OCEAN HEAT CONTENT

JIM HANSEN ON OCEAN HEAT CONTENT

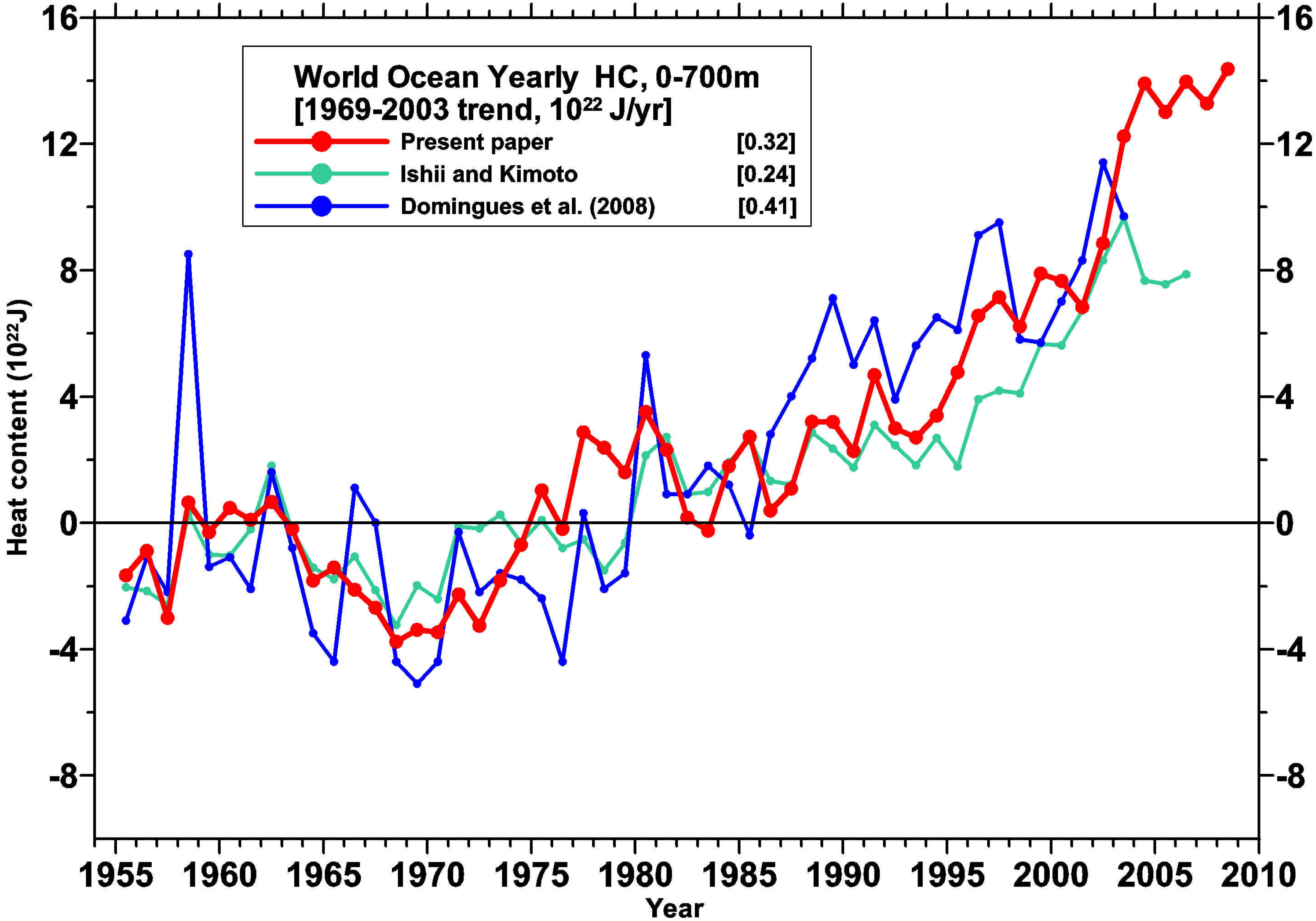
…Third, there is the most important measurement – the change of ocean heat content. Twenty years ago, when I was asked 'what is the most important measurement for global climate change', I said 'ocean heat storage, because that defines the planet's energy imbalance.

Bjerknes Lecture
American Geophysical Union Dec. 2008

HANSEN ON SEA LEVEL RISE

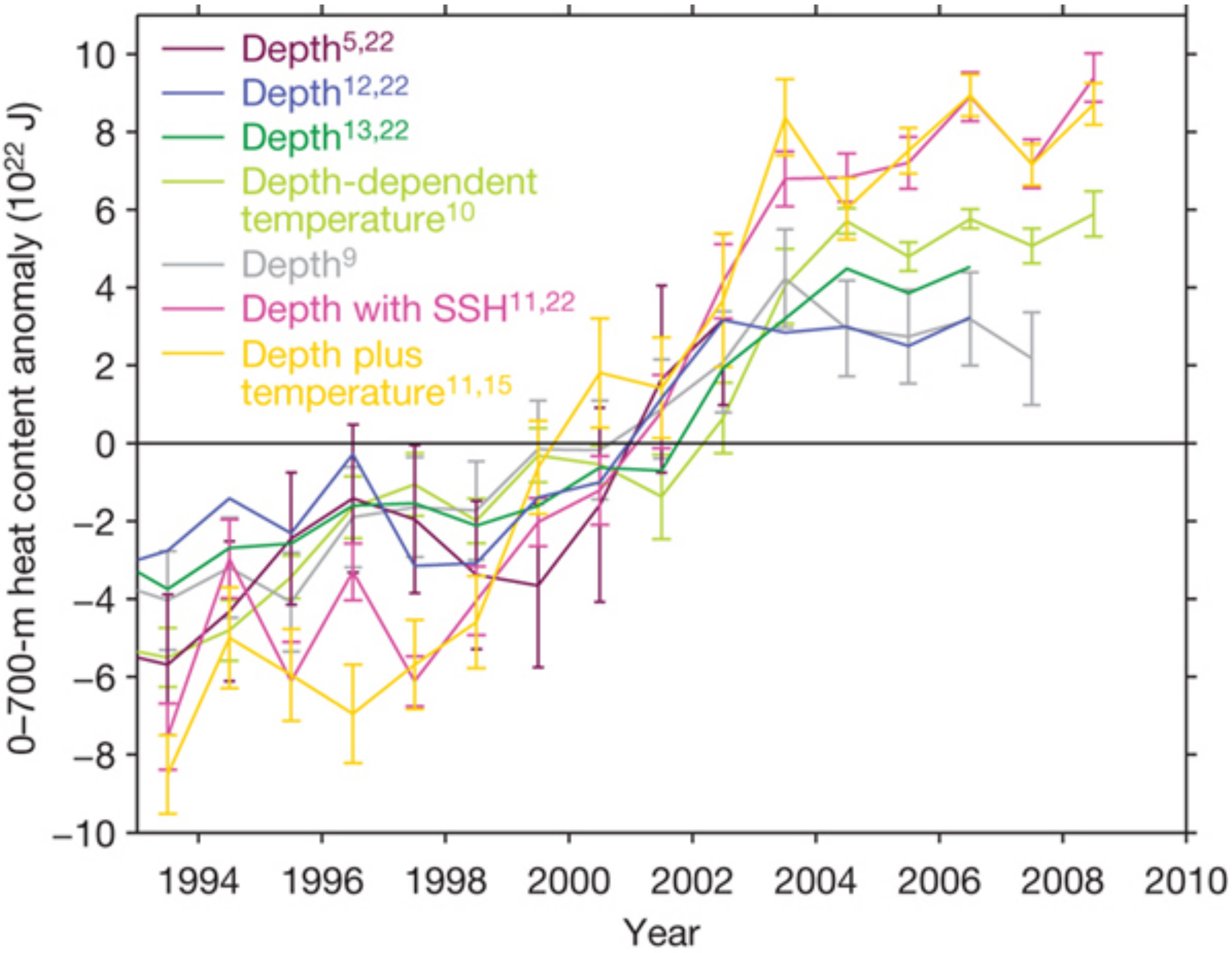
The threat of large sea level change is a principal element in my argument that the global community must aim to restrict any further global warming to less than 1 °C above the temperature in 2000. This implies a CO_2 limit of about 450 parts per million or less.

New Scientist, July 2007



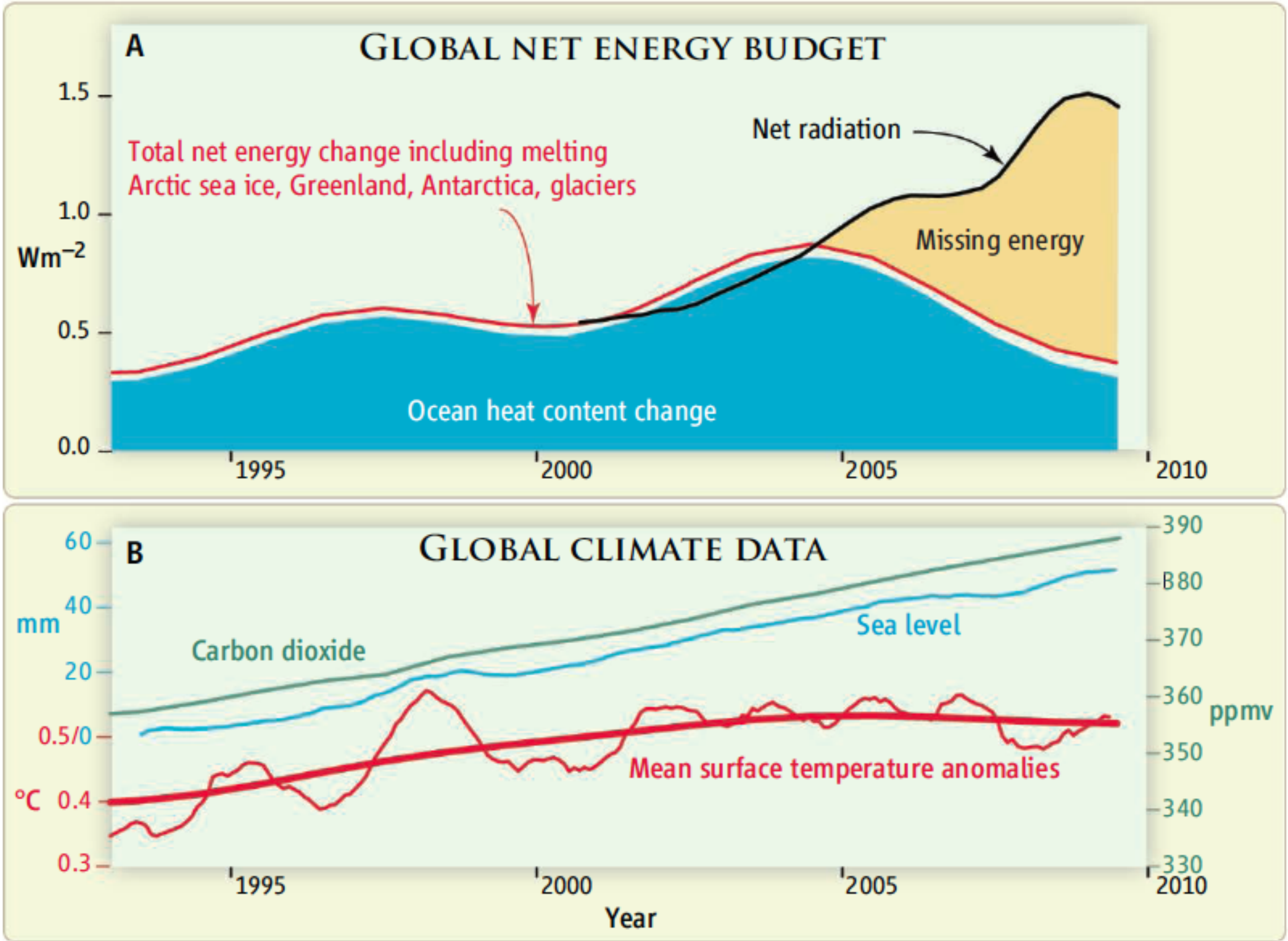
Levitus 2009

OHCA curves using published methods.

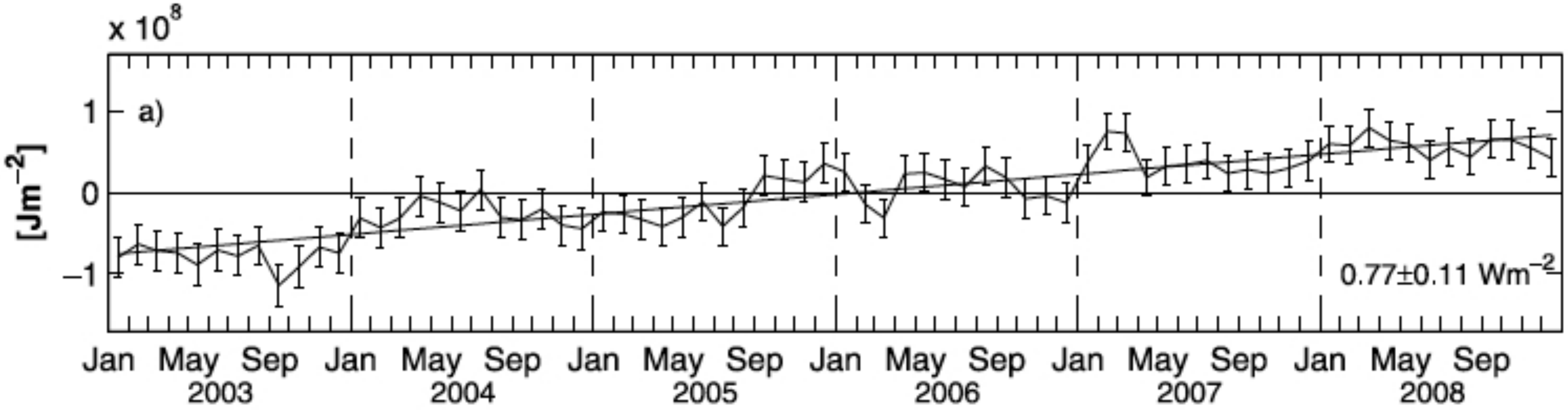


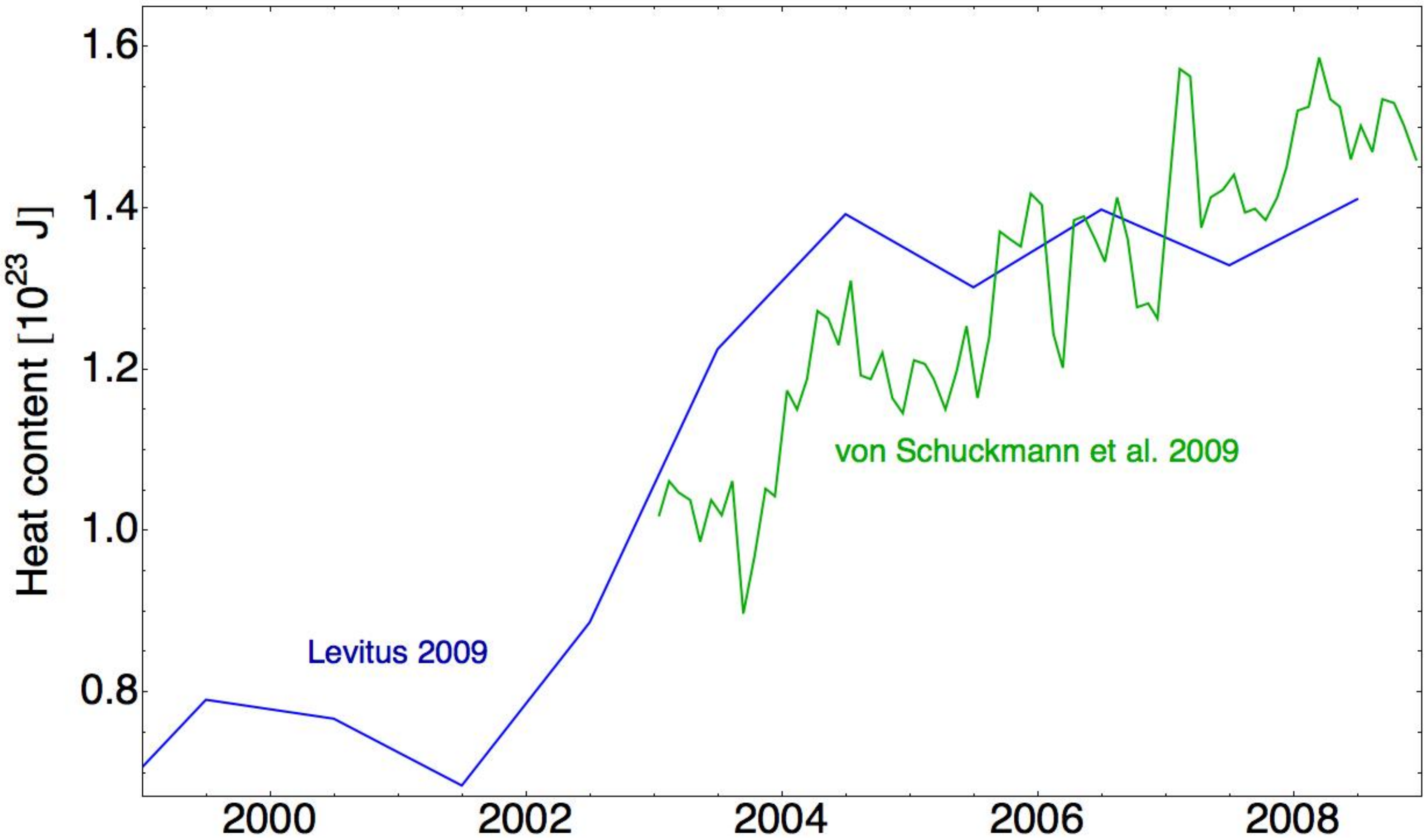
JM

Lyman et al. Vol 465|20 May 2010 nature

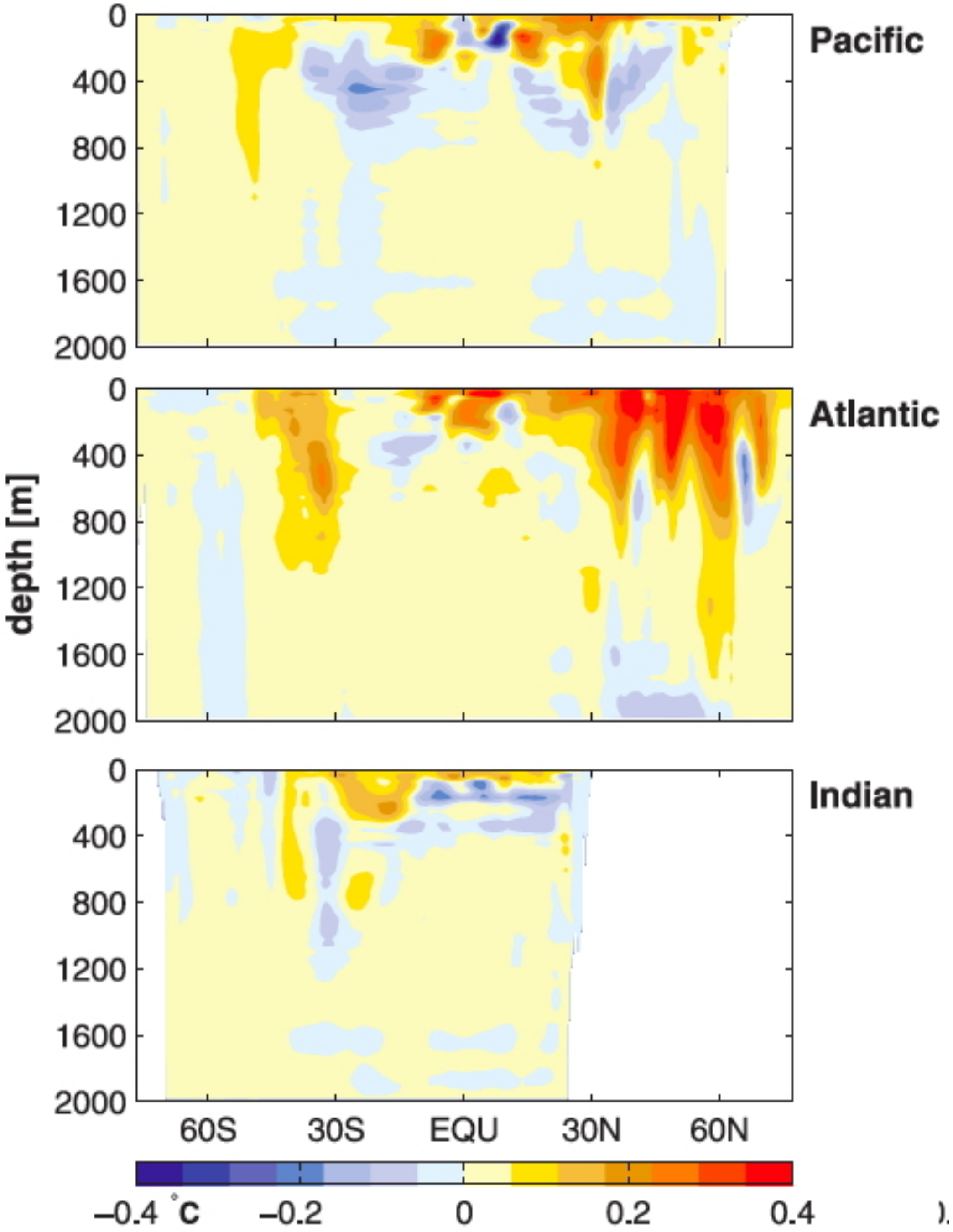


Trenberth and Fasullo, 16 APRIL 2010 VOL 328 SCIENCE

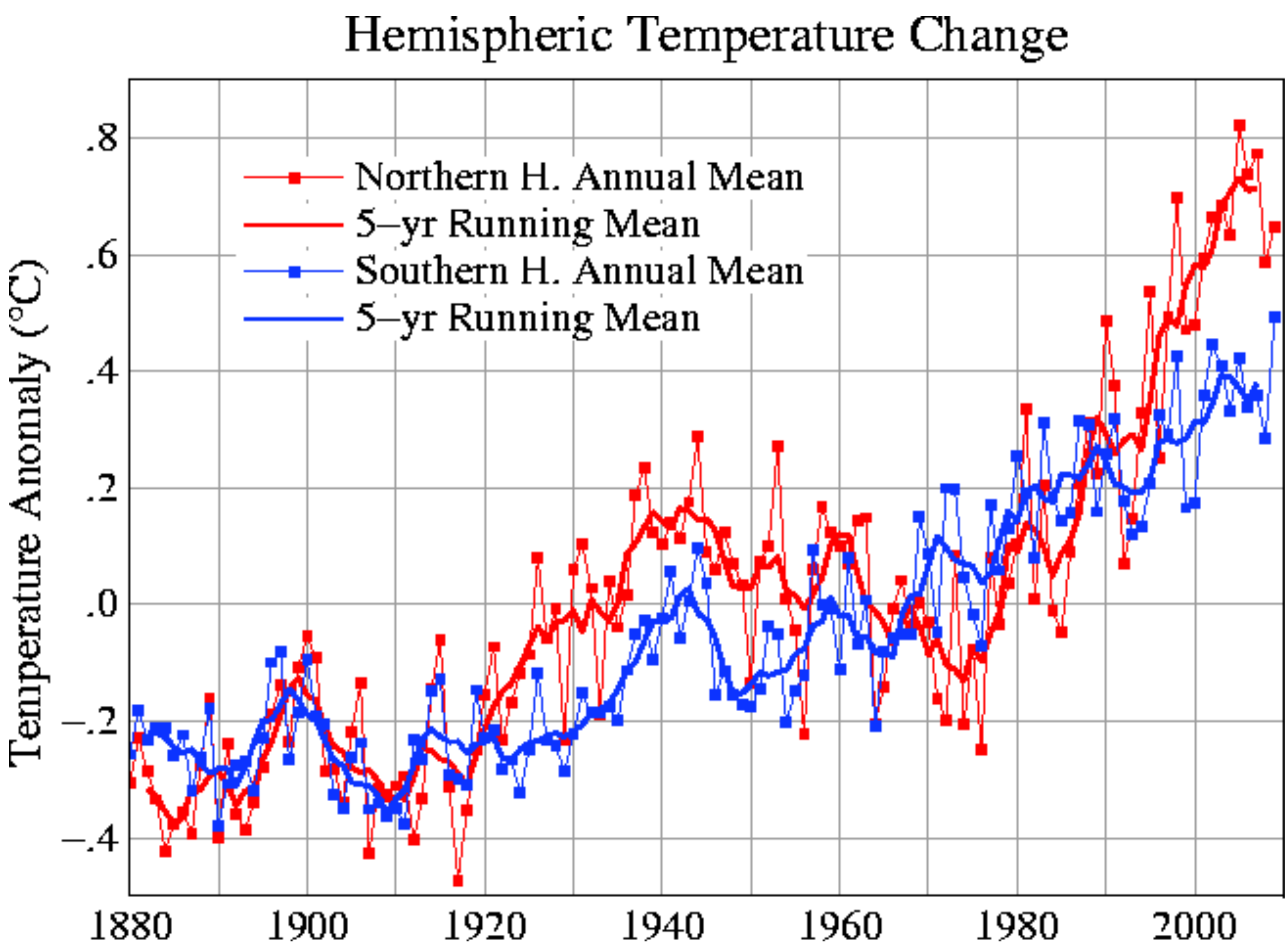




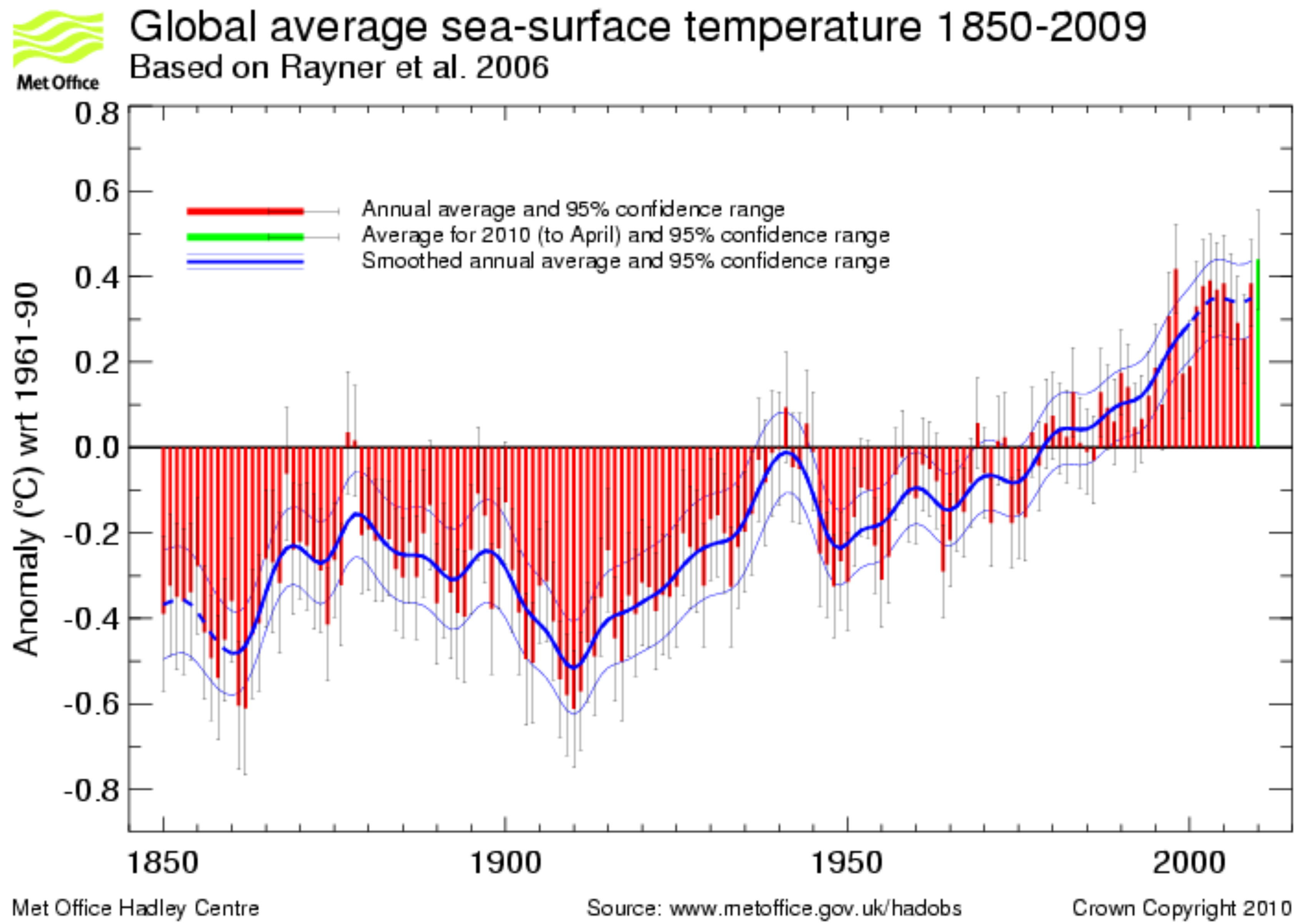
JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 114, SEPT 2009



2003–2008 anomaly
ARIVO global ocean temperature and salinity fields



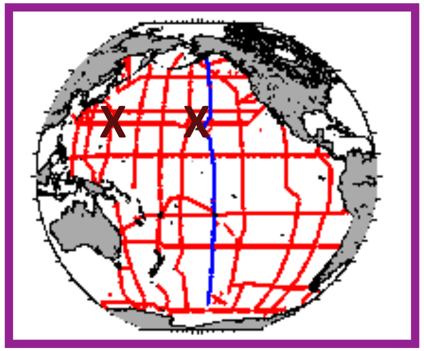
http://data.giss.nasa.gov/gistemp/graphs/Fig.A3.lrg.gif

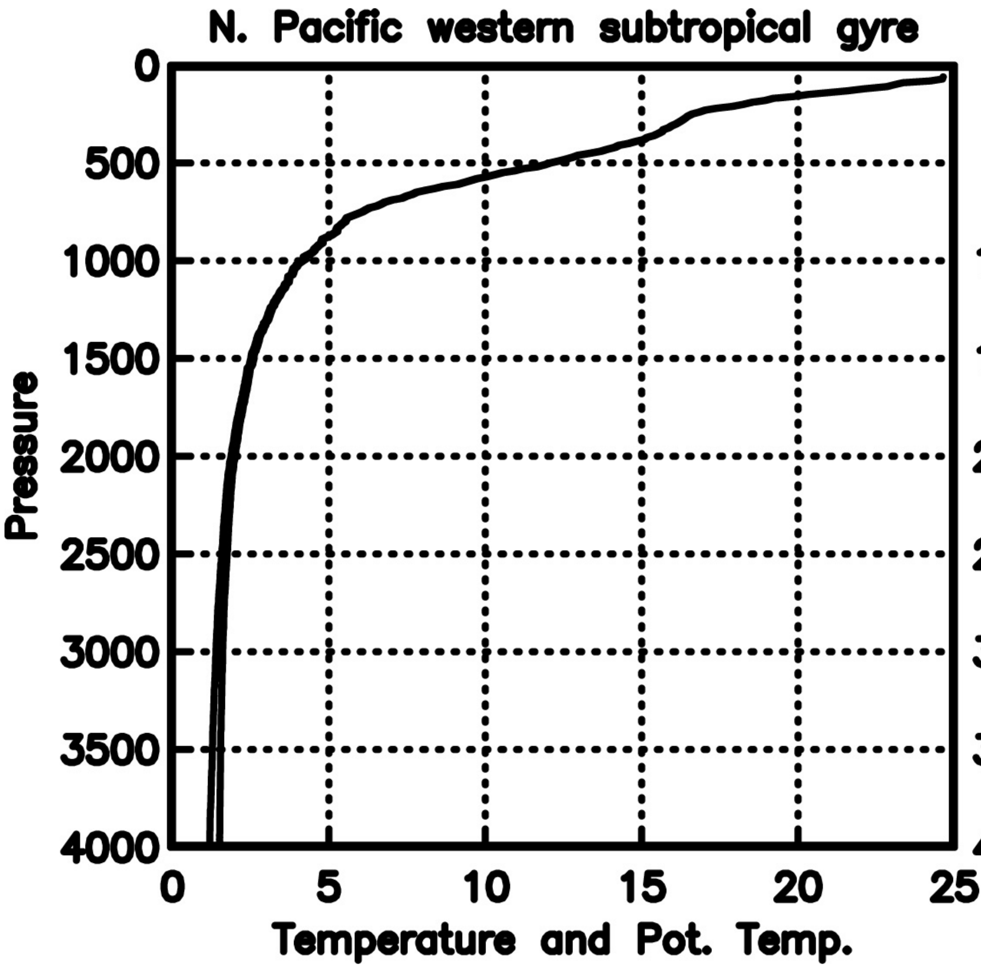


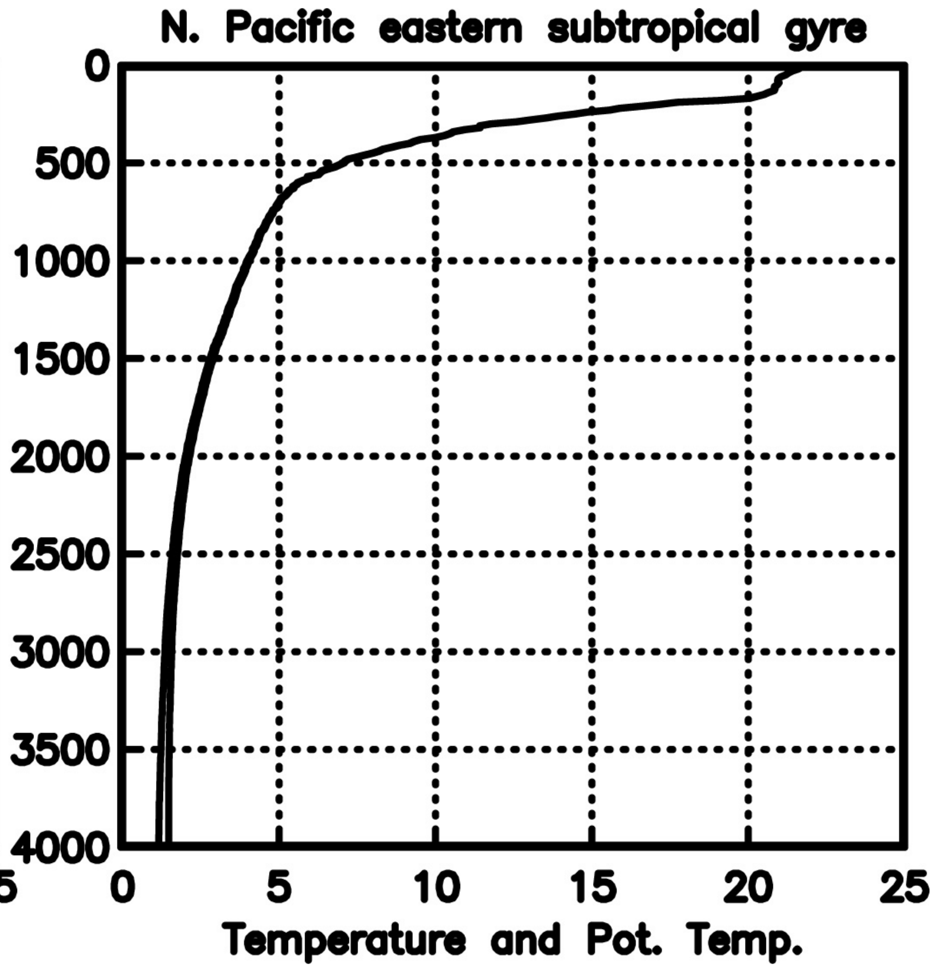
Met Office
Global average sea-surface temperature 1850-2009
Based on Rayner et al. 2006
Annual average and 95% confidence range
Average for 2010 (to April) and 95% confidence range
Smoothed annual average and 95% confidence range
Anomaly (°C) wrt 1961-90
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
1850
1900
1950
2000
Met Office Hadley Centre
Source: www.metoffice.gov.uk/hadobs
Crown Copyright 2010

Had SST2

Temperature (°C) profiles (N. Pacific)







Pickard, Emery and Talley

Deep-Sea Research, 1966, Vol. 13, pp. 707 to 730. Pergamon Press Ltd. Printed in Great Britain.

Abyssal recipes

WALTER H. MUNK*

(*Received* 31 *January* 1966)

Abstract—Vertical distributions in the interior Pacific (excluding the top and bottom kilometer) are not inconsistent with a simple model involving a constant upward vertical velocity $w \approx 1{\cdot}2$ cm day^{-1} and eddy diffusivity $\kappa \approx 1{\cdot}3$ cm^2 sec^{-1}. Thus temperature and salinity can be fitted by exponential-like solutions to $[\kappa \cdot d^2/dz^2 - w \cdot d/dz]\, T, S = 0$, with $\kappa/w \approx 1$ km the appropriate "scale height." For Carbon 14 a decay term must be included [ ] $^{14}C = \mu\, ^{14}C$; a fitting of the solution to the ob-

$$A_z \frac{\partial^2 \psi(z,t)}{\partial z^2} = W \frac{\partial \psi(z,t)}{\partial z}$$

A_z vertical eddy diffusivity
W mean vertical velocity

$\psi(z,t)$ potential temperature or tracer density

$$\text{turbulent}: \quad \kappa \hat{T}'' - w\hat{T}' = 0; \quad \kappa S'' - wS' = 0 \qquad (1a, b)$$

$$\text{laminar}: \quad \kappa_T T'' - w\hat{T}' = 0; \quad \kappa_S S'' - wS' = 0 \qquad (2a, b)$$

For the case of turbulent diffusion the same Austausch coefficient κ applies to the temperature* $\hat{T} = T - T_A$ and salinity S, thus leading to identical depth distributions and to a linear relation $T(S)$. For constant w/κ,

$$\frac{\hat{T} - \hat{T}_1}{\hat{T}_2 - \hat{T}_1} = \frac{e^{\gamma\xi} - 1}{e^{\gamma} - 1}, \quad \frac{S - S_1}{S_2 - S_1} = \frac{e^{\gamma\xi} - 1}{e^{\gamma} - 1} \qquad (3a, b)$$

where

$$\gamma = \frac{(z_2 - z_1)\, w}{\kappa}, \quad \xi = \frac{z - z_1}{z_2 - z_1}.$$

A fair fit is found for the values $\gamma = 3{\cdot}9$ with $z_1 = -4$ km, $z_2 = -1$ km; the ratio $\kappa/w = 0{\cdot}77$ km is the pertinent scale height. We do not pretend that the observed exponential-like distribution confirms the vertical diffusion-advection model, but it is

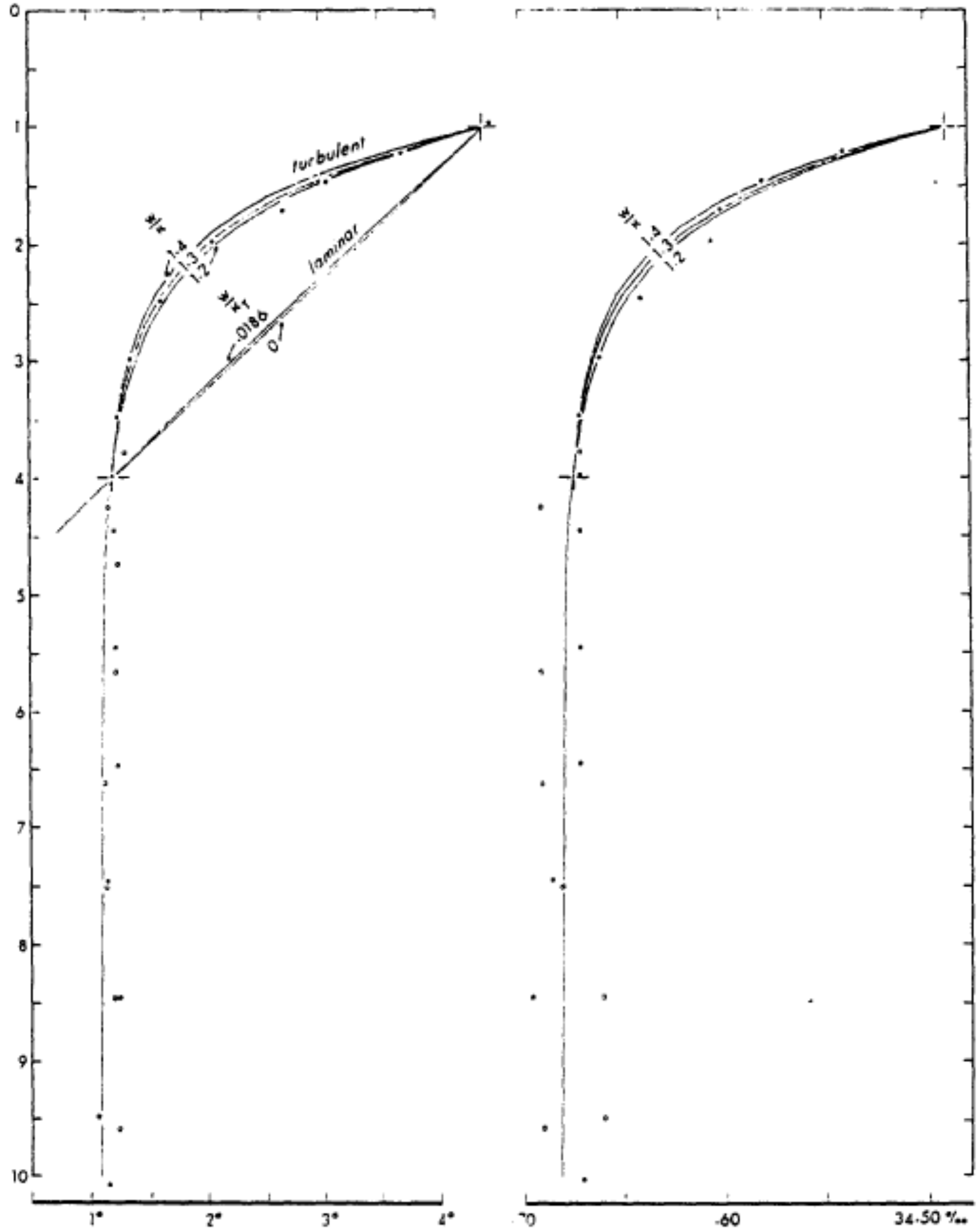


Fig. 1. Potential temperature and salinity as functions of depth (km) at stations *Snellius* 1930 : # 262, 9° 41′N, 126° 51′E, (closed circles) and *Galathea* 1951 : # 433, 9° 51′N, 126° 51′E, (open circles). Curves labeled w/κ (in units km^{-1}) are based on equations (1) and (2) for turbulent and laminar diffusion, respectively.

$A_z \approx 1.3 \times 10^{-4}\ m^2/s$
thermocline in the Pacific -> A_z/W

$W \approx 1.2$ cm/day
vertical distribution of ^{14}C -> A_z/W^2

$$\frac{\partial \psi(z,t)}{\partial t} = A_z \frac{\partial^2 \psi(z,t)}{\partial z^2} - W \frac{\partial \psi(z,t)}{\partial z}$$

$\psi(z,t)$ potential temperature or tracer density

A_z vertical eddy diffusivity

W mean vertical velocity

$A_z \approx 1.3 \times 10^{-4}$ m^2/s thermocline in the Pacific -> A_z/W

$W \approx 1.2$ cm/day vertical distribution of ^{14}C -> A_z/W^2

R. H. Stewart, Introduction to Physical Oceanography

http://oceanworld.tamu.edu/resources/ocng_textbook/contents.html

Solution is available for a step change in sea surface temperature

$$\psi(z,t) = \frac{1}{2} exp \frac{Wz}{2A_z} \left(exp \frac{-Wz}{2A_z} erfc \frac{z - Wt}{2\sqrt{A_z t}} + exp \frac{Wz}{2A_z} erfc \frac{z + Wt}{2\sqrt{A_z t}} \right)$$

The Munk limiting length is $\lambda(\infty) = -A_z/W$ ≈ 0.9 km.

As the diffusion length is $L = \sqrt{4Dt}$ the characteristic time is

$\tau = \lambda^2(\infty)/(4A_z) = A_z/(4W^2) \approx 50$ years.

The differential equation is linear and we can build up the solution for ocean temperature profile change by adding small step changes.

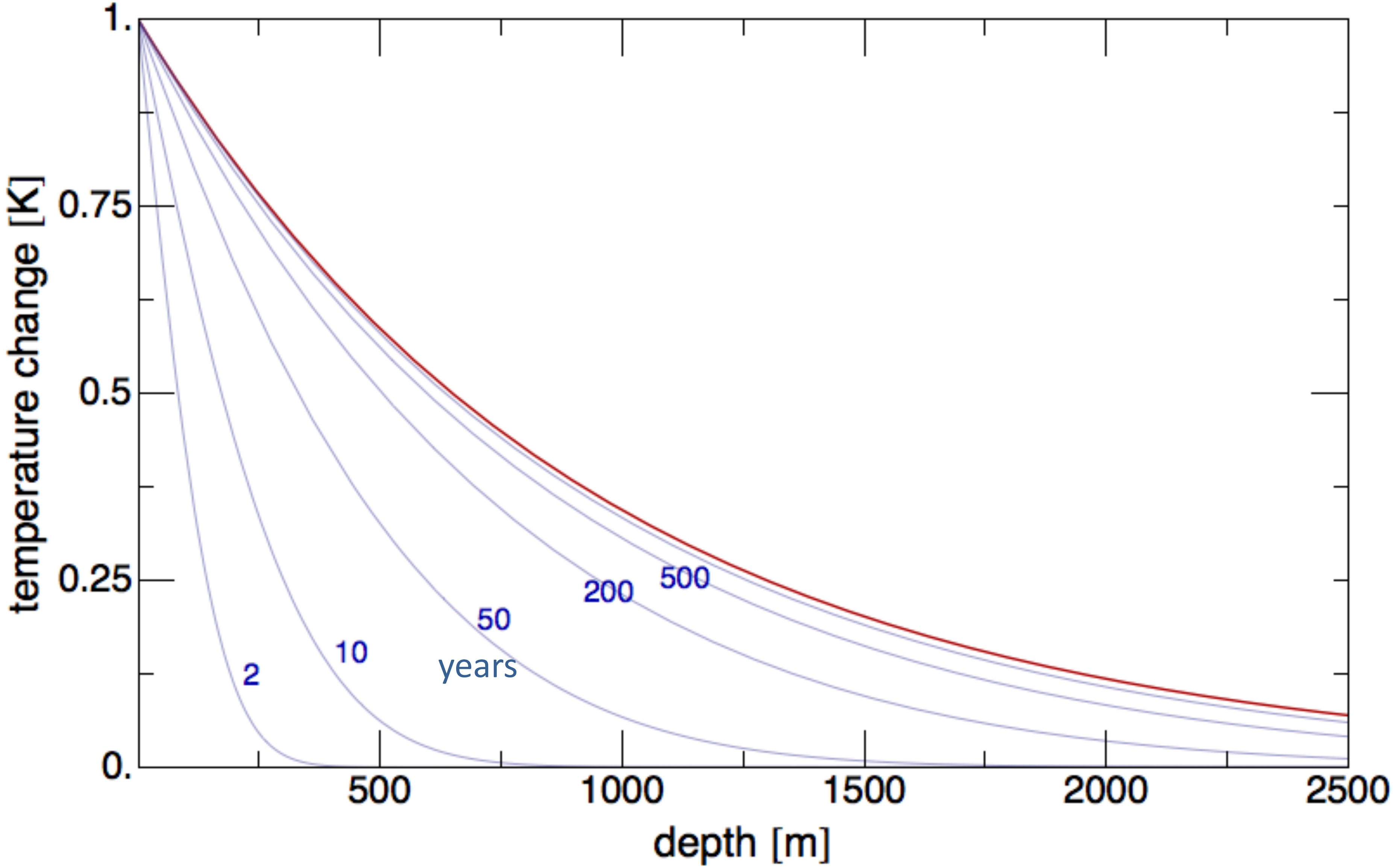
z depth

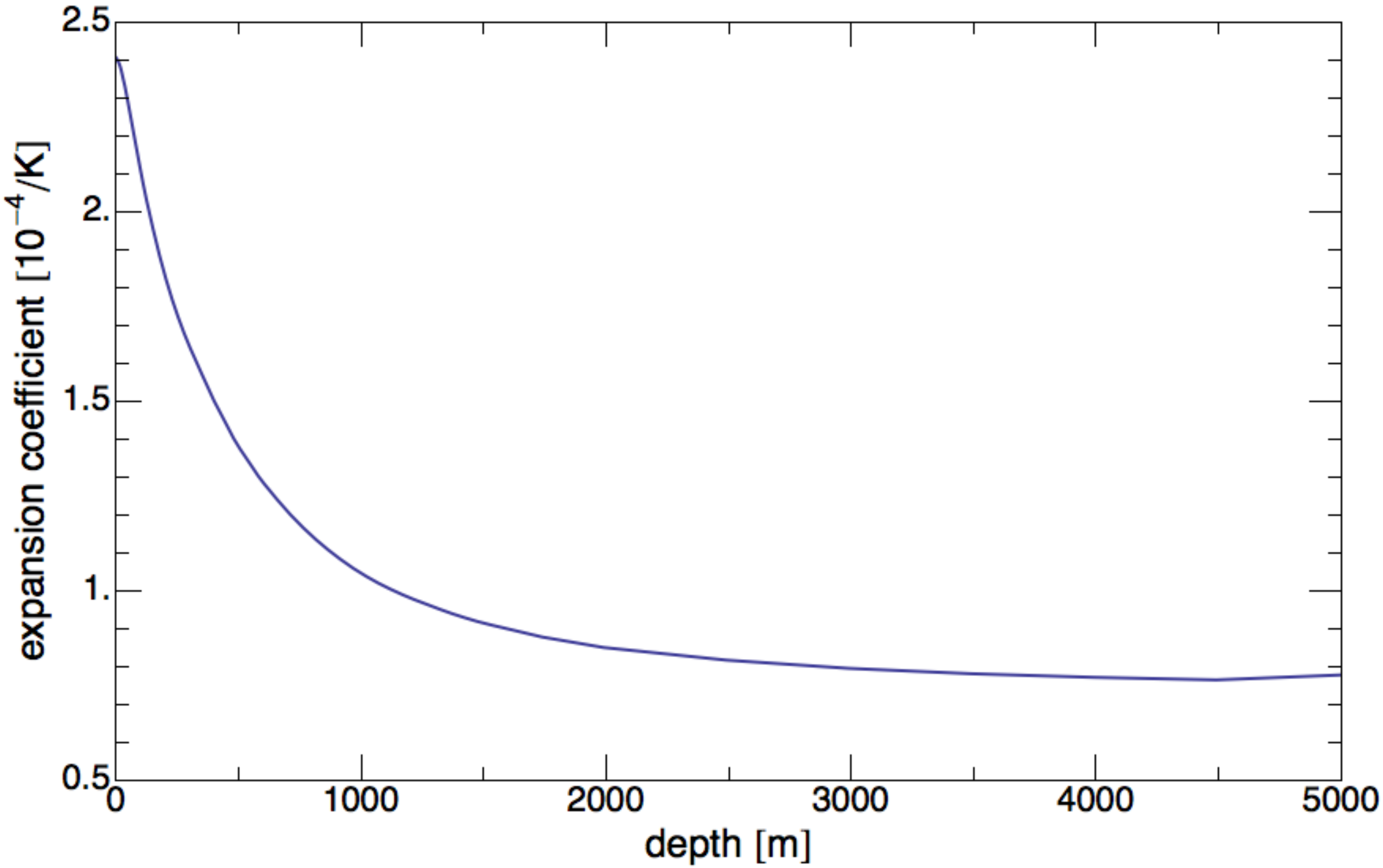
n year

k starting year

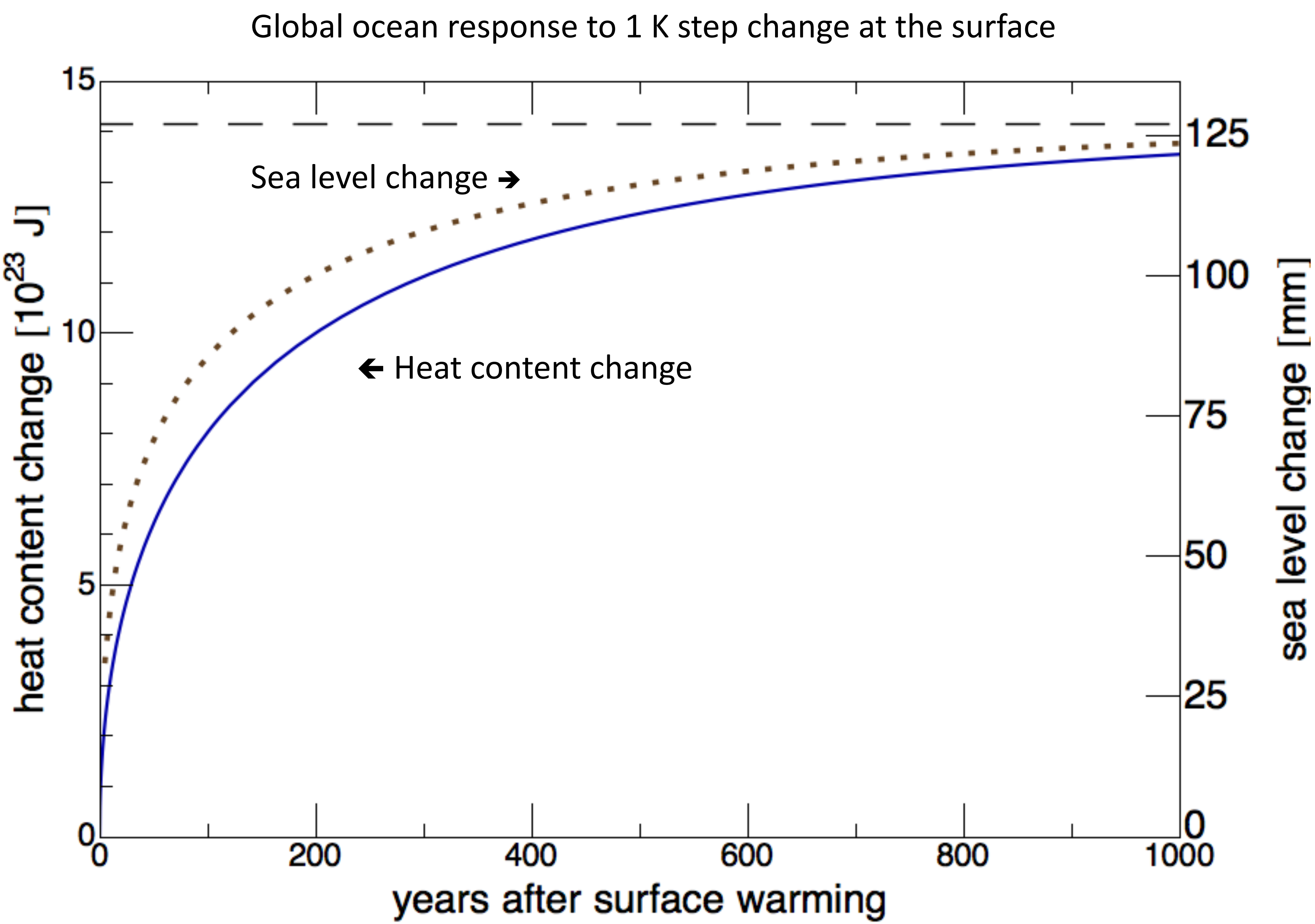
$$\vartheta(z,n,k) = \sum_{i=k+1}^{n} [SST(i) - SST(i-1)]\psi(z, n-i+1)$$

Response to a step change in temperature



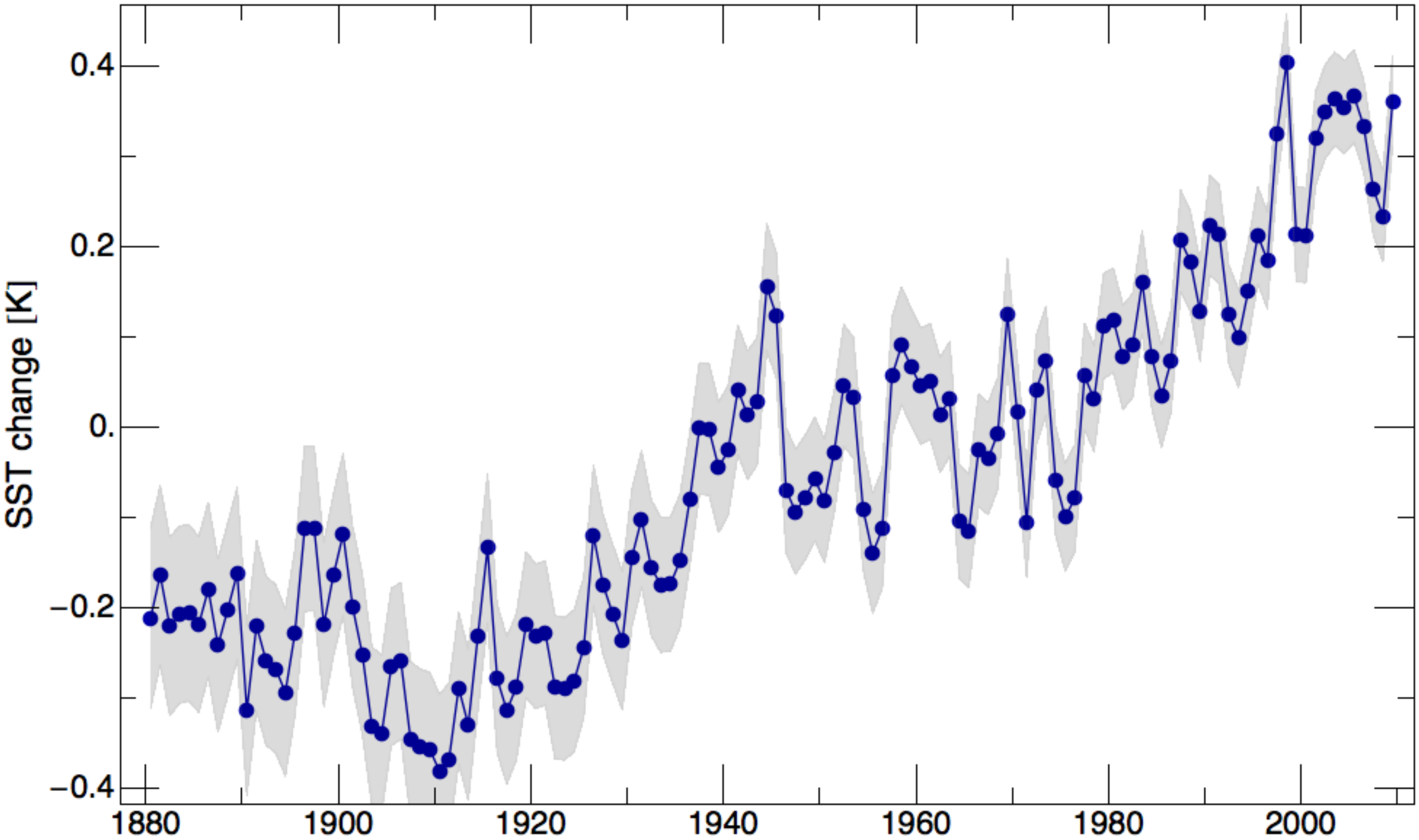


To evaluate see level change, we need the average vertical profile of the expansion coefficient, calculated here using the data from the Climatological Atlas of the World Ocean, 1982.

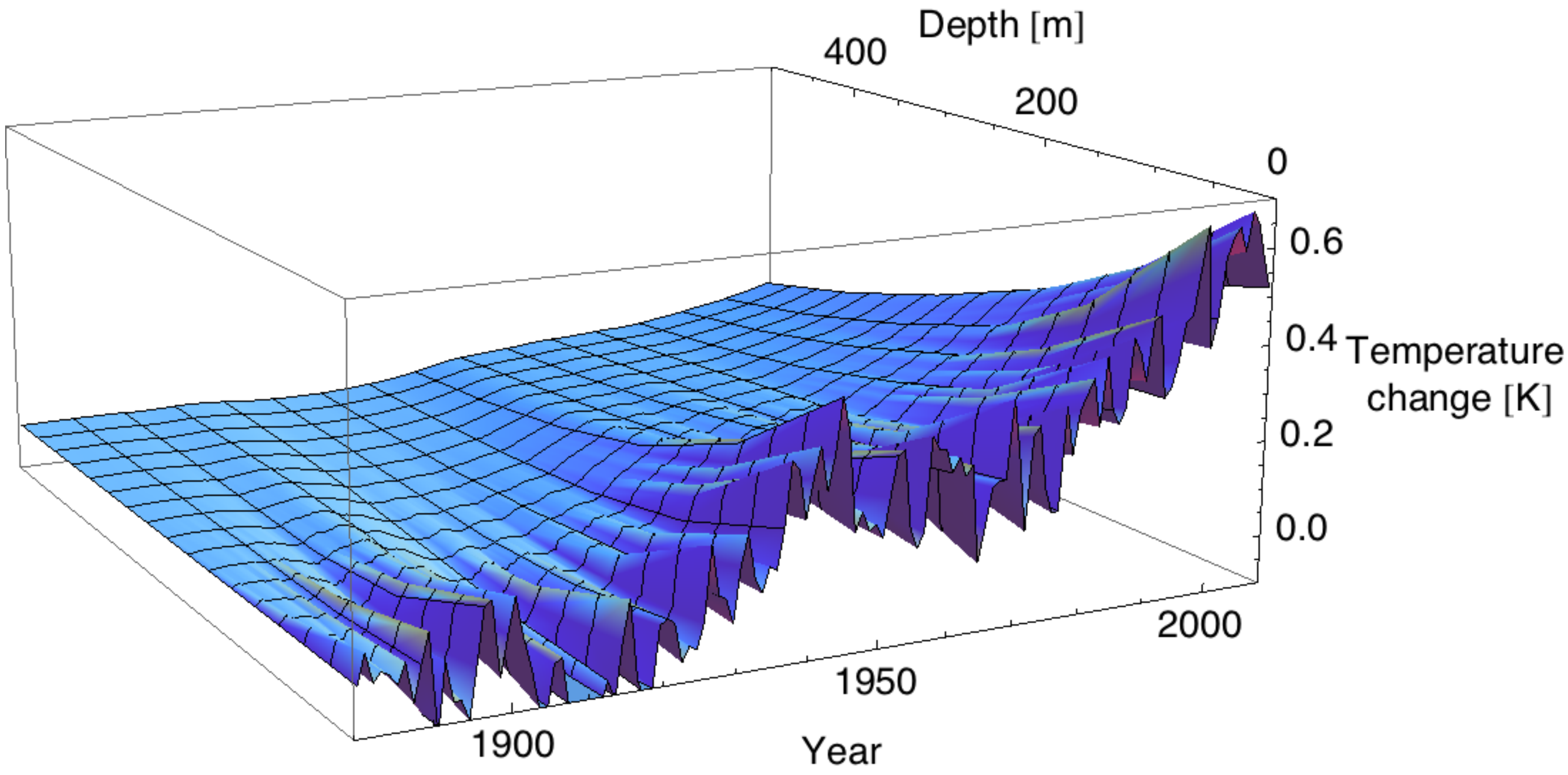


Global ocean response to 1 K step change at the surface
Sea level change
Heat content change
heat content change [10^{23} J]
sea level change [mm]
years after surface warming
0
5
10
15
0
25
50
75
100
125
0
200
400
600
800
1000

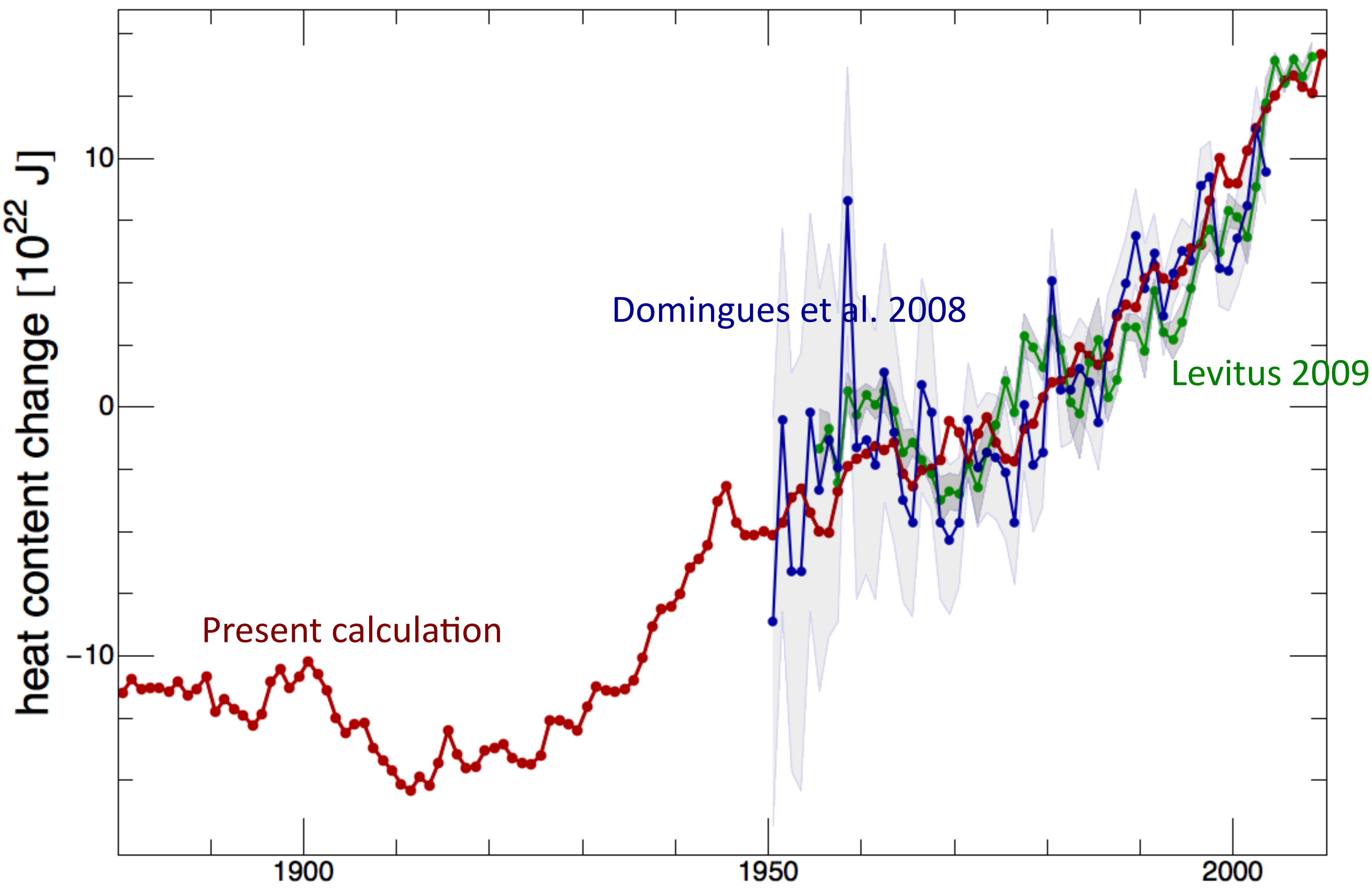
Input into the calculation are Had SST2 global average sea surface temperatures

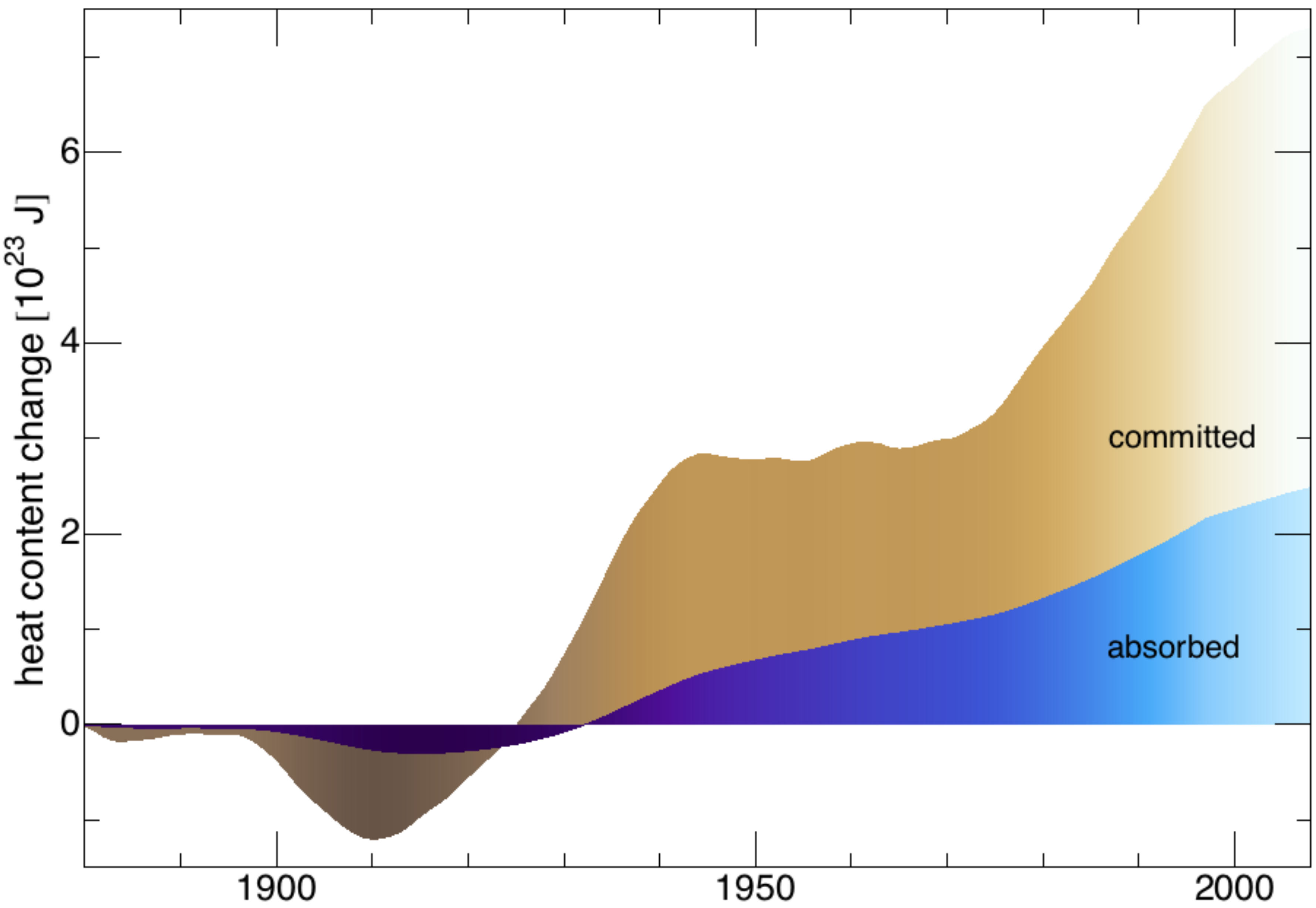


Calculated warming profile



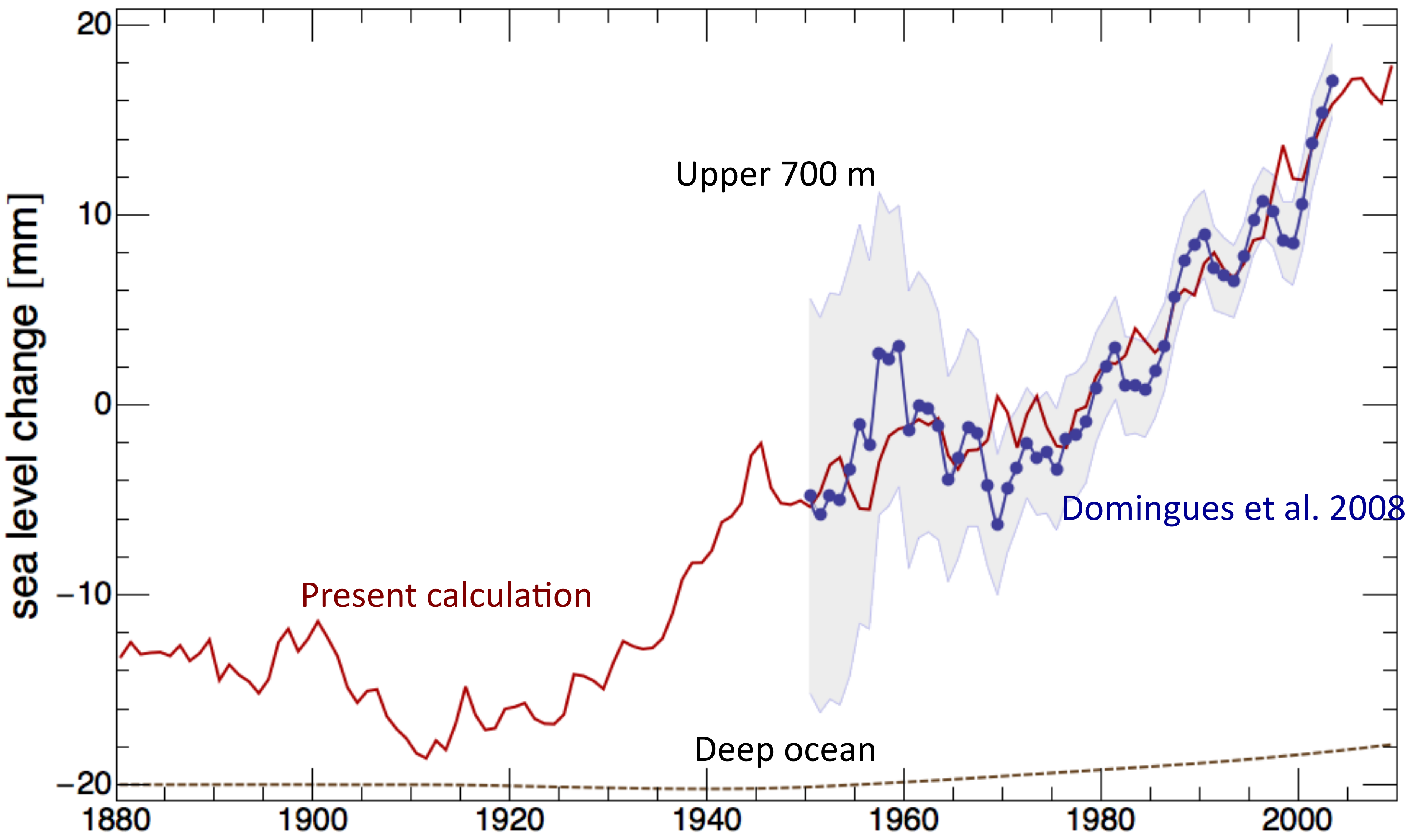
Calculated change in heat content compared to measurements
(no adjustable parameters)



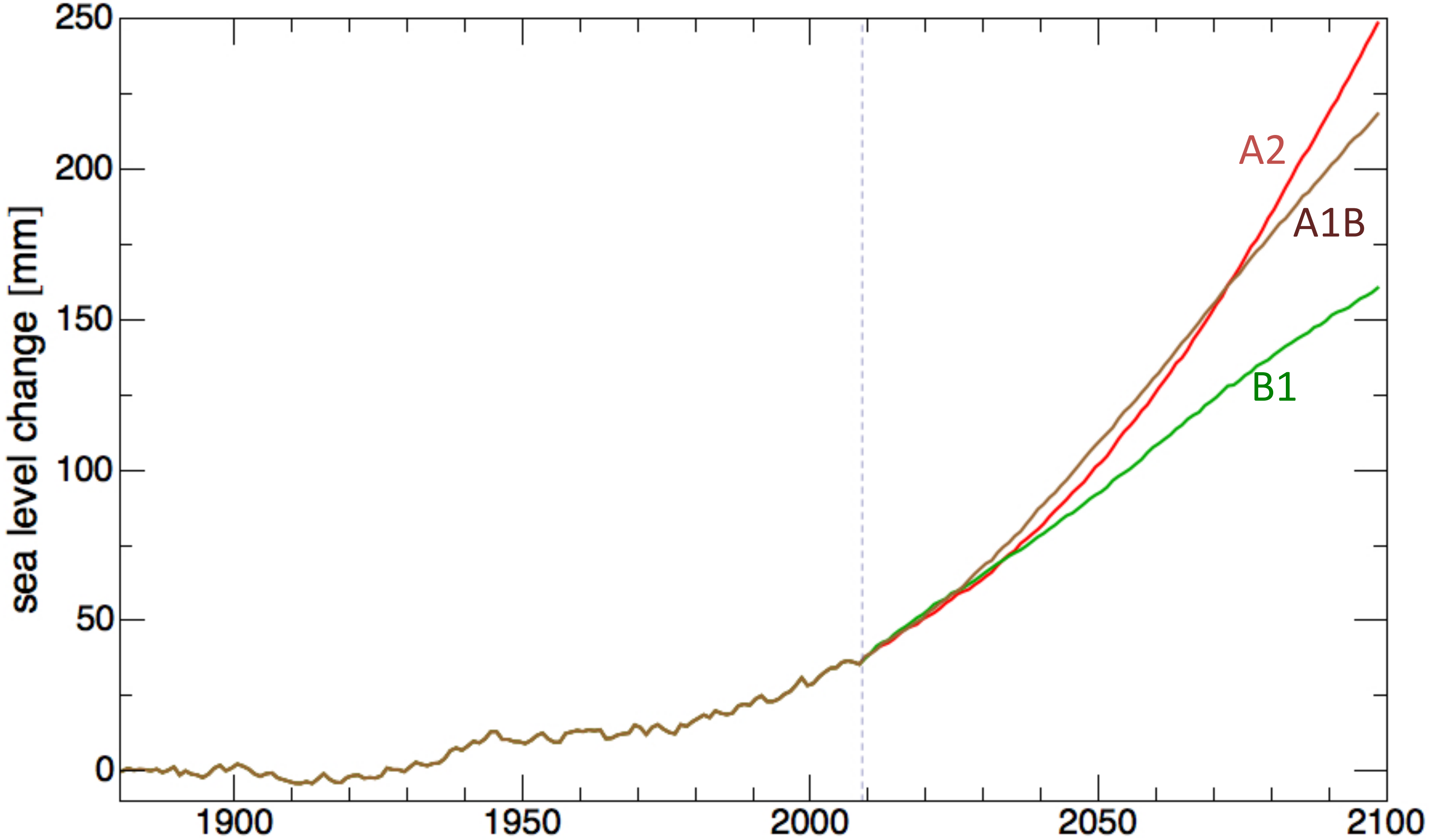


heat content change [10^{23} J]
6
4
2
0
1900
1950
2000
committed
absorbed

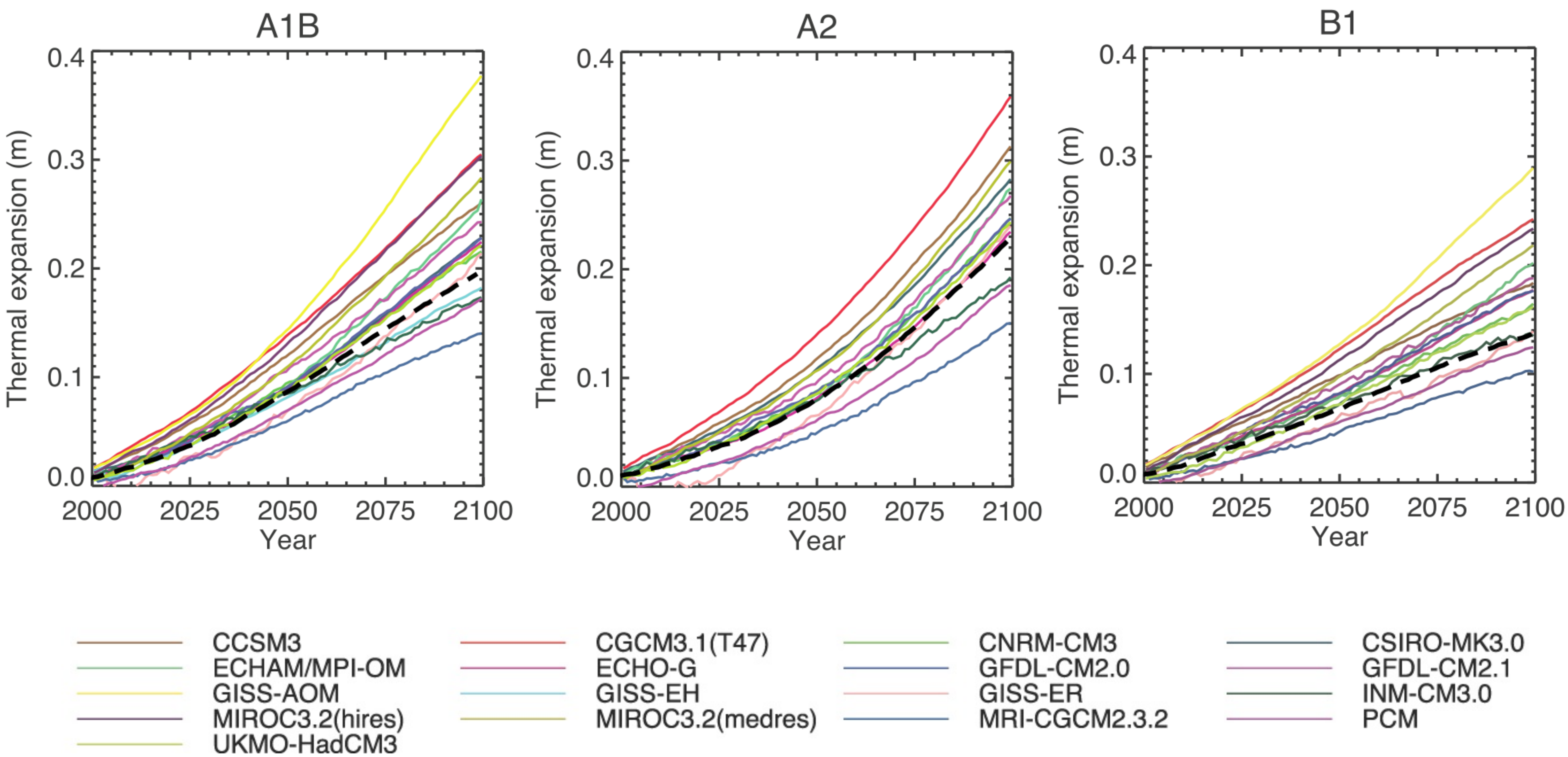
Sea level change due to thermosteric expansion compared to measurements

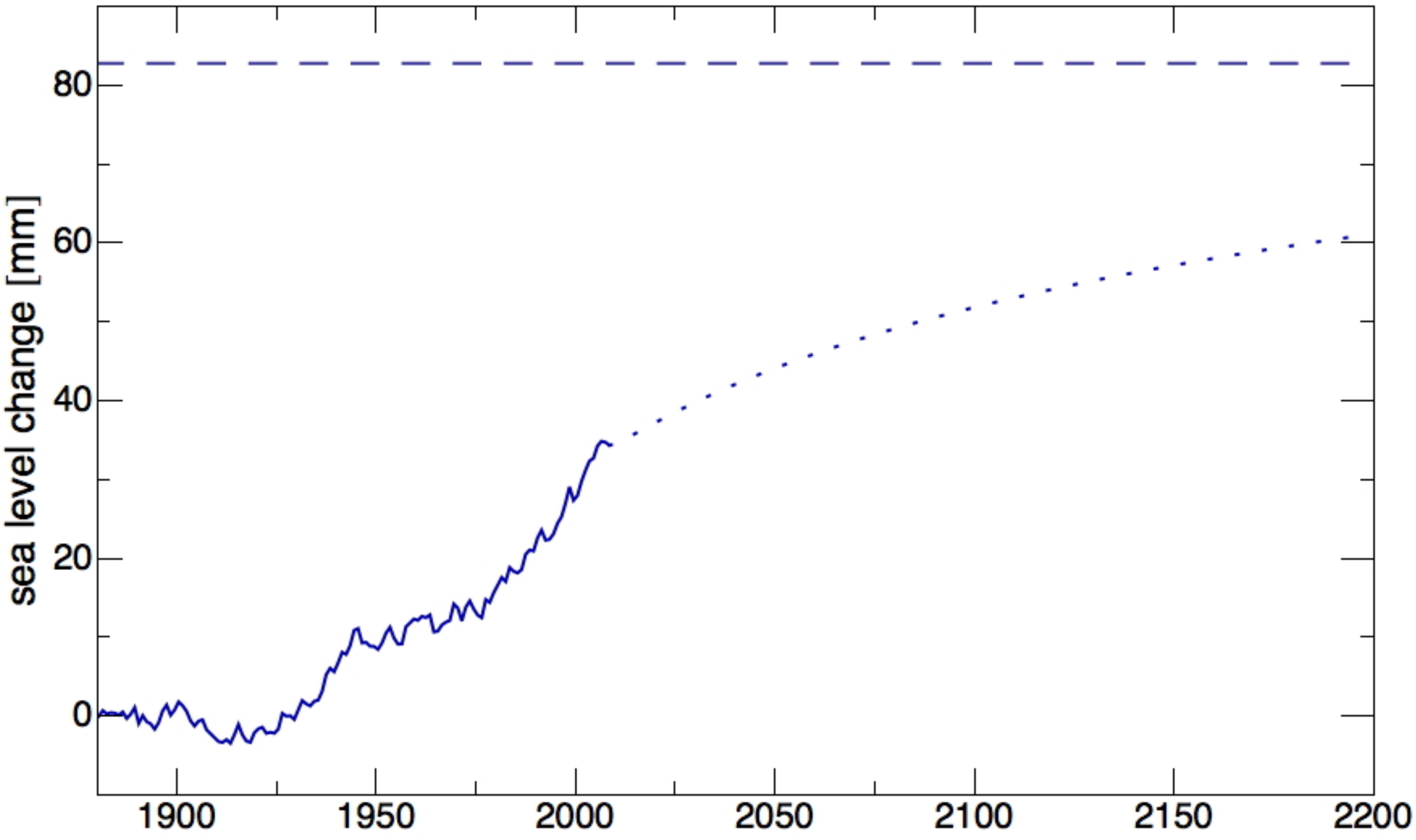


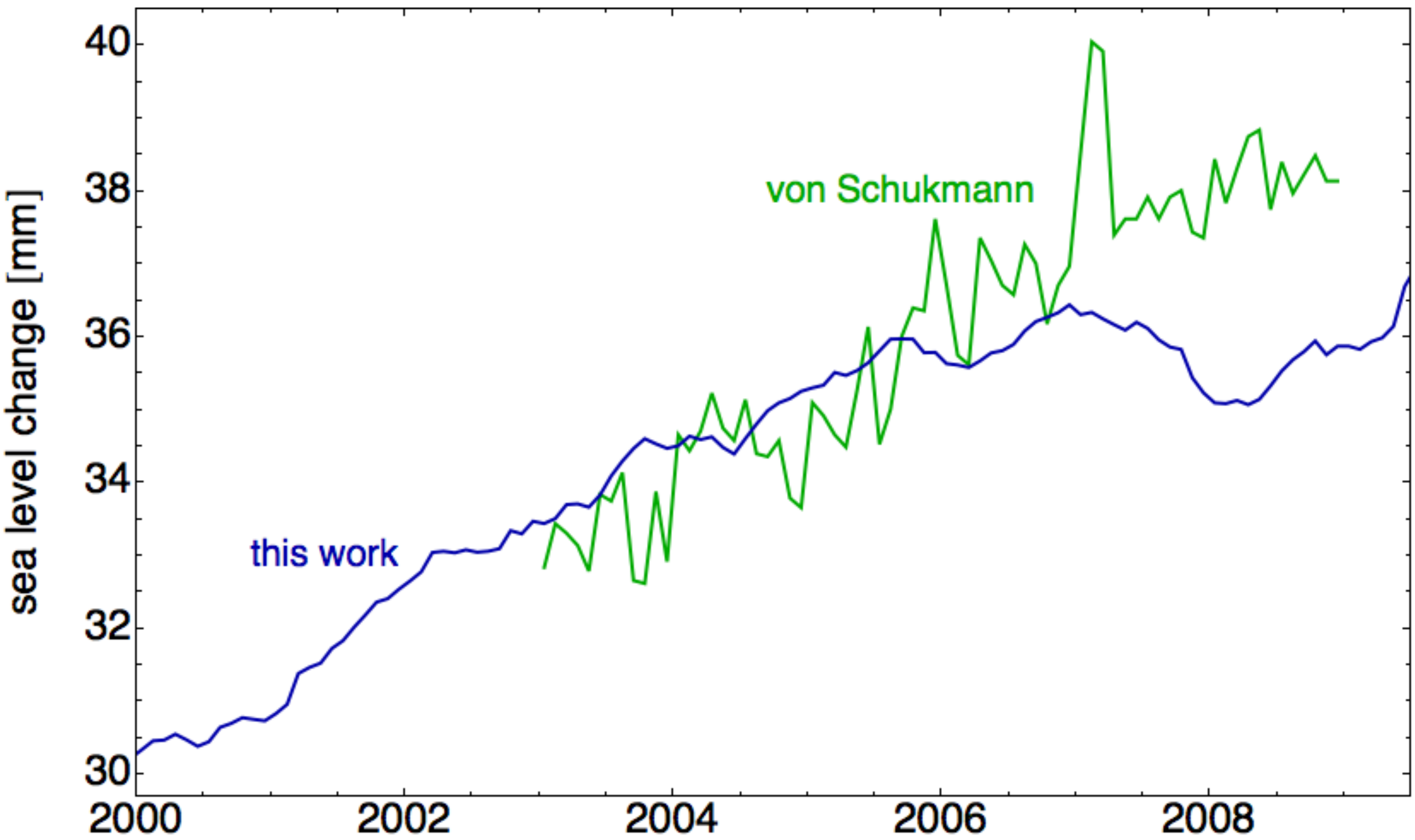
Projected thermosteric sea level change for IPCC scenarios



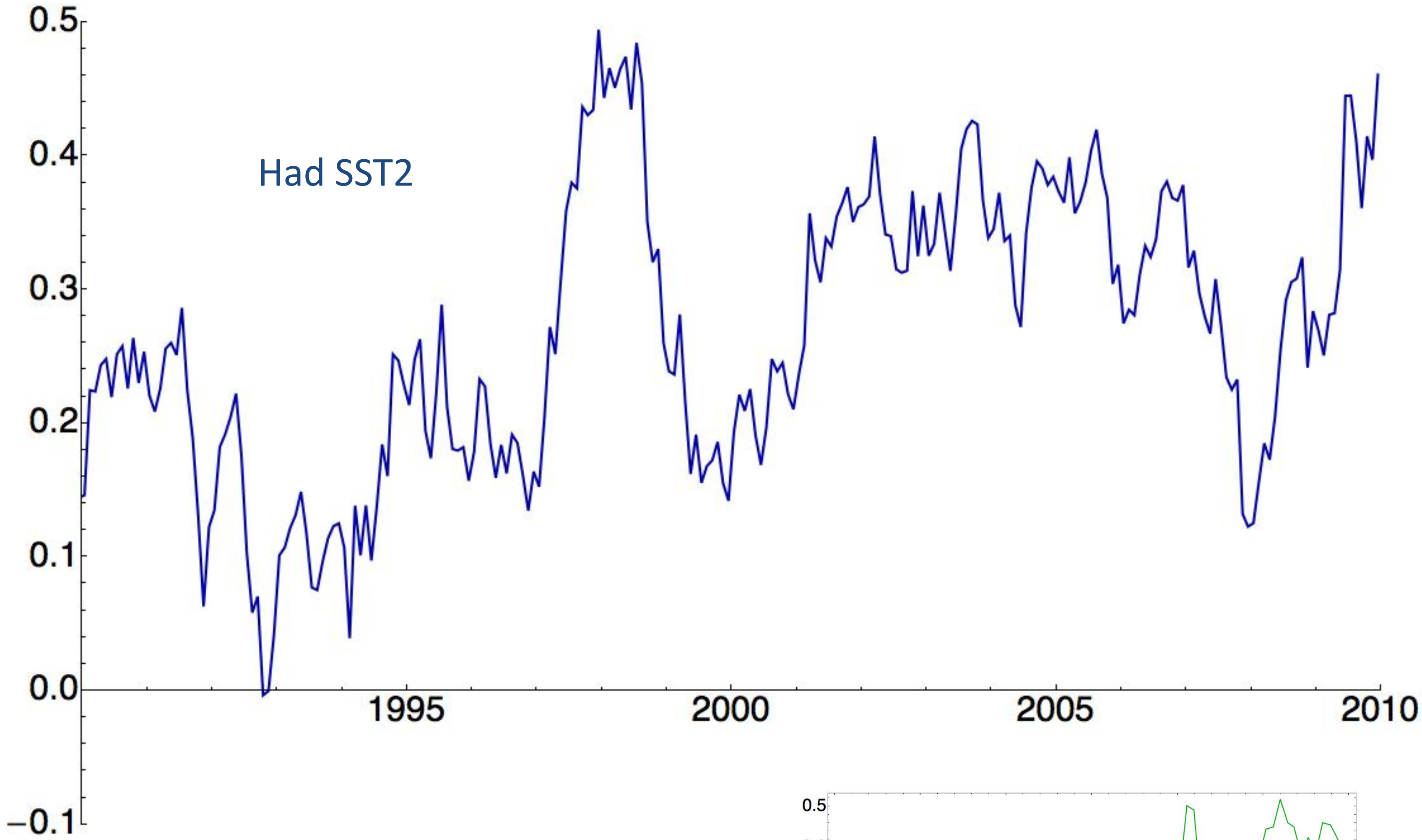
Projected steric sea level change compared to the models listed in IPCC 4th report




sea level change [mm]
80
60
40
20
0
1900
1950
2000
2050
2100
2150
2200



sea level change [mm]
40
38
36
34
32
30
2000
2002
2004
2006
2008
von Schukmann
this work



Von Schuckmann OHC