Arctic climate change: mechanisms and consequences

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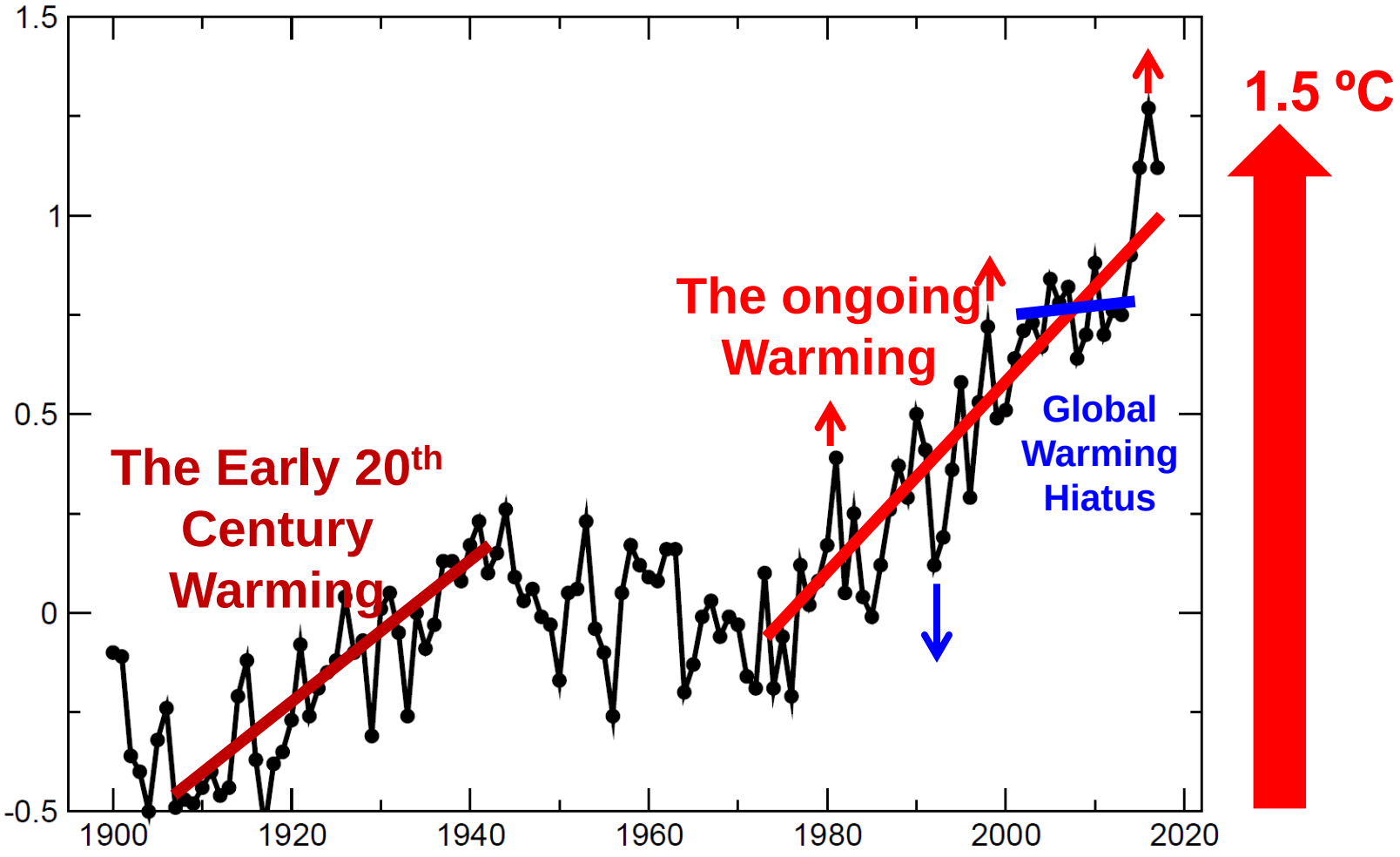
Outline

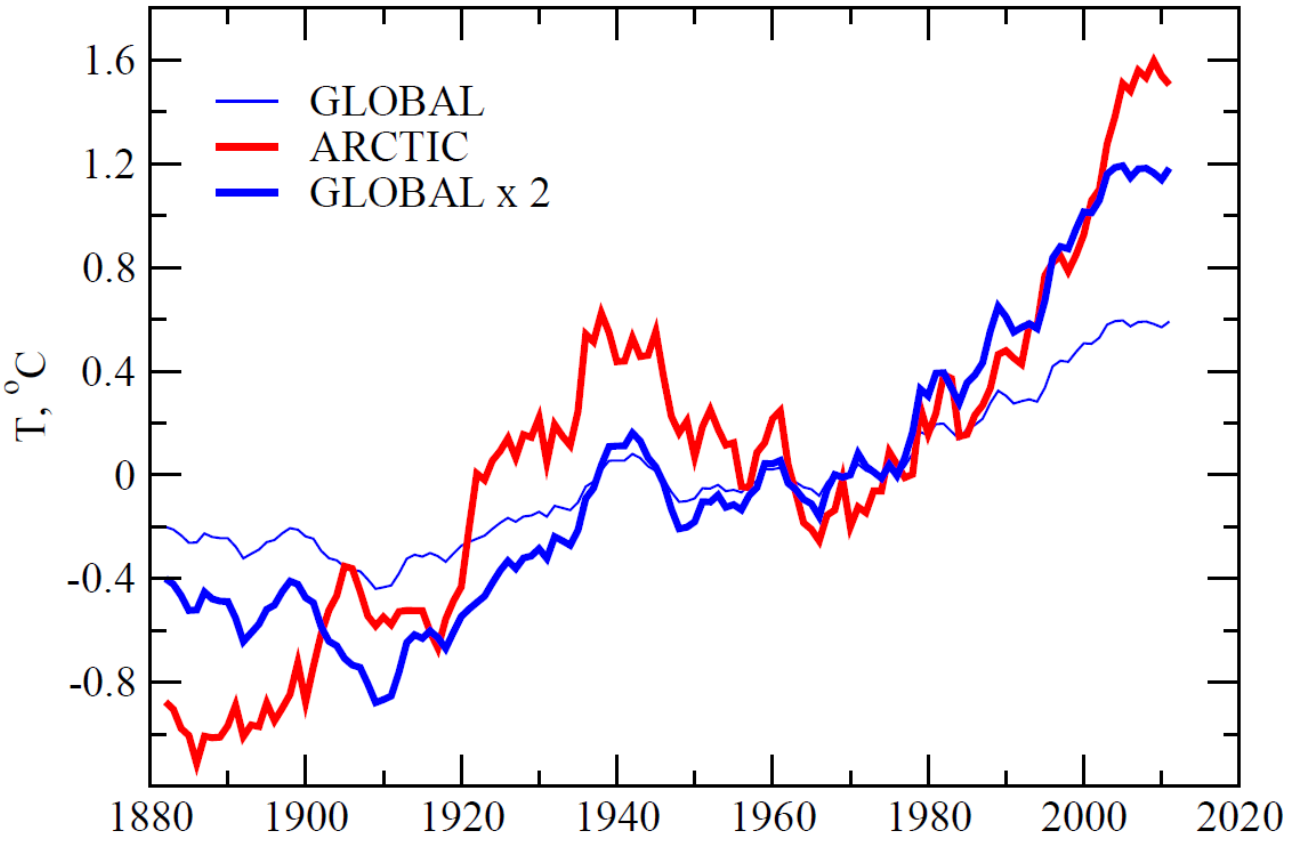
- Global and Arctic climate change
- Arctic amplification
- Arctic “cycles”
- Cold winters and Arctic sea ice
- Uncertainties of climate data and models

Global temperature evolution

Global annual surface air temperature anomalies, ºC (GISTEMP data)

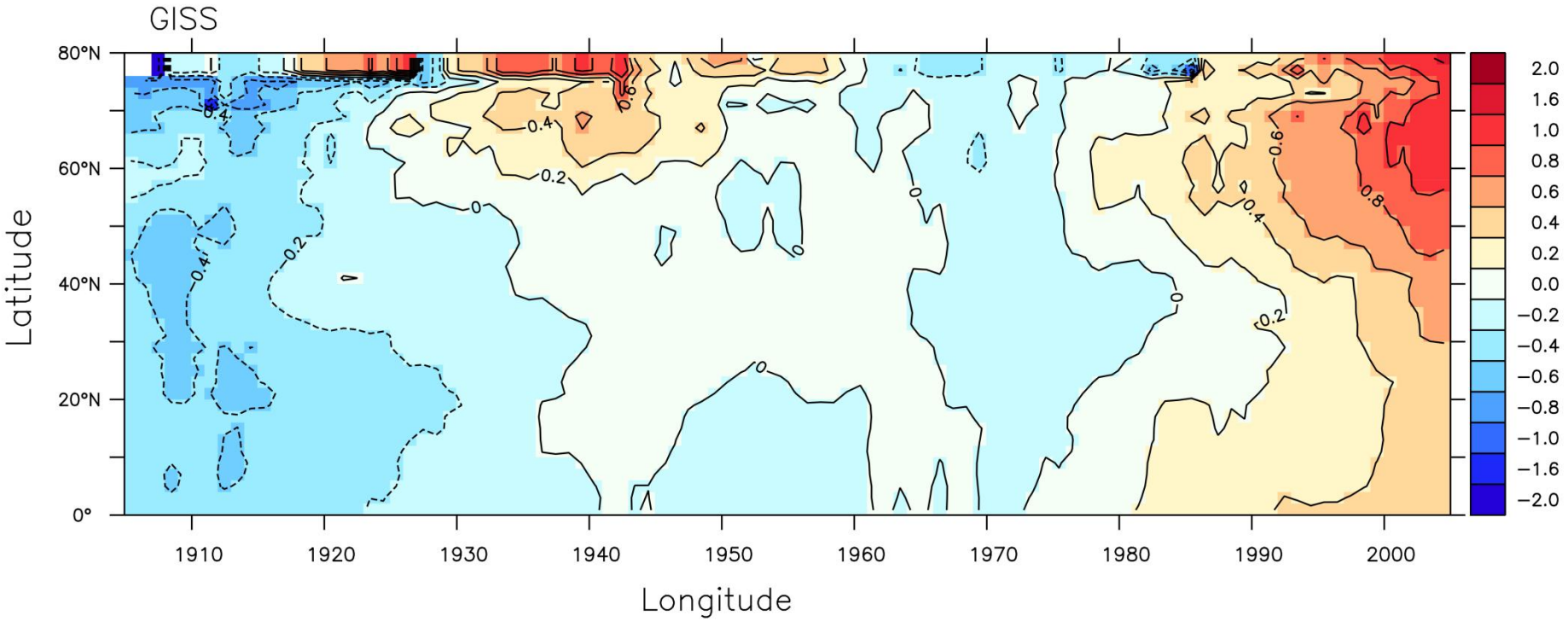


Changes of Global и Arctic annual surface temperature



- Arctic amplification of climate change
- A role of natural variability
- Non-linearity of the link between Global and Arctic temperature changes

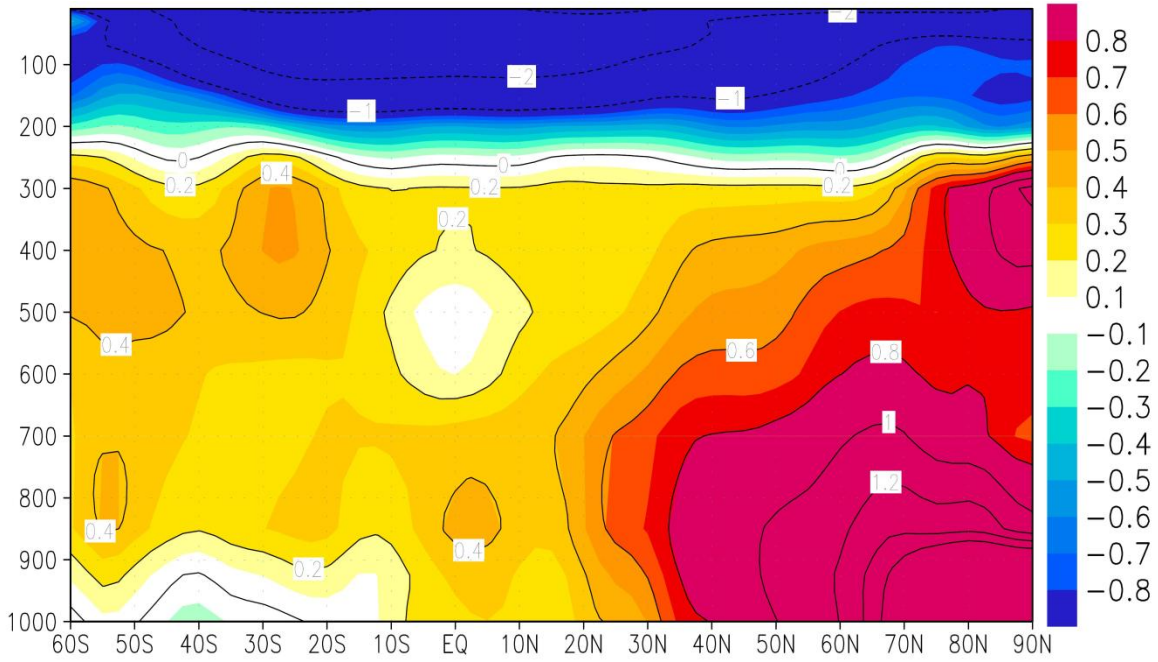
Zonal mean annual surface air temperature anomalies, ºC (GISTEMP data)



Бокучава, Семенов, 2018

Vertical structure of the temperature changes

Annual T trend 1978-2007 (°C), NCEP data



Where the enhanced Arctic warming is coming from? From below (ocean) or from above (atmosphere), or from radiative feedbacks?

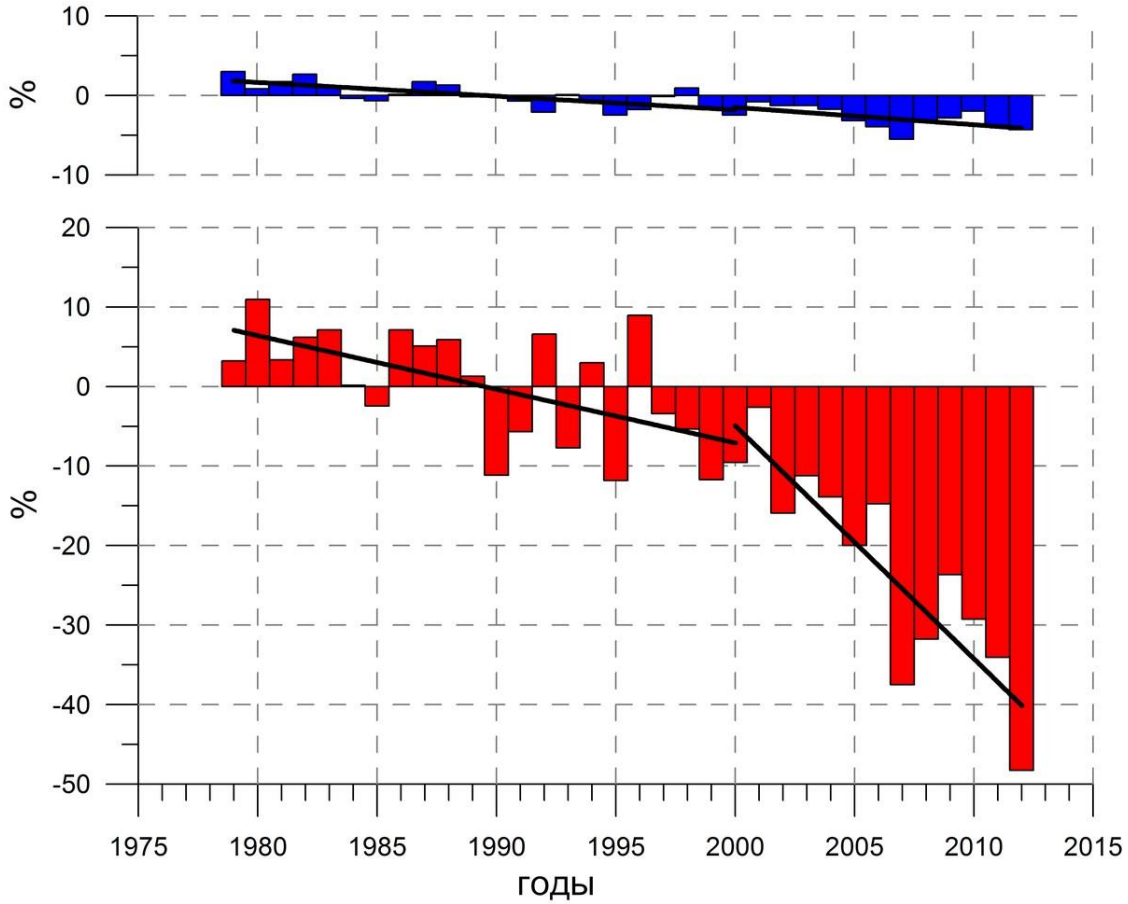
Graversen et al., 2008

Alexeev et al., 2012

Semenov et al. 2010; Семенов и др. 2014

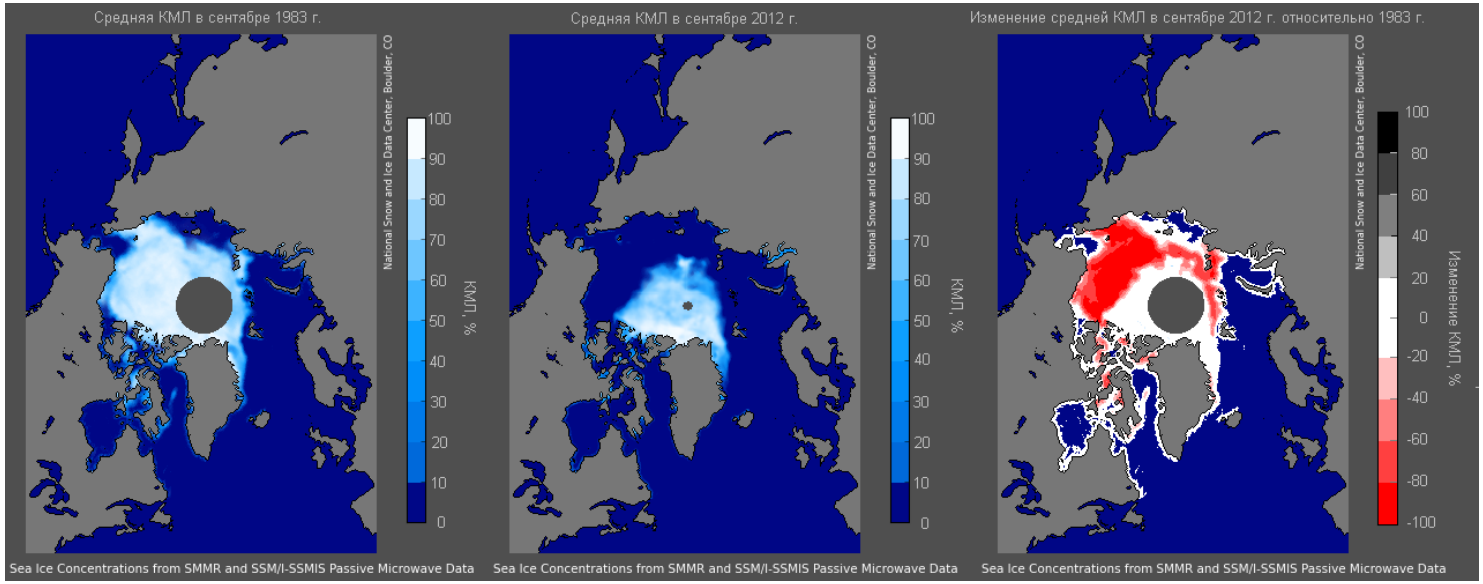
Arctic sea ice decline: extent

March and **September** Arctic sea ice extent changes (in % to 1979-2000 mean)



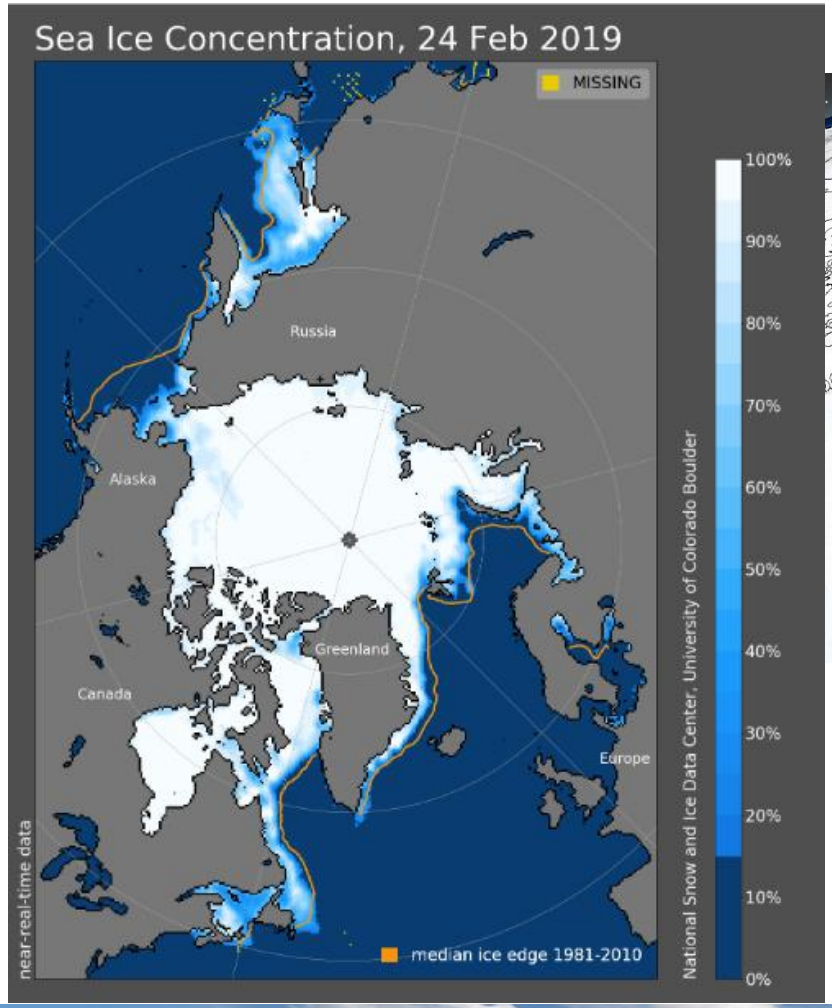
Ivanov et al. 2013

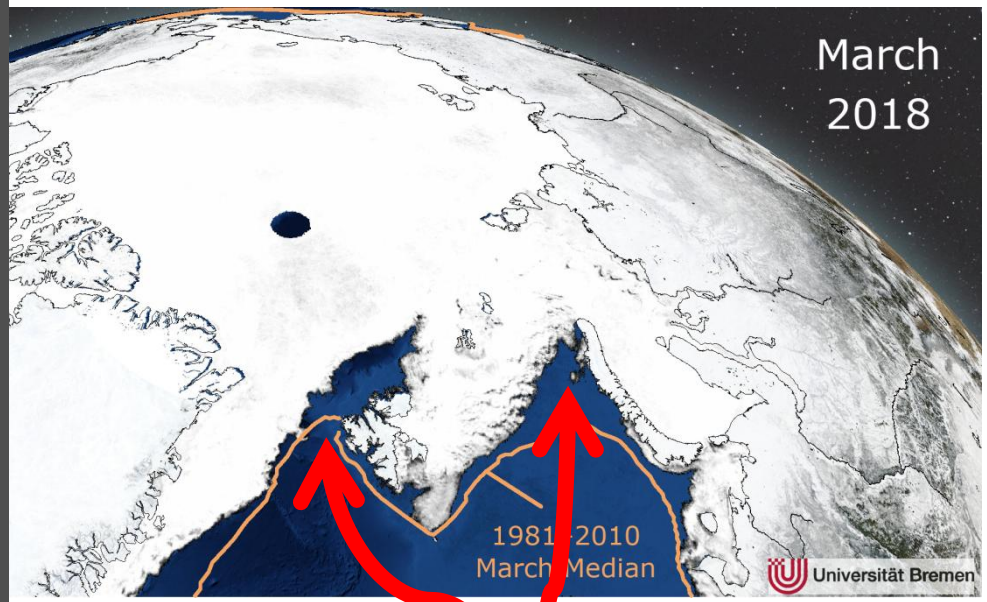
Sea ice concentration in 1983 and 2012 and their differences from satellite data



Arctic sea ice decline: extent

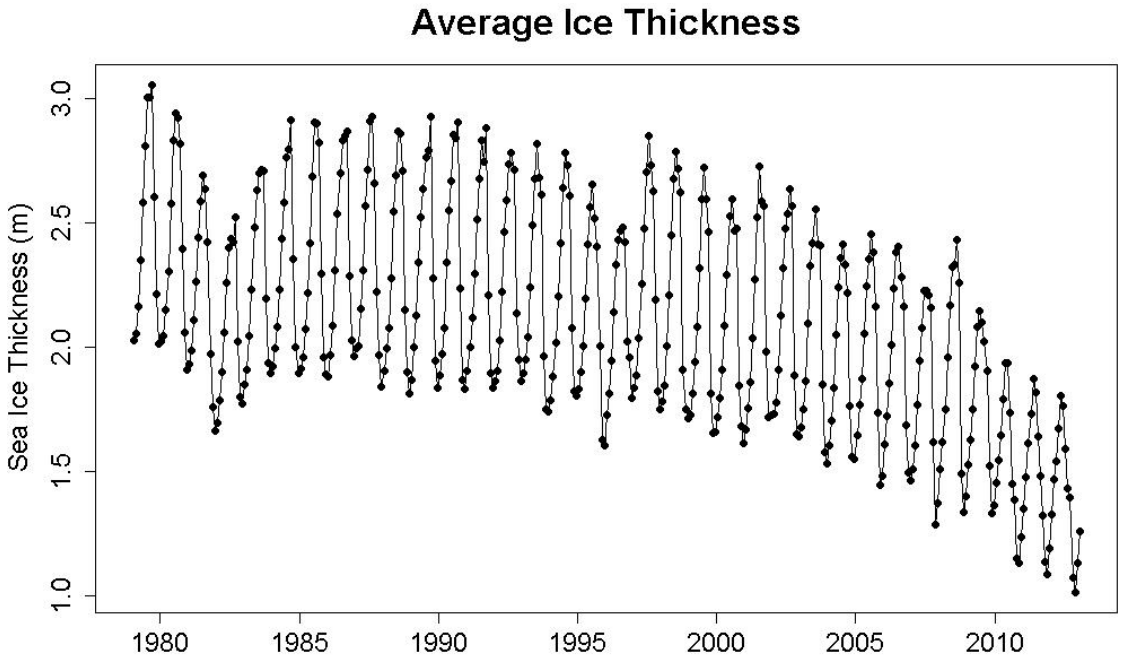
Current Barents Sea ice reduction



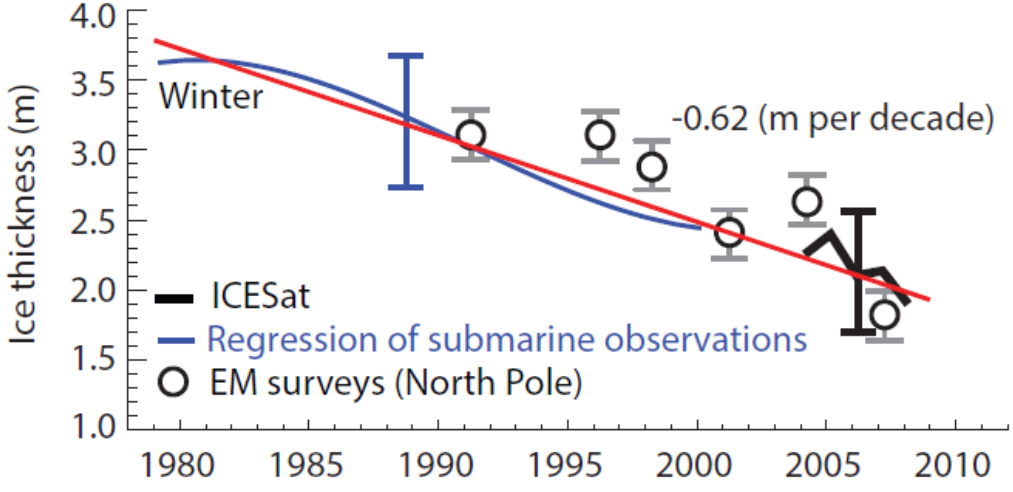


Warm Atlantic waters

Arctic sea ice decline: thickness



Pan-Arctic Ice Ocean Modeling and Assimilation System (**PIOMAS**)



IPCC AR5, 2013
Figure 4.6

Arctic amplification

What drives accelerated warming in the Arctic in the recent decades?

Enhanced ocean heat transport

Warmer and bigger volume inflow of Atlantic waters to the Arctic

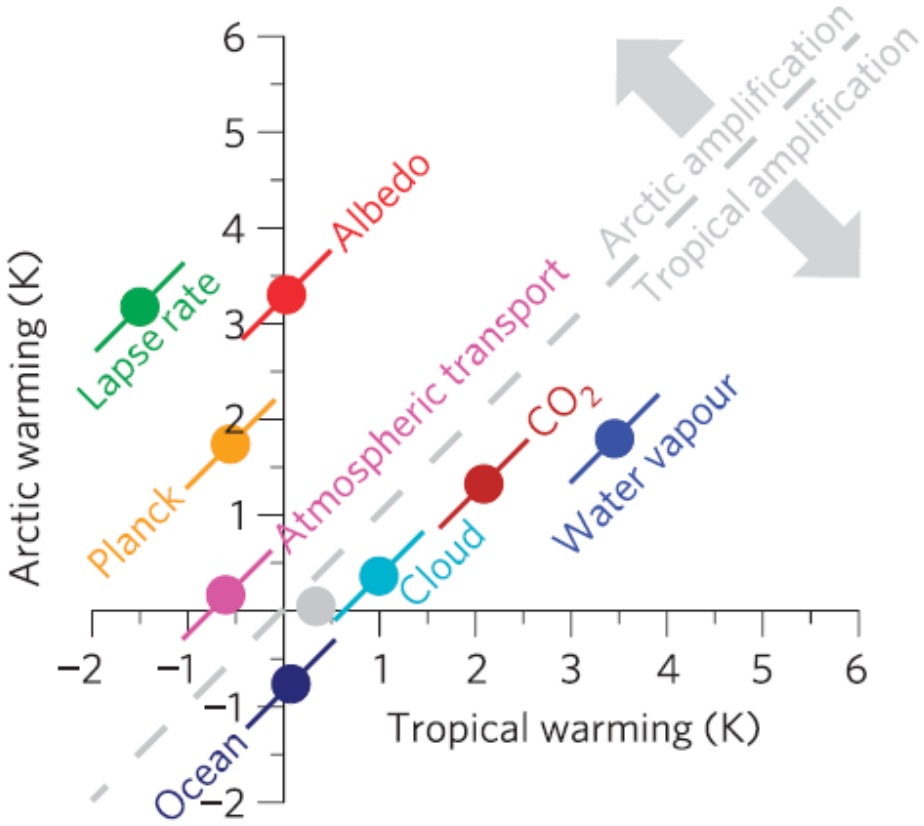
Enhanced atmosphere heat transport

Warmer and moisture atmosphere transports more heat northward despite weaker circulation, more atmospheric heat is coming from the North Pacific

Positive feedbacks enhancing external forcings

Physical processes amplifying the response to the initial forcing

What feedbacks operate in the Arctic?



Albedo

Lapse rate

Planck

Water vapour

CO2

Atmospheric transport

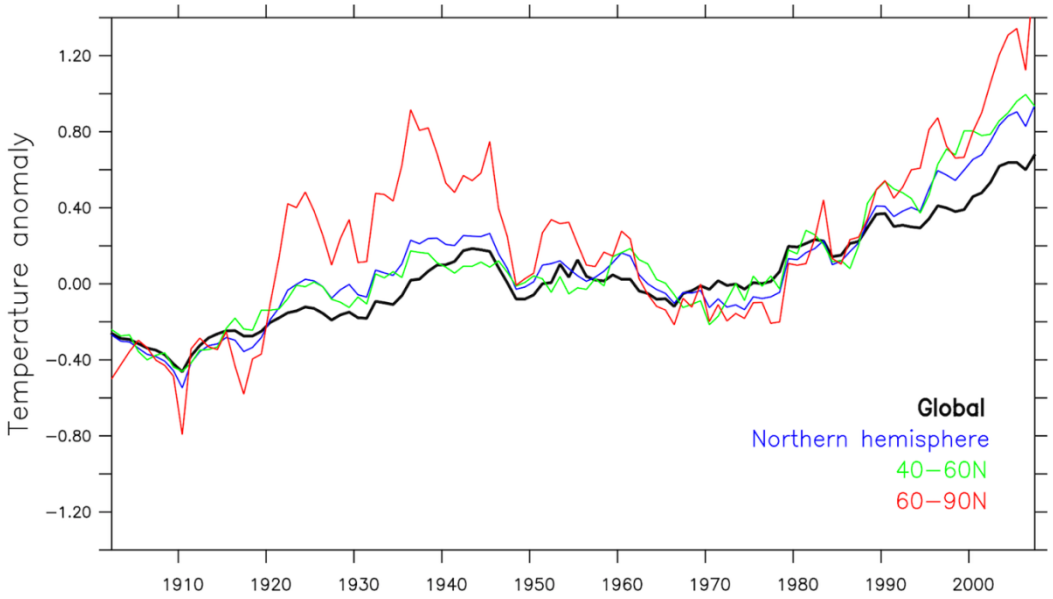
Ocean transport

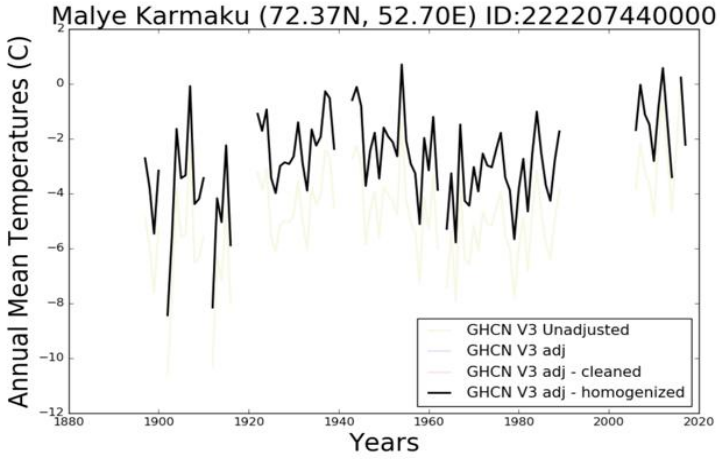
Cloud

Pithan and Mauritsen 2014, Nature Geoscience

Arctic “cycles”

Arctic, global, NH and mid-latitude SAT anomalies

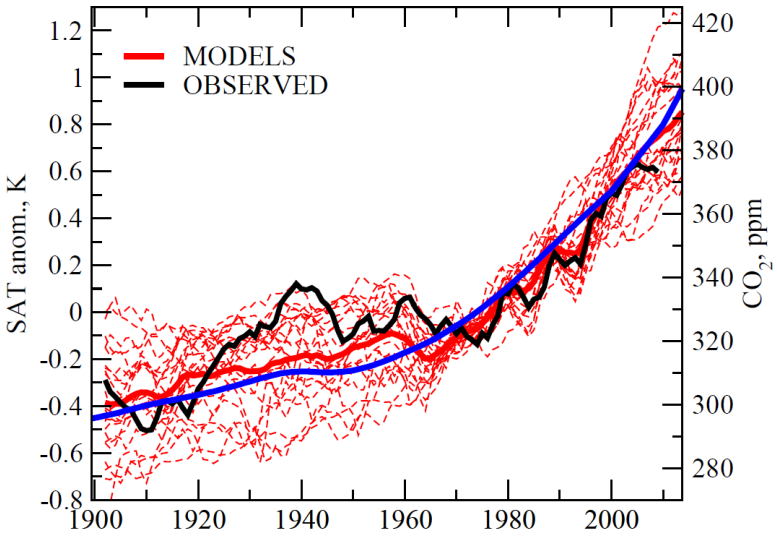




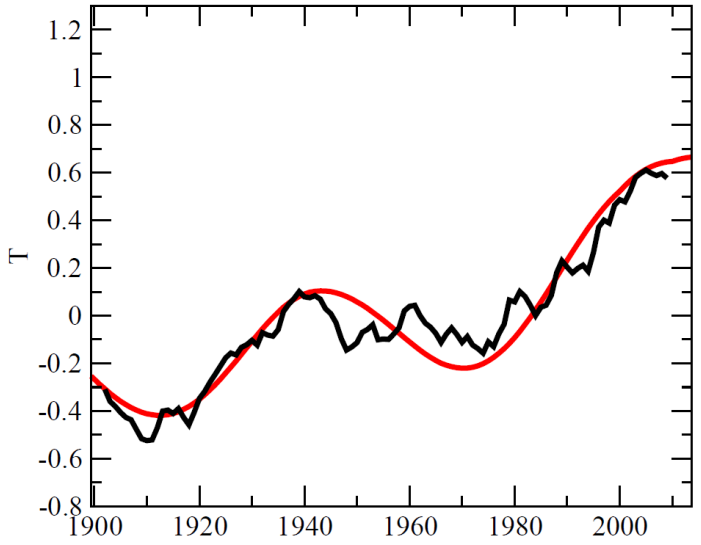
Arctic “cycles”

Climate variability as a sum of anthropogenic trend and cyclic natural variations

Annual NH mean surface air temperature:
observations and **climate models**

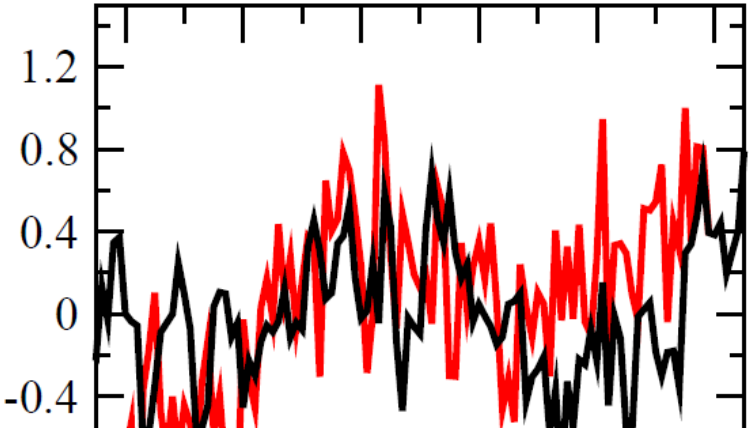


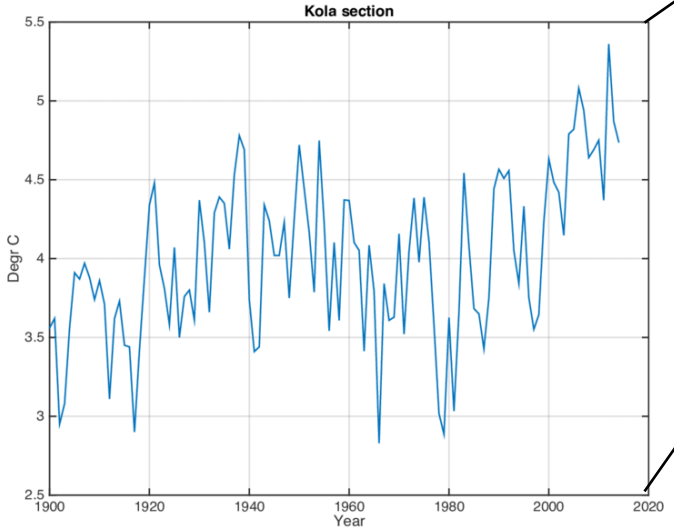
A conceptual model of cyclic long-term variations superimposed on the externally forced trend



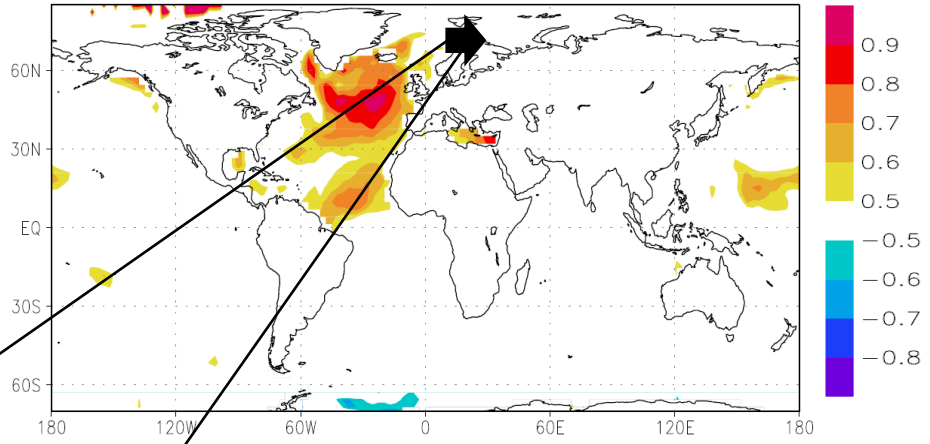
Arctic “cycles”: what drives the cycles?

Index AMO and Arctic temperature anomalies

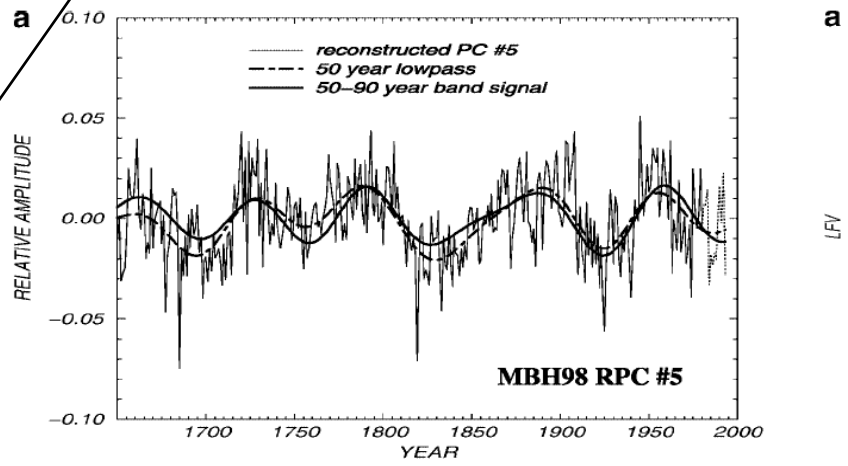




Atlantic Multidecadal Oscillation

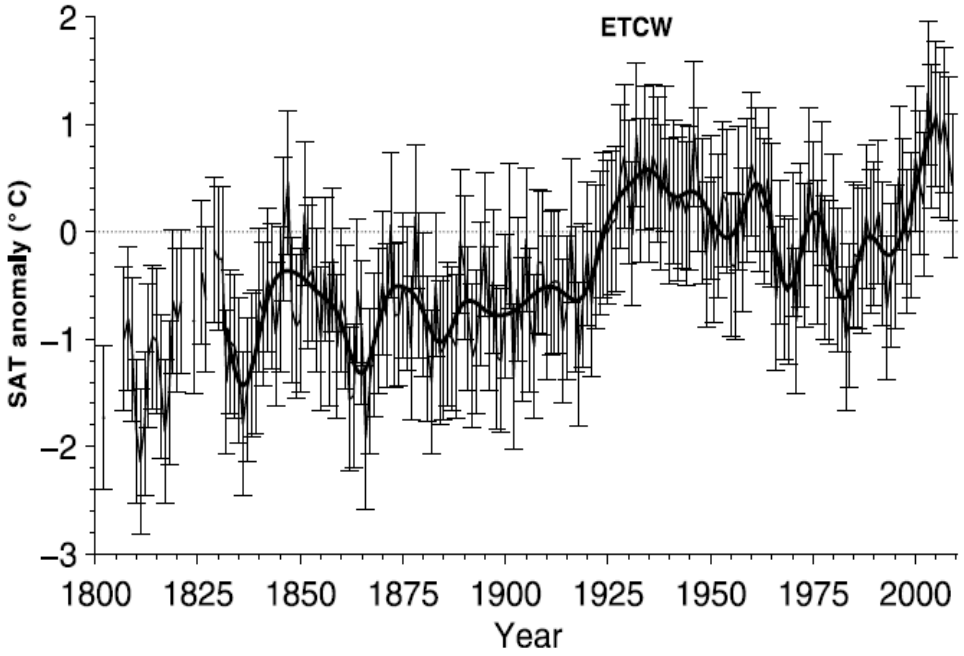


Delworth and Mann: Observed and simulated multidecadal variability



Arctic “cycles”: are there cycles?

Temperature anomalies in the Atlantic sector of the Arctic



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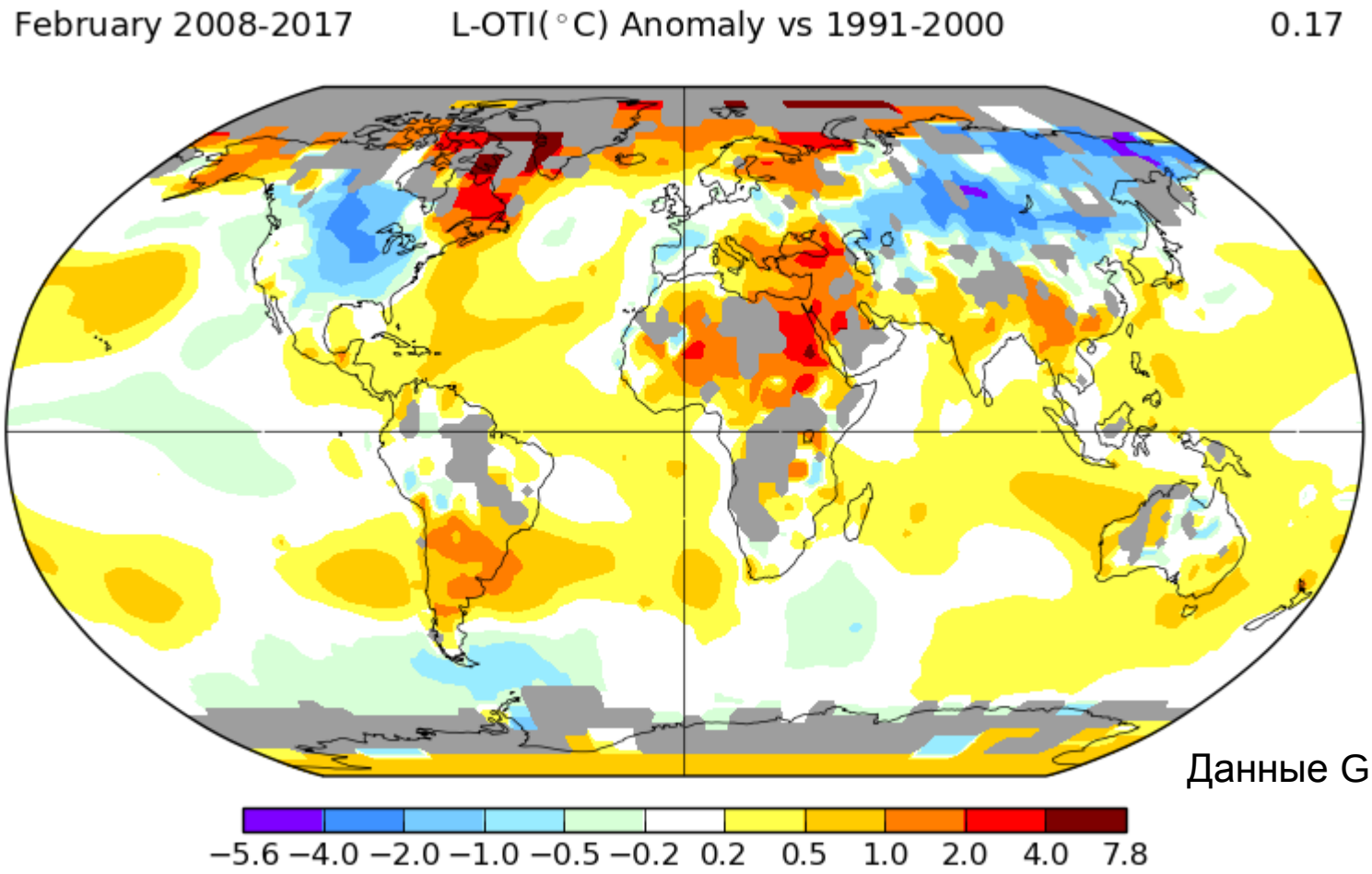
Wood et al., 2010

Cold winters and Arctic sea ice

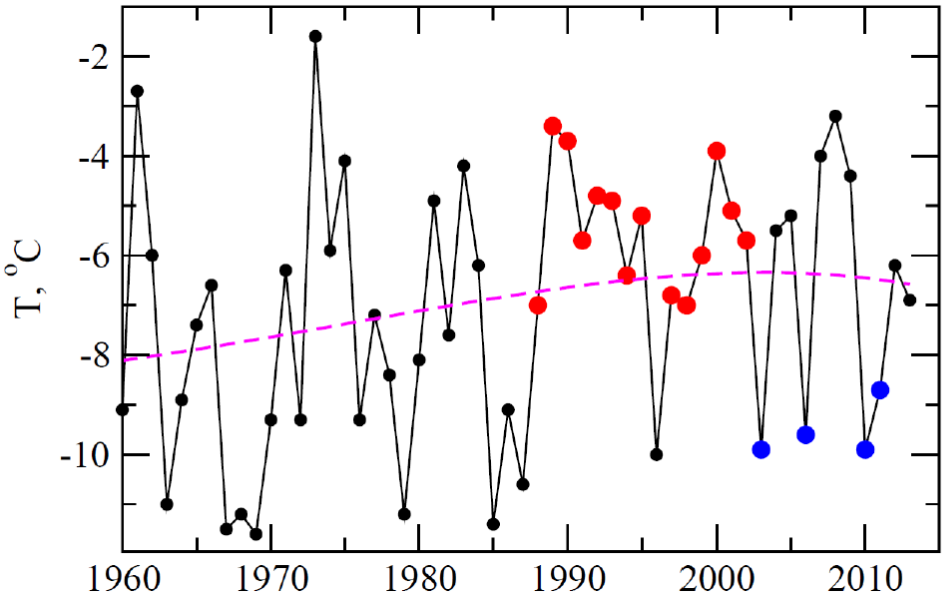
Surface air temperature changes in the recent decade (2008-2017) relative to the last decade of the 20th century (1991-2000), °C



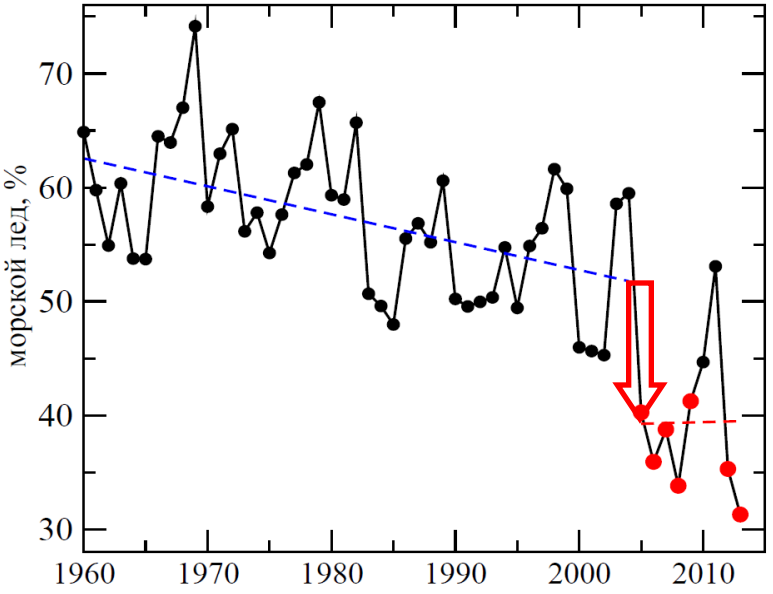
Данные GISS

Cold winters and Arctic sea ice

Moscow winter temperature, °C



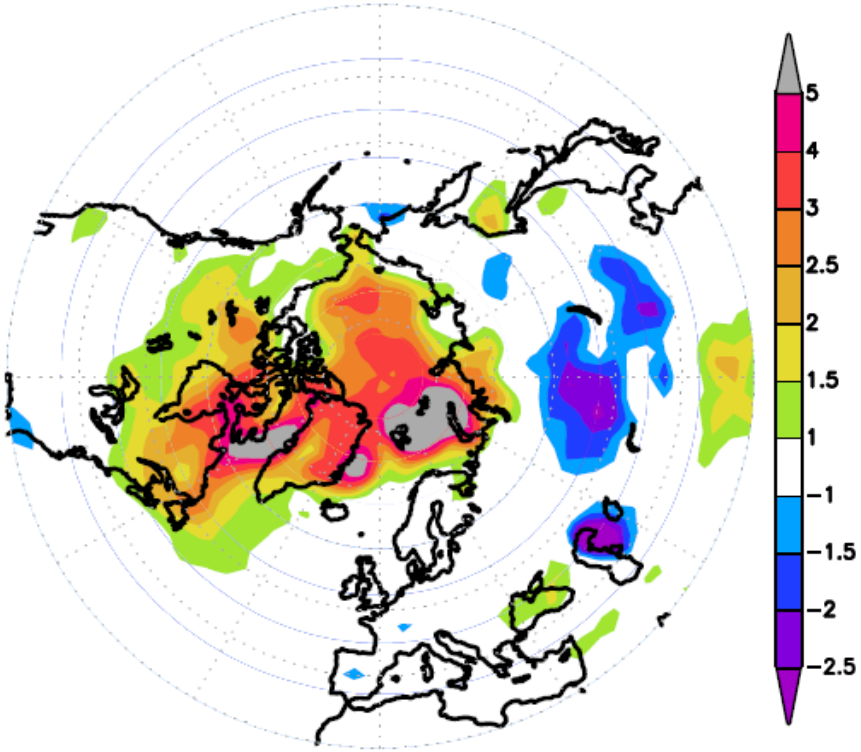
Barents and Kara Sea ice concentration, %



Cold winters and Arctic sea ice

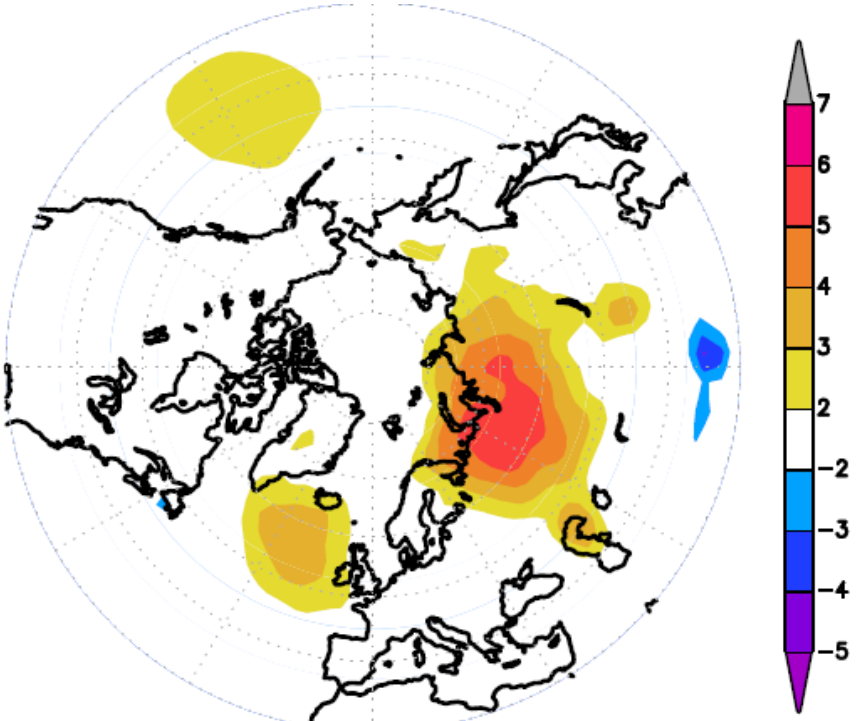
Cold winters of the beginning of the 21st century: SAT and SLP [2005-2015] anomalies

SAT, °C



“Hot Arctic – Cold Continent”

SLP, hPa



“Barents Anti-cyclone”

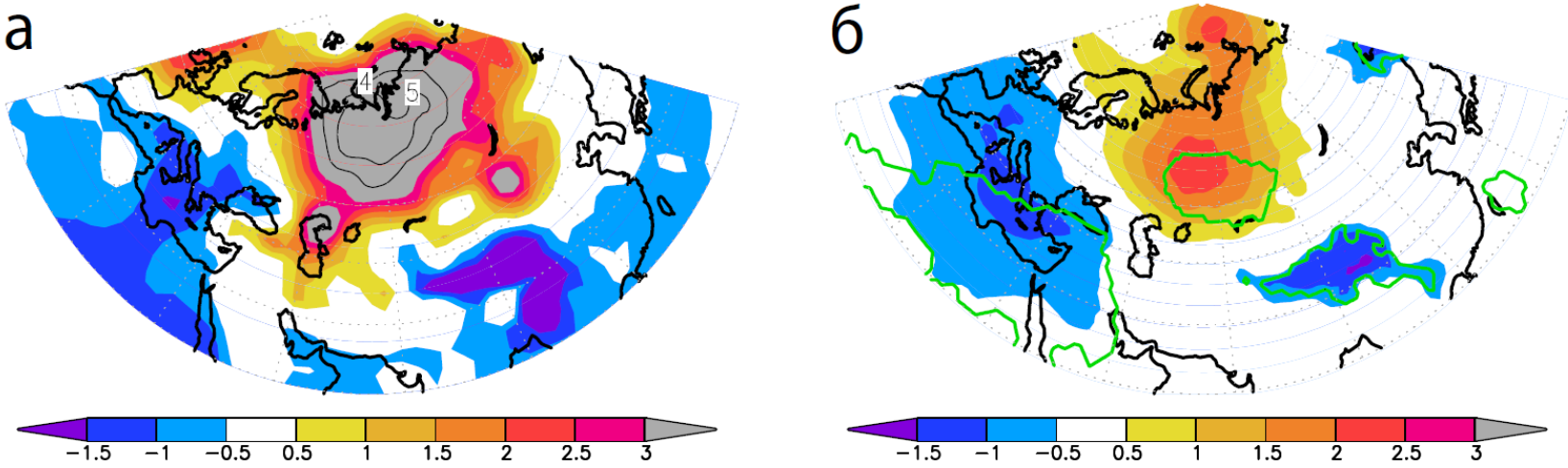
Cold winters and Arctic sea ice

Simulated SAT and SLP anomalies as a response to sea ice changes

Winter SLP anomalies 2005-2012, hPa

NCEP reanalysis

ECHAM5 model

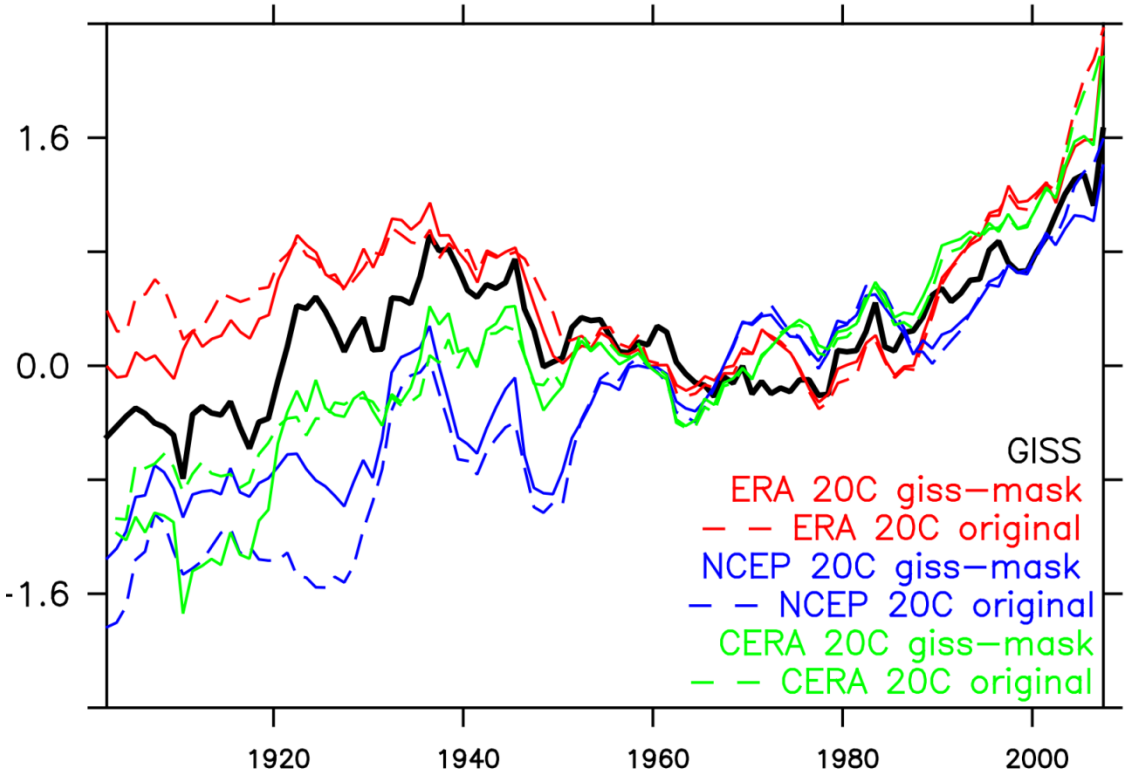


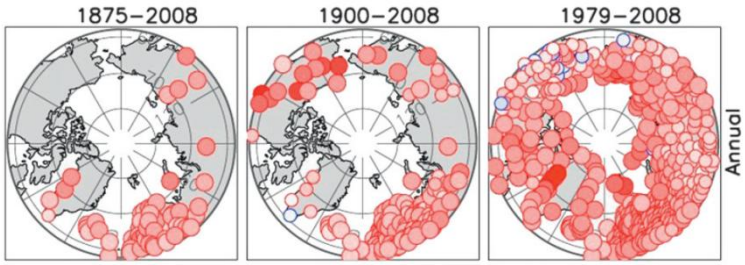
Barents Anticyclone and winter frosts can result from sea ice reduction in the Barents Sea

Petoukhov and Semenov, 2010; Semenov and Latif, 2015; Семенов 2016

Uncertainties of climate data and models

Arctic (land north to 60N) annual temperature anomalies: GISSTEMP and reanalyses





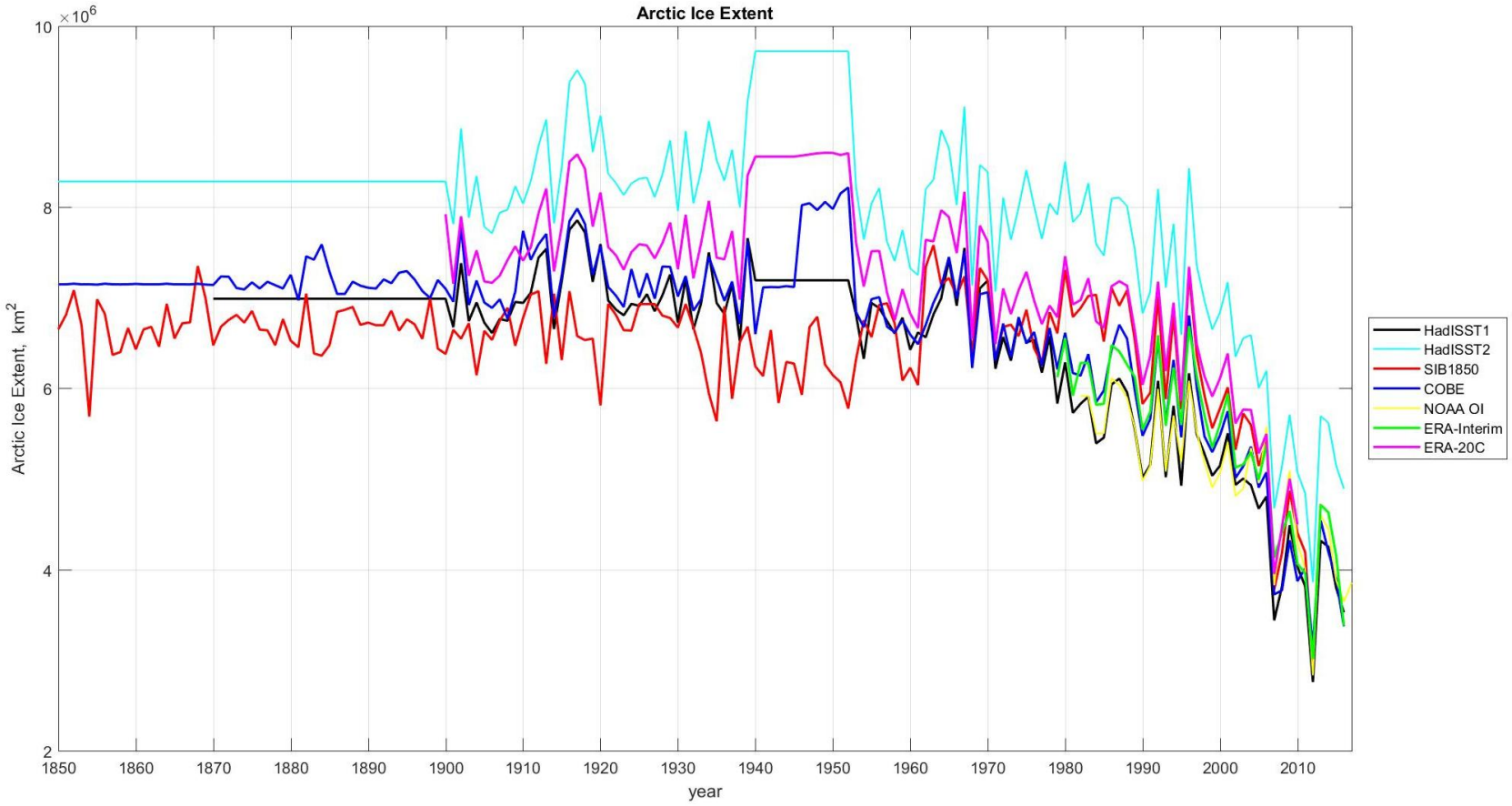
Bekryaev et al., 2010

Бокучава, Семенов, 2018

Data uncertainty is high even in the modern era period. Overall picture of Arctic climate variability back from 1960s is vague.

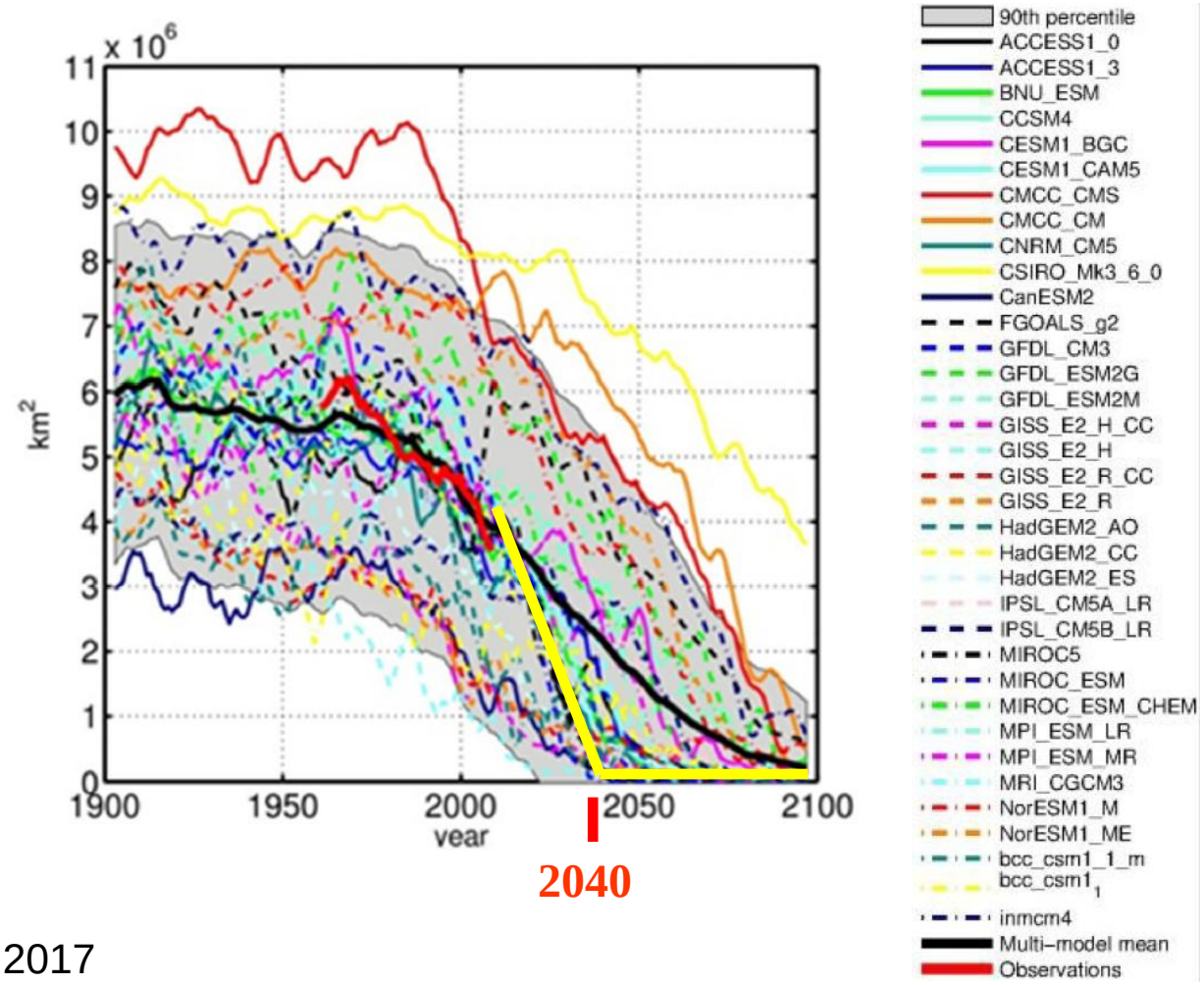
Uncertainties of climate data and models

Arctic September sea ice extent (mln. km^2) from different data sets



Uncertainties of climate data and models

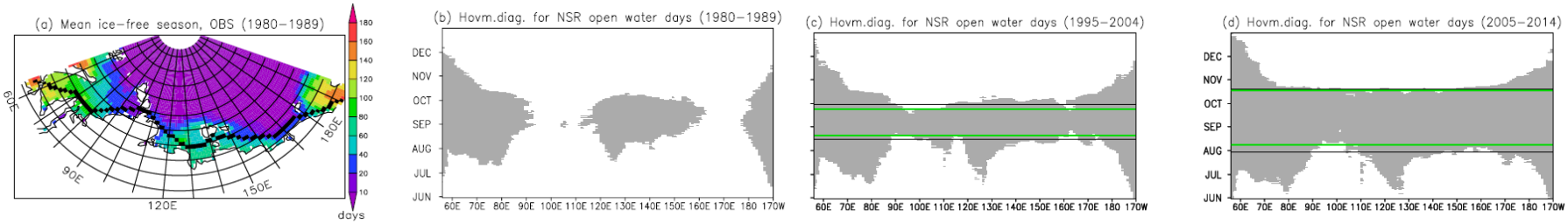
September Arctic sea ice area in CMIP5 models (RCP8.5), км^2



Семенов и др., 2017

Positive perspectives: Northern Sea Route

Duration of open water period along NSR



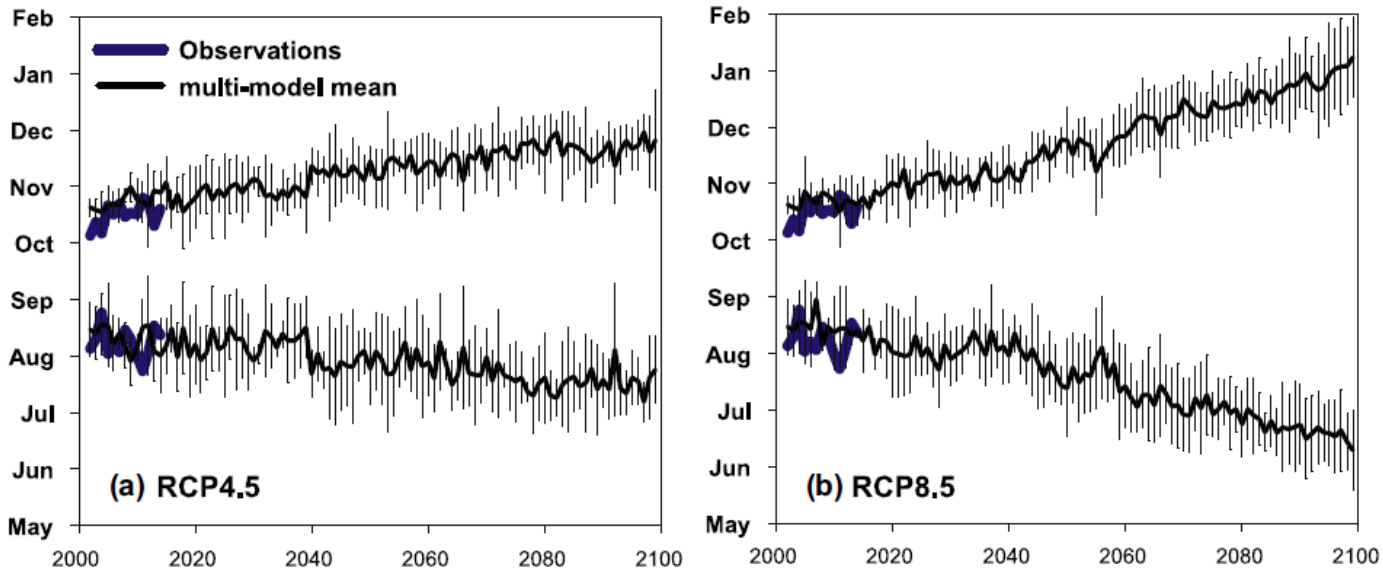


Figure 4. Ensemble-mean projections of the beginning and the end of the NSR transit navigation period ($T_{80\%}$) according to scenario RCP 4.5 (*a*) and 8.5 (*b*) averaged by using five selected models (CNRM-CM5, HadGEM2-CC, MIROC-ESM-CHEM, MPI-ESM-LR, MPI-ESM-MR). Satellite data is shown by the blue line. Vertical bars represent corresponding standard deviations based on estimates of the selected models.

Khon, Mokhov, Semenov, 2017, ERL

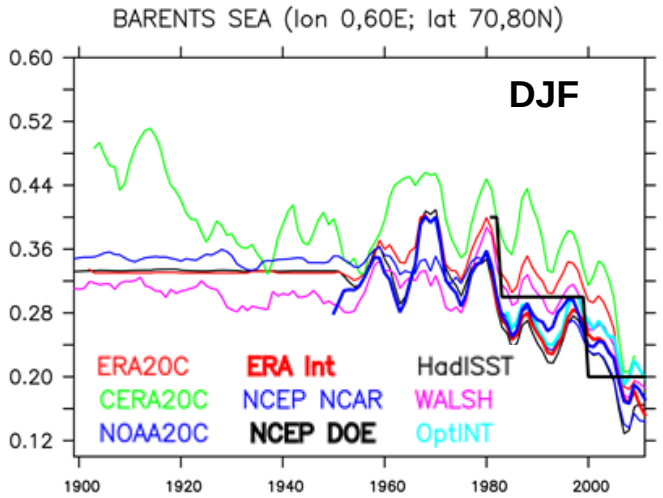
Conclusions

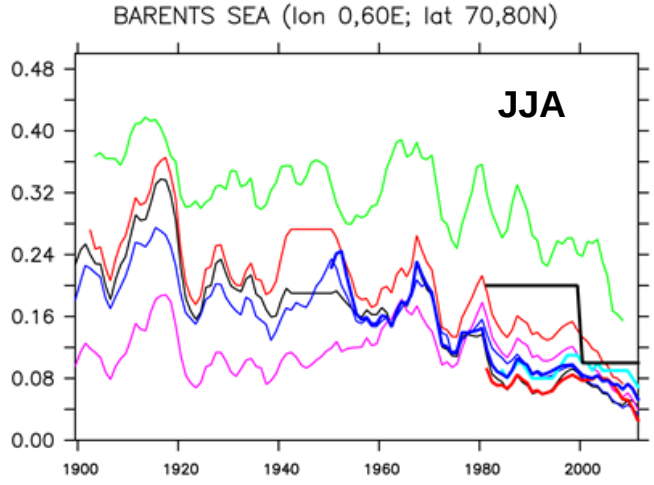
- The Arctic has been warming three times faster than the Globe in the recent decades
- The Arctic has been warming in the 21st century despite a GW hiatus
- Arctic may play important role in global climate change by controlling Equator-Pole temperature gradient
- There are a number of positive feedbacks that amplify warming in the Arctic
- There are strong indication of significant contribution from quasi cyclic natural variations to the Arctic climate changes
- Arctic sea ice reduction might be responsible for the anomalously cold winter over the northern continents in the beginning of the 21st century
- Uncertainty of the observational data and climate models is the highest in the Arctic

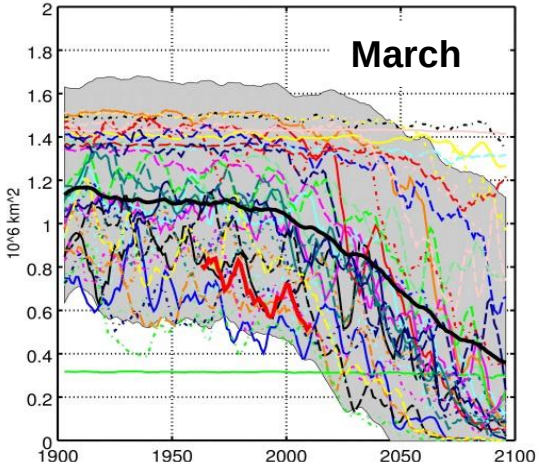
Thank you for your attention!

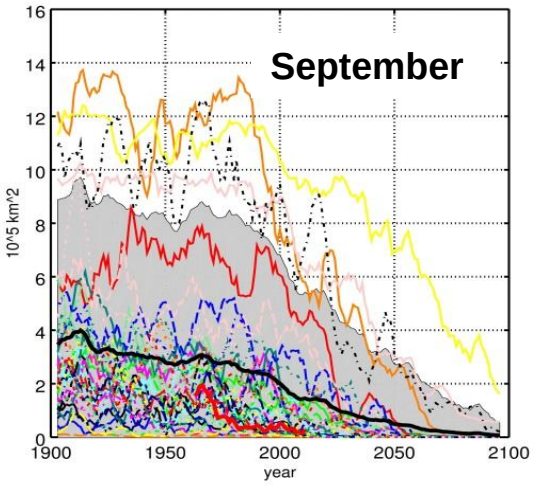
Data uncertainty in the Arctic

Averaged sea ice concentration in the Barents Sea from data, reanalyses and models





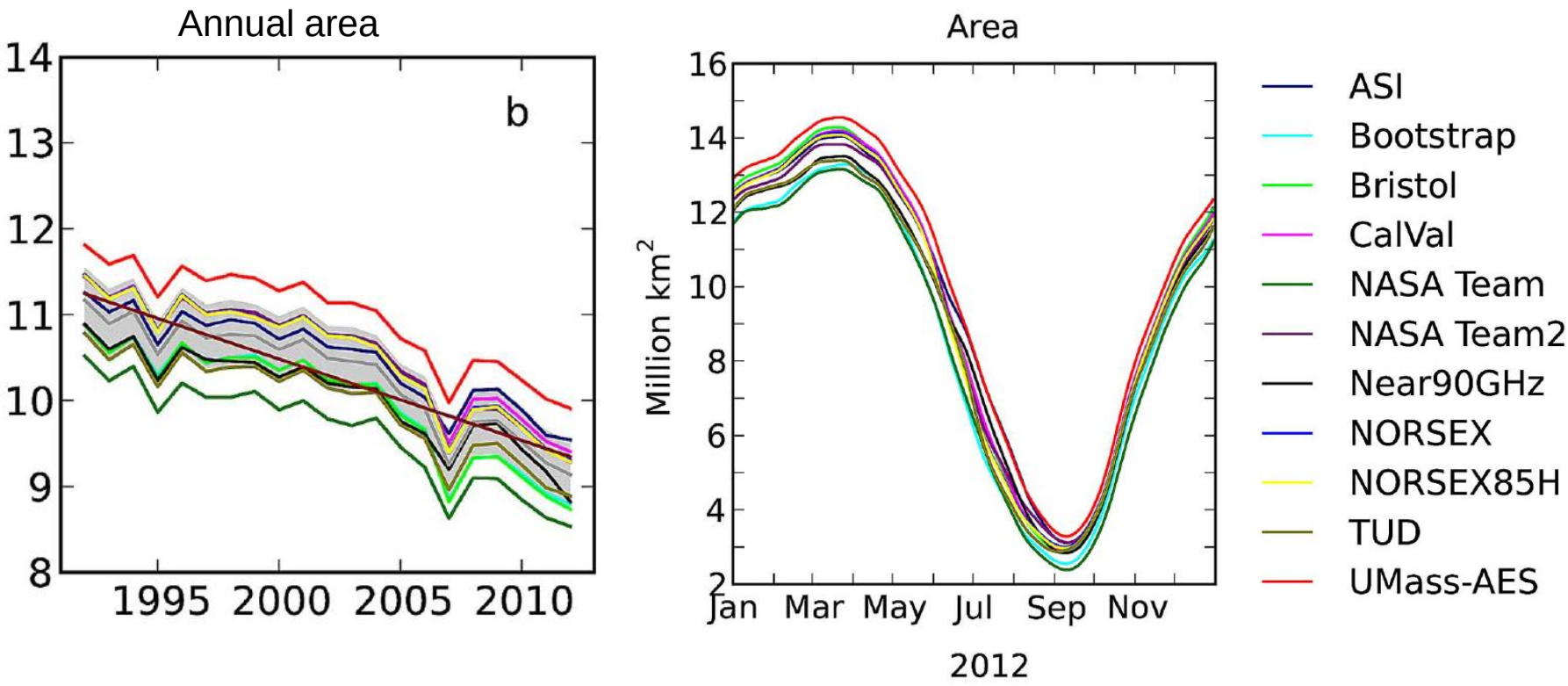




CMIP5
RCP8.5

Data uncertainty in the Arctic

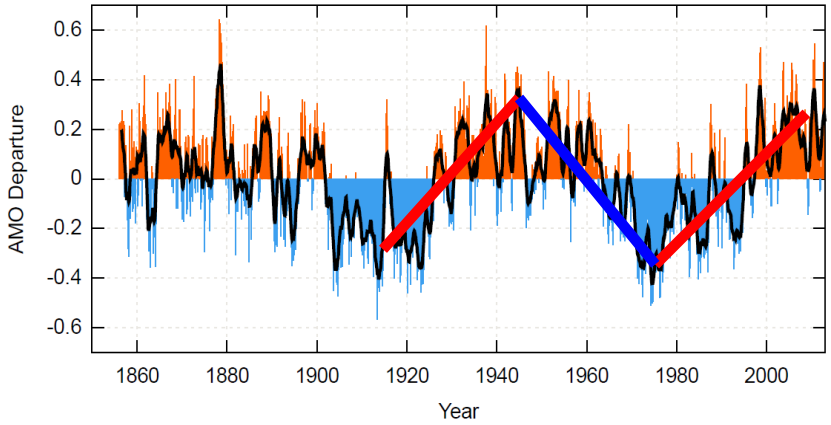
Arctic sea ice area from different SIC retrieval algorithms using the same radars



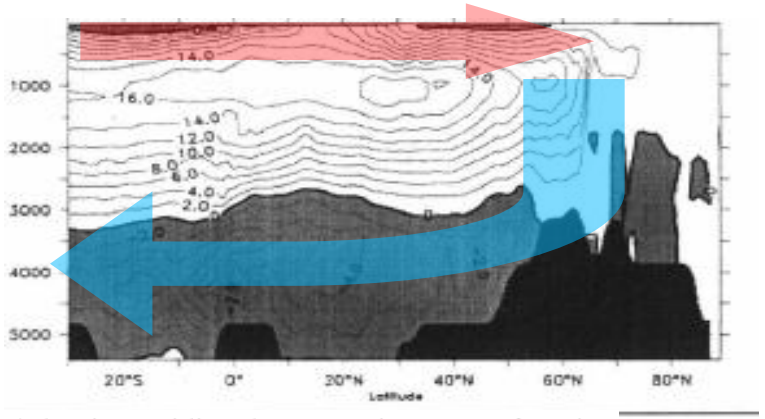
Ivanova et al., 2014

Atlantic Multidecadal Oscillation (AMO): a link to meridional overturning in the North Atlantic

AMO index: detrended SST variations in the NA, °C

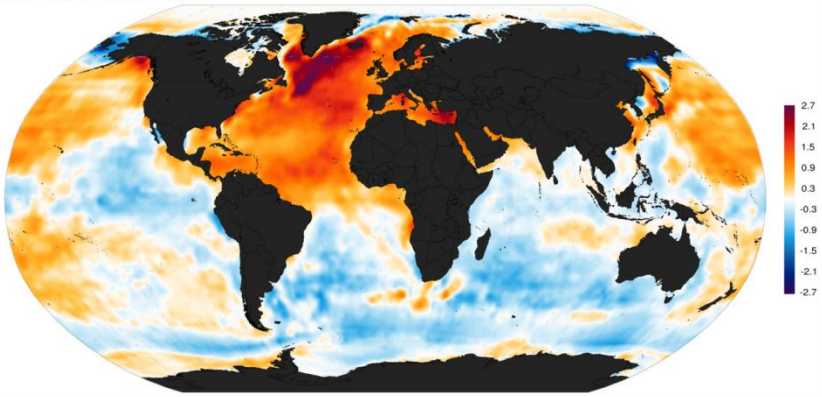


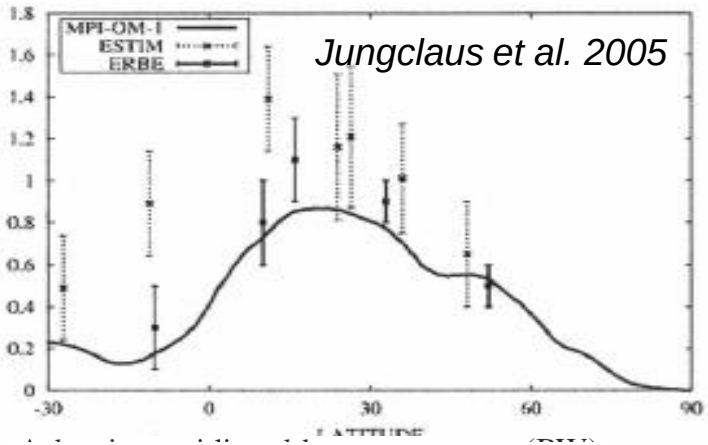
Meridional cross-section of oceanic circulation



Atlantic meridional overturning streamfunction

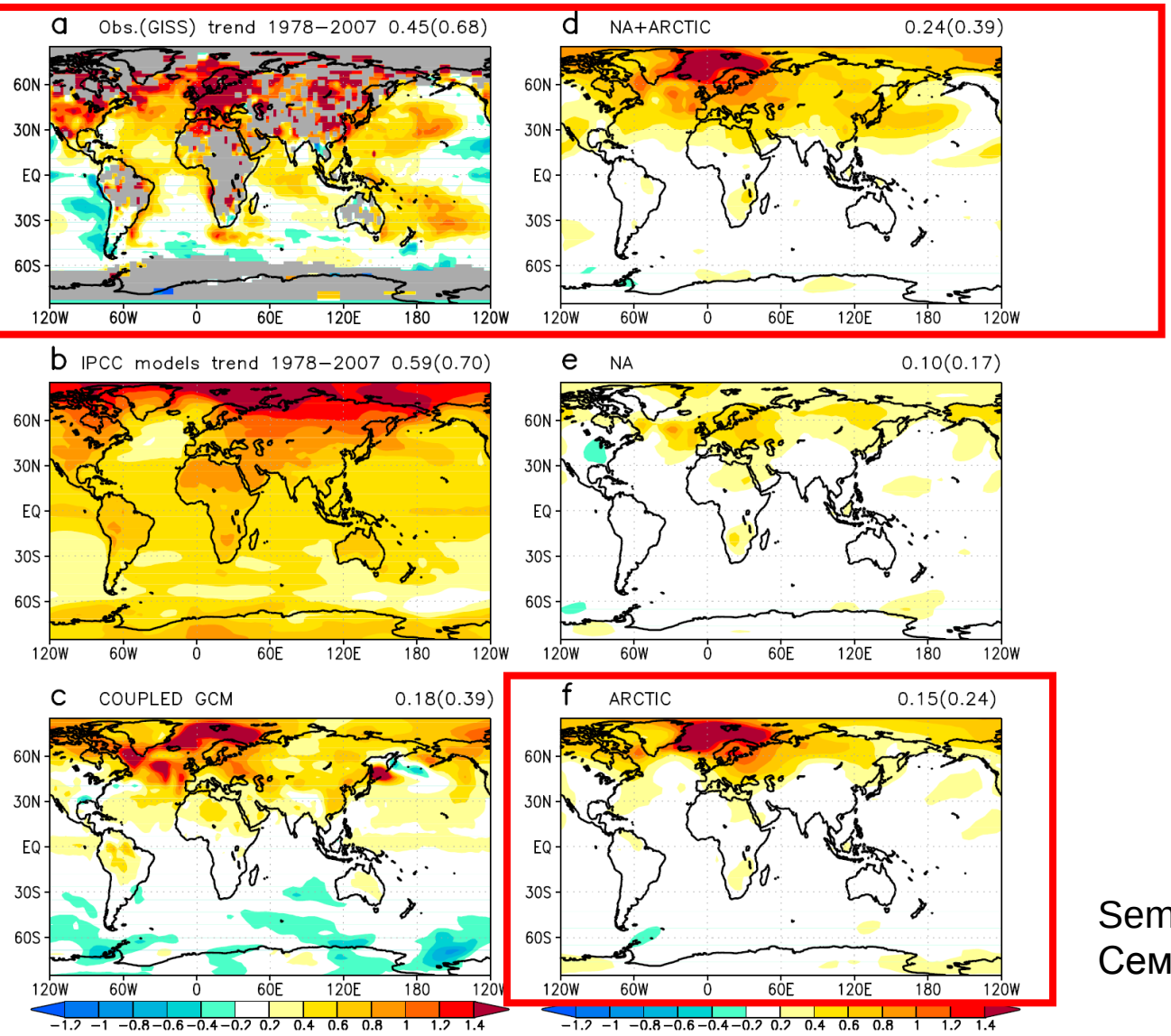
Ocean temperature anomalies related to AMO (ºC)





Ocean heat transport in the North Atlantic (PW)

ECHAM5/MLO results: annual SAT changes



Semenov et al., 2010,
Семенов и др., 2014

Temperature changes due to AMO transition from cold to warm phase (in °C and in % of the observed trend) for NH, SH and the Globe simulated in ECHAM5/MLO experiments

	NH	SH	GLOB
ATLICE	0.39 (57%)	0.08 (36%)	0.24 (53%)
ATL	0.17 (25%)	0.04 (18%)	0.10 (22%)
ICE	0.24 (35%)	0.06 (27%)	0.15 (33%)
OBS*	0.68	0.22	0.45

* trend 1978-2007 according to GISS data

Warming in the Arctic (e.g. caused by enhanced AW heat flux) reduces Equator – Pole temperature gradient and efficiently warms the whole Earth. Arctic alone may drive global climate changes.

Positive feedback between Barents Sea inflow and sea ice