Atmospheric response to Arctic sea ice decline in the CNRM-CM6 climate model

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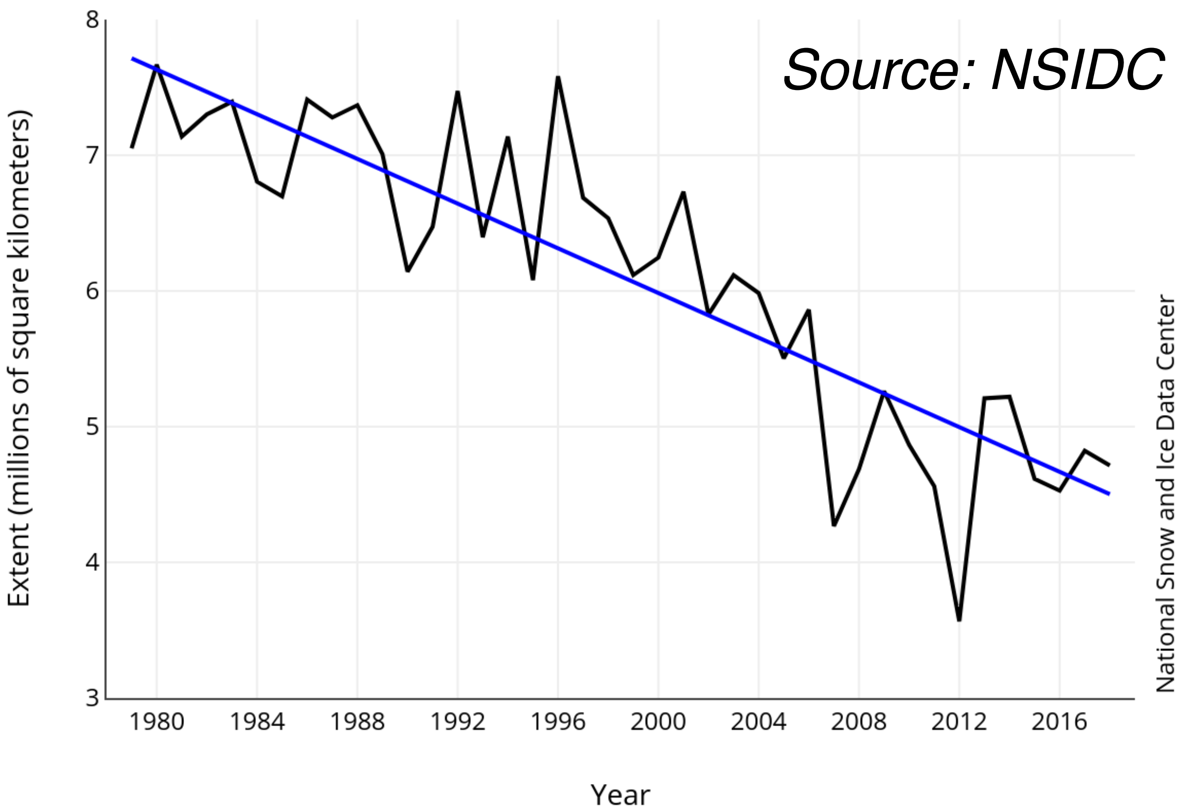
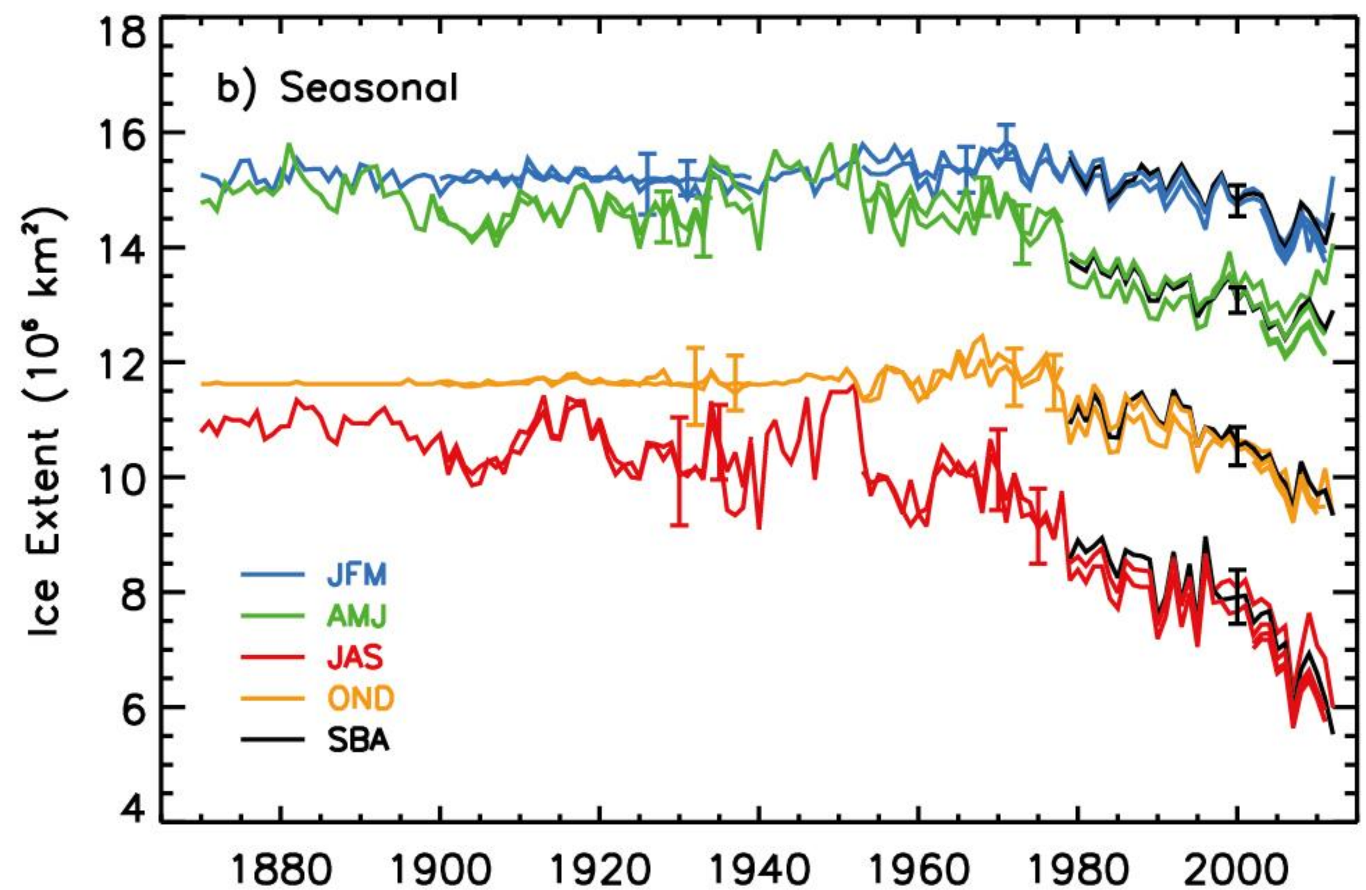
Arctic sea ice in observations

Averaged monthly Arctic Sea Ice extent September 1970-2018



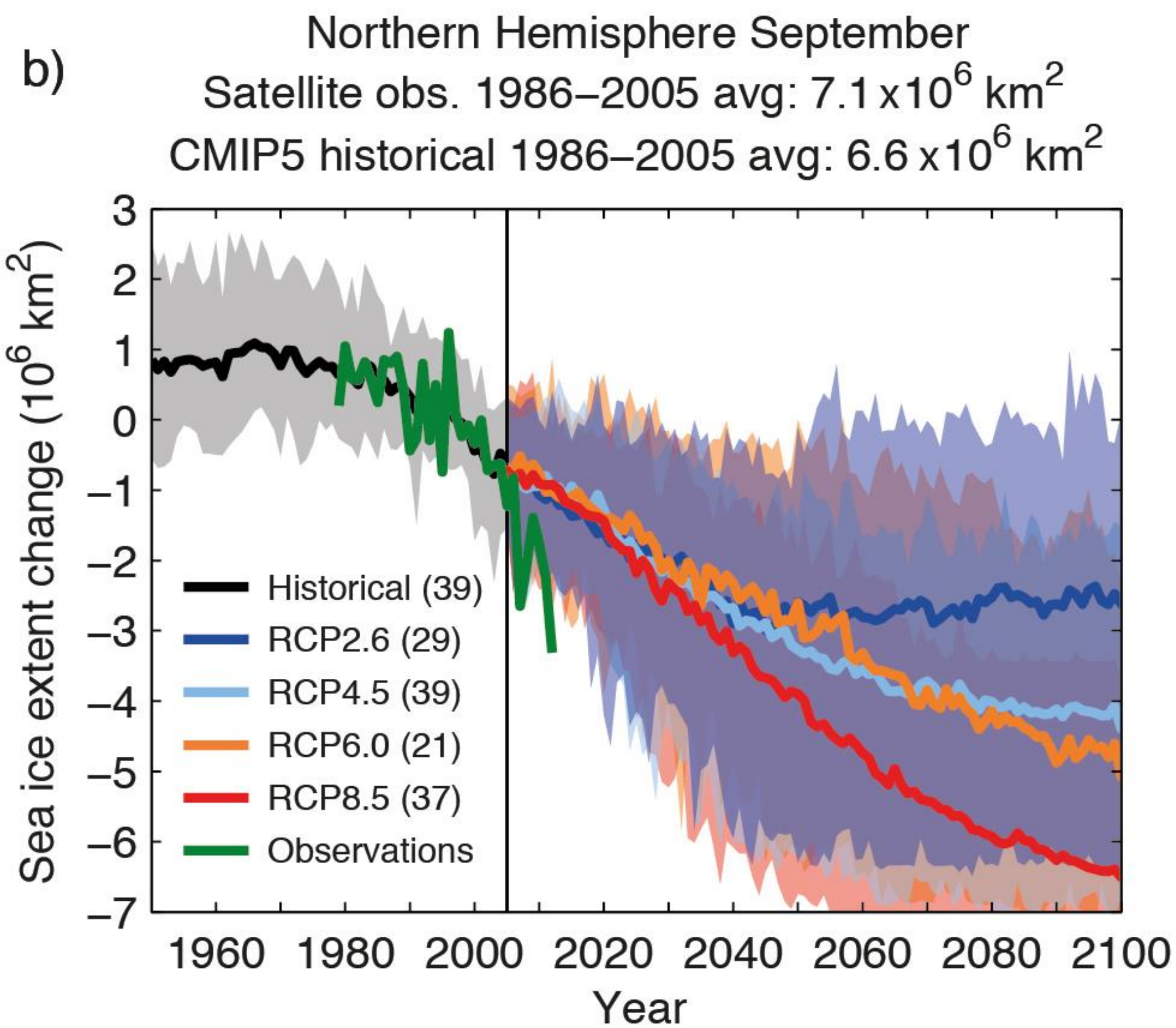
Averaged seasonal Arctic Sea Ice extent in HadISST and Walsh and Chapman reconstruction (prior 1979) and satellite estimates (after 1979)



IPCC AR5 Working Group 1
Climate Change 2013: The Physical Basis

- Summer Arctic sea ice has been declining by about 14% per decade since 1979 *(Stroeve et al. 2012)*
- All seasons show a decline even though it is less pronounced in winter

Arctic sea ice in climate projections



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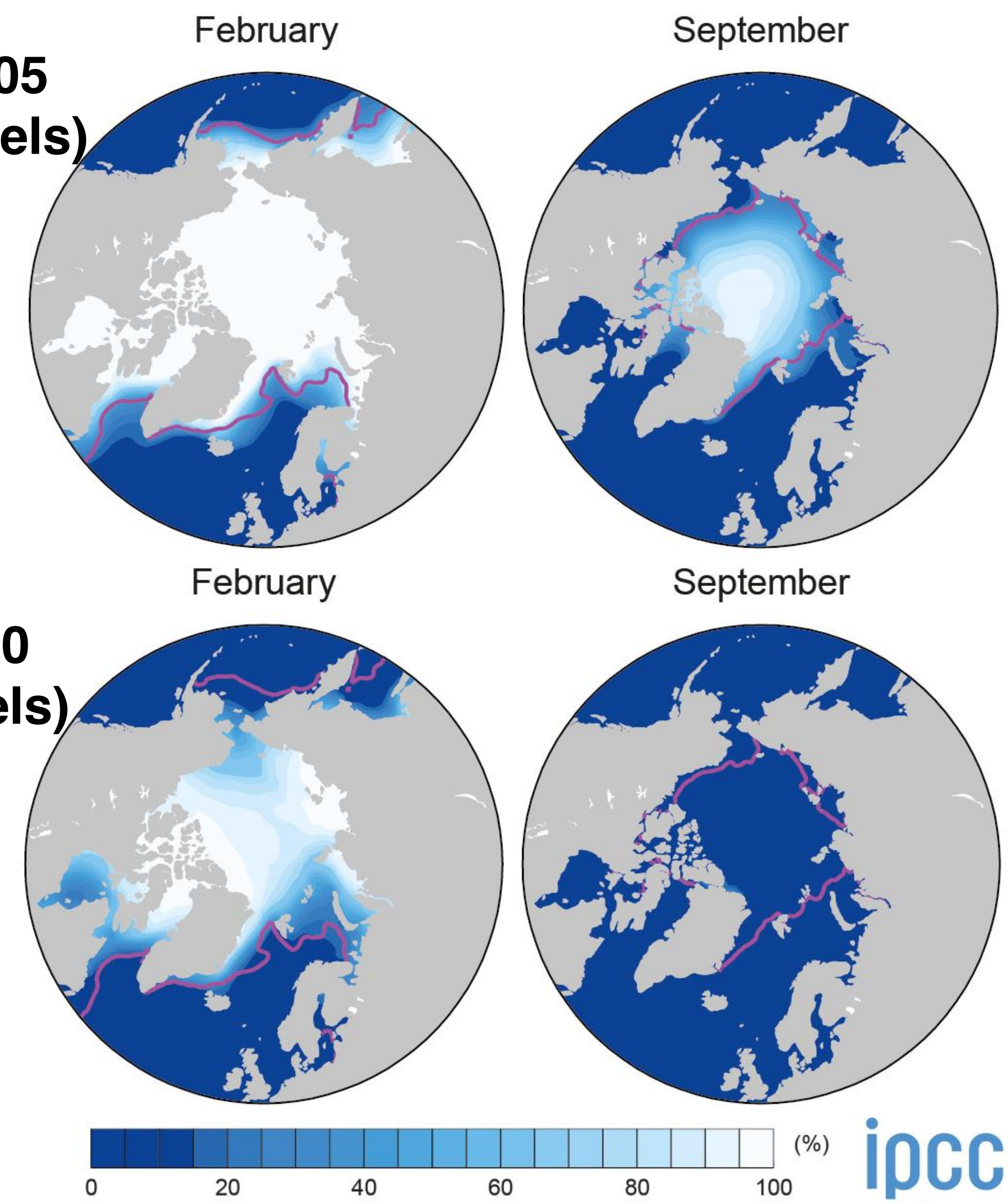
Climate Change 2013: The Physical Science Basis

Multi-model mean Arctic sea ice concentration



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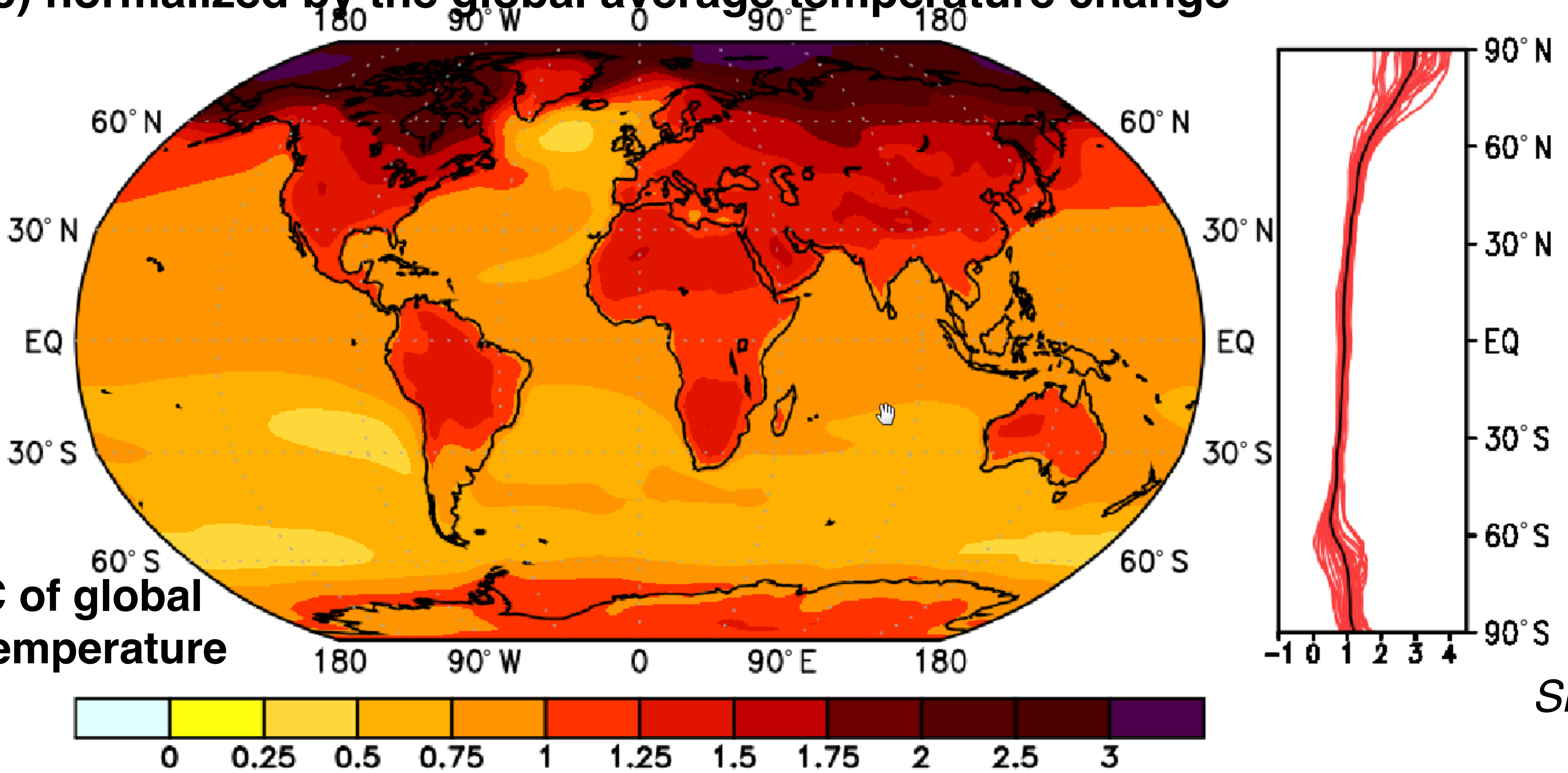
INTERGOVERNMENTAL PANEL ON climate change

High probability of having ice-free summers by 2100

Polar amplification in climate model projections

Temperature change in CMIP5 models : difference between end of 21st and 20th century (RCP8.5) normalized by the global average temperature change

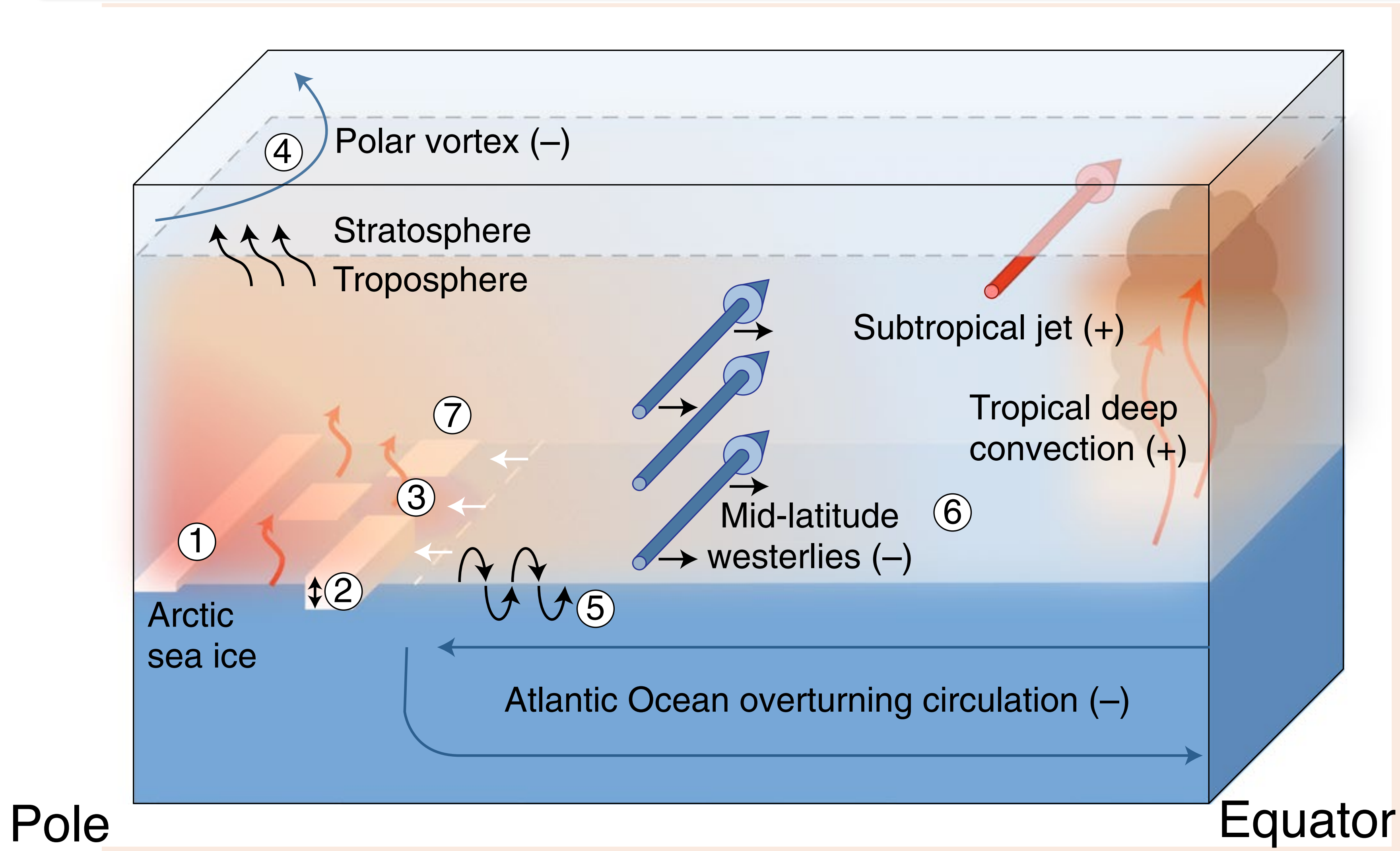


°C per 1°C of global average temperature change

Smith et al. (2019)

- Arctic amplification is a robust feature of climate model projections. But what are its main drivers? How is it linked to changes in midlatitude weather and climate ?
- Need to better understand the influence of sea ice decline on atmospheric circulation. Large body of literature (see reviews by *Cohen et al., Walsh et al. 2014, Barnes et al. 2015, Screen et al. 2018*) but still many uncertainties and controversy.
- The climate response to sea-ice loss may partly counteract other aspects of the response to increased greenhouse gases.

Proposed mechanism on the influence of sea ice decline on midlatitude weather and climate



Screen et al. (2018)

- Atmospheric response to sea ice decline not robust across models :NAM-, NAM+, other ? (e.g. *Peings et al. 2014, Screen et al. 2014, Deser et al. 2015, Blackport and Kushner 2016*)

- Need to better understand the influence of sea ice decline on atmospheric circulation.

Outline

Objective : Characterize the mid-latitude atmospheric response to an abrupt sea ice decline in the CNRM-CM6-1 model

1. **Description of the model experiments**

2. **Results/proposed mechanisms**

3. **Conclusions**

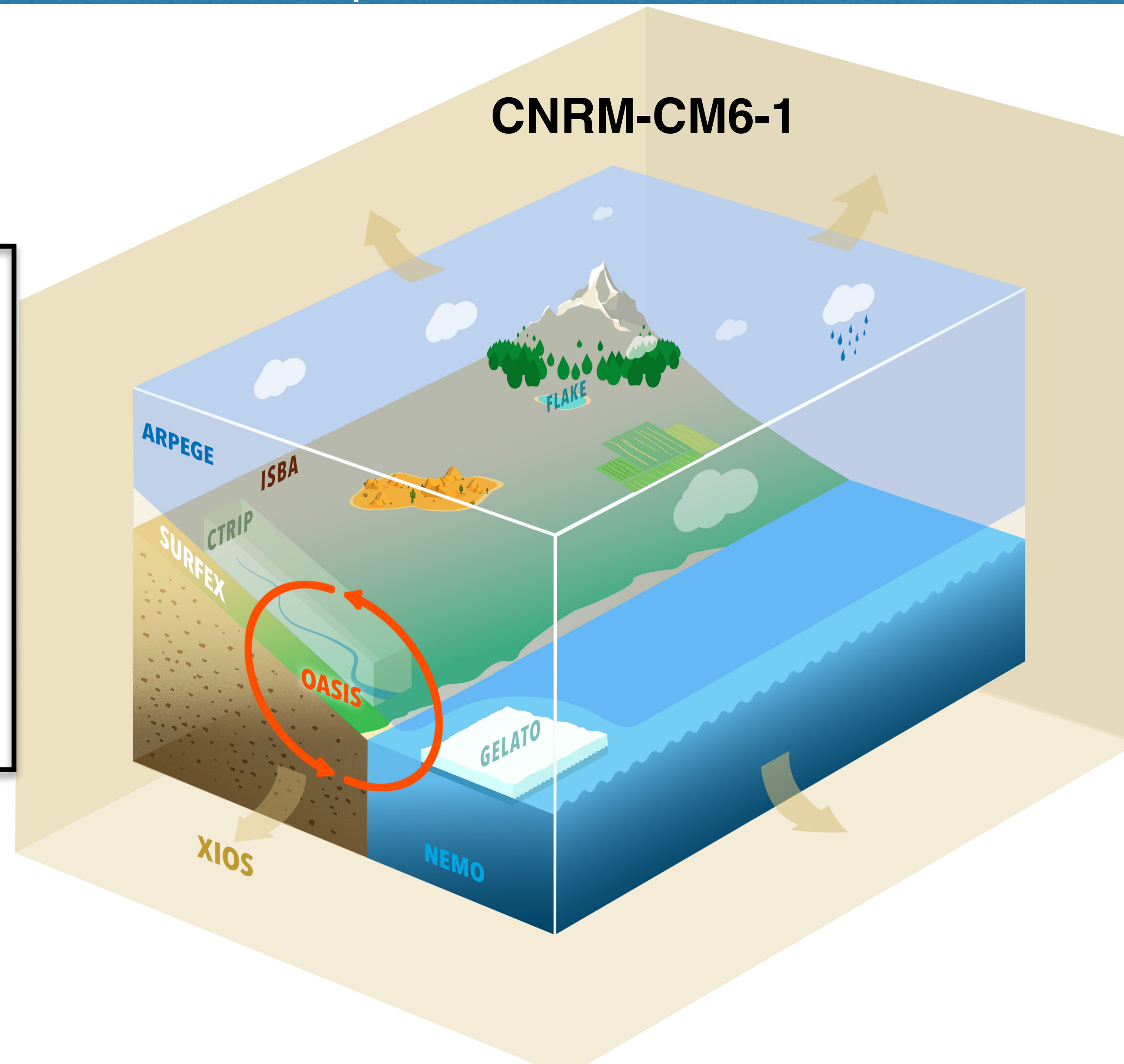
Model experiments

CNRM-CM6-1

NEMO 3.6 for ocean
GELATO v6 for sea-ice
ARPEGE-SURFEX for atm/land

2 resolutions:
LR: ORCA1 / ATM ~130km 91 levels
HR: ORCA025 – ATM ~50km 91 levels

Voldoire et al. (2019)



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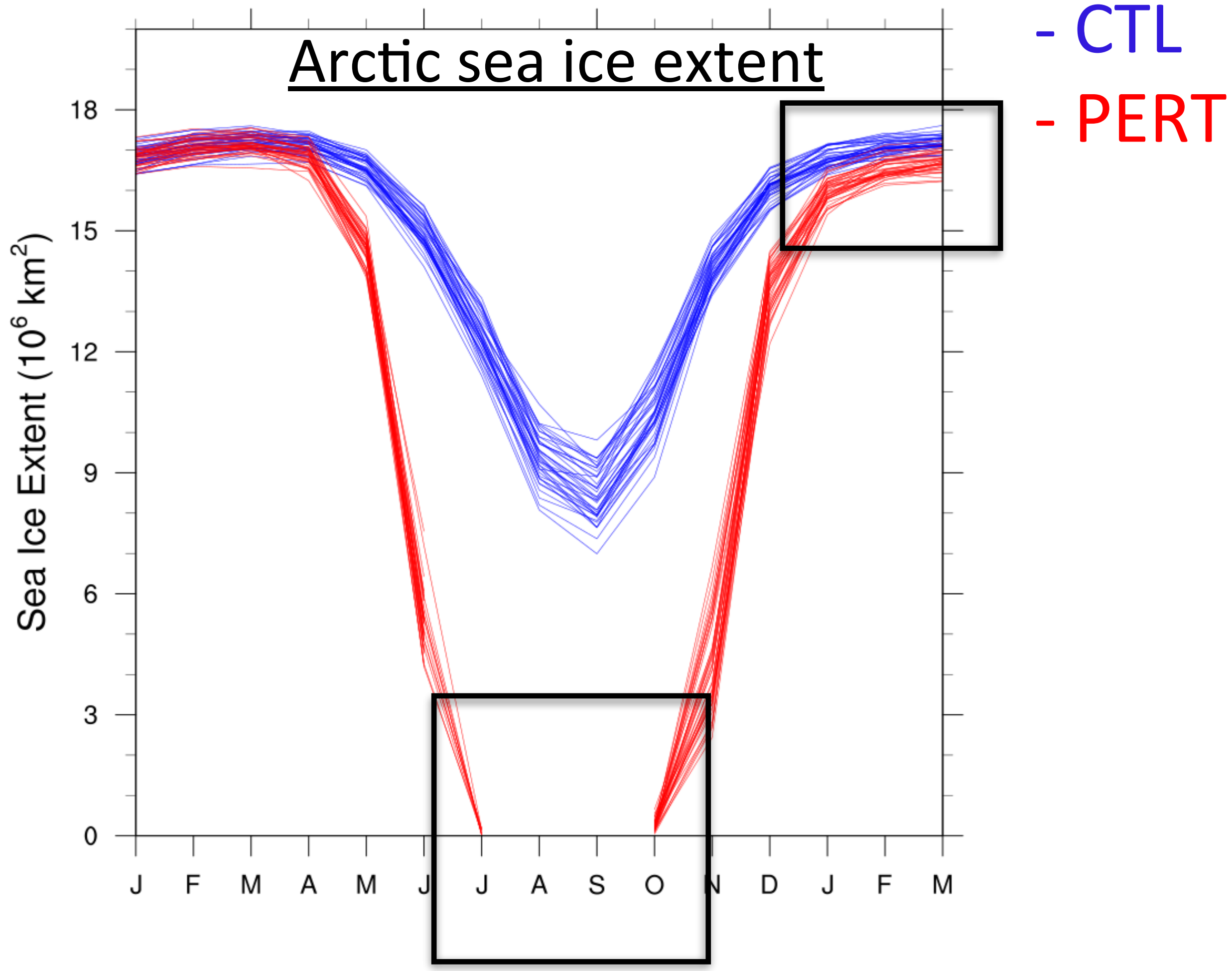
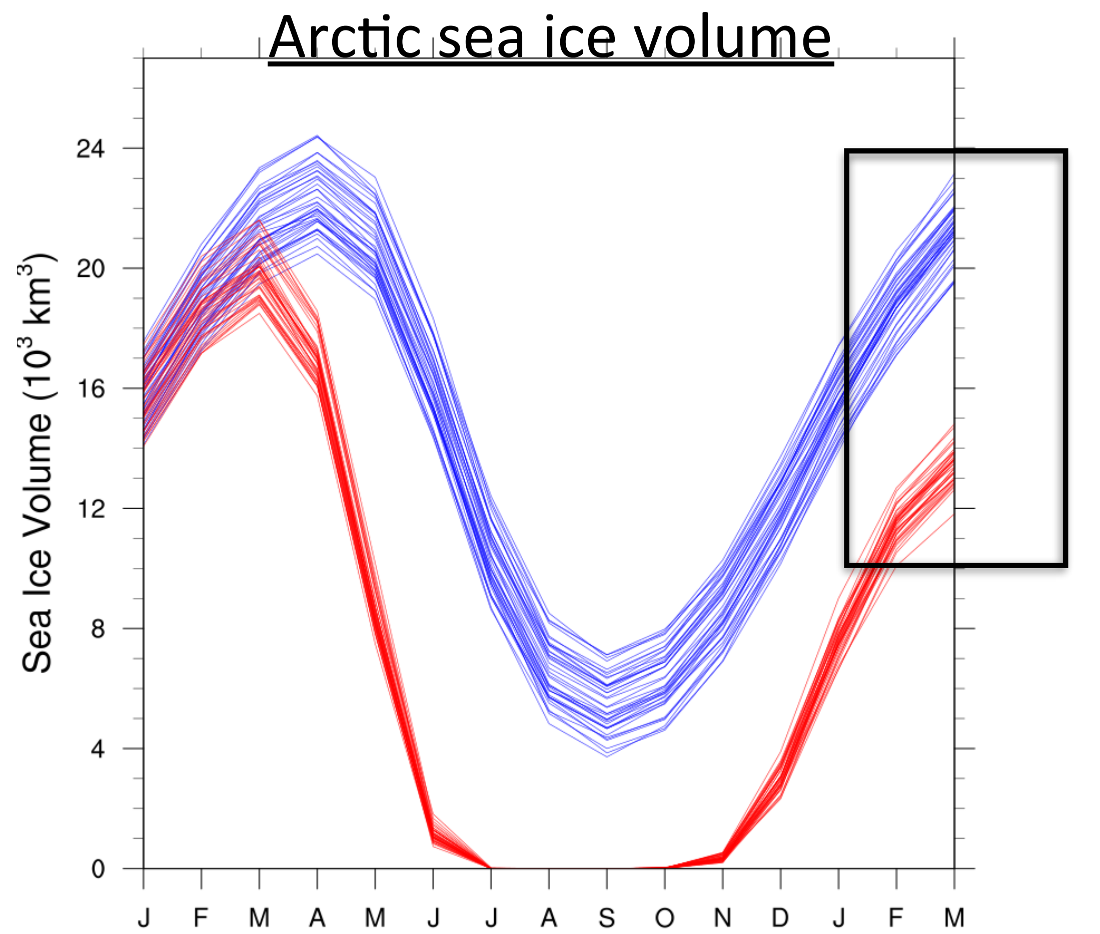
Albedo *coupled experiments* simulating a complete melt in summer (PRIMAVERA project)

- **Sea ice albedo reduced to ocean value (0.07)**
- **Initial state: 1950-control CNRM-CM6-1**
- **40 members starting January 1. Run for 24 months.**

=> Sea ice perturbation reflecting sea ice loss comparable to end of century projections

Sea ice response



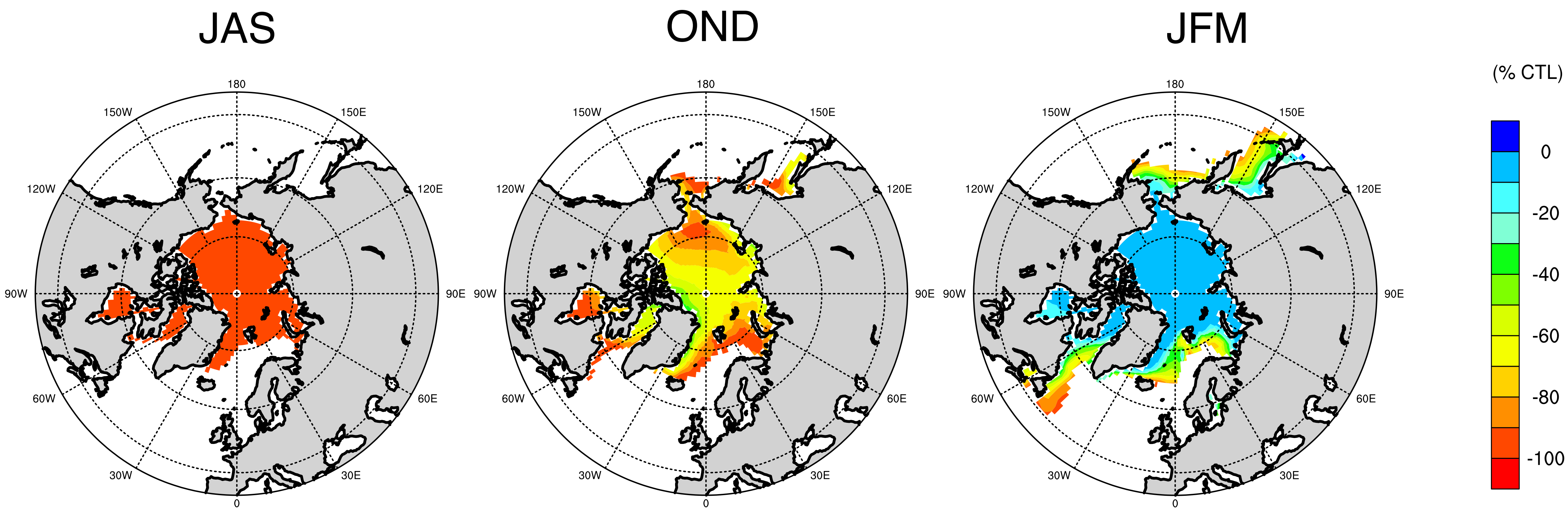


- Summer (JAS): complete sea ice loss
- Winter (JFM): SIC almost recovered but SIV loss persists

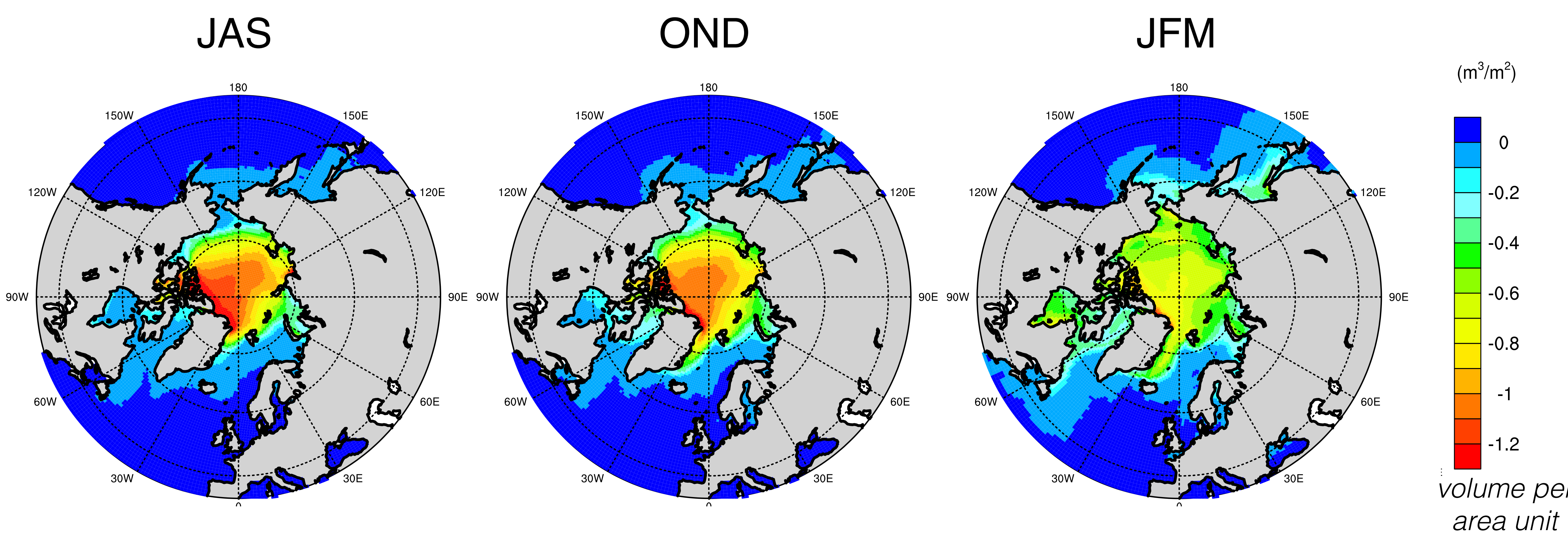
Focus on the atmospheric response (PERT - CTL) in autumn (OND) and winter (JFM) following the summer sea ice loss

Sea ice response

Sea ice concentration response (% CTL)

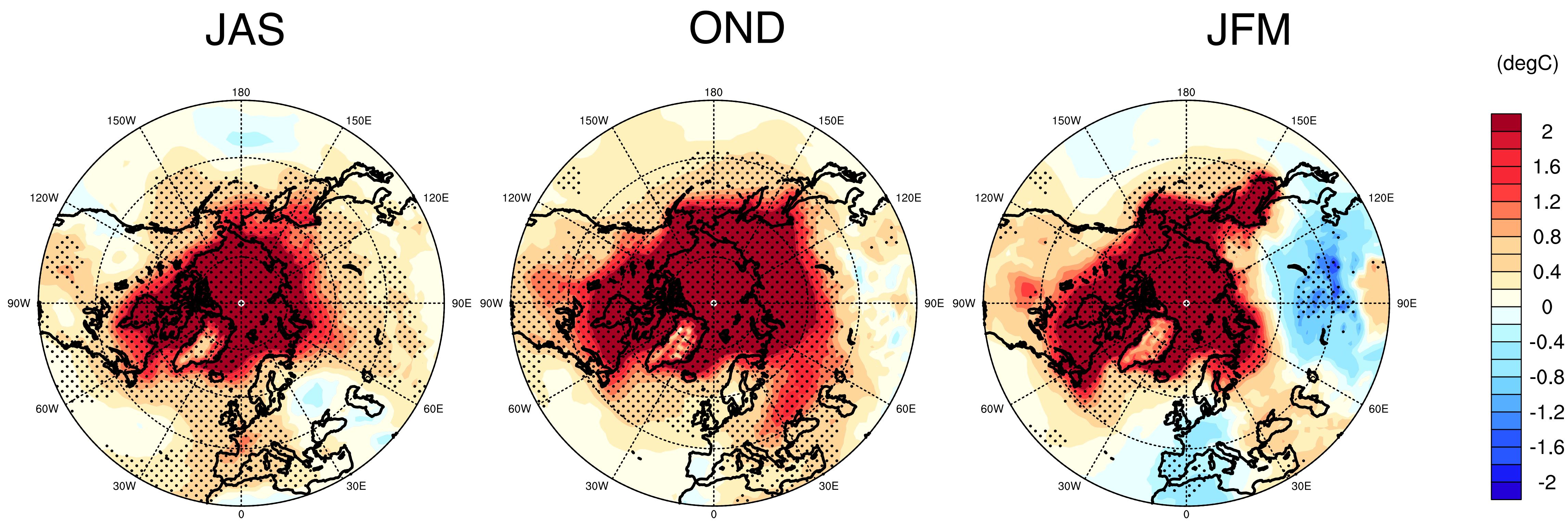


Sea ice volume response



Near surface response

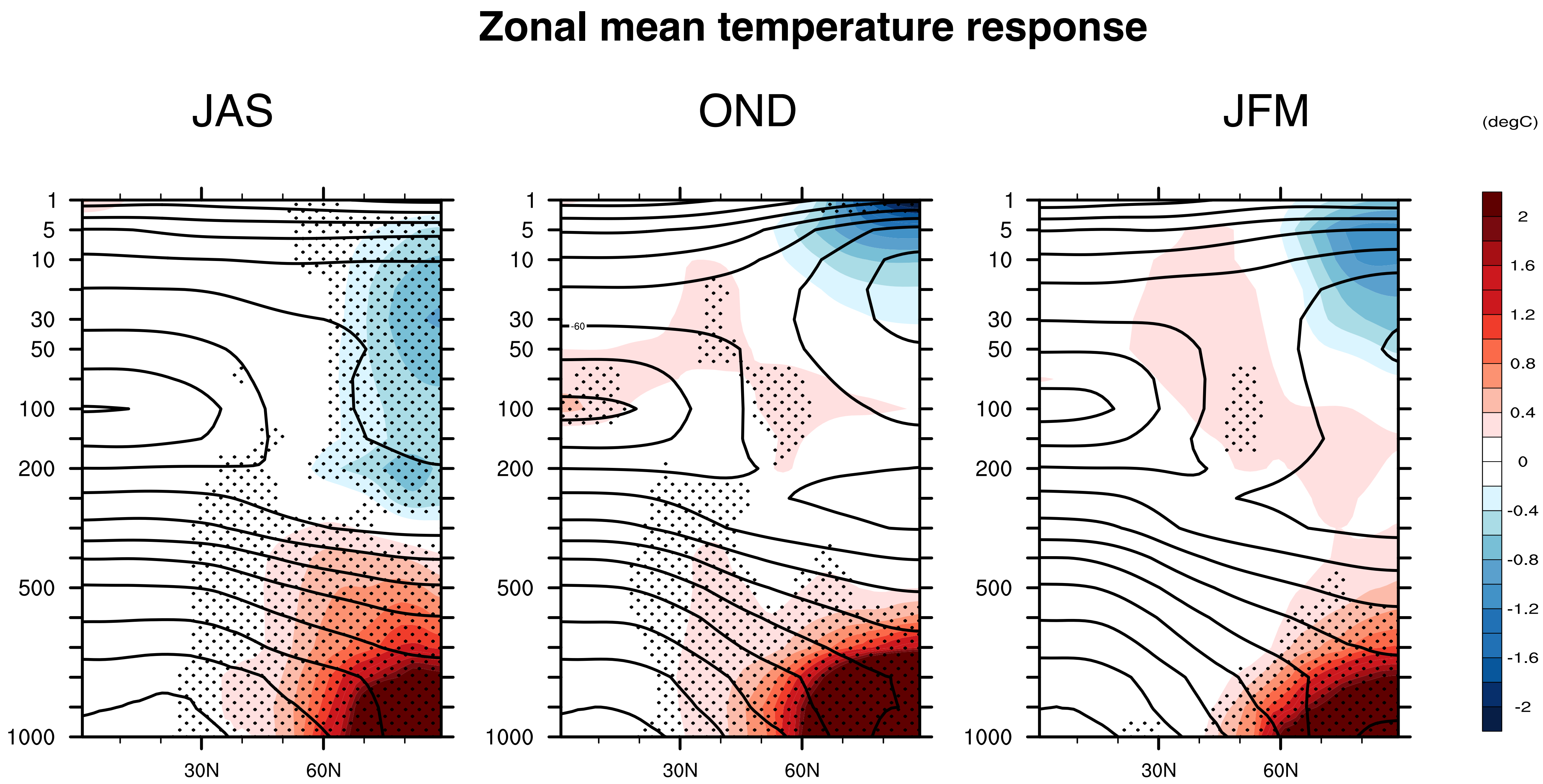
Surface air temperature response



- Strong polar amplification. Largest warming in fall (November). Maximum +22 ºC in Central Arctic in OND.

- Significant temperature response over land: Large-scale warming over the NH in summer and autumn, cooling over Western Europe and Eurasia in winter consistent with Honda et al. (2009), Mori et al. (2014, 2019)

Vertical structure of the temperature response



- Warming in the lower troposphere in response to sea ice changes, cooling in the stratosphere

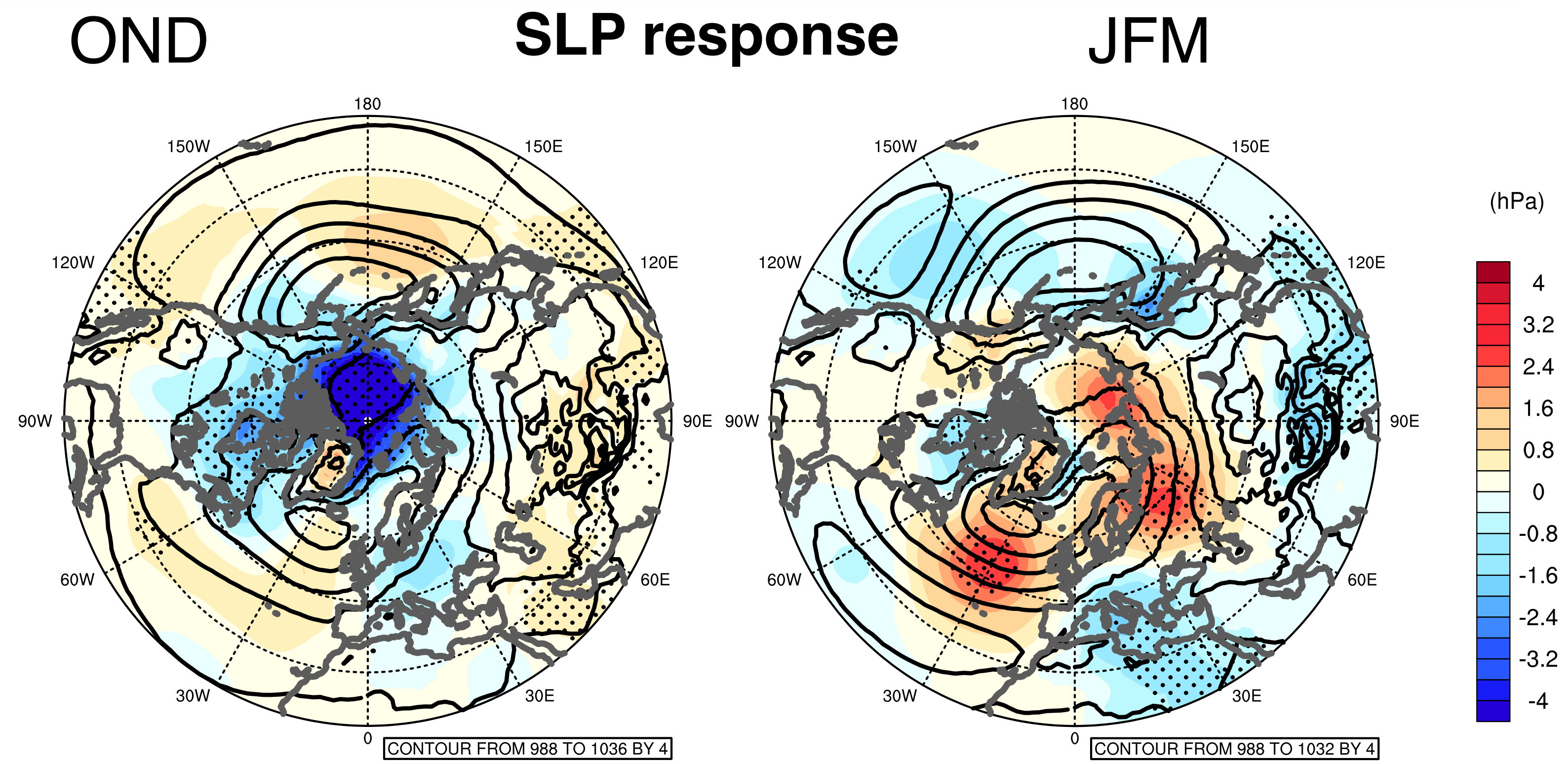
=> Arctic amplification

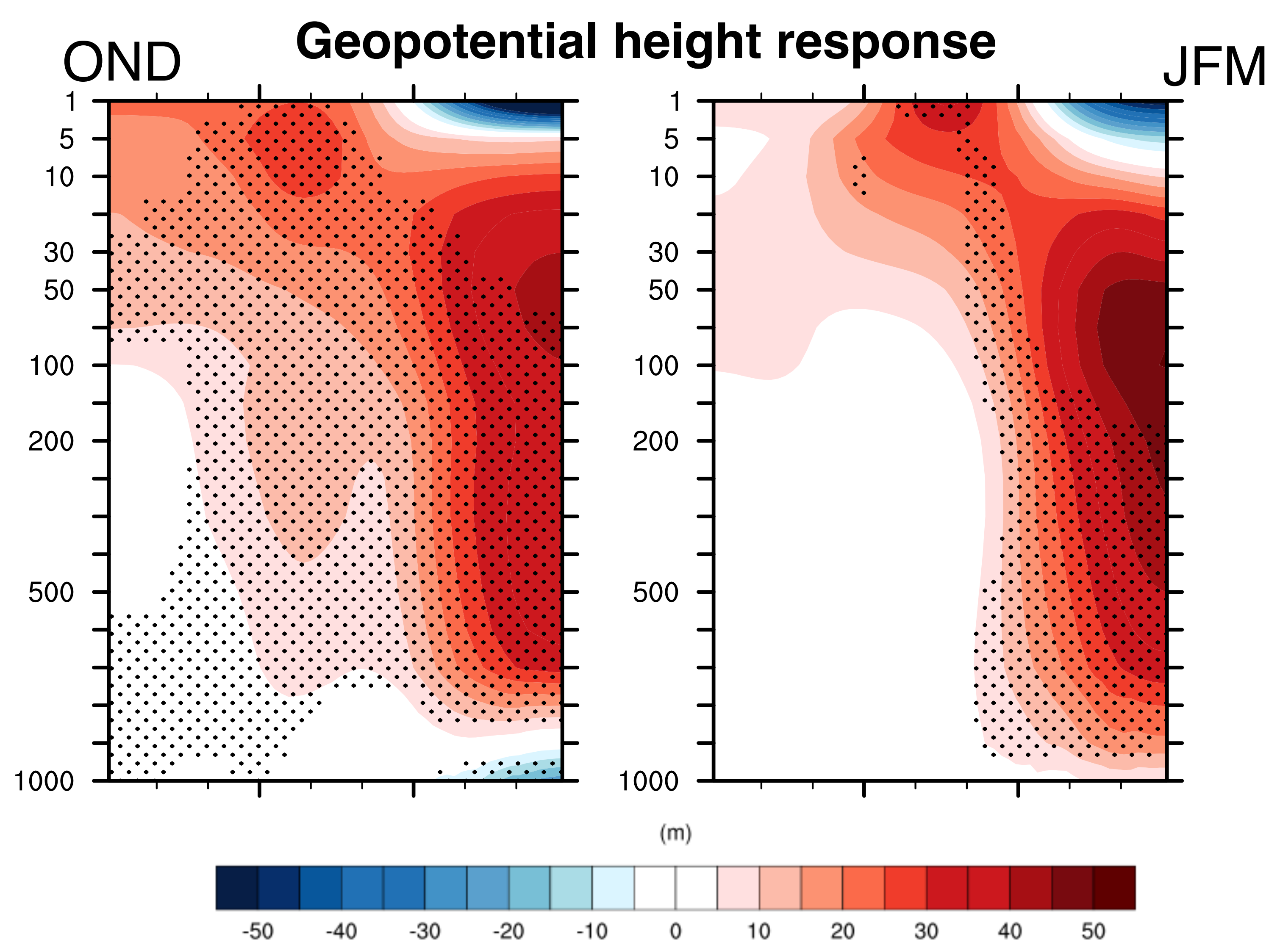
- Cooling in the stratosphere

- Weak but significant warming in the upper troposphere in the tropics due to coupling? (Deser et al. 2015)

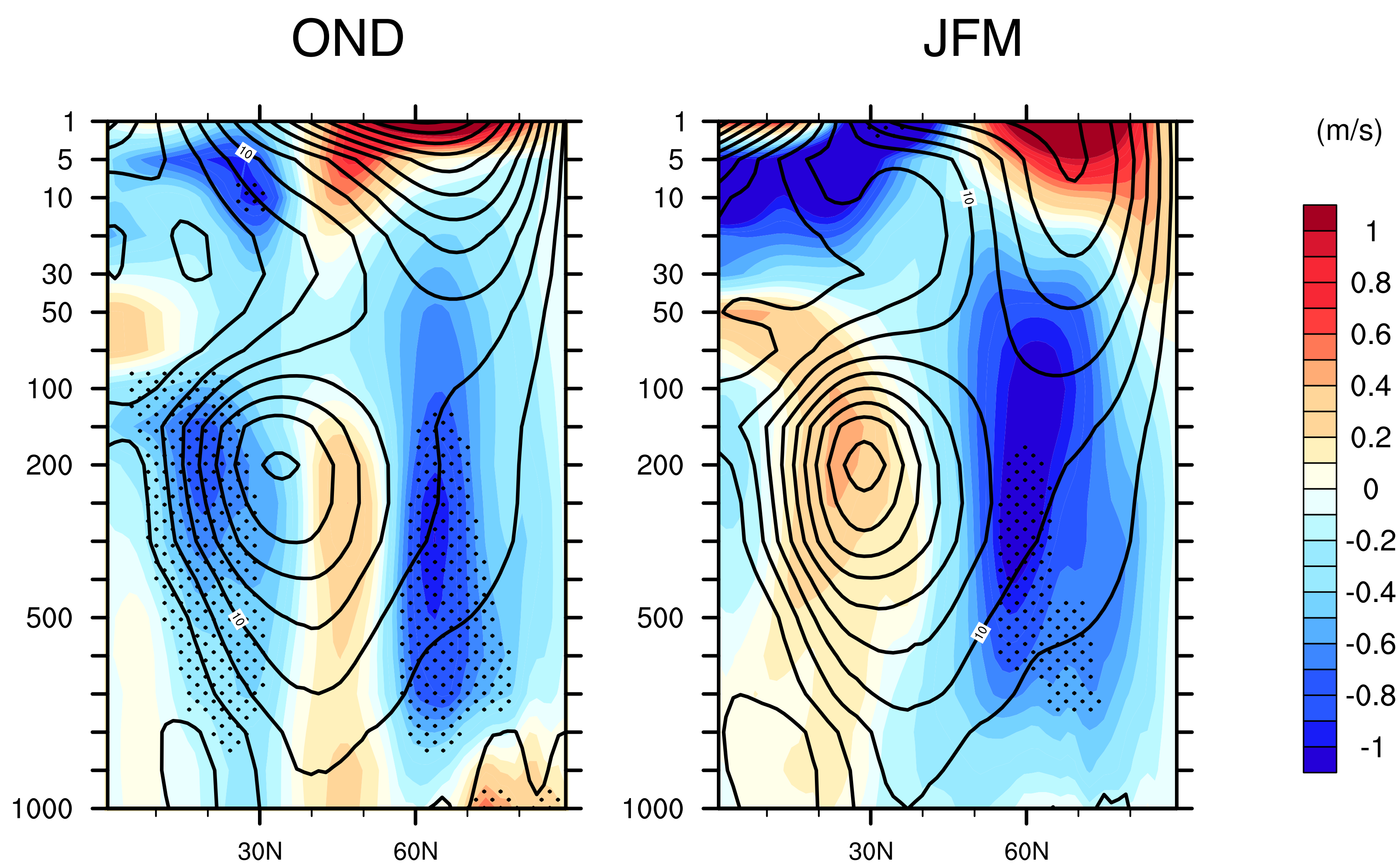
Pressure response

- Intensification of the Aleutian Low /Siberian High and weakening of the Iceland Low in winter, consistent with other coupled model studies *(Screen et al. 2018)*
- Baroclinic response in autumn, barotropic in winter. Change of sign in the upper stratosphere in the Arctic but not significant.
- The response does not project on the NAM
- Elevated height not restricted to the Arctic (effect of coupling)





Vertical structure of the response: zonal circulation

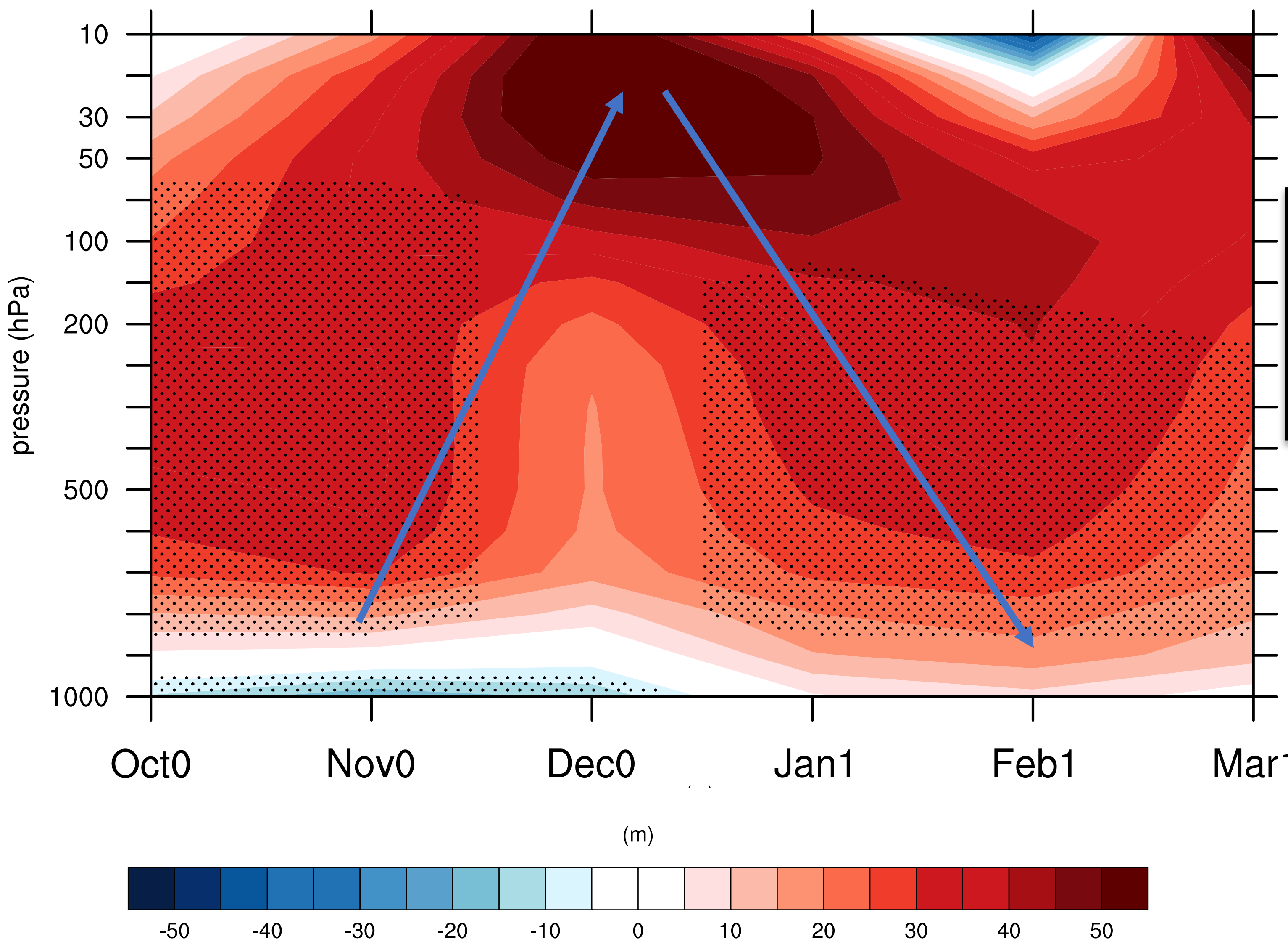


- Narrowing of the subtropical jet in autumn / equatorward shift in winter => consistent with *Peings et al. (2014), Deser et al. (2015), Sun et al. (2015), Oudar et al. (2017), Blackport and Kushner (2016,2017)*, …Weakening of the midlatitude westerlies only in JFM

- Weakening of the lower part of the polar vortex, strengthening of the core. Not significant.

Troposphere/stratosphere interactions

Evolution of the polar cap (60°N-90°N) geopotential height response



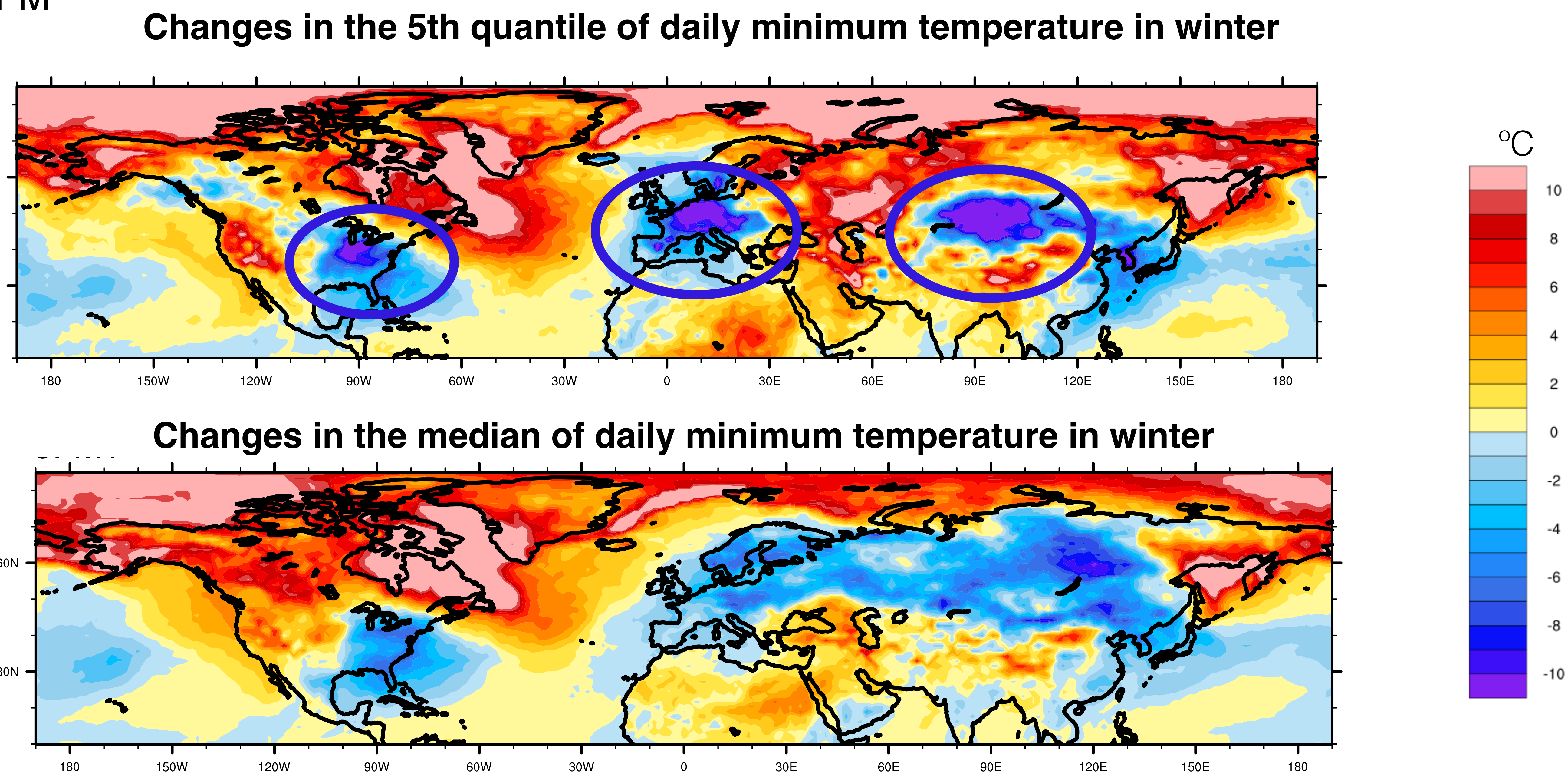
Positive anomaly: negative NAM / weakening of polar vortex

- Upward/downward propagation of planetary scale waves between the troposphere and the stratosphere in response to Arctic warming (consistent with the divergence of Eliassen-Palm fluxes)

Chripko et al. in prep

Influence of sea ice loss on winter cooling

JFM



Chripko et al. in prep

- Minimum temperatures are cooler over Eastern US, Western Europe and Eurasia
- Forced by Barents-Kara Sea as in Sun et al. (2015) and Screen et al. (2017)? Regional experiments will be analyzed to see the respective influence of Atlantic vs. Pacific forcing.

Conclusions

- CNRM-CM6-1 simulate a significant atmospheric response to the idealized Arctic sea ice decline associated to an increase of albedo and complete summer melt.

- The warming is largest in the Arctic but the circulation changes extend to the whole Northern Hemisphere and beyond and include
  - a narrowing of the subtropical jet in late fall/ a southward shift in winter
  - a weakening of the near surface westerlies in winter
  - Increased geopotential height up to the stratosphere over the polar cap and the tropics
  - Changes in temperature extremes with enhanced cooling over Eurasia / Western Europe/ N-America in winter. Due mainly to changes in circulation (not shown)

- The atmospheric response involves planetary-scale wave propagation between the troposphere and the stratosphere with a peak of upward propagation in December and a downward propagation in January/February consistent with the weaker midlatitude westerlies in winter.

- Similar response in CNRM-CM6-1-HR (not shown) except in the stratosphere

- Abrupt experiments correspond to end of century sea ice forcing. Comparison with PAMIP experiments on-going to see how the response differs from that to a more moderate sea ice melt (2°C warming).