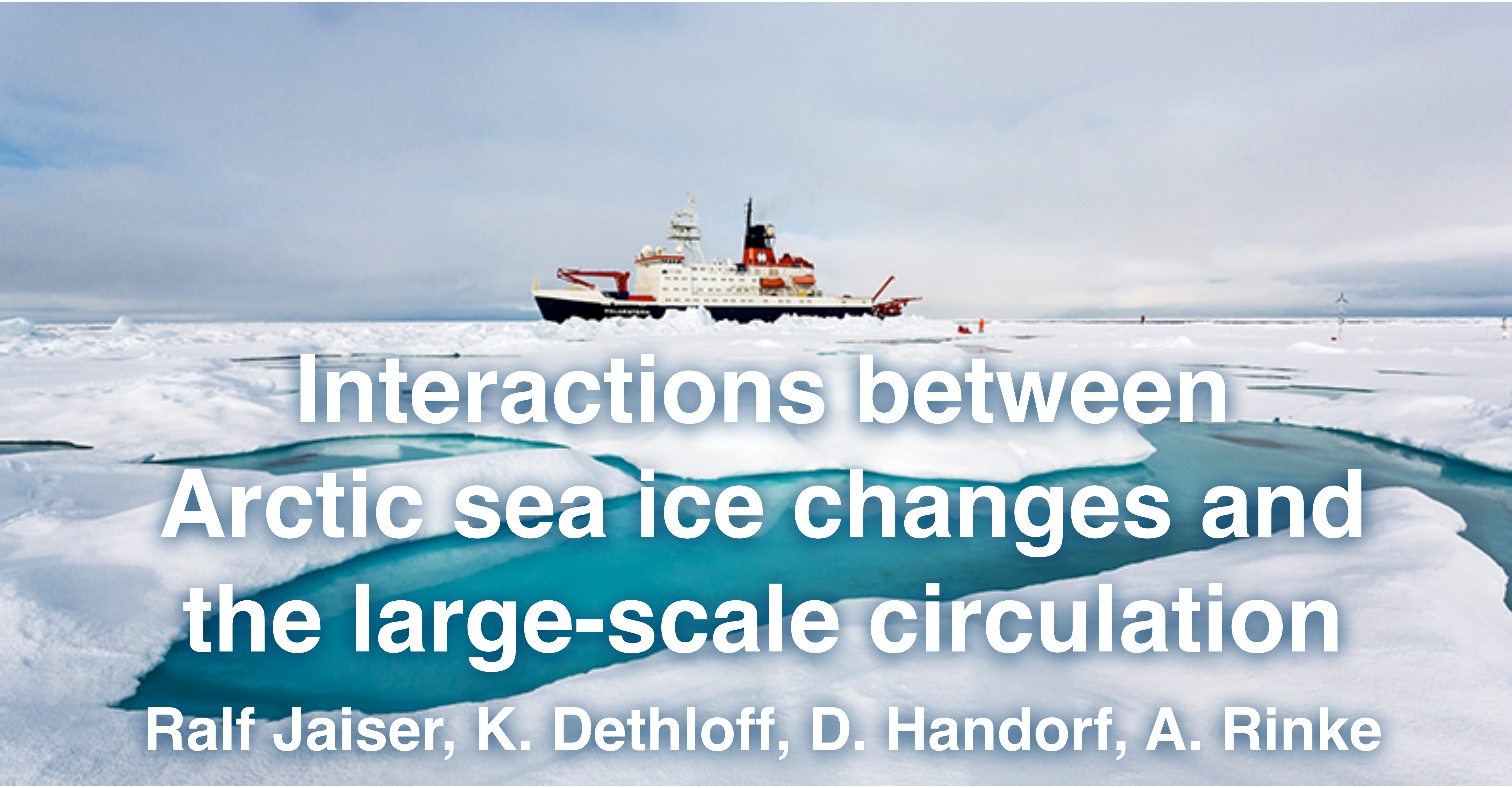
ALFRED-WEGENER-INSTITUT
HELMHOLTZ-ZENTRUM FÜR POLAR-
UND MEERESFORSCHUNG



Interactions between Arctic sea ice changes and the large-scale circulation

Ralf Jaiser, K. Dethloff, D. Handorf, A. Rinke

(Picture: S. Hendricks/AWI)

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Polar amplifiers of climate change

Stratospheric Ozone

Aerosols & Black Carbon

Clouds & Water Vapor

Carbon & Methane

Ice & Snow albedo

Cascade of atmospheric processes

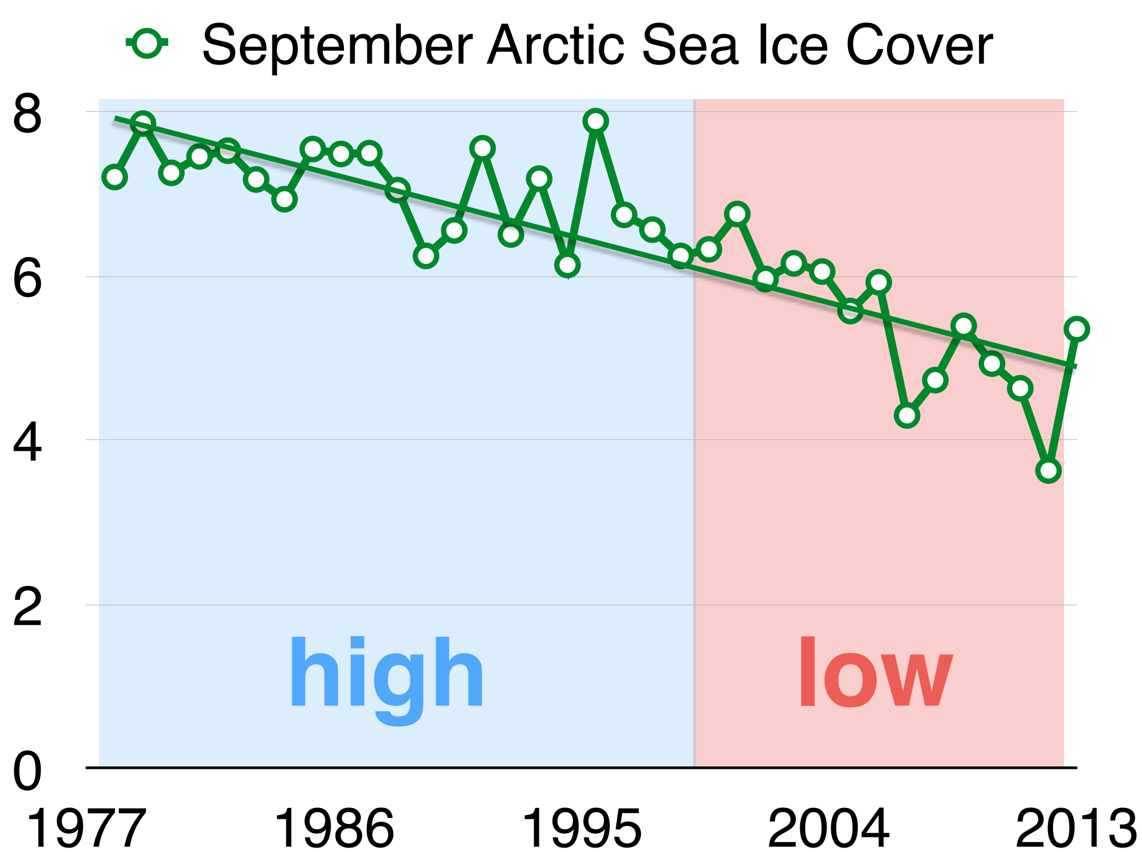
Sub-grid scale processes ➔ boundary layer turbulence

➔ synoptic cyclones ➔ planetary waves ➔ teleconnections

Nonlinear system with internally generated climate variability

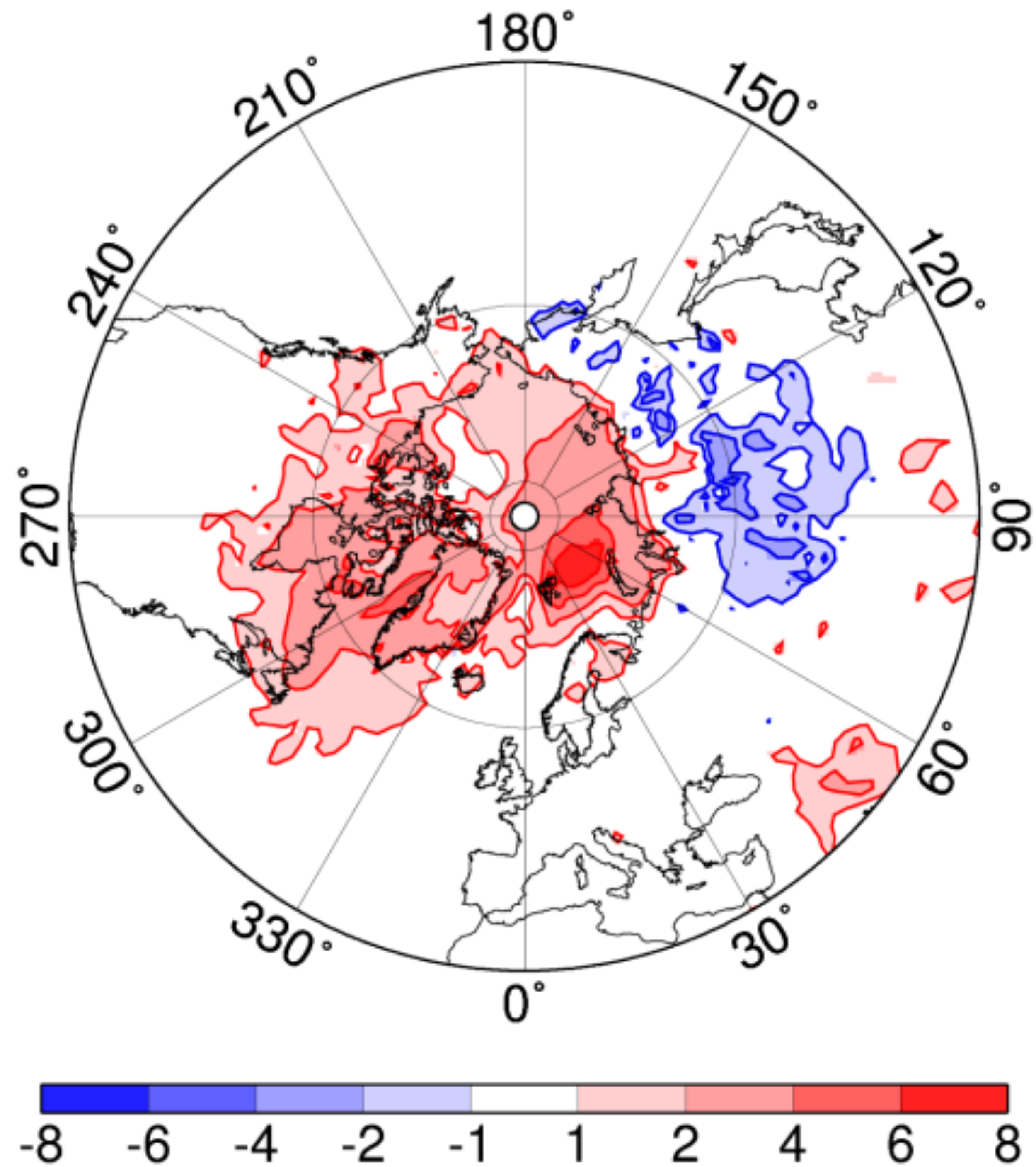
Changed heat, momentum, humidity and tracer transports between mid-latitudes and the Arctic

High and low phases of Arctic sea ice extent



- Arctic sea ice retreat
- Warming Arctic Ocean
- Enhanced October snow cover
- Stronger Siberian high
- Negative AO/NAO phases
- Colder mid-latitudes

➥Arctic Paradox



Winter (DJF) 2m temperature differences (K) low (1979-2000) minus high (2001-2012)

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Atmospheric changes in the Siberian Domain

Reduced sea ice in August/September

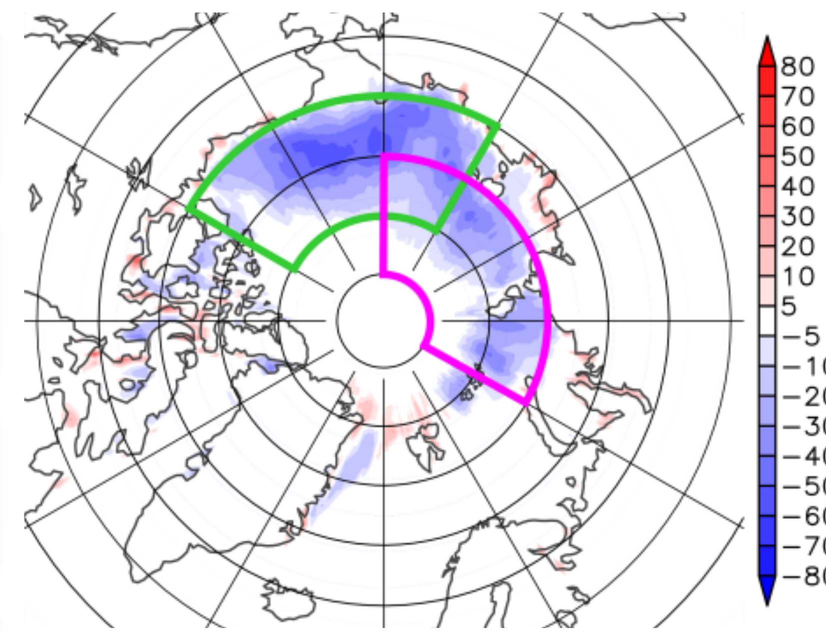
Additional heat stored in ocean

Warmer surface temperatures in following seasons

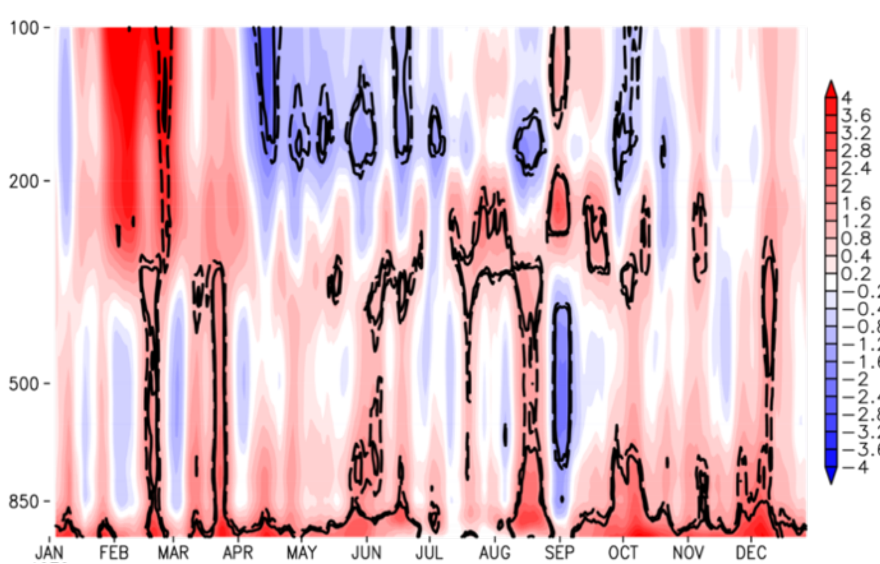
Reduced atmospheric vertical stability

Amplified baroclinic weather systems in autumn

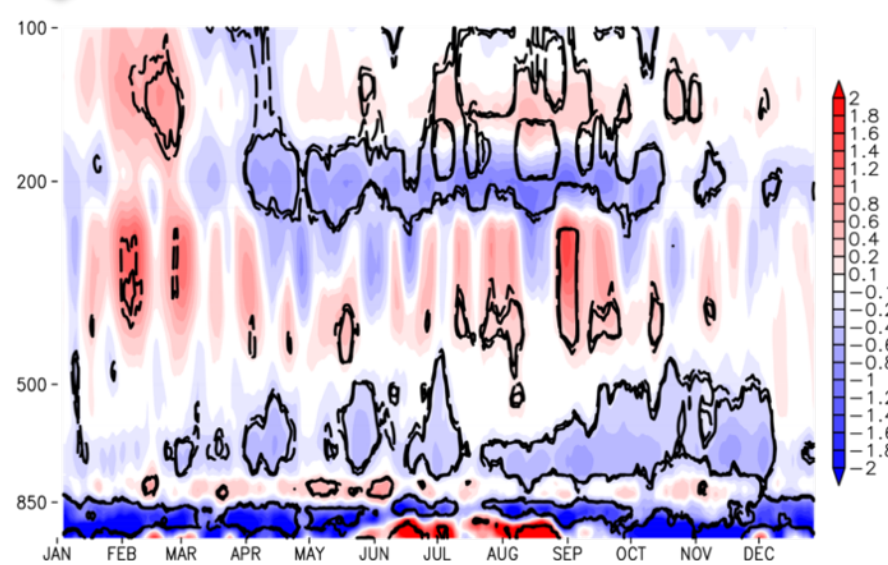
Difference of sea ice concentration low-high



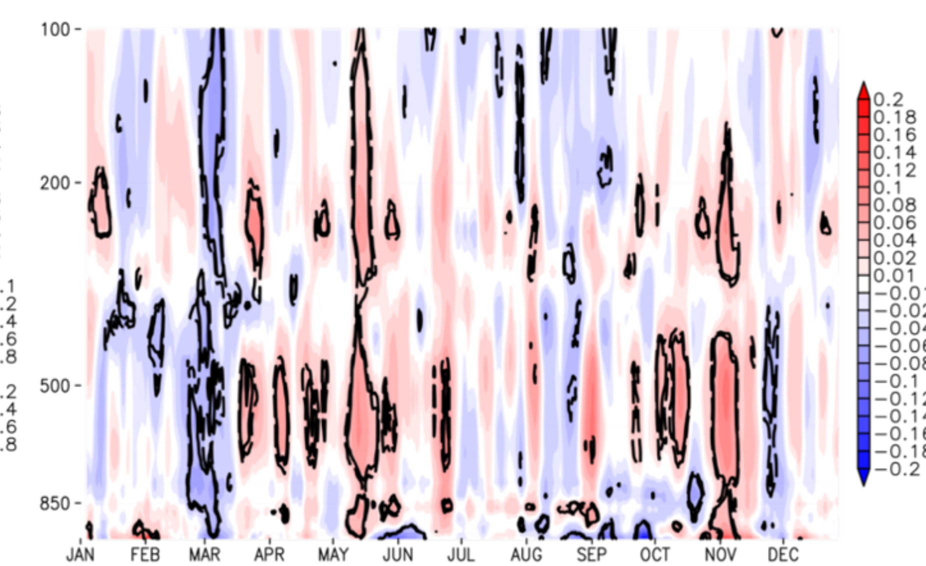
Siberian Domain in magenta



Higher
Temperatures (K)



Lower
vertical stability (10^{-3} Km^{-1})



Enhanced
Eady Growth Rate (day^{-1})

Atmospheric changes initiated by low sea ice conditions

Reduced sea ice in August/September

Additional heat stored in ocean

Warmer surface temperatures in following seasons

Reduced atmospheric vertical stability

Amplified baroclinic weather systems in autumn

Impact on planetary wave propagation in winter

Weaker stratospheric Polar Vortex

Negative NAO/AO phases

Higher probability of cold winters in Eurasia

Possible feedback

Baroclinic Arctic Response

Large-scale Barotropic Response

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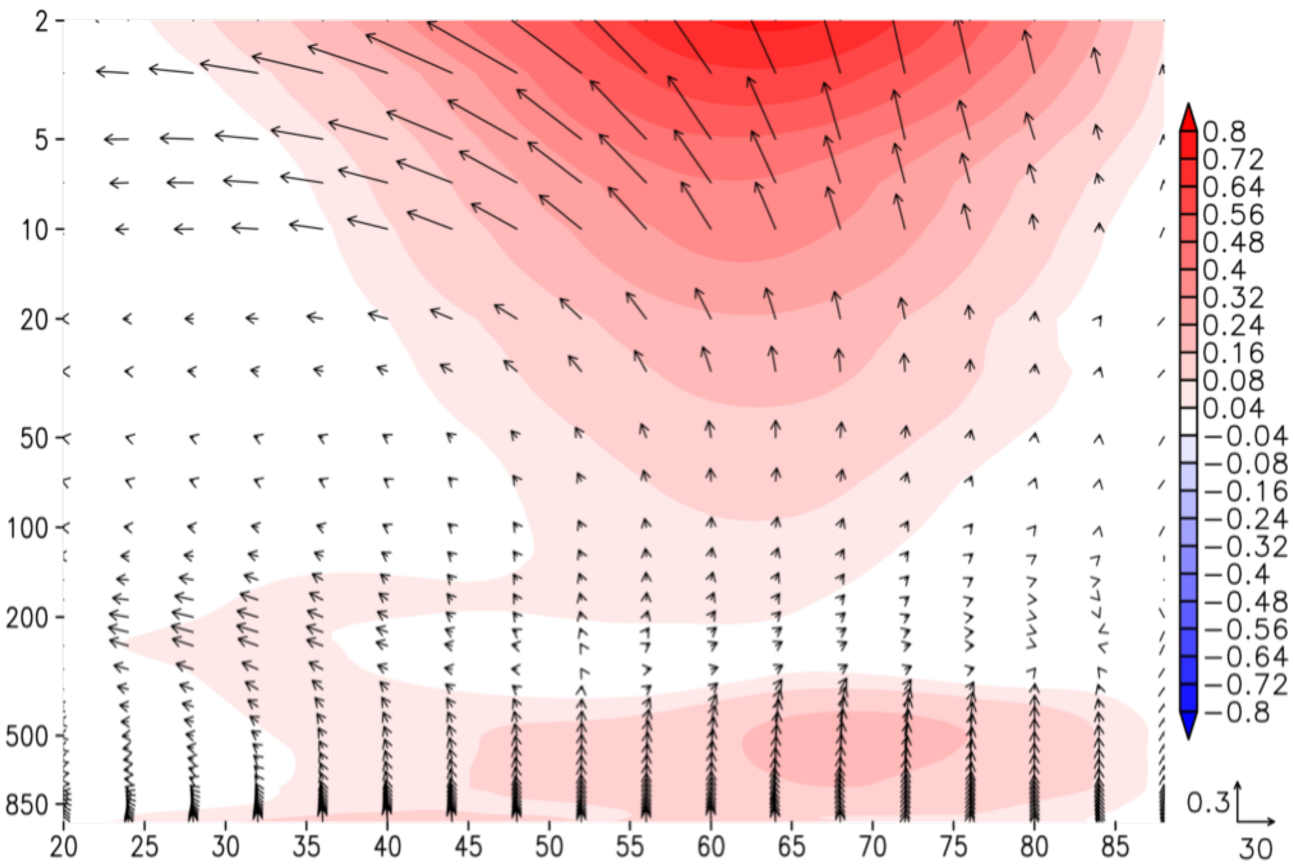
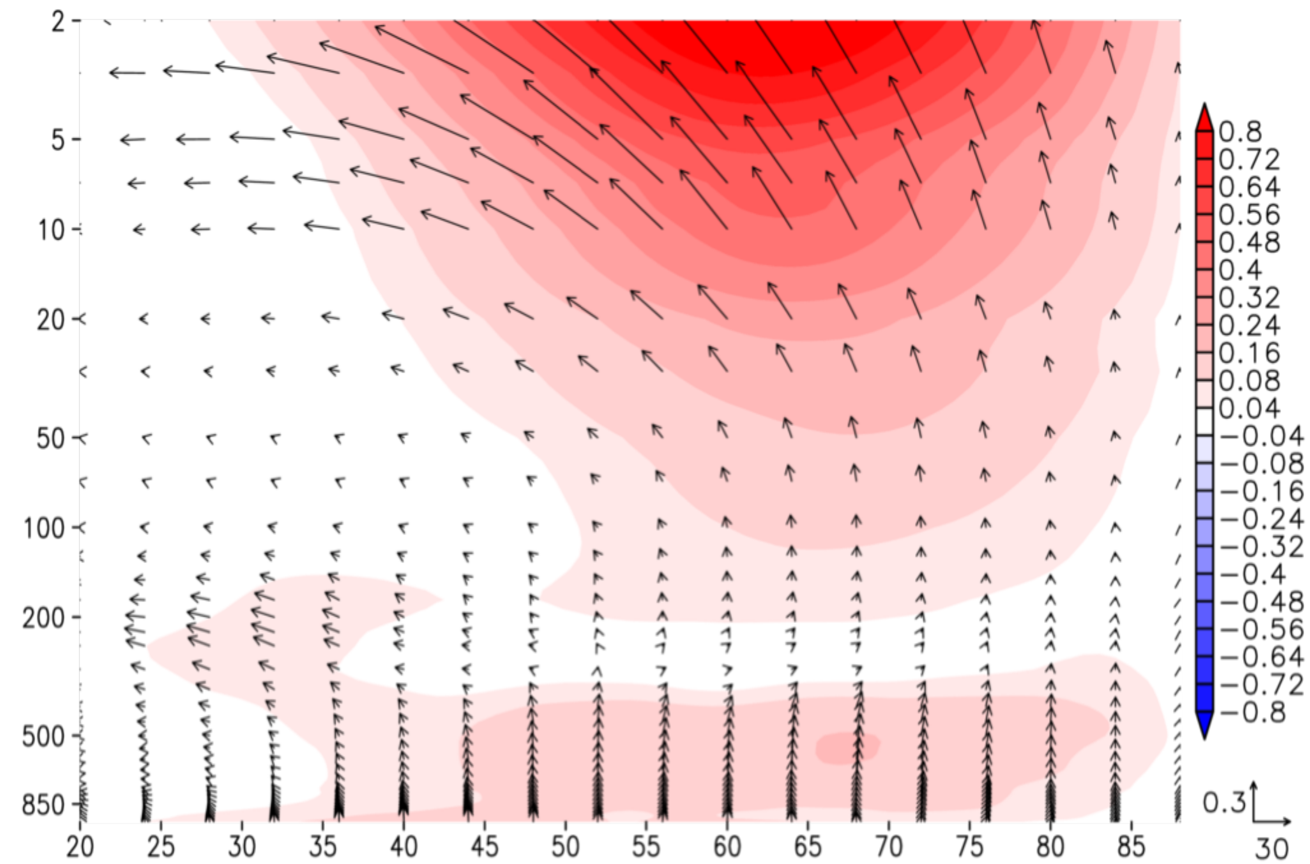
December EP-Flux changes

10-90 days filtered vertical component of Eliassen-Palm flux (m^2s^{-2}), zonal mean



High ice conditions 1979-2000



Low ice conditions 2001-2012

Localized Eliassen-Palm fluxes (EP-Flux) describe interaction between time averaged flow and the transient eddies

Vector points in direction of wave propagation, shading shows vertical EP-Flux

$$\frac{\mathrm{D}\overline{u}}{\mathrm{D}t} - fv^* = \nabla \cdot \vec{E}_u \qquad \vec{E}_u = \left[\frac{1}{2}\left(\overline{v'^2} - \overline{u'^2}\right), -\overline{u'v'}, f\frac{\overline{v'T'}}{S}\right]$$

Jaiser et al. Tellus, 2013

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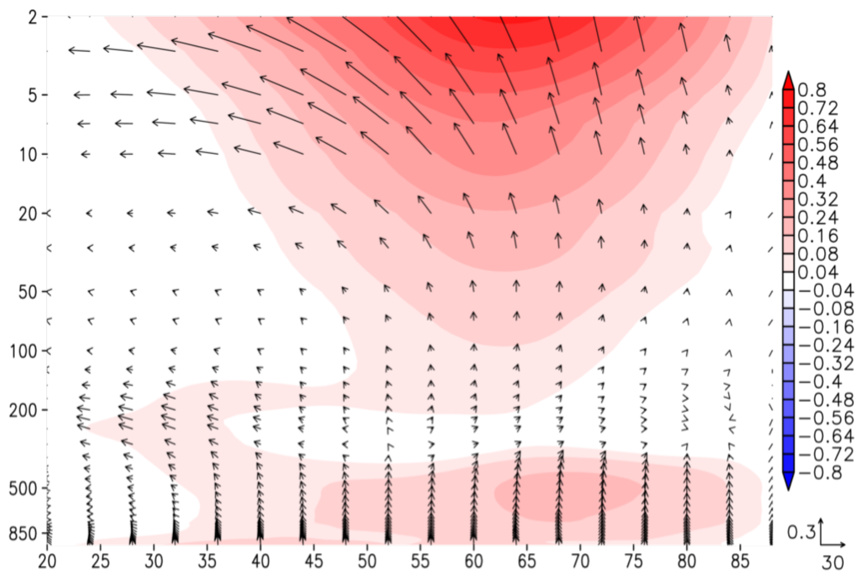
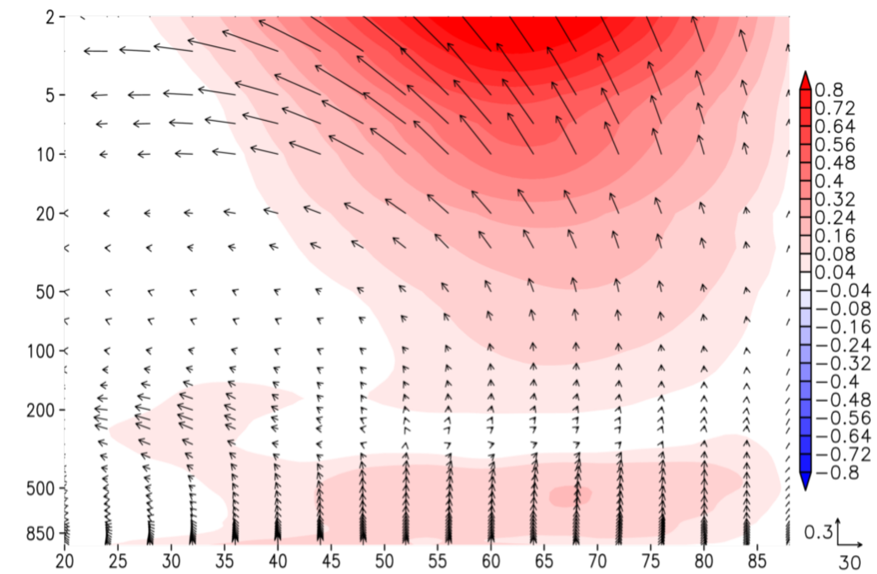
December EP-Flux changes

10-90 days filtered vertical component of Eliassen-Palm flux (m^2s^{-2}), zonal mean

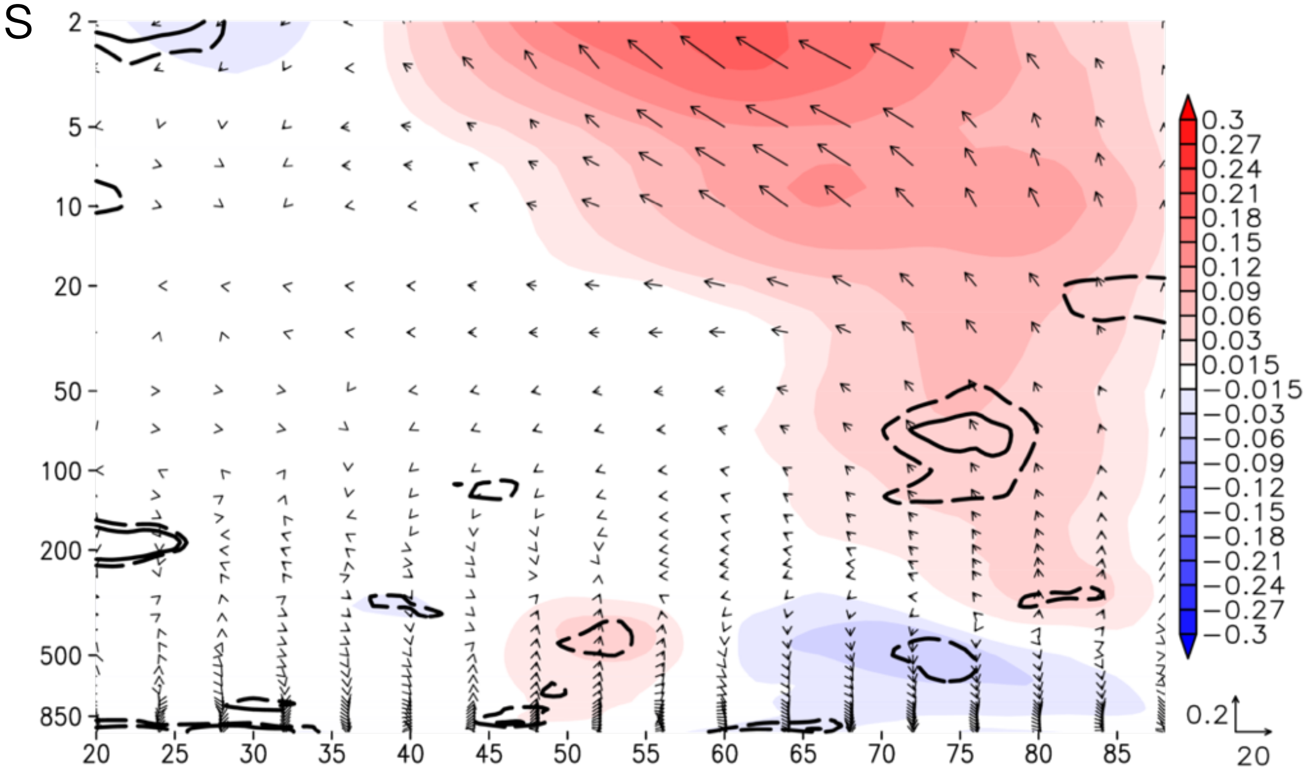


High ice conditions



Low ice conditions

Difference



- Intensified vertical EP-Flux in Arctic regions for low ice conditions
- Reaching from upper troposphere to stratosphere
- Significant with 90 % at tropopause level (black dashed lines)

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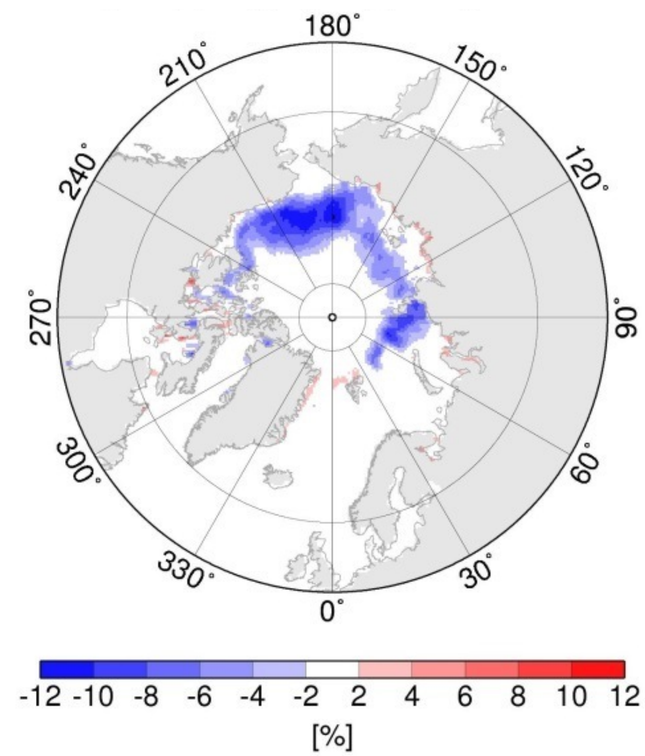
Large-scale circulation changes

Maximum Covariance Analysis (MCA):

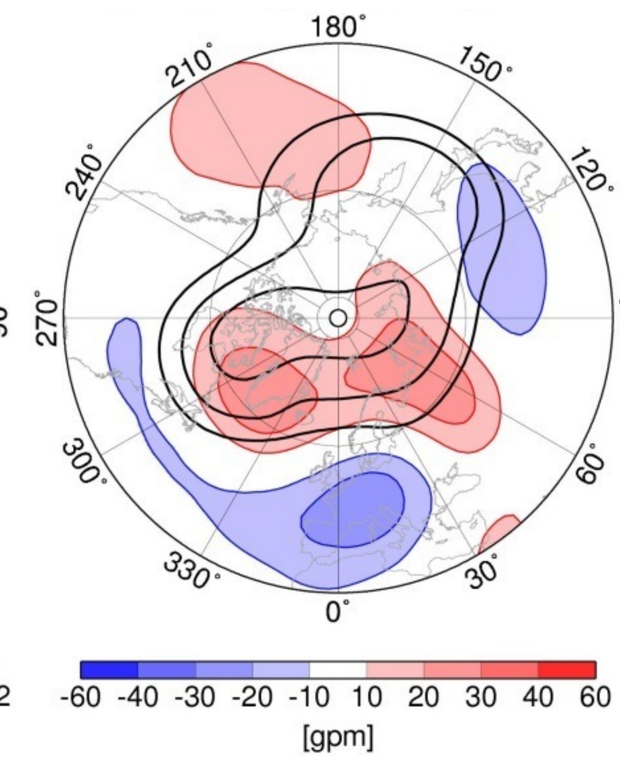
- Detect coupled patterns between climate fields
- Maximize covariance of time series associated with each pattern
- Identification of atmospheric circulation anomalies covarying with sea ice anomalies
- Decomposition of covariance matrix of data fields: Singular Value Decomposition

Variables used:

- Late summer (AS) sea ice concentration (HadISST1 data, 1979-2012)
- Mean sea level pressure & geopotential height fields in winter DJF (ERA-Interim, 1979-2012)



Pattern of sea ice concentration in AS



Pattern of associated GPH 500hPa in following winter

Jaiser et al. Tellus 2012, 2013

Large-scale circulation changes

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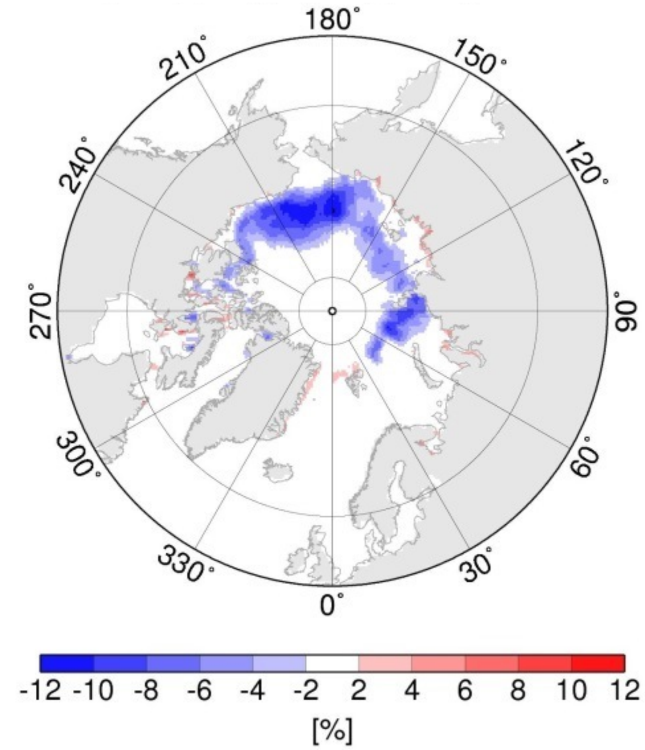
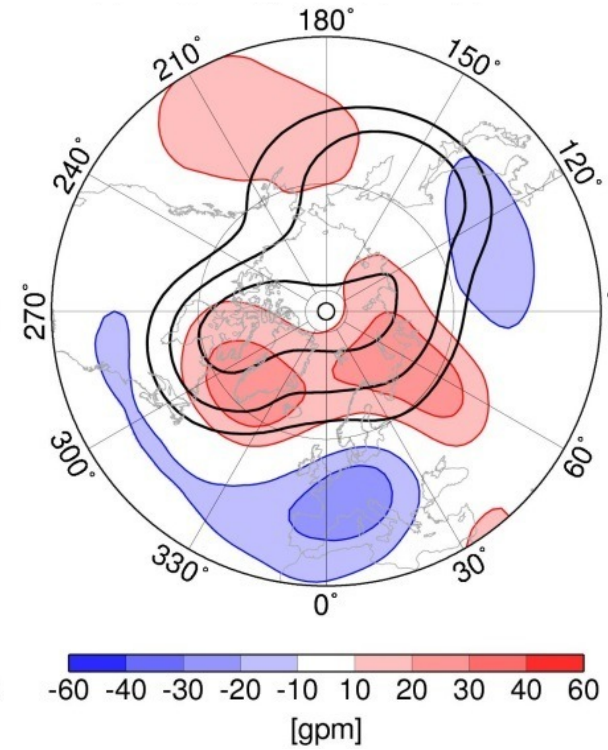
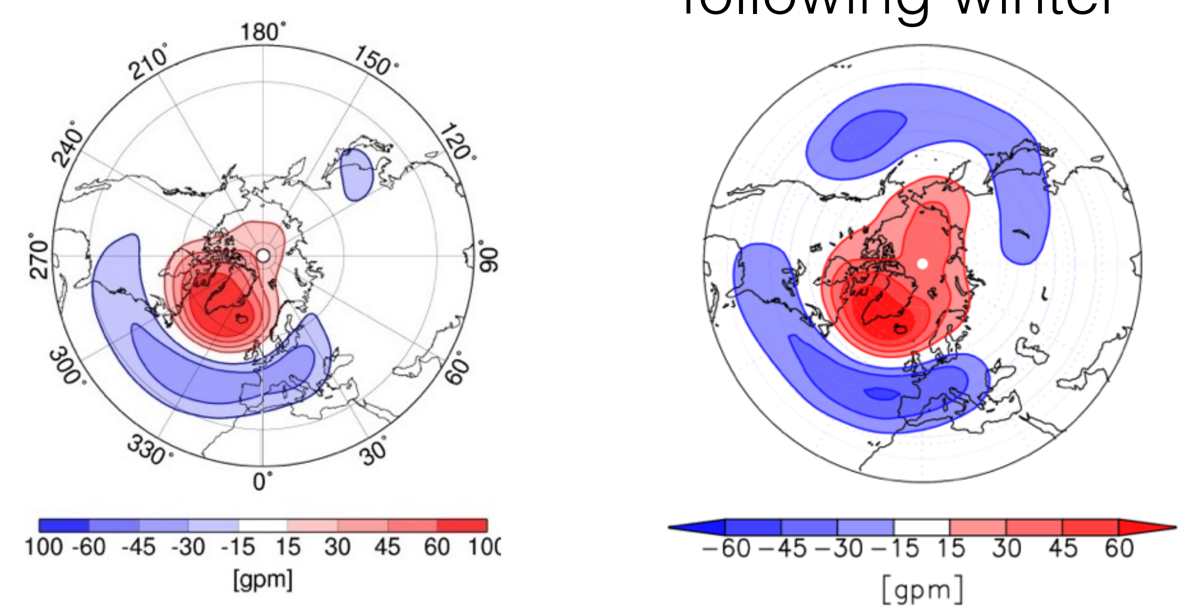


Pattern of sea ice concentration in AS



Pattern of associated GPH 500hPa in following winter



NAO- & AO-pattern in 500hPa, negative Phase

- ▸ Shift to negative NAO pattern
- ▸ Higher probability of cold winters in Europe and western Asia

Jaiser et al. Tellus 2012, 2013

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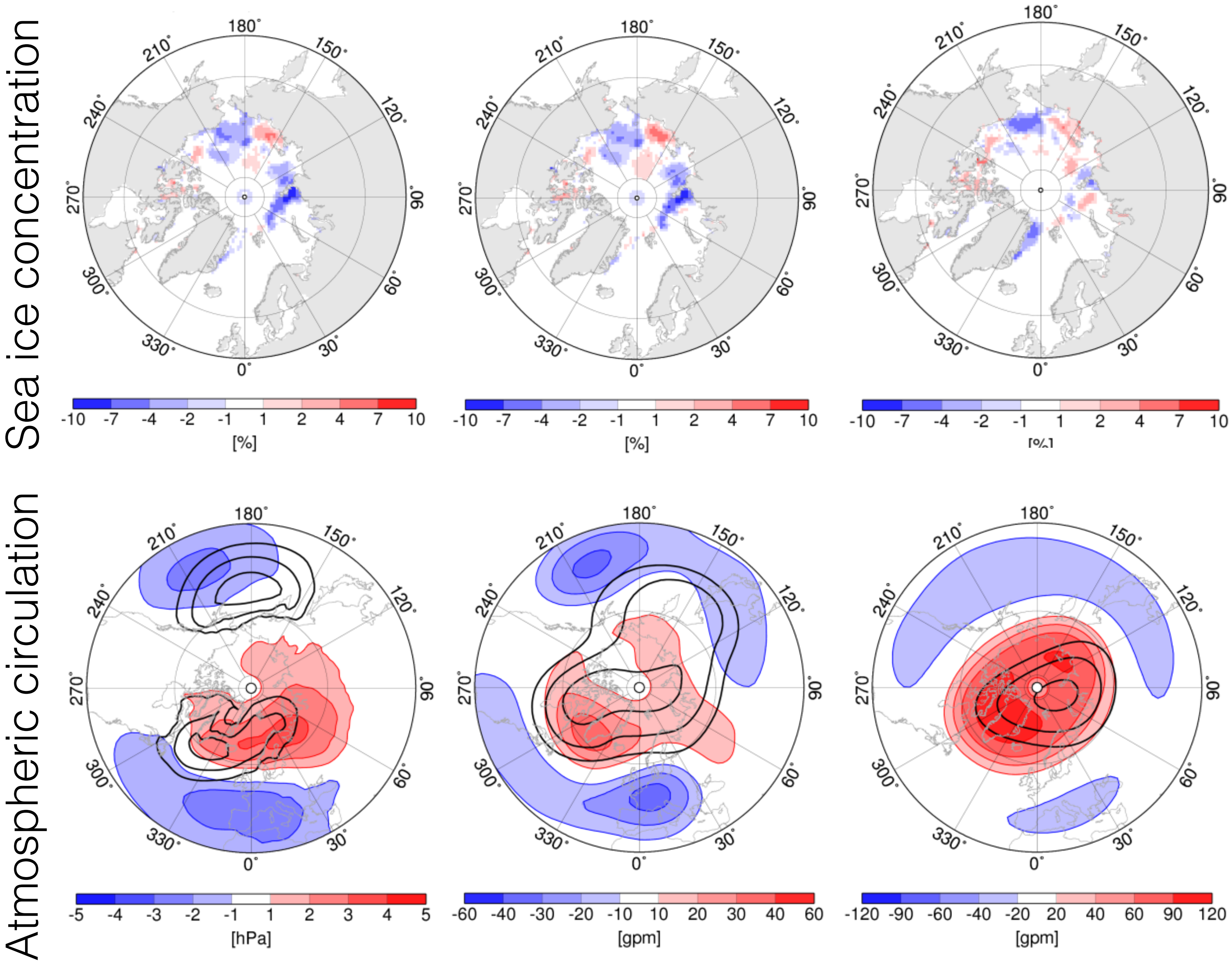
Large-scale circulation changes — Sea ice, MCA1

First pair of patterns in three different heights, 1979-2012, detrended



MSLP
44% expl. covar.

GPH 500hPa
32% expl. covar.

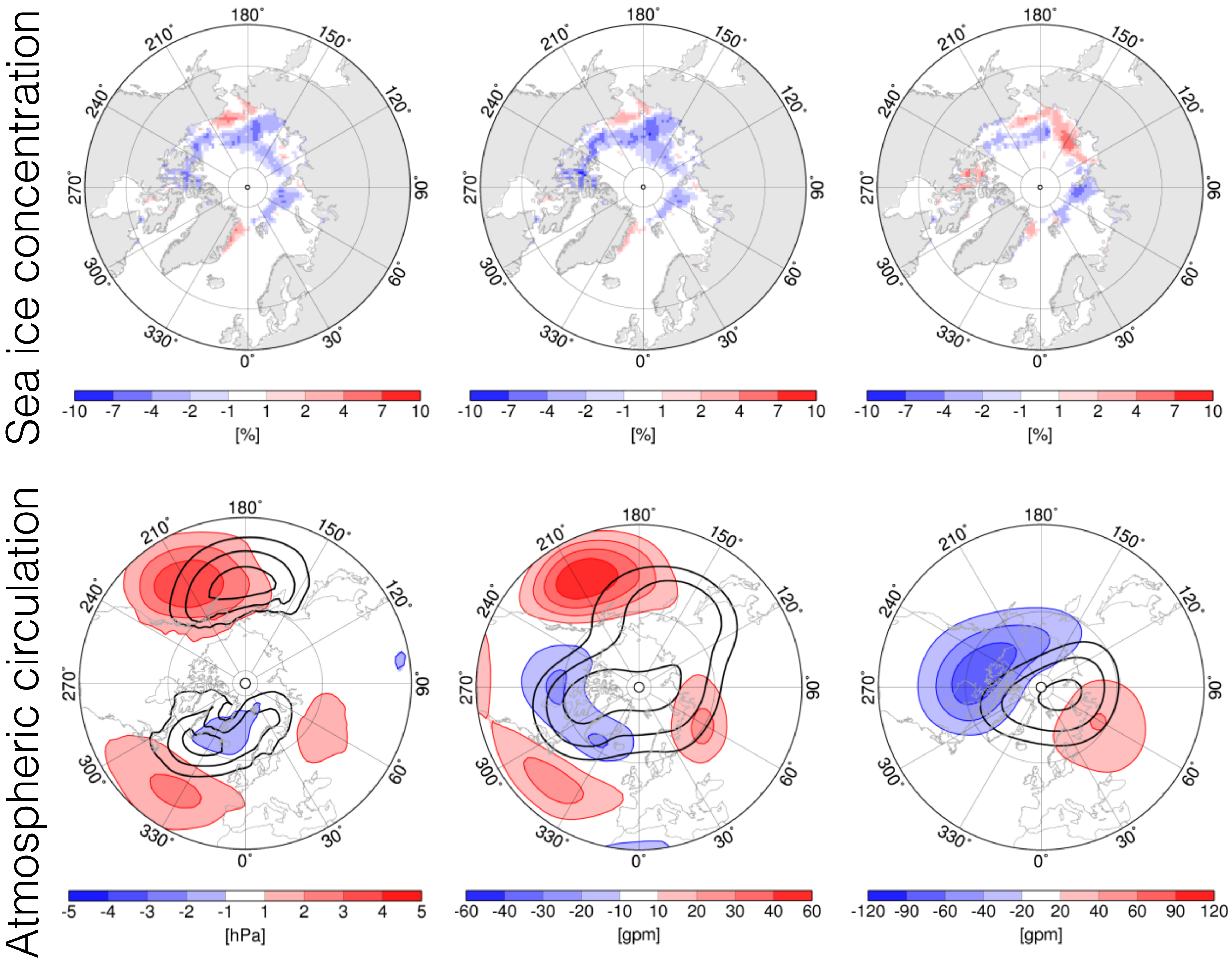
GPH 50hPa
56% expl. covar.

- Sea ice pattern is similar for MCA analysis with circulation patterns in different heights

- Hints on a barotropic pattern in troposphere and stratosphere
- AO-like in the troposphere
- Weakened stratospheric polar vortex

Large-scale circulation changes — Sea ice, MCA2

Second pair of patterns in three different heights, 1979-2012, detrended



MSLP 18% expl. covar. | GPH 500hPa 21% expl. covar. | GPH 50hPa 12% expl. covar.

- Sea ice pattern is similar for MCA analysis with circulation patterns in different heights

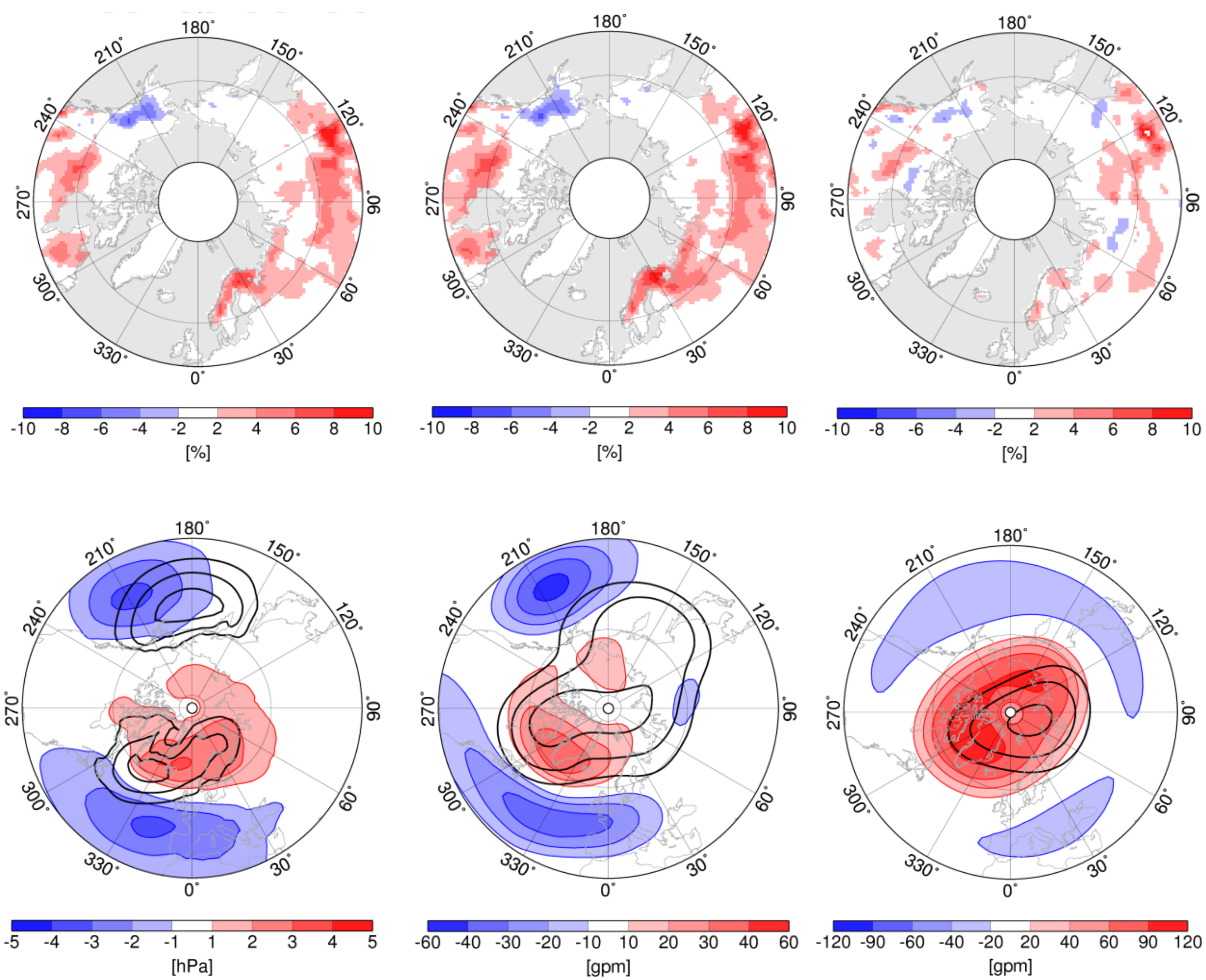
- Hints on a barotropic pattern in troposphere and stratosphere
- Wavy response in troposphere (Pacific)
- Shifted stratospheric polar vortex

Large-scale circulation changes — Snow

First pair of patterns in three different heights, 1979-2012, detrended

October snow cover

Atmospheric circulation



MSLP
45% expl. covar.

GPH 500hPa
39% expl. covar.

GPH 50hPa
42% expl. covar.

- October snow cover pattern is similar for MCA analysis with circulation patterns in different heights

- Hints on a barotropic pattern in troposphere and stratosphere
- AO-like in the troposphere
- Weakened stratospheric polar vortex
- Mechanism by Cohen et al. (2007)

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Summary — ERA-Interim Reanalysis

Atmospheric circulation changes initiated by low sea ice conditions

- Higher temperatures in years with lower sea ice concentration
  - Resulting decreased vertical stability and higher Eady Growth Rate
- Large-scale circulation anomalies coupled with sea ice concentration changes and snow cover changes
  - Barotropic from SLP to 10 hPa GPH
- Intensification of the vertical planetary scale EP flux

Are global and regional climate models able to reproduce this?

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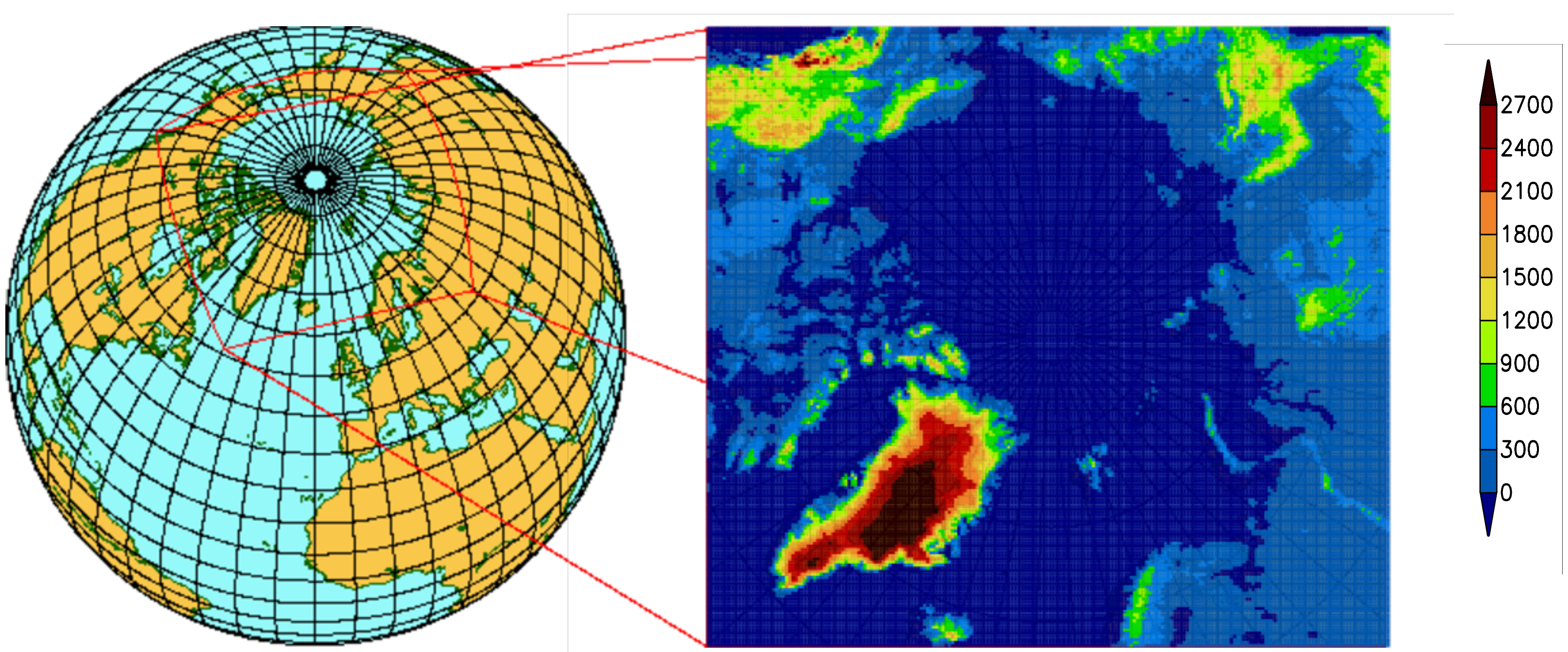
Global and regional climate models

Global atmospheric model ECHAM6 (MPI-ESM-MR)

- Atmosphere only runs (AMIP) from CMIP5 archive
- T63 spectral resolution (≈2°×2° latitude/longitude grid)
- 96 vertical levels up to 0.01 hPa
- 1979-2008, 3 ensemble members

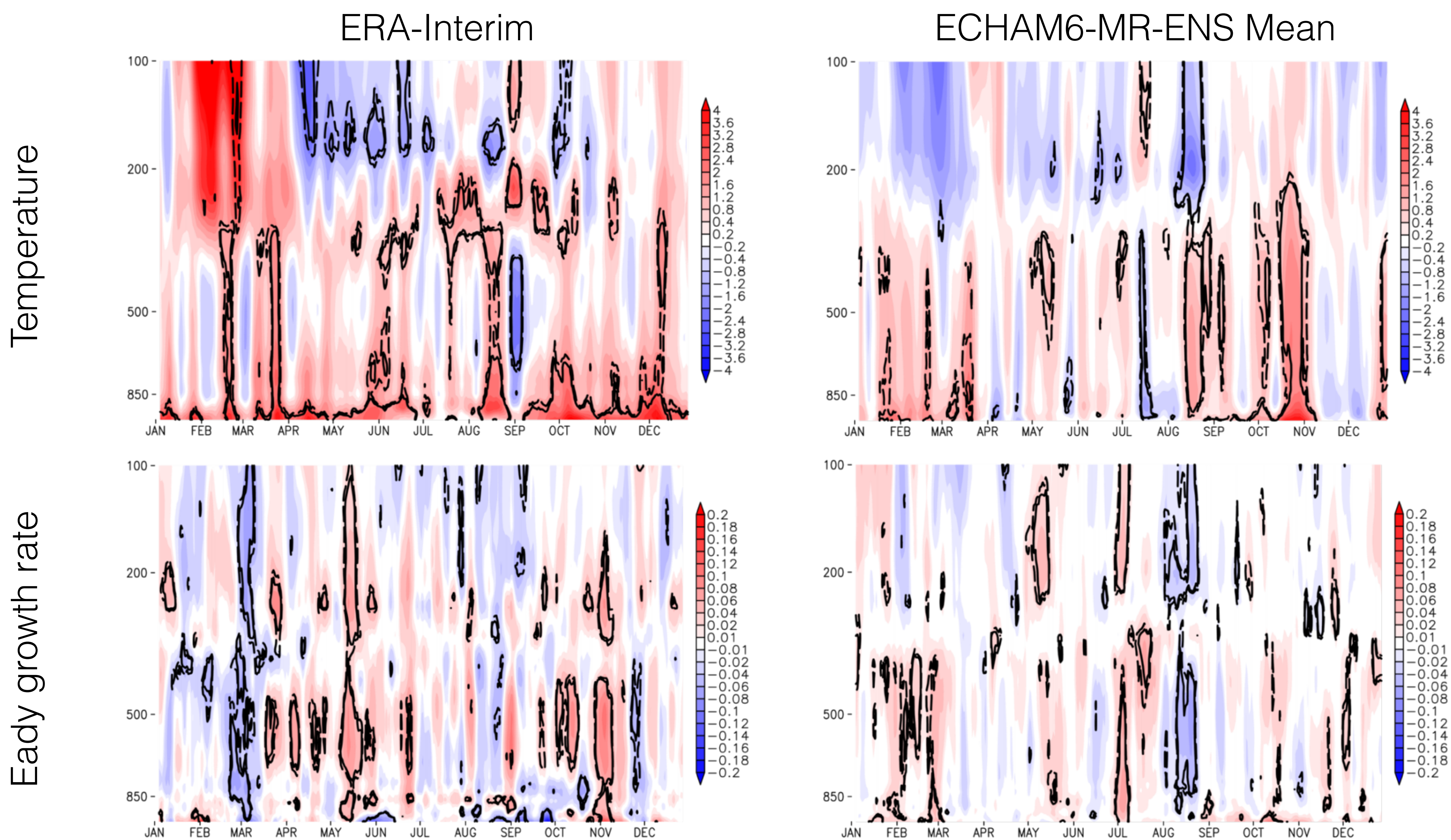
Regional Atmosphere-Ocean-Sea Ice Model HIRHAM-NAOSIM

- High horizontal resolution of regional topographic structures at the surface
- Improved simulation of hydro-dynamical instabilities and baroclinic cyclones
- **HIRHAM**: resolution 0.50°, 19 vertical levels
- **NAOSIM**: resolution 0.25°, 30 vertical levels
- Improvements in the sea-ice schemes
- 1948-2008, 7 ensemble members



Simulated atmospheric changes — Temperature

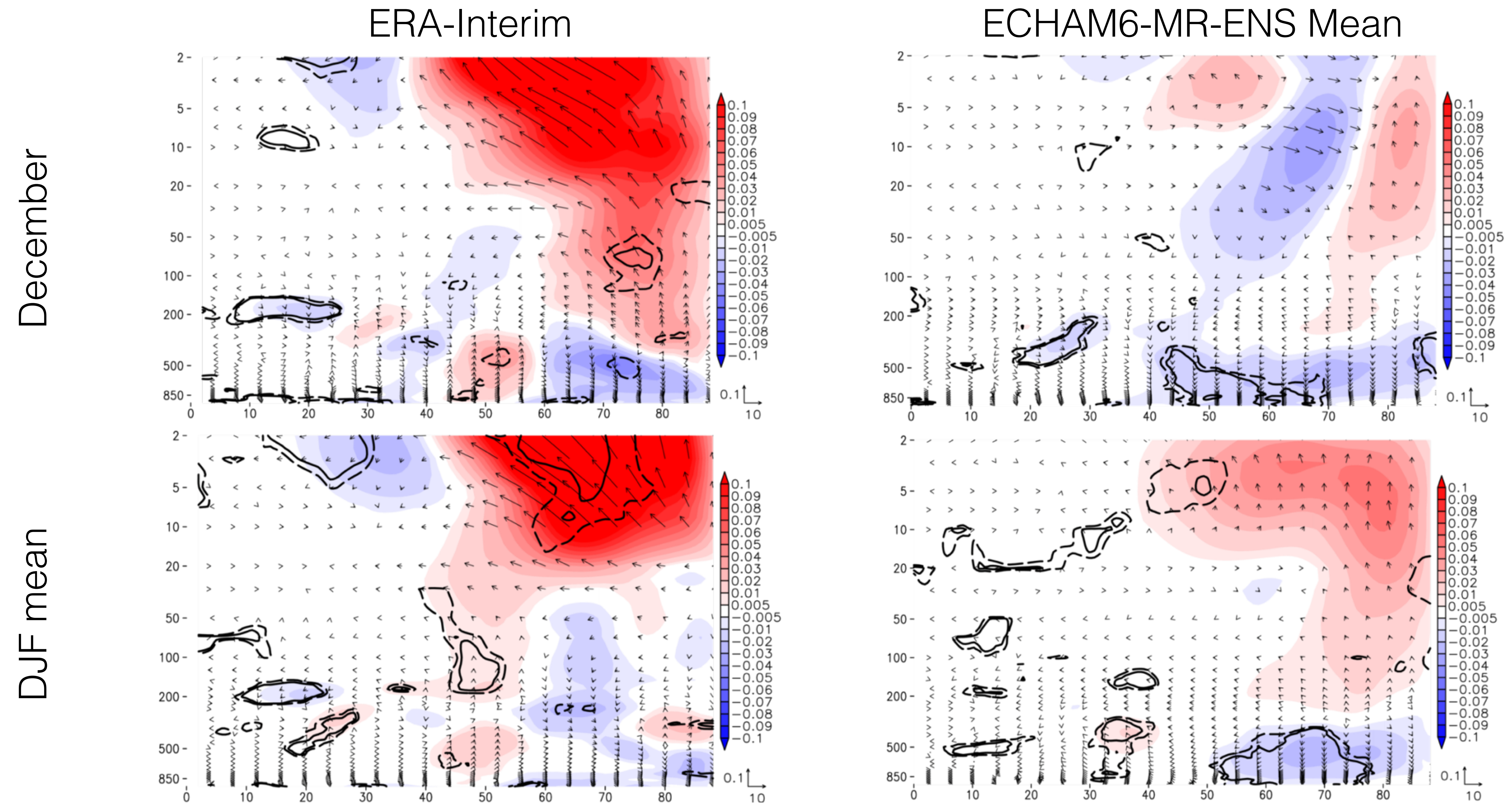
Difference low minus high ice over Siberian domain



- Near surface temperature increase is missing
- Leads to missing effect on vertical stability and Eady Growth Rate

Simulated atmospheric changes — EP-Flux

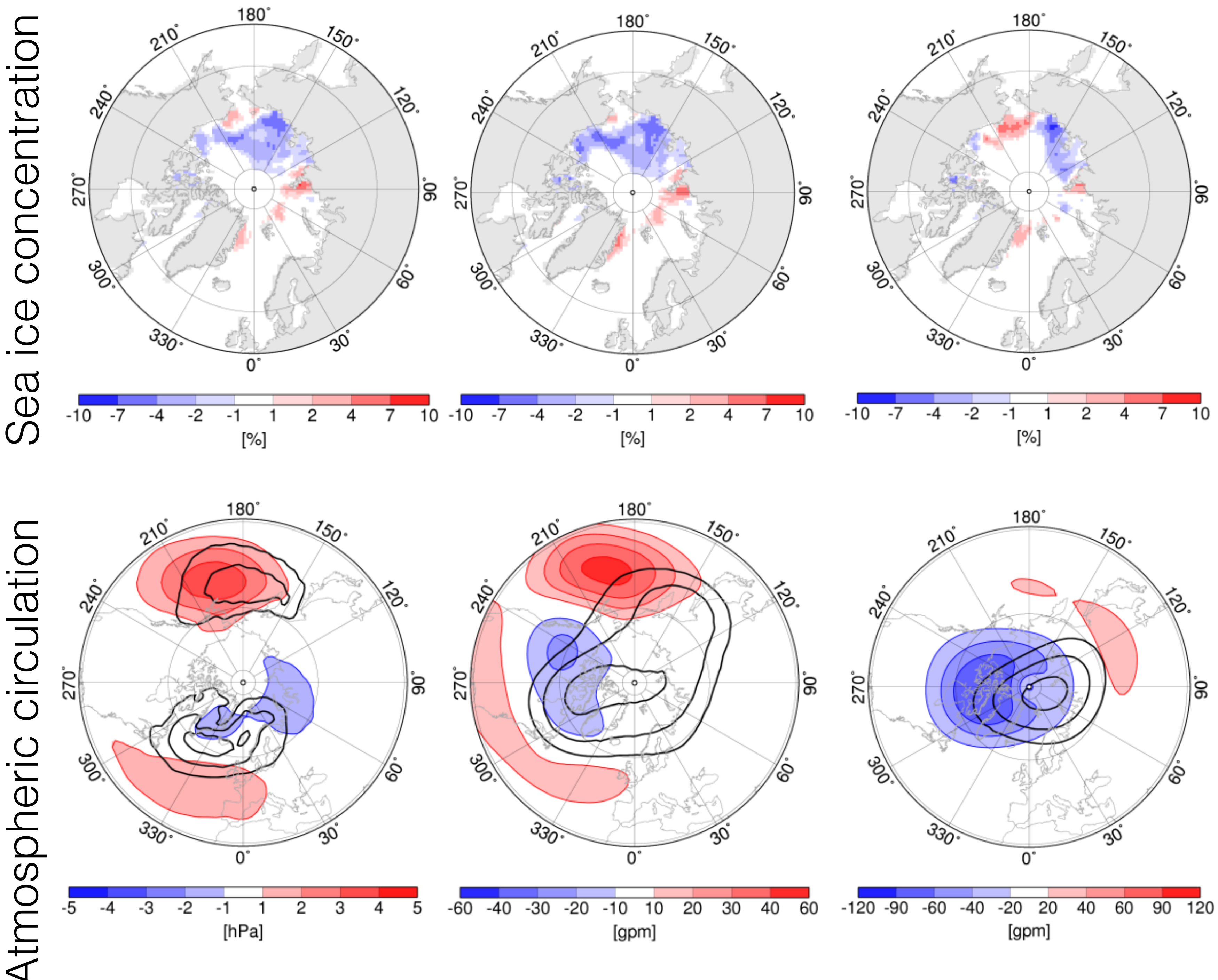
Difference low-high ice — 10-90 days filtered vert. comp. of EP-Flux, zonal mean



- Stronger upward fluxes evident in ERA-Interim
- Troposphere-Stratosphere coupling not reproduced
- Temporal behaviour not reproduced

Simulated large-scale circulation changes

First pair of patterns in different heights, ECHAM6-MR 1979-2008, detrended



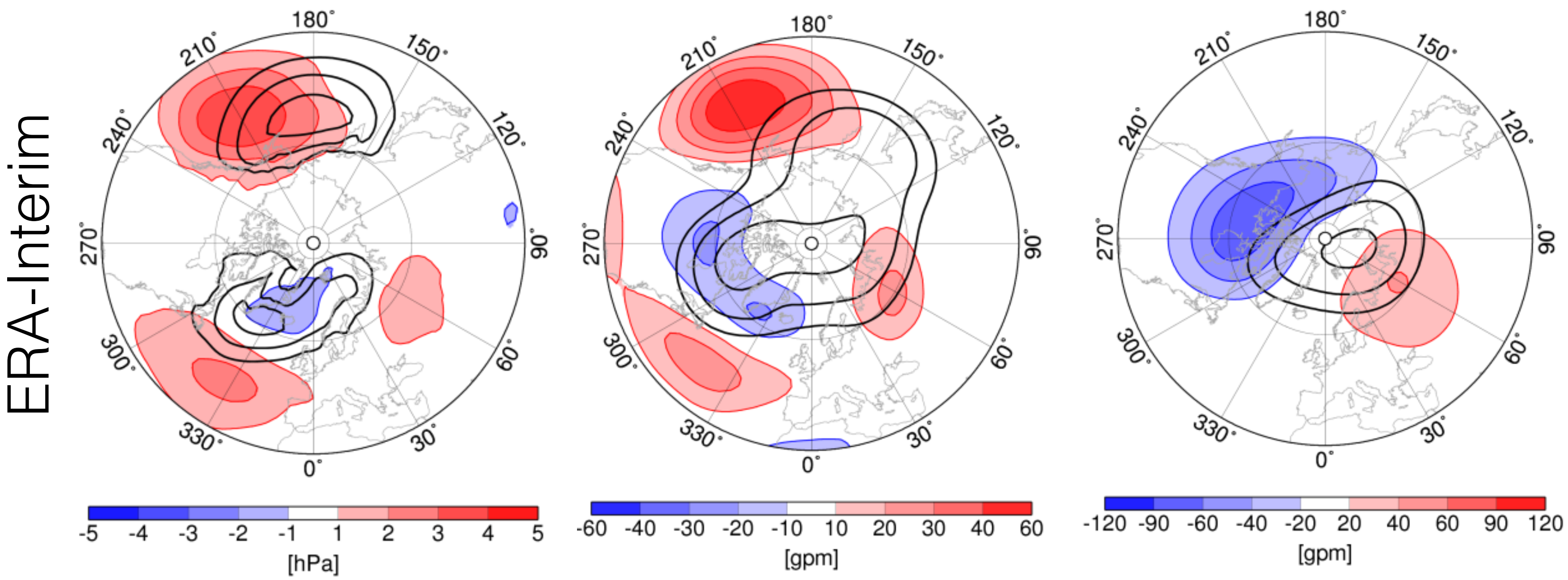
MSLP
38% expl. covar.

GPH 500hPa
37% expl. covar.

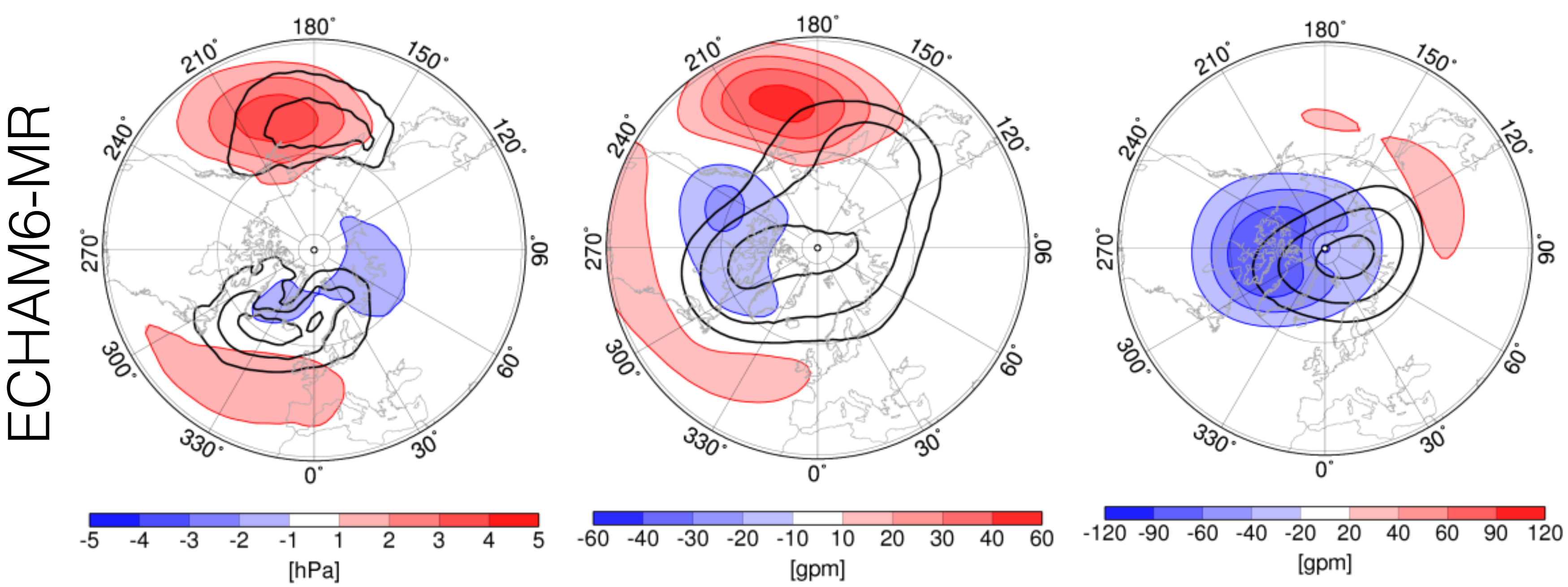
GPH 50hPa
51% expl. covar.

- Coupled sea ice pattern show a general trend of sea ice decline
- Hints on a barotropic pattern in troposphere and stratosphere
- Negative AO-like response missing

Simulated large-scale circulation changes



MSLP	GPH 500hPa	GPH 50hPa
18% expl. covar.	21% expl. covar.	12% expl. covar.



MSLP	GPH 500hPa	GPH 50hPa
38% expl. covar.	37% expl. covar.	51% expl. covar.

MCA 2 (ERA-Interim)

- negative AO-like response missing (MCA 1 in ERA-Interim)
- Stratospheric pattern different

MCA 1 (ECHAM6-MR)

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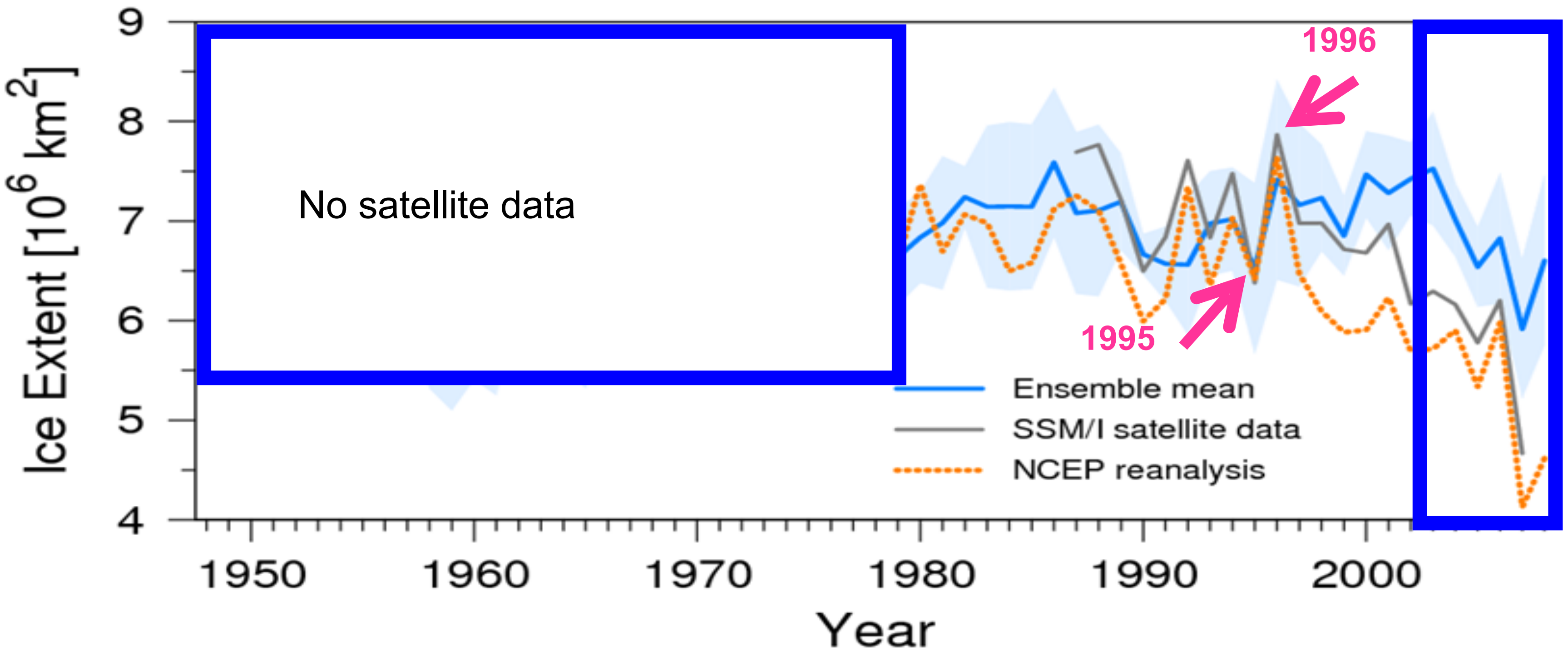
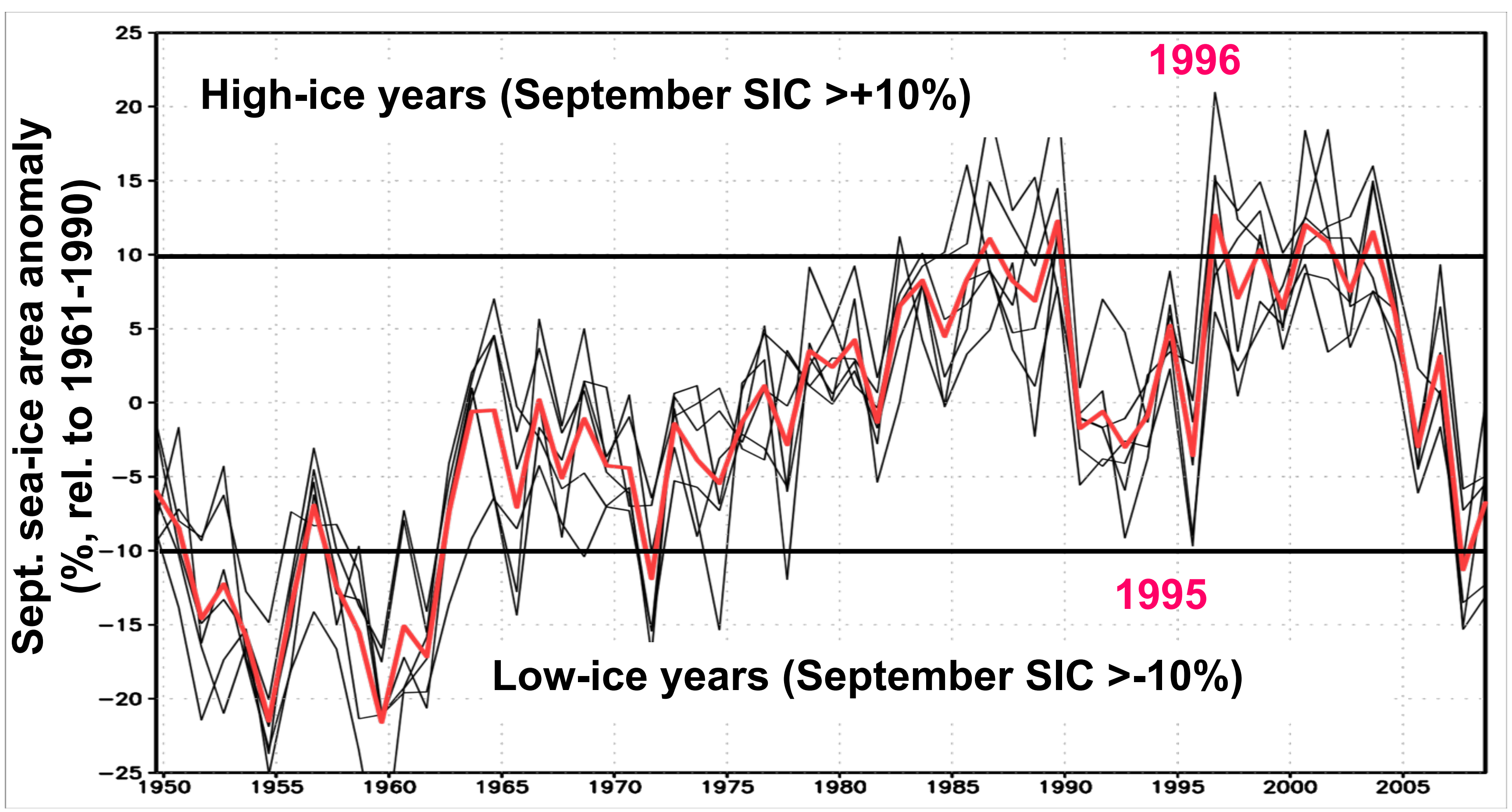
HIRHAM-NAOSIM regional climate model



Decline of sea ice extent in September after 2003 in model and observations



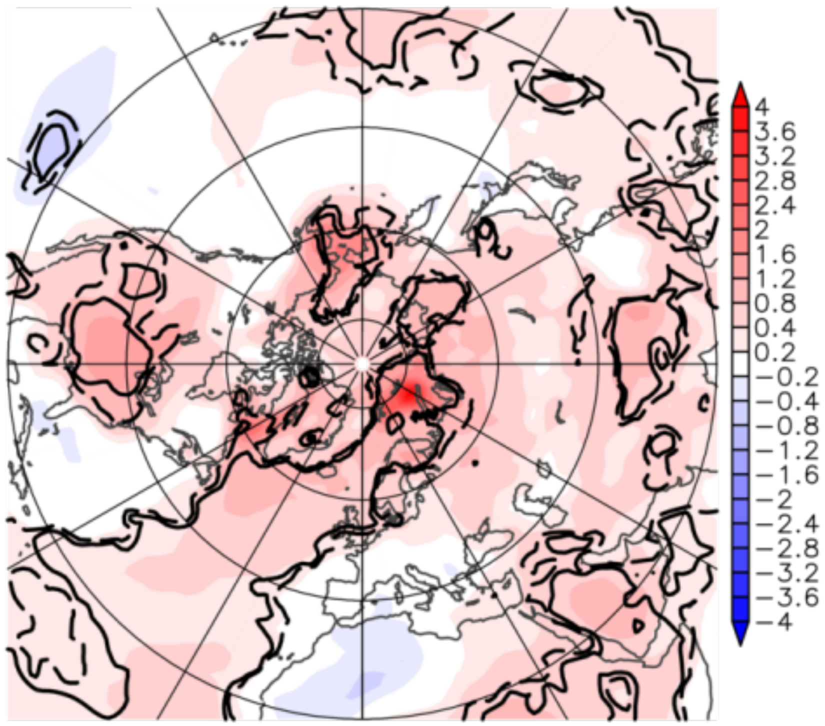
Sea-ice area anomalies (%; relative to 1961-1990)
Thick red line ensemble mean
Black lines:
7 ensemble members

Dorn et al., TC, 2012   Rinke et al. JGR, 2013

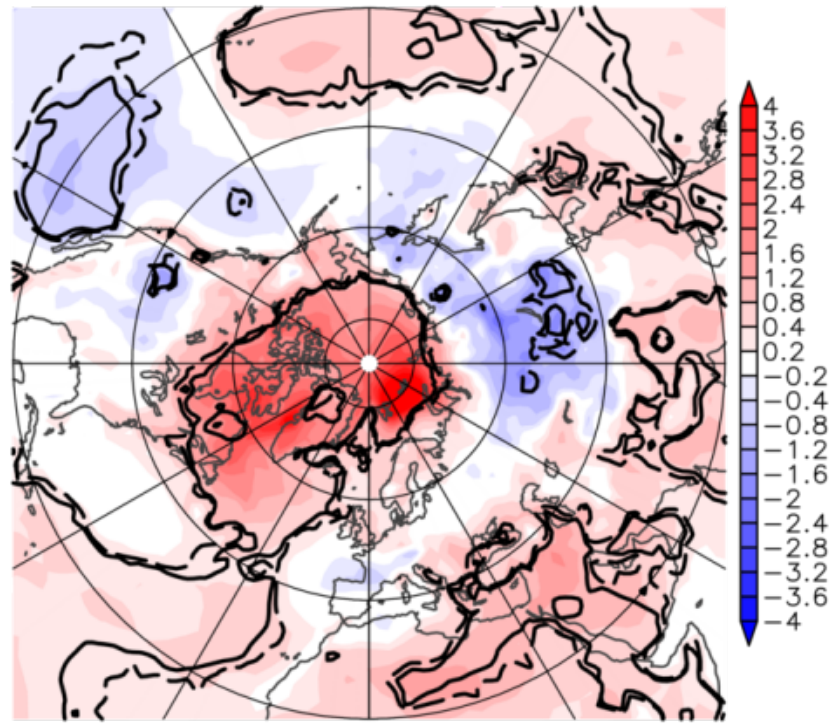
Simulated temperature patterns

Difference low minus high ice – Temperature at 975hPa (K) Winter (DJF)

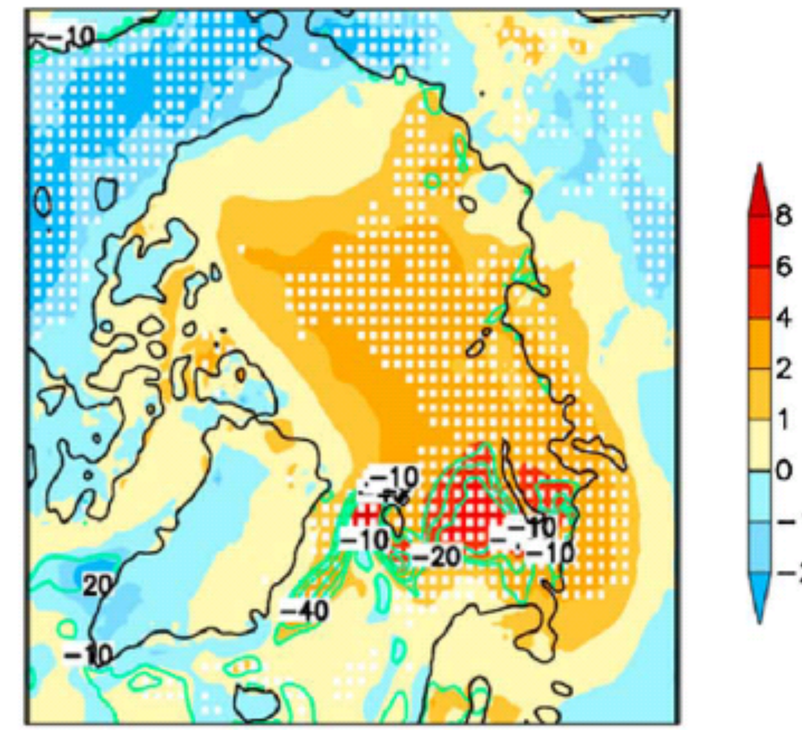
ECHAM6-MR-ENS Mean



ERA-Interim



HIRHAM-NAOSIM-ENS Mean



Black lines/White dots 95 % significance level

- Warm Arctic Cold Siberia (WACS) pattern in observations and regional model simulation
- No WACS pattern in global model simulation

Summary — regional and global models

	HIRHAM-NAOSIM	ECHAM6-ENS
Reduced sea ice in August/September	Yes	Prescribed
Additional heat stored in ocean	Yes	Prescribed
Warmer surface temperatures in following seasons	Yes, over some regions	Too weak
Reduced atmospheric vertical stability		No
Amplified baroclinic weather systems in autumn		No
Impact on planetary wave propagation in winter	Yes, in the troposphere, but different sea ice pattern	Not consistently reproduced …
Weaker stratospheric Polar Vortex		
Negative NAO/AO phases		
Higher probability of cold winters in Eurasia		