Aerosols and Clouds as Forcings and Feedbacks in Global Climate Change

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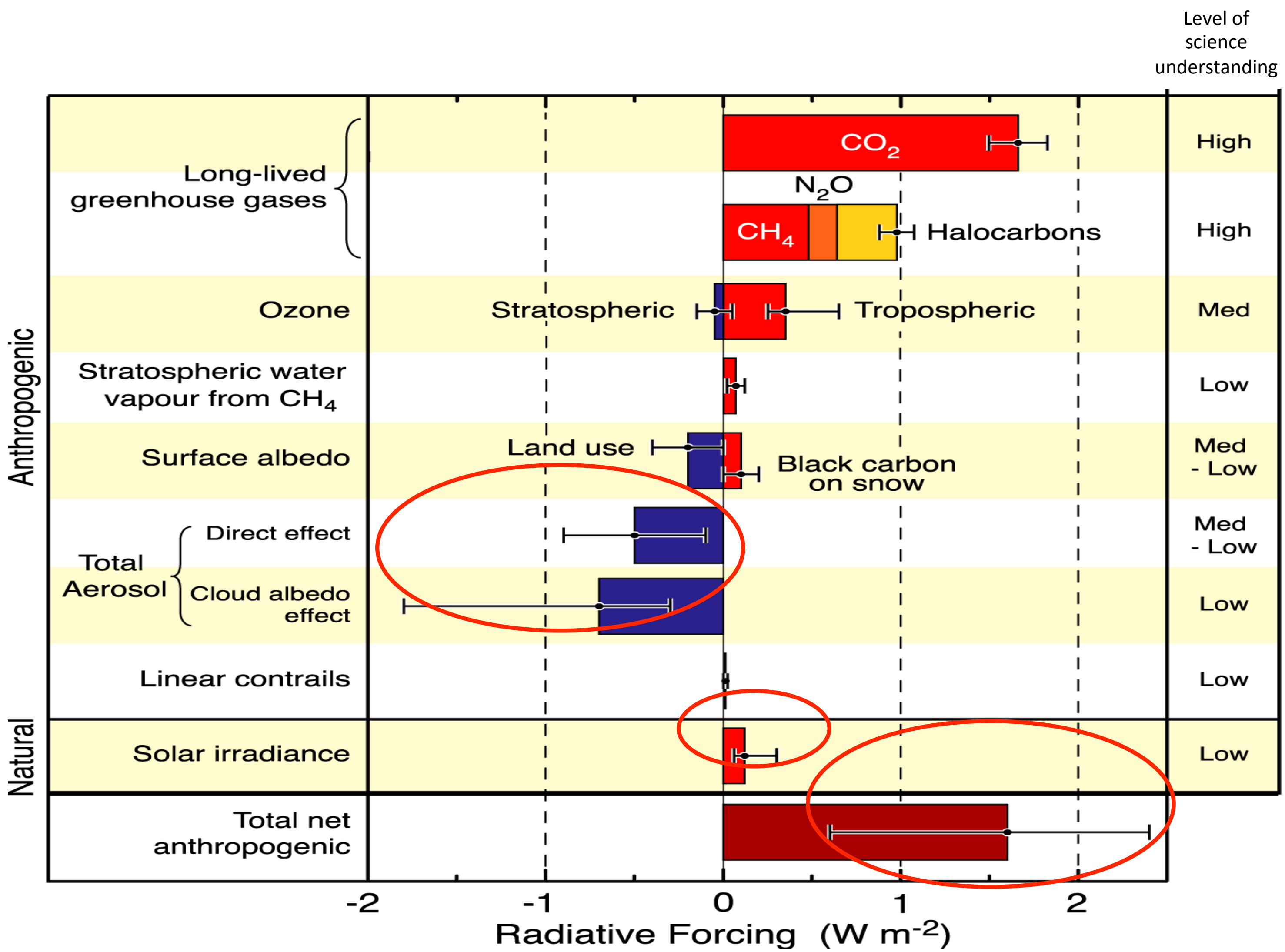
Uncertainty in aerosol climate forcing is very large

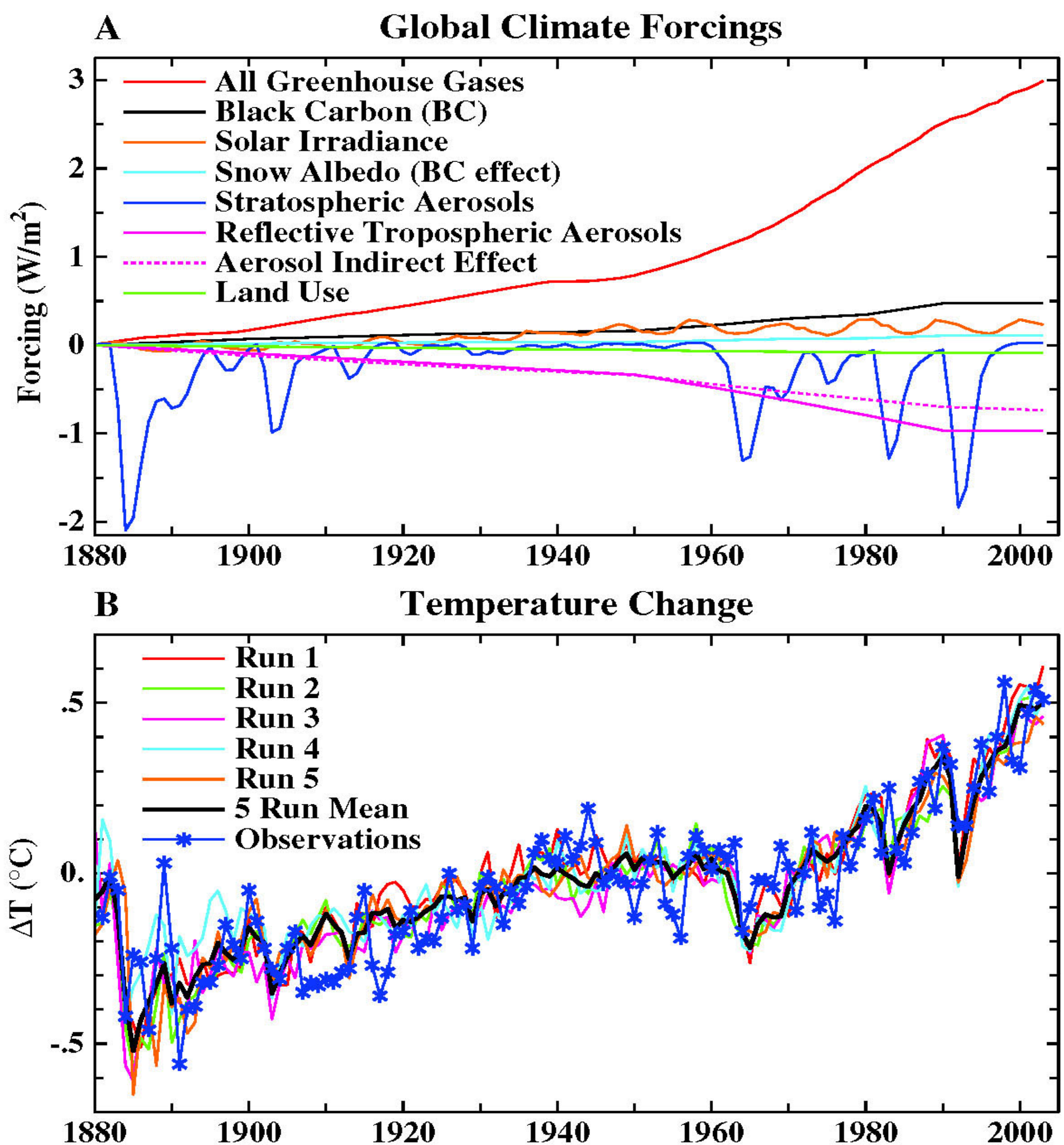


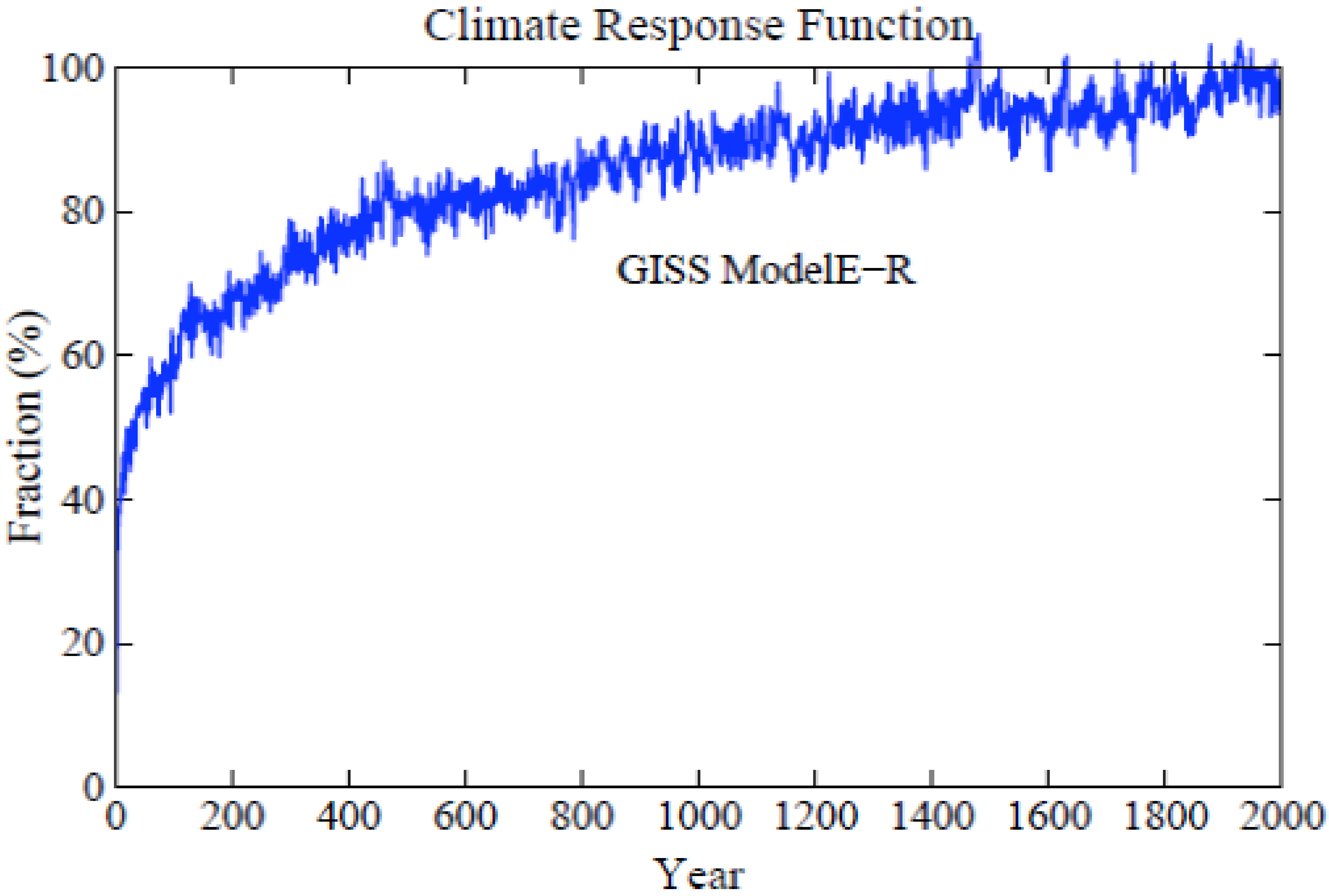
IPCC Summary for Policymakers, 2007

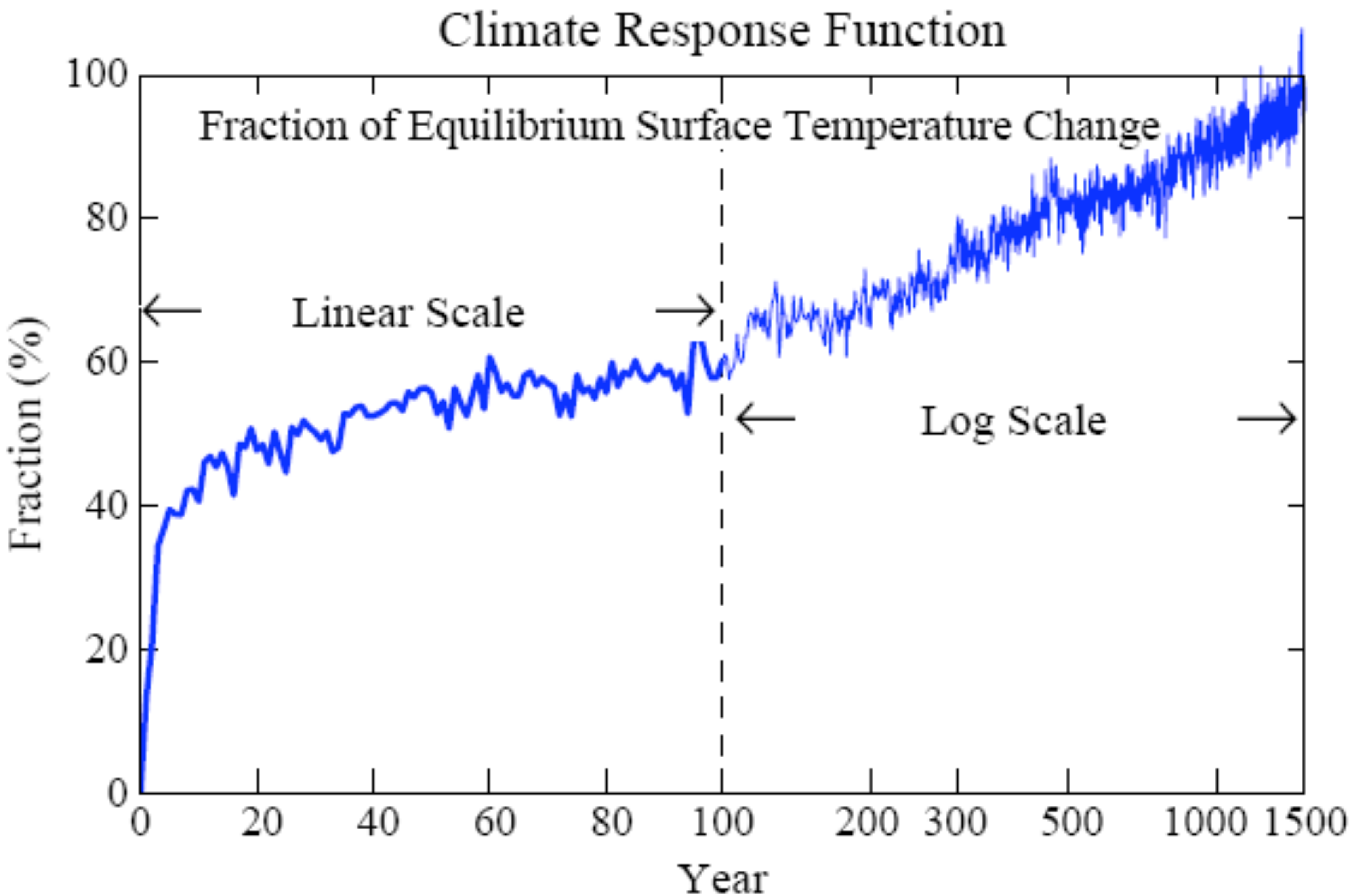
(A) Forcings used to drive climate simulations.

(B) Simulated and observed surface temperature change.

Source: Earth's energy imbalance: Confirmation and implications. *Science* **308**, 1431, 2005.

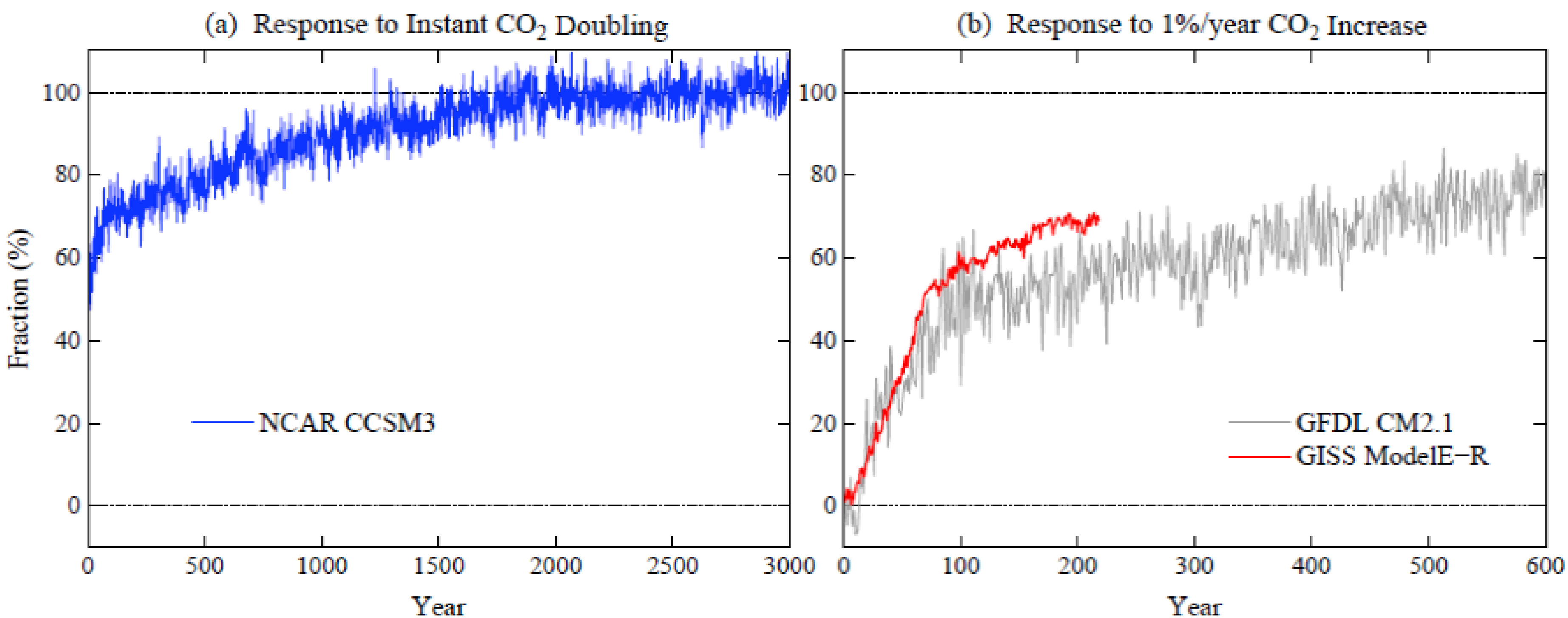



Climate Response Function
GISS ModelE−R
Fraction (%)
Year
0
20
40
60
80
100
0
200
400
600
800
1000
1200
1400
1600
1800
2000



GISS climate model reaches only 60% of equilibrium response (to a given forcing) in a century. Other models have comparably long response times.

Source: Target Atmospheric CO_2, Hansen *et al., Open Atmos. Sci. J.*, **2**, 217-231, 2008.



(a) Response to Instant CO_2 Doubling
(b) Response to 1%/year CO_2 Increase
Fraction (%)
100
80
60
40
20
0
0
500
1000
1500
2000
2500
3000
Year
NCAR CCSM3
100
200
300
400
500
600
GFDL CM2.1
GISS ModelE−R

Feedbacks

1. **Respond to Climate, not Forcing**

   → response time ~ square of climate sensitivity

2. **Slow Feedbacks**

   Further increase climate response time

3. **Charney feedbacks vs. Fast feedbacks**

   Aerosols better treated as a fast feedback

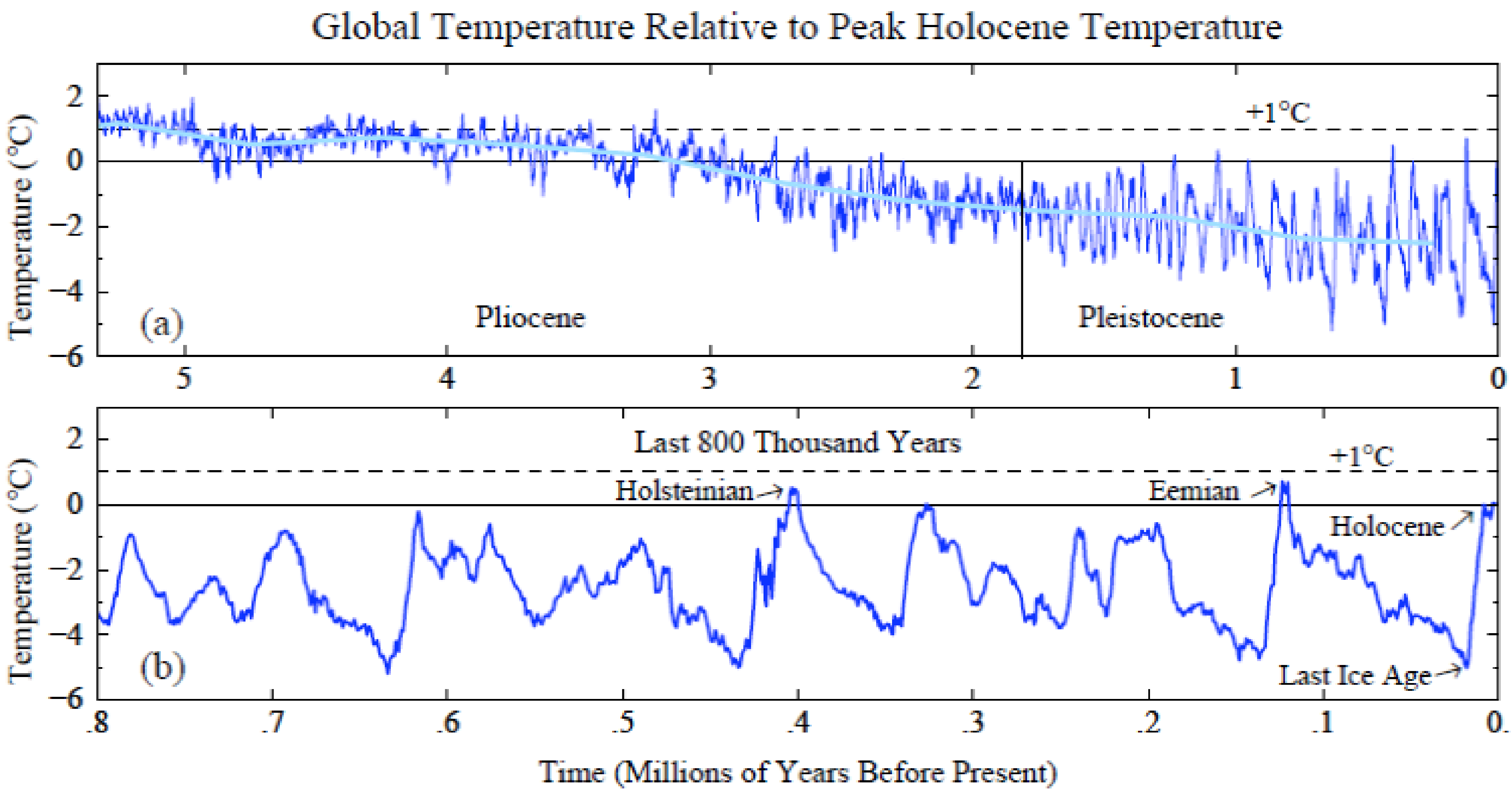
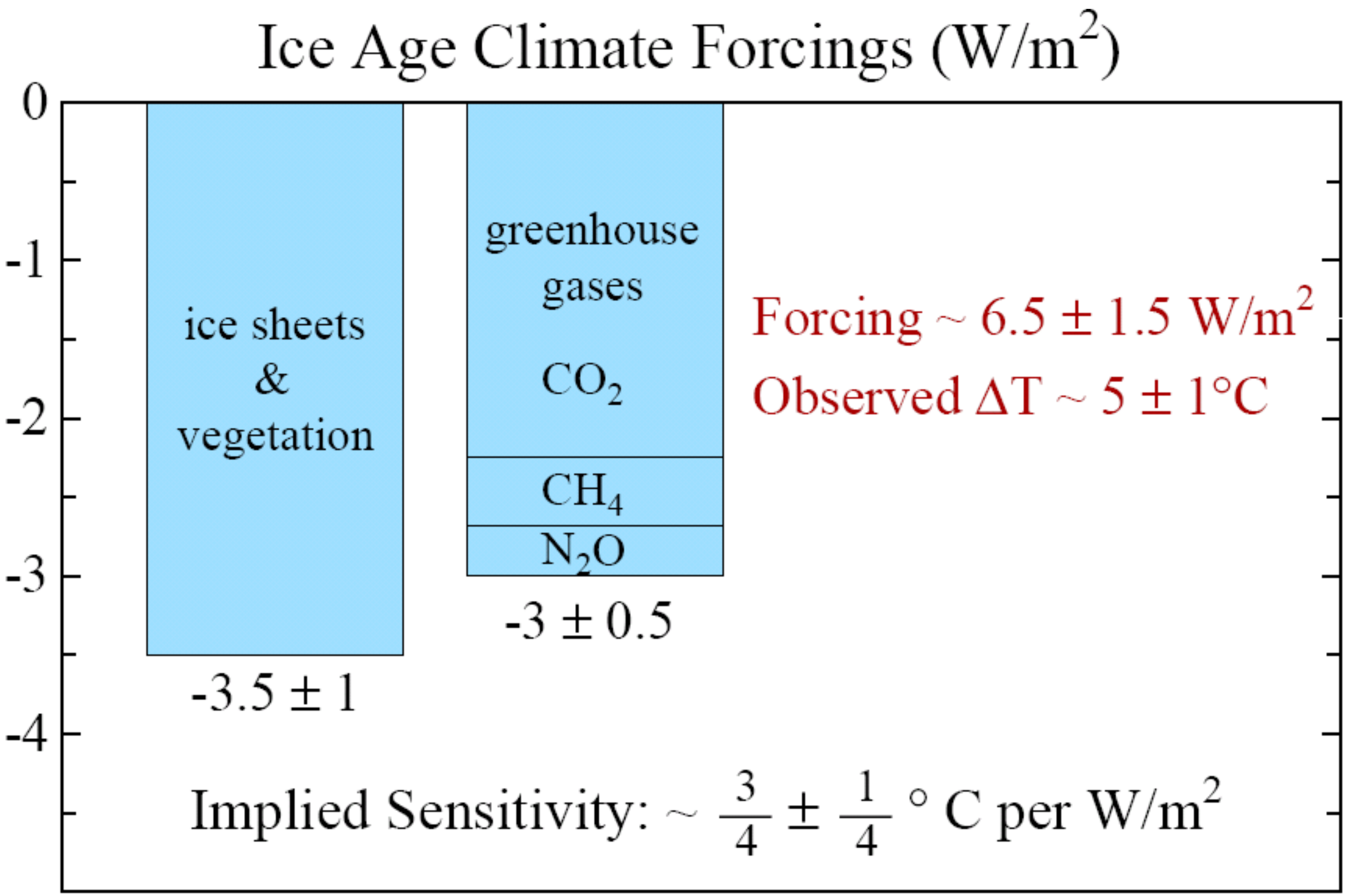
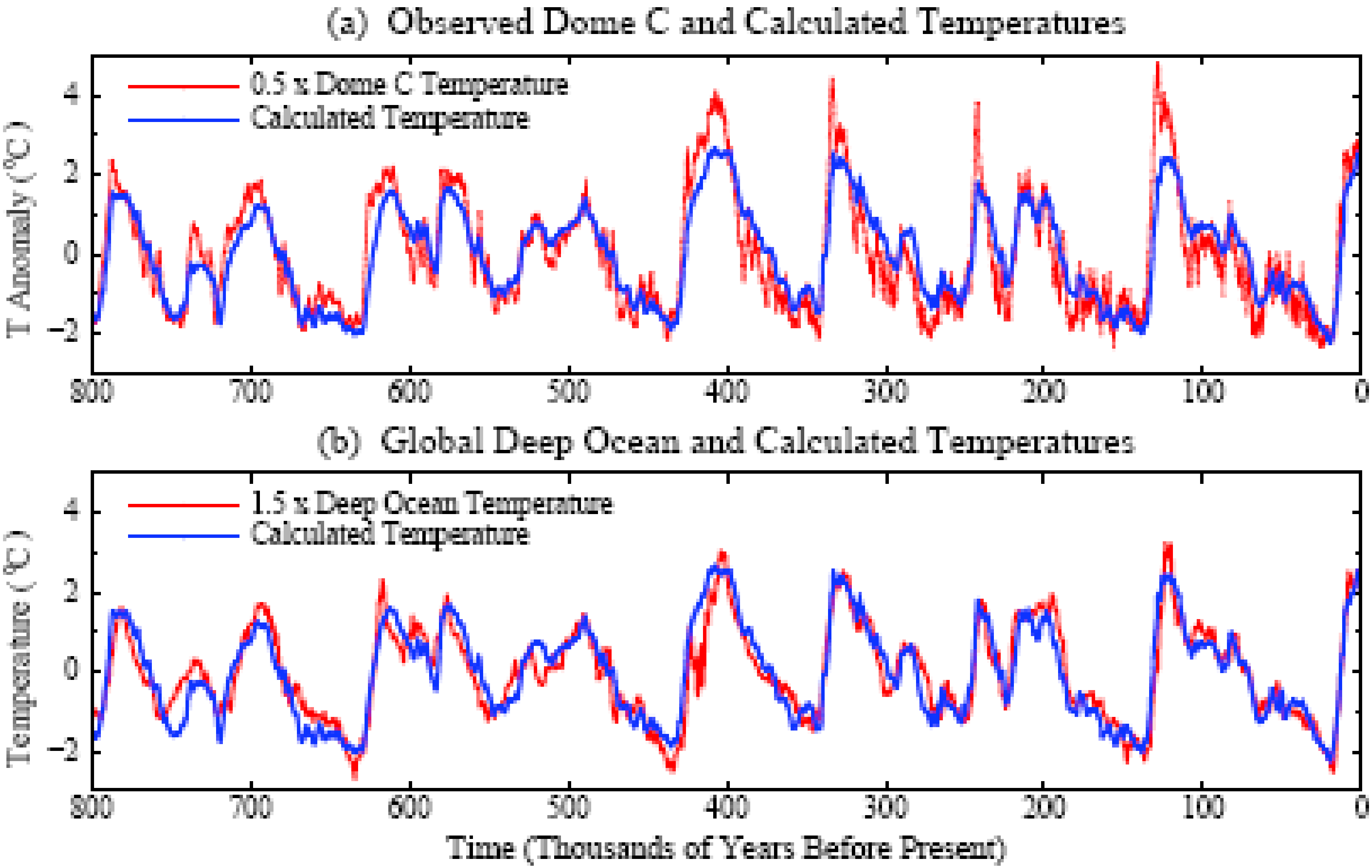


Figure 2. Global temperature relative to peak Holocene temperature (Hansen and Sato, 2011).



Climate forcings during ice age 20 ky BP, relative to the present (pre-industrial) interglacial period.



(a) Observed Dome C and Calculated Temperatures
0.5 x Dome C Temperature
Calculated Temperature
T Anomaly (°C)
4
2
0
−2
800
700
600
500
400
300
200
100
0
(b) Global Deep Ocean and Calculated Temperatures
1.5 x Deep Ocean Temperature
Calculated Temperature
Temperature (°C)
4
2
0
−2
800
700
600
500
400
300
200
100
0
Time (Thousands of Years Before Present)

Figure 4

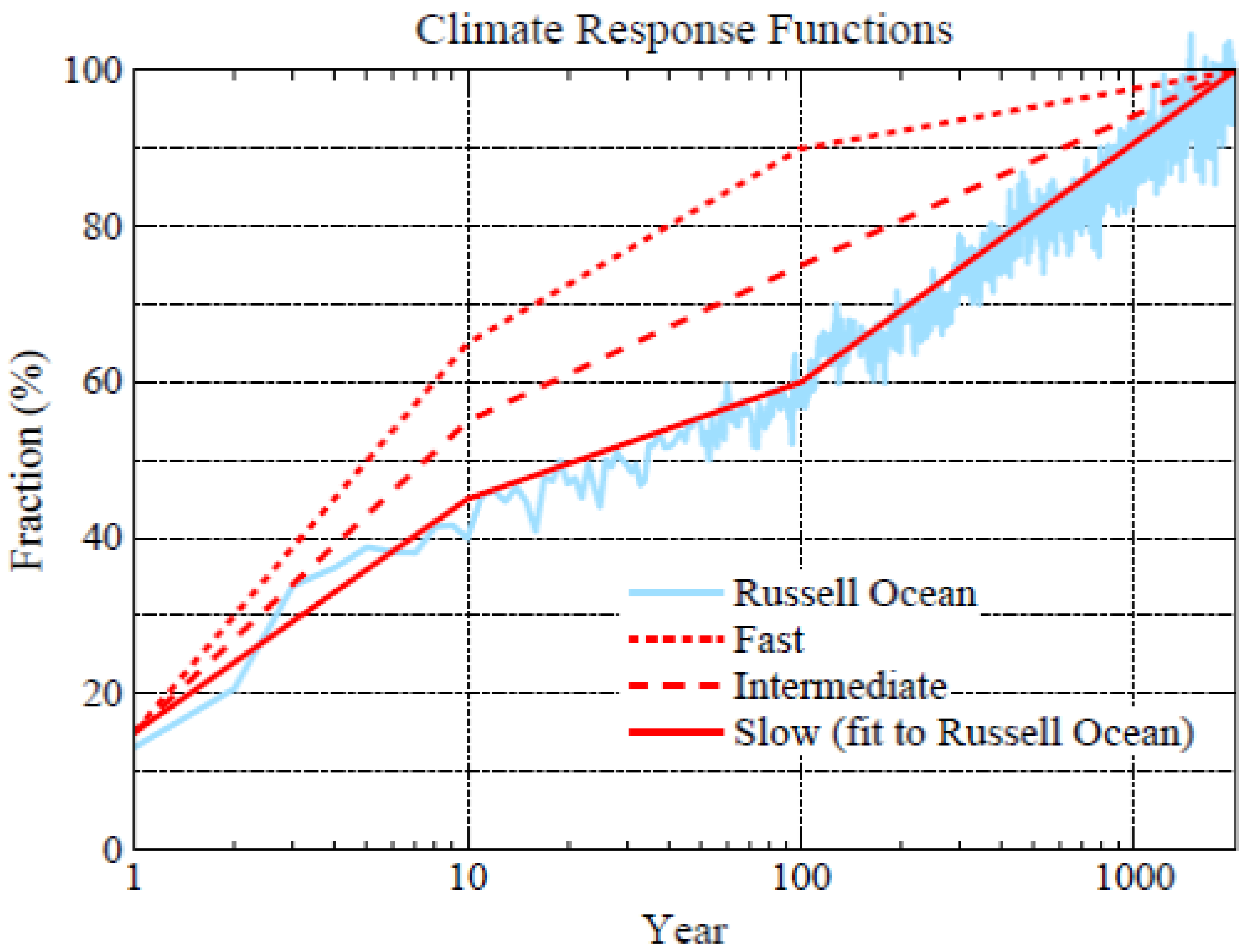

Climate Response Functions
100
80
60
40
20
0
1
10
100
1000
Fraction (%)
Year
Russell Ocean
Fast
Intermediate
Slow (fit to Russell Ocean)

Figure 5

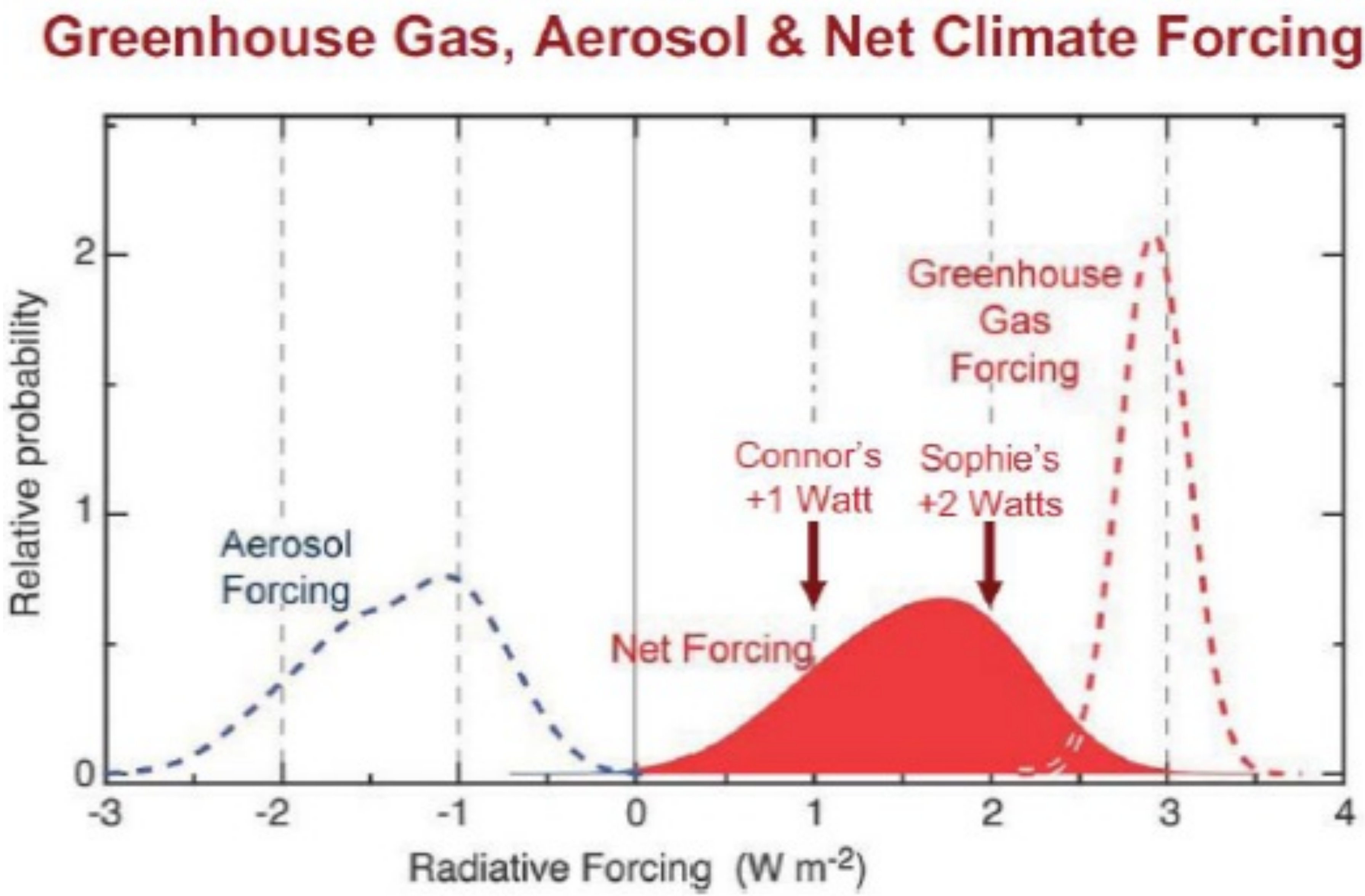
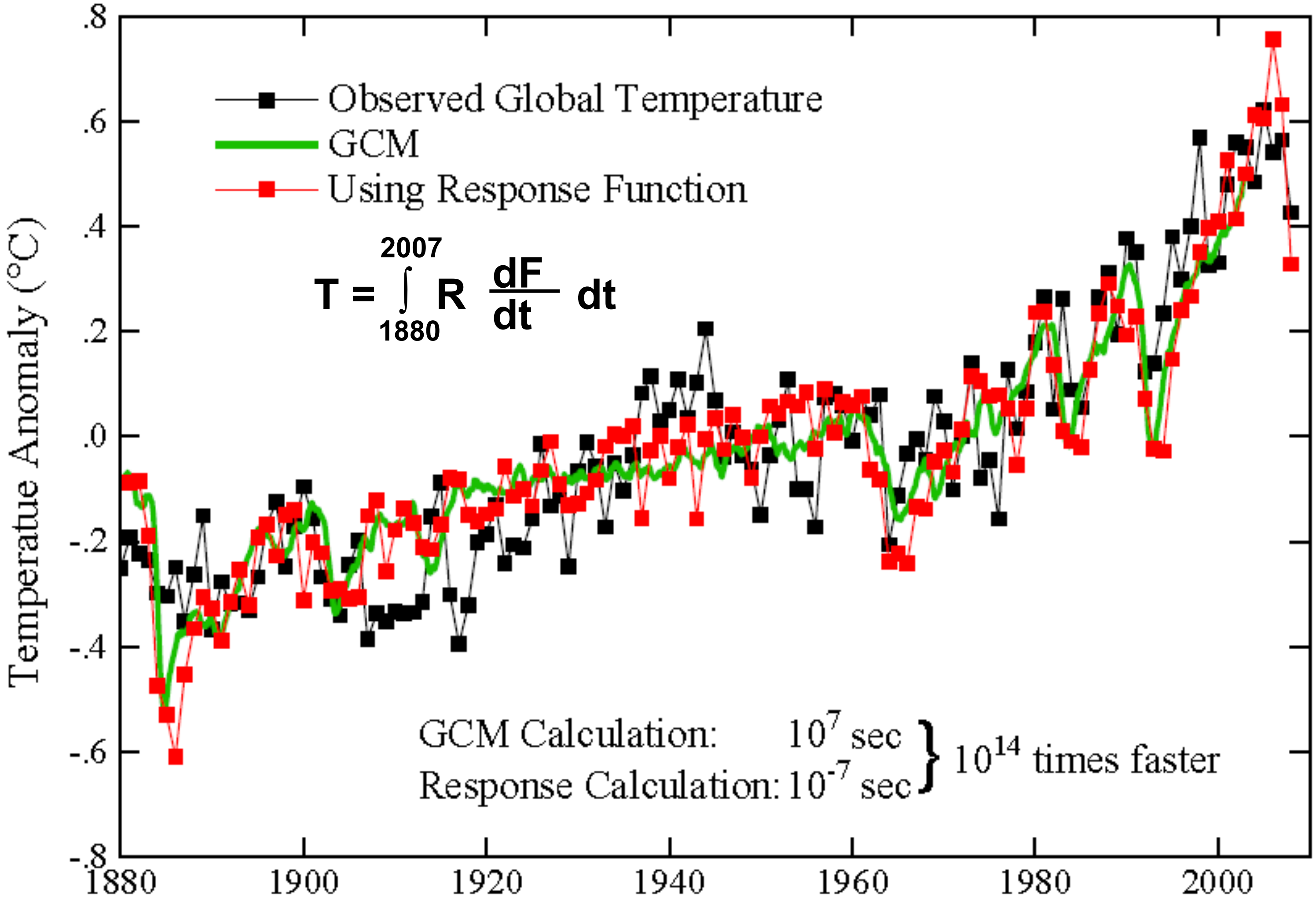
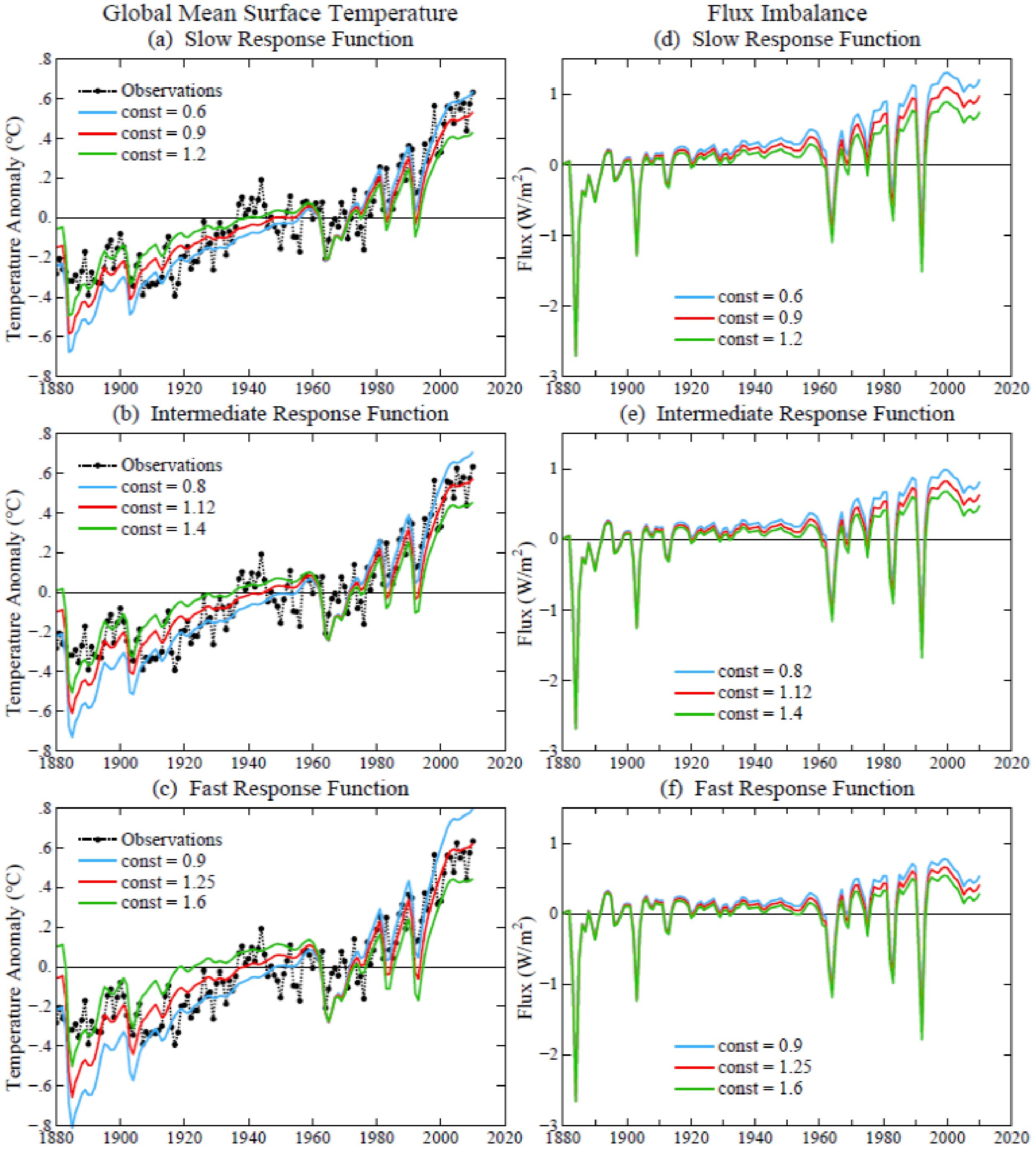

Greenhouse Gas, Aerosol & Net Climate Forcing
Relative probability
2
1
0
Greenhouse
Gas
Forcing
Connor's
+1 Watt
Sophie's
+2 Watts
Aerosol
Forcing
Net Forcing
-3
-2
-1
0
1
2
3
4
Radiative Forcing (W m-2)

Figure 2

Observed & Simulated Global Temperature

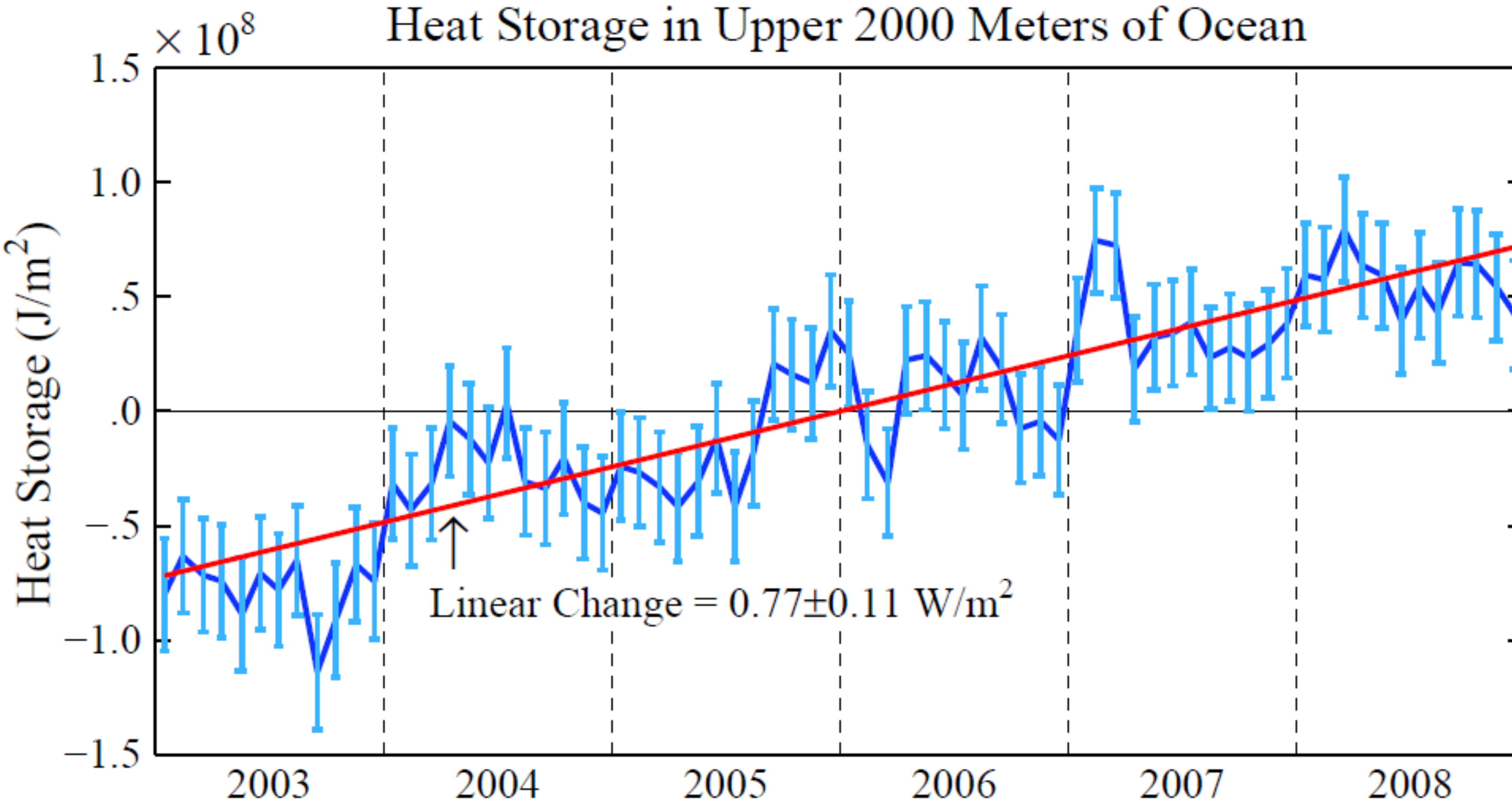


Comparison of GCM results with simple integration of the Green's function [climate response function, R(t)] multiplied by forcing F(t).



Global Mean Surface Temperature
(a) Slow Response Function
Observations
const = 0.6
const = 0.9
const = 1.2
Temperature Anomaly (°C)
(b) Intermediate Response Function
Observations
const = 0.8
const = 1.12
const = 1.4
(c) Fast Response Function
Observations
const = 0.9
const = 1.25
const = 1.6
Flux Imbalance
(d) Slow Response Function
const = 0.6
const = 0.9
const = 1.2
Flux (W/m²)
(e) Intermediate Response Function
const = 0.8
const = 1.12
const = 1.4
(f) Fast Response Function
const = 0.9
const = 1.25
const = 1.6

Figure 7



Heat storage in upper 2000 meters of ocean during 2003-2008 based on ARGO data.

Knowledge of Earth's energy imbalance is improving rapidly as ARGO data lengthens.

Data must be averaged over a decade because of El Nino/La Nina and solar variability.

Energy imbalance is smoking gun for human-made increasing greenhouse effect.

Data source: von Schuckmann *et al. J. Geophys. Res.* **114**, C09007, 2009, doi:10.1029/2008JC005237.

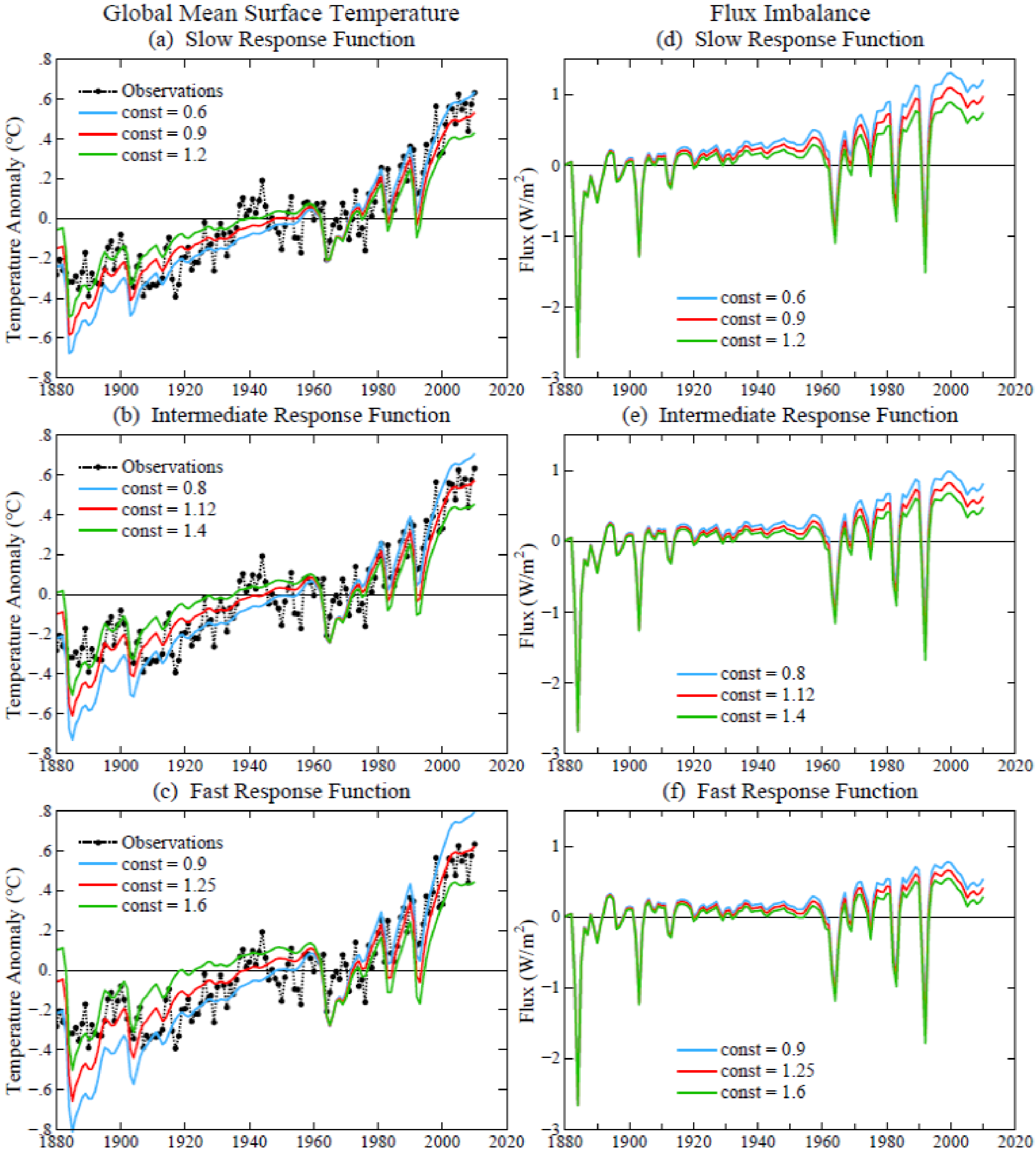


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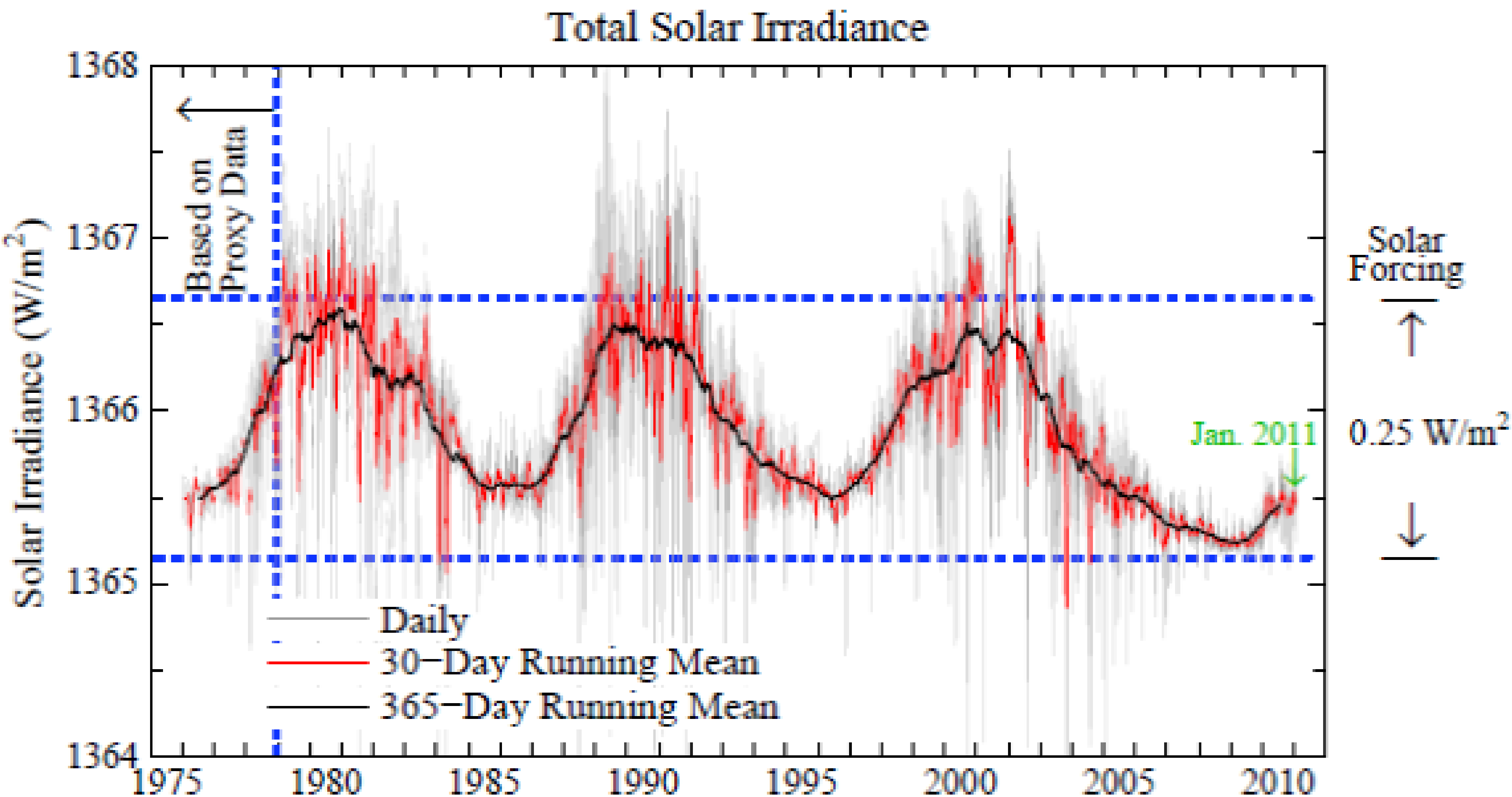
Figure 7



Total Solar Irradiance
1368
1367
1366
1365
1364
Solar Irradiance (W/m^2)
1975
1980
1985
1990
1995
2000
2005
2010
Based on Proxy Data
Solar Forcing
0.25 W/m^2
Jan. 2011
Daily
30−Day Running Mean
365−Day Running Mean

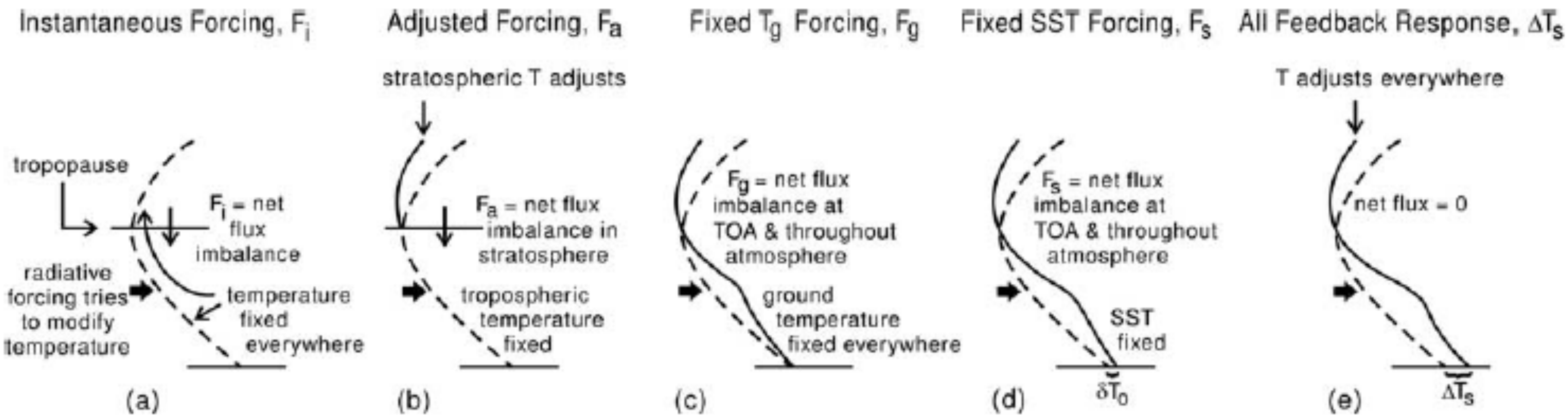


Figure 2. Cartoon comparing (a) F_i, instantaneous forcing, (b) F_a, adjusted forcing, which allows stratospheric temperature to adjust, (c) F_g, fixed T_g forcing, which allows atmospheric temperature to adjust, (d) F_s, fixed SST forcing, which allows atmospheric temperature and land temperature to adjust, and (e) ΔT_s, global surface air temperature calculated by the climate model in response to the climate forcing agent.

Forcings and Feedbacks

Forcing: Imposed Perturbation of Planet's Energy Balance

Feedback: Response of Climate System, which can Amplify or Diminish the Global Temperature Change Relative to Standard Radiative Change

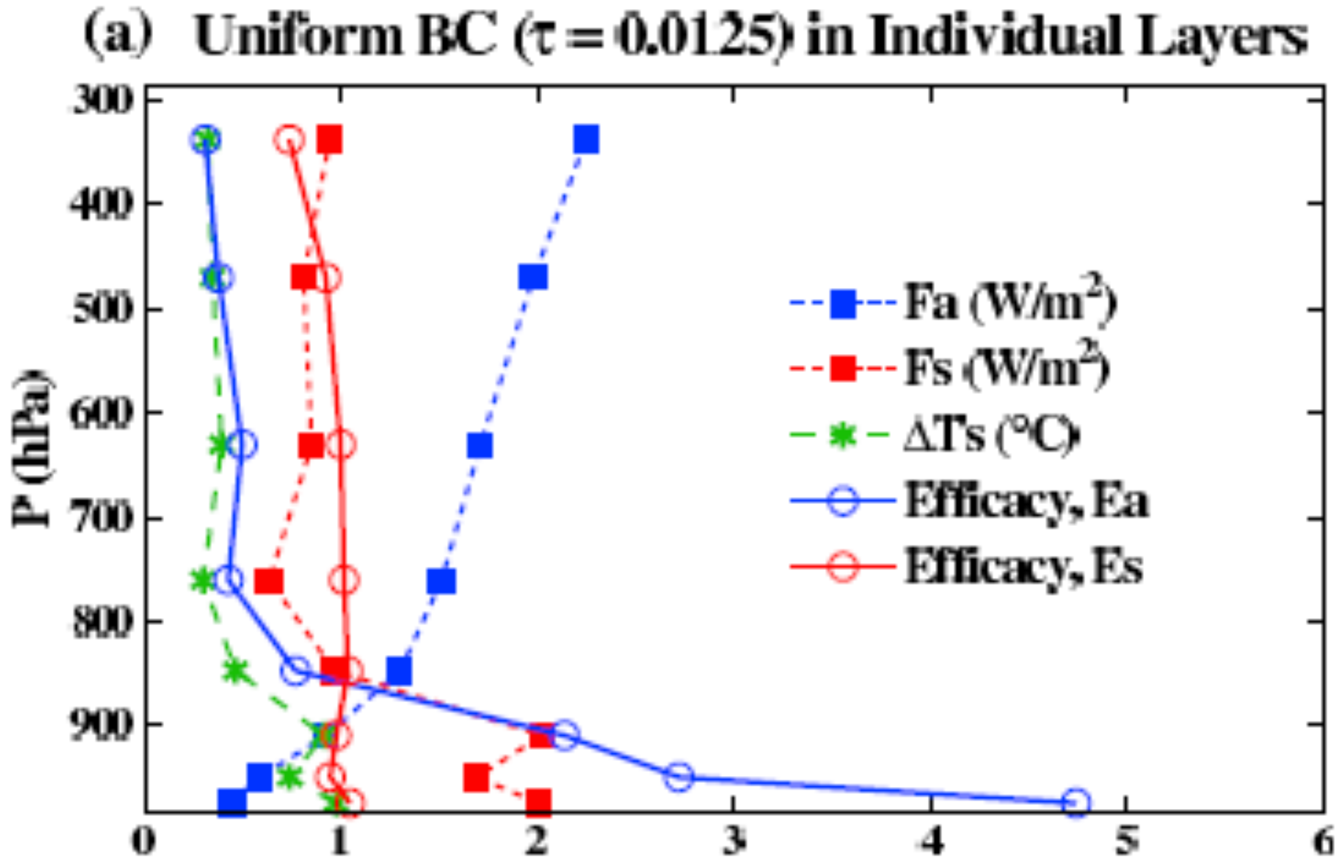


Figure 27. (a) Forcing, 81–120 year surface air temperature response, and efficacy for a globally uniform layer of BC aerosols in each of the eight lowest layers of the GISS model III. (b) Surface air temperature changes in years 81–

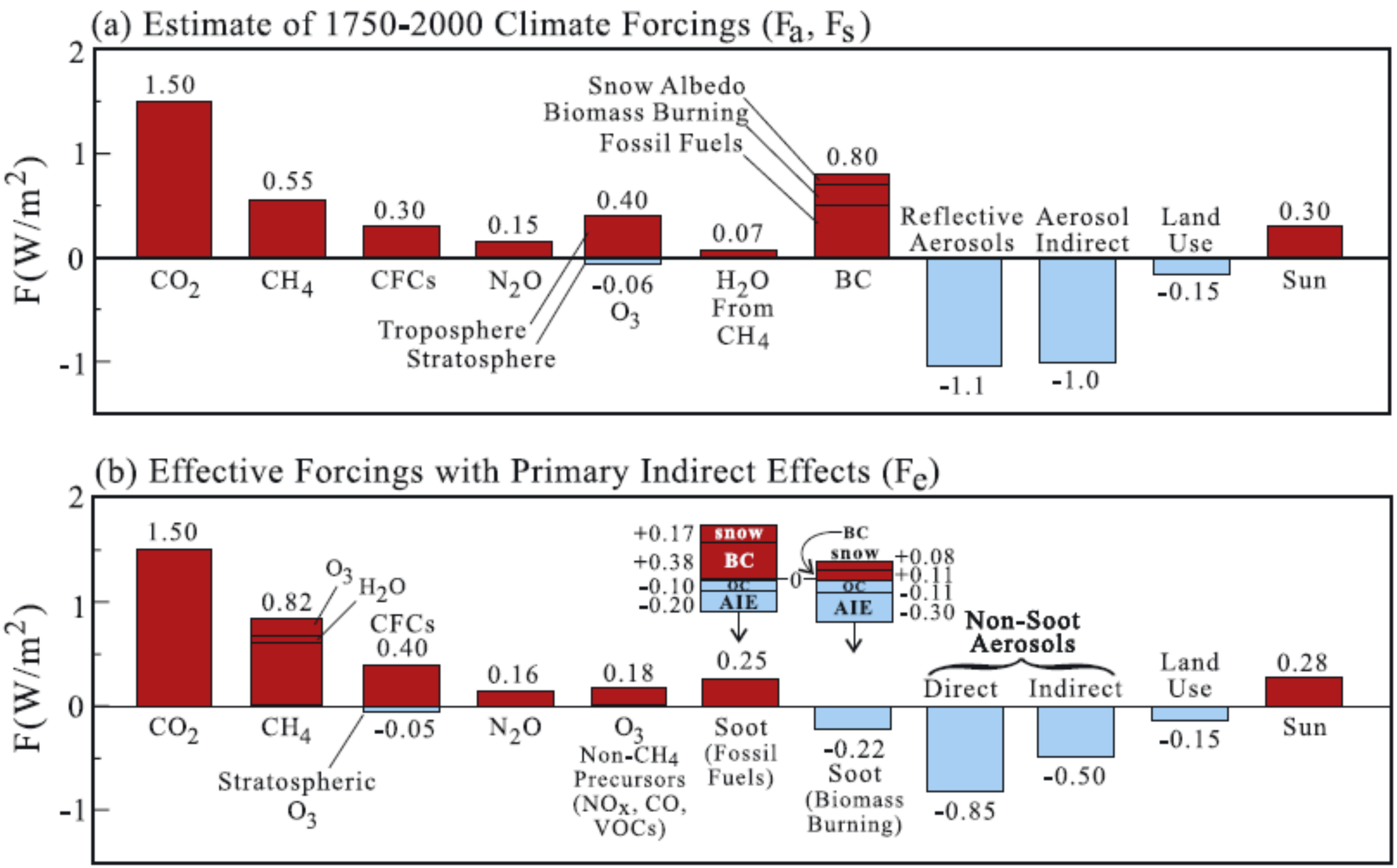


Figure 28. (a) A specific estimate of climate forcings for 1750–2000. (b) Same as Figure 28a, but with the effective forcing partially sorted by sources.

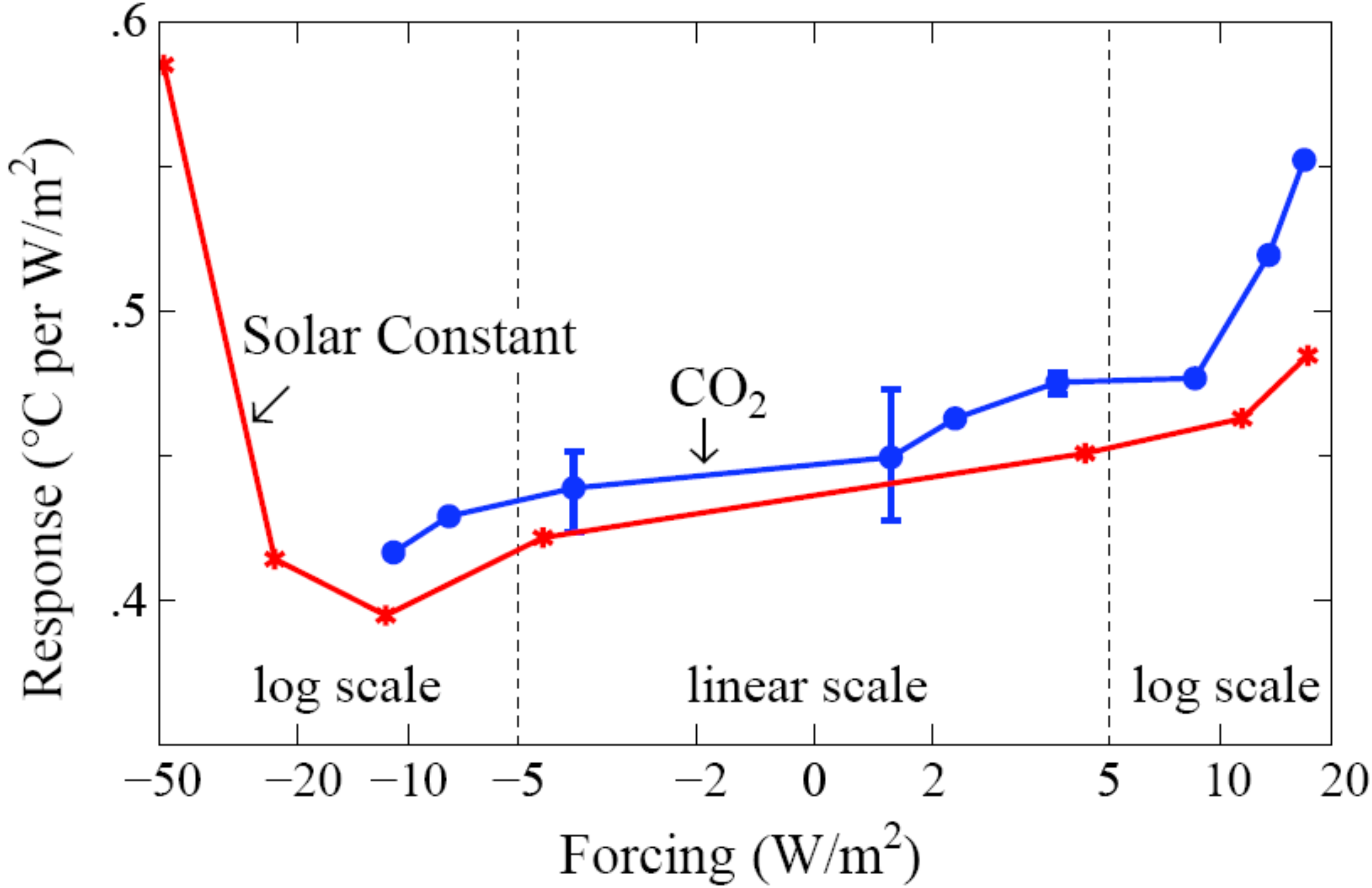


Figure S2 of “Target” paper.

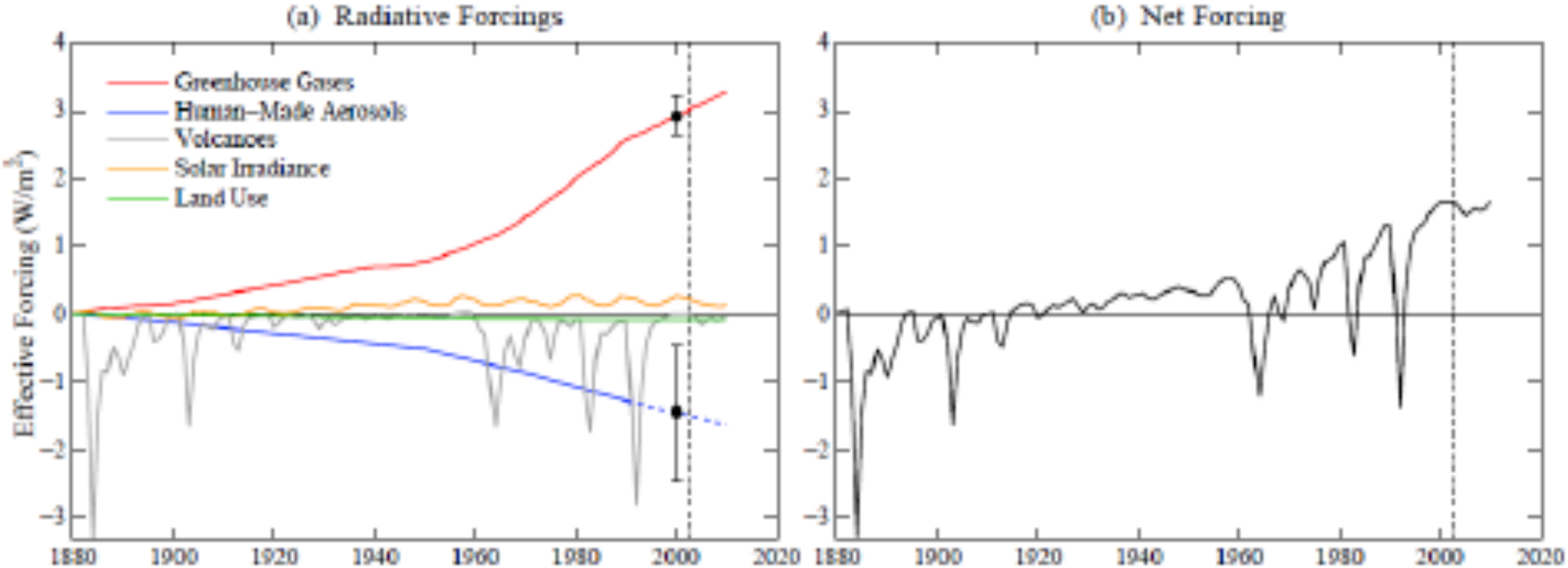
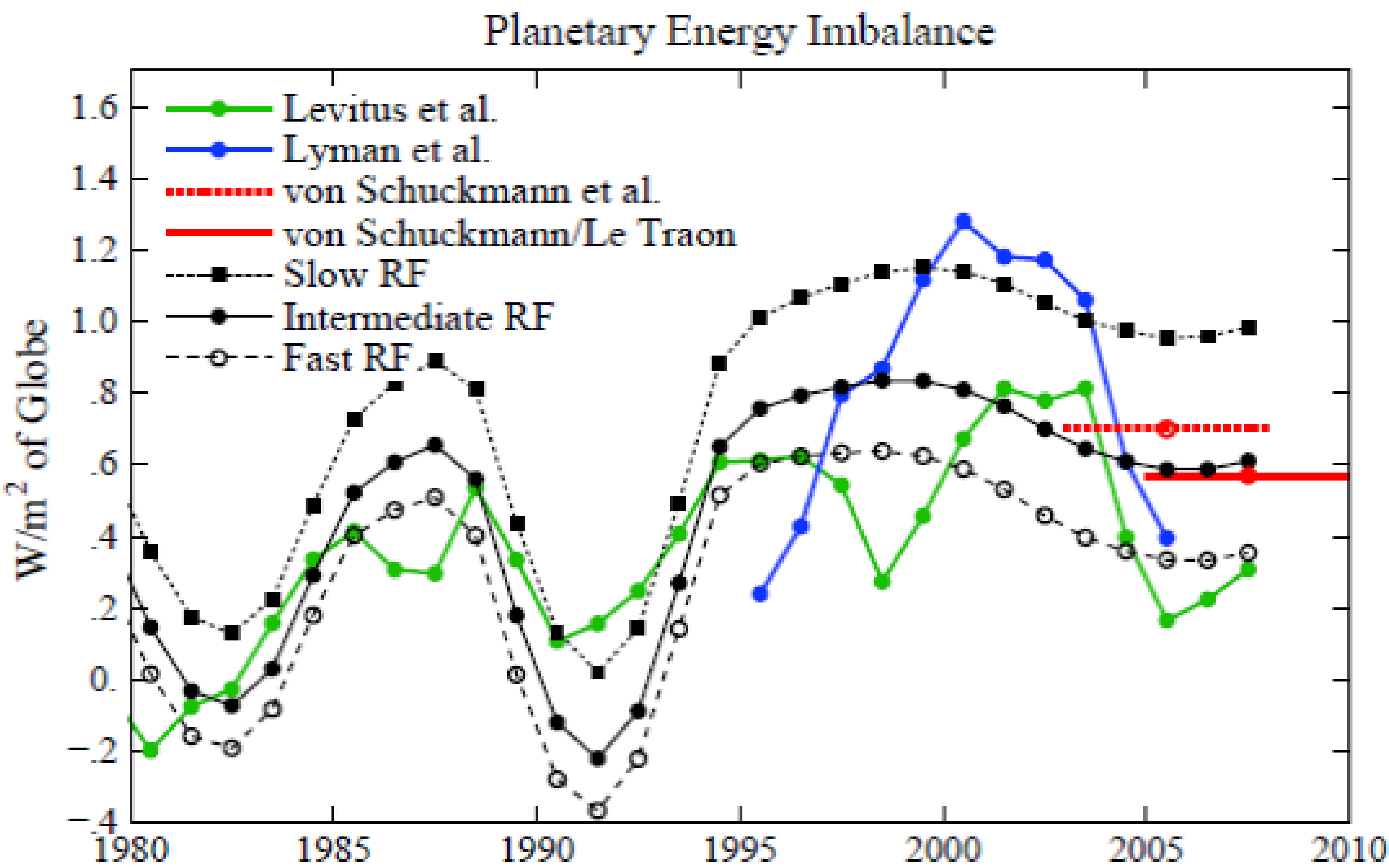
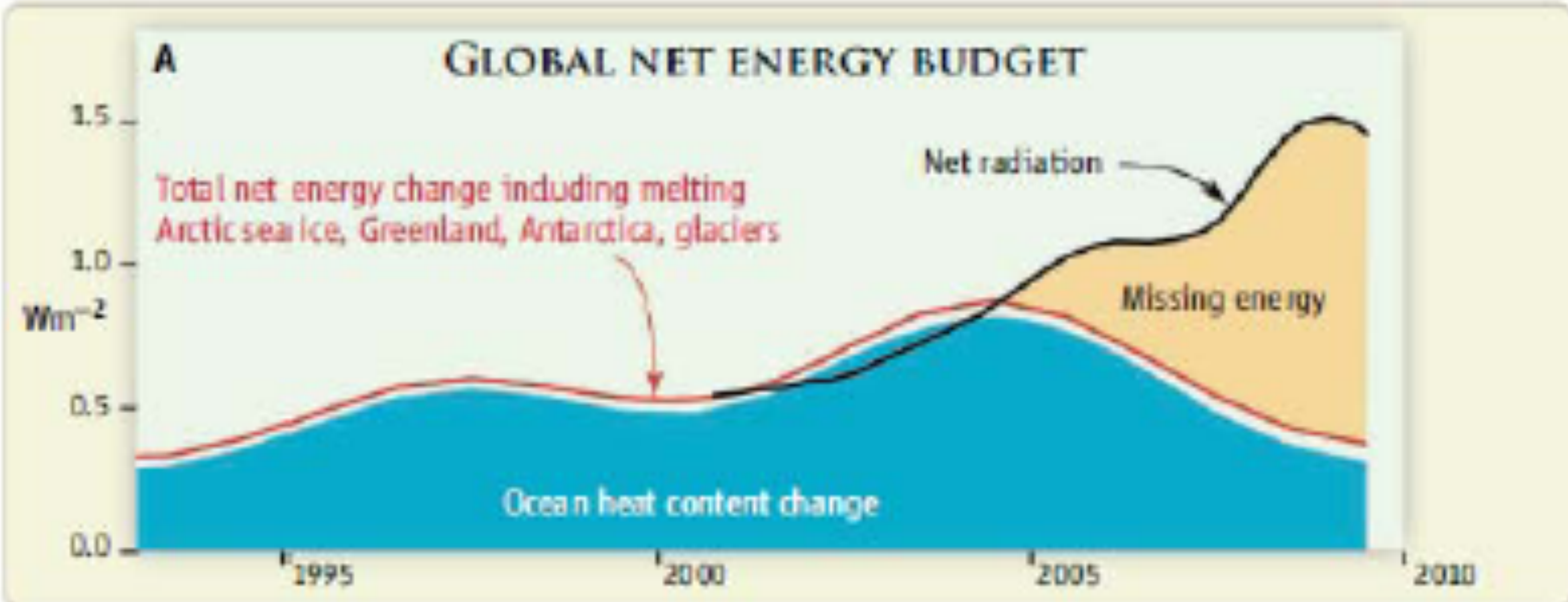
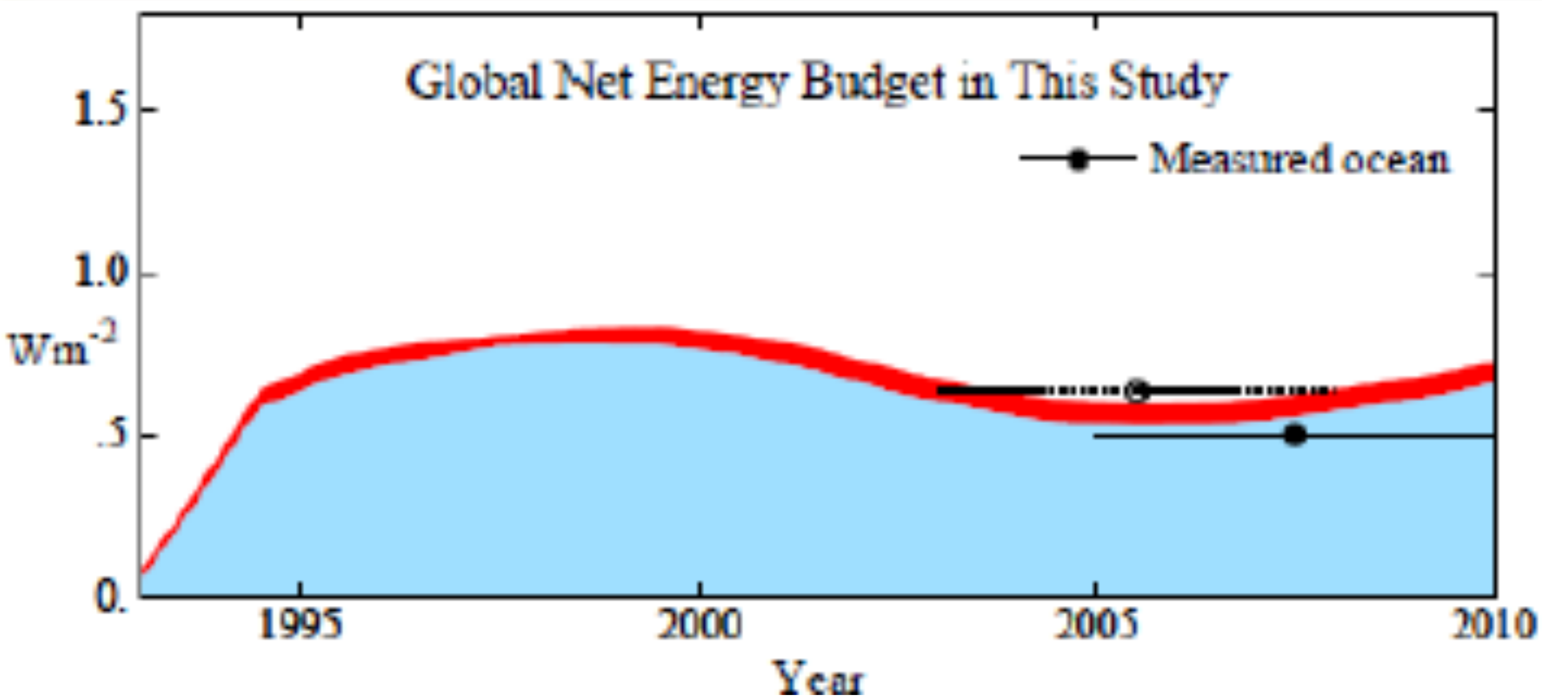


Fig. 1. Climate forcings employed in this paper. Forcings through 2003 (vertical line) are the same as used by Hansen et al. (2007), except the aerosol forcing after 1990 is approximated as -0.5 times the GHG forcing. Aerosol forcing includes all aerosol effects, including indirect effects on clouds and snow albedo. GHGs include O_3 and stratospheric H_2O, in addition to well-mixed GHGs.


Planetary Energy Imbalance
Levitus et al.
Lyman et al.
von Schuckmann et al.
von Schuckmann/Le Traon
Slow RF
Intermediate RF
Fast RF
W/m2 of Globe
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0.
−.2
−.4
1980
1985
1990
1995
2000
2005
2010


A
GLOBAL NET ENERGY BUDGET
1.5
1.0
0.5
0.0
Wm^{-2}
Total net energy change including melting
Arctic sea ice, Greenland, Antarctica, glaciers
Net radiation
Missing energy
Ocean heat content change
1995
2000
2005
2010


Global Net Energy Budget in This Study
Measured ocean
1.5
1.0
.5
0.
Wm^{-2}
1995
2000
2005
2010
Year