

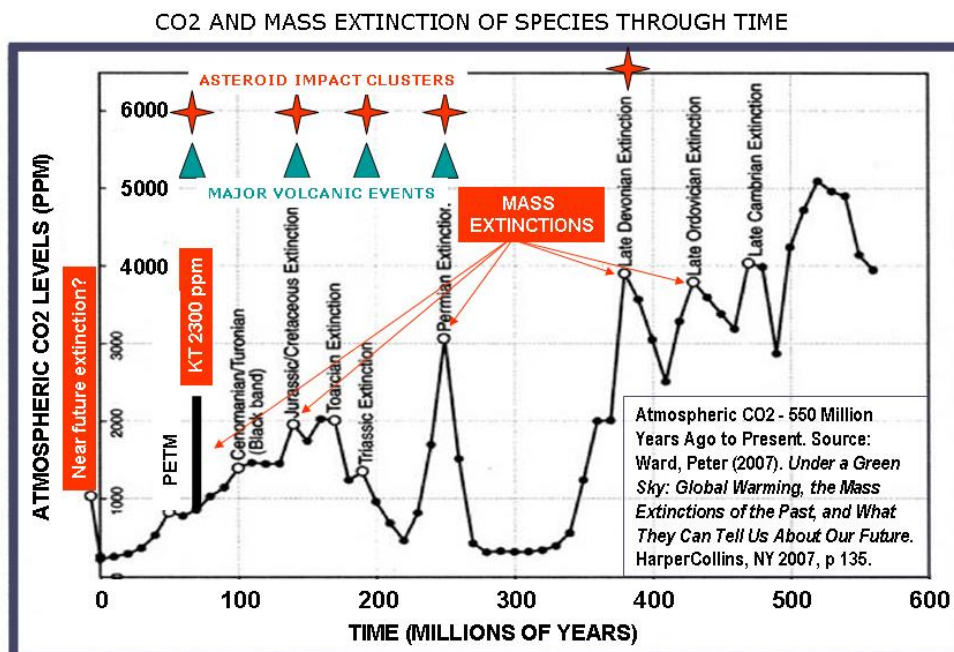
CLIMATE CHANGE AS A MAJOR GEOLOGICAL EVENT

Andrew Glikson
Earth and paleoclimate scientist
Australian National University

Major mass extinctions in the history of Earth were related, among other factors, to runaway rise in the level of atmospheric CO₂

(Peter Ward, *Under a Green Sky: Global Warming, the Mass Extinctions of the Past, and What They Can Tell Us About Our Future*. HarperCollins, NY 2007, p 135)

"We're simply talking about the very life support system of this planet" (Joachim Schellnhuber, Director, Potsdam Climate Impacts Institute, advisor to the German government) [1].



The release of more than 320 billion tons of carbon (GtC) from buried early biospheres, adding more than one half of the original carbon inventory of the atmosphere (~590 GtC), as well as the depletion of vegetation, have triggered a fundamental shift in the state of the atmosphere. Raising atmospheric CO₂ level at a rate of 2 ppm/year, a pace unprecedented in the geological record, with the exception of the effects of CO₂ released from craters excavated by large asteroid impacts, the deleterious effects of pollution and deforestation have reached a geological dimension, tracking toward conditions which existed on Earth in the mid-Pliocene, about 2.8 billion years ago [2].

Lost all too often in the climate debate is an appreciation of the delicate balance between the physical and chemical state of the atmosphere-ocean-land system and the evolving biosphere, which controls the emergence, survival and demise of species, including humans. By contrast to Venus, with its thick blanket of CO₂ and sulphur dioxide greenhouse atmosphere, exerting extreme pressure (90 bars) at the surface, or Mars with its thin (0.01 bar) CO₂ atmosphere, the presence in the Earth's atmosphere of trace concentrations of greenhouse gases (CO₂, methane, nitric oxides, ozone) modulates surface temperatures in the range of -89 and +57.7 degrees Celsius and a mean of 14 degrees Celsius, allowing the presence of liquid water and thereby of life [3].

Forming a thin breathable veneer only slightly more than one thousand the diameter of Earth, and evolving both gradually as well as through major perturbations with time, the Earth's atmosphere acts as a lungs of the biosphere, allowing an exchange of carbon gases and oxygen with plants and animals, which in turn affect the atmosphere, for example through release of methane and photosynthetic oxygen (Figure 1).

CO₂ is 28 times more soluble in water than is oxygen. Above critical threshold CO₂ becomes toxic for certain organisms. Marine organisms are more sensitive to changes in CO₂ levels than are terrestrial organisms. Excess CO₂ reduces the ability of respiratory pigments to oxygenate tissues, and makes body fluids more acidic, thereby hampering the production of carbonate hard parts like shells. Relatively modest but sustained increases in CO₂ concentrations hamper the synthesis of proteins, reduce fertilization rates, and produce deformities in calcareous hard parts. The observed pattern of marine extinctions is consistent with hypercapnia (excessive levels of CO₂), with related extinction events [4].

When the concentration of CO₂ in the atmosphere rises above a critical threshold, climate shifts to a different state. Any significant increase in the level of carbon gases triggers powerful feedbacks. These include ice melt/warm water interaction, decline of ice reflection (albedo) and increase in infrared absorption by exposed water. Further release of CO₂ from the oceans and from drying and burning vegetation shifts global climate zones toward the poles, warms the oceans and induces ocean acidification [5].

The essential physics of the infrared absorption/emission resonance of greenhouse molecules is indicated by observations in nature and laboratory studies, as portrayed in the relations between atmospheric CO₂ and mean global temperature projections (Figure 2).

During most of Earth history the oxygen-poor composition of the atmosphere resulted in dominance of reduced carbon species in the air and the oceans, including methane and carbon monoxide, allowing mainly algae and bacteria to exist in the oceans (Figure 3). It is commonly held that, about 0.7 billion years ago, in the wake of the Marinoan glaciation (so-called "Snowball Earth"), oxygenation of low-temperature water allowed development of new oxygen-

binding proteins and thereby of multicellular animals, followed by development of a rich variety of organisms - the "Cambrian explosion" [6].

The present state of the biosphere, allowing survival of large mammals and of humans on the continents, developed when CO₂ levels fell below about 500 ppm some 34 million years ago (end Eocene) [7]. At this stage, as well as following warm periods in the Oligocene (c. 25 million years ago) and mid-Miocene (about 15 million years ago), development of the Antarctic ice sheet led to a fundamental change in the global climate regime. About 2.8 million years ago (mid-Pliocene) the Greenland ice sheet and the Arctic Sea ice began to form, with further decline in global temperatures expressed through glacial-interglacial cycles regulated by orbital forcing (Milankovic cycles), with atmospheric CO₂ levels oscillating between 180 and 280 ppm CO₂ (Figure 4). These conditions allowed the emergence of humans in Africa and their migration all over the world (Figure 5) [8].

Recent paleoclimate studies, using multiple proxies (soil carbonate $\delta^{13}\text{C}$, alkenones, boron/calcium, stomata leaf pores), indicate that the current CO₂ level of 388 ppm and CO₂-equivalent level of 460 ppm (which includes the methane factor), commit warming above pre-industrial levels to 3 to 4 degrees C in the tropics and 10 degrees C in polar regions, tracking toward an ice-free Earth [2].

Small human clans post-3 million years-ago responded to changing climates through migration within and out of Africa. Homo sapiens emerged during the glacial period preceding the 124 thousand years-old Emian interglacial, when temperatures rose by about 1 degree C and sea levels by 6-8 meters relative to pre-industrial [5]. The development of agriculture and thereby human civilization had to wait until climate stabilized about 8000 years ago, when large scale irrigation along the great river valleys (the Nile, Euphrates, Hindus and Yellow River) became possible.

Since the 18th century mean global temperature has risen by about 0.8 degrees C. Another 0.5 degrees C is masked by industrial-emitted aerosols (SO₂), and further rise ensues from current melting of the ice sheets and sea ice. The polar regions, acting as the "thermostats" of the Earth, are the source of the cold air current vortices and the cold ocean currents, such as the Humboldt and California current, which keep the Earth's overall temperature balance, much as the blood stream regulates the body's temperature and the supply of oxygen.

At 4 degrees Celsius advanced to total melting of the Greenland and Antarctic ice sheets leads to sea levels tens of meters higher than at present. Further rise of CO₂-e above 500 ppm and mean global temperatures above 4 degrees C can only lead toward greenhouse Earth conditions such as existed during the Cretaceous and early Cainozoic (Figure 4) [5, 7].

A rise of atmospheric CO₂ concentration triggers feedback effects due to warming, desiccation and burning of vegetation, releasing more CO₂. The onset of methane release from polar bogs and sediments is of major concern. Ice/melt water interaction proceeds as melt water melts more ice, ice loss results in albedo loss and exposed water absorb infrared heat, resulting in an amplified feedback cycle. Because CO₂ is cumulative, with atmospheric residence time on the scale of centuries to millennia, stabilization of the climate through small incremental reduction in emission may not be sufficient to avoid runaway climate change and possible tipping points.

Climate change is appropriately described as a *global oxygenation event* affecting geological carbon deposits as well as the present biosphere. At 2 ppm/year the pace of carbon oxidation exceeds the highest recorded geological rate of 0.4 ppm/year at the Paleocene-Eocene boundary at 55 Ma, when about 2000 GtC were burnt, triggering an extinction of species [7].

Sea level rise constitutes a critical parameter which reflects all other components of climate change. Since the early 20th century the rate of sea level rise increased from about 1 mm/year to about 3.5 mm/year (1993 – 2009 mean rate 3.2+/-0.4 mm/year), representing a nearly 4 fold increase since the onset of the industrial age (Figure 6).

The Earth poles are warming at rates 3 to 4 times faster than low altitudes (Figure 7) [9]. The most detailed satellite information available shows that ice sheets in Greenland and western Antarctica are shrinking and in some places are already in runaway melt mode [10]. A new study, using 50 million laser readings from a NASA satellite, calculates changes in the height of the vulnerable but massive ice sheets and found them especially worse at their edges, where warmer water eats away from below. In some parts of Antarctica, ice sheets have been losing 30 feet a year in thickness since 2003 [10].

The consequences of open ended rise in atmospheric CO₂ are manifest in the geological record (Frontispiece). The world is in a lag period, when increasing atmospheric energy is expressed by intense hurricanes, increased pressure at mid-latitude high pressure zones and shift of climate zones toward the poles. With ensuing desertification of temperate zones, i.e. southern Europe, southern Australia, southern Africa, the desiccated forests become prey to firestorms, such as in Victoria and California.

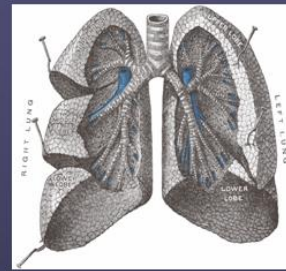
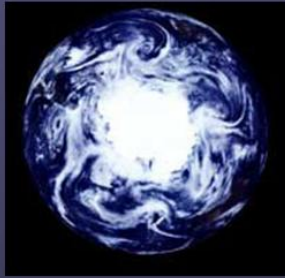
There is nowhere the 6.5 billion of contemporary humans can go, not even the barren planets into the study of which space agencies have been pouring more funding than governments allocate for environmental mitigation to date. At 460 ppm CO₂-equivalent, the climate is tracking close to the upper stability limit of the Antarctic ice sheet, defined at approximately 500 ppm [5,7]. Once transcended, mitigation measures would hardly be able to re-form the cryosphere. Humans can not argue with the physics and chemistry of the atmosphere. What is needed are urgent measures including

1. Deep cuts in carbon emissions.
2. Parallel Fast track transformation to non-polluting energy utilities – solar, solar-thermal, wind, tide, geothermal, hot rocks.
3. Global reforestation and re-vegetation campaigns, including application of biochar.

The alternative does not bear contemplation.

- [1] <http://www.reuters.com/article/idUSTRE58R3UI20090928>
- [2] Pagani M. et al. 2010.
<http://www.nature.com/ngeo/journal/v3/n1/abs/ngeo724.html>
- [3] http://en.wikipedia.org/wiki/Earth#Weather_and_climate
- [4] http://en.wikipedia.org/wiki/Permian%E2%80%93Triassic_extinction_event
- [5] Hansen et al. 2008. Target CO2: Where Should humanity aim?
http://www.columbia.edu/~jeh1/2008/TargetCO2_20080407.pdf
- [6] http://www.pbs.org/wgbh/evolution/library/03/4/l_034_02.html
- [7] Zachos J.C. et al. 2008
<http://www.nature.com/nature/journal/v451/n7176/full/nature06588.html>
- [8] deMenocal, P.B. 2004.
<http://www.ldeo.columbia.edu/~peter/Resources/Publications/deMenocal.2004.pdf>
- [9] <http://wwfblogs.org/climate/content/looking-above-normal-temperatures-they-are-arctic>
- [10] <http://www.nature.com/nature/journal/v461/n7266/full/nature08471.html>
<http://climateprogress.org/2009/10/26/nature-dynamic-thinning-of-greenland-and-antarctic-ice-sheets-glacier/>

THE ATMOSPHERE AS THE "LUNGS OF THE BIOSPHERE" (AN ANALOGY BETWEEN GLACIAL/INTERGLACIAL CYCLES AND THE LUNGS)



1. VORTEX EXPANDS

- The Earth cools
- CO₂ absorption by oceans is enhanced
- Trees grow larger with higher stomata density to allow them to absorb sparse atmospheric CO₂
- Trees release more photosynthetic oxygen
- Atmospheric oxygen is enriched

2. THE VORTEX CONTRACTS

- The Earth warms
 - CO₂ is expelled from the oceans
 - Oxygen is consumed by respiration and burnt
- EXCESS CO₂ – THE EARTH WARMS (POSSIBLE MASS EXTINCTION)

1. THE LUNGS EXPAND

- Lungs absorb oxygen for respiration

2. THE LUNGS CONTRACT

- CO₂ is exhaled

EXCESS CO₂ – ANIMALS DIE

Figure 1. The terrestrial atmosphere as "lungs of the biosphere" – an analogy.

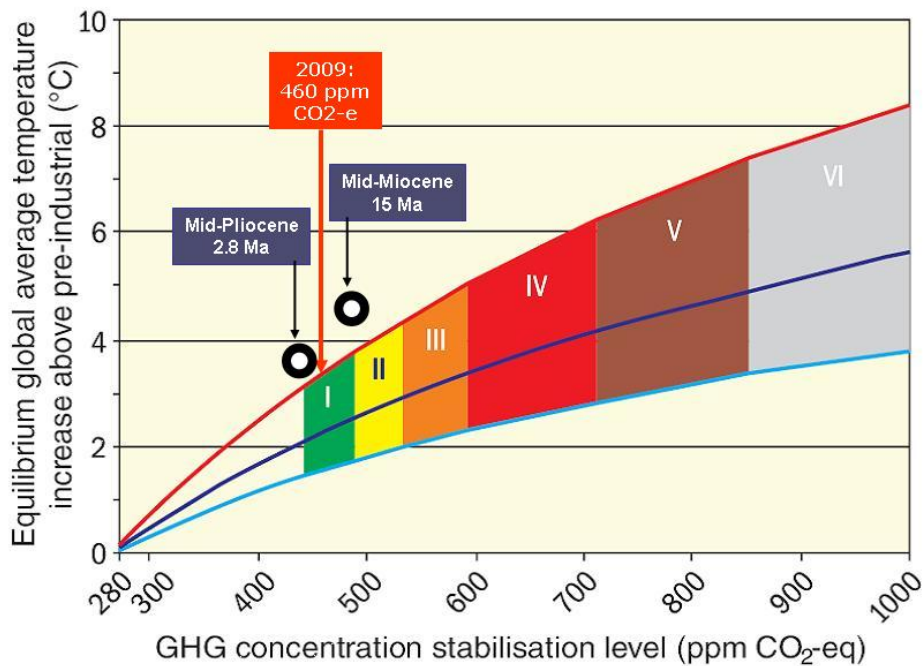


Figure 2. The relations between atmospheric CO₂-equivalent (including the radiative forcing of methane) and mean global temperature, according to Charney's climate sensitivity parameter (Hansen et al., 2007, 2008) (IPCC-2007). Circles mark new paleoclimate estimates of atmospheric conditions in the mid-Pliocene (2.8 million years ago) and the mid-Miocene (15 million years ago), with implications to current climate trajectories.



Figure 3. An artist's impression of Earth's oceans as they may have appeared up to about 1 billion years ago, when the oceans were populated by single celled algae and bacteria.

CO₂ – TEMPERATURE RELATIONS WITH TIME

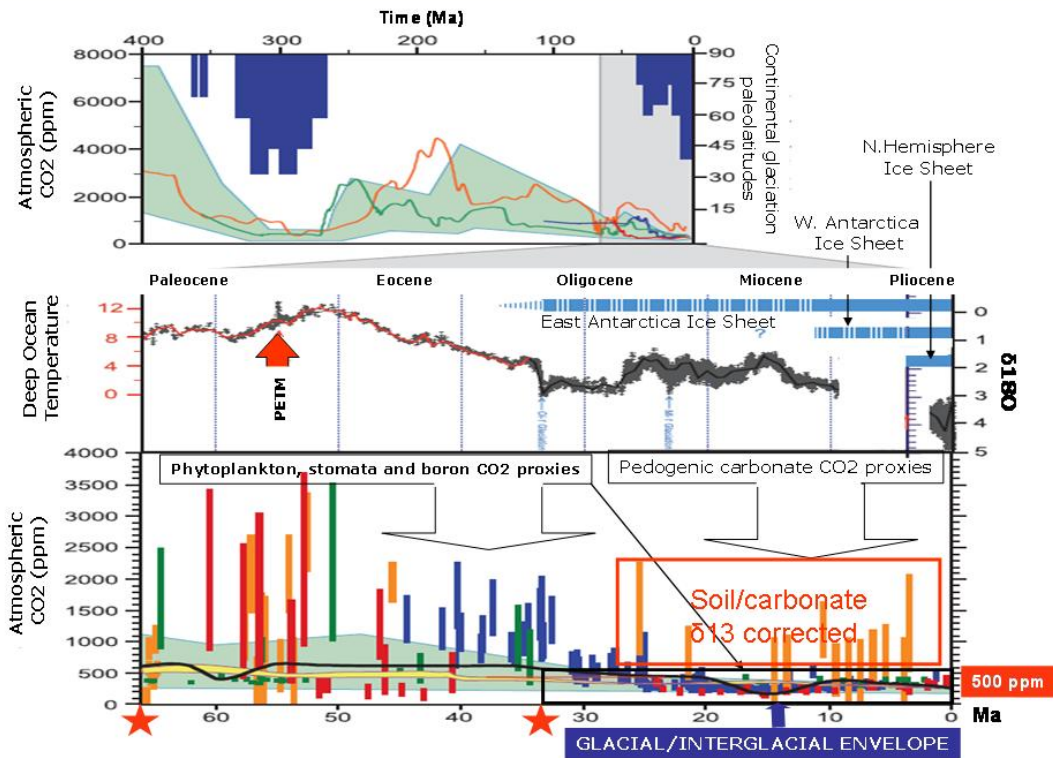


Figure 4. CO₂ and deep ocean temperature changes during the Cenozoic (since 65 million years-ago [Ma]), based on proxy studies (stomata fossil leaf pore densities; ¹³C isotopes in carbonate nodules in fossil soil), indicating the onset age of the Antarctic ice sheet (c. 34 Ma), West Antarctic ice sheet and Northern Hemisphere ice sheets (c. 3 Ma). Note the glacial-interglacial approximate upper limits at 500 ppm CO₂ [7].

RELATIONSHIPS BETWEEN CLIMATE AND FAUNAL VARIABILITY

Peter B. de Menocal, P.B., 2004, EPLS 220, 3-24

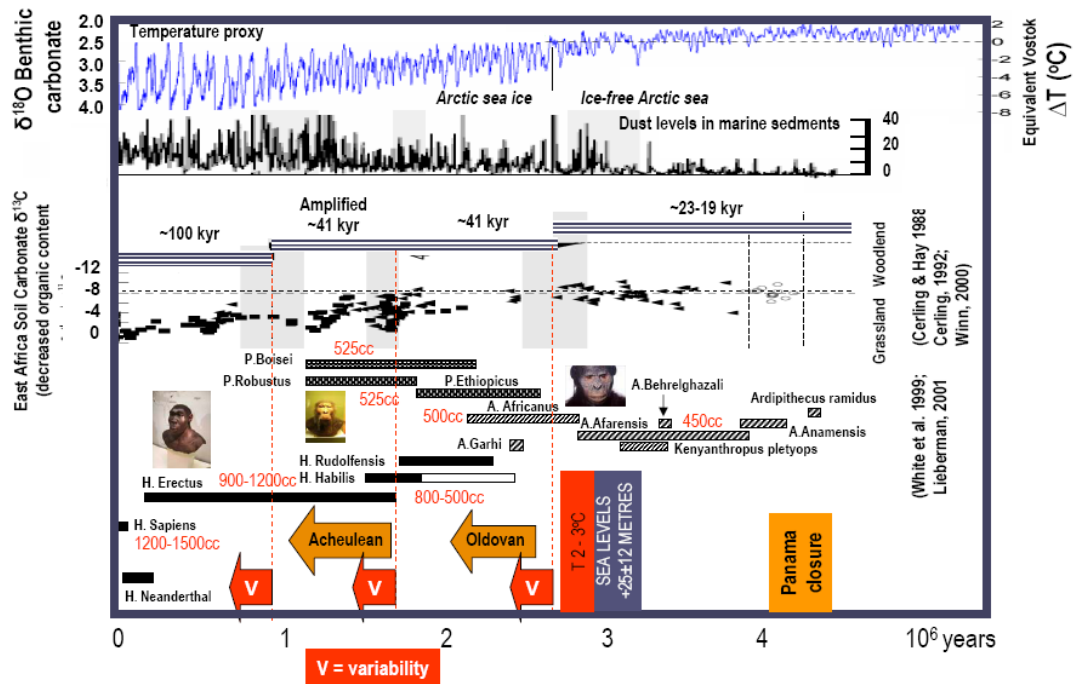


Figure 5. Human evolution in relation to the atmosphere from about 5 Ma (early Pliocene) (after deMenocal 2004) [8]. Upper blue plot represents paleo-deep sea temperature variations. Black plot represent atmospheric dustiness, corresponding to wind and glacial states. Discontinuous line below represents the duration of Milankovitch cycles. Black marks below represent development of grasslands and decrease of organic productivity as the habitats shift from tropical to savannah conditions. Discontinuous lines below represent recorded durations of human species.

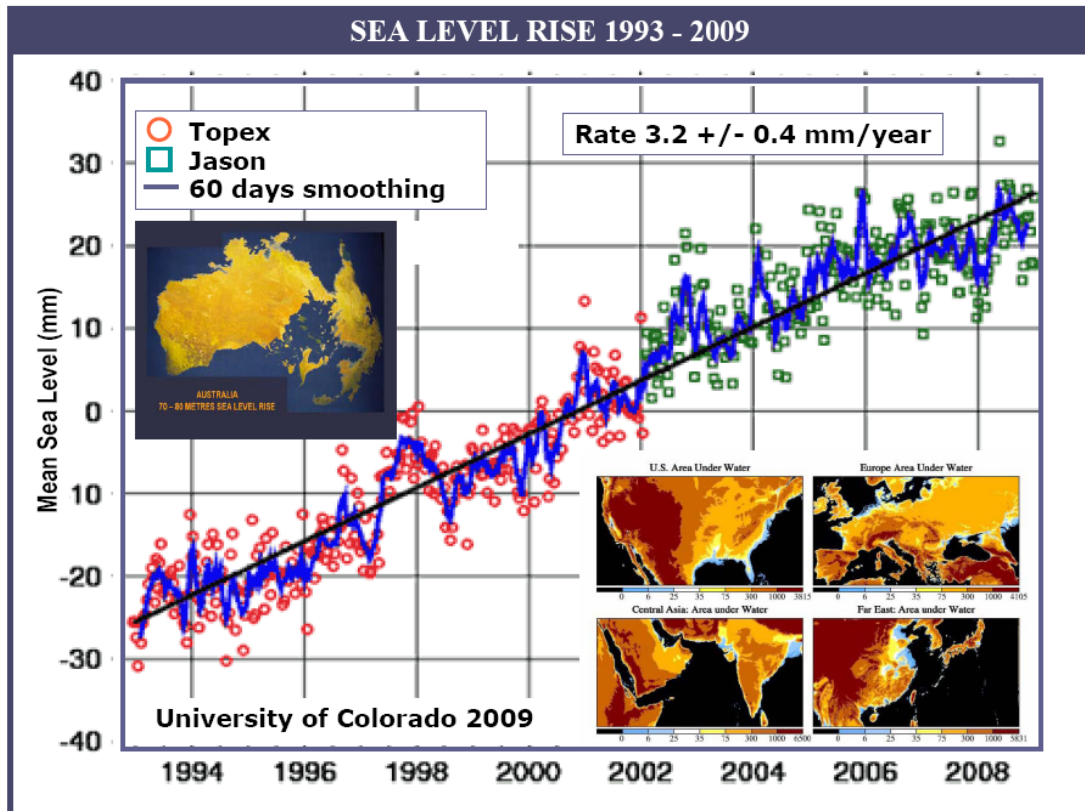
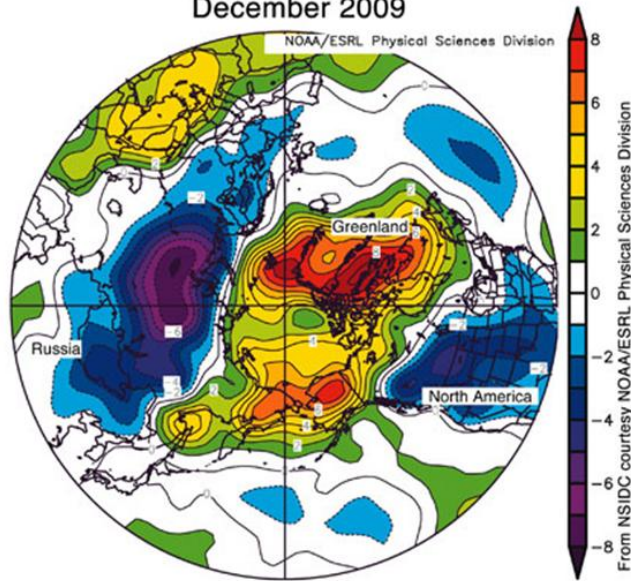


Figure 6. Sea level changes 1993 – 2009 scanned by the Topex and Jason satellites. University of Colorado, 2009 <http://sealevel.colorado.edu/>

Average Air Temperature Anomaly December 2009



(from NSIDC): Map of air temperature anomalies for December 2009, at the 925 millibar level (roughly 1,000 meters [3,000 feet] above the surface) for the region north of 30 degrees N, shows warmer than usual temperatures over the Arctic Ocean and cooler than normal temperatures over central Eurasia, the United States and southwestern Canada. Areas in orange and red correspond to strong positive (warm) anomalies. Areas in blue and purple correspond to negative (cool) anomalies.

Credit: National Snow and Ice Data Center courtesy NOAA/ESRL Physical Sciences Division

<http://wwfblogs.org/climate/content/looking-above-normal-temperatures-they-are-arctic>

Figure 7. Northern Hemisphere temperature anomalies, December, 2009 (NOAA/ESRL Physical Science Division)
<http://wwfblogs.org/climate/content/looking-above-normal-temperatures-they-are-arctic>