

**Summary Report  
ESH Holocene Principal Investigator Meeting  
May 17-19, 2005  
AGU Headquarters  
Washington, DC**

**Meeting Logistics**

In 2002, the Earth System History program of the National Science Foundation began a focused research initiative on Holocene climate variability. This interdisciplinary research program joins researchers from the Divisions of Atmosphere, Earth, and Ocean Sciences in an interdisciplinary effort to quantify the nature, magnitude and causes of Holocene climate and to assess how past variability compares to the climate variability observed during the short period of historical observations (<http://www.mesh.usc.edu/reports.htm>). In the initial phase of the Holocene initiative two objectives were given highest priority: 1) to generate reconstructions of the important climate variables at decadal to centennial resolution through the Holocene at locations that would record the behavior of the climate system (including sea surface temperatures, sea surface salinity, precipitation histories over land and ocean, air temperatures, ice extent change and deep water circulation change) and 2) to compare patterns of climate variability at various times through the Holocene with the variability of the historic period.

The first funded awards for the Holocene program began in FY2002 and by FY2005, these initial projects were nearing their final phases of research. In May of 2005, a subset of the Holocene Principal Investigators came together to discuss their initial results and to modify, if necessary, the research goals of the program based on new findings. This meeting was one of several planned during the course of Holocene project to encourage collaboration among the various paleoclimate researcher communities and to evaluate progress toward meeting the goals of the research plan. Excellent progress has been made in meeting the first objective: a growing data base of climate records from the Holocene has been generated and the initial assessment of these records has begun

Since its inception, the ESH Holocene research program has awarded approximately 130 grants to about 60 individual or multi-PI research projects. The high number of multi-PI awards reflects a truly high degree of interdisciplinary collaboration among paleoclimatologists, paleoceanographers, climate modelers and climate dynamicists. For this first meeting a subset of about 50 PIs (representing a large fraction of the awarded projects) was invited to attend (the list of attendees and the meeting agenda are posted at <http://www.mesh.usc.edu/>). Prior to the meeting each attendee submitted a written, one-page summary of research progress. These one-page summaries were compiled into a single document and distributed to each attendee before the meeting. (The compilation of research summaries is posted at <http://www.mesh.usc.edu/>).

The meeting was focused on three research questions and each attendee was asked to review the research summaries prior to the meeting with these questions in mind:

- Is there a recurrent pattern of variability within the Holocene?
- Is the latest Holocene a unique climate interval within the Holocene? Is it unique compared to previous interglacials?
- What is the origin of the observed Holocene climate variability?

During the meeting, several individuals were invited to lead discussions on these three questions, focusing the discussion on the material included in the research summaries. The results of these discussions are summarized below.

### **Session 1: Is there a recurrent pattern of variability within the Holocene?**

**Discussion leaders: Jeff Dorale (University of Iowa), Terry Quinn (University of South Florida)**

Long term variability in Holocene climate is driven by changes in orbital forcing and is punctuated by systematic centennial to millennial scale variability. The primary climate signals for both longer-term changes and millennial scale variability show up in climate proxies responding to changes in the hydrological cycle and are clearly evident on land in many in speleothem records from southern Asia (Dongge Cave) and southwestern and central North America (speleothem records of Yermale and Dorale) and are beginning to emerge from marine records of past salinity reconstructed by paired measurements of foraminiferal calcite. The link to orbital forcing may be through ENSO variability with a dry western US occurring during La Nina episodes and wet western US during El Nino episodes (Mann).

The hydrologic system appears to be very sensitive to small changes in forcing or there are important feedbacks that result in a stronger hydrologic response. Records from the western Pacific exhibit small changes in Holocene SST ( $<1$  °C) recorded in corals (Quinn) and foraminifera (Stott et al., 2004), which are coupled with large changes in foraminiferal calcite  $\delta^{18}\text{O}$  (Stott et al., 2004). These records together imply that the oxygen isotopic composition of surface waters decreased substantially from the late Holocene to the early Holocene, implying a decrease in surface salinity occurring at the same time that southern Asia became wetter (Dongge Cave) and northern South America became drier (Haug et al., 2001).

At higher latitudes, ocean and atmosphere temperature variability was amplified during the Holocene relative to the temperature changes at lower latitudes. This polar amplification is linked to the orbital/insolation forcing and to the presence of the melting ice sheets well into the early Holocene. The response of polar temperatures was about three times larger than lower latitudes on all time scales (Miller: 20<sup>th</sup> century, LIA, Holocene thermal maximum and LGM).

At higher temporal resolution, the Bond events of the Holocene appear throughout the North Atlantic and cold events in the NA correlate with dry events in many tropical and monsoon regions (Cariaco, equatorial African lakes, Dongge – Hulu cave speleothems). The link to solar variability on these time scales is still being tested, but is now evident in well dated high resolution records of moisture in south Asian speleothems. Identifying the link between possible solar forcing and climate variability on centennial to millennial time scales remains a high priority goal of the Holocene program. The results of the Holocene project suggest that the link to solar forcing is largest in proxies for the hydrological cycle. Despite substantial progress, important questions still remain about how such a small solar forcing can produce such a large response.

For both orbital and millennial time scales, a geographically coherent response of hydrological cycle is linked closely to movements of the ITCZ which produces an opposite response in the hemispheres - when northern tropics become wetter (P-E increases), the southern tropics become drier (P-E decreases). The migrations of the ITCZ affect ocean salinity, which may be an important feedback linking the atmosphere and ocean circulations. Migrations of the ITCZ appear to be the largest and most readily observed changes to the hydrological cycle, perhaps the best feedback link between atmospheric and oceanic processes.

**Session 2: Is the latest Holocene a unique climate interval within the Holocene? Is it unique compared to previous interglacials?**

**Discussion Leaders: Jerry McManus (Woods Hole Oceanographic Institution), William Ruddiman (University of Virginia)**

There is evidence of human influence on the northern hemisphere environment in many Holocene records but the timing of the earliest influence and its climate impact are in significant dispute. Ruddiman presented strong arguments - based on orbital theory and comparison with earlier interglacials with similar forcing - that decreases in atmospheric CO<sub>2</sub> and methane concentrations should have begun much earlier in the Holocene than is observed in ice cores. His argument is that human influence began in the mid-late Holocene, long before the beginning of the industrial revolution as a result of forest clearing and the beginnings of agriculture. One important but unproven consequence of this observation is that the climate system may be much more sensitive to greenhouse forcing than is currently believed: the small increases in greenhouse gases caused by humans may have already prevented the beginnings of the next ice age. An affirmation of this hypothesis would significantly change the current debate about the climate effects of increased atmospheric CO<sub>2</sub> during the past century. An outstanding question remains: is the forest clearing large enough to have increased atmospheric CO<sub>2</sub> by the 40 ppm or more required by Ruddiman's hypothesis.

Holocene climate response looked similar to the response during isotope stage 11 (McManus), yet lasting longer than the current interglacial stage. Land based records of

climate on these time scales are difficult to obtain, but one important speleothem record suggests that the central US was dryer during stage 5 than it was during the middle Holocene (Dorale).

### **Session 3: What is the origin of the observed Holocene climate variability?**

**Discussion leaders: Jean Lynch-Stieglitz (Georgia Institute of Technology), Mark Bush (Florida Institute of Technology)**

*Orbital forcing.* Evidence for orbital forcing shows up in most Holocene records of climate change including: 1) stronger northern hemisphere monsoons in the early Holocene versus the late Holocene; 2) high latitude (arctic) warmth in the mid Holocene and widespread mid Holocene peaks in lake levels throughout the tropics linked to the northern hemisphere insolation maximum; 3) and reduced ENSO forcing in the early Holocene associated with changes in E-P over the Americas,

*Solar variability:* There is evidence for a link between variations in proxies for solar variability ( $^{10}\text{Be}$ ,  $^{14}\text{C}$ ) and climate indicators of changing surface moisture balance on centennial to millennial time scales throughout the Holocene. The links appear to be very strong and best dated for low-latitude cave deposits, particularly in monsoon regions. Other correlations appear in Holocene variability of  $^{14}\text{C}$  and marine proxies of surface water salinity in the tropical Atlantic and tropical Pacific that result from migrations of the ITCZ. Yet it is still unclear how much of the variability in the ice core records  $^{14}\text{C}$  and  $^{10}\text{B}$  directly reflects changes in solar activity or were affected independently by the climate system itself. For instance the effects of reservoir changes on atmospheric  $\Delta^{14}\text{C}$  are still in dispute. Climate model simulations incorporating  $^{10}\text{Be}$  document that changing precipitation affects the surface accumulation of  $^{10}\text{Be}$  (Schmidt), perhaps making  $^{10}\text{Be}$  an unreliable indicator of solar variability.

*Atlantic MOC.* Observed Holocene reductions in Atlantic overturning circulation appear to be limited to 20% (or less) of the modern value based on sedimentary  $^{231}\text{Pa}/^{230}\text{Th}$  accumulation in the deep North Atlantic (McManus et al., 2004) and changes in the density structure of the upper water column in the Florida Straits (Lynch-Stieglitz). Tracer evidence for changes in circulation comes from benthic foraminiferal  $\delta^{13}\text{C}$  records in the North Atlantic (Oppo), which exhibit prominent minima during Holocene at times of greater ice berg discharge into the North Atlantic and colder, windier conditions at the summit of Greenland. For these changes in climate to have been the result of the observed small changes in the rate of Atlantic MOC, then there must have been large changes in its heat transport, which may have been detected in the large changes in T-S properties of the Labrador Sea Water (Marchitto and deMenocal).

*Coupled atmosphere-ocean systems.* There are strong links between PDO state of the North Pacific and the intensity of drought in the western North America. In addition orbital forcing of the ENSO system caused large changes in the moisture balance of the southwestern and central North America. Both observations point out the importance of

SST conditions in the Pacific in controlling the E-P distribution over North America on a wide variety of time scales.

*Anthropogenic forcing.* Late 20<sup>th</sup> century rates of alpine glacier melting exceed the rates observed throughout the rest of the Holocene (Thompson) and are occurring during a period of warmth unprecedented during the last millennium (Mann).

### Some Summary Bullets and Outstanding Questions

- Orbital forcing and increasing atmospheric CO<sub>2</sub> changes are responsible for long-term Holocene trends in temperature and in particular in the hydrological cycle
- The ultimate cause of centennial-millennial scale climate variability remains unclear, but some progress has been made:
  - If atmospheric  $\Delta^{14}\text{C}$  reflects variability in solar output, solar output is causing centennial and millennial climate variability in the Holocene (including LIA/MWP) in at least some regions and the link is strongest for records of hydrology and hydrography in regions affected by ITCZ migration. Outstanding questions remain:
    - There is still no mechanism for sun-climate link? How do we get at this?
    - Why do we get the response (especially in the hydrologic cycle) that we do?
    - What data would conclusively prove (or disprove) that changes in solar output cause Holocene climate change?
    - Does PDO/ENSO respond to change in solar output on centennial/millennial timescales?
  - Variability in Atlantic MOC (“salt oscillator”) during the Holocene is much smaller than seen during the deglaciation and colder climates of the late Pleistocene. Outstanding question:
    - Can small changes in overturning be coupled with large changes in poleward oceanic heat transport to provide a large climate impact?
    - How do changes in tropical sea surface salinities which are linked to ITCZ migration affect ocean circulation and climate?
  - We cannot rule out more general internal, stochastic variability in climate system to explain variability in Holocene climate and there is mixed evidence for narrow spectral peaks in records of millennial scale Holocene climate

- PDO/ENSO coupled systems drive decadal and interannual climate variability in much of western and central North America. Outstanding questions:
  - Is there a relationship between solar output and climate on these time scales?
  - Or is climate on these timescales driven solely by internal variability? Is this consistent with solar control on centennial/millennial timescales?