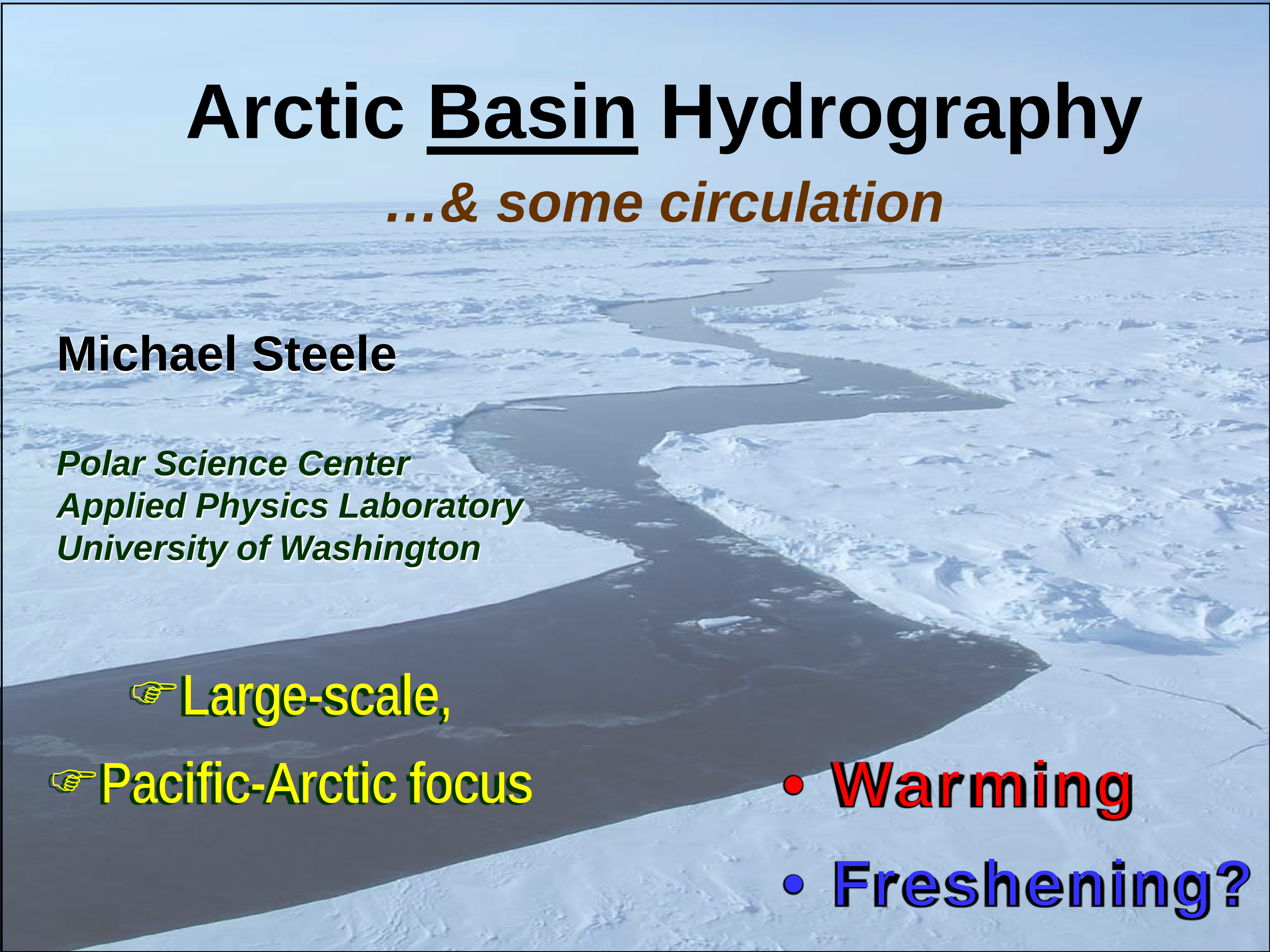


Arctic Basin Hydrography

…& some circulation

Michael Steele

Polar Science Center
Applied Physics Laboratory
University of Washington

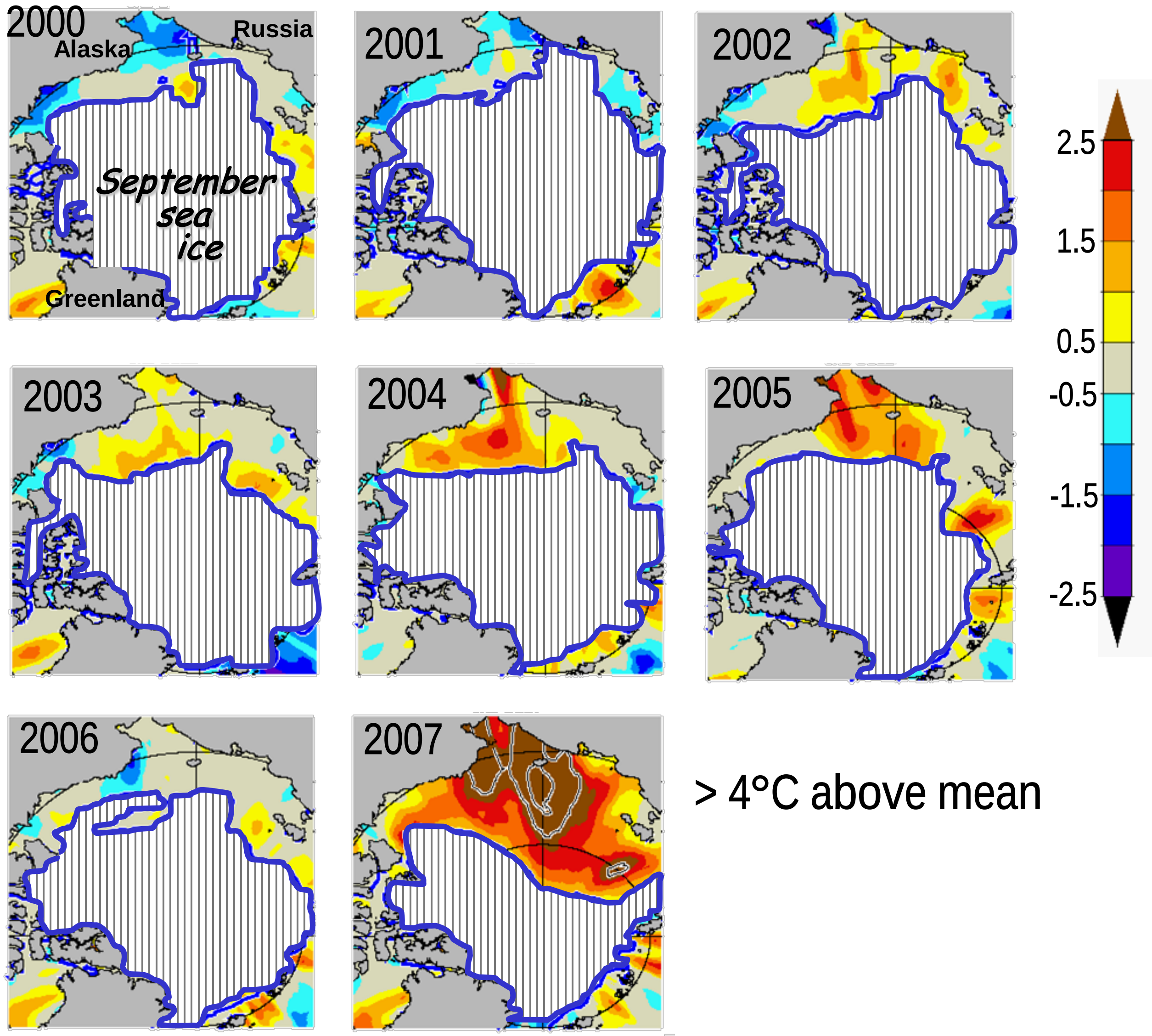
☞Large-scale,

☞Pacific-Arctic focus

- **Warming**
- **Freshening?**

Ice Retreat & Upper Ocean Warming

from Steele et al., GRL 2008



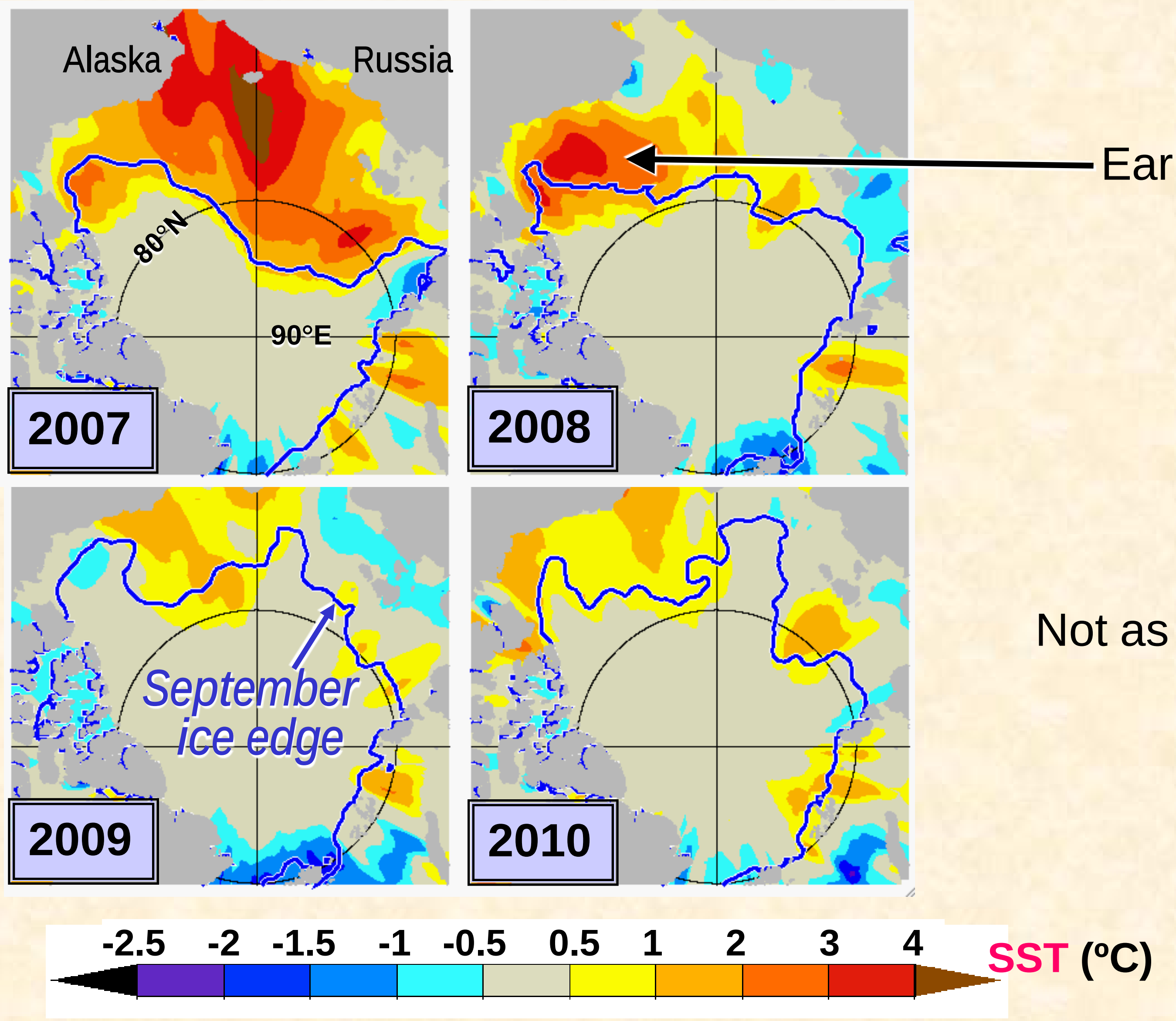
<u>Anomaly</u> of Summer ≡ JAS
Sea Surface Temperature (°C)
(relative to 1982-2007 mean)

SSTs from monthly mean AVHRR (Reynolds et al)

National Weather Service
Environmental Modeling Center

Summer SST Anomaly

(relative to 1982-2006 mean)



Early ice retreat

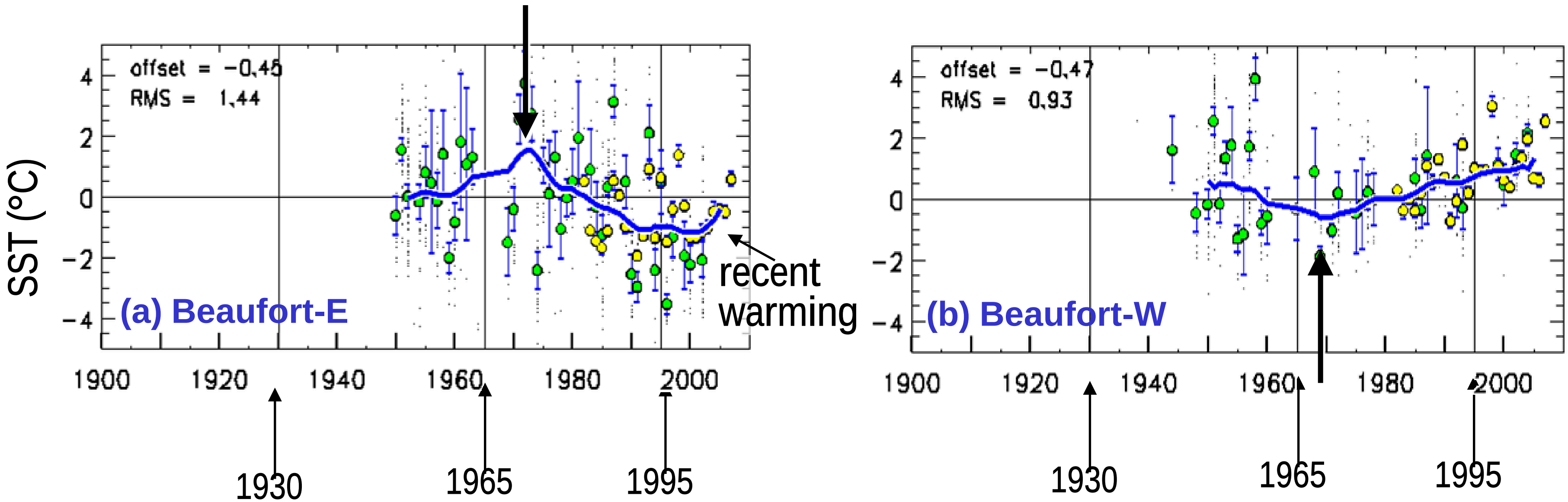
Not as warm…

summer SST trends:
regional anomaly time series

- *in situ* WOD'05
- *satellite* Reynolds et al

National Weather Service
Environmental Modeling Center

smoothed



- **Natural see-saw?**
- **Recent pan-arctic warming**

<u>Three Questions</u>

1.) What <u>*causes*</u> upper ocean warming?

2.) How much sea ice melt is forced by this warm ocean?

<u>SUMMER</u>
(Steele et al. JGR November 2010)

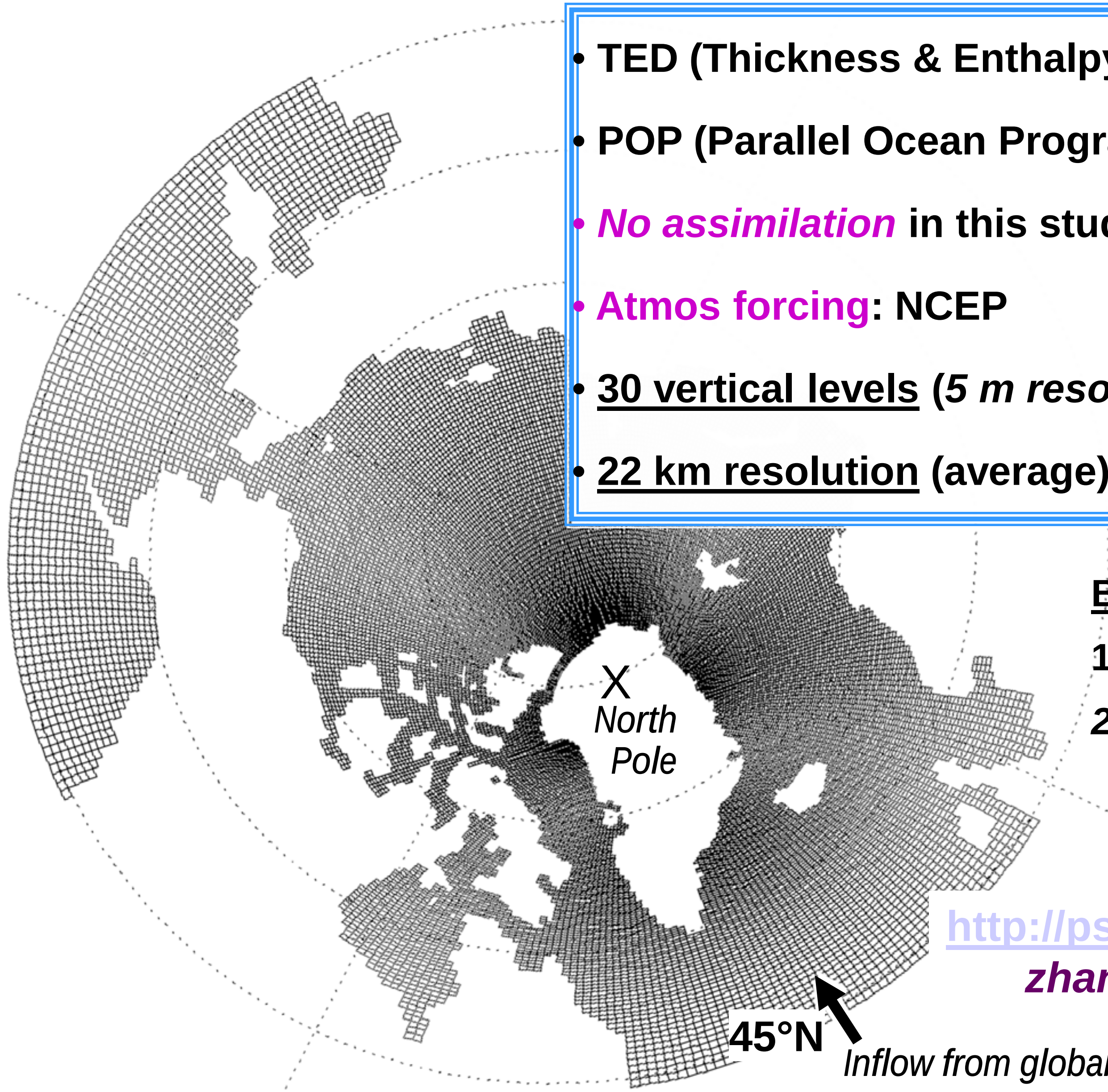
3.) What is the fate of summer heat?

<u>FALL/WINTER</u>
(Steele et al. JGR submitted)

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

Jinlun Zhang, Univ. of WA

- **TED (Thickness & Enthalpy Distribution) sea ice model**
- **POP (Parallel Ocean Program) ocean model, v. 1.4**
- ***No assimilation* in this study**
- **Atmos forcing: NCEP**
- **30 vertical levels (*5 m resolution in upper 30 m*)**
- **22 km resolution (average); *3 grid pts across Bering St.***



BESTMAS:

10 km resol. in Beaufort/Chukchi;

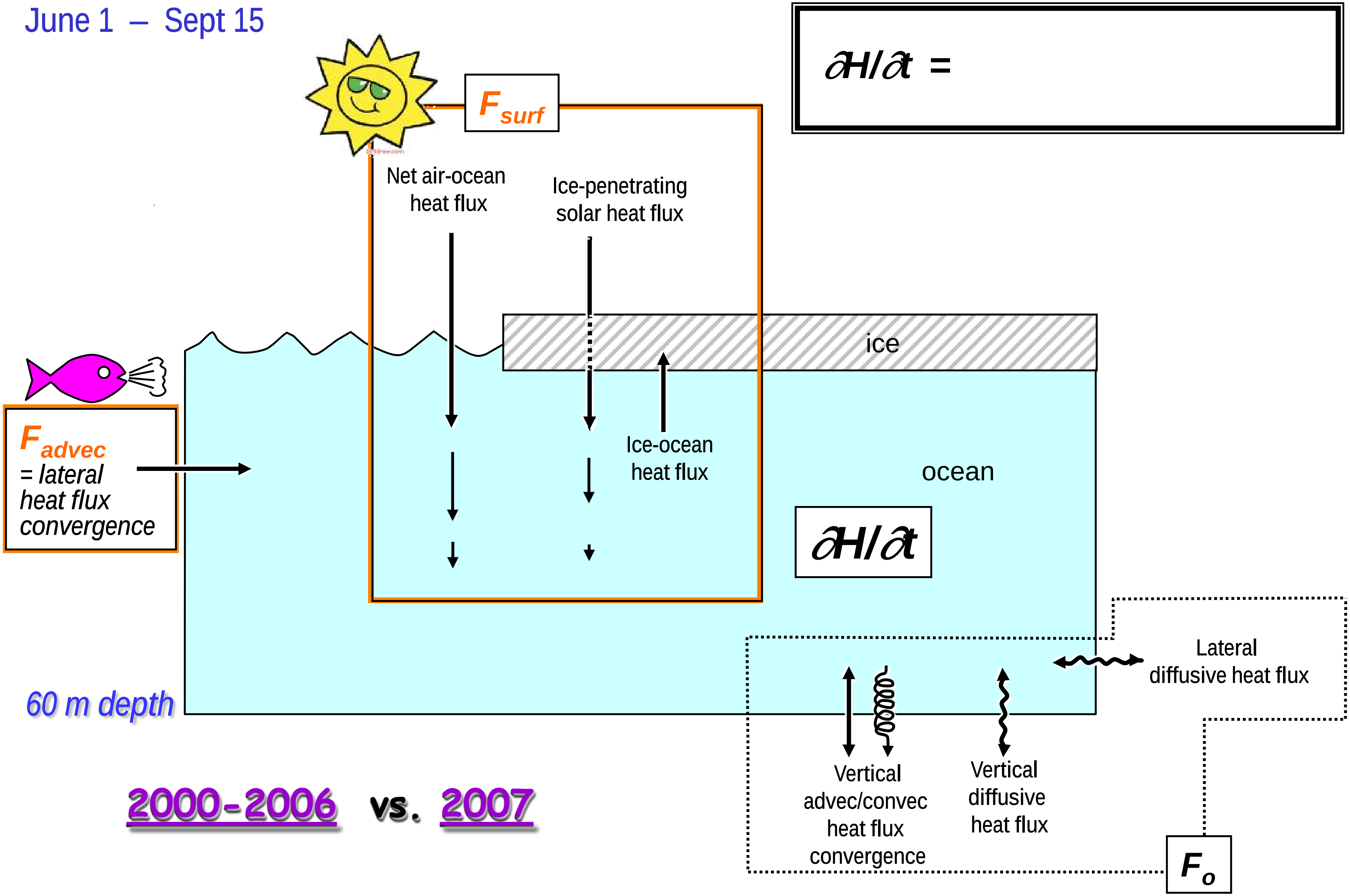
20 pts across Bering St.

http://psc.apl.washington.edu/IDAO

zhang@apl.washington.edu

Summer Upper Ocean Heat Balance

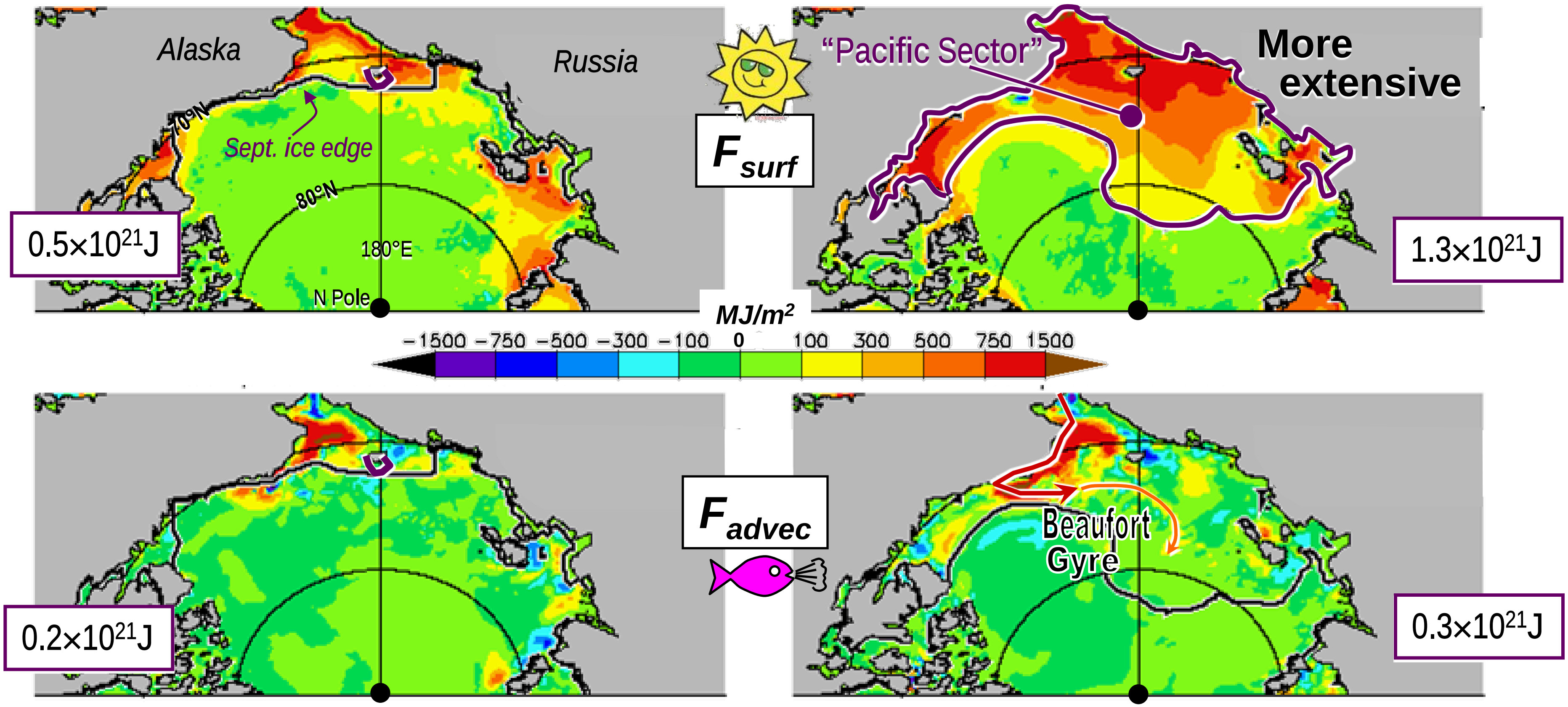
June 1 – Sept 15



2000-2006 vs. 2007

Summer Ocean Heating

2000-2006 | **2007**



F_0 < 0.1×10²¹J

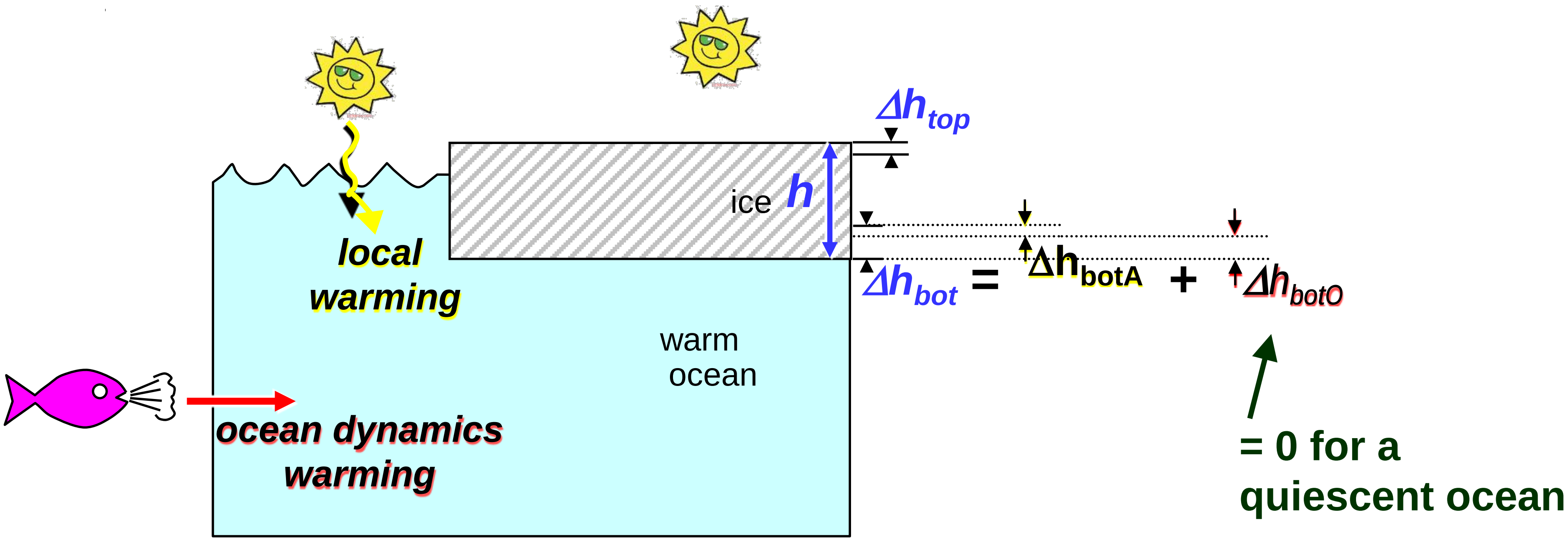
•*2007*: **Alaskan "retroflection" pathway unchanged, but stronger**

see Shimada et al., GRL 2006

F_{surf} = 70-80% of ocean surface warming

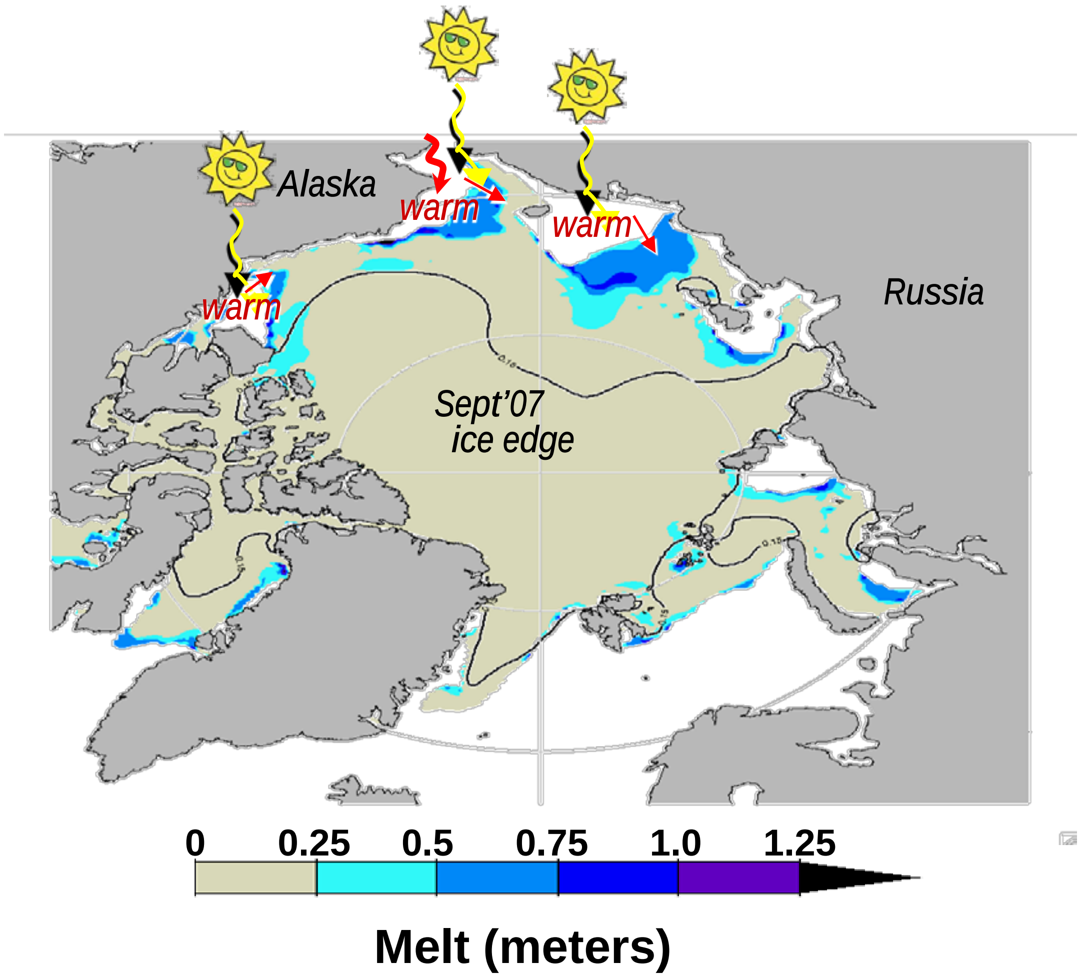
Michael Steele
Polar Science Center / APL
University of Washington

Summer Ice Mass Balance



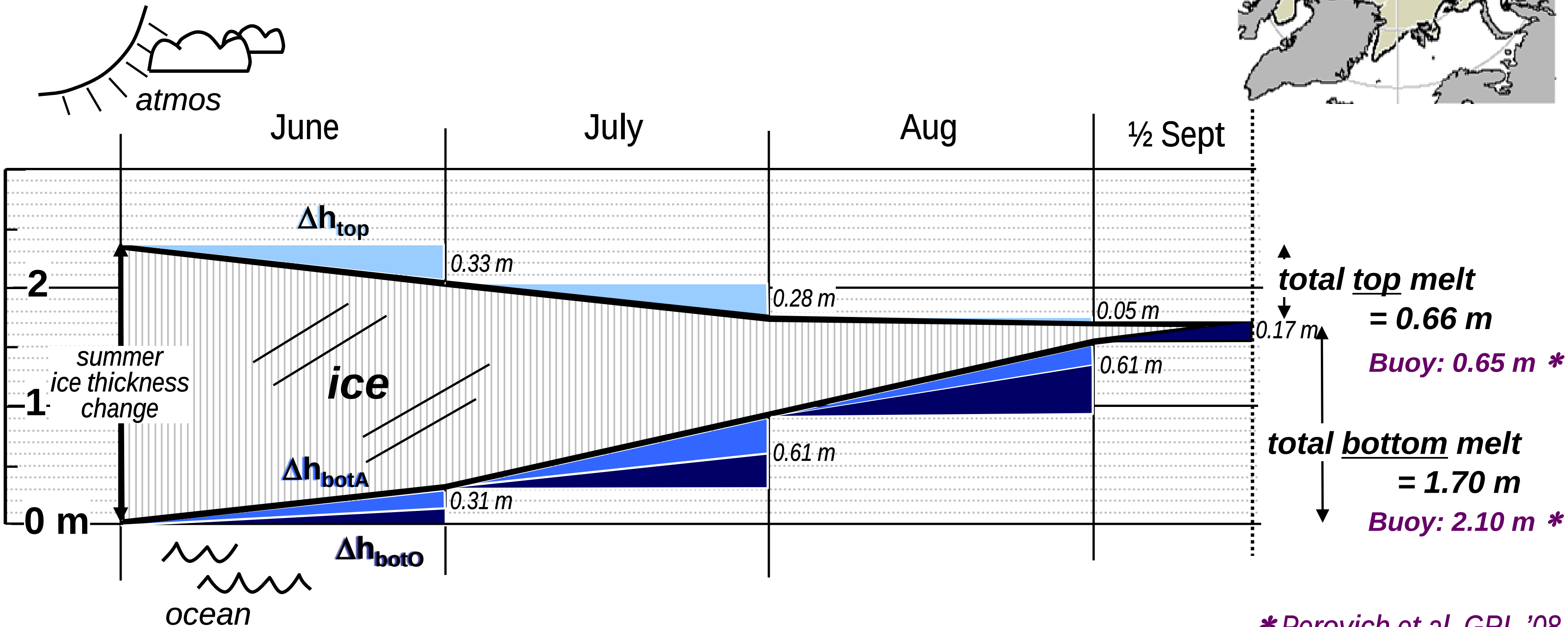
Δh_{botO} = Ice melt from ocean dynamics

July '07



- **warm SST**
- **strong advec**

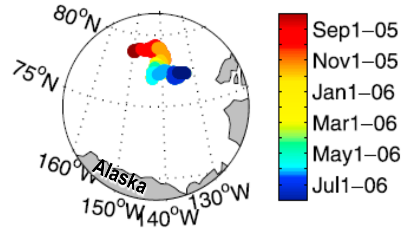
Ice *thickness* Budget: 2007



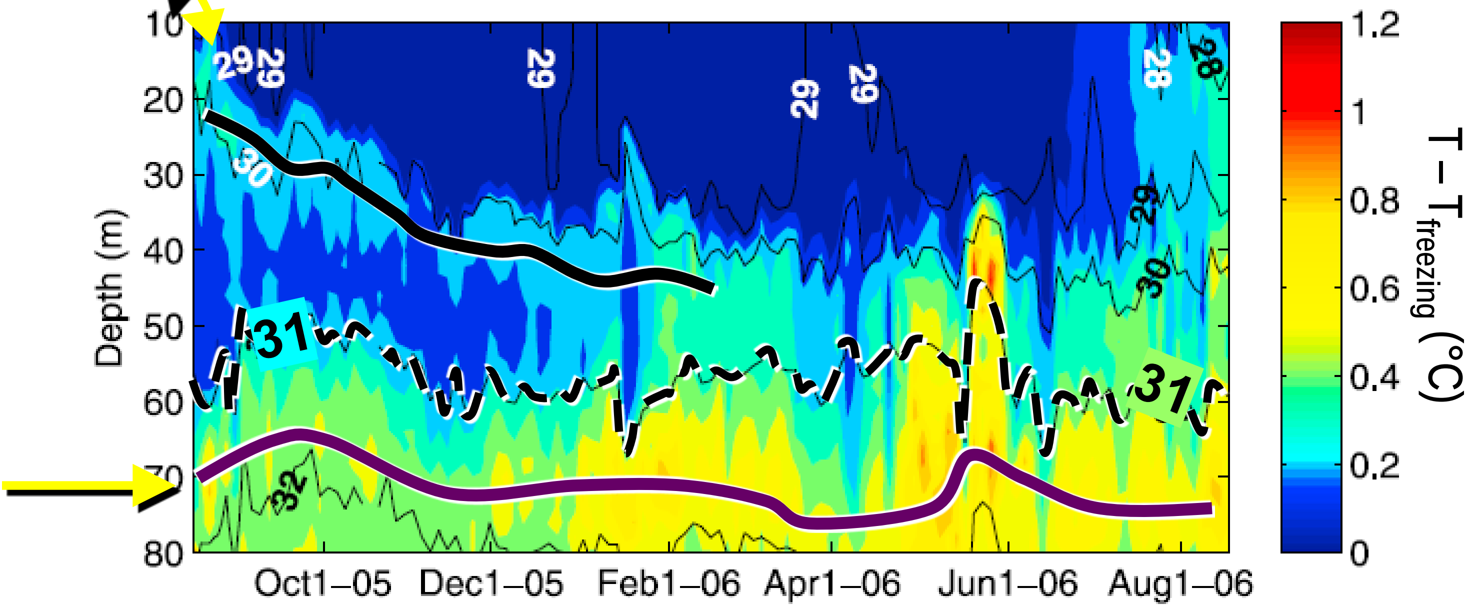
Ice area (10^6 km^2) = 2.6 | 2.2 | 1.0 | 0.7

* Perovich et al. GRL '08
Beaufort Ice Buoy

Next Question:
What is the FATE of summer ocean heat?

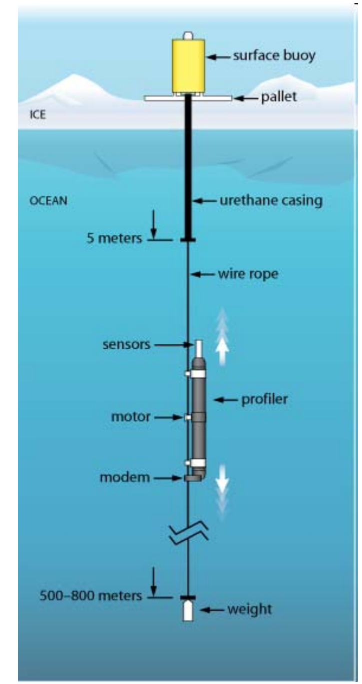


Jackson et al. JGR 2010



contours: Salinity

Data:
Ice-Tethered Profiler



Krishfield et al. J. Tech. 2008

The "<u>Near-Surface Temperature Maximum</u>" (NSTM)
…a LOCAL Tmax layer, as opposed to…
"summer Pacific Water" (sPW)

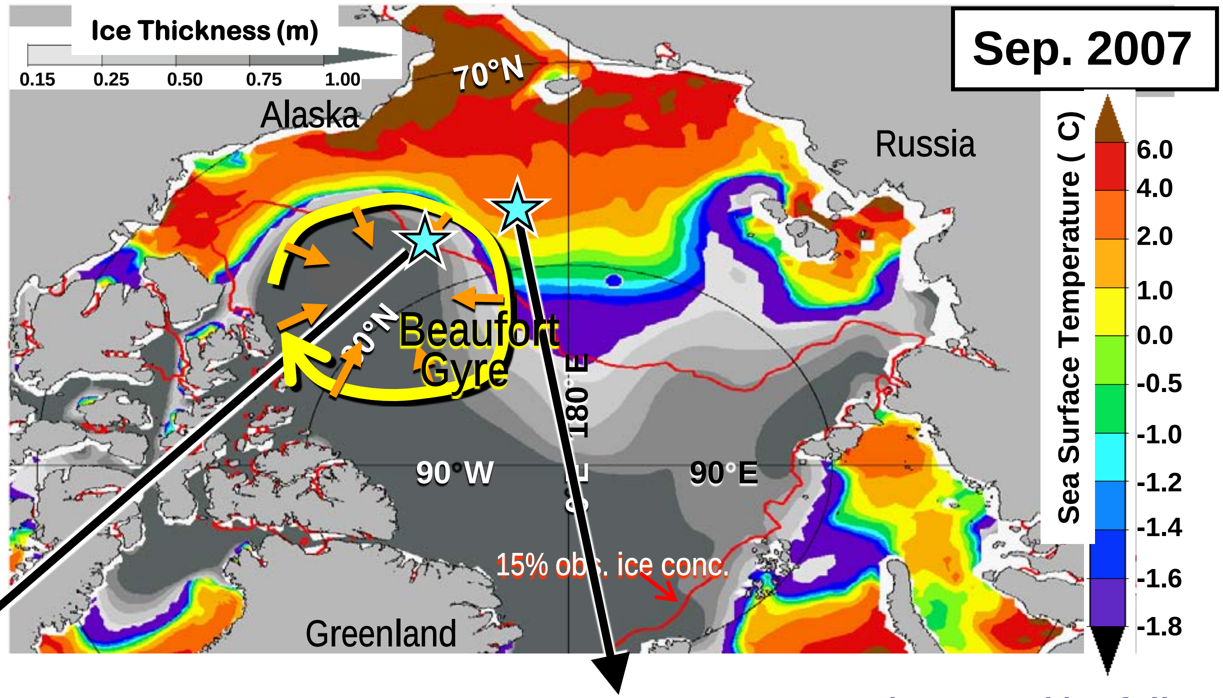
ITP data from 2007-2008: NSTM survives through the winter!

Data are sparse:
What can we learn about the NSTM from a <u>model</u>?

Steele et al. submitted (2010)

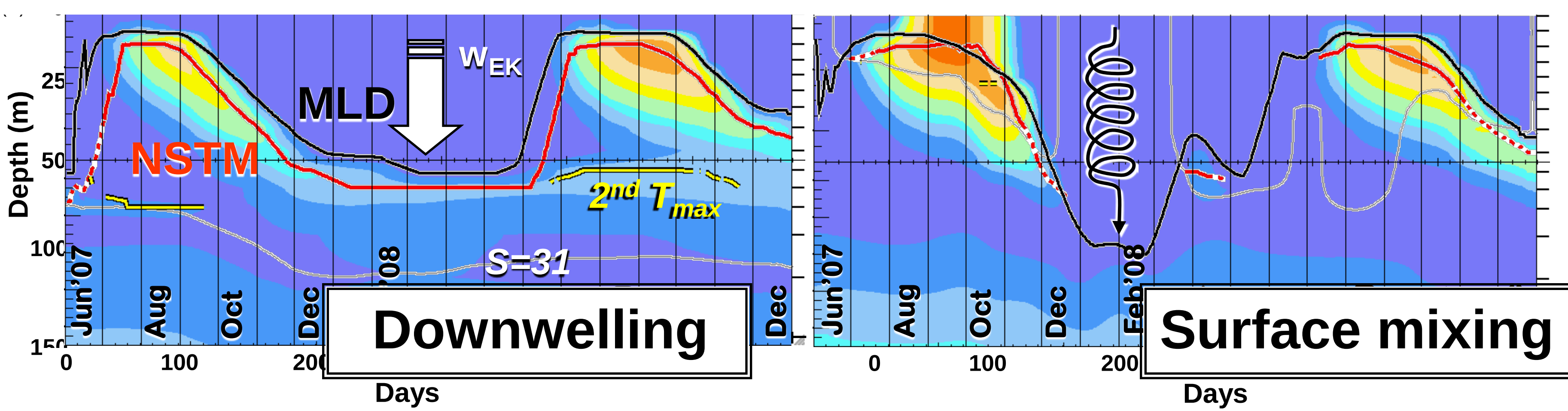
<u>Case study</u>:

June 2007 – December 2008

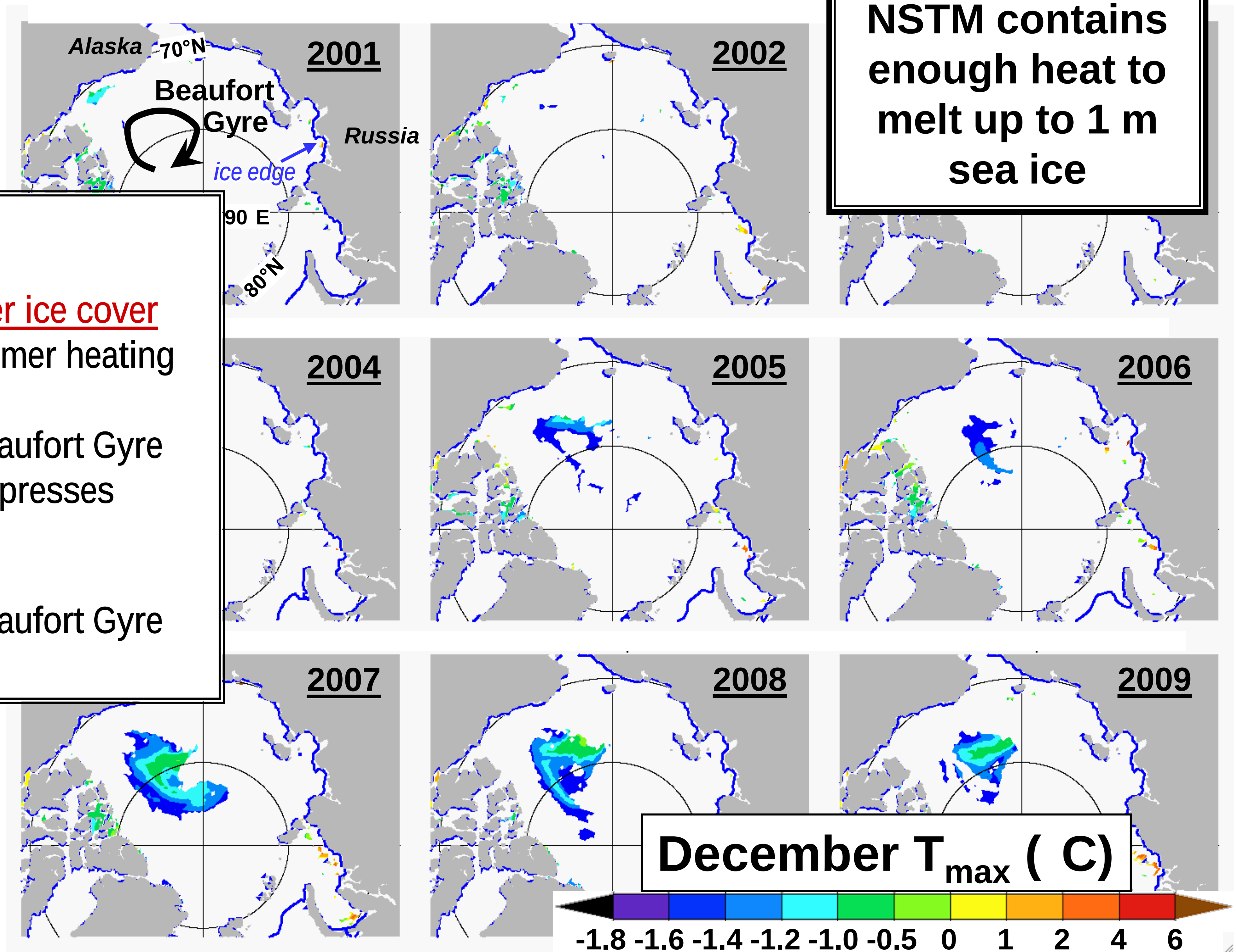


NSTM *survives through winter*

summer NSTM *destroyed by fall convection*



Recent winter survival of the NSTM: WHY?



NSTM contains enough heat to melt up to 1 m sea ice

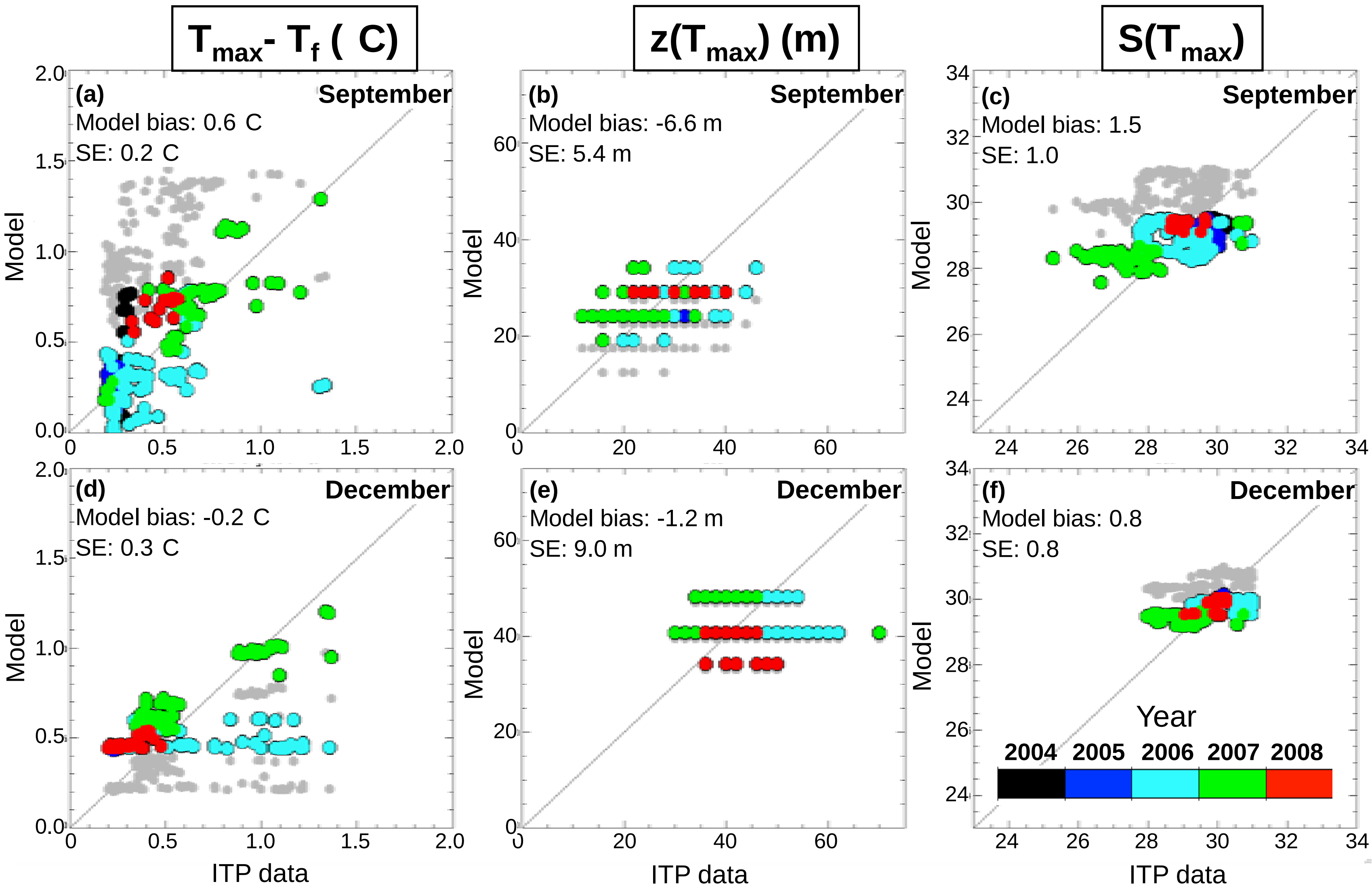
Three factors:

1.) Thinner, looser ice cover allows more summer heating

2.) Increasing Beaufort Gyre stratification suppresses surface mixing

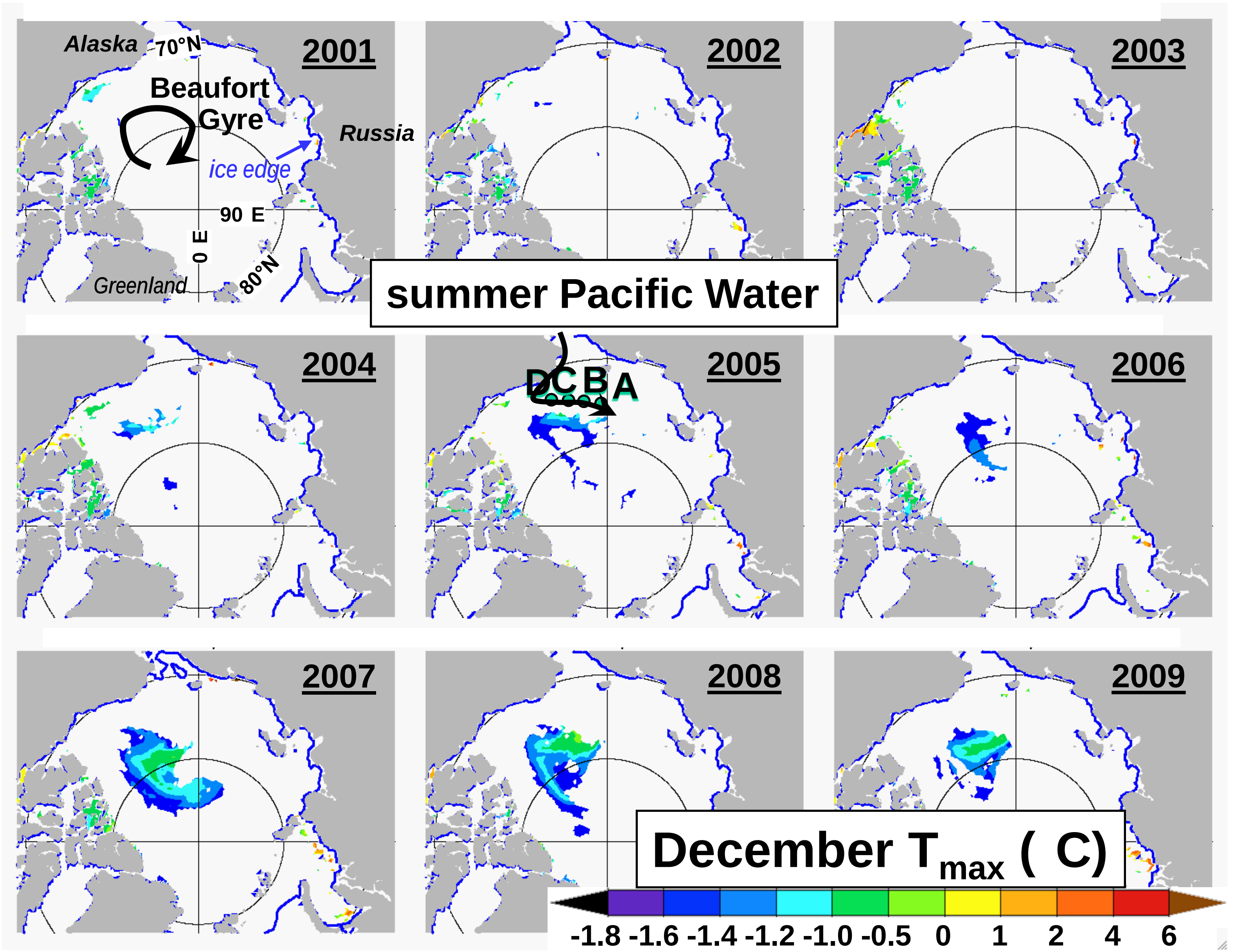
3.) Increasing Beaufort Gyre downwelling

Validation: model vs. ITP NSTM

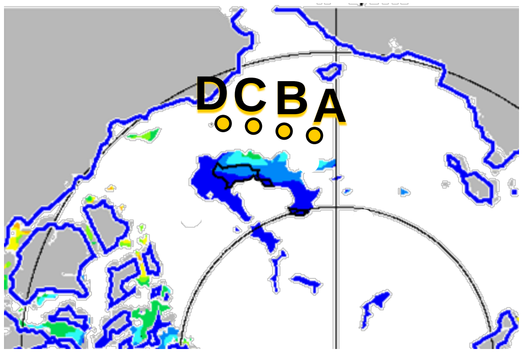


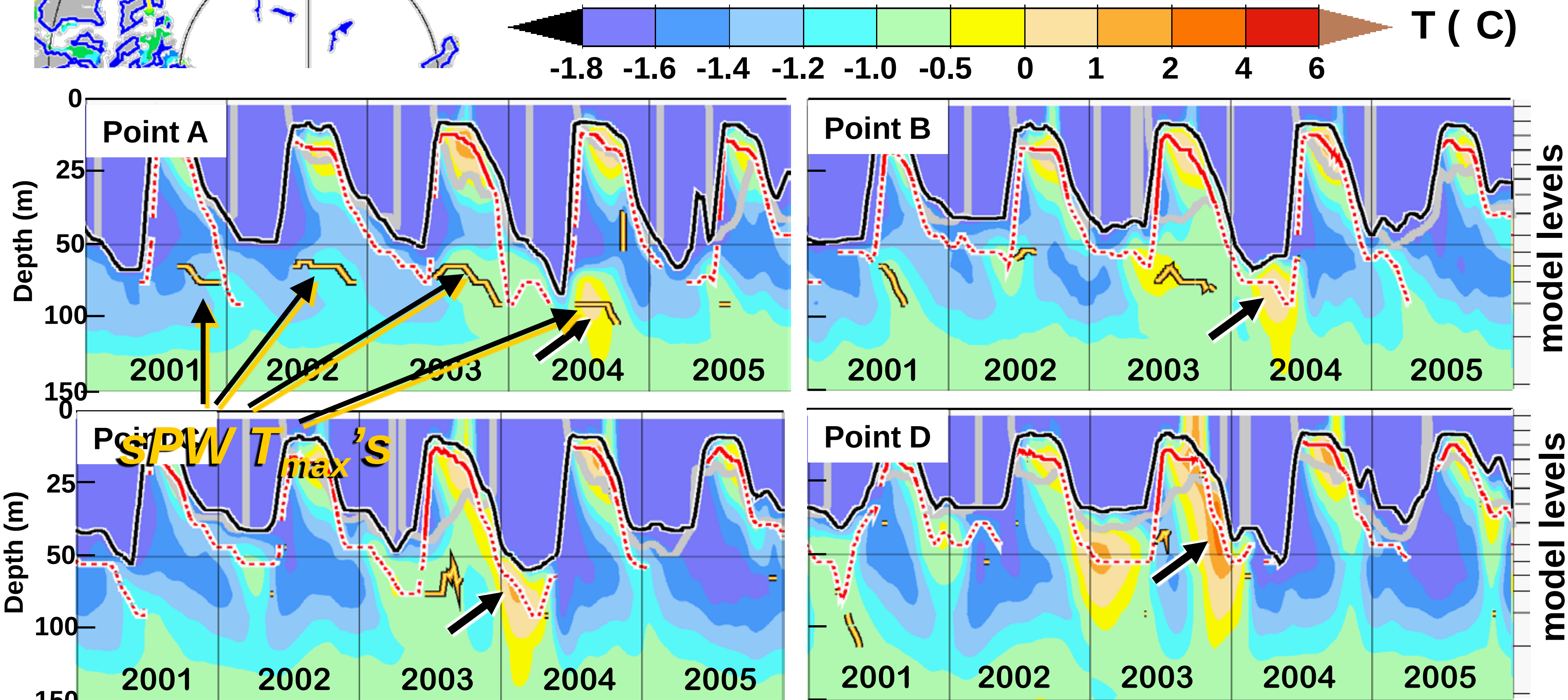
tenths of a ℃ error ***Model resolution error*** ***~1 ppt error***

Pacific Water



summer Pacific Water in the model: A sad story

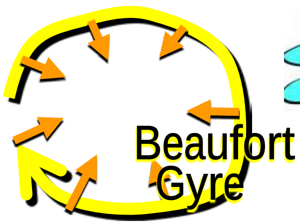


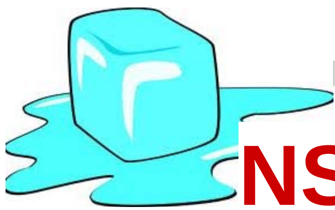


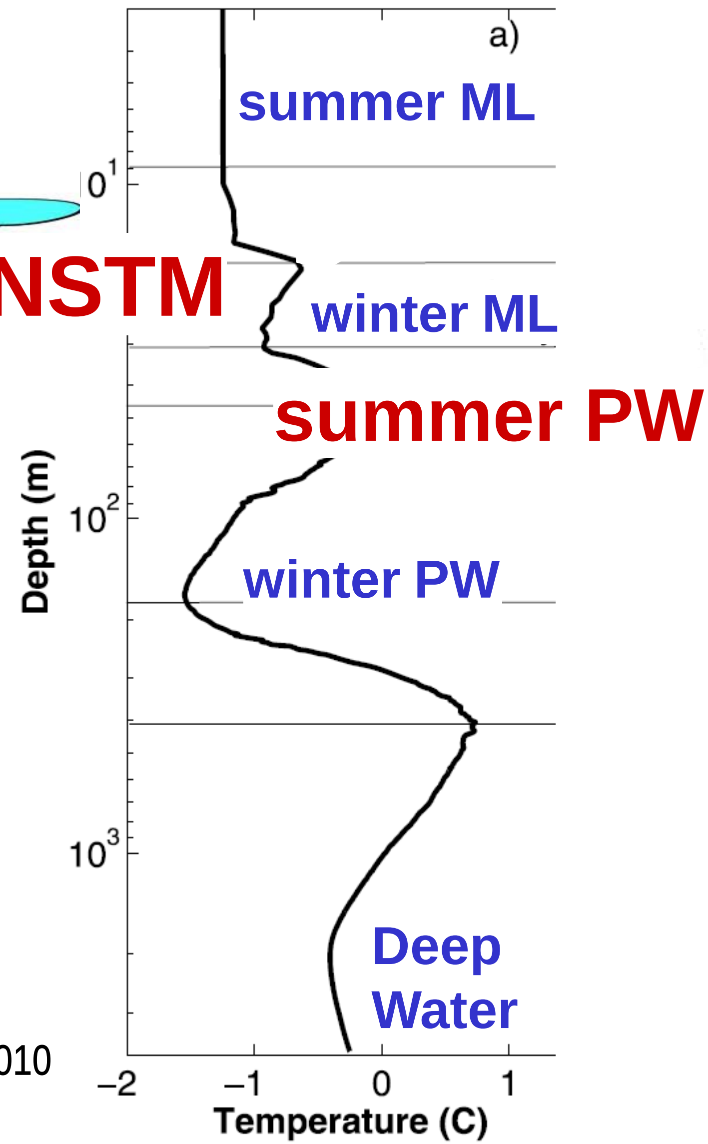
1.) sPW enters the Beaufort Gyre near NW Alaska, but…

2.) Model's <u>resolution/mixing is not adequate to maintain a sPW layer</u> at 70-100 m depth.

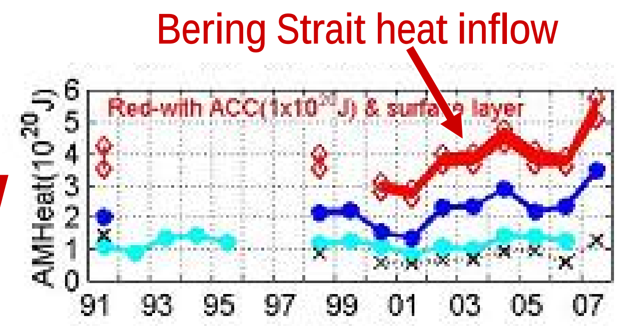
The future?







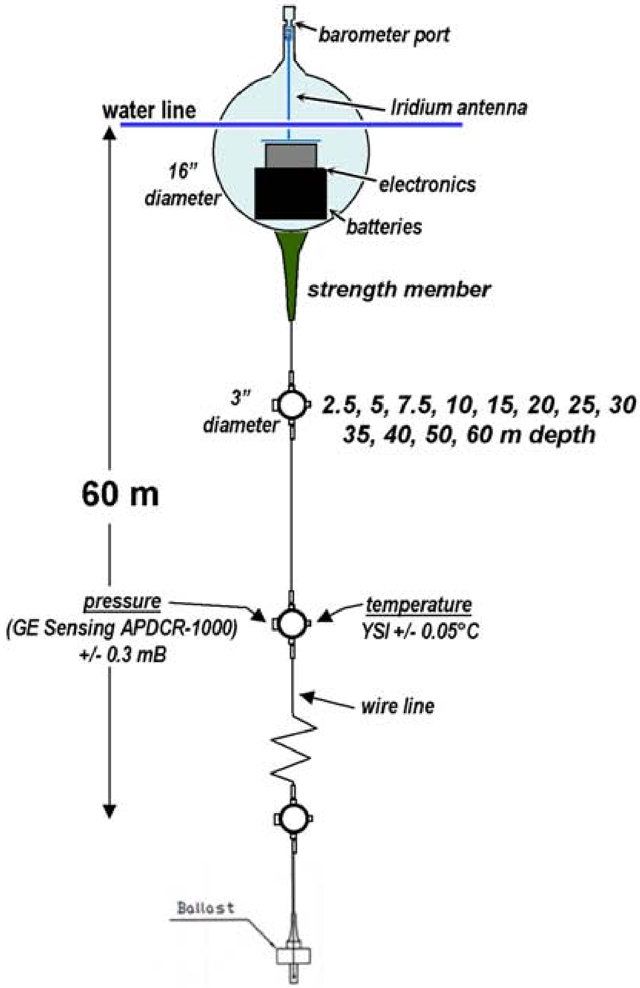
adapted from
Jackson et al., 2010



Woodgate et al. GRL (2010)

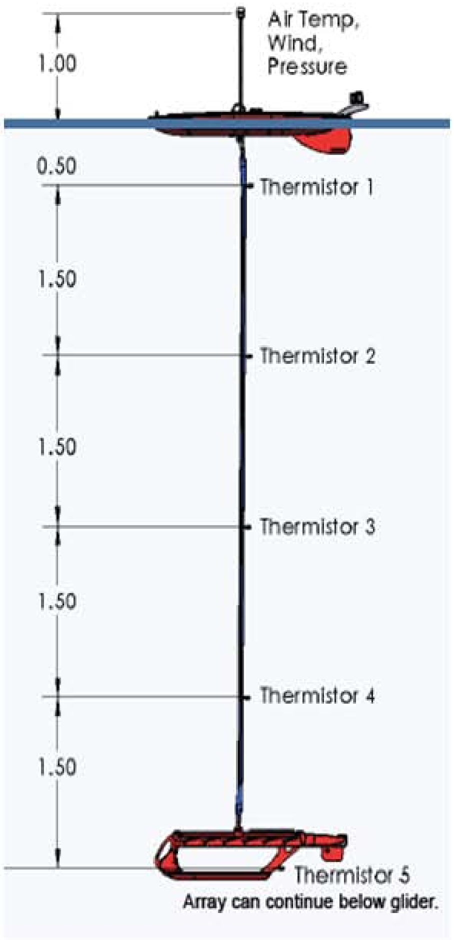
Measuring Upper Ocean Warming

buoys

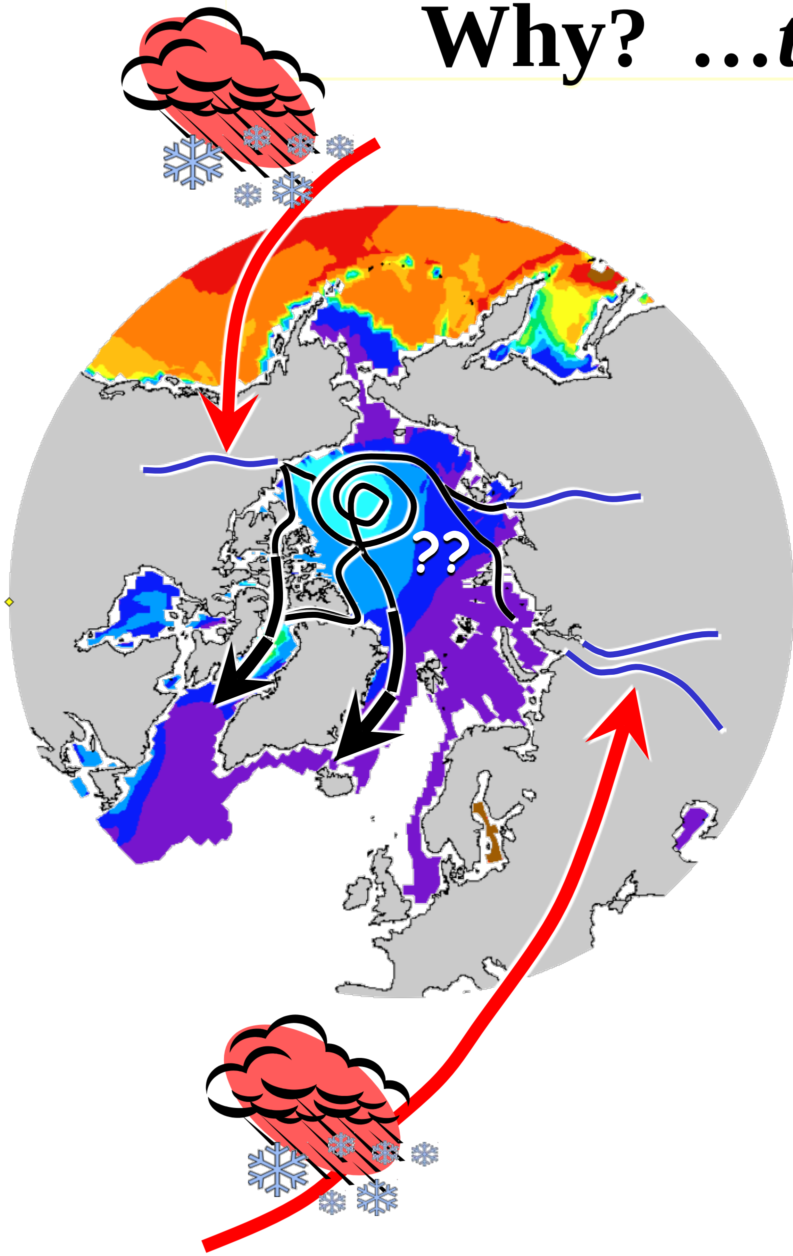


profiling floats

wave glider



The Arctic is the freshest ocean: Why? …*the first order view*



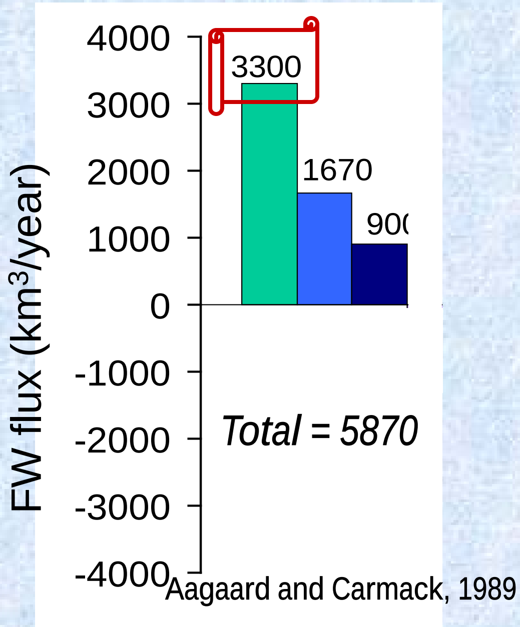
Atmos. moisture transport is the major source of FW …ie,

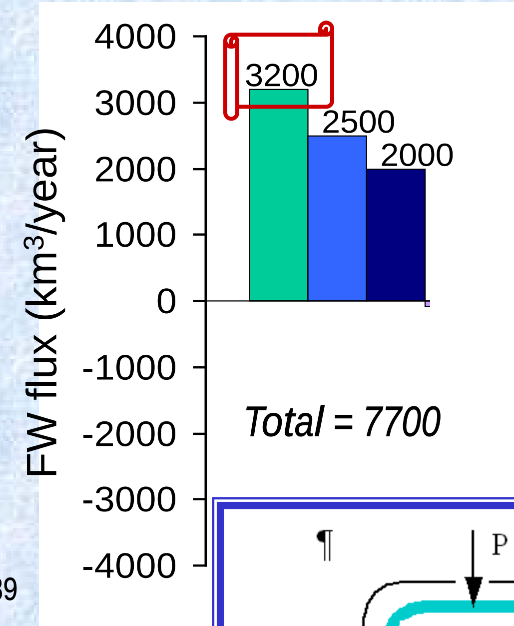
1) **storms → arctic drainage basins**

2) **rivers → ocean**
(ocean ↔ sea ice)

3) **ocean/sea ice → North Atl. Ocean**

Consider **all** the FW inputs





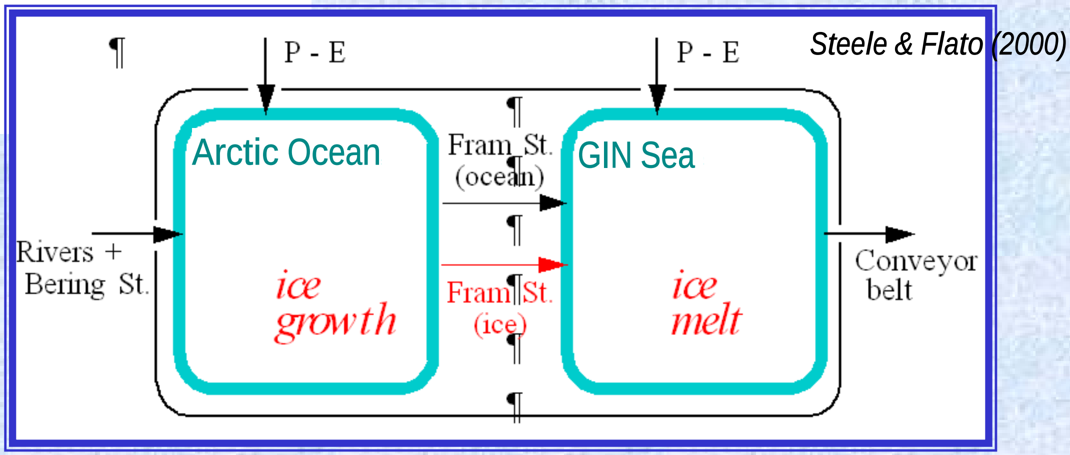
River Runoff

Bering Strait liquid

Woodgate et al., 2005

P-E

Russian ice camp data



Q: Where's the ice term?

summer is short…

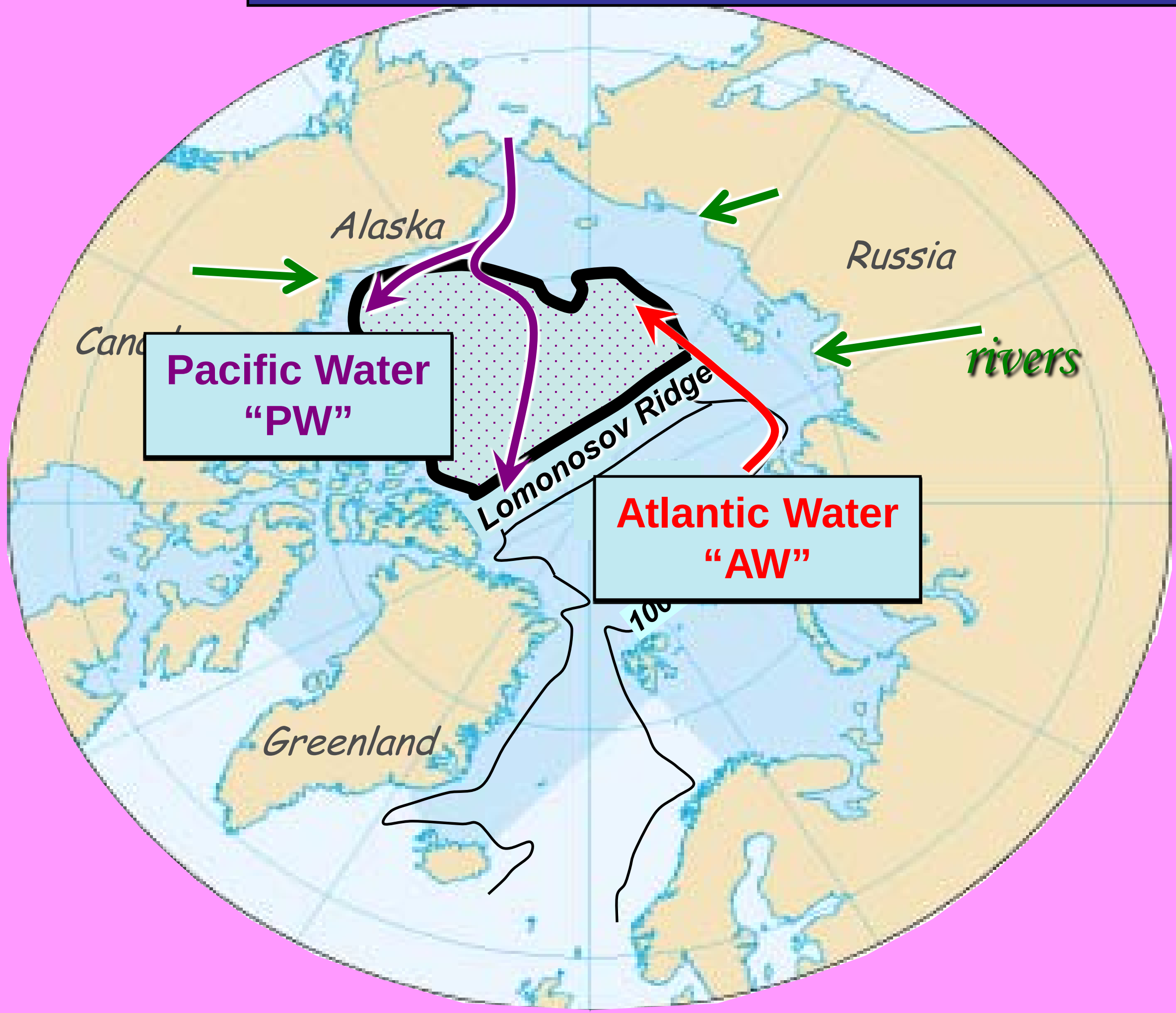
For the Arctic Ocean,

net sea ice GROWTH is a FW SINK ≅ 0.4 m/yr × 7 million km² = $\boxed{\text{2800 km}^3\text{/yr}}$

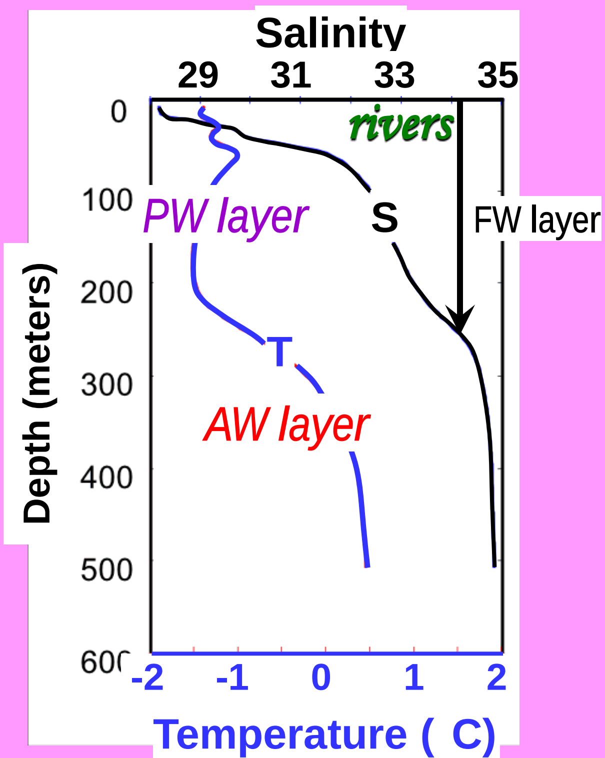
"river runoff → sea ice growth"

How it stacks up:

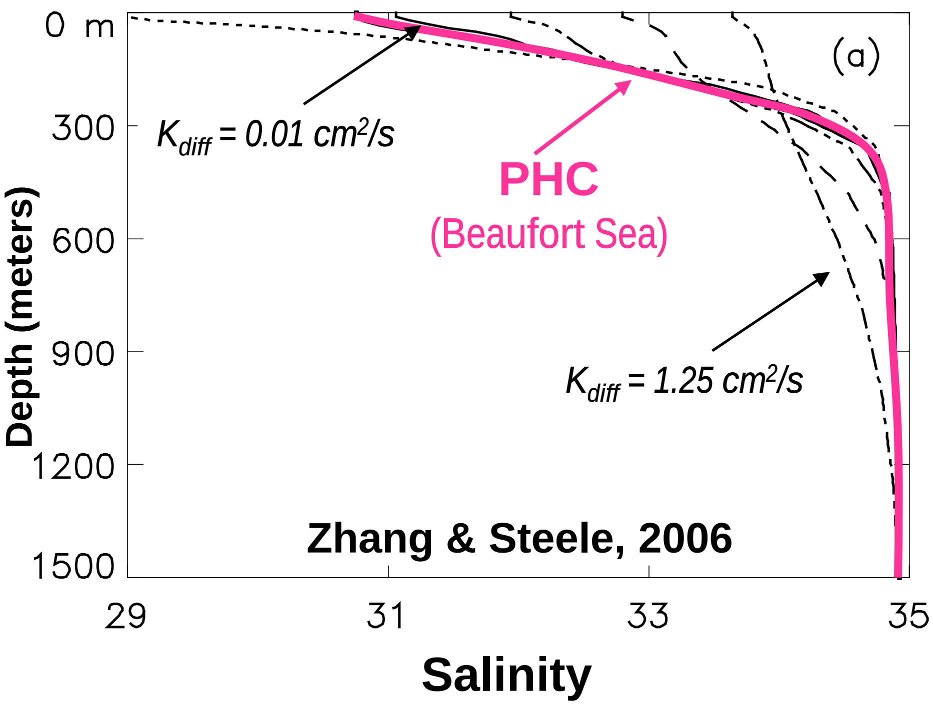
Ocean water mass structure in the *Beaufort Sea*



Winter profiles



Getting the right stratification:
The effect of "background mixing"



fresh layer

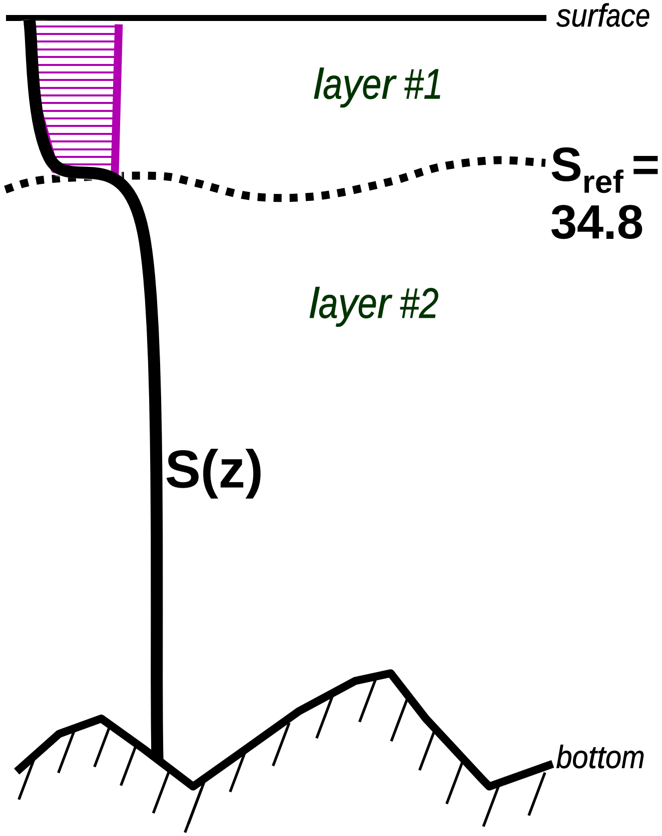
Atlantic Water layer

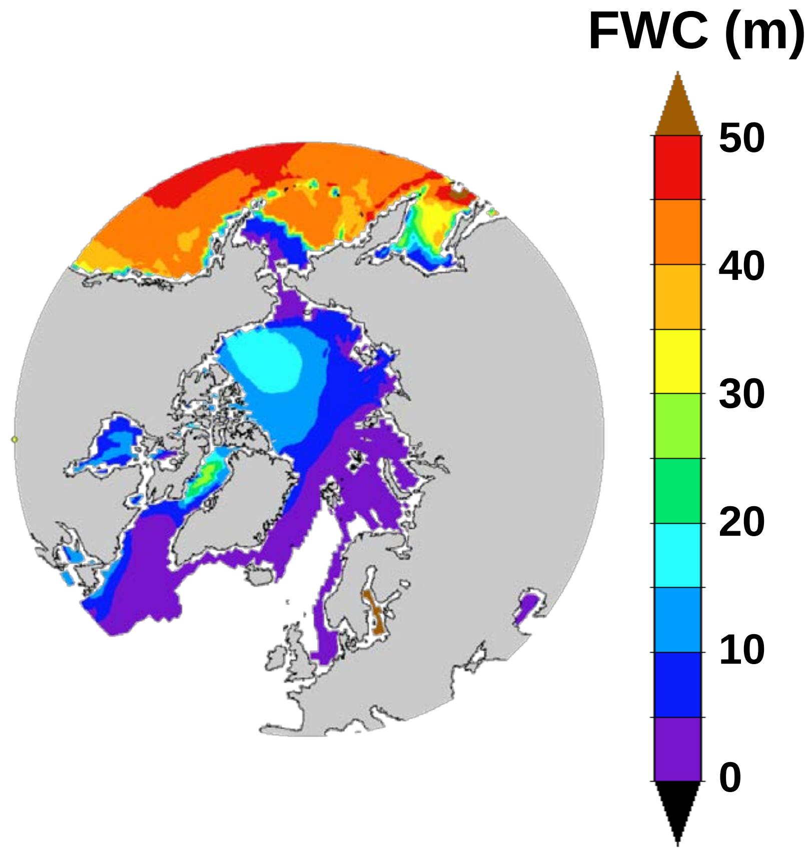
"Typical" $K_{diff} \cong 0.1$ cm^2/s; Need to *reduce mixing to levels 10 times less!*

…it's ok: sea ice suppresses mixing! *(D'Asaro & Morison, 1992)*

…for now, anyway: (Rainville & Woodgate, 2009)

FWC =
Vertical integral of FW

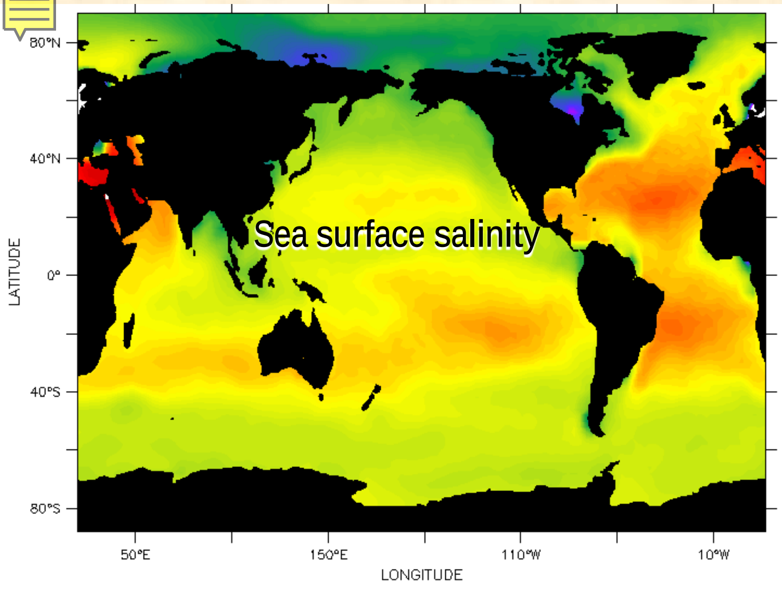




$$\mathrm{FWC} \equiv \int_{S=34.8}^{0} (S_{ref} - S)/S_{ref}\, dz$$

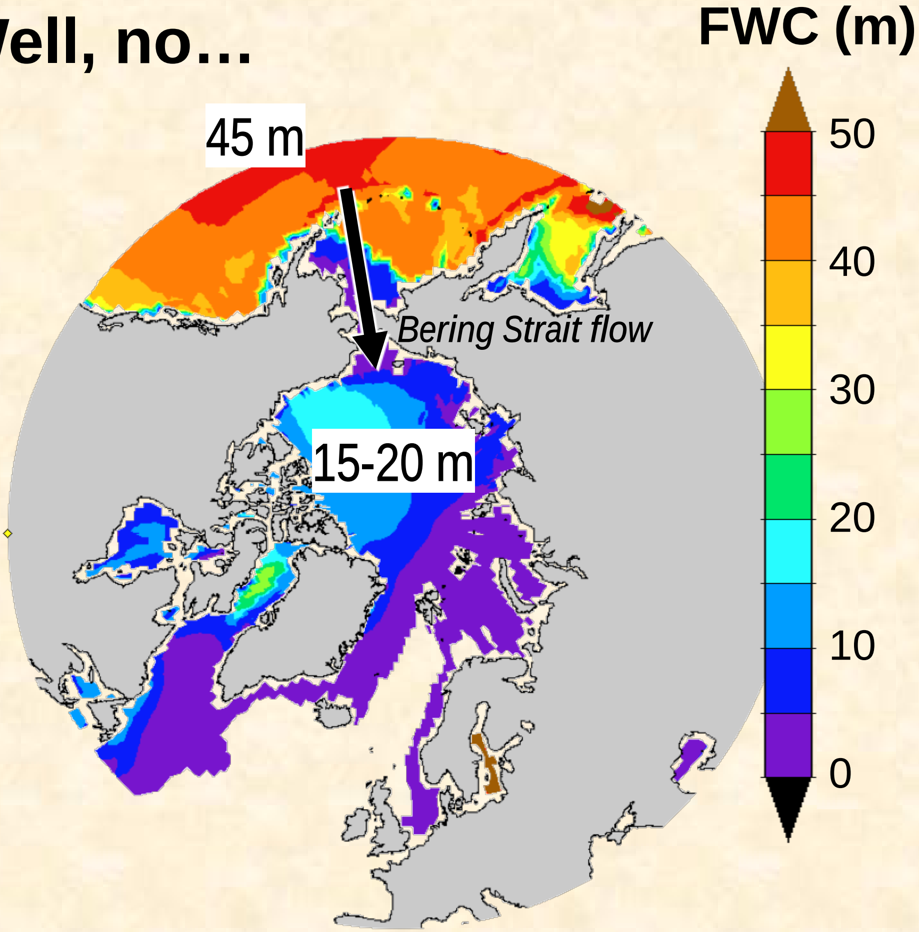
Units: meters

Sea ice melt: ~1 or 2 m/yr



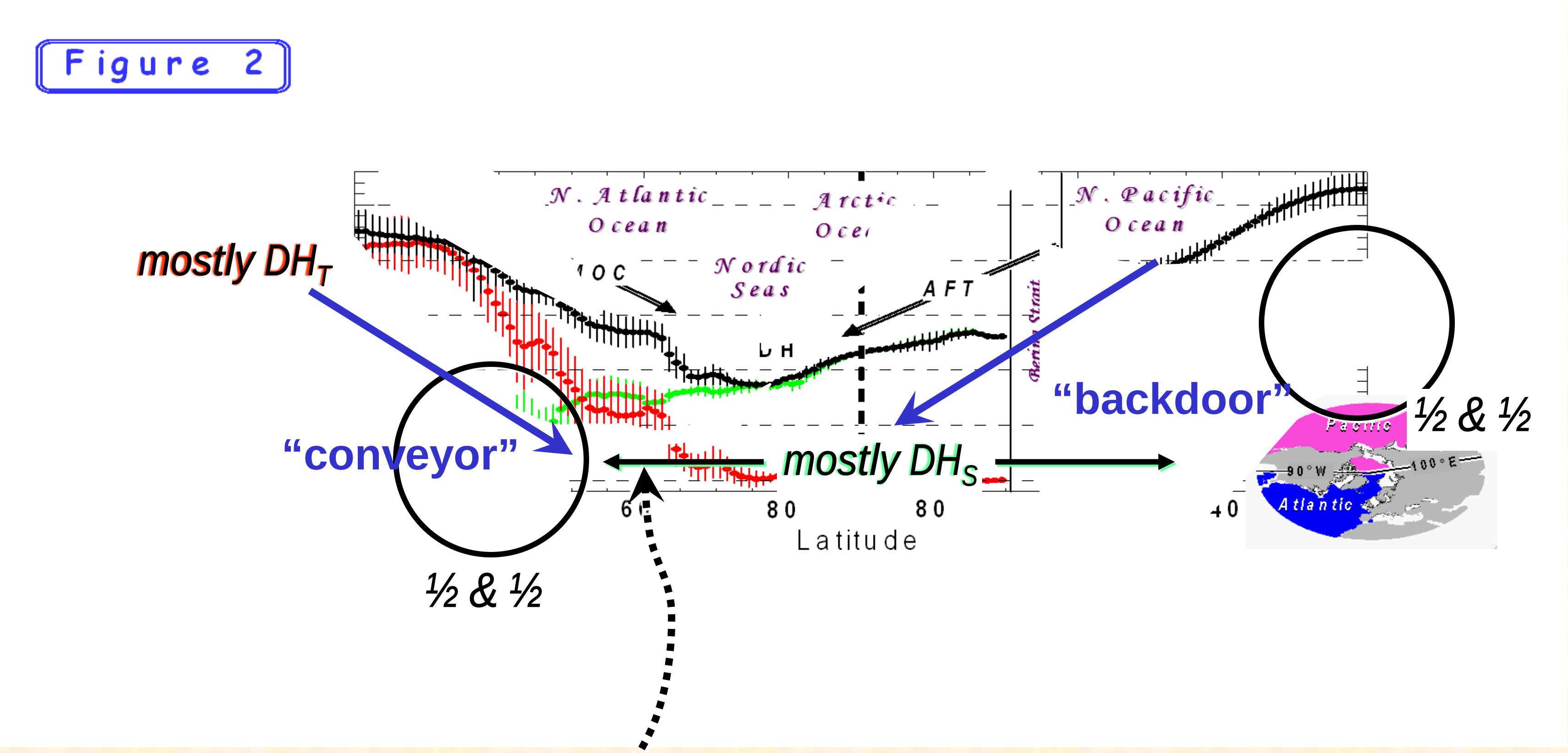
"The Arctic is the freshest ocean!"

Well, no…



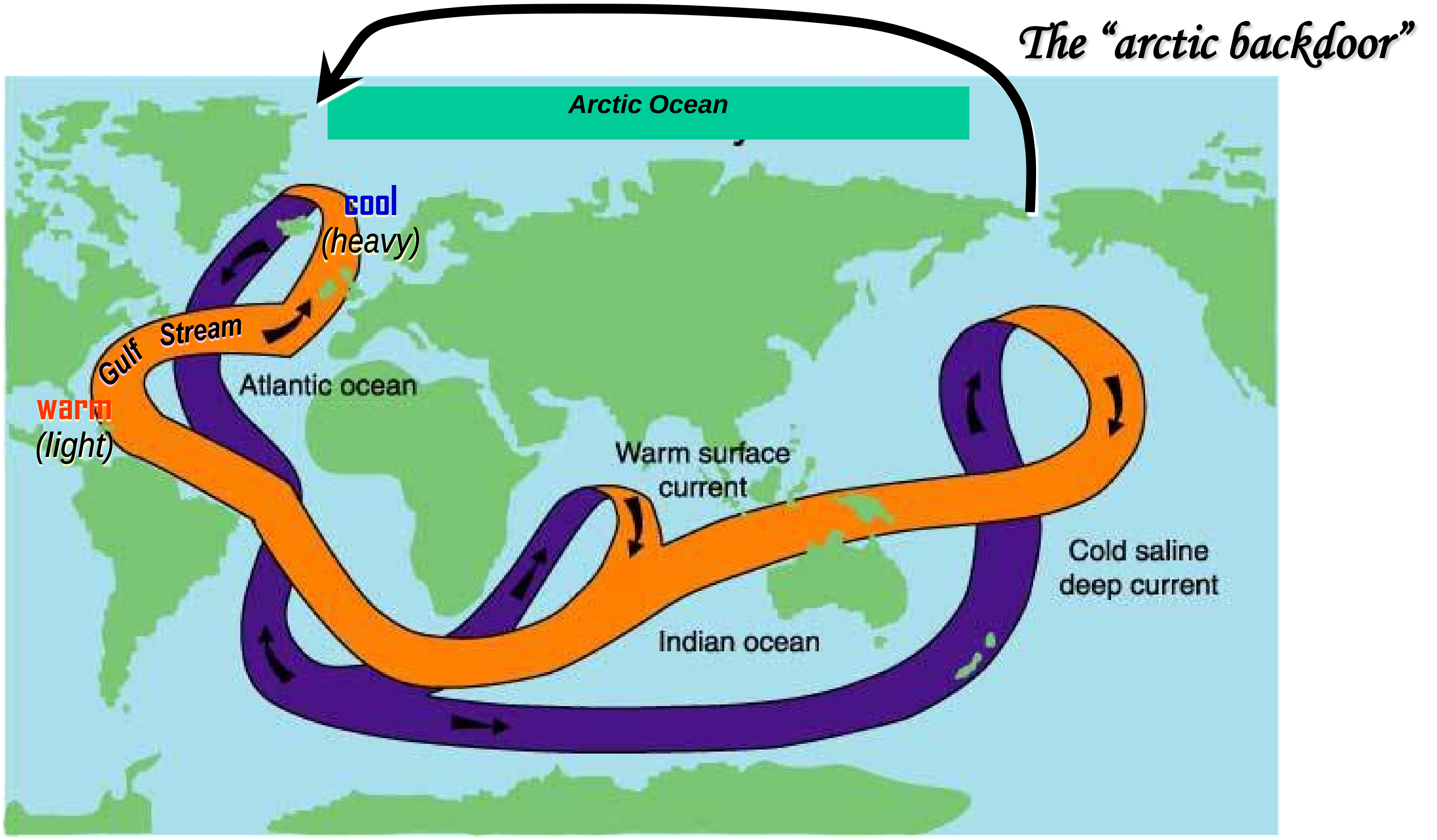
FWC ≅ factor * steric height

DH: The zonal mean view



Nordic Seas "potential well"

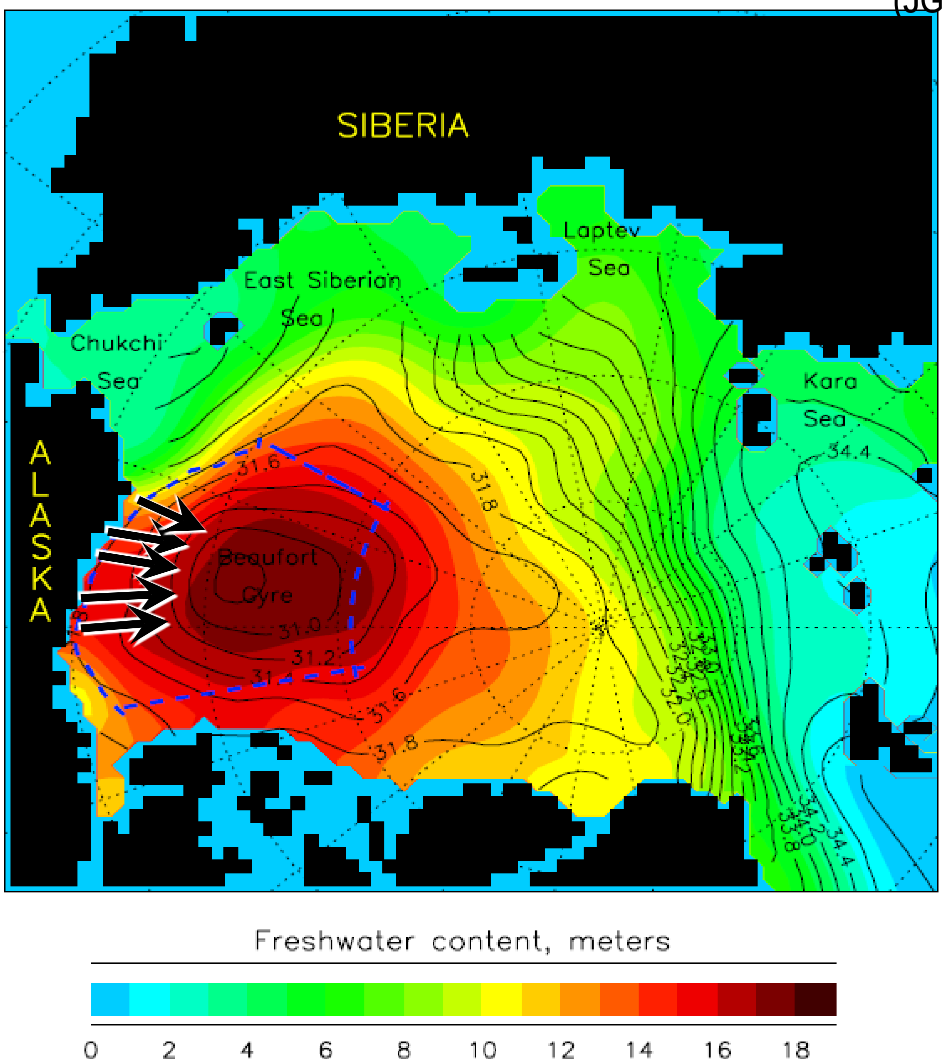
Ocean circulation pathways



FWC: Seasonal changes

PROSHUTINSKY ET AL.: BEAUFORT GYRE FRESHWATER RESERVOIR

(JGR, 2009)



There's 2 seasonal maxima:

June/July:

FWC **peak #1** from **ice melt**

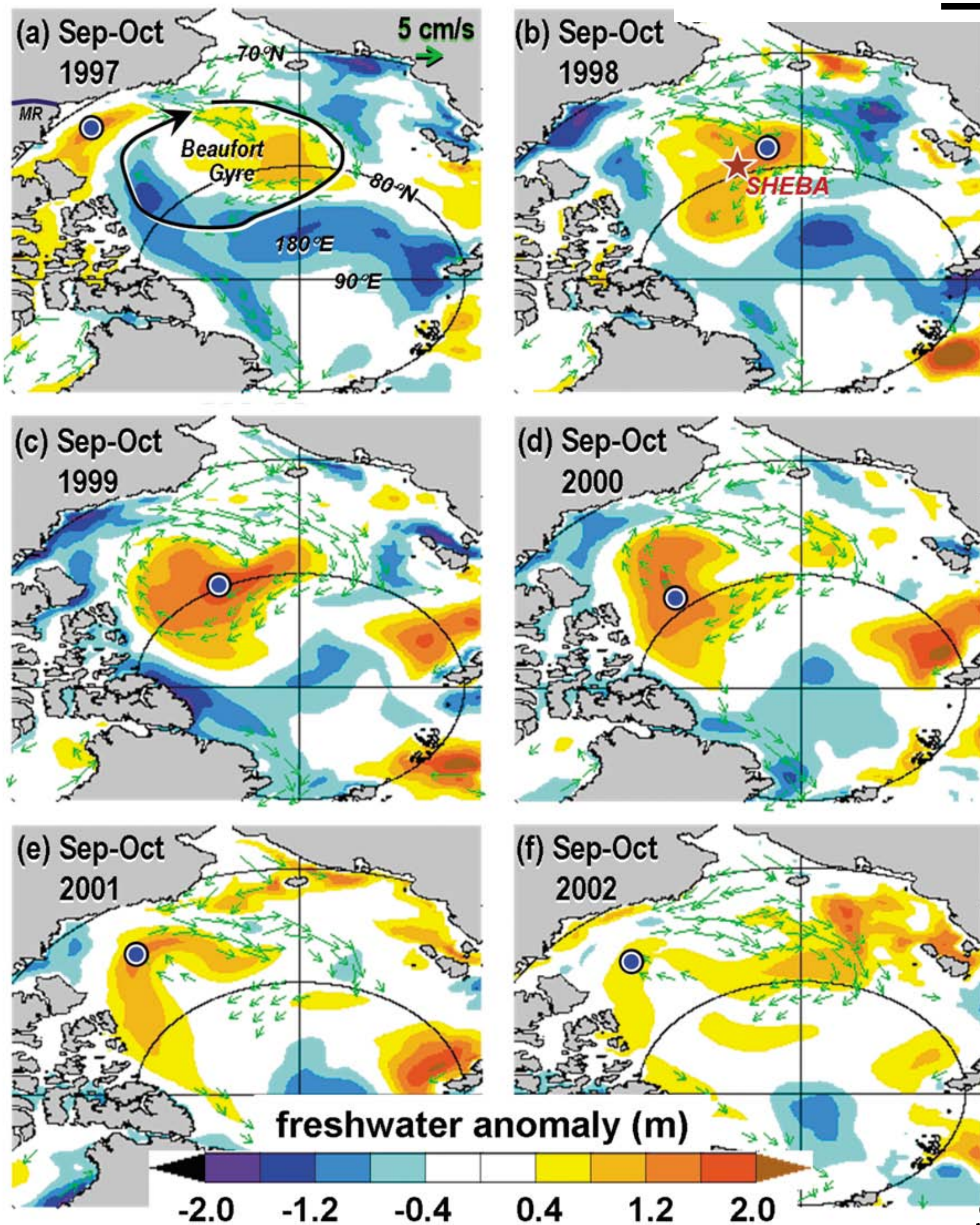
→ *upper layer freshening*

Nov/Dec/Jan:

FWC **peak #2** from **Ekman convergence**

→ *upper layer deepening*

FWC: Interannual variability



Steele et al. 2006

The SHEBA FW anomaly: A model study

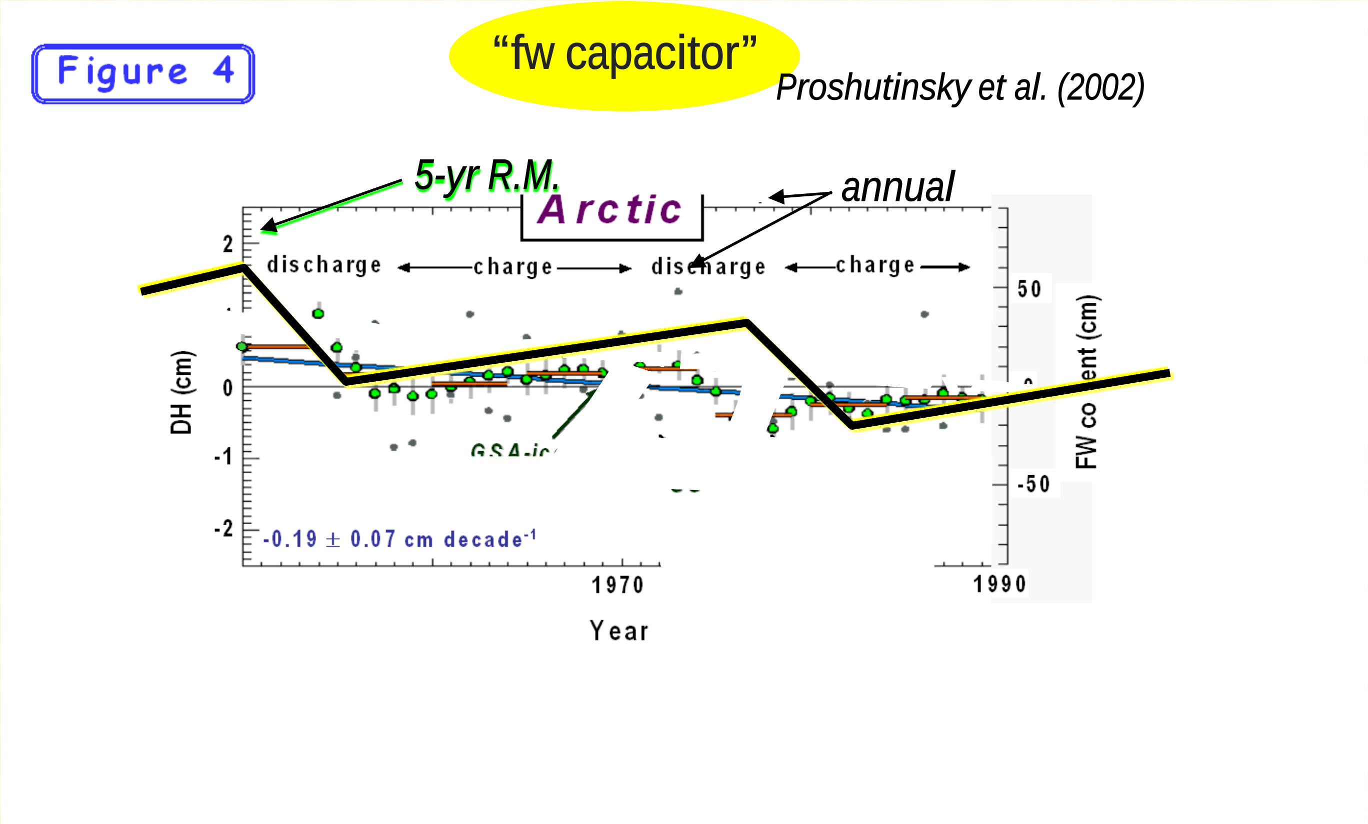
- Mackenzie River *fed FW into the Beaufort Gyre*, <u>as observed</u>, forced by:
- anomalously *strong fall SE'lies* (i.e., strong BG)
- 2007: another strong summer/fall BG anti-cyclone!

Future of the BG anticyclone?

Longer term pan-Arctic Ocean FWC

…anomalies

Steele & Ermold, 2007

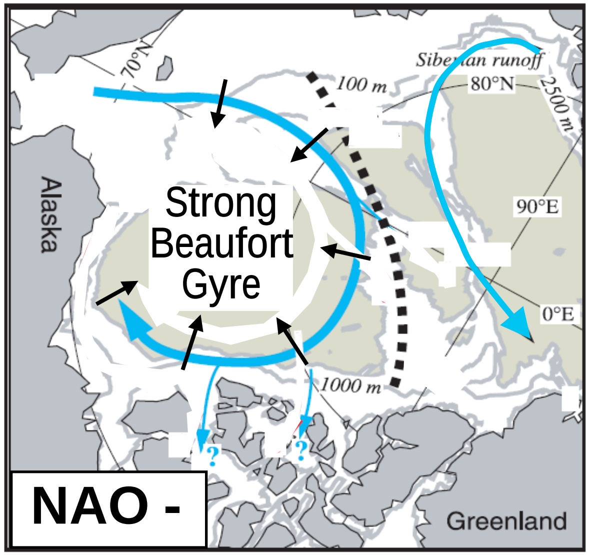


Polyakov et al. (2008):

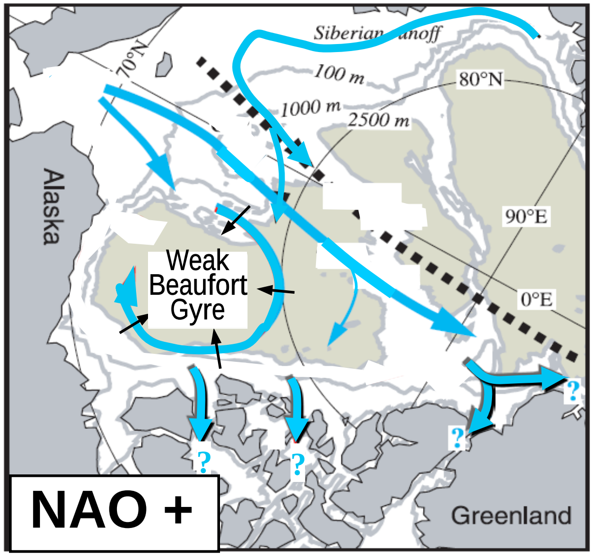
Downward trend → 1990s

Arctic Ocean getting SALTIER! Why?

Arctic FW
& the North Atlantic Oscillation

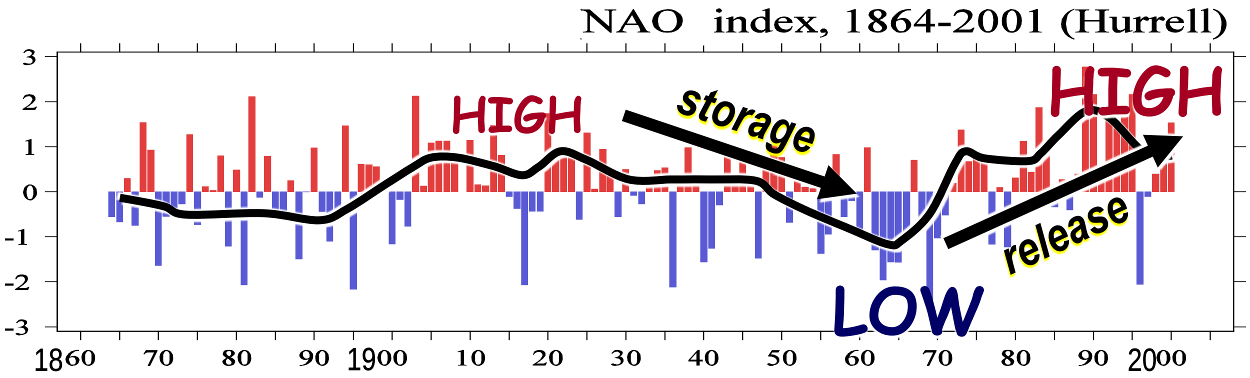


FW storage



FW release

Steele et al., 2004



Why did the Arctic Ocean get saltier?

It was the atmospheric forcing!

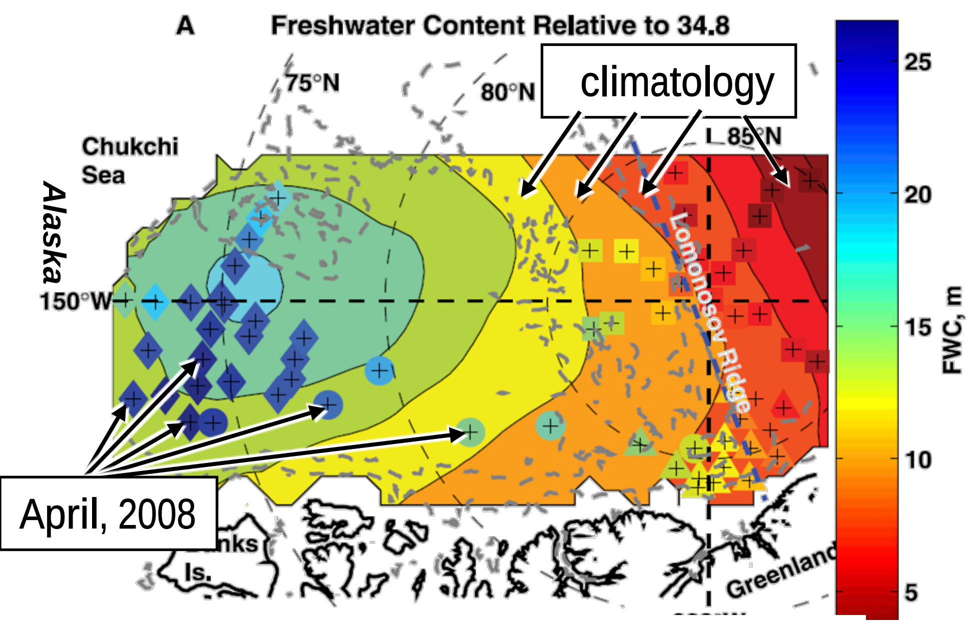
(i.e., winds → ice, ocean FW release)

(non-anthropogenic?)

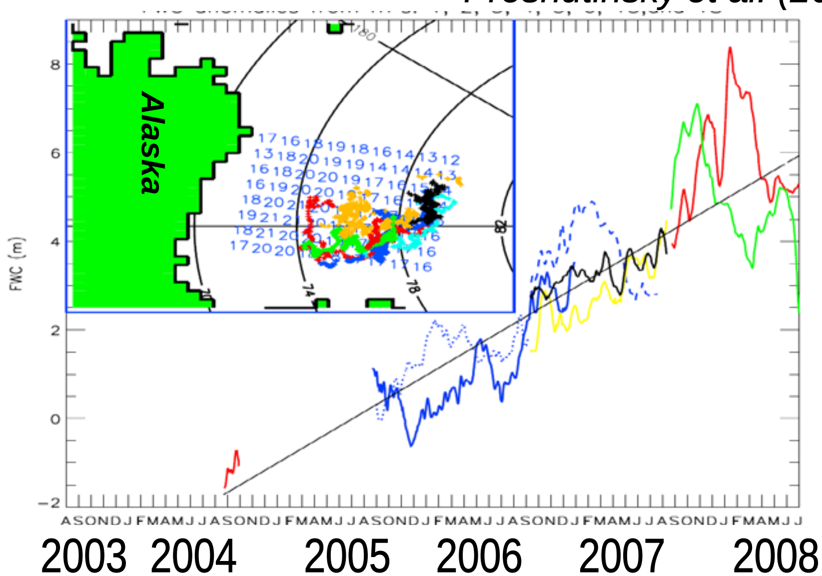
Incr. river discharge was a much *smaller* effect

The Beaufort Gyre in the 2000's

McPhee et al. (2009)

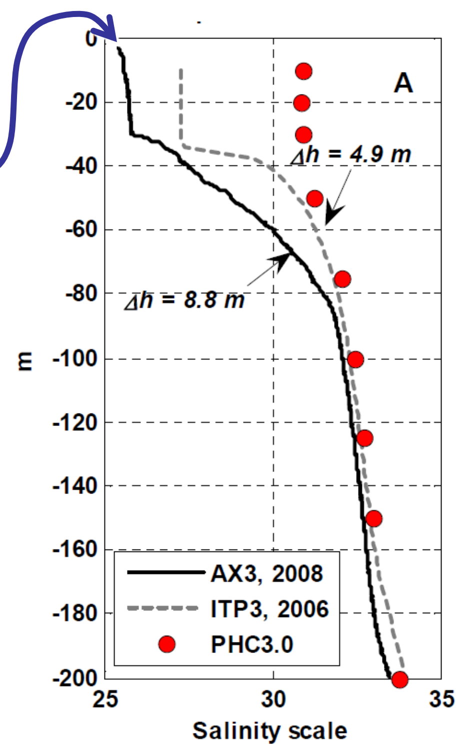


Proshutinsky et al. (2009)



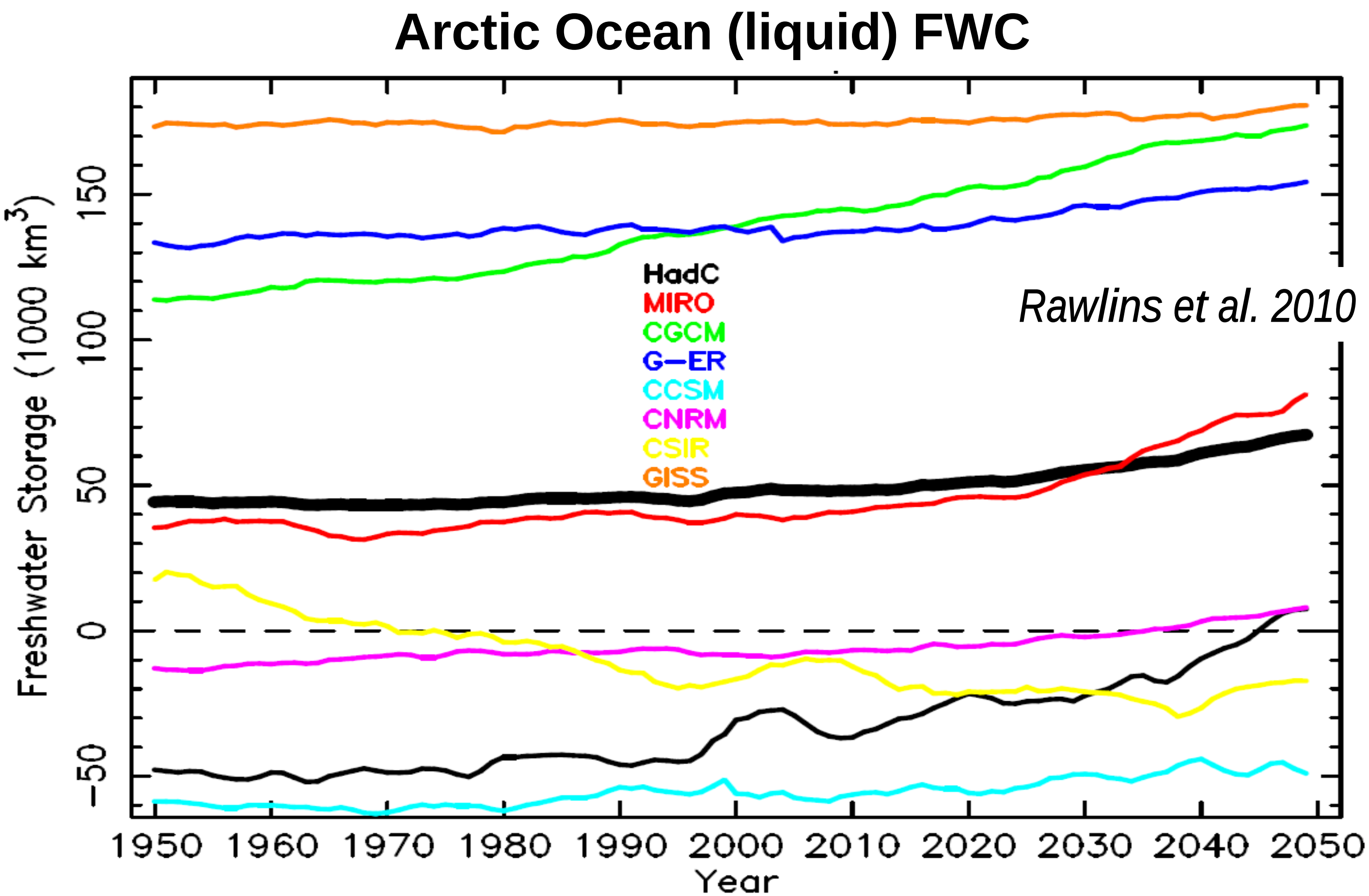
Increasing Beaufort Gyre FWC

winter
S ≅ 26!



The Longer-Term Future?

coupled model runs



The arctic will freshen …
… but when?!

Factors influencing Arctic Ocean circulation

- ***<u>sea ice thinning & retreat</u>***
  - ➢ **vertical momentum flux changes (*currents, waves, mixing*)**
  - ➢ **surface warming (*ice melt, tracer, density*)**
  - ➢ **vertical FW flux changes? (*density*)**
- ***<u>changes in the global hydrologic cycle</u>***
  - ➢ **incr. FW input (*density*)**
  - ➢ **altered Pacific-Atlantic ΔSSH? (*OMG!*)**

Arctic Ocean circulation modeling: What's new?

- **numerical improvements (*e.g, resolution*)**
- **better forcing (*e.g., atmos. reanalyses*)**
- **new tracers and diagnostics (*e.g., biology!*)**

Thank You

The arctic “sea ice refuge”
Lincoln Sea “Switchyard” project, 2009

The Changing Arctic:
Observation and Model Study

MUYIN WANG[1]
& JAMES E. OVERLAND[2]

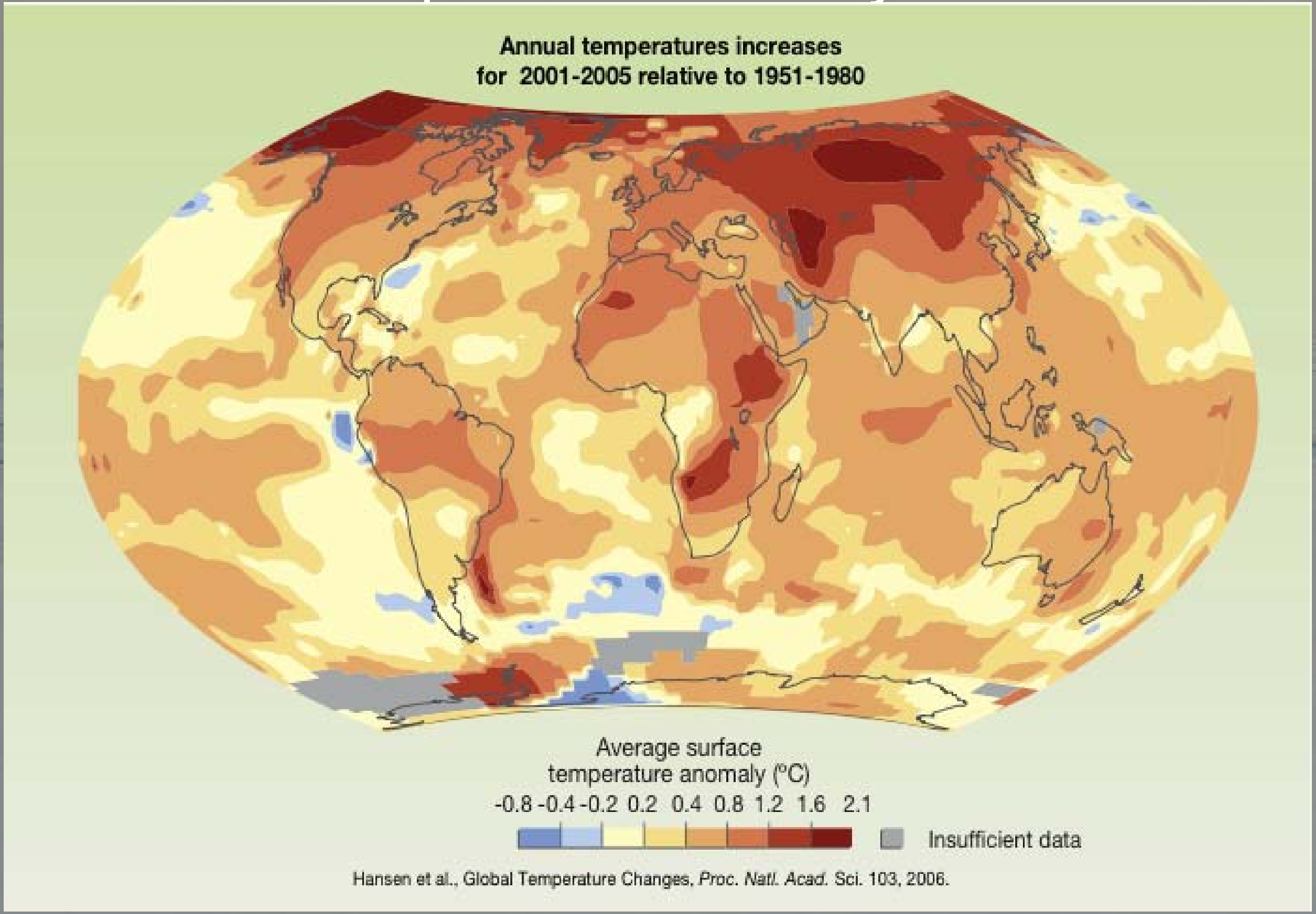
[1]JISAO/UW, [2]PMEL/NOAA

OUTLINE

- The observed changes in the Arctic
- Feedback mechanisms
- Model culling and projections of future Arctic Sea ice condition

#1 Wed Jul 07 14:48:31 2010 UTC
p: 11.0°C

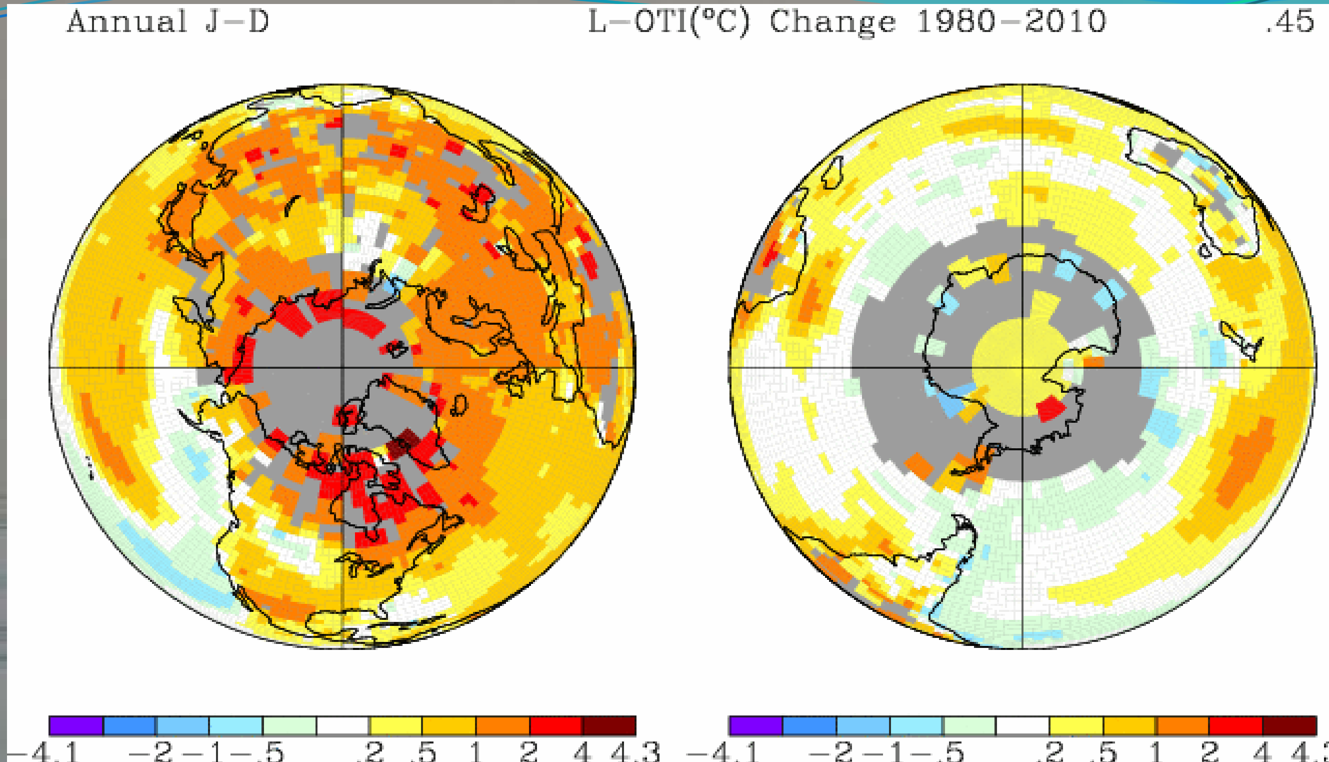
Surface Air Temperature Anomaly for 2001-2005

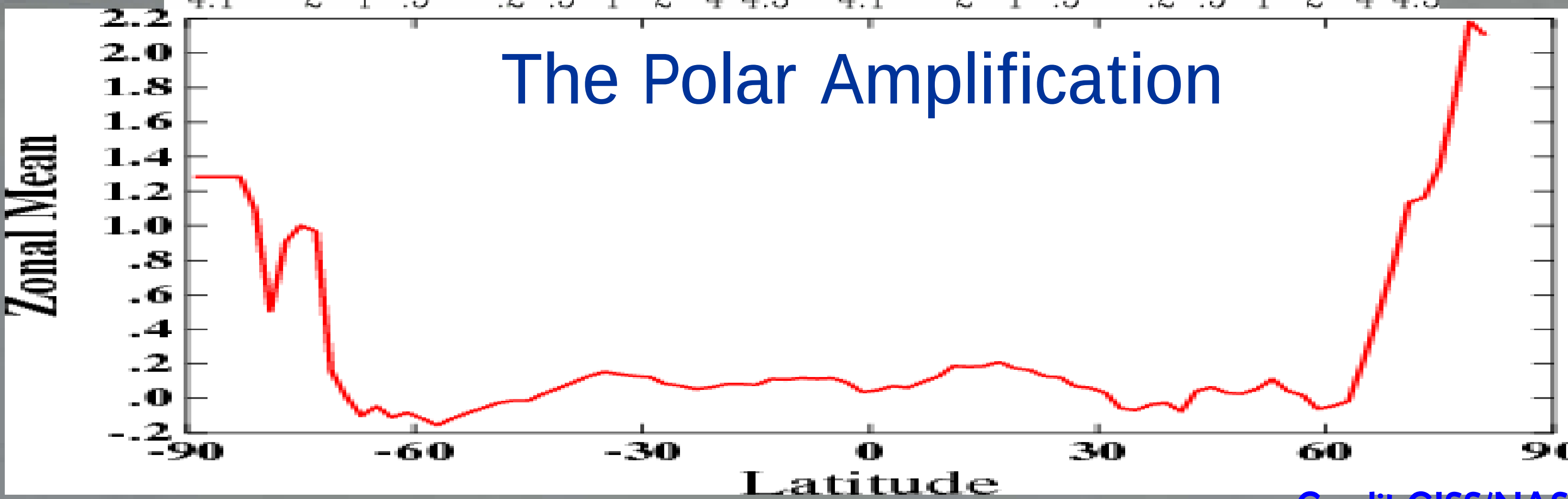


Warming is unequivocal – IPCC AR4

#1 Wed Jul 07 14:48:31 2010 UTC
p: 11.0°C

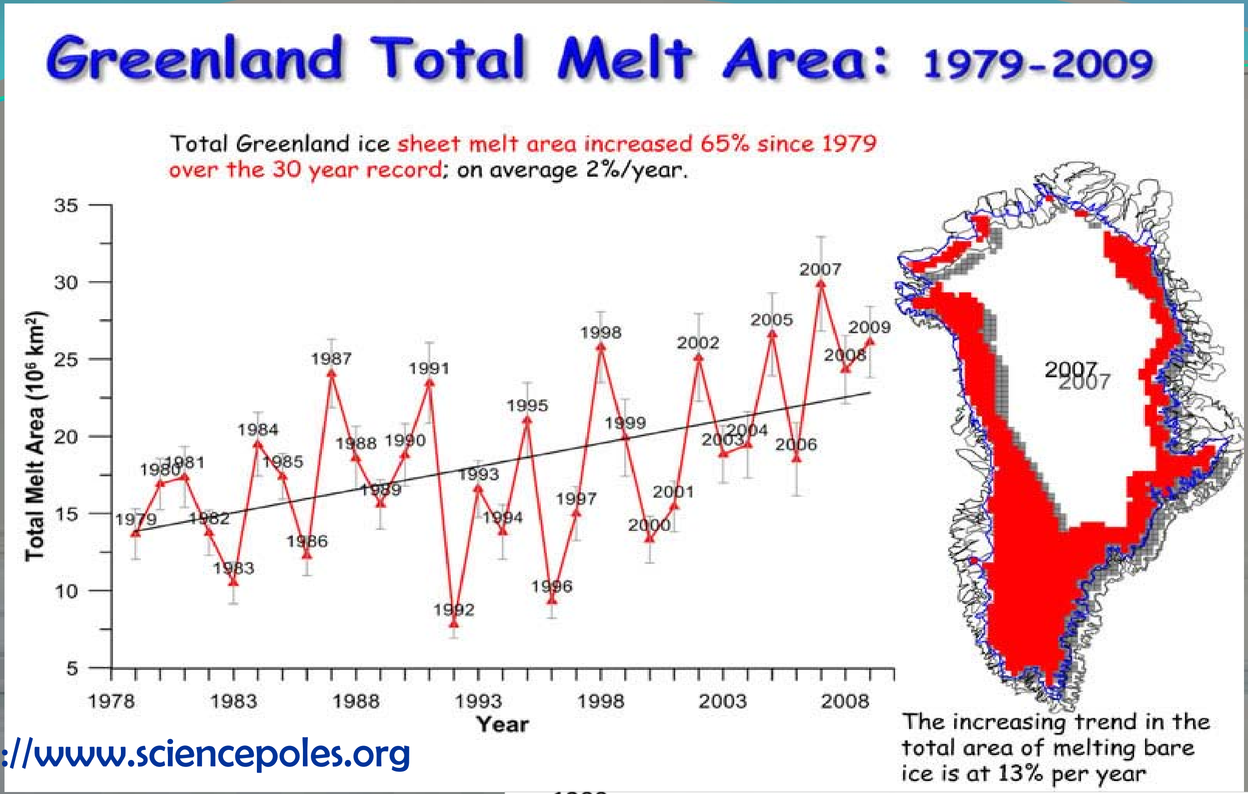
Annual Mean Surface Temperature Linear Trend



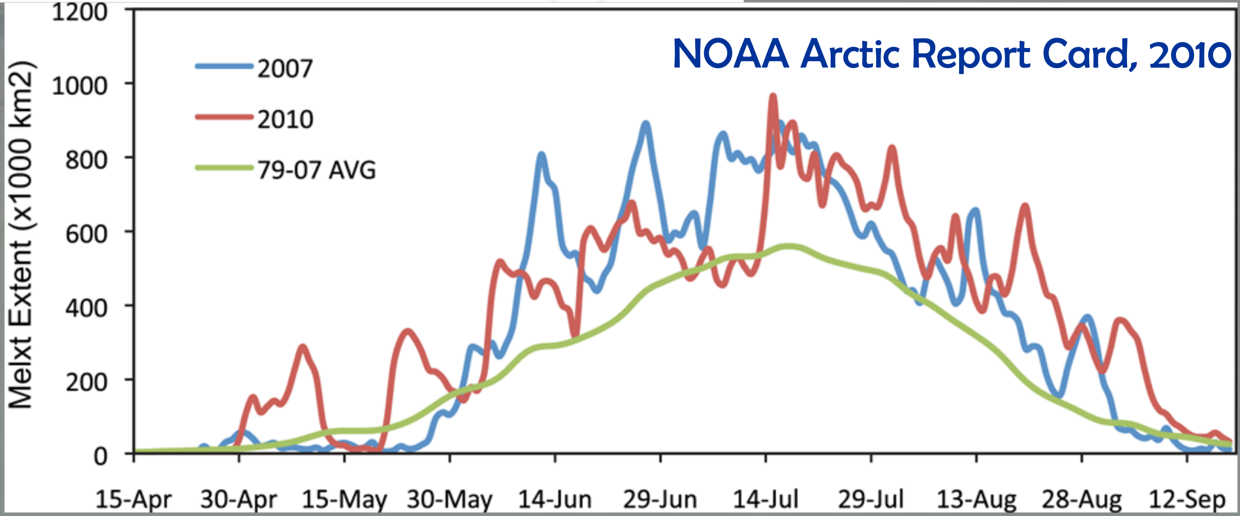


Credit:GISS/NASA

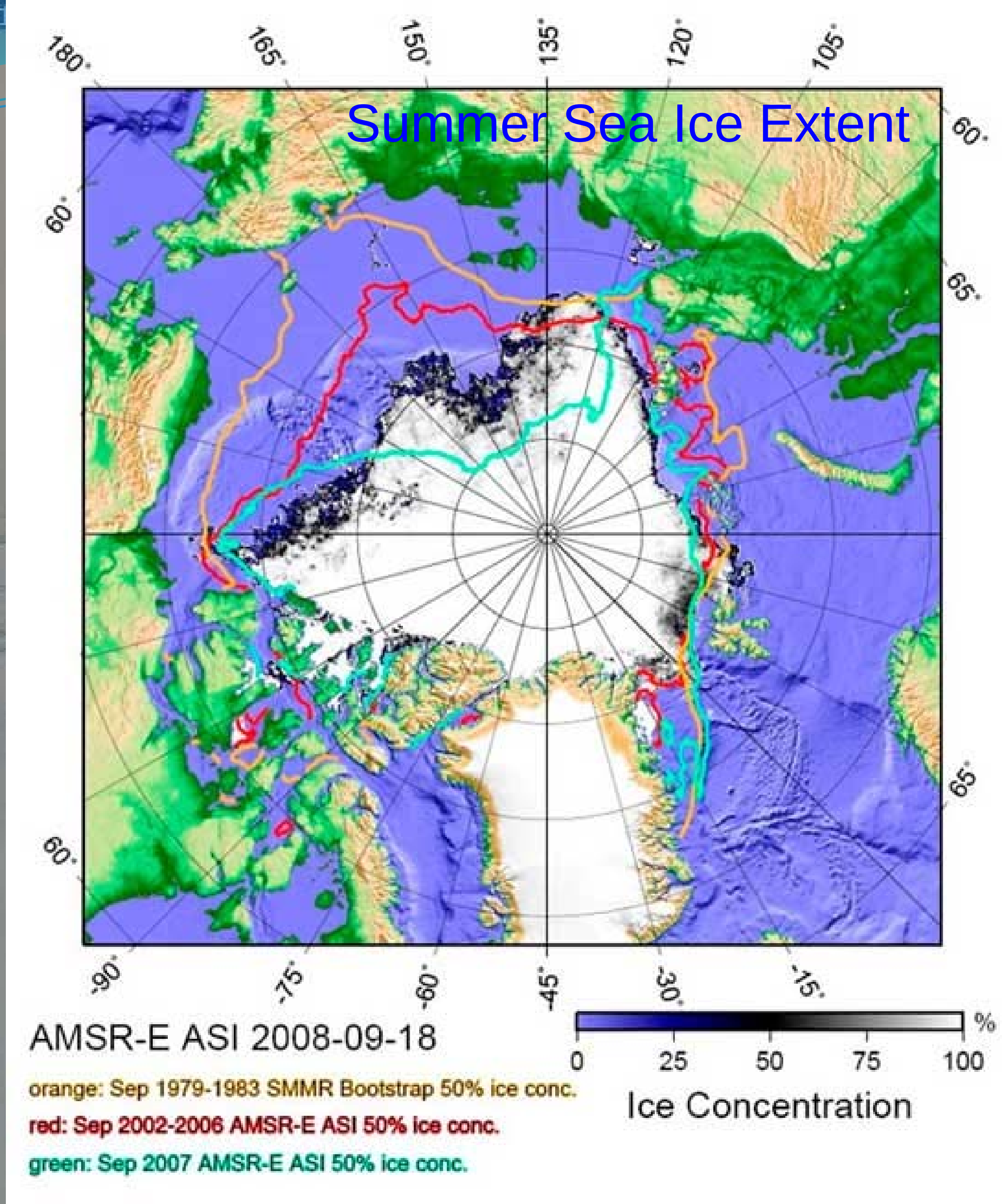
#1 Wed Jul 07 14:48:31 2010 UTC
p: 11.0°C



http://www.sciencepoles.org



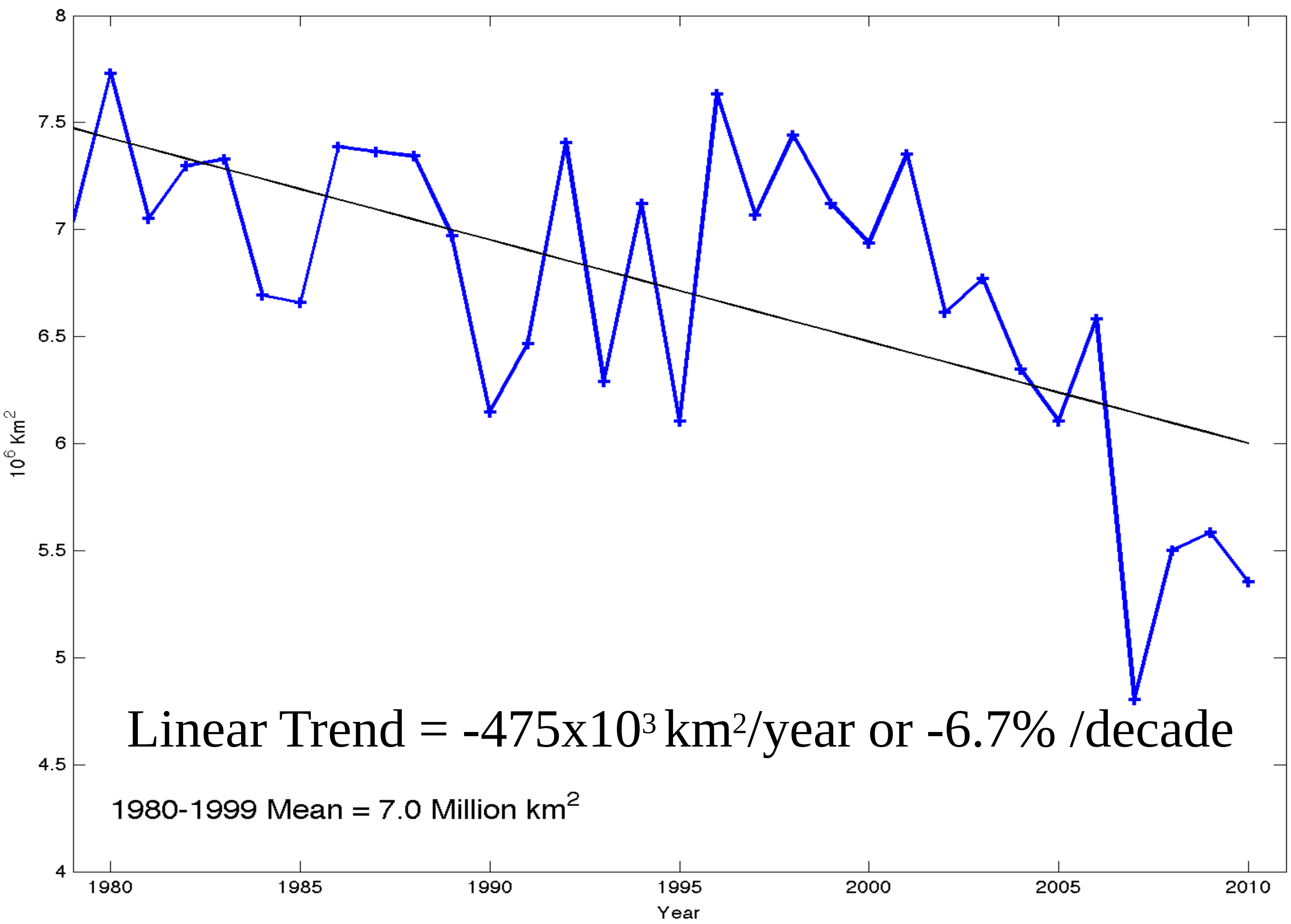
Summer Sea Ice Extent



University Bremen

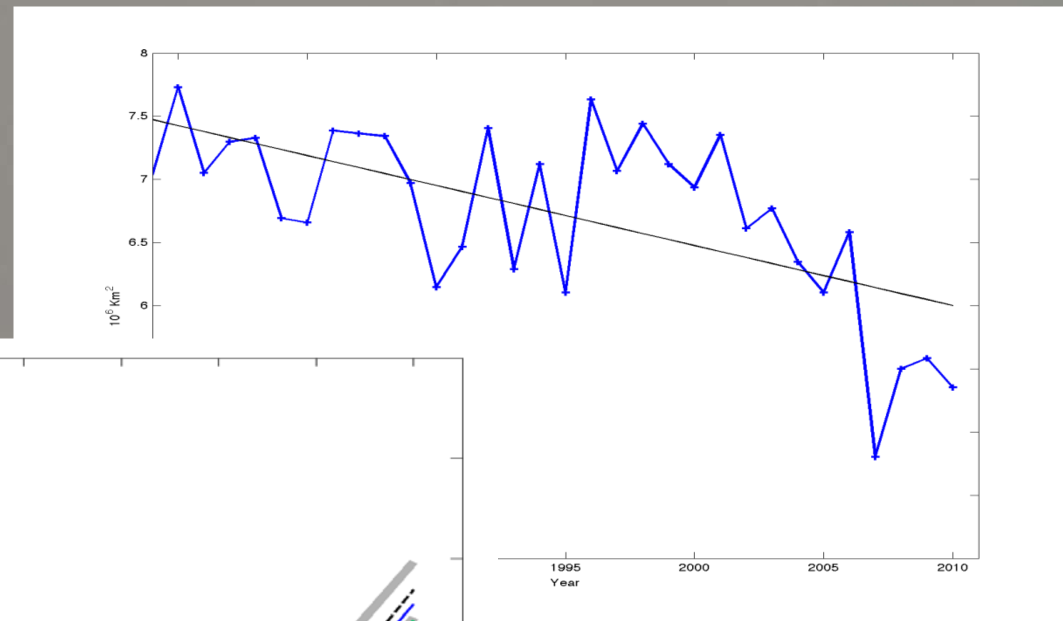
#1 Wed Jul 07 14:48:31 2010 UTC
p: 11.0°C

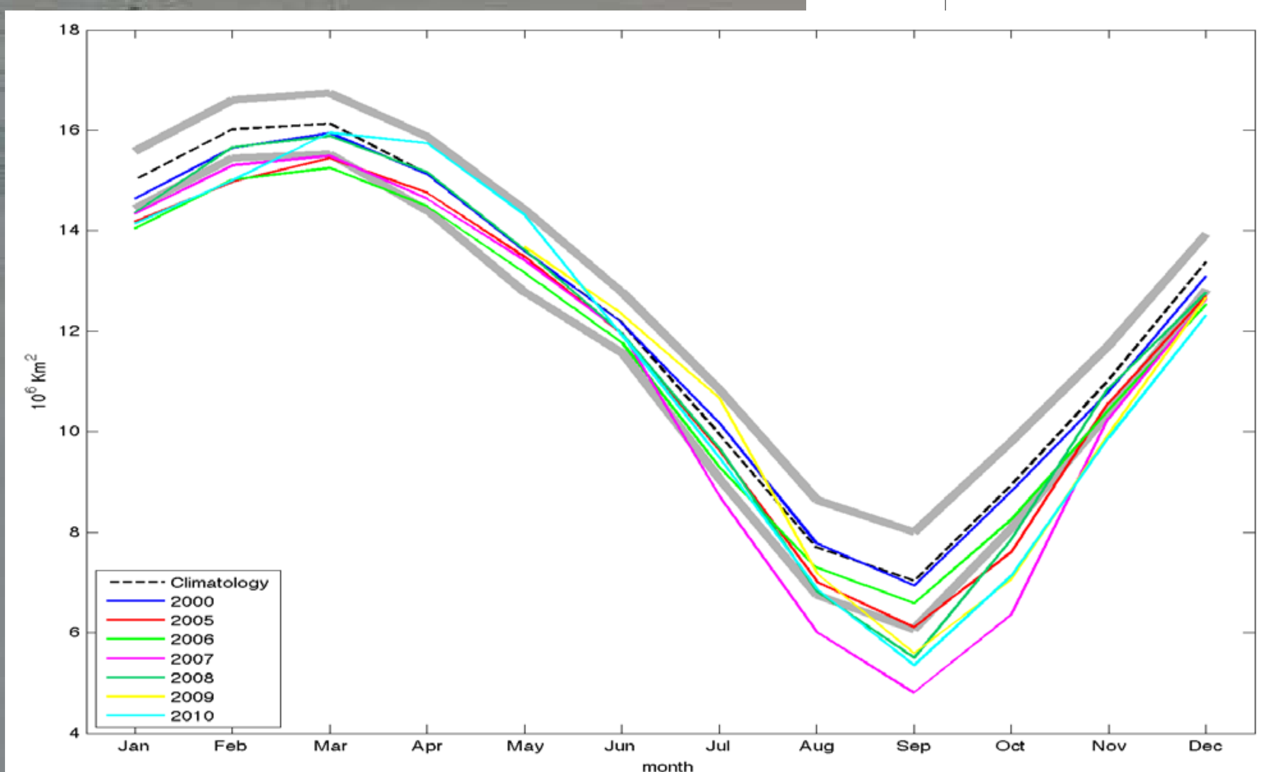
Arctic September Sea Ice Extent



#1 Wed Jul 07 14:48:31 2010 UTC
p: 11.0°C

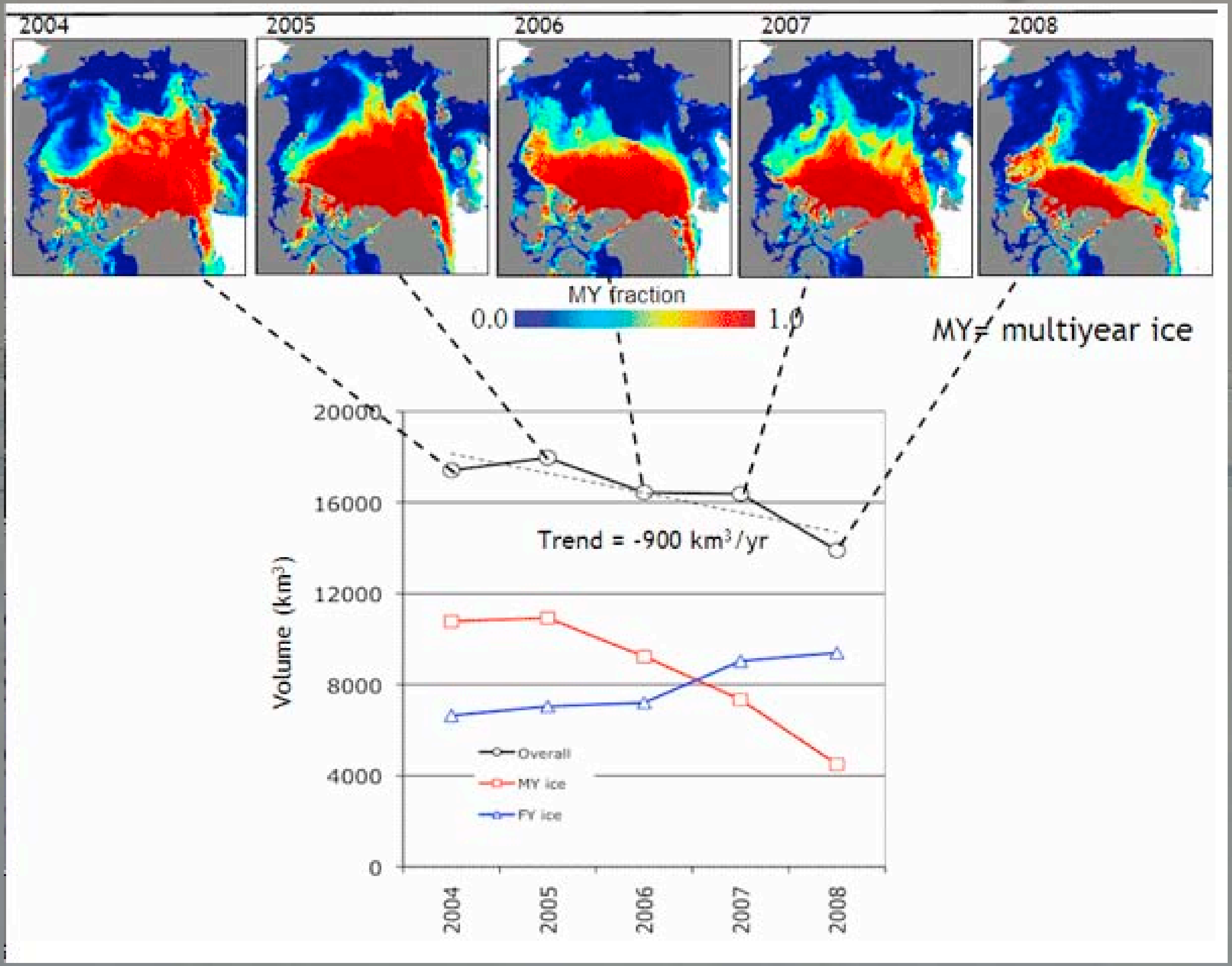
NH Sea Ice Extent





#1 Wed Jul 07 14:48:31 2010 UTC
p: 11.0°C

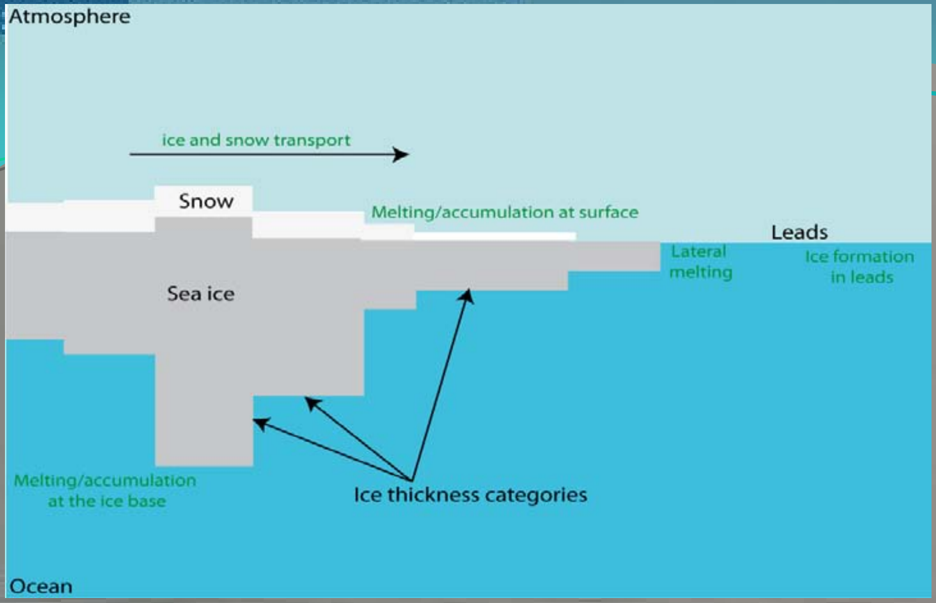
The Evolution of Multiyear Ice



Satellite Data (QuickScat)

From Ron Kwok (JPL)

#1 Wed Jul 07 14:48:31 2010 UTC



Evolution of Sea Ice Thickness

http://stratus.astr.ucl.ac.be/textbook/chapter3_node12.xml

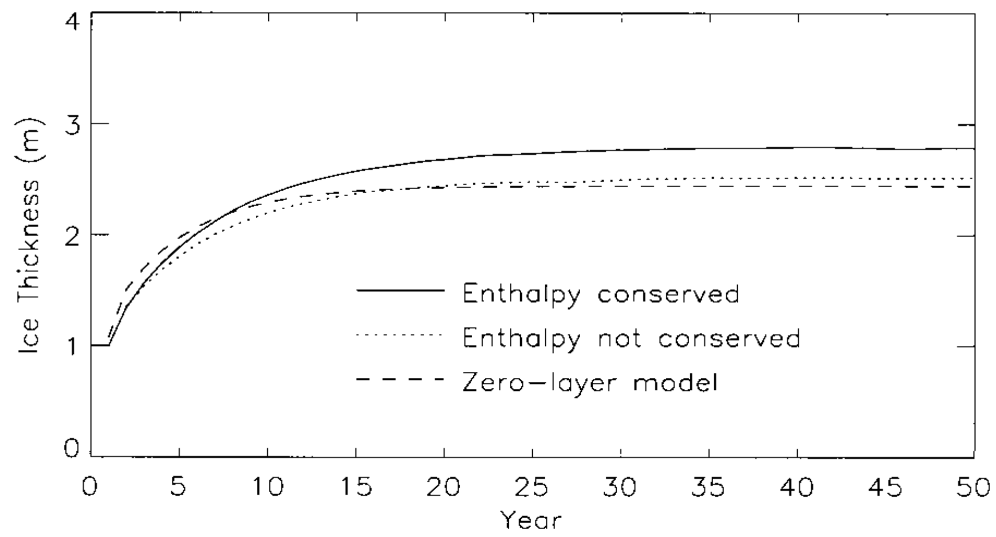


FIG. 5. Evolution of the simulated annual mean ice thickness.

Zhang and Rothrock, 2001

OUTLINE

- The observed changes in the Arctic
- Feedback mechanisms
- Model culling and projections of future Arctic Sea ice condition

#1 Wed Jul 07 14:48:31 2010 UTC
p: 11.0°C

THE FEEDBACKS

2 *a* **:** the partial reversion of the effects of a process to its source or to a preceding stage

b **:** the transmission of evaluative or corrective information about an action, event, or process to the original or controlling source; *also* **:** the information so transmitted

Merriam-Webster Dictionary

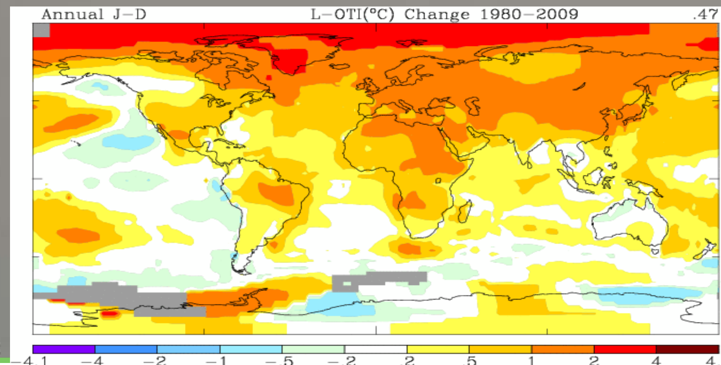
A system exhibiting **positive feedback**, in response to perturbation, acts to increase the magnitude of the perturbation.

http://en.wikipedia.org/wiki/Positive_feedback

#1 Wed Jul 07 14:48:31 2010 UTC
p: 11.0°C

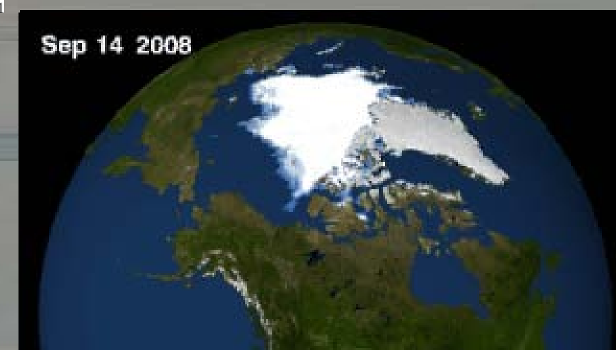
Arctic Climate System Feedbacks

Global Warming



Arctic amplification

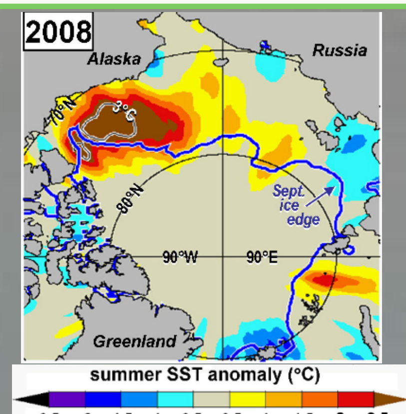
Reduction of Arctic Sea Ice



Sept Sea Ice Extent

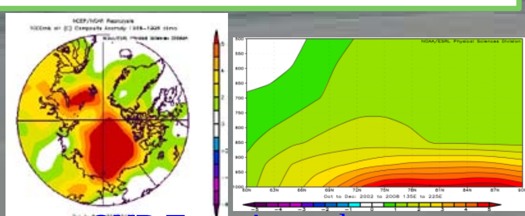
Surface albedo decrease => less sunlight being reflected from surface

Ocean Absorbs More Heat



Heat releases to atmosphere in the fall.

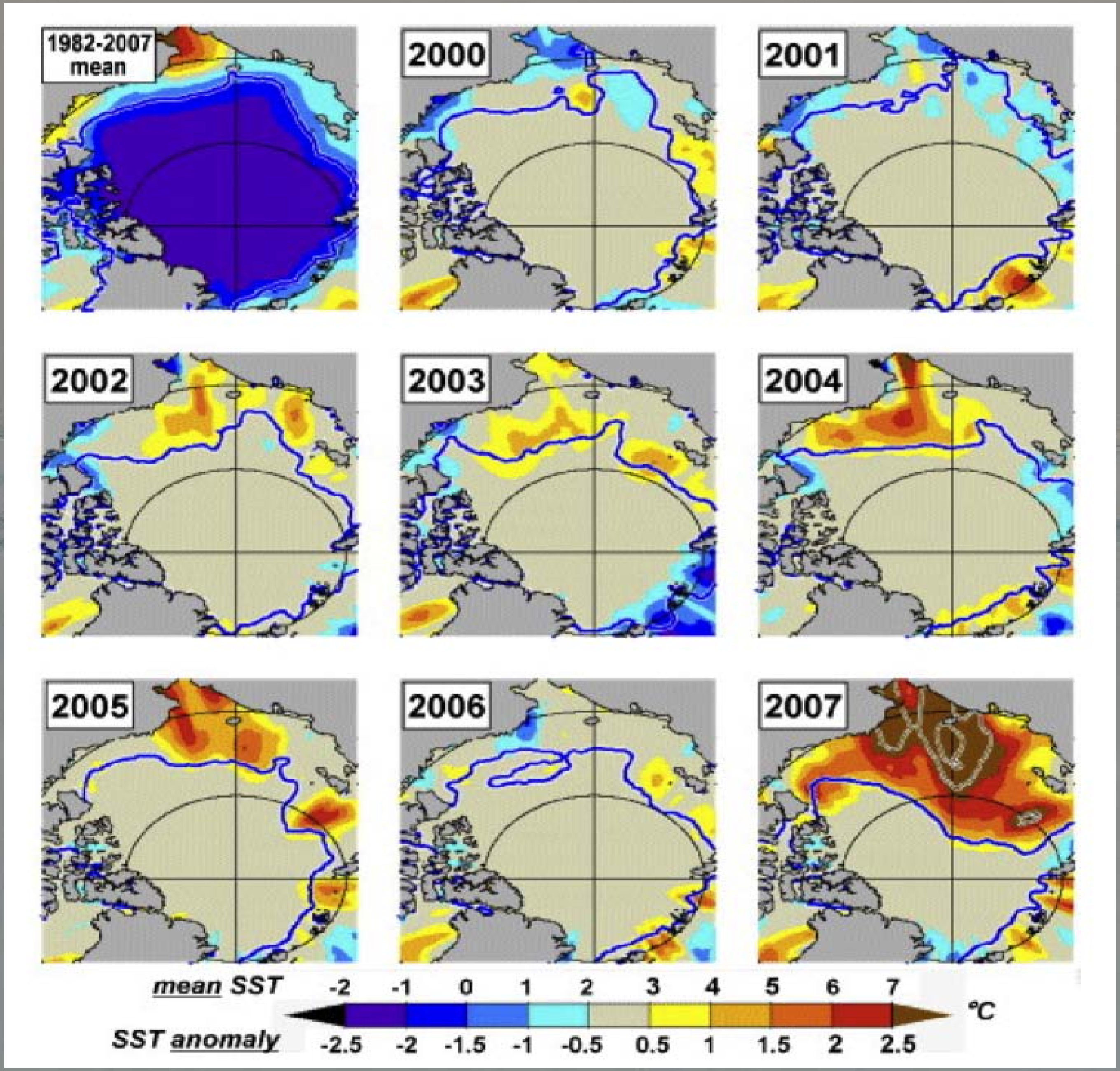
Arctic Atmosphere Warming



OND Temp Anomaly

Teleconnection and circulation pattern change

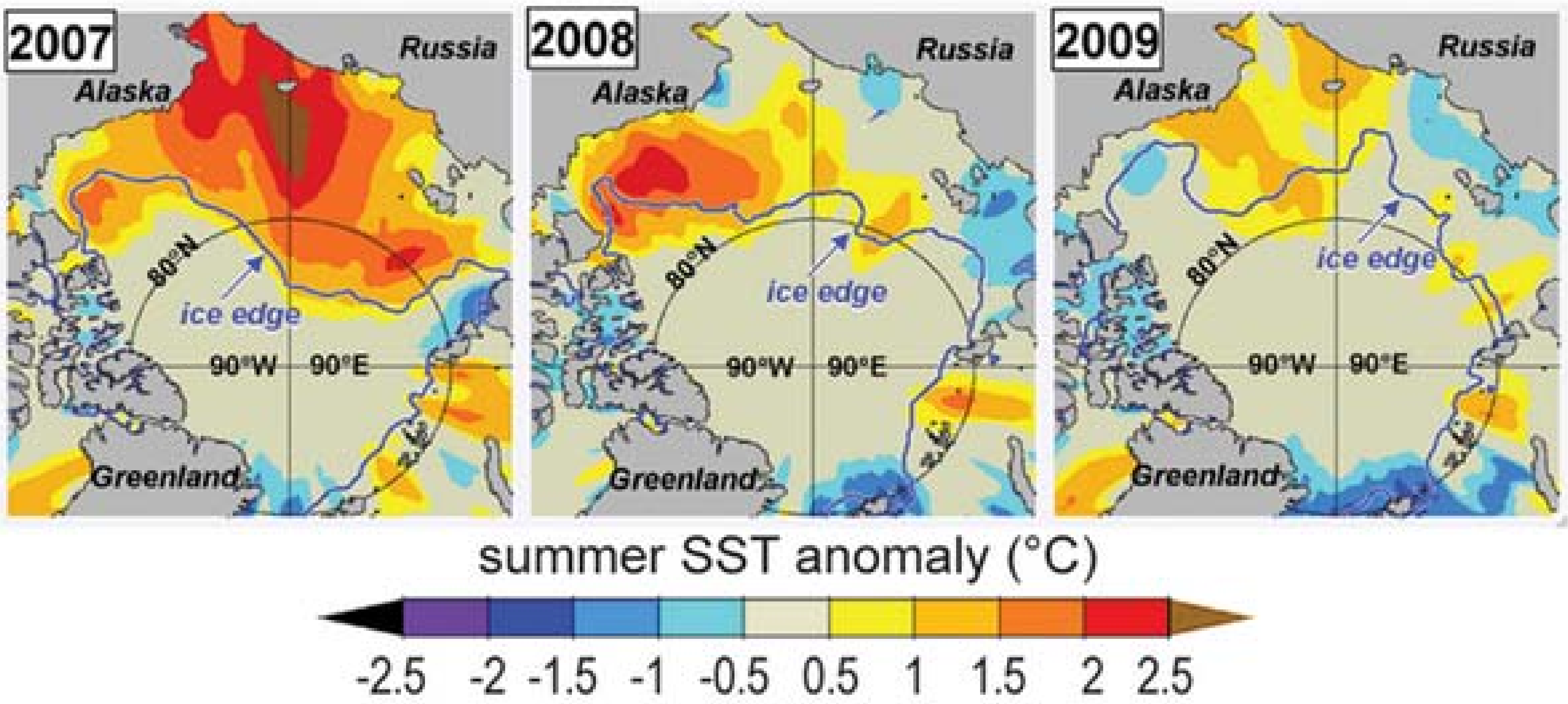
JAS SST Anomaly



#1 Wed Jul 07 14:48:31 2010 UTC
p: 11.0°C

JAS Sea Surface Temp Anomaly

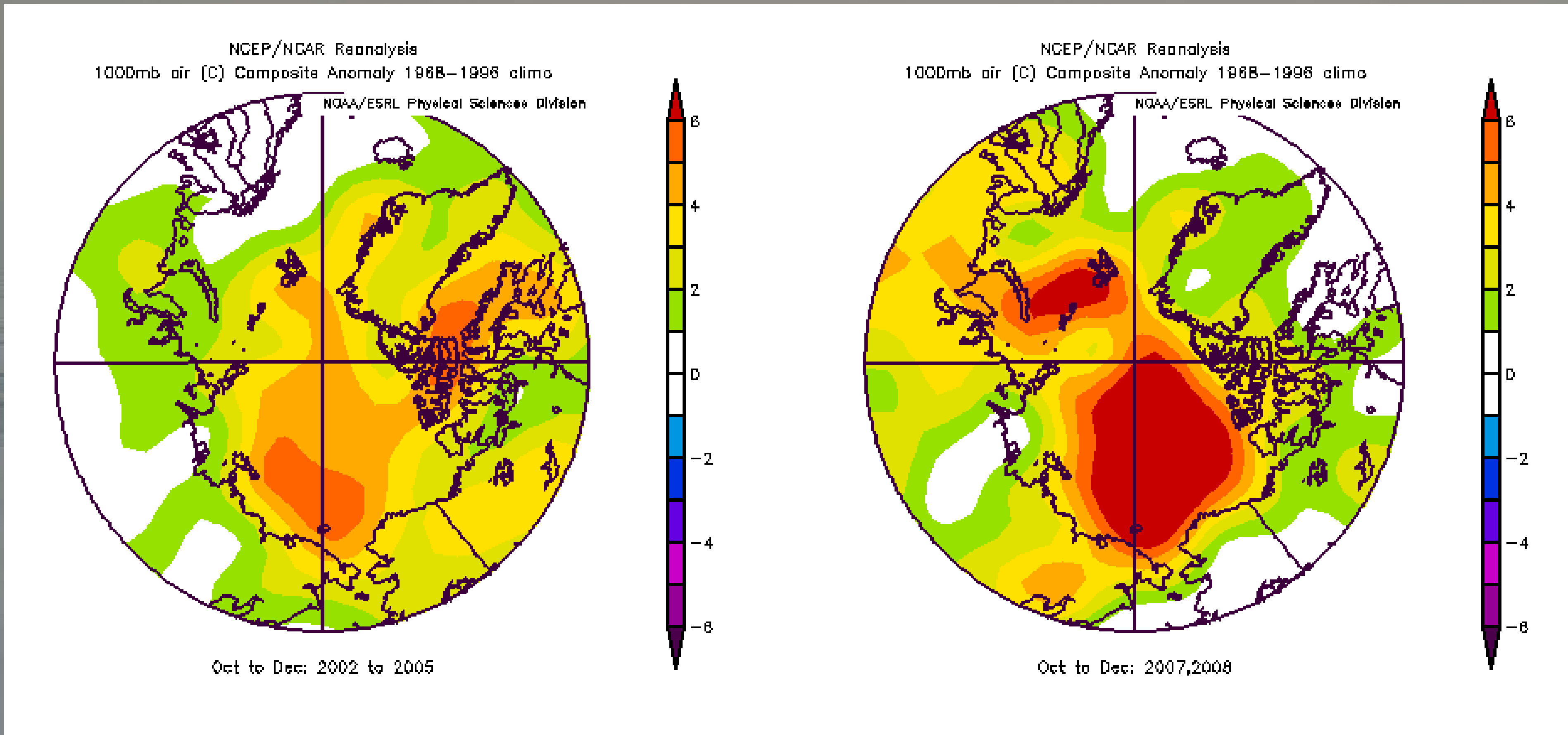
Relative to 1982-2006 mean



NOAA Arctic Report Card

#1 Wed Jul 07 14:48:31 2010 UTC
p: 11.0°C

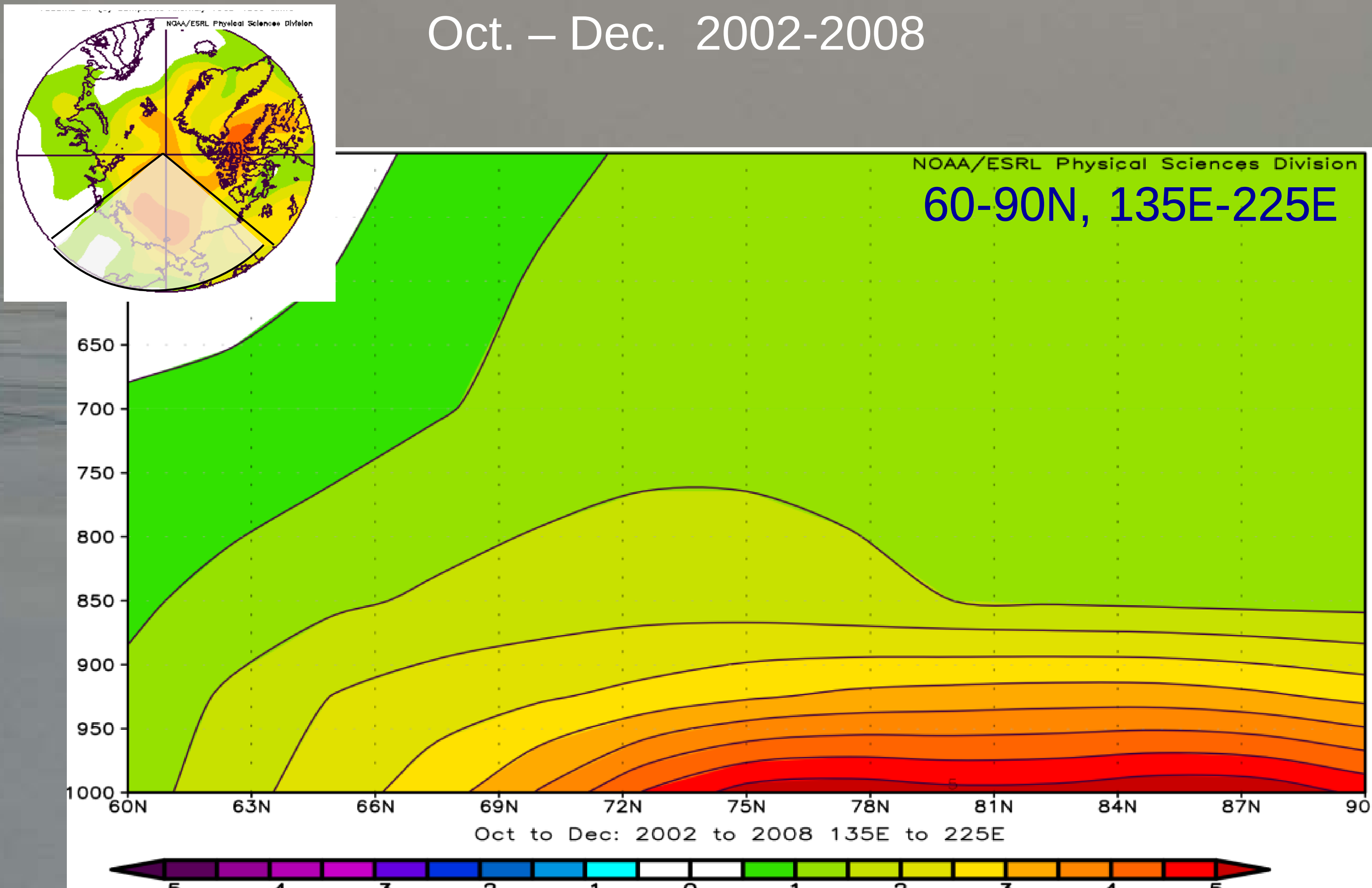
Recent (2002-2008) Central Arctic Fall Temperature Anomalies Greater Than +5° C



#1 Wed Jul 07 14:48:31 2010 UTC
p: 11.0°C

Vertical Cross Section of Temp Anomaly

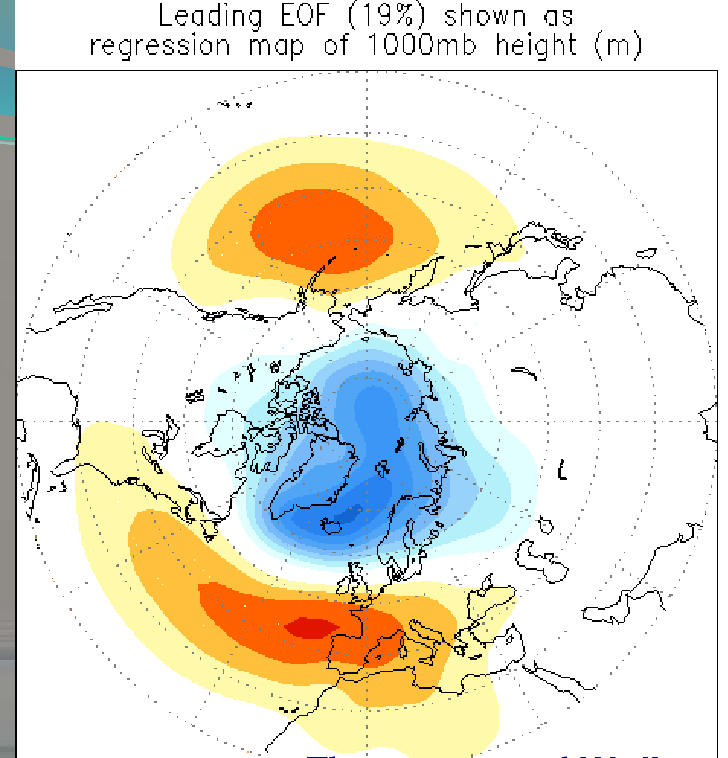
Oct. – Dec. 2002-2008



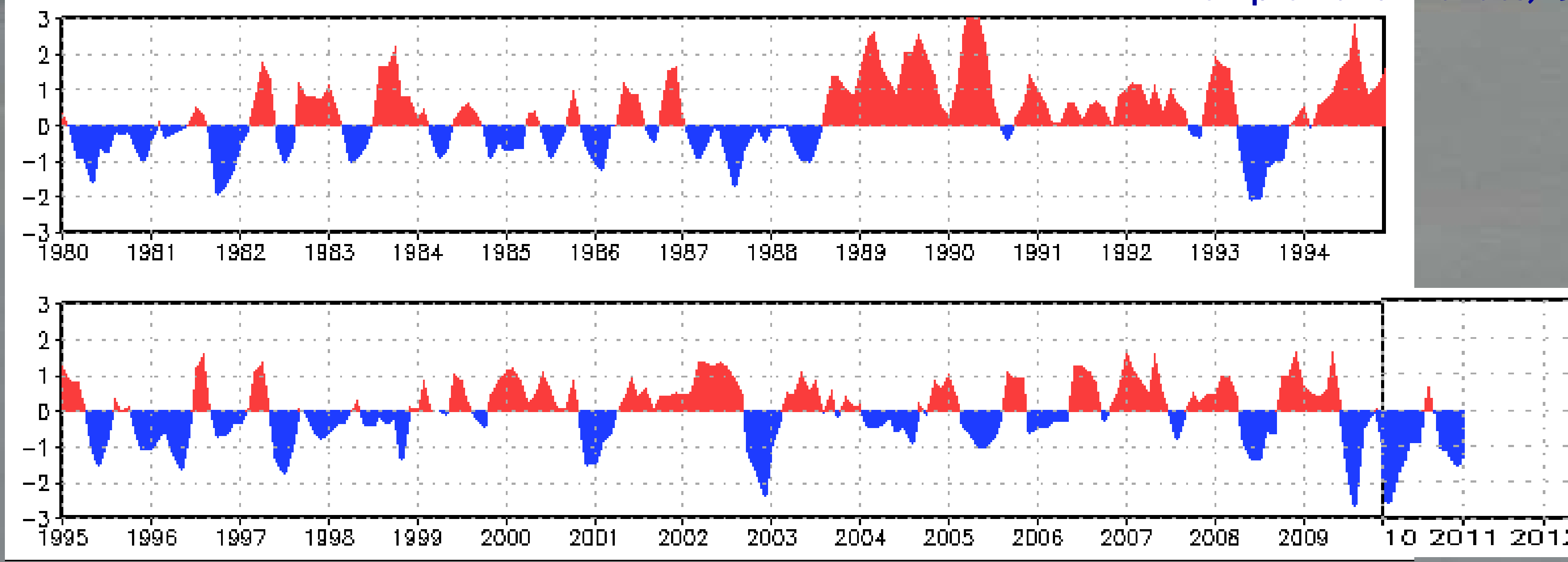
#1 Wed Jul 07 14:48:31 2010 UTC
p: 11.0°C

The Arctic Oscillation (AO)

Northern Annular Mode (NAM)

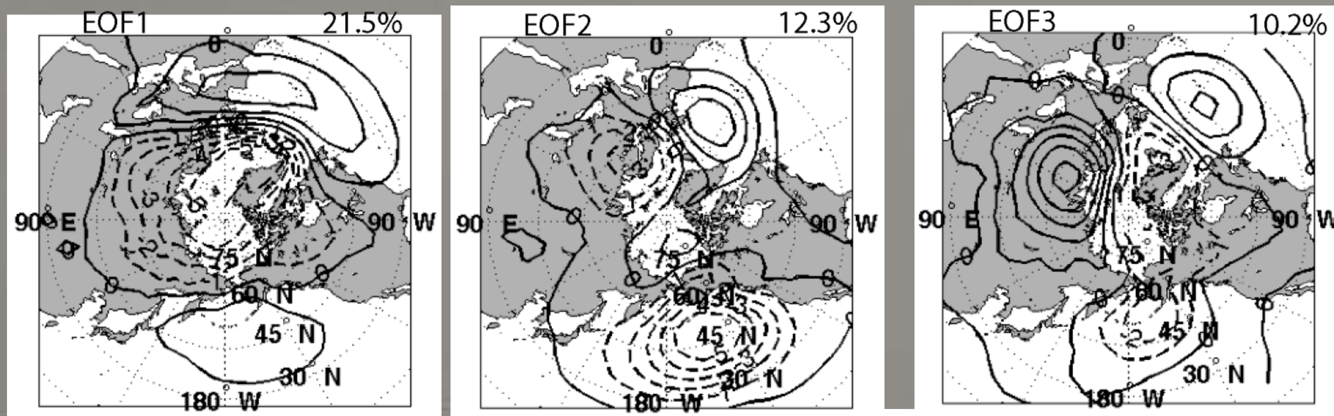


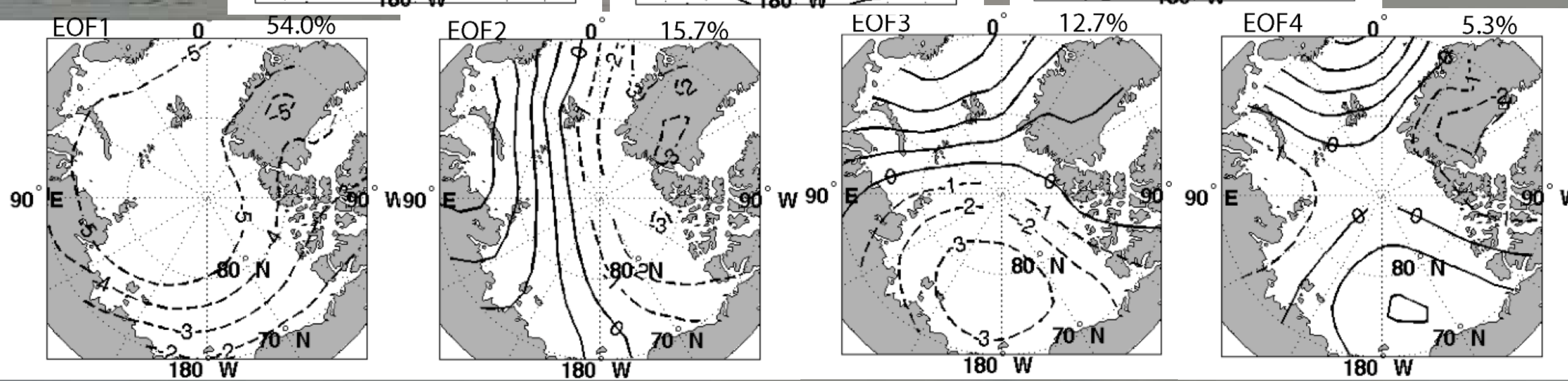
Thompson and Wallace, 1998

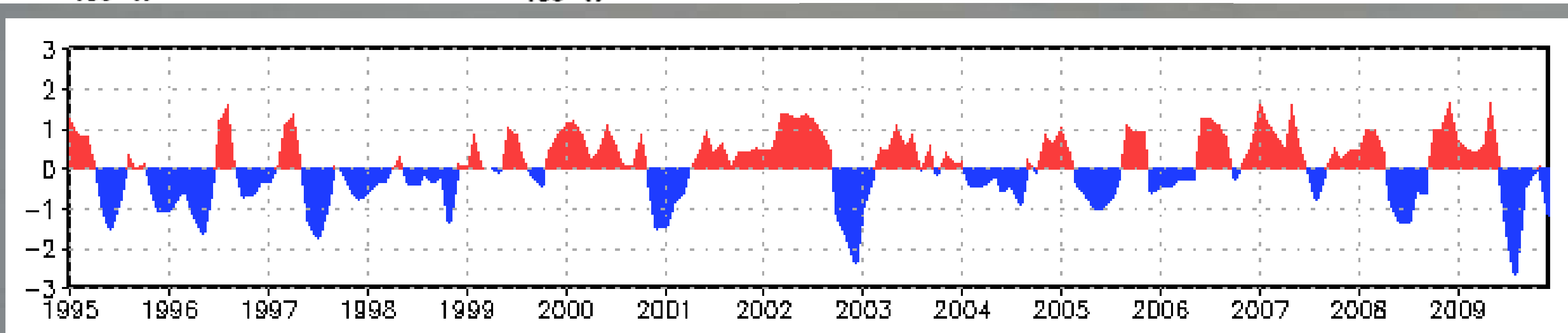


#1 Wed Jul 07 14:48:31 2010 UTC
p: 11.0°C

Arctic Oscillation & Dipole Anomaly

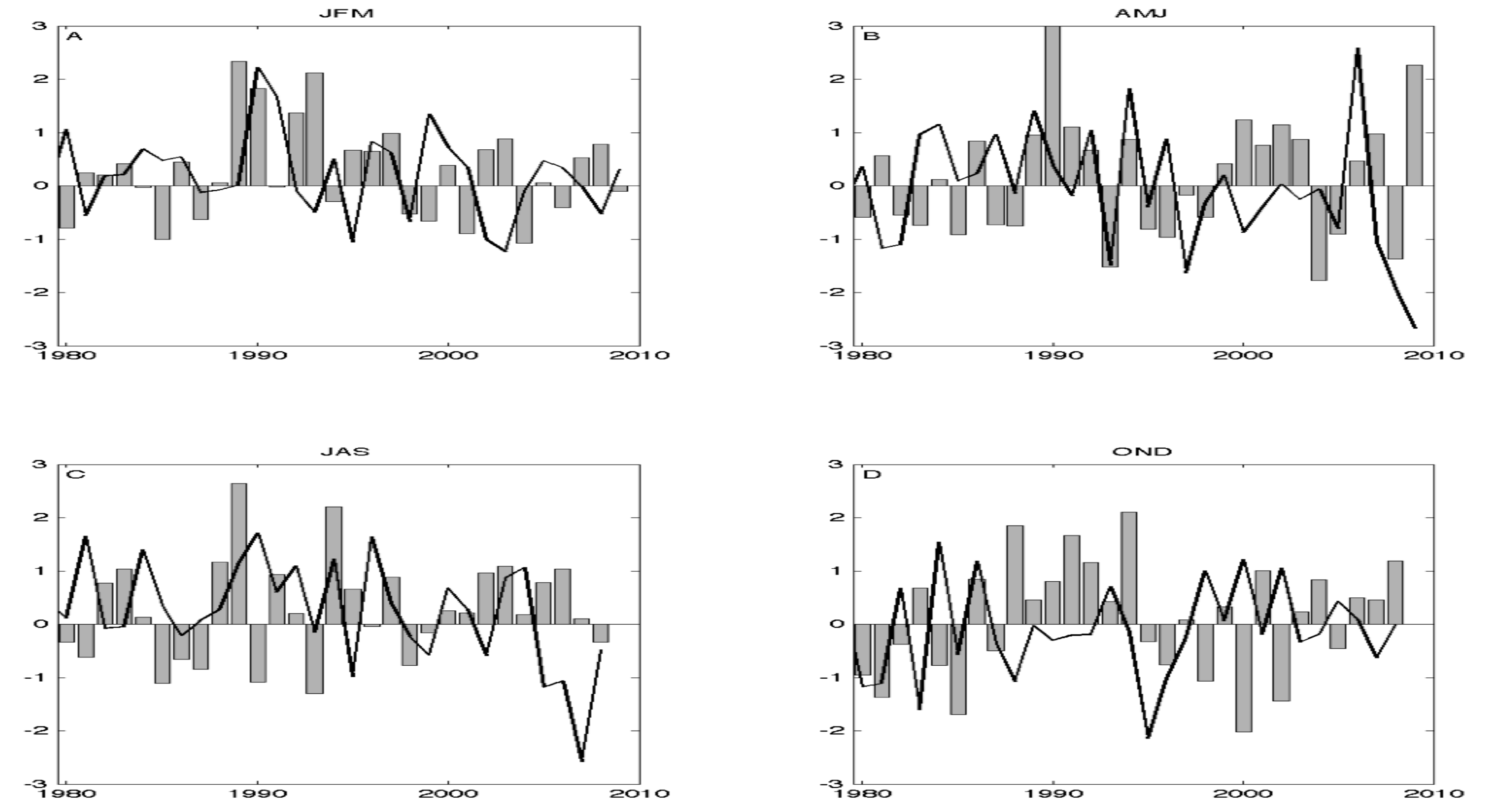






Wang et al, 2009; Overland and Wang, 2010

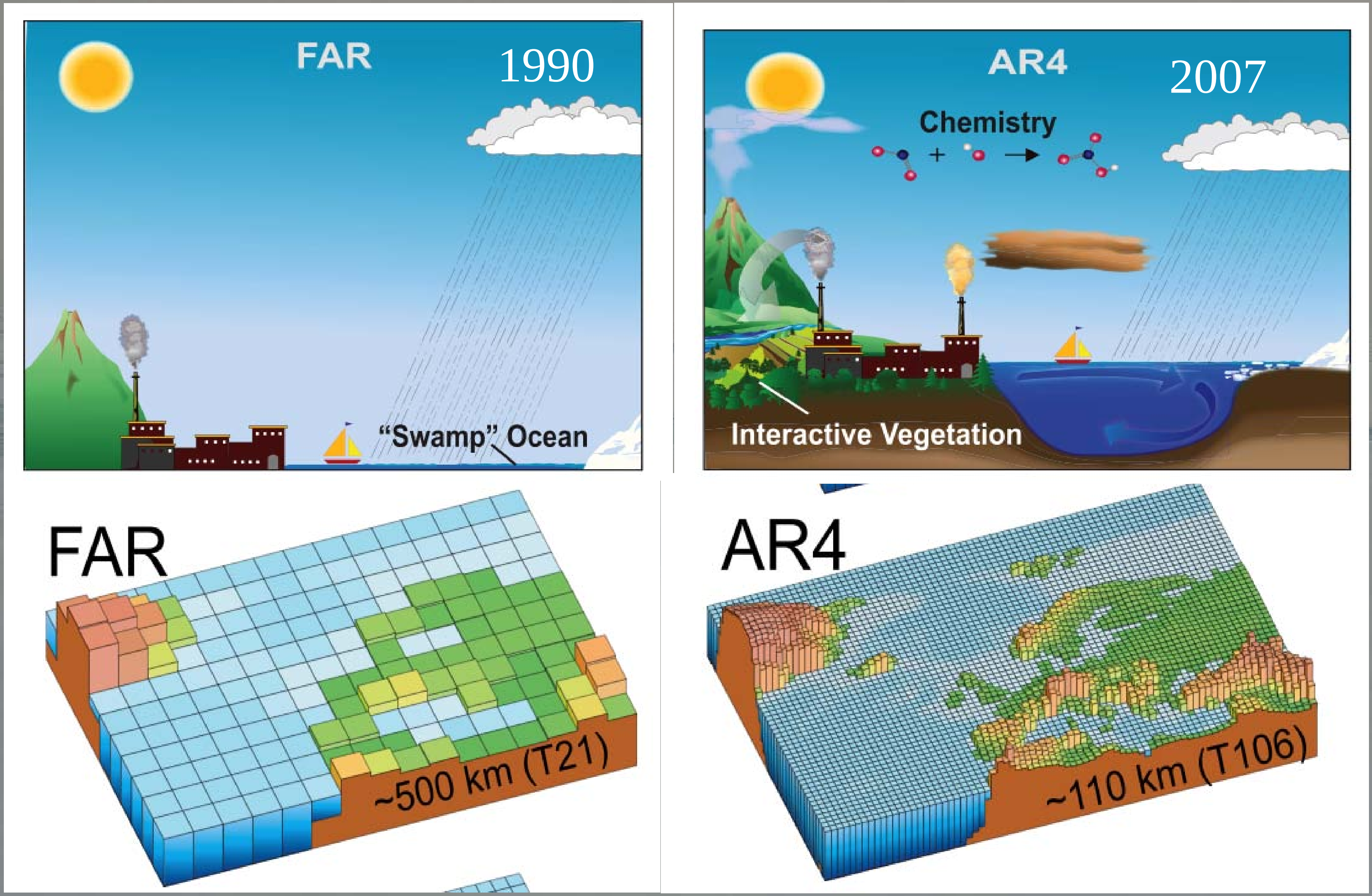
Seasonal Mean PC Series



OUTLINE

- The observed changes in the Arctic
- Feedback mechanisms
- Model culling and projections of future Arctic Sea ice condition

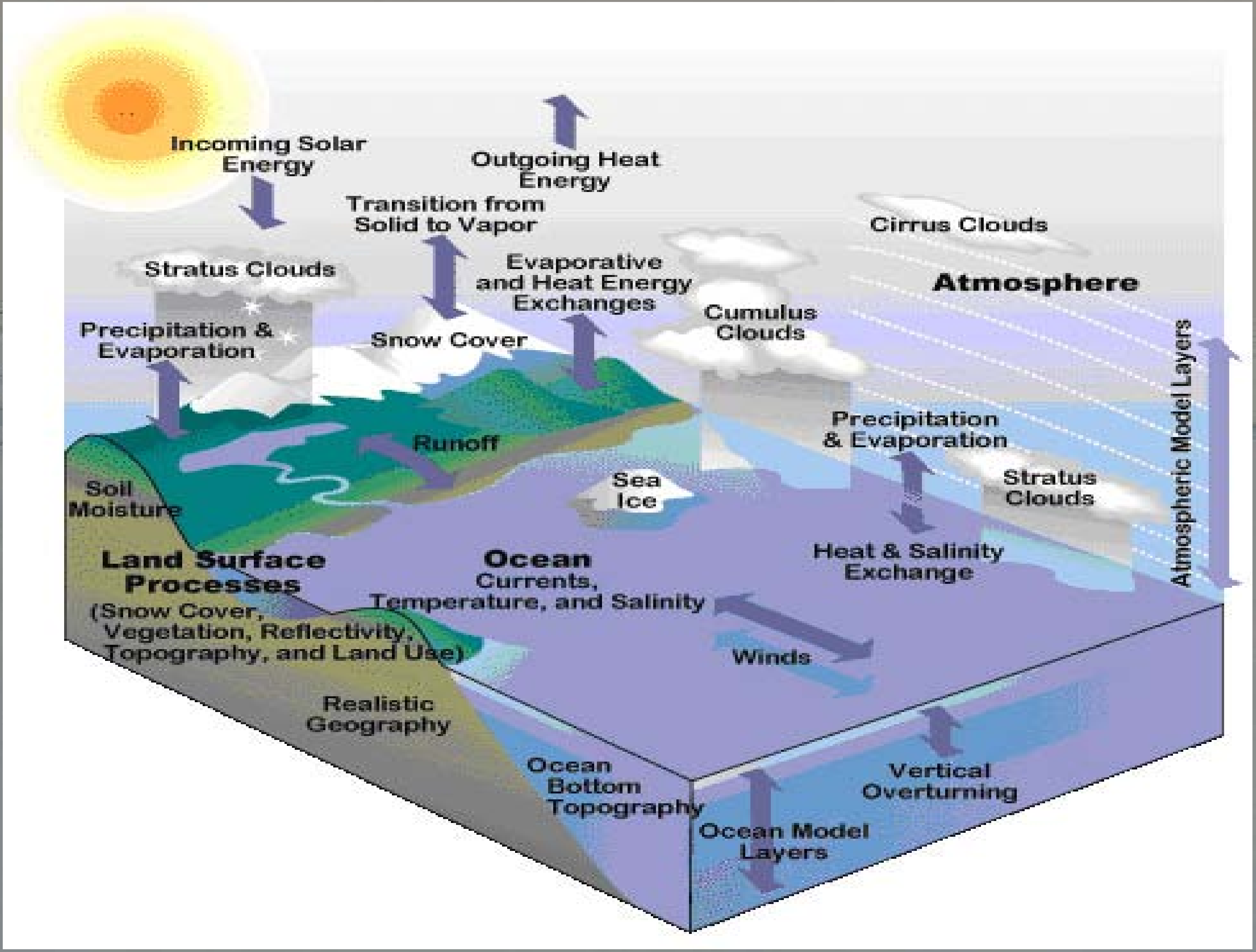
The Progress of Climate Models



IPCC, 2007

#1 Wed Jul 07 14:48:31 2010 UTC
p: 11.0°C

Model Components

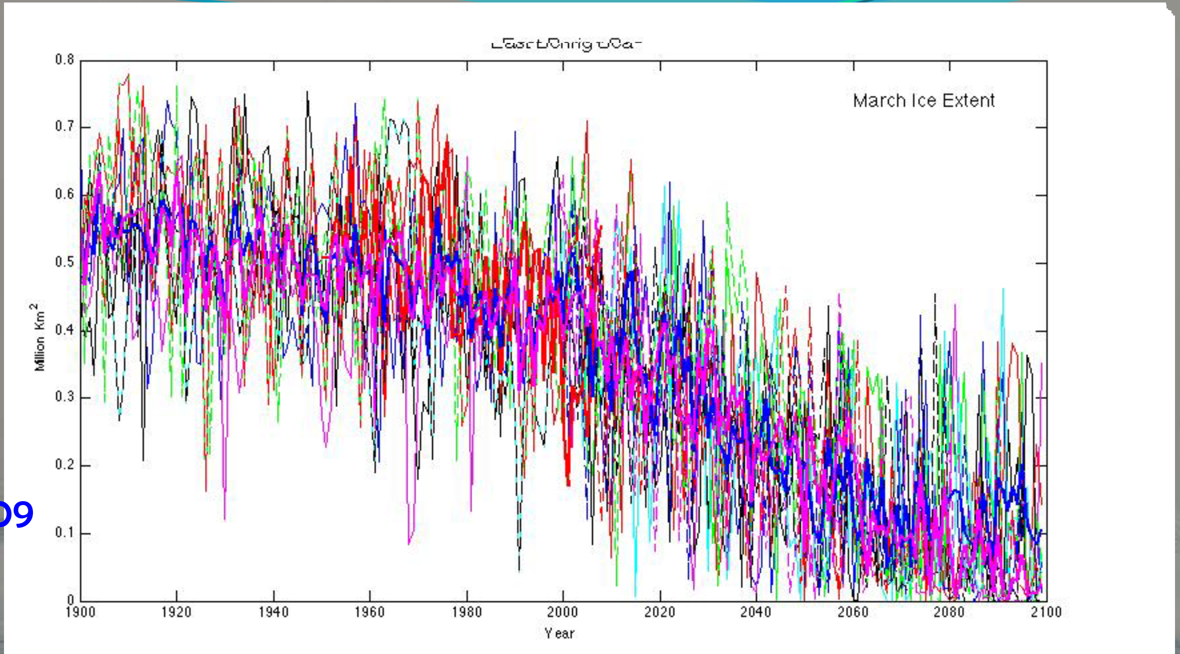


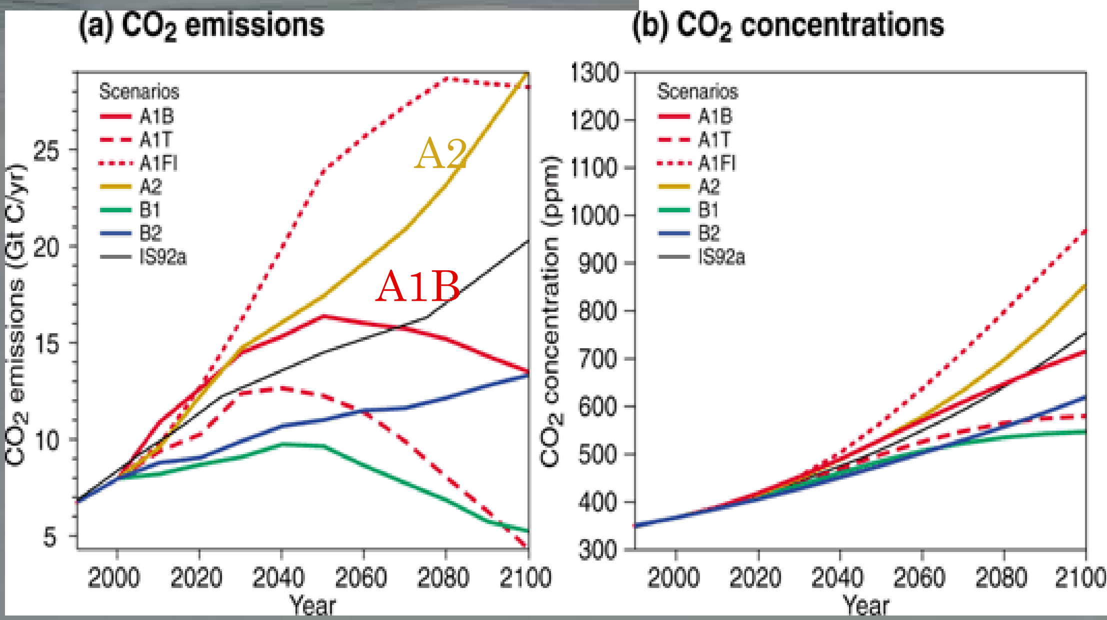
#1 Wed Jul 07 14:48:31 2010 UTC
p: 11.0°C

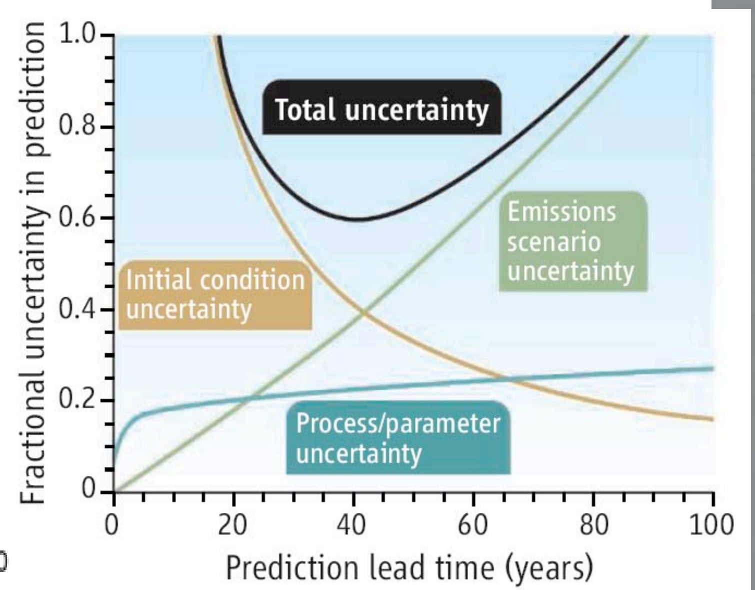
Source of Projection Uncertainties

- Internal Variability of climate system
- Model Uncertainty
- Emission Scenarios

Hawkins and Sutton, 2009



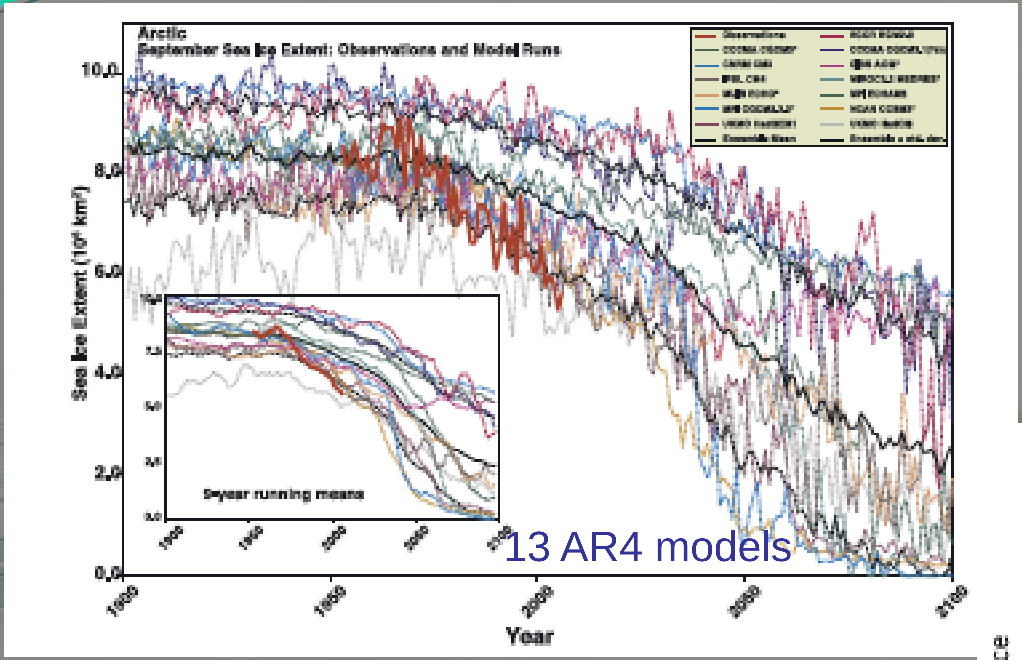




Cox and Stephenson, 2007

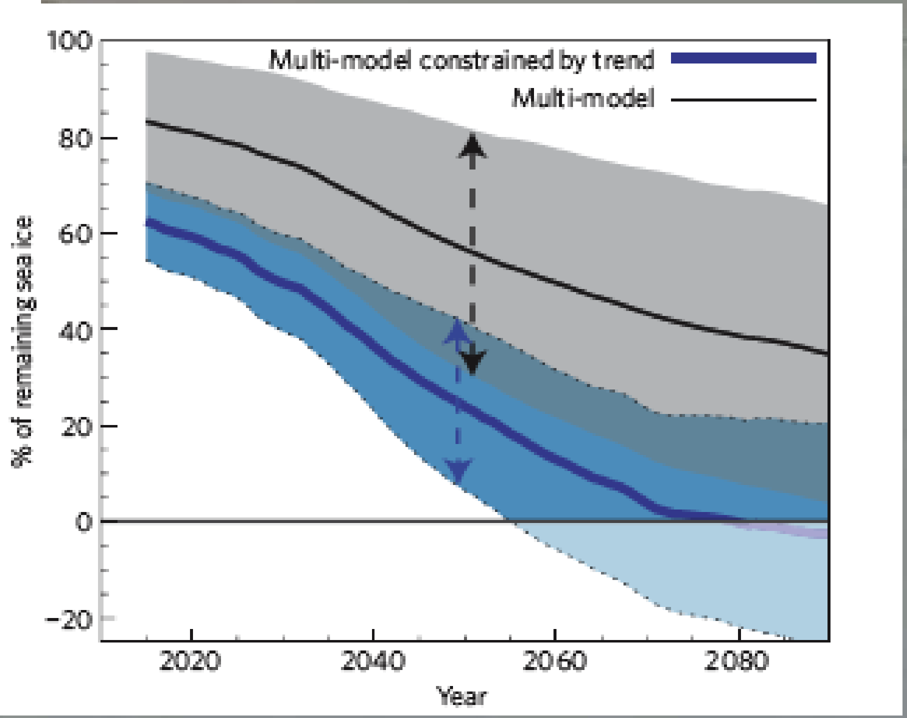
#1 Wed Jul 07 14:48:31 2010 UTC
p: 11.0°C

Model Culling



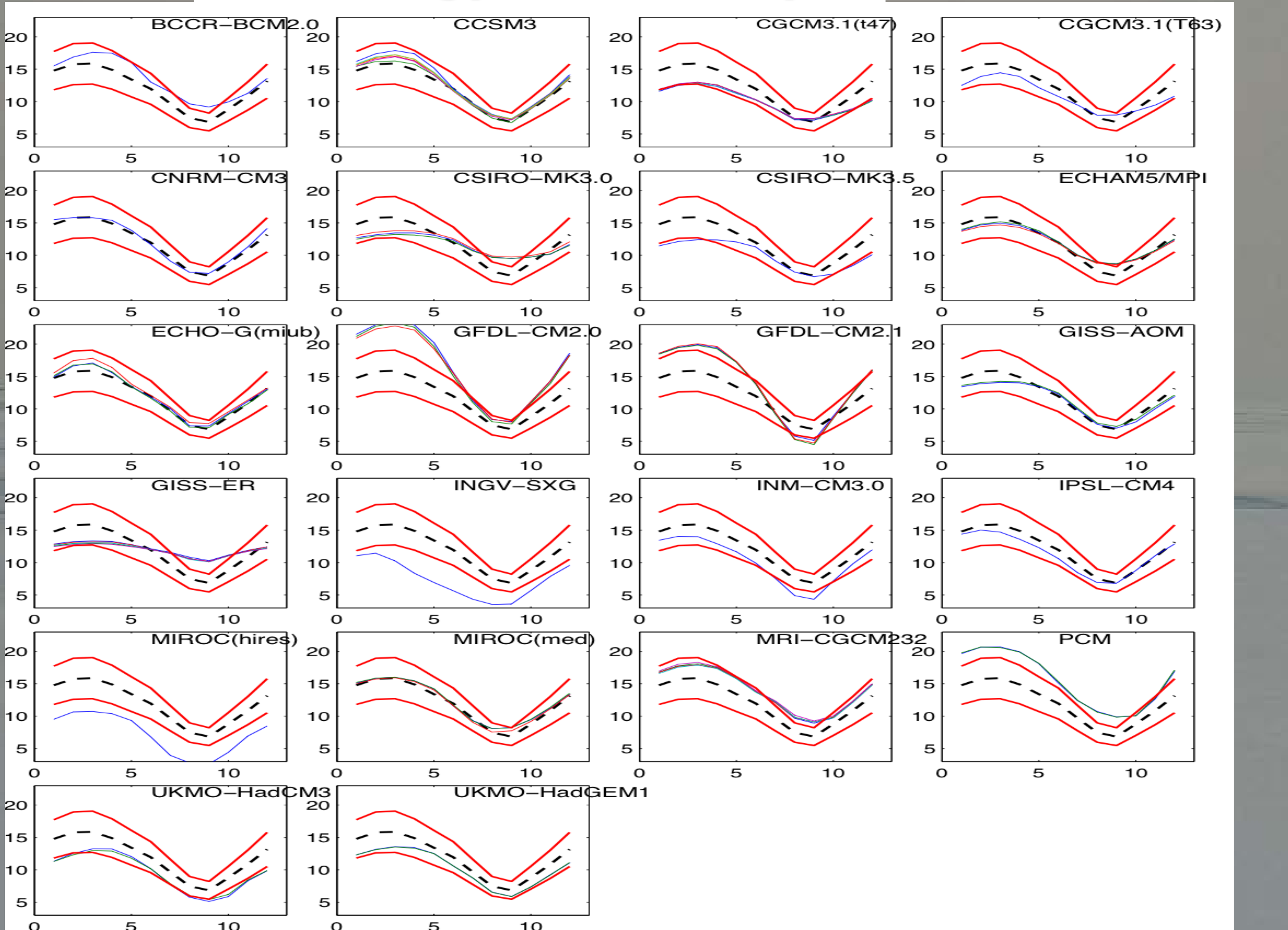
13 AR4 models

Stroeve et al. 2007

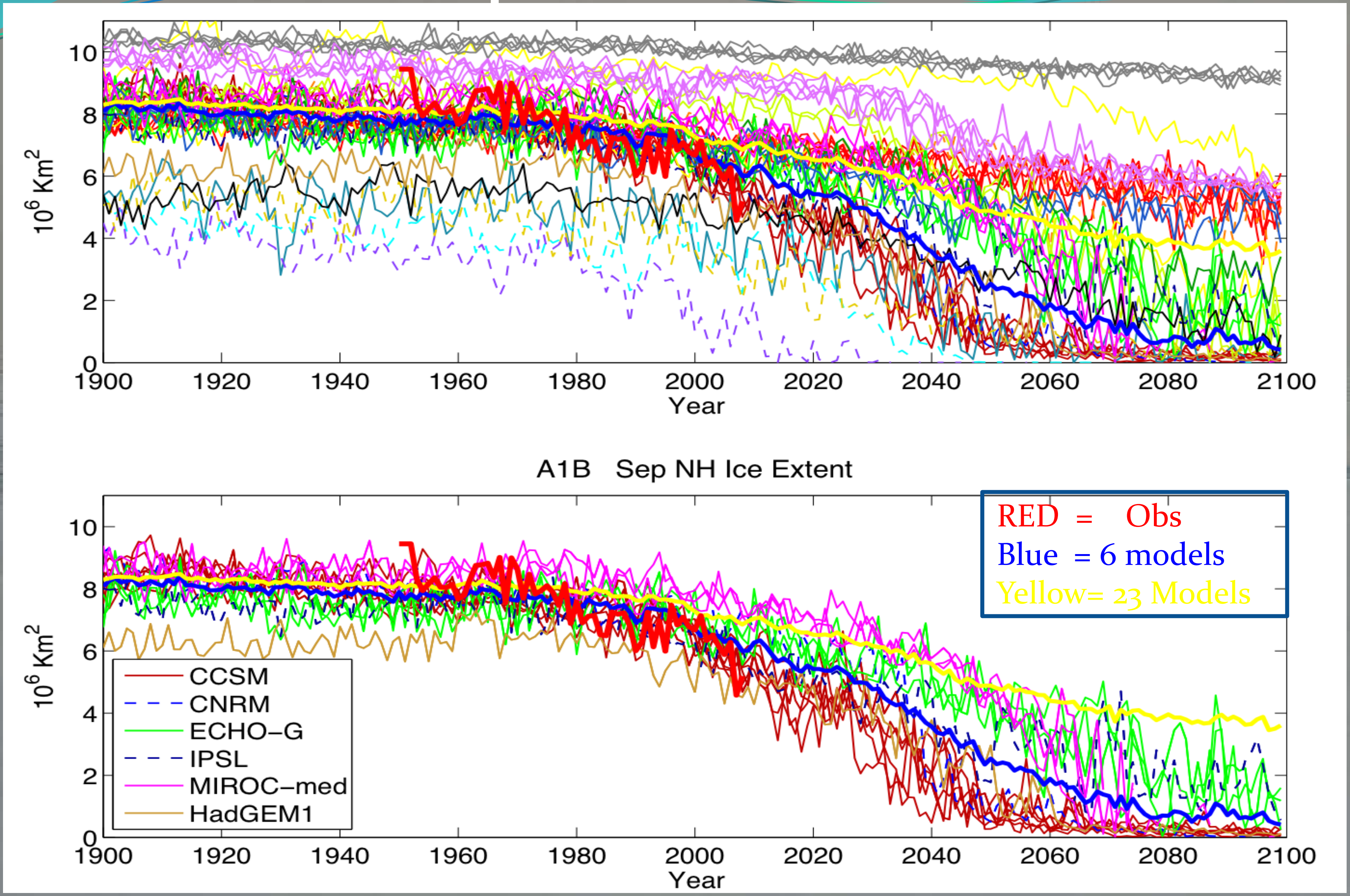


Boe et al. 2009

Climatology / Seasonal Cycle

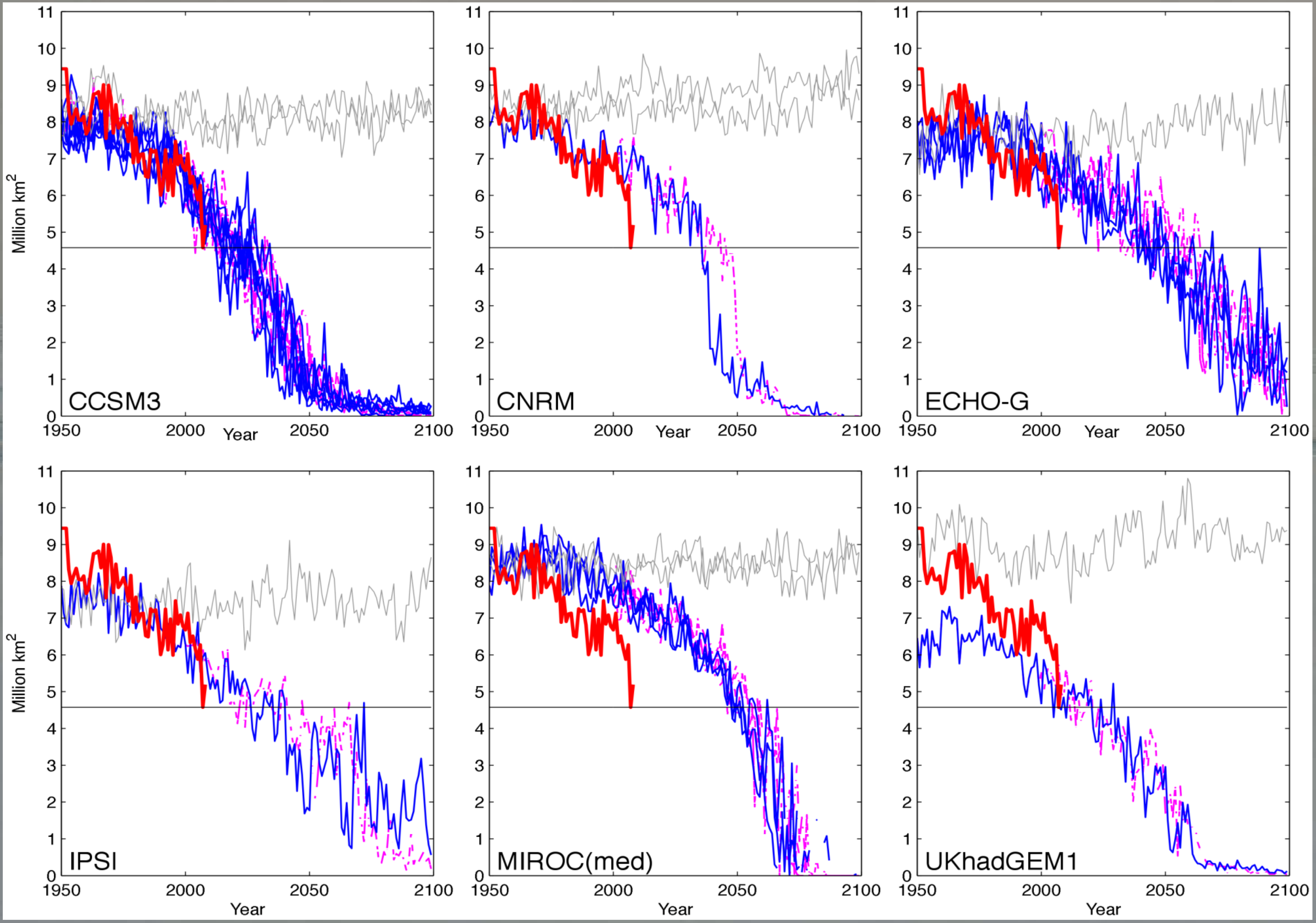


NH Sept Sea Ice Extent

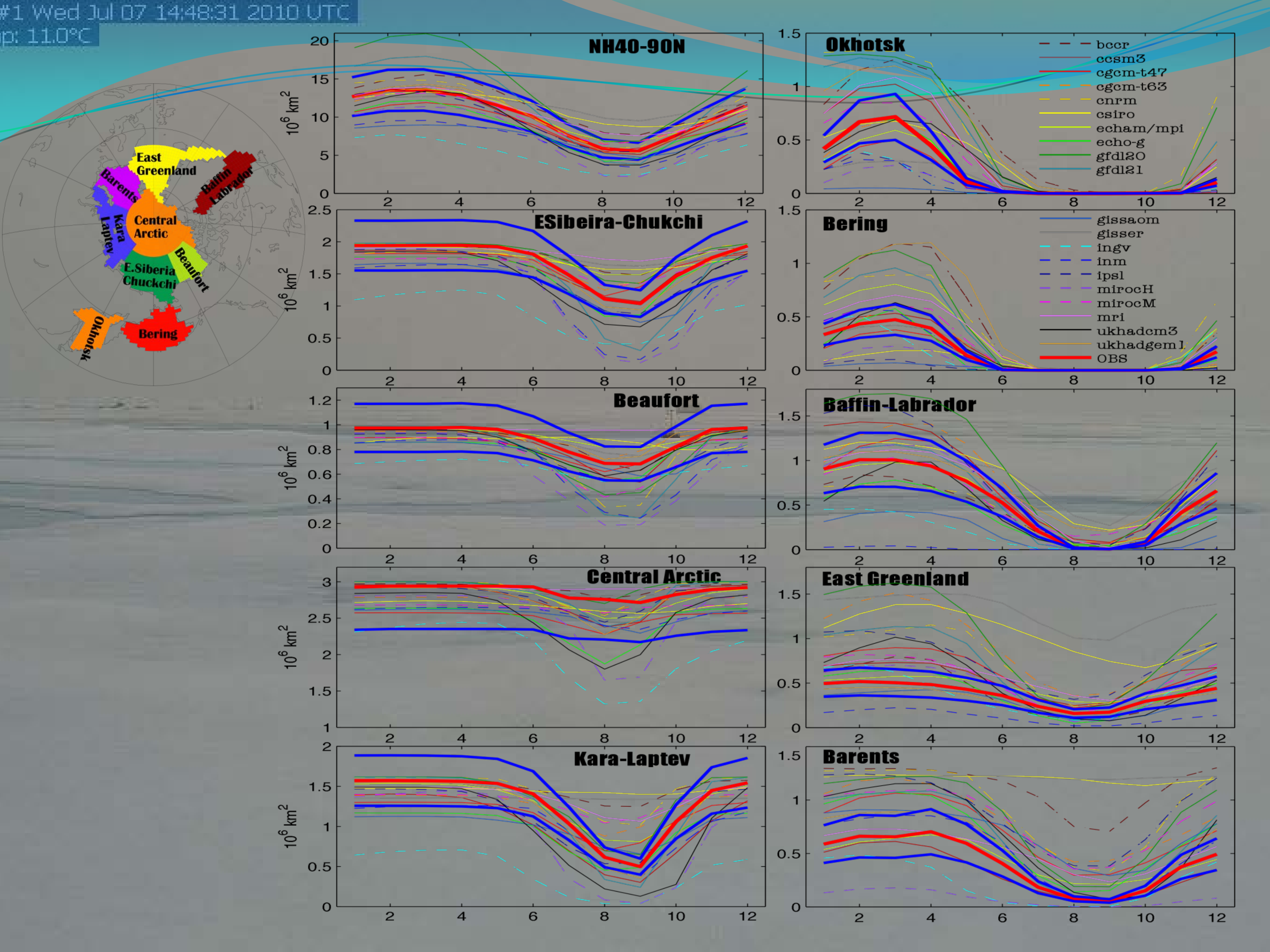


Wang and Overland 2009

September Sea Ice Extent

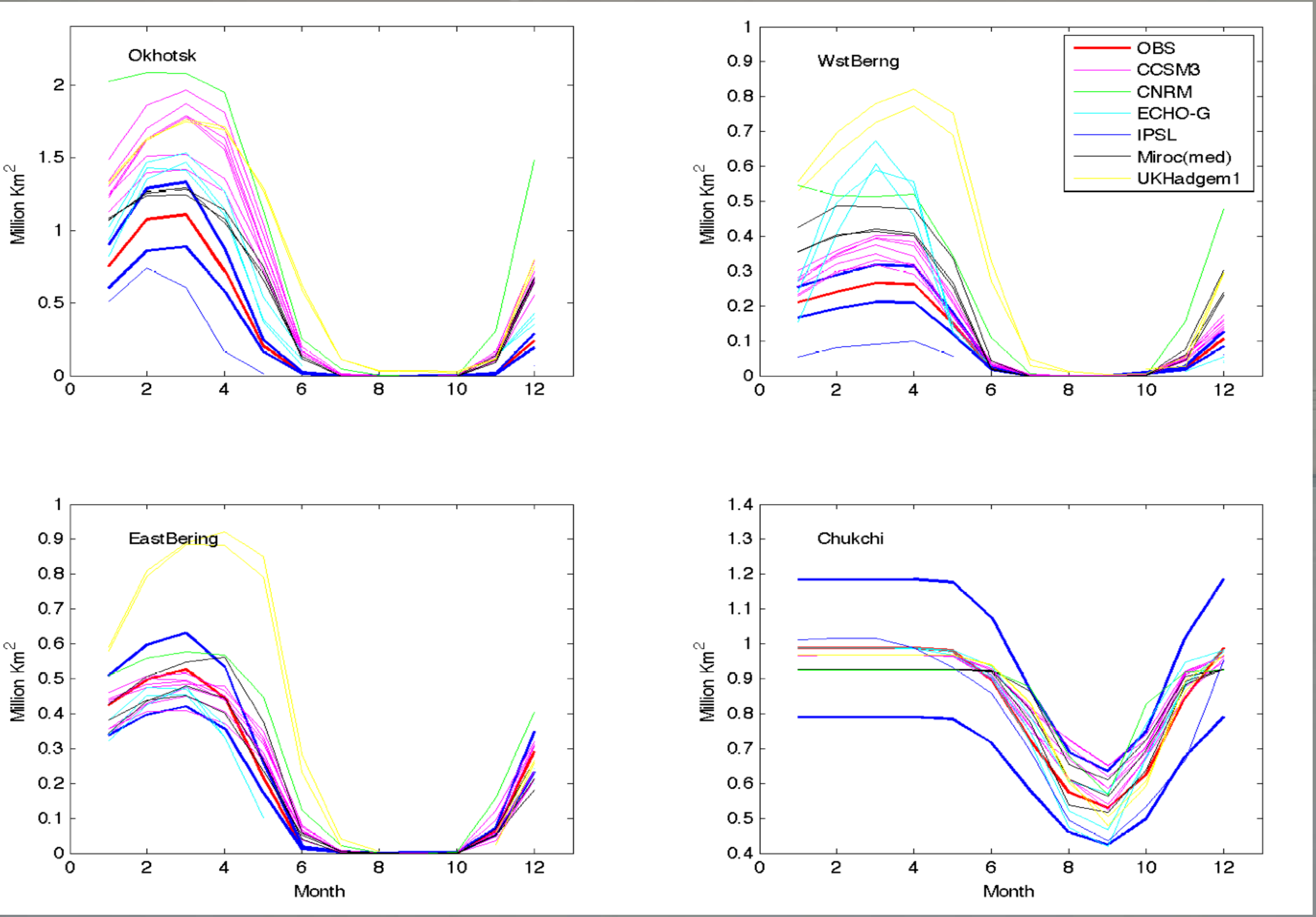


Wang and Overland, 2009



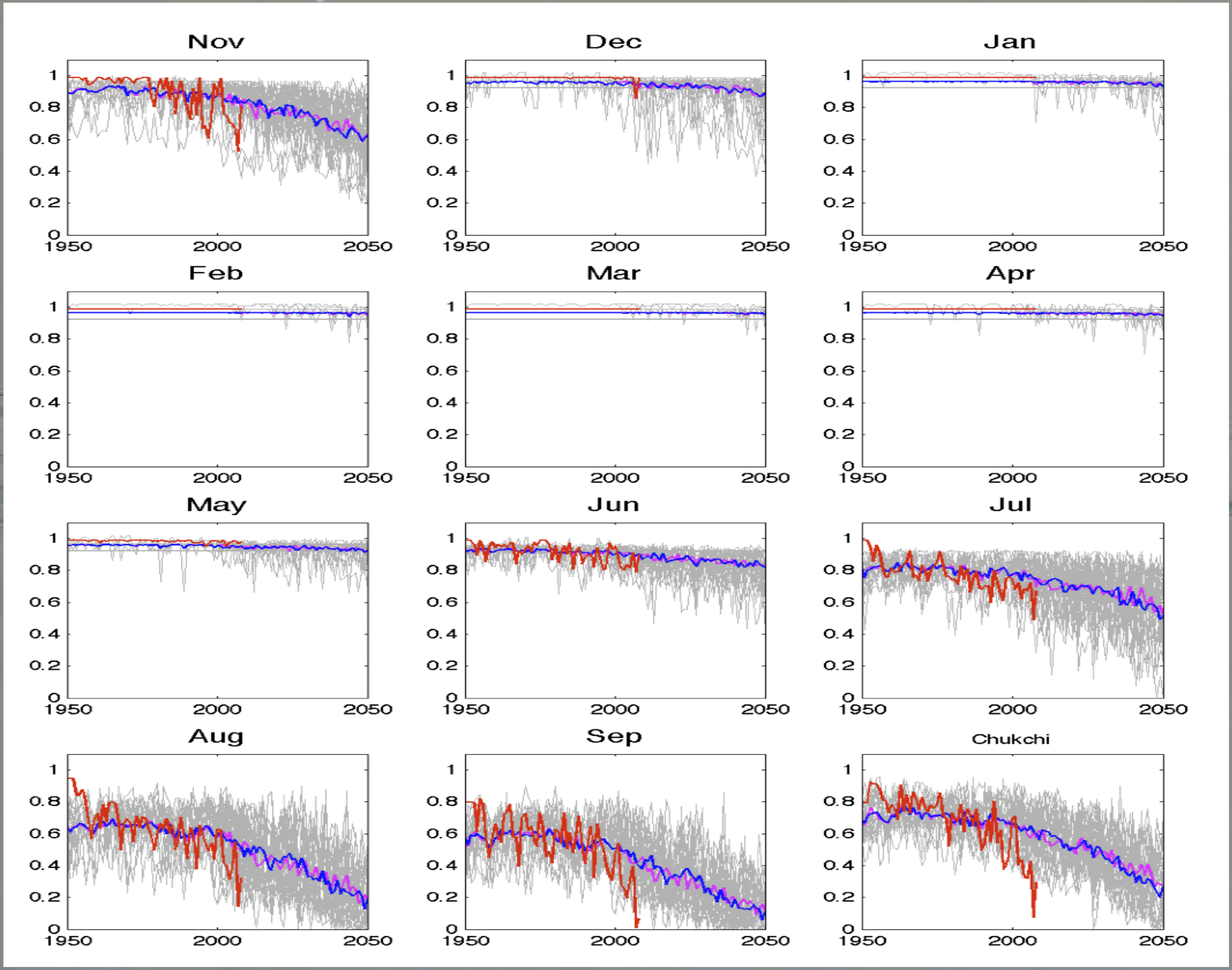
#1 Wed Jul 07 14:48:31 2010 UTC
p: 11.0°C
NH40-90N
Okhotsk
ESibeira-Chukchi
Bering
Beaufort
Baffin-Labrador
Central Arctic
East Greenland
Kara-Laptev
Barents
10^6 km^2
bccr
ccsm3
cgcm-t47
cgcm-t63
cnrm
csiro
echam/mpi
echo-g
gfdl20
gfdl21
gissaom
gisser
ingv
inm
ipsl
mirocH
mirocM
mri
ukhadcm3
ukhadgem1
OBS
East Greenland
Barents
Baffin Labrador
Central Arctic
Kara Laptev
Beaufort
E.Siberia Chuckchi
Okhotsk
Bering

Seasonal Cycle of Sea Ice Extents



#1 Wed Jul 07 14:48:31 2010 UTC
p: 11.0°C

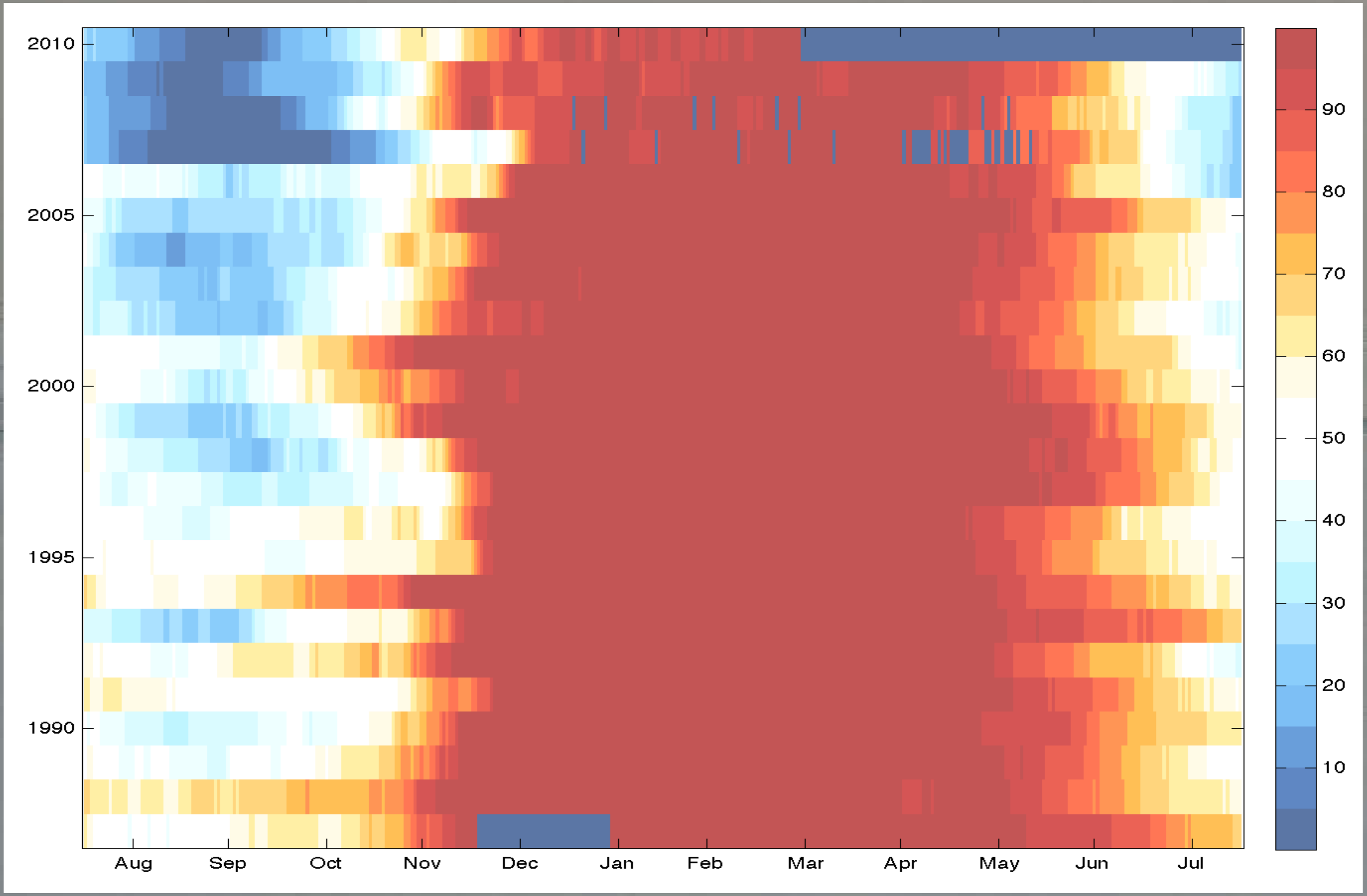
Monthly Sea Ice Extent over Chukchi Sea



#1 Wed Jul 07 14:48:31 2010 UTC
p: 11.0°C

Mean Sea Ice Concentration over the Chukchi Sea

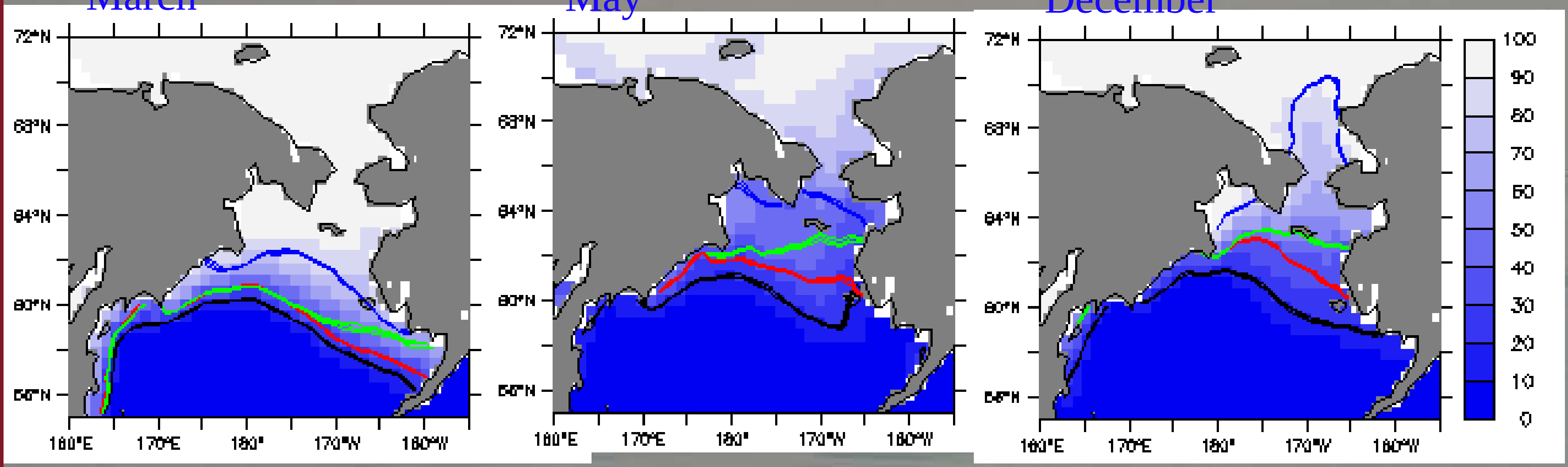
65-80N, 180-157W



Jul 07 14:48:31 2010 UTC

DECADAL MEAN ICE EDGE under A1B scenario

March May December



Current

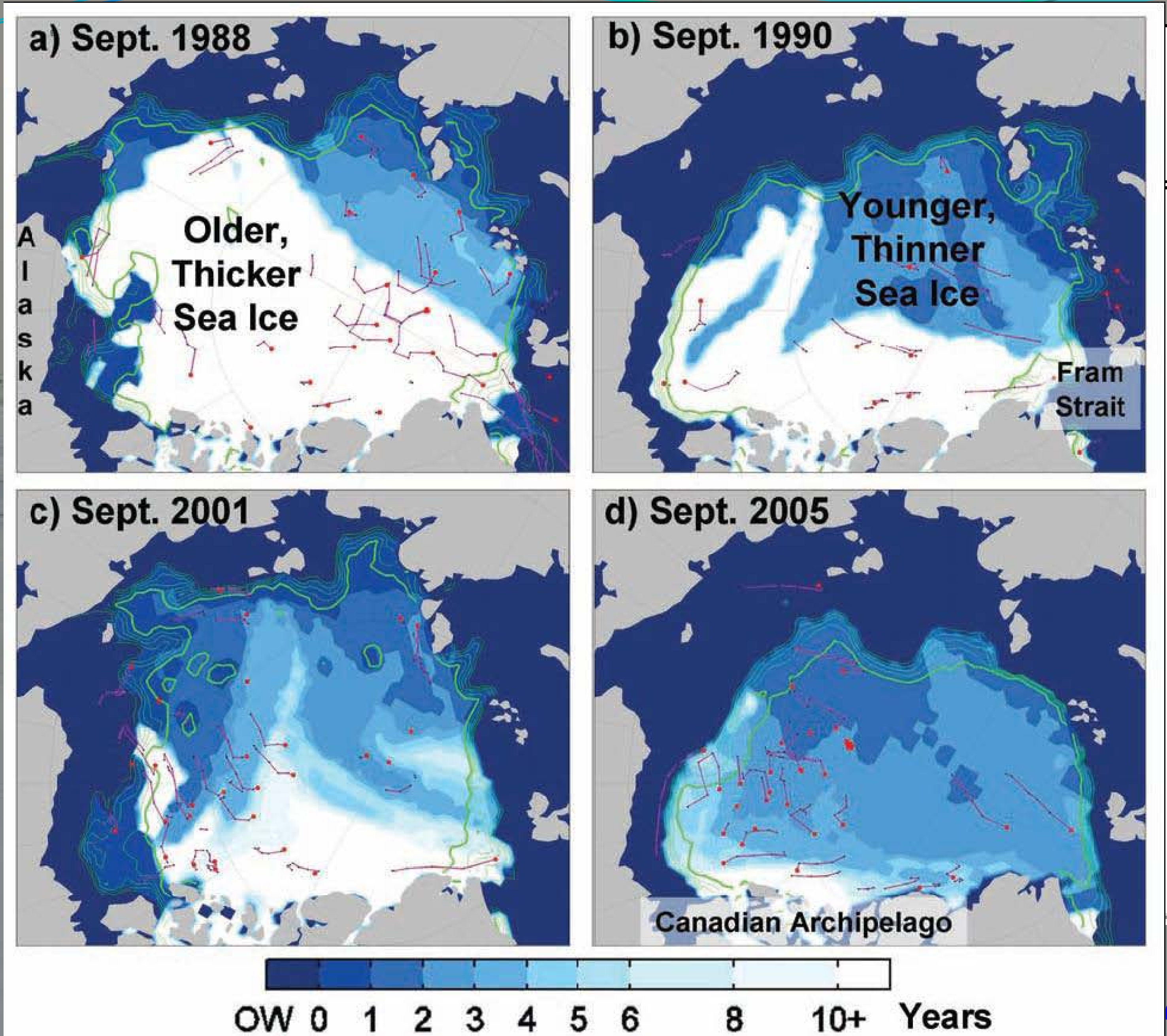
2011-19

2031-39

2051-59

CCSM3

Buoy drift and Ice Concentration



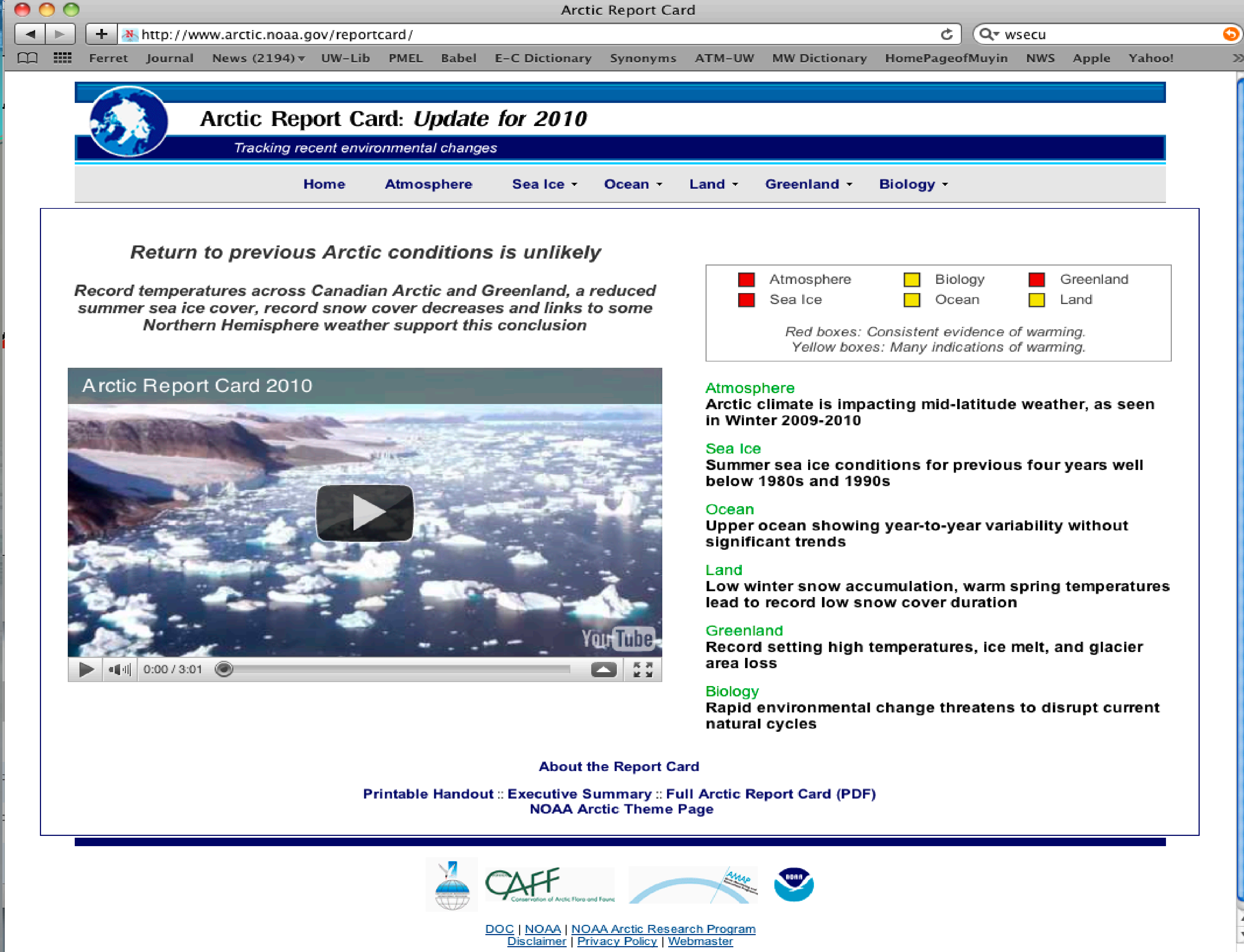
m I. Rigor

#1 Wed Jul 07 14:48:31 2010 UTC
p: 11.0°C

Ice Export Faster …

STEADY AS SHE FLOWS

In 1896, Fram became the first vessel to have ridden the Transpolar Drift Stream – one of the Arctic's ice currents. This year, Tara was the second, making the journey in less than half the time. The Transpolar Drift Stream is pushed along by westerly winds, while the other major ice current in the Arctic is the clockwise-circulating Beaufort Gyre, generated by the rotating winds created by a high-pressure atmospheric system



Arctic Report Card

http://www.arctic.noaa.gov/reportcard/

Ferret Journal News (2194) UW-Lib PMEL Babel E-C Dictionary Synonyms ATM-UW MW Dictionary HomePageofMuyin NWS Apple Yahoo!

Arctic Report Card: *Update for 2010*

Tracking recent environmental changes

Home | Atmosphere | Sea Ice | Ocean | Land | Greenland | Biology

Return to previous Arctic conditions is unlikely

Record temperatures across Canadian Arctic and Greenland, a reduced summer sea ice cover, record snow cover decreases and links to some Northern Hemisphere weather support this conclusion

Atmosphere	Biology	Greenland
Sea Ice	Ocean	Land

Red boxes: Consistent evidence of warming.
Yellow boxes: Many indications of warming.

Atmosphere
Arctic climate is impacting mid-latitude weather, as seen in Winter 2009-2010

Sea Ice
Summer sea ice conditions for previous four years well below 1980s and 1990s

Ocean
Upper ocean showing year-to-year variability without significant trends

Land
Low winter snow accumulation, warm spring temperatures lead to record low snow cover duration

Greenland
Record setting high temperatures, ice melt, and glacier area loss

Biology
Rapid environmental change threatens to disrupt current natural cycles

About the Report Card

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NOAA Arctic Theme Page

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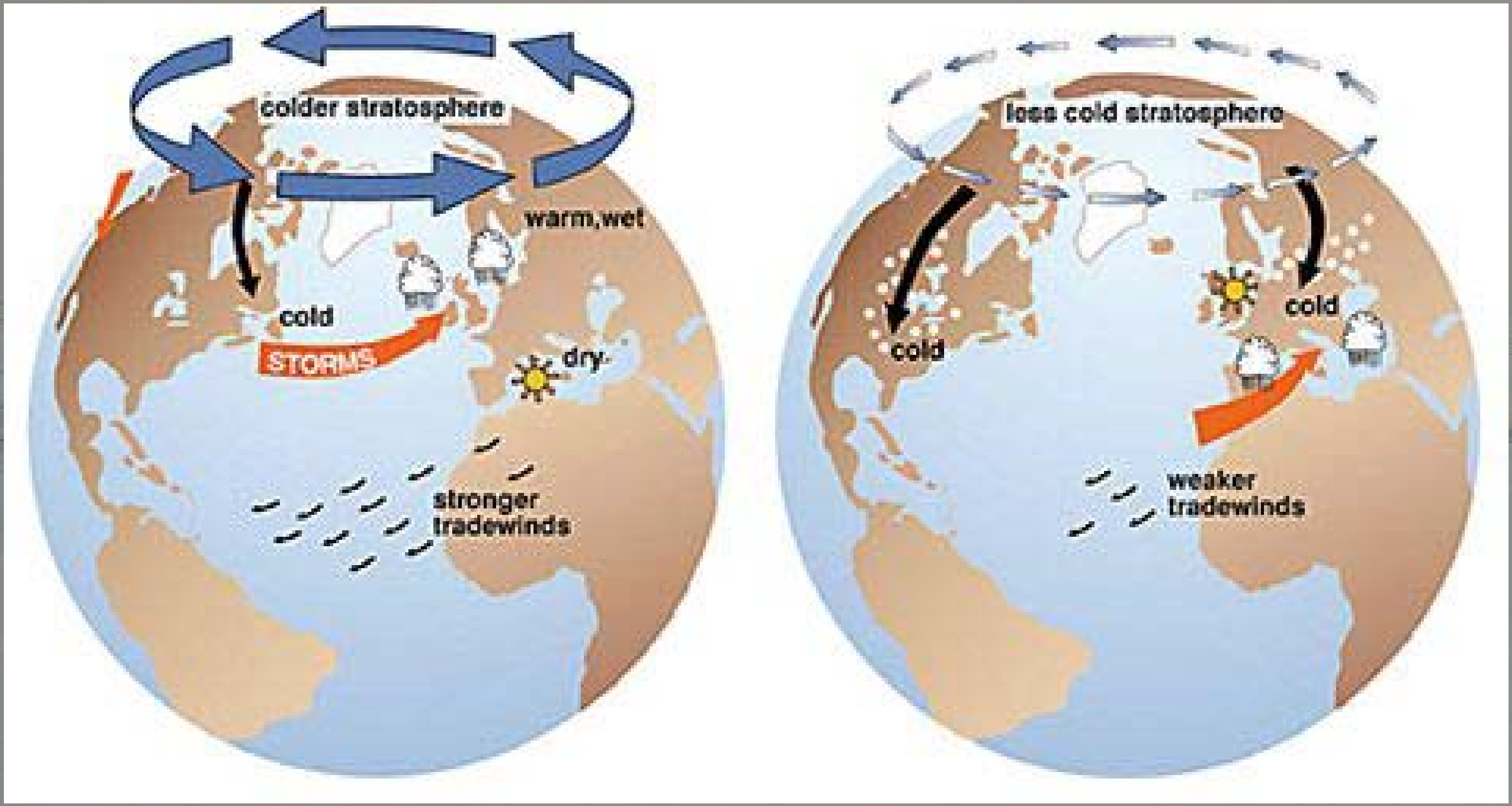
http://www.arctic.noaa.gov/reportcard/

The AO and Weather Pattern



Courtesy of J. Wallace

Toward producing reanalysis wind field over the Chukchi/Beaufort Seas via data assimilation and analysis nudging

Jing Zhang[1], Jeremy Krieger[2], Fuhong Liu[1],
Martha Shulski[3], Xiangdong Zhang[4]

[1]NOAA ISET Center, NC A&T State Unversity,
[2]ARSC, UAF,
[3]High Plains Regional Climate Center, UNL
[4]IARC, UAF

Introduction

- When performing long-term regional simulations, techniques must be used to constrain the model and maintain numerical stability.
- Data assimilation and analysis nudging are two powerful methods for improving model performance.
- Data assimilation introduces observed, high resolution information into the model simulation, increasing accuracy.
- Analysis nudging constrains the model solution and prevents errors from growing too large.

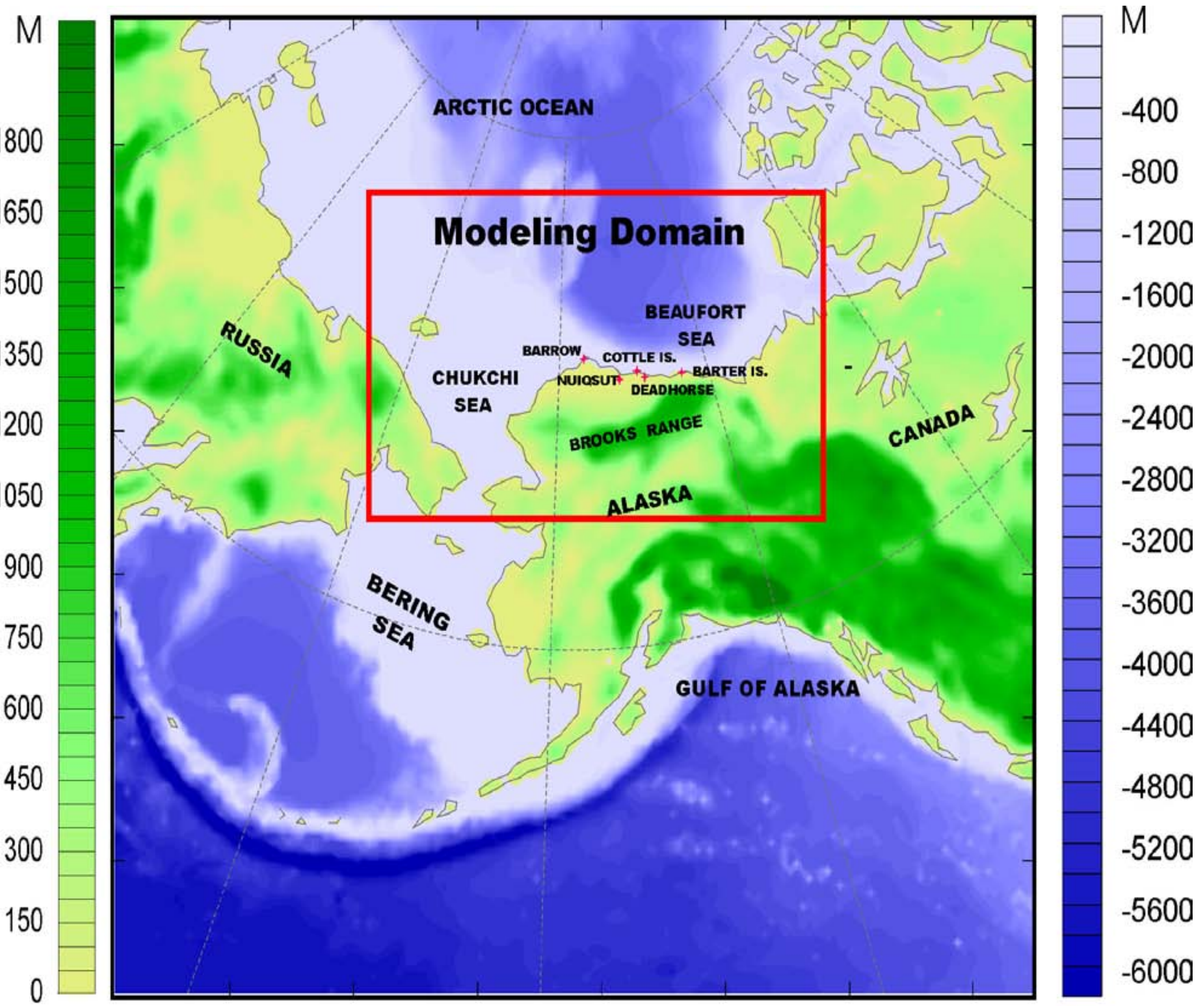
Model Configuration

Horizontal Grid Spacing: **10 km**

49 vertical levels

test periods:

Jun 30 – Aug 30



A little about data assimilation

- Assume:

  $T_m = 18°C$ (model temperature)

  $T_o = 21°C$ (observed temperature)

  T_t *true temperature, but we don't know…*

- Assume:

  $\sigma_m = 2°C$ (model error)

  $\sigma_o = 1°C$ (observational error)

  σ_m & σ_o are uncorrelated

- T will be corrected as:

$$T = a\,T_m + b\,T_o$$

- The most straightforward way to decide a & b is to minimize the mean square error of T:

$$E[(T-T_t)^2] = E[(a(T_m-T_t)+b(T_o-T_t))^2] = a^2\sigma_m^2 + b^2\sigma_o^2$$

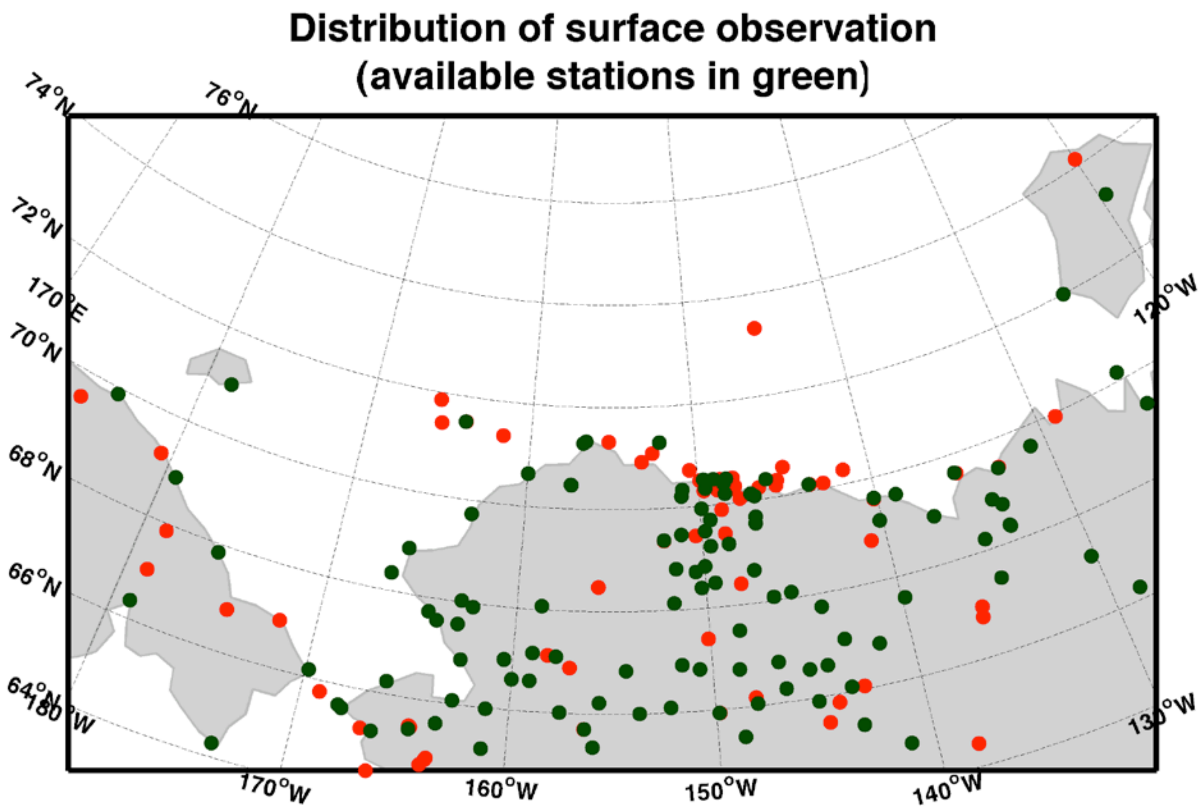
$$a = \frac{\sigma_o^2}{\sigma_o^2 + \sigma_m^2} \qquad b = \frac{\sigma_m^2}{\sigma_o^2 + \sigma_m^2}$$

Model Errors

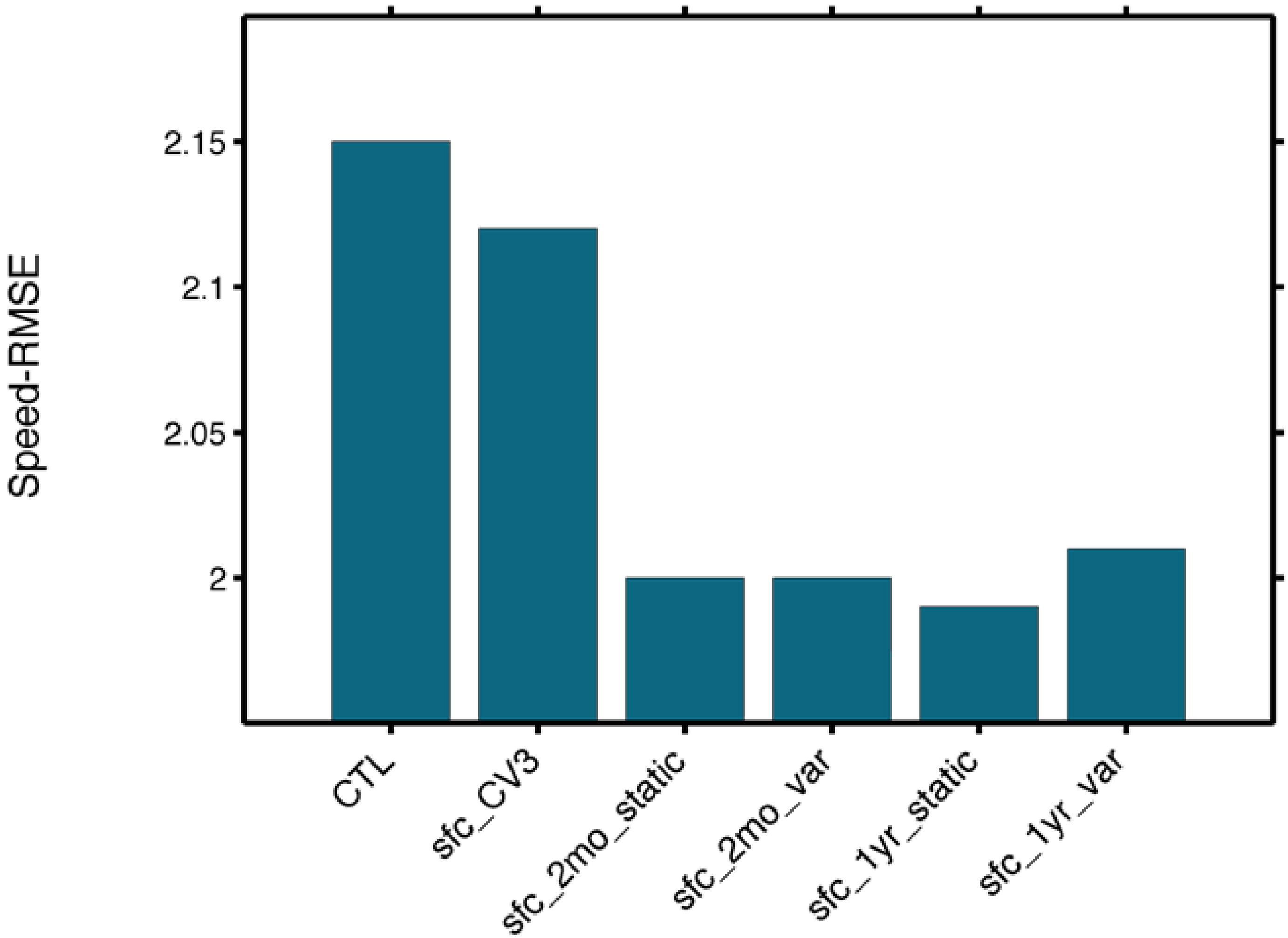
- Several model background errors (BEs) are tested, including
  - CV3 (default)
  - CV5 (customize)
    - 2-month simulation, no diurnal cycle (sfc_2mo-static)
    - 2-month simulation, with diurnal cycle (sfc_2mo-var)
    - 1-year simulation, no diurnal cycle (sfc_1yr-static)
    - 1-year simulation, with diurnal cycle (sfc_1yr-var)

Surface Observation

- Available/Total: 119/195 stations
- Once hourly (most of them)



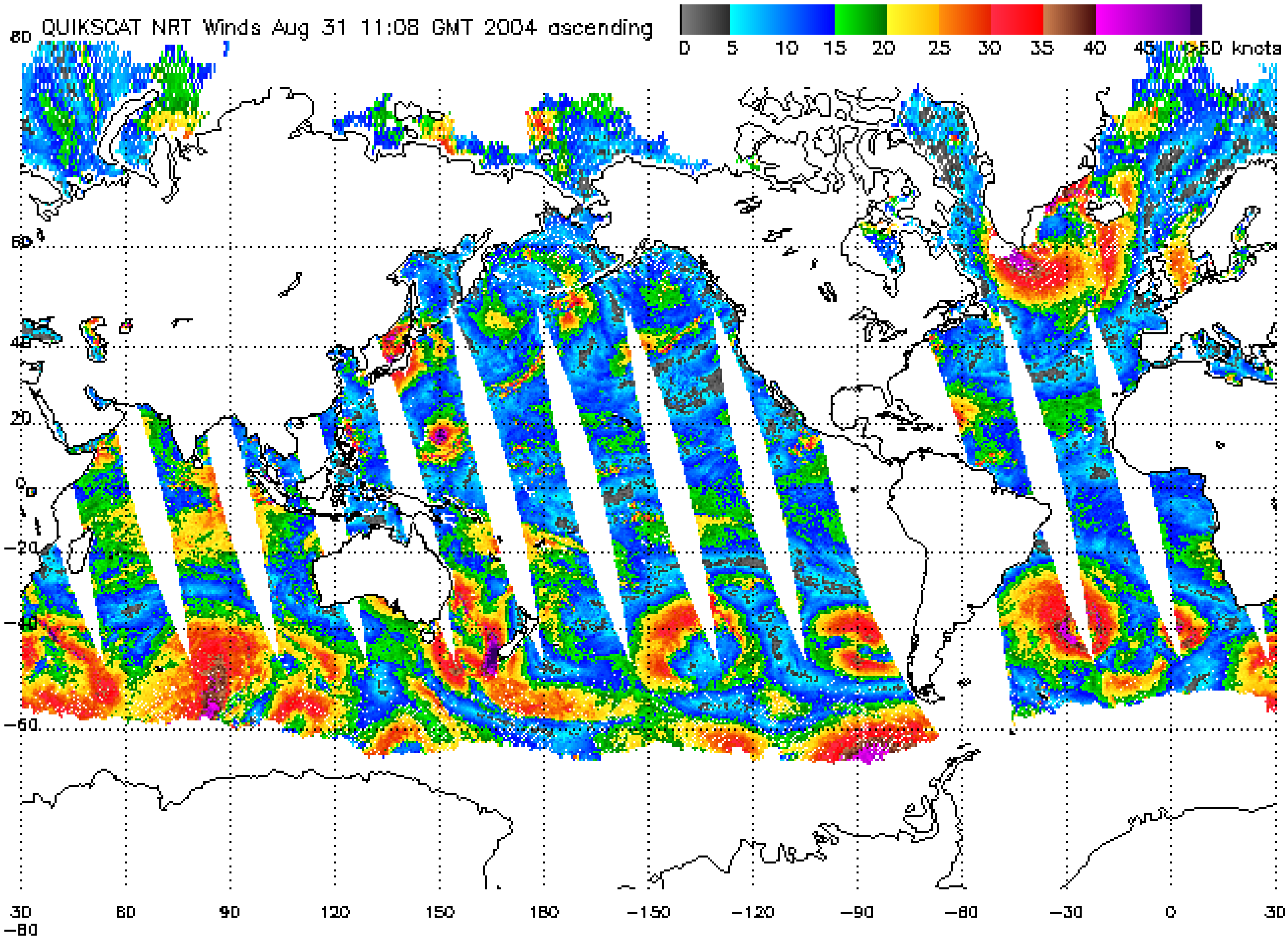
The effects of BE



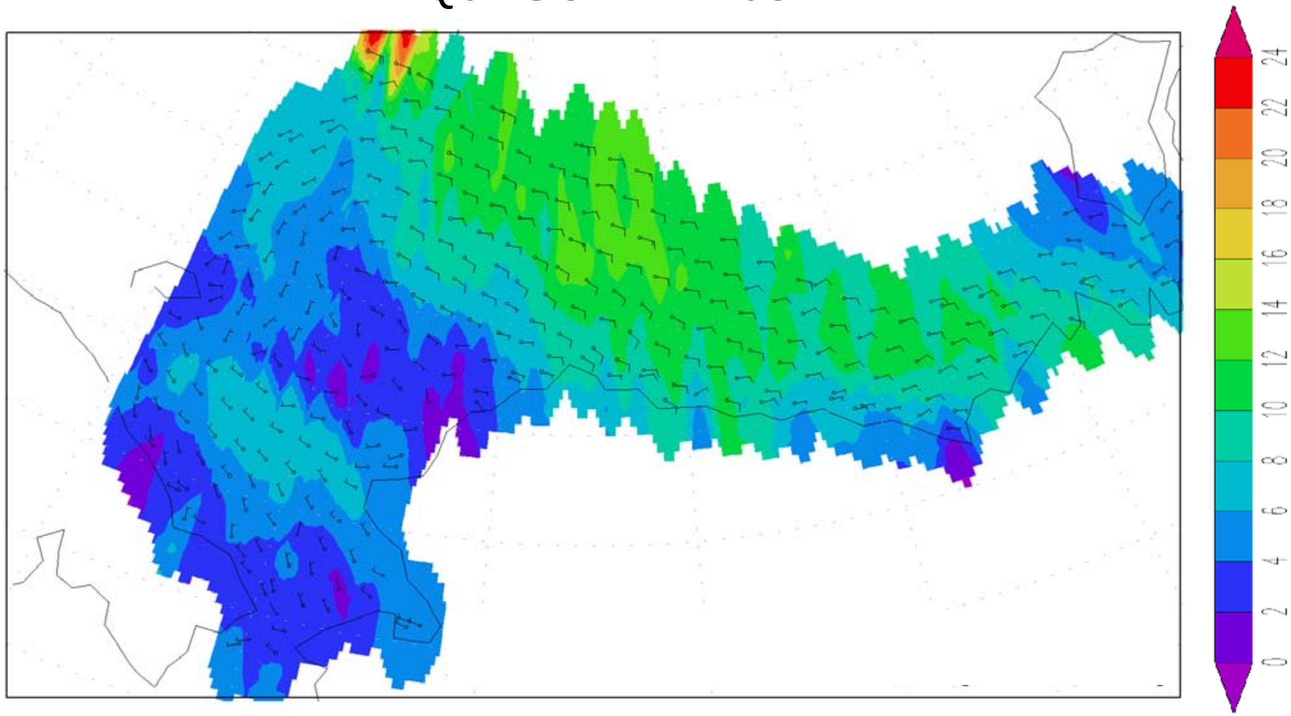
QuikSCAT Winds & Errors

- Ocean surface winds at 10 m height retrieved using observation data from NASA/JPL's SeaWinds scatterometer
- Data is available from **19 July 1999** through **21 November 2009**
- Temporal resolution: multiple times daily
- Spatial resolution: 12.5 km
- Different Wind speed errors are tested
  - 1 m/s (qscat_err1)
  - 4 m/s (qscat_err4)

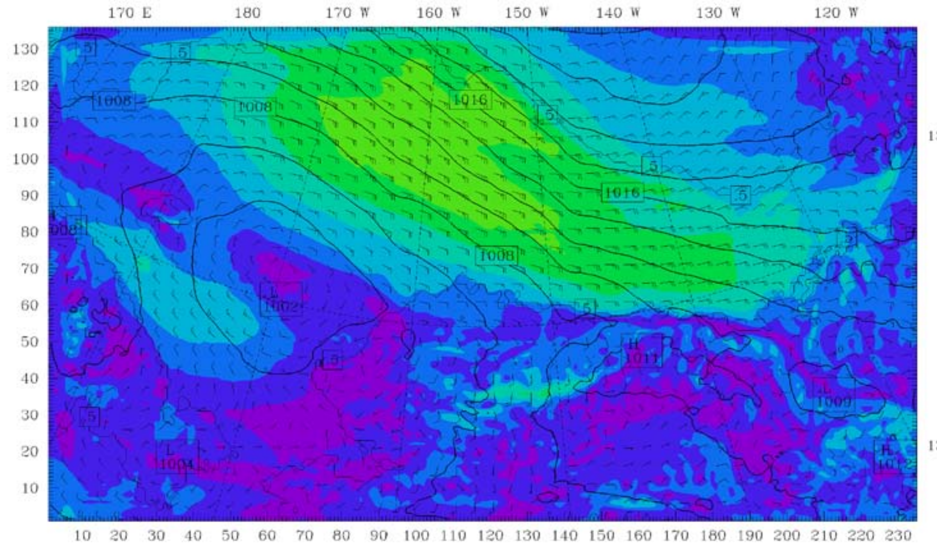
QuikSCAT Winds



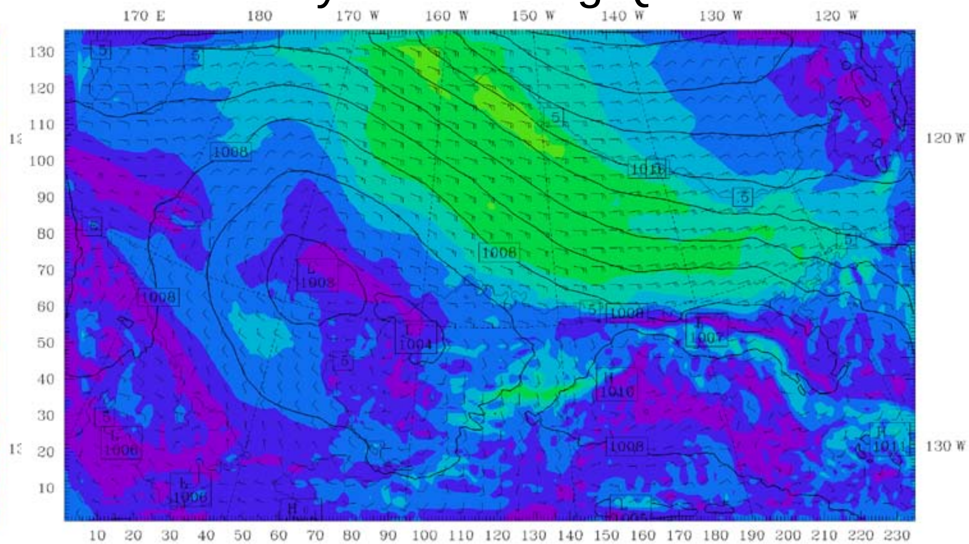
QuikSCAT Winds



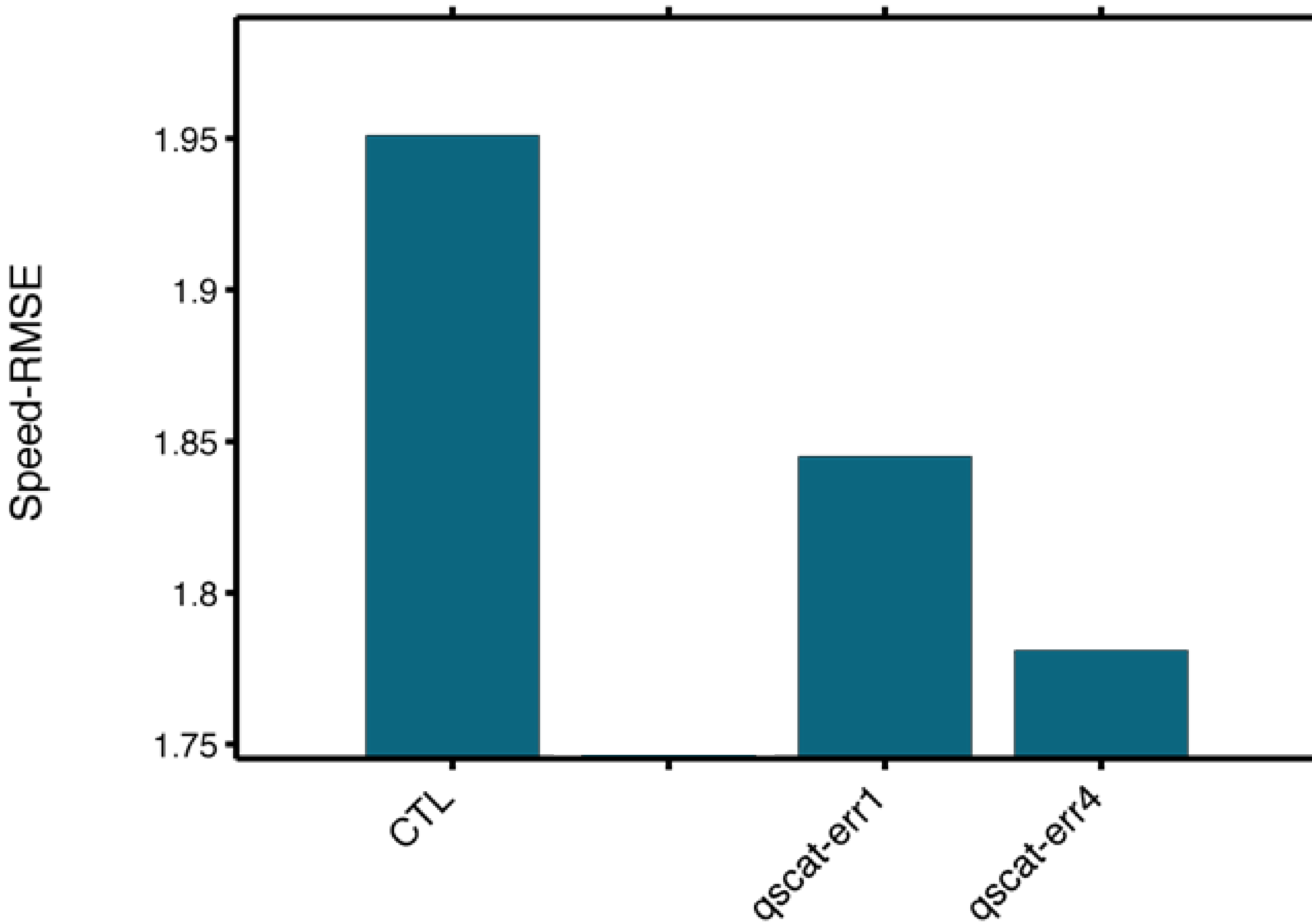
WRF initial winds



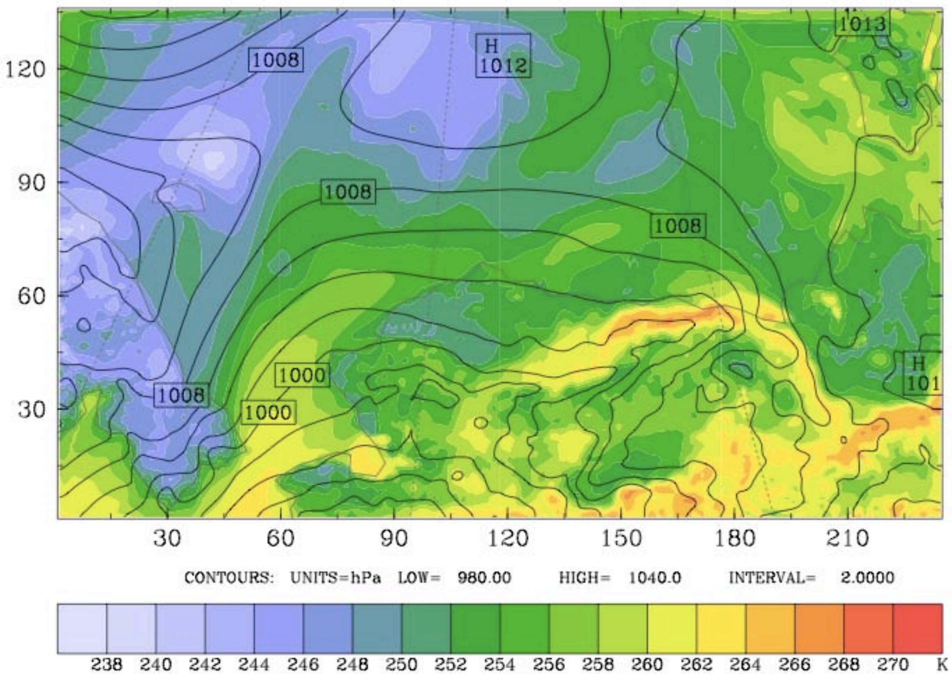
WRF re-initialization by assimilating QuikSCAT winds

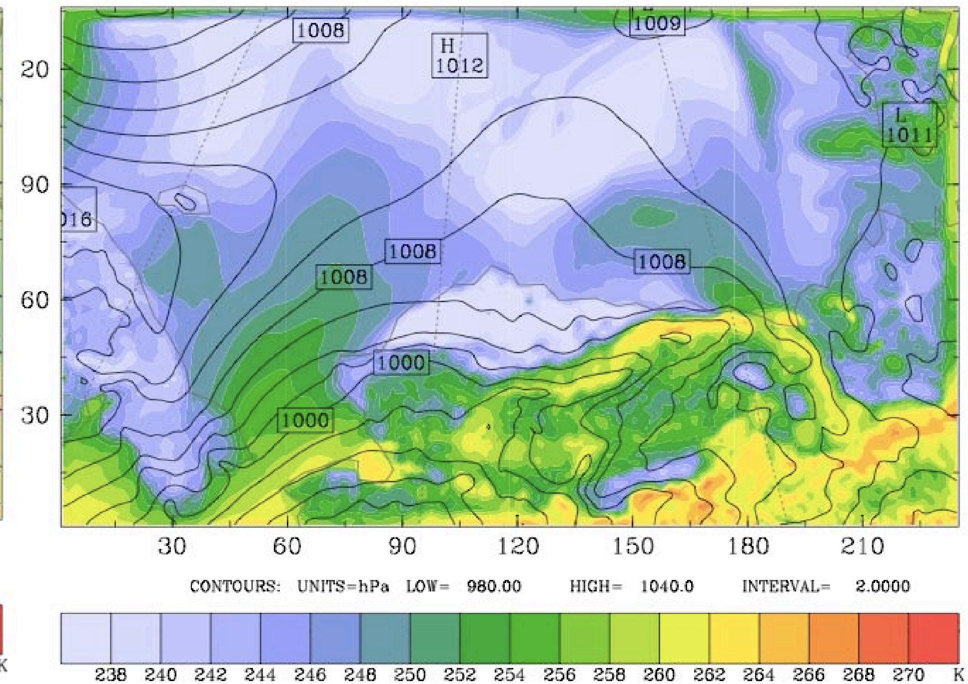


The effects of Data Errors



Comparisons between Reanalysis (left) and WRF 1-yr Simulation without Assimilation and Nudging (right)

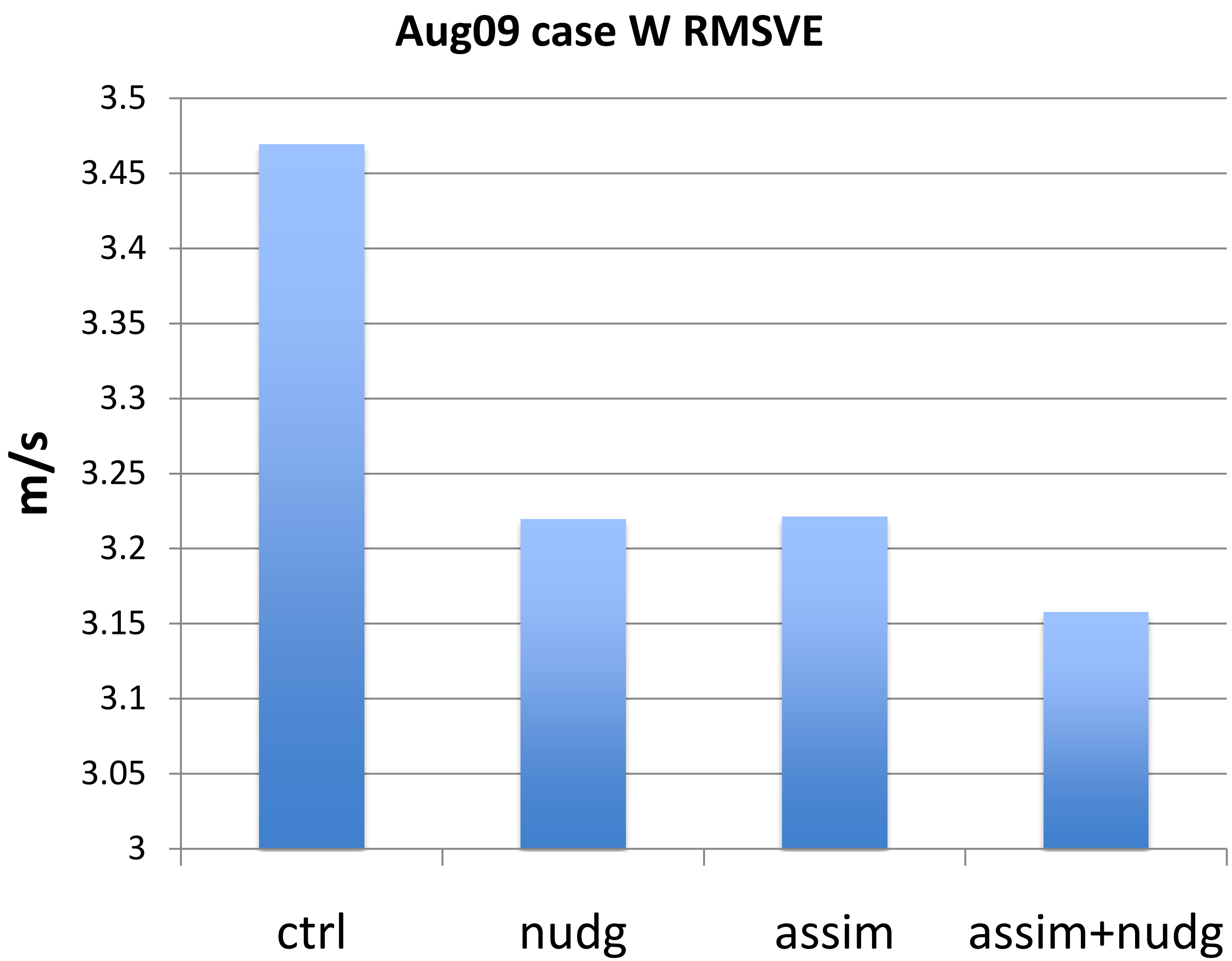




Analysis Nudging

- Analysis nudging continually guides model solution towards existing reanalysis to prevent errors from growing too large, which is very necessary for a regional climate modeling.
- WRF contains two 3-D analysis nudging options:
  - Gridpoint nudging – each gridpoint is nudged toward input dataset
  - ✓ Spectral nudging – only nudges coarser scales; better allows smaller-scale model information to be retained

Assimilation + Spectral Nudging



Final Configuration

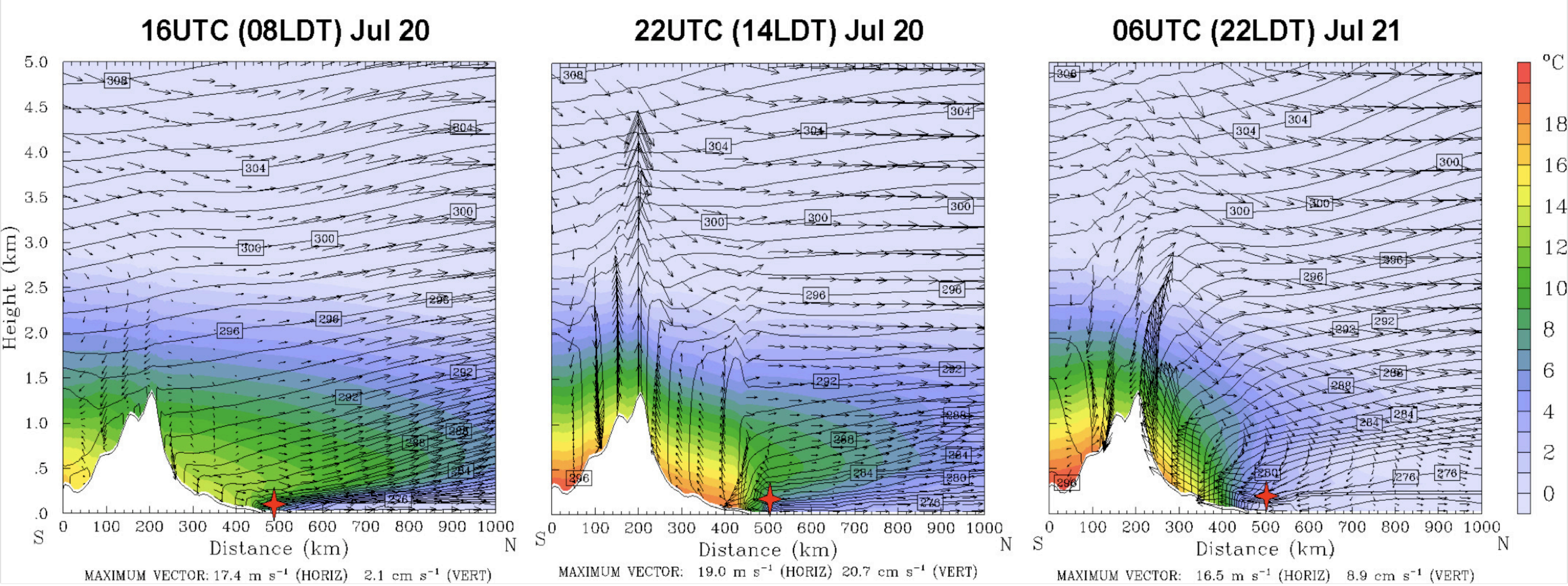
- Data assimilation of:
  - Surface stations
  - Radiosondes
  - QuikSCAT
  - MODIS profiles
  - COSMIC profiles
- Spectral nudging of all vars / levels
- Updated surface condition:
  - CMC snow depth analysis
  - AMSR-E sea ice analysis

Mesoscale Modeling – sea breeze

Unique environmental conditions:

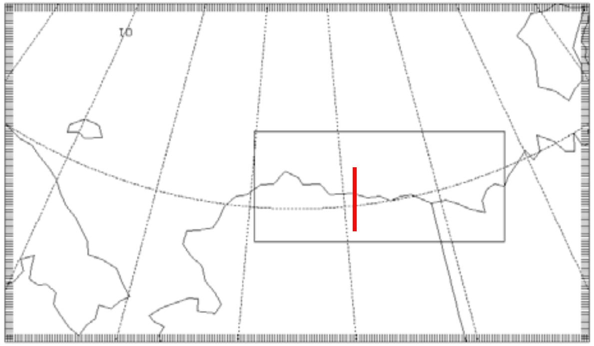
- Continuous solar radiance
- Greater Coriolis effect

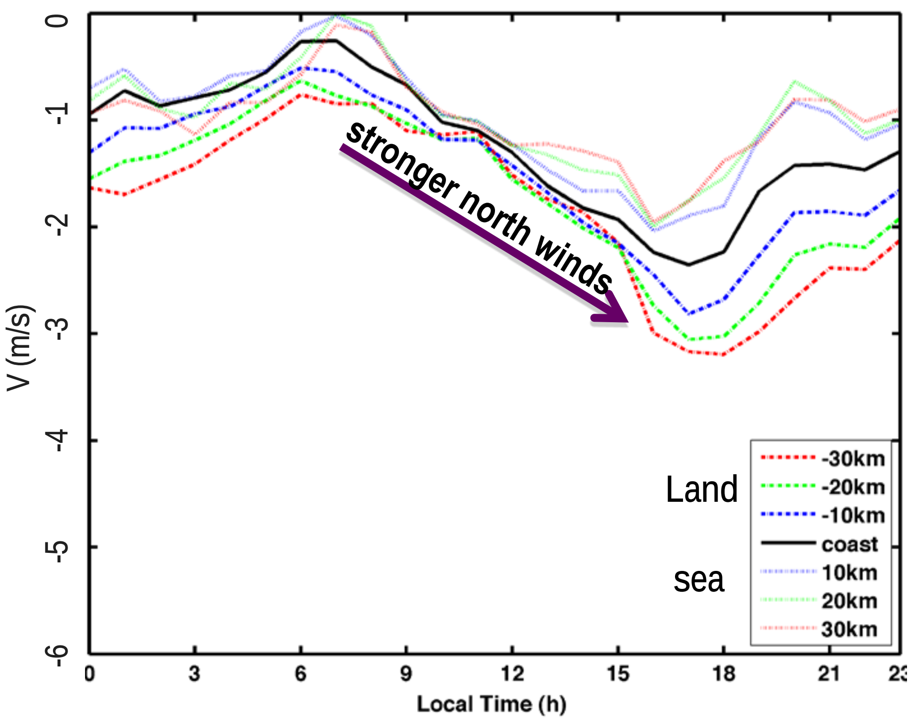
Strongest sea breeze (+mountain breeze) occurs late evening due to continuous solar radiance

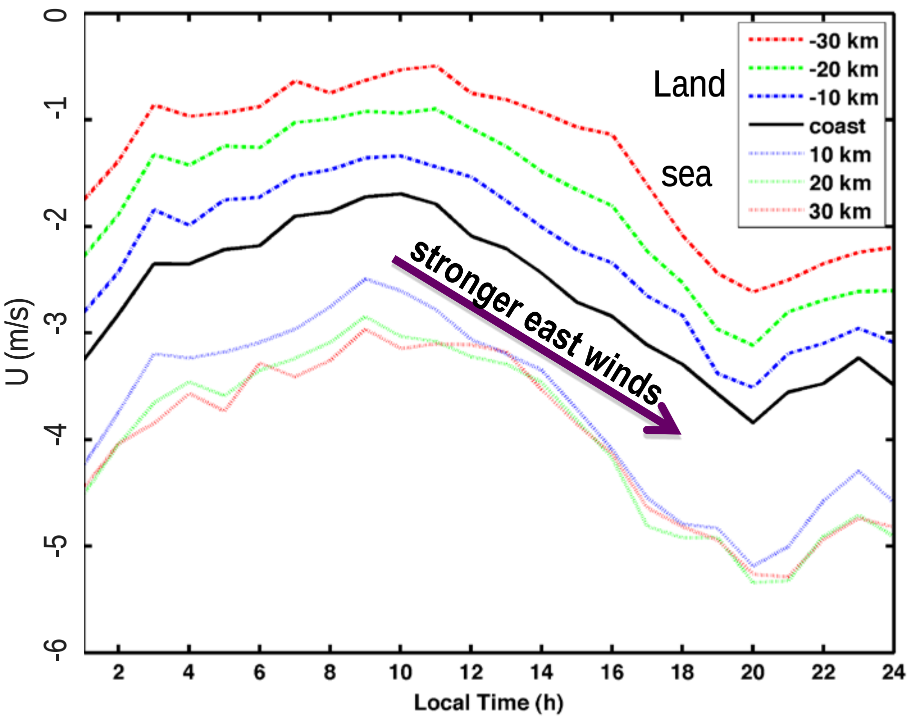


Mean diurnal variation of V and U

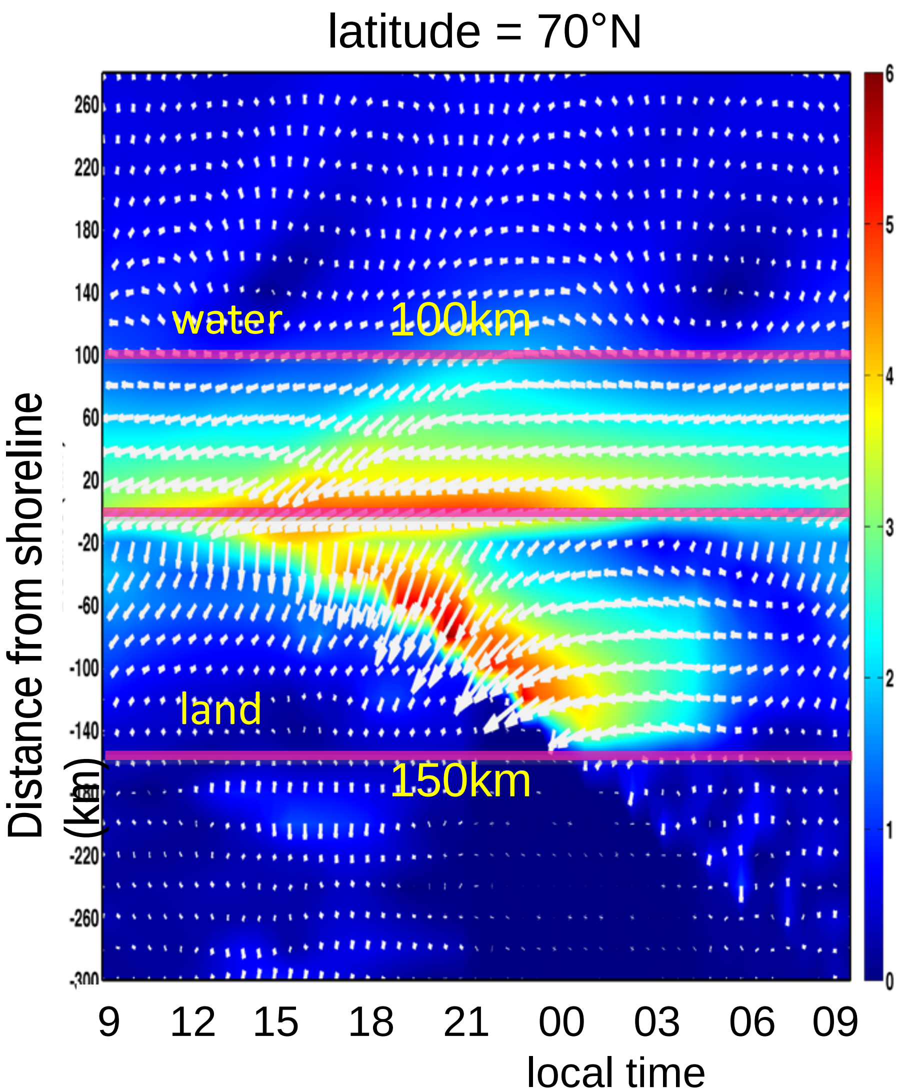
Wind fields along a north-south cross section were analyzed to show the averaged diurnal variation of U and V at different distance from the shoreline, negative values signify north and east winds





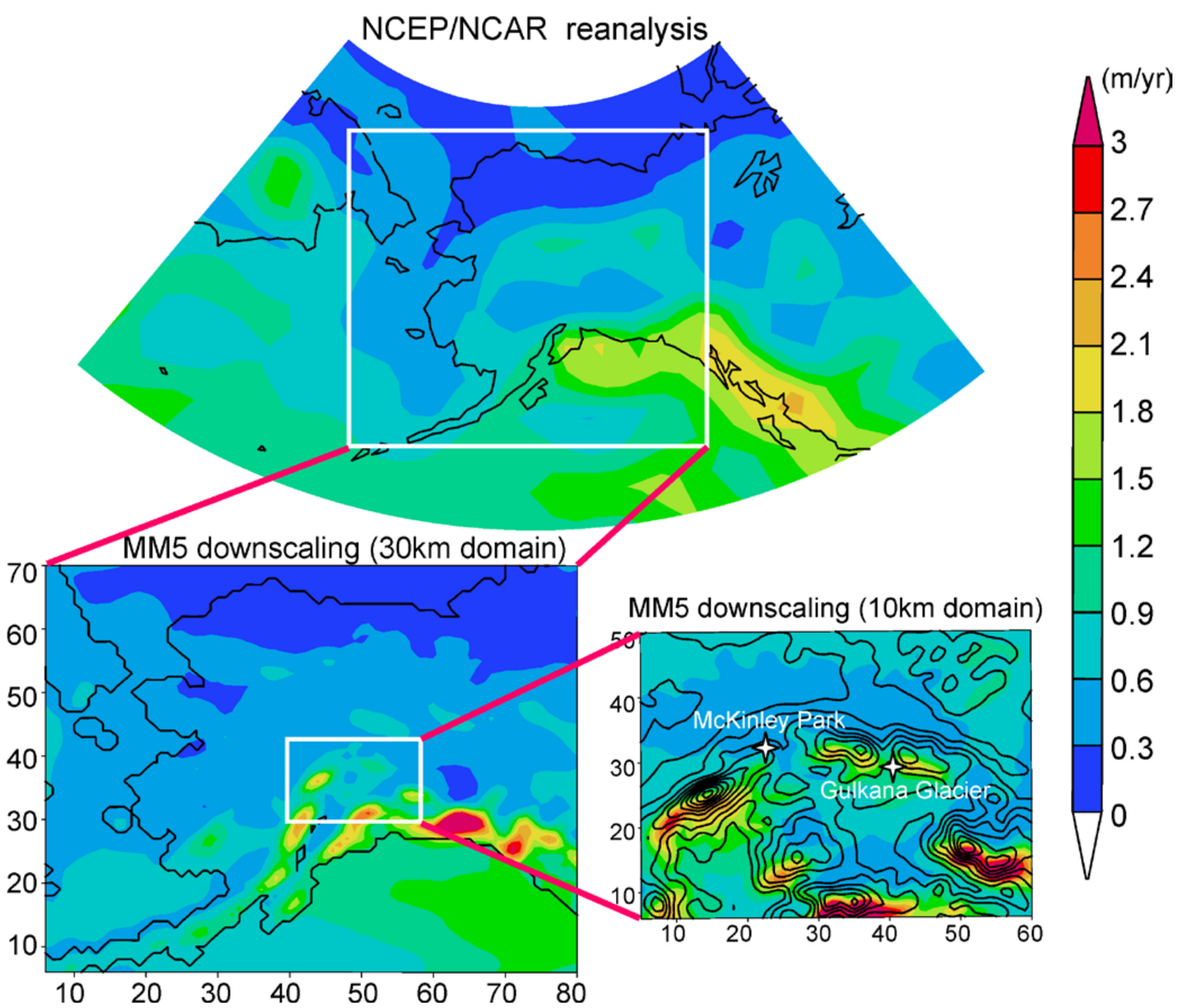


Sea Breeze Diurnal Variation in Idealized Simulation



Beyond Wind Field Reanalysis

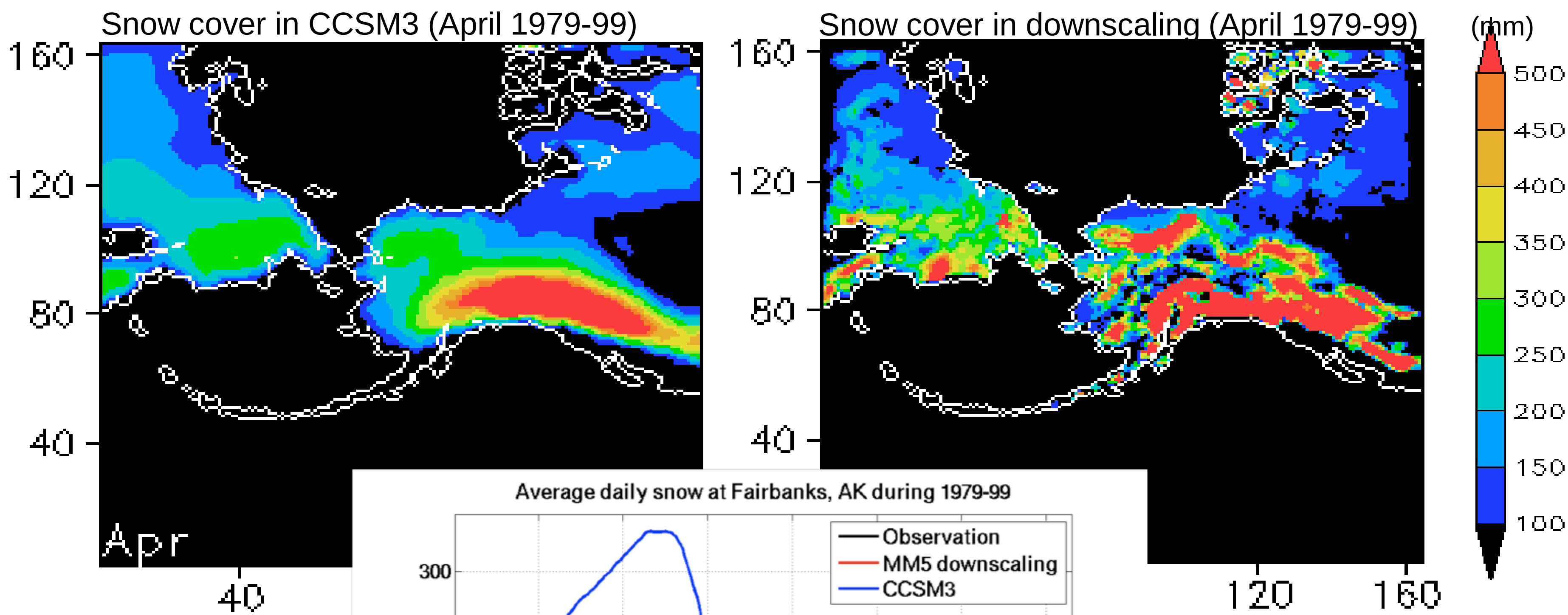
Why downscaling, not just GCM?

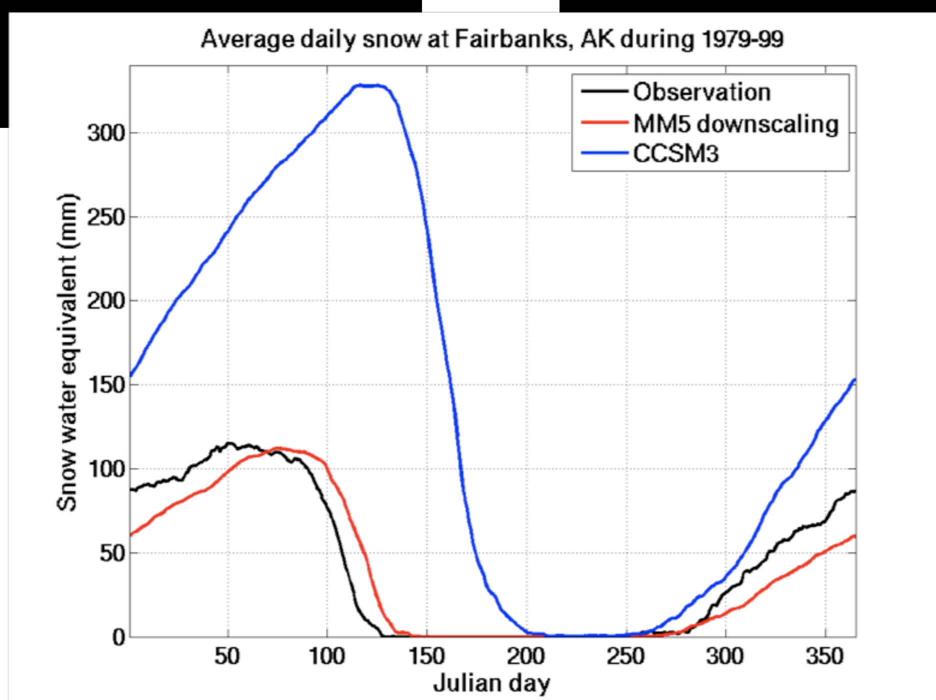


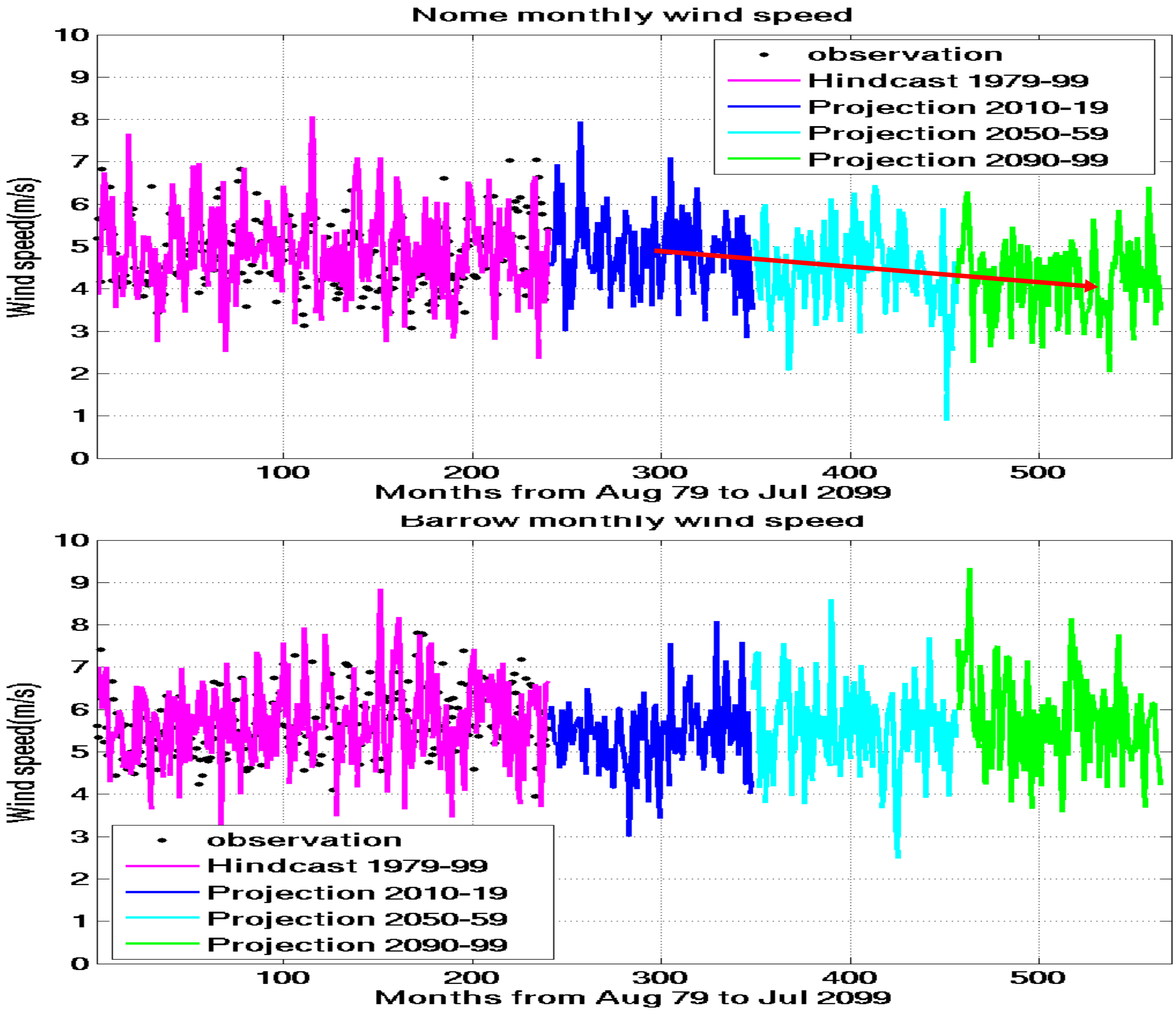
10-yr (Oct.94-Sep.04) annual mean precip.(m/yr)

(Zhang et al 2007, GRL)

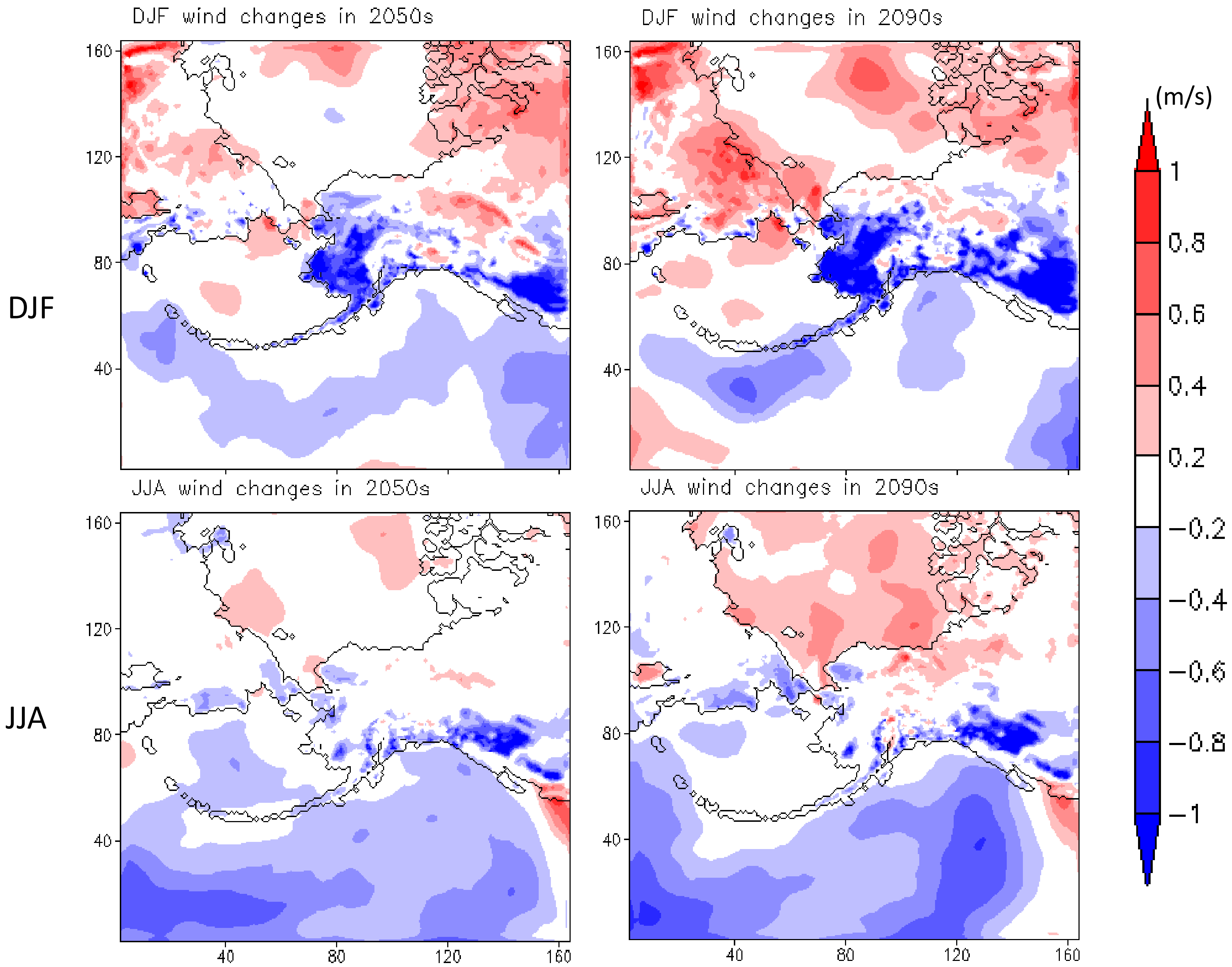
Snow Cover in CCSM3 (left) and Downscaling (right)





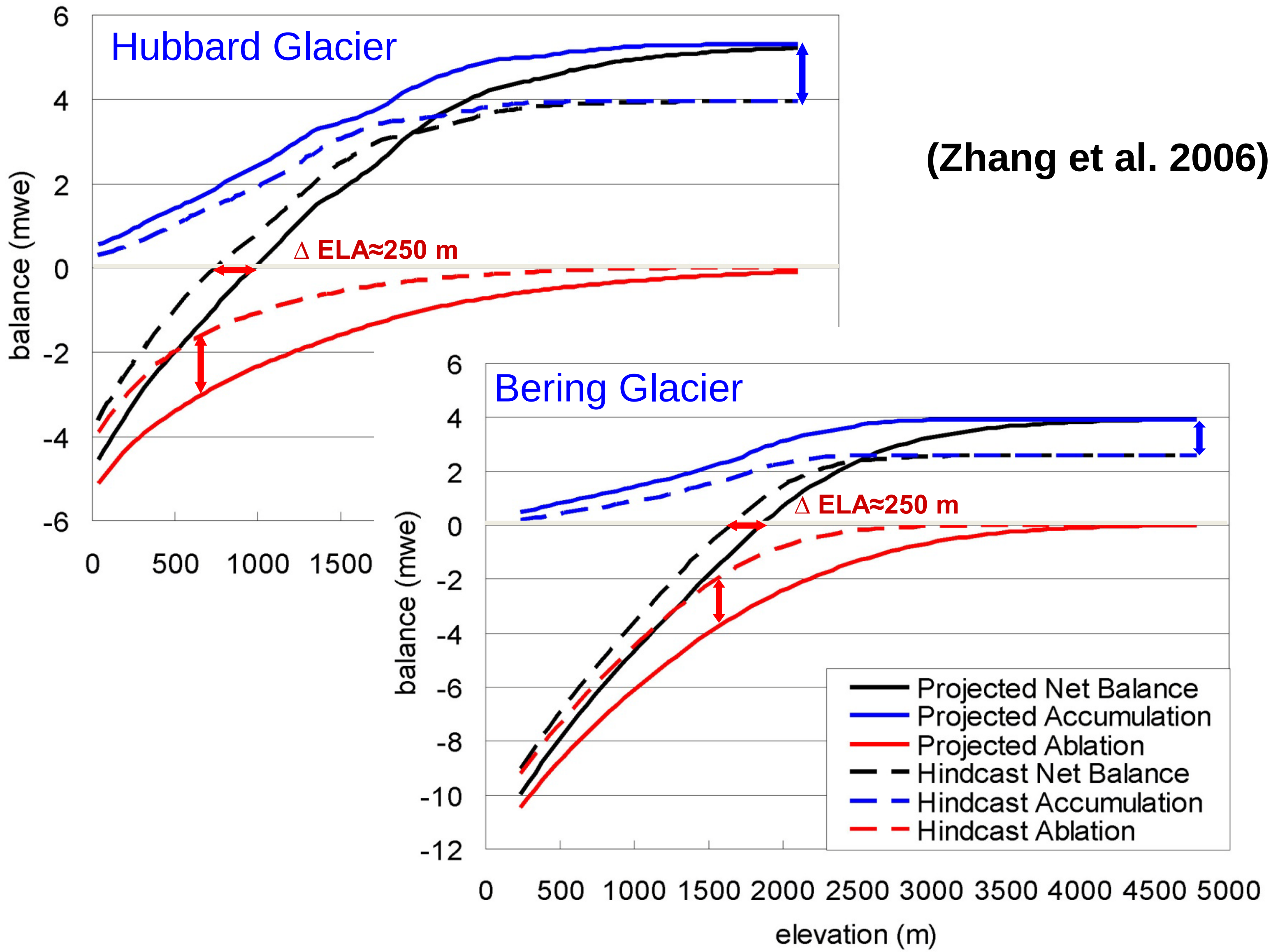


Nome monthly wind speed
observation
Hindcast 1979-99
Projection 2010-19
Projection 2050-59
Projection 2090-99
Wind speed(m/s)
0
1
2
3
4
5
6
7
8
9
10
100
200
300
400
500
Months from Aug 79 to Jul 2099
Barrow monthly wind speed
observation
Hindcast 1979-99
Projection 2010-19
Projection 2050-59
Projection 2090-99
Wind speed(m/s)
0
1
2
3
4
5
6
7
8
9
10
100
200
300
400
500
Months from Aug 79 to Jul 2099



DJF wind changes in 2050s
DJF wind changes in 2090s
JJA wind changes in 2050s
JJA wind changes in 2090s
DJF
JJA
(m/s)
1
0.8
0.6
0.4
0.2
−0.2
−0.4
−0.6
−0.8
−1
160
120
80
40

Projected (2010-19) and Hindcast (1994-04) Glacier Mass Balance

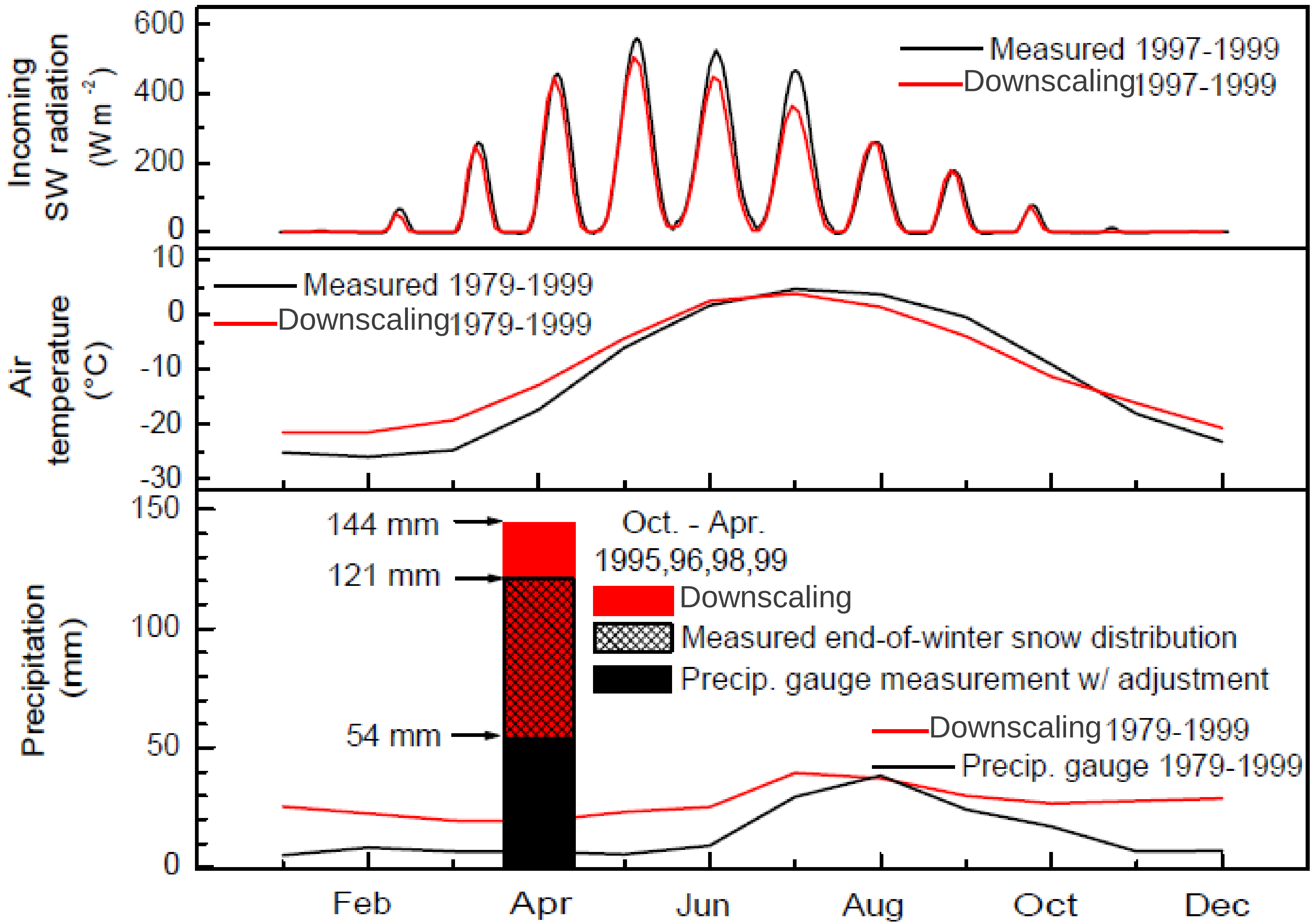


(Zhang et al. 2006)

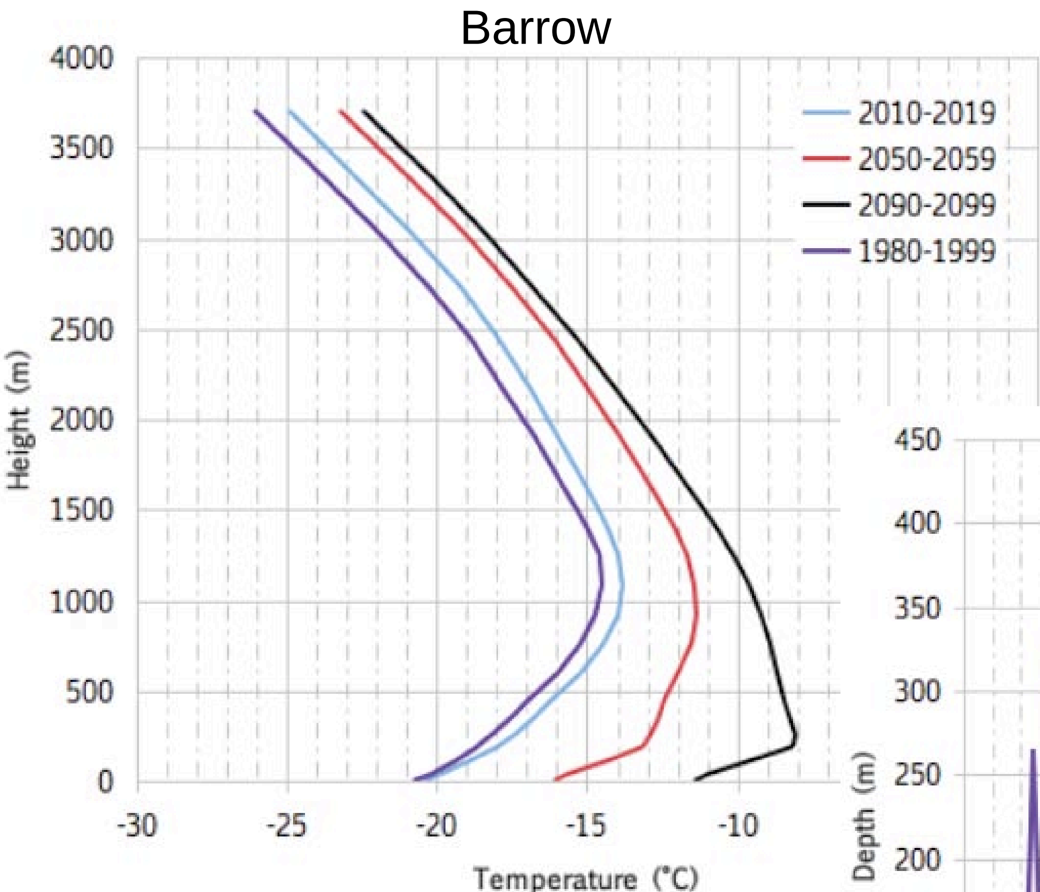
WATER BALANCE OF AN ARCTIC COASTAL WETLAND, BARROW, ALASKA: END-OF 21ST CENTURY PROJECTIONS

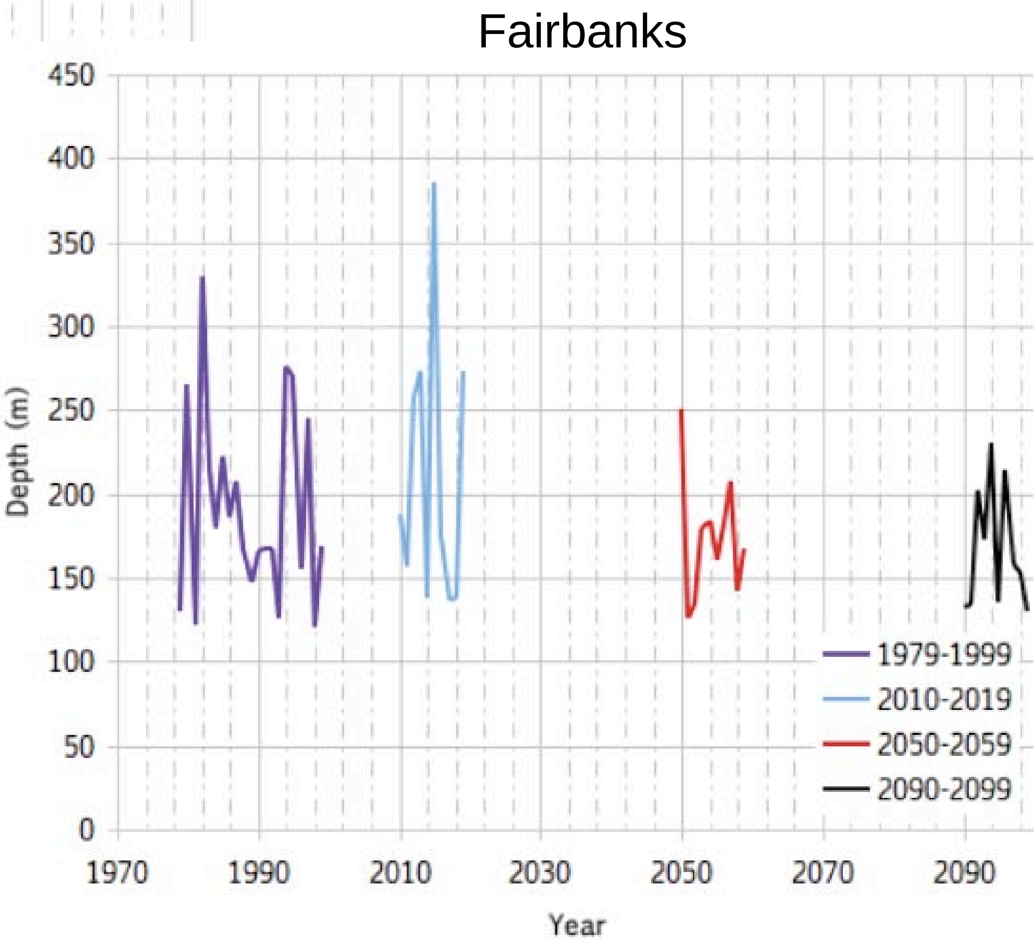
Anna K. Liljedahl et al 2011

(in preparation)



FUTURE INVERSION CLIMATE IN ALASKA DURING 21 CENTURY



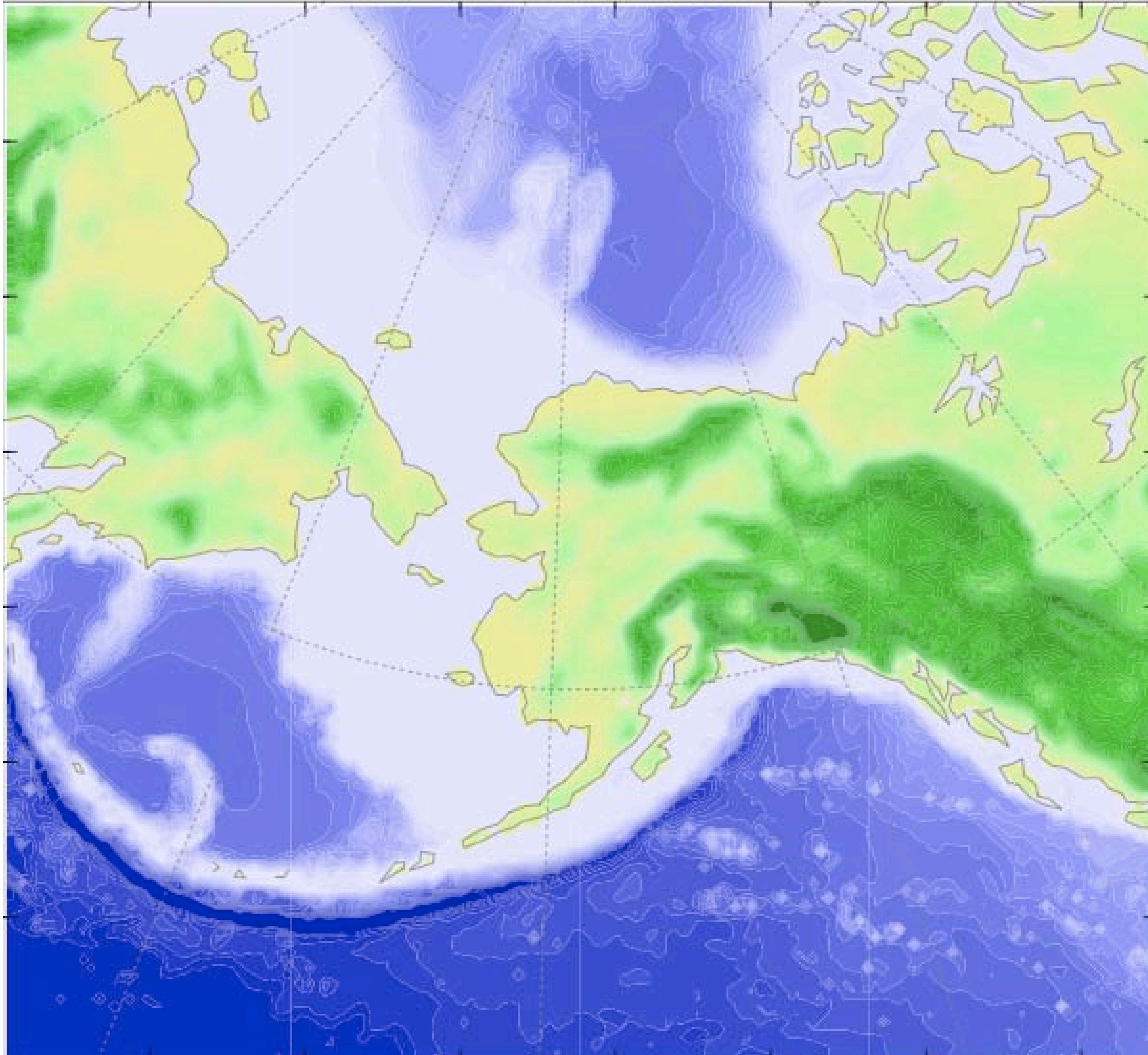


S. Bourne et al. 2009

FURTURE CONTRIBUTION OF GLACIER RUNOFF TO FRESHWATER DISCHARGE INTO GOA

ongoing project…

Downscaling Domain



Questions?

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