How Unusual Was the Co-occurrence of the 2023 Heat Extremes in North America, Europe, and China?

Background: The summer of 2023 was the hottest on record in the Northern Hemisphere. In July, heat extremes simultaneously unfolded across North America, Europe, and China. In North America alone, the extreme heat directly caused 695 deaths in the western US and Mexico. Although the concurrent heat extremes shattered instrumental data records in these regions, the brevity of instrumental records limits our capacity to discern whether such an event could occur naturally or could not happen without the influence of anthropogenic climate change. Paleoclimate reconstructions are important tools for circumventing this limitation. By reconstructing past surface temperature variations over the last millennium, we can better capture the full range of natural climate variability, thus offering a more comprehensive perspective of the climate system. This project will not only provide crucial context for evaluating the rarity and intensity of the co-occurring 2023 summer heat extremes, but also deepen our insight into the impacts of human-induced climate change.

Work Required: This project will analyze a data assimilation-based temperature reconstruction over the past 1000 years and instrumental temperature products. The student will process these data and use them to quantify the likelihood of an event similar to the 2023 event in the context of the past 1000 years. The student will also learn how these products are generated and the limitations associated with them.

Prerequisites: The student should have experience in computer programming. Prior knowledge of statistics and climate would be helpful, but is not required.

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Unveiling the Crystal Ball: Assessing the NMME Models in Forecasting El Niño/La Niña Onset

Background: The El Niño-Southern Oscillation (ENSO) serves as a planetary heartbeat, orchestrating climate dynamics worldwide as it rhythmically transitions between its cold (La Niña), neutral (neither La Niña nor El Niño), and warm (El Niño) phases. The initiation of a new phase of ENSO marks a critical juncture in Earth's climate system, setting off a series of interrelated atmospheric and oceanic phenomena that significantly alter weather and climate patterns across the globe. This complex interplay leads to the occurrence of extreme climatic events, such as intense rainfall causing flooding in certain regions, and simultaneous droughts that give rise to wildfires and heatwaves in others. In both scenarios, these events have far-reaching impacts on water resources, agricultural procedures, and ecosystems. Hence, understanding the transitional behavior of the ENSO, particularly the crucial moments when it shifts from one phase to another, is essential information necessary for managing and mitigating its adverse effects.

Analysis Required:

1) Analyze historical observational and model data (North American Multi-Model Ensemble: NMME) for relevant variables.
2) Identify historical instances of ENSO onset.
3) Establish criteria for the beginning of El Niño or La Niña phases
4) Compare observed onset dates with the modeled onset dates and assess the accuracy of the models in simulating ENSO events.
5) Apply statistical methods to find the predictive skill of models, and quantify and assess uncertainties in both observational data and model outputs.
6) Summarize findings in a clear and accessible manner for publication.

Prerequisites:

- Understanding of fundamental principles of climate science is essential. Knowledge of ENSO is a plus.
- Proficiency in statistical methods and data science techniques is necessary. Interpreting results is critical.
- Proficiency and experience in one or more of the following: NCAR Command Language (NCL), Climate Data Operator (CDO), Grid Analysis and Display System (GrADS), Python, R

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What Are the Differences in Sediment Grain Size and Contaminant Distribution in Long Island Sound?

Background: Detailed knowledge of sediment dynamics and the related distributions of habitats and contaminated sediments in estuaries is essential for successfully managing these systems. The Long Island Sound Mapping Project is a collaboration between different universities from Connecticut, New York State (including Columbia, Stony Brook, and Queens College) as well as NOAA. The overarching goal is to provide a detailed benthic habitat analysis of Long Island Sound. This is an ongoing project that is mapping Long Island Sound in several different phases. In the summer 2024, our group will collect surface sediments and possibly sediment core samples in Western Long Island Sound. Planned analyses include grain size distribution, bulk chemical composition, and stable carbon and nitrogen isotopic composition. The new results will be compared with data from previous work. Of specific interest are differences in grain size distribution and contaminants, which can provide important insights into different sediment sources and how sediments are transported in the Long Island Sound system.

Analysis Required: Under supervision of the advisors, the student would participate in collecting sediment grab samples in Long Island Sound (depending on schedule), analyzing selected sediment samples and field descriptions, integrating the results, and comparing those with existing data from other parts of the Long Island Sound. Data analysis and integration will be done using Excel and GIS software.

Prerequisites: Confidence in working with Excel and potentially ArcGIS is preferred but not required.

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What Are the Magmatic Processes That Led to The Catastrophic Eruption of Aira Volcano in Japan?

Background: Large explosive volcanic eruptions pose a major threat to millions of people around the world. Yet, there remains considerable uncertainty over the timescales and processes that lead to the accumulation of the large volumes (hundreds of km^3) of silicic magma that feed these super-volcanic eruptions. In the last decade we have seen increasing evidence that these eruptions can tap heterogeneous magmas, stored at shallow depths below the volcano (up to 2-5 km), and can accumulate rapidly (< 1,000 years). However, there remains significant debate in the field. The 400 km^3 super-eruption of Aira volcano in southern Japan (30,000 years ago) is unique because it was preceded by three smaller explosive eruptions that occurred within 3,500 years of the final catastrophic eruption, thereby providing snapshots of the magma system as it evolved. Thus, Aira provides a relatively rare opportunity to investigate the timescales and processes that lead to super-eruptions. A critical question is whether the magmas that were erupted during the three smaller eruptions are related to the magmas erupted during the catastrophic eruption. To do this, we must compare their chemical compositions. As magmas change composition due to processes such as crystallization, changes in storage depth, or injection of new magma, chemical data can record these processes and can help us to infer whether magmas shared similar histories before eruption. We have already collected major-element (e.g. Si, Al, Fe, Mg, K, Ca, Na) and trace-element (e.g. Li, Sr, Ba, La, Yb, Y, Pb) data from the pumice glass. All precursory eruptions show remarkably similar compositions and the super-eruption compositions are slightly different. However, the pumice glass only records the *final* composition of the magma before eruption. This project will investigate “melt inclusions”, which are little parcels of magma (< 0.1 mm dimeter) that get trapped inside quartz crystals at different times during crystallization, thereby provide snapshots of magma composition throughout its history.

Analysis Required: We will use an electron microprobe to collect the major element compositions of the melt inclusions. Then we will use the laser ablation inductively coupled plasma mass spectrometer (LA-ICP-MS) to collect trace element compositions. The intern will get hands-on experience using these instruments, as well as in sample preparation, data processing and analysis, and the use of a thermodynanamics modelling program (rhyolite-MELTS) that will help us to estimate the storage depth of the magmas when they were trapped within the quartz crystals.

Pre-requisites: Completion of a general chemistry/lab course and a basic geology course is preferred.

Mentors:

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How Does Climate Change Impact Aquatic Net Community Production? - A Novel Approach

Background: Anthropogenic climate change is rapidly transforming the community composition, structure, and functioning of aquatic shallow-water ecosystems globally. Increasing atmospheric CO_2 concentration and dissolution in aquatic systems, along with rapid environmental changes, have been shown to strongly impact aquatic metabolism, including gross primary productivity (GPP), total community respiration (R; both autotrophic and heterotrophic) and, therefore, net community production (NCP). These processes provide key insights into carbon cycling, energy dynamics, and food chains in any aquatic ecosystem and are important indicators of ecosystems health and alterations. However, the complexity of interactions underlying these processes requires a holistic assessment with accurate measurements of metabolism and biogeochemical fluxes. Consequently, community-wide (both benthic and planktonic) and standardized measurements of biochemical properties are essential for ecosystem management. Yet, obtaining such coupled data in the field has been proven challenging. Most measurements of aquatic metabolic and biogeochemical processes have generally quantified spatially discrete geochemical changes in the water column using a range of approaches, including *in situ* techniques in flowing systems or *ex situ* methods with bottled samples. In recent years, *in situ* enclosure experiments have been developed and used across different shallow-water habitats. While providing valuable continuous field measurements of the processes associated with either individual organisms or benthic communities, accurate characterization of diurnal cycles in total community responses cannot be achieved. Given the above, versatile and widely reproducible methods to couple climate variability to the metabolisms of shallow water communities in their natural environment is lacking.

Analysis Required: The project will develop a novel *in situ* enclosure to continuously monitor diurnal and coupled cycles in aquatic Net Community Production, Total Community Respiration, and Gross Primary Productivity for both benthos and water column under atmospheric conditions. This enclosure system will provide the first fully autonomous system capable of simultaneous measurements of aquatic metabolism, pCO_2, and weather parameters under undisturbed, natural conditions on time scales ranging from minutes to days. The work will include implementing enclosure mesocosms, building a weather station, and doing weekly testing/ measurements using the complete system in the Skunk Hollow pond on the LDEO campus. Practical work will average 25hrs./wk., with the rest of the time being focused on dataset organization, data analysis, and literature review.

Prerequisites:

- Background in environmental sciences or environmental engineering is required.
- The candidate should be methodical, well-organized with excellent time management and interpersonal skills.
- Data analysis skills and the capacity to quickly learn functioning of several monitoring equipment are desirables; laboratory experience is not required.
- The candidate should feel comfortable working in the field, machine shops, as well as laboratory environment.
- The candidate should feel comfortable commuting to the Lamont-Doherty Earth Observatory for all laboratory and field work.

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What Are the Best-Performing, Consumer-Grade Air Sensors?

Background: Air quality is a major crisis globally, leading to about 5 million premature deaths every year. The gold standard for surface observations of air pollutants are so-called reference monitors, which cost tens to hundreds of thousands of dollars and require substantial scientific experience to maintain. Consumer-grade air sensors are simpler, lower-cost devices (less than $1500 each) that can measure fine particulate matter (PM2.5) via indirect methods such as optical scattering, having the potential to democratize air quality monitoring, allowing for access to evidence than can be leveraged to promote clean air solutions. In order to get useful, actionable data out of air sensors, scientists must perform careful calibration and performance evaluation of these devices, otherwise low-quality data may proliferate.

Analysis Required: This project will take place in Lamont's newly created Air Sensors Lab, which is outfitted with a GRIMM EDM-180 reference-grade particulate matter instrument and about 10 different air sensor types made by some of the most prominent vendors around the world. Work will consist of setting up both the research-grade and low-cost instrumentation in the lab and analyzing the data. Lab work will average 20 hours per week, with the rest of the time being focused on data analysis, literature review, etc. The intern will collect the PM2.5 data from both classes of instruments (sensors and research-grade instrumentation) and analyze it for correlation and estimates of bias of the sensors. They will also compare the different sensor brands among each other to see which have the best performance metrics in terms of bias and correlation. Finally the intern will have the opportunity to "build" their own air sensors using microelectronics available in the lab, and evaluate the performance of their homemade sensor as well. We also plan to arrange a field trip to an urban air quality monitoring site in New York City to collect some urban air quality data.

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

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Can Arctic Sea Ice Melting and Arctic Amplification Lead To More Summer Extremes?

Background: There is mounting evidence that the Arctic sea ice loss not only considerably affects the climate and ecosystems within the Arctic but also has global consequences via changes in atmospheric and oceanic circulation. It's been suggested that the Arctic sea ice loss and associated amplified Arctic warming could affect the Northern Hemisphere jet streams, atmospheric blocking and extreme weather events such as heat waves and droughts.

Analysis Required: This project will analyze the connection between the Arctic amplification and summer extremes in the Northern Hemisphere midlatitudes using both observations and state-of-the-art global climate model output. In particular, the project will systematically investigate whether and how the Arctic sea ice loss affects the Arctic amplification, multitude jet streams, atmospheric blocking and summer extremes in both the past few decades and in future climate projections.

Prerequisites: General physics, interests and experience in atmospheric science, statistics and programming are required

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What Are the Major Exposure Pathways 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. Raman microscopy can unambiguously fingerprint the signals of plastic polymers. The overall goal of this study is to investigate the major exposure pathways of nanoplastics, including ingestion from drinks and inhalation from the air.

Analysis Required: This project will analyze the abundance and type of nanoplastics in popular drinks, water and air samples collected in New York City. Lab work includes isolating nanoplastics from other particles, characterizing nanoplastics using several optical approaches including Raman microscopy and SEM (Scanning Electron Microscope) imaging and analysis. Lab work will require an average of 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 New York City to collect air samples.

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

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