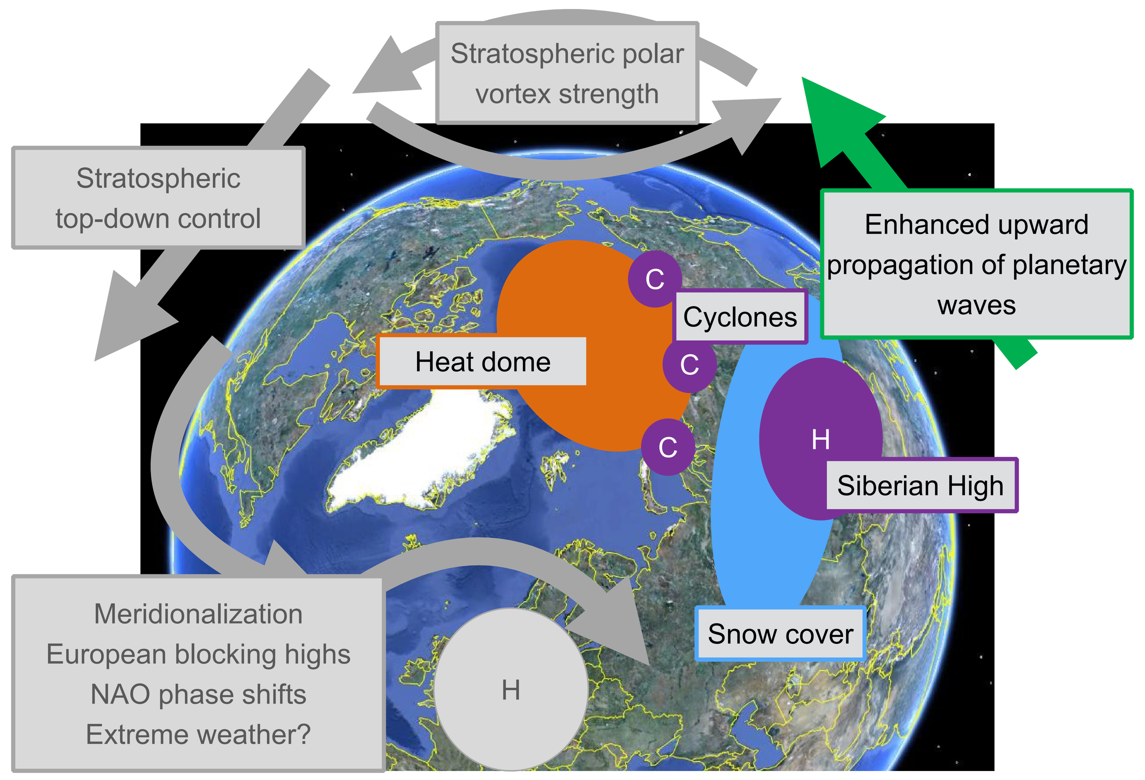
# The linkage between Arctic sea ice changes and mid-latitude atmospheric circulation – The role of synoptic-planetary wave interactions

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

## Arctic-midlatitude linkages




**Study of synoptic-planetary wave interactions is crucial for improved understanding of Arctic-midlatitude linkages**

What are suitable methods?

Study of wave interactions in atmospheric kinetic energy and enstrophy spectra and nonlinear spectral fluxes

**Research questions**

→ Can the analysis of atmospheric spectra and nonlinear spectral fluxes deliver new insights into the interactions between planetary and synoptic scales?

→ Can we detect significant changes under different Arctic sea ice conditions?

→ How develop atmospheric spectra and nonlinear spectral fluxes from autumn to late winter?

## AGCM model experiments

**AGCM For Earth Simulator (AFES)**

Spatial resolution T79/L56, daily data

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

Comparison with **ERA-Interim**

Reanalysis data set, analyzed from 1979 to 2015

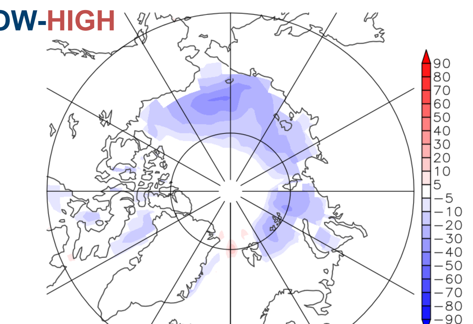
Spatial resolution T255, 6hr/daily data

**HIGH ice** (1979/80-1999/00)

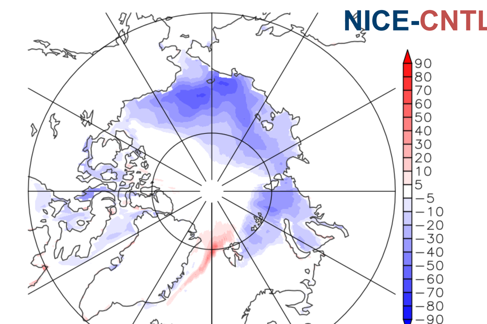
**LOW ice** (2000/01-2013/14)

## Arctic sea ice concentration maps SON

**ERA-Interim LOW-HIGH**



**AFES NICE-CNTL**



## The kinetic energy and enstrophy spectrum

Transition to spectral wavenumber space by application of spherical harmonic decomposition

→ scalar fields are expanded in spherical harmonic basis functions and truncated at total wavenumber N

→ Use of package SPHEREPACK (Adams & Swartztrauber, 1999)

Total kinetic energy $E_n$ and enstrophy spectra $G_n$ are given by

$$E_n = \frac{1}{4}\frac{a^2}{n(n+1)}\sum_{m=-n}^{n}\left(\overline{|\zeta_n^m|^2}+\overline{|\delta_n^m|^2}\right) = E_n^{rot} + E_n^{div}$$

$$G_n = \frac{n(n+1)}{a^2}E_n^{rot}$$

$\zeta_n^m$ - spherical harmonic coefficients of vorticity

$\delta_n^m$ - spherical harmonic coefficients of divergence

$n$ - total wavenumber

$m$ - zonal wavenumber

$a$ - radius of Earth

## → Nonlinear spectral interaction

The spectral budget equations for kinetic energy and enstrophy

$$\frac{\partial E_n}{\partial t} = I_n + S_n^E \qquad \frac{\partial G_n}{\partial t} = J_n + S_n^G$$

$I_n$, $J_n$ - Interaction terms (nonliear transfer) of energy and enstrophy, respectively, into wavenumber $n$

$S_n^E$, $J_n^G$ - divergent effects, sources and sinks of energy and enstrophy, respectively

Calculation of enstrophy interaction term $J_n$ by using the vorticity equation:

$$\frac{\partial \zeta}{\partial t} = -(\vec{v}\cdot\nabla)\zeta - D \Longrightarrow J_n = -\frac{1}{4}\sum_{m=-n}^{n}\left[\zeta_n^{m^*}(\vec{v}\cdot\nabla\zeta)_n^m + \zeta_n^m(\vec{v}\cdot\nabla\zeta)_n^{m^*}\right]$$

$D$ includes divergent, twisting, solenoid & friction term

The energy interaction term for the rotational part of the flow is given by

$$I_n = \frac{a^2}{n(n+1)}J_n$$

→ restriction to rotational component of the flow

→ does not provide complete energy budget, but allows to study processes relevant to large-scale turbulence

## → Nonlinear spectral fluxes

The nonlinear interaction terms only **redistribute** kinetic energy and enstrophy →

$$\sum_{n=0}^{N} I_n = 0 = \sum_{n=0}^{N} J_n$$

By adding up the nonlinear interaction terms $I_n$ and $J_n$ one can define **nonlinear spectral fluxes** of kinetic energy $F_n$ and enstrophy $H_n$ →

$$F_{n+1} = -\sum_{l=0}^{n} I_l$$

$$H_{n+1} = -\sum_{l=0}^{n} J_l$$

$F_n$, $H_n > 0$ → downscale cascade

$F_n$, $H_n < 0$ → upscale cascade

$F_n$, $H_n$ = const. → turbulent inertial range

## Synoptic-planetary scale interaction

Decomposition into stationary $\overline{\zeta_n^m}$ and transient $\zeta_n^{m'} = \zeta_n^m - \overline{\zeta_n^m}$ parts allows for better understanding of diagnosed transfer with respect to synoptic-planetary scale interaction

→ Decomposition of spectra $E_n$ and $G_n$ into two parts

$$E_n = E_{stat} + E_{trans}$$
$$G_n = G_{stat} + G_{trans}$$

→ Decomposition of nonlinear interaction terms $J_n$ and $I_n$ (triple correlation terms) into three parts (cf. Shepherd, 1987)

$$J_n = J_{stat} + J_{trans} + J_{st}$$
$$I_n = I_{stat} + I_{trans} + I_{st}$$

→ Respective spectral fluxes of kinetic energy and enstrophy follow again by summing up the nonlinear interaction terms

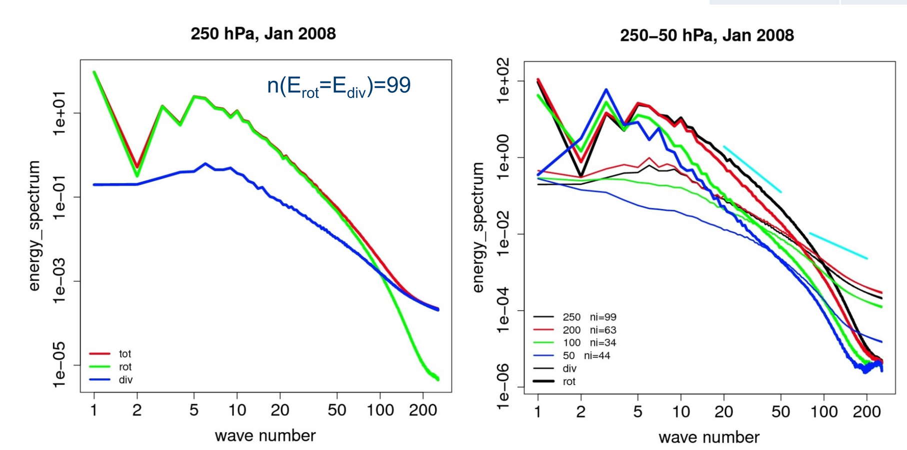
→ Fluxes $F_{st}$ and $H_{st}$ represent stationary-transient exchange of energy and enstrophy

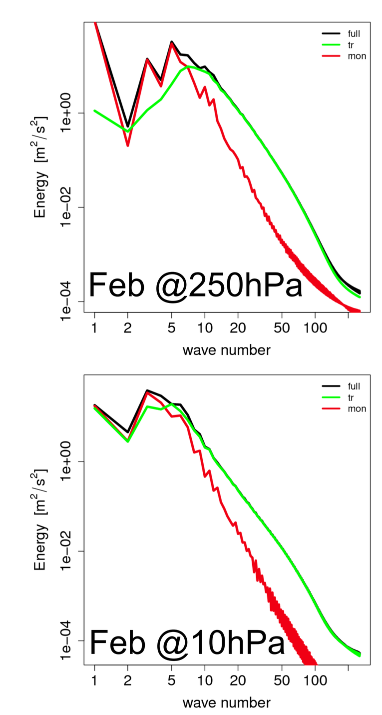
## The kinetic energy spectrum

### Mesoscale shallowing

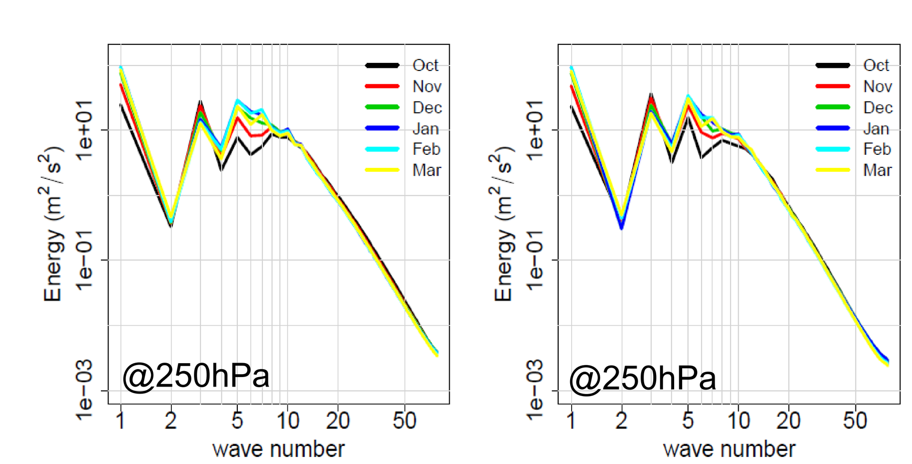
- ERA-Interim , T255, 6h, January 2008
- Mesoscale shallowing at $n(E_{vor}=E_{div})$
- Mesoscale shallowing at tropo-stratosphere transition

| Height | $n(E_{vor}=E_{div})$ |
|---|---|
| 250hPa | 99 |
| 200hPa | 63 |
| 100hPa | 34 |
| 50hPa | 44 |




### Seasonal cycle - Climatology over High Ice period



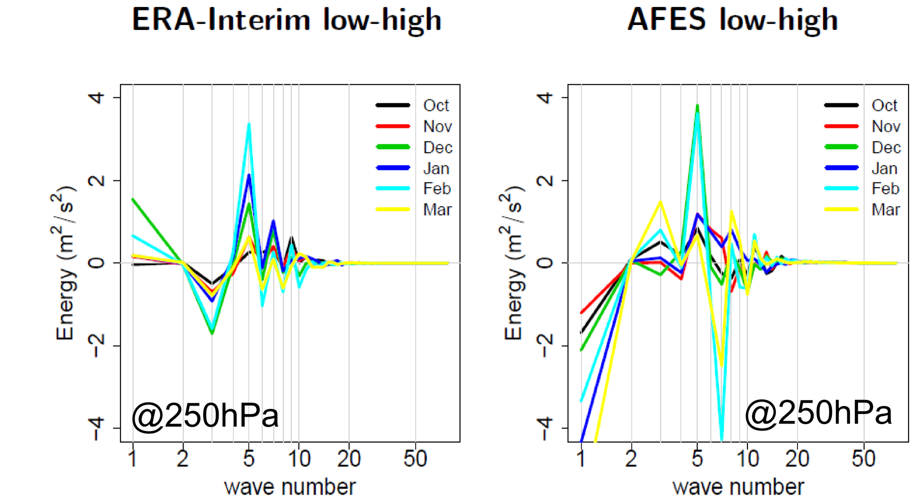

Changes with height larger than changes with season

Stationary part dominates up to n≈7-8

Transient part peaks at n≈6-8

Amplitude of seasonal cycle largest at wavenumbers 4-10

### Seasonal changes low minus high ice conditions




Largest differences in February

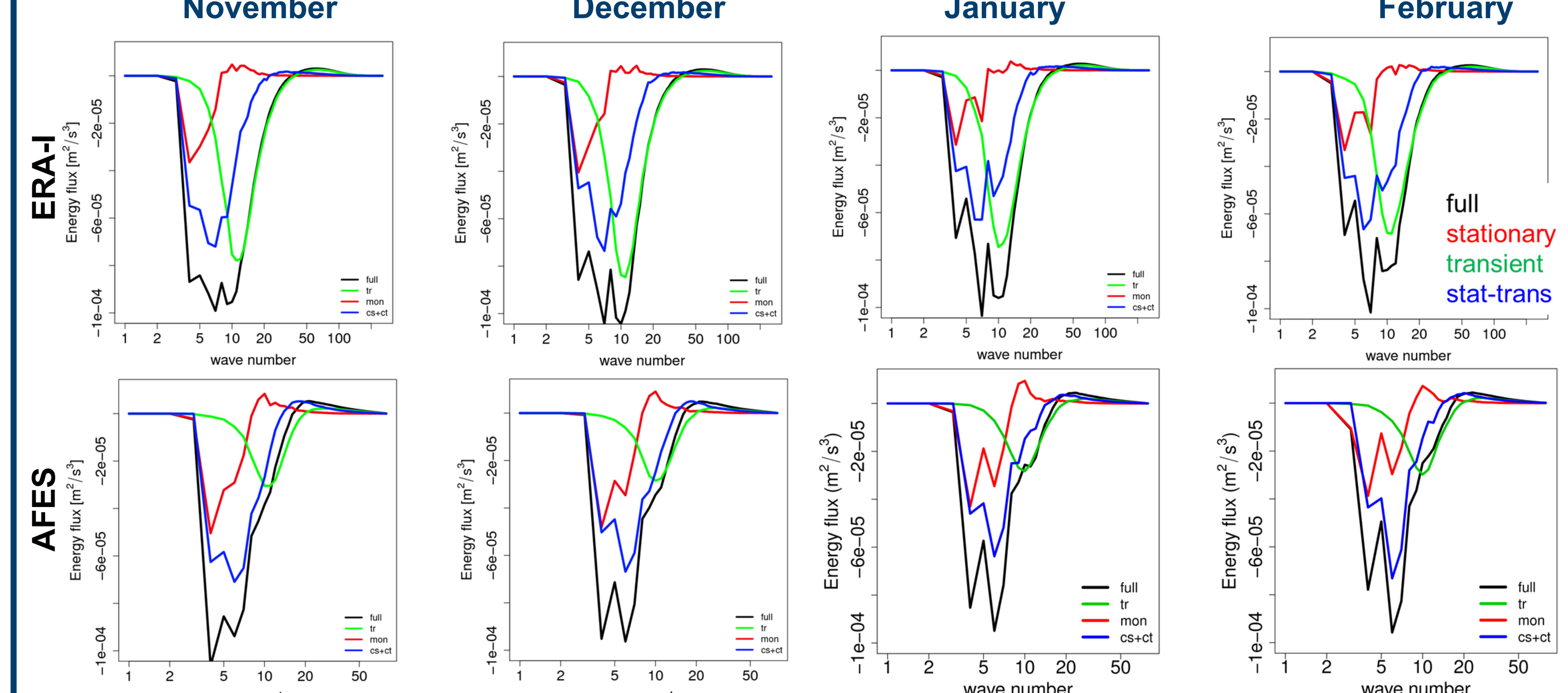
ERA-I & AFES agree especially on changes at wavenumber 5

## Summary & Outlook

- In general there is a good agreement between ERA-Interim and AFES concerning kinetic energy spectrum and nonlinear spectral fluxes, but AFES underestimates the transient terms
- Changes with respect to sea-ice showed
  → agreement between ERA-Interim and AFES in autumns and early winter, but
  → different responses in February, probably due to time shift in tropo-stratospheric interaction processes
- Future task: Study of full energy budget and cycle

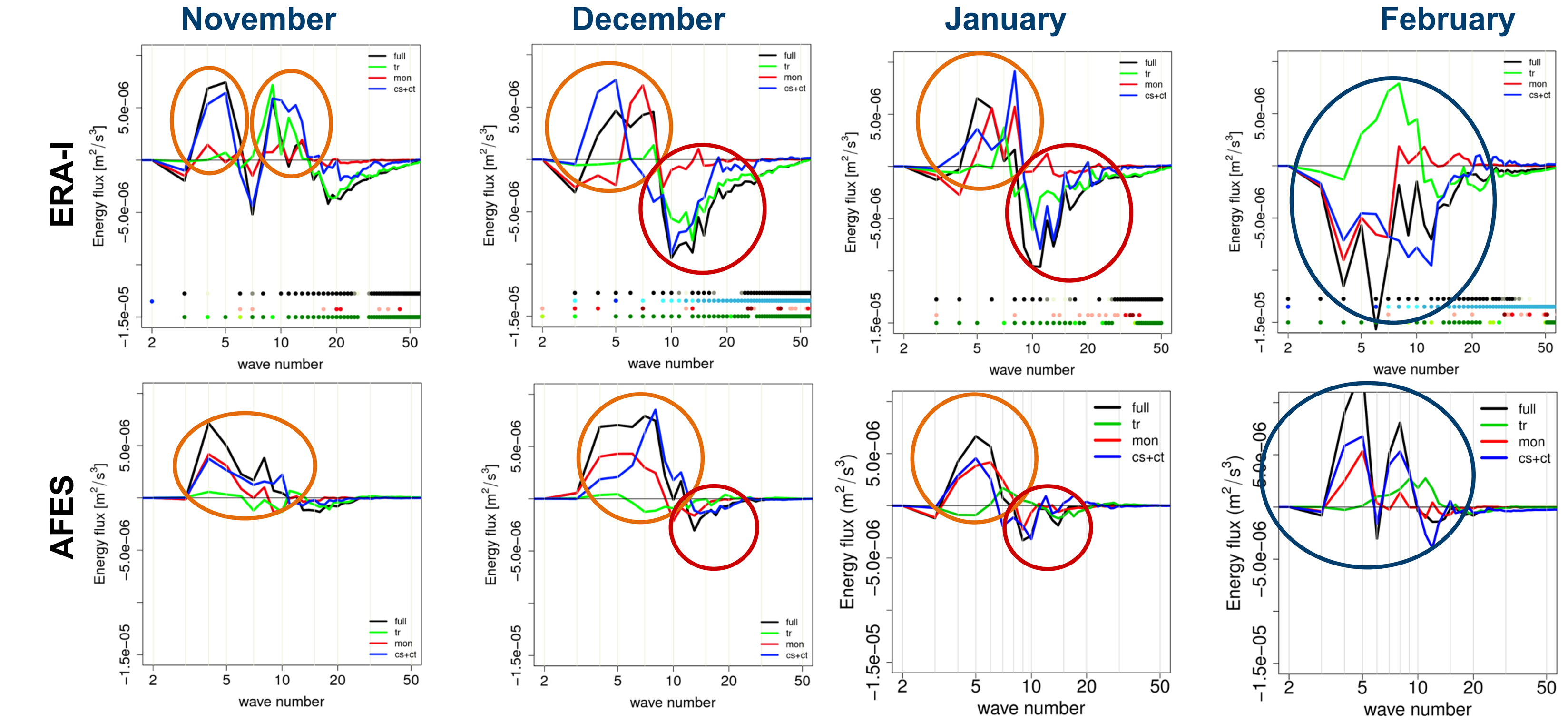
## The nonlinear spectral fluxes for kinetic energy

### Seasonal changes – Climatology @250hPa




- Changes with time and (height)
- Stat-trans interaction dominates the upscale flux up to wn 10
- transient part dominates upscale flux for wn >10
- Separation of stationary and transient contributions
- AFES underestimates the transient part (probably due to T79 vs. T255)

### Seasonal cycle of changes low minus high ice conditions




- **November:**
  less upscale energy flux on planetary and synoptic scales for low ice conditions
- **December and January**
  less upscale energy flux on planetary scales for low ice conditions (due to stationary and interaction terms)
  enhanced upscale energy flux on synoptic scale for low ice conditions (due to interaction and transient terms; larger changes for ERA-I)
  → more energy accumulated on planetary scales around wn 7-10
- **February**
  different changes in all terms in ERA-I and AFES (also in the stratosphere) could be related to time shift in tropo-stratospheric interaction processes; cf. poster Jaiser et al.)

**References**

Adams, J.C., and P. N. Swarztrauber (1999): SPHEREPACK 3.0: A model development facility. MWR, 127, 1872-1878. http://dx.doi.org/10.1175/1520-0493(1999)127<1872:SAMDF>2.0.CO;2doi:

Shepherd, T.G. (1987): A spectral view of nonlinear fluxes and stationary-transient interaction in the atmosphere. JAS, 44, 1166-1179. http://dx.doi.org/10.1175/1520-0469(1987)044<1166:ASVONF>2.0.CO;2

Crasemann, Berit (2016): Der Einfluss arktischer Meereisänderungen auf Wechselwirkungen zwischen synoptischen und planetaren Skalen in der Tropo- und Stratosphäre. 129 S., Dissertation, Univ. Potsdam (in German)

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

The SPHEREPACK software package has been obtained from https://www2.cisl.ucar.edu/resources/legacy/spherepack

[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: Dörthe Handorf, doerthe.handorf@awi.de**