ENERGY TODAY – CO₂ TOMORROW

Stephen E. Schwartz

Upton, Long Island, NY

New York University
Graduate School of Journalism
Science Health Environmental Reporting Program

www.ecd.bnl.gov/steve
ATMOSPHERIC CARBON DIOXIDE IS INCREASING

Global carbon dioxide concentration over the last thousand years

Polar ice cores

- Law Dome
- Adelie Land
- Siple
- South Pole

Mauna Loa Hawaii
INCREASE IN ATMOSPHERIC CO₂
Measurements at Mauna Loa Hawaii, representative of Northern Hemisphere

Annual fluctuation due to uptake and release of CO₂ by terrestrial vegetation.
From Forcing by Long-lived Greenhouse Gases

Why Hasn’t Earth Warmed as Much as Expected?

STEPHEN E. SCHWARTZ  
Brookhaven National Laboratory, Upton, New York

ROBERT J. CHARLSON  
University of Washington, Seattle, Washington

RALPH A. KAHN  
NASA Goddard Space Flight Center, Greenbelt, Maryland

JOHN A. OGREN  
NOAA/Earth System Research Laboratory, Boulder, Colorado

HENNING RODHE  
Department of Meteorology, Stockholm University, Stockholm, Sweden
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>
<thead>
<tr>
<th>Quantity</th>
<th>Symbol</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ doubling temperature at equilibrium</td>
<td>ΔT₂x</td>
<td>K</td>
<td>1.5</td>
</tr>
<tr>
<td>Equilibrium climate sensitivity</td>
<td>S</td>
<td>K (W m⁻²⁻¹</td>
<td>0.40</td>
</tr>
<tr>
<td>Cumulative probability that actual doubling</td>
<td></td>
<td>%</td>
<td>5</td>
</tr>
<tr>
<td>temperature &gt; ΔT₂x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expected current equilibrium increase in GMST</td>
<td>ΔTc</td>
<td>K</td>
<td>1.1</td>
</tr>
<tr>
<td>for indicated doubling temperature</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Allowable future increase in GMST</td>
<td>ΔTa</td>
<td>K</td>
<td>0.9</td>
</tr>
<tr>
<td>Allowable future increase in CO₂ mixing ratio</td>
<td>Δm₂x</td>
<td>ppm</td>
<td>164</td>
</tr>
<tr>
<td>Target CO₂ mixing ratio</td>
<td>m₂x</td>
<td>ppm</td>
<td>544</td>
</tr>
<tr>
<td>Allowable cumulative future CO₂ emission</td>
<td>Ec₂x</td>
<td>Pg C</td>
<td>697</td>
</tr>
<tr>
<td>Time at present CO₂ emission rate to reach Δm₂x</td>
<td>t₂x</td>
<td>yr</td>
<td>77</td>
</tr>
</tbody>
</table>

* The allowable incremental mixing ratio of equivalent atmospheric CO₂ above preindustrial is compatible with a target maximum temperature increase (ΔT₂x) taken here as 2 K, is evaluated as Δm₂x = (ΔT₂x - ΔTc)/S where ΔTc is the equilibrium increase in GMST that would be expected from the radiative properties of the atmosphere, and Fc in W m⁻² is the corresponding forcing; S, the equilibrium climate sensitivity in units of K W m⁻², is related to CO₂ doubling temperature at equilibrium ΔT₂x as S = ΔT₂x/Fc where Fc in W m⁻² is the forcing for doubled CO₂; and S = 0.141 W m⁻² is the specific forcing, i.e., the forcing per incremental ppm of CO₂, evaluated as F = f Δm₂x ≈ F₂x/mₐ ln2 where mₐ is the current atmospheric CO₂ mixing ratio, 380 ppm. The corresponding allowable cumulative future emissions of long-lived greenhouse gases, expressed as equivalent CO₂, is evaluated as E₂x = Δm₂x/cr where c is a conversion factor between CO₂ and other greenhouse gases. The values in the table are for ΔT₂x = 3 K, the best estimate for this quantity given by the Solomon et al. 2007 Assessment Report, and for ΔT₂x = 1.5, 2, and 4.5 K., corresponding to cumulative probability for this quantity given in the report P(ΔT₂x) = 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 = 10¹⁵ 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

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 G 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 Papale18

Terrestrial gross primary production (GPP) is the largest global CO₂ 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
Models agree that **global temperature and precipitation increase with increasing CO₂**. Projected increases exhibit **large inter-model variation**.