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

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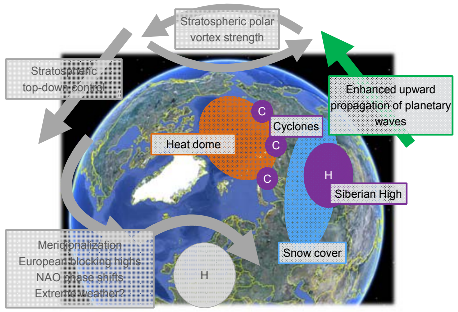
Arctic-midlatitude linkages



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

Comparisson with **ERA-Interim**

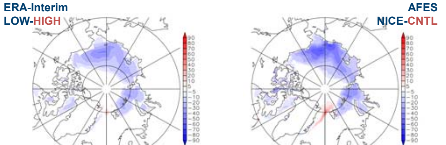
Reanalysis data set, analyzed from 1979 to 2015

Spatial resolution T255, 6hr/daily data

HIGH ice (1979/80-1999/00)

LOW ice (2000/01-2013/14)

Arctic sea ice concentration maps SON



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

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

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

ζ_n^m - spherical harmonic coefficients of vorticity
δ_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 (nonlinear 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:

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

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 →

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

$F_n, H_n > 0$ → 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 $\zeta_n^{m\prime} = \zeta_n^m - \overline{\zeta_n^m}$ 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

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

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

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

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

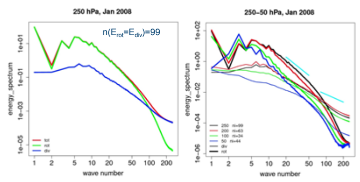
→ Fluxes F_{st} and H_{st} represent stationary-transient exchange of energy and enstrophy

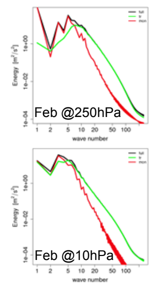
The kinetic energy spectrum

Mesoscale shallowing

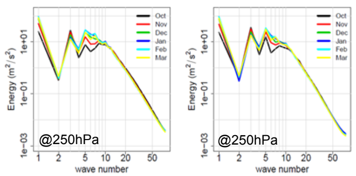
- ERA-Interim, T255, 6h, January 2008
- Mesoscale shallowing at $n(E_{vor}=E_{div})$
- Mesoscale shallowing at tropo-stratosphere transition

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



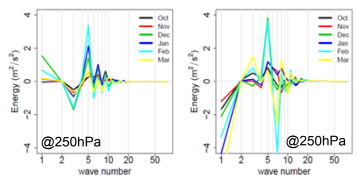


Seasonal cycle - Climatology over High Ice period



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



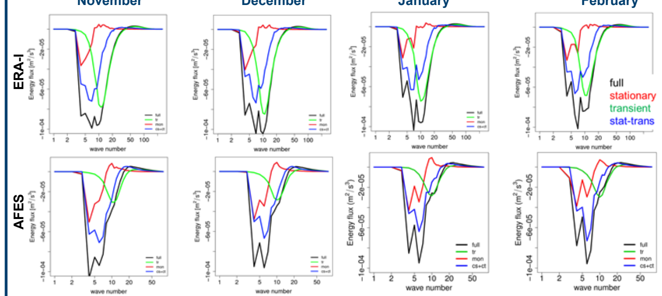
Largest differences in February
ERA-I & AFES agree especially on changes at wavenumber 5

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

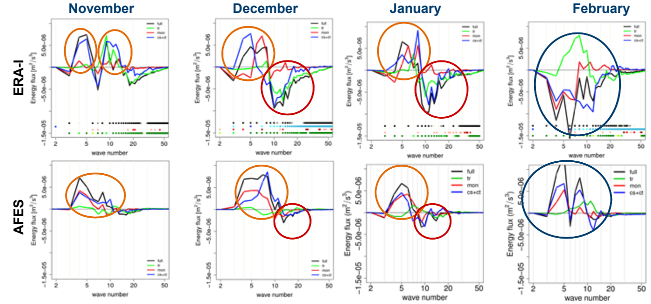
The nonlinear spectral fluxes for kinetic energy

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:

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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

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