Variability of sea ice over decadal and longer timescales

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Outline of presentation:

- 1) Recent sea ice variations
- 2) Placement into longer-term context
- 3) Decadal-to-multidecadal variations
- 4) Drivers of the low-frequency sea ice variability

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Sources of information on variations and trends of sea ice:

- 1) satellite measurements, 1970s present
- 2) historical sea ice observations: charts, ship and coastal, 1600s onward
 3) proxy paleo-reconstructions : millennia

Arctic sea ice concentrations



Sep. 12, 2012



Northern Hemisphere Sea Ice Area

Data provided by NSIDC: NASA SMMR and SSMI



Northern Hemisphere Sea Ice Anomaly

Anomaly from 1979-2008 mean





Source: IARC/JAXA, http://www.ijis.iarc.uaf.edu/en/home/seaice_extent.htm

Reduction of sea ice -- past five years relative to 1979-2005:

March maximum: about -10%

September minimum: -40 to -50%

Bering Sea ice cover, 1979-2012: No trend

km) 0.9 0.8 square 0.7 0.6 0.5 0.4 0.3 (million 0.2 0.1 0 -0.1 -0.2 -0.3 -0.4 Area -0.5 -0.6 -0.7 -0.8 Ice -0.9 -1 1980 1981 1983 1985 1985 1985 1985 1986 1988 1991 1991 1993 1993 1997 1997 1997 2008 2009 2010 2000 2003 2004 2005 2006 2007 2011 2012 2013 0 2002 1979

Bering Sea Ice Area

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CMIP5 model projections of September Arctic ice extent [from J. Stroeve, NSIDC]





Figure modified from Kay, Holland, and Jahn (2011, GRL)

10-year trends \rightarrow

~30% +'ve

CCSM4 Arctic sea ice extent trends in a warming world

20-year trends → $\sim 5\% + ve$

Seasonality of recent temperature increase: (2001-2011) minus (1951-2000) [from NASA GISS]



Projected changes of temperature: 2070-2090



Recent studies of atmospheric impacts of sea ice loss:

- Increased snowfall over northern land areas *(Liu et al., 2012, PNAS)*
- Increased incidence of blocking/meridional circulation persistent winter anomalies in middle latitudes (*Francis and Vavrus, 2011, GRL*)

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The Arctic seems to be warming up. Reports from fishermen, seal hunters, and explorers who sail the seas about Spitzbergen and the eastern Arctic, all point to a radical change in climatic conditions, and hitherto unheard-of high temperatures in that part of the earth's surface.

The oceanographic observations have, however, been even more interesting. Ice conditions were exceptional. In fact, so little ice has never before been noted. The expedition all but established a record, sailing as far north as 81° 29' in ice-free water. This is the farthest north ever reached with modern oceanographic apparatus. NOVEMBER, 1922.

THE CHANGING ARCTIC.

By George Nicolas IFFT.

[Under date of October 10, 1922, the American consul at Bergen, Norway, submitted the following report to the State Department, Washington, D. C.]

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Past Arctic sea ice coverage: Encyclopedia Britannica (1904)





Ice extent anomalies in the Russian Arctic seas, 1900-2000

Polyakov et al (2010, J. Climate)



Air temperature anomalies

Kara Sea fast ice thickness anomalies

Arctic Ocean's Atlantic water T anomalies

[Polyakov et al., 2003]

Winter ice extent in Labrador Sea, Gulf of St. Lawrence [from B. Hill, NRC Canada]

GULF and NEWFOUNDLAND ICE EXTENTS



Decadal frequency of occurrence of sea ice, Sable Island [from B. Hill, NRC Canada]



Historical sea ice extent, reconstructed back to 1870

- -- DMI (Danish) ice charts -- ACSYS ice edge data
- -- AARI (Russian) ice charts
- -- Canada (B. Hill) ice charts



Extended time series of Arctic ice extent, 1870-2011 [incorporating ACSYS, AARI sea ice data into HadISST]



Probability of a decrease of sea ice extent, 1870-2011 from one n-year period to the next n-year period



Probability of a decrease of sea ice extent, 1870-1980 from one n-year period to the next n-year period



Ice extent in the Greenland Sea, 1750-2000 and wavelet power spectra [Divine and Dick, 2006]



Recent millennial-scale reconstructions of sea ice records:

- Macais Fauria et al. (2011, *Clim. Dyn*).
 -- reconstruction for North Atlantic, back to 1200 AD
 -- tree rings, ice cores
- Kinnard et al. (2011, *Nature*)
 - -- pan-Arctic and regional, 1,450 years (back to 550 AD)
 - -- sediments, ice cores, tree rings

Reconstructed maximum of ice extent in western Nordic Seas; blue = 'observed' 5-year mean (Vinje, 2001) [Macias Fauria et al., 2010]



Reconstructed ice extent, past 1,450 years: pan-Arctic, Chukchi Sea, Fram Strait [from Kinnard et al., 2011]



What about Antarctic sea ice?

- No trend over the satellite period
- Little proxy data other than chemical species in ice cores (MSA, methanesulphonic acid)
 - → some indications of ~20% decrease of ice coverage since 1850 in East Antarctica (80°-140°E)

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Regression of winds onto year-to-year changes of Sep. ice extent [Ogi et al., 2010]

Jan-May winds

Jun-Sep winds



30-year running correlation between winter NAO and sea ice extent in western Nordic Seas *[from Macias Fauria et al., 2010]*



Arctic Ocean currents

[from Arctic Monitoring and Assessment Program]





Inflow of Atlantic Water into the Arctic Ocean: different rates during different phases of multidecadal variability? [Adapted from *Polyakov et al., 2004*]

Increase of the Atlantic Water heat content associated with multi-decadal variations could cause 0.8-1.0 m loss in ice thickness over the last 20 years.

Arctic Ocean cross-sections, temperatures in upper 500 m [from I. Polyakov, Univ. of Alaska]





Method 1 ↑ Atlantic water temperatures (Fram Strait) ↓ Method 2

Land surface air temperature anomalies

[Spielhagen et al., 2011]

Recent studies addressing drivers of low-frequency sea ice variations *in global climate models*:

- Mahajan et al. (2011, J. Clim.) -- GFDL
- Day et al. (2012, Env. Res. Lett.) five models





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



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



1000-year control simulation, GFDL CM2.1:

AMO(AMV) vs. AMOC, Arctic air temperature, sea ice extent (annual mean)

[from Mahajan et al., 2011]

Impact of positive AMOC on sea ice and air temperature [from Mahajan et al., 2011]



Correlations between September sea ice extent (SIE) and AO, AMOC, AMV(AMO) in CMIP3 models

[from Day et al., 2012, Env. Res. Lett.]

Model	r(AO, SIE)	r(AMOC, SIE)(lag)	r(AMO, SIE)	r(AHT, SIE)(lag)
CSIRO-MK3.5	-0.08*	-0.40(0)	-0.44	-0.59(1)
GFDL-CM2.1	0.11	-0.11(3)	-0.31	
GISS-ER	0.12	-0.14(0)	-0.13	-0.20(-1)
HadCM3	0.05*	-0.12(2)	-0.17	
MIROC3.2.2	-0.04^{*}	-0.17(2)	-0.21	-0.31(2)
Observed	-0.09		-0.42	

Detrended 10-yr filtered AO, AMO indices; sea ice (1953 onward) [from Day et al., 2012., Env. Res. Lett.]



Conclusions

- Present summer sea ice trend in the Arctic is unprecedented in the past 1000-2000 years, but
 - -- trend of winter ice is much smaller
 - -- regional exceptions
- Decadal and multidecadal variability in Arctic ice is prominent probability of 10- or 20-year increase of Arctic sea ice is nonnegligible
- The multidecadal variability of sea ice in the Arctic appears to associated with the AMV
- Antarctic ice trends are small over past 30 years, highly uncertain over century-millennial timescale