GPC Newsletter

Issue #19

February 2023

APS TOPICAL GROUP ON THE PHYSICS OF CLIMATE

IN THIS ISSUE

Message from the Editor

This is the nineteenth 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 GPC Chair

Hussein Aluie, U. Rochester

GPC had a great year in 2022 and we look forward to new prospects in 2023, including a rich program on climate physics at the upcoming APS March meeting and several new initiatives. In this write-up, I will attempt to give a brief update on our collective efforts.

Leadership Team: Working with GPC colleagues has been one of the most gratifying aspects of my tenure within the executive committee since joining in 2021. I am grateful for the enthusiasm and comradery that permeates our functioning, which is a fun team effort. (Continued on p. 2)

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. (Continued on p. 3)

ARTICLE: Topology in the Climate System

J. B. Marston, Brown University

Topology is the branch of mathematics concerned with the qualitative shapes of objects that remains unchanged under continuous deformations. The topological equivalence of a donut and a coffee mug (both have a single hole) is a commonly mentioned example. Another example, more closely connected to the phenomena discussed below, is known as the Hedgehog Theorem that says that it is impossible to comb the spines of a hedgehog (because there will always be at least one tuft). Similarly, if your head were a donut instead of spherical in shape, you could comb your hair smoothly without making a part –- however only the staidest individuals would make that choice. (Continued on p. 4)

Welcome from the GPC Chair

(Continued from p. 1)

I wish to thank our outgoing Past-Chair Mary Silber for her service during the past 4 years, steering the GPC during the pandemic's darkest year, and recruiting an excellent slate of candidates who ran for GPC office in December 2022. Another special thanks to outgoing members-at-large Justin Burton and Albion Lawrence for having been supportive and instrumental to our functioning. I am appreciative of William Newman, who now serves as Past-Chair, for the collaborative atmosphere we have fostered and for serving at the helm of high-profile GPC initiatives.

I congratulate our newly elected officers of the executive committee. Geoffrey Vallis (Univ. Exeter) is now our Vice-Chair, and Tiffany Shaw (Univ. Chicago) and Keith Julien (CU-Boulder) joined as members-at-large.

APS March Meeting: GPC is organizing a half-day tutorial session on Sunday March 5, as part of the 2023 APS March Meeting program in Las Vegas, Nevada. It will review the basics of climate science, emphasizing fundamental physical principles and touching on climate impacts and areas for future research relevant for physicists. The session will be comprised of four 1-hour talks covering the basics of (i) Radiation Balance, (ii) Large-Scale and Global Circulation, (iii) Small-Scale Atmospheric Dynamics, and (iv) Future Prospects and Impacts. The instructors Nadir Jeevanjee (GFDL/Princeton), Tiffany A. Shaw, (U. Chicago), Allison Wing (Florida State U.), and Michael Mann (UPenn) are all renowned experts in climate research.

The first tutorial organized by the GPC took place in 2015, when our group was only three years old. A decision to organize another tutorial was made during the 2022 March meeting due to significant interest among physicists following the 2021 Nobel Prize in Physics and an APS Nobel special session, which GPC helped convene during the 2022 March meeting, to celebrate this achievement. An *ad hoc* Tutorial Committee was formed, which comprises William Newman, Valerio Lucarini, Xiyue (Sally) Zhang, Nadir Jeevanjee, Ching-Yao Lai, Albion Lawrence, and myself. Our session proposal to APS was promptly accepted. As per APS workings, registration for the session is separate from that for the March Meeting, but GPC is subsidizing the registration costs, so it is essentially free ($10) for GPC student members. APS student members can become GPC members for free.

On Sunday evening, APS is organizing the annual Kavli Symposium, which ia comprised of four 35-min invited talks under this year's theme *Frontier Physics from Atomic to Astronomical Scales*. Of special note is the talk by GPC founding member and former chair Brad Marston (Brown Univ.) on waves within the Earth Systems. The symposium is free and open to the public.

As detailed later in this Newsletter, the following day, Monday March 6, is packed with GPC events. We are organizing two focus sessions with six invited speakers and many contributed talks on topics ranging from atmospheric and oceanic circulation, air-sea interactions, and radiative transfer, to topological waves and pattern formation, to climate stability dynamics and response to forcings, tipping points, and extreme events. GPC is also co-sponsoring a focus session with DSOFT on Monday morning under the theme "Soft Matter Meets Climate Change." Monday evening at 7 pm, we will hold our annual Business meeting, which is open to everyone, including non-members and those not registered for the March meeting. Afterward, we will have the traditional Climate Café, a casual gathering open to all where we share food and drinks at a nearby venue (TBD).

We are currently in communication with APS to explore setting up a membership table for recruiting new members during these events at the March meeting.

GPC Seminar Series: Another GPC initiative that started in 2022 and continues into 2023 is the GPC virtual seminar series. It was borne from the need to better connect with the physics community beyond the annual March meeting. In 2022, we established an *ad hoc* GPC seminar series committee with Pedram Hassanzadeh as chair, alongside Tiffany Shaw, Ching-Yao Lai, and Albion Lawrence. The series was quite successful in 2022, with 1-hour seminars occurring monthly. We aim for the seminars to connect with physicists, including those in their early careers, who are interested in climate but who are not necessarily experienced in the subject. Therefore, we request that our invited speakers include sufficient introductory materials in the talks and discuss open problems physicists can contribute to, in addition to surveying new results and discoveries. The seminars have typically garnered between 100 and 200 live attendees over Zoom. In addition to being broadcast live, the talks are available on demand, with each having been viewed anywhere between ~200 and 500 times so far. The series resumes in 2023 with a seminar by Mara Freilich (Brown Univ. and Scripps) on February 15 at noon EST.

The seminar schedule is online at (https://engage.aps.org/gpc/resources/seminar-series), where you can also access recordings of past talks. You can also sign up for the GPC seminar mailing list, to receive communication regarding the seminars. If you would like to suggest a speaker or are interested in giving a talk yourself, please contact the committee members.

APS-DFD Involvement: GPC has made a sustained effort in the last several years to support and maintain a presence at the APS Division of Fluid Dynamics (DFD) annual meeting. The meeting features a broad range of fluid mechanics topics, including several sessions devoted to geophysical fluid dynamics. In 2020, GPC co-sponsored a mini-symposium on the topic of Fluid

Dynamics of Atmospheric Clouds, which was co-organized by former GPC treasurer and DFD fellow, Raymond Shaw. In 2021, GPC organized a special focus session, Planetary Flows in Climate, and co-sponsored an invited mini-symposium titled "Fluids Next: Environmental Turbulent Flows Under the Effect of Climate Change" featuring five invited speakers. Since 2021, GPC members-at-large Justin Burton, Ching-Yao Lai, and myself have helped sort all abstracts related to geophysical fluid dynamics. On a more casual note, we started a tradition in 2021, like the Climate Café, to bring together climate aficionados at the DFD in an informal setting on Monday evening of the conference.

If you attend DFD events and are interested in being involved in these efforts, please feel free to reach out to me.

Student and Early Career Prizes: For 2023, we have doubled the monetary value of the junior prizes to $1000 each. Deadline for applications is usually in December before the March meeting. The GPC Student Prize is given to a graduate student member of the APS who is pursuing work related to the GPC mission. The GPC Early Career Award is given to an early career investigator who is a member of the APS GPC. Both awards help defray the costs of attending and participating in a GPC related session at the March Meeting.

We are also entertaining ideas for establishing a named award to allow us to better engage with the wider community of physicists and climate scientists. If you have ideas or feedback, please contact me or anyone in the GPC leadership.

APS Fellows: I wish to congratulate our newly elected APS fellows Geoffrey Vallis (U. Exeter) and Michael Ghil (ENS). The number of fellows any APS unit can nominate is proportional to the unit's membership fraction of the total APS membership. GPC's number was increased from one (1) to two (2) in 2022. We are grateful for the efforts of GPC chair-elect Valerio Lucarini, who chaired the Fellowship Committee, along with committee members Claudia Cenedese, Tiffany Shaw, and Pedram Hassanzadeh, for their efforts to canvas an excellent slate of candidates.

GPC Membership: Our membership numbers fluctuate throughout the year due to lapsed and new members. As of October 2022, GPC had 593 members, which comprises 1.25% of the total APS membership. Discounting 2020 during the height of the pandemic, our membership has increased steadily since 2019 at an annual rate of approximately 5%. Approximately 40% are student and early career scientists, 40% are regular members, and 20% are senior or lifetime members.

I believe we have an opportunity to better connect with student and early career scientists who are trying to chart their career trajectory. For example, the Statistical and Nonlinear Physics group has approximately 1,300 members of which 50% are student and early career scientists. The Data Science group, which was only established in 2019, has approximately 1,500 members of which 70% are student and early career scientists. `Early career' according to the APS definition are those with < 5 years since graduating with their final degree.

Physical Review Journals: APS publications have been engaged with GPC regarding recent editorial restructuring decisions. We are thrilled that our Chair-Elect Valerio Lucarini has been appointed as an Associate Editor for Physical Review E. Valerio will handle PRE's section on Nonlinear Dynamics and Chaos, which now explicitly includes Climate Physics as a topic.

It is also gratifying to see that Physical Review Letters is also moving in this direction, creating a new "Physics of Climate" section of their editorial board. Pierre Gentine (Columbia) has been appointed as Divisional Associate Editor (DAE) to advise PRL Editors on matters related to that section, including evaluating formal author appeals and answering requests from the Editors for informal advice on cases. In practice, DAEs also serve by pointing the Editors toward interesting work in their field, which is especially important for bringing physicists closer to climate science. It is worth noting that our Chair-Elect Valerio Lucarini is also currently serving as an Associate Editor for PRL.

Involvement: I will end my letter with an invitation to anyone interested in helping to reach out to me or anyone else in the GPC leadership.

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 is June 1, 2023. For further information regarding fellowship nominations, please email fellowship@aps.org.

Student Prize and Early Career Investigator Award: Each applicant for these honors was asked to submit a CV, an abstract for a contributed talk at the March Meeting, and a short summary of how their work fits with the GPC mission. The qualified applicants were judged by how well their work fits with the GPC mission. The review was led by Chair-Elect Valerio Lucarini.

This year's GPC Student Prize was awarded to Brett A. McKim, a graduate student from the University of Exeter, UK. He studies the physics of Earth's climate using approaches that range from back of the envelope estimations to satellite observations.

His March Meeting presentation (Session A16: 012, *The Fixed Tropopause Temperature Hypothesis: FiTT for Purpose?*) will explore the theoretical foundation of the Fixed Tropopause Temperature hypothesis which states the temperature of the tropopause (the top of the troposphere) is independent of the surface temperature.

The GPC Early Career Investigator Award was awarded to Dr. Nicole Shibley, a Postdoctoral Fellow at the Princeton Center for Theoretical Science. She received her Ph.D. in Earth & Planetary Sciences from Yale University in 2021. Her research primarily focuses on ice-ocean interactions in Earth and planetary systems, investigating questions related to climate change on Earth and the possible habitability of Solar System bodies. She is also interested in the ventilation of buildings and how fluid dynamics may be used to develop more sustainable buildings with cleaner air. Her presentation at the March Meeting 2023 (Session B65: 002, *Polar Transitions: The Arctic Ocean's Diffusive Staircase*) focuses on a small-scale mixing and heat transport process (diffusive convection) whose observational signature may shed light on changing water mass properties of the Arctic Ocean.

"The Arctic is a critical part of Earth's climate system. I am grateful to have received the APS GPC Early Career Investigator Award to support presenting my Arctic research to a diverse audience of physicists at the 2023 March Meeting." – Nicole Shibley

"There is a longstanding connection between physics and climate that goes back to Joseph Fourier and continues today. That being said, there seems to be a cultural gap that prevents the two communities from interacting more harmoniously – a gap made all the more apparent when we compare to the relationship between physics and astronomy. Participating at APS March Meeting, and the GPC events in particular, would help me to reach across the aisle – to learn what physicists know about climate, what they want to know, and what inhibits them from learning more or even joining climate science." – Brett KcKim

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APS Leadership Conference Report

William I. Newman and Xiyue (Sally) Zhang

The American Physical Society convened a Leadership Conference in Washington, DC from January 25-27 of this year. William Newman, Past Chair, and Sally Zhang, Secretary/Treasurer, attended. The conference focused on two major issues that impacts, directly or indirectly, the APS. The first is that Diversity, Equity, and Inclusivity (DEI) remains a challenge. While not a fundamental issue within the APS and its activities, it does impact hiring practices and inclusivity in academic, governmental, and industrial environments. Many current APS leaders described situations where they witnessed examples of exclusion, based upon gender, ethnicity, and other issues, but also of elitism when it comes to assessing individuals who are first-generation university attendees or come from single parent families of modest income. The accounts we heard were nothing less than disturbing and a reminder to all of us to be aware of possible systemic bias in our day-to-day lives.

The second issue, which is especially important to us, is that there is a substantial amount of misinformation and, of greater concern, disinformation propagating in the media and online and it seeks to convince the ill-informed to accept ill-founded ideas. We came to learn how psychological factors such as cognitive dissonance and confirmation bias are often exploited. The APS presentations focused on engaging the ill-informed in a non-patronizing and sharing environment to overcome the improper notions that have influenced them. It is noteworthy that the APS has been running the Science Trust Project to provide its members with online training in how to overcome such biases. This material is quite relevant to climate science.

The conference also provided superb illustrations of how facts could be provided in an engaging way by blending the talents of scientists, artists and illustrators, and communications experts. Importantly, select speakers demonstrated how effective presentations could provide a very informative and insightful introduction to a highly technical topic without expecting the audience to be able to assimilate highly technical scientific data.

A superb keynote address was presented by Matt Mountain, president of the Association of

Universities for Research in Astronomy (AURA) which builds and operates telescopes and observatories for the NSF and NASA. Previously, he was director of the Space Telescope Science Institute and prior to that led the construction of and directed Gemini Observatory. Matt is also the Telescope Scientist for James Webb Space Telescope. He described in substantial detail how NASA assembled a team of scientists, visual artists and illustrators, and video presentation experts to provide a presentation of the findings of the new instrument that could be appreciated in an enthusiastic way by the general public. Or, as the columnist George F. Will opined in the Washington Post, "the Webb Space Telescope is telling the history of everything." While the JWST has been criticized by some in the media for its cost, the skill shown by the presentation team in communicating its broader significance led Will to conclude "The Webb Space Telescope speaks well of us precisely because it has, and needs, no justification beyond the purity of its service to curiosity."

This is a lesson that all of us need to learn in order to better communicate and educate the public regarding the significance of climate physics research.

GPC 2023 Executive Committee

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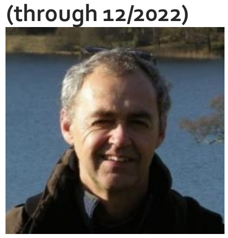
Vice Chair (through 12/2022)



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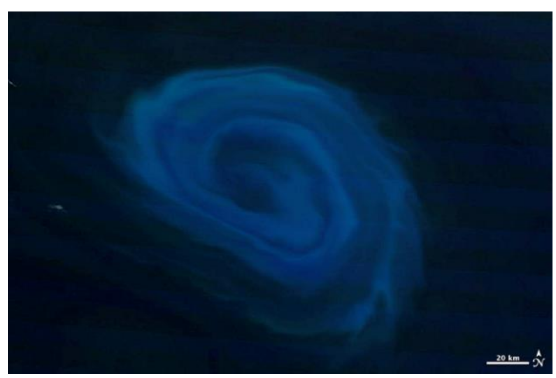
Article: Topology in the Climate System (Continued from p. 1)

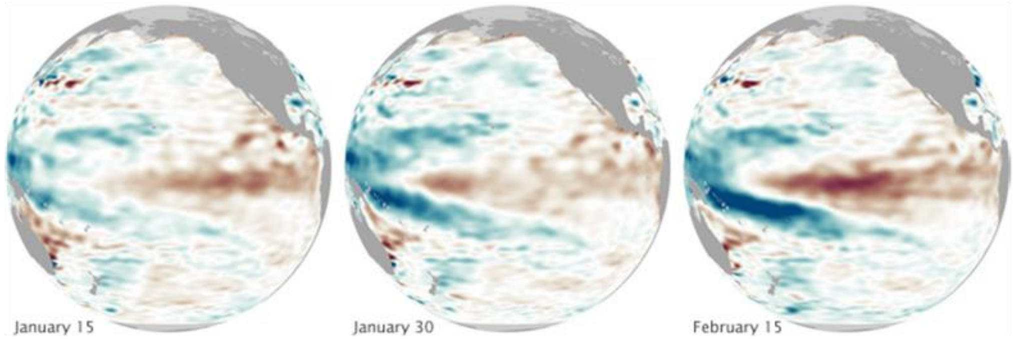
Topology is a powerful tool that turns complicated problems into simple ones, and fluids offer some compelling illustrations of topology at work. Vortex rings for instance show persistence that is rooted in topology. Clever experiments at the University of Chicago lab of William Irvine have shown that vortex rings can be tied into knots (see these videos). The persistence of vortex rings was striking enough for William Thomson (Lord Kelvin) to attempt to develop a theory of atoms based upon vortex rings in the hypothetical aether.

Kelvin's circulation theorem that states that the circulation (the line integral of the fluid velocity) around a closed loop that is advected with the fluid, and thus deformed by the internal motion, remains constant in the absence of viscosity and forcing. Tornados, hurricanes, Jupiter's red spot, and even cutoff low-pressure regions in Earth's atmosphere are all examples of persistent vortices. Vortices are also found in the oceans, spinning off the Gulf stream and other currents. Plankton trapped in the vortices make some of them visible from space (see photo at the right of one such vortex seen from space).



Plankton trapped in a vortex spinning off the southern end of Africa (image from NASA Earth Observatory).

Topology may also be applied to more abstract mathematical spaces. In work recognized by the 2016 Nobel Prize in Physics, David Thouless and his collaborators demonstrated that the



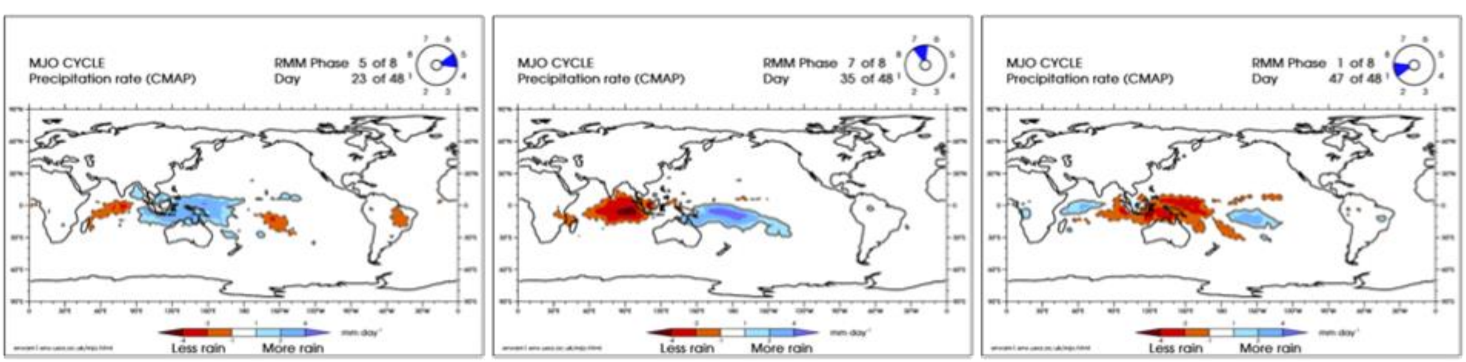
Satellite observations of the sea surface height anomaly reveal an eastward moving equatorial Kelvin wave at the onset of El Niño (NASA Earth Observatory).

quantized conductance of the integer quantum Hall effect can be understood mathematically in terms of the topology of complex-valued wavefunctions that live on a compact Brillouin zone **[1]**. The electrical Hall conductance is proportional to an integer Chern number that characterizes the topology of the wave functions. This quantization has a physical interpretation as electrical currents that propagate around the boundary of the semiconducting material in discrete modes, modes that owe their existence to the principle of *bulk-boundary correspondence*. The principle states that non-trivial topology away from a boundary implies the existence of unidirectional waves trapped along the boundary. The quantum of resistance, h/e^2, can be measured so precisely that it has now been adopted as the international standard of resistance.

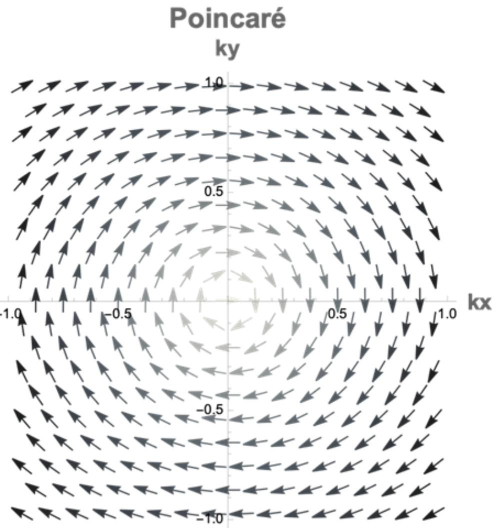
What does the quantum Hall effect have to do with Earth's climate? The Schrödinger equation is a wave equation, and much of what we understand about the climate system comes from recognizing the importance of waves in Earth's atmosphere and oceans. From planetary-scale atmospheric Rossby waves to small wind-driven waves at the ocean surface, waves are characterized by predictable periodic motion that contrasts with the broad-band randomness displayed by other aspects of the climate system. Early weather forecasting drew predictive power from the recognition of periodic wave motion. Mathematics analogous to that found in the quantum Hall effect has now found application to classical waves. Clearly Planck's constant does not play a role in classical waves and there is no quantization of transported quantities. Nevertheless, the principle of bulk-interface correspondence continues to hold.

Due to the breaking of time-reversal invariance by Earth's rotation, the Coriolis force plays a role like that of the magnetic field in the quantum Hall effect, and certain oceanic and atmospheric waves share fundamental physics with quantum matter, and topology plays an unexpected role in the movement of the atmosphere and oceans. The paper "Topological Origin of Equatorial Waves," co-written by the author **[2]** demonstrated that topology guarantees the existence of eastward propagating equatorial waves in Earth's climate system. There is a topological origin for two well-known equatorially trapped waves, the Kelvin and Yanai modes, caused by the breaking of time-reversal symmetry by Earth's rotation, that helps to explain the robustness of these waves against buffeting by the weather. This resilience is an important aspect of the robustness and predictability of El Nino variability (see figure above) and may also be important in other wavelike motion such as the Madden-Julian Oscillation (MJO) that propagates eastward along the equator (see figure below).

Delplace and Venaille have extended the reasoning to uncover the topological origin of coastal Kelvin waves **[3]**, waves that were first predicted by Kelvin in 1879 **[4]**. An important distinction between fluids and crystalline matter, however, is that fluids are continuous with no underlying periodic lattice. Continuous fluids have no Brillouin



Rain propagating eastward along the equator in the MJO [Adrian J. Matthews, Primary and successive events in the Madden-Julian Oscillation. Quarterly Journal of the Royal Meteorological Society 134, 439 — 453 (2008)].



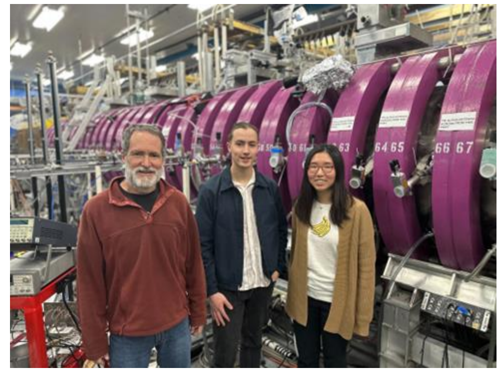
Arrows indicate the phase, and grey scale intensity the magnitude, of the complex number $\Xi = h(\boldsymbol{k})v(\boldsymbol{k})^*$ constructed from high-frequency normal mode components of sea surface height h and meridional velocity v of the linearized rotating shallow water equations. These Poincaré-gravity waves have a winding number of 1, and the winding number changes by two when one moves from the northern to the southern hemisphere. By bulk-interface correspondence we therefore expect two eastward propagating equatorial waves. These are the Kelvin and Yanai waves that were theoretically predicted in the 1960s but are now seen to have a topological origin.

zone (a mathematical construction formally characterizing the effects of periodicity on waves) so topological tools such as the integer Chern number that are well defined on compact Brillouin zones must be used with care (if at all) when applied to fluids.

Winding numbers offer a more robust topological tool — a tool that has already found application to optics where waves of topological origin also arise. Consider the normal modes of a linearized shallow-water equation in the presence of steady background rotation (the so-called f-plane approximation). Eigenmodes are defined only up to an overall amplitude and phase, so we may construct a gauge-invariant quantity, designed to be insensitive to these physically irrelevant degrees of freedom, by multiplying one component of the eigenvector (in this case the wave height) by the complex conjugate of another component (for instance the meridional velocity). A plot of this complex-valued quantity in wave vector space immediately reveals a vortex for the Poincaré-gravity waves with winding number 1 (see figure to the left).

Recently several of us have used the winding number to understand how fluid waves of topological origin can persist in the presence of background shear **[5]**. We have also found that the winding number may be discerned directly from observations, but for that story you'll have to attend my March APS Meeting talks on Sunday and Monday to learn more!

In retrospect we can now credit Kelvin with the discovery of the first wave of topological origin when thinking about the English Channel, nearly a century prior to the rediscovery of waves of topological origin in the quantum realm. Here we see the adverse effect of the siloing of physics into separate domains — in this case geophysics and quantum physics — that inhibited discoveries that could perhaps have been made earlier. It is hoped that the APS Topical Group on the Physics of Climate will help to overcome such barriers to the spread of knowledge.



The author with Brown University undergraduate Joe Hall and Dr. Ziyan Zhu of Stanford University at UCLA's Large Plasma Device, looking for waves of topological origin in a magnetized plasma [6].

References:

[1] Thouless, D. J., Kohmoto, M., Nightingale, M. P. & Dennijs, M. Quantized Hall Conductance in a Two-Dimensional Periodic Potential. *Physical Review Letters* **49**, 405–408 (1982).

[2] Delplace, P., Marston, J. B. & Venaille, A. Topological origin of equatorial waves. *Science* **358**, 1075–1077 (2017).

[3] Venaille, A. & Delplace, P. Wave topology brought to the coast. *Phys Rev Res* **3**, 043002 (2021).

[4] Thomson, W. On Gravitational Oscillations of Rotating Water. *Proceedings of the Royal Society of Edinburgh* **10**, 92–100 (1880).

[5] Zhu, Z., Li, C. & Marston, J. B. Topology of rotating stratified fluids with and without background shear flow. *arXiv:2112.04691* (2021).

[6] Parker, J. B., Marston, J. B., Tobias, S. M. & Zhu, Z. Topological Gaseous Plasmon Polariton in Realistic Plasma. *Physical Review Letters* **124**, 195001 (2020).

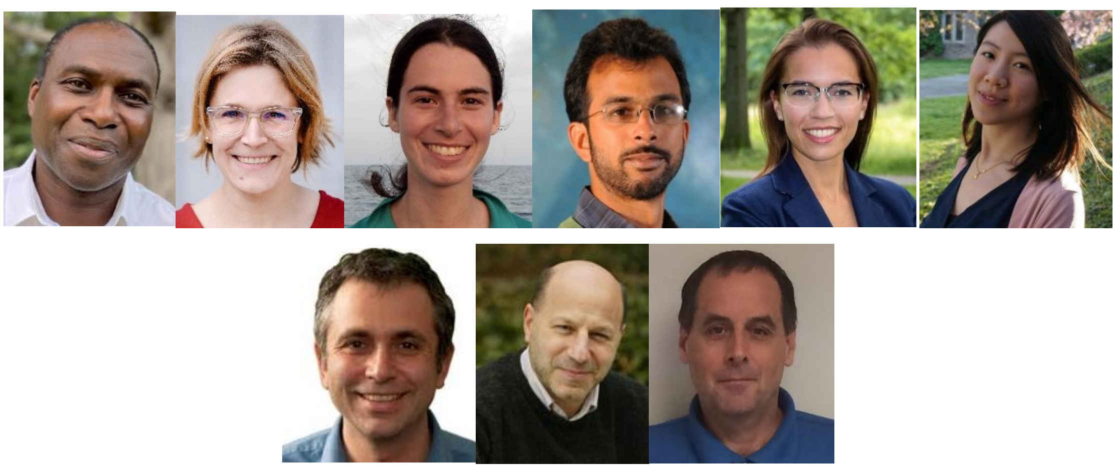
GPC Nominating Committee:

Left to right: Mary Silber (Chair), Justin Burton, Daniel Rothman, Raymond Shaw, Freddy Bouchet

The role of the Nominating Committee is to prepare a slate of candidates for the open elected positions each year. The Nominating Committee shall also respond with appropriate names to the Society's call for nomination for senior Society positions.

GPC Executive Committee Members-at-Large, Assigned Council Representative, and Newsletter Editor:

Left to right: Keith A. Julien (12/2025), Tiffany Shaw (12/2025), Mara Freilich (12/2024), Nadir Jeeanjee (12/2024), Claudia E. Brunner (12/2024), Ching-Yao Lai (12/2023), Steve Tobias (12/2023), Assigned Council Representative (DFD) Howard A. Stone, Peter Weichman (Newsletter Editor, 12/2023).



GPC Program Committee:

Left to right: Hussein Aluie (Chair), William Newman, Mara Freilich, Tiffany Shaw

The role of the Program Committee is to work with the Executive Officers in scheduling contributed papers within areas of interest to the GPC and in arranging symposia and sessions of invited papers sponsored by the GPC at Society meetings. From time to time the Program Committee may also organize special GPC meetings and workshops, some with and some without the participation of other organizations.

GPC Fellowship Committee:

Left to right: Valerio Lucarini (Chair), Claudia Cenedese (Co-Chair), Pedram Hassanzadeh, Tiffany Shaw

The Fellowship Committee shall be chaired by the Vice-Chair and shall solicit nominations and propose candidates for APS Fellowship, shall review the qualifications of such candidates, and shall submit its recommendations to the Head of the Honors Program for the Society.

APS March Meeting

This year's in-person March Meeting will take place March 5-10 in Las Vegas, Nevada. There will be a separate virtual meeting March 20-22.

Kicking off the in-person week's events, GPC is organizing a half-day tutorial session on Sunday March 5, 1:30 pm – 5:30 pm. It will review the basics of climate science, emphasizing fundamental physical principles and touching on climate impacts and areas for future research relevant for physicists. The session will cover the basics of (i) Radiation Balance, (ii) Large-Scale and Global Circulation, (iii) Small-Scale Atmospheric Dynamics, and (iv) Future Prospects and Impacts. The instructors are Nadir Jeevanjee (GFDL/Princeton), Tiffany A. Shaw, (U. Chicago), Allison Wing (Florida State U.), and Michael Mann (UPenn).

the Kavli Foundation Special Symposium taking place 7-9 pm Sunday evening, March 5, will include a presentation by Brad Marston on the topic of climate change.

Continuing with regular meeting events, the two **GPC Focus Sessions**, detailed below, will take place Monday, March 14 and Tuesday, March 15. An additional **DSOFT Focus Session**, Soft Matter Meets Climate Change, co-sponsored by GPC, will take place Thursday, March 17.

The **GPC Business Meeting** will take place 6:15-7:15 pm in the evening of Monday, March 14. The "Climate Café" will take place following this meeting.

GPC Focus Session: Rare Events, Tipping Points, and Abrupt Changes in the Climate System

Session B65, 11:30 am – 2:30 pm PDT, Monday, March 6

Invited Talks:

IAN EISENMAN
Scripps Institution of Oceanography
U. C. San Diego

Title: Heat released from the depths of the Arctic Ocean: amplified warming and tipping points

Synopsis: Surface temperature observations indicate considerably faster warming in the Arctic than in the rest of the globe. This raises questions regarding why the warming has been so concentrated in the Arctic and how the rapidly changing Arctic climate will evolve in the future. The Arctic Ocean, which covers much of the Arctic region, is characterized by an ice-covered layer of cold and relatively fresh water above warmer and saltier waters below. It is estimated that enough heat is stored at depth in the Arctic Ocean to melt all the Arctic Sea ice many times over. But this heat has historically remained trapped at depth: the seawater density differences are dominated by salinity, making the vertical stratification stable, and the sea ice cover damps wind-generated internal waves that could otherwise mix the warm waters up to the surface. In this talk, I will discuss the implications of this potentially precarious state of the Arctic Ocean as the climate warms. The talk will draw on idealized physical models with varying levels of complexity, as well as more comprehensive global climate models and findings from in situ observations. In the first part of the talk, I will discuss a proposed physical mechanism by which changing vertical heat fluxes in the Arctic Ocean contribute to the observed Arctic amplification of global warming. In the second half of the talk, I will present a novel positive feedback process involving the release of subsurface heat in the Arctic Ocean. Idealized model results show that this feedback process can give rise to a hysteresis window bounded by saddle-node bifurcations, featuring an abrupt "tipping point" under global warming when the bifurcation point is crossed. The hysteresis occurs for only a limited range of plausibly realistic parameters, however, and questions remain regarding the likelihood that this potential tipping point could occur under global warming during the coming century. Nonetheless, even in the absence of a tipping point, this positive feedback could substantially accelerate the melt of Arctic Sea ice.

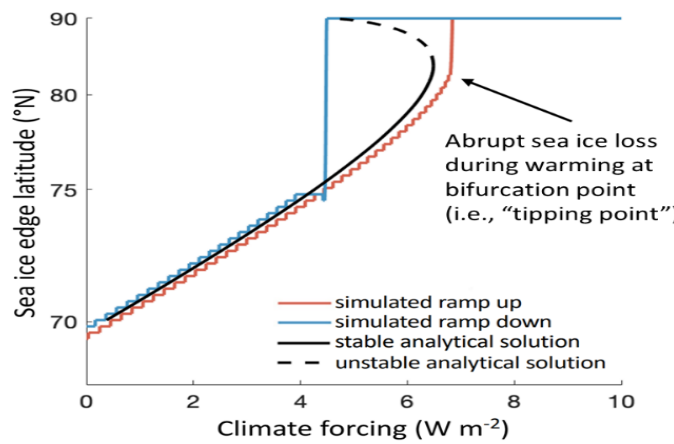


Figure adapted from Beer, Eisenman, Wagner, and Fine (in press, Journal of Physical Oceanography, 2023). Evolution of the Arctic sea ice edge latitude in response to a gradual increase and then decrease in greenhouse-driven climate forcing, as simulated by an idealized model of the global ocean and climate. The model includes a representation of a positive feedback process involving reduced vertical mixing in the ocean where sea ice is present. Note that the model simulates hysteresis in only a limited range of the parameter space. An analytical approximate steady-state solution to the numerical model is also indicated.

ALEXANDER A. ROBEL
School of Earth & Atmospheric Sciences
Georgia Tech

Title: Bifurcations in Ice Sheet Behavior and the Implications for Projections of Future Sea Level Rise

Synopsis: Sea level has been rising globally since at least the early 20th century. This rise can be explained almost entirely by the expansion of warming seawater and melting of land-based glaciers and ice sheets. More recently, the contribution of melting from the Greenland and Antarctic ice sheets to global sea level rise has increased dramatically. This increase in the rate of ice sheet melt, and corresponding acceleration in the rate of global sea level rise has largely been explained by two factors: (1) increased surface melt on the Greenland Ice Sheet, and (2) increased ice flow speeds and discharge to the ocean (through melting and ice fracture) from both ice sheets. In this talk, I will review explanations for these dramatic changes, using canonical bifurcation theories in ice sheet dynamics. I will then review more recent work adapting ideas from piecewise bifurcation theory and statistical physics to further understand enigmatic aspects of past ice sheet changes and projections of future changes. I will conclude by explaining how these ideas from physics are being used to developing better numerical models of ice sheet evolution, and improve the accuracy of future sea level projections. Such projections are already used by coastal communities as critical tools in planning for future sea level rise in order to avoid trillions of dollars in potential losses from coastal flooding globally.

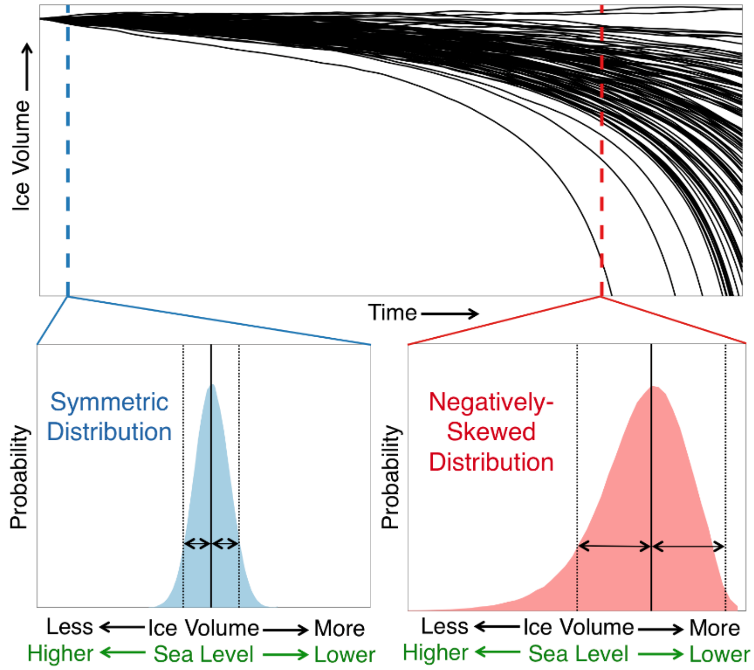
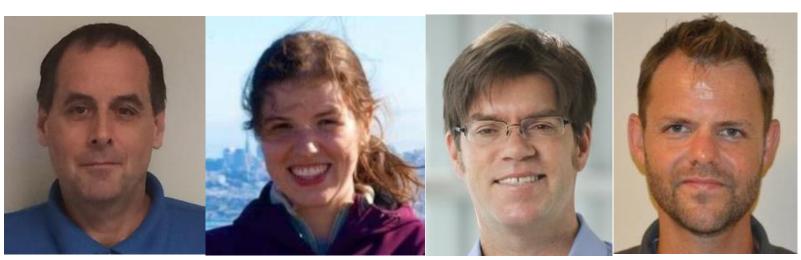


Figure from Robel et al., PNAS, 2019. (Upper) Conceptual illustration of an evolving ensemble of ice sheet model simulations, where each solid line is a single plausible realization of the future ice sheet evolution. Dashed colored lines indicate two time slices, for which probability distributions are provided (Lower Left and Lower Right). The statistical properties of the probability distribution of ensemble simulations change with time from a narrow, symmetric distribution at early times (blue dashed line, Lower Left) to a wide, asymmetric distribution with negative skewness (red dashed line, Lower Right), making the probability of ice sheet volumes below the most likely projection many times greater than that of ice sheet volumes above the most likely projection (arrows show example of ice sheet volumes above and below the most likely ice sheet volume projection).

GPC Communications Committee

Left to right: Peter Weichman (Chair), Morgan O'Neill, Albion Lawrence, Justin Burton



The role of the Communications Committee is to have oversight of the Newsletter and any other publications that may be established by the GPC. The Communications Committee shall also be responsible for keeping the physics community and other interested communities informed about climate physics issues, activities, and accomplishments through the Newsletter, GPC website and email messages.

YI ZHANG
Earth and Planetary Science
UC Berkeley

Title: A New Theory for Heat Extremes in a Changing Climate

Synopsis: Heat waves damage societies worldwide and are intensifying with global warming. An accurate projection for future heat extremes requires a fundamental understanding of the physical mechanisms. Here, we demonstrate the role of convective instability in limiting extreme temperatures and wet-bulb temperatures (heat stress) over land. We then provide a theory for an upper bound of mid-latitude surface temperatures and a theory for tropical extreme wet-bulb temperatures. Finally, we discuss how heat extremes will change with global warming based on the theory.

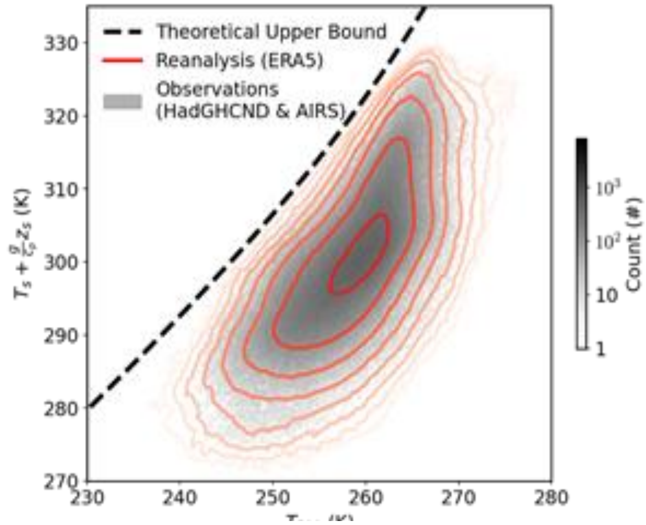


Figure adapted from Zhang and Boos (in press), PNAS. Theory (black dashed curve) for an upper bound of surface temperatures over mid-latitude land with evidence from observational datasets (shading and contours). Several mechanistic drivers of heatwaves, such as atmospheric blocking and soil moisture-atmosphere feedback, are well-known for their ability to raise surface air temperature. Here, we focus on convective instability which halts heatwave development and provides a theory that describes the observed relationship between temperatures at the surface (y axis, including local thermodynamic surface height compensation gz_s/C_p) and in the mid-troposphere (x axis).

Contributed Talks:

Nicole C. Shibley, Mary-Louise Timmermans	Polar Transitions: The Arctic Ocean's Diffusive Staircase
Peter Nekrasov, Douglas Macayeal	Assessing the long-term dynamics and stability of Arctic ice shelves with periodic roll structure
Ludovico T Giorgini	Non-Gaussian stochastic dynamical model for the El Niño southern oscillation
Alex Mendez, Mohammad M. Farazmand	Feedback-enabled transient growth can trigger cimate tipping points
Davide Faranda, Gabriele Messori, Aglae Jezequel, Pascal Yiou, Mathieu Vrac	Atmospheric circulation compounds anthropogenic warming and extreme climate impacts in Europe
Solomon Bililign	Inseparable Link between Air pollution and Climate Change

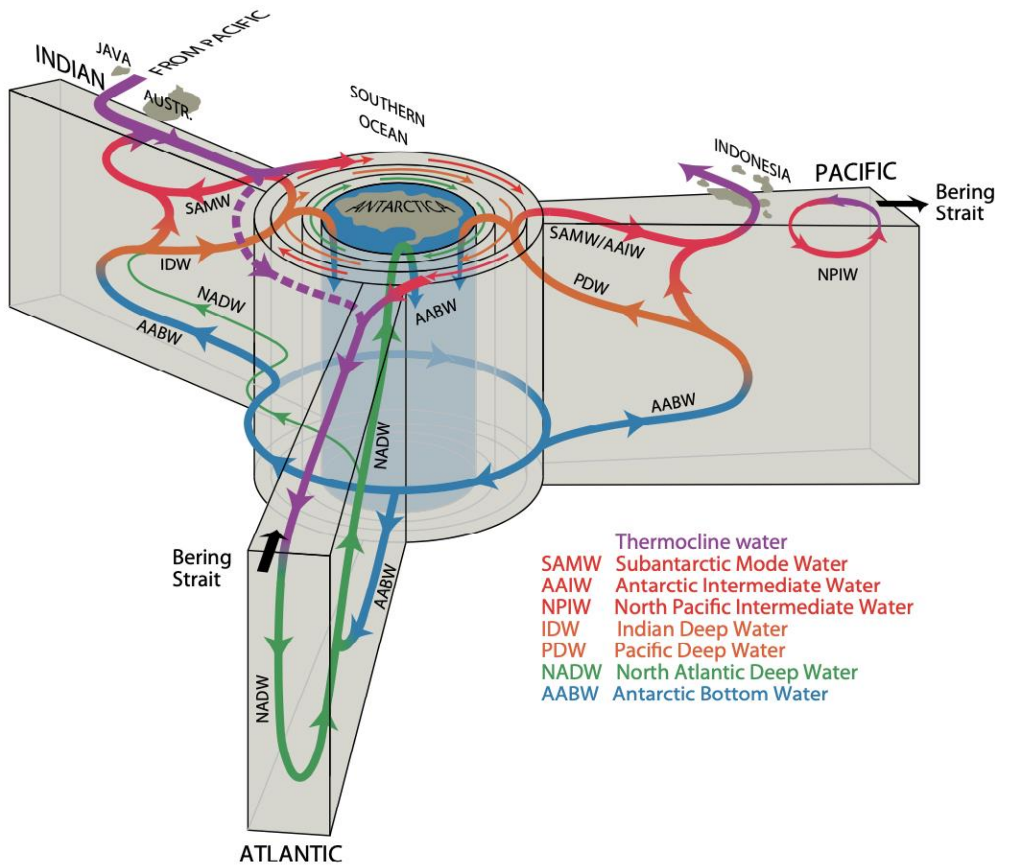
GPC Focus Session: Statistical and Nonlinear Physics of Earth and Its Climate

Session D65, 3:00 pm – 6:00 pm PDT, Monday, March 6

Invited Talks:

LYNNE TALLEY
Scripps Institution of Oceanography
U.C. San Diego

Title: The ocean's global overturning circulation and climate: from observations to process understanding



Schematic of the overturning circulation from a Southern Ocean perspective. Southern Ocean outcropping of the high-salinity North Atlantic Deep Water is depicted far to the south, with conversion to Antarctic Bottom Water close to Antarctic (blue cylinder, with formation at many locations). The low oxygen Pacific and Indian Deep Water layers, which outcrop farther north in the Antarctic Polar Current, are the most direct source of the surface water that flows northward out of the Southern Ocean and into the subtropic thermoclines. The self-contained and weak North Pacific Intermediate Water overturn is also indicated in the North Pacific.

Synopsis: The ocean's prominent partnership in climate has been evident for more than a century. Its sea surface temperature (SST) is its principal physical component that affects the atmosphere. Processes setting the observed SST distribution are myriad, and include not just air-sea heat exchange but also the ocean's lateral and vertical circulation, turbulence distribution, and stratification. And also, for more than a century, it has been understood that the ocean has a global scale overturning circulation, in which dense cold waters sink to depth at higher latitudes and rise to the surface wherever they can be forced to do so. This circulation exerts strong controls on ocean stratification, and hence affects large-scale SST variations. This in turn affects where the ocean is best poised to absorb and store excess (anthropogenic) heat. Here I summarize the global overturning circulation, the underlying global-scale pressure gradients that drive it, and its external forcing, which is a combination of buoyancy (heat and freshwater), wind, and turbulence. Critical asymmetries arising from geography exist between each of the major ocean basins, and between the northern and southern hemispheres. In the Southern Ocean, because of the open ocean that encircles Antarctica, basic dynamics dictates no flow of surface warm waters to the continent, and instead only Deep Waters from all three northern oceans are pulled southward, and then rise to the sea surface. This rise occurs in a southward and upwards spiral, with turbulence at mid-ocean ridge eddy hotspots mitigating its upward progression.

LUC DEIKE
Department of Mechanical and Aerospace Engineering
Princeton University

Title: The multi-scale physics of ocean spray aerosols generation by breaking waves and bursting bubbles

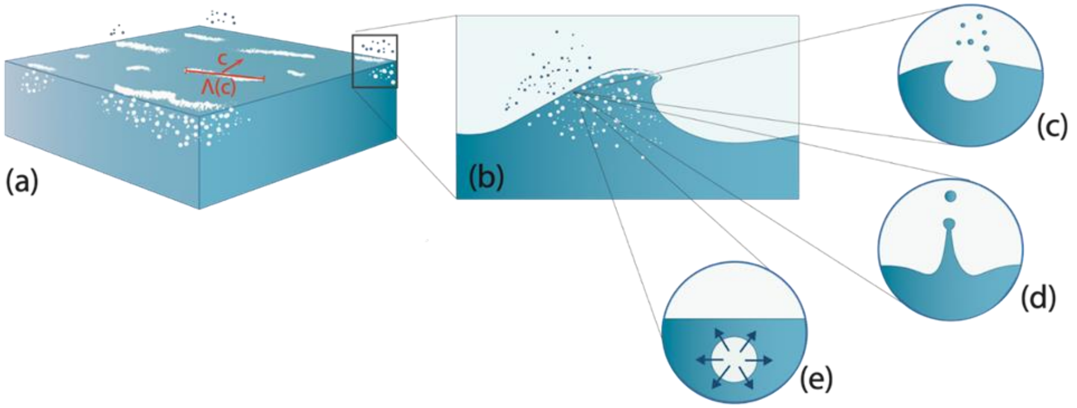


Figure adapted from Deike 2022, Ann. Rev. Fluid Mech. 54, 191-224. Sketch of the multiscale physics controlling exchange at the ocean-atmosphere interface, Breaking waves control sea spray aerosol generation and air bubble entrainment, modulating atmospheric processes such as radiative balance and cloud, or oceanic carbon uptake. At moderate to high wind speeds, breaking waves form whitecaps on the ocean surface (a, scales of 1m to 1km), while each breaking event entrains an air bubble population (b, scales from 100 microns to 1m). At the smallest scales, bubbles ranging from O(1 µm) to O(10 mm) (c,d) burst at the surface to produce liquid sea sprays via (c) film and (d) jet drops, with sizes from O(0.1 µm) to O(1 mm), and (e) exchange gas in the turbulent upper ocean.

Synopsis: Physical processes at the ocean-atmosphere interface have a large effect on climate and weather by controlling the transfer of momentum and mass. Without wave breaking, transport between the ocean and the atmosphere is through slow conduction and molecular diffusion, while wave breaking is a transitional process from laminar to turbulent flow. When waves are breaking, the surface experiences dramatic changes, with sea spray ejection in the atmosphere and air entrainment into the ocean water. In this talk I will discuss recent efforts towards improving our understanding and modeling of ocean spray aerosol production through a multi-scale approach. Ocean spray aerosol impact climate through radiative processes and while acting as cloud condensation nuclei. We combine detailed laboratory experiments and numerical simulations on turbulent multiphase flows, including wave breaking, bubble break-up in turbulence and spray production by bubble bursting together with a statistical description of breaking waves to develop a general theoretical framework. This framework aims to account for the very large range of scales involved in the process, from wave statistics scales of order of km, O(1m-1km), to wave breaking dynamics, O(1-10m), air bubble entrainment, bubble dynamics in turbulence and finally bubble bursting at the first surface, O(microns to mm). The resulting ocean spray aerosols emissions are evaluated globally and are in remarkable agreement with field observations, without being adjusted to match any existing datasets, in terms of magnitude of sea salt emissions and size distribution. The remarkable coherence between the model and observations of sea salt emissions therefore strongly supports the mechanistic approach and paves the way for improved modeling of atmospheric processes controlled by aerosols of oceanic origin.

SAMUEL N. STECHMANN
Applied and Computational Mathematics
U. Wisconsin - Madison

Title: Conservation laws for atmospheric dynamics with clouds

Synopsis: Clouds and rainfall are among the most challenging aspects of weather and climate. In addition to difficulties in observing and simulating clouds, there is a large gap in our theoretical understanding of atmospheric dynamics with clouds versus without clouds (i.e., of moist fluid dynamics versus dry fluid dynamics). Here, I will present some recent work toward closing this gap by defining basic principles of geophysical fluid dynamics (GFD) that hold even in the presence of phase changes of water. In particular, I will present cloudy versions of the conservation principles of energy and potential vorticity, the latter of which is a cloudy extension of the classic Kelvin circulation theorem.

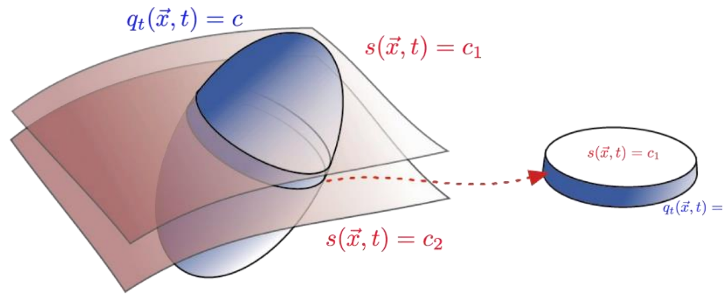


Figure from Kooloth, Smith, Stechmann, Geophysical Research Letters (2022). Geometry of a new conservation law for potential vorticity (PV) that holds for an atmosphere with clouds or an ocean with salinity. The conserved quantity is not PV of individual parcels, but PV integrated over certain cylinder-like volumes.

Contributed Talks:

Hussein Aluie, Benjamin A Storer, Michele Buzzicotti, Hemant Khatri, Stephen Griffies	Global Energy Spectrum of the General Oceanic Circulation
Jiarong Wu, Stephane Popinet, Luc Deike	Statistics of breaking wave fields with a multilayer numerical framework
William Collins	Prospects for estimating Transient Climate Response to Greenhouse Gases using the Fluctuation Dissipation Theorem
Nadir Jeevanjee	Simpson's Law and the Water Vapor Feedback
John B. Marston, Ziyan Zhu, Weixuan Xu, Jung-Eun Lee, Baylor Fox-Kemper	Observation of Waves in the Climate System with Nontrivial Topology
Mary Silber, Punit Gandhi	Impacts of changing storm characteristics in a stochastic model for dryland vegetation pattern formation

Other News Links of Interest and Upcoming Events Calendar

1. The Gordon conference on Radiation and Climate entitled *Theoretical and Observational Constraints on Climate System Behavior* will take place July 23-28, 2023 at Bates College, Lewiston, Maine.
2. The Les Houches, France, summer school entitled *200 Years of Navier-Stokes and Turbulences* will take place July 31 - August 25. This school will mark the bicentenary of Navier's work that led to the establishment of the master equations of fluid mechanics, known as the Navier-Stokes equations. This anniversary is an important event and the opportunity to take stock of the evolution of Navier-Stokes turbulence research over 200 years and of its future prospects.
   The aim of this school is to provide to Ph.D. students, post-docs and young scientists lectures given by world experts on the fundamental aspects of turbulence, reviewing both the accumulated knowledge and the remaining challenges, open questions and new fields to be explored by next generations of scientists.
3. A retrospective article entitled Manabe's Radiative–Convective Equilibrium, by Nadir Jeevanjee, Isaac Held and V. Ramaswamy, describes the distinctiveness of Manabe's 1967 paper, for which his share of the Nobel was largely awarded. This article amplifies and elaborates upon remarks by Raymond Pierrehumbert at the 2022 March Meeting GPC special session.