Atmospheric response to Arctic sea ice decline in global climate model experiments: Sensitivity to the sea ice pattern and experimental set up

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*Thanks to **Svenya Chripko**, Emilia Sanchez, Laurent Terray*

Exeter, 24 April 2019

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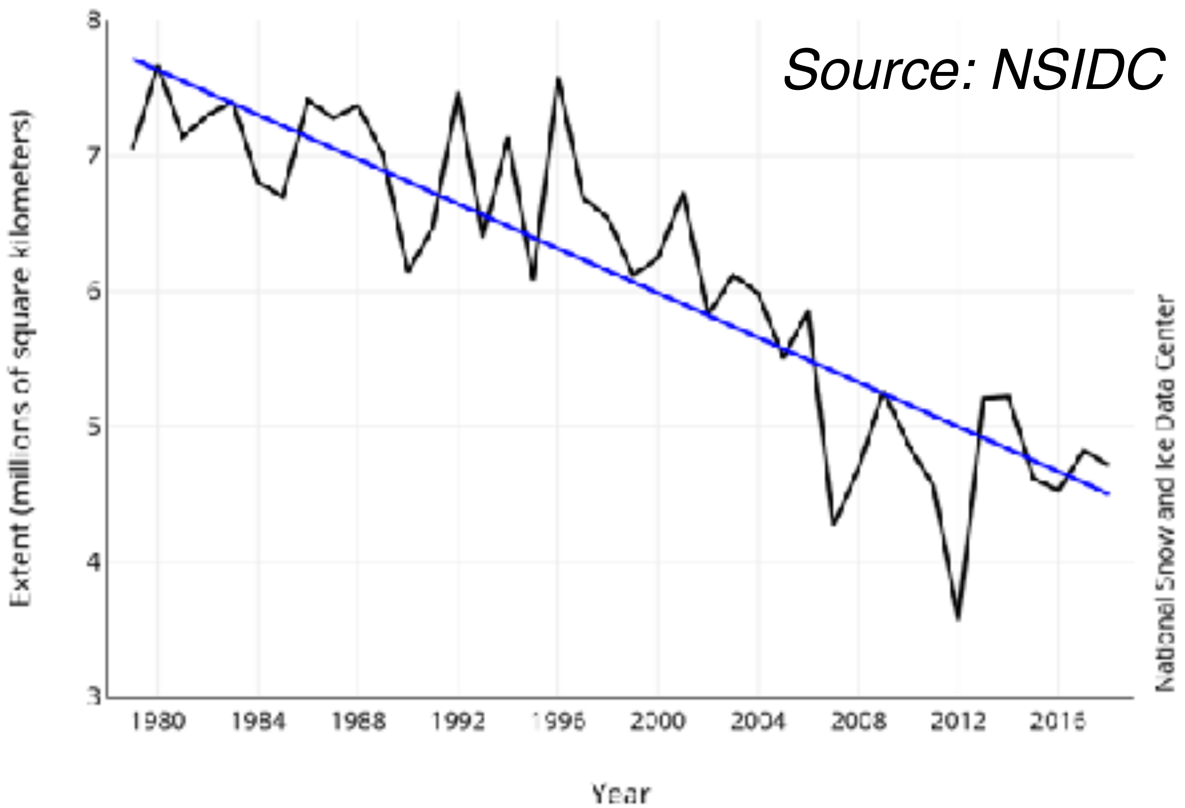
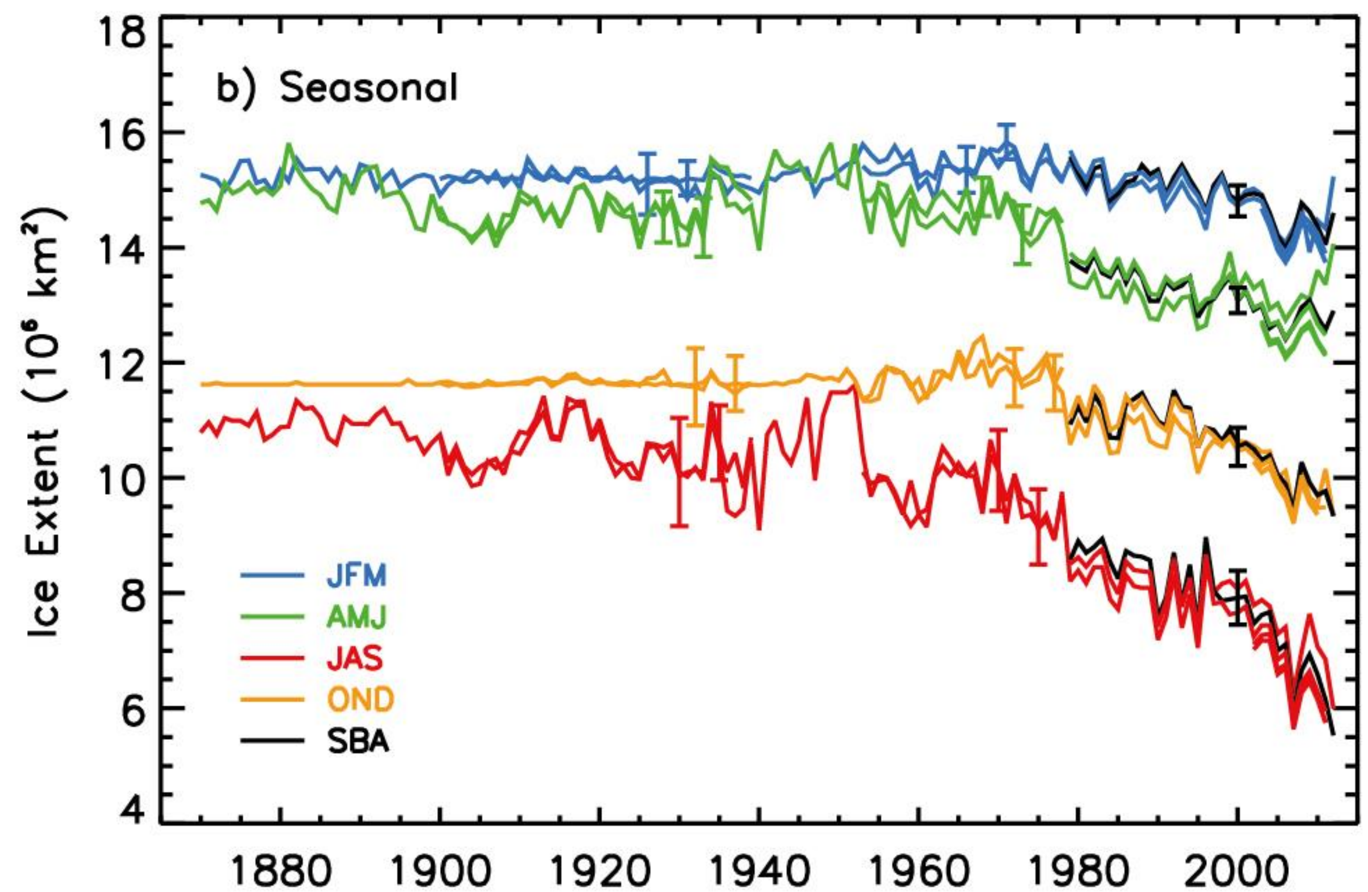
Arctic sea ice in observations

Averaged monthly Arctic Sea Ice extent September 1970-2018



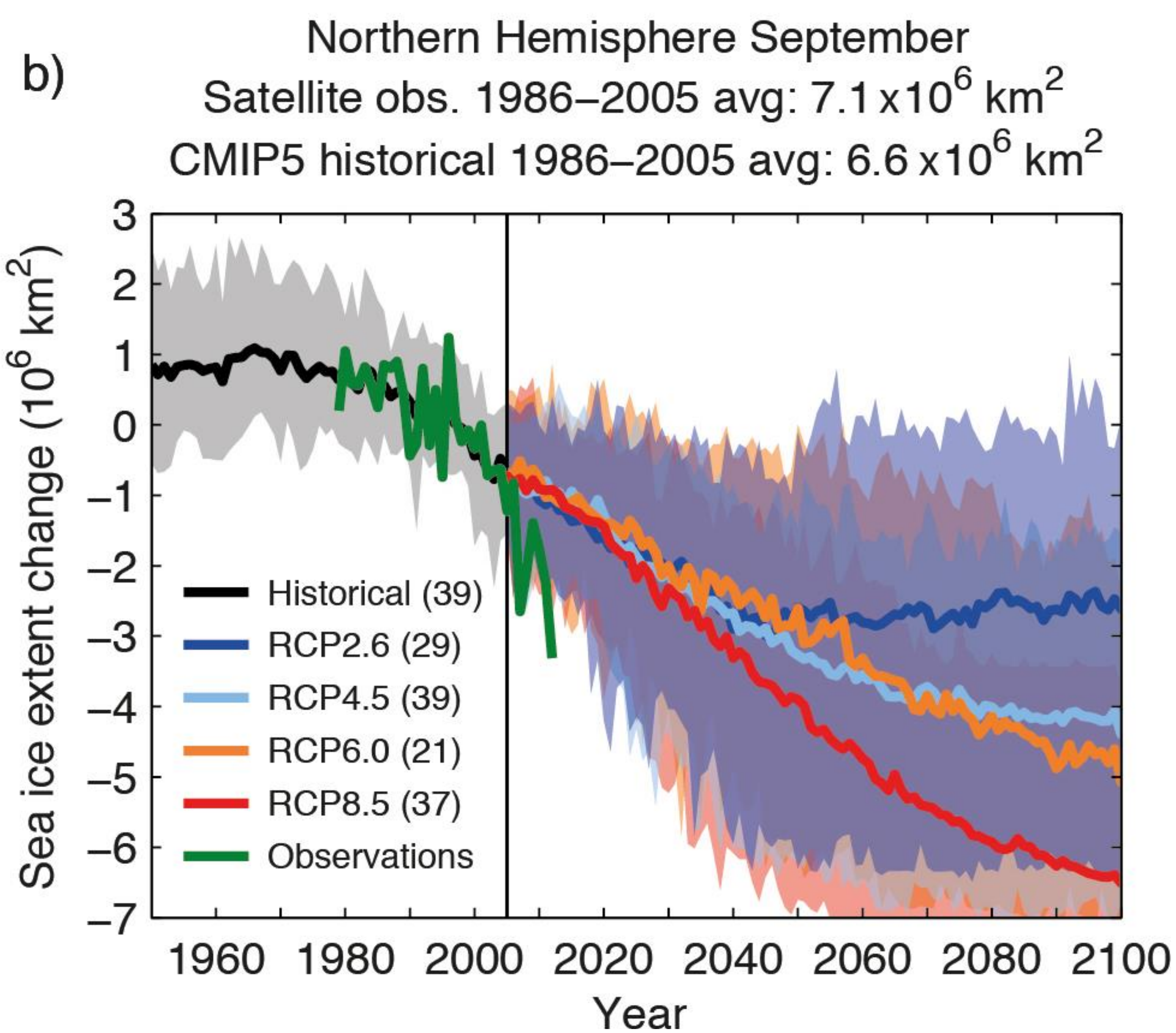
Averaged seasonal Arctic Sea Ice extent in HadISST and Walsh and Chapman reconstruction (prior 1979) and satellite estimates (after 1979)



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



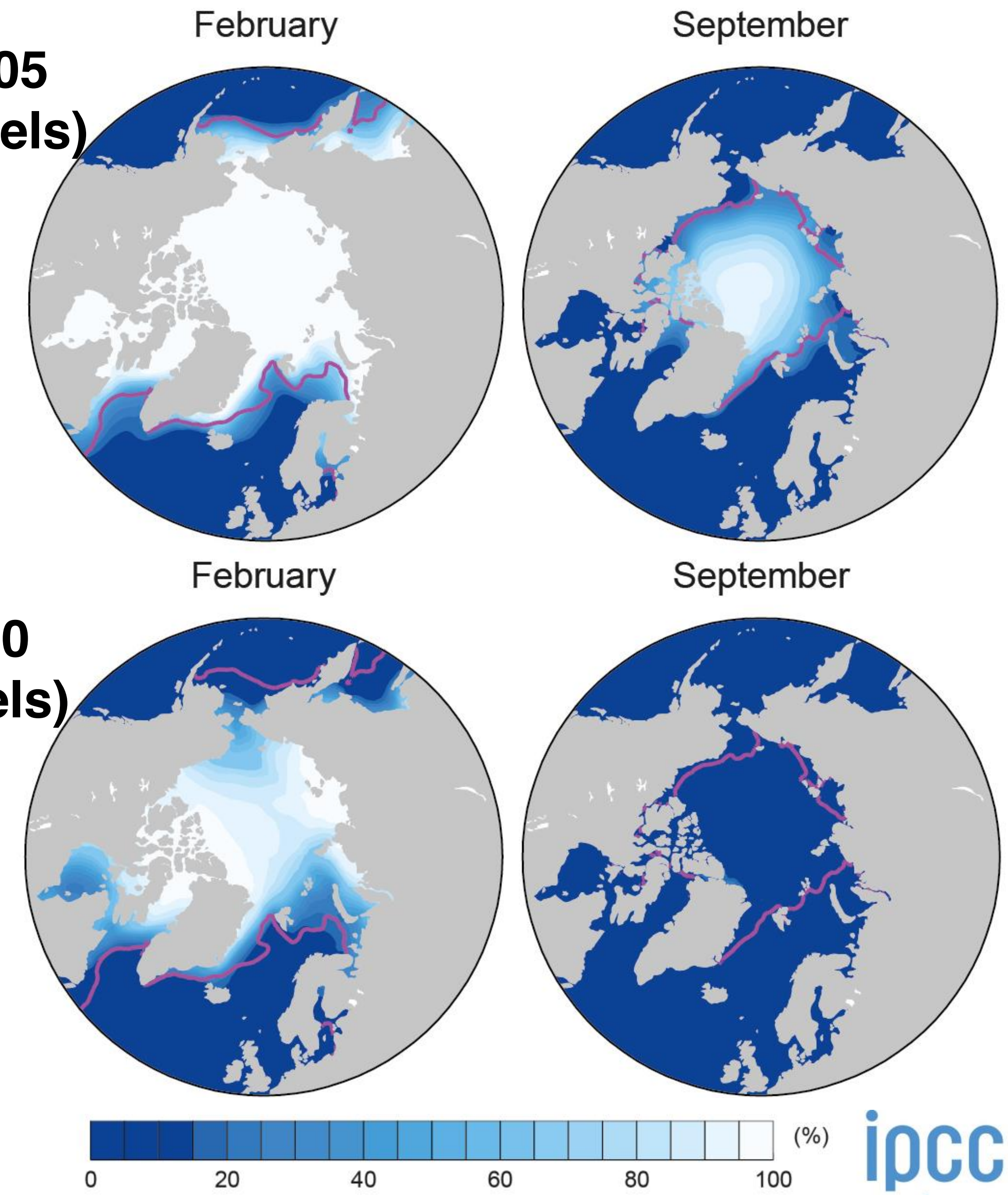
IPCC AR5 Working Group I
Climate Change 2013: The Physical Science Basis

Multi-model mean Arctic sea ice concentration

1986-2005 (39 models)

2081-2100 (37 models)

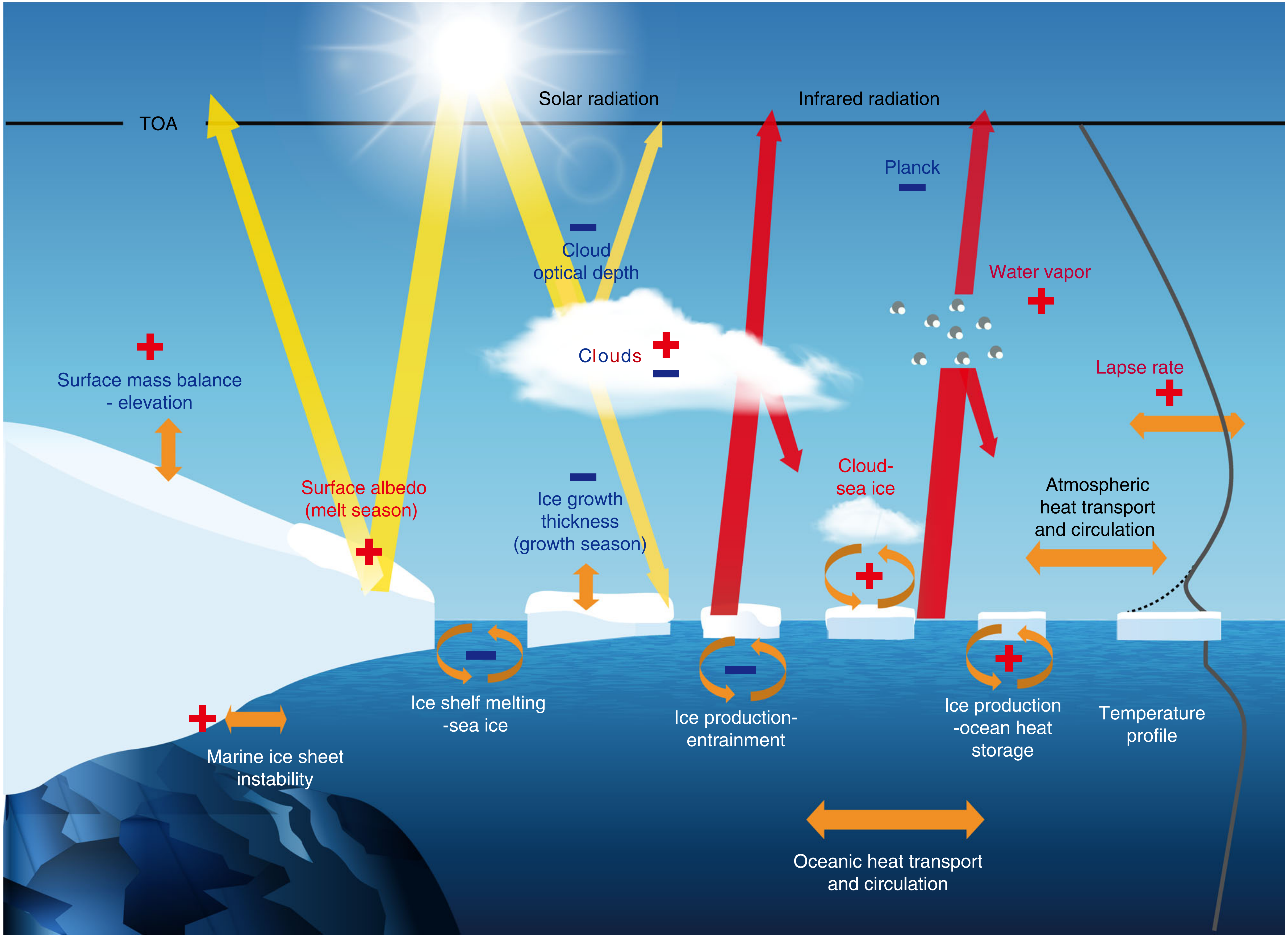
RCP8.5



INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

High probability of having ice-free summers by 2100

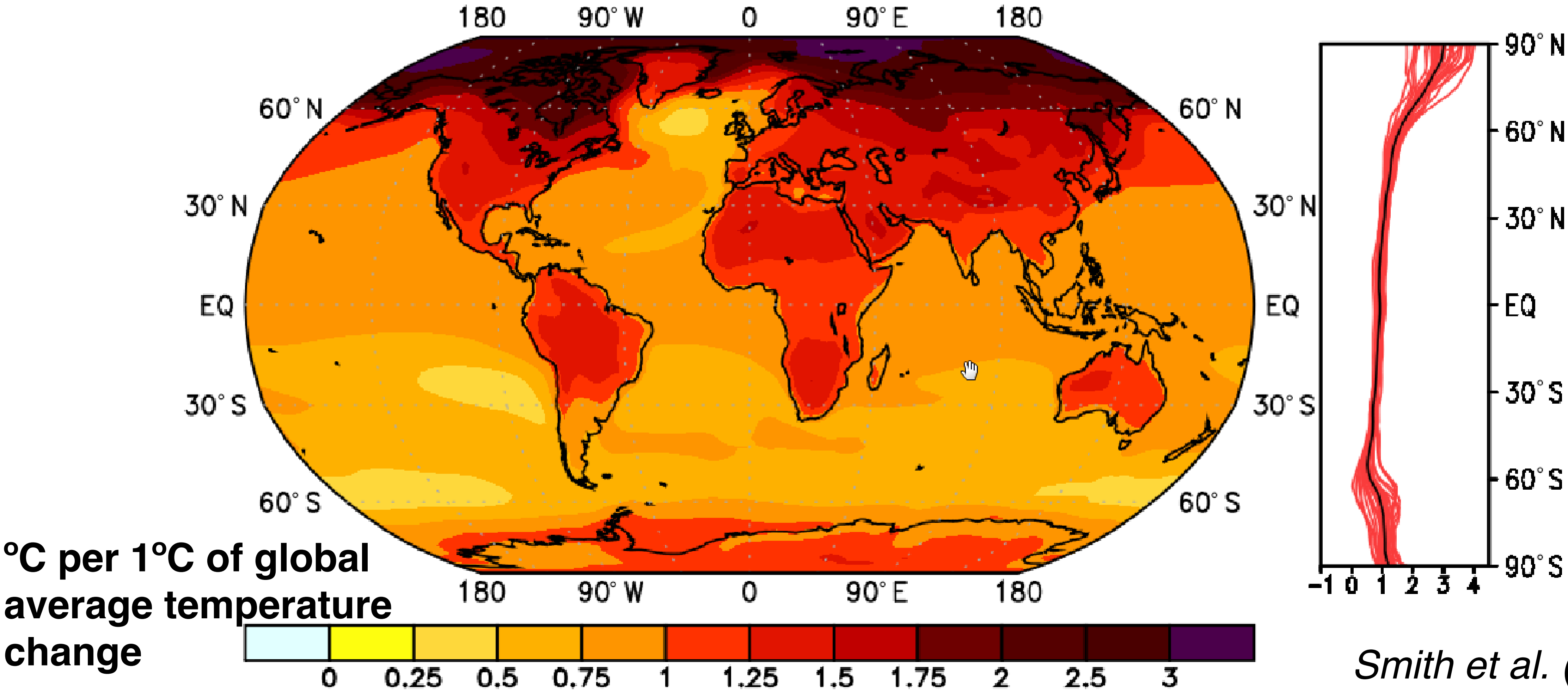
Sea ice at the heart of important local feedbacks



Goosse et al. (2018)

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

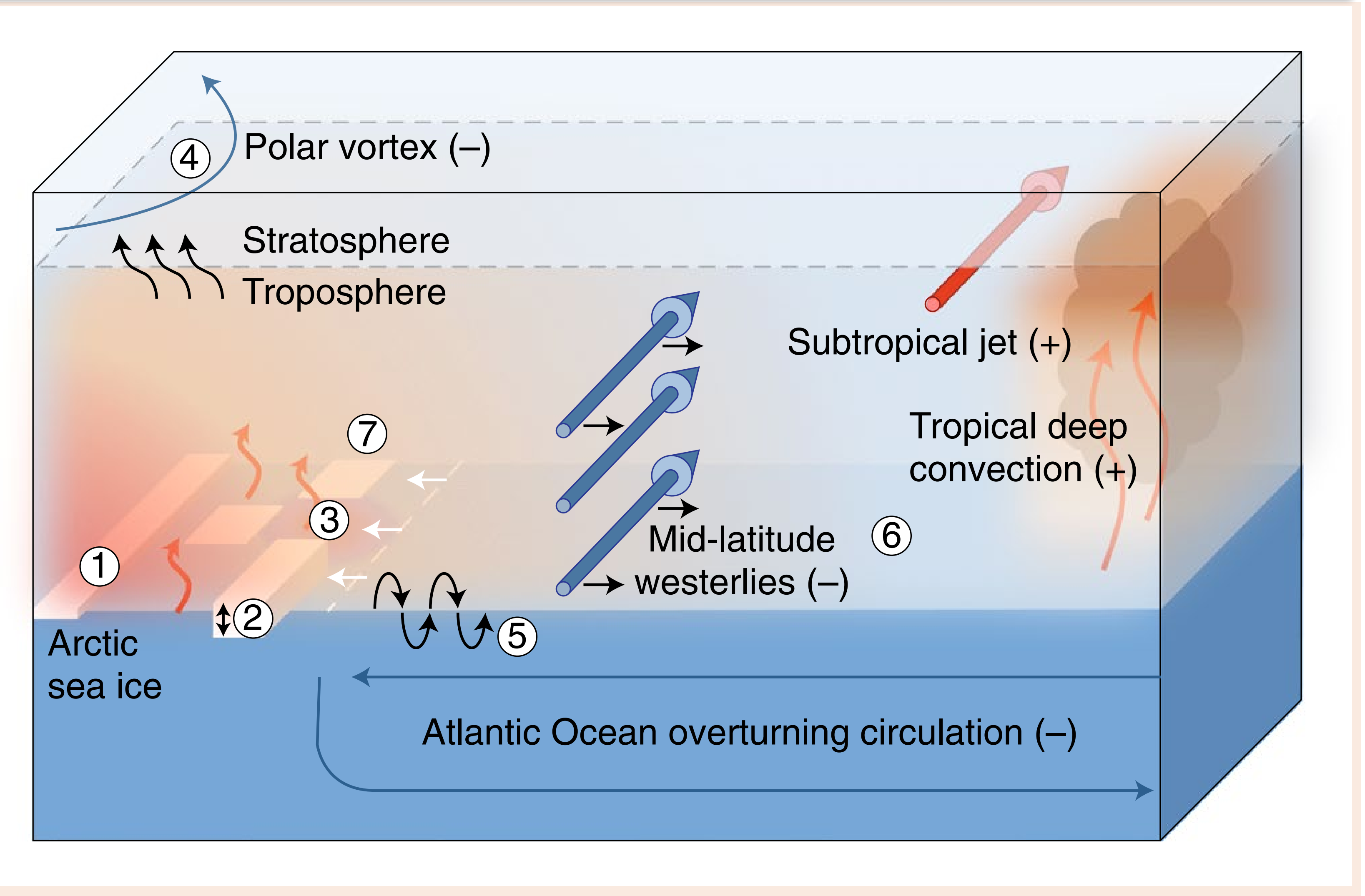


Smith et al. (2019)

- 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 ?

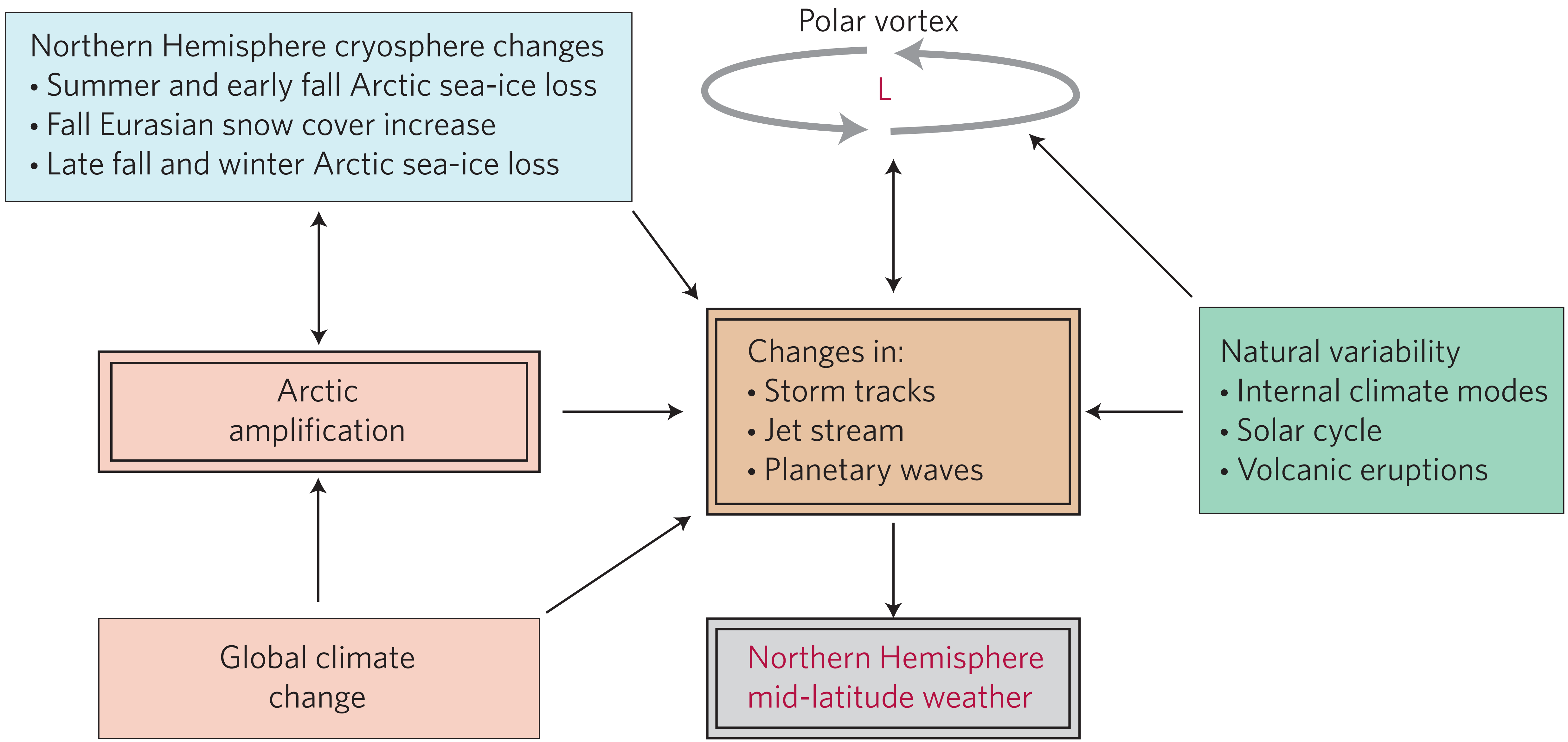
- Need to better understand the influence of sea ice decline on atmospheric circulation. Large body of literature (see reviews by *Cohen et al., Walsh et al. 2014, Barnes et al. 2015, Screen et al. 2018*) but still many uncertainties and controversy.

Summary of the mechanism of climate response to Arctic sea ice loss



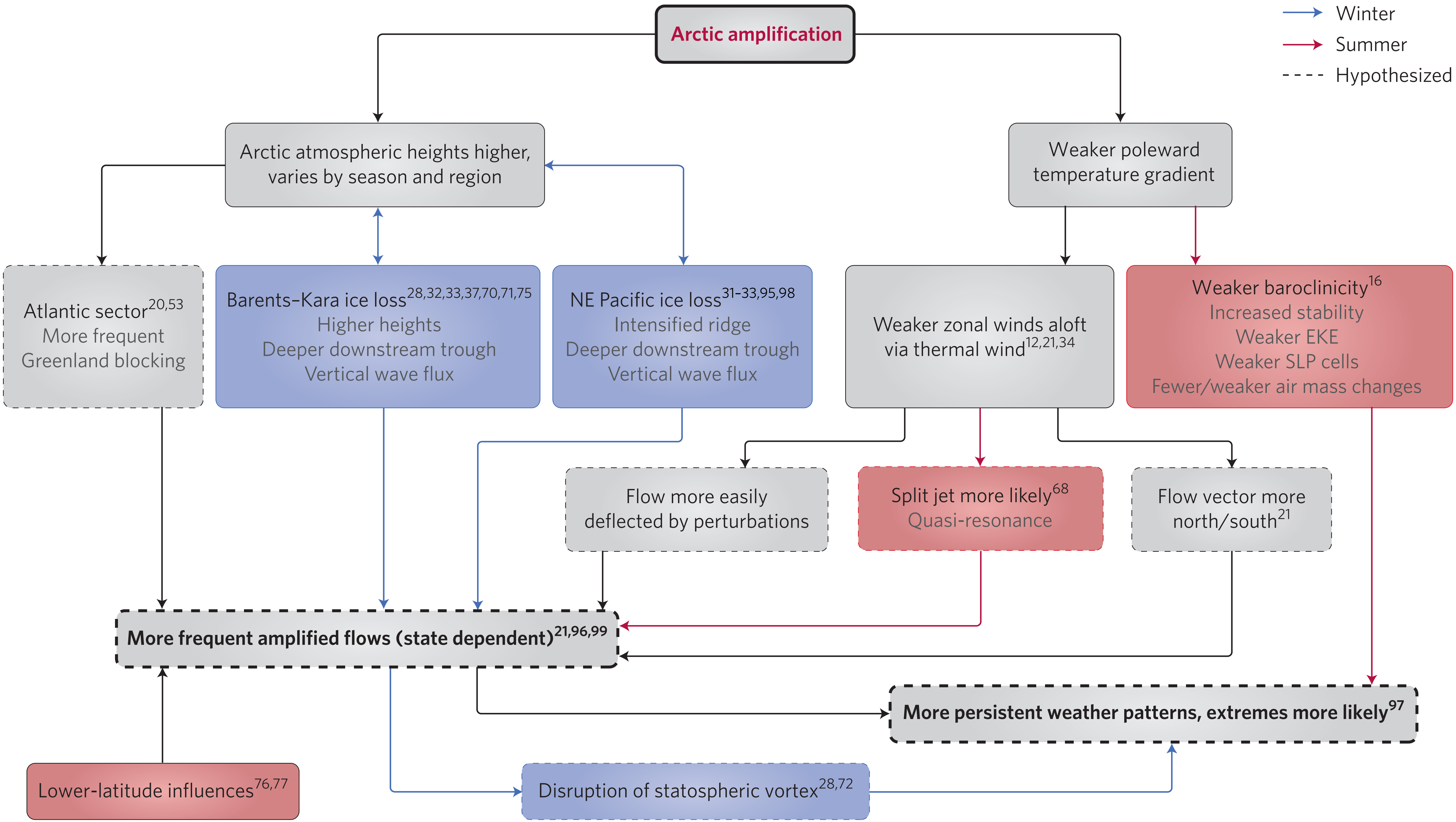
Screen et al. (2018)

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



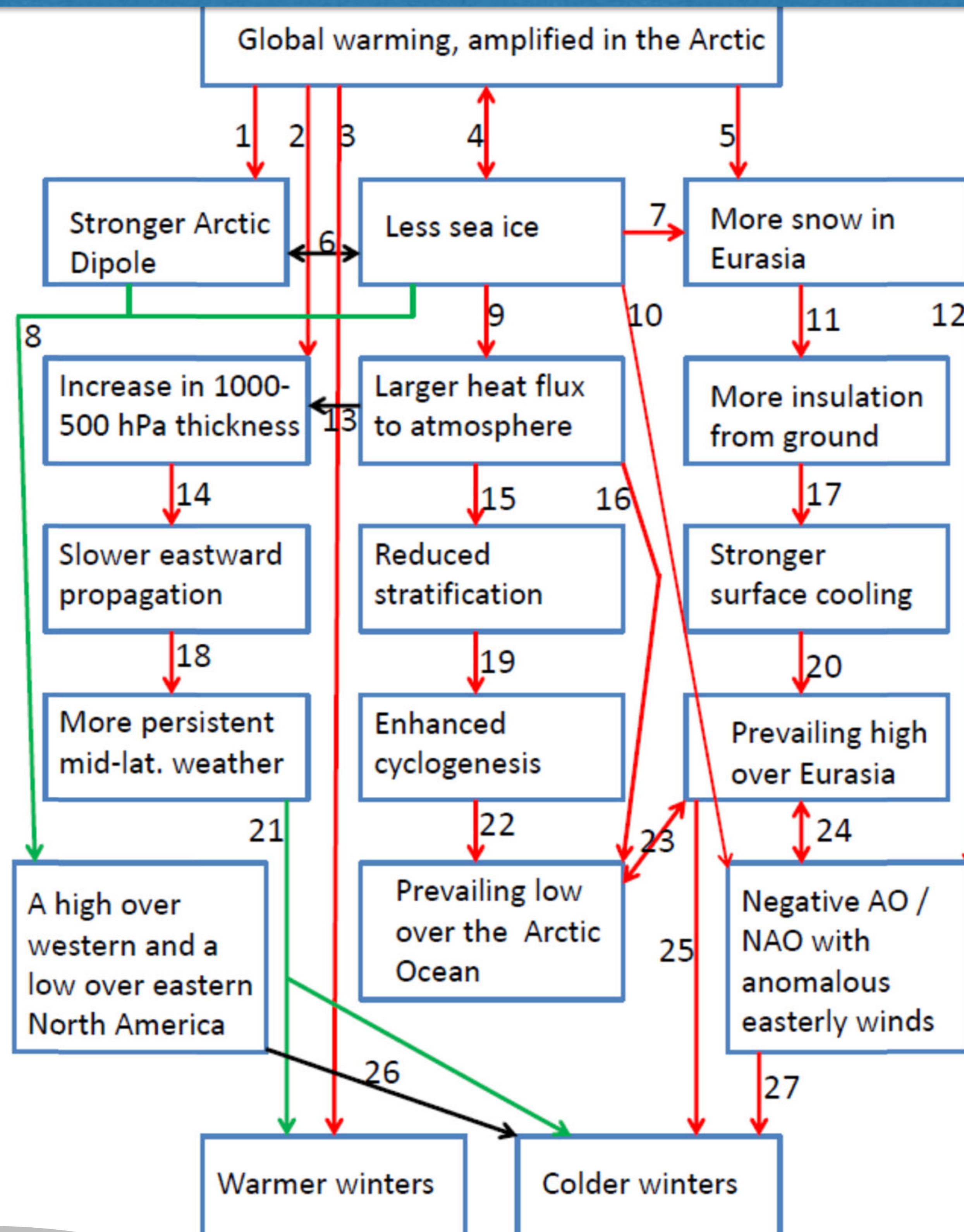
Cohen et al. (2014)

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



Overland et al. (2019)

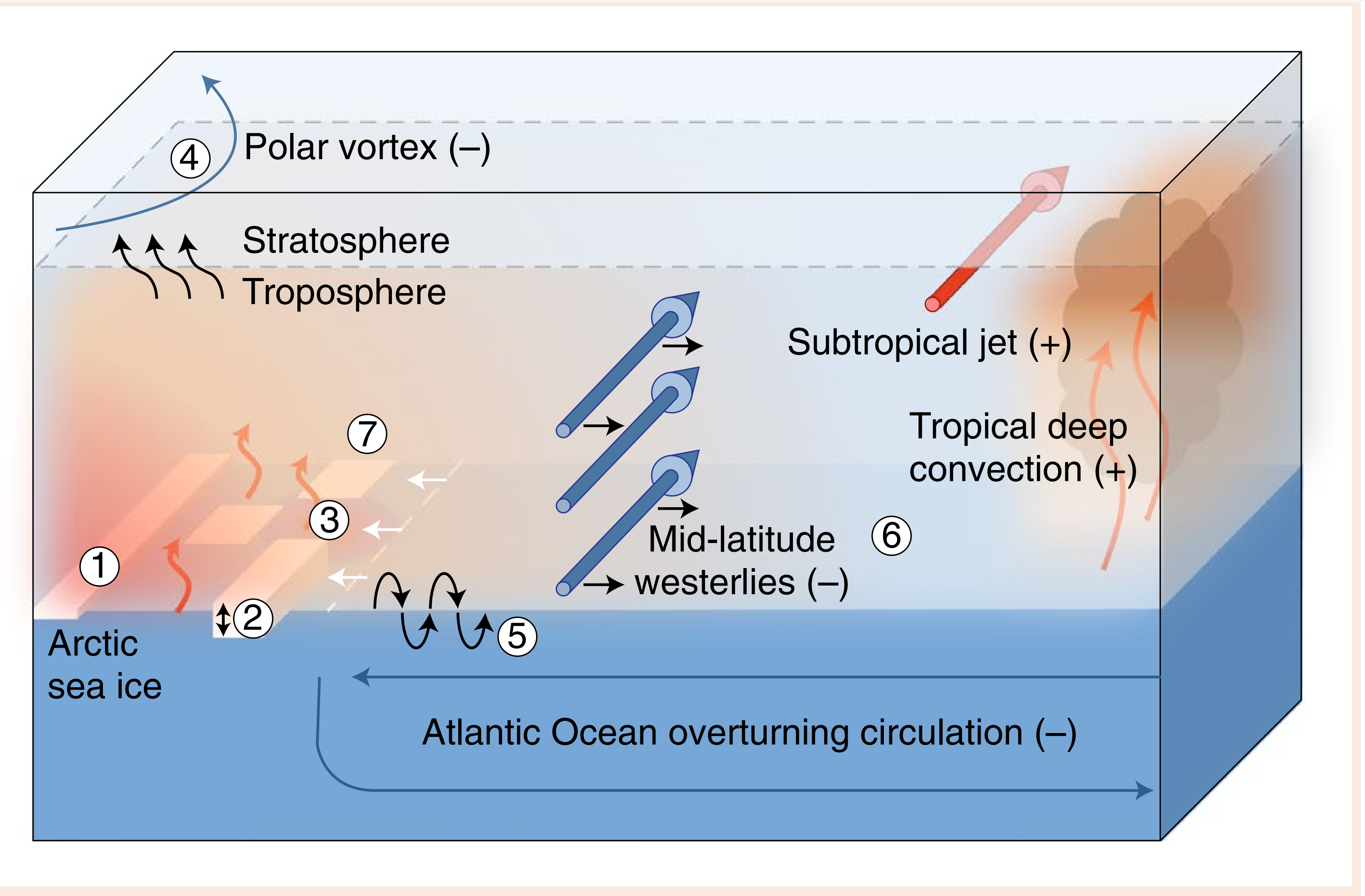
Proposed mechanism on the influence of sea ice decline on midlatitude weather and climate



Vihma (2014)

Fig. 3 Simplified schematic illustration of interactions in the climate system, with a focus on the effects of summer/autumn changes in the cryosphere on winter weather in mid-latitudes. The studies suggesting the

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



Screen et al. (2018)

Complex mechanisms with many unknowns:

What is the dynamical response to sea ice decline? What is the role of the stratosphere? Is there a direct link between sea ice decline and climate extremes like Eurasian cooling? Role of background mean state? Importance of geographical pattern of sea ice? Role of ocean/atm coupling?

=> Need for coordinated experiments! CMIP6 PAMIP (Smith et al. 2019)

Outline

Objective : Characterize the mid-latitude atmospheric response to sea ice decline in PAMIP experiments: initial results based on the CNRM-CM6-1 model

1. **Description of the model experiments**

2. **Atmospheric response to the sea ice changes associated to a 2º global warming**

3. **Comparison with abrupt sea ice melting experiments**

4. **Conclusions**

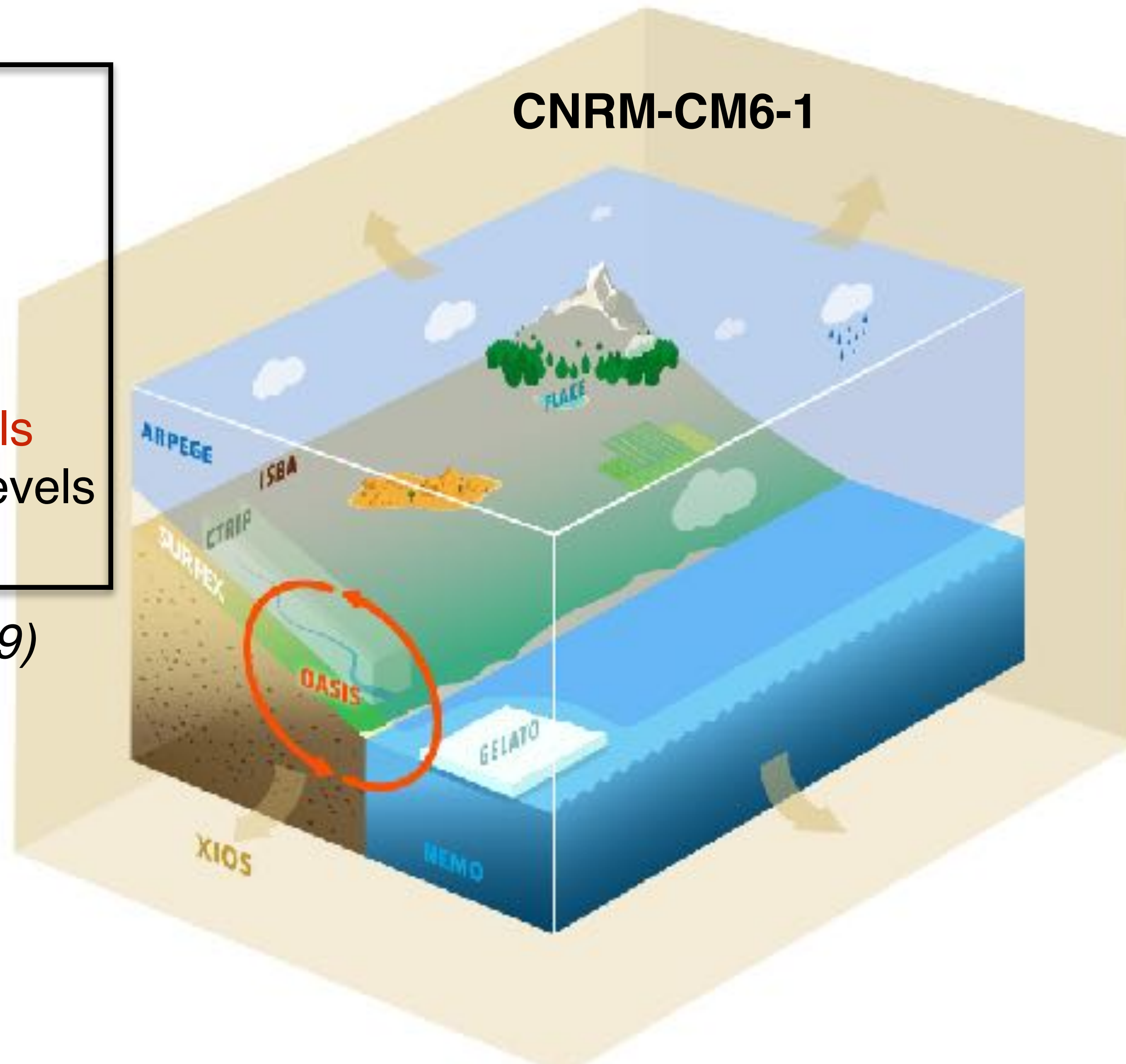
Model experiments

CNRM-CM6-1

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

2 resolutions:
LR: ORCA1 / ATM ~140km 91 levels
HR: ORCA025 – ATM ~50km 91 levels

Voldoire et al. (2019)



PAMIP experiments presented today: *atmosphere only* simulations forced by SST and Sea ice

METEO FRANCE

CERFACS

Experimental protocol

Objective: create SST/SIC forcing fields corresponding to present-day and future warming of 2ºC

1. Define the target temperature for Present Day and Future conditions.

Present-day global mean SAT = average 1979-2008 from HadCRUT4 = 14.24ºC
Pre-industrial global mean SAT = present-day SAT - global warming (0.57ºC) = 13.67ºC
Future global mean SAT = pre-industrial SAT + 2ºC = 15.67ºC

2. We use 31 CMIP5 models, historical and RCP8.5 simulations.

- For each model find the period when the 30-yr mean GLB SAT matches the target temperature.
- Average the SIC and SST forcing fields over that 30-yr period.
- Use a quantile linear regression to get sharper ice edge and give more weight to models with less sea ice and warmer SST

Note: Future SSTs imposed in grid points where future SIC deviates by more than 10% to present day value (Screen et al. 2013)

In this presentation: 2 atmosphere only simulations pdSST-pdSIC and pdSST-futArcSIC

The difference = response to future sea ice changes

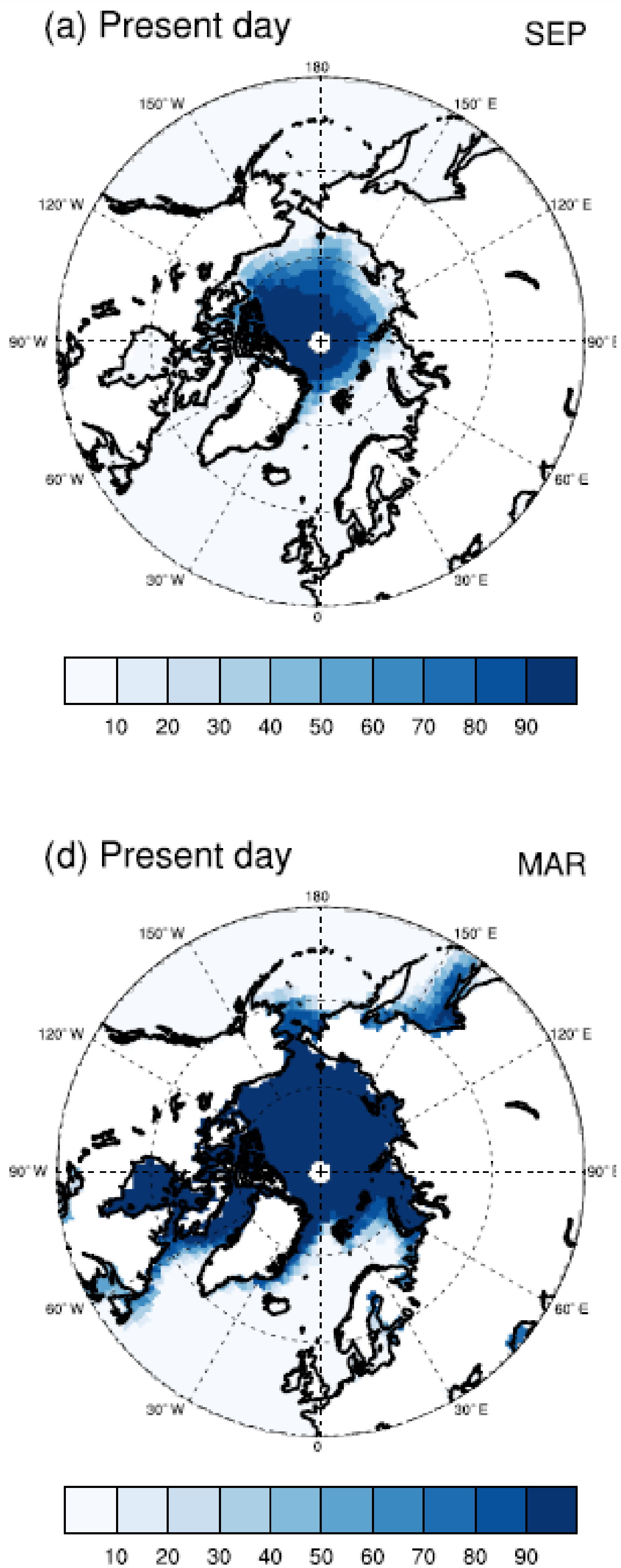
Each experiment is run for 14 months starting in April

Constant forcing yr 2000

100 members

Smith et al. (2019)

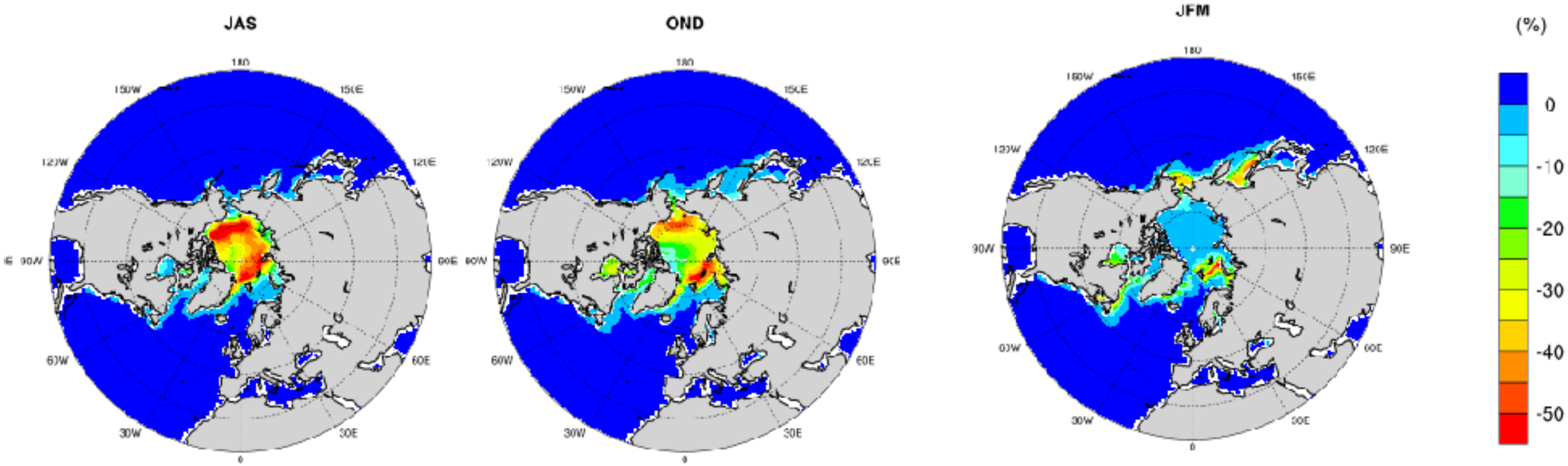
Arctic sea ice forcing



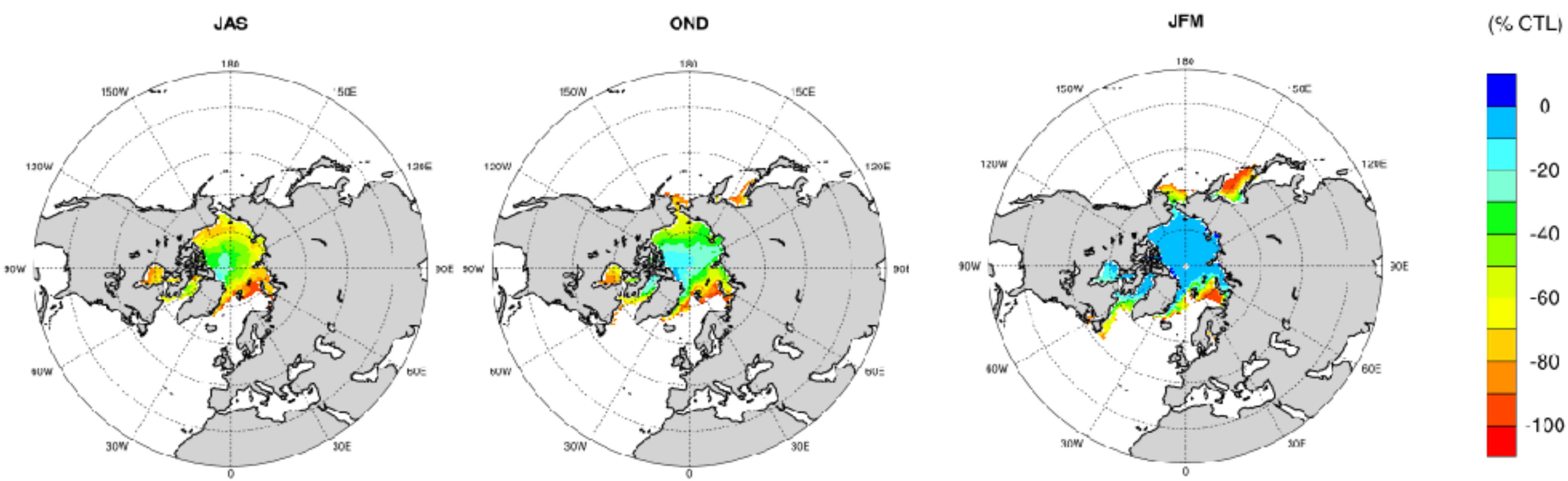
Smith et al. (2019)

Arctic sea ice forcing: seasonal means

Sea ice concentration : future minus present-day

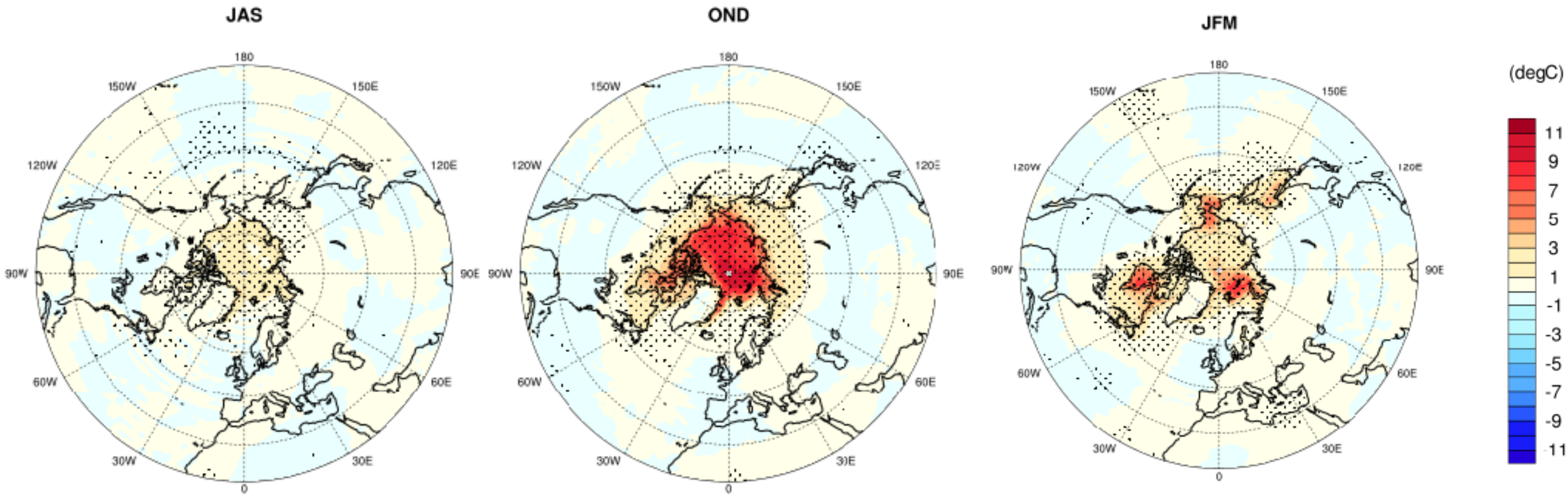


Sea ice concentration : response relative to present day state



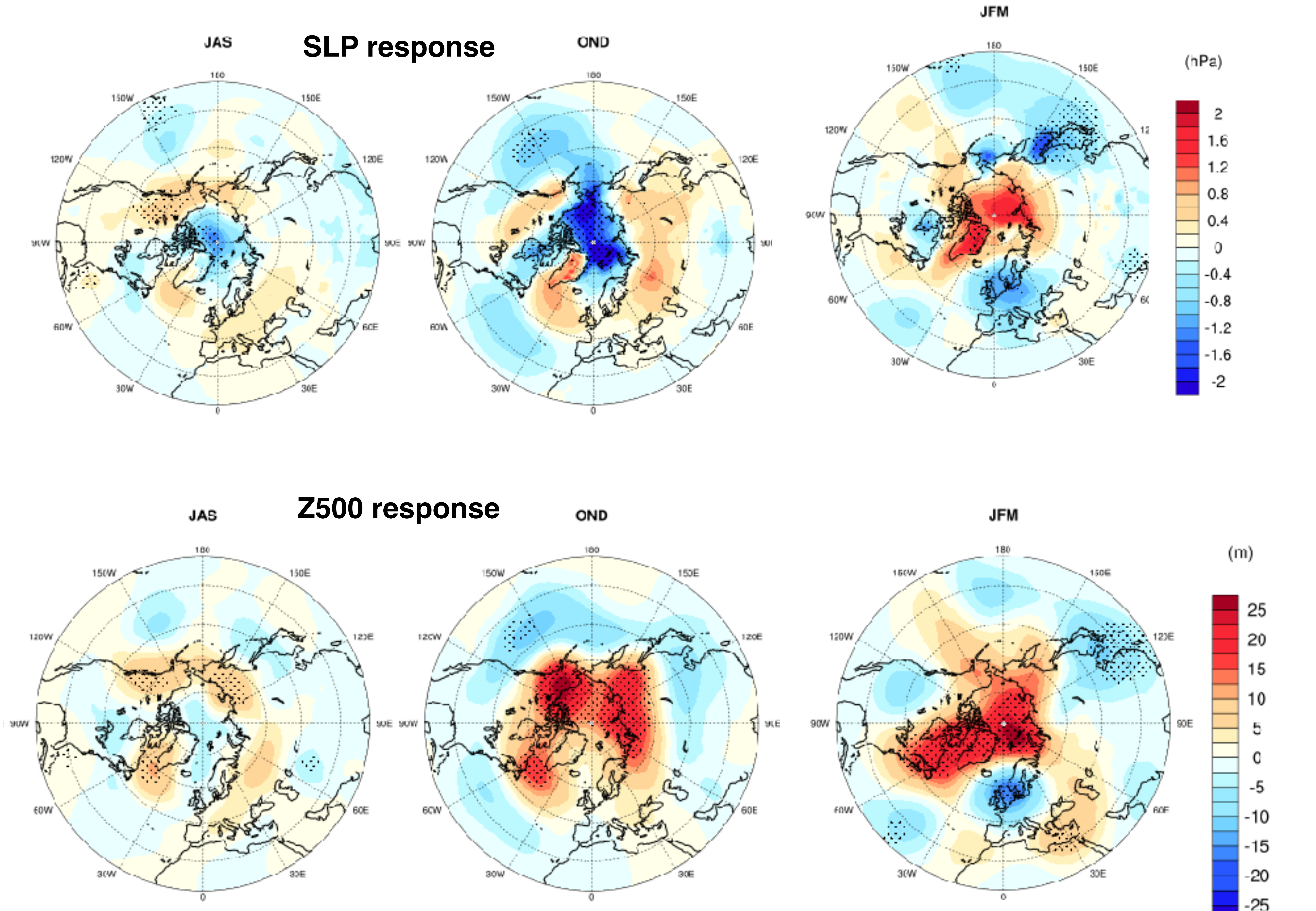
Near surface response

Surface air temperature response

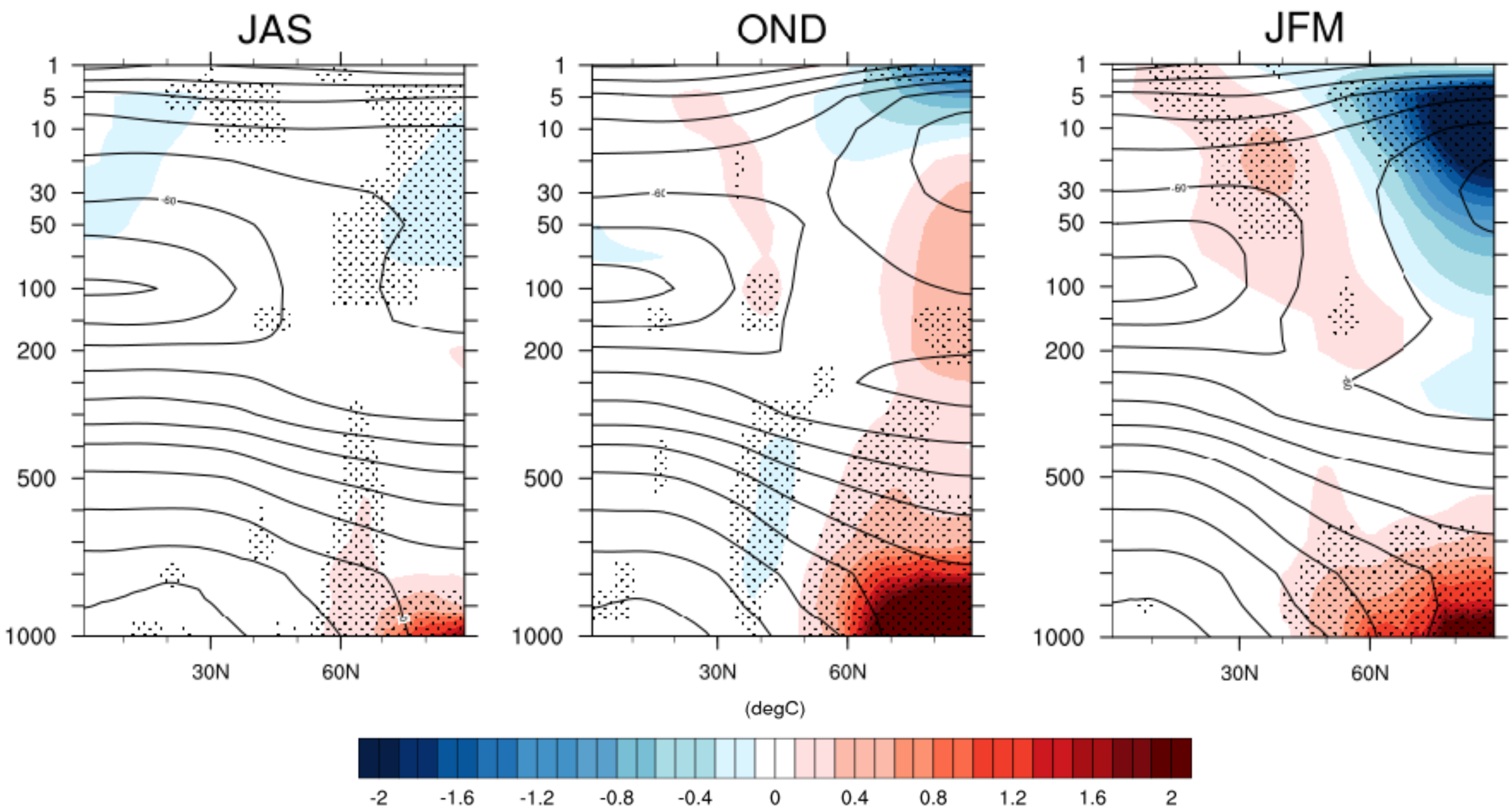


- 2ºC warming in summer
- Largest warming in fall
- Weak temperature changes over land: Warming over Siberia and North America in fall consistent with Peings et al. (2014) . No cooling over Eurasia in winter unlike Honda et al. (2009), Mori et al. (2014, 2019)

Atmospheric circulation response



Vertical structure of the response: temperature

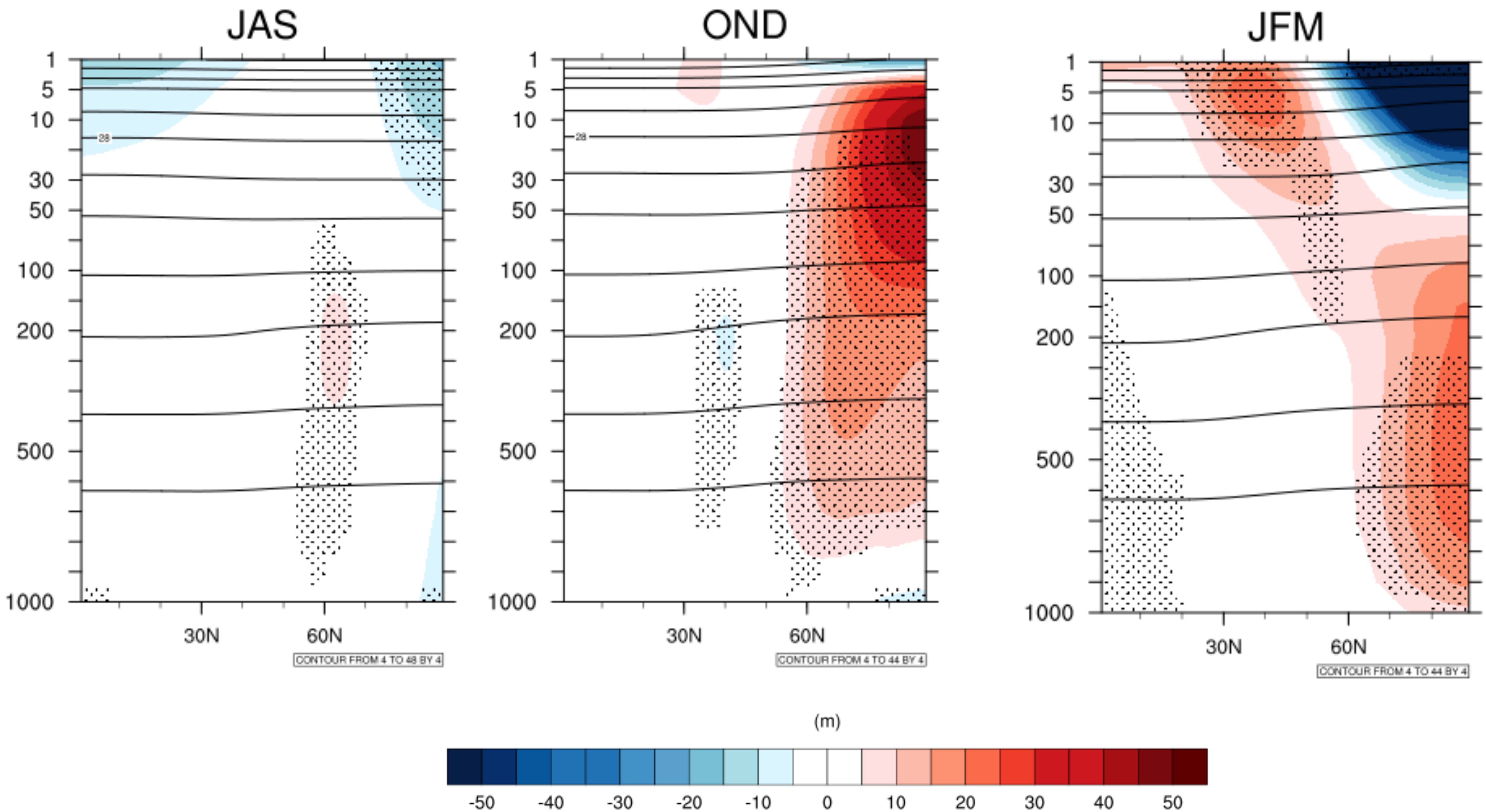


- Warming in the lower troposphere in response to sea ice changes
=> Arctic amplification

- Cooling in the stratosphere

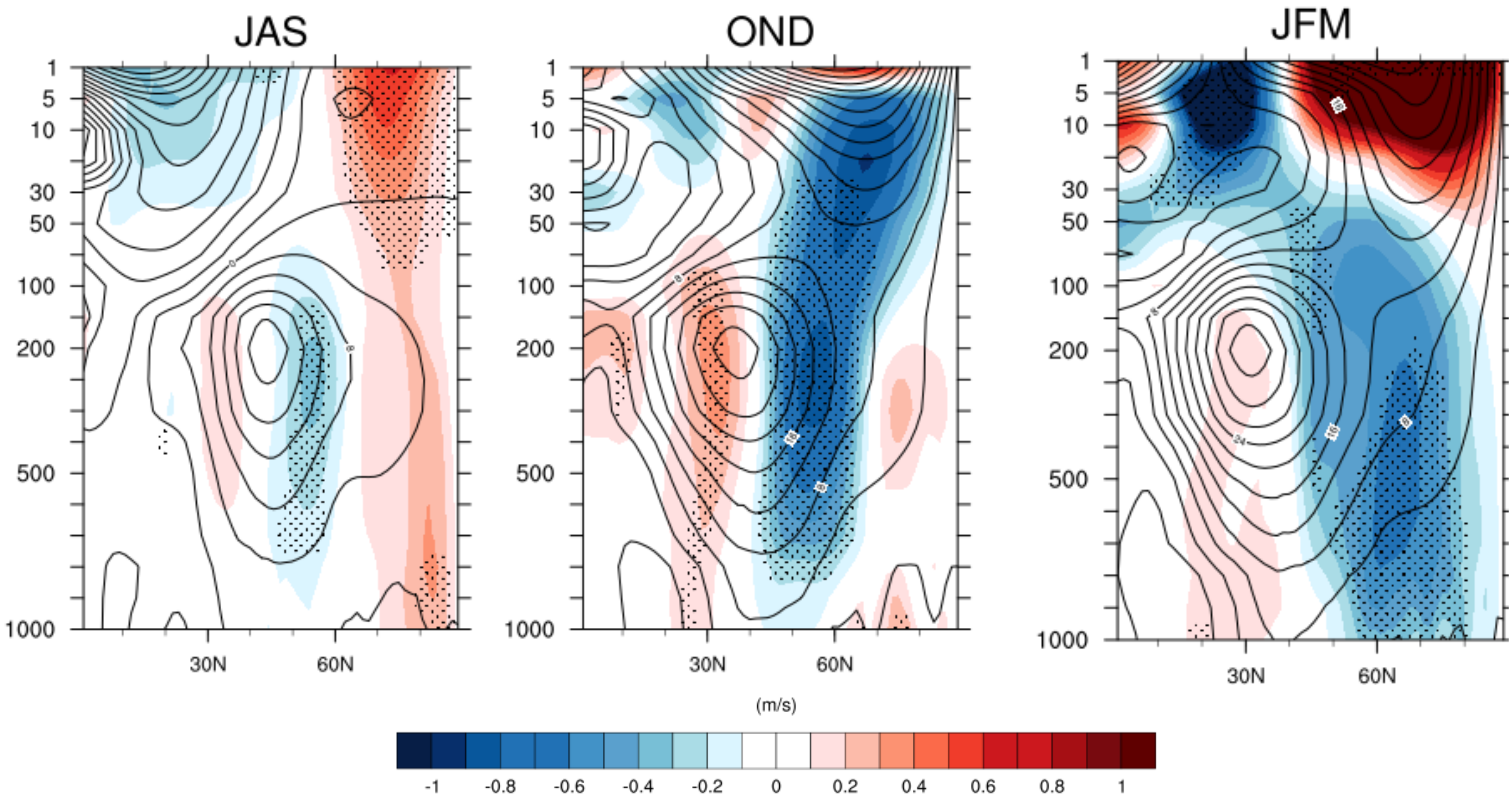
- No upper tropospheric warming in the tropics, expected in the absence of ocean-atmosphere coupling (Deser et al. 2015)

Vertical structure of the response: geopotential height



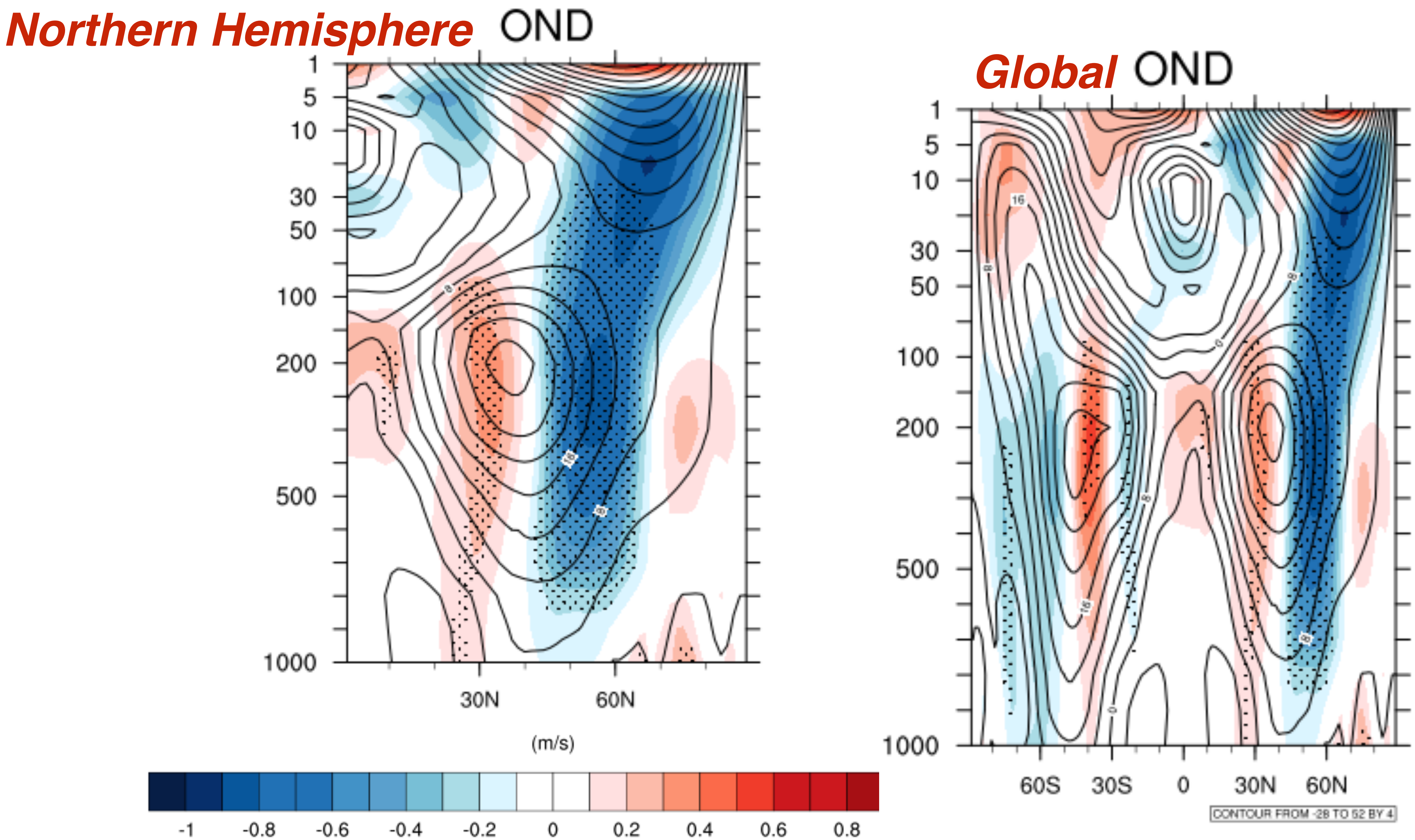
- Weak to no response in summer
- Baroclinic response in fall, amplified in the stratosphere.
- Barotropic response in winter. Change of sign in the upper stratosphere.

Vertical structure of the response: zonal circulation



- Weakening of the midlatitude westerlies and equatorward shift of the subtropical jet => 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 polar vortex in OND, strengthening in JFM

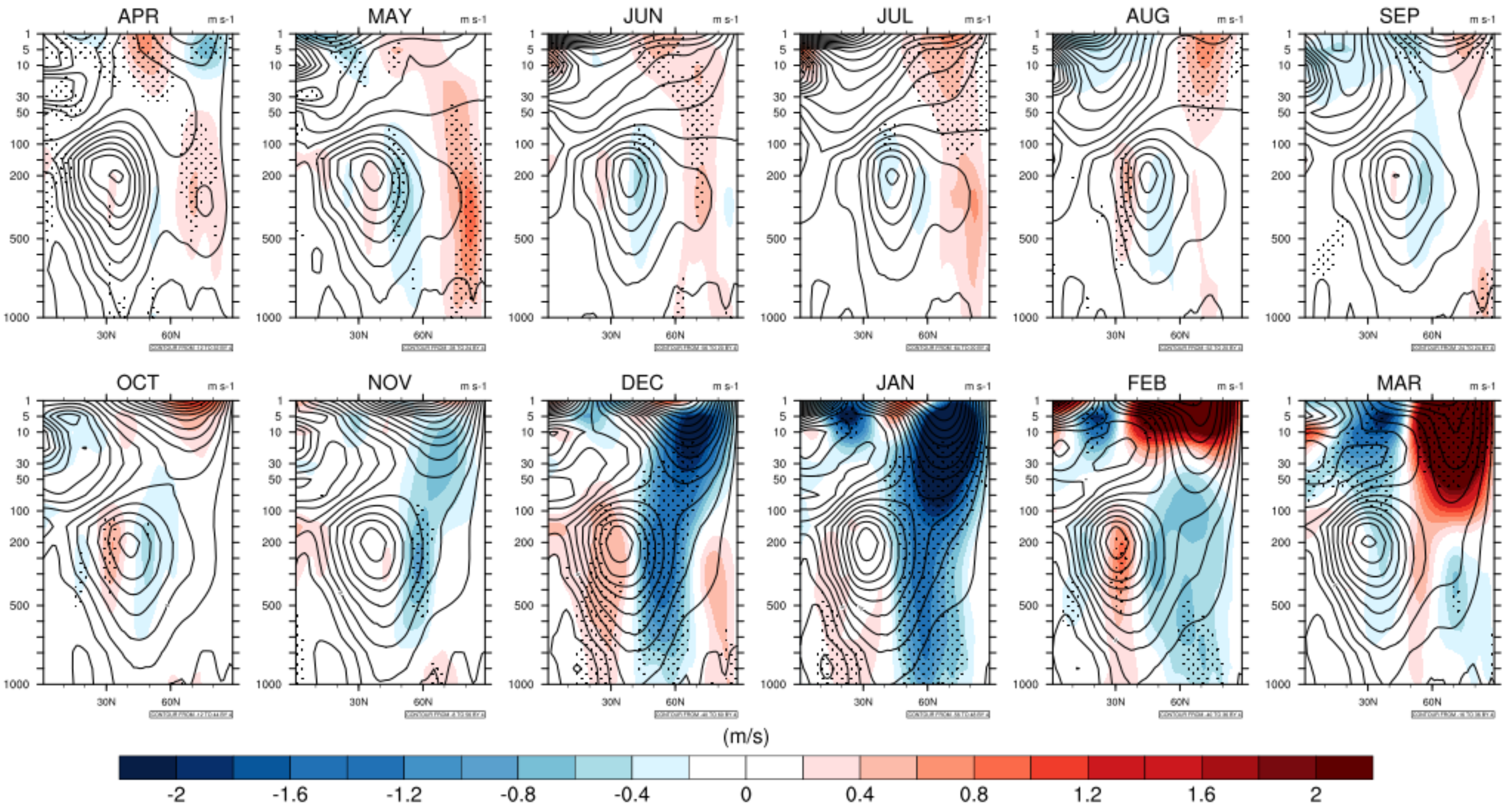
Vertical structure of the response: zonal circulation



Southern Hemisphere signal consistent with *Deser et al. (2015)* in their coupled experiment

Vertical structure of the response: zonal circulation

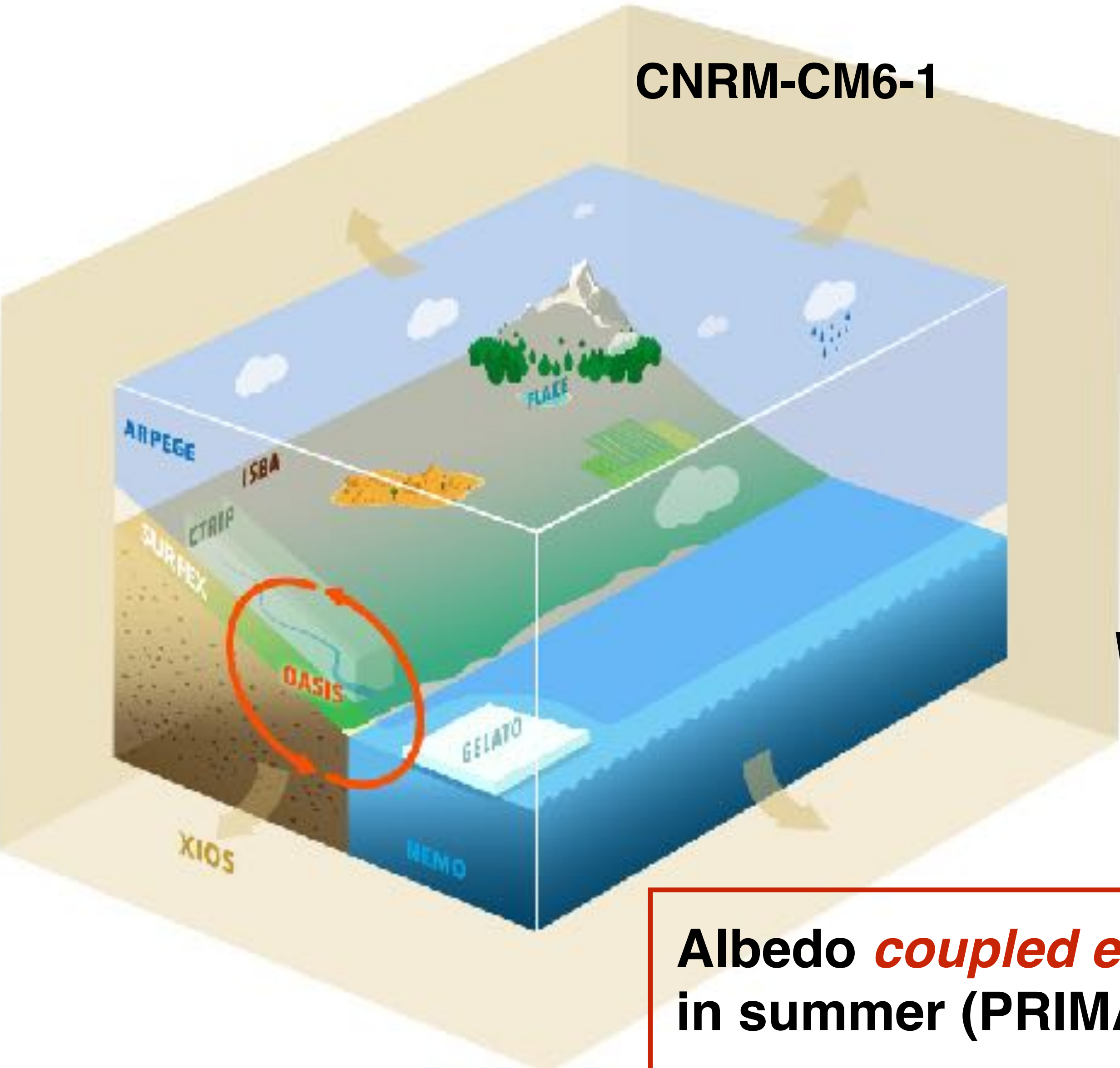
Monthly evolution of the response



Msadek et al. in prep

Protocole simulating a larger summer sea ice loss

CNRM-CM6-1



NEMO 3.6 for ocean
GELATO v6 for sea-ice
PISCESv2-gas in the ESM version
ARPEGE-SURFEX for atm/land

LR: ORCA1 / ATM ~130km 91 levels

Voldoire et al. (2019)

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

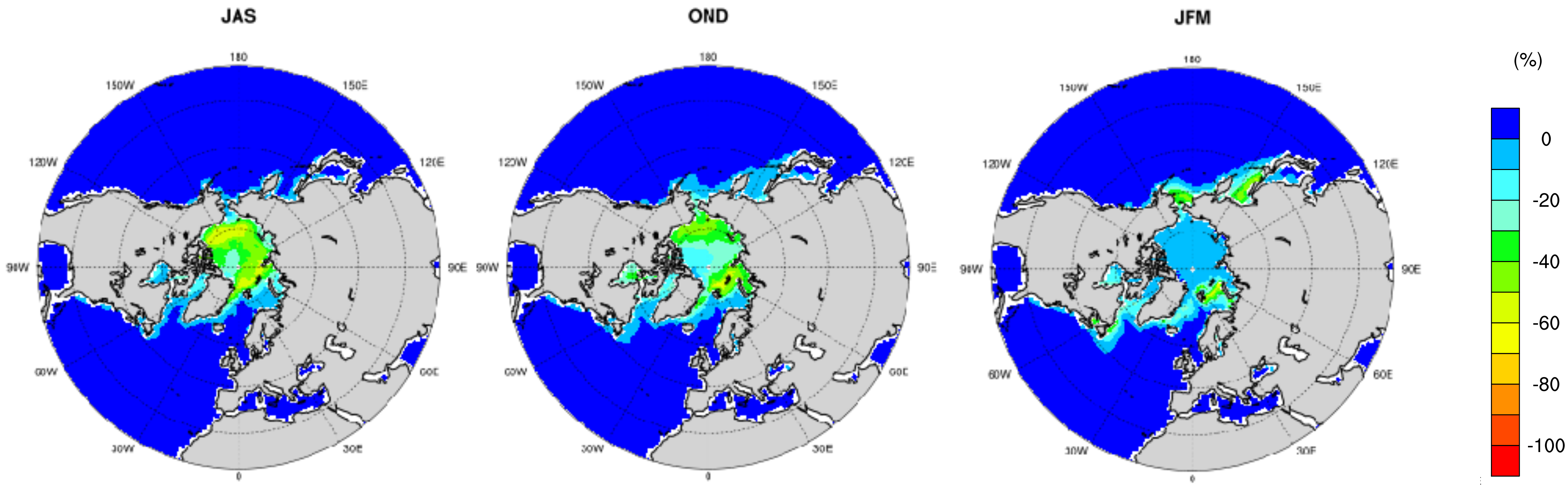
- **Sea ice albedo reduced to ocean value**
- **Initial state: 1950-control CNRM-CM6-1**
- **40 members starting January 1. Run for 24 months**

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

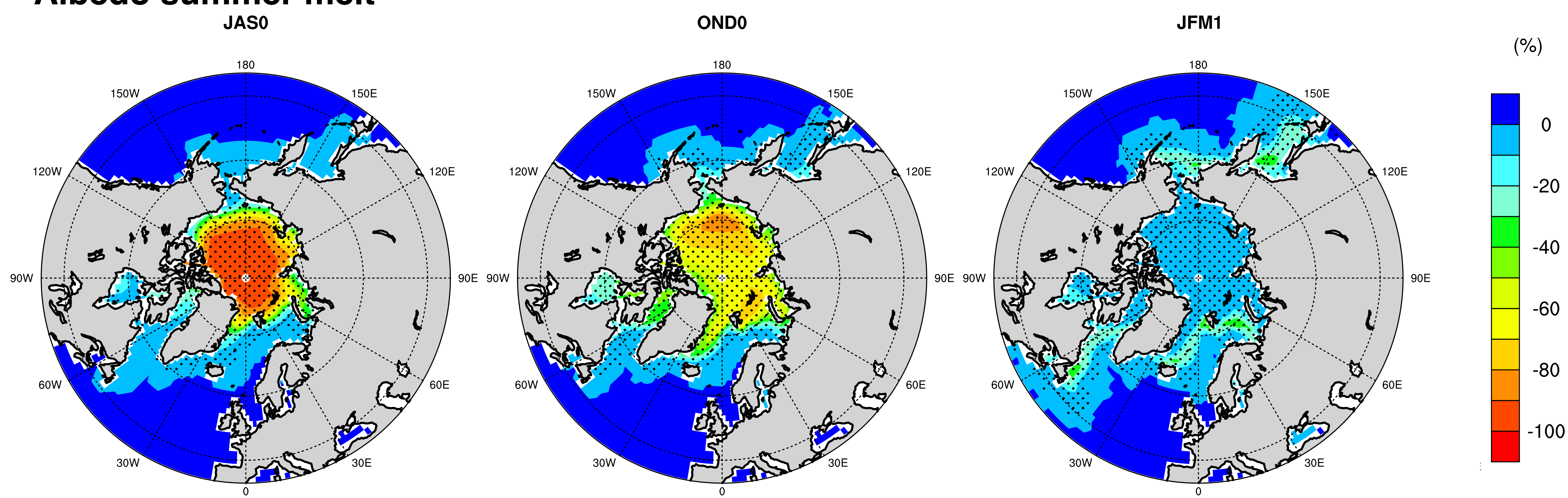
Chripko et al. in prep

Arctic sea ice forcing in the two experiments

PAMIP 2C warming

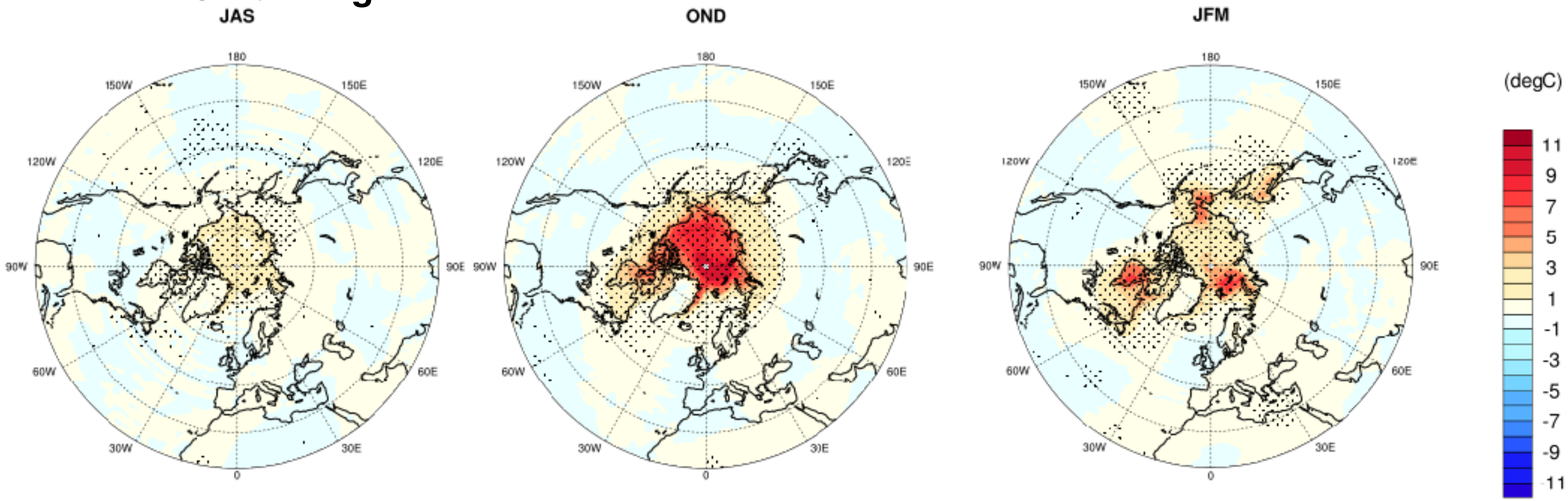


Albedo summer melt

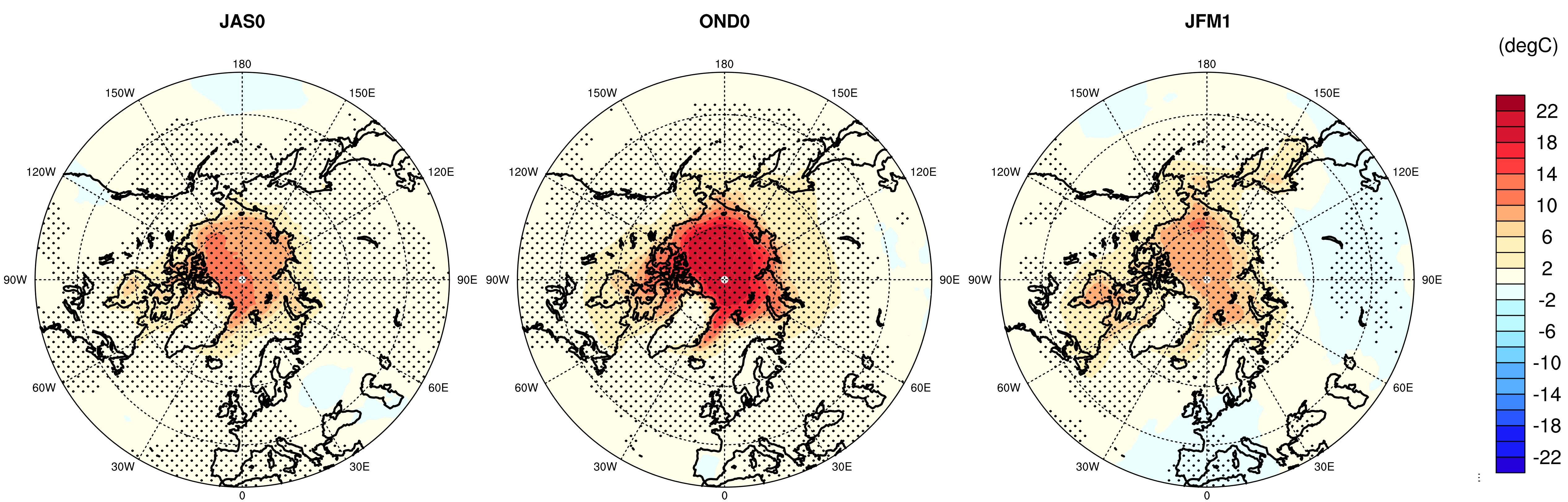


Surface air temperature response

PAMIP 2C warming



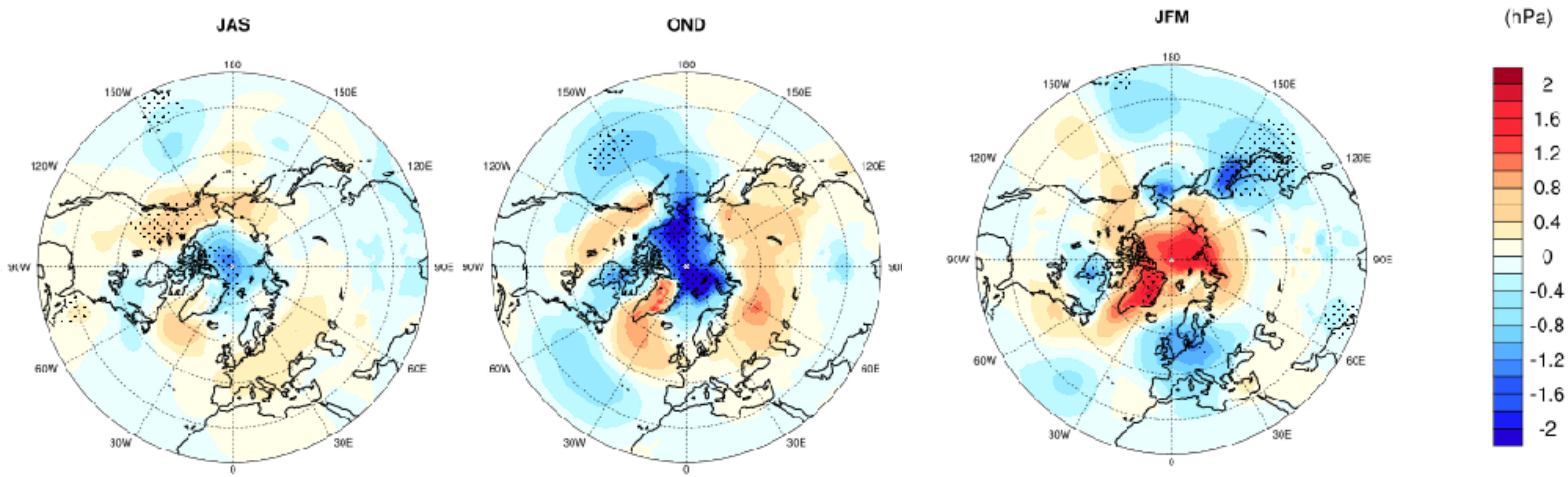
Albedo summer melt



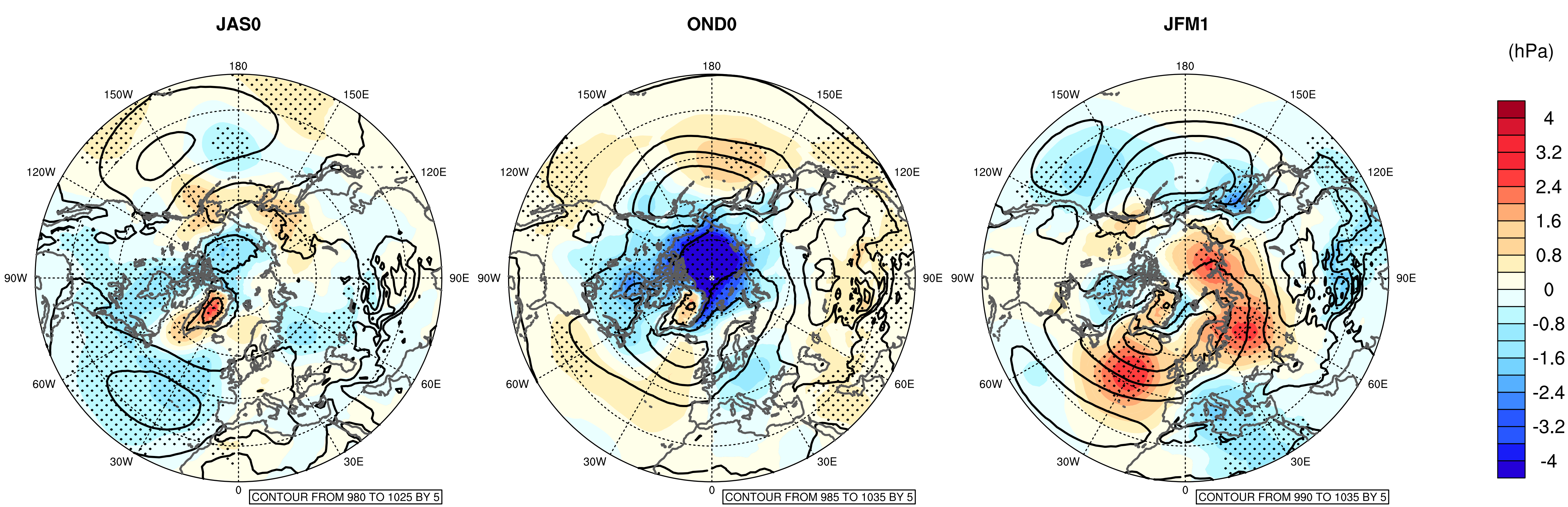
Comparison of the large scale atmospheric response

SLP

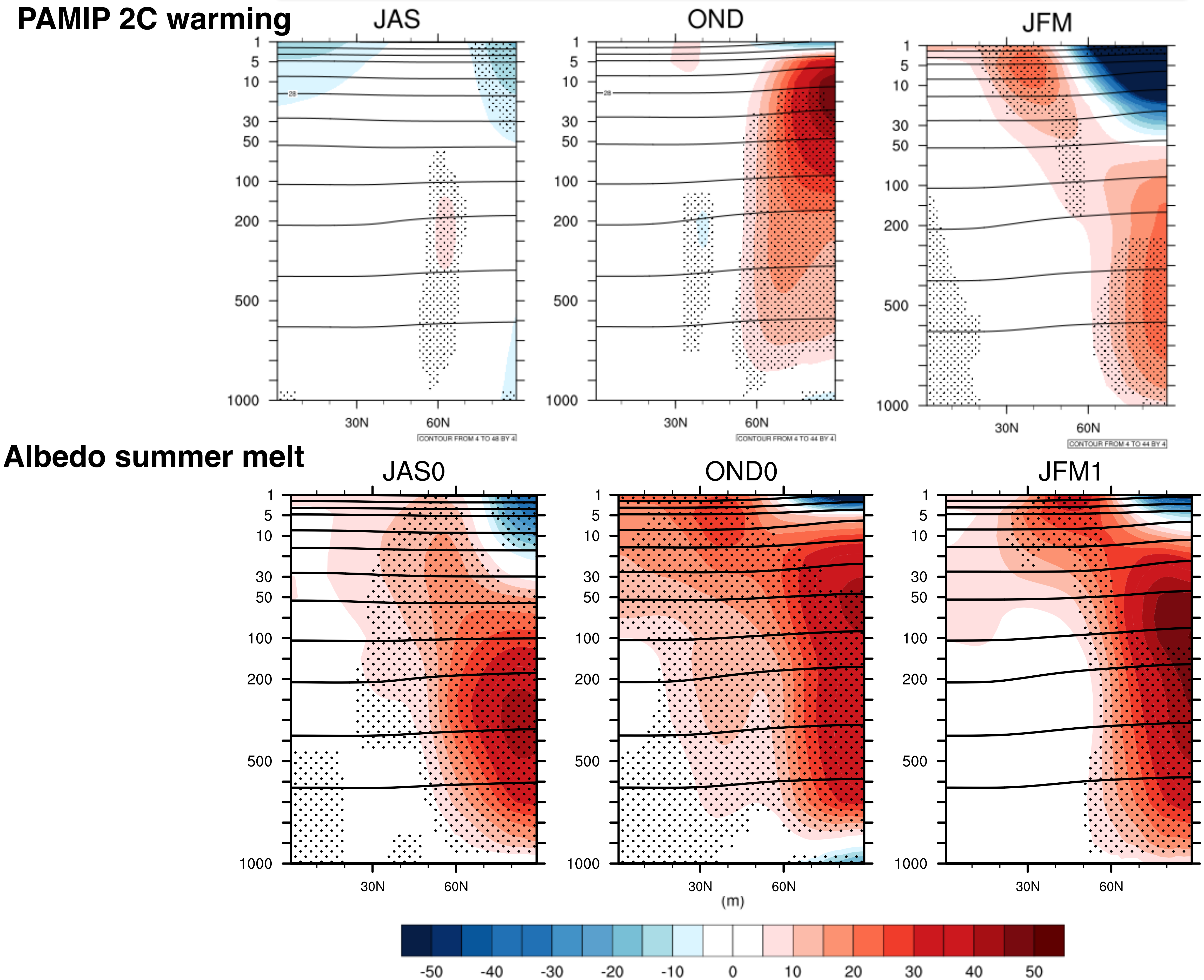
PAMIP 2C warming



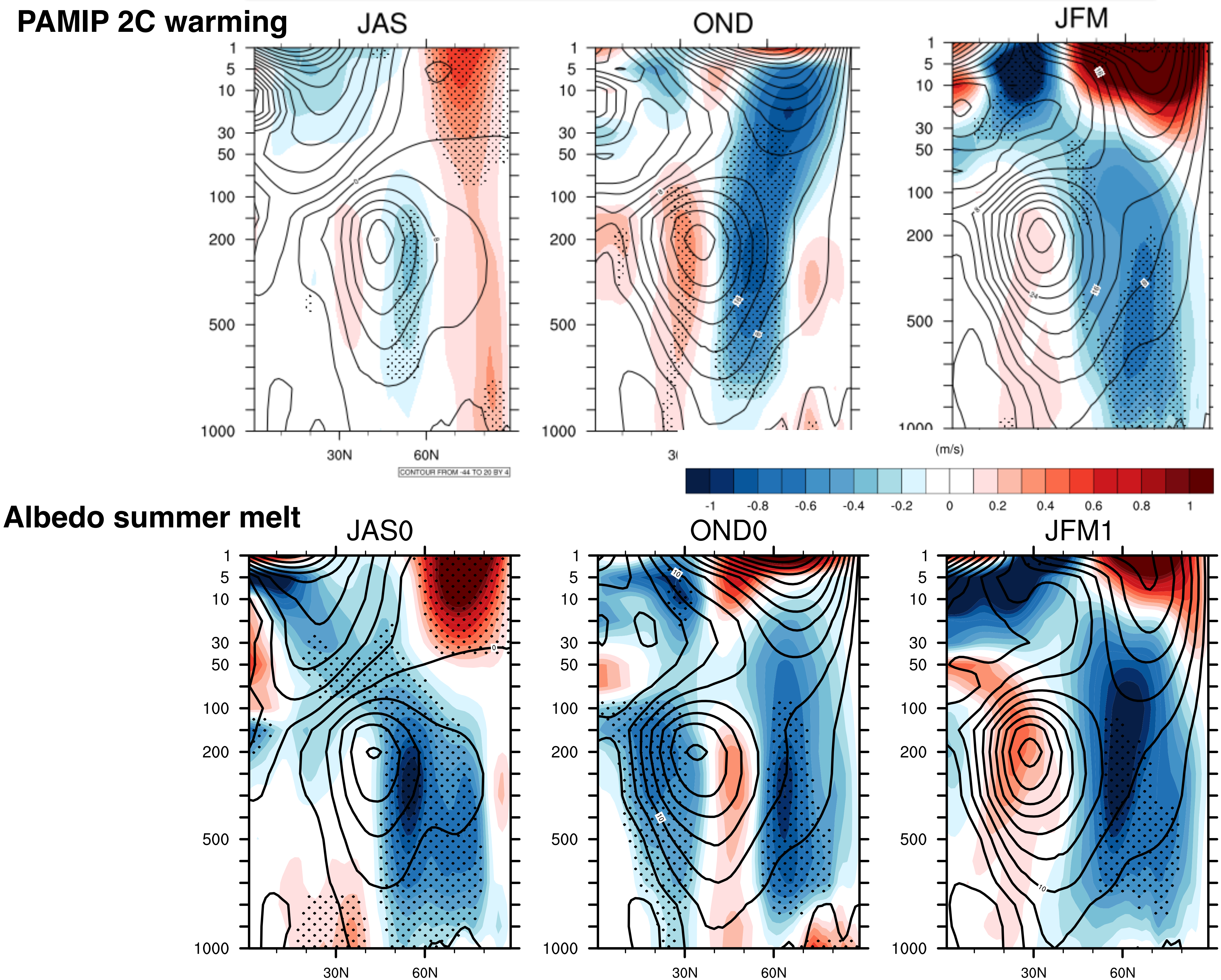
Albedo summer melt



Zonal mean response: geopotential height

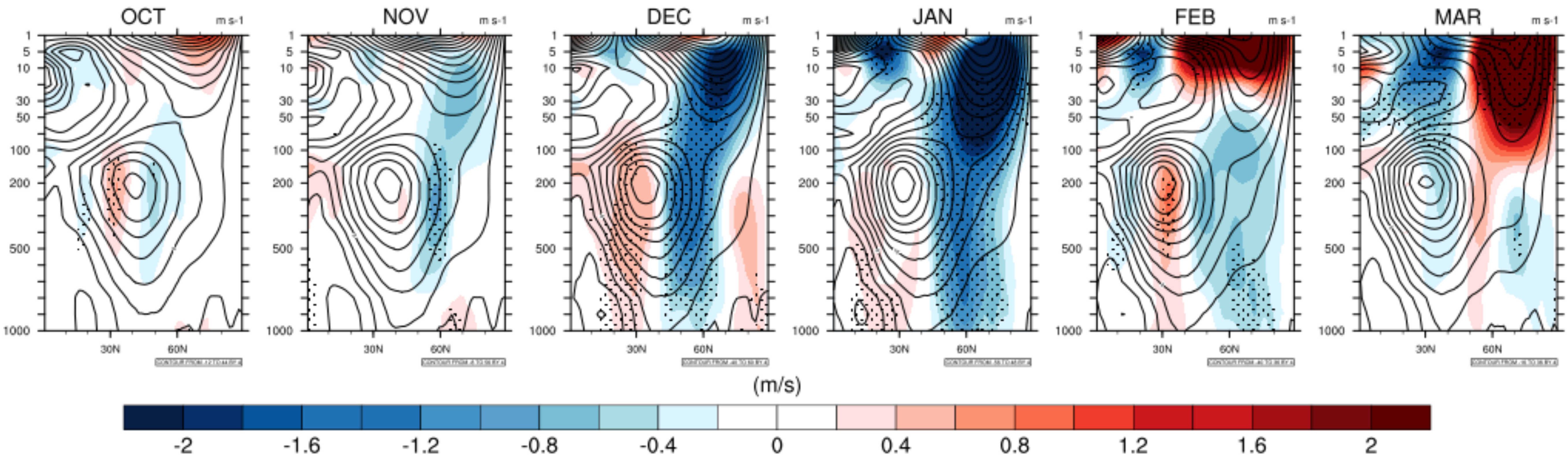


Vertical structure of the circulation response

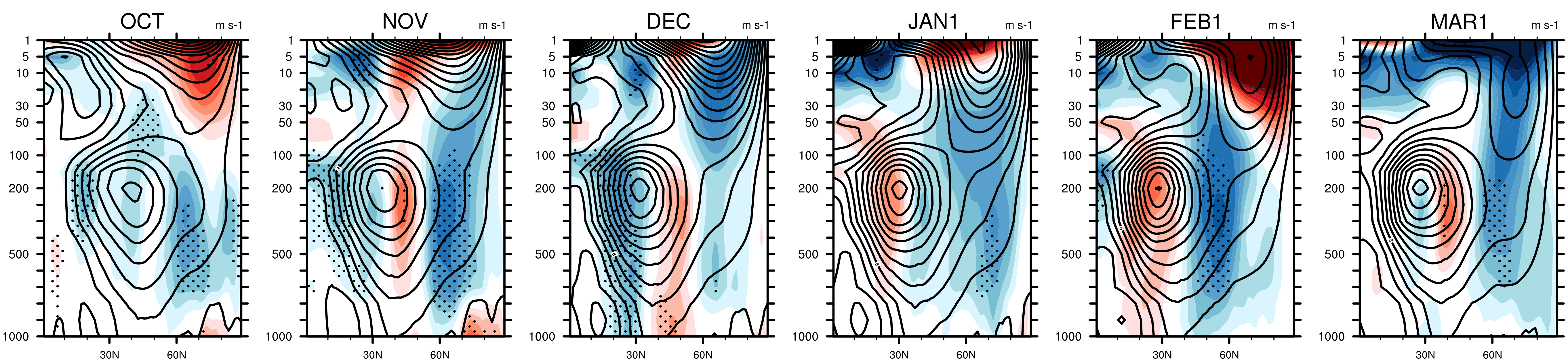


Vertical structure of the circulation response: monthly evolution

PAMIP 2C warming



Albedo summer melt



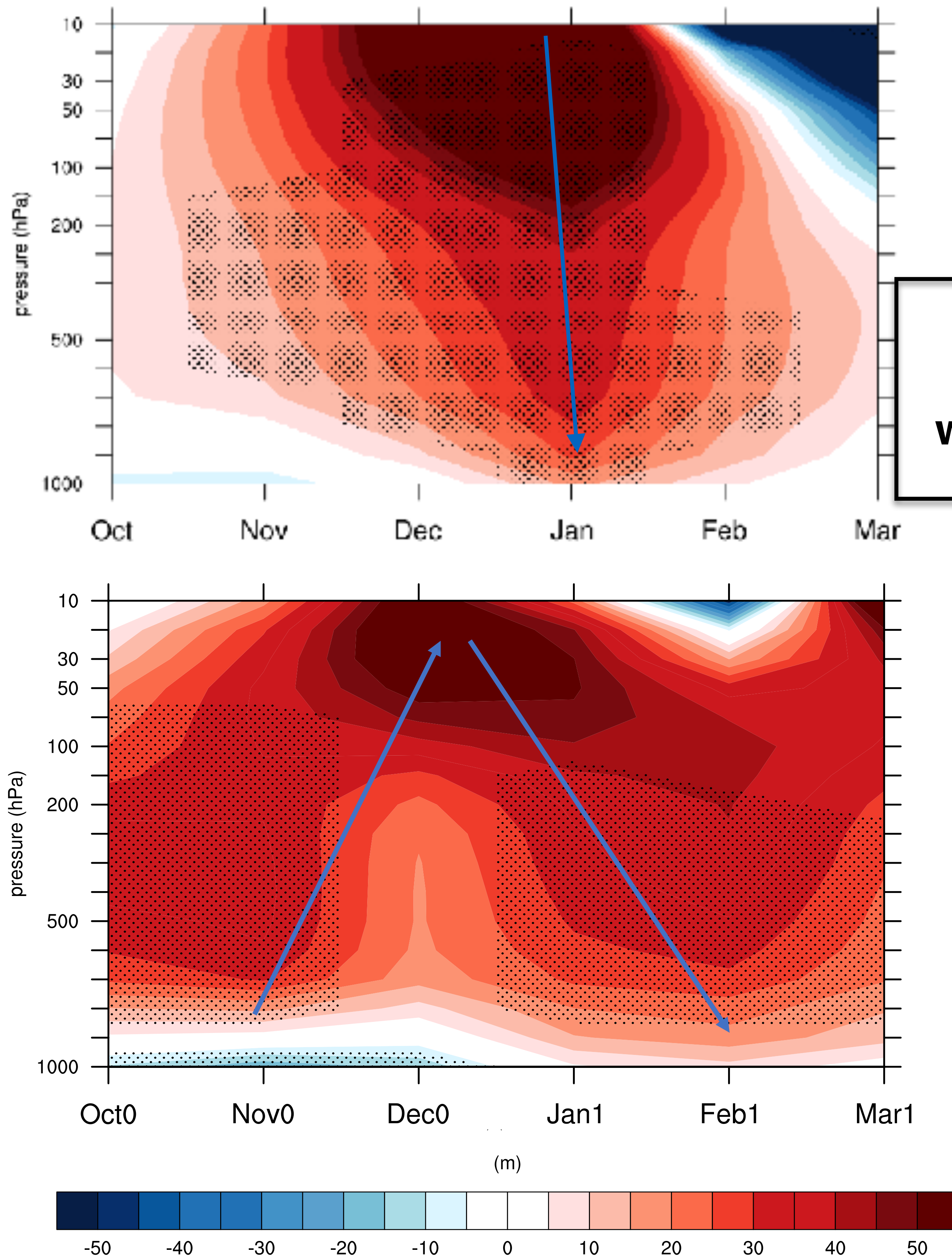
- Opposite response in the troposphere in December
- Weaker stratospheric response in Dec and Jan
- Strengthening of the polar vortex less persistent

Troposphere/stratosphere interactions

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

PAMIP 2C warming

Albedo summer melt

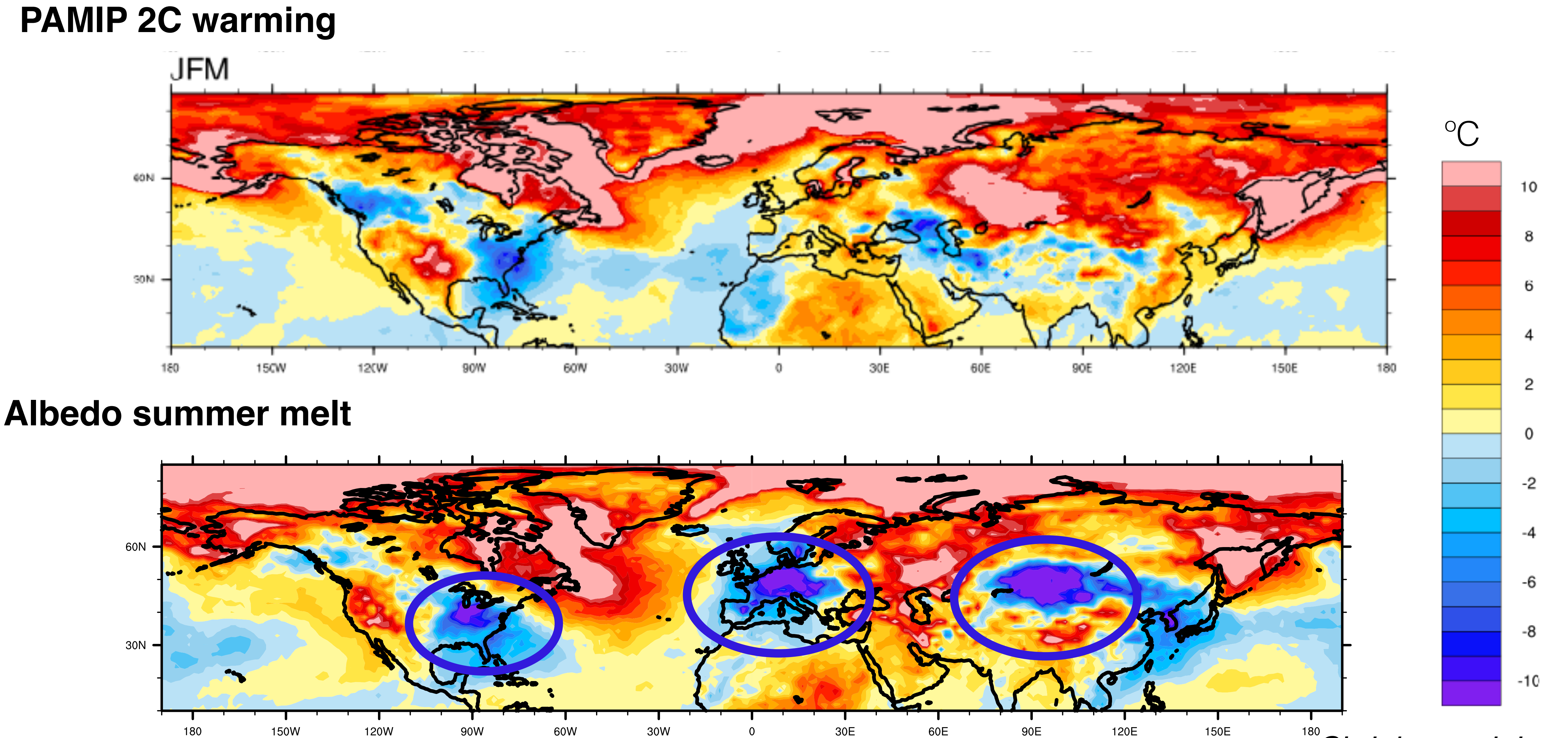


Positive anomaly: negative NAM / weakening of polar vortex

Chripko et al. in prep

Influence of sea ice loss on winter cooling

Changes in the 5th quantile of daily minimum temperature in winter



Chripko et al. in prep

- Cooling over Eastern US simulated in both experiments
- Eurasian winter cooling simulated in albedo experiments but not in PAMIP. Larger dynamical response? Larger forcing from 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

- The PAMIP atmosphere-only simulations based on CNRM-CM6-1 simulate a significant atmospheric response to the Arctic sea ice decline associated to a 2° warming that is maximum in OND and JFM.

- The warming is confined to the Arctic but the circulation changes extend to the whole Northern Hemisphere and beyond and include
  - a weakening of midlatitude westerlies and a southward shift of the subtropical jet in late fall/early winter => negative NAM
  - A weakening of the polar vortex in OND and a strengthening in JFM

- The atmospheric response resembles with a smaller magnitude to that in response to stronger sea ice forcing. The main differences in the albedo experiments are :
  - A clear summer response
  - Different tropospheric response: narrowing of the jet in OND and no change in the westerlies.
  - Weaker stratospheric response in December and January
  - Different vertical wave propagation into the polar stratosphere: affects the timing of the polar vortex changes
  - Different simulation of weather extremes: enhanced Eurasia cooling in winter

Discussion

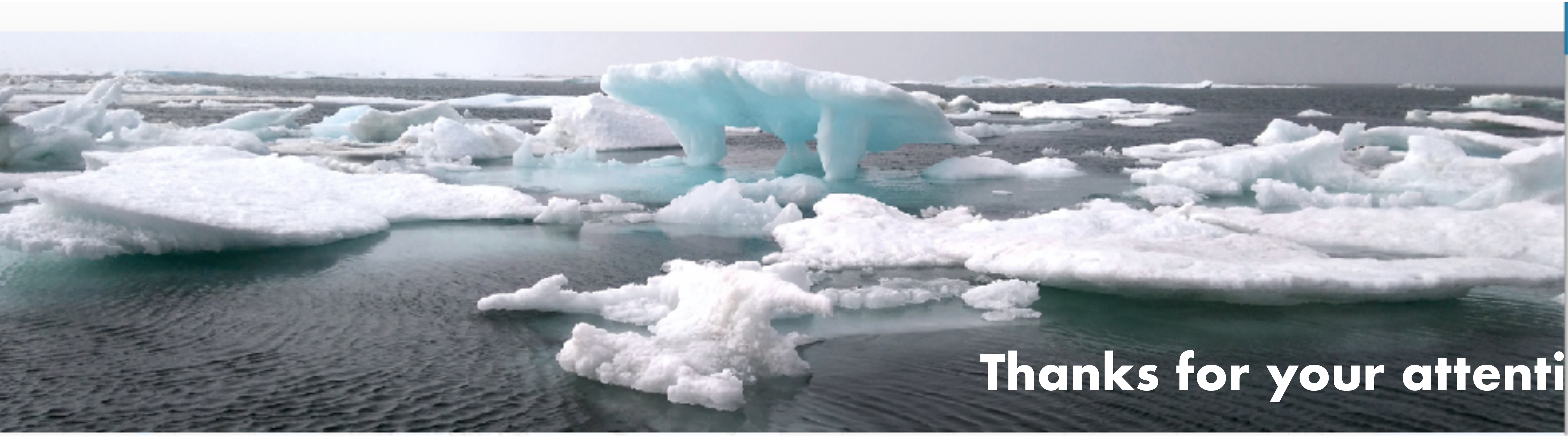
- Difficult to interpret the impact of differences in the magnitude of forcing as the relationship could be non-linear (*Petoukhov and Semenov 2010, Peings and Magnusdottir 2014, Semenov and Latif 2015, Chen et al., 2016*)

- Both experimental protocoles have important limitations:
  - PAMIP 2ºC warming: no coupling with the ocean
  - Albedo: strong sea ice forcing in summer and fall but weak in winter, forcing in the Antarctic too

- Difficult to compare the results of the two experiments because not a clean comparison (different background states, different magnitude and geographical pattern for the forcing, different model configuration, different protocole)

=> Good illustration of the limitations that motivated the coordinated PAMIP experiments!

Need to do the multi-model comparison now!


Thanks for your attenti