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A Theory of Global Climate Change on Millennial Time Scales

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Principal Investigator: Maasch, Kirk A.

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Organization: University of Maine

Title:

A Theory of Global Climate Change on Millennial Time Scales

Project Participants

Senior Personnel

Name: Maasch, Kirk

Worked for more than 160 Hours: Yes

Contribution to Project:

Name: Saltzman, Barry

Worked for more than 160 Hours: No

Contribution to Project:

Helped advise the thesis project of Heather Franco. Contributed intellectually to all aspects of the project.

Name: Sandweiss, Daniel

Worked for more than 160 Hours: Yes

Contribution to Project:

Collaborator on aspect of this project connected to Holocene climate change on millennial time scales and their connection to the time-dependent evolution of ENSO cycles.

Post-doc

Graduate Student

Name: Franco, Heather

Worked for more than 160 Hours: Yes

Contribution to Project:

As a graduate student funded with this grant Heather helped develop the low order model for ice sheets as the primary thrust of her MS thesis.

Undergraduate Student

Research Experience for Undergraduates

Organizational Partners

Other Collaborators or Contacts

Activities and Findings

Project Activities and Findings:

Millennial oscillations of Earth's climate that have occurred over the last glacial-interglacial cycle were investigated with the aim of trying to understand their cause. The large, rapid shifts that characterized the last glacial on time scales roughly 1-3 kyr and 6-16 kyr were modeled using a time-dependent, low order dynamical systems approach. Climate cycles with a period of 1-3 thousand years (kyr) are typified by temperature and hydrologic variations and are known worldwide. The amplitude of these oscillations vary. During glacial times, every 6-16 kyr immense volumes of icebergs were discharged from the northern hemisphere ice sheets into the North Atlantic ocean. These episodes of ice rafting, often

called Heinrich events, correspond with relatively warm intervals within the 1-3 kyr period oscillations. The reasons for this relationship as well as their causes are uncertain, yet important because of the connections between the sea-ice/ocean and ice sheet systems. Physical interactions are through ice accumulation rates, which depend on regional temperature, and the vigor of ocean circulation, which is effected by melting icebergs. Previous modeling studies have shown that both systems can oscillate solely through self contained internal dynamics, but also depend on external processes. The sensitivity of each individual system to perturbations of different time scales is of interest.

The lower amplitude 1-3 kyr climate cycle observed in Holocene records of climate change were studied empirically in some detail using proxy data from the Pacific basin that relate to the time-dependent evolution ENSO cycles. More specifically, mollusk assemblages from coastal Peru were used to reconstruct climate conditions, which were then linked by inferred teleconnection patterns to possible global climate change. Many independent lines of evidence indicate that El Niño was absent or significantly different between 8.8 and 5.8 (ka=calendar years BP). In northern Peru mollusk assemblages from archaeological sites are indicative of the presence of stable warm-tropical water as far south as 10°S during this time, suggesting that El Niño did not function for these millennia when global and regional climate was slightly warmer than today. Mollusk assemblages from more recent archaeological sites on the north and central coasts of Peru indicate that between around 5.8 and 3.2±0.8 ka, El Niño events were less frequent than today, with modern, rapid recurrence intervals achieved only after that time. This shift correlates with climate records throughout the Pacific basin indicating that fully modern conditions were not achieved until about that time. These changes had apparent cultural consequences: the onset of El Niño at 5.8 ka is temporally correlated with the beginning of monumental construction on the Peruvian coast, while the increase in ENSO frequency after 3.2±0.8 ka is correlated with the abandonment of monumental temples in the same region. Thus, it appears that longer term, millennial climate oscillations are in some way connected to interannual-to-decadal scale climate change.

On a longer than 1-3 kyr time scale, possibly related climate oscillations (Heinrich events) observed in the geologic record during the last glacial period were also investigated using a previously developed low order thermo-mechanical ice sheet model. The nature of these ice rafting events was explored by performing a sensitivity analysis of this low-order ice sheet model, which produces surges that are due to internal physics. The climate variables simulated by this model are average glacial height, basal water amount, and surge rate. The accumulation rate was varied from 70-400 m/ky and the range of initial height used is 850-3000 m. These two quantities change on time periods longer than the time between ice rafting events and accumulation rate is also correlated with the shorter Dansgaard/Oeschger cycles. These are the most aspects of this system to study as they impact both the surface and basal conditions of an ice sheet.

This grant supported one M.S. student in the Institute for Quaternary Studies at the University of Maine. Her thesis, A Low-Order Model Investigation of Millennial Scale Climate Change: An Initial Approach, was completed in May 1999. This work led to two AGU abstracts. Two papers on these aspects of the problem are in preparation: The role of the sea-ice/ocean system in millennial climate change, and Effects of climate change on a low-order surging ice-sheet model. With regard to lower amplitude millennial scale climate changes in the Holocene work supported in part by this grant primarily centered on the evolution of the ENSO cycle over the last 8000 years. This aspect of the research led to three AGU abstracts.

Project Training and Development:

For the 1-3 kyr cycles, commonly referred to as Dansgaard/Oeschger cycles in the last glacial, it was found that an instability driven auto-oscillation could explain the near-synchronous climate changes that have been observed on a global scale. This instability involves the sea-ice/ocean system, and includes energy balance variability due to changes in both incoming and outgoing radiation. It was also found that plausible changes in the strength of thermohaline circulation and the efficiency of the greenhouse effect over the last glacial-interglacial cycle lead to a bifurcation of the system from a high amplitude auto-oscillatory state to a low amplitude damped oscillation of about the same period. This is quite consistent with observations from the geologic record.

It was found that this range of accumulation rates yields a temporal spacing for Heinrich events ranging from 13.5 to 6 kyr, and that changes in glacier height has a large impact on the volume of ice discharged. Longer periods between ice rafting occurs with larger ice sheets (up to 25 kyr). The main finding was that variations in ice accumulation and ice sheet height, which have both longer and shorter periodicities than the observed 6-16 kyr, reproduce the time range observed in the marine record of ice rafting.

These two existing, auto-oscillatory low order models, one of which simulates an ice sheet and the other the sea-ice/ocean system were then coupled to study their physical links. Such low order models incorporate only the most essential components of a system to aid in the understanding of primary processes. First, an asynchronous coupling was achieved through an empirical relationship between temperature and accumulation rate. Temperature at sea level was obtained from the sea-ice/ocean model and these values were extrapolated to the elevation of the ice sheet using a constant lapse rate. Accumulation rates were then approximated. The next coupling is in the opposite direction where the ice sheet model predicts rafted ice volume. The primary outcome is the removal of latent heat needed to melt the icebergs from the surface ocean temperature component of the sea-ice/ocean model. Other time dependent variations in accumulation rate were also used to learn the possible effects that longer time scales of change have on an ice sheet.

The coupling from the ice sheet model to the sea-ice/ocean model did not yield results with a physical analog and thus this simplified,

preliminary attempt at coupling the models did not provide significant results. The time between ice rafting events was replicated successfully, but the ice sheet model is more sensitive to accumulation rate oscillations that are less frequent than the ice rafting events. Future work must modify the models so that ocean circulation is represented more realistically and sea level change leading to marine instabilities is incorporated for ice sheets of a critical size before a more realistic coupling is possible.

Research Training:

Heather Franco, who was supported by this grant as a graduate student, was provided with formal instruction on teaching in a classroom setting. Also, she was encouraged to, and followed through with submitting abstracts to national meetings (AGU), and presenting at these meetings. In addition, she was aided in the preparation and submission of her own research grants which led to the successful award of an EPA fellowship which she used to support herself in the last year of the MS program here at the University of Maine.

Outreach Activities:

The models that were developed in this project have been used as outreach to local high schools. The dynamical systems approach to climate modeling implemented on Apple computers with Stella software was used hands-on by students at Bangor High School and East Corinth High School, following presentations given by the PI at those schools.

Journal Publications

Sandweiss, D.H., J.B. Richardson, III, E.J. Reitz, H.B. Rollins, and K.A. Maasch, "Geoarchaeological evidence from Peru for a 5,000 BP onset of El Niño", *Science*, p. 1531, vol. 273, (1996). Published

Sandweiss, K.A. Maasch, J.B. Richardson, III, E.J. Reitz, and H.B. Rollins, "Determining the beginning of El Niño: Response", *Science*, p. 966, vol. 276, (1997). Published

Sandweiss, D.H., K.A. Maasch, and D.G. Anderson, "Transitions in the Mid-Holocene", *Science*, p. 499, vol. 283, (1999). Published

Sandweiss, D.H., K.A. Maasch, R.L. Burger, J.B. Richardson, III, H.B. Rollins, and, A. Clement, "Variation in Holocene El Niño frequencies: Climate records and cultural consequences in ancient Peru", *Geology*, p. 603, vol. 29, (2001). Published

Books or Other One-time Publications

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