Graduate Climate Conference 2015 - Abstracts

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KEYNOTE LECTURE NOV 6, 5:15 - 6:15 PM

From salt marshes to arctic tundra: Some of the surprises we are seeing with climate change

Dr. Anne E. Giblin (Marine Biological Laboratory) <agiblin@mbl.edu>

I started my career interested in the impacts that humans were having on natural systems. My thesis was on the cycling of heavy metals in sewage sludge on a salt marsh. I moved from sewage sludge to the transport of N from septic effluent into coastal waters for my post-doc. I then later spent nearly 20 years examining nitrogen cycling in sediments as part of the Boston sewage outfall relocation project. In spite of spending much of my career "going down the toilet" my interest in N cycling lead me to study N cycling in unimpacted areas such as the continental shelf and two long-term projects focused on climate change. In Plum Island we are examining how sea-level rise is impacting coastal marshes. In the Arctic we are seeing how the impact of climate change is having some unexpected impacts. While my research portfolio is eclectic, I've enjoyed the mix of basic and applied research, short and long-term studies, and single investigator and large projects. I'll talk a bit about how to decide what is right for you and whether this diverse strategy could possibly work in these more challenging times.

SESSION I: REGIONAL CLIMATE — NOV 6, 1:45 - 3:15 PM

I.0 – **Regional climate session introduction**

Vince Agard (MIT) <jvagard@mit.edu>

Although the climate system is often thought about in a global context, its complex components often operate on regional scales. As such, we can think about regional climate as the manifestation of the climate system in specific physical areas on Earth. In this session, we will explore dynamic parts of the climate system in regions ranging from the poles to the tropics. Specifically, we will hear talks examining the roles of atmospheric, oceanic, and environmental processes in controlling Arctic clouds, the South Asian Monsoon, and the predictability of El Nino. While these processes occur on regional scales, the individual mechanisms studied both affect and are affected by larger-scale climate dynamics, and they are important for furthering our understanding of the climate system as a whole.

I.1 - **The influence of atmospheric stability and circulation on cloud presence and properties in a warming Arctic**

Ariel Morrison (University of Colorado) <ariel.morrison@colorado.edu>

Cloud formation over the Arctic Ocean is influenced by a variety of factors, such as sea ice concentration, moisture availability, and atmospheric stability and circulation. Lower tropospheric stability in particular is a known control on marine stratiform clouds. Surface warming in the Arctic is amplified compared to the globe as a whole, and clouds play a role in this warming through their interactions with short- and longwave radiation. This work uses CloudSat and CALIOP satellite data from 2007-2014 combined with complementary datasets (CERES, AIRS, ERA-Interim) to analyze the processes controlling clouds over the Beaufort and Chukchi Seas, regions where recent sea ice loss has been particularly pronounced and where the annual mean state of the atmosphere has been relatively stable. Specifically, we used scatterplots for a time-independent assessment of the combined influence of sea ice concentration and atmospheric conditions on cloud properties (amount, height, phase, optical thickness). Lower tropospheric instability is correlated with large cloud fraction in the Arctic, contrary to many other marine regions around the world, but a stable atmosphere is associated

with a large range of cloud fraction values. Atmospheric circulation, among other environmental factors, is a stronger control on cloud presence. Lower tropospheric stability is not a good predictor for whether Arctic clouds form when the mean state of the atmosphere is already stable. Future work, to be completed in summer 2015, will focus on the effects of stability on cloud phase. Overall, this study seeks to quantify and understand cloud processes in a warming Arctic.

I.2 - **Mechanisms of Asian summer monsoon changes in response to anthropogenic forcing in CMIP5 models**

Xiaoqiong Li (Columbia University) <xqli@ldeo.columbia.edu>

Changes of the Asian summer monsoon in response to anthropogenic forcing are examined using obser- vations and phase 5 of the Coupled Model Intercomparison Project (CMIP5) multimodel, multirealization ensemble. In the twentieth century, CMIP5 models indicate a predominantly drying Asian monsoon, while in the twenty-first century under the representative concentration pathway 8.5 (RCP8.5) scenario, monsoon rainfall enhances across the entire Asian domain. The thermodynamic and dynamic mechanisms causing the changes are evaluated using specific humidity and winds, as well as the moisture budget. The drying trend in the CMIP5 historical simulations and the wetting trend in the RCP8.5 projections can be explained by the relative importance of dynamic and thermodynamic contributions to the total mean moisture convergence. While the thermodynamic mechanism dominates in the future, the historical rainfall changes are dominated by the changes in circulation. The relative contributions of aerosols and greenhouse gases (GHGs) on the historical monsoon change are further examined using CMIP5 single-forcing simulations. Rainfall reduces under aerosol forcing and increases under GHG forcing. Aerosol forcing dominates over the greenhouse effect during the historical period, leading to the general drying trend in the all-forcing simulations. While the thermodynamic change of mean moisture convergence in the all-forcing case is dominated by the GHG forcing, the dynamic change of mean moisture convergence in the all-forcing case is dominated by the aerosol forcing.

I.3 - **The role of African topography in the South Asian monsoon**

Ho-Hsuan Wei (California Institute of Technology) <hwei@caltech.edu>

The South Asian Monsoon (SAM) is the largest-scale monsoon with intense summertime precipitation over a large area. The cross-equatorial Somali jet is estimated to contribute up to half of the mass flux crossing the equator during the SAM season. The African topography (AT) has long been thought of as a wall and accelerates the Somali jet, which is also linked to South Asian monsoon (SAM) precipitation by transporting moisture into Indian region. Recent studies, however, show that by removing AT in GCMs, the SAM precipitation strengthens in the Indian region.

In this study, we use the GFDL AM2.1 GCM to conduct experiments with and without AT, to further examine its influence on the cross-equatorial Somali jet and the SAM. We find that when the African topography is removed, the SAM precipitation increases, consistent with the recent studies. The moisture budget shows that the enhanced meridional dynamic convergence term is the dominant one accounting for stronger precipitation. Since this meridional convergence is

related to a cyclonic anomaly over Arabian Sea when AF is removed, we explain the cyclonic anomaly by both comparing with theory of topographic Rossby waves and calculating potential vorticity (PV) budget associated with trajectory analysis. The wave patterns in our simulations are quantitatively consistent with the theory and PV budget analyses show that this cyclonic anomaly primarily arises because, in the absence of the blocking effect by the AT, air particles originate from higher latitude with larger background planetary vorticity.

I.4 - **Revisiting ENSO coupled instability theory and SST error growth in a fully coupled model**

Sarah Larson (University of Miami) <slarson@rsmas.miami.edu>

In an effort to untangle certain mechanisms contributing to the initiation of ENSO events, a coupled model framework is presented to isolate coupled instability induced SST anomaly (or error) growth in the ENSO region. The modeling framework using CCSM4 allows for seasonal ensembles of initialized simulations that are utilized to quantify the spatial and temporal behavior of coupled instabilities and the associated implications for ENSO predictability. The experimental design allows for unstable growth of initial perturbations that are not prescribed and several cases exhibit sufficiently rapid growth to produce ENSO events that do not require a previous ENSO event, large-scale wind trigger, or subsurface heat content precursor. Without these precursors, however, ENSO amplitude is reduced. The results imply that even without classical precursors, including the equatorial "recharge", ENSO events can be excited via coupled instabilities in fully coupled models. By removing the subsurface heat content precursor, however, essentially a lower bounds for ENSO predictability in CCSM4 is established, although seasonal ensembles initialized later in the calendar year retain some predictability. The initial growth exhibits strong seasonality, dependence on the initialization month, and displays a well-defined seasonal halt around September, consistent with increased background stability typical during fall. Overall, dynamically driven anomaly (or error) growth in CCSM4 is deemed best characterized by strong seasonality, dependence on the initialization month, and nonlinearity. The results pose real implications for predictability because not only are the final growth structures ENSO-like, but also there appears no clear mechanistic precursor that aids in predictability.

POSTER SESSION B.I: REGIONAL CLIMATE — NOV 7, 7:00 - 8:30 PM

B.I.1 - **Climate Change and the Sea Breeze in the North Carolina Coast**

Nicholas Luchetti (East Carolina University) <luchettin14@students.ecu.edu>

With nearly 75% of the world's population projected to live in or near coastal regions by the year 2030, understanding climatological implications of coastal phenomenon is becoming increasingly important. One such coastal phenomenon found along coastlines throughout the world is the sea breeze (SB). In the summertime, the variability of precipitation along the North Carolina coast is heavily dependent on SB-induced convection. Specifically, 50% of North Carolina coastal summer precipitation can be attributed to SB convection. This research aims to provide insight into how a warmer 21st century may alter SB evolution along the North Carolina coast by using the Weather Research and Forecasting (WRF) numerical model. The first phase of this study investigates the performance of the WRF model in reproducing present climate sea breeze events. The second phase of this study utilizes the pseudo-global warming (PGW) approach, which will allow comparison of present climate SB simulations (phase 1) to future replications of the same event, but with modified thermodynamics representing a warmer climate.

B.I.2 - **Influence of ENSO on the Great Plains Low-Level Jet**

James Danco (University of Oklahoma School of Meteorology) <jdanco@ou.edu>

The Great Plains low-level jet (GPLLJ) has been shown to significantly increase convection over the U.S. Great Plains during the spring and summer months. Therefore, it is extremely important that the main atmospheric and oceanic mechanisms influencing the GPLLJ are understood so Great Plains precipitation can be better predicted. This study uses two reanalyses and historical simulations from two CMIP5 models to examine how the strength of the GPLLJ correlates with ENSO over the twentieth century. Results from the reanalysis find that the GPLLJ is negatively correlated with ENSO in the springtime and positively in the summertime. The models, on the other hand, exhibit insignificant correlations. One of the likely reasons for this difference is the models' severe underestimation of the intensity of the GPLLJ when compared to the reanalysis. Ten-year running correlations between the GPLLJ and ENSO in the reanalysis from 1901-2005 demonstrate an increase in magnitude of the negative springtime correlations over the period but little change in the positive summertime correlations. Future work will examine how the entire suite of CMIP5 models simulates the GPLLJ and its correlation with ENSO, and if their simulation is still poor, what some of the reasons for this might be. The same will be done for AMIP models, which are forced with observed SST's, in order to determine whether poor simulations of ENSO play a significant role in the models' inability to simulate this correlation. The relationship between the GPLLJ and rainfall will be analyzed in the models as well.

B.I.3 - **First evaluation of the CCAM climate model aerosol simulation with AERONET measurements over Africa**

Hannah Horowitz (Harvard University) <hmhorow@fas.harvard.edu>

Aerosols are a major climate forcer, through direct scattering and absorbing of radiation and indirect effects on cloud properties. Africa contains both the largest source of dust aerosols (Sahara desert) and the largest single source of biomass-burning smoke aerosols (Southern Africa) globally. The different aerosol types produced (dust, organic carbon, and black carbon) include both absorbing and scattering species. An accurate representation of African aerosols in climate models is thus critical to understanding the regional and global radiative forcing of aerosols. This project aims to evaluate the current representation of aerosol particles in the Conformal Cubic Atmospheric Model (CCAM), using the CMIP5 historical emissions inventory, with observations from Aerosol Robotic Network (AERONET) stations across Africa for 1999 – 2014. We synthesize regional and seasonal variations in observed aerosol optical depth (AOD) and Ångstrom exponent (a proxy of aerosol size distribution) throughout the continent, focusing on both dust and biomass burning source regions. We compare modeled to observed monthly mean timeseries and multi-year seasonal mean AOD (with modeled totals broken down by aerosol species – sulfate, organic carbon, black carbon, dust, and sea salt), and use this evaluation to provide a basis for understanding the potential impact on climate, and for improving the CCAM aerosol parameterizations. We also use model results to characterize the export of aerosols off the African continent. The CCAM model is widely used for regional climate modeling applications, and this is the first extensive evaluation of aerosols in CCAM against observations.

B.I.4 - **Estimating the relative importance of weather and climate modes for Antarctic sea ice variability**

Tsubasa Kohyama (University of Washington) <kohyama@uw.edu>

The relationship between climate modes and Antarctic sea ice is explored by sorting the variability into intraseasonal, interannual, and decadal time scales. Cross-spectral analysis shows that geopotential height and Antarctic sea ice extent are most coherent at periods between about 20 and 40 days (the intraseasonal time scale). In this period range, where the atmospheric circulation and the sea ice extent are most tightly coupled, the dominant meteorological variabilities are associated with Rossby waves that are excited by weather dynamics, orography, and heat sources. These Rossby waves are not directly related to the El Niño Southern Oscillation (ENSO) nor the Southern Annular Mode (SAM), which have received much attention for explaining Antarctic sea ice variability. Lag regression analysis shows that Rossby waves move slowly eastward following the background flow. The southerly (northerly) wind anomalies push sea ice northward (southward) and provide cold (warm) advection. On the interannual time scale, ENSO and SAM become important, but Rossby modes remain important for sea ice. On the decadal time scale, if we remove the influence of the prominent interannual climate modes from the sea ice extent time series, the positive sea ice trends in Ross Sea and Indian Ocean become insignificant at 95 %. Thus the positive trends in Antarctic sea ice may be explained with known modes of natural interannual variability.

B.I.5 - **The snow albedo feedback in the Colorado Rockies**

Ted Letcher (University of Albany) <ted.letcher@gmail.com>

Mid-latitude mountain ranges are particularly sensitive to climate change as the loss of snow cover exposes bare ground, which further enhances warming via the snow albedo feedback (SAF). In this study, high-resolution (4km horizontal grid) regional climate simulations using the WRF model are used to investigate the SAF over the complex terrain of the Colorado headwaters (HW) region. A pair of 7-year control and pseudo global-warming (PGW) simulations is used to study the regional climate response to a large-scale climate perturbation.

We find that the SAF is the primary process driving regional scale variations in the pattern of warming. Linear feedback analysis is used to quantify the SAF in the HW. The SAF has a strong seasonal cycle, attaining a peak strength of ~4 $W\ m^{-2}\ K^{-1}$ in April when large changes in snow cover coincide with strong insolation.

Changes in the regional energy budget are investigated to determine the effects of atmospheric energy transport on the SAF warming. We find that atmospheric circulations act to export excess energy associated with the SAF away from regions of snow loss. The effects of this are two-fold: local warming is reduced where the SAF is active, and warming is enhanced in snow

free regions. Regional circulations are also modified by the SAF. We explore the interaction between the SAF and terrain-driven diurnal wind systems to better understand how the SAF affects the climate in regions of complex terrain.

SESSION II: ECOLOGY NOV 6, 3:30 - 5:00 PM

II.0 – **Ecology session introduction**

Evan Howard (MIT-WHOI Joint Program) <ehoward@whoi.edu>

Ecology is the study of the interactions between species and the environments they inhabit. As climate changes globally, an important challenge for ecologists is to understand the local impacts of altered physical environments on complex biological systems, and to relate these effects into a meaningful framework for understanding long-term prospects for ecosystem structure and potential feedbacks on biological, chemical, and physical processes. The presentations in this session focus on how ecological connections and organismal physiology may shift in response to altered climate and environmental change.

II.1 - **Effect of Extremes: how El Niño events affects reef fish population connectivity in the Hawaiian Islands**

Johanna L. K. Wren (University of Hawaii at Manoa) <jwren@hawaii.edu>

As a result of climate change, scientist predict stronger, more frequent El Niño events in the future. These events in the Central Equatorial Pacific cause increased sea surface temperatures (SST), a depressed thermocline, and decreased primary production. Due to its location in the subtropical North Pacific, the Hawaiian archipelago experiences decreased SST and increased primary production. Oceanographic changes caused by El Niño can potentially alter larval dispersal patterns throughout the Hawaiian archipelago, affecting regional population connectivity. The yellow tang, Zebrasoma flavescense, has shown increased recruitment in Hawaiʻi during El Niño years, but the underlying drivers are unknown.

The goal of this study is to determine the effects El Niño on larval dispersal and reef fish connectivity in the Hawaiian Archipelago. Using a two dimensional lagrangian particle dispersal model coupled with high resolution Hybrid Coordinate Ocean Model (HYCOM) currents for the Hawaiian Archipelago we are able to calculate annual settlement probabilities and self-recruitment values, important metrics for understanding population dynamics. By parameterizing the model after Z. flavescense we are able to compare model results to in situ recruitment data. Comparing dispersal probabilities during three years surrounding the 1998 El Niño with five years of neutral state oceanographic conditions (2009-2014), we can see if recruitment increases during El Niño and gain insight into potential drivers of dispersal during these events. Since these ecologically rare but extreme events can have a disproportionate influence on dispersal, it's important to understand the underlying drivers in order to manage for diverse coral reefs in the future.

II.2 - **Population persistence in the face of climate change and competition: a battle on two fronts**

Scott Rinnan (University of Washington) <rinnan@u.washington.edu>

Many species undergo significant shifts in population distribution in response to changes in climate. This adaptive response can introduce a species to new competition from invasive organisms, or influence the dynamics of an otherwise balanced ecosystem. How can a species ensure its own survival when faced with climate change and other species that are competing for the same resources?

We examine a two-species discrete-time, continuous-space population model to determine under what scenarios the two populations can coexist, and the criteria for persistence in a changing climate. We use this model to simulate a hypothetical native population of bull trout (Salvelinus confluentus) that is experiencing competition from invasive brook trout (S. fontinalis) as their stream habitat warms due to climate change.

Finally, we show how these population dynamics can be incorporated into climate envelope models to better account for dispersal ability and species interactions.

II.3 - **Impacts of shrub expansion on food availability for migratory passerines in western Alaska**

Molly McDermott (University of Alaska - Fairbanks) <mtmcdermott@alaska.edu>

Shrub thickets have increased in coverage across the Arctic in recent decades as temperatures have risen and permafrost has thawed. This is affecting the distribution of suitable breeding habitats for many migratory bird species, and as well as the abundance and phenology of their arthropod prey. Arthropods are sensitive indicators of temperature change and are the most important food source for songbird nestlings. However, their life cycles and habitat associations remain understudied components of arctic food webs.

My research focuses on understanding how arthropod phenology and community composition differ across a gradient of habitats from open tundra to willow-birch thickets in the boreal-Arctic transition zone of northwestern Alaska. I examine the selection of arthropod prey in this habitat gradient by two shrub-obligate species, Gray-cheeked Thrush (Catharus minimus) and Fox Sparrow (Passerella iliaca), and two tundra-nesting species, Savannah Sparrow (Passerculus sandwichensis) and Lapland Longspur (Calcarius lapponicus). I use a combination of pitfall traps and sweep net sampling to quantify the availability of arthropod prey in shrub and tundra habitats over the breeding season. I also identify the most important arthropod prey selected by adults to feed their nestlings through an analysis of crop and fecal samples and behavioral observations. Finally, I examine how spatial and temporal variation in prey availability affects nestling diet diversity. Characterizing food availability and selection in these rapidly changing habitats will help scientists model how avian populations may respond differentially to climate-mediated changes in Arctic ecosystems.

II.4 - **Climate impacts of plant structural acclimation in response to climate change**
Marlies Kovenock (University of Washington) <kovenock@uw.edu>

The climate impacts of changes in plant structure in response to climate change, called plant structural acclimations, could be drastic but are poorly understood. Vegetation modifies Earth's climate by controlling the fluxes of energy, carbon, and water. Changes in vegetation functioning and distribution have both been shown to dramatically impact climate - altering global and regional temperatures, biogeochemical and hydrological cycles, and atmospheric circulation. Of critical importance is a better understanding of how vegetation will respond to climate change and how these plant responses will feedback on climate. Field and greenhouse observations show that key plant functional traits are altered in response to elevated carbon dioxide and temperature. Yet, little is known about how these plant acclimations to climate change, which could dramatically influence plant functioning and distribution, will feedback on climate. Here, we present findings that establish an order-of-magnitude estimate of the climate impacts of a commonly observed structural acclimation to elevated carbon dioxide – a decrease in specific leaf area (m^2 leaf area/g leaf mass). We use global climate model simulations to assess the climate impacts due to the direct effect of a change in specific leaf area, as well as the associated indirect photosynthesis effect and the combined effect. Results suggest that plant structural acclimations could significantly impact regional temperatures, global carbon and hydrological cycles, and atmospheric circulation. This research will guide further inquiry into the impacts of structural acclimations on climate and plant distribution, as well as their ecological and physiological underpinnings.

POSTER SESSION B.II: ECOLOGY — NOV 7, 7:00 - 8:30 PM

B.II.1 - **Modeling spatial conservation of Hawaiian fisheries under a changing climate**
Maia Kapur (University of Hawaii) <mkapur@hawaii.edu>

Uncertainty regarding the response of coral reef ecosystems to climate change is a major concern for the conservation of fisheries and ecosystem services in tropical island societies. One of the primary challenges to investigate the dynamics of reef ecosystems under climate change is adequately representing the complex interactions of physical drivers, biological components, and anthropogenic activities. To explore the dynamics of these complex systems, we utilize a set of models to describe dominant physical forcing functions (e.g., seawater temperature anomalies, wave energy, nearshore run-off), biological interactions (e.g., larval connectivity, herbivory, piscivory), and fishery harvest on reef ecosystems across the main Hawaiian Islands under two future climate scenarios, IPCC Fifth Assessment Report Representative Concentration Pathway (RCP) 4.5 and RCP 8.5. This project utilizes CORSET (Coral Reef Scenario Evaluation Tool), a tool applied previously on Caribbean and Indo-Pacific reefs, to evaluate how different environmental scenarios and anthropogenic actions may affect food web and community structures on Hawaiian reefs. Most importantly, the model will test the efficacy of conservation techniques, such as the creation of herbivore no-take zones or reduced fishing effort. This talk will describe methodologies and preliminary results that aim to illustrate how spatially varying fishing effort may affect the community composition and other ecological characteristics of coral reefs and their associated fisheries over the next century.

B.II.2 - **High-elevation spruce-fir birds: Vulnerability to climate change and prospects for conservation within the Northern Forest**

Tim Duclos (University of Massachusetts, Amherst) <tduclos@umass.edu>

Recent research indicates that several ecological changes are occurring within the mountains of the Northern Forest. Specifically, within the White Mountain National Forest of New Hampshire, changes have been observed in climate as well as the abundance and elevational distribution of both the higher and lower elevation montane bird communities and forest communities. Much of these areas are protected as wilderness or otherwise managed against incompatible forms of land use, however, these forests and the birds that inhabit them, still remain vulnerable from external threats like that of climate change. Managers need more information regarding how these observed changes in the montane climate and vegetation may be driving the observed changes in bird community. In this study I am investigating the direct influence of climate upon montane birds versus indirect climate effects mediated by influences on habitat by measuring breeding bird abundance, predator abundance, habitat characteristics, and temperature at 150 sampling points located along elevational routes ascending 15 mountains in the White Mountain National Forest. I hypothesize that the vulnerability of birds within high-elevation forests could be a function of direct climate effects, indirect climate effects mediated by habitat change, or a function of the distribution of predators or competitors. The results of this project will increase the ability to forecast changes in populations of priority bird species in protected areas subject to climate change and to identify climate refugia and facilitate their protection from incompatible land uses.

B.II.3 - **Predicting potential maximum forest canopy height and total aboveground biomass under climate change**

Sungho Choi (Boston University) <schoi@bu.edu>

Forest canopy height and aboveground biomass (AGB) are major biophysical properties used in the forest carbon accounting across scales. Recent studies suggested modeling approaches such as simple regressions, spatial statistics or machine learning algorithms in the extensive prediction of forest height and biomass. Such models are highly predictive but often neglect physical and physiological principles underlying forest growth. Unseen conjugations of explanatory variables in those black-box type models are not directly applicable to different study regions and periods so that their prognostic applications are problematic. This research presents a new approach for the large-scale modeling of forest canopy height and aboveground biomass based on the application of the metabolic scaling theory (MST) and water-energy balance principles (Penman-Monteith (PM) equation). The MST and PM theories provide a generalized mechanistic understanding of relationships between forest structure and the geospatial predictors including topography and climatic variables. Our model, called Allometric Scaling and Resource Limitations (ASRL), has a prognostic ability and predicts ±4 m changes of maximum canopy height with 20% precipitation and 2°C temperature variations. This study also incorporates the NASA Earth Exchange (NEX) Downscaled Climate Projections (NEX-DCP30) dataset, comprising of future maximum/minimum temperature and precipitation datasets under the four Representative Concentration Pathways (RCPs) scenarios.

SESSION III: PALEOCLIMATE AND CRYOSPHERE

NOV 7, 9:30 - 11:00 AM

III.0 – **Paleoclimate and cryosphere session introduction**

Cristi Proistosescu (Harvard University) <cproist@fas.harvard.edu>
and **Ning Zhao** (MIT-WHOI Joint Program) <nzhao@whoi.edu>

Climate processes act on a very wide spectrum of time-scales. In the absences of direct observations and controlled experiments, we have to rely on proxy records and numerical simulations in order to understand variability on long time scales. This session explores a variety of proxies for reconstructing pastclimate variability on both regional and inter-hemispherical scales. Changes in temperature, water cycle, windfield and the cryosphere are presented. Of particular interests are changes in the polar regions and the cryosphere, which are explored both in terms of their history and numerical models. These have some of the largest potential for change during past, present and future.

III.1 - **Freeze-up in the Arctic Ocean: new processes in response to a changing climate**

Alice Bradley (University of Colorado - Boulder) <alice.bradley@colorado.edu>

As the Arctic is increasingly being used for economic purposes, the ability to understand and forecast the date of ice growth is more important than ever for human and environmental safety. This study examines the cooling processes in the summer mixed layer of the upper ocean between the increasingly warm late-summer Arctic Ocean and the onset of ice growth. In situ measurements of upper ocean temperatures from buoys and a number of CTD profiles in the Beaufort and Chukchi regions indicate that as expected, most of the heat in the upper ocean is lost to the atmosphere at the surface. However, a not-insubstantial amount of heat gets trapped below the summer mixed layer in temperature features similar to the Near Surface Temperate Maximum, but seemingly created through sudden decreases in mixing depth associated with passing storms. This heat will, on erosion of the summer halocline, slow the growth of sea ice likely resulting in thinner ice cover. This mechanism for trapping heat has not been previously observed, and is likely stemming from the dramatically warmer summer Arctic Ocean surface temperatures observed in recent years. The changing climate is fundamentally changing the seasonal cycle of ice growth in the Arctic Ocean.

III.2 - **Two centuries of coherent Pacific-North American climate change at decadal timescales**

Sara Sanchez (Scripps Institution of Oceanography) <scsanche@ucsd.edu>

The last several years of severe North American weather have been characterized by the presence of a resilient atmospheric ridge across the West Coast of the United States, prompting extreme drought in the western U.S. and severe winters in the Midwest and East Coast regions (Seager et al. 2014, Wang et al. 2014, Hartmann et al. 2015). This ridge has been connected to a pattern of SST anomalies off the West Coast of North America (Bond et al. 2015, Hartmann et al. 2015), but the pattern and strength of anomalies raise questions about their connection to known climatic modes, unusual tropical-extratropical interaction, and the possible influence of

anthropogenic climate change.

Here we introduce a 178 year, seasonally resolved Porites coral record from Clarion Island (18N, 115W), the westernmost island of the Revillagigedos Archipelago. The δ18O signal from the Clarion coral, when compared with tree ring records from the western United States and coral records from the central and western tropical Pacific, offers an extended framework of cohesive continental hydroclimate and oceanic variability across the Pacific basin beyond the instrumental record. The records suggest that (i.) the current conditions across the Pacific are most likely an example of coherent pan-Pacific variability featuring strong tropical/extratropical interaction; (ii.) the recurrence interval of this variability evolved slightly over the past two centuries, but spatial coherence patterns remained constant (ii.) the decadal variability of the early 19th century was especially strong, implying that the period used to define current water policy is actually a period of fairly mild variability, given a longer historical context.

III.3 - **Reconstructing past water balance changes from closed-basin lakes in the Central Andes**

Christine Chen (MIT-WHOI Joint Program) <ccy@mit.edu>

Speleothem-based oxygen isotope records provide strong evidence of anti-phased behavior of the northern and southern hemisphere summer monsoons during Heinrich events, but we lack rigorous constraints on the amount of wetting or drying occurring in monsoon regions. Studies centered on shoreline deposits of closed-basin lakes are well suited for establishing such quantitative bounds on water balance changes by providing unequivocal evidence of lake volume variations.

We present new dating constraints on lake level variations in Agua Caliente I, Salar de Loyoques, and Laguna de Tara, three closed-basin, high-altitude paleolakes on the Altiplano-Puna plateau of the Central Andes (23°S, 67°W, 4200-4500 masl). This area in northern Chile is presently home to several small (<40 km^2) lakes and salt pans surrounded by well-preserved paleoshorelines that indicate previous intervals of much wetter conditions. These basins are unique, having abandoned shorelines encrusted with abundant biologically-mediated calcium carbonate “tufa” deposits. Initial U-Th dating of these tufas and other lake carbonates reveal that these deposits are dateable to within ±50 to 300 years due to high U concentrations and low initial Th content. Our initial U-Th dates suggest that these lakes were higher in lake level during three periods: 17.5-14.5 kyr BP, coincident with Heinrich Event 1; 24-23 kyrs BP, coincident with Heinrich Event 2; and at some point between 114 and 140 kyr BP. These lake expansions correspond to 5- to 9-fold increases in lake surface area relative to modern.

Because of their location at the modern-day southwestern edge of the summer monsoon, intact shoreline preservation, and precise age control, these lakes may uniquely enable us to reconstruct the evolution of water balance (precipitation-evaporation) changes associated with Heinrich events. We also probe at North Atlantic cooling as the mechanism for these changes by comparing the precipitation response of various hosing experiments and CMIP5 paleo-simulations over the Central Andes. Our results in these lake basins act as a proof of concept, and lend us confidence in expanding our U-Th work to other shoreline tufas in the surrounding region to produce a more detailed, spatiotemporal record of water balance changes in South America.

III.4 - **Leaf wax biomarkers as proxies for regional climate variation during hominin evolution**

Rachel Lupien (Brown University) <rachel_lupien@brown.edu>

The extent to which climate variation influenced hominin evolution continues to be debated. This discussion is partly fueled by a lack of high-quality paleoclimate records from the sites of known hominin existence. To further the understanding of this relationship, we generated paleo-environment records from the early Pleistocene in East Africa using organic biomarkers from ancient lake sediments. The sediments were drilled as part of the Hominin Sites and Paleolakes Drilling Project, an international effort to study the past climate of our hominin ancestors' evolution and dispersal.

There are various theories on the link between climate change and the ability of Homo sapiens to eventually emerge and persist. Many ideas, such as the concept that a drying Africa forced humans to come out of the trees and walk upright, are overly simplistic. The more plausible "variability selection" hypothesis posits that higher-frequency environmental variations selected for generalist traits that allowed hominins to expand into variable environments.

We analyzed isotope ratios of terrestrial leaf waxes preserved in the lake sediments of West Turkana in Kenya. The sediment spans roughly 1.45-1.9 Ma, and contains some of the first fossils from the genus Homo. The biomarker hydrogen and carbon isotopes provide relatively straightforward indicators of rainfall amount and vegetation structure, respectively. The timing and nature of critical transitions in human evolution recorded in this basin are compared against these environmental records to constrain the developing evolution hypotheses.

POSTER SESSION B.III: PALEOCLIMATE AND CRYOSPHERE

NOV 7, 7:00 - 8:30 PM

B.III.1 - **Equatorial Pacific Dust Fluxes: Insights into the Intertropical Convergence Zone and the last four glacial terminations**

Alison Jacobel (Columbia University, Lamont-Doherty Earth Observatory) <jacobel@ldeo.columbia.edu>

The position of the Intertropical Convergence Zone (ITCZ) has been hypothesized to play a role in linking the climate of the poles and in predicating important changes in ocean overturning, particularly on deglacial timescales. The position of the ITCZ has also been tied to changes in equatorial upwelling strength, marine productivity, terrestrial aridity and even the collapse of civilizations such as the Classical Maya.

One method of tracking the paleo-position of the ITCZ is through the quantification of $^{230}Th_{xs,0}$-normalized ^{232}Th concentrations in marine sediments which act as proxy for dust flux. Because the ITCZ is an efficient scavenger of atmospheric particulates, changes in dust deposition can

yield insight into variations in ITCZ position. Additionally, changes in the total amount of dust can provide information about environmental conditions in dust source regions.

Here, we present high-resolution (sub millennial) records of dust flux from Marine Isotope Stage 10 through the Holocene (~350ka - 10ka) at sites in the central Equatorial Pacific. Our records provide the first evidence of an abrupt increase in northern hemisphere dust flux and a shift in the ITCZ during the penultimate deglaciation, with timing similar to that of Heinrich Event 11. We compare our data to existing records of Antarctic dust fluxes, ice volume and CO2 and discuss similarities and differences between the last four glacial terminations, providing new insights into the character of these profound variations in climate.

B.III.2 - **Reconstructing the Late Holocene record of eolian activity as a proxy for drought, Southern Great Plains, USA**

Kasey Bolles (Baylor University) <kasey_bolles@baylor.edu>

The image of a black duster is one of the most iconic images from an arduous time in American history. Dust entrained from the Great Plains, which typically bring to mind images of fertile fields and gently rolling plains, engulfed regions of the country in a "dust bowl", causing economic devastation to farmers and health issues for all. We now know that the High Plains region is the largest source of mineral dust aerosols in North America (see: Ginoux et al. 2012). However, what remains unknown are the geomorphological and sediment characteristics of dust-emitting surfaces, linkages between fluvial and adjacent eolian environments, and the spatial and temporal dynamics of dust-emission. With the recognition of dust as an important climatic driver, and that anthropogenic climate change could lead to greater dust emission, it is vital to understand these environments. This project will call on methods from a range of disciplines to quantitatively assess the landscape response to drought over the last 2000 yr BP. Intensive fieldwork will result in a database of stratigraphic, paleopedologic, ecological, geochemical and geochronological data for eolian deposits along the Red and Canadian Rivers in northern Texas, selected for their position crosscutting the distinct bioclimatic gradient that characterizes the Great Plains. Analysis will include investigation of boundary conditions and/or thresholds for dune activation under different climate regimes. In turn, drivers and feedbacks in dune evolution will be evaluated in the context of severe drought, and the spatial and temporal dynamics in fluvial-eolian system interactions will be explored.

B.III.3 - **Modeling the Deglaciation of the Greenland Ice Sheet**

Benjamin Keisling (University of Massachusetts – Amherst)
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Sea-level rise threatens the lives and livelihoods of billions of people worldwide. Today, the melting Greenland Ice Sheet (GrIS) is a major driver of sea-level rise. Unfortunately the processes through which ice-sheets retreat are not fully understood, hindering our capacity to make accurate predictions of future sea-level rise. The last major change in GrIS volume occurred at the end of the last ice age, when ice retreated from its maximum ice age extent to its more modest modern configuration. Here, we use a shallow-ice/shallow-shelf approximation hybrid model of the GrIS to study this "deglaciation." Our approach forces the ice-sheet model with surface air temperatures and ocean temperatures known from paleoclimate studies to discern the salient mechanisms that drove deglaciation for the whole ice sheet as well as within discrete basins. We present initial results from key outlet glaciers around Southwest Greenland, including Jakobshavn Isbræ, and compare the model-derived retreat rates with retreat rates inferred from field observations. If our model can adequately capture the dynamics of the last deglaciation, it may be particularly well-suited for predicting sea-level rise contributions from GrIS in the coming century.

B.III.4 - **History of grounded ice in the Ross Embayment at and since the Last Glacial Maximum using glacial deposits alongside the Hatherton Darwin glacier system, Antarctica.**

Courtney King (University of Maine) <courtney.king@maine.edu>

During the Last Glacial Maximum (LGM), the Antarctic Ice Sheet (AIS) grounded across what today is the Ross Sea. This grounded Ross Sea ice buttressed outlet glaciers flowing seaward from East Antarctica through the Transantarctic Mountains (TAM), causing them to thicken. Ice-dammed ponds containing algae formed alongside the margins of the thickened outlet glaciers. Previous studies from alongside Reedy Glacier, far south in the TAM, indicate the timing of greatest ice extent varies along its longitudinal profile: near the glacier mouth it occurred ~14-17 ka, in contrast, near the glacier head, it occurred ~7-9 ka. The timing of the subsequent recession follows similar suite with earlier retreat recorded closer to the mouth. The difference in timing along the profile is attributed to a grounded Ross Sea ice sheet causing a buttressing effect that resulted in thickening (and subsequent thinning) up glacier. Farther north, a similar history is proposed for the Hatherton-Darwin outlet glacier system (HDGS), located along the Hillary Coast of the Ross Sea. Here we present radiocarbon ages of fossil algae collected from relict lake deposits from alongside the HDGS. It is important to determine the timing of fluctuations of HDGS because it bears heavily on important implications for the future stability of the AIS as it responds to changing climate conditions.

B.III.5 - **On the role of inter-hemispheric gradients in volcanic forcing on tropical hydroclimate and oxygen isotope responses.**

Chris Colose (University at Albany) <ccolose@albany.edu>

The last 1000 years of the pre-industrial period (850-1850 C.E.) is the most recent key interval identified by the Paleoclimate Modelling Intercomparison Project Phase III (PMIP3). Data for tens of thousands of years of simulation time are available that employ estimates of time-varying volcanic aerosol, solar irradiance, greenhouse gases, land-use change, and orbital variations with fully-coupled models used to make future projections. This provides a unique laboratory setting to explore hypotheses for a climate operating under boundary conditions fairly similar to the present, and for which the largest network of high-resolution paleoclimate "proxy" data exists.

Volcanic forcing is among the most important of these forcings. The CMIP5/PMIP3 generation of last millennium simulations use two different datasets of reconstructed paleo-volcanic activity, each based on networks of sulfate peaks in ice cores. One unexplored characteristic of these datasets is the diversity of the spatial structure in forcing for different events. Here, I focus on the question of how the spatial distribution of volcanic forcing matters for the resulting climate response— in particular, whether an event in focused in the Northern or Southern

Hemisphere.

Emphasis is placed on the tropical hydroclimate response to volcanic asymmetries in forcing, as well as the resulting oxygen isotope imprint that may expressed in paleoclimate observations. Attention is given to the energetic constraints that allow the Intertropical Convergence Zone (ITCZ) to migrate in response to hemispheric asymmetries, and to diagnose how and why the ITCZ position is sensitive to aerosol forcing and the radiative feedbacks operating in these simulations.

B.III.6 - **Past, present, and future South American glacial responses to climate change**

Andrew Malone (University of Chicago) <amalone@uchicago.edu>

The retreat of modern mountain glaciers is often attributed to contemporary climate change, and geomorphic records of glacier length changes are often used to denote past climate change. However, interpreting the climate signal associated with glacier length changes requires an understanding of glacier-climate interactions. Our understanding of these interactions primarily comes from studies of northern hemisphere mid and high-latitude glaciers, but glaciers span nearly all latitudes and a variety of climates, and these interactions may vary for different regional climates. The South American Andes, which span ~55 degrees of latitude and contain glaciers nearly throughout, are ideal for studying glacier-climate interactions in different regional climates. I use a numerical glacier 1-D flowline model coupled to an energy balance ablation model to quantify glacier length changes due to temperature and precipitation rate changes for idealized Andean glaciers. I find that mid-latitude Andean glaciers (warm and wet) are the most sensitive to temperature changes while subtropical Andean glaciers (cold and dry) are the least. Also, I find that sub-tropical Andean glaciers (cold and dry) are the most sensitive to precipitation rate changes while tropical Andean glaciers (warm and wet) are the least. Finally, I find that tropical Andean glaciers require the greatest precipitation rate increases to offset the retreat from warming, making them the most vulnerable to anthropogenic warming. These results can aid interpretations of the late-Quaternary Andean glacial geomorphic record, further understanding of contemporary Andean glacial retreat, and assist water resource planning for South American populations dependent on glacial runoff.

B.III.7 - **The influence of pH on the variability of the Mg/Ca temperature proxy and other metal/calcium ratios in planktonic foraminifera**

Elisa Bonnin (University of Washington) <ebonnin@uw.edu>

The Mg/Ca ratio of foraminiferal calcite is a widely-used proxy for past ocean temperatures, however, studies conducted in the past decade have shown that the Mg/Ca ratio is not constant throughout the shell. Instead the Mg/Ca ratio of foraminiferal calcite varies systematically between day and night, a phenomenon that occurs even under constant temperatures and has yet to be explained mechanistically. This biologically driven Mg/Ca signal can be interpreted as a temperature change of greater than 10°C. In addition, the Mg/Ca of foraminiferal calcite has been shown to vary with pH, creating further variability in the Mg/Ca temperature proxy. Understanding what causes these effects, testing if they are linked, and uncovering variability in other metal/calcium-based climate proxies is an essential step for properly interpreting climate records in this archive. Using time-of-flight secondary ion mass spectrometry (ToF-SIMS), an isotope mapping technique with a spatial resolution of roughly 200 nm, we confirm previous reports that the amplitude of Mg/Ca variation is reduced significantly at increasing carbonate concentrations. This change in Mg/Ca banding is reflective of the variability in mean Mg/Ca ratios with regards to pH, suggesting that understanding the relationship between Mg/Ca banding in planktonic foraminifera and environmental conditions such as pH and salinity may allow us to correct for variability in the Mg/Ca temperature proxy. Furthermore, we uncovered a new class of banding: Na/Ca. The relationship between these two metal systems could help us understand the fundamental mechanisms driving banding leading to holistic models for metal/calcium-based climate proxies in foraminifera.

B.III.8 - **Examining the Mid- Brunhes Event in the terrestrial Arctic: an organic geochemical record from Lake El'gygytgyn, Russia**

Helen Habicht (University of Massachusetts Amherst) <mhabicht@cns.umass.edu>

Our capacity for understanding current climate change and predicting future climatic evolutions depends on our comprehension of past climate variability. The Arctic is currently undergoing rapid and unprecedented environmental change, making knowledge of its paleoclimate history critical. The Pleistocene Epoch (2.58 Ma- 11.7 ka) is characterized by strong climatic fluctuations between warm interglacial periods and cold glacial periods. These interglacials are of particular interest as they provide an anolog for comparison with the present interglacial, the Holocene (11.7 ka- present). Numerous globally distributed records have noted a dramatic increase in interglacial amplitude (i.e. warmer interglacials) after the Mid- Brunhes Event (MBE), a climatic transition ~430 ka. However, the geographic extent and mechanism of the MBE remain uncertain. This study investigates the MBE in the terrestrial Arctic using an organic geochemical approach toward sediments from Lake El'gygytgyn, Russia located 100 km north of the Arctic Circle. The record spans the interval of 250- 800 ka, providing a robust sense of climatic variability before and after the MBE. Paleoclimate temperature reconstructions are produced by analysis of branched glycerol dialkyl glycerol tetraethers (brGDGTs) and Deuterium/Hydrogen ratios of plant leaf wax n- alkanes, while n- alkane Average Chain Length (ACL) is utilized as a proxy for aridity changes. Preliminary results of this multi- proxy analysis confirm the presence of an MBE signal in the terrestrial Arctic, with warmer and wetter interglacials developing after 430 ka.

SESSION IV: ATMOSPHERIC DYNAMICS — NOV 7, 11:15 AM - 12:45 PM

IV.0 – **Atmospheric dynamics session introduction**

Andy Miller (MIT) <awmiller@mit.edu>

This session focuses on large scale processes that fundamentally shape the climate of the atmosphere. The scientific progress is often described as going from data to theory. Theories then inform further experiments and ultimately new observations. The talks in this session describe every step of this process despite coming from completely different fields of atmospheric science. The first talk introduces a new theory to interpret existing data. Two talks will cover both the formulation and the interpretation of models before the last talk will come full circle by comparing numerical results with new observations. The specific topics of the talks and posters represent the huge variety within atmospheric dynamics today. They range from the influence of ocean and land-processes on the atmosphere to the effects variations in solar radiation on the dynamics of the stratosphere and the paleoclimate.

IV.1 - **A moist formulation of the Eliassen-Palm flux diagnostic**

Ray Yamada (Courant Institute of Mathematical Sciences, NYU) <ray230@nyu.edu>

Eliassen-Palm (EP) flux diagnostics have been widely used to explain how midlatitude eddies drive the zonal-mean flow. Most commonly, the EP flux is presented in the quasi-geostrophic transformed Eulerian mean (TEM) framework, in which the explicit eddy forcing of the mean flow arises only through the EP flux divergence. Using isentropic coordinates, much work was carried out in the 1980s to generalize the EP flux for finite-amplitude waves and non-geostrophic flows. Current formulations of the EP flux are, however, mostly limited to dry dynamics, and fail to differentiate air masses by their moisture content. In this work, we address this problem by developing a formulation of the EP flux and momentum balance in moist coordinates.

The moist EP flux diagnostic is applied here to study the momentum budget in midlatitude stormtracks. Recent studies have shown that averaging the mass flux on moist isentropes leads to a much stronger meridional circulation than dry residual circulations, which inadequately capture the mass transport associated with poleward eddy moisture fluxes, such as those carried by atmospheric rivers. It is shown here that this implies a similar increase in the EP flux between the dry and moist frameworks. Physically, the increase in momentum exchange is tied to an enhancement of the form drag associated with the horizontal structure of the midlatitude eddies, where the poleward flow of moist air is located in regions of strong eastward pressure gradient.

IV.2 **Introduce a collaborative research project: Topographically bound balanced motions, and the mathematical work involved**

Zhengqing (James) Chen (Clarkson University) <zhechen@clarkson.edu>

This is an NSF project, which examines the fundamental dynamics of persistent low-level atmospheric flows which are found along the slopes of mountain ranges and other topographic features. Important examples include the Great Plains low-level jet, the South American low-level jet on the east side of the Andes, and the low-level jet found along the coast of Chile and Peru.

This project is a collaborative one. For the mathematical part, our main goals are: (1) To develop a fast numerical solver for the dynamics; And (2) In search of analytical solutions to the problem. Goal Number One has basically been finished, by developing a fast solver implementing the multigrid method. Goal Number Two is in progress, by using a novel solution method, the so-called Fokas' method. It is hoped that from the analytical solutions, more insight can be gained into the dynamics.

I would like to introduce the physical pictures of the problem and the dynamics, the numerical solutions to the dynamics, and the search for analytical solutions. More important, I would like to hear the peers' feedback, such as the climate significance of this specific atmospheric motion, the atmospheric scientists' evaluation and critics on the solutions. I am merely a student in applied mathematics, and am a total amateur in the aforementioned aspects.

IV.3 - **Unforced decadal-scale global mean warming and cooling in climate models**
Eleanor Middlemas (Rosenstiel School of Marine and Atmospheric Science - University of Miami) <e.middlemas@rsmas.miami.edu>

The current global warming hiatus has been attributed to natural variability through deep ocean heat uptake on the basis of deep ocean observations and climate models. However, questions remain about the robustness of these results across models and about the role of the ocean. In this study, we examine preindustrial control CMIP5 model runs to examine robust features associated with unforced hiatus and warming decades. We also use the same analysis techniques for two different CCSM4 models to test the role of the ocean. These models consist of AGCM CAM4 coupled to a slab ocean mixed layer and fully coupled CCSM4 with preindustrial control forcing. The AGCM-slab model cannot store heat aside from the heat capacity of the mixed layer. Our results show that CMIP5 models robustly simulate the spatial pattern of hiatus decades, but the frequency of occurrence varies considerably. All models contain an ENSO signal, suggesting a role for ENSO modulation in the frequency of hiatuses. Results from the hierarchy of CCSM4 models suggest that thermal coupling of atmosphere to ocean contributes the most to the spatial pattern of unforced decadal variability. Ocean processes strengthen the ENSO signal, which increases the variance of decadal trends and contributes to the frequency of hiatus periods, but does not affect the global pattern. This study has implications for the mechanism underlying unforced decadal variability and its interaction with anthropogenic global warming.

IV.4 - **Impacts of cloud properties and behavior on polar radiative balance**
Elin McIlhattan (University of Wisconsin - Madison) <elin@aos.wisc.edu>

Investigations of cave microclimate is important for understanding the complex relationships between cave calcite chemistry and changes in outside temperatures, cave ventilation, net rainfall, cave drip rates, and fluctuations in cave dripwater. Being a natural laboratory, a cave carries imprints of ancient and recent climates, allowing us a unique setting for studying climate change. Proper modeling and simulation of airflow in the cavern will help interpret speleothem records more accurately.

We instrumented Dragon’s Tooth Cave (Marianna, Florida, USA) with an array of instruments to characterize the ventilation patterns within the cave. Temperature, relative humidity, barometric pressure, airflow direction and rates were monitored hourly in several locations from November 2011 until September 2013. During the summer, the cave is cooler than the outside air so outside air is entering the cave through the upper entrance. Warm and buoyant atmospheric air cools down and escapes through the tunnel into Miller's Cave. During the winter the cave is warmer than the outside air so the ventilation pattern reverses: cold and

dense atmospheric air flows into the warmer cave through the Miller's tunnel, gets warmed up and escapes through the upper entrance. The analytical model of the air ventilation driven by temperature difference between the cave interior and the outside air was developed to simulate the air circulation patterns within the cave. The findings have important implications for the interpretation of speleothem paleoclimate records in terms of both, geochemistry and seasonal growth rates.

POSTER SESSION B.IV: ATMOSPHERIC DYNAMICS

NOV 7, 7:00 – 8:30 PM

B.IV.1 - **A "land kernel" to isolate the influence of the land on the atmosphere**

Marysa Lague (University of Washington) <mlague@uw.edu>

Interactions between the land and the atmosphere are complex and non-linear. Fluxes of energy, water, and carbon between the land and atmosphere can influence the climate on both local and global scales. Vegetation albedo, or color, controls how much incoming solar radiation is absorbed by the surface. Water (latent heat) fluxes from the land to the atmosphere occur through the process of evapotranspiration. Sensible heat fluxes depend on the roughness of the land/vegetation, while carbon fluxes are controlled through photosynthesis and respiration.

Many studies have considered the impacts of large-scale vegetation change on global climate. For instance, increasing forest cover in the tropics, where the surface energy budget is dominated by water fluxes, increases cloud cover and lowers global temperatures. At high latitudes, the albedo effect is dominant, so afforestation leads to increased temperatures. In temperate regions, it is unclear which surface energy budget term is dominant.

As the land models implemented in global climate models become increasingly complex, it becomes more difficult to identify the mechanisms through which large-scale vegetation is influencing climate. We conduct sensitivity studies using an idealized land model, which isolate the impact of changing individual surface parameters on the atmosphere. By systematically modifying a single surface variable (e.g. albedo or latent heat flux) at each grid point, we can calculate the sensitivity of the atmosphere to a given change in land surface. In this way, we build up a “land kernel”, which captures the first-order atmospheric response to an arbitrary change in vegetation cover.

B.IV.2 - **Robust effects of ocean heat uptake on radiative feedback and subtropical cloud cover: a study using radiative kernels**

Lance Rayborn (University at Albany, SUNY) <lrayborn@albany.edu>

Transient climate change depends on both radiative forcing and ocean heat uptake. A substantial fraction of the inter-model spread in transient warming under future emission scenarios can be attributed to differences in “efficacy” of ocean heat uptake (suppression of surface warming per unit energy flux into the deep oceans relative to CO_2 forcing). Previous studies have suggested that this efficacy depends strongly on the spatial pattern of ocean heat uptake. Rose et al (2014) studied this dependence in an ensemble of aquaplanet simulations with prescribed ocean heat uptake, and found large differences in model responses to high versus low latitude uptake. In this study we use radiative kernel analysis to accurately partition these responses into feedbacks associated with temperature, water vapor and clouds. We find large and robust differences in both clear-sky longwave feedbacks and shortwave cloud feedbacks, with high-latitude uptake exciting substantially more positive feedback (higher efficacy) than low-latitude uptake. A particularly surprising result is the robustness across several independent GCMs of the differences in subtropical low cloud feedback (positive under high-latitude uptake, strongly negative under tropical uptake). We trace these robust differences to thermodynamic constraints associated with lower-tropospheric stability and boundary layer moisture. Our results imply that global cloud feedback under global warming may be partly modulated by ocean heat uptake. Improved modeling of regional ocean processes (which set the spatial pattern of heat uptake) may thus lead to narrowing the uncertainty in transient climate response.

B.IV.3 - **Eccentricity forcing and preconditioning of unusually warm superinterglacials**

Rajarshi Roychowdhury (University of Massachusetts, Amherst)
<rajarshi.es@gmail.com>

Global climate during Quaternary and Late Pliocene is characterized by alternating glacial and interglacial conditions. Recently, several interglacials have been identified as warmer than others, like 9, 11, 31, 49, 55, 77, 87 and 91. We have statistically observed that these superinterglacials follow low eccentricity periods, with a lag of ~50kyr. The explanation we propose for this low eccentricity preconditioning of the super interglacials is directly linked to the fact that the polar ice sheets respond differently to precessional changes at different eccentricities. At low eccentricities ($e<0.015$) the effect of precession is minimal, and glacial cycles are in-phase between the two hemispheres. Thus northern and southern ice-sheet variability are concurrent, and appear to be forced by Northern-Hemisphere insolation. At higher eccentricities, precessional effects become important, and the glacial-interglacial cycles vary out-of-phase between the two hemispheres and are forced by local insolation intensities.

Using an ensemble of GCM and ice-sheet simulations covering the superinterglacials, we show that Antarctic ice-sheets follow Northern Hemisphere insolation at lower eccentricities, switching to local Southern Hemisphere insolation at higher eccentricities. This switch from northern forcing to southern forcing leads to Antarctica missing a beat in its glacial-interglacial cycles, as insolation intensities vary out-of-phase at 23 ka precessional periods. Thus, depending on the orbit, Antarctica either has an unusually long glacial or interglacial period following a low eccentricity orbit. In the latter case, prolonged warm conditions in the Southern Hemisphere preconditions the Polar Regions to produce a large response during the superinterglacials like MIS-11 or 31.

B.IV.4 - **A Comparison of Two Daily Temperature Averaging Methodologies: Uncertainties, Spatial Variability, and Societal Implications**

Jase Bernhardt (Penn State University) <Jeb5249@psu.edu>

Traditionally, daily average temperature is computed by taking the mean of two values- the maximum temperature over a 24-hour period and the minimum temperature over the same period. This data is used as the basis for numerous studies and long-term climatologies of temperature trends (e.g. 30-year normals). However, many first-order weather stations (e.g. airports) also record hourly temperature data. Using an average of the 24 hourly temperature readings to compute daily average temperature would be expected to provide a more precise and representative estimate of that particular day's temperature. Thus, these two methods of daily temperature averaging (max+min/2, average of 24 hourly temperature values) were compared for all 262 first-order weather stations across the United States for the 30-year period of 1981-2010. Preliminary data analysis indicates that a statistically significant difference exists between the two methods of temperature averaging, as well as an overestimation of temperature by the traditional method (Tmax + Tmin /2), particularly in southern and coastal portions of the Continental United States. The likely explanation for the long-term difference between the two methods is the underlying assumption of the twice-daily method that the diurnal cycle of temperature follows a symmetrical pattern. Moreover, there may be a relation in these differences to the synoptic climatology of the stations studied, which also may help to explain the spatial variability observed. Additional analysis of station normals based on hourly data could have numerous application with benefits for society, such as better determination of heat wave severity and energy usage needs.

B.IV.5 - **Atmospheric compensation of variations in tropical ocean heat transport: understanding mechanisms and implications**

Cameron Rencurrel (University at Albany, SUNY) <crencurrel@albany.edu>

The poleward transport of energy is a key aspect of the climate system, with surface ocean currents presently dominating the transport out of deep tropics, and atmospheric eddies dominating in mid-latitudes. A classic study by Stone (1978) proposed that the total heat transport is determined by astronomical parameters and highly insensitive to the detailed atmosphere-ocean dynamics. On the other hand, previous modeling work has shown that past continental configurations could have produced substantially different tropical ocean heat transport (OHT). How thoroughly does the atmosphere compensate for changes in ocean transport in terms of the top-of-atmosphere (TOA) radiative budget, what are the relevant mechanisms, and what are the consequences for surface temperature and climate? We examine these issues in a suite of aquaplanet GCM simulations subject to large prescribed variations in OHT. We find substantial but incomplete compensation, in which adjustment of the atmospheric Hadley circulation plays a key role. We separate out the dynamical and thermodynamical components of the adjustment mechanism. Increased OHT tends to warm the mid- to high latitudes without cooling the tropics due asymmetries in radiative feedback processes. The warming is accompanied by hydrological cycle changes that are completely different from those driven by greenhouse gases, suggesting that drivers of past global change might be detectable from combinations of hydroclimate and temperature proxies. Insights gained from analysis of the aquaplanet system are tested against more comprehensive simulations in order to distinguish the influences that features such as sea-ice and land surfaces have on the tropical compensation efficiency.

B.IV.6 - **Re-Analysis Data for Fine Temporal Resolution Wind Power Estimation: A Comparison of Boundary Layer Parameterizations**

Michael Davidson (MIT) michd@mit.edu

Global wind resource assessments have benefitted in recent years from re-analysis datasets, which rely on a diverse collection of measurements and a global circulation model to reconstruct complete wind profiles. With high wind energy penetration, short-term and localized fluctuations are increasingly important relative to average annual availability for power systems planning and operation. Re-analysis methods have difficulty resolving these fluctuations, which are primarily driven by boundary layer atmospheric stability. Leading methods to improve their accuracy such as downscaling are computationally expensive and geographically constrained. Hence, tractable methods using available meso-scale data able to appropriately capture the fine temporal variability of wind farms distributed across large regions could improve siting, operation and policy for power systems.

Wind power densities were constructed from Modern Era Retrospective-analysis for Research and Applications (MERRA) boundary layer flux data produced by NASA at hourly resolution over a thirty-one-year period (1979-2009). I compared these data to several unassimilated wind measurement series and identified errors attributable to diurnal changes in boundary layer stability. I intend to gather additional unassimilated wind measurement series and identify which stability terms and under what conditions these re-analysis products are useful for describing wind resources.

B.IV.7 - **Global Climate Model Simulations of a Temporary Solar Radiation Management Deployment Scenario**

Rick Russotto (University of Washington) <russotto@uw.edu>

Solar radiation management (SRM) is the idea of attempting to counteract global warming by reflecting sunlight, for example by injecting sulfate particles into the stratosphere. Most SRM modeling research so far has assumed that SRM would be used as a substitute for emissions cuts in order to hold the global mean temperature constant. This would lead to imperfect temperature cancellation at regional scales, decreases in global mean precipitation, and extremely abrupt warming as soon as SRM was ceased, and is therefore an unsustainable strategy. In response to these concerns, some have suggested instead deploying SRM on a limited, temporary basis, and coupling it with emissions cuts and possibly carbon dioxide removal (CDR) technologies. The purpose of SRM would then be to limit the rate of warming, rather than stopping it entirely.

In order to test whether such a strategy would work as intended, my collaborators and I are running the first GCM simulations of temporary a SRM deployment, combined with emissions cuts and CDR, following a pre-defined radiative forcing trajectory. We use the fully coupled Community Earth System Model (CESM) version 1.2. CO2 concentrations increase at 1%/year from 2000 to 2050, stay constant until 2075, and then decline at 1%/year until 2125. To partially offset the CO2 forcing, SRM is ramped up from 2025 to 2050, held constant until 2075, and then drawn down to zero at 2100. I will present global and regional temperature and precipitation changes under this scenario.

B.IV.8 - **Dynamical response to an upper stratospheric heating anomaly associated with the 11-year solar cycle**

Erik Lindgren (MIT) <ealindgr@mit.edu>

Variations in total solar irradiance during the 11-year solar cycle are of order 0.1%, but irradiance in the UV wavelength range varies by a few percent. Since UV light both forms and dissociates ozone, there are significant variations in both ozone concentration and temperature in the upper stratosphere over a solar cycle. Reanalysis data also show that there are statistically significant changes in zonal wind and temperature at lower altitudes over a solar cycle, all the way down to the troposphere. These differences cannot be considered direct radiative responses to the change in irradiance, and are thought to be caused by changes in atmospheric circulation. However, exactly how the circulation changes is unknown. To analyze the changes in circulation, an atmospheric GCM was run with and without a heating perturbation in the upper stratosphere. The heating perturbation was meant to represent the observed heating in the upper regions of the ozone layer. The differences between perturbed and unperturbed runs were analyzed, and the changes in circulation were not consistent with a proposed theory for downward propagation of upper stratospheric temperature anomalies. Despite this, the model runs showed significant changes in tropospheric temperature and zonal wind. In this presentation, other possible explanations for the tropospheric changes are explored.

SESSION V: HUMAN DIMENSIONS — NOV 7, 2:00 – 3:30 PM

V.0 – **Human dimensions session introduction**

Daniel Gilford (MIT) <dgilford@mit.edu>

Intersections between the human and climate systems are found throughout human history, but have perhaps never been so tangible and conspicuous as they are now. The influences of humans on the environment and vice-versa are complex, often involving questions of values and risk. These intersections may have significant educational, scientific, social, economic, and political implications. In this session, we explore societal perspectives of climate and climate change, mechanisms of adaptation and/or mitigation, the uncertainties inherent in the human/climate interactions, and the development of climate policy and decision-making.

V.1 - **Climate change education- teachers identifying as scientists**

Peggy McNeal (Western Michigan University) <peggy.m.mcneal@wmich.edu>

For the first time in the history of U.S. science curricula, the Next Generation Science Standards (NGSS) include K-12 performance expectations for global climate change, including an emphasis on anthropogenic causes. Amidst a social environment that is highly polarized, states are currently considering NGSS adoption. However, numerous self-motivated teachers already teach climate change. They are uniquely situated to help us understand the best approach to climate change education, considering the controversy surrounding it.

A qualitative study convened online focus groups of middle school teachers, currently teaching climate change, to examine motivations, dispositions and what is working. The conversation was transcribed and coded using a coding scheme guided by predictors identified in a recent study by Berkman & Plutzer (2015) that examined teacher attitudes toward evolution. They found that strong predictors of how teachers will handle the topic include:
1. Their personal values and dispositions
2. The deepness of their scientific knowledge and training
3. Their subjective assessment of their own expertise
4. Their pedagogical philosophy

Conversation with middle school teachers in focus groups revealed that they strongly identify as scientists as well as educators. Evidence included ongoing relationships with scientists, experience with climate research, involving students in collection of authentic data and presenting at conferences and in journals. According to the results, identification as a scientist is key to being a strong advocate for climate change action in the classroom. Based on these findings, it is recommended that relationships between science educators and scientists be fostered to a high degree.

V.2 - **Assessing vulnerability to extreme heat through individually experienced temperatures (IETs): New insights from Phoenix, AZ**

Evan Kuras (University of Massachusetts - Amherst) <erkuras@gmail.com>

Exposure to extreme heat has become an increasingly important human health risk in light of ongoing climate change and urbanization. Most current knowledge about heat-health vulnerability is based on measurements of air and surface temperatures, and often utilizes zip codes, census tracts, or neighborhoods as appropriate units of analysis. Little is known about temperatures individuals actually experience within neighborhoods and cities, given differential access to cooling resources, complex activity patterns, and heterogeneous thermal and social environments. By recruiting city residents from Phoenix, Arizona to measure their own Individually Experienced Temperatures (IETs), we asked how personal exposures varied within and between neighborhoods and how sensitive those exposures were to changing atmospheric conditions. In September 2014, 80 research participants from among 5 Phoenix-area neighborhoods were equipped with air temperature sensors that recorded IETs as they went about their daily lives, completed surveys and activity log phone calls, and participated in exit interviews. We found that 1) variance in mean IET was relatively equal within each neighborhood, 2) significant differences existed in average mean IET between neighborhoods, and 3) heat exposure sensitivity (defined as change in IET relative to change in outdoor temperature) varied by greater than a factor of two between some neighborhoods. In addition, IET data exposed different vulnerability patterns than more commonly used variables such as surface temperature and vegetative cover. Given a predicted rise in temperatures worldwide, IET insights can help assess differential human health impacts from hazardous atmospheric conditions, especially for vulnerable urban populations.

V.3 - **Allowances for evolving coastal flood risk under uncertain local sea-level rise**

Maya Buchanan (Princeton University) <mayakb@princeton.edu>

Sea-level rise (SLR) causes estimates of flood risk made under the assumption of stationary mean sea level to be biased low. However, adjustments to flood return levels made assuming fixed increases of sea level are also inaccurate when applied to sea level that is rising over time at an uncertain rate. To accommodate both the temporal dynamics of SLR and their uncertainty, we develop an Average Annual Design Life Level (AADLL) metric and associated Design Life SLR (DL-SLR) allowances [1,2]. The AADLL is the flood level corresponding to a time-integrated annual expected probability of occurrence (AEP) under uncertainty over the design life of an asset; DL-SLR allowances are the adjustment from 2000 levels that maintain current average risk over the design life. Given non-stationary and uncertain sea-level rise, AADLL flood levels and DL-SLR allowances provide estimates of flood protection heights and offsets for different planning horizons and different levels of confidence in SLR projections in coastal areas. Here we employ probabilistic sea-level rise projections [3] to illustrate the calculation of AADLL flood levels and DL-SLR allowances for a set of long-duration tide gauges along U.S. coastlines.

V.4 - **Is there an economic component of suicide? Evidence from climate and agriculture in India**

Tamma Carleton (University of California - Berkeley) <tcarleton@berkeley.edu>

The many determinants of suicide have long been studied by psychologists and sociologists, but only a small and more recent literature in economics has contributed to understanding this phenomenon. We utilize a comprehensive set of suicide data from India, one of the countries most publicly struggling with rising suicide rates today, to look for evidence of economically motivated suicide. Using state-level panel data on suicide rates between the years 1967 and 2010 and exogenous variation in climate, we (a) identify the causal effect of variations in temperature and precipitation on suicide rates across the country; and (b) find empirical support for an economic channel through which these shocks affect suicide. We employ a fixed effects framework to show that temperature has a positive and significant effect on suicide, but only during India's main agricultural growing season; for growing season days above 10°C, a 1°C increase in daily temperature causes an additional 170-360 suicides. Contrary to public discussions of drought and suicide in India, growing season precipitation has no identifiable impact on suicide rates. However, unexpected rainfall outside the growing season significantly increases suicide deaths, likely due to profit losses that accompany unpredicted rainfall and to flood-induced late-season crop loss. With additional mechanism tests linking suicides and yield shocks, we conclude that climate variation impacts suicide, at least in part, through economic channels. Our results provide some justification for the development of suicide prevention policies that ameliorate the negative economic shocks suffered by agriculture-dependent households in India, such as debt relief. We also contribute to a growing literature on the social and economic impacts of climate change. Suicide prevalence, an indicator of severe hardship, may capture facets of welfare previously unmeasured in the climate change literature, and thus suggests a new avenue through which we can assess the climate-welfare relationship.

POSTER SESSION V: HUMAN DIMENSIONS NOV 8, 9:55 – 11:25 AM

C.V.1 - **The socio-ecological system of razor clams and the Quinault Indian Nation: modeling the potential impacts of ocean change**

Michael Tillotson (University of Washington) <mdt3@uw.edu>

Natural resource management inherently requires balancing social, economic, and ecological objectives, often in a context of ongoing ecological and social change. On the outer coast of Washington state, cultural values and traditional lifestyles are closely entwined with the marine resources affected by ocean change. In this context, we consider ocean change to broadly include physical and biological perturbations induced by human activities (e.g. climate change, ocean acidification, fishing, coastal development, etc.). Our research aims to explore how ongoing changes to the marine environment may challenge the social-ecological system surrounding the Quinault Indian Nation's razor clam harvest. We use key informant interviews, group interviews, and participatory risk mapping to better understand the emergent effects of changes in availability of the traditional razor clam resource on the Quinault Indian Nation, and to explore how the tribal community might prepare for or adapt to these impacts. We will combine interview responses with a review of the scientific literature to craft a Bayesian belief network of the Quinault-razor clam social-ecological system. This work will identify key variables and interactions within the system, and enable the exploration of connections between razor clam availability and community-level variables like indigenous health and well-being, per capita income, and social network composition. Uncertainty around human responses to change (i.e. stated preference vs. actual behavior) will be incorporated to the extent possible. This work is an ongoing effort from graduate students in natural resource policy, genetics, population dynamics, and ecology as part of the IGERT Program on Ocean Change at the University of Washington.

C.V.2 - **Coordinating Leisure: the Fun and Forgotten Energy Policy**

Jonathan Kadish (UC Berkeley ARE) <jonathan.kadish@gmail.com>

We investigate a previously ignored policy margin in the fight against climate change: the allocation and coordination of labor and leisure. A theoretical model demonstrates that if leisure is less carbon intensive than labor and agents cannot effectively coordinate leisure without the government, then leisure policies can reduce emissions and increase the efficiency of a carbon tax. Policies that coordinate labor and leisure (e.g. weekends vs weekdays) have profound economic implications, yet to our knowledge, questions about how we could optimize our leisure coordinating policies have gone mostly unasked.

To determine whether coordinated leisure policy should be an element in optimal climate policies, we develop a novel empirical strategy to identify the effect of coordinated leisure (weekends and federal holidays) on energy consumption (electricity loads, passenger vehicle miles, and commercial air travel) in the modern United States. By controlling for variation that is unrelated to holiday treatment, including day-of-week, temperature, and seasonal variation, we estimate counterfactual consumption levels on holidays and days around holidays. These methods are designed to capture temporal displacement of energy consumption.

Preliminary results for the electricity sector reveal that coordinated leisure leads to large reductions in electricity use: 8-10% on weekends and up to 14% on holidays, with additional reductions on surrounding days. These results suggest that adjustments to the quantity of leisure coordinated by the government may simultaneously increase welfare while reducing environmental externalities. More generally, our work demonstrates the importance of considering labor market dynamics and policy-levers in the design of optimal global climate policy.

C.V.3 - **Sustainable electricity options for Kosovo**
Noah Kittner (UC Berkeley) <nrkittner@berkeley.edu>

We have developed an analytic platform to analyze the electricity options, costs, and impacts for Kosovo, a nation that is a critical part of the debate over energy access and the role of fossil fuels versus cleaner electricity options to meet growing demands for power. We find that a range of alternatives exists to meet present supply constraints all at a lower cost than constructing a proposed 600 MW coal plant. The options include energy efficiency measures, combinations of solar PV, wind, hydropower, and biomass, and the introduction of natural gas. A $30/ton shadow price on carbon increases costs of coal generation by at least $330 million USD. The results indicate that financing a 600 MW coal plant is the most expensive pathway to meet future electricity demand.

C.V.4 - **Global heat stress in the 21st century**
Ethan Coffel (Columbia University) <ec2959@columbia.edu>

Heat is the number-one weather related killer in the US and around the world. As climate change progresses during the twenty-first century and beyond, temperatures are projected to increase across the globe with some of the most dramatic changes occurring in places where infrastructure is scarce and populations are rapidly rising. As a result of rising temperatures and steady or rising levels of relative humidity, heat stress will become increasingly severe. Here we show that heat stress as measured by the heat index and the wet-bulb temperature is projected to rapidly and dramatically increase, and that by mid-century crippling summertime conditions are possible across some of the most densely populated regions of the planet. In addition, we find that between 2020 and 2070 the rate of increase in both temperature and population is projected to peak in some regions, creating significant societal stress and necessitating rapid adaptation.

C.V.5 - **An exploration of climate change education in the K-12 classroom**
Lisa Tabor (Kansas State University) <lkt7779@ksu.edu>

As a climate scientist, have you ever wondered how climate change is being taught and portrayed in the school age classroom? Have you ever wondered how our work is being translated and used to teach the next generation? Today's climate change education efforts are often broad, random, complex, and differ widely by country. Most teachers are inadequately trained to teach climate and climate change and are frequently uncertain about teaching climate change as it is portrayed as a controversial topic in the media. Yet polls report that students want to learn about climate change. In the United States there is a new initiative to teach climate change as part of the Next Generation Science Standards. This change is beneficial, but implementation of these new standards will be a significant challenge. Based on the current state of climate change education, climate scientists need to be involved in order to produce and promote quality climate education for the next generation of decision-makers.

C.V.6 - **The Climate Change Adaptation Road Maps of Metro Manila and Singapore as Coastal Metropolises in Southeast Asia**

Philip Michael I. Paje (University of the Philippines-Diliman) <philippaje@yahoo.com>

The discourse on climate change engenders the idea of a resilient city especially for coastal metropolises in the developing world. The Guide to Climate Change Adaptation in Cities (2011) published by the World Bank defines this resilience on the basis of a city's capability to respond quickly and effectively to climate change impacts. In the case of coastal metropolises, sea level rise, storm surges, and inundations count as the major physical hazards. As cities draw people in search of opportunities, the risks posed and imposed on the urban centers' resources for climate change adaptation can be considerably compromised. Free-riding city dwellers can also adversely affect a city's environment conservation programs. This is the context that frames this policy analysis of the road maps of Metro Manila and Singapore in climate change adaptation towards their respective goals of becoming resilient cities in Southeast Asia. This paper examines the formal and informal adaptation strategies that these two Southeast Asian metropolises employ. Singapore is an island city-state while Metro Manila is the Philippines' capital, major city, and center of political and economic power. Both cities have recorded disastrous flooding in the past several years. As both are economic centers in the region, these cities have much to consider, prepare, or even spend for. Furthermore, this paper will tackle the challenges and the opportunities that climate change adaptation has presented to these two coastal cities as they also deal with old and new environmental issues from energy conservation, e-waste disposals, and Clean Development Mechanisms.

C.V.7 - **Livelihood adaptation and governance changes in the aftermath of the Gulf of Maine northern shrimp moratorium**

Rebecca Gilbert (Yale University) <rebecca.gilbert@yale.edu>

The Gulf of Maine northern shrimp fishery closed in December 2014 and, despite industry and market pressure, it remains closed. The official moratorium announcement cited four hypotheses for the stock collapse: overfishing, fewer prey, more predators, and warming ocean temperatures in the Gulf of Maine. This array of stressors, in addition to consistently poor stock recruitment, has motivated the Atlantic States Marine Fisheries Commission (the Commission) to begin exploring new governance options for the fishery. Utilizing semi-structured interviews, I examined three key elements of this case study: (1) individual- and community-scale impacts of the moratorium, (2) post-collapse livelihood adaptations by former shrimp fishermen and processors, and (3) industry perceptions of the Commission's stakeholder participation process as it moves forward with the new governance changes. Preliminary results demonstrate that, lacking external assistance, many former shrimp fishermen have chosen to fish their remaining permits harder, focusing on the scallop and lobster fisheries. This choice

makes fishermen more specialized and thus less economically resilient to fluctuations in stock health. Secondly, in-depth interviews with stakeholders can reveal new considerations for the stakeholder engagement process as northern shrimp managers seek to balance science-based and societal needs-based concerns. This case study could be widely useful for managers in situations where multiple stressors, particularly climate change, put a species moratorium on the table. As marine ecosystems respond to these stressors, it is critical for managers to understand how fishery-dependent communities are responding in kind and to scrutinize their own approach to stakeholder participation during extreme management decisions.

C.V.8 - **Climate Change Adaptation in the Indus Ecoregion: A Microeconometric Approach to Study the Determinants, Impact and Cost Effectiveness of Adaptation Strategies**

Farrukh Zaman (Yale University) farrukh.zaman@yale.edu

The objective of the research is to understand the impact of climate change on food security in Pakistan, and the role of adaptation in determining this effect and possibly attenuating the costs of climate change. There are 4 broad research questions that the research plans to address: 1) what is the likely cost of climate change to agricultural households in rural Pakistan?; 2) to what extent does adaptation to climate change ameliorate these costs?; 3) what are the key determinants of adaptation to climate change; and, 4) what policy recommendations can we draw from the answers to the above? An in-depth household survey of almost 1,500 households in Punjab and Sindh provinces was conducted. The data from the survey was combined with spatial climatological data obtained from the Pakistan Meteorological Department (PMD), namely 24 years of average monthly rainfall and temperature data at a 25 km grid resolution spanning 1990 to 2014. Key findings from the analysis include: a) climate change will reduce agricultural productivity by around 8-10% by 2040 as measured by land values. This equals to approximately USD 300 worth of monetary losses per acre; b) farmers who adapt to climate change through on-farm methods: crop timing; changing inputs; crop choice; have higher yields for wheat and rice and are more food secure than non-adapters; c) households with a higher proportion of females and access to formal information services are strongly associated with an increased likelihood of adaptation. Policy recommendations are also suggested for planners and policy makers.

SESSION VI: OCEAN DYNAMICS — NOV 7, 4:00 – 5:30 PM

VI.0 - **Session introduction**

Cael Barry (MIT-WHOI Joint Program) <bcaelb@mit.edu>

Noted oceanographer Walter Munk once said "all we know for sure is that the oceans are an important sink of heat, and carbon dioxide, and of ignorance." Indeed, the ocean forms an integral component of the climate system, both in terms of storage and transport, on many scales, yet has received comparatively little attention in the climate community until recently. The ocean influences storm tracks and other weather patterns, transports heat to the poles, and its circulation affects coastal communities; sea level rise is of increasing global concern. In this session, speakers will describe analysis of observations, both new and paleo-old, and of models, both high-resolution numerical and simple-theoretical, of the relationships between the ocean and climate.

VI.1 - **A global ocean state estimate at the Last Glacial Maximum**
Dan Amrhein (MIT-WHOI Joint Program) <amrhein@mit.edu>

During the Last Glacial Maximum (LGM, ca 20,000 years ago), data suggest that a four kilometer mountain of ice lay over North America, sea level was 130 meters lower than present, and surface air temperatures at high latitudes were 10 degrees lower than in the modern. Much of the climate dynamics of the LGM and previous glaciated intervals remains shrouded in mystery, including fundamental properties of the ocean circulation and its role in transporting thermal energy and salinity. Most efforts at reconstructing the ocean during the LGM have relied either upon forward integrations of general circulation models under prescribed LGM boundary conditions or interpretation of paleo proxy records in isolation of dynamical considerations. Here I describe the first global, primitive equation simulation of the LGM ocean with boundary conditions (winds, air temperature, and other atmospheric variables) and mixing parameters derived to best fit proxy databases of sea surface temperature and passive tracers in a least-squares sense. Particular attention is paid to diagnosing quantities relevant to the global climate and to evaluating the ability of paleoceanographic observations, in conjunction with a dynamical ocean model and atmospheric bulk formulae, to constrain features of the glacial atmosphere.

VI.2 - **Southern Ocean cooling in a warming world: the role of westerly winds**
Yavor Kostov (MIT) <yavor@mit.edu>

In contrast to the global warming trend and the loss of Arctic sea ice, the Southern Ocean has exhibited a gradual decrease in sea surface temperatures (SSTs) and a net expansion of the sea ice cover over recent decades. Moreover, historical simulations with CMIP5 global climate models do not reproduce consistently the observed cooling around Antarctica and, instead, predict slow but steady warming.

Here we identify enhanced Ekman transport as a possible mechanism allowing the Southern Ocean to cool. We further discuss the discrepancy between observations and CMIP5 historical simulations. The latter do not represent consistently the strengthening and the poleward shift of the Southern Hemisphere surface westerlies – due to internal variability or an inadequate representation of ozone forcing. We propose that under a realistic evolution of surface winds, CMIP5 models can produce cooling trends around Antarctica with magnitudes and spatial patterns similar to observations. To that end we consider the unforced preindustrial control runs of CMIP5 models and examine periods with multidecadal trends in the speed and position of the Southern Hemisphere surface westerlies that are comparable to the 1979-2014 trends. Strengthening and southward displacement of surface winds produce an SST dipole around Antarctica: cooling south of 50S and warming in a zonal band along 30-50S, similar to observed patterns. The wind-induced cooling trends in the Southern Ocean are large enough to locally overwhelm the effect of greenhouse gas forcing.

We reconcile our findings with those of modeling studies which suggest that poleward intensification of the westerlies leads to warming rather than cooling trends around Antarctica. We show that the Southern Ocean response to a wind perturbation is nonmonotonic in time. An initial cooling regime can transition into a warming regime. Some of the intermodel diversity in these fast and slow responses is related to differences in the models' mean background stratification of the Southern Ocean.

VI.3 - **A multi-basin three dimensional perspective on the meridional overturning circulation in the southern ocean**

Dhruv Balwada (Florida State University) <db10d@fsu.edu>

Knowledge of residence times of deep water in the ocean is extremely important for determining the residence times of essential elements, particularly carbon, in the deep ocean and in determining if the ocean is a net source or sink of carbon.

Meridional overturning circulation is often described in a two-dimensional/zonally averaged view using simple model. In these models the upper cell of the overturning circulation is modeled as having source in the North atlantic, driven by deep convection, and a sink at the surface in the Southern ocean, driven by strong westerlies and buoyancy fluxes, with a conduit connecting them in the middle. The circulation time from the northern source to the southern sink in these models is determined by the advection time in the Atlantic Ocean and eddy processes in the southern ocean. The role of the Indian and Pacific Ocean is often ignored or undermined in these schematics and models. In this work we address the validity of this assumption by determining the 3D circulation of the deep waters, specifically in the Southern Ocean.

This is done by analyzing Southern ocean state estimate (SOSE) output in the framework of Potential Vorticity(PV) dynamics. Preliminary results show that a significant fraction of the North Atlantic deep water reaching the ACC is pushed into the Indian and Pacific oceans and the water that crosses the ACC is old circumpolar deep water that has circulated through the Indian and Pacific oceans. This greatly increases the residence time of the deep oceans and calls for better models of the overturning circulation that take account of important interbasin connections.

VI.4 - **On the first observations of summer ocean stratification and flow off the Sabrina Coast of Wilkes Land, East Antarctica**

Natalie Zielinski (Texas A&M University) <njzielinski@tamu.edu>

Ocean-ice interactions around Antarctica play a key role in the formation of dense water masses that drive Meridional Overturning Circulation (MOC) and contribute to sea-level rise through regional discharge of grounded ice. Yet, current understanding of cross-shelf flow paths and circulation on continental shelves adjacent to tidewater glaciers with decreasing ice volume trends is minimal due to sparse in-situ observations. One such region is the Totten Glacier System (TGS) in East Antarctica that has been estimated to drain one-eighth of the East Antarctic Ice Sheet and has a volume equivalent to a 6.9m rise in sea level, greater than the entire Western Antarctic Ice Sheet. In recent years, volume assessments of the TGS have suggested a decreasing trend, compelling the collection of the first hydrographic data in the 2014 austral summer. Initial analysis of the Dalton Polynya within the TGS unexpectedly revealed no Shelf Water, indicating that this polynya does not contribute to AABW. Here, injection of multiple fresh water sources overwhelms surface buoyancy loss from brine rejection. Unlike other Antarctic coastal regimes losing ice mass due to warm, deep-water intrusions, there is no evidence of cross-self flow of warm water. Instead, interaction of the Antarctic Coastal Current with local glacial and grounded ice injects meltwater at the surface and intermediate layers of the water column, dampening the formation of SW and the TGS' contribution to MOC. The currents and ice interactions observed here are likely widespread on Antarctic continental shelves, freshening waters and altering regional dense water production.

POSTER SESSION C.VI: OCEAN DYNAMICS NOV 8, 9:55 – 11:25 AM

C.VI.1 - **An adjoint sensitivity analysis of Gulf Stream path variation in the South Atlantic Bight**

Xiangming Zeng (North Carolina State University) <xzeng2@ncsu.edu>

Meanders and fluctuations of the Gulf Stream (GS) path have been observed in the South Atlantic Bight, especially near the ridge and trough bottom structure off Charleston, SC, known as the "Charleston Bump". The offshore deflection of the GS usually propagates downstream of the Bump, which can even affect the position of the GS near Cape Hatteras or even further. The position of the GS can affect the ocean circulation, water exchange, and the distribution of sea surface temperature, which moderates the ocean-to-atmosphere heat fluxes and results in variation of the local weather system. The GS status (e.g. water transport) is also an indicator of the climate variation. As a state-of-art tool, the adjoint model is used to explore the possible factors that may affect the GS path variation. The adjoint sensitivity analysis shows the influence of different factors, such as wind forcing, upstream transport, and ocean eddies, on the GS position variation in a quantitative way.

C.VI.2 - **Transport of Atlantic Water in the Alboran Sea: 2D Dynamic Systems Analysis**

Genevieve Jay Brett (MIT-WHOI Joint Program) <gbrett@mit.edu>

The Alboran Sea, at the interface of the Atlantic and Mediterranean, has large regions of chaotic flow-- motion characterized by exponential stretching and folding of fluid parcels. The surface flow usually contains two anticyclonic gyres to the south of the Atlantic Jet, which carries Atlantic Water into the region. This work studies the near-surface transport between the Atlantic Jet and the gyres in two dimensions using the MITgcm. I use Lagrangian methods to define gyre boundaries by manifolds of the fluid motion, and quantify chaotic transport using lobe dynamics, avoiding spurious fluxes caused by the gyre moving across its mean boundaries. The rates of transport by chaotic advection, parameterized turbulence, and Ekman pumping are compared and correlated with the forcing applied at the open boundaries and from the atmosphere. I find that, in budgets for the salinity and vorticity of each gyre, transport is dominated by a combination of chaotic advection and turbulent diffusion. However, seasonal variations in these budgets are large, and the vorticity budget changes dramatically with the inclusion of tides. Understanding the variations of the flow due to changing atmospheric forcing will inform possible changes in a future climate.

C.VI.3 - **Structure and variability of the shelf break East Greenland Current**

Lisbeth Håvik (University of Bergen) <lisbeth.havik@uib.no>

The East Greenland Current originates north of the Fram Strait and follows the shelf break of Greenland through the Denmark Strait and into the North Atlantic. It carries large amounts of relatively cold and fresh waters in the surface layers, and more saline and warmer waters at depth. When the current passes the Denmark Strait sill the deeper water masses are denser than the ambient water in the North Atlantic and sink towards the deep ocean as overflow plumes. These plumes from the Nordic Seas are an important source of dense water to the Atlantic Meridional Overturning Circulation. North of the Denmark Strait the East Greenland Current bifurcates into a branch following the shelf break and a separated branch flowing into the Blosseville Basin. To investigate the mechanisms behind and the results of the bifurcation and its temporal and spatial variability, we focus on the shelf break East Greenland Current. We use a year-long record of velocity and hydrography obtained from five moorings covering the full width of the shelf break East Greenland Current along the Kögur transect in the Blosseville Basin north of the Denmark Strait. With this high-resolution data set we have a unique opportunity to examine the variability of the current throughout a year, the water masses it transports and how this variability influences both the flux of fresh water into the North Atlantic and the climatic important overflow plume.

C.VI.4 - **Near-inertial waves and their interaction with ocean currents**

Alexis Riopel (McGill University) <alexis.riopel@mail.mcgill.ca>

Large-scale ocean circulation is of great importance to understand Earth's climate. Generated by wind, near-inertial waves (NIWs) are ubiquitous over oceans, but their dynamics still needs to be explored. NIWs have a very short period (a few hours) compared to the evolution of large-scale currents. Using a two-layer shallow-water model, which is an approximation for the full Navier-Stokes equations, we assess how NIWs interact with well-defined jets. The model is highly idealized — experiments are performed on a square ocean without bathymetry — but it nonetheless captures important features of NIWs interaction with the depth-averaged flow. Previous studies showed, both using theoretical models and experimental measurements, that anticyclonic flows trap NIWs. Such results are successfully reproduced with our model. Also, we emphasize how refraction of NIWs by the background current causes horizontal scale of wav es to cascade down. Finally, a particular attention is given to the energy transfer between near-inertial motion and the barotropic current. Our model may help to explain how wind-induced forcing may exchange energy with the Atlantic Meridional Overturning Circulation (AMOC). Many climate models predict changes in the AMOC strength and in wind activity due to global warming, making it crucial to understand accurately the energy transfers between NIWs and the background flow.

Session VII: Hydrology and Water Resources

Nov 8, 8:30 – 9:55 AM

VII.0 – **Hydrology and water resources session introduction**

Sarah Rosengard (MIT-WHOI Joint Program) <srosengard@whoi.edu>

Climate change will alter the global hydrological cycle, including the fluxes and distribution of water among all reservoirs on land, the oceans and the atmosphere. Describing the features of these changes, and the mechanisms that cause them, is necessary to understand how water resources will shift at the regional to local scales, as well. This session brings together a diverse repertoire of tools that shed light on these questions: from global climate models to isotope chemistry to regional satellite imagery. Presentations in this session will further explore the implications of hydrological changes for water management, and the frequency and intensity of natural disasters.

VII.1 - **The sensitivity of global mean precipitation to natural versus anthropogenic climate change**

Ryan Kramer (University of Miami/RSMAS) <rjk5079@rsmas.miami.edu>

In a climate with rising CO_2 concentrations, climate models predict that globally averaged precipitation will increase with surface warming at a much lower rate than increases in water vapor. According to previous studies, this modeled difference in the response to warming infers that global precipitation increase is dictated by atmospheric radiative cooling increases and not moisture availability. However, results from observational studies using 20 years of satellite measurements disagree with this framework, and show global-mean precipitation and water vapor have increased with surface warming at similar rates. While the modeling results represent change at long-term, anthropogenic time scales, the observational results are based on data over a limited period of record and are therefore dominated by inter-annual changes. We investigate whether the physical constraints on the hydrological cycle fundamentally differ between these time scales. Using simulations from models in phase 5 of the Coupled Model Intercomparison Project (CMIP5) we isolate and compare the inter-annual and decadal-to-century time scale responses of global-mean water vapor, precipitation and radiative cooling to surface warming. We show that while global-mean precipitation is constrained by radiative cooling on both time scales, at the longer time scales, CO_2 acts to suppress the increase of radiative cooling with warming, resulting in a reduced precipitation increase compared to inter-annual time scales. We further show that the water vapor response to warming does not have a similar dependency on CO_2 effects, which may have implications on the magnitude of atmospheric overturning circulation changes.

VII.2 - **Exploring the effects of solar radiation management on water cycling in a coupled land-atmosphere model**

Katie Dagon (Harvard University) <kdagon@fas.harvard.edu>

This work explores the impacts of geoengineering by solar radiation management (SRM), focusing on modeled changes in land-atmosphere coupling, driven by surface energy

fluxes and water cycling. SRM has been shown to roughly compensate modeled global mean temperature changes induced by greenhouse gas forcing, while changes in the hydrological cycle are inadequately compensated. This is driven by both the sensitivity of surface energy fluxes to changes in shortwave versus longwave radiation, and the physiological effect of carbon dioxide on vegetation. Water cycling changes have corresponding impacts on local climate, through changes in runoff and soil moisture. We use a dynamic land surface model to understand mechanisms central to the land-atmosphere-climate system and in particular the sensitivity of plant physiology and surface hydrology to changes in radiative forcing. Regional and seasonal changes are examined under SRM simulations with a uniform reduction in solar radiation, relative to simulations with present-day and elevated CO2 concentrations. There are significant regional impacts due to vegetation-climate interactions that are not compensated under SRM, including changes in evapotranspiration, soil moisture, and runoff. These changes depend on season and choice of baseline simulation. In the tropics, evapotranspiration decreases due to increased vegetation water use efficiency. In northern mid-latitudes, decreases in evapotranspiration do not always translate to increases in soil moisture. These results imply significant consequences for land-atmosphere coupling in a world with geoengineering, but are implicitly tied to the land surface model parameterizations for vegetation and soils.

VII.2 - **Soil moisture gradients and land-use/land-cover boundary impacts on U.S. Northern Tier Derecho development**

Adrienne Tucker (Pennsylvania State University) <azt153@psu.edu>

A derecho is a convectively-induced windstorm produced by an extratropical mesoscale convective system (MCS) with winds that exceed 25ms-1. I investigate the influence of soil moisture gradients (SMGs) and land-use/land-cover (LULC) boundaries in the U.S. North Central Plains and Upper Midwest on the development (i.e., initiation and intensification) of Northern Tier derechos. Derechos in the Northern Tier occur more frequently and produce more damage than those of other U.S. regions. I analyze SMGs and LULC boundaries to better understand why this derecho-generating corridor is so productive. I use radar and satellite imagery, validated against surface high wind reports from NOAA's Storm Prediction Center (SPC), to identify summer season (June-August) Northern Tier derechos during 2000-2014 (a total of 56 events). Soil moisture data from NOAA Climate Prediction Center (CPC), LU data from the National Land Cover Dataset (NLCD) and Normalized Difference Vegetation Index (NDVI) LC data help determine the statistical and physical associations of spatial SMGs and LULC boundaries on the initiation and intensification of Northern Tier derechos. My results from spatial analyses, principal component analyses (PCAs) and self-organizing maps (SOMs) show that spatial SMGs, LC boundaries, and thermodynamic variables support the initiation and intensification of Northern Tier derechos, while LU boundaries show little apparent influence. I use these significant variables to help infer the physical processes underlying derecho development in the Northern Tier. This research enhances our understanding of how spatial variations in boundary layer climates related to SMGs and LCCs boundaries contribute to severe storm initiation and intensification.

VII.3 - **Effects of climate change on snowpack and fire risk in the western United States**

Diana Gergel (University of Washington) <gergel@uw.edu>

Climate change is projected to result in declining snowpack, earlier snowmelt and a shorter snow season in the Western United States, which may affect fire risk. The impact of climate change on snowpack and soil moisture is evaluated for five mountain ranges in the Western United States: the Sierra Nevada, Cascades, Northern and Southern Rockies, and the White Mountains. Snow water equivalent (SWE) and soil moisture (SM) are simulated for the historical period (1950-2005) and the future period (2006-2099) using the Variable Infiltration Capacity (VIC) model, driven by ten downscaled Global Climate Models (GCMs) from the Coupled Model Intercomparison Project 5 (CMIP5) archive. For the future period, two Representative Concentration Pathways (RCPs), 4.5 and 8.5, are used. The multi-model ensemble average is computed over all GCMs. A pronounced decrease in SWE occurs in all mountain ranges and across all models, with eventual disappearance of SWE in lower elevations of the White Mountains by the 2070-2099 period. As a result, soil moisture shows an increase in March and a strong decline in August. This timing shift in soil moisture may affect the occurrence of fire, particularly at lower elevations that experience a stronger shift in snowmelt and soil moisture timing. Consequently, we evaluate the extent to which fire risk is affected.

POSTER SESSION C.VII: HYDROLOGY AND WATER RESOURCES

NOV 8, 9:55 – 11:25 AM

C.VII.1 - **Influence of convective parameterization and remote forcings on precipitation in the deep tropics**

Matthew Woelfle (University of Washington) <woelfle@atmos.washington.edu>

The predominant precipitation feature in the deep tropics is a band of convective precipitation known as the Intertropical Convergence Zone (ITCZ) which is located in the Northern Hemisphere in the annual mean in observations. However, most global climate models simulate a secondary maxima of annual mean precipitation south of the equator which is not present in observations. This bias is known as the double-ITCZ bias. Prior studies have identified convective entrainment, local radiation biases, and remote radiation biases as possible drivers of the double-ITCZ bias in modern climate models. In this study, we investigate the role of both convective parameterization in the development of this bias in the Community Earth System Model version 1 (CESM1).

We first examine the magnitude of the bias in the fully coupled model using two model configurations which differ in their representation of atmospheric convection: the default Community Atmosphere Model version 5 (CAM5) with both deep and shallow convective parameterizations active and CAM5 with the deep convection parameterization disabled. By comparing simulations with varied convective parameterizations in the model, we are able to determine the degree to which the convective parameterizations contribute to the development of the double-ITCZ bias. We also examine the role of ocean heat transport in the bias development through comparison of the fully-coupled simulations with transient ocean only simulations where the surface heat fluxes are prescribed from reanalysis.

C.VII.2 - **Stream Temperature Modeling: A Climate Change Analysis and Assessment for Aquatic Resource Managers**

Lynn Brennan (University of Massachusetts Amherst) <lynn.metcalf.brennan@gmail.com>

In the Northeast U.S. increasing stream temperatures due to climate change pose a serious threat to cool and coldwater fish communities, as well as aquatic ecosystems as a whole. In this study, three stream temperature models were implemented for two different case-study basins in the Northeast Climate Science Center region. Two coupled hydrology-stream temperature (physical) models were used: VIC-RBM and SWAT-Ficklin et al. (2012). The third model implemented was a nonlinear regression (statistical) model developed by Mohseni et al. (1998). Metrics were developed to assess these models regarding their prediction skill, data input requirements, spatial and temporal resolutions, and "user-friendliness". This comprehensive assessment will be employed (via a Structured Decision Making format) by aquatic resource managers in need of projected stream temperatures for management decisions in the face of climate change. Additionally, these models were used to predict stream temperatures under a range of future air temperature and precipitation scenarios for the study basins. These basins were the Westfield Basin (1,338 km2) in western Massachusetts and the Milwaukee Basin (2,220 km^2) in Wisconsin. The climate change analysis was done using a range of potential precipitation changes and air temperature increases (similar to a climate stress test). Precipitation scenarios ranged from 90% of observed to 130% of observed (in increments of 10%) and daily air temperature increases ranged from 0°C to 7°C (in increments of 1°C); the combinations of 5 precipitation scenarios and 8 air temperature scenarios yielded 40 different climate scenarios that were evaluated by each model.

C.VII.3 - **Assessing projected climate impacts on streamflow in small coastal basins of the Western US**

William Burke (Indiana University) <wiburke@umail.iu.edu>

Understanding the impacts of climate change on watershed hydrology, particularly streamflow quantity and timing, is becoming increasingly important to the management of our water resources. Coastal watersheds have been shown to respond differently to climate change over the past 50 years as compared to mountainous watersheds, displaying later streamflow timing opposed to the earlier streamflow timing observed in mountainous watersheds. Despite the dissimilarity of coastal watersheds, there is a lack of hydrologic modeling on coastal watersheds in particular. Through the use of five calibrated Soil and Water Assessment Tool (SWAT) coastal watershed models input with downscaled General Circulation Model (GCM) output, it is possible to assess and project future hydrology at the watershed and subwatershed scales through the 21st century. This presentation will look at the findings of this assessment at five watersheds on the West Coast of the US utilizing 21 climate models each from Representative Concentration Pathways (RCPs) 8.5 and 4.5. There will be a focus on changes in interannual quantity, timing, distribution, and variability of streamflow, comparing historic trends to those of the mid and late 21st century. Additionally, the relative roles of temperature and precipitation in determining streamflow at each site along the coast will be analyzed and discussed. Finally, long term trends, both generally and at each site will be identified and discussed.

C.VII.4 - **Modeling water isotope in convective processes**

Suqin Duan (UC-Berkeley and Tsinghua University) <suqin.duan@berkeley.edu>

An analytical model based on the bulk-plume convective water budget and Rayleigh distillation is derived for water vapor (H2O) and one of its heavy isotopes (HDO). We investigate joint changes in water vapor and water isotope variables within the convective plume and its environment under changes in the entrainment and detrainment rates. RH (the ratio of environmental to in-cloud water vapor mixing ratios) and RH′ (the ratio of environmental to in-cloud isotopic mixing ratios) both increase as the entrainment and detrainment rates increase. Variations in RH′ are closely related to variations in RH. Isotopic ratios (δD) in the convective plume, environment, and condensate increase with increasing entrainment, although in-cloud δD is largely insensitive to these changes. We provide a theoretical explanation of these relationships that establishes a theoretical range for δD in convective environments. This range provides an additional constraint for evaluating convective parameterizations.

C.VII.5 - **California anomalous winter precipitation and applications on water management**

Bor-Ting Jong (Lamont-Doherty Earth Observatory) <borting@ldeo.columbia.edu>

California receives most of its precipitation from heavy or extreme precipitation events brought by extratropical cyclones during winter, which has large annual and interannual variations. Here, I probe into the factors that cause anomalously wet winters (wetter winter) in California (the wettest 15% of winter half years in the 1900/01 to 2009/10 period). During El Niño, a well-known factor, a wave train triggered by anomalous tropical deep convections propagates northeastward, deflecting the storm track southward, which brings anomalous rainfall to California. According to reanalysis data, during wetter winters that also coincide with El Nino (wetter & El Nino), an anomalous low pressure and corresponding southerly anomaly locate at U.S. west coast, bringing moist oceanic air to California. However, an El Nino event doesn't guarantee a wetter winter. The deflection of the wave train decides if the low pressure anomaly locates right at the west coast or not. The result shows that during non-wetter & El Nino winters, the deflection of the wave train is slightly different, which moves the low pressure anomaly westward, prohibiting California from being anomalously wet. To explore the other factors, composites of wetter & Non-El Nino winters were also examined. The results show that the similar low pressure anomaly locates at west coast. However, a clear wave train propagates zonally, originated from mid-latitude, instead of tropics. In other words, coastal low pressure and southerly anomalies are consistent features for wetter winter in California. However, the origin of forcing can come from both tropics and mid-latitude.

C.VII.6 - **Changes in flow regimes with changing climate scenarios in fragmented stream networks of the Central Great Plains of Kansas.**

Sarmistha Chatterjee (University of Delaware) <sarmi@udel.edu>

The Central Great Plains of Kansas lies in a very fragile landscape of cyclical droughts, where, in spite of having various morphological and behavioral adaptations to these natural cycles, the biodiversity has been collapsing in many basins due to the sudden boom in the dam construction era. As fragmented network segments dry completely, fish populations upstream

of fragmentation points are eliminated; when re-wetted, these segments remain biodiversity dead zone. The effect is dramatic reduction of available habitat and isolation of sub populations leading to first localized and then basin-wide extirpation. With change in climate and intensification of drought cycles, temperature and precipitation patterns are expected to shift, moving towards an increment in the number of dams. In this paper, we are documenting the nature and extent of fragmentation by tracing small impoundments in Kansas and projecting it through climatic scenarios to analyze flow regimes. To simulate flow, we are projecting the fragmented stream structures through existing drought scenarios in ArcGIS Soil Water Assessment Tool (SWAT) and analyzing flow pattern through hydrologic modeling. The stream projection for the drought layer will indicate minimum flow based on individual hydrologic response units. When coupled with the dam layer, the simulations will allow us to identify tributaries that are vulnerable to get disconnected from the main stream, during events of successive droughts and thus requires immediate attention for restoration. Once established, these damages will be permanent to the hydro-eco-geomorphology of the area, where restoration would be difficult.

SESSION VIII: BIOGEOCHEMISTRY — NOV 8, 11:25 – 12:50 PM

VIII.0 - **Session introduction**

Cara Manning (MIT-WHOI Joint Program) <cmanning@whoi.edu>

Biogeochemists study the processes controlling the transfer of elements (and molecules and isotopes) between different reservoirs in the earth system. Atmospheric levels of CO_2, and thus global temperatures, are intimately linked to these biogeochemical cycles. This oral session and the accompanying posters will feature studies showcasing the broad field of biogeochemistry and the biogeochemical cycles of carbon, nitrogen, oxygen, and water. The environments studied include the terrestrial biosphere, ocean, and atmosphere, and the spatial scales range from global to local.

VIII.1 - **Empirically derived sensitivity of vegetation to climate across the globe**

Gregory R. Quetin (University of Washington) <gquetin@u.washington.edu>

To predict the response of vegetation to climate change, we must understand the physiological processes controlling productivity across large spatial scales, and thus across climate space. To date there is not a fully empirical map of climate constraints on vegetation at the global scale. We use the response of satellite-based greenness (NDVI) to inter-annual climate variations in surface air temperature (from ERA-Interim) to derive the sensitivity of vegetation to temperature and infer mechanisms of climate constraint on vegetation as represented by greenness productivity across the globe. We focus on how the sensitivity of vegetation to temperature varies and find that the actual climate constraint is a balance of resources. The majority of grid cells in simultaneously warm (above ~14 ^{o}C) and dry (below ~1000 mm/year rainfall) conditions have negative vegetation sensitivity to temperature (browner in warm years) while at places with cooler temperatures the vegetation sensitivity is generally positive

(greener in warm years). At very high rainfall levels (beyond 3000 mm/year), even the hottest vegetated places on Earth have positive sensitivity to mean annual temperature. The mean annual temperature boundary between positive and negative sensitivities changes by 9 ^{o}C depending on how much rainfall a place receives, and at the highest rainfall rates vegetation never becomes constrained by high temperatures at all. The positive temperature sensitivity of these warm wet ecosystems suggests that they may actually benefit from near term warming on the scale of inter-annual variations of temperature, able to buffer against damaging maximum temperatures with their access to water.

VIII.2 - **Cool versus warm season grasslands: How precipitation drives carbon cycling in two semiarid communities**

Katherine Moore Powell (University of Colorado) <katherine.powell@colorado.edu>

Climate models predict an increase in the intra-annual variability of precipitation, with large rain events separated by longer dry intervals (Christensen et al. 2007, Dai 2011). Water-limited ecosystems are vulnerable to changes in the water cycle, and in particular the grasslands of the US Central Great Plains. To complicate matters, land cover changes are ongoing, such as the expansion of introduced grass species, which have overrun native prairies in recent decades. In many cases, these grasses represent differing photosynthetic types that have distinct seasonal water needs. To elucidate precipitation responses in above- and below-ground carbon cycling in two different semiarid prairie communities in the same region, water, carbon, and energy fluxes were studied at grasslands sites within Rocky Flats National Wildlife Refuge during the 2013 and 2014 growing seasons. Soil gas wells, along with soil moisture and temperature plots were collocated with eddy covariance towers in a reclaimed, mixed grassland (cool season, non-native grasses) and a remnant tallgrass prairie (warm season, native grasses). Annual precipitation for 2013 dwarfed the total for 2014, largely due to the September 2013 floods. However, the timing of rain events resulted in a far more productive year in 2014 in both grassland communities. Carbon fluxes followed precipitation and subsequent soil water increases closely, with cool season vegetation more responsive in spring and fall and warm season grasses showing increased activity in the summer. In this area, it appears that the non-native grassland was better adapted to respond to variable precipitation events across both growing seasons.

VIII.3 - **Analysis of Site-Specific Isotopic Composition of Nitrogen and Oxygen in Atmospheric Nitrous Oxide at Mace Head, Ireland**

Michael McClellan (MIT) <mcclellm@mit.edu>

Atmospheric nitrous oxide (N_2O) significantly impacts Earth's climate due to its dual role as an inert potent greenhouse gas in the troposphere and as a reactive source of ozone-destroying nitrogen oxides in the stratosphere. However, there remain significant uncertainties in the global budget of this gas. The marked spatial divide in its reactivity means that all stages in the N_2O life cycle–emission, transport, and destruction–must be examined to understand the overall effect of N_2O on climate. Source and sink processes of N2O lead to varying concentrations of N_2O isotopologues ($^{14}N^{14}N^{16}O$, $^{14}N^{15}N^{16}O$, $^{15}N^{14}N^{16}O$, and $^{14}N^{14}N^{18}O$ being measured) due to preferential isotopic production and elimination in different environments. Estimation of source and sink fluxes can be improved by combining isotopically resolved N_2O

observations with chemical transport model simulations using reanalysis meteorology and treatments of isotopic signatures of specific surface sources and stratospheric intrusions. The first year of site-specific nitrogen and oxygen isotopic composition data from the Stheno-TILDAS instrument at Mace Head, Ireland is presented and compared to results from MOZART-4 (Model for Ozone and Related Chemical Tracers, version 4) chemical transport model runs including N_2O isotopic fractionation processes and various reanalysis meteorological fields (NCEP/NCAR, MERRA, and GEOS-5). This work forms the basis for future inverse modeling experiments that will improve the accuracy of isotopically differentiated N_2O emission and loss estimates.

VIII.4 - **Variability of pCO_2 in seawater on Hawaiian coral reefs**

Gerianne Terlouw (University of Hawaii at Manoa) <gterlouw@hawaii.edu>

Seawater pCO_2 variability is driven by a variety of factors, including changes in seawater temperature, rising atmospheric CO_2 concentrations, and natural biogeochemical processes on the reef. In order to understand changes in seawater pCO_2 due to ocean acidification, we must first understand the natural processes that control short-term and long-term CO_2 variability on coral reefs.
In collaboration with the NOAA/PMEL carbon program, Moored Autonomous pCO_2 ($MAPCO_2$) buoys were deployed in 2008 at four coral reefs sites around the island of Oahu, Hawaii. The $MAPCO_2$ buoys measure surface water and atmospheric CO_2, along with several water quality parameters, at three hour intervals.

Here we present a statistical evaluation and interpretation of the longest running high-resolution, coastal CO_2 time-series in the world. A description of CO_2 variability and air-sea CO_2 fluxes is presented for the four coral reef sites, and the results are compared to the CO_2 dynamics in the open ocean using data from the WHOTS $MAPCO_2$ buoy deployed at the Hawaii Ocean Time Series (HOT) site, ~100 km north of Oahu, in the North Pacific Subtropical gyre.

Continuous, high resolution monitoring of CO_2 has greatly improved our understanding of daily, sub-seasonal, seasonal, and inter-annual CO_2 dynamics in the surface ocean. These time-series data provide the basis for understanding CO_2 dynamics on Oahu's coral reefs, which will be particularly crucial in the face of changing seawater chemistry due to rising atmospheric CO2 concentrations and the consequent increase in seawater *p*CO2 and ocean acidification.

POSTER SESSION C.VIII: BIOGEOCHEMISTRY

NOV 8, 9:55 – 11:25 AM

C.VIII.1 - **Soil carbon vulnerability to land-cover change and implications for the global carbon cycle**

Katerina Georgiou (University of California, Berkeley) <kgeorgiou@berkeley.edu>

Soil is a major reservoir of carbon (C) that contains more than three times the C in vegetation. While the terrestrial biosphere acts as a sink for approximately 2.5 petagrams C per year

(PgC/yr) – equivalent to about 25% of fossil fuel emissions – anthropogenic land-use change reduces the global net land C sink by approximately 1 PgC/yr. Although most assessments of land-use focus on changes to aboveground biomass C, changes to 'live C' (above- and below-ground plant biomass) drive lagged, yet substantial, changes to 'dead C' (soil, dead wood, and litter) storage, with important implications for the overall land C balance.

Here we provide an observation- and model-based assessment of the impacts of land-cover change on total C stocks (live and dead C) over the last decade and the potential for long-term soil C storage or loss. We find that afforestation in northern latitudes counteracts deforestation in the tropics, due in part to the greater soil C content of boreal and temperate forests. Deriving geospatial estimates of the steady-state ratio of dead to live C and the turnover time of dead C, we demonstrate that, although many recent studies have focused on forests, non-forest ecosystems (particularly shrublands and savannahs) are responsible for large changes in total C stocks in response to changes in C input rates due to their high soil C content. Furthermore, we disaggregate our geospatial predictions by biome and explore the depth-resolved vulnerability of soil C globally. Our findings suggest that the response of soil to changes in plant inputs significantly contributes to regional and global C budgets.

C.VIII.2 - **Determining the Effect of Growth Rate on Hydrogen Isotope Fractionation of Algal Lipids in Two North Pacific Sites**

Marta Wolfshorndl (University of Washington) <martaw@uw.edu>

Tropical hydrologic changes have a large effect on global climate, but there does not yet exist a good indicator of rainfall variation in the tropics. Understanding past natural variability of such features as the Intertropical Convergence Zone and El Niño Southern Oscillation provides information about the extent of anthropogenic climate change today. The hydrogen isotopic composition (D/H ratio) of algal lipids has been shown to track the isotopic composition of source water in which the organism grew, providing information about precipitation variability over time. However, culture work has revealed that environmental factors such as salinity, temperature, growth rate, and irradiance also influence algal lipid D/H ratios. Here I present work determining the effect of growth rate and irradiance on the hydrogen isotope composition of alkenone-producing algae in the water column in two North Pacific locations, off the coast of Oregon and near the Hawaii Ocean Time Series site. This work corroborates empirical relationships observed in culture studies and indicates that the effects of growth rate and irradiance should be taken into account when applying the D/H isotope ratio rainfall proxy to reconstruct past climates.

C.VIII.3 – **Response of coastal dune plants to soil community gradients and changing abiotic stressors**

Diana T. Barrett (UMASS Dartmouth) <dbarrett@umassd.edu>

On coastal sand dunes, plant species abundance and distribution vary with distance from the shore. Also differences in soil community composition, as well as gradients of physical stress exist from the shoreline landward. While previous research has mainly focused on one or few of these abiotic and biotic effects on coastal plant communities, it has not definitively explained distribution in terms of these effects, nor have potential factors been presented in realistic combinations of treatments. Therefore, the aim of this study was to illuminate the relationship between coastal dune plants and both the abiotic, as well as biotic aspects of their environment in order to project species response to changing climate. I will expose seedlings of four key New England dune plant species to individual tests varying light, nutrient access, salt spray, soil salinity, and burial, as well as suites of treatments combining those stressors simulating microclimates at both the frontal dune zone and the dune back and flat such as those found on Waquoit Bay National Estuarine Research Reserve on Cape Cod. Additionally, each species will be grown in soils inoculated with either sterile soil, soil from each species' commonly occurring zone or soils from zones where the target plants are not commonly found. Experiments lasting two months each began in January 2015 and are projected to continue until Fall 2015. Results will show how these key species will respond to climatic changes such as rising seas and temperatures, and how those responses will affect the dune plant community.

POSTER SESSION A — NOV 6, 7:45 - 9:00 PM

GCC EXECUTIVE COMMITTEE MEMBERS AND LOCAL GUESTS

A.1 - **Signal propagation in the Deep Western Boundary Current**

Isabela Le Bras (MIT-WHOI Joint Program) <ilebras@whoi.edu>

The ocean transports heat from the equator to the poles, aiding to stabilize the earth's climate. The North Atlantic carries over 50% of the total oceanic heat in the northern hemisphere (Trenberth 2001), though it is half the size of the North Pacific, because it has a meridional overturning circulation and deep convection sites. This study focuses on one component of the overturning circulation in the North Atlantic, the Deep Western Boundary Current (DWBC), which carries cold, convectively formed water masses from the Nordic Seas along the North American continental slope towards the equator. The DWBC is a relatively understudied component of the overturning circulation as it is a subsurface current, rendering it difficult to measure. The Line W moored array, on the continental slope southeast of New England, measured the North Atlantic's DWBC properties and velocity from 2004 to 2014. In the analysis of this data, we find a trend of decreased production of a deep water mass (Classical Labrador Sea Water, CLSW), accompanied by a warming (+0.01 degrees C per year) and salinification (+0.001 per year). These results are consistent with measurements in the Labrador Sea (Kieke et al. 2014) and indicate an approximate 10 year travel time from the Labrador Sea to Line W. Ongoing work includes comparison with observations upstream (Fischer et al. 2010) and idealized modelling to study the effects of stirring on signal propagation.

A.2 - **An absurdly simple model for oceanic export efficiency's temperature dependence**

Cael Barry (MIT-WHOI Joint Program) <bcaelb@mit.edu>

Oceanic carbon export is well understood to be of crucial importance to the climate system, as well as a very complex process that resists simple description. In particular, empirically derived relationships between temperature and the efficiency of carbon export have been celebrated and actively studied since the turn of the millennium, offering attractive

parameterizations of this phenomenon. Here, by using arguably the simplest model possible along with established thermodynamic dependencies, we take a mechanistic approach to the temperature-export efficiency relationship. The model produces a zero-parameter Eppley-type curve that constrains the range of possible efficiency ratios, matching well with multiple data sets of export efficiency; we also compare the curve with simulation results from a global biogeochemical model. While the limitations of this approach nod to the complexity of the system in question, it provides useful constraints on and insight into the nature of carbon export.

A.3 - **Biological oxygen production across 8000 km of the South Atlantic**

Evan Howard (MIT-WHOI Joint Program) <ehoward@whoi.edu>

The biological fixation and export of carbon from the euphotic zone to the deep ocean (the biological carbon pump) is a key control on ocean carbon dioxide uptake. Two important components of the biological carbon pump are (1) gross primary production (GPP), the total photosynthetic production, and (2) net community production (NCP), the net carbon drawdown or oxygen production by the biological community. NCP should be balanced by carbon export over sufficient time and space scales. The ratio of NCP/GPP is similar to the export ratio defined by Laws et al. (2000) and reflects how tightly the ecosystem recycles carbon.

We use in situ oxygen tracers (triple oxygen isotope and oxygen:argon ratios) to evaluate meridional trends in mixed-layer GPP and NCP across ~8000 km of the tropical and subtropical South Atlantic. NCP is surprisingly uniform along most of the cruise transect, with autotrophic values typically ranging from 5-10 mmol O_2 m^{-2} d^{-1}. GPP follows similar trends as NCP such that the NCP/GPP ratio is typically 0.1-0.2. Notable exceptions to this lack of variability include two stations with highly enhanced NCP and NCP/GPP ratios compared to surrounding regions. Additionally, the transition region between the subpolar and subtropical gyres has significantly higher NCP than elsewhere along the transect.

These results highlight the broad-scale similarity of rates of biological production over large regions of the Atlantic Ocean (thousands of kilometers). The intriguing increase in variability on smaller scales indicates that mesoscale and/or submesoscale processes may be key controls on the biological carbon pump.

A.4 - **Population genomic change during a rapid range expansion: the case of the invasive lionfish, Pterois volitans**

Eleanor Bors (MIT-WHOI Joint Program) <ekbors@mit.edu>

Global change is affecting species distributions in both terrestrial and marine systems. The genomic impacts of range expansion have implications for evolution, ecology, and conservation. Marine invasive species represent a potential model for describing these impacts. Here, we consider the population genomics of the lionfish, Pterois volitans. The rapid invasion of the lionfish into waters off the US Atlantic Coast, Gulf of Mexico, and Caribbean Sea is an unprecedented marine fish invasion in both rate and ecological damage. Originally introduced in Southern Florida in the late 1980s, lionfish began expanding in 2000 and have since have spread northward to North Carolina and southward to Brazil in a matter of decades. Rapid expansion in both species may be accompanied by local adaptation and natural selection at the range edge for invasion-enhancing traits, as well as genetic drift. Strong genetic drift can lead to a phenomenon known as allele surfing, in which rare alleles become fixed near the moving range boundary. Allele surfing is of specific interest because it can lead to reduced adaptive potential of a species, impacting future evolution and fitness. Restriction enzyme associated DNA sequencing was used to generate tens of thousands of genetic markers throughout the genome. Preliminary population genomic analyses of these data from throughout the invaded range indicate that there are genetic differences in the northern and southern expansion. Additionally, genetic diversity decreases with increased distance from the point of introduction. These results help understand how range expansion in other contexts might lead to genomic change.

A.5 - **Biases in field measurements of ice nuclei concentrations**

Sarvesh Garimella (MIT) <vesh@mit.edu>

Ice nuclei (IN) play an important role in the climate system by influencing cloud properties, precipitation, and radiative transfer. Despite their importance, there are significant uncertainties in estimating IN concentrations because of the complexities of atmospheric ice nucleation processes. Field measurements of IN concentrations with Continuous Flow Diffusion Chamber (CFDC) IN counters have been vital to constrain IN number concentrations and have led to various parameterizations of IN number vs. temperature and particle concentration. These parameterizations are used in many global climate models, which are very sensitive to the treatment of cloud microphysics. However, due to non-idealities in CFDC behavior, especially at high relative humidity, many of these measurements are likely biased too low. In this study, the extent of this low bias is examined with laboratory experiments at a variety of instrument conditions using the SPectrometer for Ice Nucleation, a commercially-available CFDC-style chamber. These laboratory results are compared to theoretical calculations and computational fluid dynamics models to map the variability of this bias as a function of chamber temperature and relative humidity.

A.6 - **Variability in sea ice controls on phytoplankton bloom dynamics across the Southern Ocean**

Tyler Rohr (MIT-WHOI Joint Program) <trohr@mit.edu>

Globally, a suite of physical and biogeochemical controls govern the structure, size, and timing of seasonal phytoplankton blooms. In the Southern Ocean, the introduction of seasonal sea ice provides an additional constraining factor. From a bottom-up perspective, a reduction in sea ice can both enhance bloom development by permitting greater levels of surface PAR uninhibited by ice and suppress a bloom when reduced fresh melt water inputs and increased vulnerability to wind stress combine to create deeper mixed layers and decrease depth integrated light availability. Regions along the Western Antarctic Peninsula have already seen a contradictory response to reduced ice cover, with enhanced summertime chlorophyll concentrations in the South, and large declines to the North. This dichotomy is thought to arise from differences in the interannual mean sea ice state, with extensively ice covered regions benefiting from reduced coverage and more sparsely covered regions hindered by further reductions. The questions arises: 1) At what threshold does a reduction in sea ice transition from amplifying blooms to suppressing them? 2) How do additional considerations such as nutrient availability and trophic interactions complicate this transition? Here, we combine remote sensing observations and in-situ data (from PAL LTER) with a hierarchy of 1-D water column and global general circulation (CESM) models to access the variability in how regional differences in mean ice level combine with other environmental forcings to dictate how interannual variability (or long term trends) in ice coverage will affect bloom structure and dynamics. In doing so we will gain a better understanding of how predicted changes in sea ice will effect Southern Ocean productivity, which of course will have important repercussions in the global carbon cycle and sustainability of healthy marine ecosystems.

A.7 - **Dissolved gases are tracers of ocean carbon uptake in a coastal upwelling zone**

Cara Manning (MIT-WHOI Joint Program) <cmanning@whoi.edu>

Climate change is resulting in a decrease in the fraction of anthropogenic carbon dioxide emissions absorbed by the oceans, due to the surface ocean becoming saturated with inorganic carbon. In order to detect and predict future changes in ocean carbon uptake, we must increase the amount of data that is being collected, and develop new instruments for quantifying the ocean carbon cycle. Using data from a research cruise in Monterey Bay, California, I will show how recent advances in measurement techniques for dissolved gases have improved our ability to quantify the physical processes (e.g., air-sea gas exchange and coastal upwelling), and biological processes (e.g., photosynthesis and respiration) that affect ocean carbon uptake. Specifically, we use time-series measurements of noble gases to parameterize physical processes. We then use measurements of dissolved oxygen concentration and isotopic composition, along with our estimates of the physical oxygen fluxes, to accurately quantify net and gross productivity, and therefore the rate of export of carbon from the surface to the deep ocean. Recent instrumental developments, including field-deployable mass spectrometers and improvements in dissolved gas sensors, have enabled scientists to measure small-scale variability in dissolved gases. Increases in the number of measurements of dissolved oxygen isotopes, and improved theoretical understanding of this tracer, have allowed scientists to investigate the environmental controls on net versus gross oxygen and carbon fluxes. All of these techniques were used during the research cruise. We detected a wind-driven upwelling event, which was immediately followed by an increase in biological productivity.

A.8 - **Stratospheric response to tropospheric forcing -reanalysis vs. shallow water model**

Andy Miller (MIT) <amiller@mit.edu>

We are studying Sudden Stratospheric Warmings (SSWs). During SSWs the polar vortex, that dominates the stratosphere in winter is either displaced towards lower latitudes or split into two smaller vorticies. SSWs warm the stratosphere by more than 50K within a few days and have been shown to have significant impacts on the surface climate for about 2 months. The two different types of events are usually characterized by their dominant wavenumber (wave 1 vs. wave 2) and conventional theories suggest that tropospheric wave forcing is simply imposed on the stratosphere.

In my poster, I will show that at least in some cases, stratospheric processes convert energy

from wavenumber 1 into wavenumber 2. Thus, the type of SSW and thereby its surface impact is not only determined by the tropospheric forcing but also depends on the state of the stratosphere itself. MERRA reanalysis data is used to quantify all important stratospheric processes leading to SSWs. I will show results from case studies as well as composites of all SSWs on record. In a second step, we use a 1.5-layer shallow water equation model to test the stratospheric response to very well defined forcings. In particular, we show that wavenumber one forcings can cause wavenumber two SSWs and vice versa.

A.9 - **Dependence of modeled aerosol forcing on aerosol-cloud interactions in a coupled aerosol-climate model**

Daniel Rothenberg (MIT) <darothen@mit.edu>

Modern climate models include detailed representation of aerosol processes and their interactions with clouds and other components of the Earth system. However, most of these interactions must be parameterized since global models do not resolve the spatial and time scales on which they occur. Altough there are a wide variety of parameterizations used to couple aerosol and climate processes, there are few metrics to constrain the efficacy and accuracy of a given scheme. As a result, substituting different representations of aerosol-cloud interactions in the same modeling system can yield different baseline climate states and sensitivities to applied forcings.

In this research, we compare pre-industrial and present day aerosol emissions scenarios in a sophisticated, coupled aerosol-climate model using different aerosol activation schemes. Due to different baseline cloud microphysical states, switching these schemes can up to halve the computed aerosol indirect forcing on the climate system, even while the larger scale patterns in temperature and precipitation change remain similar. Furthermore, we note a significant non-linearity in the cloud shortwave forcing as a function of the potential CCN budget given the same background aerosol emissions in the model, suggesting a microphysical saturation effect when very high activation rate estimate are used. Finally, we show that although applying a physically-based aerosol-cloud interaction parameterization seems to positively advance the complexity of GCMs, this is akin to the practice in the last GCM generation of applying artificial limits on remote and polluted cloud droplet number.

A.10 - **A three-layer model of the global overturning circulation**

Tom Beucler <tbeucler@mit.edu>

We present idealized two and three-layers model of the oceanic circulation in a single basin with a Southern circumpolar channel. The theory relies on a balance between the effects of wind, eddies, diapycnal mixing and polar convection. Analytical solutions are obtained for the overturning streamfunction and the deep stratification. The simplicity of the resulting dynamics allows us to study their effect on the heat transport of a simple ocean basin. By following the evolution of a passive heat perturbation in our three-layer model, we obtain scaling laws for the rate at which heat enter different depths, which is a significant source of uncertainty in climate models. By studying the effects of an active heat perturbation, we obtain the adjustment time scale of the system to a given time-dependent forcing, which can help us understand the variations of the key oceanic processes for a range of different anthropogenic climate change scenarios. This model can help build physical intuition and serve as a tool to interpret the outputs of general circulation models.

A.11 - **Hydrographic structure of overflow water passing through the Denmark Strait**

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Denmark Strait Overflow Water (DSOW) constitutes the densest portion of North Atlantic Deep Water, which feeds the lower limb of the Atlantic Meridional Overturning Circulation. As such, it is critical to understand how DSOW is transferred from the upstream basins in the Nordic Seas, across the Greenland-Scotland Ridge, to the North Atlantic Ocean. Here we characterize the hydrographic structure of the different DSOW constituents at the sill before the water descends into the Irminger Sea. Temperature and salinity (T/S) data are used from 111 shipboard sections in the vicinity of the sill carried out between 1990 and 2012. The individual realizations indicate that weakly stratified "boluses" of DSOW frequent the sill and supply the densest water to the overflow. We also characterize the structure, size, and location of the boluses and relate them to the T/S modes found at the sill. Lastly, historical hydrographic data from the Nordic Seas are used to make inferences regarding the origin of the boluses.

A.12 - **Diurnal variations of tropical cyclone structure in idealized three-dimensional simulations**

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The diurnal cycle of tropical convection, including that associated with tropical cyclones (TCs), is an important aspect of Earth's weather and climate. Various observational studies have provided evidence of diurnal variations in TCs, particularly in the size of the cirrus canopy that characterizes the TC outflow layer. Moreover, recent analyses of satellite imagery have revealed the existence of remarkably predictable diurnal pulse-like features that propagate outward from the TC center. Although many aspects of the TC diurnal cycle have been well-documented, the physical mechanisms controlling its evolution remain unclear.

In this study, we investigate diurnal variations in the structure of TCs using idealized three-dimensional simulations from the cloud-permitting System for Atmospheric Modeling. The model features fully-interactive radiation, cloud microphysics, and surface fluxes. A diurnal cycle of solar radiation is imposed using perpetual equinox conditions. Two TC simulations with different background flows are examined, one in a quiescent environment and the other in low environmental vertical wind shear. We find statistically significant diurnal oscillations of azimuthally-averaged cloud-top temperature outside of the TC inner core in both cases. However, these diurnal fluctuations are more apparent in the non-sheared case, suggesting that vertical wind shear somewhat disrupts the natural oscillations of TC convection. No significant diurnal variations of the surface wind field are found in any of the simulations. These results provide a basis for a more comprehensive study of the physical processes driving the TC diurnal cycle, as well as its possible implications for TC structure and intensity changes.

A.13 - **North African dust deposition and hydroclimate over the last 70 ka**

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Past changes in atmospheric circulation and hydroclimate over North Africa can be explored by reconstructing eolian dust accumulation in West African margin sediments. Recent high-resolution reconstructions of dust deposition from West Africa (1) indicate dramatic changes in North African dust emissions over the last 20 ka, with comparable results to those found in the terrigenous accumulation rates at nearby ODP Hole 658C (2). The records show similar trends with arid conditions/high dust emissions seen during the Last Glacial Maximum, the Younger Dryas and Heinrich Event 1 (H1), and the wettest conditions of the past 20,000 years with accompanying low dust emissions during the African Humid Period. This study aims to extend the terrigenous flux record of ODP Hole 658C back to 70 ka, and in combination with grain size measurements and endmember modelling construct a dust flux record over this time interval. The dust flux record from this site will provide quantitative estimates of the magnitude of eolian deposition changes associated with previous Heinrich Stadials (H2 to H6) and summer insolation minima/maxima, giving new insight into hydroclimate changes accompanying orbital- and millennial-scale climate changes in North Africa over the last 70,000 years.

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A.14 - **An analytical model for CAPE and CIN evolution in midlatitude severe storm environments**

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While climatology has established the existence of certain regions and seasons in which severe thunderstorms are common in midlatitude continents, it is not well understood how how the thermodynamic conditions in which these storms occur are controlled by climate. Here, thermodynamic preconditions for continental atmospheric convection are examined through an analytical model for the development of a moist boundary layer in a dry adiabatic environment. The model distills the energetic precursors of continental severe convection into the simplified, idealized context of a single atmospheric column. Analytic scalings are thereby developed for peak values of convective available potential energy (CAPE) and convective inhibition (CIN) in midlatitudes. The analytical framework is then used to interpret results from a separate, numerical raditative-convective model of idealized midlatitude severe storm environments. In a broader sense, these results contribute toward the identification of climatic controls on peak values of CAPE and CIN in continental midlatitudes.

A.15 - **A new in-situ sensor for characterizing full carbonate chemistry in aquatic environments: Development and Application**

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A recently developed sensor, Channelized Optical System (CHANOS), is able to make simultaneous, in situ measurements of dissolved inorganic carbon (DIC) and pH at high frequency (one measurement cycle is ~10-15 min). With this pair of parameters, CHANOS can fully characterize the marine CO2 system with relatively small error. DIC and pH channels both use flow-through, spectrophotometric methods to detect relative absorbances of acid and base forms of a pH-sensitive indicator. For laboratory and in situ tests, precision of pH and DIC are ±0.002 and ±3.0 μmol kg^{-1}, respectively. Deployment of CHANOS in a Cape Cod salt marsh will

provide high-resolution data required to accurately quantify inorganic carbon and alkalinity export fluxes from highly dynamic salt marshes. Intertidal salt marshes are highly productive, highly vegetated coastal ecosystems that are important in exporting carbon and other biogeochemical species to the coastal ocean. Studies have shown that wetlands export organic carbon and nutrients as well as dissolved inorganic carbon (DIC) and total alkalinity (TA). Published literature contains few studies with sufficient resolution to accurately quantify marsh inorganic carbon export flux and its effects on carbonate chemistry and carbon cycling of adjacent coastal systems. Data from CHANOS in a salt marsh will help to reduce uncertainty in current estimates of marsh export and establish a baseline export flux in order to evaluate the importance of intertidal salt marshes in carbon cycling as marshes continue to be destroyed by anthropogenic perturbations such as land development and nutrient enrichment.