AIRBORNE 2010 WIND ENERGY CONFERENCE

Climate, Carbon, and Airborne Wind Energy

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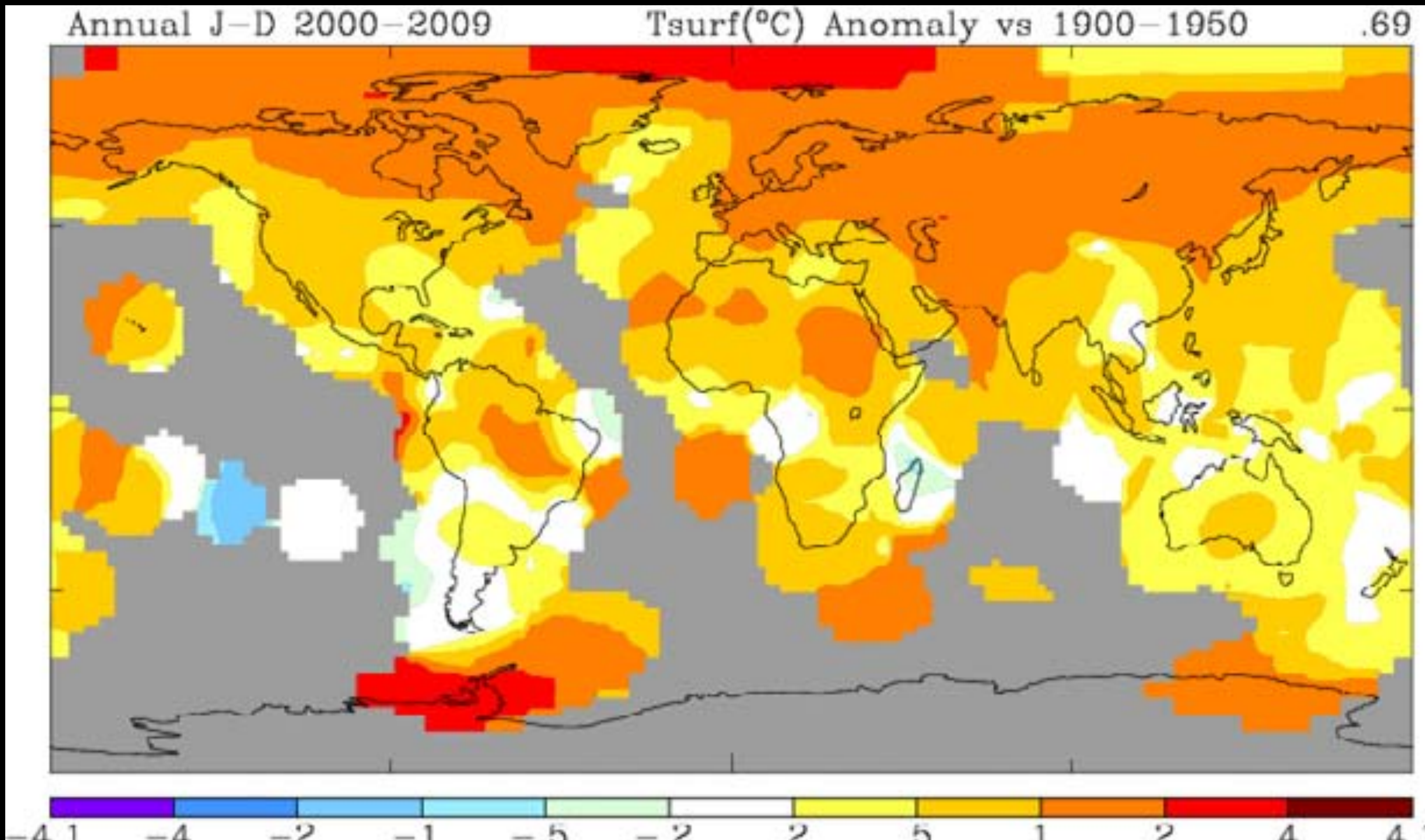
29 September 2010

Observed Temperature Change
Years 2000-2009 minus 1900-1950



ΔTemperature (°C)

http://data.giss.nasa.gov/gistemp/maps/

Probability of 2040-2060 summer being hotter than hottest on record

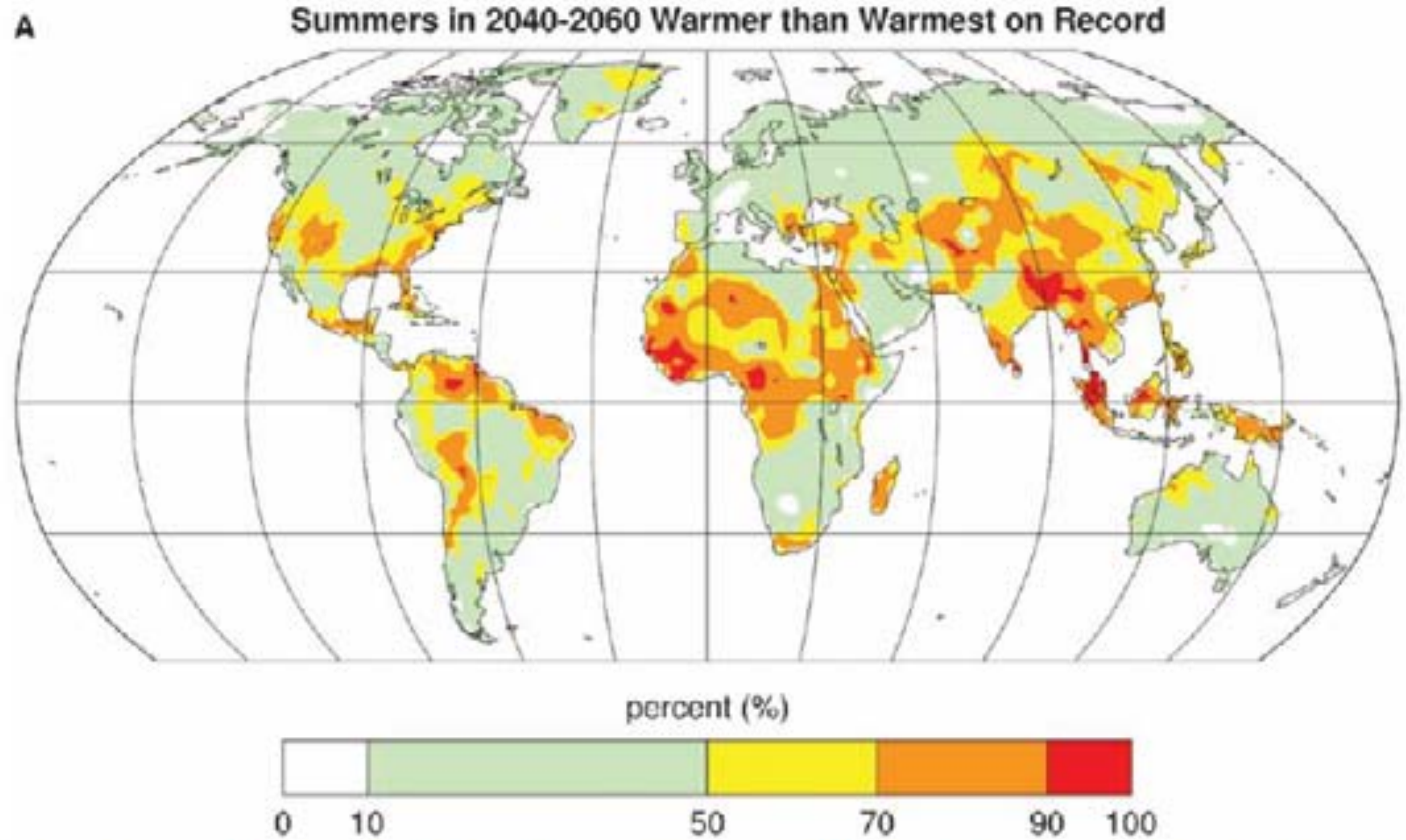
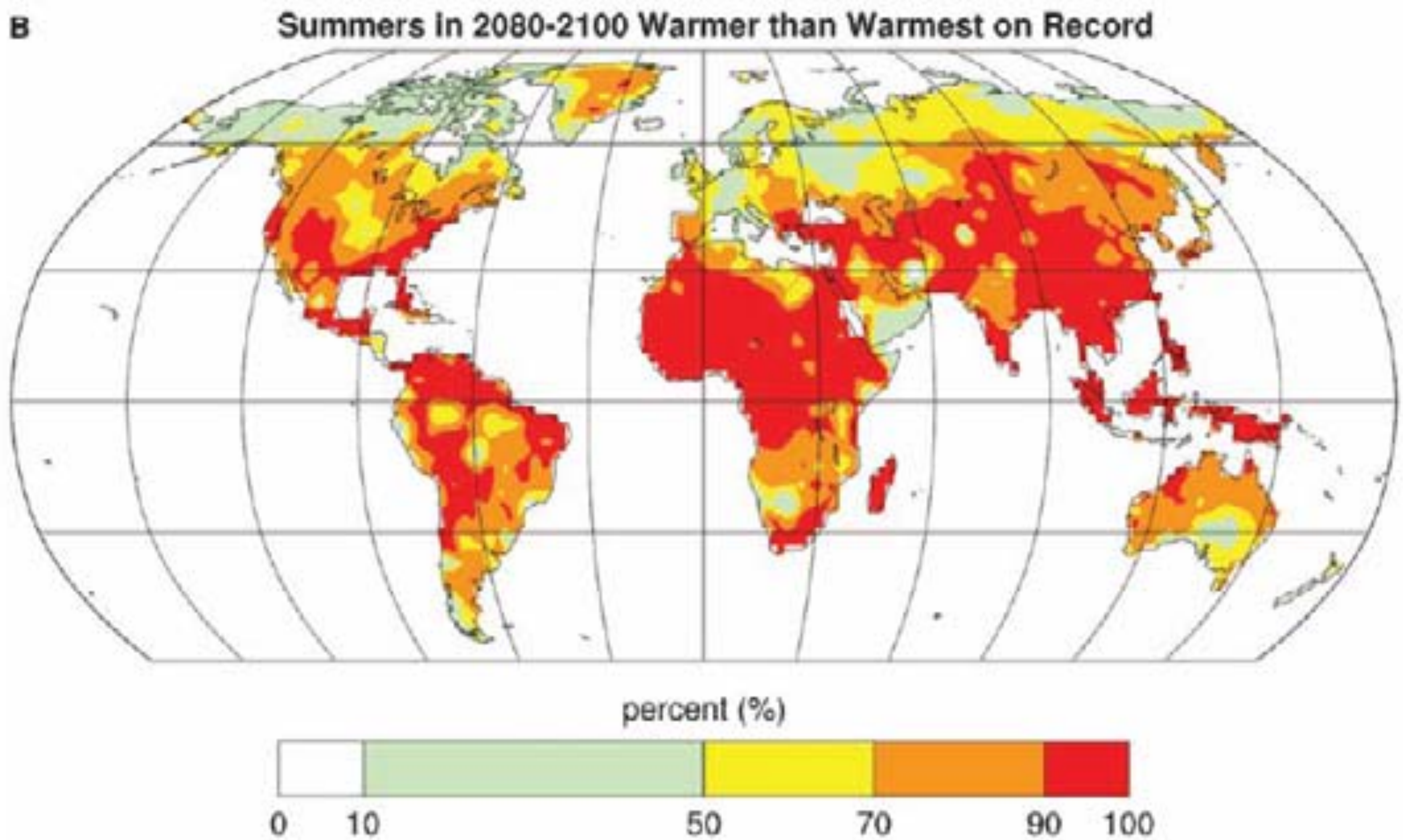


Fig. 3. Likelihood (in percent) that future summer average temperatures will exceed the highest summer temperature observed on record (**A**) for 2050 and (**B**) for 2090. For example, for places shown in red there is greater than a 90% chance that the summer-averaged temperature will exceed the highest temperature on record (1900–2006) (*22*).

David. S. Battisti[1] and Rosamond L. Naylor[2] 9 JANUARY 2009 VOL 323 SCIENCE www.sciencemag.org

Probability of 2080-2100 summer being hotter than hottest on record



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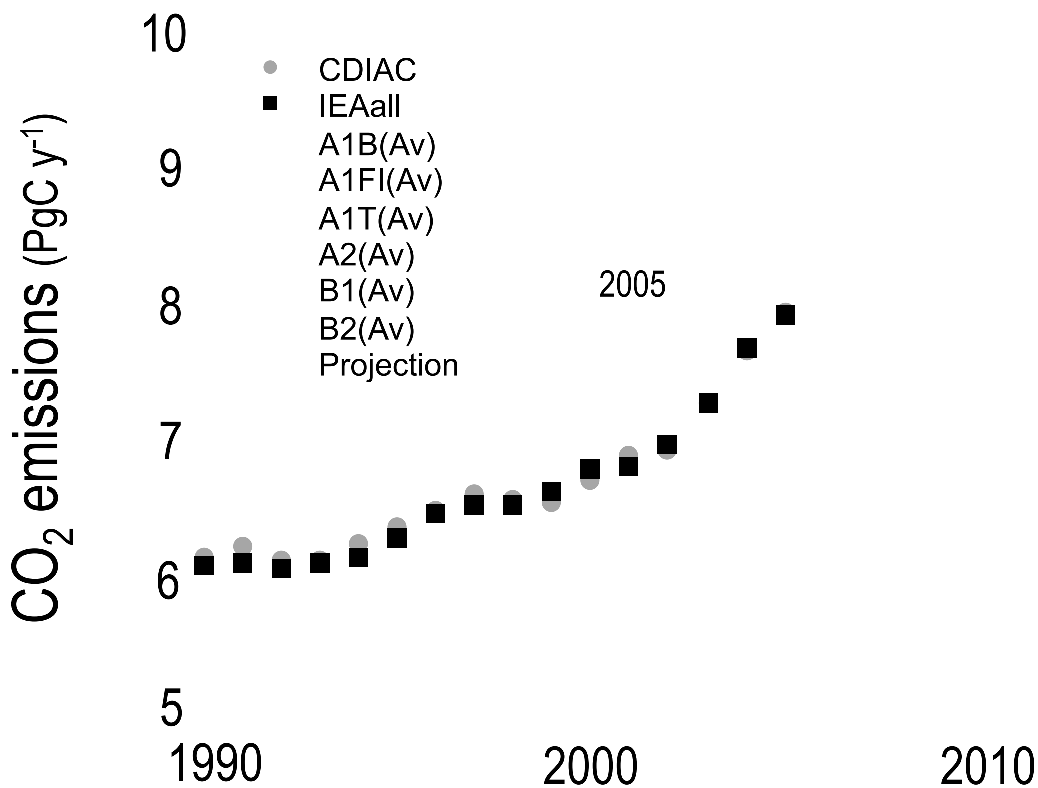
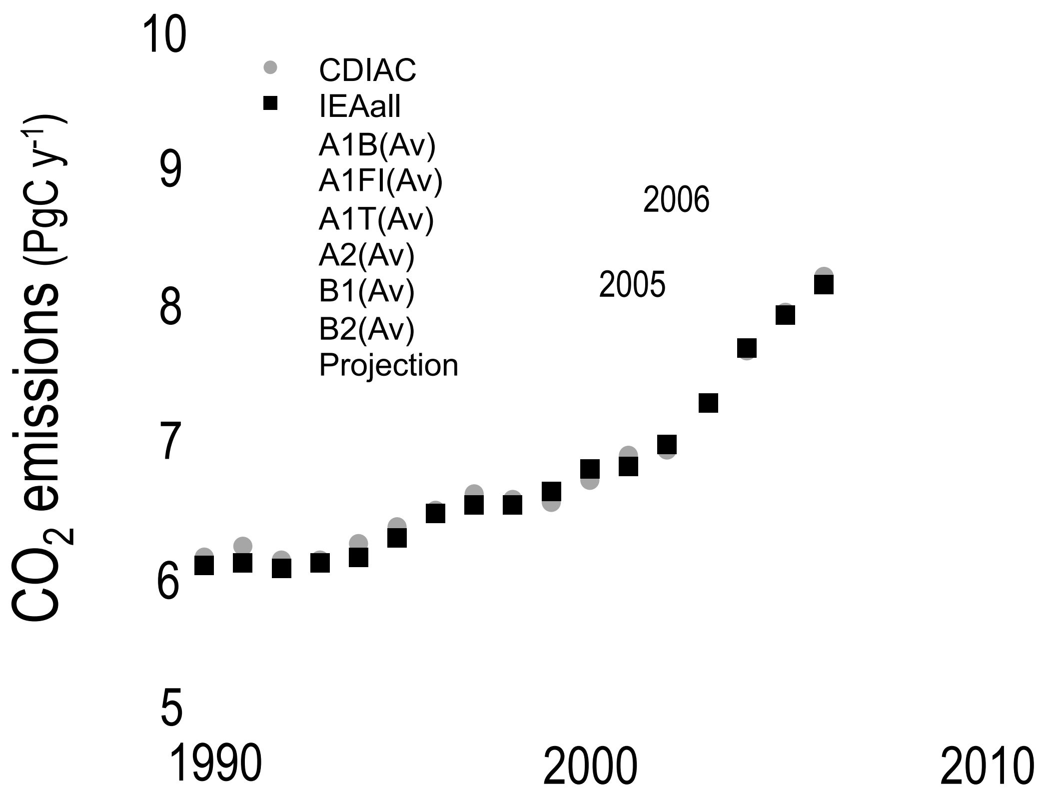
Fossil Fuel Emissions: Actual vs. IPCC Scenarios



Updated Raupach et al. 2007, PNAS

Fossil Fuel Emissions: Actual vs. IPCC Scenarios



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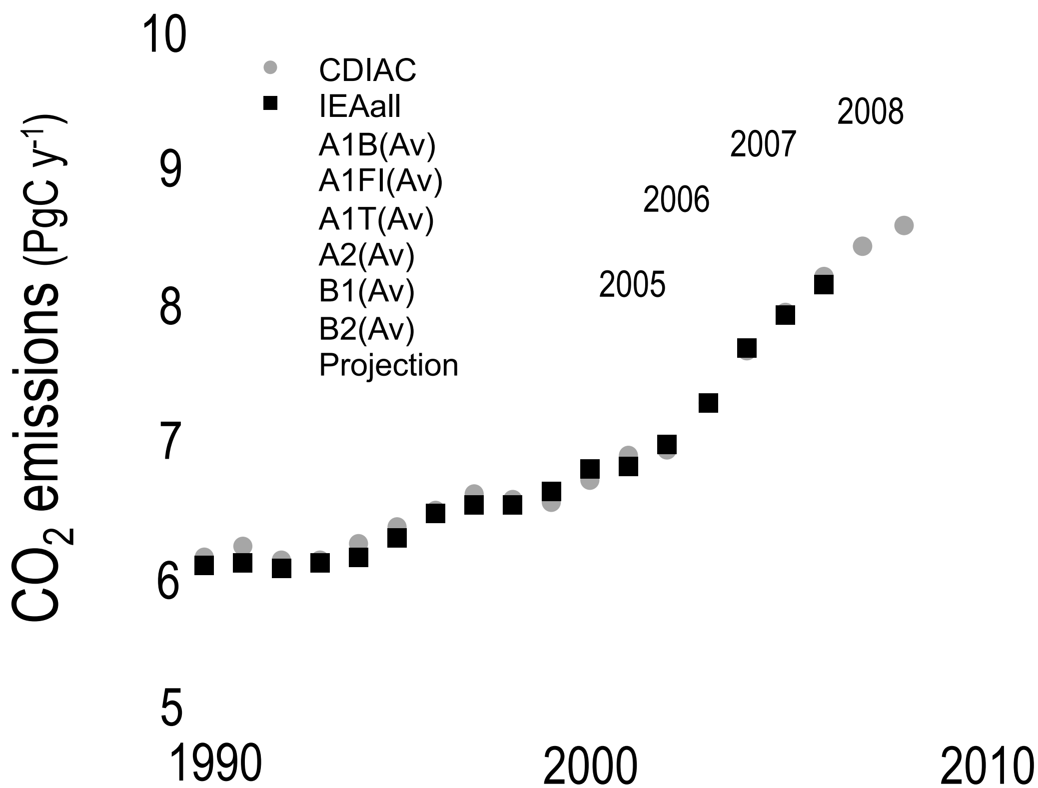
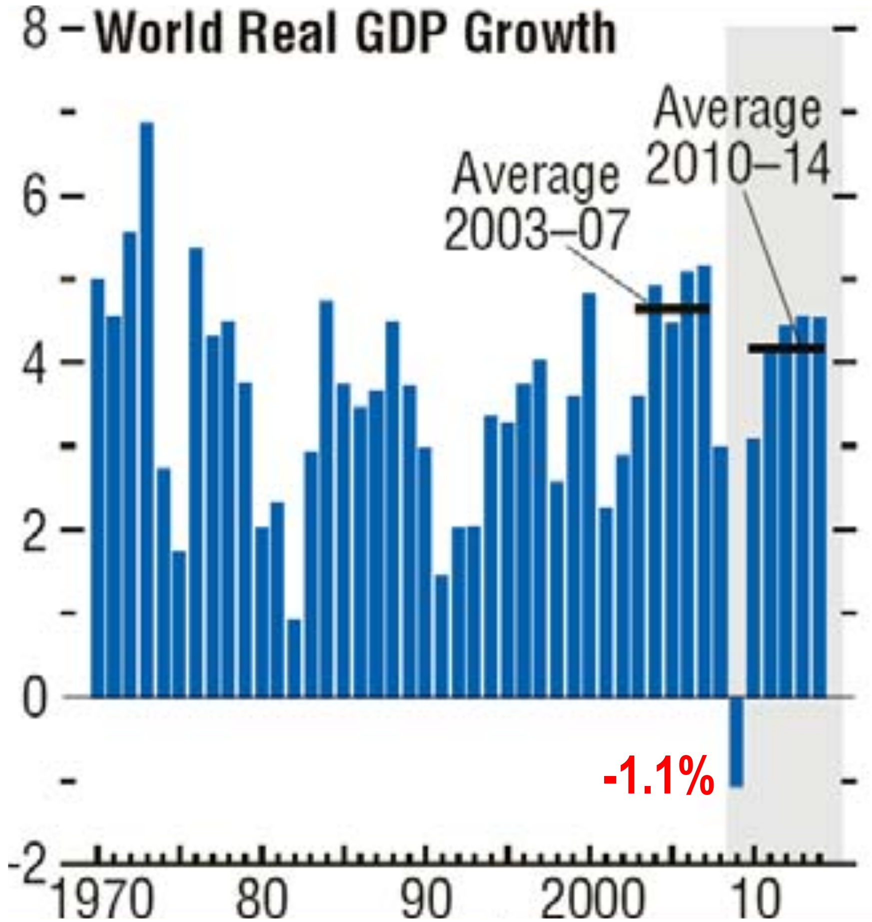


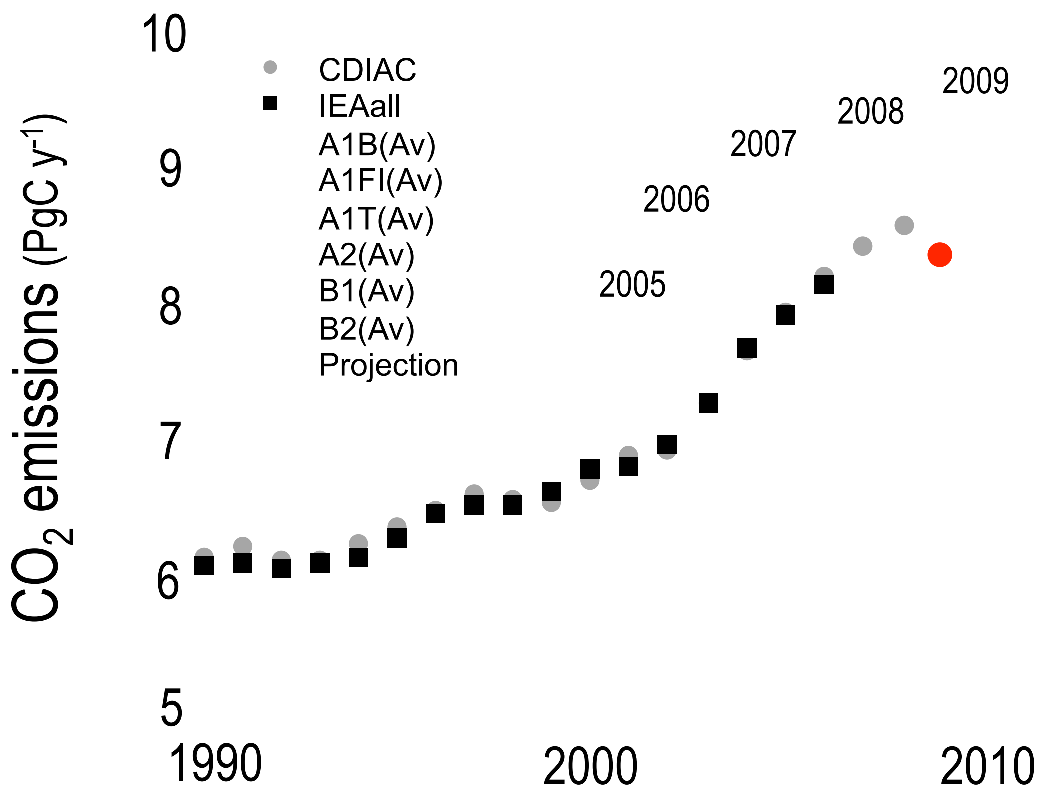
Updated Raupach et al. 2007, PNAS

Economic Crisis Impact on World GDP Growth



International Energy Agency, October 2009

Fossil Fuel Emissions: Actual vs. IPCC Scenarios

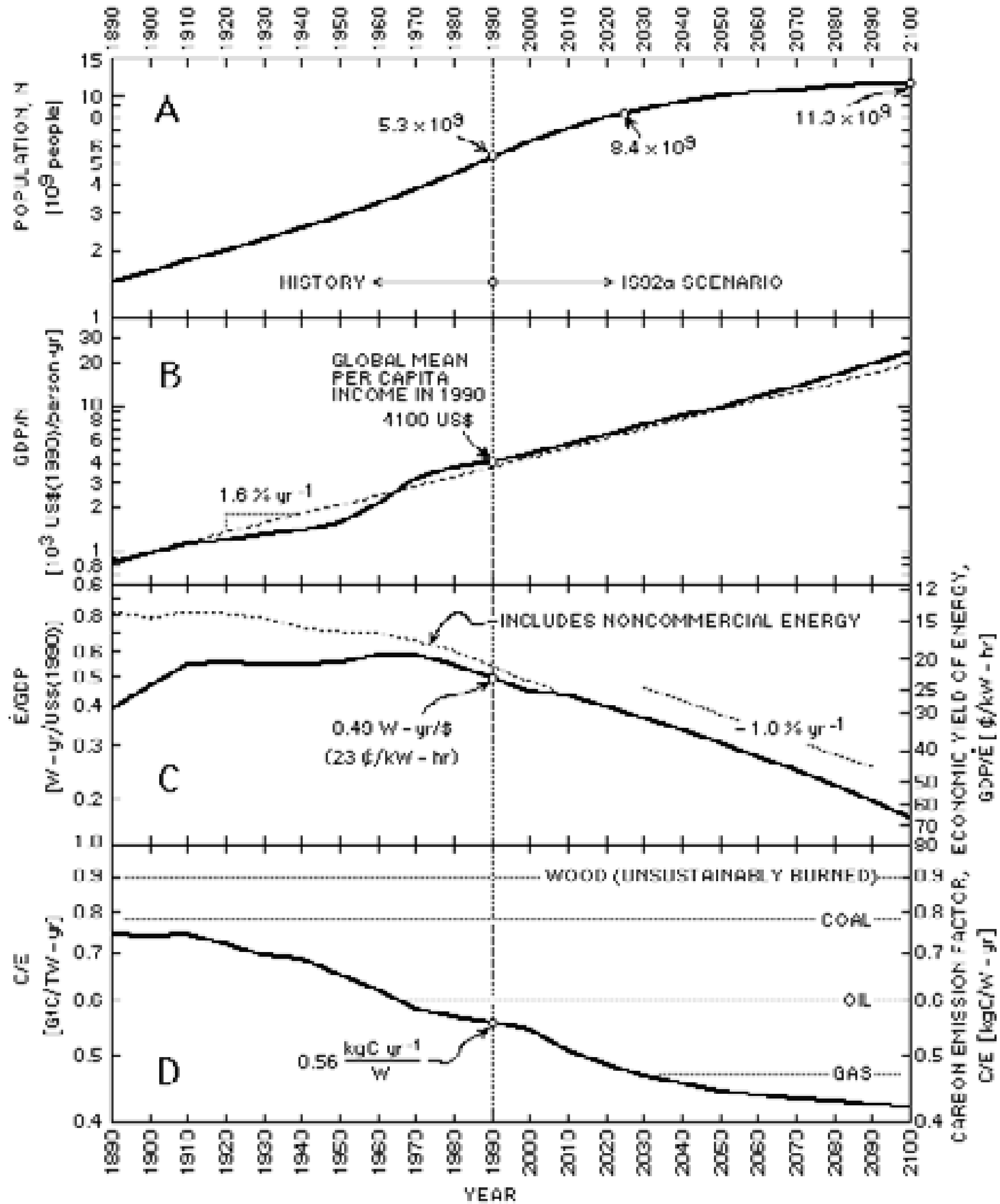


Projection **2009**:
Emissions: -2.8%
GDP: -1.1%
C intensity: -1.7%

Raupach et al. 2007, PNAS; updated Raupach unpublished; Le Quéré et al. 2009, Nature-Geo, in press

CO_2 Emissions

$$\dot{C} = N \times \left(\frac{GDP}{N}\right) \times \left(\frac{\dot{E}}{GDP}\right) \times \left(\frac{C}{E}\right)$$



NATURE | VOL 395 | 29 OCTOBER 1998

Energy implications of future stabilization of atmospheric CO_2 content

Martin I. Hoffert*, Ken Caldeira†, Atul K. Jain‡, Erik F. Haites§, L. D. Danny Harvey‖, Seth D. Potter*¶, Michael E. Schlesinger‡, Stephen H. Schneider#, Robert G. Watts*, Tom M. L. Wigley** & Donald J. Wuebbles‡

Hoffert et al., 1998

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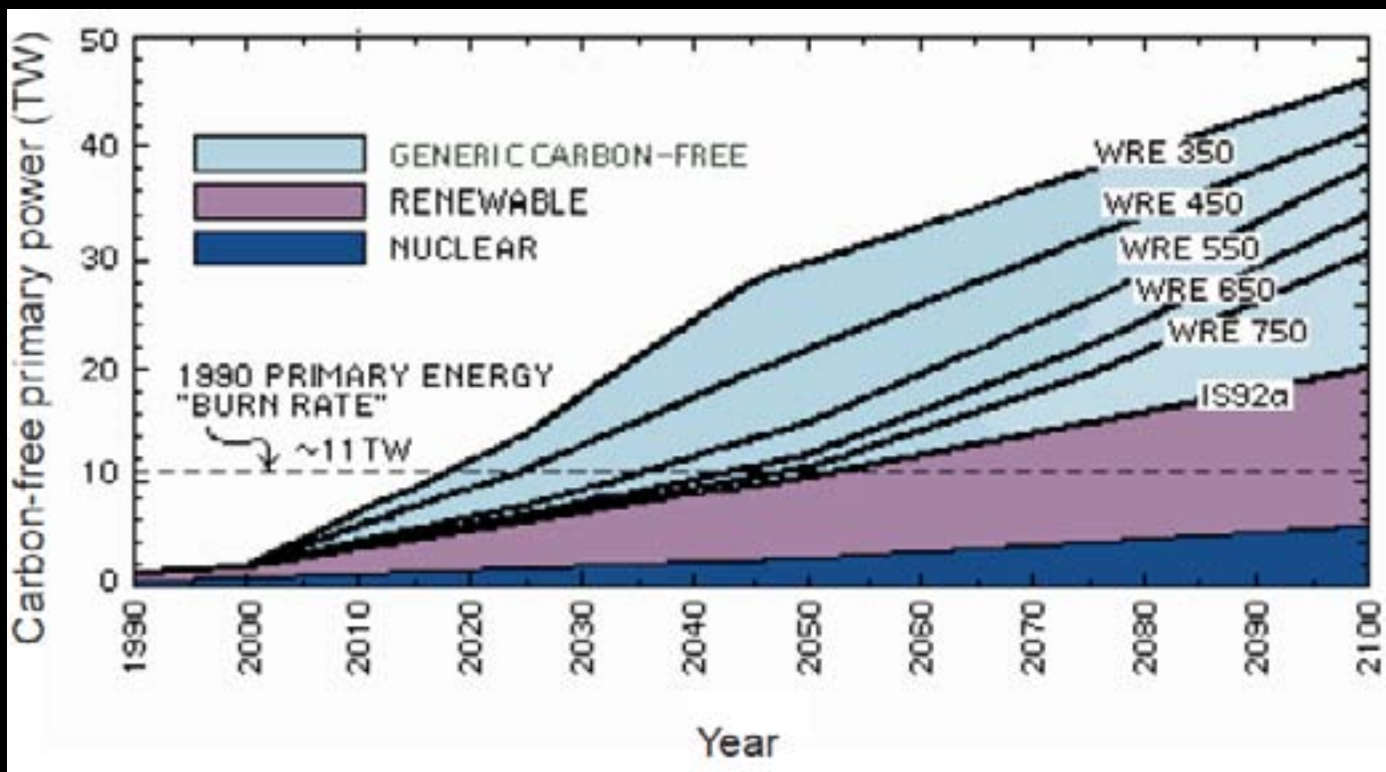

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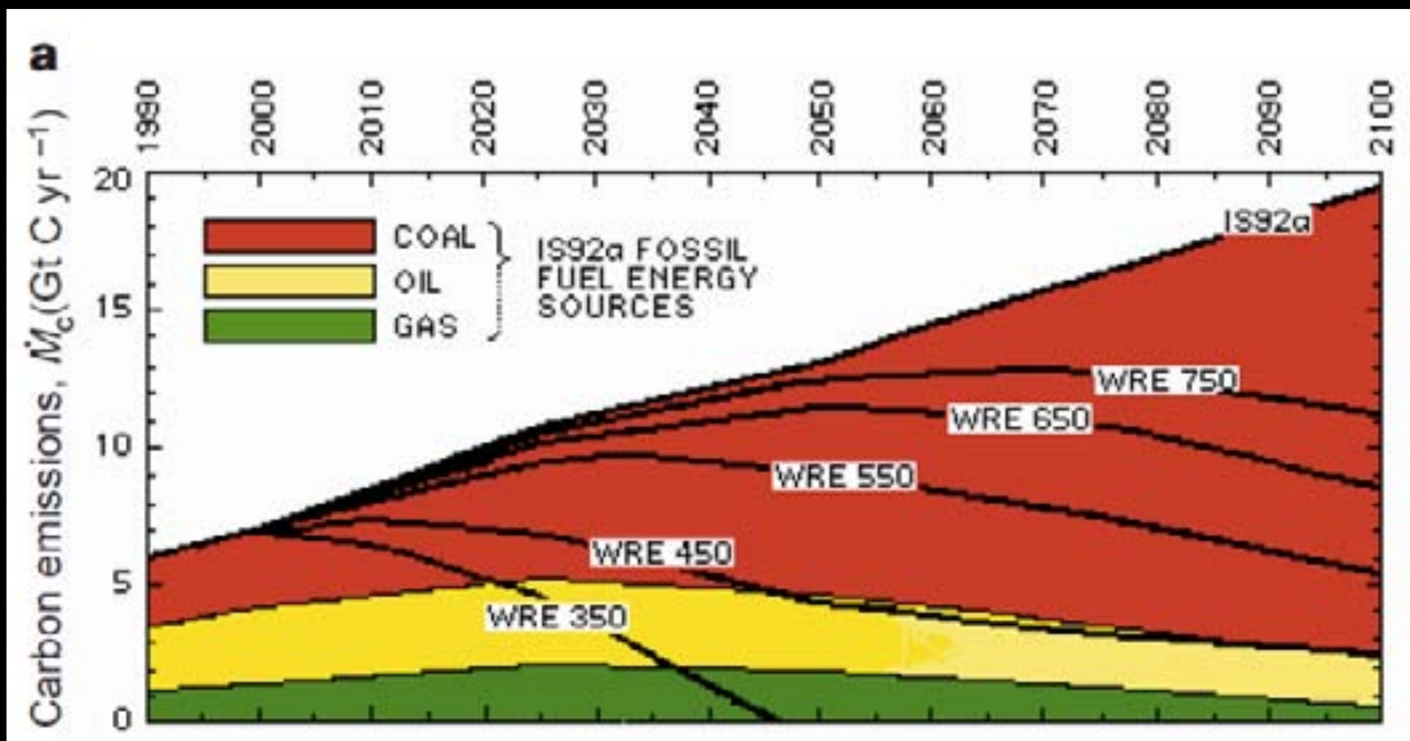

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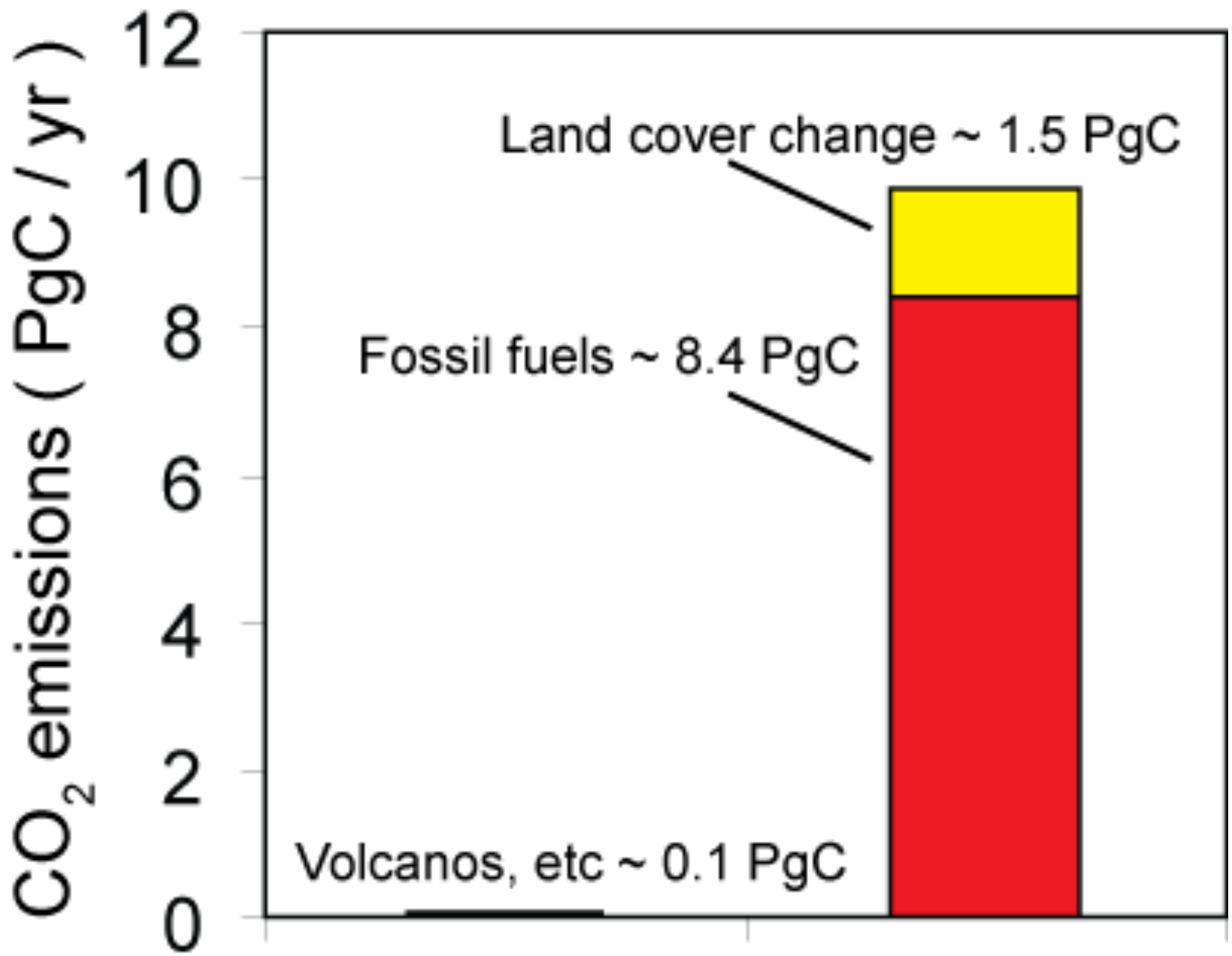
We find that CO_2 stabilization with continued economic growth will require innovative, cost-effective and carbon-emission-free technologies that can provide additional tens of terawatts of primary power in the coming decades, and certainly by the middle of the twenty-first century, even with sustained improvement in the economic productivity of primary energy.

. The magnitude of the implied infrastructure transition suggests the need for massive investments in innovative energy research.

Anthropogenic CO_2 emissions exceed natural emissions by about two orders of magnitude



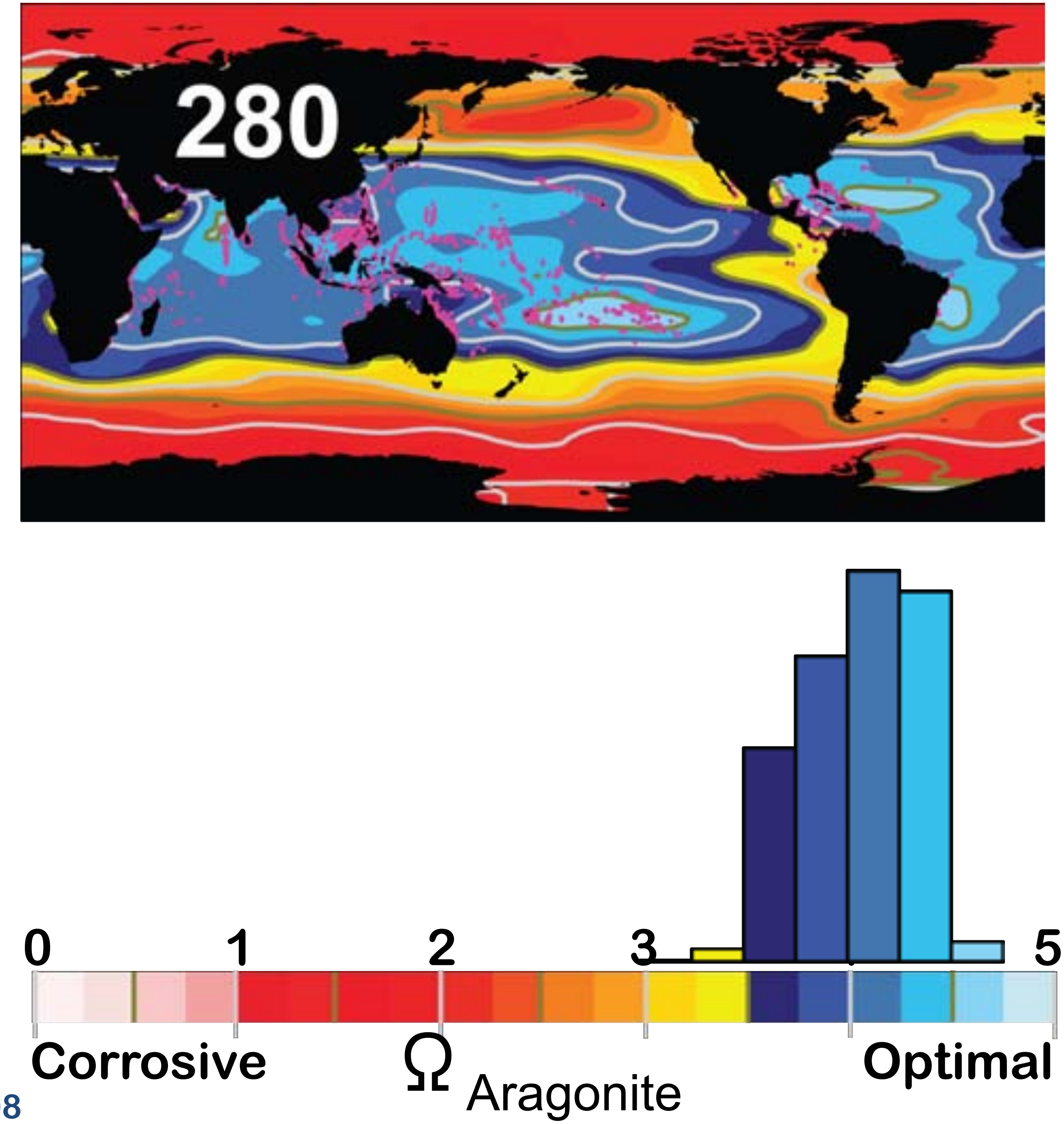
[redacted]

Distribution of corals and ocean acidification

Carbon dioxide level,

Coral reef distribution,

and chemical conditions helping drive reef formation

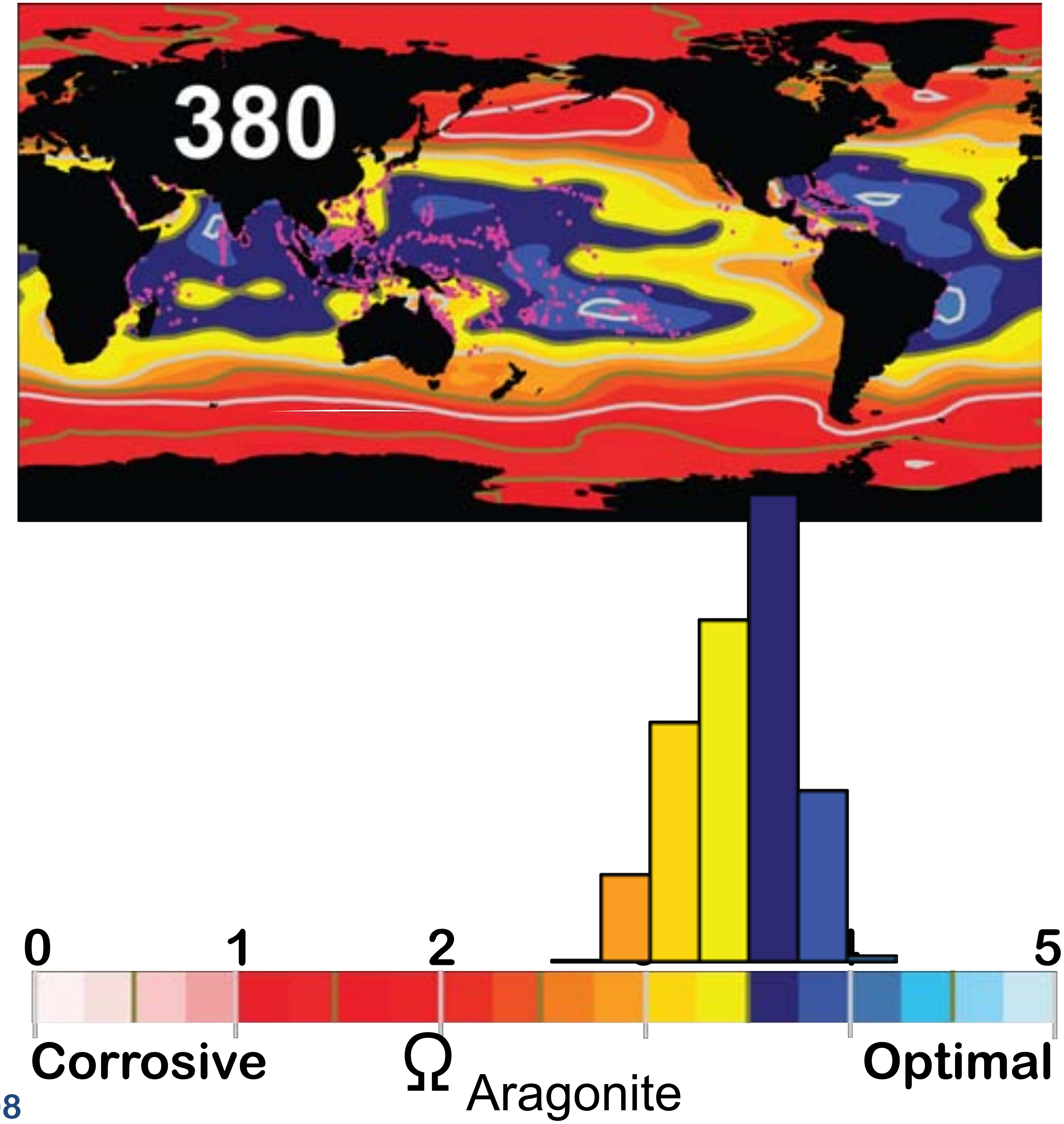


Cao and Caldeira, 2008

Carbon dioxide level,

Coral reef distribution,

and chemical conditions helping drive reef formation



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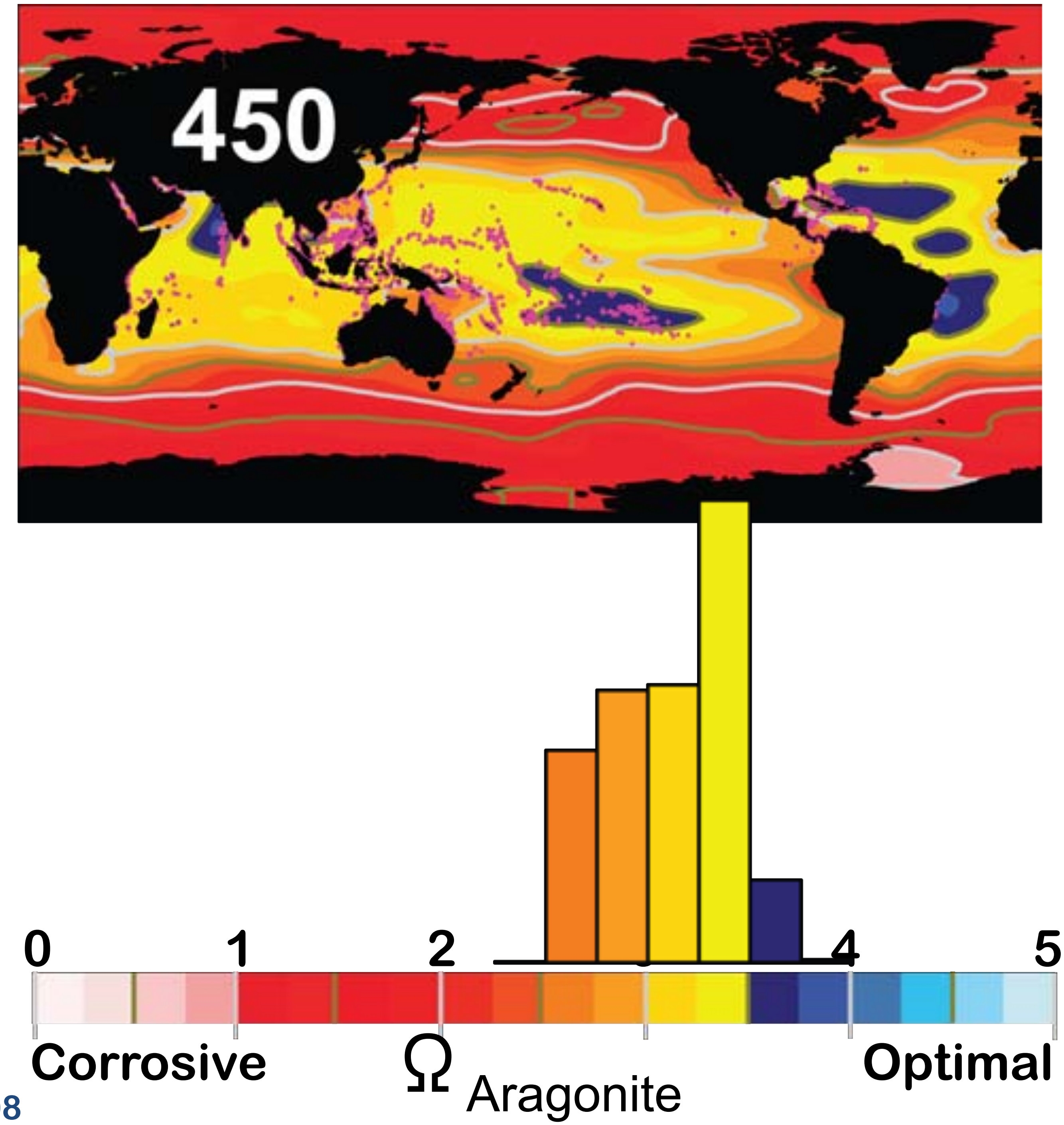

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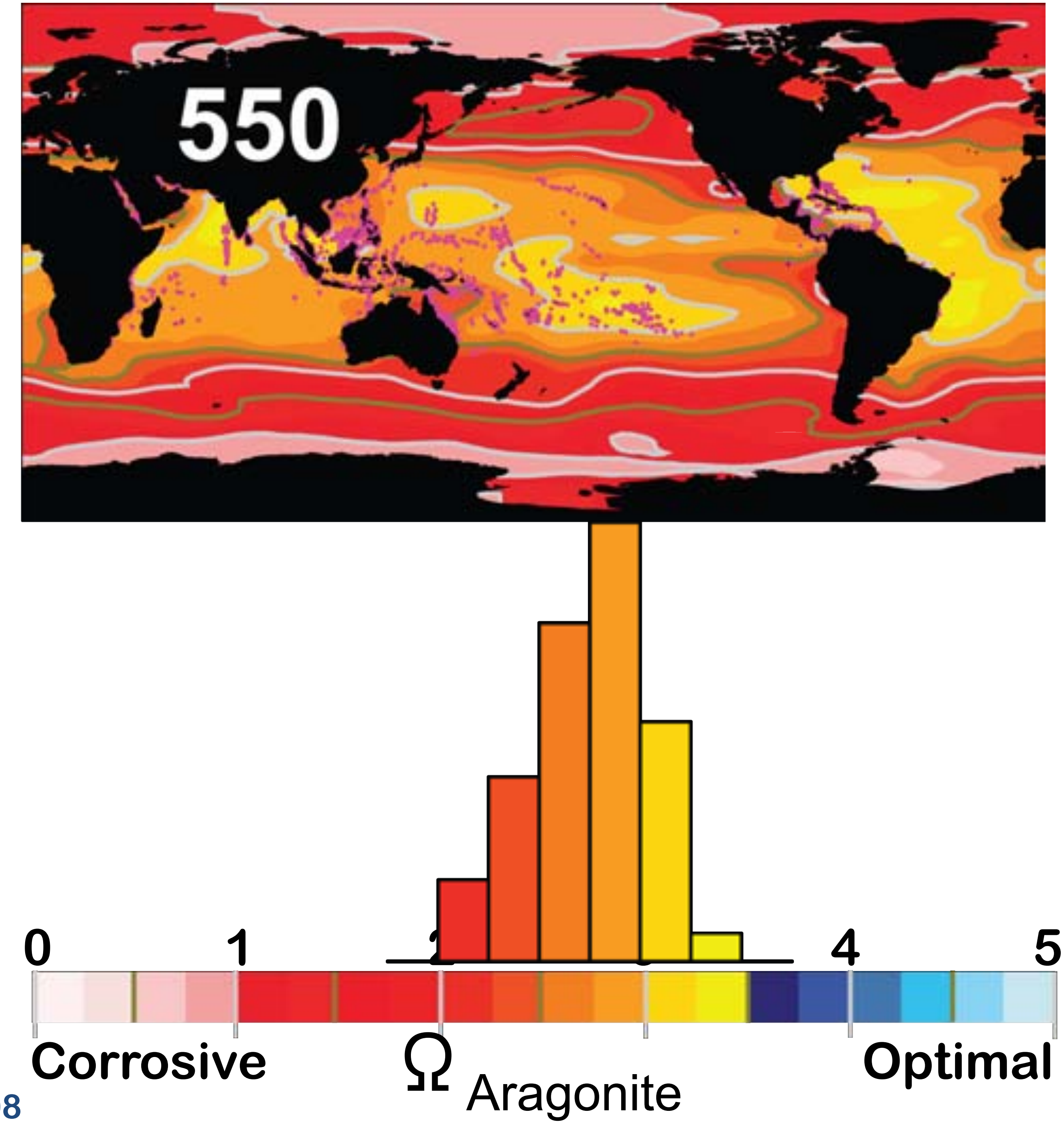

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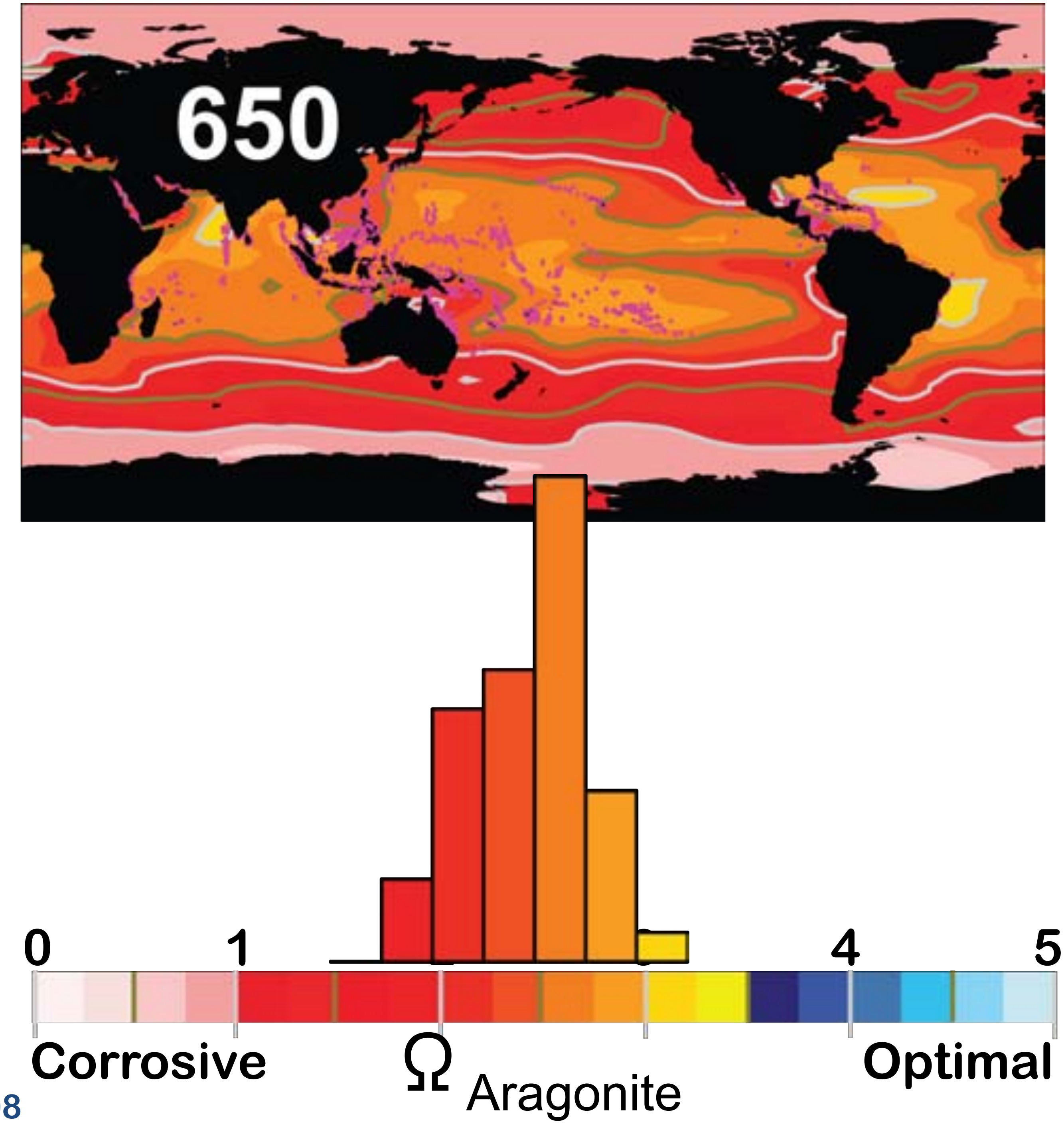

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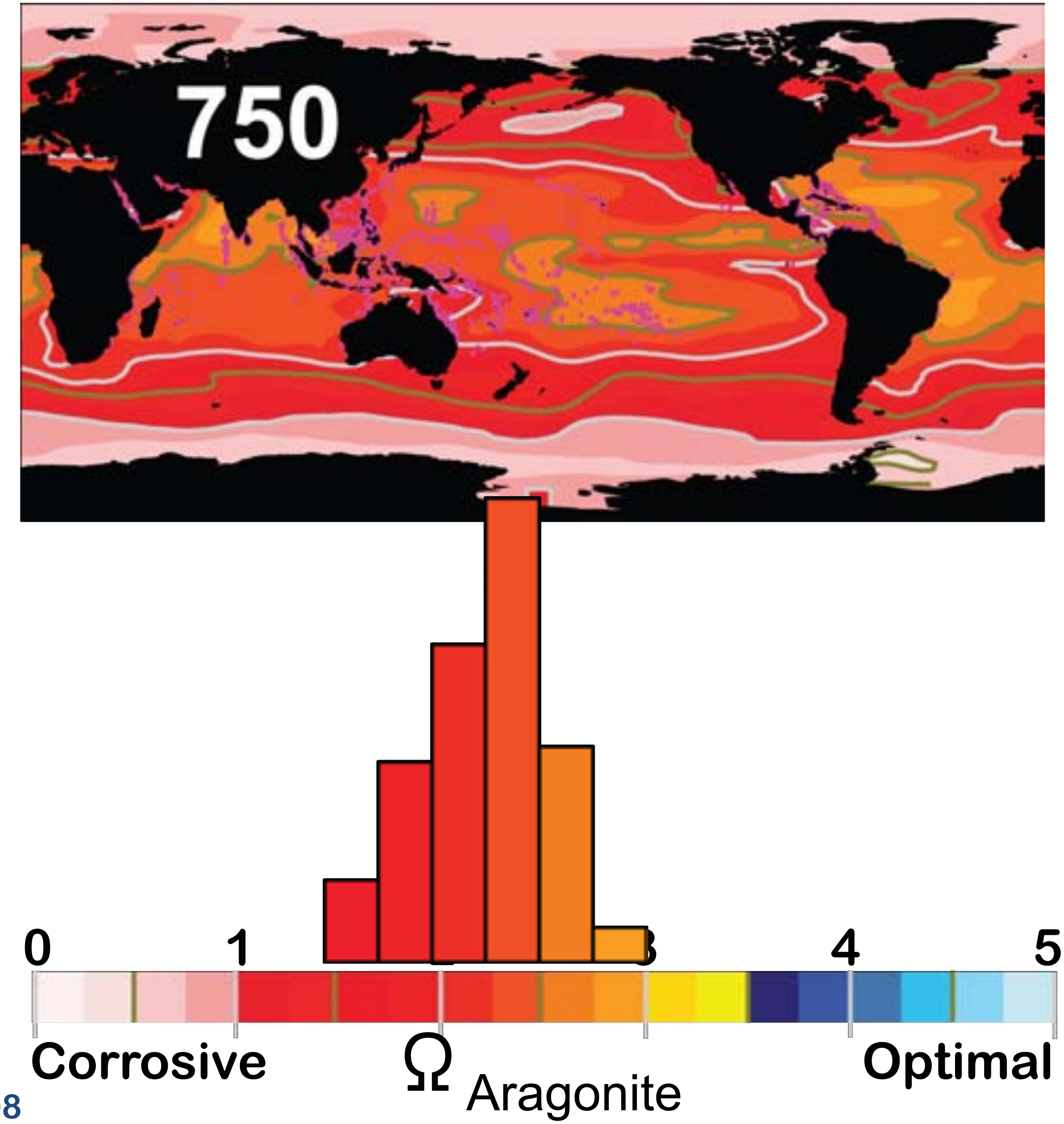
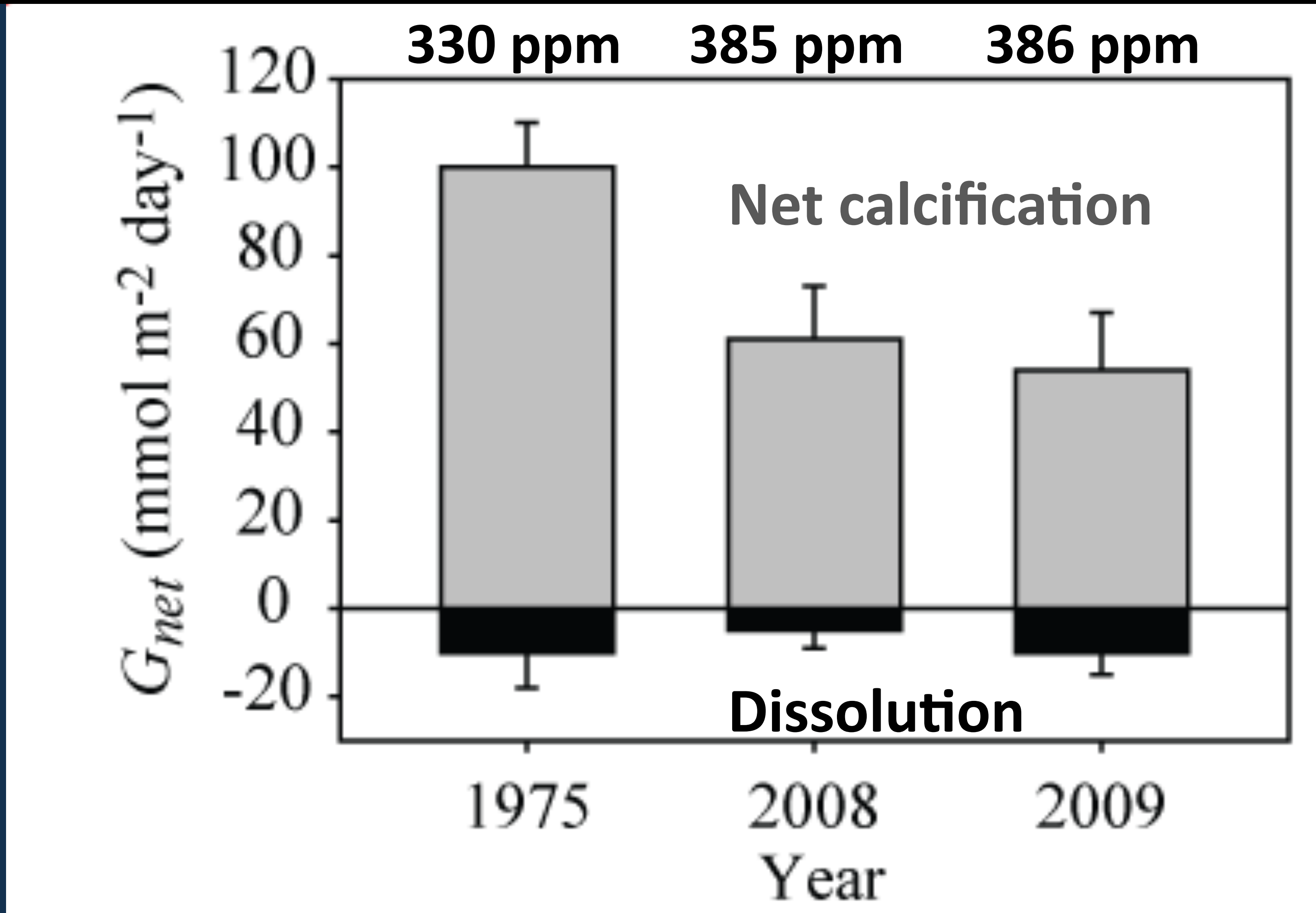
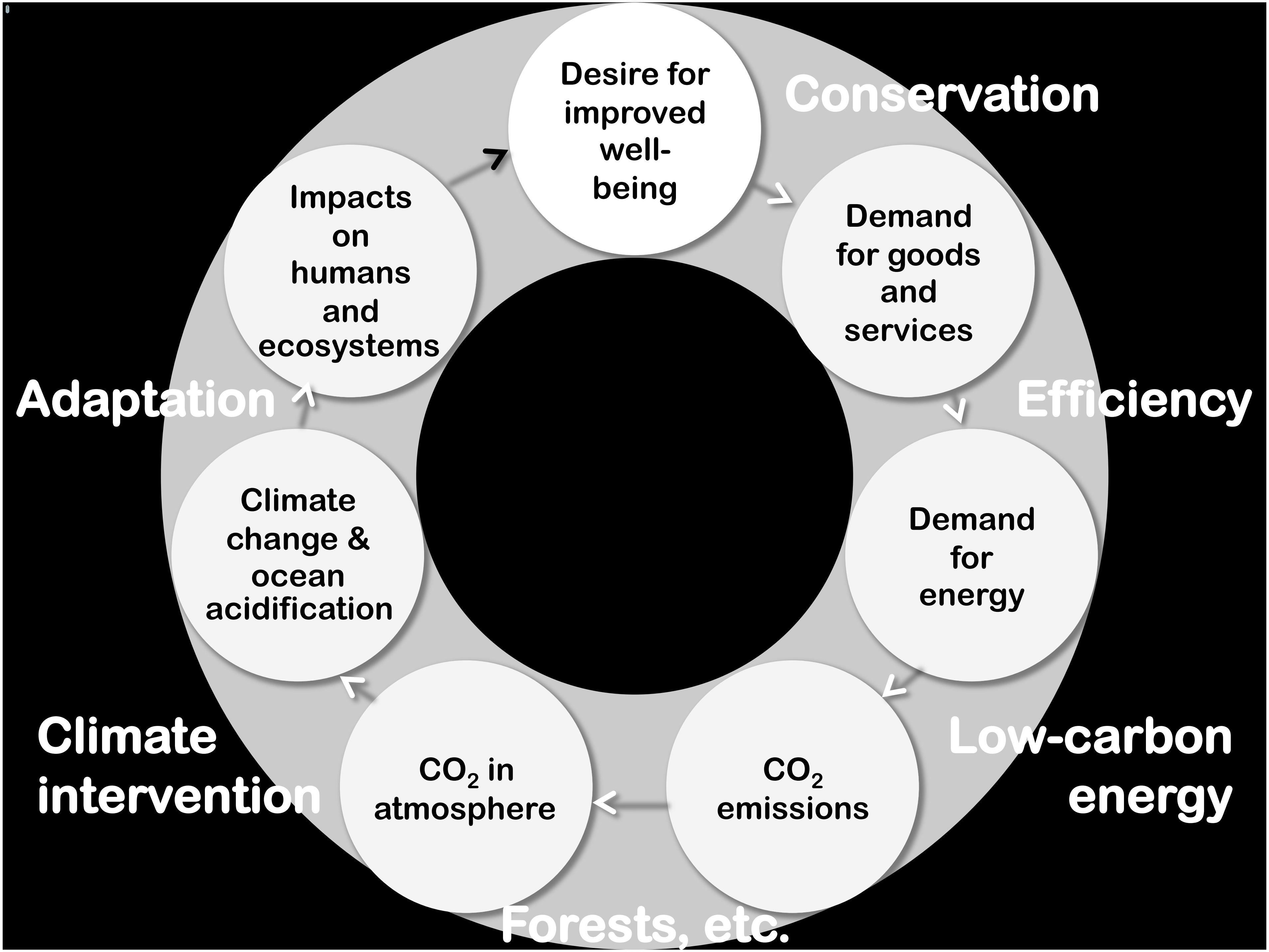


Cao and Caldeira, 2008


Oct 27, 2009 9:52 pm
Oct 27, 2009
Lizard Island
One Tree Island
© 2009 Europa Technologies
© 2009 Google
US Dept of State Geographer
© 2009 Tele Atlas
21° 11.838' S 137° 0.828' E
Google
Eye alt 6248.23 km

Net growth of coral skeletons decreased about 40% between 1975 and 2008-2009





Desire for improved well-being
Demand for goods and services
Demand for energy
CO_2 emissions
CO_2 in atmosphere
Climate change & ocean acidification
Impacts on humans and ecosystems
Conservation
Efficiency
Low-carbon energy
Forests, etc.
Climate intervention
Adaptation

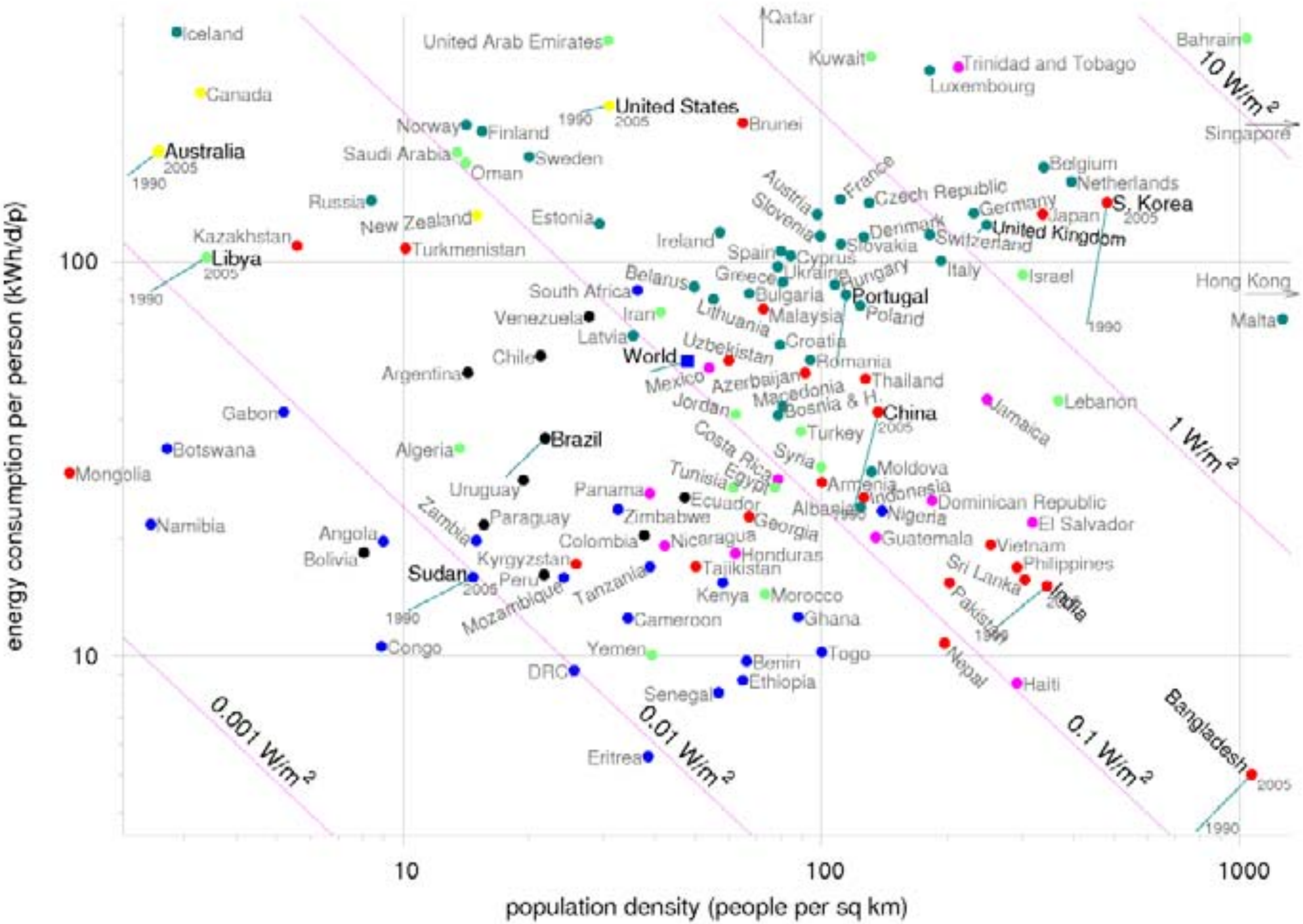
Most renewables are “energy farms”

Power per unit land area	
Wind	$2.5\,W/m^2$
Plants	$0.5\,W/m^2$
Solar PV panels	$5\text{–}20\,W/m^2$
Tidal pools	$3\,W/m^2$
Tidal stream	$8\,W/m^2$
Rain-water (highlands)	$0.24\,W/m^2$
Concentrating solar power (desert)	$15\text{–}20\,W/m^2$

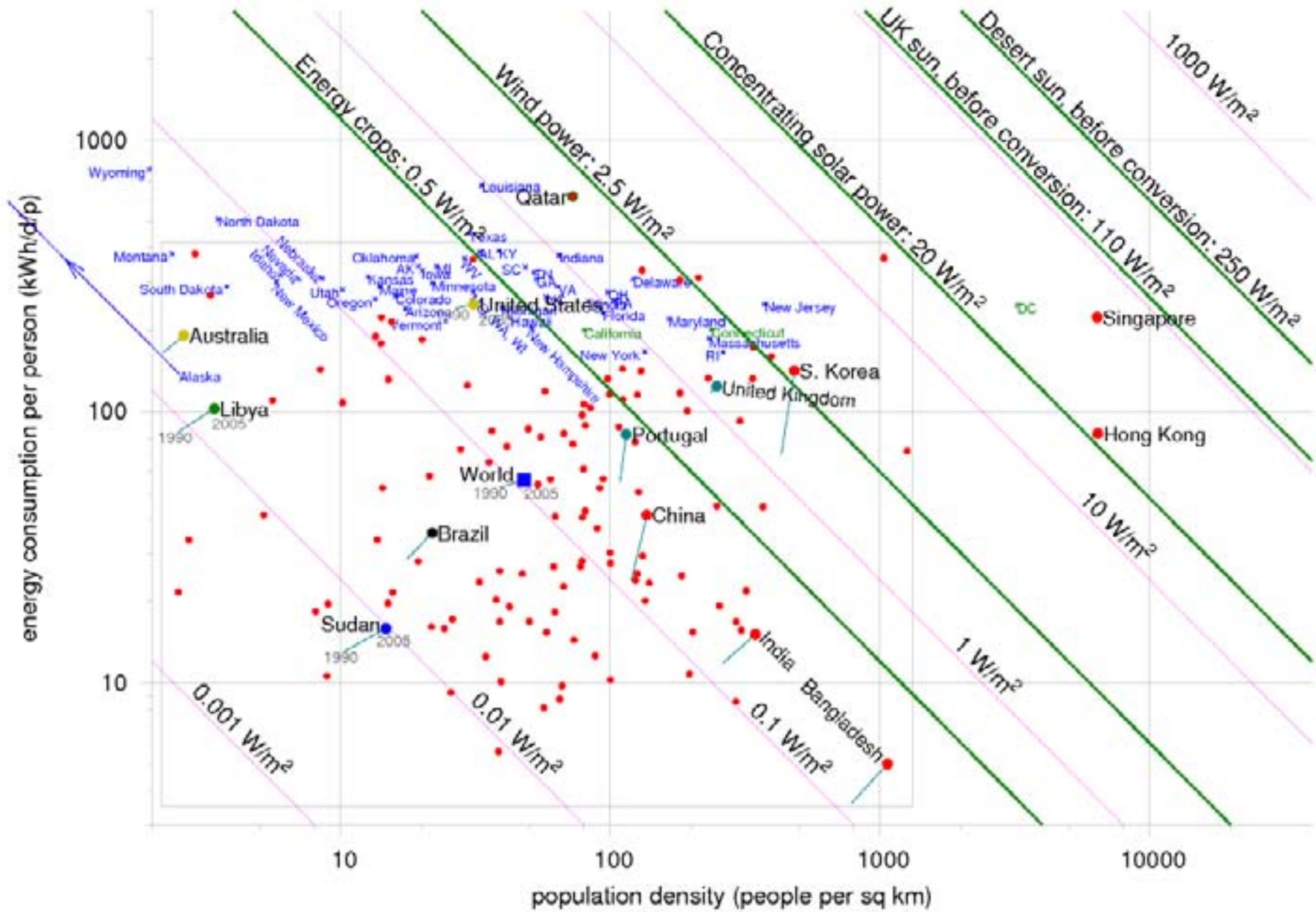
Nant-y-Moch by Dave Newbould
www.origins-photography.co.uk

- To make a difference, renewable facilities have to be country-sized

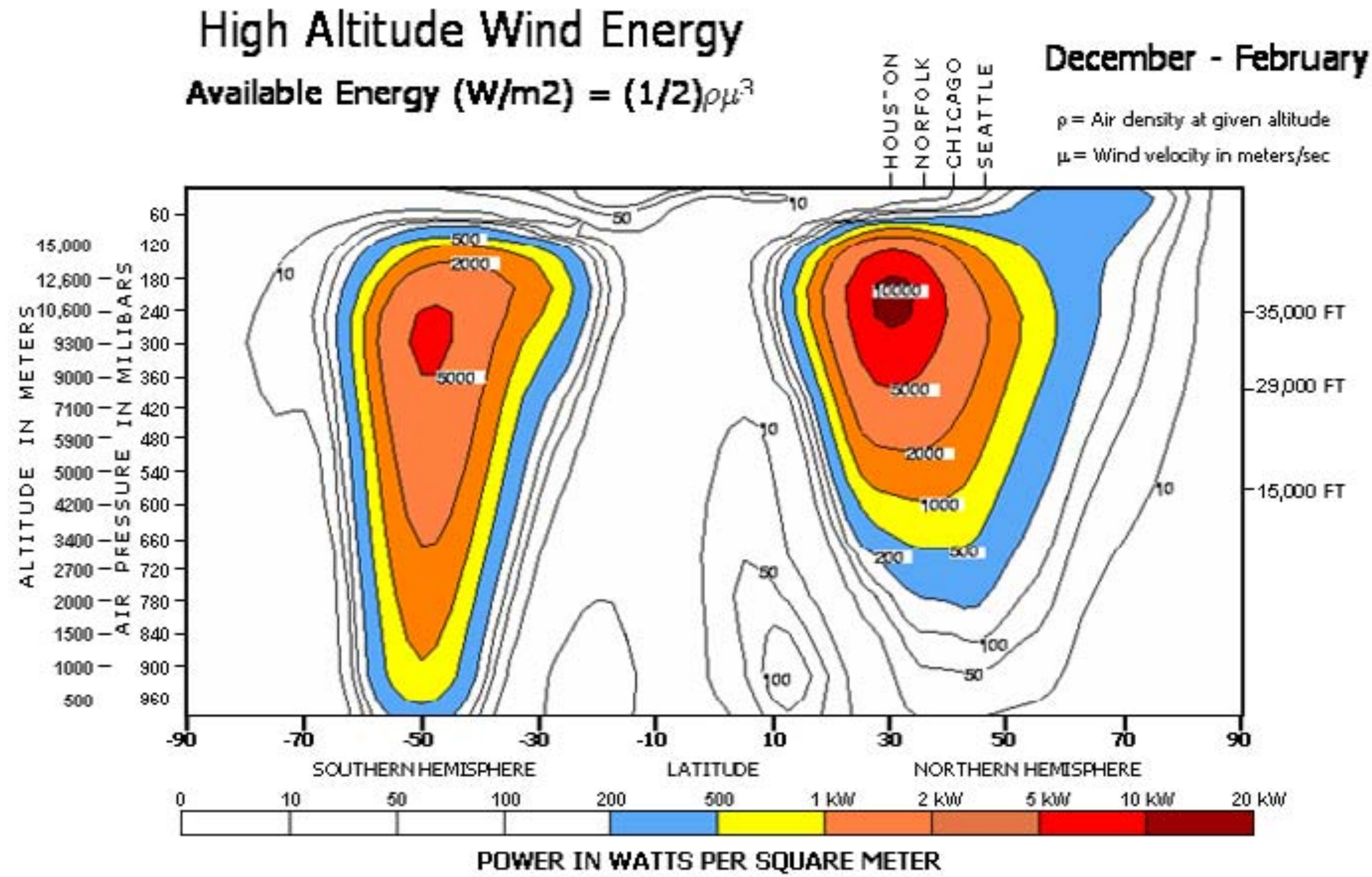
Courtesy David MacKay



Courtesy David MacKay



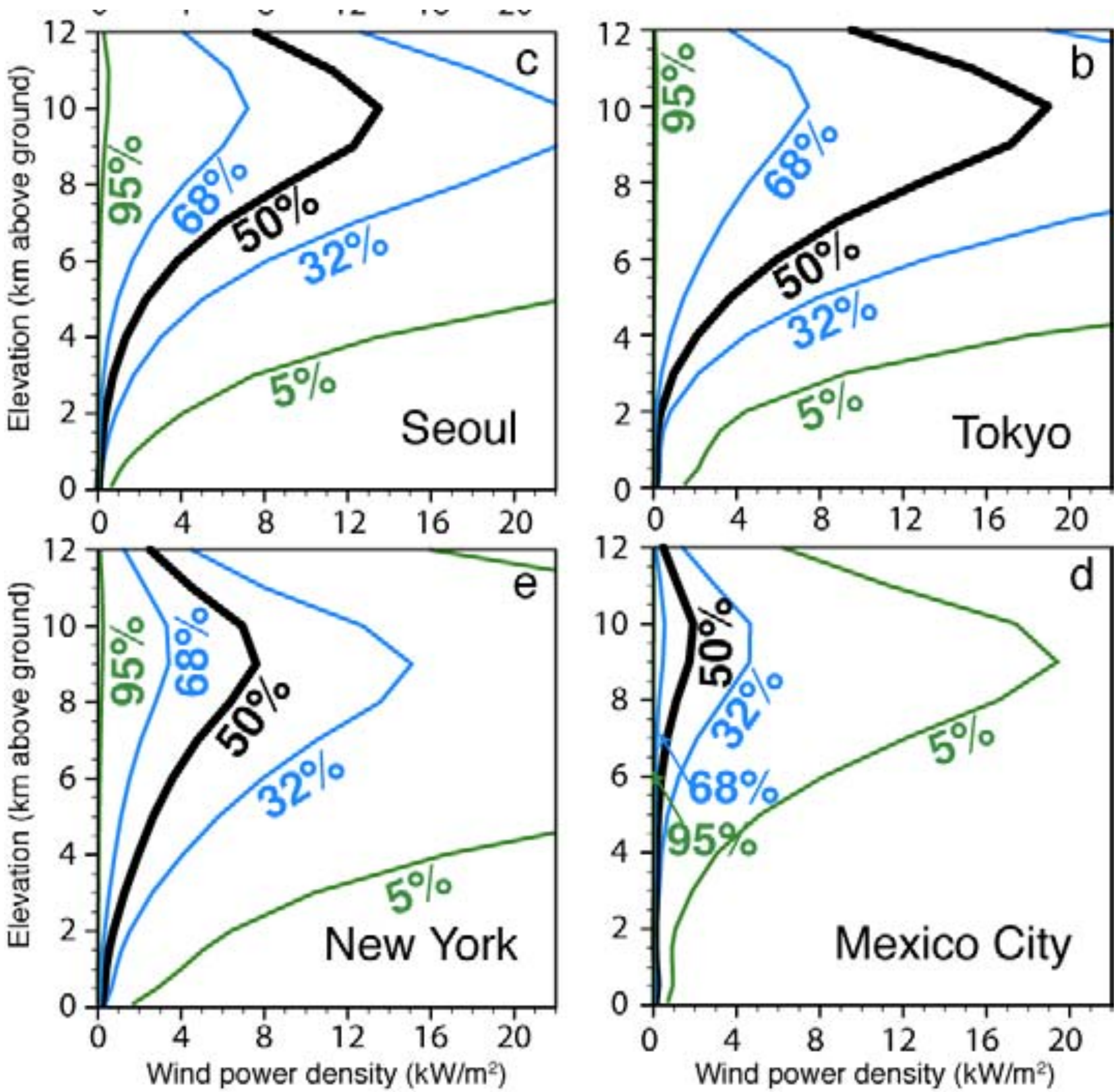
Courtesy David MacKay



Calculated by Ken Caldeira (Lawrence Livermore National Laboratory, kenc@llnl.gov),
based on ECMWF 1978-1994 seasonal mean wind and temperatures.

Additional scales and city names added by Sky WindPower Corp.

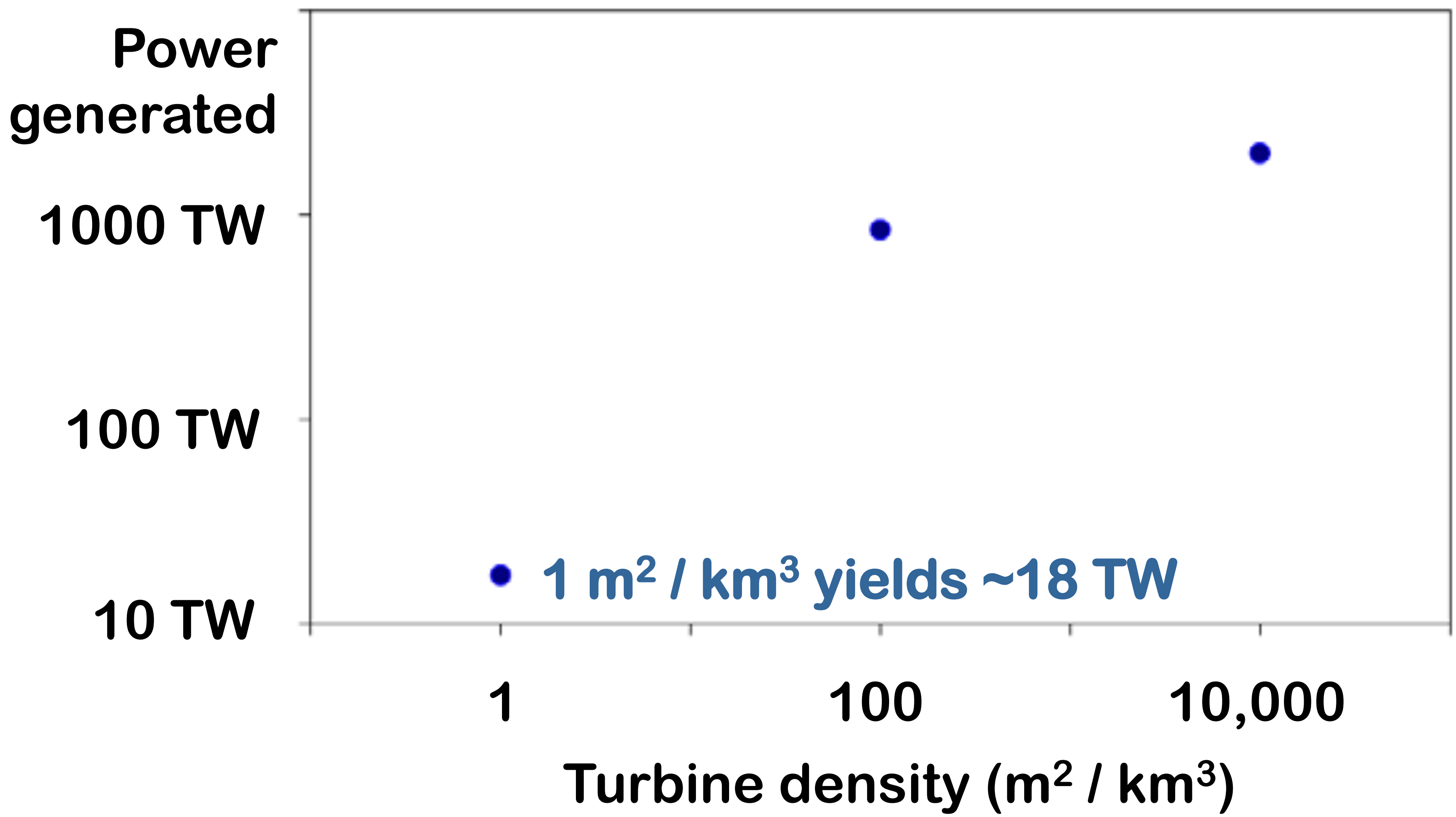
Airborne wind energy



Archer and Caldeira, 2009

Estimating maximum power available

Idealized general circulation climate model results



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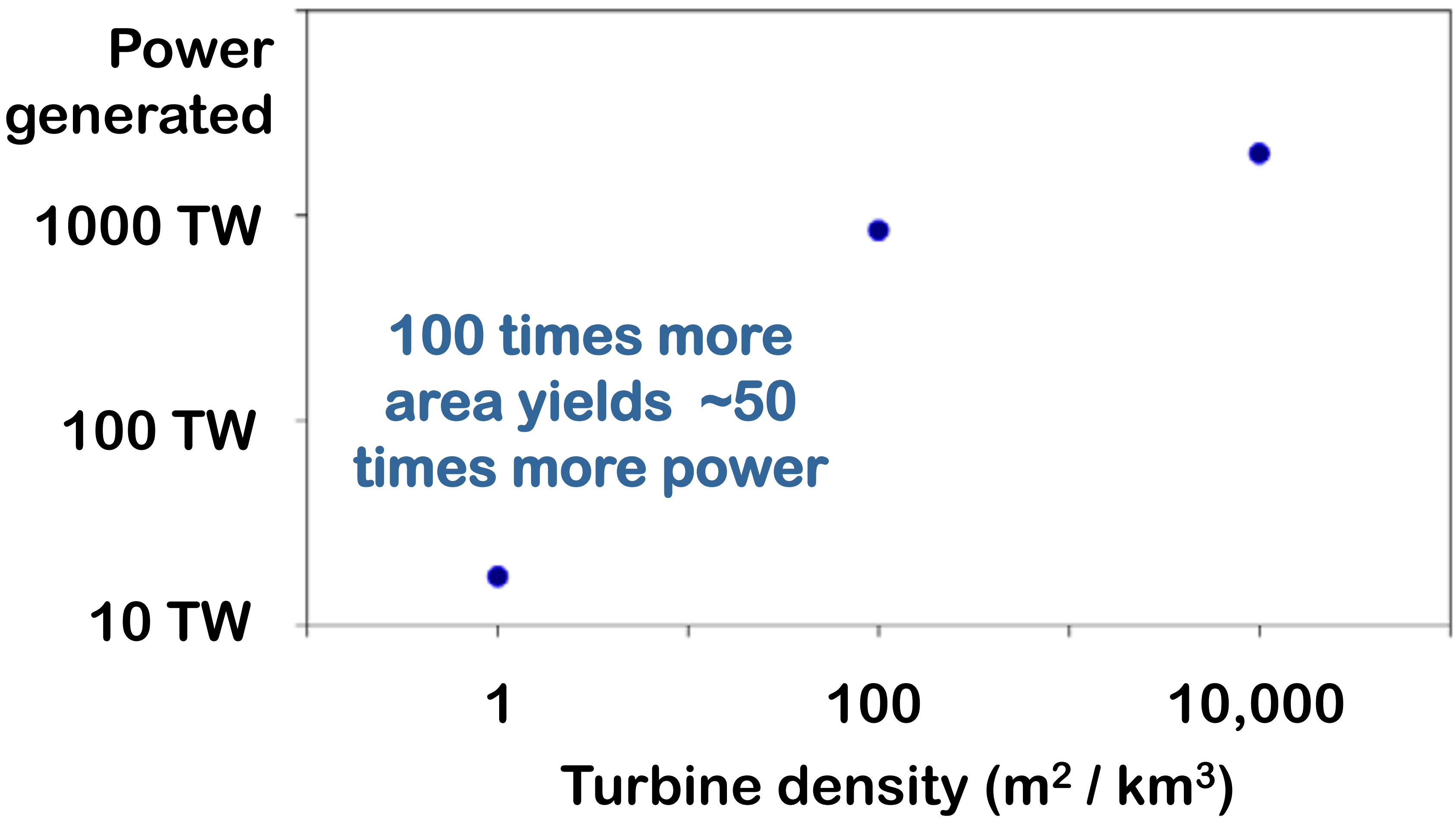

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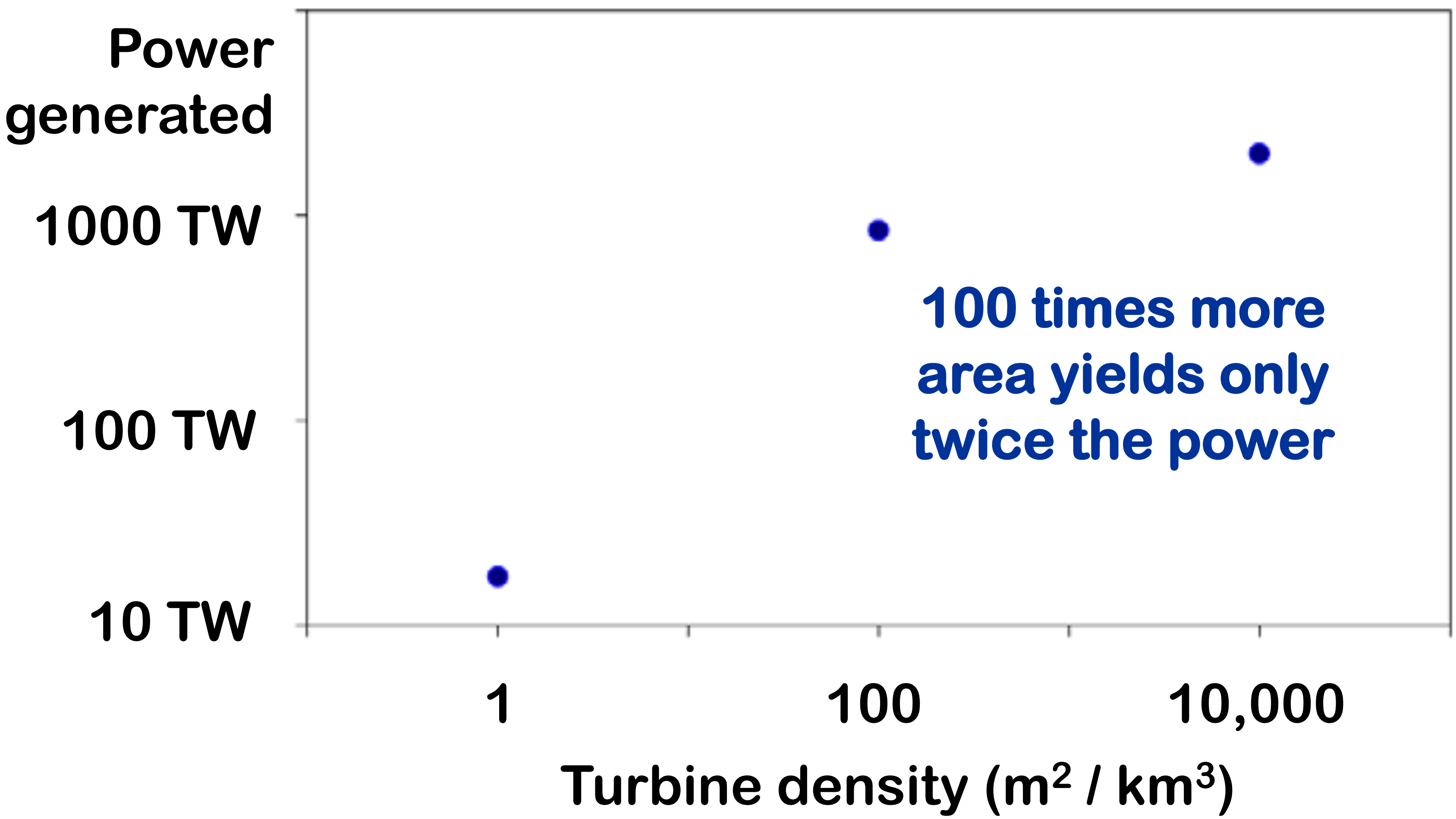

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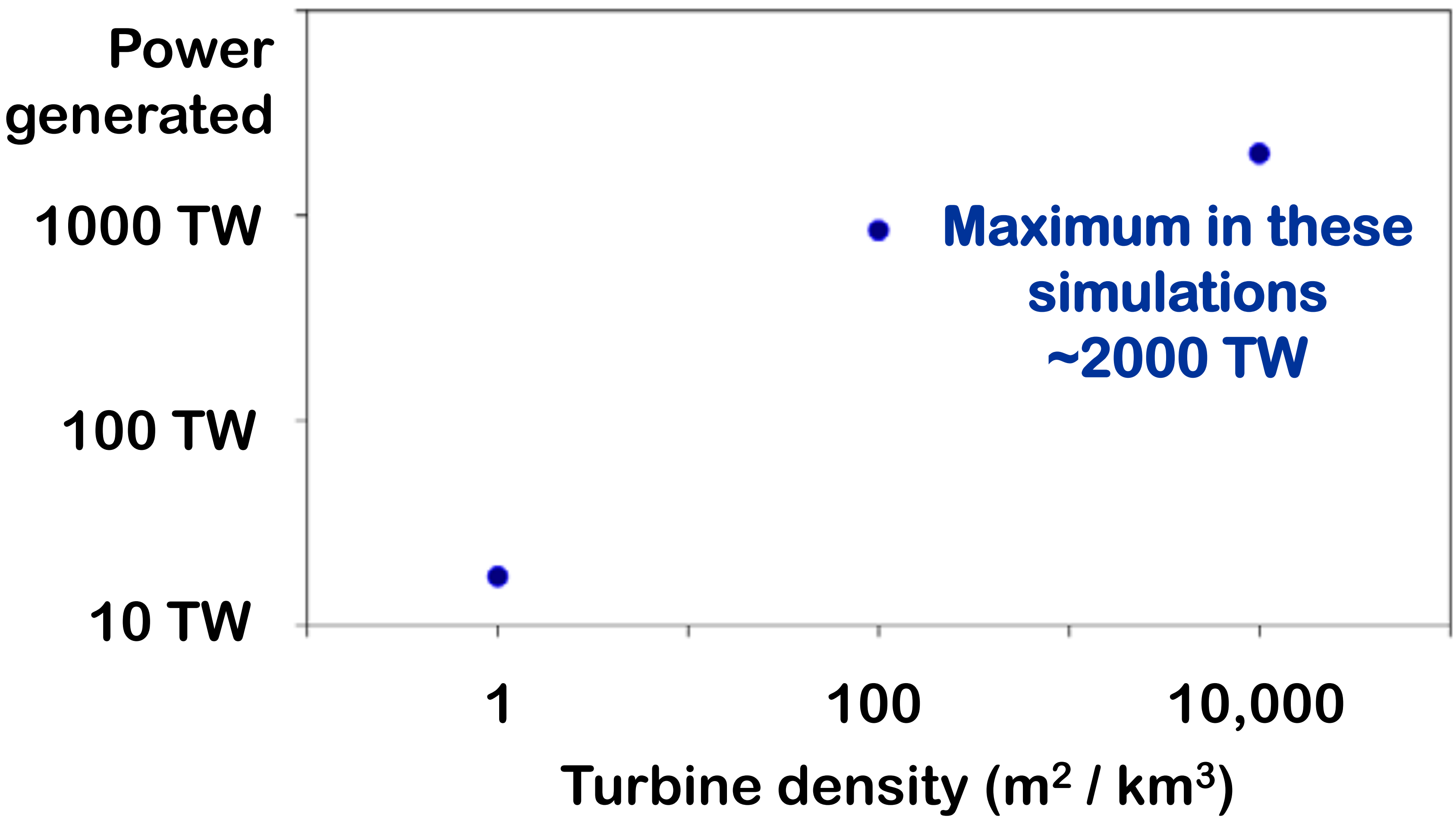
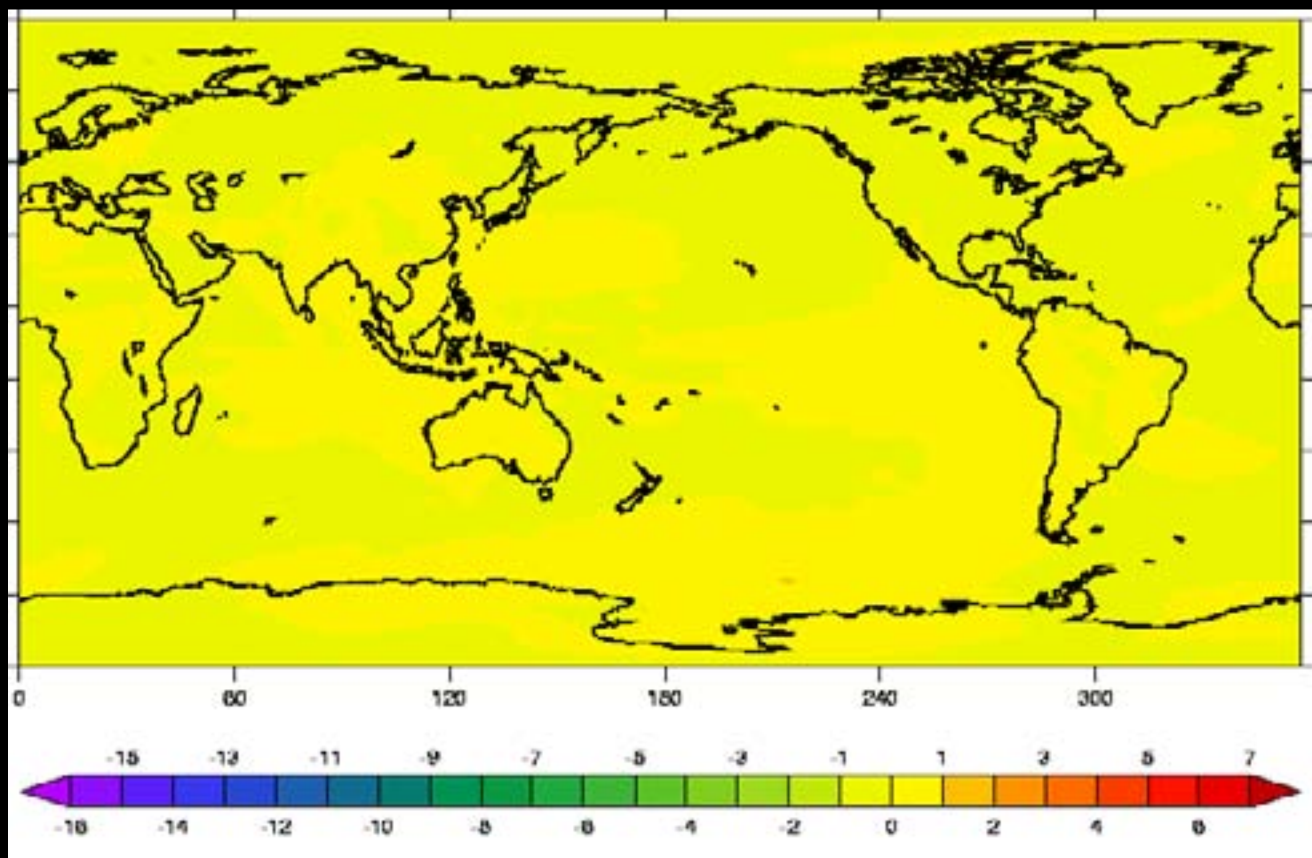
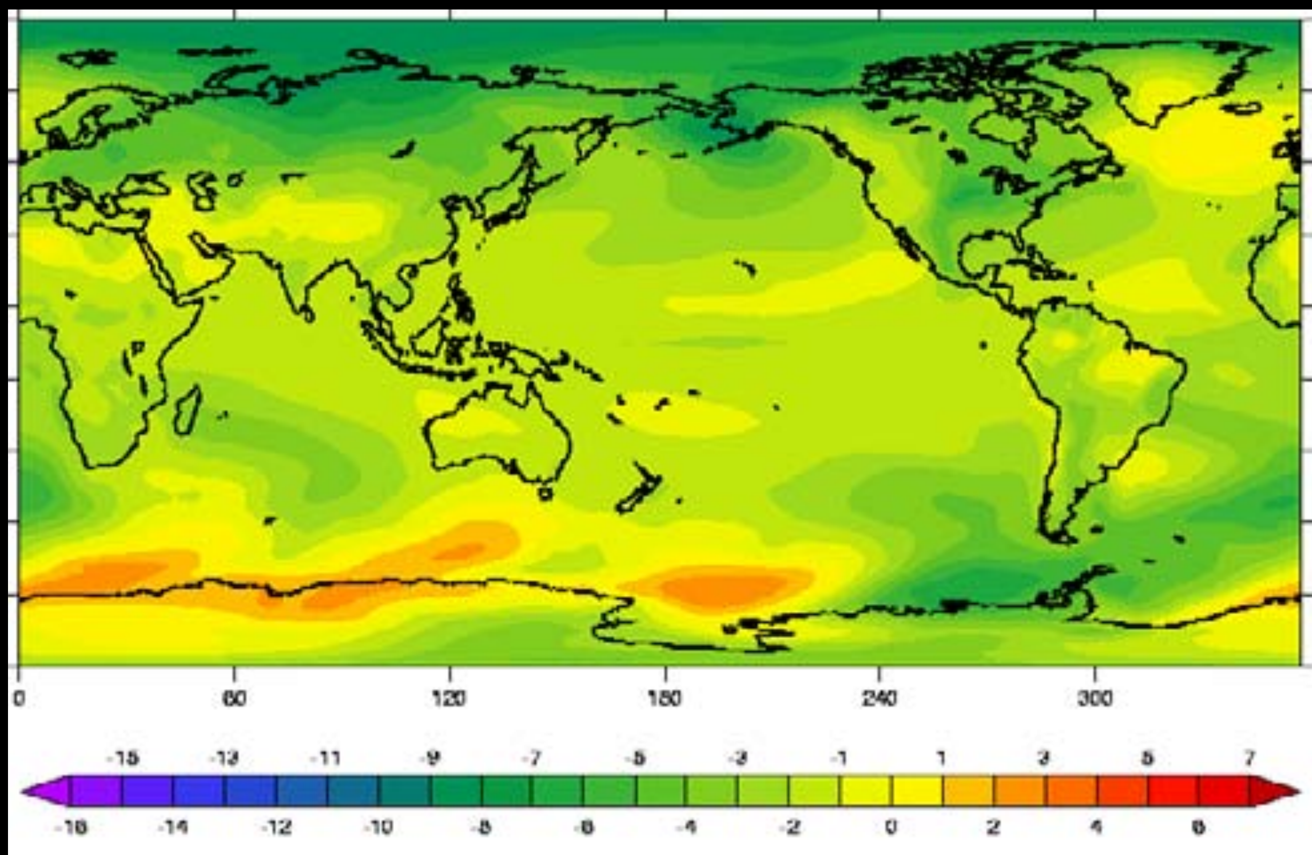


Temperature effects of massive deployment
1 m^2 / km^3 (about 18 TW)
cooling of 0.04 °C



°C

Temperature effects of massive deployment
100 m^2 / km^3 (about 84 TW)
cooling of 2.2 °C

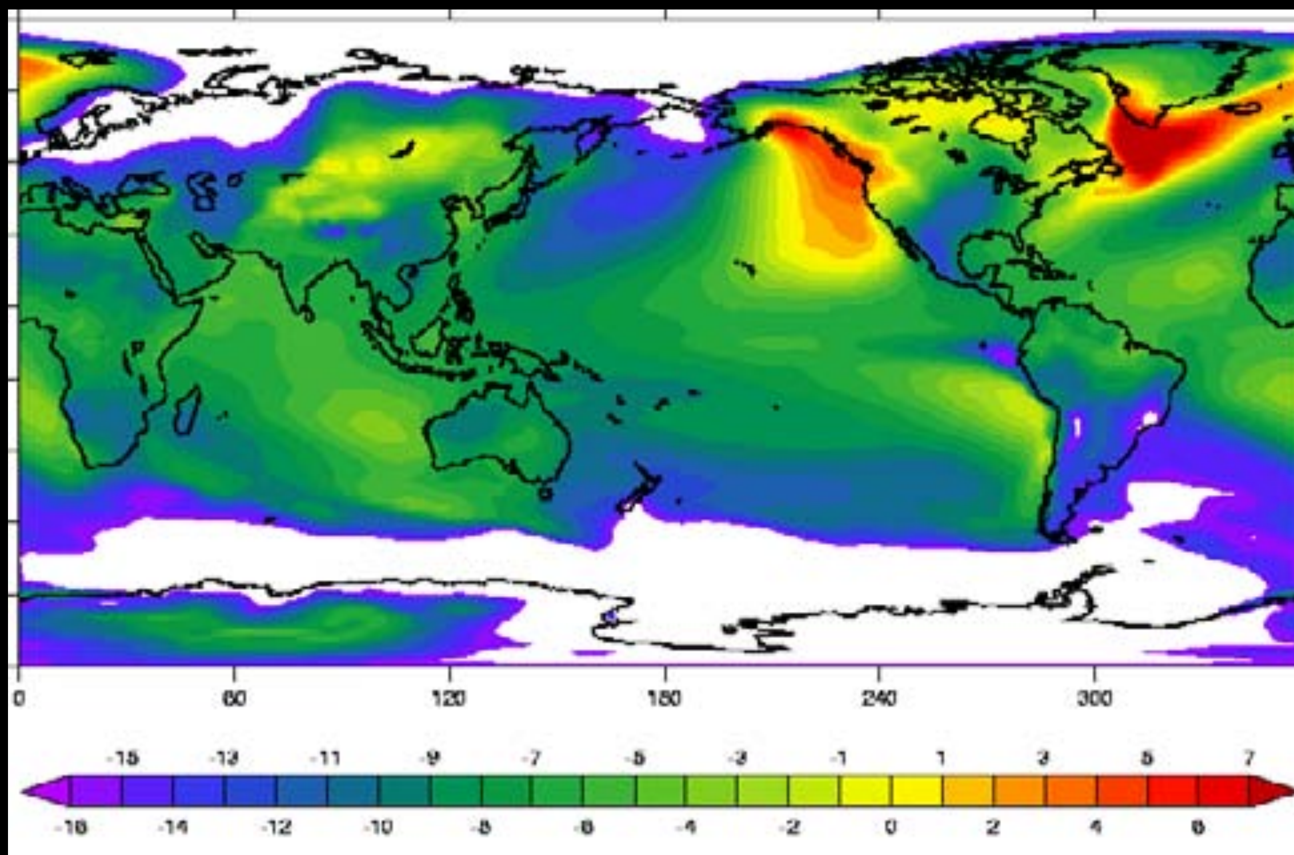


°C

Temperature effects of massive deployment

$10{,}000\ m^2 / km^3$ (about 2,010 TW)

cooling of 9.6 °C

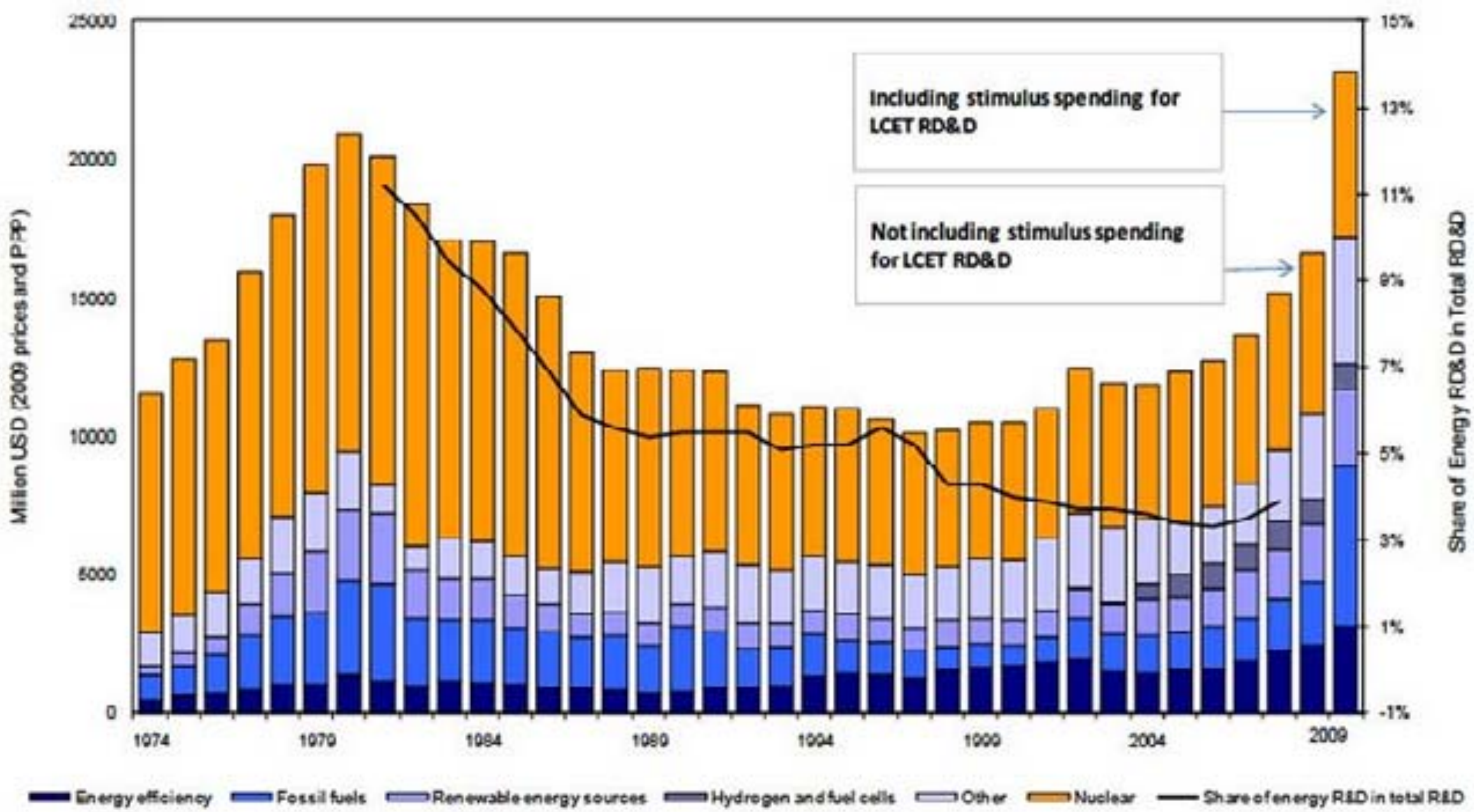


°C

At a turbine density of 1 m^2 / km^3, about 18 TWe are produced, more than enough to power modern civilization, and with no detectable adverse effects on climate.

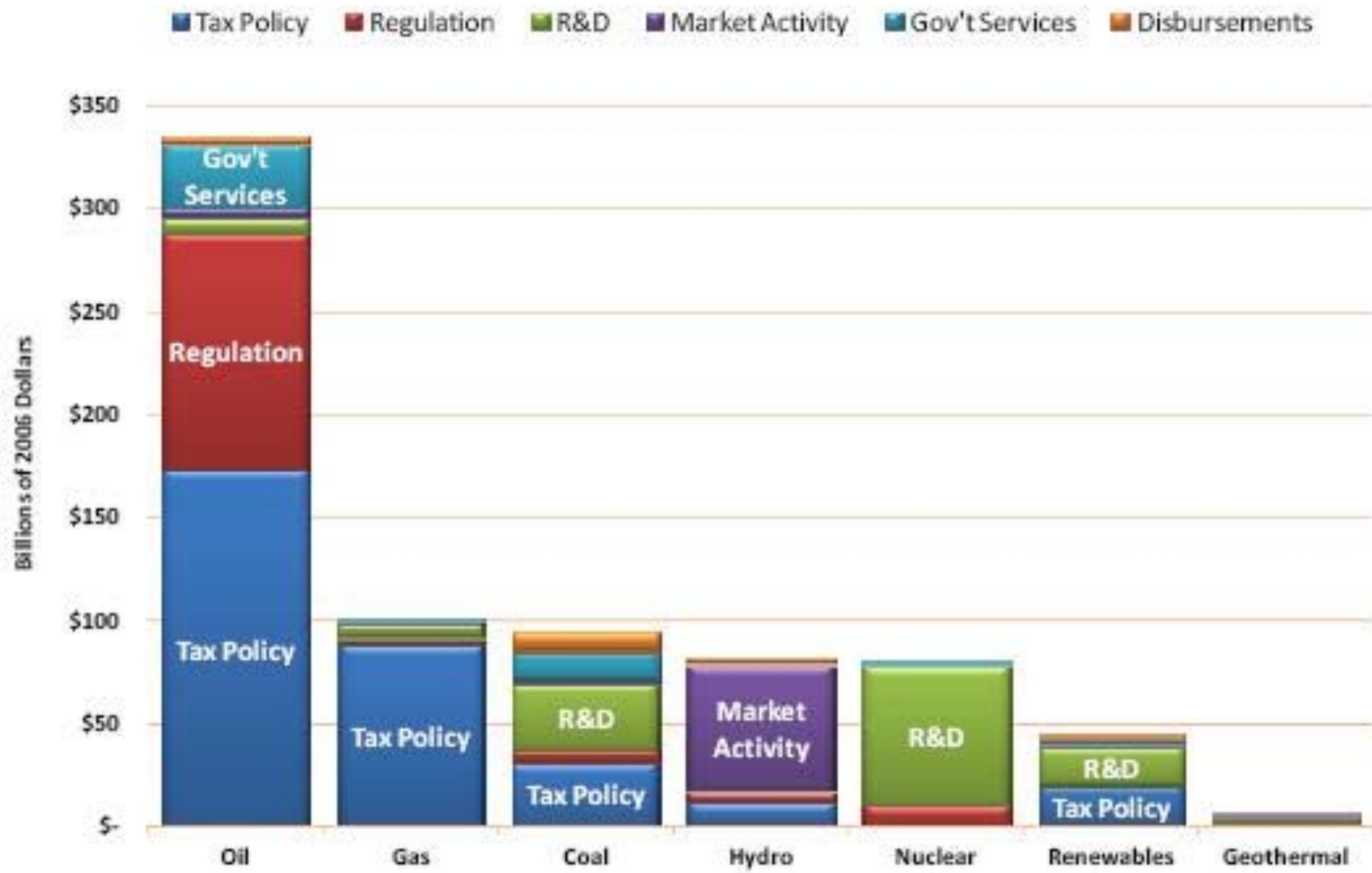
If you interfere with geophysical flows beyond the level of a few percent, unwanted side effects are likely to manifest themselves.

Figure 1: Government RD&D expenditure in IEA member countries, 1974-2009



http://iea.org/papers/2010/global_gaps.pdf

Exhibit 3 – Comparison of Federal Expenditures for Energy Development, 1950–2006



http://www.nei.org/filefolder/Bezdek_Report.pdf

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