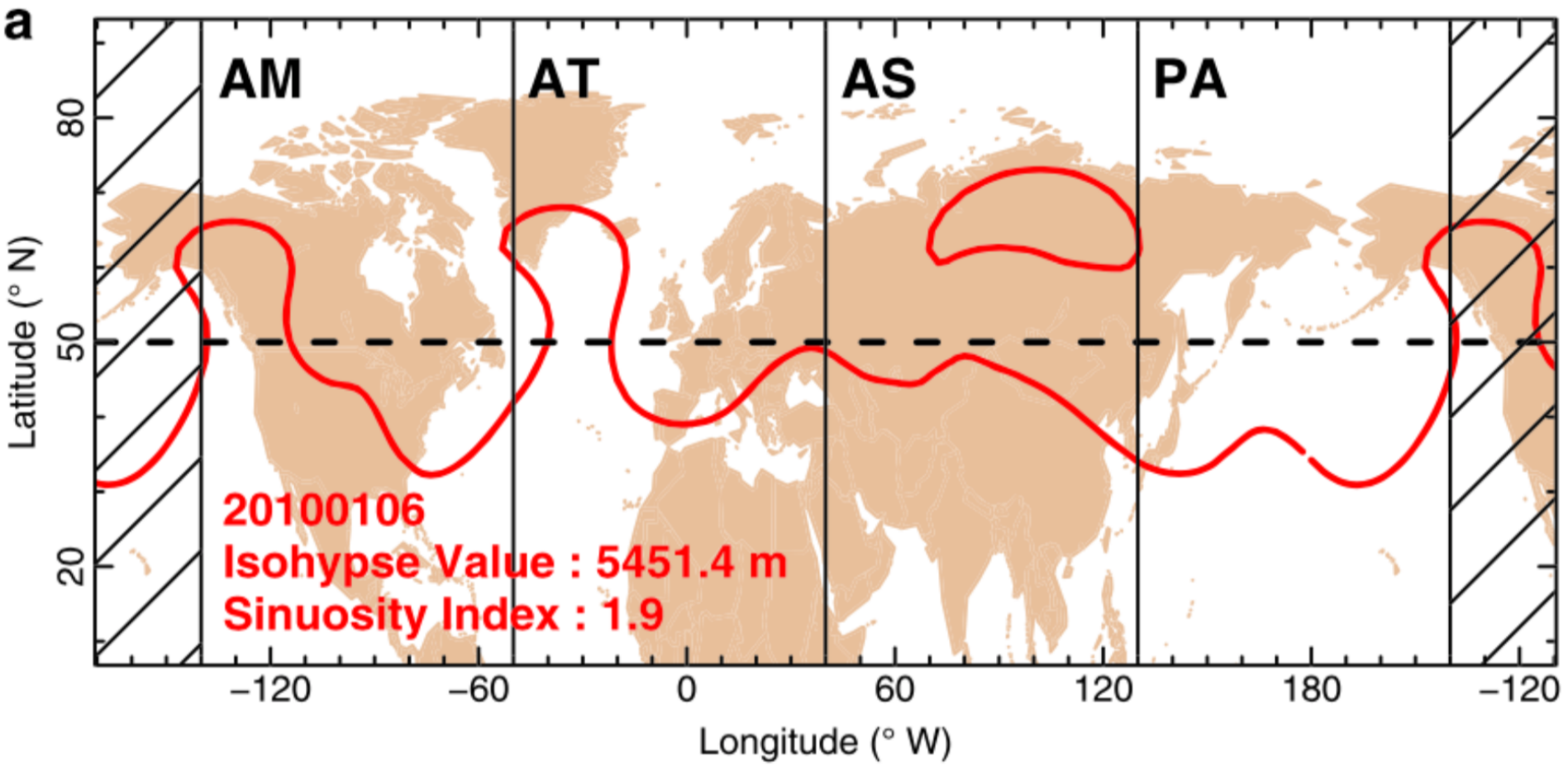


Note: AAI = 1: no Arctic Amplification

High AAI for Arctic forcing experiments

60% of Arctic Amplification due to northward energy transport

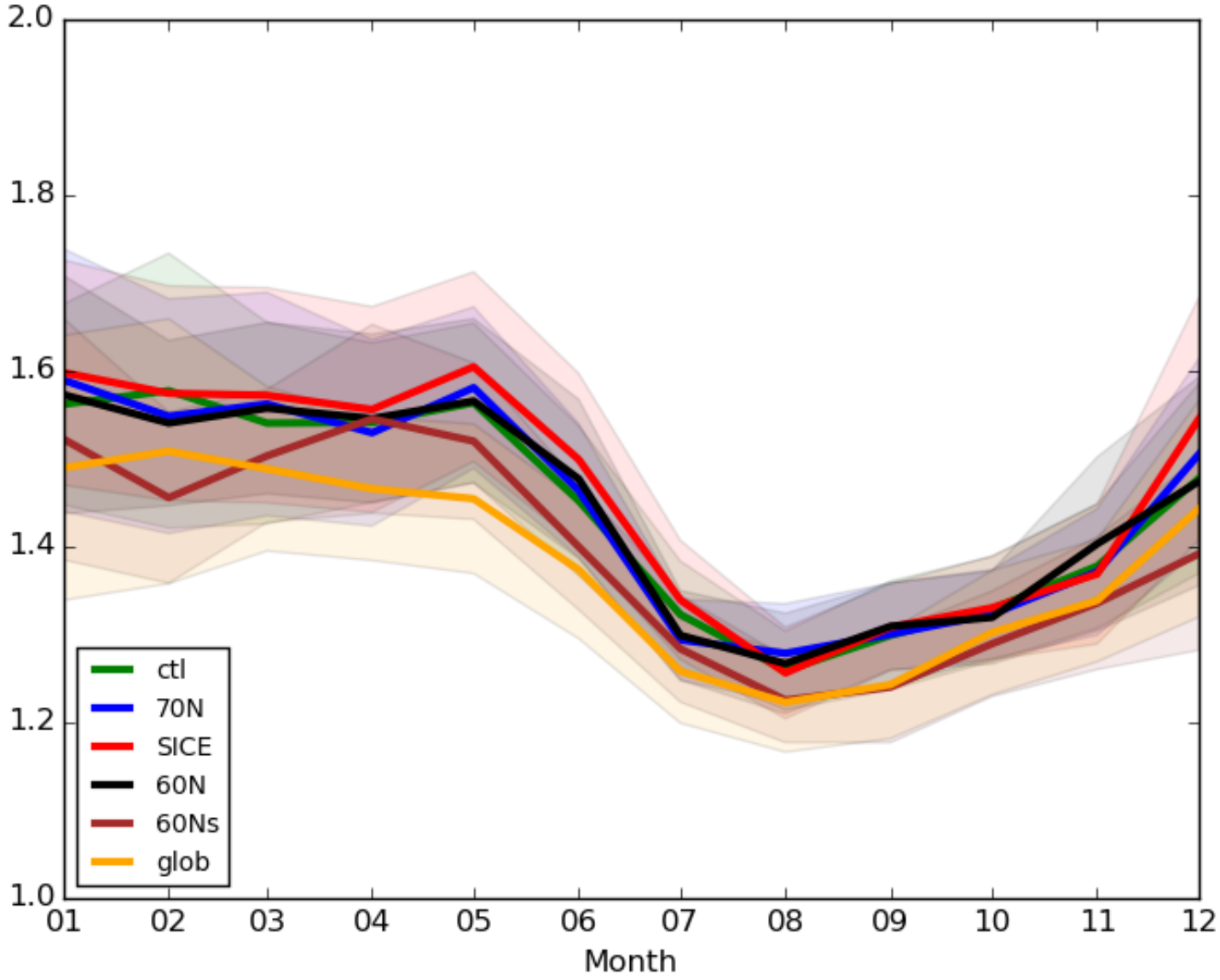
Sinuosity index (Cattiaux et al., 2016, GRL)



SI = length of isohypse / length of 50°N latitude circle

The chosen isohypse is the area average of Z500 over 30 to 70°N

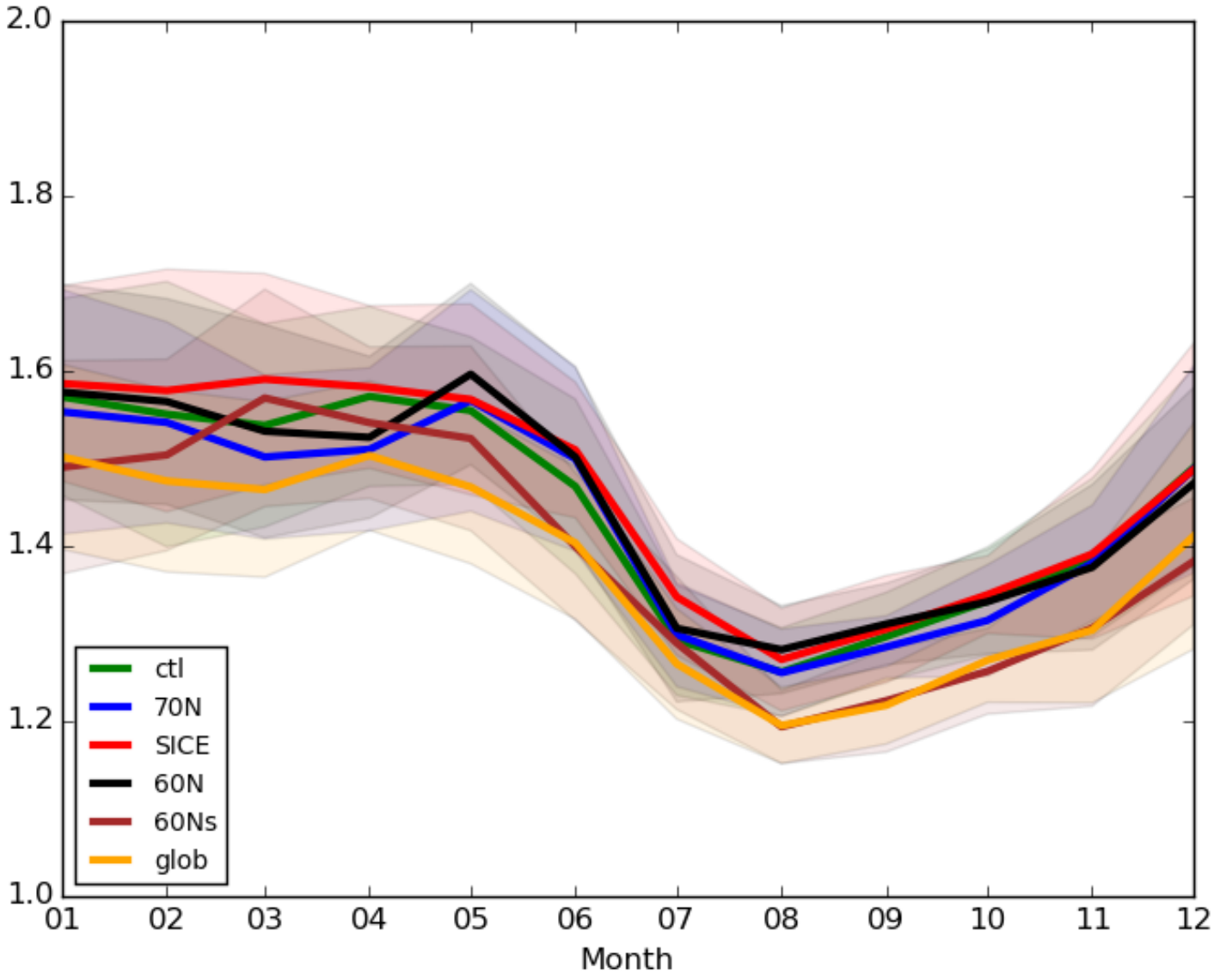
Sinuosity index NH first 30 years



Smaller sinuosity index throughout the year as a result of extra-Arctic forcing

Tendency to slightly larger sinuosity index in winter and spring as a result of Arctic forcing but signal not robust

Sinuosity index NH last 30 years



Smaller sinuosity index throughout the year as a result of extra-Arctic forcing

Tendency to slightly larger sinuosity index in winter and spring as a result of Arctic forcing but signal not robust

Conclusions

Method of regional decomposition of CO2 forcing works (see also Stuecker et al., 2018). Maybe an experiment design to be considered for PAMIP?

Above 300 hPa cooling rather than warming (expected!)

Generally despite strong CO2 forcing in the Arctic relatively little happens in the mid-latitudes, especially with increasing simulation length

The extra energy in the Arctic forcing experiments largely stays in the Arctic

If forcing only outside the Arctic, the energy transport into the Arctic is strongly increased with an increasing role of the ocean over the simulation time

Therefore, even without any Arctic forcing two thirds of the sea ice melt and Arctic Amplification exists: 60% of Arctic Amplification can be explained by extra-Arctic forcing!