

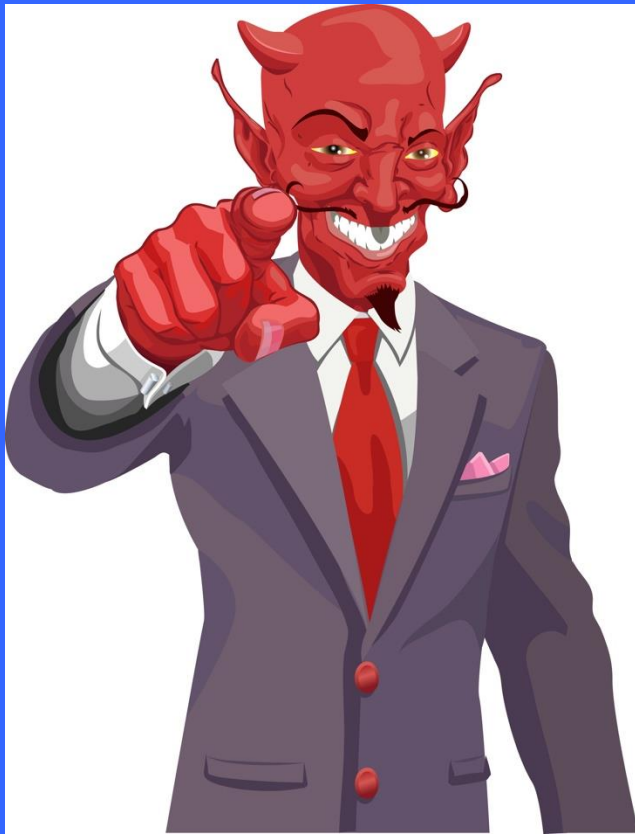


**Some Like it Hot! Some Like It Cold!
Four Billion Years of Climate Change on Planet
Earth: The Cook's Tour**

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Rising Sun Consulting, AMS
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Some like it hot!

Hot house periods: Higher levels of greenhouse gases e.g. CO₂



Some like it cold!

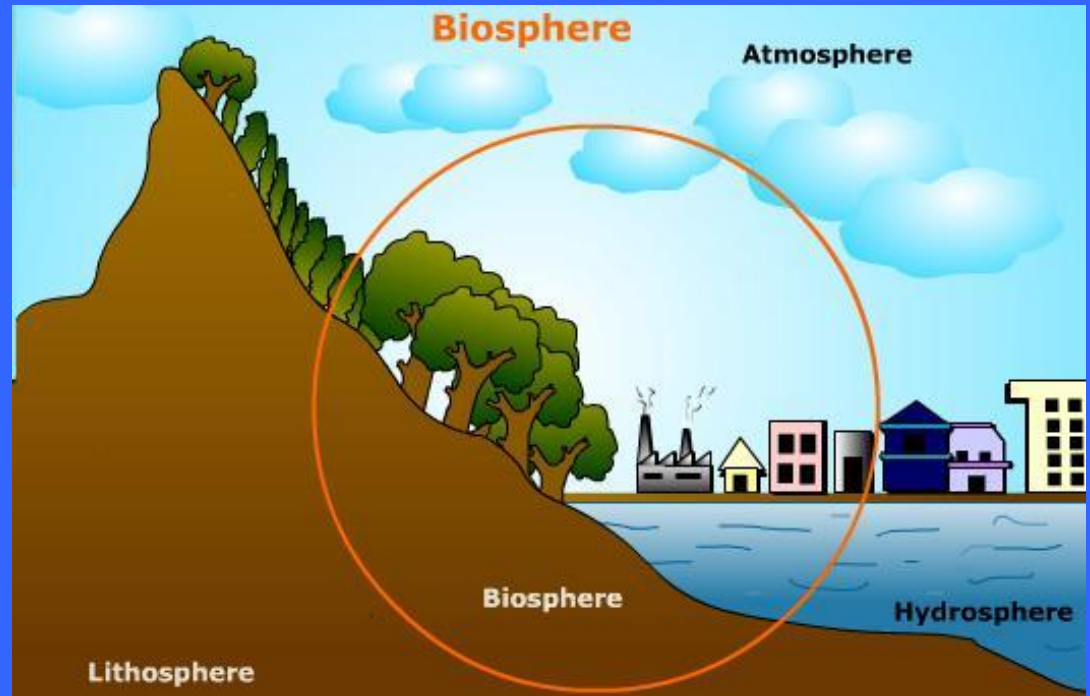
Glacial Maxima: Low CO₂ ;
Orbital + Sub Orbital forcing



New Paradigms

Interrelationships
between earth systems:

- **Chaos theory:**
Attractors, bifurcation
(tipping) points,
cascades,
- **Multiple states of
equilibrium**
- **Feedback loops**
- **Slow:** vegetation, SST, CO₂
- **Fast:** Clouds, water vapor



Stops along the “Cook’s Tour”

- 1) Forcings responsible for climate change:
Internal, External
- 2) Archean Eon:
- 3) Proterozoic Eon
- 4) Phanerozoic Eon
- 5) Expanded tour:
 - Cenozoic era
 - Pleistocene
 - Holocene
 - Anthropocene.
 -



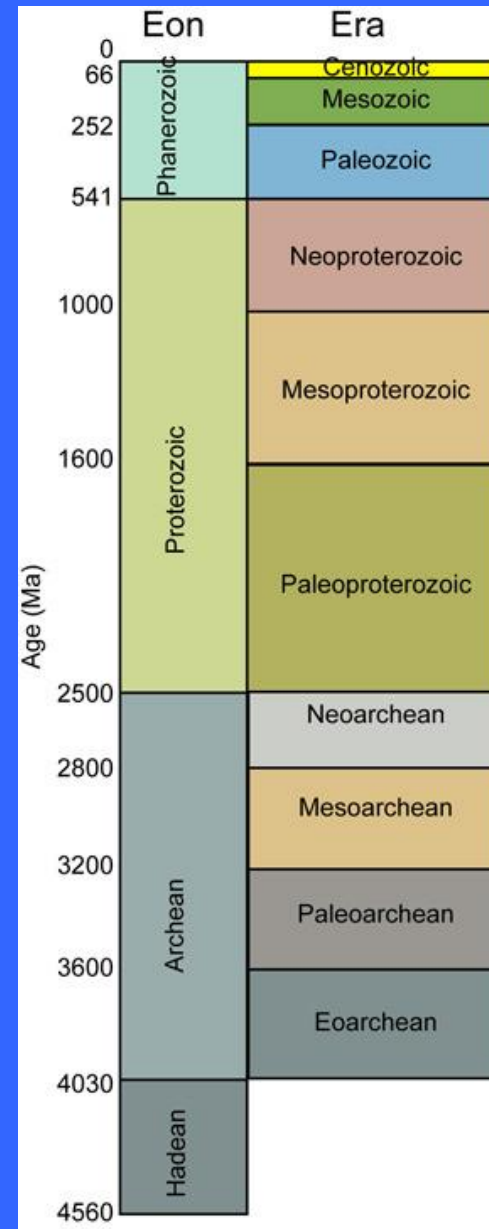
The Big Picture

External Forcing:

- **Cosmic rays**
- **Interstellar dust**
- **Earth – sun geometry**
(Milankovith cycles)
- **Bolloid impacts**

Internal forcing: *Paleocycles*

- **Plate tectonics**
Orogenesis /volcanism
- **Ocean composition**
+ circulation
- **Biosphere (CO_2 excursion**
/down draw cycles
- **Solar Variability**
- **Albedo patterns**



Forcing Overview

Feedbacks (g)

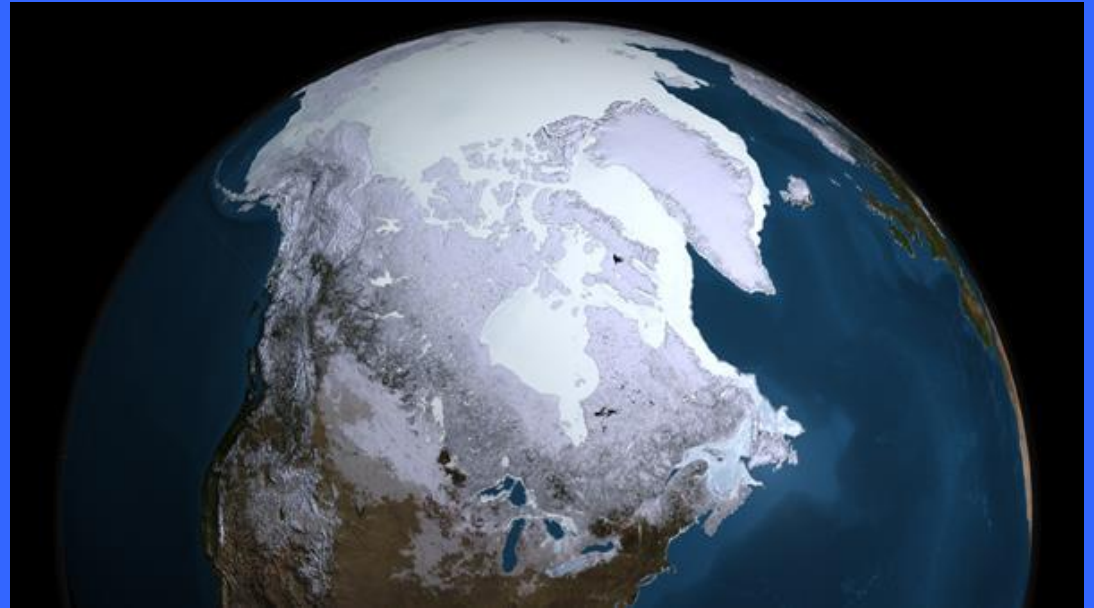
$$S = \Delta T (1 - \Sigma g)$$

g= climate sensitivity

When the value for g is large the climate is more sensitive

Energy balance and radiative forcing

$$F. = F_{sw} \downarrow (1 - \alpha.) - \sigma T^4 + F_{LW}$$

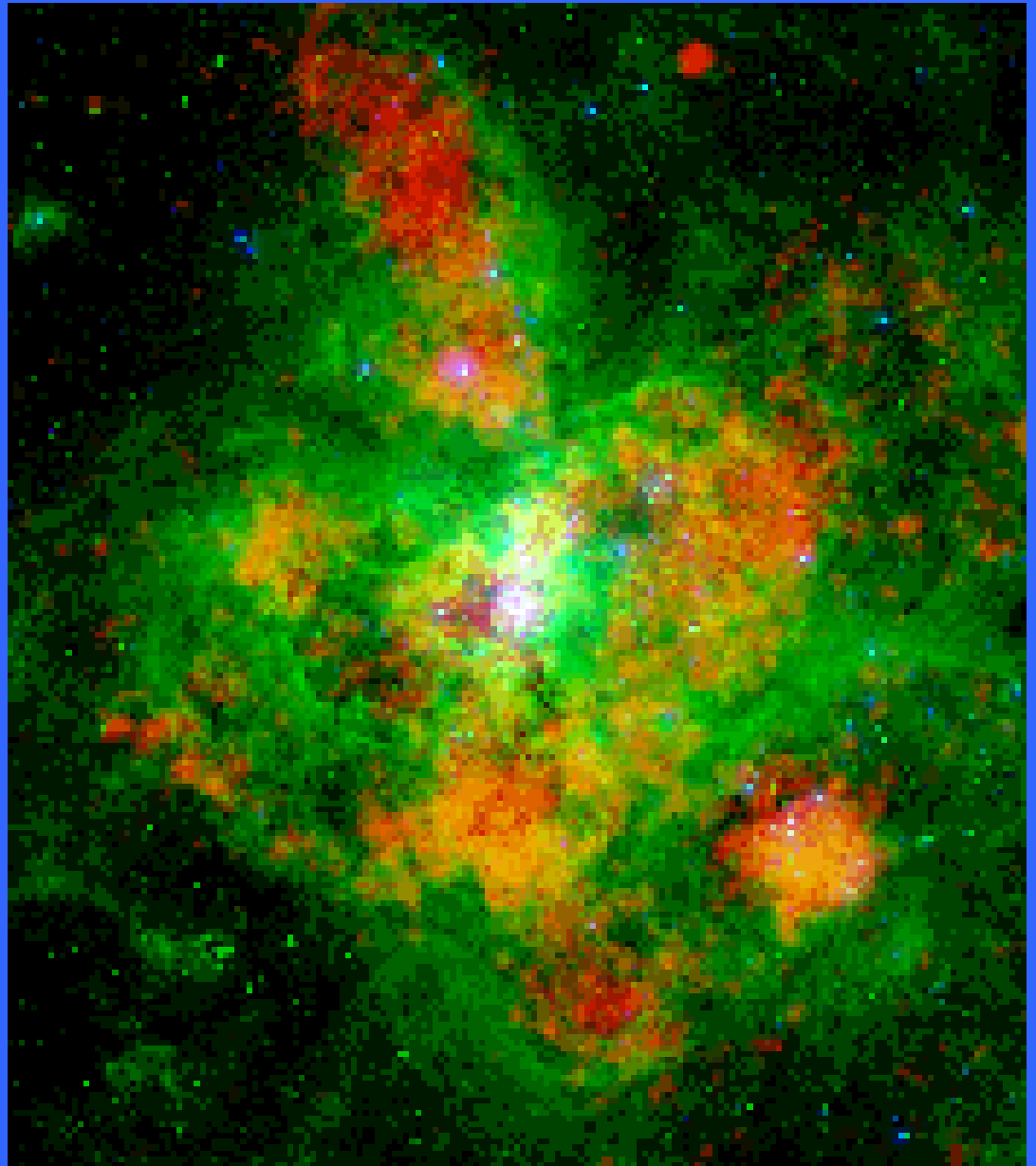


Interstellar gas / dust

Possible Impacts:

Solar dimming
= cooler regime

Solar ignition =
warmer regime.



Cosmic Rays

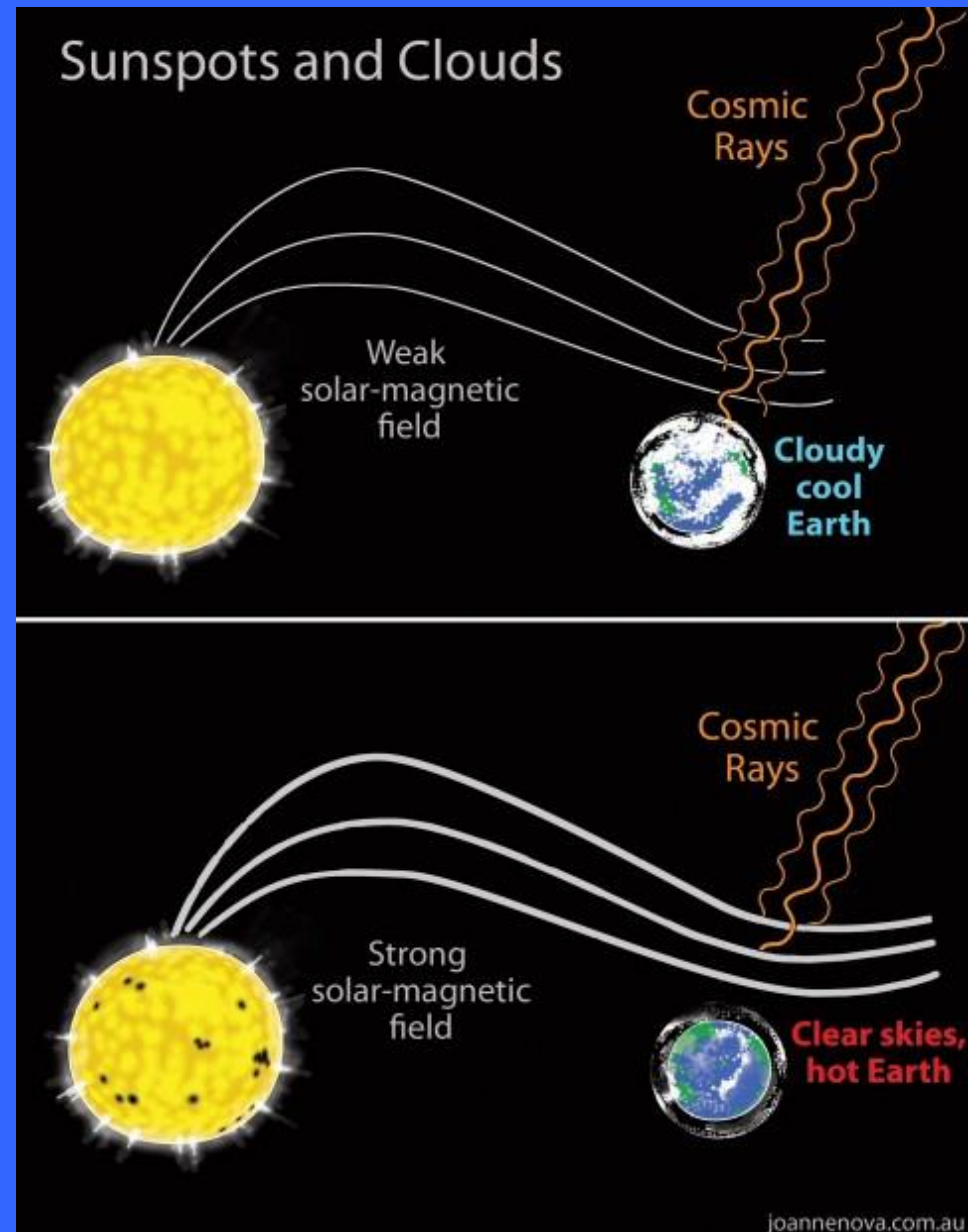
Decreased solar magnetic field =

Increased atmospheric bombardment of cosmic rays =

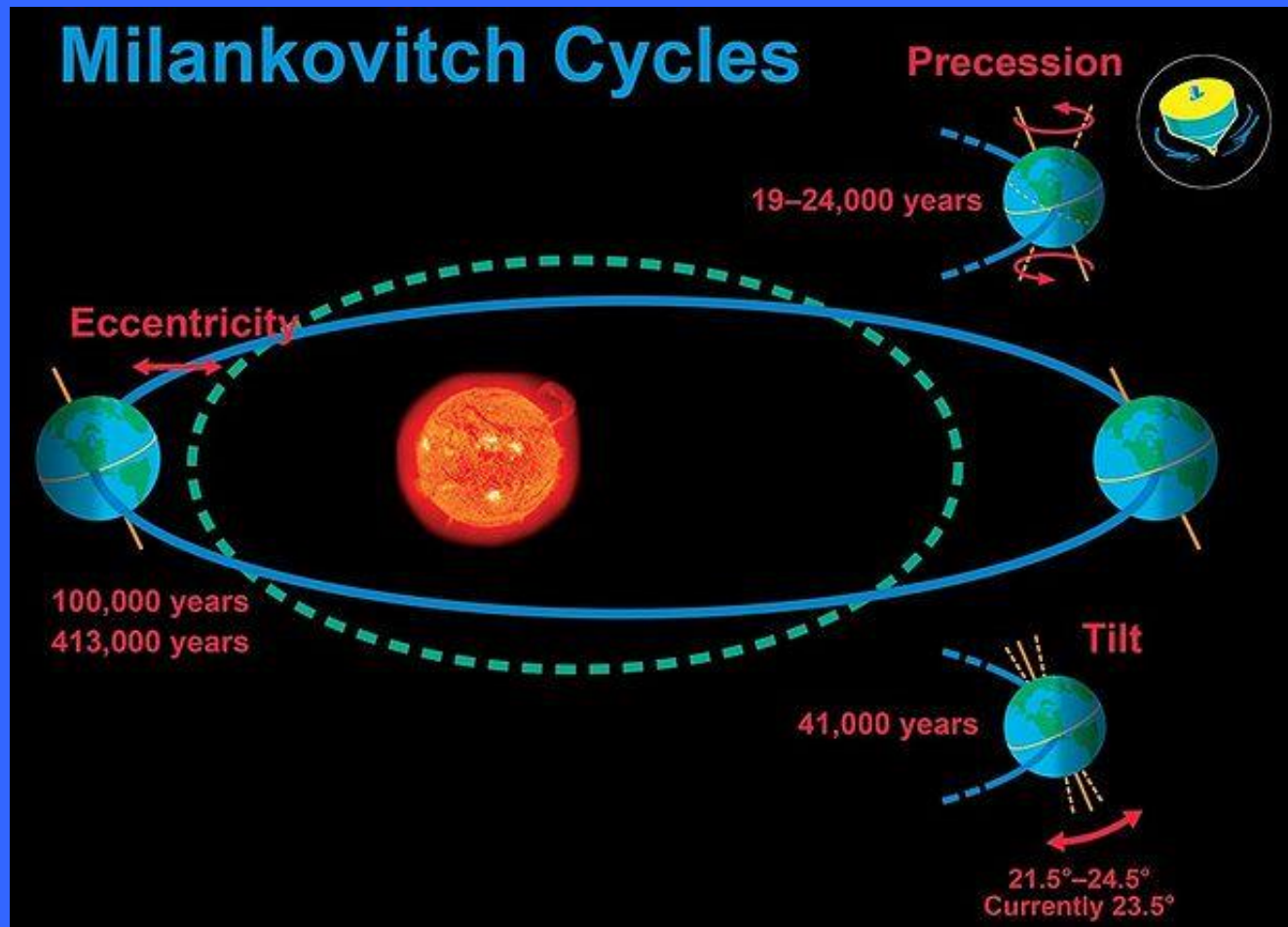
Increased production of condensation nuclei via ionization =

Increased cloud cover =

Increased albedo =
cooler regime



Milankovitch Theory: Orbital induced climate forcing: Variations in earth / sun geometry = variations in solar insolation = 3 oscillations



Solar Variability:

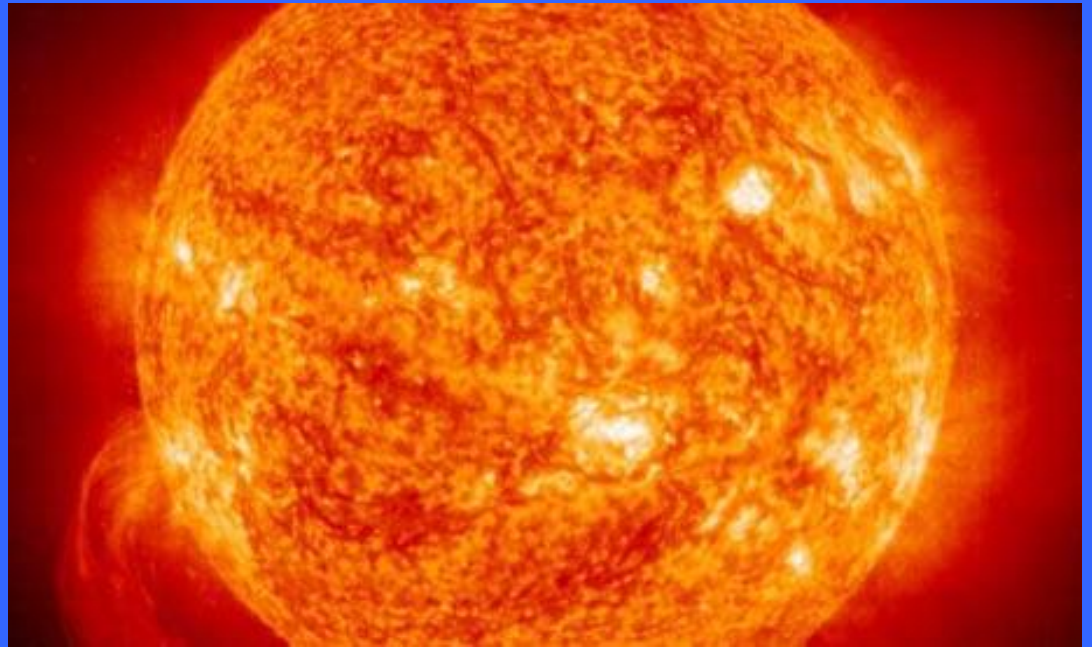
Solar constant =

1365 w/m²

Sunspot cycle: 11 yrs

Increase = increase solar output = warmer regimes

Decrease = decrease solar output = cooler regimes (“Little Ice Age” 13th – 19th century)



Bolloid Impacts

Injection of dust particles, ash, and aerosols = *increased* albedo = *decrease* in global mean temperature

Example: KT

Extinction 65 ma / bp
(Cretaceous / Tertiary
boundary



Plate tectonics: Volcanism

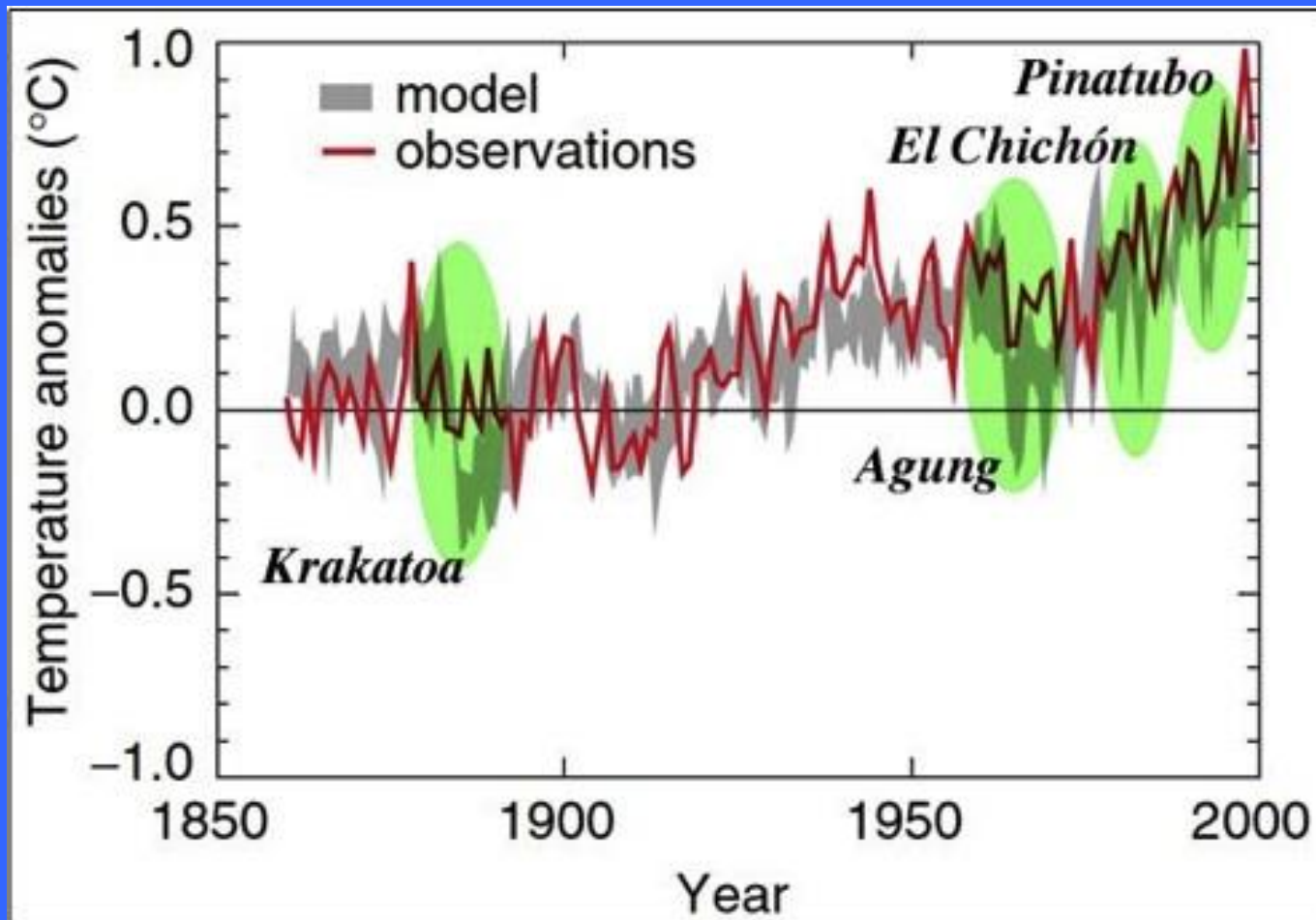
Injection of greenhouse gases e.g. $\text{CO}_2 + \text{CH}_4 =$ *warmer regime* (Deep historic 100 – >1000 x present levels?)

Injection of ash, aerosols = increase atmospheric albedo = *cooler regime*

Vegetation = CO_2 Draw down

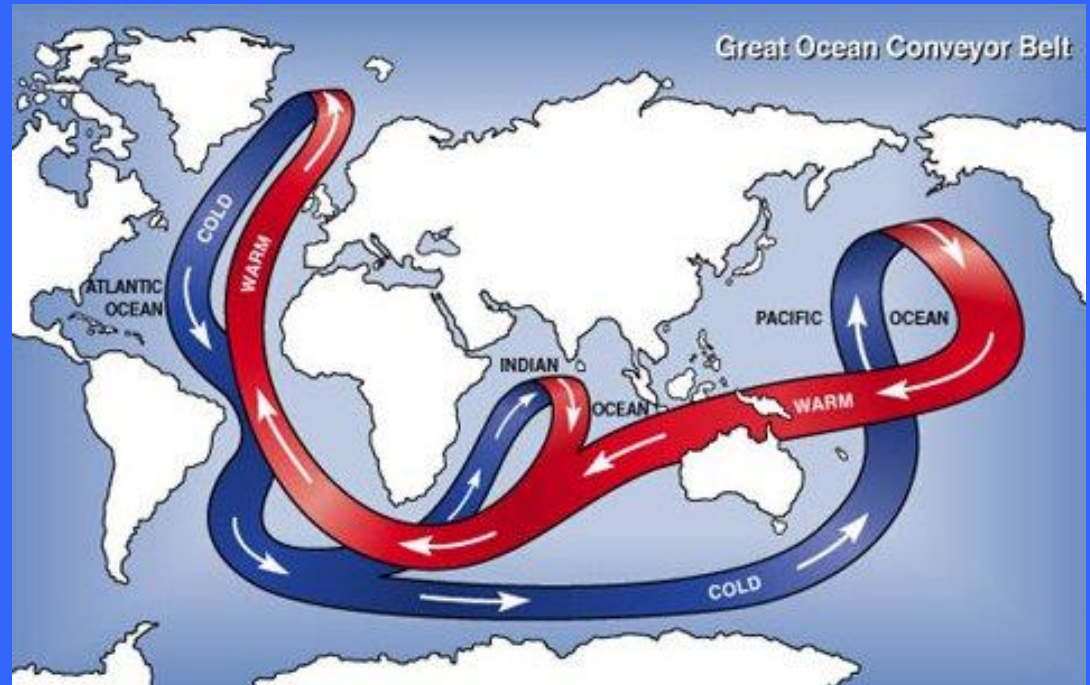


Four Major Volcanic Events 19th – 20th century



Ocean Currents

- Global circulation and distribution of temperature.
- Tectonic changes result in shifts / redistribution of temperature
- Coupled with atmospheric circulation e.g. Atlantic / Pacific gyres
- Sensitive to changes in thermohaline fluctuations



Archean Eon:

4 ba

(billion annum before present)

Dim Sun Hypothesis

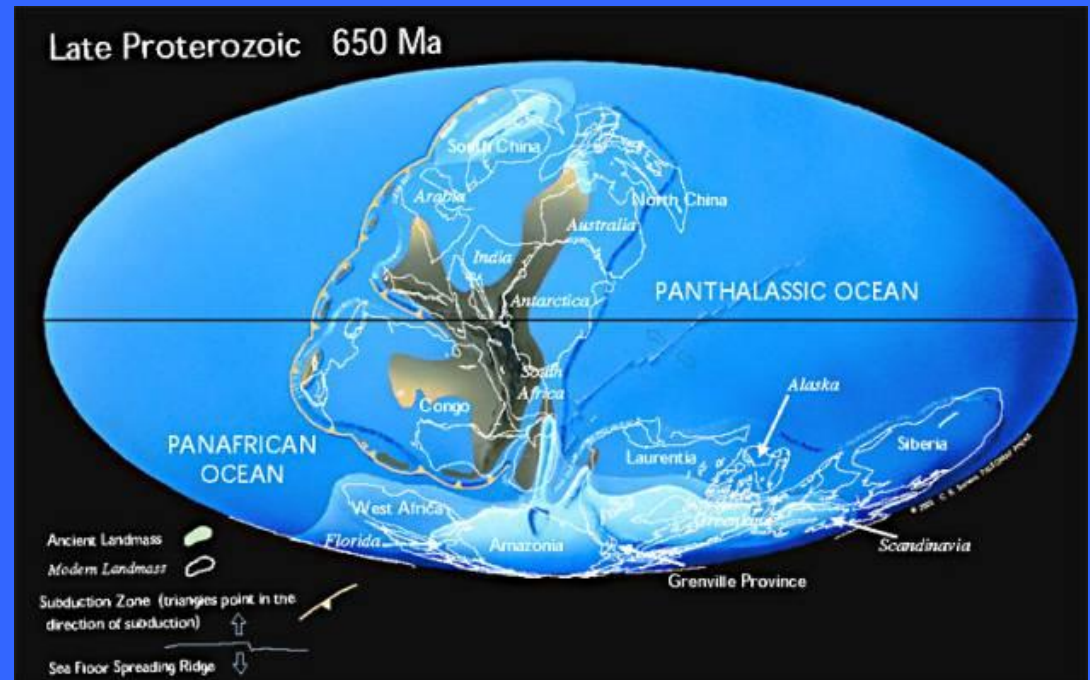
- Solar output = 30% less than present
- Greenhouse gas saturation overcompensates
- CO = 380.000 ppm(?)
- Mean global surface temp = 140 f (?)



Proterozoic Eon

850 ma bp – 650 ma bp

- Formation of Rodinia
- Oscillations: Global glacial / hot house regimes
- i.e. Snowball (Slushball?) Earth:
- Complete (partial) global glaciation



Snowball Earth

Top:

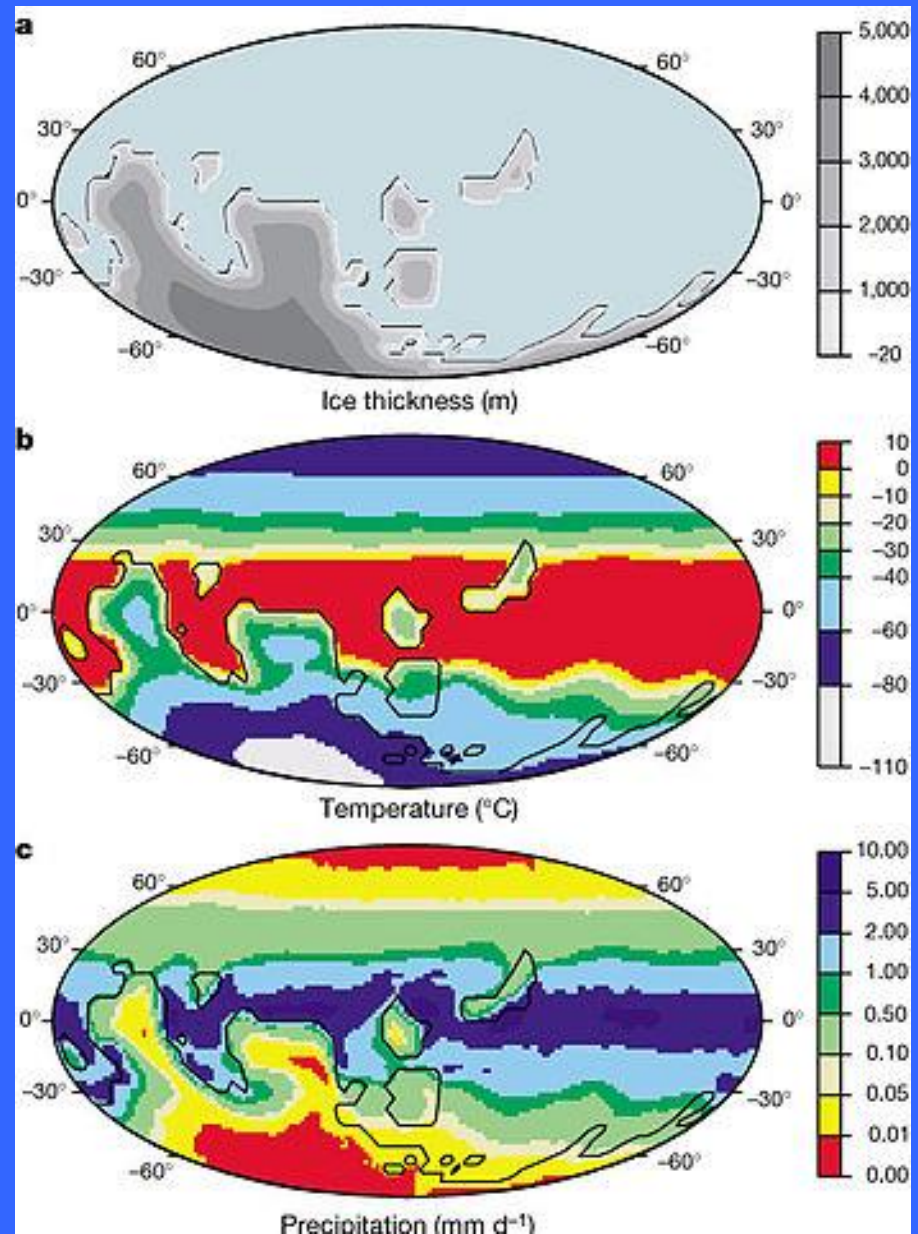
Ice thickness 0 – 5,000 m

Center:

Temperature -110 – 10°C

Bottom:

Precipitation 0 – 10,000 mm



Snowball Earth Hypothesis

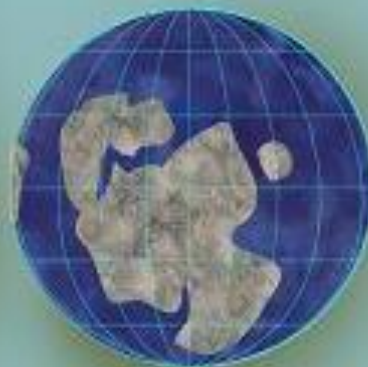
716 ma bp – 630 ma bp

Dynamic Snowball: two long-lived glaciations



Lots of ash in air from volcanic eruption cools Earth

716.5 MYA



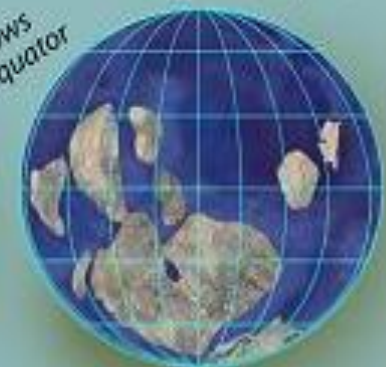
Ice-free hot-house

670 MYA



635 MYA

Ice flows to Equator



630 MYA

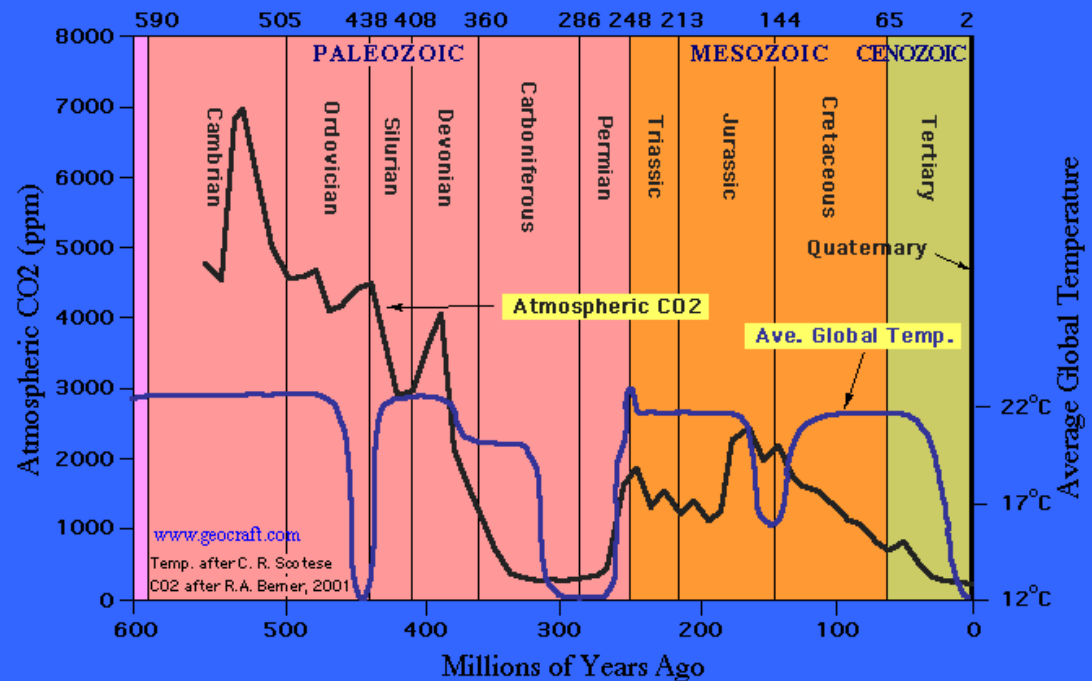


Phanerozoic Era

Temp / CO₂

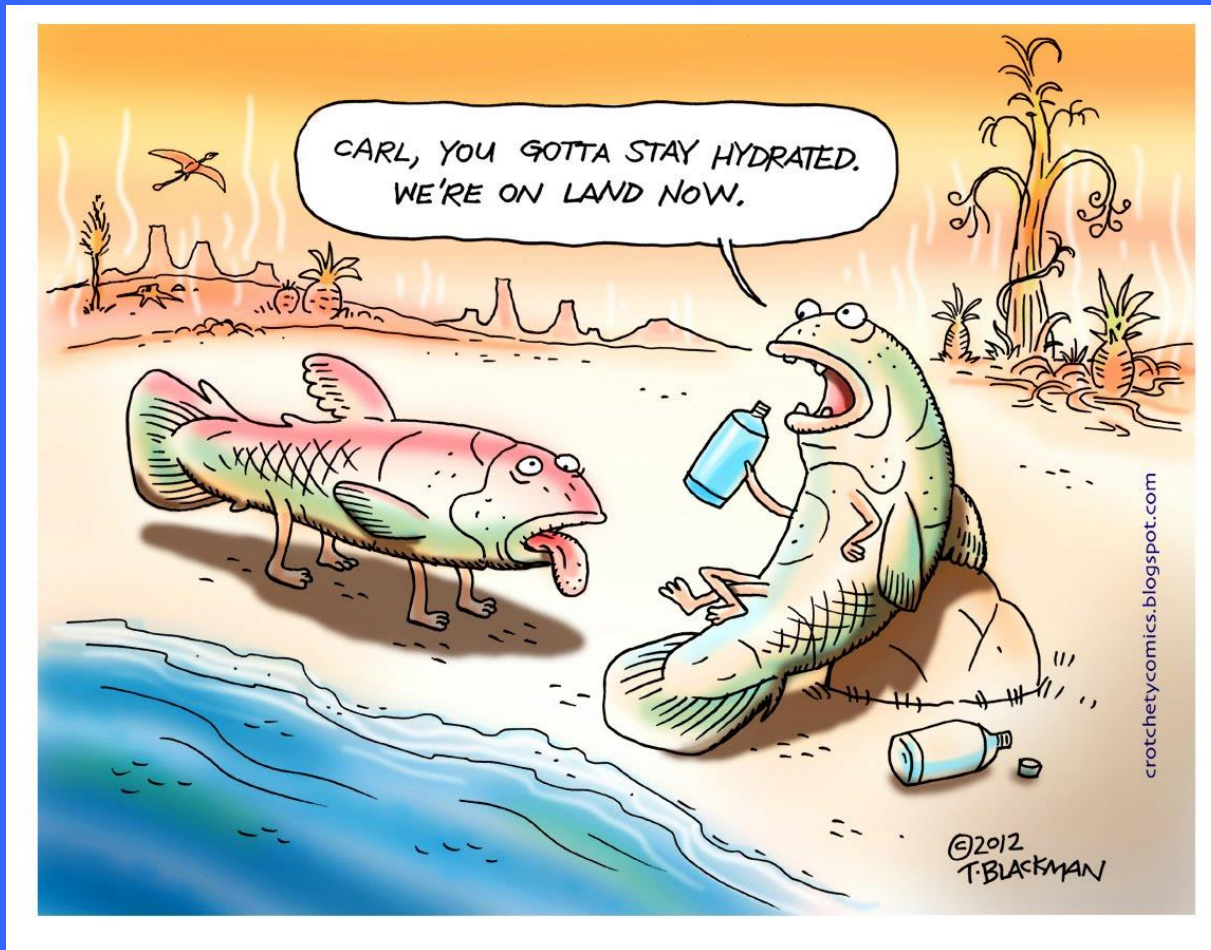
Graph (Geocarb III)
reflects additional climate forcings:

- Milankovitch Cycles
- Solar variability (-4%) during Cambrian = higher threshold for glaciation (e.g 3000 ppm)
- Increase vegetation = Increase CO₂ down draw



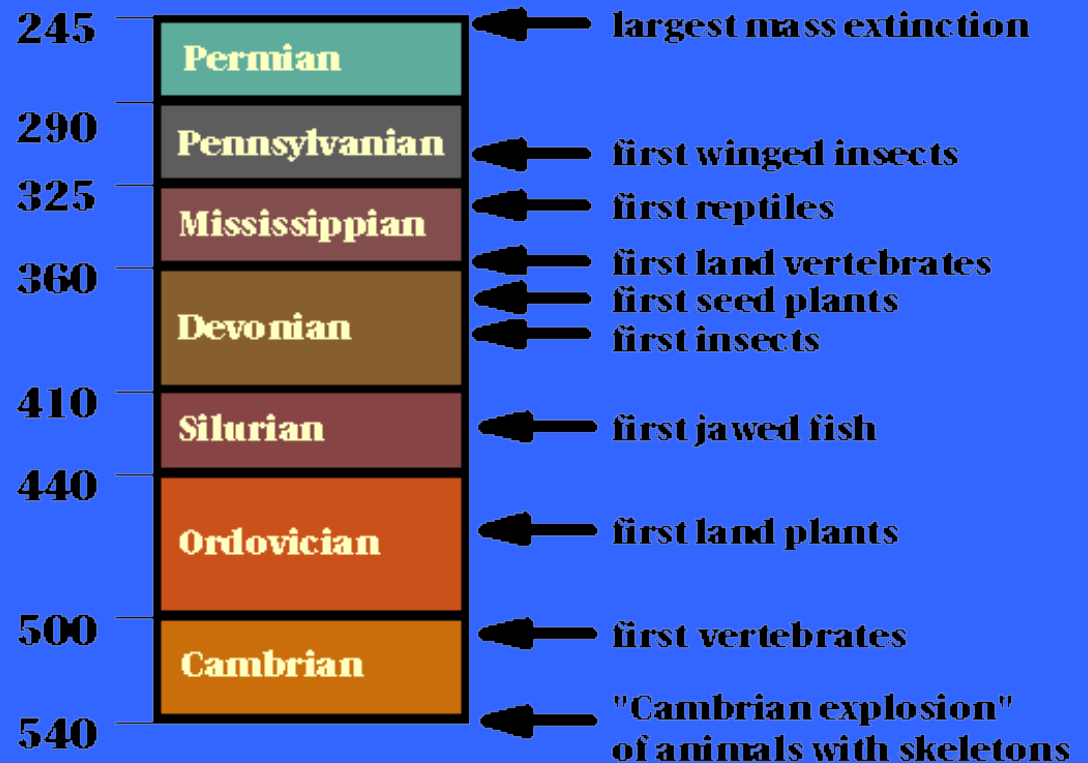
Paleozoic Era

543 ma bp = 245 ma bp



Paleozoic Era

- Oscillations between warm (dry) and cold (glacial regimes)
- Two significant extinction events e.g. Permian.
- Carboniferous 398 ma bp – 298 MA BP (significant biomass – contemporary significant petroleum resources)



Cambrian 543-490

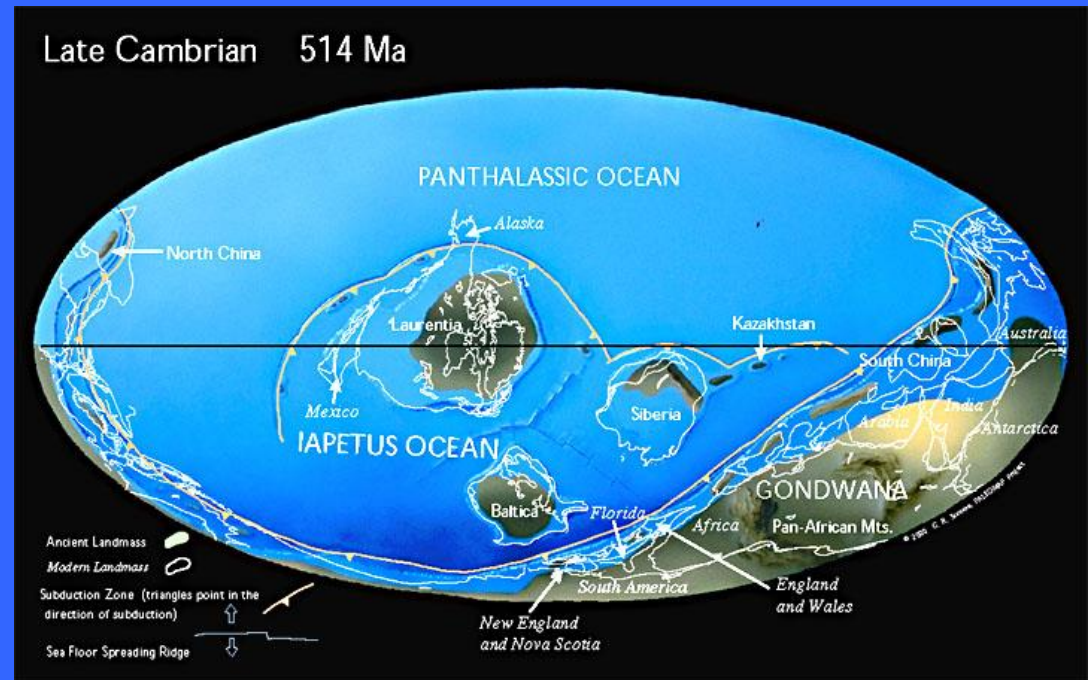
ma BP: Warm

Break up of Rodinia

**Allows free circulation
of Arctic waters =
Ice free earth =**

**Elevated CO₂ (10,000
ppm)**

Warm regime



Ordovician Period

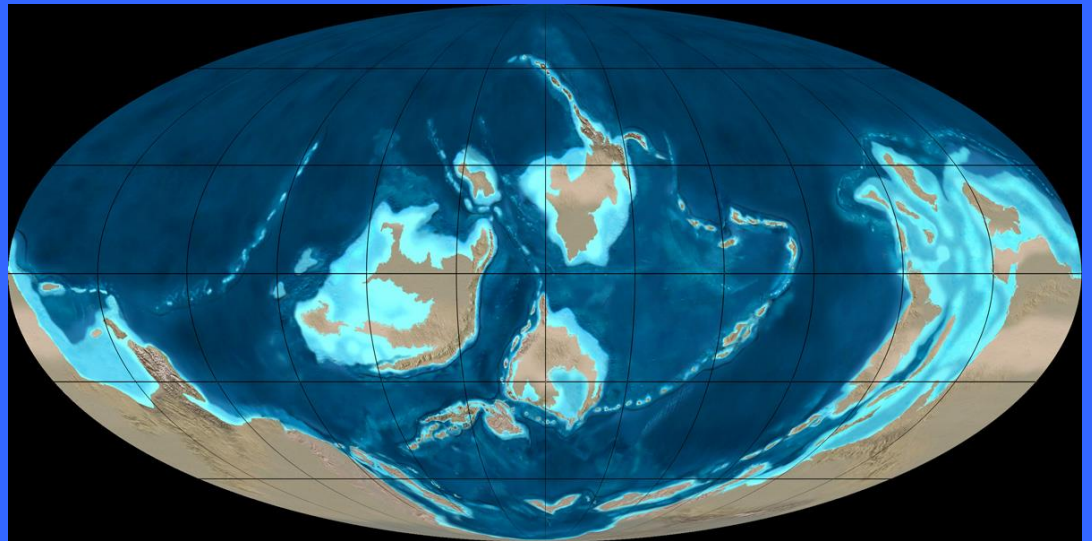
490 ma bp – 443 ma bp

Warm - Cold

445 ma bp: Significant
Glacial Event

Forcings:

- 1) *Orbital* (Shift in earth sun geometry via Milankovith cycle.
- 2) *Plate tectonics:*
Gondwana shift
toward the southern
latitudes = increased
albedo = rapid global
heat loss



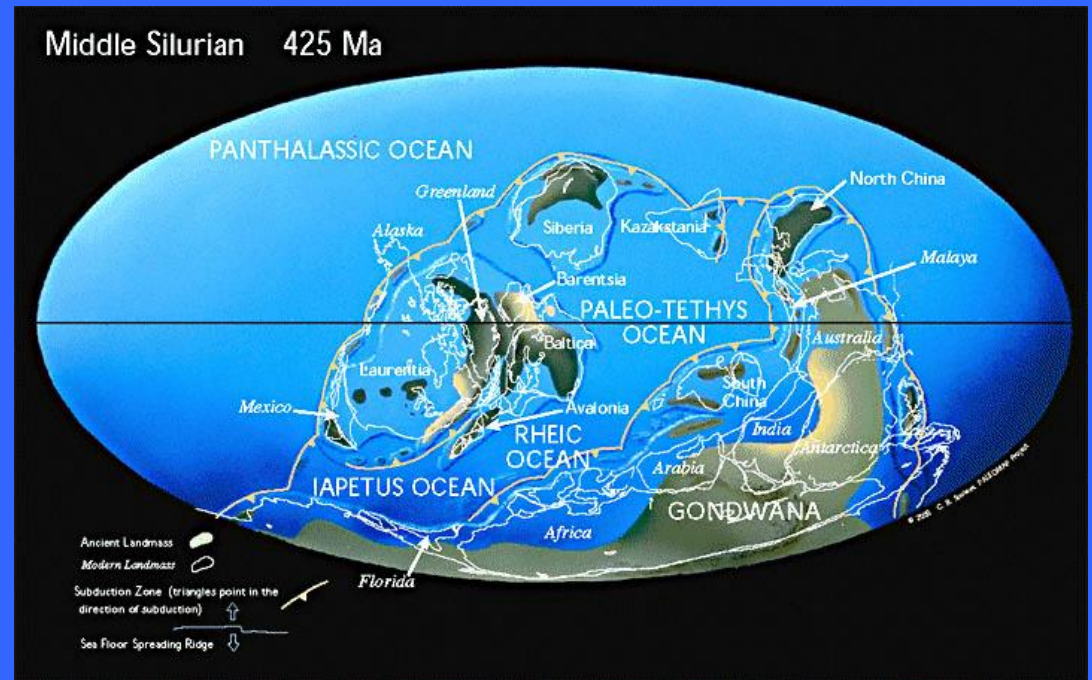
Silurian Period

443 ma bp – 417 ma bp

Greenhouse gas forcing = long, warm, stable regime.

Gondwana continues to shift toward the equator.

Glaciers nearly vanish



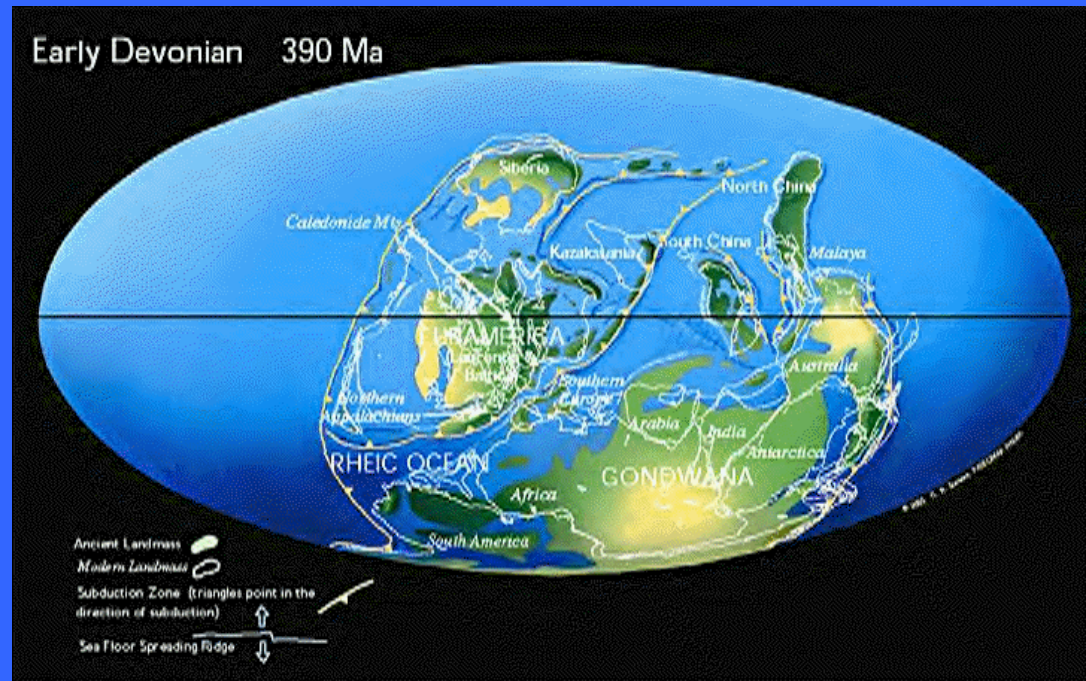
Devonian Period

417 ma bp – 354 ma bp

Shifting of Gondwana toward equator =

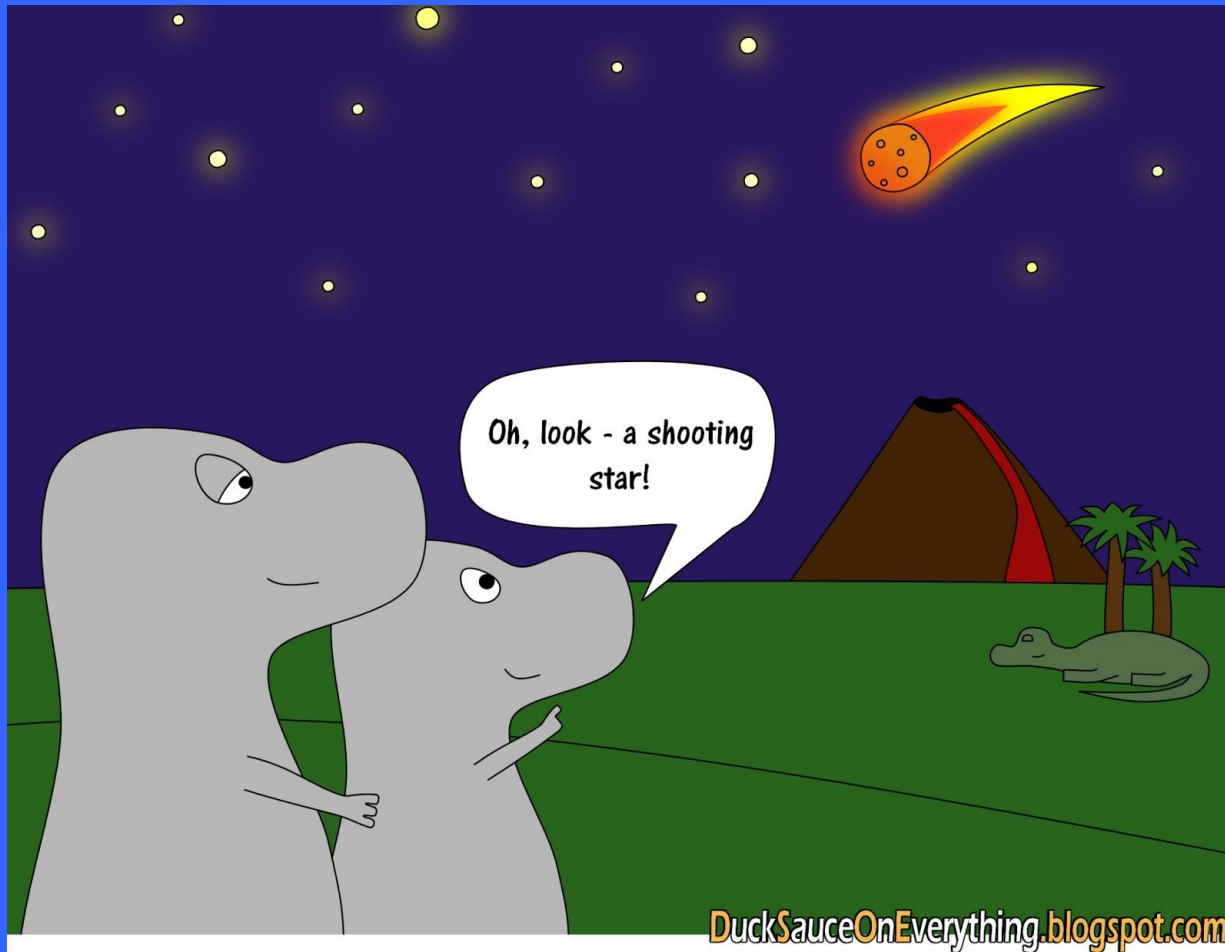
Warmer, drier, more stable regime

End of mass extinctions (bolloid impacts?)



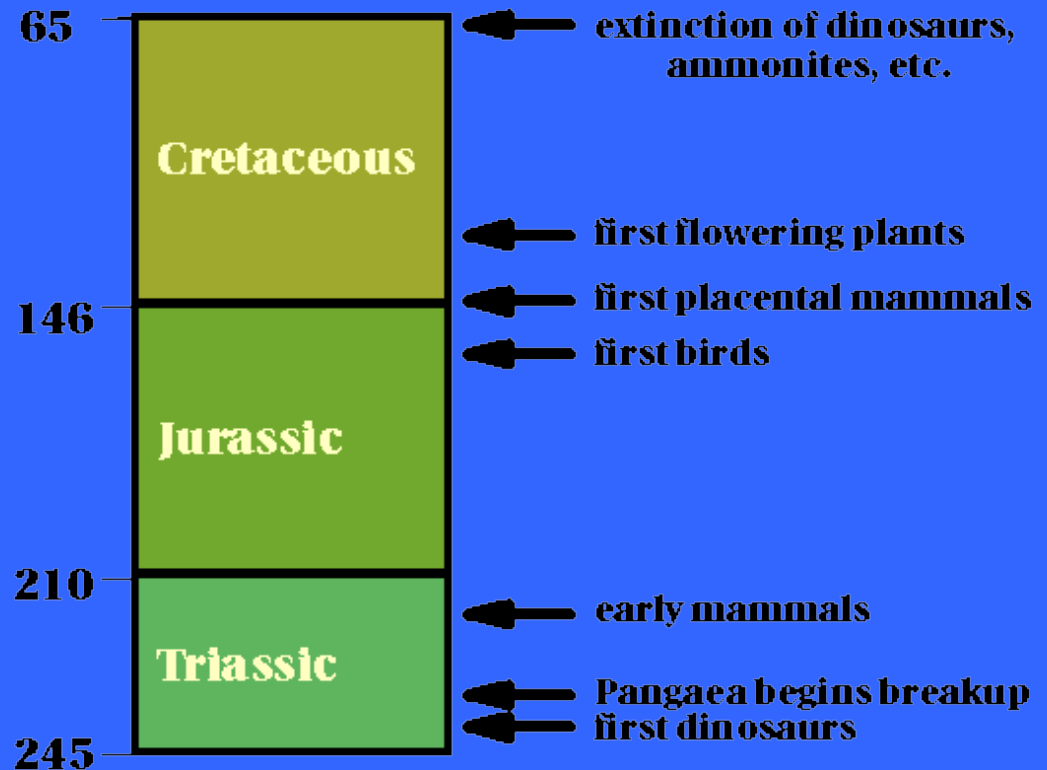
Mesozoic Era

245 ma bp - 65 ma bp



Mesozoic Era

- Warmest era of the Phanerozoic Eon
- SST 33c – 42c
CO₂ max 6500 ppm
- Equator – Pole ΔT 19c - 23c
- OAEs (Ocean Anoxic Events)
- Major extinction event K/T boundary (Bolloïd impact)



Cenozoic Era: Temperature extremes for all!

Paleo-Eocene Thermal Maximum 55
- 53 ma bp



Pleistocene Glacial Maxima (4)
1.8 ma – 10,000 ka bp



Cenozoic Era

65 ma: Rapid warm up after K/T extinction event.

Forcing: Increase GHG

54 ma: PETM (Paleo-Eocene Thermal Maximum) $\Delta T +8c - +10c$

Forcing: Methane hydrate due to increased tectonic activity

38 ma: Olig Cenozoic decline commences = ice caps

13 ma:

Era	Period	Epoch	Time Scale	
CENOZOIC	QUATERNARY	HOLOCENE	Present	
		PLEISTOCENE (ICE AGE)	10,000 years ago	
	TERTIARY	NEOGENE	PLIOCENE	1.8 million years ago
			MIOCENE	5.3 million years ago
		PALEOGENE	OLIGOCENE	23.8 million years ago
			EOCENE	33.7 million years ago
			PALEOCENE	54.8 million years ago

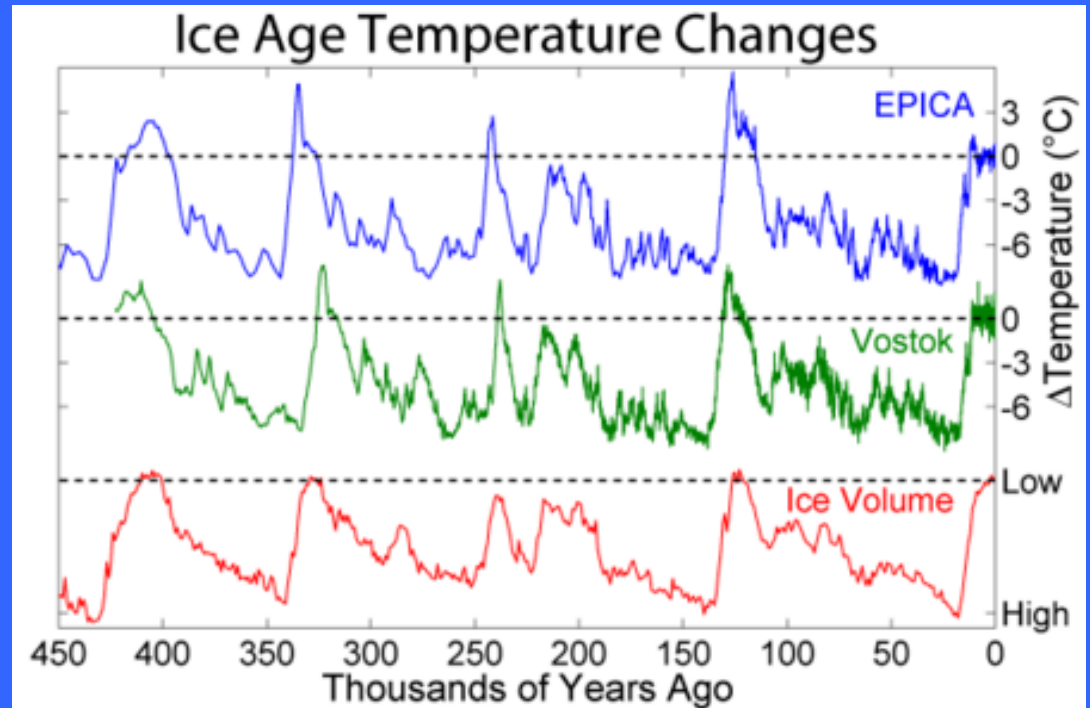
Pleistocene Epoch

2.58 ma – 11.7 ka

4 significant glacial excursions.

Mean surface temp -5 - -10 colder than present levels.

Forcings: Orbital coupled with internal (3 MA Formation of the Isthmus of Panama = shift in N. Atlantic MOD.)



Laurentide - Fenno Scandian Ice Sheet

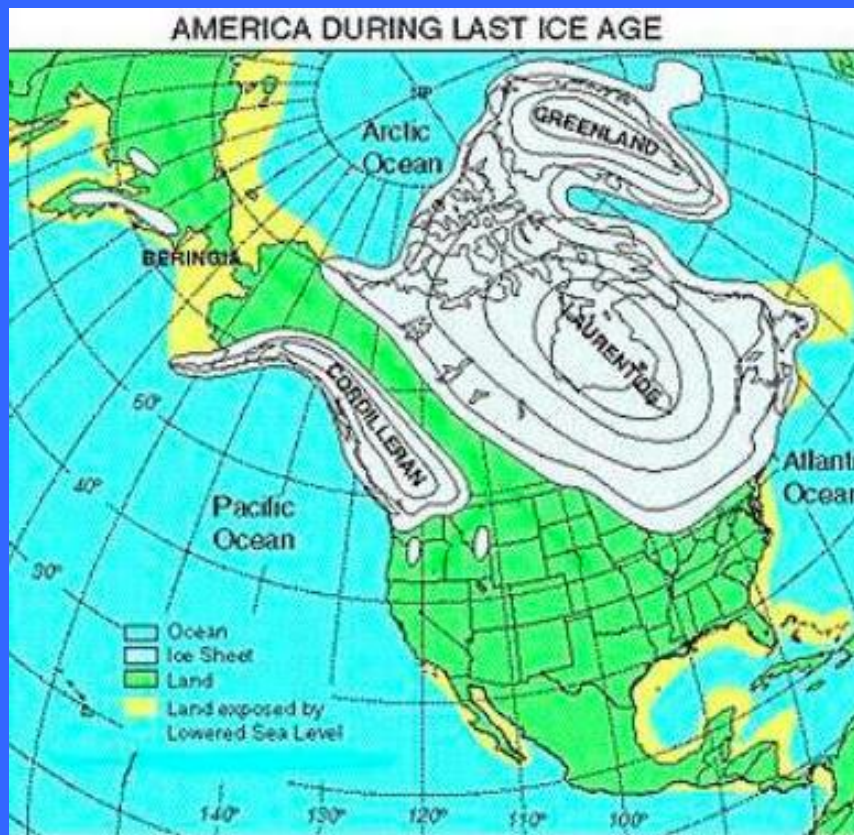
80,000 – 18,000 ka. The Cooling power of ice:

$$t + kR^2 = hR$$

$T = -6$ Ice Edge / 0c Permafrost

Ice thickness $1.5 \times 10^3\text{m} - 3 \times 10^3\text{m}$

Area = $13 \times 10^7 \text{ km}^2$



NA Weather Pattern

Baroclinic zone along terminus = "glacial feeder"



So where was “global warming” when you needed it?

Have a little heat ICE MAN!



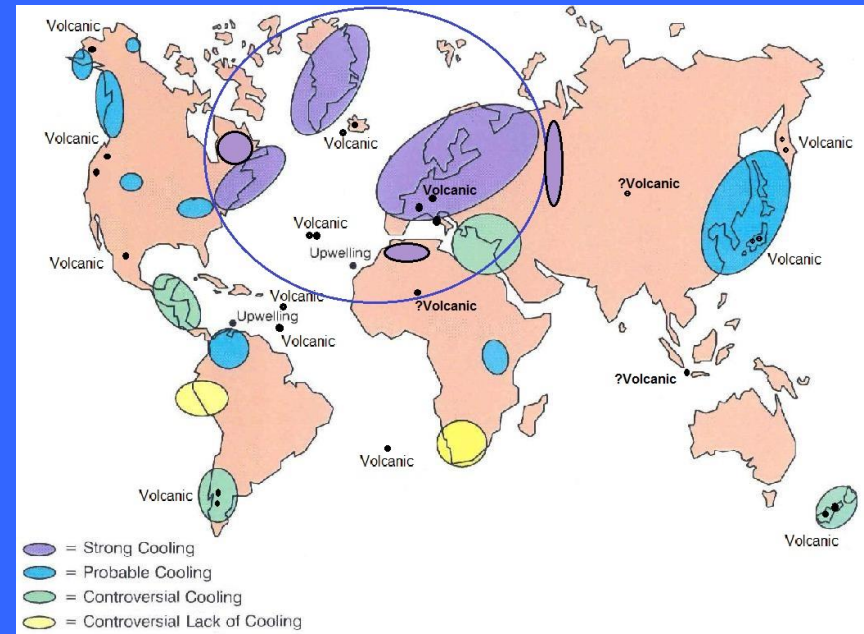
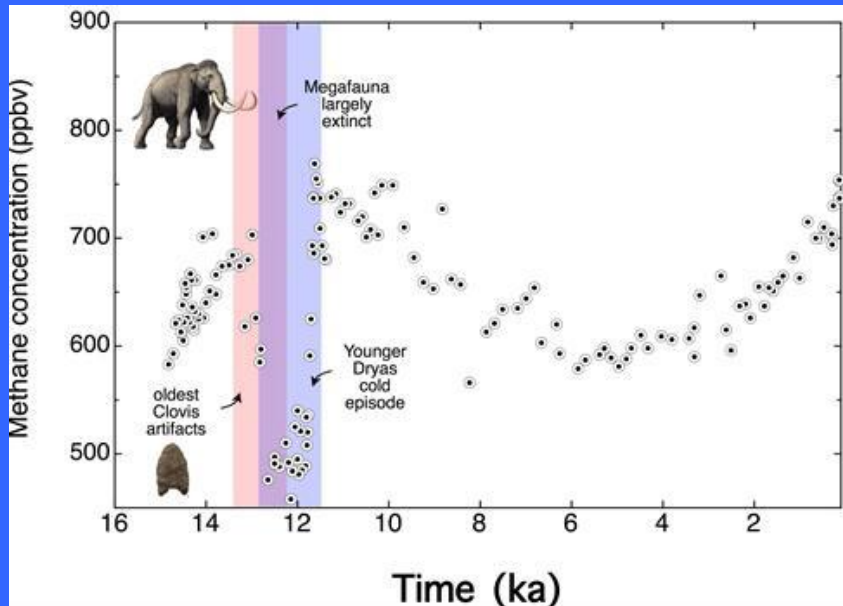
You're about 18,000 years too late dude! Just a little INCONVENIENT!



Younger Dryas Oscillation

Fresh water forcing = shut down of the N. Atlantic MOD

Cooling -5c - -10c arund the N. Atlantic Basin



The Younger Dryas Oscillation

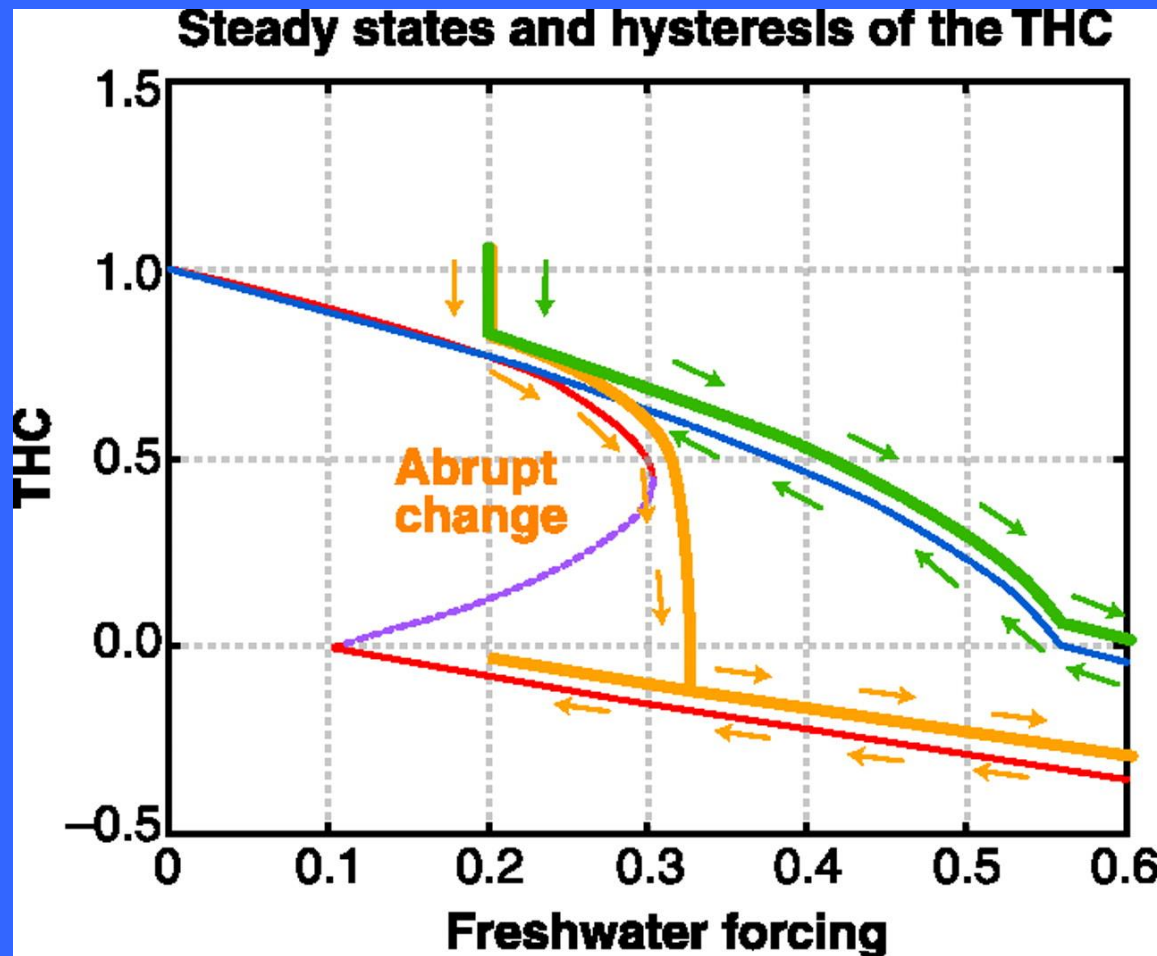
Orbital Induced (Precession) warming

Fresh water forcing = shut
down of the N. Atlantic MOD

Cooling -5c - -10c around the
the N. Atlantic Basin

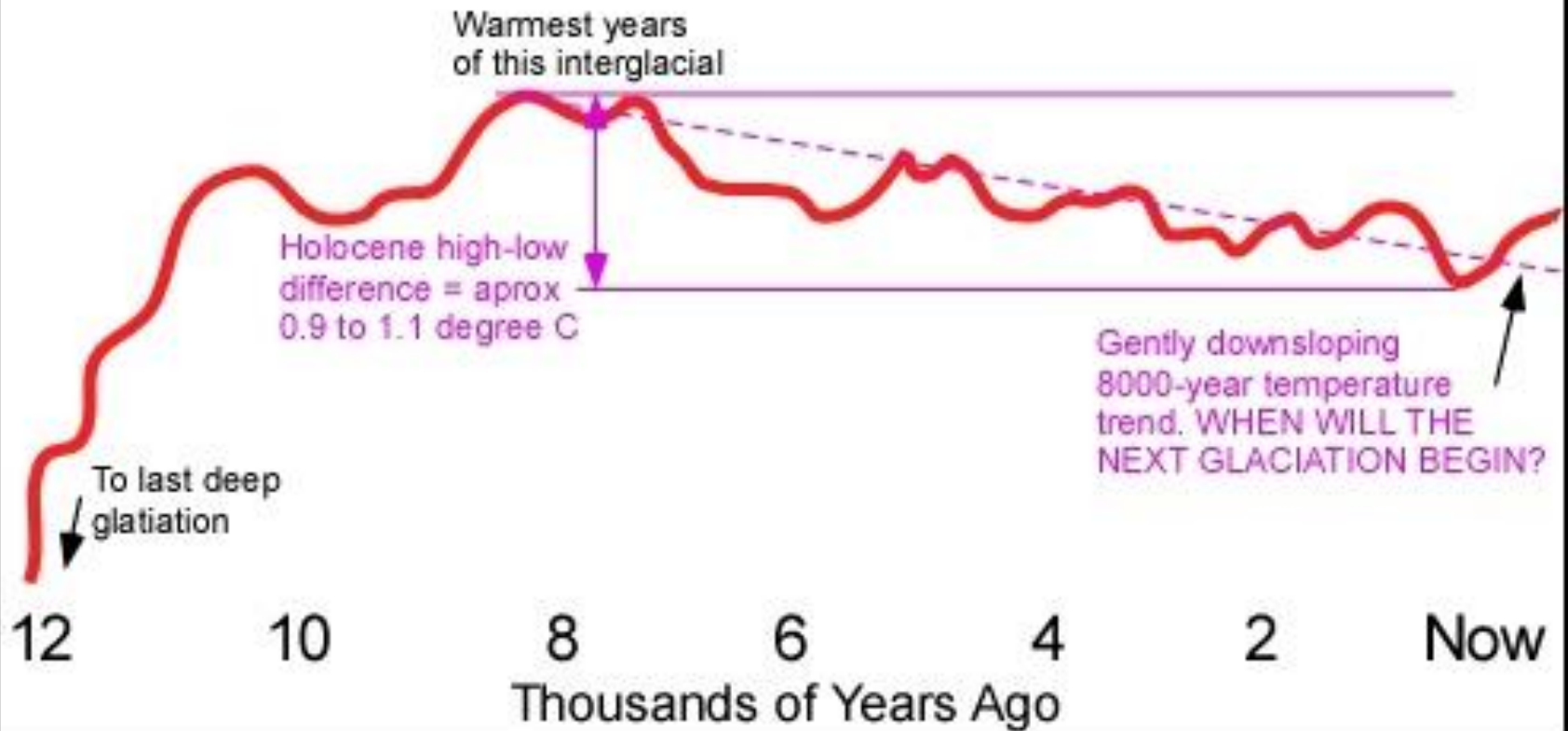


Hysteresis: N. A. Thermohaline Circulation

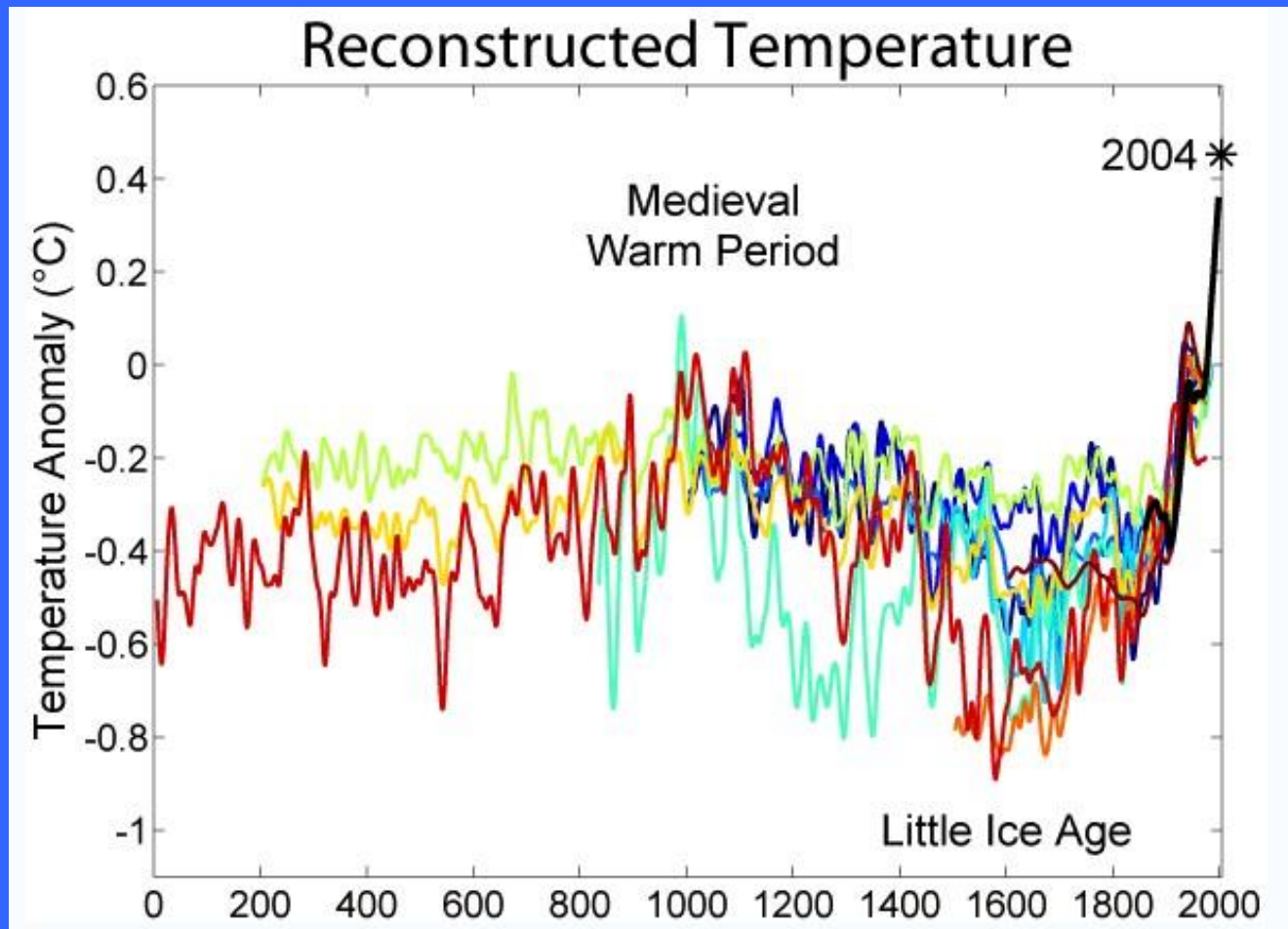


Global Mean Temperature

Holocene Interglacial - 12,000 Years



Late Holocene Epoch



Little Ice Age

1350 – 1850 A.D.

External Forcing:

Sunspot Activity:

Maunder, Dalton and
Spörer minima

Internal

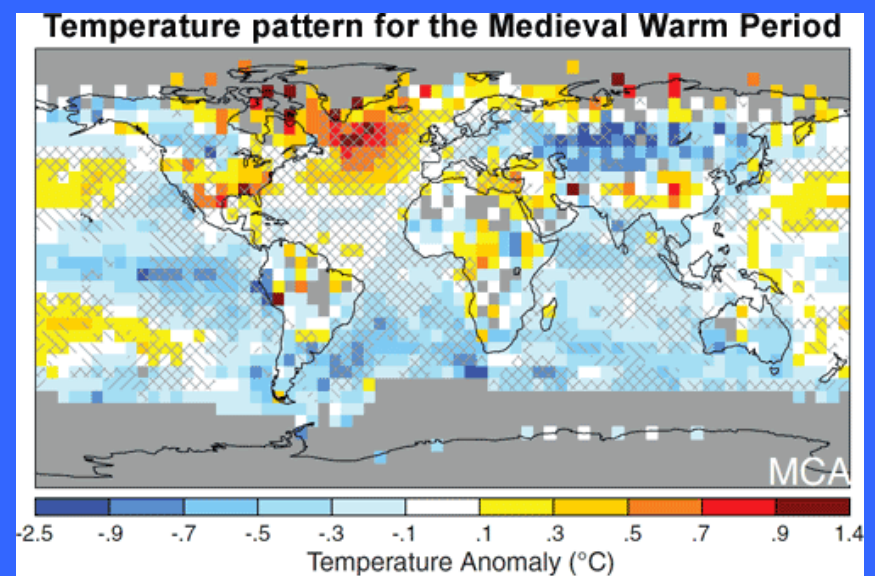
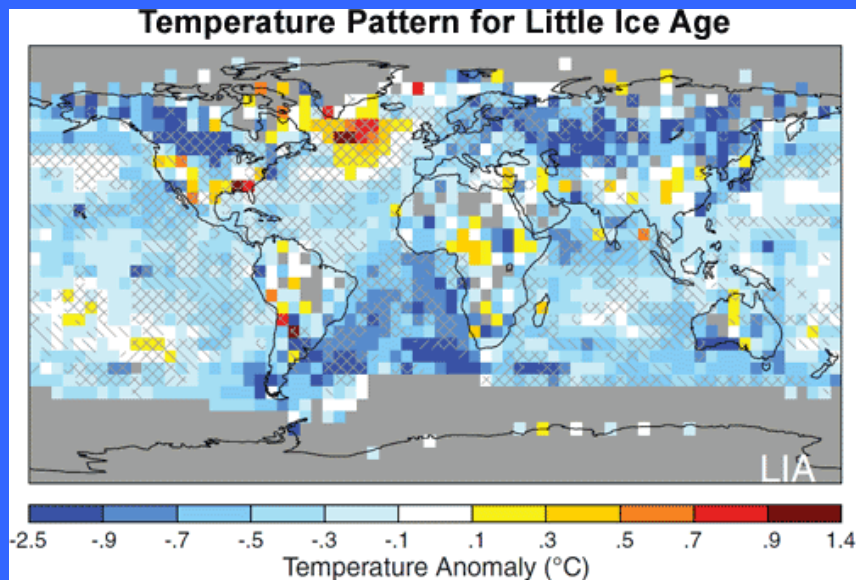
- Decrease in NAMOC
- Increase in volcanism
- Decrease in human population (agriculture) = increase CO₂ Draw Down



Late Holocene Climate Oscillations

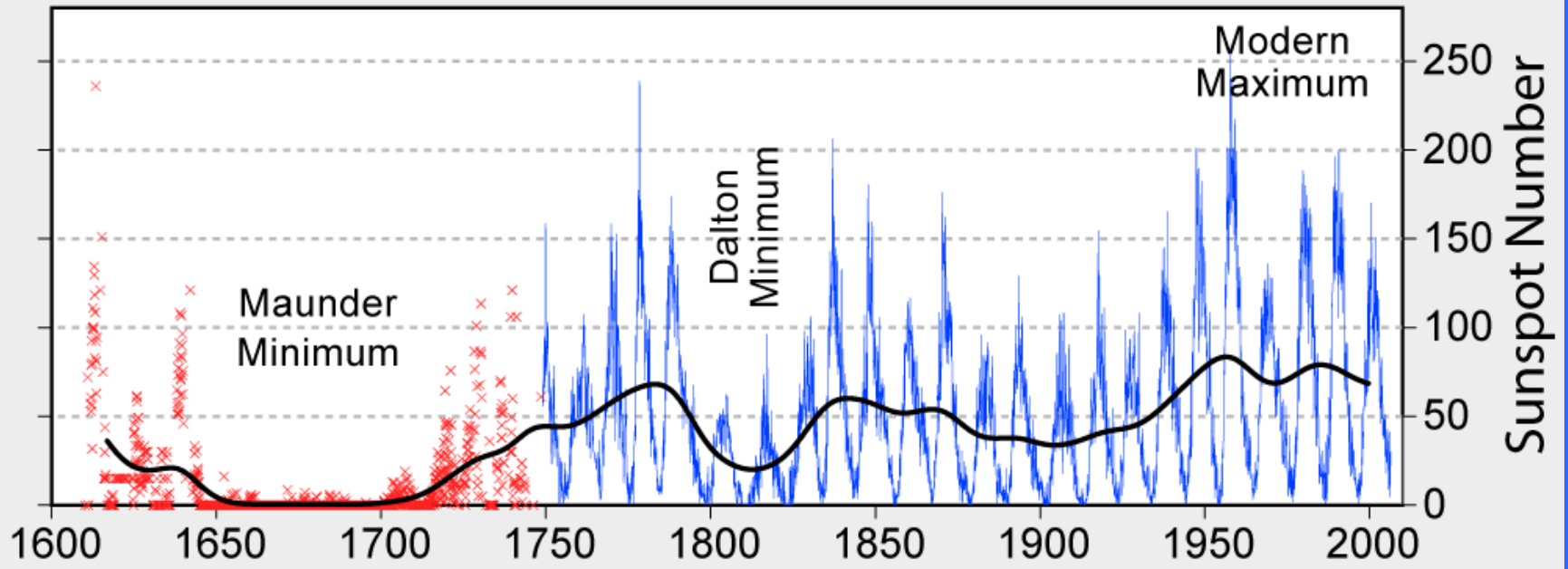
Little Ice Age 1400 – 1700
Maunder Sunspot Minima

Medieval Warm Period 950 – 1250
Prolonged La Nina?



LIA Solar Cycles

400 Years of Sunspot Observations

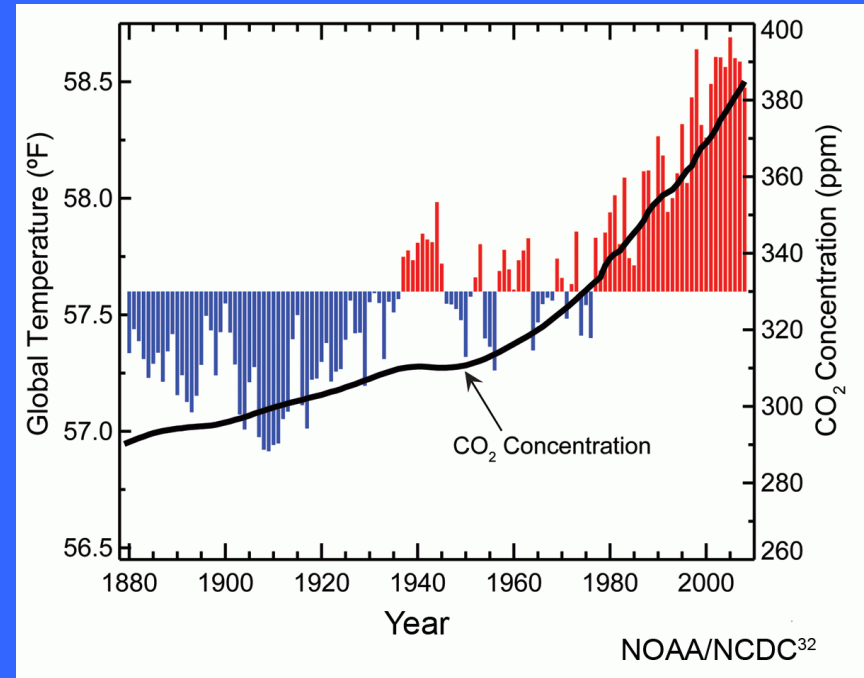


The Anthropocene

1850 - Present

“Human induced forcing” within the climate system / biosphere

$\Delta T / \Delta \text{CO}_2$ 1880 - 2005



Summary

Climate change:

*Stochastic interaction
of forcings as a function of
time:*

External (orbital)

Earth – sun geometry

Cosmic rays

Interstellar gas /dust

Internal (sub-orbital)

Biosphere - lithosphere

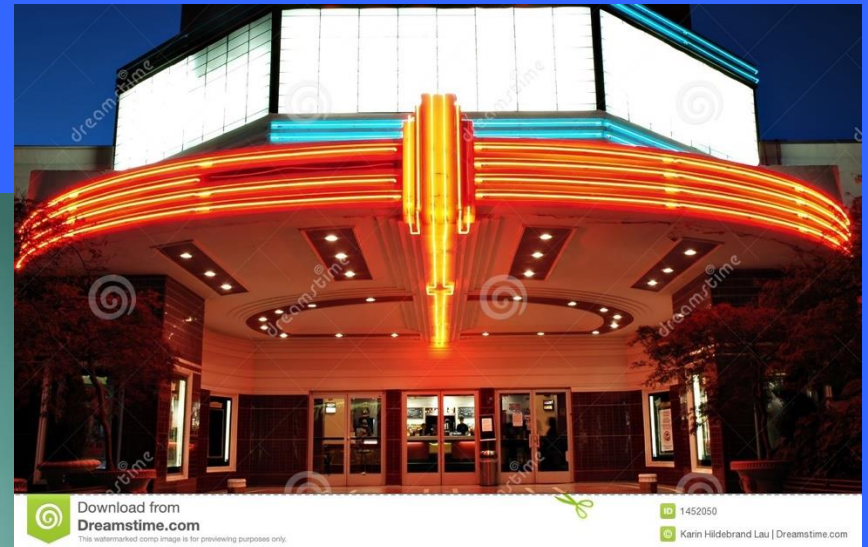
hydrosphere

= oscillations between
warm and cold regimes



Some Like It Hot! Some Like It Cold!

Coming to a theater near you!



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