



POSITIVE FEEDBACKS AND CLIMATE RUNAWAY THE NEED TO ACT WITHOUT DELAY

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Why do most of the world's governments—represented on the Intergovernmental Panel on Climate Change (IPCC)—as well as most climate scientists and the League of Women Voters of the United States—think that strong action needs to be taken to reduce greenhouse gas (GHG) emissions without further delay? Instrumental measurements for more than 50 years and ice core records going back over 650,000 years show that the concentrations of greenhouse gases are higher now than at any time in that long period. We are now in uncharted waters. ***Experts advise that GHG emissions must peak and begin declining before 2015.***

An IPCC report issued in November 2007 says that “Atmospheric concentrations of CO₂ (379 ppm) and CH₄ (1774 ppb)¹ in 2005 ***exceed by far the natural range over the last 650,000 years (emphasis added).*** Global increases in CO₂ concentrations are due primarily to fossil fuel use—with land use change providing another significant but smaller contribution. It is very likely that the observed increase in CH₄ (methane) concentration is predominantly due to agriculture and fossil fuel use.”² Increasing concentrations of GHGs in the atmosphere are trapping heat near Earth's surface and causing the global average temperature to rise.

If we allow GHG emissions from fossil fuel burning and deforestation to continue to grow at their present rates, the warming that will follow can be expected to decrease albedo³ (reflectivity) and increase the rate of absorption of solar energy near the poles, increase water vapor concentrations in the atmosphere, melt Arctic tundra, release stores of carbon from soils and sea floors, and accelerate the melting of ice. Climate change is happening more rapidly than anyone expected.⁴ We could reach a tipping point where we could have a runaway climate change—one over which we no longer have any control—when releases of carbon (especially methane) from natural reservoirs greatly exceed emissions from burning fossil fuels. The grave danger we face and the need to take vigorous global action to reduce GHG emissions without delay are clear.

Those who think that the recent scientific assessment of climate sensitivity is preliminary, that we may be able to get away with higher levels of CO₂ than 350 ppm, or that the rate of ice melting may slow down, should recall the moral and political Precautionary Principle which advises:

“... a willingness to take action in advance of scientific proof [or] evidence of the need for the proposed action on the grounds that further delay will prove ultimately most costly to society and nature, and, in the longer term, selfish and unfair to future generations.”⁵

To help you understand the seriousness of the current threat, several important concepts are discussed below: (1) feedbacks in the climate system, (2) tipping points and abrupt climate change, (3) climate sensitivity—the dependence of temperature on CO₂, (4) natural climate

change, (5) anthropogenic climate change, (6) global warming and sea level rise, and (7) time lags and the lifetime of CO₂.

(1) Feedbacks in the Climate System

Climate feedbacks may be negative or positive. Negative feedbacks cause the climate to change more slowly the larger the change becomes. An example is the more rapid uptake of CO₂ by plants as its concentration increases.⁶ Positive feedbacks—which cause the climate to change more rapidly the larger the change becomes—predominate. Positive feedbacks linked to rising temperatures⁷ include the following:

- **Decreasing albedo (reflectivity).** As snow and ice warm and melt, to be replaced by darker soil or deep blue sea, surface reflectivity decreases markedly, causing more heat to be absorbed and leading to more rapid warming. A competing effect is that cloud cover may increase as Earth warms, tending to increase the reflection of sunlight out into space.⁸
- **Increasing concentrations of water vapor.** Water vapor is a powerful, naturally occurring GHG,⁹ and the amount of it in the atmosphere at equilibrium increases as temperatures rise. Rising concentrations of water vapor cause a greater greenhouse effect, leading to further warming.
- **Increasing rates of release of carbon from natural reservoirs.** As temperatures rise, large natural reservoirs of carbon in soils and sea floors could be released as CO₂ or methane—adding to the GHGs produced directly by human activity. The releases could result from more rapid bacterial action on carbohydrates in decaying plants or from the melting of gas hydrates. There is a huge amount of carbon in soils, Arctic tundra, and permafrost, and in methane hydrate on the sea floor.

Methane hydrate is a type of ice containing up to 13% methane by weight. If it melts, the methane is released as a gas. Indeed, there are already reports that bubbles of methane can be seen rising out of the lakes that are forming in Siberia as the permafrost melts.¹⁰ Methane hydrate is stable at sufficiently low temperature and high pressure. Because temperatures are lower in the Arctic, the pressure doesn't need to be so high, and methane hydrate can be found near the surface. In much warmer areas, methane hydrate is found on the ocean floor only at depths of more than 500 meters (m) (over 1500 ft).

The amount of carbon currently in non-frozen soils and permafrost is estimated to be about 2000 GtC (gigatons [billions of metric tons]).¹¹ The amount of carbon in the form of methane present on the ocean floors is uncertain but is probably much larger; most experts put the amount at 5,000-10,000 GtC.¹² Compare these huge numbers to about 300 GtC that humans have added to the atmosphere since 1750,¹³ and the 800 GtC as CO₂ in our present atmosphere. *A very large methane release is a disaster waiting to happen.*

Methane is a powerful greenhouse gas; it traps heat much more effectively near Earth's surface than CO₂ does. Although its atmospheric concentration was only about 1.8 ppm

Positive Feedbacks And Climate Runaway The Need To Act Without Delay

(1,774 ppb) in 2005, it produced 30% as much warming as the significantly larger 379 ppm concentration of CO₂.¹⁴ To make matters worse, a warming of only 2 or 3°C¹⁵ can melt additional methane hydrate, releasing the methane as a gas. This is not just a hypothetical scenario. It happened before, 55 million years ago, at a time called the Paleocene-Eocene Thermal Maximum.¹⁶ At that time, an estimated 2,000 GtC was released as methane, causing global average temperatures to rise several degrees. Most of the methane was oxidized in the atmosphere to CO₂, part of which dissolved in the oceans, acidifying them and causing an “oceanic extinction event” (a loss of numerous marine organisms)¹⁷ at the end of the Paleocene.

(2) Tipping Points and Abrupt Climate Change

As a 2002 report from the National Academy of Sciences stated: “Abrupt climate changes were especially common when the climate system was being forced to change most rapidly. Thus, greenhouse warming and other human alterations of the earth system may increase the possibility of large, abrupt, and unwelcome regional or global climatic events. The abrupt changes of the past are not fully explained yet, *and climate models typically underestimate the size, speed, and extent of those changes*. Hence, future abrupt changes cannot be predicted with confidence, and climate surprises are to be expected.”¹⁸

(3) Climate Sensitivity—The Relationship Between CO₂ Concentration and Temperature

The build-up of atmospheric concentrations of CO₂ is of concern because it is closely correlated with increases in global average temperatures. This relationship can be explored using global climate models and by looking at Earth’s past climate history. Svante Arrhenius, a Swedish chemist, was the first to use a mathematical model to explore what would happen to Earth’s surface temperature if the CO₂ concentration were cut in half or doubled. He spent the year of 1895 doing tedious hand calculations to conclude that halving CO₂ would reduce global average temperatures by 4-5°C while doubling it would increase the temperature by 5-6°C.^{19,20} This effect on temperature of doubling came to be known as “climate sensitivity.”

The impacts expected from increases in global average temperature relative to its pre-industrial value are shown in Figure 1.

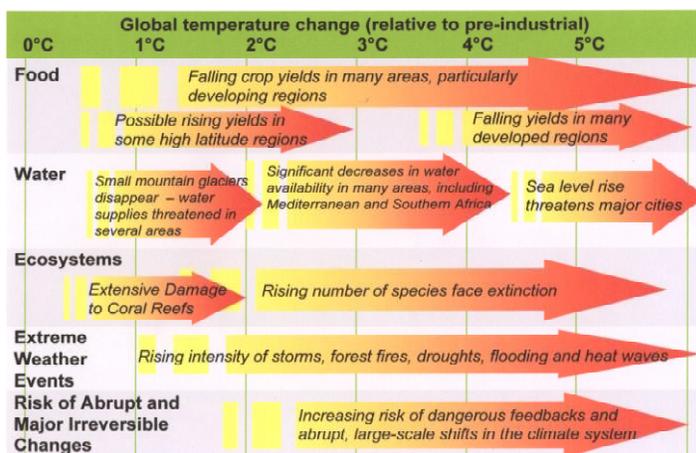


Figure 1. Expected impacts of global average temperature change. From a presentation by Sir David King.²¹

In 1750, before the Industrial Revolution, the global average temperature was about 14°C (57°F), and the atmospheric concentration of CO₂ was 280 ppm. Many, including the LWVUS,²² have recommended that the average temperature not be allowed to increase more than 2°C (3.6°F). The temperature since 1750 has increased 0.8°C (1.4°F), and CO₂ is at about 385 ppm—and increasing at over 2 ppm/year.²³ Many climate models more sophisticated than the one used by Arrhenius and run on high speed computers have projected that holding the CO₂ at 560 ppm (abbreviated 2xCO₂ [in 1750]) would increase the global average temperature about 3°C above its pre-industrial value.²⁴ Based on that projection, Dr. James Hansen, the chief climate scientist at NASA, strongly urged in 2006 that CO₂ concentrations not be allowed to increase above 450 ppm—limiting the total equilibrium temperature increase²⁵ to no more than about 1°C above what it is now.²⁶ Dr. Hansen wrote—

“This does not mean that climate impacts will be negligible if global warming is kept under 1°C (relative to year 2000), but the planetary conditions will be within a range in which we know that the climate did not go seriously haywire in the past. In contrast, if warming approaches the range 2-3°C (*a result that is extremely likely before 2100 with business-as-usual increasing emissions of CO₂*),* it is virtually certain that there will be large-scale disastrous climate impacts for humans as well as for other inhabitants of the planet...”²⁷

In more recent work in 2008,²⁸ based on Earth’s past response to changing concentrations of CO₂, Hansen and coworkers have determined that climate sensitivity is actually about 6°C for a doubling of CO₂—twice what was reported by the IPCC as recently as 2007.²⁹ Hansen’s 2008 paper concludes that the concentration is already too high, and that we should work hard to reduce global CO₂ emissions to zero and then negative (a net uptake [that is, sequestration] of CO₂) as soon as possible *to reduce CO₂ concentrations to below 350 ppm.*

Table 1 summarizes atmospheric CO₂ concentrations and the equilibrium temperature increases that can be expected for climate sensitivities of 3°C and 6°C. Concentrations and temperature changes after 2008 (shown in italics) are projections based on a 2% per year compound increase in global CO₂ emission rates.³⁰

Table 1. Calculated Equilibrium Temperature Increases as CO₂ Concentrations Increase

| Year | CO ₂ (ppm) | Equilibrium Temp. Change | |
|-------------|-----------------------|--------------------------|-------------|
| | | 3°C Sens. | 6°C Sens. |
| 1750 | 280 | 0.0 | 0.0 |
| 1988 | 350 | 1.0 | 1.9 |
| 2008 | 385 | 1.4 | 2.8 |
| <i>2028</i> | <i>450</i> | <i>2.1</i> | <i>4.1</i> |
| <i>2052</i> | <i>560</i> | <i>3.0</i> | <i>6.0</i> |
| <i>2106</i> | <i>1120</i> | <i>6.0</i> | <i>12.0</i> |

The temperature increase so far (0.8°C) is less than the equilibrium values shown because of the

* Parenthetical comments in italics are the author’s.

Positive Feedbacks And Climate Runaway The Need To Act Without Delay

slow response of the global average temperature to changes in CO₂ concentrations; the oceans take a long time to heat up. The projected future temperature changes shown may be underestimated because they assume that the fraction of CO₂ taken up by oceans and plants remains constant and that sudden large emissions of CO₂ or methane from natural carbon sinks—like Arctic tundra or methane hydrates on the sea floor—do not occur.

(4) Natural Climate Change

Incoming solar radiation, the Earth's orbital parameters, volcanic action and weathering of rock, ocean circulation, and the concentrations of greenhouse gases can all affect global climate.³¹

The planet has experienced dramatic climate changes in the past; North America as far south as New York was covered with the Laurentide ice sheet a mile thick as recently as 20,000 years ago. Three million years ago Earth was so warm that there was no Greenland ice sheet; 40 million years ago it was even warmer, and there was no Antarctic ice sheet. Prior to the Industrial Revolution (that is, prior to about 1750), climate change was due to natural causes. Now humans are making large and rapid changes in Earth's atmosphere and land surface, causing climate change that could have enormous consequences.

(5) Anthropogenic Climate Change

Burning fossil fuels (coal, oil, and natural gas), deforestation, population growth, and agricultural practices are changing the composition of the atmosphere (increasing the concentrations of CO₂ and other GHGs, soot, and sulfates) and changing the surface of the land, including melting large areas that have been covered by ice and snow. ***The large climate changes that have been observed in the past 30 years cannot be accounted for unless the effects of human activities are included.***

(6) Global Warming and Sea-Level Rise

Of all the threats posed by global warming—more severe droughts and floods, crop yield losses, more intense hurricanes, the spread of diseases, increased forest fires, species extinction, and sea level rise—the last poses perhaps the most obvious threat to modern industrial societies, with their major cities on coasts and their dependence on ports for international trade.³² As GHG concentrations and temperatures rise, sea levels also rise for two reasons: (1) Seawater expands as it warms, and (2) water runs into the oceans from glaciers melting on land.

Global mean temperature three million years ago was only 2-3°C higher than it is today while sea level was 25±10 m (80±30 ft) higher.³³ When the atmosphere last had a concentration of 560 ppm, twice what it was in 1750, about 7 million years ago, there was no Greenland ice sheet and considerably less ice in Antarctica.³⁴ If just the Greenland and the West Antarctic ice sheets melt, this would raise sea levels by 15 m (50 ft), submerging large parts of the Delmarva Peninsula,³⁵ Florida, much of Bangladesh, several small island states (e.g., the Maldives and the Marshall Islands),³⁶ and other low lying areas. A 50-ft rise would drown many large coastal cities and can aptly be called “catastrophic”. ***A recent paper using data on land elevation and population in coastal areas reports that a sea level rise of just 6 m (20 ft) would inundate over***

Positive Feedbacks And Climate Runaway The Need To Act Without Delay

2 million km² (720,000 square miles) and displace over 430 million people.³⁷ Even a 1 m rise would displace more than 100 million.

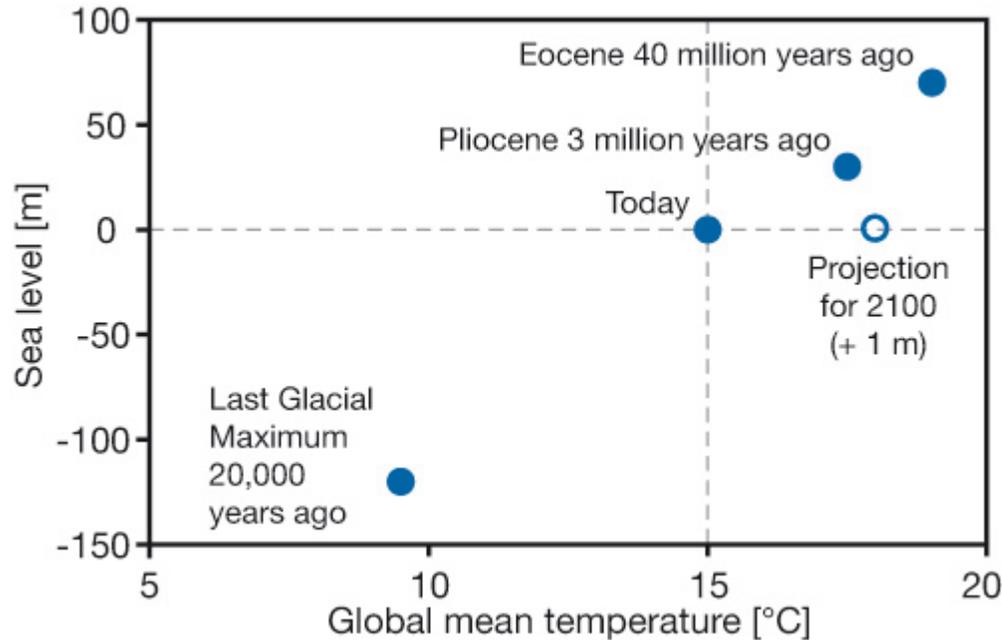


Figure 2. Relationship between global mean temperatures and changes in sea level relative to today's, from the paleoclimate record.³⁸

The relationship between global average temperature and sea level, based on earth's behavior for the past 40 million years, is shown in Figure 2. Note that the solid points represent equilibrium conditions—with enough time for the oceans, ice, and vegetation to fully respond. The open point, labeled **Projection for 2100**, which shows a projected temperature of about 18°C and a sea level rise of 1 m in 2100, is based on the fact that the ice will not have had nearly enough time by then to fully respond to the temperature change. The best straight line drawn through the solid points has a slope of 20 m/°C (37 ft/°F). ***This means that we can expect an equilibrium sea level rise of 20 meters (67 ft) for each 1°C rise in global average temperature.*** A critical question is: How rapidly will the ice melt? If we are lucky and the melting is slow enough, we may be able to manage a staged retreat from the coasts.

While we do not have good theoretical models for the melting of the polar ice sheets and the rate of sea level rise, an approach based on the observed sea levels and temperature changes during the 20th century suggests that the rate of sea level rise now is roughly proportional to the increase in global average temperature above the 14°C that it was in 1750.³⁹ ***This means that the farther we drive up the temperature by adding CO₂, the faster the sea will rise.*** At times in the past it has risen as much as 5 m in a century⁴⁰—a rate that would be very difficult to adapt to.

(7) Time Lags and the Long Lifetime of CO₂ in the Atmosphere

Positive Feedbacks And Climate Runaway The Need To Act Without Delay

The slow response of sea level to a change in global average temperature is a consequence of the huge thermal mass of the oceans, their slow mixing, and the time required to melt the polar caps. There is also a lag between the time when the composition of the atmosphere is no longer changing (net emissions of CO₂ and other GHGs are zero, i.e. their rates of addition no longer exceed their rates of removal) and when the global average temperature becomes steady. While part of the CO₂ released by burning fossil fuels is taken up by plants or dissolved in the ocean within decades, nearly 20% is still in the atmosphere 1,000 years after its release.⁴¹ Because the solubility of CO₂ in water decreases as the temperature increases, a larger fraction of the CO₂ emitted will remain in the atmosphere as the oceans warm, adding to the greenhouse effect.

Added Note

While this paper was in preparation, the Environment News Service reported that scientists from six national laboratories are launching a project to study abrupt climate change—in hopes of predicting dangerous tipping points before they occur.⁴² The name of the project will be IMPACTS, which stands for **Investigation of the Magnitudes and Probabilities of Abrupt Climate Transitions**. The initial emphasis will be on four types of abrupt climate change:

1. Instability among marine ice sheets, particularly the West Antarctic ice sheet
2. Positive feedback mechanisms in subarctic forests and arctic ecosystems, leading to rapid methane release or large-scale changes in the surface energy balance
3. Destabilization of methane hydrates—vast deposits of methane gas caged in water ice—particularly in the Arctic Ocean
4. Feedback between biosphere and atmosphere that could lead to megadroughts in North America

Precautionary Principle

For more information, a contemporary discussion of the Precautionary Principle as applied to climate change can be found on YouTube.⁴³

¹ CO₂ and CH₄ are the chemical formulas of carbon dioxide and methane; ppm and ppb are abbreviations for parts per million (by volume) and parts per billion.

² IPCC **Climate Change 2007: Synthesis Report – Summary for Policymakers**, Nov. 2007, page 5. At: http://195.70.10.65/pdf/assessment-report/ar4/syr/ar4_syr_spm.pdf

For more information on the IPCC see—
http://en.wikipedia.org/wiki/Intergovernmental_Panel_on_Climate_Change

³ The albedo (Latin for whiteness), a scientific term for reflectivity, is the fraction of incoming sunlight that is reflected back into space rather than being absorbed as heat. The albedo of ice and fresh snow is about 0.9; the albedo for deep blue sea is about 0.1.

⁴ The National Center for Atmospheric Research—in a news release titled **Arctic Ice Retreating More Quickly Than Computer Models Project**—reports that arctic sea ice is disappearing considerably faster than predicted with the models used in the recently released IPCC Group II Fourth Assessment Report of April 2007. See—
<http://www.ucar.edu/news/releases/2007/seaice.shtml>

The **Update for September 12, 2007**, in *The Cryosphere Today* reported that the Northern Hemisphere sea ice reached a new record minimum of 2.92 million square km, which is 27% below the previous record set in 2005. The minimum in 2008 was about the same size as in 2007. See: <http://arctic.atmos.uiuc.edu/cryosphere/>

⁵ **Precautionary Principle**, from http://en.wikipedia.org/wiki/Precautionary_principle

⁶ More rapid uptake of CO₂ by plants at higher CO₂ concentrations may not occur if flood, drought, fire or insect pests interfere with plant growth. A recent report says that drought in the Amazon basin in 2005 changed the rainforest from a carbon sink to a carbon source. More carbon is now being emitted than absorbed because so many trees have died. See:
<http://www.independent.co.uk/environment/climate-change/revenge-of-the-rainforest-1638524.html>

⁷ The temperature dependence of water vapor pressure, albedo, and microbial release of carbon from soils can act as a positive feedback to cool the planet under some circumstances. Past periods of extensive glaciation have been triggered by changes in Earth's orbital parameters that affected the timing and intensity of sunlight in the northern hemisphere. Once cooling started, lowered water vapor pressure, increased albedo, and reduced microbial metabolism all served to promote further cooling. See William F. Ruddiman, **Earth's Climate – Past and Future**, W.H. Freeman and Company, New York, 2001, p. 169-170.

⁸ While increasing evaporation of water might increase cloud formation and cause a cooling effect, NOAA reports little change in cloud cover over land during the period 1976-2003. See—
<http://lwf.ncdc.noaa.gov/oa/climate/globalwarming.html>

⁹ Anyone who has spent time in a desert knows that it can be extremely hot during the day when the sun is up, but it can get quite chilly at night after the sun goes down. The reason is that dry air has a much smaller greenhouse effect than moist air, so that the radiation from the earth after sundown in the desert readily escapes out into space. A large difference in temperature between day and night is characteristic of dry climates and high elevations.

¹⁰ K.M. Walther et al., **Methane Bubbling from Siberian Thaw Lakes as a Positive Feedback to Climate Warming**, *Nature Letters*, Vol. 443, Sept. 7, 2005. At—
<http://www.seas.harvard.edu/climate/pdf/2006/Walter2006.pdf>

¹¹ Ker Than, **Global Warming Could Release Permafrost Carbon**, posted on *LiveScience*, June 15, 2006. At— http://www.livescience.com/environment/060615_permafrost_carbon.html

¹² Barbara Maynard, **Burning Questions about Gas Hydrates**, *Chemistry*, pp. 27-33 (Winter 2006). At— http://acswebcontent.acs.org/chemistry/winter_2006.pdf

¹³ D. Archer, **Fate of Fossil Fuel CO₂ in Geologic Time**, *J. Geophys. Res.*, Vol. 110, 2005, C09S05. At— http://geosci.uchicago.edu/~archer/reprints/archer.ms.fate_co2.pdf

¹⁴ Figures 8 and 9 in **Technical Summary of the Working Group I Report**, IPCC Third Assessment Report, 2001, pp. 36-37. At— http://www.grida.no/climate/ipcc_tar/wg1/pdf/WG1_TAR-Front.pdf

¹⁵ Celsius (sometimes called Centigrade in the U.S.) degrees are larger than Fahrenheit degrees; 1°C is equal to 1.8°F, so that 2°C is 3.6°F and 3°C is 5.4°F.

¹⁶ James C. Zachos et al., **Rapid Acidification of the Ocean During the Paleocene-Eocene Thermal Maximum**, *Science*, **308**, pp. 1611-1615 (2005). At— <http://www.sciencemag.org/cgi/content/abstract/308/5728/1611>

¹⁷ For the effects of ocean acidification on coral reefs and other organisms that contain calcium carbonate, see **Impacts of Ocean Acidification on Coral Reefs and Other Marine Calcifiers – A Guide for Future Research**, *Report of a Workshop Sponsored by NSF, NOAA and USGS*. At— http://www.ucar.edu/communications/Final_acidification.pdf

¹⁸ **Abrupt Climate Change: Inevitable Surprises**, National Academies Press, 2002, Executive Summary, p. 1. At— http://books.nap.edu/openbook.php?record_id=10136&page=1

¹⁹ Spencer Weart, **The Discovery of Global Warming: Carbon Dioxide and the Greenhouse Effect**. At— <http://www.aip.org/history/climate/co2.htm>.

²⁰ Elizabeth Kolbert, **Field Notes from a Catastrophe: Man, Nature, and Climate Change**, Bloomsbury Publishing, New York, 2006, pp. 39-42.

²¹ Sir David King, **Climate Change: State of Urgency: the Science, the Impacts and Maintaining a Growing Economy**, PowerPoint presentation to the American Association for the Advancement of Science (AAAS), July 12, 2007. Slide 8. At— http://www.aaas.org/news/press_room/climate_change/media/20070712_king/king_presentation_20070712.pdf [or <http://tinyurl.com/bymwwg>]

²² **The United States Must Take Aggressive Action To Cut its Greenhouse Gas Emissions To Stabilize Earth's Climate**, LWV Climate Change Task Force, January 2009. At— http://www.lwv.org/AM/Template.cfm?Section=Global_Climate_Change&TEMPLATE=/CM/ContentDisplay.cfm&CONTENTID=12836 [or <http://tinyurl.com/cfhk3f>]

²³ Intergovernmental Panel on Climate Change, **IPCC Fourth Assessment Report 2007**. At— <http://www.ipcc.ch/>

²⁴ **Carbon Dioxide and Climate: A Scientific Assessment**, Jule Charney, Chair. National Academy of Sciences, Climate Research Board (1979). Washington, DC: National Academy of Sciences. At— http://www.nap.edu/catalog.php?record_id=12181

²⁵ Equilibrium temperature means the global average temperature when ice cover, vegetation, and ocean temperatures are no longer changing, the achievement of which—because of the slow melting of ice and the large thermal mass of oceans and their slow turnover—can take hundreds of years beyond the time when the composition of the atmosphere is no longer changing.

²⁶ James Hansen et al., **Climate Changes and Trace Gases**, *Philosophical Transactions of The Royal Society A*, Volume 365, Number 1856 / July 15, 2007, pp. 1925-1954. On the web at— http://pubs.giss.nasa.gov/docs/2007/2007_Hansen_etal_2.pdf

²⁷ **Declaration of James E. Hansen for the United States District Court for the District of Vermont**, Aug. 16, 2006, p. 15. At— http://www.columbia.edu/~jeh1/case_for_vermont.pdf

²⁸ James Hansen *et al.*, **Target atmospheric CO₂: Where should humanity aim?**, *Open Atmospheric Science Journal*, Volume 2, 217-231 (2008)¹; <http://dx.doi.org/10.2174/1874282300802010217>

²⁹ Intergovernmental Panel on Climate Change, **Climate Change 2007: The Physical Science Basis – Summary for Policy Makers**, February 2007, p. 12. At— <http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-spm.pdf>

³⁰ Prior to the recent economic slowdown, global carbon emissions from the burning of fossil fuels were increasing at a compound rate at over 3% per year. Michael R. Raupach *et al.*, **Global and regional drivers of accelerating CO₂ emissions**, *Proceedings of the National Academy of Sciences*, Vol. 104, No. 24, pp. 10288-10293, 2007. At: <http://www.pnas.org/content/104/24/10288.full>

Since we don't know how long slower economic growth will last, we chose a more conservative long-term growth rate of 2%/year for Table 1, which was generated using Excel.

³¹ William F. Ruddiman, *op. cit.*

³² S.P. Leatherman, **Sea Level Rise – History and Consequences**, B.C. Douglas, M.S. Kearney, Eds., *International Geophysics Series*, Vol. 75, Academic Press, San Diego, CA, 2001.

³³ J.E. Hansen, **Scientific Reticence and Sea Level Rise**, submitted to *Environmental Research Letters*, March 23, 2007. At— <http://arxiv.org/pdf/physics/0703220>

³⁴ William F. Ruddiman, *op.cit.*, p. 414.

³⁵ **Sea Level Rise and its Effect on Delaware**, University of Delaware College of Marine and Earth Studies, http://co2.cms.udel.edu/SeaLevel_DE.htm

³⁶ S.P. Leatherman *et al.*, *op. cit.* pp. 203-204. See—
http://books.google.com/books?id=DcXZF9vogtkC&pg=PA203&lpg=PA203&dq=average+elevation+of+small+island+states&source=bl&ots=Ygem_9oArJ&sig=ybBN3SUSCwBhKrA4QKYW9DWO_zI&hl=en&ei=nBWgSayYHIH8tgfY2rz5DA&sa=X&oi=book_result&resnum=2&ct=result#PPA204,M1 [or <http://tinyurl.com/dyqjsr>]

³⁷ R.J. Rowley, J.C. Kostelnick, D. Braaten, X. Li, and J. Meisel, **Risk of Rising Sea Level to Population and Land Area**, *EOS Transactions American Geophysical Union*, Vol. 88, No. 9, Feb. 27, 2007, pp. 105-116.

³⁸ **The German Advisory Council on Climate Change Special Report 2006**, Figure 3.1-1. At— http://www.wbgu.de/wbgu_sn2006_en/wbgu_sn2006_en_voll_3.html

³⁹ Stefan Rahmstorf, **A Semi-Empirical Approach to Projecting Future Sea Level Rise**, *Science*, Vol. 315, January 2007, pages 368-370, reported a 20th Century rise of 3.4 millimeters per year per °C temperature increase. He projected a rise by 2100 above the 1990 level of 0.5 to 1.4 meters. At— http://www.pik-potsdam.de/~stefan/Publications/Nature/rahmstorf_science_2007.pdf

⁴⁰ **The German Advisory Council on Climate Change Special Report 2006**. Chapter 3. At— http://www.wbgu.de/wbgu_sn2006_en/wbgu_sn2006_en_voll_3.html

⁴¹ James Hansen et al., **Climate Changes and Trace Gases**, *op. cit.*, Fig. 6a.

⁴² **U.S. National Labs Probe Abrupt Climate Change**, Environmental News Service, Sept. 22, 2008. At— <http://www.ens-newswire.com/ens/sep2008/2008-09-22-02.asp>

⁴³ YouTube, **The Most Terrifying Video You'll Ever See**, a 9.5 minute video. At— <http://www.youtube.com/watch?v=zORv8wwiadQ>