# EARTH SYSTEM SCIENCE
# FUNDED PROJECTS 2009



## I. Climate Variability

| **Primary Investigators (last names and affiliations)** | **Project Title** | **Year Funded** |
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| Huang, Bohua, Center for Ocean-Land-Atmosphere Studies | Examining the Predictability of the Tropical Atlantic Variability using Coupled Prediction Models | 2009 |
| **Abstract:** Understanding the predictability of the tropical Atlantic variability (TAV) is crucial for short-term climate prediction in the Atlantic sector. Two major TAV mechanisms are regional air-sea interaction and remote El Niño/Southern Oscillation (ENSO) influence, both potentially predictable on the seasonal-to-interannual time scales. Mid-latitude seasonal atmospheric anomalies over the North and South Atlantic may also be useful precursors for the tropical anomalies in subsequent seasons. In a dynamical forecast model, these mechanisms and their interactions should be represented realistically and initialized accurately. This study examines the TAV predictability using a coupled ocean-atmosphere general circulation model (CGCM) with realistic ocean/atmosphere initial states. In particular, we would like to understand what kind of initial surface and subsurface anomalies within the Atlantic Ocean can damp or amplify the remote ENSO influences, and vice versa. We will also examine under what conditions the midlatitude anomalies can stimulate major tropical air-sea feedback on seasonal time scales.<br><br>Our previous studies have shown that this CGCM can simulate the major TAV features realistically. For this study, we propose further improvements in its simulation and initialization. We will conduct an empirical CGCM error correction that prescribes observational climatological monthly mean low-cloud amount in the model while allowing the anomalous model sea surface temperature (SST)-low cloud feedback. The mean cloud correction targets specifically the inadequate simulation of low cloud fraction over the southeastern tropical Atlantic, which is a major component of the current CGCM systematic bias and unrealistic annual cycle in this region. The preserved anomalous SST-low cloud feedback is important for the interannual variability. To minimize the CGCM initial shock, a new model initialization technique will be tested. We will conduct a series of coupled "initialization runs", in which the coupled system is nudged continuously toward the observed climate anomalies derived from the ocean-atmosphere analyses. Initial conditions from these runs should be more in balance between the ocean and atmosphere and likely represent the low-frequency signals better than the instantaneous initial ocean-atmosphere states separately generated by uncoupled atmospheric and oceanic data assimilation systems. To take into account the potentially significant uncertainty of current oceanic analysis in the tropical Atlantic Ocean, we will use several different ocean analysis products to generate an ensemble of oceanic states with sufficient spread.<br>Using the improved CGCM, we will conduct a set of hindcast experiments for 1981-2005 to establishing its predictive skill in the tropical Atlantic. Further sensitivity case studies will be conducted using our regional coupling strategy with the observed or climatological SST anomalies prescribed in the tropical Pacific to study the relative roles of the ENSO forcing and regional air-sea interaction. To link this study more directly to operational prediction, we plan to conduct some experiments with the NCEP Climate Forecast System (CFS), which has been successfully installed at COLA. | | |
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| Vallis, Geoffrey K., Princeton University | Mechanisms and Predictability of Interannual to Interdecadal Climate Variability | 2009 |
| **Abstract:** We propose a study of the mechanisms and predictability of interannual to interdecadal climate variability. Our general goals are to to understand the underlying mechanisms for climate variability on these timescales, to identify processes that might lead to predictability, and to understand what the intrinsic limits to climate predictability are. | | |

Our main tool is a novel hierarchy of climate models, developed using the Flexible Modeling System at GFDL. At the top of the hierarchy is the state-of-the-art, IPCC-class model at GFDL. Our models directly connect to that, but are simplified by using simpler and more economical physics packages, and/or by making simplifications in the geometry. Use of such models allows more experiments to be performed, including ensemble experiments, and mechanisms to be identified. We will focus on extra-tropical variability in the Atlantic sector, including the interannual and decadal variability of the NAO, although somes aspects of the proposed work are more general. The specific topics we propose to investigate include the timescales on which the atmosphere ocean system may be regarded as truly coupled, the timescales on which the atmosphere forces the ocean, the generation and persistence of sea-surface temperature anomalies and the effects of such anomalies on the atmosphere. As appropriate, we shall use still simpler theoretical tools and analyses to try to abstract the mechanisms to their esssentials. We shall also compare and validate our models against the full coupled climate model to ensure that we are in a realistic parameter regime that is relevant to reality.

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| Schopf, Paul S. and Barry A. Klinger, George Mason University | Examining Oceanic Tropical Biases in Climate Models | 2009 |

**Abstract:** Coupled climate models used for studying climate variability and change have evolved dramatically over the past years, with increased resolution, improved numerics, and additional complexity. Coupled GCMs such as the GDFL CM2 coupled model and the NCAR CCSM are playing a major role in the IPCC assessment process, seasonal to interannual climate prediction, paleoclimate and many other studies that depend on the models' ability to faithfully reproduce the observed climate as a pre-condition for being able to draw strong conclusions about climate variability and change.

These coupled GCMs seem to have persistent and pervasive biases in their representation of current observed climate states that have proven difficult to resolve. Particularly troubling has been a large bias in the tropics, characterized by a "double ITCZ", cold equatorial Pacific SST, and warm SST along the eastern boundaries of the tropical oceans. This bias has been known since the mid-90s, and has been the subject of studies implicating the low-level stratus clouds in the region (Ma, et al, 1996), the poor resolution of the surface wind fields in AGCMs, the influences of the poorly resolved topography, and ocean resolution. The US CLIVAR program has sponsored workshops (May 2003, September, 2005, and June, 2006 Tropical Biases workshops), and the biases are a prime target of work at NCAR and NOAA GFDL. We have participated actively in all these studies and endorse the premise that a correction of these biases is crucial for the advancement of understanding and prediction of the climate. It is through these community efforts that we seek to contribute to the overall improvement in coupled GCM simulations of climate and its variability. We seek to examine oceanographic aspects of the problem and in particular, we want to examine the processes that set the equilibrium subsurface properties in the tropical ocean upwelling regions and how they might be connected.

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| Delworth, Thomas L. and Anthony J. Rosati, NOAA/ GFDL | Decadal Climate Predictability and Predictions Focus on the Atlantic | 2009 |

**Abstract:** There is currently limited understanding of the mechanisms of decadal climate variability, and of the potential predictability of the climate system on decadal time scales. Models currently used for decadal and longer climate change projections do not start their projections from the observed state of the ocean. Therefore, a potential source of skill for decadal climate change simulations is neglected. On the decadal scale, the relative roles of forced climate change and internal natural variability may be comparable. Thus, an improved understanding of decadal variability and predictability could lead to significant improvements of decadal scale climate projections. One potentially important region is the Atlantic, where multi-decadal scale warming has apparently led to increased hurricane activity. The relative contributions of anthropogenic forcing and internal variability to that increase of hurricanes is unknown, but it is precisely this question that is crucial for future estimates of hurricane activity.

We describe a systematic program of research activities whose aim is to (i) improve our understanding of the mechanisms of Atlantic decadal variability, (ii) evaluate potential predictability of the climate system, (iii) develop the necessary tools to make decadal climate predictions starting from observed ocean states, and (iv) conduct

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| ensembles of decadal climate predictions starting from estimates of the observed state of the ocean. This research will be primarily conducted using GFDL s CM2.1 global climate model, as well as future climate models currently under development at GFDL. A crucial component of the research will be the further development and use of a novel assimilation technique recently developed at GFDL. The outcome of the research should be (i) an improved understanding of the mechanisms of Atlantic decadal variability, (ii) an evaluation of decadal scale predictability, (iii) a prototype system for making decadal climate predictions, including a newly developed assimilation system that will make state of the art estimates of the ocean from modern observational networks, and (iv) several ensembles of experimental decadal scale forecasts. | | |
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| Hurrell, James W. (NCAR), Martin P. Hoerling (NOAA/ESRL) and Jon Eischeid (NOAA/ESRL) | A Multi-model Approach Toward the Attribution of<br>U.S. Climate Variation and Change | 2009 |
| **Abstract:** Key aspects of regional U.S. climate variability and change during the past century lack explanation. What, for example, are the processes and causes responsible for the observed strong seasonality in U.S. surface temperature changes as well as for the spatially inhomogeneous warming? The western U.S. has been the epicenter for warming in recent decades, particularly in spring and summer, and this has led to early snowmelt and premature maximum streamflow. At the same time, there has been a lack of warming in the central U.S., especially during summer, in spite of the warming expected in the interior continent from increasing levels of greenhouse gases in the atmosphere.<br><br>Strong decadal variations of U.S. climate during the last century have confounded both the detection and the attribution of regional climate trends. Prominent among these is the relatively abrupt shift in Pacific-North American climate in the mid-1970s. Other features include the decadal swings between U.S wet regimes (1910s, 1980s-90s) and dry regimes (1930s, 1950s, 2000s). Do these events reflect internal atmospheric variability? Are they the response to decadal variations in the state of the global ocean? What has been the role of anthropogenic forcing? Identifying the factors responsible for the observed low frequency variability is a necessary step toward implementing a credible decadal prediction system and for improving climate information for decision makers.<br><br>Our proposal will increase understanding of observed U.S. climate variability and change through parallel development and analysis of observational and model-generated datasets, and through systematic numerical experimentation to allow attribution of observed variability to processes and causes. In particular, we seek to identify those factors driving fluctuations in U.S. surface temperature and precipitation on the regional scale by employing a hierarchy of existing climate model simulations, as well as new experiments targeted specifically to elucidate the role of oceanic variability. We will employ a multi-model architecture and make resulting data available to the broader research community. | | |
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| Neelin, David and Ben Lintner, University of California – Los Angeles | Diagnosing and improving convective processes in large-scale ocean-atmosphere interaction | 2009 |
| **Abstract:** Despite the key role of precipitation in climate and climate impacts, it remains one of the most poorly modeled climate variables. In addition to well-known biases in the simulated climatology of tropical precipitation, there are also biases in tropical precipitation sensitivity to climate perturbations. For example, even if a model has its convection zone in the proper mean location vis a vis the observations, it does not necessarily follow that the sensitivity of the convection to variations in temperature, wind, or inflow water vapor is correct. Under the previous grant, we have developed a number of tools that we propose can contribute to identifying and addressing the biases in convective processes. In particular, we outline new diagnostic methods to understand the transition to strong convection, presenting preliminary examples using satellite observations of precipitation and column water vapor. We propose to apply these diagnostics to better constrain the temperature and moisture dependences of the onset of precipitation required for climate model convective parameterizations, and to contrast these measures in observations to current model simulations. We propose to complement the satellite observations with in situ sounding data for vertical structure in strongly convecting regions, beginning with the high temporal coverage Atmospheric Radiation Measurement (ARM) Program site at Nauru Island. We will focus first on quantifying the convective threshold and its dependences on thermodynamic variables. The water vapor-temperature dependence of | | |

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<tr><td colspan="3">the onset of convection can be important to mechanisms by which large-scale processes, such as the wave dynamics occurring in teleconnections, or inflow air masses from dry regions into the convective margins, interact with the small-scale convective processes. We propose to examine how variations in inflow from the dry Southeastern Pacific into the South Pacific Convergence Zone (SPCZ) interact with the threshold for the the onset of convection in models compared to observations. This will help quantify the contribution of this interaction to the mean and sensitivity biases of the convectivemargin in this region. We propose to analyze similar impacts of the variations in the moisture relative to the convective threshold in ENSO variations. We will aim to formulate our diagnostics of observed and modeled convective processes in terms that can be directly useful to modeling groups.</td></tr>
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<tr><td>Zhang, Rong-Hua, Antonio Busalacchi (University of Maryland) and William Kessler (NOAA/PMEL)</td><td>Modulation of Tropical Air-Sea Coupling by TIWs: Sources for Tropical Biases in the Pacific Climate System</td><td>2009</td></tr>
<tr><td colspan="3">Abstract: The El Niño-Southern Oscillation (ENSO) is the most important mode of interannual climate variability. At present, global climate models still suffer from substantial biases in ENSO simulation and prediction, including too-regular ENSO cycles. The cause of the irregularity of ENSO evolution is a topic with an extensive literature; the interactions with the seasonal cycle and stochastic forcing (SF) from the atmosphere are some of the proposed contributors that are still under active research. In particular, numerous modeling studies have demonstrated that stochastic forcing in the atmosphere can modulate ENSO, indicating that it is a leading candidate responsible for ENSO irregularity.<br><br>As an oceanic form of SF, tropical instability waves (TIWs) are a meso-scale phenomenon in the eastern tropical Pacific. Recent high-resolution space-based observations reveal significant two-way air-sea interactions associated with TIWs in the region; their roles in budgets of heat, salt, momentum and biogeochemical fields in the ocean have been demonstrated. At present, realistic simulations of these atmospheric response to TIW-induced sea surface temperature (SSTTIW) anomalies are a great challenge since the details of the response mechanisms in the marine boundary layer and their interactions to the overlying free troposphere are not well-known. In particular, most climate models do not realistically take into account TIW-induced meso-scale atmospheric response to SSTTIW anomalies due to a lack of high resolution in the horizontal and vertical. Therefore, the TIW-induced feedbacks from the atmosphere to the ocean and the corresponding meso-scale coupled air-sea interactions are still missing in large-scale climate modeling studies. Due to their large perturbation amplitude, TIWs are expected to have significant impact on ENSO. However, the roles of TIWs in causing ENSO irregularity are not known; their potential roles in causing model biases and improving ENSO simulation and prediction in climate models have not been examined coherently.<br><br>We propose to investigate the role of TIWs in contributing to tropical biases in ENSO simulation and prediction in large-scale climate models. We intend to utilize the feedback signature of TIWs in satellite data to develop an empirical parameterization of their atmospheric response for use in coupled climate models. As such, the effects of TIWs on simulations of mean ocean state, seasonal cycle and interannual variability can be extensively examined using a hybrid coupled model (HCM) which consists of an ocean general circulation model (OGCM) and a statistical atmospheric wind stress anomaly ($\boldsymbol{\tau}$) model over the tropical Pacific domain, a global coupled general circulation model (CGCM), and the NCEP/NOAA CFS, respectively. In support of these studies, an empirical parameterization will be first developed and tested to depict TIW-induced wind stress anomalies ($\tau$TIW) in response to SSTTIW variability in the eastern tropical Pacific Ocean using the unprecedented accuracy of satellite observations for sea surface temperature and winds. Next, the empirical parameterization scheme for $\tau$TIW will be nested into the HCM to explicitly represent TIW related meso-scale air-sea coupling. Preliminary results have demonstrated that the model can simulate both phenomena (TIWs and El Niño) very well using this innovative nesting approach, and that TIWs in the eastern equatorial Pacific can contribute to systematic biases in mean ocean state, seasonal cycle, and interannual variability through their rectified effect on large-scale air-sea coupling. Therefore, realistic representations of meso-scale processes associated with TIWs in large scale climate ocean-atmosphere models will lead to more realistic simulations of the mean state and its interannual variability associated with ENSO. Various experiments will be conducted to quantify the extent to which heat and momentum fluxes related to TIWs can contribute to systematic biases seen in large-scale climate models. The relationship between the</td></tr>
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strength of TIWs and the level of ENSO irregularity will be a focus. Model simulations will be directly compared with observations from satellite and TOGA-TAO moored buoys. Needless to say that the mechanistic understanding and nested parameterization for TIWs developed in these simplified coupled modeling experiments will be studied carefully such that we can transfer the knowledge to more realistic coupled climate models to reduce tropical biases and to enhance our predictive understanding in the IRI CGCM and the NCEP/NOAA CFS, respectively.

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| Xie, Shang-Ping (University of Hawaii) | Toward Reducing Climate Model Biases in the Equatorial Atlantic and Adjacent Continents | 2009 |

**Abstract:** In the latest model intercomparison, most coupled ocean-atmosphere general circulation models (GCMs) continue to suffer serious errors in their simulations of tropical Atlantic climate. Two errors common to all the models are 1) the failure to develop an eastern cold tongue on the equator, associated with a westerly surface wind bias and 2) an erroneous southward shift of the intertropical convergence zone (ITCZ) associated with a warm bias south of the equator. Such errors in the mean state seriously limit the models' skills in seasonal prediction and future climate projection.

Recent analyses of simulations in the IPCC Fourth Assessment Report (AR4) data archive hint that tropical Atlantic biases in coupled models originate from their atmospheric component. Specifically, the westerly wind error on the equator and the double ITCZ bias are already present during boreal spring in atmospheric simulations forced by observed SST. The spring westerly error depresses the thermocline and prevents the cold tongue from developing in the equatorial Atlantic in the subsequent season. Furthermore, studies show that simulated spring rainfall is deficient and excessive over equatorial South America and Africa, respectively, suggesting that continental precipitation biases are key to the westerly wind error over the equatorial Atlantic.

The PIs propose to identify the sources of tropical Atlantic biases and investigate how they develop in coupled GCMs using a suite of diagnostic and modeling studies. First they will develop metrics to evaluate coupled model simulations of tropical Atlantic climate and identify common sources of error. They will apply them to the AR4 output as well as the upcoming AR5 simulations as the latter become available by early 2010. They will use the NOAA/GFDL Climate Model CM 2.1 and its atmospheric component to test the hypothesis that continental rainfall biases cause the models failure to develop the equatorial cold tongue, by perturbing convective heating over tropical South America.

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| Daniel Vimont (University of Wisconsin – Madison) and David Battisti (University of Washington) | Understanding ENSO Biases in GCMs and Their Relation to Mean State Biases | 2009 |

**Abstract:** El Niño / Southern Oscillation (ENSO) variability represents the leading source of interannual variability in the tropical Pacific and globally. Our understanding of ENSO developed rapidly in the 1980's and 1990's with the development of intermediate coupled models in which ENSO variability operates around a prescribed mean state. This was a useful approach, as it has been found that ENSO characteristics are very sensitive to details of the tropical Pacific mean state and seasonal cycle. At the same time, global climate models (GCMs) have improved to the point that ENSO variability exists, in some form, in many of the current generation of GCMs. Unfortunately, large, and even small, biases in GCM simulations of the tropical mean state lead to large biases in simulations of ENSO variability. While attempts have been made to relate biases in ENSO variability to biases in the mean state of the tropical climate, analysis has been limited to analysis of existing GCM output, qualitative comparisons between GCM output and coupled dynamical theory, and analysis of modal characteristics using very simple models.

The present proposal outlines a research plan aimed at quantitatively estimating the influence of mean state biases on ENSO biases in the present generation of GCMs. This will be accomplished by development and application of a linearized version of the intermediate coupled models described above. This linear ocean / atmosphere model (LOAM) can be tuned around observed or modeled mean states, and once having done so, has been shown to reproduce characteristics of the respective observed or modeled ENSO variability (e.g. amplitude, stability, period, seasonal phase-locking, regularity). An advantage to the linear model is that it can be used to investigate the sensitivity of ENSO characteristics to specific features in the mean state by tuning model parameters to, say, observations, and substituting individual parameters derived from a model. A research strategy is described that uses

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| this model to: 1. Characterize (quantitatively) the spatial and temporal structure of modeled ENSO variability, and ENSO characteristics when the LOAM is linearized around each model's mean state. 2. Using the LOAM, conduct sensitivity studies to quantify how mean state biases affect bias in ENSO simulation. 3. Using the LOAM, conduct sensitivity studies to understand changes in ENSO behavior under future climate scenarios.<br><br>This proposal directly addresses CVP's focus area in two ways: (1) it proposes a strategy for understanding the source of bias in simulated interannual ENSO variability, and (2) it identifies specific biases in the mean state that produce those biases. By identifying ENSO sensitivity to specific mean state biases, the work will provide quantitative guidance for modeling groups trying to improve ENSO simulation. | | |
| Soden, Brian (University of Miami – RSMAS) and Gabriel Vecchi (NOAA/GFDL) | Understanding Discrepancies Between Satellite-Observed and GCM-Simulated Precipitation Change in Response to Surface Warming | 2009 |
| **Abstract:** Several recent observational studies suggest that precipitation may be increasing at a much faster rate than currently predicted by GCMs. These discrepancies appear at time-scales ranging from interannual, to decadal, to centennial and have important implications for future projections of climate change, the reliability of the observing system and the monitoring of the global water cycle. If true, such a bias in model projections would have substantial repercussions - not only for the modeling of the atmospheric energy and water budgets, but also for the model projections of the response of the atmospheric and oceanic circulation to increased CO2. However, the veracity of the satellite-observed changes in precipitation remains in question due, in large part, to uncertainties in the retrieval of precipitation from passive microwave sensors.<br><br>The PIs propose to better understand the cause of these discrepancies by performing a detailed comparison of SSMI observations and GFDL GCM simulations using a "model-to-satellite" approach in which model output is used to directly simulate the radiances which would be observed by the satellite under those conditions. The advantages of this strategy are that it avoids many of the assumptions that are required when performing retrievals and it provides a model-simulated quantity that is directly comparable to what is actually observed by the satellite. Any assumptions involved in the performing forward radiance simulation are made explicit and can be varied in a controlled framework to examine their sensitivity.<br><br>They propose to apply this strategy for comparing model-simulated microwave radiances from the GFDL GCM to the satellite-observed radiances from SSMI. From this comparison they hope to better understand the cause of bias between observed and model-simulated precipitation response to a warming climate. | | |
| Carton, James (University of Maryland) | Seasonal Biases in the Tropical Atlantic Sector in Climate Models: Causes and Impact on Interannual Variability | 2009 |
| **Abstract:** The PIs propose to complete a diagnostic examination of the relationship between bias in the representation of the seasonal cycle and CGCM simulation of climate variability, and secondly a climate modeling study using the bias-corrected seasonal cycle. They focus on the Atlantic sector partly because the bias is more severe there than in the Pacific. This proposal will extend their previous study to a multi-model analysis in order to look at the impact of this seasonal bias on errors in representation of climate variability. The PIs will also apply these results to improve representation of climate variability in CGCMs, focusing on the NOAA/GFDL CM2.1 model in cooperation with members of the GFDL climate group.<br><br>The current plan is to continue a diagnostic examination of bias in climate variability in the tropical Atlantic sector of NCEP, NCAR, and GFDL CGCMs. The analysis includes the relative roles of local dynamic and thermodynamic air-sea interactions and the remote influences of ENSO and extratropics on the tropical Atlantic sector. For CM2.1, they already have access to an interesting suite of experiments including experiments in which SST in the tropical Pacific and Indian sectors are replaced with climatological monthly SST and a flux-corrected experiment with an | | |

“improved” climatological seasonal cycle. They will design sensitivity experiments to examine the response of simplified and full atmospheric models to a bias correcting forcing. The ultimate goal of these sensitivity studies is to formulate suggestions for the improvement of coupled models.

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| Kirtman, Benjamin (Center for Ocean-Land-Atmosphere) | Seasonal Biases in the Tropical Atlantic Sector in Climate Models: Causes and Impact on Interannual Variability | 2009 |

**Abstract:** The PIs propose to examine tropical Pacific biases. They propose a different approach for understanding the systematic errors and why promising sensitivities fail to translate from one model to the next. They suggest that the errors in the mean state are, at least in part, due to errors in the simulated ENSO; and that the errors in the simulated ENSO are due to errors in the statistics of the tropical atmospheric weather. That is, if there are large errrors in the simulation of weather statistics, then the climatic simulation is seriously degraded. The PIs hypothesize that the changes - or lack thereof - in the weather statistics can explain the large differences in model sensitivity. They propose a series of novel weather noise forced CGCM simulations designed to understand the differences in coupled model biases and sensitivities. These experiments leverage their experitise with the NOAA Climate Forecast System, the NCAR Community Climate System Model and the interactive ensemble coupling strategy that has been developed by the PI.

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| Sardeshmukh, Prashant (NOAA/ESRL) | Diagnosing Local and Remote Coupling Errors in the Tropics | 2009 |

**Abstract:** The primary goal of this project is to gain a better understanding of the local and remote sources of tropical biases in climate models through an analysis of local and remote dynamical interactions. The PIs will attempt this by diagnosing both local coupled interactions and remote interactions among 8 geographically localized tropical areas (four in the tropical Pacific, two each in the Indian and Atlantic basins) in observational datasets, in the NCEP/CFS, NCAR/CCSM3, and all available IPCC model simulations, and through additional model integrations of the PIs.

The project will have substantial diagnostic and modeling phases. The plan is to estimate local and remote coupling matrices from observational data and all available climate model simulations, and to perform extensive intercomparisons among them. In the modeling phase of the project, they will attempt to reproduce the results obtained in the diagnostic phase with additional integrations of the atmospheric components of the NCAR (CAM3) and NCEP (GFS) models, but now coupled to a mixed layer ocean with simple parameterized Ekman dynamics.

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| Halliwell, George (University of Miami – RSMAS) and Carlisle Thacker (NOAA/AOML) | Observing System Simulation Experiments for the Atlantic Meridional Overturning Circulation | 2009 |

**Abstract:** This proposed National Oceanographic Partnership Program project is a collaborative effort between RSMAS and NOAA/AOML to perform Observing System Simulation Experiments (OSSEs) to determine optimum observing strategies for monitoring the Atlantic Meridional Overturning Circulation (AMOC). The most accurate possible three-dimensional estimates of the ocean state are realized by optimally combining observations with ocean model dynamics. Optimal estimates of the state of the AMOC and early detection of significant changes should therefore be obtained by constraining a data-assimilative ocean general circulation model with measurements from a cost-effective observing system. To design an efficient system, it is necessary to first identify the critical variables to be measured, the spatial configuration of sensors, and the frequency of measurements necessary to identify and to characterize temporal and spatial fluctuations. OSSE's provide an objective means to quantitatively evaluate

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| different observing system strategies. The PIs therefore propose to use the U. S. Navy ocean nowcast-forecast system based on the Hybrid-Coordinate Ocean Model (HYCOM) to perform OSSEs to evaluate potential AMOC observing systems. |

| Seager, Richard, Yochanan Kushnir, Mark Cane and Naomi Naik (LDEO/Columbia University) | Predicting North American Hydroclimate Change and Variability on Interannual to Multidecadal Time Scales | 2009 |
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| **Abstract:** Modeling work has shown that persistent droughts in Southwestern North America are forced by multiyear La Niñas in the tropical Pacific Ocean with a warm subtropical North Atlantic also playing a role in some cases. These persistent droughts, including the severe one that began after the 1997/98 El Niño, place colossal strain on regional water resources, impact agriculture, fires, ecosystems and the regional economy leading to billions of dollars in expenses in disaster relief. In addition the most recent generation of Intergovernmental Panel on Climate Change (IPCC) model climate projections (the Assessment Report 4, AR4) robustly predicts that Southwestern North America will become more arid as part of a general subtropical drying caused by an intensifying hydrological cycle and a poleward shift of the Hadley Cell border and mid-latitude storm tracks. This drying is projected to become comparable in amplitude to naturally occurring drought by mid-century. Prediction of hydroclimate variability and change on the interannual to decadal timescale, if skillful, would allow advance planning across water-sensitive parts of the region's economic and social systems.<br><br>In a collaborative effort with the NOAA's Geophysical Fluid Dynamics Laboratory (GFDL) we propose to 1) examine the mechanisms and predictability of tropical SST-forced drought on interannual to decadal timescales and 2) examine anthropogenic-induced regional drying in models and observations to determine its mechanisms, if this is occurring and when it provides a useful predictable signal that needs to be adapted to. This work will rely on the GFDL Climate Model 2.1 (CM2.1) which realistically produces multiyear La Niñas that force drought in Southwestern North America. The predictability of these will be examined in a perfect model environment allowing assessment of potential predictability with uncertainty estimates. Similar predictability experiments will be performed for multidecadal changes in tropical Pacific climate within CM2.1 that appear analogous to the 1976/77 climate shift. To determine actual predictability we will examine initialized (from the observed atmosphere-ocean state) climate change projections that will be performed as part of IPCC AR5. These experiments will include changes in radiative forcing and include hindcasts and predictions of the next years to decades. They will be examined for actual predictive skill that comes from the initial conditions as well as the relative amplitudes and character of natural variability and forced climate change. | | |
| Chang, Ping and R. Saravanan (Texas A&M University) | Investigating the Role of Noise in Decadal Climate Predictability Using a Hierarchy of Coupled Ocean-Atmosphere Models | 2009 |
| **Abstract:** This is a proposal focusing on exploring climate predictability on decadal or longer timescales. The proposed research builds upon our currently NOAA-sponsored projects in the tropical Atlantic and Pacific Oceans. These research projects have produced a set of coupled ocean-atmosphere models with novel features that we believe are well suited for understanding predictable dynamics at decadal or longer time scales. We propose to use this hierarchy of the coupled climate models to shed light on the intricate interplay among natural modes of climate variability, anthropogenic forcing and weather noise in decadal climate predictability. Our model hierarchy includes 1) an atmospheric general circulation model (CAM3) coupled to a slab ocean (CAM3-ML), 2) an atmospheric general circulation model coupled to a reduced gravity ocean (CAM3-RGO), and 3) an atmospheric general circulation model coupled to a general circulation ocean (CAM3-MOM3). These are equipped with noise filtering algorithms capable of suppressing weather noise, including the signal-noise optimization noise filter developed by | | |

Chang et al. (2007) and the interactive coupled ensemble developed by Kirtman and Shukla (2002). These noise-filtering methodologies have proven to be extremely valuable in the understanding of the role of weather noise in ENSO dynamics and its predictability. We anticipate that the same will be true in the understanding of decadal climate predictability. Large ensembles of prediction experiments will be conducted using each of these models. The experiments will be analyzed systematically to test a set of scientific hypotheses aiming at providing insight into physical mechanisms that give rise to any decadal scale predictability – one of the major objectives of this year's NOAA CVP program. An important concern in the design of decadal prediction experiments is the prohibitive computational cost of ensemble forecasts using a high-resolution, global coupled climate model for lead times of a decade or longer. Understanding the role of weather noise, and developing techniques to mitigate its effects, can help minimize the size of the ensembles needed for operational decadal prediction and substantially reduce the computational costs.

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| Newman, Matthew and Michael Alexander (NOAA/ESRL) | Assessment of Decadal Prediction and Predictability Using Empirical Models | 2009 |

**Abstract:** Given the relatively slow evolution of the ocean, it likely holds the key to North American climate predictions on sub-decadal and longer time scales. We plan to use empirical models trained on multiple variables (SST, thermocline depth, MOC strength, etc.) from ocean assimilation products to forecast the global ocean and its impact on North America. The forecast system will also include surface air temperature and winds, both to improve ocean forecasts and to predict societally relevant quantities. The same approach will also be applied to coupled climate model simulations to identify model errors, determine the processes responsible for predictability, and investigate the extent to which global climate change influences the predictability of the oceans.

Our primary forecast method will be linear inverse models (LIMs), which are currently used operationally to predict SSTs in the tropical oceans. We have recently extended the LIM prediction system to include thermocline depth and surface winds, which has improved ENSO predictions at longer leads and encouraged us to explore predictions at decadal time scales. Forecasts will be made on a seasonal basis for at least two years ahead, and on an annual basis for at least five years ahead. In addition to providing skillful forecasts, LIM also allows exploration of important aspects of the dynamical system, including processes that give rise to rapidly growing and/or persistent anomalies and limits to predictability. This information is particularly useful for decadal prediction, since not only does it help determine the construction of an initial ensemble for climate model runs, but it also helps show where observations are most needed to reduce forecast error growth. We will also evaluate the dependence of North American forecasts on information from different regions, investigating linkages between the Atlantic and the Pacific, and tropics and the extratropics.

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| Goddard, Lisa, Arthur Greene (International Research Institute for Climate and Society (IRI), Gokhan Danabasoglu (NCAR), Keith Dixon (NOAA/GFDL), Doug Smith (UK Met Office, Hadley Centre) | Diagnosing Decadal-Scale Climate Variability in Current Generation Coupled Models for Informing Near-term Climate Change Impacts | 2009 |

Abstract: As the relevance of climate change information grows, demand for that information, in particular covering the next 1-2 decades increases. On the decadal timescale, both natural and anthropogenic factors will influence the evolution of the climate. The scientific community, particularly the international modeling community, has been working towards predictions/projections that consider both the changes in atmospheric composition, relevant to climate change projections, and initial oceanic conditions, relevant to decadal-scale climate variability predictions. Initialization of dynamical models, while a very new effort, is

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| considered crucial to reducing uncertainty in the near-term climate projections. Even with initialized models, questions still exist on the degree to which they exhibit realistic variability on decadal time scales. It is imperative that we examine and document the characteristics of decadal-scale variability in CGCMs, particularly in the context of initialized predictions, in order to prepare for the experimental decadal predictions that are starting to emerge from modeling centers. The three objectives that this proposal will address are:<br><br>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.<br>2) Develop metrics and baselines for estimating the quality of decadal predictions<br>3) Design climate information products for climate risk management and planning.<br><br>We have configured a team of researchers containing scientists from the top international modeling centers involved in the generation of climate projections and experimental decadal predictions, and scientists who focus on assessing and designing information that can benefit regional climate risk management. We will assess decadal predictability through the use of baselines, and by examining the impact of initialization. In any prediction system, one must know the quality of the models, particularly in a prediction context. One must also know how to handle biases that may be masking predictability, how to appropriately quantify uncertainty, and ultimately how to communicate that information in a meaningful, yet compact and flexible manner. The results of our project will contribute to progress in all these areas through work with existing and anticipated model simulations and hindcasts from state-of-the-art CGCMs. | | |
| Emanuel, Kerry (MIT) and Gabriel Vecchi (NOAA/GFDL) | Understanding and Predicting Interannual to Multi-Decadal Variability of Atlantic Hurricane Activity | 2009 |
| Abstract: The applications of two very different methods for deducing (downscaling) tropical cyclone activity from NCAR/NCEP reanalysis data explain, respectively, 60% and 65% of interannual variations in Atlantic tropical cyclone frequency during the period 1980-2006. Yet, when one of these methods is applied to the output of simulations using a global climate model forced by observed sea surface temperature over the same period, far less variance is accounted for, and the upward trend seen in both the observations and the downscaled NCAR/NCEP re-analysis is largely absent. Moreover, when this downscaling technique is applied to ERA40 re-analysis data, the amount of variance explained is comparable to that of the global climate model, and again the upward trend is largely absent.<br><br>This proposal seeks support for an effort to understand the physical reasons for these discrepancies, and by so doing to advance our understanding of environmental control of tropical cyclone activity and its relationship with climate change. We propose to undertake a comprehensive analysis of the physical causes of the variability and trends seen in various downscaled tropical cyclone metrics, focusing on the disparity among the reanalysis-driven and global climate model-driven results. We here present a few hypotheses for the discrepancies and a plan to test these, with the goal of identifying model and/or reanalysis biases that may be affecting the results. To the extent we are successful, we can begin to assess the ability of climate models to predict future variations in tropical cyclone activity resulting from natural and anthropogenic climate variability, while at the same time increasing our understanding of the fundamental environmental controls on tropical cyclone activity. | | |
| Hurrell, James W. (NCAR), Martin P. Hoerling (NOAA/ESRL), Arun Kumar (NOAA/CPC) and Xiaowei Quan (University of Colorado) | Toward a North American Decadal Climate Prediction for the 2011-2020 | 2009 |
| Abstract: We propose to generate a probabilistic decadal prediction of North American climate for the period 2011-2020. The methodology will involve large ensemble integrations from multiple atmospheric general circulation models (AGCMs) driven by various, plausible trajectories of global sea surface temperature (SST) over the next | | |

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| decade. The latter will be derived from both uninitialized and initialized coupled climate model experiments. We are motivated by evidence that initial state information from the oceans is a key skill source in nascent attempts at decadal prediction. Furthermore, attribution studies have established that key features of observed regional decadal climate variability have been largely driven by variations in global SST. Multimodel large ensemble methods are proposed in order to generate meaningful statistics of regional climate change on decadal timescales, thereby overcoming current limitations of coupled model prediction efforts resulting from small ensemble size.<br><br>A focus of the project will be to derive an estimate of the potential skill for predicting the evolution of North American decadal climate. We will perform a comprehensive analysis of North American decadal variability from 1900 to present using existing large ensembles of AGCMs driven by observed SST variability and coupled models driven by estimates of observed changes in greenhouse gas, aerosol, solar and volcanic forcing. These will be diagnosed to quantify the variances of North American climate driven by external forcing, internal coupled ocean-atmosphere variations, and internal atmospheric variations alone. As a prelude to our proposed 2011-2020 predictions, we will analyze "decadal hindcasts" over the past twenty years using initialized coupled models and AGCMs to assess perfect-model skill and sources of uncertainty in decadal predictions and predictability. | | |
| Solomon, Amy (NOAA/ESRL) | The impact of systematic biases in Pacific and Indian Ocean SSTs on predictability of the hydrological cycle over North America in decadal climate prediction studies | 2009 |
| Abstract: The World Climate Research Program's Working Group on Coupled Modeling will be carrying out a coordinated set of model experiments that includes, for the first time, simulations of decadal climate prediction. The ultimate goal of these simulations will be to provide policymakers with information on decadal timescales to assess possible consequences of climate change. To what extent these experiments will be useful to stakeholders and policymakers will depend upon whether there is a predictable signal of climate change and to what extent this signal varies on regional scales. In this proposed research we will focus on systematic errors in the predictable signal forced by sea surface temperature (SST) biases in the coupled model's response to external forcing. In addition, we will investigate how these model biases limit predictability by impacting the spatial and temporal structure of natural variability. An active hypothesis is that the predictable signal of climate change comes from low-frequency ocean variability and it's forcing of the atmosphere. We will explore this hypothesis by studying how systematic biases in Pacific Ocean SSTs impact the decadal predictability of the hydrological cycle over North America, focused primarily on the following two questions:<br><br>1. To what extent is the predictable decadal signal over North America related to the spatial pattern of SST anomalies in the Indian and Pacific Ocean basins?<br>2. Do systematic biases in Indian and Pacific Ocean SSTs impact potential predictability over North America by forcing regional variations in the climate signal, as well as, biases in the spatial and temporal structure of natural variability?<br><br>Based on the results of previous studies, we will use model output from coupled climate model simulations of the 20th Century as unassimilated decadal climate predictions. We will then use AGCM model studies forced by SSTs output from these simulations to determine how biases in the models' response to radiative forcing (through low-frequency ocean variability) impact the decadal predictability of the hydrological cycle over North America. We will focus on identifying physical mechanisms that cause biases in predictability over North America, such as biases in the structure of the PDO. We will study the decadal predictability of the hydrological cycle by focusing our analysis on the variability of rainfall, surface temperature, and circulation patterns over North America. We will investigate strategies to correct for model biases in SSTs thereby improving probabilistic projections of decadal climate forecasts. | | |
| Stan, Cristiana (Center for Ocean-Land-Atmosphere Studies) | The Influence of Atmospheric Stochastic Noise on the Decadal Predictability of Tropical and North Pacific SST | 2009 |
| Abstract: We propose to investigate the role of atmospheric noise (due to internal dynamics) at the air-sea interface | | |

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| on the limit of decadal predictability of tropical and North Pacific regions using the NOAA-NCEP Climate Forecast System (CFS).<br><br>There is increasing evidence from observations and modeling studies that the Earth's climate system possesses natural variability on decadal timescales. Numerous physical mechanisms have been proposed for decadal variability in the tropical and North Pacific areas. However, it is not well understood which of these mechanisms underpins the decadal predictability and if the state-of-the-art climate models show any decadal forecast skill. One of the ingredients of the physical mechanisms is the stochastic weather noise (due to internal atmospheric dynamics) randomly forcing the ocean through the surface turbulent fluxes. From a climate modeling perspective, the problem is further complicated because it has to be understood as a problem of separating the predictable signal from the unpredictable background noise. We propose to use the interactive ensemble coupling strategy, which is designed to filter out the noise, to investigate the role of noise on the limit of decadal predictability.<br><br>The CFS has been exploited mostly as a monthly and seasonal forecast tool. It has also great potential for forecasts of the longer timescales, which recommends it as a suitable candidate of a multi-model ensemble forecast system. This proposed project has the following main objectives:<br><br>1. investigate the role of weather noise on the internal decadal predictability of tropical<br>and North Pacific SST;<br>2. produce a set of ensemble decadal hindcasts with CFS between 1981 and 2001;<br>3. evaluate the effects of systematic errors on the decadal forecast skill.<br><br>We expect that the results of this study will unify the three elements currently competing to explain factors which limit the decadal predictability of the SST variations. Initial conditions, boundary conditions and weather noise might all be required to explain the reality. The proposed directly contributes to the Climate Variability and Predictability (CVP) in the main priority areas of (i) understanding the limits of decadal predictability, and (ii) developing a decadal climate prediction system. | | |
| Ting, Mingfang, Yochanan Kushnir, Richard Seager and Suzana Camargo | Mechanisms and Predictability of the Global Climate Impacts of Atlantic Multidecadal Variability | 2009 |
| Abstract: Atlantic Multi-decadal Variability (AMV), also known as the Atlantic Multi-decadal Oscillation (AMO), is characterized by a sharp rise and fall of the North Atlantic basin-wide sea surface temperatures (SST) on multi-decadal time scales. During the instrumental record, AMV is characterized by a warming in the 1920-30s, a cooling in the 1960-70s and a return of the warming in the mid-1990s. Widespread consequences of these rapid temperature swings are noted by many previous studies, such as the record warming of Greenland in the 1920-30s, the drying of Sahel in the 1960-70s, the increase in drought frequency or decrease in precipitation over North America during warm phase of AMV, and change in the frequency and intensity of Atlantic hurricanes on multi-decadal time scales. Predictability studies suggest that as an oceanic phenomenon (i.e., changes in circulation and ocean thermal structure) the AMV has some potential predictability. Given that, it is important to understand the mechanisms that link AMV worldwide climate impacts, by season and location, and to quantify the influence of this phenomenon relative to that of other mechanisms such as anthropogenic influences, ENSO, and the underlying background of chaotic, and presumably unpredictable, climate variability. The proposed study will determine the worldwide climate impacts of AMV, with a particular focus on North American impacts, and the possible prediction of these based on the premise that AMV is predictable at least for a time interval of several years. To achieve this goal, we will build on analyzing instrumental and high-resolution proxy data such as available tree ring reconstruction of temperature and precipitation to build a data based statistical background. We will also use outputs from the IPCC AR4 coupled ocean-atmosphere model simulations to evaluate coupled model's AMV-climate connections. Given the short records available from observations and many of the IPCC AR4 integrations, one cannot robustly separate signal (*i.e.*, AMV impact) from noise or other influences. Therefore, the observed and modeled estimate of AMV impact will be compared with outputs from multiple member ensembles of model integrations forced with the AMV SST and analyzed with various statistical methods designed to detect signal from noise. We will focus on North American impacts of the AMV in variables such as surface air temperature, precipitation, and evaporation. Specific attention will also be given to the impact of AMV on extreme events such as tropical cyclones and extratropical storms, as well as droughts and heat waves. The underlying idea is to map out the regional and seasonal impacts of AMV relative to other climate variations on seasonal-to-interannual-todecadal time scales in a way that provides | | |

climate forecasters and decision makers with useful information on the impact of this phenomenon.

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| Magnusdottir, Gudrun | Sea-Ice Variability and the North Atlantic Oscillation on Interannual to Decadal Timescales | 2009 |

Abstract: The North Atlantic Oscillation/Northern Annular Mode (NAO/NAM, hereafter NAO) is the most important global mode of atmospheric variability in the northern extratropics especially in winter. It is expressed as a seesaw in mass between high- and mid to subtropical latitudes. This relation is especially dominant in the North Atlantic basin. Sea-ice concentration is to first order forced by the atmosphere and observations show that sea-ice variability in the North Atlantic sector of the Arctic is closely tied to the NAO. The primary mode of variability in sea ice is a dipole with nodes in the Labrador and Barents Seas, respectively. A positive NAO is associated with increased sea-ice concentration in the Labrador Sea from NAO induced wind forcing and decreased sea-ice concentration in the Barents Sea from NAO-induced, positive, oceanic heat-flux anomalies.

The NAO was in its strong positive polarity from the 1960s to the mid 1990s and during this time sea-ice concentrations decreased in the Barents Sea and increased in the Labrador Sea. When we asked the question in Atmosperic Global Climate Model (AGCM) simulations, is there a feedback from this spatial pattern of change in sea ice back onto the NAO (or atmospheric circulation), we found a clear negative feedback in the equilibrium winter response. We have recently examined the transient response to this sea-ice forcing to determine what processes control the evolution to a negative NAO. We found that the initial modest circulation response from the change in surface fluxes allows a changed configuration of Rossby wave breaking and it is the latter effect that leads to the more prominent and larger scale (equilibrium) response of a negative NAO. Thus internal (or natural) variability indirectly sets the stage for the prominent response to a changed sea ice distribution. It is the interaction of the short time-scale internal variability with the forced initial response that sets the stage for the evolution of the amplified large-scale change.

We are now entering an unchartered era in sea-ice variability. In addition to the NAO related mode of sea-ice variability (the Labrador-Barents Sea dipole), rapid anthropogenic sea-ice loss, even in winter, is an even more prominent mode of variability. Sea-ice observations are beginning to show this effect, but the clearest signature may be seen in climate model projections. Interestingly, the climate model projection show the NAO related dipole of variability as the second leading mode, the overall sea-ice decline is the first leading mode.

In this research we seek to identify, understand and quantify the dynamical feedback processes between 1)the atmospheric circulation, 2)sea-ice concentrations and 3)the oceanic heat flux, from observations and a hierarchy of numerical models with the ultimate goal of facilitating prediction of North Atlantic climate on interannual to decadal timescales. The models range from linear stochastic equations linking the NAO index and sea-ice concentration, to AGCMs, to coupled (atmosphere, sea ice, ocean) climate models with a simplified ocean that allow for easier identification of processes, to output from fully coupled state of the art climate models. With coupled reanalysis products on the horizon, the research is timely and holds great potential in the quest for decadal prediction of climate.

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| Kushnir, Yochanan, Richard Seager and Mingfang Ting (LDEO, Columbia University) | Atlantic Multidecadal Variability: Mechanisms, Impact, and Predictability: A Study Using Observations and IPCC AR4 Model Simulations | 2009 |

Abstract: Atlantic multidecadal sea surface temperature variability (AMV) is a prominent phenomenon that is thought to arise from the natural or internal interaction of the atmosphere and ocean (in contrast with the response to anthropogenic forcing). It is also associated with a wide array of significant global impacts. Models of different complexity strongly support the assertion that AMV is related to the variability of the Atlantic Meridional Overturning Circulation (AMOC) and can be thought of as the surface expression of the latter and the communicator of deep ocean variability to the atmosphere. There is also indication that the related AMV/AMOC variability is potentially predictable. Prediction of AMV should be a crucial element of any attempt to predict the evolution of climate in the coming decades even as the major element of change in this period is the effect of anthropogenic greenhouse gas (GHG) emissions. Several modeling centers have already begun to take such action with models of

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| the class used in the IPCC Fourth Assessment. In preparation for a broad community attempt at addressing near-term climate change prediction we propose a diagnostic analysis of output from a set of IPCC coupled models to systematically catalog the AMV exhibited in these models, its climatic impacts over land, its link to AMOC and atmospheric variability, and its predictability. Within each representative model we will also use three classes of model output: pre-industrial control runs, ensemble integrations with known 20th century external forcing (GHG, aerosols, solar, and volcanoes), and ensemble integration with projected 21st century GHG forcing. The analysis will deploy an array of diagnostic tools, such as optimal methods for detecting and separating between the externally forced signal and internal variability, multivariate techniques to study the spatial and temporal properties of AMV and its instantaneous and time-lagged associations to subsurface and atmospheric variability. To study modeled AMV predictability and to provide alternative insight to its dynamics we propose to use linear inverse modeling (LIM) methodology that fits model output in multivariate fields to explore modes that display non-normal growth. Identifying such modes allows for efficient assessments of error growth and predictability. Application of the analysis on a range of fully coupled modes will directly contribute to the NOAA goal to "understand and describe climate variability and change to enhance society's ability to plan and respond." | | |
| Danabasoglu, Gokhan, Joseph J. Tribbia (NCAR), Thomas L. Delworth, Anthony J. Rosati (NOAA/GFDL) and John Marshall (MIT) | Atlantic Multidecadal Variability: Mechanisms, Impact, and Predictability: A Study Using Observations and IPCC AR4 Model Simulations | 2009 |
| Abstract: The Atlantic Meridional Overturning Circulation (AMOC) of the ocean is a singular feature of the general circulation thought to play a major role in maintaining the climate of the planet. There is an intense interest in developing nowcasting and projection systems for the AMOC because of i) its association with variations in meridional ocean heat transport, North Atlantic sea surface temperatures and climatic variables such as air temperature, precipitation, drought and severe weather events such as hurricanes, (ii) its potential predictability, iii) its possible role in abrupt climate change particularly in response to anthropogenic forcing. Motivated by this background, here we propose a collaborative study between NCAR, GFDL, and MIT to:<br>1. Characterize modeled AMOC variability and its climate impacts: past, present, and future,<br>2. Identify the mechanism(s) of AMOC variability in the GFDL, MIT, and NCAR coupled models,<br>3. Explore the extent to which the AMOC is predictable by experimenting with prototype predictability systems initialized by ocean state estimates.<br><br>Our study is of particular importance because, as the community embarks on an ambitious program of study of Atlantic climate variability, a theoretical underpinning analogous to that which motivated modeling and observations of ENSO, is still lacking. It is hoped that by capitalizing on the very significant efforts in coupled global climate modeling and state estimation methodologies at NCAR, GFDL, and MIT and drawing together their complementary strengths, we will make significant progress in each of the above foci areas. | | |
| Garzoli, Sylvia, Molly Baringer and Chris Meinen (NOAA/AOML) | Evaluating Coherence and Connectivity of the AMOC and Interocean Exchanges in the South Atlantic Using Observations and Models | 2009 |
| Abstract: This research effort will start to characterize the mean and time varying pathways of the AMOC in the South Atlantic, and to evaluate the correlation between the AMOC strength and the meridional heat transport. To achieve this objective a combination of *in situ* and satellite data and model simulations will be analyzed. The motivation for focusing on the South Atlantic is threefold. First, the South Atlantic is unique as a region where oceanic properties are exchanged, mixed, and redistributed between oceans. Second, the South Atlantic is the only major ocean basin that transports heat from the poles towards the equator, strongly influenced by and influencing the surface limb of the AMOC. Third, past efforts to understand the role of the South Atlantic in the AMOC have been hampered by the limited number of observations available. | | |

## II. Carbon Cycle

| Primary Investigators (last names and affiliations) | Project Title | Year Funded |
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| Alin, SimoneNOAA/PMEL; Hales, Oregon State University | Factors Controlling the Formation of Hypoxic and Corrosive Conditions Along the Cascadia Margin | 2010 |
| **Abstract:** The goal of the project is to examine the natural and anthropogenic factors that contribute to the formation of the hypoxic and corrosive conditions that have been observed along the Cascadia Margin and provide practical algorithms to estimate aragonite saturation from routine hydrographic data sets. The proposed work consists of field observational and algorithm-development components. The core field observations consist of detailed hydrographic and biogeochemical measurements along the Cascadia Margin using a combination of existing and new resources. Observations include detailed survey cruises to collect water column data throughout the study region, high-resolution sampling with a towed undulating instrument package in select locations during the upwelling season, and moored and underway surface $CO_2$, $O_2$, and *p*H time-series measurements. All field data collected from these sampling efforts will be used in the development of algorithms that allow prediction of the onset and evolution of corrosive conditions along the coastline. These algorithms will be tuned to the physical, chemical, and biological factors specific to each sub-region. This project strongly draws from and leverages collaborations that the PIs have with a wide network of researchers working along the west coast of North America. | | |
| Andersson, Andreas, Bermuda Institute of Ocean Sciences | Mg-Calcite Mineral Dynamics in Natural Seawater System: Relevance to Oceanic Uptake of Anthropogenic $CO_2$ and Ocean Acidification | 2010 |
| Abstract: The goal of the project is to improve the current understanding of the behavior and dynamics of biogenic Mg-calcite minerals in the natural environment. This knowledge is critical to better understand the impacts of ocean acidification on marine Mg-calcite calcifiers and carbonate mineral dissolution, and how these key parameters are represented in models in order to predict the impacts of ocean acidification on marine ecosystems, biogeochemical cycles, oceanic carbon uptake, and ultimately the global carbon cycle. The research is specifically conducted in order to resolve the limitations and discrepancies currently observed in model calculations based on the different Mg-calcite solubility curves. Hypotheses to be tested in this project include:<br><br>**H1:** The average Mg-calcite mineral composition in surface sediments and Mg-calcite calcifiers is in metastable equilibrium with surface seawater based on the biogenic "minimally prepared" solubility curve<br><br>**H2:** The average Mg-calcite composition in calcareous hard-parts of a particular calcifying species decrease as a function of $CO_3^{2-}$ along a natural gradient in $CO_2$ chemistry across the Bermuda platform<br><br>**H3:** The average Mg-calcite composition in surface sediments decrease as a function of: a) decreasing surface seawater [$CO_3^{2-}$ ] across the Bermuda platform; b) decreasing pore water [$CO_3^{2-}$ ] with increasing sediment depth; and c) decreasing mineral grain size as a result of | | |

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<tr><td colspan="3">selective mineral dissolution based on mineral stability<br><br>To address these hypotheses a careful characterization of the marine $CO_2$ system in both surface seawater and pore water will be conducted concurrent with detailed characterization of carbonate mineral properties including grain size, grain constituents, and composition along a natural gradient in $CO_2$ chemistry across the Bermuda coral reef platform. The mineralogy of major marine Mg calcite calcifiers will also be analyzed in order to characterize the mineral composition of the sediment source material. It is believed that a careful characterization of Mg-calcite composition in surface sediments as well as in the source material (i.e., living organisms) together with seawater $CO_2$ parameters will provide important information in terms of the reactivity and dynamics of these minerals in the natural environment and in relation to the existing experimental solubility curves.</td></tr>
<tr><td>Keeling, Ralph, Scripps Institution of Oceanography</td><td>Measurements of Atmospheric $0_2/N_2$ $Ar/N_2$ and $CO_2$ Abundances in Relation to Carbon Cycling, Ocean Biogeochemistry and Global Change</td><td>2010</td></tr>
<tr><td colspan="3">Abstract: The goal of the project is to continue and expand time series measurements of $O_2/N_2$ and $Ar/N_2$ ratios and $CO_2$ concentration at stations maintained by the Scripps $O_2$ project. These measurements will enable refined estimates to be made of land and ocean carbon sinks and provide benchmark tests for models depicting the response of ocean biogeochemistry to changing climate on a range of time scales, extending from seasonal, El Nino, to multi-decadal. The measurements are also relevant for quantifying the global loss of $O_2$ from the oceans, or “deoxyenation” and for detecting changes in ocean ventilation and production associated with warming-induced stratification that may influence future deoxygenation. The measurement may enable improved atmospheric inversions that take account of processes internal to the ocean influencing carbon dioxide. The measurements have strong synergistic relationship to measurements by the carbon cycle group of the NOAA Global Monitoring Division, the Argo float program, to measurements made as part of the HIAPERS Pole-to-Pole (HIPPO) mission to survey the distribution of long-lived atmospheric tracers related to carbon dioxide, and to the Scripps $CO_2$ program.<br><br>The primary proposed activity involves sustaining ongoing time series at a global array of nine stations extending from the Arctic to the Antarctic along a (mostly) Pacific transect. It is proposed that three new sites be added to the flask network. Two of these new sites (Barrow and Macquarie Island) will sustain time series initiated by the Princeton atmospheric $O_2$ program that would otherwise end in January, 2010 because of the planned termination of the Princeton $O_2$ program. A third new site (Greenland Summit) is proposed based on its strategic location and the ease at which logistical support is provided from within the U.S.<br><br>An integrally related activity involves the assessment and reduction of systematic errors which may impact the ongoing measurements or the merging with these measurements with measurements of other programs. The propject supports interpretive activities related to detecting and reporting such errors. Specifically, the project supports activities to reduce errors, and enables the Scripps $O_2$ program to continue its central role in an international intercalibration effort for $O_2$ measurements, as endorsed by the World Meteorological Organization.</td></tr>
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<tr><td colspan="3">Finally, the project supports collaborative interpretive activities with investigators at other institutions to develop methods for incorporating $O_2/N_2$ measurements into atmosphere/ocean inversions for detecting trends in land and ocean sinks on decadal time scales.</td></tr>
<tr><td>Quay, Paul, University of Washington</td><td>The Impact of Biological Productivity and Phytoplankton Community Structure on $CO_2$ Uptake in the North Pacific</td><td>2010</td></tr>
<tr><td colspan="3">Abstract: The goal of the project is to understand the control that biological productivity exerts on the rate of atmospheric $CO_2$ uptake and how this productivity is related to the phytoplankton abundance and community structure of the ecosystem. This is to be be accomplished by quantifying the rates of air-sea $CO_2$ flux, biological productivity rates and phytoplankton composition across the subarctic and subtropical N. Pacific ocean. It is anticipated that the results will provide a much-needed data set to validate ocean carbon cycle model simulations of $CO_2$ uptake and improve predictions of the response of ocean's $CO_2$ uptake to global warming.<br><br>The approach utilizes ship-board analytical techniques (continuous flow mass spectrometry, flow cytometry and sensors) to obtain underway measurements of temperature, salinity, dissolved gases ($CO_2$, $O_2$ and Ar), phytoplankton composition, chlorophyll *a* and nitrate concentrations. A container ship that crosses the subtropical and subarctic gyres and intervening biologically productive frontal region that experiences very high oceanic $CO_2$ uptake rates will be used as the underway sampling platform to obtain repeated measurements along a cruise track between Hong Kong and Long Beach, CA . The seasonal and spatial (at ~ 1km resolution) variability of the air-sea $CO_2$ flux, net community production rate and ecosystem characteristics (phytoplankton composition, chlorophyll *a* and nitrate levels) across the N Pacific basin will be determined. These data will be the basis for quantifying the impact that biological productivity (and SST) has on the air-sea $CO_2$ flux and how biological productivity is related to ecosystem community structure.</td></tr>
<tr><td>Sabine, Christopher, NOAA/PMEL</td><td>Development of a Robust Moored DIC Sensor For Carbon Cycle Studies</td><td>2010</td></tr>
<tr><td colspan="3">Abstract: The goal of the project is to develop a robust and cost effective Dissolved Inorganic Carbon (DIC) sensor that can be deployed in combination with the robust moored $pCO_2$ sensor ($MAPCO_2$) previously developed by NOAA's Pacific Marine Environmental Laboratory on moorings for up to a year at a time. The sensor is based on the proven technology used in PMEL's $pCO_2$ sensor, infrared detection of $CO_2$ in a gas stream. In this application a known volume of seawater will be acidified, and the $CO_2$ that is evolved from the sample quantified. This technique has been used successfully to measure DIC on shipboard systems. While this method is fast and reliable, it has not been fully adapted for robust long-term autonomous DIC measurements on a mooring. Over the three years of this project, a prototype moored DIC sensor will be developed and field-tested in a location with already existing $pCO_2$ moorings.</td></tr>
<tr><td>Sarmiento, Jorge, Princeton University; Marinov, Irina, University of Pennsylvania</td><td>Investigating the Evolution of Ocean Stratification and its Impact on Natural and Anthropogenic Carbon Uptake in a Warming Ocean</td><td>2010</td></tr>
<tr><td colspan="3">Abstract: The goal of the project is to advance the mechanistic understanding of the response of the ocean carbon sink to changes in ocean ventilation under increasing atmospheric $CO_2$ concentrations. This objective will be accomplished by:</td></tr>
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1. Developing an expanded and improved theoretical understanding of ocean carbon pumps. This will be achieved by including the effects of the carbonate, solubility pumps and anthropogenic emissions in the investigator's previous simplified theoretical framework (Marinov et al. 2008b). The theory will be used to predict the potential impact of changes in ventilation on ocean carbon pumps and the resulting feedbacks on atmospheric $pCO_2$.

2. Designing and executing a set of coupled ocean-atmosphere model experiments suitable for evaluating the separate impacts of wind-driven and buoyancy-driven ventilation changes on the biological pump, solubility pump, and anthropogenic carbon uptake.

3. Introducing a new set of ocean physical and biogeochemical tracers and diagnostics to allow an unprecedented clean separation of ocean carbon pumps. These tools will be used to evaluate the effect of ventilation changes on both the natural biological and solubility carbon pumps and on the anthropogenic carbon uptake, the sum of which constitute the total carbon sink.

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| Schade, Gunnar, Texas A&M University | Anthropogenic and Biogenic Carbon Fluxes from Typical Urban Land Uses in Houston, Texas | 2010 |

Abstract: The goal of the project is to continue measurements of energy and trace gas fluxes at a unique urban research site in Houston, Texas, with a focus on evaluating the anthropogenic and biogenic contributions to the measured net $CO_2$ exchange at this site. The project would analyze existing and future data, support measurements for another two years, and perform additional measurements to elucidate the contributions of anthropogenic and biogenic carbon fluxes to the net carbon exchanges in a representative urban area. The objectives are to

1 separate urban anthropogenic and biogenic $CO_2$ fluxes for independent evaluation,
2. compare different separation methods,
3. analyze net and separated urban carbon flux dynamics in relation to different drivers, and
4. relate fluxes to simple land cover classifications to estimate net biogenic and anthropogenic flux contributions in similar urban areas of North America.

The proposed research will use both a recently developed quadrant analysis method to evaluate the structures of atmospheric eddies for informational content on independent surface sources (*internal* method), as well as traditional scaling methods using an anthropogenic emissions tracer, carbon monoxide, and biogenic source measurements on local vegetation and soil plots for upscaling (*external* method). Measurement activities will include the well-established eddy covariance technique expanded by a profile system, local photosynthesis and respiration measurements in collaboration with public schools and/or on private property, and seasonal evaluations of traffic density and composition, as well as natural gas use, the major direct anthropogenic $CO_2$ emission sources in this area. Through a synthesis of the gathered data, the dynamics, drivers, and distribution of biogenic and anthropogenic carbon fluxes will be studied independently, filling a gap regarding urban land covers in the current flux network.

The successful implementation of this (monitoring and analysis) project allows the assessment of the importance of constantly growing urban areas in the North American carbon cycle. It addresses identified gaps in carbon cycle knowledge and can help in validating inventories and

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| improving estimates of carbon cycling. In addition, outreach through the engagement of neighborhood schools and citizens in onsite research conveys the importance of this research directly to the involved people. | | |
| Sonnerup, Rolf, University of Washington | In-Situ Biological Carbon Fluxes in the Pacific Ocean | 2010 |
| Abstract: The goal of the project is to take advantage of two timely opportunities for studying carbon cycling in the Pacific Ocean, triple oxygen isotope analysis and transit time distributions in conjunction with sulfur hexafluoride ($SF_6$) and chlorofluorocarbon (CFC) measurements. These data will be used to determine oxygen (and carbon) cycling by computing *in-situ* depth-integrated oxygen utilization rates from a recent two-tracer TTD approach, and comparing these with oxygen production rates implied by the 17 delta and $O_2$/Ar balance in the mixed layer. Comparison of the decadal mean C-cycling rates from the thermocline with the ~ weekly rates determined in the mixed layer will provide important insights into each approach, and will provide important benchmarks for efforts to quantify oceanic C-cycling rates from chlorophyll sensed from satellites. | | |
| Stanley, Rachel, Woods Hole Oceanographic Institution | A Novel Constraint for Biogeochemical Modeling: Triple Oxygen Isotopes | 2010 |
| Abstract: The aim of the project is to incorporate triple oxygen isotopes and oxygen/argon ratios into a hierarchy of ocean models to provide unique constraints on rates of photosynthesis and respiration. This, in turn, will increase the mechanistic understanding of the carbon cycle and improve ocean models used for future climate projections.<br><br>The triple $O_2$ isotopes and $O_2$/Ar data will be used as constraints for an innovative modeling approach based on energy and its allocation into a variety of carbon pools. Firstly, their triple $O_2$ isotopes and $O_2$/Ar ratios will be incorporated into numerical, one-dimensional models for the Bermuda Atlantic Time-series Site (BATS) and the Hawaii Ocean Time-series site (HOT) to learn about isotope systematics in relatively simple systems. Next, the isotopes will be incorporated into the three-dimensional, ocean component of the global Community Climate System Model (CCSM), a model used extensively for studying human-driven climate change and carbon/climate feedbacks.<br><br>It is hypothesized that the ratio of GPP to that of NPP varies spatially and temporally, and is dependent on environmental and biogeographical factors. The oxygen isotopes and the new modeling approach will be used to study the temperature dependence of rates of photosynthesis and respiration – a potential positive feedback to global warming – and to understand why nearly all biogeochemical models overpredict production in low productivity regions. | | |

## III. Atmospheric Chemistry

| Primary Investigators (last names and affiliations) | Project Title | Year Funded |
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| Cotton, William (Colorado State University) | Simulation and Analysis of the Interaction Between Aerosols and Clouds, Precipitation and the Radiation Budget Over the Gulf of Mexico and Houston | 2009 |
| **Abstract:** We propose to perform simulations with the Regional Atmospheric Modeling System (RAMS) initialized | | |

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| with observed aerosol concentrations from the *GoMACCS 2006 field campaign.* We will then initialize RAMS with observed aerosol concentrations to assess the relative impacts of Houston area land-use, urban aerosol sources, Gulf of Mexico aerosol sources and surrounding non-urban aerosol sources, to convective cloudiness, precipitation and the radiation budget in the Houston region. An ensemble of simulations will be performed with and without urban land-use and with various background aerosol profiles, including aerosol characterization over the Gulf of Mexico, clean background land aerosol characterization, and Houston urban aerosol characterization. This ensemble of simulations for selected cases will permit factor separation analysis that will help us identify the relative effects of urban land-use and urban pollution on clouds, precipitation, and the radiation budget in the Houston area.<br><br>Differences in cloud cover, precipitation, cloud albedo, top of the atmosphere shortwave and longwave radiation budgets will be calculated as part of the factor separation analysis. In addition, the simulated data for each ensemble member will be compared with available observations in the area for the selected days including surface observations, satellite, aircraft, and WSR 88D radar data. | | |
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| Wexler, Anthony S. and Simon L. Clegg (University of California – Davis) | Improving Aerosol-Chemical Effects on Radiative Forcing in Climate Models | 2009 |
| **Abstract:** Atmospheric aerosols affect the earth's radiation budget through their ability to scatter and absorb solar radiation (the direct effect), and to modify cloud properties *via* changed cloud condensation nuclei number (CCN) (the indirect effect). The total magnitude of these effects is similar to that of greenhouse gas radiative forcing, but is of opposite sign and much more uncertain. Aerosols consist of a complex mixture of acid ammonium sulfate, nitrates, sea salt, the components of wind blown dust, and both primary and secondary organic material. The size, phase state (solid or liquid), and water content of the aerosol control both its direct radiative effects (via the complex index of refraction and single scattering albedo), and its behavior as CCN. The physical properties of the aerosol are functions of chemical composition, the partitioning of semi-volatile components, relative humidity (RH) and temperature.<br><br>In climate models the treatment of aerosols varies widely both in terms of chemical complexity - the numbers of components permitted - and the accuracy of the thermodynamic methods used to estimate gas/aerosol partitioning and water uptake. Even advanced thermodynamic modules use approximate methods to estimate the properties of the aerosol liquid phase for reasons of computational efficiency, they are coded for systems of limited composition and component properties (thus reducing flexibility) and tend to be restricted to temperatures typical of the lower troposphere. Here we address the need for an accurate, flexible, and easy to use means of calculating aerosol properties for climate change research. We will develop a state-of-the-art process model, based on the established Aerosol Inorganics Model (*AIM*), with the following properties: (i) The model will make use of the widest possible range of thermodynamic data for gases, solids, and aqueous mixtures, and its accuracy will not be limited by simplifying assumptions. (ii) It will be based upon equations for liquid phase activities created specifically for aerosol applications, including methods for internally mixed inorganic/organic aerosols developed and tested over the last five years. (iii) It will be flexible, allowing users to define the properties of aerosol organic components, and meets the needs of climate modelers by allowing aerosol systems of a range of complexity to be defined and their properties calculated. (iv) It will be implemented on the world wide web for maximum accessibility and ease-of-use by non-specialists, as *AIM* has been for many years, with input/output facilities specifically for climate scientists. Our experience is that availability on the web greatly increases the use and practical value of models such as that proposed here.<br><br>Building on a recent project to add organic compounds and a hydrophobic organic aerosol phase to the base *AIM* model (for $H^+$ - $NH4^+$ - $SO_4^{2-}$ - $NO_3^-$ - $H_2O$, from 323 K to ~200 K),[12] the work to be carried out consists of: (i) Extending the chemical model to include sea salt (NaCl), and $K^+$, $Ca^{2+}$ and $Mg^{2+}$ carbonates as functions of temperature. (ii) Adding the Kelvin effect (to calculate CCN behavior). (iii) Implementing the extended model on the *AIM* web site, adding new output facilities: first, tabulations of aerosol size, water content and mass over user-specified ranges of composition, RH, and temperature; second, the ability to reduce results for aerosol systems containing multiple inorganic and organic compounds to what would be obtained for simplified "lumped" equivalent chemical systems.<br><br>The results will enable climate scientists to improve the treatment of aerosols and their effects in global climate and | | |

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| other models, by using web-based tools incorporating state-of-the-art thermodynamic models of gas/aerosol partitioning and aerosol water uptake. It is our intention that the results of this project will serve users well into the next decade, as *AIM* has done for aerosol science since 1998. | | |
| Wood, Robert, Joel Thornton (University of Washington) and Rahul Zaveri (Pacific Northwest National Laboratory) | Lagrangian observations and modeling of aerosol-cloud interaction | 2009 |
| **Abstract:** Observationally-based and climate model estimates of the indirect effects of aerosols on cloud microphysical and radiative properties differ considerably because (a) observational assessments are plagued by an inability to control for variability in meteorological conditions that almost always accompany changes in aerosol; (b) climate models poorly resolve cloud processes and mesoscale aerosol transports, and have not been well tested using existing observational datasets. It is therefore imperative that we (a) better understand the synoptic to seasonal scale variability that drives the covariation of aerosols and meteorology, and (b) develop useful observational metrics that can test and constrain regional and global climate model predictions of aerosol-cloud interaction. The proposed work will combine satellite observations of marine boundary layer (MBL) cloud microphysical properties with a carefully constructed chemistryaerosol-cloud model in a Lagrangian framework, to better understand the covariation of microphysical and large scale meteorological processes that control the cloud condensation nucleus (CCN) population and its temporal evolution in the MBL on daily to seasonal timescales. Central to the success of our proposal is the use of microphysical retrievals from the Geostationary Observational Environmental Satellites (GOES) and from the Moderate Resolution Imaging Spectroradiometer (MODIS). Our focus will be upon cloudy MBLs over the subtropical oceans, particularly those affected by anthropogenic pollution sources.<br><br>We will use visible/near IR satellite retrievals of cloud optical thickness and effective radius during the day, and 3.7-11 and 11-12 micron brightness temperature differences at night, to estimate cloud microphysical properties. We will track airmasses, using trajectories derived from NCEP reanalyses, for approximately 2-4 days as they advect through the regions of extensive low cloud over the subtropical ocean basins. The trajectories, emissions inventories, and measurements of the aerosol size distribution will be used to initialize the Lagrangian model.<br><br>The proposed work will address three key sets of science questions: 1) How do cloud microphysical properties (cloud droplet concentration, effective radius) and macrophysical properties (liquid water path, cloud cover, height) evolve in airmasses advected over the subtropical oceans? Is the spatial distribution of changes consistent with an anthropological influence upon cloud microphysical properties? How do we use the observations to develop useful metrics for testing climate model assessments of aerosolcloud interaction? 2) How well can our chemistry-aerosol-cloud model forced with realistic dynamic and thermodynamic conditions simulate the evolution of cloud microphysical properties along trajectories in both the clean and polluted MBL? How does this compare with regional and global climate model simulations? 3) What are the key microphysical and meteorological factors controlling the geographical extent of pollution plumes as they advect over the ocean? | | |
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| Turpin, Barbara J. and Sybil Seitzinger (Rutgers University) | Investigating In-Cloud Formation Secondary Organic Aerosol Formation | 2009 |
| **Abstract:** The generally poor understanding of the sources and formation of organic particulate matter (PM) is a major source of uncertainty in predictions of the effects of aerosols on climate (*2*). This proposed research will further the understanding of atmospheric processes that link emissions of gas-phase precursors to atmospheric | | |

organic aerosol concentrations, distributions and properties. The resulting yields will be available for incorporation into climate models for improved climate prediction and effective decision-making.

There is growing evidence suggesting that, like sulfate, a substantial portion of secondary organic aerosol (SOA) is formed through aqueous phase reactions (i.e., in clouds, fogs and aerosols). In fact, in-cloud formation of SOA provides a likely explanation for a large gap observed between measurements and model predictions of organic PM in the free troposphere. The resulting organic aerosol is expected to differ from primary organic emissions in its spatial distribution and behavior (e.g., be substantially more hygroscopic) and to enhance SOA concentrations in the free troposphere. In-cloud SOA formation is only beginning to be recognized and has not yet been incorporated into climate models. As was the case for sulfate, model simulation is needed to assess the magnitude, behavior and effects of SOA formed through cloud processing. However, the kinetic data for recognized pathways are limited and many products and pathways are unknown. The proposed research is designed to address this knowledge gap.

Predictions and experiments by our group and others provide strong support for the following. Alkene and aromatic emissions are oxidized in the interstitial spaces of clouds; the water soluble products partition into cloud droplets where they oxidize further forming low volatility compounds including organic acids, organosulfonic acids and oligomers; low and semi-volatile products remain at least in part in the particle phase after droplet evaporation, forming SOA. Current models estimate 8 – 40 Tg/yr of SOA globally from gas phase reactions. Our group estimates in-cloud formation of SOA from isoprene alone to be greater than 1.6 Tg/yr. This in-cloud SOA estimate includes only organic acid products and does not include the contribution of 1) high molecular weight products, 2) other gas-phase precursors, 3) sulfur-containing organic products, or 4) aqueous-phase reactions in aerosols. The proposed research will provide more accurate SOA yields and explore the aqueous phase kinetics for glycolaldehyde, a key aqueous phase precursor.

Glycolaldehyde, glyoxal, and methylglyoxal are major water-soluble gas-phase oxidation products of isoprene, ethene, acetylene, toluene and other alkene and aromatic compounds of biogenic, marine, and anthropogenic origin. We have begun experiments with glyoxal and methylglyoxal, but not with glycolaldehyde. SOA yields (total SOA mass per precursor reacted) provide a means of accounting for the total SOA mass formed in models (including oligomers and unidentified products) in advance of the time when the products, pathways, and kinetics are fully elucidated. This strategy (i.e., use of bulk yields for modeling while developing an understanding of products and kinetics) mirrors the strategy used for prediction of SOA formation from gas-phase reactions and nucleation/condensation/ sorption of low and semi-volatile products.

Hypothesis: Cloud processing is a substantial source of SOA globally. Specific Aims: 1) Conduct aqueous phase photochemical batch reactions with glycolaldehyde; 2) evaporate droplets of reaction solutions to provide SOA yields; 3) model the reaction system, and 4) evaluate the impact of model improvements on in-cloud SOA predictions. Results will be made available for use in climate models (See letter from Dr. Jacob, expressing interest). Experiments will be conducted with $H_2O_2$+UV as a source of hydroxyl radical (·OH) and with/without sulfur and Fe. Fe and sulfur are ubiquitous participants in aqueous-phase chemistry and their effects on organic product formation are only partially understood. Precursors and products will be measured during time-series experiments and used to develop an improved understanding of formation pathways and calculate reaction rate constants.

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| Sokolik, Irina, A. Nenes, A. Stack and S. Lafon (Georgia Institute of Technology) | Characterization of Mineral Dust Aerosols to Improve Predictions of Their Impact on the Radiative Balance of the Atmosphere | 2009 |

**Abstract:** Atmospheric dust aerosols can affect the Earth's climate system via a number of complex processes by altering the radiative budget at the top-of the atmosphere and surface, causing radiative heating or cooling within the dust layer, affecting the photochemistry of the atmosphere, and changing the cloud properties and precipitation, among others. Up to now, all climate models as well as remote sensing retrievals consider dust as a single generic species. Growing evidence demonstrates that distinct regional differences of dust properties are the key factors that control dust impacts on the climate system. Therefore, there is an urgent need to improve the treatments of dust in GCMs to make their predictions more realistic. This provides the motivation for this proposal.

We propose to perform a comprehensive study of physicochemical properties of mineral dust representative of main

dust production regions; its source-dependent composition, light absorption, CCN activity, and interactions with water clouds. Our approach integrates laboratory experiments, *in situ* ground-based and satellite data, and several numerical models. The ultimate goal is to provide critical insights on dust properties and develop specific recommendations on dust treatments in the climate models required for improved assessments of dust impacts on the radiative balance of the atmosphere. The specific objectives of this study are to:
1) perform new measurements of physicochemical properties of mineral dust samples representative of major individual dust sources, including dust sources in the U.S., to provide the critical data required for improved predictions of dust direct radiative impacts;
2) investigate how the distinct regional properties of dust affect its interactions with water clouds by performing laboratory measurements and numerical modeling in the conjunction with analysis of satellite observations of mixed dust-cloud scenes;
3) investigate the role of regional differences in dust properties in affecting the radiative balance of the atmosphere directly and indirectly (via clouds) and develop recommendations for improved dust treatments in global climate models.

The proposed research is leveraged by ongoing research projects of the investigators, currently funded by NASA, NSF, DOE, and ONR. This proposed study will enable integration and the appropriate extension of this research in areas that include laboratory measurements of composition and three-dimensional morphology of dust particles, soluble species and CCN, radiative transfer, satellite remote sensing, cloud-scale modeling, and global climate modeling. Our research directly addresses the main goals identified by the NOAA Atmospheric Composition and Climate Program in FY2007 by focusing on improving the capability of climate models to simulate the effect of dust aerosols on the radiative balance of the Earth's atmosphere.

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| Hoyos, Carlos, Peter J. Webster and Judith A. Curry (Georgia Institute of Technology) | SPATIO-TEMPORAL VARIABILITY OF AEROSOL LOAD IN THE TROPICS: INTERACTION WITH PRECIPITATION AND THE RADIATION BUDGET | 2009 |

**Abstract:** Aerosols interact directly and indirectly with the radiation budget and the hydrological cycle, playing an important role in climate variability. The heterogeneous nature of aerosol distribution introduces complex radiative forcing in the climate system, leading potentially to non-linear effects in the atmospheric circulation that in turns affect the distribution of aerosols (aerosol-atmospheric circulation feedback). In spite of significant research during the past several decades, aerosol effects still represent one of the greatest uncertainties in our understanding of the climate system. The main goal of the proposed project is to improve our understanding of the mechanisms of spatio-temporal variability of aerosols in the tropics and their interactions with monsoon systems (American, South-East Asian, and West African monsoons) that are characterized by strong intraseasonal and interannual variability. We propose to study objectively the variability of aerosols retrieved from different satellites as well as their relationship to, and interaction with, different variables that characterize the dynamic and thermodynamic state of the tropical climate system.

We propose the following research framework which combines a comprehensive and detailed data analysis as well as experimental numerical modeling.

- Spatio-Temporal Aerosol Variability: Understand the main spatial and temporal modes of aerosol variability by analyzing TOMS, MODIS, POLDER and CALIPSO data. Determine the key mechanisms playing a role in the observed structure of the aerosol load annual cycle as well as in their interannual and intraseasonal variability.
- Co-Variability of Aerosols and Tropical Climate: Perform a series of diagnostic analyses to study the relationship between atmospheric circulation, rainfall and atmospheric moisture with the aerosol load in different temporal and spatial scales. The statistical analyses will be designed to assess weather the amount of aerosol has an impact in the hydrological cycle and radiative budget in the tropics as well as the role of tropical circulation in the spatio-temporal distribution of aerosols. Special attention will be given to the role of aerosols in the rainfall variability associated with the monsoon systems in Asia, Australia, Africa and the Americas given their role in the availability of water resources.
- Real-time Aerosol Outlooks: Development of an online real-time analysis and probabilistic outlooks of aerosol load distribution based on the joint probability density functions between aerosols and different atmospheric

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| variables and derived based historical information. We anticipate that we could provide daily outlooks for up to a week for the entire tropical belt (40°S-40°N) with a spatial resolution of 5° by 5°.<br>• Experimental Numerical Modeling: Regional and tropical channel versions of the WRF model with dual moment cloud microphysics scheme will be used to interpret the results obtained from the diagnostic study under different atmospheric and aerosol scenarios. Different scenarios will include both realistic as well as reduced-degrees-of-freedom cases. | | |
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| Kazil, Jan (University of Colorado), Graham Feingold (NOAA/ESRL), René Garreaud and Rainer Schmitz (Universidad de Chile) | Natural and anthropogenic gas phase emissions and cloud properties in the South-East Pacific region | 2009 |
| **Abstract:** Marine boundary layer clouds are an important element of the climate system due to their large spatial coverage and the contrast in albedo between the cloud tops and the ocean surface. Their properties, including droplet number and size, albedo, and propensity to precipitate, are strongly modulated by aerosol particles. This is particularly true in the South-East Pacific (SEP) region where the climate is governed by a tightly coupled system involving poorly understood interactions between aerosols, a persistent stratocumulus deck, precipitation, sea surface temperatures, and mesoscale dynamics. The SEP region is supplied with both natural and anthropogenic aerosol precursor gases: Dimethyl sulfide is released from the ocean into the atmosphere, while substantial amounts of sulfur dioxide are emitted from inland sources. These aerosol precursor gases affect cloud properties by initiating aerosol formation from the gas phase on the one hand, and by in-cloud aqueous oxidation on the other. Aerosol formation from the gas phase maintains marine boundary layer aerosol concentrations, while in-cloud oxidation increases aerosol mass. While frequently observed in field studies, aerosol formation from the gas phase and the growth of the resulting particles to CCN sizes is, if at all, poorly represented in current cloud and regional scale models. We propose to quantify, by means of model simulations and analysis of in-situ and satellite observations, the response of the SEP cloud layer and of its properties to forcing by natural and anthropogenic gas phase emissions, accounting for both aerosol formation from the gas phase and incloud aqueous oxidation. In the proposed work, the transport of aerosol precursor gases from their sources to locations over the SEP will be characterized by ensembles of trajectories extracted from simulations with the Weather Research and Forecasting (WRF) model. A previously developed Lagrangian model of aerosol processes, which describes aerosol formation from the gas phase and subsequent growth of the particles, will be operated along these trajectories. The trajectory ensembles will be chosen based on the VOCALS-REx campaign area, and on the movement of air masses carrying distinctly different loads of aerosol precursor gases. The aerosol properties obtained from these Lagrangian model runs will be validated with observations from the VOCALS-REx campaign, and correlated with satellite-derived cloud properties, providing a first quantification of the effect of aerosols on clouds. They will then serve to initiate Large Eddy Simulations of the SEP region cloud cover. Aerosol formation from the gas phase will be accounted for in these simulations with a previously developed algorithm. These simulations close the connection between emissions of aerosol precursor gases and cloud properties in the region; their results will be compared with VOCALS-REx measurements and satellite observations, and provide a second quantification of the effect of aerosols on clouds. The proposed work is designed to support the VOCALS science program, which aims at the understanding of aerosol, cloud and climate processes in the SEP region, and of their connection to large scale climate via their impact on the ITCZ and the ENSO. | | |
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| Knopf, Daniel A. and Josephine Y. Aller (Stony Brook University) | The Role of the Organic Aerosol Fraction on Ice Nucleation in the Atmosphere | 2009 |
| **Abstract:** A laboratory based research project is proposed to address the role of the organic aerosol fraction in ice cloud formation. The effect of chemical aging of these organic particles, by oxidation with ozone, on ice formation will also be addressed. The goal of the proposed research project is to determine the microphysical mechanisms which lead to the formation of ice crystals and clouds, thus, improving our predictive understanding of the corresponding changes in the aerosol induced radiative forcing and in the distribution of the greenhouse gas water vapor. | | |

Atmospheric aerosols can affect climate by scattering solar and terrestrial radiation but also by modification of the radiative properties of clouds when acting as cloud condensation nuclei and ice nuclei (IN). The climatic effect of aerosols, in particular aerosol-ice cloud interactions, is among the largest uncertainties in understanding Earth's climate and in predicting future climate changes. The formation of ice clouds and its impact on the radiative forcing is still poorly understood. Ice formation in the upper troposphere/lower stratosphere (UT/LS) can also affect the radiative forcing by water vapor due to a redistribution of water by sedimentation of ice crystals. This effect can cause the dehydration of the UT/LS region and results in changes to water transport into the stratosphere with important consequences for stratospheric chemistry and the ozone layer.

A large fraction of the aerosol mass can consist of organic species which can significantly alter the properties of the particle and predictably ice nucleation. Our research will focus on the role of water soluble organic compounds (WSOC) and water insoluble organic compounds (WISOC) typically encountered in biomass burning aerosol (BBA) and ocean sea spray aerosol (OSSA). Both sources can generate aerosols composed of complex mixtures of organic and inorganic/organic species. Biomass burning is a major source of gases and particles to the atmosphere and has been shown to reach the UT/LS region where low temperatures promote the formation of ice. The ocean is also a major source of aerosol particles including sea-salts, mixed inorganic/organic, and purely organic aerosols. Recent investigations have emphasized the importance of yet unidentified organic material (WSOC and WISOC), most likely of oceanic biogenic origin, in aerosol-cloud interactions. Here we will study the formation of ice from WSOC and WISOC containing aerosol particles. The response in ice nucleation after oxidation of the WSOC and WISOC by ozone will also be addressed. The organic species we will employ cover a wide range of chemical and physical properties: WSOCs such as levoglucosan, surface active species including fatty acids and humic acids, WISOCs such as oleic acid and biogenic organic material including colloids, bacteria and bacterial cell wall debris, and viruses. Homogeneous ice nucleation rate coe±cients from aqueous organic and inorganic/organic solution droplets will be derived. Heterogeneous ice nucleation rate coe±cients induced by surface-active organic species, by solid organic compounds suspended in aqueous solutions, and by solid organic species will be determined. The effect of chemical aging by ozone on ice nucleation will be studied by controlled ozone exposure of the particles prior to the formation of ice. The results of these experiments will allow the derivation of atmospheric ice particle production rates which can be parameterized for inclusion in climate models allowing improved predictive understanding of ice formation in the atmosphere.This proposed research addresses NOAA's climate goal of understanding and describing climate variability and change to enhance society's ability to plan and respond.

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| Jimenez, Jose-Luis and Joel R. Kimmel (University of Colorado) | Mass Spectral Characterization of Organic Aerosol Sources and Processes Using Novel Soft Ionization, Positive Matrix Factorization, and Elemental Analysis | 2009 |

**Abstract:** Aerosols have important effects on climate, visibility, human health, and acid, toxic, and nutrient deposition. Characterization of these impacts requires a fundamental understanding of aerosol processes, chemistry, and microphysics. The complexity of organic aerosols (OA) makes quantification of their concentration, properties, and effects particularly difficult. Owing to this complexity and to the general limitations of modern aerosol measurement techniques, accurate prediction of the effects of aerosols is challenging. And, at present, aerosols are considered by the Intergovernmental Panel on Climate Change (IPCC) as the most uncertain component in the radiative forcing of climate. The proposed research addresses this critical need with a powerful combination of newly developed aerosol mass spectrometric techniques, factor analysis of aerosol mass spectra, and organic aerosol elemental analysis.

The Aerodyne high-resolution time-of-flight aerosol mass spectrometer [3] (HR-ToF-AMS), which is able to rapidly determine the size and chemical composition of submicron aerosols, has emerged as a powerful tool for the characterization of OA, leading to a number of advances in the field. In just the past two years, factor analysis of AMS data by our group has pointed out the dominance of secondary organic aerosols (SOA) in the polluted regions of the Northern Hemisphere. Recent work using Positive Matrix Factorization (PMF) has allowed us to quantify the contributions of various primary sources, such as biomass burning aerosols (BBOA) and is leading to promising advances in the study of SOA formation and aging. Simultaneously, the high mass resolving power of the HR-ToF-AMS has enabled increased source specificity in PMF, as well as fast determination of oxygen-to-carbon ratio (O/C) of organic aerosol.

Despite this progress, analysis of organic aerosols with the HR-ToF-AMS is hampered by the extensive molecular fragmentation caused by electron impact (EI) ionization, which is the standard ionization method in all Aerodyne aerosol mass spectrometers. While it is widely surmised that organic aerosols contain hundreds to thousands of organic compounds in many chemical classes, EI-generated aerosol mass spectra are dominated by peaks corresponding to ubiquitous fragment ions, and molecular identification is generally unattainable. Instead, detected ions are sorted into broad chemical classes, such as hydrocarbon-like OA (HOA), BBOA, oxygenated OA (OOA), etc., and analysis focuses on determining total mass contributions, time trends, and O/C for these various classes.

This project aims to further develop our recently demonstrated metastable atom bombardment (MAB) HR-ToF-AMS and to deploy the instrumentation to a field study relevant to NOAA objectives, e.g., Front Range 2009 or California 2010. By limiting molecular fragmentation, MAB ionization reduces redundancies in the mass spectra of organic aerosols and enables the determination of molecular composition. We have already demonstrated the soft nature and the high sensitivity of the MAB using an HR-ToF-AMS that is configured to allow interchange between EI and MAB ionization sources on a timescale of minutes. Combination of the quantitative data retrieved from EI mass spectra with the enriched chemical information obtained by MAB ionization will yield more detailed characterization of SOA formation and aging. Likewise, the increased specificity in aerosol mass spectra will greatly expand the power of PMF to isolate OA sources. As part of the campaign analysis, we will use the enriched OA characterization in a CCN closure study and determine whether improved agreement is achieved.

The proposed research develops and applies analytical capabilities not available at present, but which are needed for attacking major uncertainties in the sources, processes, and effects of organic aerosols. The unique data generated by these techniques will furnish critically needed information on organic aerosols and submicron aerosol climatic effects that can inform climate models and scientific assessments by, for example IPCC, and through them, policy decisions.