

Orbital Frequency Variation in The Monsoons and Greenhouse Gas Concentrations

Chapter 8 - Insolation Control of Monsoons

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Insolation Control of Monsoons

recall: monsoons are seasonal reversals of atmospheric flow from summer to winter

summer: hot land, rising air (low pressure), inflow off ocean, high rainfall

winter: cold land, sinking air (high pressure), flow off land to sea, low precip.

orbitally-driven summer heating variation should also affect the strength of monsoons

should be 23,000 year (precession) cycles in monsoon strength because the effect of precession on insolation is strongest at low latitudes

Sahara lakes and Atlantic diatoms

fresh water diatoms found in deep ocean sediments west of Africa were blown from dry lake beds in northern Africa

the lakes were full during strong monsoon periods (strongest summer heating) and dried during weak monsoon periods

the diatoms are found in Atlantic sediments only periodically, in 23,000 year cycles

however, the cycles of diatom influx lag summer insolation maxima by 5,000 - 6,000

years (it takes time for the large lakes to dry up during periods of declining summer insolation)

Mediterranean stinky muds

layers of organic rich ***sapropels*** are found in cycles in Mediterranean seafloor strata they formed in periods when the deep Mediterranean was ***anoxic*** due to cessation of O₂ supply from the sea surface due to shutdown of downwelling of surface waters eastern Mediterranean surface waters very salty because evaporation >> precipitation salty, dense water sinks to the bottom, supplying O₂ to oxidize organic matter during periods of strong summer monsoons in North Africa discharge of fresh water from the Nile is much greater this “freshens” eastern Mediterranean surface water, decreasing its density sinking of surface water ceases organic matter is preserved in seafloor sediments under anoxic conditions

Pangean monsoons - Newark basin - 200 m.y. ago

cyclic sedimentation in Newark basin sedimentary sequences alternate between wetter (gray, lake bed) and drier (red, river plain) types cycles at ~20,000 yrs, ~100,000 yrs, and ~400,000 yrs apparently result from orbitally driven variations in the strength of summer monsoons

Orbital Scale Changes in Carbon Dioxide and Methane

remember: carbon dioxide (CO₂) and methane (CH₄) are both greenhouse gases CH₄ is much more powerful (much better at absorbing infrared) but it is readily oxidized in the atmosphere so it doesn't remain in air long and therefore it's concentration in the atmosphere is low

ice cores

snow -> ice

ice becomes ductile (malleable) solid under ~25 m of ice glaciers accumulate ice in central areas where ice largely moves downward ice flows away from central zone of accumulation via ductile flow

basal sliding where ice not frozen to bedrock

ice coring in Antarctica and Greenland yields several hundred thousand years of ice shallow ice can also be trenched, shows annual layering annual layering typically very subtle or not visible in more compacted ice below air bubbles get sealed in ice over time, as snow compacts/freezes into solid ice air bubbles are a little younger than the ice b/c air circulated until bubble sealed air bubbles contain the balance of gases in atmosphere at time of closure can measure abundance of CO₂ and CH₄

reliability of ice core gas measurements

comparison of CH₂ & CH₄ concentrations in young ice (last few centuries) gives good correlation with the modern instrumental record of measurements of these gases therefore we can have confidence in measuring these gases

carbon reservoirs and carbon isotopes

the major carbon reservoirs are terrestrial vegetation and soil, the atmosphere, surface ocean, and deep ocean

the deep ocean is by far the largest reservoir

most carbon in the oceans and atmosphere are inorganic

$\delta^{13}\text{C}$ for the oceans is ~ 0

$\delta^{13}\text{C}$ for the atmosphere is ~ -7 (a little lighter)

terrestrial biomass is organic carbon

$\delta^{13}\text{C}$ for terrestrial vegetation is ~ -13 to -25

(very light because photosynthesis preferentially use ^{12}C , light carbon)

Long-Term, Orbital-Scale Changes in CO_2 - Where Does it Go?

long ice cores show large changes in CO_2 correlating with ice volume ($\delta^{18}\text{O}$) change up to ~ 90 ppm or 30% change in atmospheric CO_2 concentration between glacial and interglacial periods (less CO_2 during glaciations, more during interglacials)

gases in the surface ocean mixed layer (~ 100 m) are in equilibrium with the atmosphere

so the surface oceans must also have lost up to 30% of its CO_2 during glaciations

terrestrial vegetation was diminished by $\sim 25\%$ during peak glaciation

So, where did all of the CO_2 from the atmosphere, surface ocean and terrestrial biomass go during glaciations?

since the deep ocean is by far the largest reservoir, and since that is about the only reservoir left, it must be where the CO_2 went

Model:

during glaciations (high = heavy $\delta^{18}\text{O}$) carbon is stored in the deep ocean

organic carbon from land would reduce $\delta^{13}\text{C}$ of deep ocean, benthic foraminifera by about -0.34‰ (lighter)

the light carbon would go back into terrestrial biomass during interglacials

Evidence:

$\delta^{13}\text{C}$ in benthic foraminifera throughout the oceans range from about -0.35‰ to -0.4‰

- a pretty good correspondence

How could the carbon get into the deep ocean?

CO_2 is more soluble in cold water than in warm water, so cooling would dissolve more CO_2 from the atmosphere into the ocean

biological pumping: if plankton in surface waters grew more abundantly, CO_2 would be removed from the atmosphere and stored in the deep ocean as dead plankton rain down through the ocean, gradually decaying along the way

but, how to grow more phytoplankton?

upwelling: an increase in the areas where deep, nutrient rich waters upwell to the surface, like where winds blow from land toward the ocean, would increase areas of the ocean surface where high productivity occur

iron fertilization: iron-bearing minerals in windblown glacial rock-flour (silt) could increase primary productivity and help to remove CO_2 from the atmosphere; a modern experiment with iron fertilization in the southern ocean near Antarctica has shown that additional CO_2 can be removed via iron fertilization

orbital-scale variation in methane (CH₄)

methane forms in wetlands and wet soil from decay of organic matter in reducing conditions (not enough oxygen to fully oxidize to CO₂)

CH₄ measured in bubbles in Vostok, Antarctica, ice cores

varies largely at 23,000 year precession cycles (like the monsoons)

the methane signal responding to strengthening and weakening of monsoons

and expansion and shrinking of equatorial rain belts

and arctic wetlands

CH₄ also shows variation at the 100,000 year eccentricity cycle like the glaciers

(perhaps a result of expansion and contraction of damp summer Arctic tundra belts)

orbital cycles, greenhouse gases, and ice sheets

The greenhouse gases CO₂ and CH₄ increased and decreased in time with the orbitally-driven climate cycles of the ice ages. However, they responded to orbitally driven changes in insolation and resulting temperature and rainfall patterns rather than being the primary driving force for climate change.

Overview: the ice sheets ($\delta^{18}\text{O}$), CO₂ and CH₄ are all in sync with orbital variations

all respond to orbital cycles with their own lag times

the greenhouse gases also appear to respond as positive feedbacks to changing climate/ice volume

So Al Gore's (An Inconvenient Truth) implication that during the ice ages high CO₂ causes warmer temperatures is not quite right. The inconvenient truth is that it is more complicated. The greenhouse gases act as agents of positive feedback either to changing insolation or to changing ice volume.