The shift in state of the atmosphere

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The release to the atmosphere and oceans of hundreds of billions of tons of carbon from fossil biospheres, at the rate of >2 ppm CO2 per year, is unprecedented in geological history of Earth, excepting events such as asteroid impacts which excavated and vaporized carbon-rich sediments, interfering with the carbon and oxygen cycles, which led to mass extinction of species.

The emission since 1750 of over 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, are triggering a fundamental shift in the state of the atmosphere, tracking toward conditions which exceed interglacial temperatures over the last 400,000 years and are analogous to conditions of the mid-Pliocene ~2.8 billion years ago [1] (Figure 1), the last decade 2000-2010 being the warmest since instrumental measurements commenced (Figure 2).

As stated by Joachim Schellnhuber, director of the Potsdam Climate Impacts Institute [2], "***we're simply talking about the very life support system of this planet***".

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-cryosphere system and the evolving biosphere, which controls the emergence, survival and demise of species, including humans. By contrast to Venus' thick blanket of CO_2 and SO_2 atmosphere, which exerts extreme pressure (90 bars) at the Venusian surface, and unlike Mars' thin (0.01 bar) CO_2 atmosphere, the presence in the Earth's atmosphere of trace concentrations of well-mixed greenhouse gases (GHG) (CO_2, CH_4, N_xO, O_3), has modulated surface temperatures during most of the Holocene within the range of -89 and +57.7 degrees Celsius and a mean of 14°C, allowing the presence of liquid water and thereby of life. By contrast to the long-lived GHG, water vapour has a short atmospheric residence time (9 days) and low concentrations over arid climate zones and the polar regions.

Forming a thin breathable veneer only slightly more than 1000th Earth's diameter, and evolving both gradually as well as through major perturbations with time, the 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.

As shown by numerous proxy-based paleo-climate studies, when the concentration of CO_2 in the atmosphere rises above a critical threshold, the climate shifts to a different state. Any significant increase in the level of carbon gases triggers powerful feedbacks, including ice melt/warm water interaction, decline of ice reflection (albedo) and increase in infrared absorption by exposed water. Further release of CO_2 from the oceans and from drying and burning vegetation shifts global climate zones toward the poles, warms the oceans and induces ocean acidification [3, 10].

The essential physics of the infrared absorption/emission resonance of greenhouse molecules, indicated by observations in nature and laboratory studies, is expressed by the relations between atmospheric CO_2 and mean global temperature projections (Figure 3). Increased evaporation in warming oceans results in enhanced, often abrupt, precipitation events and floods, as indicated by current trends since about 1980 (Figure 4).

During most of Earth's history the oxygen-poor composition of the atmosphere resulted in a major role of reduced carbon species in the air and the oceans, including methane and carbon monoxide, allowing mainly algae and bacteria to exist. It is commonly held that, from 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".[4].

The present state of the biosphere, allowing survival of large mammals and of humans on the continents, developed during global cooling of the upper Eocene and in particular once when CO_2 levels declined below about 500 ppm some 34 million years ago (end Eocene) [5, 7]. From this stage, interrupted by warm periods in the Oligocene (~25 million years ago) and mid-Miocene (~15 million years ago), the Antarctic ice sheet exerted a major effect on 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 controlled by orbital forcing (Milankovic cycles), with atmospheric CO_2 levels oscillating between 180 and 280 ppm CO_2 (Fig. 1), conditions which allowed the emergence of humans in Africa and their migration all over the world [6].

Recent paleoclimate studies, using multiple proxies (soil carbonate $\delta^{13}C$, alkenones, boron/calcium, stomata leaf pores), indicate that the current CO_2 level of 391 ppm and the CO_2-equivalent level of ~460 ppm (which includes the methane factor), commit warming above pre-industrial levels to global increase in greenhouse forcing equivalent to temperature rise in the range of 3 to 4°C [2] (Fig. 1) and near-10°C in polar regions, tracking toward ice-free Earth conditions.

Small human clans responded to extreme climate changes during the Pleistocene (cold fronts, storms, draughts, sea level changes) through migration within and out of Africa. *Homo sapiens* emerged during the glacial period preceding the 124 000 year-old Emian interglacial, when temperatures were about 1°C above late Holocene levels (Fig. 1) and sea levels higher by 6–8 metres [3]. The development of agriculture, and thereby of human civilisation, had to wait until the climate stabilised about 8000 years ago, when large-scale irrigation along the great river valleys (the Nile, Euphrates, Hindus and Yellow River) became possible thanks to the multi-seasonal regulation of river flow allowed by fluctuations in the source mountains snow cover.

Since the 18th century, global temperature rose by and average of ~0.8°C. Another ~0.5°C is masked by industrial-emitted aerosols (mainly SO_2). 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 affect the ENSO cycle and keep the Earth's overall temperature in balance, much as the blood stream regulates the body's temperature and the supply of oxygen.

At +4°C rise, advanced to total melting of the Greenland and west Antarctic ice sheets would lead to over 10 metres-scale sea level rise. Further rise of CO_2-

equivalent above 500 ppm and mean global temperatures above 4°C (Figure 3) could lead toward greenhouse Earth conditions such as existed during the early Eocene [5, 7].

Feedback effects associated with a rise of atmospheric CO_2 include desiccation and burning of vegetation, releasing more CO_2. 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 the exposed water absorb infrared heat, leading to an amplified feedback loop. Because CO_2 is cumulative, with atmospheric residence time on the scale of centuries to millennia, stabilisation of the climate through only small incremental reduction in emissions may not be sufficient to avoid runaway climate change and possible tipping points.

Climate change can be geologically defined as a ***global oxygenation event*** which affects fossil carbon deposits as well as the present biosphere. At 2 ppm CO_2 per year rise the pace of carbon oxidation exceeds the fastest recorded geological rate of 0.4 ppm/year at the Paleocene–Eocene boundary at 55 Ma, when about 2000 GtC were released to the atmosphere, triggering an extinction of species [5, 7].

Sea level rise constitutes the critical parameter which reflects the ***sum-total*** of other elements 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) due to thermal expansion and ice melt, i.e. a nearly four-fold increase since the onset of the industrial age.

The Earth poles are warming at rates 3 to 4 times faster than low latitudes (NASA/GISS, 2010) [8] (Figure 2). 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 (Pritchard, 2009) [9]. Laser readings from a NASA satellite indicate changes in the height of the ice sheets, especially 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.

At present the climate is in a lag period, with increasing atmospheric energy expressed by heat waves, hurricanes and floods, which increased by approximately a factor of 2 since 1980 (Figure 4), and by a shift of mid-latitude high-pressure zones toward the poles. With ensuing desertification of temperate zones, i.e. southern Europe, southern and southwest Australia, southern Africa, the desiccated forests become prey to firestorms. .

At 460 ppm CO_2-equivalent the climate is tracking close to the upper stability limit of the Antarctic ice sheet, defined at approximately 500 ppm [3, 5, 7]. Humans cannot argue with the physics and chemistry of the atmosphere, nor with the sensitivity of the oceans and marine life to changes in pH [10]. What is needed are urgent measures including deep cuts in carbon emissions and down-draw of atmospheric CO_2, fast-track transformation to non-polluting energy utilities (solar, solar-thermal, wind, tide, geothermal, hot rocks), global reforestation and re-vegetation campaigns, including application of biochar (pyrolysis of biomass).

The alternative does not bear contemplation.

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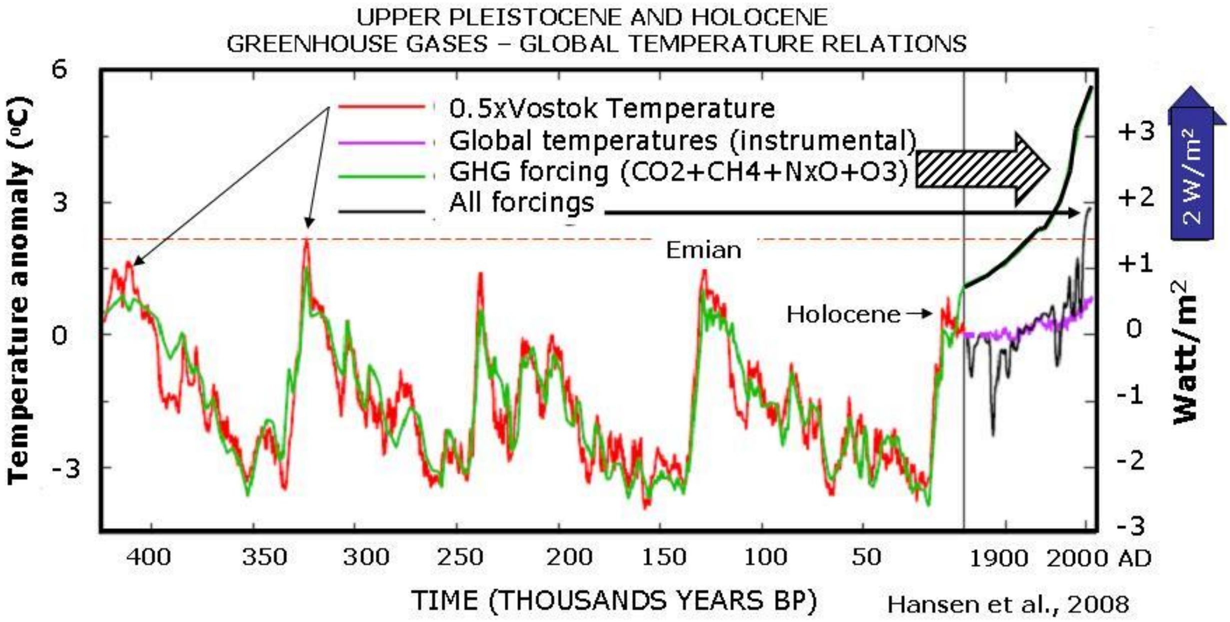

Figure. 1. Upper Pleistocene and Holocene greenhouse gases - global temperature relations (after Hansen et al., 2008), showing variations in paleo-temperature from 420 kyr (0.5xVostok ice core proxy temperatures), instrumental temperatures (from about 1850), greenhouse gas forcings (GHG: CO_2, CH_4, N2O, O_3) and all forcings (including aerosols and land use). Note the rise in GHG forcing by >2.5 Watt/m^2 since about 1850 (large arrow), exceeding previous interglacial values, and the corresponding temperature anomaly, mitigated by aerosols (line arrow).

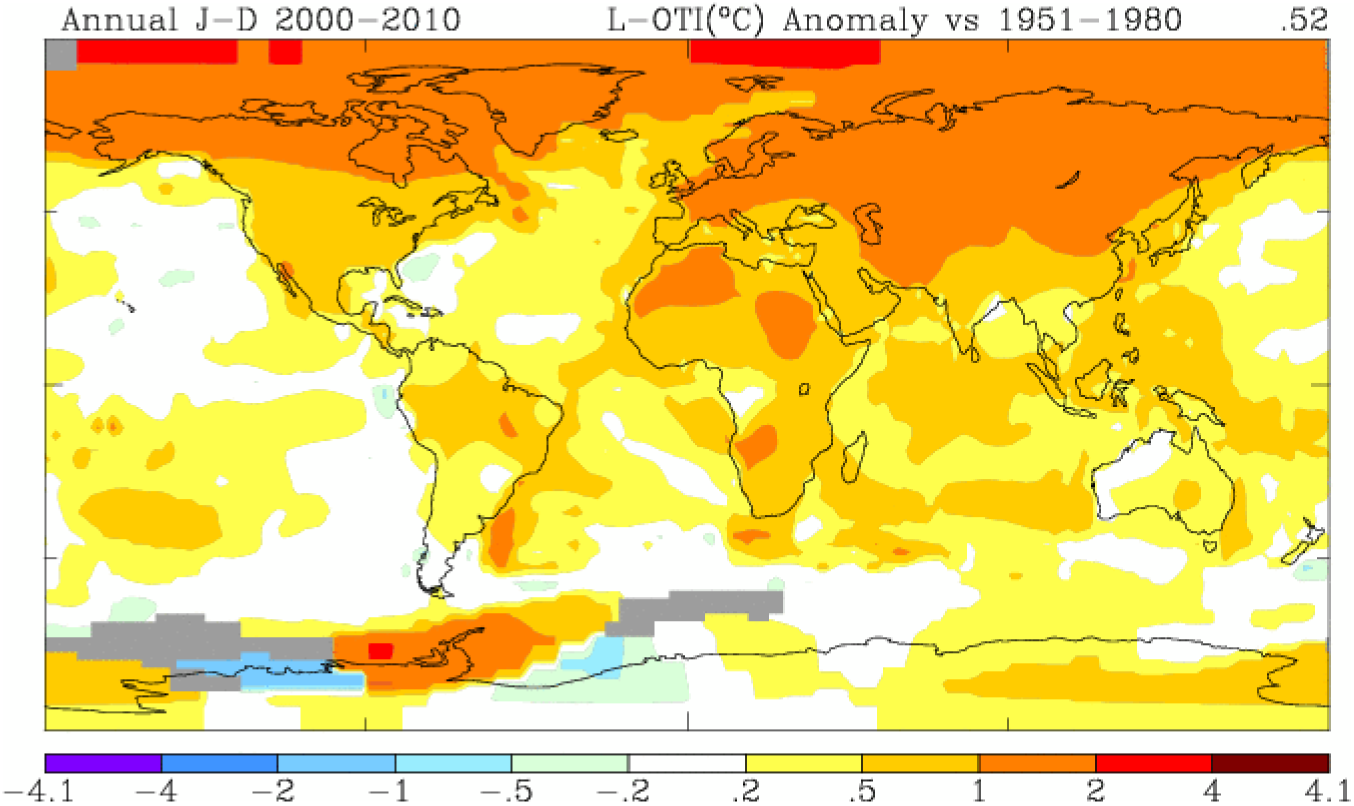

Figure 2. Mean annual (Jan-Dec) global temperatures for 2000-2010 relative to 1951-1980. http://data.giss.nasa.gov/gistemp/maps/

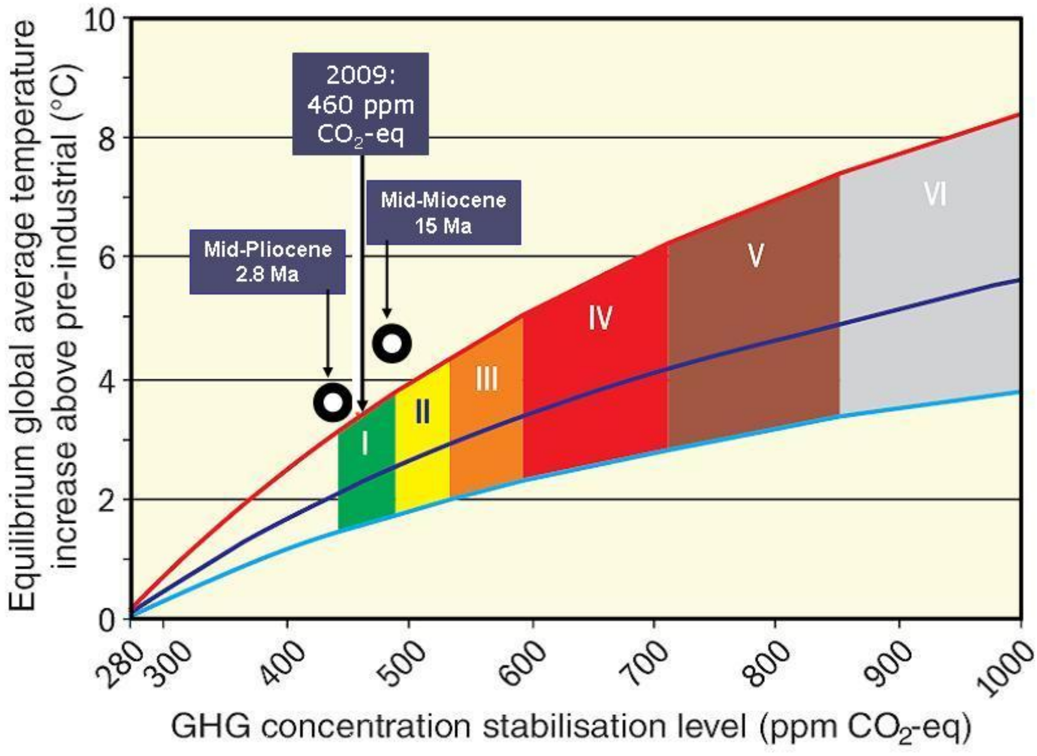

Figure 3. Projected relations between changes in atmospheric CO_2 and equilibrium global average temperature increase above pre-industrial levels, based on climate sensitivity (CS) of 3 ± 1.5°C per doubling of CO2 (IPCC-2007). The marks (I, II, III etc.) represent degrees of severity of climate change scenarios. The current CO_2-eq value of 460 (CO_2 + the CH_4 factor) is indicated. Mid-Miocene (~15 Ma) and mid-Pliocene (~2.8 Ma) parameters are proxy-based paleo-CO2 levels (Pagani et al., 2010), implying significantly higher CS values.

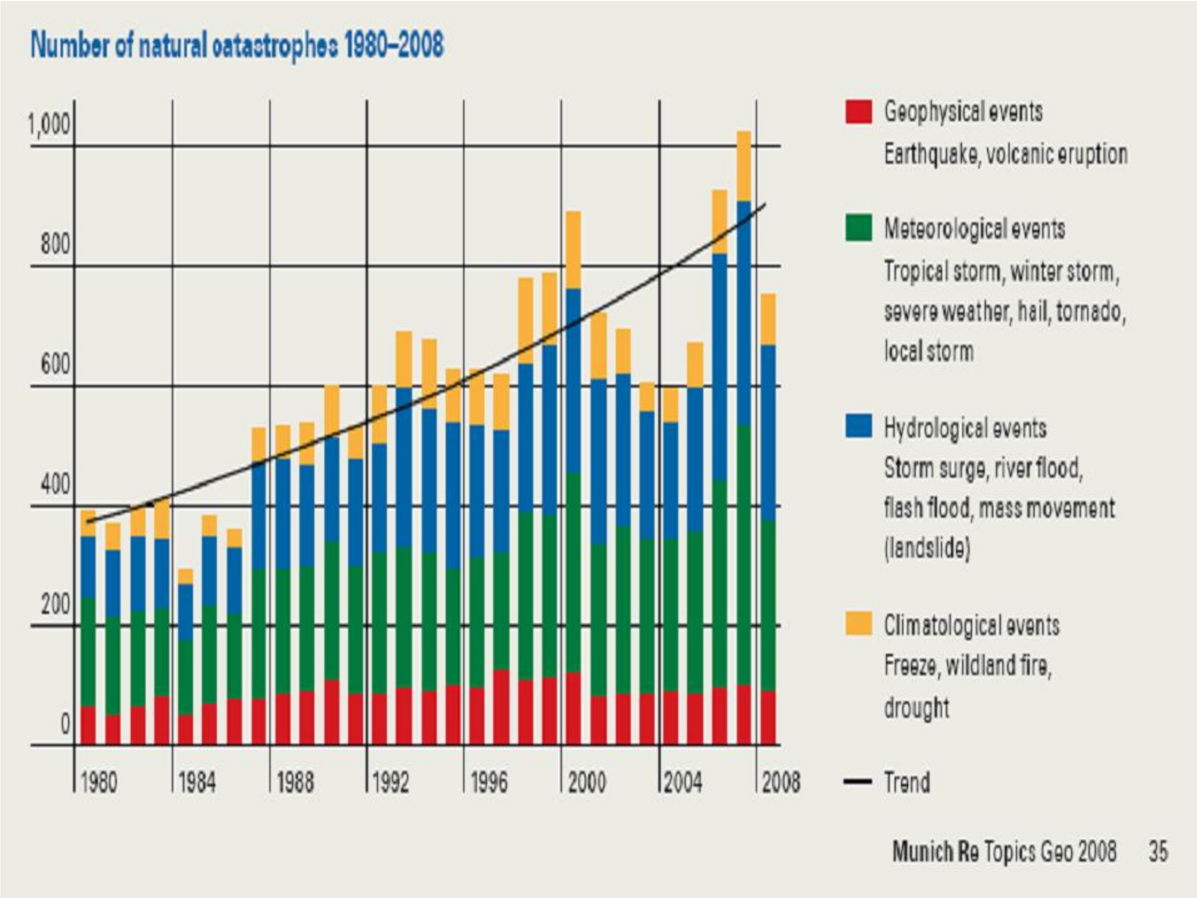

Figure 4. Frequency of global geophysical events and natural catastrophes, 1998 - 2008. From Topics Geo: Natural catastrophes 2008 analyses, assessments, positions.
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