

# Climate and the Oceans: Global Warming and the Ocean

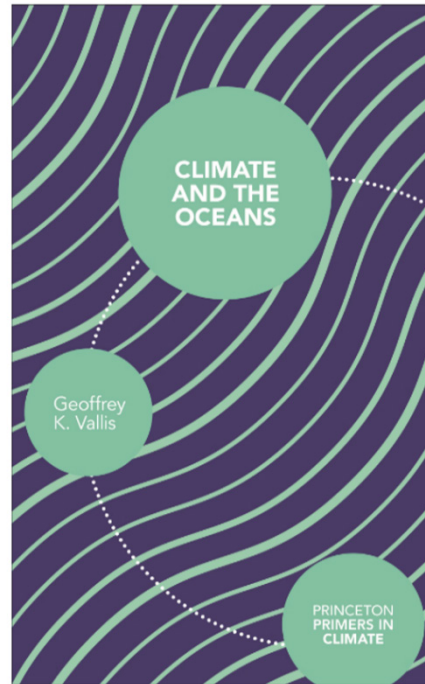
AOSC 680

Ross Salawitch

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**Lecture 19**

**10 November 2022**

## Irreversible climate change due to carbon dioxide emissions

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Contributed by Susan Solomon, December 16, 2008 (sent for review November 12, 2008)

The severity of damaging human-induced climate change depends not only on the magnitude of the change but also on the potential for irreversibility. This paper shows that the climate change that takes place due to increases in carbon dioxide concentration is largely irreversible for 1,000 years after emissions stop. Following cessation of emissions, removal of atmospheric carbon dioxide decreases radiative forcing, but is largely compensated by slower loss of heat to the ocean, so that atmospheric temperatures do not drop significantly for at least 1,000 years. Among illustrative irreversible impacts that should be expected if atmospheric carbon dioxide concentrations increase from current levels near 385 parts per million by volume (ppmv) to a peak of 450–600 ppmv over the coming century are irreversible dry-season rainfall reductions in several regions comparable to those of the “dust bowl” era and inexorable sea level rise. Thermal expansion of the warming ocean provides a conservative lower limit to irreversible global average sea level rise of at least 0.4–1.0 m if 21st century CO<sub>2</sub> concentrations exceed 600 ppmv and 0.6–1.9 m for peak CO<sub>2</sub> concentrations exceeding  $\approx 1,000$  ppmv. Additional contributions from glaciers and ice sheet contributions to future sea level rise are uncertain but may equal or exceed several meters over the next millennium or longer.

Solomon et al., PNAS, 2009: <https://www.pnas.org/doi/epdf/10.1073/pnas.0812721106>

# Committed Warming

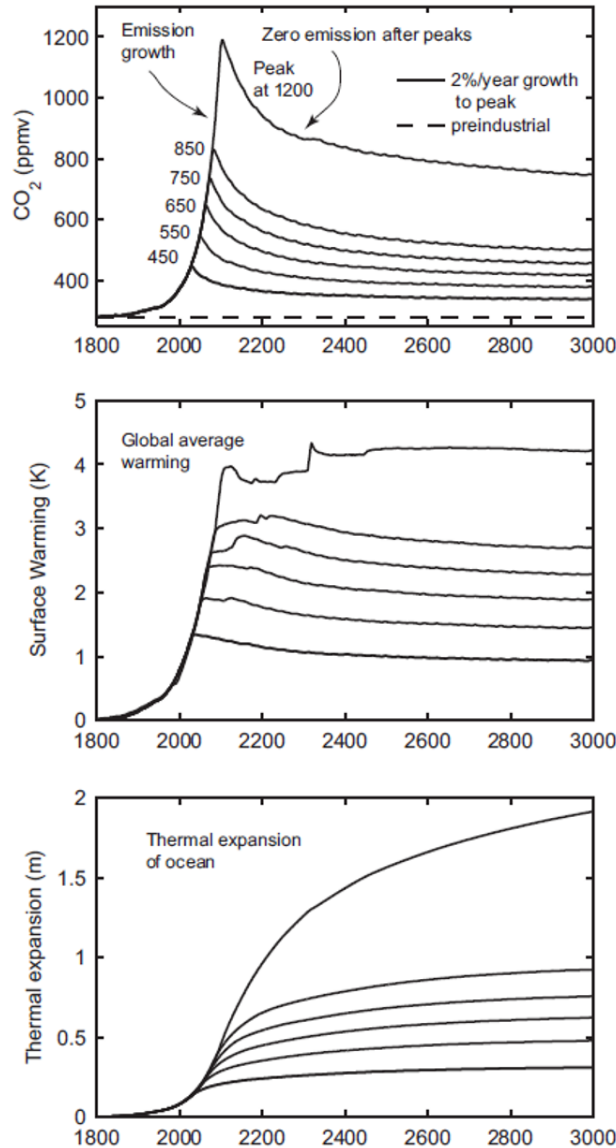
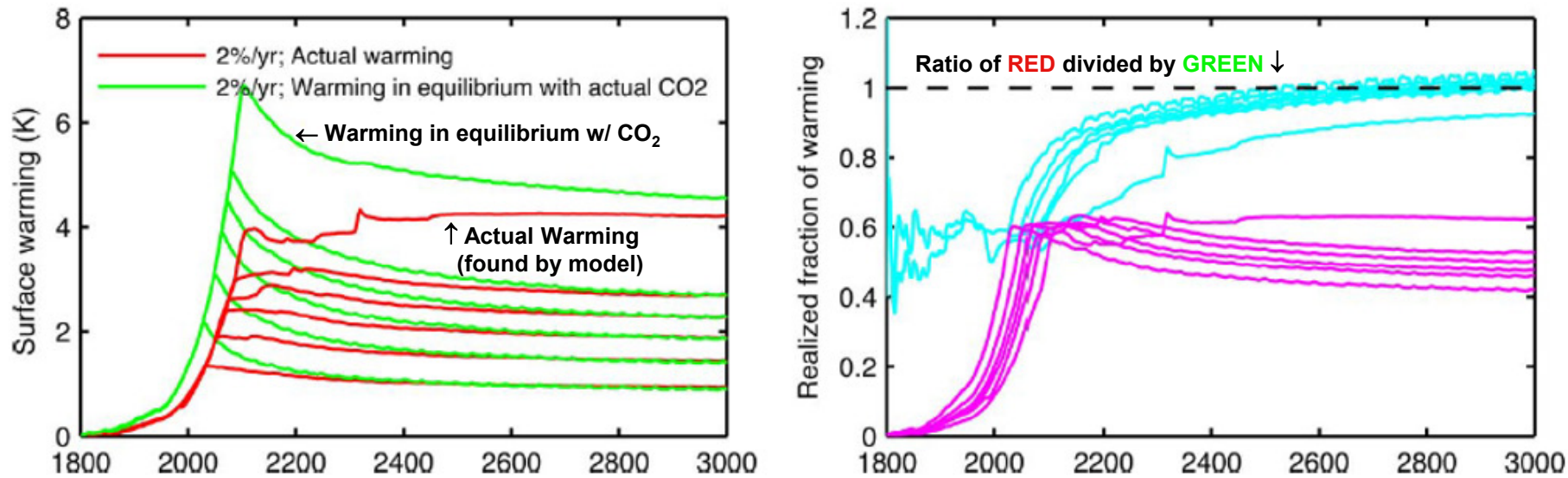


Fig. 1. Carbon dioxide and global mean climate system changes (relative to preindustrial conditions in 1765) from 1 illustrative model, the Bern 2.5CC EMIC, whose results are comparable to the suite of assessed EMICs (5, 7). Climate system responses are shown for a ramp of CO<sub>2</sub> emissions at a rate of 2%/year to peak CO<sub>2</sub> values of 450, 550, 650, 750, 850, and 1200 ppmv, followed by zero emissions. The rate of global fossil fuel CO<sub>2</sub> emission grew at  $\approx 1\%/year$  from 1980 to 2000 and  $>3\%/year$  in the period from 2000 to 2005 (13). Results have been smoothed using an 11-year running mean. The 31-year variation seen in the carbon dioxide time series is introduced by the climatology used to force the terrestrial biosphere model (15). (Top) Falloff of CO<sub>2</sub> concentrations following zero emissions after the peak. (Middle) Globally averaged surface warming (degrees Celsius) for these cases (note that this model has an equilibrium climate sensitivity of 3.2 °C for carbon dioxide doubling). Warming over land is expected to be larger than these global averaged values, with the greatest warming expected in the Arctic (5). (Bottom) Sea level rise (meters) from thermal expansion only (not including loss of glaciers, ice caps, or ice sheets).

Solomon et al., PNAS, 2009: <https://www.pnas.org/doi/epdf/10.1073/pnas.0812721106>



# Committed Warming

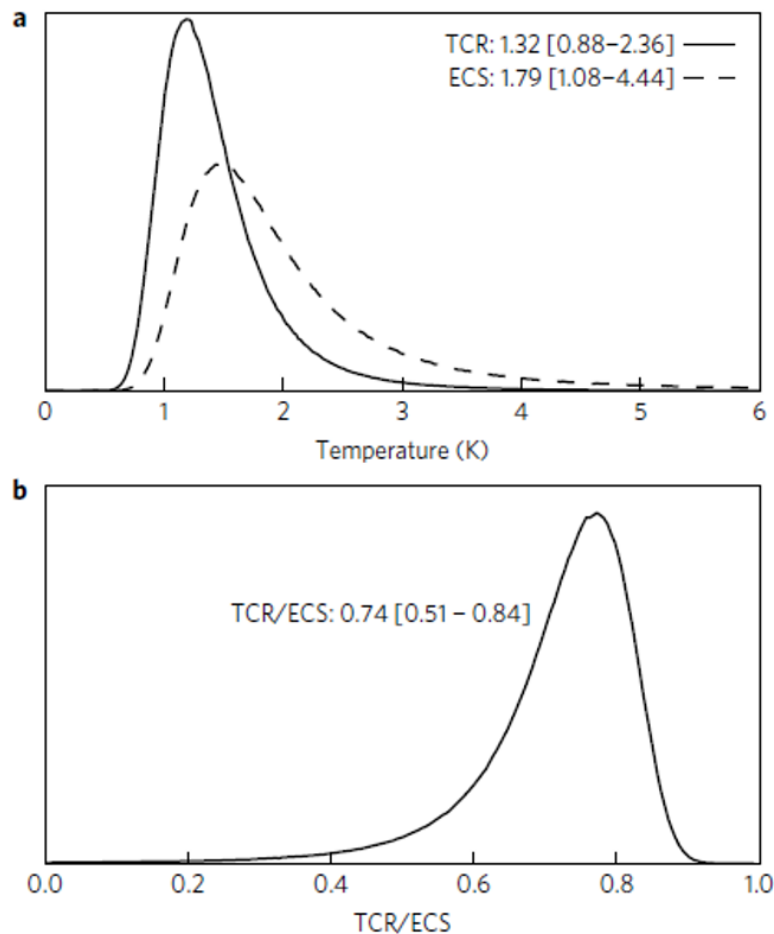


**Fig. 2.** Comparison between calculated time-dependent surface warming in the Bern2.5CC model and the values that would be expected if temperatures were in equilibrium with respect to the CO<sub>2</sub> enhancements, illustrative of 2%/year emission increases to 450, 550, 650, 750, 850, and 1,200 ppmv as in Fig. 1. (Left) The actual and equilibrium temperature changes (based upon the model's climate sensitivity at equilibrium). The cyan lines in *Right* show the ratio of actual and equilibrium temperatures (or realized fraction of the warming for the time-dependent CO<sub>2</sub> concentrations), while the magenta lines show the ratio of actual warming to the equilibrium temperature for the peak CO<sub>2</sub> concentration.

# Committed warming inferred from observations

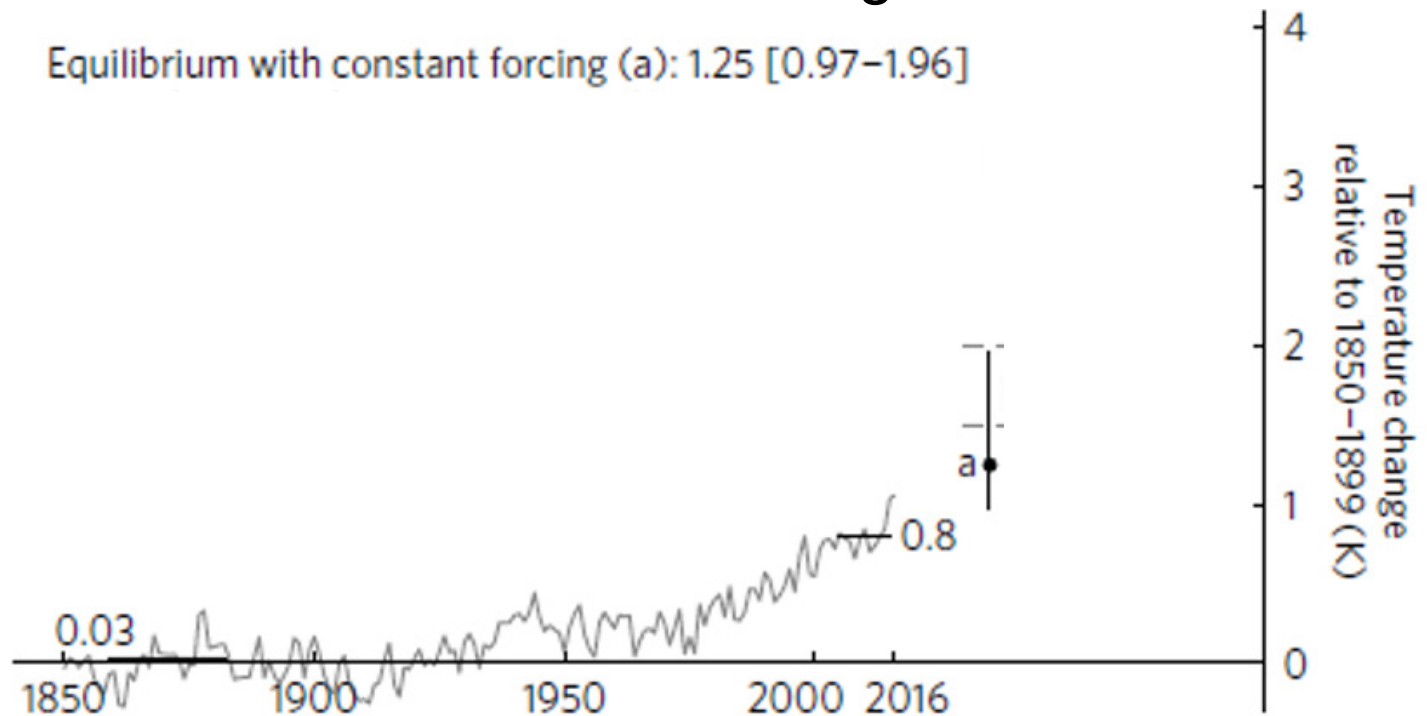
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Due to the lifetime of CO<sub>2</sub>, the thermal inertia of the oceans<sup>1,2</sup>, and the temporary impacts of short-lived aerosols<sup>3-5</sup> and reactive greenhouse gases<sup>6</sup>, the Earth's climate is not equilibrated with anthropogenic forcing. As a result, even if fossil-fuel emissions were to suddenly cease, some level of committed warming is expected due to past emissions as studied previously using climate models<sup>6-11</sup>. Here, we provide an observational-based quantification of this committed warming using the instrument record of global-mean warming<sup>12</sup>, recently improved estimates of Earth's energy imbalance<sup>13</sup>, and estimates of radiative forcing from the Fifth Assessment Report of the Intergovernmental Panel on Climate Change<sup>14</sup>. Compared with pre-industrial levels, we find a committed warming of 1.5 K (0.9–3.6, 5th–95th percentile) at equilibrium, and of 1.3 K (0.9–2.3) within this century. However, when assuming that ocean carbon uptake cancels remnant greenhouse gas-induced warming on centennial timescales, committed warming is reduced to 1.1 K (0.7–1.8). In the latter case there is a 13% risk that committed warming already exceeds the 1.5 K target set in Paris<sup>15</sup>. Regular updates of these observationally constrained committed warming estimates, although simplistic, can provide transparent guidance as uncertainty regarding transient climate sensitivity inevitably narrows<sup>16</sup> and the understanding of the limitations of the framework<sup>11,17-21</sup> is advanced.



**Figure 1 | Probabilities of transient climate response (TCR) and equilibrium climate sensitivity (ECS).** **a**, Probabilities of TCR (solid) and ECS (dashed) inferred on the basis of observed warming, estimates of historical radiative forcing and observations of present-day energy imbalance. **b**, The ratio of the quantities in **a**, which is roughly equivalent to the proportion of long-term warming realized on centennial timescales. Displayed numbers are the median and 5th–95th percentiles of each distribution.

# Committed Warming



**Figure 2** | Estimates of committed warming under five different sets of assumptions. Cases **a** (black) and **b** (red) are the equilibria with and without aerosol cooling, whereas case **c** (purple) includes the effect of removing short-lived climate forcers such as  $\text{CH}_4$ . Cases **d** (blue) and **e** (orange) are scaled with the transient climate response representative of warming within this century. Case **d** is otherwise equivalent to case **c**.

In case **e**, it is assumed that carbon uptake by the world's oceans continues on the centennial timescale.