Holocene Climate Trends

• Climate forcing
  – CO$_2$
  – Insolation

• African Humid Period and other changes in moisture balance over land

• Hypsithermal and other temperature changes
CO2 increased from 260ppm at 8kybp to 280ppm in 1850AD

slight decrease in d13C of CO2 over this interval?

Indermuhule: These observations can be explained by decrease in terrestrial biomass from 8ky to present
Broecker:  
CO2 change caused by response of ocean CO3^- to deglacial changes in terrestrial carbon  

-implies little change in d13C of CO2  
-Indermuhle still needs significant d13C change  

Broecker et al 1999
… or first sign of anthropogenic effects on atmospheric CO₂?

Figure 6. Areas of complex ‘stratified’ agriculture and simple ‘peasant’ agriculture at 2000 yrs BP (after Roberts, 1998; largely based on Lewthwaite and Sherratt, 1980). Areas of stratified agriculture include advanced civilizations of eastern China, India, and the Roman Empire, all of which had been naturally forested areas.

Ruddiman 2003
Ruddiman: CO2 change caused by early humans clearing forests for agriculture (CO2 increase, d13C decrease)
New data reveal:
1) d13C change during Holocene smaller than previously thought
2) CO2 in past interglacials didn’t necessarily go down; so CO2 in Holocene shouldn’t necessarily go down either

Consensus:
Perhaps some room for human-induced CO2 changes during Holocene, but Ruddiman’s own estimates are <15ppm

More likely that CO2 changes reflect response of ocean carbonate system to changing terrestrial biomass; mechanisms and amounts still unclear
Insolation changes dominate climate forcing during Holocene
Insolation at 6kybp

- Tilt, precession max at 10kybp, have been decreasing to present

At 6kybp, perihelion in August:
- More summer (less winter) insolation in N.H.
- Less summer (more winter) insolation in S.H.
Part 1
Holocene hydrological trends

Schematic monsoon circulation

A. Summer monsoon

B. Winter monsoon
Fig. 1 Modern precipitation patterns across the tropics and subtropics, a total precipitation (mm) and b the timing of maximum precipitation (where 0 represents January 1\textsuperscript{st} and 12 represents December 31\textsuperscript{st}). The data are derived from the Cramer Climate 2.2 data set (http://www.pik-potsdam.de/~cramer)
Orbital monsoon hypothesis (Kutzbach, 1981)
Great riverbeds evident in satellite imagery of desert Middle East
Paleo-lake level reconstructions: evaporation-precipitation balance
deMenocal et al (2000)
Site 658C

20°N JJA radiation (W/m²)

δ¹⁸O (%o, PDB)  Terrigenous (%)  CH₄ (ppb)  δ¹⁸O (%o)

Calendar age (ka BP)

African Humid Period

Holocene

YD

B-A

H1

H2

hiatus

hiatus

Terr. Flux (g/cm²/ka)

deMenocal et al. (2000)
Vegetation feedbacks can alter albedo (more rain = more vegetation = albedo decreases = warmer land)
Consensus: vegetation-precipitation feedbacks needed to get magnitude and abruptness of Holocene hydrological changes

Claussen et al., 1999
ocean feedbacks can change nature of monsoon response to insolation (blue bars); very regionally-dependent

Liu et al 2004

(modern)

(insolation + interactive ocean)

(insolation only)
Stalagmite data provide rock-solid evidence that monsoons tied to insolation – Kutzbach was right!

- China (23N) convection linked to JJA (Dykoski et al., 2005); peak at 10kybp
- Borneo (4N) convection linked to spring/fall
- Brazil (20S) convection linked to DJF (Cruz et al., 2005); peaks at 0kybp
What about the equatorial tropical Pacific?

increased ENSO activity over Holocene?

Fig. 5. Results of time series analysis (16) of the gray-scale record (Fig. 3C); age ranges are in calendar years before the present. Because of breaks in the core (Fig. 3A), we performed the time series analysis on individual sections of the core and treated these as discrete time series. There is a clear spectral evolution from the Late Glacial through the Holocene with the ENSO band (19), which progressively achieves its modern strength by ~5000 cal yr B.P.

Rodbell et al 1999
ENSO model response to insolation: weaker ENSO in early Holocene?

fossil coral best evidence; but rare and don’t agree

ENSO was weaker?

lake sediments indirect; ENSO was weaker?

Figure 2. Measures of ENSO activity in the mid- to late-Holocene. (top) Estimates of ENSO-related variance changes (computed as % changes in 2-7y variance relative to present-day 2-7y variance) in published fossil coral data; sources are Tudhope et al., 2001 (green triangles), Woodroffe et al., 2003 (blue squares), McGregor et al., 2004 (pink diamonds), Correge et al., 2000 (blue star) and Cobb et al., 2003 (red circles). (middle) Clement et al (2000) modeling results (bottom, frequency of Lake Pallcacocha flooding events (Moy et al., 2002).
West Pacific Warm Pool core; d18O & Mg/Ca

Results: trend towards lighter d18O, cooler temps. implies? causes?

Stott et al 2004
Holocene Moisture Trends

- Enhanced monsoon circulation over Africa and Asia, a consequence of increased seasonality
- Vegetation feedbacks and Ocean temperature feedbacks alter intensity of monsoon changes.
- Rapid onset and decay of “humid period” requires vegetation-atmosphere and/or ocean feedbacks
- Tropical Pacific mean state has likely evolved over Holocene, role of ENSO changes unclear
Part 2: Northern Hemisphere (Europe and North American Land Record)

- Early Holocene Warm Period
  - Hypsithermal
  - Climatic Optimum
- (7-5 kyr BP)
- Summertime warmth most pronounced
- Tilt higher in early Holocene (poles towards sun)
Holocene Temperature Records from High Northern Latitudes

Past Global Changes and Their Significance for the Future
Alverson, Oldfield and Bradley eds.
vegetation feedbacks also important for high-latitude temp. response
alkenone sediment Holocene cooling trends (Marchal et al., 2002)
Figure 3. Latitudinal variations of annual mean (a) insolation anomaly, and the zonal mean SSTA in (b) CSM (C3.5 ka, C6 ka, C8.5 ka, C11 ka) and (c) FOAM (F3 ka, F6 ka, F8 ka, and F11 ka).
Global temperature trends

• Early Holocene warmth in Northern and Southern high latitudes
• Enhanced tilt provides more annual average insolation at high latitudes (North and South)
• Enhanced seasonality in N.H. enhances annually averaged warmth (sea-ice)
• Cool low latitudes?? (global energy balance satisfied if so; but data do not support this)