What Can the Isotopic Composition of Methane Tell Us About Methane Sources in New York City?

Background and Project Description: Methane (CH_4) is a strong greenhouse gas with 84 times the warming potential of carbon dioxide (CO_2). Methane is emitted from a range of sources such as leaky natural gas lines, landfills and sewers, as well as being naturally emitted from wetlands. Each of these sources has a different ethane: methane and $^{12}CH_4/^{13}CH_4$ isotopic composition. If sources are close to each other, these can be used to determine the sources of methane. New York Metro Area is the third largest urban source of CO_2 in the world and the largest in the US. Within New York City, methane emissions are calculated from inventories maintained by various state and federal agencies. However, recent studies found that these inventories consistently underestimate methane emissions. Fossil fuels are likely responsible for most of the underestimate. The NYAAQ project has established an urban network of gas sampling sites (https://nyaaq.ldeo.columbia.edu) that we use to calculate the total amount of methane (and other gases) emitted within New York City. We have taken gas samples from methane sources across the city and the isotopic composition has been measured by colleagues in Utrecht, Netherlands. Most previous studies have used the ethane: methane ratio from natural gas pipelines to identify methane from natural gas (there is no ethane from sewers/landfills). We have identified a preferential combustion of ethane during the consumption of natural gas that would undermine that approach. However, based on single samples, combustion does not appear to affect the isotopic composition of methane. We plan to expand this analysis; taking more samples during the summer and investigating the use of $^{12}CH_4/^{13}CH_4$ isotopic composition to characterize the contribution of various methane sources to total emission.

Anticipated tasks: The undergraduate intern will undertake math-based analysis of the existing dataset, identify gaps in sample types and undertake fieldwork to take more gas samples to complete the dataset. The student will learn to use existing tools and adapt them to our specific problem. The intern will work with our team to visit sampling locations in the area, including our Observation network, and Brookhaven National Lab.

Skills required: Calculus classes including differential equations are required. Other classes/ experience in atmospheric science/chemistry, machine learning and coding experience in Python, R or MatLab, and experience working with different file formats (e.g. NetDCF4, arl, etc.) are an advantage but not essential. Experience with laser-based instruments is an advantage but not required. Some fieldwork may require long hours but most work will be lab based between fieldwork trips. As part of a larger team project, strong communication skills are required. We encourage students of all physical abilities to apply, as most sites are accessible.

Research Mentor: Roisin Commane: r.commane@columbia.edu, (617) 501-1406

How Do Faults Activate During The Initiation of a New Plate Boundary?

Background: Divergent plate boundaries facilitate the break-up of continents and creation of new oceanic crust. However, a long-standing question is how this type of plate boundary begins in ancient continental crust, particularly in areas where the lithosphere is too cold, thick, and strong to allow deformation. A region of southeast Congo which extends into northwest Zambia and northeast Angola, a little explored but important region of the African continent, presents us a special opportunity to explore this problem. This area is riddled with distributed earthquakes and the earth's surface is cut by series of subtle normal faults, defining grabens and half grabens across which stream channels are deflected in various directions. These patterns occur in a more profound manner in other parts of the world where mature active divergent plate boundaries exist (e.g., East African Rift System, Death Valley in California, Rio Grande Rift in New Mexico), thus indicating that a new divergent plate boundary is about to be born in this part of the African continent. The proposed project involves the development of an active fault database for the study area, and a quantitative characterization of vertical offset along the fault escarpments to understand the lateral variability across the area, and gain insights into how the earth's shallow crust accommodates the initiation of a new plate boundary.

Work Required: The project will utilize the available 30 m resolution Digital Elevation Model to delineate and map the surface traces of normal faults in the study area. Measurements of the vertical surface offset (scarp height) of the normal faults will be manually taken at regular distance intervals along the faults and recorded on a spreadsheet. Fault mapping and scarp height measurements will be done in ArcPro software. The datasets generated by these exercises will be used to make structural maps and fault displacement-distance scatter plots. We will then compare the distribution of fault traces and the fault offsets with the detailed bedrock geological maps of the area to infer where and how faults initiate and how they are controlled. The results may also provide insight into how the faults are propagating laterally across the area. The lessons learnt from the quantitative datasets will provide insight into how the earth's shallow crust accommodates the initiation of a new plate boundary.

Prerequisites: It is advantageous for the student to have some experience with ArcPro (or ArcMap) and with Microsoft Excel. It is also advantageous to have taken a course in Geology. However, fast learners can pick up the relevant skills needed to complete the exercises during the internship.

Mentors: Folarin Kolawole: fola@ldeo.columbia.edu, (332) 330-4658
Meritxell Colet, mcolet@ldeo.columbia.edu,507-649-7424)

What are Recent Changes in the East and West Basin of the Deep Atlantic Ocean?

Background: The ocean is a crucial component of the Earth's Climate System and serves as a major reservoir for heat, salt, freshwater and carbon. Waters that bathe the abyssal reaches of every ocean basin are formed and derive their properties at only two locations on Earth, around Antarctica and in the marginal seas of the North Atlantic. The North Atlantic Deep Water (NADW) is a major conduit of oxygen and anthropogenic carbon to the deep ocean, and its formation from the cooling of warm, northward flowing surface waters provides a substantial heat transport to high northern latitudes in the Atlantic meridional overturning circulation (AMOC). As NADW spreads southward in the Atlantic, it fills both sides of the Mid-Atlantic ridge as separate but connected basins, with a greater contribution of southern-sourced water in the eastern basin. This project is designed to allow a student to use deep sea sediments from multiple locations to explore differences in the water masses of the eastern and western basins since the last ice age through the current warm interglacial interval. The results will help provide a context for recent inferences that the production of NADW has diminished due to ongoing warming freshening, and that its collapse may even be imminent, with potentially disastrous consequences.

Work Required: The selected student will work in our shared sediment laboratory and microscopy laboratory in the New Core Lab at LDEO. Training and guidance will be provided for all procedures, which will use existing equipment including microscope, freeze-dryer, ovens, microbalance, sieves and beakers. Lab work will require 20 hrs./wk.

Pre-requisites: None, although knowledge of basic oceanography and climate is helpful.

Mentors: Jerry McManus, jmcmanus@ldeo.columbia.edu
Apollonia Arellano, arellano@ldeo.columbia.edu

What Do Seismic Wave Amplitudes Tell Us About How Heat Is Distributed in the Northern Appalachian Anomaly, a Mini-Hotspot Beneath New England?

Background: The shallow mantle beneath New England contains a large region of very slow seismic velocities, denoted the Northern Appalachian Anomaly. It is hypothesized to be associated with a 400 km wide region of mantle upwelling. Although no volcanism is known to be associated with the Northern Appalachian anomaly, small-scale Tertiary volcanism has occurred near a similar low-velocity body in Virginia. Furthermore, both regions experience frequent small earthquakes, suggesting localized stressing of the crust. Previous work has used travel times of seismic waves to image the Northern Appalachian Anomaly's internal structure, as hot temperatures are known to correlate with slow wave speeds. However, the resolution of travel-time based techniques is insufficient to answer important questions, including whether magma is present and the degree to which the crust is being affected. Recent theoretical advances suggest that seismic amplitudes are complimentary data that might provide more definitive answers to these geophysically important issues. The intern will conduct a novel analysis of US Array seismic data to quantify patterns of amplitude variation and will compare results with the prediction of a state-of-the-art seismic wave modeling code.

Analysis Required: The project is computer-based, and presumes a willingness to spend several hours each day in front of a computer screen, looking at data and results. The intern will be involved in applying previously-written Python-based data analysis code to already-collected high-quality seismic data, and in comparing results to the predictions of the SpecFEM seismic wave simulations code.

Prerequisites: The intern should be willing to learn a little geophysics. Some prior exposure to general earth science, and especially to plate tectonics, and to the Python scientific programming environment would be helpful but is not required.

Mentors: Bill Menke, menke@ldeo.columbia.edu, 845-304-5381,
http://www.ldeo.columbia.edu/users/menke/
Andrew Lloyd, andrewl@ldeo.columbia.edu

What Is the Relationship Between Marine Heat Waves and Tropical Cyclones in the Tropical Atlantic?

Background: Marine heat waves have received considerable attention in recent years. Marine heat waves are defined as events with daily sea surface temperatures exceeding the 90th percentile of the seasonally varying local daily values and persisting for at least five days. (e.g. Sen Gupta et al. 2020). Marine heat waves can have devastating impacts on local marine ecosystems and fisheries, as exemplified by the northeast Pacific marine heat waves of the 2010s. Sen Gupta et al. (1) found that across most of the extratropical oceans the most severe marine heat waves have been in recent years. In 2023, recent ocean warming caused the tropical Atlantic sea surface temperatures to be above the 75th percentile for every month of the year. Marine heat waves can also have a significant effect on tropical cyclones by significantly increasing the energy available for tropical cyclone intensification. A recent study (2) found that marine heat waves can strengthen the maximum intensity of tropical cyclones by 35.4% (or 106.72 kts). However, tropical cyclone intensification may be due to the high sea surface temperatures during marine heat waves or to circulation features that favor both marine heat waves and tropical cyclone intensification.

Analysis Required: This project will analyze the relationships among marine heat waves and tropical cyclone intensity by using tropical cyclone position and intensity data from the Atlantic hurricane database. If time permits, we will extend the work to Western North Pacific typhoons. Marine heat waves will be identified using the NOAA 1/4° daily optimum Interpolation sea surface temperature. It incorporates observations from different platforms (satellites, ships, buoys and Argo floats) into a regular global grid, from September 1981 to the present. Once we identify both the marine heat waves and tropical cyclones, tropical cyclone intensification will be examined for tropical cyclones both with and without overlap with marine heat waves. We will also examine the atmospheric conditions during those overlapping periods to determine how these characteristics link to tropical cyclone intensification.

Prerequisites: Basic knowledge of the climate system and significant skills in accessing, handling, and analyzing large quantities of data; skill in coding in Python.

Mentors: Mingfang Ting, ting@ldeo.columbia.edu, 845-365-8374; Jennifer Nakamura, jennie@ldeo.columbia.edu; Richard Seager, seager@ldeo.columbia.edu

References: (1) Sen Gupta, A., Thomsen, M., Benthuysen, J.A. et al. Drivers and impacts of the most extreme marine heatwave events. Sci Rep 10, 19359 (2020). hlps://doi.org/10.1038/s41598-020-75445-3. (2) Choi, H-Y, M-S Park, H-S Kim, & S Lee, Marine heatwave events strengthen the intensity of tropical cyclones, Comm. Earth and Environment. (2024), hlps://doi.org10.1038/s43247-024- 01239-4.

How Does Vehicle Type and Traffic Quantity Impact Air Pollution Levels and Sources on an Urban Highway?

Background: Air quality is a major crisis globally, leading to about 8.1 million premature deaths every year. Major pollutants that contribute to this mortality include fine particulate matter ($PM_{2.5}$), ultrafine particles ($PM_{0.1}$), ozone (O_3), nitrogen oxides (NO_x), and more. A key aspect of successful air quality management is understanding and attributing sources of pollutants. Traffic is a major source of air pollutants, especially NO_x, $PM_{0.1}$, and $PM_{2.5}$, but pollutant mixes vary significantly by vehicle type (truck, bus, passenger car, SUV, etc.), fuel type (diesel, gasoline), and drive cycle. Other sources of pollution, such as electricity generating units, are also sources of many of the same pollutants. Pollutant types also have differing negative health impacts and outcomes. Therefore, identifying and understanding the contributions of individual sources to pollution levels is a critical piece to reducing pollution exposure.

Analysis Required: This project will take place as part of Lamont's Air Sensors Lab, which works on air pollution and climate monitoring, modeling, and remote sensing. Work will consist of analyzing pollution data from a monitoring supersite located near Stuy Town on the FDR expressway in Manhattan. The intern will use computer programming tools (Python) to visualize and analyze air quality data. The intern will also use an unsupervised learning technique called non-negative matrix factorization to attribute sources of air pollution. The instrumentation includes a water-based condensation particle counter (CPC) to measure ultrafine particles ($PM_{0.1}$, particles less than 100 nm in diameter) and a MODULAIR sensor system to measure the particle size distribution and well as mixing ratios from several trace gases. The intern will also conduct several field visits to the monitoring location to conduct a traffic survey to be paired with the pollution data.

Prerequisites: Applicants should have experience in the Python scientific data analysis environment. Interest in air pollution is required, but detailed previous knowledge of the topics is not necessary. Any prior experience in air quality data, statistical modeling, and measurements is a plus. Students majoring in any science or engineering discipline will be competitive candidates.

Mentor: Daniel Westervelt, danielmw@ldeo.columbia.edu, 845-365-8194;

Enhancing Urban Climate Vulnerability Analysis by Machine Learning and Large Datasets

Background: Global cities contribute ~ 70% of greenhouse-gas emissions (IPCC, 2023) and experience amplified impacts from climate change in the present and in future projections, such as the urban heat island effect from intense extreme heatwaves. Urban climate vulnerability assessment is crucial for researchers and policymakers to develop better adaptation strategies to protect people, infrastructure, and economies. Megacities like New York City, Los Angeles, Mexican City, and Copenhagen exhibit local disparities in vulnerability to sea-level rise, coastal floods, extreme heatwaves, etc. (Rosenzweig et al., 2010; Reckien et al., 2018; Kim et al., 2020; Fleming et al., 2023). Developing a tailored vulnerability index for these cities can help address local challenges and prioritize resources for urban planning. The proposed index will use many indicators from large, detailed data sets that can be better processed with recent science and technical advancement in artificial intelligence and machine learning.

Data, methodology, and analysis required: This study aims to develop a climate vulnerability index system tailored to urban areas at the lowest level that relevant large data sets can be collected. At these levels, the complex data can be beyond efficient human expert review and judgement. The participating student will select one megacity in the U.S. and/or one in other countries. He or she, with guidance of the mentors, will collect data in three dimensions: physical (e.g., sea level rise, cooling sites), environmental (e.g., vegetation cover), and socioeconomic (e.g., demographics, poverty). The data will be collected from various sources, such as census and other public sources, and remote sensing sites. The proposed methodology for analysis uses advanced data science techniques such as principal component analysis, machine learning algorithms like Autoencoders and clustering. By collecting and analyzing the data at detailed levels, the research can provide a nuanced understanding of urban vulnerabilities. The research computational work will use either cloud computing (preferable AWS or Google Cloud) or NASA SEDAC servers at CIESIN facility. This work is part of a larger project, with the approach not only addressing current challenges but also suggesting a future direction where large datasets can be effectively utilized to enhance climate vulnerability analysis.

Prerequisites: Interest and knowledge in climate change research and assessment, such as Intergovernmental Panel on Climate Change reports. Interest in advanced data science like artificial intelligence and machine learning. Basic knowledge and skills in Python coding. Geographic Information System knowledge would be a plus.

Mentors: Xiaoshi Xing, xing@ciesin.columbia.edu, CIESIN and NASA SEDAC, 845-365-8967; Jung-A Lim, jl6726@columbia.edu, CIESIN and EEE at Columbia SEAS

Are Beverages and Household Water Filters Major Exposure Sources of Nanoplastics?

Background: As of 2015, about 6300 million metric tons of plastic waste have been generated worldwide. Physical weathering and photodegradation can break those plastic wastes into microplastics (MP, 5 mm to 1 μm) and nanoplastics (NP, less than 1 μm). Numerous studies have demonstrated the occurrence and adverse effects of microplastics in our living environment. However, knowledge about nanoplastics is limited mainly due to a lack of scientific techniques to identify these nanoparticles. These nanoparticles are health-relevant because they are small enough to be taken up into human tissues and to be directly passed into the brain. A recent development in Raman Microscopy at Columbia University provides an ideal approach to identifying nanoplastics due to Raman's unambiguous fingerprinting of the signals from plastic polymers. The overall goal of this study is to investigate the major exposure pathways of nanoplastics, including beverages and water after undergoing various household filtration methods.

Analysis Required: This project will analyze the abundance and type of nanoplastics in popular drinks and water and air samples collected in NYC. Lab work includes isolating nanoplastics from other particles and characterizing nanoplastics using several optical approaches including Raman and SEM. Lab work will average 30 hrs./wk., with the rest of the time being focused on data analysis, literature review, etc. We also plan to arrange a field trip to NYC to collect tap water samples after filtration.

Prerequisites: General chemistry and lab courses are required. Organic or analytical chemistry with interests in biological and environmental issues would be a plus.

Mentors: Beizhan Yan, yanbz@ldeo.columbia.edu, 845-248-1526;
Huiping Deng, hd2449@columbia.edu