

# Orbital Frequency Variation in The Monsoons and Greenhouse Gas Concentrations

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## Chapter 8 - Insolation Control of Monsoons

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section 8-1

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*Note: text italics and indented more than the rest, was not presented in lecture, Fall 2009*

## 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  $O_2$  supply from the sea surface due to shutdown of downwelling of surface waters eastern Mediterranean surface waters very salty because evaporation  $\gg$  precipitation salty, dense water sinks to the bottom, supplying  $O_2$  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  $\sim 20,000$  yrs,  $\sim 100,000$  yrs, and  $\sim 400,000$  yrs apparently result from orbitally driven variations in the strength of summer monsoons

## **Orbital Scale Changes in Carbon Dioxide and Methane**

**remember:** carbon dioxide ( $CO_2$ ) and methane ( $CH_4$ ) are both greenhouse gases  $CH_4$  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 its concentration in the atmosphere is low

### ***ice cores***

snow  $\rightarrow$  ice

ice becomes ductile (malleable) solid under  $\sim 25$  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  $CO_2$  and  $CH_4$

### ***reliability of ice core gas measurements***

*comparison of  $CH_2$  &  $CH_4$  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  $\sim 0$*

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

*terrestrial biomass is organic carbon*

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

*(very light because photosynthesis preferentially use  $^{12}\text{C}$ , light carbon)*

## **Long-Term, Orbital-Scale Changes in CO<sub>2</sub> - Where Does it Go?**

long ice cores show large changes in CO<sub>2</sub> correlating with ice volume ( $\delta^{18}\text{O}$ ) change up to  $\sim 90$  ppm or 30% change in atmospheric CO<sub>2</sub> concentration between glacial and interglacial periods (less CO<sub>2</sub> during glaciations, more during interglacials)

gases in the surface ocean mixed layer ( $\sim 100$  m) are in equilibrium with the atmosphere

so the surface oceans must also have lost up to 30% of its CO<sub>2</sub> during glaciations

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

So, where did all of the CO<sub>2</sub> 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<sub>2</sub> 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  $-0.34\text{‰}$  (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  $-0.35\text{‰}$  to  $-0.4\text{‰}$   
- a pretty good correspondence*

### **carbon isotopic ratios over time**

*$\delta^{13}\text{C}$  ratios have been approximately in sync with  $\delta^{18}\text{O}$  ratios  
with peaks at 100,000 yr intervals during the last 0.9 m.y.*

*$\delta^{13}\text{C}$  ratios were approximately in sync with  $\delta^{18}\text{O}$  ratios*

*with peaks at 41,000 yr intervals during the earlier part of the ice ages*

*these suggest that organic carbon has been cycling between terrestrial biomass and the deep oceans with each interglacial and glacial*

## **How could the carbon get into the deep ocean?**

CO<sub>2</sub> is more soluble in cold water than in warm water, so cooling would dissolve more CO<sub>2</sub> from the atmosphere into the ocean

**biological pumping:** if plankton in surface waters grew more abundantly, CO<sub>2</sub> 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<sub>2</sub> from the atmosphere; a modern experiment with iron fertilization in the southern ocean near Antarctica has shown that additional CO<sub>2</sub> can be removed via iron fertilization

**changes in deep water currents**

*North Atlantic Deep Water (NADW) and Antarctic Bottom Water (ABW) currents can be distinguished by their carbon isotope ratios*

*NADW has more positive values than ABW because of stronger biological fractionation of light carbon in the north Atlantic surface waters where NADW forms measurements of  $\delta^{13}\text{C}$  in carbonates in equatorial Atlantic strata and comparison with  $\delta^{18}\text{O}$  indicate strengthening of NADW during interglacials and displacement by ABW during glaciations, cycling at the 100,000 year cycles during the past 900,000 years perhaps this turnover increases upwelling during glaciations*

*or*

*very cold & "corrosive" Antarctic Bottom Water (ABW) replaced less corrosive North Atlantic Deep Water (NADW)*

- ABW dissolves more seafloor carbonates
- returns more CO<sub>3</sub><sup>2-</sup> to surface water

**[Note typo in original slides: incorrectly said CO<sub>2</sub>, rather than CO<sub>3</sub><sup>2-</sup>]**

- CO<sub>3</sub><sup>2-</sup> combines with CO<sub>2</sub> in H<sub>2</sub>O to produce HCO<sub>3</sub><sup>-</sup>
  - thereby removing CO<sub>2</sub> from surface waters (and atmosphere)

**orbital-scale variation in methane (CH<sub>4</sub>)**

methane forms in wetlands and wet soil from decay of organic matter in reducing conditions (not enough oxygen to fully oxidize to CO<sub>2</sub>)

CH<sub>4</sub> 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

*CH<sub>4</sub> 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 CO<sub>2</sub> and CH<sub>4</sub> 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 ( $\delta^{18}\text{O}$ ), CO<sub>2</sub> and CH<sub>4</sub> 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

**23,000 year precession cycles:**

*CH<sub>4</sub> is in sync - it can respond to year by year changes in summer insolation & rain  
CO<sub>2</sub> lags by perhaps 1000 years - changes dependent on ocean circulation changes  
ice volume ( $\delta^{18}\text{O}$ ) lags insolation by ~5000 years*

*both insolation changes and CO<sub>2</sub> and CH<sub>4</sub> changes can help drive ice sheet variations at the 23,000 year cycles*

**41,000 year tilt cycles:**

*ice volume, CO<sub>2</sub> and CH<sub>4</sub> are in sync and all lag the 41,000 yr insolation cycle  
greenhouse gases therefore don't provide a forcing mechanism for ice volume change at the 41,000 year cycles*

*they rather must act as positive feedbacks (e.g., more ice > less gas > more ice)*

**100,000 year eccentricity cycles:**

*CO<sub>2</sub> and CH<sub>4</sub> and ice volume changes are all appear very close to one another and to the eccentricity cycles (even though changes in eccentricity produces only very small changes in insolation); CO<sub>2</sub> appears to slightly lead ice volume change so it perhaps drives the 100,000 year cycles of ice sheet expansion and retreat that has been dominant during the past 600,000 to 900,000 years; the data and dating are not yet clear enough to confirm this*

So Al Gore's (An Inconvenient Truth) implication that during the ice ages high CO<sub>2</sub> 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.