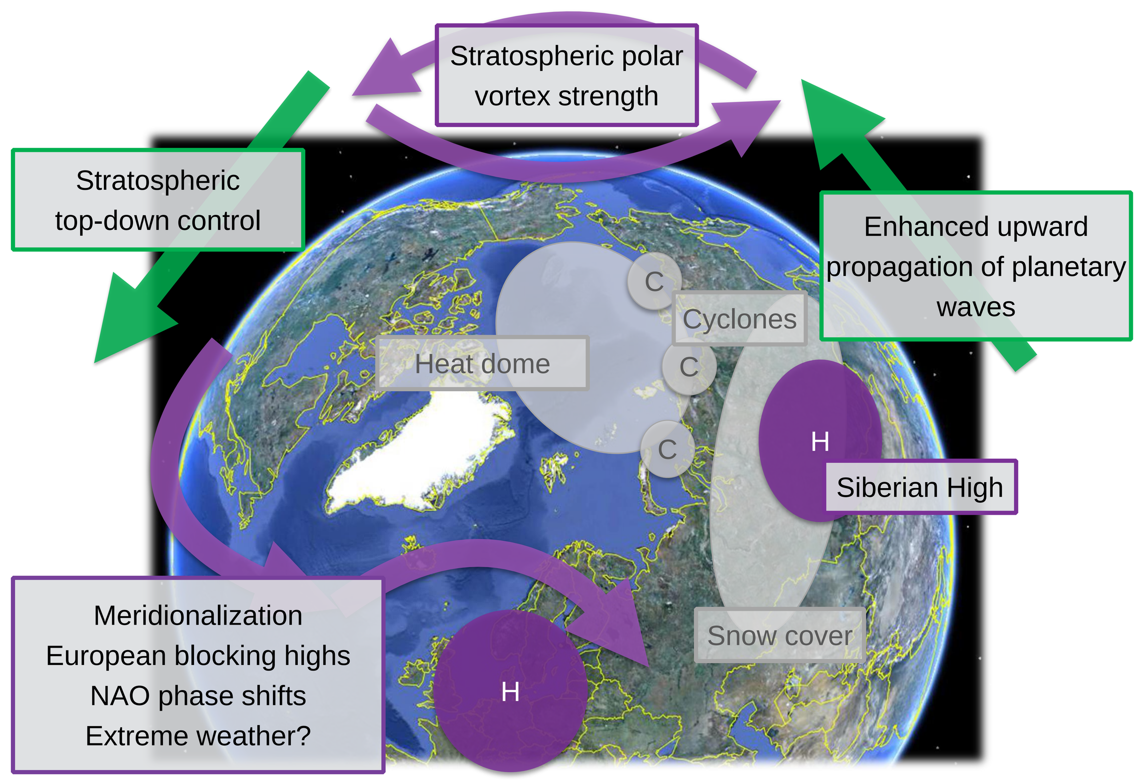
The linkage between Arctic sea ice changes and mid-latitude atmospheric circulation
The role of troposphere-stratosphere coupling

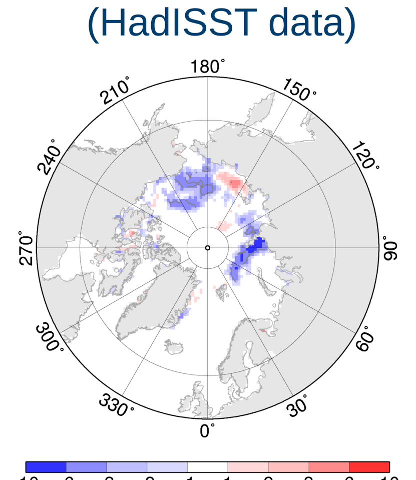
Ralf Jaiser[1], Dörthe Handorf[1], Erik Romanowsky[1], Klaus Dethloff[1], Tetsu Nakmura[2,3], Jinro Ukita[4], Koji Yamazaki[2,3]

Tropo-stratospheric interactions

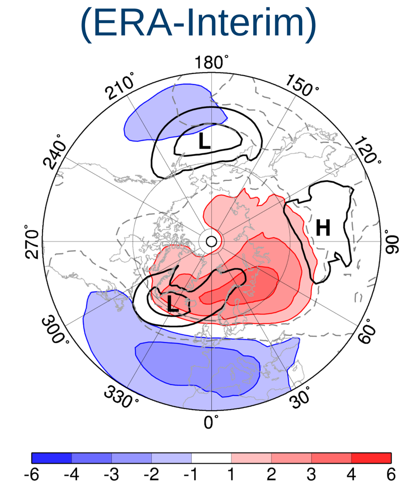


Arctic-midlatitude linkages
Coupled Patterns 1979-2015

Sea ice concentration
September
(HadISST data)



Sea level pressure
Following winter
(ERA-Interim)



- Sea ice decline statistically correlates with changes in circulation patterns
- Shifts of "centers of action"
  → similar to negative (N)AO pattern
- Observed changes involve tropo- and stratosphere
- Challenge: Mechanisms?
- Challenge: Representation in models?

Arctic-midlatitude linkages
AGCM model experiments

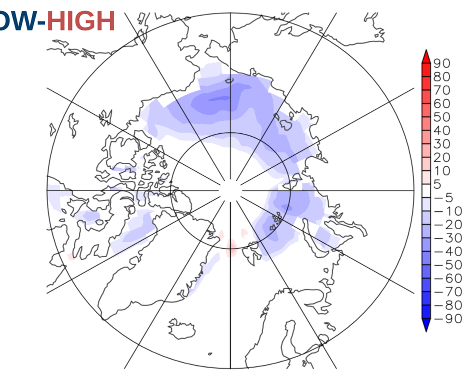
AGCM For Earth Simulator (AFES, T79/L56)
2 model runs with 60 perpetual years each
CNTL: **High ice** conditions as observed from 1979-1983
NICE: Low ice conditions as observed from 2005-2009
→ Only sea ice is different between both runs

ECHAM6 (T63/L95) with similar boundary conditions
2 model runs with 120 perpetual years each

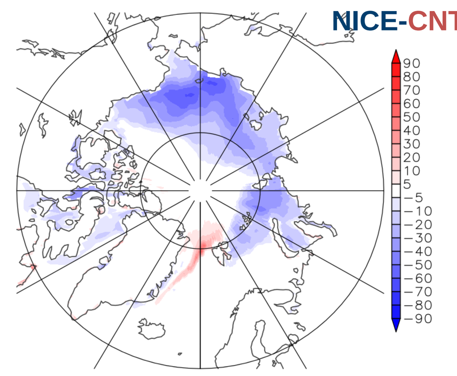
Comparisson with **ERA-Interim**
HIGH ice (1979/80-1999/00)
LOW ice (2000/01-2013/14)

Arctic sea ice concentration maps SON

ERA-Interim
LOW-HIGH

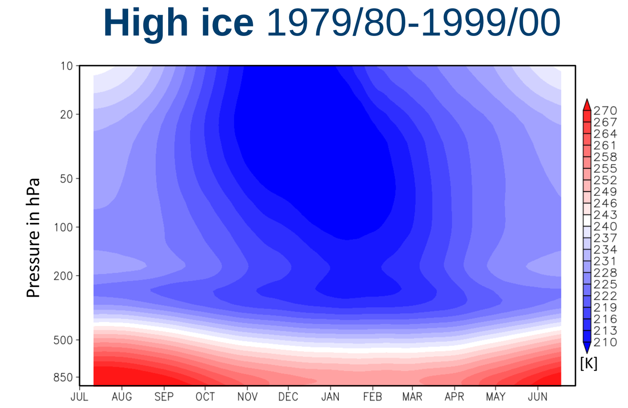


AFES
NICE-CNTL

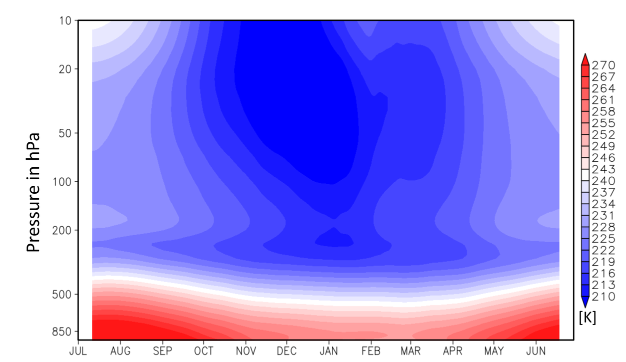


Polar cap temperature change - Temperature [K] average 65°N-85°N

Climatologies of polar cap temperature ERA-Interim
High ice 1979/80-1999/00

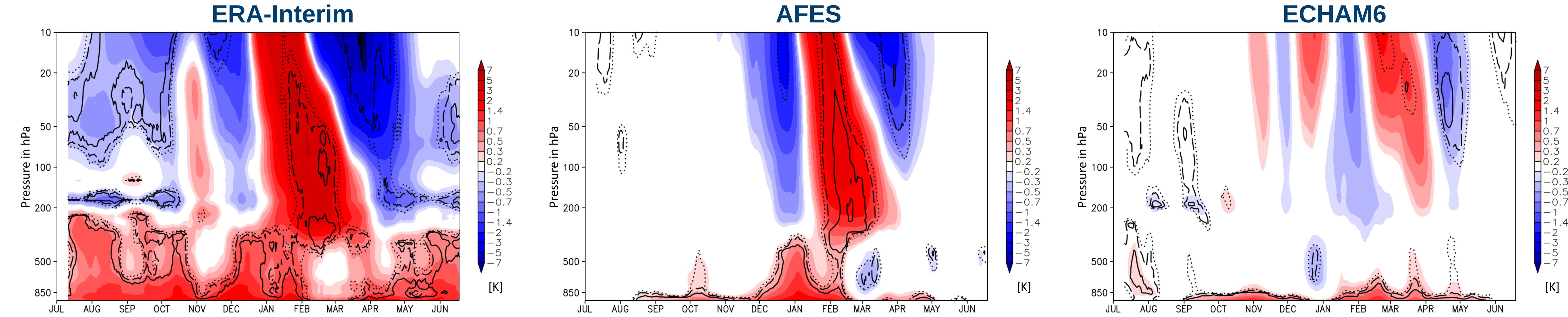


Low ice 2000/01-2013/14



Temperature [K] average 65°N-85°N low minus high ice conditions

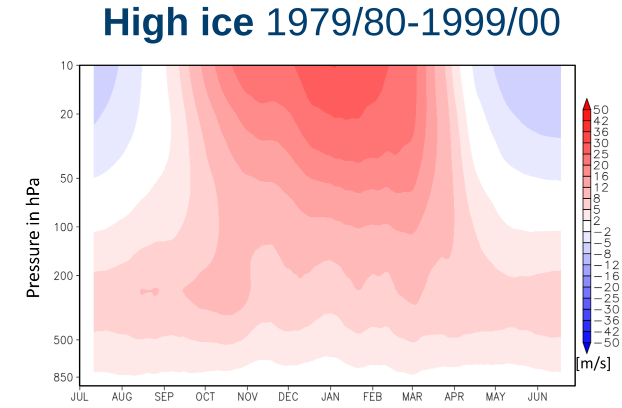
ERA-Interim **AFES** **ECHAM6**



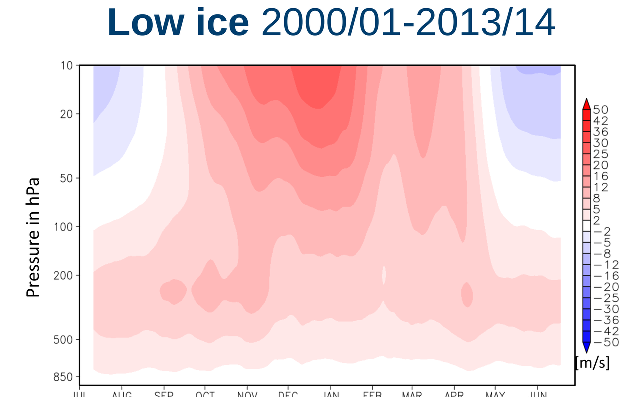
- ERA-Interim: higher tropospheric temperatures all over the year (general global warming signal)
- AFES/ECHAM6: surface warming related to sea ice alone
- Strong significant warming of polar stratosphere in late winter, but weaker signal in ECHAM6
- Polar vortex weakening?
- Very good agreement between AFES and reanalysis in winter (and autumn)

Polar cap zonal wind change - Zonal wind [m/s] average 65°N-85°N

Climatologies of polar cap zonal wind ERA-Interim
High ice 1979/80-1999/00

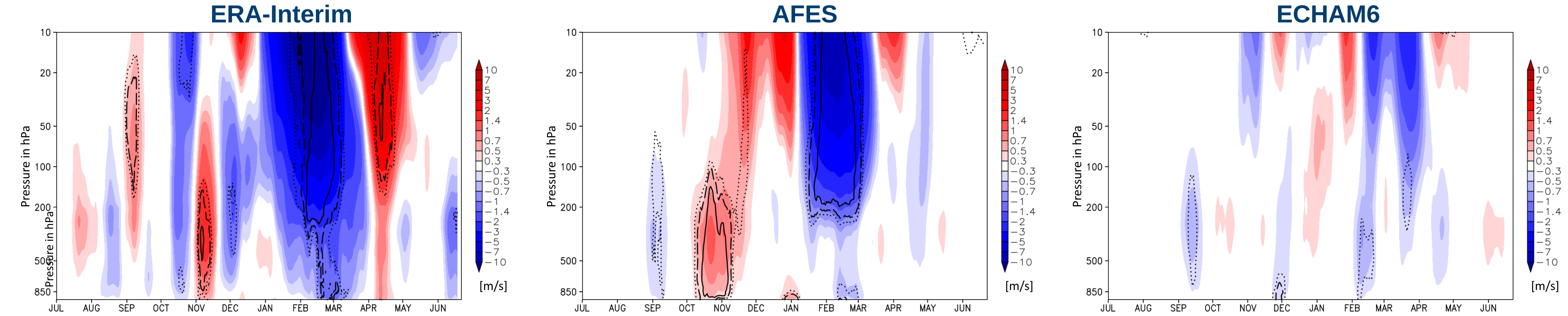


Low ice 2000/01-2013/14



Zonal wind [m/s] average 65°N-85°N low minus high ice conditions

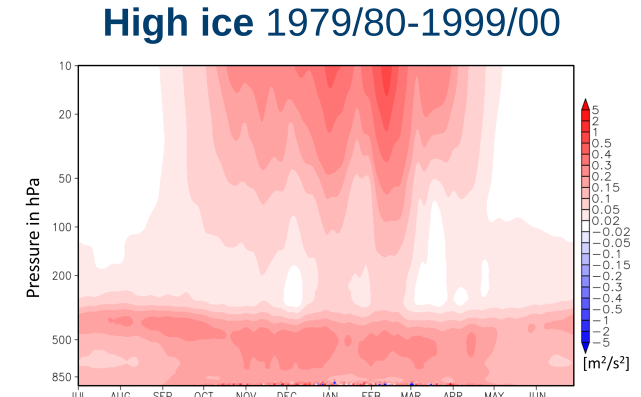
ERA-Interim **AFES** **ECHAM6**



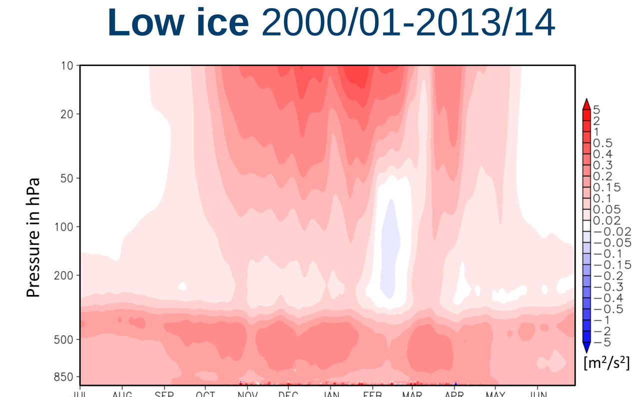
- Clear indication of stratospheric vortex weakening in February
- Stratospheric westerly winds massively reduced (in ERA-Interim and AFES)
- Signal reaching the troposphere
- Weaker signal in ECHAM
- Time delay between models and reanalysis: within weeks depending on model and point in time

Polar cap vertical wave propagation change
10-90 days filtered vertical component of EP flux vector [m^2/s^2] average 65°N-85°N

Climatologies of polar cap vertical component of EP flux vector ERA-Interim
High ice 1979/80-1999/00

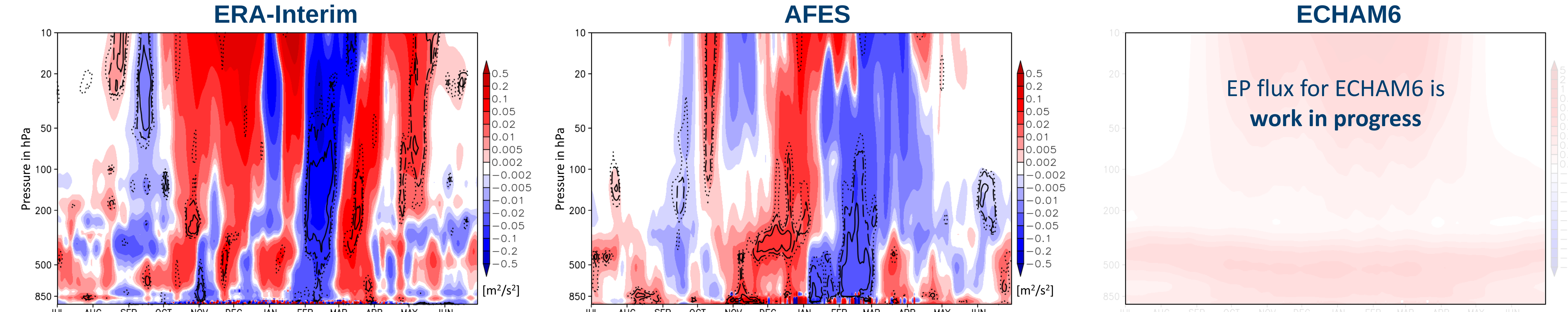


Low ice 2000/01-2013/14



Vertical component of EP flux vector [m^2/s^2] low minus high ice conditions

ERA-Interim **AFES** **ECHAM6**



- Enhanced upward propagation of planetary waves in autumn and early winter
- Disturbing the polar vortex, leading to a vortex weakening
- Vertical wave propagation is reduced in February due to the vortex weakening in ERA-Interim and AFES model simulation
- Consistency of datasets indicates clear impact of sea ice changes
- ERA-Interim is more disturbed in early winter → Impact of additional processes

Conclusions & Outlook

- Troposphere-stratosphere interaction play a crucial role for the atmospheric response to present-day sea-ice reduction
- AGCMs with realistically prescribed sea-ice reduction are able to simulate the observed signal of mid-latitude linkages
- Strength of the signal is model-dependent (e.g. in AFES stronger than ECHAM6)
- **Potential** for future studies
  Sensitivity of the model response with respect to
  → boundary forcing (e.g. turbulent surface fluxes)
  → representation of stratospheric processes (e.g. stratospheric chemistry)
- Possible change of underlying mechanisms under stronger than present-day sea-ice reduction (Nakamura et al., 2016)
- Discussion of autumn to winter development
  → Interaction between synoptic and planetary scales
  → See poster by Handorf et al.
- Discussion of late winter development
  → how is the stratospheric signal translated into the tropospheric negative (N)AO anomaly

References

Jaiser, R., Dethloff, K., Handorf, D. 2013. Stratospheric response to Arctic sea ice retreat and associated planetary wave propagation changes. Tellus A 65, 19375, doi:10.3402/tellusa.v65i0.19375.

Handorf, D., Jaiser, R., Dethloff, K., Rinke, A. Cohen, J. 2015. Impacts of Arctic sea ice and continental snow cover changes on atmospheric winter teleconnections, GRL, doi:10.1002/2015GL063203

Nakamura, T., Yamazaki, K., Iwamoto, K., Honda, M., Miyoshi, Y., Ogawa, Y., Ukita, J. 2015. A negative phase shift of the winter AO/NAO due to the recent Arctic sea-ice reduction in late autumn, JGR, 120, doi:10.1002/2014JD022848.

Jaiser, R., Nakamura, T., Handorf, D., Dethloff, K., Ukita, J., Yamazaki, K. 2016. Atmospheric winter response to Arctic sea ice changes in reanalysis data and model simulations, JGR, 121, doi:10.1002/2015JD024679

Nakamura, T., Yamazaki, K., Honda, M., Ukita, J., Jaiser, R., Handorf, D., Dethloff, K. 2016. On the atmospheric response experiment to a Blue Arctic Ocean, GRL, 43, doi:10.1002/2016GL070526.

The ERA interim data were obtained from the ECMWF web site (http://data-portal.ecmwf.int/).
The AFES simulations (Nakamura et al. 2015) were performed on the Earth Simulator at the Japan Agency for Marine-Earth Science and Technology.
Merged Hadley-NOAA/OI SST and SIC data were obtained from the Climate Data Guide (https://climatedataguide.ucar.edu/).

[1] Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Potsdam, Germany
[2] Arctic Environmental Research Center, National Institute of Polar Research, Tachikawa, Japan
[3] Faculty of Environmental Earth Science, Hokkaido University, Sapporo, Japan
[4] Department of Environmental Science, Niigata University, Niigata, Japan

Corresponding author: Ralf Jaiser, ralf.jaiser@awi.de