Climate, Water, and Carbon Program

A PROPOSAL IN RESPONSE TO THE PROVOST'S CALL FOR TARGETED INVESTMENTS

From

THE COLLEGES OF MATHEMATICAL & PHYSICAL SCIENCES, FOOD, AGRICULTURAL, & ENVIRONMENTAL SCIENCES, AND SOCIAL & BEHAVIORAL SCIENCES; THE BYRD POLAR RESEARCH CENTER; AND THE JOHN GLENN INSTITUTE

In cooperation with

A CLUSTER OF INTER-DISCIPLINARY RESEARCH ON INTERNATIONAL THEMES: CLIMATE CHANGE (CIRIT-CC)

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Executive Summary

The future of humanity and the quality of our daily lives necessitate a deeper understanding of Earth's climate system, which sustains all life and is now threatened and compromised by human activities (population growth, economic development and unsustainable resource use). For example, the melting of Kilimanjaro's ice fields has progressed from the time of Hemingway's writings in 1938, when the ice cap was thick and covered the mountain, to an expected extinction in 2020. Glacier National Park will soon lose its namesake. The loss of major alpine glaciers in our lifetimes is one of the strongest indicators of an abruptly changing climate that is happening *now* because of drastic perturbations in the global carbon cycle. The impact on water resources of this sudden shift in global temperatures can most easily be understood by the loss of snowfields that annually supply water to a billion people in the basins surrounding the Himalaya Mountains. We propose the OSU Climate, Water, and Carbon Program (CWCP) as OSU's scientific *and* policy-oriented response to these critical issues.

We are not alone in our view, which suggests the potential to leverage our proposed investment against ample external funding. The U.S. Presidential Cabinet recognizes the significance of these issues and has called for executive departments and federal agencies to focus funds on our "ability to measure, monitor, and forecast U.S. and global supplies of fresh water" [OSTP and OMB memos]. Significant reference to this issue is the topic of the highest-level policy deliberations with anticipated funding in the billions of dollars. Predictions of future climate changes are complex, requiring interdisciplinary research ranging from local field studies to global remote sensing measurements, all coupled with numerical and statistical modeling. Future governmental actions in the midst of this complexity demand an informed public policy perspective that balances sound social and physical scientific understanding.

We propose to address three science questions that are directly stated as, **"are we causing an abrupt climate change today?", "do we have enough fresh water?", and "what adaptive strategies can be implemented to offset the impact of fossil fuel combustion on biogeochemical cycles affecting climate change and water resources?"**

We are uniquely positioned to address these questions. OSU researchers pioneered alpine ice coring science; in addition, our geodetic science and hydrologic research is known worldwide. OSU is the lead U.S. institute for a proposed $350M satellite mission devoted to measuring waters in rivers, lakes, and wetlands. The CWCP is a collaborative effort of three colleges (MAPS, FAES, SBS), the Byrd Polar Research Center (BPRC), the John Glenn Institute for Public Service and Public Policy (JGI), and individual faculty from the Colleges of Engineering, Biological Sciences, and Medicine - all working in concert with the Cluster of Inter-Disciplinary Research on International Themes: Climate Change (CIRIT-CC) program in the Office of International Affairs.

When we complete the first five years of the proposed program, we expect to have established an OSU team that serves as the local, state, national and international resource for scientific and socially relevant input on issues relating to abrupt climate change, water resources (abundance and quality), and carbon cycling. We expect to have won three multi-million dollar interdisciplinary grants that directly address our science questions. We will have attracted and educated a new generation of scholars.

We are organized on the teamwork principle. Teams of researchers will address our science questions with a lean administrative structure. Teams will include the brightest and hardest working researchers; thus, as a team, they will know and design the scientific course of action for addressing each question. This is the ideal bottom-up approach to accomplishing research. Administrative oversight will be conducted via a CWCP Steering Committee, reporting to the Deans. Explicit discussion has dealt with the necessity to have management oversight and direction provided to this program through the Deans to the chair/director level. The clusters of research scientists will thus have maximum freedom to pursue their agendas.

Importance and Impact of the Climate, Water and Carbon Program

Increasing human impacts on systems that support life on Earth have set in motion a series of complex interactions with the potential to produce massive changes in climatological, ecological and socioeconomic functions. Key systems are being rapidly pushed beyond their past ranges in response to a growing human footprint. CWCP participants have come together to address critical questions on each of these systems, and importantly, their interrelationships.

1. *Does human intervention have the potential to push the climate system such that abrupt changes become more frequent, intense and rapid?* This important question will drive our efforts in Abrupt Climate Change (ACC), which includes changes on annual to multi-decadal time scales. Abundant observations support the theory that Earth may now be experiencing sudden climatic changes. As the impacts can potentially be large and climate prediction remains problematic, an increase in our knowledge and societal awareness is essential to "improve the effectiveness of human responses to reduce vulnerabilities and increase adaptive capacity" [NRC, Abrupt Climate Change Report].

2. *Do we have enough surface water to maintain society; i.e., what is the spatial and temporal variability in terrestrial surface water storage and how can we predict these variations more accurately?* Given our basic need for fresh water, there is a widespread recognition of the need for better observations and understanding of surface water distribution globally [e.g., the United Nations, the NRC, the President's OSTP and OMB, among others have acknowledged this].

3. *How is the carbon cycle being disrupted by human activities (e.g., fossil fuel combustion) and how can the cycle be re-balanced to mitigate ACC and its adverse effects?* Changes in biogeochemical cycling of carbon are closely linked to issues of climate change, water quality and quantity, and ecosystem health. For example, increases in carbon dioxide (CO_2) in the atmosphere over the past century have contributed to global warming by changing the radiative properties of our atmosphere, disrupting the global water cycle, and altering major land use patterns. Anthropogenic emissions of carbon can perhaps be offset and the rate of increase in atmospheric CO_2 concentration reduced by capturing carbon in terrestrial and aquatic ecosystems, and by developing alternative energy sources.

Universities are uniquely placed to be a central part of societal response, and universities poised to accept this growing challenge will be at the forefront of this key area of concern for society. Harvard, Columbia, and Stanford all have interdisciplinary programs somewhat similar to the CWCP. We view the program as a new way of conducting science and meeting the needs of society. Old methods of building programs along disciplinary lines fail to bring together researchers working on the same problem but from differing approaches (e.g., at many universities, including OSU, hydrology is studied in four colleges). The CWCP has already demonstrated the excitement that many faculty have for this interdisciplinary approach by bringing together researchers from across campus.

Why OSU?

Faculty members participating in the CWCP are world renowned for their research related to abrupt climate change, water resources, and biogeochemical cycling. Capitalizing on our expertise in historical climate change, climate modeling, atmospheric chemistry, carbon management, and ecological engineering, we emphasize changes in the Earth's climate and cryosphere and the impact these changes have on regional water resources and global sea level. CWCP expertise includes the following:

1. ***An internationally acclaimed group leading efforts to reconstruct the Earth's climate history using a variety of proxy indicators ranging from ice cores and corals to ocean and lake sediments.***
2. ***Nationally recognized leadership in both polar meteorology and the use of various methodologies to measure, model and predict mass balance changes for glaciers, which impact sea level change. OSU is a major partner in the recently established NSF STC Center for Remote Sensing of Ice Sheets.***
3. ***Expertise in atmospheric aerosol chemistry, which allows us to better understand the radiative effects caused by atmospheric particles that are a critical factor in cooling feedbacks to climate change.***
4. ***A proposed joint NASA-ESA satellite mission to be headquartered at OSU. This mission, named the Water And Terrestrial Elevation Recovery or WATER mission, is designed to investigate global surface water***

hydraulics (www.geology.ohio-state.edu/water). OSU's geodetic science program integrates global climate change and water cycle research, providing a distinct advantage for the CWCP because satellite techniques reach into remote regions where water storages are vast and across political boundaries where water storages are secret.

5. ***A Cluster of Inter-Disciplinary Research on International Themes: Climate Change (CIRIT-CC) has been established as a campus-wide forum for multi-disciplinary research on climatic issues. Likewise, a Carbon Management and Sequestration Center (C-MASC), has been organized under the auspices of OARDC/ FAES. The C-MASC operates in close cooperation with several national labs and institutions and already has broad-based funding. The OARDC Biofuels Project is aimed at generating clean energy from agricultural and food-processing wastes.***
6. ***The Wilma H. Schiermeier Olentangy River Wetland Research Park is a nationally and internationally recognized facility for water resource research and outreach. It serves as the centerpiece of The Ohio Center for Wetland and River Restoration, a state-wide organization focused on ecological engineering for wetland restoration and the management of water resources. The OSUE Watershed Initiative works with university researchers, agencies and local watershed groups to disseminate research findings and facilitate watershed management. An interdisciplinary Agroecosystems Management Program (AMP) has been established to improve the economic, environmental and social viability of Ohio's agriculture and rural communities through the application of ecological approaches to land use and water resource management. This program includes the widely recognized Sugar Creek Project on carbon and nutrient trading.***
7. ***The John Glenn Institute uses policy and outreach expertise to link stakeholder groups, government policy, and industrial outcomes in order to improve public understanding and public policy of technology and science issues. A linkage of science and policy is critical to the success of this program.***

Our unique, competitive advantage compared to any other university is the 50-year history of scholarly excellence at the Byrd Polar Research Center and its traditionally partnered colleges of SBS, FAES, and MAPS. Now, through the CWCP, we will couple policy issues exemplified by the outstanding efforts of the John Glenn Institute with the CWCP approach to the core science questions outlined above.

What are the Proposed Actions?

The CWCP is focused on two core actions, both designed to directly address the science questions listed above. Actions include (1) the development of a framework for the CWCP and (2) advancing a science program to enhance interdisciplinary themes. The long-term sustainability of the program will require substantial efforts in building a framework that links faculty, departments, colleges, and industry partners. The Steering Committee and Teams will interact with colleges, departments, JGI, and BPRC to influence and coordinate new faculty hiring (with an explicit primary lead from dept. chairs/school directors), create and fund new facilities, and develop mechanisms that directly engage government and industry partners.

The key framework tasks include:

1. Submission of several large, interdisciplinary proposals led by key OSU researchers. Multi-million dollar proposal opportunities are available from external funding agencies, but as successful grant writing requires considerable time and effort by the lead investigators, release time will be used to ensure their availability. As large interdisciplinary grants are often awarded jointly to multiple universities, short-term visits by leading scholars will be used to facilitate the winning of grants.
2. Development of an industry relations program enabling organizations to take advantage of research innovations, associated technologies, and the pool of talented students that will be associated with the CWCP. An excellent example of this concept is the recently funded Ohio Bioproducts Innovation Center (Ohio 3rd Frontier Initiative) where numerous industry and university partnerships are being forged. Beyond direct support of research, a program of targeted training, organizational internships, and fellowships will be developed to directly connect industry with students. The science questions at the heart of this proposal have enormous implications for individuals, local and national governments, and multinational corporations. Research on climate and water resources will influence strategic planning, drive discussions for adaptation, and ultimately help determine the investments required to address future challenges and opportunities. A major research question is to understand how Ohio's industrial and agricultural economies will evolve in response to changing climate and water resources.

It is clear that Ohio businesses already benefit from partnerships with OSU researchers in these areas. For example, carbon trading through the Chicago Climate Exchange and biofuel production from lingo-cellulosic biomass are directly linked to OSU research. The CWCP will leverage visibility and existing relationships into new and expanded research and innovative joint ventures.

3. Efforts to find, recruit, and retain the best research scientists, post-docs, and graduate students, whose talents and energy are essential to addressing the key science questions.

The second and most important core action of the CWCP is the development of a science program that addresses the questions posed earlier. Answering these questions requires a multifaceted approach utilizing our existing research strengths. The initial steps taken will focus on three geographic regions (Central Africa, the Amazon Basin, and the Ohio River Basin) exhibiting sensitivity to global climate change, water resource variability, and ecosystem productivity. The next steps will build from the first results, e.g., techniques learned from the proposed Kilimanjaro study will be applied to the more complex Himalayan climate and water systems. Likewise, lessons learned in Ohio on technologies for carbon capture (sequestration) and wetland restoration can be broadly extrapolated to national (e.g., the hurricane ravaged Gulf Coast) and international scales.

The science program will forge cooperation and create new linkages among program participants. Initial work in the three geographic regions will involve researchers with skills ranging from supercomputer computational modeling, interferometric synthetic aperture radar processing, mass spectrometry, intensive field campaigning in extreme environments, ecological engineering, policy oriented decision science, and much more. The CWCP brings these people together.

Initial science tasks include:

1. *Bellwether studies in critical geographic regions.* The three geographic areas of interest were selected because each is capable of sustained growth from external funds. Researchers will not work separately in the same location, but will jointly apply a broad spectrum of techniques so that the insights and methods from different disciplines will substantively inform one another, steer the research, and broaden understanding of the Earth's complex climate and hydrologic systems. Together, these projects will demonstrate to funding agencies that the CWCP has the scientific and organizational capability to manage multi-million dollar interdisciplinary projects. Additional details are provided in the Appendix.
   - **a.** *Studies in Central Africa, specifically Mount Kilimanjaro,* designed to examine how ecosystems will adapt to permanent hydrologic changes driven, for example, by the loss of tropical glaciers, or over-development of water resources.
   - **b.** *Research in the Amazon Basin,* providing answers to questions related to the occurrence of water in the Earth’s largest, most complex basin and containing its largest river.
   - **c.** *Studies in the Ohio River Basin* to examine the implications of ACC on the environment (especially soil, forest, and water resources), and the societal adaptations and policy developments that will be required to cope with these changes.
2. *Enhanced program capabilities.* The colleges of MAPS, FAES, and SBS are committed to the CWCP and are aligning future FTEs with the CWCP science questions. New hires will capitalize on supercomputing technology, thus fueling Ohio’s technological aspirations of terra-flop computing. Essentially, the CWCP is envisioned as a partner with colleges, departments and centers, providing guidance in the selection of new faculty FTEs. Although the skill sets provided by existing CWCP researchers are impressive, the enormous external funding potential associated with climate change issues begs the addition of new FTEs to extend program capabilities. Such FTEs might include:
   - **a.** *A scholar with established excellence in modeling the global water cycle* and its ties to climate and biogeochemistry.
   - **b.** *A global climate modeler* to incorporate the climate and water observations gathered by CWCP teams and to generate scenarios for future changes.
   - **c.** *A skilled ice dynamicist* with experience in three-dimensional ice sheet and alpine glacier modeling.

d. *A scholar trained in environmental risk analysis and decision science* to develop and promote adaptive strategies for dealing with societal issues related to abrupt climate change.

e. *A watershed hydrologist or toxicologist* to address water quality issues arising from climate induced alterations in biogeochemical cycling.

f. *A scholar with expertise in assessment of the impacts of land use/ land cover change* using remote sensing, geo-spatial statistics, simulation or other appropriate methodologies.

3. *Other interdisciplinary projects* developed from interested faculty that directly and very clearly address CWCP questions. Example projects include:

a. Studies on the movement of water through the Congo Basin, containing the world's second largest river, but where almost no research is being conducted by anyone at any institute worldwide. This would enable the CWCP to determine water volumes in the world's largest and second largest basins, thus taking a significant step toward answering the CWCP question on water abundance and availability.

b. Studies on mass changes of the Greenland ice sheet and the coupled sea level rise that result from its possible melting. These studies are directly tied to the CWCP question on ACC.

c. Studies to examine the effects of land management strategies (riparian zones, wetland restoration, agricultural tillage systems, etc.) on carbon sequestration and biogeochemical cycling of critical nutrient elements, especially nitrogen and phosphorus, responsible for Gulf Coast hypoxia.

4. *Policy implications from all these science projects.*

We have developed a parallel approach to implementation and a timeline that allows the CWCP to address key goals. The program will involve two Science Teams, one focusing specifically on issues of ice dynamics and related water resources, and a second focusing on issues of carbon sequestration and biogeochemical cycling. The emphasis and timing of projects related to the two teams is different. Team One will deploy initial resources in year 1 to initiate the ACC research project involving Mount Kilimanjaro climate and hydrology. The initial emphasis on ACC has been chosen because of the successful pioneering research OSU has already accomplished and because Kilimanjaro has become the icon for global climate change. A transition to studies highlighting global hydrology follows in years 2 and 3, respectively. Team Two will support research to create innovative land use and soil/water management technologies for reducing the net rate of increase in greenhouse gas emissions, develop adaptive strategies to deal with ACC, explore alternative energy sources and secondary environmental issues associated with energy production, and improve the quality and quantity of fresh water resources through ecologically sound restorative processes. Environmental, economic and societal impacts and their implications for public policy and international cooperation are of equal concern. The geographic focus of Team Two will be the Ohio River basin, but international verification of research results will also be an important component of the program. Partnerships are already in place through FAES and CIRIT-CC to extend and validate research results on an international scale through institutional linkages in India, Latin America, Central Asia, and East Africa.

What will be Accomplished?

The framework and research tasks described above are the foundation for addressing the CWCP core science questions. Together, these projects will demonstrate to funding agencies that the CWCP has the scientific and organizational capability of managing multi-million dollar interdisciplinary projects. For example, such demonstration is critical to convince space agencies that OSU can manage the petabytes of data and the weekly global, high-resolution hydrologic products expected from the proposed WATER satellite mission (above). Partners in the anticipated CWCP industry sponsorship program will require similar capacity demonstration. Thus, a primary goal of the CWCP is to become self-sustaining through large grants and industrial partners.

Successfully addressing the specific and socially relevant questions that underpin the CWCP requires a concentrated effort by a diverse, yet complementary cohort of creative and energetic faculty, post-docs and graduate students. Metrics for assessing program success are diverse. Early evidence of success will be an ability to attract targeted, top notch faculty and post-docs to OSU, to compete aggressively for the

best graduate students and then to train them well (measured in part by their post-degree placement). Another early indicator will be enhanced competitiveness for external awards (both individual PI and larger team led). By the third year we expect to have at least two large awards (>$1M) supporting CWCP initiatives. Other tangible metrics for scholarship (impact) include publishing cutting edge papers in the best journals, garnering citations, and serving on national and international panels. Advancing the national rankings of CWCP partnered OSU departments requires a longer-term strategy with many interdependent elements that create a feed-forward dynamic. For example, (1) a creative and energetic faculty attracts high-quality, motivated and curious students (both undergrad and grad) who compete successfully for prestigious scholarships and awards; (2) these stronger research groups are more competitive for external support (federal and industry); (3) increased resources fuel publications, citations, and recognitions; and (4) these enhancements feed back to attract even better faculty who in turn attract even better post-docs and students. The latter replenish the professoriate and build a loyal alumni base. Enhancing institutional reputation and increasing rankings requires a concerted, strategic and long-term effort such as we envision for the CWCP. Another metric of success will be CWCP recognition as the local, state, national and international resource for scientific and socially relevant input on issues relating to ACC, carbon cycling, and water resources (abundance and quality).

As the CWCP attains success with (1) knowledge generation, (2) practical application of that knowledge for the benefit of society, (3) student and post-doctoral training, (4) development of industrial partnerships, and (5) local to international recognition as the "go to" place for cutting edge knowledge of the current and future impacts of ACC, water resources, and carbon cycling – then the ability to secure more resources from a broader spectrum of federal agencies, institutions, companies and private donors will be assured. We have every intention of sustaining this initiative over the long-term (decades) although undoubtedly the CWCP's specific research foci will change as anthropogenic climate forcing and its societal impacts become more evident and as the need for scientifically sound and creative adaptation and mitigation become more urgent.

How will the Climate, Water, and Carbon Program be Organized?

The most important part of the structure is our reliance on teamwork to address the questions noted above. Teams will consist of faculty and researchers across the University rather than in a single department. The emphasis is on problem solving through interdisciplinary approaches because the questions require broad-based thinking. Teams built from experts in field methods, remote sensing, numerical and statistical modeling, data analyses, and policy making are vital for developing meaningful solutions to the science questions. The CWCP is more than an umbrella linking PIs. It will provide explicit research direction, channel financial support to activities aligned with targeted climate and water questions (above), and facilitate collaborative opportunities that will generate greater value than the sum of single PI contributions.

The CWCP is purposely lean regarding administration, thus enabling a greater flow of resources directly to the research staff conducting the actual work of the program. The fiscal contributions of MAPS, SBS, and FAES are complementary, including upcoming faculty FTEs, graduate student and post-doctoral positions, and cash aligned with CWCP goals. The Steering Committee will be responsible for the overall program by collegially working with all participants to ensure that OAA, MAPS, FAES, and SBS funds are spent on CWCP initiatives.

The CWCP operation is designed to ensure that we meet the stated goals of addressing the science questions. All participants must realize that their individual research projects will not necessarily be endorsed via equal funding for all. Rather, individual PIs will continue their independent projects, while also contributing (as appropriate) to interdisciplinary initiatives designed to address the key CWCP questions. To receive CWCP resources, researchers must be working explicitly on CWCP questions within a team format. Continued support requires a successful track record assessed using such metrics as publications (e.g., *Nature* or *Science*), external funding, and a research team designed to address a targeted initiative. Young researchers, who may not have achieved high levels of production, will be

nurtured and thereby empowered through collaborative teamwork. As they gain experience, their role on the teams will expand accordingly.

Budget: What will the CWCP Cost over Five Years (see Table 1)?

OAA cash funds are requested for the following nine elements:

1. ***Demonstration Projects:*** The program will undertake high visibility projects in Central Africa, South America, and Ohio. Funding is requested to accelerate these projects, several of which are already underway.
2. ***Seed Grants:*** Funding is requested for seed grants that contribute to the target reseach projects, and the overall program thrust.
3. ***Graduate Students:*** Graduate research and education is an integral part of the CWCP. Funding is requested for approximately 12 GA's for 5 years.
4. ***Post Graduate Fellows:*** Another essential component for the Program is postgraduate fellows. The Project is requesting support for approximately 6 fellows for 5 years.
5. ***50% Research Appointments:*** The CWCP highly values non-FTE researchers, and we can demonstrate commitments to them through 50% appointments that provide a strong, salary-based incentive to remain at OSU. Likewise, such appointments are a strong lure to bring new scientists to the CWCP.
6. ***Release-Time Funds:*** Funds from the CWCP will be used to release OSU faculty from their teaching and service responsibilities, thus allowing them time to devote to CWCP initiatives.
7. ***Visiting Scientist Program:*** The CWCP will make available funds for high impact opportunities to attract exceptional outside scientists that require immediate decisions on fund allocations.
8. ***Meetings and Undergraduate Research:*** The CWCP will support a variety of activities designed to enrich activities, including meetings and conferences, along with undergraduate research.
9. ***Startup:*** Startup funds are requested for six new faculty hires that will be made as part of the program

Colleges of SBS, FAES, and MAPS will support the CWCP through cash and FTEs:

1. ***College cash:*** As the budget indicates SBS, MAPS, and FAES have programmed $2.6M in funds in support of this initiative.
2. ***College FTEs:*** The colleges will each provide 1.5 FTEs in continuing faculty lines to the project. The Program requests a 1.5 FTE match from OAA.

Overall, the CWCP requests $10 M in funds from OAA along with 1.5 FTE. The Colleges will invest $2.6M in Cash and 4.5 FTEs.

Faculty Participants in the CWCP

Over 50 distinguished research faculty from MAPS, FAES, SBS, BPRI, and the JGI are positioned to make contributions to the CWCP, either in an advisory capacity or as participants in specific initiatives. Additional faculty from other academic units will be encouraged to participate, as needed, to form functional research teams.

Table 1: Proposed Budget for CWCP

Cash Need for Program	**Total over Five Years**
Case Studies (Kilimanjaro, Amazon, Ohio)	$4,300,000
Internal Proposals	$1,175,000
Graduate Students	$1,800,000
Post Graduate Fellows	$1,800,000
50% Research Appointments	$ 950,000
Release Time	$ 350,000
Visiting Scientists	$1,100,000
Meetings, Seminar, Lectures	$ 250,000
Undergraduate Research	$ 275,000
Startup 6 FTE ($100,000)	$ 600,000
TOTAL	$12,600,000
Cost Sharing	
Cash from MAPS, SBS, FAES	$ 2,600,000
Total Cash Request OAA	$10,000,000
Faculty Position Request	6.0 FTE
Share from Colleges	4.5 FTE
FTE Request from OAA	1.5 FTE

Appendix: More Details Regarding the Three Initial Research Projects

We will use a case study approach that develops knowledge and methodologies in a systematic fashion to generate results that can be extrapolated to regional and global scales. Table 2 identifies focus areas and presents our approach to implementation of planned research. One target area will be Mount Kilimanjaro, which has been chosen due to the successful pioneering research OSU has already accomplished and due to the fact that Kilimanjaro has become the icon of climate change in Africa. Six ice cores recovered from the ice fields atop Kilimanjaro have provided an ~11,700 year record of regional climate and environmental variability. These nearly continuous and high-resolution records document three abrupt regional climate changes at ~8.3, ~5.2 and ~4 thousand years ago. The latest event was coincident with the 'First Dark Ages', a period of the greatest historically recorded drought throughout tropical Africa that appears to have extended to the Middle East, western Asia and even to tropical South America. The 20th century wasting of the Kilimanjaro ice fields is unprecedented for the last 10,000 years, and their combined areal extent has decreased roughly 80% from ~12 km^2 in 1912 to ~2.6 km^2 in 2000. If current climatological conditions continue, Kilimanjaro's remaining ice fields are likely to disappear between 2015 and 2020. The new Kilimanjaro project begins in January, 2006. The specific objectives include measuring the area and volume of glacier loss since 2000 using new (2006) aerial photos and ground based studies. A water-sampling program will quantify the current dry season water geochemistry (e.g., stable isotopes, major anions and cations). Samples will be collected from selected wells and

springs for tritium and carbon 14 dating to determine the age of the water currently consumed in order to assess the impact that the loss of the Kilimanjaro ice fields over the next 15 years will have on regional water supplies. The initial data set will be used to develop a proposal to be submitted to the NSF in the fall of 2006. The ultimate goal is to produce a regional hydrological model that can be used to predict how the current abrupt climate change will affect water resources upon which the growing population at the base of Kilimanjaro is so dependent. We are emphasizing a novel trans-disciplinary approach that will generate new understanding and provide a transferable framework that may be applied elsewhere (e.g., arid western Andes or the Himalayas). Experts from different disciplines are not simply coordinated to work separately in the same location; rather, a spectrum of skills will be applied by a team committed to the objectives of this program. Thus, the insights and methods from different disciplines will be essential to substantively inform one another, to steer the research, and to broaden our understanding of the Earth's complex climate and hydrologic systems.

The Amazon Basin incorporates the high peaks of the Andes Mountains where ice coring has successfully demonstrated past changes in basin wide precipitation. Rainfall has varied greatly in the past and includes protracted drought periods, but the connections with basin wide hydrology and wetland carbon fluxes has not been made. The potential global impacts on climate from low water periods with much smaller wetlands may well be significant given that today's Amazon flooded areas are the largest in the world, thus impacting global carbon exchange processes. We presently have crude estimates of wetland areas that can be refined with remote sensing and basin wide hydrologic modeling. This wetland model can be projected in time with the ice core precipitation proxy and connected with carbon flux estimates that depend on knowledge of flooded areas. The expertise within the CWCP includes all components of this study: ice core climatology, Amazon hydrology, and wetland carbon fluxes and requires a team-based approach that integrates these disciplines. Completion of this study would provide firm grounding for carrying out similar studies worldwide, thus generating sustained external funding. For example, this study dovetails with the Kilimanjaro study (noted above) by carrying the ice core precipitation proxies for central Africa into the Congo Basin. This project also ties together our three core questions and, by geographically extending the project to other large-scale basins, will allow us to address them more rigorously.

The third project will focus on the Ohio River basin. This geographic area has historically been a major source of atmospheric pollution (greenhouse gases) that is now strongly linked to global warming and ACC. Consequently, there is strong motivation to develop technological options to predict, mitigate and adapt to carbon-induced climate change with its associated impacts on water resources in this region. Possible mitigation strategies that will be investigated include carbon sequestration through both natural (trees, soils, wetlands) and engineered (chemical scrubbing, geological storage) systems, as well as the development of other energy sources (H_2 cells, biofuels, etc.) as alternatives to fossil fuel consumption. The creation and adoption of such strategies will involve a dynamic coupling of industrial, social and ecological factors, including the flow of materials, energy, labor, and waste. New economic incentives (e.g., carbon trading) will also be needed to engage private industry with university researchers to quickly innovate, test, and commercialize new products that reduce greenhouse gas emissions, or that facilitate the ability of society to otherwise adapt to climate change. For example, policies that allow the public and private sectors to quickly formulate new insurance instruments that optimally share risk will help individuals and companies make adaptive decisions more effectively.

The Ohio River basin includes a diversity of landforms and land uses. It is the agricultural and industrial heartland of the United States and presents many opportunities to examine the feedback mechanisms associated with human management of natural ecosystems. In particular, efforts will be made to examine the hydrologic, geochemical and biological processes that occur in this large, complex watershed and to understand the role of the hydrologic cycle in controlling carbon, nitrogen and phosphorus budgets in an area where urban and industrial water uses compete strongly with agricultural needs. Ecological engineering methods to improve the quantity and quality of available water resources must also be developed and promoted to achieve wetland restoration, sustainable watershed management, and water purification at the household and community levels. A model-based synthesis of the

hydrological and biochemical responses to past and future climate forcing should help scientists, policymakers and the people of the Ohio River basin to make more informed decisions on the impact of ACC on water and land resources within the basin. Lessons learned here will be extrapolated to international sites through the existing CIRIT-CC framework.

Table 2. Individual Project Tasks and Timeline

	Kilimanjaro	**Amazon**	**Ohio River Basin**
Year 1	Initial seed funding* and collection of baseline field data for submission of an NSF proposal	Initial seed funding*	Seed grants and proposal submission to NSF carbon/water** and IGERT programs
Year 2	Implementation of full-scale sampling and monitoring program partially supported by NSF funds	100 years stream gauge and precipitation analysis; basin wide remote sensing of wetlands using multiple satellite data sets	Implementation of regional carbon sequestration, ecosystem management, and biofuels projects
Year 3	Develop a *Science* or *Nature* paper from the first two years of sampling results and generate a first model prediction for a climatic and hydrologic outlook for the Kilimanjaro region	Implementation of sampling program, modeling of methane and CO_2 flux rates; submission of proposals for other tropical basins, e.g., Congo	Analyses of land use on C sequestration and biogeochemical cycling; construction of C and water balance models
Year 4	Extension to (1) the Himalaya and downstream basins and (2) the tropical Andes of Peru	Extension to Congo Basin via modeling and remote sensing comparisons	Technology verification and extrapolation through CIRIT-CC; policy development
Year 5	Full external climate/water/modeling program funding, Re-fly Kilimanjaro	Full external funding for at least one, preferably more basins	Assessments of project impacts on water quality and agronomic productivity; full external funding, including industry partnerships

* Initial seed funds will be used to ensure that data sets, infrastructure, and personnel are available.
** Carbon and Water in the Earth System (NSF06-514).