GCC 2019 Program

Thursday, November 7, 2019

2:15 pm: GCC participants meet at the Ames Street crosswalk on MIT's campus (25 Ames St, Cambridge, MA, 02142)

2:30 pm: Buses 1 and 2 depart from MIT campus to Woods Hole.

2:55 pm: Bus 2 stops briefly at Boston Logan Airport (lower arrival level at terminal B, right outside gate B113) to pick up three+ students.

3:00 pm sharp: Bus 2 departs from Boston Logan Airport and continues towards Woods Hole

4:00 - 5:00 pm: Registration (1h)
Swope Center, 1st floor lobby

5:00 - 5:15 pm: Introduction (15 min)
Lillie Building, Lillie Auditorium
Co-chairs: Rose Palermo and Henri Drake (MIT-WHOI Joint Program)

5:15 - 6:15 pm: Session I. Paleoclimate, Earth, and Planetary History (1h)
Lillie Building, Lillie Auditorium
Session chairs: Jimmy Bramante and Lizzie Wallace

- Paleocurrents in a Least-Cost Pathway Model of Human Dispersal from Sunda to Sahul, 65 – 45,000 Years Ago (Marisa Borreggine)
- Assessing the sea level hypothesis with new records from the East Pacific Rise (Sarah McCart)
- Oceans on Mars: Implications and Locations (Mark Baum)

6:15 - 7:15 pm: Dinner (1h)
Swope Center, 2nd Floor Dining Hall

7:30 - 9:00 pm: Poster Session A and Mixer
Swope Center, 2nd floor lobby and Meigs Room
[See poster session assignments (A, B, or C) in table at the end of the program]

9:00 pm +: Icebreaker and Board Games
Icebreaker: *Swope Center, 2nd floor lobby and Meigs Room*
Board games are available after the icebreaker: *Smith Laboratory, Conference Room*

Friday, November 8, 2019

8:30 - 9:30 am: Breakfast (1h)
Swope Center, 2nd floor dining hall

9:30 - 11:00 am: **Session II. Climate Models and Projections** (1h 30 min)

Lillie Building, Lillie Auditorium

Session chairs: Ted Amdur and Catherine Wilka

- ❏ Climate Models: Robust and Explanatory (Ryan O'Loughlin)
- ❏ Connections between climate sensitivity and the extratropical circulation (Luke Davis)
- ❏ Global climate feedbacks from Antarctic ice sheet discharge under high future carbon emissions (Shaina Rogstad)
- ❏ Drought in the Midwest and Great Plains: Could the United States Experience Another Dust Bowl? (Catherine Nikiel)

11:00 - 11:15 am: Coffee Break (15 min)

Lillie Building, Lillie Auditorium

11:15 - 12:15 pm: Keynote Address: Heather Goldstone (WCAI, NPR station for Cape Cod) (1h)

Lillie Building, Lillie Auditorium

12:15 - 1:30 pm: Lunch (1h 15 min)

Swope Center, 2nd floor dining hall

1:30 - 3:00 pm: **Session III. Oceanography** (1h 30 min)

Lillie Building, Lillie Auditorium

Session chairs: Mara Freilich and Ali Ramadhan

- ❏ How does a more stratified ocean affect coastal upwelling? (Jing He)
- ❏ Riverine Impacts on the Dissolved Inorganic Carbon System in the Mississippi Sound (Allison Savoie)
- ❏ Local atmosphere--ocean predictability: dynamical origins, lead times, and seasonality (Eviatar Bach)
- ❏ Air-sea flux perturbations and spatial patterns of ocean heat uptake (Matthias Aengenheyster)

3:00 - 3:30 pm: Coffee Break

Lillie Building, Lillie Auditorium

3:30 - 4:45 pm: **Session IV. Ice** (1h 15 min)

Lillie Building, Lillie Auditorium

Session chairs: Joanna Millstein and Julia Wilcots

- ❏ Bed Character and Dynamics of Thwaites Glacier (Emily Schwans)
- ❏ The Effect of Antarctic Sea Ice on Southern Ocean Carbon Outgassing (Mukund Gupta)
- ❏ Importance of orography for Greenland cloud and melt response to atmospheric blocking (Lily Hahn)

4:45 - 6:15 pm: **Session V. Policy and Action** (1h 30 min)

Lillie Building, Lillie Auditorium

Session chairs: Lyssa Freese and Greta Shum

- ❏ Supporting Small Island Economies: Toolkit Design (Nickie Cammisa)

- ❏ Global Shipping Emissions Allocations and their Policy Implications (Yiqi Zhang)
- ❏ The State of Climate Change Adaptation in Canada's Protected Areas Sector (Stephanie Barr)
- ❏ Explaining Climate's (Sun)Rise on the Democratic Party Agenda (Geoffrey Henderson)

6:15 - 7:30 pm: Dinner (1 h)

Swope Center, 2nd floor dining hall

7:30 - 9:00 pm: Workshops (1h 30 min)

Locations - Lillie Building, Lillie Auditorium and Loeb Building, Rooms G70, 263, 374

- ❏ Diversi-tea: Exploring the first gen experience & the application of diversity and equity efforts (Nickie Cammisa & Alexandra Valencia Villa) - *Lillie Auditorium*
- ❏ Science and storytelling: The false dualism of the professional climate scientist and the individual living in a changing climate (Rebecca Orrison) - *Loeb G70*
- ❏ Telling a climate story (Meghana Ranganathan) - *Loeb 263*
- ❏ Amplifying research impact: communicating research findings to shape climate decisionmaking (Patrick Cage) - *Loeb 374*

9:00 pm +: Social Events

Lillie Building, Lillie Auditorium

- ❏ Movie night ("Hocus Pocus")

Smith Laboratory, Conference Room

- ❏ Board games

Local bars (self-organized; e.g., the Landfall or the Captain Kidd)

Saturday, November 9, 2019

8:30 - 9:30 am: Breakfast (1h)

Swope Center, 2nd floor dining hall

9:30 - 11:00 am: Session VI. Paleoclimate and Deep Time (1h 30 min)

Lillie Building, Lillie Auditorium

Session chairs: Noah Anderson and Michaela Fendrock

- ❏ Constraining discharges and erosional effects of glacial outburst floods in the Channeled Scablands of eastern Washington (Karin Lehnigk)
- ❏ Antarctic ice sheet growth during the Miocene Climatic Optimum: Paleoenvironmental insights from the Ross Sea (Imogen Browne)
- ❏ Deglacial to Holocene Circumpolar Deep Water paleotemperatures from the Totten Glacier System, East Antarctica (Kara Vadman)
- ❏ Ocean Overturning Circulation, Global Warming, and the Existence of Tipping Points in Deep Time (Johanna Holo)

11:00 - 11:15 am: Coffee Break (15 min)

Lillie Building, Lillie Auditorium

11:15 - 12:45 pm: Session VII. Atmospheric Science and Meteorology (1h 30 min)

Lillie Building, Lillie Auditorium
Session chairs: Ziwei Li and Colleen Golja

- ❏ The Simulated Impact of Snow Loss on Convective Precipitation over the Rocky Mountains under Climate Warming (Brendan Wallace)
- ❏ Mechanisms Controlling Rainfall over Idealized Tropical Islands in Radiative Convective Equilibrium (Martin Velez-Pardo)
- ❏ US Precipitation Modulated by Sub-seasonal Tropical Variability (Marybeth Arcodia)
- ❏ The Case for a Resilient Quasi-Biennial Oscillation (Aaron Match)

12:45 - 2:00 pm: Lunch (1h 15 min)
Swope Center, 2nd floor dining hall

2:00 - 2:15 pm: Group Photo (15 min)

2:15 - 3:30 pm: Time to explore Woods Hole or take a break (1h 15 min)
We will open the Ocean Science Discovery Center and offer walks around Woods Hole for anyone interested

3:30 - 4:55 pm: Session VIII. Biogeochemistry and Ecology (1h 25 min)
Lillie Building, Lillie Auditorium
Session chairs: Diana Dumit and Nathan Mollica

- ❏ When bigger is less: trade-offs between wood and leaf production in Arctic shrubs along a temperature and moisture gradient in West Greenland (Rebecca Finger-Higgens)
- ❏ The potential impacts of increased warming and nitrogen on Alliaria petiolata (garlic mustard) physiology across a latitudinal gradient (Michelle Jackson)
- ❏ Southern Ocean diatoms may prevent the atmospheric release of DMS (Erin Castorina)
- ❏ How Wisconsin Fens Interact with the Atmosphere (Jessica Turner)

5:05 - 6:30 pm: Session IX. Localized Climates (1h 25 min)
Lillie Building, Lillie Auditorium
Session chairs: Raphael Rousseau-Rizzi and Tristan Abbott

- ❏ The Missing Link: How Understanding Soil Organic Matter Cycling Can Help to Determine the Effectiveness of the Mangrove Blue Carbon Sink (Carey Schafer)
- ❏ Tropical hydroclimate reconstructions from coastal sinkholes in the Northern Caribbean (Anne Tamalavage)
- ❏ Southern Californian Hydroclimate and Vegetation Change Over the Past 200,000 yrs (Mark Peaple)
- ❏ Late Holocene hydroclimate variability inferred from varved sediments in Columbine Lake, Colorado (Charlotte Wiman)

6:30 - 7:30 pm: Dinner (1 h)
Swope Center, 2nd floor dining hall

7:30 - 9:00 pm: Poster Session B
Swope Center, 2nd floor lobby

[See poster session assignments (A, B, or C) in table at the end of the program]

9:00 pm +: Social Event – Annual Costume Party

Private room at Captain Kidd, a local bar in Woods Hole

Costumes encouraged but optional.

Sunday, November 10, 2019

8:30 - 10:00 am: Breakfast and Checkout

Swope Center, 2nd floor dining hall

10:00 - 11:30 am: Poster Session C (1h 30 min)

Swope Center, 2nd floor lobby

[See poster session assignments (A, B, or C) in table at the end of the program]

11:30 - 12:30 pm: Session X. Impacts and Mitigation (1h)

Lillie Building, Lillie Auditorium

Session chairs: Adrian Garcia and Praneeth Gurumurthy

- ❏ Technoeconomic feasibility and greenhouse gas reduction potential of macroalgae-based climate change mitigation actions (Patrick Cage)
- ❏ Reducing Manure Greenhouse Gas Emissions through Novel Treatment Processes (Rylie Ellison)
- ❏ How does climate affect the food security in Ethiopia? (Meijian Yang)

12:30 - 12:45 pm: Concluding Remarks (15 min)

Lillie Building, Lillie Auditorium

12:45 - 1:30pm: Lunch

Swope Center, 2nd floor dining hall

1:30 pm: Buses depart Woods Hole

3:00 pm: Bus going directly to the airport should arrive at Boston Logan Airport

3:15-3:30 pm: Buses should arrive at MIT, arrival time will depend on potential airport stop

3:30-6:00 pm: Sunday afternoon activities

Depart from MIT after dropping off bags in Building 54 (contact Henri Drakesee logistics email for details)

- ❏ MIT campus tour (Lyssa Freese)
- ❏ Harpoon beer hall visit (Colleen Golja)
- ❏ Freedom Trail walking tour (Joleen Heiderich)

END OF GRADUATE CLIMATE CONFERENCE

Poster Presentations

Name	Topic	Title	Poster Session
Mark Goldman	Atmospheric Sciences & Meteorology	Oxidation chemistry within atmospheric aerosols	A
Nadia Colombi	Atmospheric Sciences & Meteorology	Diverse Springtime Variability in Ice Nucleating Particle Properties and Sources in an Alaskan Arctic Oil-Field Location	B
Rohini Shivamoggi	Atmospheric Sciences & Meteorology	Secondary Eyewall Formation in Idealized Numerical Models	C
Veeshan T Narinesingh	Atmospheric Sciences & Meteorology	The influence of topography on blocking and general circulation	C
Garrett Limon	Atmospheric Sciences & Meteorology	Investigating a Hierarchy of Machine Learning Algorithms to Predict Physical Tendencies of Simplified Atmospheric Model Forcing	B
Tsung-Lin Hsieh	Atmospheric Sciences & Meteorology	Applications of a beta-plane turbulence theory to tropical cyclogenesis and the polar vortex	A
Colleen Golja	Atmospheric Sciences & Meteorology	The Creation of a Coupled Advection-Coagulation Model to Understand the Behavior of Aerosols Injected from the SCoPEx Payload	B
Catherine Wilka	Atmospheric Sciences & Meteorology	Novel Stratospheric Chemistry Connections to Tropical Dynamics	B
Benjamin Birner	Atmospheric Sciences and Meteorology	Validating stratospheric transport models	A
Ariel Greiner	Biogeochemistry & Ecology	Impact of Climate Change on Global Coral Reef Networks	B
Elisabet Perez Coronel	Biogeochemistry & Ecology	Seasonal methane dynamics in high-elevation lakes in the Sierra Nevada California: the role of elevation, temperature, inorganic nutrients and organic matter	A
Lindsay Capito	Biogeochemistry & Ecology	Environmental controls on Didymo bloom formation	A
Loay Jabre	Biogeochemistry & Ecology	Temperature and iron interactively influence growth in key polar diatom, with ecological and biogeochemical consequences	A
Callie Concannon	Biogeochemistry & Ecology	Long term CO2 and temperature effects on fecundity and oocyte recruitment in the Atlantic silverside	B
Alison Post	Biogeochemistry & Ecology	Sensitivity of the Shortgrass Steppe to Deluge Size	C
Carolyn Anderson	Biogeochemistry & Ecology	Soil carbon loss in vulnerable subalpine floodplains	A
Jianning Ren	Biogeochemistry & Ecology	What Is the Role of Bark Beetle Outbreaks in Driving Large Fires in Evergreen Forest Under Climate Change	B

Tianlin Wang	Biogeochemistry and Ecology	Investigation of moisture pulse-reserve in the soil-plant continuum using combined SMAP and CYGNSS observations	B
Aditya Narayan Mishra	Climate Models & Predictions	Manifestation of June 2009 extreme rainfall event over Austria in a climate change future	B
Ashesh Chattopadhyay	Climate Models & Predictions	Deep Learning Algorithms for Data-Driven Modeling of Weather/Climate and their Extremes	A
Jessica Tomaszewski	Climate Models & Predictions	Impacts of Wind Farm Wakes on the Downstream Environment: Implications for Climate	B
Katrina Fandrich	Climate Models & Predictions	Dynamical downscaling of near-term internal climate variability and change for the main Hawaiian Islands using WRF ensemble simulations	A
Casey Patrizio	Climate Models & Predictions	Quantifying the role of ocean dynamics in sea-surface temperature variability	A
Henri Drake	Climate Models & Predictions	How accurate have climate model projections been so far?	A
Ziwei Li	Climate Models & Predictions	The Learnability of Feedforward Neural Networks in Dissipative Chaotic Dynamical Systems	A
Ali Ramadhan	Climate Models & Predictions	Oceananigans.jl: Fast and friendly high-resolution ocean process modeling for long-range climate prediction	C
Lizzie Wallace	Climate Models & Predictions	Investigating the statistical significance of centennial timescale paleohurricane activity using modeled hurricane climatology over the past millennium	A
Ted Amdur	Climate Models & Predictions	Surface Temperature Response to Solar Forcing is Weak and Consistent with Climate Models	C
Colin Evans	Climate Models & Predictions	Intrinsic Century-Scale Variability in Tropical Pacific SSTs and their Influence on Western US Hydroclimate	C
Julian Spergel	Ice	Surface Meltwater Drainage and Ponding on the Amery Ice Shelf, East Antarctica	C
Lily Hahn	Ice	Importance of orography for Greenland cloud and melt response to atmospheric blocking	B
Richelle Cabatic	Ice	Quantifying upper layer ocean circulation using iceberg GPS Tracking	B
Camille Hankel	Ice	The Role of Positive Feedbacks in Abrupt Arctic Winter Sea Ice Loss in Future Warming Scenarios	C
Sierra Melton	Ice	Iceberg Calving and Meltwater Plumes at Helheim Glacier, Greenland	A
Meghana Ranganathan	Ice	Simultaneous Inversion for Glacier Bed Properties and Ice Rheology using Adjoint-Based Methods	A
Ryan Venturelli	Ice	Subglacial Carbon Pathways Associated with Whillans and Mercer ice streams: A SALSA and WISSARD Sedimentary Perspective	C

Rose Palermo	Impacts & Mitigation	The effect of accelerating sea levels on barrier island stability	C
Abel Mkulama	Impacts & Mitigation	Producing briquets from agricultural waste, reducing deforestation and minimizing biomass waste, case studies in Lilongwe, Malawi.	A
Morteza Taiebat	Impacts & Mitigation	Remarkable Energy Use Rebound Effect of Self-Driving Vehicles	C
Tae Lim	Impacts & Mitigation	Feasibility of using direct air capture as a climate backstop in the U.S. power sector	A
Udayan Singh	Impacts & Mitigation	Strategies for “on the map” deployment of negative emission technologies in the United States	A
Mary Hannah Smith	Impacts & Mitigation	Planning for climate change in Massachusetts: insights from the MVP program	B
Tianjia Liu	Impacts & Mitigation	Detection of delay in post-monsoon agricultural burning across Punjab, India: potential drivers and consequences for air quality	C
Heather Sussman	Localized Climates	Impacts of Increased Urbanization on Surface Temperature and Vegetation over Bengaluru, India	C
Maria Esther Caballero Espejo	Localized Climates	Ecosystem-based adaptation to the impacts of heavy precipitation during Coastal El Niño events in Peru	B
Tyler Scott Winkler	Localized Climates	Intense hurricane landfall frequency varied significantly in the northwestern Bahamas throughout the last 1800 years	A
Joeri Reinders	Localized Climates	Extreme Flooding Events in Southeast Texas: a Paleoflood Reconstruction	C
Rebecca Albuquerque Maranhao	Localized Climates	Water Storage Variation in the Lake Sobradinho (Northeast Brazil) from 2004 to 2014.	A
Yan Jiang	Localized Climates	Observational trends in burned area and driving forces over Central Equatorial Africa	B
Oliver Jack Billson	Oceanography	Observation of coastal storms, over an unprecidented range of wave and beach conditions	A
Kevin Rosa	Oceanography	Coastally-Refined Resolution Global Ocean Model Improves Eastern Boundary More than Western Boundary	A
Riley Brady	Oceanography	Skillful multiyear predictions of pH variability in the California Current System	B
Praneeth Gurumurthy	Oceanography	A preliminary estimate of heat budget on an inner continental shelf	B
Mara Freilich	Oceanography	Vertical fluxes and carbon cycling at ocean fronts	A
Joleen Heiderich	Oceanography	Gulf Stream Transport from Autonomous Underwater Gliders	B

Cora Hersh	Oceanography	Can GO-SHIP tell us how accurate Argo data are?	A
Alexandra Valencia Villa	Paleoclimate & Deep Time	A multi-proxie paleoclimate approach: clumped and stable isotopes on the Cariaco Basin, Venezuela	C
Anson Cheung	Paleoclimate & Deep Time	Alkenone based sea surface temperature and marine productivity reconstruction in the Santa Barbara Basin from mid Holocene to present	A
Shouyi Wang	Paleoclimate & Deep Time	Reconstructing Southern Ocean Bottom Water Ventilation During Last Deglaciation	C
Sarah McGrath	Paleoclimate & Deep Time	Indian Summer Monsoon Rainfall Reconstruction over the past 640 kyr	B
Catherine Prunella	Paleoclimate & Deep Time	Ice-ocean interactions at the Ross Sea shelf break during Plio-Pleistocene warm intervals	A
Boyang Zhao	Paleoclimate, Earth & Planetary History	Climate Change and Norse Settlement Transition	B
Rebecca Orrison	Paleoclimate, Earth & Planetary History	Spatio-temporal variability of the South American Monsoon over the past millennium	B
Minn Lin Wong	Paleoclimate, Earth, and Planetary History	South Atlantic Convergence Zone behavior over the mid-late Holocene inferred from central Brazil speleothem δ18O records.	A
Mali'o Kodis	Policy & Action	Strategic Retreat for Climate Resilience: Developing a Theory of Change	C
Justin Shawler	Policy & Action	A conceptual framework to guide transdisciplinary climate adaptation research among early career researchers	C
Nicolas Schmid	Policy & Action	Political feedback of coal phase-out: An analysis of US Presidential Elections	B
Dana Thomas	Policy & Action	Climate Adaptation in Conflict Affected Countries	C
Rebecca Gustine	Policy & Action	Forest management and climate change effects on water quality of Cedar River Watershed	A

GCC 2019 Abstracts

Atmospheric Sciences & Meteorology

The Simulated Impact of Snow Loss on Convective Precipitation over the Rocky Mountains under Climate Warming -*Brendan Wallace*

Warm season moist diurnal convection can be particularly sensitive to changes in land surface characteristics such as snow cover and soil moisture. Under climate change, for regions of mountainous terrain, reductions in snow cover expected along the low-elevation seasonal snowpack margin can alter surface albedo, soil moisture content, and mesoscale circulations which act to control available moist static energy, boundary layer height, and convective evolution. Soil moisture anomalies and their influence on warm season precipitation have been studied, but not in relation to diminishing snowpack within the spring season.

We run a set of regional climate simulations using the Weather Research and Forecasting model at 4-km grid spacing with a domain centered on the Rocky Mountains of Colorado. The simulations are conducted from April through July across a period of 7 years extending from 2006 through 2013. These simulations include a control (CTR) run, forced by reanalysis, and a pseudo global warming (PGW) run in which a fixed mean warming perturbation derived from climate models is applied to the boundary conditions. Both are forced by output from a series of 4-km WRF regional climate runs that cover a continental-scale domain. An additional CTR is performed to isolate the effects of the snow-albedo and soil moisture-precipitation feedbacks. In this experiment, snow depth, snow water equivalent, and soil moisture are forced to have the same values as the PGW state.

Factors taken into account to diagnose changes in diurnal convection include: precipitation accumulation on multiple time scales and vertically integrated cloud liquid water path. Environmental attributes like CAPE along with radiative changes in cloud cover and surface fluxes are included. Mesoscale circulations such as the mountain-plains solenoid are investigated for patterns indicative of increased forcing.

Mechanisms Controlling Rainfall over Idealized Tropical Islands in Radiative Convective Equilibrium -*Martin Velez-Pardo*

More rain falls over tropical islands than over the surrounding ocean regions. Explaining the reasons behind this enhancement can lead to greater clarity about localized atmospheric convection, and can help elucidate the potentially crucial connection between convection over the Maritime Continent and the Walker circulation, a major source of uncertainty in our current understanding of the Earth's climate variability. This work is part of an ongoing attempt to characterize the climatology of precipitation over tropical islands. Here, we present results obtained from a set of three-dimensional radiative-convective equilibrium simulations performed with the System for Atmospheric Modeling, SAM, where we explore the effects of variations in sea-surface temperature and surface moisture on rainfall over highly idealized, low-heat-capacity circular islands of varying sizes, embedded in a slab-ocean domain. We find that the daily averaged precipitation over the islands generally increases with higher sea-surface temperature, and is consistently highest over islands with radii in the 24-to-36-kilometer range. Additionally, islands with no surface moisture register higher precipitation averages than those with completely moist surfaces. We analyze how dynamical and thermodynamic aspects of the sea breeze circulation, as well as the propagation of gravity waves, explain some of the observed features of this daily cycle, such as time of highest rainfall, total amount of rain, and changes in atmospheric moisture convergence with varying SST and surface moisture. Finally, we discuss briefly how a better understanding of convection and rainfall over tropical islands can help improve current climate models.

US Precipitation Modulated by Sub-seasonal Tropical Variability -*Marybeth Arcodia*

A composite analysis reveals that the Madden-Julian Oscillation (MJO) impacts North American rainfall through perturbations in both the jet stream and low-level moisture availability. Upper level divergence associated with the tropical MJO convection drives a quasi-stationary Rossby wave response to the mid-latitudes. Results here show that when the tropical MJO convection forces the midlatitude upper-level jet to accelerate, a positive rainfall anomaly results downstream. A reverse effect is seen as the MJO propagates eastward. The explained variance of the MJO rainfall anomaly to the total anomaly ranges from between 40%-65% in the US.
To include the effects of interannual variability, the MJO and ENSO are linearly combined. ENSO and the MJO interfere both spatially and temporally to modulate North American rainfall. In some cases, the MJO can enhance an ENSO anomaly by a factor of three or overwhelm the signal and change the sign of the anomaly. Analyses of specific MJO events during an El Niño or La Niña episode reveal significant contributions to extreme events via constructive and destructive interference of the MJO and ENSO signals. Understanding tropical-extratropical interactions can lead to improved predictability of midlatitude weather on subseasonal timescales.

The Case for a Resilient Quasi-Biennial Oscillation -*Aaron Match*

Following the surprising observation of a downward propagating quasi-biennial oscillation (QBO) of winds in the equatorial stratosphere, efforts were focused on explaining the mechanism that forces the winds to oscillate. Given the observed QBO disruption in 2015/2016 and that many General Circulation Models still fail to simulate QBO-like oscillations, one may be under the impression that the QBO is a fragile phenomenon. We argue that if atmospheric parameters allow the QBO to exist, then the QBO is actually resilient, and the question becomes why the phenomenon vanishes at around 70 hPa, several kilometers above the typically assumed origins of the forcing waves. Previous investigations using one-dimensional models argued that mean upwelling stops the QBO before it reaches the wave source, forming a "buffer zone". We argue that it is not the local effects of upwelling that form the buffer zone; rather, any term that relaxes the QBO momentum against the far field momentum has a damping effect that can form a buffer zone. In addition to upwelling, enhanced diffusivity can produce a buffer zone, but in both cases the damping/buffer zone is due to communication with the far field through the lower boundary condition. Alternatively, relaxation due to horizontal momentum exchange can damp the QBO anywhere. We find that in MERRA-2, horizontal momentum fluxes and the Coriolis force play such relaxational roles in the tropical lower stratosphere with damping timescale of ~40 days at 100 hPa and might be responsible for the observed QBO buffer zone.

Biogeochemistry & Ecology

When bigger is less: trade-offs between wood and leaf production in Arctic shrubs along a temperature and moisture gradient in West Greenland *-Rebecca Finger-Higgens*

Warming environmental conditions are often credited with increasing Arctic shrub growth, yet it is unclear if tundra vegetation expansion will continue into future decades. Water-limitation may begin to limit Arctic vegetation growth if increasing air temperatures create drier soil conditions due to increases in evaporation loss and thawing permafrost induced soil drainage. However, few studies have effectively considered how dominant tundra shrub species respond to variations in both temperature and moisture conditions. To better understand the key differences in temperature variation and soil moisture on two dominant circumpolar deciduous shrubs, we utilized a natural landscape gradient in West Greenland. We found that both grey willow (Salix glauca) and dwarf birch (Betula nana) shrub growth was sensitive to variations in air temperature and soil moisture. For both species, increases in air temperature were positively correlated to greater shrub volume, with much of the additional growth due to an increase in woody biomass. Leaf biomass was best predicted by edaphic features including soil bulk density, extracted soil ammonium, and gravimetric soil moisture. Warmer soils generally tended to be drier, suggesting that ongoing warming in the area could lead to significant water losses. These findings compliment previous dendrochronological research that shows evidence of shrub sensitivity to water availability and plant water stress. Therefore, our study demonstrates that Arctic plants are sensitive to soil water availability and recommend that variations in coupled temperature-moisture dynamics be considered when predicting if, how, and where shrub expansion will occur.

The potential impacts of increased warming and nitrogen on Alliaria petiolata (garlic mustard) physiology across a latitudinal gradient -*Michelle Jackson*

Alliaria petiolata (Bieb.) Cavara & Grande (garlic mustard), is an invasive forb that has drastically altered the composition of native plant and soil communities in New England and the eastern United States. The mechanisms behind the ecological success of A. petiolata are a combination of widespread seed and the production of phytochemicals. These secondary compounds inhibit mycorrhizae beneficial to numerous local species. Extensive research has been conducted on the loss and potential recovery of such important native plant-fungal symbioses. However, the increasing effects of climate change within this region warrant further investigation into the physiological responses of A. petiolata to these novel environmental conditions. Additionally, exploring ecotypic variation of A. petiolata plants from different latitudes may inform predictions regarding global change effects on potential geographic range shifts in this species. Seeds from three different states (MA, VT, and PA), which represent a distinct temperature gradient within A. petiolata's range, will be grown in common garden conditions. Physiological, growth, and environmental measurements will be taken on plants subjected to four randomized factorial global change parameter treatments including soil warming, nitrogen, combined soil warming + nitrogen, and a control. Comparisons will be made to in situ plants ultimately addressing the following questions: 1) Does the combination of increased soil temperature and available nitrogen influence A. petiolata productivity? and 2) Is there phenotypic variation associated with the physiology of latitudinal A. petiolata ecotypes?

Southern Ocean diatoms may prevent the atmospheric release of DMS -*Erin Castorina*

Dimethylsulfide (DMS) is present in elevated concentrations in the Southern Ocean where it is associated with algae in the sea ice. The flux of DMS to the atmosphere is primarily responsible for the formation of cloud condensation nuclei, an important component of the negative feedback required to stabilize global temperatures with rising levels of atmospheric CO_2. Utilizing the synchrotron at Argonne National Laboratory in Illinois, we used X-ray absorption spectroscopy (XAS) to analyze the diatom frustule, the diatom exoskeleton. Diatoms are responsible for 0.36% of both marine and terrestrial biomass (a global total of 0.3 Gt C), and we have observed sulfide as a significant component in nearly every sample analyzed. These 49 diatom samples were taken from both the Pacific and the Indian Ocean basins of the Southern Ocean, from surface waters to a depth of 1000 meters. The reduced sulfur appears to bind with zinc, a minor nutrient initially utilized by the diatom during its growth phase. The zinc K-edge XAS analysis of the frustule indicates that roughly 40% of this nutrient is present as a sulfide which is roughly equal to the amount of zinc silicate present in the siliceous frustule. If sulfide from DMS is trapped in the diatom exoskeleton, then diatoms may be acting as a sink of DMS before it can interact with the atmosphere. Therefore, even with increased ice melt in the Antarctic, a hypothesized increase in CCN formation may not materialize, as DMS may be removed from the surface waters by the rapid diatom growth cycle.

How Wisconsin Fens Interact with the Atmosphere -*Jessica Turner*

Autors: Jessica Turner, Ankur R. Desai, Jonathan Thom, Kim Wickland, Brent Olson
The United States once held approximately 221 million acres of wetlands, but over half of the original wetlands were drained or destroyed by the mid-1980's. The Clean Water Act of 1972 initially protected wetlands because the pollution of rivers, lakes, and coastal waters had begun to impact the fishing industry and public health and safety. Understanding additional significant benefits such as the ability to sequester carbon and thus mitigate climate change should also inform restoration and protection decisions and practices regarding wetlands. Scientific understanding of land-atmosphere interactions through continuous observations of environmental fluxes is needed to do so. Coterminous USGS and AmeriFlux eddy covariance flux tower observations at a sheltered fen (US-ALQ) and a more open fen (US-Los) in Northern Wisconsin provide a unique opportunity to study similarities and differences in carbon uptake due to the sheltering effect in fens. Net ecosystem exchange of CO2(NEE) was compared during the growing seasons of 2015-2017 between the two sites. While both sites produced similar NEE during daytime, the open fen was a significantly larger CO2source at night. Both fens showed similar sensitivities of NEE to air temperature, although the open fen had a more linear relationship. Net radiation partitioning also had similarities during most months of the growing season, with significant differences between sites appearing in spring and late summer. Our work suggests that because of significant differences in sensible and latent heat fluxes, net radiation partitioning, and the strength of C sink, wetlands with tall canopies should be considered in wetland protection and restoration.

Long term CO2 and temperature effects on fecundity and oocyte recruitment in the Atlantic silverside -*Callie Concannon*

Experimental ocean acidification research has elucidated many traits in a variety of marine organisms that are impacted by rising oceanic CO2 levels. However, most experiments have focused on relatively short-term exposures, whereas long-term, whole life cycle consequences of high CO2 have rarely been studied. The Atlantic silverside (M. menidia) has become an important marine fish model to study climate change effects in coastal fish. Although silversides are relatively tolerant to increased ocean temperature and ocean acidification, whole life cycle effects like potential annual fecundity and oocyte development have not yet been assessed.
We quantified the whole life cycle effects of high CO2 x high temperature environments on potential annual fecundity and oocyte development in M. menidia. Wild M. menidia were captured via beach seining in the spring of 2018, strip-spawned, and their offspring reared to maturity under two CO2 treatments (~400 µatm and 2,200 µatm) and two temperatures (17oC and 24oC). Both 17oC and a 400 µatm are ambient values, and 24oC and 2,200 µatm are extreme values predicted for the year 2100. After 11 months, prior to spawning, fish were sampled, gonads extracted, and their ovaries preserved (n = 88 females out 377 individuals). We calculated a gonadosomatic index for both male and females. We used ImageJ to count and size the oocytes in each fish's ovaries and sent the oocytes out to Mass Histology to identify development stages and link them to corresponding size classes. Results will improve our understanding of long-term exposure impacts on the Atlantic silverside; more specifically the impacts on their reproductive output.

Sensitivity of the Shortgrass Steppe to Deluge Size -*Alison Post*

Climate change is intensifying the hydrologic cycle globally, resulting in more extreme weather events, ranging from extended droughts to more frequent large precipitation events, or deluges. While many ecosystem types will be affected by such alterations in precipitation patterns globally, arid and semi-arid systems are expected to be the most responsive. In these ecosystems, ecological processes are largely controlled by the pulsed nature of individual precipitation events, and deluges represent an extreme precipitation pulse. Since climate change models predict an overall increase in deluge magnitude, I designed an experiment to assess how deluge size affects ecosystem function in the shortgrass steppe of Northeastern Colorado. Using a replicated regression approach, I administered a single deluge of varying size (20-120 mm) to plots during peak growing season. I then monitored several ecosystem responses, including soil moisture, soil respiration, canopy greenness, and above- and below-ground net primary production (ANPP & BNPP), as well as leaf water potential, leaf length, and flowering of the dominant grass species, Bouteloua gracilis (blue grama). The shortgrass steppe was extremely sensitive to deluge size, with all measured responses exhibiting a general positive linear trend with increasing deluge size. There was little evidence of response saturation, suggesting that this ecosystem is able to effectively utilize large water inputs from deluges. These findings have important implications for understanding ecosystem functioning of the shortgrass steppe under future precipitation regimes.

Soil carbon loss in vulnerable subalpine floodplains -*Carolyn Anderson*

Floodplain soils are large and dynamic reservoirs of carbon. Floodplains experience dramatic changes in hydrology, which can strongly affect how soil carbon is either retained in or exported from the soil. Importantly, seasonal flooding dynamics are shifting with climate change, particularly in alpine and subalpine systems, making floodplains vulnerable to increased floods and droughts. This has profound implications for soil carbon retention and export, as stored soil carbon could be released as the greenhouse gas CO2 or exported into the water, affecting both soil fertility and downstream water quality. However, we do not know the mechanisms of carbon storage in these systems and thus cannot predict floodplain carbon cycling under climate change. An emerging view is that soil redox potential, or electron availability, can control the retention or export of soil carbon. The subalpine floodplain of the East River (Gothic, CO) provides a unique location to study how seasonal hydrology impacts redox potential and thus carbon export, because we can study these processes both across time (from spring snowmelt subsequent drainage) and space (across the landscape). In 2018, we leveraged these gradients to study soil carbon export. Our analyses reveal that seasonal flooding influences soil redox dynamics, which in turn influences carbon export over time. Further, selective dissolution extractions of soil reveal that minerals play a large role in carbon stabilization, and that certain minerals--particularly iron oxides--are especially important in this protection mechanism. These results suggest that shifting flooding patterns due to climate change will strongly affect floodplain carbon storage.

What Is the Role of Bark Beetle Outbreaks in Driving Large Fires in Evergreen Forest Under Climate Change -*Jianning Ren*

Climate change is likely facilitating larger wildfires in the Western U.S., although its effects are location-dependent. It influences wildfire size and severity either directly, e.g. increasing the dryness of fuel loads (thus fire susceptibility), or indirectly, e.g. through increasing the frequency of bark beetle outbreaks, which can affect forest hydrology, surface fuel loads, and the moisture conditions. However, our knowledge on how bark beetle outbreaks could alter wildfire regimes (i.e. its occurrence, extent, severity, and the system type, i.e. fuel-limited, flammability-limited, or mixed) remains very limited. Recent studies demonstrated that bark beetle outbreaks do affect fuel status and wildfire behavior. However, the response varies to multiple factors, such as time since outbreaks, tree mortality rate, and fire regimes. To characterize the responses of fuels and fire behavior to bark beetles across a range of scenarios (e.g., forest management and climate) and site-specific environmental conditions, we use the integrated ecohydrologic-fire model (i.e. RHESSys-WMFire) coupling with a beetle effects model. We use no beetle attack as the control scenario, and use multiple gradients of outbreaks frequencies and tree mortality rates as response scenarios. We then estimate wildfire size in responding to variation in outbreaks frequency and mortality rate, which will enable us to determine whether there are thresholds that would significantly shift fire regimes. We hypothesize that the effect of beetle attacks on wildfire size is largely determined by the rate of beetle-caused tree mortality, and this response will also be influenced by the extent to which the fire regime is fuel- versus flammability-limited. Beetle attacks can also increase fire severity and frequency by increasing the fuel loads. With climate change and more severe and frequent bark beetle attacks, there is a high probability of larger and more severe forest fires.

Seasonal methane dynamics in high-elevation lakes in the Sierra Nevada California: the role of elevation, temperature, inorganic nutrients and organic matter -*Elisabet Perez Coronel*

Freshwater lakes are important but uncertain sources of methane (CH_4) to the atmosphere due to limited and inconsistent measurements worldwide. High-elevation lakes, in particular, have been overlooked—despite their large numbers in mountain ranges around the world, and despite the fact that high elevations experience rapid changes in temperature with climate change that might affect methane emissions. Over a 2-year study, we examined variations in CH_4, temperature, inorganic nutrients, and organic matter in 5 mountain lakes spanning multiple elevations in the Sierra Nevada of California. We found strong seasonality in CH_4 concentrations in lake water: higher concentrations were observed in the warmest months (July-August) and lower concentrations in fall (Sep-Nov). These changes in concentrations were significantly related to temperature in the majority of the individual lakes (Lukens: $p<0.005$, $r^2 = 0.611$, Lower Cathedral: $p<0.05$, $r^2 = 0.529$ and Upper Cathedral Lake: $p<0.005$, $r^2 = 0.779$), and related to elevation across lakes ($r^2 = 0.39$, $p<0.005$). CH_4 concentrations in lakes at mid elevation (<3000 m) were strongly related to temperature, nitrite concentrations and elevation ($r^2 = 0.9$, $p<0.005$) whereas CH_4 concentrations were correlated with the DIN:DIP ratio and elevation ($r^2 = 0.48$, <0.005) in lakes at higher elevations (>3000 m). Our results suggest that seasonality in CH_4 concentrations and fluxes is substantial in freshwater lakes, such that predicted increases in temperature and nutrient loading may affect overall CH_4 emissions from mountain lakes and other freshwater ecosystems in the coming decades.

Environmental controls on Didymo bloom formation - *Lindsay Capito*

Overgrowth or “blooms” of Didymosphenia geminata (Didymo) have increased across North America in recent decades and the cause still unknown. Blooms can wreak havoc on water infrastructure and have ecological consequences for stream ecosystems. Didymo overgrowth is linked to conditions of low phosphorus, low turbidity, and low streamflow. Because glacier meltwaters are richer in particulates and phosphorus, the loss of glaciers in the mountain west could be a driving factor in the increase in Didymo blooms. Here, we examine the relationship between declining glacial cover and Didymo blooms in the Mountain West. We will assess the relationship between glaciated streams and the presence of Didymo to assess if declining glacial cover is leading to increased Didymo presence. We will accomplish this by pairing field observations with a controlled experiment wherein we will manipulate physical conditions to simulate degrees of deglaciation. By understanding the cause of Didymo overgrowth we are better able to manage valuable aquatic resources in a changing climate.

Temperature and iron interactively influence growth in key polar diatom, with ecological and biogeochemical consequences -*Loay Jabre*

Phytoplankton provide food for higher trophic levels, influence the ocean’s ability to sequester CO_2 and play a key role in regulating Earth’s climate. In addition to light, phytoplankton growth is largely governed by temperature and iron availability. Iron is an essential cofactor in many vital proteins, including those involved in photosynthesis and oxidative stress control, while temperature (thermal energy), directly influences enzymatic turnover rates. Current climate change models predict an average increase in global sea surface temperature; predictions of iron availability remain uncertain. Although the individual effects of iron and temperature have been well studied, we still lack a phenomenological and mechanistic understanding of how/if they interactively influence phytoplankton growth. In this study, we cultured Fragilariopsis cylindrus, a key polar diatom, under various iron conditions at 1 °C and 3 °C and 6 °C, and measured its growth rate, photosynthetic health and cell size. Our results illustrate an interactive temperature-iron effect where warming decreased the demand for iron and in turn alleviated iron-limited growth to some degree. Cells showed more signs of stress when iron availability was limited, but temperature did not significantly cause any stress. Additionally, we observed a plastic response of cell size to both iron and temperature, where estimated cell diameter increased with iron concentration and decreased with warming. These results suggest that climate-change mediated alterations to temperature and iron availability could have substantial ramifications to marine primary productivity and sinking rates and can ultimately influence the cycling of matter and energy in the oceans.

Impact of Climate Change on Global Coral Reef Networks -*Ariel Greiner*

Climate change threatens the existence of coral reefs around the world through mass mortality of corals following bleaching. Coral reefs, like many other marine ecosystems, are connected through the dispersal of pelagic larvae that travel along ocean currents, creating reef networks. Loss of reefs due to coral bleaching will lead to unexpected changes in the characteristics of coral reef networks, threatening network persistence and reducing the availability of source reefs. Using a larval dispersal model and existing global datasets of hypothesized reef climate refuges based on past current and future climate models, we identified how reefs worldwide are connected in networks and how those networks may be affected by reef loss induced by climate change. We explored different scenarios of reef loss, removing reefs in increments comparable to the percentage lost in the mass bleaching event of 2016, but differing in the order of reef loss. We also explored the dynamics of recolonization from the remaining living reefs to the former reef sites. We found that the pattern of loss and the recovery potential changed markedly depending on the timing of the loss of these hypothesized reef climate refuges, demonstrating their importance for maintaining global coral reef connectivity.

Ice-ocean interactions at the Ross Sea shelf break during Plio-Pleistocene warm intervals -*Catherine Prunella*

Warm intermediate-depth Southern Ocean waters are implicated in recent Antarctic ice mass loss. Because Antarctic Ice Sheet (AIS) volume controls global sea level, observed mass loss threatens coastal and low-lying communities, globally. Direct observations of AIS retreat are temporally limited, necessitating paleoceanographic records of ocean-ice interactions during past warm climate intervals. Deep-sea and ice proximal sediments record orbitally-paced glacial-interglacial fluctuations in AIS volume during the Plio-Pleistocene (~0-3 million years), but the total contribution of the AIS and the role of ocean heat in these fluctuations remains unresolved. To address the response of Antarctica's ice sheets to changing ocean temperatures during the Plio-Pleistocene, International Ocean Discovery Program (IODP) Expedition 374 recovered sediments from the Ross Sea outer-shelf (Site U1523; 74°9.02'S and 179°47.70'W, 828 m water depth). Site U1523 is close to the shelf break and sensitive to incursions of warm intermediate-depth Southern Ocean waters when the eastward-flowing Antarctic Slope Current weakens. Paleotemperature records from this location enable us to test the hypothesis that changes in Southern Ocean temperatures drove ice retreat from the continental shelf edge during Plio-Pleistocene warm intervals.

We present orbital-scale foraminifer Mg/Ca-based bottom water and surface paleotemperature records. To understand relationships between AIS volume, Southern Ocean temperatures, and intermediate-depth water influence, we pair foraminifer Mg/Ca, δ18O, and δ13C records with sedimentary facies analyses from Site U1523. These analyses enable us to assess the impact of ocean heat on past ice sheet dynamics. This unique insight from the Ross Sea continental shelf will improve the ability of climate ice sheet models to predict the rate and magnitude of ice sheet response to modern warming.

Climate Models & Predictions

Climate Models: Robust and Explanatory *-Ryan O'Loughlin*

This paper examines robustness analysis (RA) in climate modeling and focuses on climate model comparison practices such as the Coupled Model Inter-Comparison Project Phase Five (CMIP5). RA is a type of reasoning that occurs when inferring from multiple less certain lines of evidence that share some key feature, to a more certain conclusion. However, this general type of reasoning can have importantly different features in different contexts. The case of RA in climate modeling demonstrates some unique features and highlights a common mistake that philosophers often make when discussing scientific reasoning: overgeneralization. More specifically, this paper targets the generality and applicability of philosopher Jonah Schupbach's (2018) account of RA. The present paper argues that Schupbach's "unified, explanatory account of diversity," which is claimed to be true of all RA, does not capture the way in which climate models are robust. For some climate model hypotheses, it is agreement between models with shared causal assumptions about greenhouse gas forcing—rather than a diversity of assumptions— that is most relevant for robustness. Therefore, Schupbach's notion of RA does not seem to be "truer to actual cases of RA in science," at least with regard to climate model comparison practices.

The paper begins with an overview of Schupbach's conception of RA. Then climate models are discussed, with particular attention paid to how climate scientists (e.g. Knutti et al. 2016, Abramowitz et al. 2019, Fischer et al. 2013) talk about the robustness of multi-model ensembles. In light of the climate modeling literature, RA in climate modeling seems to exemplify model robustness, as originally described in Lloyd's "Model Robustness as a confirmatory virtue: The case of climate science" (2015). Crucially, Lloyd's model robustness is explanatory, like Schupbach's, but it is causally explanatory rather than explanatory in the sense of eliminating competing hypotheses.

Connections between climate sensitivity and the extratropical circulation *-Luke Davis*

The dry dynamical core represents one of the simplest possible numerical models for studying the response of the extratropical circulation to climate change. In the model, the circulation is forced by relaxing temperature to a notional "equilibrium" profile using linear damping. The linear damping coefficient plays an essential role in governing the structure of the circulation. But despite decades of research with the dry dynamical core, the role of the damping coefficient in governing the circulation has received relatively little scrutiny.
In this work, we systematically vary the damping coefficient in a dry dynamical core in order to under- stand how the amplitude of the damping influences extratropical dynamics. Critically, we prove that the local climate feedback parameter is proportional to the damping coefficient – that is, the damp- ing timescale is a measure of climate sensitivity for the dry atmosphere. The key finding is that the steady-state extratropical circulation responds to changes in this climate sensitivity.
Longer damping timescales (i.e. higher climate sensitivities) lead to a less dynamically active extratrop- ical circulation, stronger and more persistent annular modes, and equatorward shifts in the jet. When perturbed with climate change-like forcings, changing the damping timescale can also change the dy- namical response to the forcing. We argue that understanding the response of the circulation to climate change is critically dependent on understanding its climate sensitivity, and consider how climate sensi- tivity might be inferred from its effect on the circulation in the dry model and more complex general circulation models.

Global climate feedbacks from Antarctic ice sheet discharge under high future carbon emissions *-Shaina Rogstad*

Observational evidence indicates that the Antarctic Ice Sheet is losing mass at an accelerated rate, and ice sheet models highlight the potential for a significant ice collapse in the next century. The impacts of this large fresh water forcing on sea-ice formation, ocean circulation, and climate could be significant, but the current generation of GCMs don't adequately capture ice sheet meltwater discharge. Here we present results for 2005-2250 from several climate model simulations performed under IPCC future climate scenarios RCP 4.5 and 8.5 with a high-resolution, fully coupled, ocean-atmosphere-sea ice model (CESM 1.2). In each experiment, temporally and spatially variable runoff from Antarctica is prescribed from a regional dynamic/thermodynamic ice sheet/shelf model. Our results highlight a significant rise in subsurface ocean temperatures (>1C) at the ice sheet grounding line that may accelerate rates of ice melt beyond those currently projected. In contrast, the increased runoff creates a cold surface layer that allows Antarctic sea ice to continue to expand through the end of the current century causing delayed atmospheric warming. These competing feedbacks have significant implications for ice sheet evolution that can help inform the next iteration of ice sheet models and constrain future climate states.

Drought in the Midwest and Great Plains: Could the United States Experience Another Dust Bowl? *-Catherine Nikiel*

The Dust Bowl was a large-scale, long-term drought event that had a profound impact on the economic and social fabric of the Midwest and Great Plains of the United States during the 1930's – particularly the widespread devastation of burgeoning farming communities. In the present day, the Great Plains and Midwest are home to a substantial portion of the population of the United States and this region is a major producer of corn and soybean for both domestic and international consumption. The future of growing season suitability for these crops is therefore a global concern. The recently released Fourth National Climate Assessment notes that these regions are likely to see a decrease in crop yields and yield trends due to increasing heat stress with climate change. However, overall trends in drought conditions, both in the historical and future period, and the influence that humans have played in this area are still uncertain in the literature. Therefore, part of this study aims to improve understanding of the long-term trends in summer hydroclimatology in the Midwest and Great Plains. It is also reasonable to ask whether events on the scale of the Dust Bowl may happen in the future. In order to accurately describe the likelihood and characteristics of drought events in this region we first characterize the hydrologic, dynamic, and remote characteristics of the Dust Bowl using available observational and reanalysis datasets spanning the entire 20th century. Further analysis is performed to determine whether events of this type can be seen in CMIP5 GCM simulations. A careful selection process of GCMs is made in order to ensure that the important climatological features are accurately reproduced in the simulations. After identifying these events in the historical period, an analysis is presented on the expected evolution of these events under future climate scenarios.

Intrinsic Century-Scale Variability in Tropical Pacific SSTs and their Influence on Western US Hydroclimate *-Colin Evans*

It is well documented that the hydroclimate of Western North America is influenced by the state of the tropical Pacific Ocean, particularly the phase of El Niño/Southern Oscillation (ENSO). During ENSO's warm phase, the American Southwest tends to experience anomalously wet winters while the Pacific Northwest has a tendency to dry. During ENSO's cold phase, nearly opposite conditions are typical; the Southwest experiences drought while the Pacific Northwest becomes colder and wetter than average. It is expected that ENSO and its influence on Western North America hydroclimate will be altered by climate change. However, because it remains unclear how much internal natural variability is present in these teleconnections, the extent to which the teleconnections will change in future climates is difficult to discern. To gain a better understanding of natural variability in ENSO teleconnections, we use a linear inverse model (LIM) to assess the relationship between tropical Pacific sea-surface temperatures and several drought indicators, such as the Palmer Drought Severity Index (PDSI). The LIM output yields realistic teleconnection patterns with century scale variability in teleconnection strength comparable to long simulations from models included in the recent Paleoclimate Model Intercomparison Project 3 (PMIP3) and Climate Model Comparison Project Phase 5 (CMIP5) experiments. The variability in ENSO teleconnection strength inherent to the LIM indicates two important aspects of understanding ENSO teleconnections; firstly, detecting a significant change in hydroclimate from ENSO influences will be challenging, even in a changing climate; and secondly, reconstructions of past climates using proxies located in the Southwest as predictors of ENSO variations may be sensitive to variations in teleconnection strength that are not well-sampled by the relatively brief historical period.

Dynamical downscaling of near-term internal climate variability and change for the main Hawaiian Islands using WRF ensemble simulations -*Katrina Fandrich*

As climate models continue to improve, the demand from resource managers and decision-makers for more accurate climate projections is increasing. However, natural climate variability poses a limit to the confidence in regional climate change projections, in particular for the mid-21st century. The unique geographic location of the Hawaiian Islands and its regional climate provides a challenging opportunity for climate modelers. In this project, natural climate variability is examined for its impacts on near-term climate change projections. The Pacific Decadal Oscillation (PDO) and El Niño–Southern Oscillation (ENSO) are two examples of internal climate variability that effect temperature and precipitation in the Hawaiian Islands region. To study their effects, the Community Earth System Model (CESM) Large Ensemble Project (Kay et al. 2015) is used in connection with the WRF model for dynamical downscaling. Preliminary results from the WRF model output analysis indicate that by year 2071, average monthly surface temperatures in Hawaii will increase by 0.64—1.26 degrees. It is also projected that by year 2071, under negative PDO conditions, average monthly temperatures will be up to 0.30 degrees higher than those under positive PDO conditions. These results suggest that anthropogenic forcing plays a greater role than internal variability in mid-21st century temperature projections for the Hawaiian Islands. Further analyses are performed in order to determine the effects of PDO phase on future monthly and seasonal rainfall statistics in the Hawaiian Islands region. By examining the roles of internal variability on a regional scale, such as the Hawaiian Islands, it is hoped that future climate projections can be better understood and communicated to the public on a global scale as well.

Quantifying the role of ocean dynamics in sea-surface temperature variability -*Casey Patrizio*

The climate is warming, but also exhibits substantial variability across a wide range of time scales. Since the atmosphere and ocean readily exchange energy at their interface, climate variability is often associated with sea-surface temperature (SST) variability. An improved understanding of the processes that contribute to SST variability may therefore lead to more accurate predictions of the climate across the globe. Yet, there remains considerable uncertainty regarding the major drivers of SST variability, particularly the relative roles of atmospheric processes and dynamical ocean processes. To address this, we quantify the role of ocean dynamics in contributing to SST variance on a pointwise basis across the globe and across a variety of time scales. SST, surface heat fluxes and other fields are obtained from reanalyses (e.g. MERRA-2), and objectively-analyzed observationally-based product, OAFlux, from the Woods Hole Oceanographic Institution. The contribution of ocean dynamics to SST variability is quantified using an SST variance budget, with the ocean heat transport term calculated as a residual. The temporal dependency of the results is examined using a low-pass filter of varying length. We find that on shorter time scales (< 3 years), dynamical ocean processes dominate the contribution to

SST variance in many regions, particularly along western boundaries of ocean basins. On longer time scales (> 3 years) outside the Pacific, ocean dynamics and surface heat fluxes generally have similar contributions to SST variance, suggesting an important role for both atmosphere and ocean processes in many regions on long time scales. In the Pacific, atmospheric processes generally dominate the contribution to SST variance on long time scales. The results presented here are distinct from results from previous studies that used a different methodology to infer the importance of the atmosphere for short-term SST variability, and the ocean for long-term SST variability.

Impacts of Wind Farm Wakes on the Downstream Environment: Implications for Climate -*Jessica Tomaszewski*

Wind farm wakes can extend over 50 km downwind in stably stratified conditions and pose significant consequences on downwind power production, revenue generation, and the surface temperature environment. As such, wind farm wake impacts must be considered in wind resource assessments and planning.
The Weather Research and Forecasting (WRF) model includes a Wind Farm Parameterization (WFP) to estimate wind farm wake effects, but model configuration choices can influence the resulting predictions of wind farm wakes. These choices include vertical resolution, horizontal resolution, and whether or not to include the addition of turbulent kinetic energy generated by the spinning wind turbines. Despite the sensitivity to model configuration, no clear guidance currently exists on these options.
"Best practices" can be defined by comparing simulated wind farm wakes produced by varying model configurations with observations from operating wind plants or from in-situ meteorological observations. We show that insufficient model resolution can lead to drastically different conclusions regarding the impacts of wind farms on surface temperature. Namely, coarser grid spacing (> 3 km) leads to a simulated warming of the near surface environment downstream of wind turbines, whereas finer grid spacing (< 3 km) suggests that near-surface cooling occurs. These results suggest that the simulated direct impacts of wind turbines on global surface temperatures are highly sensitive to grid spacing, and must therefore be considered with caution.

Deep Learning Algorithms for Data-Driven Modeling of Weather/Climate and their Extremes -*Ashesh Chattopadhyay*

Weather and climate are usually modeled as highly non-linear PDEs coupling multiple scales of interaction amongst the physical processes governing it. These PDEs are generally computationally prohibitive since the evolution of the physical processes are dictated by the time scale of the high frequency, small scale processes such as convection, clouds, baroclinic eddies etc. In this work we present a hierarchy of climate models where in an increasing level of sophistication in developing deep learning algorithms trained only on the large scale processes' data can forecast (both in short term and long term climatology) the evolution of the large scale processes via a toy multi-scale Lorenz 96 model (in review, PRS) and the 2 layered quasi-geostrophic equations. We show, that for the fully coupled atmosphere-ocean-land-ice Community Earth System Model version 1 (CESM1), increasing the sophistication of the deep learning algorithms can predict dominant clusters in the multi-scale chaotic and non-stationary daily Z500 patterns (in revision, Scientific Reports) as well as heat waves up to 5 days ahead of time (in review, GRL). We believe that, through these data driven forecasting models, ineffective empirical parameterizations of small scale processes requiring high resolution simulations can be replaced by inexpensive data driven super-parameterization models trained on either high resolution simulation data or observational data while augmenting expensive numerical weather prediction models.

Manifestation of June 2009 extreme rainfall event over Austria in a climate change future -*Aditya Narayan Mishra*

During 22-24 June 2009, Austria witnessed a rampant rainfall spell that spread across populated areas of the country. High intensity rainfall caused 3000+ landslides in Feldbach, and property damages worth €10,000,000 in Styria itself. Numerous synoptic scale studies indicated the presence of a cut-off low over central Europe and excessive moisture convergence behind the extreme event. In a warmer climate change scenario, such an extreme precipitation event may become more intense due to higher water holding capacity of air with increased temperatures, but this reasoning may not be so straightforward considering the complex physics of precipitation. Precipitation, as a natural atmospheric phenomenon, is dependent upon the dynamic and thermodynamic characteristics of the atmosphere. While it is safe to say that the thermodynamic characteristics of the atmosphere is relatively easier to simulate with confidence using available global models, the same cannot be said about the dynamics. This can be blamed on the chaotic non-linear behavior of the atmosphere and problem in resolving sub-grid scale processes that reduce the model accuracy for longer spatial scales.
We use CCLM regional model to simulate this one particular event for a warmer future. We initially failed to simulate the event for the future using the larger EURO-CORDEX domain (25km resolution) and the smaller CCLM domain (3km resolution) in nested form, so we resorted to using the CCLM domain in standalone with idealized conditions for relative humidity and vertical lapse rate to successfully simulated the event for the future. Further, to improve the accuracy of our future case simulations, we fix the issue of deriving real(not ideal) GCM simulated inputs for parameters such as the relative humidity by improving our modeling experiment, which increases the credibility of the future case simulations.

Ice

Bed Character and Dynamics of Thwaites Glacier *-Emily Schwans*

The National Academy of Sciences identifies Thwaites Glacier (TG) as the most likely climatic tipping point for several key reasons.
First, TG is susceptible to ocean influence. Warm circumpolar deep water accesses the cavity below TG's floating shelf, weakening this stabilizing feature. TG thins and accelerates in response, increasing mass loss and triggering unstable inland grounding line migration on a retrograde slope as described by the Marine Ice Sheet Instability Hypothesis (MISI). This feedback along with TG's connection to deep marine basins in the interior of the West Antarctic Ice Sheet (WAIS) make it the most likely conduit by which the WAIS could rapidly destabilize and contribute ~3 m to global sea level rise.
The timing of this hinges on several ill-constrained or unknown parameters, including future climate forcing, bed properties, and the evolution of TG's floating ice shelf.
Model runs of TG prescribing several likely bed-types are run forward for a century under modern climatic and oceanic conditions. The system is perturbed using several shelf removal scenarios, allowing the ice front to freely evolve. Modeled mass loss and grounding line migration patterns indicate that there are stability tipping points for TG that are dependent on both shelf retention and the ability of the underlying rock to transfer stress.
This interplay highlights the key role played by the bed and shelf in (de)stabilizing TG. These results point to a need for better parameterizations of basal sliding and brittle failure of ice cliffs in order to reduce the largest uncertainties in projections of TG's evolution and its contribution to sea level rise in the next century.

The Effect of Antarctic Sea Ice on Southern Ocean Carbon Outgassing *-Mukund Gupta*

The Southern ocean plays an important part in the global carbon cycle and in the regulation of atmospheric pCO_2. In the high latitude Southern hemisphere, the ocean circulation transports carbon and nutrient-rich waters from the abyss up to the surface, thereby promoting biological activity and exchange of carbon with the atmosphere. However, since much of the upwelling occurs under the seasonal ice zone, both carbon exchange and biological activity are limited by the presence of sea ice. Motivated by the increasing number of observations in the Southern ocean, this study uses a high-resolution regional model to help quantify the controls on air-sea carbon exchange. We find that this flux is a resultant of three main drivers (temperature solubility, soft tissue pump and upwelling of stored carbon), which compete over the seasonal cycle. We then investigate the effect of sea ice on the flux through a series of numerical experiments, in which ice affects either the exchange of carbon, the light availability or both together. We find a strong compensation between these two effects, resulting in the net flux remaining almost constant for a large range of sea ice fractions. We interpret these results in light of a simple analytical model, and quantify the effects of the advective, biological and exchange timescales on the effectiveness of the compensation mechanism. Finally, we discuss the implication of these results on glacial/interglacial theories of the Pleistocene that connect the expansion of Antarctic sea ice with a decrease in atmospheric pCO2.

Importance of orography for Greenland cloud and melt response to atmospheric blocking -*Lily Hahn*

In recent decades, persistent high pressure conditions tied to the negative phase of the North Atlantic Oscillation (NAO) have occurred more frequently over the Greenland Ice Sheet (GrIS), contributing to record-breaking melt events and accelerated warming since the mid-1990s. While previous studies suggest that these atmospheric blocking conditions enhance surface melt by advecting warm air northward onto the western GrIS or by inducing adiabatic warming, more recent work indicates that Greenland blocking may additionally enhance melt through large-scale subsidence and cloud dissipation, which allows more solar radiation to reach the ice sheet surface. However, the suggestion that large-scale subsidence drives the cloud response to Greenland blocking has not yet been investigated. Additionally, evidence of regionally dependent Greenland cloud radiative effects (CRE) motivates investigation of the spatial distribution of CRE under blocking conditions. Here we use reanalysis and satellite data as well as a regional climate model to show that anticyclonic circulation anomalies over Greenland during recent extreme melt summers produce cloud changes dependent on orographic lift and descent rather than large-scale subsidence. The resulting increased cloud cover over northern Greenland promotes a dominant surface longwave warming, while reduced cloud cover in southern and marginal Greenland favors a dominant surface shortwave warming. Comparison with an idealized model simulation with flattened topography reveals that orographic effects were necessary to produce area-averaged decreasing cloud cover since the mid-1990s and the extreme melt observed in the summer of 2012. This demonstrates a key role for Greenland topography in mediating the cloud and melt response to large-scale circulation variability.

Subglacial Carbon Pathways Associated with Whillans and Mercer ice streams: A SALSA and WISSARD Sedimentary Perspective -*Ryan Venturelli*

High rates of grounding line retreat and ice mass loss from the West Antarctic Ice Sheet (WAIS) since the Last Glacial Maximum have been attributed to fast-flowing ice streams along the Siple Coast. Knowledge of specific style and timing of retreat is limited, in part, due to the poorly constrained chronologies and far-field, marine-based sedimentary records. Two subglacial access drilling efforts in the last decade, Whillans Ice Stream Subglacial Access Research Drilling (WISSARD, 2013 & 2015) and Subglacial Antarctic Lakes Scientific Access (SALSA, 2018-2019), have recovered sediment cores from subglacial archives beneath Whillans and Mercer ice streams. From these efforts, we can use subglacial lake and grounding zone sediments for reconstructions of past WAIS variability. Furthermore, knowledge of the extent and timing of past WAIS variability allows us to elucidate how relict organic matter deposited during marine incursions influences carbon cycling in subglacial environments. Here we present biogeochemical evidence constrained by acid insoluble organic matter (AIOM) Ramped PyrOx 14C ages illustrating the role of organic carbon input to these sediments during the Holocene.

These unique sedimentary records provide new information on retreat history along the Siple Coast, broadening our understanding of processes that introduce labile (thermochemically reactive) carbon to subglacial environments.

The Role of Positive Feedbacks in Abrupt Arctic Winter Sea Ice Loss in Future Warming Scenarios -*Camille Hankel*

The melting of Arctic sea ice affects global climate in many ways, from enhancing Greenland melting and thus weakening the Atlantic Meridional Overturning Circulation, to threatening high-latitude ecosystems. While summer sea ice melt under RCP8.5 warming scenarios in Global Climate Models (GCMs) is fairly well understood, the evolution of winter Arctic sea ice is not. Different GCMs disagree on important aspects of winter sea ice loss, such as its timing and whether such loss is gradual or sudden. In particular, sudden winter sea ice decline (a sign of a bifurcation, or a "tipping point") is a very stark qualitative feature of the CSIRO-Mk36 model, which experiences a 65 percent decrease in March sea ice over 14 years. Other models predict the opposite: a gradual decline in winter sea ice over the next two centuries. In this study, I try to identify the mechanisms present in different models that cause some to predict a tipping point and others a gradual decline of winter sea ice. In particular, I am searching for evidence of a positive feedback mechanism in the models that express a tipping point which could explain such rapid sea ice loss. One such possible feedback is the convective cloud feedback (Abbot and Tziperman 2008), occurring when sea ice loss due to warming leads to an increase in heat and moisture fluxes from the ocean, and thus to atmospheric convection and clouds with a strong longwave radiative forcing, which in turn lead to warming and further sea ice loss. Additional contributors examined include meridional atmospheric heat transport and air-sea fluxes. By analyzing output from different GCMs we attempt to gain insight into whether feedbacks play a role in the exhibited tipping-point behavior and to understand if gradual or abrupt wintertime Arctic sea ice loss is more likely in the future.

Iceberg Calving and Meltwater Plumes at Helheim Glacier, Greenland -*Sierra Melton*

Ice-cliff failure through calving of large icebergs may cause rapid retreat of outlet glaciers and destabilization of inland ice sheets. An improved understanding of physically-based calving mechanisms at ice cliffs is of critical importance in order to better constrain ice-sheet models and sea-level projections. We investigate calving controls and behavior with a satellite remote sensing analysis of the calving terminus of Helheim Glacier, a tidewater glacier on the east coast of Greenland that terminates in an ~100m tall ice cliff with an ice mélange and choked fjord in front. At grounded or nearly-grounded marine-terminating glacial fronts such as Helheim, calving icebergs are generally non-tabular. When non-tabular icebergs extending the entire terminus thickness calve and capsize, glacial earthquakes occur as globally detectable events. However, some wider tabular icebergs, which remain floating upright, also calve from nearly-grounded termini without producing glacial earthquakes.
Marine-terminating glacial termini are also sometimes characterized by ephemeral meltwater-plume-fed polynya features in the mélange. Polynya appearance, glacial earthquakes, and the morphology of icebergs serve as indicators of the glacier's grounding state. Our analysis focuses on the timing and locations of meltwater plumes, the relationship between the subglacial water system and calving behavior, and the grounding state through time. We identify surface meltwater pooling and associated polynyas at Helheim's terminus in high-resolution DigitalGlobe optical imagery and document temporal variability of the grounding state related to iceberg calving behavior, glacial earthquake occurrence, and meltwater polynyas. This provides insight into the variables influencing changes in calving and grounding state at Helheim, which may serve as an analogue to behavior at the future glacial margins of Antarctica after removal of ice shelves by warming ocean waters. Unstable ice cliffs could cause retreat into the deep Antarctic basins containing vast volumes of ice with the potential to contribute several meters to global sea level.

Simultaneous Inversion for Glacier Bed Properties and Ice Rheology using Adjoint-Based Methods *-Meghana Ranganathan*

Drag at the bed and along the margins of outlet glaciers are the primary forces of resistance to fast flow in outlet glaciers. Constraining reasonable values of the basal friction coefficient and the coefficient of ice viscosity in shear margins is therefore essential for making reliable projections of sea level rise. Since basal friction and ice viscosity are both important terms in the momentum balance, they are strongly coupled. As a consequence, simultaneously inferring these parameters is a challenging problem. Here, Here, we address the question of whether it is possible to derive physical meaning from joint inversions of these parameters by showing that inverse methods can accurately represent these critical parameters by minimizing the misfit to surface velocity observations. Through a series of experiments using synthetic data generated with physically plausible variations in basal friction and ice rheology, we obtain reasonable values of both basal friction and ice viscosity coefficients. We then apply these methods on the Siple Coast Ice Streams to examine spatial variability of ice rheology and basal friction across and along the shear margins. We use the numerical ice flow model Úa with an adjoint-based inversion technique to infer basal slipperiness and the rate factor in Glen's Law. Preliminary results demonstrate spatially varying basal slipperiness with increasing basal strength along the southern shear margin of Bindschadler Ice Stream.

Quantifying upper layer ocean circulation using iceberg GPS Tracking *-Richelle Cabatic*

The Greenland proglacial fjord system, where glaciers from the ice sheet reach the ocean, is an important contributor to sea level rise. When reaching the ocean, these glaciers break off icebergs. These icebergs travel through the fjord and out into the open ocean. All the while, different types of water circulate through the fjord, meeting with the glacier's terminus and affecting its stability. The tidewater glacier, Jakobshavn Isbrae, and it's fjord, Ilulissat, is of particular interest because it is the most prolific glacial system in Greenland in terms of ice export. Many studies have addressed Jakobshavn's glacial front, but little is known about Ilulissat's ocean circulation due to the difficulty of collecting field measurements in the ice-choked region. Through our study, we deploy transmitting GPS units on icebergs in Ilulissat Fjord, thereby directly tracking iceberg movement and indirectly detecting the fjord's circulation patterns. Using icebergs as proxies for surface circulation thus provides an alternative to deploying marine instruments that have minimal likelihood for survival in the treacherous fjord environment. Results of our study show that: at a distance of 35km away from the glacier terminus, iceberg movement is no longer dominated by glacial calving events; and that there are eddy circulation patterns at fjord widening locations. This study has the potential to help oceanographers understand more about Ilulissat's circulation dynamics, and can inform glaciologists about how glaciers such as Jakobshavn's acceleration is affected by this type of circulation.

Surface Meltwater Drainage and Ponding on the Amery Ice Shelf, East Antarctica *-Julian Spergel*

Surface meltwater ponding has been observed to be widespread and persistent on many of Antarctica's floating ice shelves, making it imperative to understand meltwater's effects on ice-shelf stability and break-up. This requires answering the question of how do surface meltwater drainage systems behave over decades and how do they respond to increased meltwater and more consecutive years with melt? We analyze satellite imagery of the Amery Ice Shelf (AIS) and its surface drainage network from 1973-present, using Landsat, MODIS, and WorldView imagery, and Sentinel-1 Synthetic Aperture Radar (SAR) data. We hypothesize that the formation and growth of the melt pond system is complexly dependent on decadal patterns of local climate and glacio-hydrological surface processes. We find that most lakes on the AIS freeze through in the wintertime, while a few maintain liquid beneath a lid of ice. Evidence for wintertime freeze-through suggests a gradual accumulation of impermeable ice lenses in the near-surface firn down-glacier of the drainage system. We observe that consecutive years of meltwater formation leads to an expansion of lake margins and a down-glacier extension of the drainage network. We hypothesize that warmer summertime air temperatures would lead to more consecutive years of melt, which would change near-surface firn porosity and increase the down-glacier extent of the surface drainage network. This process could extend the drainage system on AIS and on other ice shelves, and allow water to access areas vulnerable to hydro-fracturing. Large-scale ice sheet models may need to incorporate these complex interactions between melting, over-ice drainage, percolation and refreezing if they are to reliably predict the response of ice shelves to atmospheric warming.

Impacts & Mitigation

Reducing Manure Greenhouse Gas Emissions through Novel Treatment Processes *-Rylie Ellison*

In California, manure management is estimated to be one of the largest sources of methane and the largest source of nitrous oxide, with dairies being the key contributor. Along with the implementation of comprehensive regulations on air quality and water contamination from nutrients in manure, there is a clear need for the evaluation and improvement of manure management systems. The large variability of dairy manure properties and management practices make it difficult to predict the manure's nutrient value and availability for crop growth. As a result, storage and agricultural applications of manure often result in high nutrient loss to the environment. Treating manure can physically and chemically alter the organic matter to stabilize and standardize the carbon (C) and nitrogen (N) mineralization properties. Methods include anaerobic digestion, composting, and chemical treatments. One method I am investigating is enhancing solid-liquid separation with chemical coagulants traditionally used in wastewater treatment. By separating these fractions, solids can more easily be transported on or off-farm as a stable organic fertilizer. Also, methane emissions from storage of the liquid fraction has been shown to be significantly reduced while still containing the plant-available inorganic nutrient fraction. Several laboratory studies were conducted to determine the greenhouse gas emissions and C and N transformations of each separated manure fraction in storage and applied to soil. The treatment of chemically separating organic matter from manure slurry slowed the N mineralization process and reduced nitrous oxide emissions of manure solids applied to soil. Controlling the nutrient flow and availability is key to preventing nutrient losses and greenhouse gas emissions while increasing crop uptake for maximum economic value. The nutrient residual value of processed wastes can be further determined to reassess the fertilizer needs of crops.

Technoeconomic feasibility and greenhouse gas reduction potential of macroalgae-based climate change mitigation actions *-Patrick Cage*

Can seaweed aquaculture simultaneously contribute to greenhouse gas abatement and ocean restoration? Cultivated macroalgae have potential as consumables (food, fertilizer, animal feed, bioplastic), fuels (biodiesel and natural gas), antimethanogenic ruminant feed supplements, and a negative emissions technology. However, the dispersed claims in the policy and private sector discourse are generally not quantified for environmental benefits or subjected to a feasibility analysis that considers production systems and economic conditions.
This ongoing research evaluates the potential mitigation contribution of macroalgae products and processes under distinct economic conditions, policy scenarios, and production system structures. This project proposes the first typology for seaweed climate mitigation actions, evaluates the environmental benefits and economics of each action against business-as-usual and alternative mitigation actions, quantifies the potential mitigation contribution for each under a range of scenarios, and considers technoeconomic feasibility given scales of production systems and carbon pricing. Each action is evaluated for its linkages to the Sustainable Development Goals and quantified for additional passive or "automatic" carbon sequestration occurring through deep sea export of dissolved organic carbon.
Our analysis finds a sequence of climate actions with increasing production system scales and decreasing unit costs. This sequence begins with (a) sea vegetables produced artisanally, (b) progresses to other

agro-consumable substitutes (nutritional supplement, animal feed, fertilizer), (c) on to fossil replacement (single-use plastic, fuel), and (d) ultimately as a negative emissions technology. These correspond to increasing theoretical emissions reduction potentials (indicatively: 0.01% reduction global emissions, 10.5% reduction, 23.5% reduction, 100% offset). A parallel pathway is developed for antimethanogenic seaweeds as a dietary supplement for cattle and other ruminants (4.5 % reduction). We model advanced production systems for improved cost-effectiveness and propose policy realignments to enable upscaling these climate actions. Finally, we consider existing regulatory incentives and barriers, using California, Maine, and Connecticut as case studies.

How does climate affect the food security in Ethiopia? *-Meijian Yang*

According to the United Nations Office for the Coordination of Humanitarian Affairs (OCHA), in 2018, an estimated 8.13 million people were food insecure and in need of urgent assistance in Ethiopia, accounting for 8.4% of the total population. Such a serious condition is forecasted to remain unchanged in 2019. Among all drivers of food insecurity and malnutrition, climate-induced disasters ranked the No.1 driver in terms of long-term large-scale crop yield reduction and livestock death. Assisting Ethiopian farmers in reducing risks of crop yield loss from changing climate and extreme weathers is of significant importance in improving this county's food security. In this study, a process-based distributed crop model DSSAT was applied in simulating the yield of five major cereal crops (barley, maize, millet, sorghum, and wheat) in Ethiopia. With the calibrated model, the influences of both primary and secondary climate variables on cereal crop yields were assessed and evaluated at various spatiotemporal scales. Findings could help local farmers optimizing timing and allocation of those cereal crops, and reducing the potential losses from climate shocks.

Planning for climate change in Massachusetts: insights from the MVP program *-Mary Hannah Smith*

Since 2017, the state of Massachusetts has funded municipal-level climate change planning workshops to help build more resilient local communities. The Municipal Vulnerability Preparedness (MVP) program has distributed planning grants to 140 communities, and the associated Action Grant program has funded 33 projects across the state. The MVP program requires communities to engage diverse local stakeholders in a discussion about how climate change is anticipated to impact them, and generate ideas about how each community can address these challenges. This approach generates climate change insights from the ground up, and taps into local knowledge about community strengths and vulnerabilities. Review of MVP reports from the first two years of the program highlights information about the climate-related issues local leaders are most concerned about, as well as the actions that they believe are most important to reducing their community vulnerabilities. This is important new data. A better understanding of the climate change issues that engage local communities is necessary for scientists and academia to provide relevant new research to the policymakers putting climate science to work.

Remarkable Energy Use Rebound Effect of Self-Driving Vehicles *-Morteza Taiebat*

Transportation is currently the largest sources of emissions in the US, contributing to catastrophic impacts of climate change. Connected and automated vehicle (CAV) technology is expected to be an indispensable but disruptive factor in the transportation sector, transforming the mobility paradigm, transportation markets, and travelers' behavior in the coming decades. It will likely increase transportation safety to an unprecedented level, enhance mobility, provide a higher level of comfort and convenience for travelers, and reduce the cost of driving for individuals, all of which will be welfare-improving for society. At the same time, vehicle connectivity and automation will inevitably and significantly change energy demand in the transportation sector. The extent of these changes is still largely unclear and yet will have major consequences for energy supply and the environment alike.

Several characteristics of CAV technology will influence energy consumption, including improvements in route optimization, eco-driving, crash avoidance, and vehicle right-sizing, among others. Higher fuel economy reduces the energy required per mile of travel, but it also reduces the fuel cost of travel, incentivizing more travel and causing an energy "rebound effect." Moreover, CAVs are predicted to vastly reduce the time cost of travel, inducing further increases in travel and energy use.

In this study, we forecast the induced travel and rebound from CAVs using data on existing travel behavior. We develop a microeconomic model of vehicle miles traveled (VMT) choice under income and time constraints; then we use it to estimate elasticities of VMT demand with respect to fuel and time costs, with fuel cost data from the 2017 United States National Household Travel Survey (NHTS) and wage-derived predictions of travel time cost. Our central estimate of the combined price elasticity of VMT demand is -0.4, which differs substantially from previous estimates. We also find evidence that wealthier households have more elastic demand, and that households at all income levels are more sensitive to time costs than to fuel costs.

We use our estimated elasticities to simulate VMT and energy use impacts of full, private CAV adoption under a range of possible changes to the fuel and time costs of travel. We forecast a 2-47% increase in travel demand for an average household. Our results indicate that backfire – i.e., a net rise in energy use – is a possibility, especially in higher income groups. This presents a stiff challenge to policy goals for reductions in not only energy use but also traffic congestion and local and global air pollution, as CAV use increases.

Producing briquets from agricultural waste, reducing deforestation and minimizing biomass waste, case studies in Lilongwe, Malawi *-Abel Mkulama*

This paper is based on a research and development phase of a briquet prototype that would substitute the use of charcoal and fuel wood as the main source of cooking energy in Lilongwe, Malawi. It was an innovative solution for efficient utilization of agricultural waste in order to minimize depletion of forests, which are vital in absorbing carbon dioxide from the atmosphere, by providing an alternative source of cooking energy.

A needs-finding survey was conducted on 150 random sampled respondents in Chadza and Chiseka sections of Mkwinda Extension Planning Area followed by a product development where various briquet prototypes developed and scientific variables were tested to determine their efficiency. Focus group discussions were used to produce resource maps. It was discovered that there was a conflict of interest maize stalks between using them for conservation agriculture and as source of cooking energy. The research found that 31.97% of the households used maize stalks for cooking while 35.25% used charcoal, 5.7% used old sacks and clothes and only 18.5% used electricity.

A new briquet was developed using carbonization process under controlled conditions to increase calorific value, reduce smoke and ash as well as make it cost effective as compared to regular charcoal and fuelwood. These characteristics would increase adaption of briquets for cooking as well as resolve the conflict of interest for the would-be conservation farmers who use agricultural biomass as a source of energy.

Strategies for "on the map" deployment of negative emission technologies in the United States *-Udayan Singh*

Integrated assessment modeling results suggest that negative emissions to the tune of ~10 Gt-CO2 annually will be required to adhere to the 2°C target. Further, significant proportion of negative emission technologies (NETs) are projected to arise from the United States due to a shrinking carbon budget as well as increasing incentives for some NETs. In this talk, we will discuss some of the critical regional features that must be recognized for optimal strategizing of the two NETs with the highest potential – bioenergy with CO2 capture and storage (BECCS) and direct air capture (DAC).

In the case of BECCS, our geospatially-explicit costing model reveals that 35-50% of the land area in the US may have system costs incompatible with 2030 carbon prices even with advanced technology development in other segments of the supply-chain. Appealing BECCS readiness is observed in the Southeast as a result of high biomass productivity within close distances of high-potential, low-cost geologic storage opportunities. On the other hand, a large part of the country (e.g. the Midwest) may not exhibit similar viability despite biomass “hotspots” and large theoretical storage potential, owing to high injection costs.

For DAC, incorporating life-cycle energy implications is critical since utilizing electricity generated through fossil fuels results in large upstream greenhouse gas burdens. Accordingly, regions with high solar insolation compounded by suitable sequestration prospects (i.e. the Southwest and West) may be most suitable for this technology. This approach may also be prudent in managing excess solar generation in this part of the country without curtailment or large-scale electricity storage, which is currently cost-prohibitive.

Assimilating these findings emphasizes the role of coordinated policy-making in harmonizing complementary initiatives to achieve carbon mitigation nationwide. Moreover, relying on multiple technological fronts instead of a single “silver-bullet” is likely to be a more cost-effective strategy for comprehensive NET deployment.

Feasibility of using direct air capture as a climate backstop in the U.S. power sector *-Tae Lim*

We assess the technology and emissions future of the U.S. power sector to reduce its sectoral CO2 emissions by 70% in 2050 relative to 2010 when direct air capture (DAC) technology is available as a climate backstop. Based on the cost-minimizing optimization model used in this study, the CO2 emitted under business-as-usual (BAU) scenarios exceeds the 50 Gt of CO2 budget correspondent to the 70% reduction target despite its 12-37% of emissions reduction by 2050. Minimizing the overall cost of CO2 reduction depends on initiating CO2 reduction as soon as possible, by expanding low-carbon energy generating technologies (EGU) as well as retiring fossil-based plants. Each year of delay in reducing CO2 emissions by following BAU trajectories would incur an additional cost. Delays beyond 2030 would require the deployment of DAC to achieve the 70% target. Further delays till 2035 would require up to 1.5 Gt CO2 of DAC capacity. Delays beyond 2035 would make achieving 70% target out of reach for most scenarios due to ballooning cost. Compared to reducing CO2 emissions immediately, strategies of using DAC followed by delays would cost an additional 610-2070 billion USD through 2050. A DAC-based strategy is not a substitute for early CO2 reduction as they entail much the same fossil retirement and low-carbon EGU expansion as in early reduction cases, only with an accelerated pace and expanded scale as well as installing additional DAC capacity. Our results clearly highlight the importance of timely immediate preventive CO2 reduction.

Detection of delay in post-monsoon agricultural burning across Punjab, India: potential drivers and consequences for air quality *-Tianjia Liu*

Since the Green Revolution in the mid-1960s, a widespread transition to a rice-wheat rotation in the Indian state of Punjab has led to steady increases in crop yield and productivity. After harvest of the monsoon rice crop, the burning of excess crop residue in Punjab from October to November allows for rapid preparation of fields for sowing of the winter wheat crop. Here we use daily satellite remote sensing data to show that the timing of peak post-monsoon fire activity in Punjab and regional aerosol optical depth (AOD) has shifted later by approximately two weeks in Punjab from 2003-2016 (Figure 1). This shift is consistent with delays of 11-15 days in the timing of maximum greenness of the monsoon crop and smaller delays of 4-6 days in the timing of minimum greenness during the monsoon-to-winter crop transition period. The resulting compression of the harvest-to-sowing period coincides with a 40% increase in total burning and 50% increase in regional AOD. Potential drivers of these trends include agricultural intensification, variations in monsoon rainfall, and a recent groundwater policy that delays sowing of the monsoon crop. The delay and amplification of burning into the late post-monsoon season suggest greater air quality degradation and public health consequences across northern India.

Localized Climate

The Missing Link: How Understanding Soil Organic Matter Cycling Can Help to Determine the Effectiveness of the Mangrove Blue Carbon Sink -*Carey Schafer*

Coastal marine ecosystems have gained considerable attention for their ability to sequester large amounts of carbon dioxide from the atmosphere. These “blue carbon” sinks include mangrove forests, which have a small geographic footprint, yet disproportionately large soil carbon stocks. Previous emphasis on quantifying carbon stock, however, has not considered the mechanisms controlling soil organic carbon (SOC) dynamics in these ecosystems.

Combined 210Pb and radiocarbon (14C) chronologies can be applied to gain a clear understanding of SOC cycling. Whereas 210Pb dating allows for the determination of sediment accretion rates (elevation gain per year), tracking the penetration of “bomb radiocarbon” gives insight into carbon cycling within the soil. This so-called “bomb radiocarbon” is the result of thermonuclear weapons testing in the 1960s and has since exponentially decreased as it has been incorporated into various marine and terrestrial reservoirs. Determination of 14C content in organic material from cores retrieved from Ten Thousand Islands, Florida, indicate the penetration of bomb radiocarbon into deeper sediment layers (>35 cm, pre-1900). These results demonstrate the movement of young carbon into deep sedimentary layers, highlighting the potential effectiveness of the mangrove carbon sink.

Yet, these results lend minimal insight into the timescale of SOC storage. An understanding of turnover time, the rate at which carbon cycles through a system, can be determined analytically through the analysis of downcore 14C age and SOC stability distributions. Knowledge of turnover time is vital to determining the timescale of SOC storage and therefore the effectiveness of the mangrove carbon sink. My results show SOC is homogeneous in both age and stability downcore, suggesting the soil is rapidly turning over, despite the movement of young carbon downward and the upward accretion of peat. These contrasting observations can only be resolved by determining the difference between sediment accretion and long-term carbon storage which may be impacted by various SOC dynamics within mangrove soils.

Tropical hydroclimate reconstructions from coastal sinkholes in the Northern Caribbean -*Anne Tamalavage*

The UN estimates that approximately 42 million people reside in the Small Island Developing States (SIDS) of the Caribbean. Increased aridity is projected for the Caribbean into the 21st century. However, given the spatial span, effects are unlikely to be uniform. Geological and archaeological records indicate extreme droughts in the Caribbean, resulting in socioeconomic collapse (e.g. Mayans in the Yucatan and smaller populations in the Dominican Republic). Severe droughts have not been documented within the instrumental record for the Caribbean and available paleoclimate records in the northern Caribbean are few. We are therefore reconstructing regional hydroclimate variability from sediment cores taken from three coastal sinkhole basins in the northern Bahamas in order to understand the regional drivers of precipitation. Sinkholes and blueholes are ubiquitous across the carbonate landscapes of the Caribbean, and organic rich sediments accumulated within these basins record environmental variability through time. Plant wax biomarkers preserved within sedimentary organic matter carry a record of past precipitation isotopes. We have learned that terrestrial plant wax markers (n-alkanoic acids) preserved within these coastal sinkhole systems can indeed record regional hydroclimate variability through a 3000-year-old record (Blackwood sinkhole). Yet, when sedimentary inputs are dominated by coastal mangroves, the vegetation in these saline systems are known to impart a different fractionation which complicates interpretations of precipitation over the past ~1400 years. Avoiding or accounting for mangrove influence and additional plant wax biomarker reconstructions (currently in progress) from two sinkhole basins will be used to infer hydroclimate variability across the Holocene and back to the last glacial period. This plant wax based evidence will be combined with other proxies (e.g. sediment textural variability, microfossils, bulk carbon and nitrogen isotopes) and used to infer changing climate dynamics and, in particular, past regional rainfall patterns in the Caribbean.

Southern Californian Hydroclimate and Vegetation Change Over the Past 200,000 yrs -*Mark Peaple*

During the past 200,000 yrs, the climate of southern California has experienced profound shifts between wetter and drier conditions. Evidence from ancient lake high stands suggests that large lakes existed in the presently dry basins of the Mojave Desert. To investigate what was driving these hydrological shifts we used molecular proxies sampled from a 75 m core drilled in Searles Lake, southeastern California. Large fluctuations in δD of plant wax values by ~80 ‰ occur over kyr timescales, based on a preliminary age model. This is suggestive of shifting atmospheric circulation patterns between northwesterly storms, southwesterly “atmospheric rivers”, and northward incursion of the North American Monsoon. There is also 8 ‰ variability in δ13C of plant wax from -32 ‰ to -24 ‰. δ13C changes may be driven by changes in vegetation composition (C3 vs. C4) and moisture availability. The range in δ13C suggests the occurrence of C3 and C4 plants during the past 200,000 yrs. C4 plants were favored by more summer precipitation, or warmer temperatures during times of low pCO2. Preliminary brGDGT data show that temperatures during the last glacial maximum (LGM) are similar to the modern at ~19˚C, although with large variability. Lake salinity (determined through the ACE index) switched between hypersalinity and brackish conditions. We will compare our biomarker record to other proxies in from the Searles core (fluid inclusion paleotemperatures, pollen) and other regional records, including geochemical records from a deep core in Death Valley, biomarker reconstruction from Lake Elsinore, CA, and speleothem records including Devils Hole NV. This multi-site comparison will test proxy archives against each other and build a spatial record of hydrological shifts around the time of the LGM, the last interglacial, and the penultimate deglaciation, and assess their impact upon regional vegetation, ultimately testing the sensitivity of regional water availability to global drivers of climate change.

Late Holocene hydroclimate variability inferred from varved sediments in Columbine Lake, Colorado -*Charlotte Wiman*

Precipitation from alpine environments is responsible for up to 85% of the water on which communities in the southwestern United States depend. Snowpack covers less than 15% of Colorado, but is a major source of surface and groundwater. Because of the importance of surface water for communities downstream, it is necessary to understand variations in seasonal snowpack over time, and the range of snowfall extremes that can be expected. Mountain climates experience amplified warming with increased elevation, but our understanding is hampered by inadequacies in observations and models. Current instrumental snowpack data are insufficient for assessing long-term trends and variation in snowpack in the San Juan Mountains in southern Colorado. An understanding of long-term natural variability is necessary for viewing climate dynamics and baseline climate variability of the region. This study analyzes varve thickness in a sediment core from near Silverton, Colorado to produce a snowpack reconstruction for the past 2,600 years. For the period during which climatic data are available, varve thickness is significantly correlated with snow water equivalent (a measure of snowfall) at Columbine Lake. There were a series of extreme snowpack years in the 20th century and a major shift 1,000 years ago towards more frequent years of high snow water equivalent. Extreme snowpack years of the 20th century are not representative of the past three millennium. As a result, assessments of precipitation and snowfall based solely on historical evidence may greatly overestimate spring snowpack in the San Juan Mountains, which has significant implications for future water storage and Colorado River allocations.

Extreme Flooding Events in Southeast Texas: a Paleoflood Reconstruction -*Joeri Reinders*

Coastal regions are prone to extreme weather events which intensities are expected to increase under anthropogenic climate change. Recent high impact events, such as the landfall of hurricane Harvey in 2017 and the resulting floodings in the Houston area (TX), demonstrate these claims as it ranks as the costliest climate disaster in USA history. However, it remains challenging to present concrete proof for such expectations as short instrumental discharge and precipitation records hinder the extraction of trends in storm and flood magnitudes. Moreover, the absence of long records causes high uncertainties on return levels for extreme storms making it difficult for communities to prepare for events like hurricane Harvey. This study explores how unprecedented an event like Harvey is for south-east Texas by constructing a paleoflood record for the Gulf Coastal Plain. Recently, paleohydrologic techniques, such as slack water deposits, have been extended for low gradient systems by utilizing alluvial river deposits in floodplain lakes. Rivers that flood into oxbow lakes leave an imprint of coarse river sediments against fine background lake deposition. In the lab, these peaks can be detected via grain-size analyses by laser diffraction. A flood reconstruction is developed by combining these anomalies in texture with an age-depth model constructed from multiple isotopic proxies such as 210Pb, 137Cs and 14C. Research on the Rhine river has shown that flood discharge can be inferred by linear regression with grain-size of the flood deposit.
Here this method has been applied on sediment cores retrieved from four oxbow lakes along the Neches and Trinity River in May 2019. Observations of the core and preliminary results exhibit clear Harvey deposits and multiple sand intrusions deeper in the silty clay lake sediment. This points towards major flood events going back centuries in time.

Water Storage Variation in the Lake Sobradinho (Northeast Brazil) from 2004 to 2014. -*Rebecca Albuquerque Maranhao*

Although Brazil is one of the few countries in the world that has a high freshwater supply per capita, drought events are common in the Northeast region of Brazil (NEB). The lake Sobradinho, the largest reservoir of NEB, has been affected by a multi-year drought suffering a severe water loss over the years. The reservoir contributes to the socio-economic development of the NEB region and has a strong influence on the regional climate, such as near-surface temperature, humidity and wind patterns. Poor land management and poorly planned irrigation projects have increased degraded area in NEB and can potentially reduce evapotranspiration affecting the precipitation increasing the occurrence of drought events. Also, current climate models indicate that the NEB region could be one of the areas most affected by climate change in Brazil. Reduction in precipitation may cause devastating consequences for the unique biodiversity in the NEB region and local resource users who depend on it. This work aims to produce a consistent estimation of the variation of volume of water in the lake Sobradinho from 2004 to 2014. Through a combination of direct observations of elevation and surface area along with documented reservoir configurations at capacity, we estimated storage time histories. The storage estimates were highly correlated with observations ($R = 0.85$). The reservoir storage variations are in accordance with known droughts and it was observed a high variation of water volume in the years of 2008 and 2013. El Niño-Southern Oscillation over the Pacific Ocean has a strong influence on the inter-annual variability of Northeast rainfall however the worst drought occurred when La Niña event was present. The study highlights the need for public policies that comprehensively understand the climatic variables as well the human activities impacts in the reservoir for better drought management in the NEB region.

Observational trends in burned area and driving forces over Central Equatorial Africa -*Yan Jiang*

Wildfire plays a crucial role in maintaining the ecosystem, affecting the carbon cycle, and further modifying the hydrological cycle. Current estimates of global biomass burning suggest that about 87% fires occur in the tropics. Africa is the continent holding the most extensive burning. Recent widespread long-term drought and lengthening dry season length observed over Central Africa highlight the urgency to study local fire risks and changes under climate change. Here we investigated long-term burned area trends using the MODerate resolution Imaging Spectroradiometer (MODIS) and the Global Fire Emission Database (GFED4) detections over Central Equatorial Africa (CEA,10°E-40°E, 15°N-15°S) for the period 2003-2017. The 3-D connected component Labeling was applied to identify an individual fire and its size. We found that burned area declined by 3.0-3.2 Mha per year, particularly in northern CEA. The estimated decrease in burned area was attributed to both significant decrease in fire frequency and size. Fire frequency decreased by about 0.7% per year, particularly for large fires (> 0.1Mha). Fire size decreased significantly for large fires as well, which contribute to a large percentage of total burned area. Burned area decreased largely over savannas and grasslands (about 80%), while increased over evergreen forest region at the southern edge of the Congolese rainforest. A random forest regression tree procedure was used to address hypotheses concerned with anthropogenic and climatic influences on the drivers of burnt area trends. Overall, changes in burned area over CEA were less attributed to land use changes but were more affected by precipitation variations. Over savannas and grasslands, decreased burned area coincided with decreased annual total rainfall, which suppressed vegetation productivity and fuel availability. Over edges of rainforest, decreased rainfall and lengthening dry seasons dehydrated the greenness and thus made the vegetation more flammable.

Impacts of Increased Urbanization on Surface Temperature and Vegetation over Bengaluru, India -*Heather Sussman*

Bengaluru is India's third largest city by population and is noted as a prime example of rapid urbanization due to the increased presence of the information technology industry. Urban areas are typically characterized by (1) higher land surface temperatures (LST) when compared to their surroundings, known as the urban heat island (UHI) effect, and (2) lower vegetation cover and amount. As temperatures continue to warm with climate change, increased urban LST has the potential to inflict heat exhaustion on inhabitants. Therefore, it is crucial to quantify the UHI effect and associated impacts in Bengaluru as more people call Bengaluru home. Here, advanced satellite products of LST, Enhanced Vegetation Index (EVI, i.e., a vegetation abundance metric), aerosol optical depth, and land cover from the MODerate Resolution Imaging Spectroradiometer (MODIS) were used to assess changes in EVI and daytime and nighttime LST over Bengaluru and surrounding non-urban areas from 2003–2018 for the dry (December–February) and wet (August–October) seasons. Results showed that the amount of urbanized land increased by 15% from 2003–2018, and there exists a significant positive relationship between increased urbanization and LST. The mean UHI intensity was found to be of greatest magnitude during the dry season at nighttime, and an UHI signature was also observed for the wet season during both daytime and nighttime hours. Results further showed an absence of a daytime dry season UHI accompanied by a significant LST cooling trend likely attributable to an increase in aerosols that limit daytime surface warming. Understanding the relationships among urbanization, UHI intensity, and vegetation and how they change with time could be useful to project future UHI impacts in Bengaluru.

Reference: Sussman, H.S., A. Raghavendra, and L. Zhou, 2019: Impacts of Increased Urbanization on Surface Temperature and Vegetation over Bengaluru, India. (in preparation for Remote Sens.)

Ecosystem-based adaptation to the impacts of heavy precipitation during Coastal El Niño events in Peru -*Maria Esther Caballero Espejo*

This study proposes an interdisciplinary ecosystem-based adaptation strategy to cope with the impacts of future heavy precipitations in Peru during Coastal-El Nino events.The objective is to integrate climate projections, geophysical analyses, and agroeconomic assessment; as support and prerequisite for the design of a meaningful, context specific and cost-efective adaptation option. The adaptation proposal consists of El Nino projections' analysis using the outputs of the Max Planck Institute Earth System Model (MPI-ESM) for the RCP 4.5 climate scenario; danger analysis using geophysical information of mass movement susceptibility; ecosystem-based engineering design that includes a combination of diferent proportions of trees, shrubs, and crops according to the danger intensities; and agroeconomic modeling for the evaluation and optimization of the adaptation option. The projections indicate an increase in the probability of "strong" coastal-El Nino events during the rainy season for the next 50 years (2021-2070). Unlike past historical events, the associated precipitations will likely affect the northern and southern coast of Peru equally, as well as, some sloping areas of the west side of the Andes Cordillera. Those areas indicate high levels of danger as they correspond to susceptible places to mass movements activated by extraordinary rainfall. It is shown that by applying the adaptation design it is possible to decrease the danger levels by 15% in all affected lands. In addition, the agronomic analysis shows that cropland damage during El Nino events can go up to 10% in places with very high danger levels. By adapting croplands to landslides hazards, the danger levels decrease, and so an increase in the welfare can be achieved compared to when no protective measures are taken. Nevertheless, it is shown that cropland adaptation depends on the level of side benefits that agroforestry provides.

Intense hurricane landfall frequency varied significantly in the northwestern Bahamas throughout the last 1800 years -*Tyler Scott Winkler*

Four of the five most-costly observed Atlantic hurricanes have occurred since 2013, claiming ~3500 lives and ≤$336 billion USD in damage. Most models suggest warming sea surface temperatures (SST) may promote more frequent intense hurricanes, but the ~160-year instrumental hurricane record limits understanding of long-term climatic modulation of hurricanes. Proxy reconstructions using coarse-grained sediment deposits in salt-marshes, lakes, and sinkholes extend paleohurricane landfall records, but are limited spatially and temporally. Motivated by this, sediment cores (2-14.5 m long) were collected from a blue hole on the northern shore of Grand Bahama, a new environment used to generate paleohurricane reconstructions. Sedimentary analysis reveals interbedded coarse-grained sediment deposits, which archive prehistoric hurricane passage. A well-constrained sedimentary age-model reveals a linear sedimentation rate of ~0.75 cm/yr over the last 1800 years. Plotting coarse-sediment variability alongside the age-model reveals three 100-300 year-long intervals in which hurricane landfalls are more frequent than stochastic variation alone can account for. This high-resolution archive is ideal for testing the hypothesis that frequency of northwestern Bahamian hurricane landfall frequency increases when the Intertropical Convergence Zone is displaced northward and La Niña like conditions dominate, resulting in reduced vertical wind-shear and warmer Atlantic SSTs that promote hurricane formation and intensification.

Oceanography

How does a more stratified ocean affect coastal upwelling? -*Jing He*

Wind-driven coastal upwelling is an essential process that transports nutrient-rich water from the deep ocean to the surface. This process occurs worldwide and it sustains extremely high primary production, making coastal upwelling regions important for fisheries and the global carbon cycle. Studies on coastal upwelling tend to focus on the winds that drive upwelling volume transport, but it remains unclear how a warmer and more stratified ocean affects upwelling dynamics. This study contrasts the Arabian Sea and Bay of Bengal—two basins with similar wind forcing and insolation, but drastically different coastal upwelling. We quantify the effects of stratification and alongshore wind stress on upwelling source depth (the depth that upwelled water originates from) and volume transport through analyzing satellite and Argo data, as well as running numerical process-study experiments. As predicted by theory, volume transport is a linear function of the alongshore wind stress and is insensitive to stratification. However, the source depth increases with weaker stratification and stronger wind stress, and we present a scaling for this dependence. The source depth scaling allows for improved estimates of nutrient transport and primary production in these regions, and these results help us gain a more complete picture of how coastal upwelling dynamics and biological productivity will change in a warming climate.

Riverine Impacts on the Dissolved Inorganic Carbon System in the Mississippi Sound -*Allison Savoie*

As atmospheric carbon dioxide (CO2) continues to increase, dissolved CO2 in the ocean will also increase, and in turn lead to ocean acidification. There has been extensive research done in the northern Gulf of Mexico along the Louisiana Shelf on the coastal ocean acidification and few studies that have looked at the carbon dynamics along the Mississippi (MS) continental shelf. Our research focuses on dissolved inorganic carbon (DIC) and total alkalinity (TA) near the coast of the MS Sound, to understand the impacts by nearby freshwater endmembers that supply alkalinity to the area to buffer against ocean acidification. This area also has anthropogenically altered hydrology, which has led to increased freshwater inputs from the MS River through the Bonnet Carré spillway. Data from monthly sampling trips along the MS coast from August 2018 to 2019 have been collected and analyzed, in addition to weekly sampling trips from June to August 2019 in response to the spillway opening that caused increased marine mammal and oyster reef mortality. Using the data collected from this experiment we are able to calculate the pH, calcite, and aragonite saturations among other parameters, and determine if the MS Sound is a net sink or source for CO2. Previous studies have shown that waters contributed from the Mississippi-Atchafalaya River system have higher TA and DIC than those supplied from rivers that generally have a stronger influence over the MS Sound, including the Mobile, Pascagoula, Wolf and Pearl Rivers. The contribution of these less alkaline river systems to the MS Sound may leave the system more susceptible to ocean acidification with increasing levels of CO2 in the future. However, increased riverine inputs from the MS River due to human activities may lead to other problems including increased hypoxia, algal blooms, and mortality or migration of many local species.

Local atmosphere--ocean predictability: dynamical origins, lead times, and seasonality -*Eviatar Bach*

Due to the physical coupling between atmosphere and ocean, information about the ocean helps to better predict the future of the atmosphere, and in turn, information about the atmosphere helps to better predict the ocean. Here, we investigate the spatial and temporal nature of this predictability: where, for how long, and at what frequencies does the ocean significantly improve prediction of the atmosphere, and vice-versa?

We apply Granger causality, a statistical test to measure whether a variable improves prediction of another, to local time-series of sea-surface temperature (SST) and low-level atmospheric variables. We calculate the detailed spatial structure of the atmosphere-to-ocean and ocean-to-atmosphere predictability. We find that the atmosphere improves prediction of the ocean most in the extratropics, especially in regions of large SST gradients. This atmosphere-to-ocean predictability is weaker but longer-lived in the tropics, where it can last for several months in some regions. On the other hand, the ocean improves prediction of the atmosphere most significantly in the tropics, where this predictability lasts for months to over a year. We find that both the atmosphere-to-ocean and ocean-to-atmosphere predictability are maximal at low frequencies, and both are larger in the summer hemisphere.

The patterns we observe generally agree with dynamical understanding and the results of the Kalnay dynamical rule, which diagnoses the direction of forcing between the atmosphere and ocean by considering the local phase relationship between simultaneous sea-surface temperature and vorticity anomaly signals. We discuss applications to coupled data assimilation.

Air-sea flux perturbations and spatial patterns of ocean heat uptake -*Matthias Aengenheyster*

More than 90% of the energy due to global warming since 1971 has been taken up by the ocean. The rate of increase of global mean surface temperature is thus sensitive to the rate of ocean heat uptake. However, the exact determination of the air-sea heat flux is notoriously difficult. Large discrepancies between estimates make it challenging to build robust relationships between changes in fluxes and changes in ocean heat content. In addition, climate models show considerable diversity in future heat uptake patterns. These patterns are important for sea level rise and forcing atmospheric dynamics.

I am using the MITgcm model (ocean-only, low resolution) to emulate several CMIP5 models and perturb the net air-sea flux to establish physical understanding of how patterns of air-sea flux perturbations lead to patterns of ocean heat uptake. I find that globally net-zero patterns can lead to non-zero heat uptake due to the much larger heat uptake efficiency in the North Atlantic and Southern Ocean, compared to the lower latitudes. The heat uptake patterns show signatures of passive tracer uptake in the forcing regions and transport, but also large-scale changes of ocean circulation and resulting changes in heat convergence.

In addition, I am showing how important dynamically coupled ocean-atmosphere interactions are for the regional pattern of heat uptake by comparing ocean-only simulations with coupled simulations, both subjected to the same air-sea flux perturbations.

Can GO-SHIP tell us how accurate Argo data are? -*Cora Hersh*

With hundreds of papers on ocean and climate science published using data from the Argo float program each year, it is crucial to understand any systematic errors in the Argo dataset and to communicate them to users. Tracking sensor accuracies over time is difficult, particularly for pressure. To check these, we analyzed nearly 300,000 pairs of Argo and GO-SHIP (the ‘gold standard’ of ship-based CTD collection) profiles taken within 300 km and 30 days of each other. We interpolated the paired CTD profiles onto a common potential density grid and examined the probability density functions of the resulting the pressure and salinity differences (Argo minus GO-SHIP) for any biases, broken down by various cohorts (e.g. pressure sensor maker, cycle number, float type). Argo salinity bias errors in SBE41 and SBE41CP sensor data are found to be well within the stated range of +/- 0.01 psu, with salinity at depth consistently having a bias of less than +/- 0.002 psu. This indicates that there is negligible bias in Argo salinity data, a remarkable result. A possible salty bias at higher cycle numbers was observed, primarily in SBE41CP sensors, despite existing quality control procedures to remove such a drift. Due to eddy variability, pressure bias was harder to constrain than salinity, particularly for pressure sensor types (Paine, Ametek) not well-represented in the profile pairs. Our methods bound overall Druck sensor agreement with GO-SHIP to within +/- 5 dbar. However, a substantial pressure under-estimation was seen in high cycle number Druck profiles. We are seeking independent confirmation on whether this effect is real, as it is based on a small fraction of profiles.

Coastally-Refined Resolution Global Ocean Model Improves Eastern Boundary More than Western Boundary -*Kevin Rosa*

The new Energy Exascale Earth System Model (E3SM) is the first global coupled climate model where all components — ocean, sea ice, land ice, atmosphere, and land — are modeled on unstructured meshes capable of regional resolution refinement. Model resolution is the single biggest factor in determining what physics a model resolves and how computationally expensive it is to run. Regionally-refined resolution has the potential to improve accuracy in key areas at a much lower computational cost than current models (which must increase resolution globally). In this study, we ran the ocean and sea ice models of E3SM and forced with historical atmosphere forcing. Several other recent studies have evaluated E3SM's ocean and sea ice models using quasi-uniform grids but this is the first to investigate the effects of regionally-refined resolution. We started with a 60 km grid and applied an 8 km-resolution coastal band extending 500 km from the North American coastline. This is a computationally cheap way to get very high resolution in the most energetic regions of the model but does this approach actually improve the model results? We found that it depends on whether the process is locally or non-locally controlled. On the Pacific's eastern boundary, the California Current upwelling system was greatly improved by the coastal-refinement because the upwelling is largely driven by local wind forcing. The Gulf Stream western boundary current on the other hand did not improve much because its strength is determined by the southward transport in the rest of the gyre (in the low-resolution part of the Atlantic). Results like these will help prospective users of this new climate model as they decide how to set up simulations for their own studies.

Skillful multiyear predictions of pH variability in the California Current System -*Riley Brady*

The California Current System (CCS) is an Eastern Boundary Upwelling System that is characterized by high primary productivity supported by the upwelling of nutrient-rich waters from depth. These waters are also naturally corrosive, with relatively high pCO2 and relatively low pH. The compounded effects of corrosive upwelling and the diffusion of anthropogenic CO2 into surface waters has already begun to cause shell degradation in pteropods along the continental shelf. Thus, skillful seasonal to decadal forecasts of carbonate chemistry parameters, such as pH, are crucial for the proper management of living marine resources in the CCS. Here we utilize output from the Community Earth System Model Decadal Prediction Large Ensemble (CESM-DPLE), a forecasting system that initializes 40 ensemble members annually from a forced ocean sea-ice reconstruction, to consider the potential to predict pH in the CCS. We show that CESM-DPLE has statistically significant predictability in annual pH anomalies out to five years over a persistence forecast, with some regions exhibiting predictability out to eight years. Further, we find that CESM-DPLE can skillfully predict pH anomalies for multiple years when compared to the available pH observations. Predictability in CCS pH is driven by the multiyear persistence of dissolved inorganic carbon anomalies, with some contribution from the forecasting system's ability to predict sea surface temperature and alkalinity anomalies. Our results demonstrate the utility of an initialized decadal prediction ensemble for managing the onset and impacts of ocean acidification in the CCS.

Observation of coastal storms, over an unprecedented range of wave and beach conditions -*Oliver Jack Billson*

Approximately 40% of global population is concentrated within 100 km of the coast and is highly vulnerable to the effects of rising sea level and waves. Resilience of coastal infrastructure to an ever-changing climate depends largely on understanding feedbacks between atmospheric forcing, ocean waves and coastal morphodynamics. Since 1985, increases have been observed in significant wave heights with larger increases in extreme heights (90th percentiles) (Young and Ribal, 2019). Further, a 0.4% rise in global wave power in the past 70 years has seen it identified a 'potentially valuable climate change indicator' (Reguero et al, 2019). In particular, extreme wave heights and powers associated with coastal storms drive severe and potentially irreversible erosion and inundation. In addition to a steady increase from sea level rise, coastal total water levels are episodically enhanced by wave action, termed wave runup. Specifically, an increase in the contribution of low frequency (infragravity) wave energy ($f = 0.005 – 0.05$ Hz) to wave runup has been shown to increase during storms. However, understanding of storm wave processes is based on limited observation of sandy beaches. Here, a new technique designed to monitor hydrodynamics from the shoreline to deep water during the rise, peak and decay of extreme storm events, was implemented across a range of beach types. Plymouth University's Rapid Coastal Response Unit (RCRU), a versatile base equipped with pressure sensors, current meters and video cameras, designed for rapid mobilisation (< 24 hours), facilitated the collection of unique storm data, over an unprecedented range of wave and beach conditions. Wave power was found to accurately predict low frequency runup on both the sand and gravel beaches, demonstrating that, under storm wave conditions, wave height and period are the main drivers of infragravity oscillations at the shoreline, with the beach morphology playing a secondary role (Billson et al, 2019). Results suggest an observed rise in global wave power could increase the vulnerability of a range of coastal environments, through the enhancement of low frequency wave runup.

Paleoclimate & Deep Time

Constraining discharges and erosional effects of glacial outburst floods in the Channeled Scablands of eastern Washington -*Karin Lehnigk*

The Channeled Scablands of eastern Washington is a remarkable bedrock landscape characterized by deep canyons incised by Pleistocene outburst floods from ice-dammed Glacial Lake Missoula. Although it has been established that there were multiple floods throughout the late Pleistocene, it remains a challenge to constrain the discharges of individual floods, because the topography eroded and evolved during flooding. To determine individual flood discharges, we use geomorphic evidence to reconstruct the topography of Grand Coulee -- the largest Scablands canyon – at different phases of its development, and use 2D numerical modeling to pinpoint the discharge that barely inundates mapped high-water marks for each phase. We consider three phases during Grand Coulee's erosional history: a partially-eroded and ice-free canyon, a canyon partially blocked by the Cordilleran Ice Sheet at its maximum extent, and the modern, fully-eroded canyon. We simulated a range of discharges during each phase using ANUGA, a 2D shallow wave model, and quantified flood stage and other hydraulic parameters for a range of discharges for each phase. Comparison of the model results against field evidence for high-water indicators demonstrates that discharges through the ice-blocked canyon were small, on the order of 0.2 x 106 m3 s-1. The floods that drove the retreat of the Grand Coulee knickpoint had discharges of 0.7 x 106 m3 s-1. Shear stresses calculated for these discharges are close to thresholds for dominant fluvial erosion mechanisms, and suggest that canyon-forming floods were substantially lower than the 6 x 106 m3 s-1 discharge required to fill the modern canyon to high-water indicators. These floods represent substantial freshwater contributions to global ocean circulation, and by constraining their discharges we can improve global circulation models for critical climate transitions, as well as inform predictions of flood hazards as climate change increases the frequency of glacial outburst floods.

Antarctic ice sheet growth during the Miocene Climatic Optimum: Paleoenvironmental insights from the Ross Sea -*Imogen Browne*

Antarctica's ice sheets are losing mass, in part due to increased presence of warm water over its continental shelves, which raises global sea level and impacts coastal areas globally. To understand rates and magnitudes of future sea level rise, studies of past Antarctic ice sheet behavior during warm climates are essential. The Miocene Climatic Optimum (MCO; ~17-14.5 Ma) is an interval when global temperatures were 3C warmer than present, Antarctic ice sheets were smaller, and atmospheric CO2 (pCO2) was similar to what is expected in the next half century. The MCO was followed by the Middle Miocene Climate Transition (MMCT; ~14 Ma), during which Antarctica's ice sheets expanded and Earth's climate cooled. The drivers of MCO warmth and MMCT cooling and ice expansion remain unclear because atmospheric pCO2 fluctuated within a narrow range (~250-500 ppmv). This observation requires that additional forcings and feedbacks (e.g., changes in poleward transport of heat and moisture) influenced middle Antarctic ice sheet dynamics and middle Miocene climate.
International Ocean Discovery Program (IODP) Expedition 374 recovered a Miocene sedimentary sequence from Site U1521 (7541'S, 17940'W), on the Ross Sea continental shelf. MCO-age diatom-bearing/rich mudstones (~17-16 Ma) indicate open-marine conditions and reconstructed ocean temperatures indicate ~5C of

orbitally-paced warming from ~17 to 16 Ma. A regional unconformity, dated to between ~16 and 14.6 Ma, indicates a major expansion of Antarctica's ice sheets during the MCO, ~1 million years before the MMCT. We suggest that orbitally-paced changes in heat/moisture transport to the Ross Sea initiated this expansion.

Deglacial to Holocene Circumpolar Deep Water paleotemperatures from the Totten Glacier System, East Antarctica -*Kara Vadman*

The Totten Glacier system on the Sabrina Coast, East Antarctica, drains one eighth of the East Antarctic Ice Sheet and is rapidly losing mass. Recent oceanographic observations indicate that warm modified Circumpolar Deep Water (mCDW) is accessing Sabrina Coast grounding lines, suggesting the entire catchment is susceptible to destabilization from ocean heat, leading to ice loss and sea level rise. However, we have no local geologic reconstructions to put these present-day observations into context. To understand past ocean-ice interactions, we reconstructed oceanographic change from a 13-meter-long sediment core composed of laminated diatom mud and ooze collected from the continental shelf, seaward of the Sabrina Coast. We developed a chronology of the sediment sequence based on radiocarbon dating of foraminifera and sediment. The sequence records oceanic conditions from the last deglaciation (~15,000 yr before present) through the present. Our multi-proxy reconstruction uses foraminifer and diatom assemblages, foraminifer stable isotopes (d13C, d18O), and foraminifer (Mg/Ca) and organic (TEX86) paleothermometry.

Deciphering past ocean temperature in Antarctic margin sediments in the context of present day physical oceanographic observations contributes to validating ice proximal records. Our high-resolution upper ocean paleotemperature record shows a general orbital scale cooling through the Holocene and a distinct warming in the middle Holocene, consistent with evidence for warming and ice retreat at many locations around the Antarctic. The multiproxy record also demonstrates warm ocean conditions during the deglaciation and a recent increase in mCDW influence at the outlet of the Totten Glacier system. We suggest that the presence of mCDW and influence of ocean heat on regional ice extent at this time is related to wind strength, which influences the position and strength of the Antarctic Coastal Current and Antarctic Slope Current.

Ocean Overturning Circulation, Global Warming, and the Existence of Tipping Points in Deep Time -*Johanna Holo*

The investigation of hyperthermals, short-lived periods of extreme warming, over Earth's history is crucial to understanding the effects of climate change on the planet's global carbon cycle, climate, and biogeochemical cycling. The most extreme hyperthermal on record is the Paleocene-Eocene Thermal Maximum (PETM) approximately 56 Ma. The warming has been shown to have triggered an abrupt shift in deep ocean circulation and deep-water formation recorded by the carbon isotopic composition of benthic foraminifera and by seafloor carbonate dissolution patterns. Eocene Thermal Maximum 2 (ETM2) is another period of interest in which global temperatures increased rapidly due to injection of isotopically light carbon into the atmosphere. Through the use of both isotopic proxies and box modeling, such a reversal during ETM2 is investigated, including investigation of a possible temperature threshold that triggers this reversal. Carbon isotopic composition of benthic foraminifera acts as a proxy for bottom water age and corrosivity, yielding information about overturning circulation. Forams from Ocean Drilling Program site 1210 located on the Southern High of Shatsky Rise were measured and the carbon isotopic composition was compared with benthic forams collected in the Atlantic, demonstrating a reversal in the carbon isotopic gradient between basins during ETM2. I will measure another independent proxy of water mass "age," the trace metal ratio B/Ca, which can be used to reconstruct the carbonate content of deep water at a given place and time. These data will be compared with previously made C isotope and B/Ca measurements, thus allowing for comparison of bottom water chemistry between ocean basins. Furthermore, ocean carbon cycle box model, CYCLOPS, was utilized. For all ETM2 simulations, we find that the observed patterns of carbon isotopes and carbonate dissolution can be replicated with a reversal in ocean overturning via a switch from North Atlantic to North Pacific Deep water formation.

Alkenone based sea surface temperature and marine productivity reconstruction in the Santa Barbara Basin from mid Holocene to present -*Anson Cheung*

Climate variability in the Pacific Ocean is known to pose significant impacts on global and regional climate, and ecosystems. While interannual and orbital variability of the Pacific climate have been widely studied, less focus has been put on Pacific decadal to millennial timescale variability. Yet, decadal to millennial variability in the Pacific are strongly relevant to societal changes. Marine sediments collected from Santa Barbara Basin provide an opportunity to shed insights into how sea surface temperature and productivity in the Northeastern Pacific have changed across decadal to millennial timescale.

In this study, we measure alkenone contents in a sediment core collected in Santa Barbara Basin to reconstruct multidecadal (~50 year resolution) sea surface temperature (SST) variability (Uk'37) and marine productivity (C37 concentration) changes from mid Holocene to present. This record will allow us to understand SST changes in the Northeastern Pacific across timescales, its response towards external forcing, its relationship with regional ecosystem changes and hydroclimate in the Southwest United States. These results together will help us gain a better understanding on Pacific climate variability on multidecadal to millennial timescales and its potential impacts on global and regional climate, ecosystems and society.

Reconstructing Southern Ocean Bottom Water Ventilation During Last Deglaciation -*Shouyi Wang*

The mechanisms responsible for transitions between glacial and interglacial periods have yet to be clearly understood. Changes in the partitioning of CO2 between the ocean and atmosphere are thought to be a leading driver of these transitions, and are therefore essential for understanding past climate changes as well as for future projections. Our ongoing study of bottom water ventilation in the Pacific Sector of the Southern Ocean contributes to this effort.

Mn is a redox sensitive trace metal that precipitates in oxygenated marine environments. Because oxygen is stoichiometrically linked to CO2 in the deep ocean via respiration, authigenic Mn can be a proxy for bottom water ventilation and CO2 storage.

We present XRF trace metal abundance (Mn, Ti, Fe) and stable isotope data from cores taken in the Ross Sea region of the Pacific. Scans of piston cores show authigenic Mn peaks at deglaciation, indicative of abyssal reoxygenation events. Abrupt decreases in planktic d18O at consistent depths to the Mn increases support that Mn peaks correspond to the deglaciation. We interpret our deglacial oxygenation in the context of literature from other sectors of the Southern Ocean. In addition, we utilize paired benthic-planktonic 14C ages from these same cores to understand the impacts of changing ventilation in driving the deglaciation oxygenation events in the Southern Ocean.

A multi-proxie paleoclimate approach: clumped and stable isotopes on the Cariaco Basin, Venezuela -*Alexandra Valencia Villa*

Reconstructing the ocean-climate history has been essential in understanding the evolution of ice sheets, ocean properties, and global CO2 levels. Various geochemical proxies have been established using different sampling material and methodology to evaluate these components. From these, planktonic foraminifera from marine sediments have proved to be a dominant tool in unraveling paleoceanography and paleoclimatology.

However, climate reconstructions using geochemical proxies are not direct measurements thus leading to complications, restrictions, and uncertainties. This study aims to utilize a relatively new proxy, clumped isotope

paleothermometry, to address issues regarding sensitivity of water composition, and time scale variability, using planktonic foraminifera samples from the Cariaco Basin.
Using new instrumentation based at UCLA, this presentation will focus on oxygen and carbon isotope values recorded in planktonic foraminifera Globigerinoides ruber and Globigerinoides bulloides, taken from ODP Leg 165 Site 1002 Hole E.
Clumped isotope values taken from G. ruber are used to reconstruct paleotemperatures using Δ47, through the Last Glacial Maximum (~21 kyr B.P) and identify changes in seawater (δ18Osw). Paleotemperatures will be derived using multiple temperature calibrations and, with the addition of stable oxygen isotope values taken from G. bulloides, will be used to identify changes in the hydrologic cycle and ice volume. By utilizing various temperature calibrations, we will address variance within a relatively modern time period. Additionally, x-ray fluorescence core scanning and core correlation will be presented to create a strong centennial and millennial-scale oceanographic time scale.
Future work includes addressing diagenetic effects comparing glassy and frosty planktonic foraminfera shells and supplementing the time scale with foraminifera faunal assemblage data.

Indian Summer Monsoon Rainfall Reconstruction over the past 640 kyr-*Sarah McGrath*

Over half of the world's population lives in the Asian monsoon region. Understanding the mechanisms that control rainfall variability of the Asian monsoon is critical to preparing for climate change. Results from geographic extremes and different proxies have yielded strongly divergent interpretations of the drivers of the summer monsoon. Arabian Sea marine-based proxies indicate that monsoon strength responds to internal changes in greenhouse gases, ice volume, and cross-equatorial latent heat transport. Southeast Asia terrestrial proxies indicate that external insolation forcing is the primary driver of monsoon strength. Herein is presented the first terrestrial based precipitation (δDprecip) record at Site U1446 for the core monsoon zone in India over the past 640 kyr. Indian Summer Monsoon rainfall (ISMR) is reconstructed using a modern calibration of summer monsoon precipitation isotopes with total annual rainfall amount. The reconstructed ISMR shows an enhanced Indian Summer Monsoon during interglacial periods and a reduced Indian Summer Monsoon during glacial periods, with strong orbital scale variability. The terrestrial precipitation proxy δDprecip is compared with marine precipitation proxy δ18Oseawater from the same site. δDprecip shows larger isotopic variability compared to δ18Oseawater over both interglacial-glacial and precession variance. This indicates that the two precipitation proxies are capturing slightly different signals due to signal source differences or mechanistic differences in how the proxies incorporate ISMR change. The δDprecip shows large glacial-interglacial and greenhouse gas influence, suggesting an internal forcing mechanism, different than the precession dominated East Asian Speleothem monsoon precipitation proxies.

Paleoclimate, Earth, & Planetary History

Paleocurrents in a Least-Cost Pathway Model of Human Dispersal from Sunda to Sahul, 65 – 45,000 Years Ago -*Marisa Borreggine*

The timing of the human colonization of Sahul 65 – 45,000 years ago has a direct impact on our understanding of the dispersal of anatomically modern humans (AMH). This movement signifies the first modern, large migration event by sea, implying a significant level of complex language, marine technology, and colonization ability. Incorporating more sophisticated paleoclimate parameters into human migration models will shed light upon the timing of Homo sapiens dispersal from Sunda into Sahul. The least-cost pathway analysis applied to human migration models generally utilizes a combination of eustatic sea level, low-resolution ancient topography, and/or present-day ocean currents. Using robust paleo-topography and sea level reconstructions with paleoclimate inputs into the Community Earth System Model (CESM1.1.1), I produce paleocurrents for 65 – 45,000 years ago at a 1000-year resolution. These ocean currents define the potential pathways for migration from island to island from Sunda into Sahul. The least-cost pathway analysis applied to the island-hopping maritime migration model here is a function of both time spent at sea and area-weighted island-to-island inter-visibility. We find that a northern migration route around 63,000 years ago is the most likely route for colonization. This work establishes a new method for applying cost analysis to human migration pathways and lays the framework for estimating paleocurrents using the CESM, while also providing insight into the first peopling of Sahul.

Assessing the sea level hypothesis with new records from the East Pacific Rise -*Sarah McCart*

The past million years of the Earth's history is characterized by glacial maxima every ~100 thousand years, followed by intervals of abrupt warming and ice sheet retreat known as glacial terminations. While glacial cycles are paced by changes in Earth's orbit, the mechanisms responsible for glacial terminations remain poorly understood. One proposed feedback mechanism is the sea level hypothesis (SLH), where growth of ice sheets causes sea level to lower, thereby reducing pressure on mid-ocean ridges. This should in turn promote enhanced magmatism, which releases both geothermal heat and carbon dioxide, potentially serving to warm the climate and acting as a negative feedback on the size of ice sheets. Magmatic activity can be inferred using proxies of hydrothermal activity, including the flux of metals to ridge-crest sediments, and basaltic ash layers, which reflect the influence of submarine volcanic eruptions. Here we present a sediment core from the Southern East Pacific Rise (Y71-07-53, -10.88 latitude, -110.73 longitude, 3180 m water depth) that displays evidence for anomalous ridge activity during glacial Termination 2 (~130 thousand years before present; kyr BP) and glacial Termination 4 (~337 kyr BP). Elevated fluxes of iron and manganese are found during both terminations, while a discrete layer of ash shards also precedes Termination 4. The geochemistry of the glass shards confirms that the ash shards were sourced from the ridge crest. Shard settling velocities and typical deep ocean current speeds suggest the ash was lofted at least 2.7 km into the water column before settling out to the core site. The timing of this anomalous ridge activity is consistent with the SLH and implies the liquid and solid earth are coupled on glacial-interglacial timescales.

Oceans on Mars: Implications and Locations -*Mark Baum*

Whether Mars hosted an Earth-like ocean early in its history (> 3 Ga) is still a topic of ongoing debate with substantial implications for habitability. If a long-lived ocean existed, was there life? If not, why not? The primary evidence for Martian oceans is a set of putative shorelines interpreted from orbital imagery, implying a large ocean covering most of the northern hemisphere. However, because of the faint young sun, such an ocean requires very strong, long-term, yet unexplained greenhouse warming. It also requires a large amount of water available for hydrological cycling between the surface and subsurface. Using a new global model of groundwater dynamics, I will assess the partitioning of water between the ocean and the subsurface, calculating the minimum planetary water inventory required for oceans under a range of conditions. I will also discuss the potential for seas to form in other basins, particularly the giant impact basins of the southern hemisphere. One of these basins, Hellas, is by far the deepest place on Mars but has no "shoreline" features. Finally, I will draw an analogy to Earth's water partitioning. If a 2000 km basin, 5 km deeper than sea level, were scooped into the middle of a continent on Earth, would it fill with water?

Spatio-temporal variability of the South American Monsoon over the past millennium - *Rebecca Orrison*

The South American Monsoon System (SAMS) is the dominant mode of hydrologic variability in South America, and varies on interannual to centennial timescales. It is the most important source of water for the region, and

understanding the variability of the system is important for agricultural planning. Additionally, as anthropogenic forcings continue to influence the climate system, understanding the natural variability of this system is an essential basis for diagnosing sensitivity to these external forcings.
Using a growing network of proxy records, we can now understand better the historic spatiotemporal variability of the system. Initial results from comparisons between individual proxy records from speleothems and model simulations from the NCAR Community Earth System Model Last Millennium Ensemble (CESM-LME) suggest the model represents temporal variability reasonably well across the region. Additionally, both proxy data and model simulations isolate the monsoon and South Atlantic Convergence Zone (SACZ) as leading modes of precipitation variability. These results give us confidence in a valid comparison between proxy data and model simulations. Using the CESM-LME simulations forced by isolated external forcings, we have examined the influence of isolated external forcings on SAMS variability. Using a Monte Carlo Principal Component Analysis technique, we decompose spatiotemporal modes of variability from the full network of available proxy records. The comparison between the model simulations and paleoclimatological data allows us to better understand the underlying internal and external forcing mechanisms that influence SAMS variability on different timescales. Looking forward, we anticipate that these results may help us to be able to predict how changes to external forcings will influence the SAMS in the future.

Climate Change and Norse Settlement Transition -*Boyang Zhao*

Recent climate change may have large and unexpected influences on the global environment, leading to severe living conditions for billions of people on our planet. We could gain experience about the relationship between human societies and changing climate by disentangling Climate–Human–Environment interactions in the past. Here, we utilize two independent lake sediments biomarkers to reconstruct climatic variation in the past 2000 years from Southern Greenland, which was colonized by Norse people from 985 AD until early in the 15th century. The 70 cm sediment core was collected in July 2016 from Lake 578 (W45°36’, N61°04’) in Southern Greenland, and the age model is built on 210Pb, 137Cs activity and 8 terrestrial macrofossils 14C dates, using the Bchron R package. Branched glycerol dialkyl glycerol tetraethers (brGDGTs) are employed as a relatively new temperature proxy (MBT’5ME), and leaf wax deuterium isotopes (n-alkanes δD) are considered as an indicator of hydrological variability. Based on our brGDGT temperature reconstruction, there was no remarkable warmth during medieval period and no abrupt temperature drop around the time when Norse settlements were abandoned. Thus, we examined the n-alkane δD and interpret the offset between nC29-alkanes (terrestrial source) and nC23-alkanes (aquatic source) as an indicator of evaporative deuterium-enriched terrestrial plant leaf water. We found a continuous drought trend from early in the 10th century until the 16th century, covering the whole period of Norse occupancy in Southern Greenland. Overall, our detailed investigation of Lake 578 sediment biomarkers demonstrates the potential of brGDGTs for generating temperature records from Arctic lakes, leaf wax deuterium isotope for reconstructing local hydrological variability. Together, these show that drought may have had more of an impact on Norse farmers than changes in temperature; this vulnerability to drought is still felt by sheep farmers in the region today.

South Atlantic Convergence Zone behavior over the mid-late Holocene inferred from central Brazil speleothem δ18O records. - *Minn Lin Wong*

Speleothem δ18O records from cites in central Brazil under the influence of the South Atlantic Convergence Zone (SACZ) have shown invariant trends across the last two millennia. This is in contrast to other records from southeast Brazil and along the western Amazon showing decreasing δ18O values over the mid to late Holocene, which have been interpreted as an intensification of the South American Monsoon System (SASM) over the core monsoon region in response to the increasing austral summertime insolation over this period. However, the lack

of correspondence in the central Brazil sites instead suggest that rainfall dominated by SACZ influence may be disconnected from the main monsoon region.
Here we present U/Th dated speleothem δ18O records from the state of Goias in central Brazil across the mid to late Holocene, extending the current existing records at that location by 4 millennia. The new record is representative of how SACZ activity varied during the last 7000 years and will shed light on how the convergence zone responded to several climatic fluctuations such as the Little Ice Age, the Medieval Climatic Anomaly and several Bond events. Understanding the behavior and mechanics of the SACZ in response to climate fluctuations is crucial to contextualizing how rainfall over central Brazil will vary in the face of future climate changes.

Policy & Action

Supporting Small Island Economies: Toolkit Design -*Nickie Cammisa*

Small island developing nations face many unique sustainable development challenges, and are already facing dire consequences from Climate Change. As part of a large, interdisciplinary collaboration with the Waitt Foundation called the Blue Prosperity Coalition, our team at UCLA is developing resources that promote sustainable development of the Blue Economy in small island developing nations. Balancing the needs of multiple stakeholders while making decisions that benefit both marine conservation and economic development is challenging. Yet small islands do not have resources tailored to their unique marine conservation and planning needs. We aim to provide decision-making support to natural resource managers and policymakers through a toolkit that is specific to the challenges small islands face—economically, socially, and environmentally.

Global Shipping Emissions Allocations and their Policy Implications -*Yiqi Zhang*

International shipping carries approximately 90 percent of all world trade by volume and is responsible for nearly 3 percent of global CO2 emissions, a number that could raise to 6-15% of the world's share by 2050 in the absence of more stringent mitigation measures. The International Maritime Organization (IMO) has laid out ambitious plans to cut international maritime emissions by at least 50% by 2050, however, have provided no roadmap or anything to signify that this is anything beyond a dream. These emissions are also not covered by the 1992 UN Framework Convention on Climate Change (UNFCCC) nor the 2015 Paris Agreement and its associated Nationally Determined Contributions (NDCs). Successful climate change mitigation depends on coverage of all major emission sources. The political discussions on finding an agreed upon allocation mechanism for adding the CO2 emissions from international shipping to national carbon budgets under the UNFCCC date back to the late 1990s, but they have so far been fruitless. Importantly, there is a lack of quantitative analysis of the results and distributional effects of different allocation options.

The State of Climate Change Adaptation in Canada's Protected Areas Sector -*Stephanie Barr*

Conservation practice and policy have operated in much the same way for the past century, relying on conventional practices such protected area creation; however, due to climate change impacts, organizations need to adapt and adopt a wider array of strategies increase resiliency. This paper has four objectives: 1) to determine the current state of climate change adaptation in Canada's protected areas sector; 2) to evaluate any progress over the past decade; 3) to examine if institutions perceive climate change differently or have different responses to climate change; and, 4) to identify barriers to adaptation in Canada's protected areas sector. To address these objectives, we conducted an online survey (designed after a similar study conducted 12 years ago) that we distributed to provincial, territorial, and federal governments as well as environmental non-governmental organizations (ENGOs) working in conservation (n=51). Survey findings indicate that little progress has been made on adaptation in Canada's protected areas sector, despite greater certainty about the impacts of climate change. Slight differences were observed among organization types, such as in monitoring, adaptation strategies, and barriers. Overall, the majority of organizations still report that they lack the capacity to deal with climate change issues affecting protected areas and that they face barriers to implementing climate change adaptation strategies. We conclude by making recommendations to increase adaptation such as by enhancing knowledge mobilization, identifying why barriers emerge, and developing more flexible conservation objectives.

Explaining Climate's (Sun)Rise on the Democratic Party Agenda -*Geoffrey Henderson*

In recent months, climate change has gained a central place on the Democratic Party's policy agenda. Scores of Congressional representatives have co-sponsored the Green New Deal resolution and all major Democratic presidential candidates have taken a position on the proposal. Why did climate change suddenly become the party's priority? There was not a major change in the party's leadership in 2018. Scientists had long since reached consensus and large majorities of Democrats had already supported climate action for years. I posit that climate change became a priority due to the strategy of the Sunrise Movement, which has gained national attention and mobilized activist groups across the country to advocate for a Green New Deal. I argue that a social movement which makes a credible electoral challenge to party elites can elevate its issue on the party's agenda by pressuring elites to take supportive positions. I contend that party elites will perceive a challenger as credible when it mobilizes new constituencies and demonstrates an ability to set the media agenda. To test this theory, I conduct a case study of the climate movement from 2009 to 2019. I use content analysis of newspaper articles to demonstrate the movement's agenda-setting ability and employ data on group formation to measure its mobilization of new constituencies. To understand whether and how these factors affect the party's agenda, I interview movement leaders, Congressional staff, and campaign staff. Further, I conduct a synthetic control analysis to demonstrate the concept of a credible electoral challenge. Drawing on Google search and Twitter mention data, I show how the movement's public messages pressuring incumbents and candidates affect public attention and sentiment toward their targets. Finally, I use content analysis of presidential debates across multiple cycles to show how climate change has risen on the Democratic Party's agenda over time.

A conceptual framework to guide transdisciplinary climate adaptation research among early career researchers - *Justin Shawler*

Sea-level rise is projected to displace hundreds of millions of people around the globe by the end of the 21st century. Yet, retreat from large portions of the coast may be infeasible due to political, legal, and economic challenges. Thus, efforts to improve coastal resilience should apply transdisciplinary approaches that consider these factors. We discuss the process pursued to develop an integrated conceptual framework for coastal resilience and to generate transdisciplinary research questions.

Our interdisciplinary team of graduate students from five universities with backgrounds in law, landscape architecture, geosciences, ecology, and engineering, was brought together as part of a graduate training program. We began our transdisciplinary process by discussing our individual knowledge bases. To illustrate the current paradigms within our individual expertise, we created and presented frameworks based upon our unique disciplinary perspectives. Through formal and informal discussions, we developed a conceptual framework which drew from visualization techniques used in systems thinking and scenario planning, yet transcended our individual disciplines. Our team worked to ground the conceptual framework in current literature, a process that required discussion and negotiation, as well as flexibility, given that some disciplinary distinctions led to definitional differences.

To test our framework's ability to address relevant transdisciplinary research questions, we investigated adaptation to sea-level rise in Chincoteague Island, Virginia, a representative rural coastal community in the Chesapeake Bay region of the United States. Both the framework and a stakeholder engagement process led us to a research sub-topic that integrated our entire team's disciplinary knowledge, and required the generation of new knowledge from outside our core expertise. Using our framework and applied questions, we developed a transdisciplinary research proposal. By sharing our process, we offer an example of how unique and integrated theoretical approaches can be applied to generate novel research questions across disciplines.

Strategic Retreat for Climate Resilience: Developing a Theory of Change -*Mali'o Kodis*

As the impacts of climate change are felt with increased intensity and frequency across America, there is a clear need to develop innovative mechanisms for preventing damage to communities and properties in high-risk areas. In some geographies and situations, armoring-in-place may be an appropriate strategy. In some places and situations, armoring-in-place might be an appropriate strategy. In others, giving people a chance to move out of harm's way is the best option. This option - called managed or strategic retreat - involves purchasing at risk properties, and, ideally, returning them to their natural ecological function. The ideal outcome is a scaled approach to, for example, buying a home that's flooded 6 times at a better-than-market price, and returning it to a protective salt marsh.

Conservation organizations that operate with a land-trust model are poised to play an active role in both facilitating strategic retreat, and in restoring the ecological function of the vacated areas. These organizations are deft at property acquisition and restoration, and could effectively prioritize buyouts in high-risk areas that also have high ecological value. I am working with The Nature Conservancy's California and New York branches to develop a multi-pronged strategy to facilitate the uptake of strategic retreat through conservation-oriented buyouts as a climate change adaptation strategy throughout the United States. In this presentation, I will share that work, in hopes of sparking a conversation about how strategic retreat can help overcome some of the many challenges of climate change for the benefit of people and ecosystems.

Political feedback of coal phase-out: An analysis of US Presidential Elections - *Nicolas Schmid*

A fast phase-out of carbon-intensive energy technologies and simultaneous phase-in of low-carbon energy technologies is necessary to avoid dangerous levels of climate change. Due to market failures, policy intervention is required in order to enable and speed up this process of technological change. Over time, such policy-induced technological change causes feedback effects on subsequent political processes, as it creates winners and losers. Political feedback ranges from citizens changing their voting behavior, e.g. rewarding climate change-denying parties (negative feedback), to the appearance of new actors, e.g. interest groups supporting renewable energy technologies (positive feedback). My PhD project covers several political feedback processes in different geographical settings and with different actor types (interest groups, citizens, and political parties). Here, I would like to focus on the electoral feedback effects of coal phase-out in the US. The extant literature on coal phase-out is of qualitative nature and does not provide evidence for electoral feedback effects. Together with colleagues, I address this gap by analyzing – in a difference-in-difference setup – the feedback effects of decline in coal mining on electoral outcomes in the presidential elections from 2000 to 2016. The US, and particularly the region of Appalachia, has experienced a drastic and rapid decline in coal production since 2011, resulting in a loss of employment in mining of around 40% compared to 2010. Preliminary findings show that, in 2012, counties affected by coal decline had a significantly higher GOP vote share than those in the control group. The 2016

Trump campaign, which made the coal phase out even more salient, increased this effect further, but the main vote shift had already occurred in 2012. Abstracting from the US case, I discuss the implications of these findings for research on political feedback and the politics behind energy policy.

Climate Adaptation in Conflict Affected Countries -*Dana Thomas*

Research has already identified how states lacking adequate government institutions are passed over for finance, I would like to extend this research to narrow in on countries experiencing conflict specifically and compare differences in funding. Next, I plan to write out case studies of adaptation efforts in three countries. To do this I will identify countries that are currently in a state of conflict and focus on ones where climate change/resource scarcity has been an aggravating factor. Information on where these trends overlap will help me select the best possible states for case studies.

After identifying three vulnerable and conflict-prone states I will outline how climate change is expected to affect them, their current adaptive capacity, financial assistance history, how climate has played a role in the current conflict/relapse of conflict, and how conflict has hurt their ability to adapt. I will rely on existing peer-reviewed literature, government resources, and climate finance data to identify current efforts in adaptation. To identify sources of conflict and how conflict has affected adaptation efforts, I will rely on peer-reviewed literature on conflict resolution theory and first-hand sources such as newspapers, government data, and peacekeeping mission reports. After reviewing three case studies I hope identify trends and barriers to adaptation that exists in all three conflicts.

Based on a preliminary review of current adaptation funding trends, I expect this research to reveal that conflict-affected states are often “donor orphans” despite being especially vulnerable. My hypothesis is that the impacts of climate change, if not properly addressed, can contribute to the cycle of conflict. Conflict reduces government capacity, which reduces the state’s ability to respond to drought, natural disaster, etc., potentially leading to further tension over resources or exacerbated socio-economic inequality.

Forest management and climate change effects on water quality of Cedar River Watershed - *Rebecca Gustine*

Fire exclusion, fire suppression, and climate change have altered wildfire regimes in the Western Cascades during past decades. Fire season is becoming longer and burned area in the Western Cascades are projected to increase 200-400% above contemporary levels by the end of the century. Such fire-regime changes can have cascading consequences for human and natural systems, including degradation of downstream water quality. Understanding the potential consequences of an altered fire regime will be necessary for managing forested watersheds to protect highly valued resources, especially high-quality drinking water. In this study, we apply the ecohydrologic model RHESSys, coupled with the fire spread model WMFire, to investigate how climate change and forest management techniques, such as stand thinning, can affect wildfire regimes in the Cedar River Watershed in western Washington, which provides drinking water for 1.4 million people in greater Seattle area. We run multiple simulations considering different climate change and forest management scenarios to assess the vulnerability of wildfire activity in this watershed and the efficacy of management practices to reduce fire impacts. Preliminary results suggest that both forest management and climate change alter the fire regime in the Cedar River watershed. By using processes-based model with factor-controlled simulation experiments, we can better inform the water management authorities, such as Seattle Public Utilities, on how to best mitigate the risk of wildfire-induced harm to drinking water.