ENERGY TODAY – CO_2 TOMORROW

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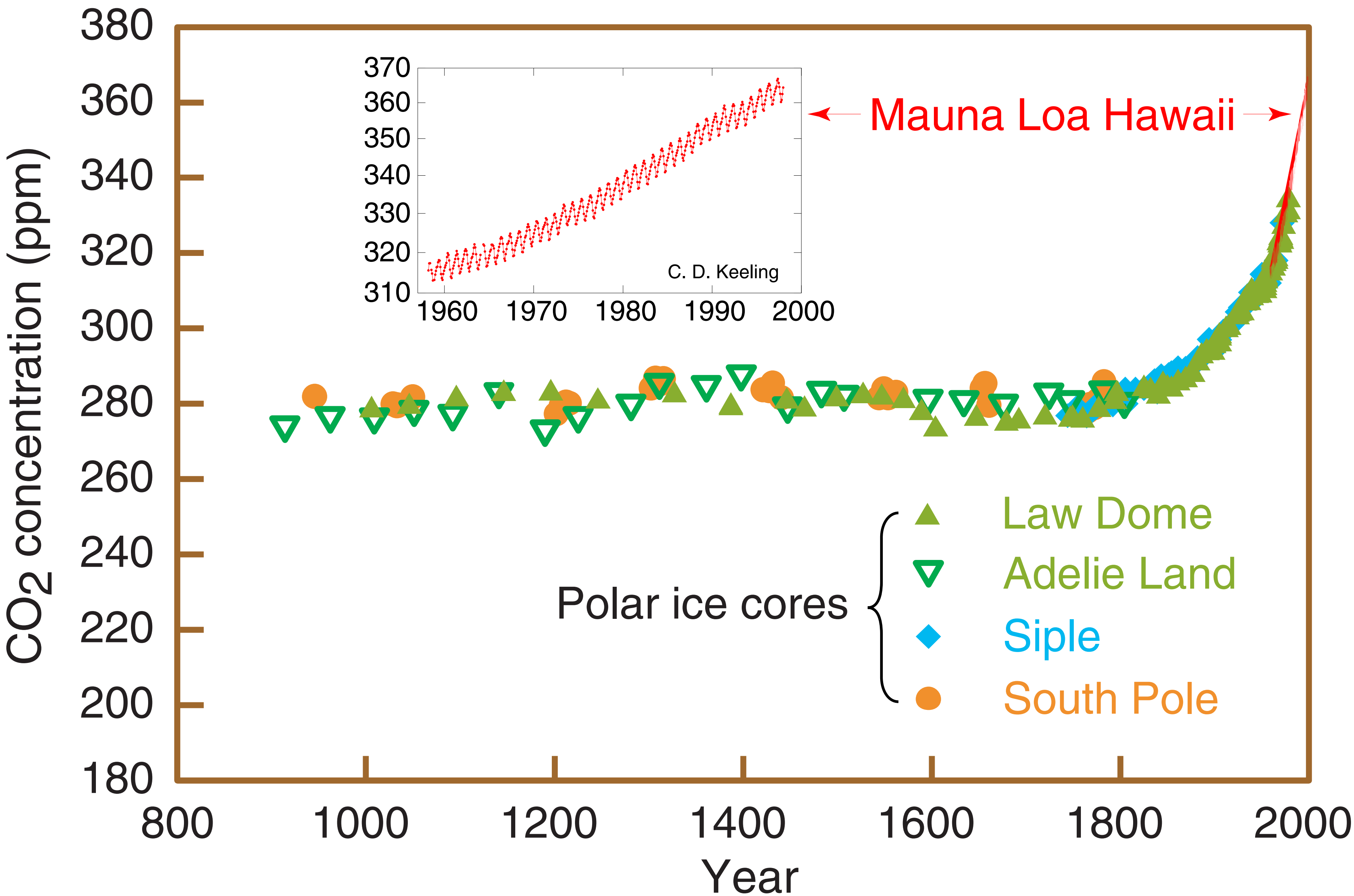
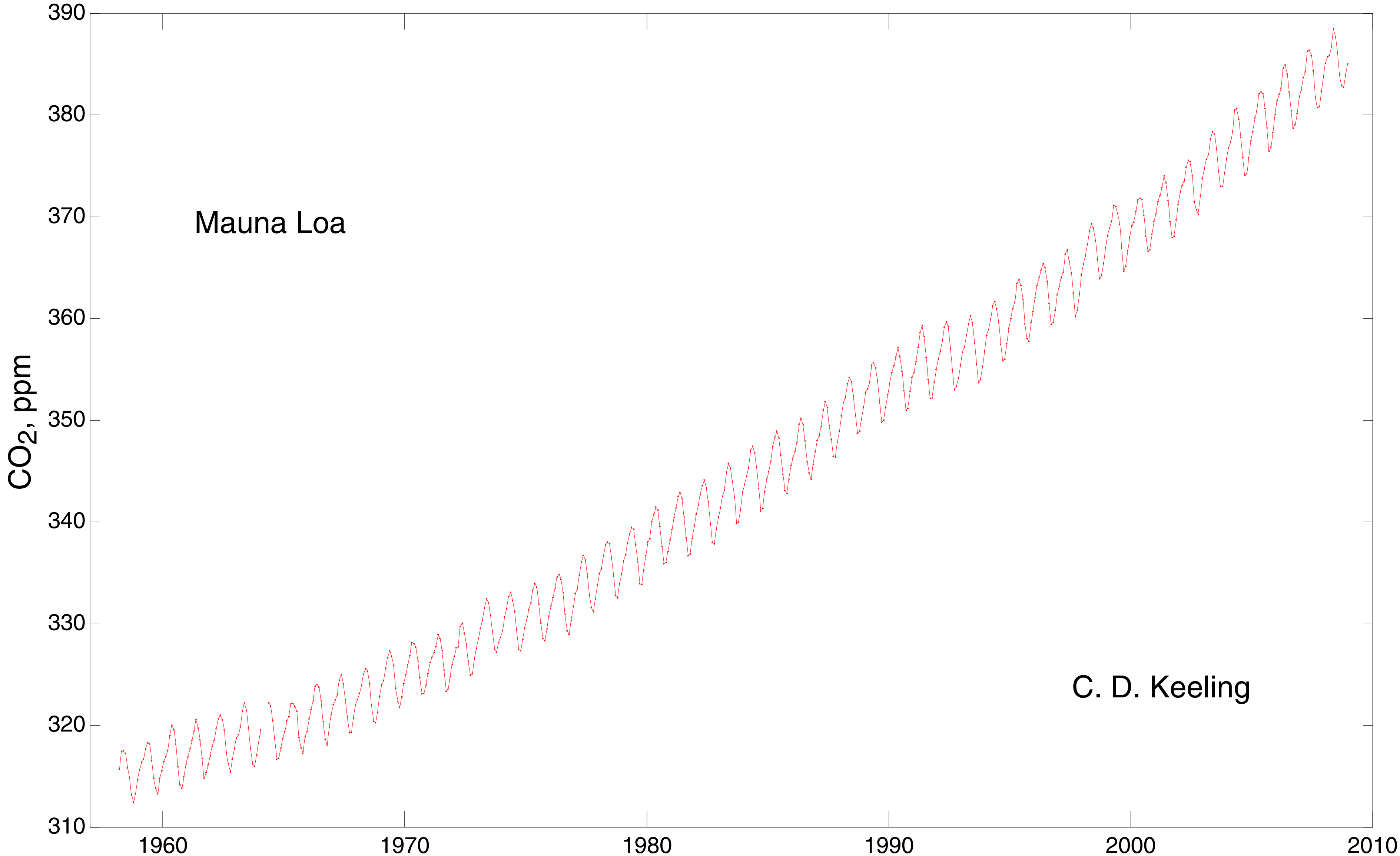
ATMOSPHERIC CARBON DIOXIDE IS INCREASING



Global carbon dioxide concentration
over the last thousand years

INCREASE IN ATMOSPHERIC CO_2

Measurements at Mauna Loa Hawaii, representative of Northern Hemisphere



Annual fluctuation due to uptake and release of CO_2 by terrestrial vegetation.

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From Forcing by Long-lived Greenhouse Gases

Why Hasn't Earth Warmed as Much as Expected?

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ABSTRACT

The observed increase in global mean surface temperature (GMST) over the industrial era is less than 40% of that expected from observed increases in long-lived greenhouse gases together with the best-estimate equilibrium climate sensitivity given by the 2007 Assessment Report of the Intergovernmental Panel on Climate Change. Possible reasons for this warming discrepancy are systematically examined here. The warming discrepancy is found to be due mainly to some combination of two factors: the IPCC best estimate of climate sensitivity being too high and/or the greenhouse gas forcing being partially offset by forcing by increased concentrations of atmospheric aerosols; the increase in global heat content due to thermal disequilibrium accounts for less than 25% of the discrepancy, and cooling by natural temperature variation can account for only about 15%. Current uncertainty in climate sensitivity is shown to preclude determining the amount of future fossil fuel CO_2 emissions that would be compatible with any chosen maximum allowable increase in GMST; even the sign of such allowable future emissions is unconstrained. Resolving this situation, by empirical determination of Earth's climate sensitivity from the historical record over the industrial period or through use of climate models whose accuracy is evaluated by their performance over this period is shown to require substantial reduction in the uncertainty of aerosol forcing over this period.

TABLE 1. Allowable future equivalent CO_2 emission* for increase in GMST above its preindustrial value not to exceed $\Delta T_{max} = 2$ K.

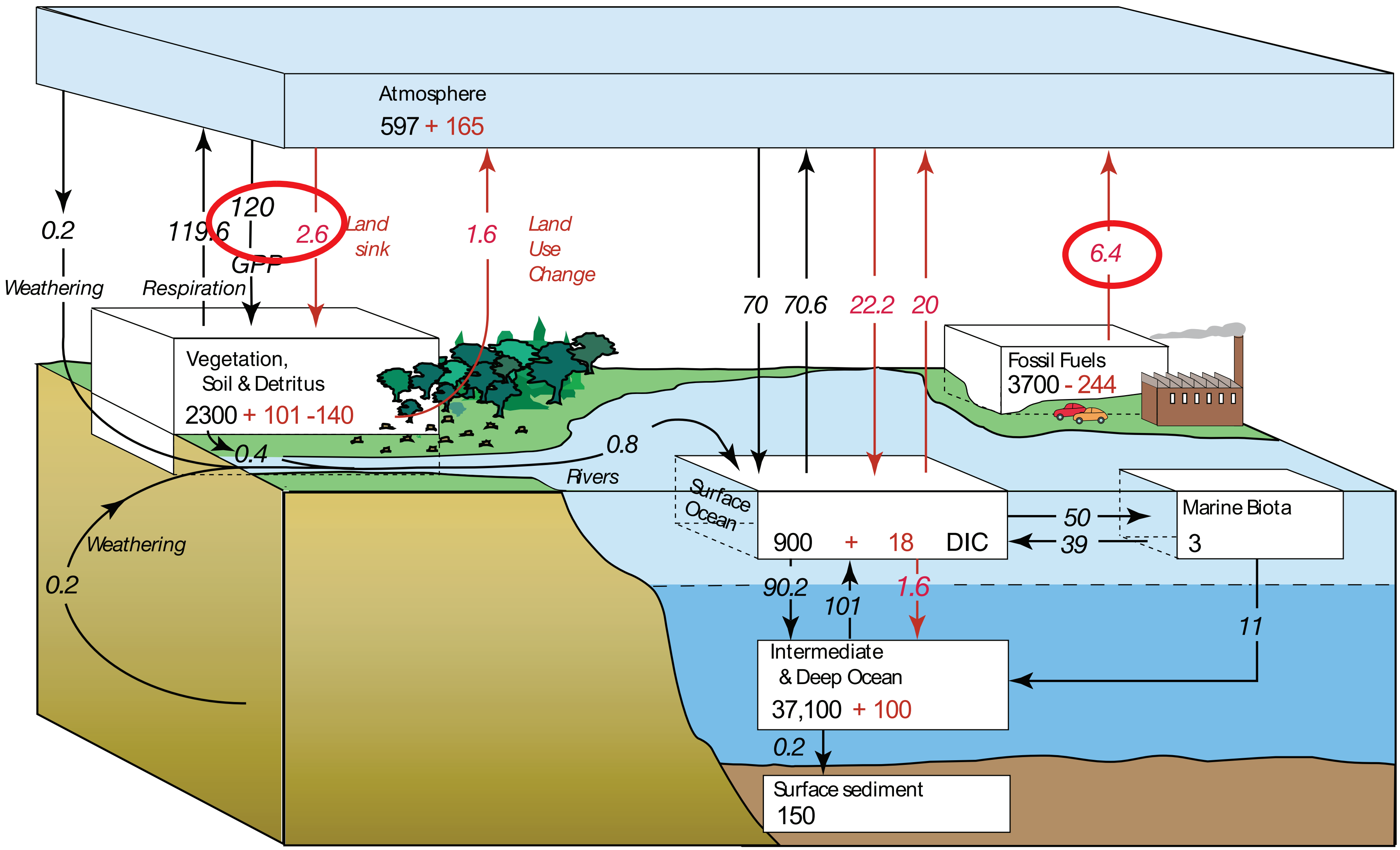
Quantity	Symbol	Unit	Value			
CO_2 doubling temperature at equilibrium	$\Delta T_{2\times}$	K	1.5	2	3	4.5
Equilibrium climate sensitivity	S	K (W m^{-2})$^{-1}$	0.40	0.54	0.81	1.21
Cumulative probability that actual doubling temperature $> \Delta T_{2\times}$	$P(\Delta T_{2\times})$	%	5	17	~50	83
Expected current equilibrium increase in GMST for indicated doubling temperature	ΔT_c	K	1.1	1.4	2.1	3.2
Allowable future increase in GMST	ΔT_a	K	0.9	0.6	−0.1	−1.2
Allowable future increase in CO_2 mixing ratio	Δm_{CO_2}	ppm	164	76	−12	−70
Target CO_2 mixing ratio	m_{CO_2}	ppm	544	456	368	310
Allowable cumulative future CO_2 emission	E_{CO_2}	Pg C	697	323	−50	−299
Time at present CO_2 emission rate to reach Δm_{CO_2}	t_{CO_2}	yr	77	36	−6	−33

* The allowable incremental mixing ratio of equivalent atmospheric CO_2 above present that is compatible with a target maximum temperature increase above preindustrial temperature ΔT_{max}, taken here as 2 K, is evaluated as $\Delta m_{CO_2} = (\Delta T_{max} - \Delta T_c)/Sf = \Delta T_{max}/Sf - F_c/f$ where ΔT_c is the equilibrium increase in GMST that would be expected from incremental long-lived gases above preindustrial in the current atmosphere, and $F_c = 2.6$ W m^{-2} is the corresponding forcing; S, the equilibrium climate sensitivity in units of K/(W m^{-2}), is related to CO_2 doubling temperature at equilibrium $\Delta T_{2\times}$ as $S = \Delta T_{2\times}/F_{2\times}$ where $F_{2\times} = 3.7$ W m^{-2} is the forcing for doubled CO_2; and $f = 0.0141$ W m^{-2} ppm^{-1} is the specific forcing, i.e., the forcing per incremental ppm of CO_2, evaluated as $f \equiv F/\Delta m_{CO_2} \approx F_{2\times}/(m_c \ln 2)$ where m_c is the current atmospheric CO_2 mixing ratio, 380 ppm. The corresponding allowable cumulative future emissions of long-lived greenhouse gases, expressed as equivalent CO_2, is evaluated as $E_{CO_2} = \Delta m_{CO_2}/cr$ where c is a conversion factor between CO_2 emission and atmospheric mixing ratio, 0.47 ppm/Pg C, and r is the fraction of emitted CO_2 that remains in the atmosphere, taken here as 0.5. The time remaining until the cumulative allowable amount of additional CO_2 would be reached at the present rate of emission of CO_2 from fossil fuel combustion and cement production $q \approx 9$ Pg C yr^{-1} (Raupach et al. 2007) is evaluated as $t_{CO_2} = E_{CO_2}/q$; a negative value indicates that the present atmospheric CO_2 mixing ratio 380 ppm exceeds the allowable value by an amount that corresponds to the indicated number of years at the present emission rate. Calculations are presented for $\Delta T_{2\times} = 3$ K, the best estimate for this quantity given by the Solomon et al. 2007 Assessment Report, and for $\Delta T_{2\times} = 1.5$, 2, and 4.5 K., corresponding to cumulative probability for this quantity given in that report $P(\Delta T_{2\times}) = 5$, 17, and 83%. The calculation neglects cooling due to forcing by aerosols and warming due to forcing by ozone, as discussed in text. 1 Pg = 1 gigatonne = 10^{15} g.

THE GLOBAL CARBON CYCLE

Preindustrial and anthropogenic perturbation (1990's)

Stocks in upright type, Pg C; *flows in italic type,* Pg C yr^{-1}



IPCC AR4, Chapter 7 (2007); after Sarmiento and Gruber (2002)

Net annual change in atmospheric carbon is difference of large fluxes.

Terrestrial Gross Carbon Dioxide Uptake: Global Distribution and Covariation with Climate

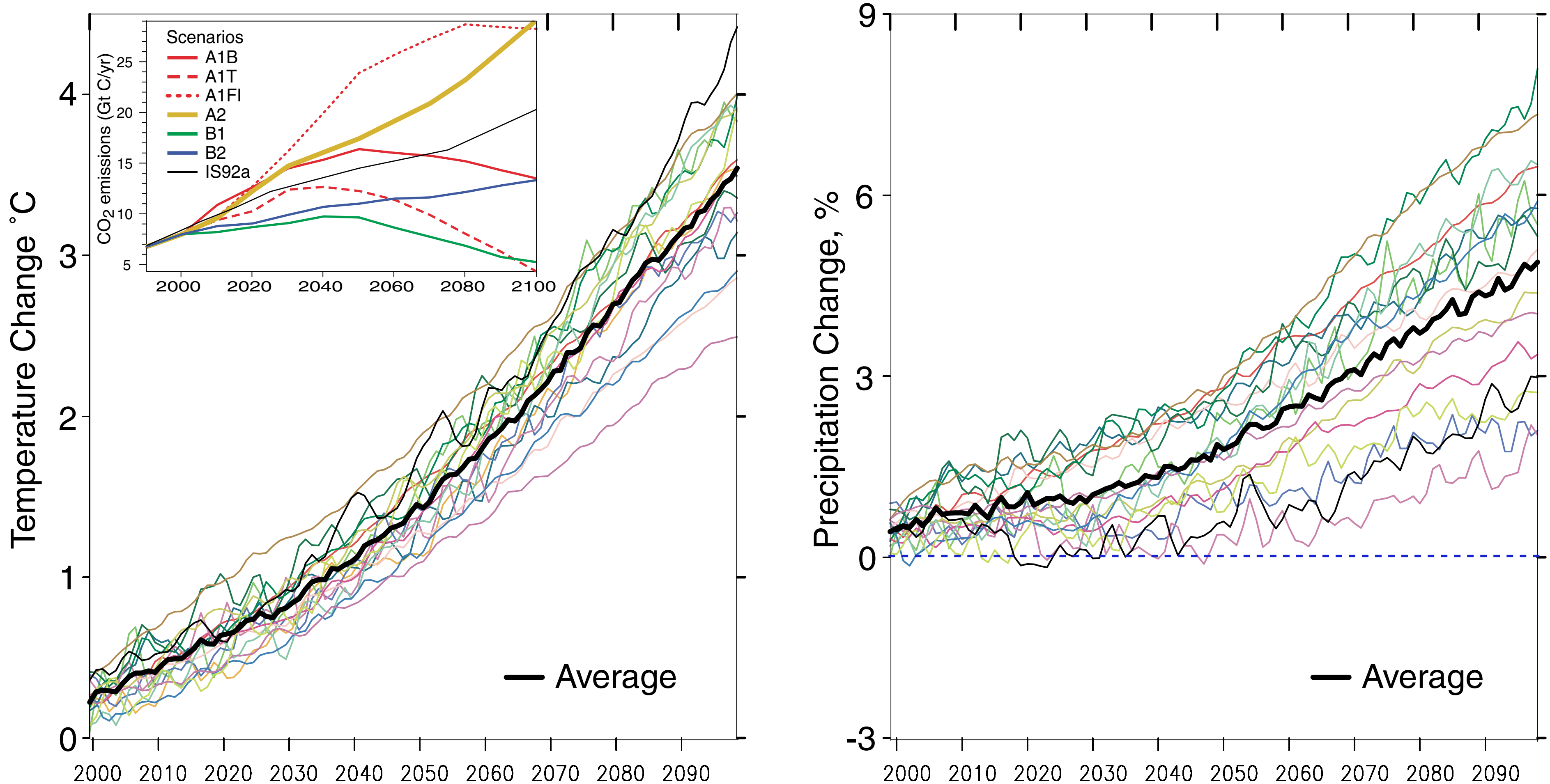
Christian Beer,[1*] Markus Reichstein,[1] Enrico Tomelleri,[1] Philippe Ciais,[2] Martin Jung,[1] Nuno Carvalhais,[1,3] Christian Rödenbeck,[4] M. Altaf Arain,[5] Dennis Baldocchi,[6] Gordon B. Bonan,[7] Alberte Bondeau,[8] Alessandro Cescatti,[9] Gitta Lasslop,[1] Anders Lindroth,[10] Mark Lomas,[11] Sebastiaan Luyssaert,[12] Hank Margolis,[13] Keith W. Oleson,[7] Olivier Roupsard,[14,15] Elmar Veenendaal,[16] Nicolas Viovy,[2] Christopher Williams,[17] F. Ian Woodward,[11] Dario Papale[18]

Terrestrial gross primary production (GPP) is the largest global CO_2 flux driving several ecosystem functions. We provide an observation-based estimate of this flux at 123 ± 8 petagrams of carbon per year (Pg C year^{-1}) using eddy covariance flux data and various diagnostic models. Tropical forests and savannahs account for 60%. GPP over 40% of the vegetated land is associated with precipitation. State-of-the-art process-oriented biosphere models used for climate predictions exhibit a large between-model variation of GPP's latitudinal patterns and show higher spatial correlations between GPP and precipitation, suggesting the existence of missing processes or feedback mechanisms which attenuate the vegetation response to climate. Our estimates of spatially distributed GPP and its covariation with climate can help improve coupled climate–carbon cycle process models.

Science, 2010

TWENTY-FIRST CENTURY CLIMATE CHANGE

Change in ***global*** temperature and precipitation for A2 emission scenario, relative to 1980-1999, calculated with 16 GCMs



IPCC, 2007

Models agree that ***global temperature and precipitation increase with increasing*** $\boldsymbol{CO_2}$.

Projected increases exhibit ***large inter-model variation***.