

About— Polar Ice

New York Times
24 October 1954

How fast does it melt? An expedition seeks the answer.

By BENJAMIN POWELL

ONE of the objectives in the forthcoming American expedition to Antarctica is to check on the status of the stupendous ice fields and glaciers of that little-known continent. The particular point of inquiry concerns whether the ice is melting at such a rate as to imperil low-lying coastal areas through raising the level of the sea in the near future. There is no saying as yet how imminent that threat might be, but there is little question that there is enough of the frozen stuff around to cause trouble if it all melted suddenly.

IN THE SOUTH

The Antarctic Continent—about 5,000,000 square miles in area, and only one-



An ice breaker off Ross Barrier.

...not be likely
...great effect if it

HOW MUCH DANGER?

A greater potential danger (nevertheless remote) is the Greenland Ice Cap. Here is an enormous, rounded hump of ice, piled over the mountains and valleys of the world's largest island. The ice covers about 700,000 square miles, leaving a sparse fringe of exposed rock around the coast. The thickness is believed to average about 1,000 feet, but soundings have indicated depths of 10,000 feet or more.

Elsewhere in the northern hemisphere are great deposits of ice and snow in the Himalayas, Alaska, the Alps and the Scandinavian mountains.

There is no doubt that the ice of the far north is melting faster than it is replaced by new snowfalls (actually most of the Arctic gets only about 8 inches of precipitation a year). Glaciers all around the northern world are receding at a clearly measurable pace, and have been for several generations. Yet the rate of melt is so slow as to leave no rise in tide levels sufficient to alarm humans. Greater solar radiation is given as the cause of the recession, but greater solar radiation also increases the rate of evaporation.

Assuming a very rapid, almost instantaneous melting of Greenland's ice alone, it has been estimated that the level of the oceans would be increased about twenty-five feet. But, scientists point out, conditions bringing that about would be of such a cataclysmic nature that there would probably be no one left around to do the worrying, anyway.

Read Widely

This section and the chapter notes are also available at *Global-Fever.org*, augmented with live links.

When undertaking this book on our global fever, I decided to write a cheerful book in parallel. It became *Almost Us: Portraits of the Apes*. You might wish to employ a similar back-and-forth strategy when reading more about our big problem.

If you haven't already, I'd suggest reading

Jared Diamond. *Collapse: How Societies Choose to Fail or Succeed*. Viking, 2005. Anthropology and ecology of past societies, not specifically global warming but the essential stage-setting. Excellent, as usual.

Al Gore. *An Inconvenient Truth*. Rodale Press, 2006. Closely follows the world-famous film that won an Oscar. As Jim Hansen says, "Al Gore may have done for global warming what 'Silent Spring' did for pesticides."

Then consider reading one or more of these books:

Robert Henson. *The Rough Guide to Climate Change*. Rough Guides, 2006. Don't be fooled by the travel-books connection. It's one of the best of the reader-friendly books that could also be used for climate courses. The author is a science writer at the National Center for Atmospheric Research in Boulder, Colorado.

Mark Lynas. *Six Degrees*. Fourth Estate, 2007. His chapter on the consequences of a 1°C fever is sobering enough, but then he works his way through the consequences of the 2, 3, 4, 5, and 6° fevers and "Choosing our future." Very well done. It also shows that with a first-class honours

degree in history and politics, you can read and understand much of climate science.

Joseph J. Romm. *Hell and High Water*. William Morrow, 2007. An excellent book of climate science plus advocacy by a former acting Assistant Secretary in the U.S. Department of Energy. The author is a Ph.D. physicist and oceanographer by training but his father was a journalist—and it shows.

Then consider these when branching out:

Brian Fagan. *The Long Summer: How Climate Changed Civilization*. Basic Books, 2004.

Tim Flannery. *The Weather Makers*. Atlantic Monthly Press, 2005.

Ross Gelbspan. *Boiling Point*. Basic Books, 2004.

Elizabeth Kolbert. *Field Notes from a Catastrophe*. Bloomsbury, 2006.

Eugene Linden. *The Winds of Change*. Simon & Schuster, 2006.

James Lovelock. *The Revenge of Gaia*. Penguin/Allen Lane, UK, 2006.

George Monbiot. *Heat: How to Stop the Planet Burning*. Penguin/Allen Lane, UK, 2006.

Fred Pearce. *The Last Generation: How Nature Will Take her Revenge for Climate Change*. Eden Project Books, UK, 2006.

A. Barrie Pittock. *Climate Change: Turning Up the Heat*. CSIRO, Australia, 2005.

Phillip W. Schewe. *The Grid*. Joseph Henry Press, Washington DC, 2007.

Spencer R. Weart. *The Discovery of Global Warming*. Harvard University Press, 2003. Updated version at www.aip.org/history/climate.

On the web, I would initially avoid search engines because of the disinformation problem for climate matters. Try

RealClimate.org, done by real climate scientists,

Society for Environmental Journalism at www.sej.org/resource/index18.htm.

Professor Stephen Schneider's climate website, stephenschneider.stanford.edu,

American Institute of Physics, www.aip.org/history/climate/links.htm

Pew Center on Climate Change, www.PewClimate.org,

Climate Institute at *Climate.org*,

ClimatePrediction.net

The National Center for Atmospheric Research at www.ucar.edu/research/climate/future.jsp.

Union of Concerned Scientists at *ClimateChoices.org*.

Rocky Mountain Institute at www.RMI.org.

World Resources Institute, at *WRI.org*. Their *Navigating Numbers*, by Kevin A. Baumert, Timothy Herzog, and Jonathan Pershing, is quite useful.

BBC's updated climate pages at [www.bbc.co.uk/sn/hottopics-climatechange/](http://www.bbc.co.uk/sn/hottopics/climatechange/)

New York Times at topics.nytimes.com/top/news/science/topics-globalwarming/index.html?8qa.

American Association for the Advancement of Science at
www.aaas.org/climate/

They all have a list of recommended links to other sites, regularly updated. The Society of Environmental Journalists has an excellent list of lists for all sides of climate change at www.sej.org/resource-/index18.htm—it even includes the Birdwatcher's Guide to Global Warming!

Armed with some of the science, you can gradually branch out to the wider web. See how quickly you can spot the front organizations for the not-a-problem promoters of business as usual through more delay. Most of them have invented fancy names for themselves in order to slip past your guard; most include some good science to help disguise their propaganda. Once you are good at it, test your skills at GlobalWarming.org. See the Union of Concerned Scientists' 2007 report on ExxonMobil's \$23-million attempt to mislead the public at ucsusa.org/assets/documents/global_warming/exxon_report.pdf.

More advanced readers should take a look at

Intergovernmental Panel on Climate Change, *2007 Summary for Policymakers* for each of the three working IPCC groups, at www.ipcc.ch. There are also Technical Chapters with all the references up to late 2005.

U.S. Global Change Research Program, *Climate Change Impacts on the United States*, USGCRP, 2001
www.usgcrp.gov/usgcrp/Library/nationalassessment/

The Arctic Council, *Arctic Climate Impact Assessment*, Arctic Council, 2005. www.acia.uaf.edu

James Hansen, "A slippery slope," *Climatic Change* 68 (February 2005): 269-279. At dx.doi.org/10.1007/s10584-005-4135-0.

Illustration List

Most of these illustrations may be freely borrowed for non-commercial and educational uses. They may be downloaded from *Global-Fever.org*.

Edvard Munch, *The Scream of Nature* vii

1. The Big Picture

1956 newspaper clipping on global warming 2

2. We're Not in Kansas Anymore

Tornado in Dimmit, Texas 12

Floods increase worldwide, decade after decade 12

Three tropical cyclones at once 14

Muir Glacier, Alaska 17

More forest fires when hot 18

Wildfires increase worldwide 18

Rain Decrease 1925-1999 North of Equator 18

3. Will This Overheated Frog Move?

Rise in global average temperature after 1850 23

The Keeling curve of rising CO₂ 23

History of fossil fuel uses and projections beyond 2004 26

The rise and fall of CFCs 27

Antarctica's giant ozone hole of 2006 28

4. "Pop!" Goes the Climate

The collapse of the Larsen B ice shelf in 2002 38

Surface melt beginning in West Antarctica 39

5. Drought's Slippery Slope

Oklahoma farm yard after 1935 dust storm 43

1934 and 1956 drought maps of U.S. 45

Decade-scale droughts in western U.S. after 1600 47

Major droughts in U.S. West during Little Age Age 48

Dust dune scene in Dust Bowl 48

Century-scale droughts in the last 2,000 years 52

Wall of dust in 1935 Texas 54

Wall of dust approaching an Oklahoma Main Street	54
Drip irrigation diagram	57
Agricultural water wasted	57
6. Why Deserts Expand	
Evaporation loss with center-pivot irrigation	58
Crop circles in Kansas	58
The ups and downs of wet and dry air	60
Desertification from expansion of Hadley Cells	61
Parched vegetation near Perth, Australia	62
Areas of reduced rainfall by 2080	64
Low morning clouds along the Amazon River	65
Amazon Basin fires and flammability zones	66
Jump in CO ₂ if tropical forests burned	69
7. From Creeps to Leaps	
New Orleans after the dikes failed	70
Inside a Seattle pothole	74
Teton Dam failure in progress	75
Airplane stalls and the power curve	81
Hillside plow	82
The collapse of the Newfoundland fisheries	82
8. What Makes a Cycle Vicious?	
Thermometers showing feedback effects	86
Negative feedback stabilizes engine speed	88
Light bulbs and the sun's input to Earth	90
Greenland thaw	94
Maximum and minimum extent of African savannas	97
9. That Pale Blue Sky	
Dust clouds from the Sahara blow across the Atlantic	100
Tug of War that is heating and cooling the Earth	103
Mount Pinatubo eruption into the stratosphere	105
The Earth's brightness (albedo map)	106
Agricultural fires worldwide	109
Special kerosene torch for starting agricultural fires	109

10. Slip Locally, Crash Globally

Graph of the growth in world use of fossil fuels	110
Fallout from coal-fired coal plants in the U.S.	110
Blue pond of melt water on shoulder of Greenland	113
Long lakes wedging open crevasses	115
Lakes along shoulder of western Greenland	116
Icebergs emerging from Jacobshavn Isbrae	117
West Antarctic Ice Sheet map	118
Sea-level rise 125,000 years ago was 6 m higher	120
Deltas of Asian rivers flooded by 6 m rise in sea level	123
Bangladesh areas flooded by 6 m rise	123
European areas flooded by a 6 m rise	124
Detail showing the Low Countries and 6 m rise	125

11. Come Hell and High Water

Map of Atlantic and Gulf Coasts with 6 m rise	126
The capital of the Maldives behind a sea wall	128
What's left of Florida after a 6 m rise	129
What's left of the Gulf Coast after a 6 m rise	131
U.S. Capitol and Pennsylvania Avenue with 6 m	133
New York and Newark with 6 m rise	134
World Trade Center entrance with 7 m rise	136
Lower Manhattan and Brooklyn with 7 m rise	136
Subway stair cascades during 1992 N'easter flood	137
Thames Barrier holding back the highest tides	137
Projected storm surge barriers for New York City	137
Population density of the U.S. East Coast strip	138
East Coast strip with 6 m sea-level rise	139
Boston and the new Harvard Peninsula with 6 m	140
San Francisco, Seattle, and Vancouver	141
Sea-level rise during the twentieth century	143
Sea-level rose much faster than 2001 IPCC estimates	144
Sea-level has risen faster than 3 m per century	145
Icequakes under Greenland outlet glaciers	146

12. Methane Is the Double Threat

Greenhouse gas fluctuations for 400,000 years	150
Canary and coal miner	153

Permafrost thaw lakes in Siberia	155
The ice that burns	156
The methane offshore of Santa Barbara, California	156
The growth in methane is slowing	157
Agriculture is a third of the emissions pie	159
The global fever score: HUMANS 13, SUN 1	160

13. Sudden Shifts in Climate

Two stable states	162
Trucks that passed the tipping point	162
Abrupt climate flips during the last 100,000 years	164
El Niño and La Niña episodes since 1970	165
Shift in Pacific Ocean thermocline during El Niño	167
Ups and downs of air across the Pacific Ocean	167
Sea level change during El Niño	169

14. A Sea of CO₂

Carbon feedbacks exaggerate predicted warming	171
A carbon-sinking zooplankton	172
World map for tiny ocean plants	172
Coral bleaching from environmental stress	174
Coral bleaching and wipeout in the Caribbean in 2005	175
Diatoms	177
The pH of ocean waters is becoming more acidic	178
Bloom in the Pacific Northwest	180
Sand dust plumes in southern Africa	180
Large bloom fertilized by dust plume from Iceland	180
Iron mixing on the Kerguelen plateau	181
Losing forest carbon sinks	182
Wave-driven pump brings nutrients to surface	184

15. The Extended Forecast

Carbon emission scenarios for 2020 and 2040 turnarounds	188
Thirty-eight years of a Greenland ice core	190
2007 IPCC scenarios of twenty-first century fever	192
Climate sensitivity range of estimates	194
Arctic sea ice declined faster than projections	196
Giant wind turbine in Sweden	201

16. Doing Things Differently

Fossil fuel use per person in major countries	203
Electricity per person in the seven most populated states	206
California has held electricity per person constant	207
68% of U.S. electricity from fossil fuels, grew 140%	209
France gets only 9% from fossil fuels, grew 260%	209
China gets 82%, grew 1100% in 32 years	210
U.K. gets 75%, grew only 60%	210
Switzerland gets 1%, grew 100%	211
India gets 85%, grew 1000%	211
A 1600 mw coal-fired power plant near Las Vegas	212
Three entire coal trains a day	212
Where U.S. energy (all uses) comes from	214
Where it goes	214
Electricity's use of energy (70 percent wasted)	215
The terminus of a 1,500 km DC transmission line	215
The best places for wind farms in the U.S.	216
North American and offshore sites for wind farms	216
Offshore sites for wind farms	216
The flywheel principle and the spinning wheel	217

17. Cleaning Up Our Act

Mount Baker and two shoreline refineries	218
Wedging strategy for stopping growth in emissions	223

18. The Climate Optimist

The power of basic knowledge (medical branch)	229
Additional impacts as global fever rises	230

19. Turning Around by 2020

The Gap between Business-as-usual and a recovery plan	238
The lights left on, all night long (U.S.)	243
The clean side of a 750 mw power plant	246
Zimmer power plant on the Ohio River	247
Few coal-fired power plants have been retrofitted in U.S.	248
Planned additional coal plants in the U.S.	248
The best places for geothermal energy in the U.S.	251
Hot Rock Energy two-well diagram	253
Two-well geothermal power plant	255

Map of nuclear power plants of the world	257
Maps of U.S. deaths from coal plant pollution	261
Comparison of AC and DC power transmission	265
Solar roofs in Ota City, Japan	266
Concentrating solar tower in Seville	267
Table of C-free energy sources, advantages and downsides	271
20. Arming for a Great War	
The path to climate restoration	274
21. Get It Right on the First Try	
The evolution of world CO2 emissions	280
The collapse on Easter Island	293
Where you are standing was underwater	317
About the author	332

Notes

The following notes are also on the web at *Global-Fever.org*, referenced by this book's page numbers and including web links to many of the citations. Author (year) citations usually refer to a book in the **What to Read** section.

vii Munch lithograph at www.jesuits.ca/orientations/Munch2.html. Letter from en.wikipedia.org/wiki/The_Scream.

Chapter 1.

The Big Picture

3 Guy Callendar, "The Artificial Production of Carbon Dioxide and Its Influence on Temperature." *Quart. J. Roy. Meteorol. Soc.* 64 (1938): 223–40.

6 Coal twice as bad, per kilowatt-hour generated: en.wikipedia.org/wiki/Energy_content_of_biofuel.

7 These estimates do not include the effects of tropical forest fires on carbon emissions, which are much more difficult to measure. When the 1997/98 El Niño episode provoked severe droughts in the Amazon and Indonesia, large areas of tropical forest burned, releasing 0.2 to 0.4 Pg of carbon to the atmosphere. If droughts become more severe in the future through more frequent and severe El Niño episodes, or the dry season becomes lengthier due to deforestation induced rainfall inhibition, or there are rainfall reductions due to global warming, then substantial portions of the 200 Pg of carbon stored globally in tropical forest trees could be transferred to the atmosphere in the coming decades. Global carbon emissions from fires during 1997/98 El Niño are estimated at 2.1 ± 0.8 PgC and South and Central America contributed ~30% of global emissions from fires. See www.joanneum.at/Carboinvent/post2012/_Bird/santilli_et_al_2005.pdf.

11 Bill McKibben, in the *New York Review of Books* (16 November 2006) at www.nybooks.com/articles/19596.

Chapter 2.**We're Not in Kansas Anymore**

12 Tornado in Dimmit, Texas: photograph by Harald Richter at www.photolib.noaa.gov/nssl/nssl0179.htm

14 Three hurricanes south of Japan on August 7, 2006, from visibleearth.nasa.gov/view_rec.php?id=20946, credit Jeff Schmaltz. "The slanting diagonal feature through the image is sunlight bouncing off the ocean into the MODIS instrument [on the satellite], a phenomenon called sunglint. The very bright swath is where the reflection is strongest."

14 Goran Ekstrom, Meredith Nettles, Victor C. Tsai, "Seasonality and increasing frequency of Greenland glacial earthquakes." *Science* 311 (2006): 1756–1758.

15 Jared Diamond, *Collapse: How Societies Choose to Fail or Succeed*. (Viking 2005), 6.

16 David Montgomery, *Dirt: The Erosion of Civilizations* (University of California Press, 2007).

17 Muir glacier pair: nsidc.org/cgi-bin/gpd_run_pairs.pl

19 Richard Lindzen, in *Newsweek* (2007) at www.msnbc.msn.com/id/17997788/site/newsweek. See also Daniel Grossman's interview, "Profile: Dissent in the Maelstrom," *Scientific American* (November 2001). Lindzen is a serious climate scientist who thinks that an "infrared Iris" associated with stratus cloud production and tall thunderheads will result in a climate sensitivity of only one-third the IPCC estimates. I hope he is right, though personally I would not go around telling people not to worry on the strength of a preliminary theory—nor describe ExxonMobil as "the only principled oil and gas company I know in the US." See news.bbc.co.uk/2/low/business/6595369.stm.

For the less established climate dissenters, a tendency to shift targets with time raises questions of whether it's really about the science or about something else. "Whatever the science is, they will try to find ways to question it," says Naomi Oreskes, a geologist and science historian at the University of California, San Diego. "That makes it clear that the issue for them is not the science." See Michael Hopkin, "Climate sceptics switch focus to economics: As the scientific case strengthens, dissenters change tack." *Nature* (10 February 2007) 582, at dx.doi.org/10.1038/445582a.

Floods and wildfires are from the figures in the 2007 IPCC report, in the WG 1 Summary for Policymakers at www.ipcc.ch. For zonal precipitation: Xuebin Zhang, et al, "Detection of human influence on twentieth-century precipitation trends," *Nature* 448(26 July 2007): 461–465, at dx.doi.org/10.1038/nature06025.

Governor Arnold Schwarzenegger of California, quoted by Thomas Friedman, "The power of green," *New York Times Magazine* (15 April 2007) at www.nytimes.com/2007/04/15/magazine/15green.t.html.

The correlation of temperature with western U.S. wildfires is from A. L. Westerling, H. G. Hidalgo, D. R. Cayan, and T. W. Swetnam. "Warming and earlier spring increase western U.S. forest wildfire activity." *Science* 313 (5789): 940 (18 August 2006). See dx.doi.org/10.1126/science.1128834.

19 John Holdren, "The energy innovation imperative." *Innovation* (Spring 2006): 11.

Chapter 3.

Will This Overheated Frog Move?

22 Svante Arrhenius, "On the influence of carbonic acid in the air upon the temperature of the ground." *Philosophical Magazine and Journal of Science (fifth series)* 41 (1896): 237–275. See Weart's history at www.aip.org/history/climate.

Roger Revelle and Hans E. Suess. "Carbon dioxide exchange between atmosphere and ocean and the question of an increase of CO₂ during the past decades." *Tellus* 9 (1957) 18-27.

26 Jim Hansen's presentation at the National Academy of Sciences in April 2006 is on his Columbia University website, www.columbia.edu/~jeh1.

28 Ozone hole, see earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=17436.

29 www.monbiot.com/archives/2005/10/25/our-own-nuclear-salesman/.

30 Ten recommendations for reducing U.S. carbon emissions:

1. Immediately freeze carbon dioxide emissions and then begin a program to reduce them by at least 90% by 2050.
2. Replace the payroll tax for Social Security and Medicare with a tax on pollution, particularly carbon dioxide.
3. Use a portion of the tax on pollution to help low-income individuals adapt as carbon emissions are reduced.

4. Work towards de-facto compliance with the Kyoto Protocol to the United Nations Framework Convention on Climate Change, and create a new, strong international treaty with a starting date of 2010 instead of 2012.
5. Enact a moratorium on the construction of any new coal-fired power plants that are not compatible with carbon capture and sequestration.
6. Create an 'Electranet,' a smart grid in which power generation is widely distributed. Homeowners and small businesses could use solar and wind energy generators and sell that energy into the grid at a rate that is determined by the market.
7. Raise Corporate Average Fuel Economy (CAFE) standards for automobiles, and set energy standards for other industries.
8. Set a date for a ban on incandescent light bulbs.
9. Create a 'Connie Mae,' a carbon-neutral mortgage association that would help homebuyers pay for energy reduction measures such as insulation and energy-efficient windows that can have high upfront expenses.
10. Have the Securities and Exchange Commission (SEC) require the disclosure of carbon emissions in corporate reporting.

From The Honorable Al Gore's testimony to the U.S. Congress in March 2007. See *EOS* 88(10 April 2007): 171.

All necessary, but far too weak. Maybe this is what it takes to get Congress moving at last, but those ten are the easy stuff, what would have been appropriate twenty years ago. If we don't do considerably more, and quickly, it will be like rearranging the desk chairs on the *Titanic*.

I would instead emphasize the 2020 urgency requiring many new nuclear or geothermal power plants, retiring many old coal plants, converting to plug-in hybrid electric vehicles, and subsidizing DC power lines to developing countries with coal.

30 UN Secretary-General Ban Ki-moon, at press conference (8 June 2007). See www.UN.org/apps/sg/offthecuff.asp?nid=1035.

31 Andrew Revkin, "Global meltdown," *AARP Magazine* (July 2007) at www.aarpmagazine.org/lifestyle/global_meltdown.html.

32 R. A. Bindshadler et al, "Tidally controlled stick-slip discharge of a West Antarctic ice stream," *Science* 301 (2003):1087-89.

- 32 Joseph J. Romm, *Hell and High Water* (William Morrow, 2007), 2.
 32 General Gordon R. Sullivan, *securityandclimate.cna.org/report* at p.10.

Chapter 4.

“Pop!” Goes the Climate

39 This satellite image shows the 2002 breakup of the Larsen B Ice Shelf. See Eugene Domack et al, “Stability of the Larsen B ice shelf on the Antarctic Peninsula during the Holocene epoch.” *Nature* 436 (2005): 681–685. This region, covering approximately 3250 km² with 200 m thick ice, had been continuously glaciated since before the end of the last glacial period. Adapted from NASA Terra/MODIS imagery via *www.GlobalWarmingArt.com*. The 2005 melt/refreeze episode is at *earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=17661*

37 William H. Calvin, “The great climate flip-flop,” *Atlantic Monthly* (January 1998). The story is elaborated in *A Brain for All Seasons: Human Evolution and Abrupt Climate Change*. (University of Chicago Press, 2002).

Chapter 5.

Drought’s Slippery Slope

40 *woodyguthrie.org/Lyrics/Dust_Storm_Disaster.htm*.

43 My synopsis of drought feedbacks derives from a brief talk in 2000 by J. M. Wallace.

43 “Fleeing a dust storm” shows farmer Arthur Coble and his sons in Cimmaron County, Oklahoma. By Arthur Rothstein, U.S. government photographer, April, 1936 (Library of Congress LOC-00241v.jpg).

44 Recent evaporation seeding the next rainfall: that is going to be a big problem in the Amazon. Today, the flat bottom of the clouds (where the dew point is) isn’t very high off the ground. But with greenhouse warming, that flat bottom will move up to much higher in the sky—and so not mix very well with the recent evaporation. The clouds will continue westward until running into the Andes and dropping some rain there. It will flow down the Amazon river as it does now but the lush vegetation on the riverbanks will be gone—likely burned off during the onset of drought.

47 Connie A. Woodhouse, Jonathan T. Overpeck, “2,000 Years of

Drought Variability in the Central United States," *Bulletin of the American Meteorological Society* 79(1998): 2693–2714.

49 Worster quote at www.pbs.org/wgbh/amex/dustbowl/peoplevents/pandeAMEX06.html.

51 Also from Woodhouse and Overpeck (1998).

51 A 1 m rise in sea level would change the frequency of what are now 100-year floods in metropolitan New York to once in every four years events. See ccir.ciesin.columbia.edu/nyc/ccir-ny_q2a.html and C. Rosenzweig and W.D. Solecki (Eds.). *Climate Change and a Global City: The Potential Consequences of Climate Variability and Change - Metro East Coast*. Report for the U.S. Global Change Research Program, National Assessment of the Potential Consequences of Climate Variability and Change for the United States (Columbia Earth Institute, New York, 2001).

52 Although originally named the Medieval Warm Period, the temperature change does not seem to have been uniform around the globe. It is best thought of as a period of widespread climate anomalies preceding the better-defined Little Ice Age.

53 Drought frequency: Richard Seager et al, "Model projections of an imminent transition to a more arid climate in southwestern North America," *Science* 316 (25 May 2007): 1181–1184 at dx.doi.org/10.1126/science.1139601.

53 Eleanor J. Burke, Simon J. Brown, Nikolaos Christidis, "Modeling the Recent Evolution of Global Drought and Projections for the Twenty-First Century with the Hadley Centre Climate Model," *Journal of Hydrometeorology* 7 (October 2006): 1113–1125.

54 Dust wall photos from NOAA's George E. Marsh Album via commons.wikimedia.org/wiki/Image:Dust.

57 Irrigation, see ga.water.usgs.gov/edu/irsprayhigh.html and www.worldwatch.org/node/811.

58 Kansas crop circle irrigation photo from earthobservatory.nasa.gov/Newsroom/NewImages/Images/kansas_AST_2001175_lrg.jpg.

Chapter 6

Why Deserts Expand

59 Kim Stanley Robinson, "Imagining Abrupt Climate Change: Terraforming Earth." Amazon Short essay (2005).

61 George Hadley, "Concerning the cause of the general trade

winds," *Philosophical Transactions*, 39 (1735).

62 Qiang Fu, Celeste M. Johanson, John M. Wallace, Thomas Reichler. "Enhanced mid-latitude tropospheric warming in satellite measurements," *Science* 312 (26 May 2006): 1179.

62 Richard Seager, et al., "Model projections of an imminent transition to a more arid climate in southwestern North America." *Science* 316 (25 May 2007): 1181–1184 at [dx.doi.org/10.1126/science.1139601](https://doi.org/10.1126/science.1139601).

62 Perth: Flannery (2005): 130. Pittock (2005): 141.

63 Long-term drought indicator blends at www.drought.unl.edu/dm/monitor.html.

68 Daniel Nepstad, see www.whrc.org/resources/online_publications/essays/2006-08-Nepstad-Independent.htm.

68 George Monbiot, *Heat* (2006): xi.

68 Fred Pearce, "Global meltdown." *The Guardian* (30 August 2006). environment.guardian.co.uk/climatechange/story/0,,1860560,00.html

Chapter 7.

From Creeps to Leaps

70 U.S. Coast Guard photograph of New Orleans on the day after Hurricane Katrina, 2005, after three levees had failed.

72 Robert Frost, in *Selected Prose of Robert Frost*, edited by H. Cox and E. C. Lathem (Collier, 1986), 33–46.

73 Snowballing, see Pittock (2005): 110ff, for an excellent discussion on nonlinear effects in climate.

75 The Teton Dam, 44 miles northeast of Idaho Falls in southeastern Idaho, failed abruptly on June 5, 1976 when being filled for the first time. Engineers were actively looking for leaks and saw a wet spot. However, the collapse progressed so rapidly that several large bulldozers were lost and downstream communities only had one hour of warning. The dam failure released nearly 300,000 acre feet of water, which flooded farmland and towns downstream at the loss of 14 lives and a cost of \$1 billion. See npdp.stanford.edu/npdp/home/npdpimages/Photo%20Gallery/fullimages/IDS00007_003_f.jpg.

76 Thomas R. Malthus, *An Essay on the Principle of Population* (printed for J. Johnson, London, 1798).

77 Restaurant lead-lag dynamics: muller.lbl.gov/pages/

news%20reports/ebexp.htm.

81 David Montgomery, *Dirt: The Erosion of Civilizations* (University of California Press, Berkeley, 2007).

82 James Martin, *The Meaning of the 21st Century* (Eden Project, London, 2007): 30. Graph of cod catch from *www.fao.org/docrep/005/y3684e/y3684e05.htm*.

85 Al Gore, on the Charlie Rose Show (September 2006).

85 Raymond T. Pierrehumbert, "Climate Change: A Catastrophe in Slow Motion," *Chicago Journal of International Law* 6 (Winter 2006): 573. See *cjil.uchicago.edu/past-issues/twin06.html*.

Chapter 8.

What Makes a Cycle Vicious?

88 Watt story from James Lovelock, *The Revenge of Gaia* (Allen Lane: London, 2006). See *en.wikipedia.org/wiki/Centrifugal_governor*. The figure is from "Discoveries & Inventions of the Nineteenth Century" by R. Routledge, 13th edition, published 1900.

89 Good use is made of positive feedback by nerve cells and muscles. It's what makes things happen quickly. It shortens your reaction time enough so that you have quick reflexes and don't go bouncing down a flight of steps. Your computer uses positive feedback in much the same way to shorten each step of the computing cycle. When the first flip-flop circuits were invented for computer bits, they operated on about the same timescale as nerve cells (milliseconds). Now they (but not the nerve cells) are a million times faster, operating in nanoseconds.

92 James Hansen, Makiko Sato, Pushker Kharecha, Gary Russell, David W Lea, Mark Siddall, "Climate change and trace gases." *Philosophical Transactions of the Royal Society A* (July 15, 2007) at *dx.doi.org/10.1098/rsta.2007.2052*.

94 K. Steffen, R. Huff, *Greenland Melt Extent, 2005* (Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, 2005); available at *cires.colorado.edu/science/groups/steffen/greenland/melt2005/*.

95 Water vapor amplifies CO₂ warming by 40–50 percent: IPCC 2007 WG1 SPM.

96 "When CO₂ increases the storage of heat in the lower atmosphere, it promotes more evaporation from the tropical oceans." By

itself, this positive feedback is somewhat self-regulating as high humidity means more clouds and their whiteness reflects some sunlight back out into space, somewhat countering the heating effect of more water vapor in the atmosphere. Since cloud formation also depends on a number of other things such as the size of smoke particles, the balancing act is not well understood yet. For example, agricultural fires create soot whose particles are large enough to seed water droplet formation. Power plants burning fossil fuels produce smaller particles and less rainfall downwind.

96 Frank J. Wentz, Lucrezia Ricciardulli, Kyle Hilburn, Carl Mears, “How Much More Rain Will Global Warming Bring?” *Science* (31 May 2007) at [dx.doi.org/10.1126/science.1140746](https://doi.org/10.1126/science.1140746).

98 Ted Scambos quote at earthobservatory.nasa.gov/Newsroom/MediaAlerts/2006/2006100323310.html.

99 Eleanor J. Burke, Simon J. Brown, Nikolaos Christidis, “Modeling the Recent Evolution of Global Drought and Projections for the Twenty-First Century with the Hadley Centre Climate Model,” *Journal of Hydrometeorology* 7 (October 2006): 1113–1125.

Chapter 9.

That Pale Blue Sky

101 David Appell, news article “The darkening Earth,” *Scientific American* (August 2004): 16–17.

In addition to balloons, sulfur could be distributed via jet fuel. To avoid adding sulfur to the lower atmosphere, one fuel tank on an airliner would be filled with sulfur-free fuel and used on the climb up to cruising altitude (which accounts for about one-quarter of a long flight’s fuel consumption). But when cruising above the weather, the sulfur-enhanced jet fuel would be used.

106 V. Ramanathan, quoted by Pearce (2006).

107 Richard A. Feely, Christopher L. Sabine, and Victoria J. Fabry, “Carbon dioxide and our ocean legacy.” National Environment Trust brochure (2006), see www.NET.org/documents/ocean_acidification.

107 Oliver Morton, “Is this what it takes to save the world?” *Nature* 447 (10 May 2007):132-136 news feature at [dx.doi.org/10.1038/447132a](https://doi.org/10.1038/447132a).

107 El Niño reduces primary production: Michael J. Behrenfeld, et al, “Climate-driven trends in contemporary ocean productivity,” *Nature* 444 (7 Dec 2006): 752–755. At [dx.doi.org/10.1038/nature05317](https://doi.org/10.1038/nature05317).

107 Power plant fallout map adapted from exhibit 3–1 in cta.policy.net/fact/mortality/mortalityabt.pdf

108 Tim Flannery (2006): 219.

109 Fire maps created by Jacques Descloitres, MODIS Rapid Response System at NASA/GSFC. See rapidfire.sci.gsfc.nasa.gov/firemaps/.

110 Deaths from coal, adapted from Exhibit 6–1 Premature Mortality Risk Attributable to PM_{2.5} from Power Plants, 2010 Baseline, at www.cleartheair.org/dirtypower/docs/abt_powerplant_whitepaper.pdf

Chapter 10. Slip Locally, Crash Globally

111 Richard Alley, quoted by Pearce (2006).

112 The Google Earth software is at earth.google.com; once installed, go to WilliamCalvin.com/2006/GoogleEarth_PlaceMarkGreenlandShoulder.kmz for a view of the pockmarked western shoulder of Greenland. Startup and find the terrain toggle so there is a readout of Lat/Long/Elev. Once positioned over the west coast of Greenland at about 70°N, start moving south, zooming in on the long east-west tongue of Jakobshaven Isbrae (once an ice shelf, until warmer waters undermined it and broke it up like Larsen B). Then move east to see the lakes on the shoulder of the ice sheet. Finally travel south, keeping lakes in sight. The drainage of these lakes is likely setting up the collapse of the southern half of the central Greenland ice sheet.

113 Melt water lake photograph is by climate scientist Sarah Das. www.who.edu/oceanus/viewImage.do?id=17710&aid=9126. See NASA photos at earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=17607.

114 Greasing the skids: Jay Zwally et al, “Surface melt-induced acceleration of Greenland ice-sheet flow,” *Science* 297(2002): 218–222. Also, from studies in Iceland, the water that gets trapped under the ice cannot refreeze if it is under so much pressure that it cannot expand into ice. And so it is forced up into whatever cracks the icy bottom affords. If finding space to expand, it freezes. The heat given up in freezing warms the surrounding ice, beginning a self-destructive cycle along the bottom of the ice sheet that crumbles the attachment to the bedrock. There’s more at www.pbs.org/wgbh/nova/transcripts/3211_megafloo.html.

- 115 Quoted by Pearce (2006): 70.
- 119 Sea-level rise, modified from figure 5.5.2 of the 2007 IPCC report SPM. It comes from an oxygen isotope record for the Red Sea over the past 470 kyr. See Siddall et al., *Nature* 423 (2003): 853–858.
- 119 Plankton appear in various roles in scenarios for pumping down carbon in an ice age. Fertilization: the higher winds of an ice age should carry a lot more iron-rich dust into the Atlantic from the Sahara and Namib deserts. Expanded habitat: the reduced meridional heat transport during an ice age cools the North Atlantic, and Lovelock (2006) argues for the cooler oceans allowing plankton to thrive in more places and so pumping down carbon faster. The jury is still out on their relative importance, and certainly regarding how they might be manipulated to solve our CO₂ problem.
- 120 J. W. Day, Jr., et al, “Emergence of complex societies after sea level stabilized.” *EOS* 88 (10 April 2007): 169.
- 122 Richard Alley quote from Pearce (2006).
- 122 David D. Zhang, Jane Zhang, Harry F. Lee, Yuan-qing He. “Climate Change and War Frequency in Eastern China over the Last Millennium.” *Human Ecology* 35 (2007):403–414 at [dx.doi.org/10.1007/s10745-007-9115-8](https://doi.org/10.1007/s10745-007-9115-8).
- 127 Flannery (2006): 140.

Chapter 11.

Come Hell and High Water

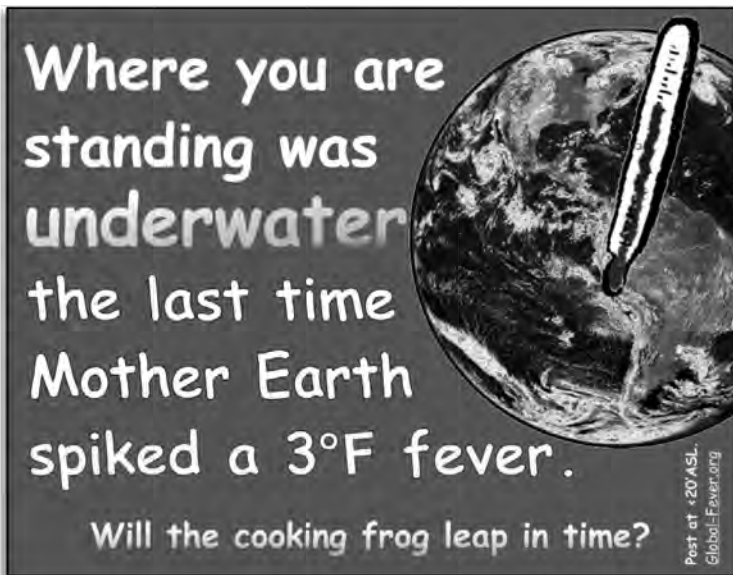
- 131 Most of the sea-level maps were produced, thanks to Jonathan Overpeck and Jeremy Weiss, with the mapping software at the University of Arizona. See www.geo.arizona.edu/dgesl/research/other/climate_change_and_sea_level/sea_level_rise/sea_level_rise.htm.
- 133 Max Mayfield, director of the National Hurricane Center, quoted in Reuters interview (22 August 2006).
- 134 NYC storm surge proposal, see www.nyas.org/ebriefreps/main.asp?intSubsectionID=2247 and metroeast_climate.ciesin.-columbia.edu/reports/infrastructure.pdf. For more on storm surges, with New York City and Long Island examples, see stormy.msrc.sunysb.edu. Includes real-time forecasts.
- 135 PATH station in Hoboken during a 1992 nor'easter. This and the WTC entry photos are from the Metro New York Hurricane Transportation Study, 1995.

Sir David King, "Climate Change Science: Adapt, Mitigate, or Ignore?" *Science* 303 (9 January 2004): 176–177.

141 Claudia Dreifus, "A Conversation With Jeffrey Mount: Giving Sacramento Good Reason to Have New Orleans on Its Mind." *New York Times* (April 18, 2006). www.nytimes.com/2006/04/18/science/18conv.html.

142 David Biello, "Conservative Climate: Consensus document may understate the climate change problem," On the Scientific American web site (18 March 2007) at www.sciam.com/print_version.cfm?articleID=5B9E73AD-E7F2-99DF-3F71280BCE41ED77.

145 The graph of sea-level rise in the last 24,000 years is from the 2007 IPCC Summary for Policymakers WG1. I have extensively modified the Washington Monument photograph at en.wikipedia.org/wiki/Image:Washington_Monument_Dusk_Jan_2006.jpg.



My print-your-own color poster, suitable for posting within 20 ft of sea level, is in a PDF file at Global-Fever.org/#posters, together with directions for determining where to post it using GPS units or Google Earth. For a similar project, see nytimes.com/2007/06/16/arts/design/16chal.html.

- 146** Göran Ekström, Meredith Nettles, and Victor C. Tsai, "Seasonality and Increasing Frequency of Greenland Glacial Earthquakes," *Science* (24 March 2006): 1756–1758 at [dx.doi.org/10.1126/science.1122112](https://doi.org/10.1126/science.1122112).
- 146** Jonathan T. Overpeck, Bette L. Otto-Bliesner, Gifford H. Miller, Daniel R. Muhs, Richard B. Alley, and Jeffrey T. Kiehl, "Paleoclimatic evidence for future ice-sheet instability and rapid sea-level rise," *Science* (24 March 2006) 1747–1750 at [dx.doi.org/10.1126/science.1115159](https://doi.org/10.1126/science.1115159).
- 146** Eric Rignot and Pannir Kanagaratnam, "Changes in the velocity structure of the Greenland Ice Sheet," *Science* (17 February 2006): 986–990. At [dx.doi.org/10.1126/science.1121381](https://doi.org/10.1126/science.1121381).
- 147** For a discussion of the 2007 IPCC estimates of sea-level rise, see Stefan Rahmstorf's discussion at www.realclimate.org/index.php/archives/2007/03/the-ipcc-sea-level-numbers/#more-427.
- 148** Mark Lynas, *Six Degrees* (Fourth Estate, 2007): 171.
- 149** Modeling data from Kurt M. Cuffey and Shawn J. Marshall, "Substantial contribution to sea-level rise during the last interglacial from the Greenland ice sheet," *Nature* 404 (6 April 2000): 591–594. At [dx.doi.org/10.1038/35007053](https://doi.org/10.1038/35007053).
- 149** Greenland ice about 125,000 years ago is inferred from models; see 2007 IPCC report WG1 technical chapters.

Chapter 12.

Methane Is the Double Threat

- 150** CO₂, CH₄ and temperature records from James E. Hansen, *Climate Change* 68 (2005): 269.
- 151** Kirpotkin, quoted by Pearce (2006): 111.
- 152** When you hear the phrase, "Doubling CO₂," it refers to the pre-industrial CO₂ level of 275 ppm being doubled to 550 ppm of CO₂ equivalents. The natural range for CO₂ between ice-age minima and maxima is about 100 parts per million. We have already gone 110 ppm past the historical maximum and need to add at least 50 ppm for the CO₂ equivalents of the increased concentrations of methane and other GHGs.
- 152** Guisepppe Etiopo, "The geological links of the ancient Delphic Oracle (Greece): A reappraisal of natural gas occurrence and origin." *Geology* (October 2006): 825–828. Since methane dilutes the oxygen

concentration of the air, anoxia likely affected the Oracle.

152 Renato Spahni, Jérôme Chappellaz, Thomas F. Stocker, Laetitia Loulergue, Gregor Hausammann, Kenji Kawamura, Jacqueline Flückiger, Jakob Schwander, Dominique Raynaud, Valérie Masson-Delmotte, and Jean Jouzel. "Atmospheric Methane and Nitrous Oxide of the Late Pleistocene from Antarctic Ice Cores," *Science* (25 November 2005): 1317–1321.

152 John M. Barry, *Rising Tide: The Great Mississippi Flood of 1927 and How It Changed America* (Simon and Shuster, 1997) 69.

154 Natural gas leaks about 2 to 4 percent: Society of Chemical Industry (2004), quoted in Lovelock (2006) p.75.

David A. Kirchgessner, Robert A. Lott, R. Michael Cowgill, Matthew R. Harrison, Theresa M. Shires, "Estimate of methane emissions from the U.S. natural gas industry," n.d., at www.epa.gov/ttn/chieflap42/ch14/related/methane.pdf.

154 LNG emissions: Richard Heede, May 2006 report at www.edcnet.org/ProgramsPages/LNGrptplusMay06.pdf.

154 T. M. Hill et al, "Climatically driven emissions of hydrocarbons from marine sediments during deglaciation," *Proceedings of the National Academy of Sciences (U.S.)* 103 (12 September 2006):13570 at dx.doi.org/10.1073/pnas.0601304103.

A. I. Best et al, "Shallow seabed methane gas could pose coastal hazard," *Eos* 87 (30 May 2006): 1.

Aerial photo by Katey Walter of Siberian thaw lakes near Cherskii, Siberia in 2003. Siberian methane video at mms://ms.groovygecko.net/groovyg/clients/nmsi/scim/antenna/siberianthaw/Siberian_broadband.wmv.

Katey Walter et al, "Methane bubbling from Siberian thaw lakes as a positive feedback to climate warming." *Nature* (7 September 2006): 443, at dx.doi.org/10.1038/nature05040.

David Archer, "Methane hydrates and anthropogenic climate change." *Biosci. Discuss.* 4 (2007): 993–1057 and see RealClimate.org/index.php?p=227.

Burning methane hydrate photograph from www.giss.nasa.gov/research/features/methane/hydrate.jpg.

157 I. J. Simpson, F. S. Rowland, S. Meinardi, and D. R. Blake, "Influence of biomass burning during recent fluctuations in the slow

growth of global tropospheric methane," *Geophysical Research Letters* 33 (2006): L22808, [dx.doi.org/10.1029/2006GL027330](https://doi.org/10.1029/2006GL027330).

157 David Archer and Victor Brovkin, "Millennial Atmospheric Lifetime of Anthropogenic CO₂," *Climatic Change* (to appear, 2007).

158 Ocean acidification figure adapted from the Hadley Centre's HadOCC model; via John Holdren's MBL slide (2006).

159 Marten Scheffer, Victor Brovkin and Peter Cox, "Positive feedback between global warming and atmospheric CO₂ concentration inferred from past climate change." *Geophysical Research Letters* (2006) at [dx.doi.org/10.1029/2005GL025044](https://doi.org/10.1029/2005GL025044).

159 M. S. Torn and J. Harte, "Missing feedbacks, asymmetric uncertainties, and the underestimation of future warming," *Geophysical Research Letters* (2006) at [dx.doi.org/10.1029/2005GL025540](https://doi.org/10.1029/2005GL025540).

159 Agricultural waste problem, see www.virtualcentre.org/en/library/key_pub/longshad/A0701E00.pdf.

Chapter 13.

Sudden Shifts in Climate

162 "Winds gusting to more than 100 mph swept across northern Utah on Friday, overturning 20 tractor-trailers....Winds reached 113 mph setting a state record...." Photo by Marta Storwick for the *Standard-Examiner* of Ogden, Utah (23 April 1999), with permission.

163 Claudia Tebaldi et al, "Going to Extremes," *Climatic Change* (December 2006). See www.ucar.edu/news/releases/2006/wetterworld.shtml.

Richard B. Alley, et al., "Abrupt climate change." *Science* 299 (2003): 2005–10.

164 See "How Likely are Major or Abrupt Climate Changes, such as Loss of Ice Sheets or Changes in Global Ocean Circulation?" in G. A. Meehl, et al, "Global Climate Projections. Section 10.2 in *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by Susan Solomon, et al. (Cambridge University Press, Cambridge and New York) at ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_10.pdf.

164 William H. Calvin, "The great climate flip-flop," *Atlantic Monthly* (January 1998). The story is elaborated in *A Brain for All Seasons: Human Evolution and Abrupt Climate Change*. (University of

Chicago Press, 2002).

166 Illustration adapted from the National Oceanic and Atmospheric Administration's El Niño Web site, www.pmel.noaa.gov/tao/el_nino. Technically, an El Niño is when mid-Pacific sea surface temperature stays more than 0.5°C above normal for four months. A La Niña is when it cools more than 0.5°C for four months (although some may use La Niña for the normal midrange as well). A La Niña situation often follows an El Niño episode and is essentially its opposite. During a La Niña, the easterly trade winds near the equator are stronger than normal. They push more warm surface waters westward across the Pacific. The colder, deeper waters that well up to the surface in their place extend far out into the central equatorial Pacific. The historical El Niño chart is at www.cpc.ncep.noaa.gov/products/analysis_monitoring/lanina/enso_evolution-status-fcsts-web.ppt

168 A. V. Fedorov et al, "The Pliocene paradox (mechanisms for a permanent El Niño)," *Science* 312 (9 June 2006): 1485 at [dx.doi.org/10.1126/science.1122666](https://doi.org/10.1126/science.1122666).

Chapter 14.

A Sea of CO₂

172 The data snapshot is from March to June, the northern sunlight making the bloom there more than in the southern hemisphere winter. Nutrients are a major limitation. Besides nutrients from rivers, they are also up-welled to the surface in some areas (line in mid-Pacific Ocean where trade winds converge, also on the west coast of continents). For the original color version of the world phytoplankton imaging, see earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=17332. Maps, see neo.sci.gsfc.nasa.gov/Search.html?group=12. If you have Google Earth installed, see neo.sci.gsfc.nasa.gov/RenderData?si=493385&cs=rgb&format=KMZ.

The pictures are thanks to Russell Hopcroft (*Cavolinia uncinata*, left), Victoria Fabry (*C. tridentata*, right), and Laurence Madin (*Salpa aspera*).

173 B. Schmitz, "Plankton cooled a greenhouse." *Nature* (14 September 2000) 407: 143–144.

174 Michael P. Lesser, "Coral reef bleaching and global climate change: Can corals survive the next century?" *Proceedings of the National Academy of Sciences (U.S.)* (2007) at [dx.doi.org/10.1073/pnas.0700910104](https://doi.org/10.1073/pnas.0700910104).

- 174** Caribbean coral losses in 2005, see *news.nationalgeographic.com/news/2006/04/0406_060406_coral.html*
- 175** J. F. Bruno, et al., "Thermal stress and coral cover as drivers of coral disease outbreaks." *PLoS Biology* 5 (2007): e124 at *dx.doi.org/10.1371/journal.pbio.0050124*.
- 175** Policy statement from the Royal Society, London, "Ocean Acidification Due to Increasing Atmospheric Carbon Dioxide" (2005) at *www.royalsoc.ac.uk/displaypagedoc.asp?id=13539*.
- 175** J.A. Kleypas, R.A. Feely, V.J. Fabry, C. Langdon, C.L. Sabine, and L.L. Robbins. "Impacts of Ocean Acidification on Coral Reefs and Other Marine Calcifiers: A Guide for Future Research" 2006 report of a workshop held 18–20 April 2005, St. Petersburg, FL, 88 pp, at *www.ucar.edu/communications/Final_acidification*.
- 176** Corinne Le Quéré, et al. "Saturation of the Southern Ocean CO₂ Sink Due to Recent Climate Change," *Science* (2007) at *dx.doi.org/10.1126/science.1136188*.
- 179** Plankton decline: Scott C. Doney, "Plankton in a warmer world." *Nature* 444 (7 December 2006) 695.
- 179** Michael J. Behrenfeld, et al. "Climate-driven trends in contemporary ocean productivity." *Nature* 444 (7 December 2006): 752–755 at *dx.doi.org/10.1038/nature05317*.
- 179** Ken Calderia, quoted by Elizabeth Kolbert, "The Darkening Sea: What carbon emissions are doing to the ocean," *New Yorker* (20 November 2006): 67–75.
- 181** Philip W. Boyd, et al. "Mesoscale Iron Enrichment Experiments 1993–2005: Synthesis and Future Directions." *Science* 315 (2 February 2007): 612–617 at *dx.doi.org/10.1126/science.1131669*.
- 181** Philip W. Boyd, "Biogeochemistry: Iron findings." *Nature* 446 (26 April 2007): 989–991.
- 181** Kerguelen analysis: Stéphane Blain, et al. "Effect of natural iron fertilization on carbon sequestration in the Southern Ocean." *Nature* 446 (26 April 2007): 1070–1074 at *dx.doi.org/10.1038/nature05700*. Kerguelen figure modified from the accompanying news article.
- 184** The wave-driven pump to raise deep water to the surface is best seen in the archived presentations at *atmocean.com*.

Chapter 15.**The Extended Forecast**

187 Joseph J. Romm, *Hell and High Water* (William Morrow, 2007): 8.

187 Mark Lynas, *Six Degrees* (Fourth Estate, London, 2007): 171.

188 The 2020 turnaround is modified from a slide in John Holdren's MBL talk (November 2006), see www.whrc.org/resources/PPT//PH_MBL_11-03-06_Clim-Chg-Challenge.ppt.

188 Tony Blair, quoted by Flannery (2005): 247.

190 The photograph shows a 1 meter section of the GISP2 ice core from a depth of 1837 meters in the Greenland Ice Sheet. From GlobalWarmingArt.com/wiki/Image:GISP2_Ice_Core.jpg.

192 Susan Solomon, D. Qin, M. Manning, R.B. Alley, T. Berntsen, N.L. Bindoff, Z. Chen, A. Chidthaisong, J.M. Gregory, G.C. Hegerl, M. Heimann, B. Hewitson, B.J. Hoskins, F. Joos, J. Jouzel, V. Kattsov, U. Lohmann, T. Matsuno, M. Molina, N. Nicholls, J. Overpeck, G. Raga, V. Ramaswamy, J. Ren, M. Rusticucci, R. Somerville, T.F. Stocker, P. Whetton, R.A. Wood and D. Wratt, "Technical Summary. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Susan Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. at ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_TS.pdf. Summary for policymakers is at www.ipcc.ch/SPM2feb07.pdf.

198 Spencer Weart, *New Scientist* (14 April 2007) 20.

199 Stefan Rahmstorf, et al., "Recent climate observations compared to projections," *Science* 316 (4 May 2007): 709 at dx.doi.org/10.1126/science.1136843.

199 James E. Hansen, "Scientific reticence and sea level rise." *Environ. Res. Lett.*, 2 (2007): 024002, at dx.doi.org/10.1088/1748-9326/2/2/024002.

199 Mark Bowen, *Thin Ice* (Henry Holt, 2005).

199 Richard A. Kerr, "Pushing the Scary Side of Global Warming," *Science* 316(8 June 2007): 1412–1415, at dx.doi.org/10.1126/science.316.5830.1412.

201 Wind turbine in Skåne, Sweden. Photograph by Väsk at commons.wikimedia.org/wiki/Image:Vindkraftverk_i_Sk%C3%A5ne_februa

ri_2005.jpg.

202 Sir Crispin Tickell (2002), at www.futurefoundation.org/documents/nty_report_apr02.pdf

Chapter 16. Doing Things Differently

204 Phillip F. Schewe, *The Grid* (Joseph Henry Press DC, 2007): 168.

206 California vs. US electrical use per person from www.eia.doe.gov/emeu/states/sep_use/total/use_csv. Table of all states at www.eia.doe.gov/emeu/states/sep_sum/plain_html/rank_use_per_cap.html.

207 Paul Krugman, "Colorless green ideas." *New York Times* (23 February 2007), select.nytimes.com/2007/02/23/opinion/23krugman.html.

209 Evolution of electricity sources from www.iea.org/Textbase/stats/graphsearch.asp.

217 Phillip F. Schewe, *The Grid* (Joseph Henry Press, 2006).

Chapter 17. Cleaning Up Our Act

221 George Monbiot, *Heat* (2006): 44.

221 Paul Falkowski, et al., "The Global Carbon Cycle: A Test of Our Knowledge of Earth as a System." *Science* 290 (13 October 2000): 291. At dx.doi.org/10.1126/science.290.5490.291.

222 Wedges, see www.princeton.edu/~cmil/resources/-stabwedge.htm.

224 UN's 2007 expert group: www.UNfoundation.org/SEG/.

Chapter 18. The Climate Optimist

228 Gregory L. Armstrong, Laura A. Conn, Robert W. Pinner. "Trends in Infectious Disease Mortality in the United States during the 20th Century." *JAMA* 281 (January 1999): 61–66.

231 E. O. Wilson (personal communication, 2006) put the extra-long, extra-warm El Niño time frame this way: "...could burn down so much of the remaining rain forests in Southeast Asia and the Amazon that as many as half the remaining species of plants and animals could face early extinction."

232 High-speed toll gates: A quick method that avoids the high costs of creating a new roadside network would be to install old cell-phone technology in the vehicle and simply use it to detect when the vehicle crosses from one cell to another—and billing accordingly. See www.newscientisttech.com/channel/tech/mg19225815.600-cellphone-

networks-could-help-with-road-tolls.html.

232 In the U.S., many people pay far more in payroll taxes (mostly Social Security, Medicare, and unemployment taxes) than they have withheld for income tax.

235 Artificial photosynthesis, see Frédéric Goettmann, Arne Thomas, Markus Antonietti, "Metal-Free Activation of CO₂ by Mesoporous Graphitic Carbon Nitride." *Angewandte Chemie* (2007) at [dx.doi.org/10.1002/anie.200603478](https://doi.org/10.1002/anie.200603478).

236 FDR 1940–1941 leadership, see pp. 44–59 in Doris Kearns Goodwin's *No ordinary time* (Simon and Shuster, 1994).

237 Jack Doyle, *Taken for a ride: Detroit's Big Three and the politics of air pollution* (2000). Indeed, I'd say that Detroit's automakers may need a new purpose in life (and I'd suggest temporarily repurposing the manned part of NASA's space program as well). All of that talent is badly needed for more important tasks.

237 Gregg Easterbrook, "Some convenient truths," *Atlantic Monthly* (September 2006). www.theatlantic.com/doc/print/200609/global-warming.

Chapter 19.

Turnaround by 2020

238 James Hansen, "How Can We Avert Dangerous Climate Change?" Testimony before U.S. Congress (2007) at arxiv.org/abs/0706.3720.

239 M. Meinshausen "What does a 2°C target mean for greenhouse gas concentrations? A brief analysis based on multi-gas emission pathways and several climate sensitivity uncertainty estimates," in *Avoiding Dangerous Climate Change*, H. J. Schellnhuber, W. Cramer, N. Nakicenovic, T. Wigley, G. Yohe eds., (Cambridge University Press, Cambridge, 2006) at www.cgd.ucar.edu/~mmalte/simcap/publications/meinshausenm_risk_of_overshooting_final_webversion.pdf.

240 George Mueller (pronounced Miller), see en.wikipedia.org/wiki/George_Mueller and futurefoundation.org/programs/hum_wrk4.htm.

243 Michael Kintner-Meyer, Kevin Schneider, Robert Pratt. "Impacts assessment of plug-in hybrid vehicles on electric utilities and regional U.S. power grids. Part 1: technical analysis." Report from U.S. Department of Energy's Pacific Northwest National

Laboratory (2007) at www.pnl.gov/energy/eed/etd/pdfs/pehv_feasibility_analysis_combined.pdf

244 Compressed air car: see en.wikipedia.org/wiki/Air_car and “World’s First Air-Powered Car: Zero Emissions by Next Summer” in *Popular Mechanics* (June 2007) at www.popularmechanics.com/automotive/new_cars/4217016.html. “India’s largest automaker is set to start producing the world’s first commercial air-powered vehicle. [It] can hit 68 mph and has a range of 125 miles. It will take only a few minutes for the CityCAT to refuel at gas stations equipped with custom air compressor units; MDI says it should cost around \$2 to fill the car’s carbon-fiber tanks with 340 liters of air at 4350 psi. Drivers also will be able to plug into the electrical grid and use the car’s built-in compressor to refill the tanks in about 4 hours.”

246 Zimmer Power Station photograph and data thanks to George Campbell. See tallgeorge.com/Zimmer.htm. Platt’s provides an excellent selection of free maps for energy resources at www.platts.com/Resources/map/archive/map_archive.html.

246 For the nuclear fuels in the fly ash, see Alex Gabbard’s analysis at www.ornl.gov/info/ornlreview/rev26-34/text/colmain.html.

246 Capture CO₂, see “Future of ‘Clean Coal’ Power Tied to (Uncertain) Success of Carbon Capture and Storage” at www.sciam.com.

246 Jeff Goodell, *Big Coal* (Houghton Mifflin, 2006).

246 MIT report, “The future of coal: options for a carbon-constrained world” (2007) at web.mit.edu/coal/The_Future_of_Coal.pdf.

From its summary illustrating the challenge of scale for carbon capture and long-term storage:

- Today fossil sources account for 80% of energy demand: Coal (25%), natural gas (21%), petroleum (34%), nuclear (6.5%), hydro (2.2%), and biomass and waste (11%). Only 0.4% of global energy demand is met by geothermal, solar and wind.
- 50% of the electricity generated in the U.S. is from coal.
- There are the equivalent of more than five hundred, 500 megawatt, coal-fired power plants in the United States with an average age of 35 years.
- China is currently constructing the equivalent of two, 500 megawatt, coal-fired power plants per week and a capacity

comparable to the entire UK power grid each year.

- One 500 megawatt coal-fired power plant produces approximately 3 million tons/year of carbon dioxide (CO₂).
- The United States produces about 1.5 billion tons per year of CO₂ from coal-burning power plants.
- If all of this CO₂ is transported for sequestration, the quantity is equivalent to three times the weight and, under typical operating conditions, one-third of the annual volume of natural gas transported by the U.S. gas pipeline system.
- If 60% of the CO₂ produced from U.S. coal-based power generation were to be captured and compressed to a liquid for geologic sequestration, its volume would about equal the total U.S. oil consumption of 20 million barrels per day.
- At present the largest sequestration project is injecting one million tons/year of carbon dioxide (CO₂) from the Sleipner gas field into a saline aquifer under the North Sea.

254 MIT also assembled a panel of 18 experts in 2006 to evaluate large-scale use of deep geothermal, led by Jefferson W. Tester, the H.P. Meissner Professor of Chemical Engineering. The report, entitled "The Future of Geothermal Energy: Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st Century," is at geothermal.inel.gov/publications/future_of_geothermal_energy.pdf.

254 The Hot Dry Rock concept at the Los Alamos National Laboratory in 1972, see www-geo.lanl.gov/expertise/geotherm.htm. R. M. Potter, E. S. Robinson, and M. C. Smith, "Method of extracting heat from dry geothermal reservoirs," U.S. Patent 3,786,858 (1974).

Dave Duchane and Don Brown, "Hot Dry Rock (HDR) geothermal energy research and development at Fenton Hill, New Mexico," *GHC Bulletin* (December 2002): 13–19, at geoheat.oit.edu/bulletin/bull23-4/art4.pdf. "It was found entirely feasible to operate the plant for extended periods of time with no on-site personnel, a fact that has important economic implications for the ultimate commercialization of HDR technology." This refers to the recirculating well side of the system with heat exchanger, not a complete plant with subsequent electricity generation from the heat exchanger. From "Building a Hot Rock Energy System" at hotrock.anu.edu.au:

Heat is extracted by pumping water through an engineered heat

exchanger connecting two or more wells. This heat exchanger is a volume of hot dry rock with enhanced permeability. It is fabricated by hydraulic stimulation. This involves pumping high pressure water into the pre-existing fracture system that is present in all rocks to varying degrees. The high pressure water opens the stressed natural fractures and facilitates micro-slippage along them. When the water pressure is released, the fractures close once more but the slippage that occurred prevents them from mating perfectly again. The result is a million-fold permanent increase in permeability along the fracture systems and a heat exchanger that can be used to extract energy.

In a typical system, an initial borehole is sunk into the hot rock mass and a hydraulic stimulation is performed. A three dimensional microseismic network deployed on the surface and in nearby wells is used to record the little noises caused by the fractures widening as the pumping continues over several weeks. In this way, the progress of the stimulation is monitored and the size and shape of the growing heat exchanger is mapped.

A second well is then drilled into the margin of the heat exchanger 500 m or more from the first well. Now water can be pumped through the underground heat exchanger and in super-heated form it can be returned to the surface. There it can have its energy extracted before being reinjected to go around the loop again.

Of course, if you drill in an earthquake-prone area, the little earthquakes that result may become strong enough to feel (see en.wikipedia.org/wiki/Hot_dry_rock_geothermal). If there are also a lot of people around to notice—as was the case in a Basel suburb in December 2006—much fuss may result even for 3.4 strength earthquakes with no injuries. The reason for locating the wells within the city was presumably the 2,700 households to be heated from the plant's excess (in addition to the 10,000 people who would get their electricity from it. It might speed deployment for Hot Rock Energy to locate wells elsewhere and use the spare heat for co-located greenhouses and such.

255 For a survey of Australia's hot rock projects, see www.pir.sa.gov.au/byteserve/petrol/prospectivity/apia_29_march07.pdf

255 Photo credits: *Ormat.com* for Lyete, The Philippines. For the

much-altered diagram, the MIT geothermal report of 2006.

257 Jon Gertner, "Atomic balm?" *New York Times Magazine* (16 July 2006).

259 Updated death toll for energy sources can be found at www.uic.com.au/nip14app.htm.

263 Advanced fast reactors: "If developed sensibly, nuclear power could be truly sustainable and essentially inexhaustible and could operate without contributing to climate change. In particular, a relatively new form of nuclear technology could overcome the principal drawbacks of current methods—namely, worries about reactor accidents, the potential for diversion of nuclear fuel into highly destructive weapons, the management of dangerous, long-lived radioactive waste, and the depletion of global reserves of economically available uranium." William H. Hannum, Gerald E. Marsh, George S. Stanford, "Smarter use of nuclear waste," *Scientific American* (December 2005): 84. At gemarsh.com/wp-content/uploads/SciAm-Dec05.pdf.

265 AC vs DC transmissions lines, illustration adapted from "Bulk power transmission at extra high voltages, a comparison between transmission lines for HVDC at voltages above 600 kV DC and 800 kV AC," an ABB Power Technologies presentation by Lars Weimers, n.d.

268 One interesting use of biofuels would be if they were burned for electricity and the CO₂ captured and sunk. It still has the hazards of CO₂ storage burps, and I cannot imagine it having the sheer capacity for sinking the accumulated atmospheric CO₂ that plankton enhancement would have. Biofuels news story by Stephen Leahy at www.ipsnews.net/news.asp?idnews=38384.

Chapter 20.

Arming for a Great War

272 Flannery quote at www.news.com.au/heraldsun/story/0,21985,21225432-661,00.html.

277 FDR in 1940: "I know that private business cannot be expected to make all of the capital investments required for expansion of plants and factories and personnel which this program calls for at once... [The] Government of the United States stands ready to advance the necessary money to help provide for the enlargement of factories, of necessary workers, the development of new sources of supply for the

hundreds of raw materials required, the development of quick mass transportation of supplies.”

A new “cost plus fixed fee” contract allowed the government to defray all costs essential to the execution of defense contracts and guarantee the contractor a profit through a fixed fee determined in advance. In other words, the government assumed primary financial responsibility for the mobilization process. From Doris Kearns Goodwin’s *No Ordinary Time* (Simon and Shuster, 1994), 59.

Chapter 21.

Get It Right on the First Try

278 David Attenborough (2006), quoted at books.guardian.co.uk/review/politicsphilosophyandsociety/0,,1945625,00.html

280 Michael R. Raupach, Gregg Marland, Philippe Ciais, Corinne Le Quéré, Josep G. Canadell, Gernot Klepper, and Christopher B. Field. “Global and regional drivers of accelerating CO₂ emissions” *PNAS* 104 (10 June 2007): 10288–10293 at dx.doi.org/10.1073/pnas.0700609104.

288 Wikipedia Projects illustrate how a Recovery Manual could be done without top-down organization: en.wikipedia.org/wiki/Wikipedia:WikiProject.

288 Behavioral economics. A useful summary is by Teresa Tritch, “Helping people help themselves,” *New York Times* (14 February 2007) at select.nytimes.com/2007/02/14/opinion/15talkingpoints.html.

292 The quote is attributed to Edmund Burke.

292 Martin Luther King, Jr., “The Casualties of the War in Vietnam.” Speech on 25 February 1967 in Los Angeles, California. See www.stanford.edu/group/King/publications/speeches/unpub/670225-001_The_Casualties_of_the_War_in_Vietnam.htm

About the Author



WILLIAM H. CALVIN

Born in 1939 in Kansas City, I grew up in real Middle America, though I now have an overlay from living in Seattle since 1962. I did a lot of journalism and photography before college, majored in physics at Northwestern University, then branched out into neurophysiology via studies at MIT, Harvard Medical School, and the University of Washington (Ph.D., Physiology & Biophysics, 1966). That biophysics background, plus a quarter-century of following the literature, is why I can talk shop with the climate scientists and oceanographers.

I'm now Affiliate Professor Emeritus at the University of Washington School of Medicine. I've had a long association with academic neurosurgeons and psychiatrists without ever having had to treat a patient. Most of my research has been about brain cells and circuits, along with the big-brain evolutionary history. I started paying attention to climate when trying to understand how our big brains evolved so rapidly during the Ice Ages. I've written fourteen books in twenty-eight years and have begun incorporating my photographs (many of which can be found via my website, *WilliamCalvin.org*).

Index

- A Brain for All Seasons*, 50, 311, 321
acidification, 155, 170, 175, 177, 178, 233, 315, 321, 323
aerosols, 101, 102, 107, 260
agriculture, 55, 56, 67, 81, 98, 159, 224, 234
air cars, 244
air conditioning, 5, 244, 275
alarmist, 196, 198, 199
albedo, 92, 102, 302
Alley, Richard, 111, 115, 120, 295, 316, 317, 319, 324
Amazon, 4, 7, 34, 59, 64, 65, 66, 67, 68, 103, 163, 167, 182, 199, 230, 302, 307, 311, 312, 325
An Inconvenient Truth, 30, 173, 297
Andes, 63, 65, 311
Angola, 180
Antarctic Peninsula, 37, 311
Antarctica, 35, 94, 111, 117, 119, 144, 145, 148, 150, 151, 190, 236, 301
anthropogenic (human-caused), 160
antibiotics, 228, 275
Apollo Project, 240
Archer, David, 295, 320
Arctic, 11, 79, 90, 98, 156, 165, 196, 300, 304
Arctic sea ice, 196, 304
Armageddon, 291
Army Corps of Engineers, 132
Arrhenius, Svante, 22, 309
Attenborough, D., 278, 330
Aum Shinrikyo, 291
Australia, 61, 62, 64, 175, 186, 201, 204, 240, 255, 265, 298, 302, 329
ballast water, 178
Baltimore, 129
Ban Ki-moon, 30, 310
Bangladesh, 35, 121, 122, 303
Barry, John M., 152
base price, 289
BEES, 235, 264, 265
behavioral economics, 288
Berra, Yogi, 239
Big Coal, 38, 246, 327
biofuels, 267, 268, 271, 330
biomass, 98, 225, 320, 327
black hole, 91
Blair, Tony, 188
bleaching, 13, 174, 175, 304, 322
bloom, 59, 176, 179, 180, 181, 182, 184, 304, 322
book burners, 287
Borneo, 59, 64
Boston, 129, 131, 138, 139, 140, 215, 303
Bowen, Mark, 199, 324
Braeman, Kathryn Moen, 295
Brazil, 64, 121, 159, 182
Broecker, Wally, 71
Burke, Edmund, 292, 312, 315, 331
Business as Usual, 193
C sinks, 285
Cairo, 63
Caldiera, Ken, 179
California, 19, 37, 59, 64, 121, 140, 154, 186, 206, 207, 208, 240, 303, 305, 308, 313, 325, 331
Canada, 79, 119, 144, 155, 180, 182, 186, 204, 240, 263
canary, 153
cap-and-trade, 221, 273
Cape Town, 59, 63
Carbon "Makeover" Commission, 222
carbon pump, 177, 285
carbon sinks, 170, 178, 182, 193, 238, 243, 268, 304
carbonate, 177, 179
Caribbean, 174, 265, 304, 322
catalytic converter, 9
cathedral, 291
cement, 3, 25, 95, 132
CFC, 28
C-fee, 222
C-free, 186, 200, 202, 217, 232, 234, 242, 243, 249, 257, 262, 267, 271, 276, 281, 283, 306
chemotherapy, 8, 9
Chernobyl, 259, 260
China, 6, 60, 122, 123, 128, 210, 258, 260, 274, 280, 283, 285, 305, 327
chlorophyll, 172
clean coal, 245
Clerk Maxwell, James, 89
Climate: defined, 189
climate models, 11, 66, 159, 191, 192
cloudiness, 101
coal, 2, 3, 4, 5, 6, 9, 16, 22, 27, 35, 38, 105, 106, 153, 202, 210, 211, 212, 213, 222, 224, 229, 233, 243, 245, 246, 247, 248, 249, 254, 255, 258, 260, 261, 264, 271, 280, 281, 282, 283, 284, 289, 290, 291, 303, 305, 310, 316, 327
coal-burning power plants, 260, 327
coccolithophore, 182
co-generation, 215
commitment, 193, 203
compound interest, 73, 89
cookie-cutter crop circles, 58
coral reefs, 174, 175, 178, 203, 281
Crutzen, Paul, 105, 108

- cyclone, 138, 184
- Darfur, 4, 281
- Das, Sarah, 113, 295, 316
- DC line, 215, 265
- DC transmission line, 265, 284, 305
- decay rate, 157
- decision paralysis, 289
- deforestation diesel, 268
- denial, 47, 49, 50, 187, 277
- Denmark, 201, 283
- Department of Energy, 248, 298, 326
- dew point, 44, 65, 191, 311
- diabetic, 4
- Diamond, Jared, 15, 269, 273, 297, 308
- diatomaceous earth, 106
- diet, 4, 5, 197, 205, 207, 227, 242, 244, 279, 285
- disinformation, 23, 27, 38, 49, 102, 104, 117, 118, 287, 289, 299
- drilling rigs, 256
- drought, 6, 34, 41, 42, 44, 45, 46, 47, 51, 52, 53, 62, 64, 65, 67, 82, 83, 99, 148, 163, 168, 182, 230, 253, 267, 268, 271, 301, 311, 313
- droughts, 4, 11, 13, 41, 45, 47, 48, 51, 52, 59, 68, 84, 87, 103, 108, 176, 192, 193, 230, 236, 249, 276, 301, 307
- dust, 41, 46, 47, 48, 51, 52, 53, 62, 100, 180, 301, 302, 312
- Dust Bowl, 49
- dust storms, 190
- earthquake, 83, 246, 252, 329
- earthquakes, 15, 56, 127, 157, 252, 308, 329
- Easter Island, 173, 306
- economists, 8, 54, 77
- Edison, Thomas, 213
- efficiencies, 38, 281
- efficiency, 10, 16, 79, 211, 222, 232, 239, 242, 244, 249, 257, 267, 271
- Egypt, 97, 123
- Ehrlich, Paul, 83
- El Niño, 6, 13, 59, 163, 165, 166, 167, 168, 170, 173, 174, 199, 224, 230, 304, 307, 315, 321, 322, 325
- exponential growth, 73, 74, 76, 89
- ExxonMobil, 104, 300, 308
- Fagan, Brian, 298
- Faustian, 229, 236, 281
- Federal Carbon Board, 222
- Federal Reserve Board, 220, 222
- feedback, 87
- Ferrell Cell, 61
- fertilizers, 233, 234
- Flannery, Tim, 30, 108, 127, 270, 272, 298, 313, 315, 317, 324, 330
- flapper valve, 184, 323
- flood zone, 129
- floods, 13, 51, 127, 135, 193, 197, 262, 276, 312
- Florida, 46, 61, 126, 128, 130, 131, 168, 303
- fossil fuel, 10, 20, 151, 152, 159, 164, 193, 196, 208, 225, 230, 231, 238, 264, 301
- Fourier, Joseph, 22
- France, 9, 29, 208, 209, 254, 257, 263, 283, 305
- frog, 24, 25, 99
- Frost, Robert, 72
- Galapagos Islands, 167, 173
- Gammon, Richard, 295
- Gardner, Debs, 295
- Gelbspan, Ross, 298
- genocides, 121, 239, 281
- geo-engineering, 104, 107, 178
- geothermal, 4, 9, 201, 212, 222, 223, 233, 250, 252, 253, 254, 255, 256, 264, 282, 283, 284, 305, 310, 327, 328, 329
- Germany, 201, 255, 264
- Gore, Al, 30, 85, 297, 310, 314
- Grand Banks, 82
- Grand Canyon, 212
- granite, 249, 251, 252, 256
- Graubard, Katherine, 295
- Great Barrier Reef, 175
- Guthrie, Woody, 40, 311
- greenhouse, 11, 19, 22, 25, 31, 35, 65, 83, 91, 92, 93, 94, 95, 96, 98, 101, 102, 104, 132, 149, 154, 156, 158, 188, 193, 233, 236, 280, 285, 311, 322, 326
- greenhouse effect, 31, 91, 95, 156
- Greenland, 4, 13, 15, 33, 35, 94, 111, 112, 113, 114, 115, 117, 119, 120, 121, 143, 144, 145, 146, 148, 149, 164, 190, 203, 219, 230, 236, 302, 303, 304, 308, 314, 316, 318, 319, 324
- greenwashing, 245
- Gulf Coast, 126, 303
- Gulf Stream, 13, 61, 163
- Guthrie, Woody, 40
- Hadley Cell, 61, 62
- Hadley, George, 61
- Hansen, James, 26, 92, 152, 173, 236, 297, 300, 309, 314, 319
- haze, 104, 107, 212
- heat exchanger, 255, 256, 328, 329
- heat island, 102
- heat pump, 250
- heat waves, 11, 13, 103, 107, 176, 182, 192, 230
- Henson, Robert, 297
- herbicide, 178
- Holdren, John, 19, 203, 309, 321, 324
- Hot Dry Rock, 251, 328
- Hot Rock Energy, 201, 251, 254, 255, 256, 282, 305, 328, 329
- hot springs, 91, 252
- humidity, 35, 43, 44, 56, 95, 96, 314
- hurricanes, 13, 14, 127, 130, 134, 168, 174, 191, 192, 308
- hybrids, 10, 233, 281
- Hydroelectric, 268, 271, 283
- hydrogen fuel cell cars, 244

- Iceland, 115, 180, 182, 250, 304, 316
 India, 64, 122, 211, 258, 262, 280, 305
 Indonesia, 159, 268, 307
 infections, 228
 influenza pandemic, 189
 insulating blanket, 155, 229
 insurance, 31, 73, 127, 129, 200, 203, 213, 269, 287
 IPCC, 11, 111, 128, 142, 143, 145, 147, 192, 194, 196, 198, 199, 300, 303, 304, 308, 309, 314, 316, 318, 319, 331
 Ireland, 78
 iron fertilization, 182
 irrigation, 21, 55, 56, 57, 63, 98, 302, 312
 island nations, 137
 Jacobshavn Isbrae, 117, 303
 Japan, 14, 259, 283, 306, 308
 Johnston, Susan, 295
 Joyce, Terry, 71
 jury, 200, 317
 Kansas, 5, 13, 15, 46, 58, 202, 269, 301, 302, 308, 312, 332
 Katrina, Hurricane 68, 70, 174, 192, 313
 Keeling curve, 23, 191, 301
 Keeling, Charles David, 22
 Kennedy, John F., 241
 Kerguelen, 181, 184, 304, 323
 King, Sir David, 135
 King, Jr., Martin Luther, 290, 292
 Kirpotin, Sergi, 151
 Kolbert, Elizabeth, 278, 298, 323
 Krugman, Paul, 207, 325
 Kyoto, 29, 204, 239, 273, 274, 309
 La Niña, 46, 304, 322
 land use, 196
 landfills, 153, 224
 leads and lags, 77, 78
 leukemia, 260
 Lewis, N., 278
 Linden, Eugene, 298
 Lindzen, Richard, 19, 308
 linear thinking, 72
 liquid natural gas (LNG), 154
 Little Ice Age, 47, 48, 51, 52, 78, 312
 London, 4, 61, 124, 134, 135, 137, 314, 323, 324
 Long Island, 133, 317
 Los Alamos National Laboratory 201, 251, 328
 Los Angeles, 63, 121, 265, 331
 Lovelock, James, 8, 9, 19, 32, 202, 239, 269, 298, 314, 317, 320
 Lynas, Mark, 46, 148, 187, 297, 319, 324
 MacCracken, Mike, 295
 Magnetic resonance imaging (MRI), 264
 makeover, 27, 201, 222, 240, 247, 270, 290, 291
 "Makeover" Commission, 222
 Malaysia, 268
 Maldives, 35, 128, 303
 Malthus, Thomas, 76
 Manhattan Project, 240
 Martin, James, 83, 290, 292, 313, 331
 Mauna Loa, 22, 23
 McKibben, Bill, 11, 307
 Medieval Warm Period, 51, 52, 312
 Mediterranean, 59, 62
 metaphors, 27, 33, 54, 55, 67, 71, 72, 83, 295
 methane, 13, 25, 95, 150, 151, 152, 153, 154, 155, 156, 157, 158, 159, 224, 233, 234, 245, 303, 304, 319, 320
 methane hydrate, 156
 Miami, 35, 121, 128, 129
 microalgae, 176
 Milankovitch factors, 144
 Miles, Ed, 176, 295
 mineralization, 252
 MIT, 140, 254, 327, 328, 329, 332
 Mitchell, Linda, 295
 Monbiot, George, 29, 68, 161, 221, 272, 298, 313, 325
 Mount Pinatubo eruption, 105, 302
 mountain glaciers, 142
 Mueller, George, 240, 326
 Muller, Richard, 77, 78
 Mumbai, 121
 Munch, Edvard, vi, 301, 307
 Namibia, 180
 NASA, 118, 240, 311, 316, 326
 natural gas, 3, 6, 151, 153, 154, 156, 201, 210, 252, 258, 319, 320, 327
 natural gas, CH₄, 151
 negative feedback, 87, 88, 89, 159
 Netherlands, 35, 121, 124, 125
 neurosurgeons, 269, 332
 New Guinea, 165, 166, 167
 New Jersey, 9, 132, 133, 134, 137
 New Orleans, 35, 68, 70, 76, 121, 129, 131, 132, 276, 302, 313, 318
 New Sacramento Bay, 141
 New York, 112, 121, 129, 130, 131, 132, 134, 135, 137, 245, 299, 303, 307, 309, 312, 317, 318, 321, 324, 325, 329, 331
 Nobel Peace Prize, 290
 No-C cars, 233
 nor'easter, 134, 135, 317
 Northwestern University, 80, 332
 nuclear bomb, 261
 nuclear magnetic resonance (NMR), 264
 nuclear power, 9, 30, 38, 210, 223, 233, 235, 246, 257, 259, 260, 261, 262, 264, 265, 275, 282, 284, 305, 329
 nutrient, 183, 184
 Nygren, Carol, 295
 Oeschger, Hans, 33, 295
 Oklahoma, 43, 46, 55, 301, 311
 Oracle at Delphi, 152
 Overpeck, J., 47, 124, 311, 312, 317, 319, 324

- ozone, 9, 13, 26, 27, 28, 29, 105, 106, 158, 301
paleoclimate, 71, 96, 189
pariah, 187
patents, 222
Pearce, Fred, 68, 298, 313, 315, 316, 317, 319
peer review, 197
permafrost, 77, 151, 155, 156
Perth, 59, 62, 63, 64, 302, 313
Peru, 65
PHEVs, 243, 244, 310
Philadelphia, 129
Philippines, 167, 168, 329
photosynthesis, 23, 93, 159, 168, 176, 235, 285, 326
phytoplankton, 119, 168, 172, 176, 179, 180, 181, 322
Pierrehumbert, Ray, 85, 295, 314
pipeline, 159, 233, 327
Pittock, A. Barrie, 295, 298, 313
Planetary Purgatory, 187
plankton, 100, 107, 168, 178, 179, 183, 235, 317
plankton management, 183
Plass, Gilbert, 22
plug-in hybrid electric vehicles, 243, 310
pluvial, 97
Polar Cell, 62
political leaders, 107, 291
politicians, 7, 22, 25, 26, 30, 38, 50, 54, 132, 219, 270
pollution, 5, 16, 35, 101, 103, 104, 107, 137, 152, 237, 239, 249, 260, 305, 309, 326
Porter, Stephen, 295
positive feedback, 33, 34, 87, 89, 92, 93, 94, 147, 314, 320
pothole, 74, 75, 302
Prius, 250
quicksand, 80
Quito, 63
radioactive fallout, 262
Rahmstorf, Stefan, 199, 295, 319, 324
rain forest, 34, 59, 67, 163, 203
Ramanathan, V., 106, 315
reactor, 9, 258, 259, 260, 261, 262, 263, 265, 329
Reagan, Ronald, 229, 290
Recovery Manual, 288
recycling, 43, 98, 263
refrigerator, 105, 108, 242
renewables, 67, 282
reprocess fuel, 263
Reville, Roger, 22
Revkin, Andrew, 31
revolutions, 276
Rhine, 121, 124, 125
Rhines, Peter, 295
Rifkin, Susan Beth, 295
Robinson, Kim Stanley, 59, 312, 328
Rockas, Peter, 295
Romm, Joseph, 32, 187, 298, 310, 324
Roosevelt, F.D., 236
Rowland, Sherry, 152
runaway, 160, 170, 178, 225, 237, 271, 277, 286, 290, 291
Russia, 103, 283
safety factor, 202
Sahara, 61, 97, 100, 302, 317
Salpa aspera, 172
San Francisco, 64, 112, 140, 141, 303
San Joaquin, 140
Santa Barbara, 154, 303
Sao Paulo, 121
Saudi Arabia, 204
savanna, 97
Scambos, Ted, 98, 315
Schewe, Phillip F., 204
Schneider, Stephen, 85, 104, 220, 295, 299, 326
sea level, 13, 35, 37, 76, 108, 111, 112, 114, 118, 119, 121, 122, 123, 124, 125, 126, 128, 129, 130, 131, 132, 133, 139, 141, 143, 145, 147, 154, 165, 168, 190, 203, 236, 303, 312, 317
sea-surface temperatures, 164
Seattle, 4, 63, 74, 78, 92, 112, 302, 303, 332
sea-wall, 125
sensitivity, 194, 196, 304, 308, 326
Shanghai, 121
Siberia, 155, 303, 320
Silicon Valley Bogs, 141
slash-and-burn, 67
slavery, 16, 231
Snowball Earth, 87, 91, 93, 163
soil, 3, 16, 21, 44, 49, 77, 82, 98, 153, 159, 170, 234, 250
soils, 11, 98, 159, 170, 268
solar, 4, 91, 93, 201, 212, 213, 217, 232, 234, 266, 282, 283, 306, 310, 327
soot, 35, 101, 109, 196, 224, 225, 315
South Africa, 263
Southeast Asia, 6, 166, 230, 325
Spain, 62, 201, 265, 266
stable states, 162, 304
Staten Island, 132
steam, 44, 87, 88, 249, 251, 252, 253, 255, 256, 259, 260, 261, 266, 274
steam turbine, 249, 252, 266
Steffen, Koni, 117
Steffen, W., 94, 272, 314
Steig, Eric, 295
Stern, Sir Nick, 230
Stocker, Tom, 295, 319, 324
storm surges, 124, 126, 128, 130, 132, 133, 134, 137, 138, 276, 317
stratosphere, 96, 106, 107, 302
succession cycle, 66
sulfur, 105, 106, 107, 152, 245, 248, 260, 273, 315
Sullivan, Gordon R., 32
sustainability, 67

- Sydney, 63
 Tampa, 129
 tankers, 154, 283
 taxes, 5, 221, 232, 233, 277, 284, 289, 326
 Tebaldi, C., 163, 321
 technofix, 228, 288
 Tel Aviv, 63
 temperature anomalies, 20
 Tennyson, Alfred, 189
 terrorists, 276
 Thames Barrier, 134, 135, 137, 303
 thermal expansion, 111, 118, 141, 147, 199
 thermostat, 88, 91
 Three Mile Island, 260, 261, 262
 Tickell, Sir Crispin, 202, 295, 325
 tipping points, 32, 34, 68, 79, 84, 186
 tobacco lobby, 208
 Tokyo, 121, 291
 topsoil, 42, 44, 46, 49, 81
 trade winds, 23, 61, 165, 166, 167, 168, 191, 312, 322
 transmission lines, 156, 234, 265, 284, 330
 tree rings, 41, 96
 troposphere, 96
 Tuvalu, 35
 Tyndall, John, 22
 typhoon, 184
 U.S., 6, 16, 26, 28, 29, 32, 46, 51, 52, 64, 126, 128, 129, 133, 138, 154, 168, 180, 186, 187, 200, 201, 204, 208, 209, 212, 220, 221, 229, 232, 240, 243, 245, 248, 251, 254, 259, 260, 261, 263, 266, 270, 273, 282, 283, 290, 298, 300, 301, 303, 305, 309, 310, 311, 312, 313, 320, 322, 326, 327, 328
 understatement, 30, 199
 upwelling, 168, 180, 183, 184
 uranium, 245, 248, 263, 330
 vicious cycle, 5, 90, 156
 Vietnam, 72, 123, 331
 Vonnegut, Kurt, 278
 voted off the island, 113, 117
 Walker Cell, 166
 Walter, Katey, 155
 Washington, DC,, 129
 water vapor, 34, 43, 44, 93, 96, 191, 314, *See* humidity
 Weart, Spencer, 198, 219, 299, 309, 324
 weather forecasts, 189
 weathering, 93
 wedge, 222, 223, 224
 Weiss, Jeremy, 124, 317
 well, 10, 22, 23, 27, 29, 38, 42, 49, 50, 53, 58, 62, 65, 67, 89, 96, 153, 175, 176, 181, 183, 197, 200, 221, 225, 234, 242, 246, 249, 252, 256, 263, 271, 282, 287, 311, 315, 322, 326
 West Antarctic Ice Sheet, 37, 121, 303
 White Earth Catastrophe, 91
 wildfires, 13, 193, 197, 309
 wind, 4, 7, 11, 40, 44, 64, 73, 163, 165, 179, 184, 201, 202, 212, 216, 217, 249, 282, 283, 304, 305, 310, 327
 Woodhouse, C., 47
 World War Two, 237
 Worster, Robert, 49
 writing, 35, 97, 198, 295, 332
 zooplankton, 172, 173, 176, 177, 179, 181, 304