Information from Paleoclimate Archives

IPCC AR5: CH 5

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ATM S 587

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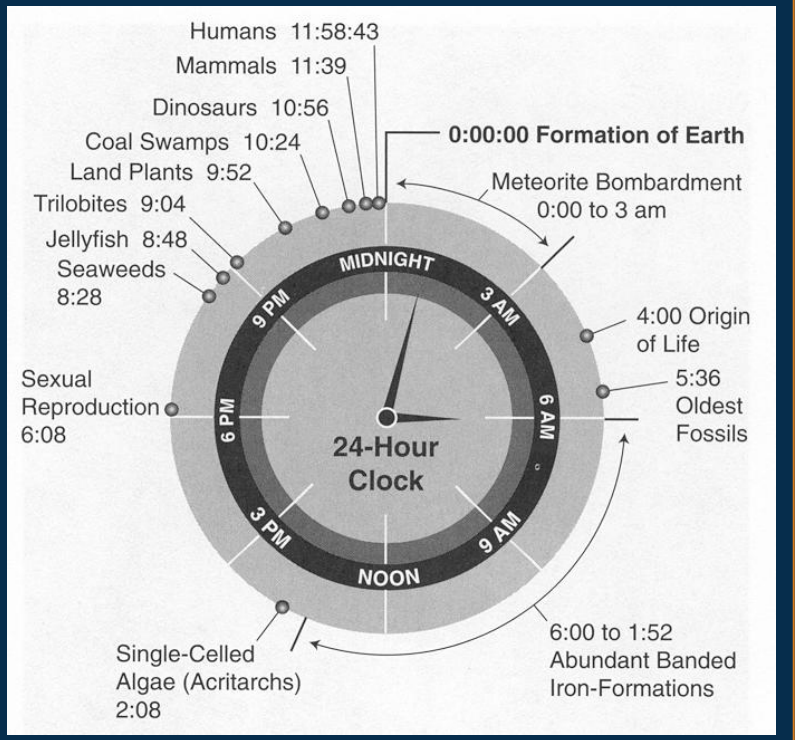
Raiders of the Lost Paleoclimate Archive

Introduction: What Future Lies in the Past?

- The Present is in the Context of the Past
  - Present is only fraction of whole
  - Similar Earth → Similar patterns and processes?
  - Want to get a "mountain top" view



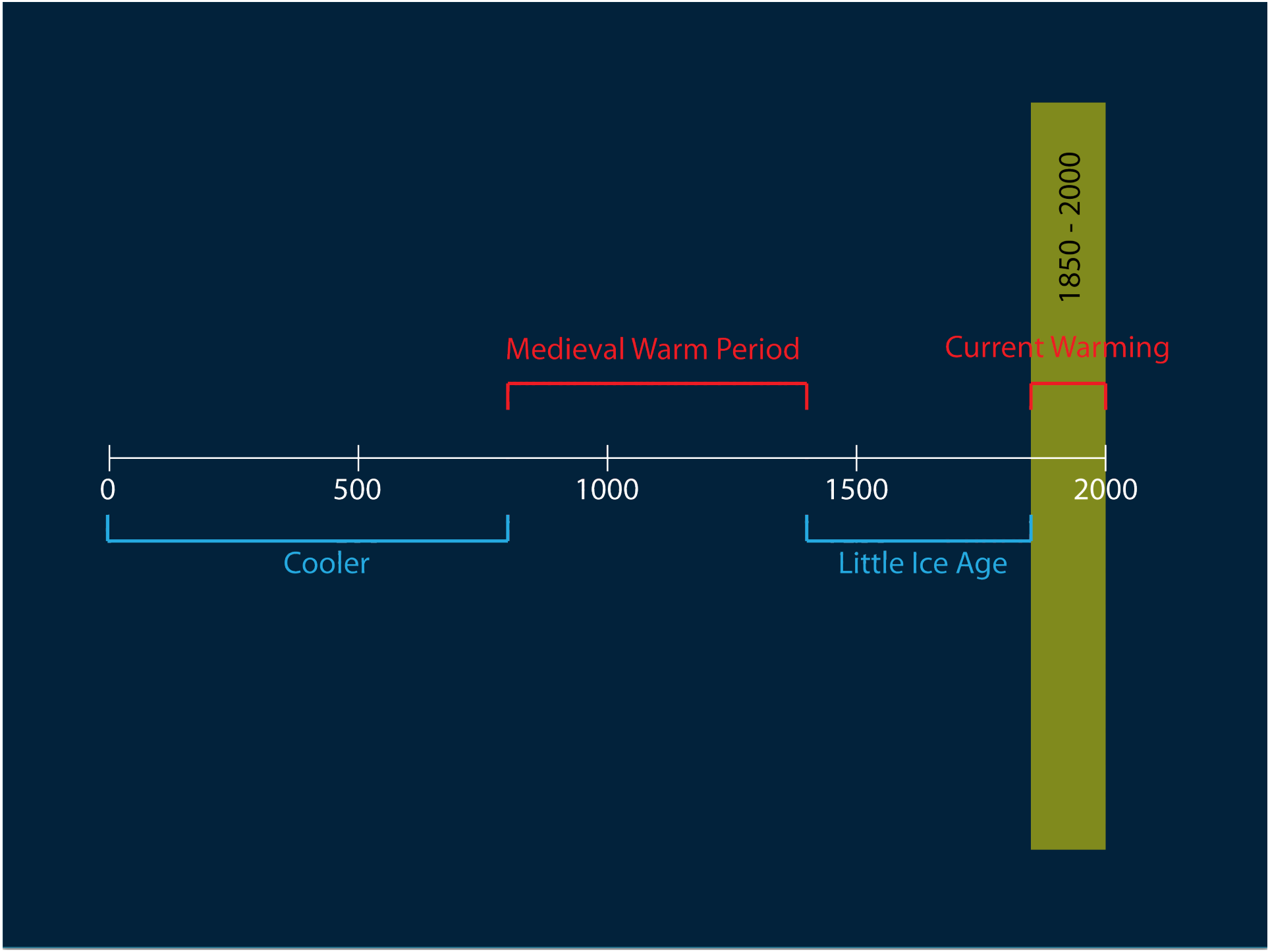
Introduction: What Future Lies in the Past?

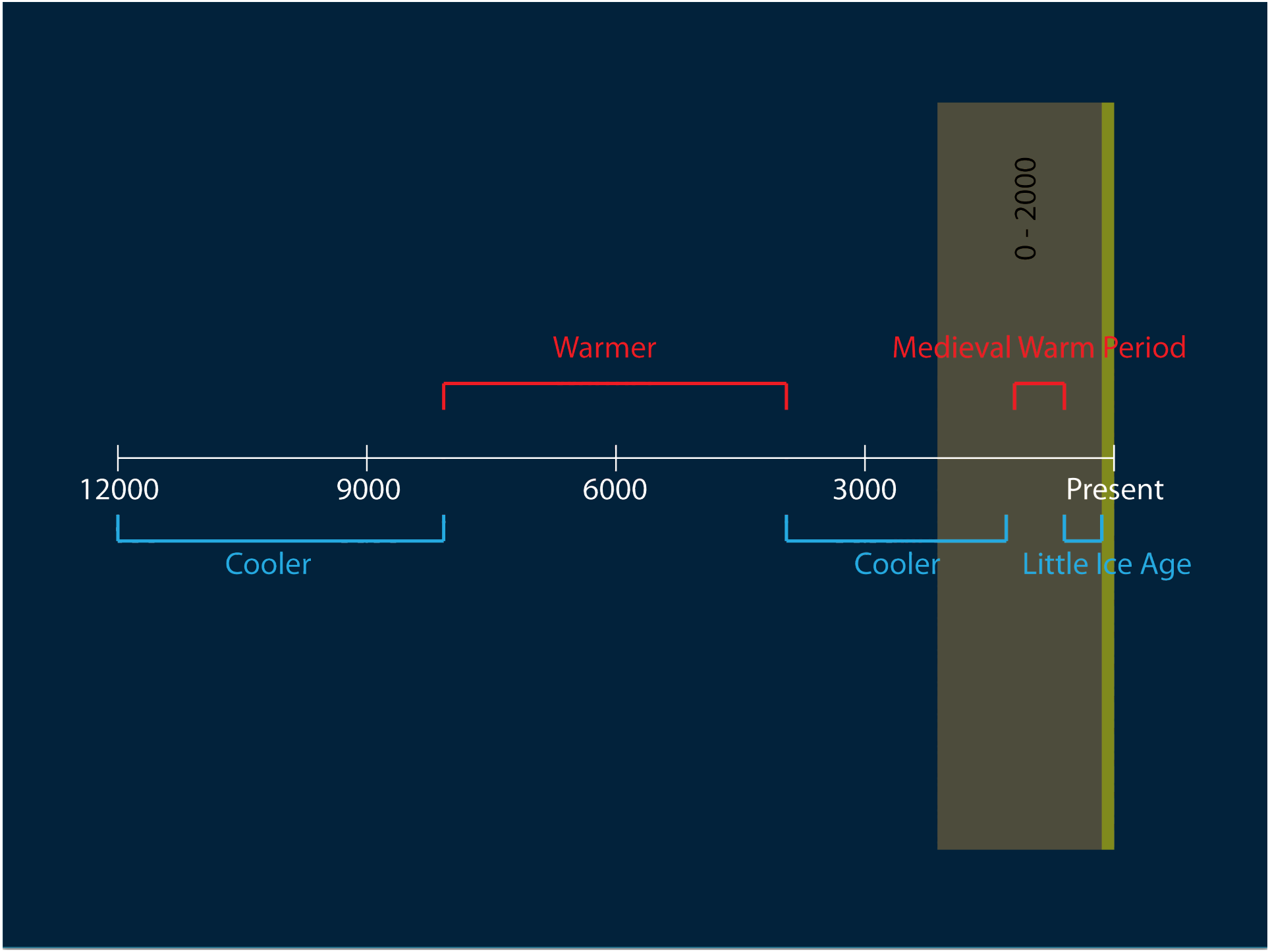
- Goals:
  - Gather proxies of past climate
  - Incorporate into models and theories
  - Use to understand present & predict future

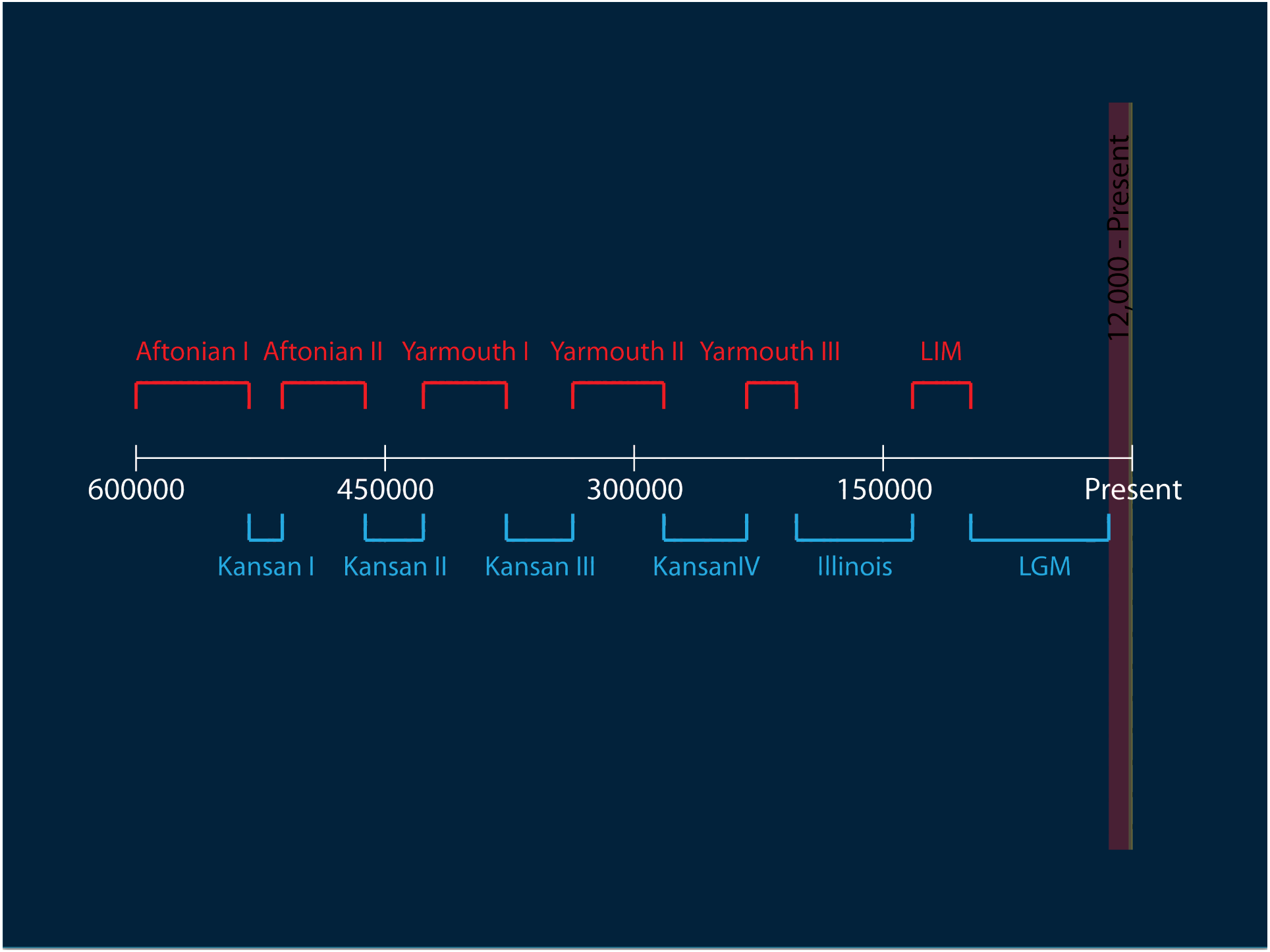
Outline

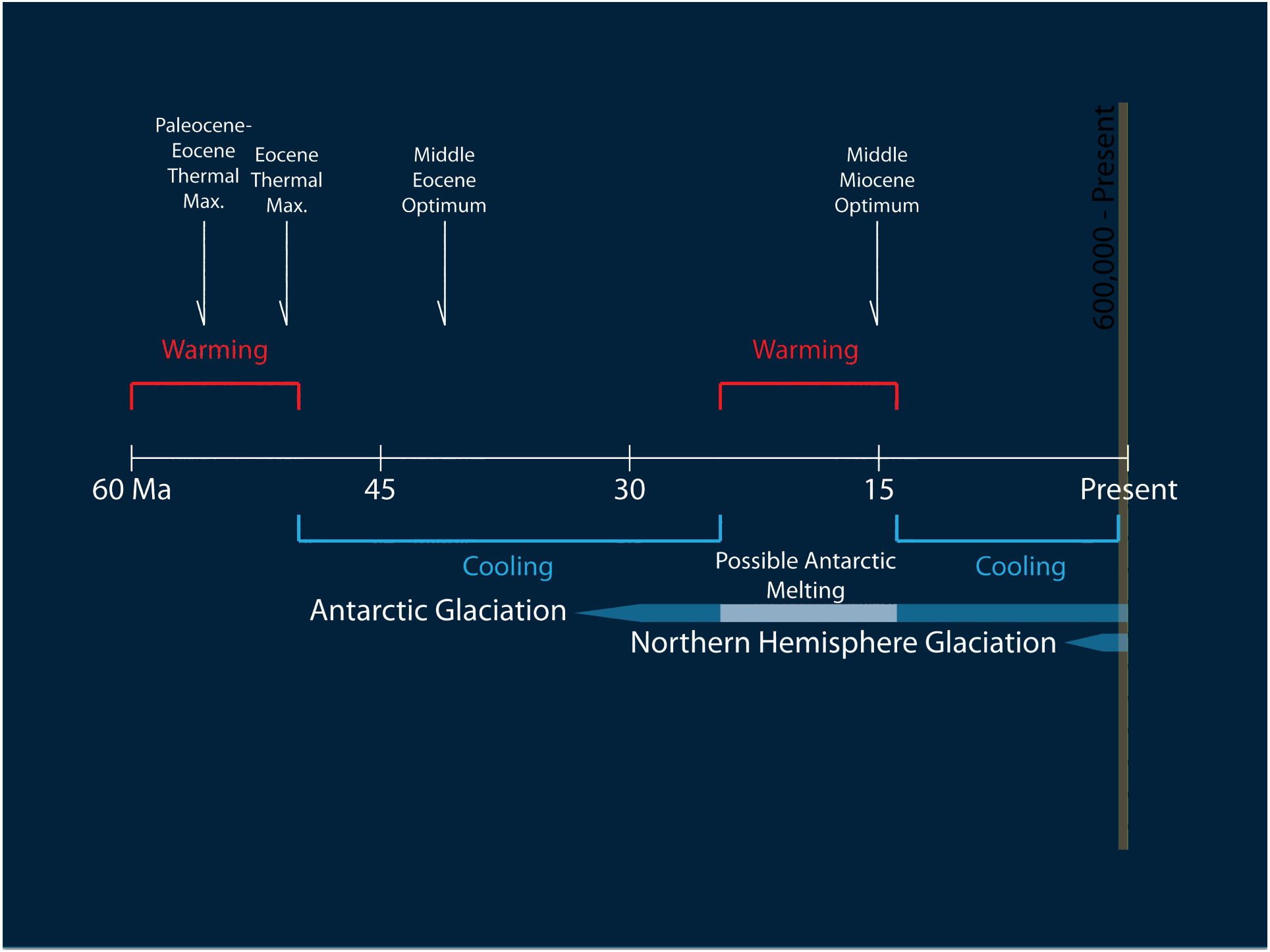
- Introductory Concepts
  - Geological periods
  - Proxies for past
  - Orbital forcing
- Brief Past/Present Comparison
  - Past values vs. current values/ rates
- In-Depth Look at Climate Variables
  - GHG concentrations
  - Temperature
  - Seal level
  - Precipitation
  - Cryosphere
  - Modes
- System Issues
  - Abrupt change
  - Irreversibility

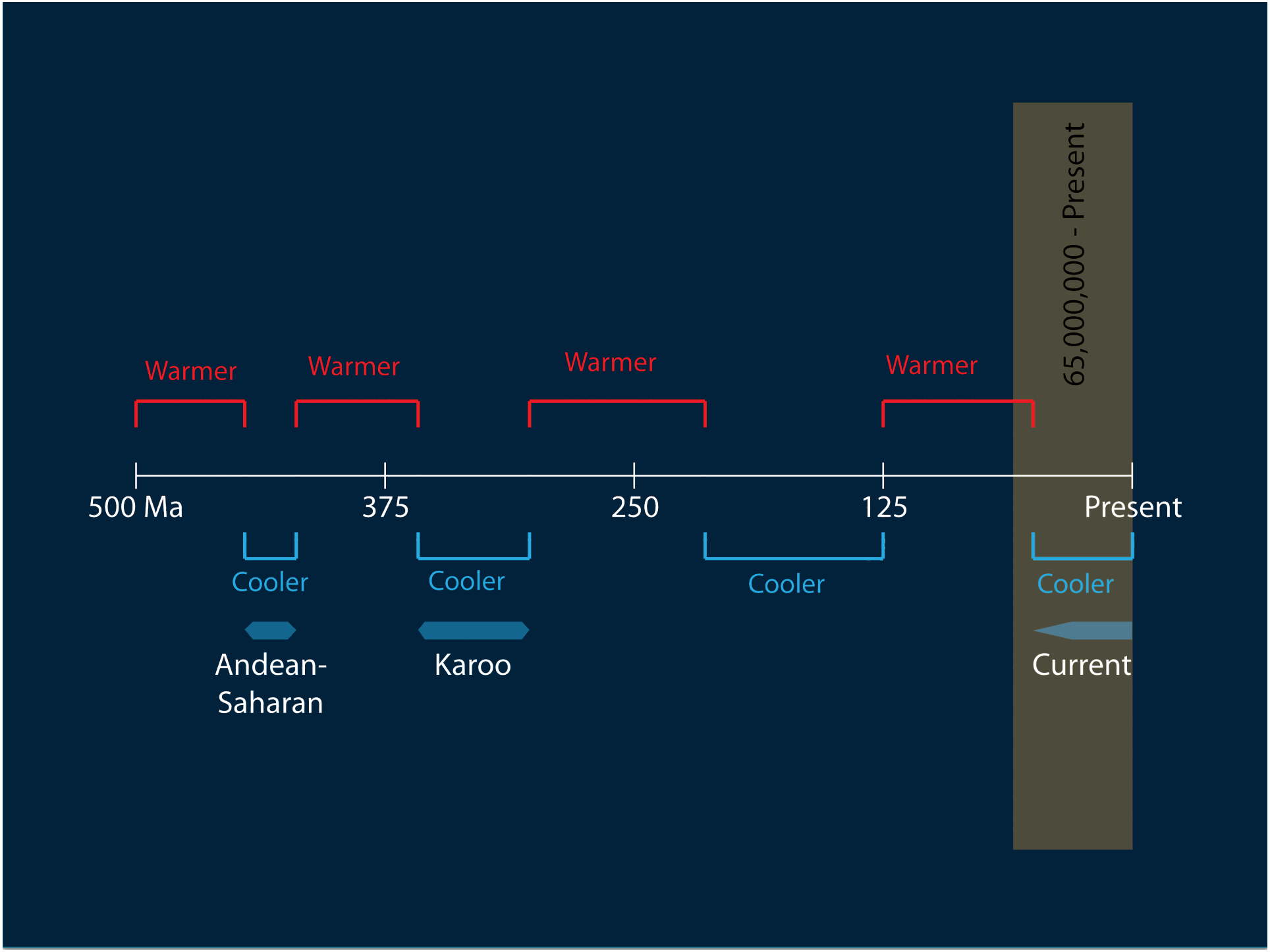

Recent Warming
1850
1900
1950
2000
Cooler than 1950


1850 - 2000
Medieval Warm Period
Current Warming
0
500
1000
1500
2000
Cooler
Little Ice Age


0 - 2000
Warmer
Medieval Warm Period
12000
9000
6000
3000
Present
Cooler
Cooler
Little Ice Age

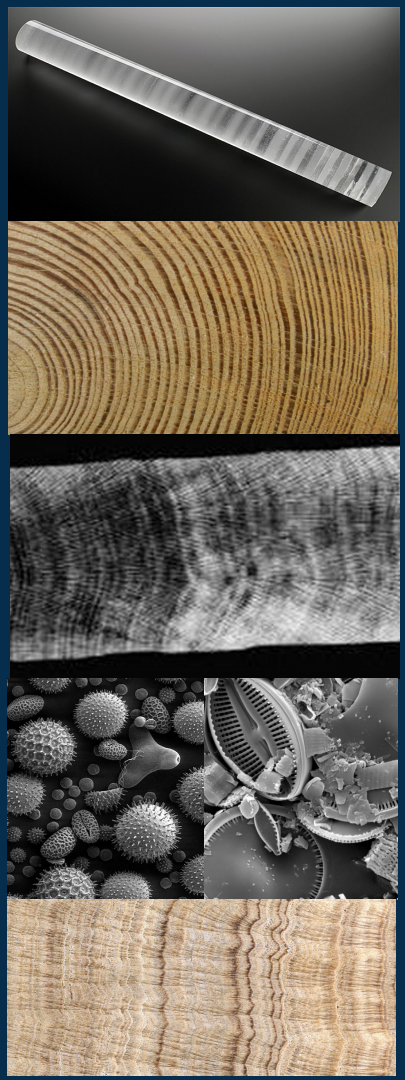

12,000 - Present
Aftonian I
Aftonian II
Yarmouth I
Yarmouth II
Yarmouth III
LIM
600000
450000
300000
150000
Present
Kansan I
Kansan II
Kansan III
KansanIV
Illinois
LGM


Paleocene-
Eocene
Thermal
Max.
Eocene
Thermal
Max.
Middle
Eocene
Optimum
Middle
Miocene
Optimum
600,000 - Present
Warming
Warming
60 Ma
45
30
15
Present
Cooling
Possible Antarctic
Melting
Cooling
Antarctic Glaciation
Northern Hemisphere Glaciation


Warmer
Warmer
Warmer
Warmer
65,000,000 - Present
500 Ma
375
250
125
Present
Cooler
Cooler
Cooler
Cooler
Andean-
Saharan
Karoo
Current

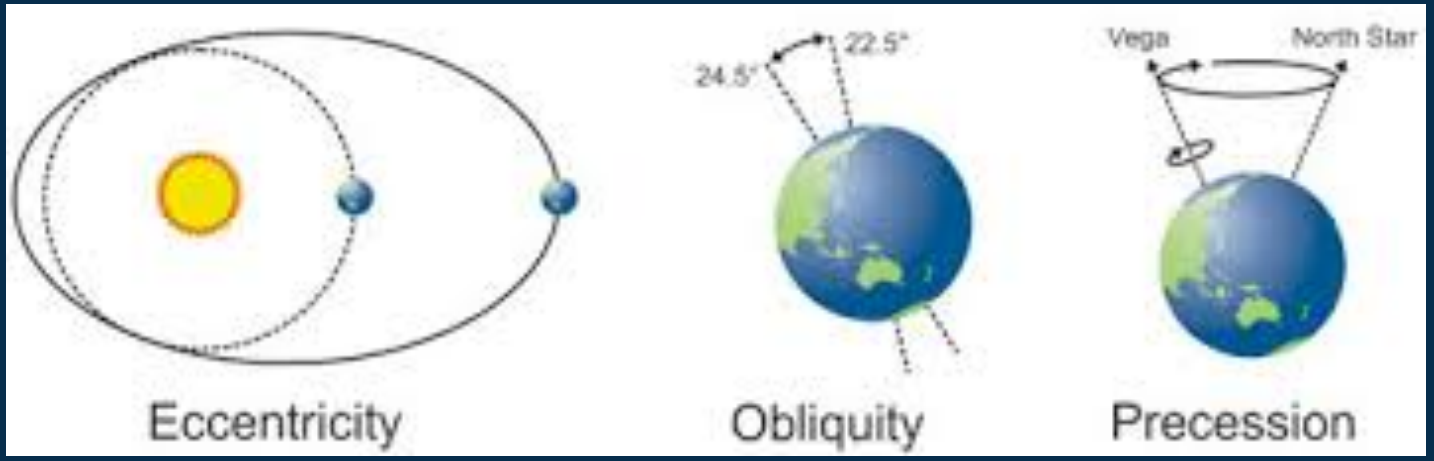
Common Paleoclimate Proxies

Proxy	*Information*	*Timespan (yrs)*	*Resolution (yrs)*
Ice Cores	Isotopes Dust Concentration Gas Bubbles	0 to 800,000	Semi-annual to centennial
Tree Rings	Dendroclimatology	0 to 10,000	Semi-annual to annual
Corals	Isotopes Sea-level rise	0 to 540 Ma	Annual to millennial
Lake/Ocean Sediments	Pollen Diatoms Foraminifera	0 to 540 Ma	Annual to millennial
Carbonates	Isotopes Speleothems Paleosols	0 to 1 Ga	Annual to 100,000s



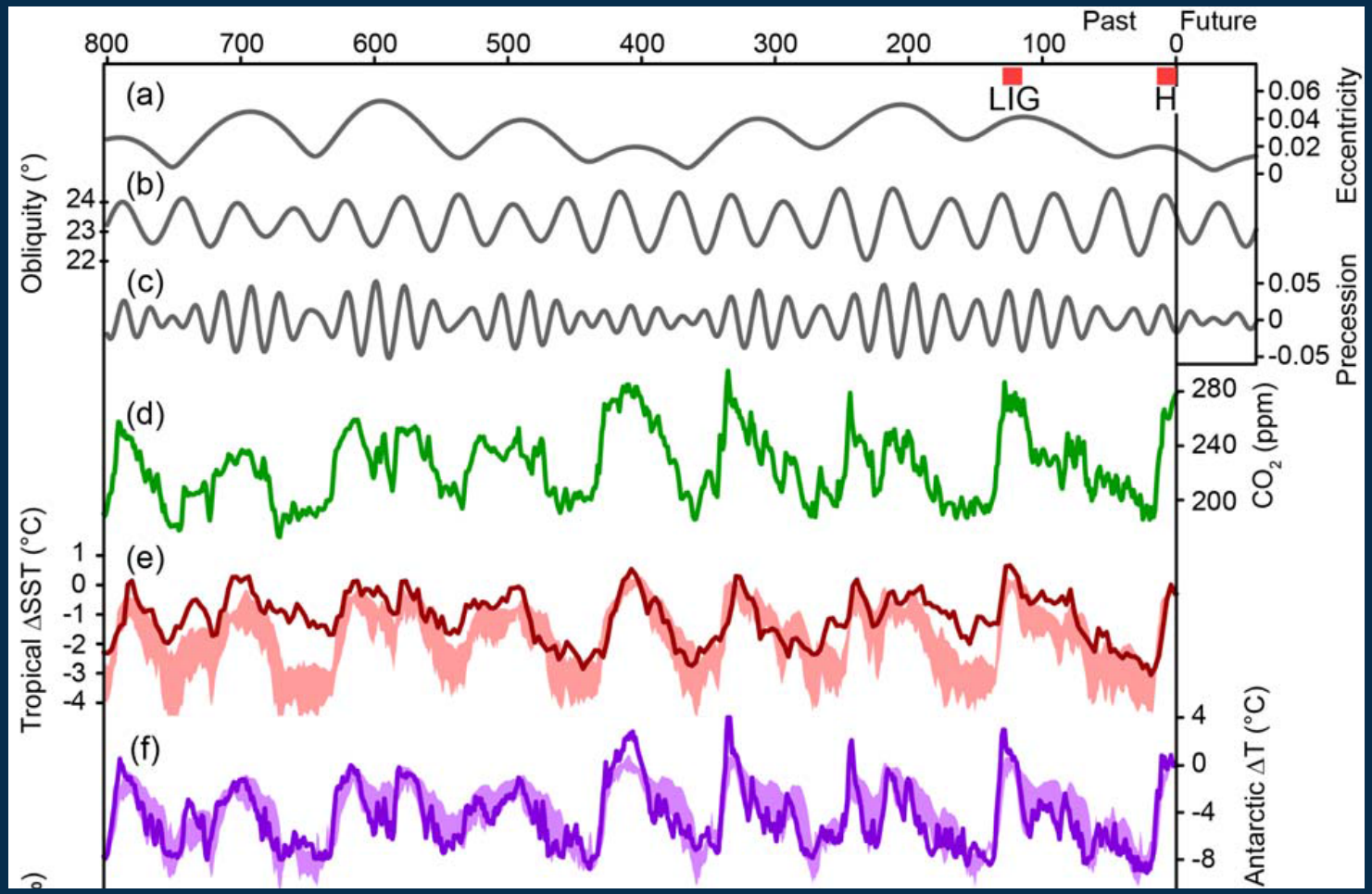
Orbital Forcing

- Mainly solar, volcanic, orbital before humans
- Variations in Earth's:
  - Eccentricity
  - Obliquity
  - Precession



~100 kyr ~41 kyr ~26 kyr

Orbital Forcing

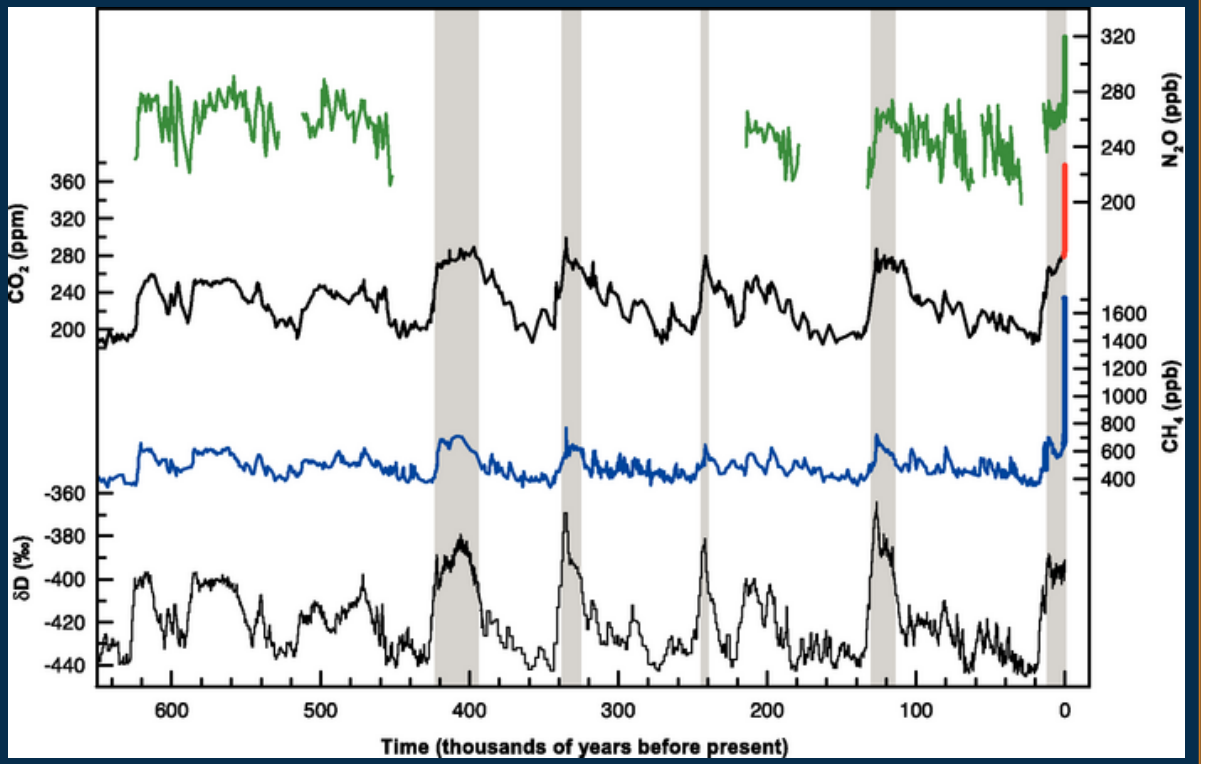


Brief Past/Present Comparison

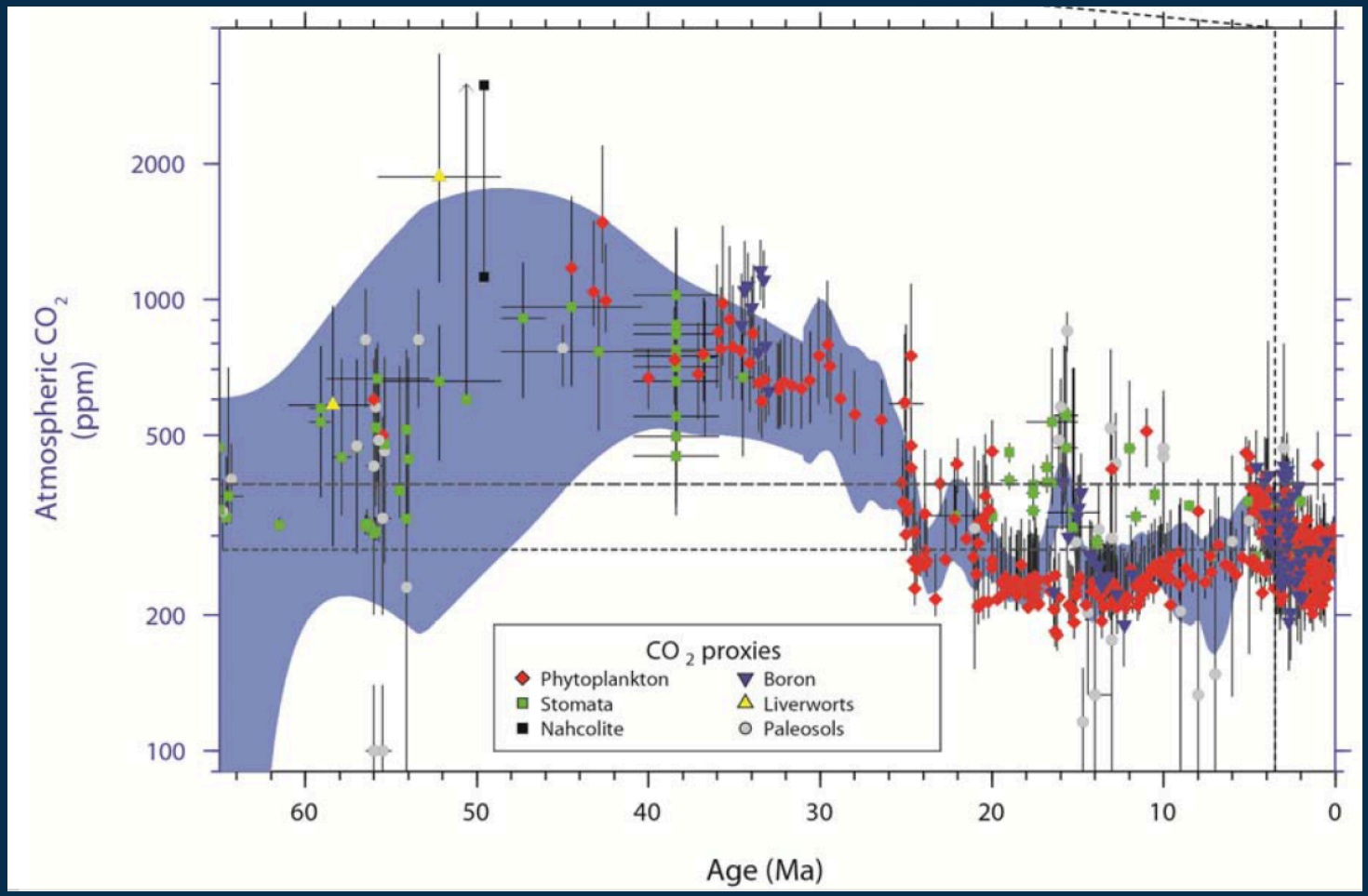
- GHGs
  - CO_2, CH_4, and N_2O are higher now than past 800 kyr
  - Have been higher (mid-Pliocene 350-400ppm, early Eocene >1000ppm CO_2)
- Temperature
  - Global mean has been much higher (mid-Pliocene +2-3.5°C, early Eocene +9-14°C)
  - Consistent amplification of response at poles
- Sea level
  - Unusually high rate in context of last few millennia
  - Has been much higher/lower (mid-Pliocene +1.4-3.4m, early Eocene +20m)

Greenhouse Gas Concentrations

- GHG data from:
  - Ice Cores
  - Fossil Soils
  - Leaf Stomata
  - Boron Isotopes
- Modern CO_2, CH_4 and N_2O all higher than observed in past 800,000 years



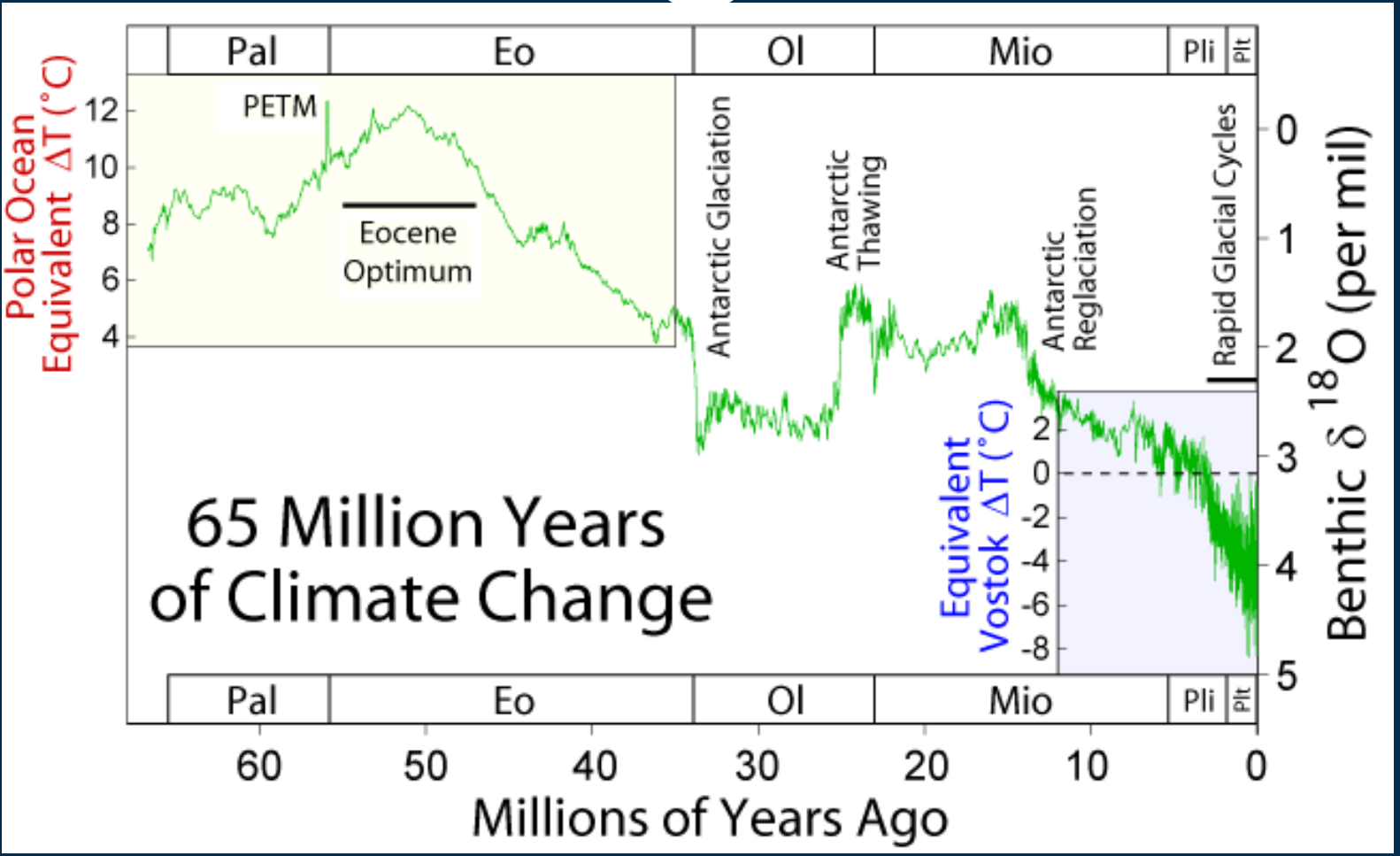
Greenhouse Gas Concentrations



Temperature (Cenozoic)

- Three Cenozoic warm periods (65 mya onward)
  - Paleocene-Eocene Thermal Maximum (PETM ~55.8 mya)
    - Massive carbon release, +4-7°C (relative to pre-industrial)
  - Early-Eocene Climatic Optimum (EECO ~53.5 mya)
    - Last time CO_2 > 1000ppm, +8-14°C
  - Mid-Pliocene Warming Period (MPWP ~3.3 mya)
    - Last time CO_2 was 350-400ppm, +1.7°C
- Hardest to quantify
  - Tectonic & biotic shifts
  - Deep ocean vs. surface temp?

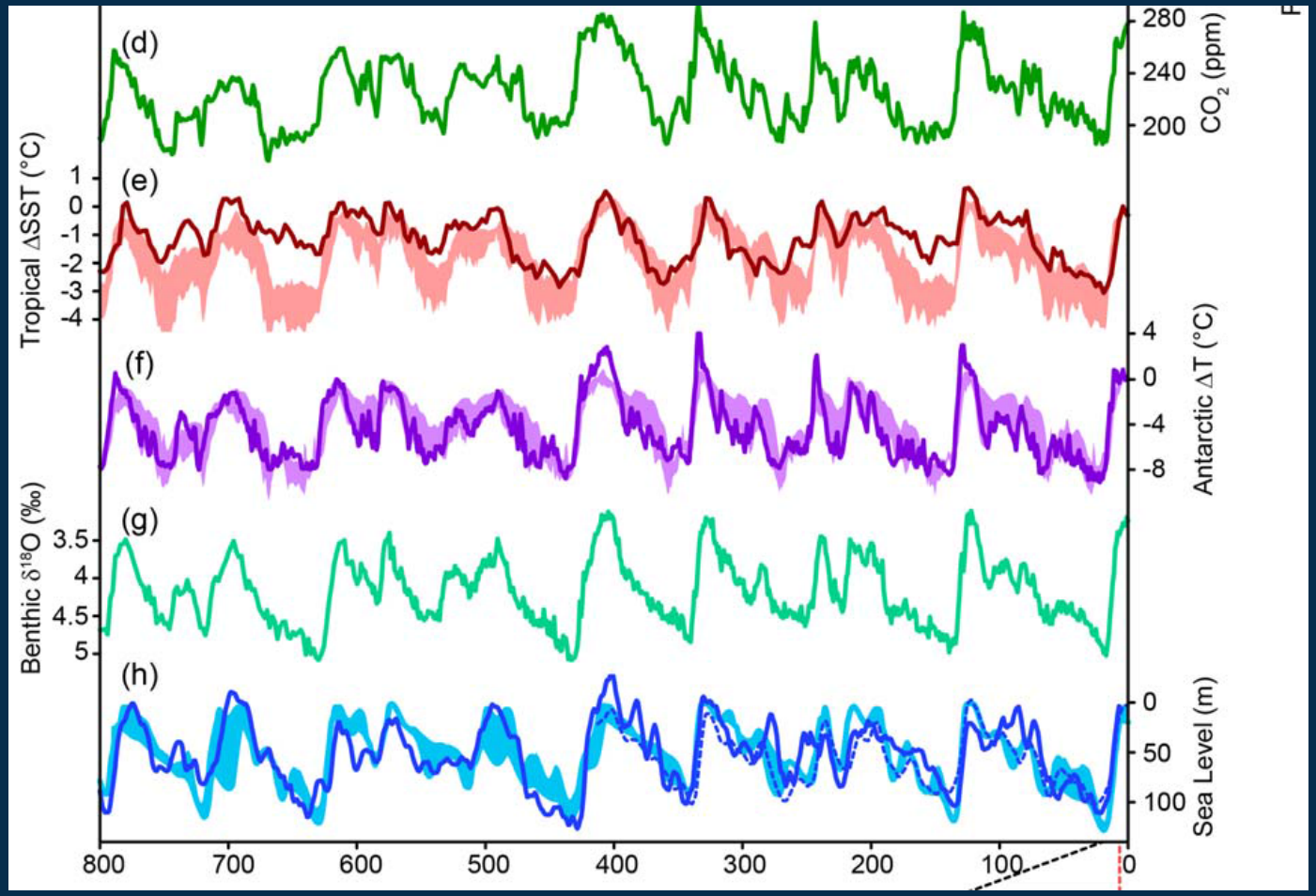
Temperature (Cenozoic)



Temperature (Pleistocene)

- Glacial Cycles (~2.5 mya – 11 kya)
  - Dansgaard-Oeschger (DO) Events
    - Fluctuate between +4°C and -8°C average
  - Last Glacial Maximum (LGM ~25 kya)
    - -6 to -10°C at poles; -4°C global average
  - Last Deglaciation (~11 kya)
    - +3-8°C over deglaciation
    - Transition from Pleistocene to Holocene (11kya-present)

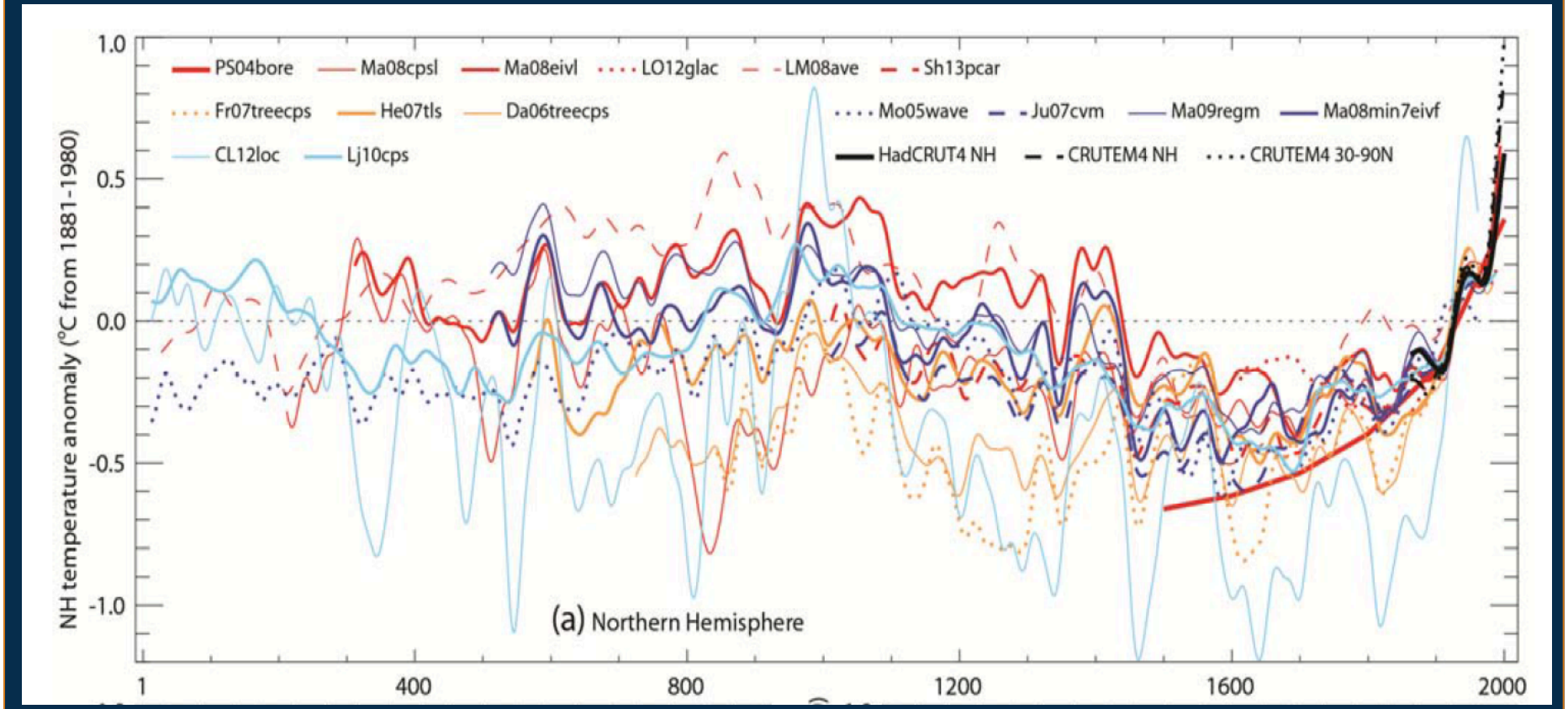
Temperature (Pleistocene)



Temperature (Recent Millennia)

- Two Noticeable Events
  - Medieval Climate Anomaly (MCA 950-1250 CE)
  - Little Ice Age (LIA 1450-1850 CE)
    - Anomalous compared to their contexts, rather than today
    - Unclear whether solar forcing, oceanic circulation, or other factors played a role
    - Were not globally synchronous
    - Mostly found in North Atlantic regions

Temperature (Recent Millennia)



Temperature Overview

- Polar Amplification
  - Can be up to 2x global average
  - Orbital forcing affects poles most
  - Sea ice/albedo & ice sheet/albedo feedbacks
- Differences in SH vs. NH
  - Oceanic temperature stratification
  - Heat transport through circulation
- Estimation of Climate Sensitivity
  - $\Delta T = \lambda \Delta F$
  - Treat slow feedbacks as forcings
  - ΔT = 1-6°C
- New Data from AR4
  - Regional temp reconstructions for last 2 kyr
  - Many regions have been as warm as today, but not globally and synchronously

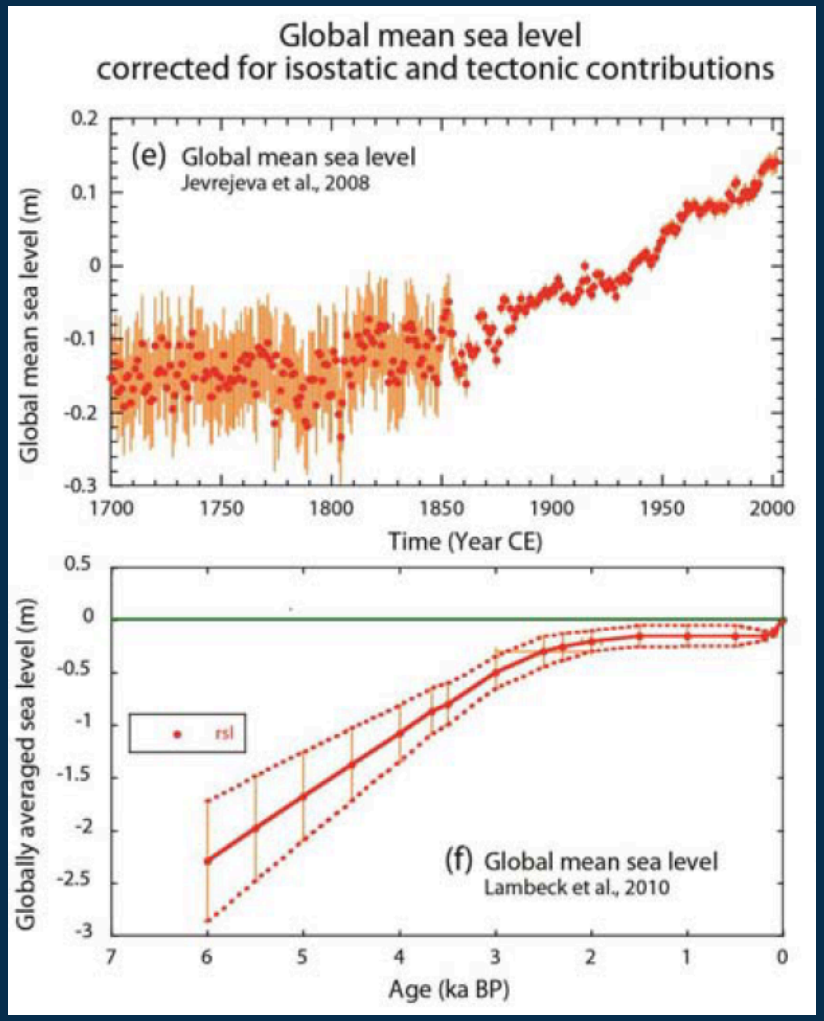
Sea Level

- Sea-level reconstructions based on:
  1. Coral reef elevation measurements
  2. Oxygen-isotope marine sediment records
  3. Estuarine sediment records
  4. Salt-march records
  5. Instrumental records

- Rate of sea-level change is unusually high for the past two millennia

- Sea-level at LGM was ~120 m lower than present

- Sea-level at LIM was ~ 5 m higher



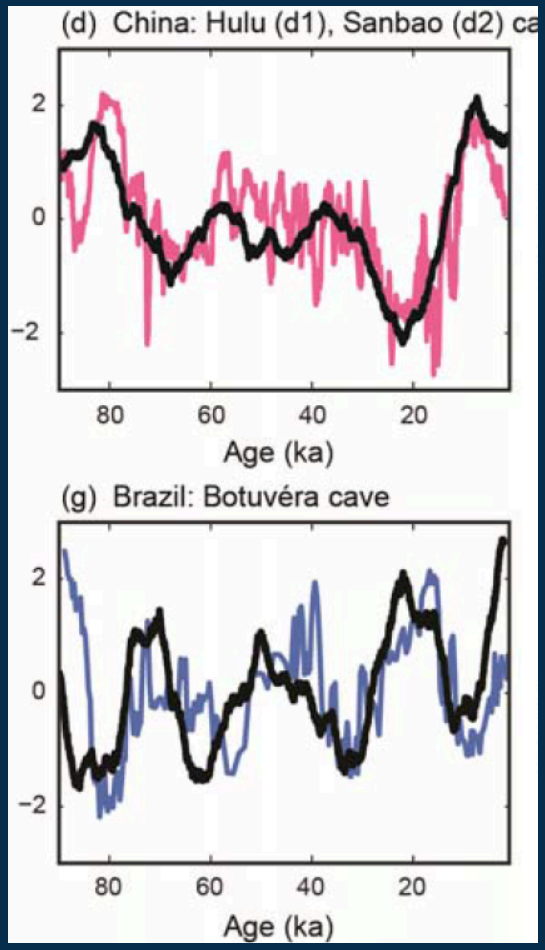
Precipitation

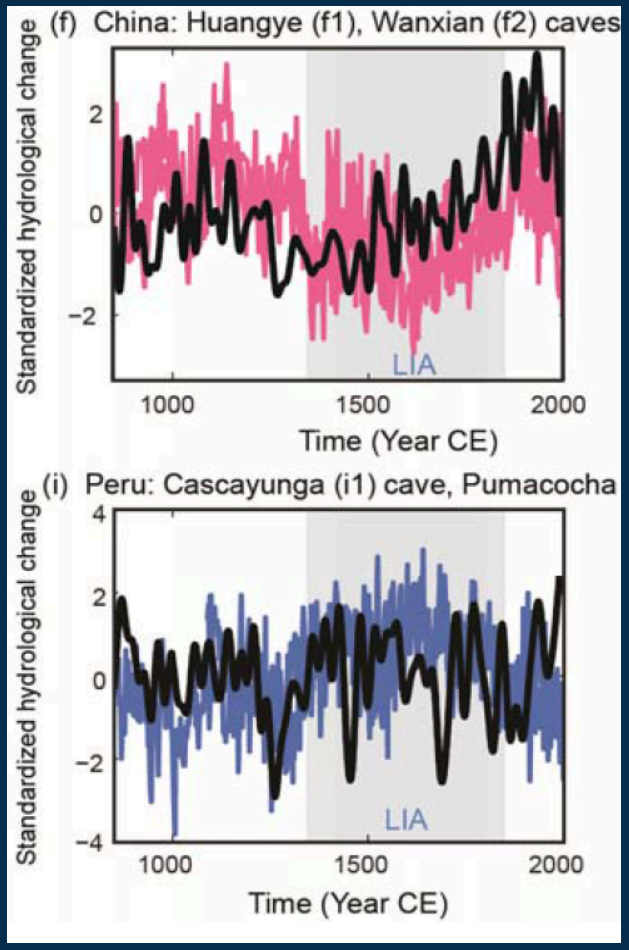
- Changes in location and intensity (regional)
  - Monsoons
    - Respond to orbital forcing
    - Rapid change with DO events
    - Mid-Holocene: drier in N. America, wetter in N. Africa
    - E. Asian monsoon: decrease during LIA compared to MCA
    - S. American monsoon showed increase during LIA
  - ITCZ
    - Shifted southward during MCA/LIA transition in Pacific

Precipitation

- Droughts
  - Decadal/multidecadal during N. American Holocene
  - Have been longer and more severe than today, esp. in MCA
- Floods
  - Generally wetter in LIA, so more flooding (regional)
  - Past floods have been larger in Europe, Mediterranean, E. Asia
  - Current floods are larger than ever in Near East, India, and central N. America

Precipitation

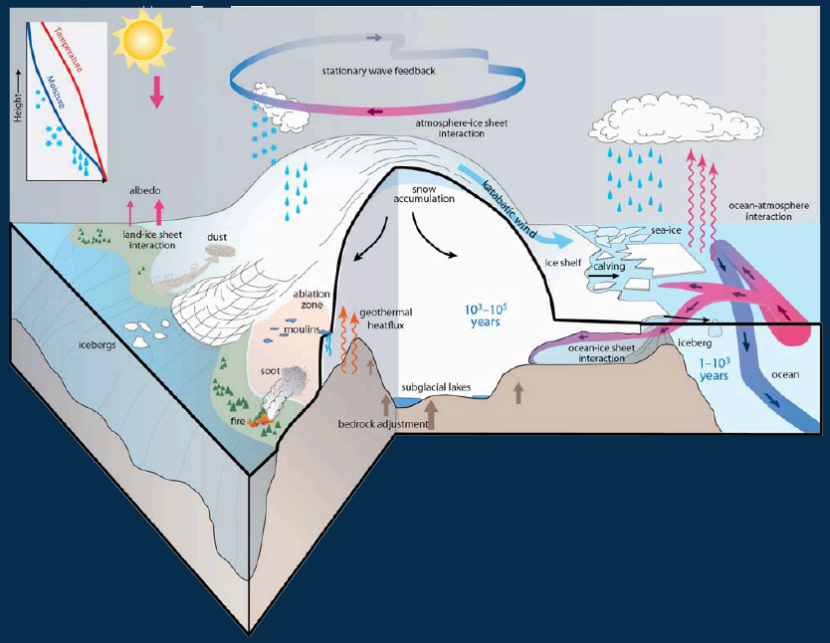




Cryosphere

Cryosphere

- Changes in volume of ice sheets leads to large changes in global sea level
- Sea-level rise potential (m):
  - East Antarctic Ice Sheet: 65
  - West Antarctic Ice Sheet: 8
  - Greenland Ice sheet: 6
  - Other ice bodies: 0.5
  - Total: ~80
- Change in cryosphere extent impacts the albedo of polar latitudes
- Small change in NH summer insolation results in ice sheet formation



Modes of Oscillation

- Climate Modes
  - ENSO
    - Interannual ENSO variation existed during the Pliocene
    - Weak during LIA
  - AMOC
    - Didn't even form until ~3 mya with isthmus of Panama
    - Strengthens during glacial maxima, weakens during deglaciation
    - Weakening can intensify ENSO
  - NAO
    - Current trend is not anomalous in past 600 yrs.
    - No significant response to solar forcing
  - SAM
    - Current trend is anomalous in past 600 yrs.

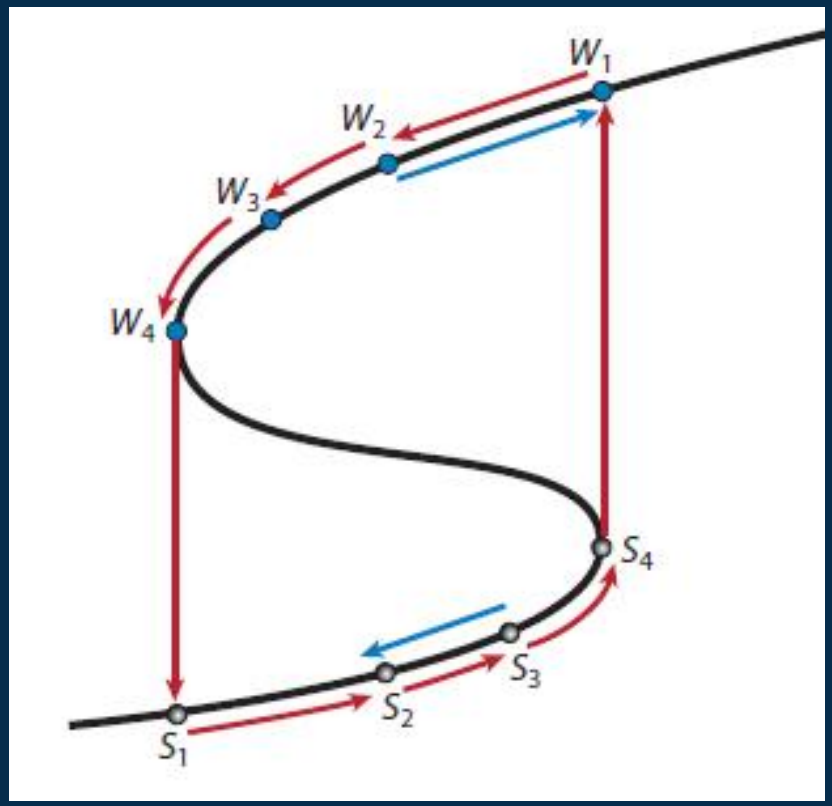
Abrupt Change

- 25 DO events during glacial cycling
  - As much as +16°C and 20m sea level change
  - Underlying mechanisms are still unresolved
    - Probably not solar forcing
    - Changes in AMOC can induce abrupt change
    - Heinrich evens preceded DO events
  - Rapid changes were not global or synchronous
    - Contrast with today

Irreversibility

- Some climate systems exhibit multiple steady states for a given set of parameters
  - East Antarctica Ice Sheet
  - Greenland Ice Sheet
  - AMOC
- Hysteresis
  - Changing a parameter flips a switch (the climate state)
  - Have to do “extra work” to flip the switch back
- Destabilization would take a while
  - Centuries to millennia
- Imminent glaciation virtually impossible in next 50 kyr
  - Sorry, Dennis Quaid (no Day After Tomorrow!)

Hysteresis Loop



Thank You!

- Questions?