

EARTH & PLANETARY SCIENCES

AT HARVARD UNIVERSITY

2017 Senior Thesis Presentations

Rachel Hampton

Mickey MacKie

Mattie M. Newman

Leore C. Lavin

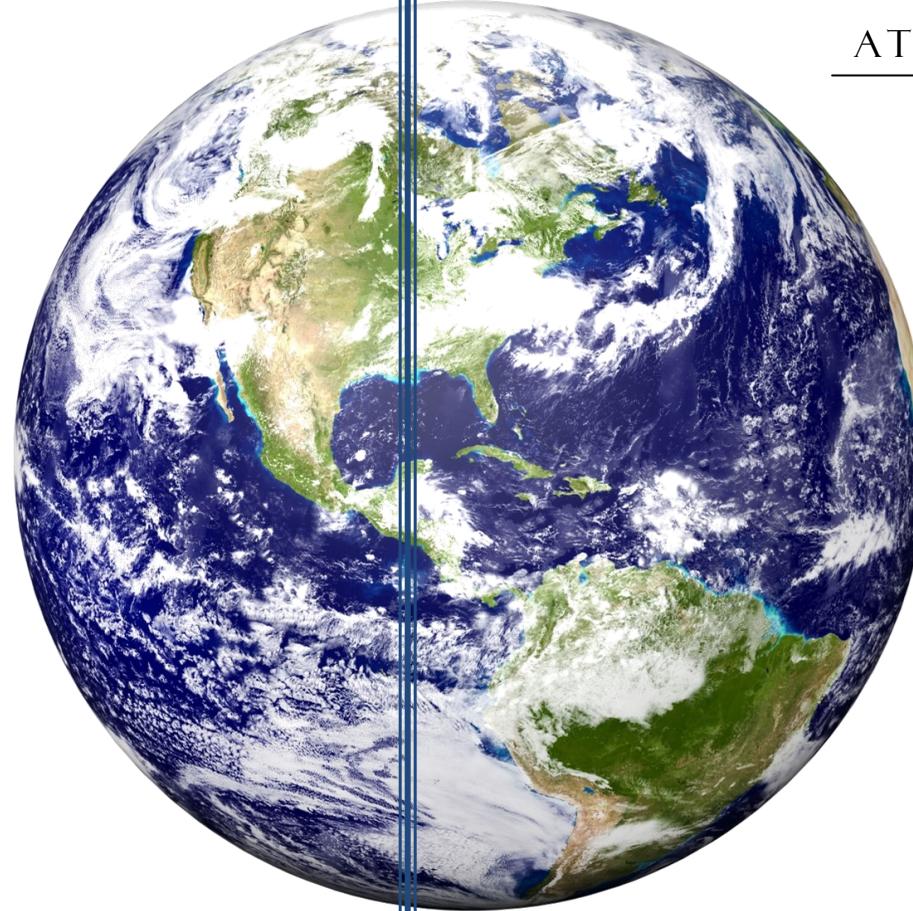
Intermission and Lunch

Matthew T. Luongo

Caroline S. Juang

Forrest K. Lewis

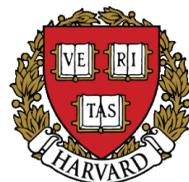
Adrienne M. Propp



Monday, May 1st, 2017 11:00-1:30 pm

Haller Hall, Geological Museum 102

*Please join us for an Undergraduate End-of-Year Reception beginning
at 1:30 pm in the Student Lounge (4th Floor, Hoffman Labs).*



MethaneSat: Detecting Methane Emissions from the Barnett Shale Region

Advisor: **Steven C. Wofsy**, Abbott Lawrence Rotch Professor of Atmospheric and Environmental Science; Co-Area Dean for Environmental Science and Engineering



Efforts to mitigate anthropogenic methane emissions, particularly in light of the recent boom in unconventional oil and gas, will increasingly depend on our ability to measure, monitor, and report emissions at high resolution and precision. There is currently no tool available that is capable of measuring methane emissions from oil and gas provinces with the required properties. MethaneSat, a proposed satellite, is a potential solution. It will operate with extremely high spatial resolution (1x1 km or 2x2 km) and precision (0.1-0.2% random error).

In this study, we perform observation system simulation experiments (OSSEs) for the Barnett Shale region of Texas to demonstrate the new information that will be provided by MethaneSat. For comparison, we perform OSSEs for MethaneSat, as well as the National Oceanic and Atmospheric Administration (NOAA) surface and aircraft network, and Greenhouse Gases Observing Satellite (GOSAT). We focus on assessing the observing systems' abilities to retrieve total emissions in the Barnett Shale, their spatial distribution, and their sharp peaks, and how this depends on uncertainty in the prior estimate and in the observations.

The results unambiguously show that MethaneSat is better able to constrain all three aspects of methane emissions than both the NOAA network and GOSAT, likely due to the high sampling density. Importantly, high uncertainty in the prior estimate does not greatly detract from these capabilities for MethaneSat as it does for the other observing systems. These results indicate that MethaneSat would be a superior tool for constraining methane emissions in oil and gas production regions where other tools are unavailable, or where we have insufficient prior information.

Quantifying the Magnitude of the Kok Effect through the Growing Season for Dominant Species in a Temperate Forest

Advisors: **J. William Munger**, Research Staff, Earth and Planetary Sciences
Steven C. Wofsy, Abbott Lawrence Rotch Professor of Atmospheric and Environmental Science; Co-Area Dean for Environmental Science and Engineering



Net ecosystem exchange of CO₂ (NEE) constitutes the balance between gross primary production (GPP) and ecosystem respiration (ER). Daytime ecosystem respiration (DER) is conventionally modeled as a temperature-based function based on nighttime NEE. Recent work at the Harvard Forest using improved isotopic partitioning instrumentation has suggested that foliar respiration is strongly inhibited by light in the early growing season, causing overestimates in conventional approximations of GPP and DER. Leaf gas exchange studies on many plant and tree species have confirmed leaf respiration in the light (R_{light}) to be less than leaf respiration in the dark (R_{dark}).

This study aimed to quantify leaf-level inhibition (the Kok effect) in major canopy trees at the Harvard Forest in central Massachusetts to compare to estimates from isotopic partitioning at the ecosystem scale. Leaf gas exchange tools were used to conduct light curves via the Kok method on samples from red oak, red maple, and hemlock trees.

R_{light} was less than R_{dark} averaged across all samples ($P < 0.005$), showing a mean inhibition of respiration of 28%. Inhibition in the early growing season was larger than inhibition in the late growing season ($P < 0.05$), though the percent decrease varied by species. R_{dark} , R_{light} , and inhibition were lower for shaded than canopy samples in all three species and remained unchanged between the hemlock new and old needles.

The inhibition measurements help refine recent unpublished estimates for the inhibition of respiration in red oak samples and provide the first detailed estimates of inhibition for hemlock and red maple trees at the Harvard Forest. The results support previous work showing ecosystem-scale foliar inhibition in the early growing season, though the magnitudes of the inhibition and its change across the growing season were less than the proposed ecosystem pattern. Future work on leaf-level Kok effect measurements is needed to help refine ecosystem carbon exchange estimates and better understand the physiological mechanisms behind the inhibition of respiration in the light.

Message from the Co-Head Tutors:

Thank you for joining us as we celebrate the accomplishments of our senior thesis writers who have spent much of their senior year tackling an exciting range of scientific problems. The senior thesis provides an opportunity for students to gain first hand experience into the full scope of academic research, from in-depth background study, to the identification of core questions, design of a research program, collection and analysis of data, and formulation of rigorous conclusions. This year's theses help constrain significant geologic events in the past, analyze faults and earthquake impacts, compare human and natural climatic records, and provide insight into measuring carbon dioxide from forests, and methane from oil and gas fields. Their efforts would not be possible without the dedicated support of faculty advisors, graduate students, and post docs. We thank these mentors and congratulate our seniors on their achievement.

Francis Macdonald and Jerry Mitrovica
Co-Head Tutors

Marine Denolle, Zhiming Kuang, Francis Macdonald, Jerry Mitrovica, Ann Pearson
Undergraduate Curriculum Committee

Esther James and Annika Quick
EPS Preceptors

Chenoweth Moffatt
Academic Program Manager

Rachel Hampton

Concentration: Earth and Planetary Sciences

The Middlesex Fells Volcanic Complex: A Revised Tectonic Model based on Geochronology, Geochemistry, and Field Data

Advisor: **Francis Macdonald**, John L. Loeb Associate Professor of the Natural Sciences and co-Head tutor



The Boston Bay area is composed of several terranes originating on the paleocontinent of Avalonia, an arc terrane that accreted onto the continent of Laurentia during the Devonian. Included in these terranes is the Middlesex Fells Volcanic Complex, a bimodal complex composed of both intrusive and extrusive igneous rocks. Initial studies suggested that this volcanic complex formed during a rift event as the Avalonian continent separated from its parent continent 700-900 Ma. New geochemical and geochronological data and field relationships observed in this study establishes a new tectonic model. U-Pb laser ablation zircon data on four samples from different units within the complex reveal that the complex erupted ~ 600 Ma. ICP-MS geochemical analysis of the metabasalt member of the complex yield a trace element signature enriched in Rb, Pb, and Sr and depleted in Th, indicating a subduction component to the melt and interpreted as an eruption into a back-arc basin. The felsic units similarly have an arc related signature when plotted on trace element spider diagrams and tectonic discrimination diagrams. Combined with the field relationships, including an erosional unconformity, stratigraphic and intrusional relationships and large faults from episodic extension events, this data suggests that the Middlesex Fells Volcanic Complex was erupted as part of the arc-sequence of Avalonia and as part of the formation of a back-arc basin well after Avalonia separated from its parent continent. This model presents a significantly younger eruption scenario for the Middlesex Fells Volcanics than previously hypothesized and may be used to study and compare to other volcanics from Avalon terranes in localities such as Newfoundland and the greater Boston area.

Caroline S. Juang

Concentration: Earth and Planetary Sciences

A Model of 25 Years of Carbon Exchange and its Factors in the Harvard Forest

Advisors: **J. William Munger**, Research Staff, Earth and Planetary Sciences
Steven C. Wofsy, Abbott Lawrence Rotch Professor of Atmospheric and Environmental Science; Co-Area Dean for Environmental Science and Engineering



The forest biosphere is an important reservoir for carbon, accounting for half of the world's CO₂ sink [Battle *et al.*, 2000; IPCC, 2013]. In the face of increasing anthropogenic carbon emissions, it is essential to understand how environmental factors affect the net drawdown of carbon dioxide (CO₂) through time in the northern mid-latitude forest ecosystem. In this thesis research, the Forest Ecosystem Model was created using Model-0 from Urbanski *et al.* (2007) to parametrize the relationship of temperature and sunlight on CO₂ exchange in the Harvard Forest in Petersham, MA [Urbanski *et al.*, 2007]. Parameters representing the ecosystem's contribution of photosynthesis and respiration to NEE were quantified in rolling 5-year periods of time by comparing the model's predicted NEE output to observed NEE measured by the Harvard Forest Environmental Measurement Station (EMS) tower. The null hypothesis, stating that the Forest Ecosystem Model will capture observed NEE, was rejected by winter seasons due to a poor model fit for the data, suggesting that other factors not accounted-for in the model are needed to fit observed NEE well. Spring and summer seasons did not reject the null hypothesis, indicating that NEE could be well-captured using sunlight and temperature. The model overall was able to capture some of the relationship between seasons, NEE, temperature, and sunlight and pinpoint anomalous years that did not represent the behavior of the ecosystem as a whole. With future improvements of the model, the Forest Ecosystem Model will have the capability of understanding changes in the ecosystem on the decadal scale and the potential to influence forest policy.

Matthew T. Luongo

Concentrations: Earth and Planetary Sciences and Engineering Sciences

Comparison and Calibration of Climate Proxy Data in Medieval Europe

Advisors: **Peter Huybers**, Professor of Earth and Planetary Sciences and Environmental Science and Engineering; Co-Director, Harvard University Center for the Environment
Michael McCormick, Francis Goelet Professor of Medieval History; Chair, Science of the Human Past



Two major sources of information on paleoclimate are historical documentary and scientific paleo proxy data. Recently, interdisciplinary research groups have sought to mesh historical and scientific data to gain a transformative understanding of paleoclimate, but the consistent study of climate history has generally lacked a statistical framework. This study develops a statistically robust methodology which considers anomalously extreme years within a database of documentary reports originally gathered from Medieval European manuscripts by the historian Pierre Alexandre. After spatially and temporally calibrating relevant paleo proxy temperature and precipitation reconstructions available through the National Oceanic and Atmospheric Administration with modern instrumental data from the Climatic Research Unit at the University of East Anglia, we sought to determine whether the historically anomalous years also stood out in the scientific record. We considered paleoclimate proxies from tree rings, speleothems, and varved lake cores. Results indicate that the year 1137 C.E., an extremely hot and dry year in the historical record, is statistically anomalous in both suites of temperature and precipitation reconstructions. Instances of extreme heat event years in the documentary record stand out in both temperature and precipitation reconstructions, while extreme precipitation event years do not, potentially due to a disconnect between the types of precipitation events emphasized by historical and scientific climate proxies. This result adds to the growing evidence of the ability to statistically identify climate events in both natural and written records. It also suggests that future studies should use statistical methods rather than corroboration when comparing scientific and historical data sets.

Emma J. "Mickey" MacKie

Concentration: Earth and Planetary Sciences

Cryogenian Stratigraphy of Northeastern Washington: A Glacial and Tectonic History

Advisor: **Francis Macdonald**, John L. Loeb Associate Professor of the Natural Sciences and co-Head tutor



The Neoproterozoic Windermere Supergroup deposited along the North American Cordillera spans the Sturtian and Marinoan Snowball Earth events and the rifting of the supercontinent Rodinia. The eastern Washington sequence of the Windermere Supergroup contains crucial information for establishing constraints on the timing of rifting and glaciation, and informing correlations of Cryogenian units between Canada and the USA. Age estimates and stratigraphic correlations for these sequences have previously been proposed but not clearly established. Here we present new geological mapping, measured stratigraphic sections, and geochemical, petrographic, and geochronological data from the Deer Trail Group, Shedroof Conglomerate, Leola Volcanics, and Monk Formation in the Salmo-Priest Wilderness of northeastern Washington. This data supports the presence of the Neoproterozoic Helmer Creek Fault, a synsedimentary northeast trending paleo-normal fault that was inverted as a Cretaceous thrust fault and repeats part of the Windermere Supergroup in northeastern Washington. Detrital zircon U-Pb dates preserve grains formed during the Grenville orogeny at ca. 1.0-1.2 Ga, the Gunbarrel magmatic event at ca. 775 Ma, and rifting throughout the duration of the Sturtian Snowball Earth event from 717-660 Ma. The age distributions do not suggest volcanism immediately prior to the Sturtian glaciation between 775 and 717 Ma and do not offer direct support for basalt weathering as a trigger for the Sturtian Snowball Earth event. However, the ages do indicate extensive synglacial volcanism, which offers a mechanism for its longevity through subaqueous weathering of basalt.

Mattie M. Newman

Concentrations: Earth and Planetary Sciences and Engineering Sciences

Evaluating Potential Linkages of the Pitas Point and Ventura Fault Systems, California: Implications for Seismic Hazards

Advisor: **John Shaw**, Harvey C. Dudley Professor of Structural and Economic Geology and Harvard College Professor, Department Chair



The offshore Pitas Point and onshore Ventura faults are aligned along strike, which has led some in the geological community to propose their connection at depth. However, this connection requires that onshore and offshore fault segments have similar subsurface geometries. This project presents an analysis of the subsurface geometry and kinematics of the Pitas Point fault to assess this potential linkage with the Ventura fault via the Sisar decollement. Our analysis specifically focuses on the region beneath the Dos Cuadras anticline in the eastern Santa Barbara Channel, where we constrain and render the geometry of the Pitas Point fault using 3-D seismic reflection data and well control.

We determine a permissible range of fault geometries through seismic interpretation, cross section construction, and balancing. The Pitas Point fault is comprised of several splays. Our analysis suggests that the main splay (referred to as the Upper Pitas Point fault (UPP)), has a listric geometry—shallowing its dip with depth. The UPP fault soles to the regional detachment at about 8.1 km. A similar mid-crustal detachment has been proposed for the onshore Ventura fault (Sisar decollement), and mapped to the south of our study area as the Lower Pitas Point fault (LPP). This common detachment provides a direct structural linkage between the Upper Pitas Point and Ventura faults, supporting the proposal that these structures are part of a combined fault system. We combine this new fault interpretation with elements of the SCEC Community Fault Model to generate a complete representation of the Ventura, Pitas Point, and Southern San Cayetano fault (V-PP-SSC) system, which has a combined surface area of about 2610 km². Utilizing the slip rate range of 6.6-10.5 mm/yr as presented by Hubbard et al. (2014) and corroborated by Marshall et al. (2017), we calculate potential maximum moment magnitude (7.4) and a recurrence interval (125-290 years) for earthquakes on this system. Due to the nature of the Santa Barbara Channel and Ventura basins, and high slip rates for the V-PP-SSC system, the combined fault system described in this study poses great risk to the urban populations of southern California.

Leore C. Lavin

Concentration: Earth and Planetary Sciences

Earthquake Hazards: An Analysis of Two Current Ground Motion Prediction Methods in Southern California

Advisor: **Marine Denolle**, Assistant Professor of Earth and Planetary Sciences



Mitigating earthquake risk in Southern California is conditional on the quality of ground motion prediction methods. Comparing earthquake ground motion prediction methods with recorded data provide clarity on prediction biases. This thesis compares the classical method of ground motion prediction, Ground Motion Prediction Equations (GMPEs), that uses empirical relations to predict shaking, and the novel method of Virtual Earthquake (VEq) approach, that uses ambient seismic noise to yield the Earth's impulse response to a virtual source. We compare these different methods, for the first time, using the mean bias and standard deviation of predicted and observed 5%-damped long period pseudo acceleration response spectra of the recent M_w 5.2 Borrego Springs event in the San Jacinto Fault Zone in Southern California. The comparison showed that the GMPE method had a stable mean bias across the tested frequencies but could not account for anomalous stress drop of the Borrego Springs event. The VEq method, on the contrary, had a frequency dependent mean bias but did account for the anomalous stress drop. It also had standard deviations on par with the GMPE method. Method comparison highlights the current limitations of each method. If current limitations are addressed through further development, the novel VEq method may prove to be a useful new tool in earthquake hazard prediction.