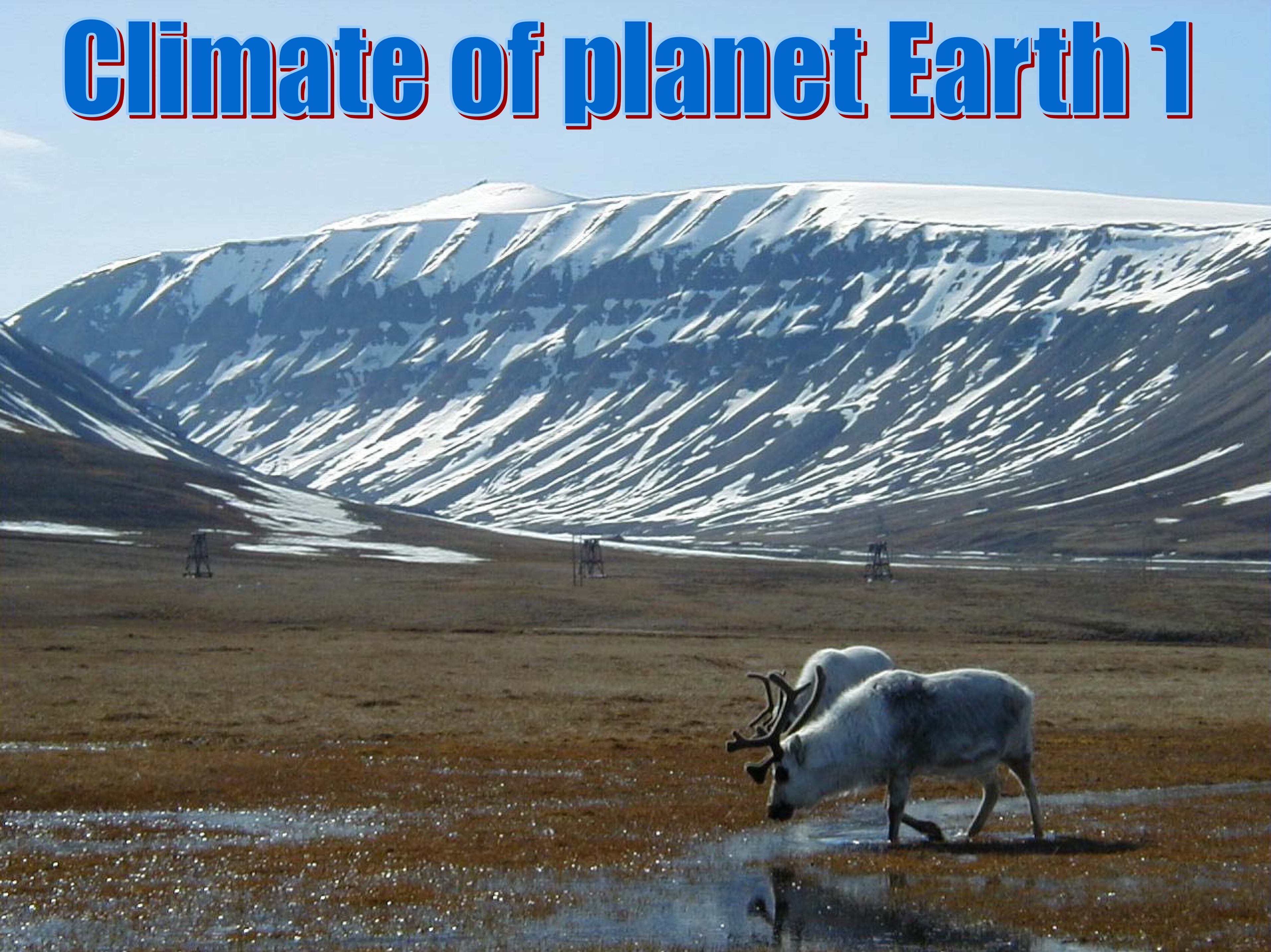
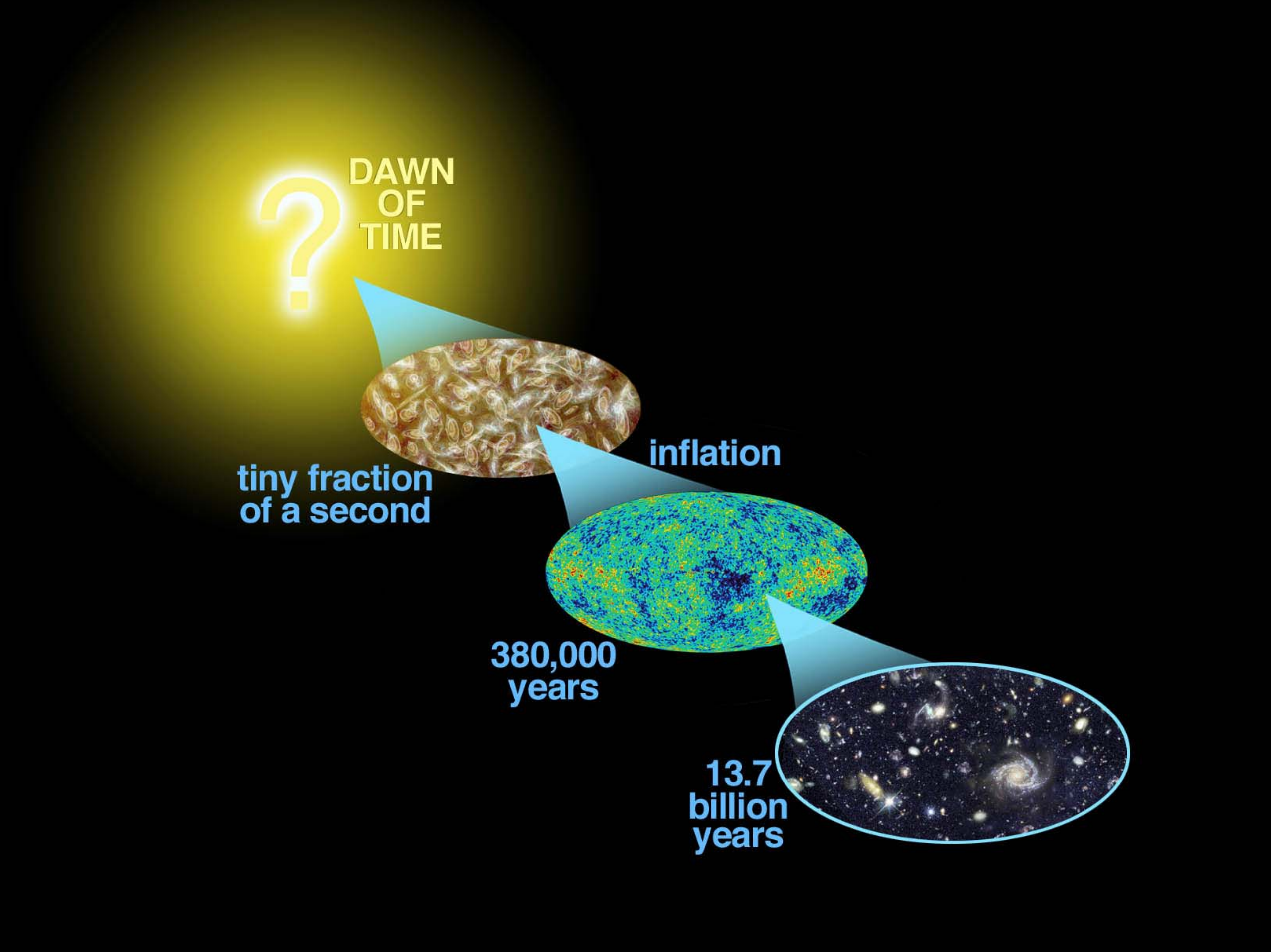
Climate of planet Earth 1

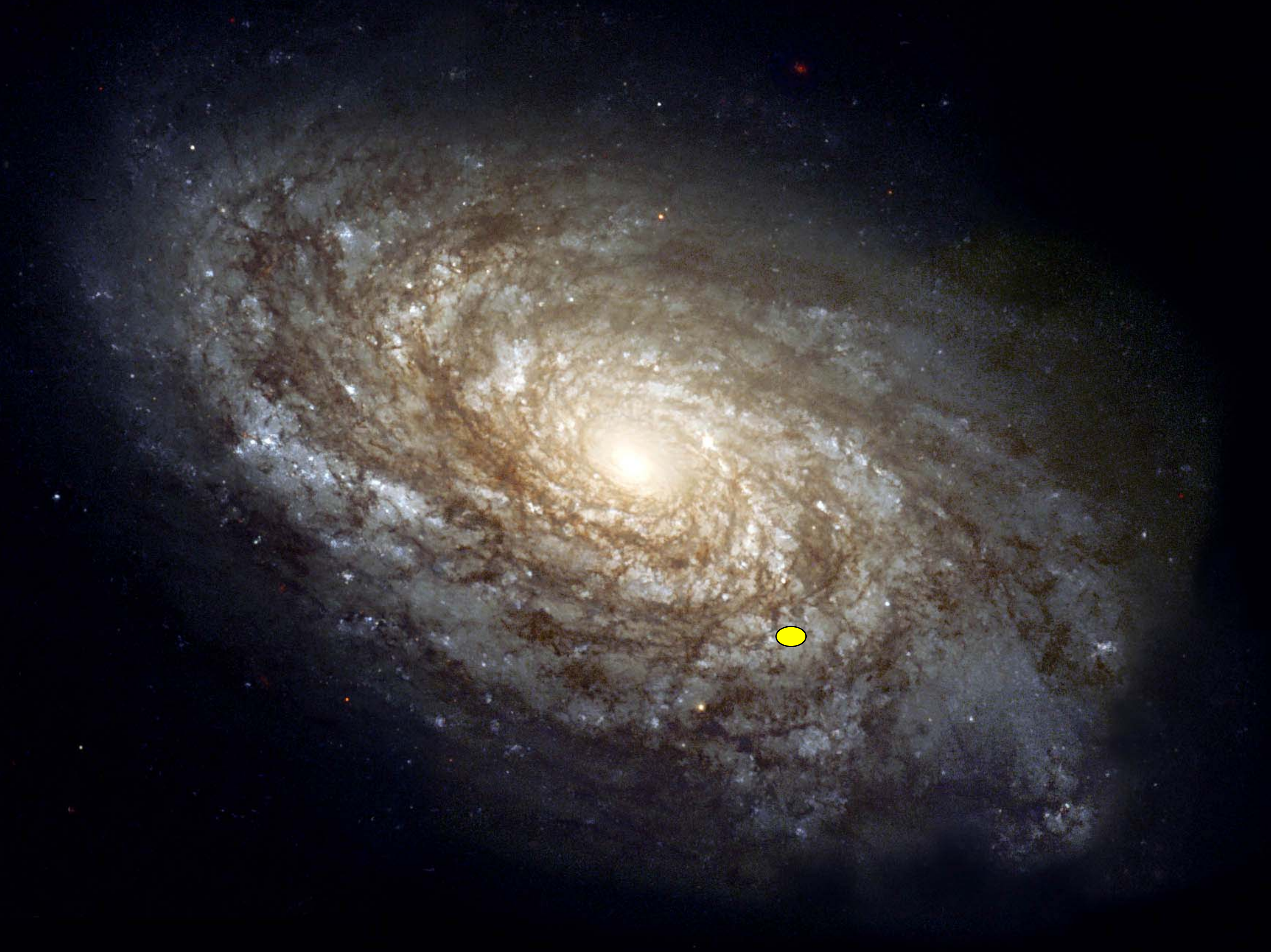


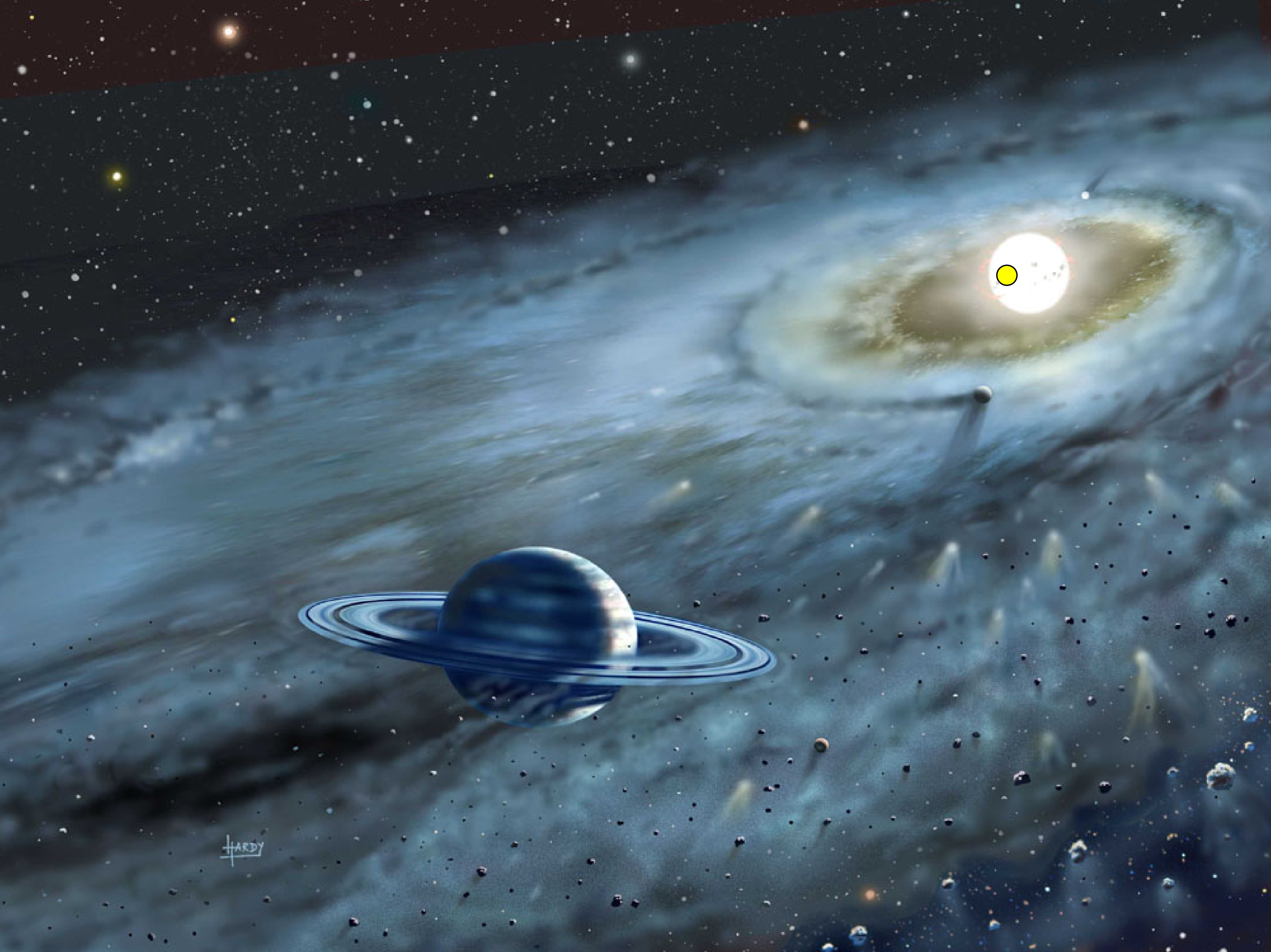
Climate of planet Earth 1

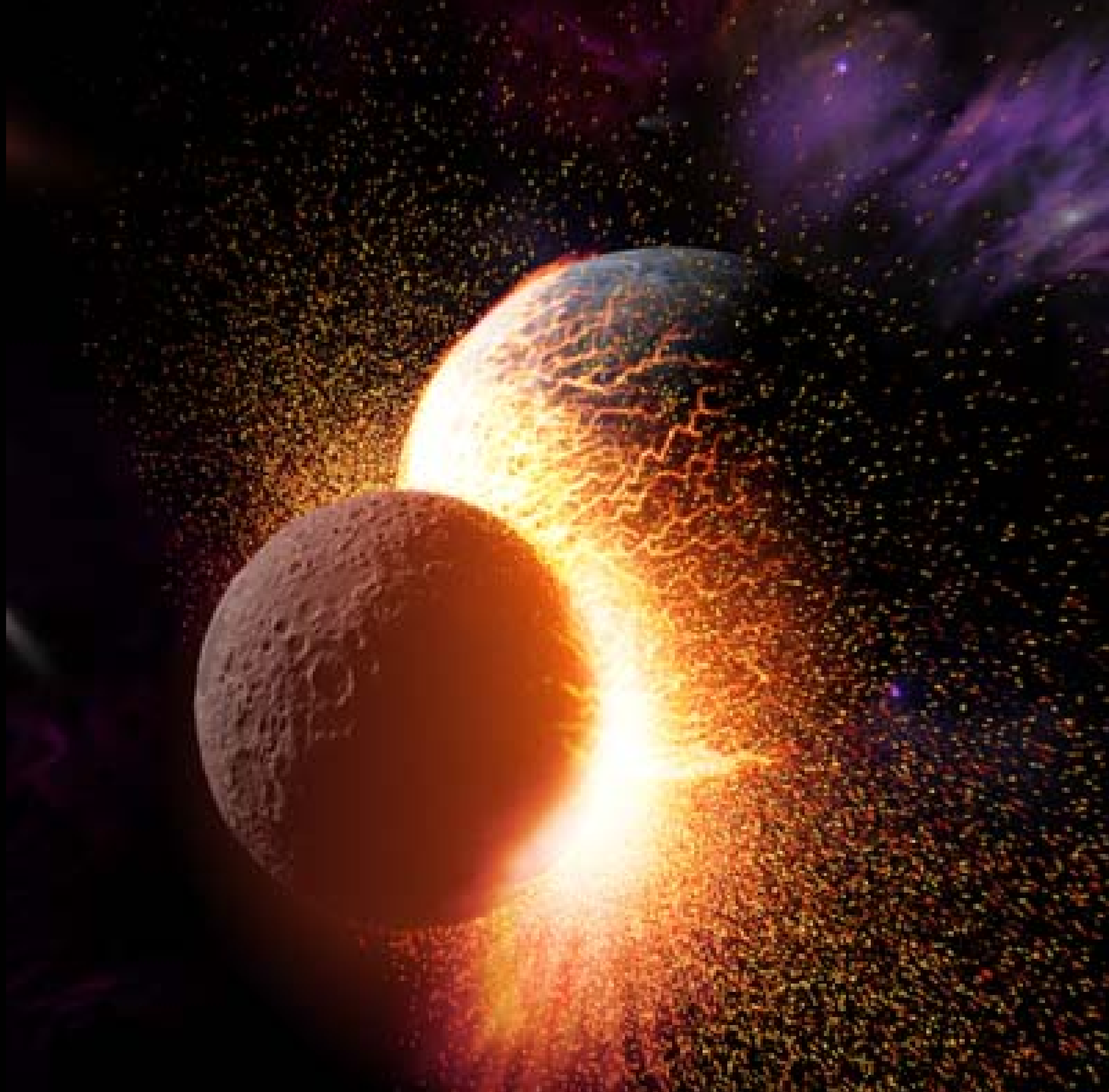
- **Basic principles**
- **Main climate drivers**
- **Climate in the geological past**

Facts about planet Earth


DAWN
OF
TIME
tiny fraction
of a second
inflation
380,000
years
13.7
billion
years




HARDY

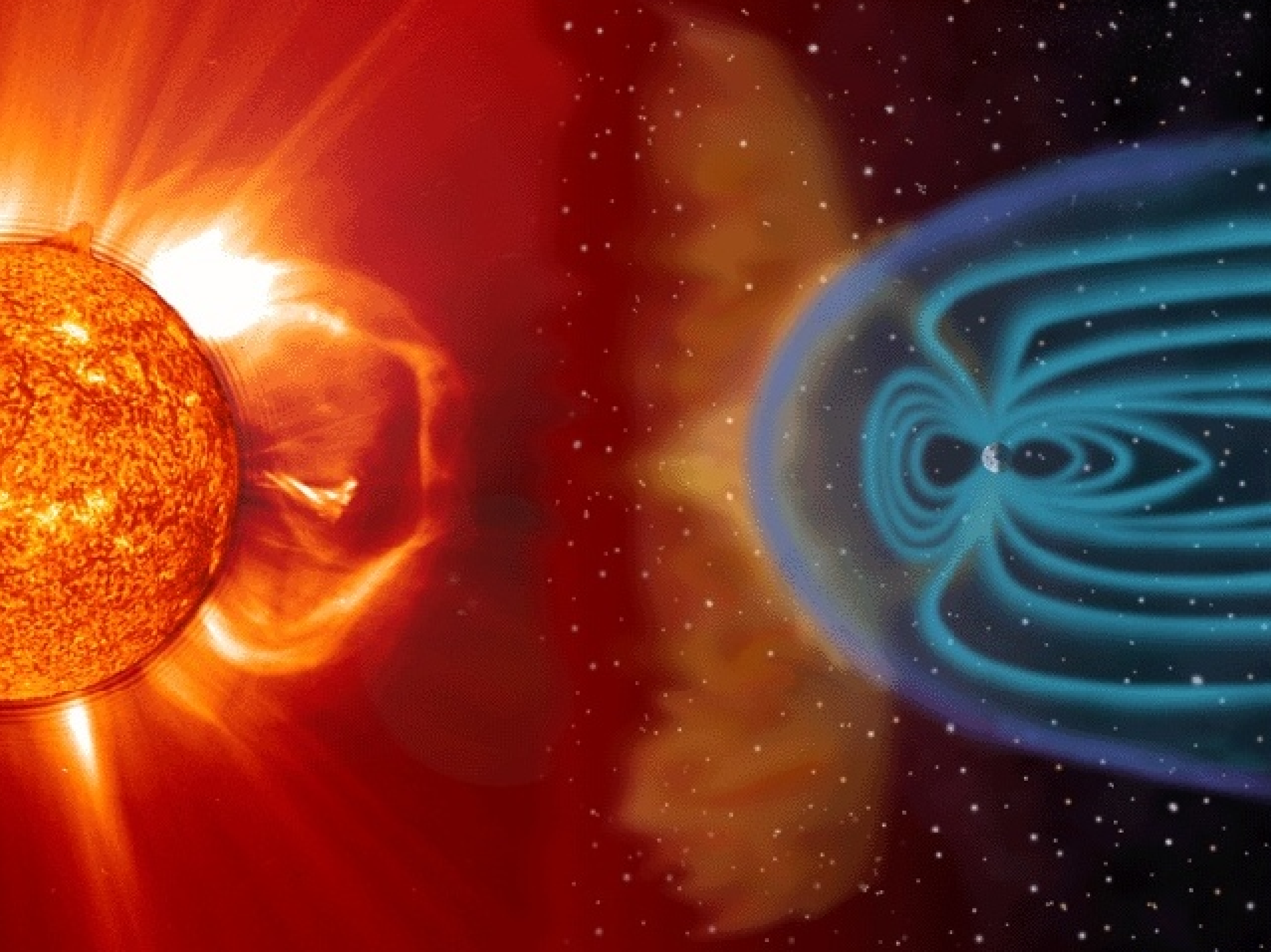


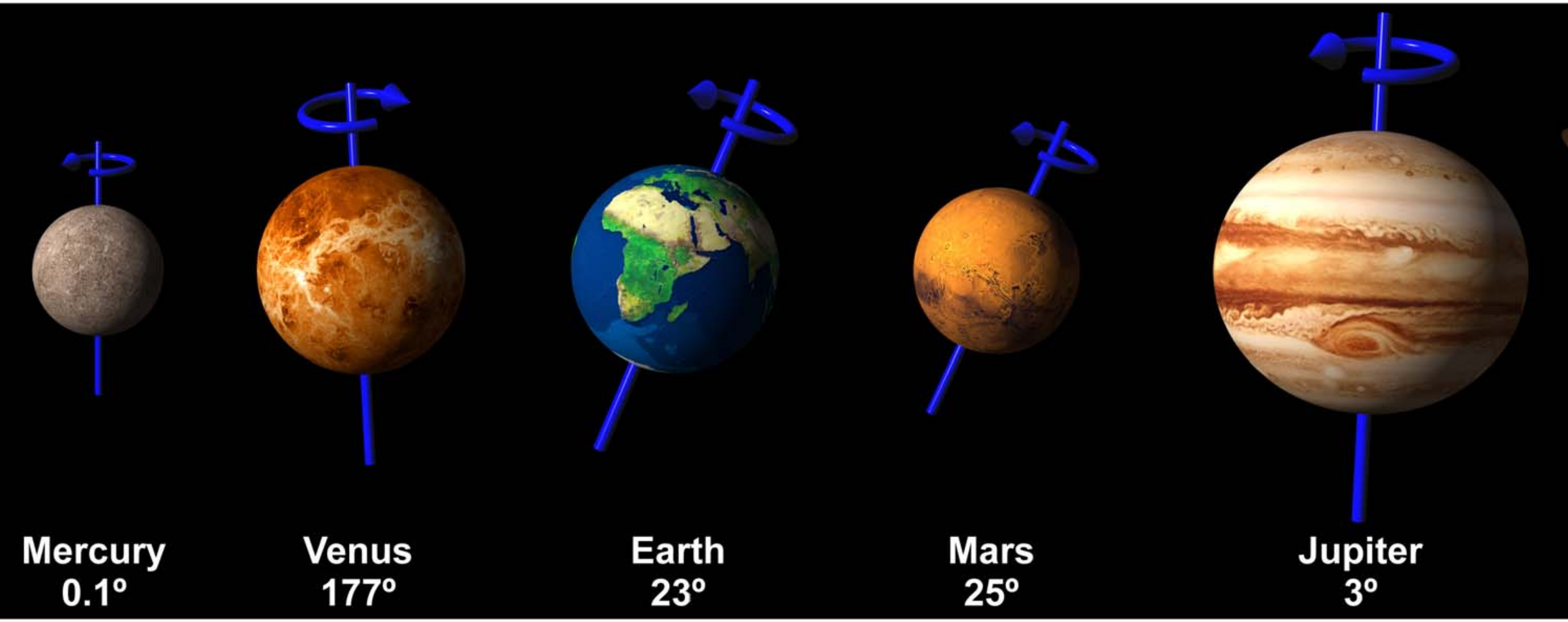
Planet Earth: an asymmetrical water planet

29% covered by land; 71% covered by oceans

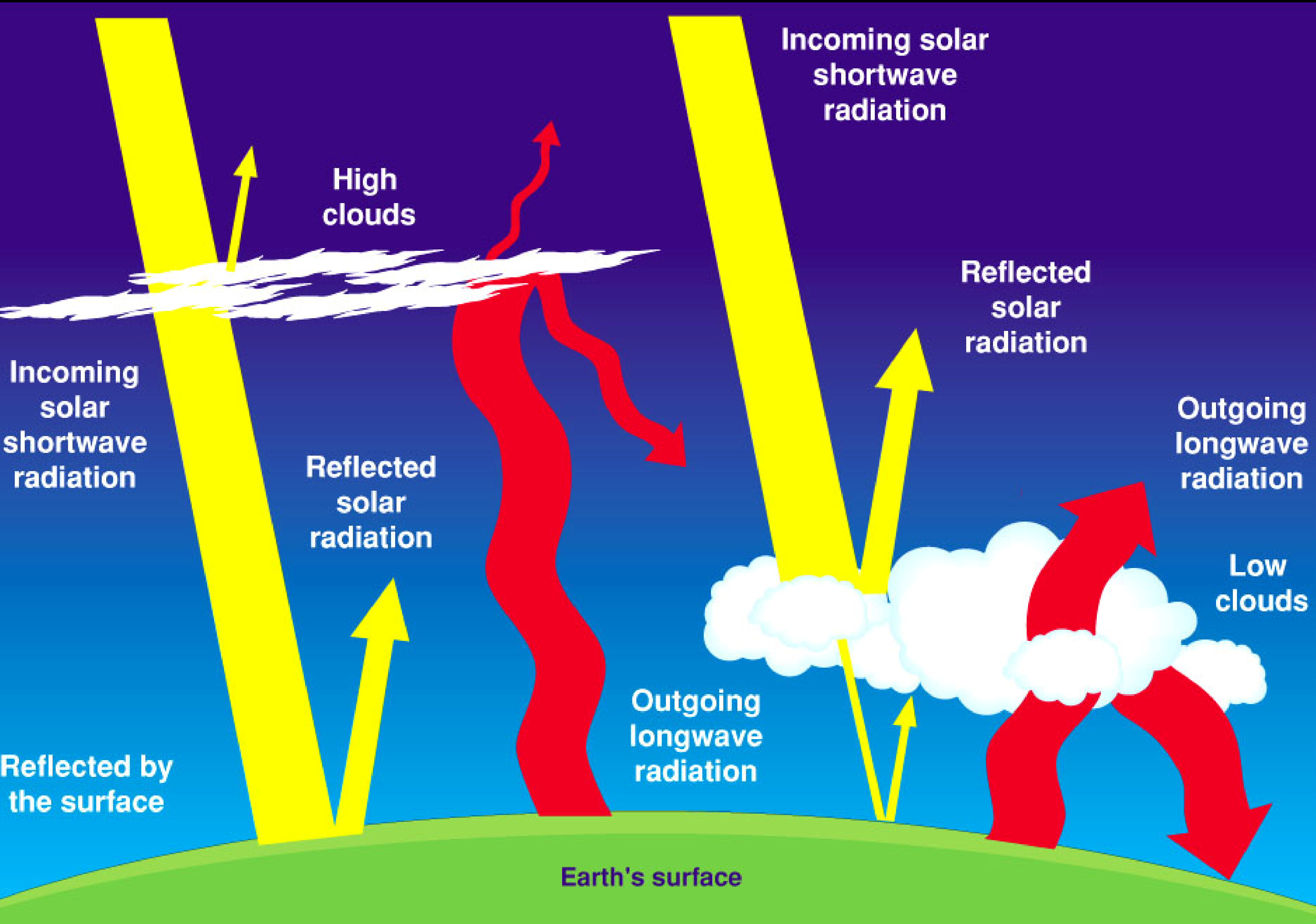
Earth Statistics

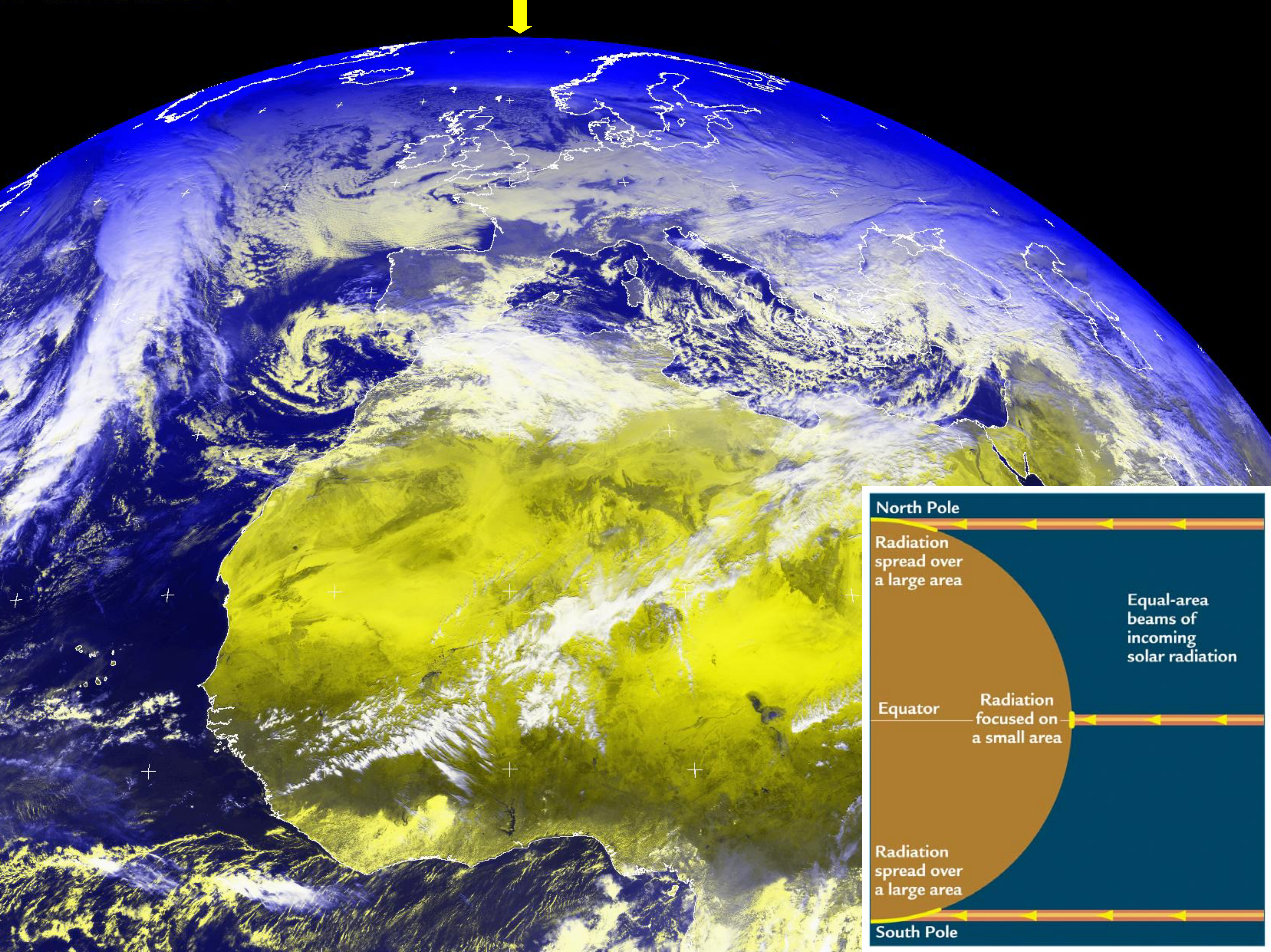
Mass (kg)	5.976e+24
Mass (Earth = 1)	1.0000e+00
Equatorial radius (km)	6,378.14
Equatorial radius (Earth = 1)	1.0000e+00
Mean density (gm/cm^3)	5.515
Mean distance from the Sun (km)	149,600,000
Mean distance from the Sun (Earth = 1)	1.0000
Rotational period (days)	0.99727
Rotational period (hours)	23.9345
Orbital period (days)	365.256
Mean orbital velocity (km/sec)	29.79
Orbital eccentricity	0.0167
Tilt of axis (degrees)	23.45
Orbital inclination (degrees)	0.000
Equatorial escape velocity (km/sec)	11.18
Equatorial surface gravity (m/sec^2)	9.78
Visual geometric albedo	0.37
Mean surface temperature	15°C
Atmospheric pressure (bars)	1.013
Atmospheric composition	
Nitrogen	77%
Oxygen	21%
Other	2%

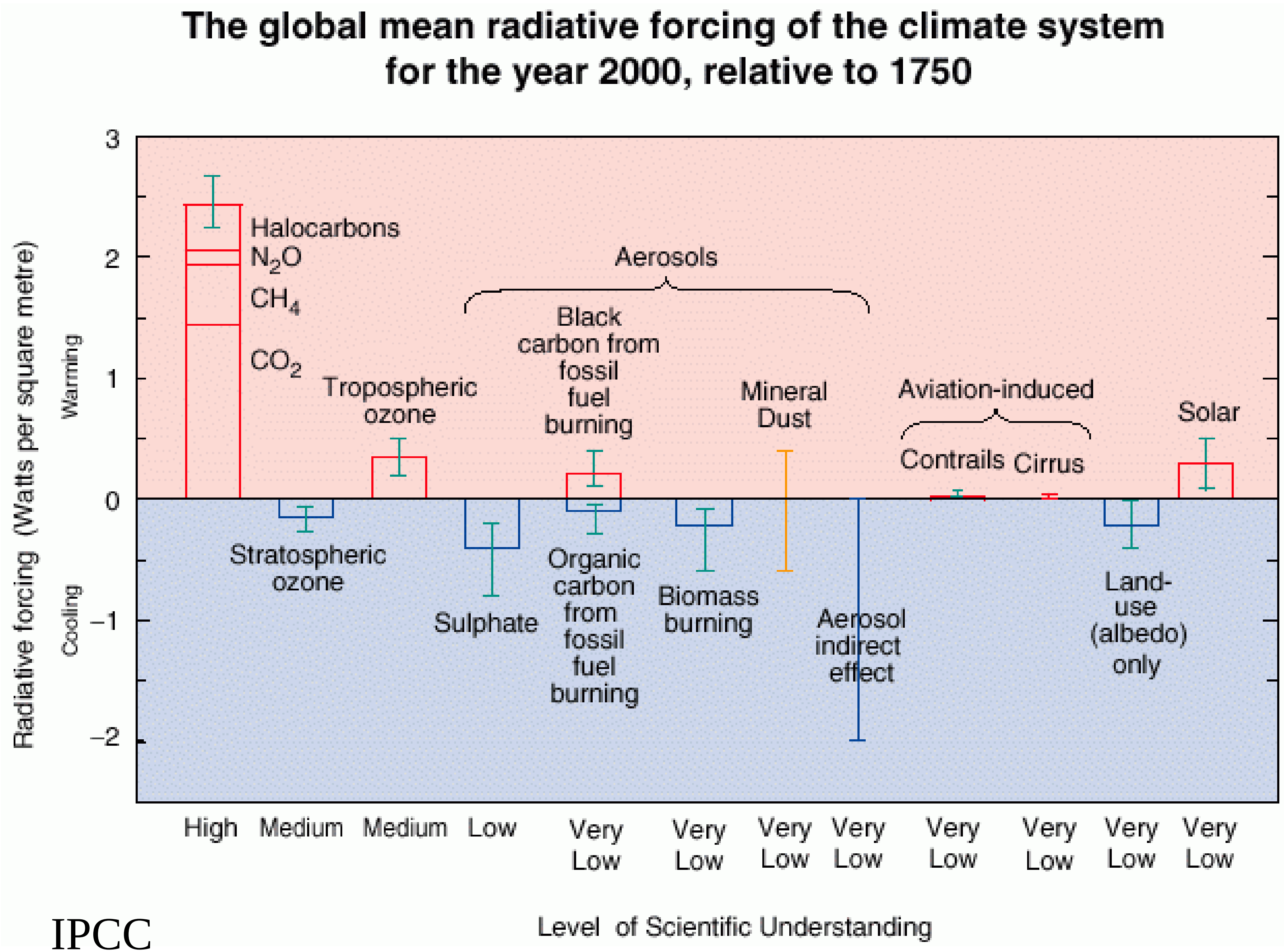




Obliquity of the Nine Planets


Incoming solar shortwave radiation
High clouds
Reflected solar radiation
Incoming solar shortwave radiation
Reflected solar radiation
Outgoing longwave radiation
Low clouds
Outgoing longwave radiation
Reflected by the surface
Earth's surface

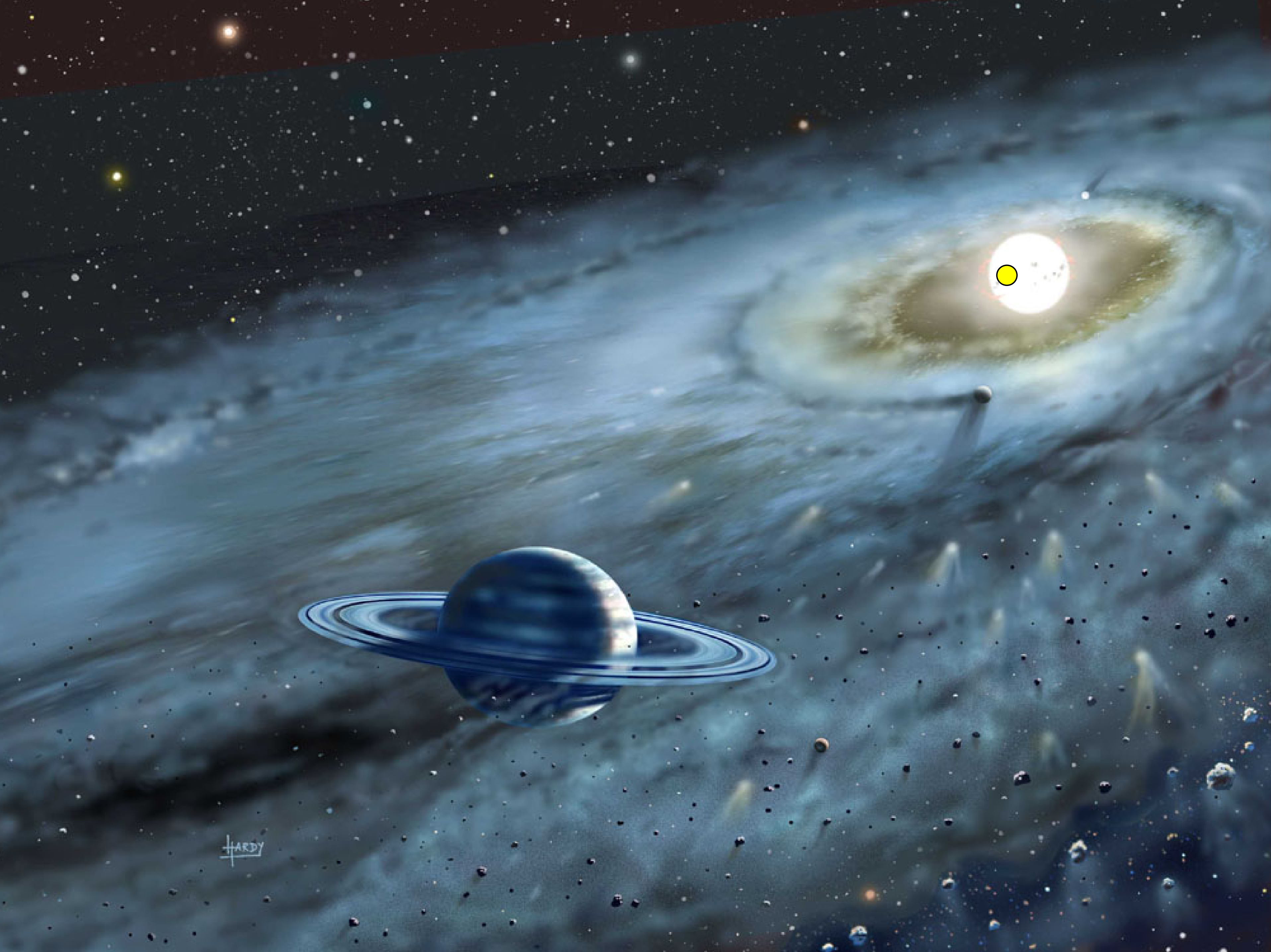

North Pole
Radiation spread over a large area
Equal-area beams of incoming solar radiation
Equator
Radiation focused on a small area
Radiation spread over a large area
South Pole

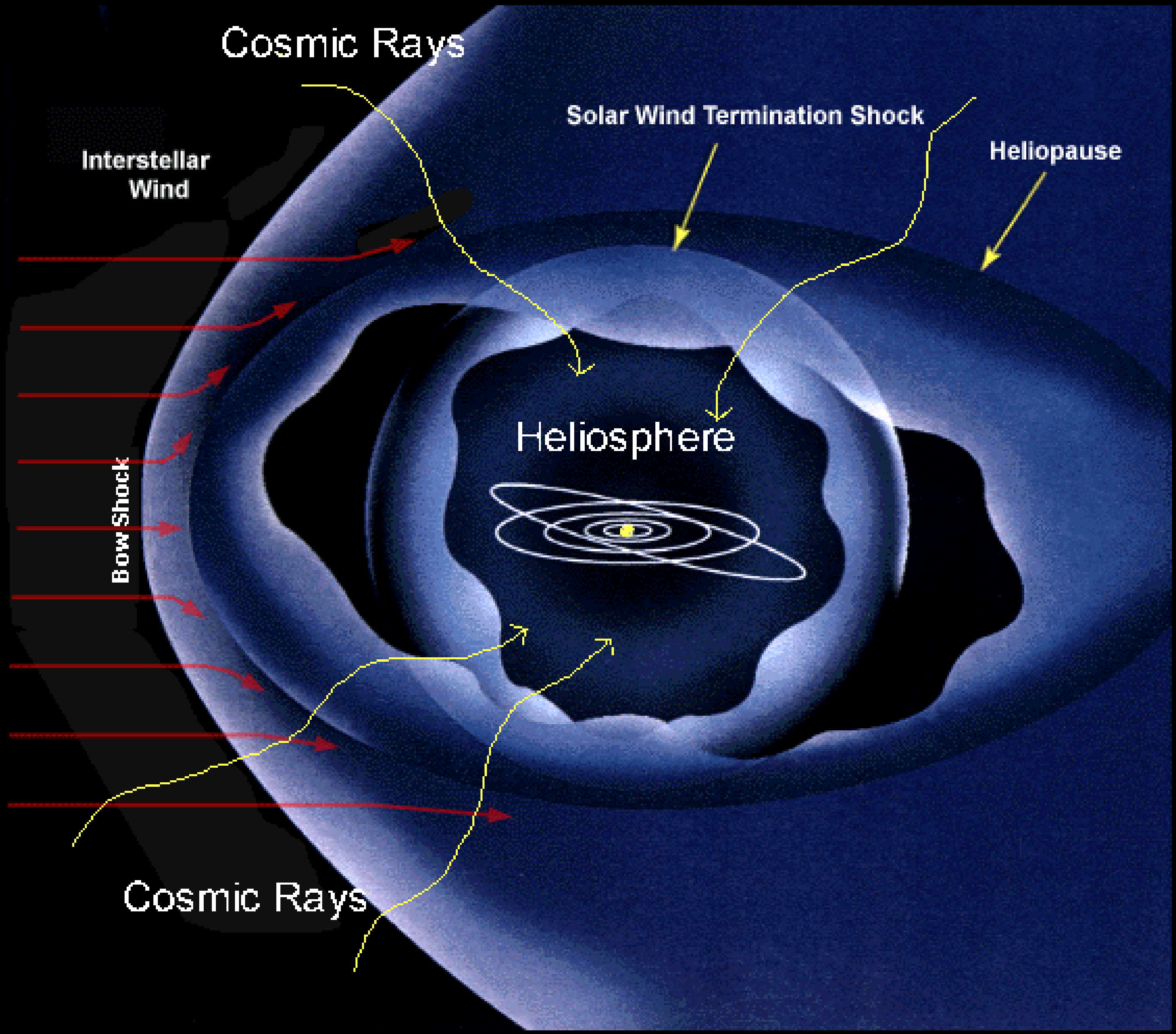


The global mean radiative forcing of the climate system
for the year 2000, relative to 1750
Radiative forcing (Watts per square metre)
Warming
Cooling
3
2
1
0
−1
−2
Halocarbons
N_2O
CH_4
CO_2
Tropospheric ozone
Stratospheric ozone
Aerosols
Black carbon from fossil fuel burning
Organic carbon from fossil fuel burning
Sulphate
Biomass burning
Mineral Dust
Aerosol indirect effect
Aviation-induced
Contrails
Cirrus
Land-use (albedo) only
Solar
High
Medium
Medium
Low
Very Low
Very Low
Very Low
Very Low
Very Low
Very Low
Very Low
Very Low
Level of Scientific Understanding

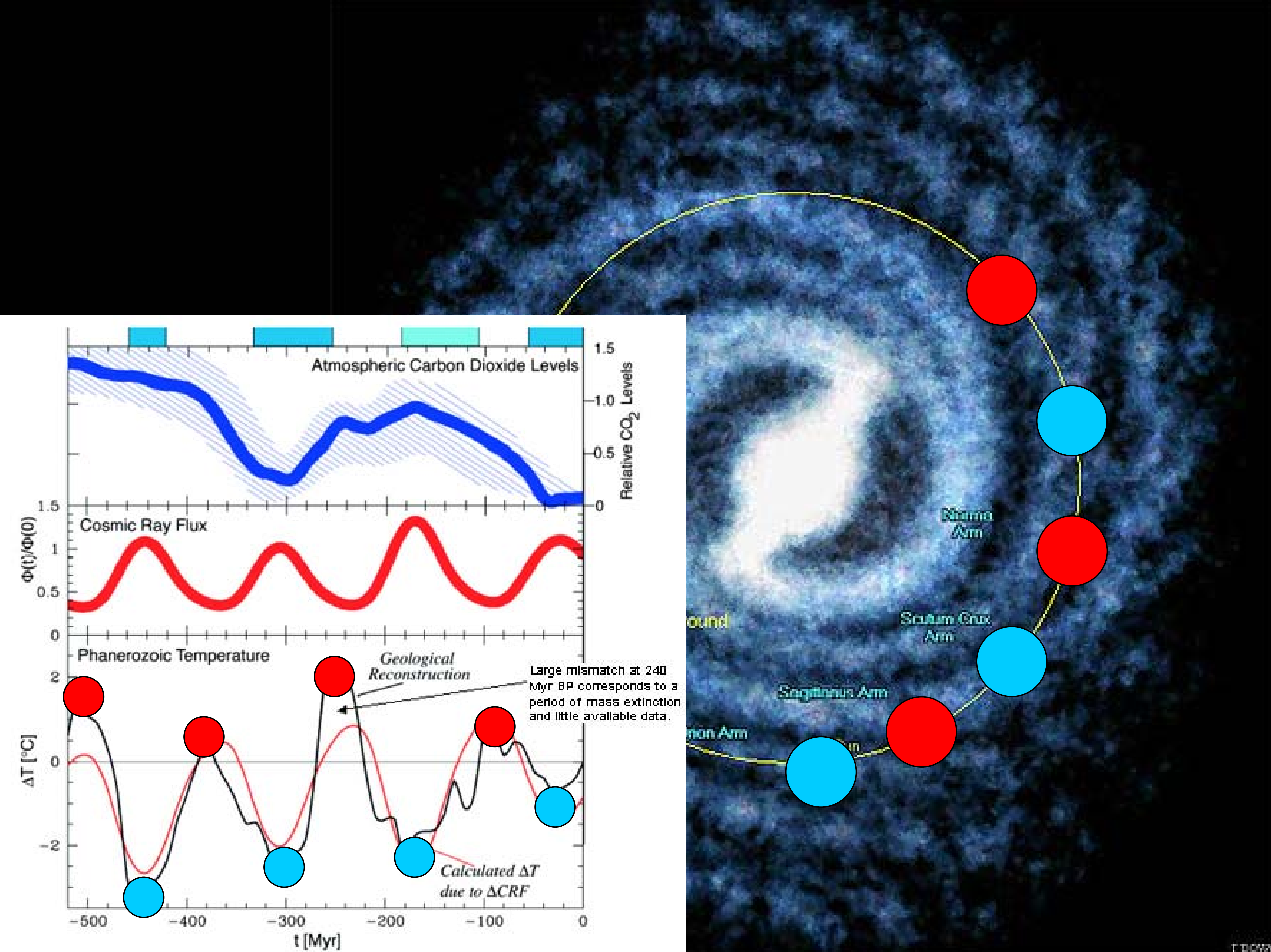
IPCC

This is it, Fredman. Unmatched evidence of a surprisingly rapid climatic change at the onset of the last ice age !


HARDY

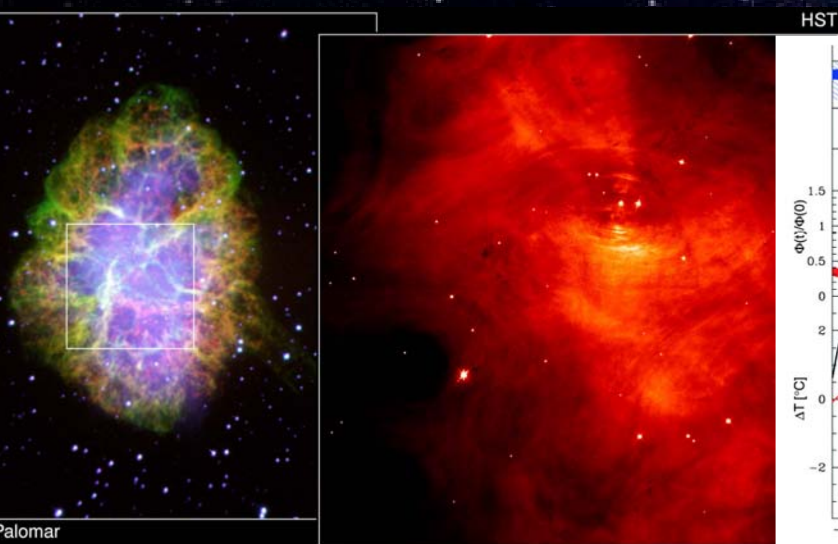


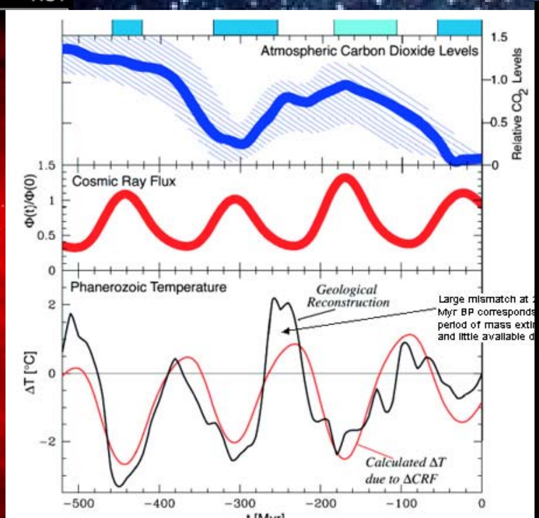
Cosmic Rays
Solar Wind Termination Shock
Heliopause
Interstellar
Wind
Heliosphere
Bow Shock
Cosmic Rays

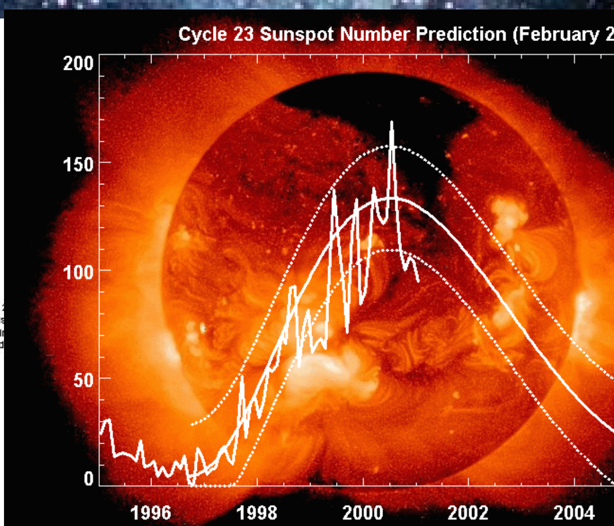

Atmospheric Carbon Dioxide Levels
Relative CO_2 Levels
Cosmic Ray Flux
$\Phi(t)/\Phi(0)$
Phanerozoic Temperature
Geological Reconstruction
Large mismatch at 240 Myr BP corresponds to a period of mass extinction and little available data.
Calculated ΔT due to ΔCRF
ΔT [°C]
t [Myr]
Norma Arm
Scutum Crux Arm
Sagittarius Arm

Supernova

Crab Nebula obsserved 1045 AD







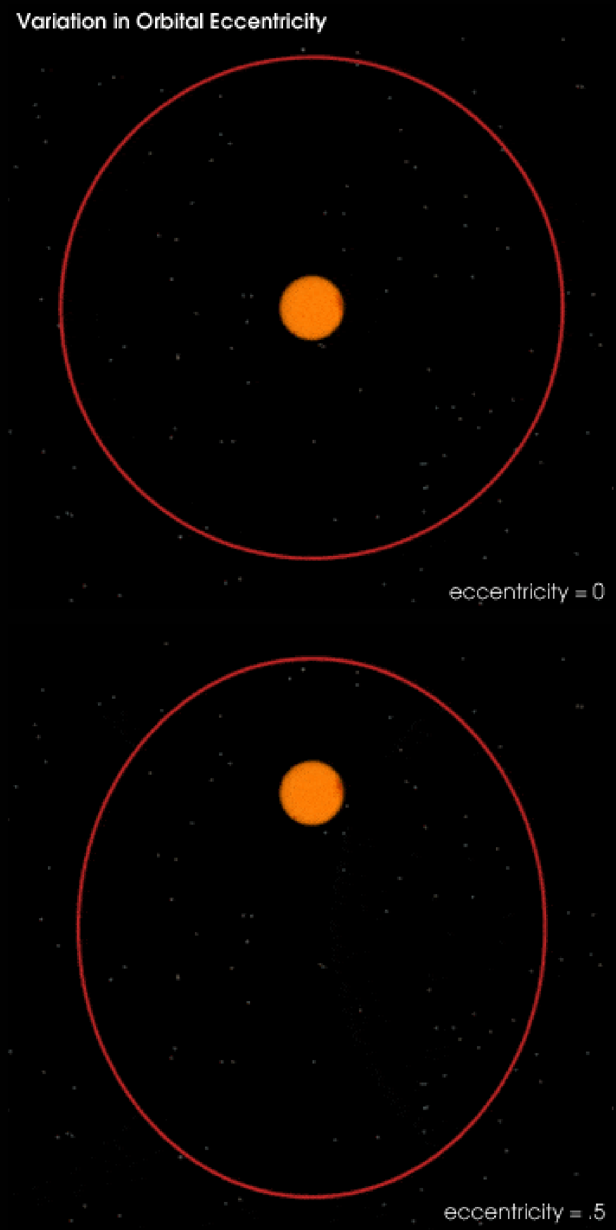
1: Variations in cosmic radiation may cause climatic changes

2: Variations in solar activity may cause climatic changes

Milutin Milankovitch 1879-1958

The Serbian astrophysicist Milutin Milankovitch dedicated his career to developing a mathematical theory of climate based on the seasonal and latitudinal variations of solar radiation received by the Earth.

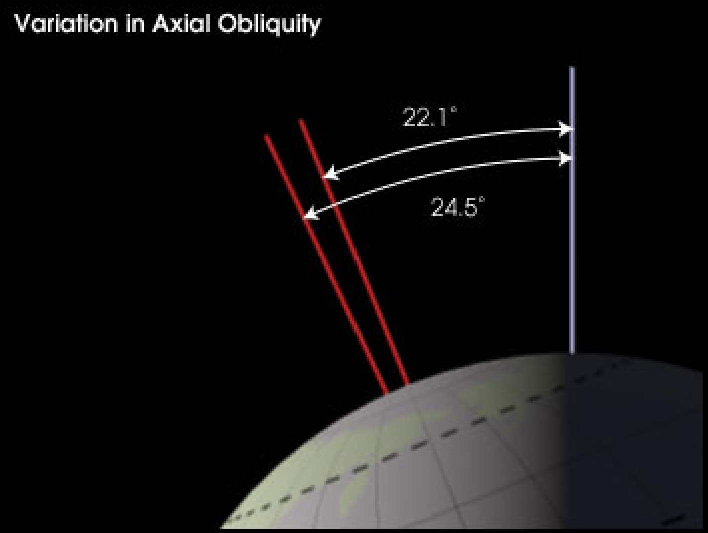
Now known as the Milankovitch Theory, it states that as the Earth travels through space around the sun, cyclical variations in three elements of Earth-sun geometry combine to produce variations in the amount of solar energy that reaches Earth.



Changes in **orbital eccentricity** affect the Earth-sun distance.

Currently, a difference of only 3 percent (5 million kilometers) exists between closest approach (perihelion), which occurs on or about January 3, and furthest departure (aphelion), which occurs on or about July 4. This difference in distance amounts to about a 6 percent increase in incoming solar radiation (insolation) from July to January.

The shape of the Earth¹s orbit changes from being elliptical (high eccentricity) to being nearly circular (low eccentricity) in a cycle that takes between 90,000 and 100,000 years. When the orbit is highly elliptical, the amount of insolation received at perihelion would be on the order of 20 to 30 percent greater than at aphelion, resulting in a substantially different climate from what we experience today.

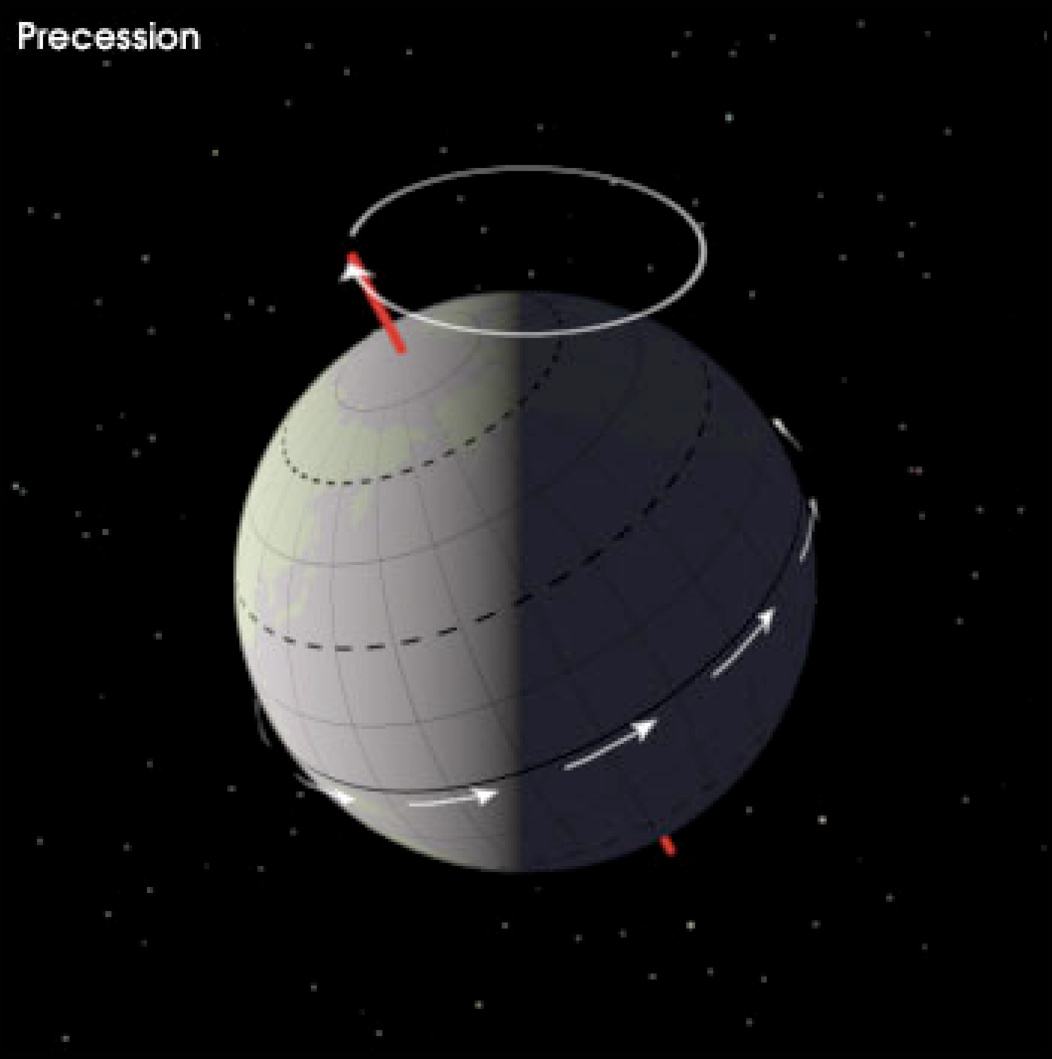


Obliquity (change in axial tilt)

As the axial tilt increases, the seasonal contrast increases so that winters are colder and summers are warmer in both hemispheres.

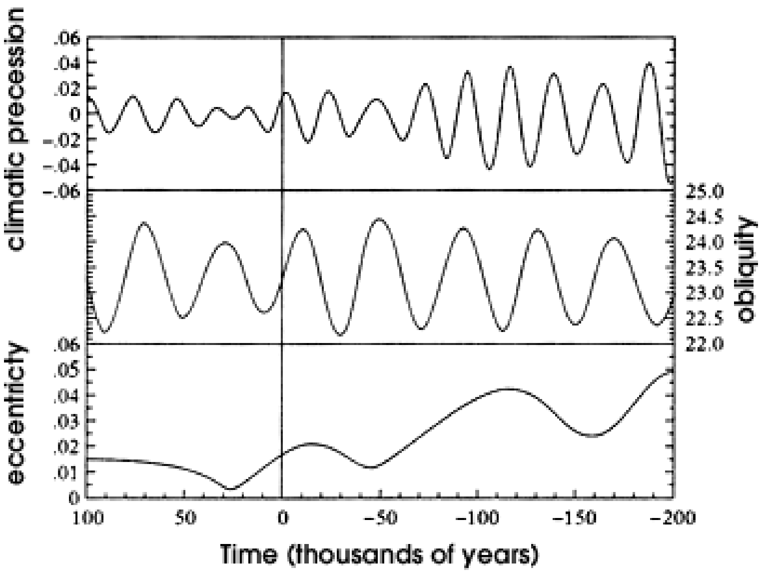
Today, the Earth's axis is tilted 23.5 degrees from the plane of its orbit around the sun. But this tilt changes. During a cycle that averages about 40,000 years, the tilt of the axis varies between 22.1 and 24.5 degrees.

More tilt means more severe seasons—warmer summers and colder winters; less tilt means less severe seasons—cooler summers and milder winters. It's the cool summers that are thought to allow snow and ice to last from year-to-year in high latitudes, eventually building up into massive ice sheets.



Precession

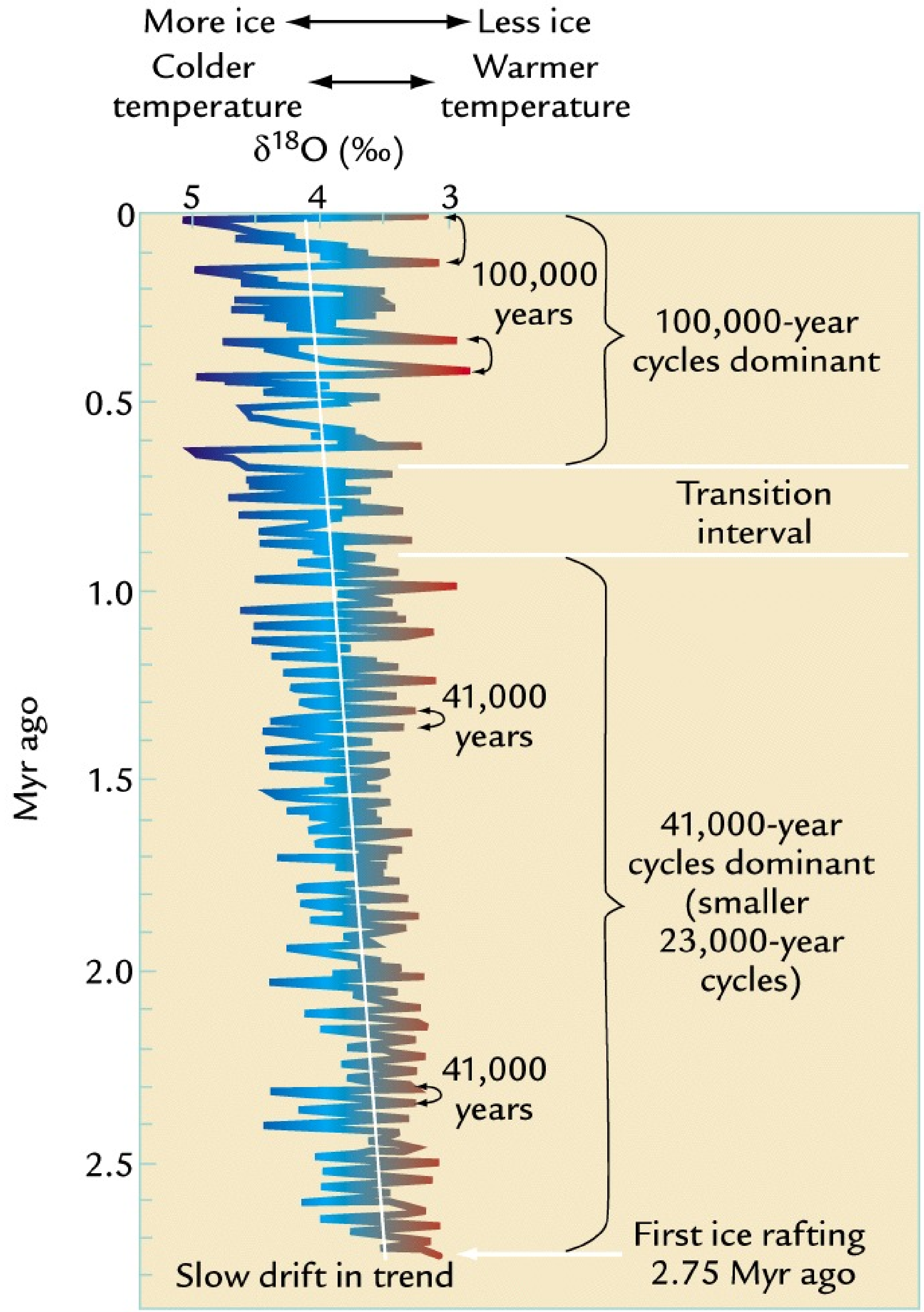
Changes in axial precession alter the dates of perihelion and aphelion, and therefore increase the seasonal contrast in one hemisphere and decrease the seasonal contrast in the other hemisphere.

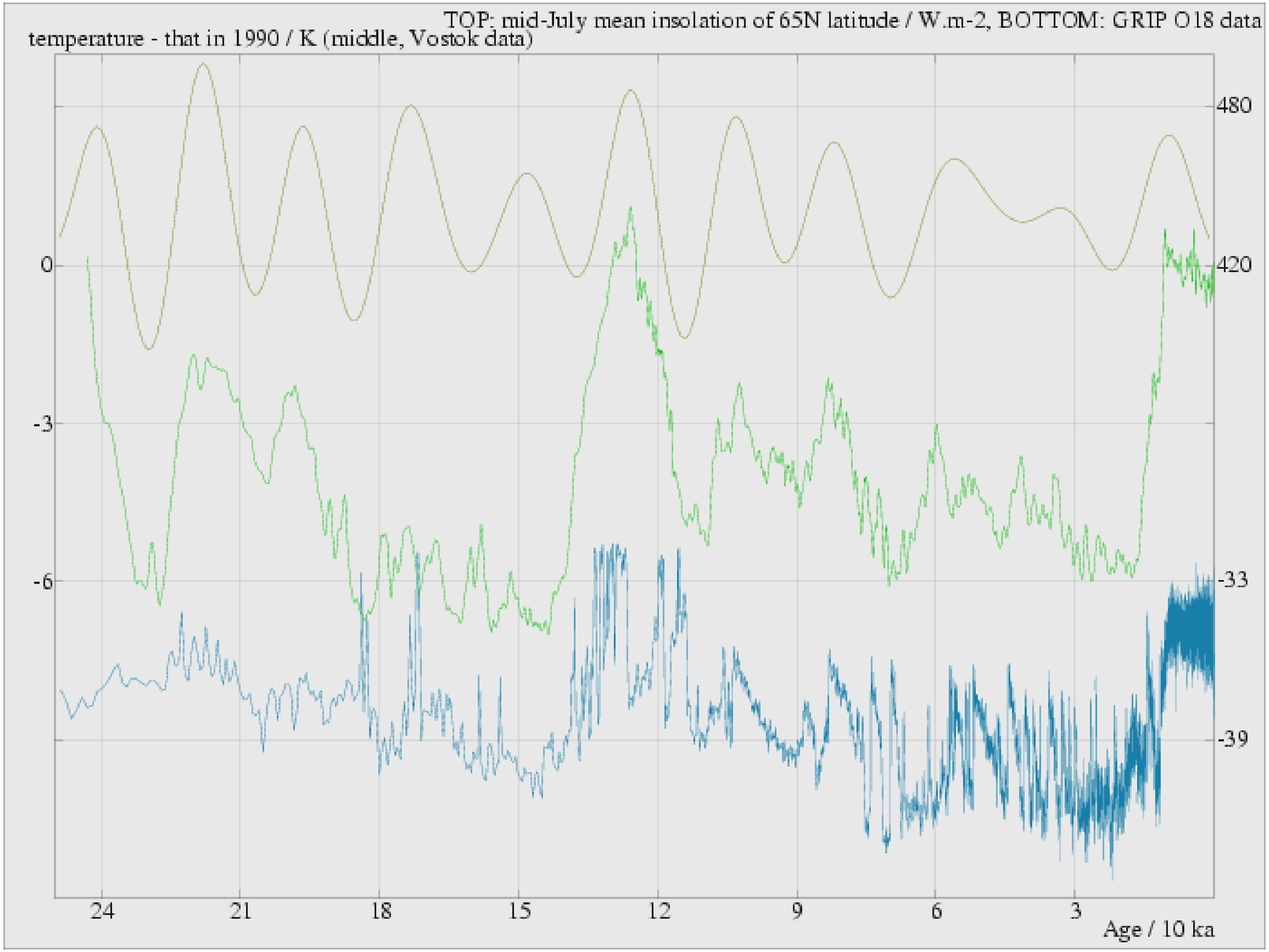


Graph showing the calculated values for 300,000 years of orbital variation by Berger and Loutre, 1991.

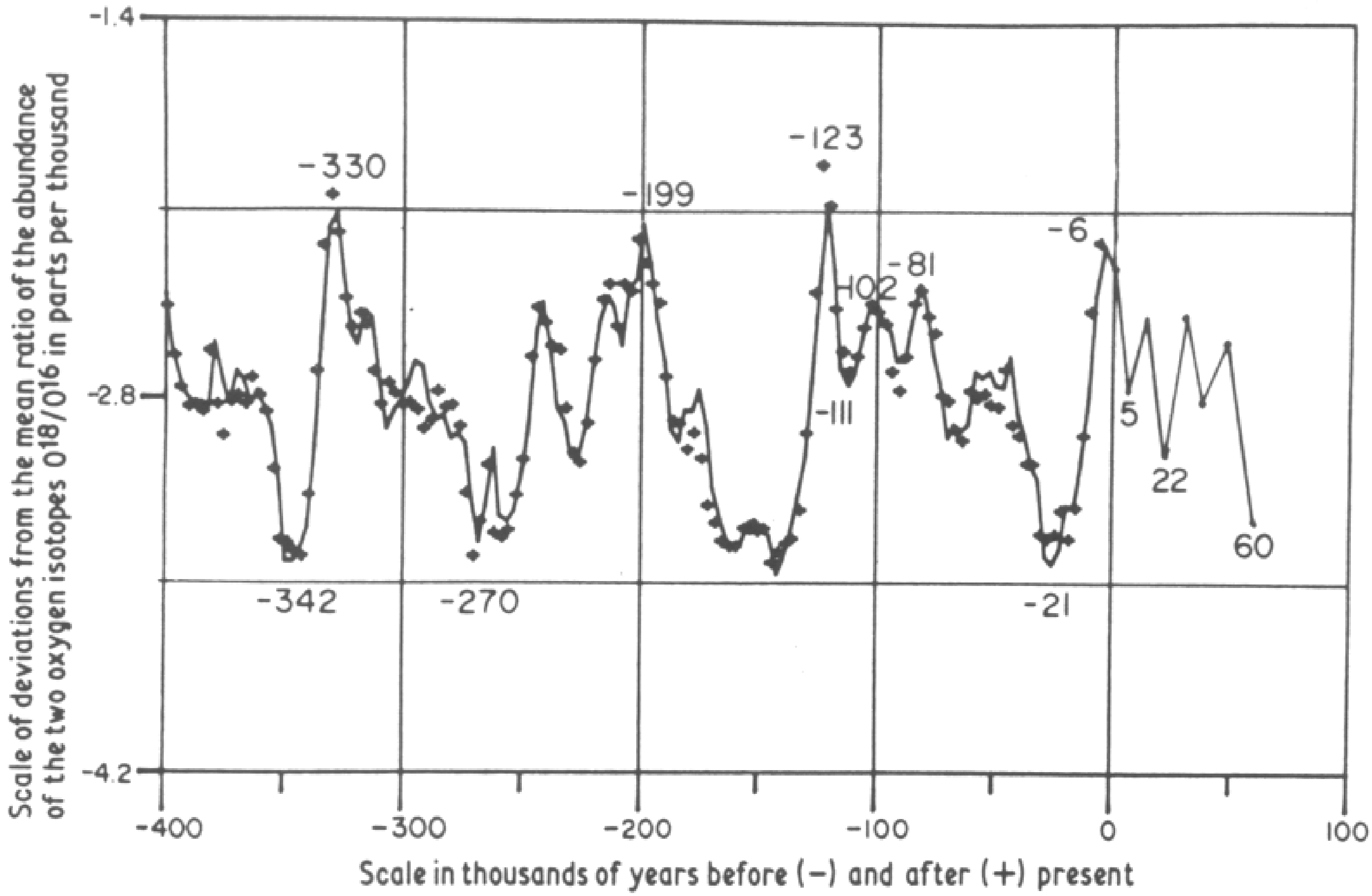
For about 50 years, however, Milankovitch's theory was largely ignored.

Using these three orbital variations, Milankovitch was able to formulate a comprehensive mathematical model that calculated latitudinal differences in insolation and the corresponding surface temperature for 600,000 years prior to the year 1800. He then attempted to correlate these changes with the growth and retreat of the Ice Ages. To do this, Milankovitch assumed that radiation changes in some latitudes and seasons are more important to ice sheet growth and decay than those in others. Then, at the suggestion of German Climatologist Vladimir Köppen, he chose summer insolation at 65 degrees North as the most important latitude and season to model, reasoning that great ice sheets grew near this latitude and that cooler summers might reduce summer snowmelt, leading to a positive annual snow budget and ice sheet growth.


More ice
Less ice
Colder temperature
Warmer temperature
δ18O (‰)
5
4
3
0
0.5
1.0
1.5
2.0
2.5
Myr ago
100,000 years
100,000-year cycles dominant
Transition interval
41,000 years
41,000-year cycles dominant (smaller 23,000-year cycles)
41,000 years
First ice rafting 2.75 Myr ago
Slow drift in trend

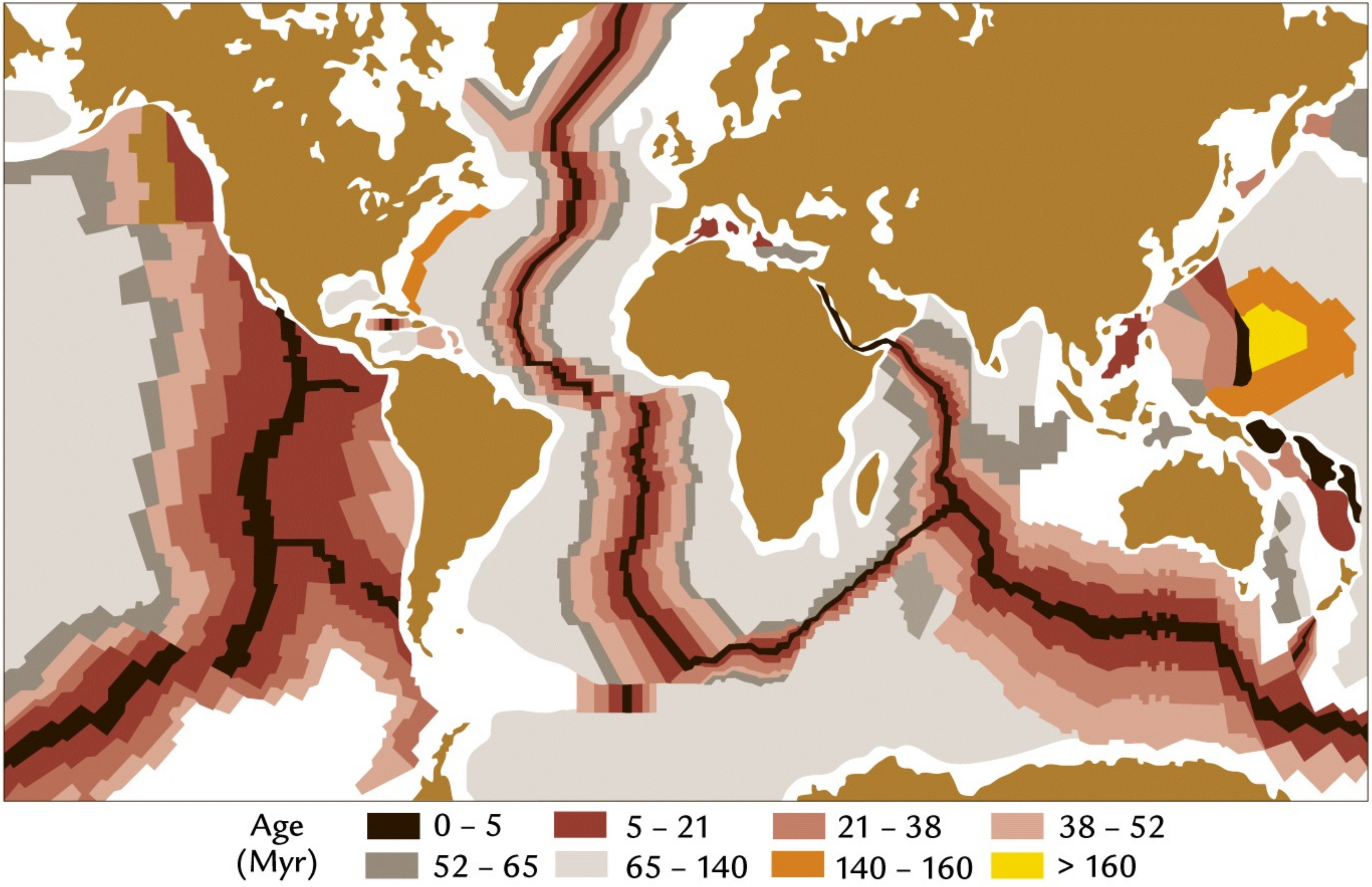


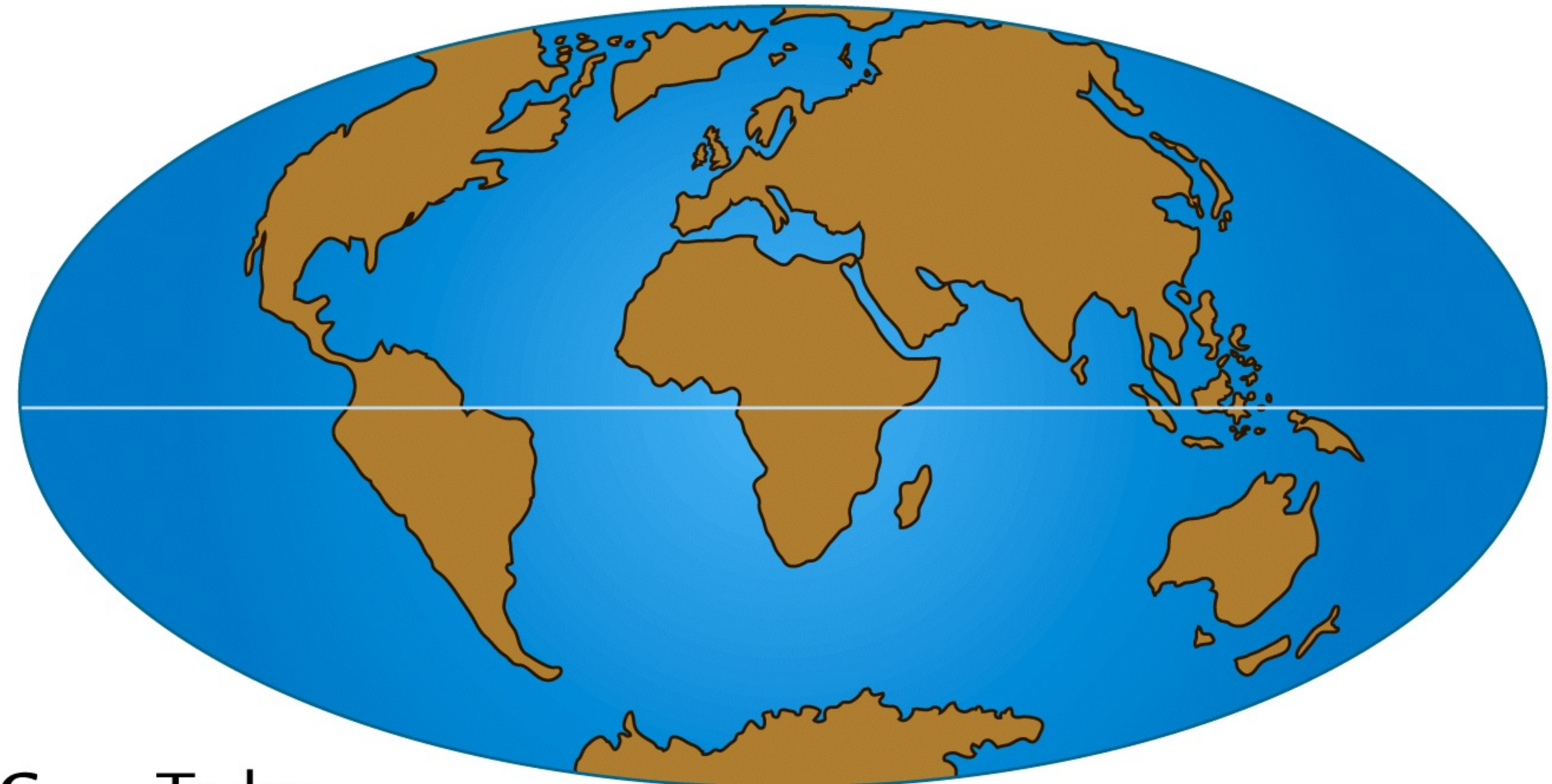
Climate and insolation since 240.000 BP.



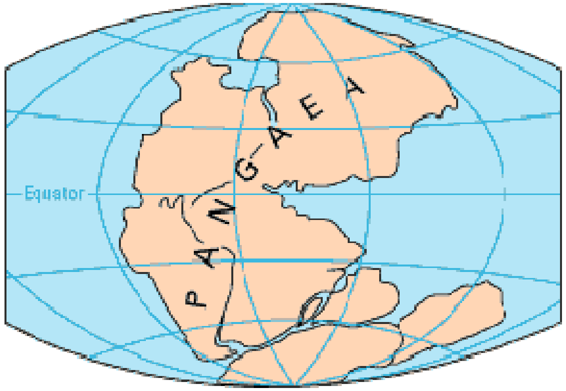
-1.4
-2.8
-4.2
-330
-342
-270
-199
-123
-111
-102
-81
-6
-21
5
22
60
-400
-300
-200
-100
0
100
Scale of deviations from the mean ratio of the abundance of the two oxygen isotopes O18/O16 in parts per thousand
Scale in thousands of years before (–) and after (+) present

Orbital orbital variations may cause climatic changes

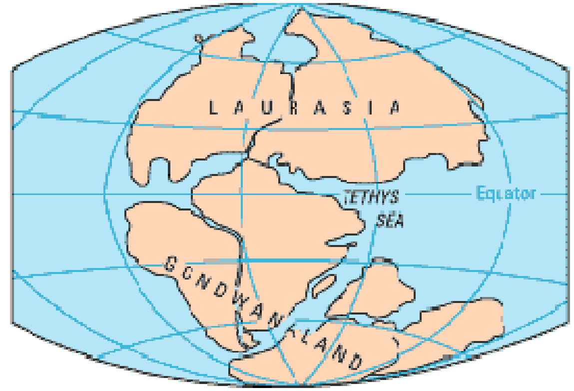

Age
(Myr)
0 – 5
5 – 21
21 – 38
38 – 52
52 – 65
65 – 140
140 – 160
> 160



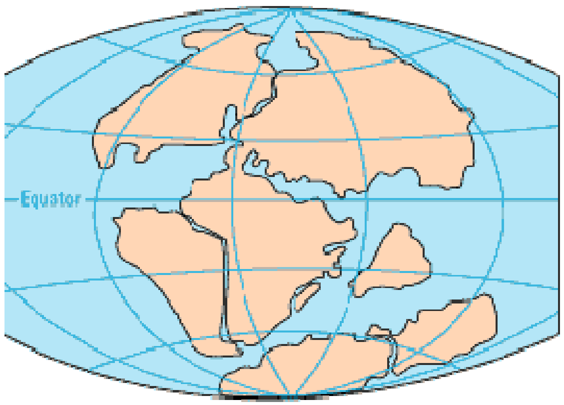
C Today



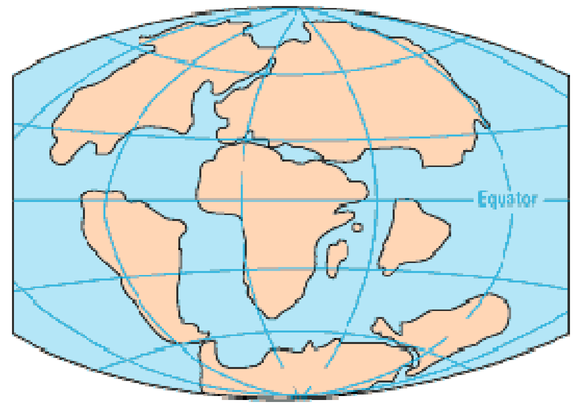
PERMIAN
225 million years ago



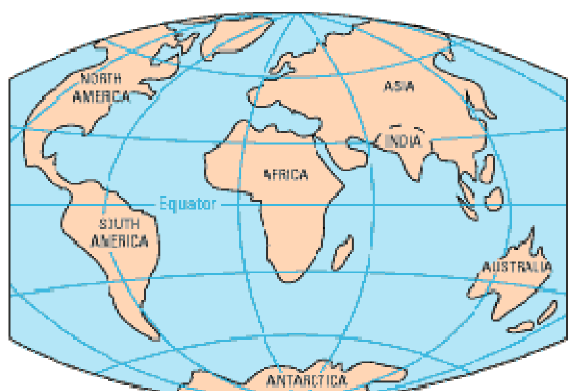
TRIASSIC
200 million years ago



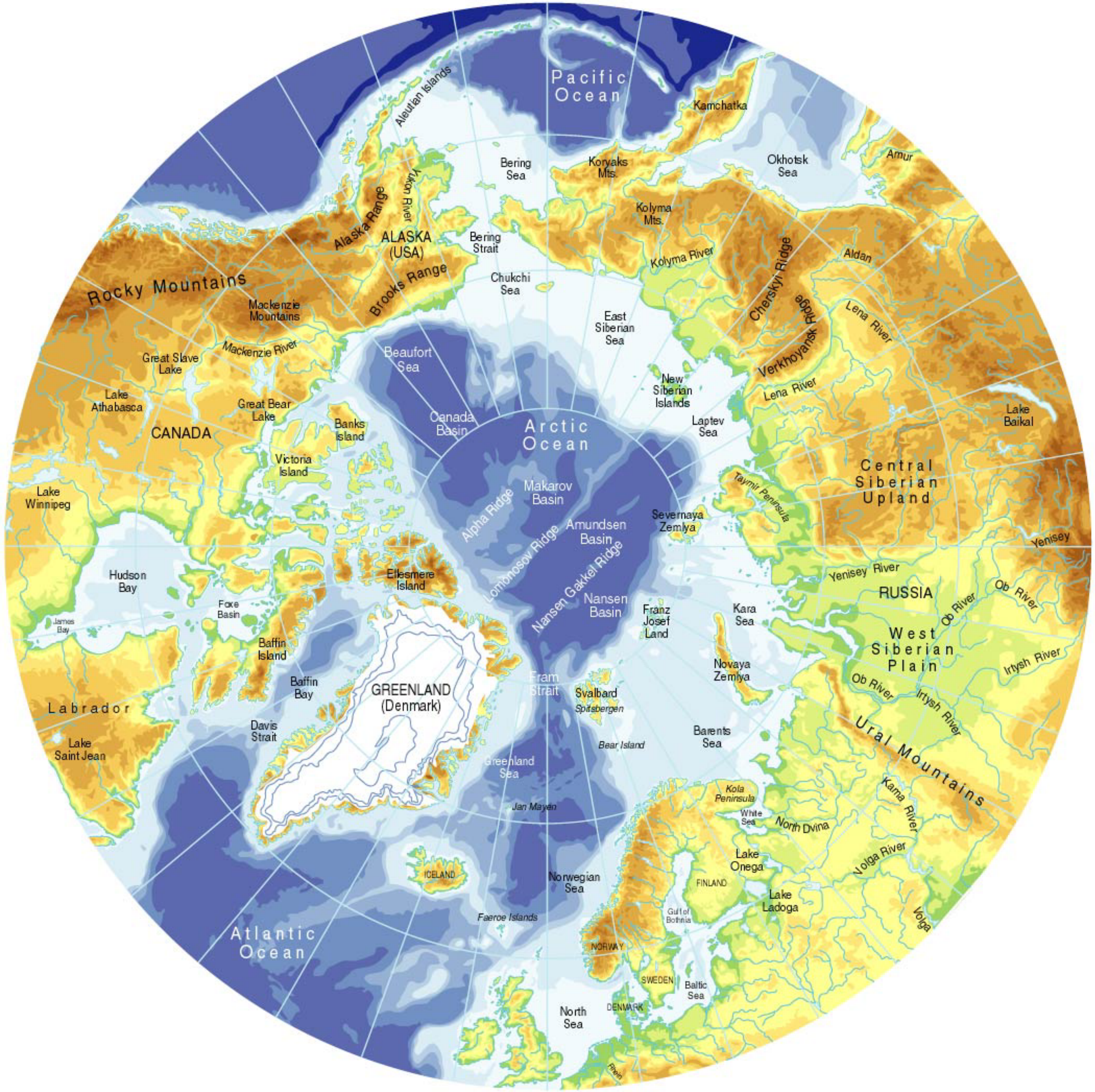
JURASSIC
135 million years ago



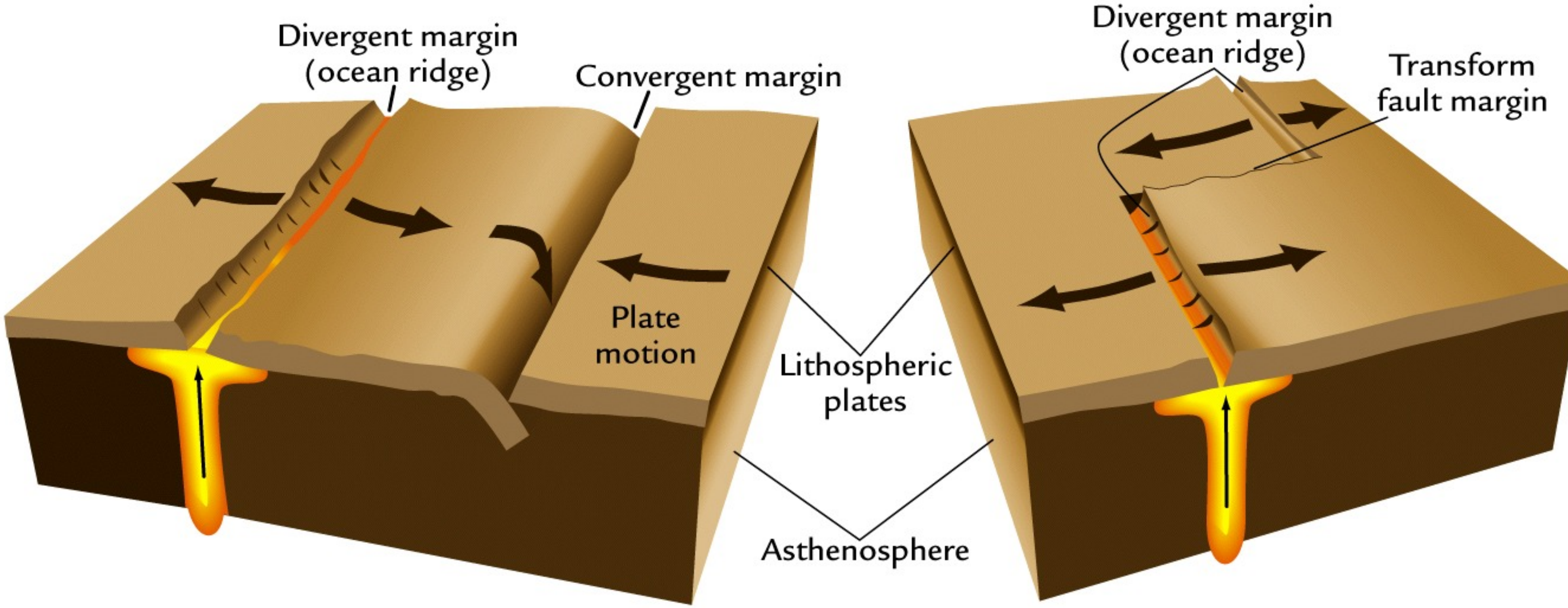
CRETACEOUS
65 million years ago



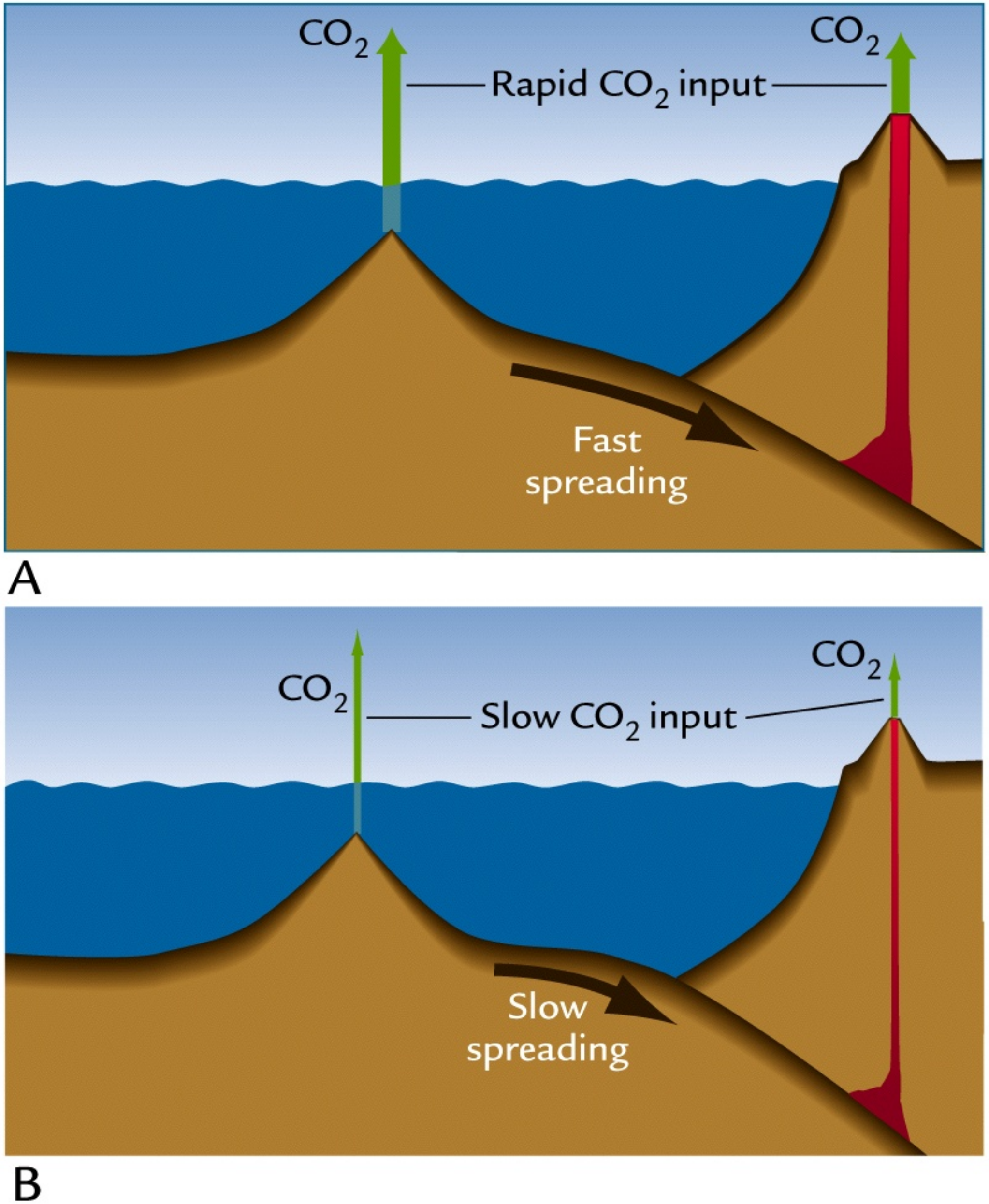
PRESENT DAY


Pacific Ocean
Aleutian Islands
Kamchatka
Bering Sea
Koryaks Mts.
Okhotsk Sea
Amur
Alaska Range
Yukon River
ALASKA (USA)
Bering Strait
Kolyma Mts.
Kolyma River
Cherskyi Ridge
Aldan
Rocky Mountains
Brooks Range
Chukchi Sea
Mackenzie Mountains
East Siberian Sea
Verkhoyansk Ridge
Lena River
Mackenzie River
Great Slave Lake
Beaufort Sea
New Siberian Islands
Lake Athabasca
Great Bear Lake
Canada Basin
Arctic Ocean
Laptev Sea
Lake Baikal
CANADA
Banks Island
Victoria Island
Makarov Basin
Taymir Peninsula
Central Siberian Upland
Lake Winnipeg
Alpha Ridge
Amundsen Basin
Severnaya Zemlya
Lomonosov Ridge
Nansen Gakkel Ridge
Yenisey
Hudson Bay
Ellesmere Island
Yenisey River
RUSSIA
Foxe Basin
Nansen Basin
Franz Josef Land
Kara Sea
Ob River
James Bay
Baffin Island
West Siberian Plain
Irtysh River
Baffin Bay
GREENLAND (Denmark)
Fram Strait
Svalbard
Spitsbergen
Novaya Zemlya
Labrador
Davis Strait
Bear Island
Barents Sea
Ural Mountains
Lake Saint Jean
Greenland Sea
Jan Mayen
Kola Peninsula
White Sea
North Dvina
Kama River
Lake Onega
Volga River
ICELAND
Norwegian Sea
FINLAND
Lake Ladoga
Gulf of Bothnia
Faeroe Islands
Volga
Atlantic Ocean
NORWAY
SWEDEN
Baltic Sea
North Sea
DENMARK
Rhein

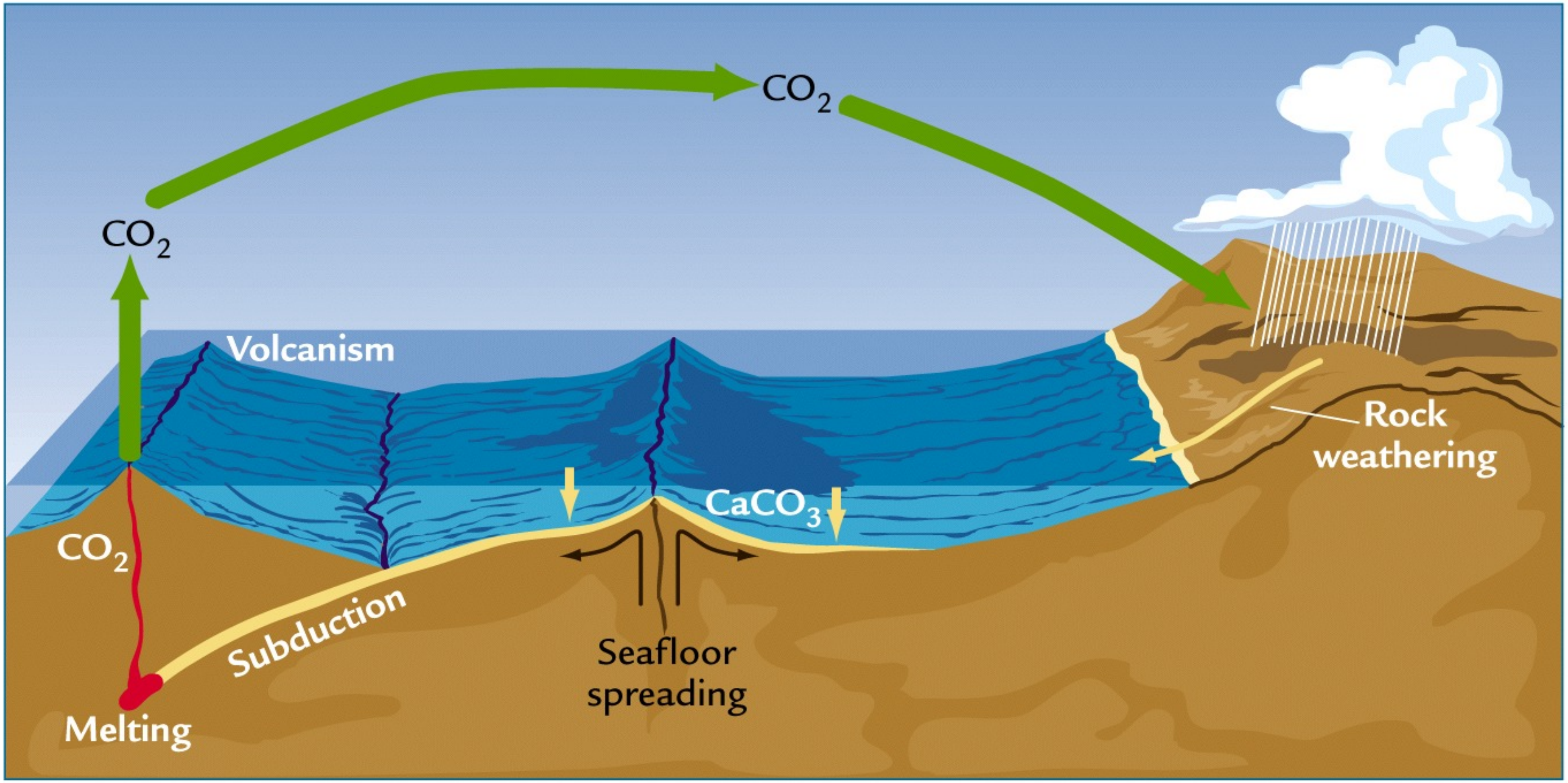
Continental drift may cause climatic changes by changing the land-sea configuration



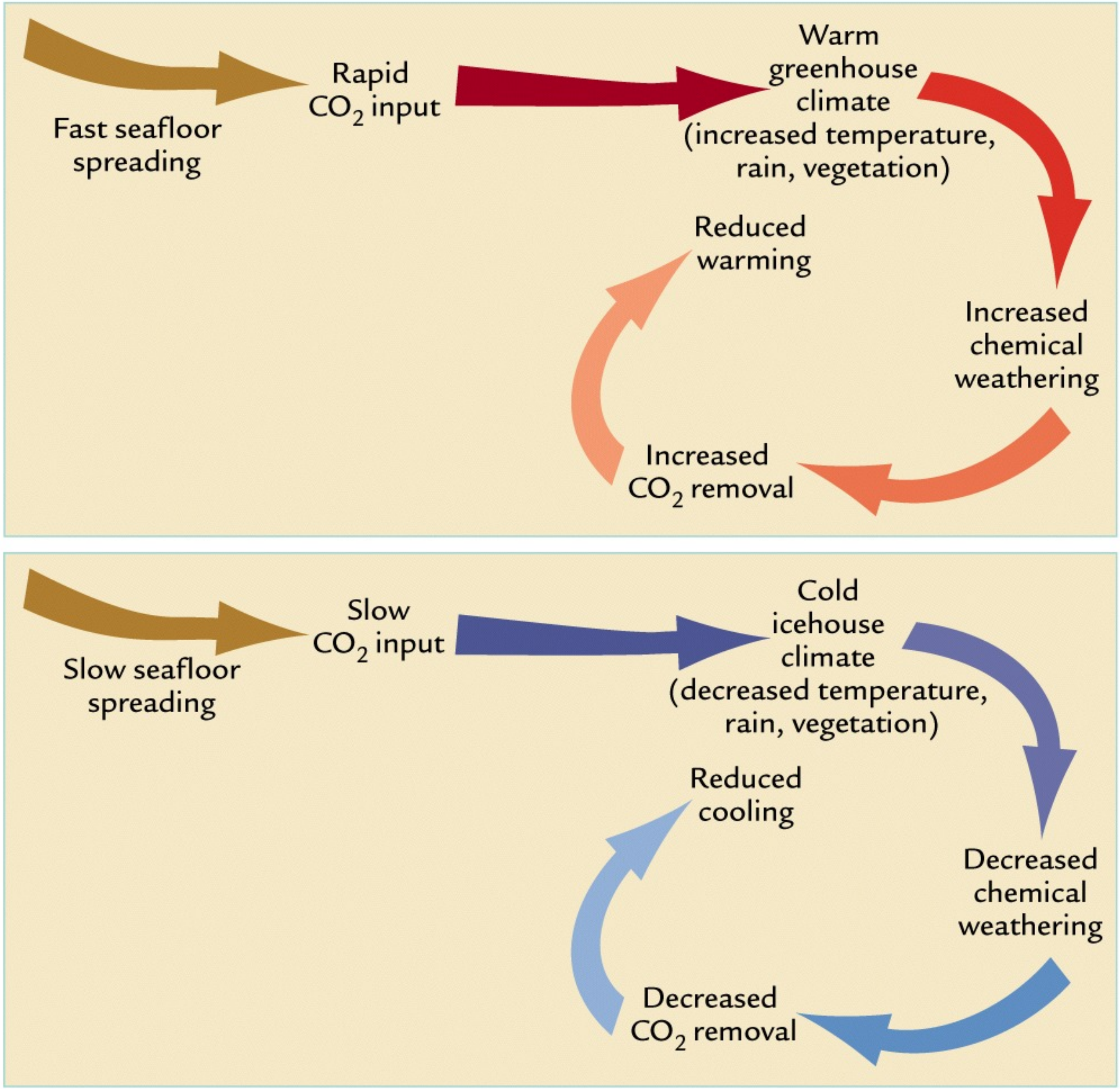
Divergent margin
(ocean ridge)
Convergent margin
Plate
motion
Lithospheric
plates
Asthenosphere
Divergent margin
(ocean ridge)
Transform
fault margin



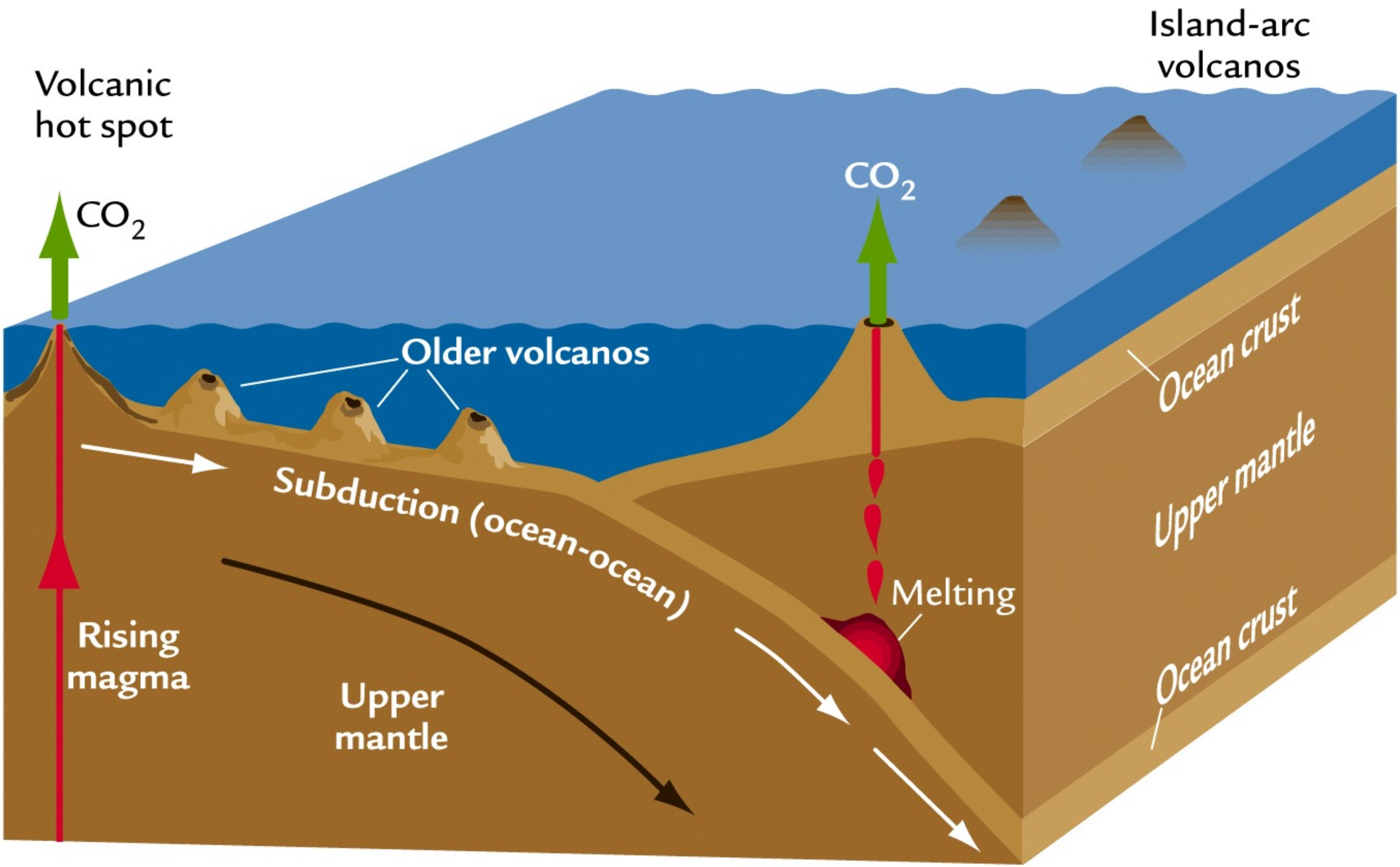
CO_2
CO_2
Rapid CO_2 input
Fast spreading
A
CO_2
CO_2
Slow CO_2 input
Slow spreading
B



CO_2
CO_2
Volcanism
Rock weathering
$CaCO_3$
CO_2
Subduction
Seafloor spreading
Melting

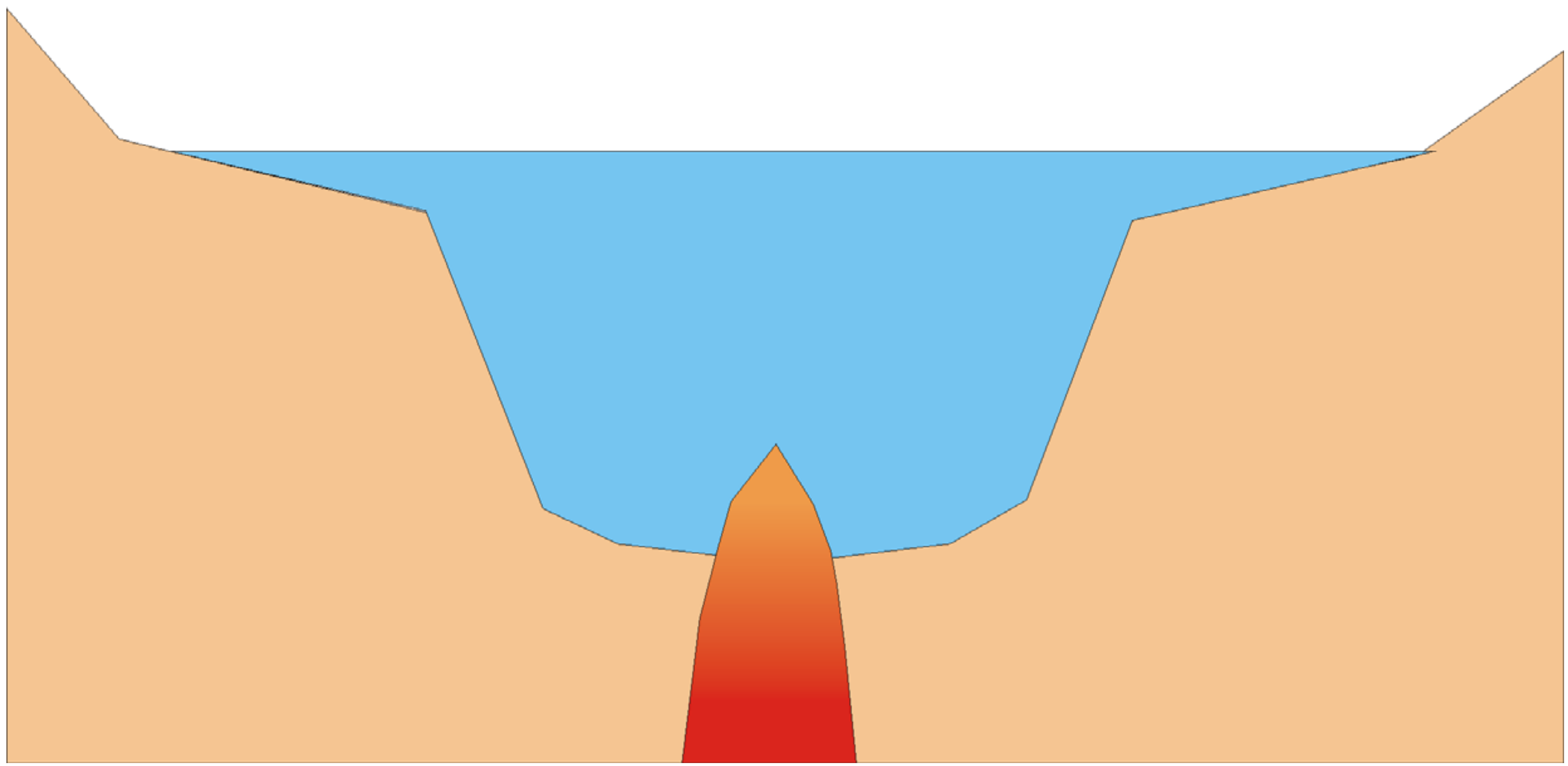

Fast seafloor spreading
Rapid CO_2 input
Warm greenhouse climate (increased temperature, rain, vegetation)
Increased chemical weathering
Increased CO_2 removal
Reduced warming
Slow seafloor spreading
Slow CO_2 input
Cold icehouse climate (decreased temperature, rain, vegetation)
Decreased chemical weathering
Decreased CO_2 removal
Reduced cooling

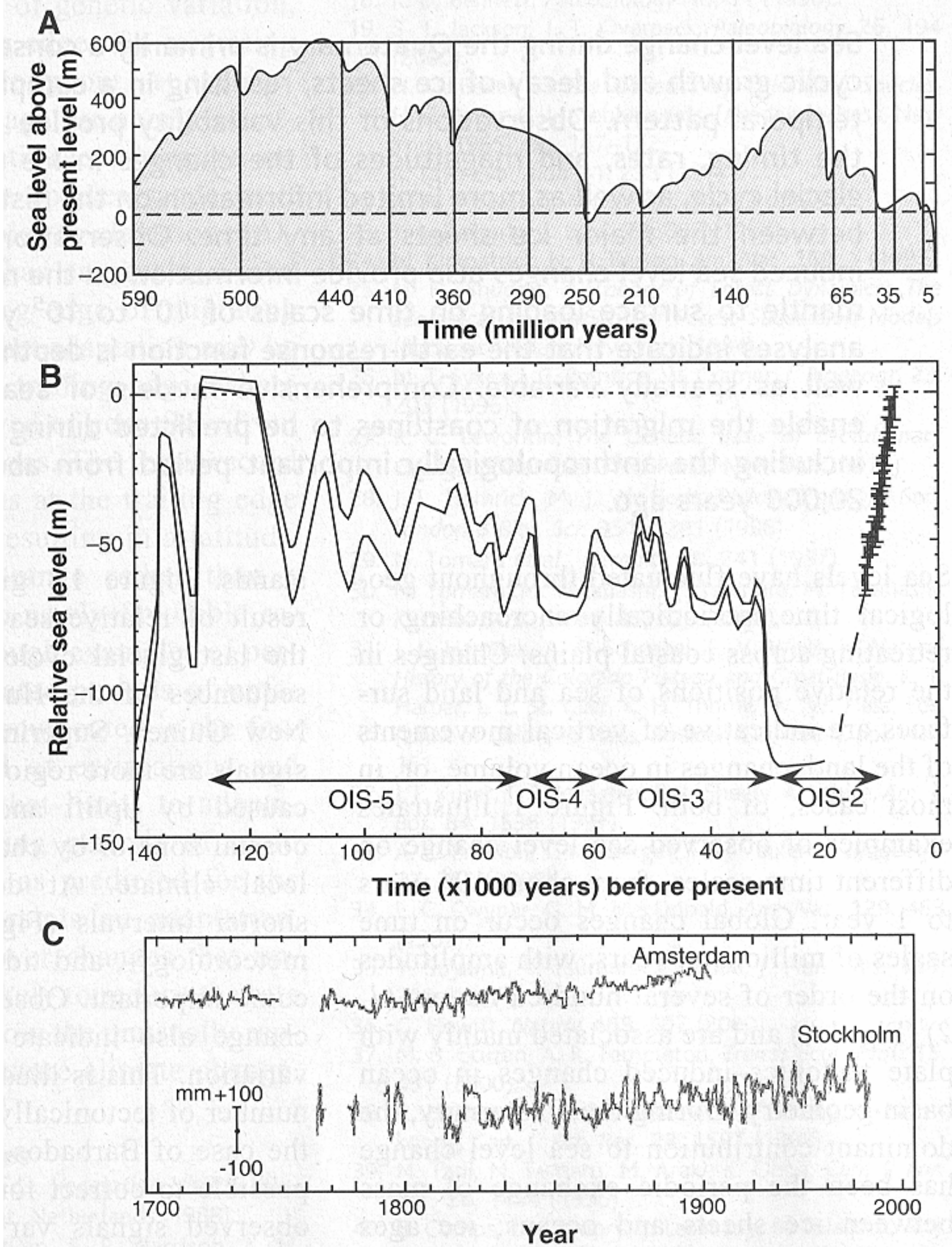
Continental drift may cause climatic changes by changing the chemistry of the atmosphere



Island-arc volcanos
Volcanic hot spot
CO_2
CO_2
Older volcanos
Ocean crust
Upper mantle
Subduction (ocean-ocean)
Melting
Ocean crust
Rising magma
Upper mantle

Periods of relative high continental drift velocity

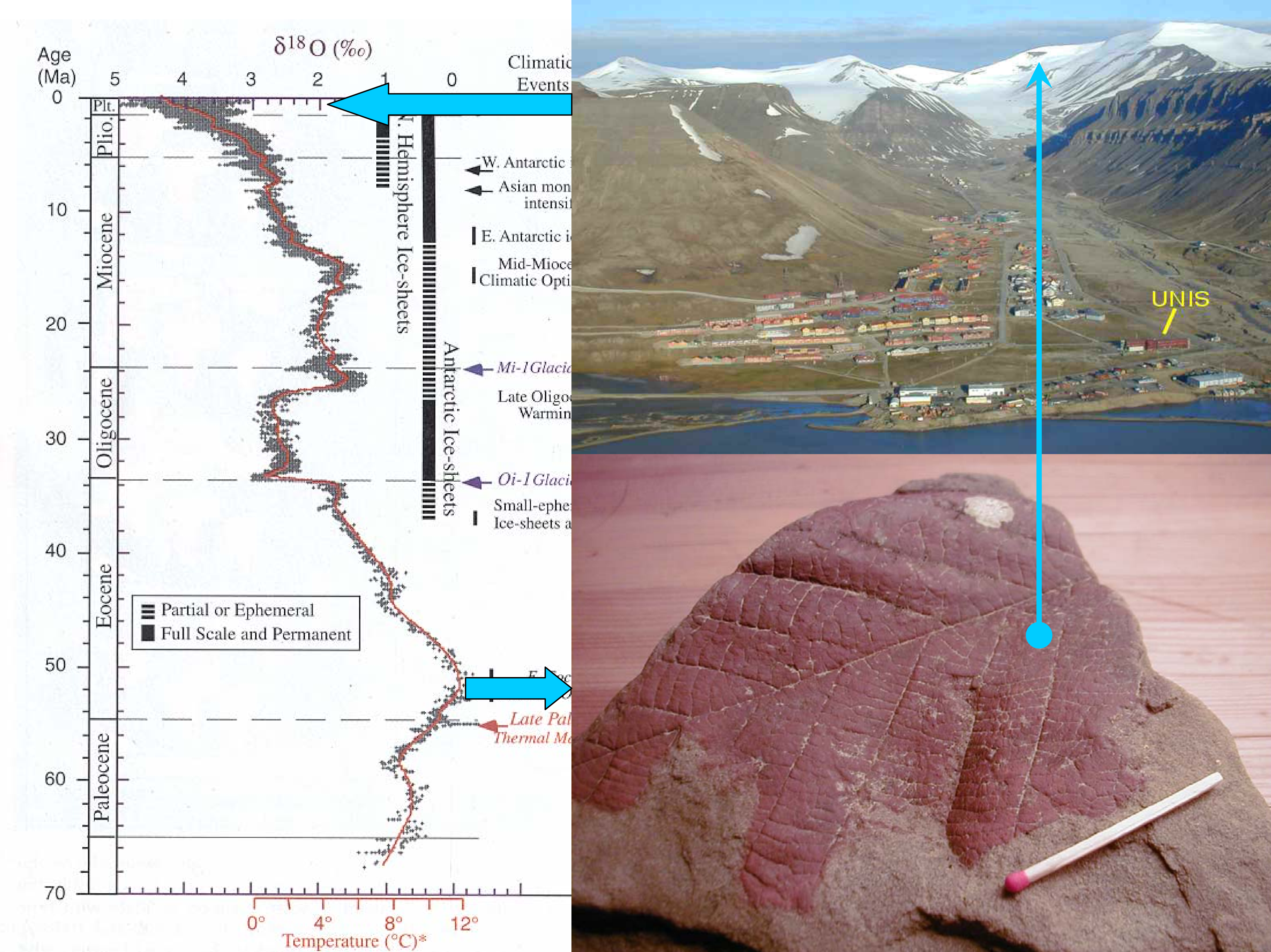


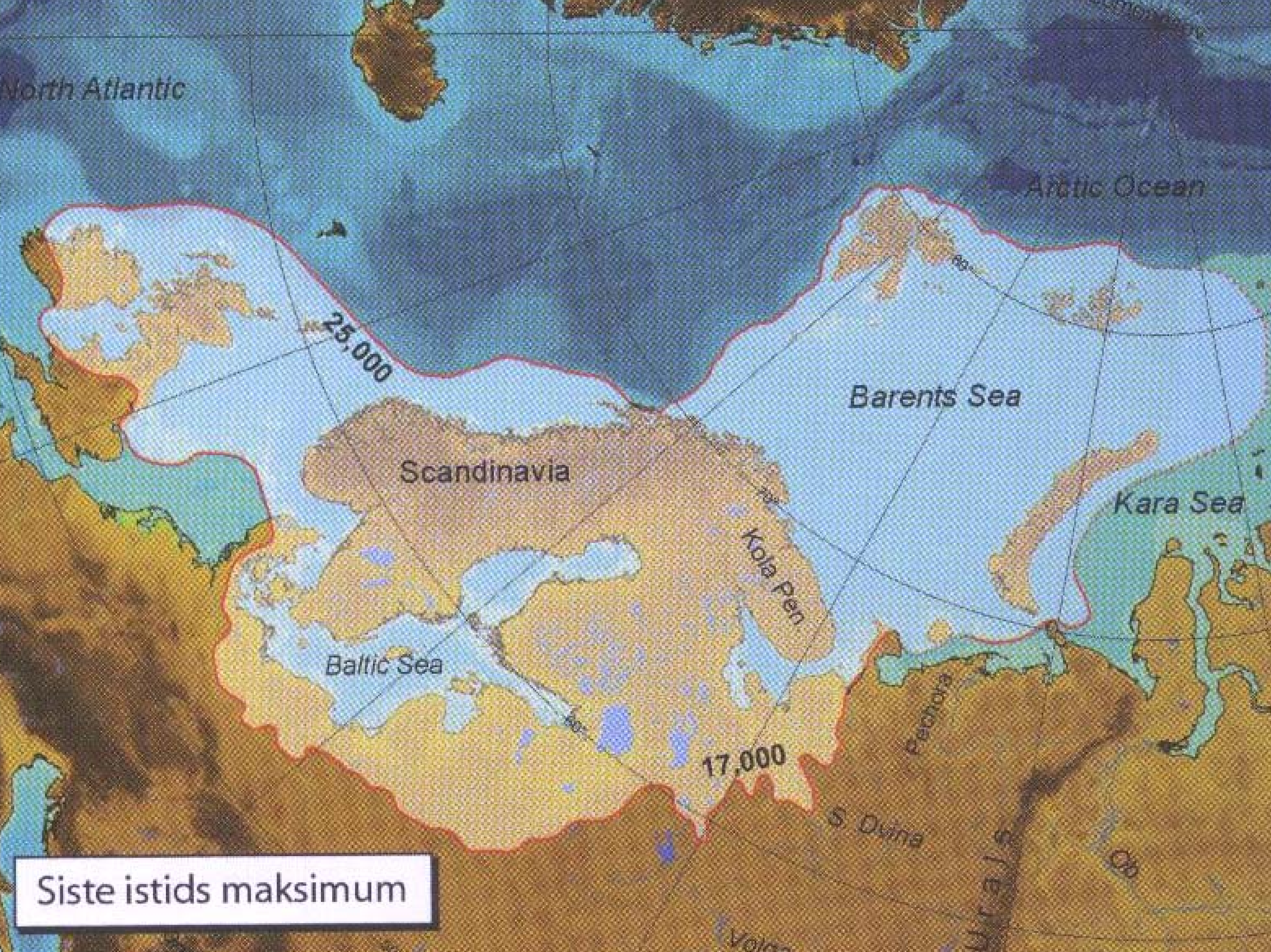

A
Sea level above present level (m)
600
400
200
0
−200
590
500
440
410
360
290
250
210
140
65
35
5
Time (million years)
B
Relative sea level (m)
0
−50
−100
−150
OIS-5
OIS-4
OIS-3
OIS-2
140
120
100
80
60
40
20
0
Time (x1000 years) before present
C
Amsterdam
Stockholm
mm +100
-100
1700
1800
1900
2000
Year

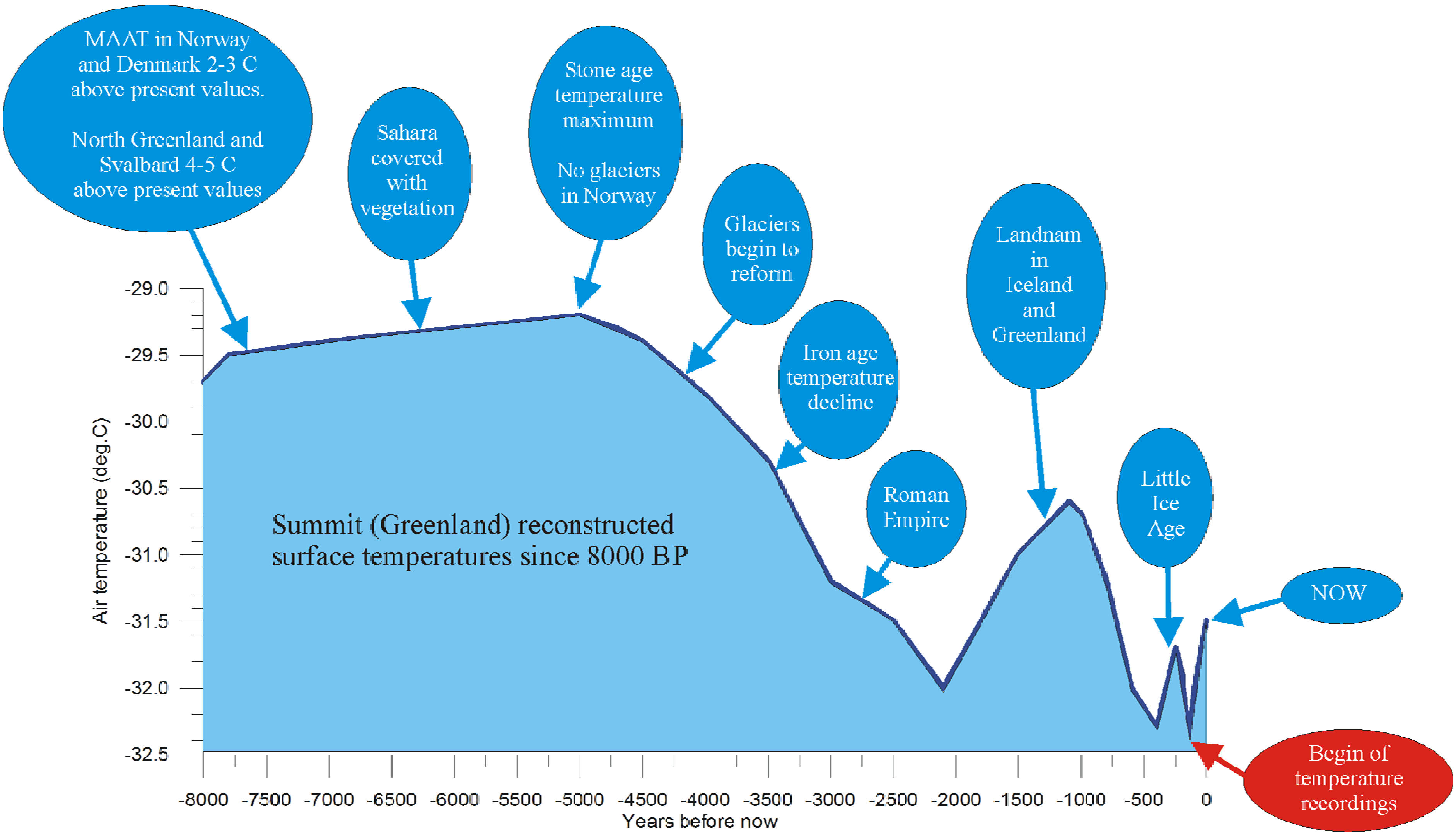
1: Continental drift may cause sea level changes by changing the ocean bottom topography

2: Sea level changes may cause climatic changes by changing the land-sea configuration


Techtonic history
Continental drift
Orbital changes
Warm tertiary climate
Quaternary glaciations
Quaternary interglacials


Age (Ma)
δ18O (‰)
5 4 3 2 1 0
Climatic Events
0
10
20
30
40
50
60
70
Plt.
Plio.
Miocene
Oligocene
Eocene
Paleocene
N. Hemisphere Ice-sheets
Antarctic Ice-sheets
W. Antarctic
Asian mon
intensi
E. Antarctic i
Mid-Mioce
Climatic Opti
Mi-1Glacia
Late Oligo
Warmin
Oi-1Glacia
Small-ephe
Ice-sheets a
Late Pal
Thermal M
Partial or Ephemeral
Full Scale and Permanent
0° 4° 8° 12°
Temperature (°C)*
UNIS


North Atlantic
Arctic Ocean
25,000
Barents Sea
Scandinavia
Kara Sea
Kola Pen
Baltic Sea
17,000
Pechora
S. Dvina
Urals
Ob
Siste istids maksimum



MAAT in Norway and Denmark 2-3 C above present values.
North Greenland and Svalbard 4-5 C above present values
Sahara covered with vegetation
Stone age temperature maximum
No glaciers in Norway
Glaciers begin to reform
Iron age temperature decline
Roman Empire
Landnam in Iceland and Greenland
Little Ice Age
NOW
Begin of temperature recordings
Summit (Greenland) reconstructed surface temperatures since 8000 BP
Air temperature (deg.C)
-29.0
-29.5
-30.0
-30.5
-31.0
-31.5
-32.0
-32.5
-8000 -7500 -7000 -6500 -6000 -5500 -5000 -4500 -4000 -3500 -3000 -2500 -2000 -1500 -1000 -500 0
Years before now


Still on the road to learning !