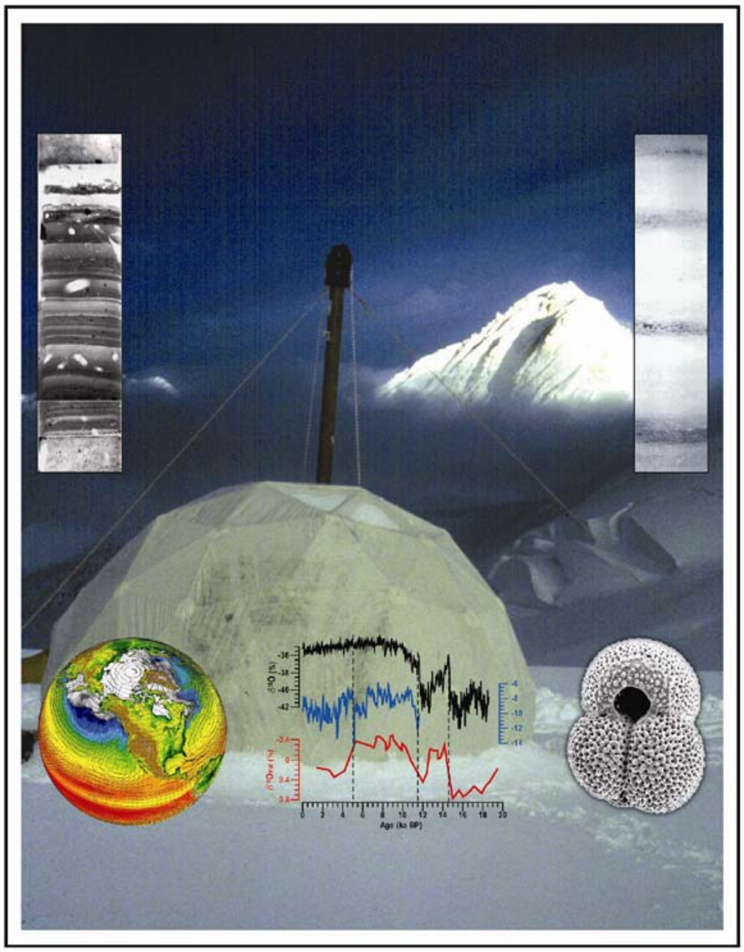
CHAPMAN CONFERENCE



CHAPMAN CONFERENCE ON ABRUPT CLIMATE CHANGE

Byrd Polar Research Center
The Ohio State University
Columbus, Ohio, USA
15–19 June 2009

UPCOMING CONFERENCES

Chapman Conference on the Biological Carbon Pump of the Oceans
Brockenhurst, Hampshire, England
1 - 4 September 2009

Chapman Conference on Examining Ecohydrological Feedbacks of Landscape Change Along Elevation Gradients in Semiarid Regions
Sun Valley, Idaho, USA
5 - 9 October 2009

Fall Meeting
San Francisco, California, USA
14 - 18 December 2009

Ocean Sciences Meeting
Portland, Oregon, USA
22 - 26 February 2010

Chapman Conference on Giant Earthquakes and Their Tsunamis
Valparaíso and Valdivia, Chile
17 - 24 May 2010

Western Pacific Geophysics Meeting
Taipei, Taiwan
22 - 25 June 2010

The Meeting of the Americas
Foz do Iguassu, Brazil
8 - 13 August 2010

For complete conference details, **http://www.agu.org/meetings/**

CHAPMAN CONFERENCE ON ABRUPT CLIMATE CHANGE

CONVENERS

- **Harunur Rashid**, Byrd Polar Research Center, The Ohio State University (United States)
- **Lonnie Thompson**, Byrd Polar Research Center, The Ohio State University (United States)
- **Leonid Polyak**, Byrd Polar Research Center, The Ohio State University (United States)

PROGRAM COMMITTEE

- **Henning Bauch**, IFM-GEOMAR (Germany)
- **Claire Waelbroeck**, LSCE-CNRS (France)
- **Valerie Masson-Delmotte**, IPSL/CEA-CNRS (France)
- **Larry Edwards**, University of Minnesota (United States)
- **Ian Hall**, School of Earth Sciences, Cardiff University (United Kingdom)
- **Ian Howat**, Byrd Polar Research Center, Ohio State University (United States)
- **Konrad Hughen**, Marine Chemistry and Geochemistry, WHOI (United States)
- **Tom Marchitto**, INSTAAR, University of Colorado (United States)
- **Antje Voelker**, LNEG (Portugal)

COSPONSORS

- National Science Foundation (NSF)
- Consortium for Ocean Leadership
- The Ohio State University (OSU)
- Climate, Water and Carbon (CWC) Initiatives of the OSU

Cover Images: The descriptions below begin with the image at the top left-hand side of the page and continue counter-clockwise.

Image-01: X-radiograph of centimeter thick sediment slice of Heinrich layer 2 from the northwest Labrador Sea. This image shows the vertical stacking of mm-thick ice-rafted detritus (IRD) and fine-grained detrital carbonate with the floating IRD (courtesy: H. Rashid; ref: Rashid et al., 2003).

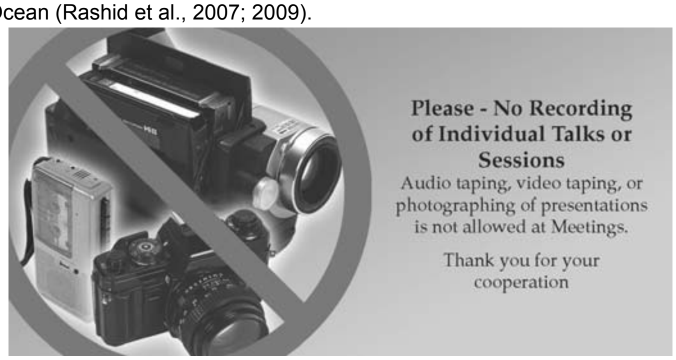
Image-02: This figure shows, for the atmosphere, vectors depicting the winds in the lowest model layer, and the sea level pressure. The ocean model surface temperatures are shown in blue to red colors and the sea ice concentration is shown in white gray. This coupled model consists of the NCAR Community Climate Model (CCM) for the atmospheric component, the Los Alamos National Laboratory Parallel Ocean Program (POP) for the ocean component, and the Naval Postgraduate School sea ice model (courtesy: Gary Strand of NCAR).

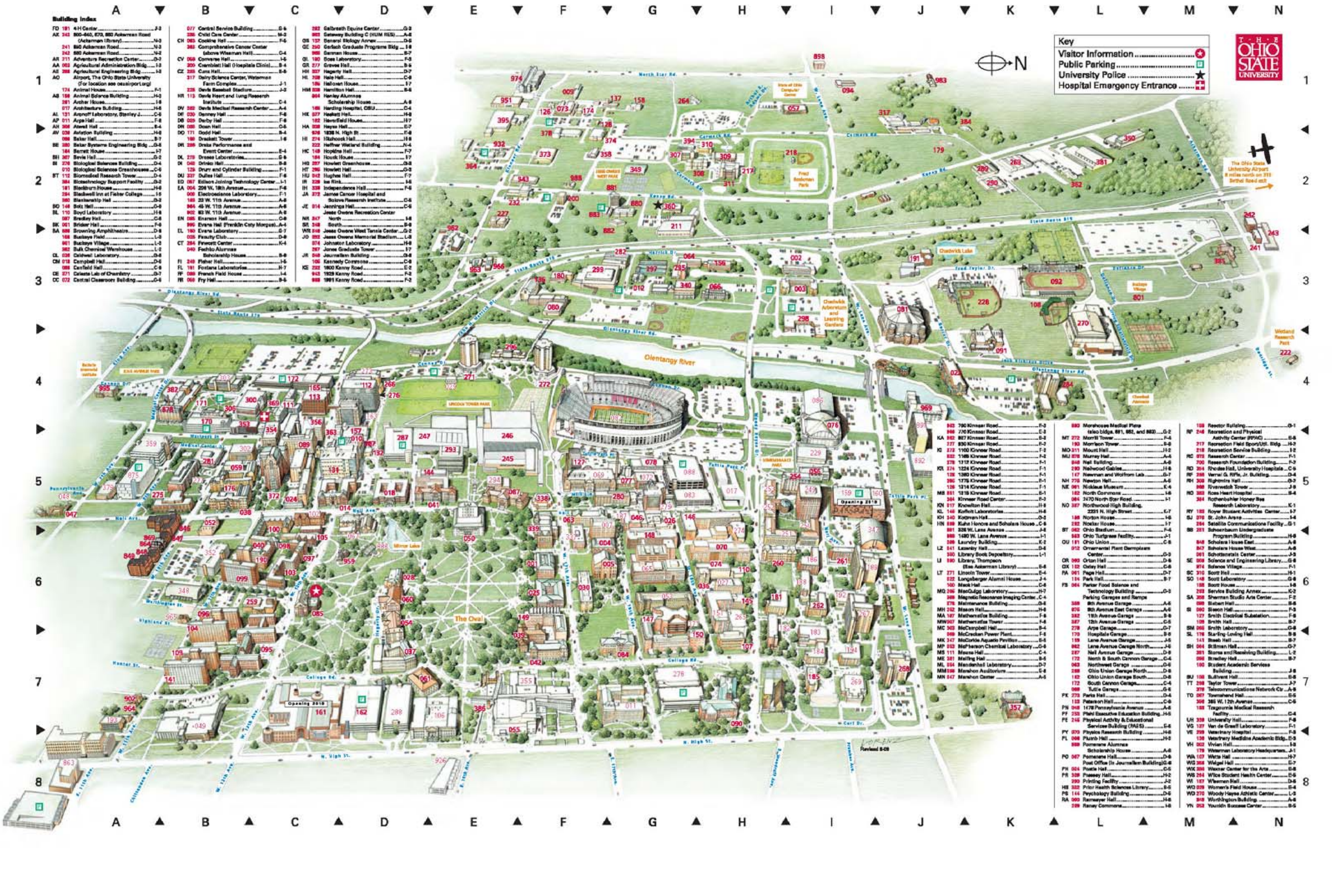
Image-03: The oxygen isotope data from the NGRIP (black) (Andersen et al., 2006) and Mount Kilimanjaro (blue) (Thompson et al., 2002) are plotted according to their independent time-scales. Seawater oxygen isotope data from the planktonic foraminifera *Globigerinoides ruber* (white variety) are also plotted which were derived from the sediment core RC12-344 from the Andaman Sea of the northern Indian Ocean (Rashid et al., 2007; 2009).

Image-04: Scanning electron microscopic (SEM) image of the planktonic foraminifera *Globigerinoides ruber* (white variety) from the Andaman Sea sediments: WD42.1mm 15.0kV x200 200µm (courtesy: H. Rashid).

Image-05: Photograph of the ice cores collected from the Guliya ice field of China. This image shows the distinct dry season dust layers while the white layers exhibit the clean wet season ice (courtesy: L. G. Thompson).

Backdrop Image: The drilling site of Dasoupu ice field, China, showing Xixibangma in the background (courtesy: L. G. Thompson).

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Chadwick Arboretum and Learning Gardens
Chadwick Lake
The Ohio State University Airport 8 miles north on 315 Bethel Road exit
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Meeting at a Glance

Sunday, 14 June
5:00 p.m. – 8:00 p.m. ♦ Registration/Info Desk
6:00 p.m. – 8:00 p.m. ♦ Ice Breaker Reception

Monday, 15 June
8:00 a.m. – 5:00 p.m. ♦ Registration/Info Desk
8:30 a.m. – 8:45 a.m. ♦ Introduction/Welcome
8:45 a.m. – 10:05 a.m. ♦ Oral Presentations
10:05 a.m. – 10:20 a.m. ♦ Refreshment Break
10:20 a.m. – 11:20 a.m. ♦ Oral Presentations
11:20 a.m. – 12:30 p.m. ♦ Discussion
12:30 p.m. – 2:00 p.m. ♦ Lunch
2:00 p.m. – 5:00 p.m. ♦ Poster Session

Tuesday, 16 June
8:30 a.m. – 5:00 p.m. ♦ Registration/Info Desk
9:00 a.m. – 10:20 a.m. ♦ Oral Presentations
10:20 a.m. – 10:35 a.m. ♦ Refreshment Break
10:35 a.m. – 11:35 a.m. ♦ Oral Presentations
11:35 a.m. – 12:30 p.m. ♦ Discussion
12:30 p.m. – 2:00 p.m. ♦ Lunch
2:00 p.m. – 5:00 p.m. ♦ Poster Session

Wednesday, 17 June
8:30 a.m. – 12:30 p.m. ♦ Registration/Info Desk
9:00 a.m. – 10:20 a.m. ♦ Oral Presentations
10:20 a.m. – 10:35 a.m. ♦ Refreshment Break
10:35 a.m. – 11:35 a.m. ♦ Oral Presentations
11:35 a.m. – 12:30 p.m. ♦ Discussion
12:30p.m. – 1:00 p.m. ♦ Lunch
1:00 p.m. – 6:00 p.m. ♦ Field Trip

Thursday, 18 June
8:30 a.m. – 5:00 p.m. ♦ Registration/Info Desk
9:00 a.m. – 10:20 a.m. ♦ Oral Presentations
10:20 a.m. – 10:35 a.m. ♦ Refreshment Break
10:35 a.m. – 11:55 a.m. ♦ Oral Presentations
11:55 a.m. – 12:45 p.m. ♦ Discussion
12:45 p.m. – 2:00 p.m. ♦ Lunch
2:00 p.m. – 5:00 p.m. ♦ Poster Session

Friday, 19 June
8:30 a.m. – 5:00 p.m. ♦ Registration/Info Desk
9:00 a.m. – 10:20 a.m. ♦ Oral Presentations
10:20 a.m. – 10:35 a.m. ♦ Refreshment Break
10:35 a.m. – 11:15 a.m. ♦ Oral Presentations
11:15 a.m. – 12:15 p.m. ♦ Discussion
12:15 p.m. ♦ Conference Conclusion

Shuttle Service Schedule

Shuttle service will be available during the following hours between the University Plaza Hotel & Conference Center and Mendenhall Laboratory:

Monday, Tuesday and Thursday:	7:30 a.m. – 8:30 a.m. 5:00 p.m. – 6:00 p.m.
Wednesday:	7:30 a.m. – 8:30 a.m. 12:30 p.m. – 1:00 p.m.
Friday:	7:30 a.m. – 8:30 a.m. 12:30 p.m. – 1:30 p.m.

Program Overview

All scientific sessions will be held at Ohio State University's Mendenhall Laboratory. Oral sessions are in Room 100. Poster sessions, as well as the Registration/Information Desk, will be located in the Foyer.

SUNDAY, 14 JUNE

6:00 p.m. – 8:00 p.m. ♦ **Ice Breaker** ♦ Baxter's Restaurant ♦ University Plaza Hotel
All meeting attendees are invited to attend this kick-off event. Enjoy a relaxing evening with friends and colleagues. Complimentary hors d'oeuvres will be provided and drinks will be available for purchase.

MONDAY, 15 JUNE

6:30 a.m. – 8:30 a.m. ♦ Complimentary breakfast buffet at the University Plaza Hotel for all hotel guests.

8:30 a.m. – 8:35 a.m. ♦ **Introductory Remarks** ♦ **Dr. Lonnie G Thompson**

8:35 a.m. – 8:45 a.m. ♦ **Conference Welcome** ♦ **Dr. Harunur Rashid**

POLAR CLIMATE VARIABILITY

CHAIR: L POLYAK (OHIO STATE UNIVERSITY, USA): CO-CHAIR: A VOELKER (LNEG, PORTUGAL)

8:45 a.m. – 9:05 a.m. ♦ **R B Alley** (Invited), *Ice-Core Records of North-Atlantic-Linked Abrupt Climate Changes*

9:05 a.m. – 9:25 a.m. ♦ **H A Bauch**, *A Massive Cold Event in the Polar North During the Last Interglacial Warm Period*

9:25 a.m. – 9:45 a.m. ♦ **B L Otto-Bliesner** (Invited), *Transient Simulation of Climate over the Last 21,000 Years (TraCE-21,000): Deglacial Evolution and Abrupt Changes*

9:45 a.m. – 10:05 a.m. ♦ **L Polyak**, *Evidence for Abrupt Climate Changes in Sedimentary Records From the Arctic Ocean*

10:05 a.m. – 10:20 a.m. ♦ **Refreshment Break** ♦ Foyer

10:20 a.m. – 10:40 a.m. ♦ **K Kawamura** (Invited), *Millennial-scale Southern Hemisphere Climatic Variability During the Last Seven Glacial Periods and its Relation to Northern Hemisphere Climate*

10:40 a.m. – 11:00 a.m. ♦ **S Marshall**, *Modelling Isotopic Discharge From the Laurentide Ice Sheet During D-O Cycles and the Last Deglaciation*

11:00 a.m. – 11:20 a.m. ♦ **O Timm**, *On the Origin of Antarctic Warming Events: A Modeling Study of Causes and Effects*

11:20 a.m. – 12:30 p.m. ♦ **Discussion**

12:30 p.m. – 2:00 p.m. ♦ **Lunch** ♦ Attendees are on their own for lunch.

2:00 p.m. – 5:00 p.m. ♦ **Poster Session** ♦ Soft drinks and snacks will be provided.

TUESDAY, 16 JUNE

6:30 a.m. – 8:30 a.m. ♦ Complimentary breakfast buffet at the University Plaza Hotel for all hotel guests.

HIGH LATITUDE ATMOSPHERE-OCEAN DYNAMICS AND THE MERIDIONAL OVERTURNING CIRCULATION

CHAIR: T MARCHITTO (INSTAAR, UNIVERSITY OF COLORADO, USA): CO-CHAIR: A TRIPATI (UNIVERSITY OF CAMBRIDGE, UNITED KINGDOM)

9:00 a.m. – 9:20 a.m. ♦ **K Pahnke** (Invited), *Increased Northward Incursion of Antarctic Intermediate Water During Heinrich Event 1 and the Younger Dryas*

9:20 a.m. – 9:40 a.m. ♦ **R Francois** (Invited), *Abrupt Changes in the Strength and Geometry of the Atlantic Meridional Overturning Circulation During the Last Deglaciation Recorded by 231Pa/230Th in North Atlantic Sediment*

9:40 a.m. – 10:00 a.m. ♦ **T L Delworth** (Invited), *CCSP Synthesis Report on Abrupt Climate Change - Atlantic Meridional Overturning Circulation*

10:00 a.m. – 10:20 a.m. ♦ **J P Severinghaus** (Invited), *Abrupt Increases in Atmospheric O-18 of O_2 (a Proxy for Monsoon Failure), Kr & Xe (Proxies for Deep Ocean Temperature), and CO_2 Recorded on the Same Time Scale by Gases in Ice Cores*

10:20 a.m. – 10:35 a.m. ♦ **Refreshment Break** ♦ Foyer

10:35 a.m. – 10:55 a.m. ♦ **A H L Voelker** (Invited), *See-Saw Patterns in Intermediate and Deep Waters of the North Atlantic Ocean Linked to Millennial-Scale Climate Variability*

10:55 a.m. – 11:15 a.m. ♦ **H Rashid**, *New Assessment for the Last Four Glacial Cycles' Northern Hemispheric Ice-Sheet Variability From the IODP Site U1313 of the North Atlantic*

11:15 a.m. – 11:35 a.m. ♦ **J Lynch-Stieglitz** (Invited), *Density Structure and Transport in the Florida Straits during the Younger Dryas and Heinrich Events 1-3*

11:35 a.m. – 12:30 p.m. ♦ **Discussion**

12:30 p.m. – 2:00 p.m. ♦ **Lunch** ♦ Attendees are on their own for lunch.

2:00 p.m. – 5:00 p.m. ♦ **Poster Session** ♦ Soft drinks and snacks will be provided.

WEDNESDAY, 17 JUNE

6:30 a.m. – 8:30 a.m. ♦ Complimentary breakfast buffet at the University Plaza Hotel for all hotel guests.

LOW TO MID-LATITUDE OCEAN-ATMOSPHERIC DYNAMICS

CHAIR: H RASHID (OHIO STATE UNIVERSITY, USA): CO-CHAIR: K PAHNKE (UNIVERSITY OF HAWAII, USA)

9:00 a.m. – 9:20 a.m. ♦ **K Hughen** (Invited), *Western Atlantic Intertropical Convergence Zone Variability over the Last Full Glacial Cycle*

9:20 a.m. – 9:40 a.m. ♦ **T M Quinn**, *Paleo-ENSO Records Derived from Fossil Corals (7-13 ka) from the Western Pacific Warm Pool*

9:40 a.m. – 10:00 a.m. ♦ **T M Marchitto**, *Millennial-Scale Variations in Eastern North Pacific Upwelling Temperatures Since the Last Deglaciation*

10:00 a.m. – 10:20 a.m. ♦ **M-T Chen**, *Millennial Sea Surface Temperature Changes Over the Past 40,000 Years in the Subtropical Western Pacific*

10:20 a.m. – 10:35 a.m. ♦ **Refreshment Break** ♦ Foyer

10:35 a.m. – 10:55 a.m. ♦ **R F Anderson** (Invited), *Wind-Driven Upwelling in the Southern Ocean and the Deglacial Rise in Atmospheric* CO_2

10:55 a.m. – 11:15 a.m. ♦ **L D Stott** (Invited), *Hypothesized Causal Link Between Glacial/Interglacial Atmospheric* CO_2 *Cycles and Liquid* CO_2 *Storage/Release From the Deep Sea*

11:15 a.m. – 11:35 a.m. ♦ **J Ahn**, *Abrupt Atmospheric* CO_2 *Changes During Antarctic Warming Event 1*

11:35 a.m. – 12:30 p.m. ♦ **Discussion**

12:30 p.m. – 1:00 p.m. ♦ **Lunch** ♦ Attendees are on their own for lunch.

1:00 p.m. – 6:00 p.m. ♦ **Field Trip to Laurentide Ice Sheet Margin at LGM, Central Ohio**
Advanced registration is required.
Professor Garry D McKenzie of the School of Earth Sciences, Ohio State University will lead the half-day field trip. The bus will depart at 1:00 p.m. from the University Plaza Hotel.

THURSDAY, 18 JUNE

6:30 a.m. – 8:30 a.m. ♦ Complimentary breakfast buffet at the University Plaza Hotel for all hotel guests.

ABRUPT CHANGES DURING THE HOLOCENE AND THEIR IMPACT ON CIVILIZATIONS

CHAIR: R S BRADLEY (UNIVERSITY OF MASSACHUSETTS, AMHERST, USA): CO-CHAIR: L G THOMPSON (OHIO STATE UNIVERSITY, USA)

9:00 a.m. – 9:20 a.m. ♦ **L G Thompson** (Invited), *Abrupt Climate Change: A Paleoclimate Perspective From the World's Highest Mountains*

9:20 a.m. – 9:40 a.m. ♦ **H Weiss** (Invited), *Social Adaptations to Holocene Abrupt Climate Changes in West Asia*

9:40 a.m. – 10:00 a.m. ♦ **R S Bradley** (Invited), *Abrupt Climate Change in the Late Holocene*

10:00 a.m. – 10:20 a.m. ♦ **B S Paliwal**, *Abrupt Holocene Climatic Change in the Northwestern India and Disappearance of Sarasvati River and the End of Vedic Civilization*

10:20 a.m. – 10:35 a.m. ♦ **Refreshment Break** ♦ Foyer

10:35 a.m. – 10:55 a.m. ♦ **J Feynman**, *Climate Stability and Development of Agricultural Societies*

10:55 a.m. – 11:15 a.m. ♦ **P deMenocal** (Invited), *The End of the African Humid Period at 5.5 ka BP: New Results on its Timing, Abruptness, and Spatial Extent*

11:15 a.m. – 11:35 a.m. ♦ **G H Miller**, *Abrupt Onset and Intensification of Ice Cap and Glacier Growth Around the Northern North Atlantic During the Little Ice Age: A Role for Volcanic Forcing?*

11:35 a.m. – 11:55 a.m. ♦ **A Tripati** (Invited), *Holocene and Glacial Temperatures From Clumped Isotope Thermometry in Foraminifera and Coccoliths*

11:55 a.m. – 12:45 p.m. ♦ **Discussion**

12:45 p.m. – 2:00 p.m. ♦ **Lunch** ♦ Attendees are on their own for lunch.

2:00 p.m. – 5:00 p.m. ♦ **Poster Session** ♦ Soft drinks and snacks will be provided.

FRIDAY, 19 JUNE

6:30 a.m. – 8:30 a.m. ♦ Complimentary breakfast buffet at the University Plaza Hotel for all hotel guests.

ABRUPT CLIMATE CHANGE DURING GLACIAL TERMINATIONS

CHAIR: R FRANCOIS (UNIVERSITY OF BRITISH COLUMBIA, CANADA): CO-CHAIR: P MARTIN (UNIVERSITY OF CHICAGO, USA)

9:00 a.m. – 9:20 a.m. ♦ **R L Edwards** (Invited), *Timing, Nature, and Causes of the Terminations of the Last Four Ice Age Cycles*

9:20 a.m. – 9:40 a.m. ♦ **P Aharon**, *Rapid Changes in Times of Climate Chaos: A Stalagmite Deglaciation Record from Dixieland*

9:40 a.m. – 10:00 a.m. ♦ **B P Flower** (Invited), *Meltwater Routing and the Atlantic Meridional Overturning Circulation During the Last Glacial-Interglacial Cycle: A Gulf of Mexico Perspective*

10:00 a.m. – 10:20 a.m. ♦ **L Tarasov**, *A Calibrated Deglacial Meltwater Chronology for the Northern Hemisphere*

10:20 a.m. – 10:35 a.m. ♦ **Refreshment Break** ♦ Foyer

10:35 a.m. – 10:55 a.m. ♦ **A V Fedorov**, *Stability of the Atlantic Meridional Overturning Circulation: Implications for Abrupt Climate Change*

10:55 a.m. – 11:15 a.m. ♦ **K J Meissner**, *The Younger Dryas: A Data to Model Comparison to Constrain the Strength of the Overturning Circulation*

11:15 a.m. – 12:15 p.m. ♦ **Discussion**

12:15 p.m. ♦ **Conclusion of Conference**

Poster Sessions

In addition to the presenting author and abstract title, each listing begins with the poster number used during the poster sessions. An asterisk after an author's name denotes the first author is a student.

Presenters are required to be present at their posters on indicated days during the poster sessions.

MONDAY, 15 JUNE; 2:00 P.M. – 5:00 P.M.

A-01 • P J Applegate*, *Effects of Sampling Criteria on the Distributions of Cosmogenic Exposure Dates from Degrading Moraines*
A-02 • E R Bash*, *Paleoclimatic Inferences in the Wasatch Mountains Based on Glacier Mass-Balance and Ice-Flow Modeling*
A-03 • M B Boslough, *Problems with the Younger Dryas Boundary (YDB) Impact Hypothesis*
A-04 • S E Engelhart*, *A Role for Greenland Mass Loss in 20th Century US Atlantic Coast Sea-Level Rise?*
A-05 • E Gaidos, *Dynamics of the Ice Shelf on Proglacial Lake Agassiz as a Stochastic Driver of Late Pleistocene Climate*
A-06 • K Gajewski, *Abrupt Climate Changes During the Holocene and Late Glacial Across North America From Pollen and Paleolimnological Records*
A-07 • F He*, *The Role of AMOC and CO_2 on the Evolution of Polar Temperature During the Last Deglaciation: a Transient GCM Study with CCSM3*
A-08 • Sharon S Hoffmann, *Abrupt and Millenial-Scale Changes in Arctic Sedimentary 231Pa/230Th*
A-09 • Juzhi Hou, *Exceptional Sensitivity of New England Climate to Abrupt Changes in Atlantic Meridional Overturning Circulation During the Early Holocene*
A-10 • E Levac, *The Impact of Early Holocene Lake Agassiz Floods Based on new Pollen, Dinoflagellate and Isotopic Data From the Northeast Newfoundland Shelf*
A-11 • C F M Lewis, *Correlating Lake Agassiz Floods to the Onset of the 8.2 cal ka Cold Event*
A-12 • Joe R Melton*, *Abrupt Climate Transitions and the delta-13CH4 Record: New Measurements and Old Corrections*
A-13 • MA Montes-Hugo, *Climate Modes and Phytoplankton Blooms in Four Major Coastal Antarctic Polynyas*
A-14 • A Orsi*, *Magnitude and Temporal Evolution of Interstadial 8 Abrupt Temperature Change Inferred From d15N and d40Ar in GISP2 Ice Using a New Least-Squares Inversion*
A-15 • F O Otieno, *Role of Insolation, Atmospheric Circulation, Greenhouse Gases and Topography on the Inception of Laurentide Ice Sheet*
A-16 • R F Spielhagen, *Arctic Ocean Freshwater Events and Their Possible Role in Abrupt Climate Changes in the Late Quaternary*
A-17 • P J Talling, *The Physical Record of Meltwater Floods as Marine Sediment Layers, and Temporal Relationships Between Meltwater Flooding and Giant Submarine Slope Failures*
A-18 • D J R Thornalley, *Meltwater Floods and Abrupt Deglacial Climate Change in the North Atlantic*
A-19 • A J Wagner, *Model Simulations of the 8.2 ka Event*
A-20 • L V Zotov, *Comparative Analysis of Benthic Foraminiferal Isotopic Records From Atlantic and Pacific Oceans Over the Past 1 Myr*

Tuesday, 16 June; 2:00 p.m. – 5:00 p.m.

B-01 • S P Bryan*, *Millennial-Scale Changes in Deep Ocean Circulation and Carbon Cycling During the Last Deglaciation: Evidence from the Arabian Sea*
B-02 • James Crampton, *Modulation of Abrupt Climate Change in the Southwest Pacific During Antarctic Cold Reversal -Younger Dryas Time*
B-03 • E D Galbraith, *A Bipolar Nutrient Seesaw Hypothesis*
B-04 • E Haam*, *A Test for the Presence of Covariance Between Time-Uncertain Series of Data With Application to a Collection of Proxy Records Showing Millennial Variability*
B-05 • A C Kemp*, *The Timing and Magnitude of a Recent Acceleration in the Rate of Relative Sea-Level Rise (North Carolina, USA)*
B-06 • Robert E Kopp, *Global and Local Sea Level During the Last Interglacial: A Probabilistic Assessment*
B-07 • D C Lund, *Sea Level Forcing of Mid-ocean Ridge Magmatism on Milankovitch Timescales*
B-08 • M Mohtadi, *High Latitude Control on Tropical Indian Ocean During the Past 22,000 Years*
B-09 • Genna M Patton*, *Mg/Ca Paleothermometry in the Central Gulf of Cadiz and the Iberian Margin During Heinrich Events*
B-10 • R De Pol-Holz, *Antarctic Intermediate Water Radiocarbon During the Last Deglaciation*
B-11 • R G Raynolds, *Communicating Past and Present Rates of Climate Change*
B-12 • J A Rial, *Modeling Abrupt Climate With Independent, Complementary Climate Models and a Possible Origin of the 1500yr Oscillation*
B-13 • A K Robertson*, *Paleoproductivity Variations in the Eastern Equatorial Pacific Over Glacial and Interglacial Timescales*
B-14 • J M Russell, *Abrupt Climate Change in the Southeast African Tropics Between 0 and 60,000 Yr BP: Testing the Influence of ITCZ Migration on Temperature and Precipitation in the Southern Tropics*
B-15 • L J Shiau*, *The Last 50,000-Year Biogenic Sedimentation, Biomarkers, and Terrigenous Input Records off the Southern Papua New Guinea (IMAGES MD052928)*
B-16 • Virendra Bahadur Singh, *Abrupt Changes in Benthic Foraminiferal Assemblages and Stable Isotope Record Around 3-4 Ma in the Southeast Indian Ocean, Signatures of Closing of the Indonesian Seaway*
B-17 • M Uchida, *Abrupt Ventilation Changes of the North Pacific Mid-Deep Water During the Last Glacial to Deglacial Period: Implications for Active North Pacific Deep Water Formation Synchronized with AMOC*
B-18 • P S Yu*, *High- to Low-Latitude Teleconnection and ENSO-Like Variability of Equatorial Pacific Climate Over the Last Glacial Cycle*

Thursday, 18 June; 2:00 p.m. – 5:00 p.m.

C-01 • Babagana Abubakar*, *The Impacts of Global Climate Change on the Lake Chad Region of Africa: The Lake Chad and Associated Problems*
C-02 • Bulent Acma, *Climate Change and Tourism: Southeastern Anatolia Region and Southeastern Anatolia Project (GAP) in Turkey as a Case Study*
C-03 • Shailesh Agrawal*, *Frequent Change in the Indian Monsoon Rainfall Intensity Over Past 30 ka and Its Impact on Vegetation: Evidence from Isotope Ratio of Soil Carbonate, Ganga Basin, India*
C-04 • M R Besonen, *Evidence for an Abrupt, Mid-1st Millennium AD Desiccation Event Recorded in Lacustrine Sediments From Central Western Turkey*
C-05 • R Boch, *Abrupt Climate Change During the Last Glacial Period Recorded in Stalagmites from the European Alps*
C-06 • C M Briggs, *Cascading Effects and Systemic Impacts of Abrupt Climate Change: Assessing Ecological and Social Tipping Points*
C-07 • K A Dwomoh, *Abrupt Change in Earth Climate*
C-08 • P Gabrielli, *The Widespread Abrupt Transition From the Holocene Thermal Maximum to the Neoglacial at ~5 kyr BP: What are the Drivers and the Mechanisms?*
C-09 • Ali Kazemi, *Scolecodonts and Their Biostratigraphy in Ordovician and Silurian Rocks, Kopet Dagh, North Iran*
C-10 • T C Kumasi*, *Land Cover Change in the Barekese River Basin of Ghana From 1973-2006*
C-11 • B Machalett*, *Long Term Seasonality Changes and Abrupt Climate Shifts Recorded in Highly Resolved Dust/Loess Sequences Across Euras*
C-12 • C Morrill, *Statistical Detection of Mid-Holocene Abrupt Climate Changes From Proxy Records*
C-13 • **I** J Orland*, *High-Resolution Paleoclimate Records From Soreq Cave Speleothems: Sub-annual Resolution by Ion Microprobe*
C-14 • A V Pastukhov, *GIS Mapping: Soil Carbon Estimates & Lowering of Permafrost Table as a Result of Abrupt Climate Change*
C-15 • H Rashid, *Demise of Indus Valley Civilizations Linked to the Decline of Indian Ocean Monsoon*
C-16 • A Ruzmaikin, *The 1500-Year Variability During the Holocene: Amplitude and Phase Relationships*
C-17 • S F Singer, *On Causes and Mechanisms of the 1500-Year Climate Cycles*
C-18 • Adi Torfstein, *Dry-spells in the Levant During the Last Deglaciation Identified by Dead Sea Lake Levels*
C-19 • X F Wang, *Rapid Amazonian Moisture Changes During the Last Glacial Period*
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Oral Presentation Abstracts

Abstracts are listed chronologically, according to the conference schedule.

Monday, 15 June

Ice-Core Records of North-Atlantic-Linked Abrupt Climate Changes

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As reviewed here, ice-core records have provided wonderfully clear views of the abrupt climate changes centered on the North Atlantic during the most recent ice-age cycle. Correlations between north and south, and with marine and terrestrial records, document the north Atlantic center of action, the strong wintertime dominance of anomalies there, the widespread anomalies involving the tropics, and the seesaw action between north and south. Much recent work points to a strong role for the North Atlantic changes in modulating Southern Ocean behavior affecting atmospheric carbon dioxide, with the strong indication that the abrupt changes really were essential in controlling the ice-age cycles themselves. Despite the success of this effort, much work remains for full understanding of these critical phenomena.

A Massive Cold Event in the Polar North During the Last Interglacial Warm Period

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The prospect of a significantly warmer Earth in the near future than ever found during the Holocene “interglacial” period (past 10,000 years) justifies the search among older warm interglacial cycles with apparently similar or even warmer environmental constraints for further evaluation. The last interglacial period, called the Eemian in Europe (centered around 125,000 years ago) and identified in marine sediments cores as marine oxygen isotope stage 5e (MIS 5e), has long been recognized as groundtruthing model for future climate development. This is because average temperatures are often believed to have generally been higher, causing global sea level to be several meters above that of the Holocene due to larger wastage of glacier ice on land such as that on Greenland. However, it has been rather difficult in the past to retrieve good climate records of the Eemian from the Polar North. Either the records are incomplete, or stratigraphically and paleoclimatologically difficult to validate. Moreover, the earlier publication of the highly variable, but clearly disturbed, Eemian climate record in the basal section of the GRIP ice core from Greenland spurred, nevertheless, a number of subsequent investigations. Using a high-resolution sediment record we now report about the last interglacial from the eastern Norwegian Sea. The data reveal the existence of one major cold event with near-glacial surface ocean conditions. The event punctuated the peak interglacial period thus subdividing MIS5e into an early warm phase and a late, but notably warmer second phase. We interpret the cold event to have been associated with a switch to a zonal atmospheric circulation regime leading to widespread eastern expansions of winter sea-ice and polar water masses. The marine records not only provide new evidence for the natural variability of a warm interglacial climate system, they also underscore the close linkage of environmental change over the North Polar region and the contemporaneous climate status quo. It is concluded that high-northern atmospheric circulation plays a vital role in mediating rapid climate changes during interglacial periods.

Transient Simulation of Climate over the Last 21,000 Years (TraCE-21,000): Deglacial Evolution and Abrupt Changes

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A transient simulation of global climate change from the Last Glacial Maximum to present employing the synchronously coupled NCAR Community Climate System Model (CCSM3) is currently being run as a DOE INCITE project. CCSM3 reproduces the major features of the deglaciation evolution and abrupt climate changes to the Bolling-Allerod (BA) warming– has about the right climate sensitivity – when forced with orbital, greenhouse gas concentrations, ice sheet evolution, and reasonable meltwater fluxes. In response to an increase in meltwater to the North Atlantic at 19 kyr BP, the ocean Atlantic Meridional Overturning Circulation (AMOC) decreases gradually to a near shutdown at Heinrich event 1 (H1). As the meltwater flux is decreased, the AMOC resumes, abruptly at the BA when the flux is decreased abruptly. Notably, CCSM3 simulates the abrupt BA warming over Greenland as a transient response of the Atlantic Meridional Overturning Circulation to the termination of Northern Hemisphere freshwater discharge associated with H1. Three effects contribute to the large BA warming: warming from ongoing carbon dioxide rise, the AMOC recovery and an AMOC overshoot. Further, EOF analysis of the transient simulation from LGM to the BA warming illustrates that for global surface temperature, the largest variability is explained by the global mode of warming associated with carbon dioxide, orbital and ice sheet changes. Most of the remaining variability is explained by the bipolar response to Northern Hemisphere freshwater forcing. For precipitation, on the other hand, the largest variability is associated with the shifting ITCZ response to the freshwater forcing, with the monsoon response to orbital variations explaining much of the rest of the variability.

Evidence for Abrupt Climate Changes in Sedimentary Records From the Arctic Ocean

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The Arctic Ocean is one of the most climatically sensitive areas on Earth due to its changeable sea-ice and snow cover, susceptibility to sea-level fluctuations, and the direct proximity to major Pleistocene ice sheets. However, rapid climate changes are difficult to identify in Arctic sedimentary records because of predominantly low sedimentation rates in the central Arctic Ocean and typically short stratigraphic range of recoverable shelf deposits. Detailed investigation of sediment cores collected on several recent expeditions such as the 2005 Healy-Oden TransArctic Expedition (HOTRAX) allow for a more thorough look at sedimentation history in the Arctic Ocean. Cores from the Alaskan margin recover Holocene to LGM sediments, which yield sedimentation rates of up to 1.5 m kyr^{-1}. These records can be correlated to deep-sea cores with lower resolution, but much longer stratigraphies. Core HLY0503-8JPC from the base of the Mendeleev Ridge slope with the average Late Quaternary sedimentation rates of 2 cm kyr^{-1} constitutes the best-resolution record for the deep-sea western Arctic Ocean thus far. Cyclic variations in lithology and foraminiferal abundance and stable-isotopic composition indicate changes in hydrographic and depositional environments between interglacial-type and glacial-type periods reflecting a combination of precessional and 100-kyr time scales, where the precessional control is possibly related to sea-ice conditions. This periodicity is complicated by abrupt iceberg- and meltwater-discharge events with variable (Laurentide vs. Eurasian) provenance. The Laurentide iceberg pulses are distinguished by high content of detrital carbonate, similar to Heinrich events in the North Atlantic, and likely indicate episodes of ice-sheet instability and activation of ice streams. Pronounced $\delta^{18}O$ depletions are indicative of voluminous, pulsed meltwater discharges related to the drainage of large proglacial lakes, such as those mapped along the southern margin of Eurasian ice sheets, or subglacial reservoirs. Episodes of elevated sedimentation rates occurring in deglacial or interglacial units may be also related to the proximity of the sea-ice margin; identification of such events is critical for reconstructing past sea-ice extent.

Millennial-scale Southern Hemisphere Climatic Variability During the Last Seven Glacial Periods and its Relation to Northern Hemisphere Climate

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Climate variability on millennial to suborbital timescales during the last glacial period have been documented in a wide variety of paleoclimatic proxies. However, its frequency and magnitude for the older glacial periods, as well as prerequisite of the millennial-scale variations, are still uncertain. We here present a new 3,035-m (720,000-yr) ice core record from Dome Fuji, Antarctica. Excellent agreement between the Dome F and Dome C isotopic records indicates homogeneous climate variability across East Antarctic plateau on millennial to orbital timescales throughout the past 720 kyr. Combination of the two records permits clear identification of multi-millennial-scale warming events in Antarctica (large Antarctic Isotope Maxima), which are found to have persisted over the last seven glacial periods, with an overall relationship between the duration of glacial period and the number of events. A closer look at Marine Isotope Stage 16, where the Dome F core’s annual layer thickness is 2-3 times larger than the Dome C core, reveals that the millennial-scale variations of dust flux are negatively correlated with temperature for all identified events, suggesting reduced aridity during large AIMs in Patagonia. In order to gain further insight into the prerequisite of occurrence of bipolar seesaw, we conducted numerical modeling of the response of climate to freshwater forcing, with a fully coupled atmosphere-ocean general circulation model (MIROC GCM). Modest fresh water (0.1 Sv) was released into the northern North Atlantic for 500 years and then stopped for another 500 years, under two different climatic states: present-day-like interglacial and intermediate glacial (such as MIS 3) conditions. The results suggest that large Antarctic warming (~1 ˚C/500 yr) and Austral precipitation increase in response to northern freshwater forcing only occur when the combination of background coldness and fresh water amount exceeds some threshold. Occurrences of very large AIMs (and abrupt CH_4 rises) in early parts of glacial periods (e.g. MIS 5a-5d) apparently contradict with a threshold concept (such as Antarctic temperature being 4^{o}C below the late Holocene level). However, the onsets of almost all AIMs fall below the threshold. We speculate that Antarctica ultimately became warmer than the threshold due to intense precession forcing (strong rise of northern summer insolation), which would maintain the freshwater supply into the North Atlantic by melting ice sheets. This could explain the absence of massive iceberg discharges (Heinrich events) for the large but infrequent bipolar seesaw sequences in the early parts of glacial periods, when ice volume was relatively small (thus relatively stable) but precession amplitude was large.

Modelling Isotopic Discharge From the Laurentide Ice Sheet During D-O Cycles and the Last Deglaciation

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Stable isotopic ratios of deuterium and oxygen in the Laurentide Ice Sheet during the last glacial cycle are not well-constrained, but these values are important to reconstructions of global sea level and surface water isotopic content where the ice sheet discharged icebergs and meltwater runoff to the ocean. Based on 3D tracer modelling of stable isotope transport in the Laurentide Ice Sheet in a model of ice sheet growth and decay, I examine the spatial distribution and temporal evolution of oxygen isotopes through the last glacial cycle. A simplified Rayleigh transport model is adapted to predict surface snow isotopic input to the ice sheet, with climate model (AGCM) wind and precipitation fields used to model vapour trajectories for the isotopic distillation. Isotopic signals are then advected through the ice sheet and the isotopic content of meltwater and iceberg discharge to the North Atlantic are modeled through time. This provides predictions of the Laurentide Ice Sheet's overall contribution to the marine oxygen-16 deficit at last glacial maximum, the isotopic signatures of millennial-scale iceberg discharge during the glaciation, and the isotopic character of meltwater pulse 1a. The initial meltwater discharge during deglaciation is relatively enriched in oxygen-18 compared with the final stages of Laurentide Ice Sheet decay, giving a non-uniform time series of isotopic runoff that may be important to marine isotope interpretations of the deglaciation.

On the Origin of Antarctic Warming Events: A Modeling Study of Causes and Effects

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It is widely accepted that millennial-scale temperature variability during Marine Isotopic Stage 3 has a characteristic out-of-phase relationship between the Northern and Southern Hemisphere. Here we present results from waterhosing intercomparison experiments and a series of paleoclimate modeling experiments that were conducted with LOVECLIM, an Earth system model of intermediate complexity. Waterhosing experiments with freshwater input into the North Atlantic show that a simulated net increase in atmospheric CO_2 following the shutdown of the Atlantic meridional overturning circulation is a major contributor to the so-called Antarctic warming events. Furthermore, the warming over Antarctica is modulated by diabatic heating anomalies in the remote tropical Pacific that excite a stationary wave pattern response over the Southern Ocean. The implications for the interpretation of Antarctic ice-core records and the importance of the global mean climate state for the Antarctic warming response are discussed.

Tuesday, 16 June

Increased Northward Incursion of Antarctic Intermediate Water During Heinrich Event 1 and the Younger Dryas

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Evidence from marine, ice core and terrestrial records indicates abrupt reorganizations of the meridional overturning circulation (MOC) in close correlation with climate fluctuations, suggesting a tight link between the two. Different water masses take on different roles in this system, but the importance of each component and their detailed interactions are still not fully understood. Yet, such understanding is paramount to the

assessment of natural variations and their potential behavior under future climate warming scenarios. Antarctic Intermediate Water (AAIW) is an important conduit of heat, freshwater and nutrients to the global ocean, partly compensates for North Atlantic Deep Water (NADW) formation, and is a major sink for anthropogenic CO2. Recent property changes of AAIW in response to current climate warming highlight its sensitivity to climate change and suggest a rapid transfer of climate and ocean perturbations in the Southern Ocean to the world oceans via AAIW. Knowledge of the behavior of AAIW in the recent geologic past is therefore critical for a better understanding of the ocean-climate system and its interactions.

Here we report neodymium isotope ratios ($^{143}Nd/^{144}Nd$) from core MD99-2198 in the western tropical Atlantic (12.09N, 61.23W, 1330m water depth) over the past 25ky. The results indicate abrupt increases in the northward extent of AAIW during Heinrich event 1, the Younger Dryas, and at ~19ky, when North Atlantic water mass formation was reduced. Similar positive excursions in mid-depth benthic stable carbon isotope records from the southwest Pacific and warming in the Southern Hemisphere suggest that AAIW formation increased, enhancing its northward reach into the North Atlantic. The inverse relationship of millennial-scale changes in NADW formation and the northward penetration of AAIW provides strong evidence for the NADW-AAIW seesaw simulated by models (e.g., Saenko et al., 2003, J. Clim. 16, 2797-2801), and suggests an active contribution of AAIW changes to abrupt MOC and climate shifts.

Abrupt Changes in the Strength and Geometry of the Atlantic Meridional Overturning Circulation During the Last Deglaciation Recorded by 231Pa/230Th in North Atlantic Sediment

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Sediment 231Pa/230Th profiles obtained from five sites in the western and eastern North Atlantic between 1710m and 4550m water depth document variations in the strength and the geometry of the Atlantic meridional overturning circulation that accompanied abrupt climate changes during the last deglaciation. We developed a simple 2-D circulation-scavenging model to interpret the data and test the sensitivity of the $^{231}Pa/^{230}Th$ record to changes in particle flux and composition. Data from the Holocene core sections indicate slow water renewal rates above ~2500m and faster overturning rates below, consistent with our understanding of modern circulation. In contrast, during the Last Glacial Maximum (LGM), the formation of Glacial North Atlantic Intermediate Water (GNAIW) resulted in a rapid overturning circulation to a depth of at least ~3000m depth, while renewal rates were significantly slower than today below ~4000m. At the onset of Heinrich event 1 (H1), the rate of the overturning circulation declined at all depths. GNAIW shoaled above 3000m while its rate of formation significantly decreased but did not totally stop. During the Bølling-Allerød (BA) that followed, the rate of meridional overturning further decreased above 2000m but increased below. Our results suggest for the first time that ocean circulation during that period was quite distinct from modern circulation, with comparatively higher renewal rates above 3,000m and lower renewal rates below, in a pattern similar to the LGM but less accentuated. The rate of the meridional overturning during the Younger Dryas (YD) was very similar to that of the BA down to 2,000 m but slightly slower below.
The coherence of these results and the absence of a clear signal that could suggest a control by particle flux or composition further support the interpretation of $^{231}Pa/^{230}Th$ in Atlantic sediments as a paleocirculation proxy, and provide additional evidence for a strong link between climate and the rate and mode of the Atlantic Meridional Overturning Circulation during the last deglaciation.

CCSP Synthesis Report on Abrupt Climate Change - Atlantic Meridional Overturning Circulation

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A recently completed US Climate Change Science Program (CCSP) Synthesis Report focused on the possibility of future abrupt climate change. One of the four foci for possible abrupt change was the Atlantic Meridional Overturning Circulation (AMOC). Here we present the central findings of that synthesis report on the AMOC. Using the terminology of IPCC AR4, we assess that it is very unlikely (less than 10% probability) that the AMOC will abruptly weaken or collapse in the 21st century. This assessment relies heavily on the fact that no current comprehensive climate model projects an abrupt AMOC change or collapse in the 21st century.

However, while the chances of such an abrupt change are relatively small, the impacts would be severe, and would include sea level rise around the North Atlantic of up to 80 centimeters (in addition to what would be expected from broad-scale warming of the global ocean and changes in land-based ice sheets due to rising CO_2), changes in atmospheric circulation conditions that influence hurricane activity, a southward shift of tropical rainfall belts with resulting agricultural impacts, and disruptions to marine ecosystems. These potential impacts, coupled with uncertainties in current climate models, argue for a strong research effort to develop the observations, understanding, and models required to predict more confidently the future evolution of the AMOC.

Abrupt Increases in Atmospheric O-18 of O_2 (a Proxy for Monsoon Failure), Kr & Xe (Proxies for Deep Ocean Temperature), and CO_2 Recorded on the Same Time Scale by Gases in Ice Cores

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Deciphering the tangled web of cause and effect during abrupt climate change is complicated by the fact that many events occur closely in time, yet dating uncertainties are commonly larger than the time between events. Ice core gas records can assist in this effort because all gas parameters are recorded on the same time scale in the same ice core. At about 18 ka, the onset of Heinrich Stadial 1 (Weak Monsoon Interval I), six different gases show near-synchronous changes. The oxygen-18 content of atmospheric molecular oxygen rises, at the same time that seawater oxygen-18 is falling, indicating an abrupt increase in the strength of the Dole Effect, which is thought to reflect the weakening of isotopically-depleted Asian monsoon rainfall. Antarctic ice core nitrogen, argon, and krypton isotopes rise, reflecting increased local temperature and snow accumulation. Methane and CO_2 also begin a gradual increase. Krypton and xenon increase between about 18-16 ka, albeit within rather large error bars at present; these gases reflect mean ocean temperature, suggesting that deep ocean temperature warmed about $2^{o}C$ during this interval. All of these changes are reconcilable in the context of a southward shift of the planet's thermal equator, but the exact causality awaits better precision, such as is expected from the WAIS Divide ice core.

See-Saw Patterns in Intermediate and Deep Waters of the North Atlantic Ocean Linked to Millennial-Scale Climate Variability

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In the eastern North Atlantic basin the Mediterranean Outflow Water (MOW) is a prominent water mass in intermediate depths (500-1500 m). Because of its high salinity and thus potential to increase a water's density it is thought to boost convection in the North Atlantic. The water masses encountered below the MOW are the North Atlantic Deep Water (NADW) and the Antarctic Bottom Water (AABW).

Paleoclimate records from the Gulf of Cadiz show that the MOW responded to abrupt climate variability. During the last glacial maximum (LGM), the MOW settled deeper in the water column (2000 m) and its flow strength increased. In addition, MOW strength increased during all the Heinrich- and Greenland stadials of the last 50 ka, thus during times when convection in the North Atlantic was either turned off or reduced. In the western Mediterranean Sea, on the other hand, deep convection, which ultimately fed the MOW, was enhanced during those times, while it was diminished during Greenland interstadials when the Atlantic's Meridional Overturning Circulation (AMOC) was strong. Hence a see-saw pattern existed between the convection centers in the North Atlantic and the Mediterranean Sea during the last glacial (Sierro et al. 2005). Since the MOW and thus the salt export from the Mediterranean Sea was strong, when AMOC was weakened, Voelker et al. (2006) postulated that the MOW might provide a trigger mechanism for the AMOC to switch from the Heinrich-/ stadial-type circulation to the interstadial one.

New records from the Portuguese margin and IODP Site U1313 now reveal that the same see-saw pattern between the AMOC and Mediterranean Sea convection/ MOW also existed during the mid-Brunhes, thus under different climate forcing. Records from site MD03-2699 on the Portuguese margin, which today is bathed in NADW, reveal that during the glacial MIS 10, 12 and 14 MOW also settled as deep as 1900 m. More importantly for the understanding of abrupt climate change, however, are the millennial-scale oscillations in MD03-2699's deep water records during the transitions from interglacials to glacials. MOW influenced site MD03-2699, whenever surface waters cooled at IODP Site U1313 and its benthic isotope records indicate a shoaling of the NADW/ AABW interface, thus a weaker AMOC. Only the glacial stage coolings during the mid-Brunhes are linked to Heinrich-type ice-rafting events, while all the other events are stadial-type coolings. Consequently, ice sheet instabilities and southward advances of subpolar waters are contributing to millennial-scale climate variabilty also during the mid-Brunhes.

New Assessment for the Last Four Glacial Cycles' Northern Hemispheric Ice-Sheet Variability From the IODP Site U1313 of the North Atlantic

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High resolution meridional overturning circulation (MOC) and sea-surface temperatures (SSTs) data covering the last four glacial cycles from the northwest Atlantic Ocean are lacking. Here we report the continuous millennial-scale ice-rafted detritus (IRD), MOC, SSTs and $\delta^{18}O_{seawater}$ data for the last four glacial cycles from the IODP Site U1313 (41°N, 32.57°W; 3425 mwd). The site was drilled at the former ODP Site 607. X-ray fluorescence data show a many-fold increase in Fe and Ti concentrations during the cold times compared to the warmer periods. We attribute such increases in Fe and Ti to sediment remobilization from the continental shelves around the North Atlantic. IRD numbers show an increase during the last glacial cycle compared to preceding three glacial cycles. Heaviest benthic $\delta^{18}O$ were associated with the MISs 12 and 10 compared to MISs 2 and 6 that were accompanied by lighter $\delta^{13}C$ in *Cibicidoides wuellerstorfi*. Lighter benthic $\delta^{18}O$ lead the planktonic $\delta^{18}O$ in *Globigerina bulloides* across the terminations I, II, IV and V by ~3-6 kyr.

Mg/Ca-SSTs in the *G. bulloides* show that the warmest temperatures in the North Atlantic were not associated with the MISs 5.5 and 11 but rather with the MIS 5.1, 5.3, 7.1, 7.3, 7.5, 9.1 and 9.5. Moreover, the warmest SSTs of MIS 11 were found in the latter part between 411 and 400 ka BP, consistent with the deuterium-based temperature estimates from the EPICA Dome C for the same interval. Our SST estimates show similarities with the strength of the Asian monsoon from the Sanbao/Hulu cave records during the MISs 2, 5.1, 5.3 and 5.5. The SSTs prior to terminations lead the global ice-volume, however, the cooler SSTs were accompanied by the heavier $\delta^{18}O$ in *G. bulloides* towards the end of the terminations (except TI).

The $\delta^{13}C$ in C. *wuellerstorfi* become progressively heavier from MISs 12 to 1 with the heaviest values during the interglacials and lighter values during the glacial periods. Superimposed on this longer trend is the millennial-scale variability that occasionally can be correlated to IRD events suggesting the meltwater-induced MOC perturbation. Additionally, we found two lighter $\delta^{13}C$ longer intervals that were not previously reported and cannot be attributed to the IRD-induced MOC reduction.

Our results suggest the following:

(1) Laurentide ice sheet was the largest during the last glacial cycle compared to three preceding glacial cycles. We infer that the Eurasian Ice Sheet must have been larger during the MISs 6, 10, and 12, compared to MISs 2 and 4, to account for the enriched benthic $\delta^{18}O$.

(2) We suggest that the addition of brines to the Antarctic Bottom Water and/or bottom water warming across the terminations I, II, IV and V can explain the benthic $\delta^{18}O$ lead over the planktonic $\delta^{18}O$ data.

(3) Our SSTs estimate is in contrast to the "stable and warmer climate for the entire MIS 11 (425-386 ka BP)" proposed earlier based on planktonic foraminiferal assemblages and $\delta^{18}O$ data.

(4) We suggest that meltwater from the ice-sheets dampen the SST warming at the end of the terminations as indicated by the heavier $\delta^{18}O$ in *G. bulloides*.

(5) *C. wuellerstorfi* $\delta^{13}C$ data suggest that the deep Atlantic Ocean was flooded by the Antarctic Bottom Water (AABW) as opposed to the deep Pacific water during the MISs 10 and 12. Our new Cd/Ca and Za/Ca data in the benthic foraminifera would shed lights into this.

Density Structure and Transport in the Florida Straits during the Younger Dryas and Heinrich Events 1-3

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It is postulated that the abrupt climate change events seen over the last glacial cycle are associated with changes in the Atlantic Meridional Overturning Circulation (AMOC). The flow through the Florida Straits contains much of the northward surface flow associated with the AMOC as well as wind-driven flow associated with the subtropical gyre. We have used oxygen isotope ratios in benthic foraminifera to reconstruct the horizontal density gradients in the Florida Straits, which can then be used to infer the vertical shear in the volume transport. This information is combined with other paleoceanographic data as well as our knowledge of ocean and atmospheric dynamics to gain insight into past changes in the circulation of the North Atlantic Ocean. The inferred decrease in density contrast across the Florida Current during the Younger Dryas implies a reduced shear in the Florida Current, consistent with other evidence for a weakening AMOC. The reduced density contrast across the Straits during the Younger Dryas is manifest as a period of relatively low oxygen isotope ratio in benthic foraminifera (low density) on the Florida Margin. We see a similar excursion in the benthic oxygen isotope ratio on the Florida Margin for Heinrich Event 1. By analogy with the Younger Dryas we suggest that the Florida Current was reduced during these times as well. However, we do not see any evidence for density excursions on the Florida Margin during Heinrich Events 2 and 3. While our Florida Margin record does not extend very far back into Marine Isotope Stage 3, we do see changes in the isotopic composition of the benthic foraminifera for D-O Events 5, 6 and 7.

Wednesday, 16 June

Western Atlantic Intertropical Convergence Zone Variability over the Last Full Glacial Cycle

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Precipitation associated with the Intertropical Convergence Zone (ITCZ) in the Atlantic basin is sensitive to fluctuations in both local insolation and remote climate forcing in the North Atlantic and equatorial Pacific. Reconstructing the pattern and timing of precipitation change in regions influenced by the ITCZ may clarify teleconnections between low and high latitudes and the mechanisms driving abrupt climate changes. Stable carbon and hydrogen isotopic compositions of individual vascular plant lipids preserved in Cariaco Basin sediments were measured at sub-millennial resolution over the last glacial cycle. High frequency oscillations in δ^{13}C of long chain fatty acids reflect changes in the relative proportion of C3 vs C4 vegetation, and hence aridity, in northern South America. These shifts coincide with millennial scale variability in the high latitude North Atlantic region, with positive excursions associated with increased biomass of arid C4 grasslands occurring during stadial periods. The largest enrichments signaling severe droughts are coeval with Heinrich Events. The corresponding δD signatures also indicate rapid shifts in the hydrological cycle. Detailed molecular level radiocarbon measurements in the modern environment indicate that a significant portion of Cariaco leaf wax compounds are pre-aged by several thousand years within the adjacent drainage basin before ultimate deposition in marine sediments. Nevertheless, much of the original climatic information is likely preserved by the remaining component, which is delivered to the ocean within ten to twenty years of biosynthesis. Over the last Glacial cycle, millennial scale drought events were modulated by a longer-term oscillation with significant power near the 21 kyr precessional spectral band. Moreover, the magnitudes of extreme drought events were further modified at 100 kyr timescales by the amplitude of the precessional cycle, with larger displacements of the ITCZ occurring during periods of enhanced seasonality. Together, these data imply that the ITCZ in this region of the tropics responded to both high and low latitude forcing, consistent with a mechanism in which millennial-scale D-O events originated at high northern latitudes and were subsequently modified by conditions in the tropics.

Paleo-ENSO Records Derived from Fossil Corals (7-13 ka) from the Western Pacific Warm Pool

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We investigate the nature of interannual variability in the Western Pacific Warm Pool using monthly resolved, multi-decadal time series of δ^{18}O and Sr/Ca variations encoded in the skeletons of massive fossil corals exposed on tectonically uplifted islands in the southwest Pacific (the Solomons and Papua New Guinea). Post-depositional alteration of our fossil coral samples is minimal based on mineralogic (XRD), petrographic (SEM, thin section) and geochemical criteria (preservation of modern marine initial d234U). A select suite of these fossil coral time series are of particular interest: 99RND (age, 7,992±42; ~40 years), 01T-B (age, 7,647±73; ~65 years), 01T-AQ (age, 10,208±44; ~30 years), 99TET-B (age, 11,987±69; ~ 30 years) and 96-PNG (age, 13,115±43; ~75 years). In this study we focus on climate variability and not mean state changes because of the inherent uncertainties associated with past estimates of surface ocean chemistry (e.g., seawater δ^{18}O and Sr/Ca) and ice volume, as well as those that are coral-based (e.g., replication). We compare geochemical time series that have been filtered to reveal variations in the ENSO band in both modern and fossil corals. Our results are consistent with the concept of an active ENSO system during the select time periods of coral growth, although the amplitude of the variations observed in the fossil corals are somewhat reduced relative to those observed in modern corals from the region.

Millennial-Scale Variations in Eastern North Pacific Upwelling Temperatures Since the Last Deglaciation

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The oxygen minimum zone of the eastern tropical/subtropical North Pacific is known to have been eroded (better oxygenated) during millennial-scale cold periods of the last ice age. The relative influences of two viable mechanisms, enhanced ventilation of intermediate waters and reduced productivity along the continental margin, have been notoriously difficult to separate. We hypothesize that productivity was reduced during stadials because of either reduced coastal upwelling, or a deepening of the regional nutricline and thermocline as occurs during modern El Niño events. A potentially valuable tracer of both processes is Mg/Ca in the upwelling-favoring planktic foraminifer *Globigerina bulloides*, which might therefore record warmer waters during stadials. Unfortunately, most high-resolution cores from along this margin are characterized by very poor preservation of calcite, which is a serious problem for planktic Mg/Ca accuracy. However, we have identified a 14 kyr-long piston core with superb calcite preservation, recovered in 1999 from Soledad Basin off Baja California (25°N, 113°W). The site is today a suboxic basin with an effective sill depth of 290 m.

We present a high-resolution record of G. bulloides Mg/Ca spanning the interval 14.2 to 2.8 ka. The first 8 kyr of the record is sampled at ~50-yr resolution, while measurements after 6.5 ka are currently spottier. During the Bølling-Allerød (B-A, prior to 12.9 ka), temperatures were slightly warmer (by ~1°C) than during most of the Holocene, suggesting somewhat weaker upwelling or a deeper thermocline. Temperatures during the Younger Dryas (YD, 12.9-11.6 ka) were indistinguishable from the B-A, implying that if upwelling weakened further during the stadial, then the expected warming may have been masked by regional cooling. An abrupt warming occurred at the end of the YD, making the pre-Boreal interval the warmest part of the record. Temperatures then oscillated with a strong 1-kyr quasi-cyclicity until at least 8 ka: millennial-scale warmings are centered at ~11.2, 10.4, 9.2, and 8.2 ka. Minimum temperatures, which we associate with strongest upwelling or shallowest thermocline, were reached during millennial-scale events only after 10 ka. Although data coverage is decreased in the late Holocene, upwelling may have weakened to deglacial-like values after ~4 ka. We attempt to place these changes in a regional context and to relate them to both orbital and millennial-scale forcing of the Hadley circulation and ENSO/PDO-type dynamics.

Millennial Sea Surface Temperature Changes Over the Past 40,000 Years in the Subtropical Western Pacific

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Ice core records of polar temperatures and greenhouse gases document persistent millennial-scale climate oscillations in global climate during the past million years. Stalagmite oxygen isotope and marine sediment temperature records also suggest dominant millennial-scale variability in the late Quaternary monsoon hydrological system. It remains unknown, however, whether warm ocean currents that transport heat and moisture to high latitudes have played a role in this millennial-scale climate variability. Here we report an AMS 14C-dated Mg/Ca sea surface temperature (SST) record based on marine sediments from the central Okinawa Trough, and document the timing and amplitude of millennial-scale changes in subtropical western Pacific surface water properties since the last glacial period. The SST variations exhibit two steps of warming since 21 ka - at 14.7 ka and 12.8 ka, and a cooling (~1.5°C) during the interval of the Younger Dryas, indicating a link to abrupt deglacial changes in the northern high latitudes. We observed relatively weak cooling (≤0.5°C) during the intervals of the last three Heinrich events. The weak cooling events are accompanied by almost no change in $\delta^{18}O$-derived sea surface salinity (SSS), possibly because of the competing effects of hydrological impacts from the East Asian Monsoon, and meridional and zonal changes in the North Pacific climate in response to a large-scale shifting of the Intertropical Convergence Zone. Between 40 and 21 ka, the timing and amplitude of millennial-scale SST and SSS variations appear to have been largely determined by the same mechanism that paced Antarctic climate changes.

Wind-Driven Upwelling in the Southern Ocean and the Deglacial Rise in Atmospheric CO_2

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Wind-driven upwelling in the ocean around Antarctica regulates the exchange of CO_2 and other gases between the deep sea and the atmosphere. Diatom productivity and burial of biogenic opal in marine sediments south of the Antarctic Polar Front are linked to the rate of upwelling, which supplies dissolved Si to the euphotic zone of the Southern Ocean. We find enhanced rates of opal burial during the termination of the last ice age in each sector of the Southern Ocean. In the record with the greatest temporal resolution, we find evidence for two intervals of enhanced upwelling, concurrent with the two intervals of rising atmospheric CO_2 concentration during deglaciation. These results provide the first direct evidence linking increased ventilation of deep water masses in the Southern Ocean to the deglacial rise in atmospheric CO_2.

We suggest that the deglacial increase in upwelling of the Southern Ocean was a response to extreme cold conditions in the Northern Hemisphere during the time intervals surrounding Heinrich Event 1 and the Younger Dryas. Paleo proxy records and model simulations both point to a reorganization of atmospheric circulation at these times, including a southward shift in the Intertropical Convergence Zone as well as a southward displacement of the Southern Hemisphere westerlies. The increased wind stress at the latitude of the Drake Passage associated with the southward displacement of the westerlies was instrumental in breaking down glacial ocean stratification while increasing the upwelling and ventilation of deep waters around Antarctica, as described by Toggweiler (Paleoceanography, 2006, doi10.1029/2005PA001154).

Similar relationships (warming in Antarctica, increased upwelling in the Southern Ocean, rising atmospheric CO_2) were associated with earlier Heinrich Events during the last glacial period, indicating that this displacement of the zonal wind systems is a robust response to reduced interhemispheric temperature gradients during these intervals.

Hypothesized Causal Link Between Glacial/Interglacial Atmospheric CO_2 Cycles and Liquid CO_2 Storage/Release From the Deep Sea

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Here we set forth a hypothesis for glacial-interglacial atmospheric CO_2 variability that involves a thermodynamic regulation of CO_2 storage and release from the margins of submarine volcanic arcs in the deep Pacific. Recent observations suggest the flux of CO_2 from submarine volcanic arcs along subducting plate boundaries in the Pacific has been underestimated and significant quantities of liquid CO_2 are accumulating in the subsurface at these sites, kept in place by a hydrate cap. We present a scenario whereby the flux of CO_2 from volcanic arcs in the Pacific decreased during glacials as the ocean cooled and the depth over which liquid CO_2 becomes denser than seawater shoaled by ~400 meters, reducing CO_2 fluxes to the water column and ultimately to the atmosphere. As the ocean warmed during the deglaciation, the zone of negative CO_2 buoyancy deepened and the flux of CO_2 into the water column increased. A test of this hypothesis will require a better constraint on the modern fluxes of CO_2 from marine arcs but we show here that the timing and the magnitude of deep sea temperature change that coincided with the rise in atmospheric CO_2 was of the right magnitude to affect the density of CO_2 in the deep sea. This mechanism would account for the deglacial decrease $\Delta^{14}C$ and the lack of a $^{13}C/^{12}C$ anomaly because the liquid CO_2 is derived from subducted marine carbonate.

Abrupt Atmospheric CO_2 Changes During Antarctic Warming Event 1

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Reconstructions of atmospheric CO_2 in the past on various time scales may help us better understand how climate and carbon cycles are linked. Here we present submillennial scale CO_2 records from the Siple Dome and Byrd ice cores, Antarctica. The time interval (37-41 ka on GISP2 time scale) is of great interest because it covers Antarctic warming event 1, Dansgaard-Oeschger events 8 and 9, and possibly Heinrich event 4. The timing of events in the Antarctic ice core records are well synchronized with Greenland ice core records via CH_4 correlations. A striking feature in both records is a rapid CO_2 drop of 6~9 ppm and followed by a rapid CO_2 rise of 14~18 ppm, at the same time that the Antarctic paleotemperature records recorded the warming associated with the Antarctic warming event 1. Each abrupt CO_2 change occurred in decades or a century. The timing of the abrupt CO_2 drop and rise is synchronous with a short CH_4 rise between Dansgaard-Oescheger events 8 and 9, in which time interval

Greenland was cold and meridional ocean circulation in the north Atlantic was reduced and probably Heinrich event 4 occurred (Skinner and Elderfield, Paleoceanography, 2007). Precise comparison of the abrupt CO_2 changes with the timing of changes in ocean circulation and Heinrich event 4 is difficult due to chronological uncertainties. Our new data reveal that atmospheric CO_2 is linked to Antarctic and northern hemispheric climate on submillennial time scales and indicate that atmospheric CO_2 can change more rapidly than has been thought previously. Possible mechanisms including changes in ocean circulation and in terrestrial carbon will be discussed at the meeting.

Thursday, 18 June

Abrupt Climate Change: A Paleoclimate Perspective From the World's Highest Mountains

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Glaciers are among the first responders to global warming, serving both as indicators and drivers of climate change. Ice core records recovered over the last 30 years from high-elevation, low-latitude ice fields, along with other proxy data, provide three primary lines of evidence for past and present abrupt climate change. First, high-resolution time series of oxygen isotopic ratios (temperature proxy) and net balance (precipitation proxy) demonstrate that the current warming at high elevations in the mid- to lower latitudes is unprecedented for at least the last two millennia. Second, the continuing retreat of most mid to low-latitude glaciers, many having persisted for thousands of years, signals a recent and abrupt change in Earth's climate system. Finally, there is strong evidence within and around these glaciers for a widespread and spatially coherent abrupt event ~5.2 ka marking the transition from early Holocene warmth to cooler conditions that was also coincident with structural changes in several civilizations. The remarkable similarity of changes in the highland and coastal cultures and climate variability, especially precipitation, implies a strong connection between prehistoric human activities and climate in this region. The ice core evidence is combined with other paleoclimatic and geoarchaeological evidence to better constrain the magnitude, extent, timing and impacts of this mid-Holocene event. New Quelccaya and Coropuna ice cores provide 1688 years of continuous, annually-resolved records of climatic and environmental variability expressed in the oxygen and hydrogen isotopic ratios, concentrations of mineral dust and various chemical species and net mass accumulation. The nature of tropical climate variability is examined in greater detail, and new insights on ENSO and monsoon-linked climate phenomena are extracted. The Quelccaya records are the "holy grail" of high resolution ice core records for tropical glaciers and clearly show that the recent acceleration of ice retreat is not driven by changes in net mass accumulation. Well-documented ice loss on Quelccaya in the Andes, Naimona'nyi in the Himalayas and Kilimanjaro in eastern Africa paint a grim future for tropical glacier histories. The current melting of high-altitude, low-latitude ice fields is consistent with model predictions for a vertical amplification of temperature in the tropics. The ongoing glacier retreat in the Andes, Himalayas and Africa has implications for the people who live in these areas and hence are on the front lines of the climate change crisis.

Social Adaptations to Holocene Abrupt Climate Changes in West Asia

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Weakened North Atlantic cyclogenesis, in many cases yet unexplained, caused the Holocene abrupt climate changes in West Asia at 8.2, 5.2, 4.2, and 3.2 kaBP. These were "double-spike" century-scale aridification and cooling events, also characterized by aeolian dust increase, deforestation, and cereal agro-production reductions across dry-farming terrains.

Regional social responses to reduced cereal agro-production developed within decades, as abruptly as the onset of the climate changes. Three social responses evident in the relatively high-resolution archaeological records of each abrupt climate change are regional abandonment, habitat-tracking, and subsistence-transfer from agriculture to pastoral nomadism.

The spatio-temporal variability of these responses was a function of historical forces (i.e., prior politico-economic situation), regional hydrogeography, and proximal region hydrogeography and settlement. To explain the variable responses to abrupt climate change in the region where the archaeological data allow their perception and measurement, we need to learn precisely:

1. the reduction in Mediterranean westerly precipitation across West Asia
2. the reduction in Euphrates and Tigris streamflow during each abrupt climate change
3. the reduction, if any, in karstic aquifer reservoirs, such as those that are the sources of the Orontes River;
4. the onset and rate of climate change, and the precise date and rate of regional abandonment, habitat-tracking and subsistence transfer to pastoral nomadism.
5. each of the above are required, as well, for understanding the return down-spike at the termination of the abrupt climate changes, which are characterized archeologically by sudden sedentarization, political state formation, increased and enhanced-surplus agro-production, and territorial expansion.

Abrupt Climate Change in the Late Holocene

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Abrupt changes in late Holocene climate mainly involve hydrological changes which affect specific regions rather than hemispheric or global disruptions. These changes result from persistent shifts in circulation patterns, often resulting in displacement of precipitation regimes or suppression of expected rainfall amounts. Hydrological changes have often led to societal disruption, precisely because they were Abrupt, Unprecedented (in the experience of societies at the time) and Persistent ("AUP"s). Such changes result from persistent regional atmospheric anomalies, the causes of which are enigmatic. Often, they resemble short-lived anomalies that are common today, but which do not have the same persistence characteristics. Why such circulation patterns occasionally persist for decades remains poorly understood, but most likely involves associated long-lived oceanic anomalies. Obtaining a better understanding of why such anomalies persist in the pre-anthropogenic world is essential as such changes may recur in the future, possibly reinforcing human-induced changes in the climate system.

Abrupt Holocene Climatic Change in the Northwestern India and Disappearance of Sarasvati River and the End of Vedic Civilization

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Ancient mythological literature of India provides the evidences of a mighty river known as the Sarasvati River (Oldham, 1886, 1893) that flew in the region between Indus River in the west and Aravalli Mountain Range in India. A well developed civilization older than Harappan Civilization called Vedic Civilization flourished along its banks and Vedas and Epics were written by ancient scholars. There are numerous citations in Vedas, Mahabharat and other Epics about the Sarasvati River flowing in this part (Kayanaraman, 1999; Vkankar,1987). It is a general belief that Srasvati River and the Vedic Civilization that flourished along the banks of this mighty river system disappeared because of the Neotectonic disturbances that took place during the Holocene period. Neotectonic disturbances resulted in drainage disorganization, reversal and at places blocking, causing the formation of several lakes in the region like Sambhar, Pachbhadra, Didwana, Talchhappar, Lunkaransar, Jamsar etc. which later turned in to saline lakes because of the centripetal drainage and desiccation (Paliwal, 1986; Roy, 1999). Saline lakes, particularly those of Sambhar, Didwana and Pachbharda in Rajasthan have been producing tones of salt for the last a few hundred years. Considering enormous quantity of salt in these lakes we will have to account for its source. 'Na' component of 'NaCl' might have been derived from the surrounding rocks but the atmosphere is the only source for 'Cl' and it is bit difficult to account for a huge deposit of salt in these lakes in a short time (Paliwal, 2008). The oldest sediments in these lakes have been dated at more than12,820 years B.P (Wasson, et al., 1983). There is a possibility that these inland basins had connections with the sea-water through trenches developed during Neotectonic activity (Paliwal, 2008). Alternatively, these saline lakes located at the junctions of deep seated sub-vertical faults have groundwater connections with the Palaeozoic evaporates situated below in the region through these faults and salt moves through them when the lakes are filled with the rain water and gets evaporated precipitating salt on desiccation (Paliwal, 2008; Laul, 2007).

Neotectonic disturbances in the region have been taking place since last 5 million years. More conspicuous signatures of these disturbances have been recorded at: (1) around 10,000 yrs. B.P., (2) around 3,000-3,500 yrs. B.P. and (3) around 11th / 13th Century (Sridhar et al., 1999). The transform fault along the northwestern margin of the Indian Plate gradually turned into a suture zone – the Indus Suture along which the Indus River has been flowing, maintaining almost the same path, for at least last 5 million years. The geomorphologic map of the region depicting the drainage pattern that existed about 5 million years ago (Clift and Blusztajn, 2005), when compared with the present day geomorphologic set-up, it reveals that there is no major change in the course of the Indus River for the last 5 million years. Of course, there are some changes in the pattern of its tributaries. The lowermost eastern tributary has changed its course remarkably and subsequently disappeared totally during this period. There is a possibility that this tributary represents the course of the Proto-Vedic Sarasvati River in the region. Similarly, the western lowermost tributary, which might represent the original Sindhu River, has also disappeared from the scene. The seven tributaries of the Indus River shown in the 5 million year ago geomorphologic map of the region represent "Sapt Sindhu" i.e. seven tributaries of the Indus River described in the Vedic Literature. Perhaps, during this period India moved further north (Paliwal, 2008).

It is a fact that the Vedic Civilization flourished along the banks of Srasvati River and the saline lakes were formed by Neotectonic disturbances resulting in drainage disorganization and blocking, In these circumstances the Sarasvati River and Vedic Civilization flourished along its banks must date back to more than 12,820 B.P. The region suffered an abrupt climatic changes reflected in lowering of sea level at the west coast of India by 100 metres around 14,500 years B.P. and rising by 80 metres 12, 500 years B.P. (Hashmi et al., 1995). Around 12,500 years B.P. Sarasvati River system was being repeatedly flooded and this caused disappearance of the Vedic Civilization. However, around 6800 years B.P. the region suffered a dry period (Paliwal, 2003) which continues till date and has been the cause of drying up of Sarasvati River which formed the eastern tributary of the Indus River. Of course Neotectonic disturbances have also played an important role in its drainage disorganization, reversal and blocking.

Climate Stability and Development of Agricultural Societies

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Modern human beings began migrating from Africa 55,000 years ago and were producing cave art by 30,000 years ago, but there was no agriculture until ~10,000 years ago. In the next few thousand years six independent agricultures developed. It is virtually certain that it was not by chance that so many new agricultures appeared in the same few thousand years. What inhibited agriculture world wide for 45,000 years and what changed 10,000 years ago? We argue that a major factor influencing the development of agricultural societies was climate stability. From the experience of four cultures we estimate that the development of agriculture needed ? 2,000 years of climate free from significant climate variations on time scales of a few centuries. Pleistocene climate-proxy records, such as the Greenland Ice Core and Cariaco Basin ocean sediments, show almost continuous large century-scale climate fluctuations. These fluctuations were very strongly damped at the termination of the Younger Dryas ? 11,600 years ago, apparently permitting agriculture to develop. The vital role of climate stability to agricultural societies is supported by the response of civilizations to the relatively mild Holocene climate changes. For example, a weak climate variation about 4,000 years disrupted Neolithic Chinese culture and destroyed the Egyptian Old Kingdom and Akkadia.

The End of the African Humid Period at 5.5 ka BP: New Results on its Timing, Abruptness, and Spatial Extent

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During the African Humid Period (AHP) much of Saharan desert was nearly completely vegetated with numerous perennial lakes and abundant fauna. In marine sediments off northwest Africa, the AHP is recognized as an interval with markedly reduced eolian dust fluxes between 14.5-5.5 ka BP. One of the remarkable features of this record is the abrupt, century-scale onset and termination of the AHP. Such abrupt climate transitions have been observed in other cores off NW Africa and in some North African paleolake records, but recent pollen evidence from northern Chad (Lake Yoa) indicates a more gradual transition spanning several millennia (Kroepelin et al. 2008).

In this study we use a N-S transect of newly-collected transect of deep-sea sediment cores off NW Africa to explore the timing, origin, and abruptness of mid-Holocene transition out of the African Humid Period. On a recent coring cruise in July, 2007, we collected 27 multicore/gravity core pairs along the NW African margin spanning 36-16°N. Earlier work at ODP Site 658 off Mauritania (20°N) had shown that the onset of hyperarid conditions near 5.5 ka BP occurred rapidly, within centuries, and was associated with a rapid increase in the supply of eolian sediment. ^{230}Th-normalized dust fluxes increased by a factor of three after the AHP and that the transition occurred within 1-2 centuries.

At ODP Site 658, the Nd isotope composition of terrigenous detritus shows little variability throughout the last 25 kyr, indicating that the contributing geological terranes have not measurably changed since the Last Glacial Maximum. In contrast, we observed large and abrupt changes in Sr isotope ratios and major and trace element concentrations associated with the AHP that closely follow the abrupt terrigenous sediment flux changes. During the AHP, $^{87}Sr/^{86}Sr$ ratios are lower and sediments have higher chemical indices of alteration. Taken together, these data indicate the supply of an additional highly-weathered, authigenic mineral phase during the AHP (derived from the same parent material) that formed in and around lake margins. We propose that increased vegetation during the AHP reduced total terrigenous fluxes to the ocean, and these newly formed Mg-rich clays that formed in association with ephemeral lakes probably became available during seasonal drying, thus dominating the terrigenous component.

Our preliminary results on the N-S sediment core transect indicate that an abrupt termination of the AHP near 5.5 ka BP can be traced from Senegal to the Canary Islands (roughly 18-28°N). Most cores have sedimentation rates that were considerably lower than at Site 658, and thus have lower resolution, but the AHP transitions were always more rapid than expected from linear orbital monsoon forcing alone. Surprisingly, we find that the end of the AHP occurred nearly synchronously for all cores along this transect, suggesting a very rapid and spatially extensive retreat of the African monsoonal rains near 5.5 ka BP.

Abrupt Onset and Intensification of Ice Cap and Glacier Growth Around the Northern North Atlantic During the Little Ice Age: A Role for Volcanic Forcing?

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Precise radiocarbon dates on dead vegetation emerging beneath retreating thin ice caps in NE Arctic Canada provide evidence of two pulses of ice cap growth, between 1250 and 1300 AD and around 1450 AD, with ice caps remaining in an expanded state until the warming of the past few decades. Similarly, a 3000 year annually resolved lacustrine record of glacier power and a complementary independent proxy for landscape instability in the highlands of Iceland show an initial jump in both records between 1250 and 1300 AD, amplification around 1450 AD, and dramatic increases around 1800 AD, retracting in the 20th Century. A subdecadal record of hillslope stability and within-lake primary productivity in sediments from a low-elevation lake in northern Iceland shows parallel changes at similar times. Sea ice proxies document the first appearance of sea ice around Iceland about 1250 AD. The similarity in the onset and intensification of Little Ice Age cold-weather proxies across a wide region of the northern North Atlantic suggests at least a regional driver of abrupt climate change. The time intervals for which these abrupt changes occur coincide with the three most intense episodes of multiple explosive volcanic eruptions that introduced large volumes of sulfate aerosols into the stratosphere. Although the direct impacts of volcanic aerosols has a duration of only a few years, the memory stored by the cooled ocean surface waters allows a cumulative effect to have a longer term impact. To explain the apparent irreversible shift to colder summers following volcanic eruptions requires additional strong positive feedbacks, most likely a consequence of expanded sea ice cover.

Holocene and Glacial Temperatures From Clumped Isotope Thermometry in Foraminifera and Coccoliths

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Accurate constraints on past ocean temperatures and compositions are critical for documenting climate change and resolving its causes. Existing proxies for temperature are uncertain because they are not thermodynamically based and are influenced by seawater composition. We report measurements of abundances of stable isotopologues of calcitic and aragonitic benthic and planktic foraminifera and coccoliths, and show that the proportions of ^{13}C-^{18}O bonds exhibits a similar temperature dependence to inorganic calcite with no apparent biological fractionation, and is independent of the composition of the water in which the mineral precipitated. Our observations indicate the 'clumping' of these heavy isotopes into bonds with each other in foraminifera and coccoliths is controlled by the equilibrium thermodynamic driving forces that distribute stable isotopes among isotopologues in the dissolved inorganic carbon pool from which the carbonates precipitate.

We report the first detailed record of past temperatures based on clumped isotope measurements of bulk sediment and foraminifera, reporting data for three sites in the West Pacific Warm Pool spanning the past 30,000 years. The warm pool is the warmest oceanic region on the planet and a primary source of heat and water vapor to the atmosphere. The temperature of this region influences the Walker circulation, and thus the El Niño-Southern Oscillation, as well as the East Asian Monsoon. Because the area has an important influence on climate over a regional and global scale, warm pool SSTs serve as a critical target for climate models, including the PMIP (Paleoclimate Modelling Intercomparison Project) group of models. At the Last Glacial Maximum, average sea surface temperatures in the West Pacific Warm Pool were 25.5±0.6ºC and the oxygen isotope ratio of surface waters was 0.9±0.1‰.

Friday, 19 June

Timing, Nature, and Causes of the Terminations of the Last Four Ice Age Cycles

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High-resolution records from Sanbao Cave, central China characterize Asian Monsoon (AM) precipitation over tens of millennia covering the ends of the 3rd and 4th to last ice age cycles. AM records for the past 4 glacial terminations can now be correlated precisely with ice core records of atmospheric gases and temperature, and marine records of ice-rafted debris and ice volume, establishing the timing and sequence of major events for all 4 terminations. In each case, observations are consistent with a classic northern hemisphere summer insolation trigger for initial breakup of large northern ice sheets, predisposed to collapse. Meltwater entering the north Atlantic alters oceanic and atmospheric circulation patterns and associated fluxes of heat and carbon, causing increases in atmospheric CO_2 and Antarctic temperatures. Increasing CO_2 and insolation drive the termination, with likely positive feedbacks between sea level and CO_2. This scenario explains the rapidity of terminations, clear from their very first characterizations (Emiliani, 1955; Broecker and von Donk (1970), as well as aspects of the "100 ky" problem, evident in the first spectral analyses of ice age cycles (Hays et al., 1976).

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Rapid Changes in Times of Climate Chaos: A Stalagmite Deglaciation Record from Dixieland

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In the last glacial cycle Gulf of Mexico served both as a source of moisture feeding the expansion of the Laurentide Ice Sheet as well as a
destination of meltwater superfloods during deglaciation. In order to better understand the nature of the rapid climate swings that are well
documented in the Greenland Ice Cores we have initiated a study of stalagmites from the DeSoto Caverns (Alabama, USA) that likely intersected
the moisture derived from the Gulf of Mexico during the last deglaciation. Combination of unusually high growth rates, pristine aragonite mineralogy, high-density U/Th dates and tight sampling (n=602) afforded generation of high fidelity O-18 and C-13 records from 17. 8 to 11.2 cal-Ka whose resolution is comparable to the contemporaneous GISP2 records. Unlike the Chinese stalagmites (Hulu Cave H82 and Dongge Cave D4) that are featureless during the early deglaciation phases, the DeSoto stalagmite (DSSG2) shows excellent agreement in relative amplitude shifts and timing of abrupt and brief cold reversals (OD1, OD2, IACP) that punctuated the deglaciation warming (Bolling/Allerod period). A prominent hiatus in the layered stalagmite deposition occurs between 12.98 and 11.81 cal-Ka that coincides precisely with the Younger Dryas cold reversal whose abrupt initiation and termination are dated at 12.85 and 11.76 cal-Ka in GISP2. The ~1.2 cal-Ka discontinuity is succeeded by a resumption in deposition showing prominent dark and light seasonal layers.
Using a forward model we interpret the negative O-18 shifts during the warm B/A interval and the O-18 positive shifts during the cold ODs and IACP as being primarily an expression of rapid shifts in rainfall sourced from GOM moisture and alternating between excessive floods and severe droughts. A mega-drought is the most likely explanation for the abrupt discontinuity in deposition during the YD cold event. We suggest that hydrologic switches of meltwater discharges to GOM had a pronounced effect on the continental rainfall pattern. The excellent correspondence documented between the DeSoto DSSG2 stalagmite from a "Humid Subtropical" climate type site and the polar GISP2 isotope record further suggests that disturbances in THC caused by repeated meltwater discharge episodes into the North Atlantic from the retreating American and European ice sheets were the principal governing factors controlling the documented isotope shifts in the Southeastern USA and Greenland.

Meltwater Routing and the Atlantic Meridional Overturning Circulation During the Last Glacial-Interglacial Cycle: A Gulf of Mexico Perspective

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Routing of low-salinity meltwater from the Laurentide Ice Sheet (LIS) into the North Atlantic via eastern outlets (e.g., St. Lawrence and Hudson River systems) and northern outlets (e.g., Hudson Straits and Arctic Ocean) is thought to have reduced Atlantic meridional overturning circulation (AMOC) and thereby triggered abrupt regional to global climate change during the last glacial-interglacial cycle. In contrast, southward meltwater flow to the Gulf of Mexico is generally thought to allow enhanced AMOC and warmer climates in the North Atlantic region. Situated at the outlet of the Mississippi River, Orca Basin is ideally located to assess the timing of inferred southern LIS meltwater flow. Cores MD02-2550 and -2551 collected by the R/V Marion Dufresne in 2002 on IMAGES cruise VIII allow sub-centennial-scale records of Mg/Ca sea-surface temperature (SST) and the oxygen isotopic composition of seawater back to ca. 45 ka. Age control is provided by over 70 AMS radiocarbon dates, nearly all in stratigraphic order. Accumulation rates range from about 25-300 cm/k.y.

We use paired Mg/Ca and oxygen isotope data on Globigerinoides ruber to isolate changes in the oxygen isotopic composition of seawater (δ^{18}Osw). The isotopic effect of global ice volume changes is then subtracted based on sea-level records. Major episodic d18Osw decreases indicating LIS meltwater input appear to match existing global sea level records, but not Dansgaard-Oeschger interstadials. Indeed, our δ^{18}Osw records exhibit similar timing and character to Antarctic air temperature records. Furthermore, persistent meltwater input during major Greenland stadials that include Heinrich Events supports a corollary of the “seasonality hypothesis” (Denton et al., 2005): summer melting of Northern Hemisphere ice sheets may have enhanced winter sea-ice formation and extreme cooling during some Greenland stadials. Finally, a 3.5 per mil increase in δ^{18}Osw centered at 10,970 radiocarbon years B.P. (the “cessation event”) appears to coincide with the onset of the Younger Dryas and with radiocarbon evidence from Cariaco Basin for AMOC reduction. Recent results with the NCAR Community Climate System model (CCSM3) indicate that southward meltwater routing directly affects AMOC, although with about 50 percent response compared to eastern routing (Otto-Bliesner et al., submitted). These results therefore support the hypothesis that meltwater routing, including “preconditioning” of North Atlantic Ocean salinity from the Gulf of Mexico, contributed to abrupt climate change during the Younger Dryas. Overall, our results indicate that glacial meltwater was a critical factor in both the genesis and seasonality of abrupt climate change.

A Calibrated Deglacial Meltwater Chronology for the Northern Hemisphere

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The spatio-temporal dependence of meltwater and iceberg discharge is generally assumed to be critical to understanding the dynamical processes involved in abrupt climate change during glacial periods. In this context, I will present a detailed set of deglacial meltwater/iceberg discharge chronologies complete with error bars for the Northern Hemisphere along with a discussion of the major sources of uncertainty. The chronologies derive from newly completed large ensemble calibrations of the MUN/UofT glacial system model for North American and Eurasian deglaciation, and a previously tuned version for the Greenland ice-sheet. The glacial systems model includes a 3D thermo-mechanically coupled ice-sheet model, bed thermal model, global visco-elastic bedrock response model, a fully coupled diagnostic down-slope surface drainage and water storage solver, and various components for computing surface mass-balance and ice calving.

Uncertainties in the model system are constrained by objective calibration against observational constraints. The North America and Eurasian chronologies are calibrated with a Bayesian Markov Chain Monte Carlos approach against a large set of relative sea observations, geodetic observations, and independently inferred ice margin chronologies. The North American chronologies also take into account fits to strand-line and marine limit observations. The Greenland model is hand-tuned against relative sealevel observations and ice borehole temperature records. Comparison of the disaggregated meltwater and iceberg discharge chronologies against climate records will provide further constraint on the meltwater mediated links between ice and climate. Most notable is further confirmation of previously found dominance of North American discharge into the Arctic Ocean around the onset of the Younger Dryas.

Stability of the Atlantic Meridional Overturning Circulation: Implications for Abrupt Climate Change

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It is believed that some of the major abrupt climate changes prominent in the paleorecord involved rapid reorganization or a shutdown of the Atlantic Meridional Overturning Circulation (AMOC). In this study, we reexamine the stability of the AMOC in an idealized 2-dimensional (zonally-integrated) ocean model. The basin of the model extends from northern high latitudes to Antarctica and includes an implicit representation of a periodic circumpolar channel in the Southern ocean. The ocean circulation is driven by buoyancy fluxes (via mixed surface boundary conditions) and wind forcing. To describe ocean mixing, we employ both diapycnal and isopycnal diffusivities, and the Gent-McWilliams parameterization to represent eddy fluxes. Under the standard surface boundary conditions taken from present-day observations, the model reproduces a realistic ocean thermal and salinity structure with realistic meridional overturning circulation. The model is very efficient computationally, which allows us to conduct sensitivity experiments in a broad parameter range. The structure, intensity, and stability of the AMOC is then extensively studied using three controls parameters: the strength of the westerly wind stress over the Southern Ocean, the magnitude of surface freshwater fluxes imposed in the Northern Atlantic, and the strength of diapycnal diffusion. In particular, we show that the intensity of the overturning increases only slightly when the wind stress over the Southern Ocean intensifies. However, a weakening of this wind stress can lead to a strong reduction of the AMOC intensity and, potentially, to its shutdown. Ultimately, our calculations produce stability maps for the AMOC that can be used, for example, to interpret results obtained by comprehensive general circulation models exhibiting different sensitivity to freshwater forcing, and to understand abrupt climate changes associated with variations in the AMOC.

The Younger Dryas: A Data to Model Comparison to Constrain the Strength of the Overturning Circulation

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The UVic Earth System Climate Model (UVic ESCM) is used to compare simulated time series of radiocarbon during the Younger Dryas with paleoceanographic records. I find that only a complete shut-down and recovery of the Atlantic Meridional Overturning Circulation can simulate both the rise in atmospheric CO_2 concentrations seen in ice core records and the peak and subsequent decrease in atmospheric Delta ^{14}C comparable to the peak recorded in the varved sediments of the Cariaco Basin. Simulated radiocarbon profiles in the western North Atlantic match well with data from deep-sea corals at the beginning of the YD, whereas planktonic/benthic foraminifera records match best with a transient state during the rapid recovery of the AMOC. The steepness of the increase in atmospheric Delta ^{14}C at ~12.9 ka cal could not be simulated with oceanic circulation changes only because the response time of the climate system is too slow.

Poster Presentation Abstracts

Abstracts are listed alphabetically, by the last name of the presenting author.

Monday, 15 June

Effects of Sampling Criteria on the Distributions of Cosmogenic Exposure Dates from Degrading Moraines

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Cosmogenic exposure dating has been used repeatedly to determine the ages of moraines thought to be associated with abrupt climate events, especially the Younger Dryas cold reversal (12.8- 11.6 ka). The spatial distribution of moraines associated with abrupt climate events provides information on the mechanisms responsible for the changes. However, only a few samples can usually be collected from any one moraine; the dates are expensive, and the chemical processing is time-consuming. Therefore, field workers select samples that appear most likely to reflect the true age of the moraine. Boulders that have fresh surfaces and stand at least a meter above the moraine crest are generally preferred. In this study, we use a Monte Carlo-based model of nuclide production in boulders on a degrading moraine to assess the influence of these sampling criteria on the inferred age of the moraine. We first invert the model against a set of exposure dates from the Waiho Loop moraine in New Zealand. This inversion yields realistic values of the model parameters (moraine age, initial moraine height, initial moraine slope, and topographic diffusivity) for late-glacial moraines. We then run the model in a forward sense, generating a probability distribution of exposure dates predicated on these parameter estimates. Next, we subsample this probability distribution using each of the two sampling criteria mentioned above. Our results suggest that sampling tall boulders is a reasonable strategy for selecting samples for cosmogenic exposure dating, but that sampling fresh boulders tends to lead to exposure dates that underestimate the ages of moraines. This conclusion is only true for moraines that have lost several meters of material from their crests over their post-depositional histories.

Paleoclimatic Inferences in the Wasatch Mountains Based on Glacier Mass-Balance and Ice-Flow Modeling

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The Wasatch Mountains of northern Utah contained numerous valley glaciers east of Lake Bonneville during the Last Glacial Maximum (LGM). While the extent and chronology of glaciation in the Wasatch Mountains and the rise and fall of Lake Bonneville are becoming increasingly well understood, inferences of climatic conditions during the LGM for this area and elsewhere in the Rocky Mountains and northern Great Basin have yielded a wide range of temperature depression estimates. For example, some previous estimates of temperature in this region range from 7° to 9° C colder than modern. However, other proxies suggest that temperature depression in this area may have been significantly greater, up to 13°C.

To address this issue, ice extent in the American Fork Canyon of the Wasatch Mountains was reconstructed and glacier modeling methods of Plummer and Phillips (2003) were applied to estimate climatic conditions during the LGM. Field-based reconstructions indicate that glaciers occupied an area of more than 20 km² in the canyon and reached maximum lengths of about 9 km. To link ice extent to climate, a physically based, two-dimensional numerical model of glacier mass balance and ice flow was applied to these valleys. Together the models simulate ice extent based on the combined effects of temperature, precipitation and solar radiation on net mass balance of a drainage basin. Results of model experiments indicate that a temperature depression of less than 10°C in the American Fork Canyon would have been accompanied by greater precipitation than modern, whereas greater temperature depressions would have required less-than-modern precipitation to sustain glaciers in the Wasatch Mountains.

Without independent estimates of either temperature or precipitation for the LGM, model results do not provide a unique combination of these two variables. However, the reconstructed pattern of glaciation in the Wasatch and Uinta Mountains during the LGM indicates a sharp westward decline in glacier equilibrium-line altitudes in valleys immediately downwind of Lake Bonneville (Munroe et al, 2006), which suggests that precipitation in the Wasatch Mountains was enhanced during the LGM.

Therefore, model results can be used to set limits on temperature and precipitation during this time. We estimate that, if temperatures during the LGM were 7° to 9.5°C less than modern, precipitation was 1.25 to 2.5 times modern. Such precipitation increases would reflect the importance of Lake Bonneville as a moisture source for valleys in the Wasatch Mountains, as suggested by previous studies.

Problems with the Younger Dryas Boundary (YDB) Impact Hypothesis

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One breakthrough of 20th-century Earth science was the recognition of impacts as an important geologic process. The most obvious result is a crater. There are more than 170 confirmed terrestrial impact structures with a non-uniform spatial distribution suggesting more to be found. Many have been erased by tectonics and erosion. Deep water impacts do not form craters, and craters in ice sheets disappear when the ice melts. There is growing speculation that such hidden impacts have caused frequent major environmental events of the Holocene, but this is inconsistent with the astronomically-constrained population of Earth-crossing asteroids.

Impacts can have consequences much more significant than excavation of a crater. The K/T boundary mass extinction is attributed to the environmental effects of a major impact, and some researchers argue that other extinctions, abrupt climate changes, and even civilization collapses have resulted from impacts. Nuclear winter models suggest that 2-km diameter asteroids exceed a "global catastrophe threshold" by injecting sufficient dust into the stratosphere to cause short-term climate changes, but would not necessarily collapse most natural ecosystems or cause mass extinctions. Globally-catastrophic impacts recur on timescales of about one million years.

The 1994 collision of Comet Shoemaker-Levy 9 with Jupiter led us recognize the significance of terrestrial airbursts caused by objects exploding violently in Earth's atmosphere. We have invoked airbursts to explain rare forms of non-volcanic glasses and melts by using high-resolution computational models to improve our understanding of atmospheric explosions, and have suggested that multiple airbursts from fragmented impactors could be responsible for regional effects.

Our models have been cited in support of the widely-publicized YDB impact hypothesis. Proponents claim that a broken comet exploded over North America, with some fragments cratering the Laurentide Ice Sheet. They suggest an abrupt climate change caused by impact-triggered meltwater forcing, along with massive wildfires, resulted in megafaunal extinctions and collapse of the Clovis culture.

We argue that the physics of fragmentation, dispersion, and airburst is not consistent with the hypothesis; that observations are no more compatible with impact than with other causes; and that the probability of the scenario is effectively nil. Moreover, millennial-scale climate events are far more frequent than catastrophic impacts, and pose a much greater threat to humanity.

A Role for Greenland Mass Loss in 20th Century US Atlantic Coast Sea-Level Rise?

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Accurate estimates of global sea-level rise in the pre-satellite era provide a context for 21st century sea-level predictions. Currently, use of tide-gauge records is complicated by the unknown contributions from changes in land level. In order to decontaminate such records we use a geological approach involving the construction of a database of various late Holocene sea-level indices for the US Atlantic Coast. Using these data, we document significant land subsidence and provide a corrected value for the average rate of sea-level rise. Moreover, we find a significant amount of spatial variability in the rate of 20th century sea-level rise, increasing from north to south, which we contend arises from Greenland ice sheet melting.

Dynamics of the Ice Shelf on Proglacial Lake Agassiz as a Stochastic Driver of Late Pleistocene Climate

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Elevated freshwater input into the North Atlantic and suppressed North Atlantic Deep Water formation is a leading explanation for abrupt climate events during the last glacial-interglacial transition, including the Younger Dryas event. Geochemical proxy records support a Lake Agassiz source of this freshwater, although an outlet for the YD event has yet to be conclusively identified. Drainage of Laurentide proglacial lake(s) was the inexorable result of glacier retreat and increased meltwater input, but discharge rates would have been controlled by the dynamics of the ice sheet margin at the lake, and (in the case of catastrophic floods) the temperature in the water column. By analogy to marine glaciers, the LIS margin along the NE lake shore would have had a grounding line and a transition to a floating ice shelf where basal stress vanished. The position of the grounding line was sensitive to lake level which was in turn affected by the formation and disappearance of ice dams, thus this system had its own dynamics irrespective of external climatic perturbations. The extent of an ice shelf was governed by the velocity of the ice sheet at the grounding line and rate of insolation-induced melting (ablation and basal melting were small). An advance of the ice shelf (and calving icebergs), rise in lake level, and regression of the grounding line constituted a positive feedback, ultimately checked by limited driving forces in the interior of the LIS. The effect of the lake's thermal inertia, which is to reduce summer melting and permit the advance of the ice shelf, would be nullified by that very advance, producing a negative feedback. I describe a simple model that captures the essential physics of these opposing forces and predicts stochastic behavior of the freshwater outflow from Lake Agassiz on centennial timescales. A key uncertainty is the seasonal overturning of the lake. If sufficient to alter Atlantic meridional overturning circulation, these perturbations may be recorded in high-resolution climate and marine geochemical records. More direct tests of the model will involve data from paleolacustrine sediment records from Agassiz and downstream lakes.

Abrupt Climate Changes During the Holocene and Late Glacial Across North America From Pollen and Paleolimnological Records

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Databases of ecological and cultural records, especially of pollen diagrams, record climate variability of several timescales during the Holocene and late glacial. Results from lake and wetland ecosystems extend geographically evidence of rapid climate change obtained from ice cores and ocean sediments. Continental and regional climate curves for North America, based on pollen diagrams from the Global Pollen database, illustrate abrupt changes on the order of every ca. 1000 years during the past 12ka. Major times of change in North American pollen records are coherent with vegetation changes in Europe. Novel analyses of the database show that even taxa that are widespread and with presumably broad climate tolerances were affected by abrupt climate changes such as the Younger Dryas and illustrate the complexity of ecosystem response to these changes. Reconstructions of freshwater as well as terrestrial ecosystems across northern Canada also show how climate variability affects terrestrial and freshwater ecosystem-level properties such as nutrient cycling. These results can be used to reconstruct the spatial patterns of abrupt climate change, as well as the impacts of climate change on ecosystem and cultures.

The Role of AMOC and CO_2 on the Evolution of Polar Temperature During the Last Deglaciation: a Transient GCM Study with CCSM3

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The dramatic deglaciation climate evolution provides a key observation for understanding abrupt climate changes and for testing climate models. Here, we present the first transient climate simulation of the deglaciation evolution from the last glacial maximum to the early Holocene in a synchronously coupled general circulation model – CCSM3. Our model simulates the major features of the deglaciation evolution reconstructed from the polar ice cores. The deglacial warming trends from Greenland and Antarctic are well captured in the simulation as the response to CO_2 increase, while the warming trend in Greenland has been interrupted by the millennial events caused by the variability of the Atlantic Meridional Overturning Circulation (AMOC). In this simulation, the cooling of Heinrich 1 is due to the collapse of the AMOC and the dramatic Bolling Allerod (BA) warming is the transient response of the AMOC to the termination of the meltwater discharge under the background CO_2 rise. The cooling of the Younger Dryas is induced by the reduction of methane and the slowdown of AMOC, but the magnitude of the cooling remains as a challenge. In Antarctic, the surface air temperature is immune to the variability of AMOC and mainly responsive to the CO_2 forcing. As a result, the Cold Reversal (ACR) is due to the pause of the increase of the CO_2 after BA.

The effects of orbital forcing, GHG (mainly CO_2) forcing and AMOC on the deglacial evolution of polar temperature have been separated through two sensitivity experiments with only orbital or GHG forcing after H1. The results from CCSM3 show that CO_2 plays dominant role over orbital forcing on the deglacial warming trend in both Greenland and Antarctic, while AMOC is instrumental in producing the millennial events in Greenland. Furthermore, these results demonstrate that

the lack of the more pronounced warming and cooling in Antarctic compared to Greenland is due to the less influence of AMOC on the Antarctic temperature.

Abrupt and Millenial-Scale Changes in Arctic Sedimentary 231Pa/230Th

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Protactinium-231 and thorium-230, produced at constant rate and in constant ratio to each other in the world ocean by uranium decay, are removed to sediments through scavenging by sinking particles. Changes in the ratio of these nuclides preserved in sediment cores, relative to their ratio of production in seawater, have been used to investigate past changes in oceanic circulation and productivity. We have produced seven records of late-glacial to Holocene changes in ^{231}Pa/^{230}Th from the central Arctic Ocean, at depths between 1 and 3.5 km. At all sites, ^{231}Pa/^{230}Th ratios in late-glacial-age sediments are below the production ratio, indicating export of ^{231}Pa from the central Arctic at all depths during this time. ^{231}Pa/^{230}Th ratios vary little in the two deepest cores (>3 km) from the late glacial to the Holocene, indicating near-steady export in the deep basins. ^{231}Pa/^{230}Th ratios in two cores from ~2 km depth in the Makarov and Amundsen Basins show millennial-scale variability in the late deglacial and early Holocene, with peaks in ^{231}Pa/^{230}Th at ~11 kyr and ~7.5 kyr. Variability is greatest in three cores between 1 and 1.5 km, which show abrupt steps up from low glacial ratios to higher deglacial and Holocene ratios. Sedimentary ratios reach the production ratio, indicating no net export of ^{231}Pa, only in the 1-1.5 km deep cores during the deglaciation and Holocene. It is not yet known where the ^{231}Pa exported from the Central Arctic water column is finally buried; it may be scavenged at continental slopes by increased particle fluxes, or exported through the deep passage of Fram Strait. Possible interpretations of the variability found in our cores include changes in particle scavenging of nuclides due to changes in productivity, shelf flooding, sea ice formation, and particle type; or changes in oceanic circulation at different depths which could affect net transport of ^{231}Pa in the water column.

Exceptional Sensitivity of New England Climate to Abrupt Changes in Atlantic Meridional Overturning Circulation During the Early Holocene

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Paleoclimate data and GCM modeling suggest that Atlantic meridional overturning circulation (AMOC) is a key driver for abrupt continental climate changes. Enigmatically, however, during the early Holocene, multiple episodes of prominent AMOC weakening inferred from stable carbon isotope ratios of North Atlantic benthic foramnifera correlate with no or only obscure continental climatic responses, raising serious questions about the effectiveness and consistency of AMOC in driving abrupt climate changes. Potentially, the obscure continental signals could also result from the inadequate sensitivity of conventional continental paleoclimate proxies to detect abrupt climate changes of relatively short duration (e.g., decade to multidecades), and/or variable regional climate sensitivity to AMOC. Here we present decadal- to multidecadal- resolution hydrogen isotopic records of aquatic and terrestrial biomarkers from Blood Pond, Massachusetts. Our data reveal, for the first time, a full series of prominent and abrupt cooling events centered around 10.6, 10.2, 9.5, 9.2, 8.4 ka during the early Holocene. These regional abrupt climatic reversals display the largest amplitudes of change among isotopic excursions around the world and coincide strongly with key intervals of weakened AMOC, demonstrating the exceptional sensitivity of New England climate to AMOC and an ineluctable linkage between significant AMOC oscillations and abrupt continental climate change.

The Impact of Early Holocene Lake Agassiz Floods Based on new Pollen, Dinoflagellate and Isotopic Data From the Northeast Newfoundland Shelf

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The drainage of glacial Lake Agassiz could be responsible for the 8.2 ka cold event recorded in the Greenland Ice Sheet and tentative links with the Preboreal Oscillation have been made (Barber et al. 1999, Nature 400: 344-348). Recent studies show clear evidence for drainage of large volumes of meltwater through Hudson Strait (Lajeunesse and St-Onge 2008, Nature Geoscience 1: 184-188). With Coriolis deflection, meltwater should southward flow over the Labrador shelf. Indeed, detrital carbonate (DC) beds in cores from the Labrador and Newfoundland shelves suggest that plumes of suspended DC sediment were carried through

Hudson Strait into the Labrador Current, and as far south as Grand Bank at least.

DC beds in cores from Notre Dame Channel have been dated and correspond with known periods of meltwater flow out of Hudson Strait. Lewis et al. 2009 (this conference) will be discussing their re-evaluation of the correction for radiocarbon dates from the Labrador and Newfoundland Shelves. In addition to this, we are proposing here new onshore-offshore correlations of dated palynological records from Newfoundland and the Newfoundland shelf. These correlations are used to verify our dating scheme and to lend support to the corrections proposed by Lewis et al. Similar onshore-offshore correlations of dated palynological records from Cartwright Saddle on the Labrador Shelf will also be shown.

Dinocyst assemblages support our hypothesis that the Labrador Current was significantly enhanced by the ouflow from Lake Agassiz. Detrital carbonate layers show increased proportions ofImpagidinium pallidum and Spiniferites elongatus indicating cooler sea surface conditions and the overall dinocyst assemblages suggest stronger vertical stratification, and hence reduced surface salinity. Transfer functions based on dinoflagellate cysts also show a reduction in sea surface salinity, before and during the DC bed.

Zonneveld (1999; Marine Micropaleontology 50: 307-317) showed that calcareous cysts of photosynthetic dinoflagellate Thoracosphaera heimii can potentially be used for paleotemperature reconstructions based on stable oxygen isotope measurements (Zonneveld et al. 2007; Marine Micropaleontology 64: 80-90). Oxygen isotope analyses performed on calcareous cysts of *T. heimii* from Notre Dame Channel will be presented. The $\delta^{18}O$ we measured are very low.

Correlating Lake Agassiz Floods to the Onset of the 8.2 cal ka Cold Event

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Energetic drainages of glacial lakes from the limestone- and dolomite-floored Hudson Bay and Hudson Strait regions carried suspended sediment which subsequently rained out over the floodwater trajectory to produce distinct sedimentary beds of enhanced detrital carbonate (DC) content. Using the DC beds as a proxy for floods emanating from Hudson Strait, our studies of sediment cores show that the Lake Agassiz and other floods turned south after leaving the Strait and flowed over the Labrador and Newfoundland shelves and upper continental slopes, not into the Labrador Sea to contribute to the 8.2 cal ka cold event, as originally proposed in 1999. The 1999 radiocarbon chronology put the Agassiz outflow 200-300 years earlier than the cold event. DC beds south of the Grand Banks of Newfoundland show that the Agassiz waters reached the Gulf Stream and were likely transported northeastward by the Atlantic Current into the Nordic seas, where they could have suppressed North Atlantic deepwater production.

Bard et al. (1994) show that corrections to North Atlantic ^{14}C dates on biogenic carbonate depend mainly on the presence of Gulf Stream subtropical water and the annual sea-ice cover duration that suppresses air-water CO_2 exchange. Gulf Stream water is absent along the Labrador and northeast Newfoundland margins, but sea ice has a significant presence. Reservoir corrections applied to ^{14}C dates on biogenic carbonate are based on the age of modern (pre-bomb) shells, and incorporate the effects of current sea-ice cover duration (5-6 months), but not necessarily former ice cover duration. Transfer function analysis of dinoflagellate assemblage data show that seasonal sea-ice durations contemporaneous with the Agassiz floods ranged up to 11 months; this difference translates to increased radiocarbon corrections of up to -200 years on foraminifera and mollusk shells. An additional -100 year correction allows for the presence of dissolved inorganic `old' carbon in oceanic waters, indicated by relatively high (5 to 50 %) contents of Paleozoic-aged DC in early Holocene sediments. When applied to Labrador and Newfoundland offshore ^{14}C dates, these adjustments show that the Agassiz floods were coeval with the onset of the 8.2 cal ka cold event recorded in Greenland ice. These findings raise confidence in concluding that ice-dam failure and rapid flooding of glacial Lake Agassiz into the North Atlantic Ocean played a significant role in causing abrupt climate change at 8.2 cal ka.

Abrupt Climate Transitions and the delta-13CH4 Record: New Measurements and Old Corrections

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We present new delta-13CH4 measurements from interstitial air extracted from ice outcropping at Pakitsoq, Greenland. Our high-resolution gas isotope record spans three different abrupt climate transitions from the Last Glacial Maximum (LGM) into the Preboreal: 1) Oldest Dryas – Bolling (OD-B, climate warming at 14.7 kyr BP), 2) Allerod – Younger Dryas (A-YD, climate cooling at 12.8 kyr BP), and 3) Younger Dryas – Preboreal (YD-PB, climate warming at 11.5 kyr BP). We note an interesting contrast between a) transitions with no apparent coupling between the methane concentration and its stable carbon isotope ratio (YD-PB) and b) transitions where the methane and its isotope ratio appear to move in concert (OD-B). Our results demonstrate the same general trend of more ^{13}C-enriched methane during colder periods in the climate record as published recently (e.g., Schaefer et al. 2006, Fischer et al. 2008). However, to properly compare our results to those recently published we must correct for the processes that can fractionate the methane as it moves from the atmosphere, within the firn and to isolation after bubble close-off. These processes include thermal, gravitational, diffusional, and dilution fractionations. We will pay particular attention to diffusional corrections as these corrections have been neglected in some of the published ice core records. Additionally, this correction is of critical importance to compare stable isotope measurements from ice between different locations and records.

Climate Modes and Phytoplankton Blooms in Four Major Coastal Antarctic Polynyas

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Coastal polynyas represent sites of intense autotrophic activity around Antarctica and are expected to change due to modifications of local and synoptic climate variability. Co-variability between major Antarctic climate modes (Southern annular mode, SAM, Multivariate ENSO Index, MEI, Pacific South American Pattern, PSA, Wave-3 pattern, W3, and Semi-annual oscillation, SAO) and phytoplankton biomass was investigated in the largest Antarctic coastal polynyas (Amundsen Sea, AS, Ross Sea, RS, D'Urville, DU, and Prydz Bay, PZ) during summer (Dec-Jan-Feb) of 1997-2007. In general, anomalies of climate indexes had the greatest influence on monthly anomalies of satellite-derived chlorophyll a concentration (Chl a) of AS and DU (Spearman rank correlation coefficient up to 0.7). Regional (e.g., W3 over AS and DU) and circumpolar (e.g., PSA) phytoplankton responses to climate variations were identified. Variability of climate modes also affected seasonal timing of Chl a (e.g., 'late' phytoplankton blooms in AS and PZ after the ENSO 'cool phase'). These modern observations provide mechanisms that can be applied to reconstruct paleo-climates scenarios from diatom records or estimate modern primary productivity levels during those years before ship data (1950s) or ocean color measurements (1980s).

Magnitude and Temporal Evolution of Interstadial 8 Abrupt Temperature Change Inferred From d15N and d40Ar in GISP2 Ice Using a New Least-Squares Inversion

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Isotopes of nitrogen and noble gases in air bubbles trapped in ice cores have proved to be useful indicators of past temperature changes. These isotopes fractionate as a result of gravity and the temperature difference between the ice surface and the depth at which bubbles close off when snow turns into ice. Therefore noble gas isotopes provide a completely independent method for estimating temperature from the traditional δ^{18}O of ice.

Here, we present a new technique for inverting the noble gas isotopic signal from GISP2 during Interstadial 8 (38,000 years ago). Based on generalized least squares, our inversion does not require specific assumptions regarding the shape of abrupt temperature changes. Comparison with the δ^{18}O history gives us a better understanding of how well δ^{18}O represents temperature, and provides additional constraints governing the coefficients used in δ^{18}O analysis.

Role of Insolation, Atmospheric Circulation, Greenhouse Gases and Topography on the Inception of Laurentide Ice Sheet

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The early Pliocene was warmer than today and the cooling that followed in the Pleistocene has been implicated to large changes in global ice volume. Superimposed on this cooling trend, the modest reduction in insolation may be sufficient to shift the climate system between glacial and interglacials. In this study, we simulated the inception of the Laurentide Ice Sheet at 115 kyr BP. The major parameters such as the orbital configuration, carbon dioxide and methane concentrations were prescribed in the comprehensive and interactive Community Climate System Model from National Center for Atmospheric Research. The focus was on the coupled land-atmosphere response. The results confirmed that cold atmospheric temperature during the melt season was more important than extreme amount of winter snowfall. Atmospheric cooling of 4°C below contemporary temperature extremes was needed to expand the perennial snow-cover into areas such as Hudson Bay which were not initially covered by ice. With the large percentage of research community currently concerned with future global climate change it is easy to forget that the last glacial cycle started from conditions that were as warm as those projected for future climates in the fourth IPCC report. Yet it took only ~5kyr to roughly build 50% of the LGM ice-volume. Considering the rest of the ice volume required another 85 kyr, the transition around 115 kyr is abrupt.

Arctic Ocean Freshwater Events and Their Possible Role in Abrupt Climate Changes in the Late Quaternary

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High-resolution sedimentary records from topographic highs and continental margins of the Arctic Ocean contain evidence for a number of freshwater events. Low oxygen and carbon isotope values of planktic foraminifers indicate a reduced salinity and an increased stratification of the upper water masses. Spread of the low-saline water can be traced isotopically well into the Amerasian Basin of the Arctic Ocean and (from sea ice formation and brine rejection) in the Arctic deep and intermediate waters. Correlation to terrestrial records from northern Eurasia with independent chronologies reveals a synchroneity of freshwater events with the decay of ice sheets on northern Eurasia and the adjacent wide shelves. These decaying ice sheets opened pathways for the discharge of large amounts of freshwater from previously ice-dammed lakes fed by the huge Siberian rivers. Comparison of Arctic records with those from the subpolar North Atlantic (Norwegian-Greenland Sea) suggests that in several cases the low-saline waters left the Arctic Ocean through the Fram Strait and enhanced the freshening of surface waters in the areas of modern deepwater formation which received freshwater also from the surrounding ice masses. By this mechanism, terrestrial and oceanic developments in the Eurasian Arctic may have contributed to weakenings of the thermohaline circulation and climate variability.

The Physical Record of Meltwater Floods as Marine Sediment Layers, and Temporal Relationships Between Meltwater Flooding and Giant Submarine Slope Failures

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The offshore continuation of meltwater flood pulses might be expected to leave behind a physical record of events as marine sediment layers. Correctly deciphering this record will help to understand the timing, scale and number of flood events. It has been proposed that meltwater discharge into the Gulf of St. Lawrence led to abrupt climate change between ~ 12.7 and ~11.5 ka B.P. during the Younger Dryas. However, sediment cores from the offshore Laurentian Fan show that repeated deposition of numerous thin sediment layers (either by meltwater plumes or by hyperpycnal gravity flows) ceased at ~ 14 ka B.P. (see Piper et al., 2007, Palaeogeography, Palaeoclimatology, Palaeocology, 246, 101-119). Why did repeated sediment deposition cease well before the Younger Dryas? Is this marine sedimentary record compatible with triggering of the Younger Dryas by meltwater flooding into the Gulf of St. Lawrence? More distal parts of the Laurentian Fan contain a single layer of sediment inferred to have been deposited at ~16.8 ka. Is this unusually thick layer related to meltwater flooding, or to large scale slope failure? The layer is thicker than the turbidite generated by the iconic 1929 submarine landslide and turbidity current.

The second aim of this contribution is to explore the relative timing of giant underwater landslides and periods of meltwater flooding. Meltwater flooding from the Laurentian ice sheet was periodically diverted into the Gulf of Mexico. The huge (> 1,000 km^3) Massingill Slump occurred in the eastern Gulf of Mexico, most likely shortly after 11 ka. Recent re-analysis of sediment cores suggests that the deposits from this event may cover a large part of the Mississippi Fan. The scale of this mass flow event may have been significantly underestimated by previous work. Slope modeling suggests that failure can be triggered by periods of rapid sediment loading, which drives lateral flow of pore fluid. Failure is predicted to occur a relatively short time after sediment loading. Such rapid sediment deposition is potentially associated with periods of meltwater flood pulses. This contribution will review evidence for (or against) temporal association and causal linkages between meltwater flooding into the Gulf of Mexico and this huge submarine slope failure.

Meltwater Floods and Abrupt Deglacial Climate Change in the North Atlantic

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Greenland ice-core records indicate that the last deglaciation was punctuated by numerous abrupt climate reversals, involving temperature changes of up to 5-10°C within decades. However the cause behind many of these events is uncertain. A likely candidate may have been the input of deglacial meltwater to the North Atlantic, which disrupted ocean circulation and triggered cooling. Yet the direct evidence of meltwater input for the majority of these abrupt climate events has so far remained undetected. Without evidence illustrating that meltwater pulses reached the high-latitude North Atlantic, their link to any subsequent abrupt climate event remains hypothetical. Furthermore, determining the phasing between existing evidence for meltwater pulses and the high resolution Greenland ice-core climate record has been hindered by uncertainty in chronologies. In this study, we use the geochemistry of planktonic foraminifera (paired δ^{18}O-Mg/Ca analysis) from a sediment core south of Iceland to reconstruct the input of meltwater to the North Atlantic during abrupt deglacial climate change. Our high resolution record can be placed on the same timescale as ice-cores and therefore provides a direct comparison between the timing of meltwater input and climate variability. Meltwater flood events coincide with the onset of numerous cold intervals, including the Older Dryas (14 ka), two events during the Allerød (at ~13.1 and 13.6 ka), the Younger Dryas (12.9 ka), and the 8.2 ka event, supporting a causal link between these abrupt climate changes and meltwater input. During the Bølling-Allerød warm interval, we find that periods of warming drive rapid meltwater discharge, which in turn induces abrupt cooling, a cessation in meltwater input, and eventual climate recovery. This suggests that feedback between climate and meltwater input produced a highly variable climate.

Model Simulations of the 8.2 ka Event

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The Atlantic meridional overturning circulation (MOC) plays an important role in determining the climate of the North Atlantic and beyond; therefore, it is essential to test the ability of coupled models to predict changes in the MOC and any resulting climate impacts. The 8.2 ka event has been previously targeted for such a test (i.e., Alley, 2003; Schmidt and LeGrande, 2005). The hypothesized cause of the 8.2 ka event is drainage of freshwater from Lake Agassiz into Hudson Bay, which appears to have slowed the MOC and affected climate in various parts of the Northern Hemisphere. The climate system before the 8.2 ka event was generally similar to that of today with a few notable exceptions, including lower greenhouse gas concentrations, increased seasonality of insolation due to orbital forcing, a remnant of the Laurentide ice sheet near Hudson Bay, and enhanced ice melt runoff down the St. Lawrence River. Using the NCAR CCSM 3.0 model, we have run experiments to determine how adding these different boundary conditions could influence the background climate state prior to the drainage of Lake Agassiz into the Hudson Bay. We find these boundary conditions have significant effects on the properties in the North Atlantic. We will discuss the reasons for these changes and their implications for the effects of freshwater forcing at 8.2 ka. We will also discuss the results of simulating a flood event at 8.2 ka using these realistic boundary conditions.

Comparative Analysis of Benthic Foraminiferal Isotopic Records From Atlantic and Pacific Oceans Over the Past 1 Myr

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Least squares adjustment and cross-spectral analysis of the time series of the foraminiferal carbon and oxygen isotope records obtained from the ocean drilling at different locations on the globe was performed. Their coherent behavior is evident for the main periodicities of 100 kyr, 41 kyr, 23 kyr, caused, as it is believed, by the Earth orbit and axis position variations. The delays between the responses to the climate changes for the northern Atlantic and tropical Pacific found to be small. The dispersion of this delays, on the contrary is large and corrective smoothing is needed for their estimation. Singular spectral analysis and prediction of the time series was also performed.

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Millennial-Scale Changes in Deep Ocean Circulation and Carbon Cycling During the Last Deglaciation: Evidence from the Arabian Sea

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The timing of changes during the most recent deglaciation reveals a tight association between deep ocean circulation, ocean carbon cycling and climate. During the deglaciation, atmospheric pCO_2 rose and atmospheric radiocarbon activity ($\Delta^{14}C$) declined in two steps; the first during Heinrich Event 1 (H1) and the second during the Younger Dryas (YD). These changes coincided with warming in Antarctica, cooling in Greenland and reduced North Atlantic Deep Water (NADW) formation. Between these two steps, during the Bølling/Allerød or Antarctic Cold Reversal, atmospheric pCO_2 and ($\Delta^{14}C$ leveled, Greenland warmed abruptly, Antarctica cooled slightly, and NADW formation increased. The concurrent changes in atmospheric pCO_2 and $\Delta^{14}C$ imply that the CO_2 added to the atmosphere must have been depleted in radiocarbon. Support for this idea was found in the reconstruction of D14 C in intermediate waters off the coast of Baja California [Marchitto et al., 2007 /Science/], which revealed pulses of radiocarbon-depleted DIC during H1 and the YD, at the same time as atmospheric pCO_2 rose and atmospheric $\Delta^{14}C$ declined. This radiocarbon-depleted carbon could only have been sourced from a sluggishly-ventilated deep ocean water mass, suggesting that changes in deep ocean circulation likely played a prominent role in the deglacial pCO_2 rise.

Here we present new intermediate water radiocarbon activity reconstructions from the Arabian Sea. These reconstructions come from two sediment cores: RC27-14 (596 m water depth) and RC27-23 (820 m water depth). Taking advantage of the strong similarity between the $\delta^{15}N$ of organic matter in these cores [Altabet et al., 2002 /Nature/] and the $\delta^{18}O$ of the GISP2 ice core [Grootes and Stuiver, 1997 /J. Geophys. Res./] we created calendar age models independent of ^{14}C. Intermediate water $\Delta^{14}C$ were then calculated using calendar ages along with ^{14}C ages of benthic foraminifera. Initial results indicate the presence of ^{14}C depleted DIC in the Arabian Sea during the time of Heinrich Event 1. Intermediate water $\Delta^{14}C$ from the shallower of the two Arabian Sea cores is less depleted than at Baja California; however, $\Delta^{14}C$ at the deeper site appears to show even greater depletion. The presence of radiocarbon-depleted DIC in the Arabian Sea indicates the $\Delta^{14}C$ signal is not isolated to the northeast Pacific, and would be consistent with a signal sourced in the Southern Ocean and transmitted through Antarctic Intermediate Water.

Modulation of Abrupt Climate Change in the Southwest Pacific During Antarctic Cold Reversal - Younger Dryas Time

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Marine and terrestrial palaeoclimate records from the New Zealand region reveal marked responses to the Antarctic Cold Reversal (ACR ~14.5-12.5 ka). However, we see no evidence for Younger Dryas (YD) cooling, with warming apparently related to termination of the ACR resuming half way through YD time (12.9 -11.5 ka).

Offshore, data from core MD97-2121, north of the Subtropical Front (STF) off northern New Zealand, provide a well-dated, stable isotope history of subtropical and Antarctic influences on the surface and deep ocean over the last deglaciation. Benthic foraminiferal $\delta^{18}O$ increased in phase with the ACR, consistent with an invigorated deep inflow forced by an expanded cryosphere. In contrast, surface waters as represented by planktic foraminiferal $\delta^{18}O$ profiles from 3 species and alkenone-based sea surface temperatures, had no immediate reaction to the ACR. It was not until ~13.5 ka that the surface ocean responded. It became cooler, less fertile and more mixed. These conditions ended part way through the YD when the local climate resumed warming.

Onshore, a well-dated pollen and chironomid record from Boundary Stream Tarn, southern New Zealand, provides a contemporaneous temperature record. A ~1 ka disruption to the late-glacial warming trend is revealed with an overall cooling consistent with the ACR. The main interval of summer temperature depression (~2-3^{o}C) lasted about 700 years during the ACR and was followed by a warming in YD time to temperatures slightly cooler than present. The larger temperature change shown by the chironomid record is attributed to the response of the proxies to differences in seasonal climate with chironomids reflecting summer temperatures and vegetation more strongly controlled by winter duration or minimum temperatures. These differences imply stronger seasonality.

The results highlight a direct linkage between Antarctica and mid-latitude climate systems and the largely asynchronous nature of the inter-hemispheric climate system during the last glacial transition. We suggest that ocean/atmosphere changes north of the STF resulted from an amelioration of polar conditions by subtropical influences. The ACR onset was blunted initially by a strengthened inflow of subtropical water, but as the ACR reached its coldest, ~13.5 ka, cooler temperatures, altered seasonality and stronger winds prevailed. By comparison, southern New Zealand where subtropical influences are reduced and the ocean/atmosphere have more direct links with Antarctica, the surface waters and terrestrial climate cooled in phase with the ACR.

A Bipolar Nutrient Seesaw Hypothesis

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Many paleoceanographic records from the northern hemisphere show decreased export production during stadial periods, which modeling studies have mechanistically linked to reduced NADW formation. However, observations have shown increases of organic matter export occurred in the southern hemisphere during Heinrich events, in opposition to the northern hemisphere trend. These same episodes have been correlated with intensified denitrification on the coast of South America, and with outgassing of carbon dioxide to the atmosphere. Taken together, these observations suggest that the nutrient supply to the southern hemisphere thermocline can vary out of phase with that of the northern hemisphere on millennial timescales. We propose that a 'bipolar nutrient seesaw' has operated on millennial timescales in the past, as follows. When NADW slows, the thermocline deepens in much of the world, particularly the Northern hemisphere, slowing the upward flux of nutrients to the sunlit surface ocean and reducing export globally. However, during times of reduced NADW formation, warming of the Southern Ocean occurs, which appears to be linked to a southward shift of the westerly winds, increasing the meridional density gradient and upwelling within the ACC. Furthermore, the subduction regions of thermocline waters shift to higher latitudes under these conditions, at which light is more scarce, and where the surface is perennially nutrient-rich. The advection of these high nutrient waters into the thermocline fuels abundant export production throughout much of the southern hemisphere, counteracting the general decline caused by the cessation of NADW formation. We explore, using a numerical ocean-biogeochemistry model, how the exchange between the Southern Ocean surface and the deep sea is modulated by winds and the overturning circulation, impacting the oceanic sequestration of carbon dioxide, as well as the flux of nutrients to the southern ocean surface and global thermocline.

A Test for the Presence of Covariance Between Time-uncertain Series of Data With Application to a Collection of Proxy Records Showing Millennial Variability

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Statistical measures of the relationships between time series are generally altered by the presence of errors in timing, i.e.~when applied to time-uncertain series.For example, the sample covariance between two time series which in truth covary will generally be decreased by errors in timing. Previous work has sought to maximize some goodness of fit between time-uncertain series either heuristically or through more quantitative methods. However, there is a danger that unrelated records can be made to appear to covary by time adjustment. Here we propose a statistical test for the presence of covariance between time-uncertain series and time-certain series wherein the probability of obtaining a maximum covariancefrom randomly realized time-uncertain series is assessed using thetheory of extreme order statistics. The results of this analytical method provide insight into the influence of timing errors upon covariance and are shown to be consistent with results derived from a Monte Carlo procedure.

We apply this methodology to test the significance of the covariance between the GISP 2 delta-18O and (1) % Reflectance at Cariaco Basin, (2) δ^{18}O at Hulu Cave China, (3) Total Organic Carbon at Arabian Sea, (4) Temperature at EDML, (5) bioturbation record at Santa Barbara, (6) $CaCO_3$ at Bermuda Rise, (7) Sea Surface Temperature at Iberian Sea, (8) δ^{18}O Botuver Cave at Brazil, (9) 13C record at South Africa, (10) δ^{18}O at New Zealand. The statisticalsignificance of the covariance between these proxies is used to evaluate proposed mechanisms of abrupt climate changes.

The Timing and Magnitude of a Recent Acceleration in the Rate of Relative Sea-Level Rise (North Carolina, USA)

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We provide records of relative sea level from two salt marshes in North Carolina for the last 2000 years to compensate for the scarcity of long tide gauge records and provide a vital tool for deciphering the causes of 20th century sea-level rise. Reconstructions were developed using a foraminifera-based transfer function (from 10 modern salt marshes) and a composite chronology (AMS, high-precision and bomb spike radiocarbon, ^{210}Pb, ^{137}Cs and a pollen chronohorizon) that were validated against regional 20th century tide gauge records. The absolute rate of relative sea-level rise (RSLR) in North Carolina during the 20th century was c. 3mm/yr, which began abruptly at the end of the 19th century and is broadly synchronous with other studies from the Atlantic coast. The magnitude of the rise at both sites (2.2mm/yr above background rates associated with continued response to pro-glacial forebulge collapse) is larger and indicative of a latitudinal trend along the US Atlantic coast and may represent a finger print of melting of the Greenland Ice Sheet. This recent acceleration in the rate of sea-level rise is unprecedented during the late Holocene.

Global and Local Sea Level During the Last Interglacial: A Probabilistic Assessment

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The Last Interglacial (LIG) stage (ca. 130--115 ka), with polar temperatures likely 3-5 °C warmer than today, serves as a partial analogue for low-end future warming scenarios. Multiple indicators suggest that LIG global sea level (GSL) was higher than at present; based upon a small set of local sea level indicators, the Intergovernmental Panel on Climate Change (IPCC)'s Fourth Assessment Report inferred an elevation of approximately 4-6 m.

While this estimate may be correct, it is based upon overly simplistic assumptions about the relationship between local sea level and global sea level. Sea level is often viewed as a simple function of changing global ice volume. This perspective neglects local variability, which arises from several factors, including the distortion of the geoid and the elastic and isostatic deformation of the solid Earth by shifting ice masses. Accurate reconstruction of past global and local sea levels, as well as ice sheet volumes, therefore requires integrating globally distributed data sets of local sea level indicators.

To assess the robustness of the IPCC's global estimate and search for patterns in local sea level that are diagnostic of meltwater sources, we have compiled a comprehensive database that includes a variety of local sea level indicators from 47 localities, as well as a global sea level record derived from oxygen isotopes. We generate a global synthesis from these data using a novel statistical approach that couples Gaussian process regression for sea level to Markov Chain Monte Carlo simulation of geochronological errors.

Our analysis strongly supports the hypothesis that global sea level during the Last Interglacial was higher than today, probably peaking between 6--9 m above the present level. This level is close to that expected from the complete melting of the Greenland Ice Sheet, or from major melting of both the Greenland and West Antarctic Ice Sheets. In the period when sea level was within 10 m of the modern value, the fastest rate of sea level rise sustained for a 1 ky period was likely about 80--110 cm per century. Combined with the evidence for mildly higher temperatures during the LIG, our results highlight the vulnerability of ice sheets to even relatively low levels of sustained global warming.

Sea Level Forcing of Mid-ocean Ridge Magmatism on Milankovitch Timescales

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It is well-documented that Iceland experienced a pulse of elevated volcanism immediately following the last deglaciation. Modeling results suggest ice sheet retreat depressurized the mantle thus enhancing melt production and magma supply to the surface (Jull and

McKenzie, 1996). Here we take a similar approach, but instead model the effect of glacial-interglacial changes in sea level on melting at mid-ocean ridges. Loading rates reaching ±2cm/year of water are comparable to the tectonic unloading rate of ~2 cm/year of mantle rock that drives magmatic activity at a slow-spreading ridge. Although the magnitude of sea level forcing is smaller than subglacial forcing, the sea level effect is globally distributed and could have significant consequences for geothermal heat delivery to the deep ocean.

We use a model of melt production based on analytical corner flow velocities coupled to the pMELTS model (Ghiorso et al. 2002; Asimow et al. 2004) of melting of the Workman and Hart (2006) depleted upper mantle source composition. We examined mid-ocean ridge systems with half-spreading rates from 10 mm/yr to 75 mm/yr and melt migration rates from 2 to 50 m/yr. For the case of 30 mm/yr half-spreading rate and 10 m/yr melt migration, we find that the rate of melt delivery to the crust varies ±30% relative to steady state conditions when the model is driven by a record of sea-level variability of the last 140 kyr. Notably, we simulate a 30% increase in melt delivery from 30 kyr BP to 20 kyr BP, driven by a 50 m decrease in sea level. Melt delivery decreased more than 50% from the Last Glacial Maximum to 5 kyr BP, driven by the ~120 m rise in sea level during the last deglaciation. Our results suggest that modest changes in hydrostatic pressure driven by ice sheet growth and decay may yield substantial alterations in magma flux at mid-ocean ridges relative to steady state conditions. These simulations raise the possibility that mantle melting may act as a negative feedback on ice sheet size by modulating deep ocean temperature. We estimate that enhanced melt production during sea level low-stands yield increases deep ocean temperature by order 0.1°C. We speculate this modest warming may contribute to deglaciations by reducing sea-ice extent in the Southern Ocean, which may in turn promote ventilation of the abyssal ocean and the release of sequestered carbon dioxide to the atmosphere.

High Latitude Control on Tropical Indian Ocean During the Past 22,000 Years

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Shell geochemistry of two surface-dwelling planktonic foraminifera served to track centennial- to millennial-scale variations in sea surface temperature (SST) and salinity (SSS) of the eastern Indian Ocean during the past 22,000 years. Annual mean SSTs during the Holocene, recorded by shell Mg/Ca of G. ruber, were on average about 2.4 degrees warmer than during the Last Glacial Maximum (LGM). Annual mean SSTs show a typical southern hemisphere pattern with an early deglacial warming at 19ka, two significant warming steps during Heinrich 1 (H1) and Younger Dryas (YD), and a slight cooling during the Antarctic Cold Reversal (ACR). Annual mean SSTs reached maximum values during the early Holocene followed by a cooling trend towards the late Holocene. Reconstructed SSTs for the boreal summer based on shell Mg/Ca of G. bulloides, however, show much stronger centennial to millennial fluctuations, a higher Holocene-LGM difference of about 4 degrees, and cooling (warming) trends during H1 and YD (ACR and towards late Holocene). A rapid warming at 8.2 ka is evident in both annual mean and boreal summer SST records. While boreal summer SSTs appear to be primarily controlled by the Australasian monsoon system, the timing of mean annual deglacial SSTs suggests a closer link to the southern hemisphere. Possible controls on mean annual SST include the rising global carbon dioxide level that would provide a direct link between high and low latitudes and instantaneous atmospheric climate feedback to the initial melting of continental ice sheets, and increased ventilation of deep water in the Southern Ocean.

The timing of annual mean and boreal summer SSS variations during the past 22 ka corresponds to the northern high-latitude temperature records implying a strong monsoonal control on these proxies. Annual mean and boreal summer SSS values were identical during the LGM and H1 suggestive of a weak summer monsoon during these periods. The onset of a stronger summer monsoon at about 15 ka is reflected by saltier conditions during the boreal summer monsoon (upwelling) season compared to the annual mean SSS that also prevailed throughout the Holocene. During H1 and YD, relatively cooler and saltier conditions in boreal summer can be explained by a reduction in the Atlantic meridional overturning circulation, which may have caused a southward displacement of the Intertropical Convergence Zone (ITCZ), a stronger austral summer monsoon, and enhanced upwelling intensities in the study area. In contrast, warmer and saltier conditions both year-round and during boreal summer at 8.2 ka suggest a reduction in the Australasian summer monsoon intensity.

Mg/Ca Paleothermometry in the Central Gulf of Cadiz and the Iberian Margin During Heinrich Events

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During the last glacial and deglacial period (16kya-46kya), the Iberian Margin experienced local sea surface temperature fluctuations as a result of melting icebergs from catastrophic calvings of the Laurentide Ice Sheet (Heinrich Events). Using Mg/Ca in species of planktonic foraminifera, we are reconstructing temperature for Heinrich Events one (H1), four (H4) and five (H5) from core MD99 2339 in the Gulf of Cadiz (35.88°N; 7.53°W, 1170m) and core MD95 2040 on the Iberian margin (35°34.91'N; 9°51.67' W, 2645m). Locally, all three of these events are quite intense showing O-18 excursions of approximately 1.5 parts per mil.

Low Mg/Ca values during the Heinrich Events imply significant local and possibly regional cooling. For example, temperatures derived from Mg/Ca during H1, H4 and H5 in the Gulf of Cadiz show a temperature oscillation of approximately 6-7°C between the start and end of each Heinrich Event. While this is a large temperature oscillation, it is of slightly smaller amplitude than the approximate 10°C swing implied by assemblage data for winters (Voelker et al., 2006) in the Gulf of Cadiz. By comparing a suite of temperature proxies in the same region (Mg/Ca, planktonic foraminiferal assemblage data and alkenones), we hope to better constrain the climate fluctuations during these time periods as well as gain insight into secondary environmental effects that complicate interpretation of the proxies strictly as temperature.

Looking at Cd/Ca and reconstructing delta O-18 of the seawater, we also have new clues about nutrient and salinity changes during these time periods, which we hope will lead to a more complete picture of the local and regional environment during Heinrich Events.

Antarctic Intermediate Water Radiocarbon During the Last Deglaciation

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One leading hypothesis regarding the mechanism by which carbon dioxide and the radiocarbon content of the atmosphere changed so dramatically during the last deglacaition involves the ventilation of an old, abyssal water reservoir at surface of the Southern Ocean. In theory, the abyssal ocean was isolated from the atmosphere during the last glacial period. Throughout the millennia, the radiocarbon content of this reservoir decreased due to radioactive decay and its carbon dioxide increased due to the rain of organic matter. At the beginning of the last deglaciation, ~18,000 yr before the present (B.P.), it is believed that the communication between those reservoirs was reestablished and, as a consequence, there was an emission of large quantities of radiocarbon-depleted carbon dioxide from the Southern Ocean's surface to the atmosphere.

Scattered direct evidence for the existence of that old reservoir has been documented, although the sequence of events has only been tentatively assessed by intermediate water radiocarbon content of benthic foraminifera in the eastern North Pacific (e.g. Marchitto et al., Science 2007). A new deglacial record of Antarctic Intermediate Water radiocarbon activity in the South Pacific off Chile does not support the interpretation for those recent findings. Throughout the deglaciation, the radiocarbon off Chile is close to or equal to the modeled well ventilated surface ocean and therefore unaffected by the upwelling and mixing with a radiocarbon depleted reservoir. Although we can't rule out the possibility that the old reservoir indeed existed, these results require an alternative mechanism by which both carbon dioxide and radiocarbon changed so dramatically in the deglacial atmosphere.

Communicating Past and Present Rates of Climate Change

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Confusion surrounding the science of climate change signals a failure to effectively communicate basic climate data to the public. Despite award-winning international commissions, graphically rich web sites sponsored by universities and government agencies, and the labor of skilled science writers and bloggers, the public is readily swayed by well-intentioned but ill-informed contrarians publishing in lightly or altogether unedited popular media. Examples are myriad, ranging from Michael Crichton's State of Fear to the February 2009 Op Ed by George Will.

At least part of our culture's inability to grasp the span and impact of climate change stems from problems with time scales. By definition we think most easily in terms of our human experience, the memories of our grandparents, our hopes and fears for our grandchildren. Historic records and images of agriculture in Greenland and frozen canals in Holland are easily tossed as red herrings to divert an audience from a careful investigation of documented trends and patterns.

The geological record of climate change is rich in temporal detail at multiple scales. At certain scales, climate patterns are clear and understood, at others, trends are subtle and continue to challenge modelers.

A compilation of climate changes over time frames spanning eight orders of magnitude has been presented at a venues ranging from oil company research centers, to Rotary clubs, Museum seminars, university forums, geological association gatherings, and High School classes as a tool to inform the public about issues of resolution, patterns of changes and their potential causes and impact. Assembling and presenting the data in consistent formats over these various time frames allow the rates and magnitudes of past climate changes to be compared so as to help place our present condition in context. This systematic presentation of graphic measurements provides audiences a tool to encourage them to make considered decisions and develop opinions based on accessible data sets and well-documented patterns.

Effective communication is imperative if we are to have broad support for proactive change. Leadership for change at Federal, State, and community levels must be built on a public consensus that proposed changes in societal behavior are both warranted and desirable for our common good.

Modeling Abrupt Climate With Independent, Complementary Climate Models and a Possible Origin of the 1500yr Oscillation

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Abrupt climate change in the form of sudden and seemingly unpredictable drastic changes in ocean temperature, salinity and density are shown to be typical results of modeling paleoclimate regimes with 3D coupled EMIC (Earth Model of Intermediate Complexity) models with fixed boundary conditions. Here we present a number of results from one EMIC that has been used in many paleoclimatic simulations, ECBilt-Clio. We show simulations that suggest the existence of millennial scale free oscillations of ocean temperature and sea ice extent and suggest that at least in climate models modulation of the Thermo-haline Circulation (THC) abrupt switches between convection and mixing oscillations by the orbital forcing of the last 100000 yr controls the timing of abrupt climate change and at the same time explain why ice core evidence of Bond's persistent ~1500 yr oscillation is somewhat elusive, appearing in only short intervals of the GRIP time series. Comparing the data with time series generated by simple stochastic differential equations we suggest that the GRIP data are the likely consequence of the combination of stochasticity (sequences of randomly distributed warming events) and order (frequency modulation by the Milankovitch insolation). Such combination of chaos and order is supported by relevant results from toy models. Whether these modeling exercises are a fair representation of the actual abrupt climate changes recorded in the ice cores is however not demonstrated.

Paleoproductivity Variations in the Eastern Equatorial Pacific Over Glacial and Interglacial Timescales

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Filippelli at al. (2007, DSR II) proposed that changes in oceanic phosphorus (P) mass balances caused by glacial sea level changes may be a potential driver for productivity variations. To test this hypothesis, a broader suite of sampling locations including additional oceanic paleoproductivity proxy data collection is necessary. The eastern equatorial Pacific (EEP) is an ideal site for productivity studies due to its high levels of nutrients and importance in terms of burial production. This research examines nutrient proxies (Ba/Ti and P/Ti ratios, isotopic indicators) of four EEP sites while also comparing the sites' glacial and interglacial productivity variations to the geochemistry and productivity results of an independent central equatorial Pacific site.

Phosphorus and other elemental data were collected from Sites 845, 848, 849, and 853 (ODP Leg 138). Our initial analysis of Ba/Ti and P/Ti ratios (an "excess" P proxy) revealed distinct productivity variations during glacial and interglacial periods. The observed variations agree with a pattern of increased productivity during glacial periods and lower productivity during interglacial periods, with a lag observed perhaps reflecting the rearrangements in oceanic nutrient mass balances posited by Filippelli et al. Central equatorial Pacific cores RR0603-03TC and RR0603-03JC (IODP site survey cruise for Proposal 626) have been used as a reference for geochemical concentration parameters, as well as a comparison tool for productivity variations among the central and eastern sites. The central equatorial geochemistry results provided support for sea level changes driving paleoproductivity variations. The similar variation patterns displayed by the EEP's geochemical data in this research could provide additional support for this hypothesis.

Abrupt Climate Change in the Southeast African Tropics Between 0 and 60,000 Yr BP: Testing the Influence of ITCZ Migration on Temperature and Precipitation in the Southern Tropics

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Precipitation reconstructions from the monsoon regions of southern Asia and northern South American indicate arid conditions during North Atlantic stadials, consistent with climate modeling experiments that predict southward migration of the Inter-Tropical Convergence Zone in response to northern high-latitude cooling. Unfortunately, terrestrial paleoclimate records from the southern hemisphere tropics are too sparse to test the models of abrupt southward ITCZ shifts, hindering our understanding of the mechanisms responsible for abrupt global climate changes. New, high-resolution analyses of the D/H ratio of terrestrial leaf waxes (δD) and TEX86 in sediment cores from Lake Tanganyika provide the first direct and independent estimates of continental precipitation and temperature, respectively, during the past 60,000 yr BP from SE Africa, and one of the longest high-resolution temperature and precipitation records from the southern tropics to date. Our record indicates abrupt arid events coeval with the Younger Dryas and Heinrich Events 1, 4, and 5, but no response to H2, H3, or D/O events, perhaps due to the differing magnitudes of the North Atlantic events, their effects on thermohaline convection, and/or the variable sensitivity of southern tropical climates to North Atlantic climate. Regional temperatures do not vary in response to Heinrich events, D/O cycles, or the YD, yet our record indicates an abrupt, 1.5^{o}C cooling identical in timing and duration to the 8.2 kyr BP event in Greenland. Wind field reconstructions from Lake Malawi, south of Tanganyika, document southward ITCZ shifts over Africa during North Atlantic stadials, despite our evidence for regionally arid conditions. Therefore, shifts in the position of the ITCZ alone cannot account for the coupling between high latitude and southern tropical precipitation. Rather, we argue that changes in the zonal gradient of sea surface temperatures in the Indian Ocean during stadials alters vapor transport and surface convergence over Africa, triggering regional precipitation anomalies. While abrupt changes in continental precipitation are not coeval with abrupt changes in temperature in our record, high-resolution analysis of new multicores indicates that the magnitude and rate of warming from 1850 AD to present exceeds that of any temperature change during the past 60 kyr BP, highlighting the sensitivity of Tanganyika temperature to abrupt changes in atmospheric CO_2 concentrations.

The Last 50,000-Year Biogenic Sedimentation, Biomarkers, and Terrigenous Input Records off the Southern Papua New Guinea (IMAGES MD052928)

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We present the last 50,000-year history of biogenic sedimentation, Uk'37-sea surface temperature (SST), C37 alkenone concentrations, branched isoprenoid tetraether (BIT) index, planktic and benthic foraminifera oxygen isotope, and 230Th–normalized fluxes of biogenic and terrigenous components recorded in core MD052928 (11°17.26'S, 148°51.60'E, water depth 2,250 m) taken from the southeastern Papua New Guinea slope during the PECTEN cruise in 2005. The age model of the core is constructed by AMS-^{14}C dating of planktic foraminifers and oxygen isotope stratigraphy of benthic foraminifers. The carbonate contents range between ~15%~50%, with higher values in the Holocene and lower values in MIS (Marine Isotope Stage) 2-3. The ^{230}Th–normalized carbonate fluxes, also higher during Holocene than during MIS 2-3, show high-frequency oscillations that mimic millennial-scale climate changes during the last deglaciation and MIS 2-3. The carbonate contents correlate well with the BIT index measured in the core. Low carbonate events coincide with high BIT indices, ^{230}Th–normalized detritus fluxes, and ^{232}Th

activity that indicate higher inputs of terrestrial organic and detrital matters, suggesting noticeable changes of soil erosion on land nearby and terrestrial fluvial input since the last glacial. The TOC contents range between 0.2%~0.4%, with higher values during MIS 2-3. High TOC contents are associated with high BIT and C_{37} alkenones, indicating an increase of terrestrial organic matters and marine productivity at the core location during the glacials. The Uk'$_{37}$-SST ranges from 26 to 28°C in MIS 2-3, and ~28.5°C in the Holocene. The phasing of the Uk'$_{37}$-SST variations appears to be similar to that of Antarctic temperature changes. The residual δ^{18}O of planktic foraminifera appears to not vary on glacial-interglacial time scales, but show obvious variations on the millennial time scales on which the terrestrial inputs exhibit significant variations. Our records suggest that more higher input and variation of terrestrial matters recorded at this site are linked to the stronger erosion or precipitation intensity on land during MIS 2~3, which may bring implications on millennial-scale changes of ITCZ migration, Australia Summer monsoon, and/or other low latitude climate mechanisms (e.g. ENSO-like).

Abrupt Changes in Benthic Foraminiferal Assemblages and Stable Isotope Record Around 3-4 Ma in the Southeast Indian Ocean, Signatures of Closing of the Indonesian Seaway

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The closing of the Indonesian seaway between Indian and Pacific Ocean around 3-4 Ma is thought to have caused extensive changes in ocean circulation, aridification of east Africa and reduction of atmospheric heat transport from the tropics to high latitudes. Here we present benthic foraminiferal assemblage and stable isotope records from ODP site 762B and 763A in the Southeast Indian Ocean which indicate abrupt changes in faunal and stable oxygen isotopic record around 3-4 Ma. The factor analysis of the faunal relative abundance data reveals major change in faunal assemblages around 3-4 Ma. The *Uvigerina proboscidea* is the most dominating assemblage abruptly increases around 3-4 Ma indicating sudden change in surface water productivity and upwelling due to weakening of Leeuwin Current. Before ~3.55 Ma Oridorsalis umbonatus-*Cibicides lobatulus* and *Cibicides wuellerstorfi* assemblages dominate along with low percentage of total infaunal taxa and higher values of species diversity. As expected on the basis of numerical simulations studies that the net effect of blockage of Indonesian Throughflow is reduction in temperature of the Southern Indian Ocean, which is clearly marked by an abrupt increase in oxygen-isotope content δ^{18}O values of benthic foraminifera the dominant proxy for temperature, show a gradual increase in δ^{18}O beginning at, ~4Myr ago, with the most obvious change since then being an increase in the amplitude of variations. The δ^{18}O results from the ODP site 763 A indicates that southeast Indian Ocean was warm during Pliocene and cooling of deep water started around 3-4 Ma and then the temperature decreases with much fluctuation during Pleistocene. These abrupt changes in faunal and isotopic records are considered to be the signatures of restricted Indonesian Throughflow due to the closing of the Indonesian seaway.

Abrupt Ventilation Changes of the North Pacific Mid-Deep Water During the Last Glacial to Deglacial Period: Implications for Active North Pacific Deep Water Formation Synchronized with AMOC

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Strong evidence exists in support of major and synchronous surface ocean deglacial paleoclimatic changes between the trans northern Pacific region and the North Atlantic. Proposals of major changes in north Pacific mid-deep waters during the last deglacial climate oscillations have remained controversial in the absence of sufficient carbonate containing sediment sequences. Study sites are close to the source of North Pacific Intermediate Waters (NPIW), and is key in understanding deglacial Pacific overturning circulation Here for the first time we present evidence for such changes from sediment sequences from the western North Pacific. 14C age differences between coexisting planktic and benthic foraminifera are presented for three well dated mid-deep depth cores as a measure of changing ventilation during deglaciation. The 3 piston and 1 gravity cores were collected from water depth of 970 m(IMAGES MD01-2409), 1179m(CK05-04 C9002-A, B) and 1366 m(MR01-K03 PC4/5) , off Japanese main island and from water depth 3390 m(NGC108), the Shatsky Rise. These records exhibit a clear antiphase relation during the deglacial between mid-deep depth ventilation of the western North Pacific and that related to the midwater Atlantic Meridional Overturning

Circulation. Ventilation rates increased during the Heinrich 1 and Younger Dryas cooling episodes and significantly decreased during the preBoreal (early Holocene) and Bølling-Ållerød (B/A) warmings. Deglacial active ventilation appears to have been controlled by surface ocean salinity changes and strong cooling in the source waters in response to changes in atmospheric teleconnections over the North Pacific driven by reorganization of oceans' overturning circulation and/or bipolar seesaw. During early deglaciation, the North Pacific Ocean may have acted as a major source for atmospheric CO_2 through active glacial NPIW ventilation.

High- to Low-Latitude Teleconnection and ENSO-Like Variability of Equatorial Pacific Climate Over the Last Glacial Cycle

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A high-resolution record of faunal changes from ODP Site 1240 (Eastern Equatorial Pacific, EEP) provides insight into the regional surface ocean circulation and global climatic condition of the last glacial cycle. Faunal-based sea surface temperature (SST) of Site 1240 was estimated by using IKM-type of transfer functions based on an updated coretop data base, with much better representation for subpolar and Eastern Boundary Current (EBC) of the southeastern Pacific. Our Site 1240 record reveals a significantly intensified cold SST condition that may result from enhanced influences from subpolar and/or EBC components into the EEP, whereas a previous result of $\delta^{13}C$ from Site 1240 reveals that a gradually reduced Equatorial Undercurent Current (EUC) since 160 kya. This implies a shifting from much stronger intrusion of EUC waters to more dominance of northward incursions of the subpolar and/or EBC currents in the EEP, particular for the last 75 kyrs. Furthermore, based on our reconstruction method the spatial and temporal SST patterns across the EEP during the MIS 6-1 indicate that path of cold tongue possibly oscillated along a meridional variation within 3^oN - 6^oS. The reconstructed longitudinal SST patterns of the EEP also suggest that long-term ENSO-like dynamics prevailing over the last glacial cycle in the topical ocean.

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The Impacts of Global Climate Change on the Lake Chad Region of Africa: The Lake Chad and Associated Problems

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The “Lake Chad” is one of the world's largest and most historical Lake located in the Sahel region of Africa which is one of the most vulnerable regions to climate change bordering North-Eastern Nigeria, North-Western Cameroon, South-Eastern Niger and South Western Chad republics. The lake was 25,000 km square in the 1940s as indicated by the historians and some geo-archaeological and historical evidences, the recent of which was the accidental discovery of an ancient Canoe dating back to over three thousand years (3000) located in about Six hundred kilometers (600) away from the present day bank of the Lake in the Nigerian Territory, in the year 1992 by a peasant farmer from the Kanuri inhabited desert areas of Damaturu-Nigeria, while digging a well in quest of water for his domestic activities as reported by Abubakar, B. (IJNA 37.2,2008), but due to the continues incessant impacts of climate change in Africa which resulted in the incessant drying of rivers especially those feeder rivers supplying over 90 % of the Lake water like the River Shari in the republic of Cameroon and the river Yobe in Nigeria has resulted those community living along the courses or banks of the feeder rivers to be blocking the rivers from supplying the water in to the Lake while trying to adapt to this climate change situation by building Dams along these feeder rivers in quest of water for their irrigational activities as well as other activities like the generation of Hydro electric city and other relevant activities. This situation has resulted in the reduction of the water of the Lake to just 1800 km square. Hence this situation has already started causing problems to the indigenous communities living around and depending on the Lake for their survival, because there is increasing drop in fishing activities in the lake as well as reduction in water supply for pastoral and irrigation farming activities in addition to other secondary impacts like the increasing rate of rural-urban migration, job loses and desert encroachments due to the growing numbers of people running into the fire wood selling businesses which depends on the deforestation of the shrubs and the little scattered trees serving as a shelter belt between the Sahara desert located in the north of the Sahel region and the fertile Lands.

Climate Change and Tourism: Southeastern Anatolia Region and Southeastern Anatolia Project (GAP) in Turkey as a Case Study

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The Republic of Turkey has a special place in the Mediterranean Region from the respects of both its social-economic structure and its geo-politic and geo-strategic importance. It is also a model for the Middle East Countries by combining the traditional and modern life styles.

The Southeastern Anatolia Project (GAP), one of the most important projects to develop the remarkable natural resources of the world, is accepted as a change for getting benefit from rich water and agricultural resources of the Southeastern Anatolia Region for Turkey and the region.

The climatic changes have been observed in the region after formation of artificial lakes and the process of watering. The terrestrial climate which has been resigned in the region has started to leave its plave to caused changes in the structure of rural tourism in the region. It is also created new types of flora and an environment for alternative tourism types.

Recent years, remarkable developments have been observed from respect of both eco-tourism and agro-tourism in the region. And, also an increase in the flow of tourists to the region also has been observed.

The main purpose of this study is to analyze the effects of climatic changes from devrestrial climate to soft are in the region. For this reason, in the first section, a brief introduction of the region and the GAP Project will be given.

In the second section, the climatic structure of the region will be examined. Also, both the climatic feature and touristic structure of the region before and after the GAP Project will be included in examination.

In the third section, the results of climatic changes and new tourism alternatives will be analyzed. Again, in this section, the existing tourism potential will be determined.

This study will present a series of policies and strategies for differential tourism and tourism development after the climatic changes in this region

Frequent Change in the Indian Monsoon Rainfall Intensity Over Past 30 ka and Its Impact on Vegetation: Evidence from Isotope Ratio of Soil Carbonate, Ganga Basin, India

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During the late Quaternary the global climate has oscillated between the glacial and interglacial condition. The Last Glacial Maxima (LGM), part of the late Quaternary period, was a time when the Earth entered into the ice age, and from LGM to Holocene the global climate has changed rapidly from full glacial to interglacial (warm climate) condition. There are records to show that the Indian summer monsoon also responded to this climatic change. But, the response of Indian monsoon in terms of hydrological budget is not clearly understood. In this study an attempt has been made to glean out the monsoonal changes during the LGM and Holocene epoch. For this purpose the oxygen and carbon isotopic ratio of Soil Carbonate (SC) associated with the late Quaternary pedogenic bed in the Ganga Basin, India are measured. The sampling of SC has been done from two core viz. Firozpur (age: >31.6 to 8 ka) and Bhognipur (age: ~32 to 8 ka) collected from the Ganga Basin. Petrography of the SC indicates little evidence of post-diagenetic alteration and thus implying retaining the pristine of isotopic ratio. Time variations of oxygen isotope ratio in composite plot show depleted phases around 22 and 10 ka indicating intensified Indian monsoon as increase in rainfall causes depletion in isotopic ratio of rain water. The intensified phase of monsoon at around 10 ka is well correlated with Holocene monsoon intensified phase recorded by other proxies. The most reduced monsoon phase is observed at ~18 ka which is contemporaneous with the LGM. The 18 ka low monsoon is synchronous with the ice cover advancement in the Himalaya suggesting link between snow cover in the Himalaya and monsoon.

The carbon isotope ratio of SC, which depend on the type of vegetation grew during soil formation, suggest mixed C3-C4 vegetation during last 30 ka in the Ganga Basin. The co-variation of carbon and oxygen isotope ratio of SC shows that during high monsoon abundance of C3 plants was higher. The monsoon-vegetation-atmospheric CO_2 relationship indicate increased the abundance of C4 plants during last 30 ka was driven by the decrease in monsoonal rainfall, and atmospheric CO_2 has negligible impact on abundance of C3-C4 plants.

Evidence for an Abrupt, Mid-1st Millennium AD Desiccation Event Recorded in Lacustrine Sediments From Central Western Turkey

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Marmara Gölü is a broad (~13 x ~5 km), shallow (~6 m max depth) lake situated in the north half of the Gediz River floodplain in central western Turkey. The lake has served as an important environmental resource, and hence a focus of cultural activity, in the region of Sardis since at least as early as the late 8th century BC when it is mentioned in Homer's Iliad as being the mother of the ancient Lydian people. Large fluctuations in lake level during recent historical times suggest the lake is very sensitive to changes in moisture balance (esp. drought) in the region. Fourteen sediment cores, arranged in two transects from shallower to deeper water, were retrieved from the western half of the lake in 2006. The sedimentary sequence records the development of a shallow lake over preexisting floodplain, followed by an abrupt desiccation event during which the entire basin apparently went dry, followed by a return to continuous lacustrine conditions till present day. The abrupt desiccation event is documented by a classic desiccation sequence—a high angle erosional surface, overlain by a unit composed of debris flows, incipient pedogenetic development, and a basal lag conglomerate of sedimentary interclasts from the preceding unit. Two preliminary AMS radiocarbon dates below the erosional unconformity suggest that the event probably occurred at some point after the first half of the 5^{th} century AD. Indications from the Sardis archaeological record suggest that the flow of water to public facilities such as baths and fountains became increasingly restricted during this period. Other proxy records suggest this desiccation event may have affected the larger, eastern Mediterranean region. In particular, the stable oxygen isotope record from Nar Gölü in central Turkey, another lacustrine record ~560 km to the east, registers the strongest desiccation event over the last 1700 years peaking around AD ~480. The Nar Gölü record has been linked via teleconnections to both the North Atlantic winter climate, and the Indian Monsoon during summers. Additional evidence showing the possible extent of this desiccation event comes from Soreq Cave (Israel) where are recent publication suggests a period of drying in the Levant region from AD 100-700 with strong fluctuations around AD 100, 400, and 500. Additional work to understand the timing, extent, and mechanism responsible for this desiccation event at Marmara Gölü is underway.

Abrupt Climate Change During the Last Glacial Period Recorded in Stalagmites from the European Alps

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Stalagmites from carefully selected cave sites in Austria and Switzerland are being studied using high-resolution stable isotopic and petrographic data, fluid-inclusion and U-Th techniques. These caves are located at the northern rim of the European Alps, which is characterized by a dominant advection of air masses from the N-Atlantic and their location thus supports the ambition to compare abrupt climate changes of the Last Glacial (D-O events) recorded in the Greenland ice, in sediments of the N-Atlantic, and in these stalagmites. Results show that the time interval between D-O events 25 and 18 is well represented in the stalagmites and typical 2-sigma dating uncertainties are in the range of 0.3 to 0.8 %, i.e. climate events during the first half of the Last Glacial cycle can be dated to within a few hundred years. Some growth phases of individual stalagmites overlap in time providing a test for internal reproducibility. The O isotope data show several distinct shifts of up to 4‰ during D-O transitions and mimic the variability seen in Greenland based on this common proxy. Several Greenland Interstadials are recorded and reflect the favourable climate conditions for speleothem growth during these relatively warm periods. Major Greenland Stadials (GS) are also represented (e.g., GS 22, GS 19, GS 18), demonstrating sustained water supply in the karst aquifer during these cold and presumably dry intervals. Moreover, remarkable details regarding the fine structure of the Greenland O isotope profiles are recorded in some of the samples (e.g. a distinct temporary warming during GS 22) due to the very high temporal resolution of the stalagmite isotope data (typically from near-annual to a few decades). These results emphasize the sensitivity of the Alpine region to abrupt climate changes during glacial periods

and also the common climate forcing of Greenland and the European Alps in a N-Atlantic context.

Cascading Effects and Systemic Impacts of Abrupt Climate Change: Assessing Ecological and Social Tipping Points

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The risks of abrupt climate change have been recognized for some years, but the issue has remained largely unexamined from an impact and risk assessment perspective. Translation of potential abrupt change to policy-relevant data must deal with uncertainties associated with “high-impact, unknown probability” events, including types of change, time horizons, and impact severity across global social, economic and political systems. Assessing the impacts of abrupt change scenarios requires robust knowledge of climate system feedback effects, such as accelerating Arctic methane releases, or albedo ‘flips’ from loss of ice cover. Similar knowledge is required of how such processes interact with not only ecological and social systems, but their inherent positive and negative feedbacks, as well. Concepts used to describe cascading effects often rely upon linear causality and imbedded assumptions concerning political responses, when recognition of complexity and underlying conditions may be more dependent upon non-linear threshold responses. This research presents a risk-vulnerability framework for assessing key systemic weaknesses and fragilities. Drawn in part from work on ecological resilience, disaster studies, risk sciences, and epidemiology, we posit that knowledge of complex systems is necessary to understand the crucial second and third-order effects of abrupt climate change. By conceptualizing related systems as scale-free, complex networks, uncertainties in risk assessment can be managed more effectively, and crucial climate-related tipping points become more easily identifiable.

Abrupt Change in Earth Climate

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Many aspects of Earth's climate system have changed abruptly in the past and are likely to change abruptly in the future. Although abrupt shifts in temperature are most dramatic in glacial climates, abrupt changes, resulting in an altered probability of drought, large floods, tropical storm landfall, and monsoon rainfall, are all important concerns even in the absence of significant anthropogenic climate forcing. Continued climate change will likely increase the probability of these types of abrupt change and also make abrupt changes in ocean circulation and sea level more likely. Although global warming may have already triggered abrupt change, current understanding and modeling capability is not sufficient to specify details of future abrupt climate change. Improved adaptation strategies are warranted, as well as efforts to avoid crossing climate change thresholds beyond which large abrupt changes in sea level, ocean circulation, and methane-clathrate release could greatly amplify the impacts of climate change.

The Widespread Abrupt Transition From the Holocene Thermal Maximum to the Neoglacial at ~5 kyr BP: What are the Drivers and the Mechanisms?

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Greenland and Antarctic ice cores point to rather stable polar temperatures during the Holocene. A completely different picture, however, comes from mid-latitude and tropical regions where multiple lines of evidence suggest that the current interglacial was not a globally stable climatic phase. The famous 5.2 kyr-old Tyrolean Iceman discovered in an ablating ice field in the Ötztaler Alps and the similarly old plants emerging intact from under the retreating Quelccaya Ice Cap in Peru are only part of the evidence pointing to a widespread and rapid climatic change. This transition includes the shift from a green to dry Sahara in Africa and the rapid advance of glaciers in the Andes and Alps and marks the end of the Holocene Thermal Maximum and the beginning of the Neoglacial period. This shift is thought to be associated with significant societal change at the time. For instance, hierarchical societies formed in the overpopulated Nile Valley and Mesopotamia while Neolithic settlements in the inner deserts of Arabia were abandoned. Marine sediments indicate that the transitions into and out of the so-called African Humid Period possibly occurred within decades, not millennia. While we understand how and why Africa was wetter during this period, we do not understand why the transitions were so abrupt. Interestingly, the drop in stable isotopes recorded in the Kilimanjaro ice core and Soreq Cave (Israel) speleothem, identify a short and extremely intense cooling at 5.2 kyr BP, rather than a rapid transition between two different climatic modes. All this adds to mounting evidence that Earth's climate seems to reach certain thresholds and then switches abruptly (within a human lifetime) also during the Holocene. Clearly, it is important to understand the drivers and the mechanisms of such abrupt changes during the current interglacial as a similar event today would strongly impact human population. Here, we discuss the possible drivers and mechanisms that operated during the abrupt Holocene Thermal Maximum to Neoglacial period transition at ~5 kyr BP.

Scolecodonts and Their Biostratigraphy in Ordovician and Silurian Rocks, Kopet Dagh, North Iran

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The Lower Palaeozoic Sequence is well exposed in Kuh-e-Saluk ,2 KM,north of GHELLI village.In ascending stratigraphic order this sequence has been devided into MILA(519 M),LASHKARAK(250 M),GHELLI(1140 M)AND NIUR (160 M) Formations.The age relationship of each rock unit,has been determinedbased on Acritarches,Chitinozoans and Scolecodont microfossils. Therefore 200 surfacesamples were selected from the Lashkarak,Ghelli and Niur Formations.A total of 31 species were encountered from the lower Palaeozoic rock units of studied area.The encountered Scolecodont species have been arranged in 3 ascending local stratigraphic zones.Zone 1-2 occures in the Ghelli formation,indicating the middle nad late Ordovician age.Zone 3 Cryptospores.But no attention was paied on occures in the Niur formation and suggest the early Silurian age (Llandovery) base on Acritarch biozones,among the encountered families of Scolecodonts,two families of Polychaetaspidae and Paulinitidae have more genera and species rather than other families. Moreover ,the Scolecodont genera and species of Silurian sediments (member 1 of Niur Fm.)have more diversity than Ordovician strata.(LASHKARAK AND GHELLI FORMATIONS).This is obviously related to cold condition in Ordovician and warm in the Silurian.

The encountered critical Scolecodonts species in this studu are:

Kettnerites fjaelensis , Kettnerites versabilis, Kettnerites microdentatus, Kettnerites sp.,, Polychaetaspis latus,, Polychaetaspis warkae, Polychaetaspis varsoviensis, Protarabellites staufferi, Kalloprion triangularis ,Mochtyella sp.,Xanioprion sp.,, Tetraprion sp,…

The above mentioned Scolecodont genera and species compared with those of contemporaneous strata from Sweden,Poland,Estonia,Italy and united states of america. This comparison reveals broad similarity with the above mentionedcountries.Therefore the Scolecodonts can be applied as a useful tool for biostratigraphy,paleoecology and paleogeography purposes.

Land Cover Change in the Barekese River Basin of Ghana From 1973-2006

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The Barekese Reservoir is a facility created to serve the purpose of reserving water for treatment and consequent consumption of the populace in the Kumasi conurbation and its environs. The reservoir which provides 80 percent of the total public water supply of the Kumasi locale is visage with persistent degradation through anthropogenic activities along its catchment area which also raises concern on the deteriorating water quality and quantity. The study examines the land cover change and assesses its impacts on the reservoir's water quality and quantity. It further projected the land cover in the catchment area from 2003-2043. Data employed in estimating land cover change were extracted from two cloud-free LANDSAT Multi-Spectral Scanner (MSS) and one LANDSAT Thematic Mapper (TM) images obtained in 1973, 1986 and 2003. All the three images were registered to the Universal Transverse Mercator (UTM), Zone 31 geographic projection. From 1973 to 1986 the closed forest decreased by 43.54% whereas the open forest increased by 52.91%. From 1986 to 2003, the open forest decreased extensively by 55.25% resulting in more grassland and open area/towns. The projections of the land cover change in Barekese catchment area reveal that vegetation cover will continue to experience a decline in area with a subsequent negative decline in closed forest in the year 2043 resulting in feedbacks in regional climate and weather. Conversely grassland and open area/towns will experience a swift rise in area from 2003-2043 impacting on water resources. Unsustainable agricultural practices, bushfires, deforestation and encroachment of the Barekese reserve as a result of rural poverty and weak institutional mechanisms are the factors responsible for the degraded land cover impacting on quality and quantity of water in the Barekese basin.

Long Term Seasonality Changes and Abrupt Climate Shifts Recorded in Highly Resolved Dust/Loess Sequences Across Euras

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The distribution of Eurasian loess deposits allows interregional palaeoclimatic investigations along a west-east transect across the entire Eurasian loess belt of the Northern Hemisphere, offering the potential to reconstruct Pleistocene atmospheric circulation patterns and aeolian dust dynamics on a wide spatial scale.

High resolution proxy data from several loess sequences across Eurasia (Serbia, Romania, Uzbekistan & Kazakhstan) provide a detailed signal of glacial-interglacial atmospheric dynamics and long term, semi-continuous trends in the aeolian dust record since marine isotope stage 10. In consideration of the modern synoptic atmospheric circulation patterns and aeolian dust transport across the Eurasian landmass, we propose that the data reflect oscillations superimposed on a long term signal of seasonality, triggered by changes in duration and permanency of the seasonal shift of the Eurasian polar front during the middle to late Pleistocene.

Unlike the similarities in long term seasonality changes across Eurasia, there are distinct differences in short-term climate variability along the studied transect from SE Europe to Central Asia. While the records in SE Europe seem to reflect short term climate oscillations controlled by regional climate dynamics and local wind systems, the highly resolved Central Asian dust archives suggest a clear pattern of rapid warming and
gradual cooling, likely to indicate a teleconnection with D/O events of the last glacial cycle.
This study utilizes new high quality data from highly resolved loess/dust records to reconstruct the timing and dynamics of past synoptic atmospheric circulation patterns across Eurasia, linking inter-hemispheric climates on time scales ranging from glacial-interglacial to (sub)millennial.

Statistical Detection of Mid-Holocene Abrupt Climate Changes From Proxy Records

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In many paleoclimate proxy records long-term climate trends through the Holocene, forced by gradually-varying orbital changes, appear to be punctuated by rapid transitions between about 6000 to 4000 calendar years ago. Previous syntheses of mid-Holocene proxy records have relied upon subjective methods of identifying these abrupt climate changes, a difficult task given the noise inherent to most Holocene records. To more objectively assess the evidence for abrupt climate change during the mid-Holocene, 292 previously-published proxy timeseries from 130 sites around the globe were analyzed statistically using established methods of changepoint detection. The records include all types of proxies (i.e., pollen, ice cores, lake sediments, marine sediments, loess, peat, speleothems). All records have a resolution of 150 years or better, well-defined age models, and clear proxy interpretations. The statistical analysis provides evidence for two abrupt changes centered at ~5.5 and ~4.1 cal ka with a broad, perhaps global, spatial distribution. The directions of climate change are regionally complex, but generally show a shift towards colder conditions around the North Atlantic, changes in mid-latitude continental aridity, a southward shift of the Intertropical Convergence Zone, and a northward shift of the Southern Hemisphere westerlies. The timing and direction of the abrupt changes suggest that minima in solar irradiance were an important trigger and that teleconnections between regions also played an important role.

High-Resolution Paleoclimate Records From Soreq Cave Speleothems: Sub-annual Resolution by Ion Microprobe

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Speleothems provide an important record of terrestrial paleoclimate over the last 500 ka. Isotopic data from calcite-dominated cave formations have been used as proxies to identify changes in annual rainfall (Orland et al., 2009, QR), monsoon strength, telecommunication of Northern Hemisphere climate aberrations, changes in vegetation cover, and other region-specific paleoclimate time-series over both short and long timescales.

As more research is devoted to understanding the trajectory of anthropogenic-induced warming, there is a need to develop high-temporal-resolution records from continental regions. In many cases, the high-resolution potential of speleothem records has yet to be fully realized. This study focuses on speleothems from the semi-arid Eastern Mediterranean region (Soreq Cave, Israel) where prior research shows that conventional drill-sampling methods permit a temporal resolution of ~10-50 years in speleothem paleoclimate records. The WiscSIMS lab at the University of Wisconsin-Madison has developed analytical techniques that yield a precision of ~0.3 ‰ (2 s.d.) in $\delta^{18}O$ from 10 micron-diameter spots, which corresponds to sub-annual-resolution measurements of stable isotopes in a speleothem. Coupled with imaging of annual growth bands by confocal laser fluorescent microscope (CLFM) in a 2200-year-old speleothem from Soreq Cave, Orland et al. (2009, QR) reports seasonal climate patterns and their variability through time.

Soreq Cave is located in the Judean Hills west of Jerusalem, a highly populated region where understanding both the past and future water budget is of great interest. As reported by Bar-Matthews et al. (2003, GCA), Soreq cave speleothems record over 185 ka of regional climate history. Soreq stalactite sample 2N grew from ~24-1.0 ka and preserves a time-series of oxygen isotope data across multiple rapid global climate change events, including the onset/termination of the Younger Dryas, the last glacial termination, abnormal variability near 8.2 ka, as well as multiple abrupt regional events. Ion microprobe analysis of $\delta^{18}O$ from >500 spots (most at sub-annual resolution) across a radial traverse of sample 2N also identifies apparent changes in the seasonal character of the record during and after the last glacial period at ~20 ka. CLFM imaging across the sample reveals changes in growth-banding characteristics that may give further insight into the varying character of seasonal climate in the region since ~20 ka. Further U-series dating by laser-ablation ICP-MS and oxygen isotope analysis by ion microprobe will enhance our understanding of the timing and magnitude of climatic events in the Eastern Mediterranean and their relation to globally-observed changes.

GIS Mapping: Soil Carbon Estimates & Lowering of Permafrost Table as a Result of Abrupt Climate Change

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A computer-based map is considered to be an important base material for comprehensive carbon budget studies under the international EU-funded CARBO-North project. The project is aimed at assessing the carbon balance at northern latitudes. The large-scale detailed soil maps were produced for the intensive study sites using QuickBird 61 cm panchromatic and 2.4 m multispectral resolution satellite images, database containing morphological descriptions and analytical data of more 200 soil profiles, total of 70 long-term permafrost monitoring sites and meteorological records. Under this study, detailed maps for the intensive sites located in taiga, forest-tundra and tundra were produced. Produced soil maps are based on the WRB (2006). GIS-based data sets were used to analyze the active layer dynamics and permafrost conditions. GIS-analyses indicate that about 60% of all infrastructure is located in the “high risk” permafrost area, here defined as the zones of isolated to discontinuous permafrost (3–90% coverage) with “warm” ground temperatures (0 to -2°C). Most of the permafrost-affected terrain will likely start to thaw within a few decades to a century. CALM sites (Circumpolar Active Layer Monitoring) located in the region revealed almost continuous increase of thaw depths and lowering of permafrost table on 23 cm during 13 years of monitoring. This forecast poses serious challenges to permafrost engineering and calls for long-term investments in adequate infrastructure that will pay back over time.

This database has been used to assess the reserves of organic carbon in different soils and within the entire basin. Spatial gradients in the distribution of soil carbon reserves have been analyzed using GIS technologies within each natural zone (tundra, forest-tundra & taiga) and intensive sites in particular.

Demise of Indus Valley Civilizations Linked to the Decline of Indian Ocean Monsoon

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The Indus Valley Harappan and Mohenjo-Daro civilizations, one of the past four great civilizations, were at their peak about 2600 to 2500 BC, when most of the agricultural expansion occurred. These civilizations began to decline at around 2000 to 1900 BC and completely abandoned their settlements between 1600 and 1400 BC. Archaeologists generally attribute the demise/abandonment of the Harappan and Mohenjo-Daro settlements to changes in the course of the Indus river, the former dried out Ghaggar-Hakra river. The link between the climate change or more precisely changes in the strength of the Indian Ocean Monsoon (IOM) and the disappearance of the Indus Valley Civilizations has rarely been explored, or the role of the IOM has been viewed as secondary. Here we reconstruct the strength of the IOM by paired $\delta^{18}O$ and Mg/Ca measurements in the planktonic foraminifera Globigerinoides ruber (white) from the sediments of the Bay of Bengal and Andaman Sea during the last 25,000 yrs BP. This data indicates a dramatic weakening of IOM at ~2500-2000 BC that coincides with the demise of the African Humid Period and a decline in the Arabian Sea productivity. These independent records suggest that the African and Indo-Asian monsoon experienced coherent rapid hydrological changes during the last glaciation and Holocene periods, including a strong decrease in the IOM strength at ~4.5 ka BP. We propose that these dramatic changes in IOM decreased the amount of rainfall over the Indian subcontinent region and may have forced the Indus Valley Civilizations to abandon their settlements.

The 1500-Year Variability During the Holocene: Amplitude and Phase Relationships

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We analyze six widely distributed North Atlantic paleoclimate data sets to examine the phase and amplitude relationships among them, focusing on the 1,500 quasi-periodic (Bond) variations. Taking into account the nonlinear and non-stationary character of this variability we apply the adaptive Empirical Mode Decomposition (EMD) method and a wavelet decomposition to the data to display the Holocene evolution of the period and phase of this variability. Comparing the evolution of the 1500-year mode with changes in other paleo proxies greatly assists in uncovering the relation of this variability to solar and ocean forcing. For example, we find that the SST variations off West Africa and at Cariaco are opposite in phase resulting in a strong 1,500 year periodicity in the cross-Atlantic temperature gradient. Such a gradient may have influenced monsoons and hence the climate in the region.

On Causes and Mechanisms of the 1500-Year Climate Cycles

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The existence of a (roughly) 1500-year climate cycle of abrupt warming and cooling, first noted in Greenland ice cores by Dansgaard and Oeschger, is well established from a multitude of geological data [Singer and Avery. Unstoppable Global Warming: Every 1500 Years. Rowman & Littlefield Publ. 2007]. The cycle appears to extend into the Holocene and can account for the Medieval Warm Period (MWP) and Little Ice Age (LIA) [Loehle and Singer 2009]. Its synchronicity seems to be preserved. Early on, Bond [2001] suggested a solar cause; but we do not know of any solar phenomenon with such a period. Nor do we know the mechanism by which the Sun could cause such abrupt climate changes. In view of the fairly precise timing of the cycle, we speculate that purely internal oscillations of the ocean-atmosphere system are unlikely to be the main cause. We also note that the amplitude of D-O events was much larger during the period of glaciation than during the current warm period of the Holocene. We therefore favor an internal oscillation triggered by a solar mechanism. This would also account for the occurrence of missing cycles. As to the actual mechanism, we favor changes in solar activity modulating the energy spectrum of Galactic Cosmic Rays [Singer 1958] and thereby the flux of GCR impinging on the Earth's atmosphere. The most reasonable way this could affect the climate is by changes in cloudiness [Svensmark 2007]. The large amplitude of the D-O events suggests a positive feedback, perhaps a greenhouse effect, ultimately limited by a negative feedback inherent in the atmosphere-ocean system. Although many puzzles still remain, the observations suggest that large-amplitude abrupt changes become less likely in a warmer climate [NRC 2002].

Dry-spells in the Levant During the Last Deglaciation Identified by Dead Sea Lake Levels

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Abrupt arid events in the post-glacial (~17.4-10 ka cal BP) Dead Sea Basin (DSB) were recorded by significant level declines in Lake Lisan and massive deposition of gypsum and salt. Between 17.4 and 16 ka cal BP, the lake dropped from its late MIS2 stand of ~ 260 m below mean sea level (m bmsl) to ~330 m bmsl, depositing a thick sequence of gypsum. At the 15th millennium BP the lake recovered, but dropped abruptly again during the 14th millennium BP to below 465 m bmsl, probably the lowest late Pleistocene stand. Then, between 13-11 ka cal BP (the Younger Dryas time interval) the lake rose above 400 m bmsl and declined again during the 11th millennium BP depositing a thick sequence of salt. The abrupt lake drops and salt deposition coincided with times of ice and melt-water discharges into the north Atlantic: Heinrich event 1 and Melt Water Pulses (e.g., MWP1a,b). Similar coincidence between ice and meltwater discharges in the north Atlantic (e.g., H-events) and arid episodes at the Levant were recorded during the colder last glacial period, calling for a persistent effect of the north Atlantic hydrology and sea ice advances on the Levant climate. The "turmoil" post–glacial period and the transition to the milder Holocene were accompanied by significant developments in human culture: the collapse of the Natufian culture during the BØlling-AllerØd (B/A) and the rise of the Pre-Pottery Neolithic cultures, PPNA and B around the 11-10 ka BP salt deposition interval marking the beginning of the "Neolithic-revolution" in the region.

Rapid Amazonian Moisture Changes During the Last Glacial Period

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Terrestrial paleoclimate records on abrupt climate events from the tropics are still rare, in particular, from Amazonia, which contains the largest tropical rainforest in the world. We have obtained a high-resolution oxygen isotopic record of cave calcite from Caverna Paraíso, Amazonia, Brazil. The chronology was determined by 110 U-Th ages from 7 stalagmites. Tests for equilibrium conditions show that their oxygen isotopic variations are primarily caused by climate change. We thus interpret the Paraíso record, spanning the last 60 thousand years, in terms of meteoric precipitation changes at this equatorial location. The oxygen isotopic profile shows significant abrupt millennial-scale variations during Marine Isotope Stage (MIS) 3, with amplitudes as large as 2 per mil. Using independent age scales, we compare the record to contemporaneous records from caves in eastern China and high-latitude ice cores. During MIS 3, the Paraíso calcite oxygen isotopic profile anti-correlates remarkably with the Hulu Cave record (Wang Y.J. et al., 2001), indicating that precipitation histories at the two sites are asynchronous, similar to our previous observations from northeastern and southern Brazil speleothems (Wang X.F., 2004, 2007). During MIS 3, Paraíso precipitation also broadly anti-correlates with Greenland D-O events (NGRIP Members, 2004) and positively correlates with Antarctic warm events (EPICA Members, 2006). Our record adds further support to the idea that abrupt climate events have a worldwide distribution during MIS 3. The observed correlations between the records support an oceanic meridional overturning circulation mechanism for driving the abrupt millennial-scale events of the last glacial period, coupled with strong air-sea feedbacks from the tropics. In combination with Andean ice core and lake records, knowledge of the meteoric precipitation oxygen isotope and moisture history of the central Amazon may shed new light on the role of the tropics in abrupt climate change.

Major Changes in the Rate of Volcanic Activity Cause Rapid Warming and Slow Cooling Predominantly in the Northern Hemisphere

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Concentrations of volcanic sulfate in the GISP2 borehole peak during times of sudden warming, are at moderate levels during times of gradual cooling, and are non-existent during times of major cooling and drought associated with the demise of many human civilizations. Large amounts of sulfur dioxide, erupted from volcanoes every few months to every year, appear to use up the oxidizing capacity of the atmosphere causing greenhouse gases to accumulate, resulting in rapid warming. Large amounts of sulfur dioxide erupted from volcanoes less frequently form sulfuric acid aerosols in the lower stratosphere that reflect sunlight, causing cooling for a few years. A sequence of such eruptions every few years to decades cools the ocean gradually, assisting Milankovitch cycles in moving the earth into ice ages. Such eruptions in historic times occur only once per century, neither cooling nor warming the earth substantially. When no large eruptions occur for decades, the oxidizing capacity of the atmosphere can increase, scrubbing the atmosphere of pollutants from the top down.

Sulfur dioxide only lasts in the atmosphere, under normal conditions, for a few weeks, limiting dispersal. More than 81% of the volcanoes of the world lie north of 10^{o}S. The Hadley Cells and other features of atmospheric circulation limit dispersal between the northern and southern hemispheres. As a result, the sulfate signal in Antarctica is less complete and the warming is less intense.

Sulfate concentrations in GISP2 became as high between 1930 and 1980 as they had been during the Bolling and Preboreal warmings. Volcanic activity had not increased, but known anthropogenic sulfur emissions did. The mechanism for warming caused by man burning fossil fuels during the 20th century appears to be similar to that caused by volcanoes during earlier warmings. Between 1980 and 2000, man decreased sulfur emissions 18% in an effort to reduce acid rain. The rapid increase in global temperature leveled off by 2000 as the oxidizing capacity of the atmosphere recovered.

The rate of volcanic activity appears to influence major ocean currents, but the details of this relationship are not yet clear. See www.tetontectonics.org/Climate.html for the published paper and related information.

Abrupt Climate Change and Ecosystem Response: A 2,000 Year History of Severe Droughts, Extreme Temperatures, and Stand-Replacing Fires in the Sierra Nevada in Response to Abrupt Climate Change

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Climate change is increasingly seen as a serious threat to modern environments and yet little is known about the environmental effects of abrupt climate change during the Holocene. I investigated the environmental effects of abrupt climate change at Coburn Lake, California over the past 2,000 years to test the hypothesis that Coburn Lake charcoal peaks represent stand-replacing fires that occurred within the Coburn Lake watershed in response to abrupt climate change. I compared the timing of Coburn Lake charcoal peaks with both the timing of the onset of droughts and the presence of temperature extremes in the Sierra Nevada. Charcoal peaks, with associated proxies for erosion, occurred at the beginning of all ten droughts in the northern Sierra Nevada, and only then, over the past 1,900 years. The environmental stress caused by the onset of severe droughts was made all the more severe due to severe temperatures, or abrupt shifts in temperatures, at the beginning of most droughts in the Sierra Nevada over the last 1,900 years. These results suggest an "abrupt climate change-severe fire hypothesis," that implies that abrupt climate change during the late Holocene caused vegetation and mountain slopes around Coburn Lake, and perhaps more widely, to be seriously out of balance with changing climates; resulting in forest die-off, stand-replacing fires, and severe soil erosion. Taken together, this study provides a rare detailed history of abrupt climate and environmental change in the Sierra Nevada over the past 2,000 years.

Recent Atmospheric Temperature Change Observed from the Microwave Sounding Unit

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Based on the satellite retrieved temperatures from the Microwave Sounding Unit (MSU) provided by National Environmental Satellite, Data, and Information Service (NESDIS), the multiple time scales from intraseasonal to interdecadal variability in the atmospheric temperature will be investigated. The MSU temperature datasets between 1979 and 2006 is available and was created from channels 2, 3 and 4 brightness temperature measurements from the TIROS-N, NOAA-10, 11, 12, and 14 satellites, which represents respectively the stratospheric, tropopause and mid-tropospheric temperature. Solar radiation forcing and the other possible forcings that may be responsible for the observed temperature variations will be discussed.

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