The deep time blueprints of anthropogenic global change

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Frontispiece: Global change

The evidence for a rapid shift in state of the terrestrial atmosphere-ocean system over the last two centuries [1] (Figure 1) requires a deep time perspective, beyond events of the day.

Of all life forms which ever existed only the genus Homo acquired the skill of igniting and transporting fire, allowing it not only warmth, protection from animals and cooking, but also a high degree of power over nature, manifested by burning large parts of the biosphere and, more recently, combustion of carbon and hydrocarbons derived from fossil biospheres at least up to 400 million years old.

The high intelligence underlying human inventions has been variously attributed to a large brain size (Chimpanzees ~395 grams; Australopithecus apheresis ~430 grams; Homo ergaster ~850 gram; Homo sapiens ~1350 grams [2]) and a high brain/body mass ratio (~1/40 [3]). However, sperm whales brains weigh ~8000 grams and elephant brains over 5000 grams [5], mice have a brain/body mass ratio similar to that of humans (1/40) and small birds a higher brain/body mass ratio (1/12 [3]). A more confident parameter of human intelligence is the large neocortex/medulla (lower part of the brain stem) ratio in the human brain (Lemurs ~10; monkeys and apes 20-50; humans 105 [4]).

Theories which try and explain the uniqueness of humans invoke its bipedal nature, language [5] and the use of stone and bone tools [6]. In these respects, however, pre-Homo sapiens hominids were hardly unique, as indicated by the bipedalism of many animals, use of tools by some animals [7], articulate design of termite nests [8], sophisticated language of insects (cf. the Bee's dance [9]), merekat calls [10], Whale echo-location calls [11] or birds navigation systems [12].

However, Homo's ability to ignite fire constitutes an exclusive blueprint, with far reaching consequences. This facility was allowed by the potentially flammable terrestrial environment where hominids emerged, namely plant-rich land surfaces (surrounded by phytoplankton-rich oceans) where photosynthesis produces an oxygen-rich atmosphere and plant decay results in formation of carbon-rich surface deposits.

The evolution of land plants in the late Silurian (~420 Ma: vascular plants: Cooksonia, Baragwanathia) and in the Permian (299–251 Ma: Cycads and Ginkgo) led to the accumulation of carbon as cellulose in trees and grasses, soils and bogs, methane hydrate and methane clathrate. During tropical eras (Silurian-Carboniferous - 443–299 Ma; early Mesozoic - 251–65 Ma) extensive fires from lightening, volcanic eruptions and underground peat fires are recorded by charcoal remains with diagnostic optical refractive indices, allowing estimates of fire frequency (Figure 2) [13]. In the Permian atmospheric oxygen exceeded 30%, a level at which even moist vegetation becomes flammable, represented in charcoal concentrations as high as 70% in coal [13].

The harnessing of fire by humans, elevating the species' oxygenating capacity by many orders of magnitude through utilization of the solar energy stored in plants and in harbivors, resulted in an increase in planetary entropy (in physics - a measure of the degree of disorder and chaos of a system) to levels approaching those triggered by the major mass extinctions in geological history [14].

Likely the mastery of fire was driven by necessity, mainly the abrupt environmental shifts when mean global temperatures varied during glacial-interglacial shifts by ~5 degrees C and local temperatures by larger amounts, when humans had to find refuge in relatively protected sub-tropical shelters, such as the East African rifts.

It is not known when precisely Hominids first succeeded to kindle fire, by percussion of flint stones or fast rotation of wooden sticks. Convincing evidence of domestic fires by Homo erectus and Homo heidelbergensis is indicated at least 300 thousand years (300 kyr) ago in Africa and the Middle East [15]. Proposed fire places as old as 750 kyr in France, 1.4 Ma in Kenya and 1.7-1.5 kyr in South Africa (Swartkrans) and China (Xihoudu) are more controversial. Early Paleolithic evidence for human-lit fires includes hearths containing charcoal, burnt bones and red clay shards heated to 400 degrees Celsius and higher temperatures. Widespread use of fire in the late Paleolithic is indicated by charred logs, charcoal, reddened areas, carbonized grass stems and plants and wooden implements hardened by fire.

A likely advantage of cooking was enhanced supply of protein, allowing an increase in brain size (Homo ergaster ~850 gram; Homo sapiens ~1350 grams [2]) [16]. Over hundreds of thousands of years, gathered during long nights around camp fires, captivated by the flickering life-like dance of the flames, humans developed curiosity, imagination, insights, cravings, fears, premonition, legends, aspiration for immortality and beliefs in deities and gods. Oldest expressions of cultural and spiritual creative minds may date back to 350,000 years ago [17], although this remains unconfirmed.

As climate conditions stabilized in the early Holocene ~8000 years ago, agriculture and production of excess food allowed these ideas to be manifested through both the creative and destructive activities of civilizations.

The stabilization of climate allowed cultivation of crops, enhanced by smelting of metals and crafting of ploughs. Extensive burning and land clearing associated with agriculture from about 10,000 years ago culminated with the combustion of fossil fuels. Ruddiman (2003) suggests the rise in CO_2 in the mid-Holocene reflects land clearing, fires and agriculture, defining the onset of an *Anthropocene* era (Figure 3), stating "*A wide array of archeological, cultural, historical and geologic evidence points to viable explanations tied to anthropogenic changes resulting from early agriculture in Eurasia, including the start of forest clearance by 8000 years ago and of rice irrigation by 5000 years ago.*" [18]. However, other authors [19] define the onset of the Anthropocene at the dawn of the industrial age in the 18th century, attributing the mid-Holocene rise of greenhouse gases to a natural perturbations during the interglacials, for example the 420-405 kyr Holsteinian interglacial [20].

Since the 18th century burning of fossil fuels and land clearing resulted in an increase in atmospheric carbon contents by 237 billion ton carbon (GtC), reaching 820 GtC at present, an increase of some ~40% [21]. Of the additional CO_2 approximately 42 per cent stays in the atmosphere which, together with other greenhouse gases, led to an increase in the atmospheric energy level of ~3.2 Watt/m2 and of potential mean global temperature by +2.3 degrees Celsius (Figure 1) [24]. Approximately -1.6 Watt/m2, equivalent to -1.1 degrees Celsius, is masked by industrially emitted sulphur aerosols.

Whereas gradual natural rates of change in atmospheric greenhouse gas levels and temperatures allowed most species to adapt and evolve, current changes occur at rates surpassing those of glacial terminations by more than an order of magnitude, an exception being fast temperature rises during the intra-glacial Dansgaard-Oeschger cycles (Figure 3).

The Earth's polar ice caps, source of cold air vortices and ocean currents such as the Humboldt and California current, which keep the Earth's overall temperature in balance, are melting at an accelerated rate [24]. Based on palaeoclimate studies, the current CO2 level of 393 ppm and of CO2-equivalent above 470 ppm commit the atmosphere to a warming trend tracking toward Pliocene-like (~2-3 degrees C above present), Miocene-like (3-4 degrees C above present) and, depending on long-term carbon emissions and feedbacks, toward ice-poor or ice-free Earth conditions.

Within a 15 km-thin biosphere, dominated by the carbon, oxygen and sulphur cycles, the dissemination of carbon and sulphur gases associated with exothermic combustion has already led to the largest greenhouse gas anomaly recorded by the ice cores and marine sediments since 55 million years ago (Figures 1 and 4) [22, 24].

The significance of human mastery of fire in terms of the consequences of enhanced entropy [23] has been underestimated. Whereas human respiration dissipates 2 to 10 calories/minute, a camp fire releases approximately 180,000 Calories/minute, the output of a 1000 megawatt/hour power plant expends some 2.4 billion calories/minute and nuclear fission orders of magnitude higher, with an increase in entropy on the scale of large geological events. While complexity increases in conurbations, the rise in atmospheric energy/heat due to the release of greenhouse gases associated with exothermic combustion results in droughts, floods and storms, degrading natural habitats.

With this perspective, the forewarning by the ancients, whose legends regard fire as stolen from the gods, as in Greek Mythology, where the titan Prometheus stole fire from the gods, breathing it into human clay figures, acquires a special meaning.

For a biological species to magnify its entropic effect on nature by orders of magnitude, developing cerebral powers which allow it to become the intelligent eyes through which the Universe explores itself, hints at yet unknown processes. Perhaps it is too much to expect a species to possess the degree of wisdom and responsibility which would allow it to control the release of such high levels of energy. Perhaps there is a price for biting the apple of knowledge. Where religions relegate the ultimate decisions to the gods, Darwinian evolution hinges on natural trends and modern western culture on human choice, the natural laws which govern the human phenomenon may never be deciphered.

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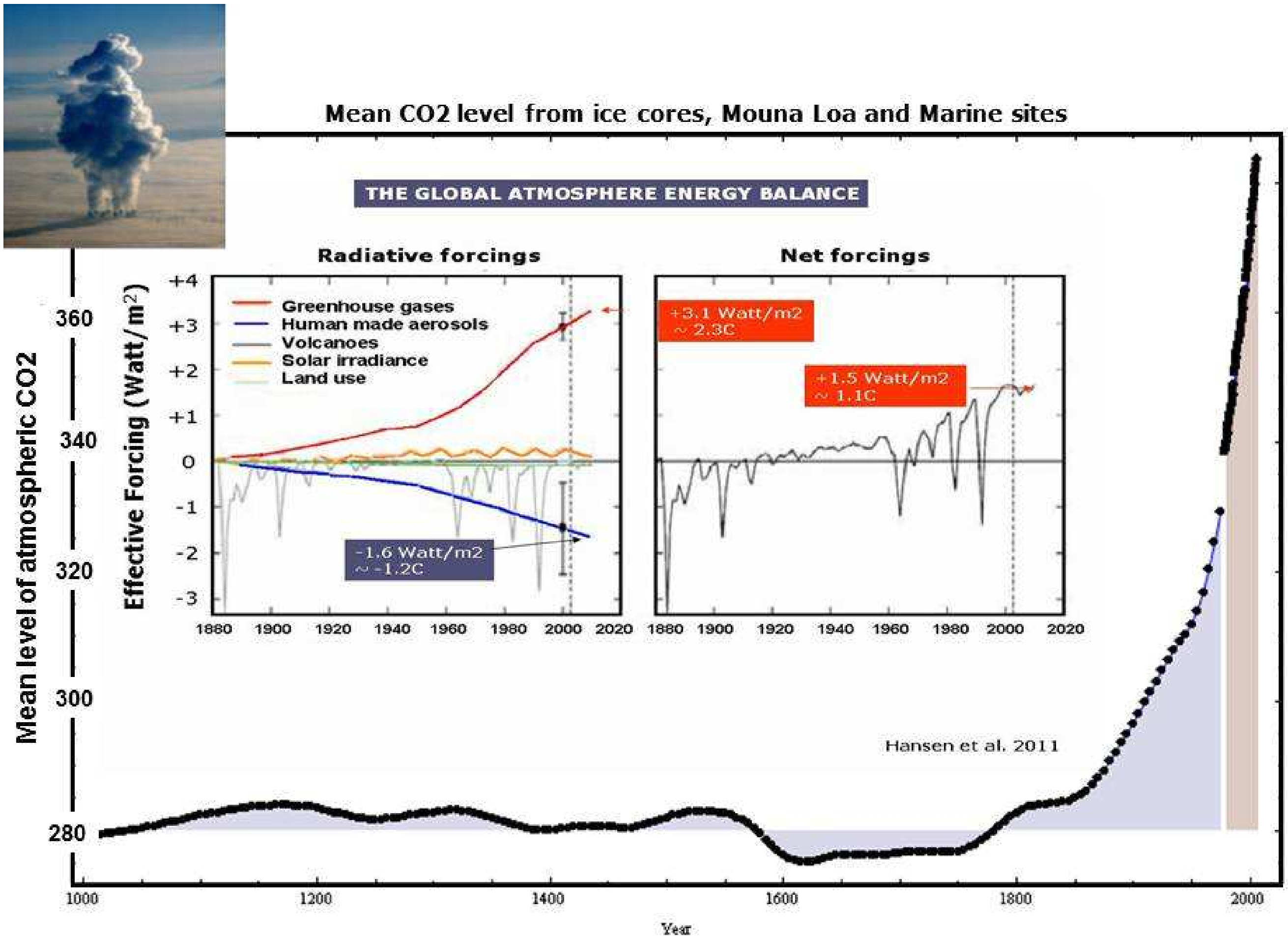

Figure 1

Mean CO2 levels from ice cores, Mouna Loa and marine sites.

Inset (Hansen et al., 2011 [24]). Left: Radiative forcings 2000 – 2011, including greenhouse gases (red), human-emitted aerosols (blue), volcanic eruptions (grey), solar radiance (yellow) and land use (green).

Right: net of the various forcings

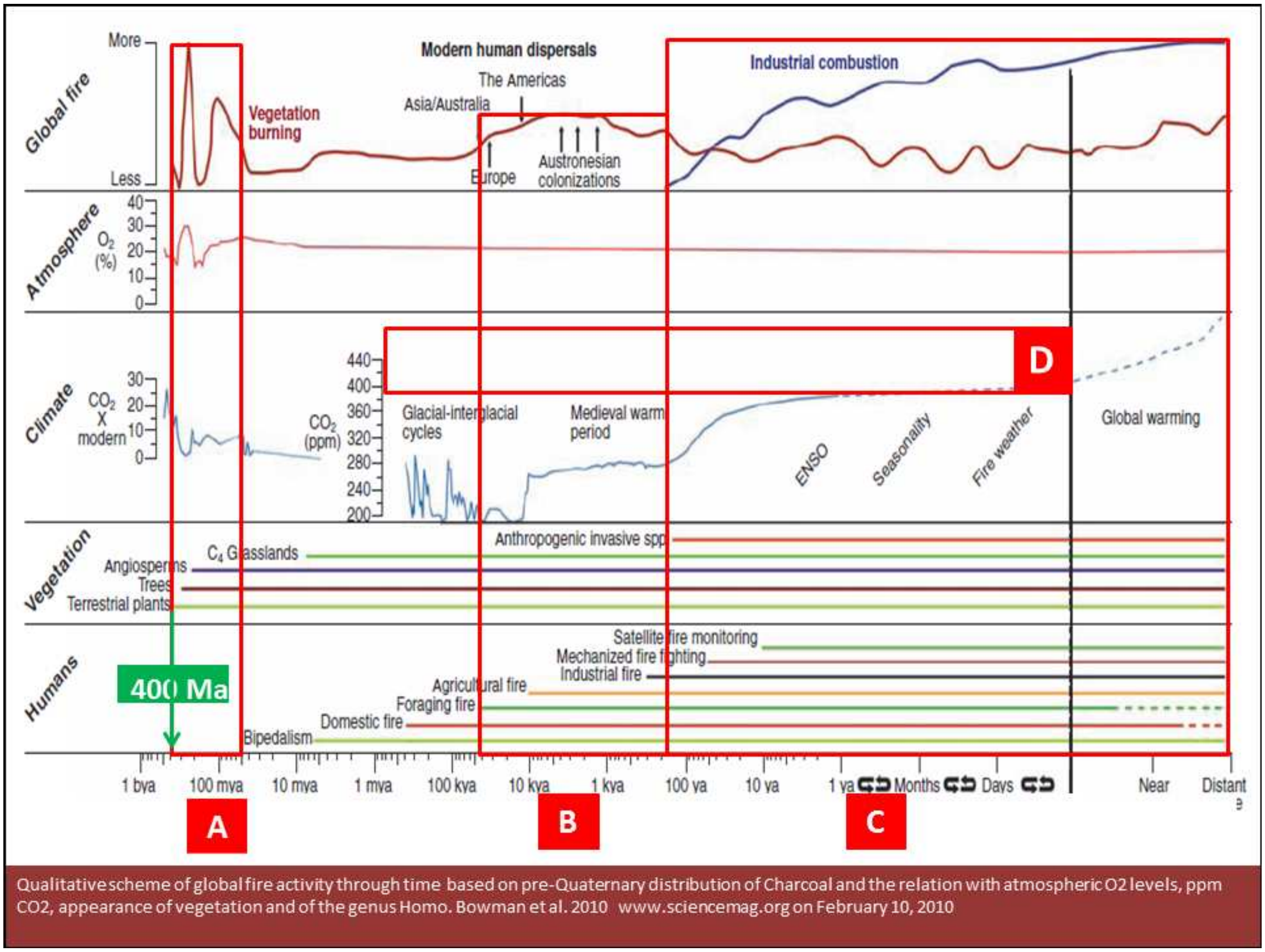

Figure 2

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 O2 content, CO2, vegetation types and the human factor. From Bowman et al. (2009) (with permission). 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).

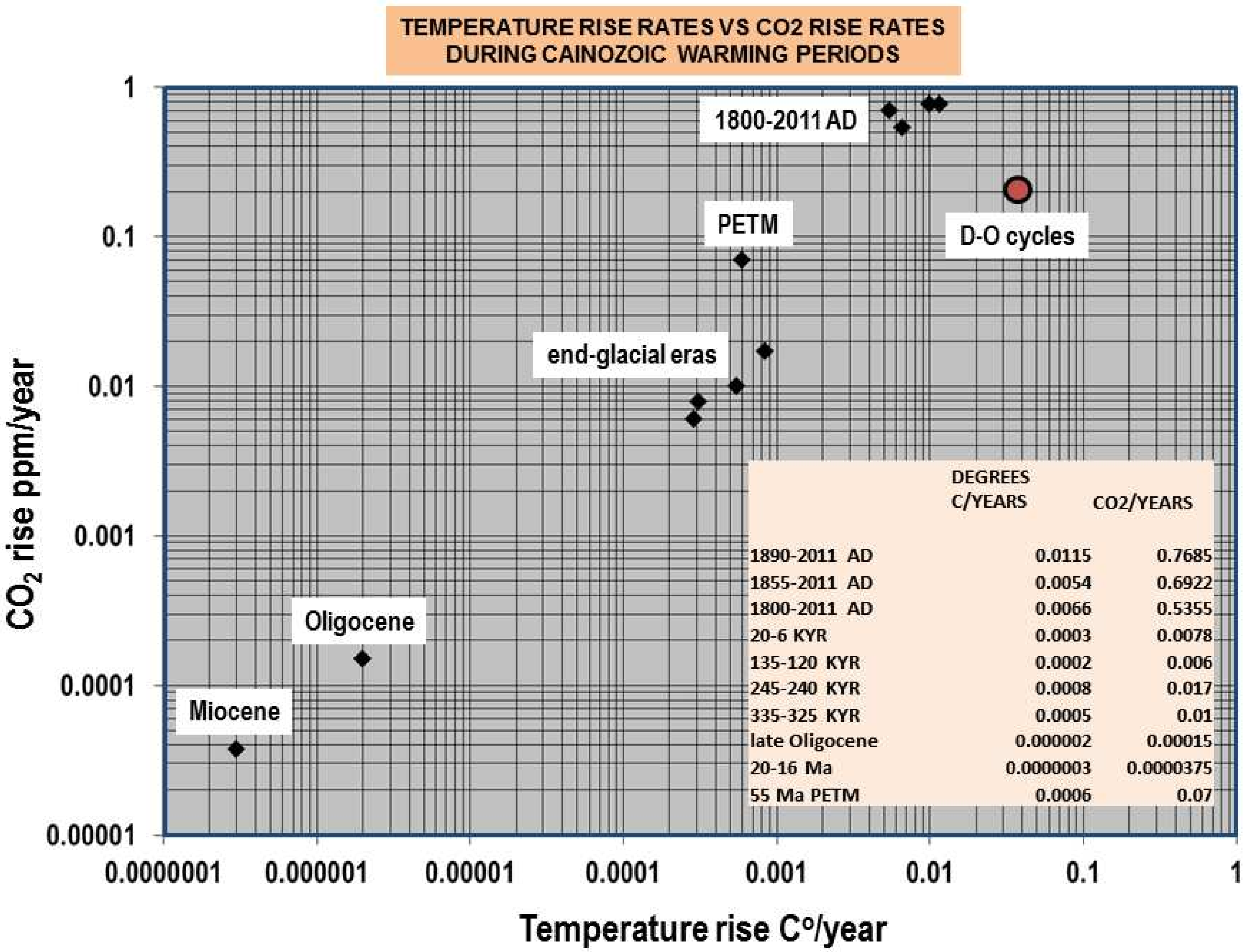

Figure 3

Relations between CO2 rise rates (ppm/year) and temperature rise rates (degrees Celsius/year) during warming periods of the PETM (Paleocene-Eocene Thermal Maximum – 55 Ma), Miocene (~20-16 Ma), late Oligocene, glacial terminations, Dansgaard-Oeschger cycles of the last glacial period (~110 – 20 kyr ago) and the last two centuries.

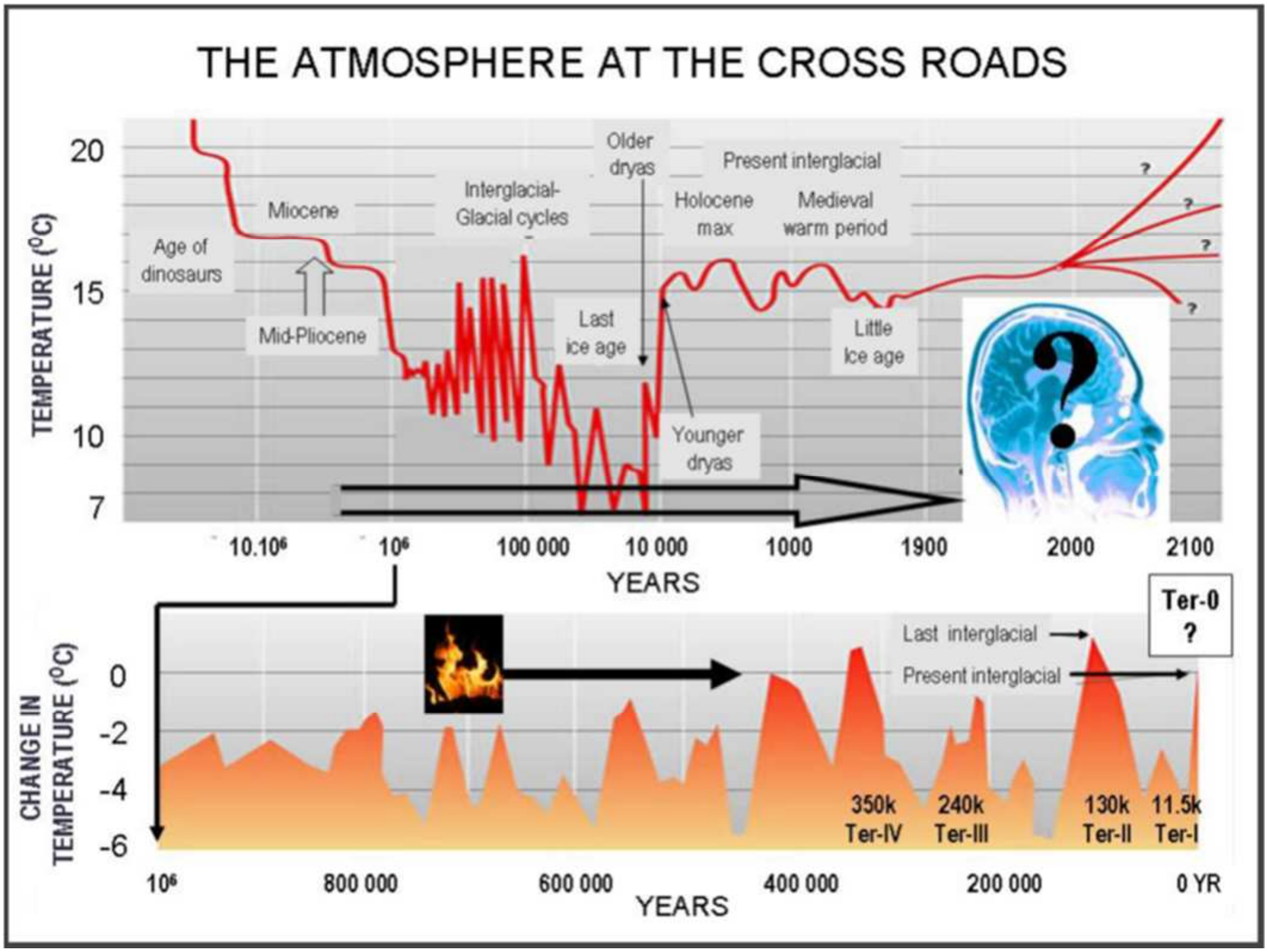

Figure 4

The atmosphere at the cross roads