Farewell to Ice: Arctic climate feedbacks and their global effects

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San Sebastian, July 2017

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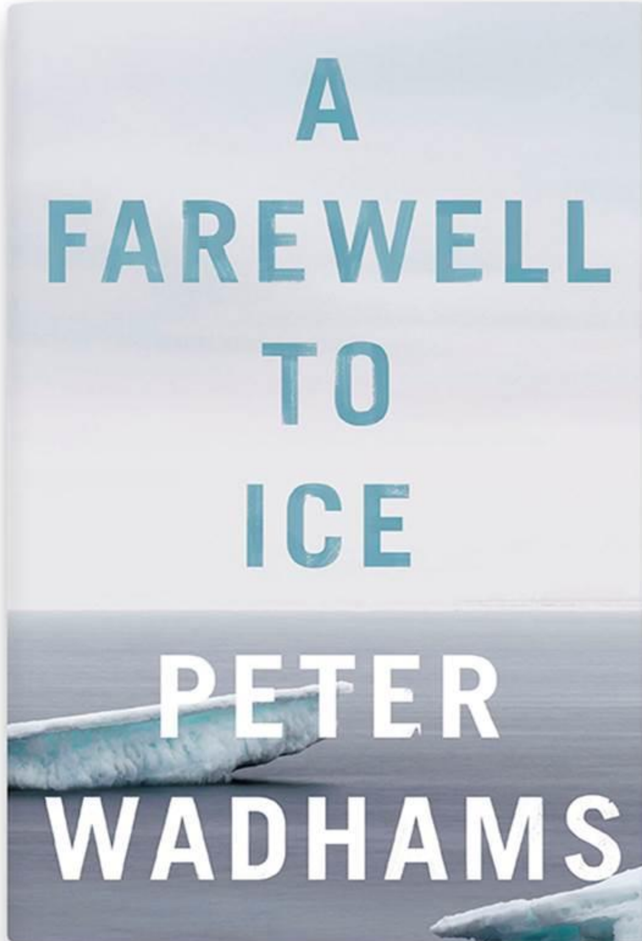

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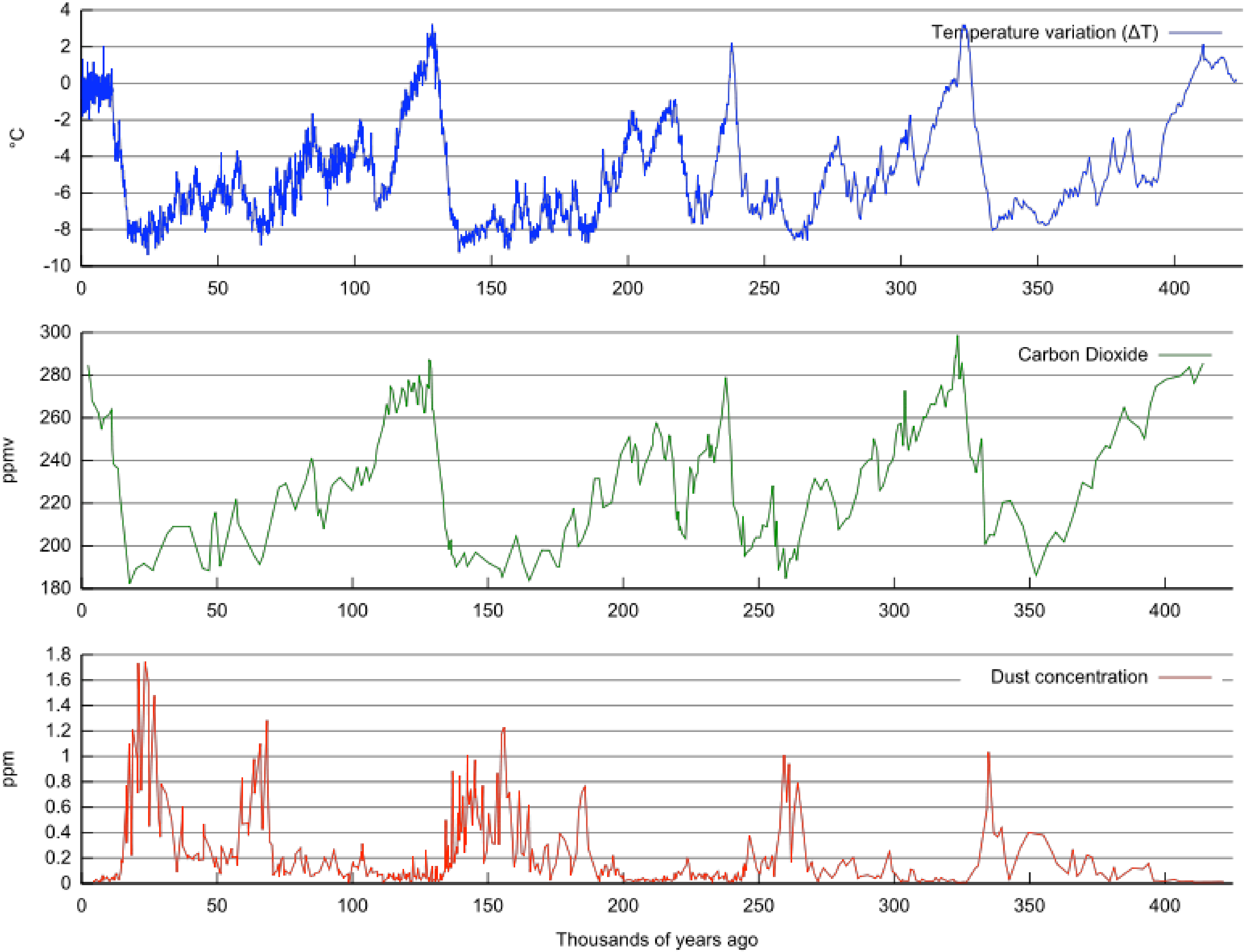
20
U. S. COAST GUARD



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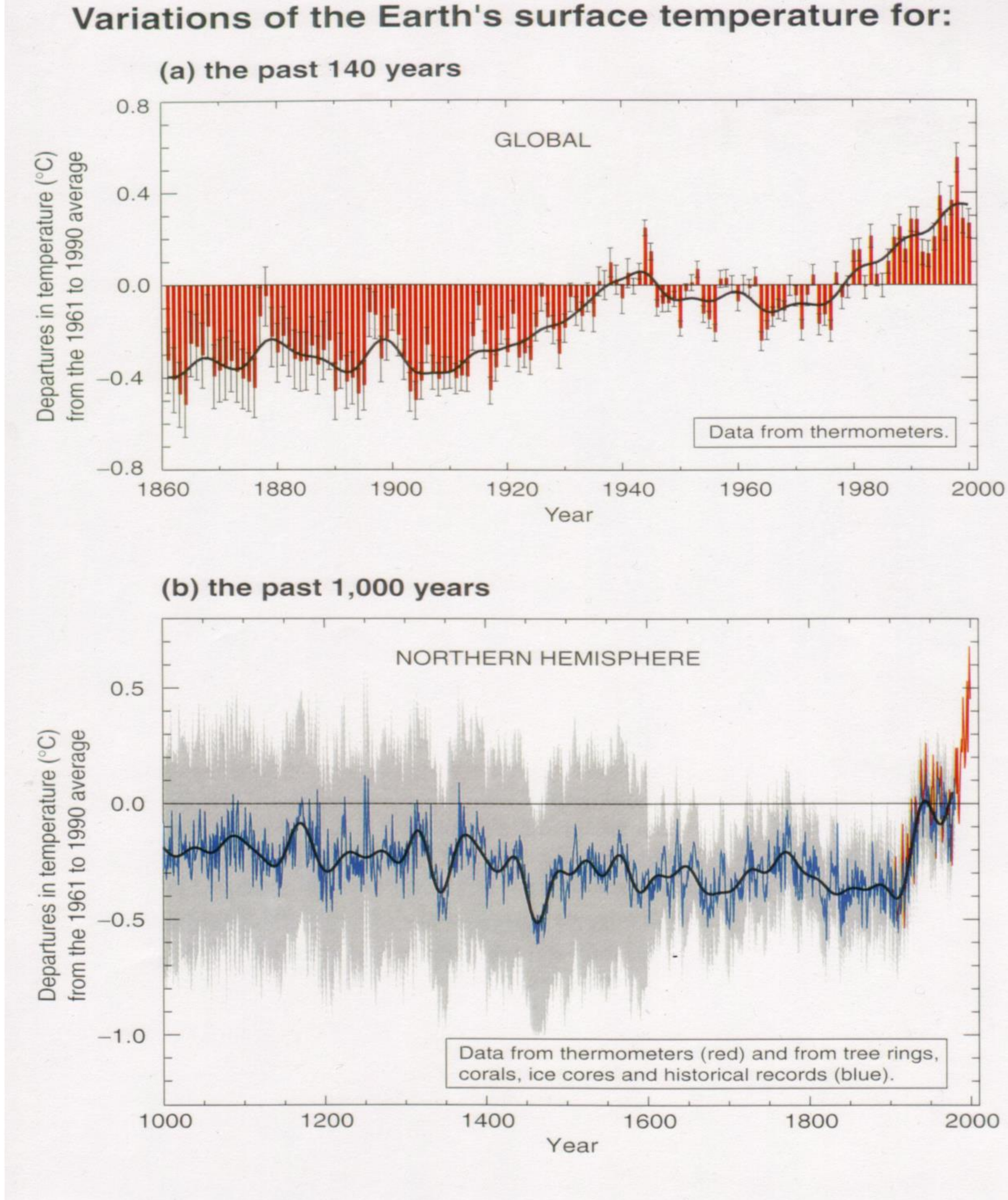
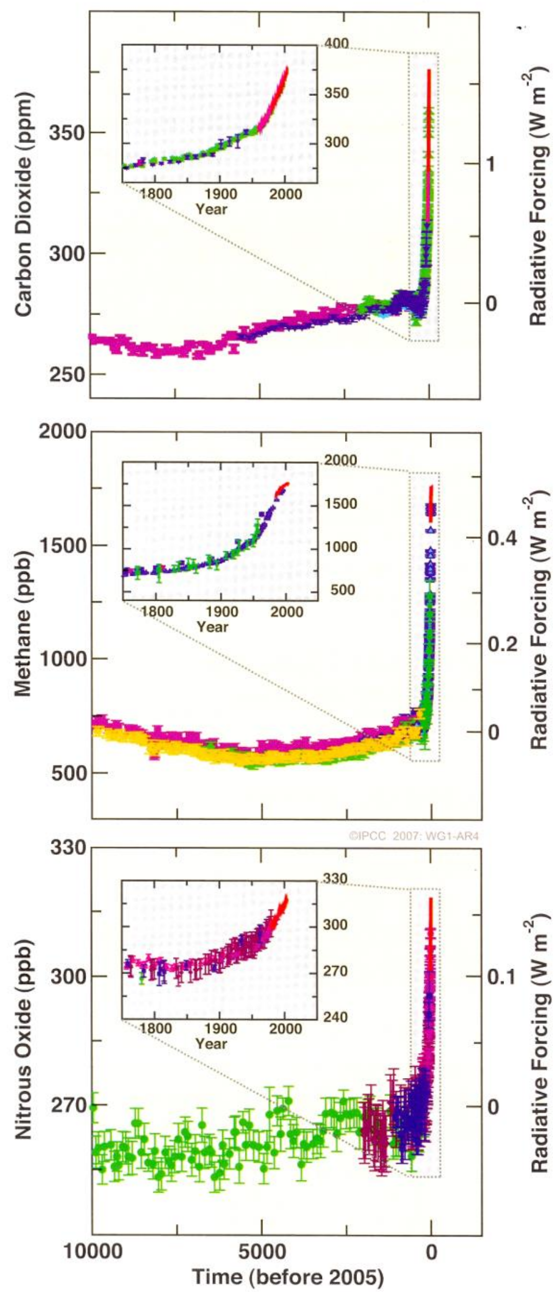
The Earth has been warming rapidly since the mid-19th Century…



Changes in Greenhouse Gases from Ice Core and Modern Data



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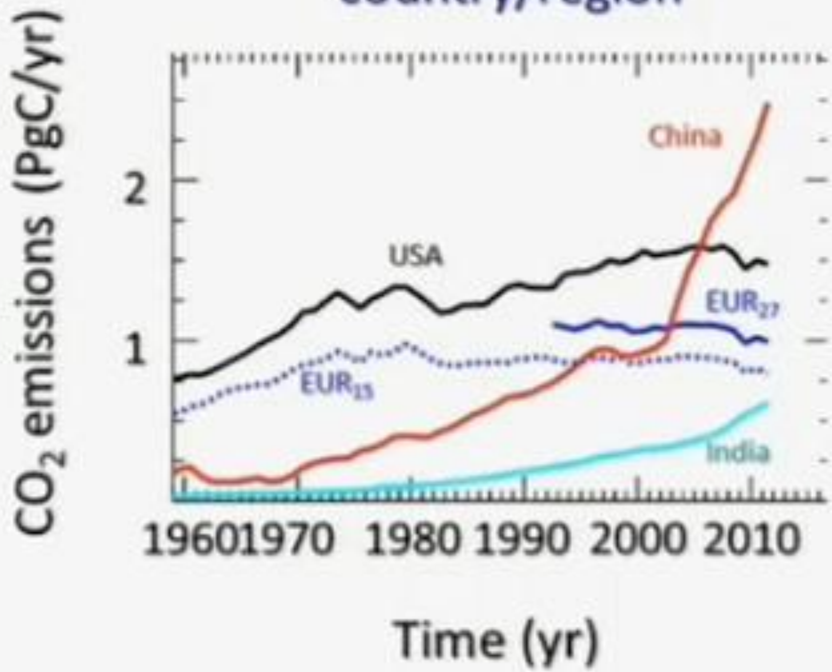
Fossil fuel & cement CO_2 emissions by country/region



Source: Peters et al. Nature Climate Change submitted, based on CDIAC data and BP energy statistics

Arctic amplification

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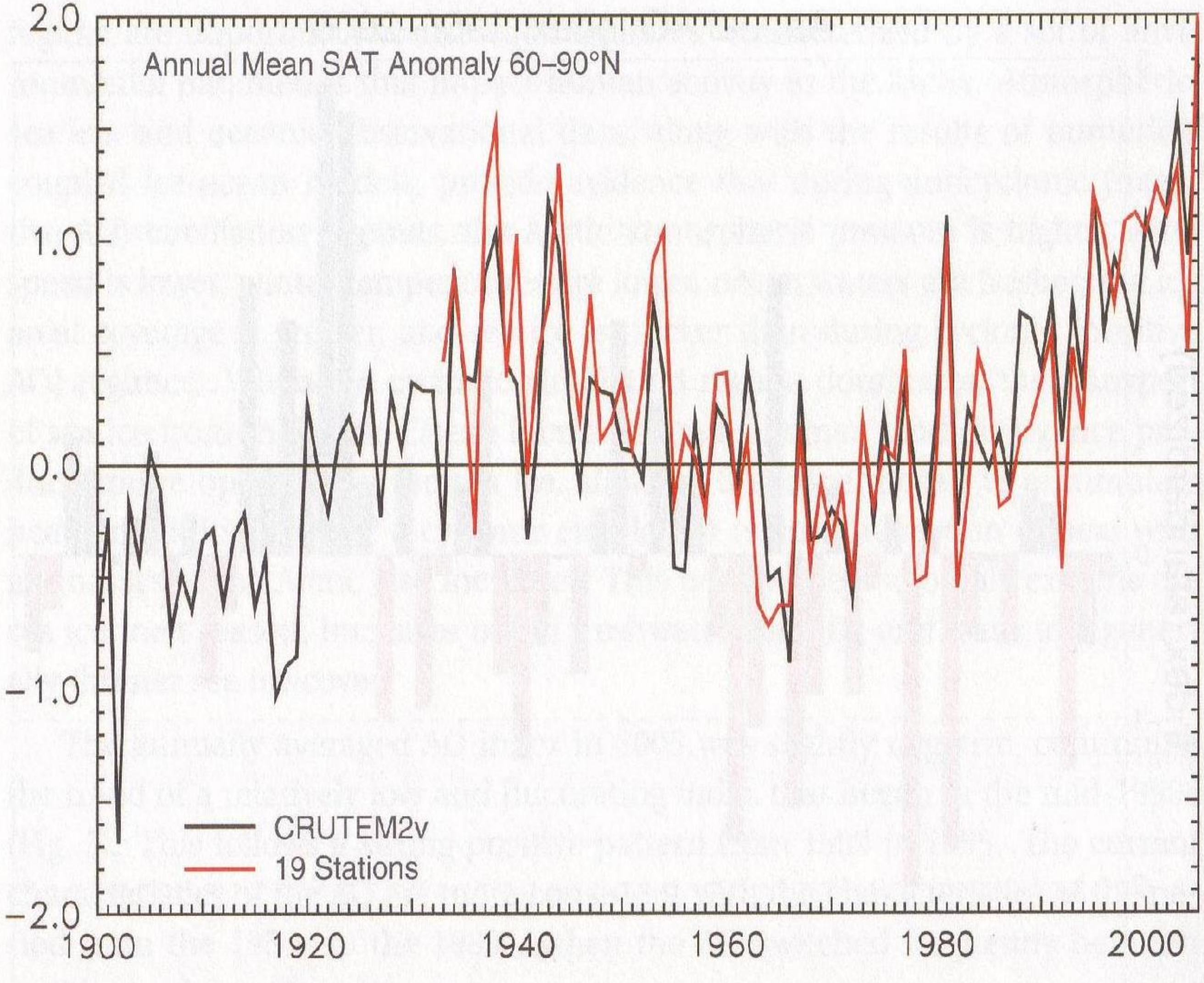

Figure 6: Arctic-wide and annual averaged surface air temperature anomalies (60°–90°N) over land for the 20th century based on the CRU TEM2V monthly data set.

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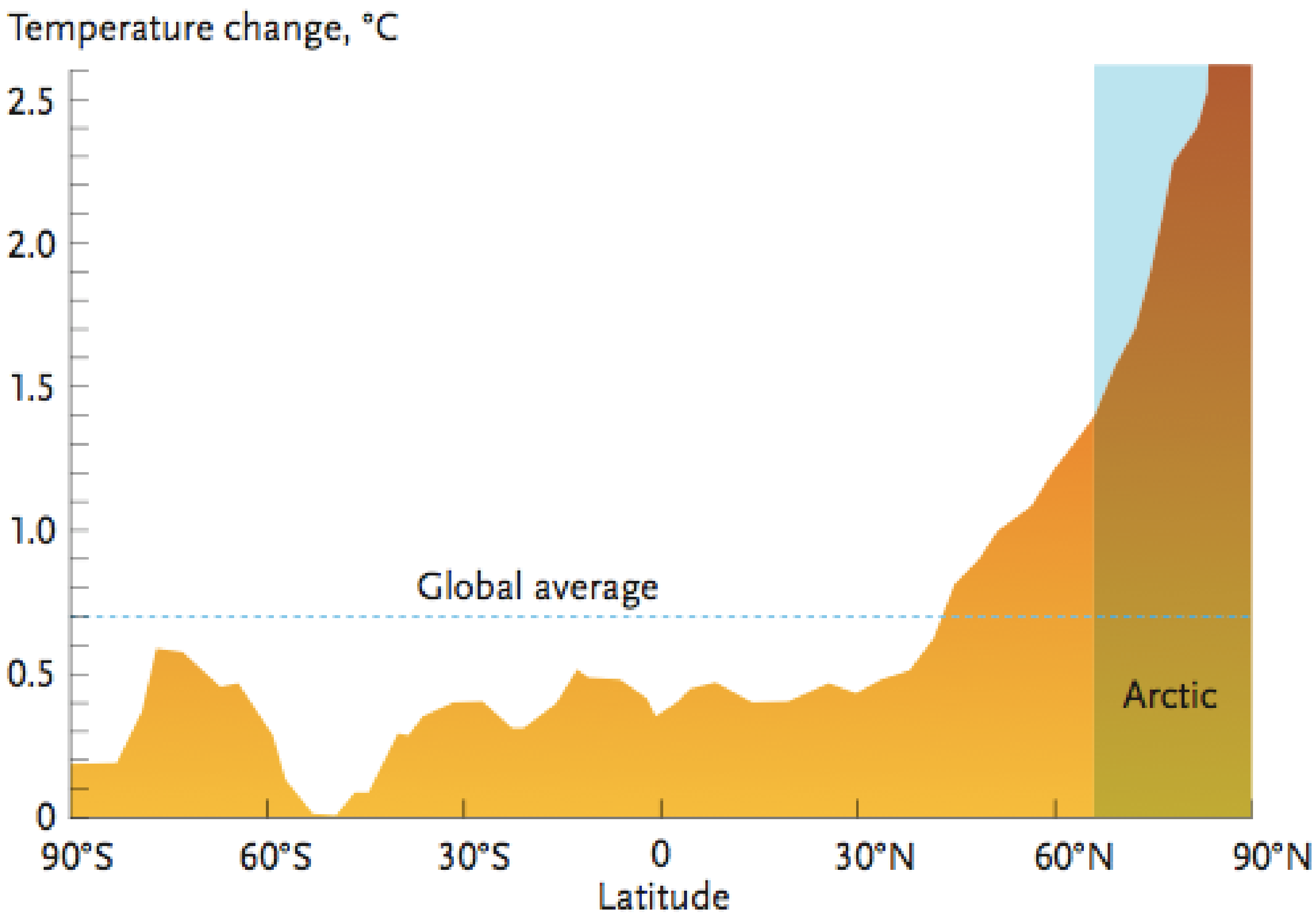
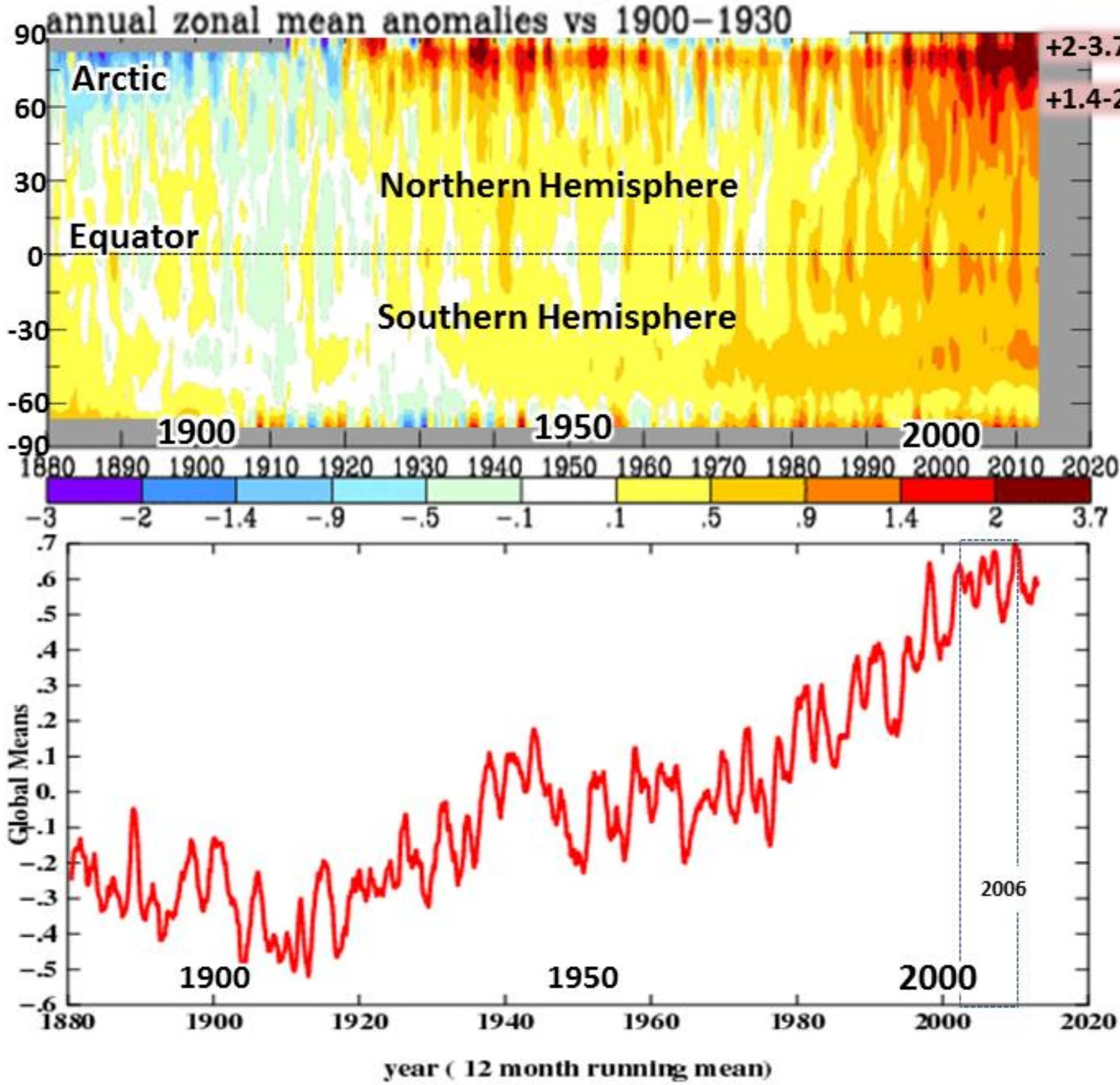
Arctic amplification



The average increase in surface temperature since the 1951–1980 reference period is greatest in the Arctic.

Global heating continues



NASA

GISS Surface Temperature Analysis
Zonal Means vs. Time
Zonal average temperature change from 1915 to 2012

Presenting the global average surface temperature change as a colour change allows us to see that the heating of the biosphere has not stopped - it is sustained at the same large increase.

The temperature increase has been the same since 2006. This temperature anomaly above the average past normal - - indicates constant heating.

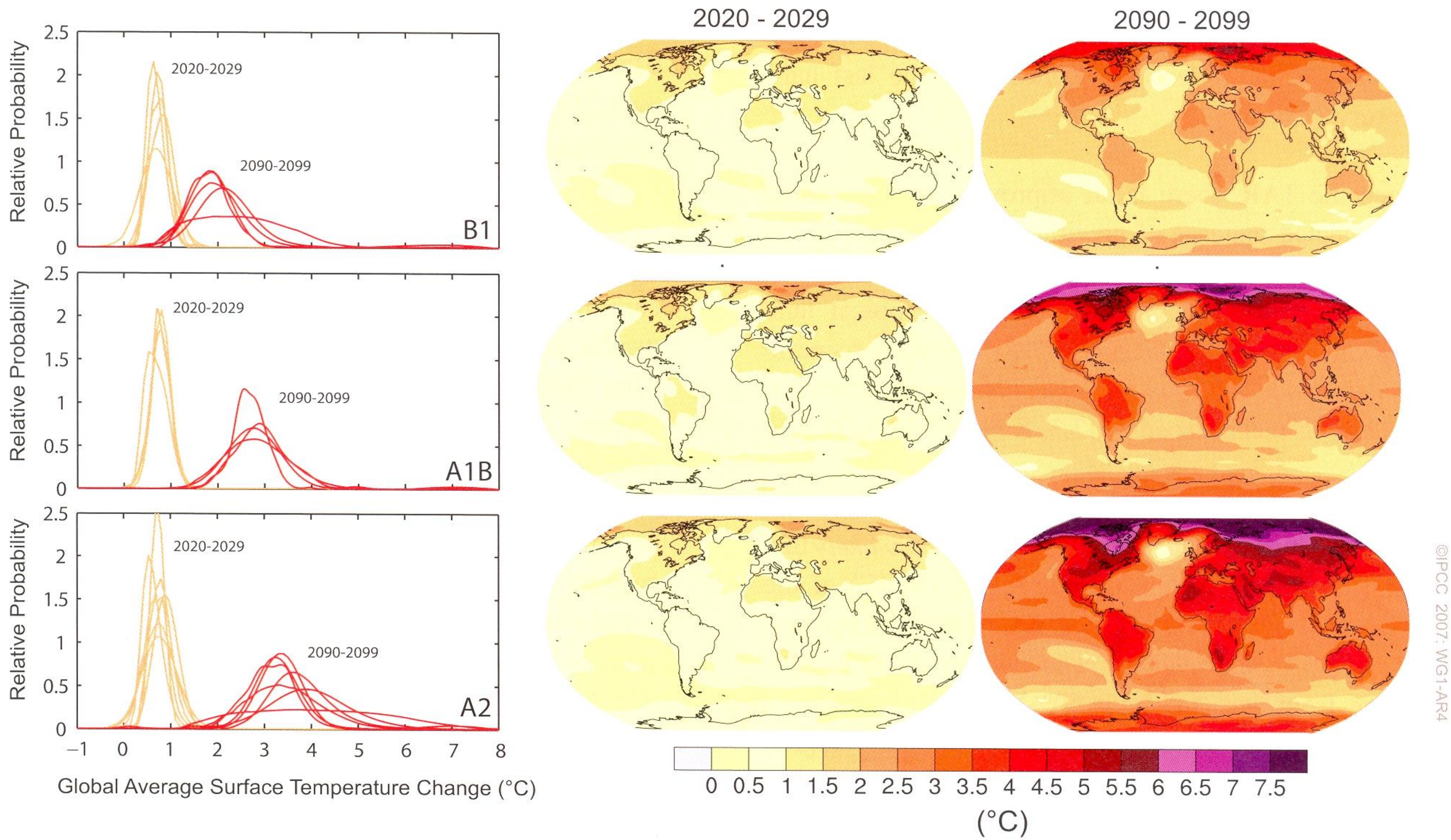
The zonal presentation shows that the NH heats up faster than the SH, and the difference increases over time of heating.

The Arctic is heating by far the fastest which is starting to affect the normally temperate NH

http://data.giss.nasa.gov/cgi-bin/cdrar/do_LTmapE.cgi

P. Carter Aug 2013

Projections of Surface Temperatures



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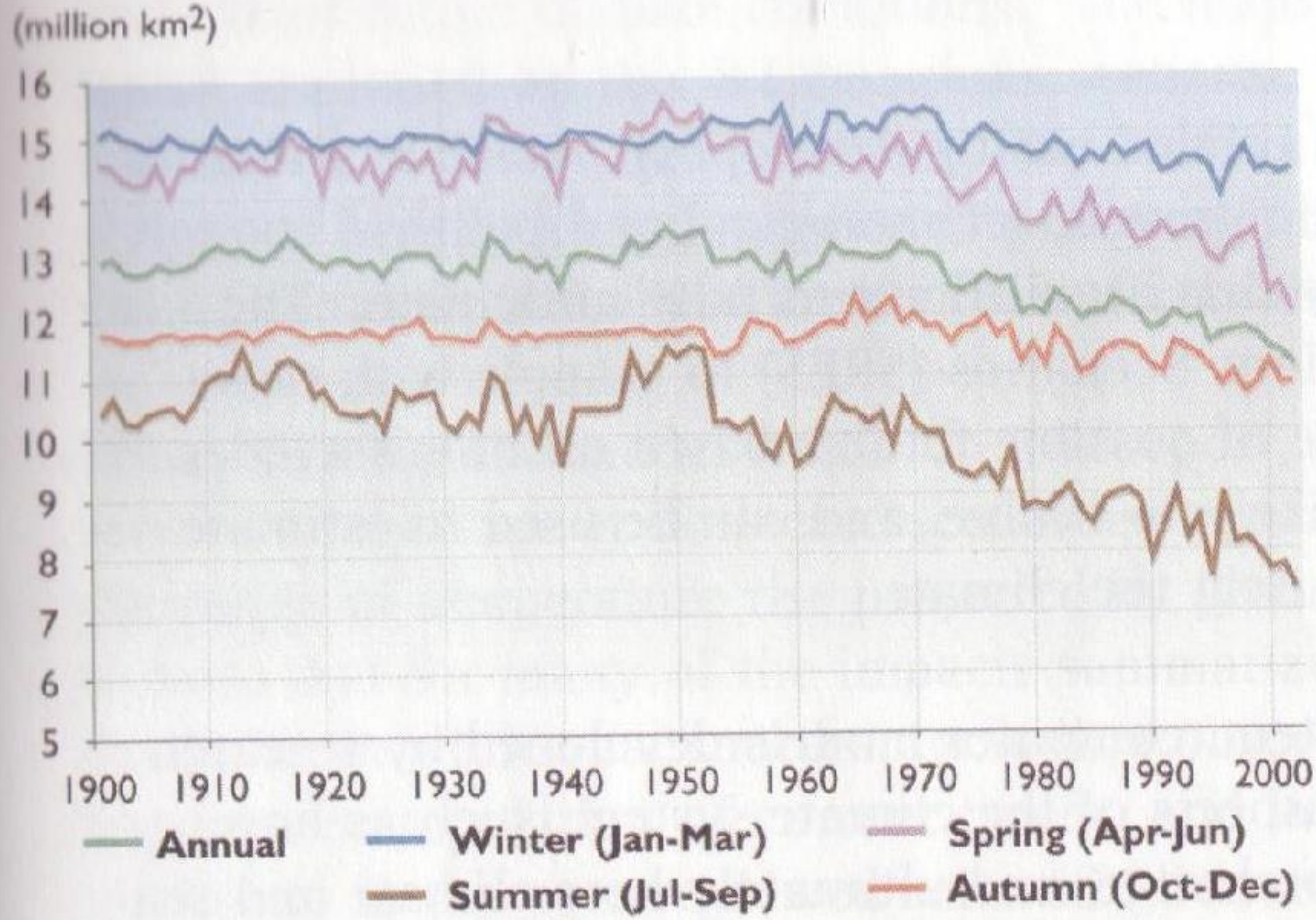
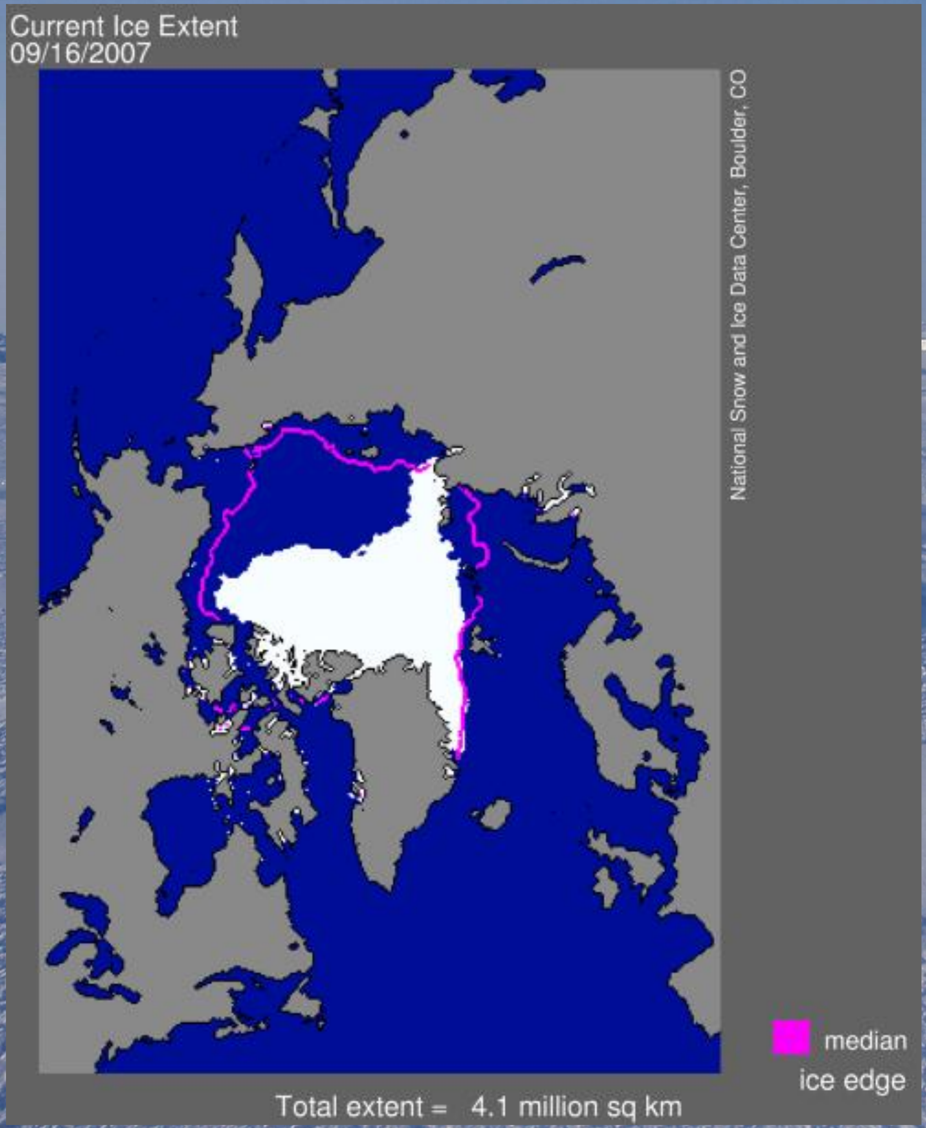
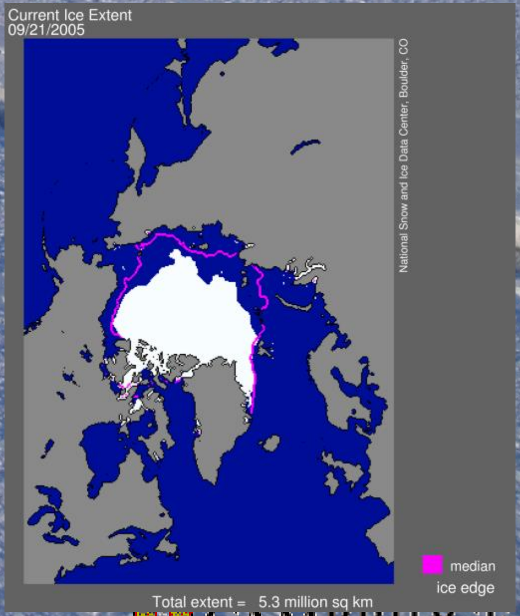
Observed seasonal Arctic sea-ice extent (1900–2003)



Record minimum ice extent in Sept. 2007





2005

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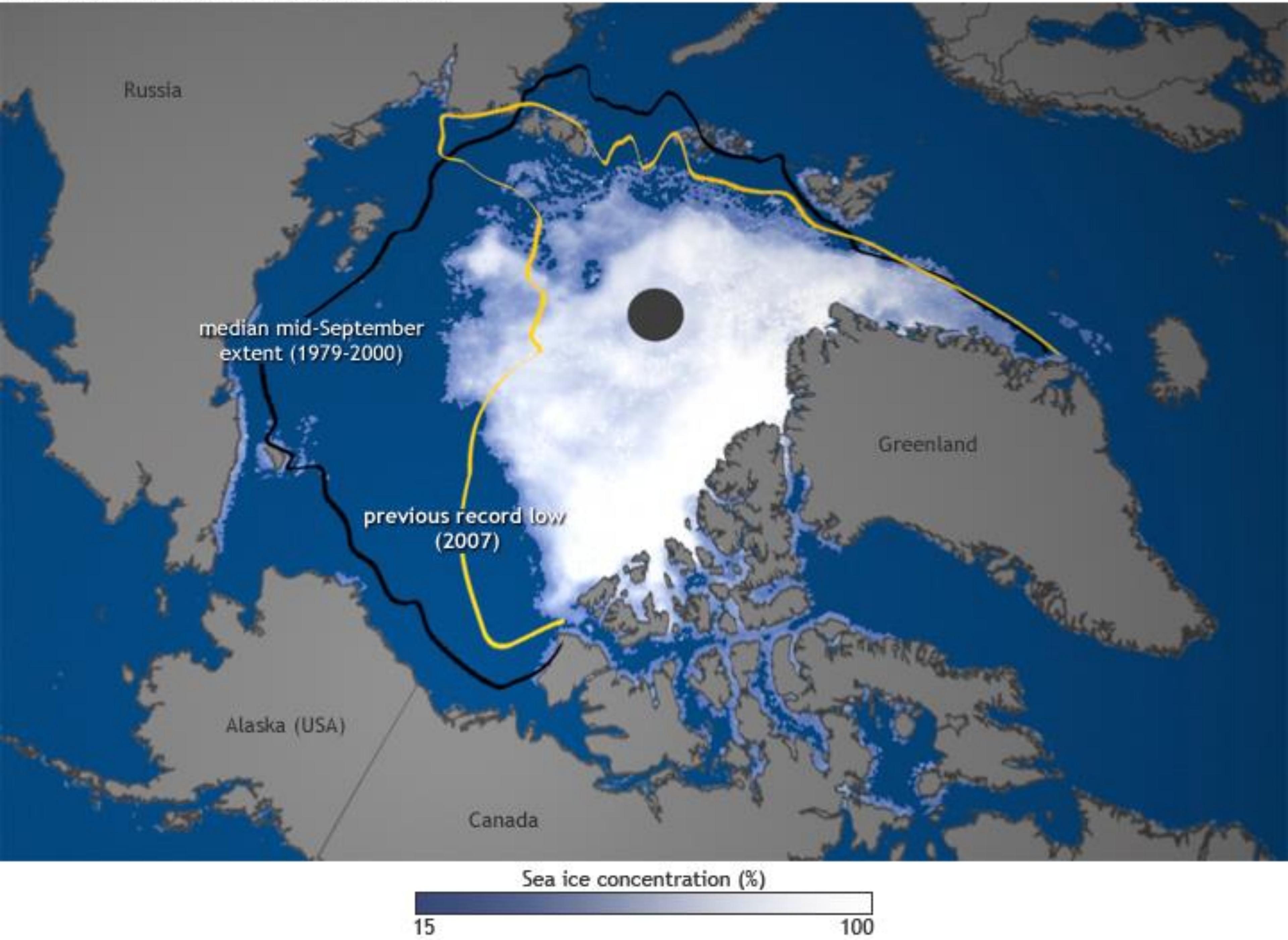
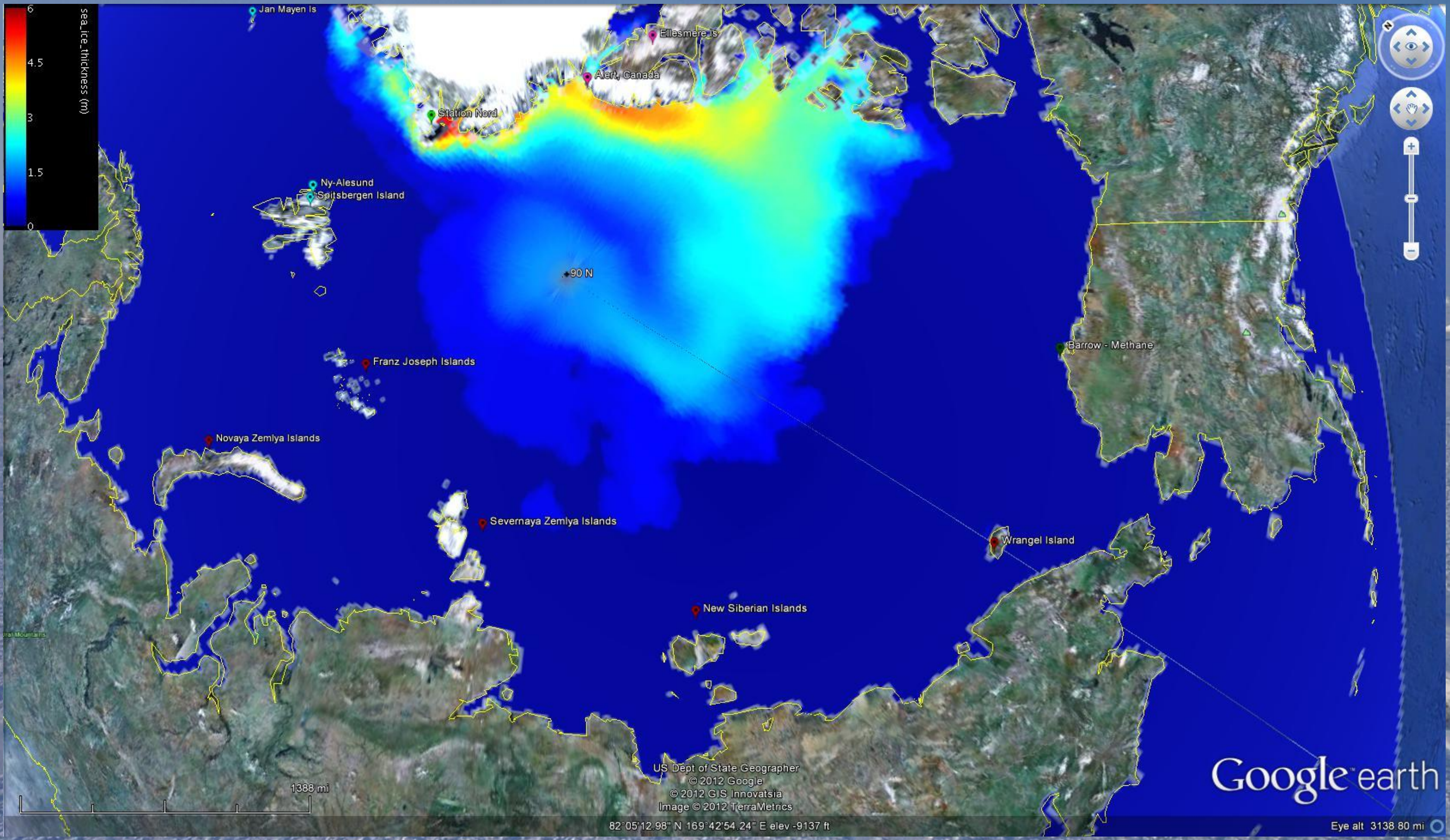
September 16, 2012 (summer minimum)





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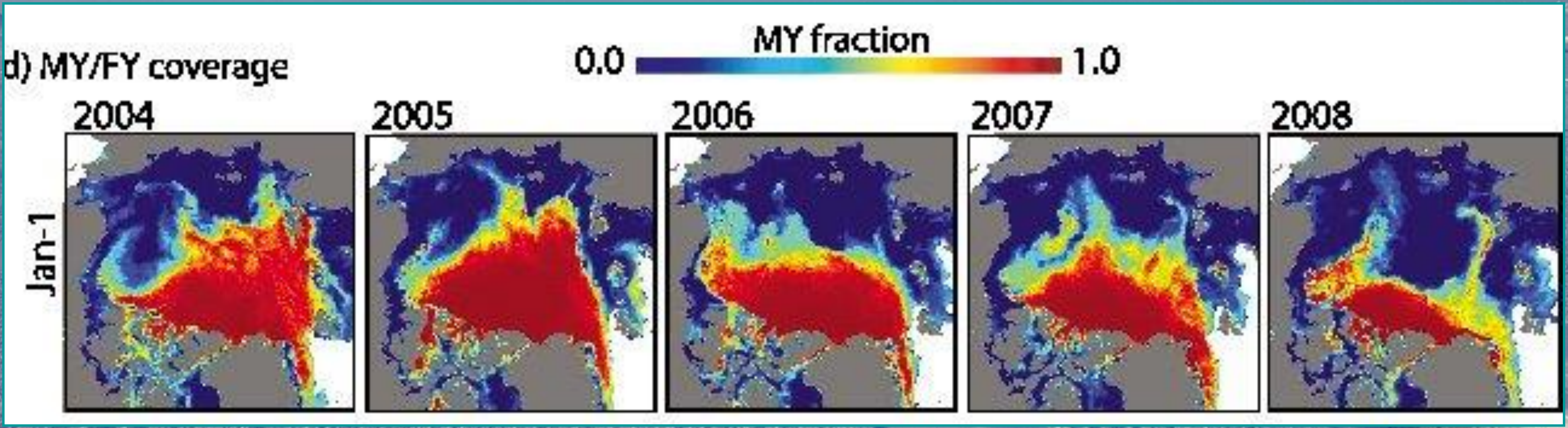
Reducing MY fraction (Kwok et al, 2009)

- Makes ice cover thinner, weaker, more dynamic



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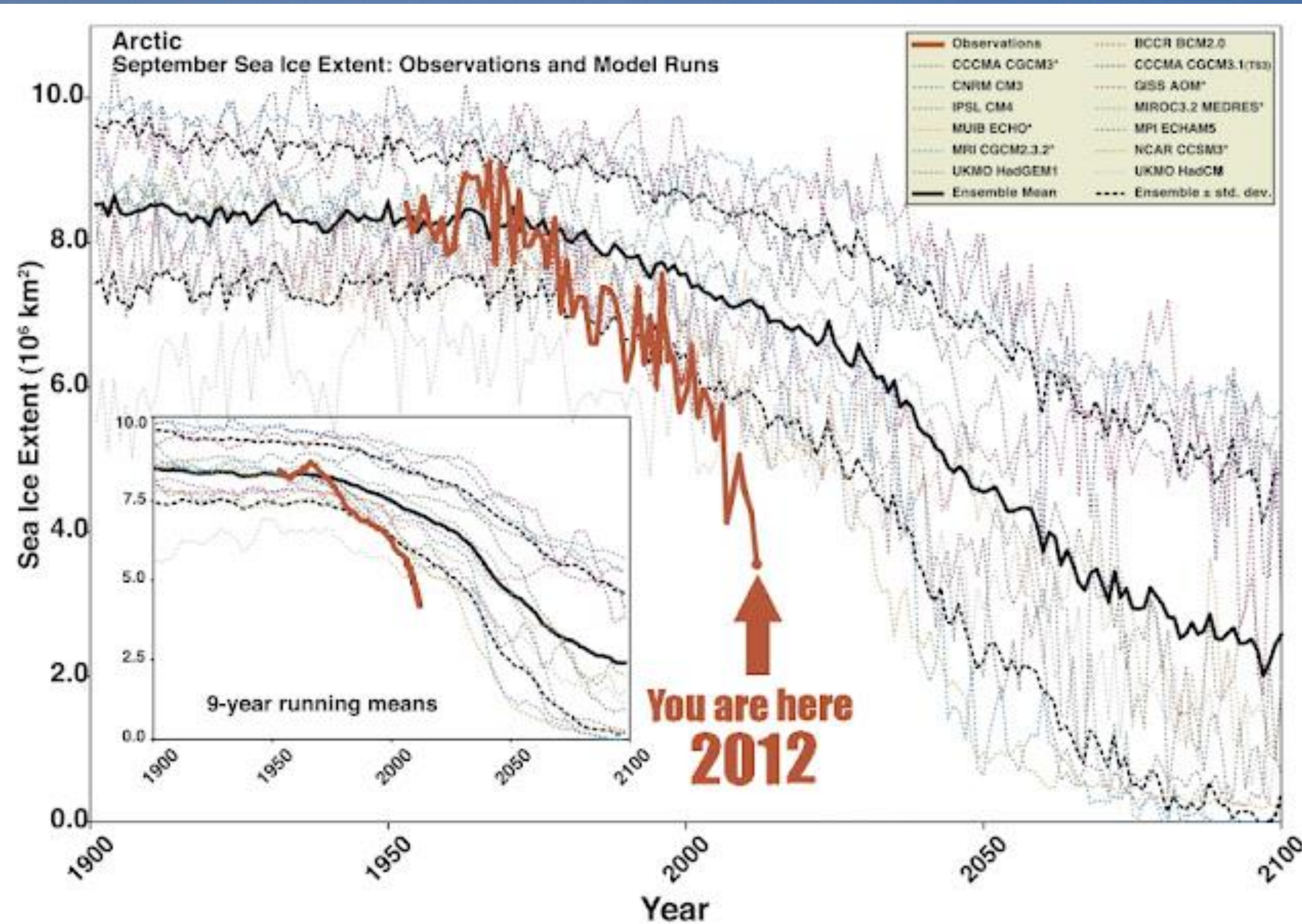

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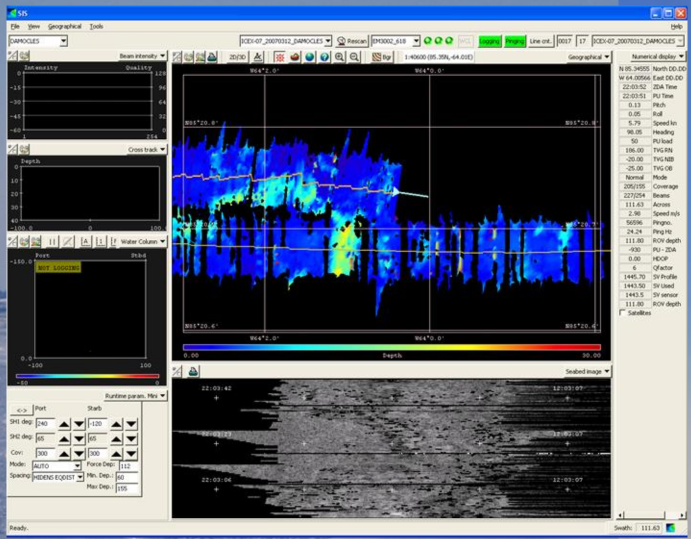
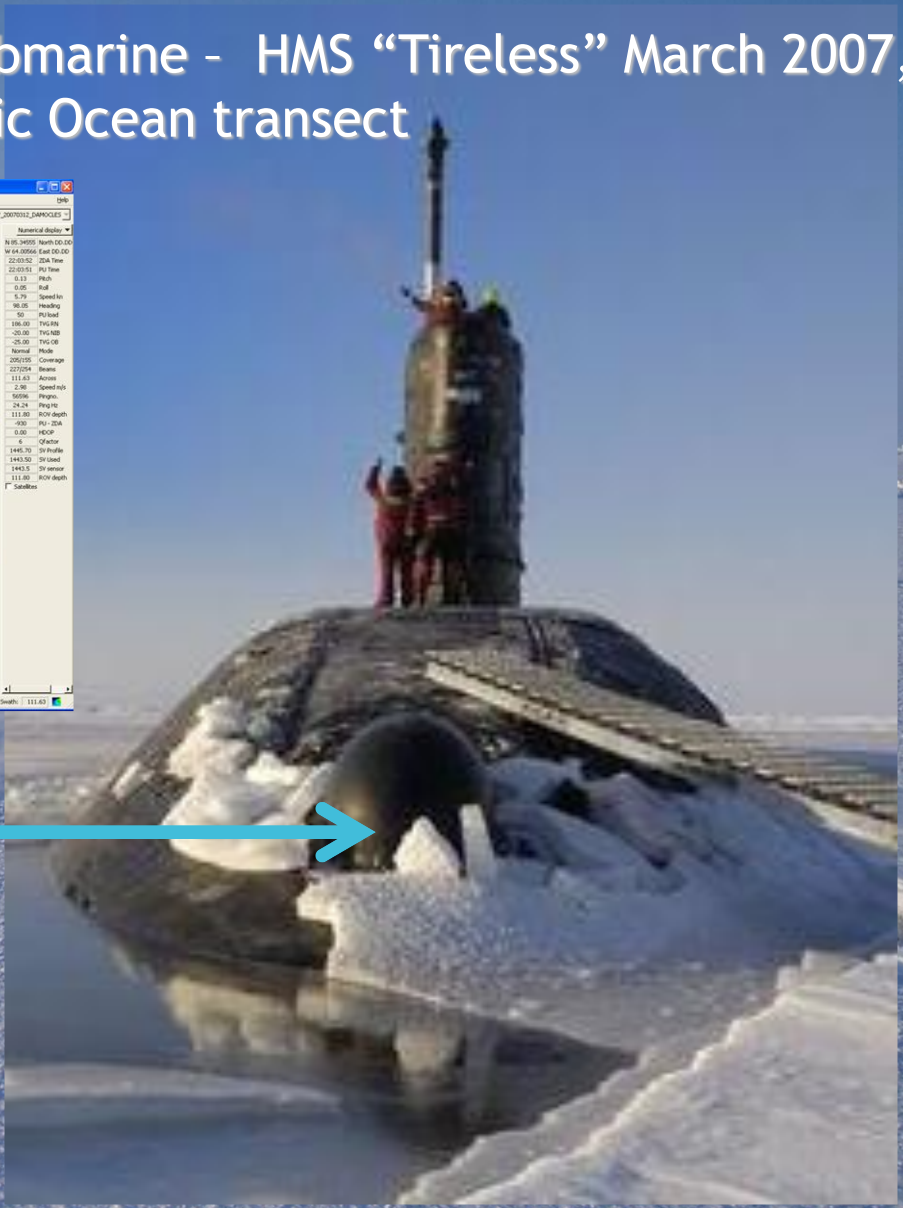
Fitting multibeam to a submarine – HMS "Tireless" March 2007, Arctic Ocean transect





EM3002 multibeam sonar in forward sonar dome

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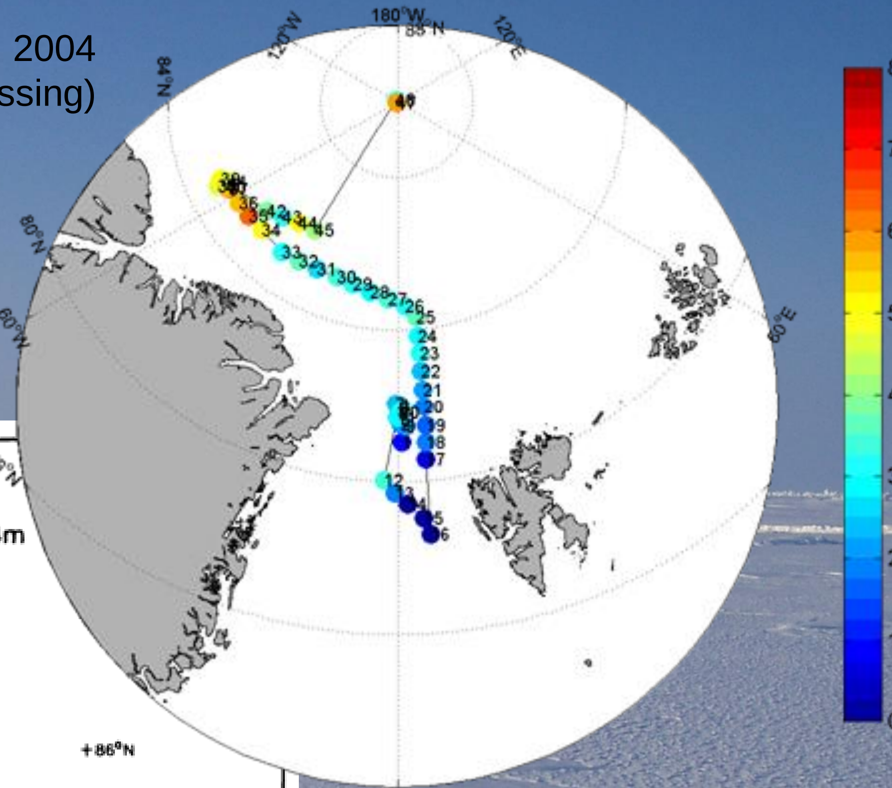
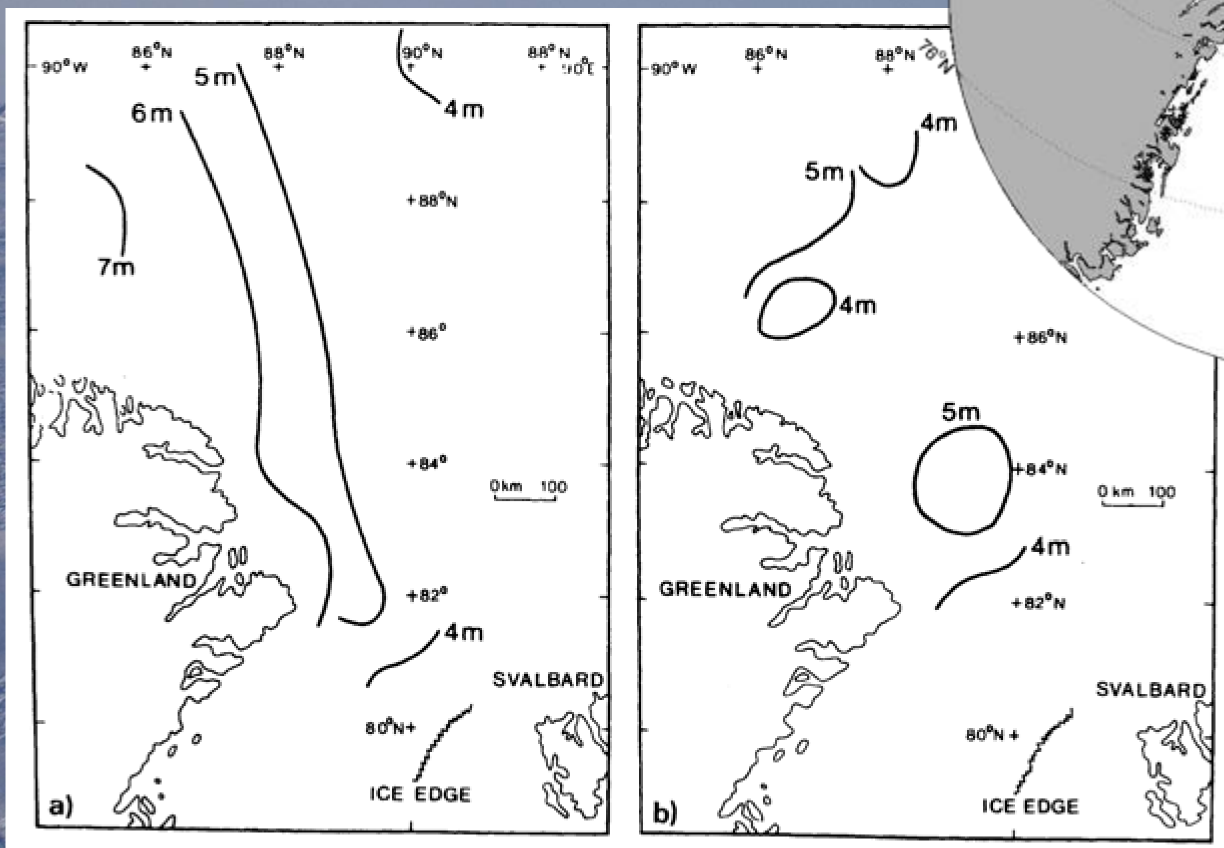
Mean drafts from April 2004
(Initial Processing)





Contour maps of mean ice drafts from Eurasian Basin, October 1976 and May 1987 (Wadhams, Nature, 1990)

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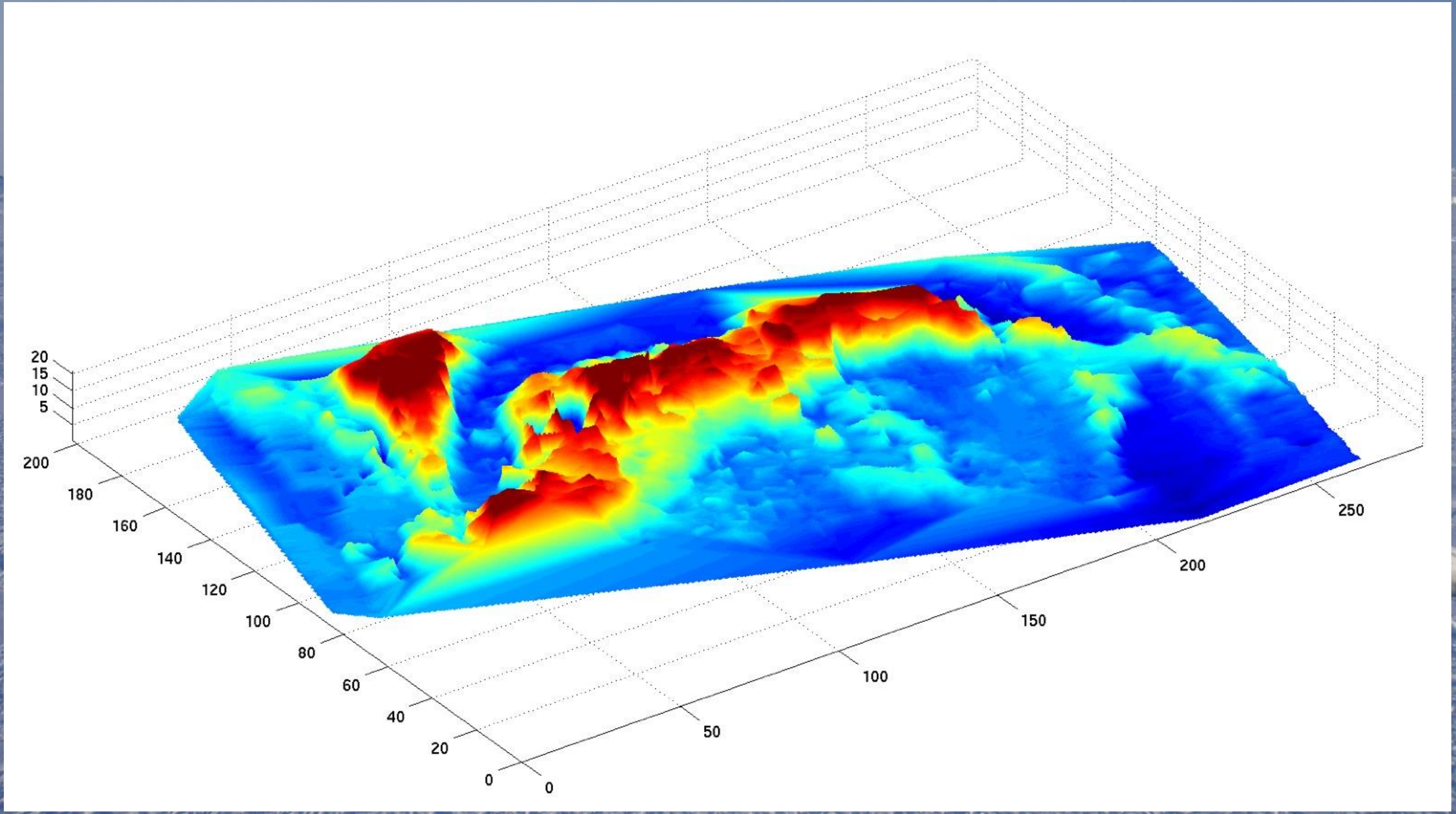
Example of multiyear ridge intersected by refrozen lead – note poorer resolution than AUV due to greater depth (120 m) and speed of vehicle. But longer range (2000 km of data).



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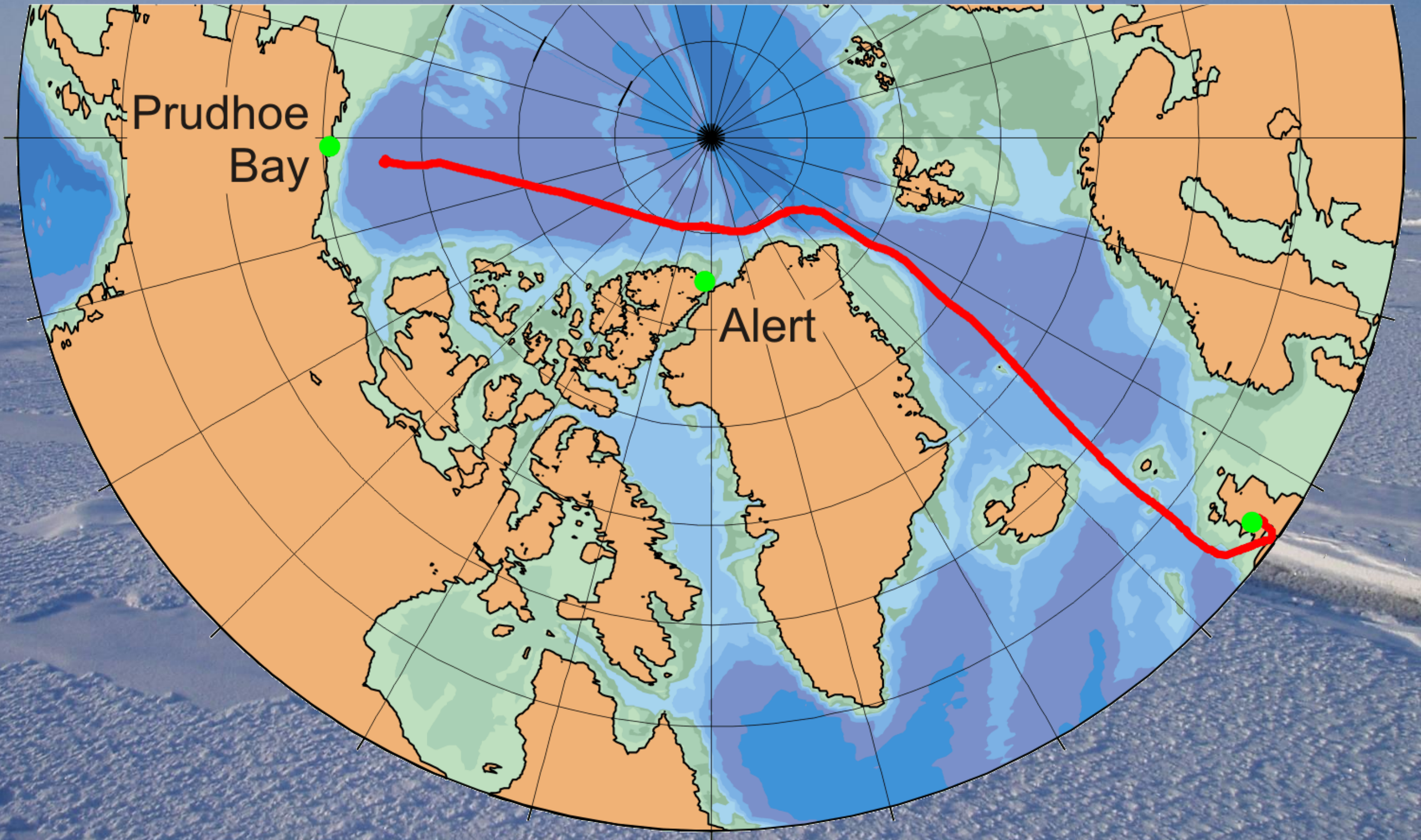
Submarine track



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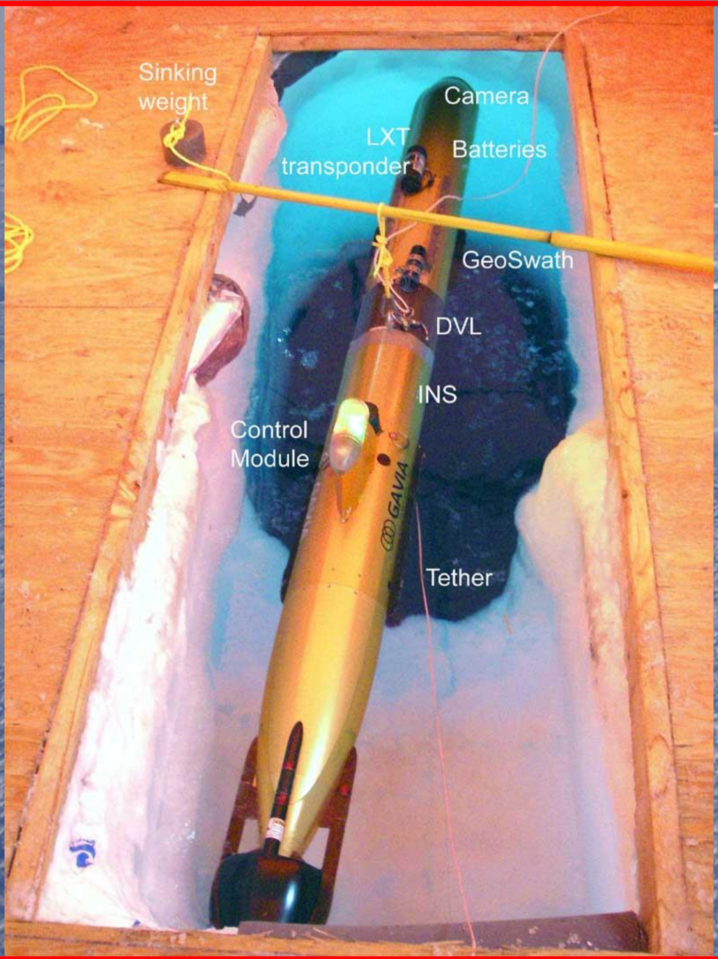
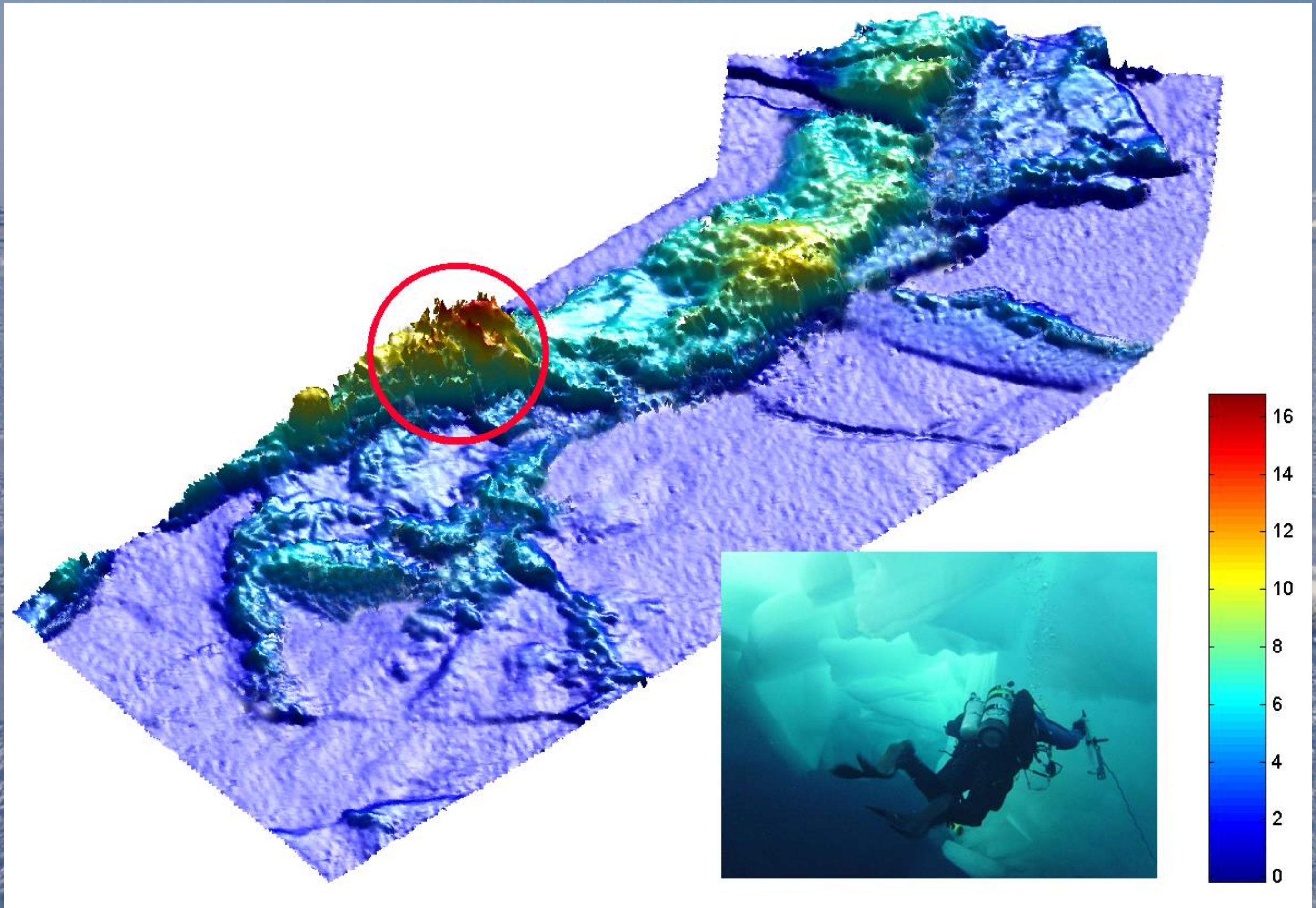
First use of a through-ice AUV – Gavia plus Geoswath sonar from APLIS 2007 ice camp in Beaufort Sea. Vehicle operated under first-year ridge (foreground) from black and red hut (background)

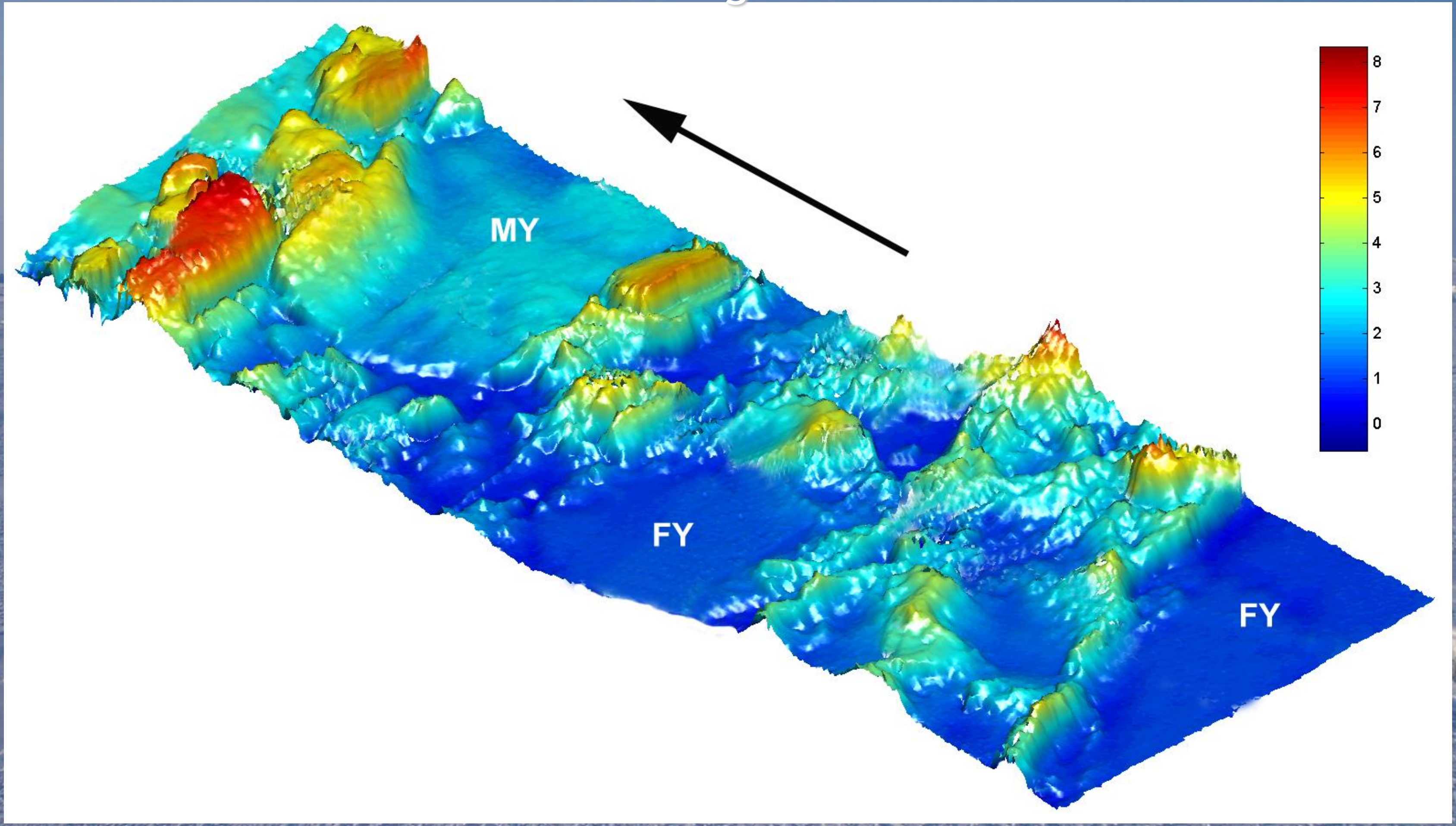



13154

High-resolution multibeam of the first-year ridge. Detail in red is genuine resolution of small broken ice blocks (see diver photo)



A nearby multiyear ridge (left back) showing very solid smoothed ice blocks intersected by leads. Isolated pinnacles in first year ice in foreground.



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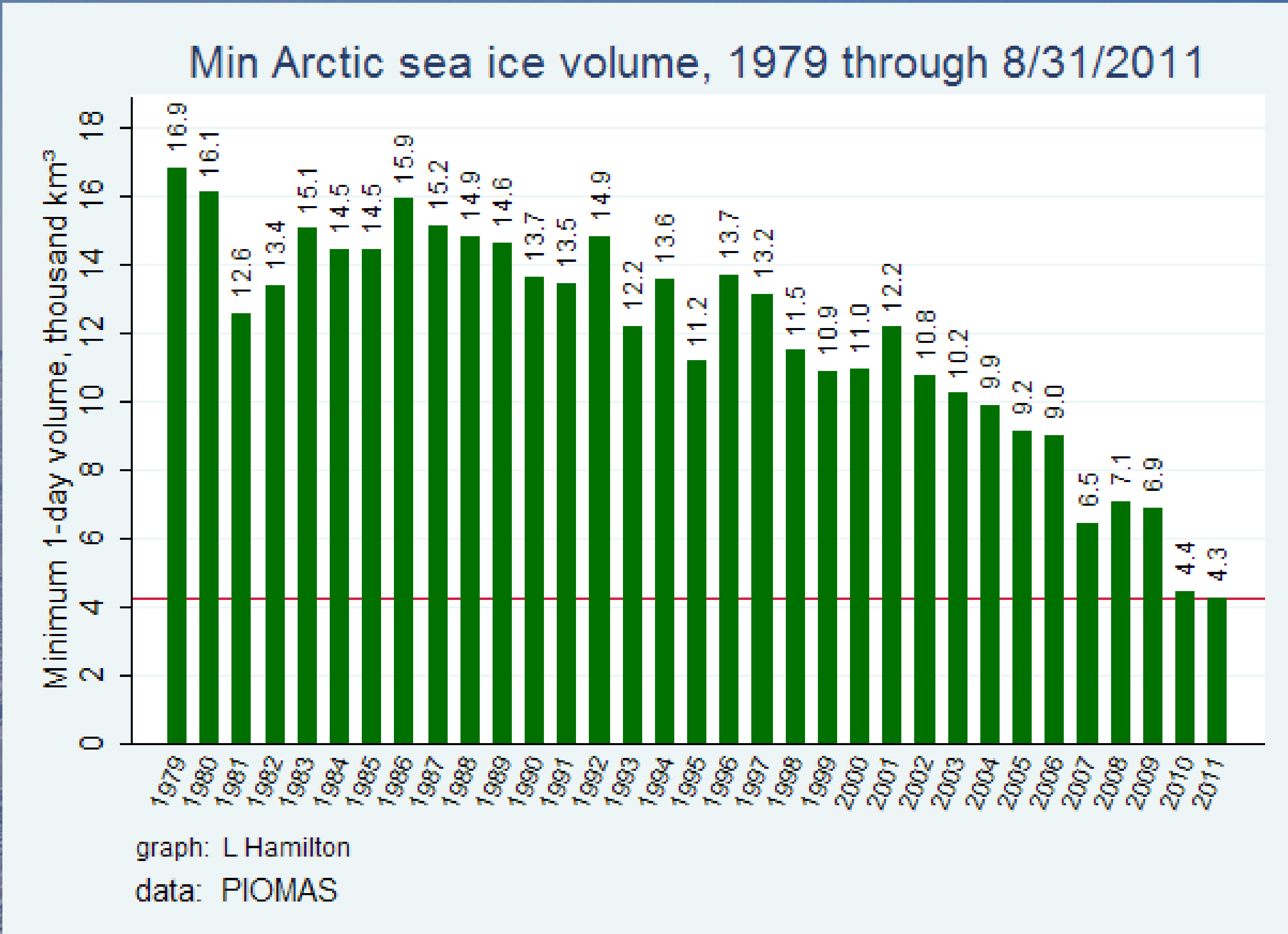

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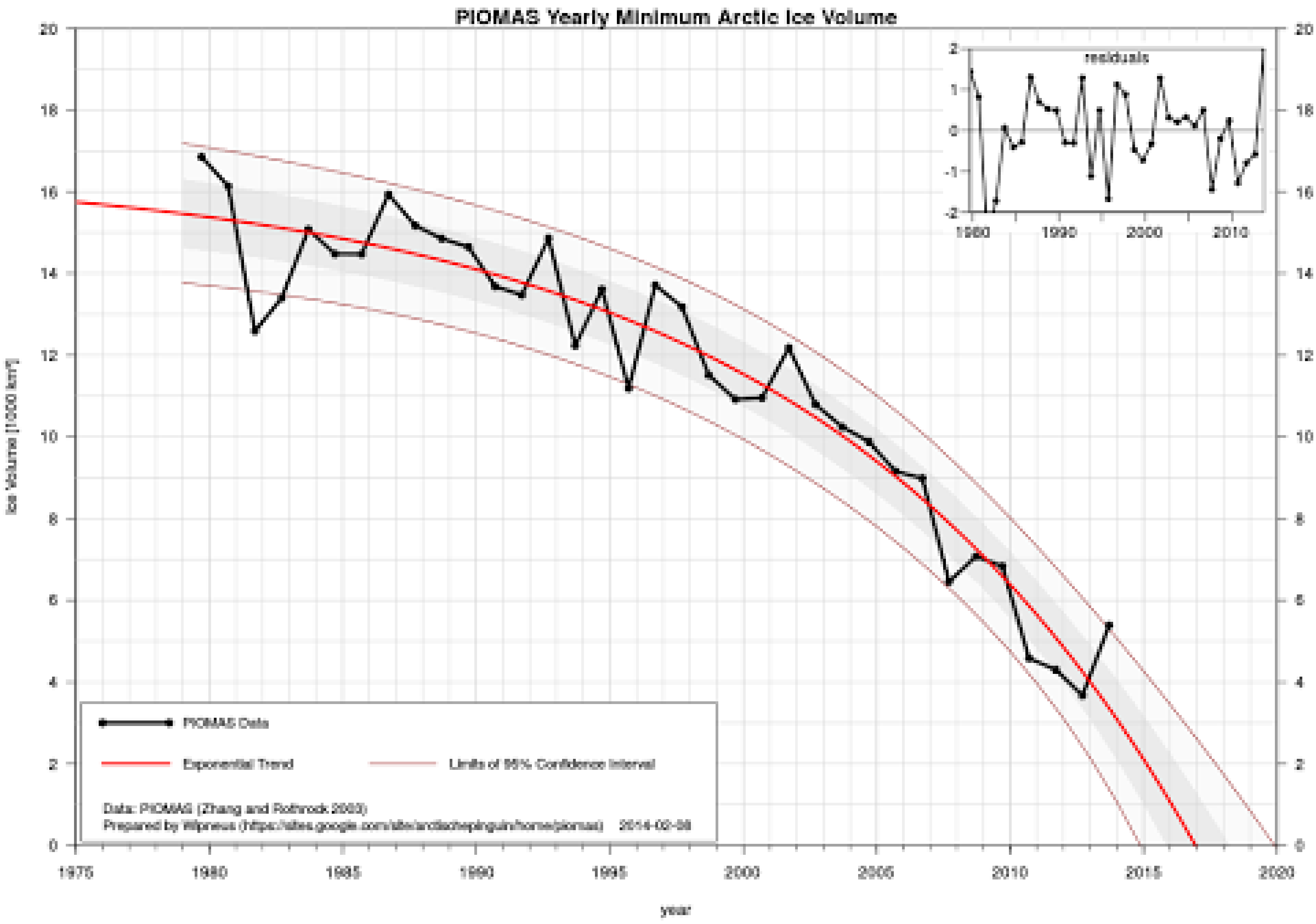
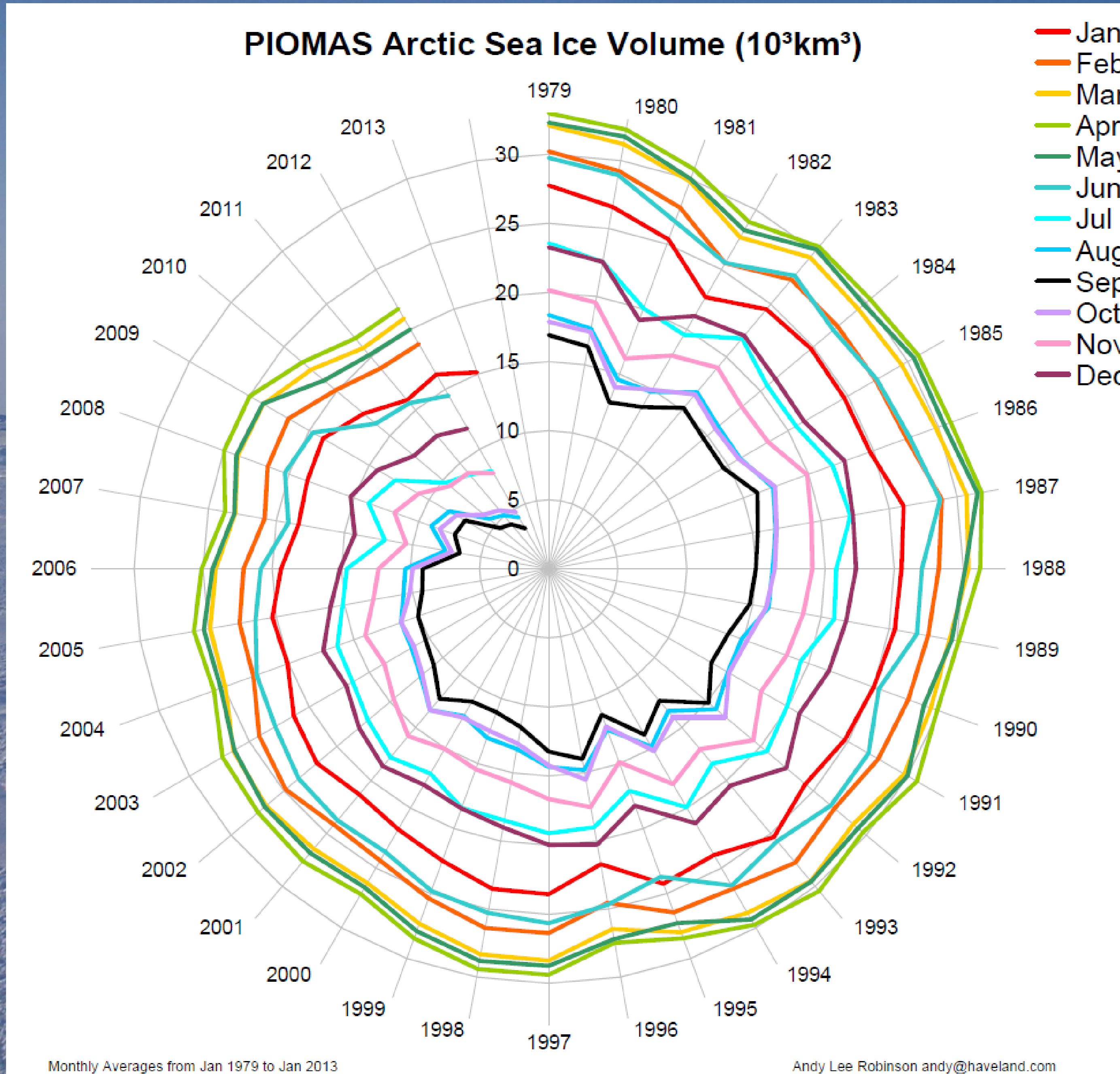
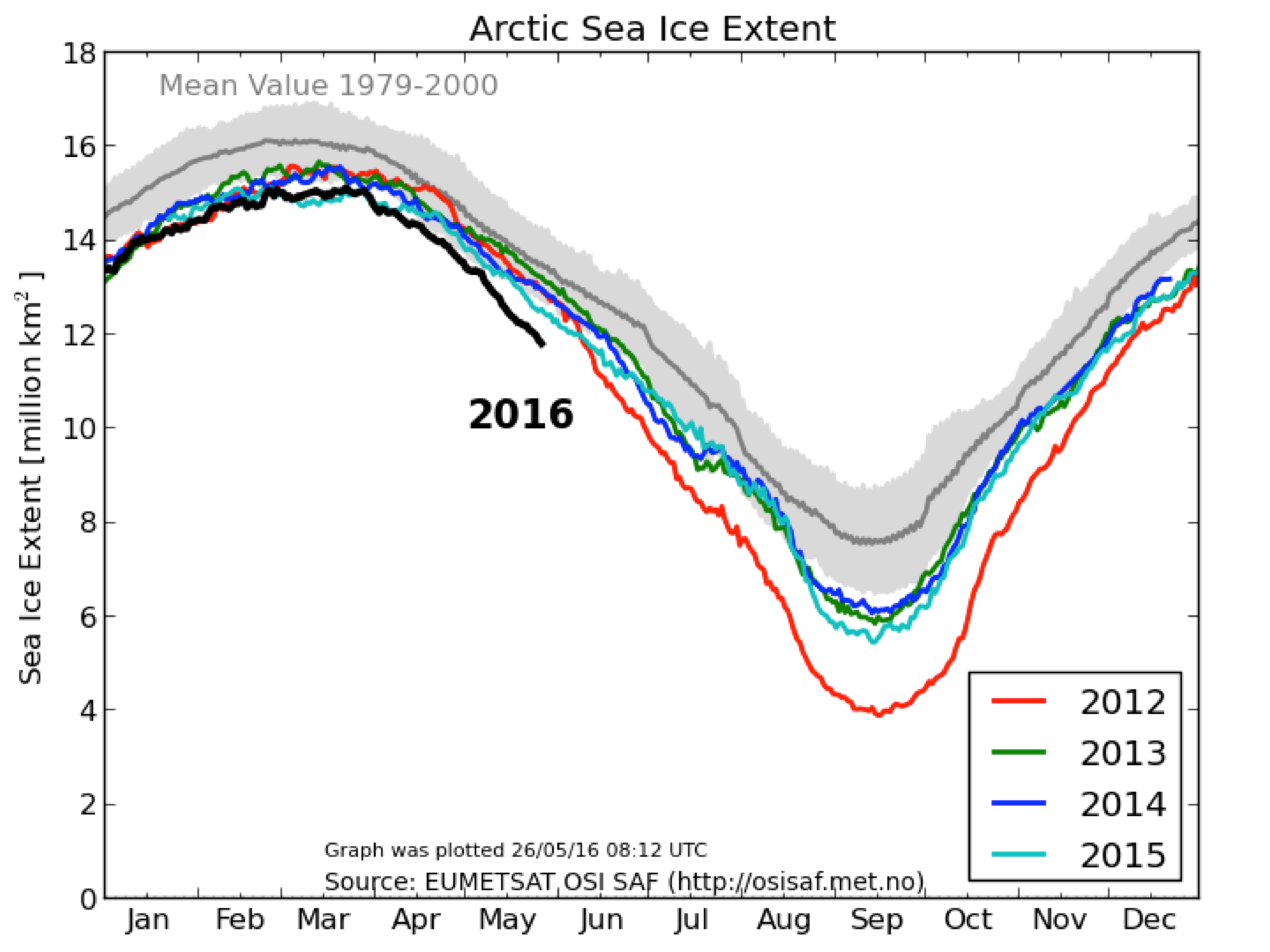

PIOMAS Yearly Minimum Arctic Ice Volume
residuals
year
PIOMAS Data
Exponential Trend
Limits of 95% Confidence Interval
Data: PIOMAS (Zhang and Rothrock 2003)
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020


PIOMAS Arctic Sea Ice Volume ($10^3 km^3$)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
0
5
10
15
20
25
30
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Monthly Averages from Jan 1979 to Jan 2013
Andy Lee Robinson andy@haveland.com


Arctic Sea Ice Extent
Mean Value 1979-2000
2016
Sea Ice Extent [million km2]
18
16
14
12
10
8
6
4
2
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2012
2013
2014
2015
Graph was plotted 26/05/16 08:12 UTC
Source: EUMETSAT OSI SAF (http://osisaf.met.no)

Impacts of Arctic warming

1. Acceleration of sea ice retreat due to thinning and composition changes, leading to albedo feedback.
2. Accelerated melt from Greenland ice sheet leading to enhanced rate of global sea level rise
3. Snowline retreat, also leading to enhanced albedo feedback
4. The threat from offshore Arctic methane
5. Extreme weather affecting food production
6. Decline in strength of the Atlantic thermohaline circulation

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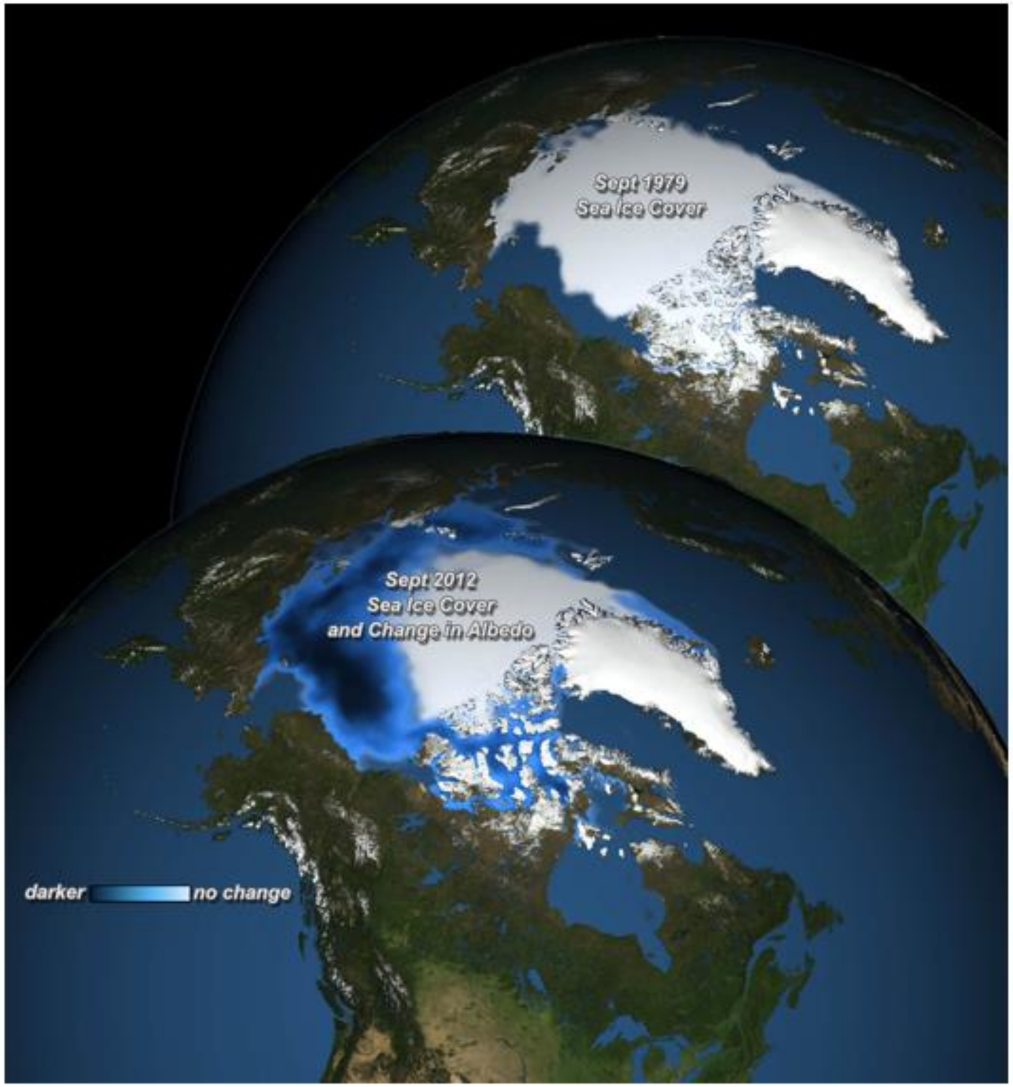
Arctic Region Ice Albedo Change, 1979-2011

52% to 48%, 6.4 W/m2 since 1979

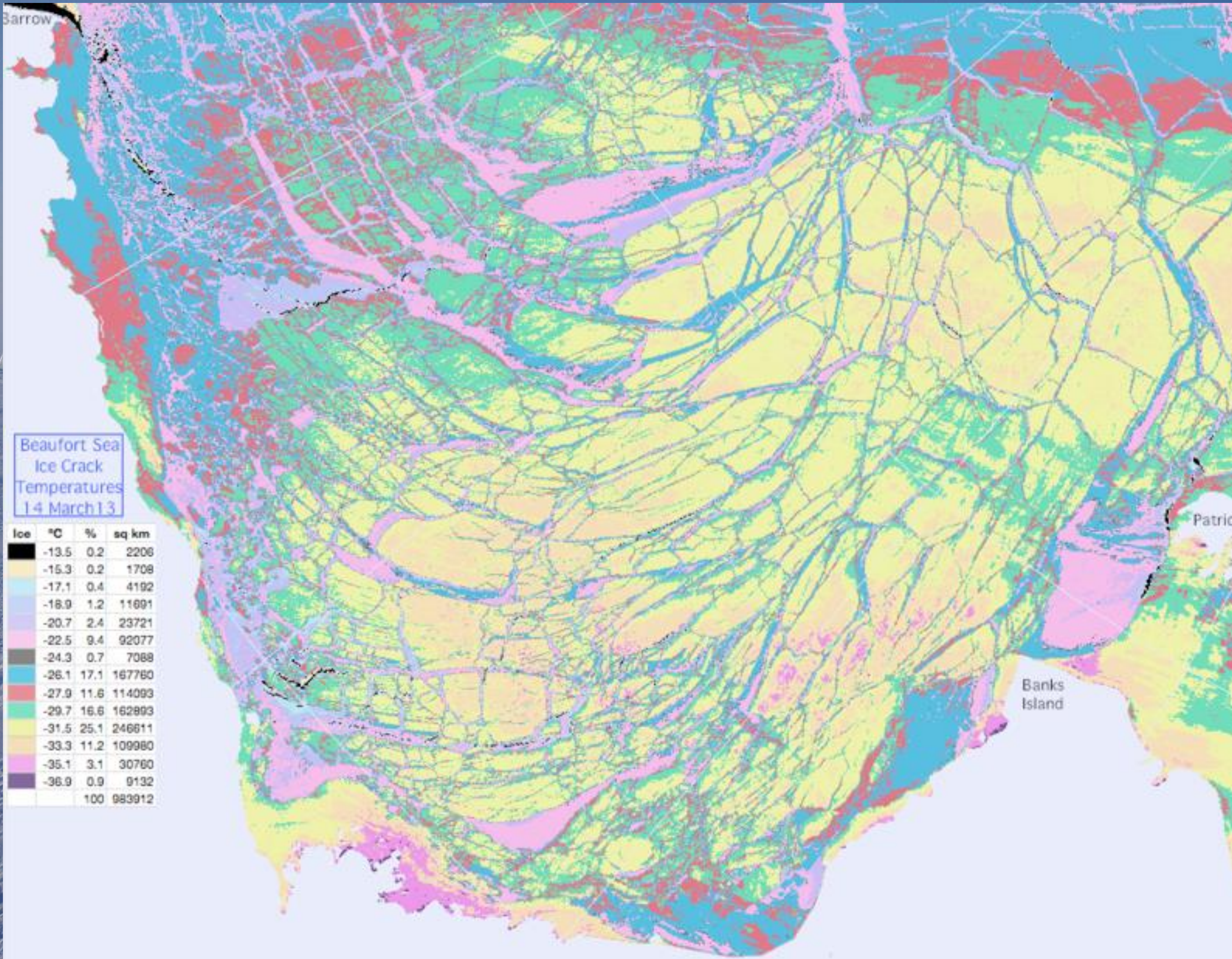
Averaged over globe, ¼ Greenhouse gas forcing over past 30 years



K. Pistone, I. Eisenman, and V. Ramanathan, PNAS, Feb. 18, 2014

A consequence for science

- The Arctic is no longer a safe place to have an ice camp



Barrow
Beaufort Sea Ice Crack Temperatures 14 March13
Ice °C % sq km
-13.5 0.2 2206
-15.3 0.2 1708
-17.1 0.4 4192
-18.9 1.2 11691
-20.7 2.4 23721
-22.5 9.4 92077
-24.3 0.7 7088
-26.1 17.1 167760
-27.9 11.6 114093
-29.7 16.6 162893
-31.5 25.1 246611
-33.3 11.2 109980
-35.1 3.1 30760
-36.9 0.9 9132
100 983912
Patrick
Banks Island

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Oil exploration will be easier

Snowline retreat and enhanced albedo feedback

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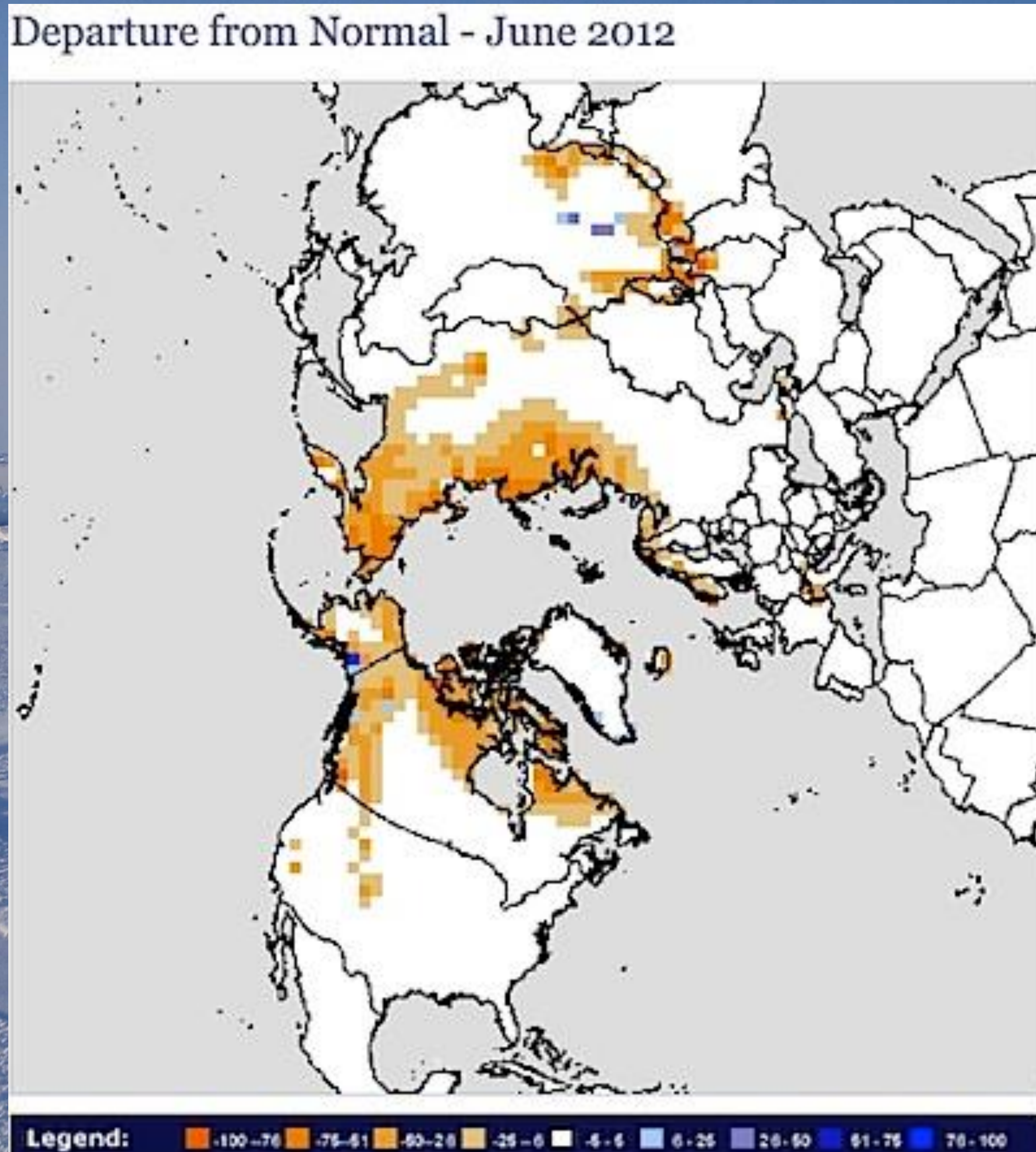

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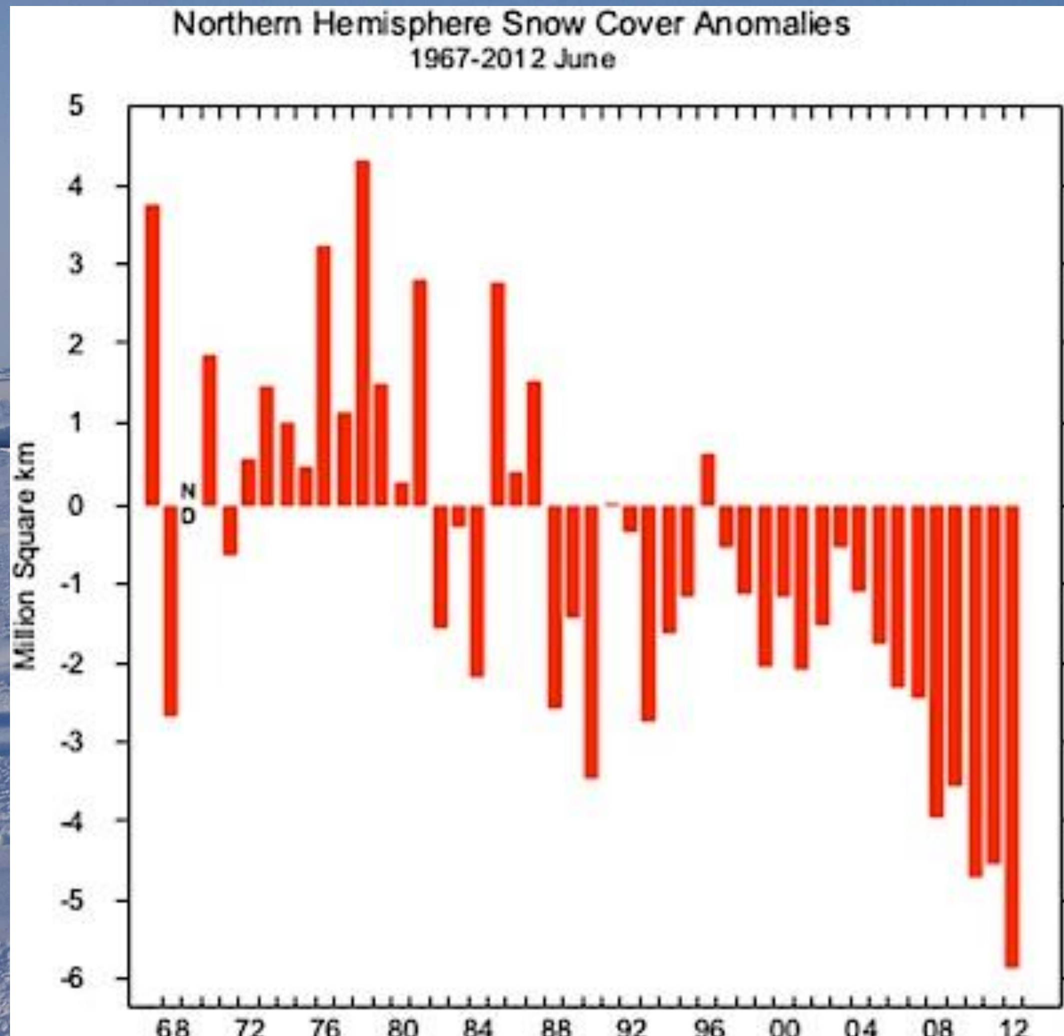

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Accelerated melt of Greenland ice sheet

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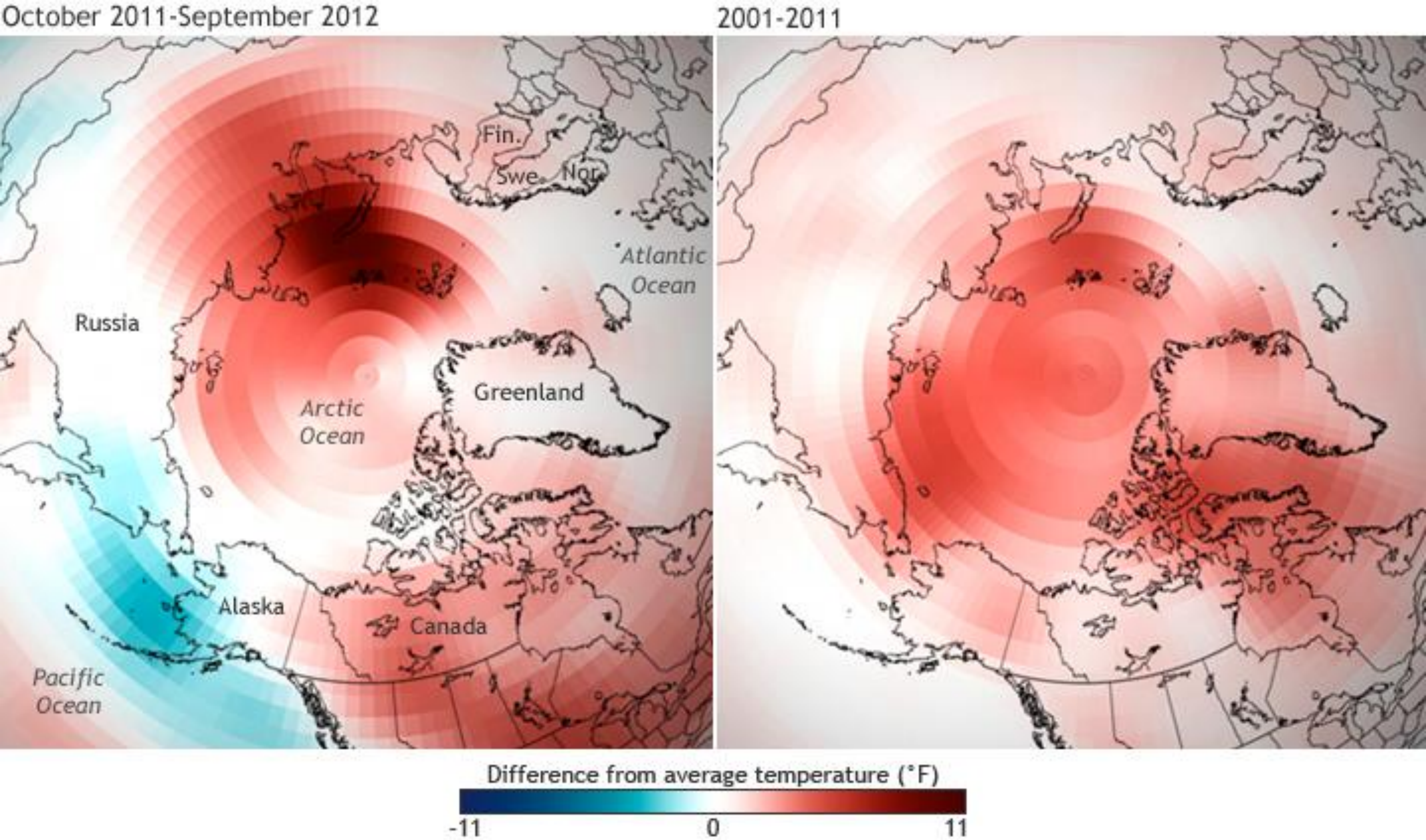
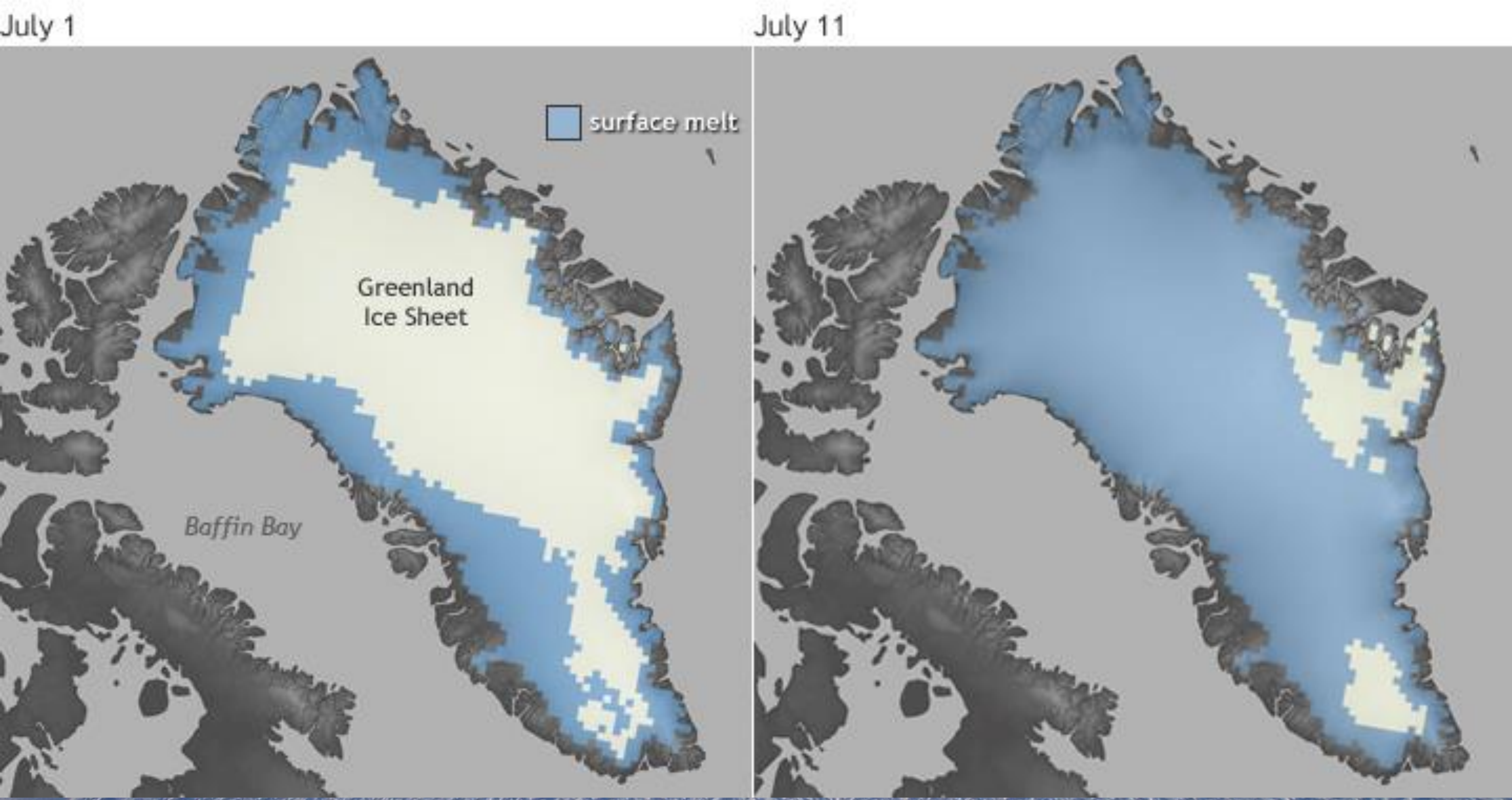

October 2011-September 2012
2001-2011
Fin.
Swe.
Nor.
Atlantic Ocean
Russia
Greenland
Arctic Ocean
Alaska
Canada
Pacific Ocean
Difference from average temperature (°F)
-11
0
11

2012 Greenland surface melt



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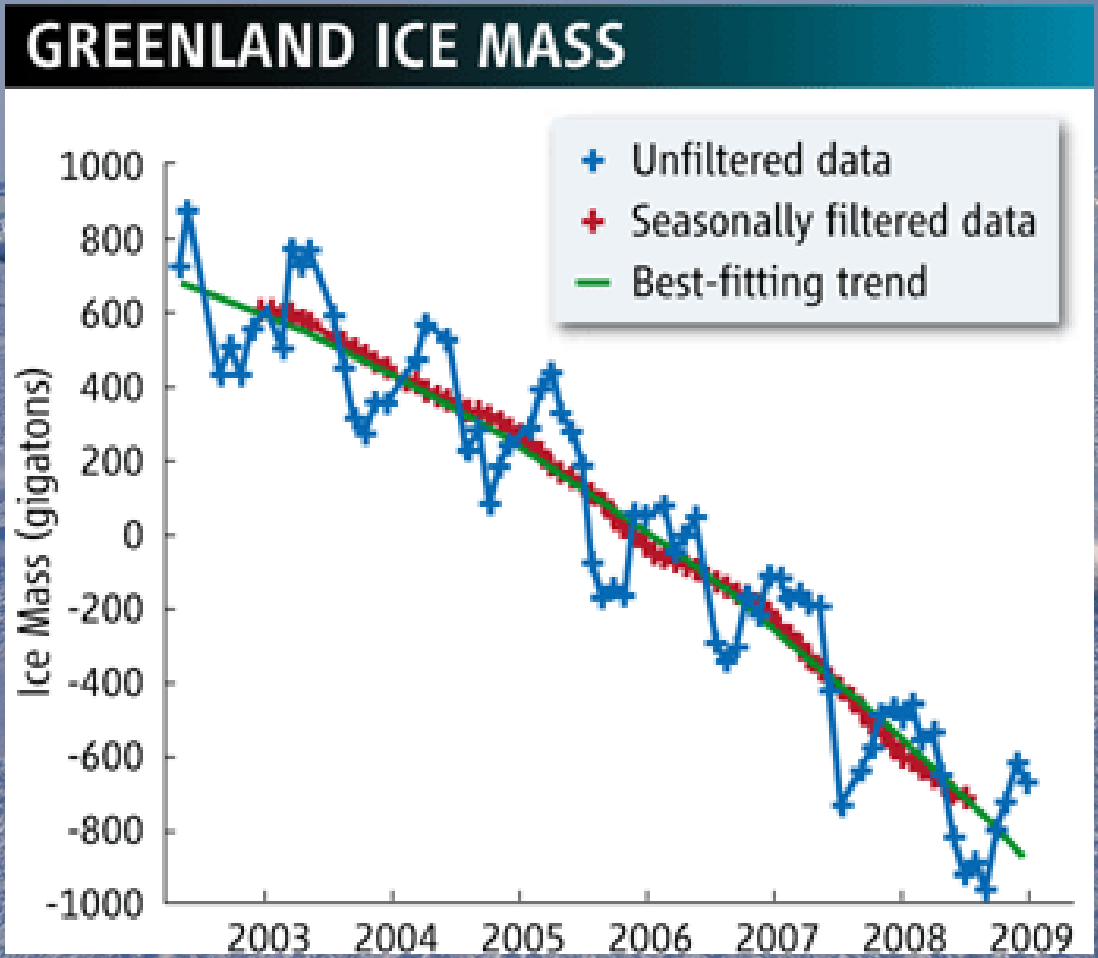
Accelerating melt from Greenland ice sheet
(Isabella Velicogna, GRL 2009, from GRACE data)
(present rate about 300 cu km/yr)



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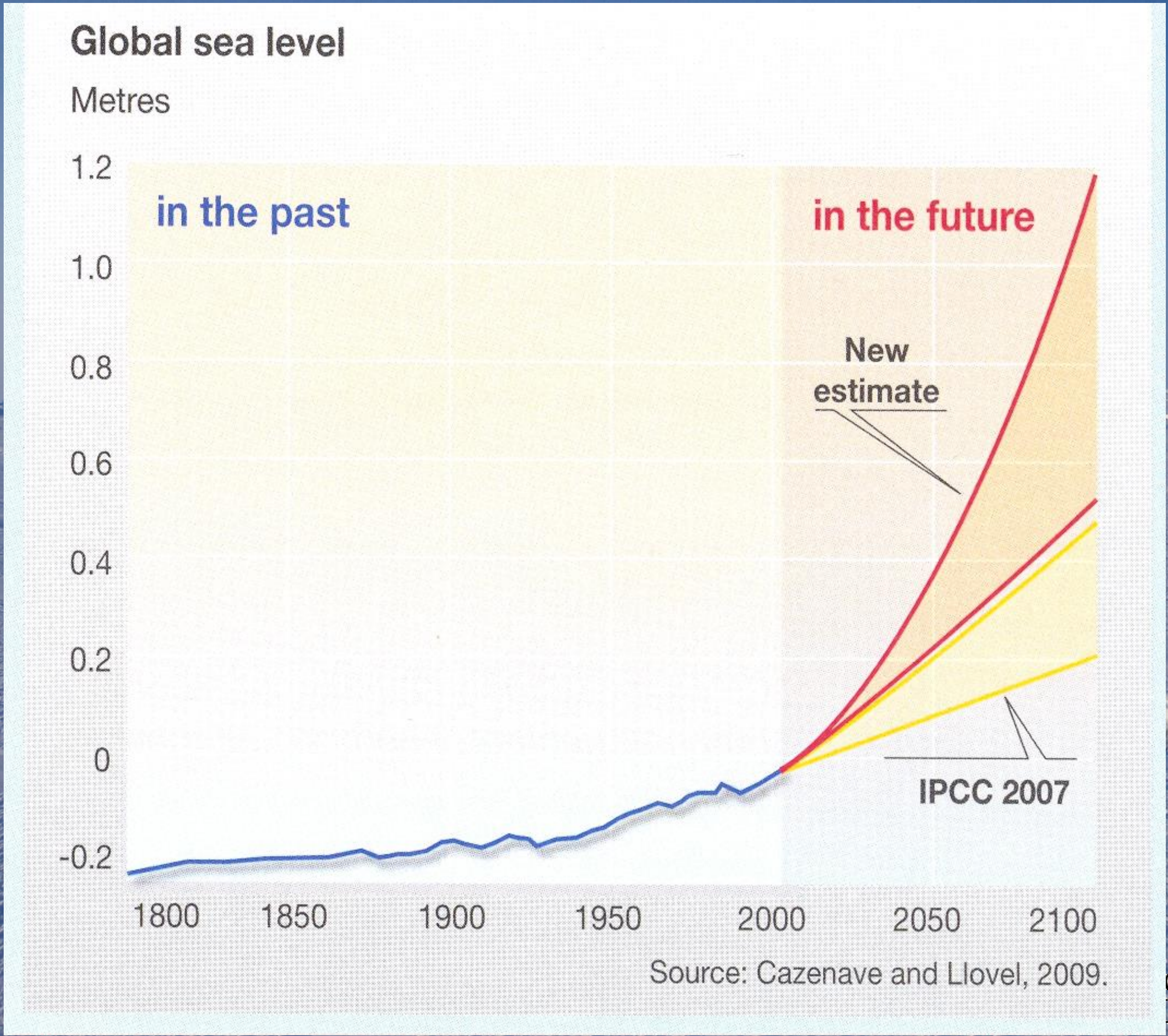
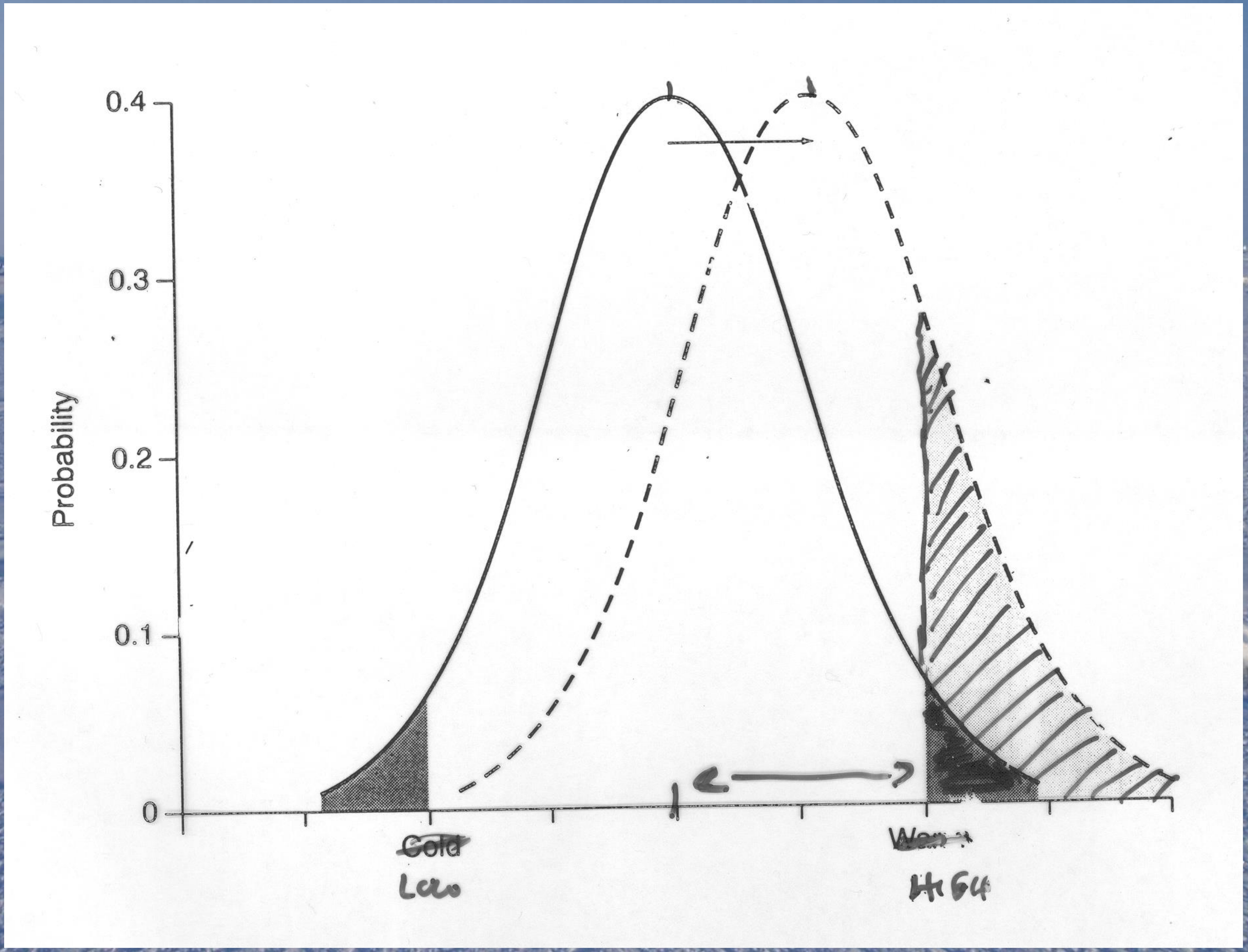

Global sea level
Metres
1.2
1.0
0.8
0.6
0.4
0.2
0
-0.2
in the past
in the future
New estimate
IPCC 2007
1800
1850
1900
1950
2000
2050
2100
Source: Cazenave and Llovel, 2009.

Sea level rise: the threat of the normal distribution.

Disproportionate effect of a change in mean sea level on the probability of a flooding event.



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The threat from offshore Arctic methane

- Over shallow continental shelves (water depth 50-100 m) in summer the warming of ice-free water extends to the bottom.
- The warmer water melts seabed permafrost, releasing methane trapped as methane hydrates in the frozen sediment.
- This has been seen bubbling up to the surface in large (1 km diameter) plumes, in areas close to shore north of Siberia
- The people who work on this phenomenon estimate that 50 Gt (50 billion tons) of methane could be released in 10 years.
- We calculated the cost of the extra warming to the planet. Using the Stern Review model we got **50 trillion dollars** over a century.

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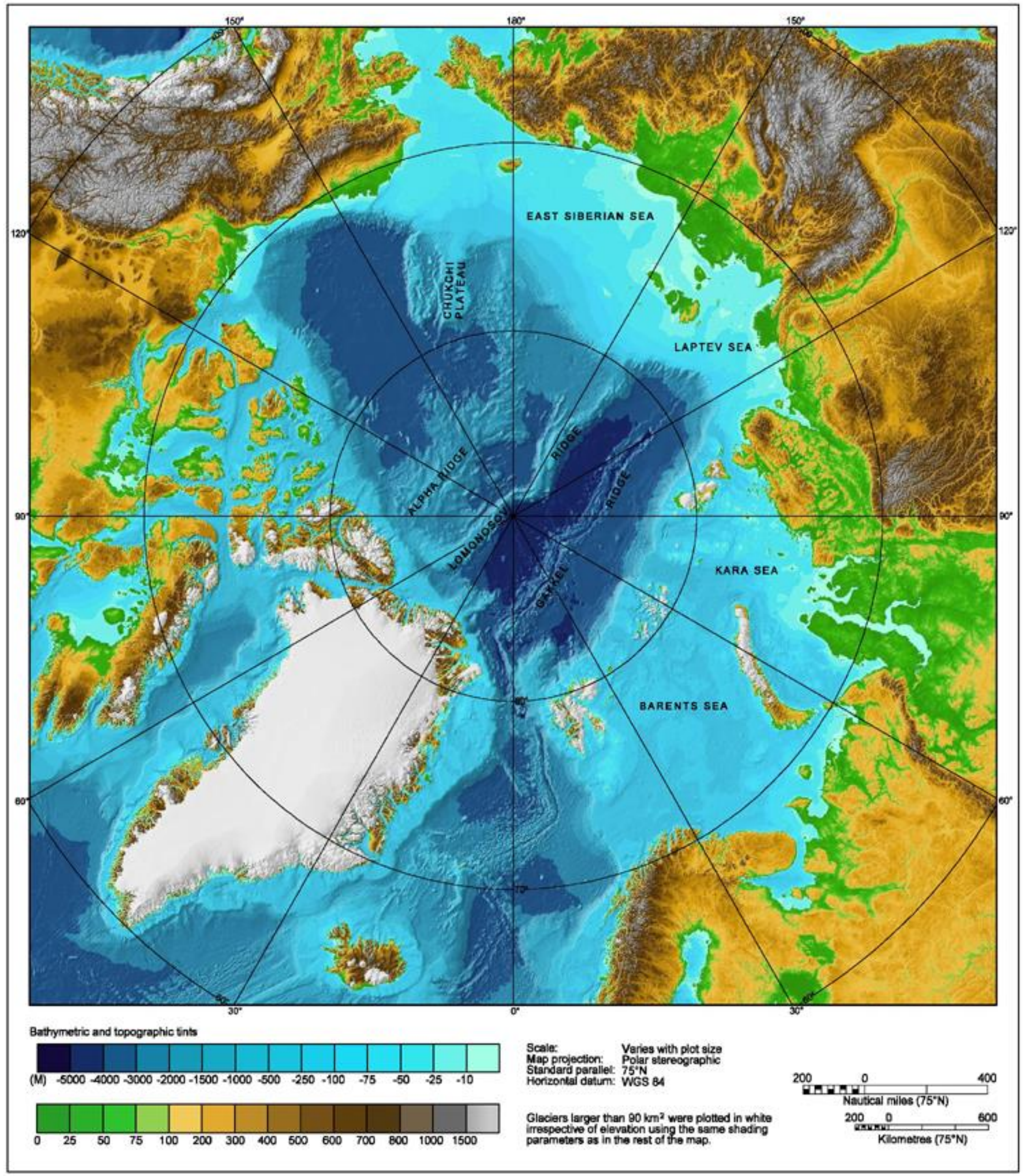
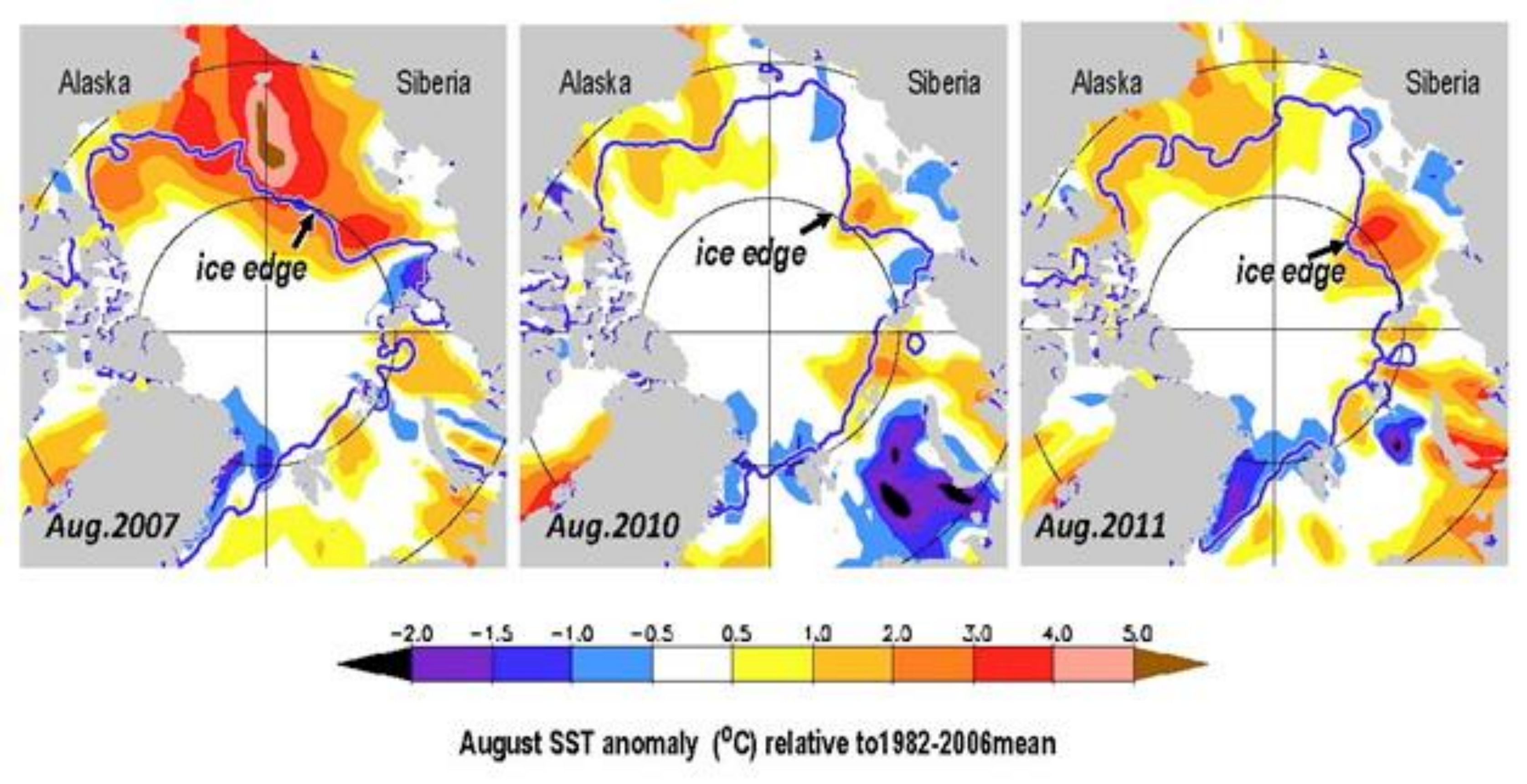
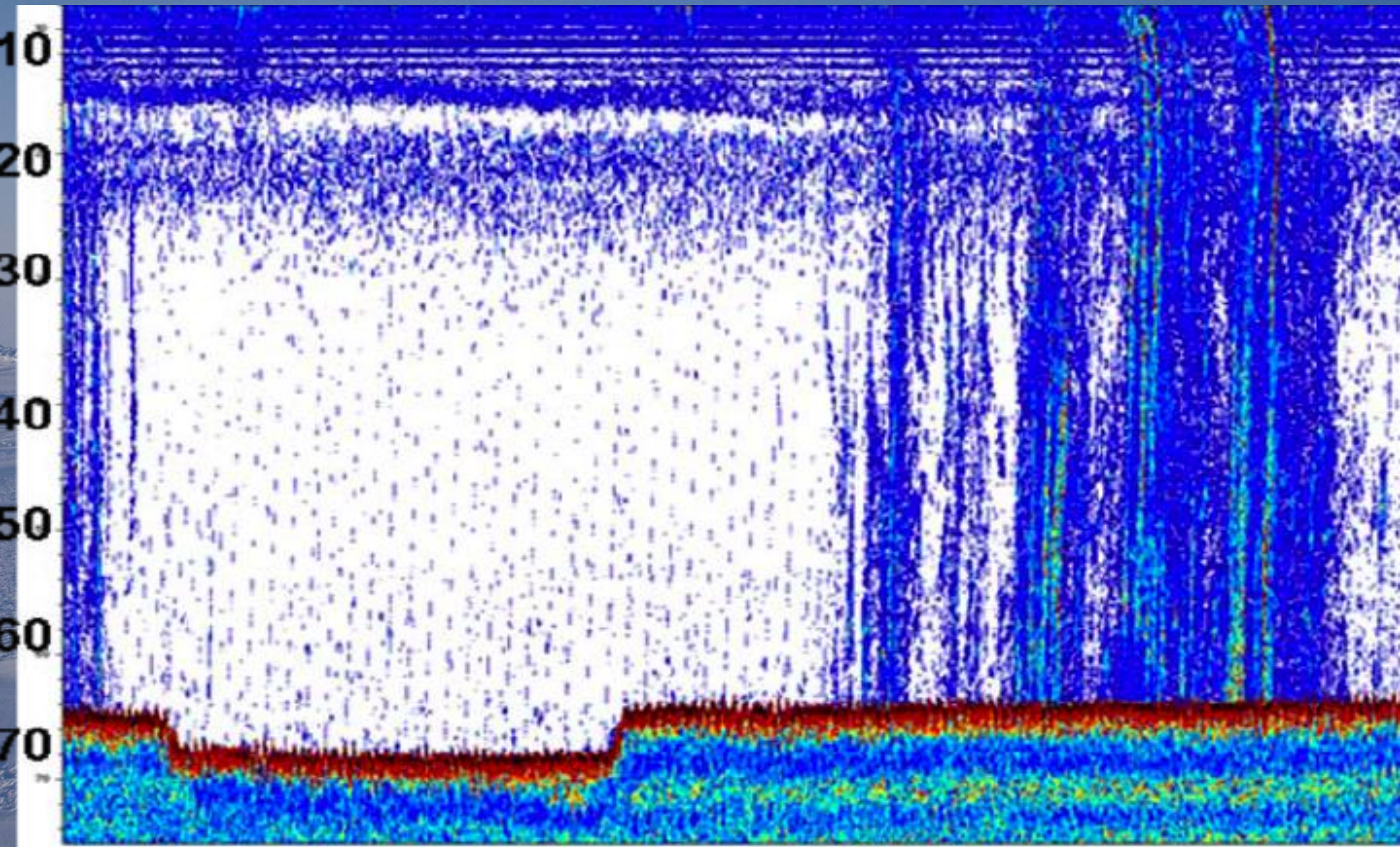


SSG Copenhage



Alaska
Siberia
ice edge
Aug.2007
Alaska
Siberia
ice edge
Aug.2010
Alaska
Siberia
ice edge
Aug.2011
-2.0
-1.5
-1.0
-0.5
0.5
1.0
2.0
3.0
4.0
5.0
August SST anomaly (°C) relative to1982-2006mean


10
20
30
40
50
60
70

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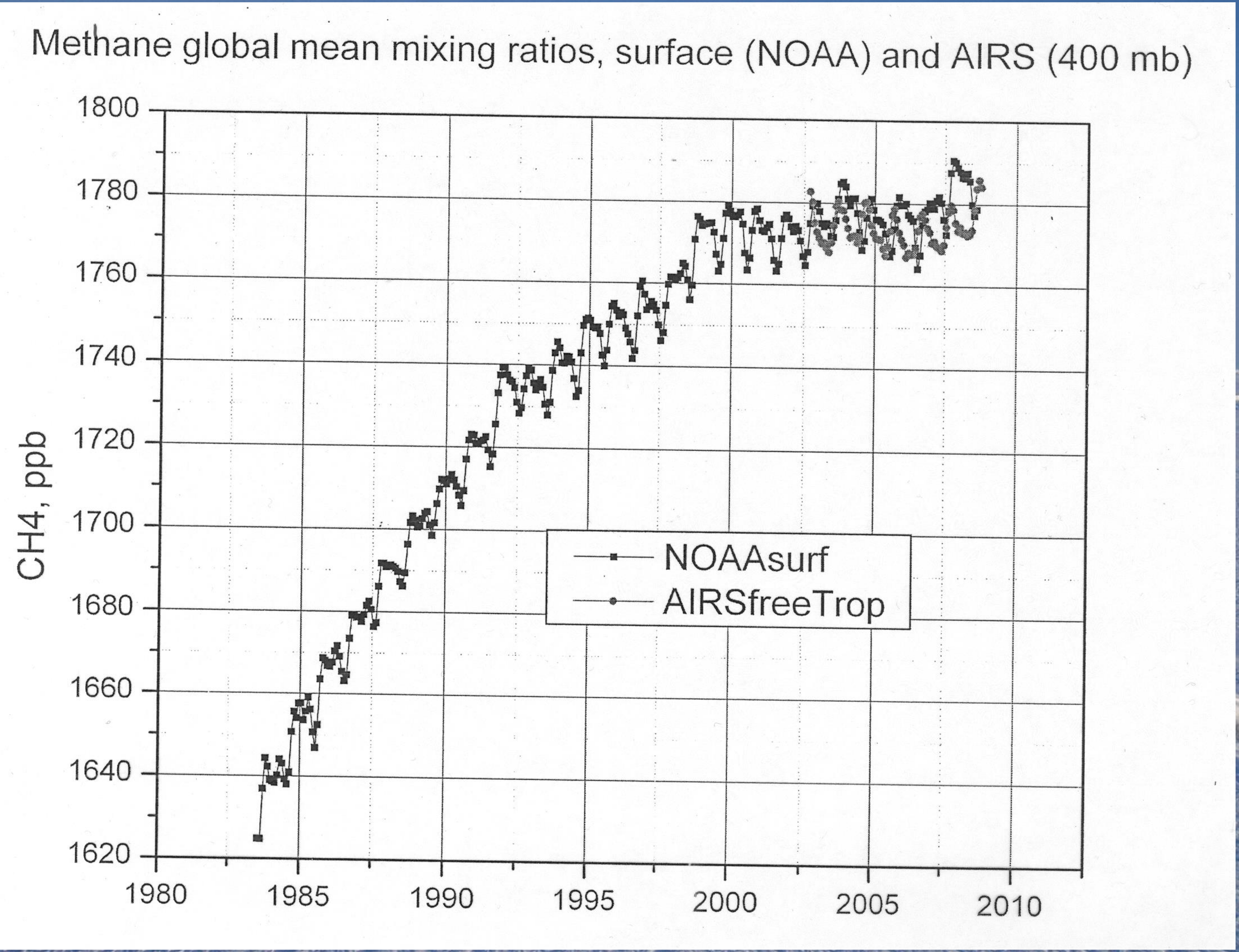

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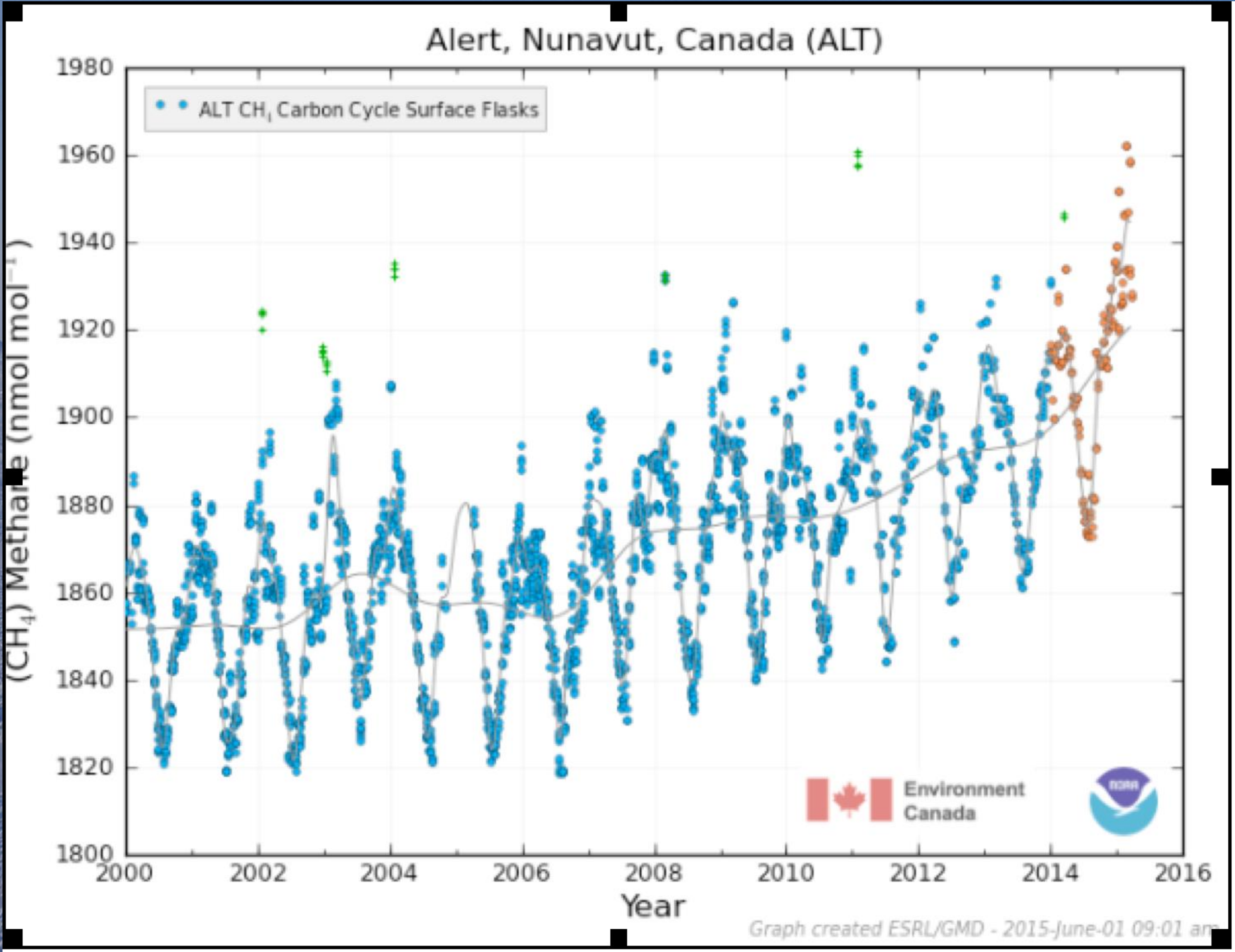
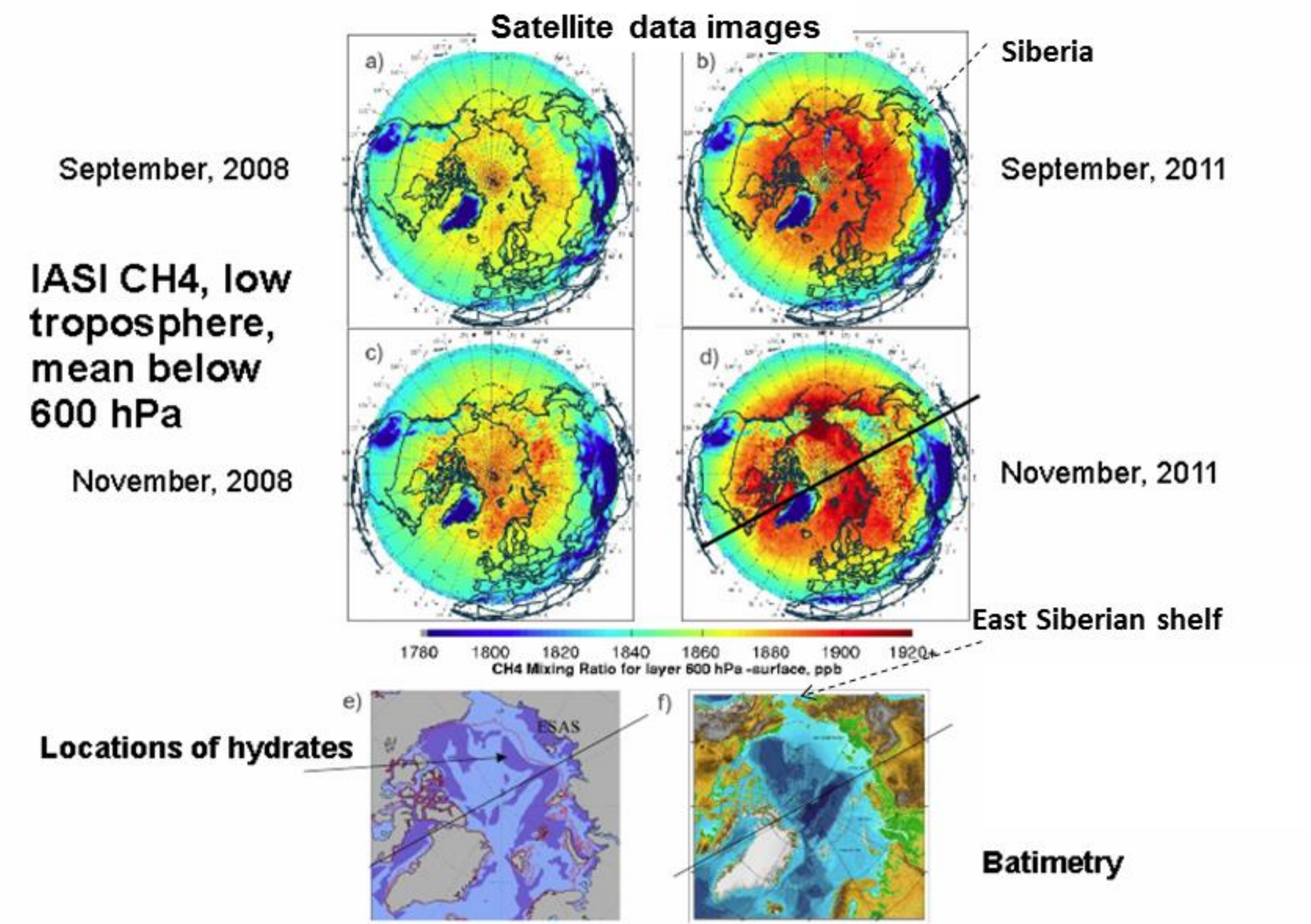

Alert, Nunavut, Canada (ALT)
ALT CH_4 Carbon Cycle Surface Flasks
1980
1960
1940
1920
1900
1880
1860
1840
1820
1800
(CH4) Methane (nmol mol⁻¹)
2000
2002
2004
2006
2008
2010
2012
2014
2016
Year
Environment Canada
Graph created ESRL/GMD - 2015-June-01 09:01 am

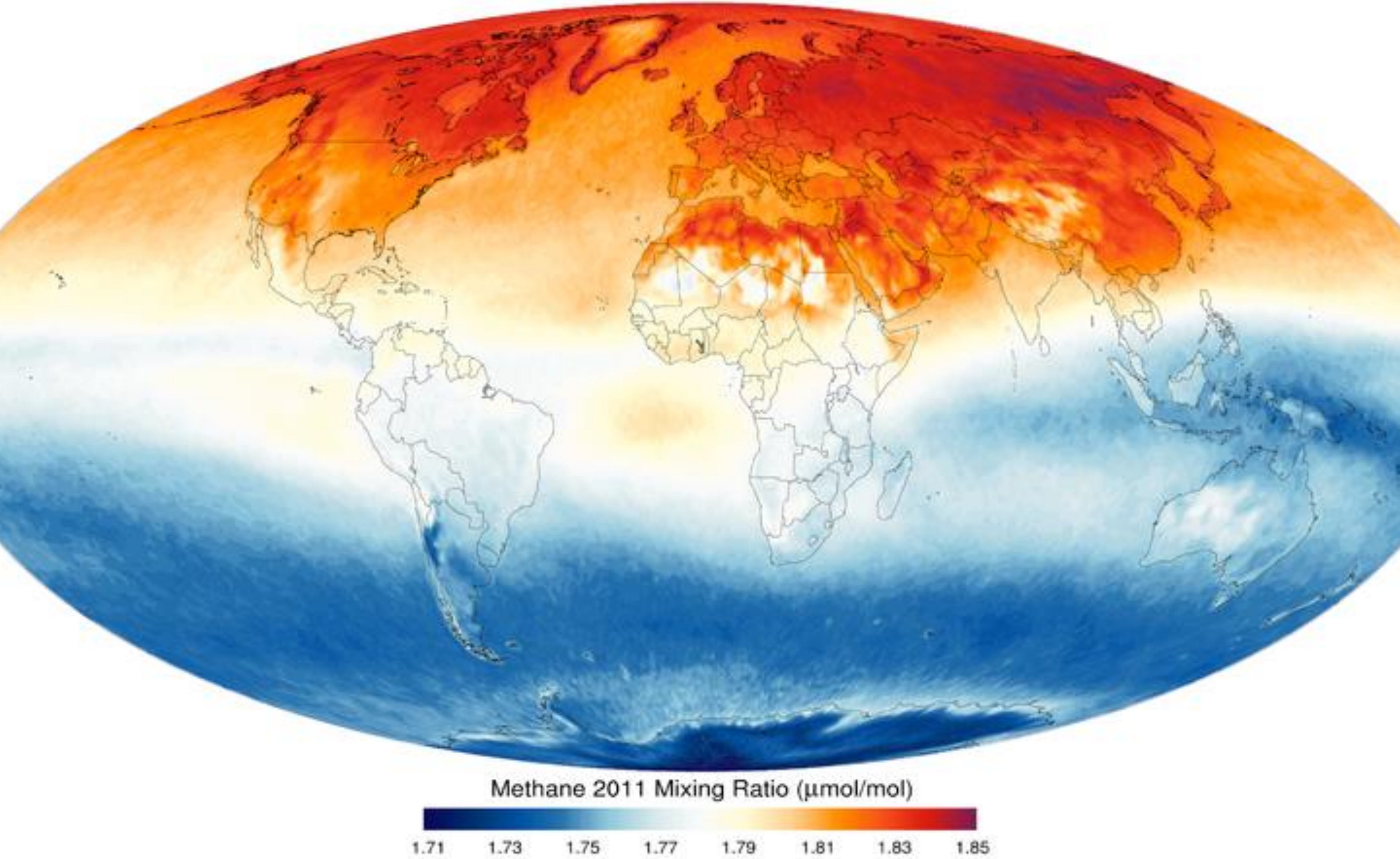
Methane emission from the Arctic shelf?

AIRS v5 and IASI low troposphere data

Leonid Yurganov, JCET/UMBC Shawn Xiong, NOAA

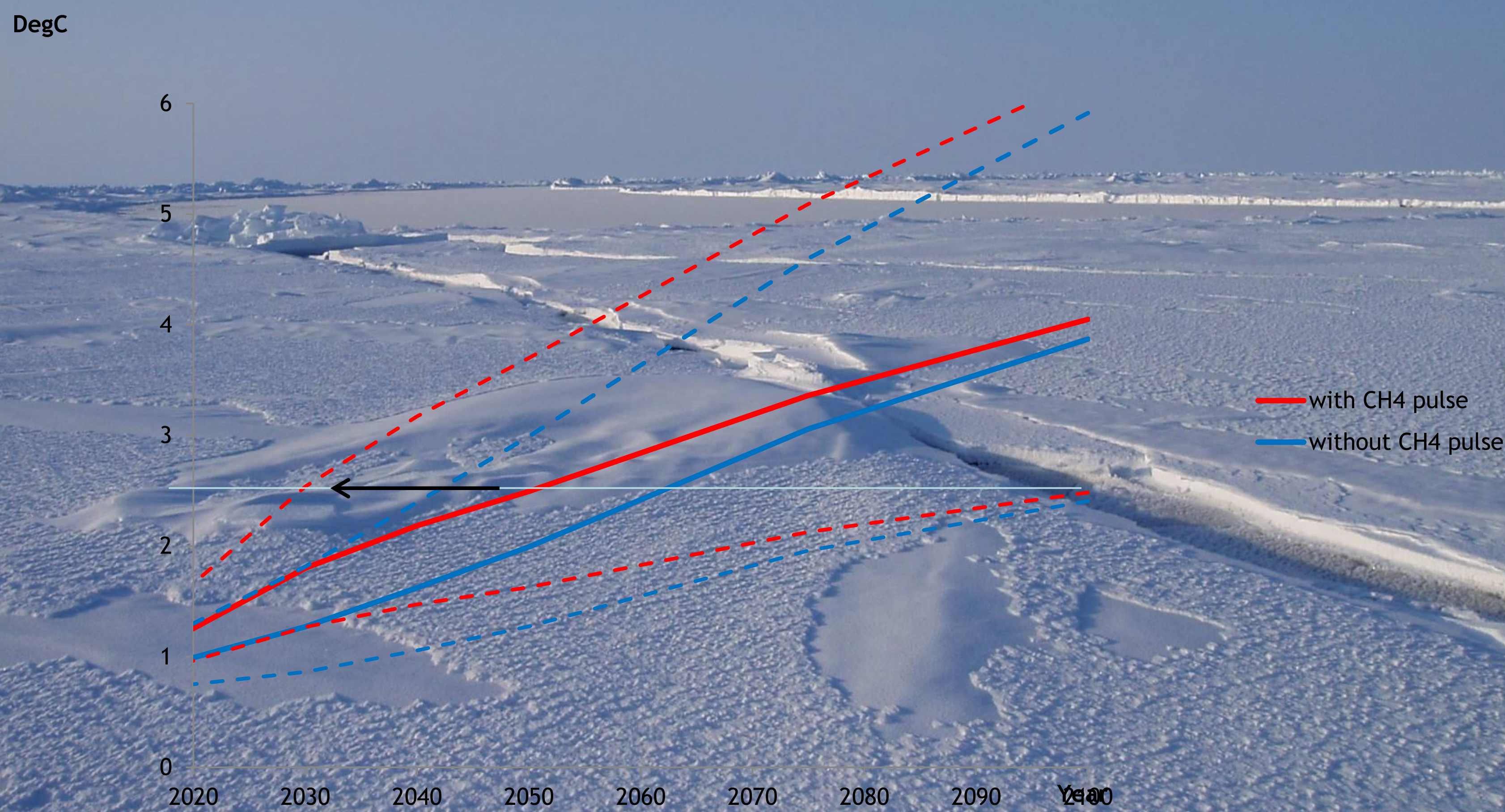
NASA Sounder Science Team Meeting, November 14, 2012, Greenbelt, MD




Methane 2011 Mixing Ratio (μmol/mol)
1.71
1.73
1.75
1.77
1.79
1.81
1.83
1.85

Effect of methane outbreak on global temperatures

Emission of 50Gt 2015-2025, three scenarios



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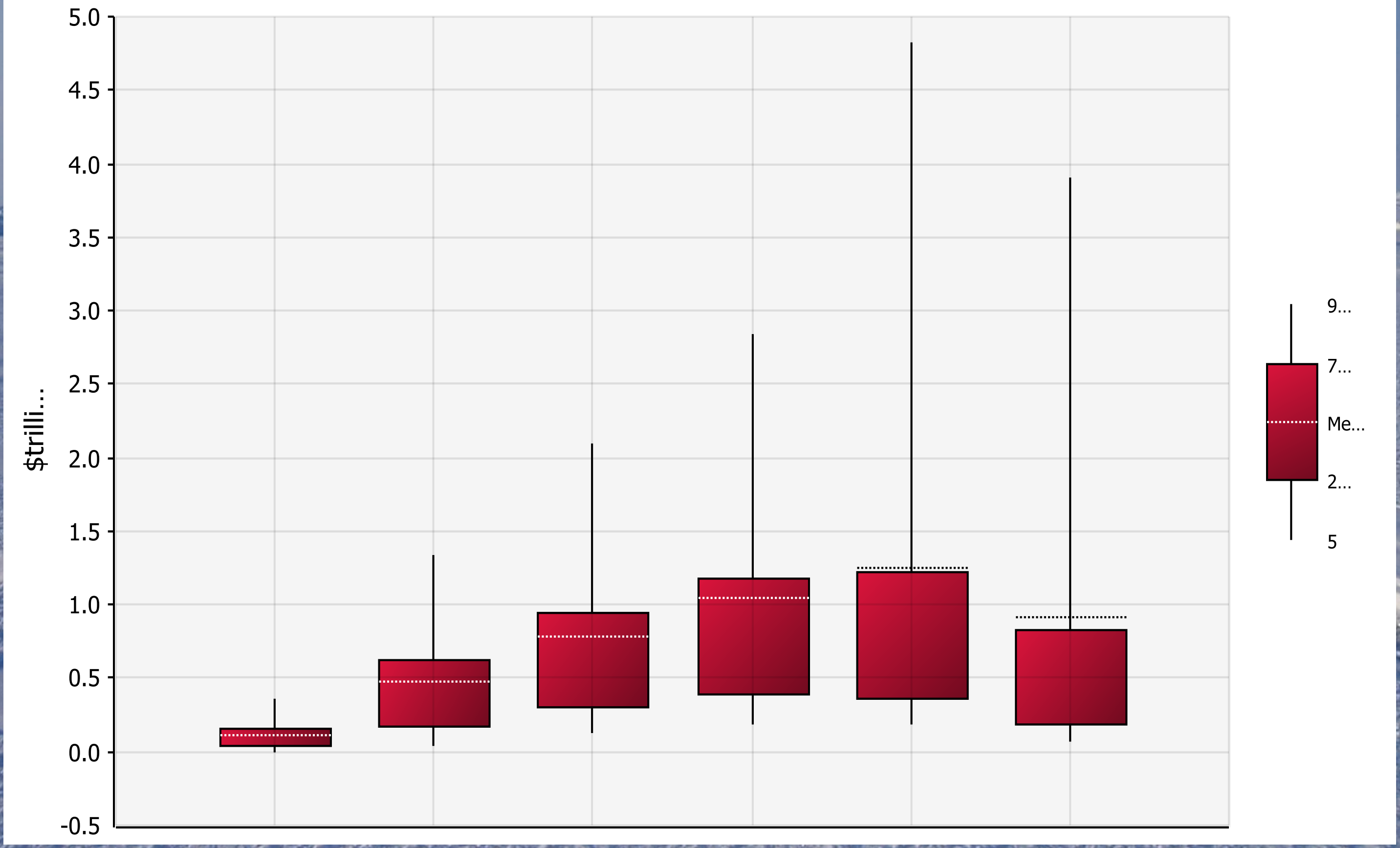
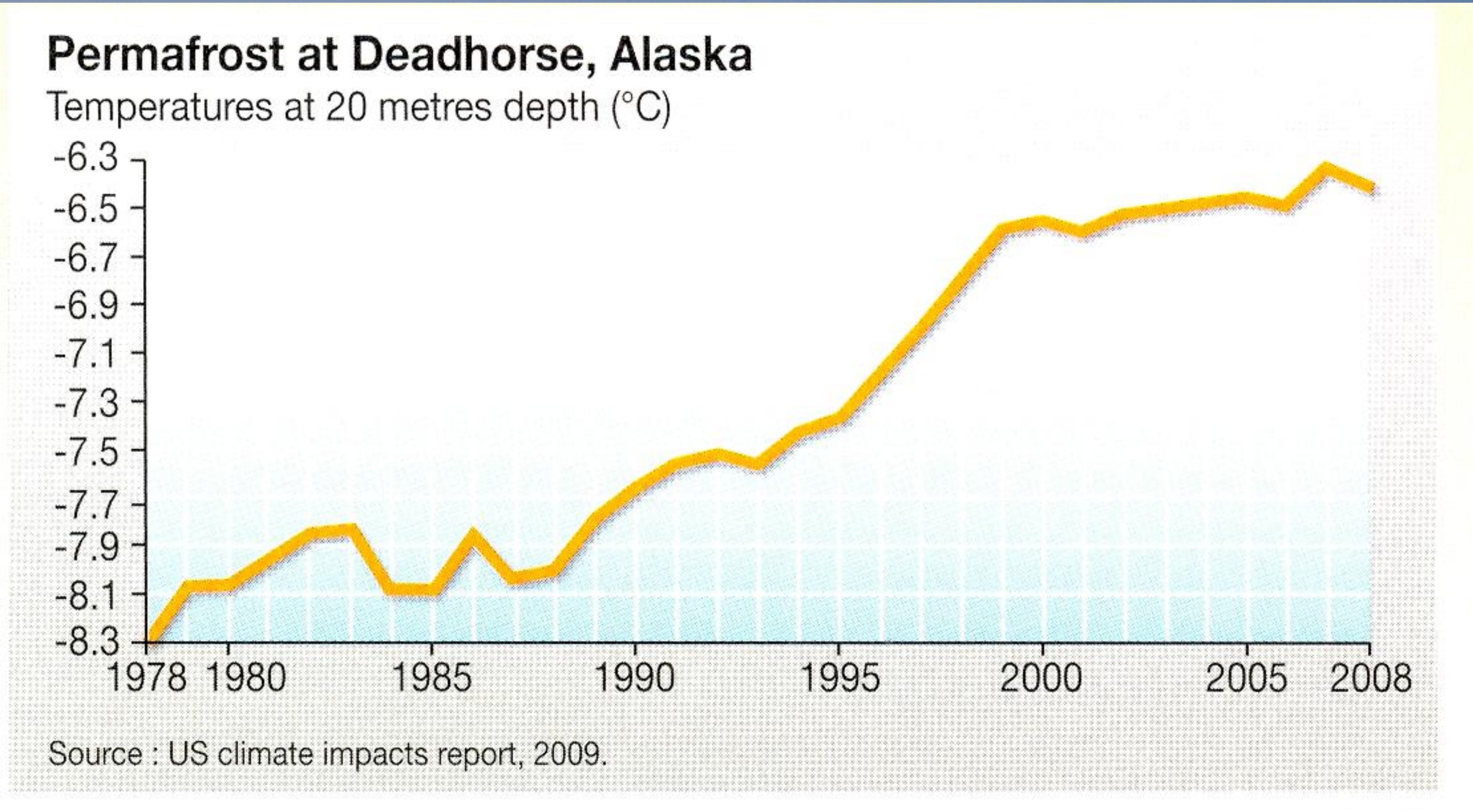
Cost of methane outbreak

per decade – total over 100 years 60 trillion dollars



Permafrost on land: the “ticking Arctic time bomb” (Science, 2012)



Extreme weather and food production

Is this an effect of Arctic sea ice retreat? Jury still out.

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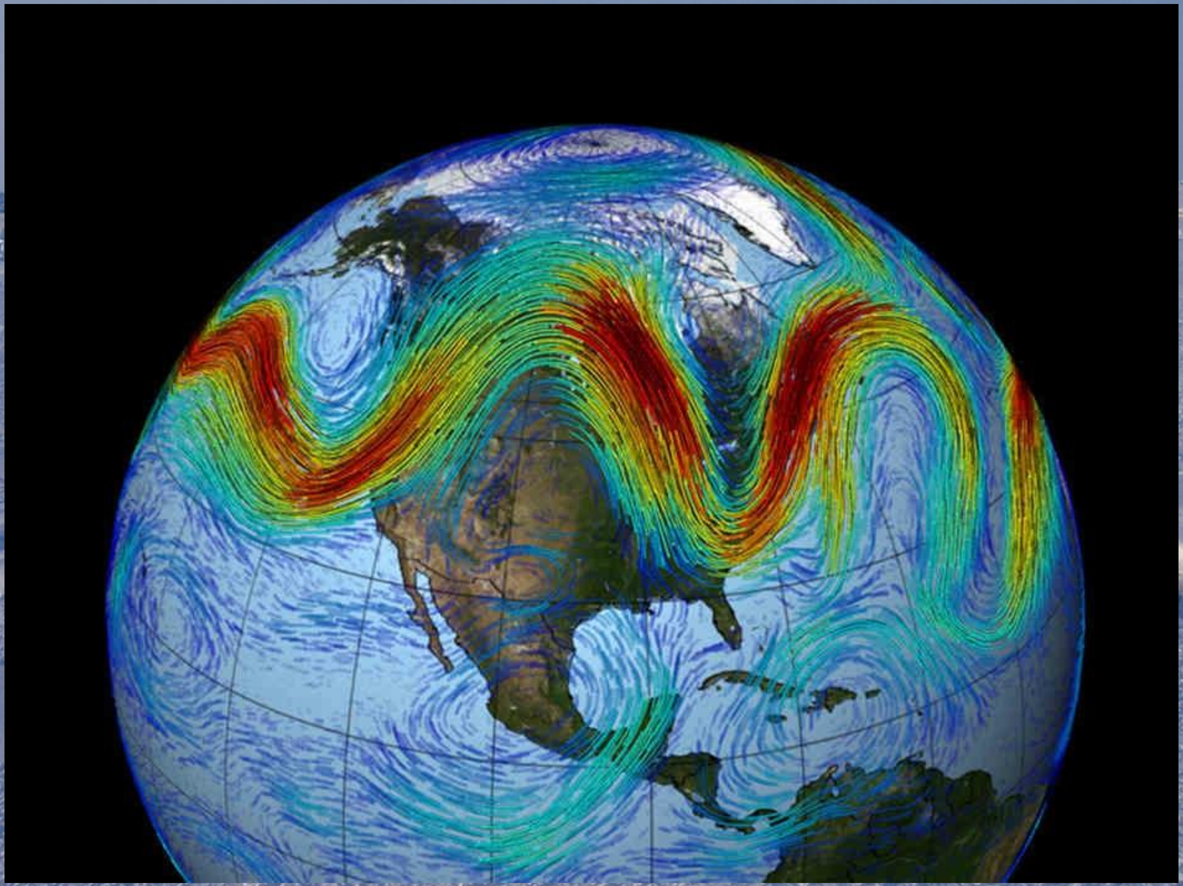
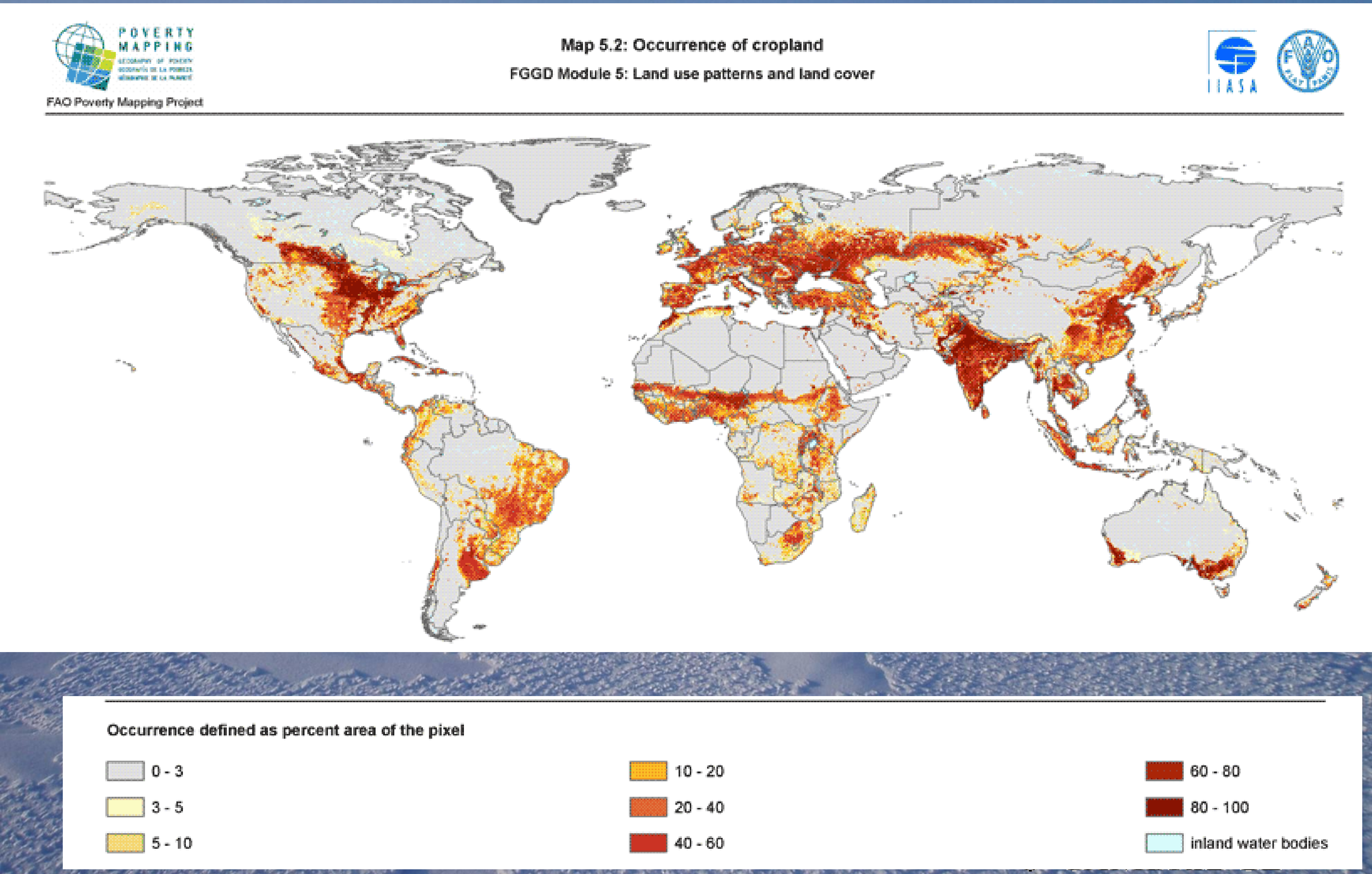
Simulation of jet stream (NASA)



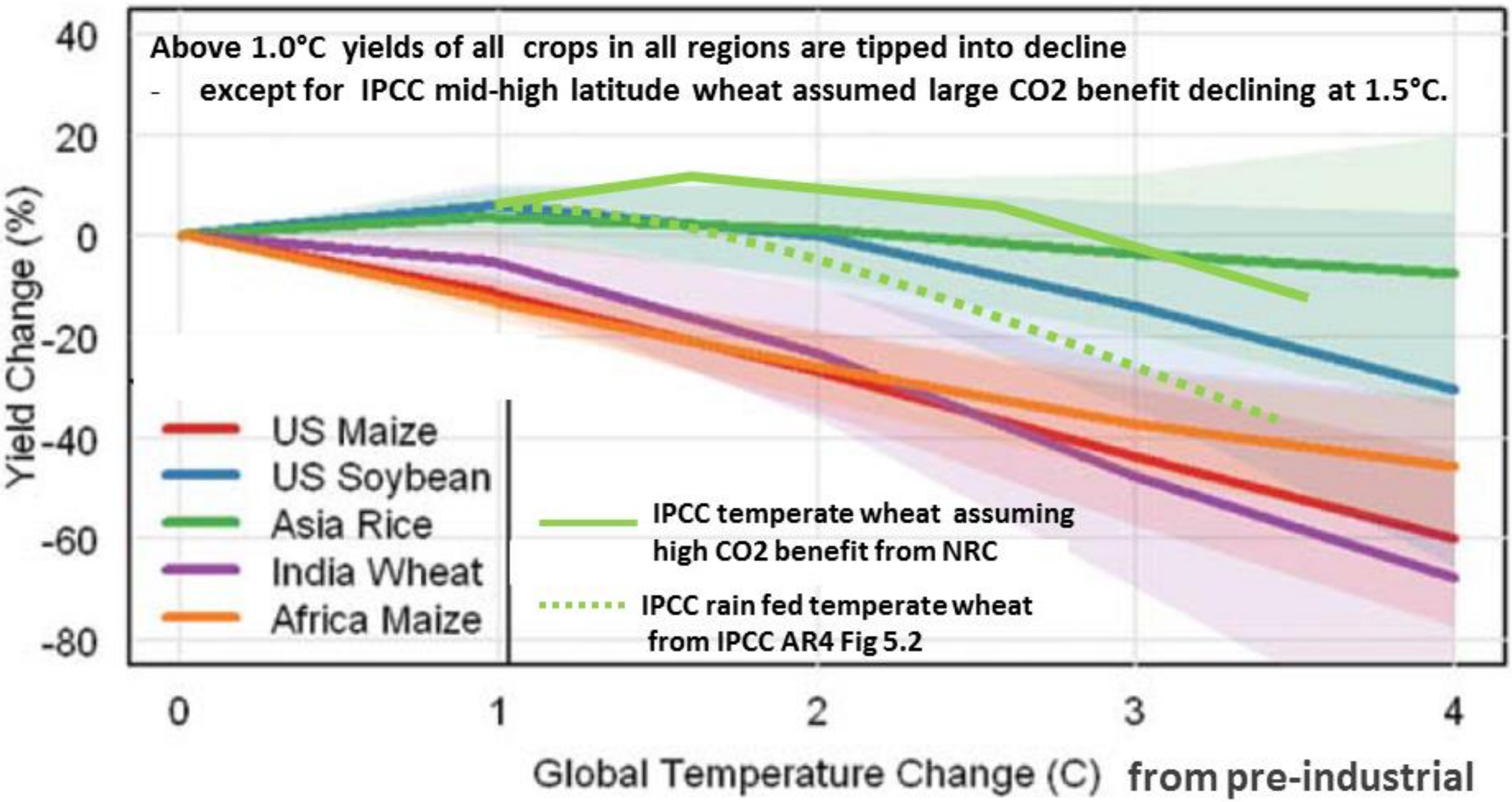
Crops



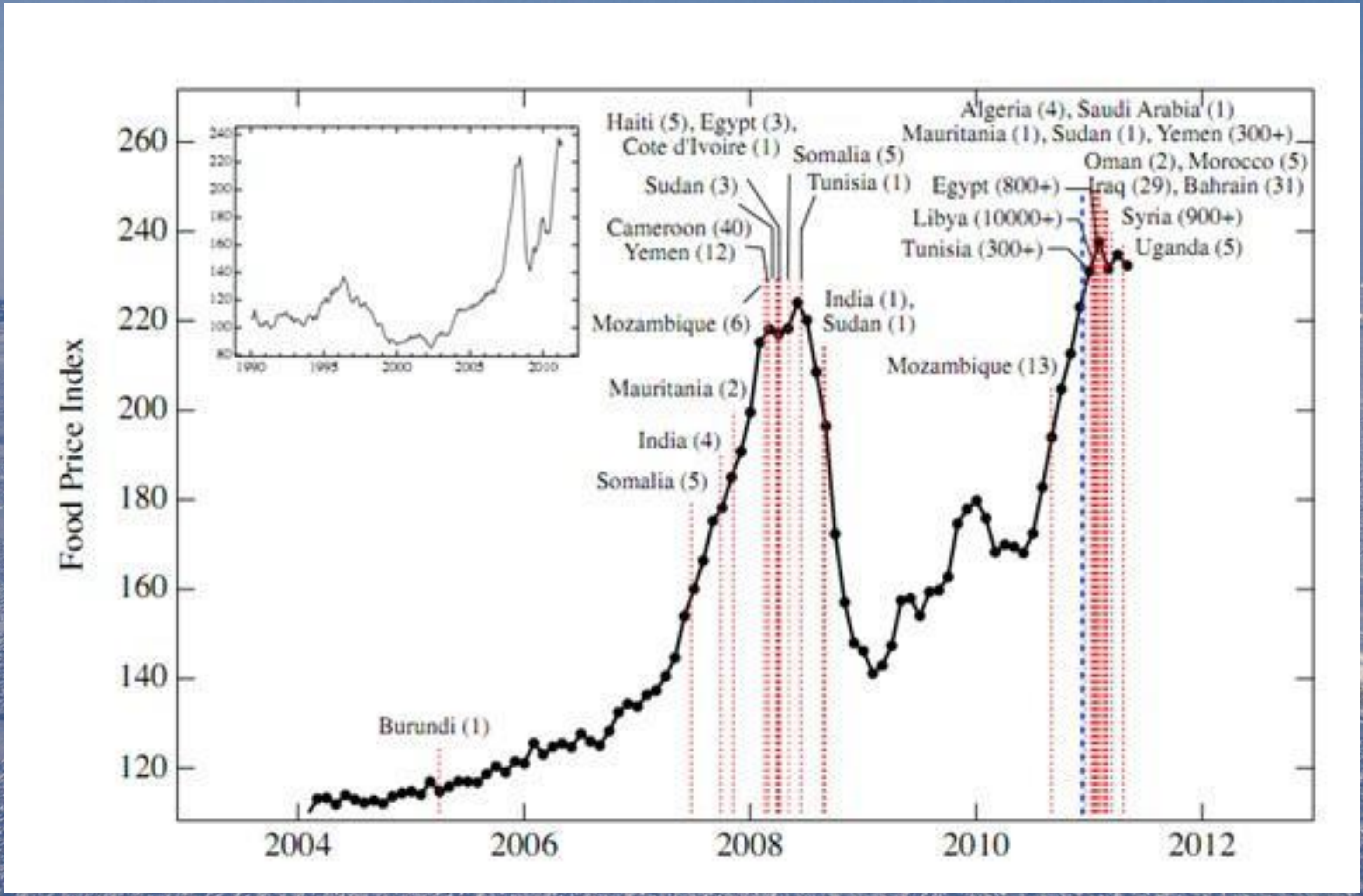
Map 5.2: Occurrence of cropland
FGGD Module 5: Land use patterns and land cover
POVERTY MAPPING
FAO Poverty Mapping Project
IIASA
Occurrence defined as percent area of the pixel
0 - 3
3 - 5
5 - 10
10 - 20
20 - 40
40 - 60
60 - 80
80 - 100
inland water bodies

National Research Council Climate Stabilization Targets 2011 5.1 p. 261-262 Food production

Loss of Crop Yields per Degree Warming



These plots are model projections that do not capture a large number of large adverse effects … *several processes have not been adequately quantified. These include weeds, insects, pathogens; changes in water resources for irrigation; surface ozone levels; flood frequencies; and respons to extremely high temperatures. changes in sustained droughts (which are likely to increase in many regions), or potential changes in year-to-year variability of yields.* NRC 2010



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Decline in strength of the Atlantic thermohaline circulation

….. The "Great Conveyor Belt"

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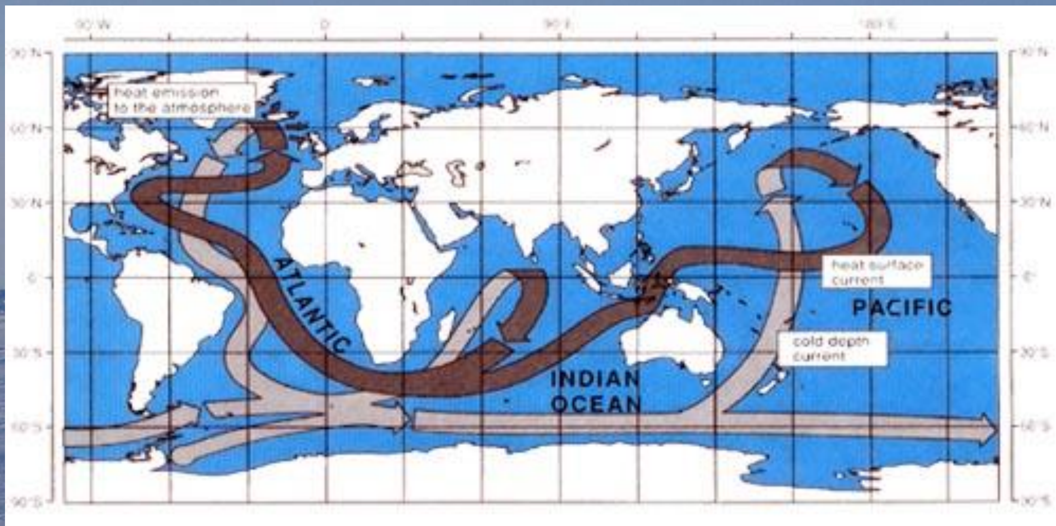
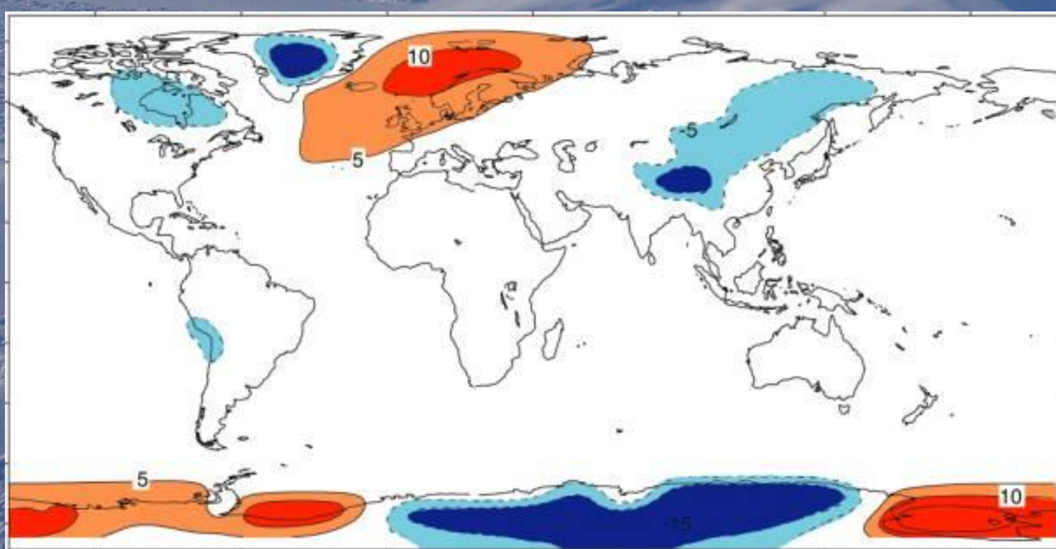
Thermohaline circulation is weakening



The large marine conveyor belt with cold deep flow and warm surface current. (Source: DKRZ/MPI-Hamburg).



Annual mean surface temperature anomalies, from NCAR data, relative to zonal averages. There is a 5-10° C warm anomaly over NW Europe and the Nordic Seas (Rahmstorf, S. A., Ganapolski, 1999).

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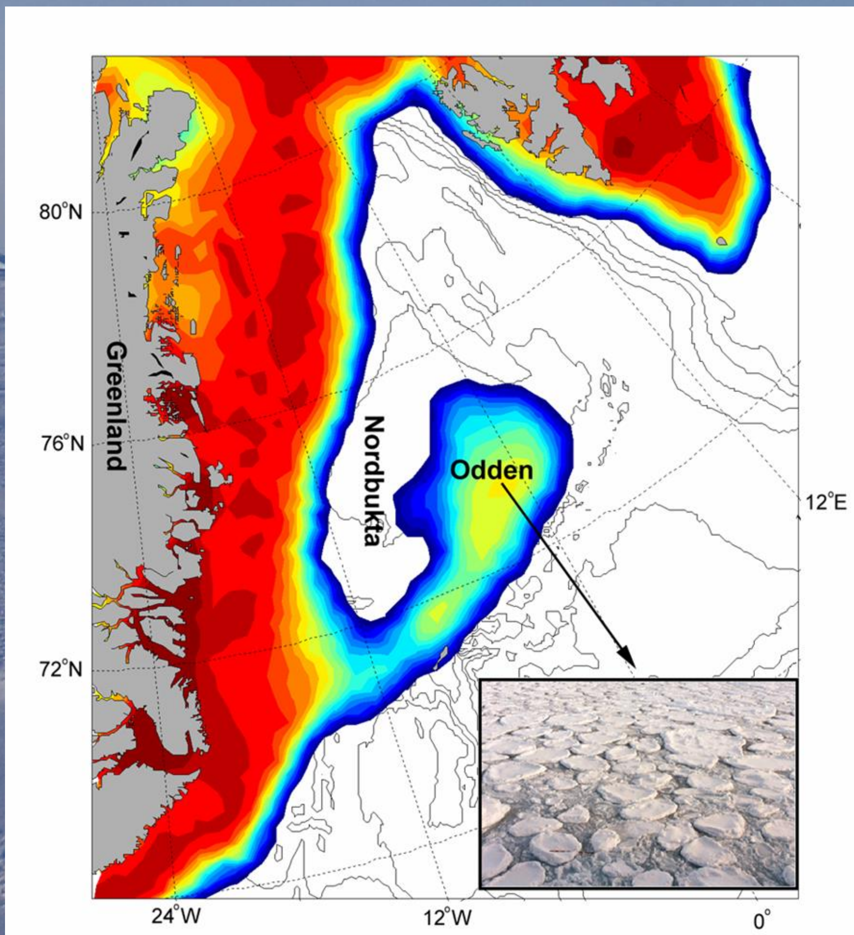

Greenland Sea in a severe winter

Convective chimneys form in the Odden ice tongue

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A convective chimney in the Greenland Sea

Discovered by “Jan Mayen” 2001, 75N 0W, 10 km diameter (Wadhams et al, 2004)

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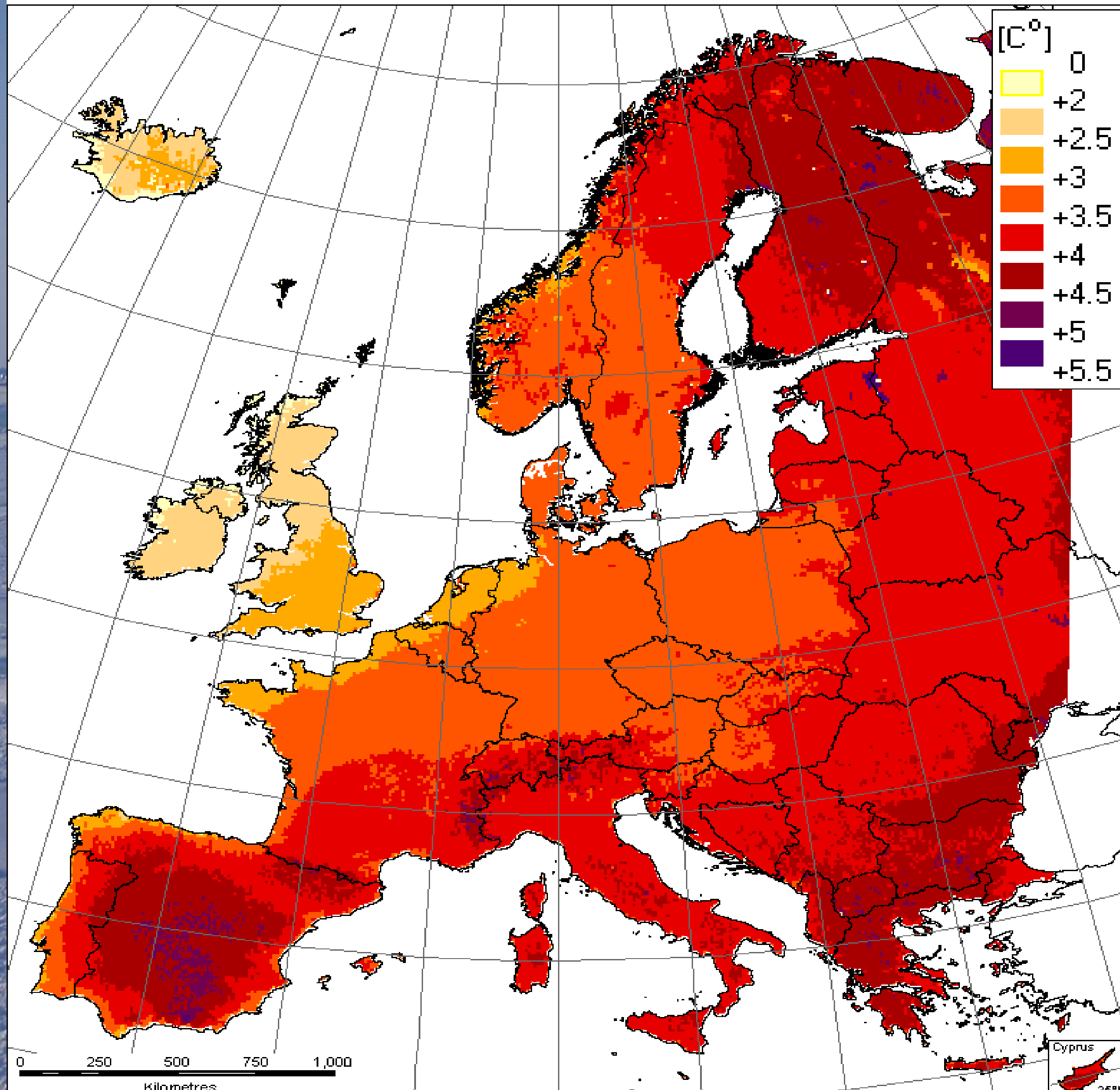
Temperature: change in mean annual temperature [C°]



What can we do?

- WARMING can be slowed by reducing carbon emissions, i.e. switching to renewable energy (which includes nuclear), but can't be slowed to less than 2 C by end of this century (Paris Agreement)

- Only real solution is taking CO2 out of atmosphere (Direct Air Capture)

- METHANE OUTBREAKS can only be stopped by restoring the Arctic sea ice; applying a yet-to-be-invented technique to dispose of seabed methane; or GEOENGINEERING

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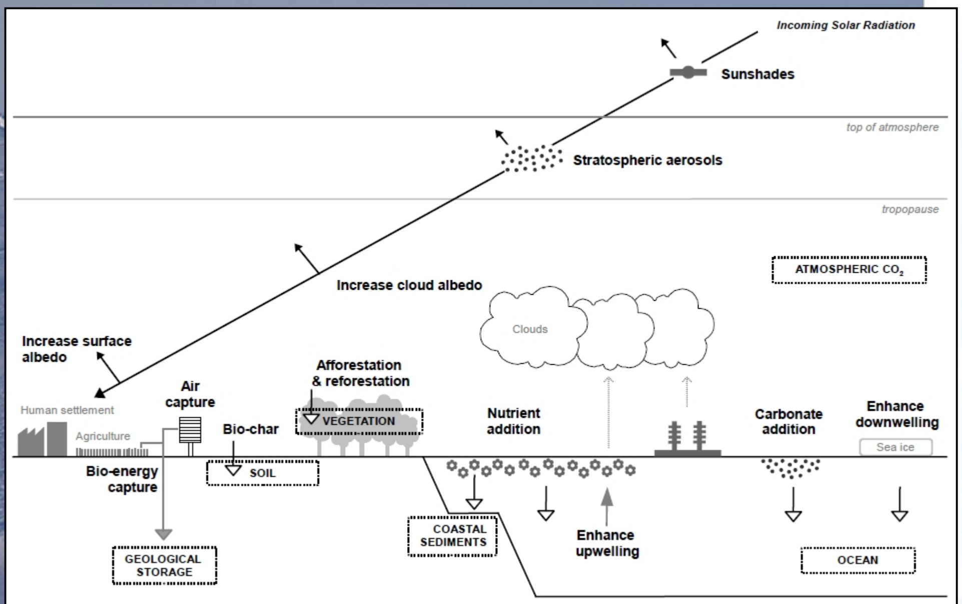
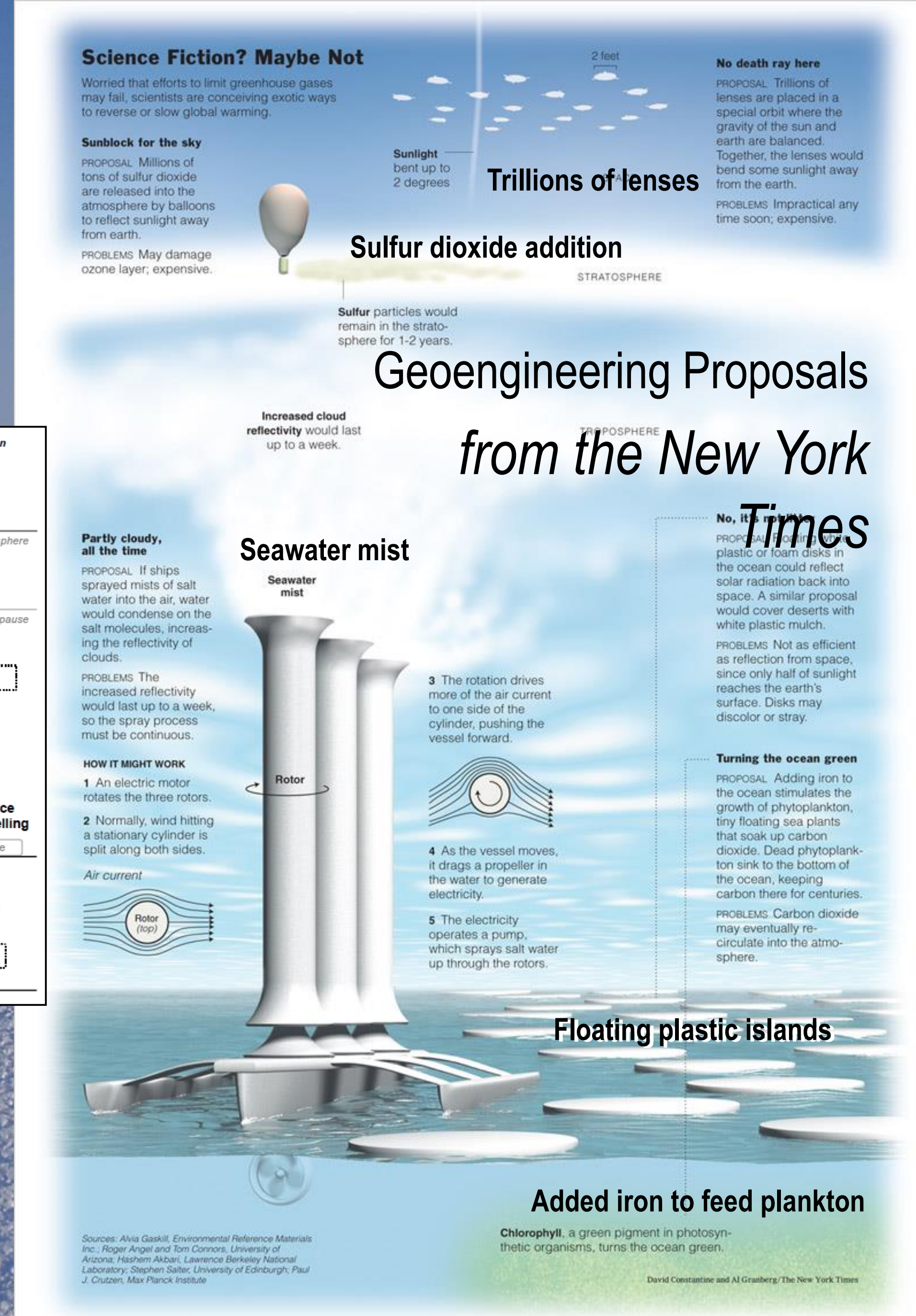
Geoengineering



Peter Fairly UEA



Geoengineering Proposals

from the New York Times

Direct air capture (DAC)

- This is the only ultimate solution.
- CO2 levels are already too high and emission reductions by themselves cannot be enough to keep warming below 2 C.
- Other carbon reduction methods have drawbacks
  - Crushed olivine rocks – too slow
  - BECCS (bioenergy with carbon capture and storage)– uses too much land (40-50% of arable land on planet)
  - Afforestation – difficult to achieve when forests are disappearing

- Techniques so far are too expensive (100s of dollars per ton). Need a method costing less than $40 per ton. A new Manhattan Project?

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Conclusions

- So long as carbon emissions continue to increase, global warming will continue to develop.
- Even if carbon emissions were to stop entirely, there would still be some continued warming for several decades.
- If present trends continue, average warming at low latitudes will be about 4° C by end of 21st Century.
- Multiply this by 2-4 for high latitudes.
- This will be accompanied by GLOBAL SEA LEVEL RISE (about 1 m in century); LOWER PRECIPITATION in key tropical regions leading to desertification, reduced food production, and loss of rain forest
- Possible surprises: methane boost from permafrost melt causing short term acceleration of warming, other effects not yet recognised (cf. ocean acidification).

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Renewed methane increase for five years (2007–2011) observed by solar FTIR spectrometry (SCIAMACHY satellite) R. Sussmann et al 2012

Methane monitoring stations in the German Alps

De-seasonalized

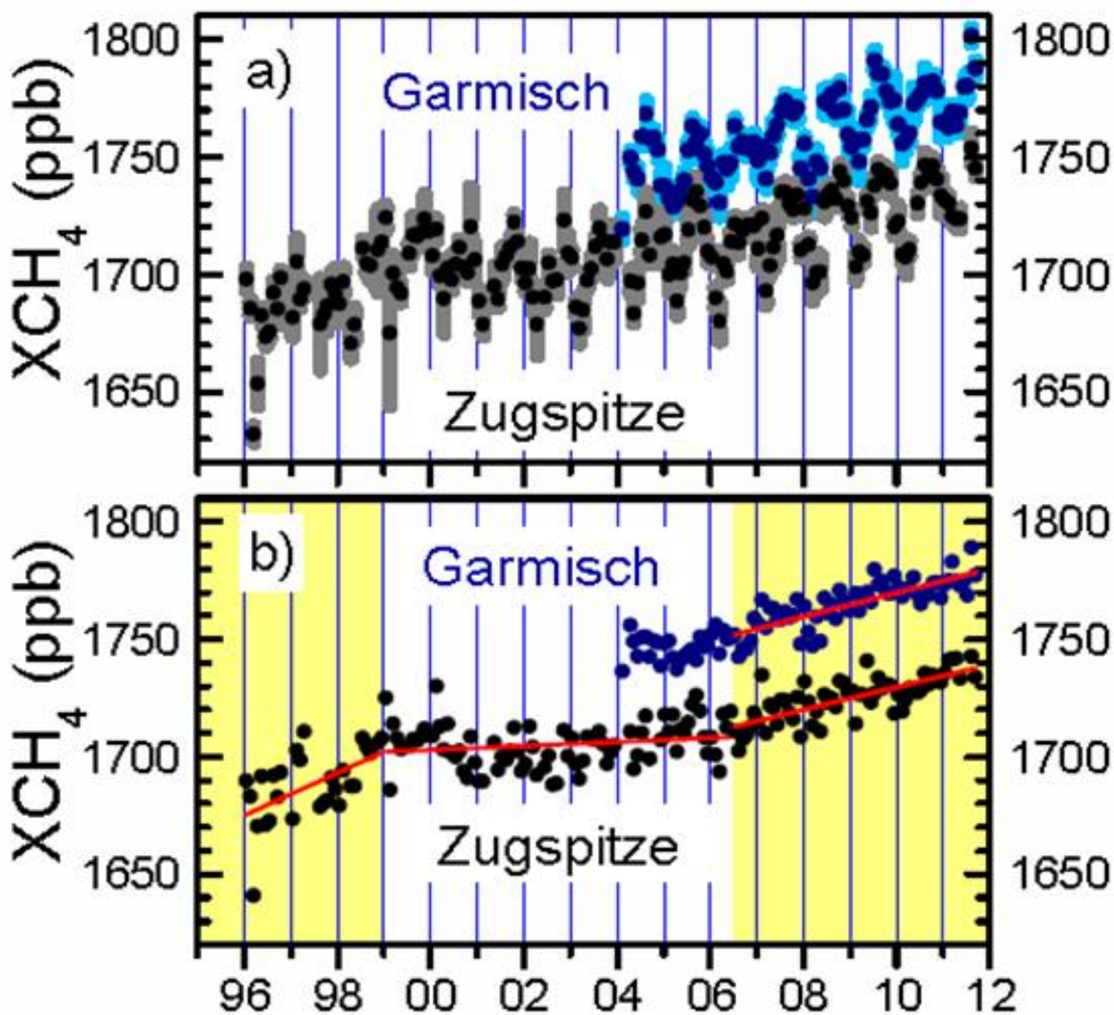
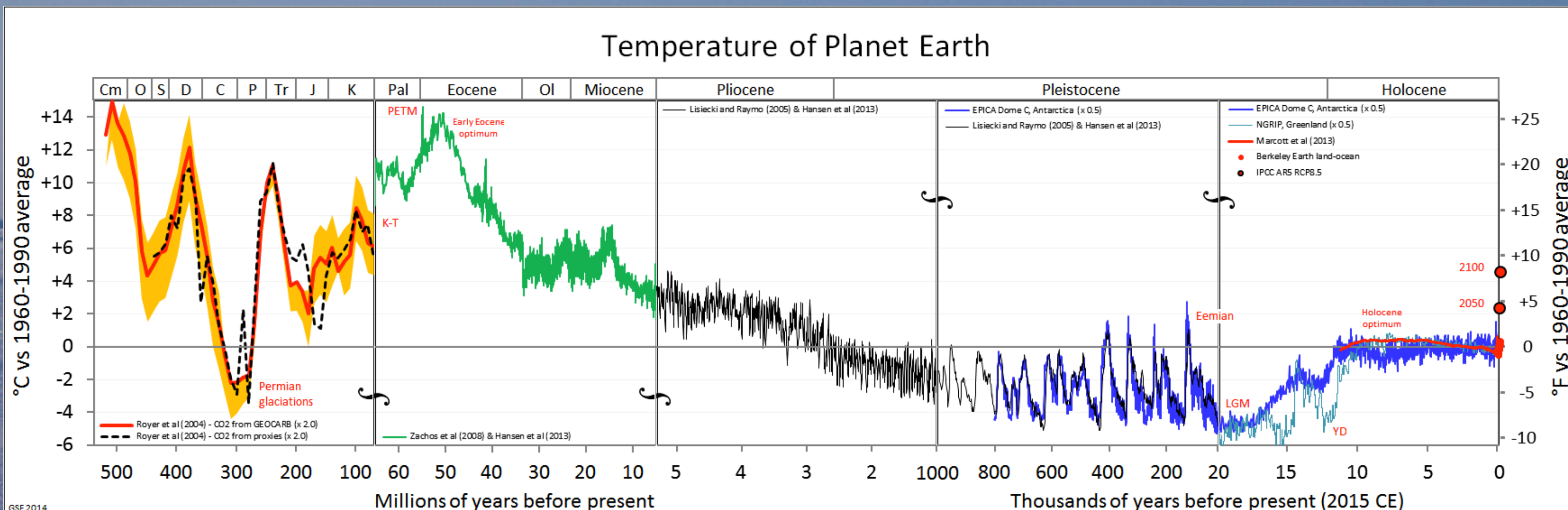


Fig. 1. (a) Time series of methane column-averaged mole fractions above Zugspitze and Garmisch (monthly means). Shaded bars indicate the statistical error of the monthly means calculated from the individual measurements ($\pm 3\ \sigma/sqrt(n)$), where n is the number of FTIR measurements per month. **(b)** De-seasonalized time series and linear trends (red lines). See Table 2 for trend magnitudes and significance.



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