MGU 2021

Michigan Geophysical Union Annual Symposium Program Booklet

Ann Arbor, Michigan | April 15-16, 2021

Contents

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Welcome to the 17th Annual Michigan Geophysical Union

Welcome to the 2021 Michigan Geophysical Union Student Research Symposium!

MGU is a student-led and student-focused conference hosted jointly by the department of Climate and Space Sciences and Engineering and the department of Earth and Environmental Sciences. We celebrate the study of geophysics and related topics at the University of Michigan, and the undergraduate and graduate students who make this research possible.

MGU had been held every year for 16 years up until Spring 2020, when our campus was disrupted by the COVID-19 pandemic. In the interests of public health MGU had to be canceled. The pandemic is still with us in 2021, but we believe that MGU is worth holding to maintain the ties that connect our departments and to promote the work of our peers. We have therefore worked hard to bring it to you in a virtual setting.

In transitioning to the online format we have unearthed new ways to come together and share our science. We hope that you too have weathered the tremendous challenges of this past year, and that you will join us in the space we've made to showcase our students.

– Camilla D. K. Harris and the MGU 2021 Organizing Committee

Acknowledgements and a Brief History of MGU

A tradition that began in 2003, the Michigan Geophysical Union has continued to grow as a direct result of increased student participation over the years. The strong foundations that have led to 17 successful conferences come from previous MGU coordinators and organizing committees who deserve our gratitude for making it possible to continue this symposium from year-to-year. The continued support of faculty and staff from both the EARTH and CLaSP departments is greatly appreciated. The positivity surrounding MGU is a key component in encouraging participation and helps us immensely in achieving our goals.

The ongoing collaboration between experienced and new members of the organizing committee lends a continuity to the event each year as new members take the reins. While there is currently no document that covers the evolution of MGU over the years, we do know that by 2009 the conference was running smoothly. Based on conversations with previous committee members, early MGU symposiums provided strong examples to follow. While venues changed and events varied, the core experience of MGU remains. The culture surrounding the symposium brings departments together and produces a true conference feel.

Between 2010 and 2012, the organizing committees brought exciting changes to the conference, perhaps most notably for students: funding for cash prizes. Students now had the chance to compete for monetary prizes based on the merits of their research! The “Audience Choice” award also originated during this time, giving students even more reason to engage with research outside of their own fields.

MGU has traditionally captured the poster hall component of conferences, where students are on-hand to discuss their displayed work with interested visitors. Starting in 2021, students also have the opportunity to deliver oral presentations to a live audience. The experience of presenting original scientific research puts a spotlight on original ideas and hard work, which can be intimidating. It helps to remember that every presentation makes us better science communicators.

MGU aims to prepare students for successful future conferences, whether their paths lead towards academia, industry, or otherwise. We strive to meet the high bar set by those who came before us and deliver the best possible student experience. Although COVID-19 currently limits audience and author interactions to a digital space, the wide range of fields and topics being presented this year offers many reasons to attend!

-MGU 2021 Organizing Committee

<u>Participating Departments</u>

We are proud to report that the 2021 Michigan Geophysical Union symposium has participants from six departments. We continue to foster an environment where students researching diverse topics can come together to share their mutual interests in the spirit of new collaborations. MGU is intended to function as a low-stress entry point and friendly forum where students can hone their presentation skills. With a wide range of fields represented, the 2021 MGU symposium is the most diverse yet!

MGU 2021 Organizing Committee

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Larry Ruff - EARTH
Zack Spica - EARTH

Schedule of Events

Tuesday, April 13

5:00 – 6:30 pm - Viewing Party for Asynchronous Presentations

Wednesday, April 14

5:00 – 6:30 pm - Viewing Party for Asynchronous Presentations

Thursday, April 15

10:00 am - Opening Remarks

10:10 am - Session 1 (10-minute Live Presentations)

11:00 am - Break

11:10 am - Session 2 (10-minute Live Presentations)

12:00 pm - Lunch

1:10 pm - Session 3 (5-minute Live Presentations)

2:10 pm - Session 4 (Q&A with Asynchronous Presenters)

3:00 pm - End-of-Day Remarks

Friday, April 16

10:00 am - Opening Remarks

10:10 am - Session 1 (10-minute Live Presentations)

11:00 am - Break

11:10 am - Session 2 (10-minute Live Presentations)

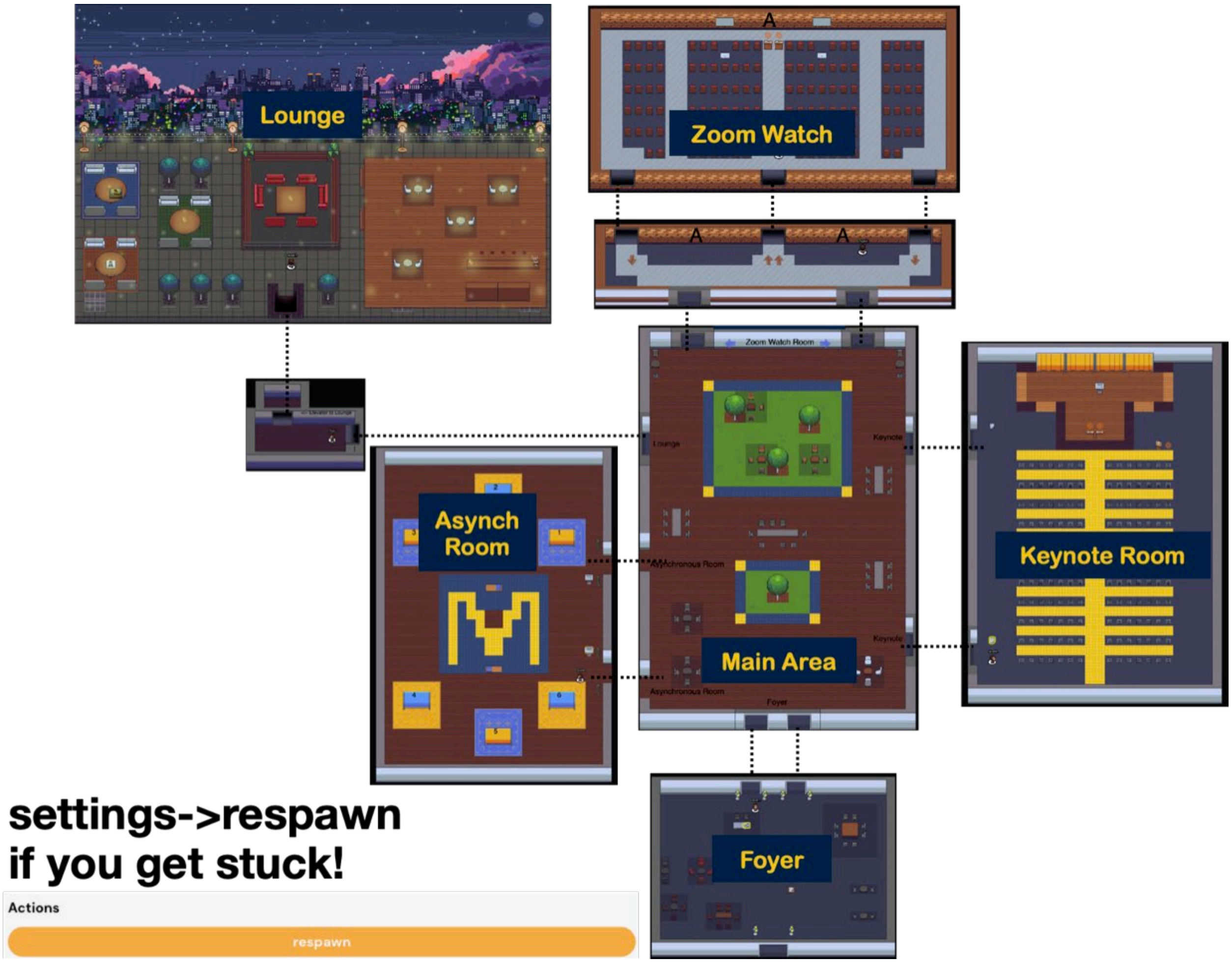
12:00 pm - Lunch

1:10 pm - Session 3 (5-minute Live Presentations)

2:10 pm - Session 4 (Q&A with Asynchronous Presenters)

3:00 pm - Closing Remarks

Gather.town Floorplan



Thursday, April 15 List of Presentations

Session 1 (10-minute Live Presentations) – 10:10 am

Session 2 (10-minute Live Presentations) - 11:10 am

Session 3 (5-minute Live Presentations) - 1:10 pm

Session 4 (Asynchronous Presentations)

Friday, April 16 List of Presentations

Session 5 (10-minute Live Presentations) - 10:10 am

Session 6 (10-minute Live Presentations) - 11:10 am

Session 7 (5-minute Live Presentations) - 1:10 pm

Session 8 (Asynchronous Presentations)

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Examining the I/Ca paleo-proxy on a molecular level: A quantum-mechanical approach to understanding the thermodynamics of iodine incorporation in marine calcite

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Trace element to calcium ratios in marine carbonates are often employed to reconstruct past environments. These ratios rely on the co-calcification of certain ions in the place of either a calcium cation (Ca^{2+}) or a carbonate anion (CO_3^{2-}) under different environmental conditions, and can provide information about ambient seawater chemistry at the time of biomineralization. The iodine-to-calcium ratio (I/Ca) in marine calcite has been used as an indicator of dissolved oxygen due to iodine's unique redox chemistry in aqueous environments, interconverting between iodate ($I(+V)O_3^-$) and iodide (I^-) along the same reduction potential as dissolved oxygen (DO) and water (O_2/H_2O), with evidence for IO_3^- as the dominant incorporated species. In the absence of culture studies to evaluate the direct relationship inclusion of IO_3^- versus I^- into the shells of marine calcifiers, computational models serve an important role in improving our understanding of trace element incorporation thermodynamics at a molecular and atomic scale. Here, we use a quantum-mechanical approach to assess the thermodynamics (Gibbs free energies of incorporation at 298.15 K) of a coupled substitution of IO_3^- and I^- alongside alkali cations Li^+, Na^+, and K^+ into a calcite supercell $[(CaCO_3)_{24}]$ from solid and aqueous source/sink phases. We find IO_3^- incorporation into the bulk is most favorable when it is partnered Na^+, however, the incorporation limit for $NaIO_3$ into the bulk calcite structure is much lower than iodine levels typical of geologic samples, regardless of whether the incorporated pair considered was from a solid or aqueous source/sink phase. This suggests that the ions are not precipitating in equilibrium with sodium and iodate in seawater. To this end, we calculated the Gibbs free energy of adsorption/incorporation alkali metal ions Na^+ paired with IO_3^-/I^- to test the role of crystal surface properties in achieving quantities of iodine that are comparable to geologic samples. The calculated values for incorporation limits into the bulk $(CaCO_3)_{24}$ solid suggest the mechanism by which $NaIO_3$ is trapped in the calcite crystal is not directly into the bulk phase, but rather through incorporation into a step or kink position.

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Examining the influence of Earth's orbit on oxygen isotope variability during the Paleocene-Eocene Thermal Maximum using CESM

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Oxygen isotope ratios ($\delta^{18}O$) are a common paleoclimate proxy used to infer past hydrological changes. For example, fossil $\delta^{18}O$ changes during the Paleocene-Eocene Thermal Maximum (PETM; ~56 Ma) have been used to study the magnitude of warming and the associated intensification of the hydrological cycle caused by a massive release of carbon into the atmosphere. An accurate interpretation of the $\delta^{18}O$ record should consider the preservation state of the proxy, analytical uncertainty, and the relationship between $\delta^{18}O$ changes and internal, and forced, climate variations. In this project we investigate the influence of Earth's orbital variability on the $\delta^{18}O$ of precipitation and seawater during the Paleocene-Eocene Thermal Maximum and its implication on the interpretation of the $\delta^{18}O$ signal in the proxy record. We conduct a suite of fully coupled climate model simulations using the water isotope-enabled Community Earth System Model version 1.2 (CESM1.2). Our simulations include CO_2 sensitivity runs with 1, 3, 6, and 9× preindustrial CO_2 levels and additional orbital sensitivity runs with configurations of maximum Northern Hemisphere Summer solar insolation, maximum Southern Hemisphere Summer solar insolation, and minimum global insolation. Our orbital simulations show how Earth's orbital configuration impacts the amount of incoming solar radiation and how that affects Earth's climate. We find that our model mean $\delta^{18}O$ values match well with the proxy records. Moreover, $\delta^{18}O$ of precipitation varies significantly, ±1.4‰ at 40°N, with orbital perturbations, indicating that part of the uncertainties in the $\delta^{18}O$ of paleoclimate proxy records can be accounted for by changes in orbital mechanics. This study illustrates the value that coupled climate models provide when interpreting paleoclimate proxy data.

Projected climate-driven changes in pollen emission season length and magnitude over the continental United States

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Atmospheric conditions affect the release of anemophilous (wind-driven) pollen, and the timing and magnitude of pollen released will be altered by climate change. Using a pollen emission model of the most prevalent wind-pollinating taxa and future climate from the Coupled Model Intercomparison Project version 6 (CMIP6), we simulate a shift in the pollen season, an increase in the pollen season duration, and in some locations, an increase in the magnitude of pollen emissions. Warmer end-of-century temperatures (4-6K) shift the start of spring pollen emissions 10-40 days earlier, while summer and fall flowering species shift the start day of their season 5-15 d later, typically leading to longer pollen season durations with reduced daily pollen maxima (5-50%). In some locations such as the Northeastern US, spring seasonal shifts increase the overlap of different vegetation taxa, increasing maximum daily pollen emission up to 20%. Increasing atmospheric CO2 may increase the production of pollen, and our sensitivity test that doubles pollen production by end of century increases continental-scale pollen emissions by 10-120%. Together, these suggest that increasing pollen amounts and longer pollen seasons will increase the likelihood for seasonal allergies.

Structure and evolutionary implications of tail clubs attributed to the sauropod dinosaur *Kotasaurus yamapalliensis* from the early to middle Jurassic of India

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Tail clubs evolved independently multiple times within vertebrates, including at least twice within dinosaurs. The best known and most complex dinosaurian tail clubs evolved within ankylosaurs, a group of extensively armored herbivorous dinosaurs. Ankylosaur tail clubs were formed by the posterior most tail vertebrae interlocking to form a stiff "handle" that was enveloped by osteoderms forming a "knob". Structurally simpler tail clubs have been reported for sauropods, the group of herbivorous dinosaurs with long necks and best known for their gigantic sizes—sauropods are the largest land animals known. Sauropod tail clubs are reported from the Jurassic of China (*Shunosaurus, Omeisaurus,* and *Mamenchisaurus*). Unlike the tail clubs of ankylosaurs, sauropod tail clubs did not have any interlocking tail vertebrae or enveloping osteoderms. The club was essentially a modified last tail vertebra or vertebrae fused together into a clublike structure.

In this study we report on tail club elements from the Kota Formation of India (Lower to Middle Jurassic), which has produced abundant but mostly disarticulated remains of the sauropods *Kotasaurus yamanpalliensis* and *Barapasaurus tagorei*. These remains were collected from geographically adjacent sets of localities and are housed in distinct collections. Four tail clubs were recovered among the nearly 400 bones attributed to *Kotasaurus*. These elements are similar in shape to the tail clubs attributed to *Shunosaurus* and *Omeisaurus*—bilaterally symmetrical and roughly ellipsoid in dorsal outline. Computed Tomography (CT) scans of the Kota tail clubs are presented to explain the internal structures. We provisionally attribute the tail clubs to *Kotasaurus*, but additional data are required to formalize this claim.

Kotasaurus, *Barapasaurus*, and the Chinese sauropods are all classified as basal sauropods—sauropods from the Late to Middle Jurassic that represent the early evolutionary stages of sauropods. Basal sauropods represent less than 10% of the fossil record of sauropods, yet sauropod tail clubs are known only from basal sauropods. This apparent exclusivity, and similarities between some of the Indian and Chinese tail clubs raises evolutionary questions such as whether tail clubs and associated structures evolved once, multiple times, or were gained and then lost within basal sauropods.

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A long-snouted marine bonytongue fish from the early Eocene of Morocco and the phylogenetic affinities of marine osteoglossids

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Osteoglossid bonytongues (arapaimas, arowanas and relatives) are extant tropical freshwater fishes with a relatively abundant and diverse fossil record. Most osteoglossid fossils come from a 25-million-year interval in the early Paleogene, when these fishes were distributed worldwide in both freshwater and marine environments. Despite the biogeographic and palaeoecological relevance of these fossils, the evolutionary relationships between these Paleogene forms and extant bonytongues remain unclear. Here we describe a new genus of bonytongue from early Eocene marine deposits of Morocco, represented by a three-dimensional articulated skull with associated pectoral girdle. This taxon is characterized by an elongated snout, contrasting with the short jaws usually found in marine representatives of the clade. A revision of morphological characters in bonytongues allows us to place this new genus, together with other marine and freshwater Eocene taxa, within crown osteoglossids and closely related to extant arapaimines. This discovery not only increases the known taxonomic diversity of marine bonytongues, but highlights how these fishes diversified in a wide range of morphologies that likely reflect a previously underappreciated ecological variety. Overall, the bonytongue fossil record hints at a diverse marine radiation of these predatory fishes after the Cretaceous–Paleogene mass extinction and at a complex biogeographical and ecological history –including intercontinental dispersal and several major environmental transitions– during the first 25 million years of the Cenozoic.

A Paleozoic Lost World: The unexplored diversity of fishes in the Paleozoic of South America

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The Paleozoic was a time of significant change in the history of vertebrate evolution, not only due to the invasion of land but also the explosive diversification of fishes that typifies the fossil record from the Devonian to the Permian. However, most of our knowledge of Paleozoic fish evolution is based on a handful of localities primarily in the northern hemisphere that represent only a fraction of expected diversity across this time interval. Despite an abundance of well-known Paleozoic fishes, this geographic gap in knowledge has left the relationships of Paleozoic fishes poorly resolved. South America was situated at high latitudes during this time, and therefore may preserve a drastically different vertebrate fauna from that of North America and Europe. Nevertheless, the Paleozoic fish record of South America has remained relatively unexplored, with less than 40 recognized fish species described across a 235 million year time interval. This is less than the number of fish species known in the Paleozoic strata of the United Kingdom, an area of land 4% the size of South America. Here we demonstrate the paleontological potential of South America for Paleozoic paleoichthyology, by means of the described diversity and novel occurrences. New occurrences from the Early Devonian of southern Brazil represent one of the oldest and first circumpolar actinopterygians known from the Paleozoic, within an endemic fauna dominated by invertebrates. There are several Early and Middle Devonian localities spread across the entirety of the continent, representing a possible natural laboratory for understanding differences in fish fauna composition along a spectrum of climatic zones ranging from circumpolar to semi-tropical. Furthermore, new well-preserved occurrences from Carboniferous–Permian localities in southern Brazil indicate a mixture of fishes resembling both late Paleozoic and Triassic biotas from North America and Europe, indicating that the current estimated ranges for several groups might be underestimated as a result of sampling biases. Therefore, we expect that increasing the collection effort in the Paleozoic of South America might provide insight into poorly known taxa and extend the range both temporally and geographically of well-known taxa from the northern hemisphere.

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Iron controls photomineralization of dissolved organic matter in arctic surface waters

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The oxidation of dissolved organic matter (DOM) to carbon dioxide by sunlight (photomineralization) accounts for approximately 50% of the carbon dioxide produced in the water column of arctic surface waters.[1] Despite the importance of photomineralization within the arctic carbon cycle, controls on the lability of DOM to photomineralization remain poorly understood. Dissolved iron is one potential control on the lability of DOM to photomineralization, as it is thought to catalyze the oxidation of organic acids within DOM during sunlight exposure. However, a relationship between iron and the lability of DOM to photomineralization in surface waters has yet to be shown. To address this knowledge gap, we quantified the lability of DOM to photomineralization in arctic surface waters representing a natural gradient in iron concentrations. The lability of DOM to photomineralization was positively correlated with iron concentrations in these surface waters. Furthermore, the lability of DOM to photomineralization in high-iron surface waters was found to be a function of sunlight exposure time. Over the course of 14 hours of exposure to natural sunlight, the lability of DOM in high-iron surface waters decreased by an average of 40%. In contrast, in low-iron surface waters, the lability of DOM to photomineralization did not depend strongly on the duration of sunlight exposure. These results suggest that a highly labile pool of DOM complexed with iron is converted to carbon dioxide more rapidly than the bulk DOM during sunlight exposure, leaving behind less labile DOM over time. Our findings support other emerging evidence that photomineralization is an important pathway for carbon dioxide production in high-iron surface waters, both in the arctic and worldwide.

References

1. Cory, R.M., Ward, C.P., Crump, B.C. & Kling, G.W. Sunlight controls water column processing of carbon in arctic fresh waters. *Science* **345**, 925–928 (2014).

Photoferrotrophy in Archean ocean analogs generates iron-bearing precipitates

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Banded iron formations (BIFs) are one of our best surviving records of early Earth's (bio)geochemical processes. These chemically precipitated marine rocks are often characterized by alternating layers of chert (SiO_2) and iron-rich minerals. Despite decades of intensive study, the mechanism for BIF deposition remains enigmatic, especially for units formed prior to the rise of atmospheric oxygen ~2.45 billion years ago (Ga). Traditional models propose that BIFs are derived from the oxidation of soluble ferrous (Fe^{2+}) iron to ferric (Fe^{3+}) oxides in the ferruginous, high-silica waters of Archean (4.0-2.5 Ga) oceans. However, this interpretation has been challenged by recent analyses of well-preserved cherts from 3.5-2.4 Ga BIFs, which instead suggest that low-Fe^{3+} iron silicates were primary precipitates that formed before iron oxides[1]. Nanoscale spectroscopic and imaging techniques have identified primary iron silicate inclusions as greenalite ($(Fe^{2+},Fe^{3+})_{2-3}Si_2O_5(OH)_4$) containing low (10-20%) levels of ferric iron[2]. One hypothesized route for the generation of low-Fe^{3+} mineral precipitates invokes the activity of photoferrotrophic bacteria, which oxidize Fe^{2+} to Fe^{3+} using light as an energy source. This microbial metabolism likely operated in Archean oceans and would have been sufficient to produce the volume of BIFs observed today. Modern representatives of these photoferrotrophs provide a means to test whether this metabolism can produce iron silicates similar to those observed in BIFs.

Here I present results from time series experiments in which pure cultures of the photoferrotroph *Rhodopseudomonas palustris* TIE-1 were grown in anoxic medium simulating the Archean ocean (pH = 7.0, 1.0 mM initial Fe^{2+}, and between 0-1.9 mM initial Si). Precipitates generated were harvested at regular intervals and characterized using a combination of Raman spectroscopy and scanning electron microscopy (SEM) coupled with energy-dispersive X-ray spectroscopy (EDS). Preliminary results demonstrate that these photoferrotrophs produced an ensemble of minerals ranging from amorphous silica-rich phases to metastable green rusts ((Fe^{2+}, Fe^{3+})-hydroxyl salts). While additional analyses are required to fully identify initial precipitates and the final stabilized mineral products, our findings suggest that microbial iron oxidation in ferruginous and high-silica waters is indeed capable of generating iron- and silica-bearing precipitates.

Connecting Antarctic sea ice and mid-latitude precipitation

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Climatic changes induce many significant changes to weather patterns. These mechanisms interact to drive consequences which are not immediately obvious. One such connection involves the apparent relationship between polar sea ice extent and midlatitude precipitation timing and location. This correlation, its mechanisms, and possible influences on weather are decently understood with respect to the Northern Hemisphere. However, the analogous relation for the Southern Hemisphere has been studied less, despite evidence for its existence.

We explore the teleconnection between sea ice extent and lower latitude precipitation over the Southern Hemisphere. We will explore these unknown variables through observational and modeling techniques. Observations of sea ice coverage using ICESAT and ICESAT-2 will be compared with reanalysis data in order to understand the variability of sea ice extent and its impact on midlatitude precipitation. This model will allow study of the importance of regional variations on the relationship and its evolution over time, including projecting it with the future warming climate.

Identifying the genesis of Fe-Ti oxide- and sulfide-bearing ultramafic intrusions in the Duluth complex through sulfide geochemical analysis

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During the formation of the 1.1 Ga Midcontinent Rift System, a series of massive mafic intrusions were emplaced in northeast Minnesota and are referred to as the Duluth Complex. Rock types include a series of gabbroic, troctolitic and anorthositic intrusions that protruded into the Archean and Paleoproterozoic footwall, which comprises banded iron formation and other metasedimentary rocks. The western margin of the complex is home to 14 different Fe-Ti oxide-bearing bodies containing ilmenite, magnetite and titanomagnetite. While these oxide-bearing ultramafic intrusions (OUIs) have been identified in field studies, their exact genesis is unknown. Three hypotheses have emerged that attempt to explain the origin of the OUIs, none of which has been rigorously tested. To investigate the origin of the OUIs, we studied the sulfide geochemistry of two spatially distant OUIs: Longnose, which is located in the Partridge River Intrusion, and Titac (sec. 34), which is located in the Western Margin Intrusion. Published compositional data for sulfides from these OUIs is sparse, with most studies reporting a very brief overview of the sulfide abundances, mineralogies and stable sulfur isotopes. These studies reported that Titac and Longnose contain, respectively, 1-5 modal percent sulfide, primarily chalcopyrite and bornite, and 1 modal percent sulfide, nearly all of which being chalcopyrite. Our petrographic study of samples from Titac and Longnose revealed a greater abundance and variety of sulfides in samples from *both* deposits. As the first systematic geochemical comparison of sulfides between OUIs, our research began with scanning electron microscopy (SEM) to image the sulfide grains, followed by energy dispersive spectroscopy (EDS) to identify a range of different sulfides present within the OUI, and finally electron probe microanalysis (EPMA) to quantitatively determine the elemental makeup of the sulfides. Initial analysis of these data demonstrates that chalcopyrite is the modally dominant sulfide in both Titac and Longnose, with trace bornite, sphalerite and millerite found in both deposits as well. Pyrite and pentlandite were found only in the Titac samples, whereas chalcocite was only found at Longnose. With similar bulk sulfide content across the two deposits, these initial results suggest a consequently similar genesis across both of the OUIs. However, given the relative abundance of Fe-rich pyrite and pentlandite in Titac, further stable sulfur isotope and trace element studies will be required to affirm this conclusion.

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Influence of fault zone maturity on fully dynamic earthquake cycles

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We study the mechanical response of coseismic damage evolution and interseismic healing of fault damage zones over multiple earthquake cycles using fully dynamic earthquake cycle simulations in a 2D vertical strike-slip fault. We develop physical models to show that the evolving strength of fault zone structures during the seismic cycle can have pronounced effects on the temporal evolution of the locked and creeping segments on the fault. Our numerical simulations in an immature fault damage zone show a combination of small/moderate earthquakes (relative to the width of the seismogenic zone) with irregular recurrence intervals, predominantly subsurface events, and an abundance of slow-slip events in between the earthquakes. Such small earthquakes result in an incomplete stress drop along the fault segment, thereby exhibiting spatial and temporal variability in rupture extent and recurrence interval. Earthquake stress drops from these earthquakes are not uniform but spatially variable along depth, and the residual stress peaks from previous earthquakes can influence the location of the said slow-slip events. However, mature fault damage zones with high compliance exhibit pulse-like ruptures that extend throughout the seismogenic zone resulting in a more complete stress drop and surface-reaching ruptures. These earthquakes also exhibit regular recurrence intervals and uniform rupture extents. Our results suggest that the fault zone strength evolution in the form of healing and coseismic damage can explain these observed differences between a mature and an immature fault zone and provide us a better understanding of the stages of fault zone evolution.

The evolution of the Candelaria iron oxide copper-gold (IOCG) system, Chile: Insights from titanite, apatite, and magnetite U-Pb geochronology and trace elements

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With the increasing global demand for electricity and continued push to transition from fossil fuels towards renewable energy, understanding the formation of mineral deposits that host resources necessary for renewable energy is of the utmost importance. Iron oxide copper gold (IOCG) deposits are a source of copper and an array of other resources critical to modern technology and carbon-free energy (e.g. iron, cobalt, gold, rare earth elements, uranium). Despite the importance of IOCG deposits, there remains much uncertainty in how these deposits form. While there are generally accepted geological characteristics of IOCGs, there is debate as to the source and composition of fluids associated with these deposits, and how these relate to iron oxide apatite (IOA) deposits. The Candelaria IOCG deposit located in northern Chile is an example of a world-class IOCG deposit, which has a documented transition in mineralization style with depth to a more IOA style of mineralization. This transition makes Candelaria an excellent deposit to study to better understand the relationship between IOA and IOCG deposits.

This study analyzes samples from a 1000 meter drill core from the Candelaria deposit to determine ages of mineral crystallization using U-Pb and trace elemental concentrations in titanite, apatite, and magnetite. Reported ages in this study are 114.93 +/- 1.11 Ma for titanite, 115.43 +/- 0.73 Ma for apatite, and 126.32 +/- 4.94 Ma for magnetite. No resolvable difference in model age was observed when calculated by depth or perceived mineral textural zonation. Ages for titanite and apatite are consistent with previously reported ages for primary copper mineralization at the Candelaria mine (~115 Ma). The magnetite age is consistent with an unpublished Candelaria actinolite Ar-Ar isotopic system age dated at ~12.15 +/- 0.63 Ma. These ages indicate there could be two separate ages of mineralization at Candelaria: one at 115 Ma, and one around 121-126 Ma. The differences in trace element chemistry observed in these samples show there is variation in source fluids throughout the Candelaria deposit that could be used to differentiate between and understand the formation of IOCG and IOA deposits. Ongoing and future work aims to constrain and explain these differences, with an emphasis on geochemical, temporal, and temperature differences between mineral textural generations. Understanding the relationship between these differing mineralization styles at Candelaria will aid our broader understanding of IOCG systems as a whole and could help aid future copper exploration.

Using mercury stable isotopes to identify sources of inorganic mercury and methylmercury to an aquatic food web

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Mercury is a toxic metal that is harmful to the health of humans and wildlife. In heavily contaminated ecosystems, mercury can persist in sediment and soil for decades or longer. Within the environment, certain types of bacteria can convert inorganic mercury into a form called methylmercury, which is even more toxic and can bioaccumulate in food webs. Various pools of inorganic mercury and methylmercury often contain different ratios of mercury stable isotopes, giving them unique isotopic signatures which can be used to distinguish between different sources of inorganic mercury and methylmercury to a food web. We are using this technique to identify sources of mercury to the aquatic food web of East Fork Poplar Creek, a point-source contaminated stream in Oak Ridge, Tennessee, USA. To do this, we measure the total mercury and methylmercury concentrations of various aquatic organisms at different trophic levels, as well as their total mercury isotopic composition. This information allows us to estimate the isotopic signatures of inorganic mercury and methylmercury within the food web. These values can then be compared to measurements of the isotopic composition of inorganic mercury and methylmercury within sediment, soil, biofilm, or any other potential sources of mercury. Our preliminary data shows that the isotopic composition (δ^{202}Hg and Δ^{199}Hg values) of inorganic mercury and methylmercury within the food web differ between the upstream and downstream sites. For inorganic mercury within the food web, δ^{202}Hg values increase and Δ^{199}Hg values decrease along the flow path. This trend aligns with the shift in isotopic composition of biofilm and suspended particulates, whereas streambed sediment does not display this trend. Thus, it appears that inorganic mercury enters the food web through consumption of biofilm and/or suspended particulates, rather than through uptake of sediment particles. For methylmercury within the food web, δ^{202}Hg values at both sites are much lower than δ^{202}Hg values measured for any potential source material. This is to be expected, however, as thus far we have only measured the total mercury isotopic composition of source materials and have not yet measured the isotopic signature of methylmercury within source materials directly. Our next step is to extract methylmercury out of streambed sediment and biofilm so that we can directly measure its isotopic composition and determine whether sediment and/or biofilm may be sources of methylmercury to the food web.

No fear, your peers are here: Peer mentoring in CLASP

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Over the past four years Ph.D. students have organized a peer mentoring program in the University of Michigan Ann Arbor Department of Climate and Space Sciences and Engineering (CLASP). The program was needed to ease the transition of first year students into graduate school. The peer mentoring program began as a light-weight pilot program designed to seed semi-professional friendships without over-burdening participants and organizers. Over time the program has evolved through the influence of the organizers and in response to constructive feedback to include more student populations and better address the unique concerns of CLASP students. During the year of 2020 in person meetings were prohibited due to public health concerns, so the mentoring program transitioned to a virtual format. The peer mentoring program has been a tremendous success by any measure; mentors and mentees have benefited from the program and expressed their resounding support for its continued operation.

Olivine geochemistry from Fe-Ti oxide-bearing ultramafic intrusions in the Duluth Complex, MN

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The Duluth Complex is a 1.1 billion year old series of magmatic intrusions that comprise of many different igneous rocks, among which include troctolites, gabbros, and anorthosites. The southern portion of the Complex hosts 14 different ultramafic intrusions along the western margin that contain significant Fe-Ti oxide mineralization, called oxide-bearing ultramafic intrusions (OUIs). There are currently three competing hypotheses about the genesis of these OUIs, but none of them have been rigorously tested. However, there are many minerals which can be used as proxies to discover more about their genesis, such as olivine. Since it is a solid solution mineral (with compositions ranging from end members forsterite, Mg_2SiO_4 to fayalite, Fe_2SiO_4) and is one of the first minerals to crystallize from a melt, we can gain a lot of information about formation of magma when it was crystallized from its composition alone. Two OUIs in particular, Titac and Longnose, were studied in thin section using a variety of tools, including a petrographic microscope, a scanning electron microscope (SEM), and an electron probe microanalyzer (EPMA). The petrographic microscope and SEM showed that olivine formed in many different textures. In Titac, olivine forms trapezoidal and tubular shapes, and is very fractured. In Longnose, olivine forms in streams and is ropy, and appears a lot more striated. Under the EPMA, compositions of olivine were measured. The data show that olivine compositions in the Longnose increase in forsterite content with depth, as they start at around Fo_{60}, then increase to a bit less than Fo_{70}. The Titac, however, has the opposite relationship, at the top it has a forsterite content of about Fo_{60}, then decreases with depth until it reaches around Fo_{30}. This indicates that the magma that formed Longnose was more primitive compared to the magma that formed Titac because it has a higher magnesium content. Since olivine is one of the first minerals to crystallize out of magma, this gives an account of the magmatic composition of the melt phase. This, along with the different shapes of olivine crystallization, can be used to understand how magma was emplaced in the OUIs.

Multistep reduction kinetics calculation of actinyl-EDTA complexes using quantum-mechanical method

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The mobility and solubility of actinides (U, Np, and Pu) strongly depend on their oxidation states. U(IV) is sparingly soluble, forming insoluble minerals such as uraninite, whereas U(VI) is several orders of magnitude more soluble than U(IV). The reduction of actinyl to relatively insoluble form is decreased when they are complexed by inorganic, such as carbonates, or organic ligands. Ethylenediaminetetraacetic acid (EDTA) is such an organic ligand that forms a stable complex with metal ions and widely used in industries and agriculture. Thus, there is a concern that actinides released to soil or groundwater can form a stable and soluble EDTA complex, which may enhance the mobility of actinyls and makes them more bioavailable. However, this is still not well characterized in terms of kinetics. Here, we study the reduction kinetics of actinyl-EDTA complex, using quantum-mechanical calculations. The principle is to approach the actinyl-EDTA and a reductant in small incremental distances and calculate the system energy at each interval. The overall reaction is then broken down into four sub-processes (encounter frequency in bulk solution, the formation of outer-sphere complex, transition from outer- to inner-sphere complex, and transfer of electrons) to determine the reaction rates of each step using the activation energy barriers and attempt frequencies derived from the system energy curve. This process-based series of calculations will allow us to predict rate law changes and potential changes in the rate-limiting step in a more systematic way in different environments.

Imaging the Mantle Transition Zone under USArray using long-period SH wave reverberation

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The main mineral in the mantle, olivine, has been found to undergo phase transfromations under certain pressure and temperature conditions. The mantle transition zone (MTZ) is a globally distributed layer at the depth range of 410-660 km, where the upper mantle transite to the lower mantle. At around 410 km, the α phase olivine transform to the β phase (wadsleyite); at around 660 km, the β phase olivine transform to the γ phase (ringwoodite). Although the average depth of MTZ has been investigated globally to be around 410-660 km, the regional variation of transition depth related to the geothermal gradient, pressure, and water content, is indicative of the mantle structure and the tectonic history.

While maintain the same chemical component, the changes of phase in olivine result in differences in physical properties such as density and strength, such that seismic waves will reflect on the transition interface. In this research, we use the reverberation of long-period (20-80 Hz) SH waves reflected at 410 and 660 discontinuities to image the transition depth under 48 conterminous United States. We sucessfully image 410 and 660 discontinuities by stacking seismograms recorded at USArray stations. We obtain clear and stable discontinuities in the eastern US, but more ambiguous results in the west coast. Some studies observed a thinner MTZ in the western US than the eastern part, whereas our results show no such discrepency. In light of this, we did simulations using synthetic waveforms based on 1-D velocity model PREM and 3D model S40RTS. The results show that pure western and eastern velocity contrast might be mapped as structure discrepency. We found that the ray-theoretical travel time correction perform well on the calibration of velocity contrast. Additionally, we tested MTZ with 2 by 2, 5 by 5, and 8 by 8 degrees checkboard topography to explore the resolution of SH reverberation. The SH reverberation is found to suitably resolve 5 by 5 and 8 by 8 topography, but loses resolution for 2 by 2 topography, indicating that smaller than 2 by 2 degrees variations are unreliable.

Observations of size-resolved atmospheric aerosol composition in coastal Maine during winter

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Aerosols play an important role in atmospheric chemistry by providing surfaces for chemical reactions to occur. These particles also have large impacts on climate and human health. The reactions occurring on aerosols are affected by their chemical composition, which usually varies among aerosols of different sizes. For this research, size-resolved particles ranging from 0.25-2.5 μM were collected over twenty-three days at coastal Maine in January 2019. Inorganic ion concentrations (including sodium, chloride, sulfate, nitrate) were measured using ion chromatography. These concentrations were compared to a previous study of aerosol composition from coastal Maine in summer 2002 to study the differences between summer and winter (this study). Additionally, the online NOAA HYSPLIT model was run to learn about the origin of the air parcels arriving at the sampling location. The study of the chemical composition of these aerosols will improve our understanding of how aerosols contribute to chemical reactions in the atmosphere and affect climate and health.

Impacts of spatially varying eddy diffusion coefficient in the lower thermosphere on the ionosphere and thermosphere using GITM-Sensitivity Study

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Gravity waves propagate up from the Earth's lower atmosphere into the Mesosphere and Lower Thermosphere (MLT) where they break, resulting in turbulent mixing, composition change, momentum and heat deposition in the upper atmosphere. These effects in the ionosphere and thermosphere (IT) are parametrized in the IT models through the eddy diffusion coefficient (K_{zz}) at the lower boundary (~97-100 km). The temporal variation of K_{zz} has been studied well and a globally uniform but time-varying value has been used in some IT models (TIE-GCM). However, with the availability of MLT temperature and densities from the SABER instrument on the TIMED satellite, it has been observed that gravity wave activity is not uniform across the globe and exhibits latitudinal variability with seasons. In this study, we use the Global Ionosphere Thermosphere Model (GITM) to understand the effect of spatially non-uniform K_{zz} on the composition, dynamics and temperature of the middle-upper thermosphere and ionosphere. In GITM, K_{zz} is used as a conduction term in the thermodynamic equation and as a source term in the continuity equation. We find that when an area with large K_{zz} is introduced at the equatorial latitudes, it affects the properties of the whole globe (8-15%). The largest changes in the global properties of the thermosphere are through the conduction term in the thermodynamic equation. At a constant pressure surface, there is a decrease in atomic oxygen and temperature. This results in increase of molecular nitrogen which further affects the horizontal winds via change in pressure gradient forces across the globe. On the other hand, the effect of large K_{zz} at polar latitudes is smaller and more confined in one hemisphere. The local effects of non-uniform K_{zz} are thus not negligible as they feedback into the electron densities (TEC) and F2 peak height (hmF2).

Photochemical yields of hydrogen peroxide production in Lake Erie

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Hydrogen peroxide (H_2O_2) is a reactive oxygen species found in all sunlit waters on Earth and involved in many biogeochemical processes important for water quality. For example, high concentrations of H_2O_2 in the eutrophic waters of Lake Erie have been hypothesized to influence microbial community composition during harmful algal blooms (HABs) that form every summer. However, controls on H_2O_2 concentration remain too poorly understood to evaluate impacts of H_2O_2 on HABs. One knowledge gap is the extent to which photochemical processes contribute to the high H_2O_2 concentrations in Lake Erie. In sunlit waters, absorption of sunlight by the chromophoric fraction of dissolved organic matter (CDOM) is a major source of H_2O_2 (photochemical production of H_2O_2). The key control on the photochemical production of H_2O_2 is the yield of H_2O_2 produced per mole photon of sunlight absorbed by CDOM. Few studies have quantified photochemical yields of H_2O_2 production in freshwaters, and no study has determined the magnitude or range of photochemical yields of H_2O_2 production in Lake Erie. To address this knowledge gap, photochemical yields of H_2O_2 were quantified weekly from June – September 2019 in Lake Erie. The photochemical yields of H_2O_2 production in Lake Erie waters were within the range reported in other freshwaters. The photochemical yields of H_2O_2 production in Lake Erie waters decreased about four-fold from June through September. These results show that rates of photochemical H_2O_2 production in Lake Erie are highest in early summer when sunlight, CDOM concentrations, and photochemical yields of H_2O_2 production are higher compared to late summer. The results of this study demonstrate that photochemical production of H_2O_2 contributes substantially to the high H_2O_2 concentrations observed in early summer in Lake Erie. Therefore, it is likely that photochemical production of H_2O_2 influences microbial community composition during HABs in Lake Erie.

Size resolved composition of atmospheric particles during winter in coastal Maine

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Atmospheric aerosols have important impacts on human health and climate. Aerosols are defined as a solid or liquid suspended in a gas and feature complex composition across a wide range of diameters. Different diameter aerosols have varying effects on the environment and health. Aerosol particle samples were collected in East Boothbay, Maine during January 2019. An impactor was used to collect aerosol samples with diameters less than 2.5 µm on filters at five size cuts. The resulting size-resolved inorganic ion composition of these aerosol samples was determined, with specific focus on sodium, bromide, chloride, and sulfate. The variance in composition with respect to particle diameter will be discussed.

Voice activated assistant for Gateway Lunar Space Station

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The Bioastronautics and Life Support Systems (BLiSS) Research team here at the University of Michigan won a proposal through NASA's Moon to Mars X-HAB Academic Innovation Challenge to design and develop a Voice Management System for application on the Lunar Gateway. Our project began with the initial development of a design language, identifying use cases for VUI (on the Lunar Gateway and future crewed lunar bases), and identifying background noise issues in these environments. The resulting focus from these is background noise mitigation, conversation design, and voice technologies. The team is developing software that will be compatible with NASA's current rover, suit, and other interfaces where it will help astronauts do simple tasks such as keeping schedules, responding to simple requests, assisting with research, communicating with other astronauts, and monitoring the environment. The language of the VUI will be optimized for astronauts specifically, making sure not to be too complex or too simple - to be as effective as possible. In order to mitigate background noise, we are looking into active and passive noise cancellation which is being tested using acoustic panels in the research lab at UM. This research will ensure that while on the lunar gateway, the system will be able to pick up all requests by astronauts regardless of general noise coming from the space station itself, space, or other activities. The full system is being researched and developed over the 2020/2021 year and we would like to present our current results in a poster during your conference. The poster will focus on what our overall idea for the system is including a design of the system software and hardware along with our findings/progress thus far.

Springtime atmospheric ozone depletion at Oliktok Point, Alaska

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Arctic snow interacts with the lower atmosphere. In the Arctic, surface snow is a significant source of atmospheric bromine (Br_2), which photolyzes to produce bromine atoms that react with ozone (O_3), a common atmospheric oxidant, and elemental mercury. The emission of Br_2 from the snowpack is dependent on its bromide and chloride content. Near-surface ozone depletion events (ODEs) occur when atmospheric ozone rapidly drops to near-zero levels. This phenomenon is known to occur in the Polar Regions during springtime. In this work, an ODE that occurred in Oliktok Point, Alaska during March 2020 will be discussed. This event was characterized using measured Br_2, O_3, snow inorganic ion concentrations, and meteorological data including air temperature and wind speed.

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Mixing state of secondary species in Alaskan Arctic aerosol during the fall-winter transition

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ABSTRACT TEXT REDACTED AT AUTHOR'S REQUEST

The role of North American mesoscale convective systems on the development of the June 2017 European heatwave and its predictability

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The summer months over the Midwest are conducive to the formation of large agglomerations of persistent thunderstorms, termed mesoscale convective systems (MCSs). Recent research has identified that North American MCSs often precede instances of high-pressure weather patterns over Europe which are instrumental in summertime heatwaves. State-of-the-art weather forecasting models struggle to accurately predict the onset of high-pressure weather patterns over Europe, which may impede weather forecasters' ability to anticipate heatwaves in advance. Understanding the role that North American MCSs play in the onset and maintenance of European heatwaves may illuminate reasons as to why state-of-the-art forecasting models struggle to accurately predict these weather extremes.

We present a case study analysis of the 2017 European heatwave (Jun 10-23), selected based on the occurrence of multiple MCS outbreaks over the Mid-West prior to and during the onset of the heatwave. We provide an atmospheric dynamics perspective on how the Midwest MCSs impact the atmospheric flow over Europe and contribute to the formation of the heatwave. We perform a sensitivity analysis to identify geographic regions which have the greatest impact on the event's forecast to investigate whether North American MCSs played a key role in its formation and/or maintenance.

Self-Attraction and Loading in the MPAS-Ocean Model

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When considering the effects of tides on the ocean, there are several factors to consider beyond the primary tidal forcing of the moon and sun. These include frictional damping effects in the form of bottom drag as well as self-attraction and loading (SAL). As the tide moves, the solid earth itself expands and contracts due to the change in loading pressure of the ocean water above. SAL encompasses the effects resulting from the yielding of the solid earth and the self-gravitation of the ocean tide and the deformed earth. As part of the Integrated Coastal Modeling (ICoM) project, our broad goal is to help create an earth system model capable of predicting coastal processes and resulting coastal hazards due to changes in the surrounding systems (e.g., urban development, global climate change) over the next 100 years. ICoM uses a collection of models including land, river, atmosphere, sea ice, and ocean models. We work as part of the tides team implementing improved tidal calculations into the MPAS-Ocean model component. Currently, the model uses a scalar approximation of the SAL term, but this is insufficient for highly accurate tides because it assumes SAL affects all spatial scales equally. To improve this, we calculate the effects of SAL using a full spherical harmonic decomposition which allows each harmonic to be scaled by the appropriate load Love factor. Further work involves comparing the benefits of the improved accuracy to the computational cost incurred by the full calculation. Later, we plan to use the model to better understand interactions between tides and other earth system components, such as estuaries.

Geochemistry of Fe-Ti oxide minerals in Fe-Ti oxide-bearing ultramafic intrusions in the Duluth Complex, Minnesota

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The Duluth Complex is a 1.1 Ga large mafic intrusion that was emplaced as part of the Midcontinent Rift System. Located in northeastern Minnesota, the Duluth Complex hosts numerous types of mineral deposits, including Cu-Ni, PGE, Mn, Ti, and others, yet remains largely undeveloped. Significant Fe-Ti±V mineralization has remained particularly unstudied over the past 20 years and represents one of the United States' most promising domestic resources of these energy- and infrastructure-critical metals. Fe-Ti±V mineralization is hosted in 14 oxide-bearing ultramafic intrusions along the western margin of the Duluth Complex. Although all are broadly similar in mineralogy, three contrasting genetic models have been proposed to explain the source of Fe and how the deposits formed. There exists incredibly scarce geochemical evidence to support or refute any of the three models, and the main objective of this project is to unravel the genesis of Fe-Ti oxide-bearing ultramafic intrusions.

Focusing on the Longnose and Titac intrusions, two well-drilled intrusions ~40 km apart hosted in the Partridge River and Western Margin intrusions, respectively, we used detailed optical and microbeam methods to compare the textures and compositions of Fe-Ti oxides (ilmenite, titanomagnetite, and magnetite) to gain insight into their origins. Both intrusions show similar textures despite differing proportions of ilmenite and titanomagnetite, with Longnose typically having higher amounts of ilmenite. Magnetite is present as thin, secondary veins cross-cutting existing minerals in both intrusions, being more pervasive in the Titac Intrusion. Major and minor element compositions of titanomagnetite and ilmenite are similar between Longnose and Titac, and temperatures calculated using the Mg content in magnetite give similar temperature ranges (950-1000°C for Longnose; 800-1000°C for Titac) for the deposition of magnetite in both intrusions. The larger temperature range and higher proportion of magnetite in Titac is possibly due to more pervasive alteration.

The initial results of this study point towards a similar genesis for Fe-Ti oxide minerals in both the Longnose and Titac intrusions, despite being hosted in different rock types and intrusions. Future work will involve measuring stable Fe and Ti isotopes of the oxide minerals to fingerprint the metal sources, a key unanswered question in how these deposits formed.

Experimentally elucidating sulfur and rare earth element partitioning between apatite and hydrothermal fluids as a function of temperature and fluid composition

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The mineral apatite -$Ca_{10}(PO_4)_6(F,Cl,OH)_2$- is nearly ubiquitous in terrestrial geologic systems and can incorporate nearly one-third of the periodic table of elements, including sulfur (S) and rare earth elements (REEs). Polyvalent S (e.g.,S^{6+}, S^{2-}) is critical for the transport and enrichment of base and precious metals in igneous and hydrothermal mineral deposits. Because of their magnetic and luminescent properties, REEs are important for the manufacturing and development of renewable energy and consumer technologies. Experimental studies demonstrate the role of oxygen fugacity (fO_2) as the master variable controlling the $S^{6+}/\Sigma S$ ratio in silicate melts, igneous apatite, and hydrothermal fluids. Studies of metasomatized apatite in natural systems revealed the presence of secondary REE phases, intra-apatite zonation of S and REEs, and the depletion or enrichment of polyvalent S within natural apatite. To our knowledge, no experimental studies have explored the effects of temperature, fluid composition, and fO_2 on S and REE partitioning between apatite and hydrothermal fluids at pressure, temperatures, and fluid compositions relevant for upper crustal systems. I hypothesize that the composition of metasomatized apatite reflects changes in the pressure, temperature, fluid composition, and fO_2 of hydrothermal fluids, revealing the potential of apatite as a geochemical proxy for hydrothermal fluid evolution.

Here, I will discuss results from new experiments conducted at 100 MPa, 500–800 °C, variable fluid compositions (mHCl, mH2SO4, Na2Si2O5), and buffered at NNO and NNO+1 designed to constrain the partitioning behavior of S and REEs between fluid and fluorapatite [$Ca_{10}(PO_4)_6(F)_2$]; Durango fluorapatite was used as starting material. Run product apatite grains were analyzed by EPMA, SEM EDX element mapping and CL images. The data revealed altered regions of apatite exhibit Na, Si, and S concentrations below their detection limits; 308, 154, and 44 ppm, respectively. REEs and PO_4 leached from starting apatite during dissolution-reprecipitation resulted in the growth of secondary REE phases, e.g., monazite. The data also reveal that the extent of apatite-fluid reactivity decreases with increasing temperature. This effect is plausibly explained by decreasing acid dissociation, demonstrating the importance of temperature and fluid composition for S and REE mobilization in apatite-saturated systems.

Frequency-difference backprojection of earthquakes

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How can we image the slip history (rupture) of an earthquake more accurately and clearly? The ruptures of large earthquakes can be very complex. It can be challenging to image these ruptures accurately because of errors in the calculated wave arrival times, which increase as slip propagates away from the hypocenter. The imaging results often vary depending on the array(s) and method used, which can make the rupture speed of an earthquake unclear.

Hence, we modified conventional earthquake imaging with the “frequency-difference” technique, which has been shown to locate acoustic sources with lower uncertainty. We tested its efficacy through synthetic tests and investigated the 2015 Gorkha, Nepal earthquake using a global array, as studies disagree on its initial (~0-20s) rupture speed. Our conventional imaging results show a slow initial rupture speed (~1km/s), but further development is still needed for the frequency-difference method.

Ti isotopes in magnetite: A potential tool for deconvolving ore-forming processes in IOA and IOCG deposits

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Meeting humanity's mineral resource needs is critical for expanding and maintaining our existing technological infrastructure. Establishing effective resource vectoring criteria makes the exploration and development of mineral deposits technologically and economically feasible. Iron oxide apatite (IOA) and Iron oxide copper gold (IOCG) deposits may host economically significant concentrations of Fe, Cu, U, and REE, as well as recoverable concentrations of Au, Ag, Co, and other resources vital for emerging technologies in the renewable energy sector. Despite hosting important mineral resources, IOA and IOCG deposits are poorly understood with respect to the processes resulting in the formation of the ore. We propose the use of Ti isotopes in magnetite, a major ore phase in IOA and IOCG deposits, to better understand the precipitation of the primary Fe oxide ore in these systems. Although no data exists for Ti isotopes in magnetite from economically significant Fe oxide deposits, previous work suggests that the precipitation of Fe-Ti oxides in magmatic systems is the primary driver of Ti isotope fractionation on Earth. Further, prior work suggests that Ti isotope compositions are geochemically resilient in hydrothermally altered materials. These two characteristics make Ti isotopes a promising tool for understanding IOA and IOCG deposits, whose Fe oxide resources are interpreted by many to originate as magmatic Fe oxides that become hydrothermally overprinted during later mineralization events. We expect the Ti isotope composition of magnetite to vary as a function of 1) the initial Ti isotope composition of the source magma and 2) the extent of Fe oxide precipitation during ore formation. All common Fe and Ti oxide minerals prefer to incorporate lighter Ti isotopes during growth; therefore, the residual melt will become more enriched in heavier Ti isotopes as Fe oxide minerals precipitate and are removed. The proposed research would generate the first dataset for Ti isotopes in magnetite from an economically significant Fe oxide deposit. The results of this work may be used to develop Ti isotopes as a tool for mineral resource vectoring for IOA, IOCG, and other Fe-Ti oxide-rich mineral deposits.

Understanding the formation of diagenetic braunite and its implications for the ancient manganese cycle

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Manganese, a multivalent transition metal present in the earth's crust, is often used as a paleo-redox proxy because of its unique chemistry. This element is highly soluble in its reduced form (Mn(II)), only substituting in small amounts for iron in igneous minerals and for calcium in carbonates. As a result, manganese-enriched deposits primarily derive from oxidized Mn(III) and Mn(IV), which form insoluble (hydr)oxides. Critically, this element has a particularly high redox potential, and is only oxidized and concentrated in the sediments through interactions with oxygen or oxygen-related species in modern environments. Thus, large deposits of manganese minerals are considered tracers for oxygen. Braunite ($Mn(II)Mn(III)_6SiO_{12}$) is a pervasive mineral in Paleoproterozoic and Neoproterozoic manganese deposits, thought to be related to global oxygenation events. Although there is limited knowledge concerning braunite formation and its precursors, sedimentary textures suggest this mineral is an early diagenetic phase. We hypothesize that manganese (IV) oxides (MnO_2) are reduced in the sediment to feitknechtite by aqueous Mn(II). Feitknechtite can subsequently undergo post-depositional diagenetic reactions, and through interaction with silica in pore water, may develop into braunite. We tested this hypothesis by first synthesizing feitknechtite (Mn(III)O(OH)) from MnO_2 and then aging it at low temperature with aqueous Mn(II) and sodium orthosilicate (Na_4SiO_4) to mimic diagenesis, exploring our experimental products using Raman spectroscopy. Understanding the formation of braunite could explain the depositional history and post-depositional processes of manganese-bearing sedimentary environments. Furthermore, our experiments provide new insight on the cycling of manganese in the environment.

Quantitative study of energy transfer at earth's magnetopause

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Energy transfer between the solar wind and earth's magnetosphere is quantified and studied using 3D surface detection and integration of Space Weather Modeling Framework (SWMF) simulation results. The event is a portion of a multiple coronal mass ejection (CME) impact on February 18 2014. The magnetopause boundary surface is identified using isosurfaces of the 3D field data, and the energy and power within the enclosed volume is evaluated using surface and volume integrals. Results show net power transfer at the boundary is dominated by Poynting flux, consistent with previous work by Pulkkinen and Palmroth. While net hydrodynamic energy transfer is small, both hydrodynamic energy flux and Poynting flux are found to be larger than the net transfers (i.e., the boundary processes include both energy injection and escape). The energy transfer pattern is explored qualitatively with 3D visualizations and the geometry is described using combinations of volume, surface area, and subsolar distance.

"…and it flipped!"
Geomagnetic study of a magnetic excursion event

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A mere ~40 thousand years ago, the Earth's magnetic field reduced in strength and the dipole axis tilted by more than 70 degrees in latitude causing a major paleomagnetospheric excursion called the Laschamp event. Recent estimates have suggested that during the peak of this event, the magnetic field was only 6% of modern values and the aurora extended all the way to 40 degrees latitude. Using three first-principles-based models, we present high-resolution simulations of the magnetic field and the near-Earth plasma environment, and discern the location of the aurora. The LSMOD.2 model is used to determine the magnetic multipole to the tenth spherical harmonics over a range of periods spanning from 50 thousand years ago (ka) to 30 ka, with higher temporal resolution available during the peak of the event (~42 ka). The multipolar magnetic field is applied onto the BATS-R-US global magnetohydrodynamic (MHD) model, which simulates the magnetosphere and emulates the current systems and plasma transport of the time using the magnetic multipole values as input. Lastly, the global plasma values are mapped onto ionospheric levels and the MAGNIT physics-driven aurora model is used to estimate the location and strength of the aurora. Our initial findings indicate that over time, the structure and strength of the magnetic field changed drastically causing the magnetosphere to reduce sharply in size and the magnetic field to change its poles. This caused significant changes in the inner magnetosphere where the day-side magnetosphere virtually disappeared during the peak of the event. The auroral estimations show that the massive dipole tilt in the magnetic axis could easily have moved the auroral oval to equatorial latitudes, explaining why the aurora could have been visible at lower latitudes.

A long-snouted crocodylian from the Eocene of Pakistan provides insights of gavialoid paleobiogeography

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Crocodiles are a group of semi-aquatic reptiles today represented by three living families, Crocodylidae, Alligatoridae, and Gavialidae. There are fifteen living species of true crocodiles, eight species of alligators, and only one gavialoid species, *Gavialis gangeticus*, a geographically restricted crocodyliform from India and Nepal. During the last two decades, the increased attention to these crocodyliforms led to the description of 20 new extinct species with occurrences across the world, which shows that Gavialidae was a diverse group. Despite this, the gavialoid fossil record in the Indo-Pakistan region remains scarce. The only fossil occurrences are from the *Gavialis* species and came from Miocene–Pliocene rocks of India's Siwalik Hills. Then, when gavialoids arrived in the Indo-Pakistan subcontinent for the first time in the geologic record, how many species occupied this region, and which processes led to this group's dispersal until their decline remains unknown. Consequently, this leaves a significant gap in the fossil record in this region, which is essential for understanding the evolution of gavialoids before India-Pakistan's collision with Eurasia and closure of the Tethys Sea.

Here we present a new genus and species of long-snouted crocodylian, *Pakigavialis pravus*, collected from an Eocene marine deposit of the upper Domanda Formation that preserves most of its skull, lower jaw, and two articulated vertebrae. A detailed description of the bone elements and phylogenetic analyses shows a close morphological similarity with other fossil gharials from Europe and North America (*Eosuchus*). The preliminary results of the phylogenetic analysis resolved the new crocodylian within Gavialidae closely related to *Eosuchus*, consistent with the morphological description. It suggests they were present in Indo-Pakistan during the Eocene (42 Ma), which is ~20 Ma before previously thought. Its close relationship with European and North American gharials suggests that this group probably dispersed throughout the Tethys Sea during the Paleogene. The fact that *Pakigavialis pravus* came from an entirely marine deposit shows that this species could, at least, withstand saltwater as proposed for basal gharials recovered from marginal or coastal marine sediments. The discovery of a new gharial from the Eocene of Pakistan shows evidence that this group was present in the Indo-Pakistan and subsequent collision with the Eurasian plate followed by the closure of the Tethys Sea restricted gavialoids to their current freshwater habitat. This project highlights the importance of including fossil and paleoenvironmental information to understand the ecological and evolutionary history of modern groups.

Spatial and temporal trends in stable oxygen isotopes of eggshells and waters

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Stable oxygen isotopes of carbonates ($\delta^{18}O$) are used to understand the environment and climate conditions that existed during carbonate formation. Carbonates formed by animals are known as biogenic carbonates and include eggshells, tooth carbonate, and shells. Biogenic carbonate $\delta^{18}O$ values ($\delta^{18}O_{carbonate}$) are related to the $\delta^{18}O$ values of animal body waters ($\delta^{18}O_{water}$), which are dependent on $\delta^{18}O$ of input waters, environment and animal physiology. Chicken eggshells (*Gallus gallus domesticus*) form rapidly (on the order of days) and are useful for assessing short climatic snapshots of the environment. However, in order to interpret eggshell data from the geologic record, it is important to understand how the $\delta^{18}O$ values of biogenic carbonates and input waters are related, which can be accomplished using modern analog studies. In this experiment, we analyzed paired eggshell and water samples from sites in Peru and Michigan to understand the relationship between $\delta^{18}O$ values of eggshells and input waters. Building upon previous controlled feeding experiments and established animal body water models, we expect the $\delta^{18}O$ isotope composition of eggshells from domesticated chickens to reflect the $\delta^{18}O$ values of ingested waters. We analyzed 30 water samples and 37 eggshell samples, collected from a single site in Michigan over a 12-week period and from 25 different sites across southern Peru. Michigan ground water (n = 5) and eggshell (n = 12) $\delta^{18}O$ values ranged from -9.5‰ to -8.8‰ (SMOW) and 15.5‰ to 24.1‰ (SMOW), respectively. Southern Peru surface water and eggshell samples (n = 25) have $\delta^{18}O$ values ranging from -17‰ to -3.5‰ (SMOW) and 19.6‰ to 26.5‰ (SMOW), respectively. As expected, $\delta^{18}O$ values of waters and eggshells are strongly correlated in our Michigan dataset (Pearson's r = 0.78), however, only weak correlation is observed in the Peru dataset (r = 0.32). Additional work is required to understand how factors such as animal physiology and environmental conditions ultimately influence $\delta^{18}O_{carbonate}$ values, however, our initial results suggest that $\delta^{18}O$ values of waters and eggshells are linked. More broadly, modern calibration studies, such as this work, are a critical starting point for quantitative paleoenvironmental reconstructions from oxygen isotopes of fossil and archeological eggshell samples (e.g., dinosaur or ostrich eggshells).

Prediction of dispersal potential of fossil equids

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During the Miocene, the geographic ranges of North American horses (Equidae) extended from Florida, throughout the Great Plains, to California. These species exhibit both temporal and spatial variation with overlapping occurences. However, some extinct lineages appear to be rarer relative to other species. This includes *Megahippus sp.,* which is seldom found west of the present-day Mississippi river. Other species, such as *Neohipparion sp.* and *Nannippus sp.* are found across a much broader geographic range. Our study aims to determine how equid lineages responded to tectonic episodes and climate change. To explore this topic, we are generating a dataset of geographic ranges and feeding ecologies to compare with changes in the physical environments inhabited by equids.

We compiled information on feeding ecologies for eleven fossil horse taxa, then gathered location, formation, and geochronologic data from the Fossilworks database where available. The species featured in our study include: *Cormohipparion occidentale, Cormohipparion sp., Hipparion forcei, Hipparion sp., Hipparion tehonese, Hypohippus sp, Megahippus sp., Nannippus sp., Neohipparion sp., and Pliohippus leardi, and Pliohippus sp..* We used these data to determine the most geographically broad and restricted species. Feeding ecology data was then used to inform predictions about each taxon's potential for geographical dispersal.

Towards the end of the Miocene, a global cooling climate coincided with expansion of C4 grasslands in North America. During such vegetation shifts, it would be expected that generalist grazers would be the most successful in the colonization of increasingly grassy habitats, whereas specialist browsers would be the least successful. *Neohipparion sp.* and *Nannippus sp.* are thought to have been generalist grazers, based on their hyspodont dentition and isotope analyses. These species once occupied a broad geographic range, from as far south as present-day Mexico City to as far north as present-day Edmonton, Alberta, and stretching from the East to West coast of North America. *Megahippus sp.* is thought to have been a browser due to its brachydont teeth, which would have restricted its ability to thrive in expanding grasslands. This species is found in a much more geographically restricted range than the other major species groups analyzed, with most localities centered around the Great Plains and the Southwest United States.

Isotopic and trace element vital effects as records of biological control over skeletogenesis in Maastrichtian (69-66 Ma) Antarctic bivalves

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Since the early days of oxygen isotope paleothermometry, it has been known that biological processes can cause shell material to precipitate out of isotopic equilibrium with ambient water. So-called "vital effects" have complicated paleoenvironmental interpretations using many species of cnidarians, echinoderms, brachiopods, and mollusks. While studies of modern bivalves have revealed much about the biological controls on skeletogenesis, these processes and their ramifications for the chemistry of shell material in the fossil record remain poorly understood. Here, we present new evidence for systematic and persistent differences in $\delta^{18}O$, $\delta^{13}C$, Δ_{47}, and Sr/Ca values between discrete shell layers in five bivalve genera (*Cucullaea*, *Lahillia*, *Eselaevitrigonia*, *Nordenskjoldia*, *Dozyia*) from the Maastrichtian (69-66 Ma) of Seymour Island, Antarctica. The outer layers of these shells appear to be faithful recorders of environmental conditions, but the interior layers can be either enriched or depleted in ^{18}O, ^{13}C, and/or Sr relative to the outer layers. We explore several physiological mechanisms that could introduce the observed isotopic variations at various steps in the biomineralization process, including kinetic and pH effects and calcification rate. Interrogating vital effects in the isotopic and elemental record of fossil bivalves may reveal new information about the physiology of these ancient organisms, providing insight into the selectivity of an under-studied dimension of biodiversity across mass extinctions.

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Late Miocene tectonic influence on taxonomic diversity in a Mojave basin

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The fossil record allows us to examine the effects of changes in the physical environment on mammalian diversification and distribution. Shifts in geographic ranges or the appearance of new species coinciding with environmental changes invite analysis of causal processes. The Middle to Late Miocene (12.5-8.0 Ma) was a period of global cooling and decreasing mammal diversity in western North America. Study of mammalian faunas from individual basin records will extend our understanding of environmental conditions that led to this decline. The Dove Spring Formation of southern California contains abundant fossil mammals that provide a dataset for testing the responses of mammalian lineages and faunas to a region reshaped by tectonic episodes and a changing climate. Eighteen ash layers interbedded throughout the Dove Spring provide a well-constrained chronology for 701 localities holding 6278 fossil specimens.

After placing localities into geographic and stratigraphic context using database records, field notes, and geologic maps, we found strong correlations between fossil localities, specimens, and species richness. The majority of localities and specimens occur between 10.5 and 9.5 Ma, with species richness also peaking during this interval. We calculated estimates of mean standing diversity to determine the expected species richness throughout the section.

We used taxonomic diversity metrics to estimate the number of originations and extinctions within the section, finding that peaks in origination across taxonomic groups occur at 10.5 Ma, but extinction peaked at 9.5 Ma for large mammals. Rate metrics calculated based on originations and extinctions support the validity of these signals, with per-capita rates that peak at the same intervals. A peak in extinction rate at 9.5 Ma suggests that a proportionally significant loss of diversity occurred during this time, as it coincides with the most samples recovered and highest species richness.

The appearances and disappearances recorded in the section may represent species shifting their range in or out of the site. Tectonic episodes of basin rotation, translation, and extension altered the Dove Spring's depositional area and coincide with some of these changes in diversity, particularly the peak in diversity at 9.5 Ma. Further investigation will reveal whether or not there is a strong connection between changes in the basin area and the faunal communities that inhabited it.

Ferric iron triggers greenalite formation in simulated Archean seawater

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Sedimentary rock deposits provide the best records of (bio)geochemical cycles in the ancient ocean. Studies of these sedimentary archives show that greenalite, an Fe[II] silicate with low levels of Fe[III], was an early chemical precipitate from the Archean ocean. To better understand the formation of greenalite, we explored controls on iron silicate precipitation through experiments in simulated Archean seawater, under exclusively ferrous conditions or supplemented with low Fe[III]. Our results confirm a pH-driven process promoting the precipitation of iron-rich silicate phases, and they also reveal an important mechanism in which minor concentrations of Fe[III] promote the precipitation of well-ordered greenalite among other phases. This discovery of an Fe[III]-triggering iron silicate formation process suggests that Archean greenalite could represent signals of iron oxidation reactions, potentially mediated by life, in circumneutral ancient seawater.

Biological and environmental influences on stable isotopes of carbonates in microbial mats

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Geochemical signatures from carbonates in lithified microbial mats inform much of our understanding of life and environments on the early Earth, where microbial mats were ubiquitous. In modern systems, microbes influence geochemical signals such as the stable isotope composition ($\delta^{13}C$ and $\delta^{18}O$) of organic matter and dissolved inorganic carbon in the surrounding environment, which can be captured in marine carbonates. Here, microbial mats on Little Ambergris Cay, Turks and Caicos are used to study the influence of microbial activity on $\delta^{13}C$ and $\delta^{18}O$ values of carbonate grains within the mats. SEM images show these grains to be a mixture of allochthonous grains (primarily ooids), aggregates, and grains that appear to have precipitated *in situ*. The mat microbial community is dominated by cyanobacteria, but $\delta^{13}C$ values of carbonates precipitated *in situ* are inconsistent with seawater or photosynthetic influence, suggesting that respiration is impacting carbonate precipitation. These $\delta^{13}C$ and $\delta^{18}O$ values can be temporarily shifted towards seawater values by large-scale events such as hurricanes, demonstrating that both biological and short-term environmental factors may influence buffering capacity of microbial carbonates and the type(s) of information recorded in geochemical records. These results inform interpretations of carbonates formed in microbial mat ecosystems preserved in the rock record by demonstrating that stable isotope signals in such carbonates are formed by a combination of biological and environmental factors that are not necessarily representative of the seawater or the dominant community members.

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A simple numerical model to predict the effect of moisture recycling on the triple oxygen isotope ($\Delta'^{17}O$) composition of downwind precipitation

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Continental evapotranspiration (ET) is characterized by land-atmosphere moisture fluxes. Downwind of regions with substantial ET fluxes, such as the Amazon and Great Lakes regions, recycled moisture can greatly contribute to regional water budgets and influence the isotopic composition of precipitation ($\delta^{18}O_P$, $\delta^{17}O_P$, δ^2H_P, d-excess$_P$, $\Delta'^{17}O_P$). We compare a model of Rayleigh Distillation (control) to a model which re-incorporates an ET component into the downwind air mass (experimental). We simulate moisture recycling in the Amazon using our experimental model to explore effects on downwind 'continentality,' and d-excess$_P$ and $\Delta'^{17}O_P$ values. The roll of recycled moisture in the Amazon has previously been inferred from direct measurements of $\delta^{18}O_P$ and δ^2H_P by Salati et al. (1979) who observe reduced continentality across the Amazon ($\Delta\delta^{18}O$ = –0.75 ‰ per 10^3 km compared to values of $\Delta\delta^{18}O$ ca. –2 ‰ per 10^3 km in Europe (Rozanski et al., 1993)) and in the high (>10 ‰) d-excess values of downwind precipitation which increase by ~3 ‰ from the eastern to western sides of the Amazon basin. As with d-excess, evaporated vapor should increase the $\Delta'^{17}O_P$ values of downwind precipitation, however, this is the first study that uses either empirical datasets or simple models to evaluate this hypothesis.

Compared to the control model, the experimental model yields both a reduced continental effect on $\delta^{18}O_P$, $\delta^{17}O_P$, and δ^2H_P and an increase in d-excess$_P$ and $\Delta'^{17}O_P$ values. Model outputs are highly sensitive to both the magnitude and the E/T ratio of the ET flux. Additionally, we observe that ET fluxes have a cumulative effect on the isotopic composition of precipitation through multiple rainout and recycling events. As such, ET has minimal effects proximal to the moisture source and maximum effects are observed distally to the moisture source.

This work has two main implications: First, recycled moisture is an important component of continental water budgets, such that augmenting regional hydrology (e.g. via deforestation or damming) could have profound effects on downwind water budgets. Second, very few systematic studies of $\Delta'^{17}O_P$ have been conducted to date. We show that under most normal hydrologic conditions, the effect of moisture recycling on $\Delta'^{17}O_P$ will be smaller than or the same order of magnitude as analytical precision. Therefore this simple model has a variety of highly useful applications towards understanding and interpreting regional hydrologic and climate datasets.

Exploring the impact of fossil specimen digitization

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The digitization and accessibility of natural history collections, such as that held by the U-M Museum of Paleontology, Invertebrate Paleontology Collection (UMMP-IP), is a crucial component of research that allows researchers from all over the world to analyze and interpret data. Regionally important collections, such as UMMP-IP, house specimens that have the potential to bolster our understanding of specific geologic periods and geographic regions and are critical for long-term biodiversity and climate change research. The UMMP-IP, like many institutions, has only digitized a fraction of their collections and have not yet made their current database available through global data aggregators. To investigate the impact UMMP-IP's current digitized database could have if added into iDigBio (a data aggregator), data from both repositories were extracted according to various criteria (such as genus, locality, and geologic context). Entries in UMMP-IP's database are not standardized, and as such, the data had to be cleaned once exported. To demonstrate UMMP-IP's impact on iDigBio, several datasets were compared and combined. These datasets included the important genera, *Paraspirifer* and *Hexagonaria,* as well as UMMP-IP's geographic and temporal focus — the Devonian of Michigan. Since the UMMP-IP's database is incomplete, we performed a comparison study with another regionally important collection, the Cincinnati Museum Center, Invertebrate Paleontology Collection (CMC-IP). The CMC-IP possesses a collection of Ordovician material from Ohio similar to UMMP-IP's Devonian of Michigan collection. Our data visualizations show that if added to iDigBio, UMMP-IP's digitized *Paraspirifer* data would account for 93% of total occurrences. In addition, UMMP-IP's *Hexagonaria* data would account for 59% of iDigBio's total occurrences, and UMMP-IP would provide 32% of the total Michigan occurrences. In the case study of the CMC-IP's impact on iDigBio, it was found that the CMC-IP provided 24–27% of the *Platystrophia* and *Streptelasma* occurrences available in iDigBio. The CMC-IP also provided 11–17% of iDigBio's Ordovician and Ohio occurrence data, and 34% of iDigBio's combined Ordovician of Ohio occurrence data. Through these comparisons, it is clear that, just as CMC-IP greatly impacted iDigBio by making their data public, adding UMMP-IP's current database of digitized fossil occurrences would dramatically change the representation of ancient life aggregated in iDigBio. Therefore, digitizing the rest of the UMMP-IP's fossil specimens and making them available worldwide through online databases such as iDigBio would greatly benefit the scientific community and our understanding of the rich ecosystems of the past.

Testing mineral signals for ancient microbial iron respiration in Precambrian Banded Iron Formations (BIFs)

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Unraveling the history of vast chemical deposits known as Banded Iron Formations (BIFs) from the Archean ocean is critical to understanding the evolution of microbial life on early Earth, particularly in the absence of a robust fossil record. The initial BIF precipitate is classically interpreted as iron oxides (Fe^{3+}) potentially derived from biological activities. However, recent discoveries of iron silicate nanoparticle inclusions in 2.4 to 3.5 billion-year-old South African and Australian BIFs revealed the presence of early-forming iron clay minerals[1]. Iron clay precipitation has been hypothesized as a byproduct of microbial iron oxide respiration in BIF sediments[2]. Indeed, the iron clay inclusions contain 10-20 % Fe^{3+}, which could be relict Fe^{3+} from initial iron oxide minerals reduced through post-depositional iron respiration[3]. This project experimentally investigates whether iron-reducing bacteria constitute a viable pathway for iron clay precipitation by examining biologically-induced mineralogical transformations under siliceous and high-iron concentrations simulating Archean sediments. We are exploring the secondary biomineral production in incubations amended with variable iron and silica concentrations and inoculated with a model marine iron-reducing bacterium, *Shewanella putrefaciens* CN32, to study how iron substrates and geochemical conditions alter the products of iron respiration. In a solution replicating the predicted Archean sedimentary pore water geochemistry but with excess organic carbon (lactate), our experiments test whether there are differences in the biomineral product(s) generated from an Fe^{3+}-silica coprecipitate compared to iron oxides in the presence or absence of aqueous silica. We characterize the reduced mineral phases harvested from 90-day incubations using Raman spectroscopy, electron microscopy, powder x-ray diffraction, and synchrotron-based techniques to identify mineral precipitates and track nanoscale distributions of Fe^{2+}/Fe^{3+}. These analyses will allow us to compare our experimental minerals with iron clay BIF inclusions to clarify the role of microbial iron respiration in the formation of iron clays and establish whether iron clay inclusions could be biosignatures of iron-reducing metabolisms on early Earth.

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Clumped isotope-derived climate trends leading up to the End-Cretaceous extinction in Northwest Europe

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Understanding the role of climate in past mass extinction events provides important context regarding the impacts of anthropogenic climate change on the modern biosphere. At the end of the Maastrichtian Age (~66 Ma), the Cretaceous-Paleogene (K-Pg) mass extinction wiped out ~70% of species, a rate comparable to projections of extinction resulting from modern global warming. Ambiguity persists concerning the cause of the K-Pg mass extinction due to two significant geological events dating very closely to the K-Pg boundary: the main eruptions of the Deccan Traps volcanic province and the Chicxulub bolide impact. Although the majority of the extinction likely occurred at the time of bolide impact, there is increasing evidence showing that global warming driven by increasing atmospheric CO_2 at the onset of the most intense phase of Deccan volcanic eruptions may have destabilized ecosystems and set the stage for amplified extinction when the bolide hit. Here, we employ clumped isotope paleothermometry in combination with oxygen and carbon stable isotope analysis of Maastrichtian-age fossil shells from the ENCI Quarry in the Southeast Netherlands (the type section of the Maastrichtian interval) to reconstruct a climate record for northwest Europe to better constrain the magnitude of local and global climate change during this important and volatile time period. This study is the first to use clumped isotope paleothermometry applied to late Maastrichtian-age oysters to obtain a profile of changing temperature and seawater $\delta^{18}O$ for the ~1.4 Myrs leading up to the K-Pg extinction from the type section for the Maastrichtian interval. This record is then interpreted in terms of both local climate history, as well as regional and global climate change.

Constraining paleo-evaporation using triple oxygen isotopes at Bear Lake, Utah/Idaho from the LGM to Holocene

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The Bear Lake, Utah/Idaho carbonate record contains 225,000 years of western U.S. climate history persevered in lake core sediments. Investigating the influence on lake carbonate oxygen isotope records of local evaporation in the basin, relative to regional changes in precipitation, can be achieved by coupling clumped (Δ_{47}) and triple oxygen isotope ($\Delta^{17}O$) measurements of the carbonate core. While authigenic calcite and aragonite dominate the top portion of this core, detrital dolomite in the lower portion poses a complication to interpreting data (especially paleotemperatures) from 10-15 meters below lake floor (mblf), where authigenic carbonate is less abundant. Dolomite often records elevated clumped isotope temperatures compared to calcite, or aragonite, and upon initial clumped isotope analysis, the temperatures from this interval were notably higher than expected (10-55℃ ± 4℃), accompanied by a positive ~ 5 per mil $\delta^{18}O$ and negative ~20 per meg shift in $\Delta^{17}O$ moving from the Last Glacial Maximum into the Holocene. Calcite, aragonite, and dolomite react at different rates in phosphoric acid. Accordingly, I will use offline temperature stepped acid-digestions (at 25℃ and 50℃) to separate, and measure, the isotopic signals from the aragonite/calcite and dolomite components to gain a better understanding of the influence dolomite has on this stable isotope record. Separation of the mixed isotopic signals reveals low Δ_{47} temperatures (10-35℃ ± 4℃) for the authigenic carbonate and high Δ_{47} temperatures (40-55℃ ± 4℃) for the dolomite, suggesting that, despite the small detrital dolomite abundance, it has a large influence on the Δ_{47} temperature in the core, especially where carbonates are less abundant. Further offline reactions will help determine whether the dolomite present also alters the $\Delta^{17}O$. If so, does it mute, or amplify patterns observed in the $\Delta^{17}O$ record? Distinguishing between the authigenic carbonate isotope signature from the detrital one is key to unraveling the climate history contained within lake cores and will provide valuable insight for further paleolimnology studies.

Where did they come from, where did they go: examining niche conservatism through time in a primarily tropical plant lineage

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Many plant and animal species will be greatly affected by anthropogenic climate change in the coming years, which raises the question of whether climatic niches of species change. Fossils can provide insight on how organisms were affected by climatic change through larger timescales. While the fossil record has been used to test for niche conservatism (organismal preservation of original ecological traits over time) in fossil invertebrates to determine how the environmental constraints for these organisms have changed through time compared to the modern, niche conservatism is largely unexplored in plants, despite being invaluable to terrestrial ecosystems and global agriculture. In this study, we aim to test if climatic niche constraints have remained consistent through time by characterizing climate niches of living ginger plants (Zingiberaceae) and comparing them with the paleo-niches reconstructed based on fossil distribution. Gingers are primarily found in the tropics today, but have they inhabited tropical climates since their origin in the Cretaceous? If ginger niches have remained conserved through time, then we can use extant ginger climate regimes for reconstructing past climates. To test this, we used ArcGIS Pro to calculate the modern climate niches of Zingiberaceae and its four subfamilies from living occurrence data and bioclimatic variable data, namely cold month mean temperature (CMMT), mean annual temperature (MAT), and mean annual precipitation (MAP). Fossil ginger occurrences were collected from the literature, with the distribution mapped using GPlates and PALEOMAP. Based on cold month mean temperature (CMMT) and mean annual temperature (MAT), only one subfamily is deemed as tropical (CMMT > 18ºC) while the rest are subtropical (CMMT < 18ºC, but MAT is > 16ºC). The fossil ginger distribution shows a Cretaceous presence in both higher latitudes and the tropics, but then remains only in those upper latitudes for the rest of the Cenozoic fossil record. With impending paleoclimate modeling data, we expect to confirm that the climatic conditions for these upper latitude fossil gingers was similar to those of the modern day, as much of the Cenozoic had expanded (sub)tropical climates. If this assertion is correct, then we can use fossil ginger occurrences for reconstructing past climates. Fossil gingers today are taxonomically placed in either Zingiberaceae or the subfamily Alpinioideae, but we recommend to only use Alpinioideae-linked fossils because species of this group better represent a subtropical climate regime, since some living species within the other subfamilies of Zingiberaceae can persist in below freezing conditions.

Exploring discrete & continuous characters in a comparative framework

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Continuous and discrete characters have a long history in the paleontological study of morphological diversity. Continuous data tend to be used in techniques meant to measure “distance” in some statistical space, while discrete data have been a staple in many kinds of evolutionary reconstructions. The goal of using these data is to find a way to quantify anatomical diversity and rates of morphological change. However, both discrete and continuous datasets are typically either analytically siloed, continuous characters are discretized, or a variety of *post-hoc* approaches are taken to handle problems associated with discrete characters. To address these issues, we assembled discrete and continuous characters for a fossil-rich and well-studied clade—coelacanths—which were then analyzed under a common framework with the aim of assessing the degree of similarity in overall disparity through time. We first inferred phylogenetic relationships and jointly estimated branch divergence times and evolutionary rates using published character matrices in a Bayesian framework under the Fossilized-Birth Death model. Branch-specific evolutionary rates generated during this analysis were used to estimate rates of discrete character evolution over time. We then landmarked a subset of the taxa that had either full body fossils or full reconstructions available to capture shape data. A Principal Component Analysis (PCA) was run and the output was used alongside the inferred phylogenetic tree as the input for a Bayesian trait analysis. These newly-generated branch-specific evolutionary rates were used to estimate rates of continuous character evolution over time. The results demonstrate that, when assessed under a comparative framework, discrete and continuous data show nearly identical patterns of disparity through time for coelacanths—peaking in the Devonian, Permian, and Triassic, with declining rates to recent. Although methodologically promising, it should be noted that different underlying evolutionary processes can yield the same patterns of disparity over time. Further, this novel comparative method can only co-estimate rates and phylogeny for discrete but not continuous data. Nevertheless, these exploratory experiments lay the groundwork for more rigorous future comparative work within and among datasets and clades, which may elucidate underlying patterns of morphological disparity and help identify the processes that generated them.

Recipe for V-rich magnetite in iron oxide apatite deposits

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ABSTRACT TEXT REDACTED AT AUTHOR'S REQUEST

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A population viability analysis of fossil mammoths and its implications for modern conservation

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Past extinctions help inform efforts to prevent future extinctions, but the ways paleontologists and neontologists study extinction are different. The modern conservation biology concept of endangered species—those at risk of going extinct—cannot easily be applied to extinct species in the fossil record. Nonetheless, the fossil record offers a wealth of evidence of extinctions and their causes. Here I ask what interbirth intervals (IBIs) are necessary for a hypothetical population of extinct mammoths to persist using a population viability analysis (a conservation biology tool). The fates of populations of mammoths and modern elephants depend largely on IBIs, which may be inferred from variations in growth increment sizes in fossil material and are observable in modern populations. I use modeling software previously used with elephants (Vortex10) to find IBIs that lead to long-term decline of a 1000-individual mammoth population using mortality rates and population structure from the modern elephant literature. I compare the IBI parameter-space of the models with IBIs inferred from fossil mammoths, which were hunted by humans during the changing climates of the latest Pleistocene and Holocene. Then, I introduce a harvest of animals to the model, and find unsustainable harvest rates at different IBIs. In the mammoth model without harvesting, extinction is likely with an IBI of around 10 years, holding other parameters constant. In mammoth fossils, inferred IBIs range from approximately 4 to 8 years. In the model, an IBI of 8 years, combined with as little as 1% harvest of the population per year guarantees extinction within 1000 years. Hunting rates of 3% of the population per year are sufficient to drive mammoths to extinction even with faster reproduction at an IBI of 4 years. Reductions in population size in many simulations do not reach modern thresholds to classify a species as "endangered" until after 100 years. IBI in multiparous but single-offspring species like elephants and mammoths may therefore be a better early indicator of species extinction risk than rates of population decline alone, because in long-lived animals, measurable population decline can require centuries to become manifest. More data are needed to show exactly how IBI and other life history parameters changed through time during the decline of mammoths, but this information could contribute to understanding the extinction risk of apparently stable elephant populations, and to how we define endangered species in general.

Dietary strategies of artiodactyls in relation to climate and topography, with implications for paleoecology

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Artiodactyla is a taxonomically diverse order of large-bodied terrestrial mammals, exhibiting a broad range of adaptations, niches, and morphologies. They have been widely studied for applications in paleoecological and paleoenvironmental reconstructions. Here we investigate the species richness of artiodactyls with different diets in relation to climate and topography. Our data consist of 1984 occurrences of 160 artiodactyl species, 9 climatic variables, and elevation for 329 faunal localities around the world. Species were divided into six feeding categories based on detailed forage selectivity and preferences documented in the literature. Categories include obligate grazers, variable grazers, intermediate feeders, browsers, frugivores, generalists, and omnivores. Multivariate analyses identify seasonal extremes of temperature and precipitation as the most useful predictors of species richness in feeding categories. Intermediate feeding categories show a weak relationship with environmental variables. Frugivores and grazers, the dietary extremes in our classification, occupy limited ranges of climate envelope. Because of their restricted climatic niche space, identifying frugivory and grazing in the fossil record would be useful for recognizing certain paleoenvironments and paleoclimates. Variation in modern richness patterns exist among continents, with the highest richness of all feeding categories occurring in Africa, significantly influencing the global pattern. Ungulates consitute a widely distributed and diverse component of the Cenozoic fossil record, making an understanding of the distribution of modern ungulate species and their dietary ecologies especially useful for paleoenvironmental reconstructions.

Seasonally Variable Aquifer Discharge and Cooler Climate in Bermuda during the Last Interglacial Revealed by Subannual Clumped Isotope Analysis

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Faunal analog reconstructions suggest that Last Interglacial (MIS 5e) sea surface temperatures (SSTs) were cooler around Bermuda and in the Caribbean. Here we describe new and revised clumped isotope measurements of *Cittarium pica* fossil shells supporting previous findings of cooler than modern temperatures in Bermuda during the Last Interglacial. We resolve temperature and $\delta^{18}O_w$ differences between two closely-located and apparently coeval sites described in Winkelstern et al. (2017) through reprocessing raw isotopic data with the updated Brand/IUPAC parameters. New subannual-resolution clumped isotope data reveal large variations in $\delta^{18}O_w$ out of phase with seasonal temperature changes (i.e. lower $\delta^{18}O_w$ values in winter). Supported by modern $\delta^{18}O_w$ measurements identifying similar processes occurring today, we suggest past variations in coastal $\delta^{18}O_w$ were driven by seasonally variable freshwater discharge from a subterranean aquifer beneath the island. Taken together, our results emphasize the importance of $\delta^{18}O_w$ in controlling carbonate $\delta^{18}O$, and suggest that typical assumptions of constant $\delta^{18}O_w$ should be made cautiously in nearshore settings and can contribute to less accurate reconstructions of paleotemperature.

Student Showcase

2021 MGU Awards

EARTH

1st Prize, 10-minute talks:	Kristin Barton
1st Prize, 5-minute talks:	Kevin Velez
1st Prize, Asynchronous talks:	Cecilia Howard
2nd Prize, Asynchronous talks:	Maria A. Rodriguez-Mustafa
Undergraduate Prize:	Amartya Kattemalavadi
People's Choice, 5-minute talks:	Emma Rieb

CLaSP

1st Prize, 10-minute talks:	Alexander Lojko
1st Prize, 5-minute talks:	Austin Brenner
1st Prize, Asynchronous talks	Tara Vega and the BLiSS Team
People's Choice, 10-minute talks:	Alexander Lojko
People's Choice, Asynchronous talks:	Tara Vega and the BLiSS Team

EARTH PhDs Defended

2021

Meredith Calogero - High-resolution numerical thermal modeling of timescales and mechanisms of rhyolite genesis and transport as a consequence of basalt influx: applications to the Long Valley volcanic field, CA

Aaron Kurz - Mercury stable isotopes identify past and present mercury sources and cycling

Marlon Ramos - Physics-based simulations of large earthquake rupture processes

Derek Smith - The impact of microbial interactions and hydrogen peroxide on western lake erie cyanobacterial blooms

2020

Xiaojing Du - A high-resolution reconstruction of Southern California hydroclimate during the Holocene: Interannual precipitation variability response to climate forcing – March 27, 2020

Phoebe Aron - Tracing natural water cycling and variability with stable water isotopes

Jameson Jolles - Insights on the temperatures, mechanisms, and timescales of voluminous (>600 km3) high SiO2 (75-77 wt%) rhyolite melt generation at Long Valley, CA

Molly Ng - Evaluation and application of links between leaf anatomy and climate in Metasequoia (Cupressaceae)

Mark Robbins - Evolution of late season meltwater in alpine and arctic glaciers: Sampling strategies and geochemical observations

Hong (Dora) Shen - Mountain-climate interactions in the Himalayan-Tibet and Andean orogens

Rebekah Stein - Carbon and water dynamics in modern and ancient plants and soils

Adrianna Trusiak – The role of iron in the arctic carbon cycle

Yi Wang – Annual to millennial-scale Oxygen Minimum Zone expansion on the Southern California margin: proxies and drivers

EARTH MS Awarded

2020

Rebecca Dzombak - Stable climate in India during Deccan volcanism suggests limited influence on K–Pg extinction

Mara Page - The stable isotope ecology of mammals in the southern Kenyan Rift Valley

Allison Pease - Liquidus Determination of the Fe-S and (Fe, Ni)-S Systems at 14 and 24 GPa: Implications for the Mercurian Core

Serena Scholz - Use of high-resolution oxygen isotope sclerochronology of turritellid gastropods to reconstruct seasonal-scale precipitation regimes

Melanie Shadix - Using leaf carbon isotope values to investigate plant response to high latitude climate change

CLaSP PhDs Defended

Winter 2021

David Mayers - New applications of satellite-measured tropical cyclone wind speeds

Tianlin Wang - Engineering calibration and physical principles of GNSS-reflectometry for Earth remote sensing

Fall 2020

Yeimy Rivera - Investigating nonequilibrium ionization and recombination processes in solar wind and transient plasma

Rajeswari Balasubramaniam - Investigating the sensitivity of spaceborne GNSS-R measurements to ocean surface winds and rain

Zachary Butterfield - A multi-scale assessment of solar-induced chlorophyll fluorescence and its relation to Northern Hemisphere forest productivity

Summer 2020

Ryan Dewey - Dipolarizations in Mercury's magnetotail: Characteristics and consequences in a miniature magnetosphere

Hongyang Zhou - Coupled kinetic-fluid simulations of Ganymede's magnetosphere and hybrid parallelization of the MHD model

Alicia Petersen - Space weather propagation in the inner heliosphere

Jamie Ward - The effects of light-absorbing aerosols, blocking, and clouds on Greenland's surface

Winter 2020

Daniel Vech - Transition of solar wind turbulence from MHD to kinetic scales

Yi-Hsuan Chen - Influences of surface spectral emissivity and cloud longwave scattering on climate simulations

Mojtaba Akhavan-Tafti - Evolution of flux transfer events at the magnetopause: MMS observations and global hybrid-Vlasov simulations

Abigail Azari - A data-driven understanding of plasma transport in Saturn’s magnetic environment

Fall 2019

Alexander Hegedus - Probing the universe with space based low-frequency radio measurements

Samantha Basile - Evaluating uncertainty in model representations of land-atmosphere carbon exchange and atmosphere-watershed interactions toward informed climate change impact planning

CLaSP MS and MEG Awarded

2020

Donald Anderson

Kelsen Case

Jesus Christian

John Cole

Korinn Detter

Shengjie Dong

Logan Fettes

Julia Garner

Ethan Gregory

Minna He

Michael Huff

Parker Kurlander

Bryant Hawkes

Sakina Almas Mohammed Slayem Alblooshi

Stephen Barr

James Cooney

Eva-Marie Anna Louise Dupuy

Ian Hoeck

Amit Kothekar

Dylan Martinez

Abigail Meisel

Rafal Ogorek

Alexander Sena

Nicholas Simon

Kyle Webster

Karlie Wells

2019

Megan Avery

Pranika Gupta

Minna He

Taylor Morton

Sunil Subramanian Raghuraman

Annika Stoldt

Ryan Whitney