A Jackson School of Geosciences Initiative in Climate and Environmental Change Science

Global to Regional Climate and Environmental Change: Paleoclimate Records and Modeling of Abrupt Climate Transitions, Teleconnections, and Impacts on Texas

Introduction

Climate change and its many consequences will play an ever more prominent role in scientific research and human affairs, whether triggered by purely natural or anthropogenically modified mechanisms. Climate models attempt to predict how climate will change in the future. However, existing models do not typically consider impacts on geographic scales representative of the local climate regimes of Texas and its surrounding states. For Texas, the critical parameter in future climate change most likely will be its influence on water resources. The impact of El Niño-Southern Oscillation (ENSO) events on Texas rainfall is an example of how global-scale climate change and teleconnections affect us. Another shortcoming of climate models is that climate change may not be the gradual process often assumed in future climate scenarios. Paleoclimate evidence shows that changes can be quite abrupt and opposite in direction to preceeding trends. We need to learn more about abrupt changes in paleoclimate records and their regional consequences in order to better assess the impact of any future abrupt changes.

We propose a comprehensive research and education plan to make UT-Austin a leader in this field and a critical resource for a wide range of academic and government agencies. A Jackson School of Geosciences (JSG) initiative in climate change would emphasize several synergistic components. These include 1) generating paleoclimate records for climatically sensitive areas of the globe such as the tropical oceans, Greenland, and Texas, 2) application of climate models to understanding the mechanisms of abrupt climate change and the global to regional teleconnections of the climate system, and 3) investigating climate and environmental change impacts at global-to-regional scales with particular emphasis on Texas and surrounding regions. These themes are of broad national and international interest and developing this plan would benefit the JSG in a number of ways, as discussed below.

Three Main Themes for the Climate Change Initiative

Climate change research is inherently multi-disciplinary. Each of the three JSG units has its own unique strengths in climate-related science. These include generating paleoclimate records, climate modeling, downscaling climate models to regions such as Texas, and in many aspects of climate change impacts including water resources. We are linked through the Environmental Science Institute (ESI) to numerous UT groups that are involved in a vast range of environmental and global change issues. In addition to these groups, a climate change initiative would link us with other Texas universities and both federal and state agencies involved in global change research and impacts.

We would emphasize three main inter-related themes in our climate initiative that embody our unique interests and strengths in climate as a coupled system that includes interactions

between the atmosphere, ocean, ice sheets, land surface, subsurface hydrology, and other subsystems.

1. Connections between regional and global scales.

The Intergovernmental Panel on Climate Change (2001) and the US Climate Change Science Program (2002) have recognized the critical need for enhanced capability to predict regional climate changes. Texas is in a unique position to address how global change research is tied to regional scale predictability. Examples of issues that regional predictions would address include energy resources and demands, droughts, floods, hurricanes, ground water availability, land cover change, soil erosion, biodiversity, and air quality. Regional climate system modeling tools, once developed, will provide a capability for regional predictions/applications.

We propose to embed a regional climate model of Texas and surrounding areas into global-scale climate models. We will first attempt to reconstruct the past 100 years of Texas climate as well as provide high-resolution predictions of Texas's future climate given projected increases in atmospheric CO_2 concentrations. We are particularly interested in evaluating how changes in global climate may affect the spatial and temporal dependence of aquifer recharge in central Texas. This research will be combined with a longer-term paleoclimate perspective through the use of local climate proxies (detailed below) that provide a direct means for estimating how moisture availability at the subsurface has been affected by global climate events in the past.

2. Abrupt Climate Transitions

The observation of global scale, abrupt climate transitions in paleoclimate records is one of the most important discoveries of climate science. They exemplify an inherently interesting property of complex dynamical systems, and yet remain unexplained. Although there have not been any large abrupt climate transitions in recent history, there exists a realistic expectation that such events would be more likely in the not-too-distant future as the climate system is forced out of its current balance by greenhouse gas emissions (NRC, 2002). Difficulty in understanding the processes involved in abrupt climate transitions is compounded by the fact that climate models fail miserably in reproducing the amplitude and global extent of transitions that have been observed in the paleoclimate record.

The JSG climate program is uniquely suited to address fundamental questions concerning: 1) What is the role of the tropical Pacific in global climate transition events in the past? 2) What is the role of the Greenland ice sheet in past and future changes in global ocean circulation? 3) What are the mechanisms and thresholds that cause abrupt transitions on both global and regional scales? Our research plan involves using the best available instrumental data that exist for examining important processes within a modern context and then using geologic records to examine these same processes within a paleoclimate and, hopefully, a non-stable context. We also plan to use stochastic inversion techniques (already under development at the Institute for Geophysics) to help us make connections between the models, data, and theory and identify where key thresholds exist.

Role of the Tropical Pacific. JSG scientists are leaders in extracting precise paleoclimate records from tropical speleothems and from living and fossil corals. These records are ideal for establishing tropical ocean climate history, particularly that of the Western Pacific Warm Pool (WPWP). Yet, such records are few despite growing recognition of the WPWP as a critical component of the modern global climate system. Corals provide ~200 yr-long subannually resolved climate records for any time and place where well preserved specimens can be acquired, including the Gulf of Mexico. Some cave speleothems have records resolvable down to one year, but most of them provide much longer overviews of climate change on the 10^3 to 10^5 yr scale. In combination, speleothems and corals allow us to document and compare tropical maritime climate history in a given area on both short and long time scales. Climate modelers in the JSG would examine relationships between tropical ocean climate variability and extratropical regions such as Texas, consider climate forcing mechanisms, and investigate the physical basis for teleconnections between tropical oceans and the rest of the world. We already have submitted proposals to produce climate records from the tropical Pacific and from Texas, but this effort could be accelerated to place the JSG at the forefront in tropical ocean paleoclimate studies and extratropical teleconnections.

Role of the Greenland ice sheet. Abrupt climate changes were defined first in annually layered Greenland ice cores and subsequently recognized in other climate records. It is commonly believed that abrupt climate transitions observed in the Greenland ice cores are related to major reorganizations of the meridional overturning circulation (MOC) within the Atlantic (although we still do not know how these changes explain the extent of what is observed globally). Many models predict that the MOC will weaken in the future due to an increase in atmospheric moisture convergence to the higher northern latitudes. Models also indicate that a decrease of the MOC strength reduces the circulation's stability and thereby increases the chance it could collapse completely. An open question is what may be the role, especially the timing, of the melting Greenland ice sheet to the high latitude freshwater balance. The JSG is in a unique position to collect observations of the internal layers of Greenland ice using aerogeophysical surveys, something that is currently being done in Antarctica. The structure of these internal layers is indicative of ice sheet behavior and climate forcing through time. These observations would provide perhaps the best perspective on the history of Greenland ice sheet dynamics and the potential for the ice sheet to undergo sudden changes to its mass balance and supply of freshwater to the North Atlantic.

3. Impacts of Climate Change

Our research initiative and the insights it provides will impact our understanding of a wide range of factors affecting people in Texas and elsewhere. These include energy demands, population growth, surface and ground water availability, land use and land cover change, biodiversity, climate change and air quality, droughts and floods, and sea level rise. Recent global-scale studies by UT-Austin scientists strongly suggest that a significant impact of global climate change in the 20th century is already discernible in animal and plant populations. The combination of rapid temperature rise and other stresses, such as habitat destruction, could easily disrupt species connections and lead to changes in communities, and to numerous possible extinctions (Root et al., 2003; Parmesan and Yohe, 2003). What will be the impact of climate change on Texas ecosystems? What will be the impact on Texas' water resources? The first step

in answering these questions is to determine how climate may change, how a given change will affect different parts of the Texas region, and then to evaluate how ecosystems, streams and aquifers will respond to such changes.

Several steps are needed to address the potential impacts of climate change on the Texas region. These include:

1. State-of-the-art regional climate system models focusing on Texas, the Gulf of Mexico and surrounding areas must be developed and tested.
2. We will construct high-resolution records of climate change in Texas. Dendrochronology, speleothems, Gulf of Mexico corals, travertine spring deposits, cave sediments and fossil records can be integrated to provide a range of spatial and temporal scales of local responses to the climate system.
3. A remote sensing and global change researcher is part of the DGS faculty hiring plan. It would be advantageous to develop strengths in areas of new technology, such as detecting global drought by satellite imagery. This is a new remote sensing method for detecting droughts early, and to estimate drought potential conditions prior to drought onset, that is based on the use of vegetation health indices (Kogan, 2002). Researchers that made use of these and other methods, such as LIDAR, would be able to provide important data for testing and validating the new climate models to be developed above and for the sensitive detection of climate change impacts.
4. We will organize, plan, and establish a comprehensive environmental monitoring network for Texas by bringing together the efforts of different state and federal agencies that are carrying out different monitoring functions. This would complement a hydrologic observatory if plans to establish one in Texas are carried out via the proposed JSG Water Initiative.

Initial Program

We envision a program that would build over a period of five to ten years. Significant initial progress towards these research priorities can be achieved within the first three years, with the support of approximately six new students and five research-associate level personnel. These human resources include 1) a full-time software engineer and a mesoscale climate modeler to develop a regional climate model of Texas that could incorporate a series of modules for surface and groundwater hydrology, dynamic vegetation, atmospheric chemistry, coastal ocean, etc. 2) specialists in carbonates (for coral and speleothem studies) and in dendrochronology for developing proxy records of past tropical Pacific and Texas' climates, and 3) a glaciologist who would help create a comprehensive model of ice sheet dynamics. We place particular importance on the support of six new graduate students to solidify the young climate program as an essentially academic endeavor capable of producing researchers with the best that the Jackson School has to offer.

The initial program focuses on building or enhancing our capabilities to conduct the proposed studies and generating the records that become the subject of scientific inquiry. Limited funds are also requested to support the collection and analysis of coral, speleothem, and tree specimens from the tropical Pacific and Texas. The model development work can be accomplished largely by the resources that exist within the Jackson School which now include 54-processors of a 576-processor super-computer being built at the Texas Advanced Computing

Center in the spring of 2003. However, after the initial first three years, significant funding would need to be dedicated toward an enhanced computing facility.

Benefits of the proposed initiative to the Jackson School of Geosciences

Developing this proposed initiative would provide numerous potential benefits to the JSG, including the following:

1. Climate and environmental change are of wide and growing interest in the academic, industrial and government sectors, and funding opportunities should continue to grow. Establishing a premier center for climate change studies will enhance JSG's competitiveness in attracting top graduate students and funding targeted at interdisciplinary graduate student training (e.g., NSF's IGERT program), and provide numerous opportunities for public outreach.
2. This initiative will develop and integrate growing programs in all three JSG units, including UTIG's Climate Group, DGS' new research direction, and BEG's CO_2 sequestration program and LIDAR.
3. Without such an initiative, the JSG will not be a candidate for significant funding opportunities such as the industry and foundation support recently given to similar programs at Stanford ($175M), Princeton ($15M), and Caltech ($600M).
4. Climate change will have a fundamental control on the future of Texas' water resources, yet very little is understood regarding how our regional climate will respond to global climate change. This initiative can thus provide critical information to a number of stakeholders that do not have the climate science expertise needed to inform their decision-making. These stakeholders include TCEQ, TWDB, LCRA, EAA, EPA, and the Texas Department of Agriculture. This research will also have many synergies with the proposed JSG Water Initiative, UT-Austin's chemical engineering program in Texas air quality monitoring and modeling, CSR, TACC, ESI, and Texas A&M's oceanography and meteorology program.

Summary

Global change and particularly climate change and its impacts are a growing topic of scientific research and societal concern. The JSG is well positioned to make important contributions to this realm of scientific investigation for the sake both of the State of Texas and humankind. Through a coordinated effort to accelerate development of some aspects of our climate change and impacts program, and to develop new complementary research directions, we have an opportunity to become a world-class climate change research center. Development of global-to-regional climate modeling tools, generation of paleoclimate records, investigation of abrupt climate transitions and impacts as well as other aspects of our program would also provide a framework for training graduate students and post-docs and for bringing scientific results into undergraduate classroom teaching. A strong climate change initiative in the JSG will link faculty members, scientists and students from a wide range of units including the Center for Space Research, Biological Sciences, Geography, the ESI, and a broad array of UT and non-UT organizations.

List of Participants

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