The Impact of AMOC on Arctic Sea-ice Variability

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Conclusions and Caveats

- GFDL CM2.1 unforced simulation shows that AMOC can significantly modulate Arctic sea-ice on decadal/multi-decadal scales.

- The spatial pattern of AMOC associated Arctic variability in GFDL CM2.1 is similar to the observed trend in the Winter season.

- AMOC seems to have little impact on Pacific sector of the Arctic in GFDL CM2.1, where the observed decline is the strongest in the summer.

- AMOC fingerprints suggest that the AMOC has been strengthening in the past few decades.

- A strengthening AMOC could have contributed to the observed decline in the Arctic Sea-ice in the Winter, but not in the summer based on GFDL CM2.1 results.

- AR2 model of AMOC fingerprints predicts a decline of the AMOC in the coming years, suggesting a weakening of the decrease in Arctic sea-ice.

- The above results are based on GFDL CM2.1 and 50 years of observational data.
Motivation

- CMIP3 models forced with GHG not capturing observed Arctic sea-ice decline

- A strong role for decadal/multi-decadal natural variability

- AMOC is the largest source of decadal/multi-decadal variability

*Stroeve et al., 2007*
Motivation

Jennifer Kay, WCRP, 2011
(Kay et al., 2011)
Background: AMOC

Atlantic Multidecadal Oscillation (AMO)

Zhang and Delworth (2006)

Knight et al. (2005)
Data and Model

- **Observations:**
  - Zakharov Arctic sea-ice extent (EXT) 1900-1999 (Zakharov et al. 1997)
  - NANSEN Surface Air Temperature (SAT) (Kuzmina et al. 2008)
  - Levitus optimally interpolated ocean temperature data 1955-2009
  - AVISO DUACS altimetry SSH data 1993-2008

- **Models:**
  - GFDL CM2.1 pre-industrial 1000-year long segment
  - GFDL Coupled Data Assimilation (CDA) (Zhang 2007):
    - Incorporates Argo Array data 2001-2008
GFDL CM2.1 Simulated AMOC

AMOC index Spectrum

Msadek et al. 2010, GRL

AMOC Fingerprints

Time Series: AMOC index, SSH, Tsub, AMO

Zhang 2008, GRL
Arctic sea-ice and surface air temperature

a. GFDL CM2.1 Arctic Surface Air Temperature (SAT) and Sea-ice Extent (EXT)

b. Observed Arctic Surface Air Temperature (SAT) and Sea-ice Extent (EXT)

Mahajan et al (2011)
Simulated Arctic Sea-ice

<table>
<thead>
<tr>
<th>Mean</th>
<th>Standard Deviation</th>
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<td>GFDL CM2.1</td>
<td>Observations</td>
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</table>

Mahajan et al (2011)
AMOC and AMO

a. Time-series: AMO index and AMOC index

![Graph showing time-series of AMO index and AMOC index. The correlation coefficient $r(\text{AMO, AMOC}) = 0.65$.](Mahajan et al. 2011)
AMO and Arctic

b. Time-series: **AMO index** and **Arctic Surface Air Temperature (SAT)**

![Graph showing AMO index and Arctic SAT over time]

\[ r(\text{AMO}, \text{SAT}) = 0.56 \]

\[ \text{Normalized Index vs. Year} \]

\[ \text{Year} = 0 \rightarrow 1000 \]

\[ \text{Normalized Index} = -3 \rightarrow 3 \]

\[ \text{r(AMO, SAT) = 0.56} \]

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c. Time-series: **AMO index** and **Arctic sea-ice extent (EXT)**

![Graph showing AMO index and Arctic sea-ice extent over time]

\[ r(\text{AMO}, \text{EXT}) = -0.57 \]

\[ \text{Normalized Index vs. Year} \]

\[ \text{Year} = 0 \rightarrow 1000 \]

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\[ \text{r(AMO, EXT) = -0.57} \]

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Mahajan et al (2011)
AMO and Arctic

2σ Composite  Surface Air Temp.  Sea-ice Thickness  Sea-ice Conc.

Mahajan et al (2011)
Simulated AMOC and Arctic

Mahajan et al. (2011)
Simulated AMOC and Arctic

2σ Composite | Surface Air Temp. | Sea-ice Thickness | Sea-ice Conc.

Winter

Summer

Mahajan et al (2011)
Observed Sea-ice Trend 1979-2009

Regr. AMO (GFDL CM2.1) Observed Trend

Winter

Summer

Mahajan et al (2011)
AMOC Fingerprints

North Atlantic Currents

Northern Recirculation Gyre (NRG)

Subpolar Gyre

Dipole induced by strengthening of AMOC

Zhang (2008)

Warming

Weakened Subpolar Gyre

Cooling

Enhanced NRG

Southward Shift of Gulf Stream

Courtesy: http://www.mar.dfo-mpo.gc.ca
AMOC Fingerprints

Spatial Pattern

Zhang (2008)

CDA

Mahajan et al (2011)

Time-series

Zhang (2008)
AMOC Fingerprints

Observation Tsub, CDA Tsub, Observation SSH: Time Series of PC 1

- Observed Tsub
- CDA Tsub
- SSH

Correlation Coefficients:
- \( r(\text{Obs. Tsub, CDA Tsub}) = 0.95 \)
- \( r(\text{Obs. Tsub, SSH}) = 0.88 \)
- \( r(\text{CDA Tsub, SSH}) = 0.91 \)

Mahajan et al. (2011)
Statistical Prediction

Strategy:
1. Model fingerprints time-series using Auto-Regressive (AR) models

   AR2 model (SBC criterion):

   \[ x(t) = ax(t-1) + bx(t-2) + e(t) \]

2. Estimate AR model parameters from observed Tsub timeseries and make predictions
3. Use the same model to predict SSH and CDA Tsub timeseries

Hindcasts

Mahajan et al (2011)
AR2 Validation

Mahajan et al (2011)
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