APS Topical Group on the Physics of Climate
GPC

GPC Newsletter

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IN THIS ISSUE

APS TOPICAL GROUP ON THE PHYSICS OF CLIMATE

Message from the Editor

This is the twenty-third GPC Newsletter, published twice per year. You, the GPC membership, can be of enormous value. We invite comments, event notices, letters, and especially specific suggestions for content. Any of the above, addressed to GPCnews@aps.org, will be gratefully acknowledged in a timely fashion.

Welcome from the incoming GPC Chair

Morgan O'Neill, U. Toronto

I very recently returned from the APS Annual Leadership Meeting, in my role as GPC Chair-Elect (I will become chair formally at the Global Physics Summit in March). Given the chilly climate that we find ourselves in, I will note that in this message for the Newsletter, I am speaking *to* the GPC membership, not *for* it, obviously. At the Annual Leadership Meeting I learned about how the American Physical Society, along with sister societies such as the American Meteorological Society, the American Geophysical Union and The Geological Society of America, put up a historic and largely successful effort in defense of maintaining government support for basic science. As an international member of the APS, I was not invited to participate in the Congressional Visit Day (fair enough, as I do not receive US federal funding for my research regardless), but I heard about how effective the APS outreach is. You've seen some of these related campaigns in your inbox through your GPC membership. Personalized outreach from informed citizens is clearly making a real difference.

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APS Fellows Nominations, GPC Student Prize, GPC Early Career Investigator Award

APS GPC Members may nominate colleagues to become APS Fellows through GPC. You are invited to nominate those who have made exceptional contributions to promoting the advancement and diffusion of knowledge concerning the physics, measurement, and modeling of climate processes, within the domain of natural science and outside the domains of societal impact and policy, legislation, and broader societal issues.

Selection as an APS Fellow by one's professional peers is a great honor. The number of Fellows elected annually cannot exceed 0.5% of Society membership.

Any current APS member can initiate a nomination. The membership of APS is diverse and global, and the Fellows of APS should reflect that diversity. Fellowship nominations of women, members of underrepresented minority groups, and scientists from outside the United States are especially encouraged.

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ARTICLE: Tropical Cyclones and Climate: Insights from Fluid Dynamics

Pinaki Chakraborty (Okinawa Inst. Sci. Tech.), Morgan O'Neill (U. Toronto), Kerry Emanuel (MIT), and Suzana Camargo (Columbia U.)

On November 3, 2025 APS DFD organized its 3rd Online Forum on the societal impact of fluid dynamics titled Tropical Cyclones and Climate: Insights from Fluid Dynamics. Fluid dynamics is clearly central to understanding the intricate relationship between global warming and tropical cyclones (hurricanes in the Atlantic and typhoons in the Pacific). The panel was composed of leading experts exploring how multiphase flow, thermodynamics, ocean–atmosphere interactions, and large-scale circulation shape the formation, evolution, and impacts of these powerful storms. The discussion highlighted advances in forecasting, preparedness, and resilience, while also exploring emerging frontiers in research and technology. For this article each panelist was invited to highlight key elements from their presentation.

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Welcome from the incoming GPC Chair

(Continued from p. 1)

But of course, climate science has a special target on its back that most research areas represented by the APS do not suffer from. The dramatic achievement of the United Nation's Intergovernmental Panel on Climate Change, in marshalling thousands of scientists from all over the world to evaluate and synthesize the best current understanding of climate change roughly every seven years for policymakers, is essentially unequaled. In direct contrast, the US Department of Energy issued a Climate Working Group Report on 29 July 2025, "A Critical Review of Impacts of Greenhouse Gas Emissions on the US Climate," which offered a rather radical departure from the strengthening consensus around the speed and impacts of climate change, with just five authors. I recommend having a look at a particular response to this report, Climate Experts' Review of the DOE Climate Working Group Report (Dessler and Kopp (Ed.) 2025), with over 85 authors.

The blows keep coming. The first page of the Dessler/Kopp Summary for Policy Makers mentions the Environmental Protection Agency's 2009 Endangerment Finding, which regards carbon dioxide as a pollutant with significant impacts on public health. The EPA just terminated that finding on 12 February of this year (you can read the American Meteorological Society's rapid response to this decision here). Not only will manufacturers no longer have to report vehicle/engine greenhouse gas emissions, they will no longer even need to measure them.

And in parallel, the jewel of American atmospheric science research, the National Center for Atmospheric Research (NCAR) based primarily in Boulder, Colorado, may be imminently closed down (you can read more about NCAR in Physics Today, 12 February 2026 by J. Duncombe). The APS joined other societies in defense of NCAR's vital role in advancing science for society. The NSF has issued a Dear Colleague letter, as well as a brief press release that management and operations of the NCAR-Wyoming Supercomputing Center would transition to a "third-party operator."

These impacts have cascaded to GPC, greatly limiting the ability of many relevant scientific experts to contribute to our activities at the 2026 Global Physics Summit. Let me tell you: as GPC program chair this year, I advertised our interest in abstract submissions to the NCAR community in nearby Boulder very heavily, through multiple channels. In spite of our outreach to this incredible community of scientists, very few submissions were received, and we are able to assemble only three sessions on the Monday of the GPS.

Nevertheless, we did get a very high quality of abstracts this year, and we have terrific sessions that include a mix of experimental and observational work, machine learning, climate physics education, and theory, among other topics. The diversity of research represents an opportunity for APS members broadly to engage with climate physics from a place of expertise. Further to that aim, we will offer a tutorial on Sunday, 15 March, titled Cross-disciplinary physics for understanding climate. Our speakers will show how applications from the fields of condensed matter, fluid dynamics, quantum mechanics, AI and soft matter have helped drive important discoveries in climate physics. Attendees will be provided with datasets and scripts that will allow us to continue exploring these methods at home.

And I would particularly like to invite you to join our Invited Symposium, on 16 March, titled The Extraordinary Science of Canceled and At-Risk Climate Programs. We will have five speakers who are closely involved in large scale climate observation or computation efforts that are under threat, to tell us about the remarkable monitoring and discovery opportunities that these climate programs make possible.

To halt the observation and study of the Earth system is analogous to saying, forget the vaccine, you should not even know the nature of the disease. Beyond the immense societal risk of climate change, the danger that we are faced with is the further loss of a shared reality, as the rigor required to establish a scientific consensus is obfuscated, dismissed, or rendered impossible. I am personally gravely concerned.

What is the answer to these challenges? The Group on the Physics of Climate was established as an international home for physicists who are studying, teaching, or interested in learning more about the Earth system from first principles, using the tools of physics to make discoveries. We want to learn from each other and challenge each other. Our sessions have always included unconventional, and occasionally fringe ideas. This is our apolitical remit. However, on the issue of support for the natural sciences, we do have a clear position: the value to the public of understanding the physics of climate is incalculable. It is not a waste of resources and it is not a threat. And as physical scientists, we know that an absence of evidence (which one could achieve through, say, failing to pursue brilliant Earth-observing programs and laboratories) is not evidence of absence.

I invite your engagement with the GPC, through our executive committee positions, our standing committees, our well-attended virtual seminar series, and our activities at the Global Physics Summit. Now is the time to dig into our curiosity and our expertise. Let's believe our eyes, and insist that we can see.

APS Fellows Nominations and Student Prizes

(Continued from p. 1)

For information on how to nominate, and a list of current Fellows, please see the APS Fellows webpage.

The deadline for submitting fellowship nominations for review by the GPC Fellowship Committee, currently led by Vice Chair Gregory Chini, is June 1, 2026. For further information regarding fellowship nominations, please email fellowship@aps.org.

Student Prize and Early Career Investigator Award: Each applicant for these honors is asked to submit a CV, an abstract for a contributed talk at the Global Physics Summit, and a short summary of how their work fits with the GPC mission. The qualified applicants are judged by how well their work fits with the GPC mission.

ARTICLE: Tropical Cyclones and Climate: Insights from Fluid Dynamics

(Continued from p. 1)

I. In Praise of Conceptual Models

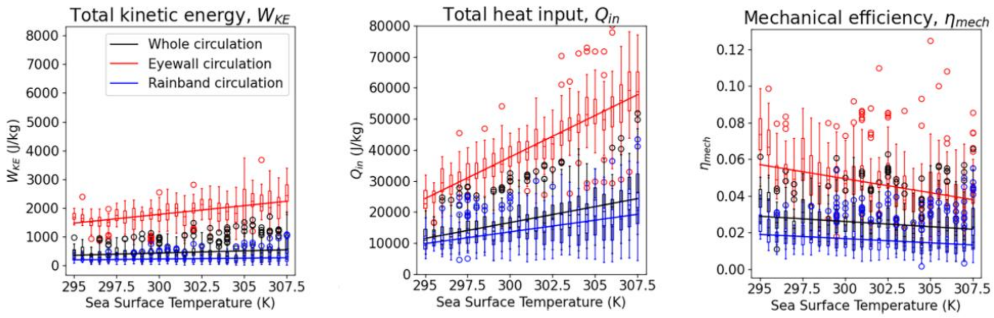
Pinaki Chakraborty

A hurricane embodies dizzying complexity. Within its eyewall, air, water vapor, ice, and graupel collide in an intensely turbulent flow. Phase changes—evaporation, condensation, and freezing—drive the storm's violent energetics. To forecast these systems, meteorologists solve coupled, non-linear, partial differential equations. While these numerical simulations are essential for prediction, they often obscure the underlying physics behind a deluge of data. To understand hurricane behavior, we must turn to conceptual models.

Consider the link between global warming and hurricane intensity. While simulations indicate that a warmer climate breeds more powerful storms, the underlying causal mechanism lies buried in intricate computations. Fellow panelist Kerry Emanuel clarifies this by idealizing the hurricane as a Carnot heat engine. This model bypasses chaotic minutiae to focus on the fundamental thermodynamic cycle: the storm absorbs heat from the warm ocean and exhausts it into the cold tropopause.

Through this lens, complexity collapses into an elegant proportionality. The maximum potential intensity ($V_{\max}$) is determined by the temperature of the sea surface (T_s) and the tropopause (T_o): $V_{\max} \propto \sqrt{(T_s - T_o)/T_o}$. As the sea warms relative to the upper atmosphere, the engine's thermal efficiency increases, which engenders stronger storms. Unfathomable complexity gets distilled into lucid physical principles.

Beyond clarity, this model guides the refinement of simulations. Because computers cannot resolve every scale—such as the microscopic entrainment of vapor—researchers rely on "parameterizations." Emanuel's framework identifies which sub-grid processes exert the most significant influence on a storm's intensity. By balancing computing power with theoretical elegance, we gain both a forecast and an insight. Technology continues to provide increasingly powerful tools, yet human ingenuity in crafting conceptual models remains at the heart of comprehending complexity.



Increase of total kinetic energy and total heat input, but reduction in mechanical efficiency, of tropical cyclones and their substructures with increasing sea surface temperature (Regibeau-Rockett, et al., 2023 J. Clim).

II. Moist Heat Engine Thermodynamics

Morgan O'Neill

Tropical cyclones (TCs), and indeed all moist convection on Earth, are sloppy, highly irreversible heat engines. Water can be in all three phases out of equilibrium with the surrounding air, and hydrometeors drag the atmosphere as they fall. My research group has focused on the moist thermodynamics of TCs beyond the radius of maximum winds; we are interested in the entire system as a heat engine. Laurel Regibeau-Rockett led several studies on how the mechanical efficiency of the cyclones and other tropical convection will change as sea surface temperatures (SSTs) increase. In a study along with NYU's Olivier Pauluis, who pioneered some of the tools and frameworks for studying the entropy budget of moist convection, she found that TCs should become less efficient heat engines as SSTs increase (see **Figure above**). This makes intuitive sense: the Clausius Clapeyron relation tells us that water vapor content increases 6-7% per degree of warming, meaning that there is more potential for irreversible processes to reduce the energy available to drive the cyclone wind field. TCs did get stronger in our simple simulations with warmer SST; but they got much more irreversible as well. That latter rate outcompeted the former, leading to a decrease in mechanical efficiency of the overall cyclone.

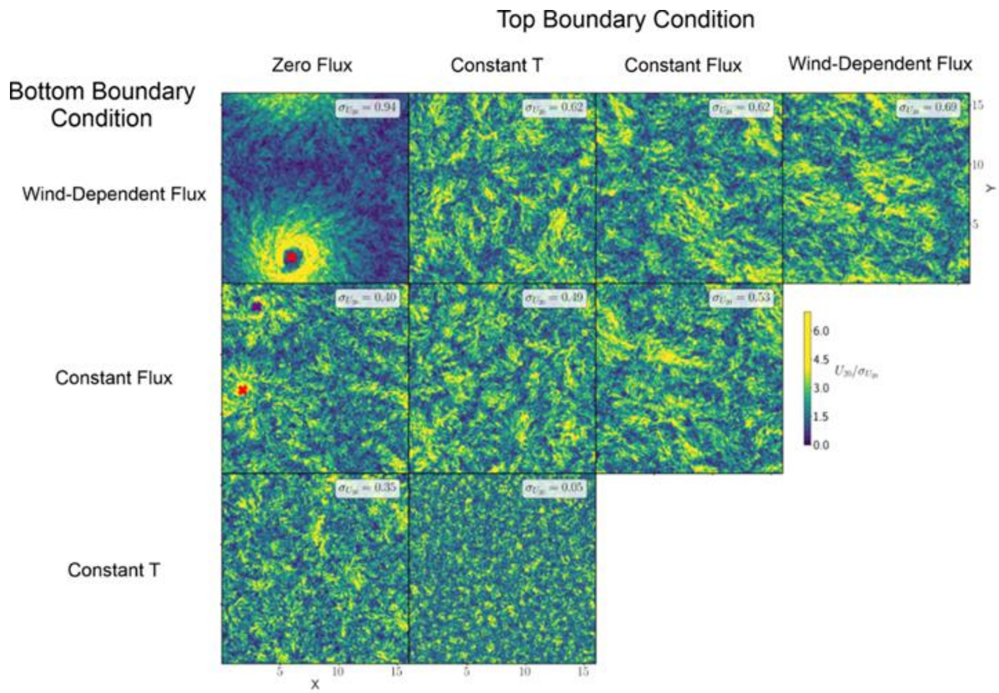
Another interesting fluid dynamical problem is wave breaking above the cloud tops of TCs. They are among the tallest and most energetic storms on Earth, and they drive poorly-understood mixing in the upper troposphere/lower stratosphere (UTLS) region. This mixing is responsible for moving tracers like water vapor, ozone and aerosols between the two layers of atmosphere, and it is not well characterized by existing parameterizations. Only recently have numerical simulations been able to marginally resolve what appears to be the relevant dynamics up there; I suspect that horizontal grid spacing of no worse than 500 m is necessary to capture the wave breaking responsible for this mixing. This is a highly three-dimensional, time-evolving problem, where you need to simulate the whole storm just to find a few sparse, extreme mixing events at the UTLS. There is no accepted consensus on the order-of-magnitude of the positive stratospheric water vapor feedback yet, so this is an interesting climate problem too.

III. Physics of the Air-Sea Interface in Tropical Cyclones

Kerry Emanuel

While most scientists outside of the tropical cyclone (TC) physics community still believe that these vortices are a form of organization of deep, moist convection, research over the last few decades has shown that they are directly driven by enthalpy fluxes from a liquid or solid surface that is not in thermodynamic equilibrium with a fluid above it. In the case of the Earth, this disequilibrium is the result of the jump in infrared emissivity between the ocean and an atmosphere in approximate radiative-convective equilibrium. TCs only happen when the system is also rotating, the flow near the boundary is already fully turbulent, and the surface is "rough" in the sense that turbulence, rather than molecular diffusivity, limits the enthalpy flux through the boundary. In these conditions, the enthalpy flux depends on both the degree of thermodynamic disequilibrium, and the macro wind speed near the surface. It is the wind-dependence of the surface enthalpy flux that makes TCs possible.

The **Figure to the right** displays snapshots in the horizontal plane of the wind speed in numerical experiments of rotating parallel-plate convection at very high Rayleigh Number. Each snapshot is for different combinations of upper and lower thermal boundary conditions. Only the simulation with wind-dependent enthalpy flux and the lower boundary, and no flux at the top boundary, produces TCs (upper left subplot). There is no phase change of water in these simulations, disproving the idea that these vortices are driven by internal phase changes.



Velez-Pardo, M., and T. W. Cronin, 2023: Large-scale circulations and dry tropical cyclones in direct numerical simulations of rotating Rayleigh–Bénard convection. *Journal of the Atmospheric Sciences*, **80**, 2221–2237

One important problem that confronts those who would model real TCs is that much of the surface enthalpy flux that drives these storms occurs in conditions of extraordinary surface wind speeds. Under such conditions, the air-sea transition tends toward an emulsion, with bubble-filled water grading to spray-filled air. Numerous efforts to understand heat and momentum fluxes through such a transition layer, employing laboratory apparatus, similarity theory, direct numerical simulations of two-phase fluids, and even field measurements in real hurricanes, have yielded only highly uncertain estimates of transfer coefficients. Arguably our best estimates of these coefficients come from what wind-speed-dependent values are needed to make accurate numerical hindcasts of real storms. This hardly constitutes a deep understanding. I hope that physicists and others will recognize this as a problem of deep, inherent scientific interest and great potential utility.

IV. Hurricane Evolution Forecasting
Suzana J. Camargo

Given the large dangers associated with hurricane hazards (winds, storm surge, rainfall), accurate hurricane forecasts are essential. In the last decades there has been substantial improvement in the forecasting of hurricane tracks and landfall locations, associated with hurricane movement, with the forecast errors exhibiting a large decrease. The lead times that are feasible to issue skillful track forecasts have also extended as these forecasts improved. In contrast, while the forecasts of hurricane intensity (winds) have improved, the progress has not been following the same pace as for hurricane tracks. One of the reasons is that the processes associated with hurricane intensity are very complex and involve dynamical (e.g. angular momentum) and convective coupling, in particular eyewall replacement. During an eyewall replacement, the original eyewall of the hurricane (where the strongest winds occur) weakens, as new eyewall forms further from the center of the storm and eventually replaces the inner eyewall and the storm re-intensifies. Forecasting the exact timing and duration of these processes is extremely challenging, but can determine how strong the hurricane will be at the time of the landfall as it interacts with the coastline and can impact the coastal population and infra-structure.

There has also been significant progress in forecasting the rainfall amounts associated with hurricanes, but the evaluation of this aspect of the forecasts is not routine, as track and intensity. Only in the last few years forecasts of storm surge heights became standard, and the skill of these forecasts improved. There is certainly still room for improvement of storm surge forecasts in the next few years.

Improvements in hurricane forecasting rely on progress in multiple fronts: new theoretical understanding of the how hurricanes behave, better numerical weather forecasting models and data assimilation methods, increase in the number of and quality of observations collected and made available for data assimilation, from satellites to dropsondes, as well as drones.

As in all other aspects of our life, in the last couple of years the value of AI for improving hurricane forecasts was made abundantly clear. In 2025, AI based models, from private industry as well as from weather centers performed extremely well in forecasting hurricane tracks, in some cases better than traditional numerical weather prediction models. While this is certainly a new and important frontier, it is important to continue to invest in the improvement of the standard numerical weather models, as well as in obtaining new observations. Historically we learned that the combination of multiple techniques and approaches tend to lead to the largest probability of making huge leaps in the progress in atmospheric sciences and forecasting.

Brief Report: Kavli Institute Program on Soft Earth Geophysics

Field trip exploring debris basins from the Montecito debris flow in January 2018

From January-March of 2026, the Kavli Institute for Theoretical Physics at the University of California, Santa Barbara hosted a program on "Soft Earth Geophysics." The program was organized by Profs. Doug Jerolmack (UPENN), Nathalie Vriend (CU Boulder), and Vashan Wright (Scripps Institute). Several GPC members participated in the program as residents for 2-4 weeks. The defining theme of the program is that Earth's surface is "…a thin skin of particulate and living material that is fragile, excited by a broad spectrum of perturbations, and flickers across metastable states." Understanding this soft earth is existential and necessary to manage the risk of increasingly dangerous natural hazards such as landslides and earthquakes. Some of these hazards are directly impacted by climate change. For example, wildfires, debris flows, and other consequences of extreme weather are much more likely in a warming climate.

The workshop was kicked off with a 4-day conference from January 6-9, 2026. As is tradition for KITP programs, all talks are posted online. The conference (and the program) featured physicists, engineers, earth scientists, modelers, experimentalists, theorists, and field scientists. Topics ranged from the rheology of glacial ice to the forecasting of landslides. Jill Marshall (Portland State) discussed the cracking of rock from tree roots, which are stressed due to winds on the tree canopy. Many talks brought ideas developed in the physics community over decades, and applied them to messy, complex, real-world problems. A key theme underlying the discussion was that climate change is bringing these problems front and center. Increasing rainfall affects forests, deserts, and glaciers. Everyone recognized the need to draw more early career researchers into these interdisciplinary fields.

Prominent examples of this are debris flows that follow wildfires. In January 2018, a rapid period of rainfall occurred after wildfire in Montecito, California (near Santa Barbara). Wildfires cook the soil and make it especially hydrophobic. Intense rain is barely absorbed by the soil, and the runoff can form fast-moving and damaging debris flows full of mud and boulders about the size of small automobiles. The debris flow in Montecito killed 23 people and caused nearly 200 million dollars in damage to homes and property. During the program, Prof. Doug Jerolmack led a field trip for participants to the site of the debris flow, where evidence was abounded. For many participants, this was their first foray into the field to see first-hand the consequences of extreme weather.

Supporting Eunice Newton Foote Award Endowment

In the fall of 2023, the APS Topical Group on the Physics of Climate (GPC) proposed to establish the first APS prize recognizing climate physics research. Eunice Newton Foote (1819-1888) was a trailblazing female scientist, and a suffragist who lived in upstate New York and worked with Susan B. Anthony and Elizabeth C Stanton. She pioneered the investigation of radiative effects of water vapor and carbon dioxide, presaging the discovery of the greenhouse effect. Foote was the first to demonstrate the ability of atmospheric water vapor and carbon dioxide to absorb and be heated by solar radiation. Her work, which pre-dated John Tyndall's discovery of the greenhouse effect, fell into obscurity only to be recognized over 100 years later and is now widely regarded as one of the most significant early discoveries in climate physics. APS GPC is currently one of the few APS units without an APS-level prize, nor is there APS-level prize honoring research in climate physics.

The Eunice Newton Foote Award will be an endowed award and will carry a monetary prize each year for the award winner. It will contribute to building the climate research community and honor the wide range of physicists who have, are, and will contribute to addressing fundamental scientific, technological, and social problems.

For 2026, the GPC will continue to fundraise for the inaugural award. This prize will establish the importance of climate research in the physics community, as from the early days of climate science, physicists made major contributions to the field. Climate change is one of the biggest challenges of our time, and scientific research and teaching are critical to addressing climate change. Climate science is an interdisciplinary field, and physics is one of the core climate science disciplines. APS GPC is currently one of the few APS units without an APS-level prize, nor is there an APS-level prize honoring research in climate physics. Now, the award is biennial, meaning that we are only $52k away from reaching our goal ($75k). We encourage all GPC members to consider donating to this important cause, and to solidify Eunice Foote's legacy with the APS community. For more information about donations, please see the website, or contact Vice Chair elect, Justin C. Burton.

JOINT MARCH MEETING AND APRIL MEETING
APS Global Physics Summit

This year's Global Physics Summit will take place March 15-20 in Denver, Colorado, consisting of both in-person and virtual components.

There will be a **GPC Invited Session** and two **GPC Focus Sessions**, detailed below, all taking place on Monday, March 16.

We will also offer a tutorial on Sunday, 15 March, titled Cross-disciplinary physics for understanding climate. Our speakers will show how applications from the fields of condensed matter, fluid dynamics, quantum mechanics, AI and soft matter have helped drive important discoveries in climate physics. Attendees will be provided with datasets and scripts that will allow them to continue exploring these methods at home.

The GPC Business Meeting will take place 6:45-7:45 pm in the evening of Monday, March 16. The "Climate Café" will take place following this meeting.

Closely related is a **Round Table discussion** Physics and Climate: The Past, Present, and Future from 10:00-11:00 am on Tuesday, March 17 in Convention Center Room 712. During this event, APS Editors of the Physical Review journals will engage with invited scientists and participants to discuss the unique challenges and opportunities in the study of climate and Earth's sustainability, an inherently multidisciplinary field with critical applications for our planet's future. The panelists will be APS President Brad Marston (Brown University), Morgan O'Neill (University of Toronto), Valerio Lucarini (University of Leicester), and the discussion will be moderated by Serena Dalena (Physical Review Letters, Senior Editor).

GPC Invited Session: The Extraordinary Science of Canceled and At-Risk Climate Programs

Session MAR-B03, 12:00 pm –3:00 pm MST, Monday, March 16

CHRISTOPHER W. O'DELL
Cooperative Institute for Research in the Atmosphere
Colorado State University
Fort Collins, CO

Title: The Scientific and Societal Importance of the Orbiting Carbon Observatories

Synopsis: In July 2014, under foggy skies, the second Orbiting Carbon Observatory (OCO-2) satellite successfully lifted off from Vandenberg Air Force in California into low earth orbit, following the failed launch of the original OCO satellite in 2009. It was followed by the installation of its near twin, OCO-3, on the International Space Station in 2019. Together, OCO-2 and OCO-3 measure and monitor two primary aspects of the earth's carbon cycle, the column-mean concentration of carbon dioxide (XCO_2), and Solar-Induced chlorophyll Fluorescence from terrestrial plants (SIF). The OCOs make these measurements with their high-spectral resolution near-infrared spectrometers, which measure the spectra of reflected sunlight in three spectral bands centered on 765 nm, 1610 nm, and 2060 nm wavelength. OCO-2 and OCO-3 are funded and managed by NASA, and have been making measurements for over 11 and 6 years, respectively. Further, both instruments are healthy and should be able to continue observations for many years to come.

In this presentation, I will discuss the importance of these measurements, from both a scientific and societal point of view. NASA's space-based measurements of XCO_2 and SIF have led to a much-improved understanding of carbon uptake by the land biosphere, a key service by the earth to limit the growth rate of atmospheric CO_2. They have led us to be able to better predict agricultural-relevant quantities such as crop yields and flash droughts. We have quantified mean biospheric uptake of CO_2 from dozens of the larger nation-states on earth, helping to better quantify their total carbon emissions. Crucially, this success has led to a large international effort to build next-generation satellite instruments based on the same technology, but with significantly enhanced capabilities related to spatial sampling and coverage. Continuing to operate these uniquely-capable satellite instruments will enable us to continue measuring and monitoring critical aspects of the earth's carbon cycle for years into the future, bridging the gap until the next-gen instruments come online.

OCO-2 maps sources of carbon dioxide emissions. Credit: NASA Jet Propulsion Laboratory

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ARLYN ANDREWS
Silver Lining

Title: Towards a Wholistic and Sustainable Atmospheric/Earth Observing System

Synopsis: US and global Earth observation capabilities have evolved dramatically since the International Geophysical Year of 1957/58, which kickstarted an era of exploration and discovery. Many satellite and *in situ* measurement techniques and data analysis systems are mature and support operational applications for Numerical Weather Prediction (NWP) and beyond. Computing and communications have kept pace with sensor development, and we are well into the age of "big data" and machine learning/AI. Societal benefits and technological potential for expanded and sustained observations now far exceeds available government resources, and this situation predates recent efforts to reduce federal spending by cutting programs and

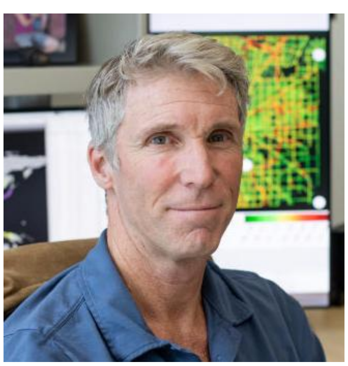
SOAR: Aircraft and Ships of Opportunity

reducing the federal workforce. For example, the 2017 Decadal Survey of Earth Science and Applications from Space identified many more high-value observables than can realistically be supported by the US government in the foreseeable future and did not attempt to define or scope critical *in situ* observations. We will present examples of potential new, targeted atmospheric observations to support climate science, applications, and decision support, including measurements of aerosols, greenhouse gases and radiation, with emphasis on the use of platforms of opportunity (e.g., cargo ships and commercial aircraft) and emerging mechanisms for engaging private sector and philanthropic partners. We will focus on the feasibility and potential for expanded "reference quality" measurements to anchor the atmospheric observing system and unlock unrealized potential value of existing and candidate new observations, by ensuring compatibility across sensors and platforms over timescales of decades.

GEOFFREY K. VALLIS
Department of Mathematics
University of Exeter, UK

Title: Weather and Climate Research at National Laboratories: Benefits to Science and Society

Synopsis: The national science laboratories in the USA have played an outsize role in advancing weather and climate science over the last half century, both in developing the tools we use and in the discoveries made. For example, the General Circulation Models developed at these labs have enabled quantitative predictions of the future climate to be made, classes of organized tropical weather systems were first identified at the labs, and the development of Lidar (now commonly used in robo-taxis like Waymo) was accelerated through its early use and development for cloud observations. In this talk I will discuss a small sample of these contributions, and how they have advanced science and benefitted society.



KEVIN R. GURNEY
Northern Arizona University
Flagstaff, AZ

Title: Neighborhood scale greenhouse gas and heat emissions in the Southwest Integrated Field Laboratory experiment

Synopsis: Accurate estimation of greenhouse gas and anthropogenic heat emissions are increasingly important for decisionmakers at sub-national scales where both the impacts and preventative measures are most acutely felt and mitigated. As part of the Southwest Integrated Urban Field Laboratory (SWIFL), one of four large multi-institutional research efforts awarded by the Department of Energy, the SWIFL project was focused on modeling, observing, and linking extreme heat, air quality, and greenhouse gas emissions to practical decision-making and resilient solution engagement with three of the largest cities in the state of Arizona. As a consequence of changing priorities at the Federal scale, the funding support for this and all the IFL experiments was cut slightly over midway through the five years of funded research. I will share the outcomes achieved in the abridged research timeline, focusing on our efforts to better quantify and understand both greenhouse gas emissions and anthropogenic heat production at extremely fine space and time scales for the cities of Phoenix, Tucson, and Flagstaff Arizona. The research shows a surprisingly large amount of heat from the on-road sector driven by the rapidly expanding vehicle miles traveled in these growing Southwest cities. The growth pattern in the Phoenix urban area in particular shows traditional emission results from urban sprawl and associated extensivity. Finally, I will present new AI-enabled sensing of onroad vehicular composition which relied on citizen science volunteers throughout the state of Arizona. This has implications for the accuracy of decades of vehicular modeling in the U.S.

LYNNE TALLEY
Scripps Institute of Oceanography
UC San Diego

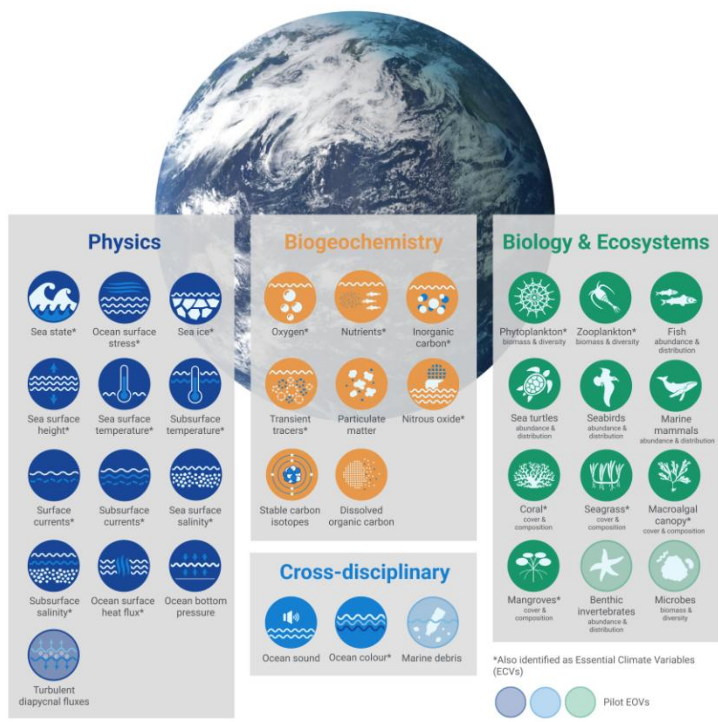
Title: Sustained ocean observations in the Global Ocean Observing System: societal and scientific importance and challenges for long-term operations

Synopsis: The Global Ocean Observing System (GOOS) is the international network of sustained ocean observation programs that provide long-term, accurate, public data sets that are critical for a wide range of applications. Over many years, GOOS has developed a clearly defined set of Essential Ocean Variables (EOVs), and their required accuracies and sampling strategies, that are fundamental to documenting physical, chemical and biological ocean processes on time scales from weeks to centuries.

The two GOOS networks that provide global interior ocean coverage are highlighted: OneArgo and GO-SHIP (Global Ocean Ship-Based Hydrographic Investigations Program).

OneArgo plays a central role in tracking and predicting sea level change, ocean heat and carbon content, acidification and deoxygenation, through frequent autonomous profiling throughout the ocean basins. For more than 20 years, Argo has provided global coverage of temperature and salinity, which has become essential to ocean, climate and weather forecasting services. Expansion over the last 10 years to global BGC sensor coverage is already transforming ocean biogeochemical and ecosystem state evaluation and forecasting.

GO-SHIP ship-based data are the global source of information about deep ocean warming and biogeochemical change. Data are collected along transects of the ocean basins, from the ocean surface to ocean bottom, on approximately decadal time scales. GO-SHIP's global, highest-accuracy, multi-parameter, full



GOOS Essential Ocean Variables

water column measurements complement and serve as a reference for other ship measurements, profiling floats and other autonomous systems, including OneArgo. OneArgo and GO-SHIP provide reliable, public and easily accessible data, similar to atmospheric data that are also collected in a sustained manner. Both networks have essential evolution of technology. Both rely on personnel who have strong commitment to maintaining the continuity and excellence of the observations.

International observing systems face major challenges with sustaining funding. The US provides about 50% of the global effort in OneArgo and GO-SHIP, which means that continuity of US funding is essential for their health. Potential impacts of funding deficits on the essential products of these observing systems will be discussed.

GPC Focus Session: Radiation and Clouds: From Microphysics to Geoengineering

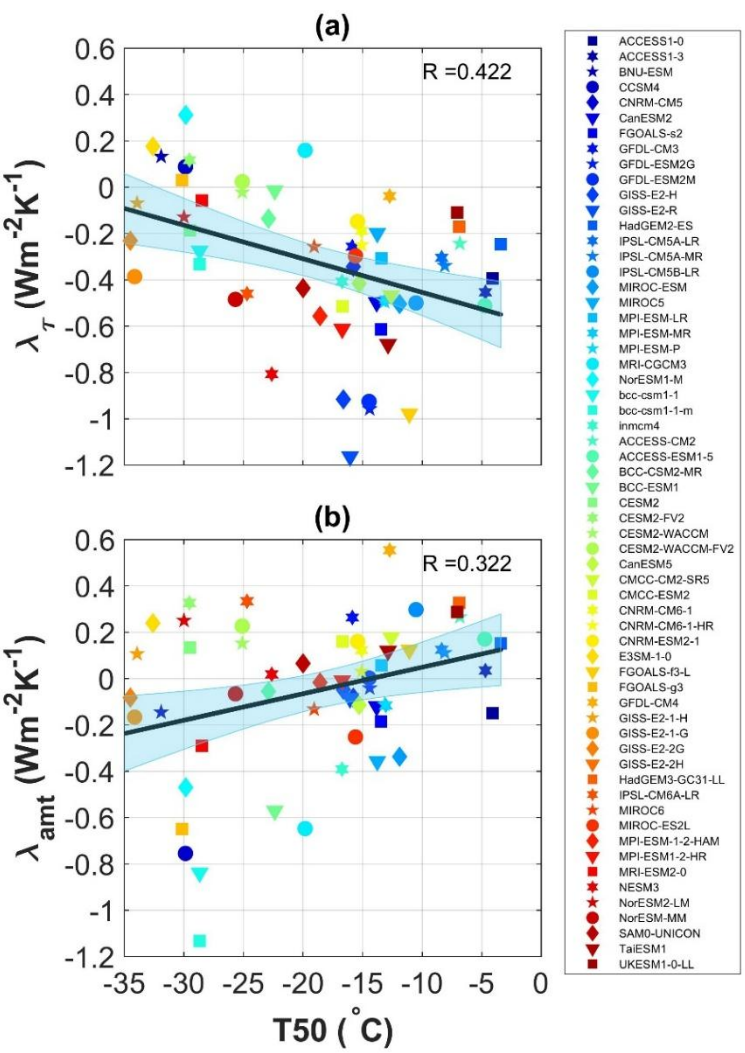
Session MAR-A52, 8:00 am –10:48 am MST, Monday, March 16

Invited Talks:

IVY TAN
Department of Physics
University of Colorado, Boulder

Title: Cloud Microphysics, Radiation, and Arctic Warming: The Tug-of-War Between Cloud Amount and Cloud Opacity

Synopsis: The Arctic is warming at roughly four times the pace of the rest of the globe, a phenomenon projected to persist through at least the end of the 21st century. While reductions in surface albedo are widely recognized as the primary driver of Arctic amplification, clouds remain the largest source of uncertainty in projections of future Arctic warming. In particular, it is unclear whether clouds will ultimately amplify or dampen surface warming. This uncertainty stems from limited understanding of key ice cloud microphysical processes – such as ice nucleation and secondary ice production – that determine cloud extent and optical properties, as well as from the scarcity of long-term, consistent satellite and *in situ*



Changes in shortwave radiative fluxes at the top of the atmosphere, due to changes in (a) cloud opacity and (b) cloud cover, in response to surface warming as a function of the temperature at which half of clouds are glaciated (abscissa) in Earth's extratropics. Each data point represents a climate model participating in the fifth and sixth phases of the Coupled Model Intercomparison Project (CMIP). The negative slope in panel (a) shows that cloud opacity increases in response to a warming perturbation which acts as negative feedback to cool the climate system when clouds tend to rapidly glaciate. This is offset by the positive slope in panel (b) which shows that cloud cover decreases in response to a warming perturbation which acts as a less negative or more positive feedback to heat the climate system when clouds tend to glaciate more rapidly.

observations of cloud properties in the Arctic.

In this talk, I present a new 21-year dataset of cloud opacity derived from measurements by the U.S. Department of Energy's Atmospheric Emitted Radiance Interferometer (AERI) at the North Slope of Alaska that offers superior observations of low-level clouds compared to satellite-based measurements by virtue of its surface-based perspective. By analyzing these data alongside complementary ground-based remote sensing observations, we assess how changes in both macroscopic and microphysical cloud properties have contributed to regional Arctic surface warming. We find that cloud opacity decreases with warming during winter and summer but increases more strongly during autumn and spring, leading to a net surface cooling from opacity changes. On an annual-mean basis, however, reductions in low-level cloud coverage dominate the cloud contribution to net surface warming, with this effect partially offset by summertime decreases in ice particle size.

Together, these results reveal a "tug-of-war" between cloud fraction and cloud opacity in the Arctic, which operates in the opposite direction to that simulated by over 60 climate models participating in the fifth and sixth phases of the Cloud Model Intercomparison Project used to inform the IPCC reports. Our findings provide a valuable observational constraint for evaluating and improving the representation of cloud microphysics and cloud–radiation interactions in climate models.

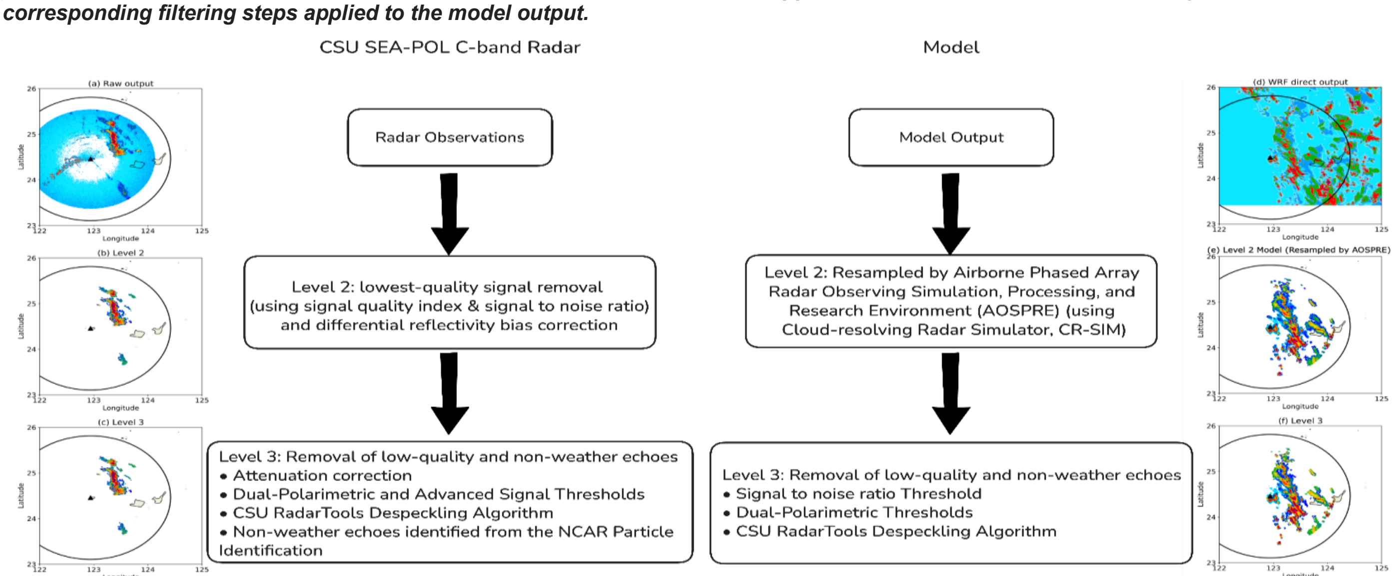
TING-YU CHA
NSF NCAR
Boulder, Colorado

Title: Advancing Tropical Maritime Convection Prediction: An Integrated Modeling and Observation Approach

Synopsis: Accurate Earth system prediction relies on both models and observations, yet both sources possess distinct uncertainties. Models are limited by initial condition errors and structural deficiencies in physical parameterizations. These deficiencies are especially magnified in tropical maritime environments, where physics parameterizations may misrepresent key processes given their primary development for mid-latitude continental systems. Concurrently, observations are subject to instrument limitations, retrieval algorithm assumptions, sampling biases. Consequently, standard merging techniques like statistical bias correction and data assimilation often fail to account for this full spectrum of uncertainty.

To address this, the NSF NCAR INFORM initiative facilitates a better integration of observational datasets with community models.

Flowchart and results illustrating the Quality Control (QC) procedure for CSU SEA-POL C-band radar observations and the proposed filtering algorithm for model output data. In the figure, the triangle represents the SEA-POL radar location, the circle denotes the 150 km radar detection range, and the shading represents the radar reflectivity. Both the radar QC and the model filtering protocols follow the three-stage process outlined in the flowchart. The left column demonstrates the results applied to the SEA-POL data, while the right column shows the corresponding filtering steps applied to the model output.



In this invited talk, we present an observation-informed workflow that rigorously addresses uncertainties in both sources to diagnose and correct model bias. We focus on a tropical maritime squall line observed during the 2022 PRECIP field campaign.

First, we address the gap between model physics and observational reality. To account for uncertainties in observational quality control and sampling, we process model output through the CR-SIM forward operator and apply identical quality control to real SEA-POL radar observations. This observation-informed approach reveals that a microphysics scheme overestimates raindrop size due to a misrepresentation of the efficient breakup characteristic of tropical maritime convection. Targeted corrections to these processes substantially reduce model bias.

Second, we broaden this investigation by examining multiple microphysics schemes to quantify their impact on the representation of tropical maritime convection. We aim to leverage internal characteristics—specifically radar-observable microphysical properties—to diagnose and correct systematic biases. By constraining these internal processes, we evaluate how observation-informed physics improvements propagate upscale to enhance the simulation of convective organization and longevity. This analysis demonstrates how our workflow guides targeted corrections, ensuring the simulated storm structure aligns with the observed state.

Contributed Talks:

Trude Eidhammer	Understanding Sensitivity of Climate with Perturbed Parameter Ensembles
Ian Norwood, Kyle Gorkowski, Claudio Mazzoleni	Quantifying Electric Field Effects on Coarse Dust Settling in a Controlled Dust Plume Environment
Ju-Hye Kim, Ethan Gutmann	How well do numerical model simulations reproduce the diurnal cycle of radiation, valley wind, and cloud cover in the Colorado East River Basin?
Xiyue Zhang, Bijita Thapa Magar	Understanding the Observed Bimodality of Arctic Winter Boundary Layer States
Brad Marston, Daniel Ibarra	Removing atmospheric carbon dioxide using large land areas will change earth albedo and force climate
Ilaria Quaglia, Simone Tilmes, Charles Bardeen, Francis Vitt, Sandro Vattioni, Timofei Sukhodolov, Gabriel Chiodo, Yunqian Zhu	Implementation of stratospheric injections of solid particles in WACCM6-CARMA

GPC Focus Session: Climate Physics: Insights from Theory, Models, and AI

Session MAR-C52, 3:30 – 6:18 pm PST, Monday, March 16

Invited Talk:

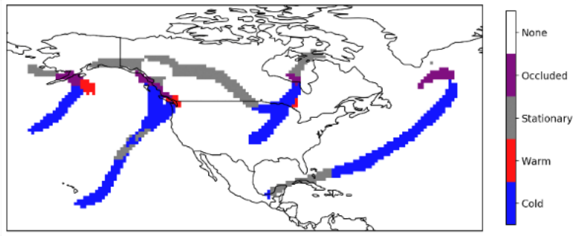
KATIE DAGON
NSF NCAR
Boulder, Colorado

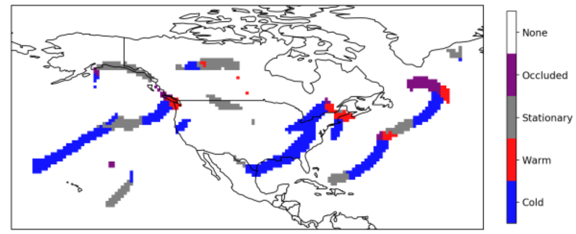
Title: Machine Learning for Climate Modeling

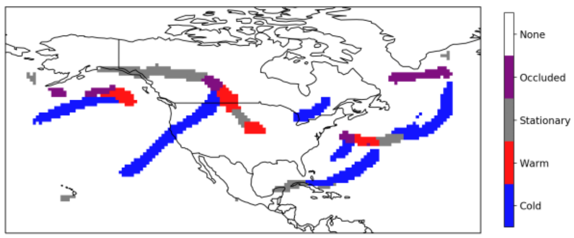
Synopsis: Climate models are essential tools for understanding Earth system processes and feedbacks. In this talk I will discuss two examples of how machine learning can be applied to further climate science research using climate models.

First, I will discuss a machine learning-approach to emulation and parameter calibration with a land model. Using a perturbed physics ensemble of model simulations, we train an emulator to predict model output given a set of land parameters as input. By comparing the emulated model output with biophysical observations, we can optimize parameter values and help constrain emergent features of the climate system such as the land carbon sink.

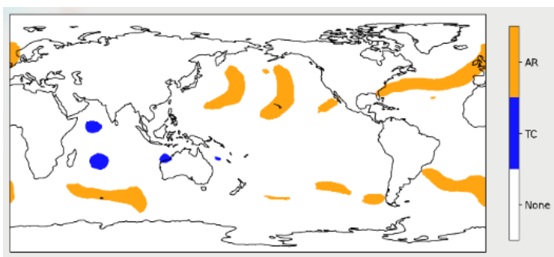
Second, I will discuss work using machine learning to automatically detect weather features that produce extreme precipitation events. Here we use a suite of deep learning algorithms to identify fronts and atmospheric rivers in a climate model and evaluate the results using observational and reanalysis products. To study how these features might change with climate change, we compare results between model simulations using present-day and future climate forcing.

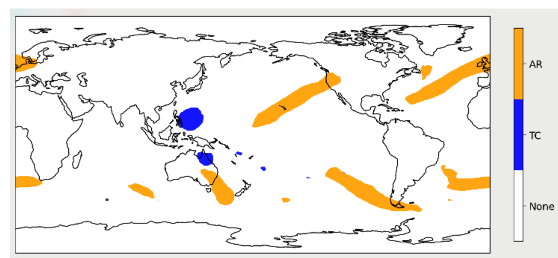


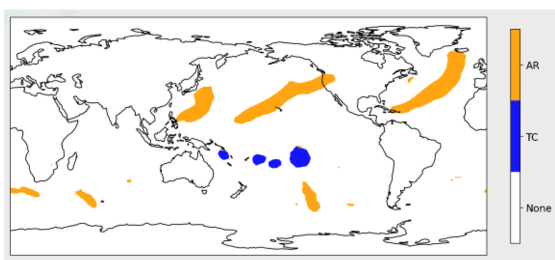




Weather front snapshots of four different types (cold, warm, stationary, and occluded) over North America detected in the output of a Community Earth System Model simulation using a deep learning algorithm. Fronts shown here are taken from a larger set detected at 3 hourly increments over one month of simulation output in January 2000.







Snapshots of atmospheric rivers (ARs) and tropical cyclones (TCs) detected in the output of a global Community Earth System Model simulation using a deep learning algorithm. Events shown here are taken from a larger set detected at 3 hourly increments over approximately one month of simulation output from January-February 2000.

Contributed Talks:

Pedram Hassanzadeh, Amaury Lancelin, Alex Wikner, Dorian Abbot, Jonathan Weare, Freddy Bouchet, Willow Stenglein, Y. Qiang Sun, Laurent Dubus	Teaching AI weather models to forecast gray swan extreme events
Vandana Singh	Physical Climate Storylining in the Introductory Undergraduate Classroom: a transdisciplinary approach
Joseph J. Trout, Maxim Wunder, Gabriel Tagiaroli, Olivia Williams	Using Surface Temperature Data to Teach Data Time Series Analysis
Perrin Wesley Davidson, Daniel Rothman	Nonlinear mechanism of climatic variability
Cyrus Cooper Taylor	A Simple Model to Understand and Assess the Increase in the Earth's Energy Imbalance
William D. Collins, Ankur Mahesh, Travis O'Brien, Paul Goddard, Sinclair Zebaze, Shashank Subramanian, James Duncan, Oliver Watt-Meyer, Boris Bonev, Thorsten Kurth, Karthik Kashinath, Michael Pritchard	Examining Earth's Fast Radiative Feedbacks Using Machine-Learning-Based Emulators of the Climate System
Anna Kathryn Pauls, Colin Towery, Peter Hamlington	Simulations of stratified aqueous plumes dispersion at the submesoscale
Valerio Lucarini, Yuzuru Sato, Chiara Maiocchi, Andrey Gritsun	Heterogeneity of the Attractor of the Lorenz '96 Model: Lyapunov Analysis, Unstable Periodic Orbits, and Shadowing Properties