Arctic-midlatitudes climate linkages: the current status and prospects

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Arctic-midlatitudes climate linkage

“A physical relationship between climate variations in the Arctic and NH midlatitude (via atmospheric teleconnection)”

For sea ice, Honda et al. (2009), Overland et al. (2011), Francis and Vavrus (2012) etc
For snow, Fletcher et al. (2007), Peings et al. (2012)

Its development follows a cycle of a hypothesis, skepticism, debate, new results – perhaps a paradigm shift

The idea of stratosphere-troposphere coupling is essential
Observational evidence for the linkage
Temp and SLP anomalies associated with Arctic SIE (Sep)

- Cold temp anomalies spread from Siberia to the Euro-Atlantic sector
- Circulation anomalies for the Siberia High and NAO(-) progressively

Data: JRA-55 1979/80-2009/10
Arctic-midlatitudes climate linkage via stratosphere

Deceleration by wave-mean flow interaction

Upward propagation of planetary waves

Polar vortex

Stratosphere

Troposphere

Eurasian cold anomalies

Jet
Weaker polar vortex

Intra-seasonal progression of cold anomalies from Eurasia to Euro-Atlantic sector

Arctic-midlatitudes climate linkage via stratosphere

Early winter cold anomalies

Late winter cold anomalies

Stratosphere

Troposphere

Intra-seasonal progression of cold anomalies from Eurasia to Euro-Atlantic sector
Key components

- Upward propagation of planetary waves (enhanced poleward eddy heat flux)
- Modulation of atmospheric circulation (e.g. shift of the AO/NAO phase)
- Enhancement of residual mean meridional circulation – dynamical positive feedback
Sea ice reduction experiment using a fully stratosphere-resolving model, Nakamura et al. (2015, 2016)

<table>
<thead>
<tr>
<th>Honda et al. 2009</th>
<th>This experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGCM for Earth Simulator (AFES)</td>
<td></td>
</tr>
<tr>
<td>T42L20, 8hPa</td>
<td>T79L56, 0.08 hPa</td>
</tr>
<tr>
<td>Seasonal ensemble run (n=28)</td>
<td>Perpetual run for 20~60yrs X runs</td>
</tr>
<tr>
<td>SST climate</td>
<td>SST (1979-83 ave)</td>
</tr>
<tr>
<td>Siberian sea ice</td>
<td>NH sea ice</td>
</tr>
</tbody>
</table>

Boundary conditions
Merged Hadley-NOAA/OI SST and SIC (Hurrell et al., 2008)
Fixes BCs for CO2, CH4, CFCs, O3, aerosols and solar

<table>
<thead>
<tr>
<th></th>
<th>Run yrs</th>
<th>SST &lt;30N</th>
<th>SST &gt;50N</th>
<th>SEA ICE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HICE</strong></td>
<td>60</td>
<td>Past (1979-83)</td>
<td>Past</td>
<td>Past (1979-83)</td>
</tr>
<tr>
<td><strong>Global</strong></td>
<td>20</td>
<td>Recent</td>
<td>Recent</td>
<td>Recent</td>
</tr>
<tr>
<td><strong>Northern</strong></td>
<td>20</td>
<td>Past</td>
<td>Recent</td>
<td>Recent</td>
</tr>
<tr>
<td><strong>LICE</strong></td>
<td>60</td>
<td>Past</td>
<td>Past</td>
<td>Recent (2005-09)</td>
</tr>
</tbody>
</table>

To validate for Arctic sea ice impacts
Mechanism: wave-mean flow interaction

Nakamura et al., 2015; 2016; Jaiser et al., in rev; Hoshi et al. sub.; King et al., 2015

Model Results (LICE - HICE)

Δ $\bar{u}$ at 60N and
Δ $v^*T^*$ at 100 hPa ave >40N

Polar vortex strength

Poleward eddy heat flux

JRA-55, 1979-2015

Regression coeff of $\bar{u}$ at 60N and $v^*T^*$ at 100 hPa on BK SIE index (ND)

Arctic sea ice loss results in increased poleward eddy heat flux (upward propagation of planetary wave), weaker polar vortex, downward propagation of signals, towards the negative phase of the tropospheric AO/NAO
Results from sea ice reduction experiment
AO (EOF1-z500, >30N, DJF) response

- Shifts the AO distribution towards its negative phase
- Changes the probability of extreme events; e.g. increase in cold events in the Euro-Atlantic sector
- Modulates atmospheric circulation

Nakamura et al. 2015
Evidence for the stratospheric pathway

In FREE (Lice – Hice) the eddy heat flux increases prior to the weakened polar vortex with a subsequent downward propagation of signals. When restored this becomes less pronounced. The strongest evidence yet of the stratospheric pathway.

Nakamura et al. 2016
The Barents-Kara Seas as a source region

Sea ice
Snow
SST in sub-Arctic
SST in lower latitudes

Arctic-midlatitudes climate linkage
Poleward eddy heat flux

Polar vortex
AO/NAO phases
Residual circulation
Jet and blocking

Summer-to-fall
Simulated $\Delta v^*T^*$ at 100hPa

Purple: poleward eddy heat flux from Low-ICE

Winter
Reg. of geopotential height on $v^*T^*$ index

Longitude-height cross-section at 60N
Questions and issues

- Internal variability (robustness) – AMIP-type comparison

We have collaboration with the Norwegian GREENICE Project!

- Mechanism: Strato-Troposphere coupling and more?

- Combined influences from other forcings such as ENSO

- Present versus future sea ice loss
# Blue Arctic Experiment

Simulations with even less sea ice

## Experiment Design

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Run period</th>
<th>SST</th>
<th>Sea ice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control High ICE</td>
<td>150 yrs</td>
<td>Climatology (1979-2010)</td>
<td>1979-1883 Ice Area Max. 50cm thickness</td>
</tr>
<tr>
<td>Low ICE</td>
<td>150 yrs</td>
<td>Climatology</td>
<td>2005-2009 Area Max. 50 cm thickness</td>
</tr>
<tr>
<td>Im30 Lower ICE</td>
<td>150 yrs</td>
<td>Climatology</td>
<td>1979-1883 Ice Area Max. 20 cm thickness No ice if thinner than 5 cm</td>
</tr>
<tr>
<td>Im40 Lowest ICE</td>
<td>150 yrs</td>
<td>Climatology</td>
<td>1979-1883 Ice Area Max. 10 cm thickness No ice if thinner than 5 cm</td>
</tr>
<tr>
<td>Blue Arctic</td>
<td>150 yrs</td>
<td>Climatology</td>
<td>Ice free year-around</td>
</tr>
</tbody>
</table>

Nakamura et al., sub
Zonal-mean zonal winds
Polar vortex/AO strength

Poleward eddy heat flux
Upward propagation of waves

Wave amplitudes
Planetary wave strength

- A gradual shift with less strato-troposphere coupling
- Tropospheric processes dominate in the Blue Arctic conditions

Nakamura et al., sub
Emerging evidence for the Arctic-midlatitudes climate linkage by stratosphere-troposphere coupling

Provides intra-seasonal to seasonal time-scale prediction potential and identifies the Barents-Kara Seas as a critical region

Longer sea ice time-scale provides inter-annual to sub-decadal time scale prediction potential
The NAO is related to North Atlantic cyclone activities and ocean heat transport through the Barents Sea Opening (BSO) to influence Barents sea ice variability.

Ongoing Collaboration

- NordForsk/GREENICE Project (PI: Noel Keenlyside)
  WP1: Impact of cryosphere changes on the large-scale atmospheric circulation
- Belmont Forum/InterDec (PI: Daniela Matei/MPI, Task leaders from U Bergen, NERSC)
- Ny-Alesund’s Atmospheric Research Flagship Programme on aerosols and clouds

References