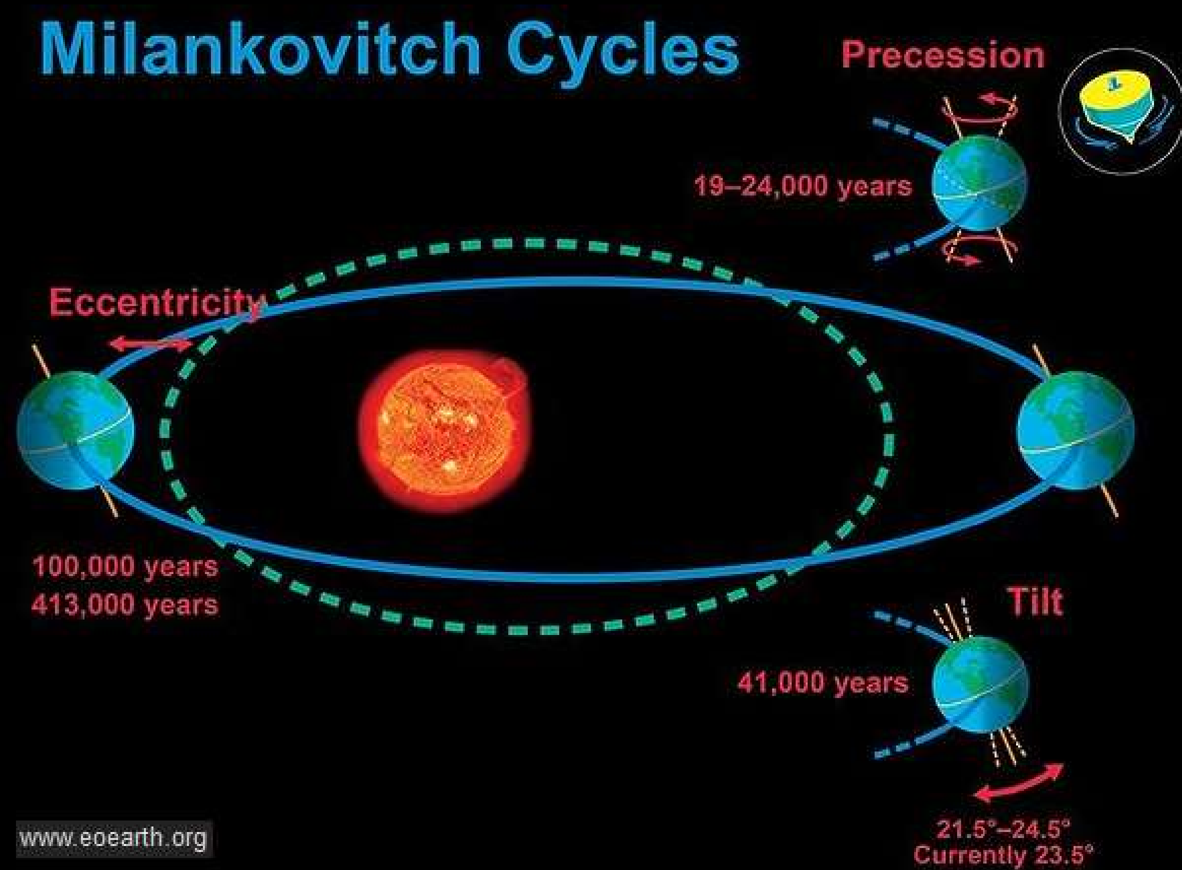
CLIMATE CYCLES AND HUMANITY

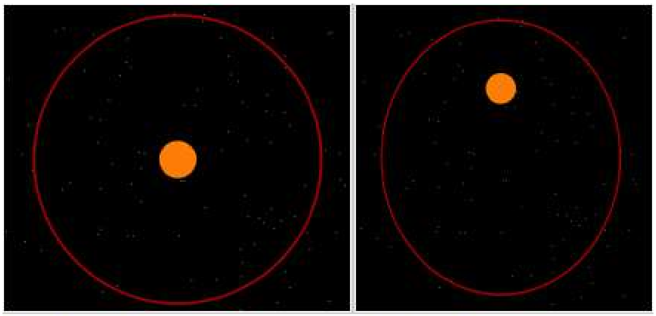


Sources: http://en.wikipedia.org/wiki/Milankovitch_cycles
http://commons.wikimedia.org/wiki/File:Phanerozoic_Climate_Change.png

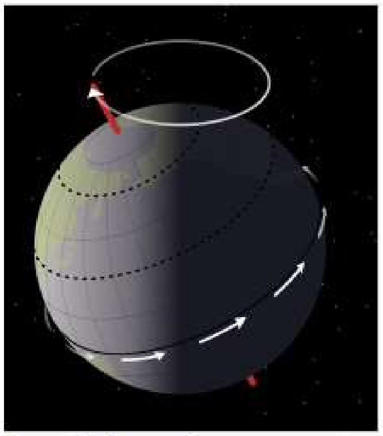
2022; 2012 GCHERMAN

MILANKOVIC THEORY

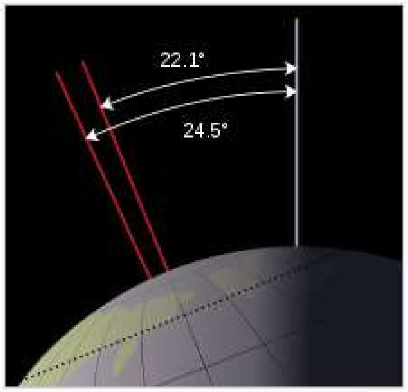
- Describes the collective effects of changes in the Earth's movements upon its climate, named after Serbian civil engineer and mathematician Milutin Milanković, who worked on it during First World War internment. Milanković mathematically theorized that variations in eccentricity, axial tilt, and precession of the Earth's orbit determined climatic patterns on Earth through *orbital forcing*, also know as *radiative forcing*.
- The Earth's axis completes one full cycle of precession approximately every 26,000 years as the elliptical orbit rotates more slowly. The combined effect of the two precessions leads to a **~21,000**-year (21 kyr) seasonal period.
- The angle between Earth's rotational axis and the normal to the plane of its orbit (obliquity) oscillates between 22.1° and 24.5° on a **41,000**-year (41 kyr) cycle. It is currently 23.44° degrees and decreasing.



Circular orbit, no eccentricity. Orbit with 0.5 eccentricity.



Precessional movement.



22.1–24.5° range of Earth's obliquity.

From Wikipedia, the free encyclopedia

70,000 (70 kyr), 100 kyr, and 400 kyr CLIMATE FACTORS

- **Orbital inclination** - The inclination of Earth's orbit drifts up and down relative to its present orbit *with a period of about 70,000 years (70 kyr).* Milankovic did not study this 3D movement, known as "precession of the ecliptic" or "planetary precession". *The invariable plane*, the plane that represents the angular momentum of the solar system, is approximately the orbital plane of Jupiter, the largest planet.

- A dominant, **100 kyr eccentricity period of Earth's orbit** closely matches the pattern of recent ice ages.
- ***Both the 100 kyr and 400 kyr eccentricity periods stem from gravitational** interactions of Earth with Venus (smaller but close) and Jupiter (very large and far).*
- The 400 kyr component is called the 'long' eccentricity cycle, and of all of Earth's orbital frequencies, is demonstrably the most stable.

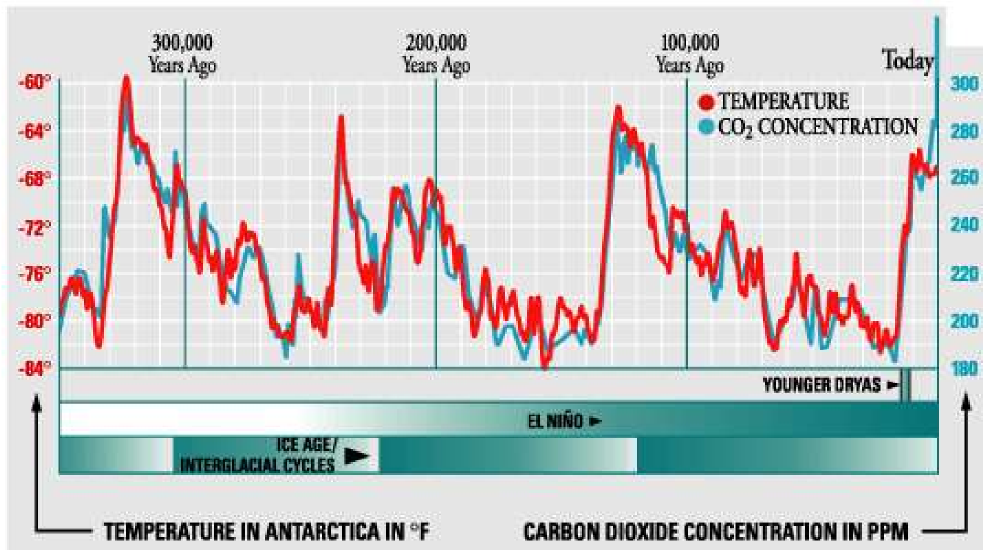


Figure 1: Carbon dioxide (parts per million, ppm) and temperature (Fahrenheit) from the Vostok Ice Core. Recently the record has been extended back more than 650,000 years (Siegenthalter et al., 2005, Science)

Milankovic Theory From Wikipedia, the free encyclopedia

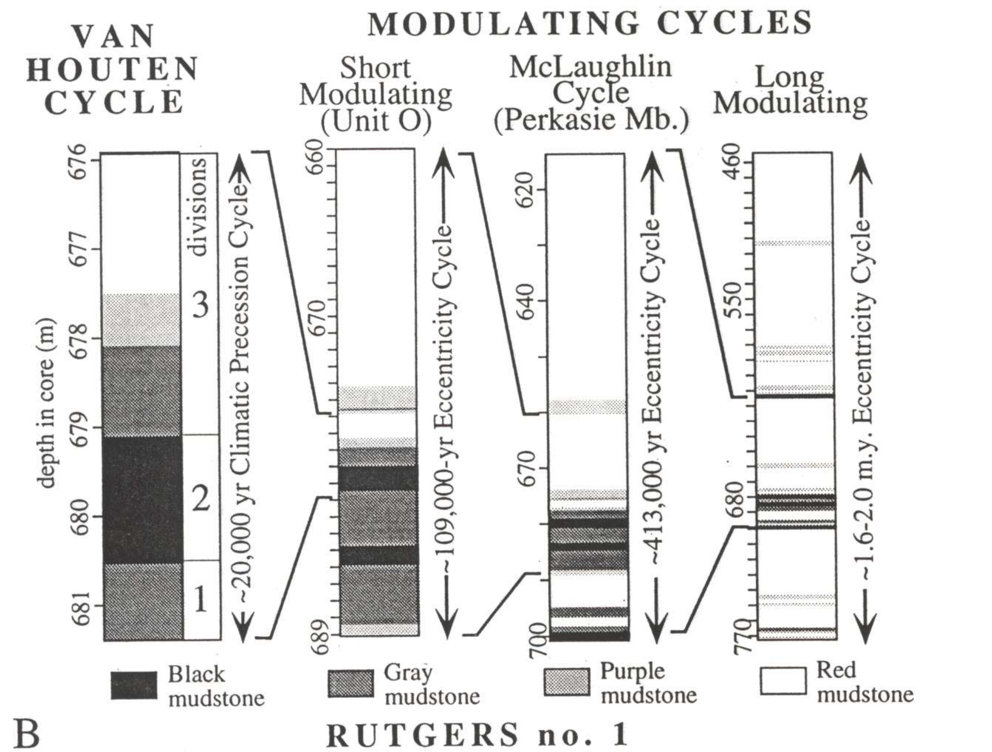
https://www.sciencedirect.com/topics/earth-and-planetary-sciences/eccentricity

THE MID-PLESTOCENE TRANSITION ABOUT 1 Myr to 800 kyr

- Between1 to 3 Myr ago, climate cycles matched the 41 kyr cycle in *orbital obliquity*, but about one million years ago after a Mid-Pleistocene Transition (MPT) Earth's climate fluctuations more closely match 100 kyr periods of orbital eccentricity.
- The *transition problem* refers to the need to explain what changed during the MPT.
- The MPT has been modeled and reproduced in numerical simulations that include a decreasing trend in carbon dioxide and glacially induced removal of regolith.

High-resolution stratigraphy of the Newark rift basin (early Mesozoic, eastern North America)

Paul E. Olsen
Dennis V. Kent
Bruce Cornet*
William K. Witte*
} *Lamont-Doherty Earth Observatory of Columbia University, Palisades, New York 10964*
Roy W. Schlische *Department of Geological Sciences, Rutgers University, Busch Campus, Piscataway, New Jersey 08855-1179*



Olsen, and others, 1996

THE PAST 3,000,000 YEARS (3 Myr) OF CLIMATE CHANGE

SCIENCE ADVANCES | RESEARCH ARTICLE

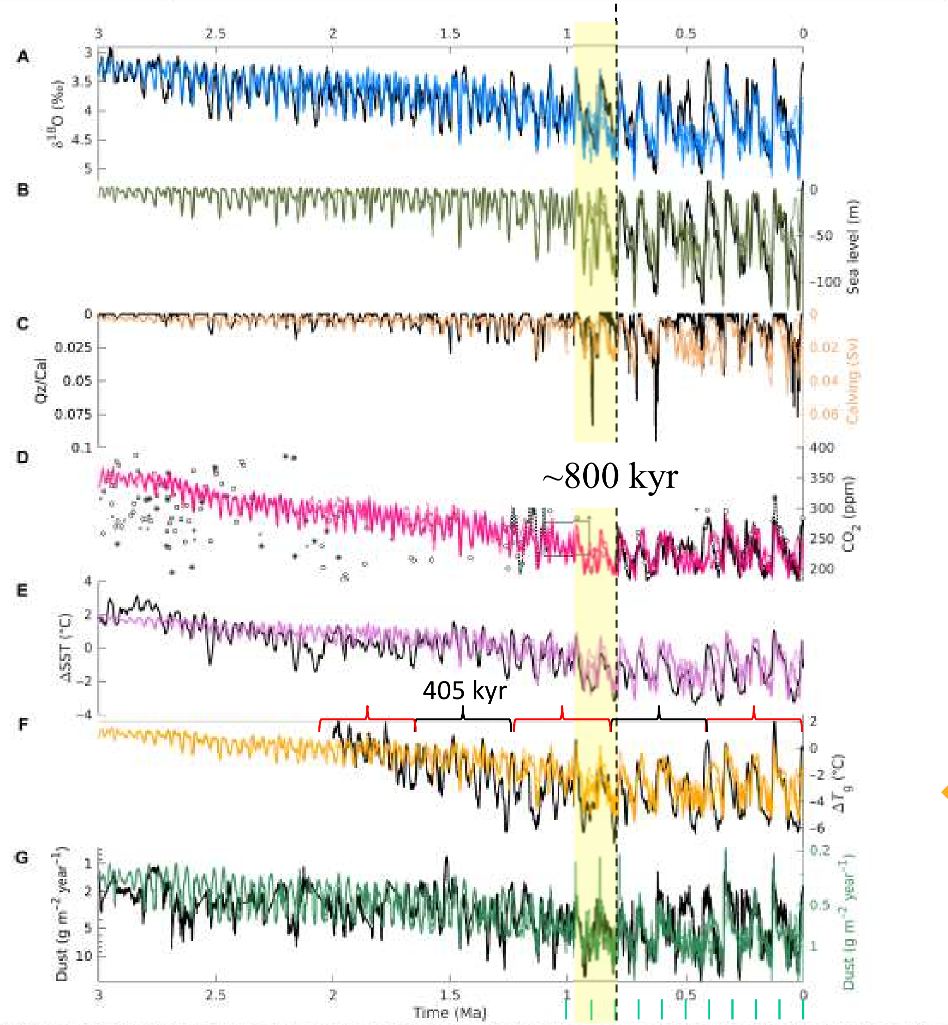


Fig. 2. Transient modeling results. Results of model simulations driven by orbital forcing, optimal regolith removal scenario, and optimal volcanic outgassing scenario. In all panels, observations are shown in black and model results are shown as colored lines. (**A**) Benthic $\delta^{18}O$ compared to the stack of (*3*). (**B**) Relative sea level compared to (*49*). (**C**) Calving from the Laurentide ice sheet into the North Atlantic compared to a proxy for ice-rafted debris at site U1313 (*30*). (**D**) Atmospheric CO_2 concentration compared to ice core data (solid line) (*50*) and other proxies [circles: (*16*); squares: (*18*); *: (*51*); + and x: (*19*); diamonds: (*52*); black box: (*15*); dotted lines: (*17*)]. (**E**) SST anomalies compared to the stack of (*18*). (**F**) Global annual surface air temperature compared to reconstructions (*53*). (**G**) Southern Ocean dust deposition compared to data (*54*).

The last geomagnetic reversal 781 kyr

Gradstein, Felix M.; Ogg, James G.; Smith, Alan G., eds. (2004). *A Geological Time Scale* (3rd ed.).

Australasian tektite strewn field 790 kyr

Schneider D.A., Kent D.V. & Mello G.A. 1992. A detailed chronology of the Australasian impact event, the Brunhes-Matuyama geomagnetic polarity reversal, and global climatic change. Earth and Planetary Science Letters 111, 395-405.

Mid-Pleistocene climate change ~1 Myr to 800 kyr

Willeit, M., Ganopolski, A., Calov, R., and Brovkin, M, 2019, Mid-Pleistocene transition in glacial cycles explained by declining CO2 and regolith removal: Science Advances v. 5, no. 4.

THE PAST 800 kyr OF CLIMATE CHANGE

Clim. Past, 7, 361–380, 2011
www.clim-past.net/7/361/2011/
doi:10.5194/cp-7-361-2011

Climate of the Past

Interglacial and glacial variability from the last 800 ka in marine, ice and terrestrial archives

N. Lang[1,*] and E. W. Wolff[1]

[1]British Antarctic Survey, High Cross, Madingley Road, Cambridge CB3 0ET, UK
[*]now at: National Isotope Centre, 30 Gracefield Rd, Gracefield, Wellington 5010, New Zealand

Received: 24 September 2010 – Published in Clim. Past Discuss.: 15 October 2010
Revised: 24 January 2011 – Accepted: 22 February 2011 – Published: 21 April 2011

Abstract. We have compiled 37 ice, marine and terrestrial palaeoclimate records covering the last 800 000 years in order to assess the pattern of glacial and interglacial strength, and termination amplitude. Records were selected based on their length, completeness and resolution, and their age models were updated, where required, by alignment to the LR04 benthic $\delta^{18}O$ stack. The resulting compilation allows comparison of individual glacial to interglacial transitions with confidence, but the level of synchronisation is inadequate for discussion of temporal phasing. The comparison of interglacials and glacials concentrates on the peaks immediately before and after terminations; particularly strong and weak glacials and interglacials have been identified. This confirms that strong interglacials are confined to the last 450 ka, and that this is a globally robust pattern; however weak interglacials (i.e. marine isotope stage 7) can still occur in this later period. Strong glacial periods are also concentrated in the recent half of the records, although marine isotope stage 16 is strong in many $\delta^{18}O$ records. Strong interglacials, particularly in the marine isotopic records, tend to follow strong glacials, suggesting that we should not expect interglacial strength to be strongly influenced by the instantaneous astronomical forcing. Many interglacials have a complex structure, with multiple peaks and troughs whose origin needs to be understood. However this compilation emphasises the under-representation of terrestrial environments and highlights the need for long palaeoclimate records from these areas. The main result of this work is the compiled datasets and maps of interglacial strength which provide a target for modelling studies and for conceptual understanding.

Correspondence to: N. Lang
(n.lang@gns.cri.nz)

1 Introduction

The climate of the recent third of the Quaternary is most clearly characterised by the alternation between cold glacial periods and warm interglacials; the dominant period of these climate cycles is 100 ka (e.g. Imbrie et al., 1993). In the four most recent climate cycles, the glacial periods are much longer than the interglacials. This climate signal is observed in marine sediments (Lisiecki and Raymo, 2005), in land records (Tzedakis et al., 2006) and in ice cores (Jouzel et al., 2007). The terms "glacial" and "interglacial" emphasise the changes in ice volume and sea level associated with the appearance and disappearance of large northern hemisphere ice sheets; however the general pattern is seen in numerous proxies related, for example, to temperature and the hydrological cycle, ocean conditions, and patterns of vegetation. The EPICA Dome C (EDC) ice core record shows that atmospheric composition, and in particular the concentrations of the greenhouse gases CO_2 and CH_4, has a similar pattern; these records were recently extended to 800 ka (Loulergue et al., 2008; Lüthi et al., 2008).

Understanding the causes of glacial-interglacial cycles requires not just replication of a "typical" glacial cycle, but an understanding of how slightly different external forcing and internal feedback mechanisms can lead to a wide range of responses. In recent years particular attention has been paid to the range of behaviours seen in interglacials (Tzedakis et al., 2009). The emergence of a longer ice core record has prompted a re-evaluation, reinforcing the view that each glacial-interglacial cycle has an individual pattern, which in the Antarctic ice cores is most clearly seen in interglacial variability (Jouzel et al., 2007). A first description (EPICA, 2004) was that interglacials before 450 ka ago were weak (cool) and long, while the more recent ones were strong and short. The implication is that a step change occurred around 430 ka ago (mid-Brunhes). However, with the new EDC3 age

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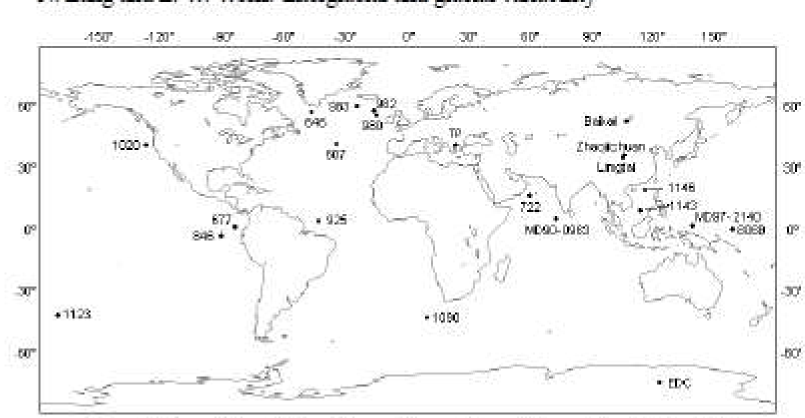


Fig. 1. Location of palaeoclimate records included in this synthesis.

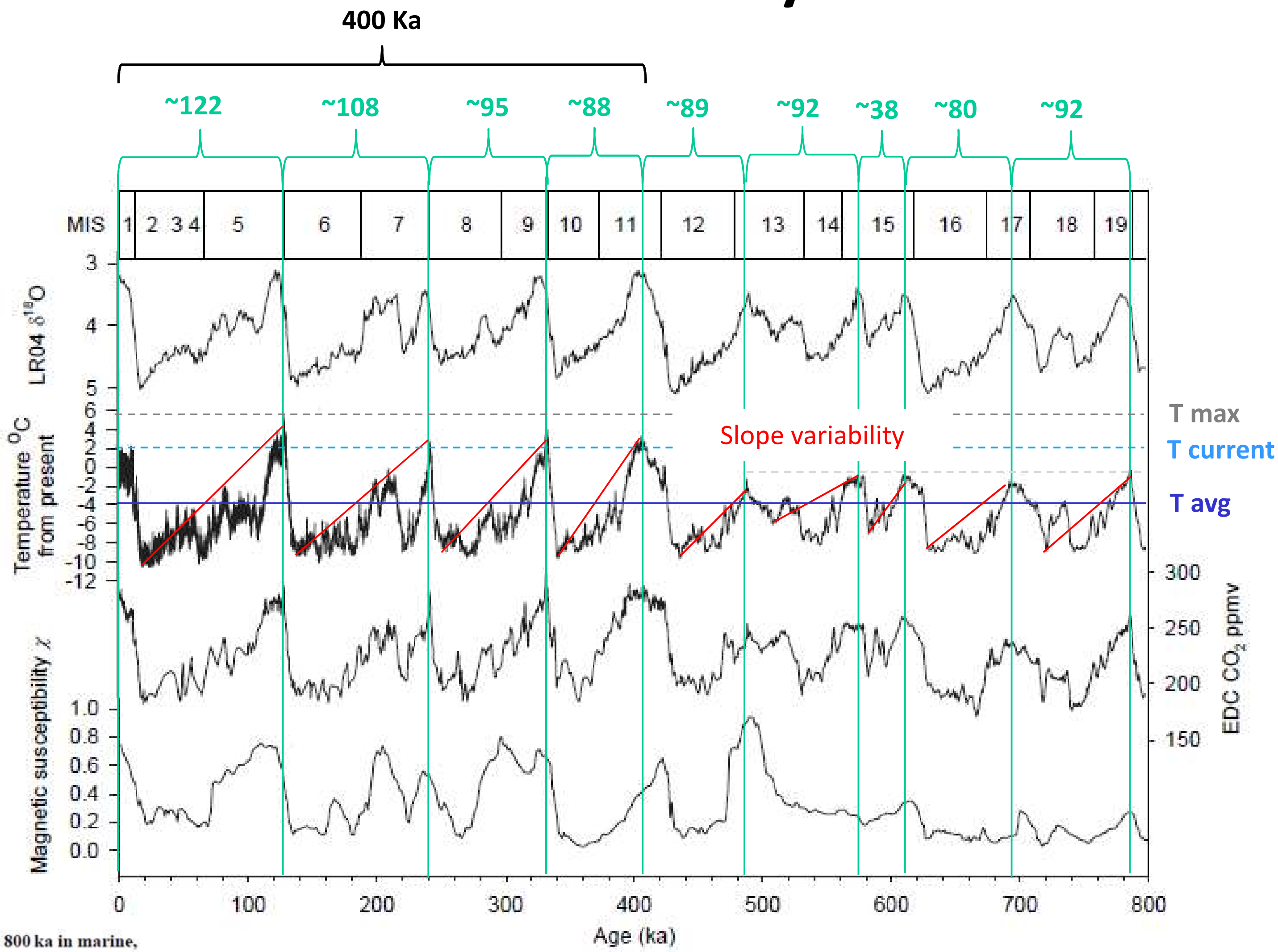
Table 1. Palaeoclimate records included in this synthesis.

Site/record	Parameter	Location	Resolution*	References
EDC	CO_2 concentration	East Antarctica	0.8 ± 0.7	Loulergue et al. (2008)
	CH_4 concentration		0.4 ± 0.3	Lüthi et al. (2008)
	δD		1.0	Jouzel et al. (2007)
LR04	$\delta^{18}O$ (b)	Global stack	ka average	Lisiecki and Raymo (2005)
DSDP 607	Mg/Ca BWT	North Atlantic	4.1 ± 2.8	Sosdian and Rosenthal (2009)
	SST (foram assemblage)		2.2 ± 1.7	Ruddiman et al. (1989)
ODP 646	$\delta^{18}O$ (p)	North Atlantic	2.6 ± 1.0	de Vernal and Hillaire-Marcel (2008)**
ODP 677	$\delta^{18}O$ (b/p)	East Equatorial Pacific	$2.5\pm1.3/2.4\pm1.2$	Shackleton and Hall (1989)
ODP 722	$U^{k'}_{37}$SST	Indian Ocean	1.7 ± 0.9	Herbert et al. (2010)
ODP 806B	$\delta^{18}O$ (p)	West Equatorial Pacific	2.3 ± 2.2	Medina Elizalde and Lea (2005)
	Mg/Ca SST		2.3 ± 2.2	
ODP 846	$\delta^{18}O$ (b)	East Equatorial Pacific	2.5 ± 1.6	Mix et al. (1995)
	$U^{k'}_{37}$ SST		2.3 ± 1.3	Liu and Herbert (2004)
ODP 925	$\delta^{18}O$ (b)	West EquatorialAtlantic	2.4 ± 1.6	Bickert et al. (1997)
ODP 980	$\delta^{18}O$ (b)	North Atlantic	0.7 ± 0.7	Raymo et al. (2004)
ODP 982	$\delta^{18}O$ (b / p)	North Atlantic	$2.3\pm1.5/2.0\pm1.0$	Venz and Hodell (1999)
	$U^{k'}_{37}$SST		4.6 ± 3.0	Lawrence et al. (2009)
ODP 983	$\delta^{18}O$ (b)	North Atlantic	0.9 ± 1.5	Raymo et al. (2004)
ODP 1020	$U^{k'}_{37}$SST	North East Pacific	2.2 ± 0.8	Herbert et al. (2001)
ODP 1090	$\delta^{18}O$ (b/p)	Southern Ocean	$1.7\pm1.7/1.2\pm0.6$	Hodell et al. (2003)
	U^{k}_{37} index SST		2.4 ± 1.7	Martinez-Garcia et al. (2009)
ODP 1123	$\delta^{18}O$ (b)	Southern Ocean	2.4 ± 0.8	Hall et al. (2001)
	SST (foram assemblage)		2.4 ± 0.8	Crundwell et al. (2008)
ODP 1143	$\delta^{18}O$ (b)	South China Sea	2.4 ± 1.9	Tian et al. (2002)
ODP 1146	$\delta^{18}O$ (b/p)	South China Sea	$2.0\pm1.4/1.7\pm1.1$	Clemens and Prell (2004)
	$U^{k'}_{37}$SST		1.7 ± 1.1	Herbert et al. (2010)
MD90-0963	$\delta^{18}O$ (p)	Indian Ocean	2.1 ± 1.3	Bassinot et al. (1994)
MD97-2140	Mg/Ca SST	West Equatorial Pacific	4.0 ± 2.8	de Garidel-Thoron et al. (2005)
Zhaojichuan/	Mass accumulation rate	Chinese Loess Plateau	1	Sun and An (2005)
Lingtai	Magnetic susceptibility		1	
LakeBaikal	Biogenic silica	Southern Siberia	0.5 ± 0.2	Prokopenko et al. (2006)
Tenaghi Philippon	Arboreal pollen	Greece	1.3 ± 0.7	Tzedakis et al. (2006)

*Resolution (in ka) averaged over the last 800 ka, b = benthic, p = planktonic, BWT = bottom water temperature, SST = sea surface temperature. The LR04 stack "ka average" refers to the 1 ka intervals over which points from the individual datasets were averaged.
**Based on data in Aksu et al. (1989).

CLIMATE VARIABILITY OVER THE PAST 800 kyr

- The past 400 kyr has seen relatively extreme temperatures ranges occurring about every ~100 kyr when compared to the prior 400 kyr period.
- Note that along with increased temperature fluctuations, the past 400 kyr has experienced an increase of time between very warm periods, as if *the system has been slowing down.*



Interglacial and glacial variability from the last 800 ka in marine, ice and terrestrial archives

N. Lang[1,*] and E. W. Wolff[1]
[1]British Antarctic Survey, High Cross, Madingley Road, Cambridge CB3 0ET, UK
[*]now at: National Isotope Centre, 30 Gracefield Rd, Gracefield, Wellington 5010, New Zealand

Received: 24 September 2010 – Published in Clim. Past Discuss.: 15 October 2010
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Modified and supplemented from Fig. 2d. EPICA Dome C records on EDC3 timescale, and terrestrial records (on individual timescales); LR04 benthic stack and corresponding marine isotope stages (MIS) from LR04.

PULSES OF EARTH'S ORBITAL-ECCENTRICITY OVER THE PAST 30 Myr

A&A 532, A89 (2011)
DOI: 10.1051/0004-6361/201116836
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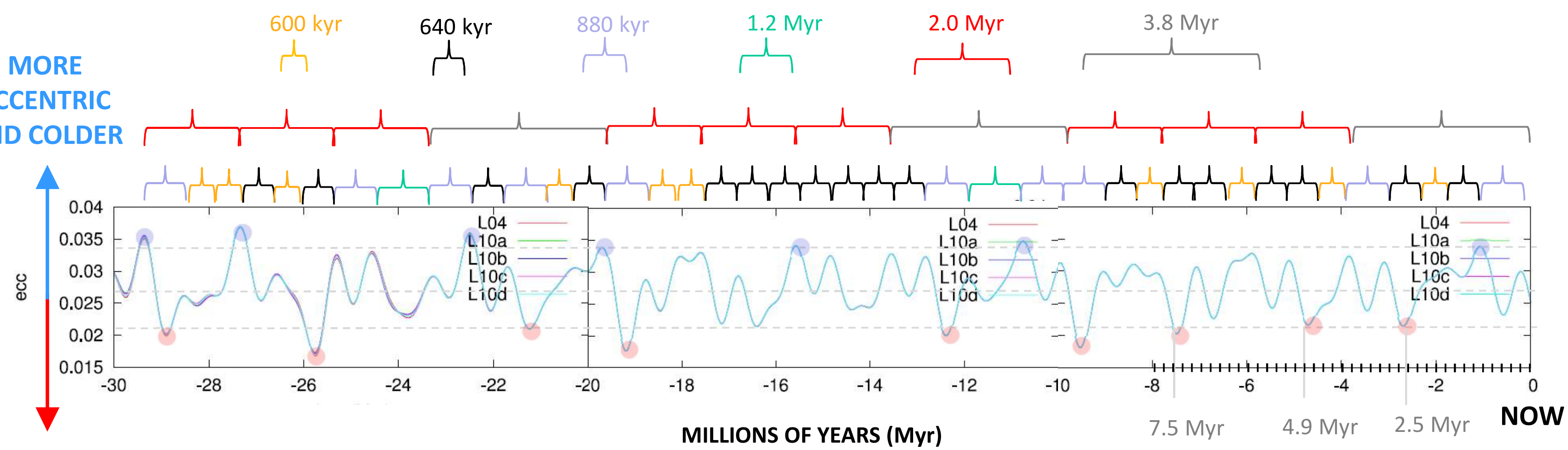
Astronomy & Astrophysics

La2010: a new orbital solution for the long-term motion of the Earth*

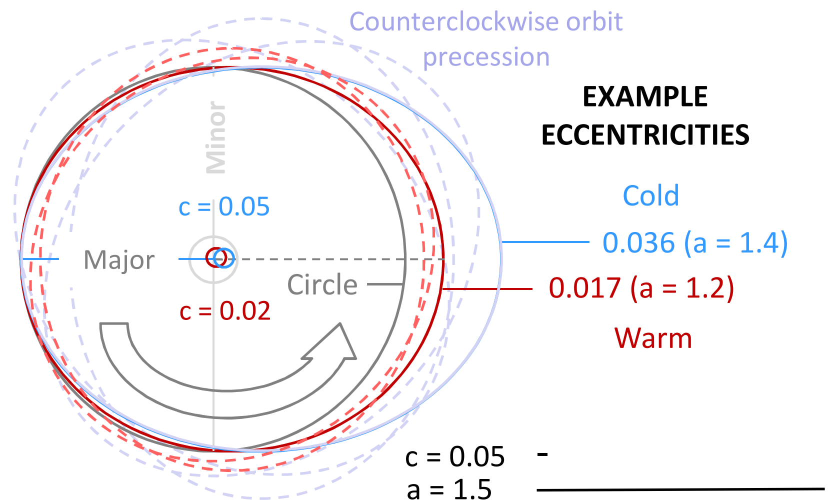
J. Laskar[1], A. Fienga[1,2], M. Gastineau[1], and H. Manche[1]

MORE ECCENTRIC AND COLDER



LESS ECCENTRIC AND WARMER

EARTH'S ORBIT OVER THIS TIME HAS BEEN ONLY MILDLY ECCENTRIC WITH **e** RANGING BETWEEN ~0.018 AND 0.035



Eccentricity (**e**) = c/a where **c** is the *focal distance* to the elliptical center to the ellipse focus (internal), and **a** is the *vertex distance* from the center (perimeter)

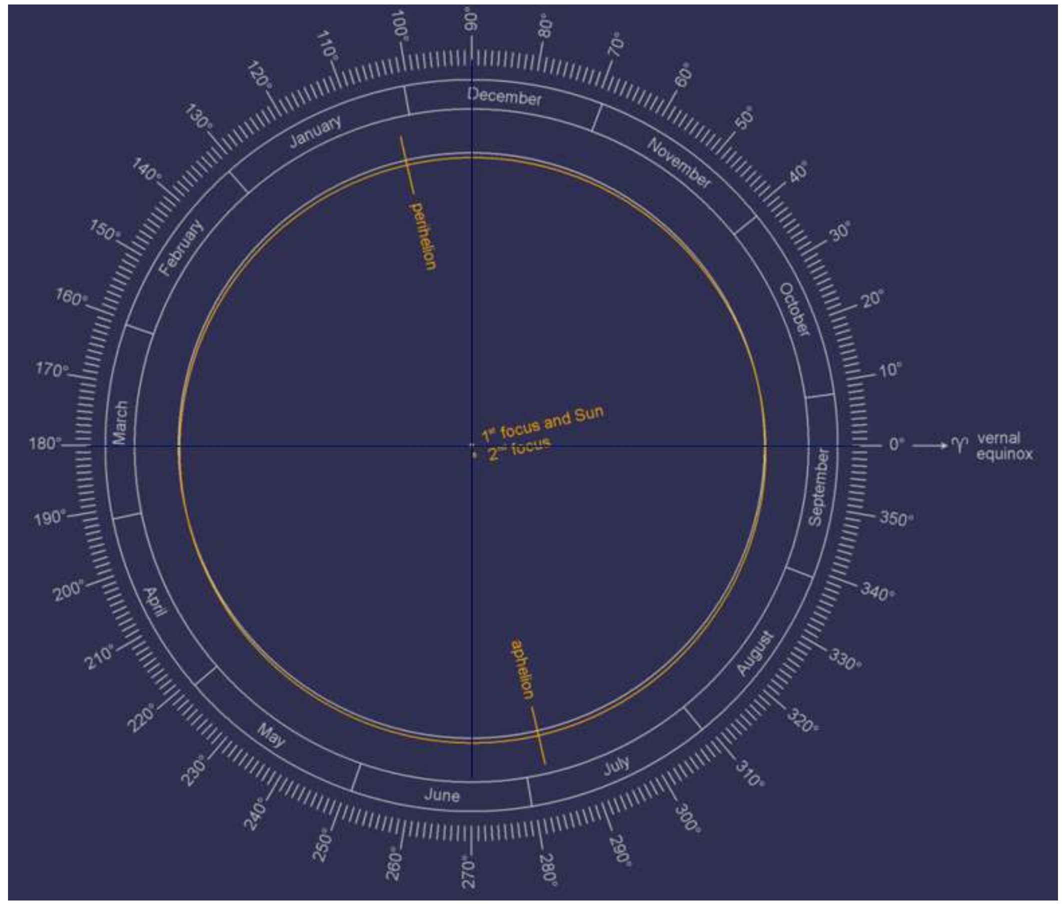
EARTH | Orbital Variation (Including Milankovitch Cycles)

H. Pälike, in Encyclopedia of Geology, 2005

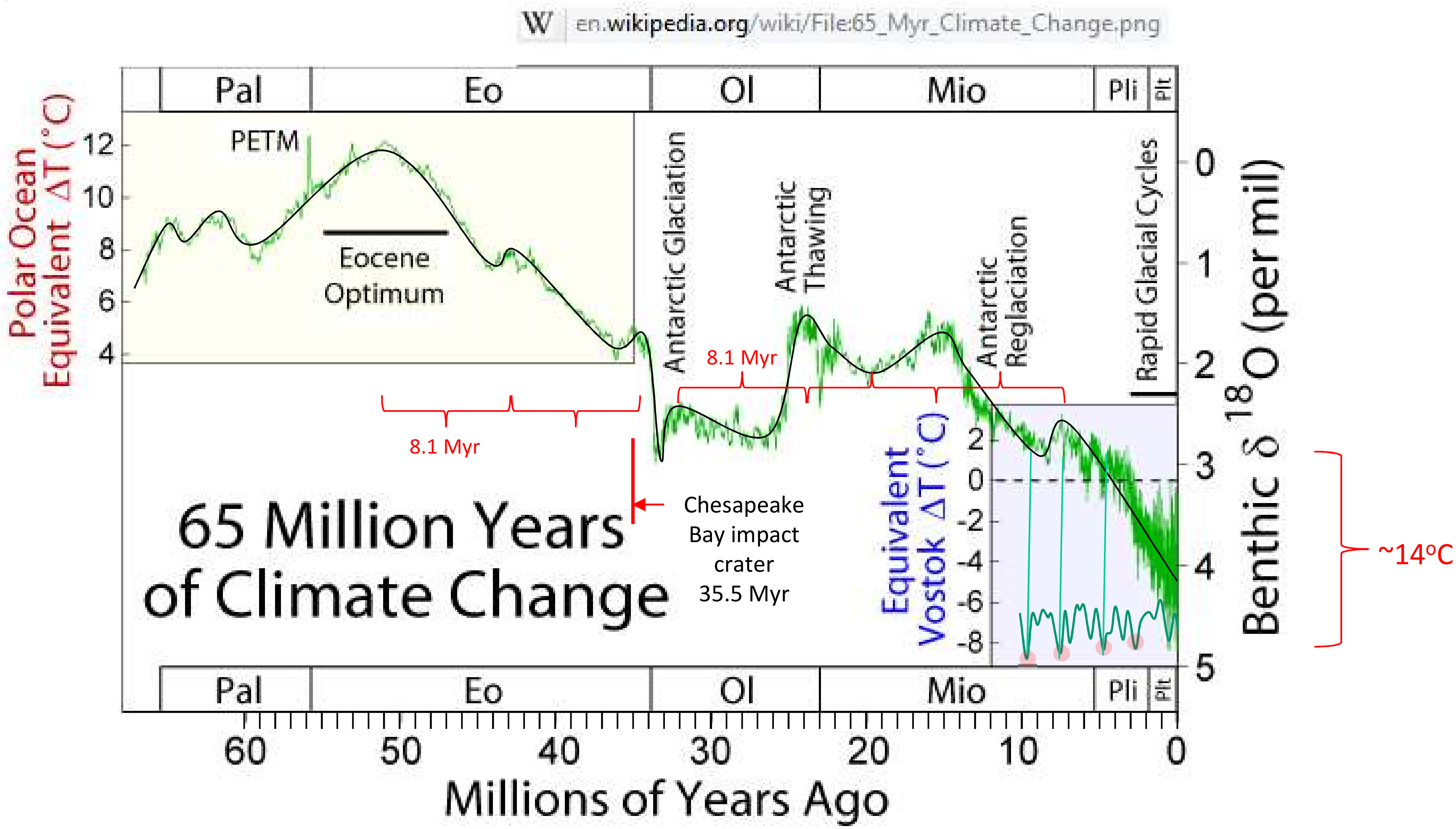
Eccentricity

Earth's orbital eccentricity e quantifies the deviation of Earth's orbital path from the shape of a circle. It is the only orbital parameter that controls the total amount of solar radiation received by Earth, averaged over the course of 1 year. The present eccentricity of Earth is $e \approx 0.01671$. In the past, it has varied between 0 and ~ 0.06. The eccentricity value can be used to compute the difference in the distance from Earth to the Sun between their closest and furthest approaches (perihelion and aphelion); presently, this amounts to $2e \approx 3.3\%$. At maximum eccentricity, the annual variation of solar insolation due to eccentricity is thus 24%. Although the exact values of orbital parameters should be computed by numerical integration, it is possible to approximate the calculation as a series of quasiperiodic terms, some of which are listed in Table 2. It is important to point out that the eccentricity frequencies are completely independent of the precession frequency p. Earth's eccentricity frequency component with the largest amplitude has a period of approximately 400 ky, which arises mainly from the interactions of the planets Venus and Jupiter, due to their close approach and large mass, respectively. This component is called the 'long' eccentricity cycle, and of all of Earth's orbital frequencies, it is considered to be the most stable. Additional terms can be found with periods clustered around ~ 96 and ~ 127 ky. These are called 'short' eccentricity cycles.

EARTH'S CURRENT ORBIT



THE PAST 60 Myr OF CLIMATE CHANGE

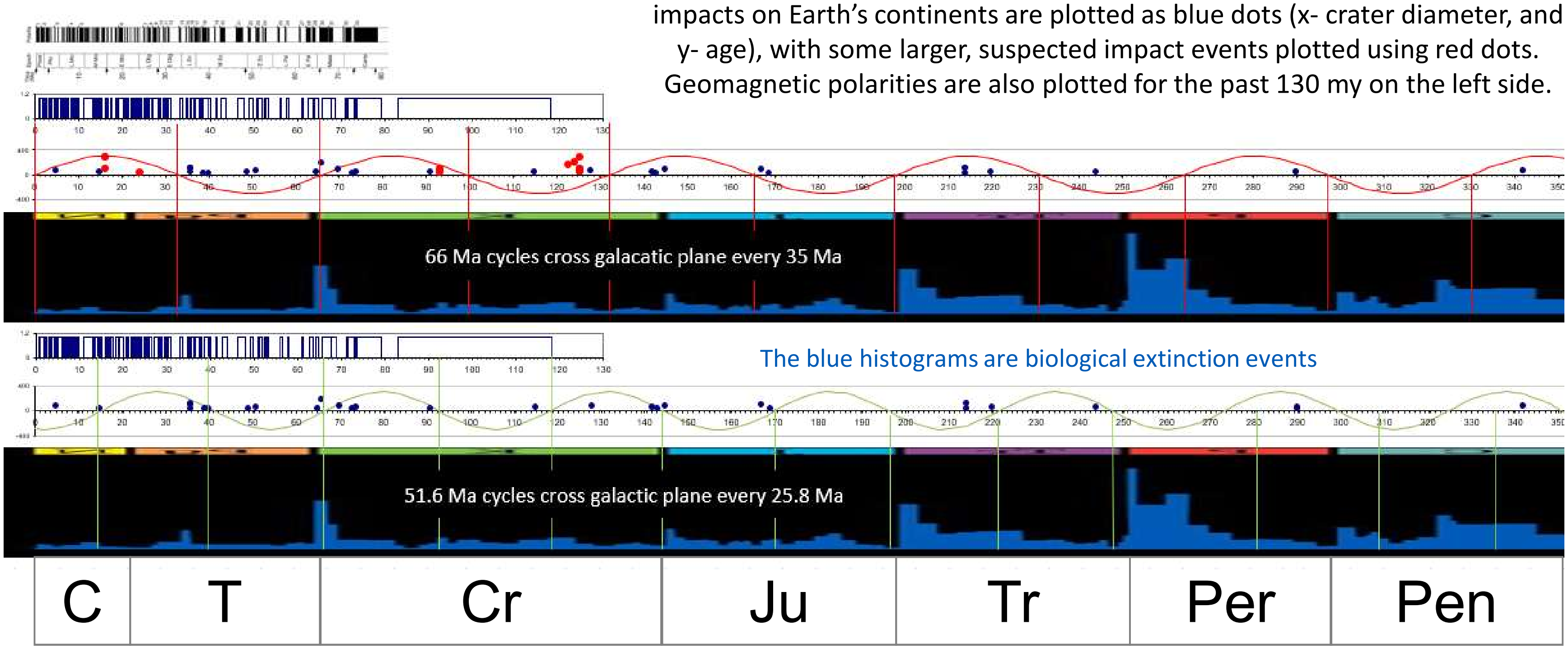


The data are based on a compilation of oxygen isotope measurements ($\delta^{18}O$) on benthic foraminifera by Zachos et al. (2001) which reflect a combination of local temperature changes in their environment and changes in the isotopic composition of sea water associated with the growth and retreat of continental ice sheets

350 Myr OF SOLAR SYSTEM OSCILLATION, BOLIDE IMPACTS AND BIOLOGICAL EXTINCTIONS ON EARTH, ALSO SHOWING 118 Myr OF MAGNETIC FLUX

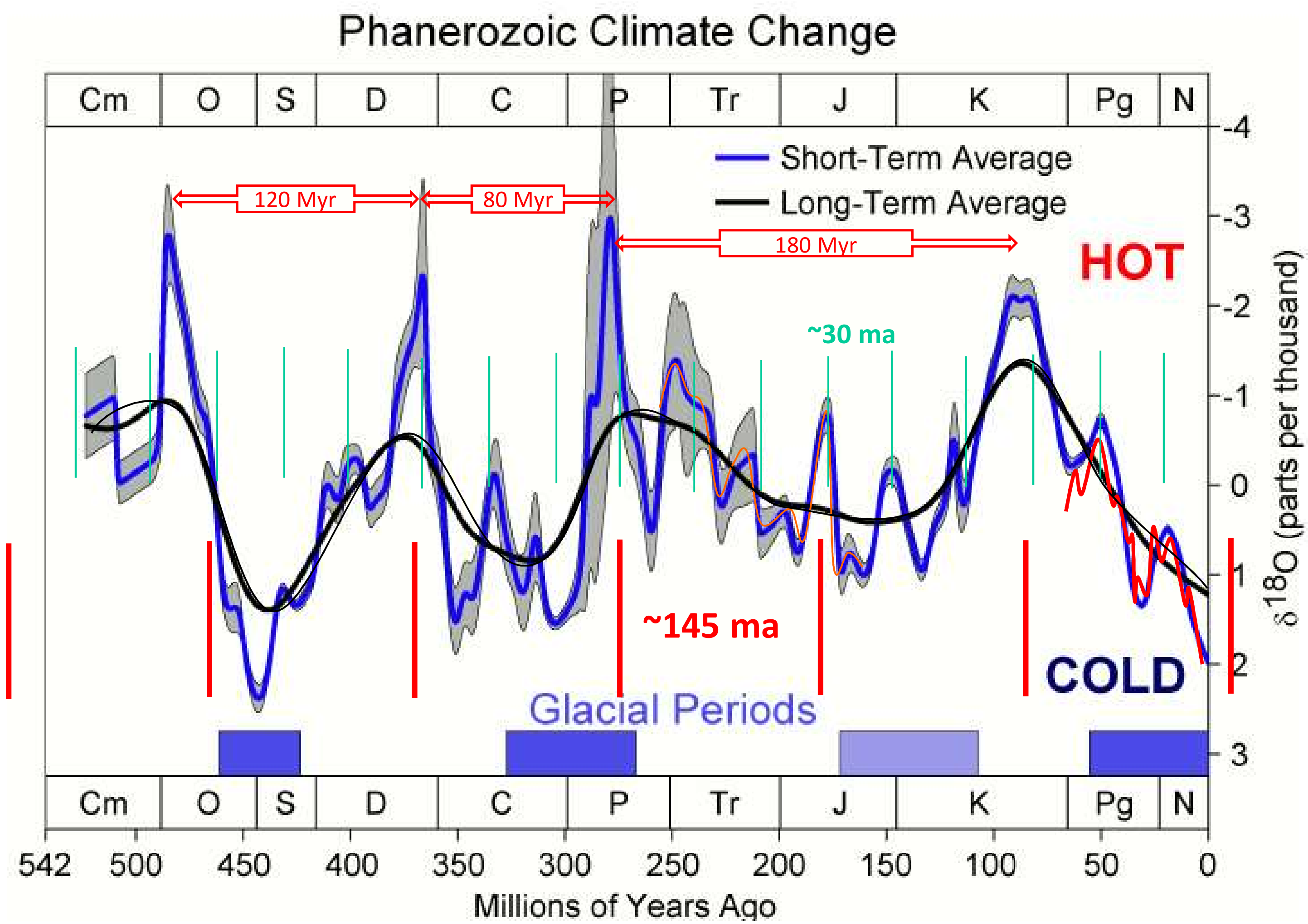
- Our Solar System bobs up and down periodically with respect to the Galactic invariable plane where the highest concentration of mass occurs.
- Earth crosses the axial plane about every 30 Myr.

Stylistic, periodic sine waves are plotted below for both 66.0 Myr (top-red) and 51.6 Myr (bottom-green) cycles. The diameters and ages of known bolide impacts on Earth's continents are plotted as blue dots (x- crater diameter, and y- age), with some larger, suspected impact events plotted using red dots. Geomagnetic polarities are also plotted for the past 130 my on the left side.



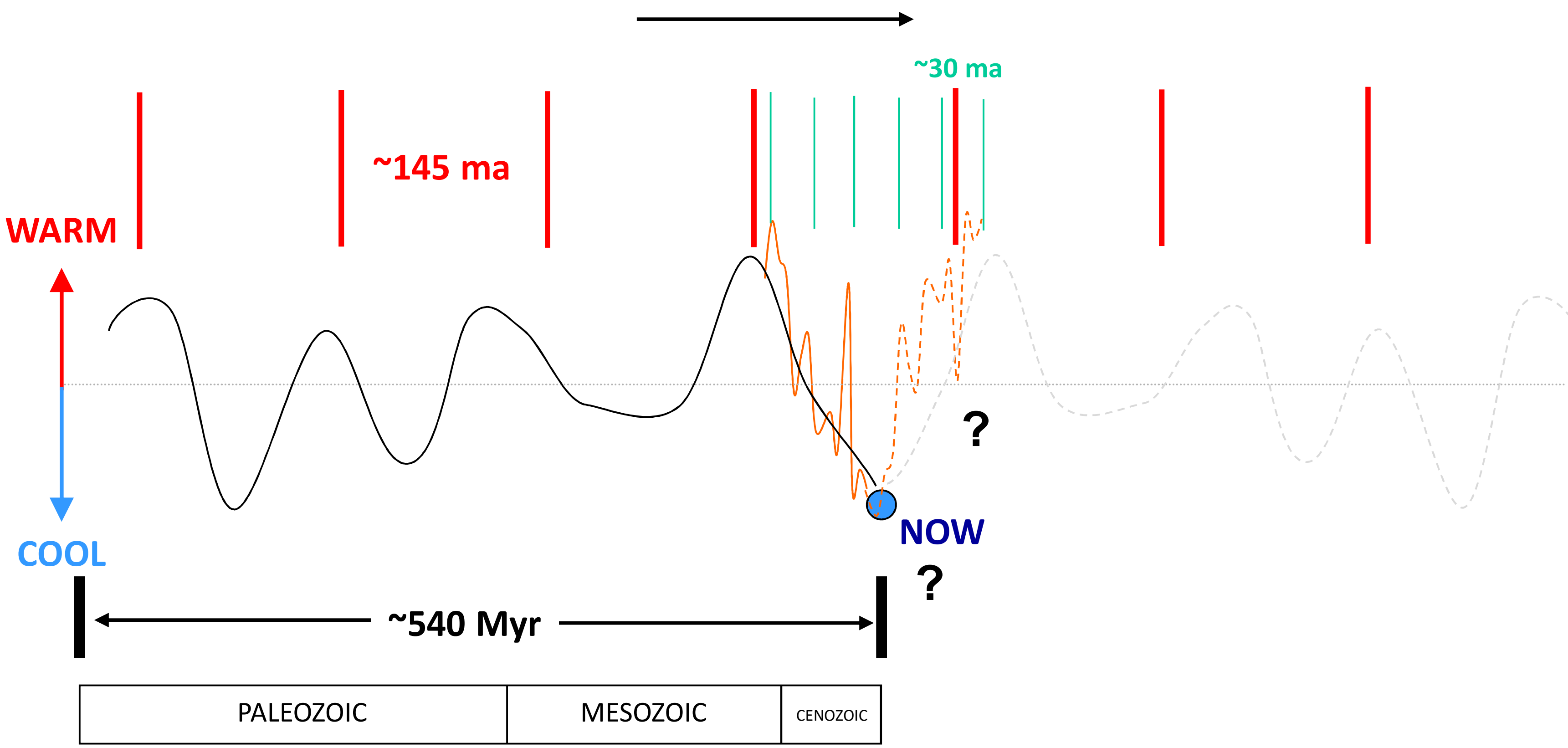
THE PAST 542 Myr OF CLIMATE CHANGE

commons.wikimedia.org/wiki/File:Phanerozoic_Climate_Change.png



Veizer, J., Ala, D., Azmy, K., Bruckschen, P., Buhl, D., Bruhn, F., Carden, G.A.F., Diener, A., Ebneth, S., Godderis, Y., Jasper, T., Korte, C., Pawellek, F., Podlaha, O. and Strauss, H. (1999) 87Sr/86Sr, d^{13}C and d^{18}O evolution of Phanerozoic seawater. *Chemical Geology* 161, 59-88. The ~30 and ~145 Ma cycles are from eyeballing the trends.

STYLISTIC DEPICTIONS OF LONG-TERM CLIMATE CHANGE ON EARTH THROUGH GEOLOGICAL TIME



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object.cato.org/sites/cato.org/files/serials/files/regulation/1992/4/v15n2-9.pdf

Global Warming

The Origin and Nature of the Alleged Scientific Consensus

Richard S. Lindzen

Most of the literate world today regards "global warming" as both real and dangerous. Indeed, the diplomatic activity concerning warming might lead one to believe that it is the major crisis confronting mankind. The June 1992 Earth Summit in Rio de Janeiro, Brazil, focused on international agreements to deal with that threat, and the heads of state from dozens of countries attended. I must state at the outset, that, as a scientist, I can find no substantive basis for the warming scenarios being popularly described. Moreover, according to many studies I have read by economists, agronomists, and hydrologists, there would be little difficulty adapting to such warming if it were to occur. Such was also the conclusion of the recent National Research Council's report on adapting to global change. Many aspects of the catastrophic scenario have already been largely discounted by the scientific community. For example, fears of massive sea-level increases accompanied many of the early discussions of global warming, but those estimates have been steadily reduced by orders of magnitude, and now it is widely agreed that even the potential contribution of warming to sea-level rise would be swamped by other more important factors.

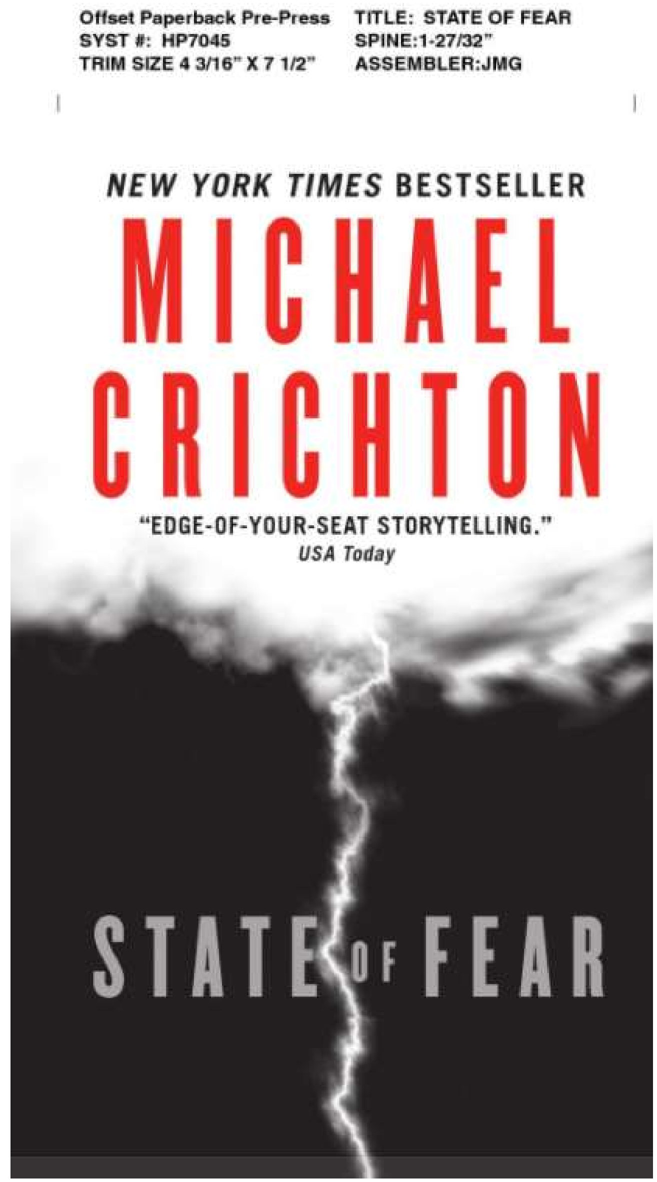
Richard S. Lindzen is the Alfred P. Sloan Professor of Meteorology at the Massachusetts Institute of Technology.

To show why I assert that there is no substantive basis for predictions of sizeable global warming due to observed increases in minor greenhouse gases such as carbon dioxide, methane, and chlorofluorocarbons, I shall briefly review the science associated with those predictions.

Summary of Scientific Issues

Before even considering "greenhouse theory," it may be helpful to begin with the issue that is almost always taken as a given—that carbon dioxide will inevitably increase to values double and even quadruple present values. Evidence from the analysis of ice cores and after 1958 from direct atmospheric sampling shows that the amount of carbon dioxide in the air has been increasing since 1800. Before 1800 the density was about 275 parts per million by volume. Today it is about 355 parts per million by volume. The increase is generally believed to be due to the combination of increased burning of fossil fuels and before 1905 to deforestation. The total source is estimated to have been increasing exponentially at least until 1973. From 1973 until 1990 the rate of increase has been much slower, however. About half the production of carbon dioxide has appeared in the atmosphere.

Predicting what will happen to carbon dioxide over the next century is a rather uncertain matter. By assuming a shift toward the increased use of coal, rapid advances in the third world's standard

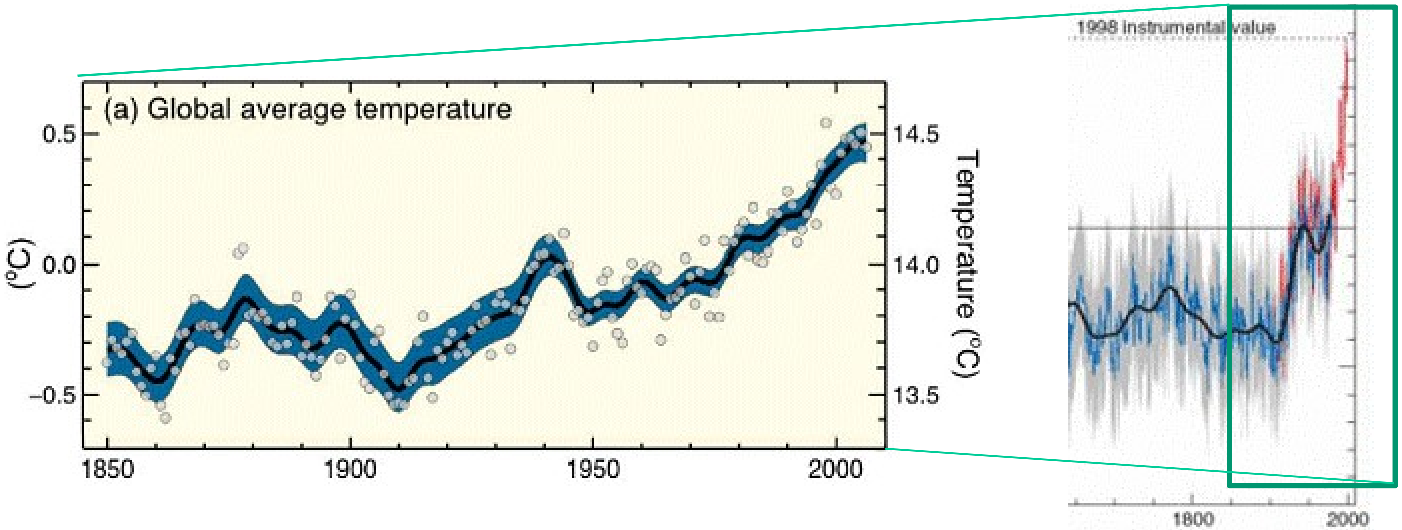


http://object.cato.org/sites/cato.org/files/serials/files/regulation/1992/4/v15n2-9.pdf

GLOBAL CLIMATE GRAPHS

IPCC and the Hockey Stick

The Intergovernmental Panel on Climate Change (IPCC) is a United Nations based group focused on evaluating global climate change. The following figure is from their AR4 report (2007). It shows their calculated global average temperature for 1850 to 2006.



The figure to the right is known as the “hockey-stick” graph (due to its shape) which has been debunked by the National Academy of Sciences, because of the manner in which data are skewed by selective reprentation and innacurate models.

http://appinsys.com/globalwarming/GW_Part1_PreHistoricalRecord.htm

THE PAST 3 Myr of CLIMATE CHANGE AND HUMAN ANCESTORY

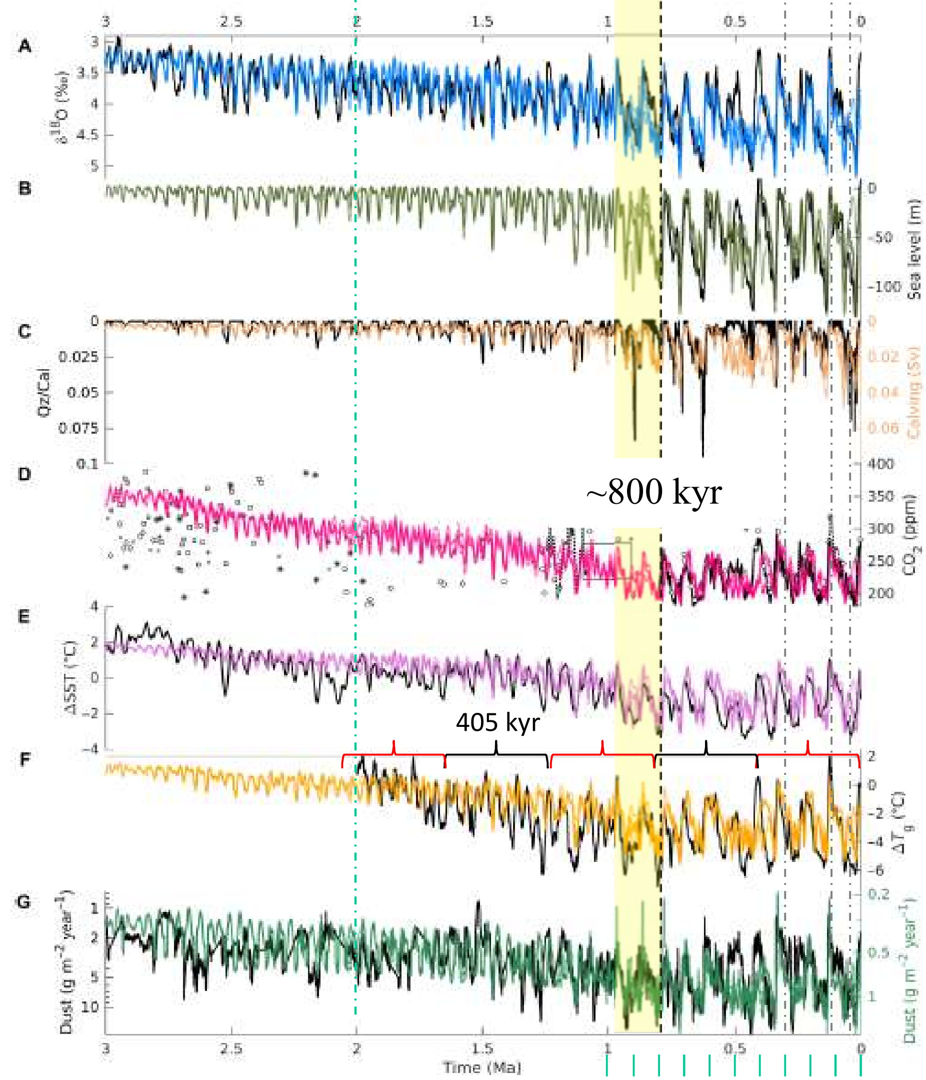
Extinct

Homo Erectus
~ 2 Myr to ~108 kyr

Neanderthal ~ 800 kyr (?) to ~40 Ka

Homo Sapiens (Humans) ~ 300 kyr to ?

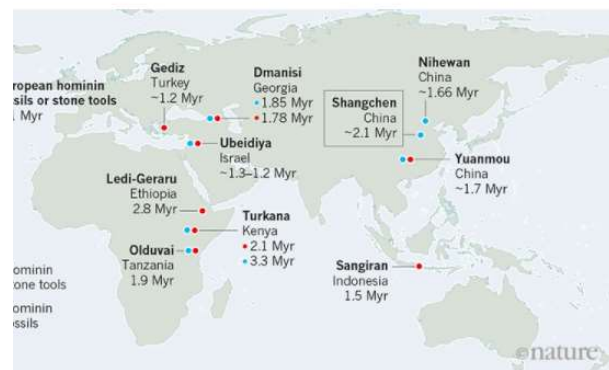
SCIENCE ADVANCES | RESEARCH ARTICLE



com/articles/d41586-018-05293-9

Just a single finger bone can suffice to document a hominin presence[2]. However, hominins began to fashion tools from stones, at least 3.3 million years the purposely chipped cobbles and flakes that they produced became er calling card that can attest to a hominin presence.

now, the oldest known hominin site outside Africa[4] was in Dmanisi, gia. Excavations at that site uncovered spectacular finds of the roughly illion- to 1.78-million-year-old remains of multiple hominins and stone Numerous later sites of hominin activity, at locations stretching from rn Europe[5] to eastern Asia[6], have also been investigated thoroughly. Zhu olleagues' report of signs of a hominin presence at Shangchen in China's Plateau (Fig. 1) is based on evidence from only stone tools, and the rchers found that these tools were distributed in layers of sediment that back to about 2.1 million years ago.



1 | Ancient sites of hominin presence. Zhu *et al.*[1] report their discovery of approximately 2.1-year-old stone tools at Shangchen in China's Loess Plateau, which provides the earliest known e for the presence of hominins (the evolutionary group that includes humans, extinct species of us *Homo* and related bipedal species) outside Africa. The dates (Myr, million years ago) and s of some of the important earliest known sites of hominin fossils and stone tools are shown.

DOMINANT PERIODS OF EARTH'S ORBITAL EVOLUTION

THE ASTRONOMICAL JOURNAL, 159:10 (16pp), 2020 January
https://doi.org/10.3847/1538-3881/ab5365

Quantifying the Influence of Jupiter on the Earth's Orbital Cycles

Jonathan Horner[1], Pam Vervoort[2], Stephen R. Kane[2], Alma Y. Ceja[2], David Waltham[3], James Gilmore[4], and Sandra Kirtland Turner[2]

[1] Centre for Astrophysics, University of Southern Queensland, Toowoomba, QLD 4350, Australia; jonathan.horner@usq.edu.au
[2] Department of Earth and Planetary Sciences, University of California, Riverside, CA 92521, USA
[3] Department of Earth Sciences, Royal Holloway University of London, Egham, UK
[4] Australian Centre for Astrobiology, UNSW Australia, Sydney, New South Wales 2052, Australia
Received 2019 March 1; revised 2019 October 29; accepted 2019 October 30; published 2019 December 12

Abstract

A wealth of Earth-sized exoplanets will be discovered in the coming years, providing a large pool of candidates from which the targets for the search for life beyond the solar system will be chosen. The target selection process will require the leveraging of all available information in order to maximize the robustness of the target list and make the most productive use of follow-up resources. Here, we present the results of a suite of n-body simulations that demonstrate the degree to which the orbital architecture of the solar system impacts the variability of Earth's orbital elements. By varying the orbit of Jupiter and keeping the initial orbits of the other planets constant, we demonstrate how subtle changes in solar system architecture could alter the Earth's orbital evolution—a key factor in the Milankovitch cycles that alter the amount and distribution of solar insolation, thereby driving periodic climate change on our planet. The amplitudes and frequencies of Earth's modern orbital cycles fall in the middle of the range seen in our runs for all parameters considered—neither unusually fast nor slow, neither large nor small. This finding runs counter to the "Rare Earth" hypothesis, which suggests that conditions on Earth are so unusual that life elsewhere is essentially impossible. Our results highlight how dynamical simulations of newly discovered exoplanetary systems could be used as an additional means to assess the potential targets of biosignature searches, and thereby help focus the search for life to the most promising targets.

Unified Astronomy Thesaurus concepts: Astrobiology (74); N-body simulations (1083); Gravitational interaction (669); Exoplanet systems (484); Dynamical evolution (421)

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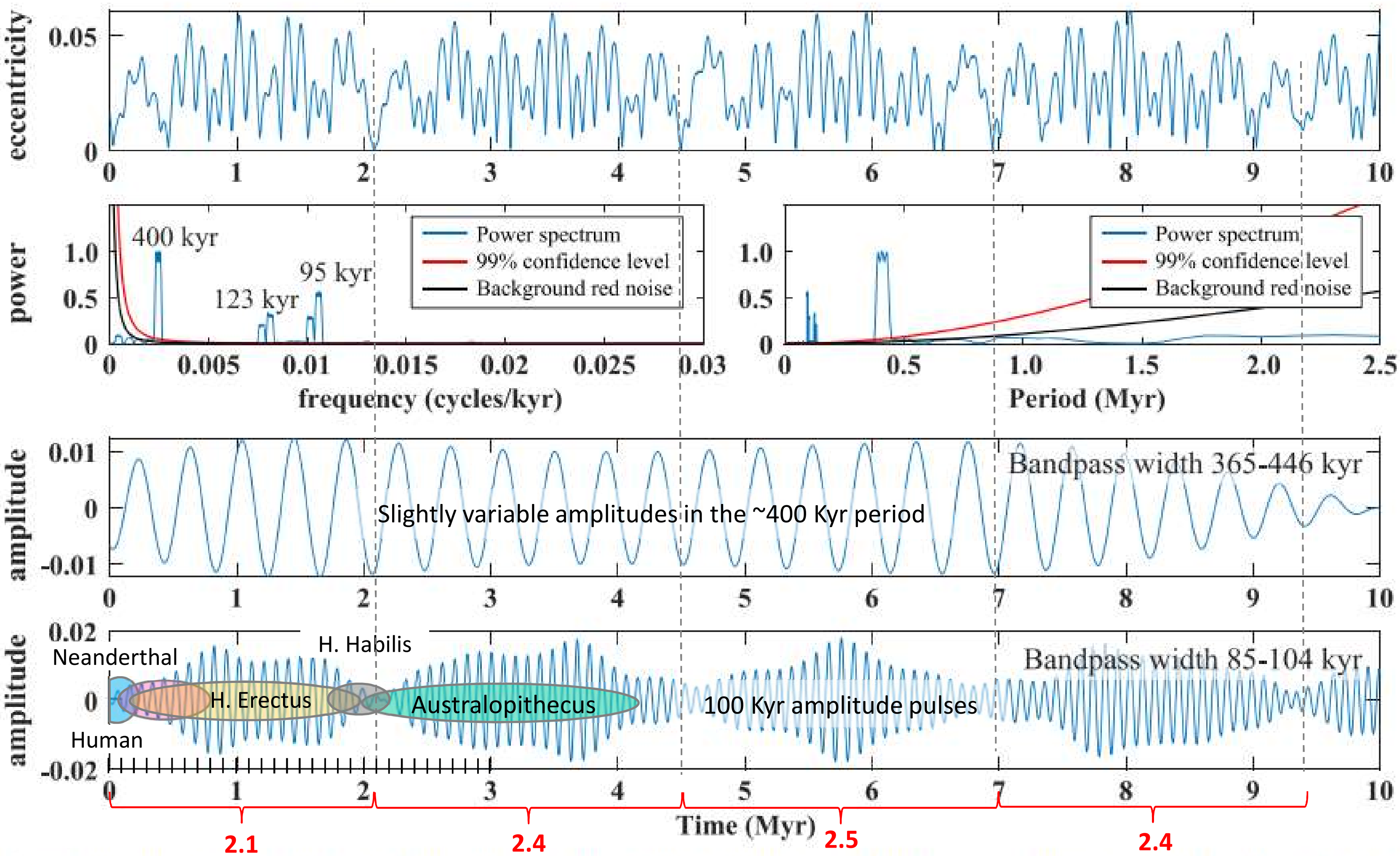

Figure 3. Illustration of the means by which the amplitude and frequency of the dominant periods of Earth's orbital evolution are determined in this work. The top panel shows the time variation of Earth's orbital eccentricity for the individual member of our 41,652 dynamically stable simulations that most closely resembles the current configuration of the solar system, with Jupiter located at 5.203 au and with an eccentricity of 0.049. The two panels in the second row show the normalized multitaper power spectrum of the time series (blue), in the frequency domain (left) and the period domain (right). The black line indicates the background robust autoregressive red noise model, and the red line shows the 99% confidence level above that red noise. The three most powerful and significant cycles detected have periods of 400, 123, and 95 kyr, consistent with the eccentricity oscillations that we experience on Earth. The plots on the third and fourth rows show the bandpass filtered signal for the 400 and 95 kyr cycle, calculated with a bandpass width that is 10% of the period.

SUMMARY 1

1. Earth's past climate cycles are recoded in geological episodes of glaciation, deposition of sediment, and fossil records.

2. Radiative forcing of Earth's climate produces reoccurring, slightly varying, cyclic periods arising from orbital fluctuations primarily involving the Sun, Venus, and Jupiter; it's a wobbly system.

3. Climate change happens on the order of thousands to millions of years as shown by Milanković theory with ~20 kyr, ~100 kyr, ~400 kyr, ~1 Myr, and ~2 Myr periodicities.

4. Longer-period climate cycles of ~ 4 Myr, 6 Myr, 8 Myr, 30 Myr, and perhaps ~145 Myr may also occur based on the geological record and other considerations.

SUMMARY 2

5. The last 400 kyr period has seen significant surface-temperature temperature fluxes reaching ~14^o C that can occur suddenly over ~10 kyr time (at least four times).

6. The length of time between warmer climate periods has gradually been increasing over the past 400 kyr.

7. Earth orbit is now nearly circular, and we are in an interglacial, warm period, near the top range of global temperatures reached in the past 2 Myr during evolution of the Homo genus.

8. Our current, warm temperatures were equaled about 220 kyr ago, and only surpassed briefly about 318 kyr and 405 kyr.

SUMMARY 3

9. Earth is heading toward a period of gradual cooling over the next ~120 kyr, and we may not have yet reached peak temperatures, but we are close to the downturn.

10. Humans have evolved within the past 400 kyr during a time of extreme, and sometimes rapid climate change.

11. Time will tell how human activity perturbs these astronomically forced cycles.