Impact of Low Frequency Variability of the Atlantic Ocean on Arctic Sea Ice Extent

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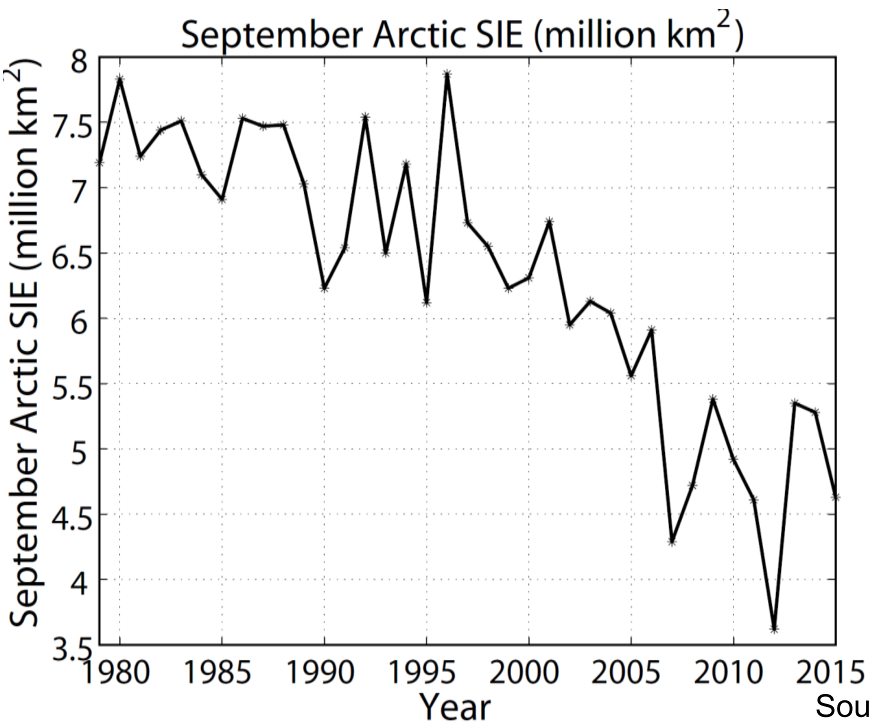
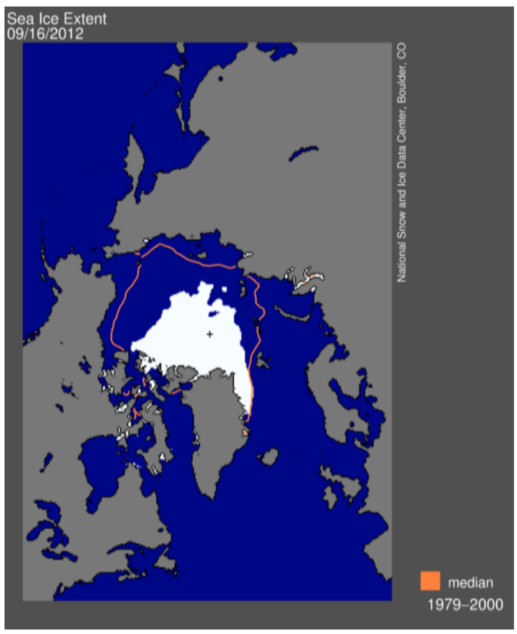
Introduction

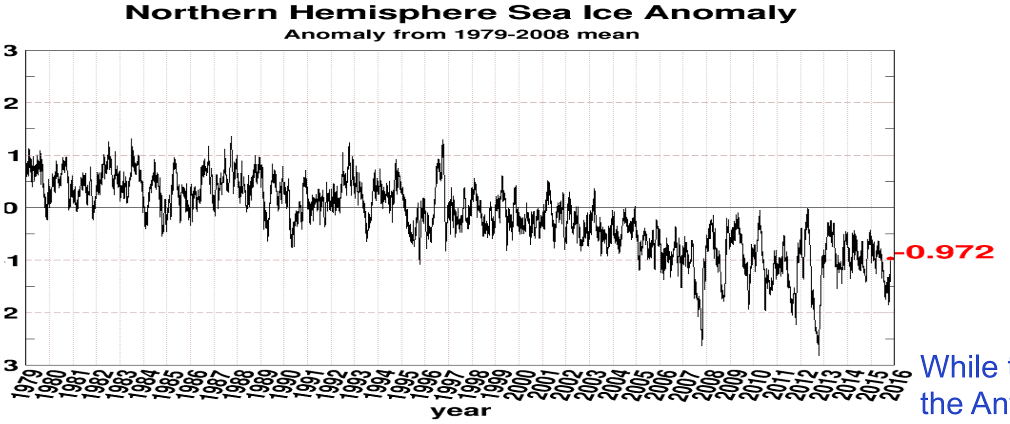


09/16/2012



Source: NSIDC

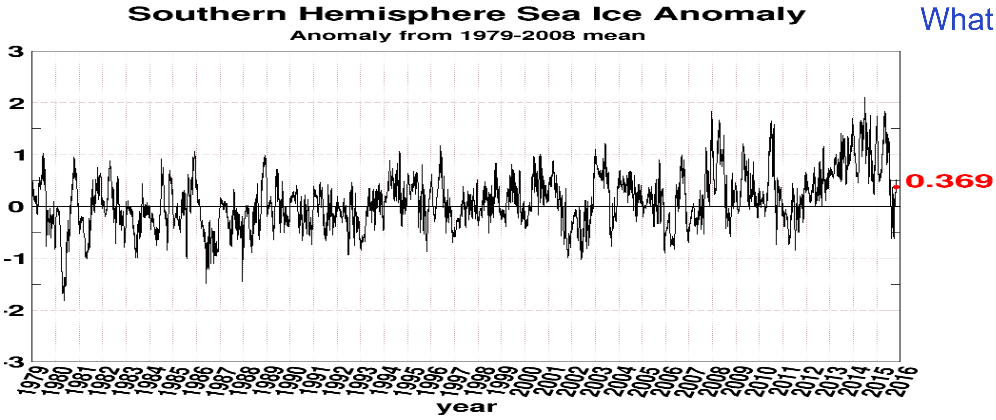
Satellite observations reveal a substantial decline trend in September Arctic sea ice extent since 1979, which has often been attributed in large part to the increase in greenhouse gases



UIUC, Cryosphere Today

While the Arctic sea ice extent (SIE) dec
the Antarctica sea ice extent (SIE) incre
since 1979.

What causes the opposite trends?



Observed Multidecadal Variations in Arctic SAT

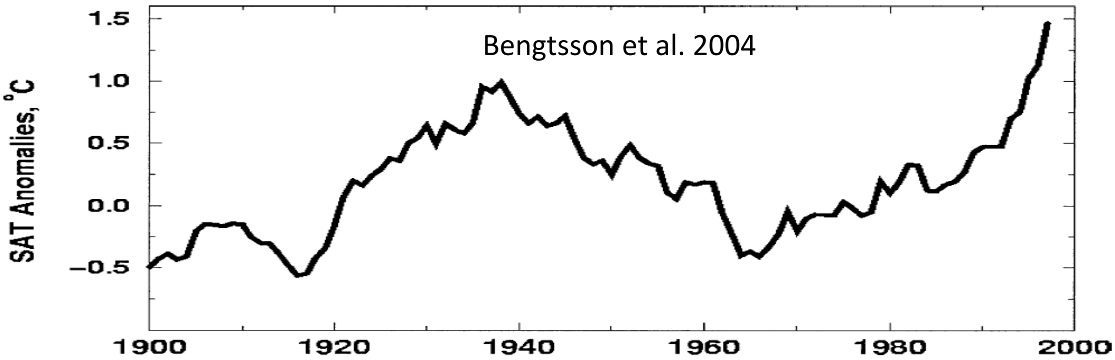
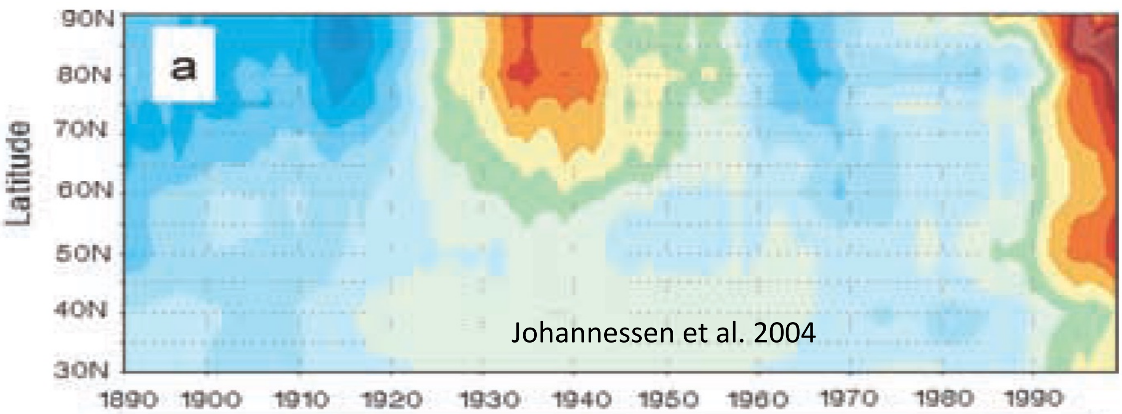
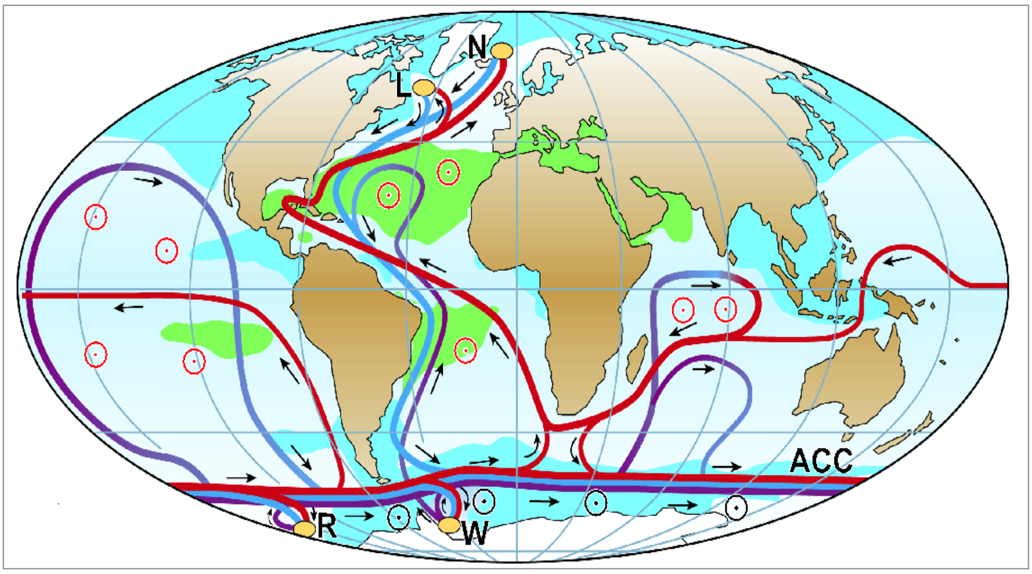


FIG. 1. Annual mean Arctic SAT anomalies (°C, area averaged from 60°–90°N) from Johannessen et al. (2004), 5-yr running mean.



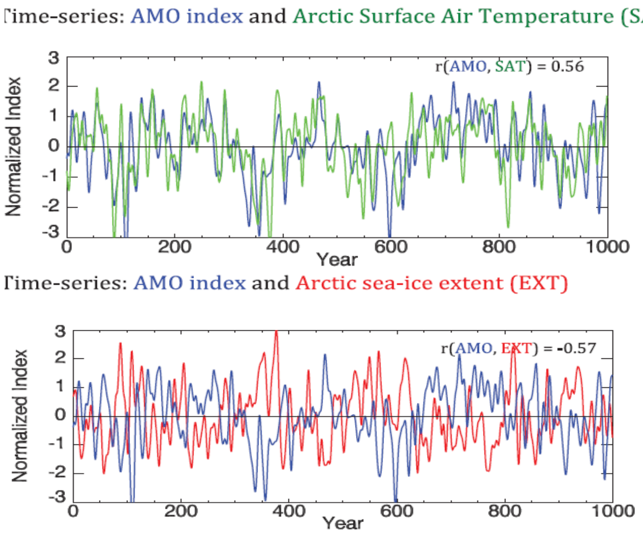
Atlantic Meridional Overturning Circulation (AMOC)



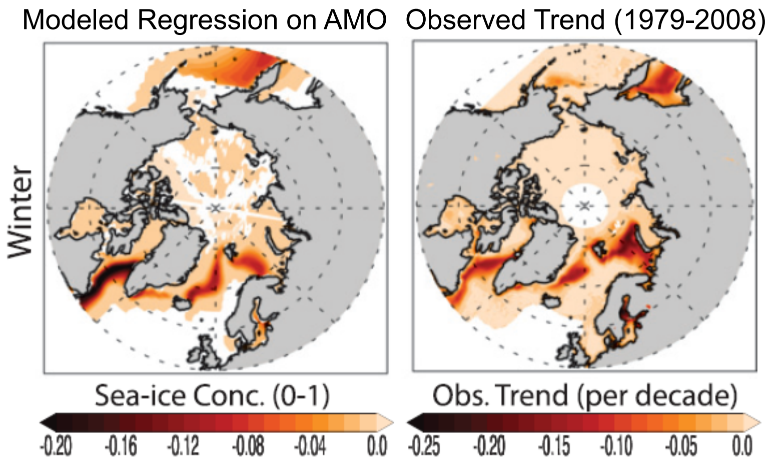
Kuklbrodt et al. 2007

What is the role of low frequency AMOC variability
in the observed Arctic sea ice decline since 1979?

Impact of AMOC on Winter Arctic Sea Ice Variability



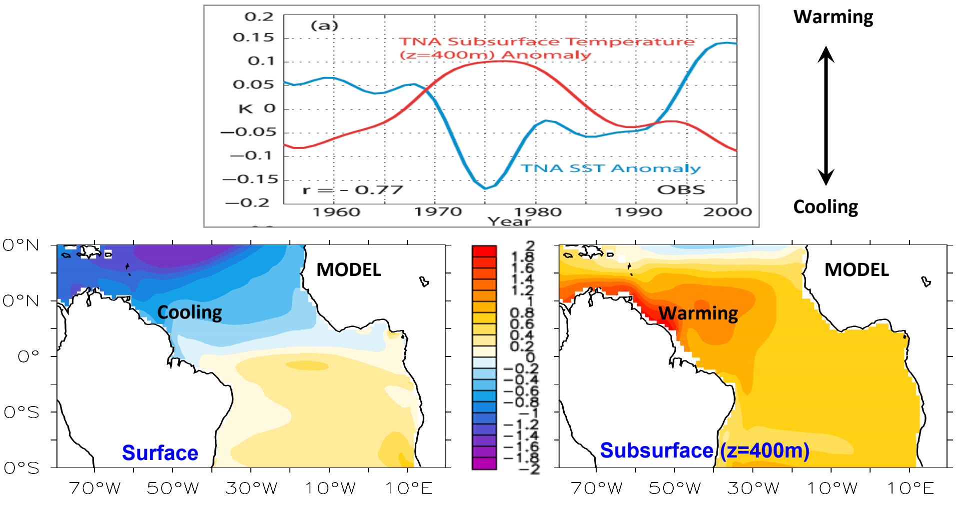
GFDL CM2.1 1000-year control simulation



(Mahajan, Zhang, and Delworth, 2011)

- Winter Arctic sea ice in the Atlantic side declines with an intensified AMOC
- Similar spatial patterns suggest a possible role of the AMOC in the observed sea ice decline
- The anti-correlation between AMO and winter Arctic sea ice is also found in other CMIP3 models (Day et al. 2012) and paleo records (Miles et al. 2014)

Tropical Fingerprint of AMOC Variations



Ocean temperature anomaly due to the weakening of AMOC from GFDL CM2.1 water hosing experiment

Zhang, 2007

The weakening of the AMOC lead

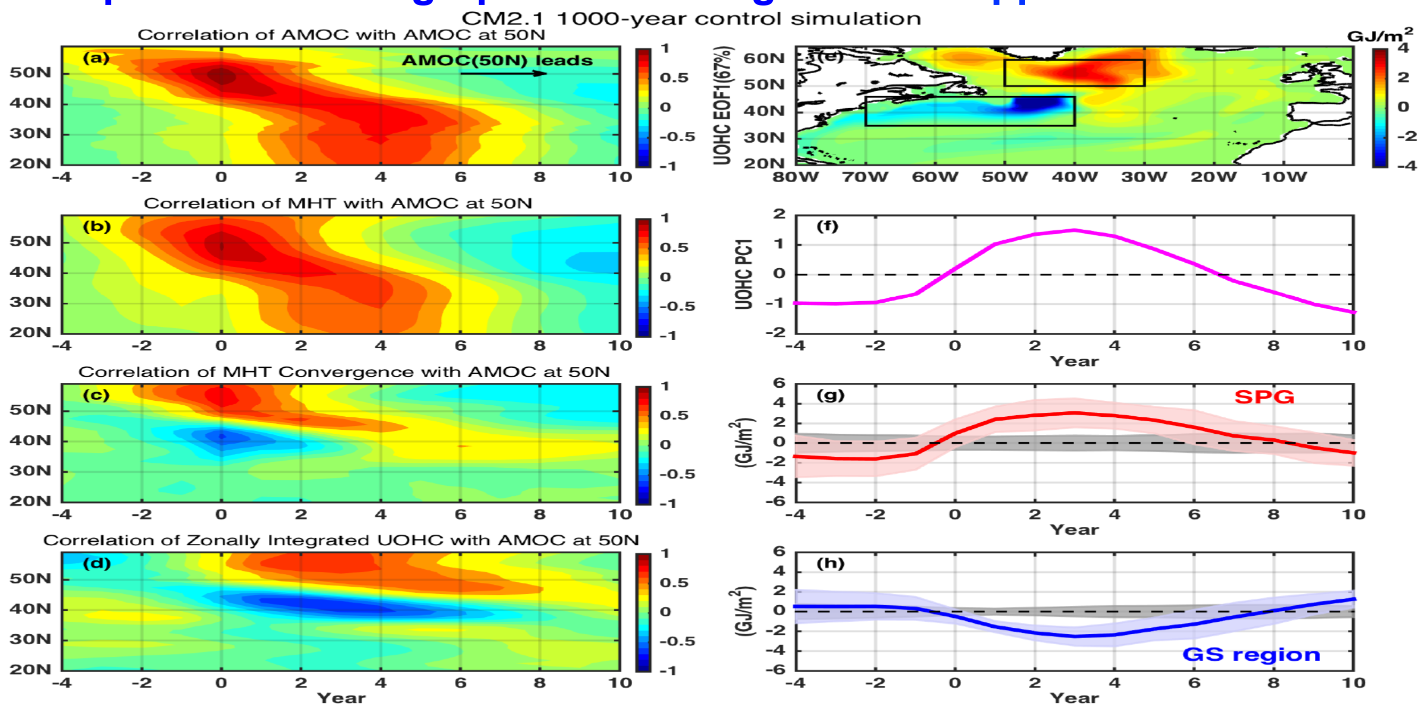
- A southward shift of the Intertro Convergence Zone (ITCZ) and surface cooling
- Thermocline deepening/weake western boundary current and subsurface warming in the TNA

Observed Tropical North Atlantic (TNA) SST is anti-correlated with TNA subsurface ocean temperature

The anti-correlated variations is shown to be a fingerprint of AMOC variations, suggesting the AMOC was weakened during the 70's and strengthened since then

The AMOC induced anti-correlated TNA surface and subsurface temperature variations are also found in CMIP5 mode (Wang and Zhang, 2013) and paleo records (Schmidt et al. 2012, PNAS)

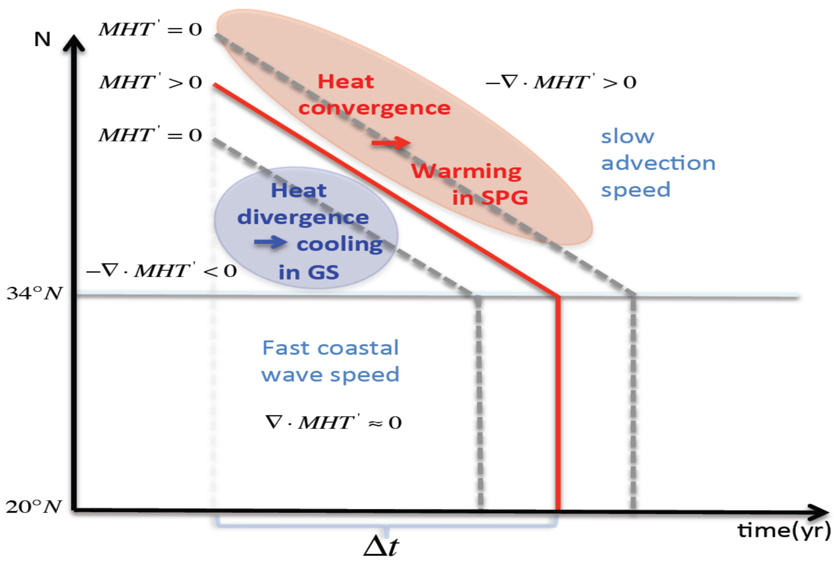
xtra-tropical AMOC Fingerprint – Leading Mode of Upper Ocean Heat Cont



Zhang and Zhang, 2015

Similar southward AMOC propagation also exists in isopycnal coordinate model GFDL CM2G (Wang et al., 2015), and high-resolution models GFDL CM2.5 (Zhang et al., 2011) and UK HiGEM (M. Thomas, personal communication, 2015)

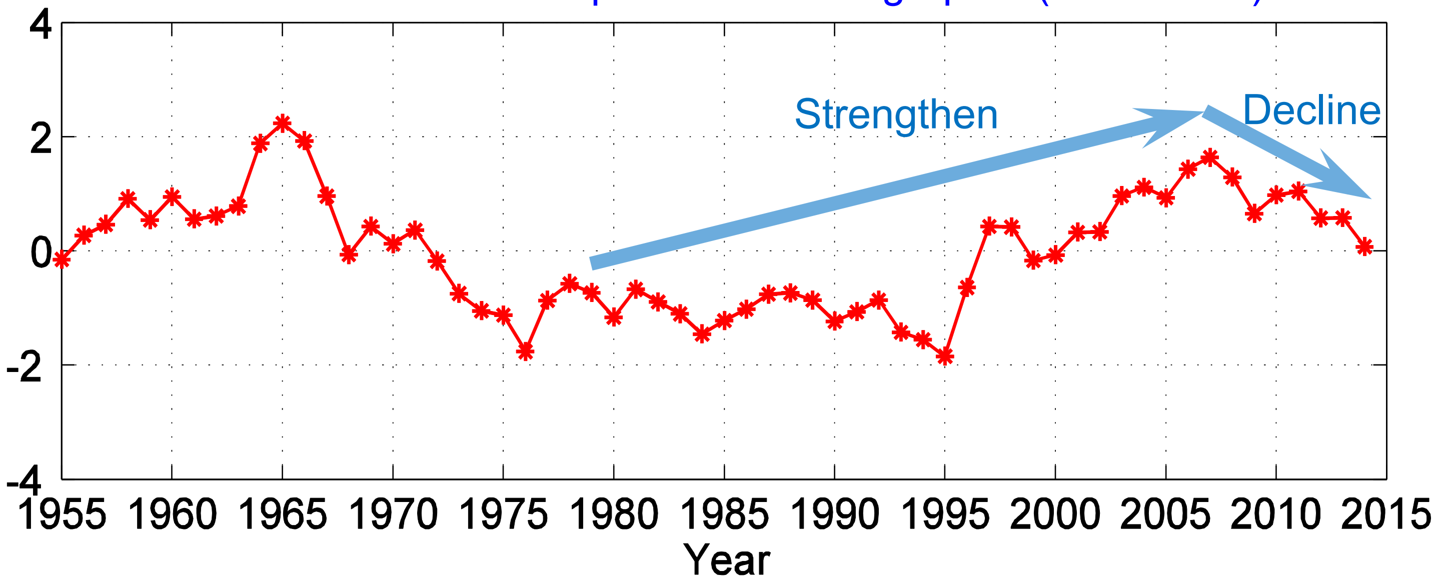
Schematic Diagram for the Mechanism of the Evolution of the AMOC Fingerprint



Zhang and Zhang, 2015

slow propagation of the AMOC anomaly is crucial for the evolution and the enhanced decadal predictability of the AMO
erprint, consistent with recent decadal prediction studies that successfully predicted the warm shift in the North Atlantic S
ng the mid 1990s by initializing a stronger AMOC at northern high latitudes (Robson et al., 2012; Yeager et al., 2012; Ya
2013; Msadek et al., 2014)

Observed Extra-tropical AMOC Fingerprint (1955-2014)



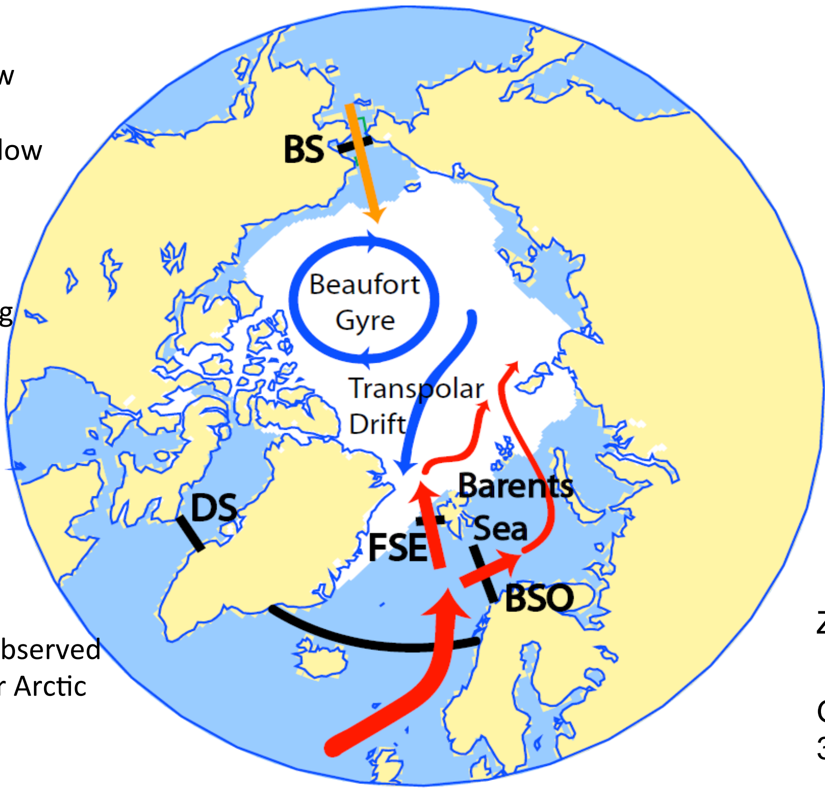
Mechanisms for Low Frequency Variability of Summer Arctic Sea Ice Exte

\rrow: Atlantic Inflow

ge Arrow: Pacific Inflow

Barents Sea Opening
East Fram Strait
)avis Strait
ering Strait

e color represents Observed
ıtological September Arctic
ver 1979-2013

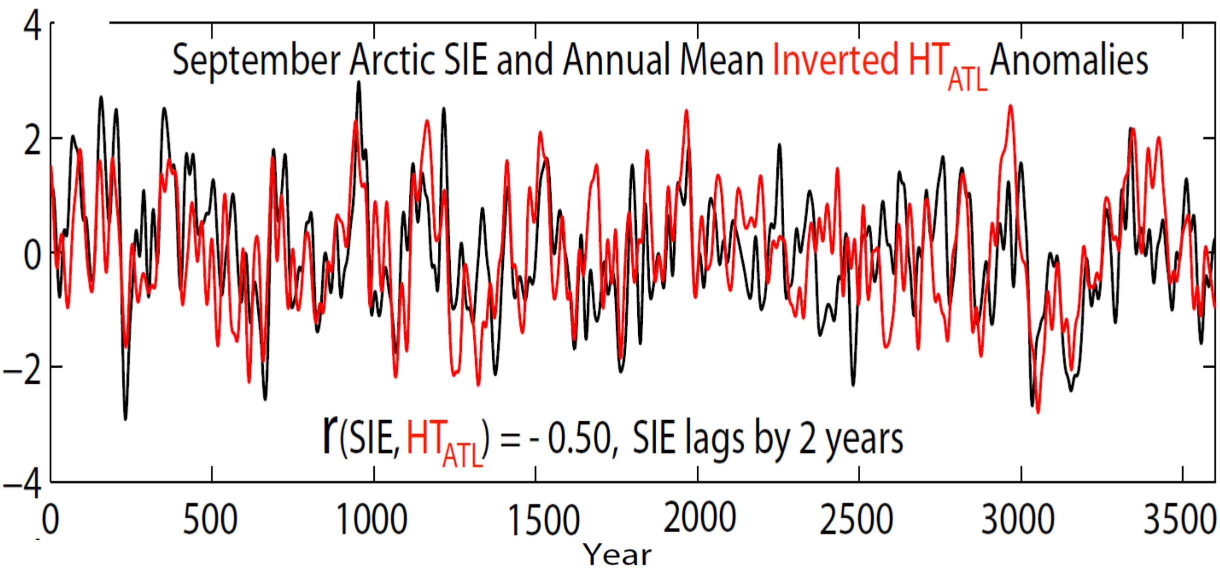


The Atlantic inflow enters the
mainly through the Iceland-
Scotland Ridge and further spl
into two main branches:
one enters the Barents Sea acı
the Barents Sea Opening (BSO
the other flows northward as t
West Spitsbergen Current acrc
the east Fram Strait (FSE);
both eventually reach central /

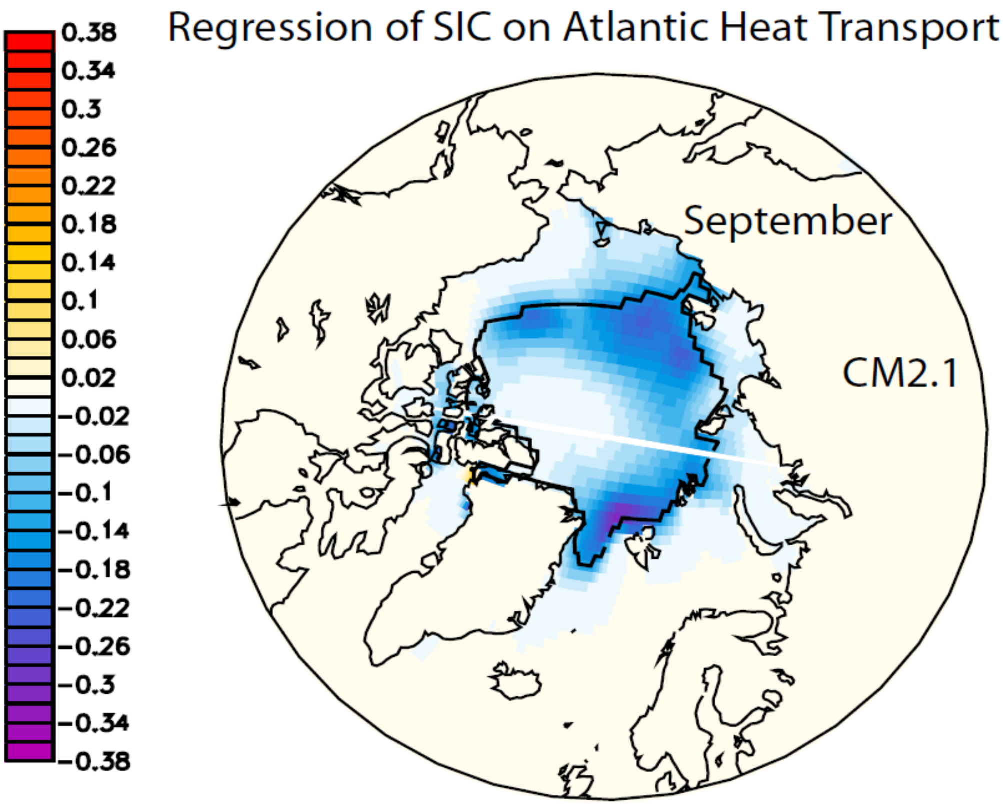
Zhang, 2015, PNAS

GFDL CM2.1
3600-year Control Simulatior

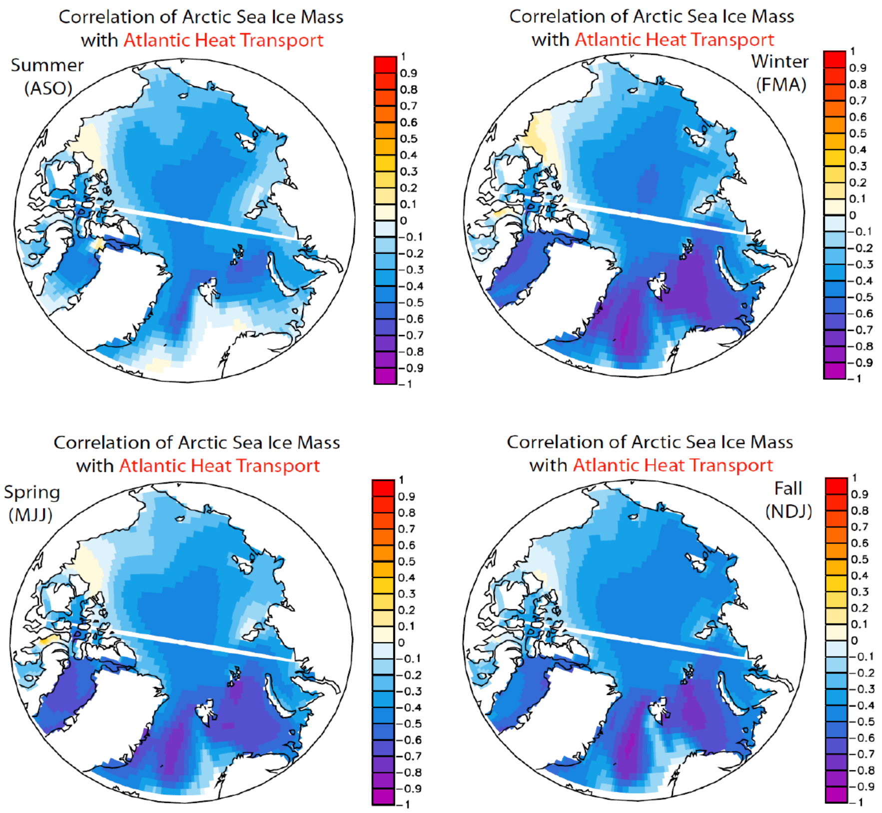
HT_{ATL} : Northward Atlantic Heat Transport across the Arctic Circle



GFDL CM2.1   3600-year Control Simulation



Impact of Atlantic heat transport on Arctic Sea Ice Mass at All Seasons



Schematic of Main Gateways of Atlantic and Pacific Inflow Entering the Arctic and Arctic Ocean Circulation

rrow: Atlantic Inflow

ge Arrow: Pacific Inflow

Barents Sea Opening
East Fram Strait
avis Strait
ering Strait

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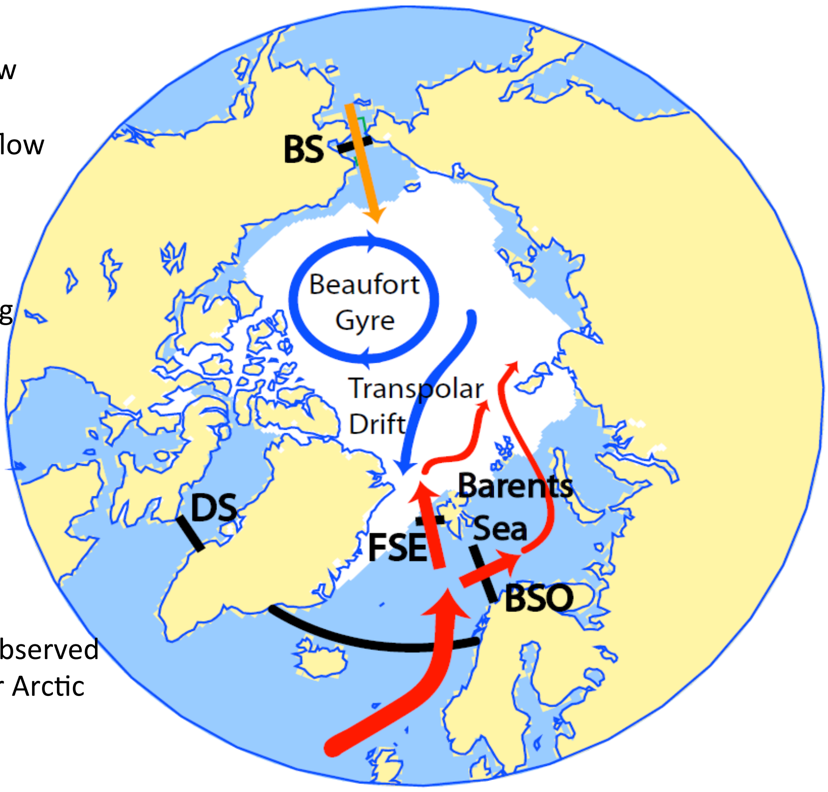

The Atlantic inflow enters the mainly through the Iceland-Scotland Ridge and further spl into two main branches:
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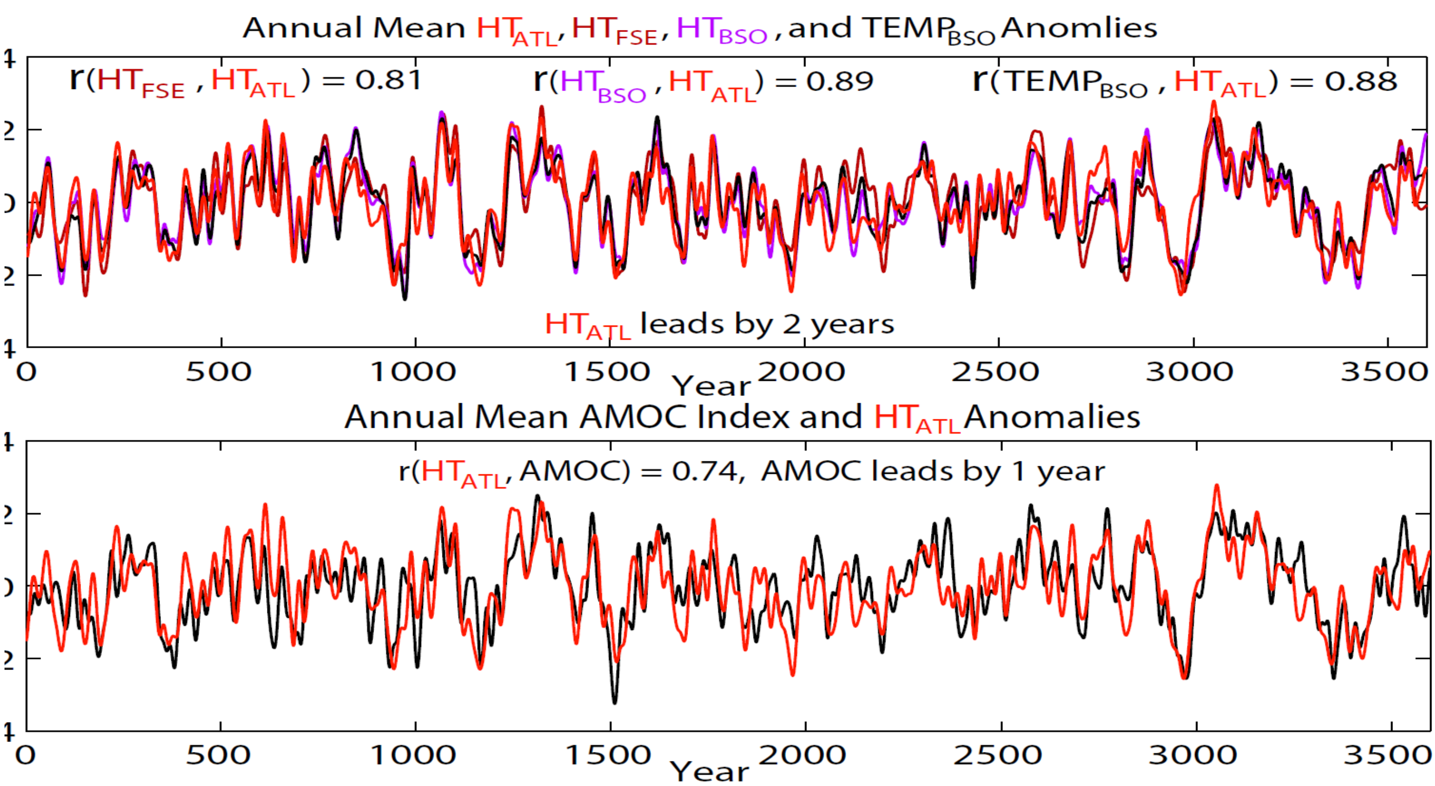
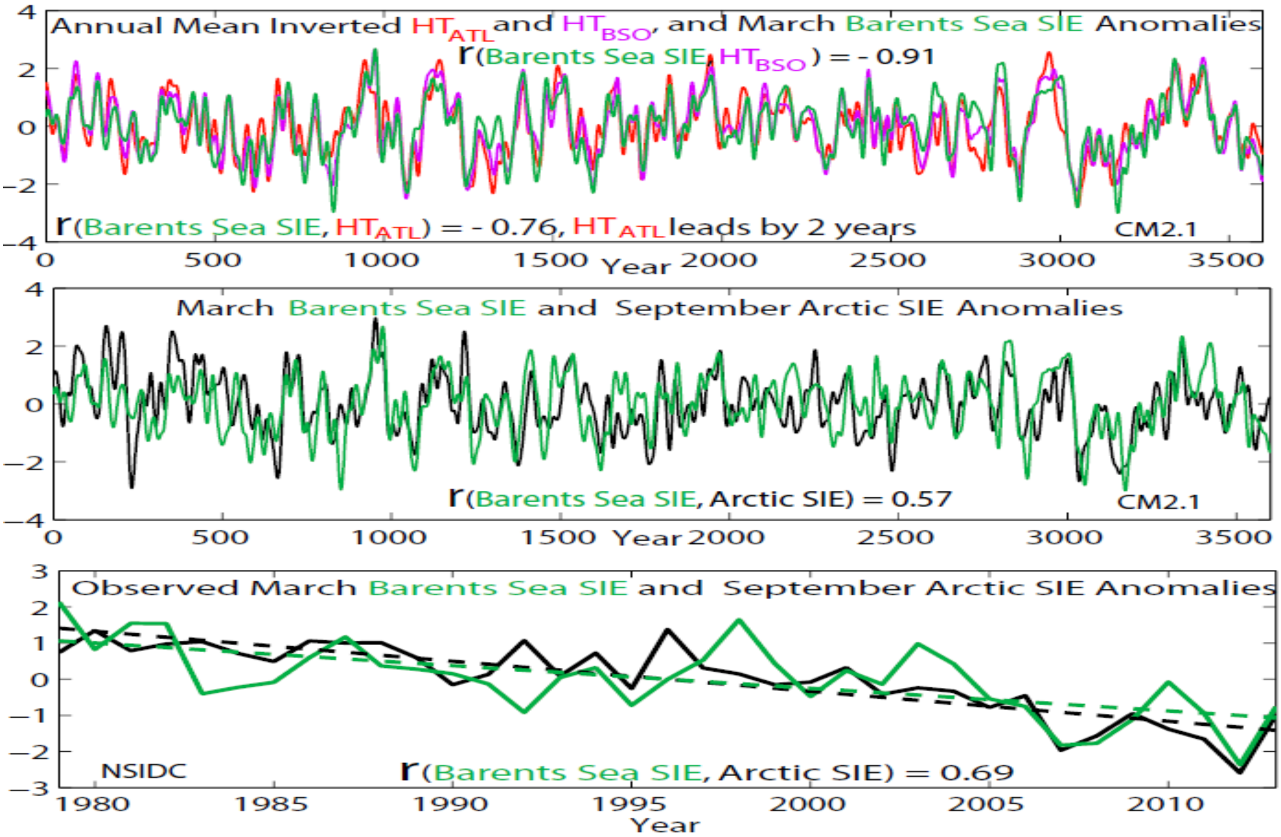


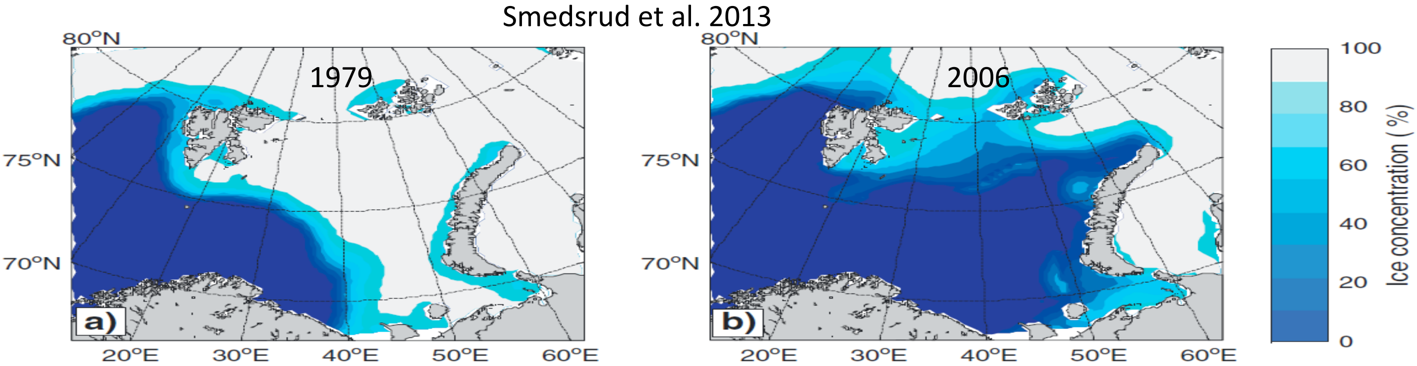
HT_{BSO} : Eastward Heat Transport across BSO; HT_{FSE}: Northward Heat Transport across FSE
$TEMP_{BSO}$: averaged Atlantic Water temperature at 200m along BSO
AMOC index : maximum of Atlantic meridional overturning streamfunction at 45^{o}N in density space

Linkage with March Barents Sea SIE Variability

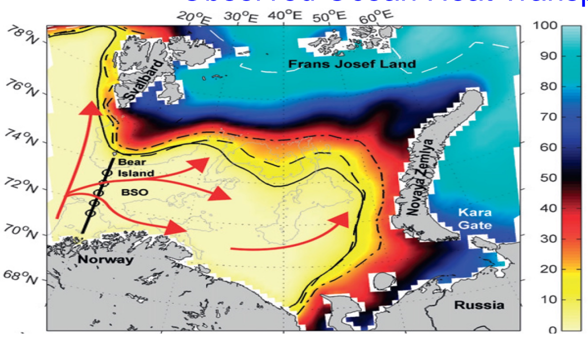


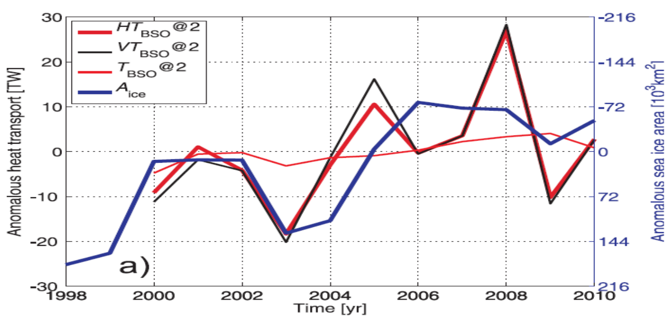
Observed (NSIDC) Barents Sea Ice Concentration in Late Winter (March-April)

Smedsrud et al. 2013



Observed Ocean Heat Transport across Barents Sea Opening (HT_{BSO})

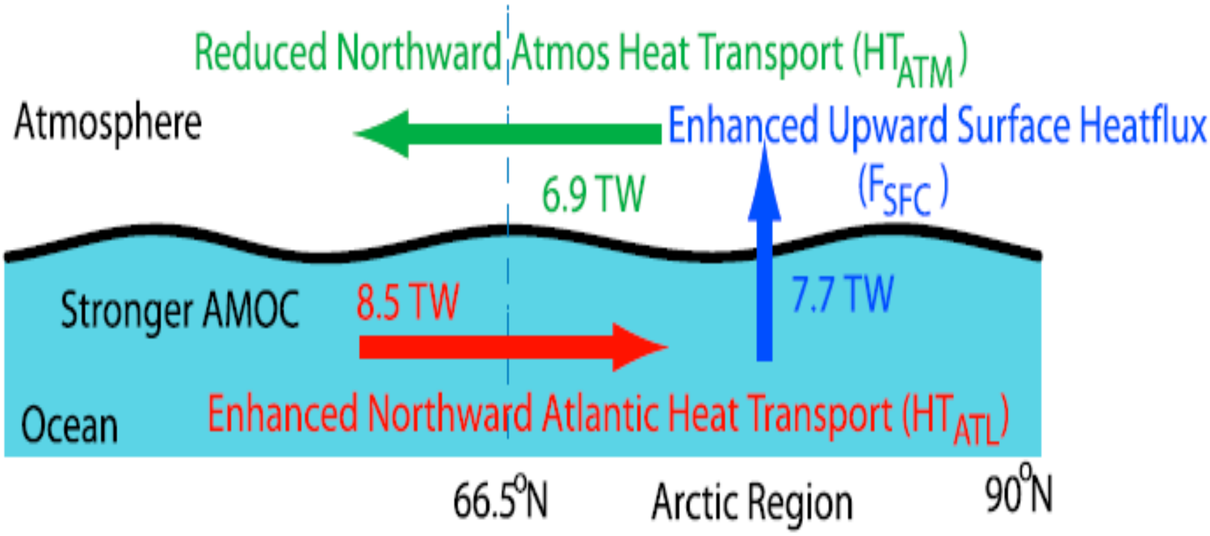




A rthun et al. 2012

The observed increase in HT_{BSO} is also found as a prime driver for the observed sea ice decline in Barents

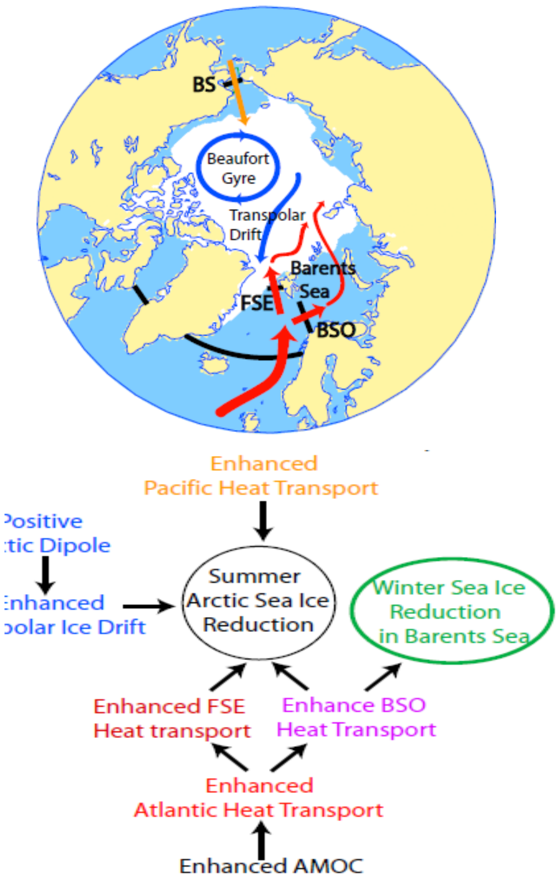
Response of Atmosphere Heat Transport

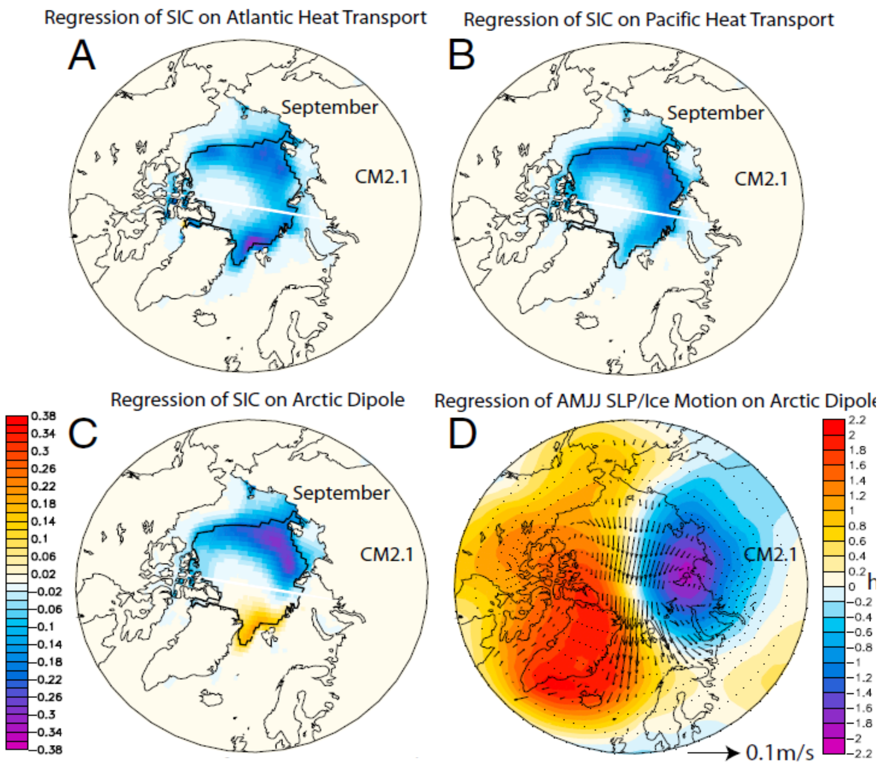


The Bjerknes compensation (Bjerknes, 1964) has been found at decadal time scale (Shaffrey & Sutton, 2(Jungclaus & Koenigk, 2010; Farneti and Vallis, 2013)

At multidecadal/centennial time scale, the coherences among HT_{ATL}, Arctic SHF, and inverted HT_{ATM} are r higher than those at decadal time scale

Changes in HT_{ATM} are forced by anti-correlated changes in HT_{ATL} thus provide a negative feedback to September Arctic SIE variations





Summary and Discussions

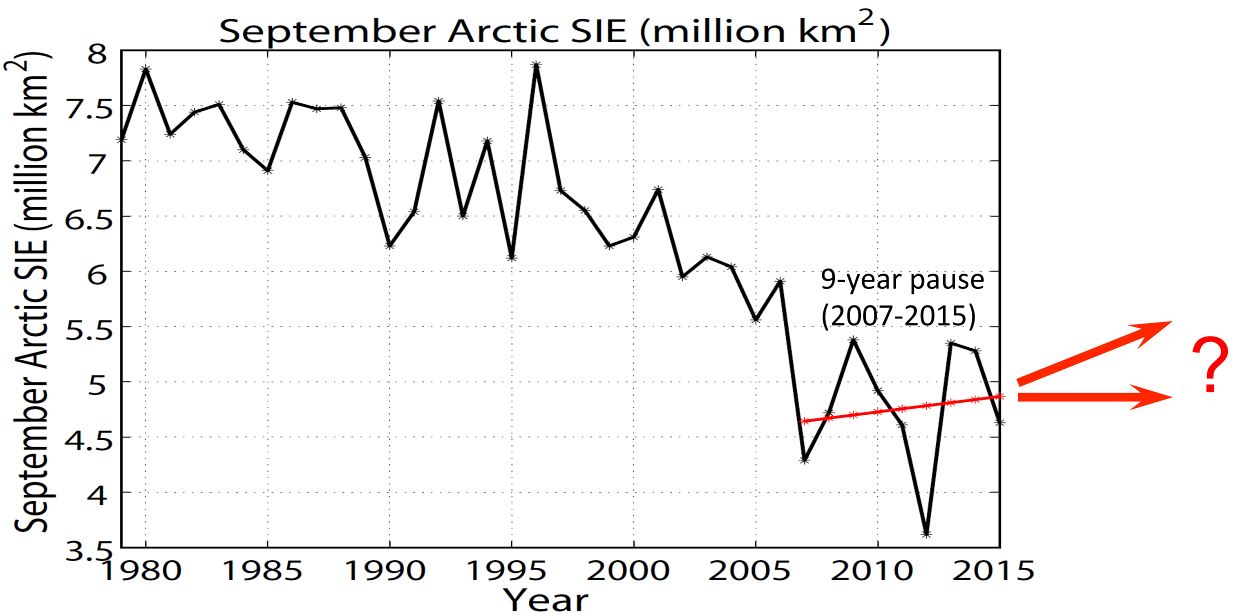
The AMOC variability and the associated Atlantic heat transport into the Arc ıave played a significant role in the low frequency variability of summer Arctic SI

Summer Arctic SIE variations are significantly correlated with winter SIE variatio n Barents Sea in both modeled results and observations, indicating the importa ole of the Atlantic heat transport into the Arctic

AMOC fingerprints indicate a strengthening of AMOC since mid 70's, consiste with the observed decline of Arctic sea ice

At low frequency, changes in atmosphere heat transport into the Arctic are forc by anti-correlated changes in the Atlantic heat transport into the Arctic, th provide a negative feedback to changes in summer Arctic SIE

Enhanced Pacific heat transport into the Arctic and Positive Arctic Dipole also contribute to summer Arctic sea ice decline



Very recent study identified a 7-year pause (2007-2013) in summer Arctic sea ice decline (Swart et al. 2015). If the AMOC continues to weaken in the near future, there might be a longer *hiatus* in the September Arctic SIE decline