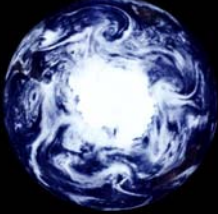



**"Target Atmospheric CO₂:
Where Should Humanity Aim?"**
by James Hansen, et al



Richard McGehee
Seminar on the Mathematics of
Climate Change
School of Mathematics
April 16, 2008

<http://photojournal.jpl.nasa.gov/jpeg/PIA00729.jpg>


Target CO₂
Where Should Humanity Aim?



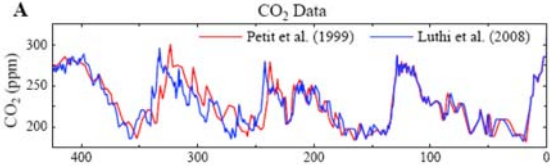
"If humanity wishes to preserve a planet similar to that on which civilization developed and to which life on Earth is adapted, paleoclimate evidence and ongoing climate change suggest that CO₂ will need to be reduced from its current 385 ppm to at most **350 ppm.**"

Hansen, et al, 2008, p. 1

Target CO₂
CO₂ During Glacial Cycles





A



Pre-industrial: 280 ppm
Current: 385 ppm
Hansen Target: 350 ppm

Hansen, et al, 2008, p. S18


Target CO₂
IPCC Predictions

Six different scenarios.
Most optimistic: hold CO₂ below 560 ppm during 21st century.

Global Climate Projections, IPCC AR4, p.803
http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Print_CH10.pdf

Target CO₂
Hansen 2007 Target




GISS (Goddard Institute for Space Studies) Atmospheric ModelE driven by **1880-2003** forcings and extended to 2100 IPCC scenarios produced "effects that may be highly disruptive."
Alternative scenario (keeping CO₂ below **450 ppm**) is not so bad.

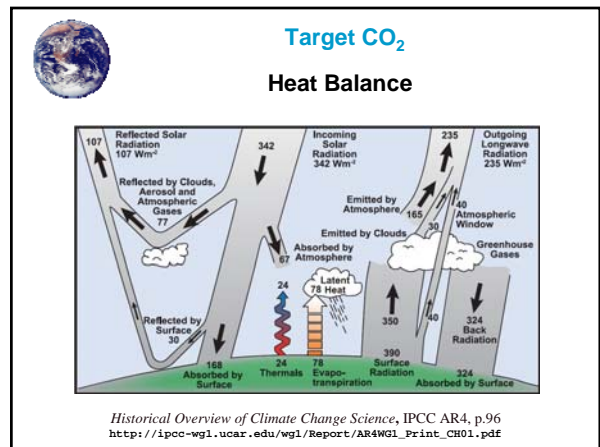
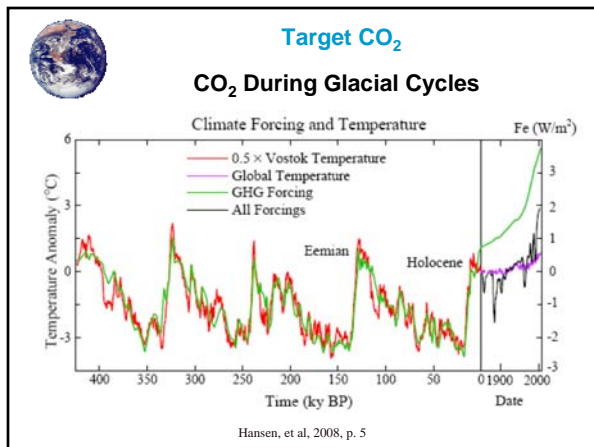
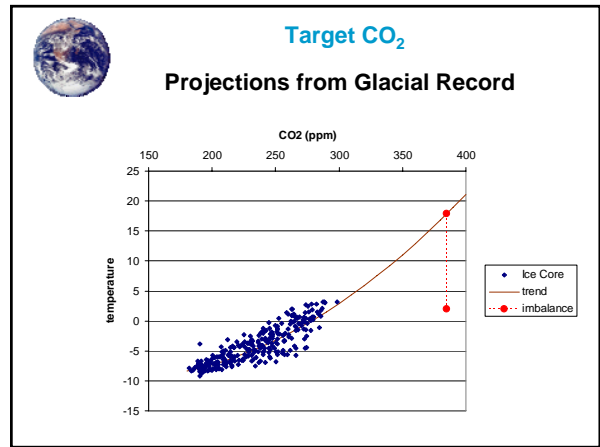
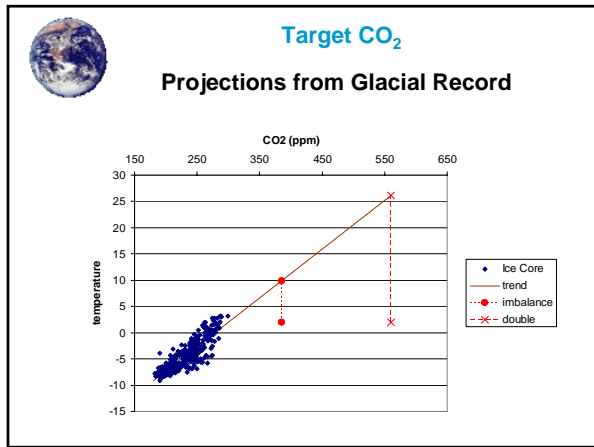
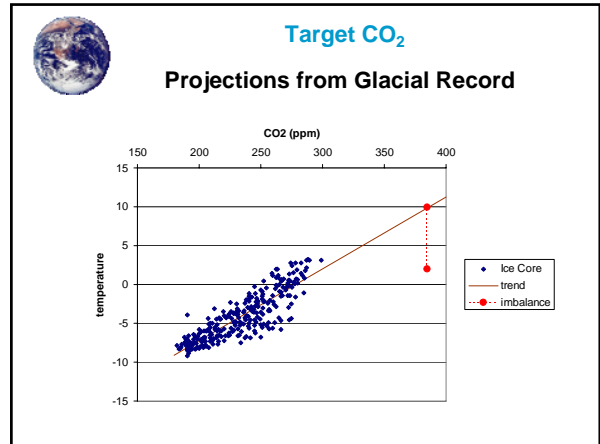
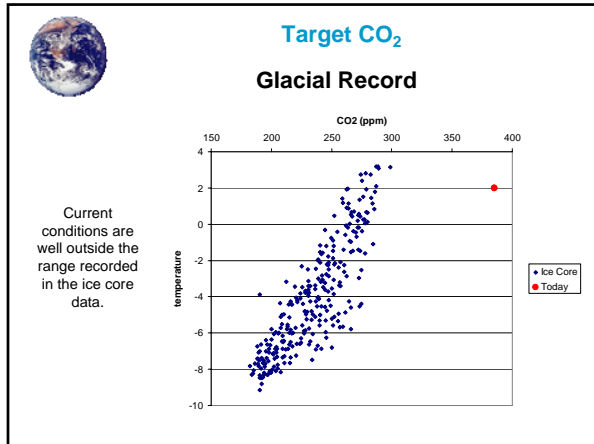
Hansen (2008): It is insufficient to look only at 1880-2003.


J. Hansen et al., *Atmos. Chem. Phys.* 7, 2287 (2007).

Target CO₂
What Data Are Relevant?



1880 – 2003 A.D.	Historical Record
400 Kyr – 0 Kyr bp	Glacial Record
40 Myr – 30 Myr bp	Ocean Sediment Record






Target CO₂

Energy Units

Average Insolation: 342 Watts per square meter
 Surface area of Earth: $5.1 \times 10^{14} \text{ m}^2$
 Total Insolation: $1.74 \times 10^{17} \text{ W}$
 (about 200,000,000 huge power plants)
 1 Watt year = 8.77 Kilowatt hours
 Yearly Total Insolation: $1.74 \times 10^{17} \text{ W yr}$
 Yearly Insolation: 342 W yr m^{-2}




Target CO₂

Heat Capacities

Assume *all* insolation goes toward warming.

Warm air 1°C:
 0.32 W yr m^{-2} or 8 hours
 Warm land surface 1°C:
 0.7 W yr m^{-2} or 18 hours
 Warm ocean 1°C to depth of 1 km
 93 W yr m^{-2} or 3.3 months
 Melt enough ice to raise sea level 1 m
 (assuming ice temperature -10°C and sea temperature 15°C)
 9.3 W yr m^{-2} or 10 days
 Melt all ice on Earth:
 650 W yr m^{-2} or 23 months

Hansen, et al, 2005, Table S1




Target CO₂

Heat Capacities

Assume global heat imbalance of 1 W m^{-2} .

Warm air 1°C:
 0.32 W yr m^{-2} or 3.8 months
 Warm land surface 1°C:
 0.7 W yr m^{-2} or 8.4 months
 Warm ocean 1°C to depth of 1 km
 93 W yr m^{-2} or 93 years
 Melt enough ice to raise sea level 1 m
 (assuming ice temperature -10°C and sea temperature 15°C)
 9.3 W yr m^{-2} or 9.3 years
 Melt all ice on Earth:
 650 W yr m^{-2} or 650 years

Hansen, et al, 2005, Table S1




Target CO₂

Heat Imbalance

Claim: During the glacial cycles, the average heat imbalance has been a fraction of 1 W m^{-2} .

Proof: A heat imbalance of 1 W m^{-2} would raise the sea level 100 meters in 930 years. But it took 10,000 years. The imbalance was more like 0.1 W m^{-2} .

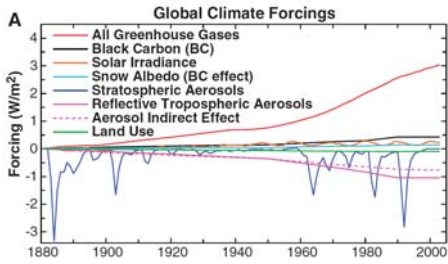
Hansen, et al, 2008, p. 2




Target CO₂

Heat Imbalance

The current heat imbalance is $0.85 \pm 0.15 \text{ W m}^{-2}$.

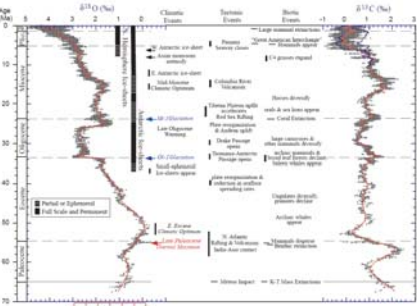


Hansen, et al, 2005, p. 1432

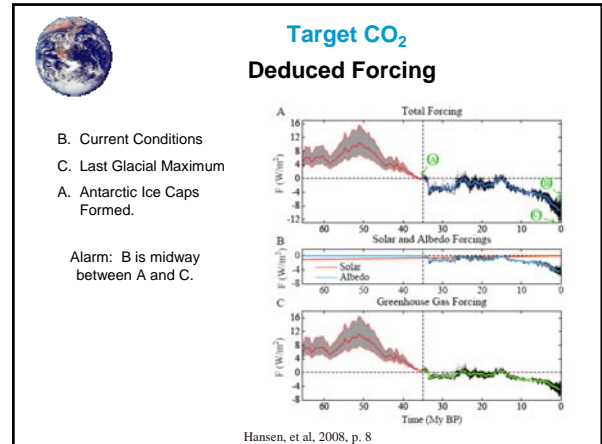
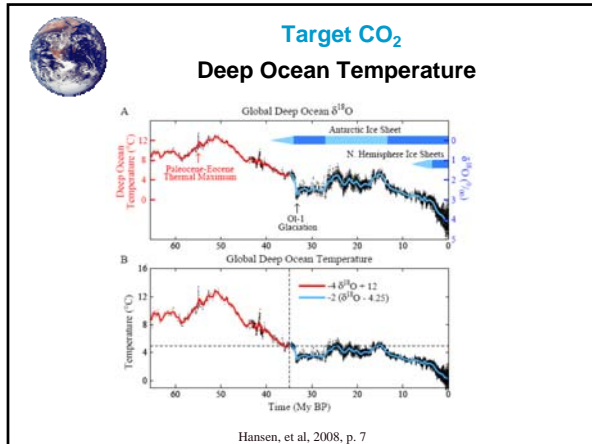


Milankovitch Cycles

Cenozoic Era



Zachos, et al, Science 292 (2001), p. 689



- ### Target CO₂ Claims
1. Pleistocene and Holocene (last 1.8 Myr) cycles are driven by Milankovitch with CO₂ and albedo feedbacks.
 2. Paleocene and Eocene (35-65 Myr bp) climate was driven by higher levels of atmospheric CO₂ caused by plate tectonics.
 3. Antarctic ice caps formed (OI-1 glaciation) at the Eocene – Oligocene boundary (35 Myr bp) when CO₂ levels fell to 425 ± 75 ppm, again caused by plate tectonics.
 4. The current level of 385 ppm is within the error bounds of estimates at the OI-1 boundary.
- Hansen, et al, 2008

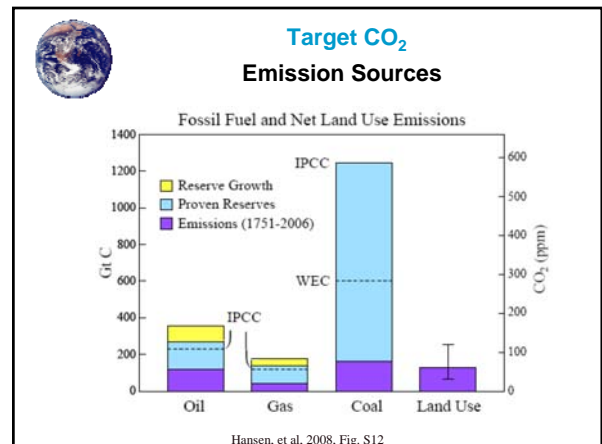
- ### Target CO₂ Claims
5. Although the current forcing is only 0.85 W m⁻² above preindustrial levels, the albedo feedbacks have not fully developed yet.
 6. Taking feedbacks into account, a CO₂ change from 180 to 285 ppm (glacial cycles) corresponds to 2.6 W m⁻², while a further change from 285 to 450 ppm corresponds to an additional 2.7 W m⁻², which is the estimated forcing at the OI-1 glaciation (35 Myr bp) and during the intermittent Antarctic glaciations (15 – 25 Myr bp).
 7. A sustained CO₂ level of 450 ppm could lead to an ice-free Earth.
- Hansen, et al, 2008, p. 9

Target CO₂ Conclusion

Let's be safe and keep the level CO₂ level below 350 ppm.

How?

Hansen, et al, 2008





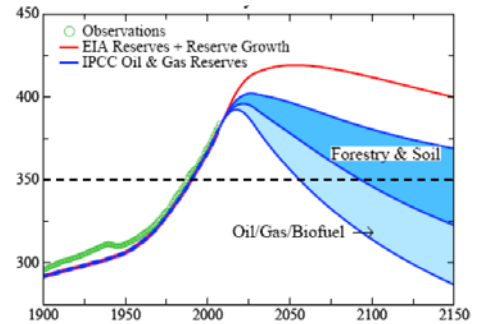
Target CO₂ Proposal

1. Phase out all coal use by 2030. (or use coal only with carbon capture and sequestration (CCS))
2. Change land use practices to return carbon to soils. (reforestation, "biochar")
3. Biofuels with CCS.

Hansen, et al, 2008



Target CO₂ Proposal



Hansen, et al, 2008, Fig. 6



Target CO₂ References

1. James Hansen, Makiko Sato, Pushker Kharecha, David Beerling, Valerie Masson-Delmotte, Mark Pagani, Maureen Raymo, Dana L. Royer, & James C. Zachos, 2008, "Target Atmospheric CO₂: Where Should Humanity Aim?" *preprint*.
2. J. Hansen, M. Sato, R. Ruedy, P. Kharecha, A. Lacis, R. Miller, L. Nazarenko, K. Lo, G. A. Schmidt, G. Russell, I. Aleinov, S. Bauer, E. Baum, B. Cairns, V. Canuto, M. Chandler, Y. Cheng, A. Cohen, A. Del Genio, G. Faluvegi, E. Fleming, A. Friend, T. Hall, C. Jackman, J. Jonas, M. Kelley, N. Y. Kiang, D. Koch, G. Labow, J. Lerner, S. Menon, T. Novakov, V. Oinas, Ja. Perlwitz, Ju. Perlwitz, D. Rind, A. Romanou, R. Schmunk, D. Shindell, P. Stone, S. Sun, D. Streets, N. Tausnev, D. Thresher, N. Unger, M. Yao, and S. Zhang, 2007, "Dangerous human-made interference with climate: a GISS modelE study," *Atmos. Chem. Phys.* **7**, 2287-2312.
3. James Hansen, Larissa Nazarenko, Reto Ruedy, Makiko Sato, Josh Willis, Anthony Del Genio, Dorothy Koch, Andrew Lacis, Ken Lo, Surabi Menon, Tica Novakov, Judith Perlwitz, Gary Russell, Gavin A. Schmidt, Nicholas Tausnev, "Earth's Energy Imbalance: Confirmation and Implications," *Science* **308**, 1431-1435.