

## BEYOND 2 DEGREES CELSIUS

Implications of NASA/GISS updates for the Earth energy balance, global temperatures, ice melt and sea level rise

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30 May, 2011

The Earth energy balance—namely the difference between energy/heat absorbed by the Earth from solar radiation and the energy/heat emitted back to space—estimated at +3.1 Watt/m<sup>2</sup>, equivalent to a +2.3 degrees C (based on climate sensitivity of 3C per doubling of CO<sub>2</sub>) (Hansen et al., 2011 [1]), is currently in part mitigated by the cooling effect of albedo-enhancing sulphur aerosols (~ -1.6 Watt/m<sup>2</sup> = ~ -1.2C) emitted from fossil fuels and industry, which effectively act as a global geo-engineering process (Figure 1). Had it not been for this short-lived (few years-long) cooling effect the internationally agreed maximum temperature target of <2 degrees C would be transcended.

According to the IPCC AR4 (2007) [2] mean global land/ocean temperature since 1880 has risen by about +0.8C, which translates to more than +4C rise in the polar region of northern Canada, Greenland and Siberia [3] (Figure 2), triggering feedback-amplified ice melting accelerating between 2002 and 2010 [4] (Figure 3) and related sea level rise at a rate of 3.0+/-0.4 mm/year between 1993-2010 (Figure 4A). Melting of Arctic ice leading to increased evaporation can result in the advance of cold fronts into the north Atlantic (Figure 4B).

The measured global warming of +0.8C is lagging behind the +1.1C rise required by the energy imbalance (Figure 1B), a lag attributable to the buffering effect of the oceans. The temperature rise lag period has been estimated as 35 years [5].

Prior to the Copenhagen conference in 2009 the European Union obtained the agreement of relevant partners—including China, India, Russia, and the United States—to commit to an upper two-degree C ceiling on further rise in mean global temperature in order to avoid the risk of dangerous climate change [6]. However, a rise beyond 2 degrees Celsius may lead to tipping points in the atmosphere/ocean system [10]. As stated by the NASA/GISS climate science group [11]

*“Decreasing CO<sub>2</sub> was the main cause of a cooling trend that began 50 million years ago, large scale glaciation occurring when CO<sub>2</sub> fell to 425±75 ppm, a level that will be exceeded within decades, barring prompt policy changes. If humanity wishes to preserve a planet similar to that on which civilization developed and to which life on Earth is adapted, paleoclimate evidence and ongoing climate change suggest that CO<sub>2</sub> will need to be reduced from its current 385 ppm to at most 350 ppm. The largest uncertainty in the target arises from possible changes of non-CO<sub>2</sub> forcings. An initial 350 ppm CO<sub>2</sub> target may be achievable by phasing out coal use except where CO<sub>2</sub> is captured and adopting agricultural and forestry practices that sequester carbon. If the present overshoot of this target CO<sub>2</sub> is not brief, there is a possibility of seeding irreversible catastrophic effects.”*

With current CO<sub>2</sub> levels rising to ~28,000 million tons by 2010 (Figure 5) at rates fluctuating around ~2 ppm/year, reaching a level of 393.18 ppm at Mauna Loa in April 2011 [7] (Figure 6), with a total CO<sub>2</sub>-e (which includes CO<sub>2</sub> + the equivalent effect of methane) of >460 ppm [8], the NASA/GISS study [1] implies

global warming committed to reach 2.3 degrees C once the aerosol effect dissipates [12] (Figure 1). This effective though unintended geoengineering measure, acting as a transient shield from a near-doubling of global warming, further lowers ocean pH on top of CO<sub>2</sub> sequestration.

Had the proposed Australian reduction of 5 percent in the rate of carbon emissions by 2020 relative to 2000 [9] been a figure adopted world-side, global emissions would be reduced from ~24,000 million tons/year to 22,500 million tons/year, hardly causing a dent in the current trajectory above 393 ppm CO<sub>2</sub> toward levels at which the polar ice sheets are further destabilized (Figure 3).

It is not clear whether deep reduction in carbon emissions will be sufficient to stem the amplifying feedbacks associated with greenhouse gas warming and ice/melt water interactions. Barring an indefinite maintenance of sulphur aerosol emissions, deep emission cuts need to be accompanied by atmospheric CO<sub>2</sub> draw-down by means of fast-track tree planting, application of biochar methods and chemical CO<sub>2</sub> sequestration. As shown by the intensifying spate of extreme weather events around the globe (Figure 7) the alternative bears no contemplation.

[1] Earth's Energy Imbalance and Implications. James Hansen, Makiko Sato, Pushker Kharecha.  
[http://www.columbia.edu/~jeh1/mailings/2011/20110415\\_EnergyImbalancePaper.pdf](http://www.columbia.edu/~jeh1/mailings/2011/20110415_EnergyImbalancePaper.pdf)

[2] [http://www.ipcc.ch/publications\\_and\\_data/ar4/wg1/en/spmssp-direct-observations.html](http://www.ipcc.ch/publications_and_data/ar4/wg1/en/spmssp-direct-observations.html)

[3] <http://data.giss.nasa.gov/gistemp/graphs/>

[4] <http://www.agu.org/pubs/crossref/2011/2011GL046583.shtml>, Paleoclimate Implications for Human-Made Climate Change. James E. Hansen and Makiko Sato. <http://arxiv.org/ftp/arxiv/papers/1105/1105.0968.pdf>,

[5] <http://www.extremeweatherheroes.org/science-of-extreme-weather/global-evidence.aspx>

[6] <http://www.policyinnovations.org/ideas/innovations/data/000178>,  
[http://www.european-climate-forum.net/fileadmin/ecf-documents/publications/articles-and-papers/jaeger-jaeger\\_three-views-of-two-degrees.pdf](http://www.european-climate-forum.net/fileadmin/ecf-documents/publications/articles-and-papers/jaeger-jaeger_three-views-of-two-degrees.pdf)

[7] <http://www.esrl.noaa.gov/gmd/ccgg/trends/>

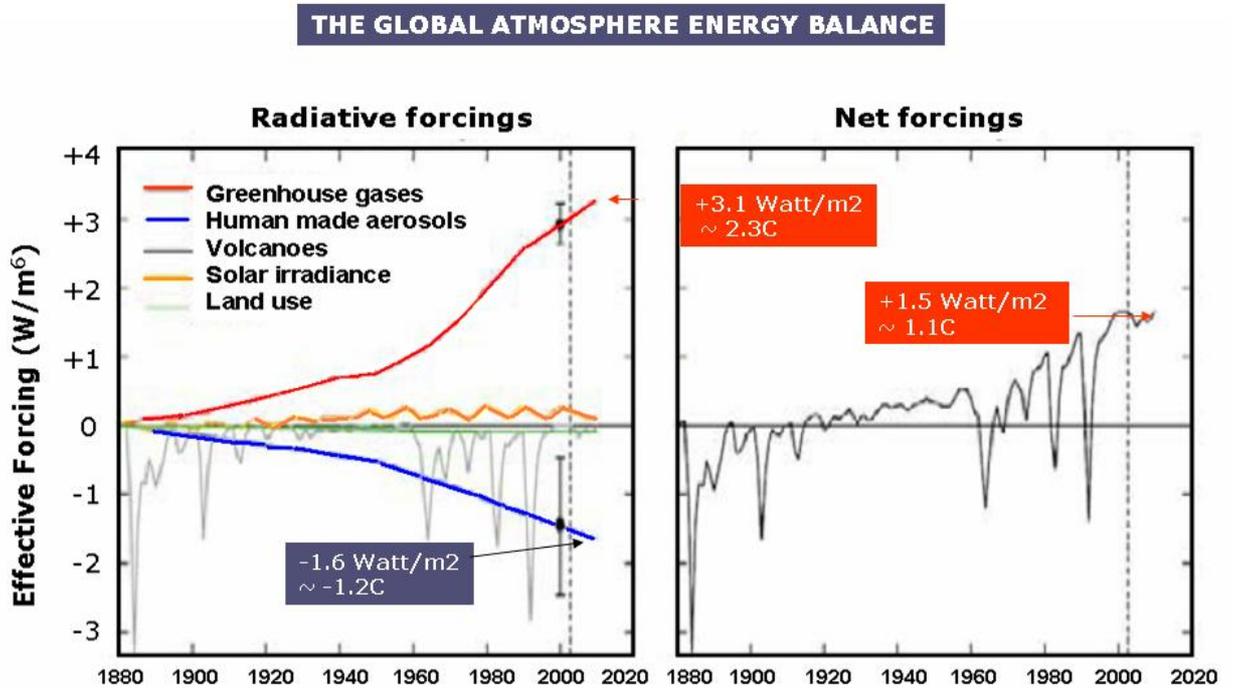
[8] [http://www.anu.edu.au/climatechange/wp-content/uploads/2009/07/synthesis\\_report\\_-\\_01072009.pdf](http://www.anu.edu.au/climatechange/wp-content/uploads/2009/07/synthesis_report_-_01072009.pdf)

[9] <http://www.greencarcongress.com/2008/12/australia-sets.html>

[10] <http://researchpages.net/esmg/people/tim-lenton/tipping-points/>,  
<http://universitypost.dk/article/two-degrees-warmer-may-be-past-tipping-point>,  
<http://www.bitsofscience.org/hansen-paleoclimate-2-degrees-892/>,  
<http://www.nybooks.com/articles/archives/2006/jul/13/the-threat-to-the-planet/>

[11] [http://www.columbia.edu/~jeh1/2008/TargetCO2\\_20080407.pdf](http://www.columbia.edu/~jeh1/2008/TargetCO2_20080407.pdf)

[12] Frequency of global extreme weather events and geophysical events, 1998 - 2008. From Topics Geo: Natural catastrophes 2008 analyses, assessments and positions.  
<https://www.munichre.com/touch/login/en/service/login.aspx?ReturnUrl=/touch/publications/en/list/default.aspx?id=1060>



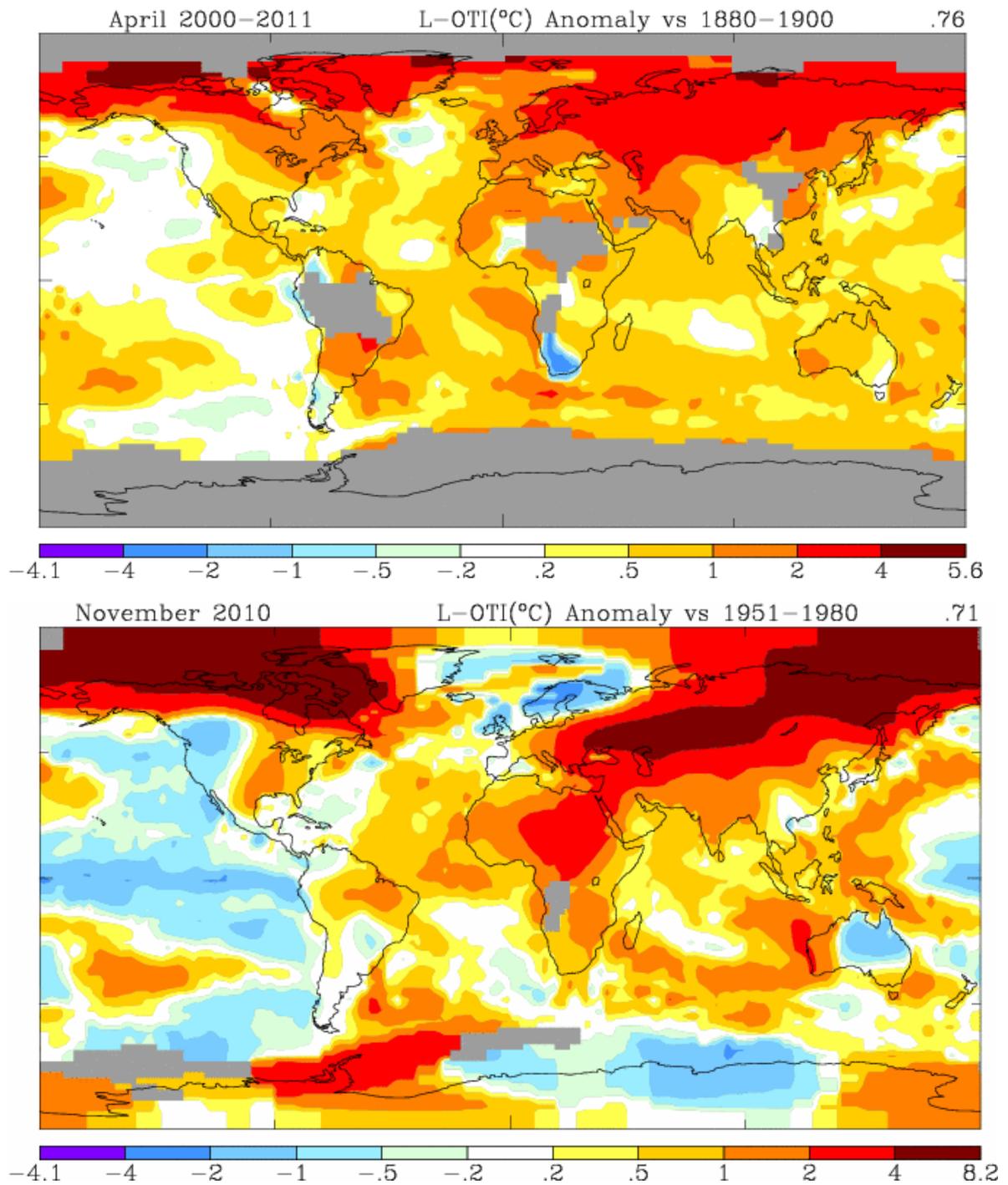
Hansen et al. 2011

**Figure 1**

- A.** Development of radiative forcing 1880-2010 in terms of energy changes of greenhouse gases (CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, O<sub>3</sub>), human emitted aerosols (mainly SO<sub>2</sub>), volcanic eruptions, solar radiation and land use.
- B.** Net variations in global energy levels (based on A).

Hansen et al. 2011.

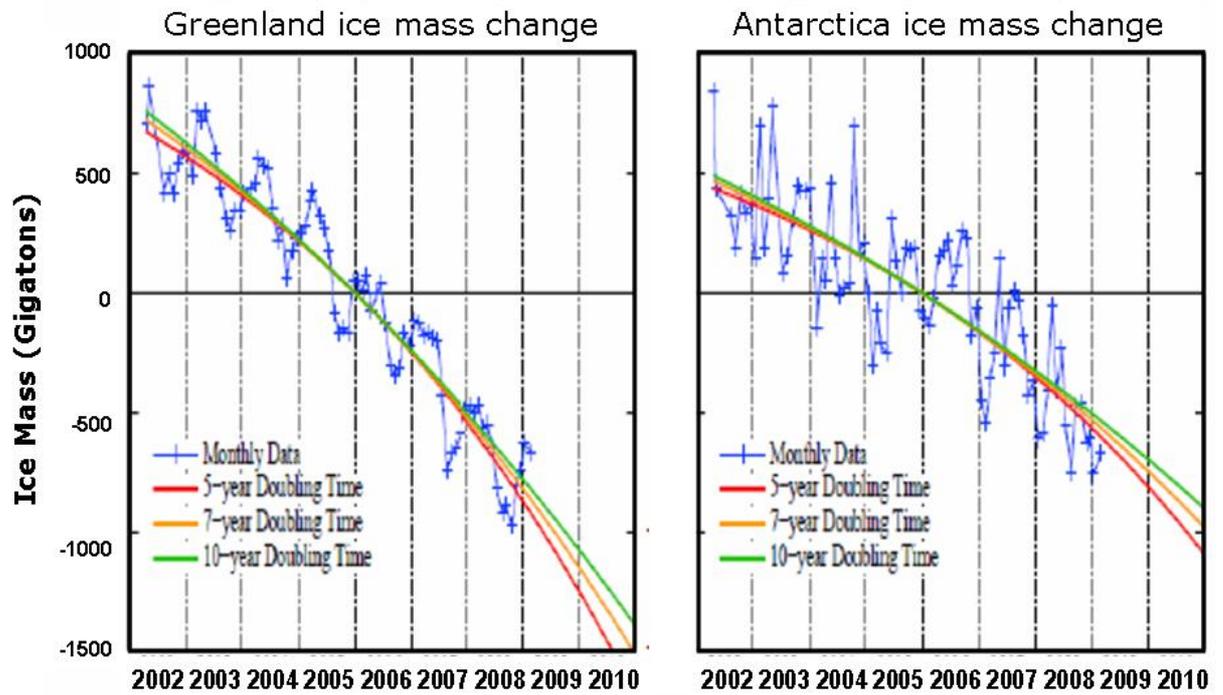
[http://www.columbia.edu/~jeh1/mailings/2011/20110415\\_EnergyImbalancePaper.pdf](http://www.columbia.edu/~jeh1/mailings/2011/20110415_EnergyImbalancePaper.pdf)



**Figure 2.**

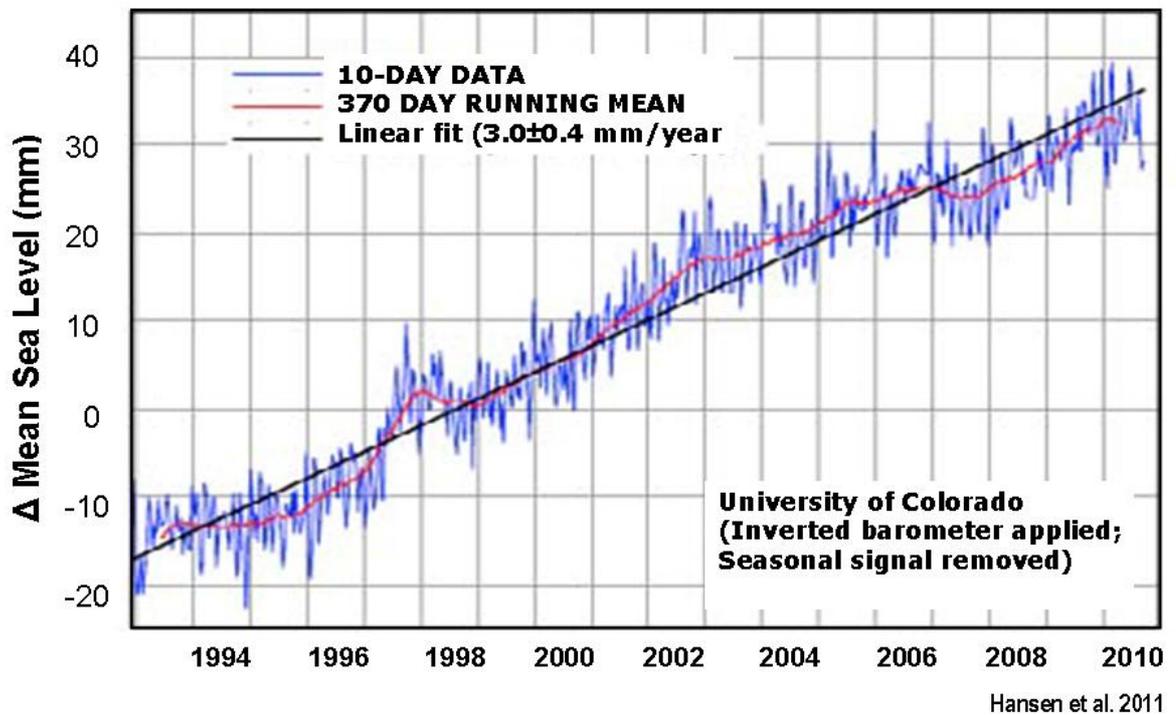
- A. Mean global temperature variations for April 2000-2011 relative to April 1880-1900.
- B. November 2010 anomalies relative to November 1951-1980, showing a North Atlantic Arctic front.

<http://data.giss.nasa.gov/gistemp/graphs/>



**Figure 3.**

Decadal, annual and seasonal changes in ice masses in Greenland and Antarctica from gravitational field measurements by Velicogna (2009) (Hansen and Sato, 2011). <http://www.agu.org/pubs/crossref/2011/2011GL046583.shtml>



**Figure 4**

Mean sea level rise between 1993-2010 in terms of 10-days data, 370 days running mean and a linear fit, based on satellite altimeter measurements calibrated with tide-gauge measurements (Nerem et al., 2006). University of Colorado. After Hansen et al. 2011.

[http://www.columbia.edu/~jeh1/mailings/2011/20110415\\_EnergyImbalancePaper.pdf](http://www.columbia.edu/~jeh1/mailings/2011/20110415_EnergyImbalancePaper.pdf)

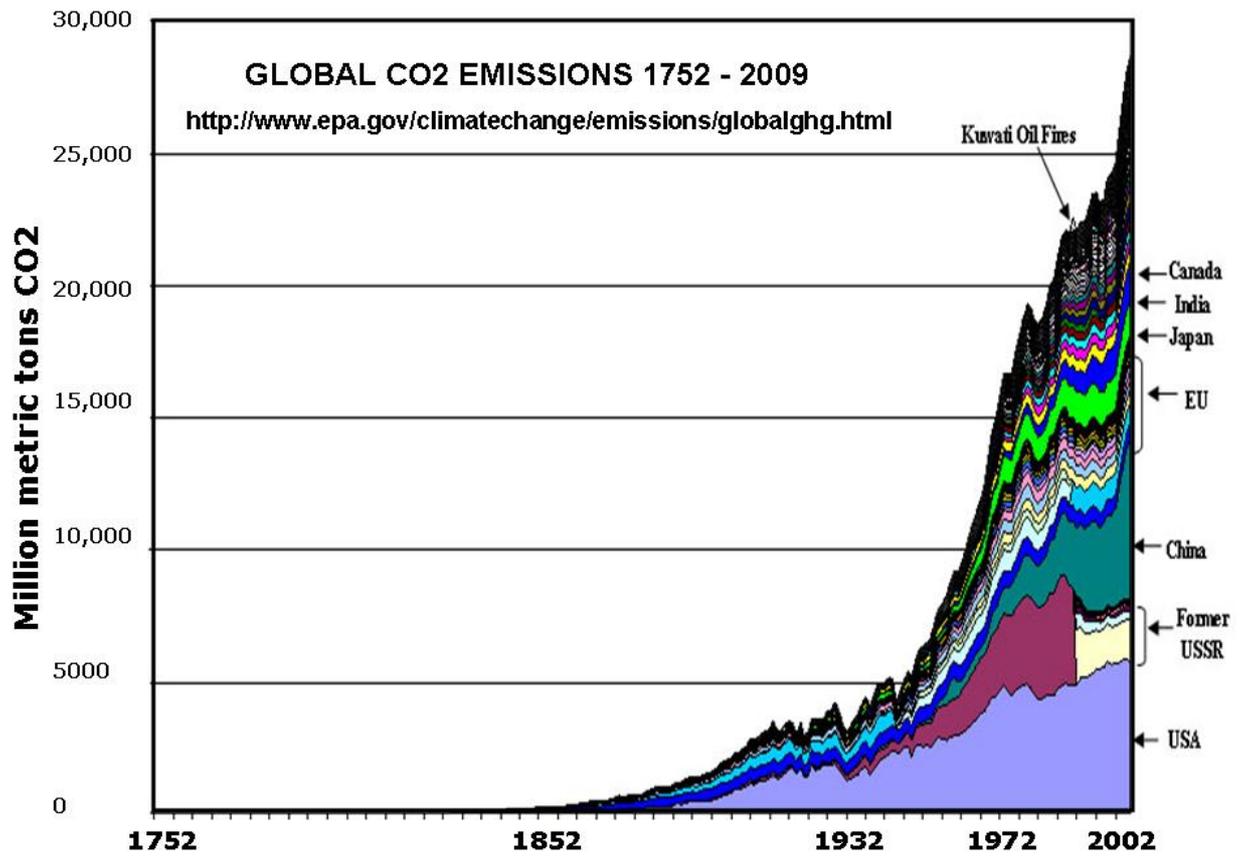
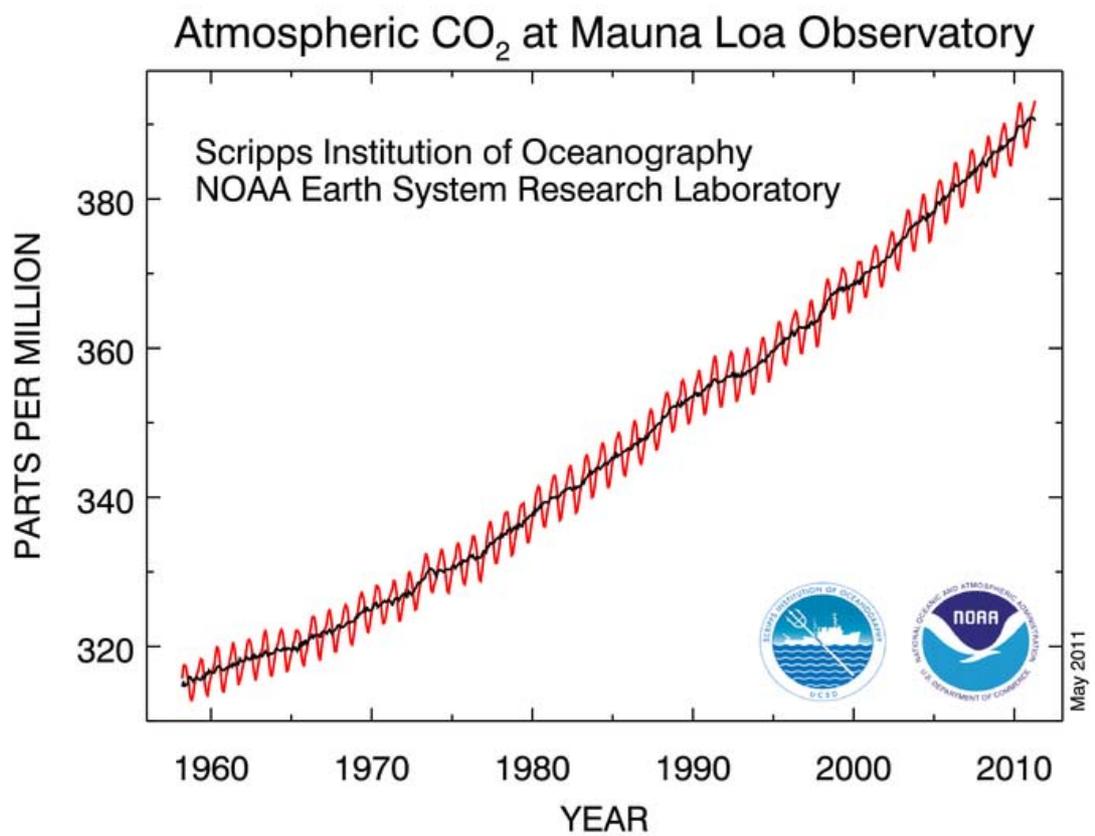


Figure 5

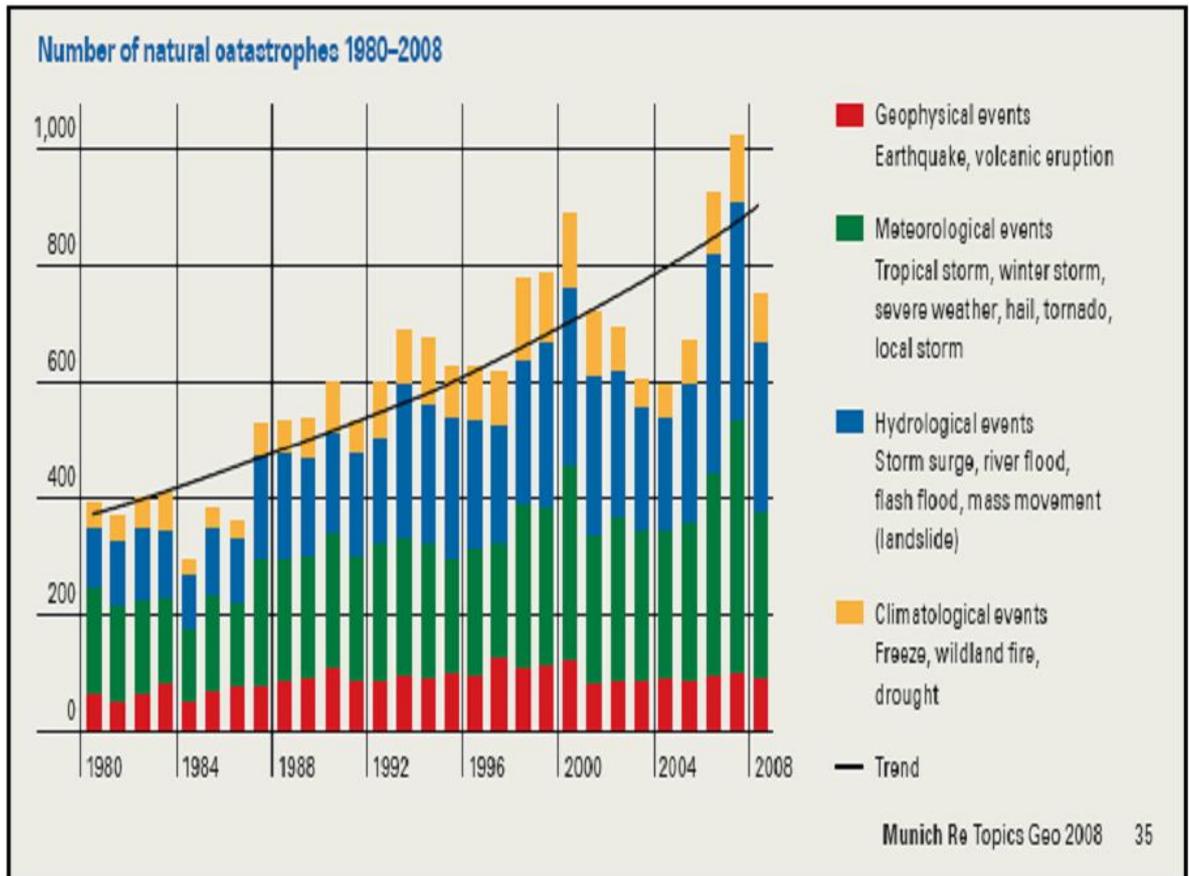
Global carbon emissions in million tons of CO2 in terms of countries and total global emission. <http://www.epa.gov/climatechange/emissions/globalghg.html>



**Figure 6.**

Atmospheric CO<sub>2</sub> concentrations at Mauna Loa Observatory.

<http://www.esrl.noaa.gov/gmd/ccgg/trends/>



**Figure 7**

Frequency of global extreme weather events and geophysical events, 1980 - 2008. From Topics Geo: Natural catastrophes 2008 analyses, assessments and positions.

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