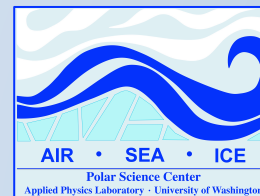


# ***Trends in momentum transfer into the Arctic Ocean and the concept of optimal ice concentration***

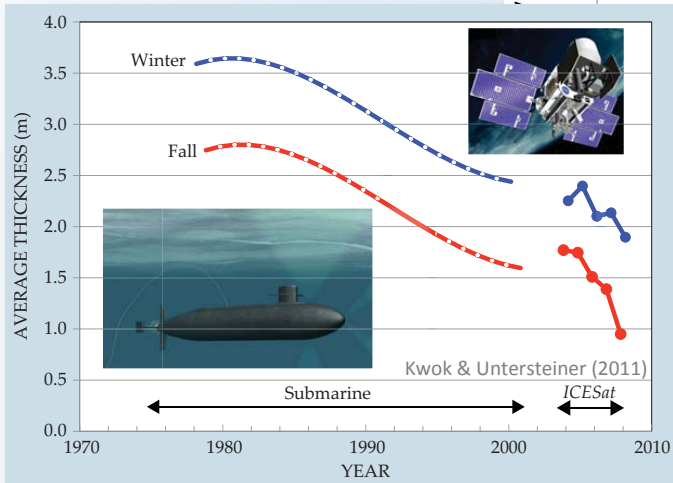
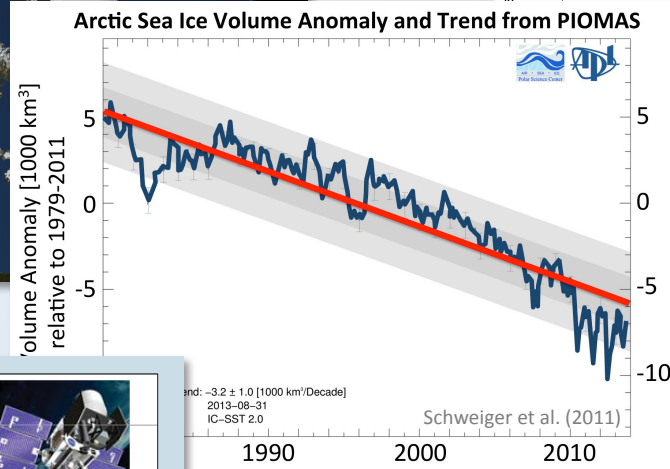
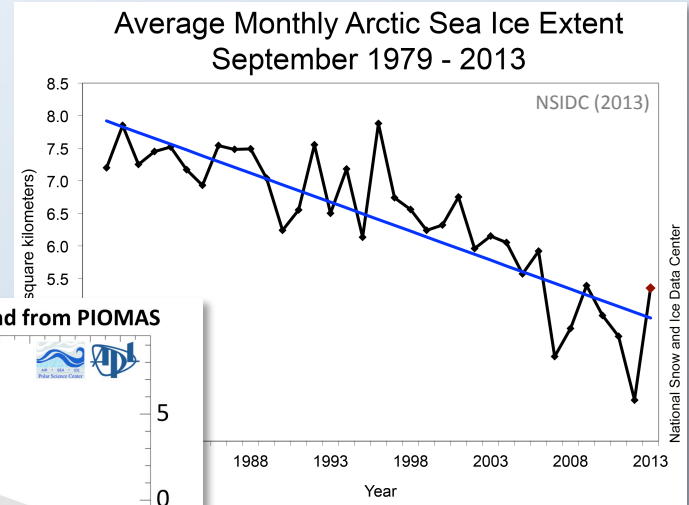
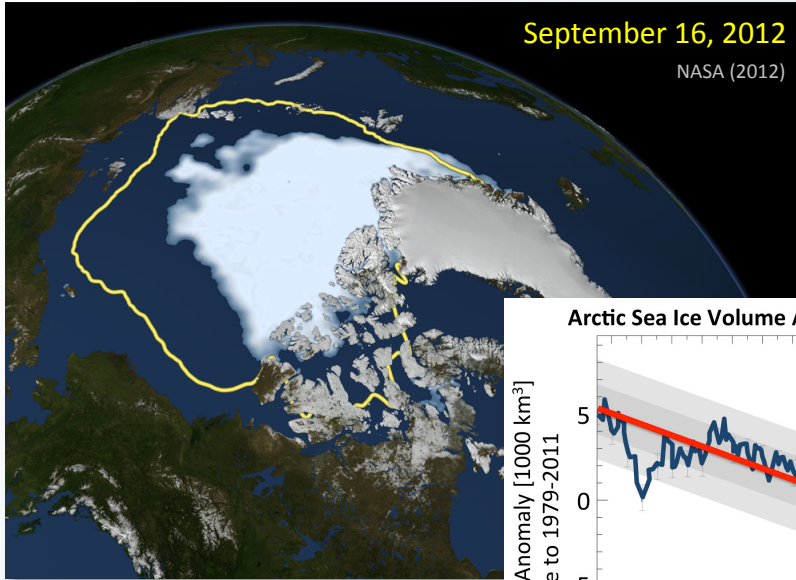
**Torge Martin, Mike Steele, and Jinlun Zhang**

*Polar Science Center, Applied Physics Lab, University of Washington*

2<sup>nd</sup> FAMOS workshop  
Woods Hole  
October 23, 2013



# The Arctic sea ice cover is shrinking

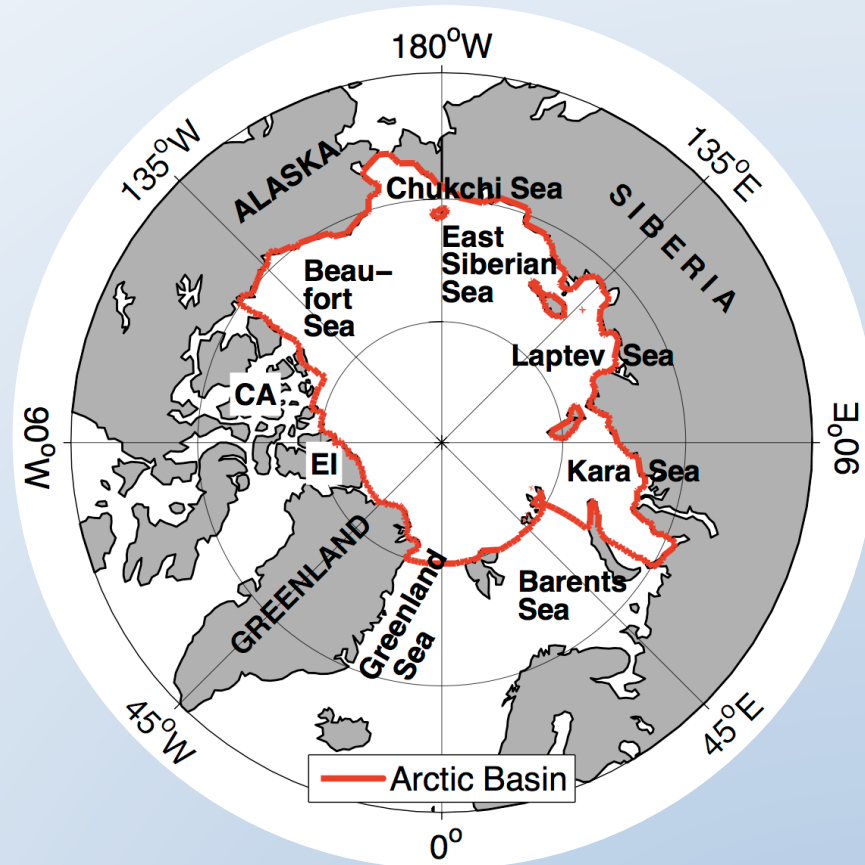


***Does this mean the momentum flux into the Arctic Ocean is increasing?***

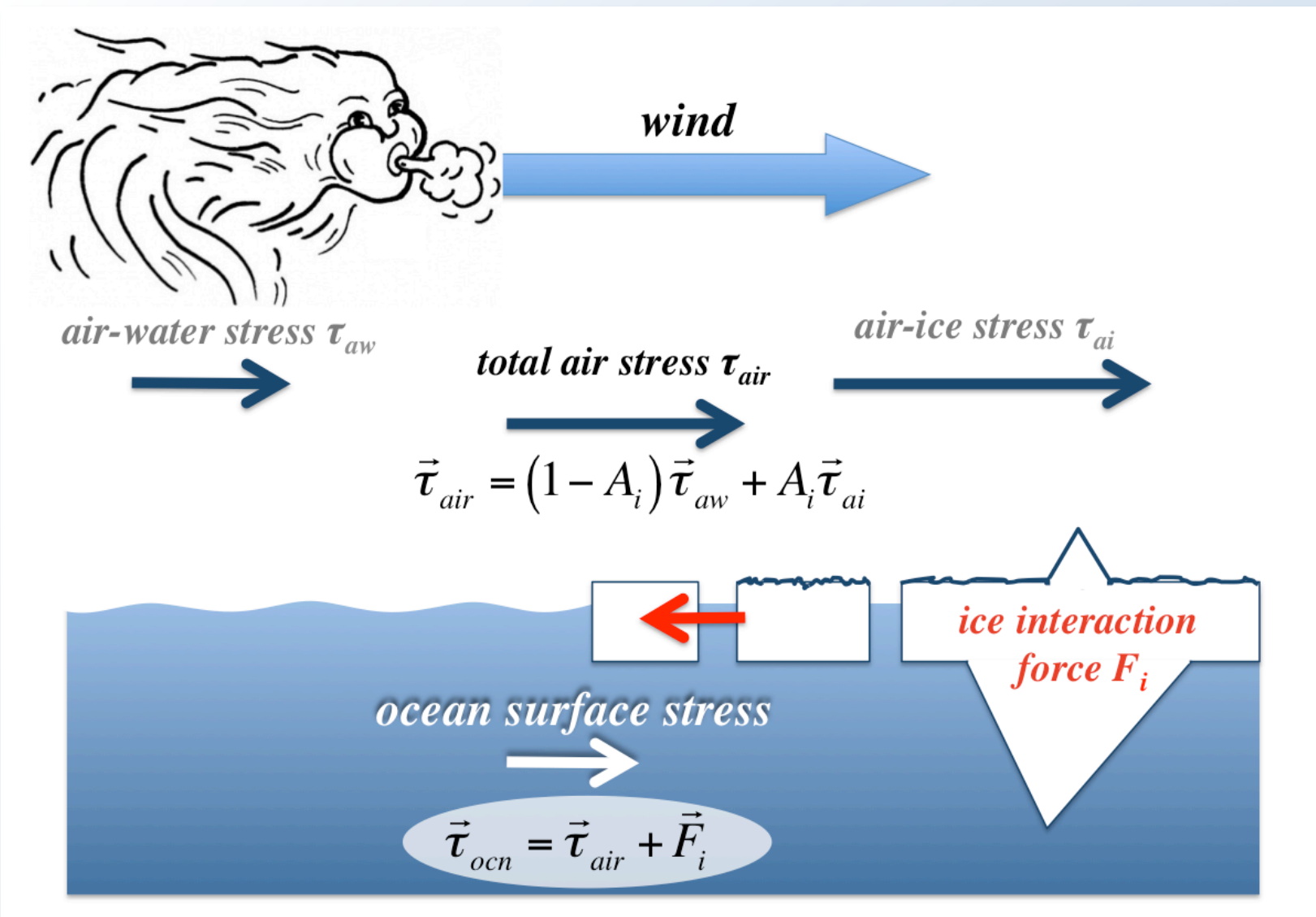


# A model study

- **PIOMAS**: Pan-arctic Ice Ocean Model and Assimilation System  
(*Zhang and Rothrock, 2003*)
- **1979-2012**, daily output
- grid covers area north of  $43^{\circ}\text{N}$ , horizontal resolution  $\sim 22$  km, 30 vertical ocean levels, 12 ice/snow categories
- NCEP/NCAR forcing
- **atmospheric surface layer model as used by CCSM**
- assimilation of sea ice edge provided by NSIDC  
(*Nolin et al., 1998*)
- **embedded sea ice** (*Hibler and Bryan, 1987*)



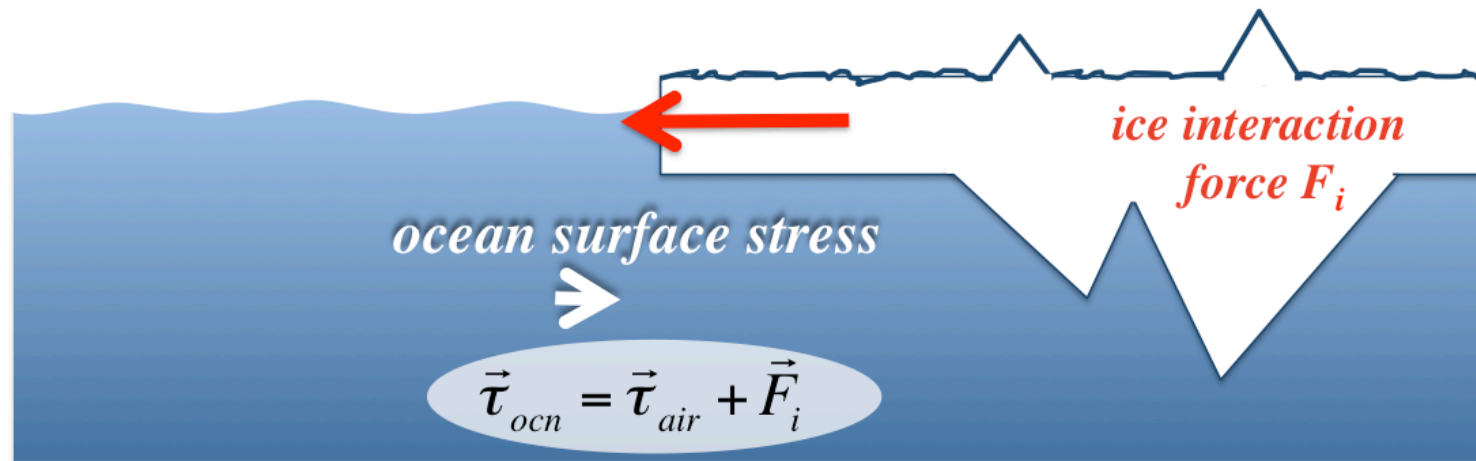
# What affects momentum transfer into the ocean?



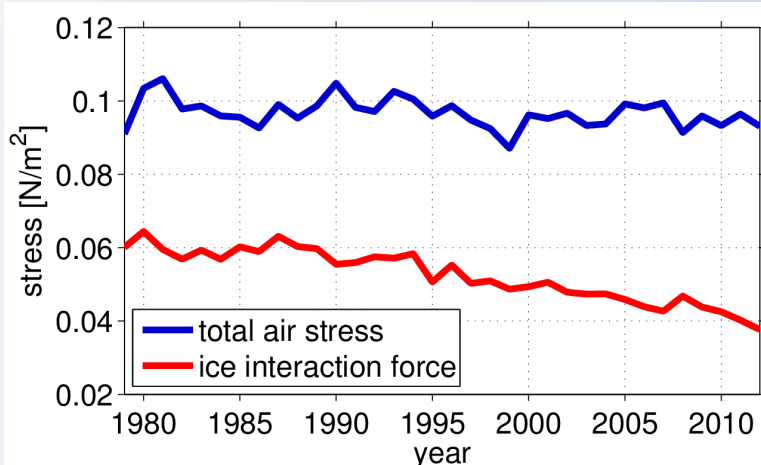
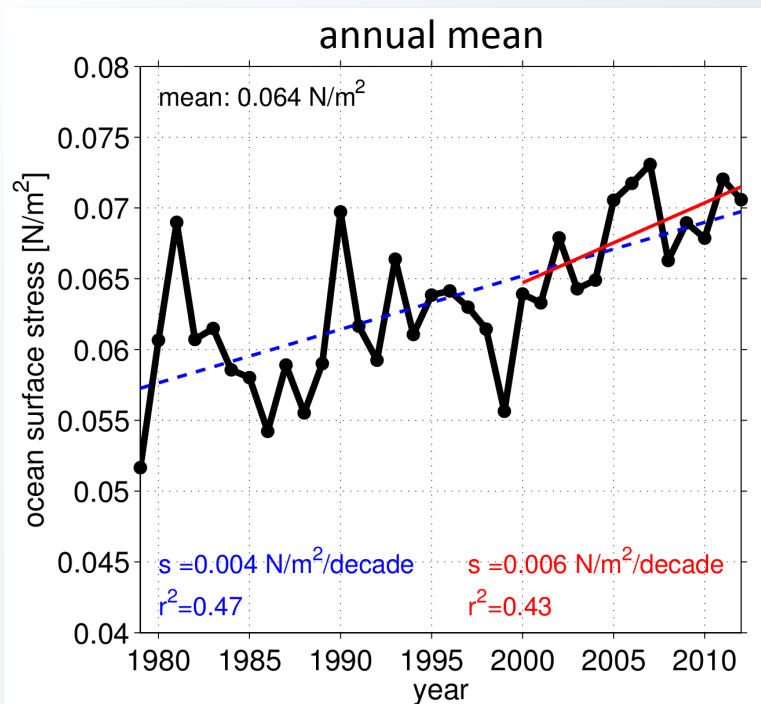
# What affects momentum transfer into the ocean?



*While the surface **wind** is the ultimate **source** of momentum, **sea ice** effectively **moderates** the momentum **transfer**.*



# Arctic Basin mean ocean surface stress trend



**winter:**

0.0054 N/m<sup>2</sup>/decade

**spring:**

0.0051 N/m<sup>2</sup>/decade

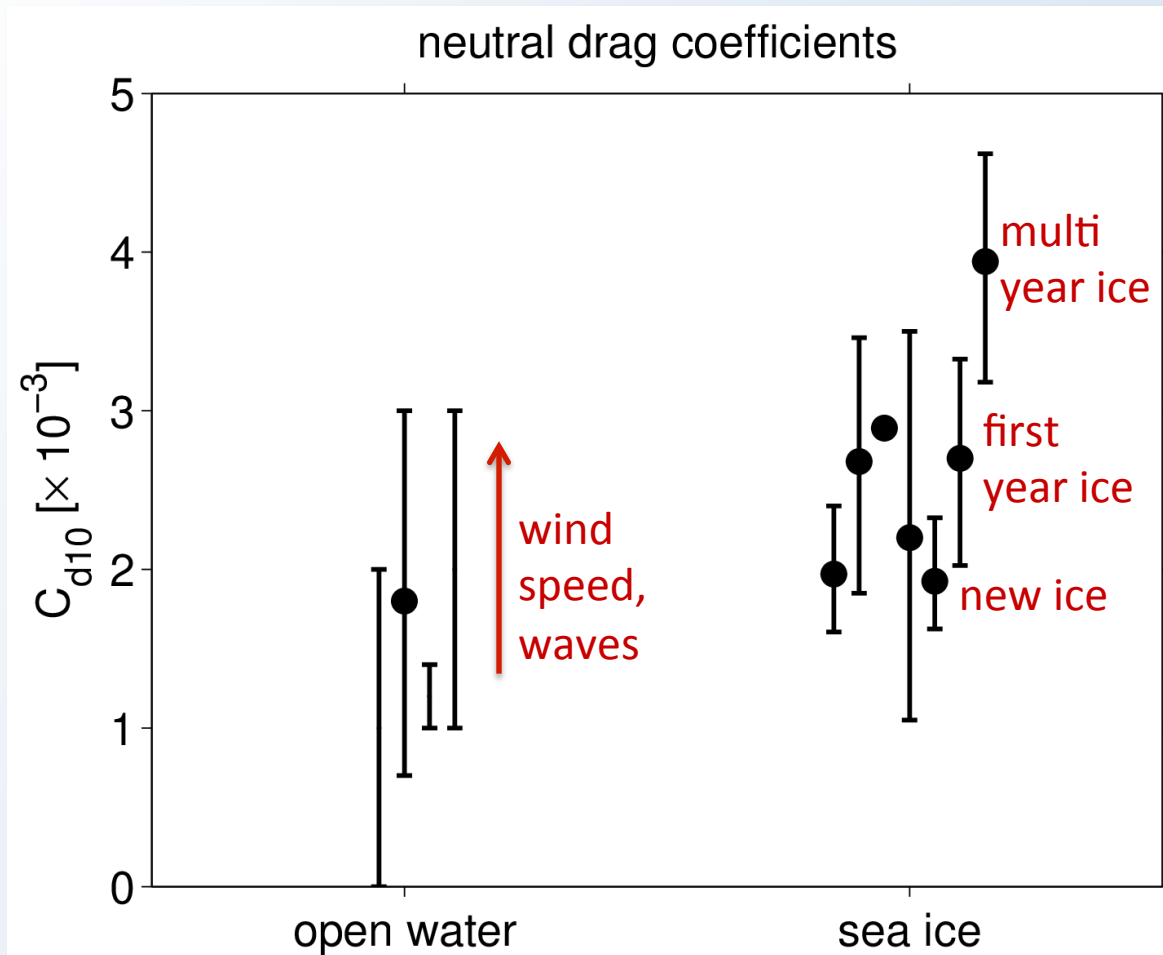
**fall:**

0.0069 N/m<sup>2</sup>/decade



*decline in  
ice interaction force  
causes increase in  
momentum transfer*

# Open water vs. sea ice surface roughness

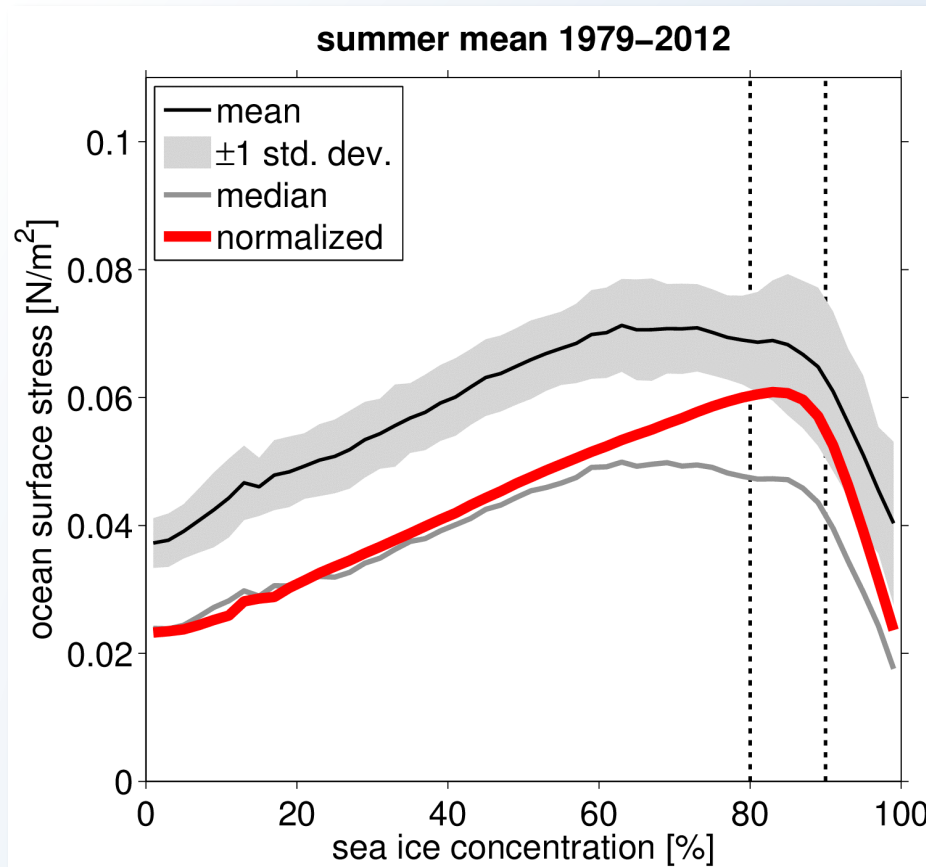


Data from:  
 Anderson (1987)  
 Guest and Davidson (1987, 1991)  
 Kara et al. (2007)  
 Lüpkes and Birnbaum (2005)  
 Schröder et al (2003)  
 Smith (1988)  
 Taylor et al. (2001)

***On average sea ice is rougher than open water***

# The concept of optimal ice concentration

... optimal for **maximal** momentum transfer into ocean

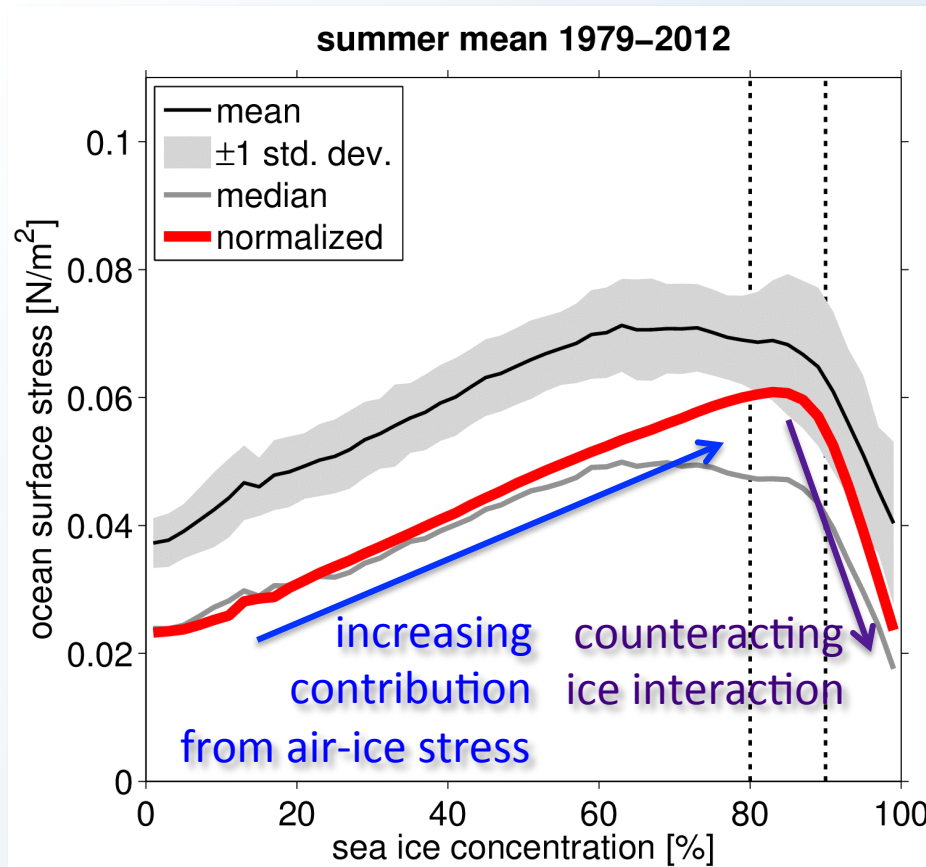


***Ice concentrations of 80-90% are optimal for maximizing momentum input into the ocean***



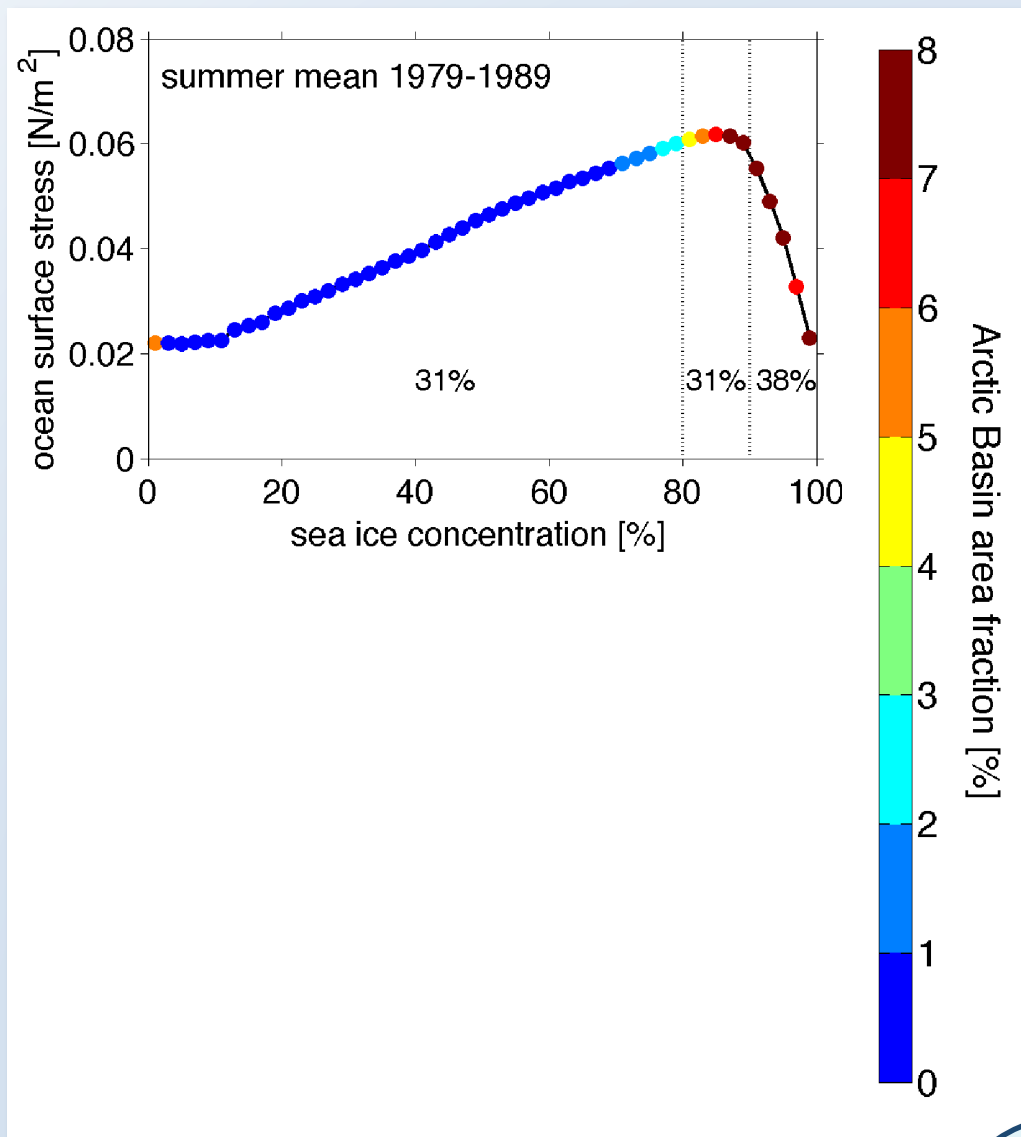
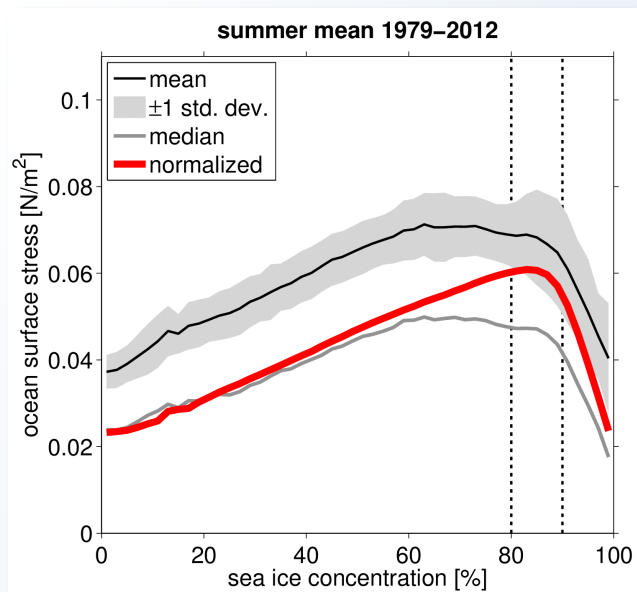
# The concept of optimal ice concentration

... optimal for **maximal** momentum transfer into ocean



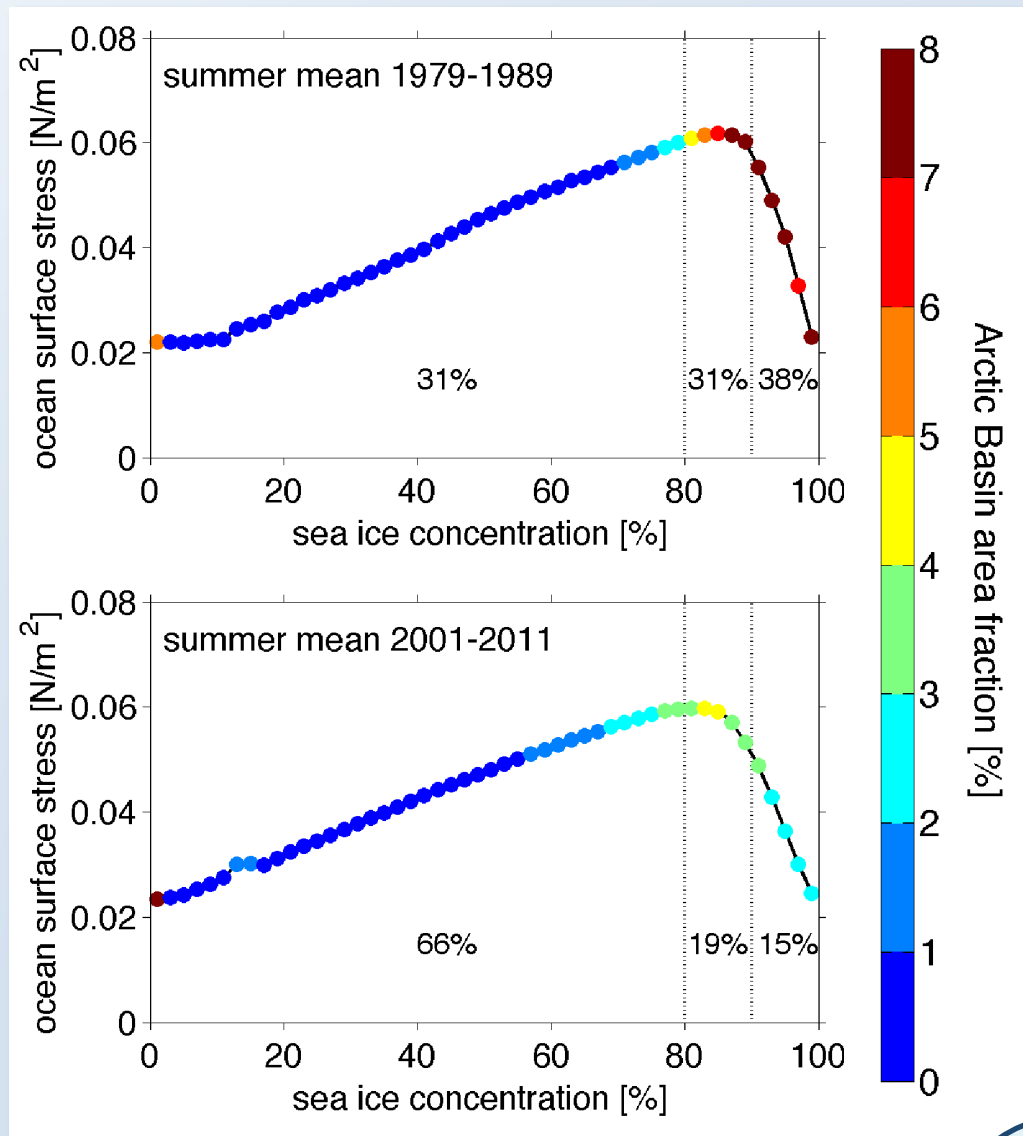
**Ice concentrations of 80-90% are optimal for maximizing momentum input into the ocean**

# Sea ice retreat and optimal ice concentration



# Sea ice retreat and optimal ice concentration

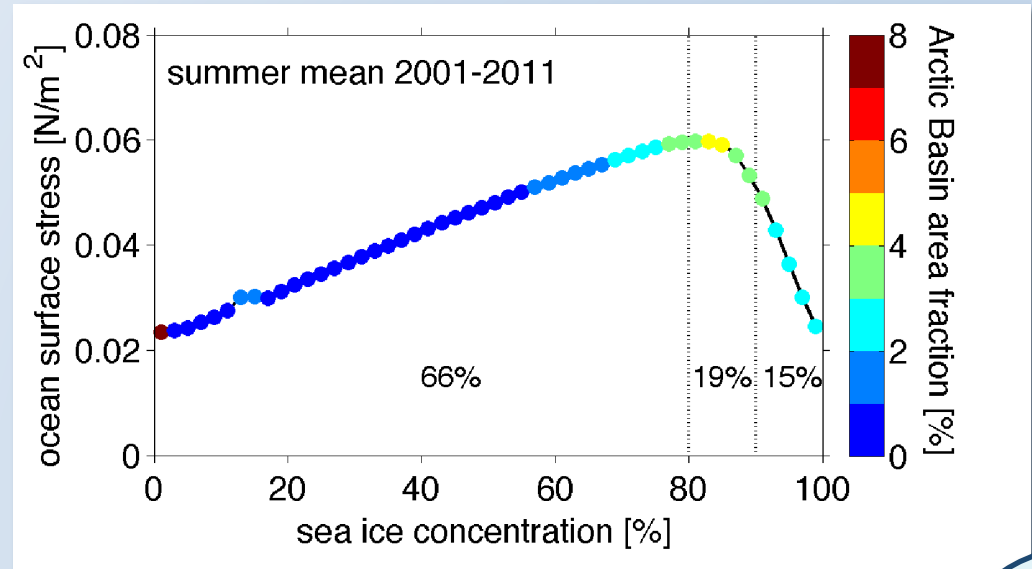
- In the **1980s** the Arctic ice pack was on the “compact side” – too compact for optimal ice concentration and maximal momentum transfer
- In the **2000s** the pack ice is very loose – too loose for being optimal for momentum transfer



# Sea ice retreat and optimal ice concentration

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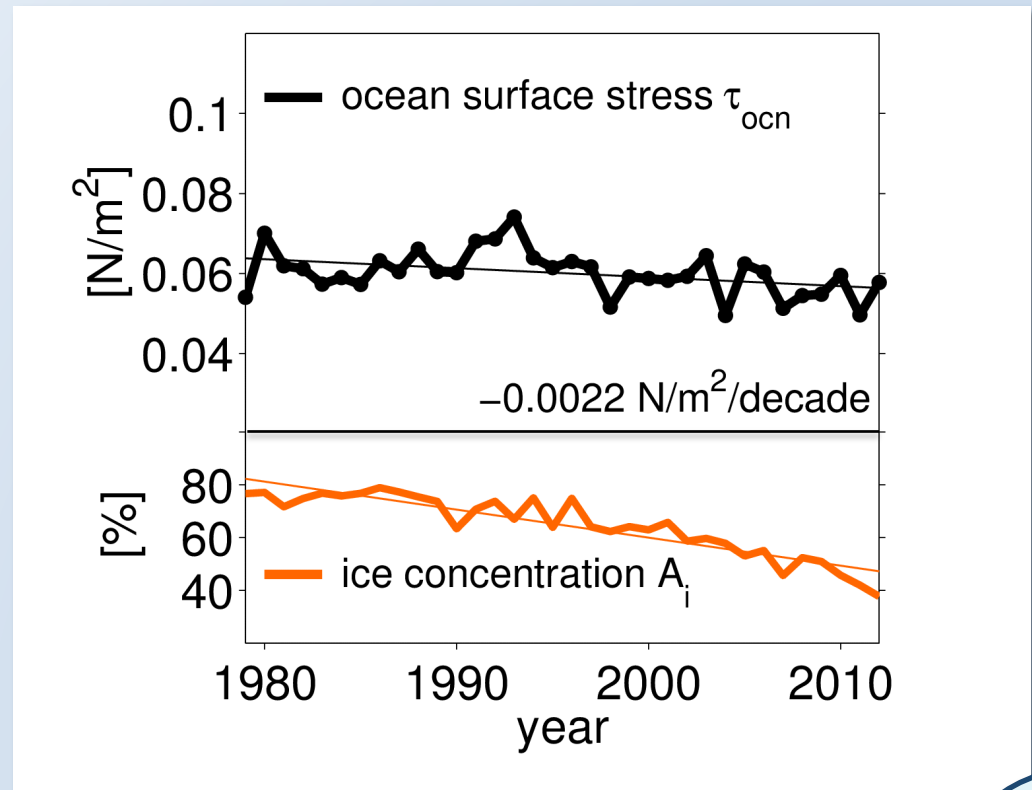
*Meaning that in a “new” Arctic less momentum must be transferred into the ocean during summer ...*



# Sea ice retreat and optimal ice concentration

*Meaning that in a “new” Arctic less momentum must be transferred into the ocean during summer ...*

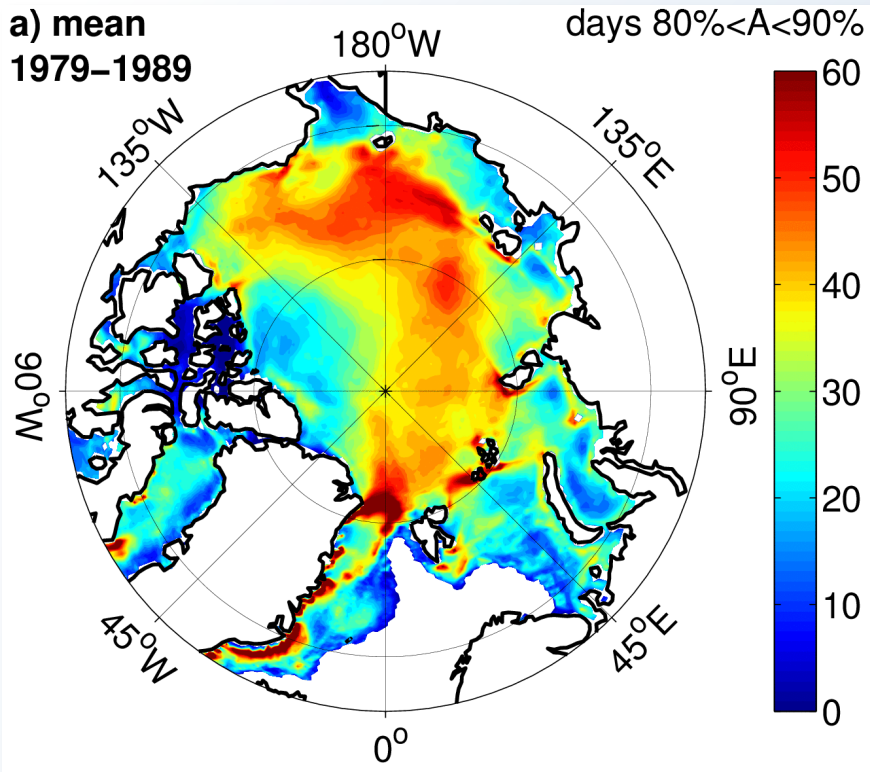
*... but that a greater area of the Arctic Ocean passes through optimal conditions **twice a year** enhancing momentum flux in **spring and fall**.*



# Where do we find optimal ice conditions?

a) mean  
1979–1989

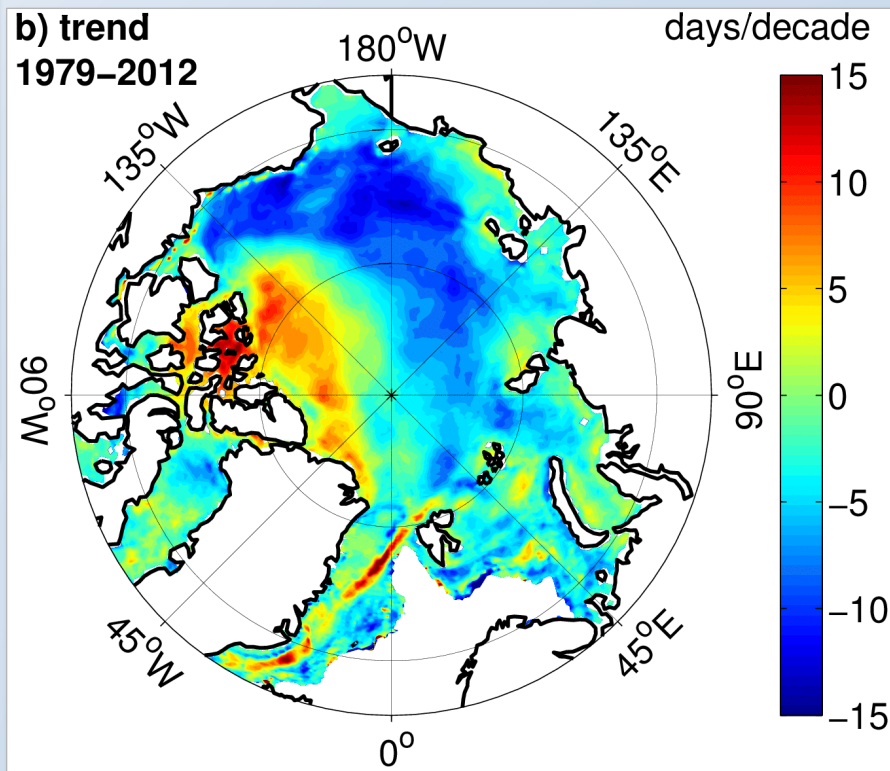
days  $80\% < A < 90\%$



This is where the Arctic Ocean used to have optimal ice conditions ...

b) trend  
1979–2012

days/decade



... and this is where we are headed:

## ***Does sea ice retreat increase momentum influx?***

- **Yes**, at least in **winter, spring and fall** the thinner and thus weaker ice enables enhanced momentum transfer from the atmosphere into the ocean; we find an **increase of 9-12%**.
- **But in summer**, the momentum influx **decreases** because the area of the Arctic Ocean with **optimal ice concentrations** is decreasing; the 1979-2012 **trend is -4%**.

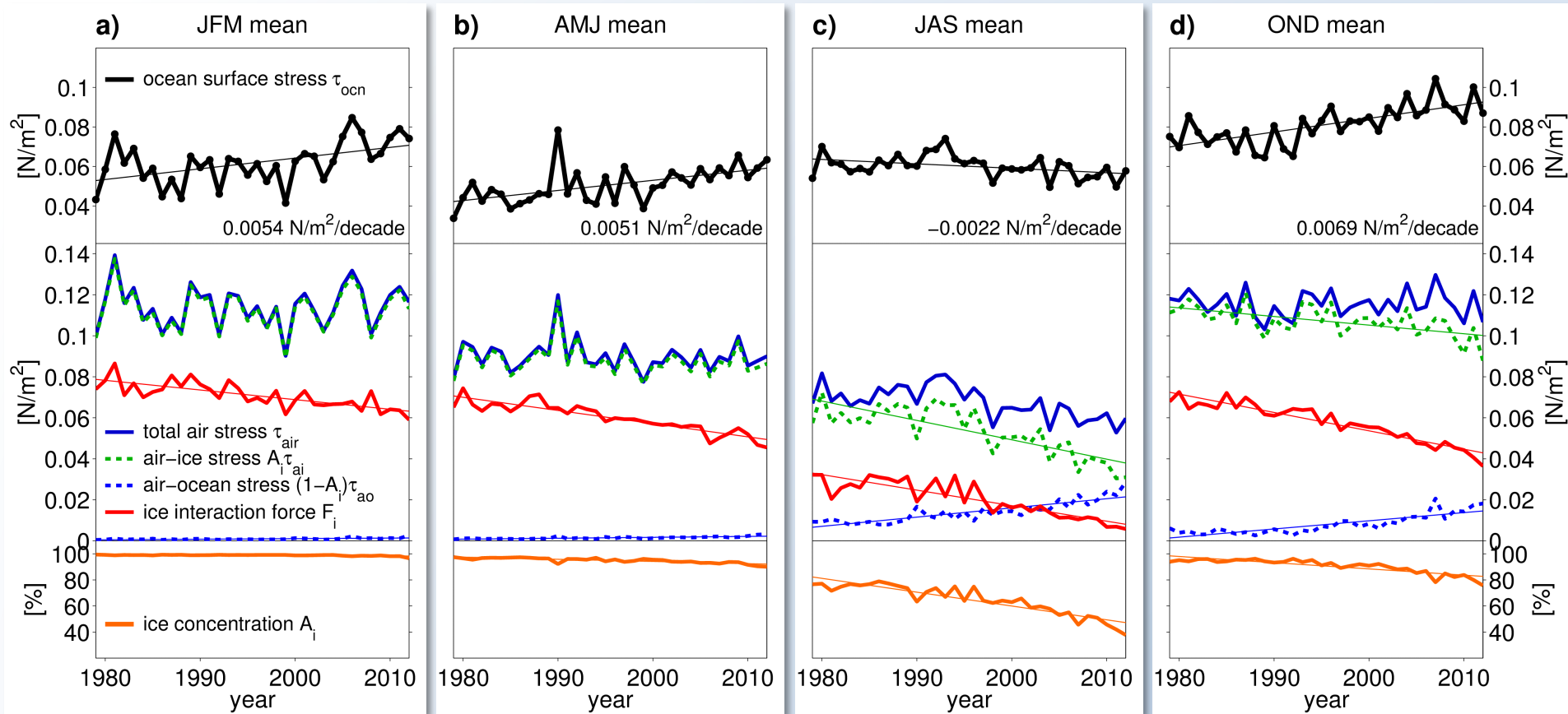
## ***What did we learn?***

- **Sea ice**, known for inhibiting flux exchanges between ocean and atmosphere (“insulator”), can act as an **“amplifier”** for momentum transfer!

## ***What does the future hold?***

- Summer conditions may extend into fall and possibly spring.
- More storms, particularly in fall, may increase momentum input despite loss of optimal ice concentrations.

# Stress trends: all seasons

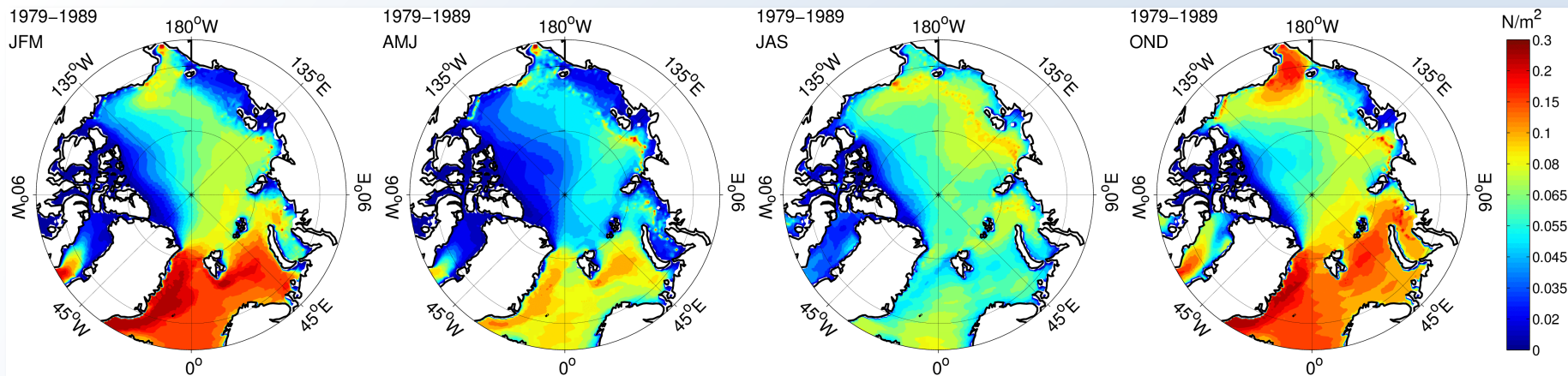


- **Winter:** ocean stress increases due to decreasing ice interaction force
- **Summer:** ocean stress decreases for ice concentration less than optimal
- **Fall:** increasing wind speeds counteract decreasing ice concentration



# Ocean surface stress changes in the 2000s

10 year mean: 1979-1989

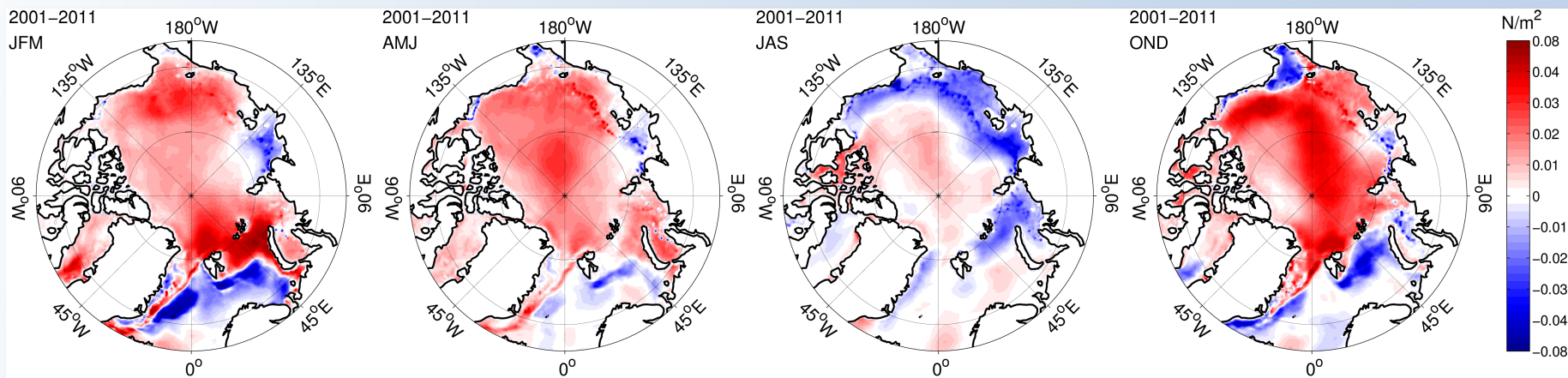


winter

spring

summer

fall



difference of 2001-2011 to 1979-1989