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Arctic Climate Change
Economy and Society

ALFRED-WEGENER-INSTITUT
HELMHOLTZ-ZENTRUM FÜR POLAR-
UND MEERESFORSCHUNG

Climate change in the Arctic

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Overview

- Climate change and internal/natural variability
- Past observations
- Past simulations
- Possible future change
- Summary

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Climate Change and Internal Variability

- Climate change:
  - change in the state of the climate that persists for an extended period, **typically decades or longer**
  - due to internal processes and/or **external forcings**
- Internal variability:
  - caused by **internal climate system processes**
  - is present on all time scales

Definitions from IPCC AR4 WG1 Chapter 9.1.1

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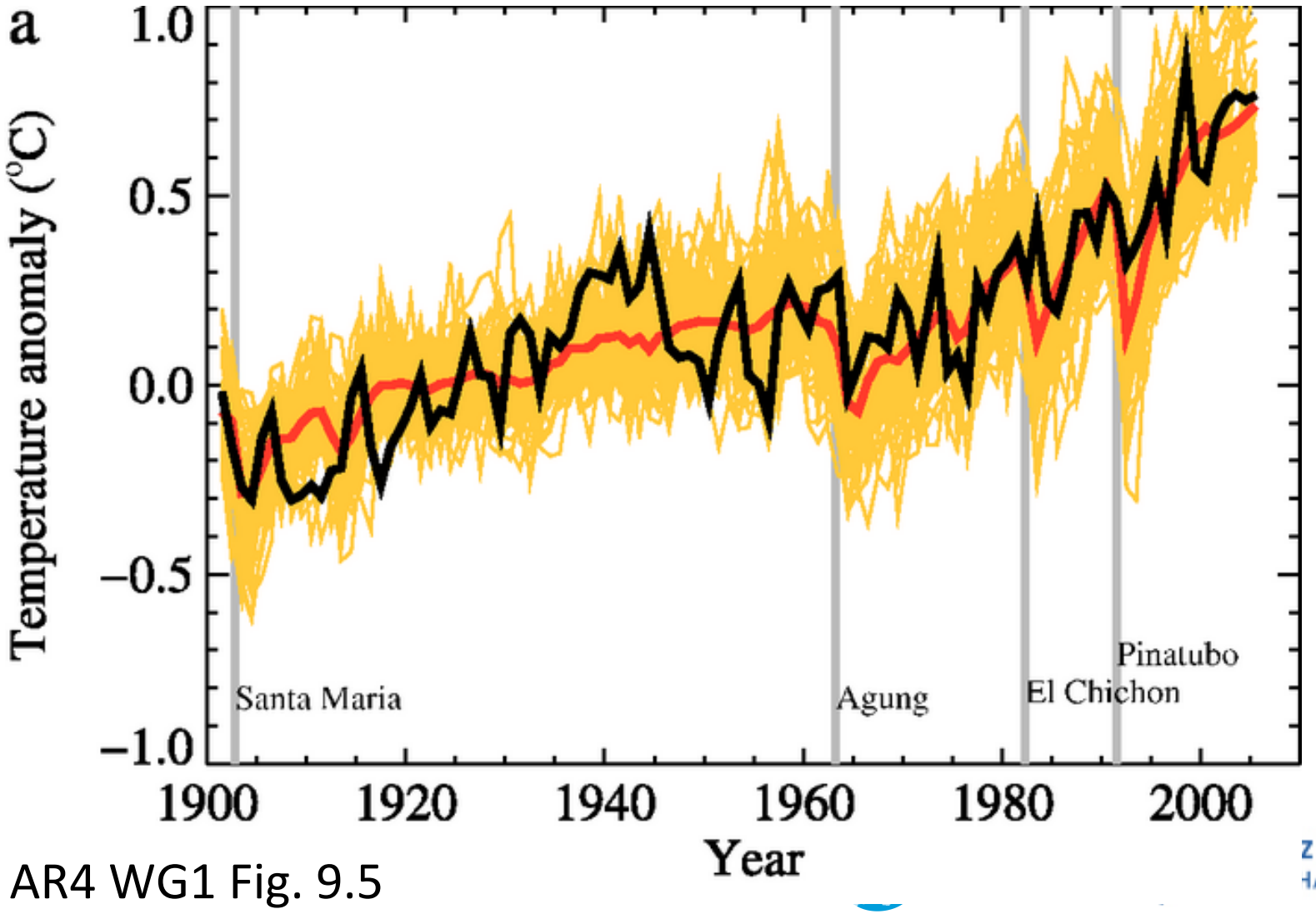
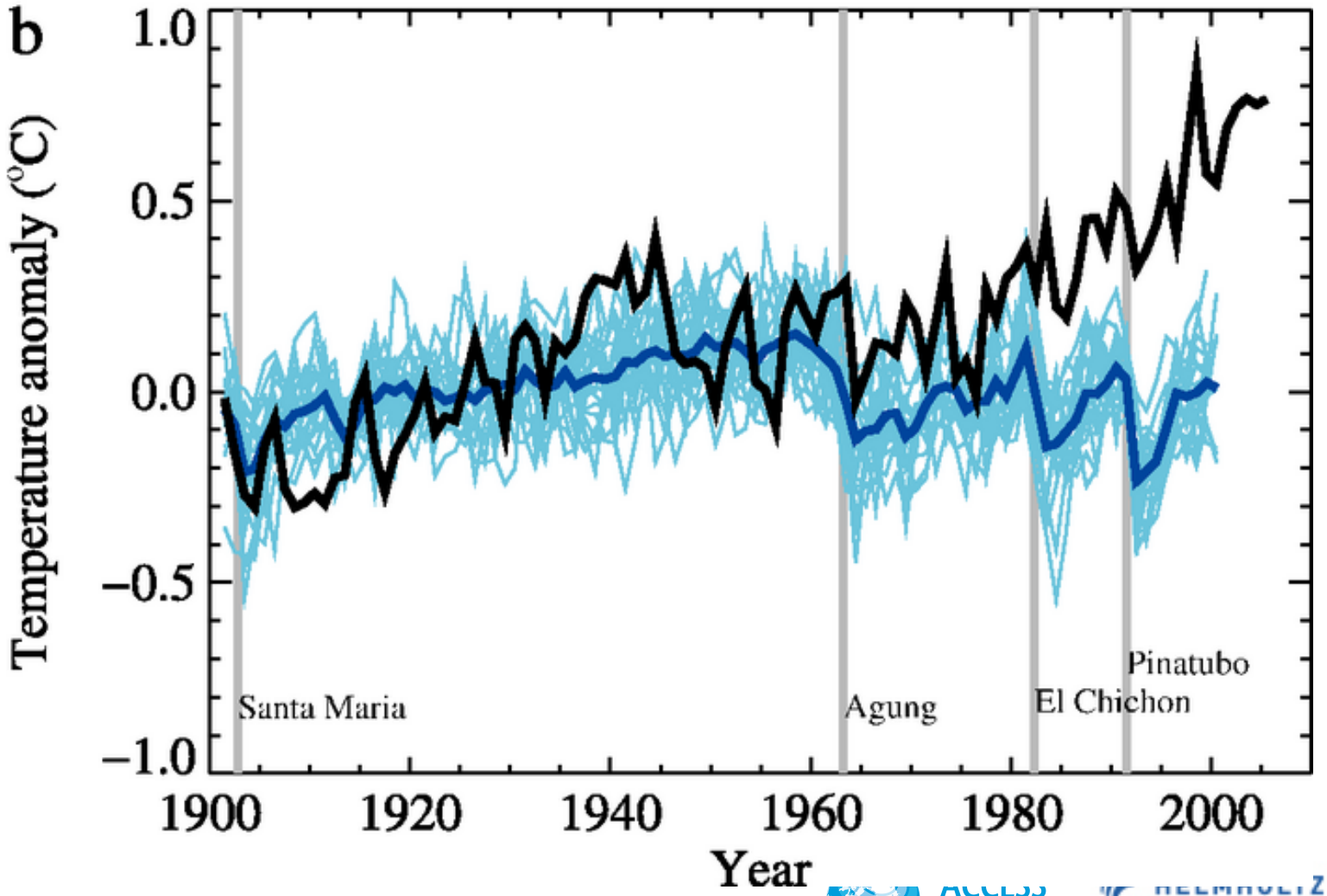
Definitions from IPCC AR4 WG1 Chapter 9.1.1

Climate Change and Internal Variability



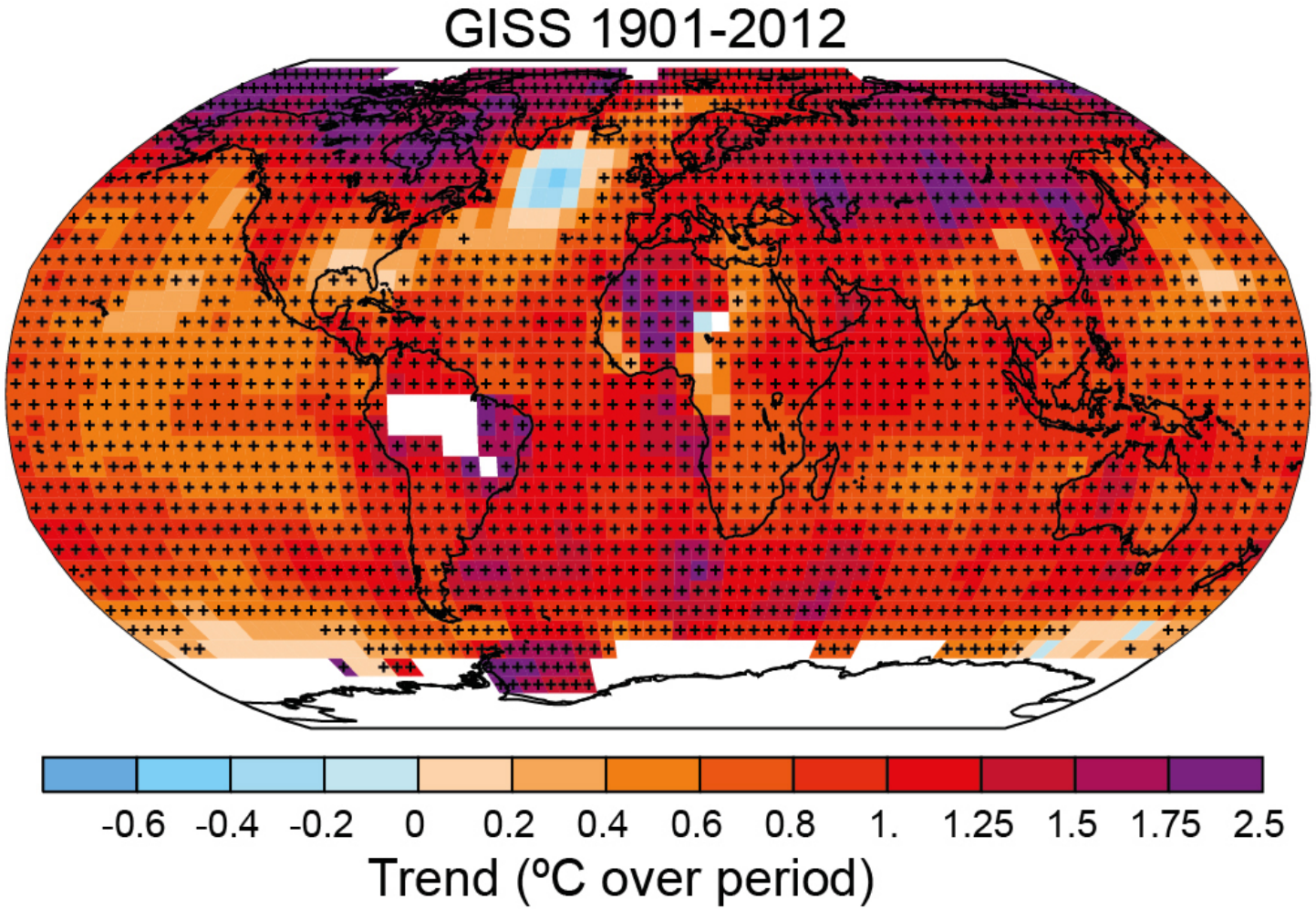
IPCC AR4 WG1 Fig. 9.5

Climate Change and Internal Variability



IPCC AR4 WG1 Fig. 9.5

Climate change:
Trend in surface temperature



IPCC AR5 WG1 Fig. 2.21

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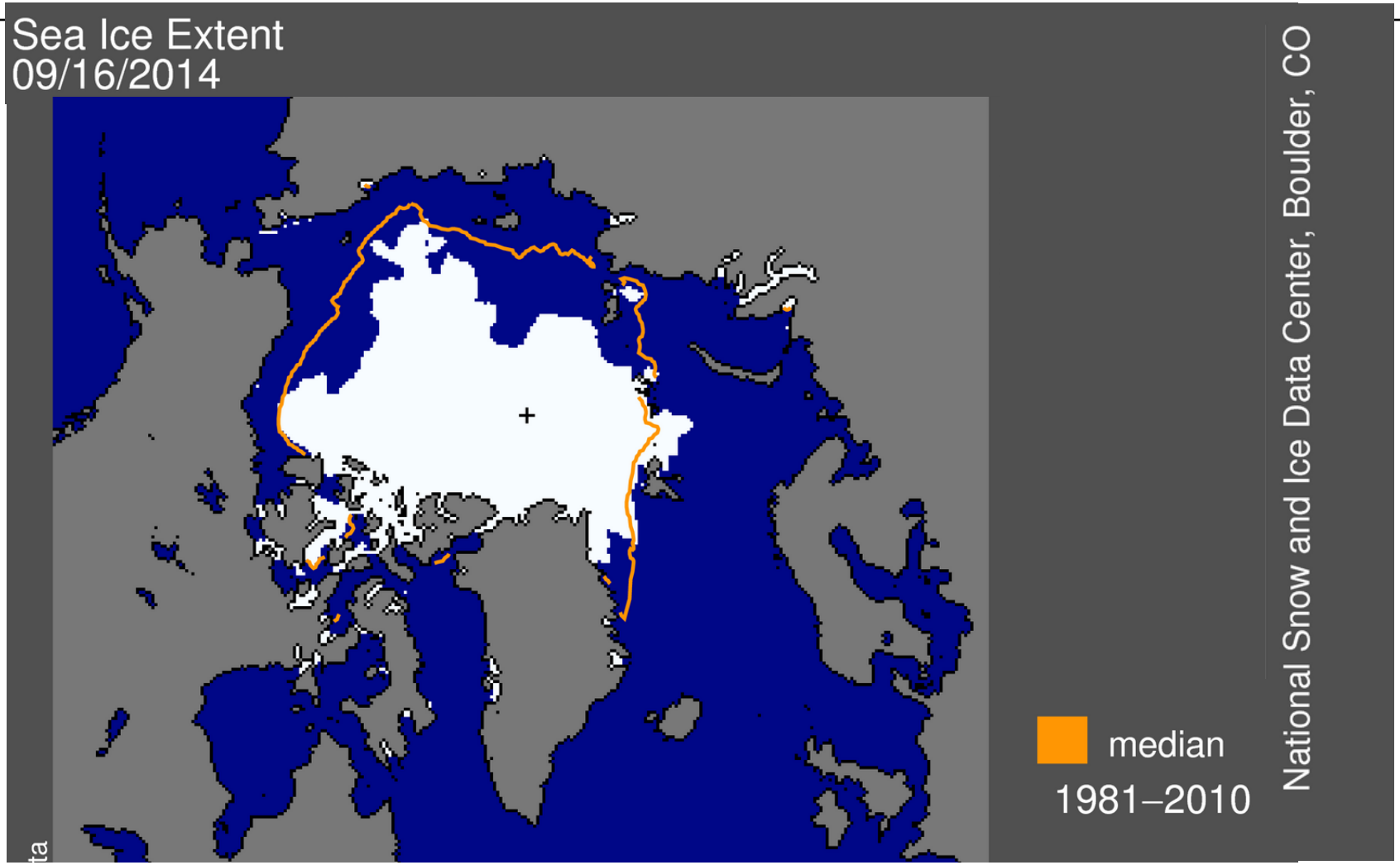
Arctic sea-ice



https://nsidc.org/arcticseaicenews/

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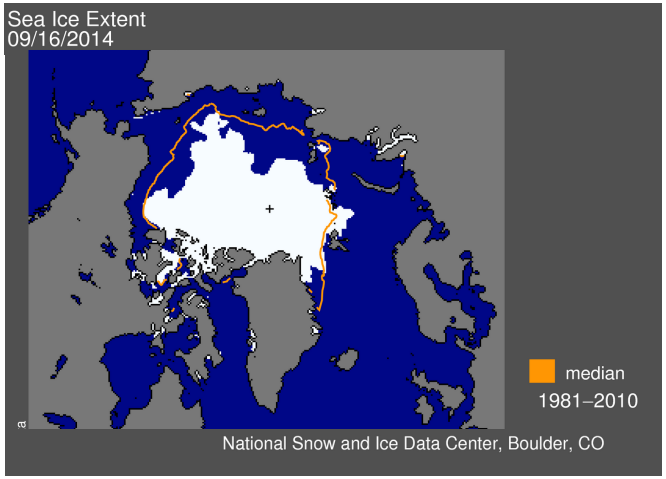
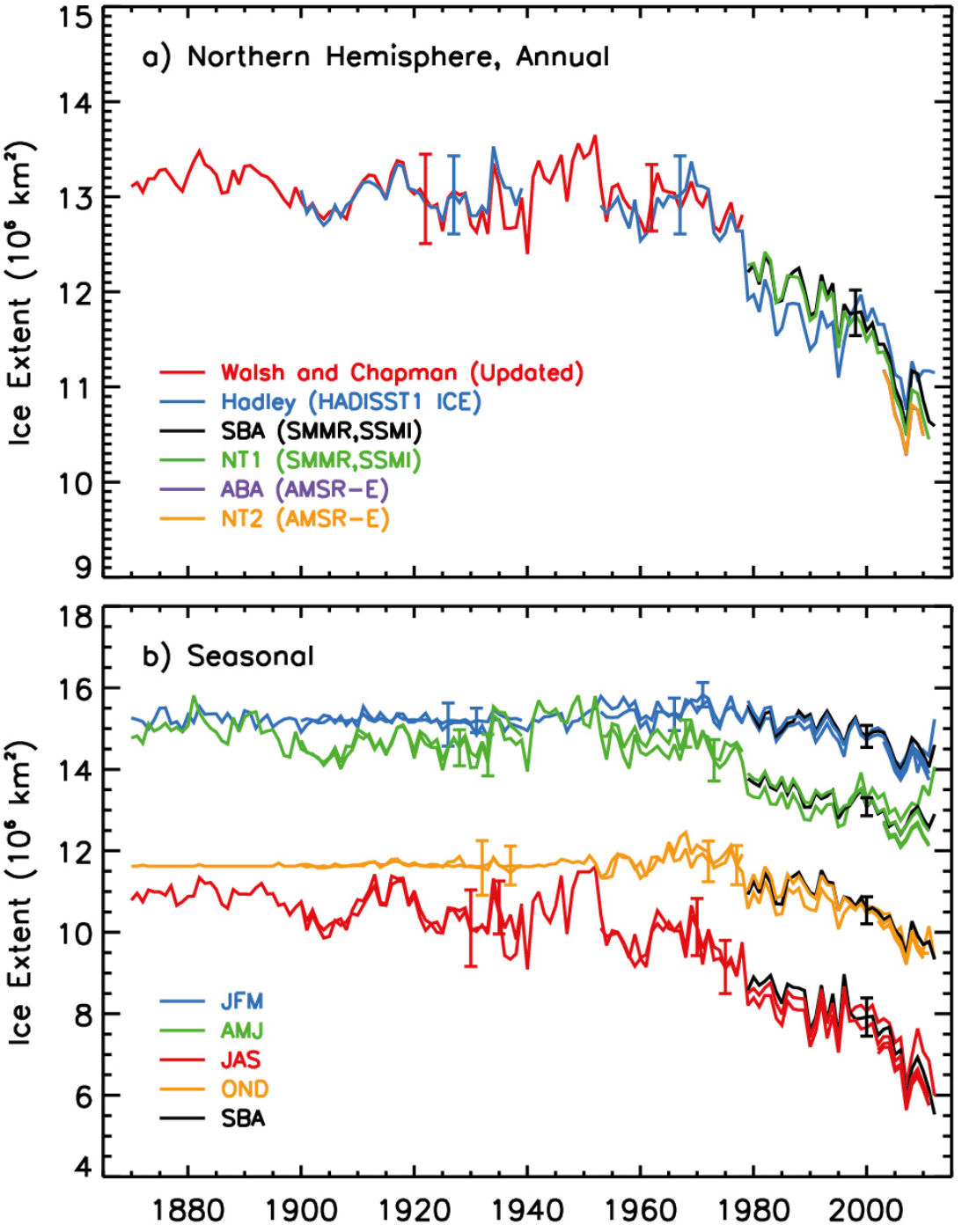
Arctic sea-ice

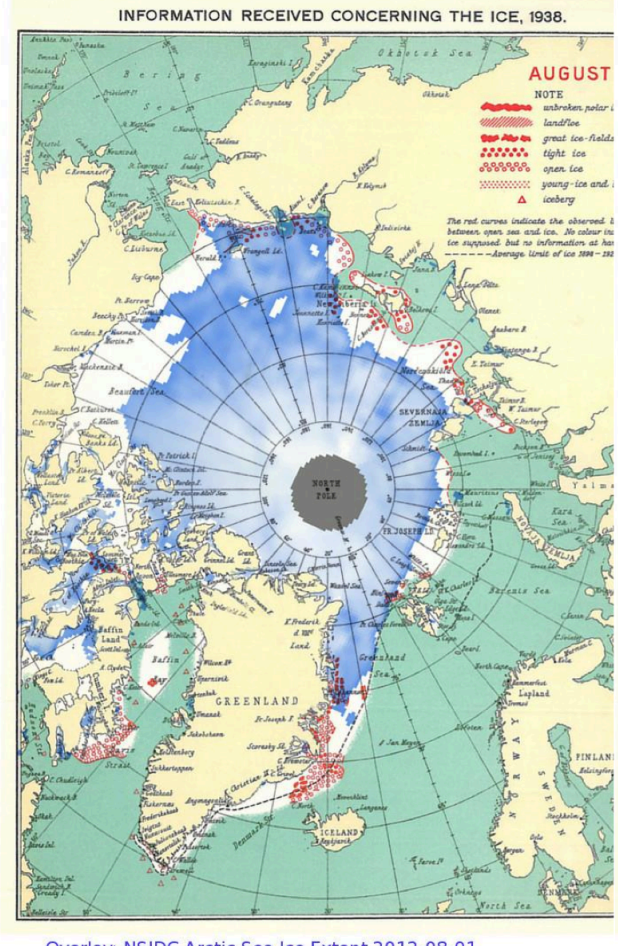


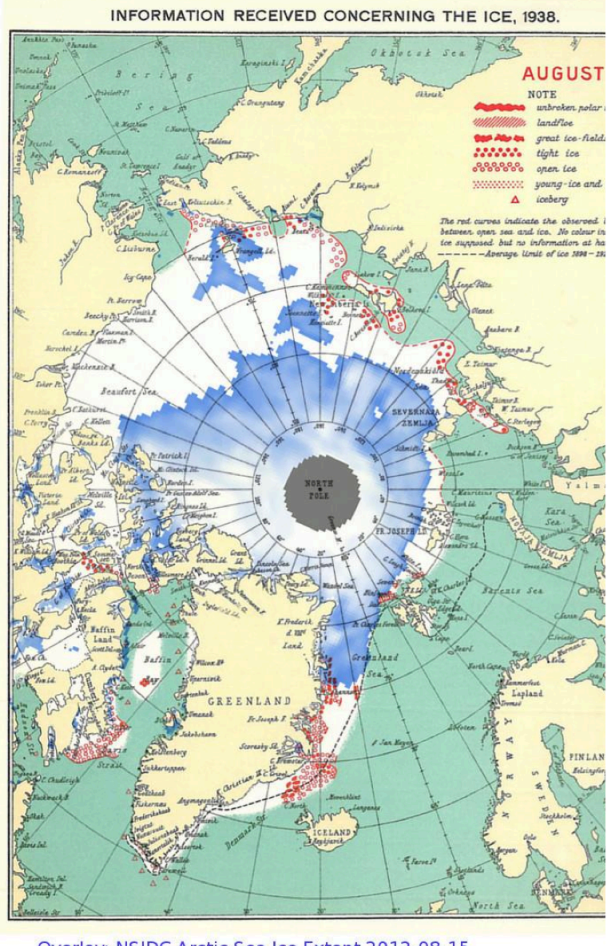
IPCC AR5 WG1 Fig. 4.3



Sea ice extent

ACCESS report D1.31 by P.P. Shirshov Institute of Oceanology of Russian Academy of Sciences





Map by Denmark Meteorological Institute
August 1938

red marks: actual ice observations

blue shade: overlaying NSIDC sea ice extent
August 2012

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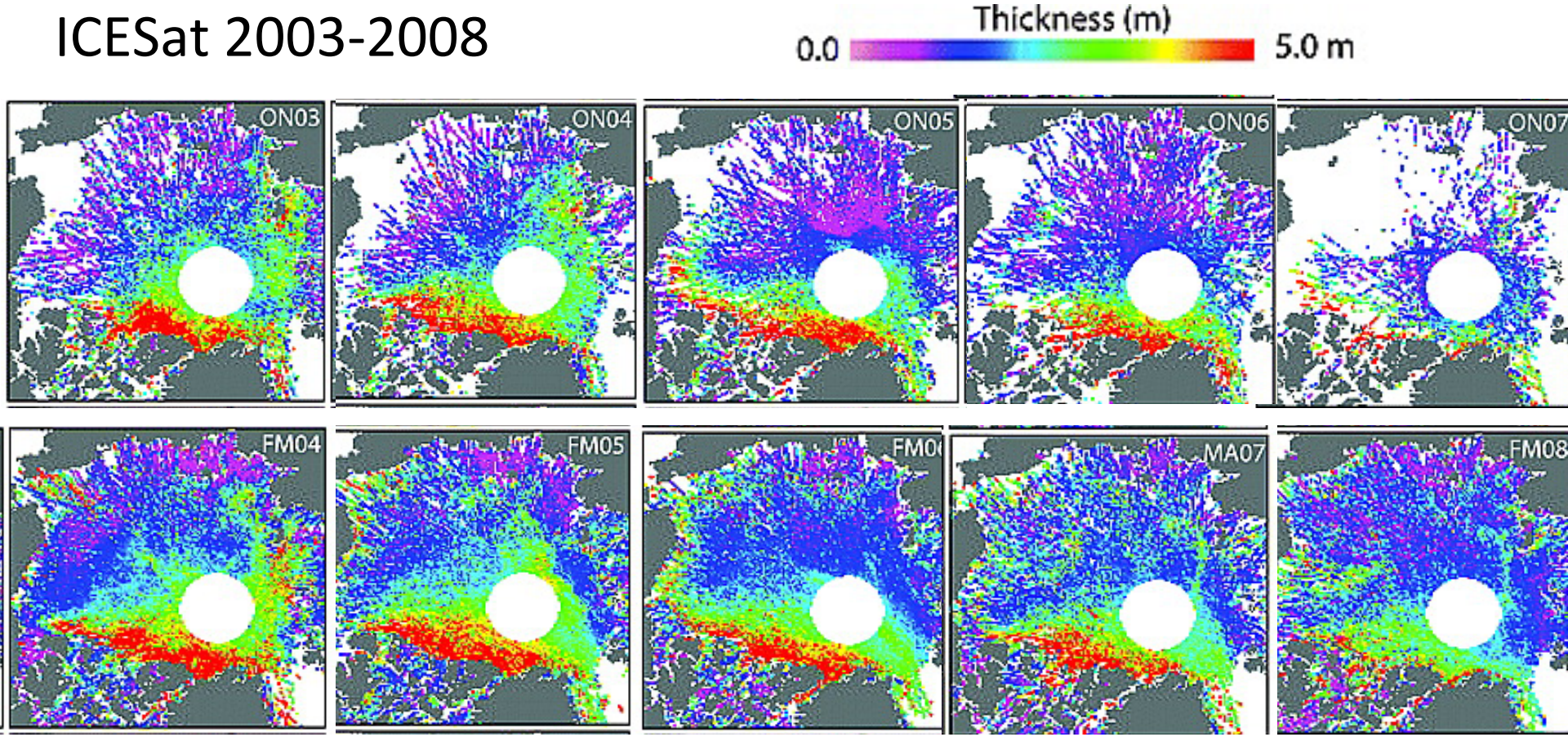
Sea ice thickness

ICESat 2003-2008



Kwok et al., 2009 JGR

DOI: 10.1029/2009JC005312

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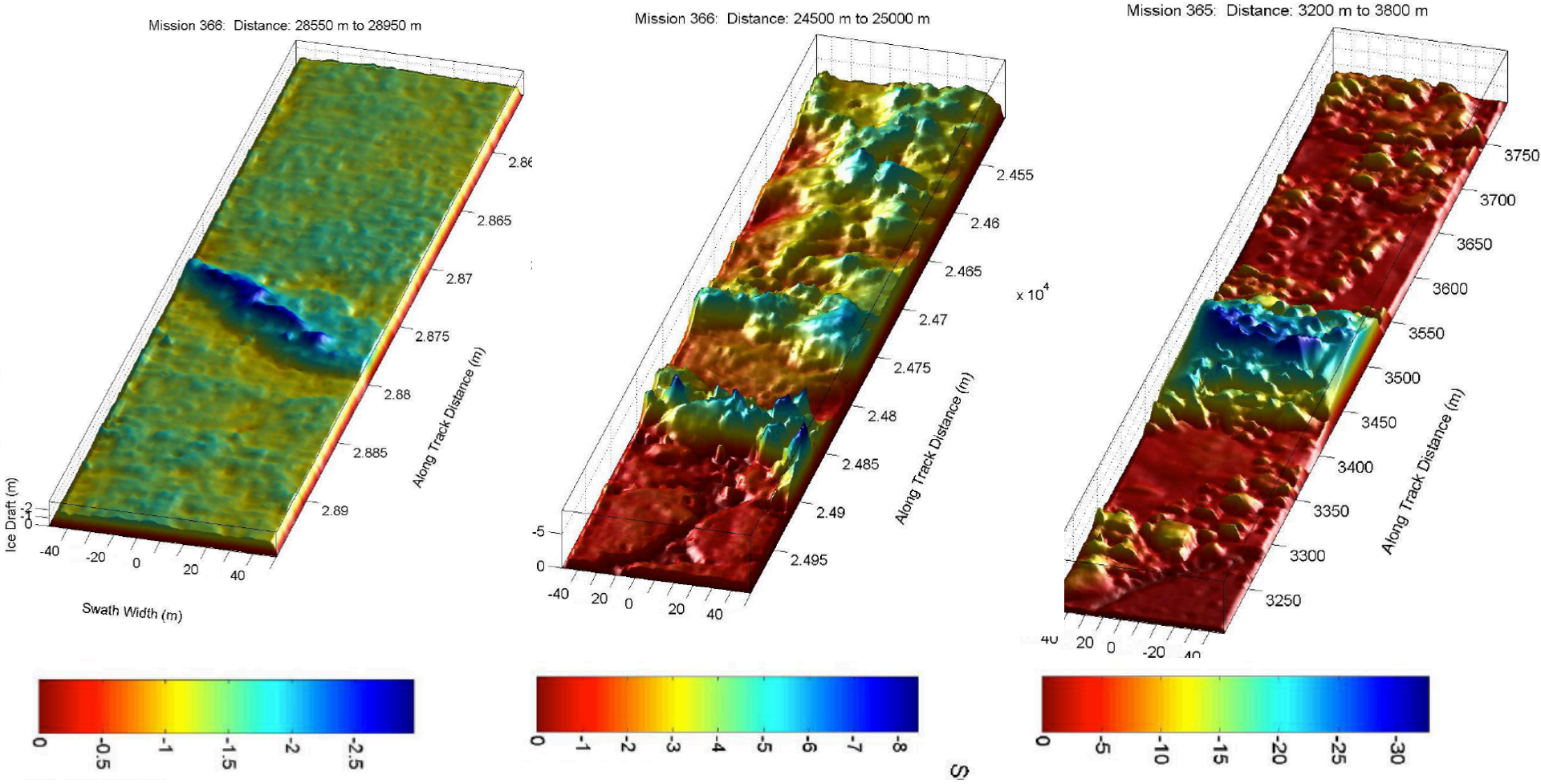
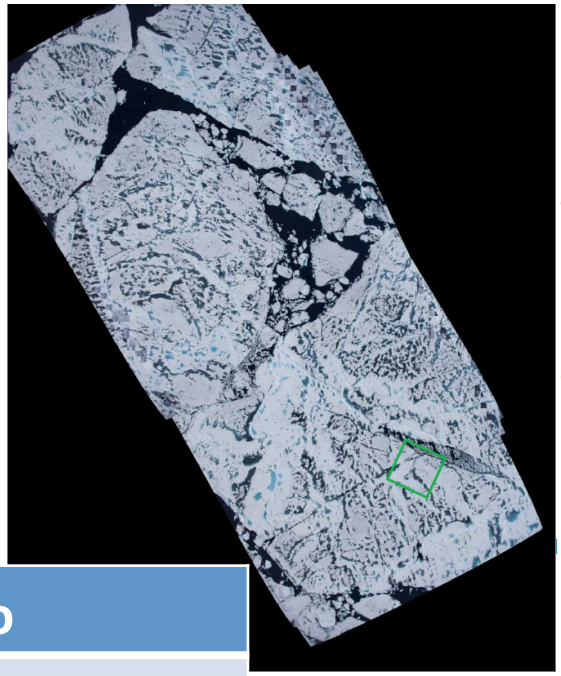
Under-ice topography in Fram Strait 2012

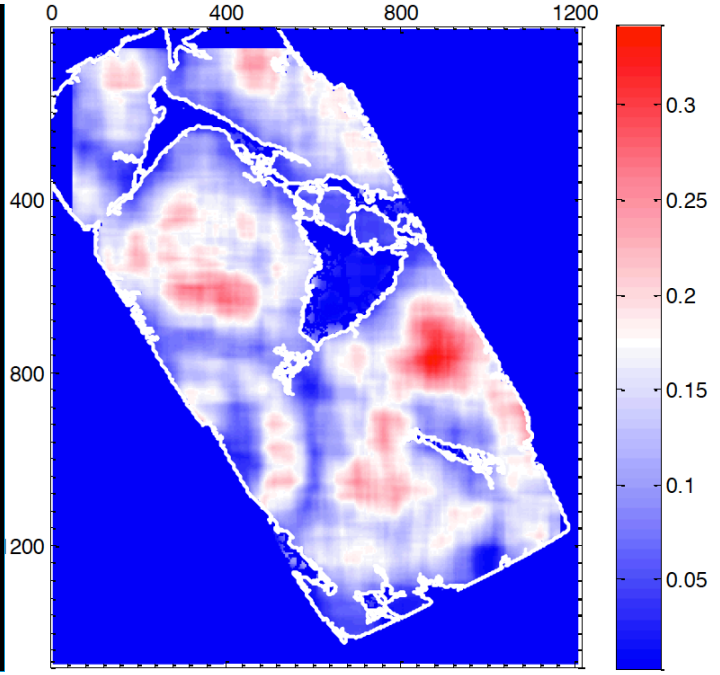
ACCESS report D1.26 by University of Cambridge



Melt ponds in Jul/Aug 2012

ACCESS report D1.22 by Norwegian Polar Institute





Surface type	Albedo
open water	0.07
white ice	0.55
bright pond	0.34
dark pond	0.15

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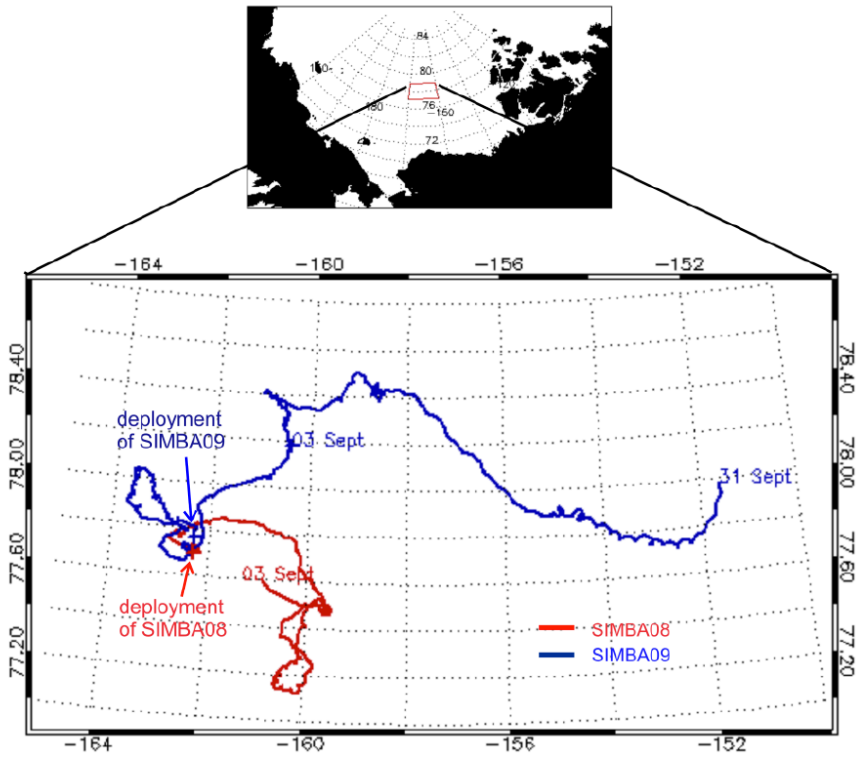
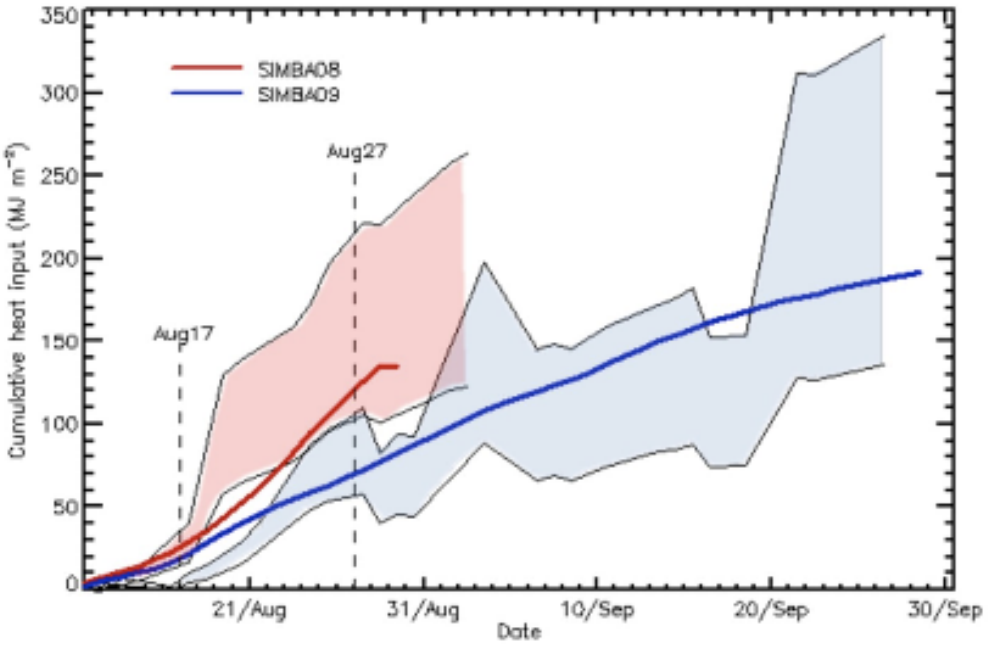
Ocean-Sea Ice heat exchange Chukchi Sea Aug-Sep 2011

ACCESS report D1.23 by Scottish Association for Marine Science





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Definition: IPCC models

- **C**oupled **M**odel **I**ntercomparison **P**roject (CMIP)

  standard experimental protocol for studying the output of coupled atmos.-ocean general circulation models (AOGCMs)
- by World Climate Research Programme (WCRP)
- standard experiments:
  - historical simulation (1850-2005)
  - future emission scenarios (2006-2100)
  - etc.
- IPCC AR4: CMIP**3** models
- IPCC AR5: CMIP**5** models
- freely available

  http://pcmdi9.llnl.gov/esgf-web-fe

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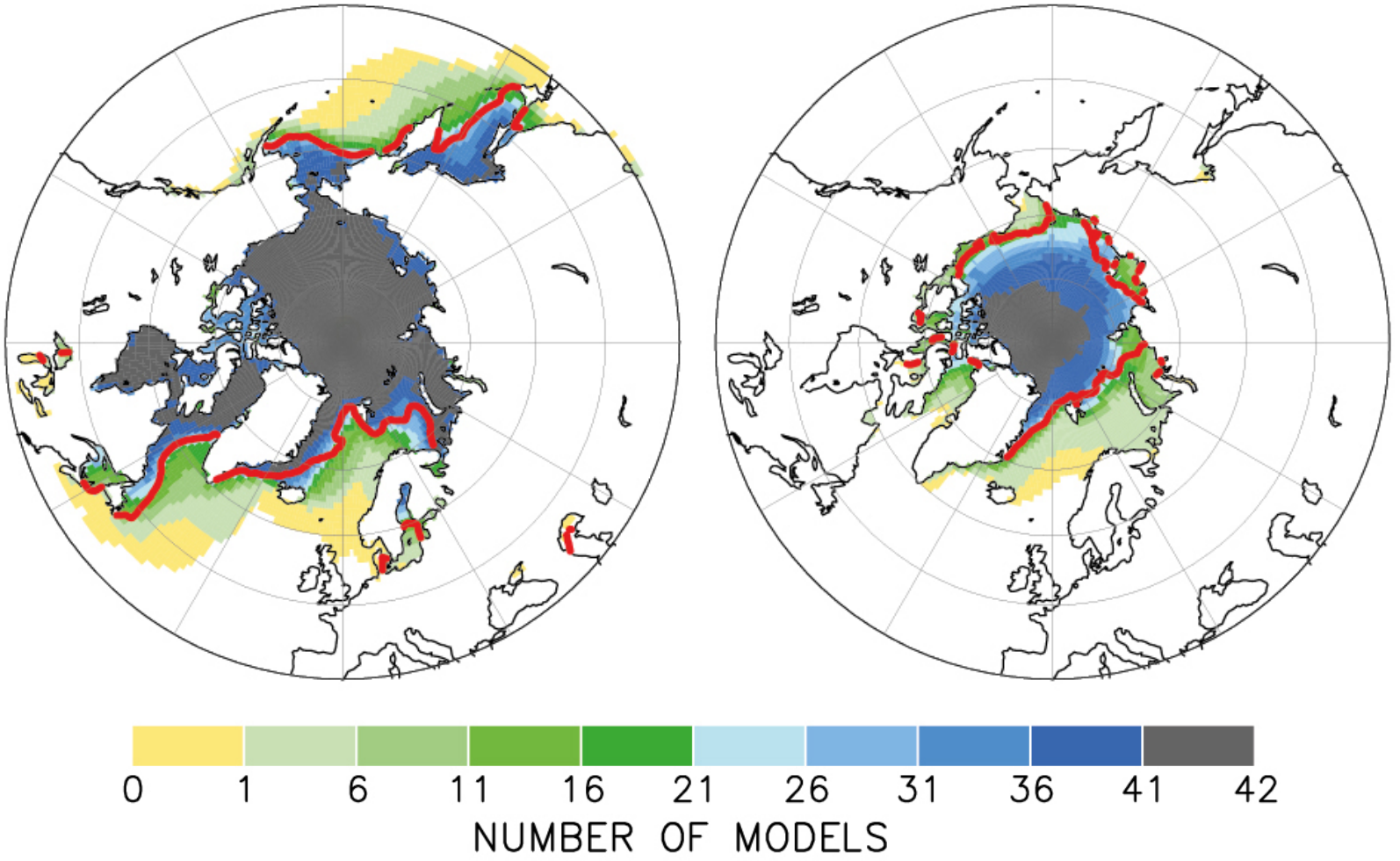
Past simulations: IPCC CMIP5 models



IPCC AR5 WG1 Fig. 9.23

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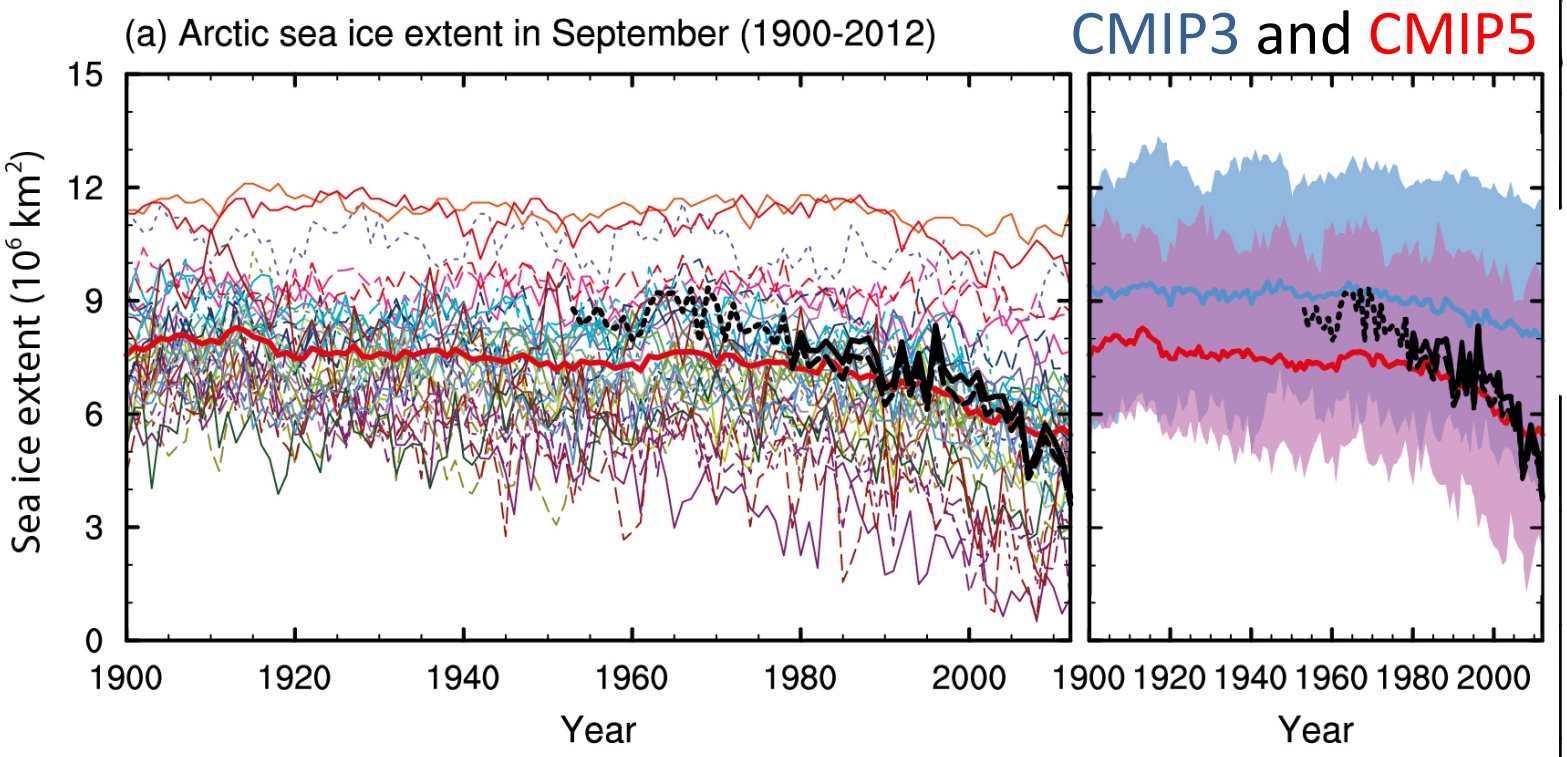
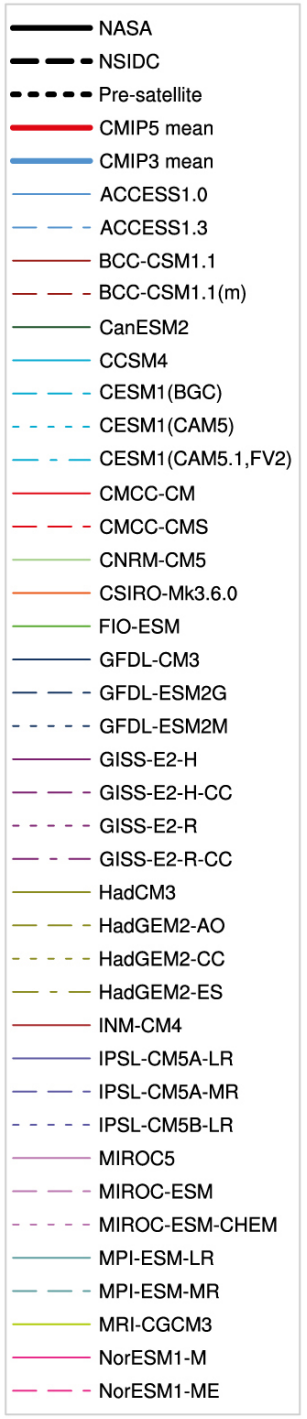
Past simulations: IPCC CMIP5 models





IPCC AR5 WG1 Fig. 9.24

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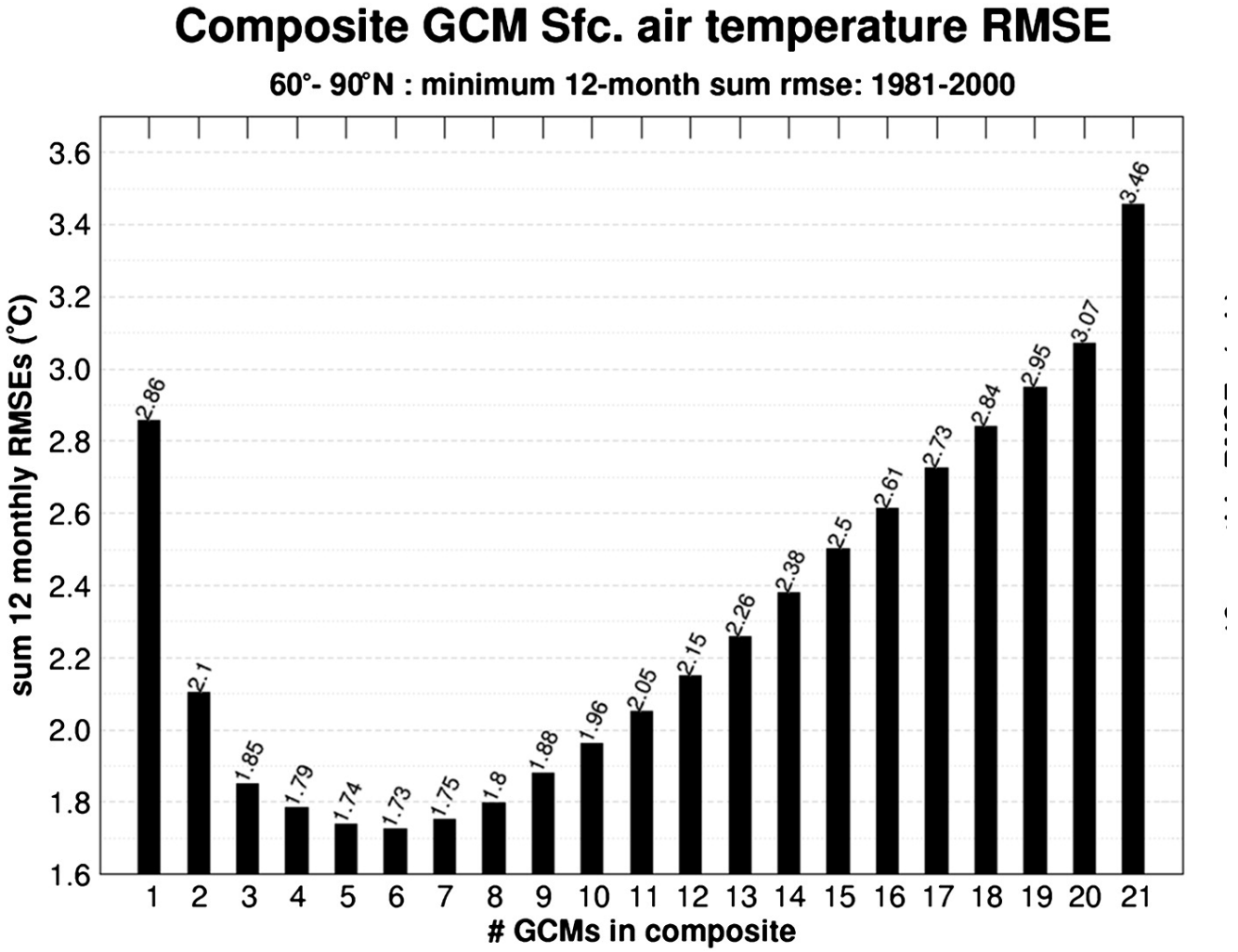
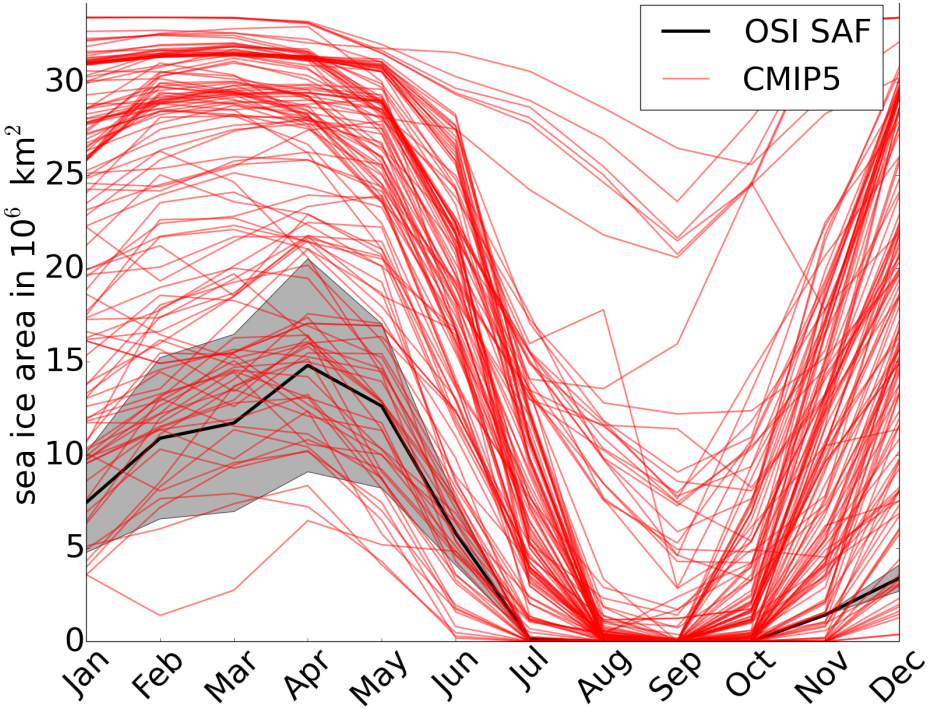
Past simulations: IPCC CMIP3 models



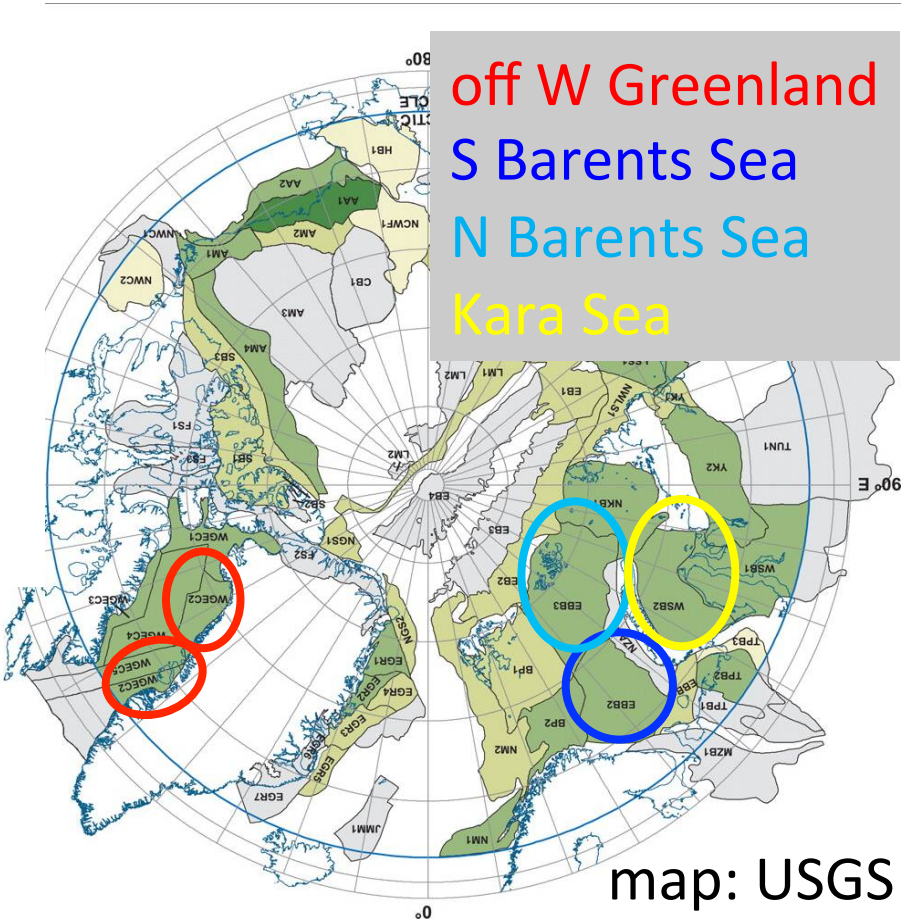
Overland et al., 2011 DOI:10.1175/2010jcli3462.1

The diversity of past sea ice concentration (sic)

ACCESS report D1.51 by Alfred Wegener Institute



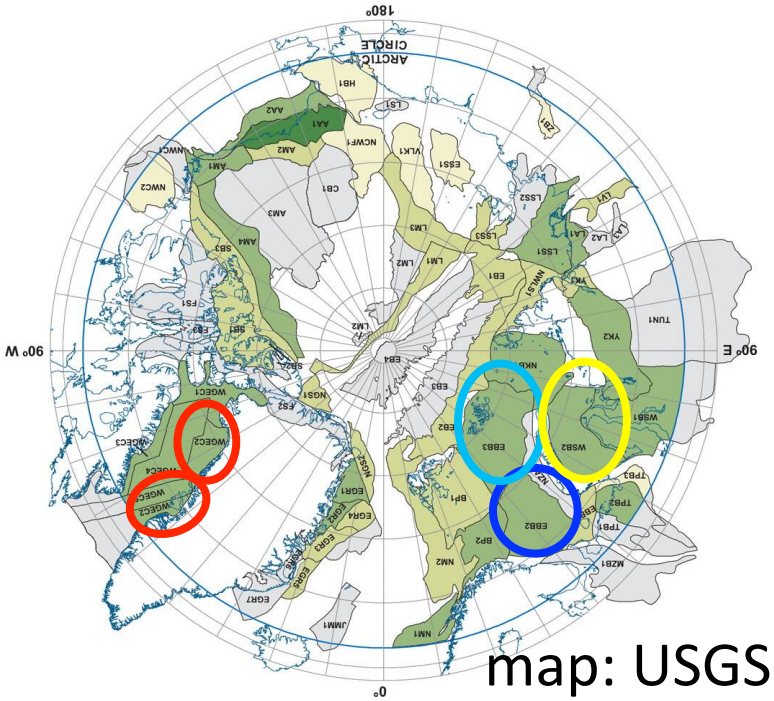
Mean seasonal cycle 1979-2005
area integrated sic
Southern Barents Sea



map: USGS

How to select the better models?

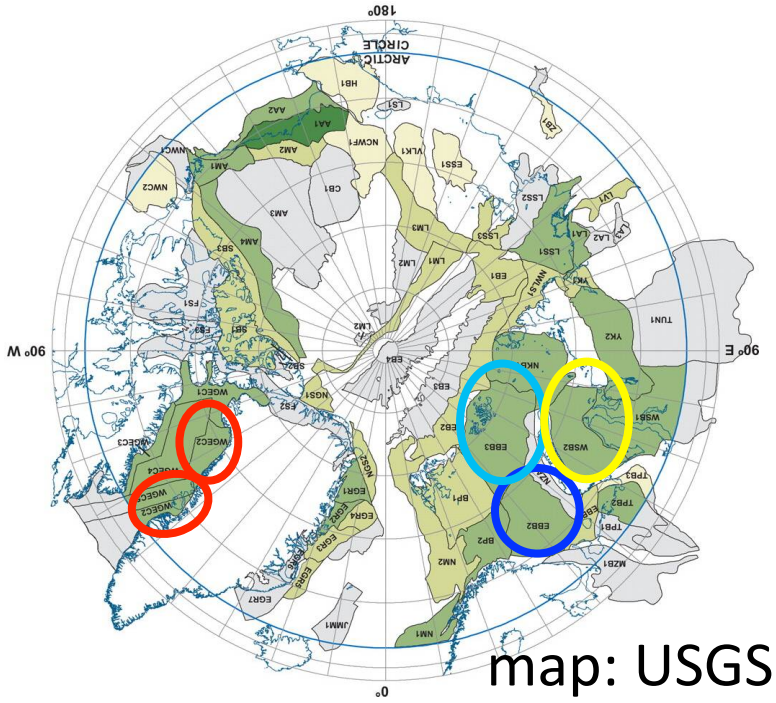
- histor. experiment: monthly mean sic
- mean seasonal cycle 1979-2005
- difference to satellite derived sic
  - OSI SAF by EUMETSAT
- $$\text{misfit} = \frac{1}{2}\sum\left[\frac{\left(\text{sic}_{\text{model}} - \text{sic}_{\text{satellite}}\right)^2}{\text{weights}}\right]$$
- for each grid point,
  integrate over regions



map: USGS

How to select the better models?

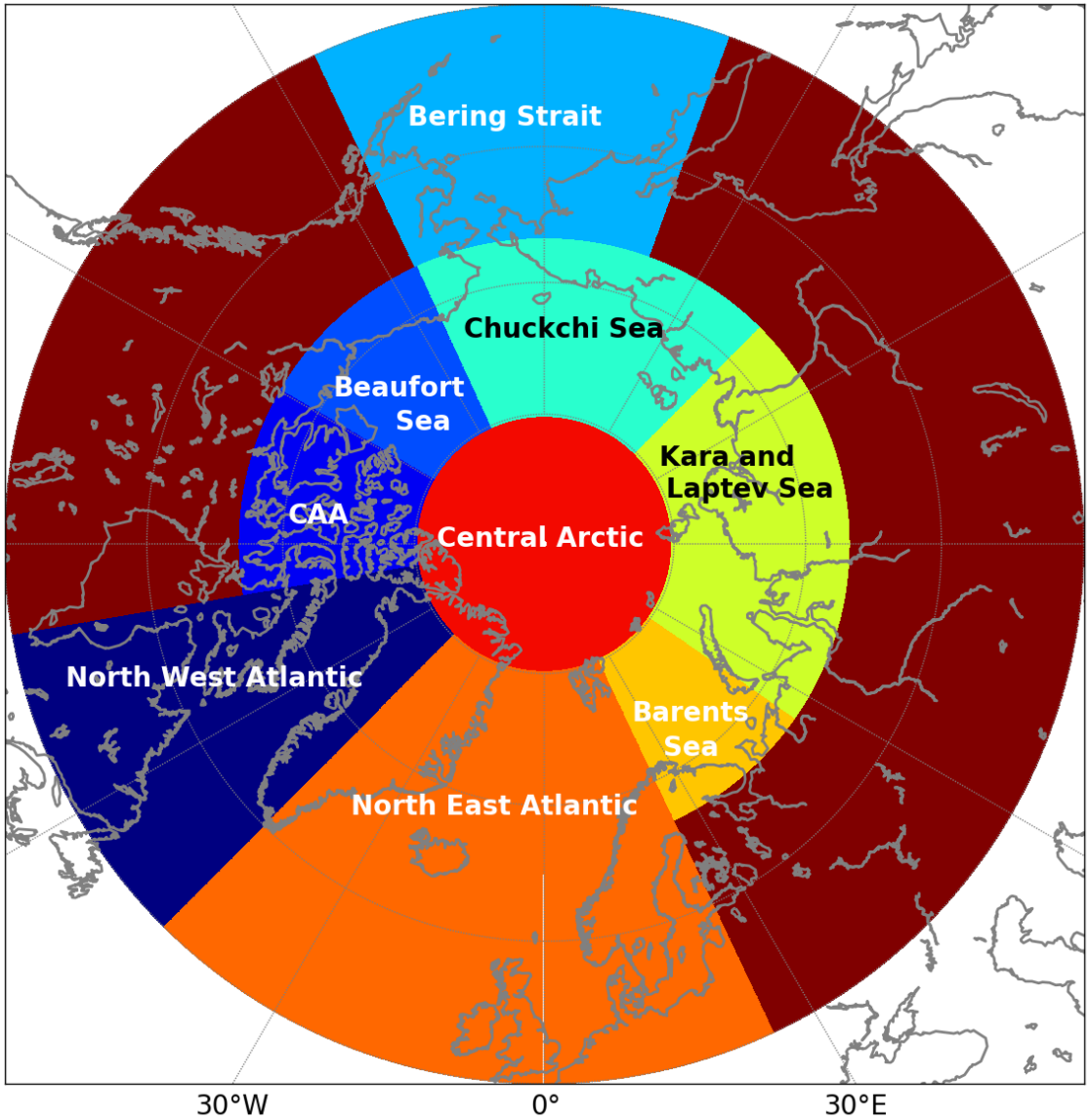
rank	OSI SAF WP4.1 regions	norm. misfit sum over WP4.1 regions
1	MPI-ESM-LR	1.000
2	MIROC4h	0.998
3	MPI-ESM-MR	0.997
4	GFDL-CM3	0.988
5	NorESM1-M	0.979
6	MPI-ESM-P	0.966
7	ACCESS1-0	0.926
8	NorESM1-ME	0.882
9	inmcm4	0.878
10	CCSM4	0.859



map: USGS

How to select the better models?

- repeat analysis for total Arctic Ocean
- OSISAF 1979-2005 and
- SSMI IFREMER 1992-2005



How to select the better models?

rank	OSI SAF 1979-2005 WP4.1 regions	norm. misfit WP4.1 regions	OSI SAF 1979-2005 whole Arctic	norm. misfit whole Arctic	SSMI IFREMER 1992-2005 whole Arctic	norm. misfit whole Arctic
1	MPI-ESM-LR	1.000	MPI-ESM-LR	1.000	MPI-ESM-LR	1.000
2	MIROC4h	0.998	MPI-ESM-P	0.984	MPI-ESM-MR	0.959
3	MPI-ESM-MR	0.997	MPI-ESM-MR	0.980	CCSM4	0.952
4	GFDL-CM3	0.988	NorESM1-M	0.930	EC-EARTH	0.945
5	NorESM1-M	0.979	NorESM1-ME	0.890	MPI-ESM-P	0.945
6	MPI-ESM-P	0.966	CCSM4	0.888	CESM1-CAM-1FV2	0.944
7	ACCESS1-0	0.926	GFDL-CM3	0.853	NorESM1-ME	0.937
8	NorESM1-ME	0.882	IPSL-CM5A-MR	0.853	NorESM1-M	0.934
9	inmcm4	0.878	MIROC-ESM	0.847	GFDL-CM3	0.932
10	CCSM4	0.859	MIROC-ESM-CHEM	0.840	CNRM-CM5	0.913

How to select the better models?

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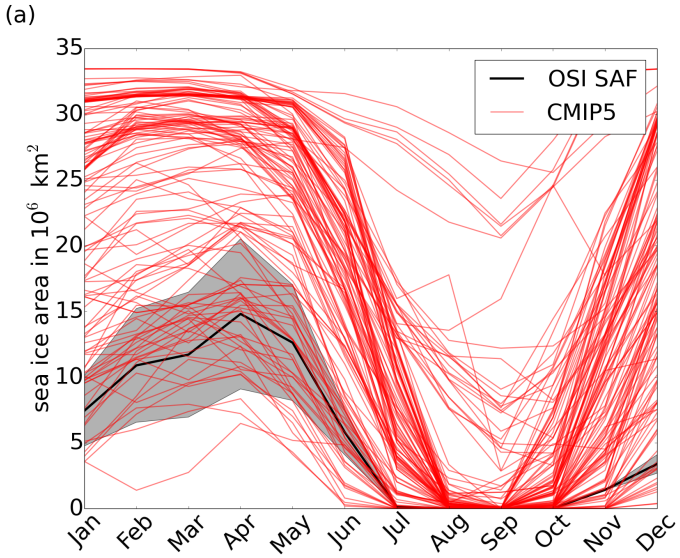

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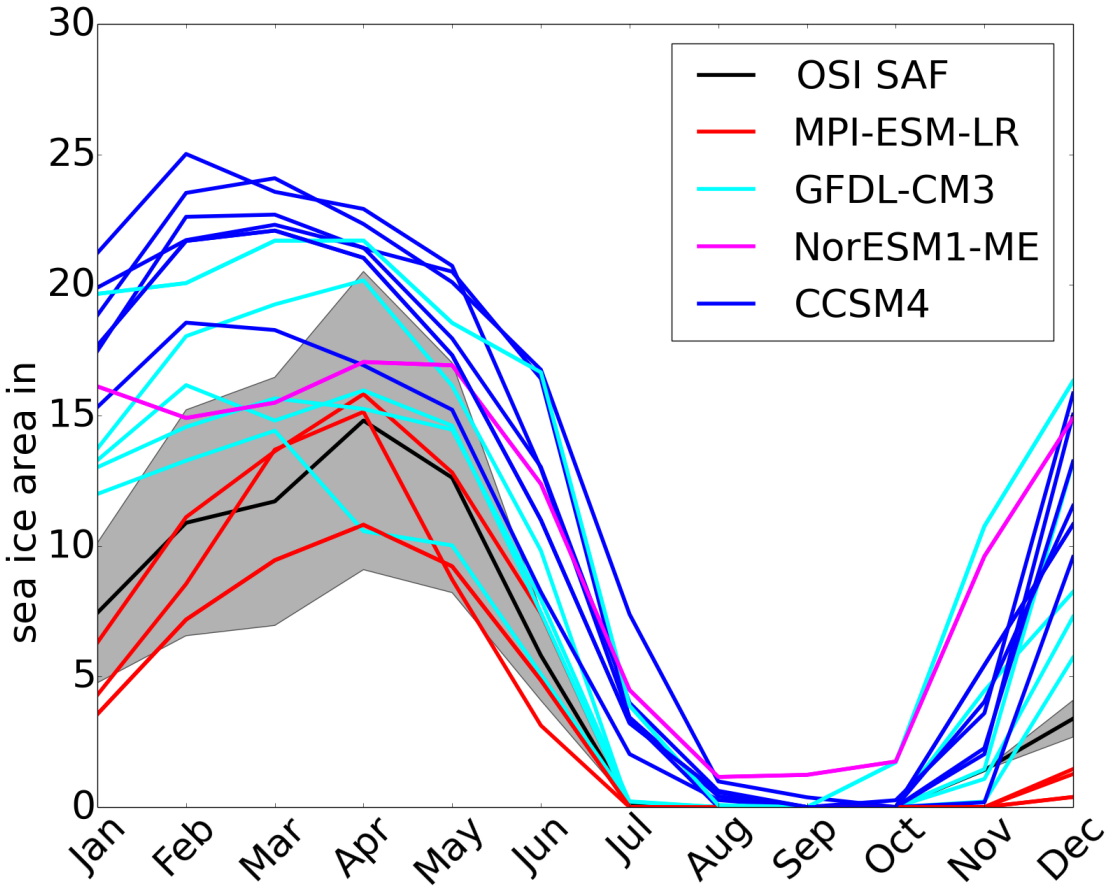

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Emission Scenarios

Representative Concentration Pathways (RCP)

Name	Radiative forcing	Concentration of CO2-equiv. in ppm	Pathway
RCP8.5	> 8.5 W m^{-2} in 2100	> 1370 in 2100	rising
RCP6.0	~ 6 W m^{-2} at stabilization after 2100	~ 850 at stabilization after 2100	stabilization without overshoot
RCP4.5	~ 4.5 W m^{-2} at stabilization after 2100	~ 650 at stabilization after 2100	stabilization without overshoot
RCP2.6	Peak at ~3 W m^{-2} before 2100 and then declines	peak at ~ 490 before 2100 and then declines	peak and decline

Moss et al., 2010

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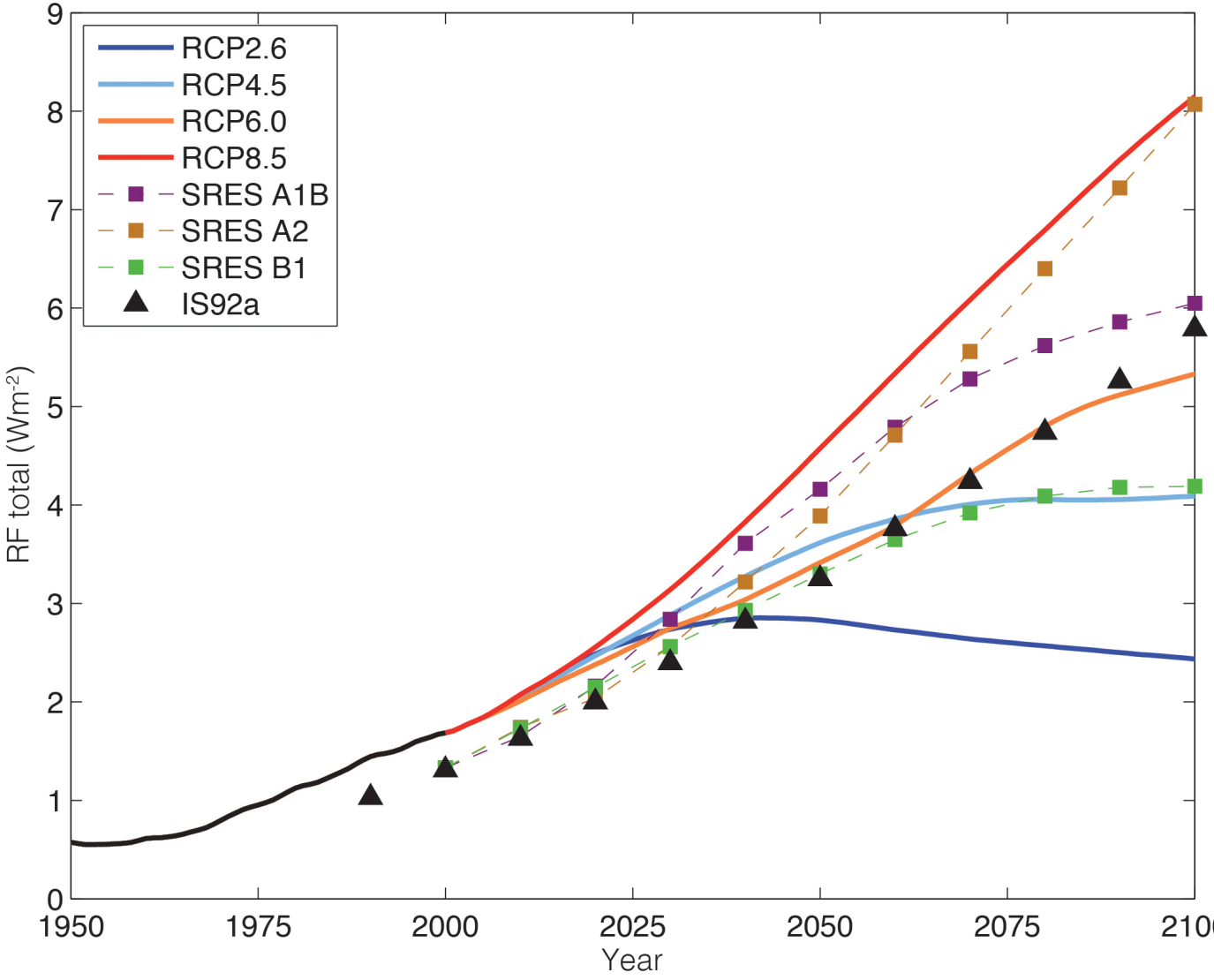
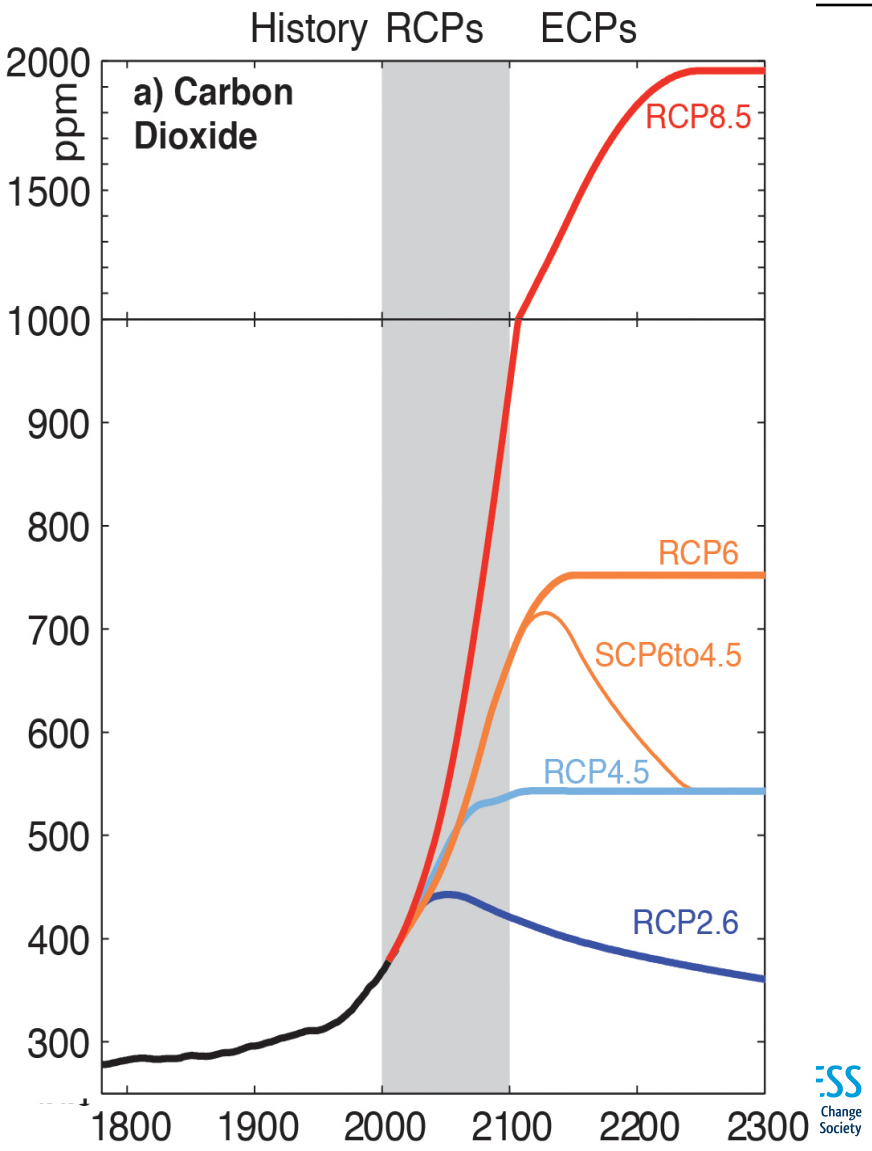
Future Emission Scenarios



IPCC AR5 WG1 Fig. 1.15

Future Emission Scenarios



IPCC AR5 WG1 Box 1.1 Fig. 2

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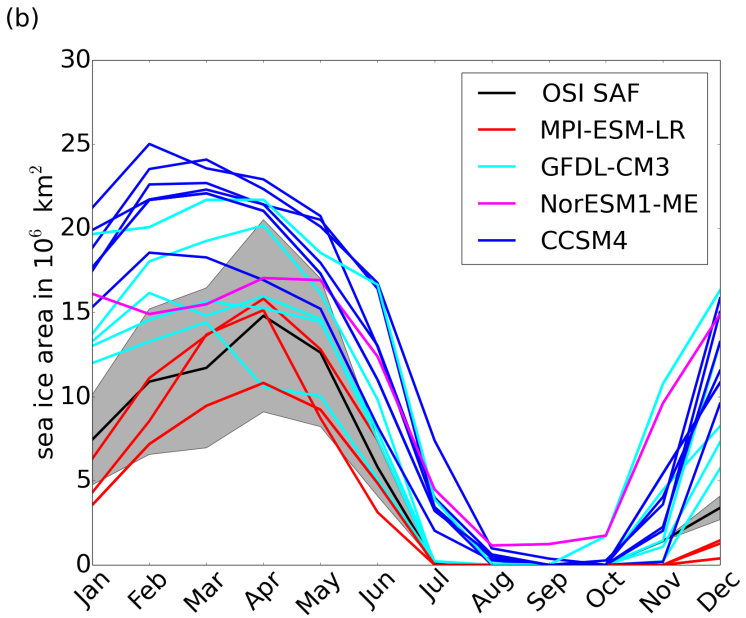
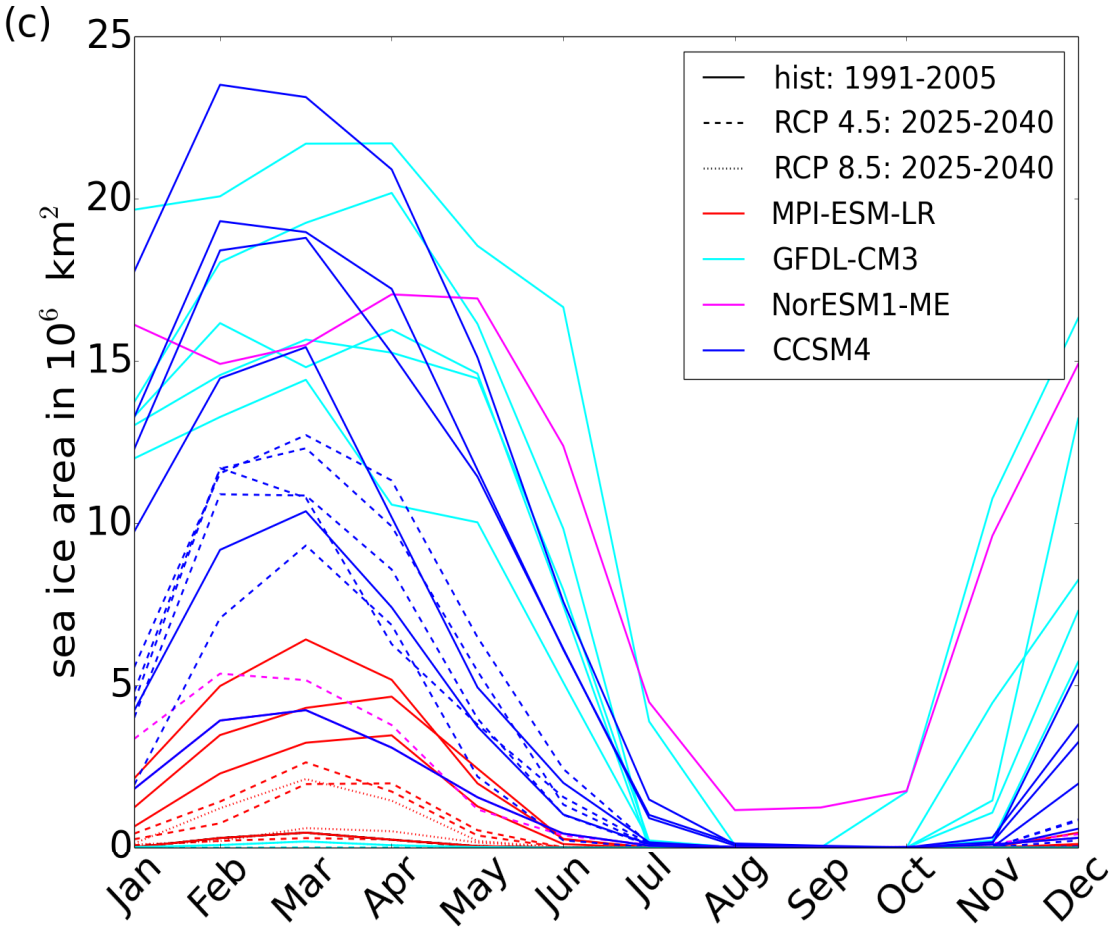
The diversity of future sea ice concentration (sic)

ACCESS report D1.51 by Alfred-Wegener-Institut



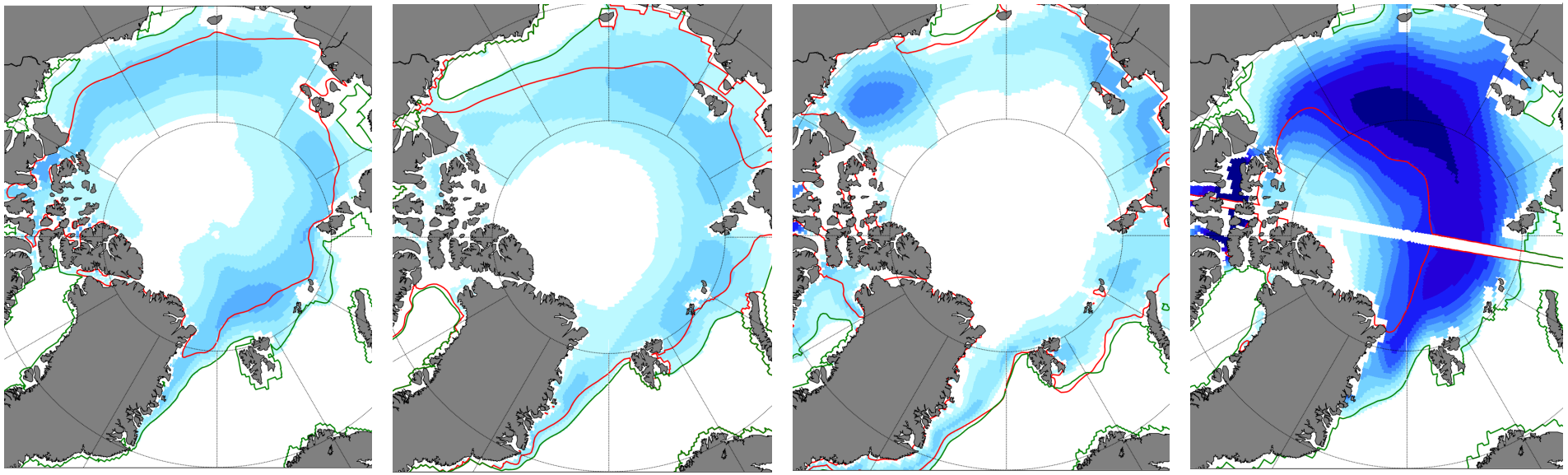


Southern Barents Sea

Future change in September sic mean(2025-2040)-mean(1991-2005)

RCP 4.5

MPI-ESM-LR CCSM4 NorESM1-ME GFDL-CM3



sic = 15%
1991-2005
2025-2040

−100 −90 −80 −70 −60 −50 −40 −30 −20 −10 0
%

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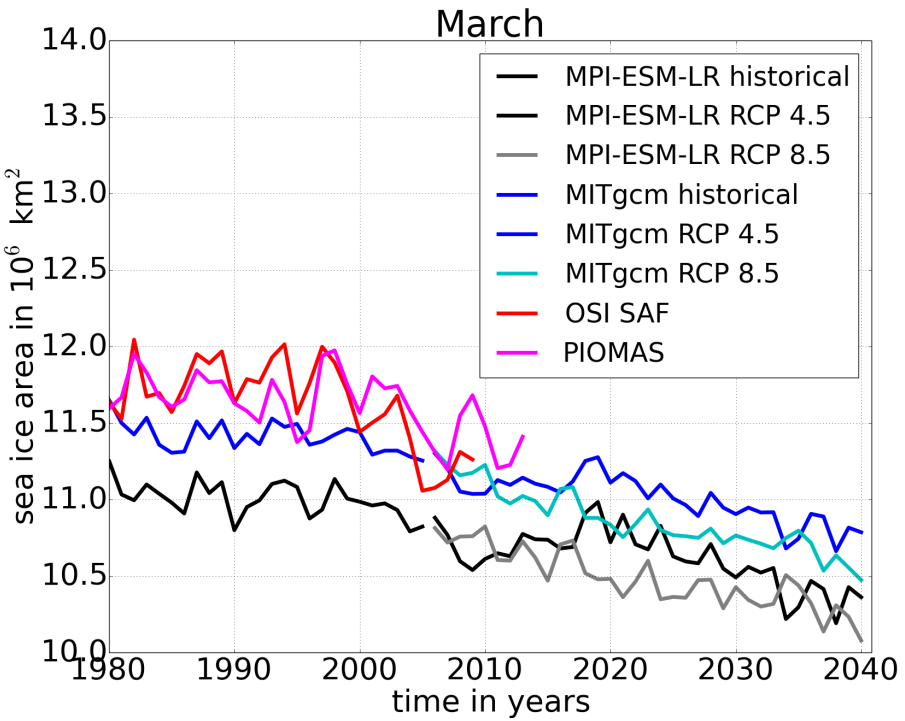
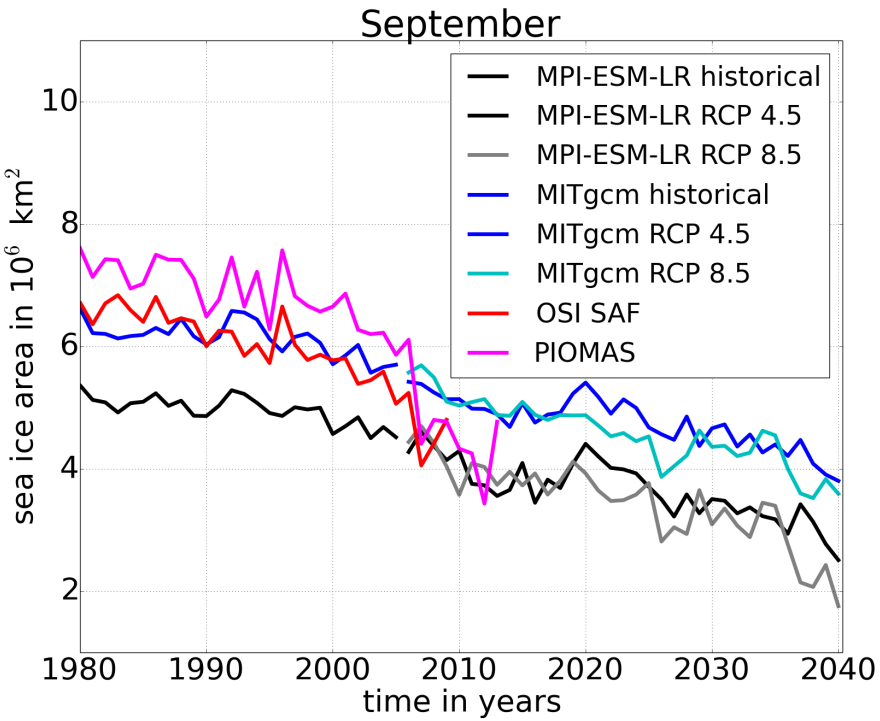
Sea-ice area





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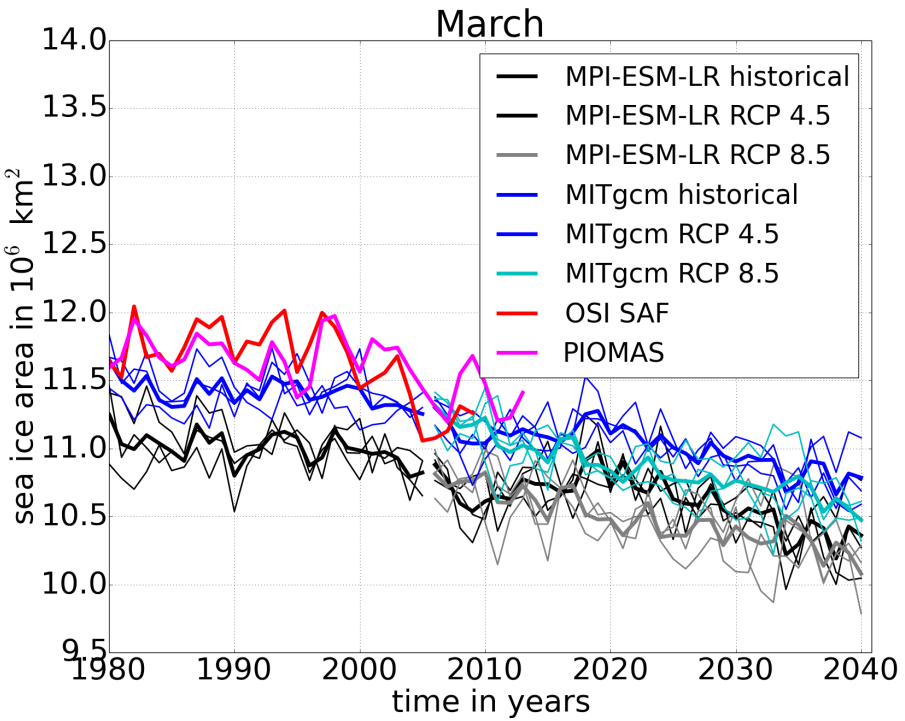

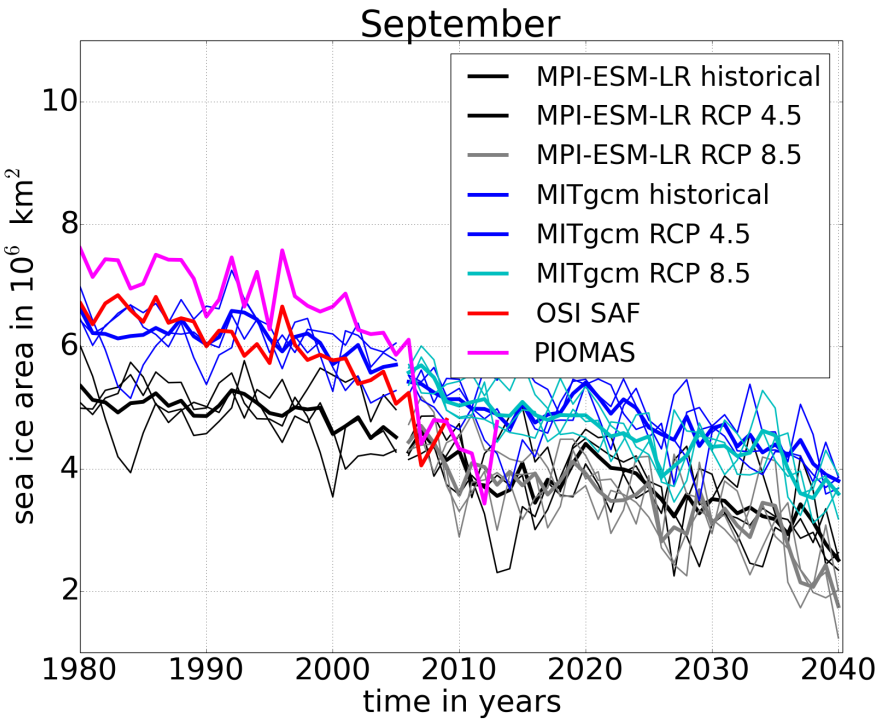

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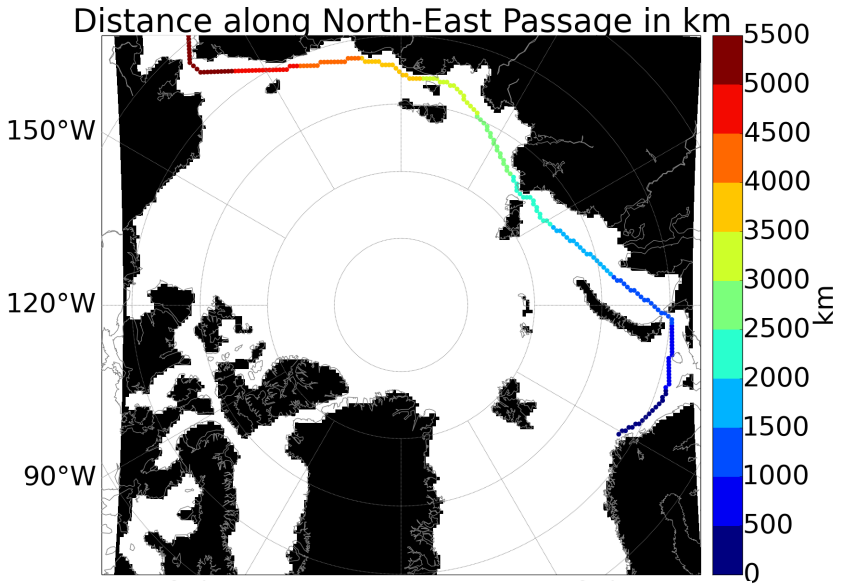
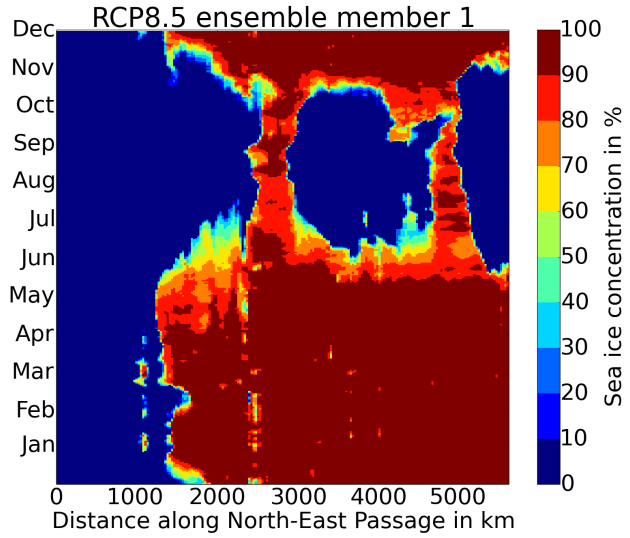
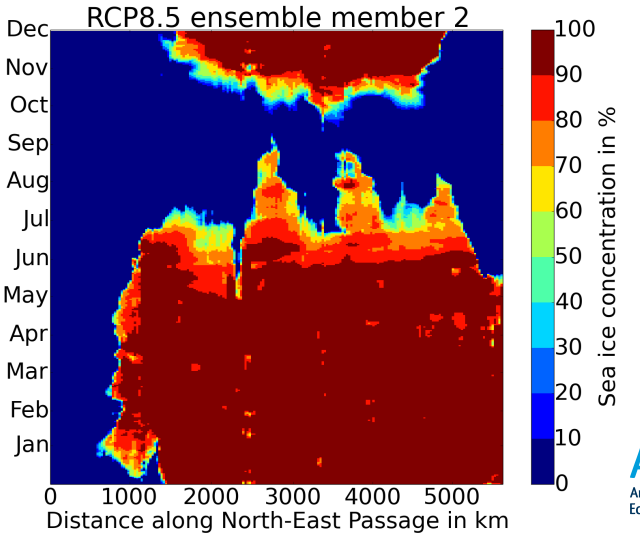
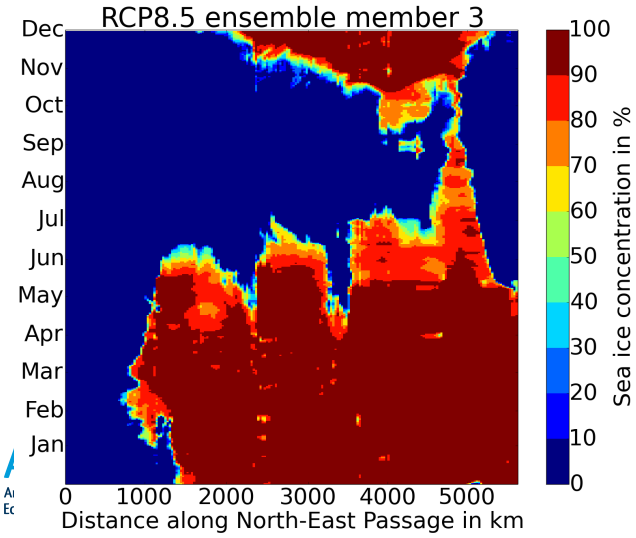
Sic along a Northeast Passage



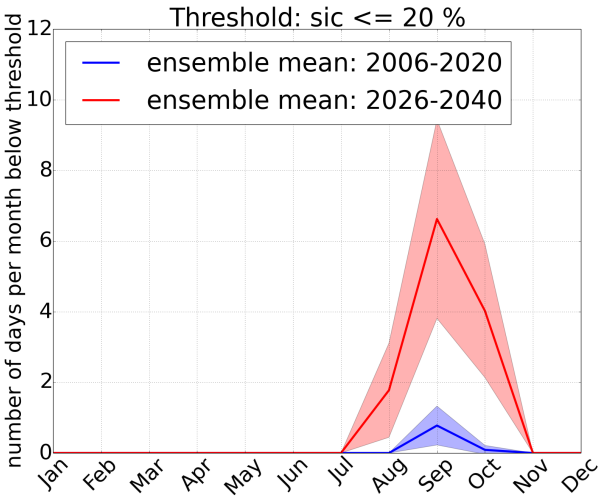


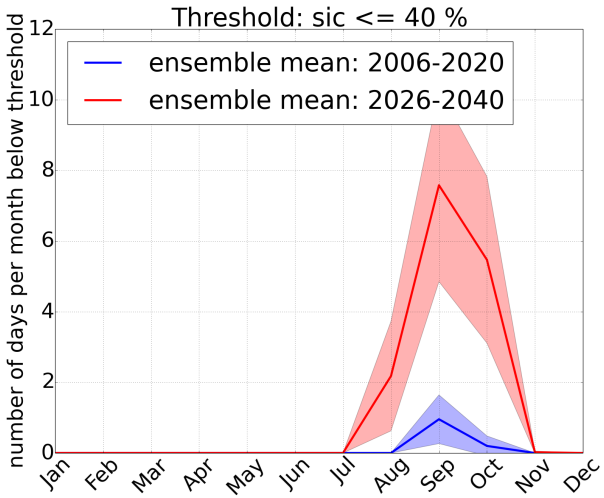


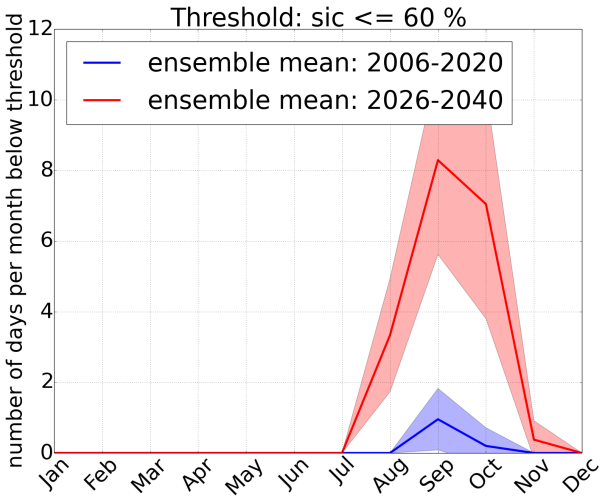


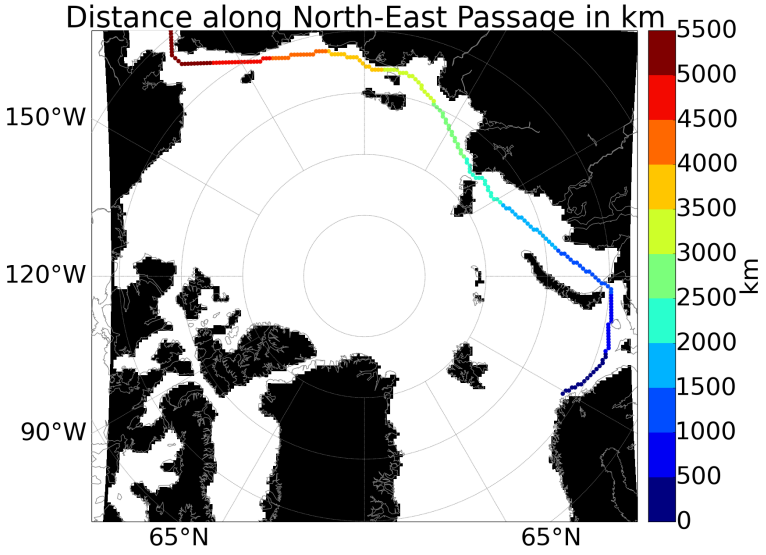
Sic along a Northeast Passage

RCP 8.5









Summary

- Arctic climate change
  - large effects on global climate
  - due to feedback loops (e.g. ice-albedo feedback)
- Monitoring climate change in the Arctic for decades
  - we understand big picture
  - some details not yet known
- Applying models for estimation of future change
  - uncertainties decrease but slowly

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Arctic Climate Change
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