Earth's Energy Imbalance
and
Ocean Heat Storage

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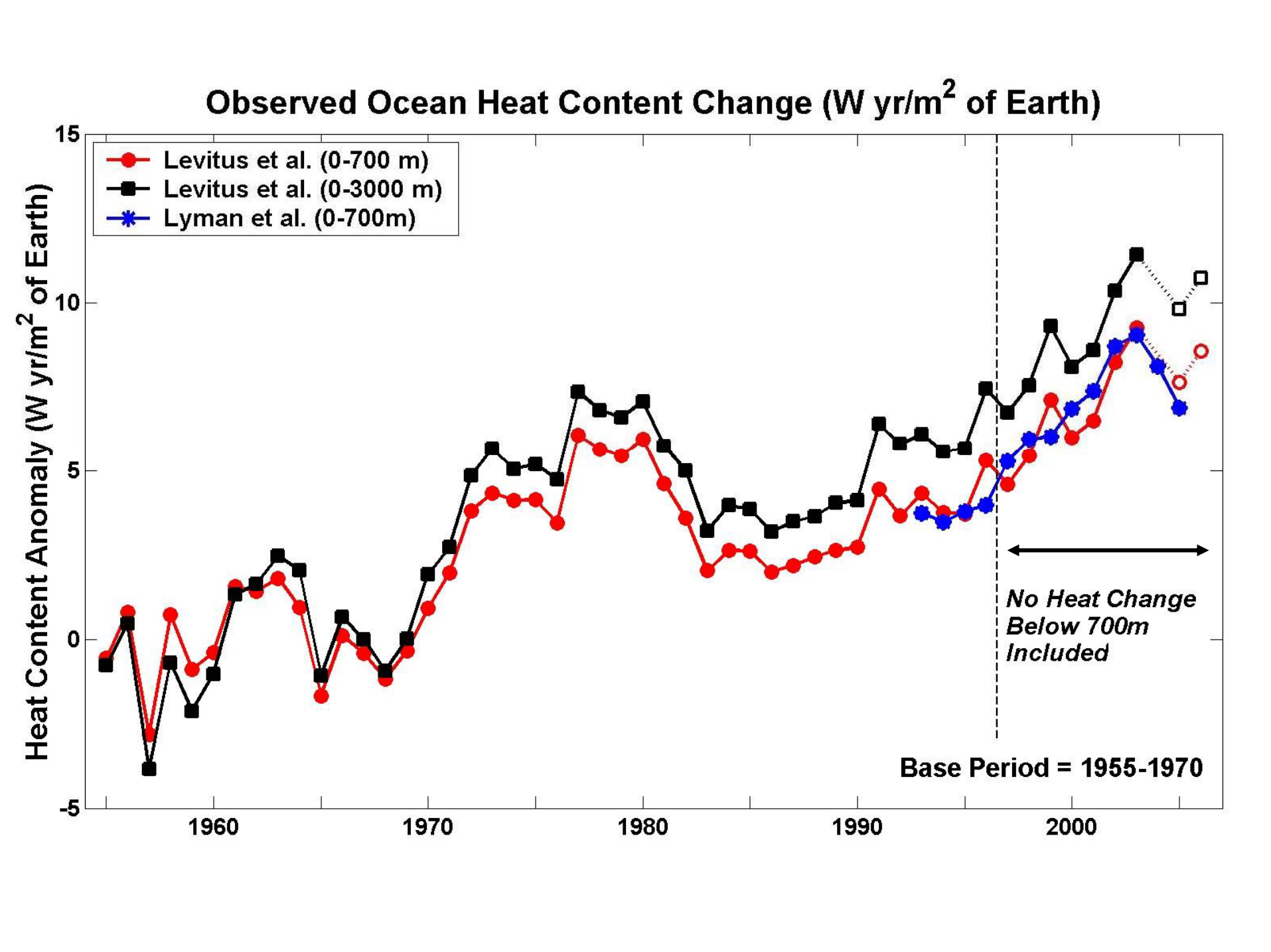
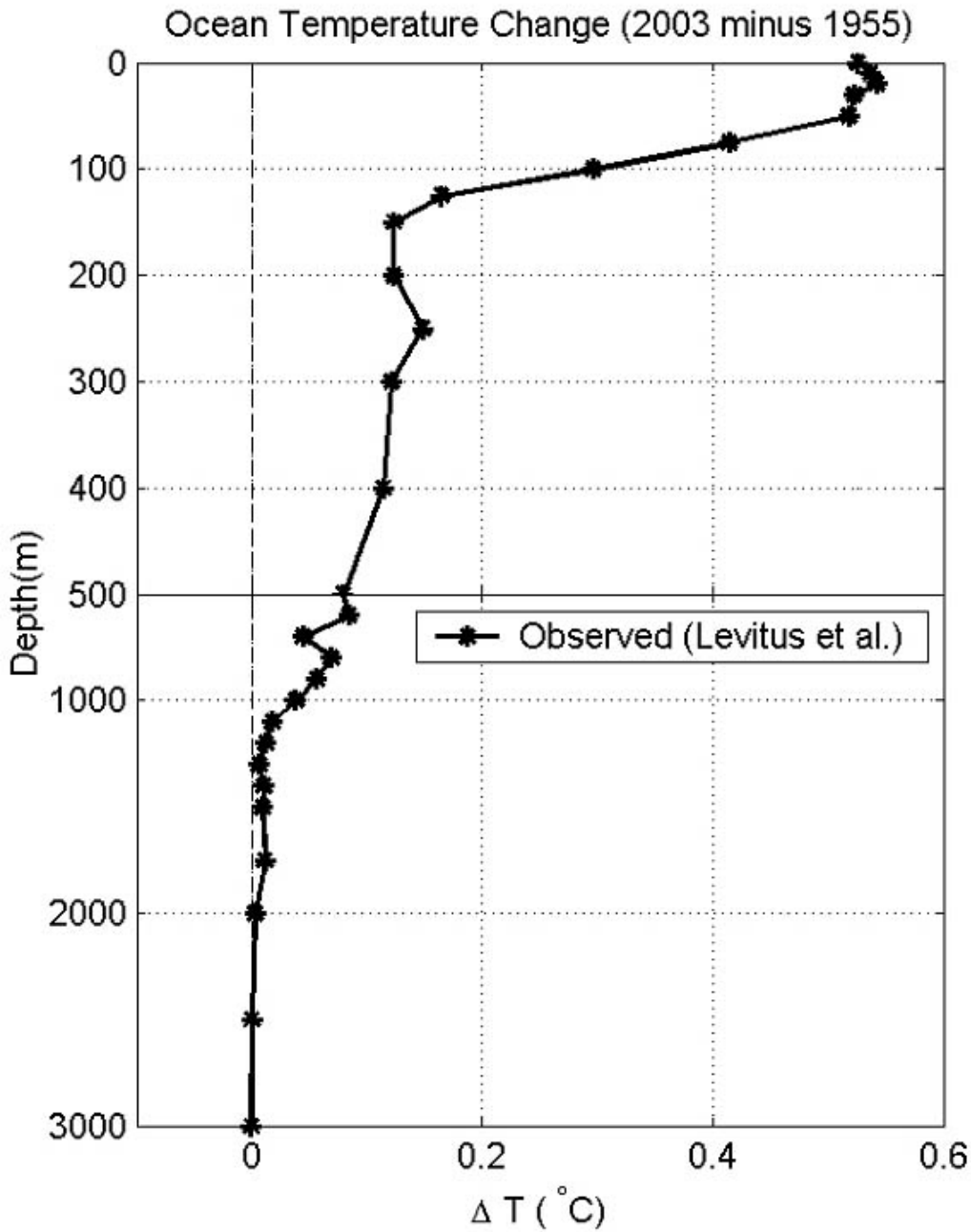
Implications of Energy Imbalance

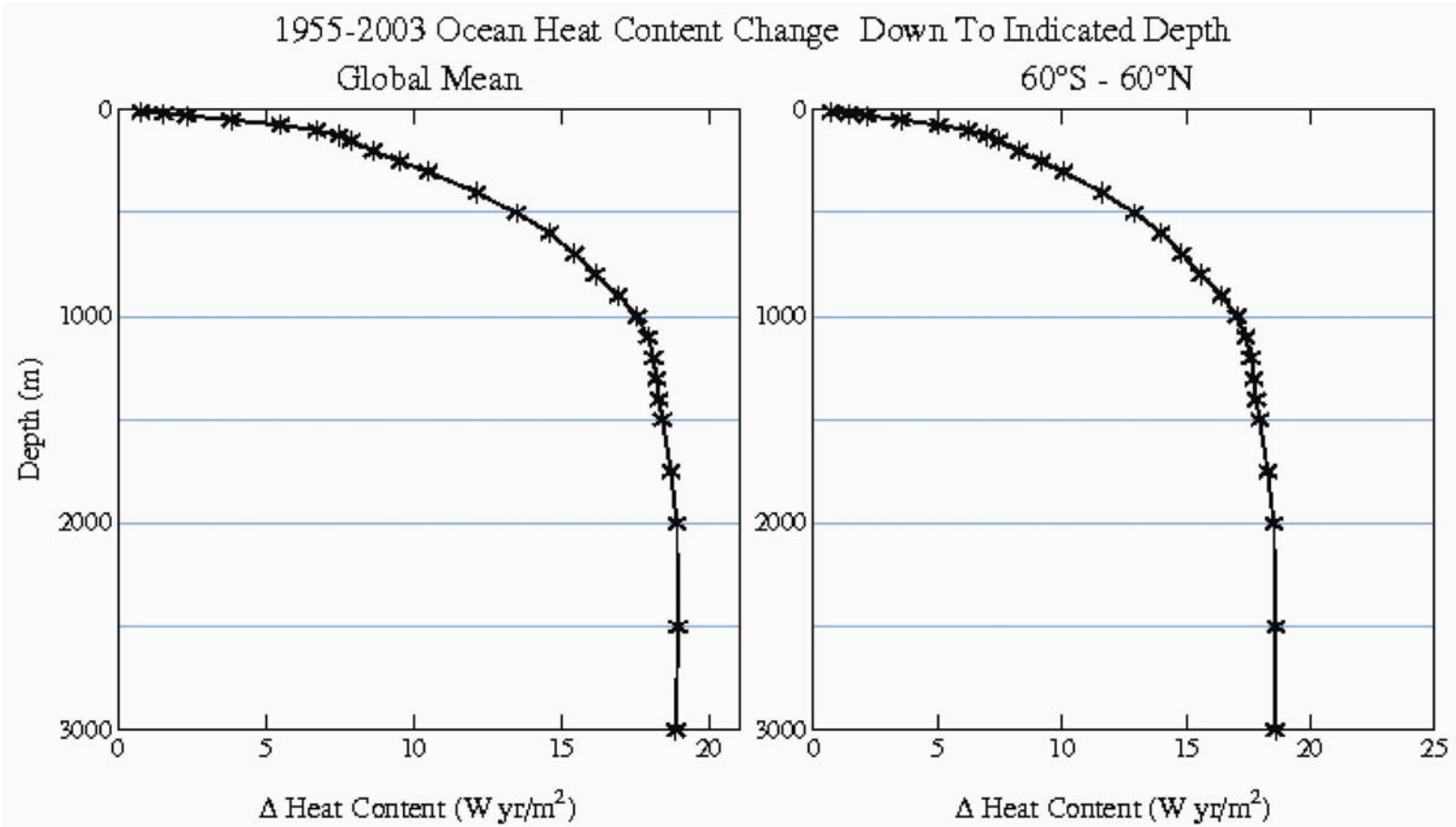
1. **Global warming "in the pipeline"**
   - **prior estimates from 1992-2003 and 1955-2003 ocean heat storage → ~ 0.5ºC "in pipeline"**

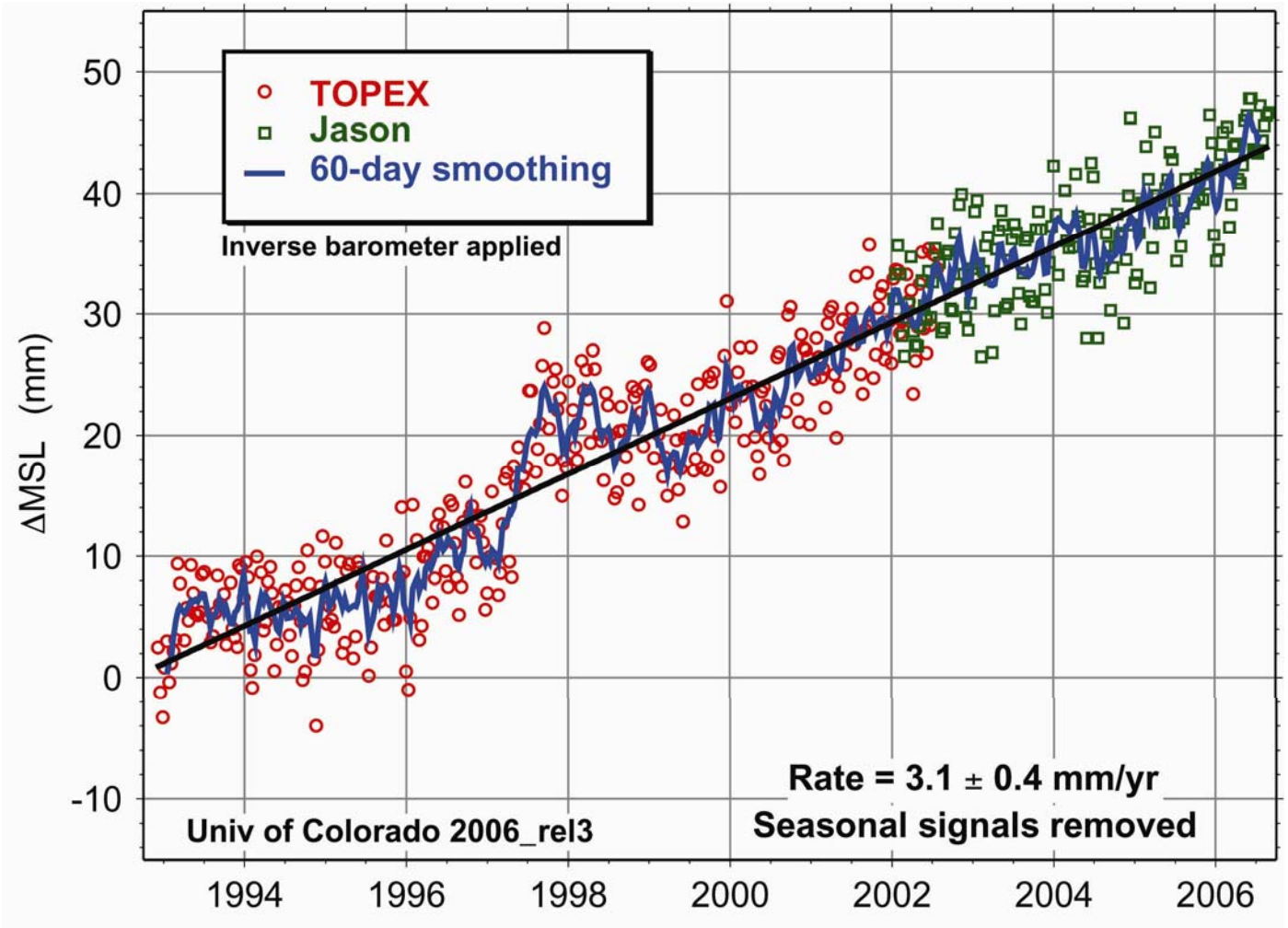
2. **Climate sensitivity**
   - **smaller imbalance, other things equal, implies smaller sensitivity**

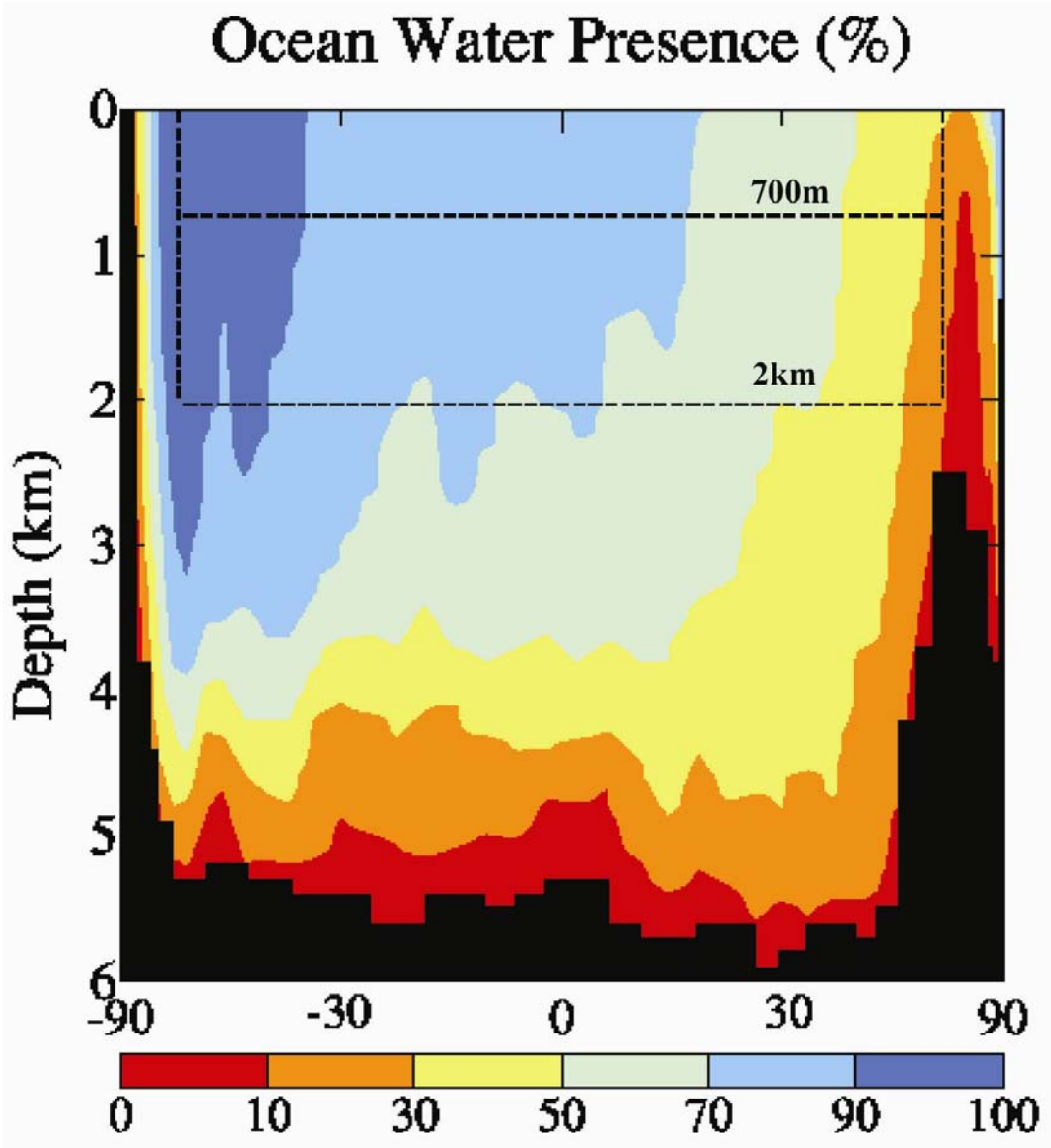
Are prior estimates modified by new data?

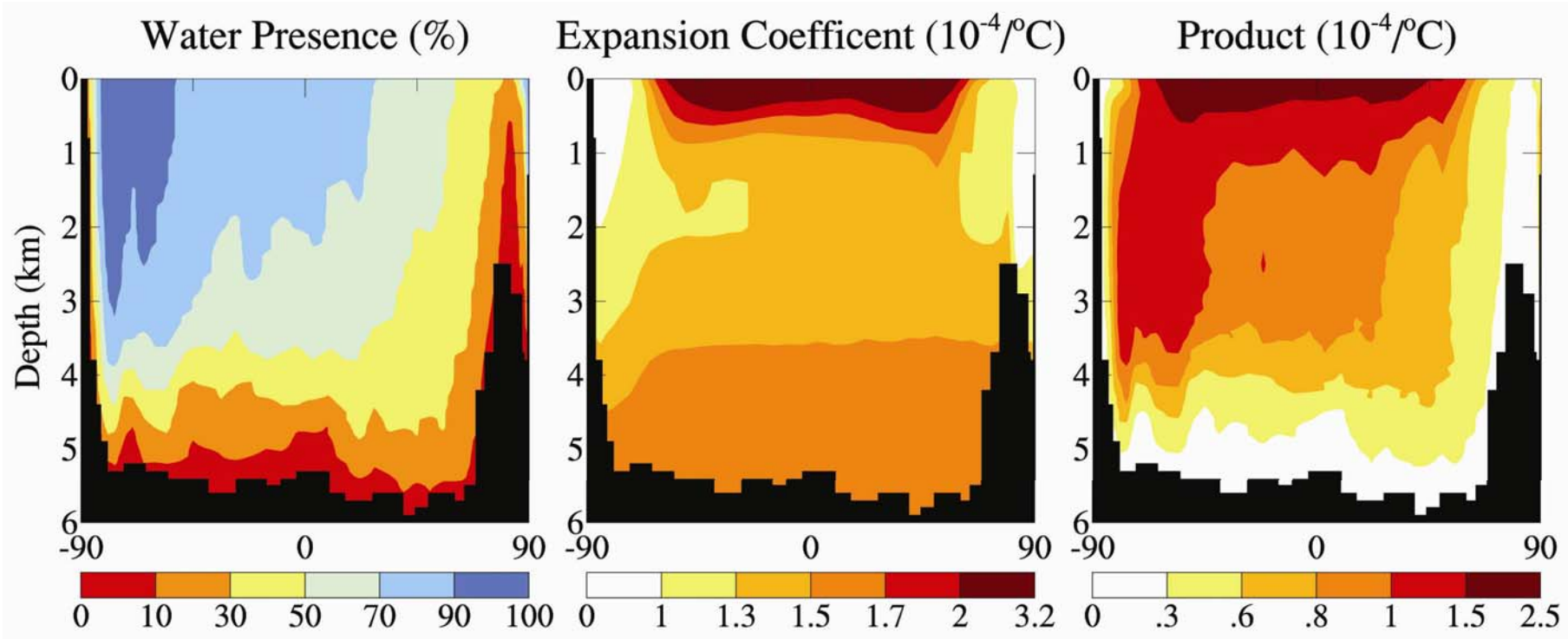

Observed Ocean Heat Content Change (W yr/m2 of Earth)
Levitus et al. (0-700 m)
Levitus et al. (0-3000 m)
Lyman et al. (0-700m)
Heat Content Anomaly (W yr/m2 of Earth)
15
10
5
0
-5
1960
1970
1980
1990
2000
No Heat Change
Below 700m
Included
Base Period = 1955-1970

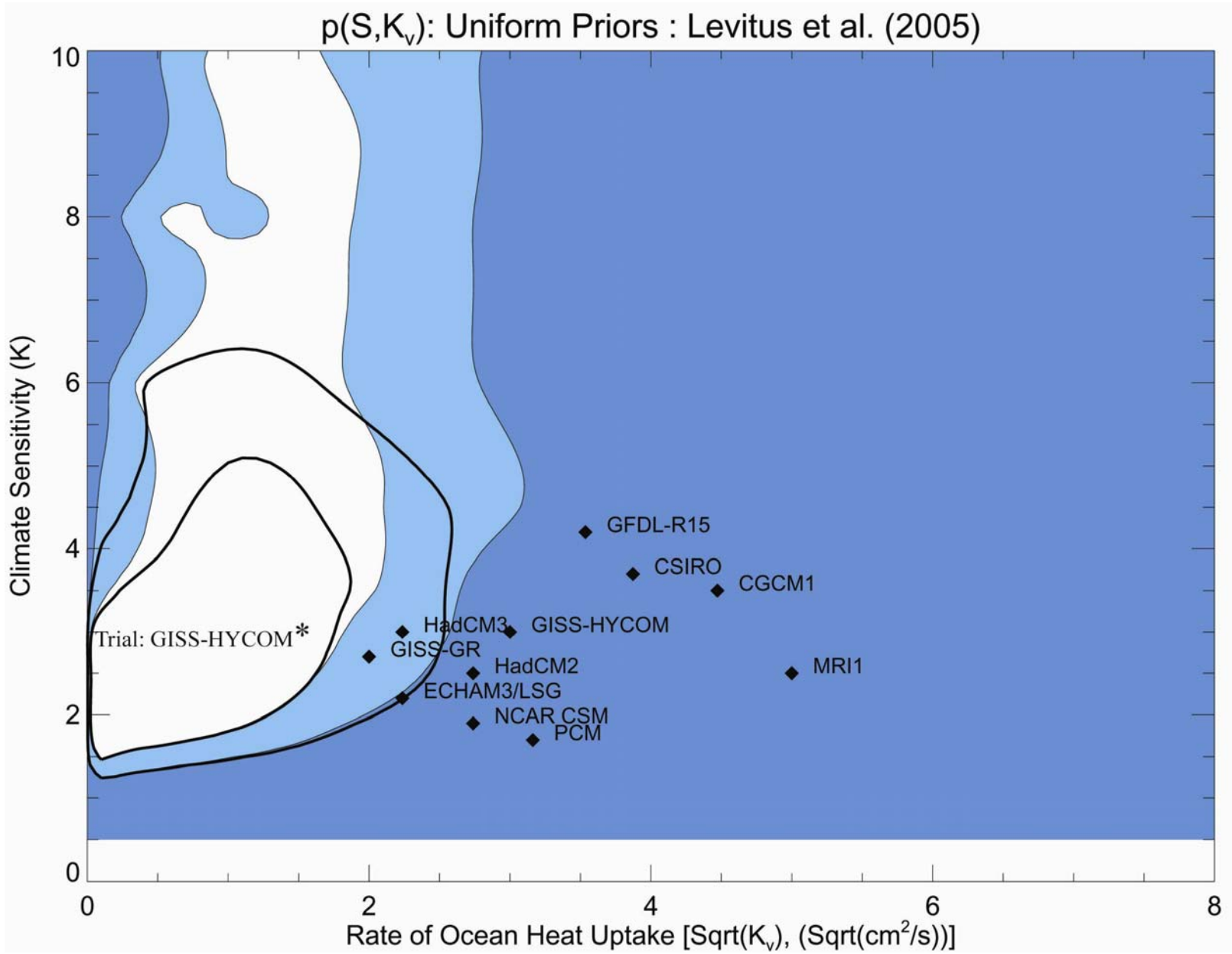

Ocean Temperature Change (2003 minus 1955)
Depth(m)
0
100
200
300
400
500
1000
2000
3000
0
0.2
0.4
0.6
Δ T (°C)
Observed (Levitus et al.)

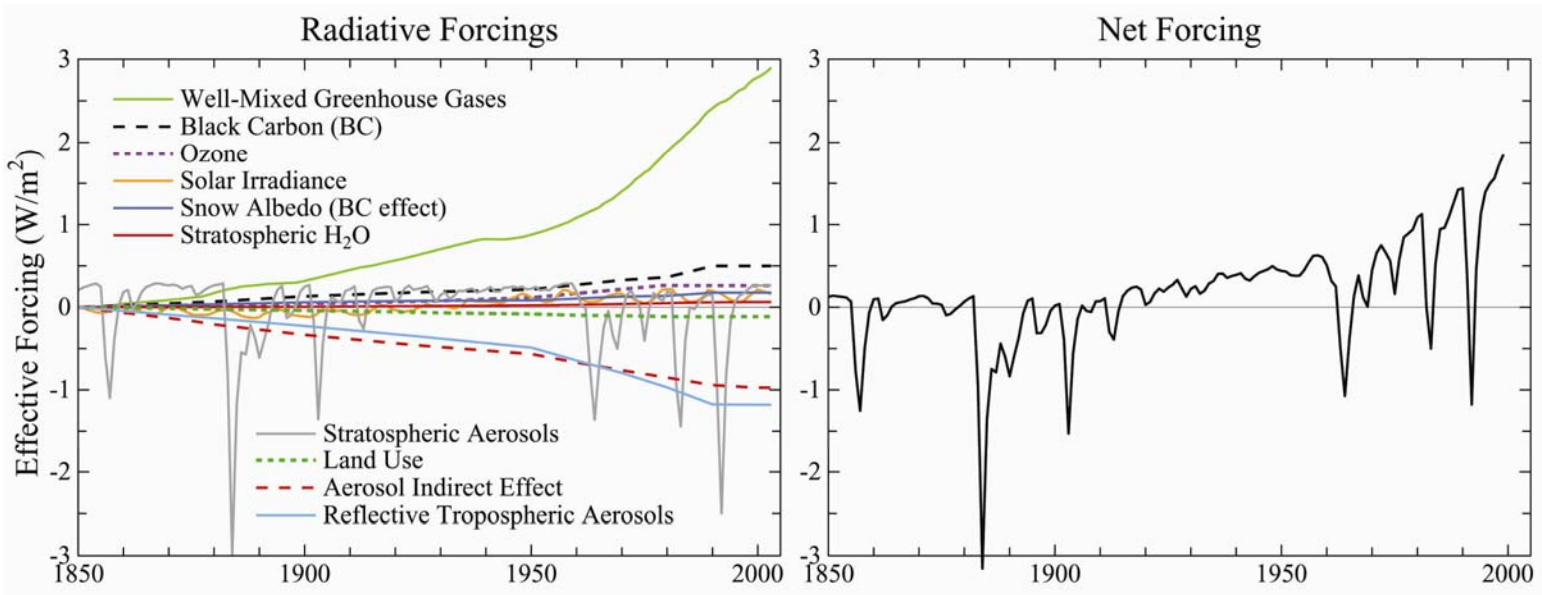

1955-2003 Ocean Heat Content Change Down To Indicated Depth
Global Mean
60°S - 60°N
Depth (m)
0
1000
2000
3000
0
5
10
15
20
25
Δ Heat Content (W yr/m²)
Δ Heat Content (W yr/m²)

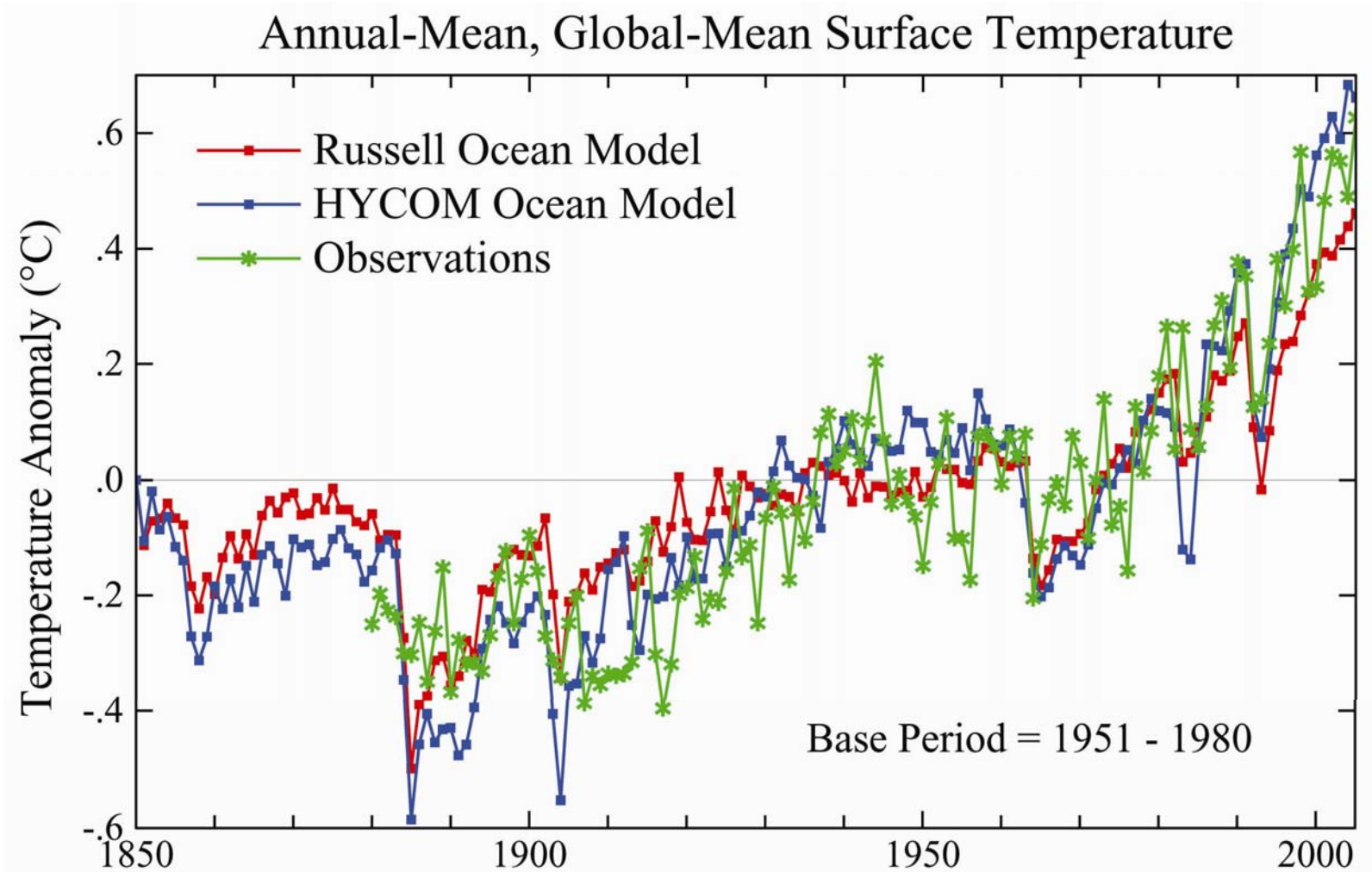

TOPEX
Jason
60-day smoothing
Inverse barometer applied
ΔMSL (mm)
50
40
30
20
10
0
-10
1994
1996
1998
2000
2002
2004
2006
Rate = 3.1 ± 0.4 mm/yr
Seasonal signals removed
Univ of Colorado 2006_rel3

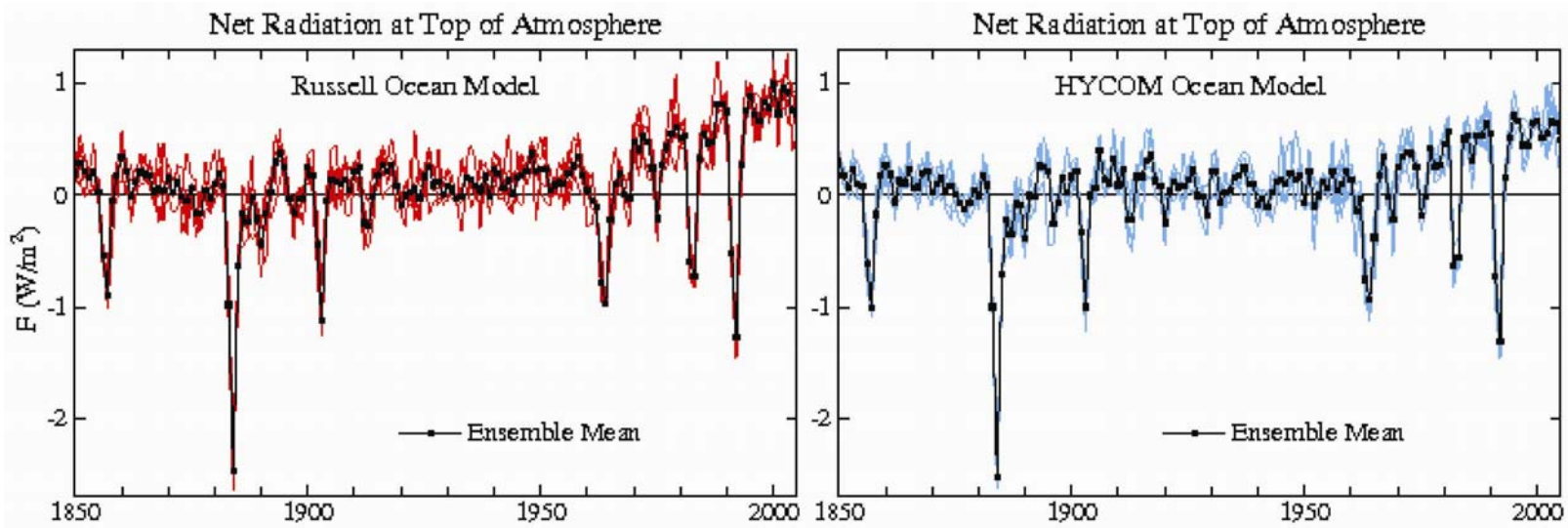

Ocean Water Presence (%)
Depth (km)
0
1
2
3
4
5
6
700m
2km
-90
-30
0
30
90
0
10
30
50
70
90
100

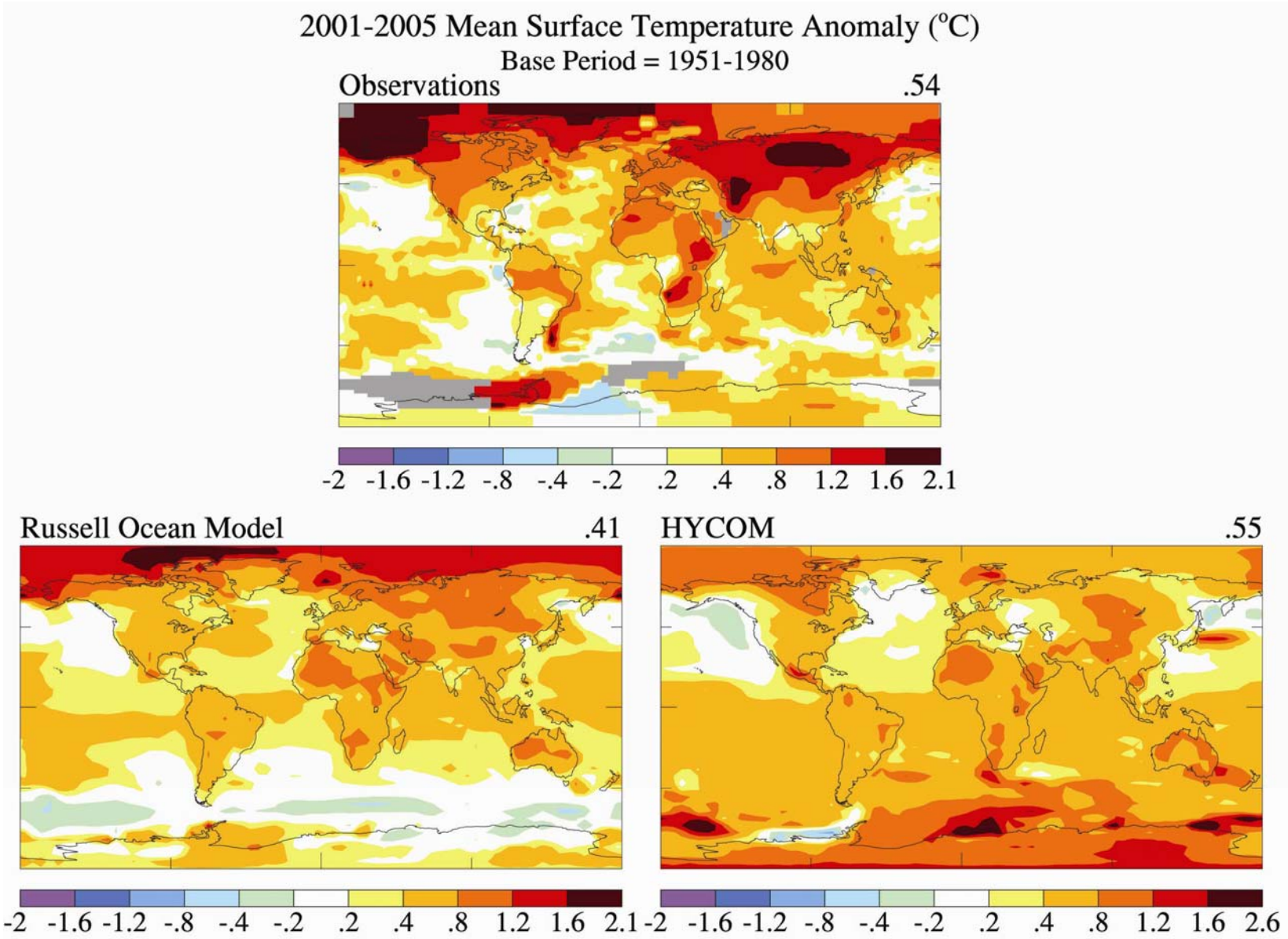

Water Presence (%)
Expansion Coefficent (10^{-4}/°C)
Product (10^{-4}/°C)
Depth (km)
0
1
2
3
4
5
6
-90
0
90
0 10 30 50 70 90 100
0 1 1.3 1.5 1.7 2 3.2
0 .3 .6 .8 1 1.5 2.5

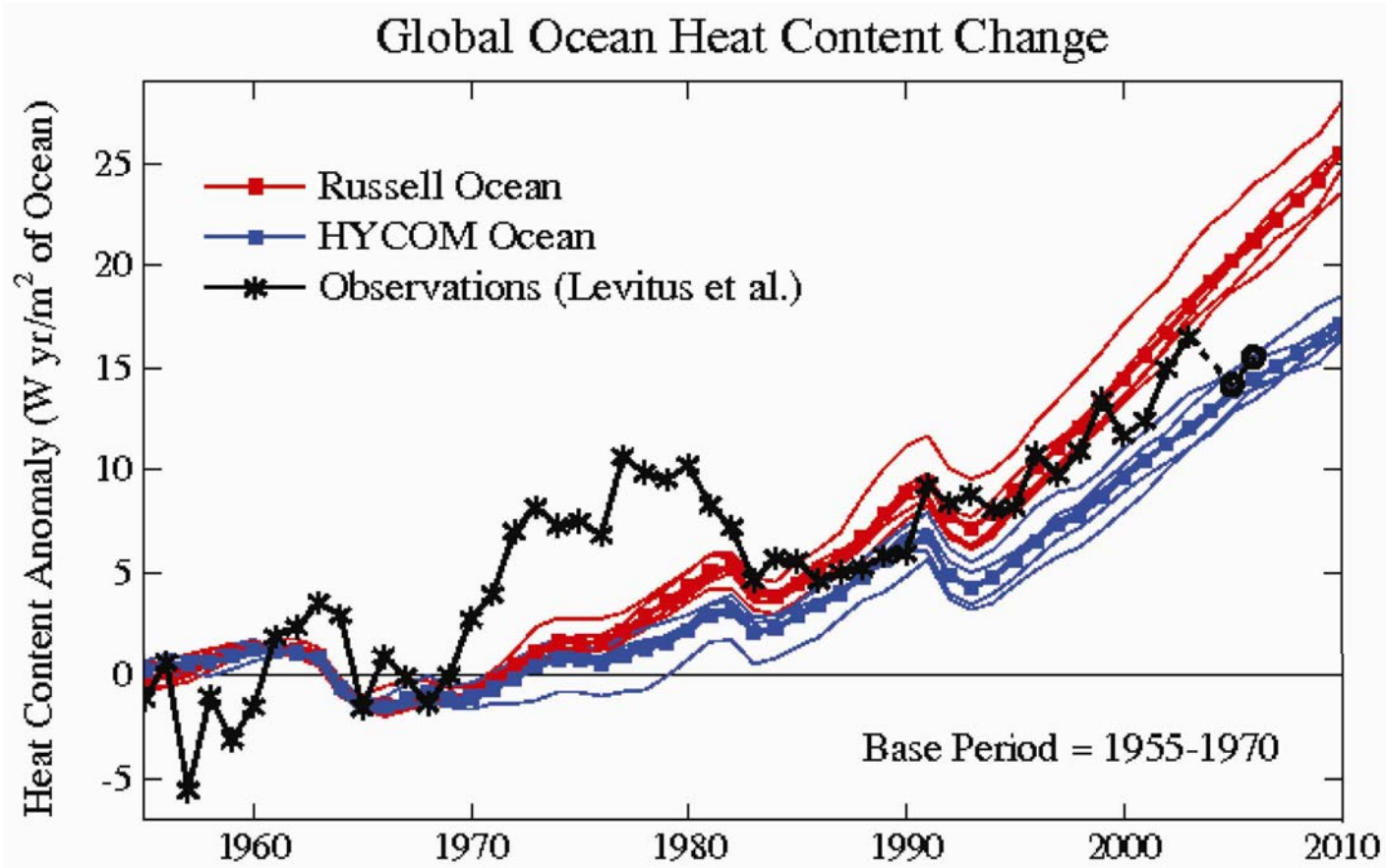

p(S,Kv): Uniform Priors : Levitus et al. (2005)
Climate Sensitivity (K)
Rate of Ocean Heat Uptake [Sqrt(Kv), (Sqrt(cm2/s))]
0
2
4
6
8
10
Trial: GISS-HYCOM*
GFDL-R15
CSIRO
CGCM1
HadCM3
GISS-HYCOM
GISS-GR
HadCM2
MRI1
ECHAM3/LSG
NCAR CSM
PCM


Radiative Forcings
Net Forcing
Effective Forcing (W/m^2)
Well-Mixed Greenhouse Gases
Black Carbon (BC)
Ozone
Solar Irradiance
Snow Albedo (BC effect)
Stratospheric H_2O
Stratospheric Aerosols
Land Use
Aerosol Indirect Effect
Reflective Tropospheric Aerosols
3
2
1
0
-1
-2
-3
1850
1900
1950
2000


Annual-Mean, Global-Mean Surface Temperature
Russell Ocean Model
HYCOM Ocean Model
Observations
Temperature Anomaly (°C)
.6
.4
.2
.0
-.2
-.4
-.6
1850
1900
1950
2000
Base Period = 1951 - 1980


Net Radiation at Top of Atmosphere
Russell Ocean Model
F (W/m²)
1
0
-1
-2
Ensemble Mean
1850
1900
1950
2000
Net Radiation at Top of Atmosphere
HYCOM Ocean Model
1
0
-1
-2
Ensemble Mean
1850
1900
1950
2000


2001-2005 Mean Surface Temperature Anomaly (°C)
Base Period = 1951-1980
Observations
.54
-2 -1.6 -1.2 -.8 -.4 -.2 .2 .4 .8 1.2 1.6 2.1
Russell Ocean Model
.41
-2 -1.6 -1.2 -.8 -.4 -.2 .2 .4 .8 1.2 1.6 2.1
HYCOM
.55
-2 -1.6 -1.2 -.8 -.4 -.2 .2 .4 .8 1.2 1.6 2.6

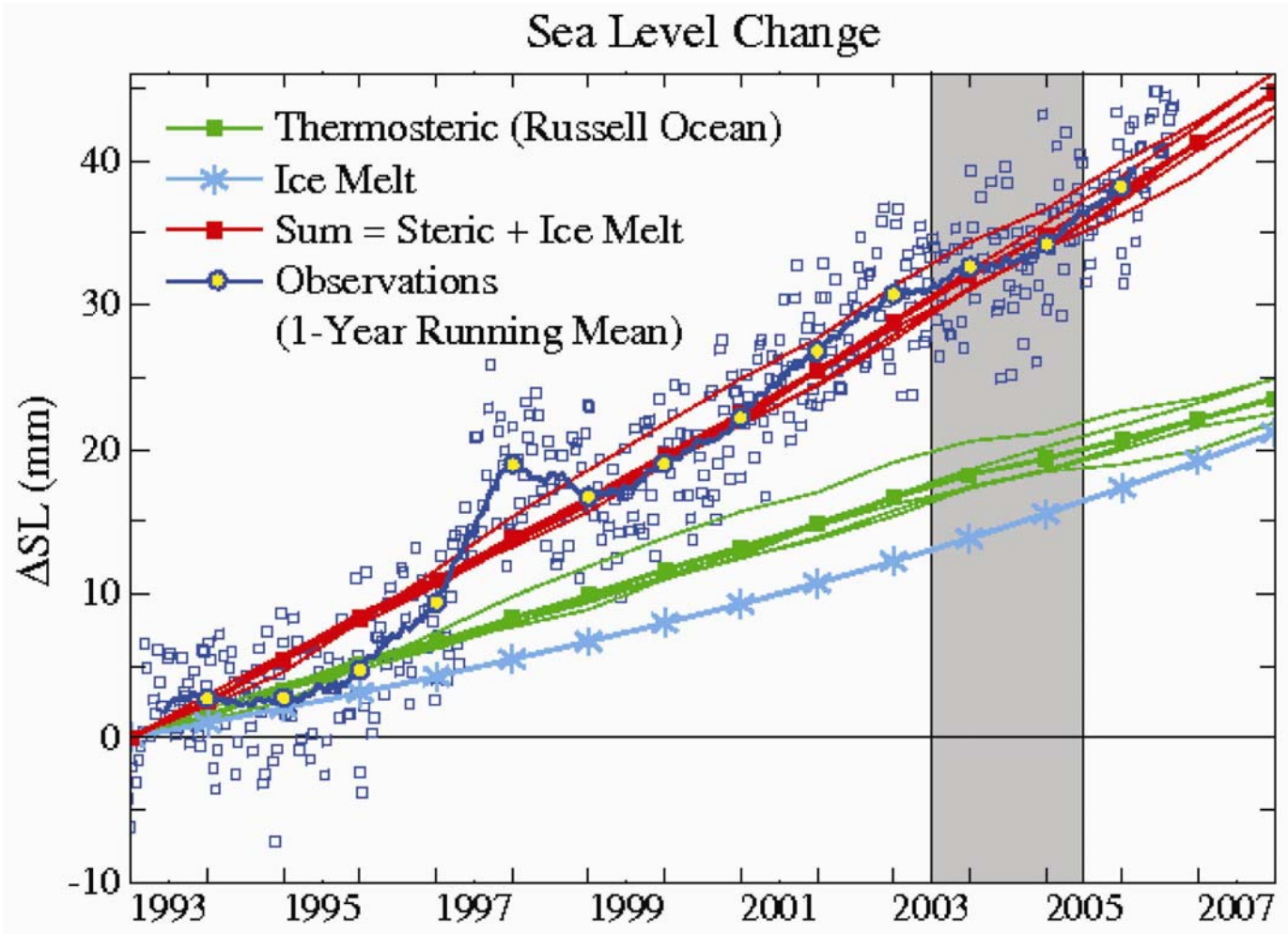

Global Ocean Heat Content Change
Heat Content Anomaly (W yr/m^2 of Ocean)
Russell Ocean
HYCOM Ocean
Observations (Levitus et al.)
Base Period = 1955-1970
25
20
15
10
5
0
-5
1960
1970
1980
1990
2000
2010

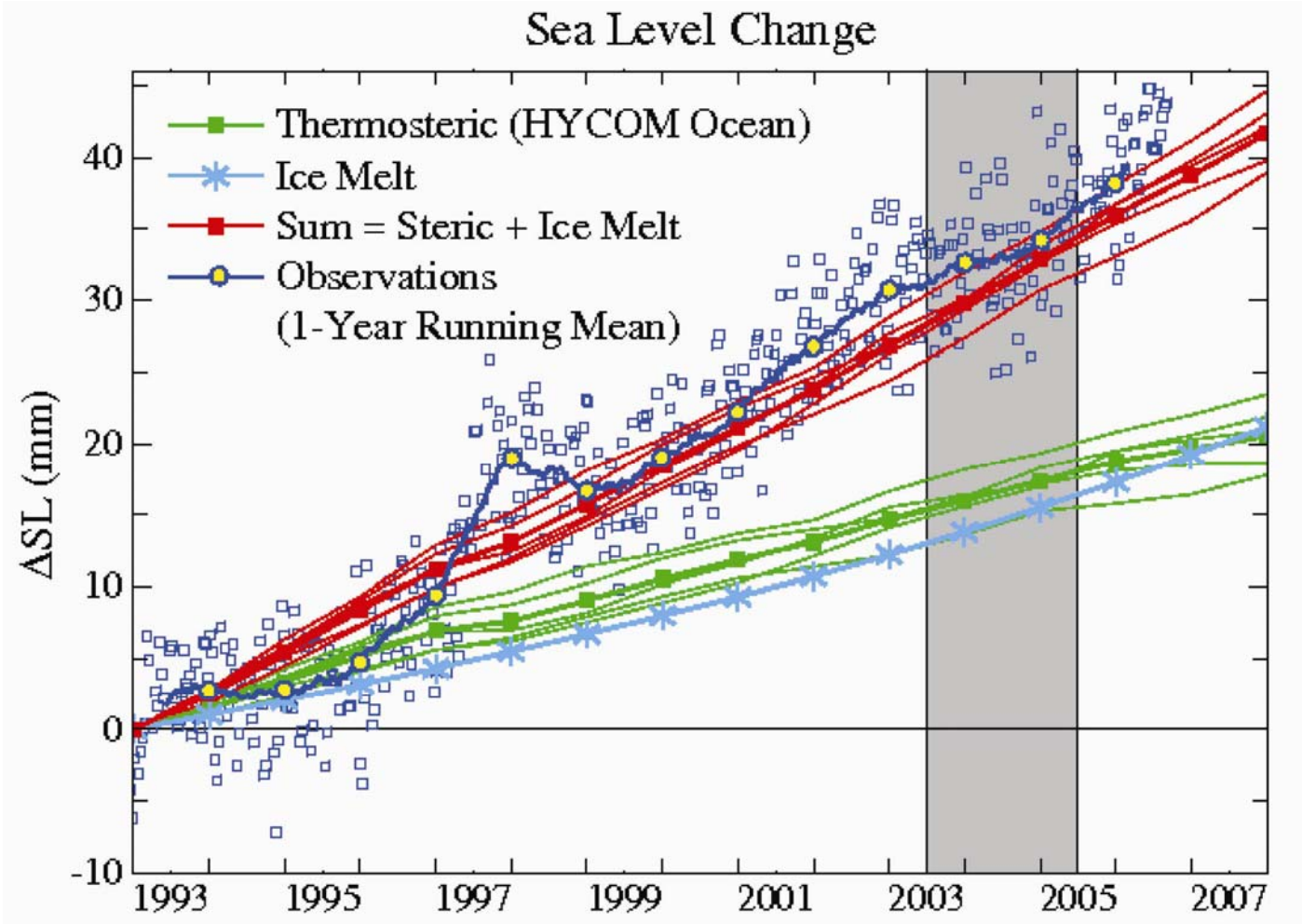
Ice Mass Gain or Loss (Gt/year)

	1993	2000	2005
East Antarctica	+25	+25	+50
West Antarctica	-40	-50	-150
Greenland	-50	-100	-200
Alaska	-100	-100	-100
Other Small Glaciers	-200	-250	-250
Total	-365	-475	-650

Notes

(1) Sources: Many references as compiled by Meier, M.F., et al., Disappearing glacial ice: A global analysis (preprint); see also Casenave, A., How fast are the ice sheets melting?, Science, 2006.


Sea Level Change
Thermosteric (Russell Ocean)
Ice Melt
Sum = Steric + Ice Melt
Observations
(1-Year Running Mean)
ΔSL (mm)
40
30
20
10
0
-10
1993
1995
1997
1999
2001
2003
2005
2007


Sea Level Change
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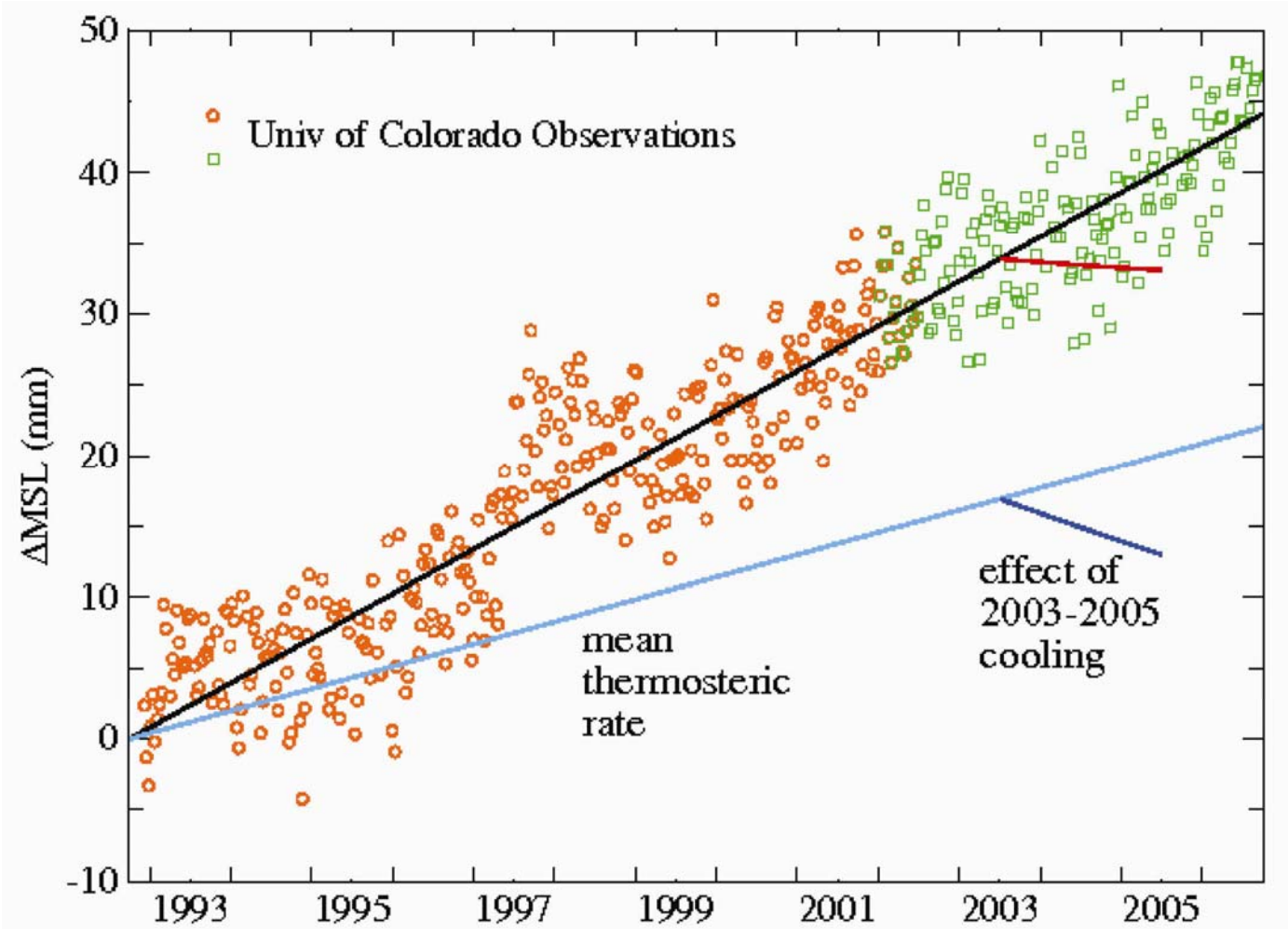
Observations
(1-Year Running Mean)
ΔSL (mm)
40
30
20
10
0
-10
1993
1995
1997
1999
2001
2003
2005
2007


Univ of Colorado Observations
ΔMSL (mm)
50
40
30
20
10
0
-10
1993
1995
1997
1999
2001
2003
2005
mean
thermosteric
rate
effect of
2003-2005
cooling

Planetary Energy Imbalance

1. **Russell Ocean → ~0.85 W/m^2 in 2005**
   → ~ 0.6ºC warming "in pipeline"
2. **Modified HYCOM Ocean → ~0.6 W/m^2 in 2005**
   → ~ 0.4ºC warming "in pipeline"

→ No Change to ~0.5°C Estimate

Other Terms in Current Planetary Energy Imbalance

1. **Non-Ocean Terms → >~0.06 W/m^2**

   0.013 sea ice melt (1% reduction)
   0.015 land ice (1.5mm sea level)
   0.025 ground warming
   0.006 air warming

2. **Deep Ocean & Polar → >~0.1 W/m^2**

   - Suggested by sparse data
   - Suggested by coupled models

Principal Conclusions

1. **No Change in Estimated Global Warming in the Pipeline (~0.5°C)**

2. **Need More Complete Data on Ocean Temperature Change**

Southern Ocean Could Slow Global Warming

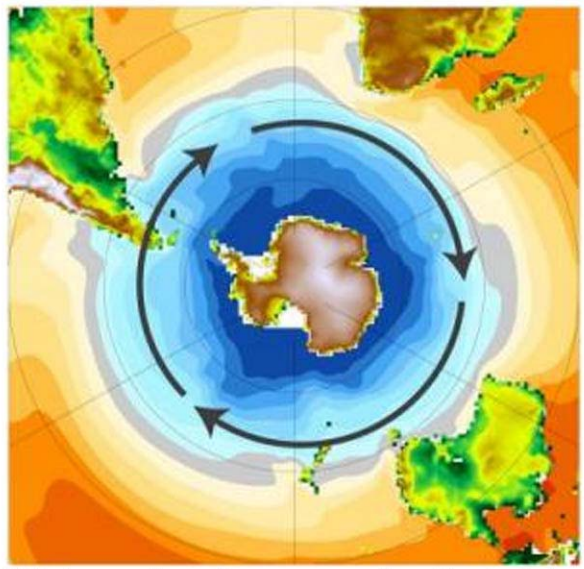
The Southern Ocean may slow the rate of global warming by absorbing significantly more heat and carbon dioxide than previously thought, according to new research.

The Southern Hemisphere westerly winds have moved southward in the last 30 years. A new climate model predicts that as the winds shift south, they can do a better job of transferring heat and carbon dioxide from the surface waters surrounding Antarctica into the deeper, colder waters.

The new finding surprised the scientists, said lead researcher Joellen L. Russell. "We think it will slow global warming. It won't reverse or stop it, but it will slow the rate of increase."

The new model Russell and her colleagues developed provides a realistic simulation of the Southern Hemisphere westerlies and Southern Ocean circulation.

Previous climate models did not have the winds properly located. In simulations of present-day climate, those models distorted the ocean's response to future increases in greenhouse gases.



This image shows the oceans and continents that surround Antarctica. The tip of South America is on the upper left, the tip of Africa is at the upper right and Australia is at the bottom right. The ocean colors indicate temperature, with the darkest blue indicating the coldest water. The black arrows show the direction the Southern Hemisphere westerly winds and the Antarctic Circumpolar Current take as they swirl around the southernmost continent. (Credit: Copyright 2006 Paul J. Goodman, The University of Arizona)