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

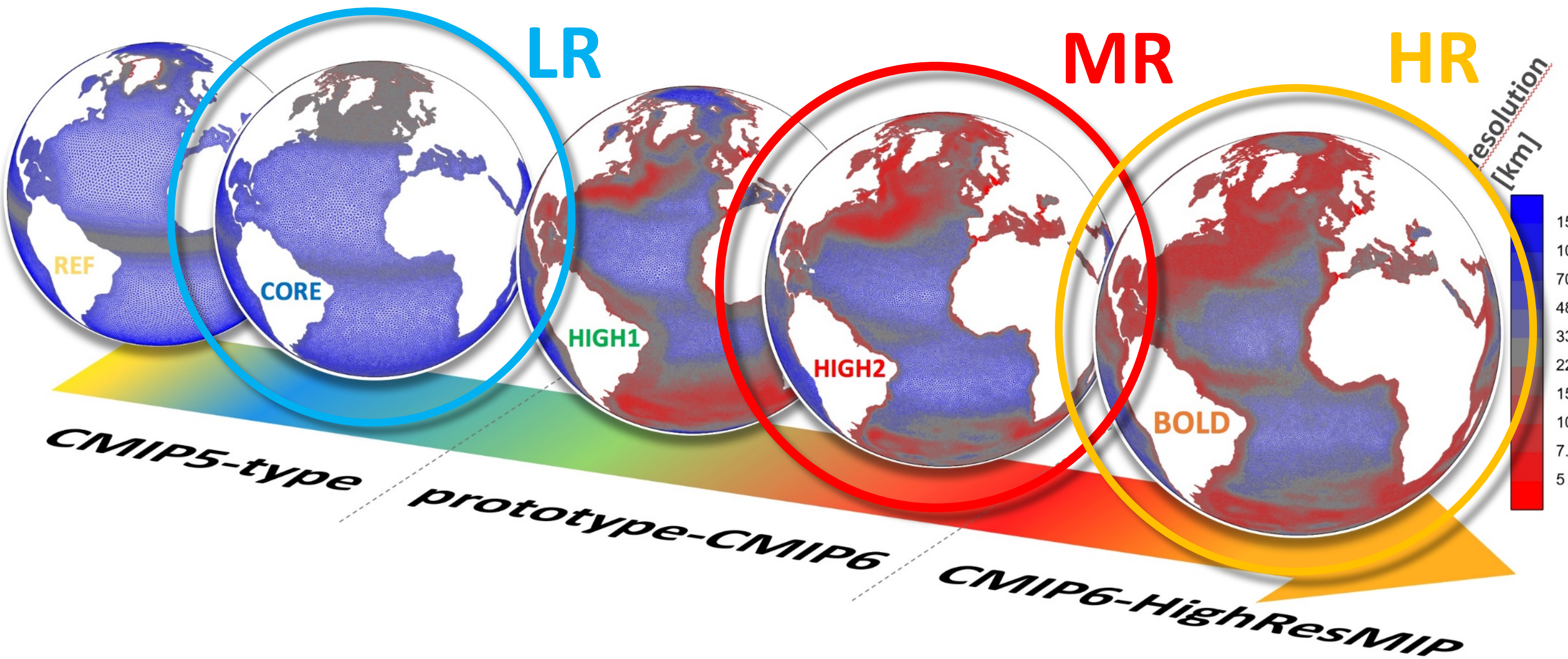
Many studies have investigated the impact of such Arctic sea ice decline on the Northern mid-latitudes

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

Novel approach:
regionally prescribe 4*CO2 concentrations

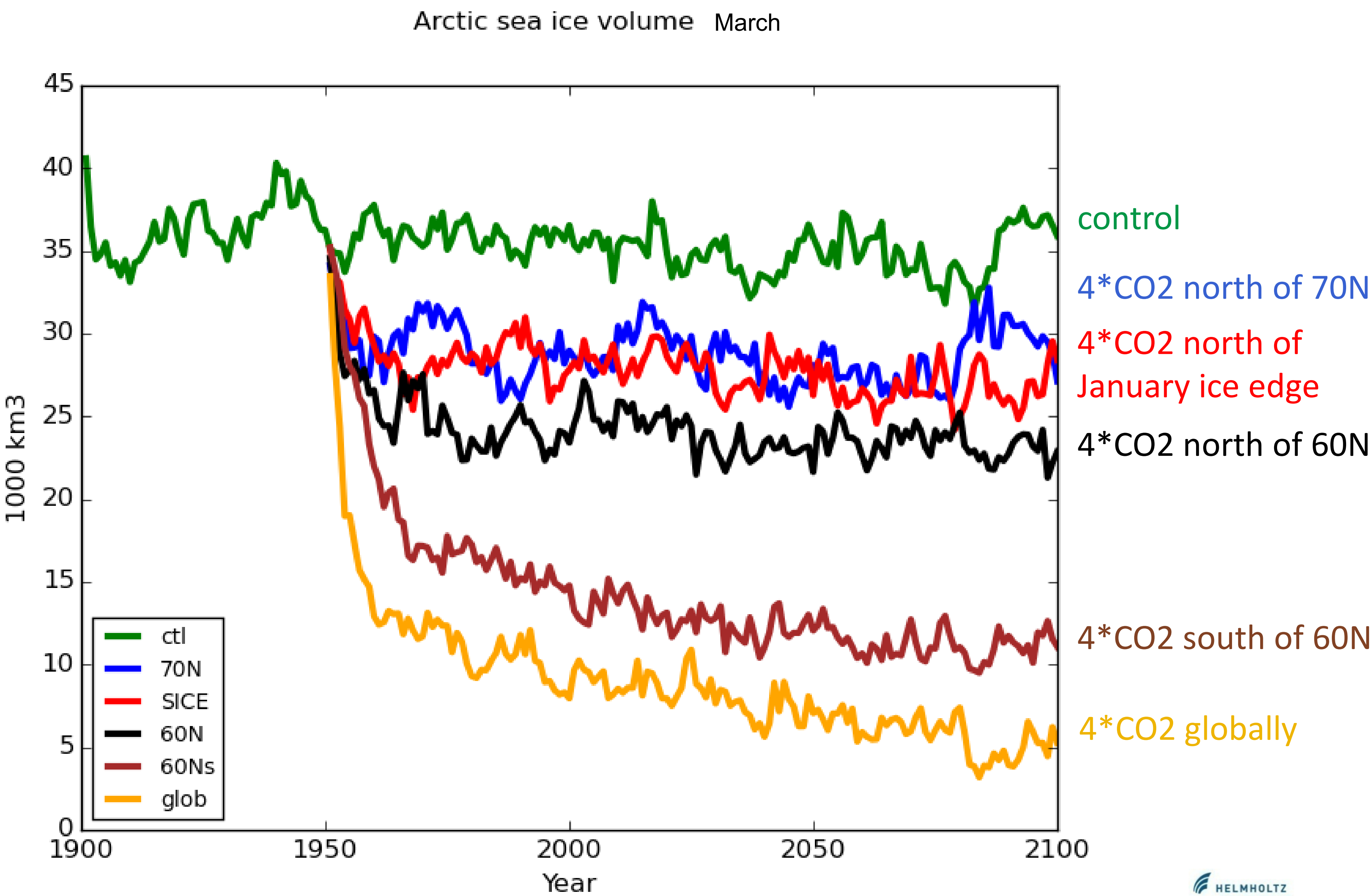
The tool: AWI-CM 1.1 (CMIP6 version)

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



Rackow et al. (2018)

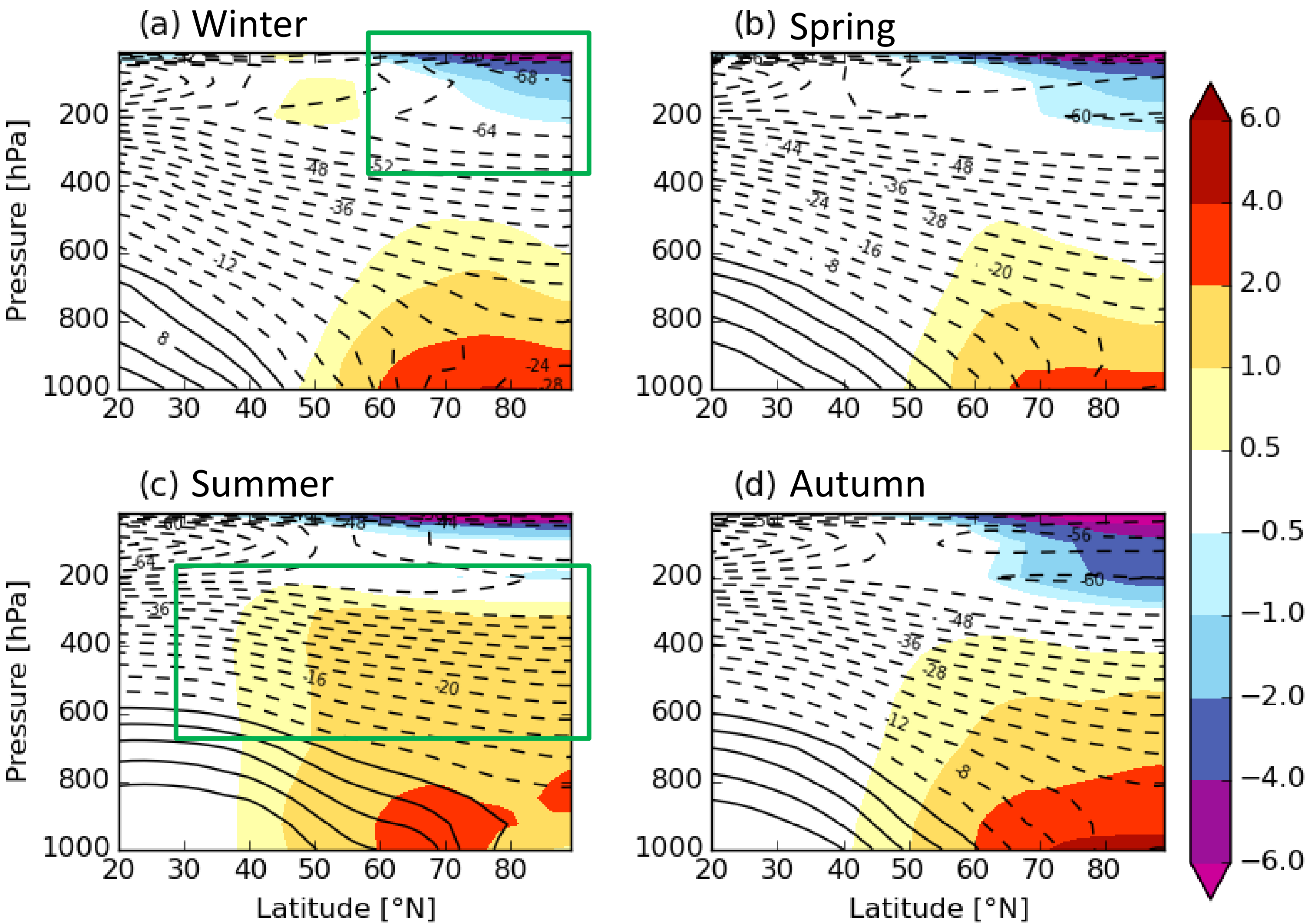
Experiments



Response in the temperature profile

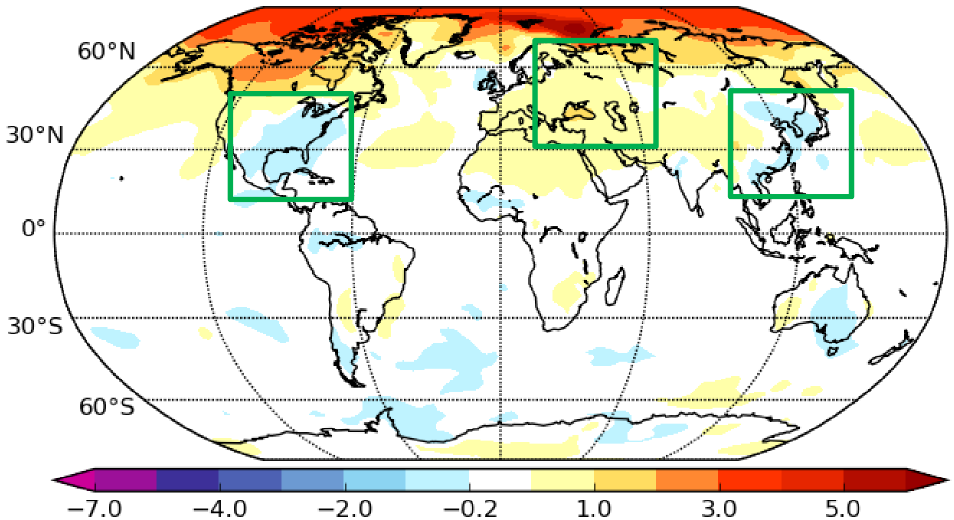
4*CO_2 north of 60 N for the first 30 years

Warming restricted to near-surface, except for summer

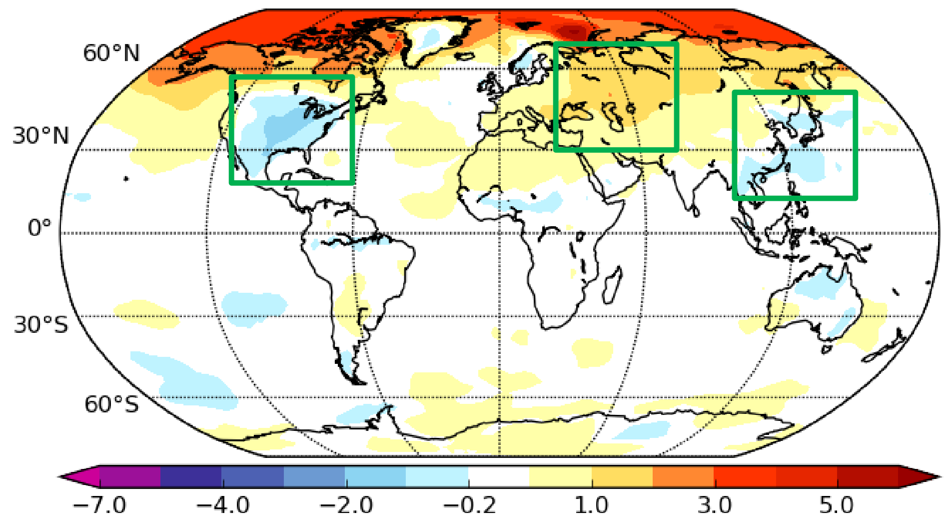


Winter 2 m temperature response (K)

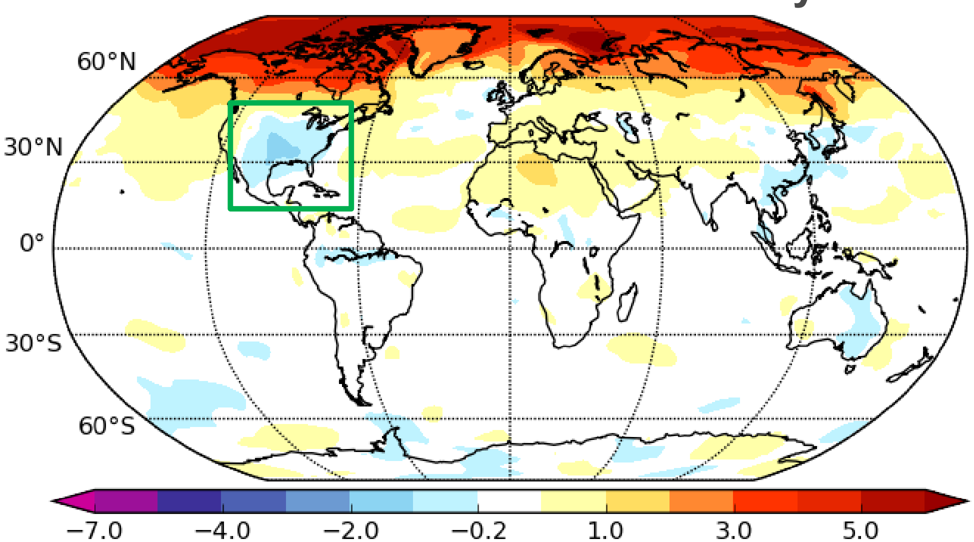
4*CO2 north of 70 N for the first 30 years



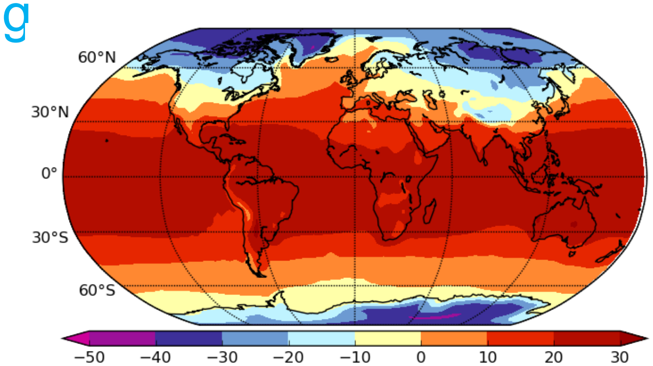
4*CO2 north ice edge for the first 30 years



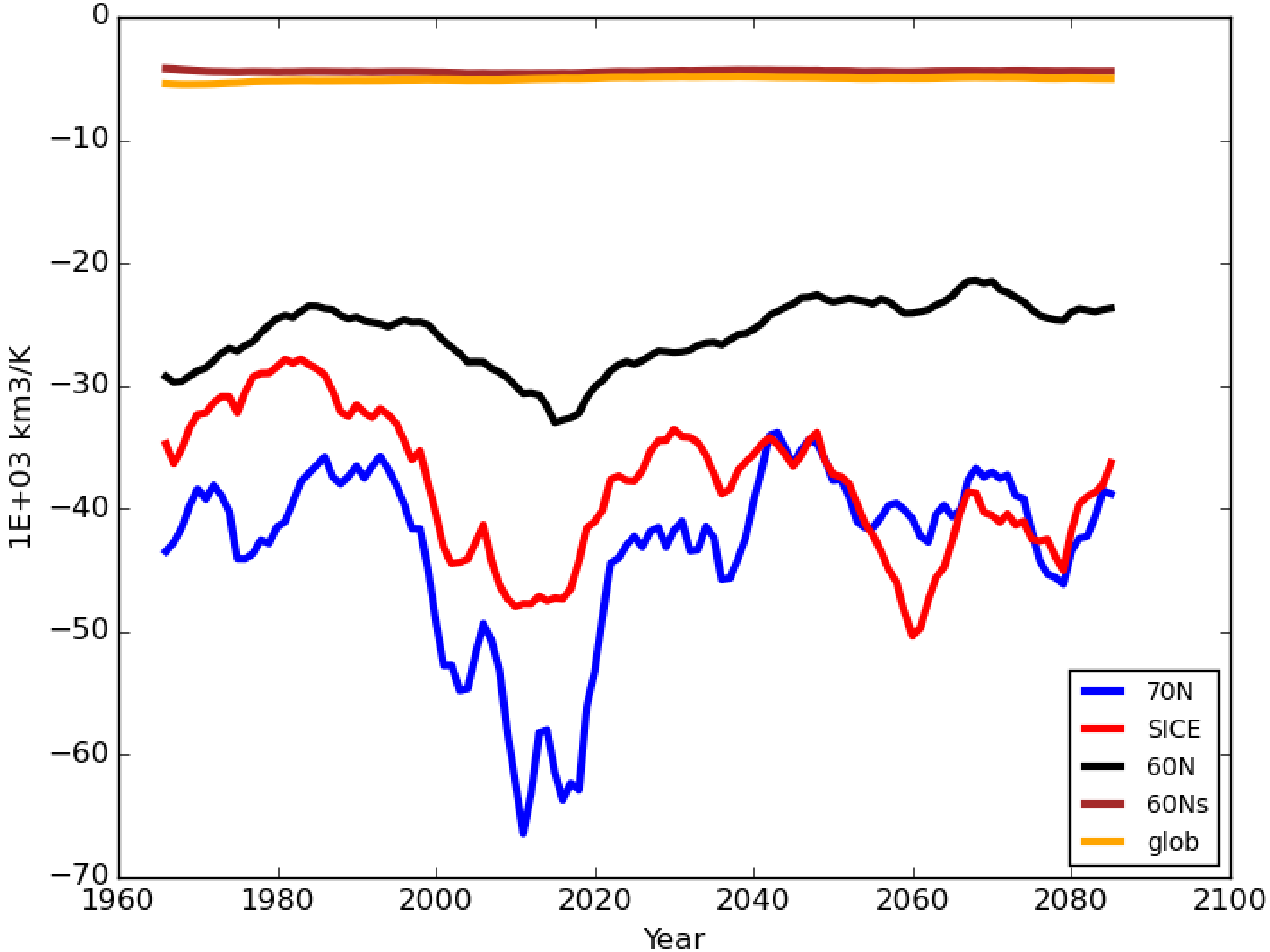
4*CO2 north of 60 N for the first 30 years



North America and East Asia cooling without stratospheric warming



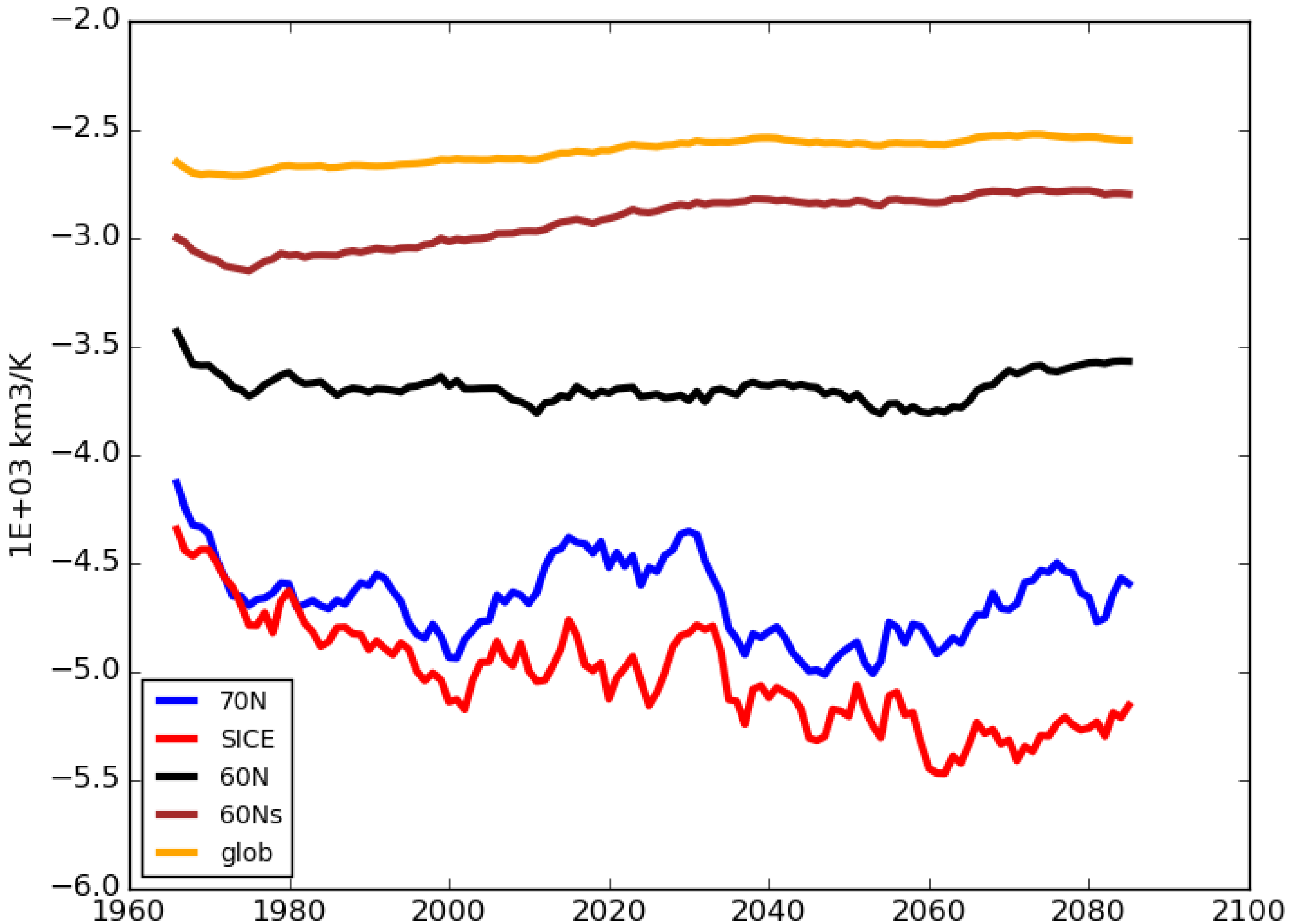
Ice volume change normalized with global temperature increase



Regional Arctic CO_2 forcing efficient in reducing Arctic sea ice volume – energy remains in the Arctic

Energy transport from extra-Arctic into Arctic efficient: nearly as much sea ice melted in 60Ns compared to glob simulation

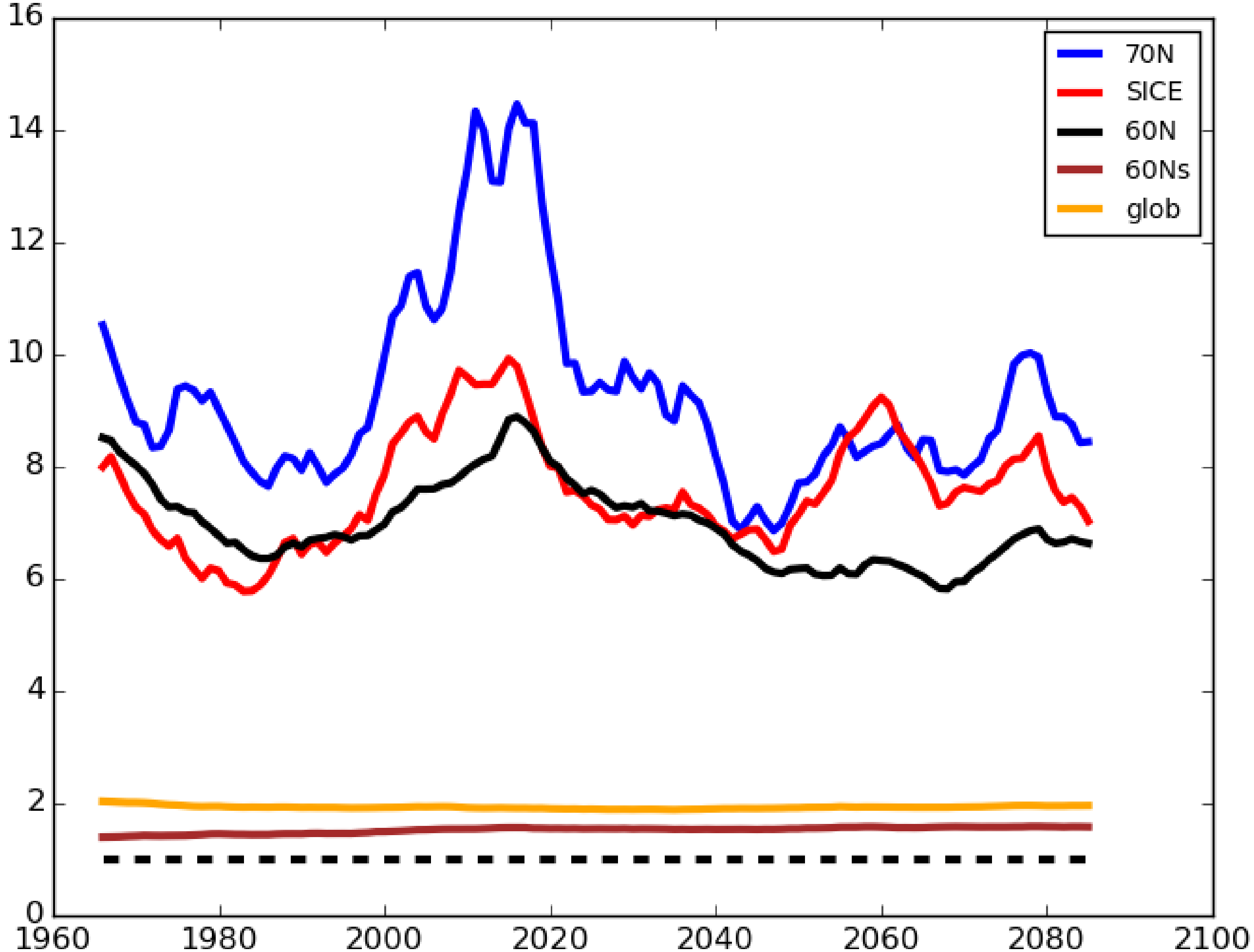
Ice volume change normalized with 60N Arctic temperature increase



Regional Arctic CO_2 forcing efficient in reducing Arctic sea ice volume – energy remains in the Arctic

Energy transport from extra-Arctic into Arctic efficient: more sea ice melted per degree Arctic warming in 60Ns compared to glob simulation

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



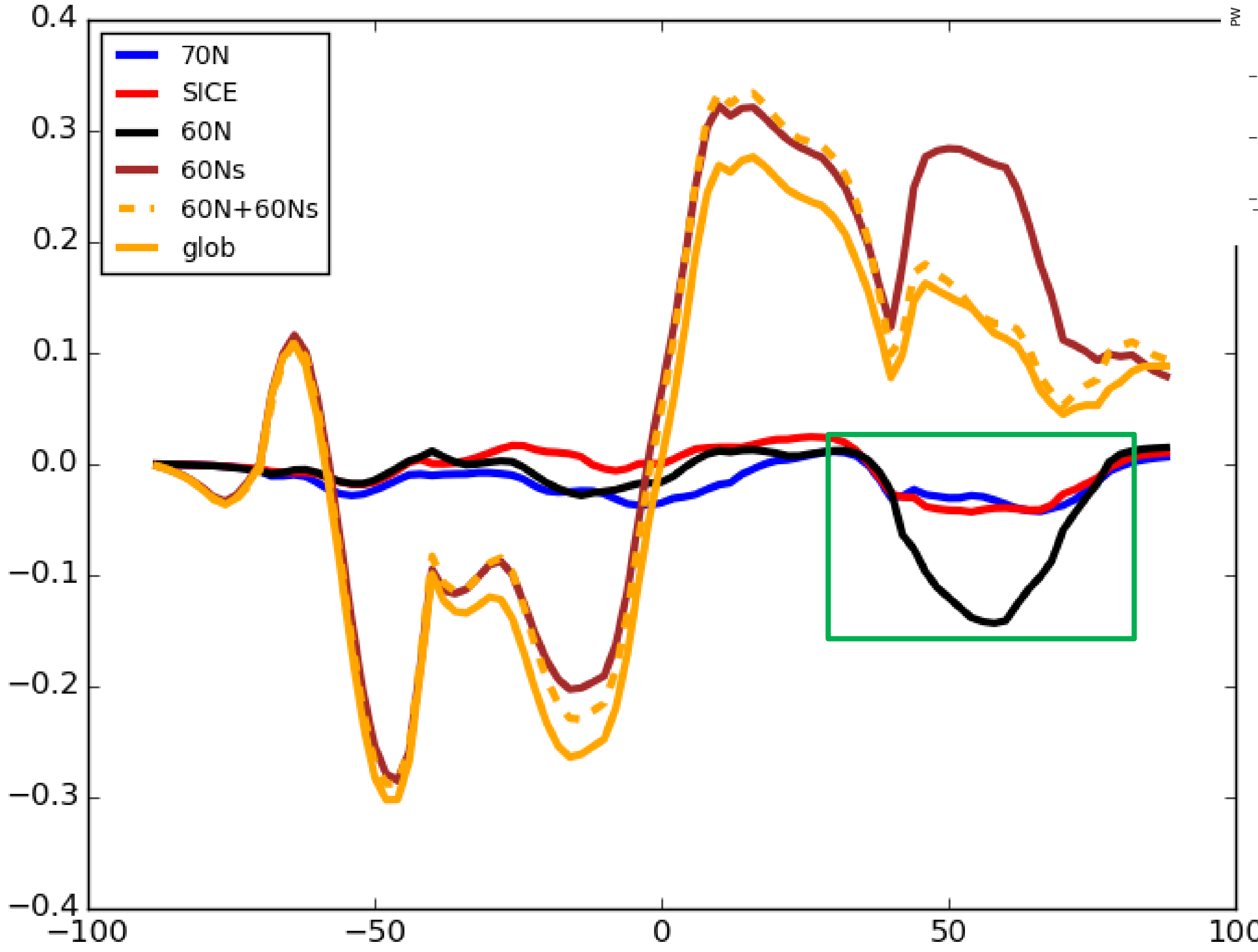
Note: AAI = 1: no Arctic Amplification

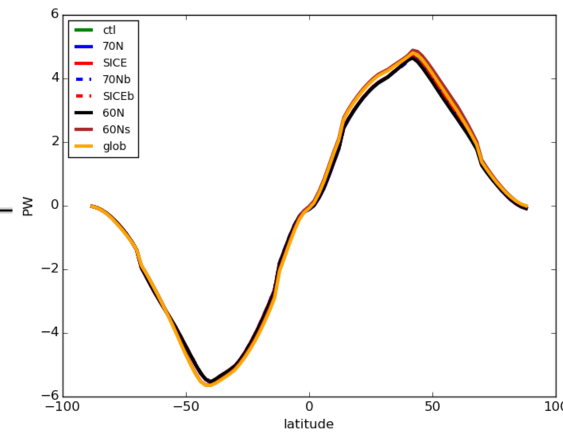
High AAI for Arctic forcing experiments

60% of Arctic Amplification due to northward energy transport

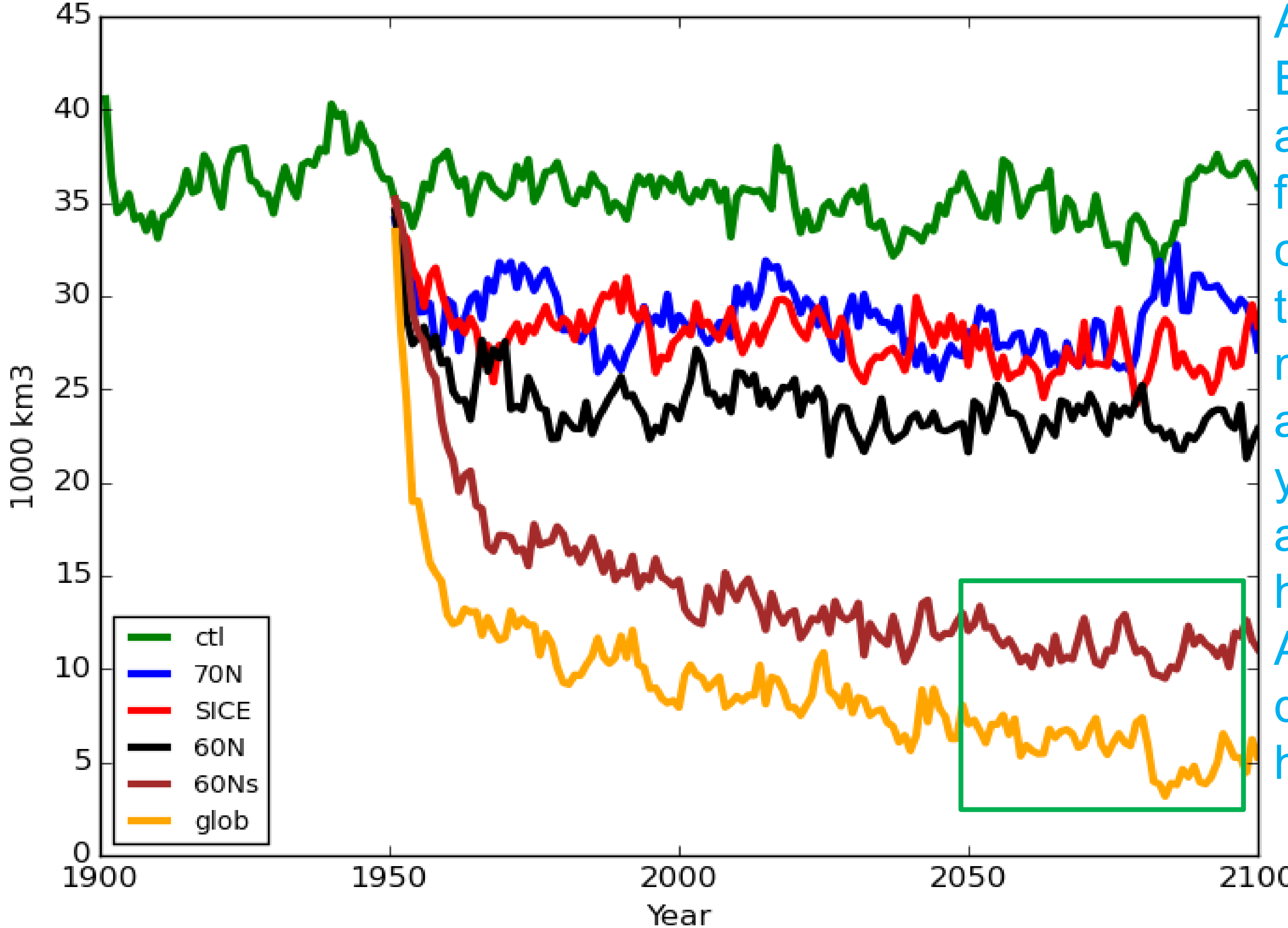
Meridional atm. energy transport (PW)

Difference to control simulation, first 30 years





Arctic sea ice volume in March

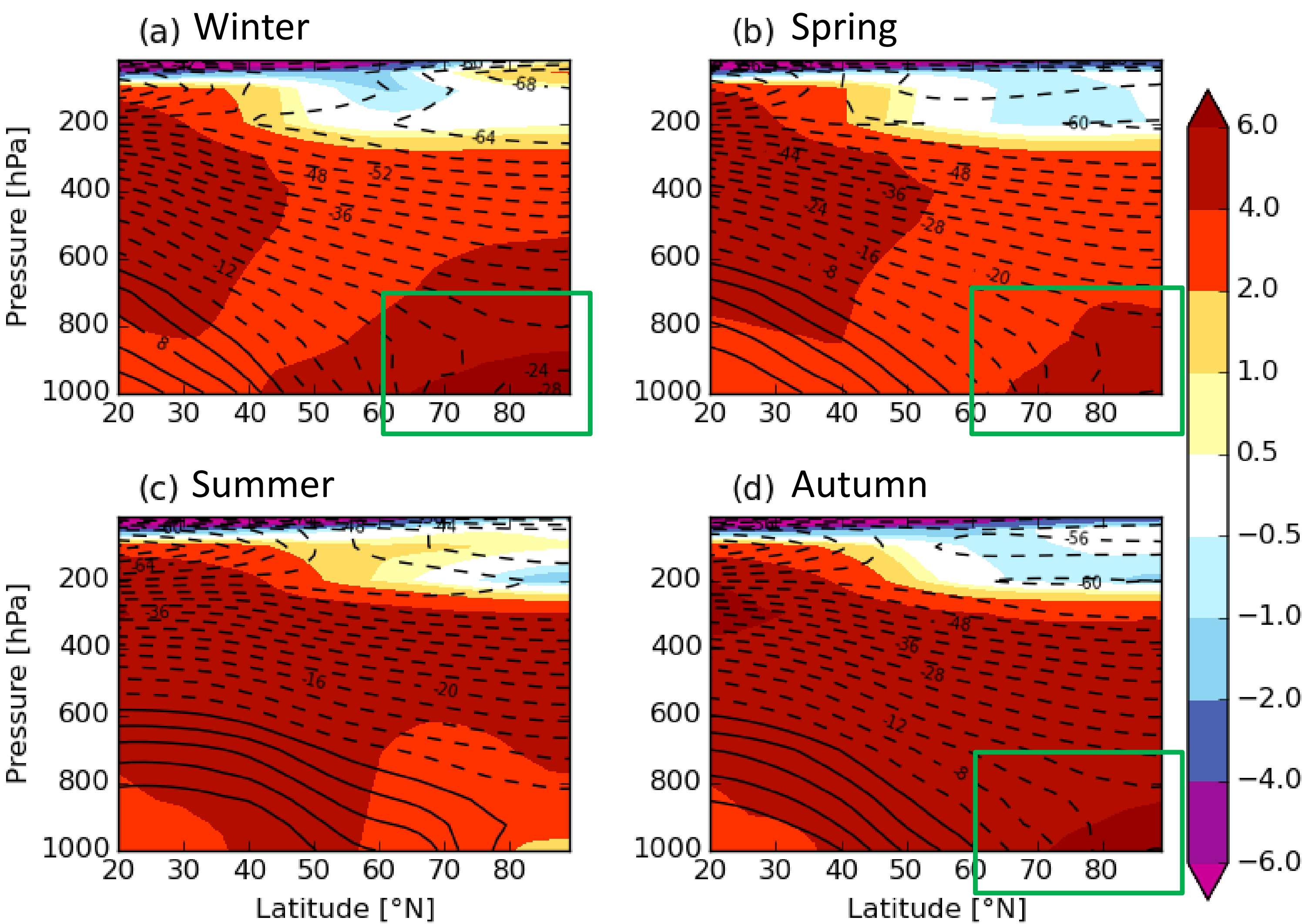


Strong extra-Arctic impact: Even without any Arctic forcing (brown curve) half of the sea ice is melted in around 15 years through atmospheric heat transport. Another sixth due to oceanic heat transport.

Response in the temperature profile

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

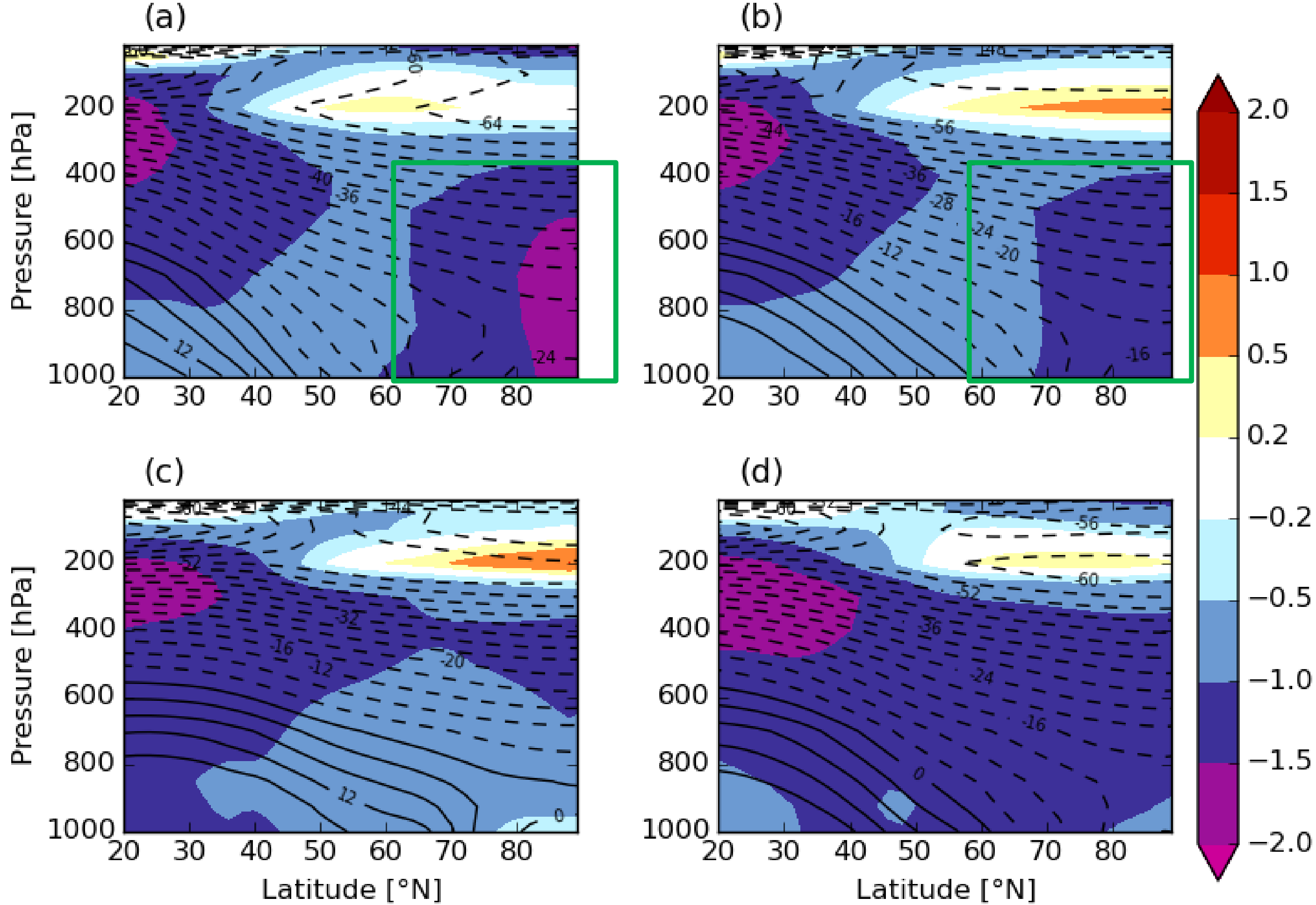
Arctic amplification without Arctic forcing except for summer!



Preliminary PAMIP results (exp. 1.3)

piSST minus pdSST (SIC unchanged)

Arctic amplification without Arctic forcing in winter and some extent spring!



Conclusions

Method of regional decomposition of CO_2 forcing works – response largely additive. Maybe an experiment design to be considered for APPLICATE / PAMIP?

Above 300 hPa cooling rather than warming (expected!)

Generally despite strong CO_2 forcing in the Arctic relatively little happens in the mid-latitudes.

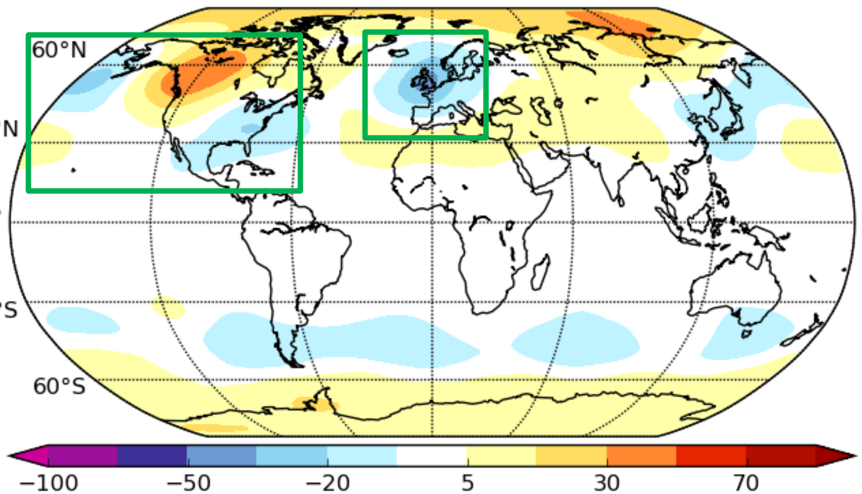
The extra energy in the Arctic forcing experiments largely stays in the Arctic

If forcing only outside the Arctic, the energy transport into the Arctic is strongly increased.

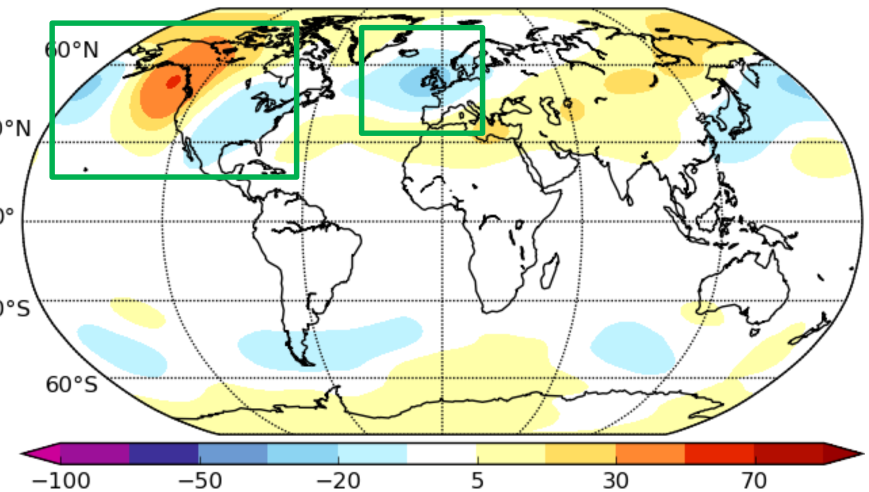
Therefore, even without any Arctic forcing two thirds of the sea ice melt and Arctic Amplification exists!

Winter 500 hPa geopot response (m)

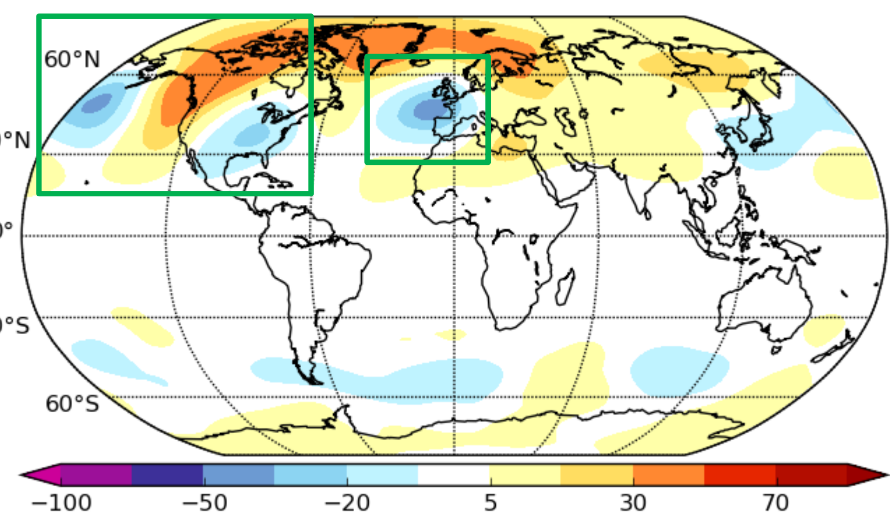
4*CO2 north of 70 N for the first 30 years



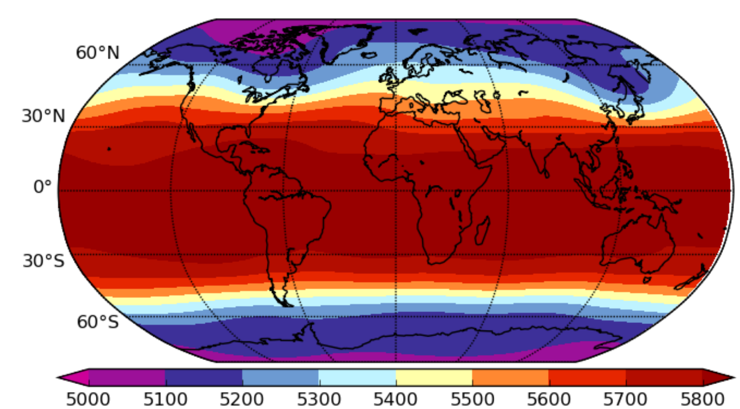
4*CO2 north ice edge for the first 30 years



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

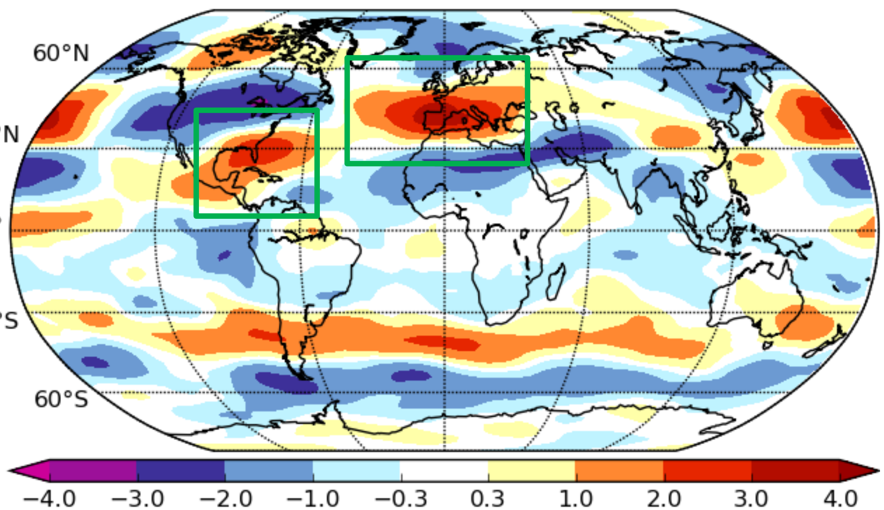


PNA pattern visible, but small anomalies!

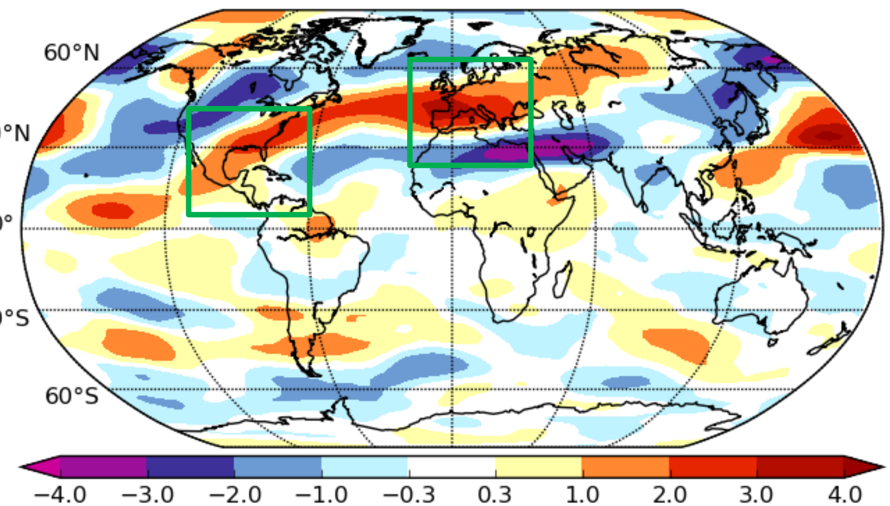


Winter U 300 response (m/s)

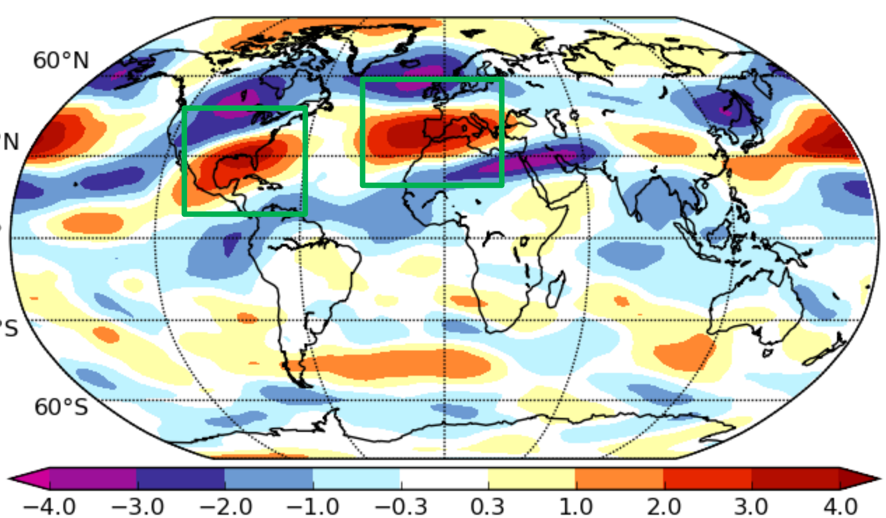
4*CO2 north of 70 N for the first 30 years



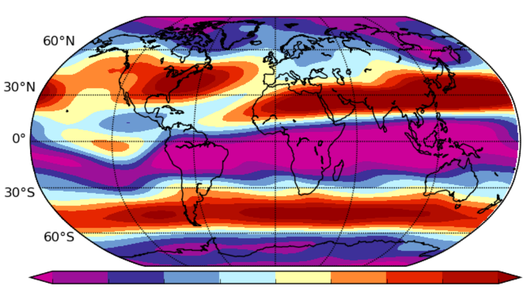
4*CO2 north ice edge for the first 30 years



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



Positive anomalies stretching from Gulf of Mexico / Florida to Southern Europe – surrounded by negative anomalies. But small anomalies!



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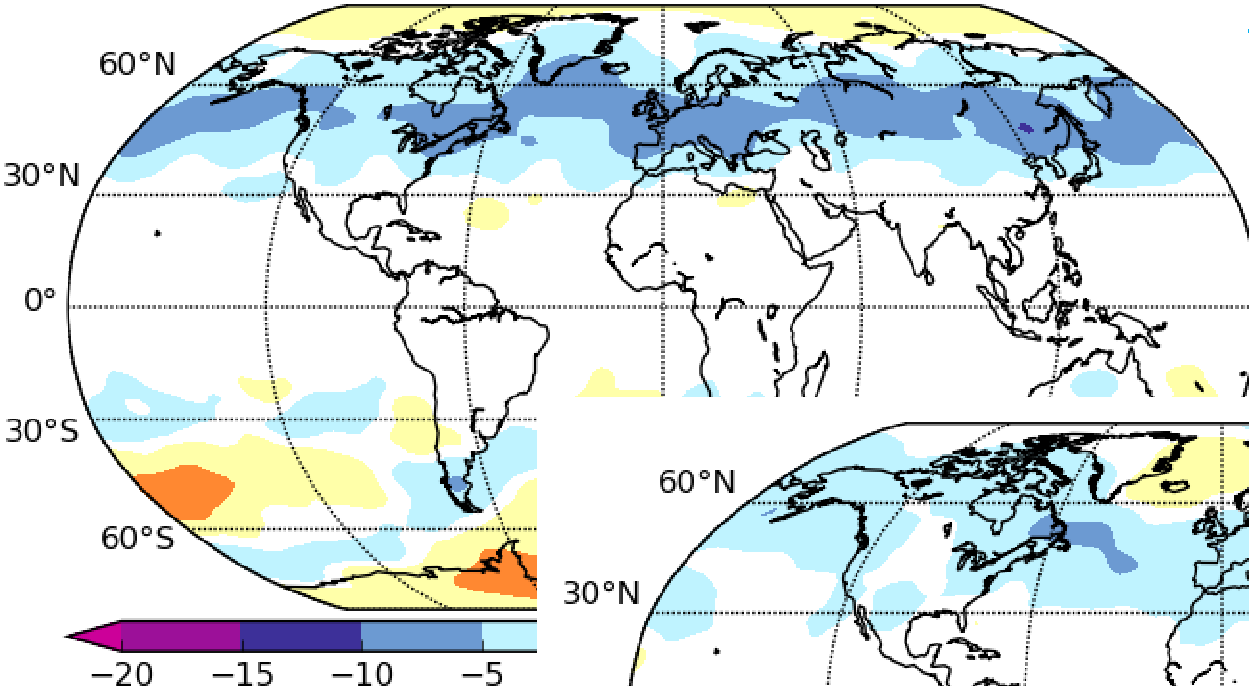
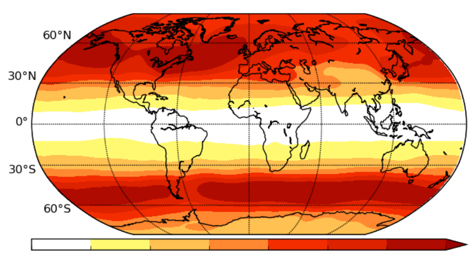
Synoptic activity 500 hPa (m)

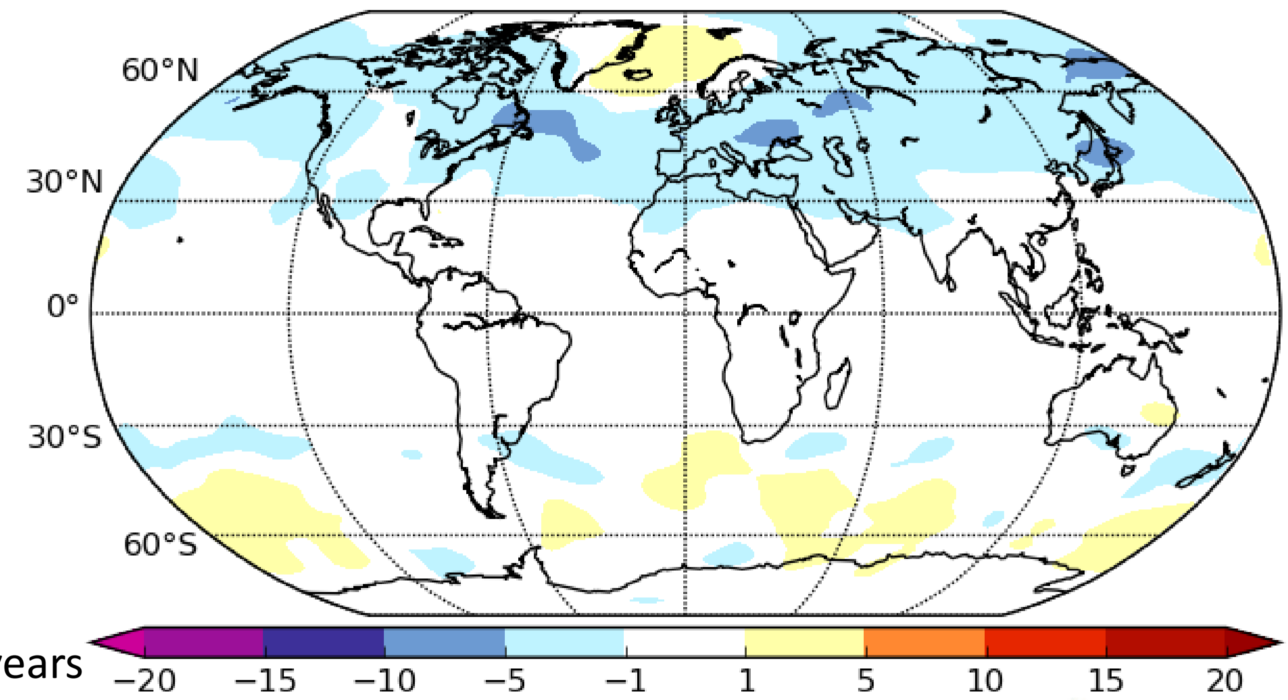
4*CO2 north of 60 N, DJF

Less exchange Arctic – extra Arctic

First 30 years



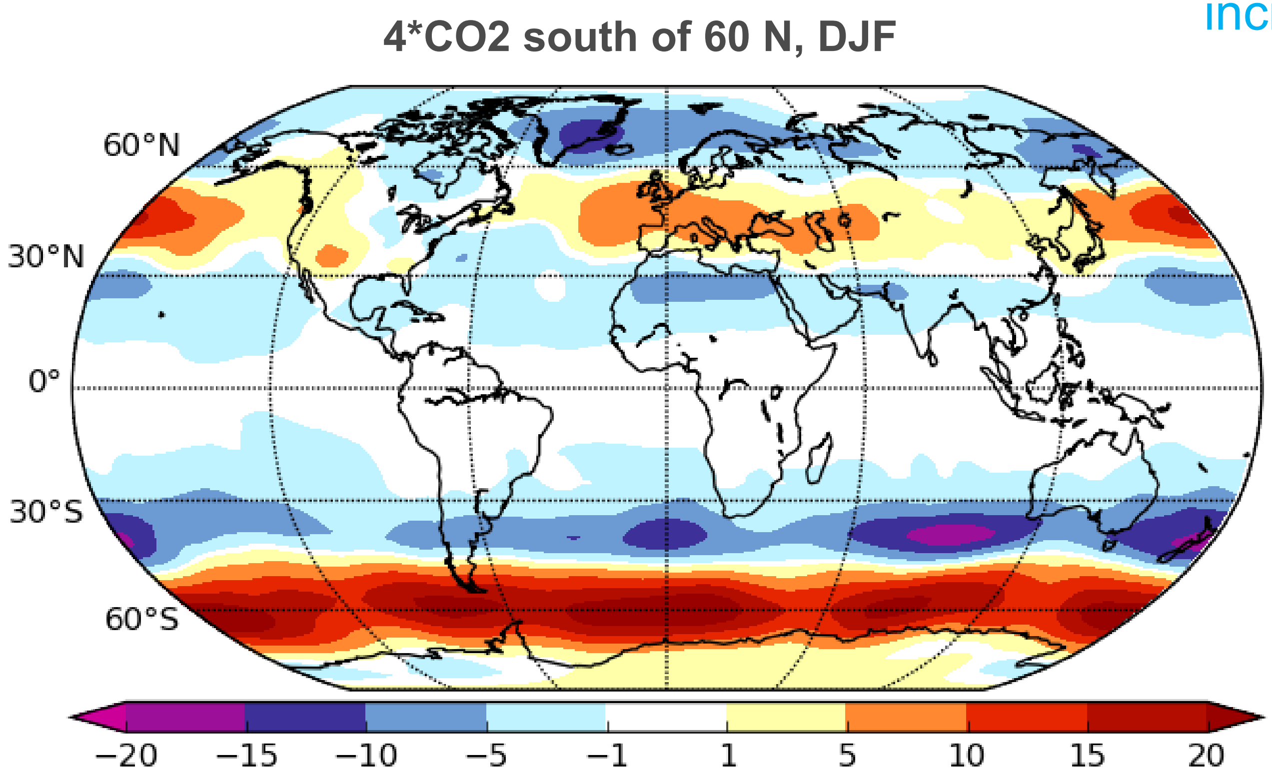




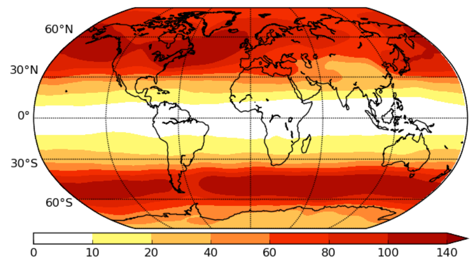
Last 120 years

Synoptic activity 500 hPa (m)

Redistribution of increase/decrease areas

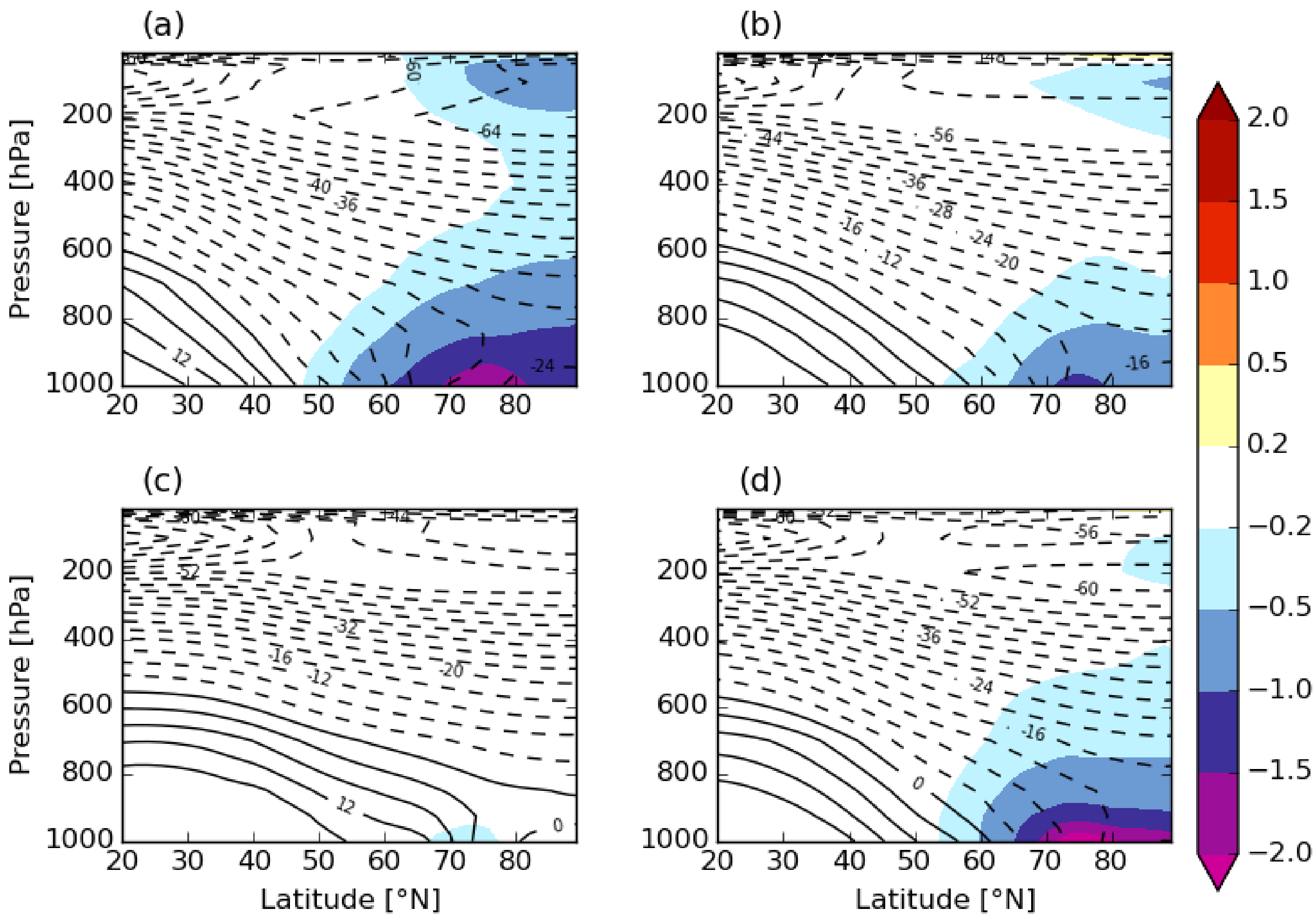


First 30 years



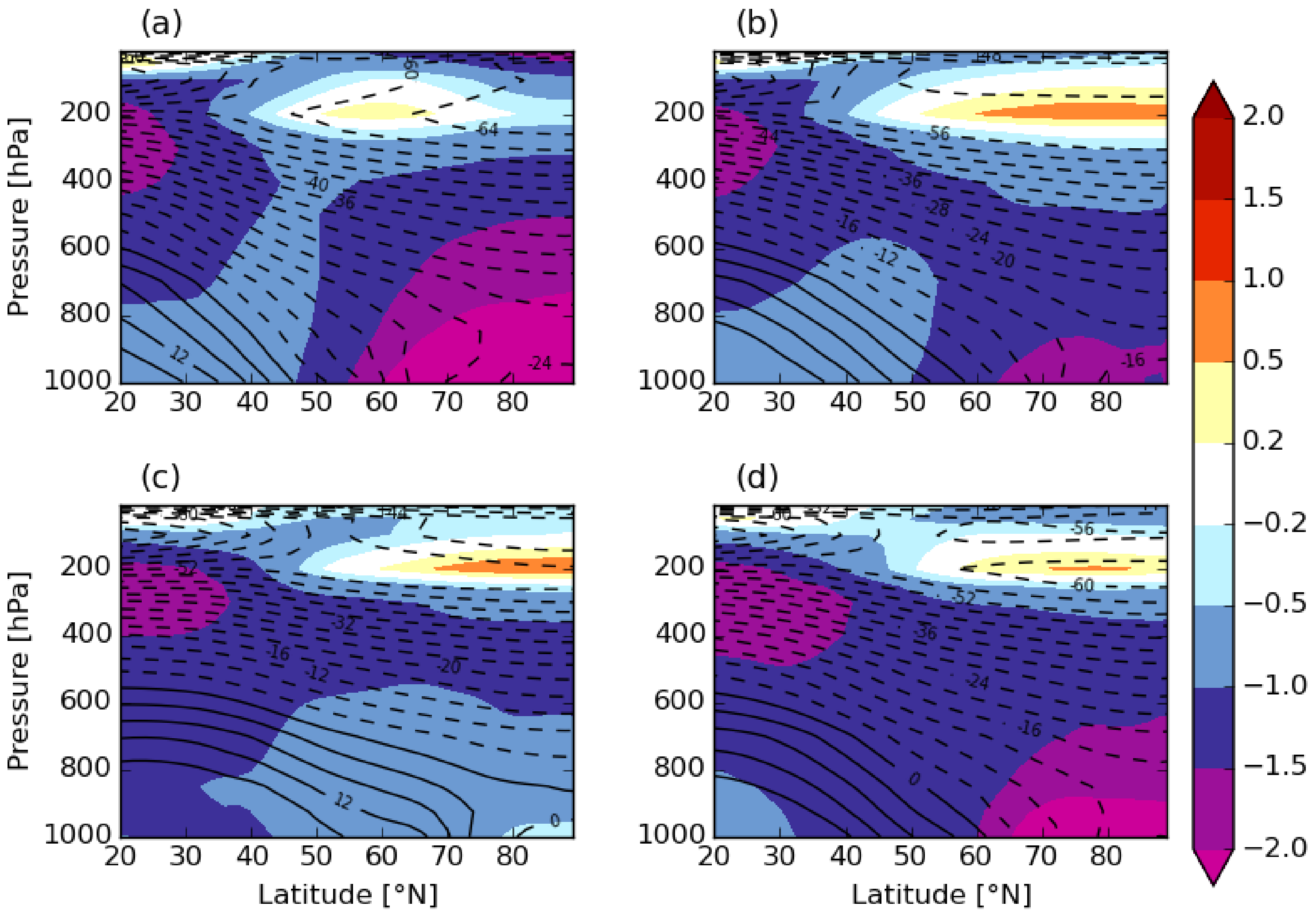
Preliminary PAMIP results (exp. 1.5)

piSIC minus pdSIC (SST unchanged)



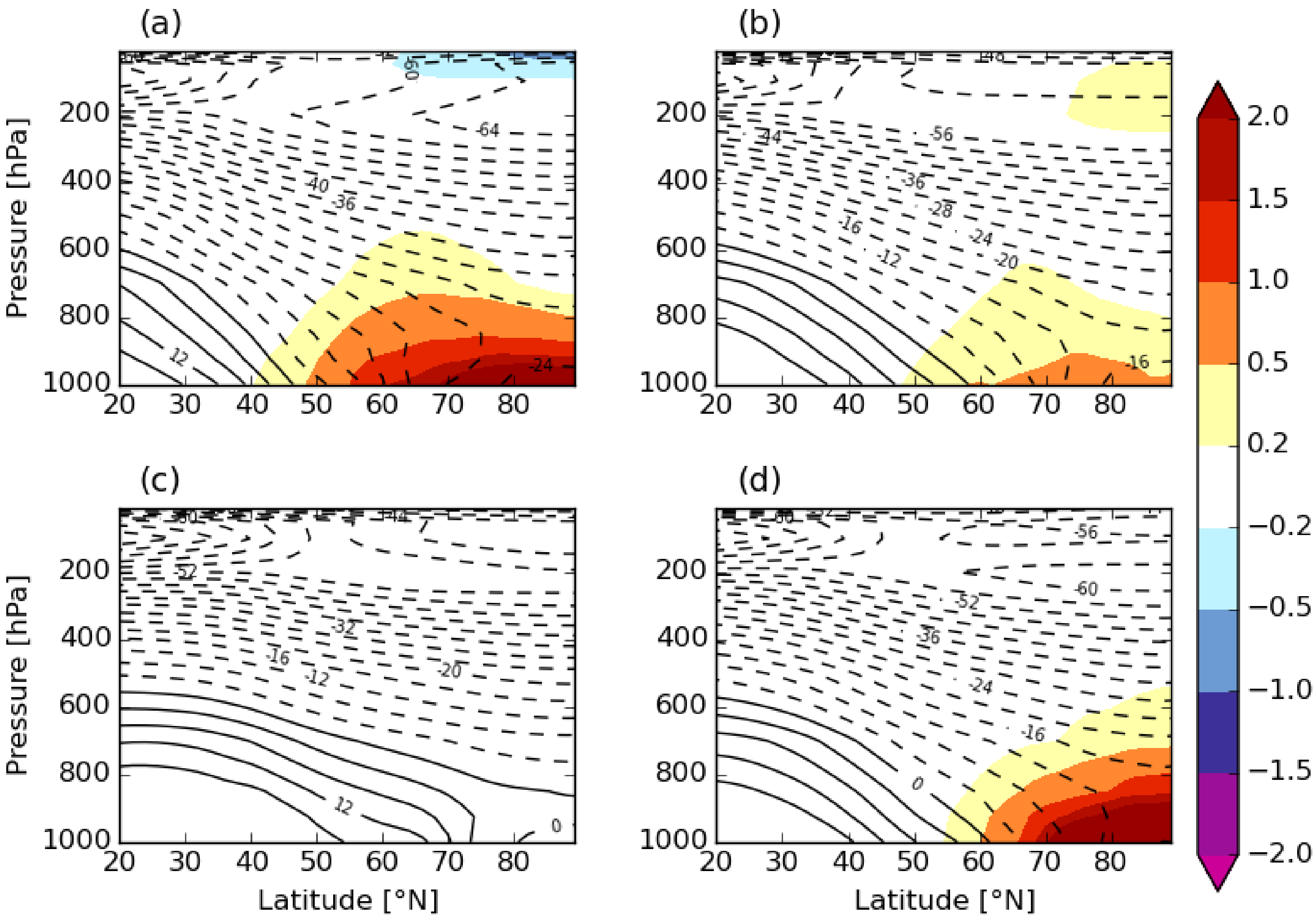
Preliminary PAMIP results (exp. 1.2)

piSST / piSIC minus pdSST / pdSIC



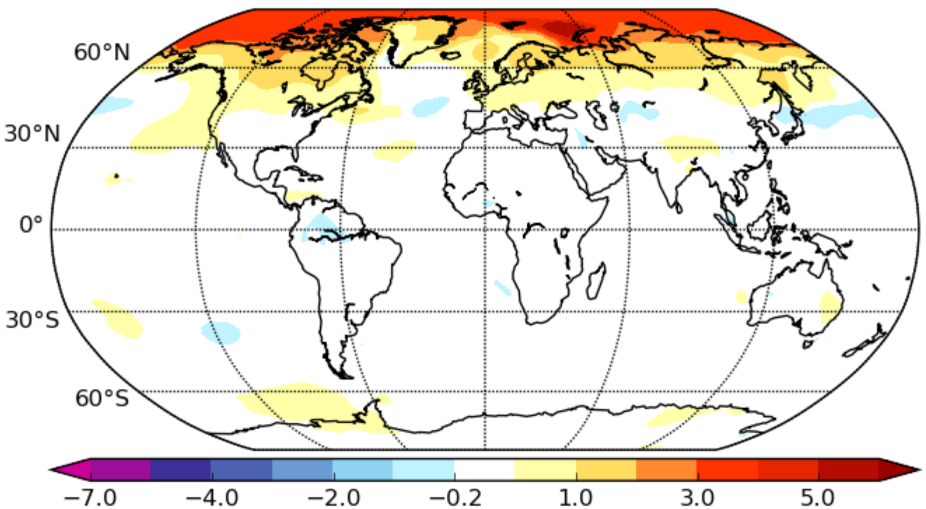
Preliminary PAMIP results (exp. 1.6)

fuSIC minus pdSIC (SST unchanged)

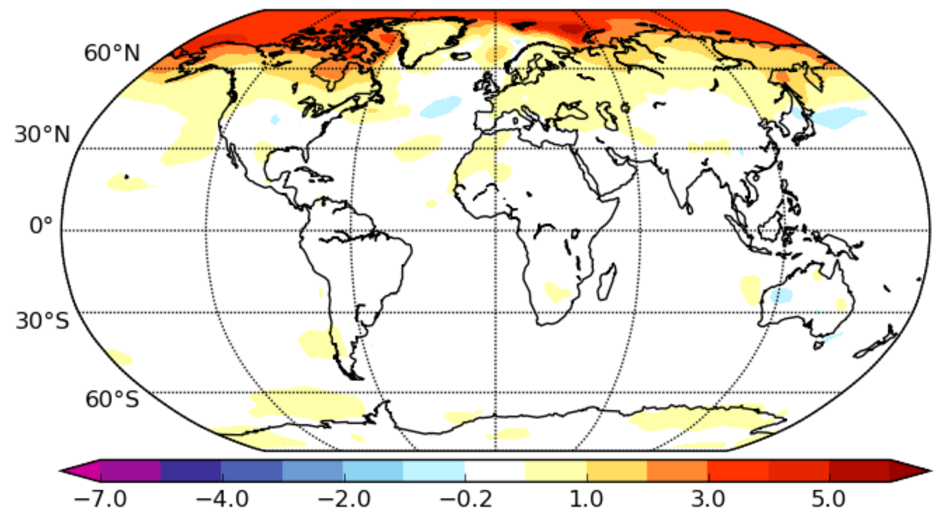


Winter 2 m temperature response (K)

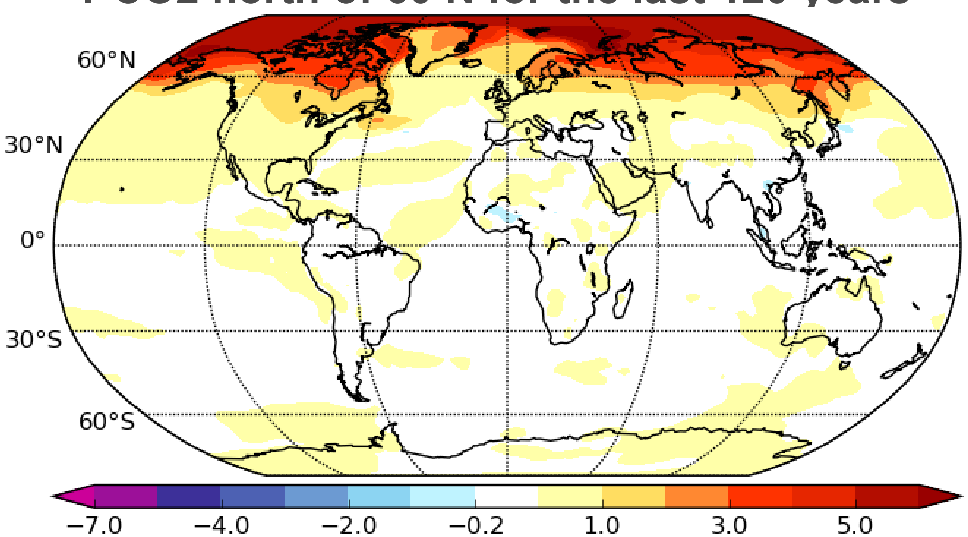
4*CO2 north of 70 N for the last 120 years



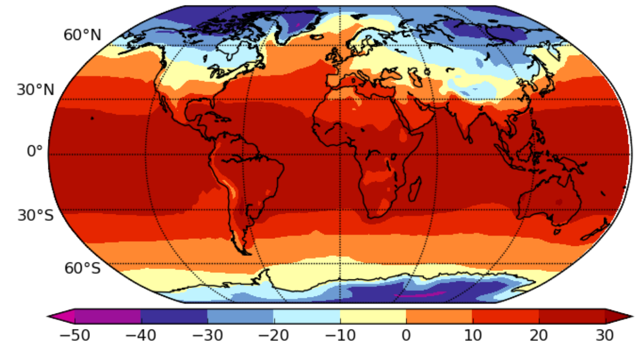
4*CO2 north ice edge for the last 120 years



4*CO2 north of 60 N for the last 120 years

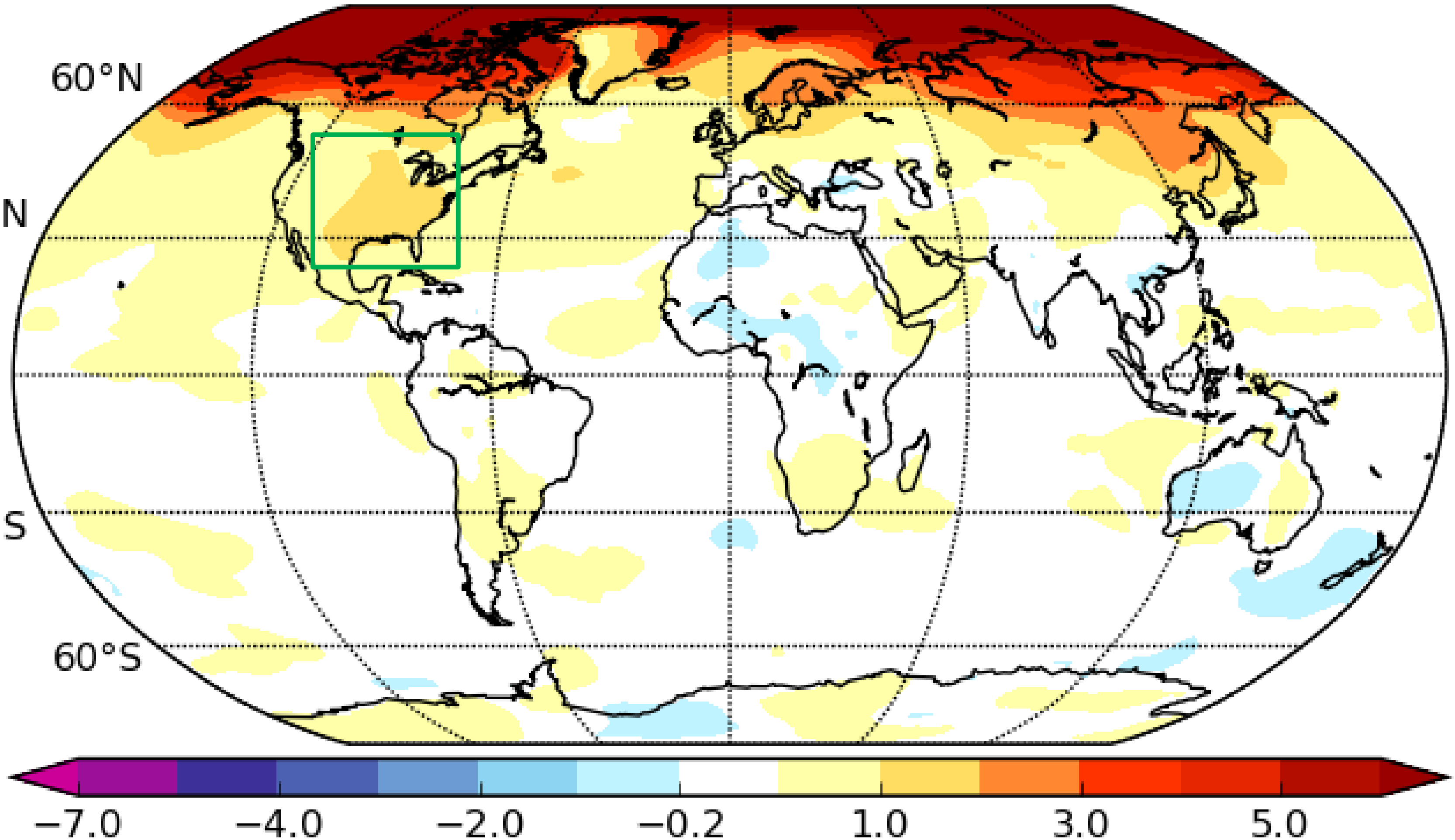


Mid-latitude warming over the continents



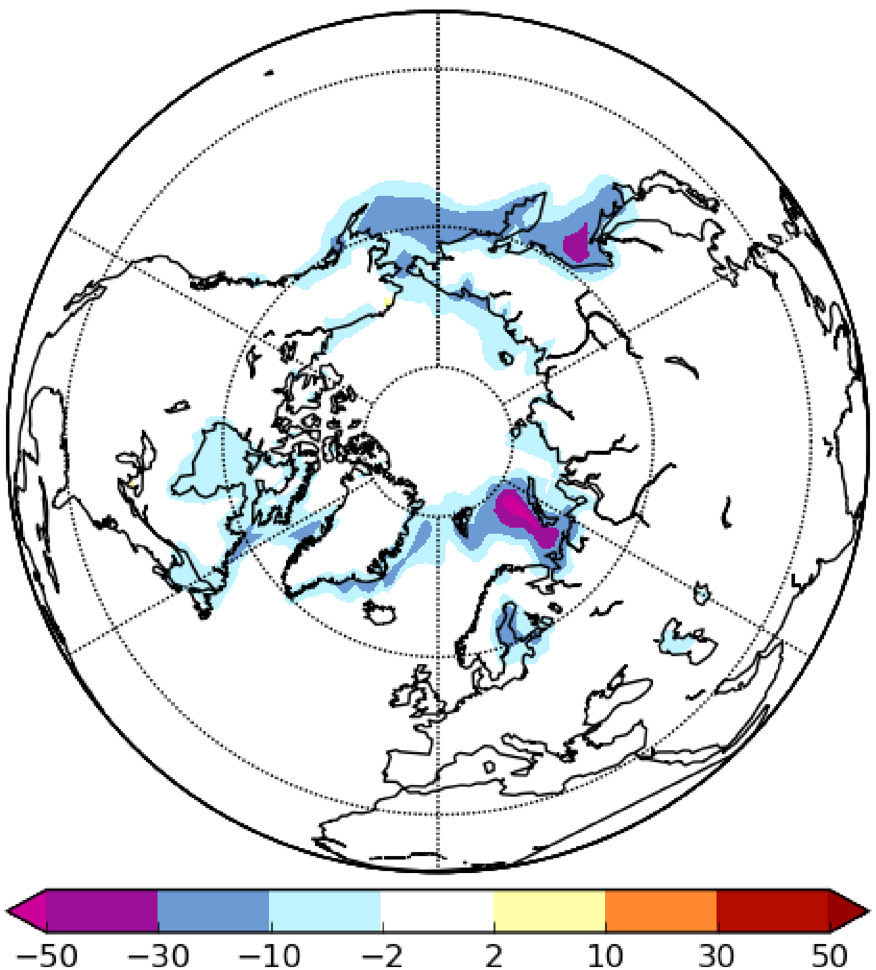
Winter 2 m temperature response (K)

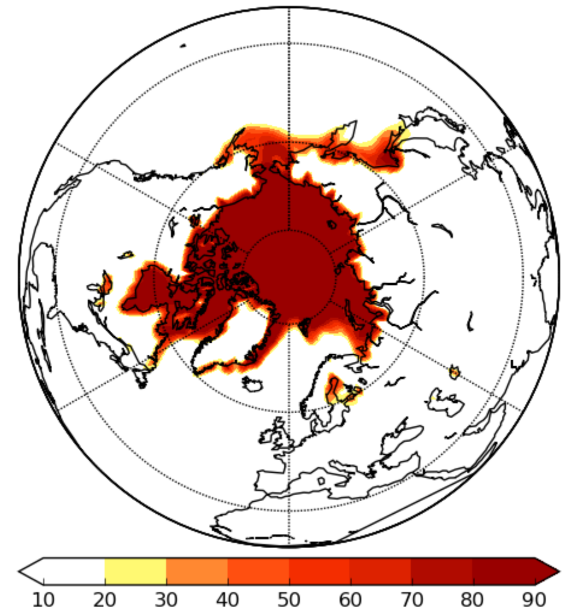
4*CO2 globally versus 4*CO2 south of 60N for the first 30 years



Arctic sea ice concentration response (%)

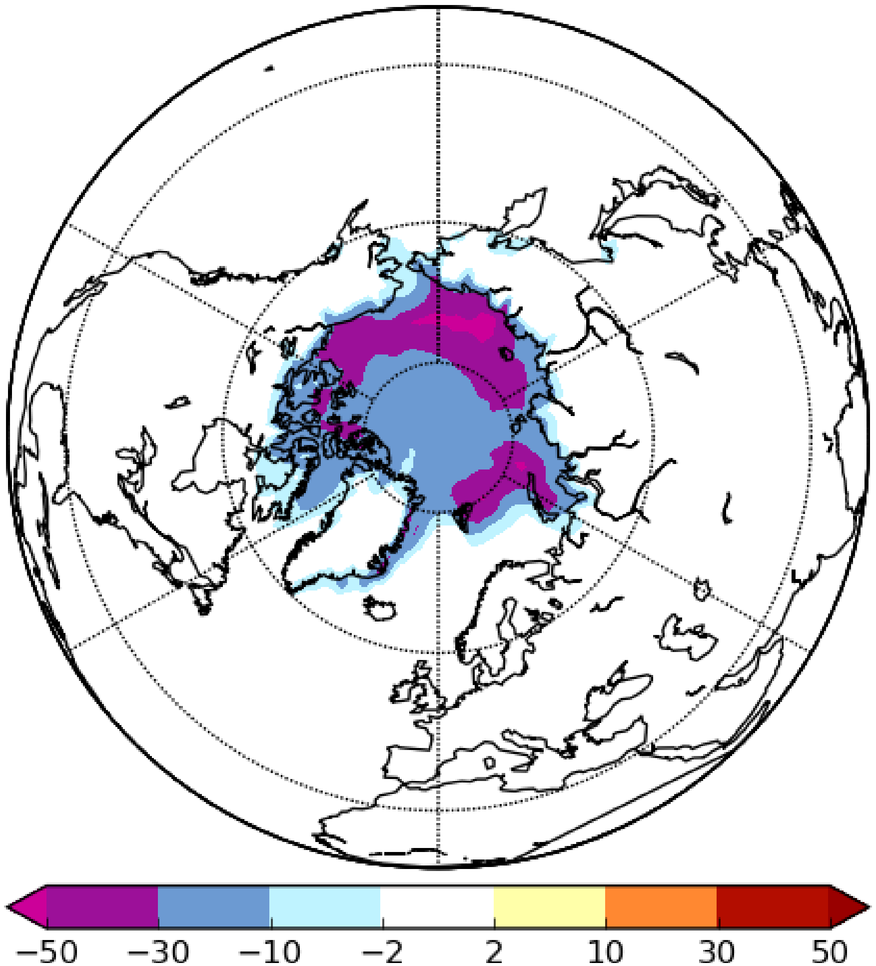
4*CO2 north of 60 N, last 30 years, MAM

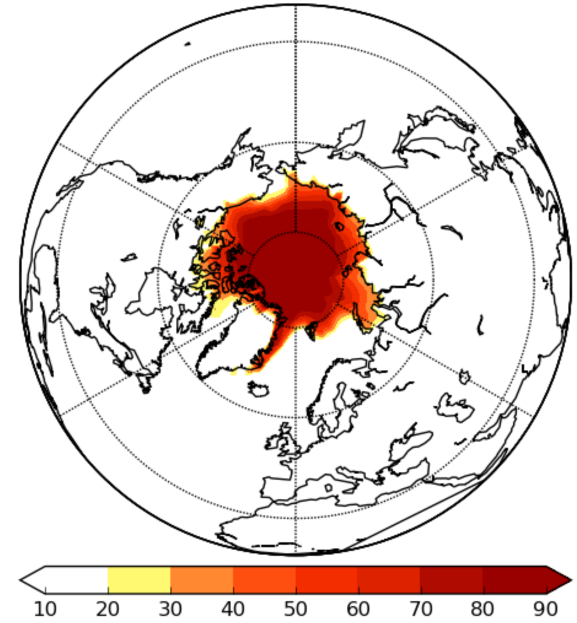




Arctic sea ice concentration response (%)

4*CO2 north of 60 N, last 30 years, SON

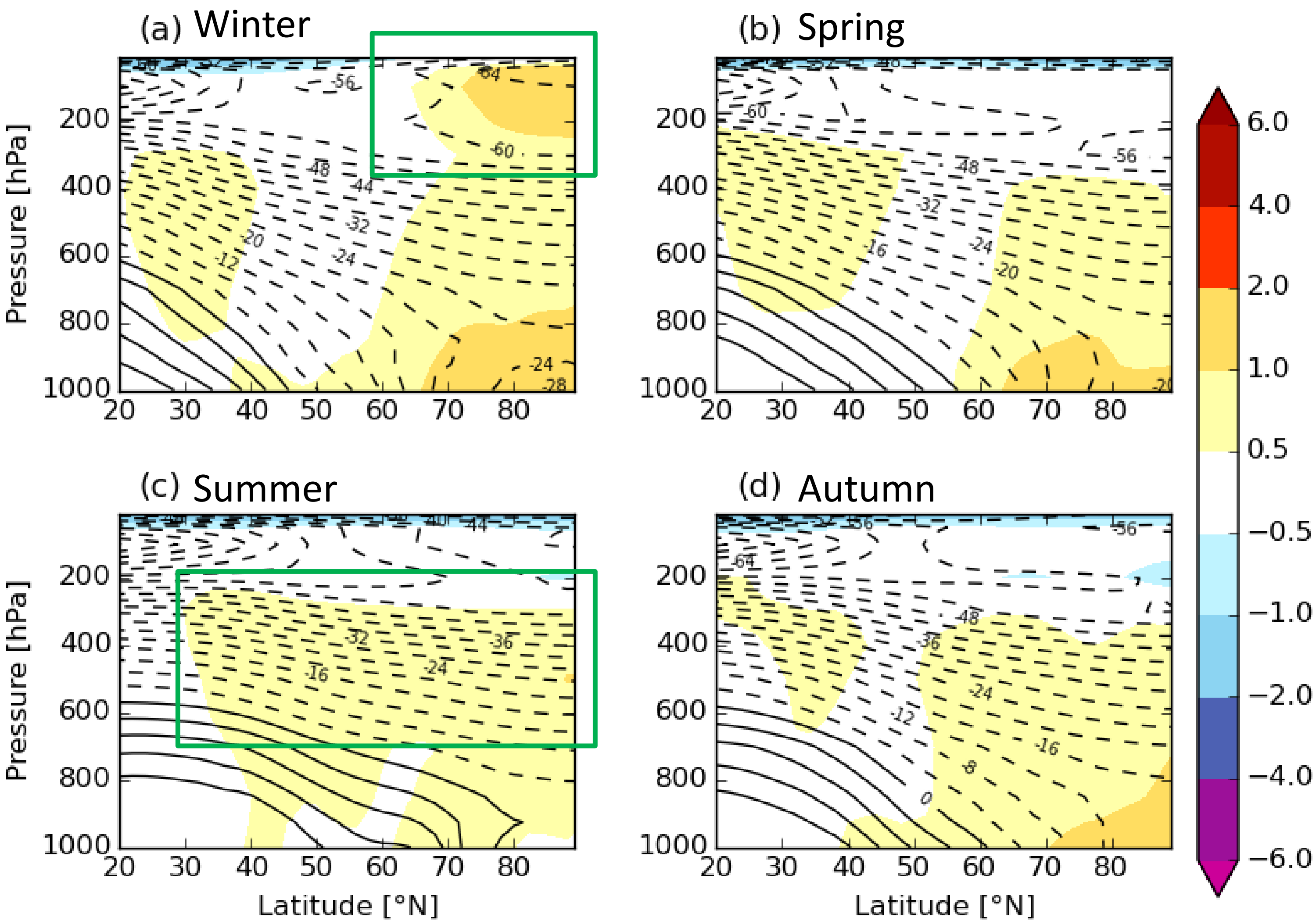




Excursion: CMIP6 1%CO2 exp

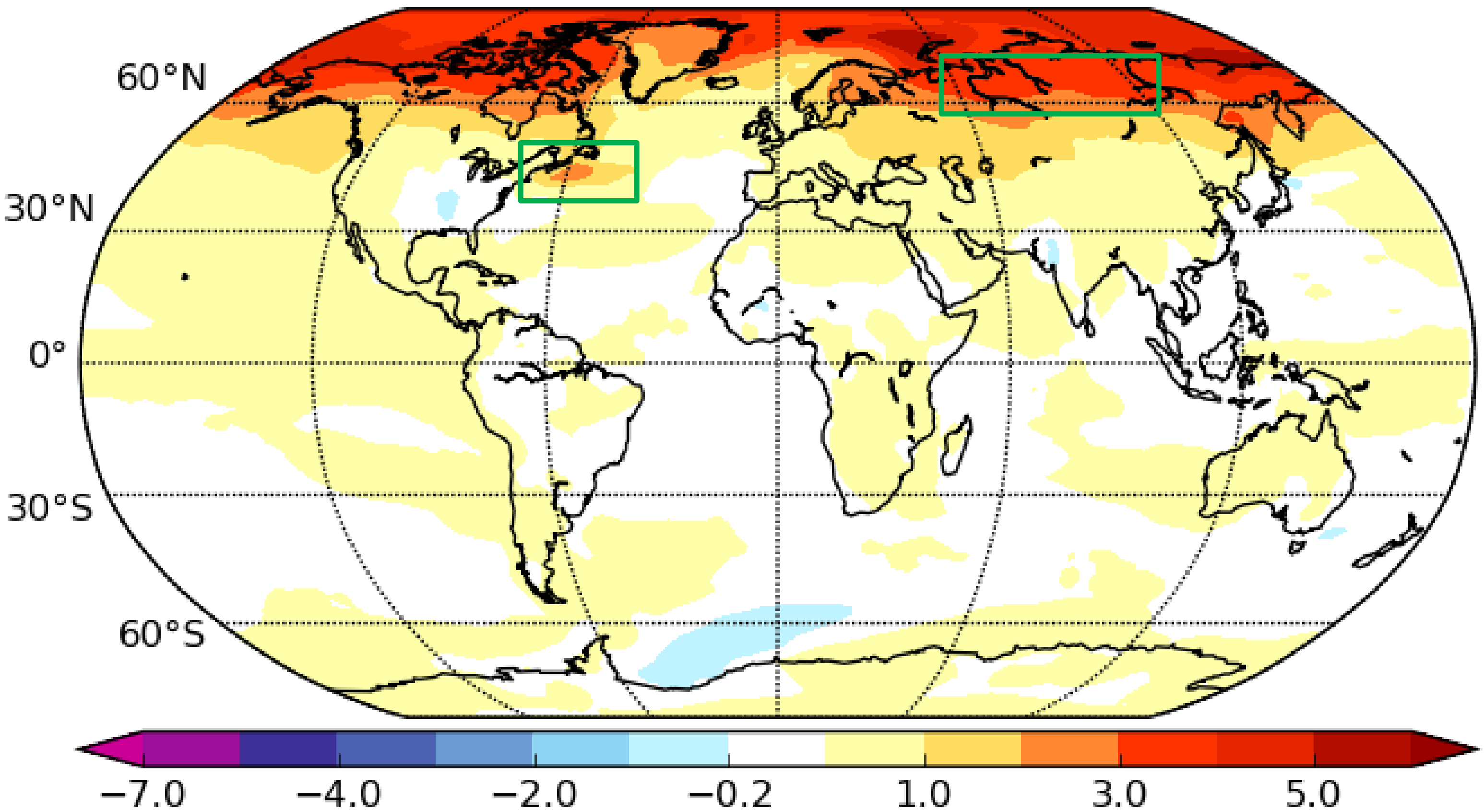
1%CO2 / year increase for the first 30 years

Warming in winter also in stratosphere



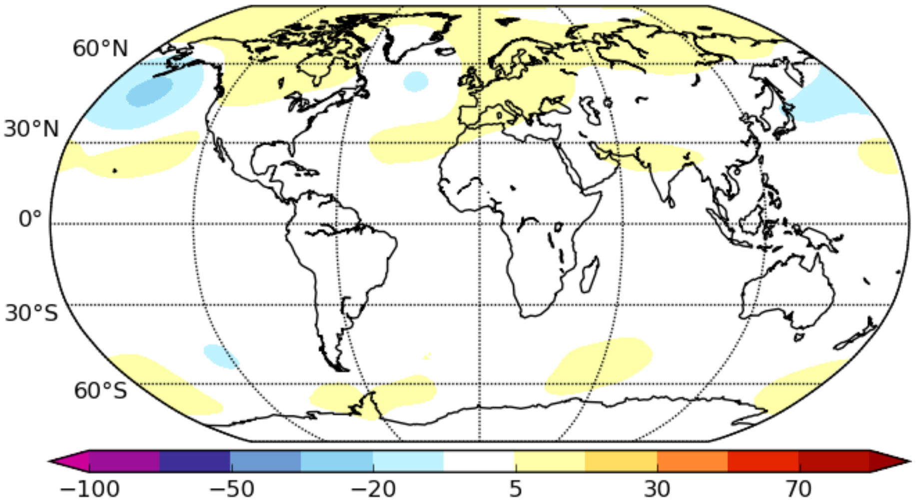
Yearly 2 m temperature response

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

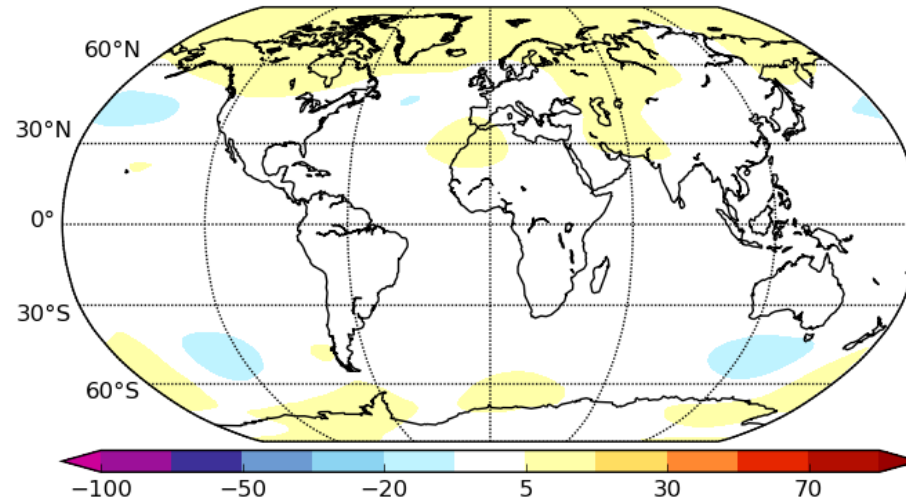


Winter 500 hPa geopot response (m)

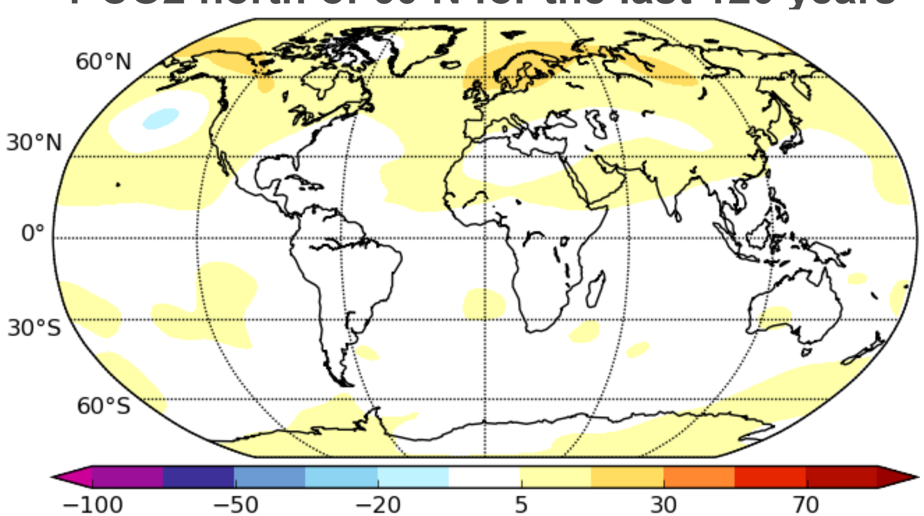
4*CO2 north of 70 N for the last 120 years



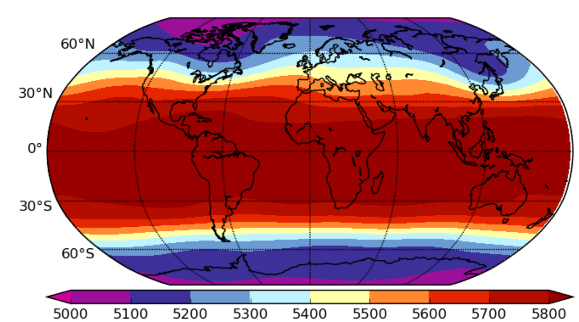
4*CO2 north ice edge for the last 120 years



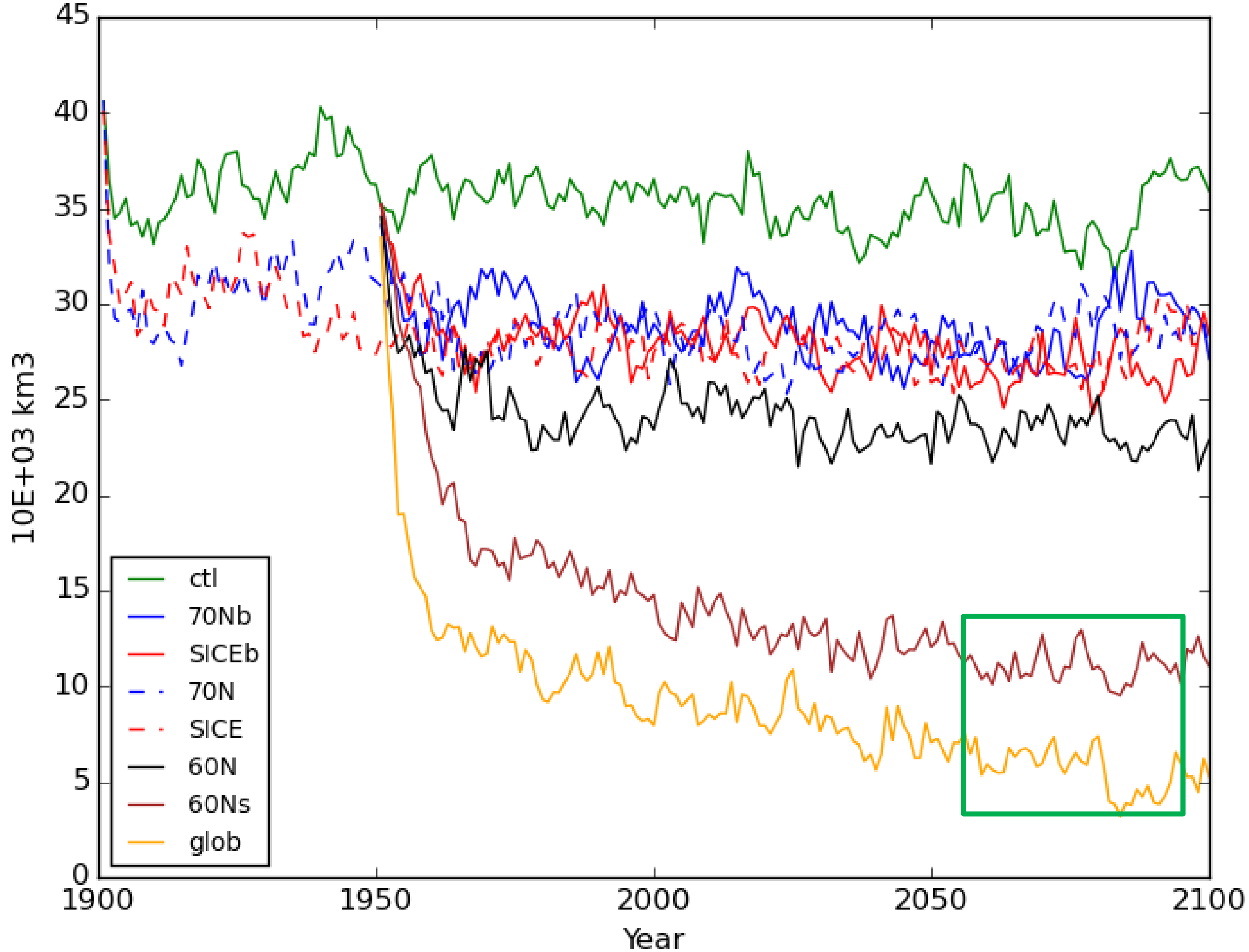
4*CO2 north of 60 N for the last 120 years



Generally increase in the Northern Hemisphere, especially in 60N simulation. Only some limited area decrease persists in the North Pacific

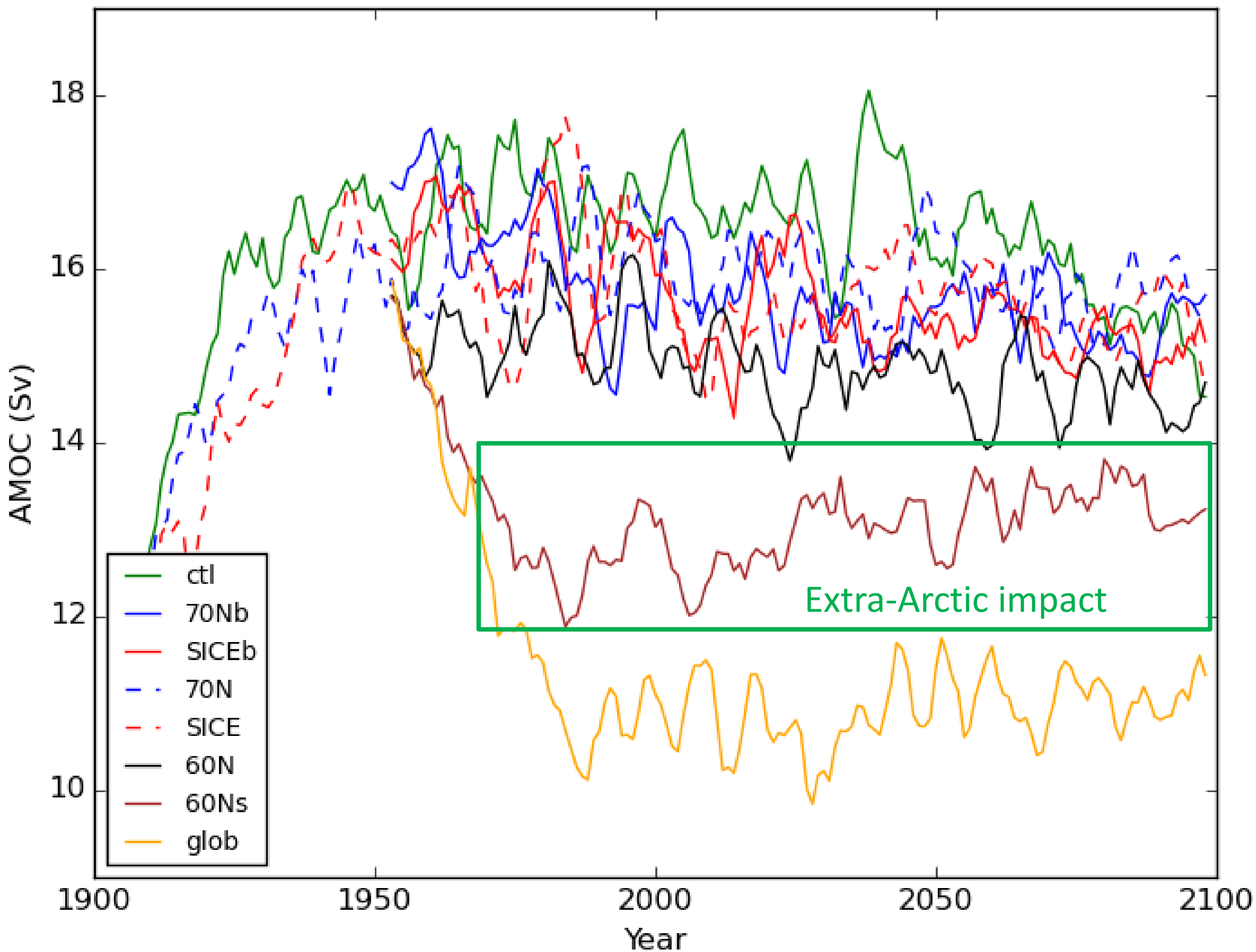


Arctic sea ice volume



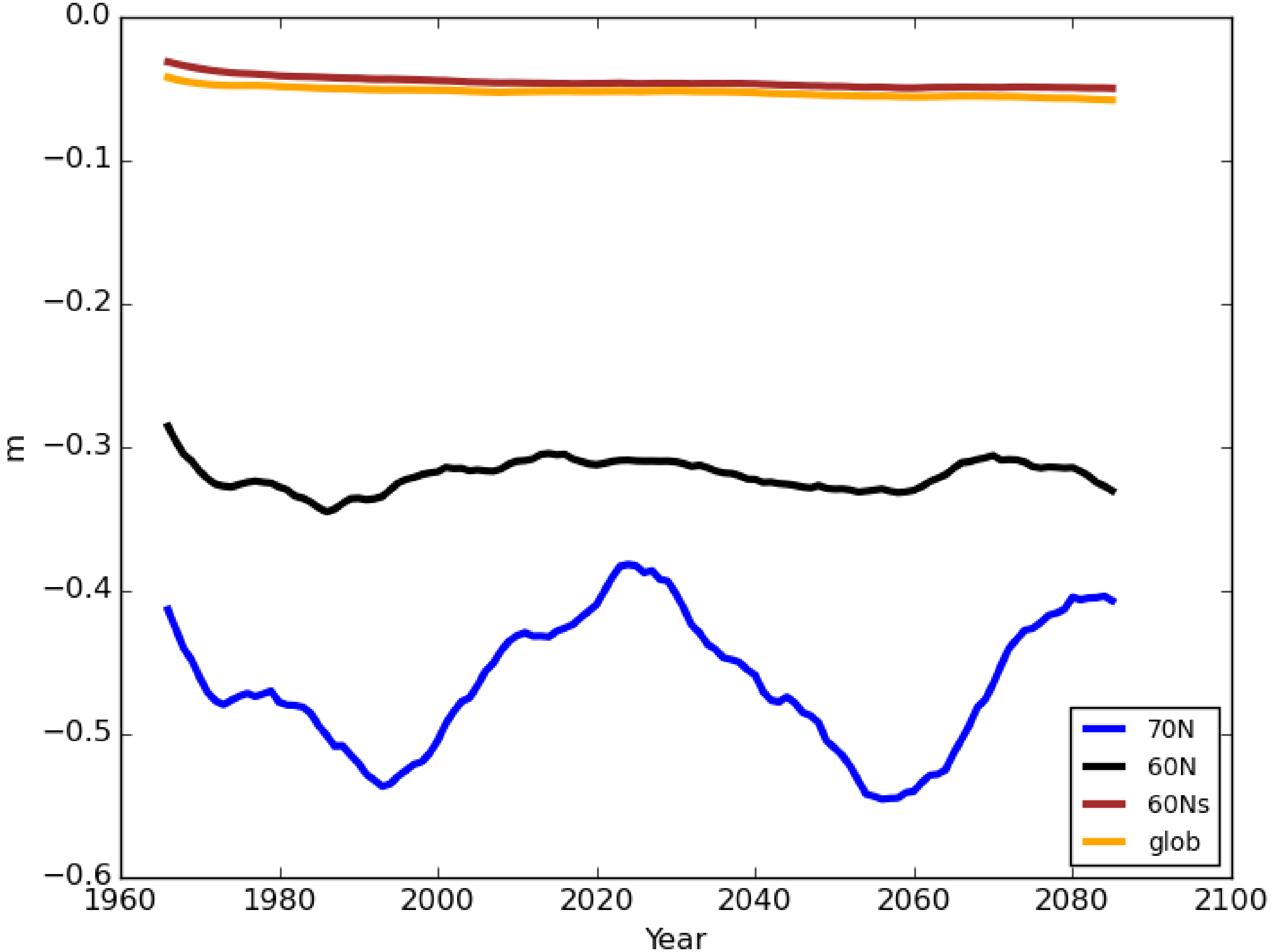
Strong extra-Arctic impact

AMOC at 45 N

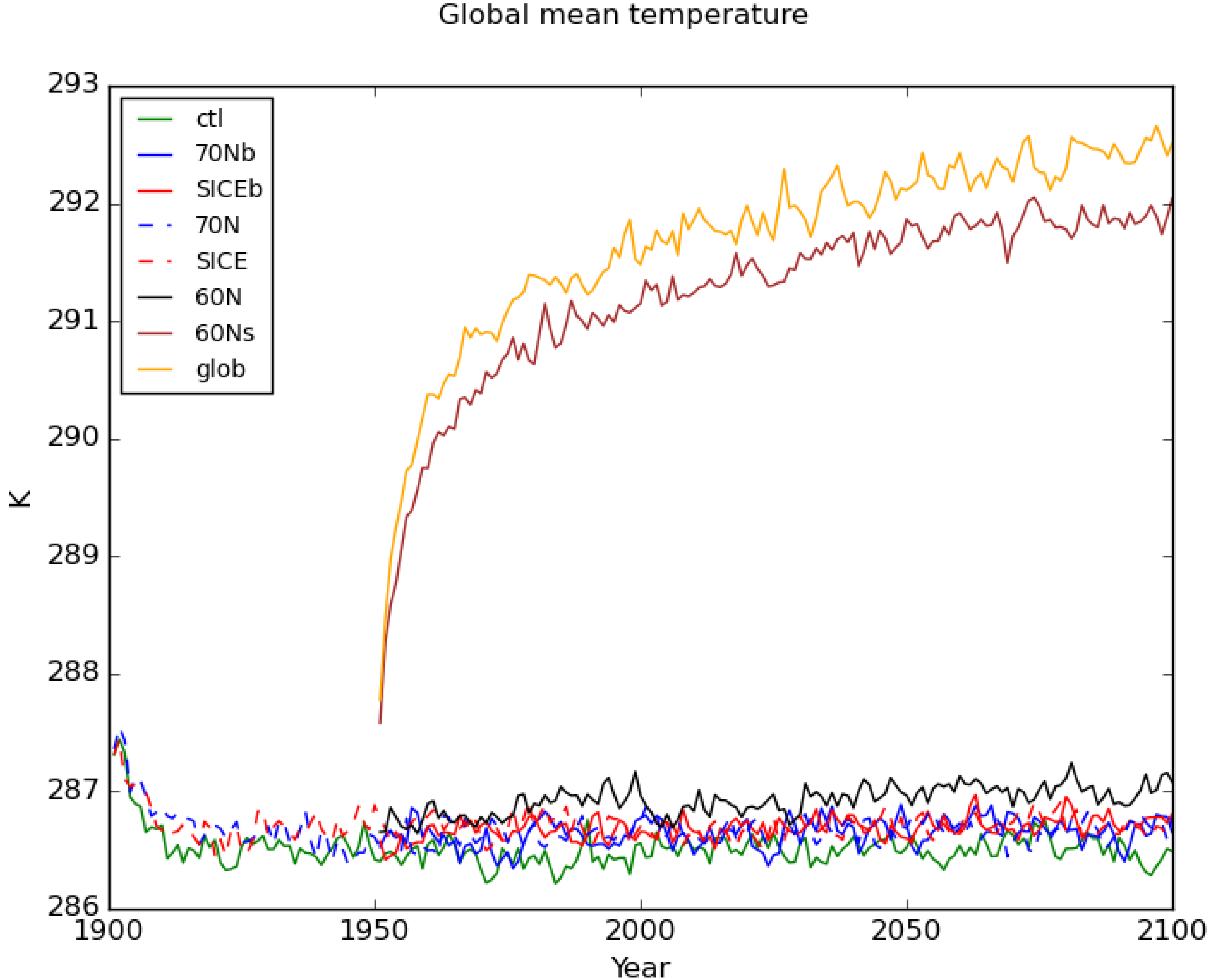


18
16
14
12
10
1900
1950
2000
2050
2100
Year
AMOC (Sv)
ctl
70Nb
SICEb
70N
SICE
60N
60Ns
glob
Extra-Arctic impact

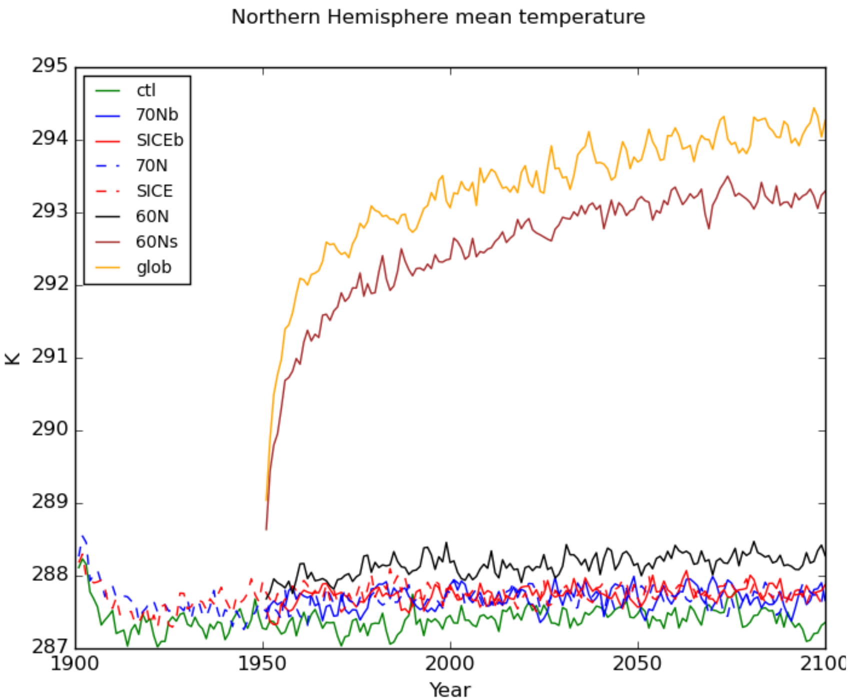
Ice volume change normalized with CO2 forcing area

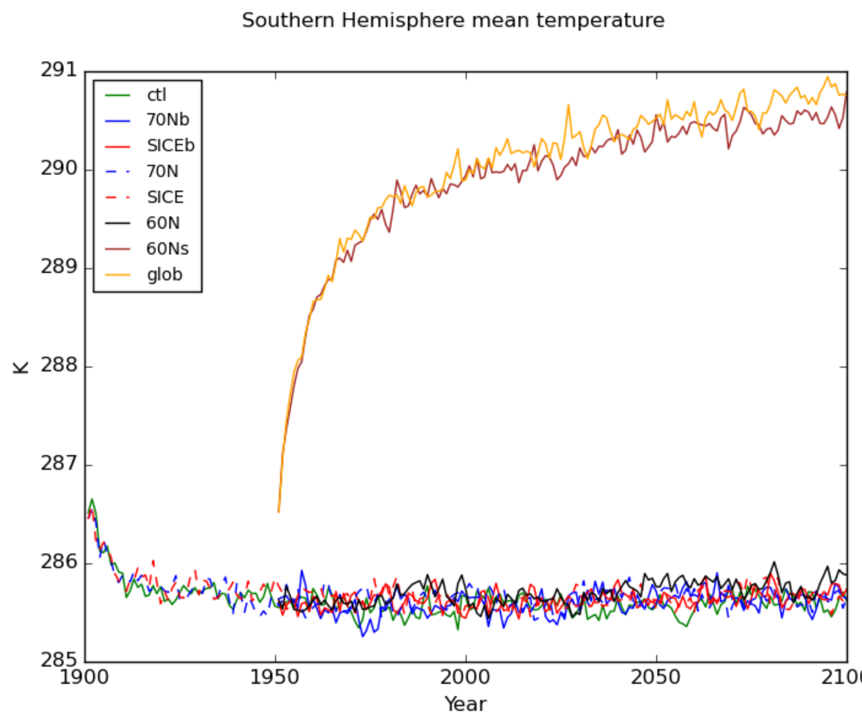


2 m temperature



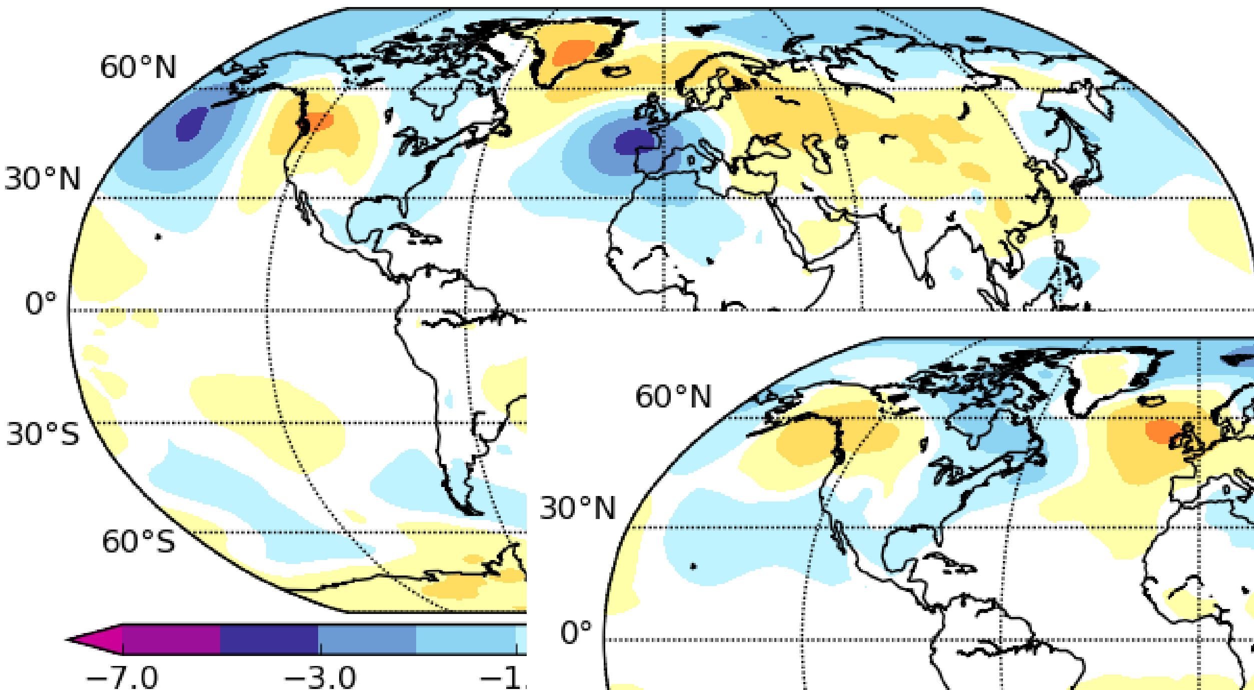
2 m temperature



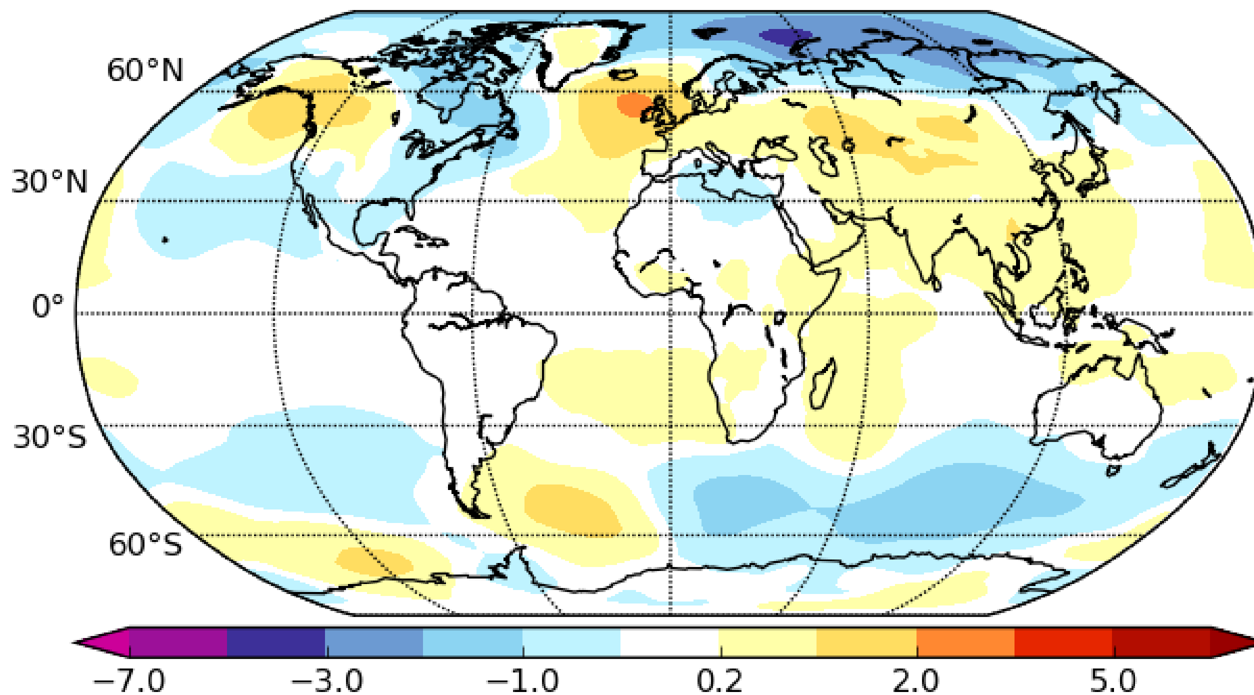


Mean sea level pressure (hPa)

4*CO2 north of 60 N, DJF



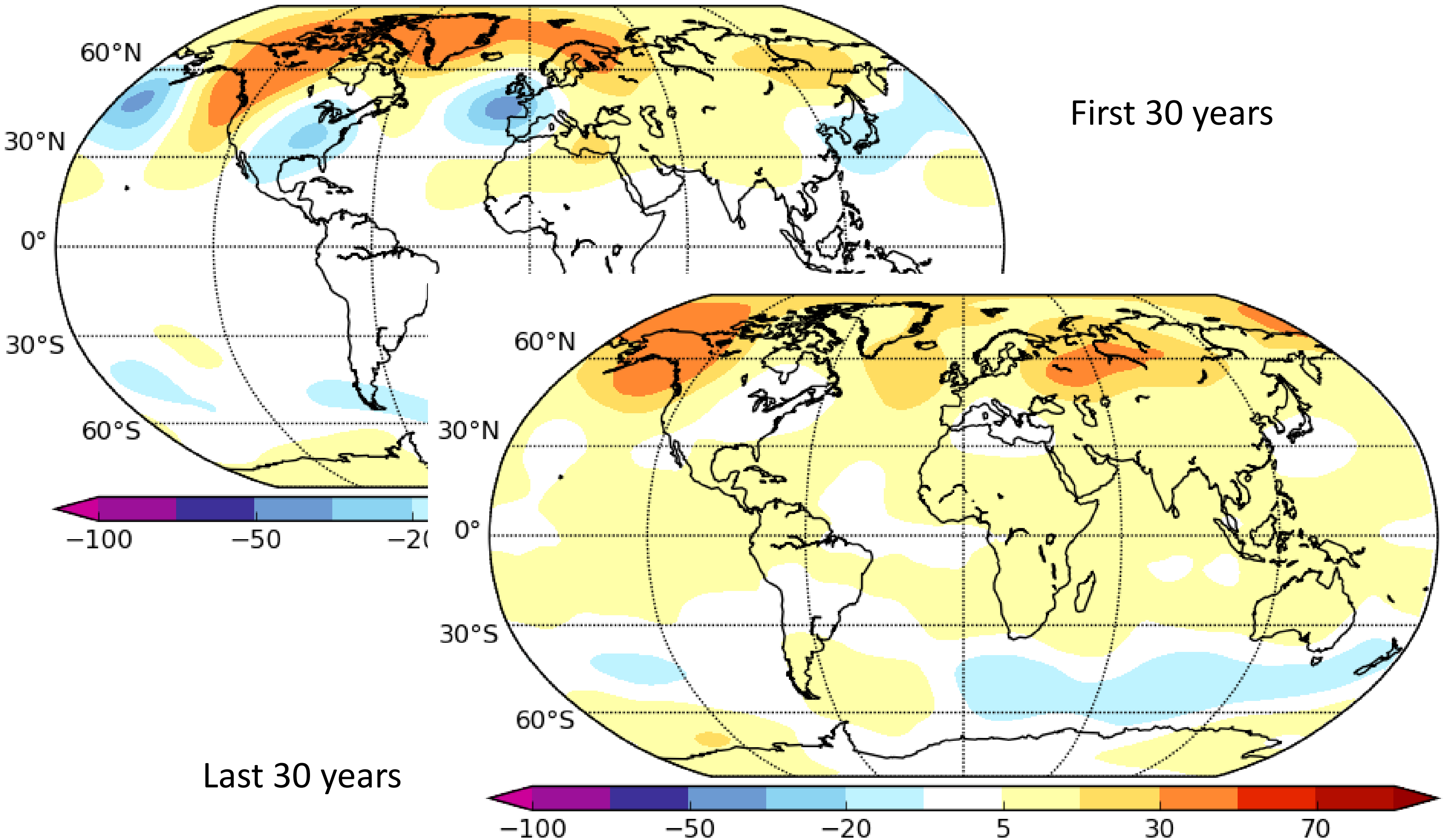
First 30 years



Last 30 years

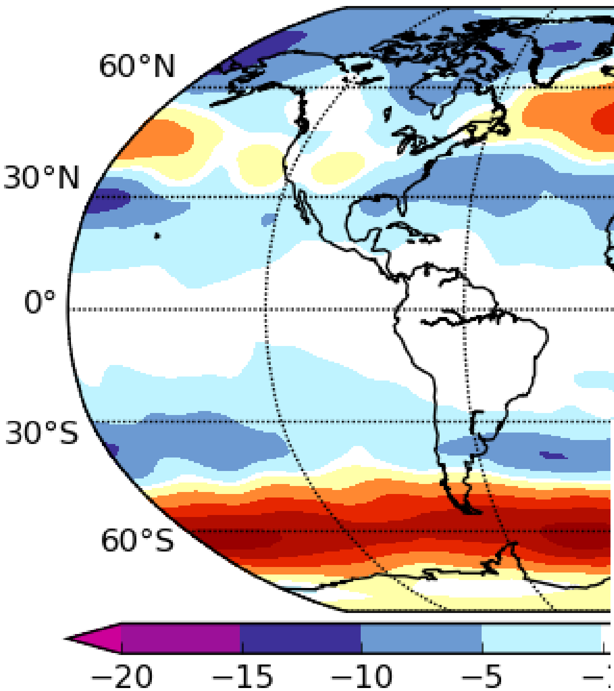
500 hPa geopotential height (m)

4*CO2 north of 60 N, DJF

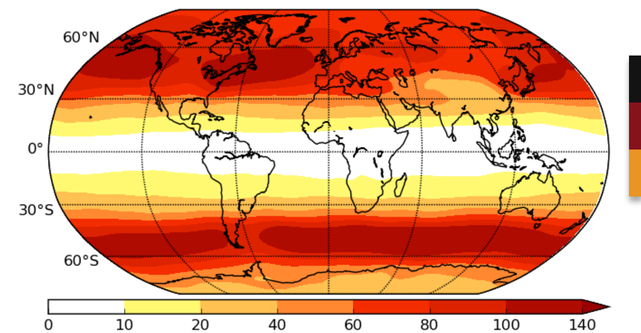


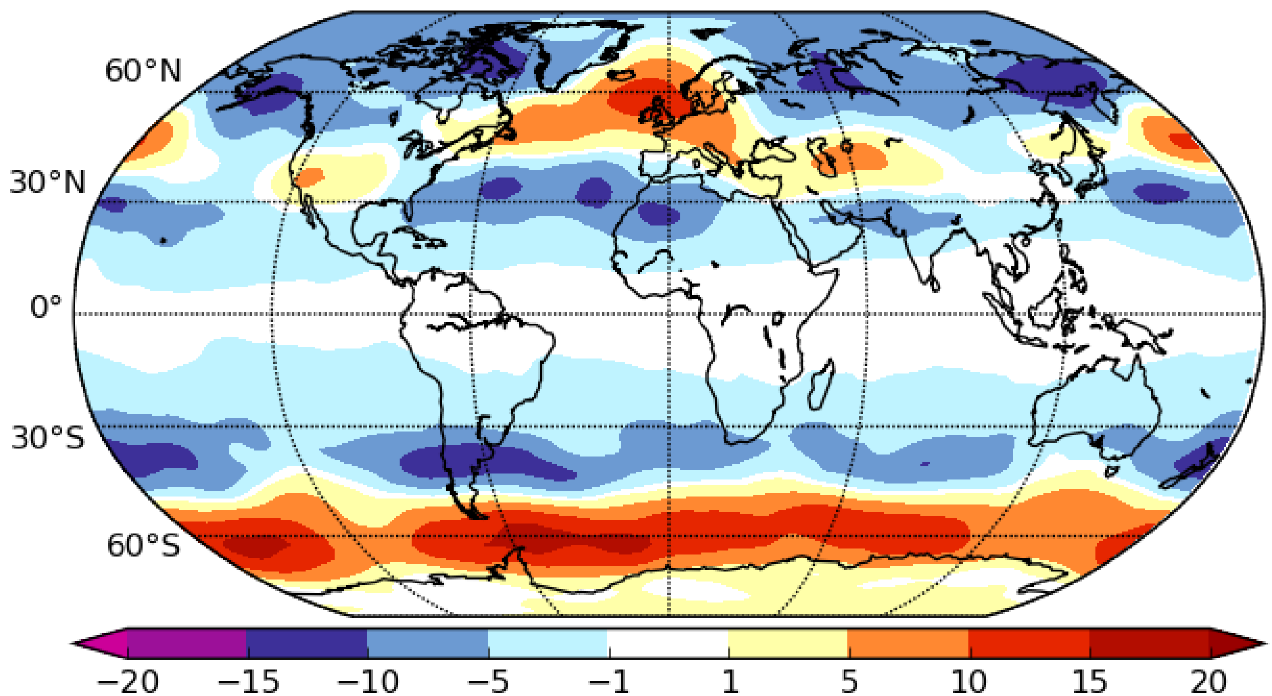
Synoptic activity 500 hPa (m)

4*CO2 glob, DJF



First 30 years

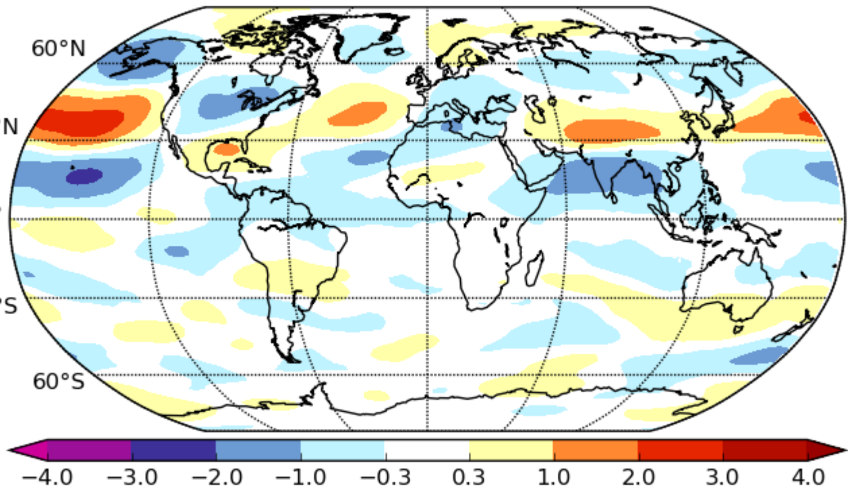




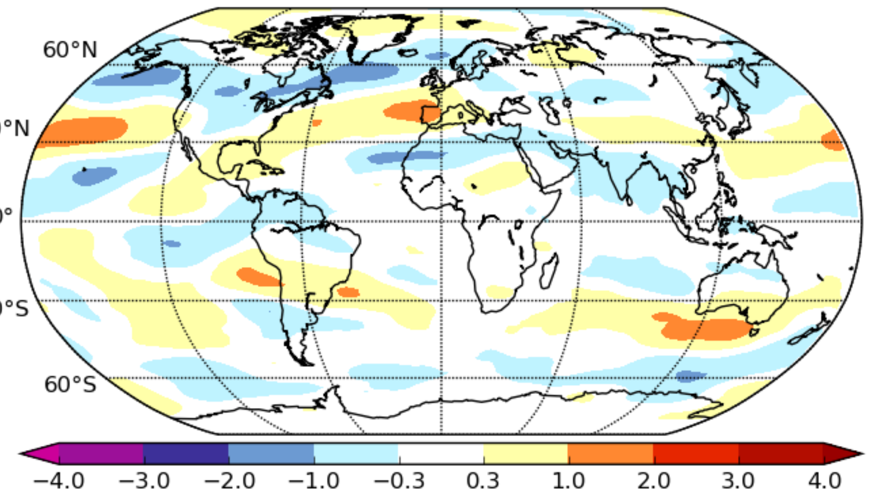
Last 30 years

Winter U 300 response (m/s)

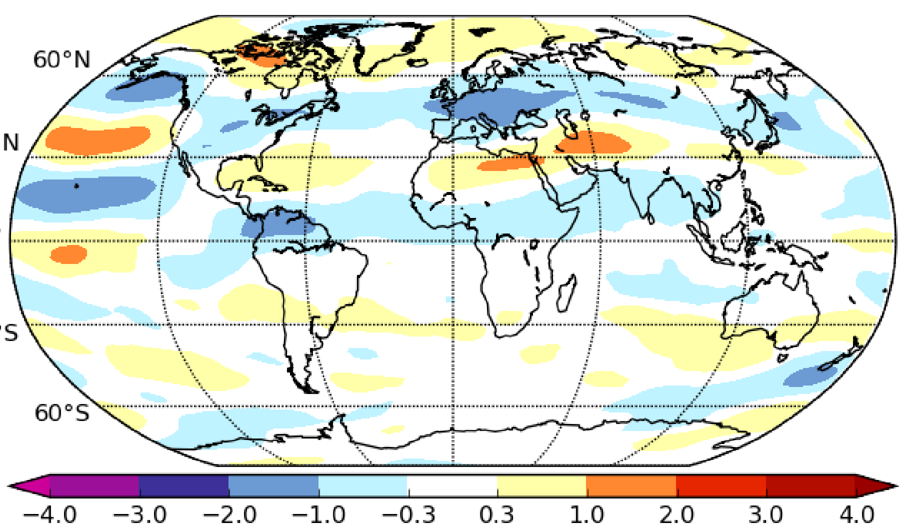
4*CO2 north of 70 N for the last 120 years



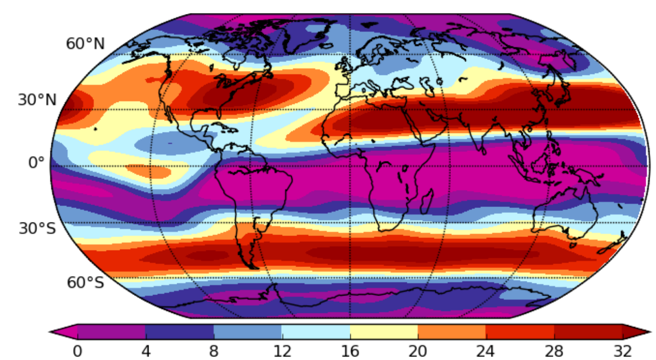
4*CO2 north ice edge for the last 120 years



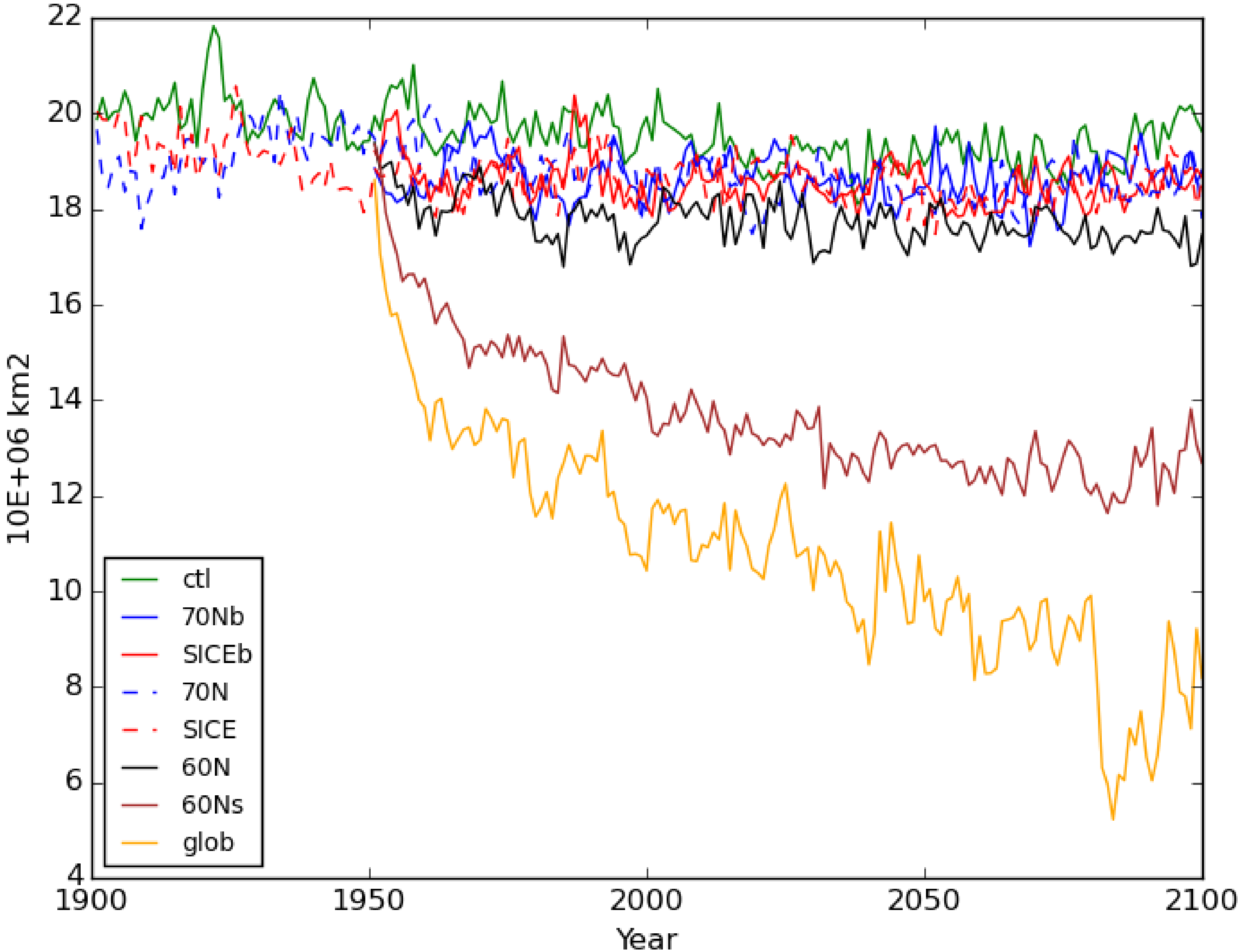
4*CO2 north of 60 N for the last 120 years



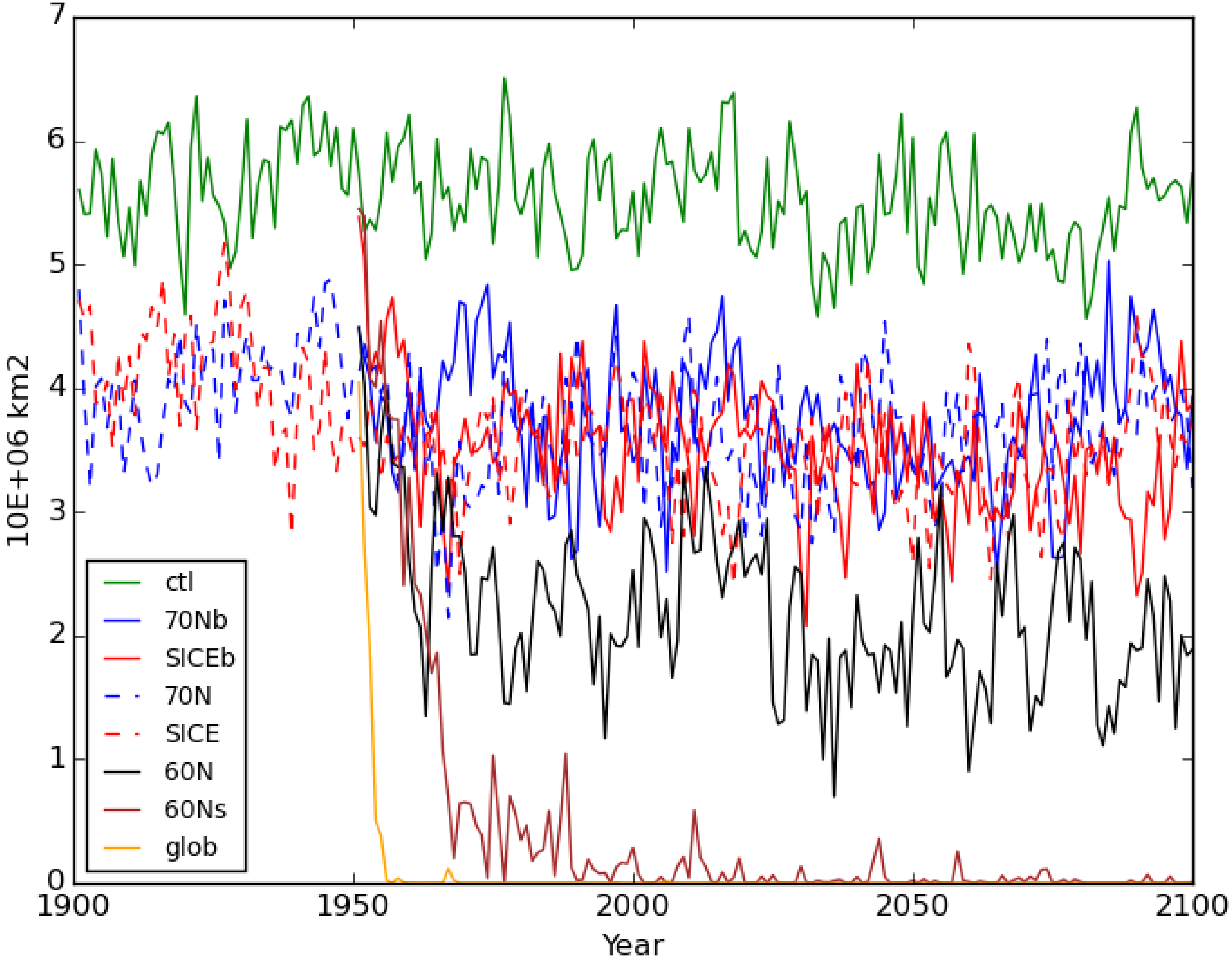
Pattern much weaker and modulated over Europe



Arctic sea ice area March



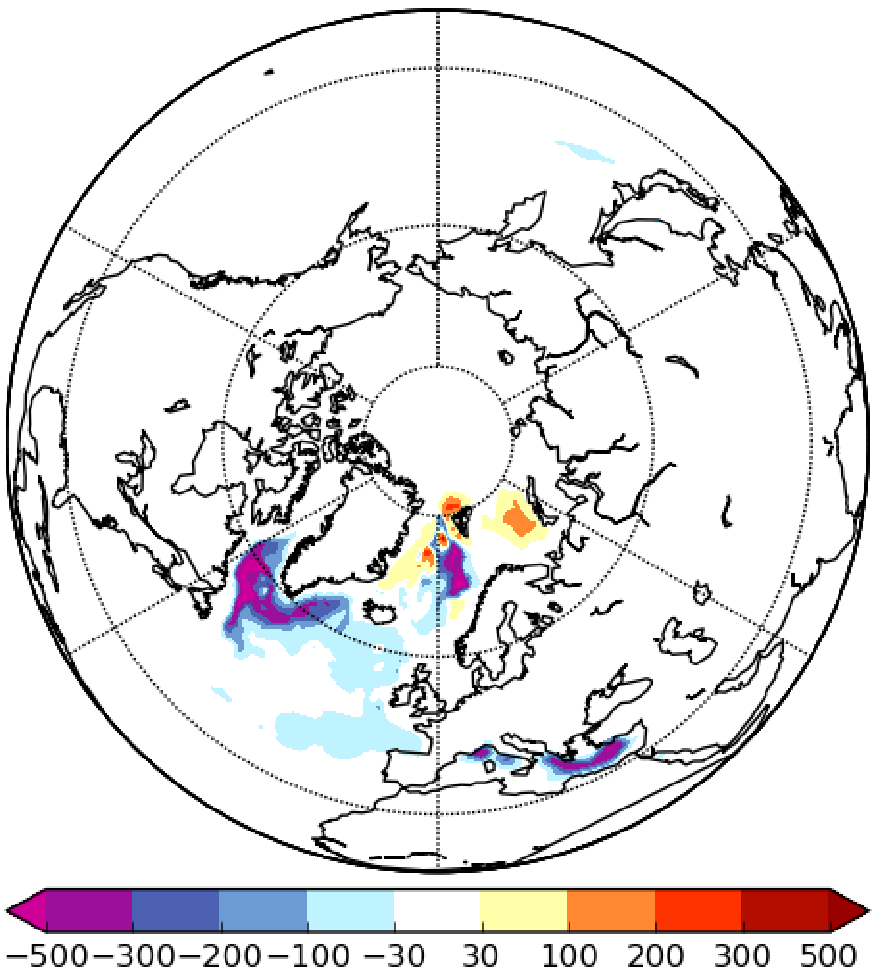
Arctic sea ice area September



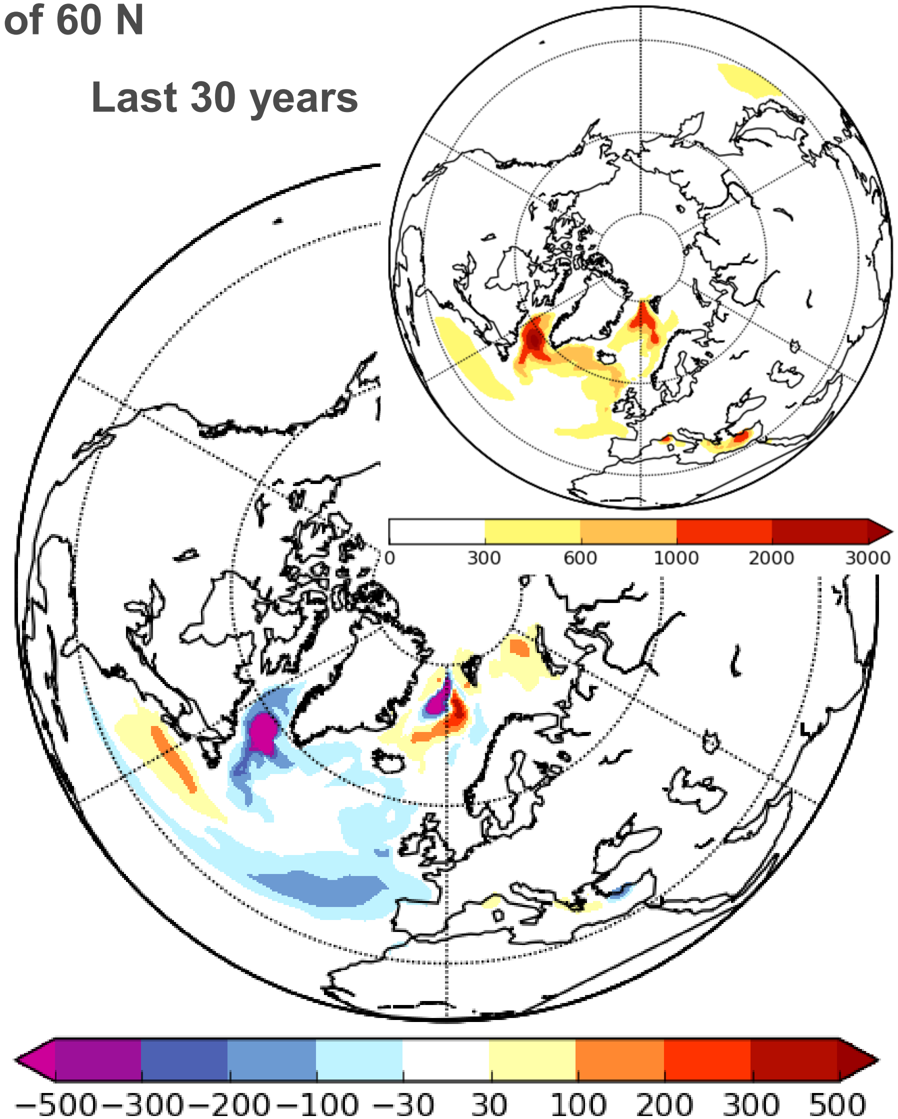
Ocean mixed layer depth anomaly

4*CO2 north of 60 N

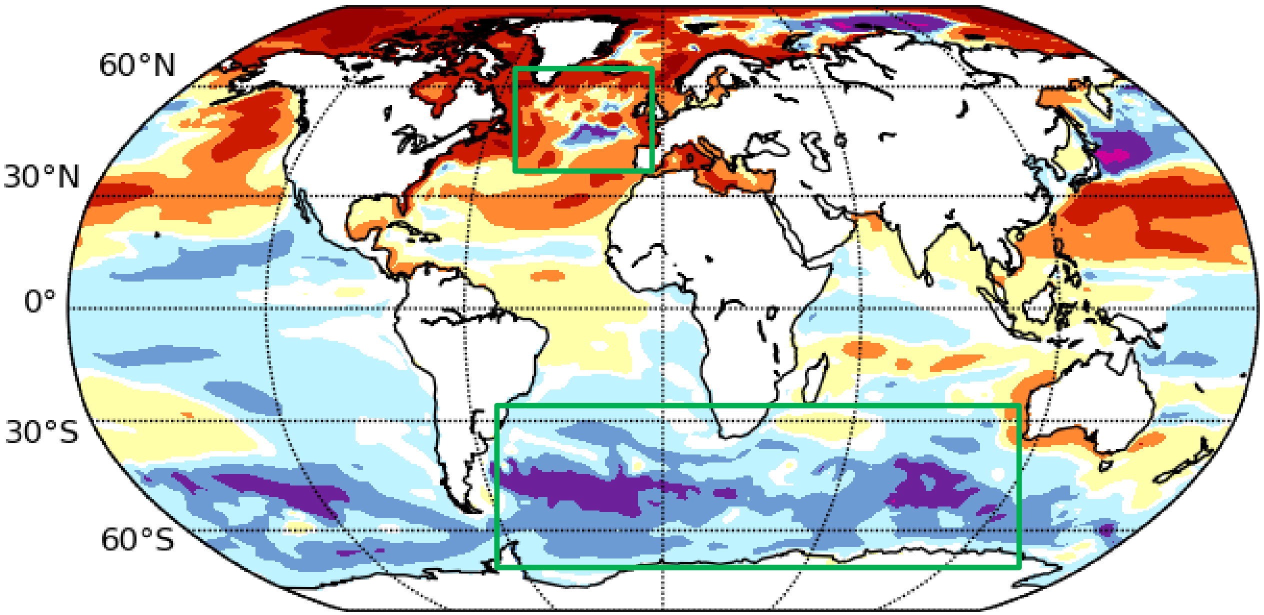
First 30 years



Last 30 years

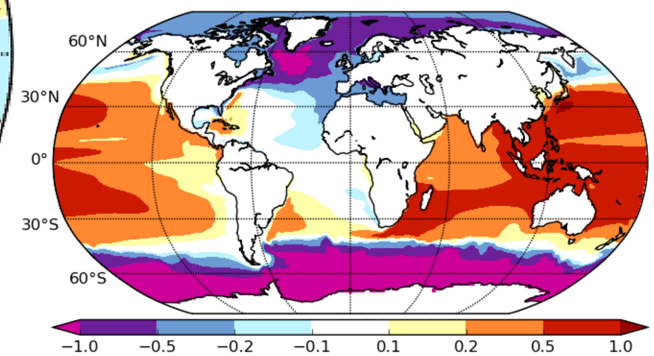


Sea surface height (m)

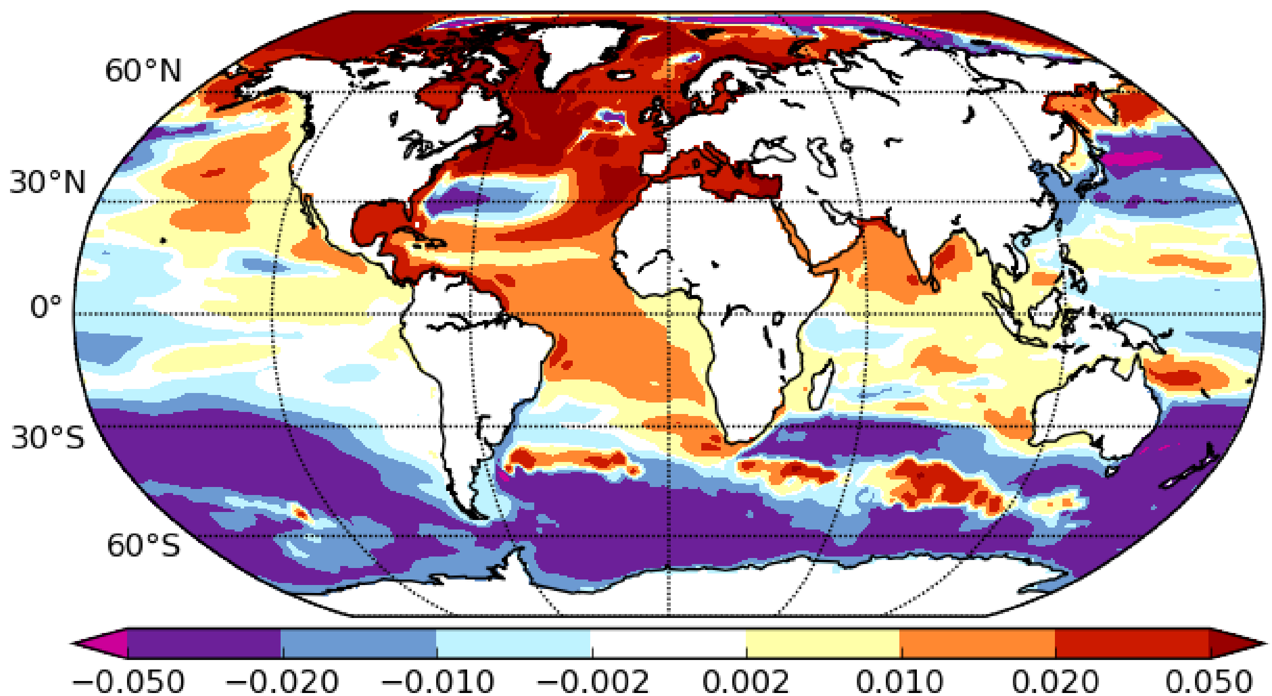


4*CO2 north of 60 N, DJF

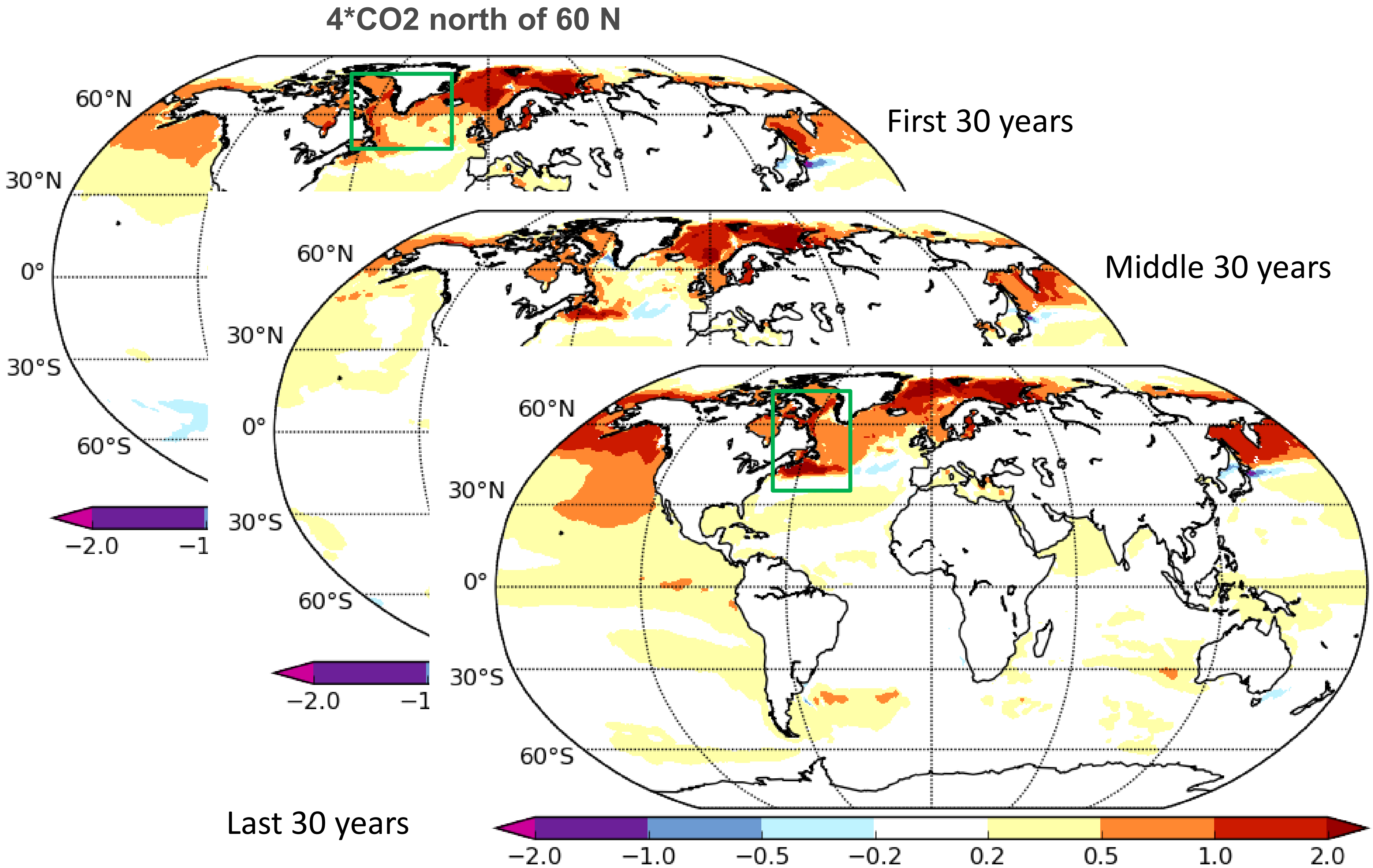
First 30 years



Last 30 years



Ocean temperature response (K) 15 m



Salinity response (psu) 15 m