Contrasting Antarctic and Arctic atmospheric responses to future sea-ice loss

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Motivation

The effect of Arctic sea ice loss has received a lot of attention.

nature geoscience
REVIEW ARTICLE
PUBLISHED ONLINE: 17 AUGUST 2014 | DOI: 10.1038/NGEO2234

Recent Arctic amplification and extreme mid-latitude weather

Judah Cohen[1*], James A. Screen[2], Jason C. Furtado[1], Mathew Barlow[3,4], David Whittleston[5], Dim Coumou[6], Jennifer Francis[7], Klaus Dethloff[8], Dara Entekhabi[5], James Overland[9] and Justin Jones[1]

The Arctic region has warmed more than twice as fast as the global average — a phenomenon known as Arctic amplification. The rapid Arctic warming has contributed to dramatic melting of Arctic sea ice and spring snow cover, at a pace greater than that simulated by climate models. These profound changes to the Arctic system have coincided with a period of ostensibly more frequent extreme weather events across the Northern Hemisphere mid-latitudes, including severe winters. The possibility of a link between Arctic change and mid-latitude weather has spurred research activities that reveal three potential dynamical pathways linking Arctic amplification to mid-latitude weather: changes in storm tracks, the jet stream, and planetary waves and their associated energy propagation. Through changes in these key atmospheric features, it is possible, in principle, for sea ice and snow cover to jointly influence … climate change influences these pheno… tainties regarding the magnitude of su… and additional Arctic observations, an… the influences on mid-latitude weather…

Surv Geophys (2014) 35:1175–1214
DOI 10.1007/s10712-014-9284-0

Effects of Arctic Sea Ice Decline on Weather and Climate: A Review

Timo Vihma

Received: 23 May 2013 / Accepted: 3 February 2014 / Published online: 9 March 2014
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Opinion

The impact of Arctic warming on the midlatitude jet-stream: Can it? Has it? Will it?

Elizabeth A Barnes[1*] and James A Screen[2]

The Arctic lower atmosphere has warmed more rapidly than that of the globe as a whole, and this has been accompanied by unprecedented sea ice melt. Such large environmental changes are already having prof… fauna, and inhabitants of the Arctic region. An open qu… these Arctic changes have an effect on the jet-stream an… patterns farther south. This broad question has recentl… and media attention, but conclusions appear contradict… We argue that one point of confusion has arisen due … question being posed. In this study, we frame our inq… questions: *Can Arctic warming influence the midlatitude je… significantly influenced the midlatitude jet-stream? Will … influence the midlatitude jet-stream?* We argue that fram… the three questions: *Can it?, Has it?, and Will it?* provid… themes emerging in the literature as well as highlights …
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CLIMATE SCIENCE

Far-flung effects of Arctic warming

Arctic warming affects weather and climate thousands of miles to the south. Scientists are split on how large this effect is.

James A. Screen

The Arctic has changed profoundly in a short period of time. During September, when the sea ice reaches its annual minimum, ice extent has declined by 50% and ice thickness by 85% since the late 1970s. The Arctic is warming rapidly, at a pace two to three times the planet's average — a phenomenon referred to as Arctic amplification. These changes at the pole do not occur in isolation from the rest of the globe. Scientists are grappling to understand the implications of Arctic warming for places thousands of miles further south[1,2]. A three-day workshop (http://go.nature.com/2mB6w3t) in February 2017 titled 'Arctic Change and its Influence on Mid-latitude Climate and Weather' emphasized that the connection is not one-way from the Arctic to the mid-latitudes but also works in reverse, and that observations and climate models give differing estimates of the extent to which mid-latitude climate is influenced by Arctic warming.

The climate system can be split into three broad latitudinal domains: the tropics, the mid-latitudes and the polar regions. Each has its own unique characteristics and responses to climate change. However, each domain is highly interconnected to the others. If Arctic warming causes changes in weather patterns in mid-latitudes, where a vast number of people live, it would be important to know about it. However, separating out one domain's influence on another is not an easy task.

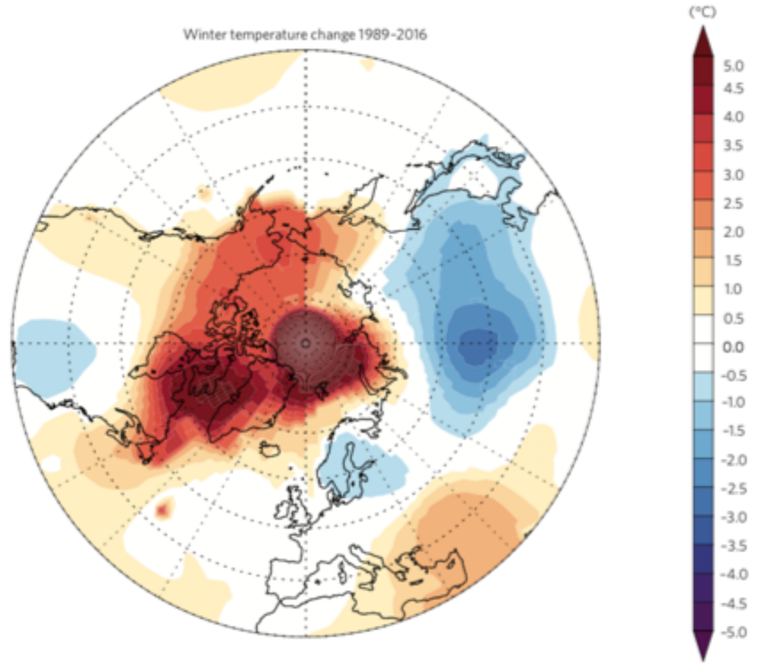


Figure 1 | Warm Arctic–cold Eurasia. Between 1989 and 2016, Arctic winter temperatures have risen substantially faster than the global mean (red shading), whereas Eurasian winters have become colder (blue shading). The global mean winter temperature rise over the same period was 0.5 °C. A workshop in February examined possible links between these contrasting trends and revealed differences between observational analyses and model studies, as well as among different climate models. Data from NASA GISTEMP (https://data.giss.nasa.gov/gistemp/).

Motivation

Yet the effect of future Antarctic sea ice loss has received far less attention.

- *Kidston et al 2011 (GRL)* found no impact from a reduction in Antarctic sea ice extent using CAM3.
- *Bader et al 2013 (Clim. Dyn.)* investigated sea ice loss in Austral winter and found a robust impact on the jet, in agreement with previous work by *Menendez et al 1999 (Clim. Dyn.)*.

So the effect of projected Antarctic sea ice loss on the atmosphere is still largely an open question.

Motivation

The main questions which we aim to address are:

- Is there a significant impact of Antarctic sea ice loss on the tropospheric circulation?
- How do these impacts differ from the response to Arctic sea ice loss in the
    a) Strength
    b) Seasonality
    c) Regional structure
- What role does the stratosphere play?

Experimental Setup

- Perform three time-slice experiments in atmosphere only mode, each for 150 years
    1. Control experiment 1955-1969 averaged sea ice conditions
    2. Same as control but with Antarctic sea ice at 2085-2099 conditions
    3. Same as control but with Arctic sea ice at 2085-2099 conditions
- All other forcings (CO_2, ODSs etc.) are kept at 1955 values.
- Future sea ice predictions averaged from three members of WACCM run out to 2100 under RCP 8.5 conditions.
- Change SSTs to future SSTs only in areas where ice has melted
- Similar approach to *Sun, Deser and Tomas 2015 (J. Climate)*

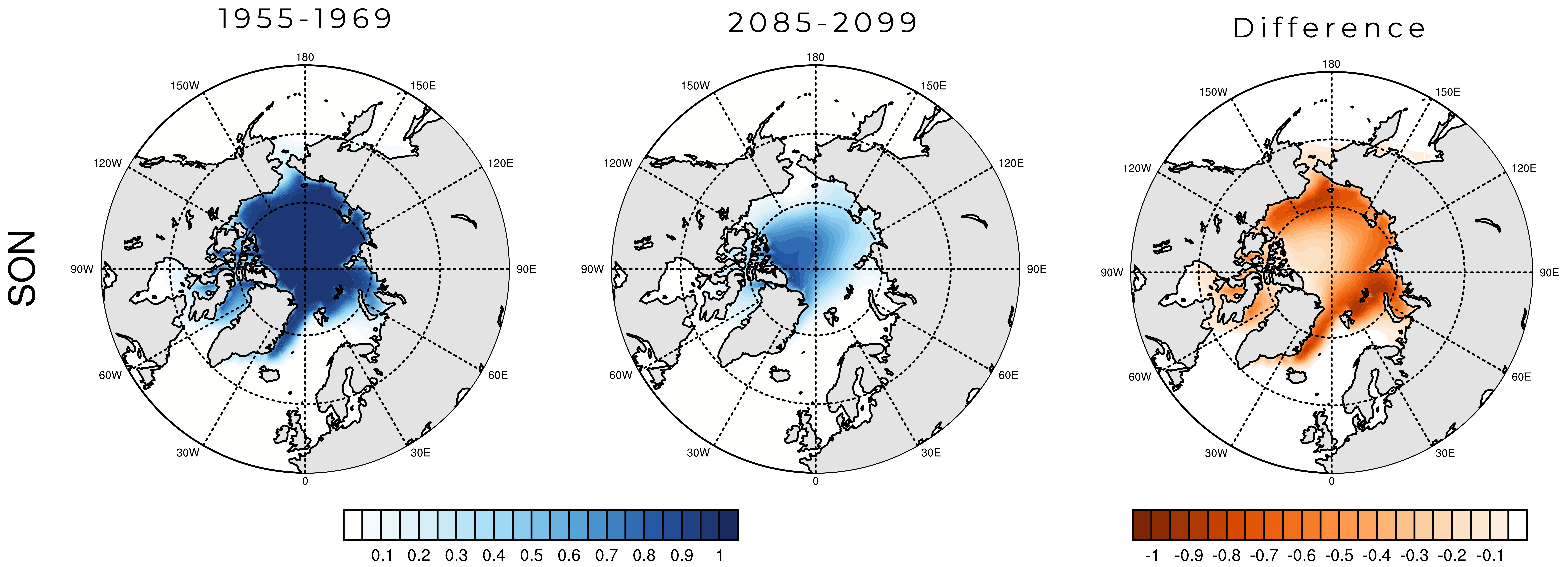
Model

Community Earth System Model (CESM)
Whole Atmosphere Community Climate Model (WACCM):

- High top model which participated in CMIP5
- Ran in atmosphere-only mode
- 2° by 2.5° horizontal resolution
- 66 vertical levels with model lid extending up to lower thermosphere
- Simulates climatological Arctic and Antarctic sea ice conditions well

Imposed Sea Ice

ARCTIC:



Imposed Sea Ice

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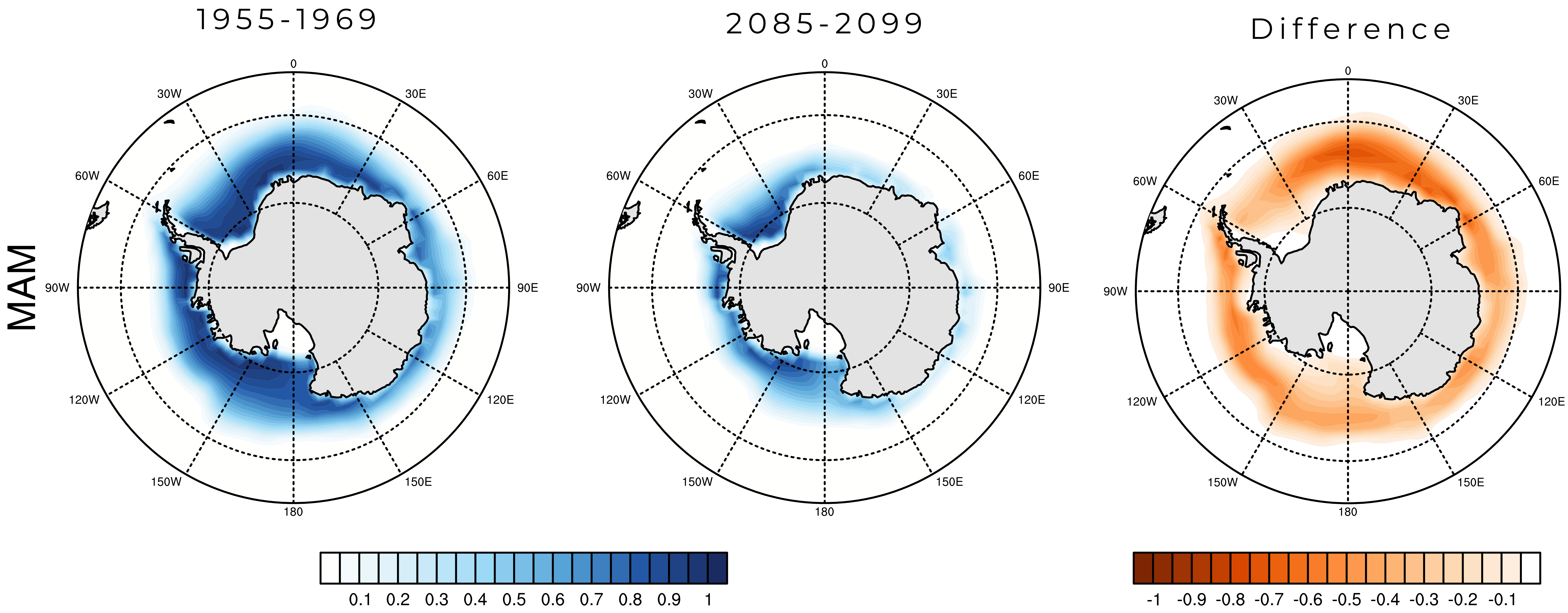
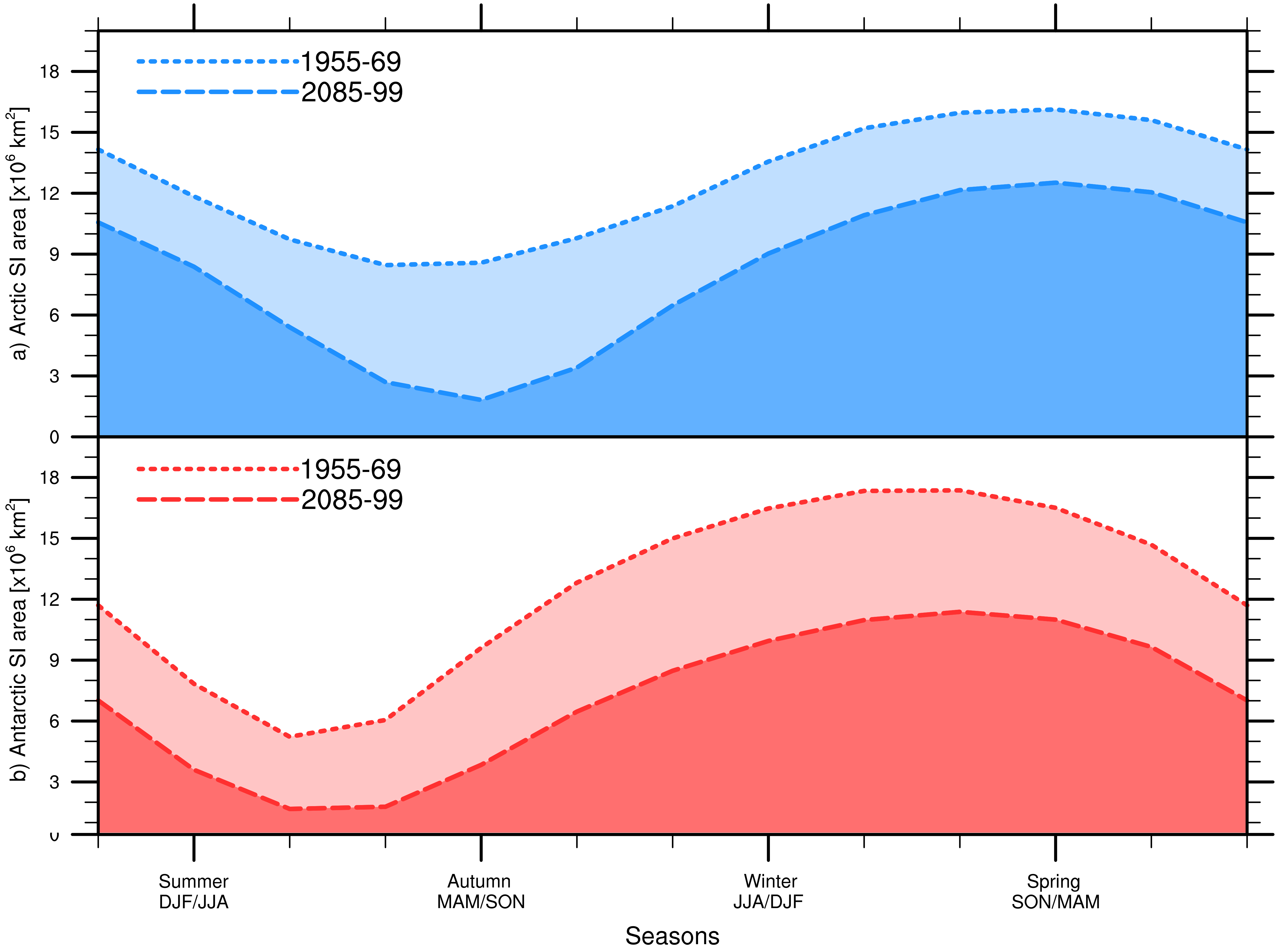


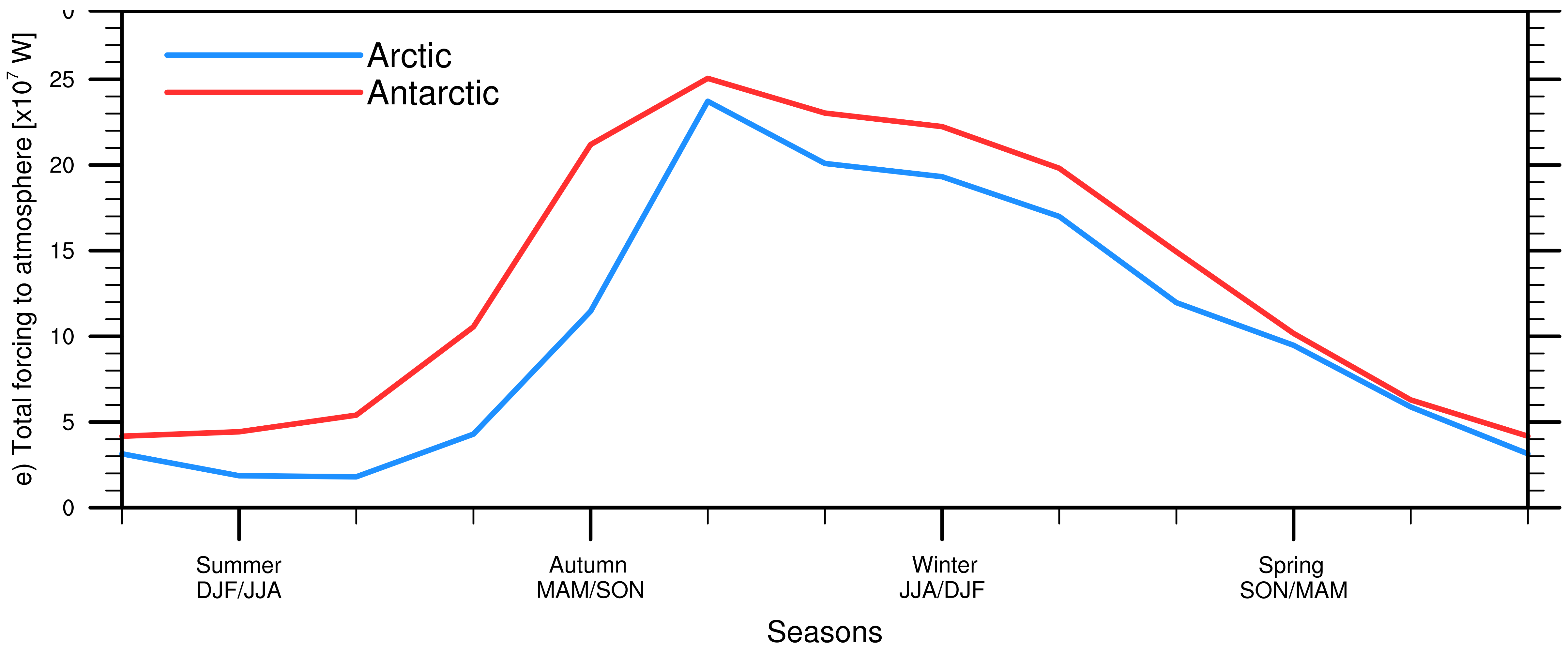
Imposed Sea Ice

Arctic sea ice seasonal cycle



Antarctic sea ice seasonal cycle

Total forcing from heat flux to the atmosphere



Temp. Response

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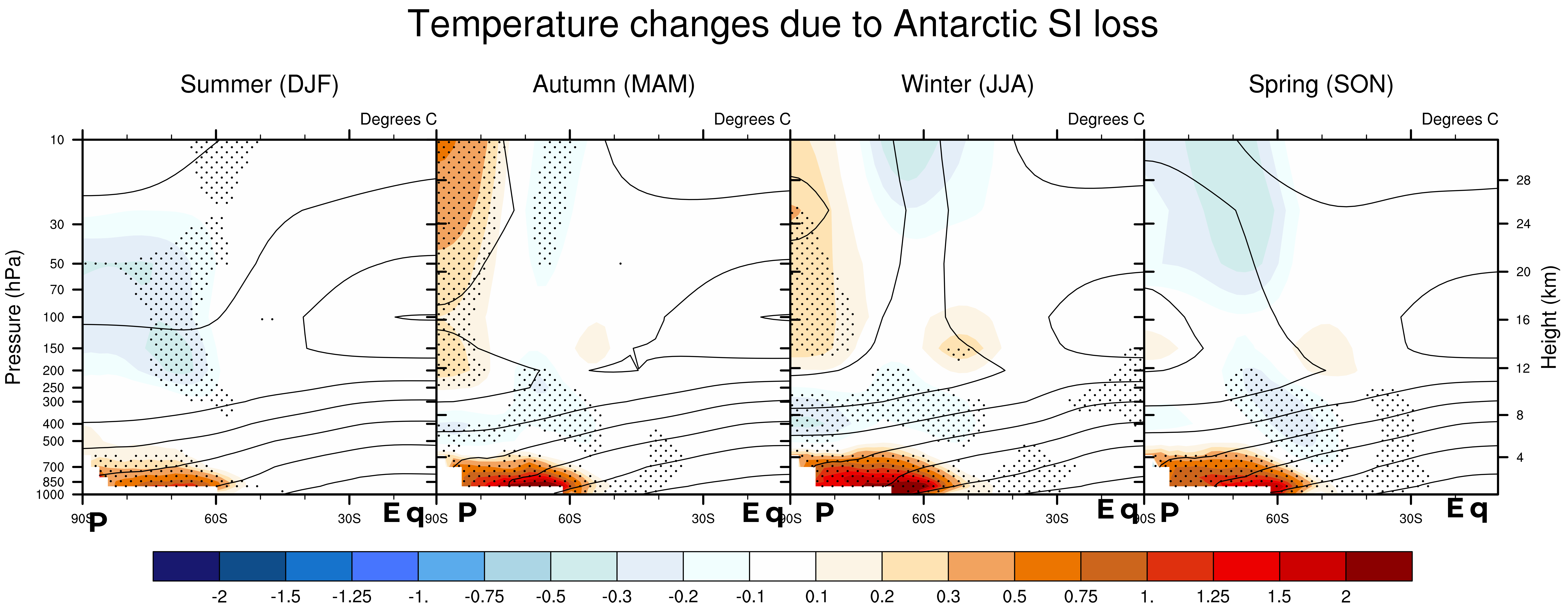
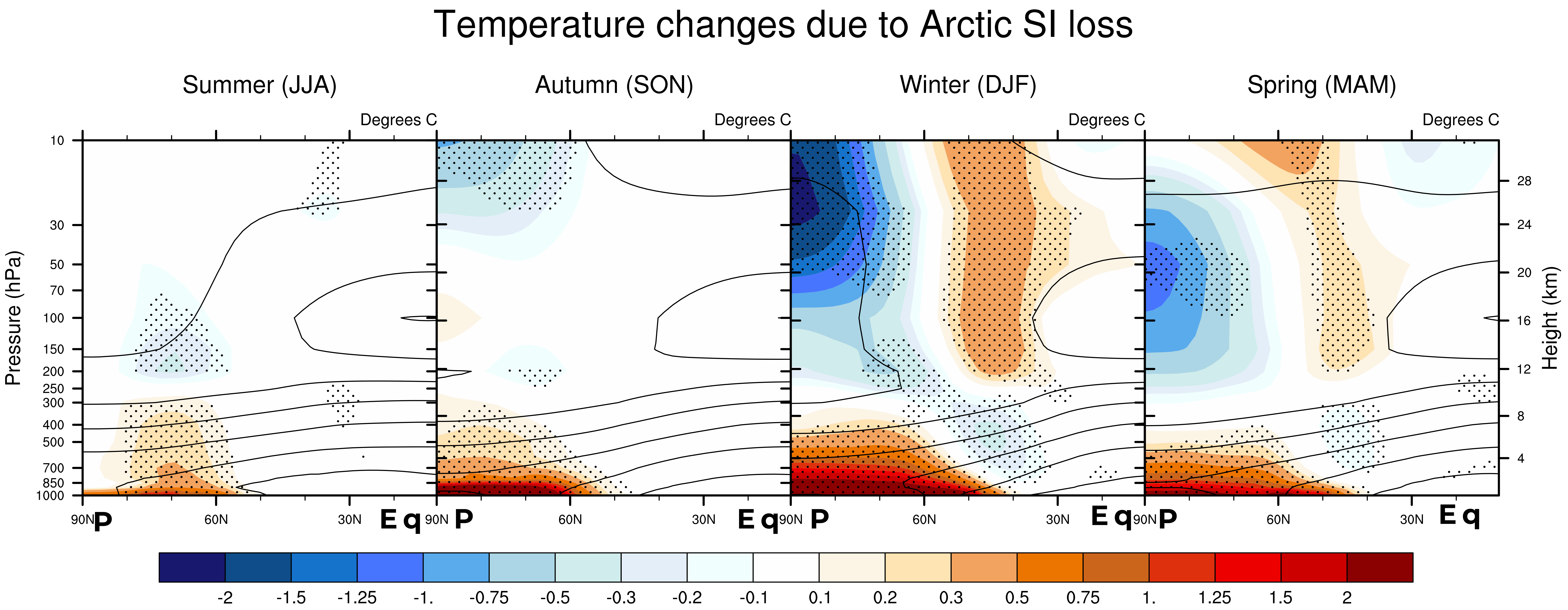


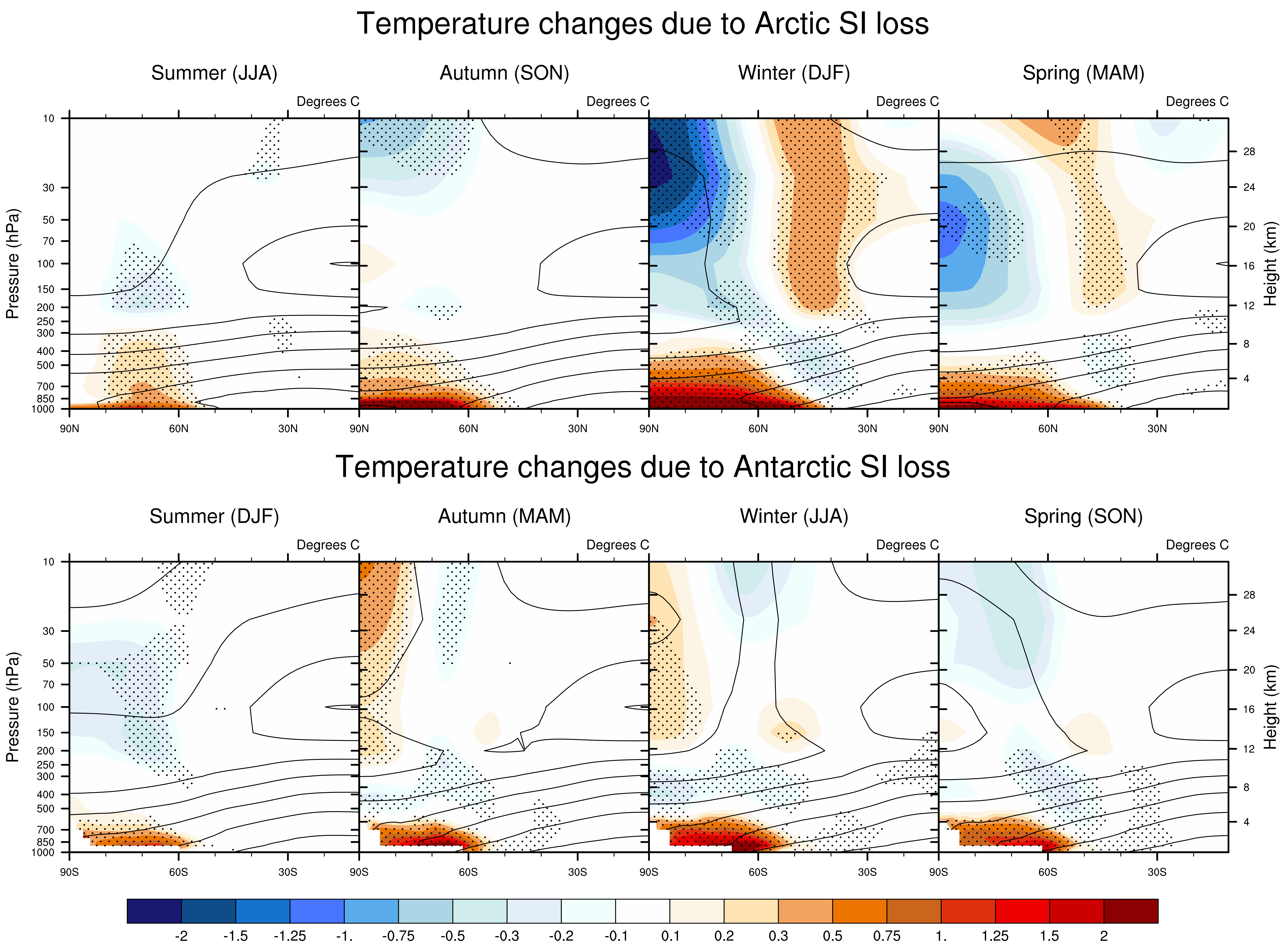
Temp. Response

ARCTIC:

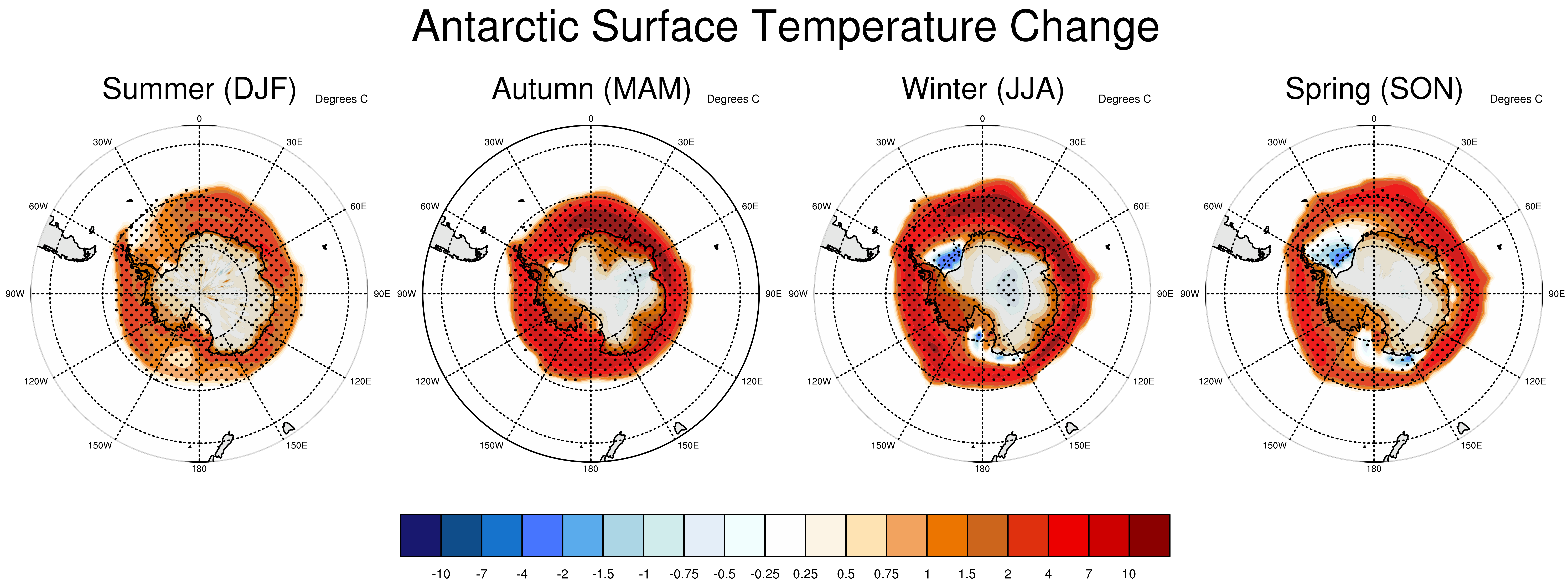


Temp. Response

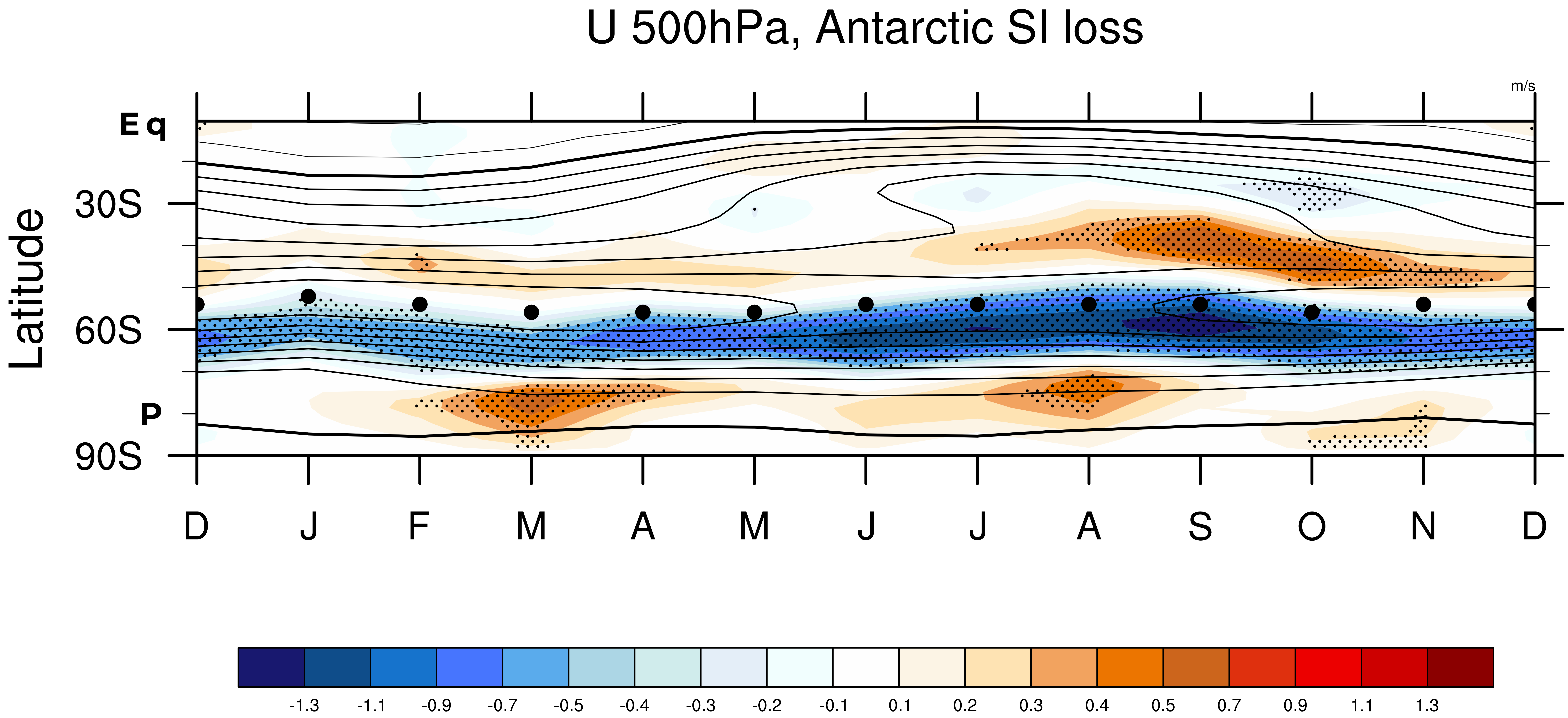
- Temperature response trapped at high latitudes and near the surface.
- Antarctic response is of weaker amplitude but less seasonally varying.
- Weaker stratospheric response to Antarctic sea ice loss.



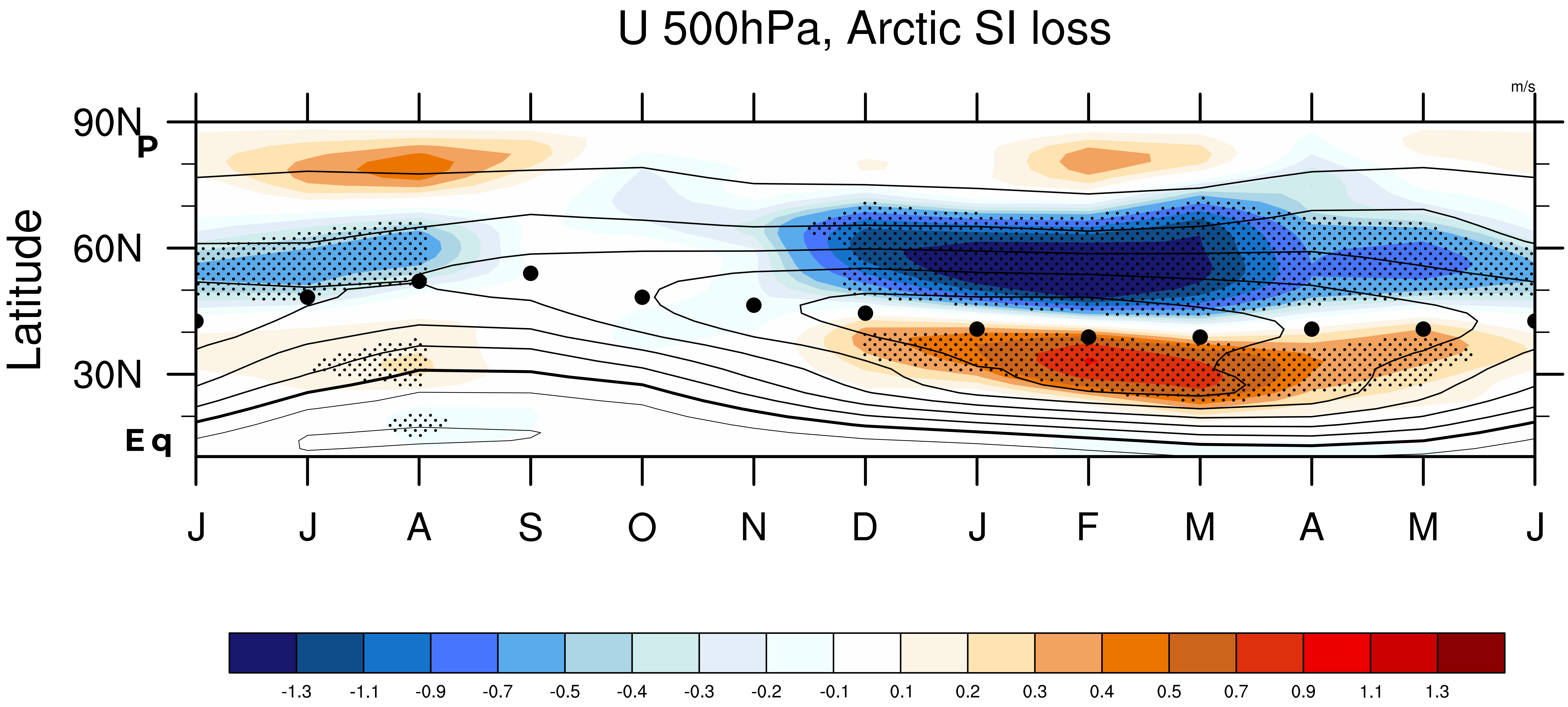
Surface Response



Zonal Wind Response

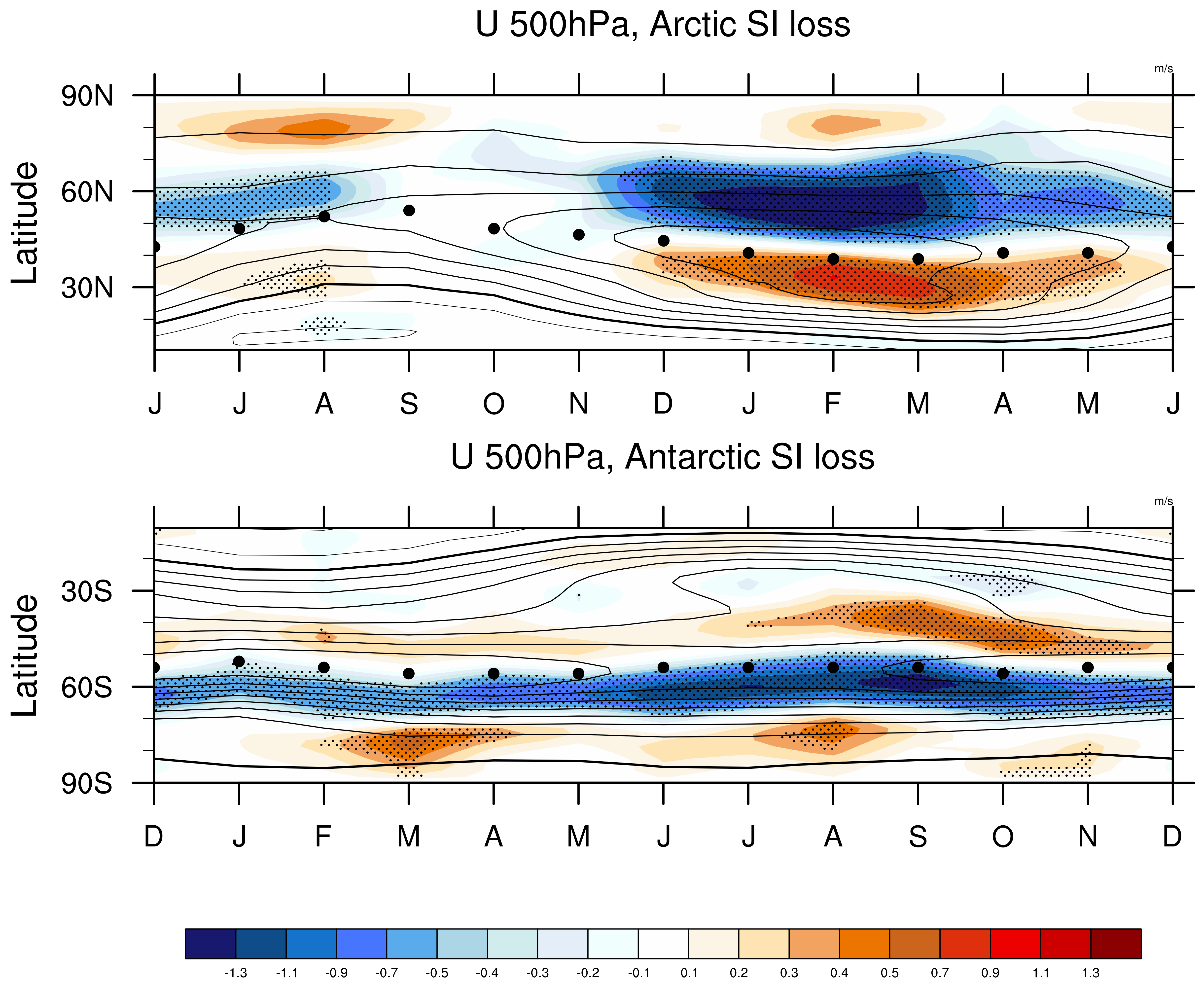


Zonal Wind Response



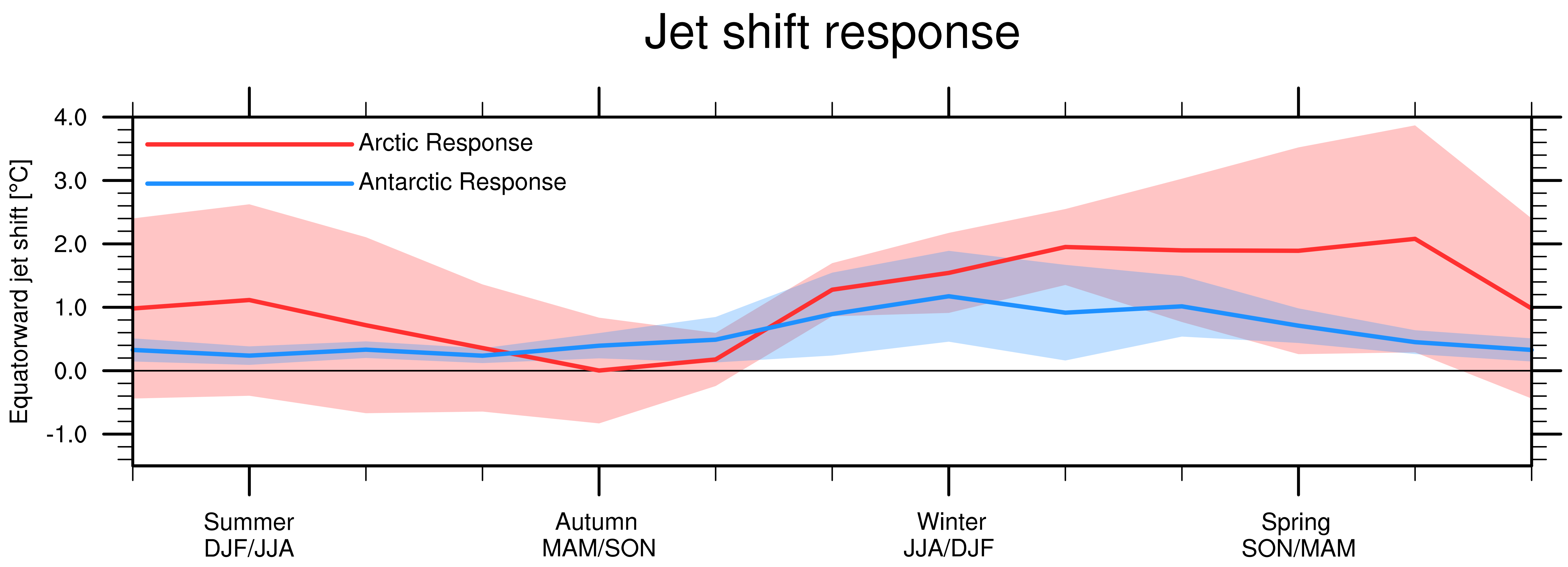
Zonal Wind Response

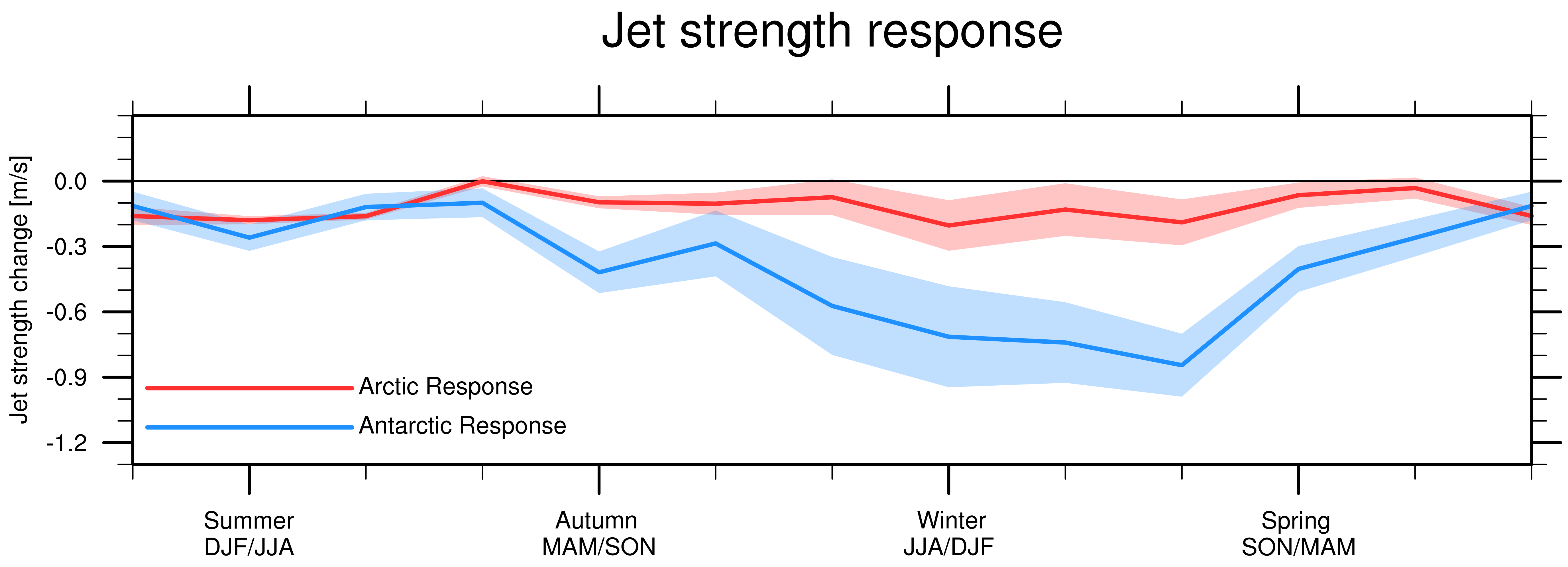
- Equatorward jet shift in each hemisphere due to sea ice loss
- Negative feedback on poleward jet shift associated with increased greenhouse gas emissions
- Response to Antarctic sea ice loss can evident year round.



Zonal Wind Response

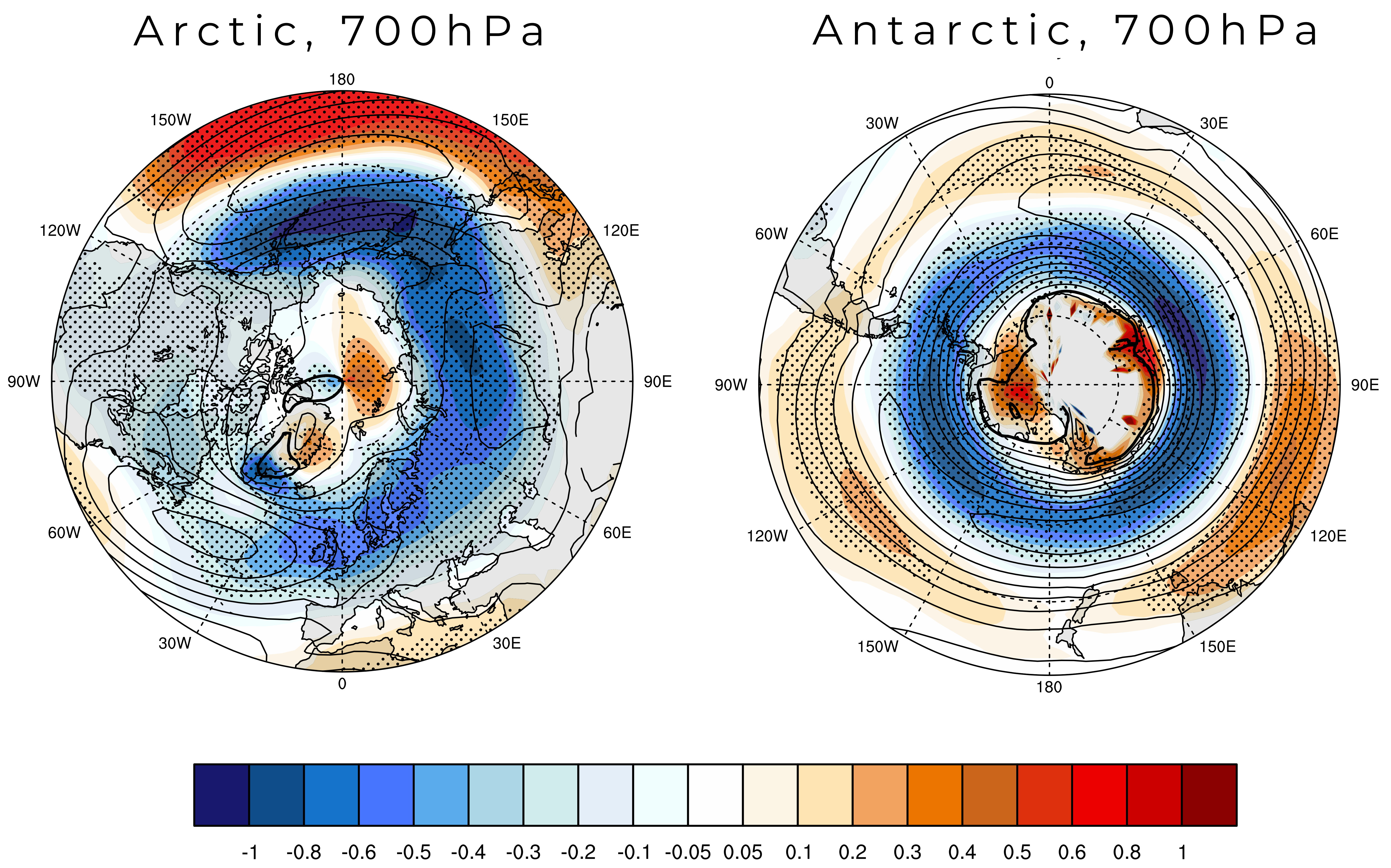
- Equatorward jet shift in each hemisphere due to sea ice loss
- Shift is less seasonally varying in Southern Hemisphere
- Sea ice loss results in a jet weakening, with a much larger amplitude in the Antarctic response *(Bracegirdle et al, 2018)*





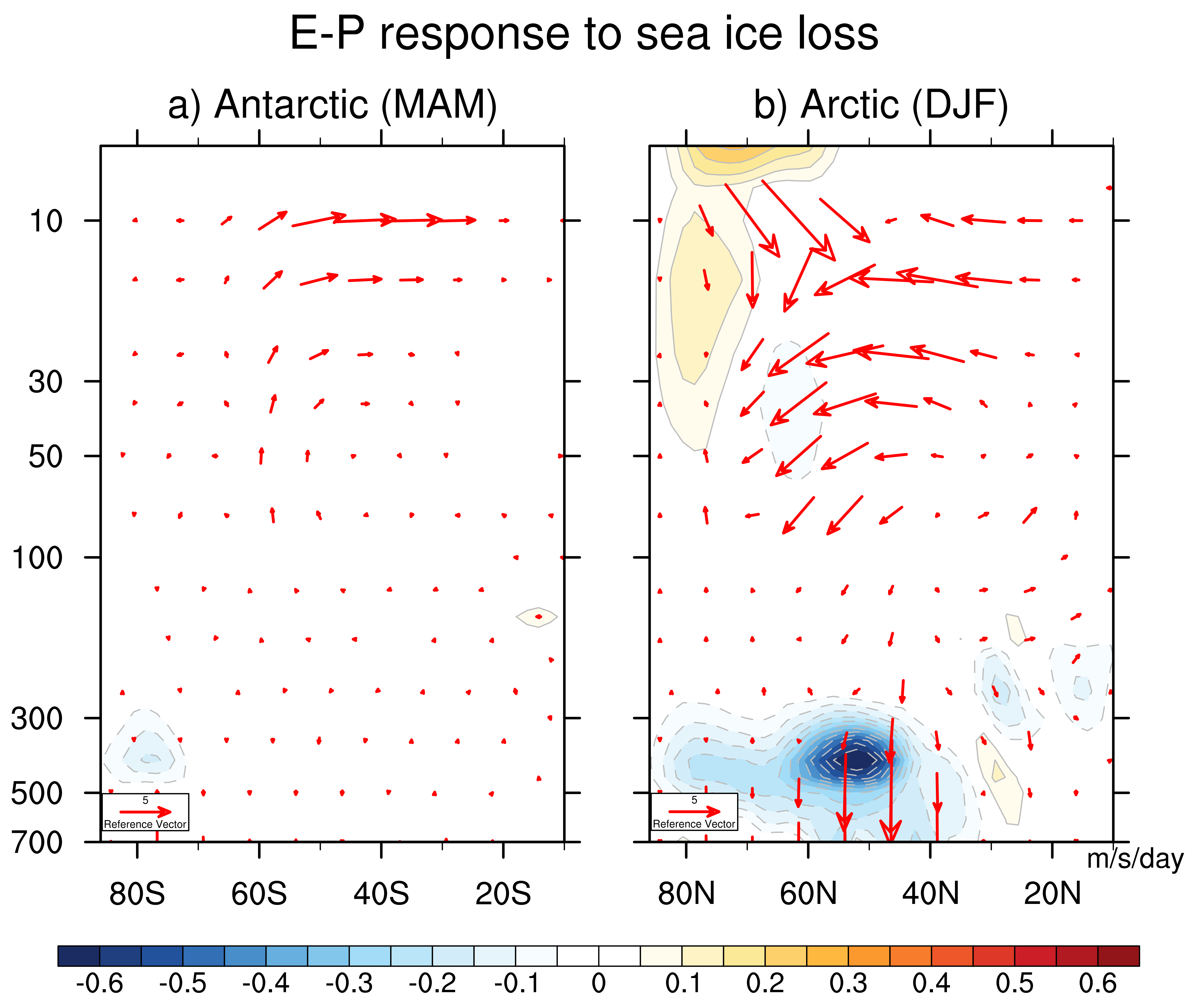
Zonal Wind Response

- In this model, Arctic response is largest in Pacific region
- Antarctic response is zonally symmetric



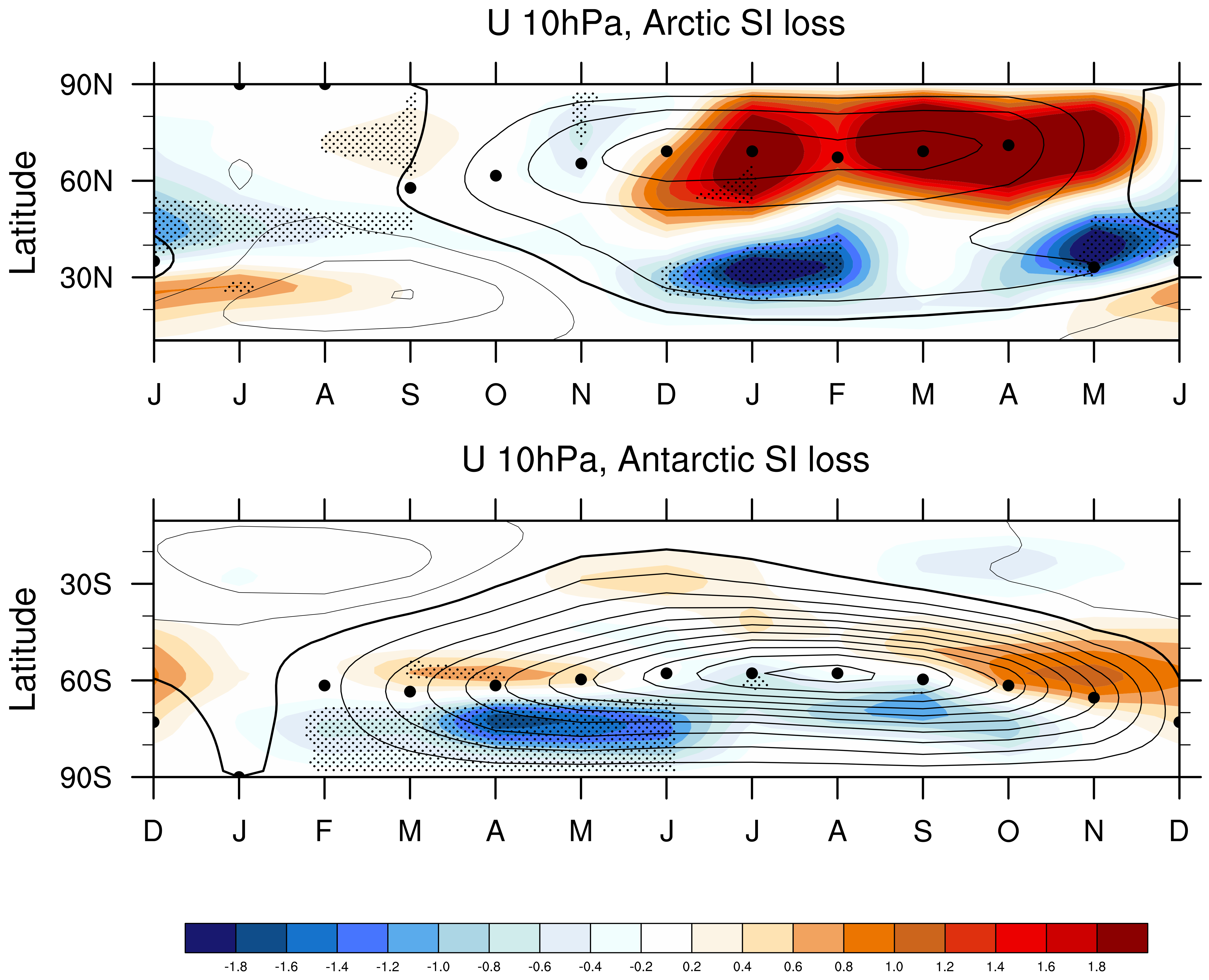
Stratospheric Response

- Stratospheric response largest in winter in Arctic and autumn in Antarctic
- Stratospheric response much smaller in response to Antarctic sea ice loss
- Response is, if anything, opposite



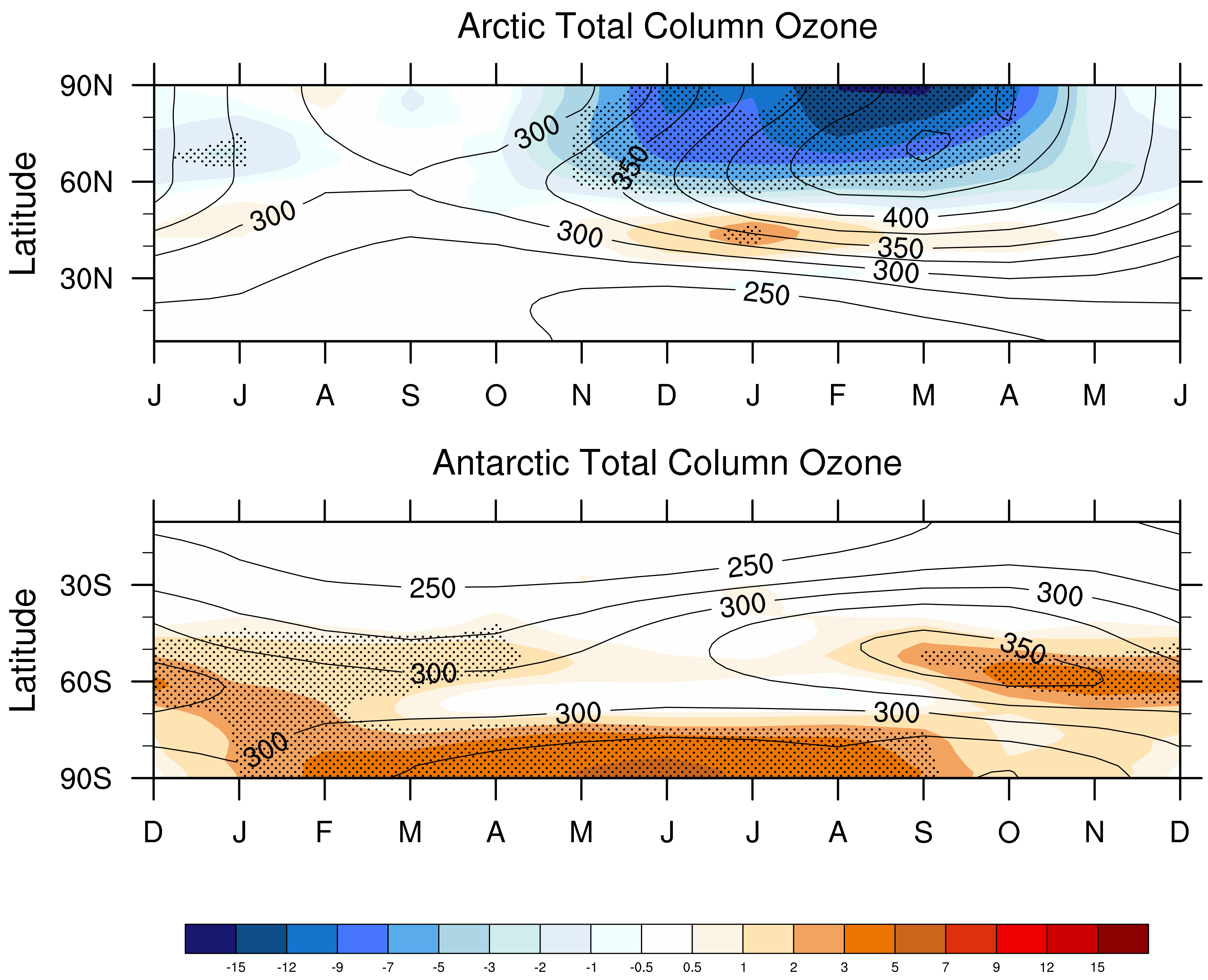
Stratospheric Response

- For the Arctic winter, despite very similar experiments with same model, response is opposite to that of Sun et al (2015) either because of:
    a) Large internal variability
    b) Highly sensitive to difference in sea ice conditions or climatological conditions



Ozone Response

- Arctic sea ice loss results in reduction in total column ozone for winter and spring
- Antarctic sea ice loss, results in a small, but statistically significant, increase in polar total column ozone throughout much of the year (*apart from austral spring*)

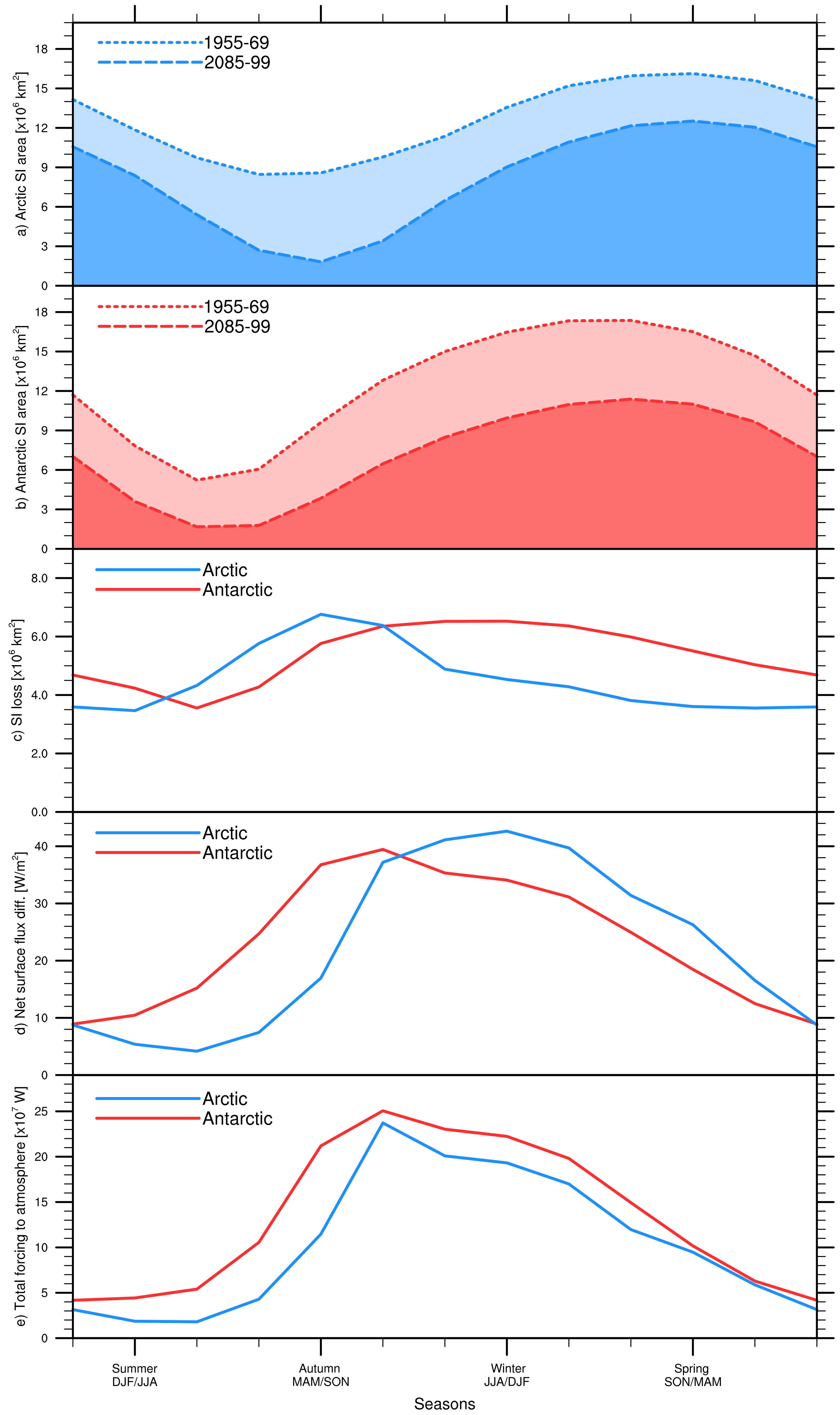


Conclusions

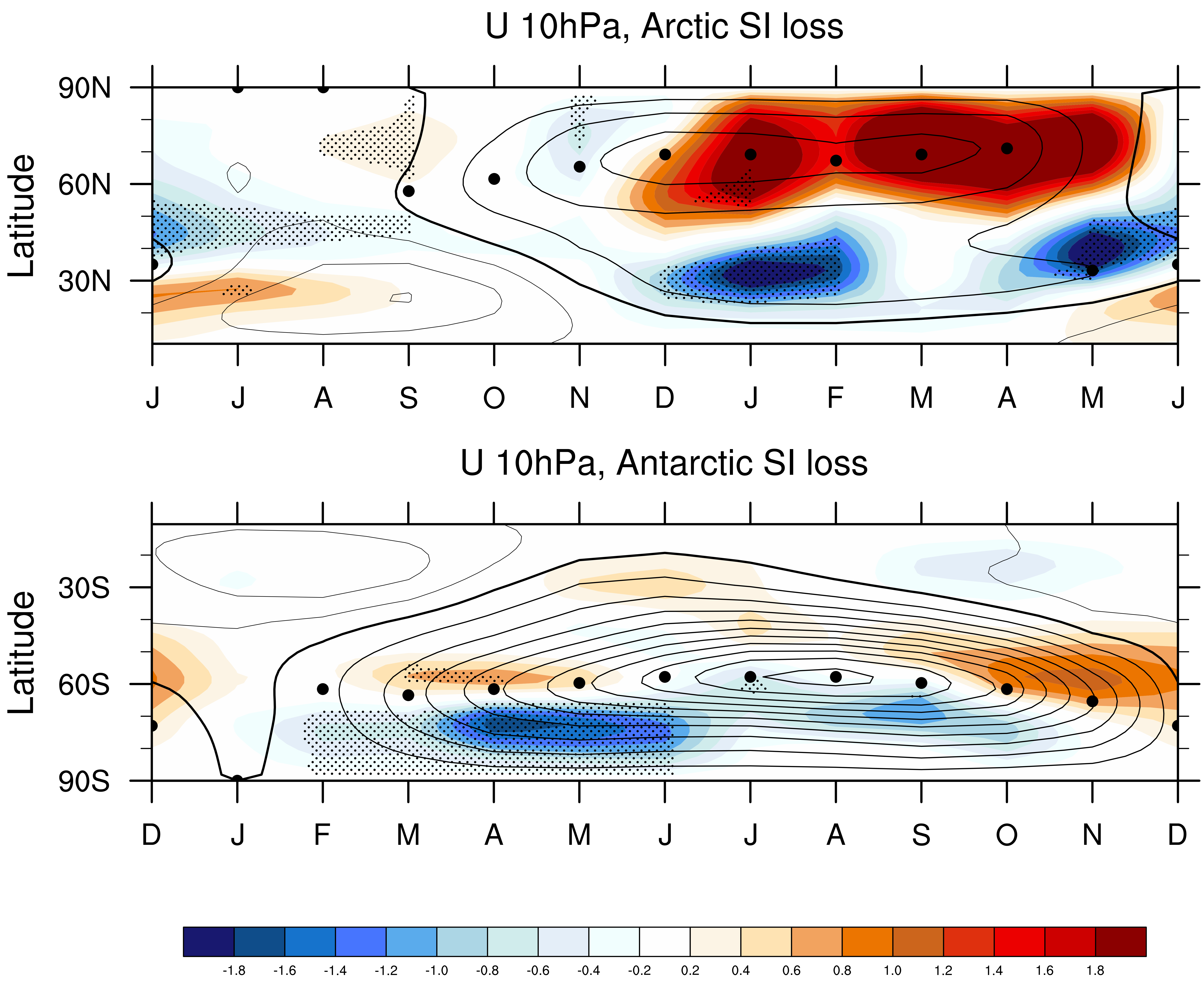
- Response to Antarctic sea ice loss is of comparable amplitude to the Arctic but different in character:
    - Response to Antarctic sea ice loss is evident throughout the year
    - More zonally symmetric.
    - Amplitude is somewhat smaller
- Temperature response is limited to high latitudes and trapped near the surface.
- Surface temperature response does not penetrate continent of Antarctica.
- Sea ice loss produces a negative feedback on the circulation shift, but jet strength is also important in the Antarctic
- Stratospheric response seems highly sensitive

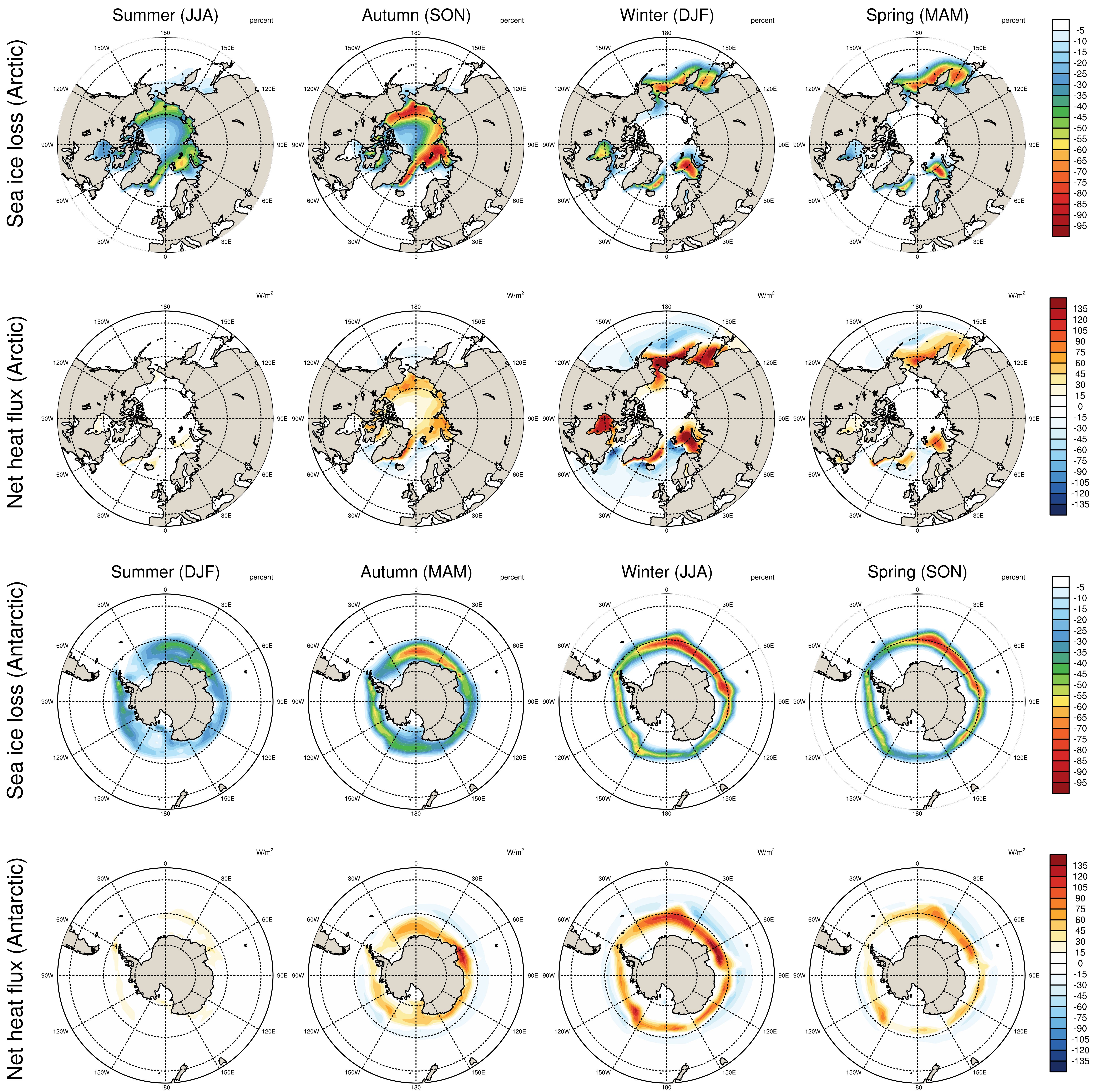
Discussion

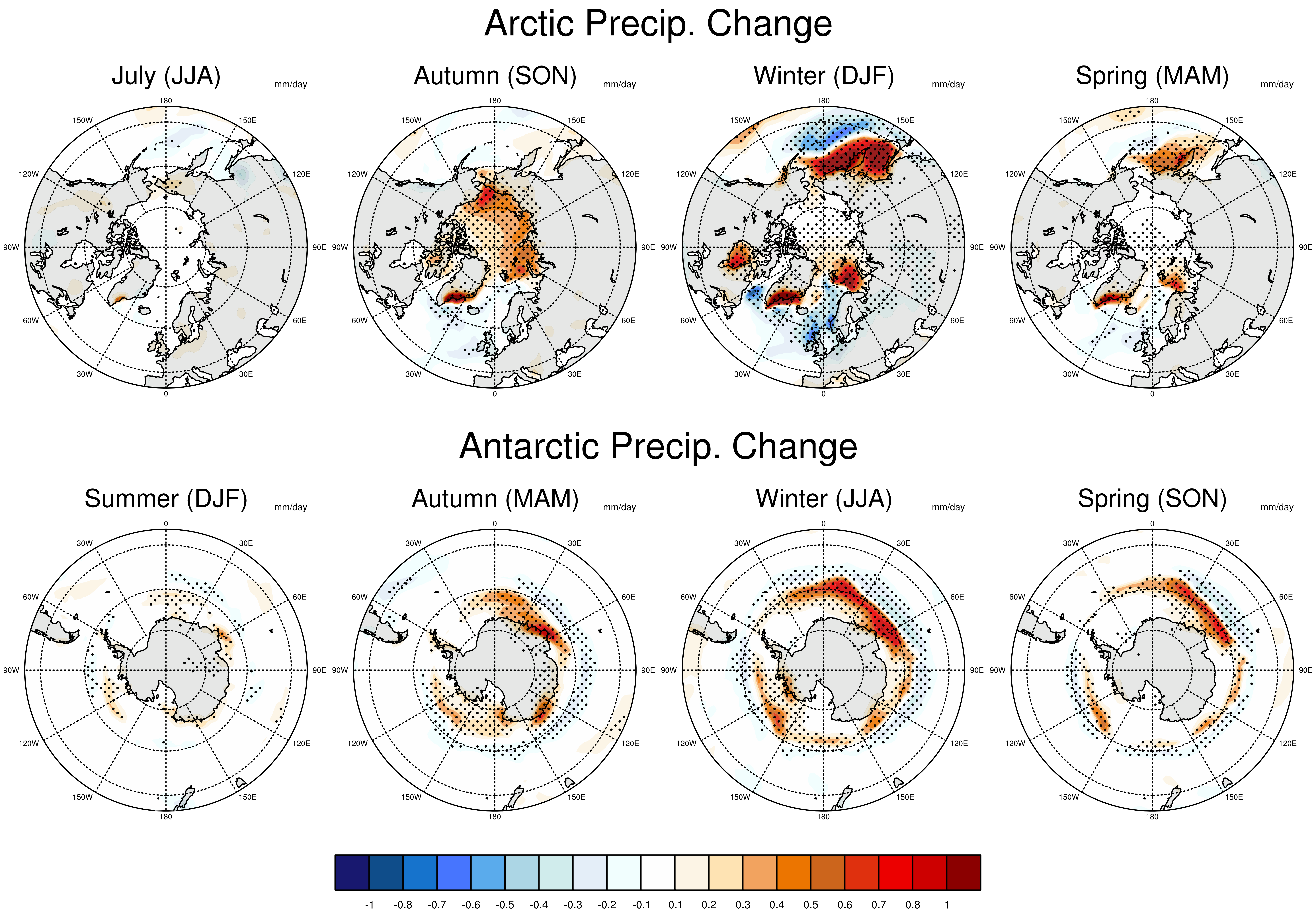
- Our results confirm and extend findings of *Bader et al 2013 (Clim. Dyn.)*, but more climate model studies are needed
- How important is coupling with an interactive ocean for the response to future Antarctic sea ice losses?
- Current Antarctic sea ice observations do not fall within the model simulations
  - ➢ Our results offer an idea of the amplitude of errors if sea ice loss does not occur.



1955-69
2085-99
a) Arctic SI area [x10^6 km^2]
b) Antarctic SI area [x10^6 km^2]
Arctic
Antarctic
c) SI loss [x10^6 km^2]
d) Net surface flux diff. [W/m^2]
e) Total forcing to atmosphere [x10^7 W]
Summer
DJF/JJA
Autumn
MAM/SON
Winter
JJA/DJF
Spring
SON/MAM
Seasons


U 10hPa, Arctic SI loss
Latitude
90N
60N
30N
J J A S O N D J F M A M J
U 10hPa, Antarctic SI loss
Latitude
30S
60S
90S
D J F M A M J J A S O N D
-1.8 -1.6 -1.4 -1.2 -1.0 -0.8 -0.6 -0.4 -0.2 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8


Summer (JJA)
Autumn (SON)
Winter (DJF)
Spring (MAM)
Sea ice loss (Arctic)
Net heat flux (Arctic)
Summer (DJF)
Autumn (MAM)
Winter (JJA)
Spring (SON)
Sea ice loss (Antarctic)
Net heat flux (Antarctic)
percent
W/m²
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
-55
-60
-65
-70
-75
-80
-85
-90
-95
135
120
105
90
75
60
45
30
15
0
-15
-30
-45
-60
-75
-90
-105
-120
-135


Arctic Precip. Change
July (JJA)
Autumn (SON)
Winter (DJF)
Spring (MAM)
mm/day
Antarctic Precip. Change
Summer (DJF)
Autumn (MAM)
Winter (JJA)
Spring (SON)
mm/day
-1 -0.8 -0.7 -0.6 -0.5 -0.4 -0.3 -0.2 -0.1 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 1