CICAR Annual Performance Report
July 1, 2010 - June 30, 2011

NOAA AWARD Numbers: NA03OAR4320179 expired June 30, 2011
NA08OAR4320754
NA08OAR4320912

Prepared for:
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Cooperative Institute for Climate Applications and Research
EARTH INSTITUTE | COLUMBIA UNIVERSITY
CICAR 2011 Annual Performance Report to NOAA

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Preface

Document Purpose
The annual report for the Cooperative Institute for Climate Applications and Research (CICAR), a Cooperative Institute (CI) funded by the National Oceanic and Atmospheric Administration (NOAA) Office of Oceanic and Atmospheric Research (OAR), is a requirement of the OAR CI Program. The CICAR annual report describes all actively funded research projects, education initiatives, and public information and outreach programs conducted under CICAR NOAA grants NA03OAR4320179, NA08OAR4320754, and shadow award NA08OAR4320912 for the fiscal year ended June 30, 2011.

As a contributor to the OAR Cooperative Institute Program, CICAR research will, on a yearly basis, actively address NOAA’s next generation Strategic Plan for long-term Climate Adaptation and Mitigation - An informed society anticipating and responding to climate and its impacts.

Document Distribution
The CICAR annual report is distributed to the NOAA/OAR Cooperative Institute Program Office and is available in PDF version on both the NOAA Research Council CI web site http://www.nrc.noaa.gov/ci/locations/index.html and the CICAR http://www.cicar.ei.columbia.edu/ web site.

Document Contents
The 2011 CICAR annual report is a comprehensive written review of the administrative and research activity for the Institute’s eighth year of operation, began July 1, 2010 and ended June 30, 2011.

About CICAR

Mission Statement
The Cooperative Institute for Climate Applications and Research evaluates, understands, and predicts climate variability and change through the collection and analysis of modern and paleoclimate data and the use of Earth system models. We provide climate information to society through education and the development of applications and tools for assessing climate-related risks.

Overview
The Cooperative Institute for Climate Applications and Research (CICAR) was established in November 2003 as a research partnership between the National Oceanic and Atmospheric Administration and Columbia University In The City of New York. CICAR research themes are: (1) Earth system modeling; (2) Modern and paleoclimate observations; and (3) Climate variability and change applications research.

The NOAA funded research portfolio at Lamont grew out of a clear strategic vision of scientists at LDEO and NOAA. This vision stipulated that ocean observations and coupled ocean-atmosphere modeling is key to understanding long-term climate variability and change and to developing climate prediction capabilities. It also emphasized paleoclimate research as providing climate scenarios quite unlike those revealed in the short instrumental record, thus helping to expand our view of the Earth climate system and challenging our conceptual understanding and modeling capability. Actively pursuing these ideas, LDEO scientists have conducted research
based on observations (instrumental and proxy), analysis, and models and worked with NOAA to form programs and set research directions.

At the core of the CICAR research agenda is the collaboration between LDEO and two NOAA climate-oriented organizations: the Climate Program Office (CPO) and the Geophysical Fluid Dynamics Laboratory (GFDL). The CPO leads the NOAA involvement in the U.S. Climate and Global Change (C&GC) Program and sponsors scientific research aimed at understanding climate variability and its predictability. GFDL is “charged with producing timely and reliable knowledge and assessments on natural climate variability and anthropogenic change” through the development of Earth system models and theoretical understanding. Both these missions are consistent with the CICAR climate research agenda.

Structure

CICAR is administered by Columbia University through its Lamont-Doherty Earth Observatory and is located at the Observatory’s Palisades, New York campus. The Institute consists of the Director, who is an official of Columbia University, an administrative staff, an Advisory Committee, an Executive Board, and the scientific and support staff of the CICAR, who are members of LDEO and other units of The Earth Institute, Columbia University. The Geophysical Fluid Dynamics Laboratory, a NOAA Research facility, is the Institute’s principal connection to NOAA.

Research Overview

The Cooperative Institute for Climate Applications and Research develops and promotes research to address a wide range of physical and social science topics consistent with the CICAR mandate. The project summaries appearing in the research section include: observations and model development required for the prediction of seasonal-to-interannual and long-term climate variability; collecting instrumental observations and developing and archiving proxy records for deepening the understanding of climate variability and change; and for the development of tools for providing climate information to society to assess risk and make decisions.

The CICAR program of research and education strives to:

- Create a center of excellence dedicated to understanding the evolution of the Earth’s past and present climate and predict its future trajectory.
- Create a long-term research partnership between NOAA and the Columbia University climate research community to enhance NOAA’s research capabilities in the area of climate observations, modeling, and prediction.
- Contribute to NOAA’s goal to enhance society’s ability to plan and respond to climate variability and change by developing methods and tools for providing climate information to users and decision makers.
- Provide a basis for streamlining the administrative process for several established cooperative projects within Columbia University and NOAA – competitive and non-competitive.
- Develop specific research projects that address critical research needs in:
  - Climate modeling and prediction
  - Modern and paleoclimate research
  - Climate forecast applications research
- Create undergraduate-to-graduate level research and education opportunities that reflect NOAA priorities and interest through student participation in related science projects and by bringing NOAA science perspectives into the classroom.
• Identify opportunities and establish means to communicate climate research development to the public to facilitate broader understanding of climate related issues and their impact on society.
• Maintain close contact and research collaboration with the two other NOAA centers at Columbia, the International Research Institute for Climate and society, and the Consortium for Climate Risk in the Urban Northeast.

Synergies

The CICAR partnership benefits NOAA through synergies with various research centers at Columbia University (CU) particularly within the Earth Institute (EI). Collaborations and joint activities exist between CICAR and the International Research Institute for Climate and Society (IRI); the Consortium for Climate Risk in the Urban Northeast (CCRUN) a NOAA funded RISA and the Center for International Earth Science Information Network (CIESIN). CICAR also maintains ties with Columbia University’s Center for Research on Environmental Decisions (CRED); the Earth Institute Center for Hazard and Risk Assessment (CHRR); and the Columbia Climate Center (CCC).

Research projects and related education activities under CICAR address three overarching themes:

Theme I: Earth System Modeling
• Developing and improving climate models and modeling tools (e.g., data assimilation procedures) to simulate and predict climate variability and change.
• Designing climate experiments with numerical models of varying complexity to test hypotheses regarding, and to promote the understanding of, climate variability and change.
• Applying statistical tools to data and model output to study observed modes of climate variability, their simulation by climate models, and their predictability.
• Analyzing historical data to create spatially and temporally uniform information for research and applications.

Theme II: Modern and Paleoclimate Observations
• Developing, collecting, analyzing, archiving, and interpreting climate proxy data records to improve understanding of past climate variability and change on all time scales.
• Monitoring and observing the key ocean regions to understand the ocean role in climate and to improve climate models.

Theme III: Climate Variability and Change Applications Research
• Developing applications and tools that enable the translation of climate research and information to decision makers in the areas of agriculture, water resources, health, economics, and policy.
• Studying the interaction between providers of climate information and users and decision makers to improve communication for the benefit of society.

Operational Strategy by Task
The Institutes primary operational and research strategy is divided into four (4) tasks:
Task I: Administrative activities
Task II: Specialized science support activities
Task III: Proposed and currently funded individual projects
Task IV: Collaborative education program
Executive Summary

1. Overview
The Cooperative Institute for Climate Applications and Research (CICAR) 2011 Annual Report summarizes the research, administrative, and educational activities for the 2010-11 fiscal year, the third year of a five-year continuation of our cooperative agreement with NOAA. Institute activities reflect a continued commitment to our traditional themes. Significant this year was the continued strengthening of collaboration with the two other NOAA funded projects at Columbia: the International Research Institute for Climate and Society (IRI) and the Consortium for Climate Risk in the Urban Northeast (CCRUN) a NOAA funded RISA. This effort brings together the physical aspects of climate research with the application aspects and the building of bridges between climate science and stakeholders and decision makers in public and government sectors in the US and abroad. In this sense CICAR finds itself in a unique position to help these two organizations, which operate under a fixed, less flexible annual budget.

The CICAR research portfolio was adversely impacted in FY10/11 by the NOAA decision to award competitive funding for projects proposed under the Institute, directly to Columbia University and without reference to CICAR. These six awards are substantial, multi-year projects that represent significant research investment and outcomes, relevant to our mission and the NOAA Climate Goal. We applaud the NOAA decision to amend this practice in FY12 by linking future awards to the CIs using the award special conditions document and the CI Memorandum of Agreement. As in previous years CICAR Task I Administration remains underfunded thus limiting our ability to support education and outreach programs and to attend Cooperative Institute meetings and other invited NOAA administrative events.

During FY11, CICAR administered 35 research and education projects including the Institute’s core administrative budget. This number includes: one project (inactive with remaining funds) that was funded under the original CICAR award NA03OAR4320179, which expired June 30, 2011; nine projects funded under the Institutional continuation award NA08OAR4320754; and 26 projects funded under the Shadow award NA08OAR4320912.

CICAR research and education projects are organized along three themes: (I) earth system modeling, (II) modern and paleoclimate observations, and (III) climate variability and change applications research. In FY11 we identified 15 projects under Theme I, 16 projects under Theme II, and 4 under Theme III.

Collaboration with GFDL continued to be one of CICAR’s key objectives. The CICAR director maintains contact with the GFDL director and CICAR PIs, particularly those involved in Theme I who interact with GFDL scientists, to identify a collaborative research agenda for the two groups. Out of these efforts grew a new project funded by CPO entitled: “Predicting North American hydroclimate change and variability on the interannual to multidecadal timescale”, which will look into the skill of the realistically initialized decadal prediction runs with the new generation of GFDL coupled climate
models. Work on this project began last year and saw fruits already in the form of two collaborative papers. We are also collaborating with GFDL in other ways and make intense use of GFDL models in our study of the Atlantic Meridional Overturning Circulation (AMOC) impact on global climate. Previous plans to collaborate with GFDL on a climate model simulation of the last millennium, involving intensive comparisons with proxy data are still in discussion and are reflected in a large proposal submitted to CPO in the fall of 2009 and funded at the end of the 2010 fiscal year (see more below). CPO also makes funding available for collaboration with NOAA/NCEP to advance their climate prediction system. NOAA’s Office of Ocean of Climate Observations provides funding for the continuing CICAR monitoring of key ocean choke points such as the ocean areas surrounding Indonesia and the Philippines Islands and the areas around the West Antarctic Peninsula, where ocean and sea ice meet the continental ice shelf.

2. Research highlights

CICAR research spans a broad range of subjects that are classified by the three Themes indicated above. This classification is the basis for the organization of the bulk of this report. To evaluate the impact of CICAR research it is helpful to sub-group the works under each Theme according to the scientific context of the research as is attempted below. Note that this quick review of research highlights is not meant to be comprehensive. The interested reader should follow the individual reports to gain better appreciation of the CICAR scientific achievements.

Theme I: Earth System Modeling: Work under this Theme focused in three different areas: (I) Advancing climate prediction and methodologies and model development; (II) Building predictive understanding of Global to Continental scale climate variability, particularly in the world semi-arid regions; (III) Modeling and understanding the late-Holocene climate and the implication to for future climate change. CICAR scientists working under this theme made advances in:

- Building predictive understanding of the climate system, spanning phenomena from the intra-seasonal (hurricanes and the Madden-Julian Oscillation) to the decadal time scales (Atlantic multidecadal Oscillation and Pacific decadal variability).
- Improving numerical assimilation and forecasting systems for ENSO prediction (in particular work with the NCEP CFS).
- Improving the representation of probabilistic forecast results both on the interannual and decadal time scales.

Theme II: Modern and Paleoclimate Observations: Research under Theme II can be broadly divided into two subcategories: (I) Modern observations of oceanic variability and (II) Analysis of paleoclimate observation to advance understanding of long-term, free and forced climate variability. Under this theme CICAR scientists continued to monitor Arctic and Antarctic small and large-scale ocean process that are important for global water mass formation. They also continue to operate the unique monitoring system (based on international collaboration) of the Indonesian Throughflow. During this fiscal year, analysis of Holocene climate proxies under CICAR is winding down as NOAA ended support of our “Abrupt Change in a Warming World” (ACCWW) project.
Analysis of proxies form the recent two millennia is continuing at our Tree Ring Laboratory and under a project funded by NOAA but outside of CICAR entitled: “Global Decadal Hydroclimate Predictability, Variability and Change” (GloDecH)

**Theme III: Climate Variability and Change Applications Research:** This category entails several research projects that support education and outreach related mainly to the dissemination and societal use of climate information. The projects involve enhancement of IRI activities in several experimental areas under seed funding from the NOAA/CPO. Much of CICAR contribution to this Theme is done through direct collaboration of CICAR scientists in collaborative work with the IRI and with CCRUN.
Task I Administrative

Addresses the administrative functions of the Institute and supports the CICAR director and one administrative staff member.

The CICAR Director has been engaged during the past year in an array of scientific, educational and administrative activities with various offices and institutes at The National Oceanic and Atmospheric Administration (NOAA) and The Earth Institute, Columbia University.

To guide CICAR activities and to represent CICAR science to NOAA, the Director met in person with OAR, Climate Program Office, and GFDL leaders as well as participated in a NOAA SRC meeting and in NOAA constituent conference calls and webinars throughout the year. These meetings served the need to inform Columbia on the developments within NOAA Research and in particular with respect to the NOAA Climate Goal.

To convey NOAA’s developing strategic and organizational plans to the Columbia University research community, the Director held meetings with key investigators and leaders of the Earth Institute. This included meetings with the CICAR Advisory Committee and a series of meetings of a committee formed to determine Columbia University’s response to the NOAA Climate Service announcement and the steps NOAA has been taking to form a new Climate Service Line Office. One outcome of these discussions was to establish regular, monthly meetings between the CICAR Director, the Director of the International Research Institute for Climate and Society (IRI) and the Director of the newly formed Consortium on Climate Risk in the Urban Northeast (CCRUN) thus creating a forum of all NOAA funded institutes on the Columbia Campus. These discussions lead to increased collaboration between investigators and to the announcement of a seminar series to discuss the link between climate prediction and climate decisions researchers across Columbia University.

Other administrative activities of the CICAR Director included routine meetings with the Director of the Lamont-Doherty Earth Observatory, participation in the Annual CREST External Board meeting, and completion of the NOAA Memorandum of Agreement and signing by Columbia University.

On the education side, CICAR hosted a visit from NOAA Corp with the intention to discuss how to expose the Columbia graduating students to the NOAA Corp and thus help in the Corp recruiting activities. This discussion is to be continued at the beginning of the 2011/12 Academic Year. CICAR Director also represented CICAR’s climate research as part of the “World Economic Forum Global Leadership Fellows Training” organized by the Columbia School of Continuing Education.
CICAR 2011 Annual Performance Report
From July 1, 2010 to June 30, 2011
PI Yochanan Kushnir

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Advisory Committee Organization Chart

The CICAR Advisory Committee helps define scientific strategies for the Institute that will best address the needs of Climate Services at OAR, which should help NOAA in “providing the transparent, reliable, timely and easily accessible information that America requires.” The Advisory Committee brings together academic and scientific leadership from research divisions and centers at The Earth Institute, Columbia University with expertise in data, science, engineering, health, and education.

The Director and Committee work to develop crosscutting initiatives in support of the NOAA Climate Mission Goal to “Understand Climate Variability and Change to Enhance Society’s Ability to Plan and Respond.”
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April 11, 2011

CICAR Advisory Committee Meeting, Yochanan Kushnir - Director

Comer Building – Video Conference Room 3rd Floor
Start: 2:00 PM   End: 3:30 PM

Discussion Items:

1. NOAA news
   a. Status of the “competitive projects” issue
   b. Funding competitive projects in FY2011
   c. 2012 plan for a transition to Climate Service
   d. Invitation to represent CICAR at the NOAA Climate Directors meeting
   e. MOA

2. Report on CICAR activities: IRI, CCRUN, CRED

3. Discussion of Climate research at CU in relation to NOAA
Executive Board and Organization Chart

The CICAR Executive Board members are charged with invigorating the Institute’s commitment to new and existing scientific program areas and counseling the CICAR Director on matters of policy, budget, and ways to improve coordination of research programs with other institutions or agencies.

![Executive Board Organization Chart]

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CICAR 2011 Annual Performance Report
From July 1, 2010 to June 30, 2011
PI Yochanan Kushnir
Administrative Activities July 1, 2010 – June 30, 2011

The CICAR Director has been engaged during the past year in an array of scientific, educational and administrative activities with various offices and institutes at The National Oceanic and Atmospheric Administration (NOAA) and The Earth Institute, Columbia University.

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Lamont Open House Welcomes Science and Nature Lovers of All Ages

October 8, 2010

On a crisp autumn Saturday, Oct. 2, Lamont-Doherty Earth Observatory opened its doors to the community for its annual Open House: a day of free lectures, demonstrations and workshops for adults and children.

This year’s theme, “Earth on Alert,” highlighted work by Lamont-Doherty scientists on hazards that have dominated recent headlines—the Gulf oil spill, the Haitian and Chilean earthquakes, and the Iceland volcano.

The event, which drew over three thousand people, featured activities for science enthusiasts of all ages, including a walking tour of the Lamont forest led by tree ring scientists and a display of old and current earthquake-monitoring seismometers. Other activities and presentations included a panel discussion on careers for students with advanced science degrees; an exhibit simulating an erupting volcano; and faculty lectures on subjects such as hurricanes and climate change, and clean drinking water in Bangladesh.

The Observatory has been awarded a highly competitive matching grant from the National Institute of Standards and Technology (NIST) to partially support the construction of the Ultra Clean Lab, housed within the new Comer Geochemistry Building.
October 2, 2010 marked the return of the Lamont-Doherty Open House an annual event that enables CICAR to showcase NOAA-sponsored science at The Earth Institute, Columbia University. For CICAR this is a volunteer effort with no funding beyond the Task 1 materials and supplies budget. CICAR administration arranges lectures and prepares and distributes print materials in support of NOAA’s Mission: Science, Service, and Stewardship. Scientists engage everyday citizens in the conversation of climate to further NOAA’s message of a well-informed citizenry.

CICAR PIs Professor Arnold Gordon and Lamont Associate Research Professor Suzana Camargo spoke to the general public about their research. The audience was afforded time to speak with the scientists - asking questions and making comments.
11:30 A.M.

LECTURE

Division of Ocean and Climate Physics

Featured Presenter Suzana Camargo,
Lamont Associate Research Professor

Hurricanes and Climate Change: What Can We Expect for the Future?

Collaborations

Augmenting CICAR Climate Science at Columbia University

CICAR and International Research Institute for Climate and Society (IRI)
- Conduct a discussion group on decadal climate prediction - science, verification (metrics) and information, driven by mutual research interests and activities, and mutual involvement in national panels. 
- Motivation: IPCC AR5 and the NOAA Climate Service plan.
- Planning efforts for a Joint Science and Technology Center on "climate extremes". 
- Motivation: NOAA Climate Service plan and NSF STC REP. 
- Other partners: Columbia University Water Center, National Center for Disaster Preparedness, Stevens Institute of Technology, City University of New York (CREST).

CICAR, IRI and the Columbia Center for Research on Environmental Decisions (CRED)
Conduct monthly discussion group meetings on "Decadal Predictions and Decadal Decisions": Understanding how stakeholders make decisions and how decadal predictions can best serve informed decision-making. 
- Motivation: IPCC AR5 and the NOAA Climate Service plan and IRI-CICAR interaction on decadal predictions (see above).

CICAR - Columbia Water Center (CWC)
- Collaborate under a NOAA funded project "Climatic Predictability of Extreme Floods in the United States" with the objective of "...comprehensively integrates both short- and long-term climate prediction with disaster preparation/response, new approaches to infrastructure design and management and innovative financial instruments--an end-to-end approach for climate risk management."
- Engagement through regularly scheduled monthly meeting of the CWC Consortium. Additional participants from the IRI, GISS, and several CU engineering departments contribute individual expertise towards finding group solutions to hydrologic issues in the near and long-term.
- Motivation: Create dialog between different groups interested in hydroclimate and global water issues.

CICAR and the Center for Climate Risks in the Urban Northeast (CCRUN)
CCRUN is a new NOAA-funded RISA project situated in Columbia University with partner institutions in the Northeast (University of Massachusetts Amherst, City College/CUNY, Stevens Institute of Technology and Drexel University). CICAR participates in CCRUN providing climate science research capabilities - initially involved in launching research into coastal impacts of extreme storms.

CICAR involvement in education
CICAR Scientists are participating in general graduate teaching at Columbia and also in specially designed professional programs such as the M.A. in Climate and Society: a "twelve-month M.A. Program in Climate and Society trains professionals and academics to understand and cope with the impacts of climate variability and climate change on society and the environment. This rigorous program emphasizes the problems of developing societies", and the MPA in Environmental Science and Policy which "trains sophisticated public managers and policymakers who apply innovative, systems-based thinking to environmental issues" by offering "a high-quality graduate program in management and policy analysis that emphasizes practical skills and is enriched by ecological and planetary science."

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Begin forwarded message:

From: Alice Gottschling <Alice.Gottschling@noaa.gov>
Date: July 12, 2010 11:47:12 AM EDT
To: noaa.ci.admin.contacts@noaa.gov
Subject: New "Hot Item" Article from CICAR
FYI: NOAA/OAR Research Web Page

Please find below the latest Cooperative/Joint Institute "Hot Item" article submitted by the Cooperative Institute for Climate Applications and Research (CICAR). Your may view this article as well as previously published CI/JI articles (archived) at http://hotitems.oar.noaa.gov.

**Asian Monsoon Failure and Megadrought During the Last Millennium**

Research for this project was supported in part by funding from the NOAA Climate Program Office through the Cooperative Institute for Climate Applications and Research (CICAR) located at the Lamont-Doherty Earth Observatory (LDEO), The Earth Institute at Columbia University.

The dynamical processes that govern the Asian monsoon system are complex and not sufficiently understood to model and predict its behavior, due in part to inadequate long-term climate observations. The Monsoon Asia Drought Atlas (MADA), a seasonally resolved gridded spatial reconstruction of Asian monsoon droughts and pluvials over the past millennium, derived from a network of tree-ring chronologies resulted from more than 15 years of research by scientists at the Lamont-Doherty Earth Observatory. MADA provides the spatiotemporal details of known historic monsoon failures and reveals the occurrence, severity, and fingerprint of previously unknown monsoon megadroughts and their close linkages to large-scale patterns of tropical Indo-Pacific sea surface temperatures. MADA thus provides a long-term context for recent monsoon variability that is critically needed for climate modeling, prediction, and attribution.

**Background:** The Asian monsoon system affects more than half the world’s population and when the rains fail to come, people can go hungry or worse. There is intense interest in how El Niño and the monsoon are related and how both are affected by a warming climate, and how monsoon extremes may affect the growing populations that depend on the rains.
**Significance:** The atlas is valuable to monsoon forecasters because the record is long enough and the spatial areas detailed enough that modelers can pick out short-term and long-term patterns, said Bin Wang, a meteorologist and monsoon modeler at the University of Hawaii who was not involved in the study. “It is extremely valuable for validating climate models’ simulation and understanding their origins in terms of model physics,” he said. The study, published in the journal Science, is expected not only to help historians understand how environment has affected the past, but to aid scientists trying to understand the potential for large-scale disruptions of weather in the face of changing climate. This research supports the NOAA climate mission goal two to “Understand Climate Variability and Change to Enhance Society’s Ability to Plan and Respond.”

http://www.sciencemag.org/cgi/content/full/328/5977/486

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Task II Specialized Science Support Activities

Task II provides for specialized support scientists employed by Columbia University, Lamont-Doherty Earth Observatory but located at the NOAA Geophysical Fluid Dynamics Laboratory (GFDL) in Princeton, New Jersey. These CICAR employees are meant to enhance the technical and scientific expertise at GFDL required to execute collaborative projects and to address specific needs that require expertise not available at GFDL.

The Institute’s initial five-year budget cycle allowed for five scientific support hires as does the CICAR continuation award, which began in July 2008. To date these positions have not been filled.
Task III Individual and Collaborative Principal Investigator (PI) Research Projects

Task III encompasses the bulk of individual and collaborative PI research at the Lamont-Doherty Earth Observatory, The Earth Institute, Columbia University. This work is supported by grants from NOAA and is compliant with the research themes of the Cooperative Institute for Climate Applications and Research.

The Task III projects strengthen the CICAR research agenda in line with the themes and represent the main thrust of the Institute’s scientific agenda for the coming year.
Theme I Earth System Modeling

INDIVIDUAL AND COLLABORATIVE PI RESEARCH PROJECTS

CICAR Award # NA03OAR4320179 (June 30, 2011 end date)
1. Schlosser, P., Abrupt Climate Change Studies: Infrastructure

CICAR Institutional Extension Award # NA08OAR4320754
1. Schlosser, P., Global Oceanic 3HE Data Sets: Calibration tools for Models of the Upward Branch of the Deep Ocean Global Conveyor

CICAR Shadow Award # NA08OAR4320912
1. Camargo, S., Towards a Better Understanding of the Relationship Between Climate Change and Tropical Cyclone
2. Cane, M., Generation and Evaluation of Long-Term Retrospective Forecasts with NCEP Climate Forecast System: Predictability of ENSO and Drought
3. Goddard, L., Diagnosing Decadal-Scale Climate Variability in Current Generation Coupled Models for Informing Near-Term Climate Change Impacts
4. Goddard, L., Recalibrating and Combining Ensemble Predictions
5. Kaplan, A., Error Models for Remotely-Sensed Sea Surface Heights and Temperatures in Ocean Data Assimilation
7. Martinson, D., Abrupt Climate Change in a Warming World (ACCWW): Abrupt Change in the West Antarctic Peninsula in a Warmer World
8. Schlosser, P., ACCWW: Infrastructure
9. Seager, R., ACCWW: Modeling and Understanding Late Holocene and Near Term Future Hydroclimate Change
10. Seager, R., Mechanisms and Predictability of Multi-Basin Influences on North American Drought
11. Seager, R., Predicting North American Hydroclimate Change and Variability on Interannual to Multidecadal Timescale

TOTAL THEME I PROJECTS: 15
No activity to report. The remaining funds in CICAR Award number NA03OAR4320179 were approved for use to conduct a mini-conference under this Infrastructure project but the award end date was not extended in time to allow for this activity.
Research Goals

The main goals of the Lamont-Doherty component of this project were to (1) create a global dataset of helium gas concentrations and helium isotope ratios, (2) to translate these data into a global distribution of mantle-derived dissolved helium, and (3) participate in the comparison of these data with ocean GCMs in order to estimate the flux of mantle helium from the ocean sea-floor. Additionally, we have sought to identify gaps in the knowledge of the geographic distribution of the helium source by comparing source estimates with the observed distribution of mantle helium.

Education Goals

Our educational goals have been to train graduate and undergraduate students in ocean geochemical tracer techniques and to provide internships for public high school teachers and students interested in the Earth Sciences.

Research Progress

The global helium database was assembled, quality controlled, and gridded. The resulting product, integrating over 25,000 measurements from over 1,500 profiles, is a significant milestone in the study of dissolved gas tracers in the Ocean. The helium measurements, merged with neon, temperature and salinity data, were translated to a mantle helium distribution in the global ocean. The mantle helium database has been used to critique and validate several runs of the Princeton/GFDL ocean model with varying mixing schemes. The database was used to identify a previously unproven source of mantle helium in the Southern Ocean. The dataset was used to replicate the “Munk” calculation of vertical diffusivities in the abyssal Pacific Ocean, this time with a tracer that enters the ocean in the abyss, as opposed to oxygen and carbon-14, which enter from the atmosphere.
**Highlights**

The previously accepted ocean-floor flux of mantle helium to the ocean was shown to be overestimated by a factor of about 2. (Bianchi, et al., 2010). Distributions of mantle helium on isopycnal surfaces were used to track the source down to seven specific volcanic formations that we predict are home to active vent fields. (Winckler, et al., 2010).

The effective, passive-tracer based, vertical diffusivity coefficient in the abyssal ocean, away from boundaries, was found to be between 0.6 and 1.2 cm²/s. This value is consistent with the Munk estimate, but is significantly higher than the estimate derived from purposeful, in situ tracer releases in similar areas. (Schlosser, et al., in prep, and presented at the Ocean Sciences meeting, Portland, 2010).

**Societal Benefits**

Vertical exchange between the ocean mixed layer and the abyss is a critical parameter in understanding the fate of CO₂ anomalies in the atmosphere. Vertical exchange, and its variation in time, is also critical to assessing the potential of the ocean to reorganize the partition of heat between the surface and the abyss. Mantle helium, with its distinctive source function and its conservative behavior in the ocean interior, offers novel insights into dispersion and vertical exchange of ocean properties. In that way, it improves the scientific grounding of policy proposals and decisions.

**Awards & Honors**

P. Schlosser was elected Fellow of AAAS and Fellow of the Explorer’s Club. He was a member of the NAS panel on ‘Future Science Opportunities in Antarctica and the Southern Ocean.’

**Education & Outreach**

- During the time-period of the Award, researcher Newton has been Program Manager of several Columbia outreach programs, partnering with NYC public schools at the grades 6-12 level. As part of these programs, approximately a dozen high school students have worked as summer interns on projects related to the helium database (cruise preparations, sample tracking, data analysis).
- A Columbia undergraduate, Andrew Babbin, worked on the quality control of the helium dataset as part of his Senior Thesis. Babbin coded a routine for semi-automated auditing of error estimates relative to smoothed profiles calculated at each station in the dataset. Babbin is currently a PhD candidate at Princeton University in Oceanography.

**Personnel**

Research Scientists: 2.

**Journal Articles**

Bianchi, D., Sarmiento, J.L., Gnanadesikan, A., Key, R.M., Schlosser, P., and Newton, R.: Low helium flux from the mantle inferred from simulations of oceanic helium isotope.


**Conference proceedings**

Research Goals

The goals of this project are to improve our understanding of what controls the variability of tropical cyclone (TC) activity, to improve the attribution of changes in TC activity to climate change, and to reduce the uncertainty in predictions of changes in TC activity associated with long-term global climate change. The approaches we use involve an empirical genesis potential (GP) index and idealized simulations of tropical cyclones.

Research Progress

Update on topics that appeared in the previous report (2010):

- Tropical cyclone activity and Quasi-biennial Oscillation: The paper (Camargo and Sobel, 2010) was revised, accepted for publication and published in the *Journal of Climate.*

- Projected future changes in tropical summer climate: The paper (Sobel and Camargo, 2011) was revised, accepted for publication and published in the *Journal of Climate.*

- Potential Intensity and SST in a single column model: Ramsay and Sobel (2011) was accepted for publication and published in the *Journal of Climate.*

Revised Genesis Potential Index:

We continued our collaboration with Michael K. Tippett (IRI, Columbia University), a statistics expert in this part of the project. We developed an improved index for tropical cyclogenesis using a Poisson regression between the observed climatology of tropical cyclogenesis (TCG) and large-scale climate variables is used to construct a TCG index. The regression methodology is objective and provides a framework for the selection of the climate variables in the index. The feature of the new index, which leads to the greatest improvement, is a functional dependence on low-level absolute vorticity that causes the index response to absolute vorticity to saturate when absolute vorticity exceeds a threshold. This feature reduces some biases of the index and improves the fidelity of its spatial distribution to the observed climatology of genesis. Although the index is fit to climatological data, it reproduces some aspects interannual variability when applied to interannually varying data. Overall the new index compares
positively to the genesis potential index (GPI) whose derivation, computation and analysis is more complex in part due to its dependence on potential intensity.

We finished writing the paper summarizing these results (Tippett et al., 2011), submitted the paper and revised it. The paper was published earlier this year in the *Journal of Climate*.

In collaboration with GFDL scientists Gabriel Vecchi and Ming Zhao, we followed up on this topic and applied the same genesis index development algorithm to the HIRAM-GFDL model, focusing on climate change. We explored various different venues:

- Applied the reanalyses index to the HIRAM data and compared with the HIRAM tropical cyclone statistics in the present and in future scenarios.
- Obtained a model genesis index based on the model large-scale environmental variables and model tropical cyclones in the present. We then compared with the reanalysis index and with the model TCs and environmental variables in future scenarios.
- Obtained a model genesis index based on the model large-scale environmental variables in model tropical cyclones in future scenarios and examined how the coefficients differ from the model genesis coefficients in the present as well as the reanalysis genesis index coefficients.

The HIRAM model produces fewer tropical cyclones in the future than in the present, in most of future scenarios examined (different SSTs in the future). We would like the genesis index to reproduce the change of the number of TCs in the model globally and regionally. One of the important results we obtained is that if we use total SST as one of the environmental variables in the genesis index, the changes in the number of TCs in the future are not well reproduce, even though the Poisson regression using that variable is a reasonable choice for the present. The changes in the number of TCs are in much better agreement in the future, when either relative SST or potential intensity is used.

We presented preliminary versions of these results in various workshops. We are currently finalizing the analysis using additional future scenarios recently provided by GFDL. Once this analysis is done, we will write a manuscript with these results.

**Idealized hurricane simulations using the WRF model**

A. Sobel, S. Camargo and L. Polvani worked with the postdoctoral researcher Shuguang Wang on the WRF model idealized simulations.

We used the idealized WRF model version developed at NCAR and we performed various idealized simulations with the WRF model using NCAR computers. We did a few simulations with different values of sea surface temperature (SST) as well, in order to test the sensitivity of the model to SSTs. To realize our research goals we need to develop a greater degree of control and understanding of the model. An important step is to study radiative-convective equilibrium states; idealized hurricane simulations are from
some perspectives best performed starting from such states perturbed by initial vortices.

However, the energy budget of the WRF model was not closing. In radiative-convective equilibrium there should be a budget closure between moisture static energy and precipitation vs. evaporation, however this is not the case in the WRF model. The water budget, in particular, can be off up to 50%. The reason for this discrepancy was some bugs in the WRF model that were identified by S. Wang and reported to the WRF developers. By correcting these bugs the energy and water budget close with an accuracy of 1%.

The next step was to do idealized hurricane simulations. The problem that we decided to explore was to examine the effect of the outflow temperature $T_o$ on hurricane intensity, and study the impact of tropopause temperature on the outflow temperature. Our interest in the outflow temperature is due to the potential intensity theory for hurricane intensity, which relates the theoretical maximum intensity a hurricane can achieve with the difference between SST and the outflow temperature. However, theories often make crude approximations of the outflow temperature, which is poorly constrained by observations and numerical models.

S. Wang set up the WRF model using a simplified radiation cooling using a simple Newtonian relaxation scheme. The troposphere is cooled at a constant rate 1.2 K/day, which is close to the observed climatology. Using this simple radiation scheme, the model can archive the radiative-convective equilibrium (RCE) state with isothermal stratospheric where temperature is $T_o$.

Simulations of hurricane are conducted using a large numerical domain of 6000x6000x26 km$^3$ with grid spacing of 15 km, and a nest domain of (1500x1500x26 km$^3$) with grid spacing of 5 km. Convective parameterization is turned off in the inner domain. $T_o$ is the key parameter to be varied. We give a large range of $T_o$: -90, -80, -70, -60°C. Consistent the potential intensity theory, colder stratosphere leads to stronger hurricanes. The simulated hurricanes achieve a quasi-steady state after a short spin-up period of roughly 3 days, much like previous results using 2D models.

Until now, we used a single value of SST and varied $T_o$, we are currently repeating these experiments using a range of values for SST. Once the experiments are finalized we will write a paper with these results.

Hurricane tracks and the large-scale environment

Following up on our papers on the influence of the large-scale influence on Atlantic hurricane tracks, we collaborated with 2 post-doctoral researchers at Columbia (Hamish Ramsay and Daeyhun Kim) focusing our analysis on southern hemisphere tropical cyclone tracks. We wrote a paper on this topic, which is currently in review:

A probabilistic clustering method is used to describe various aspects of tropical cyclone (TC) tracks in the Southern Hemisphere, for the period 1969-2008. A total of 7 clusters are examined: three in the South Indian Ocean, three in the Australian Region, and one in the South Pacific Ocean. Large-scale environmental variables related to TC genesis in each cluster are explored, including sea surface temperature, low-level relative vorticity, deep-layer vertical wind shear, outgoing longwave radiation, El Niño-Southern Oscillation (ENSO) and the Madden-Julian Oscillation (MJO). Composite maps, constructed 2 days prior to genesis, show some of these to be significant precursors to TC formation – most prominently, westerly wind anomalies equatorward of the main development regions. Clusters are also evaluated with respect to their genesis location, seasonality, mean peak intensity, track duration, landfall location, and intensity at landfall. ENSO is found to play a significant role in modulating annual frequency and mean genesis location in three of the seven clusters (two in the South Indian Ocean and one in the Pacific). The ENSO-modulating effect on genesis frequency is caused primarily by changes in low-level zonal flow between the equator and 10°S, and associated relative vorticity changes in the main development regions. ENSO also has a significant effect on mean genesis location in three clusters, with TCs forming further equatorward (poleward) during El Niño (La Niña) in addition to large shifts in mean longitude. The MJO has a strong influence on TC genesis in all clusters, though the amount modulation is found to be sensitive to the definition of the MJO.

**Highlights**

We developed an improved genesis index using a Poisson regression and in the process of developing this index, obtained a better understanding of the role of vorticity in hurricane genesis. Then, we applied the same methodology to the HIRAM climate model from GFDL to examine the changes that occur due to climate change. Using an idealized version of the WRF model in radiative-convective equilibrium, we explored the dependency of the intensity with outflow temperature. We determined specific types of southern hemisphere tracks that are influenced by ENSO. We determined that the modulation of frequency by ENSO is mainly caused by changes in the zonal flow in low latitudes and the associated vorticity changes in the main development regions. We also determined a modulation of genesis location by ENSO in specific tropical cyclone clusters.

**Societal Benefits**

Our research is leading to a better understanding of the how climate affects tropical cyclones in various time-scales.

**Other Research Connections**

Awards & Honors

- **Suzana J. Camargo**: American Geophysical Union, 2010 Editors’ Citation for Excellence in Refereeing for Geophysical Research Letters.
- **Adam H. Sobel**: 7th Excellence in Mentoring Award, Lamont-Doherty Earth Observatory, May 2010.

Education & Outreach

Research advisor or mentor


Invited Lectures


Public Outreach

- **S. J. Camargo**: Participation in the Career Day at Nyack Middle School, Nyack, NY, March, 31 2011.

Personnel

- Research Scientists: 4, Research Support Staff: 1.

Journal articles


**Conference proceedings / workshops**


Research Goals

General research goals
1. Develop a coupled data assimilation procedure for CFS
2. Test the procedure for the modern era; use it for the past 150 years
3. Perform retrospective forecasts for the past 150 years
4. Assess model skills in NINO and drought forecast
5. Design bias correction schemes for operational forecast

Education Goals
Train graduate students and make presentations at relevant workshops.

Research Progress
In collaboration with our colleagues at NCEP, we have made considerable progress in the following two areas:

1. **Identification of systematic biases in the CFS.** Our previous retrospective ENSO forecast experiments indicate that the CFS may carry significant systematic bias in its SST climatology. To assess this bias, we ran the model in a quasi-free mode, i.e., no data assimilation was performed between 50S and 60N, and the SST field was linearly relaxed to observation over the polar bands of 60S-70S and 50N-60N. Since the NCEP team had done a similar CMIP 4-member ensemble experiment, we could compare the SST climatology produced by our free run, and that from the NCEP ensemble run, with the 1971-2000 SST climatology of the Hadley Centre SST dataset. Both experiments show considerable SST biases, especially at high latitudes, along the western boundary currents, and in the tropical Pacific and Atlantic Oceans. The biases are not exactly the same in our experiment and that of the NCEP, but they follow similar patterns and have comparable amplitudes. It seems that the CFS by itself is not able to correctly simulate the deep water formation processes in the polar
regions and thus creates large biases in places where the thermocline is close to the surface. Simply fixing SST toward high latitudes, which is the current scheme in the CFS, cannot solve the problem. Before a physics-based correction is achieved, we will try to relax the 3-dimensional hydrography to observed climatology in the polar regions, in hope of getting the mean thermocline right, which is crucial for simulation and prediction of short-term climate variability.

2. **Studies on ENSO prediction and predictability.** Aside from CFS-based analysis and model experiments, we have also carried out a series of related studies on ENSO prediction and predictability using other models and methods. In particular, we have worked on the following:

1. Construct linear models based on the 20th century climate simulations of five selected IPCC AR4 coupled systems, and use them for multi-model ensemble prediction of the tropical Indo-Pacific SST (Wu and Chen, 2010);

2. Develop methodologies of ensemble construction and probabilistic ENSO prediction, and verify them using the LDEO5 model (Cheng et al., 2010);

3. Evaluate the interannual biases induced by the surface freshwater flux in the tropical Pacific, and elucidate the coupled feedbacks involved (Zhang et al., 2010);

4. Demonstrate the impact and necessity of coupled data assimilation for ENSO prediction, based on the evolution history of LDEO model as well as the preliminary results of the CFS (Chen, 2010);

5. Identify the characteristics of Indo-Pacific Tripole, an intrinsic mode of tropical climate variability, and discuss its implications for climate prediction (Chen, 2011).

6. Identify and understand changes in the equatorial Pacific, the seat of ENSO, in a warming world (Wang and Cane, 2011; Wang, 2010).

**Societal Benefits**

The project aims at improving predictions of ENSO and drought, which undoubtedly will bring significant societal benefits when completed.

**Other Research Connections**

This project is a collaborative effort of LDEO and NCEP scientists. During the course of our research, we also have close collaboration with the scientists from the University of Maryland and the University of Northern British Columbia.

**Education & Outreach**

- The project has supported the latter stages of the PhD research of Daiwei Wang.
- Our 150-year coupled assimilation model output, as well as forecasts runs, were converted to NetCDF format, and posted on the LDEO data library for easy access and analysis:
  
Selected Presentations
Chen, D., China’s Argo program: general strategy and recent progress. Invited Talk, The 8th Cross-Strait Ocean Science Workshop, Hualian, Taiwan, September, 2010.

Personnel
Research Scientists: 3, Research Support Staff: 1.

Journal articles

Books / articles-in-books

Ph.D. dissertation
Wang, Daiwei 2010: The tropical Pacific Ocean in a warming climate.
Research Goals
The three objectives that this proposal will address are:
1. Determine the fidelity of the surface expression of oceanic decadal variability, and the associated climate teleconnections, in several state-of-the-art CGCMs, with particular emphasis on the impact of initialization.
2. Develop metrics and baselines for estimating the quality of decadal predictions
3. Design climate information products for climate risk management and planning.

Education Goals
Educational goals mainly target sectoral scientists and decision makers, however materials and tools developed in this project are being used also in the Columbia University MA program on Climate & Society. We have been developing a map room (Time Scales map room) and another web site (proto-type website for US CLIVAR work on verification framework for decadal predictions) that allow for these communities to view information relevant to decadal-scale climate information and predictions. These will be described below.

Research Progress
Over the past year, we have made substantial progress on all of our research goals. However, most of our work to date has focused on the second two goals:

(2) Develop metrics and baselines for estimating the quality of decadal predictions.
Q1: Can initialized decadal predictions provide information on natural climate variability, improving the quality of climate information based on climate change projections?

As co-chair of the US CLIVAR Decadal Predictability Working Group, the PI (and 2 of the co-PIs) have been coordinating and leading the work on the second objective of the WG, which is to develop a verification framework for assessing the quality of decadal
prediction hindcasts. As a result, we have developed a small set of core metrics associated with specific baselines (or reference forecasts) to address the deterministic and probabilistic quality of the information in the hindcasts. With data provided by the co-PIs from NCAR and Hadley Centre (in addition to data from WG member at Canadian Climate Centre) we have begun the verifications and have developed a prototype webpage to display the results for the different models, such as those shown in Figures 1 and 2. The deterministic metric uses the uninitialized hindcasts as the baseline against which to question whether the initialization adds information to the interannual-to-decadal predictions (Figure 1). We find that the initialization offers little additional skill for most regions, and that different predictions differ in where the additional skill is realized. The probabilistic metrics address how one might quantify uncertainty in the predictions, and thus uses a reference of standard error in the ensemble mean prediction against which is compared the information in the ensemble members. We find that almost universally, the information in the ensemble members is probabilistically unreliable. A paper is in preparation that represents the collective effort of the working group.

**Q2: What is the magnitude of low-frequency variability relative to the anthropogenic trends on which it will evolve and relative to the superimposed year-to-year variability?**

We have been addressing this question in two ways. In the first, we have simply taken observations of 20th century temperature and precipitation and have decomposed these into three time-scales that broadly coincide with trends (as estimated by IPCC model simulations of globally-average temperature), decadal-scale variability, and year-to-year variability. A map room was developed (Figure 3) to examine patterns and magnitudes of the variability at different timescales, and also the ability to look at grid-scale or regionally averaged timeseries for the decomposition. A news report was written for EOS on the maproom and associated methodology, which is now in press.

The second approach to addressing the climatological statistics of climate variability versus climate change is related to the maproom approach. Once the trend component is removed, in the absence of decadal-scale predictability, the timeseries is treated as white noise. Stochastic synthetic timeseries then can be generated for specific locations, assuming sufficient length of observed record. It is envisioned that this “decadal climatology” can also serve as a prediction baseline for probabilistic interannual-to-decadal predictions. So far, this has been tested in one of our focus regions (SE South America). The methodology has also been applied within other projects, and in fact the specific approach and output format was motivated by a hydrology project in the western cape of South Africa. A paper has been submitted describing our methodology in the context of that project.

**Design climate information products for climate risk management and planning**

The research addressing our second research goal is an important input to this final goal. In particular, both the Timescales Maproom and the stochastic-simulations constitute
(Q3) information that can serve as a starting point for climate risk management and planning.

Additionally the decadal prediction verification is a complementary element that can inform whether there may be prediction skill that can be considered along with the climatological odds to better inform decision-making. As part of that effort, we have begun to quantify the uncertainties (or range of possibilities) on the information at various timescales, and will continue to work on that as we start to layer the information across timescales.

Societal Benefits

We envision this work to be a critical element in designing climate information products for climate risk management and planning. This work contributes to a portfolio of information on near-term climate change, with particular emphasis on predictability and prediction from initialized dynamical models, which will be prominent in the IPCC-AR5.

Other Research Connections

• No-cost partners supplying data and collaborators:
  • Doug Smith, Hadley Centre, UK
  • Keith Dixon GFDL, USA
  • Gohkan Danabasaglu, NCAR, USA

Education & Outreach

Web sites:

Data added to IRI Data Library:
• Decadal hindcasts from Hadley Centre (perturbed physics ensemble with HadCM3), NCAR (CCSM4), Canadian Climate Centre (CCCma), CCSM3 runs from RSMAS

Mentoring:
• Post-doctoral Research Fellow, Paula Gonzalez

Information developed under this project has been used in public outreach and training workshops for (1) World Economic Forum Global Leadership Fellows Training, (2) Climate Risk Business group of the International Financial Corporation, a World Bank group.

Presentations –
• WGOMD-GCOS meeting – Boulder, CO, Sep 2010
• Seminar on decadal variability and prediction for Center for Research on Environmental Decisions (CRED, a NSF-DMUU at Columbia) – Nov 2010
• Seminar for agricultural researchers in INIA Uruguay (part of Ministry of Agriculture in Uruguay) – Montevideo, Uruguay, Nov 2010
• National Climate Assessment planning meeting – Washington D.C., Dec 2010
• Aspen Global Change Institute meeting on Decadal Prediction – Aspen, CO, Jun 2011

**Personnel**
Research Scientists: 2, Post Doctoral Fellow: 1.

**Journal articles**

**Figure 1.** Mean squared skill score (MSSS) for decadal temperature hindcasts from Hadley Centre. Top row: MSSS between the initialized hindcasts (“forecasts”) and the uninitialized hindcasts (“reference”); middle row: MSSS between the initialized hindcasts (“forecasts”) and the climatological mean (“reference”); bottom: MSSS between the uninitialized hindcasts (“forecasts”) and the climatological mean (“reference”). Observed and model data has been smoothed as described in text. The forecast target is year 2-9 years following the initialization.
Figure 2. Continuous ranked probability skill score (CRPSS, top) of the initialized temperature hindcasts testing uncertainty quantification for Hadley Centre; middle: cumulative ranked probability score (CRPS) using average ensemble spread, and bottom: CRPS using standard error of ensemble mean prediction. Ensemble mean prediction has been adjusted for conditional bias. Observed and model data has been smoothed as described in text. Forecast target is year 2-9 after initialization.
Figure 3. Snapshot of the IRI Time Scales Maproom prototype. (Some revisions may be implemented before release on the IRI web site.) The global map shows the percent of total variance in the decadal band for Jun-Aug precipitation for 1900-2007. For data averaged over the area outlined by the red box, the inset shows (left) the initial timeseries with superimposed long-term trend, (middle) decadal and (right) interannual components.
Research Goals

Our goal is to develop a probabilistically reliable seasonal forecasting system that can provide user-defined seasonal forecasts based on the full estimate of the probability distribution and deliver that interactively through a web-based map/graphics tool.

Research Progress

In this year, we have continued to refine the methodology primarily for recalibrating the models. The model calibration has been performed using multi-variate regression based on EOF structures, thus allowing for spatial corrections. Penalized regression methods were found to help forecast reliability and select predictors more effectively than cross-validation or AIC. In practice, the regression parameters must be estimated from data. The problem is that in seasonal forecasting, forecast histories are short, and skill is modest, both of which lead to substantial sampling errors in the estimates. This work examined two problems where sampling error affects the reliability of regression-calibrated forecasts and developed solutions based on two “penalized” methods: ridge regression and lasso regression (Hoerl and Kennard 1988; Tibshirani 1996). The first problem is that, even in a univariate setting, ordinary least squares estimates lead to unreliable forecasts. The second problem is that in the context of multivariate MOS, common methods of predictor selection lead to negative skill and unreliable forecasts.

The probabilistic information (e.g. tercile probabilities) generated directly from models, may appear skillful in the tropics – in terms of metrics such as the Ranked Probability Skill Score (RPSS), but they also yield negative RPSS in many regions, especially in the extra-tropics as seen in Fig. 1(a). This results in overall poor reliability due to overconfidence (Fig. 2(a)). The RPSS averaged over all grid points is also negative. Estimating tercile probabilities from a cross-validated linear regression model on a grid-point basis reduces the area with negative skill and improves reliability (not shown); the average RPSS is 0.041. However, estimating the regression coefficients using ordinary least squares leads to a positive bias in the signal variance, which manifests itself as a
slight overconfidence in the reliability diagram. Estimating regression coefficients using ridge regression removes this overconfidence and improves the average RPSS to 0.045 as seen in Figs. 1(b) and 2(b). Importantly, the specification of the ridge parameter must be included in the cross-validation procedure.

A simple multivariate extension of the grid-point regression is one that uses spatial patterns as predictors. Here we use correlation-based EOFs of model output as predictors. Fig. 1(c) shows that this results in an increase in RPSS in many regions, especially in the tropics, but also is also accompanied by negative RPSS areas, especially regions that in Fig. 1(b) showed no skill. The average RPSS is 0.36, and the reliability diagram in Fig. 2(c) shows overconfidence. Again this is due to excessive forecast signal, especially in areas where a climatological forecast of equal odds is more appropriate. One way to proceed is to cast the problem as models selection one, where one must choose between a pattern-based regression forecast and a climatological forecast. Methods like cross-validation and AIC can be used to select the model. This model selection approach offers some improvement, and was used in the previous iteration, but does not entirely eliminate areas of negative skill and forecast overconfidence. Lasso regression, which was implemented this year, is similar to ridge regression but more aggressively eliminates poor predictors. Fig. 1(d) shows that lasso regression retains much of the skill improvements of EOF regression while not introducing negative skill and improving reliability (Fig. 2(d)); average RPSS is 0.65.

We are currently in the process of setting up the interactive “flexible forecast format” map room (described in the previous annual report) on our web site, using the newly implemented methodology.

**Societal Benefits**

This project will produce reliable, probabilistic seasonal forecasts from multi-model ensembles through the use of statistical recalibration, based on the historical performance of those models; the methodology and demonstration of this will be the output for the forecast community. For the climate risk and decision making communities, we are developing interactively accessible maps and point-wise distributions of those full probability distributions that are relevant to the user-determined needs.

**Other Research Connections**

- Malaquias Pena Mendez (SAIC-EMC/NCEP/NOAA)
- Huug van den Dool (Climate Prediction Center, NCEP/NWS/NOAA)

**Education & Outreach**

**Personnel**

Research Scientists: 3, Research Support Staff: 1.

**Publications**

A paper is in preparation, and the work methodology and resulting forecasts have been presented at a meeting, but there were no proceedings.

Figure 1: Ranked probability skill score (RPSS) for forecasts of DJF 2m-temperature from (a) ensemble frequency, (b) gridpoint ridge regression, (c) EOF regression and (d) lasso regression.
Figure 2: Reliability diagrams for forecasts of DJF 2m-temperature from (a) ensemble frequency, (b) gridpoint ridge regression, (c) EOF regression and (d) lasso regression.
Research Goals

To use power spectral descriptions of physical fields to characterize error in satellite data sets for sea surface heights and temperatures in a form convenient for use in ocean data assimilation procedures. The characterization should include location-dependent variances and spatial and temporal covariances. Model representation error will be estimated on the basis of GSFC/GMAO and NCEP/EMC ocean runs with realistic and perturbed forcing and their comparison with satellite data fields. Because the misspecification of observational and representation error are deemed partly responsible for the suboptimality and inaccurate posterior uncertainty estimates in data assimilation systems, improved error estimates are important for the overall success of ocean data assimilation and climate prediction.

Education Goals

To involve students in the use of satellite data and statistical analyses of ocean variability.

Research Progress

A systematic comparison of sea surface height fields from the NCEP MOM3 ocean data assimilation experiments (performed and provided by D.Behringer) with the satellite altimetry fields were performed. Assimilation of temperature profiles and altimetry resulted in a significant improvement of model fields (Figure 1). The large portion of the remaining error, however, was found to be due to the relative spatial smoothness of model fields compared to the observational data averaged to the model’s nominal grid resolution, as seen from the altimetry fields (Figure 2). Indeed, applying a spatial filter (5° running averages) in zonal direction to the altimetry fields, but not to the model fields, improved their comparison (cf. panels b,d,f with panels a,c,e, respectively, in Figure 1). The pattern of the filtered-out variability (Figure 2d) is very similar to the observational error pattern found earlier in this project in the comparison of gridded satellite altimetry fields with tide gauge records. Here the same pattern is interpreted as a contribution to the model representation error. Therefore, the scaled version of this
pattern is proposed for modeling the combined observational and representation error in ocean model runs with satellite altimetry data assimilation.

**Highlights**

1. Systematic intercomparisons of the NCEP MOM3 ocean data assimilation experiments by D. Behringer were performed.

2. Error maps for the monthly gridded altimetry fields were reinterpreted as contributions to the MOM3 model representation error, due to the higher smoothness of model fields compared to the altimetry fields.

3. Assimilation of satellite altimetry data into ocean models can use a scaled version of sea surface height small-scale variability maps, where a scaling parameter is used to take into account model representation error.

**Societal Benefits**

Because the misspecification of observational and representation error may be partly responsible for the suboptimality and inaccurate posterior uncertainty estimates in data assimilation systems, improved error estimates are important for the overall success of ocean data assimilation and climate prediction. This project addresses the NESDIS/JCSDA program priority “Ocean Data Assimilation for Prediction on Daily to Seasonal Time Scales”, mostly its focus area “Estimation of observational error characteristics” with an additional contribution to the focus area “Validation of ocean assimilation products and forecasts with satellite products.”

**Other Research Connections**

- Interagency: GMAO/NASA, EMC/NCEP/NOAA
- Research Partnerships: JCSDA
- Collaborators: M. Rienecker, C. Keppenne, J. Jacob (GMAO, GSFC, NASA); D. Behringer (EMC, NCEP, NOAA)

**Academic Participation**

- Kaplan: Modeling Altimetry Data Error for Ocean Data Assimilation, 8th JCSDA Workshop on Satellite Data Assimilation, University of Maryland at Baltimore County, May 4-5, 2010.


- A.Kaplan and M.A.Cane: Effects of Altimetry Data Assimilation and Error Models on Analyzed Ocean Fields, 9h JCSDA Workshop on Satellite Data Assimilation, University of Maryland, College Park, MD, May 24-25, 2011
**Personnel**

Research Scientists: 2, Research Support Staff: 1

Conference proceedings / workshops
Figure 1. Comparison of SSH monthly anomalies from the NCEP MOM3 ocean data assimilation experiments (performed and provided by D.Behringer) with the satellite altimetry. All panels show standard deviations of model and altimetry differences (cm) for the 1993-2007 period. Model fields are from three MOM3 runs: `control` (CTL), assimilation of temperature and salinity profiles (TS), and assimilation of those together with the satellite altimetry (TSA). The satellite altimetry fields interpolated onto the model grid, whose zonal resolution is 1° (Alt), are used in panels (a), (c), and (e). For the use in panels (b), (d), and (f), Alt fields were filtered by the 5° running mean filter (fAlt).
Figure 2. Comparison of the SSH monthly anomalies from the MOM3 model products (name abbreviations are the same as in the previous figure) and from the satellite altimetry taken at model resolution (1° in zonal direction) with their respective filtered versions (using the 5° running mean filter in the zonal direction). All panels show standard deviations (cm) of the difference between filtered and unfiltered fields. Color bars in panels (a), (b), and (c) cover 0 to 3.2 cm range; a color bar in the panel (d) covers 0 to 20 cm range.
Research Goals:

Systematically catalog the physical characteristics of Atlantic Multidecadal Variability in IPCC AR4 models, evaluate the associated climatic impacts over land, the link to AMOC and atmospheric variability, and assess its predictability.

Research Progress

Progress was made in four major areas:

1. **Investigating the mechanisms of decadal variability in the GFDL CM2.1 model**: with output from a couple thousand years of the GFDL CM2.1 pre-industrial control, we were able to conduct a robust diagnostic study of Atlantic decadal variability. In particular we focused on a ~20 year quasi-periodic cycle in subpolar and subtropical SSTs. Here we identified and study the link between the Basin’s meridional overturning circulation (AMOC) variability and SST changes. We were able to show that the variability is forced by stochastic atmospheric windstress and heat flux forcing associated with the interannual variability of the North Atlantic Oscillation (NAO). The NAO generates SST anomalies through surface forcing such that when it is in a positive (negative) phase it forces negative (positive) anomalies in the subpolar gyre and positive (negative) in the subtropics. At the same time the NAO forces barotropic and baroclinic responses in the deep ocean which set up a slow process of northward ocean heat transport that acts as a negative feedback on the surface forcing. This interaction creates the quasi-periodic oscillation.

2. **Using Linear Inverse Modeling (LIM) to identify dynamical modes of variability and their potential predictability**: We formulated a LIM based on the three-dimensional (X, Y, and Z), Atlantic ocean state variables – temperature and Salinity from the 2000 years CM2.1 output. To identify the dynamical modes of the system we used the LIM setting to calculate the Basin’s principal oscillation patterns (POPs). The POPs were classified by the relationship between their periods and decay time and the patterns that have long decay times were examined. The ~20-year quasi-period oscillation described in item (i) above is clearly identified in the POP analysis, suggesting that it is an important internal mode of the North Atlantic. Using the POP decomposition we
were able to sho that in a mix of identifyable group of modes, the ~20-year patterns can exhibit rapid non-normal growth, which entails amplitude doubling in five years and is potentiall predictable for about a decade.

3. Begin application of LIM to study predictability of AMV: We developed a collaboration with GFDL scientist Rym Msadek to study the application of our LIM representation of the GFDL CM2.1 ocean component for prediction. We are basing our analysis on a set of perfect model experiments conducted at GFDL a year or so ago. Our current goal is to study what makes some initial states more predictable than other. We are currently studying the mix of POPs (see (ii) above) in the initial conditions and also experimenting with LIM predictions from these initial states using different subsets of the full POP-based state representation.

4. Global impacts of AMV: We continued our investigation to look at the global impacts of Atlantic multi-decadal SST variability. A paper summarizing our recent results was accepted for publication in GRL.

**Highlights**

Diagnostic analysis of GFDL CM2.1 control output reveals a distinct quasi-oscillatory behavior that can be understood as resulting from stochastic atmospheric forcing of an internal ocean mode. The mode is potentially predictable because it decays rather slowly and it can also lead to explosive growth of SST anomalies with potential impact on the surrounding climate.

**Societal Benefits**

An important element in societal adaptation to climate variability and change is more robust assessment on the relative role of natural and anthropogenic forcing in determining trends in surface air temperature and precipitation. This study moves to addresses mode clearly and in mode details Atlantic Multidecadal Variability.

**Other Research Connections**

Results from this study are relevant to the ongoing efforts on “initialized decadal predictions” therefore we are in contact with GFDL and NCAR and other international efforts to discuss results and exchange information.

Work on this subject is reported to the group of investigators working on the NOAA project: “Global Decadal Hydroclimate Predictability, Variability and Change” (GloDecH).

**Education & Outreach**

We are reporting on our activities to the US CLIVAR Decadal Prediction Working Group.

Results from research supported by this project were presented in several seminars and meetings:
- 27 July 2010, Cambridge MA: Harvard University Brown Bag seminar
• 9 February 2011, LDEO: Presentation to the monthly meeting of the GloDecH project.
• 27 January 2010, Princeton NJ: GFDL Seminar

**Personnel**


**Journal articles**

**Figure 1:** The correlation between the leading principal components (PC) of the CM2.1 5m, wintertime, North Atlantic ocean temperature and the 5m-temperature field. The analysis is based on a 500-year segment of CM2.1 output integrated with the pre-industrial CO2 concentration.

**Figure 2:** Top: the cross-correlation between the two PCs of CM2.1 wintertime 5m, North Atlantic ocean temperature. The relationship points at the quasi-periodic nature of the variability and the quadratic relationship between them, suggesting the propagation of anomalies from the subpolar gyre region to the subtropics. Bottom: The cross correlation between the leading PC of the model’s wintertime sea level pressure field, which corresponds to the model’s North Atlantic Oscillation (NAO), in its negative phase, and the leading PC of 5m ocean temperature field. The relationship points at weaker than normal subpolar westerlies forcing a warming of the underlying ocean surface.
Figure 3: The cross correlation between the first PC of 5m ocean temperature and the upper ocean, zonally-averaged poleward heat transport through the latitude of 50°N. The relationship indicates a negative feedback interaction where heat flowing into (and out of) the subpolar gyre region is in quadrature with the upper ocean heat content.
Research Goals

Goal of the 2010 research was to finalize investigation of the West Antarctic Peninsula (WAP) mooring data to identify inter-annually consistent mechanisms by which warm Upper Circumpolar Deep Water (UCDW) enters the WAP continental shelf.

Location of study area (mooring locations indicated on detailed right panel; shading indicates bathymetry; darker is shallow, lighter deep). Analysis designed to determine how UCDW moves from ACC over continental slope onto shelf, in particular from mooring #2 to #1 (these moorings situated where UCDW is most concentrated).
Identifying mechanism of delivery is necessary for improved representation in the climate models and forecasting future sea level rise from glacial melt (driven by presence of UCDW).

**Education Goals**
Same as previous years: Inform the public of the sensitivity of the west Antarctic glacial system to inflow of warm ocean water, in this particular case, to some of the specific mechanisms by which this warm water gets onto the continental shelf where it can access the glacial ice at the coastal margins.

**Research Progress**
We have finished the analysis of the mooring data, and results are being written into a paper for publication.

**Highlights**
This work has been highly successful; the data clearly show that the UCDW makes its way from the Antarctic Circumpolar Current (ACC; flowing along the slope-shelf break) by generation of eddies midway up the WAP (at our mooring site #2). They form where the deep Marguerite Trough, cutting across the continental shelf intersects the slope at a location where the shelf break turns abruptly seaward into the oncoming ACC. The ACC hits the northern wall of the trough (previously documented) and the resulting pressure head drives water into the trough. This water does not overflow from the trough onto the nominal shelf floor. Rather, eddies are also generated at this location above the shelf floor and these eddies track the bathymetry while being advected across the shelf along the trough’s northern wall. They intersect our mooring situated 60 km into the shelf, where we have noted that the eddies are clearly identified by several features: (1) the ocean heat content increases abruptly when the eddies cross, and the rate of OHC increase shows nearly the same rate of change (suggesting that the eddies have similar characteristics and likely flowing along the same bathymetric path), (2) the core of each of these increased OHC events show waters warmer than $1.7^\circ$C, water that is *only* present as pure UCDW in the ACC over the slope when delivered to this region, (3) the velocity structure of these warm core events are clearly rotational consistent with eddies (rotary spectra show them to be circulating at a velocity very close to the inertial time scale). Using the current meter data on the mooring, we determine the mean background flow during the presence of an eddy. The time the eddies are present at the mooring multiplied by the background drift speed gives an estimate of eddy diameter, $L_D$, (actually of a chord length, with the longer chord lengths likely closer to the true eddy diameter). The mean $L_D$ for years 2007, 2008 and 2101 (recall we were unable to recover the mooring for 2009), showed a slightly skewed Gaussian type distribution (skewed toward longer chords for those eddies passing over closer to their true center). Mean eddy radii and Rossby internal radii of deformation at the formation location (mooring #2) are:
<table>
<thead>
<tr>
<th>Year</th>
<th>Number of eddies</th>
<th>Mean eddy radius</th>
<th>Rossby radius</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>44</td>
<td>4.45 ± 0.52 km</td>
<td>4.45</td>
</tr>
<tr>
<td>2008</td>
<td>43</td>
<td>5.17 ± 0.73 km</td>
<td>3.30</td>
</tr>
<tr>
<td>2010</td>
<td>37</td>
<td>3.65 ± 0.37 km</td>
<td>3.43</td>
</tr>
</tbody>
</table>

Since the eddy radii are actually chord lengths, shorter than the true radii, their agreement with the expected size given the Rossby numbers is remarkably consistent.

Eddies observed at mooring #3 (100 km north of #2) show similar characteristics, slightly cooler core and between 65 and 75% fewer in number. It is not clear if these eddies move north from site #2 since we expect that the general current structure would be moving eddies from site #2 to the south, not north. We will look into this when we obtain more velocity data from the extensive glider runs being conducted in this study area.

**Societal Benefits**

Improved understanding of ocean heat delivery will lead to better simulations and forecasts of future sea level rise, and disposition of west Antarctic glacial ice. A fundamental issue facing glacial modelers today involves how the warm UCDW is moved onto the shelf where it can make direct contact with glacial ice at the continental margins.

**Other Research Connections**

This research is jointly sponsored by NSF, through funding of the Palmer LTER (Long Term Ecological Research) program and the Antarctic IPY SASSI (Synoptic Antarctic Slope-Shelf Interaction) project.

**Education & Outreach**

Outreach is achieved through the formal outreach group in the Palmer LTER project. E.g., during the last research cruise (Martinson was Chief Scientist), Martinson participated in a live blog where he communicated interesting results directly to K-12 classrooms and answered students' questions about those results and any questions of general interest involving work in the Antarctic.

**Personnel**

Research Scientists: 1, Support Staff: 2.
Grappling mooring for recovery during storm (blue arrow points to orange float barely visible in whitewater).
Pulling mooring onto deck during Antarctic storm.
Research Goals

The Abrupt Climate Change in a Warming World (ACWW) is the latest incarnation of a long running NOAA funded program of integrated research at Lamont into the problem of abrupt climate change. The focus is on (1) climate change in the late Pleistocene and Holocene periods and (2) near term future abrupt change, including social impacts of anticipated change.

Specific goals vary widely among the various projects supported under the ACCWW umbrella. The unique benefit of ACCWW is that it fosters the development of novel hypotheses concerning abrupt climate change by bringing together scientists from different disciplines. Over the years of combined effort under ARCHES and later ACCWW we have seen new ideas emerge concerning the origin of abrupt climate change, the transmission of these climate signals throughout the world, and the consequences at regional to global scales. The Infrastructure scope of ACCWW nurtures this interdisciplinary work by supporting conferences and workshops where scientists from various disciplines interact in a stimulating and collegial environment.

Research Progress

Progress by each of the individual projects is described in their individual reports.

Highlights

Described under Research Goals.

Societal Benefits

Society is susceptible to the consequences of climate change, and the consequences could be severe if climate change were to occur abruptly. Knowledge of the nature of abrupt climate change, including how it occurs and the anticipated consequences, will help society to be better prepared to deal with climate change.

The integrated approach of ACCWW provides tangible benefits in addressing the “how”, “why”, and “what” of abrupt climate change. From studies of freshwater forcing in...
regions of deepwater formation to studies of sea surface temperature patterns, ACCWW scientists are discovering how climate variability is initiated. By comparing records worldwide ACCWW scientists are learning how and why climate variability is propagated throughout the ocean and atmosphere system. By examining historical records and paleo proxy archives ACCWW scientists develop new insights concerning regional to global manifestations of abrupt climate change.

These goals are uniquely pursued under the interdisciplinary environment of ACCWW. Such a holistic approach could not be achieved from monitoring programs or modeling studies conducted in isolation.

Other Research Connections

Although there are no formal partnerships, scores of scientists from agencies and institutions worldwide interact with ACCWW each year through conferences and workshops supported through this infrastructure award. This point is illustrated in the meeting agendas appended at the end of this report.

Awards & Honors

Described in project reports of individual projects.

Education & Outreach

Described in project reports of individual projects.

Personnel

Administrative: 1.

The infrastructure award does not support individual scientists, students or post docs. This award supports all participating ACCWW scientists, students and post docs through various conferences and workshops.

Conference proceedings / workshops

Two conferences supported by the ACCWW award were held at Lamont during the reporting period: 1) A workshop on “Dust records for a changing world” (24-26 May 2010) and 2) “Geological constraints for Antarctic ice sheet models” (13 - 15 April 2011). The agenda for each workshop is appended below.
AGENDA

May 24, Monday
9:00-9:30 Welcome and introduction to goals (Gisela Winckler and Natalie Mahowald)
9:30-10:00 Overview of DIRTMAP (Barbara Maher)
10:00-10:30 Current climate dust and observations: how do they inform the paleo community (Joe Prospero)
10:30-11:00 Coffee break
11:00-11:20 The role of terrestrial sediments in understanding the dust cycle (Helen M. Roberts)
11:20-11:40 The role of ice cores in understanding the dust cycle (Anna Wegner)
11:40-12:00 The role of marine sediments in understanding the dust cycle (David McGee and Gisela Winckler)
12:00-12:20 Plio-Pleistocene dust flux variability in the Subantarctic Atlantic (Alfredo Martínez-Garcia)
12:20-12:40 Aridity changes in the Sahel and their relation to Atlantic-Ocean circulation during the last 57 kyr: inferences from marine sediments off Senegal (Jan-Berend Stuut)
12:45-2:00 Lunch (group lunch, catered at Lamont Hall)
2:00-5:30 Poster session (Coffee Break 3:15-3:45)
6:00 Group Dinner at Sidewalk Bistro, Piermont
Transfer back to the Hotel by Lamont buses (David, Mike Kaplan, Gisela).
WORKSHOP DUSTSPEC: DUST RECORDS FOR A CHANGING WORLD
SPONSORED BY NOAA ACCWW AND INQUA
LAMONT HALL, MAY 24 - MAY 26, 2010
ORGANIZERS: G. WINCKLER (LDEO), N. MAHOWALD (CORNELL) AND B. MAHER (LANCASTER)

AGENDA

May 25, Tuesday
9:00-9:20 Lake sediment records of dust fluxes (Ashley Ballyntine)
9:20-9:40 Current climate deposition to oceans and ocean nutrients (Chris Measures)
9:40-10:00 Glacial flour as a reactive source of iron to the Gulf of Alaska: reflections on modern processes and their implications for the paleo record (John Crusius)
10:00-10:20 Preliminary findings on the geochemical and microbiological fingerprinting of Australian aeolian dust (Patrick De Deckker)
10:20-10:40 Dust and coral data (Sujoy Mukhopadhyay)
10:40-11:10 Coffee Break
11:10-11:30 The role of dust in climate (Ron Miller)
11:30-11:50 Features of modern dust activity and long range transport of dust from Patagonia based on satellite and surface observations (Santiago Gasso)
11:50-12:10 Identification of natural and anthropogenic dust sources and their evolution for the past 3 decades (Paul Ginoux)
12:15-1:30 Lunch (group lunch, catered at Lamont Hall)
1:30-2:30 Plenary session
   What kind of database do we want? How to construct?
2:30-3:30 Working groups
3:30-4:00 Coffee Break
4:00-5:00 Working groups
5:00-5:30 Plenary session: findings of working groups (short oral summaries by rapporteurs)
5:30-6:30 Reception/Cocktail Hour (outside Lamont Hall)
6:30-8:30 Conference Dinner at Lamont Hall
WORKSHOP DUSTSPEC: DUST RECORDS FOR A CHANGING WORLD
SPONSORED BY NOAA ACCWW AND INQUA
LAMONT HALL, MAY 24 - MAY 26, 2010
ORGANIZERS: G. WINCKLER (LDEO), N. MAHOWALD (CORNELL) AND B. MAHER (LANCASTER)

AGENDA

Wednesday May 26

9:00-9:30   Plenary discussion (short presentations by *rapporteurs*)

9:30-10:30  Working groups

10:30-11:00 Coffee Break

11:00-12:00 Plenary discussion

12:00-2:00  Lunch
'Geological constraints for Antarctic ice sheet models: what do we have and what do we need?'

Workshop at Lamont-Doherty Earth Observatory, April 13-15 2011

PROGRAMME

Wednesday April 13

Welcome
09:10 Joerg Schaefer
Introduction and aims of the workshop
09:15 Greg Balco

Terrestrial chronologies  (chair: Joerg Schaefer)

Greg Balco
09:30 Introduction to the surface exposure dating method
John Stone
09:45 Deglaciation chronology of various sites in East and West Antarctica
Perry Spector
10:30 Holocene Deglaciation of the Ross Sea Embayment

BREAK
10:45

Gordon Bromley
11:00 Revisiting the deglacial history of Reedy Glacier, southern Transantarctic Mountains
Robert Ackert
11:15 Gauging WAIS elevations prior to the last highstand: Utilizing cosmogenic nuclides in supraglacial debris and bedrock in interior West Antarctica
Jo Johnson
11:45 The post-LGM thinning history of Pine Island Glacier, and some results from the N and W Antarctic Peninsula

LUNCH
12:15

Greg Balco
13:15 Results from the northeast Antarctic Peninsula, no results from the Pensacola Mountains, and some ideas about relating exposure ages to glaciological observations
Jorge Strelin
13:45 Glacier stratigraphy in the northern tip of Antarctic Peninsula
Mike Kaplan
14:15 Pleistocene East Antarctic Ice Sheet History as Recorded in Chronology and Sediment Provenance of High-elevation TAM Moraines

DISCUSSION/BREAK
14:30
Marine geology and chronology  
(chair: Gordon Bromley)

Eugene Domack  
Future targets for marine and terrestrial geochronology in the Antarctic and refinement of radiocarbon dating methods and interpretation of marine sequences  
15:15

Frank Nitsche
Amundsen Sea
Evidence of paleo ice dynamic from the continental shelf morphology in the Amundsen Sea  
15:45

C-D Hillenbrand  
Post-LGM ice-sheet retreat from the West Antarctic shelf in the Bellingshausen and Amundsen seas: Current knowledge and open questions  
16:15

DISCUSSION  
16:45

New developments

Joerg Schaefer/Irene Schimmelpfennig  
Cosmogenic in-situ 14C at LDEO and the new 14C/10Be tool  
17:00

Tom Guilderson  
Applications of 14C-Geochronology to Antarctic Marine Sediments: Complications and (or?) Opportunities  
17:15

Wrap-up  
17:30

Evening  
19:00  
Dinner in Lamont Hall

(Pre-dinner drinks from 18:00)

Thursday April 14
Summary of Wednesday

The wider context  
(chair: Mike Kaplan)

Rob Briggs  
Use of observations to constrain a large ensemble glacial systems model analysis for Antarctic deglaciation  
09:30

Erik Ivins
Dynamics
10:00  
Geodetic Data for Constraining Present-Day and Holocene Antarctic Mass

Claus-Dieter Hillenbrand
10:30  
Did the West Antarctic Ice Sheet collapse during the middle-late Pleistocene?

DISCUSSION/BREAK  
11:00

Elizabeth Pierce
Marine Sediments
Antarctica's Climatic History from Isotopic Sedimentary Provenance Studies of  
11:30

Robin Bell/Kirsty Tinto
12:00  
Change in West Antarctica from a geophysical view
LUNCH
12:30

Seth Campbell  
Ice-penetrating radar investigation of glacier structure and dynamics near exposure-dating sites in the Pensacola Mountains
13:30

Tim Creyts
14:00
Implications of subglacial water in West Antarctica

Doug Martinson
14:30
Dramatically warming water adjacent to western Antarctica

DISCUSSION/BREAK
14:45

DISCUSSION GROUPS (format tba)
15:15

Wrap-up and dinner logistics
17:15

Evening
Dinner at Sidewalk Bistro, Piermont
18:15

Friday April 15

Summary of Thursday, and aims for today
09:30

Group 1 leader report and time for discussion 09:45
Group 2 leader report and time for discussion 10:15
Group 3 leader report and time for discussion 10:45

BREAK
11:15

Wrap-up and planning
11:30

End of workshop and LUNCH
12:30
Research Goals

The overall goal of this project is to study change and variability in the global hydrological cycle during the last millennium and into the future and to contrast the changes due to processes internal to the climate system (ocean-atmosphere-land interactions) or to natural external forcing (solar, volcanic) with anthropogenic forcing (greenhouse gas emissions).

Education Goals

- To train the next generation of scientists specializing in climate variability and predictability and familiarize them with the theoretical background and tools of research in this field.
- When possible, to expose undergraduates student to modern climate research through on-site, one-on-one internship program.
- To use knowledge gained through research to enrich teaching activities to undergraduate and graduate students in disciplinary and inter-disciplinary programs through lectures and web posting of research results.

Research Progress

Work under this award is terminating as we transition to working on essentially the same topics under the new award Global Decadal Hydroclimate Variability and Change: A Data-Enriched Modeling Study which began in fall 2010. Under the finishing ACCWW award we have completed some studies that were already underway as very briefly listed below.

- Completed and published a paper arguing for the linear wave refraction idea of how the Pacific storm track responds to ENSO.
- Conducted a study of the atmospheric circulation response to an instantaneous doubling of carbon dioxide to examine cause and effect in the poleward shift of the stormtracks and jet streams.
• Completed a study of the thermodynamic and dynamic mechanisms for large scale changes in the hydrological cycle in response to global warming within IPCC AR4 models.
• Examined study of the abrupt drop in Dead Sea level at 3200K years BP (the mid Bronze Age Crisis) and its connection to climate events worldwide and submitted a paper for publication.
• Revised and resubmitted a paper addressing a comparison between AR4 models simulations of Western US precipitation and observations.

**Highlights**
Since this project is terminating no new highlights are listed. See last years report for key items.

**Societal Benefits**
Hydroclimate variability and change are a matter of serious concern worldwide. Research on how these aspects of climate impact water availability and quality is important for building robust prediction capabilities and provide information to decision makers and the general public as they seek specific solution to adapt.

**Other Research Connections**
This work meshes well with and is complemented by research on tropical influences on the atmosphere, which is funded by NSF. In the course of this work we partnered with NOAA/GFDL and NASA/GISS.

**Education & Outreach**
We have involved several graduate students in conducting research on various aspects related to the project objectives. In addition we have regularly worked with undergraduate student, either as summer interns or work-study students with the goals of giving them a climate research experience. In most cases these students were funded by other sources and created opportunities to augment our own work.

**Personnel**

**Journal articles**


*Books / articles-in-books*

CICAR

AWARD NO. NA08OAR4320912
PROJECT TITLE The Mechanisms and Predictability of Multi-Basin Influences on North American Drought
PROJECT ACCOUNT NO. 5-62130
CICAR TASK AND THEME Task III Theme I
PRINCIPAL INVESTIGATORS Richard Seager / Huei-Ping Huang / Yochanan Kushnir
AFFILIATION Lamont-Doherty Earth Observatory
NOAA PROGRAM & MANAGER Climate Variability & Predictability
NOAA GOAL 2

Research Goals

This project aims to quantify the impact of tropical Indo-Pacific, Atlantic, and Intra-Americas Sea SST on North American droughts. The principal methodology adopted in this study is ensemble numerical modeling using atmospheric and partially coupled general circulation models (GCMs) forced with observed SST. In addition, the outputs from IPCC simulations using fully coupled GCMs driven by greenhouse gas (GHG) forcing are analyzed. The overriding goal is to determine the relationships among global and regional SSTs, GHG forcing, and North American droughts in present and future climate.

Research Progress

1. Multi-box SST experiments

We have completed the last few numerical experiments for deducing the impact of SST anomalies on seasonal precipitation over North America. Figure 1 shows the January-May precipitation anomalies forced by (a) "American West Coast" (AWC), (b) "American East Coast" (AEC), and (c) tropical South American (TSA) SST anomalies. Each simulation was run for 30 years with a repeated seasonal cycle of the "control" SST plus an imposed SST anomaly (which does not vary with season) with a fixed amplitude of +1.5°C. The precipitation response to this SST anomaly is defined as the difference between the perturbed run and the control run. The definition of the AWC, AEC, and TSA boxes are shown in Fig. 2. For winter-spring precipitation anomalies, two major findings are: (1) The TSA SST anomaly produced drying over southwest U.S. and northern Mexico and wetness over northwest U.S., both qualitatively similar to the effect of a positive TNA SST anomaly; (2) A positive AWC SST anomaly produced a surprisingly significant positive rainfall anomaly over much of the U.S., especially the west coast. This is interesting because a positive SST anomaly over the AWC region is known to often accompany El Nino. The sign of the response in precipitation shown in Fig. 1a is the same as the typical response of North American precipitation to a positive tropical eastern pacific SST anomaly from GCM simulations. Thus, the AWC SST anomaly actually acts to enhance this typical ENSO response. Given this insight, we will add extra experiments with the atmospheric model forced by combined AWC+tropical...
Eastern Pacific SST anomalies. In Fig. 1, the AEC SST anomaly produced only a weak response in precipitation over the U.S. This is consistent with the prevailing view from previous studies that the low-frequency atmosphere-ocean variability in the northern North Atlantic has a greater influence on the climate in Europe but weaker influence on North America.

Our results of the simulations with SST boxes in the Atlantic Ocean, Intra-Americas Sea, and North American coastal regions are summarized in Fig. 2. Figure 2a shows the impact of the SST anomalies on the precipitation anomaly over southwest U.S. and northern Mexico (marked by the red box). The number in each box indicates the response in January-May cumulative rainfall, in mm, to a +1.5C SST anomaly in that box. Green and brown indicate an increase and decrease in precipitation. Figure 2b is similar to Fig. 2a but for the influence of the SST anomalies on the precipitation over northwest U.S.

2. Process studies for SST-precipitation connection

We have continued analyzing the processes that connect the remote SST anomalies to precipitation anomalies over the U.S. We are extending our previous analysis for TNA to the new boxes of TSA, IAS, and AWC. In general, the SST anomalies generate height anomalies over the U.S. that are consistent with the pattern of the precipitation anomalies in these cases. Figure 3 shows the 200 hPa height anomalies due to (a) IAS, and (b) AWC SST forcing. The approximate location of the center of the SST box (IAS or AWC) is marked by a red cross. For the IAS case, the SST anomaly produced a positive height anomaly over the southern U.S., consistent with dryness. The AWC SST forcing produced a negative height anomaly over much of the continental U.S., consistent with wetness over this region.

3. Downscaling for precipitation

Our analysis of the relation between remote SST anomalies and North American precipitation has relied on GCM simulations using a global atmospheric model. Over the course of our investigations, we recognized that the relatively coarse resolution of the global GCM might be a source of bias. To address the potential impact of model resolution on the simulated precipitation, we performed a set of climate downscaling experiments for the southwest U.S. Using the WRF model, we completed four sets of runs, each spans 7 winters from 2003-2009, using 6-hourly NCEP reanalysis data as the large-scale boundary condition. The 4 sets of runs are all with multiple nesting and with the horizontal resolution of innermost domain (that covers the State of Arizona) set to 12, 6, 6, and 3 km, respectively. The two sets of 6 km runs consist of one with cumulus convective scheme turned on and one with it turned off. The 12 km runs are with the convective scheme turned on and 3 km runs with it turned off. The key conclusion from these exercises is that the intensity and temporal characteristics of precipitation keep changing with resolution. As the model resolution is refined, in addition to the increase in the total seasonal rainfall, we also see an increase in the intensity of the extreme events. A large number of the most extreme rainfall events produced by the 3 km runs are muted in the 12 km runs. Our results indicate the need for further investigation of a possible bias in the GCM-produced rainfall due to coarse resolution.
Highlights

- Completion of the SST-box experiments for the Atlantic Ocean, Intra-Americas Sea, and North American coastal regions; the influences of the SST anomalies in these boxes on the rainfall anomalies over the U.S. are quantified.

- Clarification of the connection between the SST anomalies in the Atlantic-North American sector and rainfall anomalies over the U.S. by the process of generation of Rossby wave trains; The geopotential height anomalies associated with the wave trains are consistent with the patterns of rainfall anomalies.

- Completion of a set climate downscaling experiments that helps demonstrate that, over the southwest U.S., the seasonal-mean rainfall in the regional climate model simulation keeps increasing with the model resolution.

Societal Benefits

Understanding what controls the hydrological variability over North America is key to developing predictive capabilities for the onset and duration of drought period. This is important to decision makers particularly in the area of water resource management.

Education & Outreach

Graduate students Yutian Wu (Columbia University) and Ashish Sharma (Arizona State University) participated in part of the research of this project mentored by Seager (CU) and Huang (ASU).

Personnel

Research Scientists: 3, Research Support Staff: 1.

Journal articles


Conference proceedings / workshops

**Figures**

*Figure 1.* January-May precipitation anomalies forced by (a) "American West Coast" (AWC), (b) "American East Coast" (AEC), and (c) tropical South American (TSA) SST anomalies. The boxes are defined in Fig. 2.
Figure 2 (a). Summary of the impact of the SST anomalies on the precipitation anomaly over southwest U.S. and northern Mexico (marked by the red box). The number in each box indicates the response in January-May cumulative rainfall, in mm, to a +1.5°C SST anomaly in that box. Green and brown indicate an increase and decrease in precipitation. (b) Similar to (a) but for the influence of the SST anomalies on the precipitation over northwest U.S.
Figure 3. The 200 hPa height anomaly as the response to (a) IAS, and (b) AWC SST forcing. The red cross indicates the center of the SST box.
Research Goals

In the proposal the work plan for Year 1 stated:

We will begin with the analysis of the coupled atmosphere-ocean states for naturally occurring drought and anthropogenically-induced subtropical drying in currently existing model simulations with CM2.1. We will begin the perfect model predictability experiments examining S/I prediction. We will conduct the large, ensemble of short integrations that examine atmosphere response to changes in naturally occurring and anthropogenic-induced SST changes. Characterize the dynamical system from 2000 year.

These remain our goals for this year.

Education Goals

The PIs will continue their wide efforts to inform and educate the general public and stakeholders on the implications, causes and consequences of climate change focusing on water related issues. This includes interviews with print, broadcast and Internet media, public presentations, popular publications and presentations at meetings where stakeholders gather as well as comprehensive web sites describing the research and providing access to data and publications.

Research Progress

In this year we have built upon the analysis of the thermodynamic and dynamic mechanisms for changes in the large-scale hydrological cycle in response to global warming that was published in Journal of Climate in 2010. We have now contrasted the mechanisms of hydroclimate change to those of hydroclimate variability. It was found that the latter are ‘dynamics-dominated’ in that they are primarily driven by circulation anomalies combining with the mean humidity field. This contrasts with the mechanisms of hydroclimate change that combine influences from changes in circulation and increases in specific humidity (and, hence, are ‘thermodynamics-mediated’). This distinction was applied to the post-1979 climate record from the 20th Century Reanalysis,
chosen for its relative homogeneity in time free of jumps to changes in instruments etc. The full three-dimensional circulation and humidity fields were separated into components due to natural variability and a residual that contained any radiatively forced change. The residual moisture budget field was checked against prediction from IPCC AR4 models for what should have happened to date as a consequence of radiatively forced change. It was found that there is evidence within the 20CR for increases in $P_E$ in equatorial and mid-to-high latitude regions with drying in the subtropical regions as predicted by AR4. Further the 20CR, once the influences of natural variability have been removed, has changes in circulation that are consistent with the hydrological changes and those expected as a consequence of anthropogenic radiative forcing. This work has been accepted for publication in Journal of Climate.

Working with our GFDL partners (A. Rosati, G. Vecchi and A. Wittenberg), a set of perfect model predictability runs initialized at interesting times of the tropical Pacific variability in a long coupled run have been performed at GFDL. These predictability experiments are being analyzed to look at predictability of tropical Pacific variability on the interannual to multiyear timescale and in particular whether multiyear La Niña events (associated with widespread droughts across the subtropics to mid-latitudes, including North America) are predictable. As of now, the analysis seems to indicate that any predictability is limited within this model environment. Initialized predictions as part of CMIP5/AR5 will be examined when available.

We have also completed and published a study of an apparently unpredictable major event in the climate history of western North America: the early twentieth century North American pluvial. This was a period (about 1905-17) of high moisture availability and streamflow that extended from Mexico to Canada and from the Pacific across the Mississippi basin. Whereas the epic multiyear droughts of the West are all linked to persistent, multiyear La Niña conditions in the tropical Pacific, the pluvial was not although there were some helpful El Niño events within it. Instead what is striking, and shown by our analysis, is that a prolonged cool period drew down evaporative demand and increased soil moisture and streamflow. The causes of this cooling are not known. In addition we were able to show that a large number of winters with positive Arctic Oscillations (10 in all) favored wet conditions across the West. Given that the causes of pluvial were partly due to the AO and the cool conditions it is no surprise that models forced by historical SSTs fail to simulate it. This work cautions that atmospheric variability can lead to significant hydroclimate anomalies in North America that cannot be expected to be predicted from SSTs.

We also completed our work on the generation of mean and transient atmospheric circulation anomalies over the Pacific-North America sector in response to ENSO SST anomalies. A second paper on this was published that advances our theory of linear wave refraction as an explanation for the meridional shifts of the Pacific storm track associated with ENSO events.
Also, although it was not part of the original proposal, we published a paper on the causes of the snowy winter of 2009/10 in the southern and central eastern U.S. and northwest Europe. Analyzing snow data and Reanalyses we concluded that the record-breaking snow anomalies were caused by the combination of a record-breaking negative seasonal mean negative NAO and a moderately strong El Niño event. The latter shifted to storm track south while the former placed bitter cold air over the eastern U.S. so that precipitation fell as snow. In Western Europe the snow was more solely due to the negative NAO. Since only the El Niño part of this has proven predictability snowy winters like that of 2009/10 will remain largely unpredictable.

**Highlights**

- Demonstration on the basis of fully three dimensional estimates of the atmospheric state that hydroclimate change over recent decades is broadly consistent with a strong component of internal climate variability plus a component due to the impacts of radiatively-forced change to date. The forced component in the observations is comparable in pattern, magnitude and causes to that predicted by the IPCC AR4 models. This raises confidence in the model projections of more severe hydroclimate change to come.

- Explanation of the dynamical causes of extreme snowy winters in the eastern U.S. in terms of ENSO and the NAO.

**Societal Benefits**

The work raises confidence in model projections of serious hydroclimate change to come by demonstrating that hydroclimate change over recent decades contains a component consistent with model projections to date. This agreement suggests that planners in the region should take the model projections of hydroclimate change over North America into account in future decision-making.

Explaining the cause of extreme winters also has societal benefit even if predictability of these events remains limited, it is useful to know how often they can be expected and if they are natural events or the consequence of anthropogenic change. There is tremendous popular interest in these events and a great desire to have them explained which we were able to do for winter 2009/10.

**Other Research Connections**

This award is one of several from NOAA and NSF that collectively fund our groups research into hydroclimate variability and change over the last millennium and into the near term future. This award is focused on the predictability part of that work.

**Presentations**


Seager, R., A mechanisms-based approach to distinguishing between natural variability of, and radiatively-forced change in, hydroclimate. AGU Fall Meeting, 2010.


Kushnir, Y., Recent Results from the Study of Atlantic Multidecadal Variability at Lamont. GFDL Seminar, 27 January 2011.

Seager, R., A mechanisms-based approach to detecting recent anthropogenic hydroclimate change. WCRP Workshop of Drought Predictability and Prediction, Barcelona, Spain, March, 2011.


Kushnir, Y., Recent Results from the Study of Atlantic Multidecadal Variability at Lamont. GFDL Seminar, 27 January 2011 (Invited).
Web site

We also maintain and update the ‘Drought Research at Lamont Doherty Earth Observatory’ website (http://www.ldeo.columbia.edu/res/div/ocp/drought/) that presents in a user-friendly manner our research findings. Complete model simulations are archived with access to all via the IRI/LDEO data library. The PIs provide numerous interviews with print, broadcast and online media. (In July 2010 our work on drying of the southwest was mentioned in a New York Times op-ed piece for example.)

Personnel

Research Scientists: 4, Research Support Staff: 2.

Journal articles


Research Goals
Our project has two primary Research goals:
1. Contribute to improving the simulation of the Madden-Julian Oscillation (MJO) in the Atmosphere Model 3 (AM3) of the Geophysical Fluid Dynamics Laboratory (GFDL);
2. Provide understanding of MJO physics by diagnosing the mechanisms operating in the AM3, as well as in the earlier (but still operational) model AM2.

Education Goals
Training of a postdoc.

Research Progress
To address the first research goal, postdoctoral researcher Jim Benedict has been conducting sensitivity tests with the GFDL AM3 to examine sensitivity of the Madden-Julian oscillation (MJO) simulation to entrainment, rain evaporation, triggering, and other aspects of the convection parameterization. We have found that the simulation of the Madden-Julian oscillation in AM3 can be substantially improved by making the convection scheme interact more realistically with its large-scale environment through improvements to entrainment treatment and rain re-evaporation. Both of these changes increase sensitivity to tropospheric humidity, which improves the MJO. A substantial diagnosis of the spectral and cross spectral quantities of different model simulations was conducted, as well as relation of changes in mean state simulation to model parameters was conducted. Further process-oriented diagnosis of the model is taking place to isolate the reasons for such model sensitivity.

Regarding the second research goal, we have argued in recent publications (Sobel et al. 2008, 2010; the) that interactive feedbacks involving surface moist enthalpy fluxes, both turbulent and radiative, are important to the dynamics of tropical intraseasonal variability. Evidence in favor of this hypothesis includes sensitivity experiments performed with a
small number of general circulation and idealized models. Our work in year 2 has continued to explore this hypothesis.

An aquaplanet atmospheric general circulation model simulation with a robust intraseasonal oscillation was analyzed by Maloney et al. (2010), as discussed in last year’s report. The model intraseasonal oscillation resembles a moisture mode that is destabilized by wind-evaporation feedback, and that propagates eastward through advection of anomalous humidity by the sum of perturbation winds and mean westerly flow. A mechanism denial experiment in which intraseasonal latent heat flux variability is removed largely eliminates intraseasonal wind and precipitation variability. Reducing the lower-troposphere westerly flow in the warm pool by reducing the zonal SST gradient slows eastward propagation, supporting the importance of horizontal advection by the low-level wind to eastward propagation. Further work indicated that basic state zonal asymmetries and surface mean westerlies are important for producing a realistic MJO (Figure 1). In year 2, an experiment was performed and analyzed in which longwave radiative heating was prescribed to be near climatology. The results suggest that both radiative and wind-evaporation feedbacks may help to destabilize the model MJO.

The sensitivity of a simulated Madden Julian Oscillation (MJO) was investigated in the NCAR Community Atmosphere Model 3.1 with the relaxed Arakawa-Schubert convection scheme by analyzing the model’s response to varying the strength of two moisture sensitivity parameters. A higher value of either the minimum entrainment rate or rain evaporation fraction results in increased intraseasonal variability, a more coherent MJO, and enhanced moisture-convection feedbacks in the model.

Analysis of the mean column integrated and normalized moist static energy (MSE) budget reveals a substantial reduction of gross moist stability for increased minimum entrainment.

Systematic relationships between aspects of intraseasonal variability (ISV) and mean state bias were shown in a number of atmospheric general circulation model (AGCM) simulations, including the GFDL AM2. Strong-ISV models simulate excessive rainfall over the south Asian summer monsoon and the northwest Pacific monsoon regions during boreal summer. Three sets of paired simulations, in which only one parameter in the convection scheme is changed to enhance the moisture sensitivity of convection, are used to explore common differences between the two groups in greater detail. In strong-ISV models, the mean and the standard deviation of surface latent heat flux is greater, convective rain fraction is smaller, and tropical tropospheric temperatures are lower compared to weak-ISV models.

Air-sea interactions and their impact on intraseasonal convective organization were investigated by comparing two five-year simulations from the super parameterized Community Atmosphere Model version 3.0 (SP-CAM). The first is forced using prescribed sea-surface temperatures (SSTs). The second is identical except that a simplified oceanic mixed-layer model is used to predict tropical SST anomalies that are
coupled to the atmosphere. Convective development east of the MJO precipitation center is more favorable in the coupled versus the uncoupled version, resulting in more realistic organization and clearer eastward propagation of the MJO in the coupled SP-CAM.

Our theoretical work has resulted in development of an idealized semi-empirical model in which the MJO is represented as a moisture mode destabilized by surface flux and radiative feedbacks. The model is one-dimensional in longitude, but is nonlinear, modeling both the mean state and perturbations using the weak temperature gradient approximation. There is a prognostic moist static energy equation, but no separate temperature or momentum equation. Winds are modeled as a quasi-stationary linear response to heating. This work has been submitted for publication in J. Atmos. Sci.

In the more observational component of this project, analysis of the MISMO soundings has been complemented by comparison to soundings from the AIRS satellite. We have come to realize that the mean temperature and moisture profiles in the Indian ocean are – perhaps surprisingly - not sufficiently constrained by observations for purposes of model verification, forecasting, or mechanistic understanding. It is important to pin this down better, and this work will continue in year 3.

**Highlights**

- Detailed sensitivity studies reveal parameter settings in Donner scheme (the convective parameterization of the GFDL AM3 model) leading to improved simulation of the MJO.
- Detailed understanding of the relative roles of surface flux feedbacks and cloud-radiative interactions in an aqua-planet simulation, which simulates a very strong MJO.
- Development of a novel idealized model for the MJO in which it is modeled as a nonlinear stationary moisture mode destabilized by WISHE and cloud-radiative feedbacks (as found in the aqua-planet GCM simulations).

**Societal Benefits**

The AM2 and AM3 models are being used for prediction on a range of time scales. The MJO is of interest for its own right as a target for prediction, but also interacts with a range of other phenomena, including ENSO, tropical cyclones, midlatitude storms, other precipitation extremes, etc. If we can improve the simulation of the MJO, this will have clear societal benefit through improvement of all these aspects of prediction.

The basic mechanisms responsible for the MJO remain unknown after 40 years of study. The MJO is arguably the most important mode of variability in the climate system (at least at sub-decadal time scales), which is so poorly understood. Our theoretical work, partly supported by this project and closely coupled to the modeling work which is supported by the project, represents a novel approach which we believe holds out some hope for solving this longstanding and critically important problem.
Other Research Connections (interagency, partnerships, collaborations)

Sobel is leading another project involving diagnosis, simulation, and analysis of the MJO in the NASA Goddard Institute for Space Studies (GISS) climate model, specifically the new model being used for the fifth IPCC Assessment Report. There has been good synergy between the two projects with many discussions between both teams.

Prof. In-Sik Kang of Seoul National University spent his sabbatical at LDEO during April-December 2010. Prof. Kang is an expert on the MJO with much experience in simulation and diagnosis of it. We interacted with him closely during his stay here and he is a co-author on one of our papers. He is

Awards & Honors

In summer 2010, Sobel was awarded the 7th Lamont-Doherty Earth Observatory Award for Excellence in Mentoring.

Personnel

Research Support Staff: 1, Post Doctoral Fellows: 1.

Journal articles


**Figures**

**Figure 1.** Differences in tropical precipitation variability between simulations with east-west ocean temperature variations (left), and east-west uniform temperatures (right).
Research Goals

The overall objective of this project is to separate the global climate impacts due to the natural Atlantic Multidecadal Variability from that due to anthropogenic forcing, and to understand the underlying mechanisms and possible predictability of these impacts.

Education Goals

None specific

Research Progress

Our main effort continued to be on identifying the AMV spatial and temporal characteristics and climate impacts in IPCC model simulations of the pre-industrial, the 20th Century, and the 21st Century forcing. It was found that despite the differences in temporal characteristics (usually with shorter time scale compared to observed 60-80 years and less periodic compared to 20th Century observations), the spatial structure of the AMV in all of the cases in terms of North Atlantic SST, from pre-industrial to 21st Century are very similar with a comma shaped SST anomalies extending from the subpolar North Atlantic along the eastern part of the basin to subtropical North Atlantic (Fig. 1, left panels). The precipitation impacts are also similar in all cases such as the impact on Sahel rainfall (Fig. 1, right panels). A paper summarizing the results is in press currently in Geophysical Research Letters.

We also completed a set of GCM experiments with prescribed AMV SST over the Atlantic basin using NCAR CAM4. The atmospheric responses in terms of SLP, surface wind, and precipitation are generally similar in the Atlantic domain. But there are discrepancies in remote responses such as the Indian monsoon and North American rainfall. Further experiments using ocean heat flux related to AMV and a mixed layer ocean is currently planned to tease out the relationship between subtropical and subpolar AMV-related SST patterns and their impacts.
We have also computed hurricane potential intensity (PI) and genesis potential for the 20th Century simulations with historical SST forcing. Results show that local Atlantic SST influence on hurricane PI is the dominant factor in AMV case, in sharp contrasts to the global warming-related SST case where the relative changes in local SST has to be taken into account. A paper is currently in preparation for the Journal of Climate.

**Highlights**

- AMV spatial patterns are insensitive to external radiative forcing ranging from pre-industrial to 21st Century despite the different temporal behavior.
- AMV-related precipitation changes are mainly related to a shift of ITCZ in the tropical Atlantic due to the local SST changes.
- AMV-SST influences hurricane potential intensity strongly over the Atlantic domain.

**Societal Benefits**

The understanding of the AMV-related climate impacts, such as the Sahel rainfall change, is extremely useful for near-term climate prediction.

**Other Research Connections**

The PI was invited by the fishery community to a workshop discussing the possible impacts of AMV-related climate anomalies on fishery in June 2011 at Woods Hole Oceanographic Institute.

**Education & Outreach**

One Ph.D. student (Colin Kelley) is partially supported by the project for his Ph.D. thesis research on Mediterranean drying trend and its possible links to anthropogenic forcing versus natural causes, including AMV.

- Results from this research efforts are integrated into the Lamont Global decadal hydroclimate group activities including monthly presentations and website listings.
- Presented an invited talk on AMV and its possible impacts at a ICES workshop held at Woods Hole Oceanographic Institute in June 2011 for the fishery community.

**Personnel**

Research Scientists: 3, Research Support Staff: 1, Administrative: 1, Graduate Students: 1.

**Journal articles:**

Figure 1. Annual mean global surface temperature regression onto the AMV indices for (a) observations, (b) 20th Century, (c) 21st Century, and (d) Preindustrial CMIP3 model simulations. (e)-(h) same as (a)-(d), but for precipitation. Stippling in (a) and (e) indicates 95% confidence level based on Monte Carlo test, in (b), (c), (f), and (g) indicates 18 out of 23 models showing the same sign regression coefficients, in (d) and (h) indicates 16 out of 20 models showing the same sign regression coefficients. Contours in right panels are for climatological precipitation contoured at 2 mm/day intervals.
Theme II Modern and Paleoclimate Observations

INDIVIDUAL AND COLLABORATIVE PI RESEARCH PROJECTS

CICAR Institutional Extension Award # NA08OAR4320754
1. Gordon, A., Monitoring the Indonesian Throughflow in Makassar Strait
2. Huber, B., Weddell Sea Moorings
3. McGillis, W., Boundary Layer Experiments of Coral Reef Calcification and Net O₂ Production
4. Takahashi, T., Underway CO₂ Measurements Abroad the RV IB Palmer and Data Management of the Global VOS Program

CICAR Shadow Award # NA08OAR4320912
1. Anderson, R., Abrupt Climate Change in a Warming World (ACCWW): Holocene Variability of the Deep Limb Meridional Overturning Circulation
2. Broecker, W., ACCWW: Meridional Hydrology Variability and Synthesis of Ocean Circulation
3. Cook, E., ACCWW: Lessons from Holocene Paleo and Modern Instrumental Records and Model Simulations
4. D’Arrigo, R., Paleoclimate Reconstructions (PR) Challenge: A Community Program to Benchmark Methods Used to Reconstruct the Climate of the Last 1-2,000 Years
5. deMenocal, P., ACCWW: Holocene Variability of Atlantic Surface Properties and West African Aridity
8. Hemming, S., ACCWW: Radiogenic Isotope Tracer Paleo-Proxy Scope
11. Schlosser, P., ACCWW: Abrupt Climate Change in a Warming World: Synthesis of Tracer Data
12. Smethie, W., ACCWW: Modern Instrumental Records-CFCs

TOTAL THEME II PROJECTS: 16
Research Goals

The Indonesian Throughflow (ITF) transfers sea water, heat and freshwater from the western Pacific into the tropical Indian Ocean, at a rate of ~11 to 15 million m³/sec [Figure 1]. The strong monsoonal winds and tides amidst the complex sea floor morphology of the archipelago stretching from SE Asia to Australia, alter the temperature and salinity profiles of the ITF, which in combination with the velocity profile, link via an ocean route the Pacific and Indian Ocean climate systems. As the ITF region is at the nexus of ENSO (El Niño/La Niña) and the Asian monsoon phenomena, it is highly likely, as indicated by model studies, that the ITF serves as a key component of the larger scale climate system.

Recording the ITF, and its connection to fluctuations in ENSO and the Asian monsoon, is an effective and cost effective way to monitor a component of the larger scale ocean and climate system, with the intent to enable a climate predictive capability. As Makassar Strait is the pathway for 80-85% of the total ITF, it is the obvious core of an ITF monitoring array.

The NOAA funded Makassar moorings is part of a growing international effort to observe the ITF. See Australian and Korean program discussion below “Highlights.”
From INSTANT: Inflow ~ 13 Sv; outflow ~ 15 Sv; \[\Delta 2 \text{ Sv imbalance over 3 years, uncertainty or missing passages (Halmahera Sea)}\]?

Figure 1. Transport values in $10^6 \text{m}^3/\text{sec}$ within the passages measured by the INSTANT program, 2004-2006. The italics numbers in black represent transport values based on pre-INSTANT data: Makassar Strait, 1997; Lombok Strait, 1985; Timor Passage (south of Timor) from March 1992 to April 1993; Ombai Strait (north of Timor) for 1996. The pre-INSTANT value of 1.5 Sv for the Lifamatola Passage represents overflow of dense water at depths greater than 1500 m based on 3.5 months of current meter measurement in early 1985. The red numbers are the 3-year mean transports measured by INSTANT. In Lifamatola Passage, the green number is the INSTANT overflow transport $>1250$ m, and the red number is the total transport measured by INSTANT below 200 m. The “Question Marks” are targeted to be addressed as part of the GATEWAY program.

**Education Goals**

Capacity building with the Indonesian partners has been arranged for rotation cruise (presently scheduled for July 2011). The educational component involved training in mooring recovery/deployment and data downloading from the instruments.

**Research Progress**

1. **Project Summary**

   After much discussion with our Indonesian counterparts [BRKP] the recovery and re-deployment of the NOAA-MAK mooring (Figure 2), which is funded by the 2010/11 increment to NA08OAR4320754, is now scheduled for late July/early August 2011. The recovery of the mooring in 2011 will extend the Makassar throughflow time series from
the present 5.5 years to 7.5 years. This extended time series will enable us to investigate the effects of ENSO and the Indian Ocean Dipole on the ITF. The data are currently available at http://www.ldeo.columbia.edu/~bhuber/OCO_ITF.

![Makassar Monitoring Deployed 1 June 2009](image)

**Figure 2.** The NOAA-MAK mooring configuration of the 2006-2009 mooring recovered on 31 May 2009. The moorings will be recovered, data downloaded and replacement mooring deployed in July/August 2011.

As the ITF weaves through many passages of the Indonesian seas, from the Pacific inflow channels to the export channels to the Indian Ocean, a sustained observational array of mooring for measuring all of the pathways is not yet financially practical. However, a significant step towards this goal is met by monitoring the throughflow with Makassar Strait, which carries ~80-85% (>90% of the thermocline layer component) of the ITF. This is presently underway with the NOAA/OCO funded current measuring mooring near 3°S in the Labani Channel constriction of Makassar Strait.
The Arlindo 1996/98; INSTANT, 2004/06, and NOAA Makassar time series 2007-2009 is shown in Figure 3. The July 2011 mooring rotation will provide continuation of the time series, which can further test the ITF interactive links with ENSO.

Figure 3. Arlindo, INSTANT, NOAA ITF time series, a total of 7 years of record. The Makassar transport profile shows a thermocline maximum, the surface layer transport on average is inhibited. The shape of the profile and associated ‘temperature’ transport varies with ENSO.

2. Scientific Accomplishments

In an attempt to explain the time changes observed in the Makassar transport profile (Figure 3) and its connections to the western Pacific warm pool and South China Sea processes, Arnold L. Gordon presented in a keynote address at the IOC Westpac meeting in Busan, Korea, last week of March 2011: “ITF and Western Pacific Warm Pool” Abstract: The transfer of western Pacific Ocean water into the Indian Ocean in what is referred to as the Indonesian Throughflow (ITF) influences the heat and freshwater inventories, and associated sea surface temperature (SST) of these oceans. The ITF effects on SST patterns in turn links the ocean to such climate phenomena as ENSO and the IOD. A 2004-2009 time series of the Makassar Strait throughflow, the primary component of the ITF sheds light on the nature of the Pacific Ocean contribution and its possible impact of the Western Pacific Warm Pool (WPWP). The depth profile of the
Pacific water flowing into Makassar Strait exhibits thermocline intensification, and hence the transport-weighted temperature is cooler than might otherwise be expected. The participation of warm surface ocean water in the ITF is restricted, which may protect the WPWP from larger leakage into the Indian Ocean. The restriction of the surface water component of the ITF is likely a consequence of the injection of low salinity, buoyant surface water from the South China Sea (SCS) into the Makassar Strait, which blocks entry of Mindanao Current surface water into Makassar Strait. The SCS surface water derived from the Pacific Ocean via the Luzon Strait, which is diluted with excess freshwater, before entering into Makassar Strait, both from the south through Karimata Strait and from the north by a pathway through the Sulu Sea and Sibutu Passage. The SCS throughflow (Luzon Strait to Makassar Strait) may be ENSO dependent. During El Niño the SCS throughflow high, which blocks and hence reduces the surface layer contribution into the ITF from the Mindanao Current; during La Niña, the SCS throughflow low, which allows greater contribution of Mindanao current surface water into the ITF. The Warm Pool leakage into the Indian Ocean associated impact of SST may be greater La Niña, not just because of the higher sea level in the western tropical Pacific but also because of the reduced 'freshwater plug' of the SCS throughflow. In this way, SCS hydrological budget and throughflow has an impact of the SST patterns and ENSO and IOD. To explore this hypothesis requires a coordinated international effort to observe and model the sources and characteristics of various depth layers composing the ITF, spanning ENSO and IOD cycles.

The Hypothesis (Figure 4):

Gordon et al 2003 proposes that the low salinity, buoyant water flowing eastward from the SCS to the Java Sea via Karimata Strait acts to retard the Makassar surface layer throughflow. Here we expand on that theme, that there are two streams of low salinity SCS water affecting Makassar Strait: Karimata and Sibutu throughflow from the Sulu Sea into the western Sulawesi Sea [northern Makassar Strait].
Figure 4. Surface layer routing into the Makassar Strait via the South China Sea varies with ENSO’s affect of the Luzon Strait throughflow.

Main points:
• The restriction of WPWP surface ocean water entry into the ITF is likely a consequence of the injection of low salinity/buoyant surface SCS water into the Indonesian seas. The source of the SCS water is western Pacific water at Luzon Strait, 19°-21°N. The process is called the SCS throughflow.
• Low salinity SCS surface water enters Makassar Strait by two portals: 1) through the Karimata Strait (Java Sea); 2) into the Sulu Sea via the Mindoro Strait and then through the Sibutu Passage into the Sulawesi Sea and northern Makassar Strait.
• During El Niño SCS input into Makassar Strait is large, blocking surface layer contribution into the ITF via the 0°-5°N Mindanao/Halmahera Retroflections portal, making for a cooler ITF; during La Niña the SCS throughflow is low, allowing greater contribution of surface water into the ITF by way of the Mindanao/Halmahera Retroflections portal, warmer ITF, with consequences to the Pacific equatorial stratification and circulation, and the western Pacific warm pool.

What, if any, information was jeopardized due to a lack of funding, lack of instrumentation, or inability to carry out the work? The NOAA-MAK mooring is adequate for monitoring the major component of the ITF inflow, noting that the throughflow with Makassar Strait carries ~80-85% (>90% of the thermocline layer component) of the ITF. However, monitoring of the export routes of the ITF into the Indian Ocean via the channels of the Sunda Islands would provide a much fuller view of
the ITF and its connections to the climate system. A more complete ITF observing system would enable assessment of the modification of ITF waters within the Indonesian seas, which is governed by sea-air exchange, the critical link between the atmosphere and ocean. It is recommended that a mooring in Lombok Strait be added at the same time in 2011 that the Makassar mooring is recovered/re-deployed. Sharing of the ship time will reduce the ship costs / mooring.

**Highlights**

Collaboration, to network the NOAA funded Makassar mooring into an international full array approach:

The Australian Integrated Marine Observing System [IMOS] Indonesian Through Flow Moorings forms an important companion ITF project to the NOAA-OCO funded Makassar mooring. Together we are well on our way to a more complete ITF observing system. Susan Wijffels & Bernadette Sloyan, CSIRO and Craig Steinberg & Richard Brinkman, Australian Institute of Marine Science supervise iMOS-Indonesia.

The aim of the IMOS is to monitor the sub-inertial heat and volume transport variability between Australia and Alor Island, including the flow across the shallow Australian shelf (Table 1).

### Table 1 IMOS ITF Mooring locations and depths

<table>
<thead>
<tr>
<th>Location</th>
<th>ITF code</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Depth (m LAT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joseph Bonaparte</td>
<td>JBG</td>
<td>128º 58.075’ E</td>
<td>13º 36.491’ S</td>
<td>59</td>
</tr>
<tr>
<td>Flat Top Bank</td>
<td>FTB</td>
<td>128º 28.611’ E</td>
<td>12º 17.404’ S</td>
<td>103</td>
</tr>
<tr>
<td>Margaret Harries</td>
<td>MHB</td>
<td>127º 59.992’ E</td>
<td>10º 59.993’ S</td>
<td>145</td>
</tr>
<tr>
<td>Banks</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Timor South</td>
<td>TIS</td>
<td>127º 33.199’ E</td>
<td>9º 49.023’ S</td>
<td>465</td>
</tr>
<tr>
<td>Timor Sill</td>
<td></td>
<td>127.37</td>
<td>-9.30</td>
<td>3007</td>
</tr>
<tr>
<td>Timor North</td>
<td>127.22</td>
<td>-8.90</td>
<td>1173</td>
<td></td>
</tr>
<tr>
<td>Ombai</td>
<td>125º 3.86’E</td>
<td>8º 32.00’S</td>
<td>3224</td>
<td></td>
</tr>
</tbody>
</table>

The Australian mooring array will be deployed in 2010/2011: two in Timor Passage and one in Ombai Strait. Instrumentation on the moorings will include profilers 150 kHz and 75kHz ADCPs, Seabird SBE39s, discrete current meters and Pressure Inverted Echo Sounders. The deepwater mooring array to be deployed by CSIRO will integrate at the Australian continental shelf with the northern mooring coastal array operated by AIMS. The deepwater moorings will provide profile velocity data above 500 m and point source velocity between 500 m and 1200 m (depth of controlling sill). Temperature and salinity
data will be collected for the entire water column. The NW Shelf moorings were deployed in June 2010 and the deeper moorings in the Timor Sea are planned for deployment in June 2011. The deeper moorings will be serviced every 18 months to 2 years.

From Susan Wijffels, 21 June 2011: “we have just successfully deployed 1 mooring at the INSTANT Ombai South site and 2 tall moorings at the western end of the Timor Passage. These were deployed in two legs from the small AIMS vessel, RV Solander. The ITF was strong in Ombai and its usual steady self in Timor. We also deployed a PIES at Ombai to see whether it may assist in projecting temperature up to the surface. The shelf array will continue to be maintained as well.”

KORDI/NOAA: The Korea Ocean Research & Development Institute (KORDI) is developing an additional international companion program, called GATEWAY- to study the tropical western Pacific feed into the ITF. This program was discussed at the IOC Westpacific meeting last week of March 2011 in Busan, Korea. Prof. Arnold Gordon of LDEO at Columbia University will organize an international project called GATEWAY to investigate the source, magnitude and dynamics of the western tropical Pacific feed into the ITF. GATEWAY will be coordinated with other programs measuring the ITF within the Indonesian seas, which may be viewed as INSTANT II. A small KORDI/LDEO meeting at LDEO on 19th September 2011 to discuss the GATEWAY program, specifically the PIES array. PIES: Pressure Inverted Echo Sounder. It is a bottom moored instrument that produces a time series of the total water column pressure and average temperature, which allows for monitoring of the sea level changes associated with ocean circulation changes.

Societal Benefits

The Indonesian Throughflow moves mass, heat and freshwater from the Pacific Ocean into the Indian Ocean. The Makassar throughflow time series reveals a strong impact to the state of ENSO, mostly in the depth of the thermocline maximum along channel current (shallower/warmer in La Nina; deeper/cooler in El Nino). We expect that this has a major affect on the surface layer temperature of the tropical Indian Ocean, with linkage to the Asian monsoon. If this hypothesis proves right, the societal benefit to the NOAA funded Makassar Strait time series will be very significant.

Personnel

Research Scientists: 1, Research Support Staff: 2, Administrative: 1, Graduate Students: 1.

Conference proceedings / workshops

Gordon, A.L., 2011 ITF and Western Pacific Warm Pool
Keynote presentation at the 8th IOC Westpac International Science Symposium meeting,
Busan Korea (Photo):
The waterways of the Indonesian seas link the tropical Pacific Ocean with the Indian Ocean. The resultant interocean transfer of seawater from the Pacific to the Indian Ocean, referred to as the Indonesian Throughflow (ITF), is ten times greater than all of the river flow of the Earth. The ITF has a major impact on the heat content and sea surface temperature patterns of the Indian Ocean, and also affects the western Pacific. As shifts in sea surface temperature patterns are so closely linked to El Niño and the Asian monsoon, both of which have a major impact on society, understanding the ITF relationship to the regional and global climate system is essential in predicting climate change. To advance understanding and our ability to model and predict ITF coupling to climate and marine ecosystems requires sustained observations of the ITF behavior.

Directly after the recovery of the NSF funded INSTANT western Makassar mooring in November 2006, a NOAA funded mooring (NOAA-MAK) was deployed at the same site (2°51’ S; 118°28’ E). We now have a 5.5-year continuous time series of the Makassar Throughflow that carries 80 to 85% of the ITF. The NOAA-MAK time series from late November 2006 to the end of May 2009 spans a predominately La Niña period (when the throughflow is expected to increase) reaching a peak in strength in early 2008; a weak El Niño (when the throughflow is expected to decrease) in the latter half of 2006 (Fig. a). The Indian Ocean Dipole Mode Index (DMI) switched into a positive mode during 2006, remaining so throughout the NOAA-MAK time series. Positive DMI is related to lower sea level in the eastern tropical Indian Ocean and an increase in the ITF. Three consecutive years with a positive DMI have not been detected in the historical SST records. This unprecedented long period of +DMI is likely linked to the shift in the Makassar throughflow and ITF.

The Makassar throughflow change observed by the NOAA-MAK (late 2006 to mid-2009) relative to the INSTANT period (2004 to late 2006) (Fig. b) was: (1) The thermocline flow was intensified, with a maximum speed near 75 m composed of warmer upper thermocline water, rather than at 140 m marking the mid-thermocline; (2) Increase of the Makassar throughflow transport from the 2004-2006 average of 11.6 Sverdrup (Sv = 106 m3/s) to 13.5 Sv in 2007-2008, with an increase in transport weighted temperature from 15°C to 18°C. The +DMI is likely related to these significant changes. We expect that the change in the ITF profile will eventually affect the Indian Ocean surface layer temperature. As the observational time series lengthen we will develop a more quantitative grasp of the ocean and climate coupled system.

Research Goals

Observations of the properties of deep and bottom waters exiting the Weddell Sea are an essential component of efforts to understand the links among atmosphere, sea-ice, ice shelves and deep water formation processes which contribute to the southern ocean thermohaline circulation and its variability. This project maintains deep and bottom water focused oceanographic moorings south of the South Orkney Islands in the Northwest Weddell Sea to provide a time series of the combined outflow (currents and temperature/salinity) of Antarctic Deep and Bottom Water drawn from various sites within the Weddell Sea. Preliminary analyses of the data retrieved from the mooring suite supported by this project through early 2009 reveal significant variability in deep and bottom water characteristics exiting the Weddell, on multi-year time scales as well as annual cycles. Indeed, the annual cycles have been greatly attenuated or are absent in some years. Efforts to elucidate possible changes in bottom water based only on repeat hydrographic measurements may be compromised by both strong annual periodicity and significant interannual variability of the type observed in the moored data set so far. Continuing the time series will be crucial in understanding the nature of the long-period changes already observed in the bottom water, and being able link the observed variability to variations in ocean-ice-atmosphere interactions which determine not just the rates of bottom water formation, but their characteristics as well.

For the performance period 1 July 2011 to 30 June 2012

The Weddell Sea and Orkney Passage moorings were serviced in March 2011 during cruise JR252 on the BAS vessel RRS James Clark Ross. Mooring M3 was successfully recovered and redeployed. Mooring M2 was not recovered, but a replacement mooring was redeployed at the same location. The three Orkney Passage moorings were recovered and replaced with a new network of 5 moorings with higher spatial resolution across the Orkney Passage. The work plan for the period 1 July 2011 – 30 June 2012 includes:

- Calibration of moored sensors recovered during the March 2011 cruise. Return shipment of moored sensors recovered will likely take several months following the end of the cruise, pushing the calibration dates into the next FY period.
• Processing of data recovered during the cruise and subsequent distribution of the data on the project web site.
• Upgrading of the existing data set and web products to conform to the recently adopted netCDF-based Climate and Forecast data format.
• Continued analysis of the Orkney Plateau and Orkney Passage time series in collaboration with our BAS colleagues.
• Preparation of the next mooring cruise, anticipated for austral summer 2012/2013.
• Evaluation of methods for allowing more frequent data capture from the moorings.

We plan to pursue the goal of providing near real time data from the moorings by coordinating with an ongoing engineering effort of the Instrumentation Group of AOML’s Physical Oceanography Division (PhOD). They are developing a method for periodically retrieving data from moored sensors: the Adaptable Bottom Instrument Information Shuttle System (ABISS – see http://www.aoml.noaa.gov/phod/instrument_development/abiiss/index.php). ABISS may be ideally suited for collecting and relaying data from the Orkney Plateau moorings, once the final engineering and test phases have been completed at AOML. The Weddell moorings offer special challenges, owing both to the depth of the moorings and sea ice cover during part of the year. Noting that Add Tasks will likely not be possible in the coming fiscal year, our efforts during this period will focus only on coordination with AOML of data requirements, telemetry specifications, and possible testing opportunities. This coordination can be accomplished within the level basic budget in anticipation of a future Add Task to fully implement the technology.

Education Goals

While this project does not have a specific education component, we continue to strive to engage undergraduate and graduate students in the data analysis activities as the time series data sets mature. During the past year, one of our undergraduate work-study students participated in the publication of two peer-reviewed journal articles.

Research Progress

The world's deep oceans are filled with water masses formed at the continental margins of Antarctica. The Weddell Sea is a major source of these so-called Antarctic Deep and Bottom Waters. Relatively warm, saline Circumpolar Deep Water (CDW) enters the Weddell Gyre to the east of the Greenwich Meridian. As it traverses the gyre, it feeds bottom water-forming processes on the continental shelves, and interacts with floating ice shelves to produce a variety of Weddell Deep and Bottom water types. Because these formation processes include heat exchange with the atmosphere and ice shelves, the properties of the water masses formed carry an imprint of any recent changes in atmospheric and shelf ice characteristics, including temperature, distribution of shelf and sea ice, and shifts in large scale wind stress patterns such as those associated with the Southern Annular Mode (SAM) and ENSO.
This project maintains deep and bottom water focused oceanographic moorings south of the South Orkney Islands in the Northwest Weddell Sea to provide a time series of the combined outflow (currents and temperature/salinity) of Antarctic Deep and Bottom Water drawn from various sites within the Weddell Sea. The observation sites were selected to monitor the integrated properties of the outflowing deep and bottom waters after they have traversed the key formation sites in the western Weddell Sea.

Figure 1. Weddell mooring locations, and schematic of deep and bottom water flow from source regions to the mooring array.

The moorings were initially installed and maintained as part of the NOAA-funded Consortium on Oceans Role in Climate: AbRupt climate CHangE Studies (CORC-ARCHES) Southern Ocean Modern Observations program. First installed in April 1999, the moorings have been serviced using ship time made available by other polar programs, primarily through the National Science Foundation Office of Polar Programs (OPP), and principal investigators funded by OPP who graciously allow our team to sail on their cruises. As time and resources allow during the mooring maintenance cruises, oceanographic stations to collect profiles of conductivity, temperature and tracers (CTD/tracer) are occupied at the mooring sites and at stations distributed along a line between the mooring locations (Figure 1). The cost of ship time devoted to the mooring
work and associated CTD/tracer stations, typically 3 to 5 days was supported by funding from OCO.

Beginning in 2007, ship time has been made available under the auspices of an Agreement of Cooperation between Lamont-Doherty Earth Observatory of Columbia University (LDEO) and the British Antarctic Survey (BAS). The agreement with BAS provides for sharing of equipment, personnel, and data between LDEO and BAS to allow the mooring sites to be serviced at nominally two-year intervals, with BAS providing the ship time to do so. Under this agreement, by sharing material resources with BAS, we have been able to expand the mooring array to encompass the Orkney Passage to the east of the Orkney Plateau, a site of potential escape of Weddell Deep Water into the Southern Ocean. Our collaboration with BAS will continue, so this work is part of an international effort.

Data collection: frequency and availability

Because the ship time required for servicing the moorings is made available on an opportunity basis, the moorings are not serviced at regularly scheduled intervals. We plan for a nominal two-year cycle, but the moorings are designed with a lifetime in excess of three years in the event that ship time is unavailable on the 2-year cycle. Moored instrument data and whatever oceanographic profile data we are able to collect are therefore available on a nominal two-year cycle. The moorings are located in regions that are seasonally covered by sea ice so all data are recorded internally and must be recovered during the service calls. The recovered data are quality controlled, and made available via the web, generally within 6 months of their recovery from the moorings. The data and descriptions of the moored instruments are presently available at http://www.ldeo.columbia.edu/res/div/ocp/projects/corc.shtml and by request to bhuber@ldeo.columbia.edu. The data will be migrated to a new data portal during FY2011-12 activities. Descriptions of the moorings and metadata are catalogued at OceanSITES (http://www.oceansites.org/).
Figure 2. Weddell mooring configurations and positions: RCM current meters are being replaced with acoustic current meters as budget allows. New temperature and temperature/salinity recorders are purchased in off-field years and phased into the mooring array to allow for return and recalibration of older units.

Accomplishments

Fieldwork

The Weddell Sea and Orkney Passage moorings were serviced in March 2011 during cruise JR252 on the BAS vessel RRS James Clark Ross. Mooring M3 was successfully recovered and redeployed. Mooring M2 was not recovered, but a replacement mooring was redeployed at the same location. The three Orkney Passage
moorings were recovered and replaced with a new network of 5 moorings with higher spatial resolution across the Orkney Passage.

Data analysis, presentation and publication of results

We had three manuscripts published during this reporting period. A poster was presented at the international XXXI SCAR Open Science Conference held in Buenos Aires. Details are provided in section 5. A brief summary of published results is provided here.

Antarctic Bottom Water (AABW) is approximately 70% more voluminous in the global abyssal ocean than North Atlantic Deep Water (NADW), covering more than twice the sea floor area than NADW. Observations within the Southern Ocean’s Pacific sector reveal a decadal trend of decreasing salinity by increased glacial melt water, which if continued might be expected to reduce the formation rate of bottom water. Trends in the Weddell Sea are less clear, and the data set available to examine trends is limited.

The cyclonic flowing Weddell Gyre is the dominant circulation feature south of the Antarctic Circumpolar Current in the Southern Ocean’s Atlantic sector. Relatively warm circumpolar deep water enters the Weddell Gyre east of the Greenwich Meridian, cooling as it proceeds westward within the coastal current forming the gyre's poleward limb. Eventually reaching the southwestern Weddell Sea and the eastern margins of Antarctic Peninsula, it spreads onto the continental shelf. Sea-air-ice exchange over the shelf forms dense, freezing point, high salinity shelf water (HSSW). The dense shelf water is exported across the outer edge of the shelf, producing Weddell Sea Bottom Water (WSBW). The WSBW thus formed mixes with overlying water in the Weddell basin before escaping the gyre to contribute to AABW in the abyssal Southern Ocean.

Temperature/salinity (T/S) sensors and current meters on moorings maintained by this project southeast of the South Orkney Islands (Fig. 1&2) provide a multi-year time series within the axis of the eastward flowing WSBW stream. We find a distinct seasonal cycle of bottom water characteristics at the deepest mooring, M3, interrupted by an anomalous warm period in 2000 (Fig. 3). The six-year 1999-2005 record from the shallower mooring M2 within the Weddell Sea Deep Water (WSDW- a mixture of WSBW and Weddell Warm Deep Water) shows the 2000 anomaly but does not display a distinct seasonal cycle. It is likely that the annual signal is attenuated during the mixing process leading to WSDW. At M3 the bottom potential temperature (θ°C) multi-year mean seasonal cycle ranges from -0.85°C to -0.96°C, with the coldest pulse in May/June and the warmest in October/November. The monthly time series range is nearly 0.3°C, with the daily θ°C fluctuations of 0.1°C from the monthly curve.

The timing and amplitude of the cold and warm pulses vary from year to year. The coldest events occurred in 1999 and 2002, while 2000 was devoid of cold events. After 2002 the deviations from the mean seasonal cycle are small, with slight cooling from late 2003 into early 2005. The bottom salinity also reveals interannual changes, with relatively salty bottom water observed in 2001 and 2002. The salinity variability at M3
forms a ‘fan-like’ distribution, suggesting a variable source of the shelf water end-member (Fig. 4). The $\theta$/S characteristics indicate a Ronne Ice Shelf HSSW origin, with the lower salinity WSBW derived from the shelf further north along the eastern margins of Antarctic Peninsula, probably associated with the Larsen ice shelves.

Figure 2. Location of Weddell Sea moorings: The bottom depths and mooring location are: M2: 3096 m, 62°38’S; 43°15’W; M3: 4560 m, 63°32’S; 41°47’W. A potential temperature (PT) and salinity (Sa) section along the line shown on the map passing by each mooring, obtained in 1997 shows the mooring setting relative to the thermohaline stratification. The record length mean bottom current (cm/sec) is shown in vector form at M2 and M3.
Figure 3a-b. 8-year time series at mooring M2 and M3. 30-day running mean potential temperature, salinity and bottom speed time series at M2 and M3 (a). M3 temperature and salinity are color coded by distance from the sea floor as shown in the insert in a. M2 potential temperature and salinity time series 15 m distance from the sea floor, are shown as a dashed blue line. The vertical dashed gray lines denote mooring recovery/re-deployment times. b, the M3 bottom potential temperature daily (gray line), the monthly (blue line) and the mean seasonal cycle (red line). The 2004 gap in M3 bottom temperature is filled with data from the instrument at 4447 m, offset by the mean difference between it and the bottom temp record (-0.027°C).
Figure 3c. Time series at mooring M2 including most recently collected data. The gap 2004-2007 is over plotted with observations obtained at the Orkney Passage mooring M4 (redeployed in 2007 as OP3). Note the near absence of seasonal signals, while the interannual variability is apparent, especially warming from 1999 to 2000, coinciding with the absence of a seasonal cold event at M3.

The rate of export of shelf waters to form WSDW and WSBW, and their corresponding properties, depend upon several factors: suitable wind/sea ice conditions for dense shelf water formation, the abundance of shelf water available for export, and the timing and strength of the mechanisms which allow the dense shelf water to escape to flow down slope. We hypothesize that the annual and interannual signals evidenced in the moored data can be related to seasonal and interannual patterns in the regional winds, year-to-year variations in which are closely tied to climate indices such as the Southern Annular Mode (SAM) and El Nino/ Southern Oscillation. These relationships are explored in Figure 5.

The above results have been published in Nature Geoscience (Gordon, et al. 2010 – See publications below).
Figure 4. Potential temperature and salinity at the sea floor from M2 and M3, April 1999 to February 2007, color-coded for bottom speed [cm/sec]. The yellow dots are from the 1997 section shown in Fig. 1. The θ/S location of the cold and warm phases of the seasonal cycle for each year is identified.

A quantitative, statistical approach to exploring these relationships was published in the Journal of Geophysical Research (Darren C. McKee, Xiaojun Yuan, Arnold L. Gordon, Bruce Huber, Zhaoqian Dong: Climate Impact on Interannual Variability of Weddell Sea Bottom Water).

A third paper (Meredith et al. 2011) explores the relationship between temperature variability in the deep water measured on the Orkney Plateau and variability in the temperature of the Weddell outflow measured on the north slope of the Orkney Plateau, in the Scotia Sea.
Figure 5. a) NCEP–DOE Reanalysis Climatology, 1996–2008 in 67°S to 76°S; 45°W-62°W
b) Spatially averaged meridional wind speed, within the solid red domain indicated in Figure 2 map. The blue arrows mark the time of anomalous cold bottom water at M3; a red arrow marks the anomalously warm period of 2000 and a second red arrow marks a weaker warm anomaly in 2002. The blue lines denote periods of sustained strong northward winds; the red lines denote periods of near zero or reversals in the meridional winds. c) Wind stress curl anomaly within the dashed red domain indicated in the Figure 2 map. The red lines denote periods of reduced wind stress curl, and by inference diminished Weddell Gyre; while the blue lines are periods of increased wind stress curl and gyre intensity. Arrows are the same as in b. d) SAM index (dashed line), M3 bottom temperature anomaly (gray solid line) and NINO3.4 index (dotted line). The left vertical axis corresponds to the SAM index while the right vertical axis corresponds to the M3 bottom temperature anomaly. The temperature variability in NINO3.4 is scaled so as to fit on the temperature axis though it actually varies from -1.67 to 2.65 deg C.
**Highlights**

1. With the recovery of mooring M3 and the 3 Orkney Passage moorings, the Weddell time series has been extended another 2 years. Started in 1999, the Orkney Plateau time series is now 11 years long. The data are presently available at [http://www.ldeo.columbia.edu/res/div/ocp/projects/corc.shtml](http://www.ldeo.columbia.edu/res/div/ocp/projects/corc.shtml) and by request to bhuber@ldeo.columbia.edu. The data will be migrated to a new data portal during FY2011-12 activities.

2. Deep and bottom water properties exiting the Weddell Gyre are found to exhibit significant annual cycles, the timing of which vary from year to year.

3. In addition to the annual signal, interannual variability is exhibited which can be tied to processes in the southwest Weddell Sea. (Gordon, et al., 2010)

4. The interannual variability is correlated with climate indices such as ENSO and SAM through their influence on wind patterns in the deep and bottom water formation regions of the southwest Weddell Sea. (McKee, et al., 2011)

5. The Orkney Plateau time series and an overlapping time series recorded within the outflow of AABW from the Weddell Sea indicate that increased outflow temperatures are synchronous with stronger boundary current flows. These changes occur rapidly in response to changes in wind forcing. The observed synchronicity indicates that the previously detected weakening of the export of the colder forms of AABW from the Weddell Sea need not be associated with a reduction in the total flux of AABW exported via this route (Meredith, et al. 2011)

**Societal Benefits**

Deep and bottom water formation in the Southern Ocean plays a key role in the meridional overturning circulation of the oceans, and hence is a key component of the climate system. Observing and understanding the variability in the formation processes over interannual and longer time scales is a crucial component of the climate observation system.

**Other Research Connections**

Beginning in 2007, this project has benefited from a close collaboration with colleagues at the British Antarctic Survey (BAS). Ship time has been made available under the auspices of an Agreement of Cooperation between Lamont-Doherty Earth Observatory of Columbia University (LDEO) and BAS. The agreement provides for sharing of equipment, personnel, and data between LDEO and BAS to allow the mooring sites to be serviced at nominally two-year intervals, with BAS providing the ship time to do so. Under this agreement, by sharing material resources with BAS, we have been able to expand the mooring array to encompass the Orkney Passage to the east of the Orkney Plateau, a site of potential escape of Weddell Deep Water into the Southern Ocean.

**Personnel**

Research Scientists: 1, Research Support Staff: 3, Administrative: 1, Undergraduate Students: 1.
Journal articles


Conference proceedings / workshops

Research Goals

The goal is to employ the **boundary-layer gradient method** as a plausible and innovative technique. The near bottom flux of a chemical constituent into or out of the sediment or biota on the seafloor is determined from the product of the vertical eddy diffusivity related to drag coefficient estimated from measurements of horizontal velocity at two closely spaced depth just above the seafloor and the concentration gradient of the constituent of interest measured over the same depth interval. We have been able to show that application of this method using oxygen sensors produces net photosynthesis and respiration rates that agree well with those determined by Eulerian and dome methods. The strong utility of the method is that it can be applied to constituents for which no chemical sensor exists but which can be measured from water samples. We have developed water samplers that slowly fill two 1-liter bags from two depths simultaneously. A suite of these samplers will be deployed to collect samples at different times of the day or night from which we can determine the concentration gradient of total alkalinity (Talk) and from that we can then determine the rate of calcification. The Coral Reef Oxygen Sensor System with Talk (CROSS-Talk) package is a light-weight unistructure made of plastic tubing that stands 1 m high that carries an acoustic Doppler Velocimeter (ADV), two Aanderaa oxygen optodes, a MAVS time of flight 3-D velocimeter, a fast-response oxygen sensor, and six automated duplex water samplers. The instrument measures the oxygen flux every two minutes and the flux of the chemical constituents determined from the bag samples every hour or however often the bag samples are programmed to be collected. The footprint of the measurement is an oval that is approximately 30-50 m². The boundary-layer gradient flux method has the potential to open up a large spectrum of chemical constituents for which we will now be able to measure their seafloor fluxes under completely natural, unperturbed conditions.

Education Goals

There is a growing recognition within the field of biological oceanography that transport of nutrients and other materials into and out of corals, other sessile animals and benthic algae is mass transport limited and strongly affected by the local flow field...
surrounding the organism (Atkinson et al. 1992, 1994; Lesser et al. 1994; Baird and Atkinson 1997). This means that we need to move away from methods for measuring metabolism that involve enclosing the organism and altering the hydrodynamic environment to methods that measure flux in the free and ambient environment. Control volume experiments are one approach. This involves measuring the transport of water and material into and out of a water volume in all directions by deploying instruments in all corners of that volume. The method can be powerful, but involves a lot of equipment to measure the full water column for both material and velocity at different corners of the volume. Many different instruments are required, and they must be very accurate and precise in order to get accurate mass balances. This technique also uses the residual of what comes in and out of the vertical control volume surfaces to determine the flux from the top and bottom of the control volume – usually the benthic and air-water interface. The mass-balance technique requires some spatial and temporal averaging in the control volume as well.

**Research Progress**

Boundary layer methods have been used for decades to measure gas exchange over terrestrial surfaces. For example, the DC and GF methods are routinely used to measure the CO2 flux over vegetative fields and forest canopies where the signal to noise ratio for CO2 sensors is high. Infrared gas analyzers (IRGA) are commonly used to measure the CO2 concentration by absorptance (Edson, 2001). The direct covariance method correlates the gas concentration signals with the vertical velocity typically measured using high frequency velocity sensors to provide a direct estimate of the flux:

\[ F_G = \overline{w'G'} \]  \hspace{1cm} (1)

where the overbar represents a time average, and \( w' \) and \( G' \) are the fluctuating components of the vertical velocity and dissolved chemical constituent of interest, respectively. The gradient method assumes that the profile is directly proportional to the flux

\[ F_G = K_M \frac{d\bar{G}}{dz} \]  \hspace{1cm} (2)

where \( z \) is the height above the surface and \( K_M \) is the variable of proportionality known as the eddy diffusivity for mass: \( K_M = u_\ast \kappa z/\phi \). The surface friction velocity \( u_\ast \), von Karman’s constant \( \kappa \), and \( \phi \) is the stability function are all accurately known or measured terms.

As a proof of concept a study was conducted in a shallow, warm-water coral reef environment in La Parguera, Puerto Rico. ADVs, MAVs, an ADCP, and Aanderaa optode oxygen sensors were deployed on a frame at 0.50 m above the bottom (mean height of the surrounding corals) and at 1.5 m above the bottom. Current speed and oxygen concentration were logged every two minutes over a 48-hr period. At the beginning and end of the deployment the oxygen sensors were positioned side by side to obtain data so that any small offset or biases in the signals could be corrected in the time
series. Discrete oxygen samples were collected to provide a check on the accuracy of the oxygen signals. Discrete oxygen samples were also collected upstream and downstream of the location of the boundary layer flux measurements so that oxygen flux could also be determined by the Eulerian upstream-downstream mass balance method (Marsh and Smith, 1978). The data obtained are presented below. Figure 4 shows the oxygen flux computed by the boundary layer flux method as a function of the time of day. The data for the two days are overlapped to emphasize the fact that the data show a very reasonable and repeatable pattern from day to day, i.e. respiration at night and net photosynthesis that increases through the morning and declines during the afternoon.

**Highlights**

The metabolism of Cayo Enrique Reef, Puerto Rico, was studied using *in situ* methods during March 2009. Benthic O$_2$ fluxes were used to calculate net community production using both the boundary layer gradient and enclosure techniques. The boundary layer O$_2$ gradient and the drag coefficients were used to calculate productivity ranging from -12.3 to 13.7 mmol O$_2$ m$^{-2}$ h$^{-1}$. Productivity measurements from the enclosure method ranged from -11.0 to 12.9 mmol O$_2$ m$^{-2}$ h$^{-1}$. During the study, the mean hourly difference between the methods was 0.65 mmol O$_2$ m$^{-2}$ h$^{-1}$ ($r^2 = 0.92$), resulting in well-reconciled estimates of net community production between the boundary layer (-33.1 mmol m$^{-2}$ d$^{-1}$) and enclosure (-46.3 mmol m$^{-2}$ d$^{-1}$) techniques. The results of these independent approaches corroborate quantified rates of metabolism at Cayo Enrique Reef. Close agreement between methods demonstrates that boundary layer measurements can provide near real-time assessments of coral reef health.

**Societal Benefits**

With the awareness that the surface ocean is becoming more acidic due to the uptake of anthropogenic CO$_2$ and that the resulting decrease in carbonate ion concentration is attributing to a decline in the calcification rate of many organisms, there is a pressing need to develop methods that can easily and reliably measure the calcification rates of these organisms under natural conditions so that any changes that may be occurring can be detected. Two new methods have recently been shown to permit the continuous measurement of *in-situ* rates of oxygen evolution and consumption of benthic communities. These are the control-volume method (Falter et al. 2008) and the eddy-correlation method (Berg et al. 2003; Berg and Huettel 2008). Both methods show great promise of revolutionizing our understanding of how the photosynthesis and respiration rates of natural benthic communities vary in time and space and what factors control those rates. The lack of a reliable sensor that accurately measures total alkalinity directly or a pair of sensors from which TA can be computed precludes the application of either of these techniques at this time.

**Awards & Honors**


**Interagency**

NSF and NASA Ocean Acidification research.
Personnel
Research Scientists: 1, Research Support Staff: 1, Post Doctoral Fellows: 1, Graduate Students: 2, Undergraduate Students: 3.

Journal articles

Figure 1. The Coral Reef Oxygen Sensor System (CROSS) deployed in the reefal system of Media Luna, Puerto Rico. The noninvasive PVC frame minimizes flow distortion. The CROSS includes a near surface ADV, an upward facing MAVS, 2 optodes at 10 cm and 80 cm, and an AMT fast-response oxygen sensor. Water sampling equipment (not shown) for TA to perform BLG flux measurements of calcification and respiration. The CROSS contains an internal and external battery pack for extended operation and an Autonomous Low Power System that simultaneously measures all instruments on a single purpose processing chip.
Figure 2. Time series of data from Media Luna Reef in La Parguera, Puerto Rico collected using the boundary layer flux method March 2009. Data show periods of net oxygen production (photosynthesis) at midday and net oxygen consumption (respiration) at night. The top plot shows the simultaneous dissolved oxygen measurements. DO is measured every 10 seconds. Data show hourly average. The middle plot shows the BLG net O$_2$ production measured using the simultaneous gradients in oxygen and velocity. The bottom plot shows the cumulative average diel net O$_2$ production from the week deployment.
Figure 3. Oxygen flux rates from Media Luna Reef, La Parguera, Puerto Rico. Comparison showing good agreement between boundary layer and Eulerian upstream-downstream methods.

Figure 4: Average diurnal net O\textsubscript{2} production from the March 2009 deployment. PAR (dashed-line), CROSS (circles), and SHARQ (squares) are shown for comparison. Vertical bars are the standard deviation. The productivity is light sensitive. Continuous overlap did not exist for CROSS and SHARQ measurements. Over the 8-day period, the diurnal NCP data are in very good agreement.
Research Goals

The primary objective of this proposed investigation is to determine the space-time distribution of the ocean surface pCO₂ and the sea-air pCO₂ difference. Combining the sea-air pCO₂ difference with the CO₂ gas transfer rate which is being investigated by other scientific groups, a reliable net sea-air flux of CO₂ over regional to global scales can be determined based solely on the observations. The results of the proposed work will give us an improved geographical coverage and time trends for the sea-air CO₂ transfer flux over the global ocean.

Education Goals

The new observations made for surface ocean pCO₂ and a multi-year database assembled under this grant are stored at the Carbon Dioxide Information and Analysis Center (CDIAC), Oak Ridge, TN, which is the national and international data center designated for CO₂ data for the air and oceans. Students and researchers can freely access the up-to-date, surface ocean pCO₂ data for their study and analysis.

Research Progress

Version 2010 of the “LDEO Surface Water pCO₂ Database” has been release to the public via CDIAC <http://cdiac.ornl.gov/oceans/LDEO_Underway_Database/>. This version contains approximately 5.2 million measurements of CO₂ partial pressure in surface waters over the global oceans during 1957-2010. About a half million new pCO₂ data from 21 new expeditions have been added to the previous Version 2009.

Highlights

Weakening of the Southern Ocean CO₂ sink

The Southern Ocean is one of the major source areas for the deep-water formation that governs transport of atmospheric CO₂ in the ocean interiors. Wintertime surface water pCO₂ in the ice-free zone of the Southern Ocean is important for assessment of ocean’s uptake and long-time storage of atmospheric CO₂. The observations made aboard the RVIB Palmer and RV Gould with support from this grant contributed...
significantly to our understanding of the Southern Ocean. We have found that, over the past 5 decades since 1962, the surface water pCO$_2$ within a SST zone of 1.5°C and 4.5°C has increased at a mean rate of 2.1±0.4 uatm/yr (Figure 1). This is faster than the atmospheric CO$_2$ increase rate of 1.6 uatm/yr, suggesting that the sea-air pCO$_2$ difference is reduced and the CO$_2$ sink intensity over the Southern Ocean is weakening. Since the biological activities are minimum and the vertical mixing of subsurface waters is maximum during the winter months, the observed fast increase may indicate that the deep-water upwelling or meridional overturning rates have increased. This is consistent with the conclusion by Le Quéré et al. (2007) who used the ocean biogeochemistry GCMs and the inversion of atmospheric CO$_2$ data.

**Figure 1.** Time-trend of surface water pCO$_2$ in the ice-free zone of the Southern Ocean in temperatures between 0.8°C and 3.5°C observed during the winter months (late June through mid-November) 1962-2010. The black and gray dots are individual data obtained during non-El Nino and El Nino months respectively. The open circles are monthly mean values and the linear regression trend line (heavy black) is computed using the monthly mean values. The spatial distribution of the seawater pCO$_2$ observations is shown on the right. An analysis of three five temperature zones ranging from 1.5°C to 4.5°C yields a mean rate of 2.1 ±0.4 µatm/yr, that is faster than the mean atmospheric CO$_2$ increase rate of 1.6 uatm/yr.

**Societal Benefits**

Global climate change may be attributable to the accumulation of CO$_2$ and other greenhouse gases in the atmosphere. The global society will be impacted significantly if changes are continued or accelerated. The oceans is absorbing about 30% of the industrial CO$_2$ emitted into the atmosphere, thus partially alleviating the climate change.
The rate of CO₂ uptake by the oceans may change in response to the climate change, and is being monitored by the work supported by this grant.

Other Research Connections
The pCO₂ measurements are made aboard many US and international ships, which are supported by NOAA (e.g., RV Brown and RV Kaimimoana), NSF (e.g. RVIB Palmer, RV Gould, RV Langseth, RV Atlantic Explorer), USCG (USCGC Healy), Marine Research Institute of Iceland, and many shipping companies (e.g. Explorer of the Seas, Columbus Waikato) and private foundations (MV Turmoil). Without generous collaborations with these government agencies and commercial companies and private foundations, this work would not have been accomplished.

Awards & Honors
Takahashi received the “2010 Champions of the Earth” award of the United Nations Environmental Program (UNEP).

Interagency
See above “Other Research Connections”.

Member, Scientific Steering Committee, “Ocean Carbon Biogeochemistry” program, (supported by NSF, NOAA, NASA, USGS)

Education & Outreach
• Global Ocean Surface Water Partial Pressure of CO₂ Database (Takahashi et al., 2010, 2011) (Open to the public at CDIAC. See the full citations in the “Publications” section.)

• An open web site is established at the following URL for all the participants of the NOAA/VOS program be able to access of the data in an uniform electronic format. : http://www.ldeo.columbia.edu/CO2. The site provides not only the numerical data, but also maps showing the ship’s tracks for each data file.

Personnel
Research Scientists: 1, Research Support Staff: 3.

Journal articles


*Reports*


Research Goals

The original goal for this project was to determine the variability in wind-driven upwelling in the Southern Ocean during the Holocene. This project builds on our NOAA-ARCHES work in which changes in upwelling in the Southern Ocean were assessed using an opal flux proxy for upwelling. Results of that work indicate that a reorganization of global wind systems is the primary mechanism linking manifestations of past abrupt climate changes found at many locations worldwide, and we seek to establish whether or not the Southern Ocean has experienced significant variability in wind-driven upwelling during the Holocene period.

Research Progress

At the time this report was written we have just completed the last of the analyses of Holocene sediments described in our original proposal. As is often the case, some results exhibit unexpected departures from overall trends. Consequently, we need to reanalyze a subset of our samples before we feel confident to release an interpretation of our results.

More important are our ongoing efforts to communicate about the new findings from our previous research supported by the NOAA ARCHES program. Specifically, here, we refer to the growing body of evidence that many features of abrupt climate change, especially those that involve anti-phased behavior in the northern and southern hemispheres, are driven primarily by reorganization of global atmospheric circulation driven by changes in global meridional temperature gradients.

This finding is of utmost importance for two reasons. First, it represents a novel and fundamental insight into the mechanics of climate change. Second, comparing paleoclimate records with models, especially in the Southern Hemisphere, reveals a potential major weakness in coupled Atmosphere-Ocean General Circulation Models (AOGCMS).
Interest in the “wind hypothesis” has grown rapidly during the past year, as reflected in the number of invited presentations given by Anderson (see below), including a special invitation to speak before the Swedish Royal Academy of Sciences.

Controversy surrounding the wind hypothesis is growing as well. In particular, modelers frequently decline to mention the wind hypothesis because its principle features do not appear in model results from simulations of the last glacial maximum or the deglaciation. This is manifest by the failure to mention the wind hypothesis at all in three of the most recent papers describing model simulations of the carbon cycle through the most recent glacial termination (Bourrwa wr L., 2011; Brovkin et al., 2011; Menviel et al., 2011). Failure to mention the wind hypothesis is not due to ignorance on the part of the authors. Anderson has communicated personally about the wind hypothesis with the lead authors of two of the three papers cited above. Rather, the authors choose to ignore this hypothesis when describing model results for the links between climate and CO₂.

Skepticism among modelers is waning, however, in part due to the recent results from the atmospheric model (CCM3) of Lee et al., (2011). The paper by Lee et al. is important not only because the model reproduces an increase in wind intensity over the Southern Ocean in response to cold stadial conditions over the North Atlantic, but also because the authors provide a sound theoretical basis to explain the interhemispheric teleconnection that underlies this response.

By contrast with the modelers, observational scientists working on the mid latitudes of the Southern Hemisphere, both with respect to ocean circulation and in the context of changes in mountain glaciers, note that paleo observations are consistent with the wind hypothesis (Kaplan et al., 2010; Beal et al., 2011).

The wind hypothesis provides a unifying mechanism to explain observed features of abrupt climate change during deglaciation, as well as corollary features linked to the termination of the ice age itself (Denton et al., 2010). The hypothesis provides the foundation for a globally consistent mechanism to explain regional climate variability in response to freshwater forcing of the North Atlantic Ocean. Consequently, it is important that the climate community critically examine the evidence for and against the wind hypothesis. For this reason, Anderson continues to give talks worldwide (see list below) to encourage scientists from many subdisciplines of climate research to get involved in the debate.

References Cited:


**Highlights**

Our evidence that the reorganization of atmospheric circulation was the primary factor responsible for the global teleconnection of abrupt climate change in the past, as well as a key element in regulating climate-related changes in the CO2 content of the atmosphere, has received a great deal of attention. These conclusions are not uncontroversial, but they have stimulated many other scientists to learn more about our findings. This has led to a number of invited talks (see list below). Furthermore, Anderson was awarded the C.C. Patterson Medal from the Geochemical Society in recognition of the importance of these contributions.

**Societal Benefits**

This work contributes to our understanding of the role of the ocean and the atmosphere in abrupt climate change, and of the specific processes involved in past abrupt climate changes. This knowledge is vital to the development and testing of models that can be used to make meaningful predictions about whether or not increasing concentrations of anthropogenic greenhouse gases might induce abrupt climate changes in the future.

**Awards & Honors**

Anderson received the C.C. Patterson Medal (Environmental Geochemistry) from the Geochemical Society in June 2010, in recognition of the significance of his NOAA-supported paper on Wind-Driven Upwelling in the Southern Ocean and the Deglacial Rise in Atmospheric CO2 (*Science*, 2009).

**Personnel**

Research Scientists: 1, Research Support Staff: 2.

**Journal articles**


**Conference proceedings / workshops/ invited talks**

2011 Title: The role of the winds in past climate change and CO2; 26 May, Woods Hole Oceanographic Institution, Southern Ocean and Climate Change Lecture Series.

2011 Title: The role of the winds in past climate change and CO2; 31 January, Rutgers University, Institute of Coastal and Marine Science.

2010 Title: The role of the winds in past climate change and CO2; 17 November, Royal Swedish Academy of Sciences, Stockholm.

2010 Title: Medal: The Bipolar Seesaw Versus the Winds; 15 June, Patterson Medal Lecture, Geochemical Society Goldschmidt Conference, Knoxville, Tennessee.

2010 Title: The role of the winds in past climate change and CO2; Anderson, R. F., Fall 2010 AGU; (PP24A-04)
Research Progress

We have expanded our ocean program by implementing B/Ca measurements on benthic foraminifera aimed at making a reliable reconstruction of the evolution of deep ocean carbonate ion concentration over the last 25 kyrs (i.e., from peak glacial through deglaciation and into the Holocene). This effort is being carried out by post doc Jimin Yu.
Research Goals
The research goals have been oriented towards the eventual development of a near-global reconstruction of hydroclimatic variability from long tree-ring records. This process started out with the development of the North American Drought Atlas (NADA) in 2004, the Monsoon Asia Drought Atlas (MADA) in 2010, and presently the Old World Drought Atlas (OWDA) now under development (see Fig. 1). Work on the OWDA began with this ACCWW project, but it has now transitioned over completely since 2010 to a newer independent NOAA sponsored project “Towards Near-global Reconstruction and Understanding of Hydroclimate Variability and Change over the Past Several Centuries” (NA10OAR4310123). There is no financial support for the OWDA left in the ACCWW grant, nor for any other activities, so all further activities on ACCWW have consequently been terminated and shifted over totally to NA10OAR4310123. Thus, this report should be regarded as the Final Report of my participation in ACCWW, with no future work planned or possible due a lack any remaining financial support from the project.

Education Goals
None specifically, but when complete the OWDA will be publicly available for both research and educational use, which is expected to be great judging from how much the NADA has been used for those purposes by others.

Research Progress
ACCWW funding was instrumental in holding the first OWDA workshop at the Climatic Research Unit, University of East Anglia, Norwich on June –10, 2009. This led to the establishment of collaborative links with several European scientists who have generously contributed tree-ring data for developing the OWDA. The work in central and northern Europe is presently most advanced and the value of archaeological tree-ring data there for extending tree-ring chronologies for use in the OWDA has been demonstrated. More data is being received on a steady basis for the eventual development of the
necessary tree-ring network for reconstruction past drought over the OWDA domain (Fig. 1).

Regarding ‘signal free’ tree-ring standardization, which is the state-of-the-art way to preserve common medium-to-low frequency signals due to climate in tree-ring chronologies, we have worked directly with the inventor of the ‘signal free’ method, Dr. Tom Melvin of the Climatic Research Unit (University of East Anglia) to develop an identical version of that method, which is now ready to be used for the OWDA project. All of the tree-ring chronologies used in the OWDA network will be standardized using this method, with attention paid to preserving as much low-frequency variance as possible out to centennial or longer timescales. This will include using a ‘signal free’ version of the Regional Curve Standardization (RCS) method, which can potentially preserve low-frequency variability that approaches the overall length of the tree-ring chronology being developed.

**Highlights**

To provide some sense of how successful we expect the OWDA to be in reconstructing drought over the past 1000+ years in northern and central Europe, we show in Fig. 2 some correlation maps between long tree-ring chronologies of oak and pine and the June-August average scPDSI calculated for Europe by Gerard van der Schrier at KNMI. It should be noted that there has been some doubt expressed by some concerning how drought sensitive tree growth is in this generally moist part of Europe. The correlation maps clearly show that these tree-ring chronologies, both oak and pine and all 1000+ years long, have strong local-to-regional drought signals in them that will enable the reconstruction of drought there. This is proof that what we have proposed to do can and will be done.

**Societal Benefits**

Understanding the causes of drought from a mechanistic perspective will enable the development of better long-term prediction methods. In an increasingly water-limited world this ability would have huge societal benefits and the OWDA will contribute to that goal by providing new fields of hydroclimatic variability for testing climate models and the hypothesized causes of severe megadroughts not present in the modern instrumental record.

**Other Research Connections**

I have developed a number of partnerships and collaborations with a growing number of European tree-ring scientists who have agreed to provide tree-ring data for development of the OWDA. Noteworthy collaborators include Keith Briffa and Tom Melvin (Climatic Research Unit, University of East Anglia, Norwich, UK), Rob Wilson (School of Geography & Geosciences, University of St. Andrews, St. Andrews, Scotland), David Brown (Palaeoecology Centre, Queens University, Belfast, Northern Ireland), Ulf Büntgen and David Frank (Swiss Federal Research Institute for Forest, Snow and Landscape Research, Birmensdorf, Switzerland), Willy Tegel (Institute for Forest Growth, University of Freiburg, Freiburg, Germany), Terje Thun, Section of
Archaeometry, Norwegian University of Science and Technology, Trondheim, Norway), Nesibe Köse (Forest Botany Department, Istanbul University, Istanbul, Turkey), Emilia Gutierrez (Department of Ecology, University of Barcelona, Barcelona, Spain), and Samuli Helama (Arctic Centre, University of Lapland, Rovaniemi, Finland). Many of these connections were fostered through the initial support of ACCWW funding for producing the OWDA.

Awards & Honors
None.

Education & Outreach
None.

Personnel

Research Scientists:
Edward R. Cook, PI, Richard Seager, co-PI, Yochanan Kushnir, co-PI

Research Support Staff:
Jennifer Nakamura

Personnel funded by this project and obtaining NOAA employment within this reporting period
None.

Publications
None.

Conference proceedings / workshops


Figures
Figure 1. A map of relevant NH land areas that shows how the OWDA will fit in with the NADA and MADA. The spatial domain of the OWDA is highlighted in blue.

Figure 2. Correlation maps between millennium-length northern European oak and pine tree-ring chronologies and June-August scPDSI over (mostly) the 20th century. The blue stars show the chronology locations. All shaded areas are significant the p<0.10 level.
Research Progress

Considerable progress has been made during the past year. This progress has primarily been on two fronts. Procedures have been adapted and implemented for producing tree-ring pseudo-proxy data sets (with associated calibration and verification data) based on temperature and precipitation results from radiatively forced climate model simulations covering the past millennium. Second, a web site for providing the calibration, verification and pseudo-proxy data to the reconstruction community, and for reconstruction researchers to post reconstruction results, has been developed and placed in operation.

Work on important elements of the project had been delayed waiting for project personnel issues to be resolved. After discussions with co-PI D’Arrigo and others in the paleo-climate community during the latter half of 2010, it was decided that the project would have to carry on without the vision and guidance of the original lead PI. A revised work plan, in line with the project’s original goals, was developed by co-PI’s Graham and D’Arrigo and Gene Wahl, with input and contributions from an ad-hoc advisory group including Ed Cook, Kevin Anchukaitis and Dave Anderson.

Under that plan, the following work has been accomplished.

1. A Matlab package (a “wrapper”) for driving the tree-ring growth simulation model VS-Lite (Tolwinski-Ward et. al., 2010) has been developed and ported to run on Linux using the Matlab “clone” Octave with netcdf support. VS-Lite was developed and generously made available to the project by Suz Tolwinski-Ward. The basic structure of the Matlab “wrapper” was kindly contributed by K. Anchukaitis. This package does the following:
• Uses locations (latitude, longitude) for a user-selected network of proxy sites that have been used in past studies to reconstruct hemispheric or global average temperatures from proxy data. To date, the networks of Esper et al. (2007; 14 sites) and D’Arrigo et al. (2006; 66 sites) have been implemented. A version of the Mann et al. (1998, 1999; 104 sites) network, much as used by Smerdon et al. (2010), will be implemented soon, but further work is required to develop algorithms for non-tree-ring pseudo-proxies and to allow for (as possible) inter-model differences in land-ocean distributions.

• Inputs gridded monthly temperature and precipitation output from climate model simulations. These input files are most conveniently in netcdf format so that the associated spatial meta-data can be used automatically. Typically, these model results will be radiatively-driven simulations covering the past millennium. To date, tree-ring pseudo-proxies have been developed using 1) the ensemble of five “weak solar” simulations (800-1205 AD) from the Max Planck Institute (MPI) COSMOS modeling system (Jungclaus et al. 2010), and 2) the spline-detrended version of the simulation with CCSM described by Ammann et al. (2007). Additionally, we have access to results from the high-solar COSMOS simulations, and the ERIK2 simulations (Gonzalez-Rouco, 2006; MPI ECHO-2 CGCM). Eventually, climate model results will be available from ~10 other models from the PMIP3 “past millennium” collection. The monthly temperature and precipitation data from the climate models are interpolated to the spatial locations of the pseudo-proxy sites.

• Runs an ensemble of ten VS-Lite simulations using semi-randomized settings for the temperature and soil-moisture growth sensitivity parameters in VS-Lite for each tree-ring proxy location. These results are averaged, standardized, and archived. Additionally, the precipitation, temperature, and soil moisture data for each site are archived.

• Calculates and archives N. Hemisphere mean temperature for each model simulation.

2. Under the direction of Gene Wahl (with additional guidance and support from David Anderson), NOAA NCDC staff have developed the PR-CHALLENGE website (now on-line at http://ncdc.noaa.gov/paleo/pubs/pr_challenge.html). While the site is still under development and its data complement is being filled out, it presents background information for the PR-Challenge project, gives access to calibration, verification and pseudo-proxy data, and describes procedures for contributing and scoring reconstructions and providing reconstruction code.

Although a great deal of progress has been made on the PR-Challenge project during the past year, much work remains to be accomplished. At this time, only data from the Esper et al. network is on the PR-Challenge web site (this to be used in the “Theme 1” of the PR-Challenge project as outlined in the original proposal). We are in the process of
responding to requests for additional products related to “Theme 1” and will add those shortly. For “Theme 2” (the D’Arrigo et al. network and ancillary information), the pseudo-tree-ring chronologies have been generated. It is expected that all information for this theme will be on-line the near future, after the “Theme 1” products are complete. “Theme 3” (the Mann et al. network and ancillary information) involves preparation of pseudo-proxy data sets other than tree rings (corals, ice core indices, lacustrine isotopes). Initial work has begun for this. In addition, we anticipate adding results from some of the other climate models noted above. We will request a 9-month no-cost extension to finish these tasks, and the development of a proposal for a PR-follow-on Challenge II project.

This grant also provided minor support for preparation of a paper concerning synthesis of proxy- and model-inferred circulation changes and their possible causes during the Medieval Climate Anomaly (Graham et al. 2010).

References


**Personnel**

Research Scientists: 1.

**Journal articles**

**D’Arrigo, R., K. Anchukaitis, B. Buckley, E. Cook and R. Wilson.** North Atlantic Oscillation climate signature in West Virginia red cedar over the past millennium. In review, *Global and Planetary Change, Special Issue on Medieval Climate Anomaly (MCA).*


**Presentations**

Research Goals

Our research goals for this year were to begin our research on NW African aridity changes over the latest Holocene. The aim of this project has been to use newly-collected (OC437-7 cruise, 2009) sediment cores taken off the NW African margin as records of past variations in the export of African mineral dust from the hyperarid Saharan desert interior. We first conducted a low-resolution radiocarbon dating survey of these cores to determine which would be most suitable for high-resolution analyses of the Holocene interval.

The objective of the work has been to use these core records to characterize the timing and abruptness of the Mid-late Holocene end of the African Humid Period near 5,000 years BP, and to conduct detailed records of the most recent millennia to put more recent changes within a longer geological context.

Education Goals

The education goals of this project are to train graduate students and post-docs in our sediment geochemistry analytical methods, and to present these results in national and international meetings, and smaller, local groups. Outreach opportunities were presented based on appearances in two documentaries on African climate change (NOVA and The History Channel).

Research Progress

We conducted detailed CaCO3 percentage analyses on many cores to define the timing and amplitude of the AHP transition (Figure right). All cores from 27-19°N document a pronounced AHP interval between 12-5 ka BP, a
period of reduced dust fluxes resulting from more humid conditions in the Sahel-Saharan regions.

With Post-doc Dr. David McGee (supported on an NCAR fellowship) we next conducted U-Th geochemistry on several cores to calculate Th-normalized fluxes of dust supply to three cores of this larger collection. Impressively, these data document greatly reduced mineral dust fluxes (by factors of 3-5) during the AHP (Figure below).

Additionally, another NCAR post-doc working with me (Dr. Jess Tierney) has determined past changes in the abundances of plant leaf wax lipid molecules in these cores to track past changes in the vegetation of the region over this same period. This approach represents a very promising, novel way to document past changes in the vegetation amount, type, and precipitation regime using the concentration, $\delta^{13}$C and $\delta$D isotopic compositions of the leaf waxes preserved in these cores, respectively.

These results were both surprising and illuminating (Figure right). The leaf wax abundances for the northernmost core has high values only during the last Glacial (15-20 ka BP), confirming previous work that documented the southward extension of the Mediterranean flora during this time. For the middle core in the transect (GC49), the plant wax abundances are relatively unchanged during the AHP and this suggests that most of the early Holocene “wetting up” of North Africa occurred south of this latitude – an important constraint. The southernmost core
(GC-68), the plant wax concentrations are at a maximum during the AHP, as expected – this region is the driest region today, so great precipitation during the AHP would have promoted more vegetation cover.

Our current focus has been to work on the highest resolution core, GC68, which has sufficiently high accumulation rates to offer decadal-scale sampling resolution for the last two millennia. This is our current focus to conduct detailed Th-ex dust flux and leaf wax biomarker concentration and isotopic analyses to place the climate variations of recent millennia within this longer Holocene perspective. Samples have been collected and prepared for analysis, which we hope to complete in the coming months.

**Highlights**

- The early Holocene African Humid Period (12-5 ka BP) is detected in a suite of sediment cores taken along the NW African margin.

- The AHP is recognized by low dust concentrations and absolute dust fluxes (from Th normalization), and variable plant wax biomolecule abundances.

- The highest resolution sediment cores have been identified. Cores have been sampled and prepared for analysis.

**Awards & Honors**

- 2011 Schwarzbach-Kolloquium Lecturer, University of Köln

**Education & Outreach**

Dr. deMenocal’s research on this project was featured in two documentaries:

2. *Becoming Human* NOVA (TV, 2010)

**Personnel**

Post Doctoral Fellows: 1.

**Conference proceedings / workshops**


Cleroux, C, deMenocal, P., Arbuszewski, J. Deglacial evolution of the Atlantic ITCZ. Fall EOS, Fall 2010 Meeting Program with abstracts., 2011.
Research Goals

The prime goal of the research is to establish detailed Holocene glacial moraine chronologies at middle latitudes of the two polar hemispheres. The project is a joint venture between Lamont-Doherty (PI Joerg Schaefer) and the University of Maine (PI George Denton). The primary tools are moraine mapping tied to state-of-the-art $^{10}$Be exposure dating. Such chronologies can be transferred directly to temperature changes through the Holocene by reconstructing snowline values for each of the dated moraines. Glaciers respond very sensitively to changes in summer temperature and thus afford excellent proxies for past climate changes. The comparison of glacier records between the hemispheres can isolate the causative mechanisms for Holocene climate changes. This will place the ongoing worldwide retreat of mountain glaciers in a firm backdrop of natural Holocene climate changes in both polar hemispheres.

Education Goals

The education goals are to provide for the training of graduate students in earth sciences. Three graduate students have or will receive degrees as part of the funded research.

Research Progress

During the reporting period, fieldwork was carried out on the Holocene glacial history of the Southern Alps of New Zealand in January-March of 2011. Laboratory work at Lamont-Doherty was carried out throughout the reporting period. Late-glacial moraines have been dated and the results published in Nature and Nature Geoscience for Tasman River valley and for Irishman’s Stream valley. A production-rate value for the accumulation of $^{10}$Be in boulders in moraines, an essential background for precise and accurate exposure dating, has been established for the Southern Alps and published in Quaternary Geochronology. A hypothesis has been formulated and published in Science to explain the transition from glacial to interglacial that ushered in Holocene climate in the first place. Fieldwork and laboratory analyses for this project, along with publication of additional papers, will be completed during the coming year.
**Highlights**

**Finished**
- Establishment of production rate of 10Be in moraine boulders in the Southern Alps published in Quaternary Geoscience.
- Hypothesis for the last termination published in Science.

**In progress**

The detailed Holocene history of temperature-sensitive mountain glaciers in the Southern Alps of New Zealand is nearing completion. Figure 1 shows the moraine map and exposure chronology of Holocene moraines fronting Cameron Glacier in the central Southern Alps. Figure 2 illustrates the moraine maps and 10Be exposure chronology of Holocene moraines fronting Mueller, Hooker, and Tasman Glaciers, all in the central Southern Alps. This figure is updated from Schaefer et al. (2009, Science 324, 622-625).

In both cases the exposure dates are calculated with the 10Be production rate determined in the Southern Alps and published in Quaternary Geochronology. Because individual moraine chronologies are almost never complete, these records from four glaciers must be patched together to obtain a comprehensive Holocene sequence. The resulting comprehensive chronology is presented in Table 1. This chronology is then transformed to a comprehensive Holocene temperature record by reconstructing the equilibrium line, or snowline, associated with each of the dated moraines. Figure 3 shows the result compared against the Holocene history of mountain glaciers in the European Alps on the other side of the planet. It is immediately obvious that the glacier history in the middle latitudes of the two polar hemispheres, at least in the sectors of the Southern and European Alps show opposite behavior, both long term and short term. As also shown in Figure 3, the correspondence in each hemisphere with the orbital trend of summer insolation intensity suggests a fundamental role of the opposing insolation signals. However, several arguments can be made that these insolation signals by themselves were not sufficient, but that they must have been leveraged. One possibility is shown in the middle panel of Figure 3, which depicts the Holocene shift of the Intertropical Convergence Zone. Throughout the Holocene the ITCZ has moved southward as the Northern Hemisphere cooled. There is independent evidence that during the Little Ice Age the Pacific sector of the ITCZ moved south about 500 km, in concert with the spread of sea ice in the North Atlantic and the weakening of the Asian monsoon. The implication is that the global wind belts may have shifted southward, thus leveraging the opposing climate signals in the two polar hemispheres. In any case, the striking discovery is that this general Holocene trend of the asynchronous glacier behavior in the two polar hemispheres is interrupted in the last 100 years, when glaciers in both hemispheres retreat simultaneously, in contrast to earlier in the Holocene. Such synchronous global retreat is a novel feature of the Holocene and requires a forcing agent that produces symmetric warming on opposite sides of the planet. The likely agent to cause this anomalous behavior in the most recent century of the Holocene is the build-up of fossil CO2 in the atmosphere since the beginning of the industrial revolution.
Societal Benefits

The American Museum of Natural History in New York City selected this project for the production of a documentary film to be shown on the great wall of the Museum, beginning this coming fall. This documentary will also be shared with 32 other natural history museums in North America and Europe. The total viewing audience is estimated to be 10 million persons. A film crew under the direction of Vivian Trakinski of the American Museum of Natural History filmed the fieldwork in the Southern Alps in February of 2011 and the laboratory work at Lamont in June of 2011. The production should be complete in September of 2011, to be followed shortly by showing in the Museum.

Other Research Connections

This research was carried out by the combined efforts of personnel at Lamont-Doherty Earth Observatory and the University of Maine. The PI at Lamont-Doherty is Joerg Schaefer and the PI at the University of Maine is George Denton. The research was also a cooperative effort with GNS Science, Lower Hutt and Dunedin, New Zealand. David Barrell of the Dunedin office represented GNS Science in the project.

Awards & Honors

Tobias Koffman was awarded a three-year graduate fellowship by the National Science Foundation in nation-wide competition.

Education & Outreach

- G. H. Denton and J. M. Schaefer were research advisors and mentors to Aaron Putnam (PhD student), Kathryn Ladig (MS student), and Tobias Koffman (PhD student).
- Aaron Putnam presented research papers at the annual meeting of the Comer Science and Education Foundation in Soldiers Grove (Wisconsin), as well as at the INQUA meeting in Bern (Switzerland).

Personnel

Research Scientists: 3, Graduate Students: 3.

Journal articles


Hall, B. L., T. Koffman and G. H. Denton, 2010: Reduced ice cover on the western Antarctic Peninsula during the Medieval Warm Period. Geology, 38, 635-638.


Books / articles-in-books

Ph.D. dissertations
Research Goals

This project falls within the Modern Observation component of ACCWW. It includes the themes: *Trends of ocean properties* and *Choke Points and the Meridional overturning circulation*.

The Fluctuations in Ocean Heat and Freshwater Inventory and of Interocean Exchange funding was nearly depleted in the 2010-11 CICAR year. During the year we closed out the ACCWW funded activities with: investigation of monthly fluctuations and meso-scale (<200 km) texture in the SSS.

Education Goals

Graduate student Julius Busecke [Department of Earth & Environmental Sciences at Columbia] enrolled in 2010, and is now working with the North Atlantic SSS data described below.

Research Progress

The subtropical gyres of the ocean are characterized by anticyclonic circulation with swift western boundary currents and slower; equatorially- bounded return flows in the interior. Within the central “hubs” of these regimes, the localized influence of evaporation under the trade winds, acting in concert with the convergent Ekman transports, dominates the upper ocean stratification and circulation (*Figure 1, 2*). Within these hubs, climatological mean surface salinity gradients are weak, thus reducing the importance of transport convergence by the gyre-scale circulation. Additionally, the dilution effect of coastal river discharge is zero.

The figures and text are from last year; figures that have been expanded or updated are with red figure captions. We investigated the seasonality of the North Atlantic subtropical sea surface salinity (SSS) maximum regime, and its relations to the wind field. We investigated the SSS structure (texture) across the subtropical SSS-max using Voluntary Observing Ship (VOS) tracks (Delcroix et al., Deep Sea Res., 2005; see figure 3-
Figure 1. Time-mean surface salinity
Figure 1: Monthly SSS in the North Atlantic

Figure 1. The seasonal shape of the 37.0 isohaline encompassing the North Atlantic subtropical sea surface maximum
**Figure 2a.** Ekman transport vectors in Sverdrups (1 Sv = 10⁶ m³ s⁻¹) and 10 cm contours of mean dynamic topography of the sea surface. In color, the long-term mean sea surface salinity (defined as the upper 20 m salinity average). Ekman transports were computed across 2.5°x2.5° latitude-longitude cells using long-term mean wind stresses based on ECMWF ERA-40 monthly data (Uppala et al. 2005). Sea surface salinity was computed from the 1°x1° World Ocean Atlas 2005 (Antonov et al. 2006). Nikolai Maximenko and Peter Niiler provided the 1990-2002 mean ocean dynamic topography data (Maximenko and Niiler, 2005).

**Figure 2a:** monthly Ekman Transport field

**Figure 2b.** Long-term average (1958-2001) of the vertical integral of the divergence of moisture flux (color; units= kg m⁻² s⁻¹ x 1000) computed from monthly ECMWF ERA-40 data.
Evaporation minus precipitation (contours; units in m yr\(^{-1}\)) estimated from ERA-40 monthly surface large-scale and convective precipitation and evaporation data. If the time rate of change of precipitable water is assumed to be zero, then the vertically integrated water vapor flux divergence, can be used to estimate source (E > P) and sink (E < P) regions of atmospheric moisture.

The annual excess of evaporation over precipitation, in excess of 1 m/yr at its maximum, acts to increase SSS within the subtropical ocean. Seasonality in the value of E-P is evident (Figure 3). SSS/(E-P) trends suggest that ocean processes are of significance in establishing the annual SSS cycle. Candidates: Horizontal freshwater flux by eddies or Ekman transport, during stronger winter winds? Vertical mixing?

Figure 3. SSS/(E-P) trends in the North Atlantic subtropical regime
Figure 3, update 1: Validated SSS data in The Tropical Oceans. The SSS data are derived mainly from Voluntary Observing Ship (VOS) tracks (Delcroix et al., Deep Sea Res., 2005). A ship track is defined by a polygon. For each track, all SSS data collected in a surface delimited by a polygon were considered to compute the mean and standard deviation values, and the mean monthly years.
Ekman transport, driven by the trades and westerlies, restores the salt balance by introducing lower salinity surface water from adjacent latitude belts into the subtropical hub. This Ekman mass transport drives convergence and downwelling of the salty subtropical surface water, which spreads towards the tropics as a salinity maximum layer near 150 m. In this manner the regional or localized subtropical sea-air forcing establishes a shallow meridional overturning circulation (ShallMOC), in what may be considered the oceanic equivalent of the atmospheric Hadley Cell, stretching from the evaporative, convergent subtropical regime to the wetter, divergent tropics. As the surface layer is warmed in the tropics, the shallow meridional overturning circulation represents one aspect of the poleward transport of heat and freshwater within the latitude band equatorward of ~30° in both hemispheres, a region encompassing half of the area on the globe and where the oceans carry the largest portion of the planetary heat transport.

Reverdin et al. (2007) find that seasonal anomalies in sea surface salinity have spatial scales of typically 500–1000 km and display a 1–2 month lag to freshwater flux anomalies at the air–sea interface and to the horizontal Ekman advection. They suggest that in the northeast Atlantic the late-boreal spring/summer season is less active than the boreal winter/early-spring season in forcing the seasonal SSS variability. In the northeastern mid-latitude Atlantic, SSS is positively correlated with SST, with SSS slightly lagging SST.
Figure 4. Annual mean sea surface salinity (upper 20 m) and sub-surface salinity maximum and a time series of their anomalies for the North Atlantic subtropical gyre and time series of the sea surface salinity anomaly. Data extracted from the World Ocean Database 2005 (Boyer et al., 2006). Dark circles represent the yearly average of the data; vertical lines represent one standard deviation. The small gray circles represent the individual yearly values for each box. In green, salinity pentad anomalies for the same region (Boyer et al., 2005) and its standard deviation, from 1955-59 to 1994-1998, using levels 1 to 3, corresponding to 0 to 20 m.

The time series of the subtropical SSS and subsurface S-max suggest a slow increase in salinity, though since the late 1990s this trend may have reversed (Figure 4). We speculate that the North Atlantic subtropical salinity is linked to water vapor flux across Central America (Figure 5).
Zonal comp. for box2 (red) shows an increase of 0.84 kg m⁻¹s⁻¹yr⁻¹ for the period 1958-2002

**Figure 5.** Satellite measurements of surface winds (QuickSCAT 10-m) and sea surface temperature (from a satellite microwave radiometer, TMI) averaged for January 2000. Dark shading over land indicates elevation in excess of 300 m., strong offshore flow downstream of the gaps in the mountain ranges, with monthly mean wind speeds as high as 10 m/s, gives rise to local sea surface temperature minima and enhanced chlorophyll concentrations (Fig. from the U.S. CLIVAR Pan American Research, A Scientific Prospectus and Implementation Pan, January 2001). The boxes indicate the areas where the zonal and meridional water vapor flux components were averaged for the period 1957-2002. (b) Vertical integral of eastward (red) and northward (blue) water vapor flux from ECMWF ERA-40 monthly mean model resolution gridded surface fields. Units = kg m⁻¹ s⁻¹. Color lines represent the 12-month running mean and the solid black line the annual averages.

**Highlights**

The trends of increasing salinity of the upper layers of the North Atlantic subtropical regime of the last ~60 years, may have reversed since ~2000. The North Atlantic subtropical SSS-max regime displays much spatial and temporal variability than previously appreciated. It is likely that the overall freshwater (salinity) budget of the SSS-max regime involves more than E-P and Ekman transport, but must also reflect eddy fluxes.

**Societal Benefits**

We are investigating trends in the marine hydrological cycle, a major, but poorly resolved component of the global hydrological cycle, which is undergoing changes associated with the more general climate change.

**Other Research Connections**

Our work is related to the NASA program to study trends in sea surface salinity, associated with the Aquarius satellite to be launched in late 2010.

**Personnel**

Research Scientists: 1, Research Support Staff: 2, Graduate Students: 1.
Research Goals

The overarching research goal for our scope is the application of radiogenic isotopes to understanding past climate changes and processes in the ocean and on land. This is a broad scope, and we both have leveraged this support as widely as possible. The specific goals that are benefitting from this funding are the characterization of dust sources from Africa, constraining hydroclimate changes from lake archives, understanding past ocean circulation, and understanding ice sheet dynamics during times of rapid climate change.

Education Goals

Bring the excitement of research to students at all levels, and integrate research into our teaching and outreach.

Research Progress

The progress has not been as fast as we had hoped, but substantial work is ongoing. We are still waiting for elemental analyses from the terrigenous clastic residues that we prepared and sent to BU- that lab has had troubles, but is making a concerted effort to finish the analyses this summer. When the analyses and solutions are returned to us, we still hope to contribute radiogenic isotope analyses to those samples. This is expected to result in at least two papers on which Jenna Cole is the lead author.

We have also not progressed as far as we had hoped on the extraction of fish debris from marine sediments. Cathleen Dale decided to work on a different project. We had a senior thesis student, Dan Meyers, work on using elutriation to isolate the debris from the carbonate shells. He made some progress, but we still need to do more to come up with a routine procedure. This is a priority and we’re continuing to work on it.

Both of us have individually made progress on our research on Mono Lake and Dead Sea sediments, and we still hope to put together a detailed comparison of the wet and dry intervals in these two basins. Getting a really reliable chronology is key. The Dead Sea
record has a better chronology, but we are making significant progress with U-series
dating of the Mono record.

**Highlights**

- Precise age on the highest lake level of the last glacial cycle at Mono Lake
- Manuscripts completed on ice rafting in North Atlantic sediments
- Elutriation strategy appears to have promise for isolating fish debris for Nd.

**Societal Benefits**

Through our research and connections with students at all levels, we benefit
society by training the next generations of Earth Scientists. Additionally we contribute to
the annual Lamont Open house and show results from this research. And we are
convinced that our efforts to document past climate changes and connections / causes /
effects will benefit society due to the increased understanding of the sensitivity of the
climate system.

**Other Research Connections**

This funding has been a fantastic catalyst for leveraging our ability to perform
research on paleoclimate at a high level. Because of the progress this grant has allowed us
to make, we have many connections and grants that would not likely have happened
otherwise. These include several NSF grants for paleoceanography studies, and a fruitful
collaboration with Ian Hall (Cardiff University) and Rainer Zahn (Barcelona), as well as
with Peter DeMenocal on the African dust.

**Education & Outreach**

We have used the research to bring the excitement of new discoveries into the
classroom, to mentor undergraduate interns, senior thesis students and graduate students,
and to provide an opportunity for research experience for post-graduate students who are
thinking of going to graduate school.

**Personnel**

- Research Support Staff: 1, Undergraduate Students: 1.

**Books / articles-in-books**

Downing, G. E., and S. R. Hemming, *in revision*, Late glacial and deglacial history of ice
rafting in the Labrador Sea: a perspective from radiogenic isotopes in marine
Tracers of Provenance, GSA Special Paper.
Research Goals

Investigate the nature of evolving seawater properties on the West Antarctic continental shelf and the causes and implications of those changes. For example, what fraction of the freshening of shelf water in the Ross Sea over more than 50 years, now one of the longest records in the ocean near Antarctica, results from decreasing production of sea ice, increased melting of continental ice upstream, changes in ocean currents, and undocumented increases in precipitation minus evaporation.

Research Progress

A paper analyzing our findings beneath the ice shelf extension of the accelerating Pine Island Glacier, published online in Nature Geoscience a few days prior to the start of this reporting period, has its citation updated below. A second paper utilizing ship-based measurements from the same and earlier expeditions into the Amundsen Sea was also published online in Nature Geoscience in June 2011. A paper describing our lengthening record of freshening in the Ross Sea and discussing related changes and implications, published in the Journal of Climate in September 2010, also has its citation updated below. Work is underway on an analysis of ocean-ice interactions beneath the little-studied Getz Ice Shelf.

Highlights

We have reported AUV-derived evidence that the Pine Island Glacier was recently grounded on a transverse submarine bank, but ‘warm’ Circumpolar Deep Water (CDW) can now flow over that ridge and melt its thicker ice upstream. This change has been accompanied by thinning ice, unstable grounding line retreat and faster glacier flow. While both the volume and temperature of CDW have increased in the adjacent Pine Island Bay over the past 15 years, a calculated 50% increase in the PIG Ice Shelf melt rate resulted mainly from a stronger ocean circulation. Its melting has exceeded accelerating glacier flow, with the CDW now nearly 4°C above the in situ melting point and having access to the deep and vulnerable PIG grounding line. The Getz Ice Shelf released more meltwater in 2007 that the smaller, faster-melting PIG Ice Shelf, or the much larger Ross and Ronne Ice Shelves, but occupies a more variable ocean environment and may not be a major factor in downstream freshening. That Ross Sea
freshening record now displays the largest salinity declines in the southern hemisphere over the past half-century.

**Societal Benefits**

A better understanding of ice-ocean interactions near Antarctica should eventually help to determine how much of the current and future sea level rise can be expected from the West Antarctic Ice Sheet. At present the main negative ice sheet imbalance seems to be coming from the Amundsen Sea sector.

**Other Research Connections**

Our studies during this period have been carried out in collaboration with international partners, including those at the British Antarctic Survey and the Alfred-Wegener Institute. This effort has included joint meetings in Palisades in November 2010 and in La Jolla in June, 2011. While the work outlined here has been funded mainly by NSF and Lamont the parallel support from NOAA has nonetheless been helpful in our analyses and reporting. Unfortunately, external support has declined as the significance of unresolved ocean-ice interaction questions has risen. Why, e.g., is the ocean freshening in the same location that sea ice production is reported to be increasing?

**Education & Outreach**

We have advised Columbia and other students, leading, e.g., to a manuscript recently submitted to the Annals of Glaciology that should also become a chapter in a graduate thesis. Aside from the Fall AGU meeting (Nitsche & Jacobs (C43C-0560), initial results from our ocean measurements near Getz Ice Shelf and along the Antarctic coastline from McMurdo to Marguerite Bay were presented at an IGS meeting in La Jolla in early June 2011. Time has expended on interviews and related outreach in response to the publications below, along with journal and proposal reviews, and providing information solicited, e.g., on ‘Future Science Opportunities in the Antarctic and Southern Ocean.’ We have completed the editing of recent ocean data sets that were then reported to the National Oceanographic Data Center and to the GEOTRACES database at the British ODC.

**Personnel**

Research Scientists: 1, Research Support Staff: 1.

**Journal articles**


**Reports**


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**Figure 1. (Top/HSSW)** Declining salinity in high-salinity shelf water in the SW Ross Sea, from bottle and CTD casts averaged over 200-800 m, or at 500 m, 08 Dec – 23 Feb, 1958-2008. *(Top/AASW)* More rapidly decreasing salinity in surface currents (<200 m) along the front of the Ross Ice Shelf (RIS; squares) and near the Antarctic Slope Front (ASF; triangles). *(Middle)* Decreasing shelf water salinity influence on downstream bottom and deep water salinity, shown by T/S snapshots at the lower ends of ocean profiles seaward of the continental slope (insert) where bottom water from the Ross Sea moves westward along the continental margin. Dashed lines extend the bottom water and lower deep water trends to the shelf water freezing temperature ($T_f$). Thin black isopycnals are referenced to 2000 dbar, 37.16 ~ a neutral density of 28.27. *(Bottom)* Salinity of bottom water in the NW Ross Sea and seaward of George V Coast (~140-150°E) has declined at −1/3 the rate of HSSW. Each symbol is a cruise average, the mean of the deepest 600 m from stations in the 1500-2500-m depth range. Separate regressions show -0.012/decade change in the George V area and -0.008/decade in the Ross Sea.

Figure from Jacobs (2010), based on information in Jacobs & Giulivi (2010).
Research Goals

The basic goal of this section is to understand in detail the inter-hemispheric pattern (phasing and amplitude) of glacier fluctuations throughout the Holocene period up to present day and, in turn, to add a new perspective towards climate variations during the period of human civilizations. We focus on the synthesis of new results from key moraine sequences in New Zealand and the Swiss Alps with existing data, and the rigorous assessment regarding the inter-hemispheric pattern of climate change and the underlying driving mechanisms. We expect to answer climatic key questions such as: (i) was the Little Ice Age global and (ii) how important is solar forcing for global climate change?

Adjusting to the 2-year time frame of the project, we have selected two moraine sequences for mapping and dating from the Southern Alps in New Zealand (45ºS) and the Swiss Alps (46ºN), respectively, in order to accomplish the basic goal of north-south phasing of Holocene climate events. It should be noted that the proposed chronological studies in these areas are highly leveraged, as the necessary background geologic investigations in all three areas were funded by the CSEF. What is left to be accomplished is the construction of maps of Holocene moraine systems in each area, the completion of detailed $^{10}$Be surface-exposure chronologies for each mapped moraine system, the synthesis of the results with existing data, and finally the rigorous assessment of the results regarding the inter-hemispheric pattern of climate change and the underlying driving mechanisms. For a detailed list of annual activities, see also the budget justification section. The field areas selected are as follows:

- **Southern Alps of New Zealand**: Moraine systems of LaPeruse, Cameron, Sibbald, and Leibig Glaciers in New Zealand's Southern Alps. These moraine systems, which are among the best in New Zealand, will test whether we can replicate the pilot results from the $^{10}$Be chronology of moraines in front of Mueller Glacier. The objective is to develop a robust chronology for Holocene climate oscillations centered on 45ºS.
- **Swiss Alps**: The Holocene moraine sequence of the Tsidjiore Nouve Glacier in the Swiss Alps at 46ºS. This Holocene moraine system is one of the classics of the Swiss Alps. Our dating work in Switzerland is leveraged by funds from the CSEF, the
Lamont Climate Center, and by cooperation with the research program of Professor Christian Schlüchter of the University of Bern in Switzerland. Our pilot data illustrates the enormous potential of Tsidjiore Nouve Glacier to yield a detailed 10Be chronology for this region of Switzerland, where the northern Little Ice Age and Medieval Warm Period are best defined.

Research Progress

- Results are included in the three publications listed below.
- Transformational progress in the techniques used to track Holocene mountain glacier fluctuations affords for novel insights in our climate system. Following up on the extensive field work lead by PI Denton (U Maine), we have established glacier fluctuation chronologies of unprecedented resolution and precision for the Cameron, Ashburton and Mt Lucia (Liebig Range) Glaciers in New Zealand’s Southern Alps.
- We have executed a successful field campaign to the Swiss Alps and have established a unique Holocene glacier chronology for the Western and Central Alps.
- We have introduced a novel isotopic tool to quantify Holocene periods of ‘smaller-than-today’ glaciers.

Highlights

- We have developed uniformly applicable isotopic tools to explore moraines and proglacial bedrock as climate archive on a global scale.
- Our results show robust, substantial differences in patterns of Holocene glacier fluctuations between mid-latitude mountain glaciers in both hemispheres, arguing against a 'global Little Ice Age'.
- This work offers novel and deep insights into the drivers of Holocene climate in both hemispheres. While our results argue against insolation as major driving force, a continuous southwards migration of wind patterns during the early and mid-Holocene is consistent with our glacier reconstructions.

Other Research Connections (interagency, partnerships, collaborations)

- Schaefer hosted the NOAA/NSF sponsored workshop ‘Climate-Glaciers-Society’ at Lamont, November 2009. This workshop brought together experts and scholars from the earth science, hydrology, economic and social sciences and established a strong foundation for a multi-PI/multi-year initiative connecting the earth sciences directly to societal problems resulting from the near-global glacier retreat.
- Schaefer hosted Prof. Robert C. Finkel, UC Berkeley, a pioneer and leading analytical radiochemist in the field of cosmogenic nuclide science, as NOAA sponsored visiting scientist at Lamont June/July 2011.
- Schaefer will host Prof. Jason Briner, SUNY Buffalo, a leading expert in Holocene variations and stability of the Greenland Ice Sheet at Lamont in spring 2012.

Education & Outreach

PhD student Brent Goehring (CU, now NOAA postdoctoral fellow at Penn State) has been involved in a leading role and is the lead-author of the Rhone Glacier paper.
Personnel
Research Support Staff: 1, Graduate Students: 1.

Journal articles


Research Goals:
The main goals of the original proposal concerning modern circulation were “to utilize the instrumental [modern] observations of the ocean, as well as paleo records for the investigation of climate change across a range of spatial and temporal scales.”

Within this overarching goal we focused our activities during the reporting period on goal [A] Trends of ocean properties: Under this objective we investigated the interaction between the floating Ross Ice Shelf in Antarctica and the shelf water circulating in the cavity below the ice shelf. After estimating the glacial melt water production underneath the RIS during a previous period of the project (Loose et al., 2009) we investigated the connection between the hydrological system underneath the Antarctic Ice Sheet, specifically its role in melting the floating ice sheets and its transfer into the ocean (shelf waters).

We also investigated the gas transfer through sea ice covered regions to estimate the CO2 uptake in these areas. Uncertainties in the uptake of CO2 in sea-ice covered regions places a large uncertainty in modeling past and future climates and the abrupt changes that occurred in the past and possibly will occur in the future.

Education Goals
Train students on the undergraduate and graduate level.

Research Progress
We evaluated the terrestrial Helium isotope signal detected in the Ice Shelf Water plume that flows out from underneath the RIS and compared its isotopic signature with Helium found in subglacial lakes and the ice frozen to the underside of the Antarctic Ice Sheet. The isotopic signature is identical providing strong indication that fresh water from the hydrological system under the Antarctic Ice Sheet is transferred in considerable amounts into the cavity underneath the RIS and from there into the shelf waters. We summarized these results in an abstracts for presentation at the upcoming Ocean Science Meeting in Salt Lake City in February 2012 (Schlosser et al., 2011).
A publication on gas transfer in sea-ice covered regions is in press (Loose and Schlosser, 2011).

**Highlights**

*We feel that the connection of the helium found in the Ice Shelf Water plume is the first direct observation of water from the subglacial hydrological system in the ocean. If this can be substantiated it is a major new finding that can be used to develop strategies for determining the flux of subglacial water into the ocean across the RIS grounding line.**

**Societal Benefits**

Ocean interaction with floating glacial ice sheets have been identified as one of the major factors determining mass loss of glacial ice sheets. Thus, they have direct relevance for future sea level rise (Future Science Opportunities in Antarctica and the Southern Ocean Committee on Future Science Opportunities in Antarctica and the Southern Ocean Polar Research Board Division on Earth and Life Studies).

**Awards & Honors**

P. Schlosser was elected Fellow of AAAS and Fellow of the Explorer’s Club. He was a member of the NAS panel on ‘Future Science Opportunities in Antarctica and the Southern Ocean.’

**Education & Outreach**

A summer intern (Angelica Pasqualini) worked on the project during the past two summers.

**Personnel**

Research Scientists: 1, Research Support Staff: 1, Administrative: 1, Undergraduate Students: 1.

**Journal articles**

Article from previous work in the project on which present work is built:


Article in press:

Conference proceedings / workshops

Submitted abstract:

P. Schlosser, A. Pasqualini, G. Winckler, and S. Jacobs, 2011: Transfer of subglacial water across the grounding line of the Ross Ice Shelf: indications from helium isotope data. Submitted for presentation at the Ocean Science Meeting; Salt Lake City; February 2012.
Research Goals
Gain a better understanding of the transformation of surface water into subsurface water masses in the high latitude regions of the North Atlantic and Southern oceans, which drives the global thermohaline circulation, and investigate the rate of this circulation and its temporal variability. This will be accomplished using the distributions of transient tracers, such as CFCs and tritium, measured as part of the WOCE and CLIVAR international programs, as well as smaller programs, to delineate circulation pathways of recently formed deep water and to estimate rates of formation from tracer inventories.

Education Goals
Provide research opportunities for undergraduate and graduate students and postdoctoral scientists in the fields of chemical and physical oceanography.

Research Progress
We have acquired all of the CFC data collected in the North Atlantic Ocean from 2001 – 2005 and calculated the CFC-11 inventories for the North Atlantic Deep Water components (Upper Labrador Sea Water, Classical Labrador Sea Water, Iceland-Scotland Overflow Water, Denmark Strait Overflow Water). Some of the sections repeated sections that were done in the 1997-1998 time frame. For these sections we calculated the differences in CFC-11 inventories for the two time periods. These results show that for the western subtropical Atlantic, the CFC-11 inventory increased by about 37% for Upper Labrador Sea Water, 36% for Classical Labrador Sea Water, 103% for Iceland Scotland Overflow Water and 54% for Denmark Strait Overflow Water during the average 5 year period between the occupations. The next step is to map the CFC-11 inventory data for the 2001-2005 time period, integrate the maps to obtain the total CFC-11 inventories and calculate the formation rates for North Atlantic Deep Water components from the change in inventory since the 1997-1998 time period.
Societal Benefits

This research focuses on understanding the transformation of surface water into subsurface water masses at high latitudes, which drives the global thermohaline meridional overturning circulation. This is an important component of the earth’s climate system for heat transport and for the exchange of carbon dioxide and other gases between the atmosphere and the deep ocean. A better knowledge of this process is crucial for understanding and predicting the earth’s climate and thus for making decisions on how to address problems caused by the increase in greenhouse gases.

Personnel

Research Scientists: 1, Research Support Staff: 2, Administrative: 1.
Theme III Applications Research

INDIVIDUAL AND COLLABORATIVE PI RESEARCH PROJECTS

CICAR Award # NA03OAR4320179
   No active projects

CICAR Institutional Extension Award # NA08OAR4320754
   2. Zebiak, S., Identifying, Sharing and Showcasing Decision Support Products and Information from the Climate and Societal Interactions Program
   3. Zebiak, S., International Internships for Climate and Society

CICAR Shadow Award # NA08OAR4320912
   1. Schlosser, P., Abrupt Climate Change in a Warming World: Earth Institute Climate Center

TOTAL THEME III PROJECTS: 4
Research Goals

Enhance the prospects for economic growth in developing countries through the strategic use of climate information.

Education Goals

Produce education materials and outreach activities that improve the ability of water managers to manage hydroclimatic variability.

Research Progress

Progress has been made on the assessment of climate risks to economic growth and in generating new interest in the use of climate information for adaptation.

Highlights

- The peer reviewed research paper “Hydroclimatic risk to economic growth in Sub-Saharan Africa” (Climatic Change, DOI: 10.1007/s10584-010-9956-9) was published.
- Continued effort was made on the book Managing Climate Risk in Water Supply Systems, including contact with two potential publishers, UNESCO and IWA.

Societal Benefits

This effort contributes to the water and adaptation community’s awareness of the potential for adaptation to climate change through the use of seasonal climate forecasts.

Other Research Connections

Recent highlights include engage with the World Bank that has led to new climate risk assessments of the Indus River Basin and a second phase study of the Niger River Basin.

Research Goals
Enhance the prospects for economic growth in developing countries through the strategic use of climate information.

Education Goals
Produce education materials and outreach activities that improve the ability of water managers to manage hydroclimatic variability.

Research Progress
Progress has been made on the assessment of climate risks to economic growth and in generating new interest in the use of climate information for adaptation.

Highlights
- The peer reviewed research paper “Hydroclimatic risk to economic growth in Sub-Saharan Africa” (Climatic Change, DOI: 10.1007/s10584-010-9956-9) was published.
- Continued effort was made on the book Managing Climate Risk in Water Supply Systems, including contact with two potential publishers, UNESCO and IWA.

Societal Benefits
This effort contributes to the water and adaptation community’s awareness of the potential for adaptation to climate change through the use of seasonal climate forecasts.

Other Research Connections
Recent highlights include engage with the World Bank that has led to new climate risk assessments of the Indus River Basin and a second phase study of the Niger River Basin.
Awards & Honors
PI Brown was recognized with the ASCE Huber Research Prize.

Education & Outreach
The book material has been publicly launched on the Internet through the IRI: http://crk.iri.columbia.edu/water. This was covered and picked up by the media: http://www.preventionweb.net/english/professional/news/v.php?id=19714

Personnel
Research Scientists: 1.

Journal articles
Research Goals
To identify, catalog, share and showcase decision-support products and information from the Climate and Societal Interactions Program

Research Progress
Two primary areas of activity in this report period
1. Interviewing and meeting with various groups funded by the CSI program so as to identify and begin to compile relevant activities and products that will ultimately be organized in a searchable database.
2. Assisting leadership of the NOAA Climate Services web portal to enhance and improve the web site, and to develop public-facing content.

(Note: While this project had a July 2010 start date, it was not until January 2011 that funds cleared and the Communications Coordinator position was filled.)

Highlights
Identifying/organizing CSI activities
• 78 PIs contacted about work through the various CSI grants for information about their projects and mining for successes
• In-person meetings with PIs and other RISA/SARP/TRACS project members at AMS and CPASW as well as a site visit to Boulder, CO (planning site visit to Gainesville from October 4-7; also in discussion about a visit to Seattle)
• Drafted a short list of successes for CSI program managers to review (pending feedback); will guide second half of work in focusing in specific types of successes
• Managing files and correspondences in a series of spreadsheets in preparation for CSI website database
• Prepared mockups of web pages for CSI database

Societal Benefits
Current activities are helping societally relevant research and products developed by CSI funded activities to come into public/interagency view.

Other Research Connections
Please see “Identifying/organizing CSI activities” in Highlights section above.

Education & Outreach
NOAA Climate Portal
• Updated the “Understanding Climate” rotator. Forty-seven updates posted about climate-related events/publications/conferences of interest to decision makers.
• Prepared mockup web pages for climate.gov content featuring CSI projects
• Worked with David Herring to pull together a Climate Decision team which will work on these content types
• Currently also working with Rebecca Lindsey to merge this new team with the existing ClimateWatch team and start producing content

Support of IRI communications and outreach activities
• Writing monthly articles for the Earth Institute’s State of the Planet blog, featuring information from IRI’s climate briefing (one post has led to a derivative story on climate.gov, which also featured an image created from data from the IRI Data Library)
• Researching and writing two homepage stories (in production) for IRI website about education and research activities.
• Event support (photography)
• Managing IRI’s social media (Twitter, Flickr, Vimeo)

Personnel
Administrative: 2.
Research Goals

The International Internship program is designed to allow students in the MA program in Climate and Society to learn about the climate information needs and capabilities of humanitarian and development organizations. During the first period covered by this report the internships have focused on the International Federation of Red Cross and Red Crescent Societies (IFRC). The IFRC has great potential to utilize climate and weather forecasts across timescales to trigger actions that save lives and protect livelihoods. However, there are many challenges to using probabilistic forecast information in decision-making. Student interns from the Climate and Society Masters program are working to support Red Cross/Red Crescent (RC/RC) offices in this challenging effort to anticipate and manage climate-related risks. In 2009, students conducted surveys, interviews, meetings and workshops over a two-month period in order to: 1) better understand the humanitarian needs for, and current use of, weather and climate information and 2) formulate recommendations for information providers and RC/RC users alike, so that forecasts across timescales can be communicated, interpreted and utilized in a more effective and timely manner.

Education Goals

- To apply knowledge gained in the Climate and Society Masters program at Columbia University, to the real world challenges of climate risk management within the Red Cross/Red Crescent.
- The twelve-month M.A. Program in Climate and Society trains professionals and academics to understand and cope with the impacts of climate variability and climate change on society and the environment. This rigorous program emphasizes the climate-sensitive problems of developing societies. The International Research Institute for Climate and Society (IRI) has been central to the design of the program, as well as to the mentoring and teaching of its students.
Research Progress

In 2009, ten student interns, with supervision from IRI advisors, worked with Red Cross/Red Crescent offices at the zone/region/national and community levels in Central America, Africa, Asia and the Pacific. Student internships varied according to the needs and capacities for use, of climate and weather information in individual offices. However, students shared many common observations across offices and made a number of cross cutting recommendations. Their findings and recommendations are detailed in their individual internship reports and summarized in the attached brochure entitled ‘The Access and Use of Climate and Weather Information in the International Federation of Red Cross and Red Crescent Societies: Initial Observations from the Field.’ The brochure and student findings were presented at a side event at the 2009 World Climate Conference-3 in Geneva.

Highlights

The internships greatly enhance IRI’s ability to support the International Federation of Red Cross and Red Crescent Societies in its ‘Partnership to Save Lives,’ which was established in 2007. The students and their advisors bring IRI expertise in climate risk management directly to RC/RC offices throughout the world. The level of personal interaction and resulting recommendations from the interns, have also helped the IRI to make improvements to it’s RC/RC map room, and provide more user-friendly guidance through it’s helpdesk -which offers quick answers to questions related to climate and weather from RC/RC decision makers.

In 2009, three of the students presented their internship findings on a panel of scientists and practitioners from the IRI, International Federation, RC/RC Climate Centre and African Centre of Meteorological Application for Development (ACMAD) at the World Climate Conference-3. Thus, the internships have not only made a significant contribution in terms of IRI’s current delivery and future vision of climate services, but also to the global discussion on developing a framework for climate services.

Societal Benefits

The societal benefits of the internship program are significant. RC/RC offices throughout the world, and particularly in developing countries, are vulnerable to being overwhelmed and caught-off guard by increasing climate-related hazards. Knowledge of climate variability and change, and the ability to monitor forecasts across timescales and design no-regrets early action strategies are essential for the RC/RC to help mitigate the consequences of changing climate risks on the lives, livelihoods and health of vulnerable populations.

Other Research Connections

- In addition to the IRI-International Federation-RC/RC Climate Centre collaboration supported by the internships, the internships strengthen linkages between meteorological, hydrological and climate information providers in region with local
RC/RC offices, and provide opportunities for IRI to support local capacity to deliver user-friendly climate services.

- The close collaboration between IRI and the IFRC has also in part led to a request from UN OCHA to IRI to produce a post-earthquake Haiti Weather and Climate Risk website, for disaster managers to monitor rainfall and hurricane forecasts across timescales in http://iri.columbia.edu/haiti/.

**Awards & Honors**

Individual students have also been awarded supplemental internship funds from the Institute for Latin American Studies at Columbia University and the Chevron Grant Student Initiative Fund.

**Education & Outreach**

**Presentations**

- All students present on their internship findings at the local RC/RC office hosting them, as well as at Columbia University, for their classmates and IRI advisors during the Climate and Society summer seminar in August.

**In progress-expected educational tools**

- An online curriculum to communicate climate change and its potential impact on Red Cross/Red Crescent work.
- Short films on climate risks in Uganda.

**IRI Academic Internship Advisors**

- Esther Conrad, Senior Staff Associate, Asia and Pacific Regional Program.
- Francesco Fiondella, Communications Officer, Office of the Director General.
- Molly Hellmuth, Director, Climate and Society Publication Secretariat.
- Paul Block, Associate Research Scientist, Hydroclimatology and Water Resources Management.
- Simon Mason, Research Scientist, Forecasting Prediction Research.
- Sylwia Trzaska, Associate Research Scientist, Climate Variability

**Climate and Society Graduate Student Interns 2009**

<table>
<thead>
<tr>
<th>Amir Jina</th>
<th>Julie Arrighi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brian Kahn</td>
<td>Mary Mwangi</td>
</tr>
<tr>
<td>Caitlin Kopcik</td>
<td>Meaghan Daly</td>
</tr>
<tr>
<td>Cynthia Thomson</td>
<td>Nickleson Cook</td>
</tr>
<tr>
<td>Jessica Sharoff</td>
<td>Ujala Qadir</td>
</tr>
</tbody>
</table>

**Personnel**

Research Support Staff: 1.
Reports

Figures, photographs, illustrations

Short video: ‘Climate Science for Humanitarian Work: Insights from IRI-IFRC Young Scholars.’ Available online: http://www.youtube.com/watch?v=9VRAzpvachw

Figure: IFRC office locations where students conducted research: http://www.climatecentre.org/downloads/Image/Interns/Placement%20interns%20on%20worldmap.pdf

IRI’s interns featured on the RC/RC Climate Centre’s webpage on Young Scholars for Humanitarian Work: http://www.climatecentre.org/site/young-scholars
Research Goals

Per request of the principal investigators of the *Abrupt Climate in a Warming World* (ACCWW) project, the Columbia Climate Center solicited proposals to meet the goal of linking the physical science in ACCWW with decision makers and the general public. It was recognized that social scientists must be engaged to make that connection in a more meaningful way. Two projects were chosen: *Impacts of a Changing Climate on Water Allocation Rules in the SW United States* (Heikkila, Schlager and Siegfried) and *Bridging Social and Physical Sciences, Outreach and Communication* (Carr and Marx). These projects were chosen in January of 2009, thus the period of performance has been shorter than other parts of the ACCWW project.

The goal of *Impacts of a Changing Climate on Water Allocation Rules in the SW United States* is to understand the interaction between climate information and interstate water allocation rules and how water laws and institutions might cope under different climate change scenarios. There are three project components: 1) a survey of water managers in the Southwest to identify how climate information is used and shared, 2) an analysis of policy changes in southwestern states to better assess how policies change and respond to drought conditions, 3) a model of the performance of interstate water allocation rules under different scenarios of climate change and water allocation.

The goal of *Bridging Social and Physical Sciences, Outreach and Communication* is to enhance the outreach and communication of the research team of the ACCWW project by taking advantage of expertise on how information is understood and how decisions are made.

Education Goals

The two projects aim to train students in scientific research, data analysis, programming and communication skills. The webpage serves to translate research and provide outreach which will improve societal understanding of abrupt climate change.
Research Progress

*Impacts of a Changing Climate on Water Allocation Rules in the SW United States* has made significant progress in all three elements of the project.

The research team has completed the survey of water providers in the Upper Rio Grande. The population of public and non-profit water providers, identified through online sources and directories in the Upper Rio Grande communities in New Mexico and Colorado was 96. Contact information for about 10% of these water providers was outdated or inaccurate. All surveys were conducted by telephone. An initial invitation letter was requested (following IRB approval of the survey design), up to three contact attempts were made (per IRB requirements). The final response rate was approximately 40%. The survey included 35 questions covering organizational structure, water resources/supplies, daily operations, and use of climate and weather data, and organizational networks. Survey data are currently being analyzed will be analyzed using standard statistical techniques, where feasible with survey responses. ANOVA may be used to compare responses from participants in different regions (e.g. New Mexico vs. Colorado) or from different water industry sectors. Open-ended questions will be coded and analyzed using standard statistical data analysis techniques or descriptive analyses. All results and findings will be presented using aggregated data. The team has submitted a proposal to the Association for Policy Analysis and Management to present results at its 2011 annual meeting.

The analysis of policy changes in response to drought conditions continues. The database of all water laws passed since the 1930s for the three states of the Rio Grande Basin (Colorado, New Mexico and Texas) and time series of climatic conditions is the basis to evaluate the responsiveness of institutions and legal frameworks to changing environmental conditions. The analysis this year has focused on identifying annual, decadal, and era-based trends in the Colorado data. The decadal and era-based analyses appear to be more robust for detecting climatic trends. Similar analyses will be completed for New Mexico and Texas. Data from the Colorado analyses have been analyzed and recently presented at the Universities Council on Water Resources annual meeting in Boulder, CO by one of our masters-level research assistants who assisted with data analysis and has used the Colorado data in his master’s thesis. A paper to be submitted for publication is scheduled for completion at the end of the summer of 2011.

The modeling study of the performance of interstate water allocation rules continues with development of the three models. The conceptual model of rainfall and runoff (RRM) in Costilla Creek explicitly incorporates subsurface water and snow storage. The model was successfully calibrated using water gauge data for the period 1990-2009. The model is driven by in-situ temperature and precipitation measured at SNOTEL stations in the higher elevations of the catchment and evapotranspiration. An important goal is to adequately account for interannual to decadal variability in the region as well as to capture trends such as rising average temperatures associated with climate change. To this end, time series of temperature and precipitation are used to predict near-term (i.e. 2010 – 2050 timeframe) basin flows. These time series are derived from GCM scenario
output coupled with a statistical downscaling approach (Hidden-Markov Models). These time series will drive the RRM. The implications of past and future flow variability for management and planning in the downstream will be addressed with an agent-based model for the proof-of-concept has been established in a toy model basin. It is assumed that the multiple agents are decision making units that act in a stochastic, and hence uncertain, environment while trying to maximize individual utilities that are derived from the consumptive and non-consumptive allocation in space and time. Both models have been prepared for full interfacing with the Matlab programming tool. Hence, we are now in the position to perform simulation-optimization runs to assess requirements for efficient and equitable water use under different climate scenarios. Finally, a generic conflict model for upstream and downstream stakeholder interaction has been developed. It captures and formalizes conflict by explicitly accounting for negative in-stream effects downstream resulting from upstream space-time modifications of the runoff. Results from the models were presented by Prof. Tobias Siegfried at the American Geophysical Union’s Annual Meeting, December 13-17, 2010.

*Bridging Social and Physical Sciences, Outreach and Communication* has established the webpage “Abrupt Change in a Warming World” (http://climate.columbia.edu/?id=abrupt_change), with initial content focused on two meetings: DUSTPEC: Dust Records For A Changing World Workshop, held May 24 to 26, 2010; and the 2009 Annual Meeting, held July 8 to 10 2009. These meeting webpages include an introduction, a summary of each talk and almost all of the presentations in pdf format. A series of interviews with the investigators of the Abrupt Climate Change in a Warming World project have been carried out and text is being prepared for a comprehensive webpage to highlight the research, the extraordinarily interdisciplinary nature of the work, and the societal implications of abrupt change for water resource management, health, sea level rise, agricultural production and food security, migration and national security, and other topics.

**Societal Benefits**

*Impacts of a Changing Climate on Water Allocation Rules in the SW United States* works directly with policymakers. The analysis of existing laws and policies and the agent-based modeling assess how water managers within different institutions have used climate information in the past and how they can better use climate information in the present and future.

*Bridging Social and Physical Sciences, Outreach and Communication* aims precisely to communicate ACCWW results in a manner that enables informed decisions by stakeholders such as water managers, health care agencies, farmers associations, shipping companies, policy makers, and the general public. Given recent research in economics, psychology, anthropology, and political science on how users and groups of users understand and incorporate climate information in their decision process highlights the need for significant collaboration and partnerships between social and physical scientists. The project thus aims to lay the framework to establish these collaborations across disciplines, to be better informed on how best to communicate results to key decision
makers, and to have a roadmap on how to place ACCWW results into the appropriate context to raise awareness and enable informed decisions.

**Personnel**

Research Scientists: 4, Research Support Staff: 3, Administrative: 1, Graduate Students: 2, Undergraduate Students: 2.
Task IV Collaborative Education Programs and Projects

In budget year 2010 - 2011 funds were unavailable to continue the Institute’s commitment to education through support for graduate students and CICAR postdoctoral fellowships.
Table 1. Principal Investigators and Projects July 1, 2010 – June 30, 2011

<table>
<thead>
<tr>
<th>Principal Investigator</th>
<th>Project</th>
<th>Goal</th>
<th>Task</th>
<th>Theme</th>
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<tbody>
<tr>
<td>NA03OAR4320179 June 30, 2011 award expired</td>
<td>1. Schlosser, Peter ARCHES: Infrastructure (no activity to report)</td>
<td>2</td>
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<td>NA08OAR4320754 Institutional extension</td>
<td>1. Brown, Casey Improving Economic Development through Prediction and Management of Hydro Climate Variability</td>
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<tr>
<td></td>
<td>2. Gordon, Arnold Monitoring the Indonesian Throughflow in Makassar Strait</td>
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<td></td>
<td>3. Huber, Bruce Weddell Sea Moorings</td>
<td>2</td>
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<td></td>
<td>4. Kushnir, Yochanan The Cooperative Institute for Climate Applications and Research</td>
<td>2</td>
<td>3</td>
<td>n/a</td>
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<td></td>
<td>5. McGillis, Wade Boundary Layer Experiments of Coral Reef Calcification and Net O2 Production</td>
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<td></td>
<td>6. Schlosser, Peter Global Oceanic 3HE Data Sets: Calibration tools for Models of the Upward Branch of the Deep Ocean Global Conveyor</td>
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<td></td>
<td>7. Takahashi, Taro Underway CO2 Measurements Aboard the RV IB Palmer and Data Management of the Global VOS Program</td>
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<td></td>
<td>8. Zebiak, Stephen Identifying, Sharing and Showcasing Decision Support Products and Information from the Climate and Societal Interactions Program</td>
<td>2</td>
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<td></td>
<td>9. Zebiak, Stephen International Internships for Climate and Society</td>
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<tr>
<td>Principal Investigator</td>
<td>Project</td>
<td>Goal</td>
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<tr>
<td>2. Broecker, Wallace</td>
<td>ACCWW: Meridional Hydrology Variability and Synthesis of Ocean Circulation</td>
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<td>3. Camargo, Suzana</td>
<td>Towards a Better Understanding of the Relationship Between Climate Change and Tropical Cyclone</td>
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<td>4. Cane, Mark</td>
<td>Generation and Evaluation of Long-Term Retrospective Forecasts with NCEP Climate Forecast System: Predictability of ENSO and Drought</td>
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<tr>
<td>5. Cook, Edward</td>
<td>ACCWW: Lessons from Holocene Paleo and Modern Instrumental Records and Model Simulations</td>
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<td>6. D’Arrigo, Rosanne</td>
<td>Paleoclimate Reconstructions (PR) Challenge: A Community Program to Benchmark Methods Used to Reconstruct the Climate of the Last 1-2,000 Years</td>
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<td>7. deMenocal, Peter</td>
<td>ACCWW: Holocene Variability of Atlantic Surface Properties and West African Aridity</td>
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<tr>
<td>8. Denton, George</td>
<td>ACCWW: Lessons From Holocene Paleo and Modern Instrumental Records, and Model Simulations</td>
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<tr>
<td>9. Goddard, Lisa</td>
<td>Diagnosing Decadal-Scale Climate Variability in Current Generation Coupled Models for Informing Near-Term Climate Change Impacts</td>
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<td>10. Goddard, Lisa</td>
<td>Recalibrating and Combining Ensemble Predictions</td>
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<td>12. Hemming, Sydney</td>
<td>ACCWW: Radiogenic Isotope Tracer Paleo-Proxy Scope</td>
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<td>13. Jacobs, Stanley</td>
<td>ACCWW: Southern Ocean-Ice Sheet Interactions</td>
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Table 1. continued

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<th>Principal Investigator</th>
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<th>Task</th>
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<tr>
<td>14. Kaplan, Alexey</td>
<td>Error Models for Remotely-Sensed Sea Surface Heights and Temperatures in Ocean Data Assimilation</td>
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<td>16. Martinson, Douglas</td>
<td>ACCWW: Abrupt Change in the West Antarctic Peninsula in a Warmer World</td>
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<td>18. Schlosser, Peter</td>
<td>ACCWW: Infrastructure</td>
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<tr>
<td>19. Schlosser, Peter</td>
<td>ACCWW: Abrupt Climate Change in a Warming World: Synthesis of Tracer Data</td>
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<td>20. Schlosser, Peter</td>
<td>ACCWW: Earth Institute Climate Center</td>
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<td>21. Seager, Richard</td>
<td>ACCWW: Modeling and Understanding Late Holocene and Near Term Future Hydroclimate Change</td>
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<td>22. Seager, Richard</td>
<td>Mechanisms and Predictability of Multi-Basin Influences on North American Drought</td>
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<td>23. Seager, Richard</td>
<td>Predicting North American Hydroclimate Change and Variability on Interannual to Multidecadal Timescale</td>
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<td>24. Smethie, William</td>
<td>ACCWW: Modern Instrumental Records-CFCs</td>
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<td>25. Sobel, Adam</td>
<td>The Madden-Julian Oscillation: Model Development and Diagnosis of Mechanisms</td>
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<td>26. Ting, Mingfang</td>
<td>Mechanisms and Predictability of the Global Climate Impacts of Atlantic Multidecadal Variability</td>
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</table>

2011 Total projects reported on for all CICAR awards: 36 (includes CICAR Task I funding) * sub-theme
Table 2. Funding Analysis

CICAR Projects FY11 All Awards

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<tr>
<th>Goal 2</th>
<th>Task 1</th>
<th>Task 2</th>
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<td>36</td>
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Legend:
- **Total**
- **Theme 3**
- **Theme 2**
- **Theme 1**
Table 3. Personnel Information July 1, 2010 – June 30, 2011

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<tr>
<th>Category</th>
<th>Number</th>
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<th>B.A.</th>
<th>B.S.</th>
<th>M.A</th>
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<td>Research Scientist</td>
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<td>Research Support Staff</td>
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<td>Administration</td>
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<td>Graduate</td>
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<td><strong>Total Support&gt;50%</strong></td>
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<td>Research Scientist</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Postdoctoral Fellow</td>
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<td></td>
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<td>1</td>
<td></td>
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<td>Research Support Staff</td>
<td>19</td>
<td></td>
<td>3</td>
<td>14</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Administration</td>
<td>7</td>
<td></td>
<td>5</td>
<td>1</td>
<td>1</td>
<td></td>
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</tr>
<tr>
<td>Graduate</td>
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<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total Support&lt;50%</strong></td>
<td>52</td>
<td>11</td>
<td>15</td>
<td>25</td>
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</tr>
<tr>
<td><strong>Total Support 2010-2011</strong></td>
<td>63</td>
<td>12</td>
<td>1</td>
<td>22</td>
<td>28</td>
<td></td>
<td></td>
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<td>NOAA Employment</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Located at GFDL</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
Table 4. Lead Author: Total Publications July 1, 2003 – June 30, 2011

<table>
<thead>
<tr>
<th></th>
<th>CICAR Lead Author</th>
<th>NOAA Lead Author</th>
<th>Other Lead Author</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010 - 2011</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peer Reviewed</td>
<td>34</td>
<td>4</td>
<td>13</td>
<td>51</td>
</tr>
<tr>
<td>Non-Peer Reviewed</td>
<td>24</td>
<td>1</td>
<td>1</td>
<td>26</td>
</tr>
<tr>
<td><strong>Total Publications 2010</strong></td>
<td><strong>58</strong></td>
<td><strong>5</strong></td>
<td><strong>14</strong></td>
<td><strong>77</strong></td>
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<tr>
<td>2009 - 2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peer Reviewed</td>
<td>27</td>
<td>2</td>
<td>19</td>
<td>48</td>
</tr>
<tr>
<td>Non-Peer Reviewed</td>
<td>24</td>
<td>1</td>
<td>4</td>
<td>29</td>
</tr>
<tr>
<td><strong>Total Publications 2010</strong></td>
<td><strong>51</strong></td>
<td><strong>3</strong></td>
<td><strong>23</strong></td>
<td><strong>77</strong></td>
</tr>
<tr>
<td>2008 - 2009</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peer Reviewed</td>
<td>39</td>
<td>0</td>
<td>27</td>
<td>66</td>
</tr>
<tr>
<td>Non-Peer Reviewed</td>
<td>6</td>
<td>0</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td><strong>Total Publications 2009</strong></td>
<td><strong>45</strong></td>
<td><strong>0</strong></td>
<td><strong>30</strong></td>
<td><strong>75</strong></td>
</tr>
<tr>
<td>2007 – 2008</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peer Reviewed</td>
<td>34</td>
<td>0</td>
<td>11</td>
<td>45</td>
</tr>
<tr>
<td>Non-Peer Reviewed</td>
<td>8</td>
<td>0</td>
<td>3</td>
<td>11</td>
</tr>
<tr>
<td><strong>Total Publications 2008</strong></td>
<td><strong>42</strong></td>
<td><strong>0</strong></td>
<td><strong>14</strong></td>
<td><strong>56</strong></td>
</tr>
</tbody>
</table>


Table 4. Lead Author

<table>
<thead>
<tr>
<th></th>
<th>CICAR Lead Author</th>
<th>NOAA Lead Author</th>
<th>Other Lead Author</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006 - 2007</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Peer Reviewed</td>
<td>29</td>
<td>1</td>
<td>25</td>
<td>55</td>
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<tr>
<td>Non-Peer Reviewed</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td><strong>Total Publications</strong></td>
<td><strong>32</strong></td>
<td><strong>2</strong></td>
<td><strong>26</strong></td>
<td><strong>60</strong></td>
</tr>
<tr>
<td>2005 - 2006</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peer Reviewed</td>
<td>36</td>
<td>3</td>
<td>22</td>
<td>61</td>
</tr>
<tr>
<td>Non-Peer Reviewed</td>
<td>0</td>
<td>2</td>
<td>11</td>
<td>13</td>
</tr>
<tr>
<td><strong>Total Publications</strong></td>
<td><strong>36</strong></td>
<td><strong>5</strong></td>
<td><strong>33</strong></td>
<td><strong>74</strong></td>
</tr>
<tr>
<td>2004 - 2005</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peer Reviewed</td>
<td>38</td>
<td>0</td>
<td>30</td>
<td>68</td>
</tr>
<tr>
<td>Non-Peer Reviewed</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total Publications</strong></td>
<td><strong>38</strong></td>
<td><strong>0</strong></td>
<td><strong>30</strong></td>
<td><strong>68</strong></td>
</tr>
<tr>
<td>2003 – 2004</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peer Reviewed</td>
<td>4</td>
<td>0</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Non-Peer Reviewed</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total Publications</strong></td>
<td><strong>5</strong></td>
<td><strong>0</strong></td>
<td><strong>4</strong></td>
<td><strong>9</strong></td>
</tr>
<tr>
<td><strong>Total Publications 2003 - 2011</strong></td>
<td><strong>307</strong></td>
<td><strong>15</strong></td>
<td><strong>174</strong></td>
<td><strong>496</strong></td>
</tr>
</tbody>
</table>
Publications 2010 – 2011

Journal articles


Books / articles-in-books


Conference proceedings / workshops


3. Anderson, R. F., 2010: The role of the winds in past climate change and CO₂; Anderson, R. F., Fall 2010 AGU; (PP24A-04)


5. Anderson, R. F., 2011: The role of the winds in past climate change and CO₂; 31 January, Rutgers University, Institute of Coastal and Marine Science.


Reports


**Ph.D. dissertation**


*Total Publications July 1, 2010 – June 30, 2011: 77*
Tropical Atlantic ITCZ and the African Humid Seasonal Cycle in the export of boreal water

In situ cosmogenic Be-10 production rate

The role of the winds in past climate change and

Journal Article

Seager, R. and N. Naik 2011

Deglacial evolution of the Atlantic ITCZ. Fall EOS, 92, 11-12.

Journal Article


Cluster analysis of tropical cyclone tracks in the

Journal Article

Kossin, J. P., S. J. Camargo and M. Sitkowski 2011:

Northern hemisphere winter snow anomalies: X

2011:

ITF and Western Pacific Warm Pool. Keynote

Camargo, S., M. Ting and Y. Kushnir 2011

Jenkins, A., P. Dutrieux, S. Jacobs, S. McPhail, J. and

Hydroclimatic risk to economic growth in Sub-

2011

DOI: Research Support Award No.

Hannah, W. M. and E. D. Maloney Jun-11

Climate modulation of North Atlantic hurricane

NA08OAR4320754

The role of the winds in past climate change and

Smerdon, J. E., A. Kaplan, D. Chang and M. N. and

Finkel, B. Goehring and S. M. Kelley, 2011

deMenocal

and E. Cook, 2011


Using opal and organinc carbon as proxies for the

Presentation by S. Camargo at the Goldschmidt Conference, Knoxville, Tennessee. 2010:

Throughflow on the POGO, Partnership for

Corredor 2011

presentaiton by S. Camargo at the AAGD-04, Taipei, Taiwan, June 2010 (oral presentation by Corredor). 04)

Response in the troposphere.

The role of the winds in past climate change and

Journal Article

Smerdon, J. E., A. Kaplan, D. Chang and M. N.

Finkel, B. Goehring and S. M. Kelley, 2011

deMenocal

and E. Cook, 2011


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Corredor 2011

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Journal Article

Smerdon, J. E., A. Kaplan, D. Chang and M. N.

Finkel, B. Goehring and S. M. Kelley, 2011

deMenocal

and E. Cook, 2011


Using opal and organinc carbon as proxies for the

Presentation by S. Camargo at the Goldschmidt Conference, Knoxville, Tennessee. 2010:

Throughflow on the POGO, Partnership for

Corredor 2011

presentaiton by S. Camargo at the AAGD-04, Taipei, Taiwan, June 2010 (oral presentation by Corredor). 04)

Response in the troposphere.
MEMORANDUM FOR:   NOAA Office of Oceanic and Atmospheric Research Cooperative Institute Awardees

FROM:      Cherri Helms
            OAR Cooperative Institutes Program

SUBJECT: Performance Reporting

DATE: January 13, 2011

This memorandum provides an explanation of the report content and when to submit the annual performance report for cooperative institute (CI) awards managed by the NOAA Office of Oceanic and Atmospheric Research (OAR). This memorandum covers four categories of awards related to CIs: (1) Main institutional Awards initiated before 2006, (2) Main institutional awards initiated on or after January 1, 2006, (3) Extension institutional awards, and (4) Shadow awards. OAR CIs and the type(s) of their outstanding awards are listed in Table 1 at the end of this memorandum. The schedule for submitting annual reports is based on award category:

(1) Main Institutional Awards Initiated before January 2006 – All progress reports will cover the same period and be due according to the schedule established before 2006. The performance period is for one-year period starting on the annual anniversary date of the award. The report is due 90 days after the performance period. Because NOAA’s Grants Online system currently imposes the requirements described for category (2) awards, category (1) awards must initially submit a copy of this memorandum along with a list of projects that will be described in the performance report when it is submitted within 90 days of the end of the performance period. This list must be submitted as the progress report in Grants Online within 30 days after the award anniversary date and indicate the deadline for submitting the final version of the annual report.

Example: If the main institutional award began on July 1, 2005, then the most recent performance report would cover the period July 1, 2009 – June 30, 2010 and be due by September 30, 2010. A list of projects that will be described in the annual report and a list of all NOAA employees who provided the PI with the funding for each project described in the annual report must be submitted to Grants Online as the main progress report by July 31, 2011 and include text that indicates that the final version of the annual report will be submitted by September 30, 2010. The project list and the final version of the performance report will be re-submitted as the progress report for the one-year period in Grants Online.

(2) Main Institutional Awards Initiated on or after January 1, 2006 (this includes previous CIs who successfully competed for a CI award after January 1, 2006) – The initial progress report covers the first nine-month period and is due 30 days after the initial period. Subsequent reports cover twelve-month periods and are due 30 days after the end of period.

Example: If the main institutional award begins on July 1, 2006, then the first performance report will cover the period from July 1, 2006 – March 31, 2007 and will be due on April 30, 2007. The next performance report will cover the period April 1, 2007 – March 31, 2008 and will be due on April 30, 2008.

(3) Extension institutional awards (only applies to initial awards that were created before January 1, 2006) – These awards were created when the NOAA Research Council recommended that CI awards established before January 1, 2006 be extended to allow NOAA additional time to complete competitions under NOAA’s new CI policy (NAO 216-107). The performance period and requirements for submitting a list of projects that will be reported on are the same as that
described in (1). If there is an overlapping period between the main institutional award and the extension institutional award then one master performance report can be attached to both awards, but there should be a clear explanation in the report that the CI is doing this, including a reference to both award numbers.

(4) Shadow Awards – Shadow awards were created to allow CI projects selected competitively through a NOAA program to be funded for the entire period of the project, even if it extends beyond the end of the main institutional award. Performance reporting requirements are similar to those described for category (1) awards and are associated with the date of the main shadow award and not the period of any individual project, regardless of when the main institutional award began. A progress report for each shadow award project should be submitted as a separate document.

As a requirement of the cooperative institute cooperative agreement, each institution must submit an annual report that describes all NOAA-funded research activities during the preceding award year that were funded in the proceeding performance period for each CI-associated award. This report is reviewed by the CI Program Manager and the NOAA programs that sponsor the research and becomes part of the official grant file.

When preparing the information in the annual report for the main (or extension) institutional award described above, please follow the guidelines listed below. The annual reports for Shadow Awards need to include a progress report for each project and do not need to include any tables or additional information described below; however, the institutional award report should include the shadow award statistics in the tabular data since these are being funded through the CI.

(1) NOAA requires all annual reports to be submitted electronically through Grants Online. At their discretion, CIs may send a courtesy copy of the annual report to the OAR CI Program Manager.

(2) Include a table of contents.

(3) Annual reports should report on performance for all NOAA-funded projects, including those listed on all amendment documents approved throughout the performance period described in the beginning of this memorandum. These project titles and a description of the annual performance associated with this project should appear in the annual report along with the name NOAA Sponsor and NOAA office of the primary technical contact for each project. As described earlier, at least one objective should be clearly stated for each project along with an adequate description of the research that was conducted during the report year.

(4) For each project, identify the related NOAA goal(s) from the NOAA Strategic Plan: (Goal 1) Protect, Restore, and Manage the Use of Coastal and Ocean Resources Through Ecosystem-based Management; (Goal 2) Understand Climate Variability and Change to Enhance Society’s Ability to Plan and Respond; (Goal 3) Serve Society’s Needs for Weather and Water Information; (Goal 4) Support the Nation’s Commerce with Information for Safe, Efficient, and Environmentally Sound Transportation; or (Goal 5) Mission Support.

(5) Since CI general activities are part of the CI proposal, this information should be included in the report. Provide an introductory section that includes:

- a general description of the Institute and its core activities, including all education and outreach activities,
- a list of all the award numbers are related to this CI,
- a description of how the CI is managed, including mission and vision statements, and the organizational structure,
• an executive summary of important research activities and results in 1-3 pages,
• a distribution of NOAA funding by Institute task and theme (e.g., pie chart with percentages),
• if the CI-NOAA MOU identified a Council of Fellows and an Executive Board, provide the names of the current Fellows and a list of all meeting dates,
• a general description of Task I activities, including percentage of funding (e.g., pie chart with percentages) used for administration, post-docs/visiting scientists, student support, education and outreach activities, and other research support.

(6) Use appendices to provide:

• Publication Documentation

  1. total count of publications for the reporting period and previous periods categorized by NOAA lead author, Institute (or subgrantee) lead author, and other lead author and whether it was peer-reviewed and non peer-reviewed (including presentations);

Example for showing the total number of publications:

<table>
<thead>
<tr>
<th>Institute Lead Author</th>
<th>NOAA Lead Author</th>
<th>Other Lead Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010-2011</td>
<td>2010-2011</td>
<td>2010-2011</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Peer Reviewed</th>
<th>Non Peer Reviewed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

  2. each publication should reference the source that provided the support for the project, i.e. the award number, the amendment and project title;
  3. each publication should reference the publication Journal, including the date published, volume number, page number and citation number;
  4. breakout each article, paper, proceedings, and presentation completed in reporting period to show if they are or are not related to Deep Water Horizon (DWH) projects.

Example for showing the publication types (see excel spreadsheet):

<table>
<thead>
<tr>
<th>CI Name</th>
<th>PI Name / Author Names</th>
<th>Publication Date</th>
<th>Publication Title</th>
<th>Published In (Journal Name, volume and page number)</th>
<th>Type of Publication</th>
<th>Citation No. (Digital Object Identifier)</th>
<th>Research Support Award No.</th>
<th>CI Lead Author</th>
<th>NOAA Lead Author</th>
<th>Other Lead Author</th>
<th>Peer Reviewed</th>
<th>Non Peer Reviewed</th>
</tr>
</thead>
</table>
Employee Support Documentation

1. the total number of employees by job title and terminal degree that receive at least 50% support from NOAA, postdocs and visiting scientists;
2. total number of undergraduate and graduate students receiving any level of support;
3. number of employees (including postdocs and visiting scientists) that received less than 50% annual salary support;
4. for Institutes that award subcontracts, please obtain only information on the number of supported postdocs and students from your subgrantees.
5. the number of employees/students that receive 100% of their funding from an OAR laboratory and/or are located within that laboratory;
6. the number of employees/students that were hired by NOAA within the last year.

Example for showing the total number of employees:

<table>
<thead>
<tr>
<th>Personnel Category</th>
<th>Number</th>
<th>B.S.</th>
<th>M.S.</th>
<th>Ph.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research Scientist</td>
<td>5</td>
<td>0</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Visiting Scientist</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Postdoctoral Fellow</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Research Support Staff</td>
<td>20</td>
<td>15</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Administrative</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total (≥ 50% support)</strong></td>
<td>34</td>
<td>18</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>Undergraduate Students</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Graduate Students</td>
<td>6</td>
<td>5</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Employees that receive &lt; 50% NOAA Funding (not including students)</td>
<td>24</td>
<td>10</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>
Located at Lab (include name of lab) | 29-AOML, 6-SEFSC | 
--- | --- |
Obtained NOAA employment within the last year | 1 |

(7) The preliminary project list and final version of the performance report must be submitted by the deadlines described in the beginning of this memorandum. The final version will also be made available on the NOAA CI Web site, http://www.nrc.noaa.gov/ci.
AWARD NOS.  
NA03OAR4320179, NA08OAR4320754, and NA08OAR4320912 (shadow)

PROJECT TITLE  
The Cooperative Institute for Climate Applications and Research (CICAR)

PRINCIPAL INVESTIGATOR  
Yochanan Kushnir

AFFILIATION  
Lamont-Doherty Earth Observatory
The Earth Observatory, Columbia University in the City of New York

NOAA PROGRAM & DIRECTOR  
OAR Cooperative Institutes Program
Philip Hoffman 301-734-1090  
philip.hoffman@noaa.gov

CICAR PROGRESS REPORT PROJECT LISTING JULY 1, 2010 – JUNE 30, 2011

The CICAR Annual Progress Report for the 12-month period ended June 30, 2011 will be submitted on Grants Online by September 30, 2011. All 35 CICAR projects address the NOAA climate goal to “understand climate variability and change to enhance society’s ability to plan and respond.”

Main Institutional Award number NA0OAR4320179 expires June 30, 2011:

1. ARCHES Infrastructure  
   PI Schlosser  
   PM James Todd 301-734-1258  
   jim.todd@noaa.gov

Institutional Continuation Award number NA08OAR4320754

   PI Schlosser  
   PM Venkatachala Ramaswamy 609-452-6510  
   v.ramaswamy@noaa.gov

2. Monitoring the Indonesian Throughflow in Makassar Strait  
   PI Gordon  
   PM Diane Stanitski 301-427-2465  
   diane.stanitski@noaa.gov
3. Weddell Sea Moorings
   PI Huber
   PM Diane Stanitski 301-427-2465 diane.stanitski@noaa.gov

4. Boundary Layer Experiments of Coral Reef Calcification and Net O₂ Production
   PI McGillis
   PM Wanninkhof 305-361-4379 rik.wanninkhof@noaa.gov

5. Underway CO₂ Measurements Aboard the RVIB Palmer and Data Management of the Global VOS
   PI Takahashi
   PM Joel M. Levy 301-427-2462 joel.levy@noaa.gov

6. PECASE: Improving Economic Development Through Prediction and Management of HydroClimate Variability
   PI Brown
   PM Philip Hoffman 301-734-1090 philip.hoffman@noaa.gov

7. International Internships for Climate and Society
   PI Zebiak
   PM Chet Ropelewski 301-734-1210 chet.ropelewski@noaa.gov

8. CICAR Administrative Task I
   PI Kushnir
   PM Philip Hoffman 301-734-1090 philip.hoffman@noaa.gov

9. Identifying, Sharing and Showcasing Decision Support Products and Information from the Climate and Societal Interactions Program
   PI Zebiak
   PM Sarah Abdelrahim 301-734-1224 sarah.abdelrahim@noaa.gov

Shadow Award number NA08OAR4320912 (individual reports due GOL by September 30)

1. Towards a Better Understanding of the Relationship Between Climate Change and Tropical Cyclone
   PI Camargo
   PM Christopher D. Miller 301-734-1241 christopher.d.miller@noaa.gov

2. Generation and Evaluation of Long-Term Retrospective Forecasts with NCEP Climate Forecast System: Predictability of ENSO and Drought
   PI Cane
   PM Jin Huang 301-734-1226 jin.huang@noaa.gov
3. Diagnosing Decadal-Scale Climate Variability in Current Generation Coupled Models for Informing Near-Term Climate Change Impacts  
   PI Goddard  
   PM James Todd 301-734-1258 jim.todd@noaa.gov

4. Recalibrating and Combining Ensemble Predictions  
   PI Goddard  
   PM Mooney 301-734-1242 kenneth.mooney@noaa.gov

5. Error Models for Remotely-Sensed Sea Surface Heights and Temperatures in Ocean Data Assimilation  
   PI Kaplan  
   PM Sid Boukabara 301-763-8136 x 195 sid.boukabara@noaa.gov

   PI Kushnir  
   PM James Todd 301-734-1258 jim.todd@noaa.gov

7. ACCWW: Abrupt Change in the West Antarctic Peninsula in a Warmer World  
   PI Martinson  
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25. ACCWW: Abrupt Climate Change in a Warming World: CFCs
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26. ACCWW: Earth Institute Climate Center
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