Atmospheric response to Arctic sea ice decline in the CNRM model: Initial results from PAMIP experiments

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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

- 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

=> motivation for the PAMIP experiments
Objective: create SST/SIC forcing fields corresponding to present-day and future warming of 2°C

1. Define the target temperature for Present Day and Future conditions.
   
   Present-day global mean SAT = average 1979-2008 from HadCRUT4 = 14.24°C  
   Pre-industrial global mean SAT = present-day SAT - global warming (0.57°C) = 13.67°C  
   Future global mean SAT = pre-industrial SAT + 2°C = 15.67°C

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: atmosphere only simulations
Control: pdSST-pdSIC
Perturbed experiments: pdSST-futArcSIC / pdSST-futOkhotskSIC / pdSST-futBKSeasSIC
The difference = response to future sea ice changes

Each experiment is run for 14 months starting in April
Constant forcing yr 2000
100 members (200 members in some cases)
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
Arctic sea ice forcing patterns

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). Weak cooling over Eurasia, not significant unlike Honda et al. (2009), Mori et al. (2014, 2019).
Controlling the False Discovery Rate (Wilks 2016)

Atmospheric circulation response

SLP response - FDR test

Z500 response - FDR test
Atmospheric circulation response

SLP response - 100 members

SLP response - 200 members
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)
- 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.
Troposphere/stratosphere interactions?

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

Positive anomaly: negative NAM / weakening of polar vortex

1st year

December: peak of upward propagation of atmospheric dilatation from the surface to the stratosphere, 1 month after the maximum surface warming.

Downward propagation of the stratospheric anomaly back to the troposphere and the surface in winter (peak in February) → Upward and downward propagation of planetary-scale waves in response to Arctic sea ice loss can affect the circulation and weaken the westerlies (not shown) (Eliassen-Palm flux diagnostic, S. Chripko et al. in prep).

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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

JAS 100 members

OND

JFM

200 members + FDR test

JAS

OND

JFM
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- 200 members
Arctic sea ice forcing for the regional experiments

Sea ice anomaly imposed in the Barents-Kara Sea only

Sea ice anomaly imposed in the Sea of Okhotsk only
Response to regional forcing for zonal mean zonal winds

All
OND

Okhotsk
OND

Barents Kara Sea
OND

JFM

JFM

JFM

1
10
100
1000
30N 60N
30N 60N
30N 60N

1
10
100
1000
30N 60N
30N 60N
30N 60N

1
10
100
1000
30N 60N
30N 60N
30N 60N

-1 -0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8 1

(m/s)
The PAMIP atmosphere-only simulations based on CNRM-CM6-1 simulate a significant atmospheric response to the Arctic sea ice decline associated to a global-mean 2° warming:

- The near surface warming (polar amplification) is largest in OND
- Significant changes in the atmospheric circulation are found 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
- A weakening of the polar vortex in OND (mainly December) and a strengthening in JFM (significant only in March)

The zonal mean zonal wind response to regional sea ice forcing shows that:

- The contribution of the Barents/Kara Sea is dominant in OND.
- In JFM both Atlantic and Pacific sea ice anomalies contribute to the total response: same sign in the troposphere (southward shift of the jet), opposite sign on the stratosphere.
The atmospheric response over land is small and hardly significant, especially when accounting for the FDR

100 members are not enough to get a significant response for the midlatitude winds and in the mid/upper stratosphere
=> the signal we are looking at is small!

The use of seasonal means to show the stratospheric response to Arctic sea ice decline can be misleading as there is a large month-to-month variability in the response.

The response to sea ice changes is small compared to that to future SST warming (opposite in the troposphere, same sign in the stratosphere)

The lack of ocean-atmosphere coupling might affect the results shown here
Thanks for your attention
additional slides
Near surface response

Surface air temperature response

100 members

200 members
Influence of sea ice loss on winter cooling

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

PAMIP 2C warming

- 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.

Albedo summer melt

Chripko et al. in prep
Vertical structure of the response: zonal circulation

Monthly evolution of the response- 100 members
Response to fut SST

zg 60-90 N response
Response to futSSTpdSIC

futArcSICpdSST

piSSTpiSIC

futSSTpdSIC

(OND)

(m/s)
Response to regional forcing

Barents-Kara

surface air temperature

Okhotsk
Response to regional forcing

Barents-Kara slp

(hPa)

2
1.6
1.2
0.8
0.4
0
-0.4
-0.8
-1.2
-1.6
-2
ta response pdSST-futArcSIC

(degC)

-3  -2.5  -2   -1.5  -1   -0.5  0    0.5   1    1.5   2    2.5   3