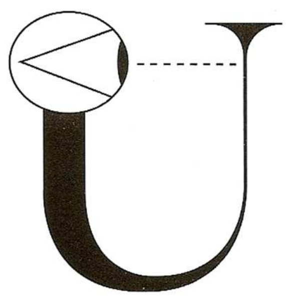
A Fire Species

An essay in honor of Carl Sagan

By Andrew Glikson
Earth and paleo-climate science
Australian National University



Prologue

Unique among all creatures the genus Homo is defined by its bipedalism, an increase in its cranial volume from Australopithecines (A. *garhi* ~450 cubic centimetres [cc]) to Hominines (Groves, 1993; Stringer, 1994; Klein and Edgar, 2002; Zimmer, 2005; McHenry, 2009)[1], and cultural features—including the use of tools. The later include stone, bone and wood tools of the Lower Palaeolithic (~2.6-0.3 million years ago [Ma]), the Oldowan industry (2.6-1.7 Ma) and the more sophisticated Acheulean industry (from ~1.7 Ma). However, whereas these and other attributes are shared by many species, it is the use of fire which distinguishes Homo from other members of the animal kingdom. Born on a flammable biosphere coated with a carbon-rich layer, the facility of Homo to ignite fire has become its blueprint, all the way from clans of nomad bipeds to civilizations capable of releasing energy and increase entropy in nature many orders of magnitude higher than human physical capacity. Perched around camp fires over hundreds of thousands of years the mesmerizing effect of the flickering life-like dance of campfire flames on the human mind inspired imagination, likely leading to the premonition of death, which gave rise to a craving for immortality, omniscience and omnipotence expressed by burial, cremation and construction of monuments.

A flammable biosphere

During much of Earth's history the oxygen-poor levels of the atmosphere and oceans[2], dominated by reduced carbon compounds such as methane, restricted life to methanogenic bacteria, sulphur bacteria, cyanobacteria and algae. From about 0.7 billion years ago (Ga), in the wake of global glaciation, the so-called Snowball Earth, elevated oxygen levels in cold water allowed synthesis of oxygen-binding proteins, which allowed the development of multicellular animals, followed by proliferation of life in the *Cambrian explosion*[3] at about 530 million years ago (Ma).

The emergence of land plants in the late Silurian (c.420 Ma), the earliest being vascular plants (*Cooksonia, Baragwanathia*), and later Cycads and Ginkgo in the Permian (299 – 251 Ma), combined with the rise in photosynthetic oxygen above 13%, set the stage for land fires, coating of many parts of the land with a thin layer of carbon, located in cellulose in trees, grasses, in soils, bogs and as methane hydrate and methane clathrate deposits in bogs, sediments and permafrost. The carbon, when combined with the oxygen emitted through photosynthesis, ensued in a flammable land surface, repeatedly ignited by lightning

---

[1] From A. garhi (~450 cc) to Hominines (H. habilis ~600 cc) about ~2.3-2.4 Ma, and H. heidelbergensis about 0.6 Ma (~1100-1400 cc), overlapping the range of H. neanderthalensis (1200-1900 cc) and H. sapiens (1350-1400 cc)
[2] As low as 10^{-4} bars at 3.4 billion years ago (Krull-Devatzes et al., 2010).
[3] Cambrian Explosion of life, rapid appearance of new animal species around 530 million years ago (Gould, Gould, J. 1989. Wonderful Life: The Burgess Shale and the Nature of History, New York: W. W. Norton, ISBN 0-393-02705-8. 347 pp.

and volcanic eruptions through time. Burial of carbon in sediments has stored the fuel over geological periods—pending the arrival of Homo sapiens.

Prior to the mastery of fire by Homo wildfires were ignited by lightening, incandescent fallout from volcanic eruptions and ejected material from asteroid triggers. The role of extensive fires lit by lightning or instantaneous combustion during warm periods, including the Silurian-Carboniferous (443 – 299 Ma) and the Mesozoic era (251 – 65 Ma), is represented by charcoal remains whose origin as residues from fires is identified by their high optical refractive indices[4] (Figure 1). Permian coals formed during a period when atmospheric oxygen exceeded 30 percent, a level at which even moist vegetation becomes flammable, may contain concentrations of charcoal as high as 70 percent[5]

By the Late Eocene (~40 Ma) and the Oligocene (34–23 Ma) atmospheric sequestration of carbon di-oxide (CO_2) through weathering of the rising Tibetan Plateau, with consequent cooling, has allowed habitation of the continents by large mammals. This was followed at 34 Ma by isolation of the Antarctic continent by the circum-Antarctic current and the growth of its large ice sheet, the source of cold ocean currents and atmospheric fronts, thereby acting as the Earth's "thermostat". Following a series of warmer periods in the Oligocene (34 – 23 Ma), mid-Miocene (c.16 Ma) and the Pliocene (c.5.2 - 2.8 Ma), about 2.8 Ma-ago the Greenland ice sheet and the Arctic Sea ice began to form. Further decline in global temperatures followed, expressed by glacial–interglacial cycles controlled by orbital forcing of the Milankovic cycles[6]. An intensifying plunge into deeper glacial cycles from the onset of the Pleistocene (2.8 Ma – 10,000 years-ago), with atmospheric CO_2 levels oscillating between 180 and 280 parts per million (ppm), saw the opening of savannah, emergence of the genus Homo in Africa and subsequent out-of-Africa migrations of a succession of human species.

Since the 18th century, the large-scale release of fossil carbon, compounded with land clearing, extensive fires and thereby the reduction of photosynthesis, is compounded with carbon feedbacks from soils, tropical and high latitude bogs and permafrost. The current extraction of known economic carbon reserves, including Coal – 900 billion tons (GtC), Oil - 150 GtC, Gas – 105 GtC, oil shale and tar sands, would lead to atmospheric CO2 to levels similar to those of the early Eocene (c.50 Ma), with mean global temperatures over 6 degrees Celsius relative to the present. The unprecedented rate at which CO_2 is rising, c.2 ppm/year, threatens a mass extinction of species.

A fire species

Partial bipedalism, including a switch between two and four legged locomotion, is common among some mammals (cf. bears, meerkats, lemurs, gibbons, Kangaroos, birds and their dinosaur ancestors and sprinting lizards. Homo sapiens' brain mass (c.1400 gram) is lower

[4] Glasspool et al., 2004; Scott and Glasspool, 2005; Bowman et al., 2009.
[5] Scott and Glasspool, 2005.
[6] Milankovic cycles: cyclic variations in the Earth's orbit and angle relative to the sun, including eccentricity, obliquity and precession.

than that of whales (brain c.6 kg; body c.50,000 kg) and elephants (brain c.7 kg; body c.9000 kg). On the other hand Homo has a brain/body weight ratio of 0.025, higher than elephants and whales and similar to mice (c.0.025). However, Homo's brain/body weight ratio is lower than that of birds (c.0.08), likely related to the high sociability of birds, whose high neocortex to brain ratio enhances communications[7]

Numerous organisms construct articulate structures and use tools, examples being the elaborate architecture of termite nests, spider webs, beaver dams, the use of rudimentary tools by some primates, including chimpanzees and orang-utans. Examples of articulate language among animals include the bee dance, bird songs and whales and dolphins echo sounds, possibly not less sophisticated than the languages of original prehistoric humans, if not that of Shakespeare some 2 million years later.

The appearance of a species which has learnt how to kindle fire has led to a quantum leap in terrestrial evolution. For the first time the flammable carbon-rich biosphere could be ignited by a living organism. Carbon, the fourth most abundant element in the Universe by mass after Hydrogen, Helium and Oxygen, constitutes the key element of life on Earth. Evolution, marked by both gradual processes as well as abrupt mass extinctions of species (Figure 2), is strongly perturbed by external events[8]. Thus, most extinction events were triggered by extensive volcanic activity and asteroid or comet impact, with profound effects on the atmosphere-ocean system and on the biosphere, including the release of greenhouse gases and aerosols.

Small human clans responded to extreme climate changes during the Pleistocene—including cold fronts, storms, droughts and sea level changes—through migration within and out of Africa. Homo sapiens emerged during the glacial period which preceded the 124 thousand years-old (kyr) Eemian interglacial, when temperatures rose temporarily to nearly 1 degree Celsius above late Holocene (from 10,000 years-ago) levels and seas were higher by 6–8 metres[9]. However, the development of agriculture, and thereby of human civilization, did not occur until the climate stabilised about 8000 years ago, when large-scale irrigation along the great river valleys—the Nile, Euphrates, Indus and Yellow Rivers—became possible thanks to year-round river flows, allowed by a balance between snow accretion and melting rates in source mountain terrains.

It is likely that, like other major inventions, the mastery of fire was driven by necessity under the acute environmental pressures associated with the descent from warm Pliocene conditions to Pleistocene ice ages[10] (Figure 3). It will probably never be known by what means fire was mastered, whether by percussion of flint stones or fast turning of wooden sticks surrounded with tinder, and whether the invention occurred in one or more times and places. The transport of embers allowed a utilization of fire in areas too humid for ignition.

[7] Dunbar, 1996.
[8] Keller, 2005; Glikson, 2004, 2005, 2010.
[9] Hansen and Sato, 2011
[10] Chandler et al., 2008; deMenocal, 2004

Clear evidence has been uncovered of the use of fire by Homo *erectus* and Homo *Heidelbergensis* at least 300 kyr-ago in Africa and the Middle East. Evidence for fire in sites as old as 750 kyr-old in France and 1.4 Ma-old in Kenya are controversial[11]. Possible records ~1.7–1.5 Ma-old were recovered in excavations at Swartkrans (South Africa), Chesowanja (Kenya), Xihoudu (Shanxi Province, China) and Yuanmou (Yunnan Province, China), including black, grey, and greyish-green discoloration of mammalian bones suggestive of burning (Table 1). During the earliest lower Palaeolithic conditions about 2 degrees Celsius warmer than in the mean Holocene (Figure 3) have allowed human migration through open vegetated savannah in the Sahara and Arabian Peninsula. To the extent fire was mastered by Homo *erectus* in the early Palaeolithic, this would have coincided with accentuation of intermittent glacial conditions associated with the amplification of 41 thousand years-long Milankovic obliquity cycles between about 1.8 Ma and 1.5 Ma, a period of increased climate variability (Figure 3). In so far as fire was mastered by Homo *heidelbergensis* at about 400 kyr, this would have coincided with the stage when ice ages reached their maxima. Early Palaeolithic evidence for human-lit fires includes hearths containing charcoal, burnt bones in hearths, burnt bones with cut marks and red clay shards heated to 400 degrees Celsius and higher temperatures. Sustained burning is attested by cone-shaped depressions containing red clay and burnt stones.

In so far as the discovery of fire may date back to the mid-Palaeolithic, it is not clear how extensive was its use at that stage. By contrast, late Palaeolithic use of fire has been widespread, as testified by the artefacts related to the use of fire, including charred logs, charcoal, reddened areas, carbonized grass stems and plants, and wooden implements which may have been hardened by fire. Robust evidence for a widespread use of fire is evident from about 125 kyr (Table 1). Penetration of humans into central and northern Europe, including by H. *heidelbergensis* (about 600,000 – 400,000 years ago) and H. *neanderthalensis* (about 600 – 30 kyr) was facilitated by the use of fire for warmth, cooking and hunting. However, according to other versions[12] evidence for the use of fire, including rocks scarred by heat and burned bones, is absent in Europe until around 400 kyr, which implies humans penetrated northern latitudes even before the mastery of fire.

Wrangham (2009) interpreted the increase in brain size and drop in tooth size of Homo *erectus* (brain - 900-1200 cc) at about c.1.9 – 1.7 Ma relative to H. *habilis* (brain - 500-900 cc) as a consequence of cooking of meat and thereby easier digestion of proteins, relieving early humans from energy-consuming chewing and allowing an increase in the brain blood supply. However, to date little or no confident evidence exists for a mastery of fire at that time. More reliable evidence for the use of fire comes from the Bnot Ya'akov Bridge, Israel, where between 790 – 690 kyr H. *erectus* or H. *ergaster* produced stone tools, butchered animals, gathered plant food and controlled fire[13]. At that stage glacial/interglacial cycles accentuated to ±6 degrees Celsius and sea level fluctuations to near ±100 metres. Intensification of glacial-interglacial cycles controlled intermittent dispersal of fauna, including humans, between Africa, the Middle East, southern and south-eastern Asia[14].

[11] Stevens, 1989; Hovers and Kuhn, 2004
[12] Roebroeks and Villa, 2011
[13] Stevens, 1989
[14] Dennell and Roebroeks, 2005

Some of the best information on prehistoric fires relates to burning strategies used by native people in Africa[15], North America[16] and Australia[17]. Aboriginal 'firestick farming' associated with maintenance of small-scale habitat mosaics increases hunting productivity and foraging for small burrowing prey, including lizards, leading to extensive habitat changes, possibly including the extinction of mega-fauna[18]. Maori colonization of New Zealand 700-800 years-ago led to loss of half the South Island's temperate forest[19]. These practices intensified upon European colonization, with extensive land cultivation and animal husbandry.

Fire and entropy

Further to ignition sparked by lightning, volcanic eruptions, spontaneous combustion of peat, or meteorite falls, the colonization of land by plants in the early Palaeozoic[20], ensuing in an enhanced release of photosynthetic oxygen, set the stage for extensive land surface fires. Combustion became part of the natural cycle of fire-adapted (pyrophyte) plants, enhancing the distribution of seeds and control of parasites. With the exception of anaerobic chemotropic bacteria which metabolize sulphur, carbon and metals, photosynthesis by phytoplankton and plants, deriving energy from the sun, has become the base of the food chain. Plants utilize about one thousandth of the approximately 5.7×10^{24} Joules[21] of solar energy annually irradiated to the earth's surface, absorbing 3×10^{21} Joules/year to fix large amounts of CO_2 (2×10^{11} ton/year)[22]. Oxygenation reactions by plant-consuming organisms, including humans, as well as through fire, enhance degradation and entropy. The total amount oxidized by human through metabolism and oxygenation are estimated at 3×10^{20} Joules/year.

The harnessing of fire by humans has elevated the species' oxygenating capacity by many orders of magnitude, through utilization of solar energy stored in plants by photosynthesis[23] Homo has raised entropy[24] by combustion and nuclear fission to levels approaching those of global volcanic events and asteroid impact events. Through Earth history these events have abruptly and episodically elevated atmospheric concentrations of greenhouse gases and aerosols, leading to mass extinction of species[25]. Thus, whereas human respiration

[15] Laris, 2002; Sheuyange et al., 2005
[16] Stephens et al., 2007
[17] Bird et al., 2008
[18] Miller et al., 2005
[19] McGlone and Wilmshurst, 1999
[20] Rothwell et al., 1989
[21] One Joule – The energy expended applying a force of one Newton over a distance of one metre; One Newton - net force required to accelerate a mass of one kilogram at a rate of one meter per second squared.
[22] Hall, 1979
[23] Kittel and Kroemer, 1980
[24] Entropy – Inevitable and steady dissipation of heat and mechanical energy within a system.
[25] Glikson, 2005, 2010; Keller, 2005.

dissipates 2 to 10 calories[26] per minute, a camp fire covering one square meter releases approximately 180,000 Calories per minute, whereas the output of a 1000 Megawatt/hour power plant expends some 2.4 billion calories per minute, namely some 200 million times the human respiration.

The phenomenon of life, magnified many-fold by in complex technological civilizations, notably in cities, entails local and transient increases in anti-entropy[27]. This, however, comes at the expense of an increase in entropy in cleared, degraded and depleted environments from which cities derived their resources. Since the industrial revolution the oxygenation of fossil carbon relics of ancient biospheres has increased the dissipation of energy stored in plants and plant remains by many orders of magnitude, as represented by the rise in carbon emissions from landscape and biomass burning by 2 to 4 billion ton carbon per year, and from fossil fuel combustion by 7.2 billion tons per year[28]. By the Twenty-first century the total anthropogenic carbon release from fossil fuel combustion and fires rose over 9.2 billion tons per year, with far reaching consequences for the atmosphere-ocean-cryosphere-biosphere system.

Fire and human mythology

A dominant theme of fire mythologies constitutes its illegitimate acquisition by humans, as in the legend of the Titan Prometheus breathing fire he stole from the gods into human clay figures. According to the *Rig Veda* the hero Mātariśvan recovered fire, which had been hidden from mankind. In Cherokee myth, after Possum and Buzzard had failed to steal fire, Grandmother Spider used her web to sneak into the land of light. She stole fire, hiding it in a clay pot. Among various Native American tribes of the Pacific Northwest and First Nations, fire was stolen and given to humans by Coyote, Beaver or Dog. According to some Yukon First Nations people, Crow stole fire from a volcano in the middle of the water. According to the Creek Indians, Rabbit stole fire from the Weasels. In Algonguin myth, Rabbit stole fire from an old man and his two daughters. In Ojibwa myth, *Nanabozho* the hare stole fire and gave it to humans. In Polynesian myth, Maui stole fire from the Mudhens. In the Book of *Enoch*, the fallen angels and Azazel teach early mankind to use tools and fire.

Since fire allows humans warmth, protection from animals, and facilitates cooking, pottery and migration to cold parts of the planet, intuitively the implications of these stories are difficult to comprehend. However, over the millennia, culminating in the Anthropocene[29], the hidden meanings of these forewarnings have become increasingly clear.

Perched around camp fires during long nights over hundreds of thousands of years, humans, captivated by the mesmerizing effects of the flickering life-like flames, have

---

[26] Calory - The energy needed to raise the temperature of 1 gram of water through 1 degrees Celsius.
[27] Margulis, Lynn. & Sagan, Dorion. (1995). What Is Life?. Berkeley: University of California Press
[28] Bowman et al., 2009
[29] The Anthropocene – the era marked by major human effects on nature through deforestation and pollution (Ruddiman, 2003; Steffen et al., 2007).

developed imagination, insights, cravings, fears and premonitions of death, and thereby aspiration for immortality, omniscience and omnipotence, leading to the concept of a god. Pantheistic gods revered the Earth, the rocks and living creatures whereas subsequent monotheistic sky god religions in part regarded Earth as a corridor to heaven. The effects of fire on the human mind are consistent with experiences by those who have camped over long periods around campfires, as has this author. Fear, an instinctive sense arising in an animal when endangered, has been extended in the human mind to engender risks in advance. At least since 130,000 years-ago, a yearning for immortality is expressed in burial sites. An example is the Skhul cave, Mount Carmel, Israel, where skeletons are painted in red ochre and were surrounded by tools[30]. Grand monuments to the afterlife, including the Egyptian pyramids and Chinese imperial burial caves, entombed entire entourage destined to serve the rulers in the hereafter, such as Emperor Qin Shi Huang's terracotta army[31]. Cremation may have constituted a special way of combining the spirit of the deceased and fire, allowing a passage of the soul to eternity.

A premonition of death may have resulted in tension between foresights acquired by the neocortex and the instant reflexes of the mammalian brain[32]. Whereas cerebral intelligence invents tools, develops techniques and identifies future dangers, the primitive brain reacts intuitively, examples being the motherly instinct and defensive/aggressive instincts, serving procreation and survival respectively[33]. However, this pattern is disrupted were premonition or advanced fears perceived by the neocortex arise, when instinctive responses by the mammalian brain need to be arrested or delayed. In turn, the neocortex equips responses by the mammalian brain with tools and weapons unleashed on enemies.

The fear of death, originating around camp fires, may have evolved as a factor at the root of war. Further than biological procreation-related murders such as among Chimpanzees, or infanticide by rival baboons, among humans war has become intertwined with a spiritual human quest—the appeasement of the gods by blood sacrifice. Running through human history is the ritual mass sacrifice of the young, whether babies thrown into the fire of the god Moloch, or the blood cult by Maya and Aztecs[34], or the sacrifice of an entire generation in World War I. In war, to kill an enemy constitutes a quest for immortality, as expressed in a Maya war song (1300-1521 AD): *"There is nothing like death in war, nothing like flowering death, so precious to him who gives life, Far off I see it, my heart yearns for it."*

With the onset of space exploration, the Sputnik space craft, Lunar landing and sojourns to the outer solar system, human mythology has been extended into a space cult, alluding to colonization of the planets where, presumably H. *sapiens* will continue to devastate new environments. Some allude to human dominance of the Universe. These myths ignore the principal observation arising from planetary exploration—barring a possible presence of bacteria Good planets are hard to come by.

[30] Hovers and Kuhn, 2004
[31] Wood, 2008
[32] Koestler, 1986
[33] Dawkins, 1976
[34] Clendinnen, 1995

H. sapiens' war against nature

Nature includes species whose activities are capable of devastating entire habitats, examples being toxic viruses and bacteria, fire ant armies, locusts and rabbits. Parasitic host-destroying organisms include species of fungi, worms, arthropods, annelids and vertebrates, e.g. oxpeckers, vampire bats. The mastery of fire has enabled Homo to magnify its potential to consume energy and increase entropy on a huge scale. For example, under suitable temperature, drought and wind conditions, a single individual can ignite an entire countryside. By the mid-20th century the application of nuclear fission places a single individual in command of a nuclear trigger potentially able to devastate the entire biosphere.

North American Indian cultures involved deliberate seasonal or periodic burnings aimed at forming mosaics of resource diversity, environmental stability, predictability, and the maintenance of transition zones (ecotones)[35]. Incidental burnings were associated with camp fires, hunting, smoke signals and inter-tribal wars. Repeated controlled surface burns on a cycle of one to three years were broken by occasional escape of wild fires and periodic conflagrations during times of drought[36]. Even under ideal circumstances, accidents occurred, Fire signals escaped and campfires spread. As a result valuable range was untimely scorched, buffalo driven away, and villages threatened. So extensive were the cumulative effects of these fires that the overall effect of Indian occupation of the Americas extensively replaced forested land with grassland or savannah or, where the forest persisted, opened it up and freed it from underbrush. Once European settlers occupied lands forest re-growth occurred in some areas.

Major studies of the North American fire regimes[37] listed numerous factors underlying their deliberate and accidental ignition, including:

1. Burning aimed at diversion of big game (deer, elk, bison) into for hunting and opening of open prairie and meadows for host pasture and grazing and opening of small areas to trap other game (rabbits, racoon, bears. ducks, geese).
2. Burning to clear areas for planting of crops, corn and tobacco, to facilitate grass seed, berry and medicine plant collection, to prevent abandoned fields from overgrowth, to clear grass and brush to facilitate the gathering of acorns, roast mescal and obtain salt from grasses.
3. Insect collection, forming fire enclaves for collection of insects (crickets, grasshoppers, moths) and collection of honey from bees.
4. Protection of settlements from wild fires.
5. Protection from pests (rodents, snakes, black flies, mosquitos)
6. War and signalling, including burning strategies against enemies.
7. Burning and girdling of trees for firewood and timber.
8. Worship and spiritual rain dances.

[35] Lewis 1985
[36] Pyne, 1982, 1995
[37] Lewis, 1965; Kay, 1994; Russell, 1983

9. Clearing undergrowth for access and travel.

Burning practices of the North American Indians and other people[38] were primarily aimed at land clearing for agriculture and for hunting. The rise of agricultural civilisations capable of supporting armies has unleashed *scorched earth* strategies on massive scales. Examples include the razing of circum-Mediterranean forests and agricultural lands by retreating armies, as recorded for example by Gibbon (1788) in connection with the advance of the Emperor Julian into Mesopotamia:

"… *on the approach of the Romans, the rich and smiling prospect was instantly blasted. Wherever they moved ... the cattle was driven away; the grass and ripe corn were consumed with fire; and, as soon as the flames had subsided which interrupted the march of Julian, he beheld the melancholy face of a smoking and naked desert."*

Commenting on the critical role of fires Bowman et al. (2009) state: *"Fire is a worldwide phenomenon that appears in the geological record soon after the appearance of terrestrial plants. Fire influences global ecosystem patterns and processes, including vegetation distribution and structure, the carbon cycle, and climate. Although humans and fire have always coexisted, our capacity to manage fire remains imperfect and may become more difficult in the future as climate change alters fire regimes."*

The Anthropocene

The dawn of the Neolithic owes its origin to the cultivation of crops, pottery, smelting of metals—iron, copper, gold—possibly discovered accidentally around camp fires, leading to crafting of ploughs to till the land and swords to kill enemies. Extensive burning and land clearing during the Holocene, culminating with internal combustion, have further magnified entropy. During this time the level of biomass burning, as indicated by residual charcoal deposits, reached levels as high as the combustion of fossil fuels during the first part of the 20th century[39] (Figure 1). Ruddiman (2003) defines the onset of an Anthropocene period from a rise in CO_2 6000 years-ago and of methane 4000 years-ago, arising from land clearing, fires and cultivation. Kutzbach et al. (2010), comparing Holocene with temperature variations of earlier interglacial periods, estimates the rise of anthropogenic greenhouse gas levels during the Holocene has prevented a decline in temperatures by as much as ~2.7 degrees Celsius into the next glacial phase.

By contrast, Crutzen and Stoermer (2000) and Steffen et al. (2007) define the onset of the Anthropocene at the dawn of the industrial age. According to this classification the earlier rise of CO_2 and methane is related to a natural trend, as based on comparisons with the 420-405 kyr Holsteinian interglacial[40]. Other factors supporting this conclusion are CO_2 mass balance calculation[41], CO_2 ocean sequestration rates and calcite compensation[42]. Whereas

[38] Obaa and Weladjib, 2005
[39] Bowman et al. (2009),
[40] Broecker and Stocker, 2006
[41] Stocker et al., 2011

the signature of anthropogenic pre-historic emissions may be masked by natural variations, there is little doubt human-triggered fires and land clearing have contributed to an increase in entropy throughout the Holocene.

Burning of fossil fuels since c.1750 AD has led to date to an increase in mean global temperature by +0.8° Celsius[43]. A further rise of +1.1°C is masked by industrially emitted sulphur aerosols, whereas lag effects induced by the ocean account for a further 0.3° Celsius[44] (Figure 4). The polar regions, source of cold air vortices and cold ocean currents such as the Humboldt and California current, which keep the Earth's overall temperature in balance, are melting at an accelerated rate[45]. Based on palaeoclimate studies[46], the current levels of CO2 (393 ppm) and CO_2-equivalent (above 460 ppm, a value which includes methane and nitrous oxide) commit the atmosphere to a warming trend tracking toward ice-free Earth conditions.

By the onset of the Third millennium the release to the atmosphere and oceans of more than 320 GtC from fossil biospheres is proceeding at an annual rate of approximately 2 parts per million CO_2 per year, a rate unprecedented in geological history. An exception is the release to the atmosphere of some 2000 billion tons carbon at the Palaeocene–Eocene boundary at 55 million years ago[47], estimated to have raised atmospheric CO_2 levels at a rate of about 0.4 ppm/year, with an attendant extinction event. Other exceptions are volcanic eruptions and asteroid impacts which have ignited regional to global wildfires[48] and, in the case of impacts, excavated and vaporized carbon-rich sediments. Human-generated emissions are adding to the atmosphere near 37 per cent of the original carbon inventory of c.590 GtC, reaching 810 GtC. About one third of the rise is due to fires, land clearing and the depletion of vegetation.

Since the 1980s global temperature, ice melt and sea level rise has been lagging behind rising atmospheric energy levels. Climate change is expressed by a shift of mid-latitude high-pressure zones toward the poles, by heat waves, hurricanes and floods, which have increased by about a factor of two to three since 1980. With ensuing desertification of temperate zones, e.g. southern Europe, south and southwest Australia and southern Africa, forests become prey to firestorms. These changes result in powerful feedbacks, including ice melt/warm water interaction, decline of ice albedo and increase in infrared absorption by exposed water. Further release of CO2 from the oceans and from drying and burning vegetation is shifting global climate zones toward the poles, warming the oceans and inducing ocean acidification. Increased evaporation in warming oceans results in enhanced, often abrupt, precipitation events and floods.

---

[42] Joos et al., 2004
[43] IPCC, AR4, 2007
[44] Hansen et al., 2011
[45] Rignot and Velicogna, 2011
[46] Using multiple proxies, including soil carbonate δ13C, alkenones, boron/calcium, stomata leaf pores.
[47] Zachos et al., 2008
[48] Durda and Kring, 2004

At 460 parts per million CO_2-equivalent the climate is tracking just under the upper stability limit of the Antarctic ice sheet, defined at approximately 500 ppm[49], approaching tipping points[50]. These changes shift the state of the atmosphere to conditions analogous to those of the late Pliocene 2.8 Ma-ago (Figure 3). At +3 to 4° Celsius temperature rise above Holocene conditions advanced to total melting of the Greenland and west Antarctic ice sheets lead to over 10 metres sea level rise. Further rise of total CO_2-equivalent above 500 ppm and mean global temperatures above 4° Celsius could lead to greenhouse Earth conditions such as existed during the early Eocene some 50 million years ago.

Sea level rise constitutes the sum-total of other climate change processes, including thermal expansion, melting ice sheets and mountain glaciers. Since the early 20th century, the rate of sea level rise increased from about 1 mm/year to about 3.5 mm/year, the 1993–2009 rate being 3.2+/-0.4 mm/year, nearly a four-fold increase since the onset of the industrial age[51]. Human-induced climate change constitutes a global oxygenation event on a geological scale, affecting both the present biosphere and the fossil remains of ancient biospheres. As stated by Joachim Schellnhuber, director of the Potsdam Climate Impacts Institute, "*we're simply talking about the very life support system of this planet*".[52]

An uncharted future

By the First decade of the Twenty first century the energy balance of the atmosphere, i.e. the difference between incoming and outgoing radiation, is estimated as 3.2 Watt/square meter[53] (Figure 4). With estimated carbon reserves of Coal (c.900 GtC), Oil (c.150 GtC), Gas (c.105 GtC), oil shale (c.540 GtC), and open ended reserves of tar sand and coal seam gas. In addition, with unstable methane hydrates in permafrost and in polar lakes and seas, Homo *sapiens* appears bent on extracting and transferring carbon into the atmosphere on a scale tracking toward pre-ice age conditions. During these eras atmospheric CO_2 levels in the range of 2000-3000 ppm resulted in temperatures 5 to 10^{o} Celsius higher than at present, reflected by the inundation of large parts of the continents by shallow seas. A mean global temperature rise of 4 - 5^{o} Celsius would ensue in near-total melting of the Earth's polar ice, inundating vast coastal and low lying planes in Europe, south and southeast Asia, north China, the Amazon, South Australia and New South Wales. A future projection according to Berger and Loutre's paper (2002) "*An Exceptionally Long Interglacial Ahead*?" states:

"*The present day CO2 concentration (*393 ppm by 2011) *is already well above typical interglacial values of ~290 ppmv. This study models increases to up to 750 ppmv over the next 200 years, returning to natural levels by 1000 years. The results suggest that, under very small insolation variations, there is a threshold value of CO2 above which the Greenland ice sheet disappears. The climate system may take 50,000 years to assimilate*

---

49 Zachos et al., 2001
50 Lenton, 2009
51 Rahmstorf, 2007.
52 http://www.reuters.com/article/2009/09/28/us-climate-science-idUSTRE58R3UI20090928
53 Hansen et al., 2011; Hansen and Sato, 2011

the impacts of human activities during the early third millennium. In this case an "irreversible greenhouse effect" could become the most likely future climate. If the Greenland and west Antarctic ice sheets disappear completely, then today's "Anthropocene" may only be a transition between the Quaternary and the next geological period".

The mid-Miocene warm period[54] allows an analogy with conditions toward which Earth is currently tracking. At that stage expansion of C_4[55] drought-resistant savannah grasses replaces C_3 grasslands and woodlands, in response to an increase in droughts and a fire regime, with feedback effects increasing the level of greenhouse gases. Only small ice caps existed during this period and sea levels were about 50 metres higher than late Holocene[56]. However, whereas the transition from end-Miocene conditions to the present occurred over some 5 million years, the rise of mean global temperature since the 18th century to 2.3° Celsius, at a rate of ~2 ppm CO_2/year, can only be defined as catastrophic, hardly allowing species to adopt.

In Frank Drake's formula, estimating the frequency of technical civilizations in the Milky Way galaxy:

N = R*fp*ne*fl*fi*fc*L[57]

The parameter **L** is estimated by Carl Sagan on the scale of a few hundred years, with implications for carbon-based civilization[58]. The rapid warming and ocean acidification would hardly allow survival of large mammals and many other species. Small clans of people may survive in sub-polar regions, high altitude ocean islands and sheltered mountain valleys, human endurance through the extreme climate upheavals of the glacial-interglacial periods having equipped some to withstand the most challenging conditions. Indigenous races adapted to tropical conditions, such as in Africa and the Amazon, will have an advantage over Indo-European races adjusted to temperate climate zones. Likely to survive would be grasses, insects and possibly sub-polar organisms. Warm low-pH oceans would be severely depleted in phytoplankton, krill and higher marine life. A yet higher scale of Mass Extinction

---

[54] Keeley and Rundel, 2005. CO2 levels for the mid-Miocene (14-16 Ma) are estimated between 300-600 ppm (Kurschner et al., 2008), 300-370 ppm and 460-580 ppm (You et al., 2009), and temperatures calibrated to >2° Celsius (Kurschner et al., 2008) to about 3-4° Celsius higher than the late Holocene (You et al., 2010),

[55] C_3 and C_4 grasses: http://www.dpi.nsw.gov.au/agriculture/field/pastures-and-rangelands/native-pastures/what-are-c3-and-c4-native-grass

[56] You et al., 2010

[57] N = number of communicative civilizations;
R = rate of formation of suitable stars;
fp = fraction of those stars with planets; ne = number of Earth-like planets per solar system;
fl = fraction of planets with life;
fi = fraction of those planets with intelligent life;
fc = fraction of those planets with communicating technology;
L = lifetime of communicating civilizations.

[58] Moriarty and Honnery, 2011

would ensue from a nuclear coup-de-grace, increasingly likely on a planet in crisis, compounding a '*greenhouse summer'* with a '*nuclear winter'*.

A new cycle of evolution commences.

This daunting spectre invokes fundamental questions regarding natural laws and intelligence. Teilhard de Chardin (1959, p.111) hinted at the existence of laws of complexity giving rise to awareness and consciousness, stating:

"*The more complex a being is, so our scale of complexity tells us, the more it is centred upon itself and therefore the more aware does it become. In other words the higher the degree of complexity in a living creature, the higher its consciousness, and vice versa. The two properties vary in parallel and simultaneously. If we depict them in diagrammatic form, they are equivalent and interchangeable*."

In terms of little-explored and counter-intuitive laws of nature, including complexity theory and quantum information theory, an inherent intelligence, manifesting itself in the design and self-repair of biomolecules, beyond the basic laws of chemistry, has reached an insight into the Universe, as expressed by Carl Sagan (Cosmos, 1980):

"*For we are the local embodiment of a Cosmos grown to self-awareness. We have begun to contemplate our origins: star stuff pondering the stars; organised assemblages of ten billion billion billion atoms considering the evolution of atoms; tracing the long journey by which, here at least, consciousness arose. Our loyalties are to the species and the planet. WE speak for the Earth. Our obligation to survive is owed not just to ourselves but also to that Cosmos, ancient and vast, from which we spring*."

For a biological species to magnify its entropic effect by orders of magnitude, developing cerebral power allowing it to become the intelligent eyes through which the Universe explores itself, hints at yet unknown natural laws. Perhaps it is too much to expect a species to possess the ultimate wisdom and responsibility allowing it to control the level of energy it learn to master, through fire, combustion and nuclear fission.

Science has gained deep perceptions into the nature of the universe, yet the big *why questions* remain evasive. Why a big bang, why life, why consciousness? Undecipherable laws which hint at an intelligence inherent in nature itself and the concept of God, declared by the great traditions, merge into a single mystery Homo may never decipher.

"*But thought is the slave of life,*
and life is time's fool,
and time, that takes survey of all the world,
time must have a stop"
(Henry IV, William Shakespeare)

Acknowledgements

I am grateful to Robert Attenborough, Jacky French, Bryan Furnass, Colin Groves, Clive Hamilton, Tony McMichael, Keryn Oude-Egberink, Leanne Pattison and Bruce Radke and Karyn Schultz for their comments.

References

Berger, A. and Loutre, M.F., 2002. An Exceptionally Long Interglacial Ahead? *Science*, **297** (5585): 1287-1288.

Bird, R., Bird, D.W., Codding, B. F., Parker, C. H. and Jones, J. H., 2008. The 'fire stick farming' hypothesis: Australian Aboriginal foraging strategies, biodiversity, and anthropogenic fire mosaics. *Proc. Nat. Acad. Sci.*, **105** (39): 14796–14801.

Bowman, D.M. et al., 2009. Fire in the Earth system. *Science*, **24** (324): 481-484

Broecker, W.C. and Stocker, T.F., 2006. The Holocene CO2 rise: anthropogenic or natural? *Eos* **87**(3): 27-29.

Chandler, M., Dowsett, H. and Haywood, A., 2008. The PRISM Model/Data Cooperative: Mid-Pliocene data-model comparisons. *PAGES News*, **16** No. 2.

Clendinnen, Inga, 1995. *Aztecs: An Interpretation*. Cambridge University Press. 389 pp.

Crutzen, P. J. and Stoermer, E. F., 2000. The 'Anthropocene'. *Global Change Newsletter* **41**: 17–18.

de Menocal, P.B., 2004. African climate change and faunal evolution during the Pliocene-Pleistocene. *Earth and Planetary Science Letters (Frontiers),* **220:** 3-24.

Dawkins, R., 1976. *The Selfish Gene*. Oxford University Press. 384 pp.

Dennell, R.W. and Roebroeks, W., 2005. Out of Africa: An Asian perspective on early human dispersal from Africa. Nature 438: 1099-1104.

Dunbar, R., 1996. Grooming, gossip and the evolution of language. Faber and Faber, London. 219 pp.

Durda, D.D. and Kring, D.A., 2004. Ignition threshold for impact-generated fires. J. Geophysical Research 109, 1-14.

Gibbon, Edward, 1788. *The Decline and Fall of the Roman Empire*. http://books.google.com/books?id=f8-2ONV-foQC&pg=PA158.

Groves, C., 1993. Our earliest ancestors. In Burenhult, Goran (ed.), *The First Humans: Human Origins and History to 10,000 BC*. New York: Harper-Collins Publishers. pp. 33-40, 42-45, 47-52.

Glasspool, I.J., Edwards. D. and Axe, L., 2004. Charcoal in the Silurian as evidence for the earliest wildfire. *Geology*, **32:** 381-383

Glikson, A.Y., 2004. Extraterrestrial impact episodes and Archaean to early Proterozoic (3.8-2.4 Ga) habitats of life. In: Thomas, P.J., Chyba, C.F.and McKay, C.P. (eds) Comets and the Origins of Life, Springer Verlag, Heidelberg, Germany. pp. 253-283.

Glikson, A.Y., 2005. Asteroid/comet impact clusters, flood basalts and Mass Extinctions: Significance of isotopic age overlaps. *Earth and Planetary Science Letters,* **236**: 933-937.

Glikson, A.Y., 2010. Homo *sapiens*, the Anthropocene Carbon Oxidation Event and the Shift in the State of the Atmosphere. *Journal of Cosmology*, **8**: 1866-1879

Hall, D.O, 1979. In *Biomass for Energy,* Ed. Hall, D.O., 1-18, UK Section of International Solar Energy Society, London.

Hansen, J.E., Sato, M., 2011. Paleoclimate Implications for Human-Made Climate Change. http://arxiv.org/abs/1105.0968

Hansen, J.E., Sato, M. and Kharecha, P., Earth's Energy Imbalance and Implications. http://arxiv.org/abs/1105.1140

Hovers, E. and Kuhn, S. (eds), 2004. Transitions Before the Transition: Evolution and Stability in the Middle Palaeolithic and Middle Stone Age. Springer: New York: pp. 171-188.

Joos, F., Gerber, S., Prentice, I.C., Otto-Bliesner, B.L. and Valdes, P.J., 2004. Transient simulations of Holocene atmospheric carbon dioxide and terrestrial carbon since the Last Glacial Maximum. *Global Biogeochem. Cycles*, **18**, GB2002.

Kay, C.E., 1994. Aboriginal Overkill and Native Burning: Implications for Modern Ecosystem Management." *Western Journal of Applied Forestry*, **10**:121-126.

Keeley, J.E. and Rundel, P.W., 2005. Fire and the Miocene expansion of C_4 grasslands. *Ecology Letters*, **7**: 683–690.

Keller, G., 2005. Impacts, volcanism and mass extinction: random coincidence or cause and effect? Australian Journal of Earth Science **52/4**, 725-757.

Kittel, Ch. and Kroemer H., 1980. *Thermal Physics,* 2nd Ed., W.H. Freeman and Company, San Francisco, 1980.

Koestler, A., 1986. *Janus: A Summing Up*. Picador Books.

Kurschner, W.M., Zlatko K. and Dilcher, D., 2008. The impact of Miocene atmospheric carbon dioxide fluctuations on climate and the evolution of terrestrial ecosystems. *Proc. Nat. Acad. Sci,* **105**: 449–453

Klein, R.G. and Edgar, B., 2002. *The Dawn of Human Culture*. Wiley and Son, New York, 288 pp.

Krull-Davatzes, A., Byerly, G. and Lowe, D., 2010. Evidence for a low O2 Archaean atmosphere from nickel-rich chrome spinels in 3.24 Ga impact spherules, Barberton greenstone belt, South Africa. *Earth Planet. Sci. Lett*.**, 296**: 319-328.

Kutzbach, J.E., Ruddiman, W.F., Vavrus, S.J. and Philippon, G., 2010. Climate model simulation of anthropogenic influence on greenhouse-induced climate change (early agriculture to modern): the role of ocean feedbacks. *Climatic Change* (2010) **99**: 351–381.

Laris, P., 2002. Burning the seasonal mosaic: Preventative burning strategies in the wooded savanna of Southern Mali. *Hum. Ecol.,* **30**: 155–186.

Lenton, T.M., 2009. Tipping points in the Earth system. Earth system modelling group at UEA. http://researchpages.net/esmg/people/tim-lenton/tipping-points/

Lewis, H.T., 1985. Why Indians Burned: Specific Versus General Reasons. In James E. Lotan, et al., *Proceedings--Symposium and Workshop on Wilderness Fire: Missoula, Montana*, November, 15-18, 1983.

McGlone, M.S. and Wilmshurst, J., 1999. Dating initial Maori environmental impacts in New Zealand. *J. Quarter. Sci.,* **59**, 5-16

McHenry, H.M., 2009. *Human Evolution*. In M. Ruse & J. Travis. Evolution: The First Four Billion Years. The Belknap Press of Harvard University Press. 265 pp.

Miller, G.H., Fogel, M.L., Magee, J.W., Gagan, M.K. and Johnson, B.J., 2005. Ecosystem Collapse in Pleistocene Australia and a Human Role in Megafaunal Extinction. *Science*, **309**, 287

Moriarty, P. and Honnery, D., 2011*. The Rise and Fall of Carbon Civilization*. Springer. Berlin. 218 pp.

Obaa, G., Weladjib, and R.B., 2005. Effects of anthropogenic fire history on savanna vegetation in northeastern Namibia. *J. Environ. Manag*., **75**: 189–198.

Pyne, S.J., 1982. *Fire in America: A Cultural History of Wild and Rural Fire*. Princeton, NJ: Princeton University Press.

Pyne, S.J., 1995. *World Fire: The Culture of Fire on Earth*. New York, NY, Henry Holt and Company.

Rahmstorf, S. R. 2007. A semi-empirical approach to projecting future sea level rise. *Science*, **315**: 368 – 370.

Rignot, E. Rignot and Velicogna, I., 2011. Acceleration of the contribution of the Greenland and Antarctic ice sheets to sea level rise. *Geophys. Res. Lett.* 38: 5 pp doi:10.1029/2011GL046583.

Roebroeks, W. and Villa, P., 2011. On the earliest evidence for habitual use of fire in Europe. http://johnhawks.net/node/15346.

Rothwell, G. W., Scheckler, S. E., Gillespie, W. H., 1989. "Elkinsia gen. nov., a Late Devonian gymnosperm with cupulate ovules". *Botanical Gazette,* **150**: 170–189.

Ruddiman, W.F., 2003. The anthropogenic greenhouse era began thousands of years ago. *Climate Change.* **61**: 261–293.

Russell, E.W.B., 1983. Indian-Set Fires in the Forests of the Northeast United States. E*cology*, **64**: 78-88.

Scott,, A.C. and Glasspool, I.J., 2005. Charcoal reflectance as a proxy for the emplacement temperature of pyroclastic flow deposits. *Geology*, **33**: 589-592.

Steffen, W., Crutzen, P.J. and McNeill, J.R., 2007. The Anthropocene: Are Humans Now Overwhelming the Great Forces of Nature? *Ambio*, **36**: 614-621.

Stephens, S.L., Martin, R.E., Clinton, N.E., 2007. Prehistoric fire area and emissions from California's forests, woodlands, shrub lands and grasslands. *Forest Ecol. Manage*., **251**: 205–216.

Stevens, J.R., 1989. Hominid Use of Fire in the Lower and Middle Pleistocene: A Review of the Evidence. *Current Anthropology*. University of Chicago Press, **30**: 1–26.

Stocker, B., Strassmann, K. and Joos, F. 2010. Sensitivity of Holocene atmospheric CO2 and the modern carbon budget to early human land use: analysis with a process-based model. *Biogeosciences Discussions*, **7**: 921-952.

Stringer, C.B., 1994. Evolution of early humans. In: S. Jones, R. Martin, D. Pilbeam (eds.). *The Cambridge Encyclopedia of Human Evolution*. Cambridge University Press. 242 pp.

Teilhard de Chardin, P., 1959. *The Future of Man*. Random House, Bertelsmann. 332 pp.

You, Y., 2010. Climate-model evaluation of the contribution of sea-surface temperature and carbon dioxide to the Middle Miocene Climate Optimum as a possible analogue of future climate change. *Aust. J. Earth Sci.,* **57**: 207–219.

Wrangham, R., 2009. Catching fire: how cooking made us human. Basic Books, New York, 320 pp.

Wood, F., 2008. China's First Emperor and His Terracotta Warriors. Macmillan publishing. ISBN 0312381123, 9780312381127.

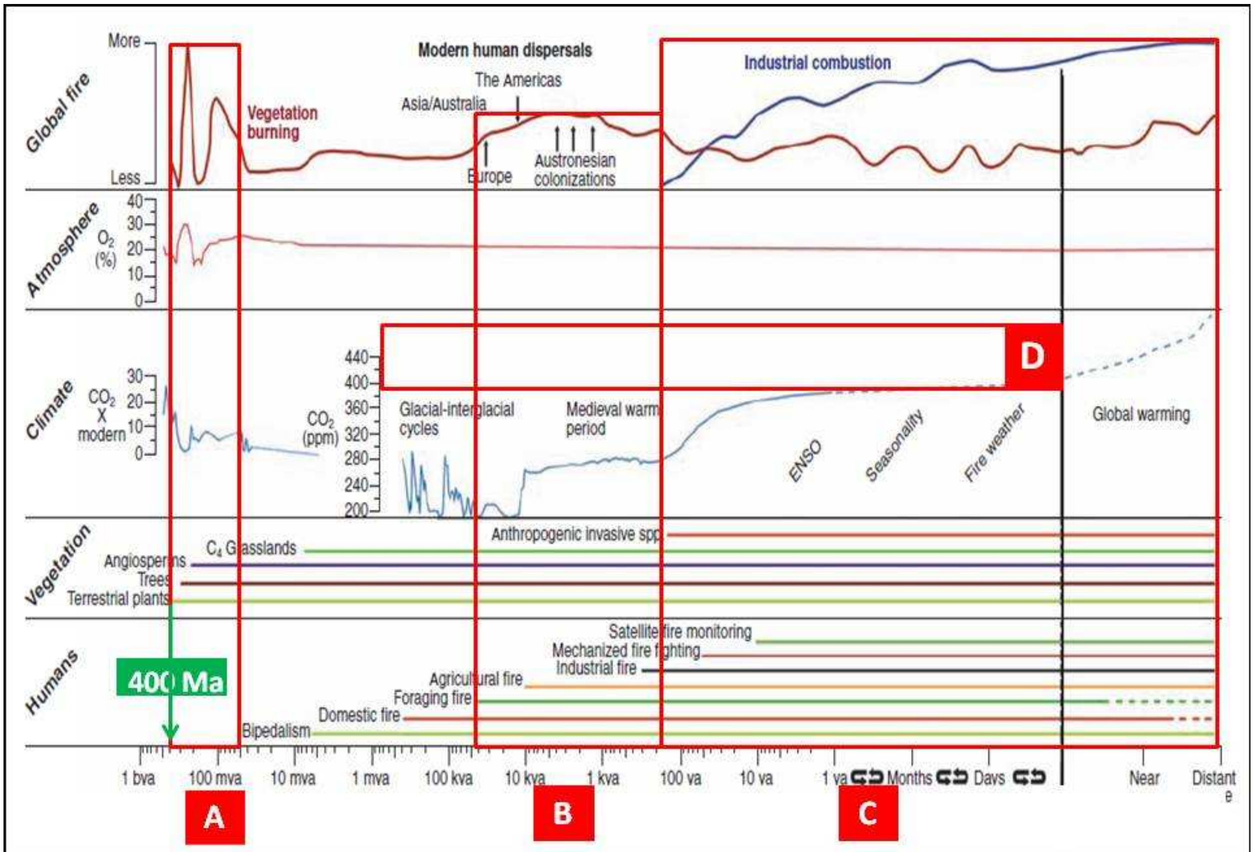
Zachos, J., Pagani, M., Sloan, L., Thomas, E. and Billups, K., 2001. Trends, Rhythms, and Aberrations in Global Climate 65 Ma to Present. *Science*, **292**, 5517: 686-693.

Zachos, J.C, Dickens, G.R.; Zeebe, R.E., 2008. An early Cenozoic perspective on greenhouse warming and carbon cycle dynamics. Nature 451 (7176): 279–83.

Zimmer, C., 2005. *Smithsonian Intimate Guide to Human Origins*. Madison Press Books, Totonto. 176 pp.

Table 1. Prehistoric sites containing evidence or possible evidence of human use of fire.

1.7 Ma	Yuanmou, Yunnan Province	blackened mammal bones
1.5 Ma	Swartkan, South Africa	burnt bones were found among Acheulean tools, bone tools, and bones with hominid-inflicted cut marks.
1.42 Ma	Chesowanja, Kenya	red clay shards. heated to 400C to harden but re-interpreted as bushfire
1.5 Ma	Koobi Fora Kenya	red clay shards heating at 200–400C
	Olorgesailie Kenya	"hearth-like depression". microscopic charcoal
	Gadeb, Ethiopia	welded tuff near Acheulean artefacts
~1.0 Ma	Wonderwerk Cave, Northern Cape province, South Africa	burned bone and ashed plant remain: carbonate-hydroxylapatite—undergoes characteristic recrystallization at approximately >500 °C
0.79 – 0.69 Ma	Bnot Yaakov Bridge Israel	Burnt flintstones; H. erectus or H. ergaster
0.83 – 0.5 Ma	TJava	H. *erectus* fossils; blackened bone and charcoal deposits
	Xihoudu in Shanxi Province	evidence of burning by the black, grey, and greyish-green discoloration of mammalian bones
0.7 – 0.2 Ma	Cave of Hearths in South Africa	
130,000 to 120,000 BP	Klasies River Mouth	
110,000 to 61,000 BP	Kalambo Falls in Zambia	artefacts related to the use of fire by humans: charred logs, charcoal, reddened areas, carbonized grass stems and plants, and wooden implements which may have been hardened by fire.
72,000 BP	Stillbay culture. South Africa	Fire was used to heat treat silcrete stones to increase their workability before they were knapped into tools by
0.7 – 0.2 Ma	Cave of Hearths in South Africa	



Qualitative scheme of global fire activity through time based on pre-Quaternary distribution of Charcoal and the relation with atmospheric O2 levels, ppm CO2, appearance of vegetation and of the genus Homo. Bowman et al. 2010 www.sciencemag.org on February 10, 2010

Figure 1.

Qualitative scheme of global fire activity through time, based on pre-Quaternary, Quaternary and Holocene charcoal records and on modern satellite observations, correlated with atmospheric O_2 content, CO_2, vegetation types and the human factor. From Bowman et al. (2009). Frames: (A) Palaeozoic and Mesozoic warm periods intervened by the Permian ice age; (B) Qualitative representation of the effects of prehistoric human-lit fires; (C) Effects of industrial combustion; (D) The interval between current CO2 levels and the upper stability limit of the Antarctic ice sheet (~500±50 ppm CO2).

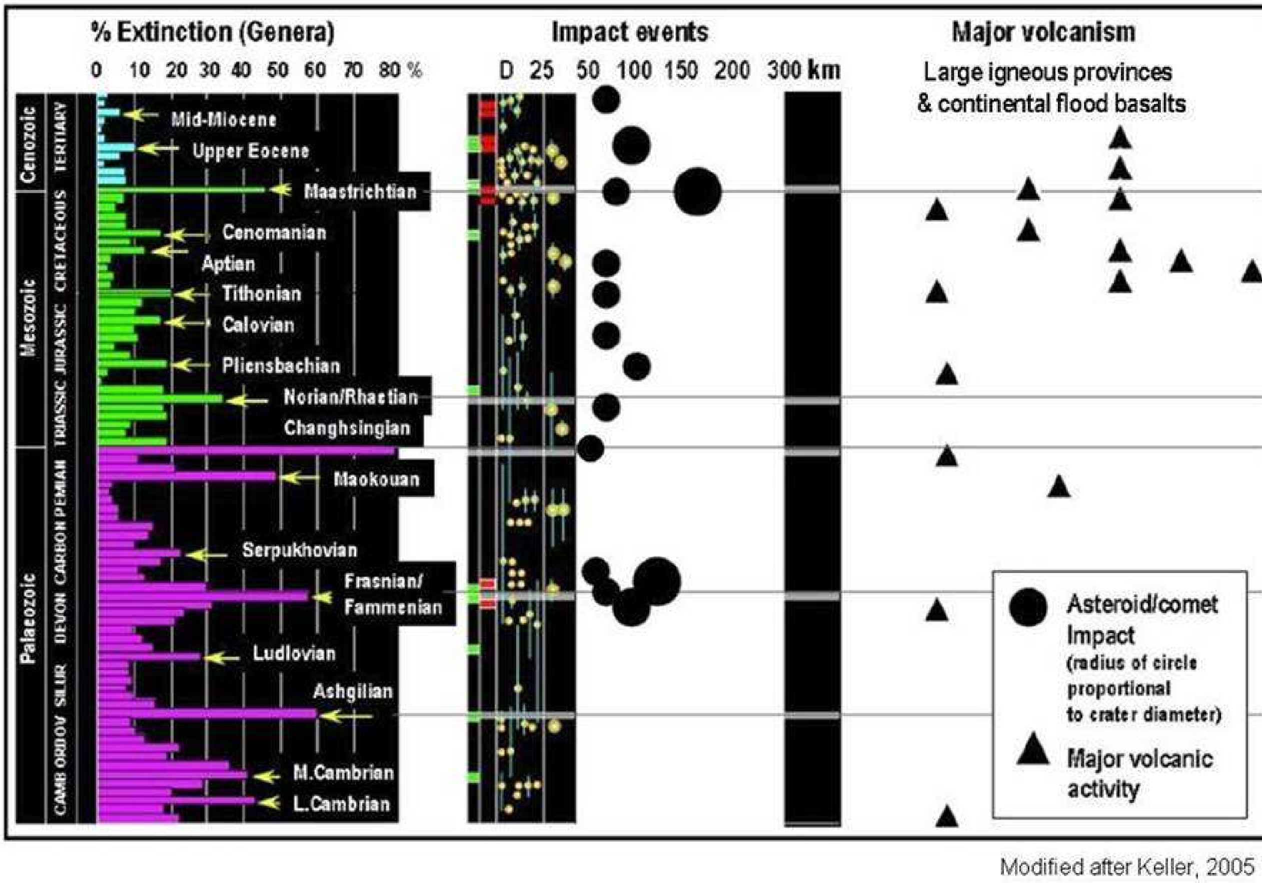


Figure 2.

Faunal Extinction events through the Phanerozoic, showing percent extinction of genera, correlated with asteroid and impact events. After Keller, 2005.

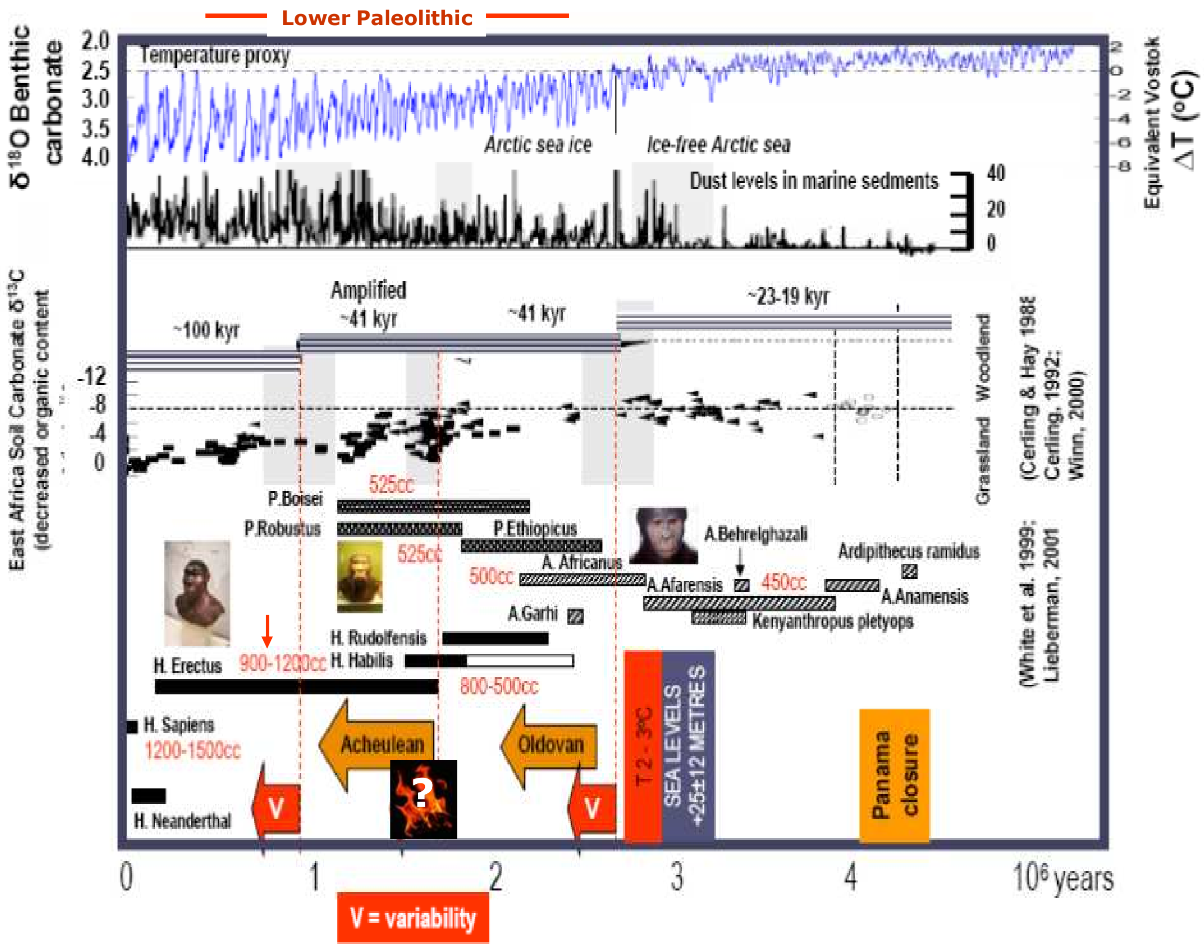


Figure 3.

Geological and anthropological evolution since the Pliocene, indicating (1) proxy-based temperature fluctuations; (2) rise in dust levels in marine sediment which represent glacial erosion; (3) changes in the Milankovic cycles (from precession-based 19-23 kyr cycles to obliquity-based 41 kyr cycles to eccentricity-based 100 kyr cycles); (4) changes in δ13 level (organic matter content) of sediments and (5) Australopithacus, Paranthropus and Homo genus evolution. Modified after DeMenocal (2004).

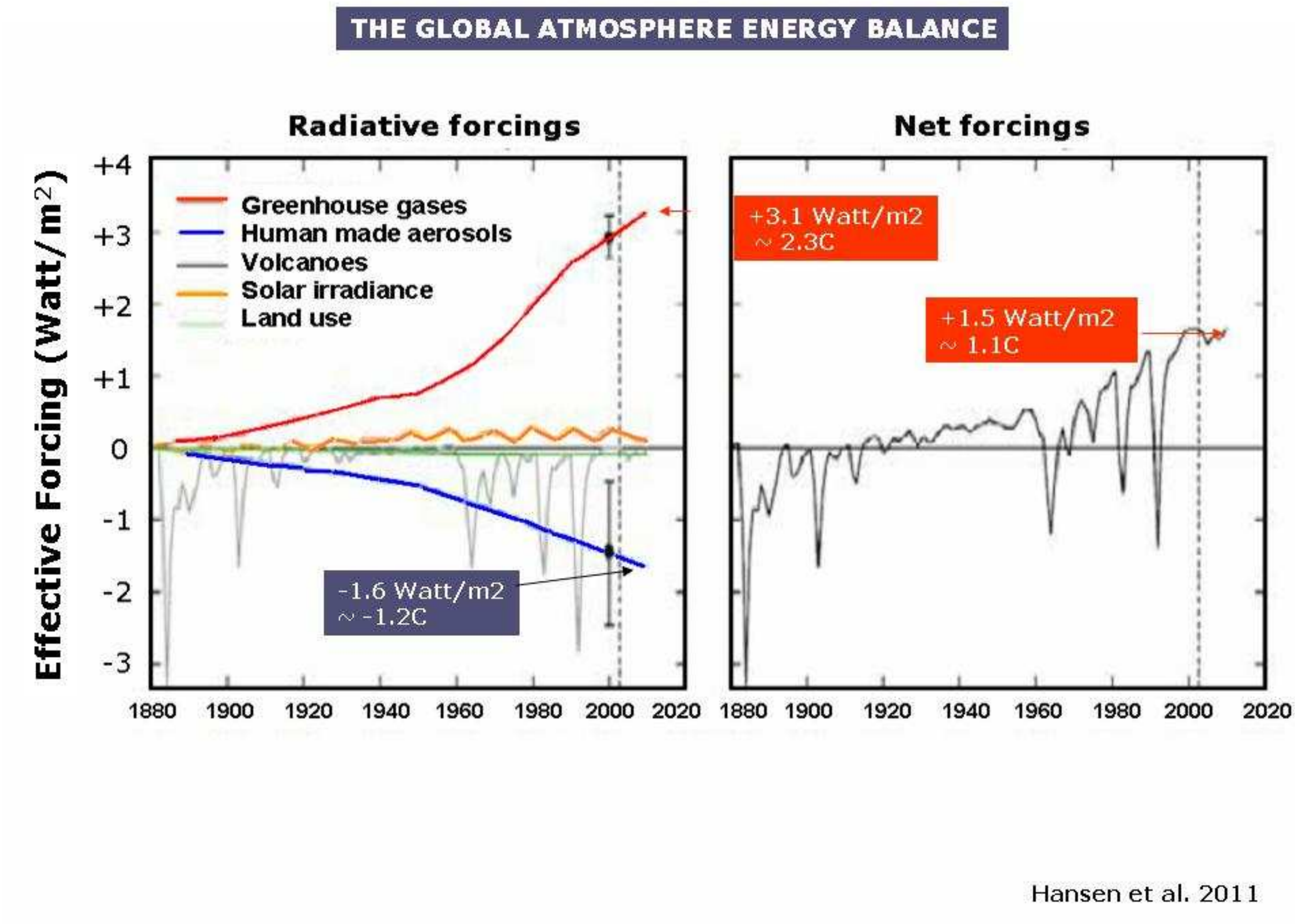


Figure 4.

Left: 1880 – 2010 forcing (Watt/m2) trends of greenhouse gases, human-made aerosols, volcanic eruptions, solar irradiance and land use; Right: 1880–2010 balance between the forcing shown on the left, indicating that: (1) total energy rise due to greenhouse gas has reached +3.2 Watt/m2, equivalent to +2.3°C and (2) sulphur aerosols are keeping the atmosphere cooler by -1.6 Watt/m2, i.e. -1.2°C. (after Hansen et al., 2011).