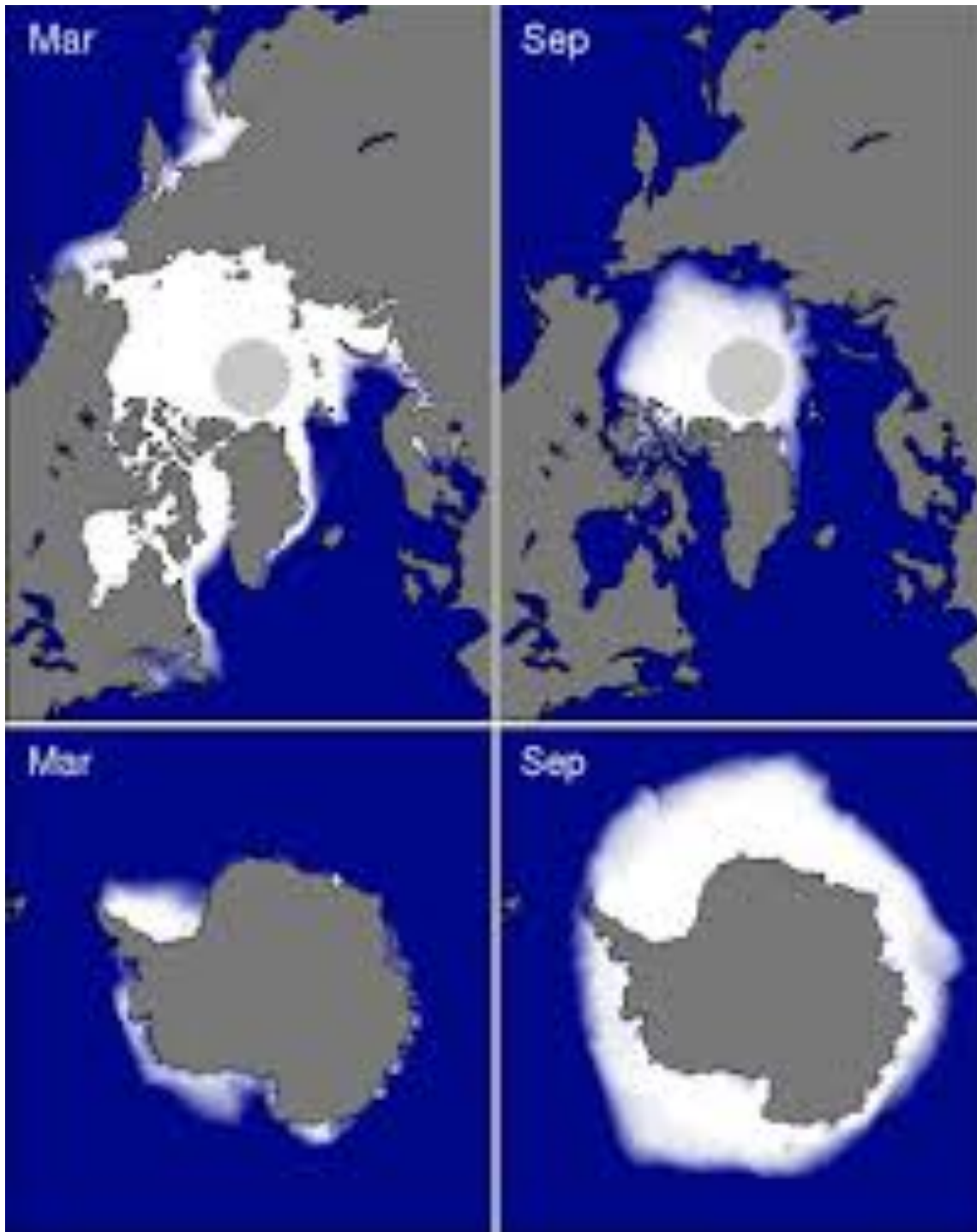


Climate dynamics of sea ice



Judith Curry
Georgia Tech





Annual cycle of sea ice extent

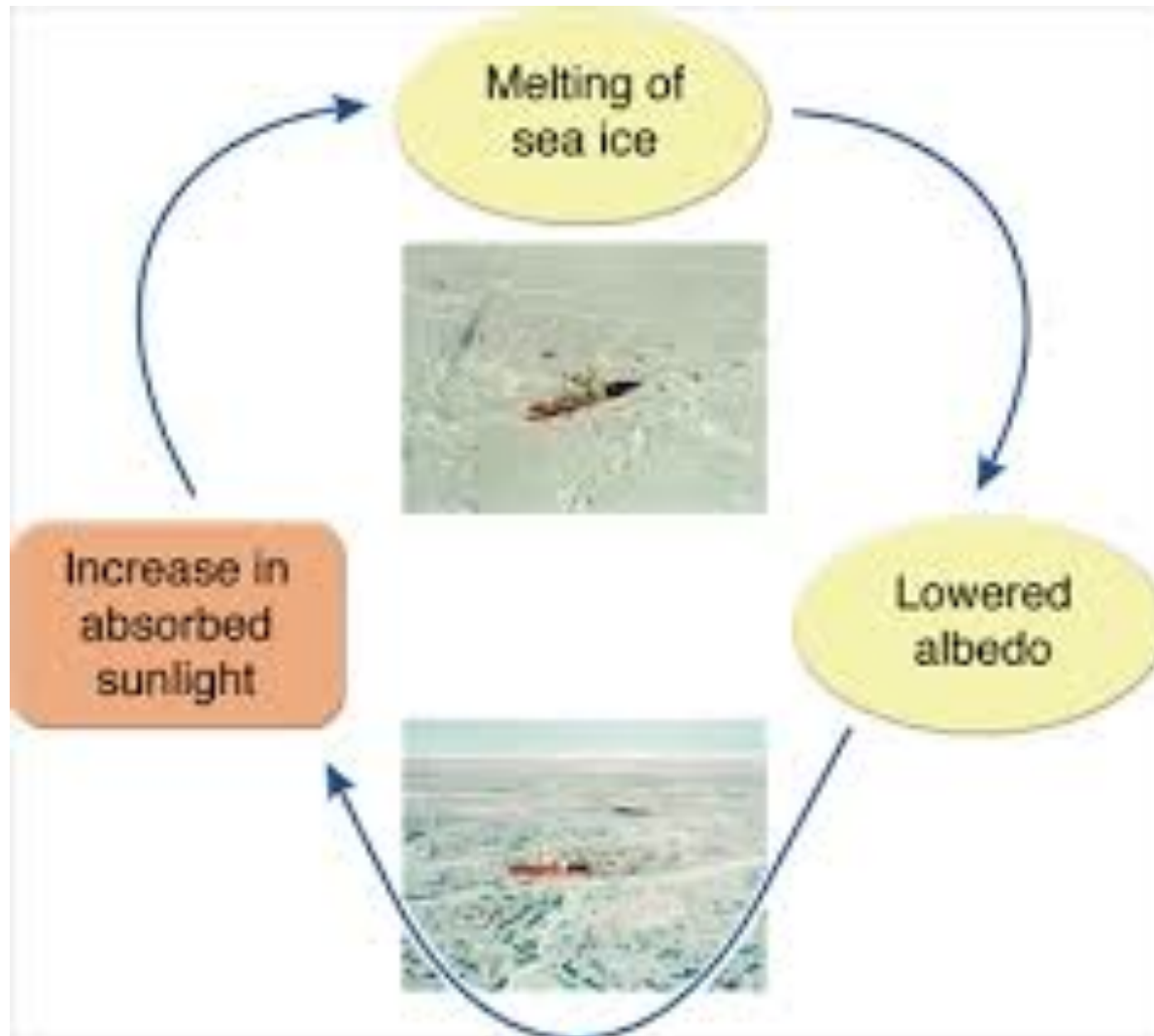
Northern hemisphere

Southern hemisphere

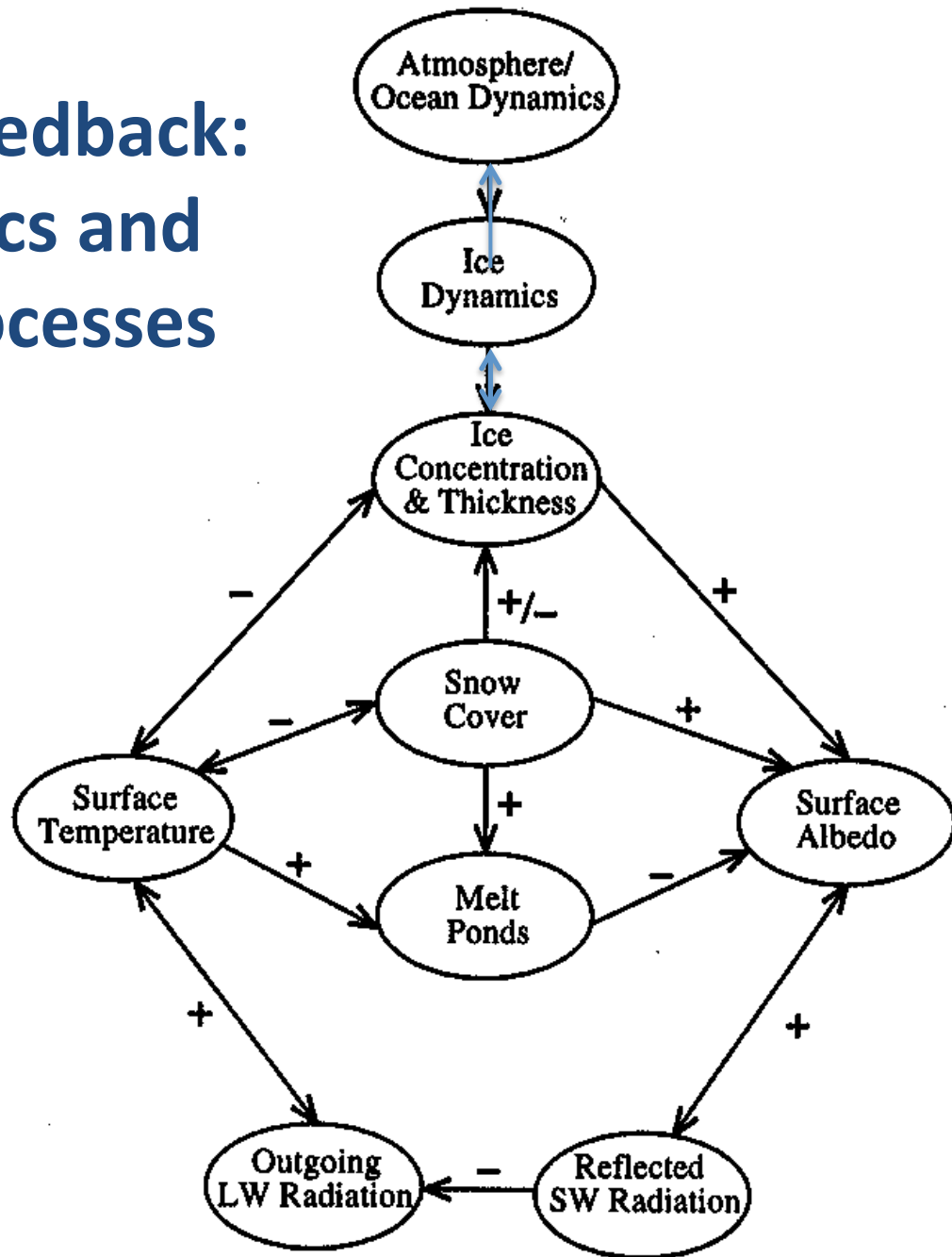
Importance of sea ice climate dynamics

- Global warming/cooling: amplified by the ice-albedo feedback
- Sea ice freezing/melting influences ocean deep water formation and thermohaline circulation
- NH sea ice bridges communication between the atmosphere and ocean in multidecadal modes of climate variability

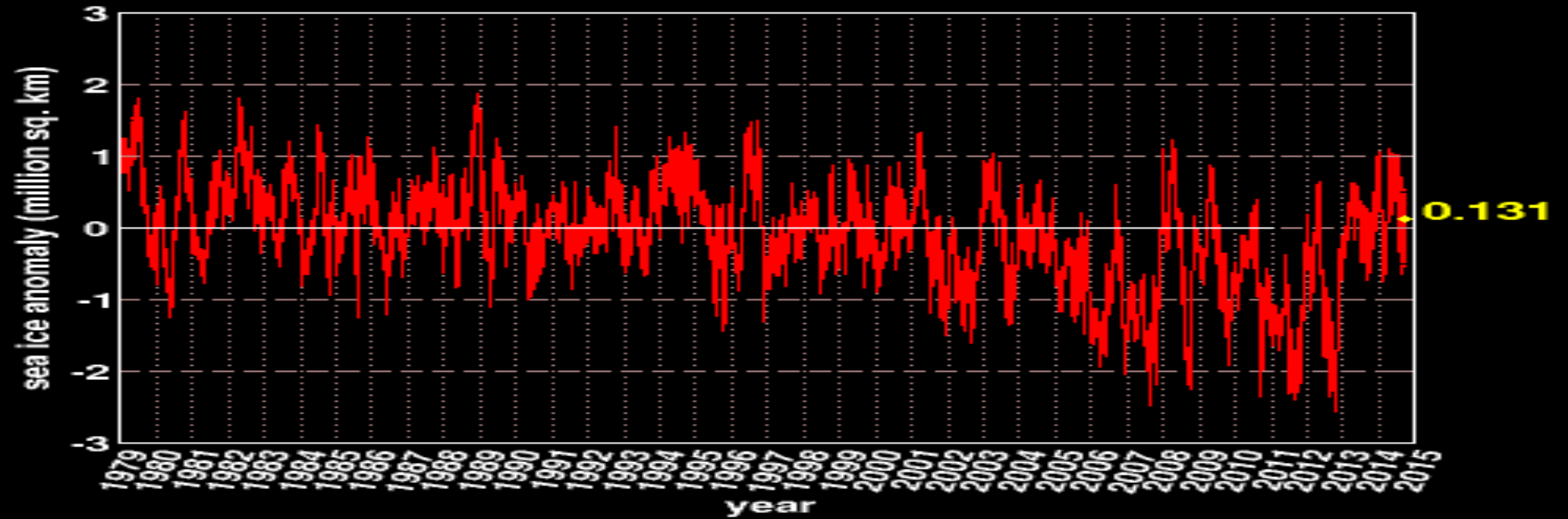
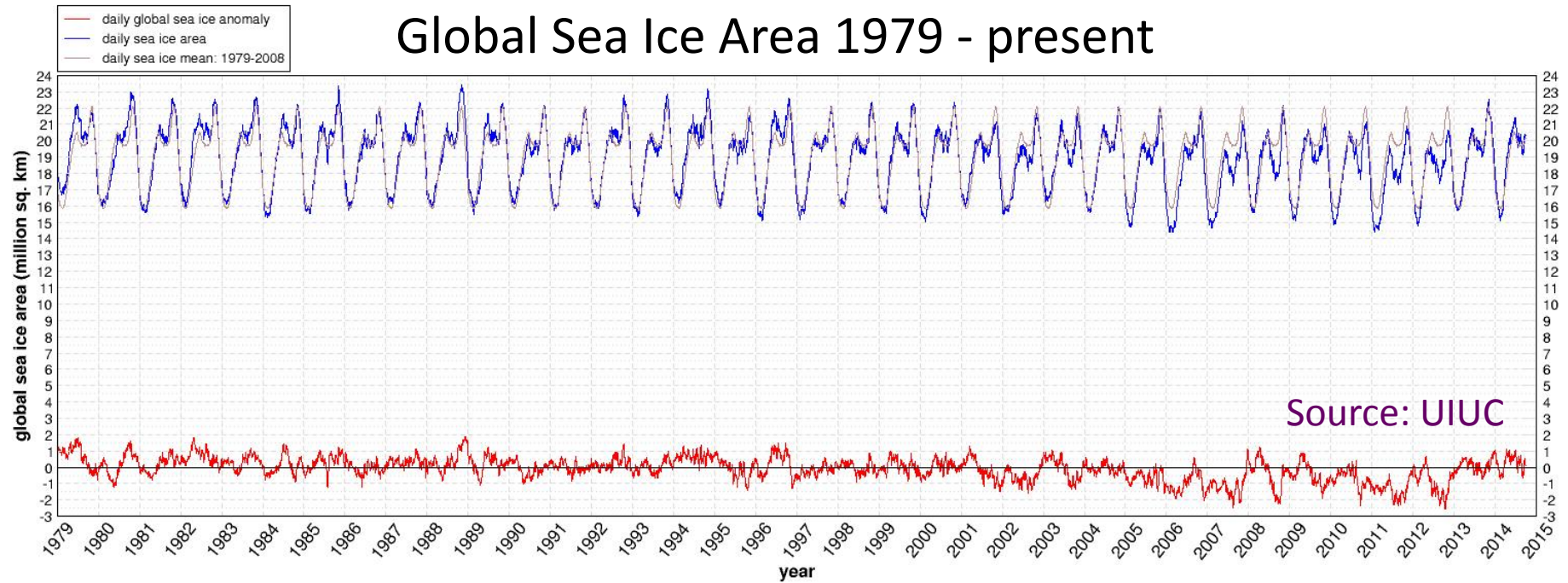
Ice – albedo feedback



Sea – ice albedo feedback: large-scale dynamics and internal sea ice processes

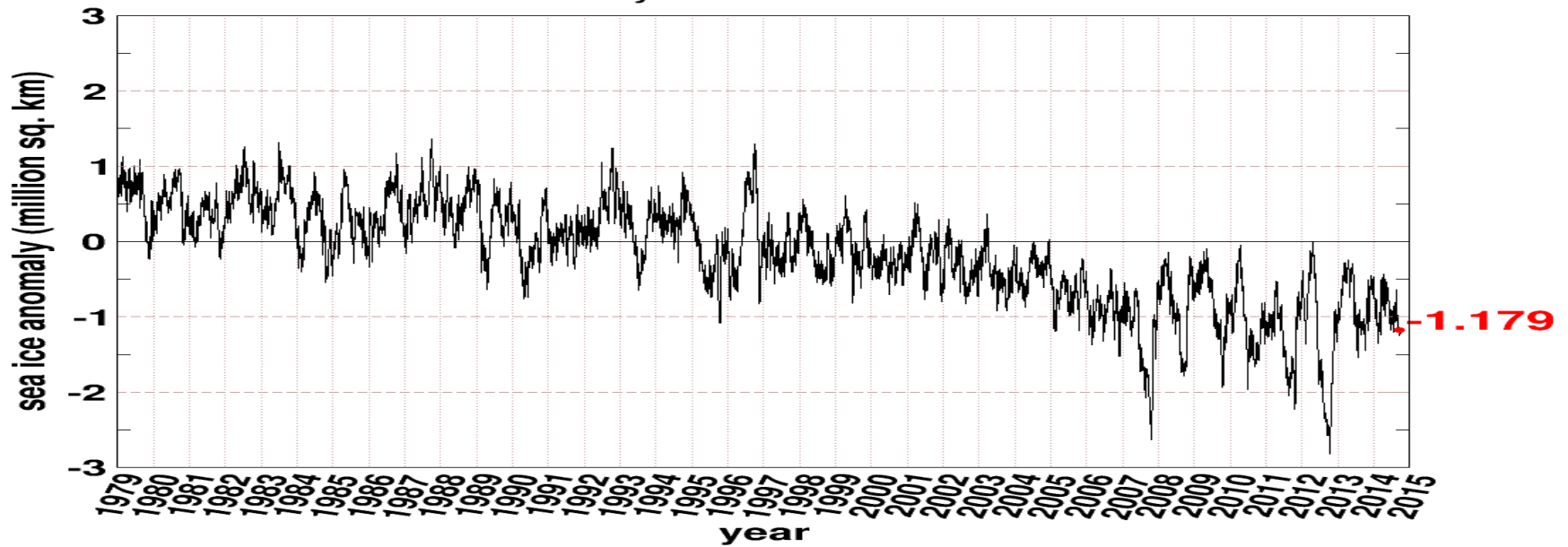


Global Sea Ice Area 1979 - present



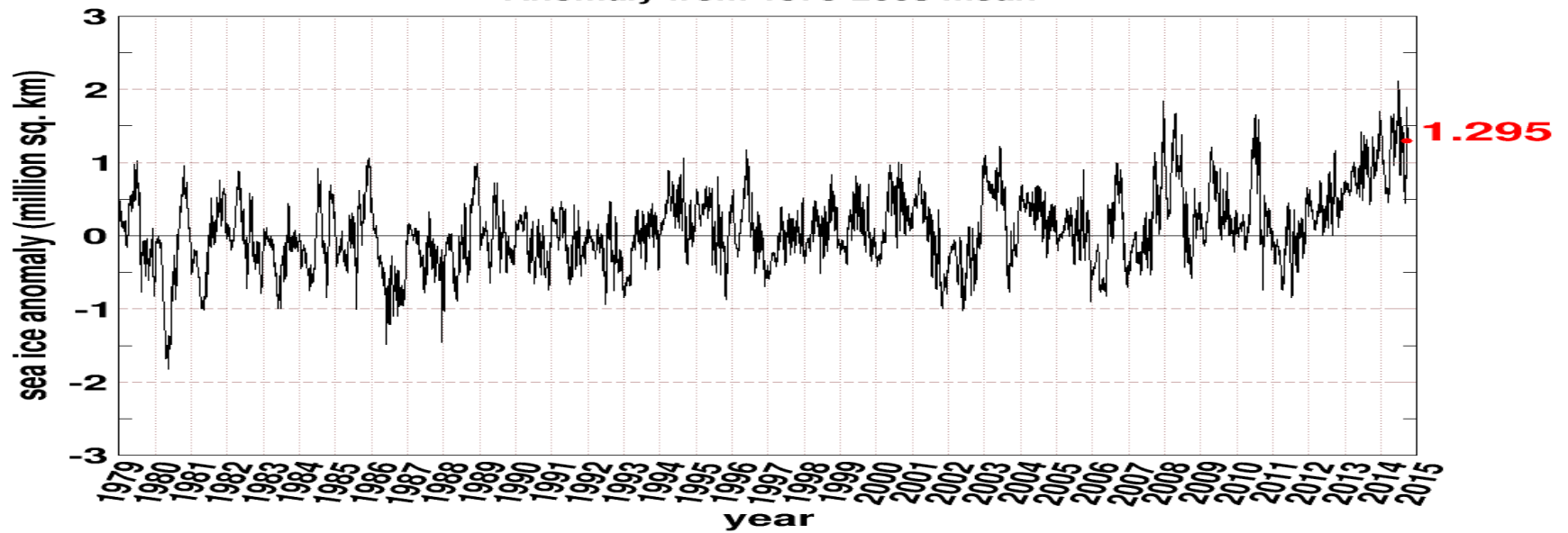
Northern Hemisphere Sea Ice Anomaly

Anomaly from 1979-2008 mean



Southern Hemisphere Sea Ice Anomaly

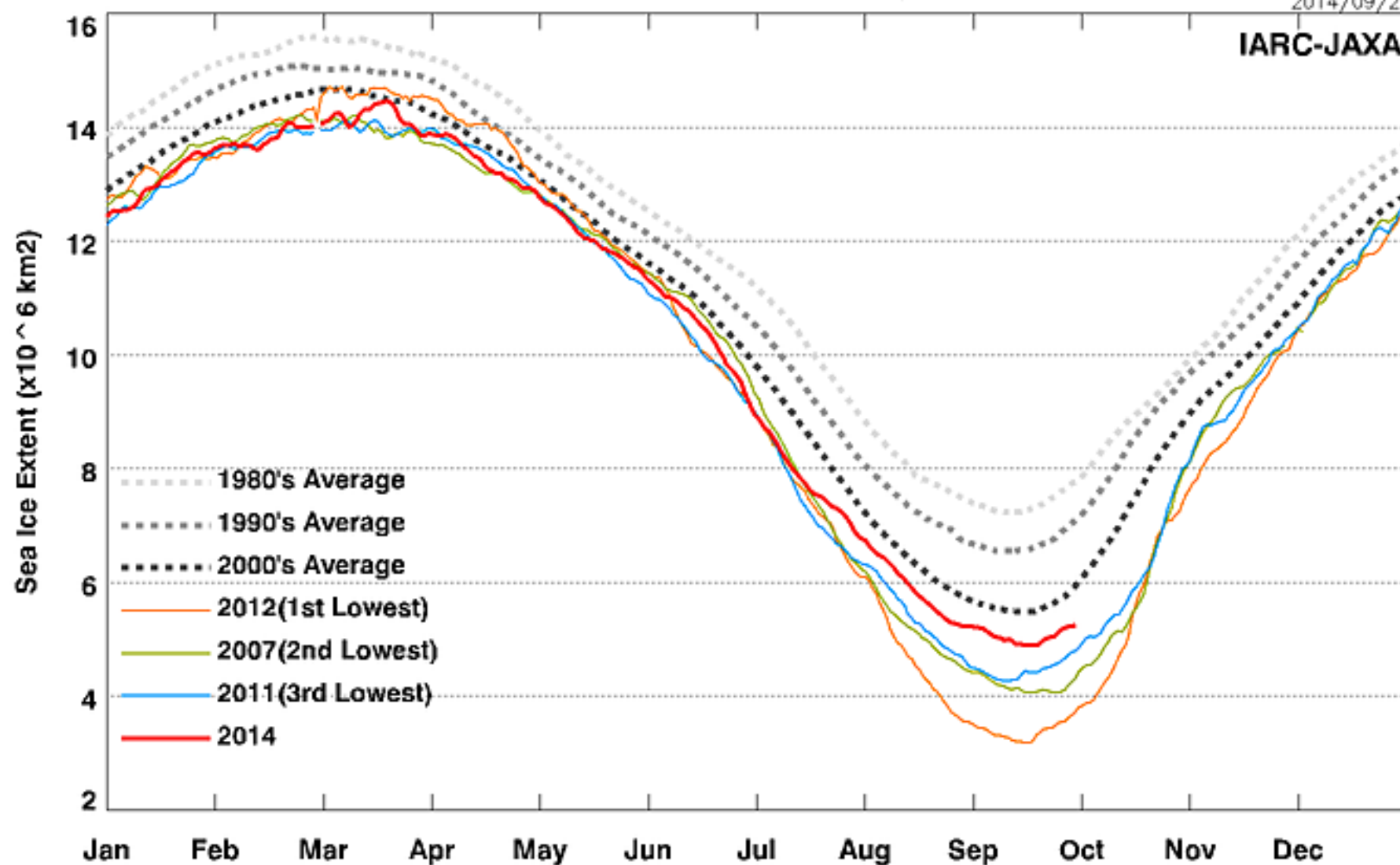
Anomaly from 1979-2008 mean



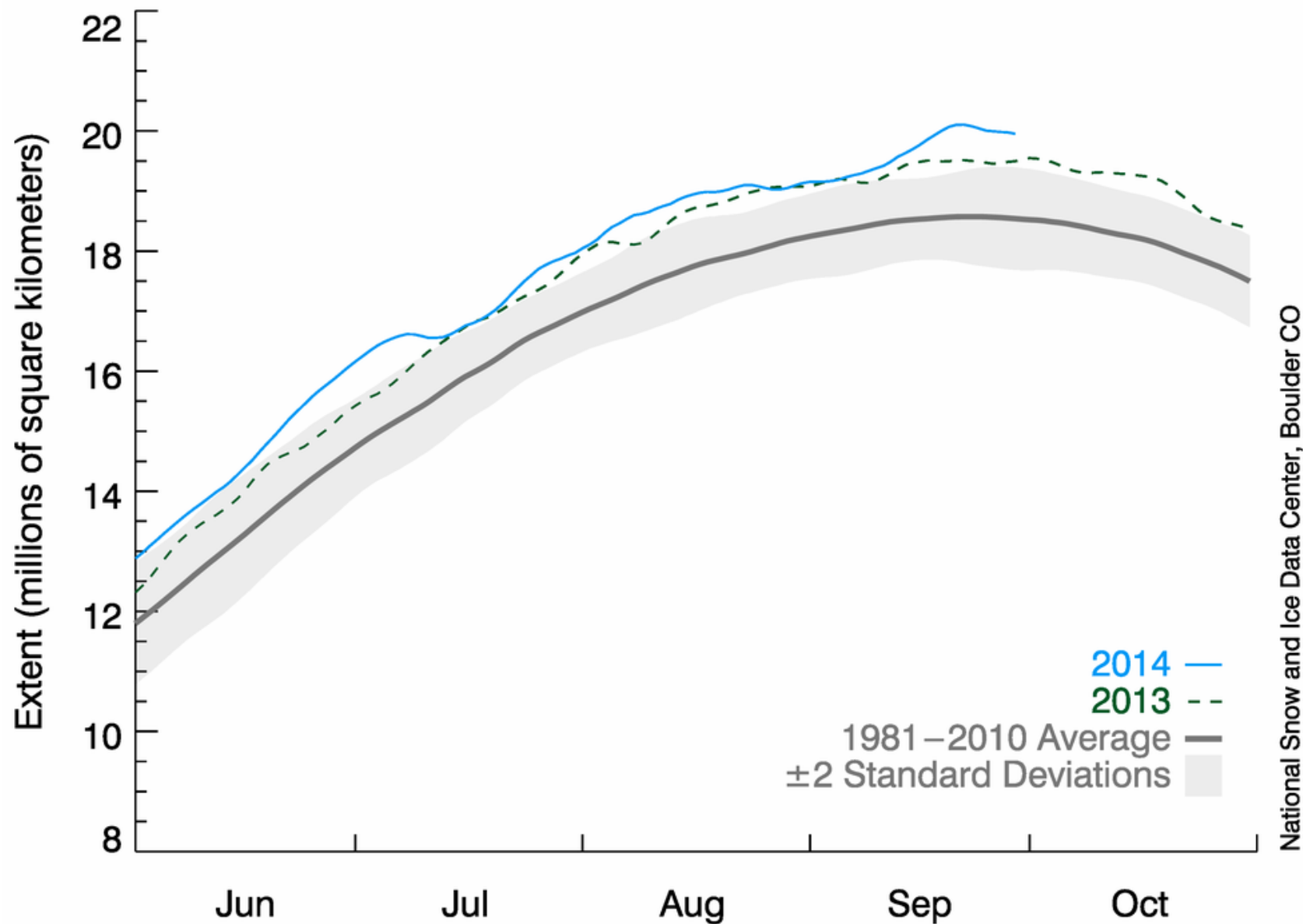
Arctic Sea Ice Extent (Ver.2)

2014/09/29

IARC-JAXA



Antarctic Sea Ice Extent (Area of ocean with at least 15% sea ice)

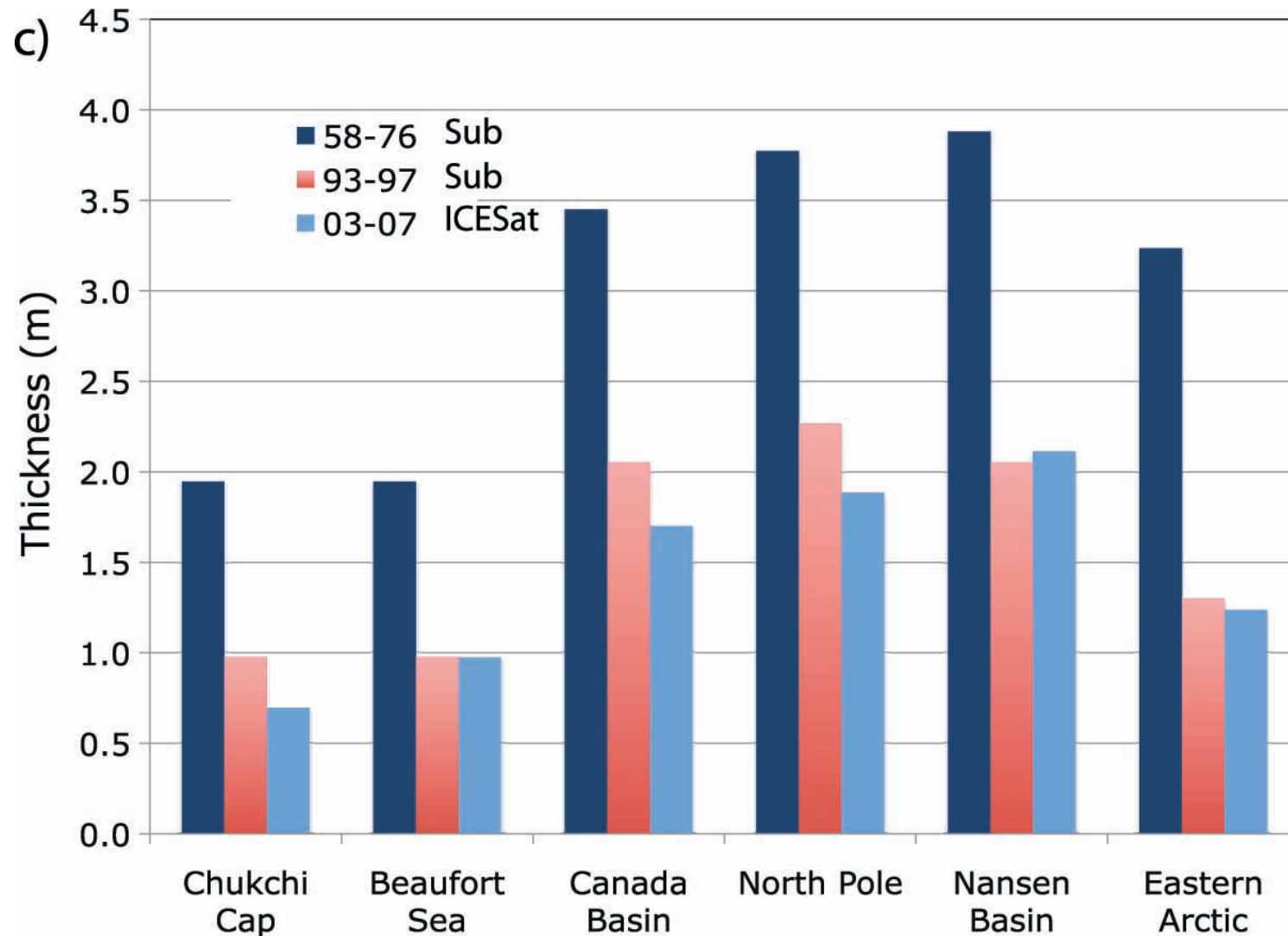


29 Sep 2014

National Snow and Ice Data Center, Boulder CO

Arctic Sea Ice Thickness

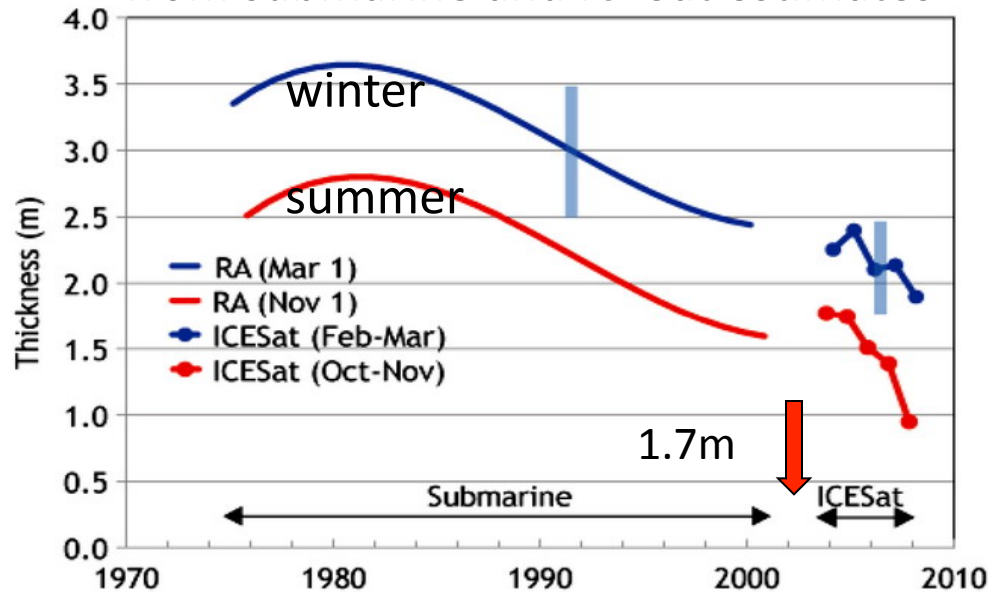
Submarine and Satellite Record 1958-2007



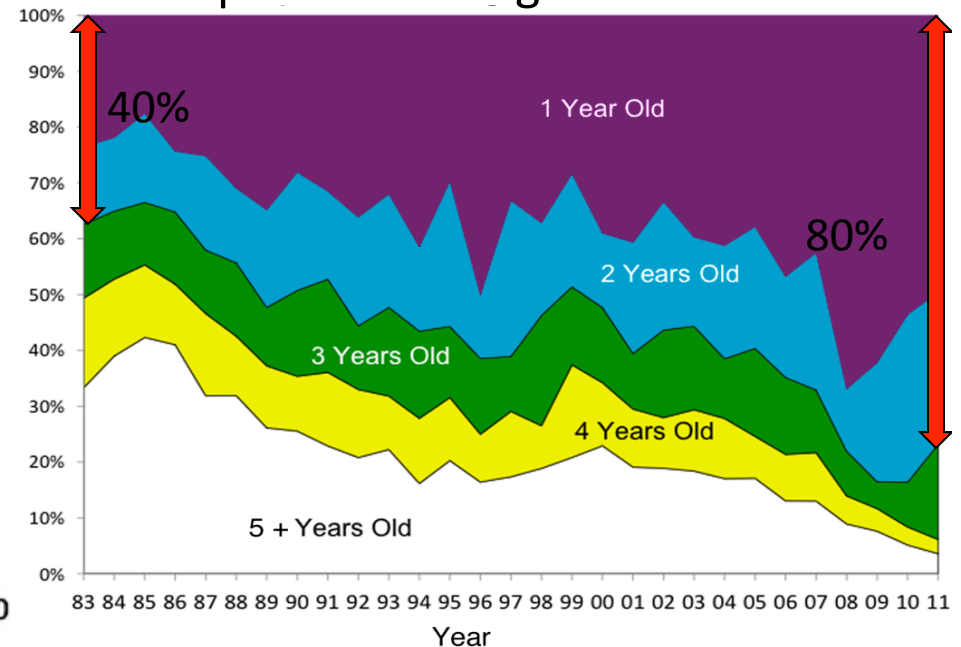
Reference: Kwok & Rothrock, Geophysical Research Letters, 2009

Arctic sea ice enters a new regime (thinner and younger)

Interannual changes in ice thickness
from submarine and ICESat estimates

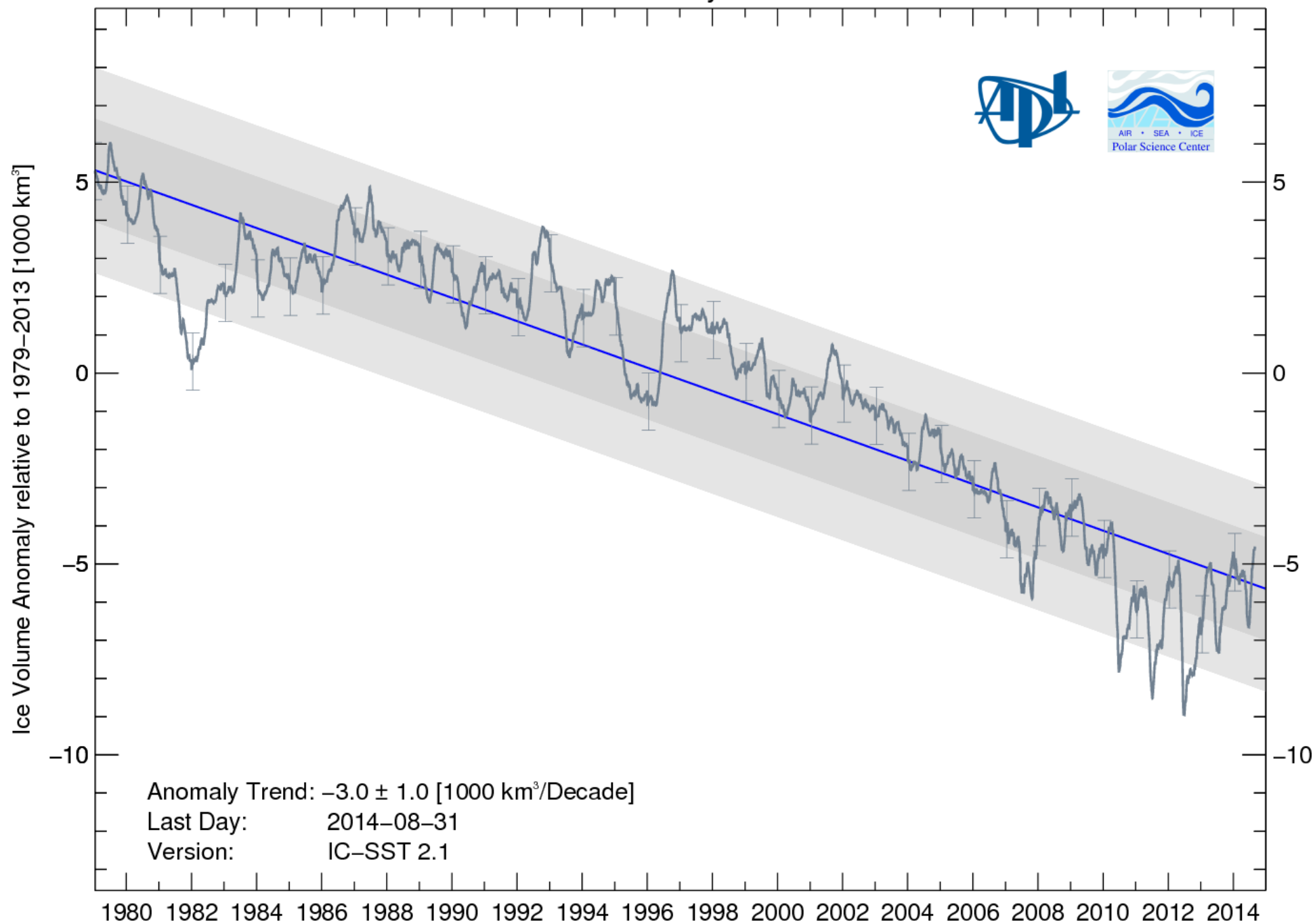


September ice age 1983-2011



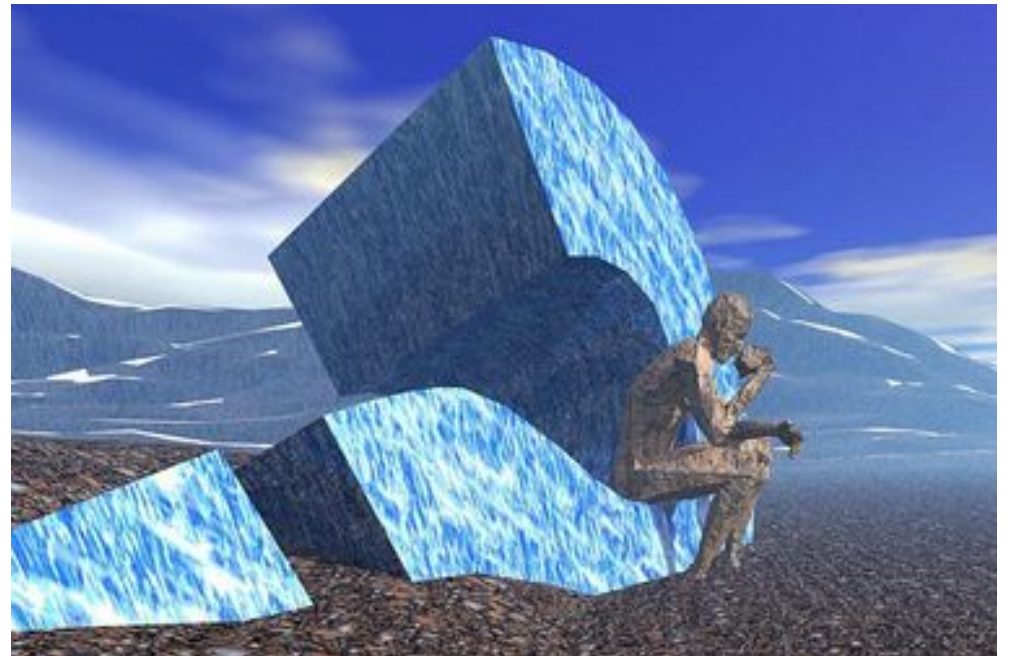
Kwok and Rothrock, 2009

Arctic Sea Ice Volume Anomaly and Trend from PIOMAS



Big questions:

- Is the recent Arctic sea ice decline unusual in the last 100-200 years?
- Is the current Arctic sea ice decline caused by anthropogenic global warming?
- Why is the Antarctic sea ice extent increasing?



THE CHANGING ARCTIC.

By GEORGE NICOLAS IFFT.

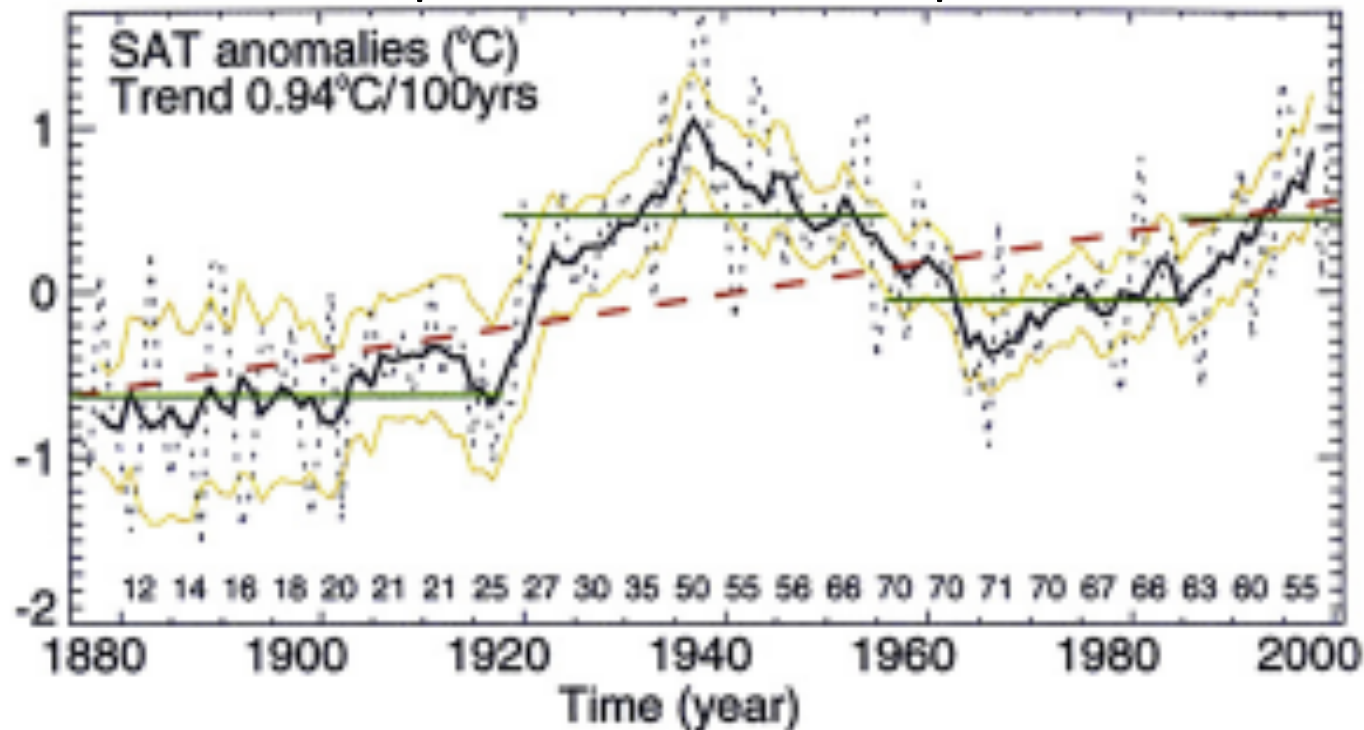
[Under date of October 10, 1922, the American consul at Bergen, Norway, submitted the following report to the State Department, Washington, D. C.]

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 $81^{\circ} 29'$ in ice-free water. This is the farthest north ever reached with modern oceanographic apparatus.

IPCC AR5 Ch 10: “Arctic temperature anomalies in the 1930s were apparently as large as those in the 1990s and 2000s. There is still considerable discussion of the ultimate causes of the warm temperature anomalies that occurred in the Arctic in the 1920s and 1930s.”

Surface air temperature anomalies poleward of 62N



Back to 1870*: Plans for a gridded sea ice product based on observations

J. Walsh¹, F. Fetterer², W. Chapman³ and A. Tivy¹

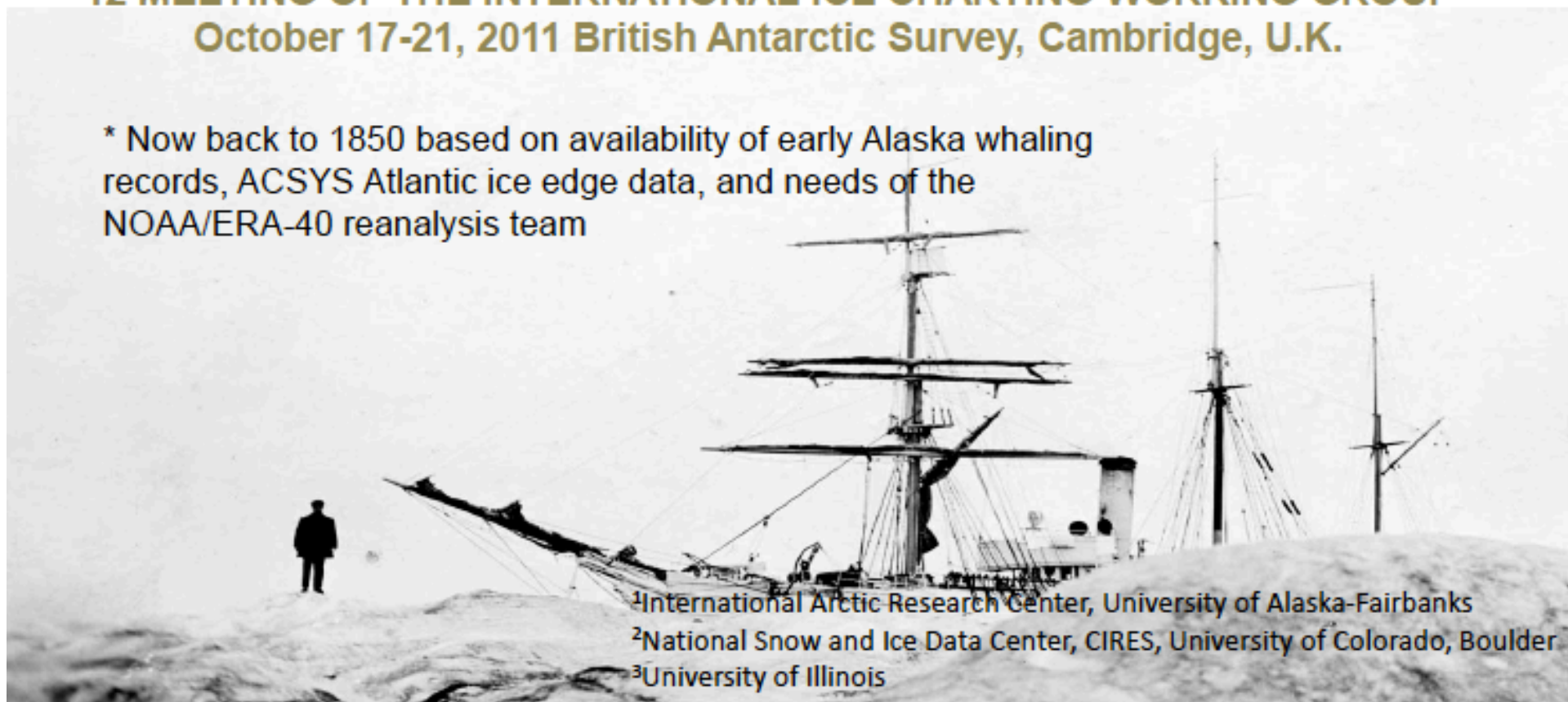
12 MEETING OF THE INTERNATIONAL ICE CHARTING WORKING GROUP
October 17-21, 2011 British Antarctic Survey, Cambridge, U.K.

* Now back to 1850 based on availability of early Alaska whaling records, ACSYS Atlantic ice edge data, and needs of the NOAA/ERA-40 reanalysis team

¹International Arctic Research Center, University of Alaska-Fairbanks

²National Snow and Ice Data Center, CIRES, University of Colorado, Boulder

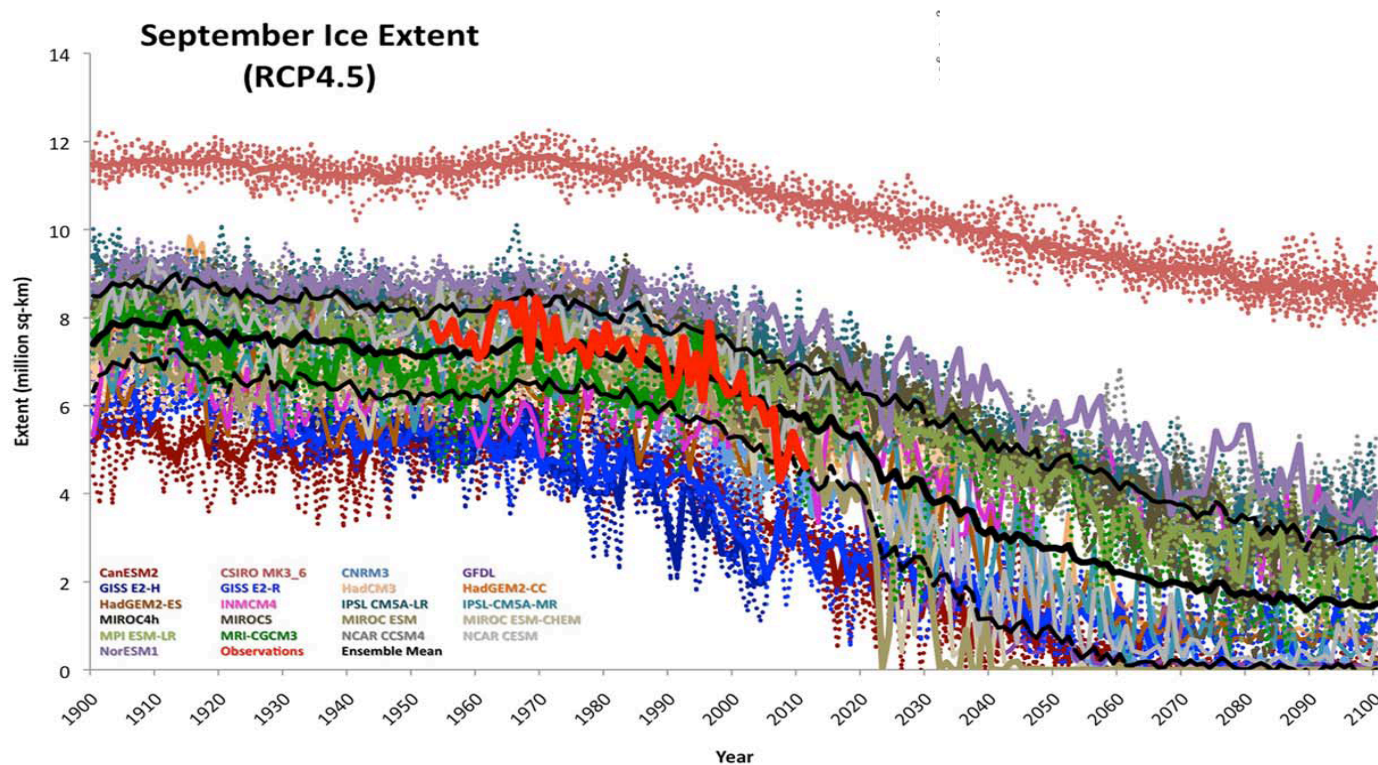
³University of Illinois



IPCC AR5 Ch 10:

“It is **likely** that there has been an anthropogenic contribution to the very substantial Arctic warming over the past 50 years.”

“Comparing trends from the CCSM4 ensemble to observed trends suggests that internal variability could account for approximately half of the observed 1979–2005 September Arctic sea ice extent loss.”



Stroeve et al. 2012

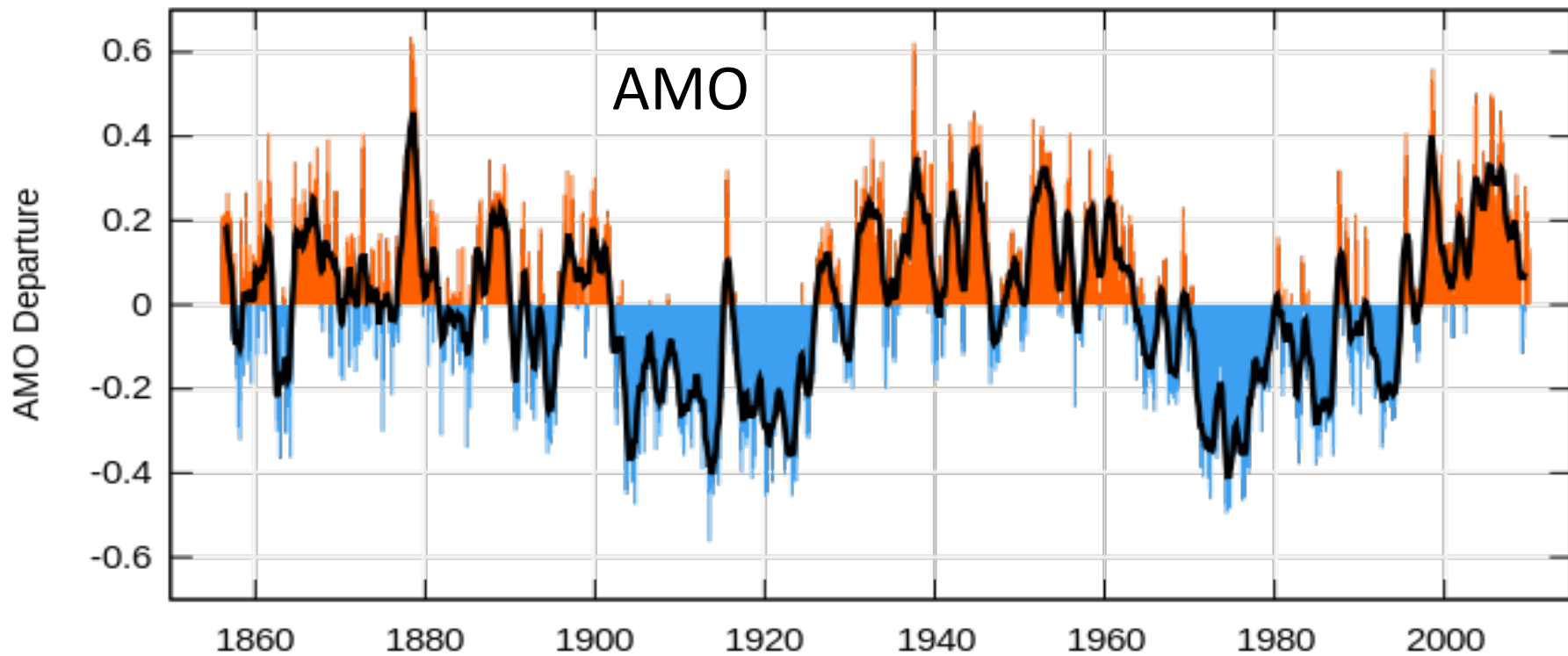
Disagreement between models and observations

Climate models underpredict the recent sea ice decline, find potentially ice free in 2050:

- Models are too insensitive; Arctic sea ice is on a 'spiral of death' trajectory and ice free Arctic is imminent

---- OR ---

- Models fail to account adequately for multidecadal climate variability and we could see at least a partial recovery of the sea ice

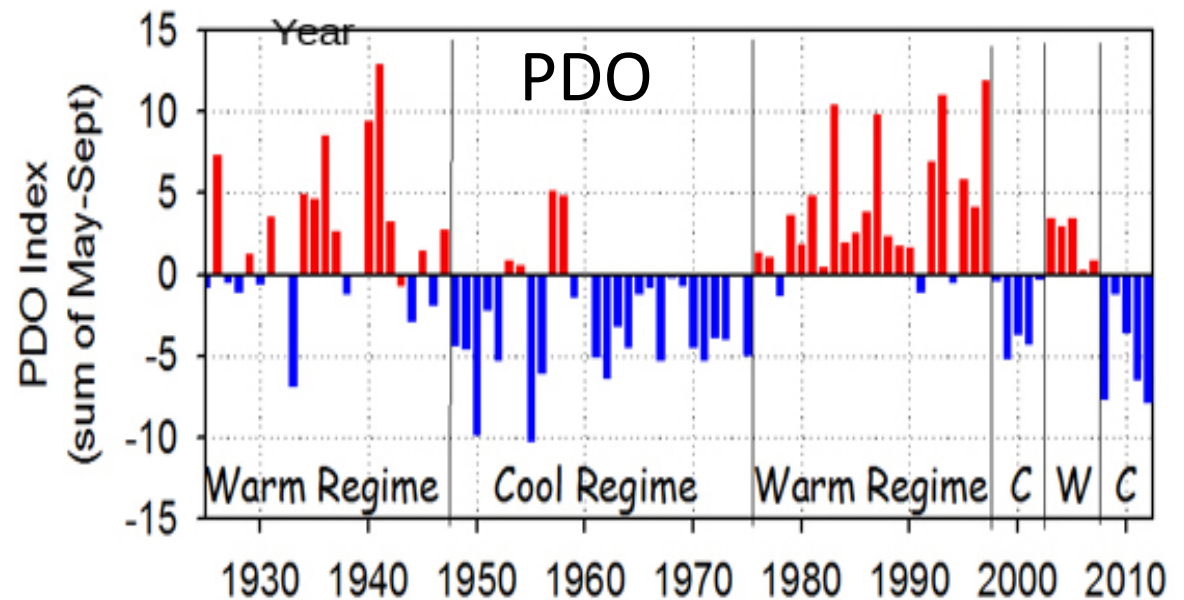


Currently:

- Warm AMO
- Cool PDO

Previous analogue:

- 1946-1964



Hypothesis

Climate as a Stadium Wave:

Wyatt and Curry 2013



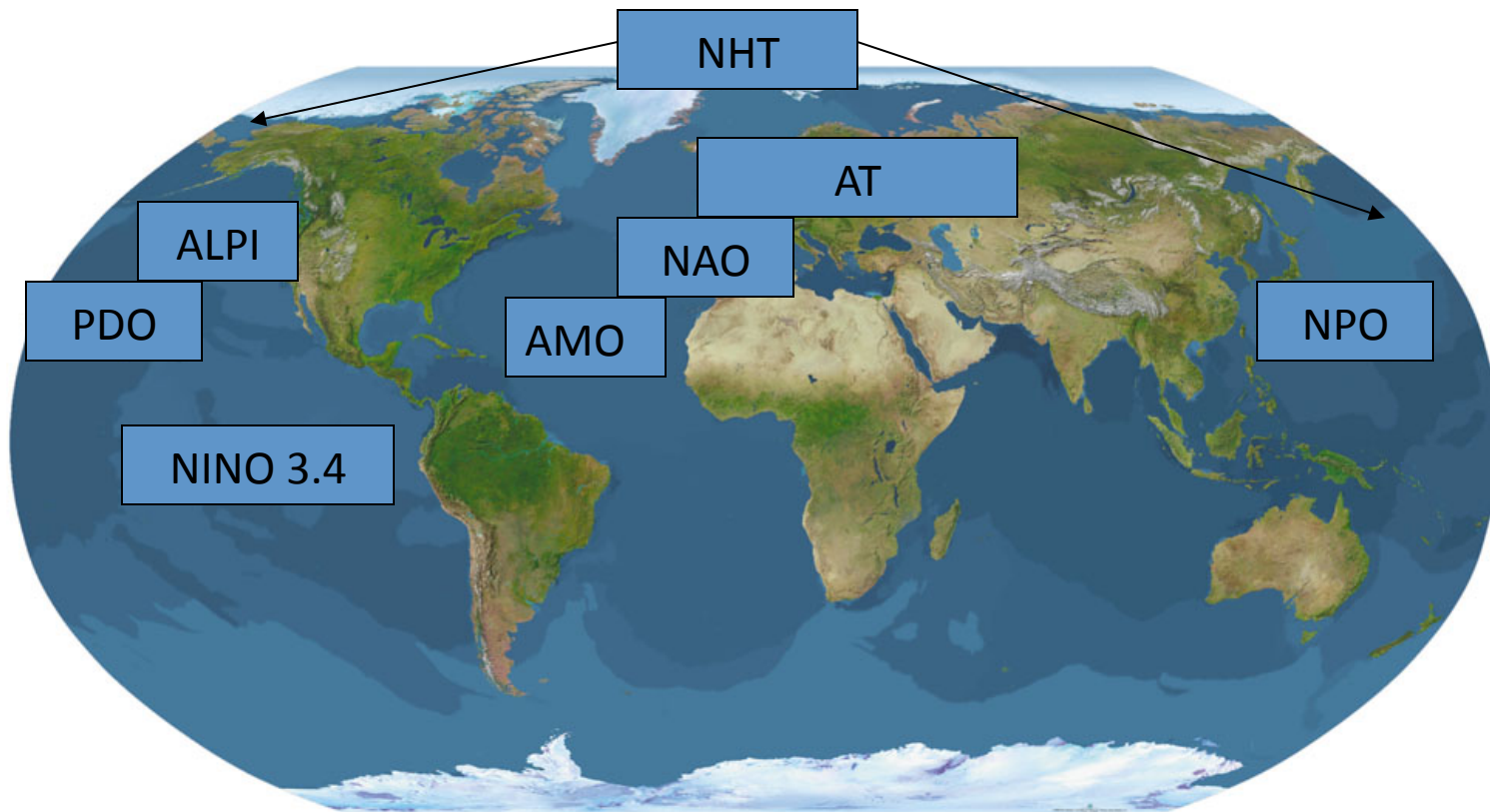
“Stadium Wave”

Designed and Created by Sarah Engels-Greer
www.blueboxbabe.blogspot.com

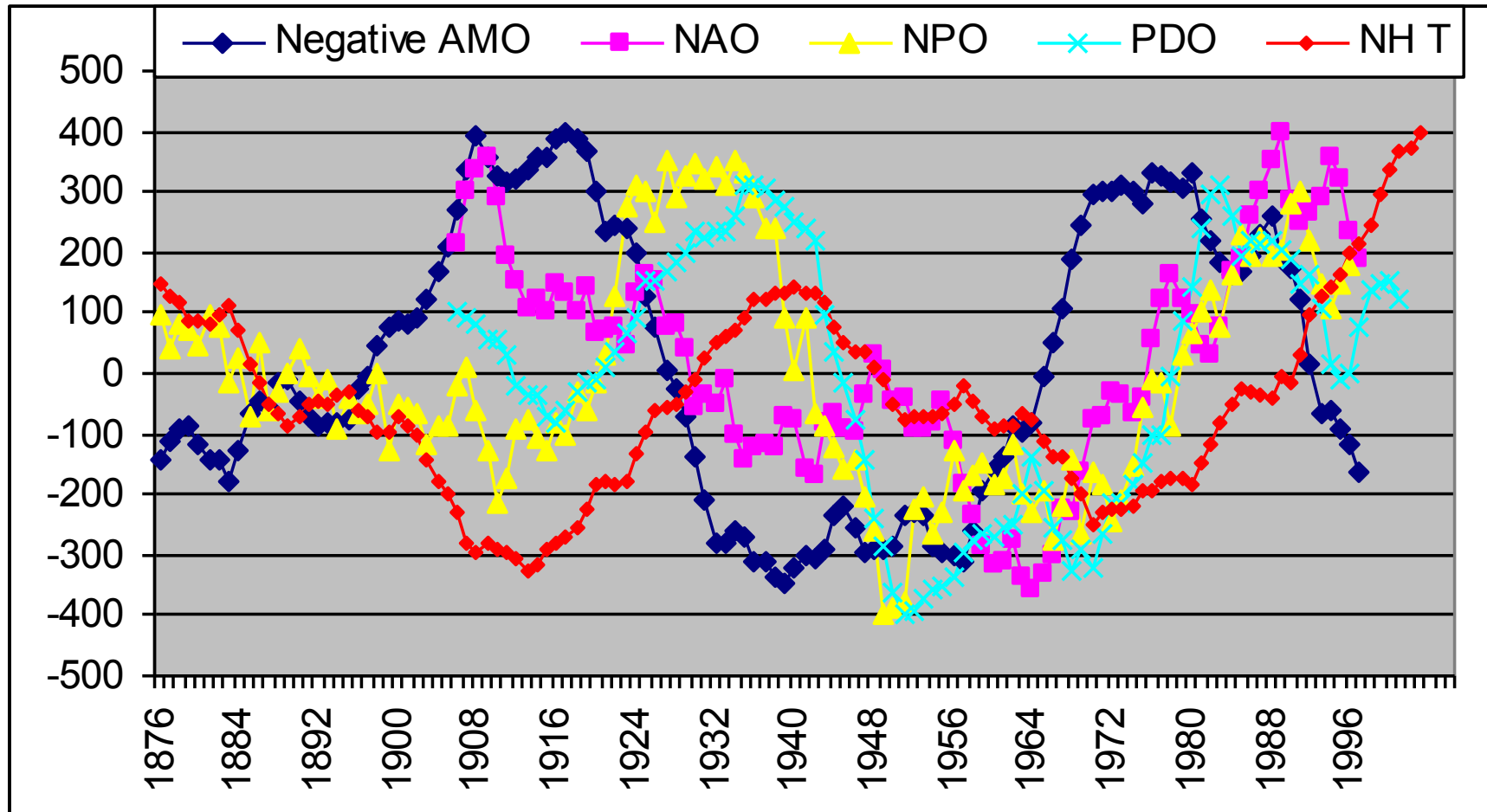
Propagation of a low-frequency climate-signal through a network of atmospheric, ice, and oceanic self-sustained oscillating indices

Indices DJFM:

NHT, AMO, AT,
NAO, NINO3.4,
NPO, PDO, ALPI

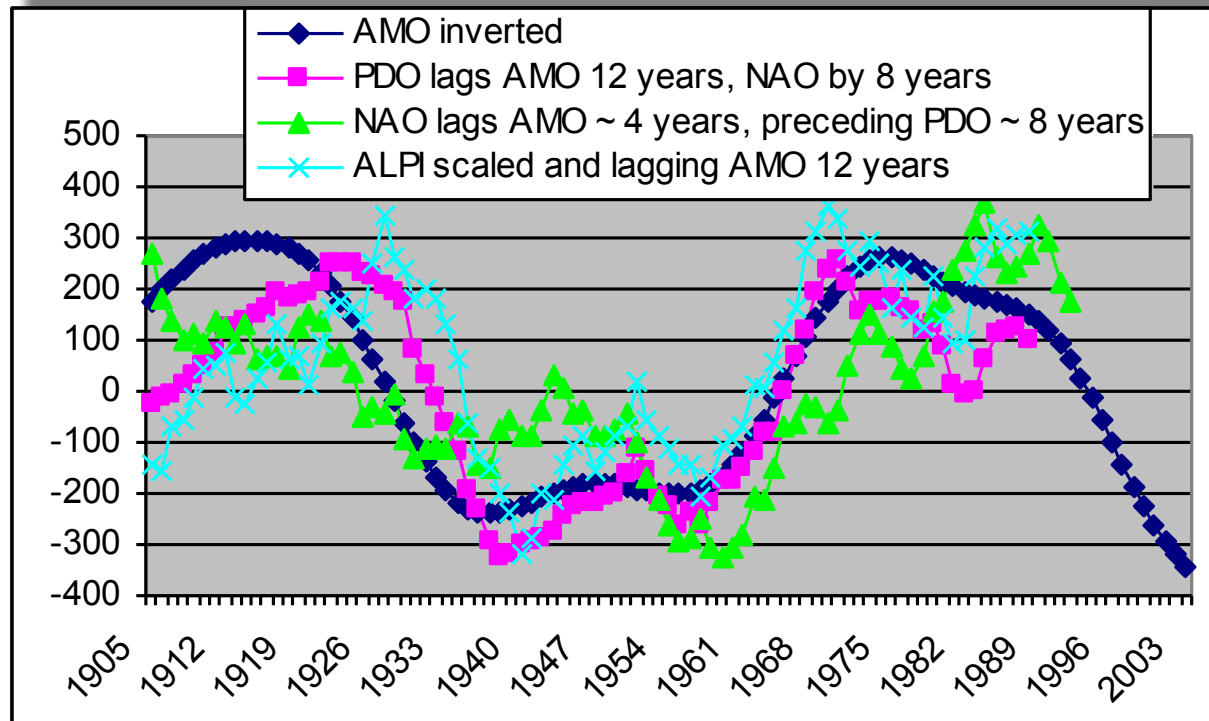


“Real Time” timeseries (detrended, 13 yr smooth):
-NHT, -AMO, NAO, NPO, PDO



Random Red-Noise? or Coherent Signal?

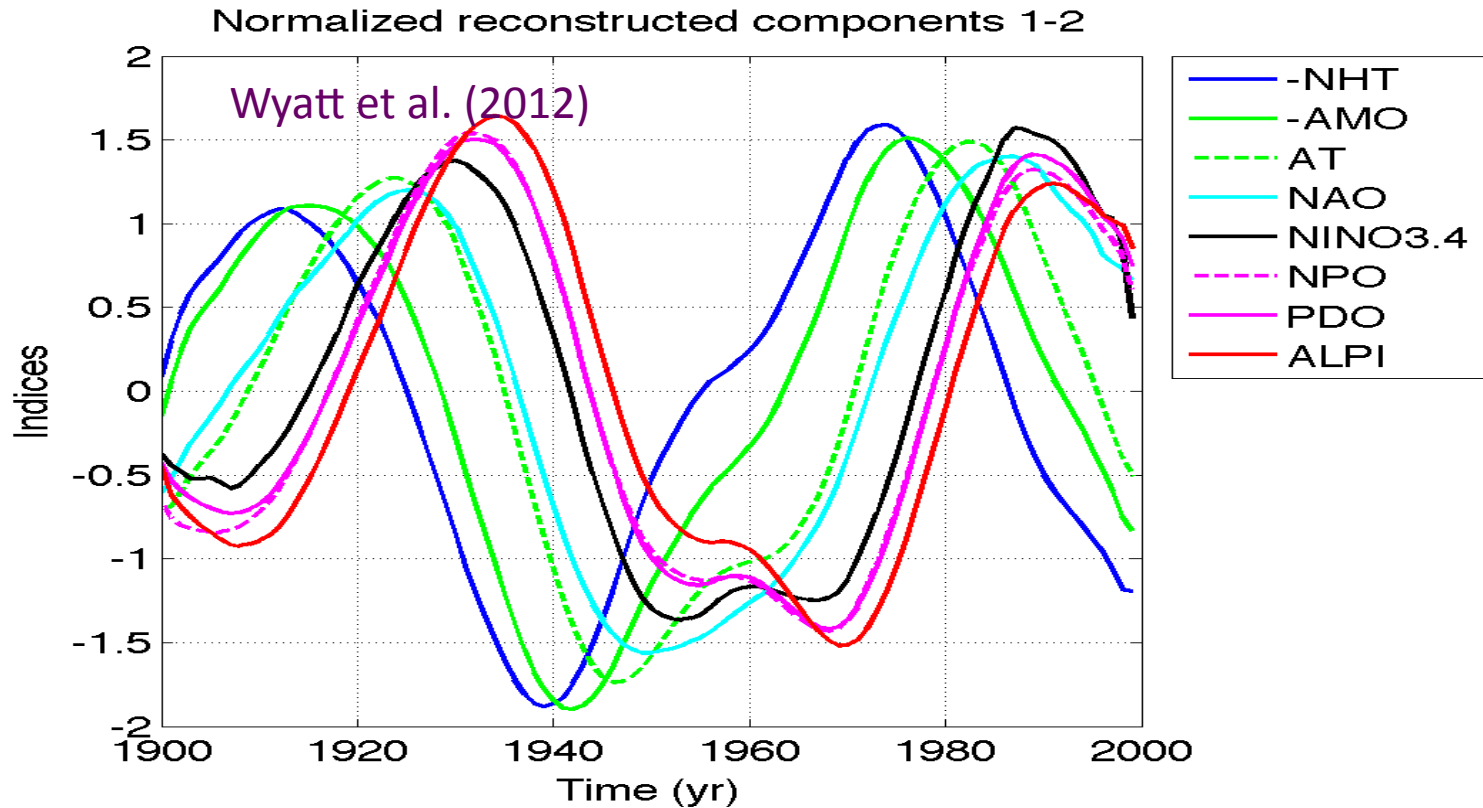
-AMO (4y) +NAO (8y) +PDO (4y) +ALPI



- Lagged correlations of multidecadal signal in various indices
- Multi-channel Singular Spectrum Analysis (M-SSA) assesses significance of signal

Climate as a stadium wave

www.wyattonearth.net



The 'stadium wave' climate signal propagates across the NH through a network of ocean, ice, and atmospheric circulation regimes that self-organize into a collective tempo.

M-SSA is used to extract and characterize dominant spatio-temporal patterns of variability shared by indices within a network.

Stadium Wave Wheel

Wyatt & Curry, 2013: Climate Dynamics

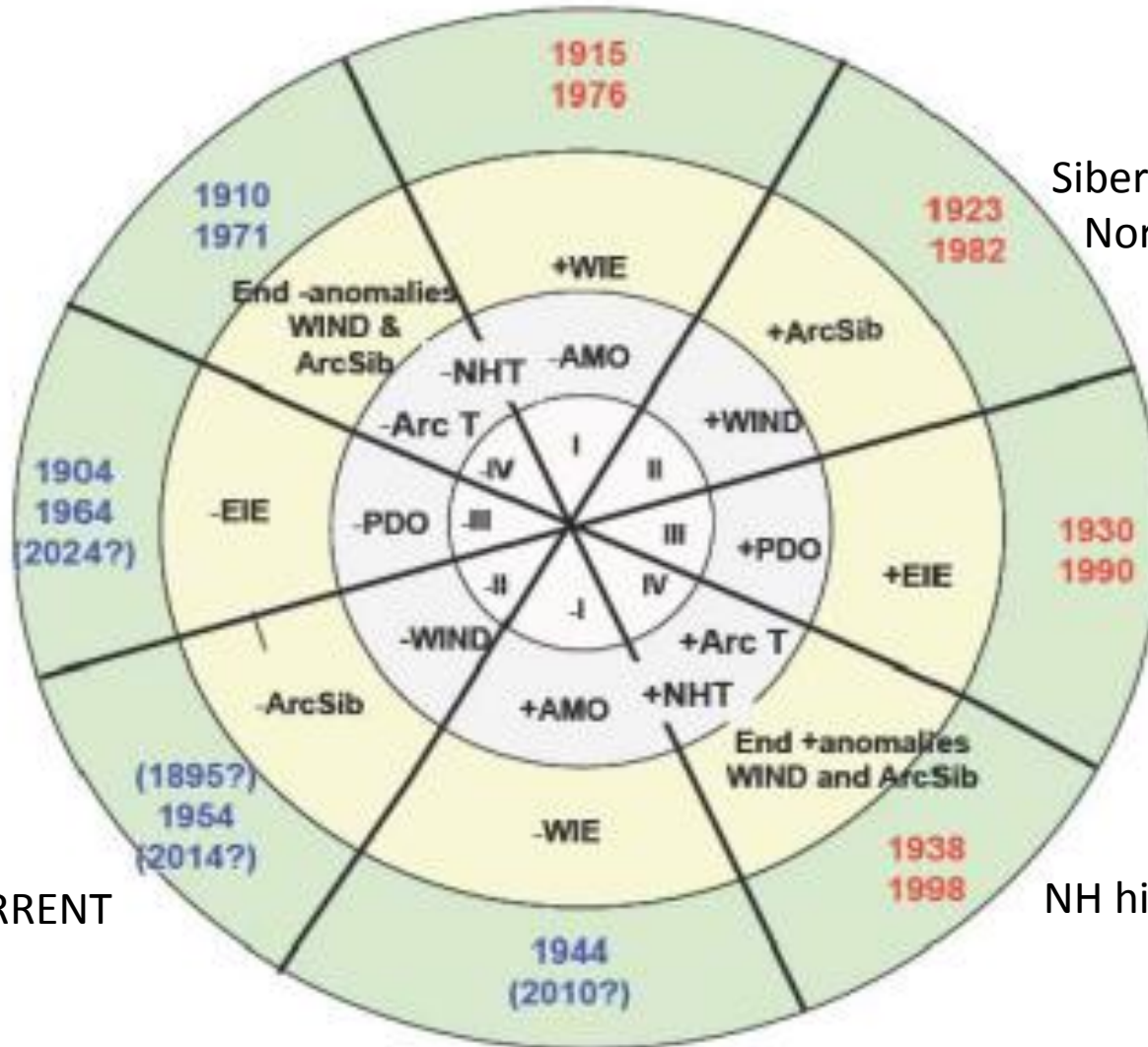
N. Atlantic sector of the Arctic

Siberian sector of the Arctic;
North Pacific

North Pacific

NH high latitudes

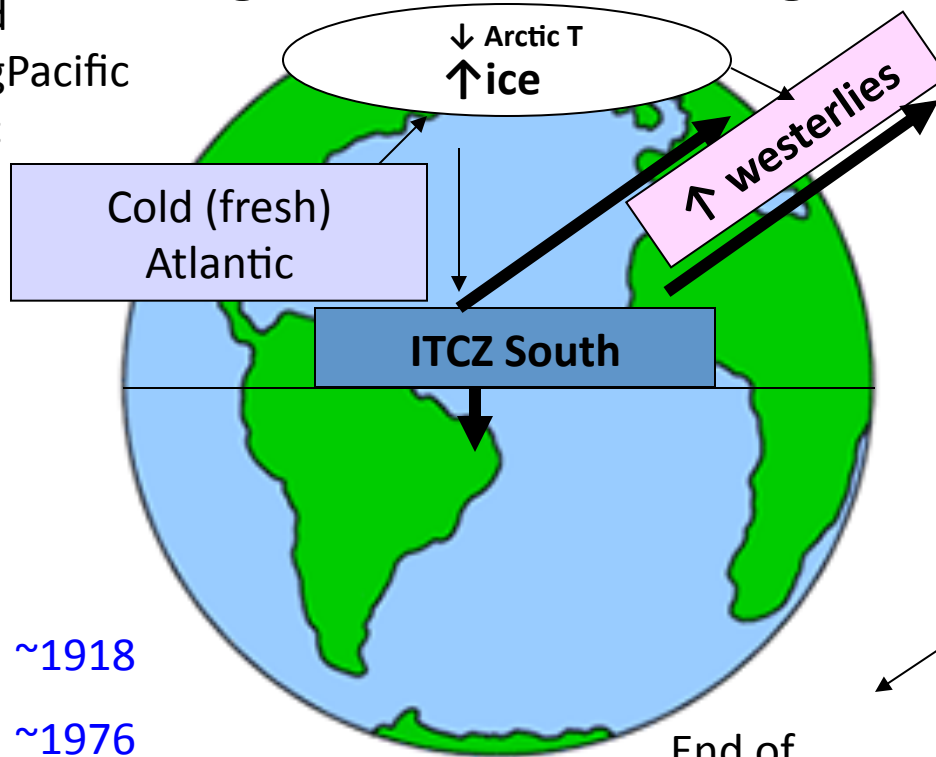
CURRENT



- 19th & 20th century tempo of 60-64 years.
- Continued cool phase into the 2030's

Regime shift to warming

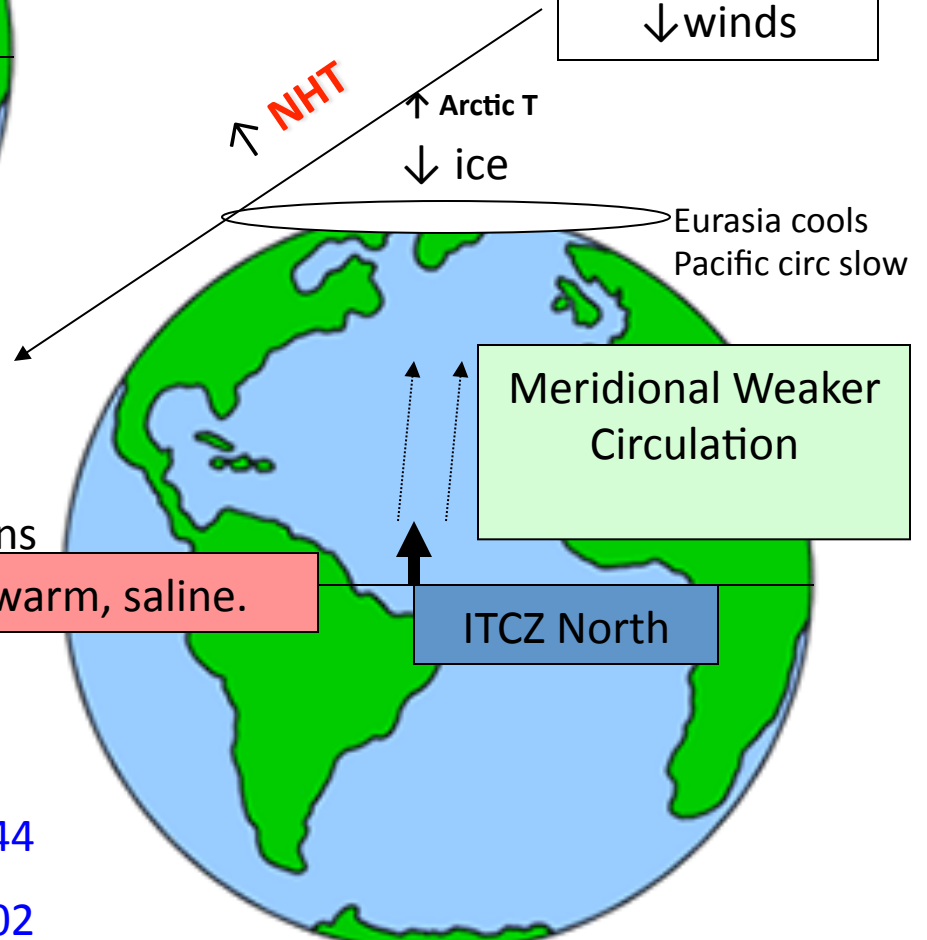
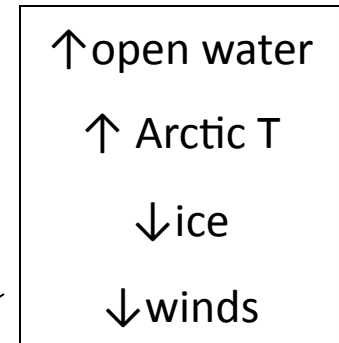
End
negPacific
circ



~1918

~1976

Warms Eurasia
Intensifies Pacific circulation



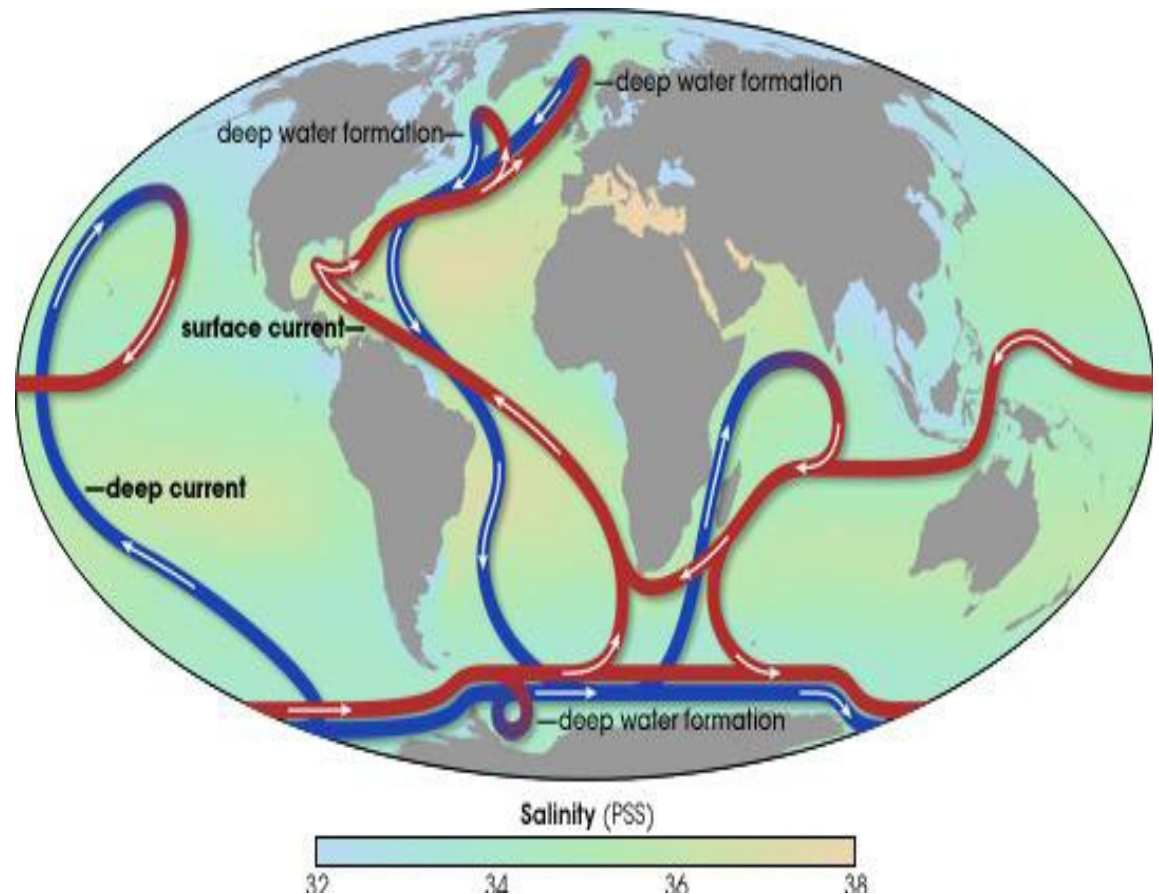
~1944

~2002

Regime shift to cooling

Ocean thermohaline circulation

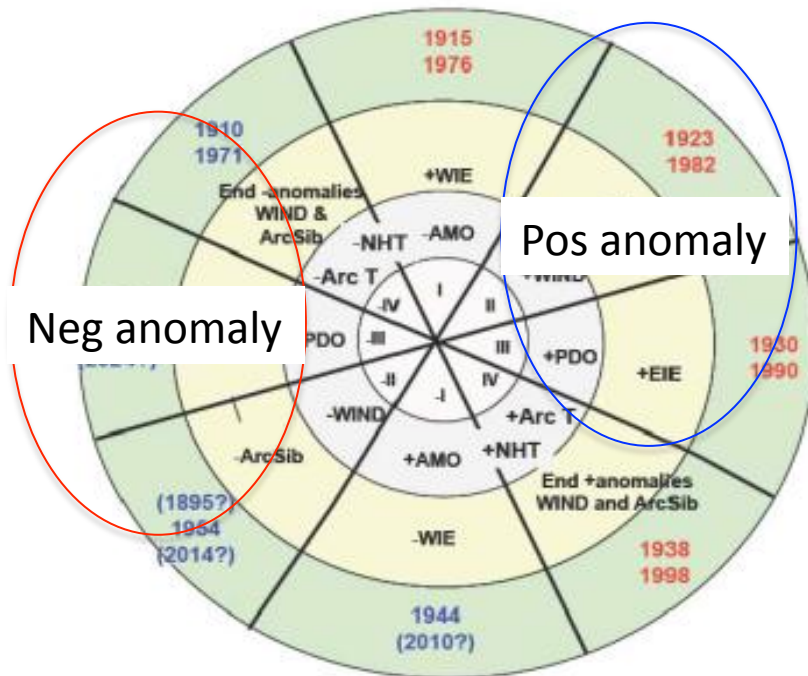
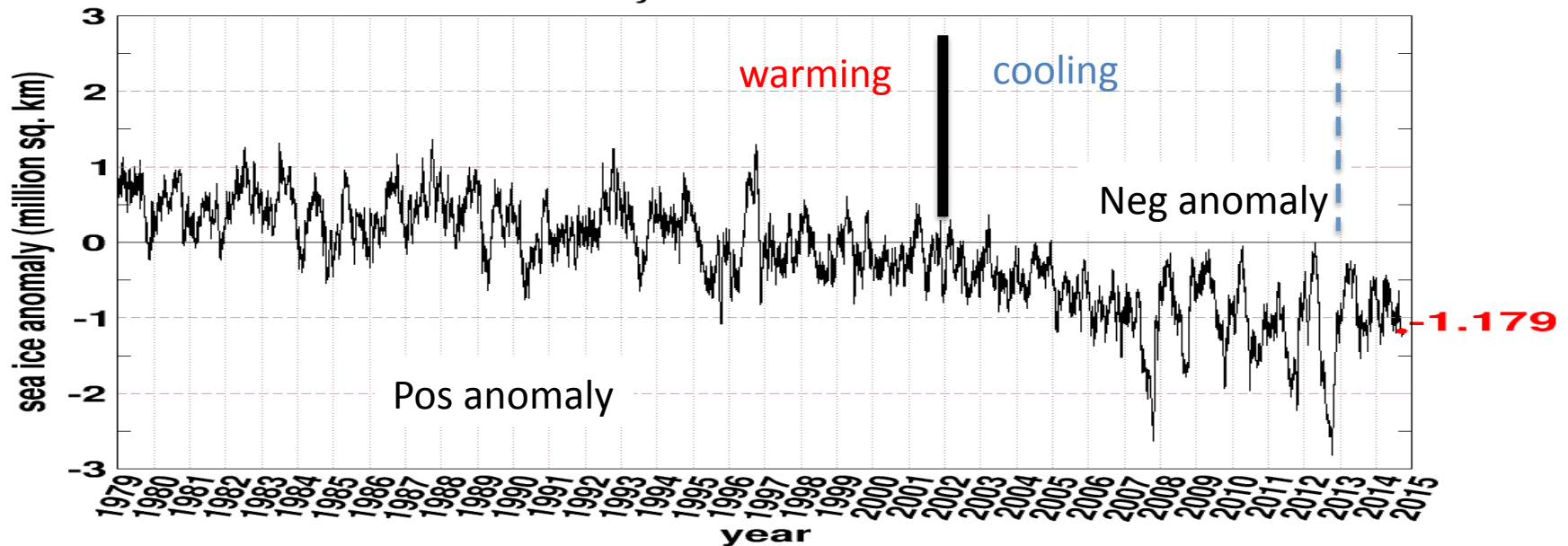
- When sea water freezes to form sea ice, salt is rejected into the ocean.
- Salinity of the surface water increases where sea ice is formed.
- Water with a higher salinity has higher density than water with lower salinity.
- Salty water sinks to lower levels in the ocean, while warmer water from the south replaces what used to be surface water.



Role of sea ice in the stadium wave

- 1) Eurasian-Arctic shelf sea-ice plays a strong role in the propagation of the hemispheric climate signal
- 2) multidecadal patterns of internal saline Rossby modes and North Atlantic-Arctic salinity exchange
- 3) multidecadal fluctuations of heat and salt advection and their role in sea-ice formation
- 4) Ice influences basin-scale meridional temperature gradient
- 5) atmospheric response to this ice-induced temperature gradient
- 6) the many consequences of that atmospheric response, largely due to the regime-related geographical shifts of the atmospheric and oceanic centers-of-action, and reinforced by oceanic centers of action

Anomaly from 1979-2008 mean

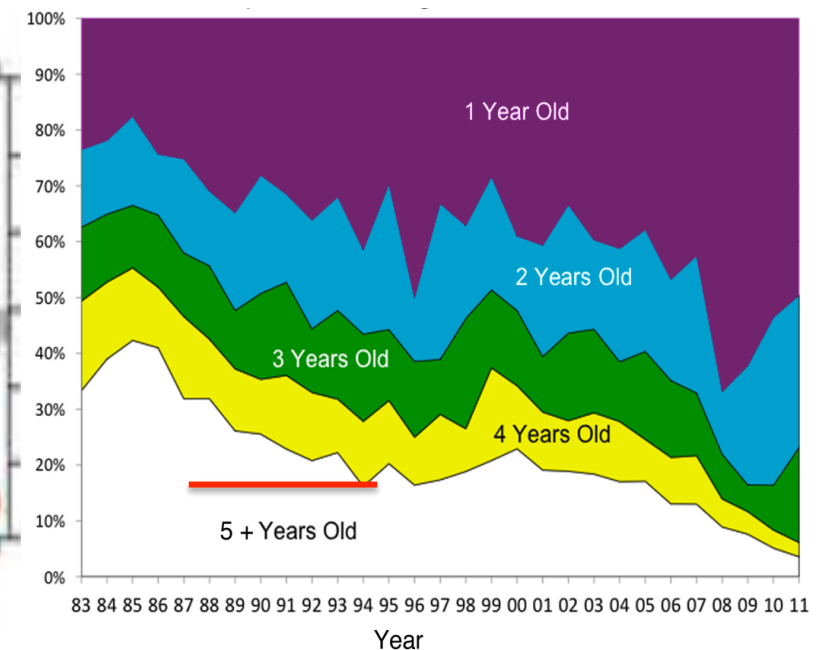
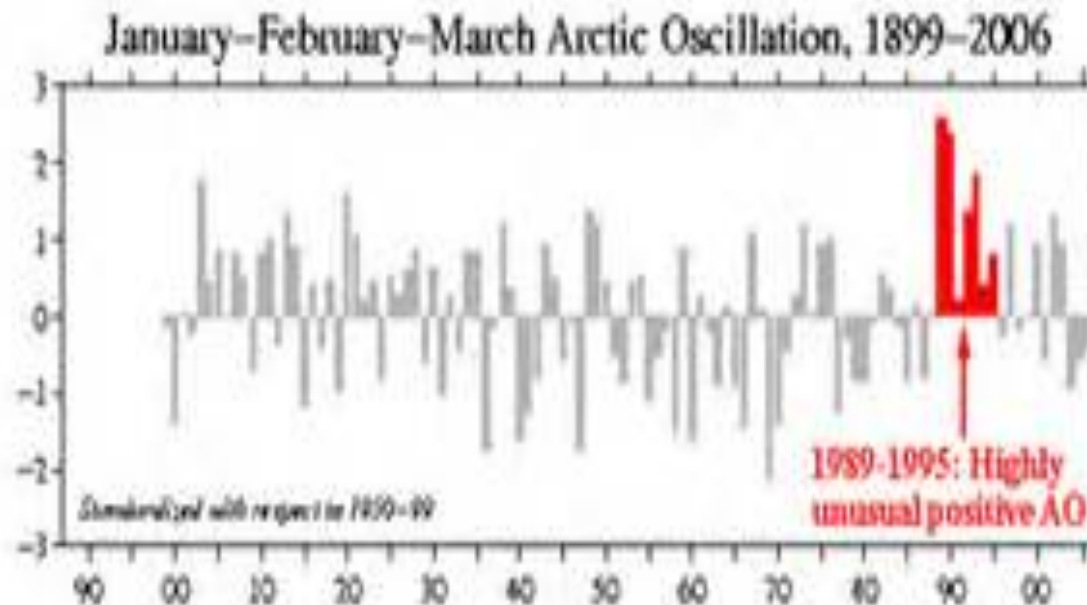


Stadium wave hypothesis predicts a reversal in the sea ice decline over the next 1-2 decades



1989-1995: Anomalous positive anomaly of Arctic Oscillation

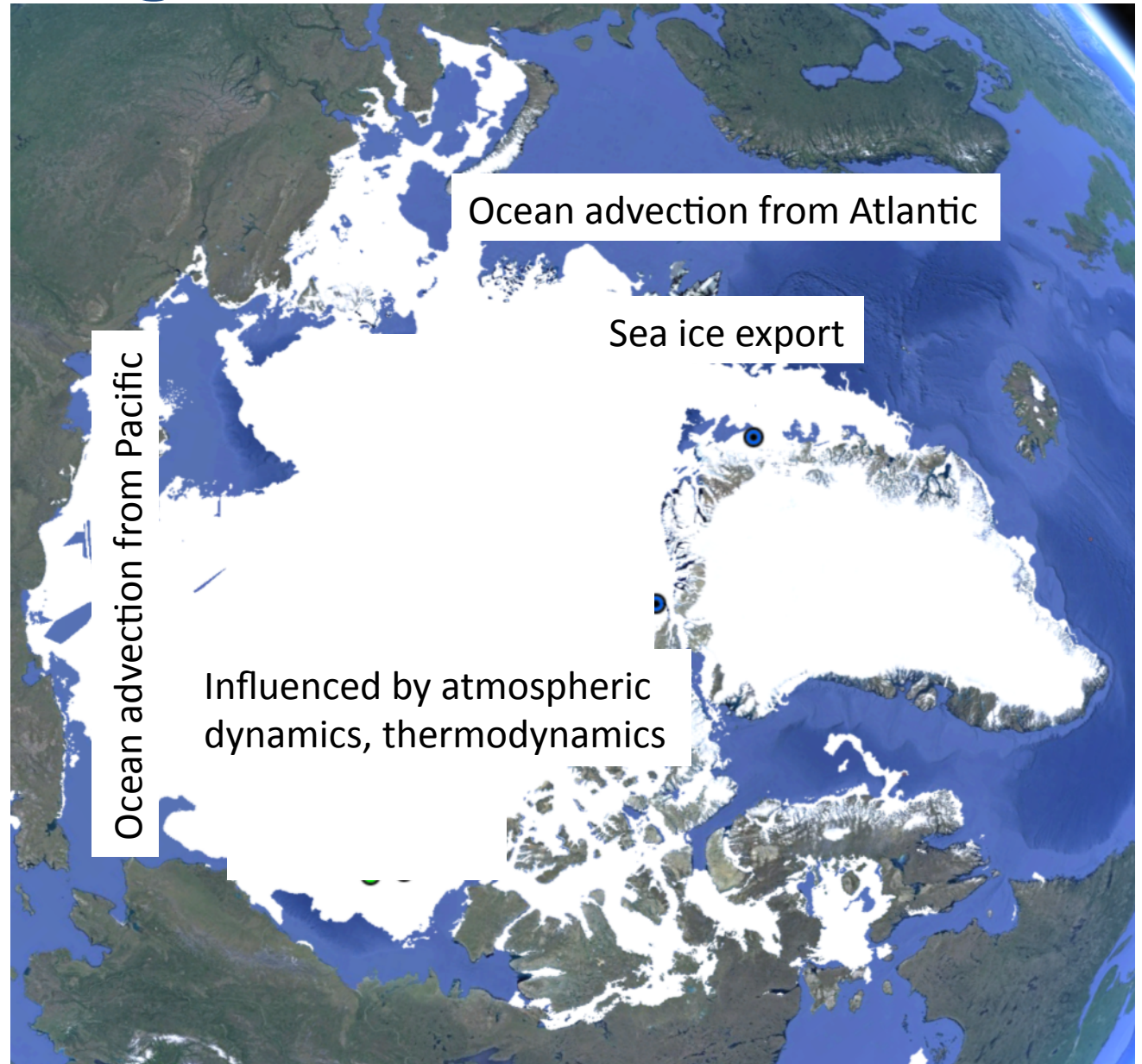
→ Enhanced transpolar drift
→ Flushing of multiyear ice through the Fram Strait



Regional factors

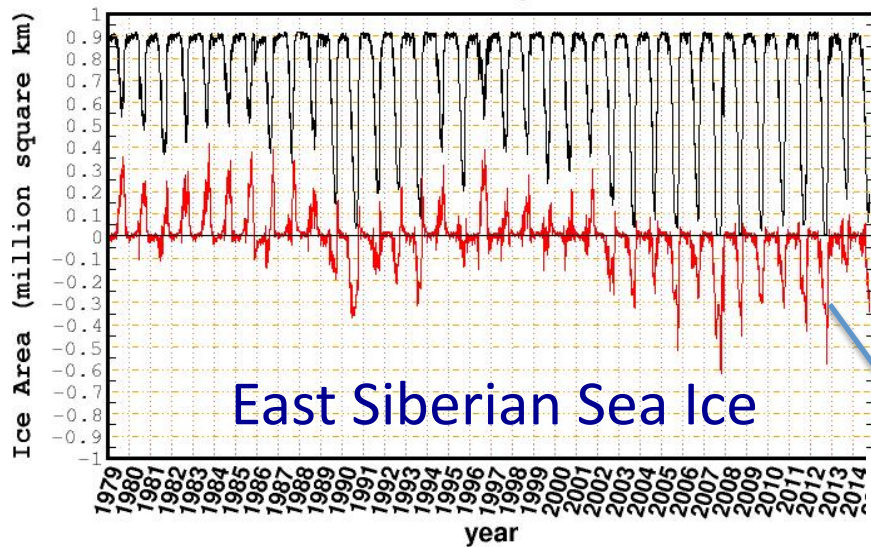
Geographical variations give rise to regional variations in processes that contribute to sea ice decline/growth

Hence ocean and atm dynamics contributes to regional variations in sea ice decline/growth



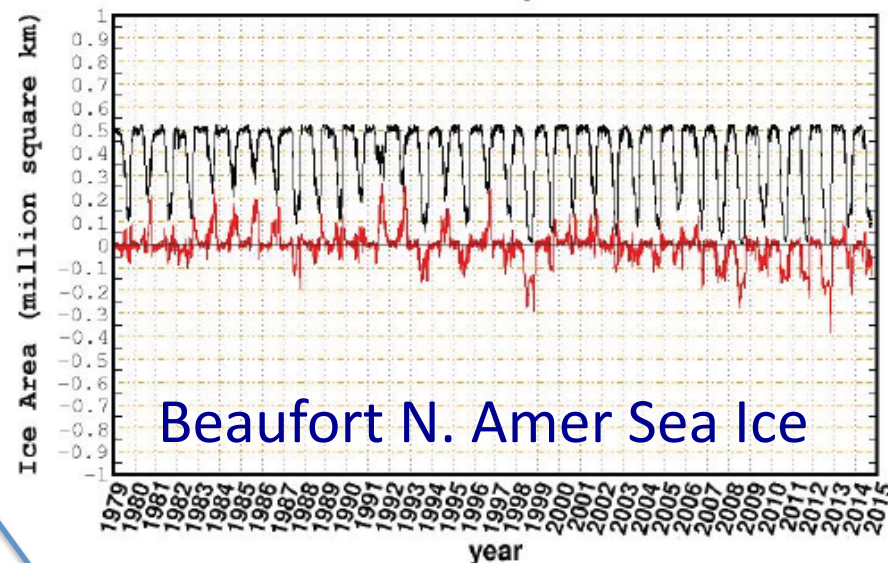
Current East Siberian Sea Ice Area

recent 365 days shown



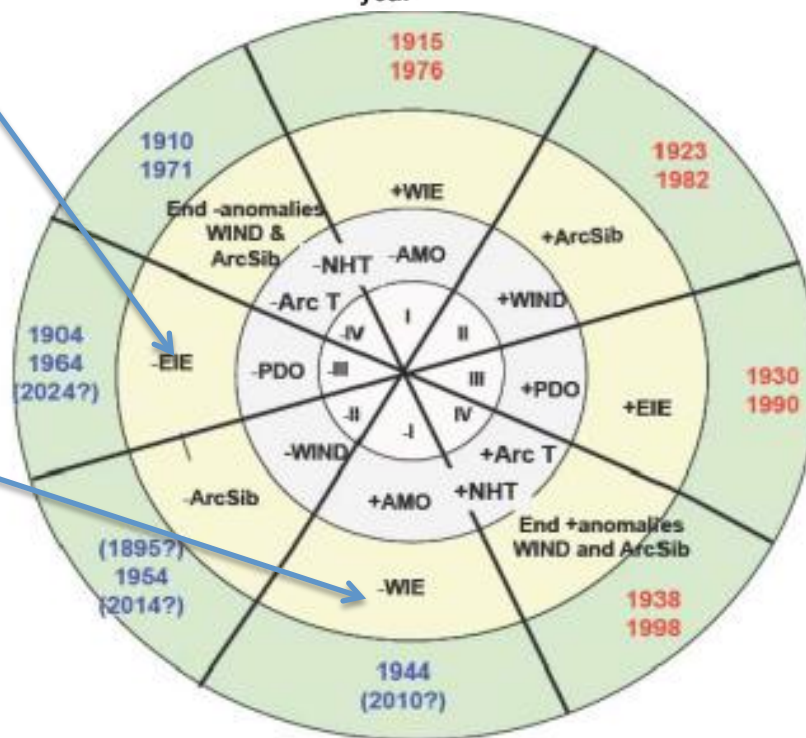
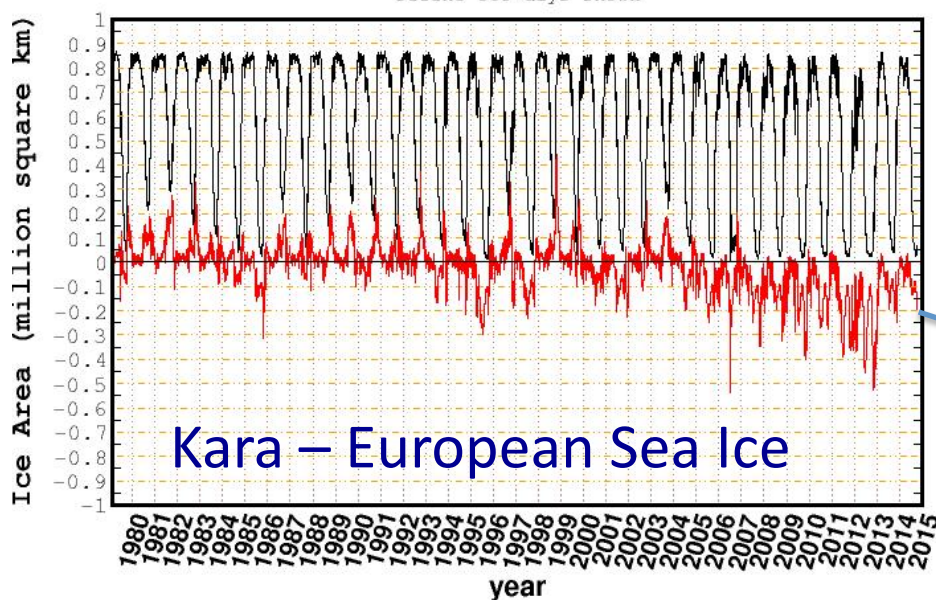
Current Beaufort Sea Ice Area

recent 365 days shown

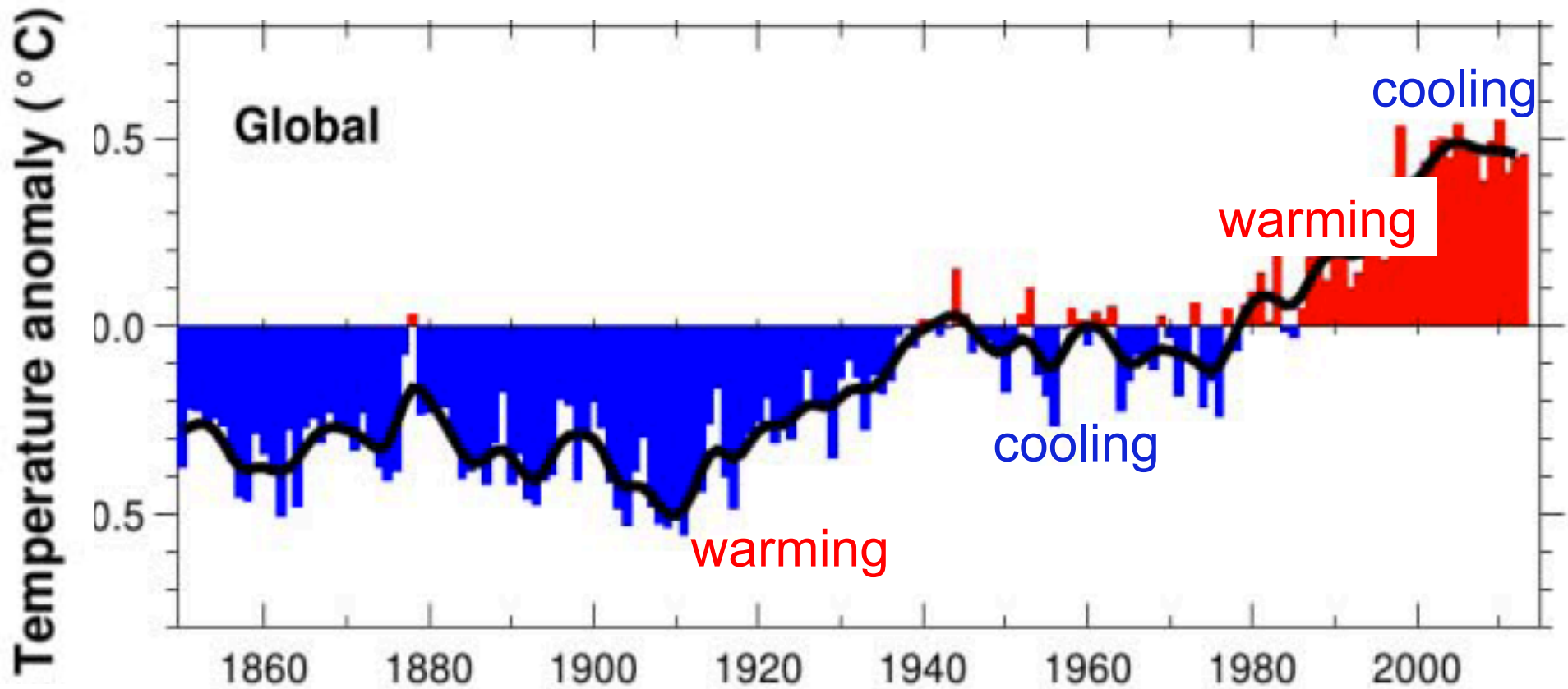


Current Kara Sea Ice Area

recent 365 days shown

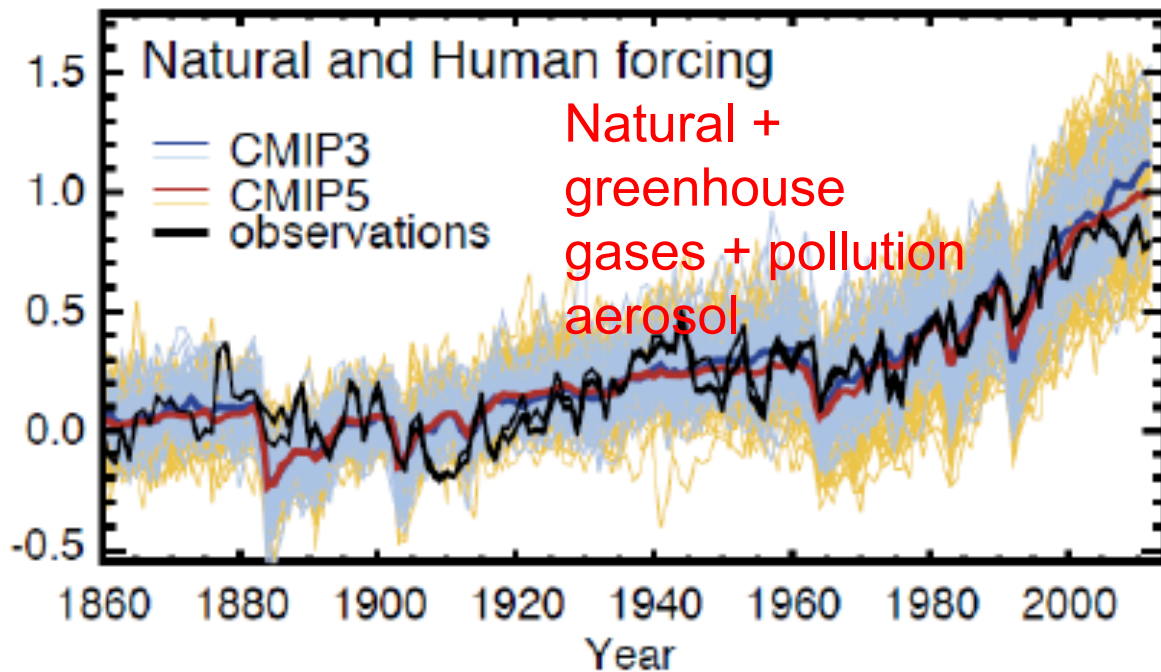
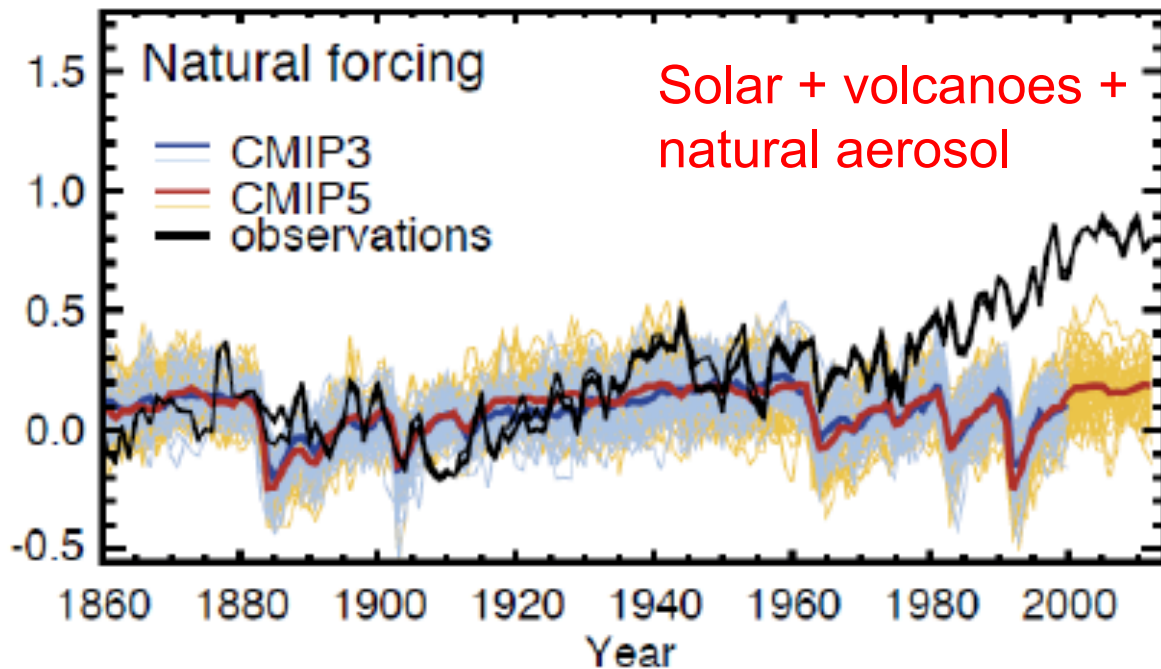


Global surface temperature anomaly



Natural variability as per the stadium wave provides for a stair step evolution against background of overall warming trend

Human impact on warming apparent post 1980



What has caused the warming?

Warming since 1950:
IPCC - Human forcing

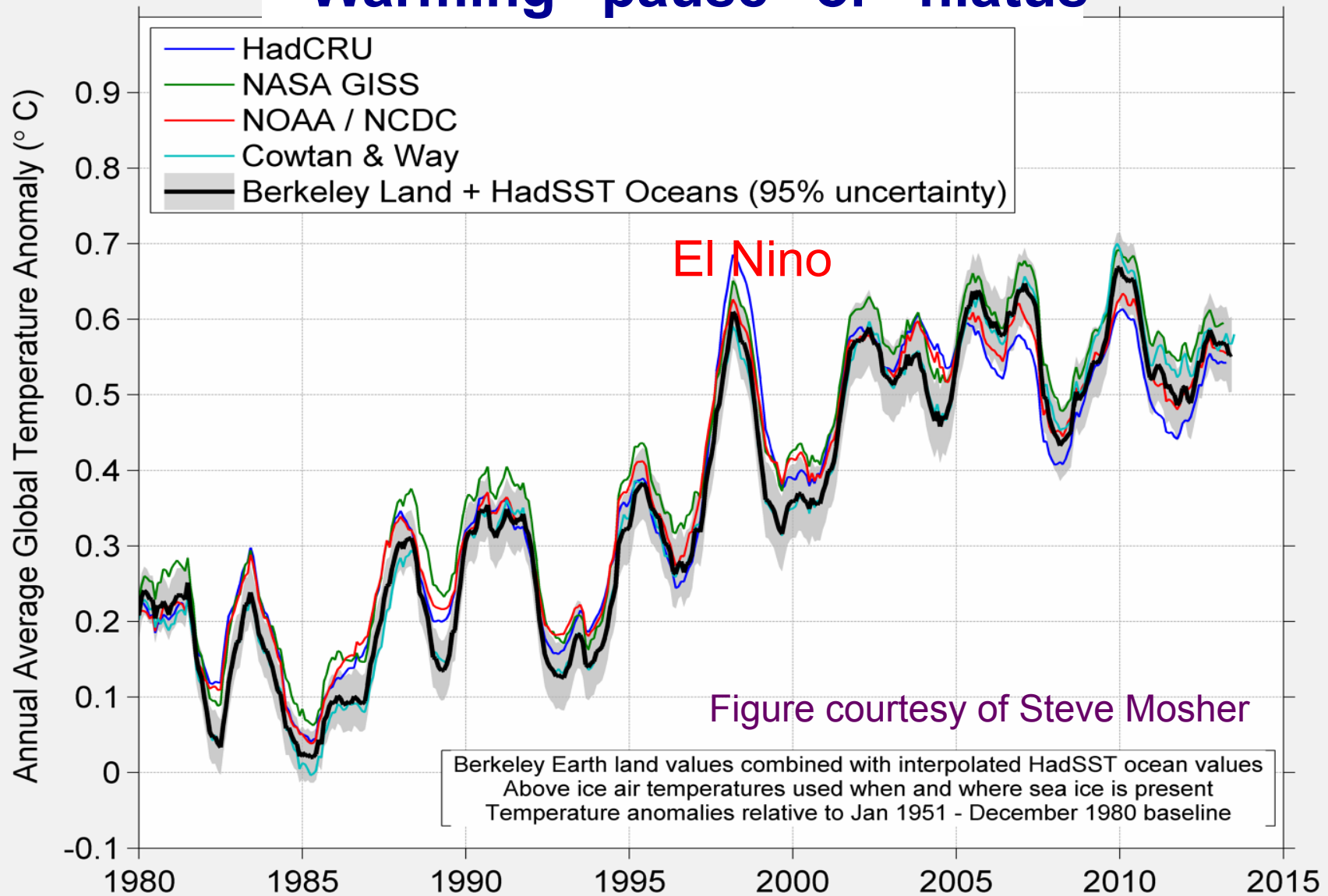
Warming 1910-1940:
Models produce slight warming due to reduced volcanic activity and small human effects

Cooling 1940-1975:
Not reproduced by the models

Flat in 21st century: Not reproduced by models

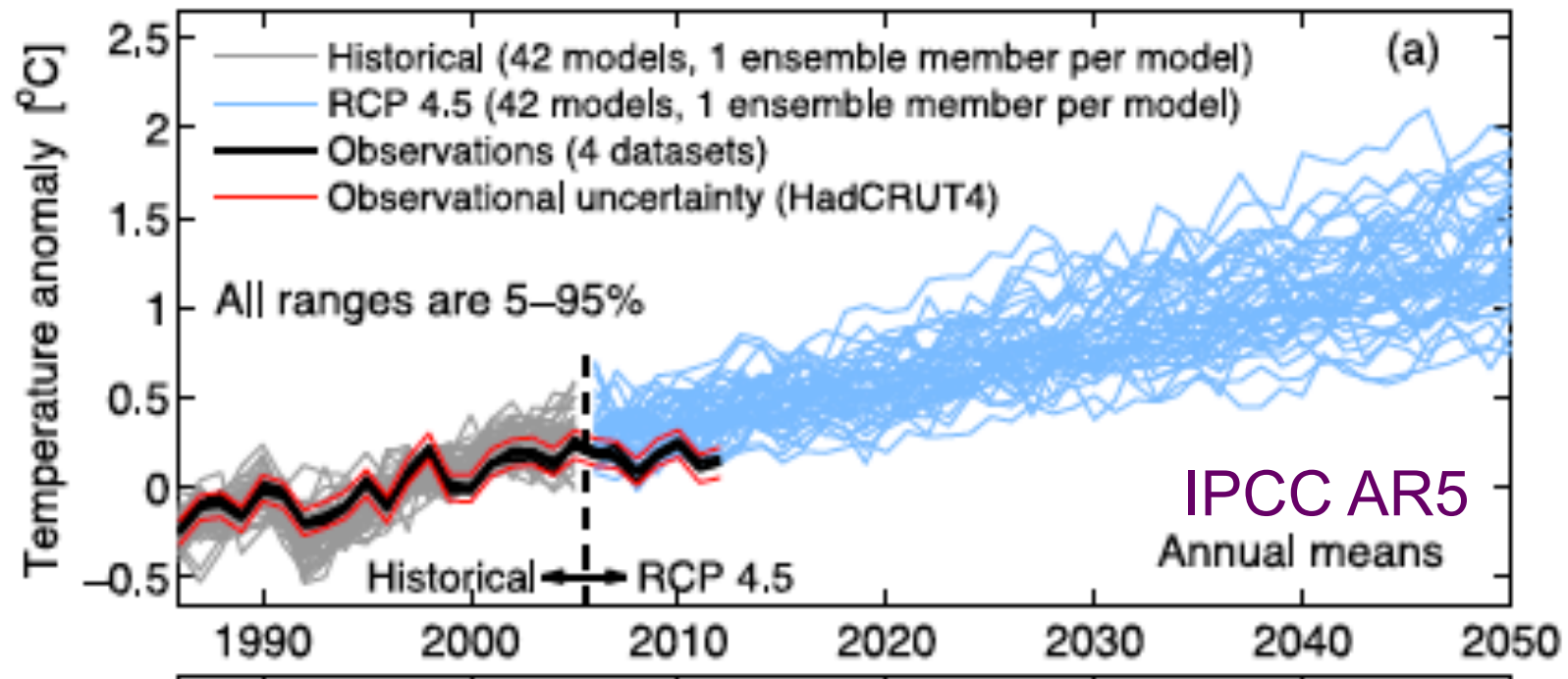
IPCC AR5 Chapter 10

Warming 'pause' or 'hiatus'



IPCC AR4: Surface temperature expected to increase 0.2°C/decade in early 21st century

Significance of the 'pause' since 1998



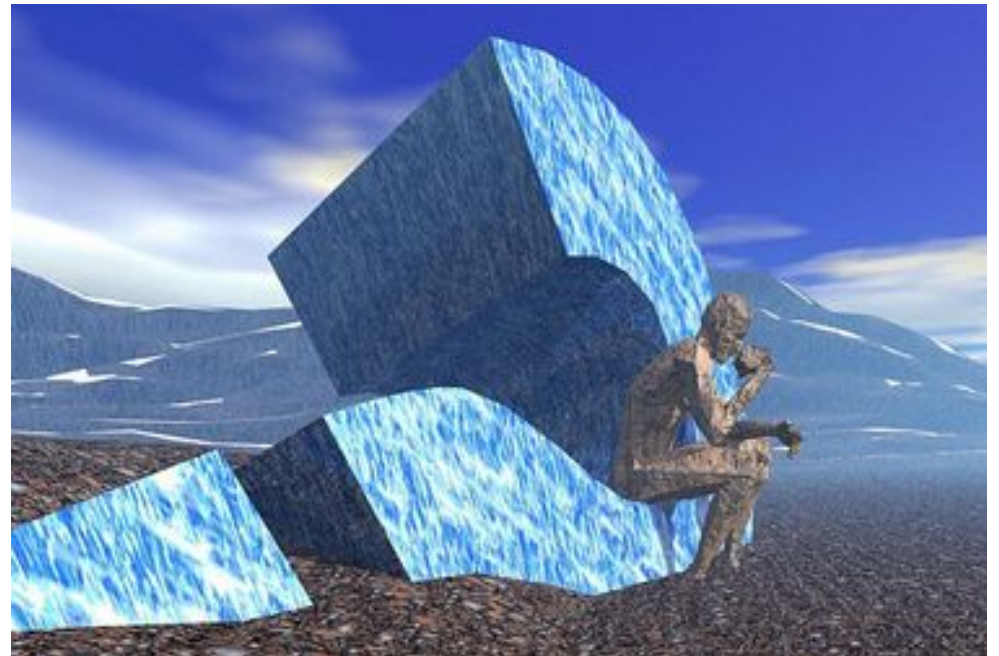
CO₂ concentration since 1998: ~ +25% of total human impact

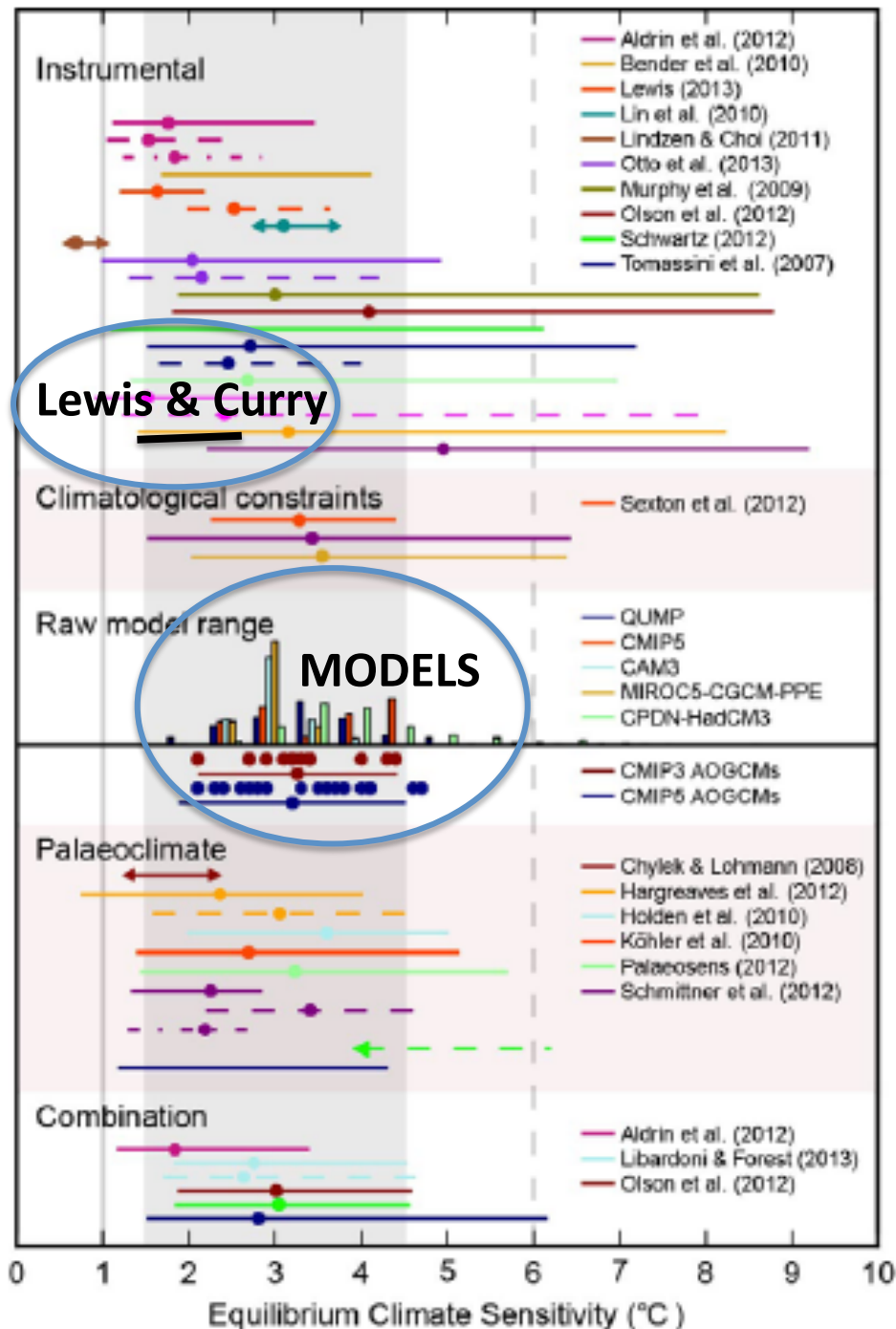
Under conditions of human-caused greenhouse forcing:

- modeled 'pauses' longer than 15 years are rare;
- probability of a modeled pause exceeding 20 yrs is vanishing small

Questions raised by the discrepancy between models & observations

- Are climate models too sensitive to greenhouse forcing?
- Is climate model treatment of natural climate variability inadequate?
- Are climate model projections of 21st century warming too high?





IPCC AR5: Equilibrium climate sensitivity is likely in the range **1.5°C to 4.5°C**, extremely unlikely less than 1°C, and very unlikely greater than 6°C.

Lewis and Curry 2014: Observation analysis finds likely range for equilibrium climate sensitivity is **1.25-2.45°C**

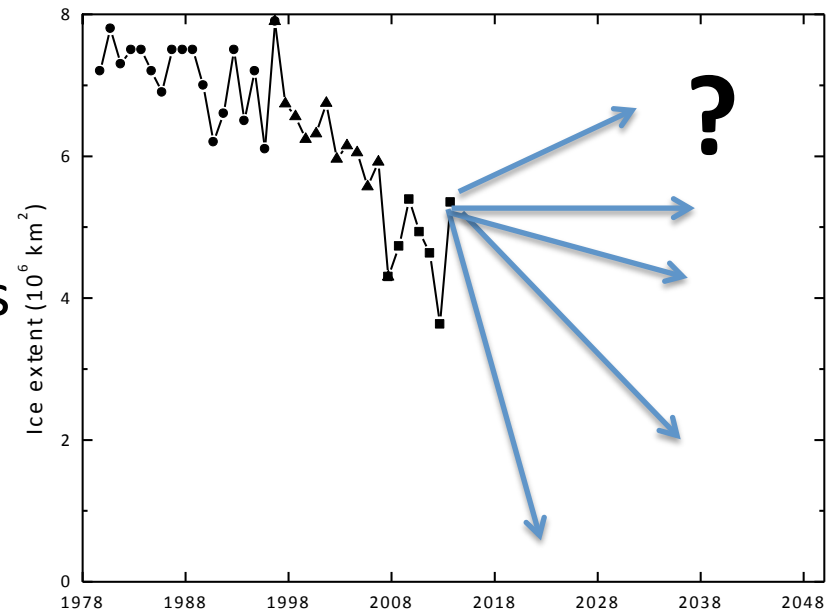
Whither the Arctic Ocean sea ice?

Important role for natural variability suggested by:

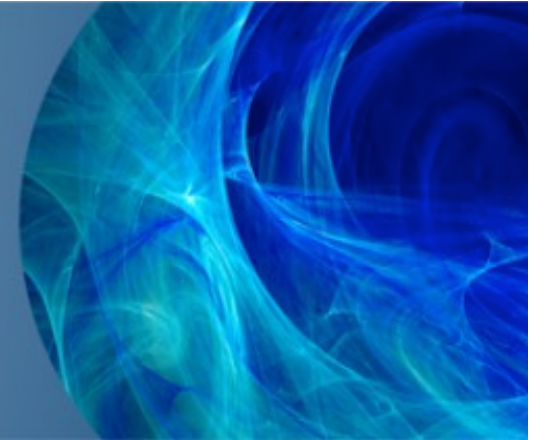
- Increasing Antarctic sea ice
- Hiatus in global surface warming
- Evidence that climate models are too sensitive to CO₂

Stadium wave hypothesis suggests:

- Continued sea ice decline in Siberian sector for another decade
- Reversal of overall decline in 2020's
- Increasing sea ice extent into 2050's
- Importance relative to AGW?
- Critical importance of early 20th century sea ice observations

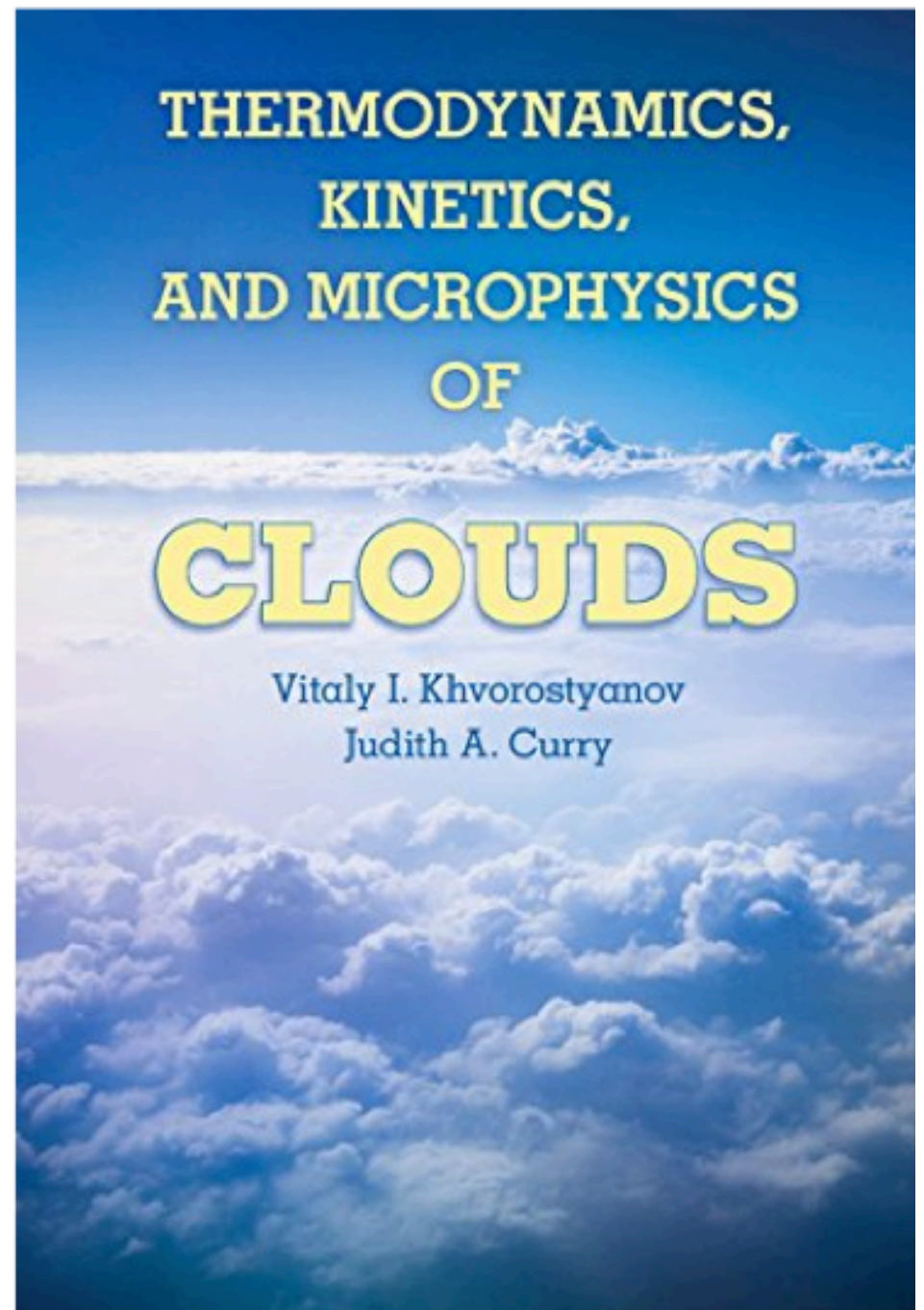
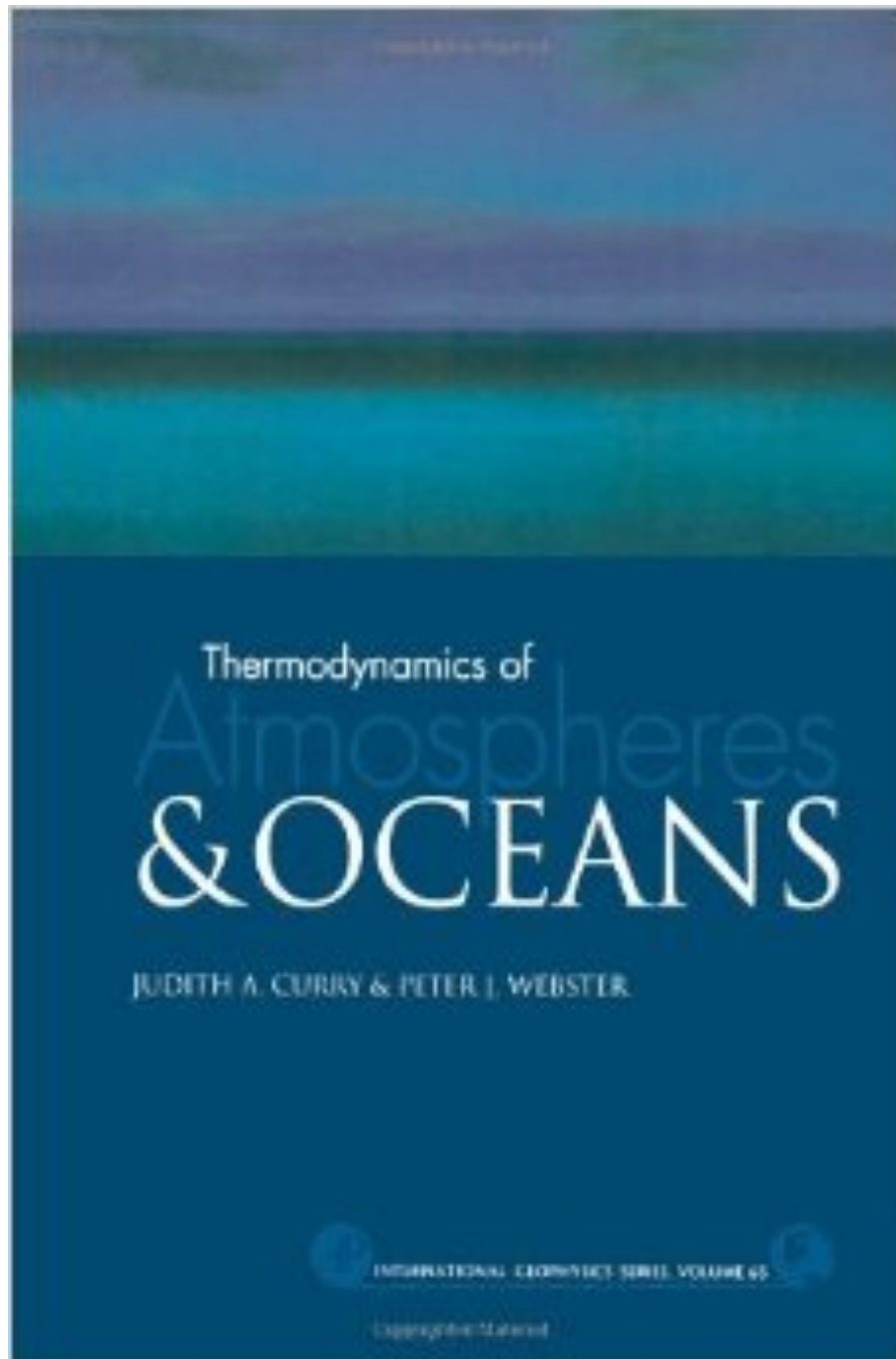


Climate Etc.



<http://judithcurry.com>

Climate Etc. blog provides a forum for technical experts and the interested public to engage in a discussion on topics related to climate science, its impacts and policy options.





Thanks for your attention!