The Climate Change Institute

A University of Maine Signature Research Area

Table of Contents

Introduction

What is climate change? We (humans, animals, plants) are all connected to, impacted by and integrally involved in the climate system. Climate and its building block, weather, extend from the uppermost reaches of Earth's atmosphere into the oceans, lakes, streams, soil, fields, forests and rocks. Climate and weather have been molding the Earth's surface through long-term variations and catastrophic changes ever since Earth gained an atmosphere some 4.5 billion years ago. Climate and weather have been feared and revered ever since humans emerged and plants, animals and humans migrated, thrived and ceased to exist in response to climate change. The scientific study of climate and weather goes back at least 1000 years and more likely much longer and our earliest ancestors understood intuitively the value and consequences of changes in climate and weather. There is no escape from climate/weather change. It influences where we can live, our health, our economy, our art and music, and our overall quality of life. Controls on climate and weather, underlying mechanisms of change, human and ecological impacts and their implications cannot be defined by a simple disciplinary description. Rather, climate change calls for (if not demands) multi- and inter-disciplinary approaches that include physical, chemical, biological and social dimensions and feedbacks.

What is climate change at the University of Maine? Climate change is one of the primary signature research strengths of the University of Maine. It includes highly integrated undergraduate and graduate educational opportunities and highly integrated service products that are dedicated to improving the well being of the University, the State of Maine, the nation and the world. The Climate Change Institute is at the heart of climate change strengths at the University of Maine. Recent events highlight how the Climate Change Institute has evolved beyond a singular focus of research, to being a leader and a vehicle for broad integration of climate change strengths across campus and throughout Maine.

In 2006 the Climate Change Institute conducted a survey of University of Maine faculty who considered their research to be related to climate change culminating in a document entitled: "Climate Change and Maine". The researchers who contributed were primarily from the Climate Change Institute and associated academic, research and service units (currently this includes: the Schools of Biology and Ecology, Computing and Information Sciences, Earth and Climate Sciences (half of SECS faculty are also CCI faculty and SECS offers undergraduate and graduate degrees in climate sciences), Marine Sciences, Forest Resources, Food and Agriculture, Policy and International Affairs (CCI and SPIA share an NSF IGERT that will over five years support 25 PhD graduate students over the five years – the first ever to address abrupt climate change), and the Department of Anthropology (almost half of Anthropology faculty are jointly appointed in CCI and they offer undergraduate and graduate degrees associated with climate science), the Hudson Museum, the Center for Research in STEM Education (RISE Center)) and others not directly associated with the Climate Change Institute who were conducting state-of-the-art climate research in units such as: the Department of Civil and Environmental Engineering, the Department of Chemistry, the Department of Physics and Astronomy, the Department of Resource Economics and Policy, the Laboratory for Surface Science and Technology, the Margaret Chase Smith Center and the Mitchell Center. One of the abstracts appearing in the CCI-initiated 2006 report was entitled: "Understanding and mitigating the environmental footprint of the University of Maine". It was co-authored by Climate Change Institute/ School of Earth and Climate Sciences graduate students L. Stearns, S. Kaspari and D. Dixon (now University of Maine Sustainability Officer) with mentoring by CCI faculty and VP J. Waldron. This research represented an early contribution to the current, highly successful sustainability emphasis at the University of Maine put forth in President Ferguson's "Blue Sky Report".

In 2008 the Climate Change Institute organized "Climate Change 21 – Choices for the 21st Century – An Interactive Public Forum – Environmental Festival". Well over 500 participants from throughout the State of Maine attended. The event was truly unique

bringing together individuals from all walks of life with the common purpose of expressing and understanding the impacts of climate change on their lives in Maine. It also recognized and elevated the stature of even more University of Maine strengths in climate related research, education and service by highlighting faculty and student climate-related projects not just in the physical, chemical, biological and social sciences but also in music, sculpture, painting, performance and literature – in sum engaging almost all of the University. There was little doubt by the end of this event that the University of Maine's faculty, staff and students were deeply engaged in the full breadth of climate change learning and discovery.

In 2009, the Climate Change Institute was requested by then Governor John Baldacci, to organize an assessment of climate change specific to Maine that resulted in the widely acclaimed report "Maine's Climate Future (MCF)", edited by G. Jacobson, I. Fernandez, P. Mayewski and C. Schmitt, with significant input from a broad range of University of Maine faculty and staff for a total of more than 70 scientists including those from state agencies, NGOs, and the private sector across Maine. MCF has become the foundation document for understanding climate change in Maine and emerging impacts, and it is the framework for ongoing efforts at mitigation and adaptation.

In 2012 the Climate Change Institute, in collaboration with the School for Policy and International Affairs, competed for and was successfully awarded (under the leadership of our Associate Director Jasmine Saros) a highly competitive NSF IGERT (Integrative Graduate Education and Research Traineeship) that will support 25 PhD students by the end of this 5 - year grant. The IGERT is entitled "Adaptation to Abrupt Climate Change (A2C2)" and it is the first such IGERT addressing the fact that climate does not operate linearly, but rather non-linearly and frequently in very abrupt shifts that are so critical to societal response. CCI was well placed to undertake this revolutionary IGERT because some of its researchers have been pioneers in the identification and understanding of abrupt climate change. IGERT A2C2 graduates will become leaders in physical, chemical, biological and social applications of abrupt climate change and in bringing to the scientific community and the public an understanding of the realities of abrupt climate change. This is not a hypothetical concern for the future. The largest rise in temperature in the last 11,500 years is currently in play over parts of the Arctic (Mayewski et al., 2013). The subsequent dramatic impact on North American climate (drought in the west, extreme cold in the east and considerable climate instability) is what we have been experiencing in the past few months to years.

In 2014 the Climate Change Institute will once again take a leadership role in University of Maine climate change programs by organizing: "Climate Adaptation and Sustainability (CLAS) - Building a Framework and Platform for Climate Adaptation and Sustainability Planning for Maine Communities". The meeting will be open to 300 on-site participants from throughout Maine (notably town planners, policy makers, community groups, NGOs) with live and archived web coverage. The CLAS meeting will showcase University of Maine climate expertise and an array of Climate Change Institute software that can be used by researchers and the public to understand and interpret climate change data and impacts plus planning tools for them to develop community based CLAS plans. Upon completion of the conference CCI will develop a similar approach for use at the national and international level opening up the potential for a Maine based intellectual industry in climate understanding, prediction, adaptation and sustainability planning. This initiative could lead to Maine based employment for a wide range of climate change experts trained by the University of Maine. The CLAS activity will build upon on emerging collaborations between CCI and several partners including Sea Grant, University of Maine Cooperative Extension and the University of Maine School of Business.

The Climate Change Institute's role as "nucleus" and "framework" for the University of Maine's climate change strength. It is clear from the foregoing that climate change is wide-ranging and is not captured by any single discipline or unit at the University of Maine, or any single institution in the world. That said, much of the momentum for the growing reputation of the University of Maine in climate change has been leveraged from the international reputation of the research strengths of the Climate Change Institute. As noted in the examples of recent Climate Change Institute-led events above, ongoing and historical

strengths have grown to be an integrating framework across many disciplines and units on Maine's flagship campus and beyond, encompassing undergraduate and graduate education, a broad array of research, and outreach to stakeholders and government. The Climate Change Institute has emerged as the focal point for climate change at the University of Maine.

Prior to 2002 the Climate Change Institute (CCI) (http://climatechange.umaine.edu) was known as the Institute for Quaternary Studies - founded by Prof. Harold Borns in 1972. CCI is now one of the oldest climate research organizations in the world and likely the first with a multi- and inter-disciplinary focus. CCI is a global leader in research, and in combination with its University of Maine academic unit partners, it offers an extremely strong and unique array of research and educational opportunities for both undergraduate and graduate students including undergraduate and graduate degrees in Climate Science through the School of Earth and Climate Sciences and the Department of Anthropology and a Graduate certificate in Interdisciplinary Climate Studies through the foregoing the School of Biology and Ecology and CCI. In addition, many of the faculty involved with CCI train undergraduate and graduate students in the area of climate change through other academic programs on campus such as Ecology and Environmental Sciences.

CCI integrates transformational field, laboratory and modeling activities to understand the physical, chemical, biological and socio-cultural components of the climate system of the past and present, to better predict future changes in climate and their impacts here in Maine and across the globe. CCI investigations span the last 2 million years to the present - a time of multi-millennial to centennial scale climate changes punctuated by abrupt and dramatic (annual to decadal) shifts in climate. CCI investigations inform predictions for future climate change based upon an understanding of the full dynamic range of the natural climate system and the evolving significant influence of human activity. CCI has a legacy of major scientific contributions to understanding the timing, causes, and mechanisms of natural and human-forced climate change, and on the effects of physical and chemical climate changes on humans and ecosystems.

"Exploration and Discovery" is the Institute's slogan following the example of its Honorary Member, the great explorer Thor Heyerdahl, and the 40+ years of exploration and discovery by Institute members. The Institute fosters exploration, learning and discovery through excellence in faculty and graduate student research, addresses local through global needs through basic and applied research, and contributes research-based knowledge to make a difference in people's lives.

CCI's Purpose: CCI is dedicated to improving the quality of life for people in Maine and around the world, and promoting responsible stewardship of human, natural and financial resources, now and in the future.

CCI's Major Themes: CCI has eight major themes (Figure 1) that together describe the breadth of CCI's contributions and linkages across the University of Maine and at state, national and international levels, and expectations for the future of CCI and climate change at the University of Maine.

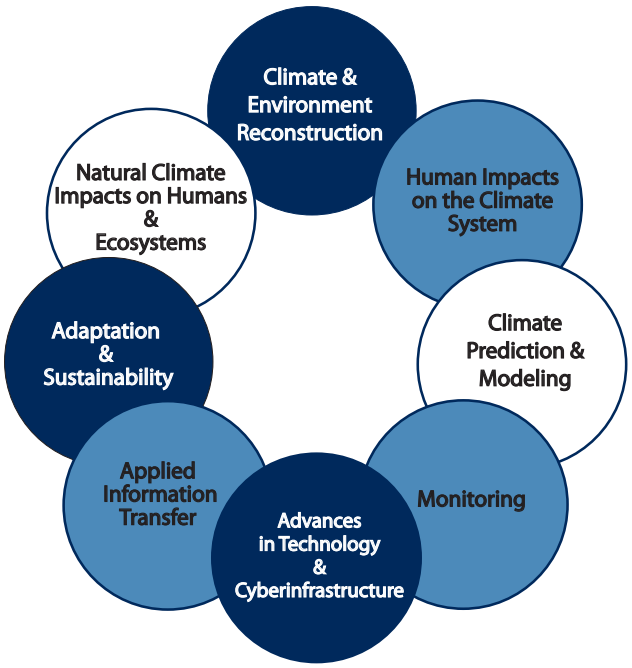

Figure 1. CCI themes.

Addressing the 7 Signature Research Area Concerns Defined in the Signature Research Area Request for Proposals

1. Demonstrates a strong "fit to place". The mission of the Climate Change Institute is vitally linked to the widely accepted realization that an understanding of climate change (natural and human-forced) and its implications is absolutely critical to the future of society, ecosystems, the economy, and governance. As a consequence, CCI continues to experience ever-broadening interactions with other disciplines, with University of Maine research, academic and outreach units, and with local, national and international partners. Because climate change underpins the fabric of our society, CCI faces rapidly emerging opportunities for application of its findings and expertise to critical issues including:

- climate change-induced hazards (e.g., severe storms, floods, sea level rise, coastal erosion, drought, heat waves)
- health threats (e.g., heat stress, drought/flood, disease, air pollution, storms)
- economic and social challenges (e.g., water availability and quality, energy, food security, military security, civil unrest, agriculture, recreation, urbanization)
- climate change-based decision-making by individuals, NGOs and governmental units.

Transformative contributions that meet Maine's cultural, workforce, and economic needs, and actively build on Maine's existing and future resource base:

The climate and environment of Maine has changed dramatically in the last several thousand years. Melting ice sheets have forced the evolution of sea level, lakes and rivers; forests and animals have migrated into and out of the region; agriculture and industry have emerged; population distribution has changed; cultural patterns and socio-economic complexity have changed; energy and transportation needs have increased; air and water quality has changed; and Maine's interaction with national and global economies and the changing dynamics of security has intensified dramatically. Woven within all of the foregoing is climate change and the realization by the scientific community, the White House and the Pentagon, and governments around the world that climate change is amongst the most serious and ever-present security issues on the planet (Figure 2). Assessing Maine's place in this security web is essential to planning Maine's future.

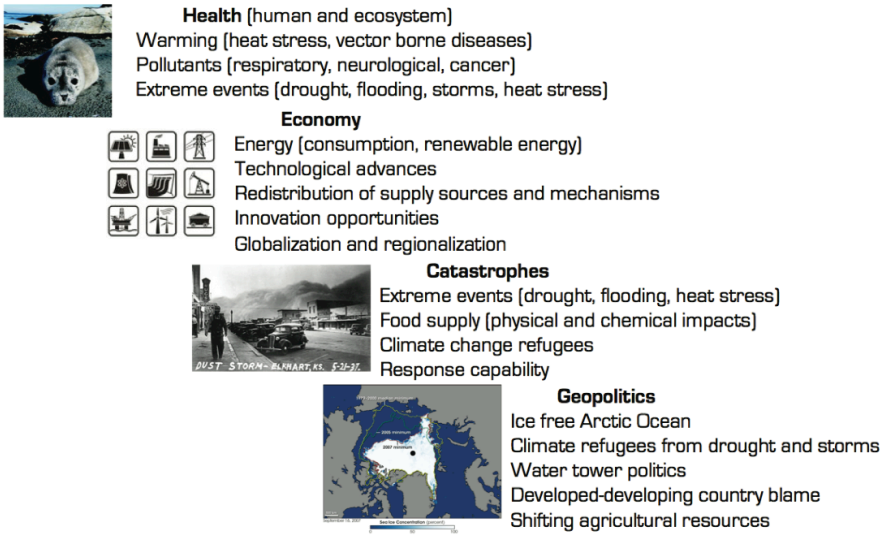

Figure 2. Climate change is a security issue and Maine is integrally embedded within the consequences.

Several general examples of CCI's role in understanding and predicting the impact of changes in Maine's climate and weather follow:

- Monitoring past and present state of Maine's lakes, forests, soils and coast to prepare Maine's people and their way of life for the future.
- Making climate data accessible to the scientific community and public through CCI-produced innovative, highly transparent software and cyberinfrastructure that allows Mainers and the world to make informed decisions related to environmental change (eg., 10green™, Climate Reanalyzer™, p301).
- Informing Maine and the nation of health implications of their changing air quality.
- Monitoring ice sheet and glacier volume changes to assess current and future sea level rise for coastal Maine's coastal societies and ecosystems.
- Developing local to global scale climate model predictions to evaluate threats to Maine including: in-migration of biological agents such as Lyme tick and frequency of heat waves.
- Predicting future wind speed distribution for planned deployment of offshore wind power to assure maximum efficiency of this remarkable Maine resource.
- Establishing the intersection of climate and policy for Maine's natural resource industries, notably: lobster, forestry, agriculture and tourism.
- Conducting conferences to inform and empower the public (eg., Climate Change in the 21st Century (2009); Building A Framework and Platform for Climate Change Adaptation and Sustainability (CLAS) Planning for Maine Communities (2014)).
- Examining past and present Native community interactions with Maine's environment.
- Developing climate and environmental outreach projects for K-12 students and teachers, the public and tourists through lectures, pamphlets, curricula and maps (eg., ECM, ITEST, Maine's Ice Age Trail).
- Work with the Maine Office of Chief Medical Examiner and Department of Public Safety in death investigation, disaster response, and related policy analysis.
- Inquiry into sustainability policy including analysis of efforts to balance social, ecological and economic sustainabilities.

2. **Distinctive area with international and national reputation.** Humanly recorded climate barely extends back one century in time. Throughout most of the Southern Hemisphere, the world's mountainous regions and the oceans this record is barely 2 - 3 decades long and often completely lacking. CCI's global array of research investigations (Figure 3) and unique perspective (Figure 4) extends the short humanly transcribed record back in time for centuries to tens of millennia to understand past dynamic climate range and search for analogs that, coupled with modern climate can be used to make predictions for future climate at local to global scales.

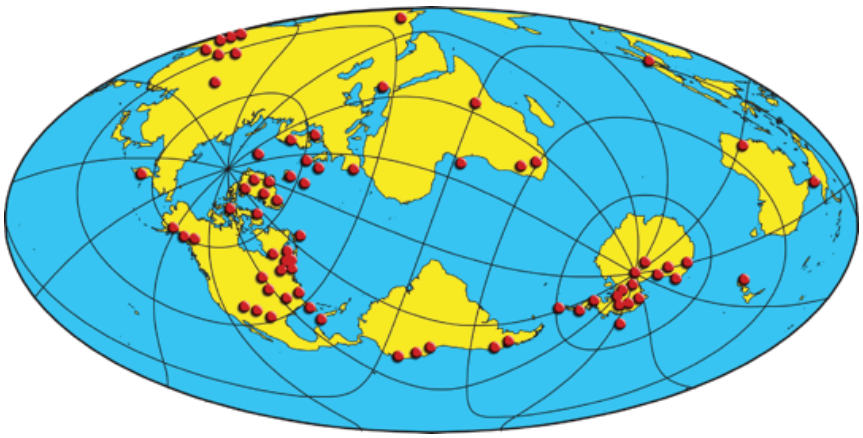

Figure 3. CCI research areas.

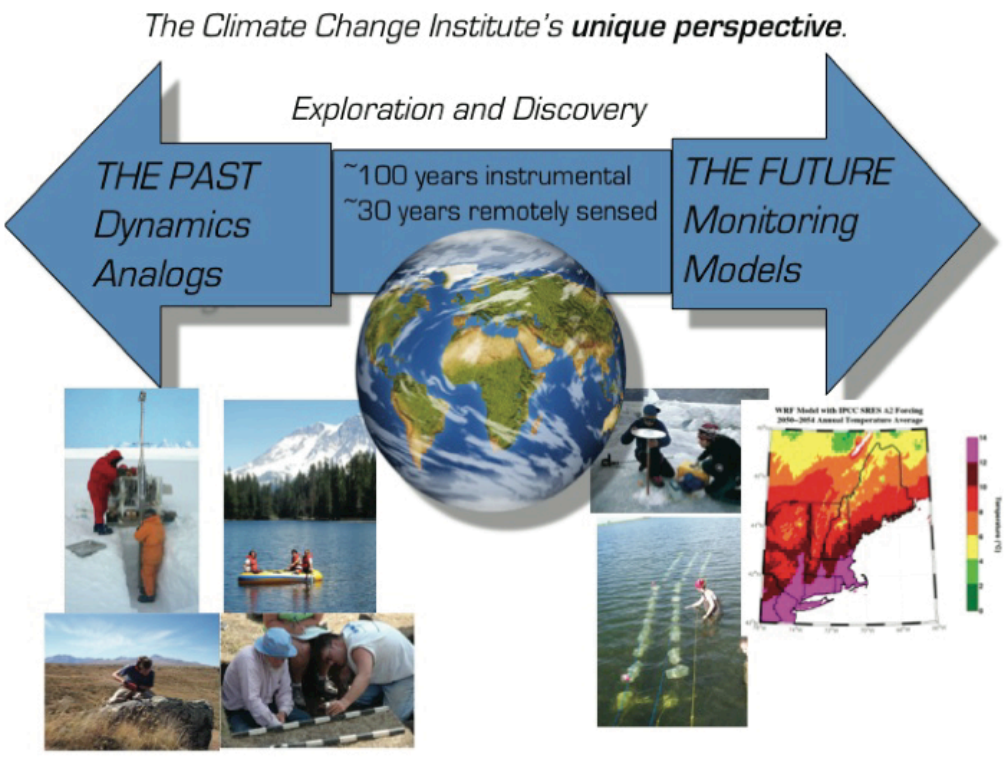

Figure 4. CCI's unique perspective combines the use of robust archives of past climate and environment (eg., ice cores, lake sediments, exposure age dating, and human artifacts) with instrumentally recorded data and monitoring (eg., sea level rise, glacier dynamics, lake chemistry) into weather- to climate-scale descriptions of current and future conditions that enhance planning outcomes and guide climate adaptation and mitigation planning.

Examples of the transformative contributions to science and society produced through CCI's global network of research and unique perspective follow:

- Unraveling the effects of multiple forcing of climate and threshold effects.
- Abrupt climate change - impacts on past civilizations and ecosystems and potential for development of precursors for predicting future abrupt change.
- Causes and implications (eg., sea level, ocean and atmospheric circulation, hydrologic) of massive, fast decay of past and current marine based ice sheets in the Arctic and Antarctic.
- Ecosystem sequencing and climate change at regional to global scales.
- Natural and human drivers of change in the chemistry of the atmosphere.
- Emergence of New World cultures and its relationship to climate change.
- Cutting-edge production of software for the emerging massive data array related to CCI technological innovations (eg., WM Keck Laser Ice Facility and remote sensing).
- Examination of how social and cultural factors (e.g. wealth, power, race, religion, cultural norms) influence vulnerability and resilience to climate change.
- Understanding both local and global climate impacts on human health related to population displacement due to rising sea levels; potential mortality and morbidity due to extreme weather; increase in chemical pollutant levels; and rising prevalence of new vector-borne diseases, and effective policy responses.

- The cultural, economic, social and political influences (including status competition) on resource consumption and global implications for moderating greenhouse gas emissions.
- Extreme-environments education and research training (CCI mounts >30 expeditions per year throughout Maine, the polar regions and high altitude sites). These expeditions require specialized equipment, innovative logistics and training that in sum yield a new breed of technologically advanced remote-expedition qualified researchers. For more detail concerning CCI expeditions visit: http://climatechange.umaine.edu/research/contributions and climatechange.umaine.edu/research/expeditions
- CCI researchers have conceived and led many major national and international climate research projects such as: GISP2 (20 US institutions) and ITASE (21 nations). For more detail visit: http://climatechange.umaine.edu/research/hosted-research
- Hundreds of media interviews (eg., *LA and NY Times, BDN, Christian Science Monitor, CBS 60 Minutes, Fox, NOVA, NPR Fresh Air, Diane Rhem, Global Post,* feature length films *(eg., Thin Ice* (2013), *Years of Living Dangerously* (2014)).
- CCI researchers receive several major national to international honors/awards per year including: University of Maine's first and all three subsequent (4 total) University of Maine members of the National Academy of Sciences, the first internationally selected Medal for Excellence in Antarctic Research, honorary PhDs from several international universities, major student awards, four Distinguished University of Maine Professorships, Maine Environmental Hero Award, and election to fellowship in: The Explorers Club, The American Association for the Advancement of Science, The American Geophysical Union, The American Polar Society, and The Geological Society of America.

3. **High level of productivity (historically and currently).** Institute founder Prof. Hal Borns brought the first NSF grant to the University of Maine and CCI has continued at a very high level of grant and publication success ever since. CCI has the only person in Maine on the ISI Most Highly Cited peer reviewed publication list and many others with very high citation ratings. CCI has maintained a very high level of productivity with respect to the number of successful grants gained by CCI members, grant success rate, awards and honors for members, major media attention, presentations to the public and scientific community, research expeditions and peer-reviewed publications (Figure 5).

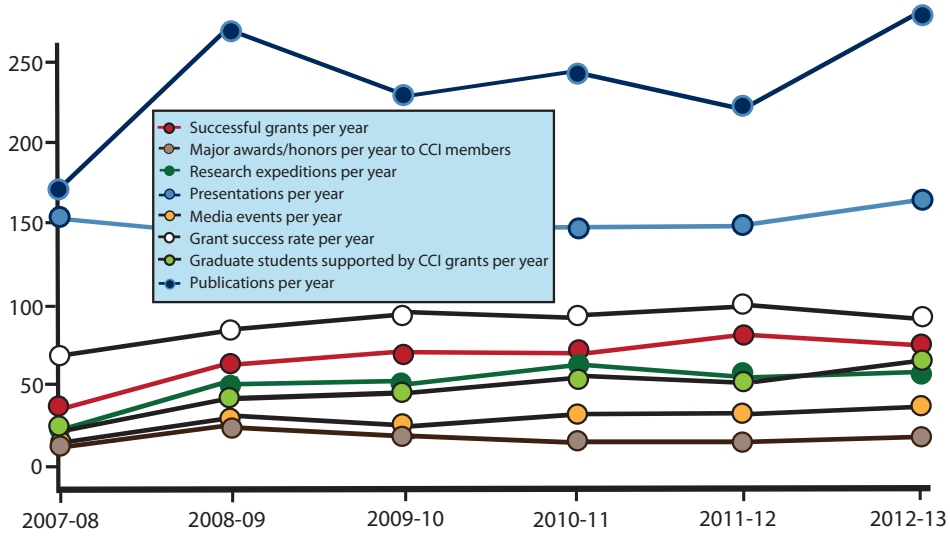

Figure 5. CCI productivity history.

4. **Proven record of sustainability re: personnel, facilities, and funding.** Over the past four decades CCI has earned and maintained an international reputation in recognition of the unique climate perspective it provides. Institute researchers have contributed substantially to the understanding of past, present, and future climate change as demonstrated by the numerous high profile honors received by our faculty and students. Institute research is supported by highly competitive, peer-reviewed grants from a variety of sources (Figure 6 with a proven record of sustainability (Figures 5, 6, 7, 8) as CCI has grown from approximately 35 members in 2000 to the current 130 members.

Figure 6. CCI extramural funding is from a broad range of federal, foundation and private sources.

5. **Leverages existing resources.** Examples follow:
   - Three of the "Faculty Five" who brought MEIF to the University are CCI faculty.
   - CCI administers ~90-100 grant accounts/year for an average of ~$10 million/year (Figure 7) and a grant success record of ~80% (US average success 10-20%) (Figure 5).
   - CCI grants have yielded more than $10 million in state-of-the-art-equipment.
   - Currently CCI has 130 members (61 faculty with 11 jointly funded between CCI and academic units), 4 research faculty with partial to no support from the university, 52 graduate students (the vast majority are supported by CCI administered federal grants (Figure 5)), 6 post-docs supported by CCI grants, and 7 staff (grants and university support).
   - The 11 CCI jointly funded tenure track positions (7 in the School of Earth and Climate Sciences, 2 in the Department of Anthropology, 2 in the School of Biology and Ecology) offer considerable curricula and research strength to their respective academic units.
   - Return on university investment (ROI counted as total E&G and MEIF allocated to CCI) has been ~$8-10/year for at least the last five years (Figure 8) with the average amount raised by each CCI grant researcher supported by E&G/MEIF (total 11) ~ $800,000/year.
   - ROI for CCI Research faculty is ~$21 for every one dollar invested in CCI research faculty by the university with some receiving no investment yet returning $635,000 on a single grant. Adding research faculty to CCI will increase grant revenue and

undergraduate and graduate education because these faculty support student stipends and regularly teach courses (unsupported).

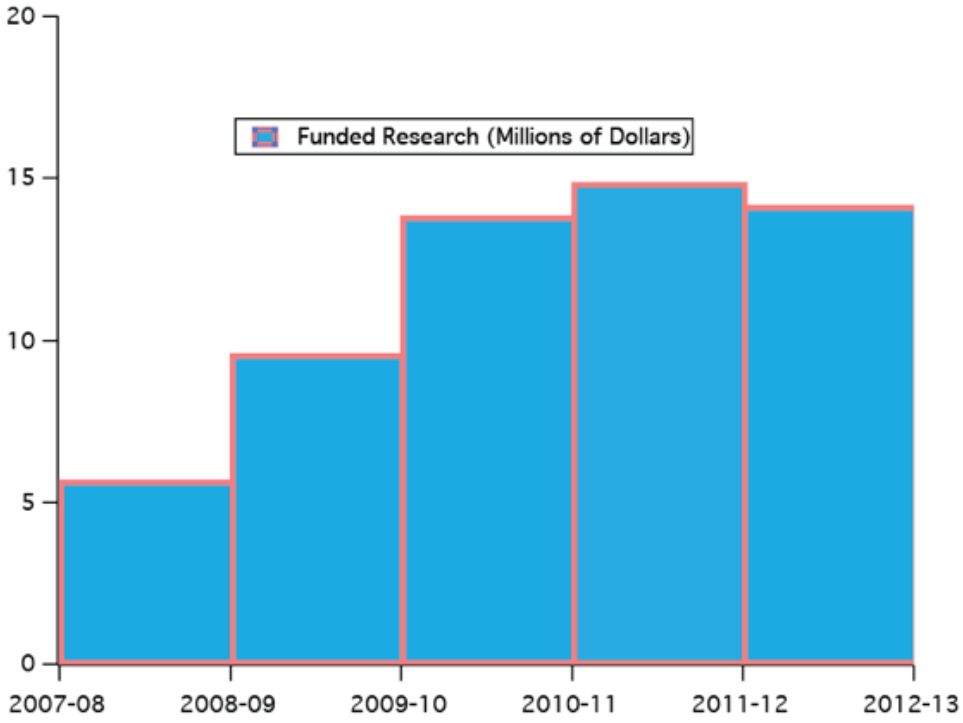

Figure 7. Proposal driven funds (in millions of dollars per year) raised by CCI members.

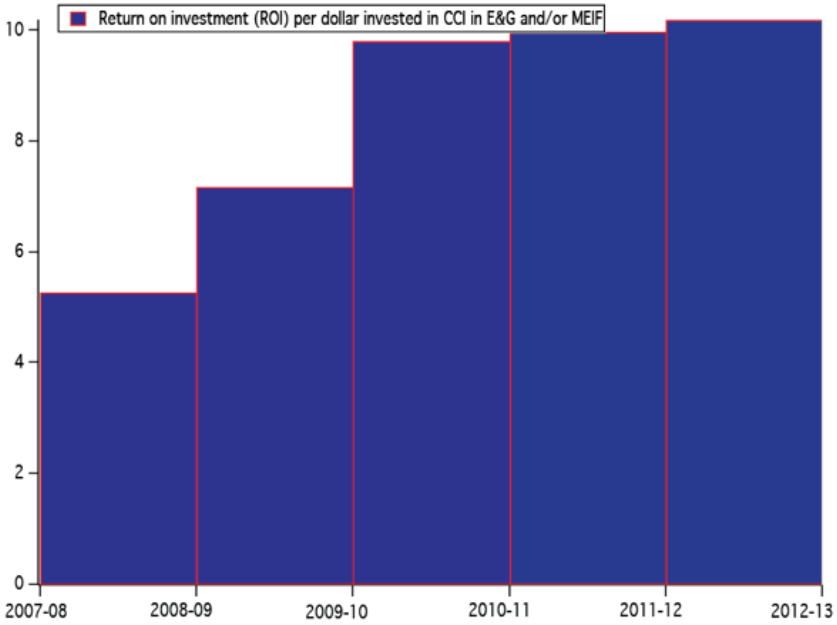

Figure 8. Return of investment (ROI) is the ratio of dollars attracted by CCI researchers divided by the dollars in E&G and/or MEIF allocated to CCI researchers by the University of Maine.

6. **Is interdisciplinary and/or multidisciplinary.** CCI researchers work all over the world (Figure 3) and CCI offers both a national and an international model for inter- and multi-disciplinary research and education (Figures 1, 2, 4). CCI's view of climate change invokes physical, chemical, biological, socio-cultural and economic aspects of interactions with and application of climate change understanding. CCI has been at the vanguard of the rapidly evolving concept that "climate change" as used in the public forum is a major global to local scale security issue - it impacts human and ecosystem health, the economy, catastrophes and geopolitics (Figure 2).

7. **Integrates with the teaching and service missions.** CCI's partners and stakeholders include:

- *Within the University of Maine* - The Schools of Biology and Ecology, Computing and Information Sciences, Earth and Climate Sciences (half of SECS faculty are also CCI faculty and SECS offers undergraduate and graduate degrees in climate sciences), Marine Sciences, Forest Resources, Food and Agriculture, Policy and International Affairs (CCI and SPIA share an NSF IGERT that will support 25 PhD graduate students over five years – first ever to address abrupt climate change), Department of Anthropology (half of the Anthropology faculty are associated with CCI and they offer undergraduate and graduate degrees associated with climate science), the Honors College, LASST, the Department of Chemistry, the Department of Physics and Astronomy, the Hudson Museum, the Center for Research in STEM Education (RISE Center), the Foster Innovation Center.
- *Emerging Associations Within the University of Maine* – examples include: climate and health with the School of Biology and Ecology and the National Center for Geographical Information and Analysis (NCGIA), environmental sensor development and data transmission with NCGIA and LAAST, innovations in past, present and future climate visualization with VEMI (Virtual Environment and Multimodal Interaction), *Abrupt Climate Change, Business and Policy* course with the Business School and the School for Policy and International Affairs, and a new joint Climate Change Institute, School of Earth and Climate Sciences, School of Biology & Ecology and Department of Anthropology Graduate Certificate in Interdisciplinary Climate Studies.
- *Within Maine* - Bangor, Lewiston-Auburn and Portland Water Districts, the Department of Water Resources, the Maine Department of the Environmental Protection, the Maine Department of Transportation, the Maine Centers for Disease Control, the Maine Geological Survey, the Maine State Museum, the Lobsterman's Association, the Gulf of Maine Research Institute, The Island Institute, The Nature Conservancy, Audubon, Manomet Observatory, Conservation Law Foundation, Maine Natural Resources Council, Maine Physical Sciences Partnerships, Schoodic Education and Research Center, Acadia National Park, Unity College, College of the Atlantic, Maine Lakes Environmental Association, Kezar Lake Watershed Association, Acadia National Park, Big Reed Forest Reserve, Maine Natural History Observatory, University of Maine – Presque Isle, Toothacher Pond Association, Maine Coastal Island Wildlife Reserve, Penobscot Bay Teacher's Collaborative, Preti Flaherty Law, MicMac Environmental Monitoring Laboratory, Maine Lung Association, Eastern Maine Medical Center, Maine Estuarine Research Institute and the Maine School of Law.
- *Federal including* - Acadia National Park, US Department of Agriculture, US Forest Service, US Geological Survey, Oak Ridge Laboratory, National Center for Atmospheric Research, University Corporation for Atmospheric Research, National Weather Center, US Fish and Wildlife, Homeland Security.
- *US institutions including* - Dartmouth College, Harvard University, Lamont-Doherty Earth Observatory, Princeton University, University of Washington, University of Nebraska, University of Oklahoma, Appalachian State University, University of Cincinnati, Texas Tech University, Kansas State University, University of Wisconsin, Brown University, University

of Wyoming, Harvard Forest, University of Minnesota Natural Resources Institute, Minnesota Pollution Control Agency, Washington State University, Washington Central University, Konza Prairie Long-Term Ecological Research Station, McMurdo (Antarctica) Long-Term Ecological Research Station, American Museum of Natural History, Boston Museum of Science, University of California – Santa Cruz, Berkeley, Santa Barbara, Brigham Young University, Michigan Technical University, Woods Hole Oceanographic Institute.

- *International including* - Academic, governmental and non-governmental organizations in Australia, New Zealand, Canada, Brazil, Chile, Colombia, Argentina, Peru, India, Nepal, Czech Republic, Ecuador, China, South Korea, Tajikistan, Kazakhstan, England, Scotland, Ireland, Denmark, Switzerland, Germany, France, Italy, Spain, Sweden, Norway, Greenland, Iceland and most recently: association with the University of the Arctic consortium and the South Atlantic Environmental Research Institute (Falkland Islands).

How can climate change at the University of Maine and the Climate Change Institute thrive and grow?

For climate change and the Climate Change Institute at the University of Maine to continue to function at the cutting edge of climate change and continue to thrive and lead in the nation and the world requires the following:

- Continued growth in tenure track faculty positions shared between CCI and its legacy academic partners (School of Earth and Climate Sciences, Department of Anthropology, School of Biology and Ecology) and continued collaboration between CCI and cooperating faculty in several academic and research units such as: School of Computing and Information Sciences, the Department of Chemistry, School of Marine Sciences, School of Forest Resources.
- Addition to CCI of research faculty supported at least partially by E&G and/or MEIF with compensation for teaching.
- Expansion and/or addition of transformative new directions for CCI and climate change at the University of Maine including cyberinfrastructure with an emphasis on data integration, analysis and visualization.
- Resources to enhance outreach via CCI and CCI partners to address the increasing demand for climate information, mitigation support, and adaptation and sustainability strategies.

During spring-winter 2014 the Climate Change Institute developed through a combination of faculty/staff meetings, a retreat, and several writing iterations a series of "white papers" intended to lay out the projected needs for existing and emerging themes for the Climate Change Institute and its University of Maine partners to undertake over the 2015-2020 period. The white paper for each theme summarizes the intellectual merit, broader impacts, associated partners, potential funding sources and projected needs (Appendix A).

The themes include:

Climate change indicators, adaptation and outreach
Climate modeling and earth systems visualization
Cyberinfrastructure, and data mining
Drivers of sea level change past, present and future – and impacts on civilization
Ecological response to past, present and future climate change
Human dimensions of climate change: past, present and future
Marine geology
Radar investigation of ice sheet beds
Sustainability, adaptation and resilience
Tephrochronology and volcanic forcing

Appendix A - Climate Change Institute Theme White Papers

Climate Change Indicators, Adaptation, and Outreach

Intellectual Merit:
The overarching concept is to strengthen the role of CCI in leading efforts to utilize environmental monitoring (broadly defined) in support of human adaptation to a changing climate. The focus begins with leading the University of Maine efforts in this arena, and extends to the national and global scale. Climate change indicators would include a data/web portal with tools and links to monitoring programs and web sites. Climate change adaptation and outreach would focus on developing evidence-based actions. The educational component would focus on outreach to spur mitigation and adaptation.

Broader Impacts:
This area is highly interdisciplinary, as well as bridging the functions of the University of Maine between education, research and outreach. CCI is already accomplishing some of these goals, but there are growing opportunities and needs. In many areas, CCI can partner with other academic, research and outreach units at the university and beyond to carry out this enterprise.
NOTE: *A key concept from the group discussion was that this 'outreach' activity actually cuts across almost all of CCI areas of activity, and may not represent a discrete research "theme" as described elsewhere in this strategic planning effort.*

Associated Partners:
It is realistic to think that essentially all units on campus could be partners in this endeavor, and examples exist where this is happening across disciplinary boundaries. These could include targeted, hypothesis-driven research projects, or outreach to address information needs in climate change mitigation and adaptation that are increasingly important to society.

Potential Funding Sources:
Foundations and agencies (e.g., Mellon, NSF, NOAA) are the logical possibilities. More opportunities exist for hypothesis-driven research initiatives while supporting stronger outreach components remains challenging.

Personnel and Facilities:
No unique research equipment is required. Existing faculty and staff provide the core expertise. Funding would be required to expand the current efforts, which could add personnel and needs for office space and support. Funding for new or enhanced environmental monitoring programs would presumably come from the funded programs. If CCI is to move further into the role of utilizing environmental monitoring and other research data to inform and support human mitigation of and adaptation to changing climate, additional staff resources are required for coordinating communications and outreach in support of the CCI faculty and their partners.

Climate Modeling and Earth Systems Visualization

Disciplines:
Atmosphere modeling, ice-sheet modeling, ocean modeling, silicate earth modeling, data visualization, computer science, web design and development.

Related Research Themes:
Cyber Infrastructure and Data Mining

Intellectual Merit and Broader Impact:
Numerical models are extraordinary tools for understanding Earth's climate (atmosphere, oceanosphere, biosphere, cryosphere) and other natural systems (e.g., lithosphere). As human population and impact on the planet expands, numerical models become increasingly important for their capacity to predict changes in future climate and resource availability. We propose to 1) expand climate modeling and 2) data visualization capabilities at CCI for the benefit of Maine stakeholders.

Our climate modeling will focus on high-resolution downscaling of reanalysis and general circulation model (GCM) in order to evaluate recent and future-predicted changes in temperature, precipitation, and wind across Maine. We will help interpret how these changing metrics affect Maine citizens and industry. This work will also include global research using the UMaine Ice Sheet Model (UMISM) and lithospheric models to investigate sea-level changes and tectonic-climate linkages.

The data visualization component of this research will center on expanding CCI's existing Climate Reanalyzer (http://cci-reanalyzer.org) and 10Green (http://10green.org) web apps for the purpose of providing simplified public access to an array of climate models and data for the benefit to Maine educators, students, and policy makers. Climate Reanalyzer currently provides access to more than a dozen datasets, including reanalysis, weather forecast, and daily meteorological station records. The websites receives on average 400-700 visits per day (and with spikes of 1000-2500 recorded during media reported extreme weather events). 10Green provides access to U.S. EPA air quality data in Maine and the U.S. Although the work proposed here will focus most directly on Maine, it will be expandable to national and global scales.

Existing Facilities:
The majority of necessary software and hardware facilities for our proposed research area already exist amongst CCI collaborators, and thus further expansion will require only limited financial support. Our existing resources follow:

Climate Reanalyzer and 10Green
Climate Reanalyzer (cci-reanalyzer.org) provides a simple, consistent framework for visualizing about two dozen climate models (reanalysis and GCMs), weather forecast models, and meteorological station data (GHCN). The software includes interactive user interfaces, and the ability to export maps to a variety of formats, including Google Earth KML. 10Green (10green.org) provides easy access to public air quality data collected by the U.S. EPA. The software could be expanded to host global air quality and environmental datasets.

Geodynamics and Numerical Modeling Laboratory
The Koons Geodynamics and Numerical Modeling Laboratory houses an array of multi-core desktop computer systems capable of intensive numerical use. Software includes MATLAB, COMSOL Multiphysics, FLAC3D, NCL, NCO, and C and Fortran

compilers. Birkel also maintains three high-end 12-core desktop servers that host Climate Reanalyzer and run the Weather Research and Forecasting (WRF) model for downscaling weather forecasts. Machines within the scope of the laboratory have combined storage capacity of ~ 30 Tb.

UMaine Advanced Computing Group – Supercomputing Cluster and Visualization Wall

Birkel and Koons maintain active collaboration with members Bruce Segee, Yifeng Zhu, and Steve Cousins of the UMaine Advanced Computing Group (ACG) (http://acg.umaine.edu). The ACG offers High-Performance Parallel Computing (HPC) with up to 640 processing cores online at any one time. ACG also provides a data visualization cluster and has a data storage capacity of nearly 400 Tb.

The ACG furthermore maintains tiled high-resolution display walls that enable unique interrogation of ultra-large pixel images. Display walls afford the benefit of providing context for large spatial datasets without the need to zoom and pan, as is necessary on limited display systems. The display wall is applicable to research, but likely serves greatest purpose for educational experiences.

NCAR/UCAR Supercomputing Facilities

The chief facility is Yellowstone, a 1.5-petaflop high-performance IBM iDataPlex cluster that features 72,576 Intel Sandy Bridge processors and 144.6 TB of memory (https://www2.cisl.ucar.edu/resources/yellowstone). Birkel and graduate students have active accounts on the NCAR system, on which they run WRF for regional climate modeling. NCAR/UCAR supercomputing resources are available to faculty and students at any U.S. higher education institution per relevant NSF grant, or by research application.

Advancement Requirements:

- At least 1 tenure track faculty position in Climate Modeling and Data Visualization or related field.
- At least 1 postdoctoral researcher to assist with climate modeling and software development.

Potential Funding Sources:

NSF, NOAA, NASA, UMaine, Private Foundations, State of Maine

Cyberinfrastructure and Data Mining

Tools for advancing scientific research and innovation

Disciplines:
Cyberinfrastructure, data mining, data visualization, computer programming

Summary Statement Goal:
To further expand the cyberinfrastructure and data mining initiative at the CCI to help advance interdisciplinary climate research and education. This will insure future advances in the field of climate change research that the CCI has pioneered.

Other Themes: The work is close to **Climate Modeling and Earth Systems Visualization theme**

Intellectual Merit:
1. Automate climate data collection, assimilation and visualization.
2. Develop 'smart data integration' tools to advance climate change research.
3. Design new pattern recognition algorithms for data mining
4. Design computer systems that handle an increased volume of data with reduced data mining time and research domain specific algorithms.

Possible Focus Areas:
Automation of research instrumentation and data processing.
Designing association rules and patterns for data mining.
Rapid (real time) data processing.
Better understand which research areas will benefit from the automation.
Expand data storage and handling capacity (collect everything).

Broader Impacts:
Relative to CCI, University of Maine, climate change research and application
New computation tools and data managing framework will:

- Provide a solid foundation for interdisciplinary research and collaboration within a wide area of scientific disciplines.
- Simplify public access to the latest climate data products.
- Data processing transparency will enable users to trace all data mining steps and evaluate utilized algorithms.
- Make climate change research results open and replicable.
- Expand visibility of CCI research programs to a wide community.

Associated Partners:
Climate Change Institute (CCI), School of Computing & Information Science (SCIS), Office of Sustainability, School of Earth and Climate Sciences (SECS)

Potential Funding Sources:
NSF, NOAA, NASA, EPA, State of Maine (e.g., DACF, DEP, DIFW$\dots$), UMaine, Private industry e.g., insurance companies, real estate organizations).

Potential Collaborators:
Fei Chai, Andrew C. Thomas, Huijie Xue (all at SMS), Andrew S. Reeve (SECS), Sean D. Birkel, James L. Fastook, Peter O. Koons, Kirk A. Maasch

Projected:

- One or two postdoc positions through CCI $60-120 k per year
- Computer server related expenses $3-4k per year
- Summer internship for international graduate students: $8-10 k per summer

Drivers of Sea-level Change Past, Present, and Future – and Impacts on Civilization

Disciplines:
Ice-sheet extent
Glacial geology, marine geology, glaciology, ice-sheet modelling, climate modelling
Sea-level change
Relative sea level, isostasy, ice-sheet modelling
Coastal populations
Coastal adaptation, peopling of Americas

Intellectual Merit: Models that predict the rates and magnitude of future sea-level rise depend heavily on knowledge of the drivers of sea-level change at a variety of timescales. Over long (~100 ka) time frames, sea level is controlled by glacial/interglacial cycles, which cause the buildup and demise of ice sheets. However, the origin of these cycles, including both the underlying cause of ice ages and the transition from 41,000 to 100,000-yr cycles in the mid-Pleistocene, remains poorly understood. Moreover, dynamic glacier response to both these long-term cycles, as well as to short-term variations, such as the 21st-century warming, remains one of the largest uncertainties in predicting future sea-level change.

In addition to global sea-level changes, local relative sea level also varies over time due to the isostatic response of the land to changing ice and sediment volumes. Local sea-level changes have the potential to impact coastal morphology, human settlement and migration patterns and our understanding of them (both recent and in the distant past), and evolution and speciation of organisms.

Broader Impacts:
With nearly 6000 km of coastline, Maine is especially vulnerable to sea-level rise. Changing sea levels have significant, but often unquantifiable impacts. For example, rising sea levels are anticipated to have adverse social and economic effects through flooding of coastal communities. However, there also are less visible impacts. For instance, rising sea levels also would lead to a change in the shape of the Gulf of Maine, potentially altering tidal range. Tidal range influences a variety of aspects, ranging from marine fisheries to coastal erosion.

The impact of sea-level change on coastal communities is not limited to the present day. Sea-level change has influenced coastal settlement patterns and adaptations on archaeological timescales, as well as migration of humans across the earth. Moreover, relative sea-level change dictates what evidence of these past civilizations is preserved and available for study. For example, coastal erosion of existing shell middens in Maine and around the world has resulted in the loss of cultural materials from a context that would otherwise have excellent preservation.

Historic and Existing Strengths:
The institute has had historic strengths in the following fields related to sea-level change:

- Glacial mapping and chronology (North America, Antarctica, South America, New Zealand)
- Study of glaciomarine sediments on northern continental shelves (Maine, Ireland)
- Ice-sheet and glacier modelling (North America, Antarctica, New Zealand)

- Post-glacial relative sea level (Maine, Ireland, Greenland, Antarctica)
- Coastal settlement and marine adaptation of people in the Americas (Maine, Peru)

Existing Infrastructure:
The institute and related departments host several laboratories involved in this work, including the Sedimentology laboratory in Bryand Global Sciences and the Glacial Geology and Geochronology laboratory in Sawyer. The Glacial Geology and Geochronology facilities provide room for analyses of sediments and preparation of samples for radiocarbon dating. A clean laboratory allows us to conduct more detailed geochemical analyses, including U-series and cosmogenic isotope dating. In addition, the glacial geology group is well-equipped with coring devices and platforms, drills, and a variety of other field gear necessary to place a group in the field at any location worldwide. Marine geology infrastructure includes seismic reflection, side scan sonar and multibeam bathymetric mapping equipment, ground-penetrating radar with antennae of 3 frequencies, terrestrial and marine vibracorers as well as a completely equipped workshop and large storage building, a catamaran rigged to work in lakes and shallow bays, a trailer to transport equipment and a modern, well equipped sedimentology lab. Other resources available to the group include the University of Maine Ice Sheet Model (UMISM).

Future Needs:
Looking to the future, our most pressing need will be the replacement of existing faculty as retirements progress. Additional faculty positions that we would seek include 1) a cosmogenic isotope geochemist with an emphasis in using the dating technique to address problems of climate change, and 2) an ocean-atmosphere modeller. Cosmogenic dating has now become a vital part of virtually every surficial geologic field, because of its ability to resolve when surfaces became exposed. This has important implications for geology-based climate science (i.e., reconstructions of past glacier extents to derive ice-volume or temperature changes), as well as for geomorphology (i.e., shoreline terraces, sea cliffs), and potentially for archaeology. Moreover, it is becoming increasingly clear that major shifts in global climate that lead to sea-level changes arise through non-linear interactions within the ocean-atmosphere system. Accordingly, we also request a faculty position in ocean-atmosphere interaction to be filled by an individual who can integrate natural observations with emerging global and regional models of ocean-atmospheric circulation.

Ecological Response to Past, Present & Future Climate Change

Summary Statement:
To better understand past, present, and future effects of climate on ecological responses, our goals for the next 5 years are to:

1. fill key gaps in expertise in ecosystem-scale processes and linkages, microbial ecology/ geomicrobiology, and plant physiology through a combination of 1-2 tenure-track positions, 1-2 research assistant professor positions (for whom the 40% return on IDC will be critical), and 1-2 postdoctoral research associates;
2. renovate facilities to provide temperature-controlled experimental capabilities;
3. expand stable isotope capabilities to include organic analysis (an important new analytical capacity);
4. expand collaboration between this theme and others in CCI, particularly those focused on modeling, adaptation, and cross-system linkages.

Intellectual Merit: This theme merges the two previous research areas of Paleoecology and Ecosystems. Both areas have grown substantially in the past few years, and more researchers in these areas conduct research that cuts across these two themes. Merging them into one will foster more collaboration within this theme as well as with other themes.

This Ecology theme will serve as: 1) the primary one in CCI focused on the biological and biogeochemical response to climate change; 2) a cornerstone of ecosystem research across themes; and 3) the scientific foundation for the role of ecosystem services in mitigation and adaptation.

Ecosystems and the ecosystem services (e.g., food security, fiber, renewable energy, clean water, recreation, habitat, carbon sequestration) they provide are the foundation of our society and economy, and provide critical feedbacks to the climate system (e.g., GHGs, albedo). Ecosystems also encompass the individuals and populations of organisms whose interactions make up the food webs upon which ecosystem services rely. This research focuses on the effects of both chemical and physical changes in our environment on the organisms and processes that underlie ecosystem function. This research encompasses issues such as acid deposition, reactive nitrogen, biodiversity, eutrophication, mercury and heavy metals, as well as changing temperature and moisture regimes on both short-term (weather) and long-term (climate) timescales. Key components of this research have been long-term perspectives on ecological responses to climate change through paleoecology, and long-term empirical research of modern day changes in ecosystem function through time utilizing observatories from single lake systems to whole calibrated watersheds. Furthermore, the arrival of new researchers at UMaine has broadened capacity to conduct experimental research on ecosystems responses to past, present and future climate scenarios.
Broader impacts: Understanding ecological response to past, present, and future climate change is of vital relevance to everyone. Consequences of ecological responses are likely to be especially relevant to:

- Policymakers, agencies, and municipalities that regulate shoreline, marine, riparian, and forest ecosystems, land-use zoning and development.
- Agencies that manage Maine's natural resource assets such as Department of Environmental Protection, Department of Agriculture, Conservation, and Forestry, Department of Inland Fisheries and Wildlife, and Department of Marine Resources.
- Landowners, including land trusts, parks, and conservation organizations, who seek to conserve the diversity and resilience of Maine's habitats, wildlife, and ecosystems.

Stewardship and management decisions depend on understanding ecosystem responses to climate change such as population dynamics of invasive species, impacts to forest health, changes in seasonality and in forest disturbance regimes.

- Native American communities whose traditional and contemporary culture is intimately tied to the organisms and ecosystesm services of Maine landscapes.
- Businesses that depend on one or more of Maine's ecosystems for success. Examples include Maine's lobster fishery, agriculture, forestry, skiing and other outdoor recreational sports, hunting and fishing, and tourism.
- K-12 and undergraduate students (and their teachers) who will live in and depend upon ecosystems that are continuing to change in response to climate. We serve the K-12 audience by supporting (1) Student-Teacher-Scientist partnerships that engage students in ecosystem research projects in the field in partnership with University researchers; (2) professional development opportunities for science teachers that support teaching of environmental and ecosystem studies and climate change; (3) access to sources of data relevant to environmental and ecosystem responses to climate change.

"Maine's Climate Future" and "People and Nature" were published to reach many of these audiences, and we collaborate with many of them through speaking engagements, committees, task forces, and other meetings and exchanges. The goal of serving these audiences overlaps with the goals of the Climate change indicators, adaptation, and sustainability sub-group, and the broader goals of enhancing CCI's value to stakeholders in Maine communities and beyond.

Associated Partners:
This theme involves faculty, staff and students from SBE, SFR, SECS, SMS, and ANT. Many of our partners are highlighted in the Broader Impacts above. We also have international collaborations in New Zealand and Australia, the UK, Argentina, Peru, the Falklands, France, Czech Republic, Germany, and Canada.

Potential Funding Sources:
NSF, DOE, DOI, NSRC, NAC CESU, USDA NIFA, Maine DEP, NOAA, US EPA, Maine WRRI, private industry, foundations.

Personnel and Facilities: (current and projected)
In addition to the personnel listed above, current facilities include the Paleoecology Laboratory and the Sawyer Water Research Laboratory in addition to faculty laboratories. We have (or have had) access to field sites and research stations: Acadia National Park, Holt Forest, Penobscot Experiment Forest, University Forest, Howland Research Station, Bear Brook watershed, Baxter Park, MAFES Farms (Highmoor, Rogers, Witter, Aroostook), Weymouth Point Watershed, and The Nature Conservancy as well as distributed research networks such as long-term atmospheric deposition stations, lake monitoring sites, and weather stations.

Future priority faculty hires for this area include an aquatic ecosystem ecologist, a hydrologist focused on terrestrial-aquatic linkages, a geomicrobiologist, a mammalian ecologist, a bioclimatologist, and an ecophysiologist. In particular, we note that our expertise at the ecosystem level has lost breadth at the university in recent years, leaving a critical gap in our capacity for ecological research. Building this capacity in and through CCI will enable us to achieve both CCI and university aspirations for deepening our strengths in the climate change signature program area.

Future priority investments in facilities include the addition of an organic stable isotope facility, the addition of a temperature-controlled facility for conducting experiments, and replacement of aging analytical equipment that is in high demand. Expanded core storage and greenhouse space, cost-effective access to suitable vehicles for field research, are also needed. A University field site with field station designed for inter- and multi-disciplinary research for long term, ongoing ecosystem study is also desirable.

The Human Dimensions of Climate Change: Past, Present, and Future

Intellectual Merit:
Human activity created the current climate threat, and research on the former is vital to understanding and responding to the latter. Over the next five years, our anthropological and archaeological research team will advance knowledge in three key areas: climate reconstruction; the impacts of natural-social system dynamics on climate variability; and the social-science/climate interface.

Climate Reconstruction
The archaeological record contains proxies that allow us both to reconstruct past environments, climates, and paleo-climatic change and to calibrate other climate proxies. Our researchers have recovered climate records from sites across the world and have made important contributions to understanding ENSO events. This work will continue over the next 5 years.

In Maine, our research goes back 13,000 years and tracks forward to recent times. We specialize in reconstructing Gulf of Maine ecological history, marine stocks, and human/marine interactions. This research will continue and will take on increasing urgency because data sources are largely restricted to coastal shell middens, which are threatened by rising sea levels.

The Reciprocal Impacts of Coupled Natural-social System Dynamics on Climate Variability
We study multiple dimensions of the coupled natural-social dynamics of the Anthropocene – the age of humans and their domination of earth's ecosystems – with particular foci on abrupt and long-term climate change. We plan to expand our analysis of: a) past and present human demographic increase, settlement expansion, resource consumption, carbon combustion, and land-use change; and b) the impacts of these processes on biodiversity loss, on other threats to ecosystem functioning, on human health, and on disaster exposure.

Our research considers the causes and implications of these changes. What has distinguished, and will continue to mark, our investigations is an emphasis not just on their economic but also on their political, social, and cosmological dimensions.

The Social Science/Climate Interface: Projection, Adaptation, and Sustainability Policy
The foregoing investigations inform research on policy related to climate-change prediction, mitigation, and adaptation. We will continue to expand our research on selected climate-policy issues, including the social drivers of greenhouse gas emissions and the development and use of predictive models of anthropogenic ocean warming, acidification, and vector-borne disease in fishery and health adaptation policy, respectively. We shall also expand a new focus on environmentally-equitable carbon-accounting schemes.

Potential Funding Sources:
With the human dimensions of climate change increasing their presence on research and public agendas and debates about the Anthropocene, anthropology and archaeology are increasingly recognized as a necessary part of understanding both social and natural systems. These developments will open wider areas in research funding. In addition to standard archaeological and anthropological sources, we anticipate submissions to sources such as NSF 14-601: Dynamics of Coupled Natural

and Human Systems (CNH), and NSF 12-551: International Research Experiences for Students (IRES).

Broader Impacts:
For many years, our archaeological research has involved CCI Masters students and IPhD Doctoral students, and with the new Anthropology and Environmental Policy PhD program, we now involve PhD students in climate policy development. Thesis projects range from investigation of sea-level rise worldwide and ENSO events in Peru through abrupt climate-change events in the Gulf of Maine to lobster fishery policy under climate change in the Gulf of Maine.

Future Personnel and Facility Needs:
Recent developments in the Anthropology Department have produced a long-anticipated critical mass in core faculty working on the human dimensions of the environment in general and climate-change in particular. To capitalize on the opportunities this condition offers, it is critical this base strength be maintained.

In addition, we can expand these opportunities with the following hires (1a and 1b top priority, 2 next priority):

1a) An archaeologist specialized in modeling climate and environment to help advance the modeling capabilities of both archaeologists and anthropologists in CCI.

1b) A social anthropologist specialized in climate adaptation/sustainability policy to advance the momentum we are rapidly gaining in analysis of the social science/climate interface.

2) A new laboratory manager to replace the one lost to budget cuts a few years ago is important not only to support our archaeological work but also to maintain our status as a federal repository for northeast archaeology.

Many current equipment needs are met through cooperation with other CCI faculty; future equipment needs will be modest.

Outreach:
Our anthropological and archaeological research in climate-change, adaptation, and sustainability has multiple pro-active outreach implications. Our personnel already work, for instance, on the cultural impacts of environmental change and invasive species on Maine livelihoods such as fishing. They liaise with Maine's Native and non-Native communities to understand and engage past and present environmental issues. They work with policy makers in Sweden and China on carbon accounting and in Maine on the implications of climate data for Maine health, disaster planning, and disaster response.

Marine Geology

Short Description:

Marine Geology has been part of the Climate Change Institute since its formation, and continues to form an important discipline linking Earth Sciences, CCI and Marine Sciences. Much of the long-term record of climate change was developed from marine cores using sediments, fossils, and proxy indicators of change such as stable isotopes and geochemical indicators. Based on numerous reviews and participation on panels, such as the NSF Marine Geology and Geophysics panel, it is clear that this effort continues to be a fruitful, fundable area of research and student recruitment that is at the core of many programs around the US. A possible expansion in faculty positions, or at least one or more retirement replacements, could be targeted toward global change records in marine stratigraphy.

Our present strengths include research in sea-level change and resulting changes in environments and sedimentary systems. We also conduct cross-disciplinary studies in archaeology/anthropology with marine and coastal geology to understand the response of shorelines and the people who inhabit them to rising sea level and associated coastal processes, in locations such as the Maine coast, Peru, Northern Ireland, Scotland, and many other locations. With the recent explosion of human populations in coastal areas, there is a practical need to develop quantitative measurements and models for how coastal environments have changed, are changing, and will likely change as the level of the sea rises and storms frequently alter the shore. This was abundantly illustrated during Superstorm Sandy in 2012, which not incidentally resulted in large infusions of research funding along the northeast coast. In this area we have often worked with state agencies (Marine Resources, Maine Geological Survey, State Planning Office).

We have current strengths in research in shelf environments such as the Gulf of Maine, the Irish and Celtic Seas, and proposed work in the Falkland Islands. These studies are of particular significance in investigating shelves affected by Pleistocene glaciation, glacioisostatic responses, and complex sea-level responses. We have ongoing projects with scientists from the UK and Canada, and expect to continue to expand collaborative efforts elsewhere, as in past projects in the Caribbean Sea, the mid-Atlantic shelf, the Eastern Mediterranean Sea, and other regions. We have an extensive tool kit of remote sensing geophysical equipment and computer processing, coring devices, samplers and loggers, and mapping equipment. We also operate comprehensive sedimentology laboratories.

Marine Geology research is conducted with a strong emphasis on M.S. and Ph.D. students, but we also involved undergraduate students in projects. Thesis projects have ranged from local coastal studies, investigation of sea-level changes in salt marshes, nearshore marine geophysical and coring projects, major offshore geological oceanographic research, research in Maine Lakes, and a number of geoarchaeological studies. One notable lack to this point has been sponsoring of post-doctoral researchers, but this avenue should certainly be explored.

Our future needs include maintenance of existing hardware and software. Digital seismic and sidescan sonar equipment are near the end of their lifespan, and will need replacement. A new multibeam sonar system is in its first full field season, and we expect it to be a crucial tool for new research and student theses. New equipment, including a terrestrial LIDAR device and deeper-penetrating, lower frequency ground-penetrating radar antennae would greatly augment our equipment list and open up new research opportunities.

The most important looming issue, however, is replacement of existing faculty who are nearing retirement. Return to a model in which Marine Geology faculty were hired in a joint appointment between the School of Earth and Climate Sciences and one or both of the School of Marine Sciences, and the Climate Change Institute can have positive outcomes, as has been the case for more than 30 years. The present faculty occupying positions concerned with sedimentology and nearshore marine systems have proven their viability for more than three decades.

An important new position to consider is a paleoceanographer. This would not actually be a new position in the Institute, as Detmar Schniker and Tom Kellogg were productive in the field in the field from the 1970's through the 2000's. Paleoceanography is a vital and active field, with major funding available through NSF Ocean Science directorates. The record of climate change is available through four major sources: 1) glacial geology, in the form of sediments and landscapes on land and nearshore; 2) sea-level records from shoreline deposits (beaches, coral reefs, other) on land and nearshore; 3) ice core records from ice sheets and mountain glaciers; and 4) marine sediments recovered from coring and deep-sea drilling expeditions. The marine sediment record provides a longer and more diverse record of past climate change than any of the other three sources. It is based on proxies such as basic sedimentology, marine microfossils, stable isotopes, mineralogy, and organic geochemical signatures, such as alkenones. A paleoceanographer would interface well with programs in Earth Sciences and Marine Sciences. A specific disciplinary focus could include any of the specialties mentioned above, and also provide for basic needs in teaching and graduate advising in the areas of marine geology, sedimentology, and stratigraphy.

Radar investigations of Ice Sheet Beds

Radar has been used as a tool for surveying the topography of major ice sheets for many years. These surveys have been extended by Dr Gordon Oswald, a Research Professor at CCI, to determine the presence and distribution of subglacial water in support of ice sheet modeling activities. This technique has been brought to a state of effectiveness, and has yielded maps of the Greenland Ice Sheet's basal state. Its output is now being put to use by modelers at the University of Kansas. Further work may be needed as the state of modeling advances; however for now the activity is in a stable state and awaits progress by the glaciological modeling community.

Radar as a Tool for Climate Investigations:
The study of climate is closely linked with that of atmospheric temperature, humidity and movement, and therefore with the dynamic state of all layers of the airspace. Radar has been used for many years to study the motion of air and precipitation. The design of radar for these purposes is well understood, and is embodied in the US NexRad system, run by the National Weather Service, an agency of the National Oceanic and Atmospheric Administration (NOAA). However, air surveillance is undergoing a period of challenge by extreme weather events as well as by wind farm interference, air space intensification including unmanned drones, and pressure on its use of spectrum.

New forms of radar surveillance are becoming available, that will enhance the capacity of surveillance sensors. One of these is Holographic Radar; a staring array technology with tremendous capability for acquiring and discriminating different scattering targets and media. In essence, the entire motion of targets or turbulence within a defined volume of air is simultaneously and continuously acquired by the radar processor. In addition to detection and tracking of aircraft, in this case models of air flow and dynamics can be used to detect and investigate the scattering responses of both precipitation and air turbulence.

This form of radar is accessible for atmospheric studies by CCI through Dr Oswald, who while conducting research at CCI is also Chief Technology Officer of Aveillant Ltd, a developer of Holographic Radar. These devices are beginning to enter service in the air transport sector, as offering a clutter-free radar capable of discriminating different classes of targets. The key application anticipated is the detection and study, through imaging, of extreme weather events. Dr Oswald would propose to respond to CCI initiatives or requirements for such studies by making available expertise and potentially equipment or radar data.

Sustainability, Adaptation, and Resilience

Summary Statement:
The modern world has seldom had to face a threat as all-encompassing as accelerating climate change. Adapting to the reality of our current and future climate change while also achieving the resilience necessary to maintain social, ecological, and economic sustainability is the overriding challenge of the 21st century. Realizing sustainability is essential for the future of society and all other life on the planet. The CCI, fast becoming a leader in adaptation planning, is ideally suited to house a Certificate (or similar) qualification in Sustainability, Adaptation, and Resilience.

Intellectual Merit:
This theme will advance CCI's role in providing climate change adaptation education. The Institute has demonstrated its existing expertise in the realm of Climate Adaptation and Sustainability with the recently-held CLAS conference. It was clear, from the large numbers of conference participants, that there is a real interest in, and need for, adaptation planning and sustainability education. While the University requires all undergraduates to receive a certain amount of sustainability-related course content (primarily via the Population & the Environment sub-category of the Human Values and Social Context portion of the General Education Requirements), there is currently no requirement for graduate-level students to receive any sustainability-related content whatsoever. A certificate qualification, using modern online tools such as CCI's Climate Reanalyzer and coursework focused on the ecological, social and economic dimensions of sustainability, will provide a high-level educational product aimed at the upper level undergraduate and graduate students here at UMaine. Additionally, an online version of the certificate would extend the reach of this product to external interested parties far beyond Maine's borders. UMaine already offers a significant variety of climate- and sustainability-related course content. Organizing the appropriate existing course options into a training "package" is relatively achievable without significant investment in new course development. In addition, student interest in this subject can further drive future curriculum development as demand dictates.

Broader Impacts:
- Educate students and public decision-makers about climate change adaptation, resilience, and sustainability, while at the same time developing methods to mitigate further change.
- Demonstrate that from a human perspective, all systems have constraints, including the Earth.
- Train students how to recognize the interdependence and interconnectedness of Human and Earth systems.
- Teach students about the social, economic and political variables that impact the Earth's systems and shape both vulnerability and adaptive capacity.
- Educate students about the barriers to adaptation, resilience, and sustainability, including education and awareness, political will, economic investment, and uncertainty.
- Empower students with the knowledge and tools needed to change our currently unsustainable way of life for a sustainable future.

Associated Partners:
Potentially, any department that offers climate change or sustainability related course content.

Potential Funding Sources:
NSF, UMaine, State of Maine, EPA, Non-profits (e.g. Pew Charitable Trust)

Current Personnel and Facilities:
Daniel Dixon, Molly Schauffler, Cynthia Isenhour, Ivan Fernandez, Paul Roscoe, and Paul Mayewski. UMaine currently offers 70 sustainability-related courses from 25 different schools and departments. Assuming that an online version of the certificate is offered, collaboration with the Continuing and Distance Education Office will be important.

Projected Personnel and Facilities:
This educational product will require a full- or part-time sustainability education coordinator to gather, organize, and deliver available course content each semester. The University will need to provide incentives for educators from multiple departments to teach beyond their walls, and provide appropriate recognition for doing so.

Tephrochronology and Volcanic Forcing

Background:
Since the mid 60's CCI faculty and graduate students have been applying tephrochronological methods in paleoclimate research: e.g., Borns, Bromley, Burke, Denton, Hall, Kurbatov, Marchant, Mayewski, Rademaker, Saros, Sandweiss, Vandergoes.

Current research on volcanic aerosols and particles preserved in polar ice cores being conducted by Kurbatov in cooperation with CCI members: Dixon, Kreutz, Mayewski contributes to improving fundamental understanding of the impacts of Earth's volcanism on the climate system, changes in atmospheric circulation, and atmospheric chemistry from days to millennia.

Recently, newly developed methods in sample preparation and advances in analytical instrumentation have successfully demonstrated that it is also possible to detect super small tephra particles (cryptotephra) in a diverse range of paleoclimate archives (e.g., peat bogs, lake and marine sediments) and determine associated source eruptions. Globally distributed tephra layers provide unique time synchronization points to link records from different regional and depositional environments. For example, far-travelled volcanic ashes (tephras) from Holocene eruptions in Alaska and the Pacific northwest have been traced to the easternmost extent of North America or Alaskan "White River Ash" was correlated to the volcanic ash found in Greenland and northern Europe. While the field of cryptotephra was advanced in Europe, in the US only limited research and development has taken place in the last decade. The utilization of cryptotephra should provide a unique opportunity to develop a cryptotephra framework in the northeastern part of the United States and precisely link a wealth of existing paleoclimate information in Maine with global data sets.

Summary Statement:
We propose to utilize new methods for cryptotephra detection and parameterization to precisely synchronize global paleoclimate records. In order to continue advancing climate change research, the Climate Change Institute at the University of Maine needs additional internal resources to expand our existing expertise on polar tephrochronoloy and volcanic forcing of climate. To build a strong, highly competitive research and educational program we would like to reinforce the expertise in regional tephrochronology, volcanology, geochemistry and petrology. The proposed addition is closely linked to the "Understanding of Climate Change" mission of the Climate Change institute.

Intellectual Merit:
- Advance understanding of transport of ultra fine tephra particles in the atmosphere during the different states of the climate system.
- Contribute to a global paleoclimate events synchronization framework by linking paleoclimate data from peat bogs, lakes, and tree rings with global paleoclimate archives.
- Evaluate sporadic impacts of volcanic products on Maine ecosystems.

Possible Focus Areas:
- Cryptotephra sampling and preparation from lakes, peat bogs and marine records.

- Advance methodology for geochemical measurements (fingerprinting) of small cryptotephra.
- Regional history of volcanism.
- Volcanic product transport, deposition and impact on climate system.
- Interaction of volcanic products and atmospheric chemistry.

Broader Impacts:
Relative to CCI, University of Maine, climate change research and application a new tephrochronological framework will:

- Provide a solid foundation for identifying global time markers required for correlating different paleoclimate datasets. It will broaden interactions with other Maine research, academic and outreach units within the University, local, national and international partners. In general, global paleoclimate reconstructions contribute to better understanding past, present and future climate change-based decision-making by individuals, NGOs and governmental units.
- Develop relatively new and maintain in-house expertise required for cryptotephra work.

Associated Partners:
UM academic & research units, Climate Change Institute (CCI), School of Earth and Climate Sciences (SECS).

Potential Funding Sources:
NSF, NASA, State of Maine

Personnel and Facilities:
Tephrochronology Current
Andrei V. Kurbatov, Martin G. Yates.
Clean room, sample preparation facilities, microprobe, Scanning Electron Microscope, LA ICP-MS.

Projected:
Additional tenure track faculty position(s) probably also affiliated with the legacy academic partner Geochemistry-Petrology at the School of Earth and Climate Sciences.