APS Topical Group on the Physics of Climate
GPC

GPC Newsletter

Issue #20

February 2024

IN THIS ISSUE

APS TOPICAL GROUP ON THE PHYSICS OF CLIMATE

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 incoming GPC Chair

Valerio Lucarini, U. Reading

Dear GPC Members: I am very enthusiastic about becoming Chair of the Group. Just after the conclusion of the APS March Meeting 2024 I will take over the baton from Hussein Aluie, who has done a great job in chairing the group and who has provided me with invaluable help and great suggestions in these months leading to my new role. *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. 2*

ARTICLE: Global Ocean Cascades and the Atmospheric Role

Benjamin Storer, University of Rochester

Using a deterministic rather than statistical analysis framework, our research team has developed a new methodology for probing and modeling the multiscale physics of how oceanic and atmospheric circulations couple to Earth's climate system. In 2022, we used this approach to extract the gyre-scale ocean currents at every time step in a global ocean dataset (Storer *et al.*, *Nature Communications*, 2022). Traditionally, extracting these gyres relied on long-time averages or statistical processing (empirical orthogonal functions, EOFs), which limited our ability to study the dynamics underlying the different scales. This new methodology, *commutative coarse-graining*, preserves the fundamental physics of the system, while disentangling the currents. The mathematical method was developed by

Continued on p. 3

ARTICLE: Recollections from the 2023 Aspen Center for Physics Fluids Workshop (Part II)

Peter B. Weichman, BAE Systems FAST Labs

During the (somewhat chilly) two-week period May 28 – June 11, 2023 the Aspen Center for Physics hosted a workshop on *Geometric and Field Theoretic Methods for Astro-, Geo-, Bio-physical Fluids* organized by B. Helen Burgess, James Cho, Albion Lawrence, and Jane Wang and attended by approximately 20 participants (happily including your author). *Continued on p. 5*

Welcome from the GPC Chair

(Continued from p. 1)

Since entering the Chair line, my involvement in APS has grown year by year. I am glad to see the great potential of our group and notice that many of our members, like myself, are from the European community. We need to further increase the strength, visibility, and attractiveness of the group. Something I would love to achieve soon is a better coordination with the Nonlinear Geophysics section of AGU, the Nonlinear Processes in Geosciences section of EGU, and the Mathematics for Planet Earth and Geophysics Activity SIAM groups. I think that we should organize a joint ambitious scientific initiative in the form of an advanced workshop/school dedicated to the mathematics and physics of the climate crisis. The work we are pursuing at a rather fundamental level is key to advancing the scientific knowledge needed to understand and anticipate the key aspect of climate variability and climate change. Our fellows could play an extremely useful ambassadorial role at this regard.

Another area where I would love to see more coordinated effort is at the editorial/publishing level. We could probably take better advantage of the opportunities offered by Physical Review E and Physical Review Letters.

The last role I have been playing as Chair Elect is the GPC Program Committee Chair for the 2024 APS March meeting. I am very glad to report that we have an exciting (and dense) program awaiting us in Minneapolis. As detailed later in this Newsletter, all the GPC-led sessions will take place in room 211AB on Monday March 4th 2024:

A64: Statistical and Nonlinear Physics of Earth and its Climate, from 8:00 a.m. – 11:00 a.m.

B64: Diversity of Planetary Circulation Regimes: Our Solar System and Beyond, from 11:30 a.m. – 1:18 p.m.

D64: Extreme Events, Tipping Points, and Abrupt Changes in the Climate System, from 3:00 p.m. – 5:24 p.m.

The second session is a novelty for the March meeting as it is arguably the first time that a specific event is devoted to planetary atmospheres and their possibly exotic regimes of circulation.

Our activities will continue after the end of the last session, as the GPC Business meeting will follow thereafter (7:00 p.m.-8:00 p.m.).

Two further sessions, co-sponsored by GPC and led by the Division of Soft Matter, should be of interest for many of us, and will take place in room 102F:

K34: Soft Earth Geophysics, from 3:00 pm – 6:00 pm on Tuesday March 5.

M34: Soft and Living Matter in Geophysical Flows, from 8:00 a.m. – 10:48 a.m. on Wednesday, March 6.

We hope to see you there!

A Brief Update from the Outgoing GPC Chair

Hussein Aluie

I wish the incoming GPC Chair, Valerio Lucarini, the very best as he takes over the GPC leadership at the annual GPC business meeting during the APS 2024 March meeting. I will use this opportunity to provide a brief update since the last Newsletter.

APS-level Award

In the Fall 2023 Newsletter, I mentioned our efforts to establish an APS-level award. I am happy to report that GPC's proposal to establish the first APS-level award for climate research was approved unanimously by the APS Council in October. It will be named in honor of Eunice Newton Foote (1819-1888), a trailblazing female scientist and a suffragist who lived in upstate NY. Foote pioneered the investigation of radiative effects of water vapor and carbon dioxide, presaging the discovery of the greenhouse effect. I managed to convince GPC Chair-Elect Geoff Vallis to serve as Chair of the ad-hoc GPC Fundraising Committee. The committee currently consists of Geoff Vallis (Chair), Morgan O'Neill, Valerio Lucarini, Hussein Aluie, Xiyue (Sally) Zhang, Justin Burton, and Steve Tobias. We have now transitioned to the early stages of fundraising with the hope of launching the award in January 2025.

Amendments to the GPC Bylaws

Important changes to the GPC Bylaws were approved by the APS Council in October and ratified by GPC membership in December. Of these, three are worth highlighting.

1. Introduce two new 1-year Executive Committee positions for Junior Scientist Members-at-Large (either a student or an early career scientist, as defined by APS), while retiring the 3-year student Members-at-Large position. This is to encourage more participation from junior scientists in GPC activities and governance.
2. Modify our "Areas of Scientific Inquiry" to include understanding climates of other planets within our solar system and beyond. Credit is due to William Newman for this proposal. We believe that this broadening of our scope will benefit our understanding of climate physics by encouraging engagement from the planetary science community.
3. Change the "Terms of Office" of Officers and Members-at-Large of the Executive Committee to begin at the close of the GPC business meeting during the APS March meeting. This is in line with the Terms of Office of many of the large APS units (divisions) and removes many undesirable ramifications to our unit's governance from having had to adhere to the calendar year.

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, 2024. 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.

Two Early Career Investigator Awards were made this year. The first was awarded to Yue (Olivia) Meng, Stanford University. Her March Meeting presentation (Session K34:2, *3D Discrete Element Model and Continuum Theory for Quasi-static Granular Flow of Ice Mélange)* focuses on calving dynamics of ice bergs and mass loss of ice sheets. The second was awarded to Rui Yang, University of Twente. His research focus includes pattern formation in nonequilibrium fluids and fluid dynamics of droplets.

GPC 2024 Executive Committee

Chair (through 3/2025):

Valerio Lucarini
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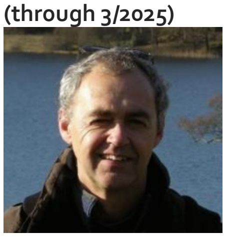
Reading, UK
v.lucarini@reading.ac.uk

Chair-Elect (through 3/2025)



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Secretary/Treasurer (through 3/2025):

Xiyue Zhang
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ARTICLE: Global Ocean Cascades and the Atmospheric role – *continued from p. 1*

Aluie in 2019 and subsequently implemented into an advanced code by Storer and Aluie, and allows us to study energy on scales ranging from the globe circumference odown to the smallest scales contained in the data (Storer and Aluie, *JOSS*, 2023) -- see **Figure 1**.

The methodology generalizes the notion of a spectral decomposition to inhomogeneous flows, without relying on orthogonal basis functions. It allowed us to quantify the energy content of all resolved scales in the oceanic circulation and build the first truly global power spectrum of the oceans (Storer *et al.*, *Nature Communications* 2022; Buzzicotti *et al.*, *JAMES*, 2023). We found that the spectral peak is at 10^4 km, and is due to the Antarctic Circumpolar Current (ACC). We also found a smaller peak at $\sim 3x10^3$ km due to the norther hemisphere gyres and a power-law scaling at scales larger than 10^3 km in both hemispheres. Previous studies of energy spectra in the ocean relied on Fourier analysis within box regions and it was widely accepted that the spectral peak is due to mesoscale eddies at scales of order 100 km (e.g. Ferrari and Wunsch, Ann. Rev. Fluid Mech. 2009). Our analysis

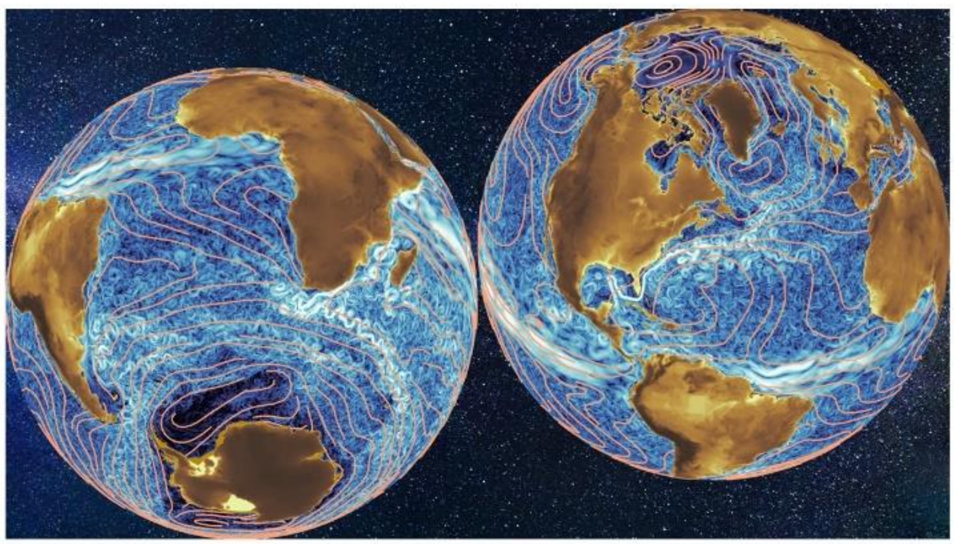


Figure 1: Observing the Ocean Gyres: Large-scale Ocean gyre circulations drawn on-top of ocean kinetic energy

finds these as well, but as our work demonstrates, scale analysis in boxes suffers from the box itself; it is not possible to analyze any scales larger than the artificial box size.

Compared to energy spectra, analysis of the energy transfer between scales within boxes (i.e., the turbulent cascade) suffers from compounded uncertainty due to the elimination of gyre scales, which introduces uncontrolled errors to the calculation of the cascade even at length scales smaller than the box size (Aluie *et al.*, JPO 2018). In Storer *et al.*, *Science Advances*, 2023, we performed the first global analysis of energy scale transfer in the ocean and uncovered an energy pathway that transfers energy between the ocean mesoscales, which are the ocean's weather systems at scales of order 100 km,

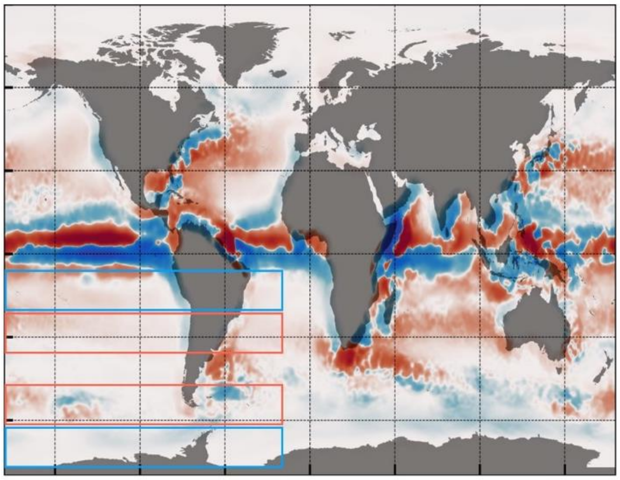


Figure 2: Mapping the Global Transfer of Energy: Illustration of energy transfer between gyre scales and smaller scales. Red (blue) indicates energy moving to smaller (larger) scales: i.e., the gyre-piston is compressing (expanding).

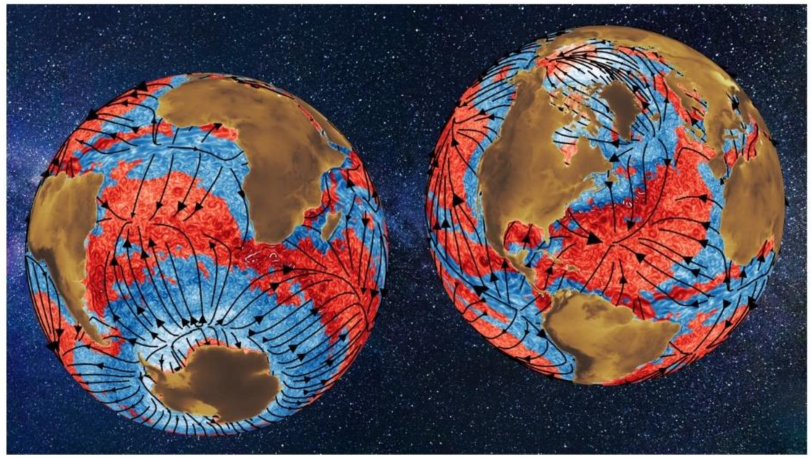


Figure 3: Coupling Gyre Scales with Oceanic Weather: Black arrows show the large-scale atmosphere-induced ocean currents, on top of the ocean kinetic energy. Red shows 'squeezing', where energy is pushed to smaller scales, and blue 'expansion', where energy is stretched out into larger scales.

and the larger climate-scale gyres – see **Figure 2**. This transfer is mediated by the global atmospheric circulation, i.e. the Hadley, Ferrel, and polar cells.

The underlying mechanism can be thought of as a piston compressing a gas. When the piston compresses, it does work on the gas, transferring energy to and heating it up. When the eastward/westward winds blow over the ocean, the rotation of the Earth causes them to produce northward/southward ocean currents, called Ekman flow. Because the direction of the wind changes from the poles, to the jet stream, to the equator, this causes the Ekman flow to compress (convergence) and expand (divergence) at different latitudes. This large-scale compression/expansion forms the piston, acting on the highly energetic mesoscales, the 'gas'. Where the piston compresses, energy is transferred from the large-scales into the smaller scales, and where it expands energy is pulled from the smaller scales all the way up to the larger climate scales. This transfer mechanism was not recognized or hypothesized before. Our analysis also revealed that an atmospheric band near the equator called the "intertropical convergence zone," which produces 30 percent of global precipitation, causes an intense amount of downscale energy transfer in the ocean – see **Figure 3**.

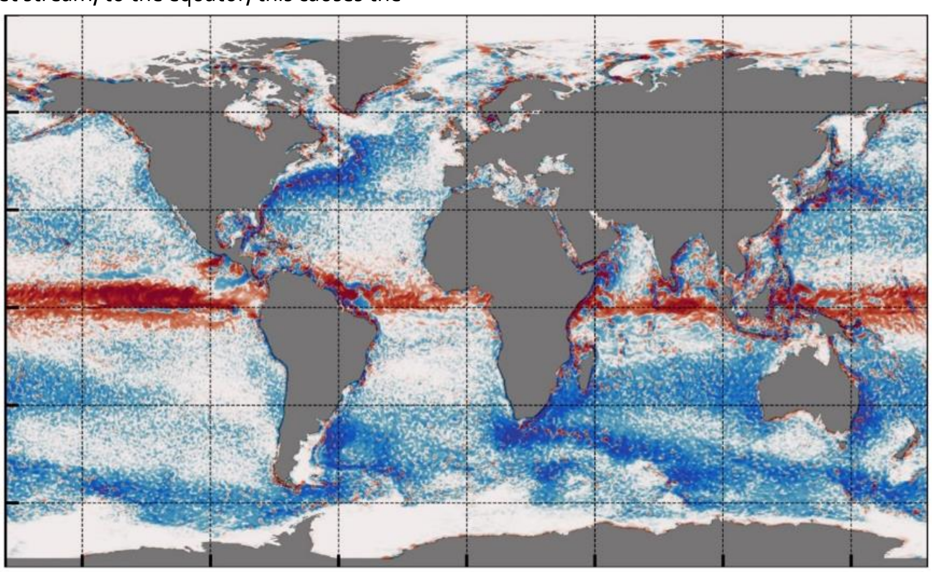


Figure 4: Energy Exchange of Ocean Weather: The study also quantifies the energy exchange that occurs in the ocean 'weather', namely the mesoscales.

The ocean has weather patterns similar to what we experience on land, but on different time and length scales – see **Figure 4**. A weather pattern on land might last a few days and be about 500 km wide, while oceanic weather patterns such as swirling eddies last three to four weeks but are about one-fifth the size. Scientists have long speculated that these ubiquitous and seemingly incoherent motions in the ocean communicate with climate scales, but the mechanism has always been vague because it was not clear how to disentangle this complex system to measure their interactions. The methodology we have developed can do exactly that.

References

B. A. Storer and H. Aluie, "FlowSieve: A Coarse-Graining Utility for Geophysical Flows on the Sphere," Journal of Open Source Software **8**(84), 4277 (2023) https://doi.org/10.21105/joss.04277.

B. A. Storer, M. Buzzicotti, H. Khatri, S. M. Griffies, S. M. and H. Aluie, "Global cascade of kinetic energy in the ocean and the atmospheric imprint," Science Advances, 9(51) (2023) https://doi.org/10.1126/sciadv.adi7420.

M. Buzzicotti, B. A. Storer, H. Khatri, S. M. Griffies and H. Aluie, "Spatio-Temporal Coarse-Graining Decomposition of the Global Ocean Geostrophic Kinetic Energy," Journal of Advances in Modeling Earth Systems, **15**(6) (2023) https://doi.org/10.1029/2023MS003693.

B. A. Storer, M. Buzzicotti, H. Khatri, S. M. Griffies and H. Aluie, "Global energy spectrum of the general oceanic circulation," Nature Communications, **13**(1), 5314 (2022) https://doi.org/10.1038/s41467-022-33031-3.

H. Aluie, "Convolutions on the sphere: commutation with differential operators," GEM - International Journal on Geomathematics **10**(1), 9 (2019) https://doi.org/10.1007/s13137-019-0123-9.

H. Aluie, M. Hecht, and G. K. Vallis, "Mapping the Energy Cascade in the North Atlantic Ocean: The Coarse-graining Approach," Journal of Physical Oceanography **48**, 225–244 (2018). https://doi.org/10.1175/JPO-D-17-0100.1.

R. Ferrari and C. Wunsch, "Ocean circulation kinetic energy: Reservoirs, sources, and sinks," Annual Review of Fluid Mechanics **41**, 253–282 (2009) https://doi.org/10.1146/annurev.fluid.40.111406.102139.

GPC Nominating Committee:

Left to right: William Newman (Chair), Justin Burton, Raymond Shaw, Tiffany Shaw, Eloisa Bentivegna

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.

ARTICLE: Recollections from the 2023 Aspen Center for Physics Fluids Summer Program (Part II) – *continued from p. 1*

As is standard for Aspen "summer" events, there were a limited number of presentations on a rather wide variety of topics, but with most of the time reserved for personal scientific exploration, collaboration, and networking.

The workshop was motivated by numerous rapidly developing, high impact results spanning astrophysical, geophysical, and biophysical fluids, including a wealth of new data, computational challenges, and conceptual puzzles. The goal of the workshop was to bring together an interdisciplinary group of scientists studying astrophysical and geophysical fluid dynamics, climate science, theoretical fluid and plasma physics, biological physics, turbulence, and field theory to form new connections that will drive these fields forward. More specific to the theoretical approaches of special interest to the workshop, the systems of interest can reside in parameter regimes (e.g., strong rotation, stratification, viscosity, or magnetization) that allow analytical control, and are thus amenable to quantitatively accurate applications of modern geometric and field-theoretic techniques, such as asymptotic methods for path integrals, renormalization group and effective field theory approaches, generalized symmetries, holographic "gauge/gravity" duality, geometric phases, and topologically protected excitations. In return, specific fluid systems can also provide a context for new formal developments in classical, quantum, and statistical field theories.

This article, separated into two parts (see the GPC Fall 2023 Newsletter for Part I) due to length limitations, aims to summarize some of the key features of the remarkably broad array of invited talks, hopefully motivating readers to delve deeper and perhaps inspiring some of those desired connections to their own fields of interest.

Previously published in PART I:

Brad Marston (Brown University) "*Waves of Topological Origin in the Fluid Earth System and Beyond*"

Geoffrey Stanley (University of Victoria), *"Untangling multi-valued functional relations using the Reeb graph on oceanic neutral surfaces"*

Stefanella Boatto (Federal U. of Rio de Janeiro) "*Vortex and gravitational modeling: a long journey with a rich mathematical history*"

Joonas Nattila (Columbia/Flatiron) *"Neutron Star Weather Forecasting"*

PART II:

Muni Zhou (Princeton University), "*Inverse energy transfer in non-helical turbulence enabled by magnetic vortex merger.*

Inverse cascades in two-dimensional turbulent systems are often responsible for the emergence, at large times, of large-scale coherent structures from a chaotic background. Examples include large-scale eddies in gas giant atmospheres, stabilized by simultaneous conservation of energy and vorticity that in combination strongly inhibit the breakup of such structures. A corresponding 3D inverse transfer of magnetic energy from small to large scales in highly conducting plasmas is important for understanding the origin of large-scale magnetic fields that are ubiquitous in space and astrophysical systems – ranging in scale from planets, to stars, to accretion disks around black holes, all the way to the galactic interstellar medium, and to the hot gas in the intra-cluster medium. The leading paradigm in this case invokes turbulent magnetohydrodynamic (MHD) dynamos, driven by turbulence coupled with large-scale differential rotation. However, a seed magnetic field of sufficient strength and sufficiently large coherence length to overcome resistive

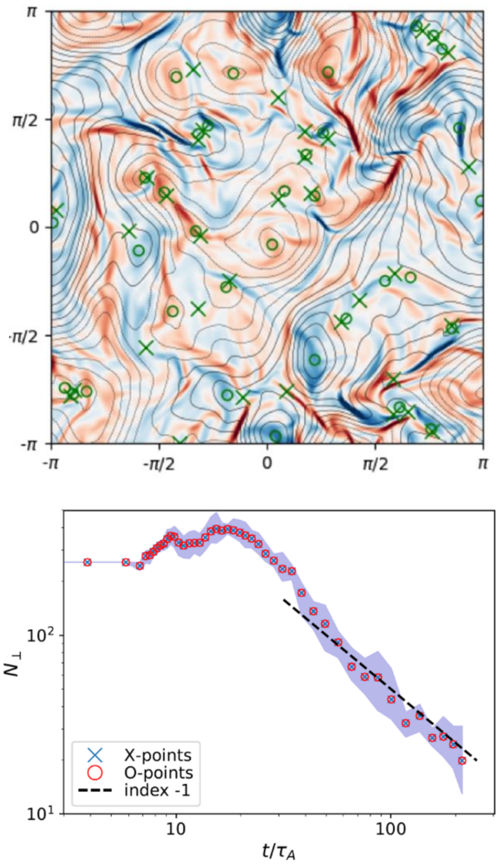


Figure 1: Top: Horizonal slice (xy-plane) of the current density J_z (colors) and magnetic flux ψ (contours) at time step $t = 100$ in units of the Alfvén time. Green circles identify flux extrema; green crosses mark the saddle points. Bottom: These two types of symbols come in pairs, and the coarsening of their number $N_\perp(t)$ over time is one way to quantify the inverse cascade. **The $1/t$ power law is a prediction of the analytic scaling theory.**
(https://doi.org/10.1017/S0022377820000641)

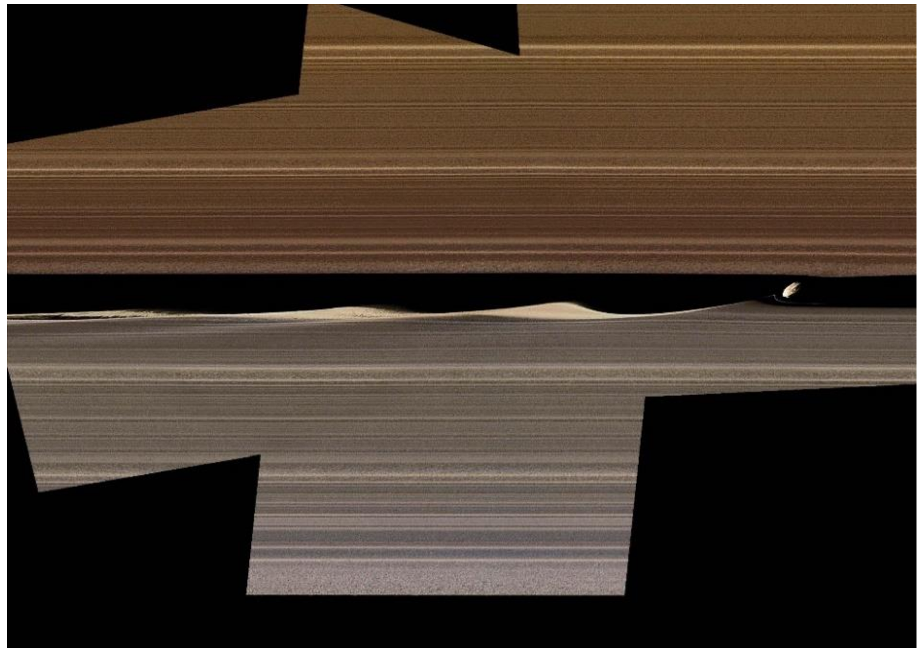


Figure 2: Enhanced-color image mosaic of Daphnis, one of the moons embedded in the Keeler Gap a 42 km wide gap in the A ring. Daphnis is seen kicking up three waves in the gap's outer edge. In each successive crest, the shape of the wave changes as the ring particles within the crest interact and collide with each other. Many intricate, never-before observed features appear in this image.
https://photojournal.jpl.nasa.gov/catalog/PIA23167

losses is still required, subsequently traversing many orders of magnitude in coherence length to reach the desired, extremely large, astronomical scales. For some systems (e.g., solar heliosphere), a picture of a complex, volume-filling network of magnetic flux ropes has emerged, undergoing some type of 3D merging dynamics enabled by magnetic reconnection. In support of such a picture, Muni reported on the results of a reduced MHD model of a 3D array of identical magnetic flux tubes, with long-time evolution dictated by flux-tube mergers, dynamically constrained by the conservation of the magnetic potential and axial fluxes of each tube. The result is an analytical logarithmic multiscale-type model of the time evolution of the energy-containing scales. Like 2D fluids, the system is predicted to exhibit an inverse transfer of magnetic energy that terminates only at the system scale. These basic scaling conclusions are quantitatively supported by direct numerical simulation of the MHD equations (**Figure 1**).

Glen Stewart (U. Colorado), "Dynamical Surprises in Saturn's Rings"

The NASA Cassini-Huygens mission (2004-2017) provided an unprecedented view into numerous aspects of the dynamics of Saturn's rings. Glen gave a fascinating overview of a number of these phenomena. From afar, the rings look like relatively homogeneous collection of orbiting rocks of various sizes. However, high resolution star occlusion measurements, in which the star brightness is tracked, show that the B ring is densely packed with clumps, 30-50 meters across, separated by nearly empty gaps. These constantly colliding clumps are neatly organized, with larger rocks closer to their centers, and smaller particles at the edges. Glen speculates that there may a nematic liquid crystal type alignment mechanism at work here driven by gravitational and orbital forces. One of the most important drivers of processes in the rings is the gravitational influence of a subset of Saturn's more than 60 moons. A radial spiral density wave in Saturn's inner B Ring is formed through a 2:1 resonance with the moon Janus, with wavelength decreasing as the wave propagates away from the resonance position. Moreover, Janus co-orbits with another moon Epimetheus. Every four years they migrate radially and switch positions relative to Saturn. Thus, in a co-orbiting frame of reference, each Moon traverses a horseshoe orbit about the pair's shared mean orbital radius, approaching within 15,000 km of each other before switching position and separating again. As this migration occurs, so too do the resonance locations and accompanying spiral density waves between the rings and the two Moons. Nonlinear interference between relocated density waves launches a solitary wave that travels through the rings with a velocity approximately twice that of the local spiral density wave group velocity. A few other fascinating details: Small, embedded moons produce propeller-shaped structures that extended downstream from the moon. A Keeler Gap edge wave is formed by the passage of the moon Daphnis, embedded in the A ring (**Figure 2**).

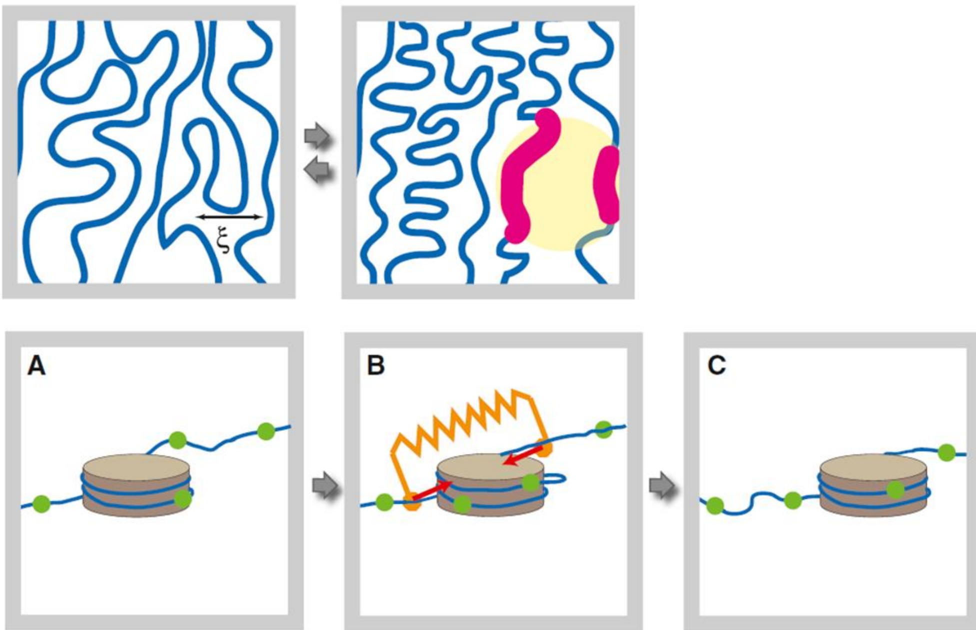


Figure 3: The top two panels show an example of a "scalar event" in which the chromatin fiber is chemically altered, and which is accompanied by influx or efflux of solvent, coupling to a compressional fluid mode. The bottom three panels show a "vector event" in which (B) a chromatin remodeling enzyme binds to a nucleosome (disc) and applies equal but opposite forces on opposite sides of the nucleosome, leading to an excess of DNA wound around the nucleosome. Following enzyme detachment (C) the extra DNA is released, resulting in nucleosome translation (relative to A). The result is a point dipole-like vector forcing event on the fluid coupling to the shear mode. **(https://doi.org/10.1016/j.bpj.2014.03.038)**

Alexander (Shura) Grosberg (NYU), "Nuclear Chromodynamics (hydrodynamics of genetic material inside the nucleus of a live cell)"

It is quite remarkable that cell nucleus chromatin hydrodynamics (functional form of DNA in cells) is a simple as it appears to be. Despite it being formed by a few single DNA strands, it is so densely packed that the connectivity plays almost no role, and a continuum, highly viscous fluid model appears to provide a valid description. Sura described a two-fluid model, along with comparisons with experiment, in which the content of a nucleus is described as a chromatin solution with the nucleoplasm playing the role of the solvent and the chromatin fiber that of a solute. Fluid motion is driven by natural cell activities, such ATP hydrolysis. There are both "scalar events" which drive compressional modes where the chromatin fiber moves relative to the solvent, and "vector events" which generate shear modes where the chromatin fiber moves together with the solvent (**Figures 3, 4**). These different types of events are visible in the velocity correlation functions, for which the theoretical predictions were successfully compared with recent single cell experiments undergoing different levels of ATP activity. There are obvious questions whether this nuclear chromodynamics plays a significant role in cell operation, perhaps influenced by some evolutionary pressure, or whether it is simply an accidental biproduct. This remains an open question, but Sura speculated that these dynamics might enhance transport rates of important molecules from the cell interior to the cell boundary and beyond, and thereby enhance intercell communication, such as gene expression, in some evolutionary impactful way.

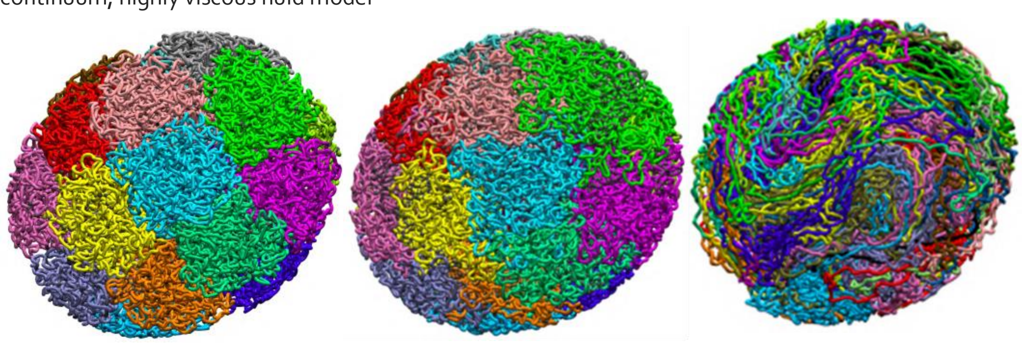


Figure 4: Example result of a simulation of chromatin dynamics under the influence of passive and active "euchromatic blocks." The former generates the "scalar event" cross-linking changes (Figure 3, upper row). The latter generates force dipoles that capture the "vector event" microscopic stresses exerted by nuclear ATP (Figure 3, lower row). The left panel here shows the initial condition; the middle panel the result of passive events only; the right panel the result of active events only. The shear flows generated by the latter clearly lead to much stronger intermixing. **(https://www.biorxiv.org/content/10.1101/2022.02.22.481494v1)**

Luca Comisso (Columbia) and Albion Lawrence (Brandeis), "Geometry and symmetries in relativistic MHD"

A remarkable prediction of nonrelativistic ideal (perfectly conducting) magnetohydrodynamics (MHD) is a kind of magnetic field line conservation in a smooth flow. Thus, two plasma elements connected by a magnetic field line at a given time will remain connected by at any subsequent time. The lines will stretch and bend as they are advected by the flow but maintain their topological identity, and this property is often expressed by saying that they are "frozen" into the plasma. Mathematically, this is expressed by the MHD evolution equation

$$\partial_t(\mathbf{dl} \times \mathbf{B}) = -(\mathbf{dl} \times \mathbf{B}) - \big((\mathbf{dl} \times \mathbf{B}) \times \nabla\big) \times \mathbf{v}$$

Here $\mathbf{dl}$ is the vector connecting two infinitesimally separated fluid elements, and it follows that if we choose $\mathbf{dl}$ to be parallel to $\mathbf{B}$ at an initial time, hence $\mathbf{dl} \times \mathbf{B} = \mathbf{0}$, it will remain so for all future times. This property imposes strong constraints on the plasma dynamics, and provides the basis for concepts such as magnetic topology, and magnetic reconnection enabled by singularities in the flow velocity field $\mathbf{v}$. In his talk, Luca showed that such dynamically preserved magnetofluid connections persist also in non-ideal plasmas in curved spacetime, hence including gravity, which could be important in plasmas surround black holes, or in the early Universe. In a model (**Figure**

5) that includes thermal-inertial effects, thermal electromotive effects and Hall effects, these generalized connections are demonstrated through the emergence of a generalized magnetofluid field tensor field $M^{\mu\nu}$ that unifies electromagnetic and fluid fields.

$$\frac{1}{4en}\nabla_\nu\left[\frac{\xi h}{ne}\left(U^\mu J^\nu + J^\mu U^\nu - \frac{\Delta\mu}{ne}J^\mu J^\nu\right)\right]$$
$$= \frac{1}{2ne}\nabla^\mu\left(p\Delta\mu - \Delta p\right) + \left(U_\nu - \frac{\Delta\mu}{ne}J_\nu\right)F^{\mu\nu}$$
$$-\eta\left[J^\mu - \rho_e'(1+\Theta)U^\mu\right],$$

Figure 5: Generalized Ohm's Law in curved spacetime, coupling the 4-velocity U^μ, 4-current density J^μ, electromagnetic field tensor $F^{\mu\nu}$, etc. The gradient ∇_ν is the covariant derivative associated with the space-time metric $g_{\mu\nu}$. This equation is the starting point for the generalization of the $d\boldsymbol{l} \times \boldsymbol{B}$ evolution equation.
https://journals.aps.org/prd/abstract/10.1103/PhysRevD.102.023032

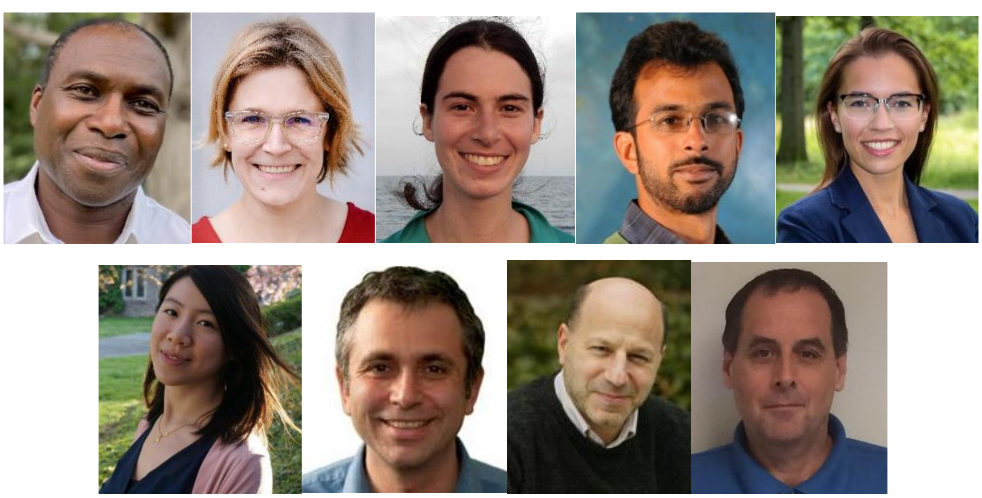
GPC Fellowship Committee:

Left to right: Geoffrey Vallis (Chair), Pedram Hassanzadeh, Pascale Garaud, Brad Marston

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.

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

Left to right: Keith A. Julien (3/2026), Tiffany Shaw (3/2026), Mara Freilich (3/2025), Nadir Jeevanjee (3/2025), Claudia E. Brunner (12/2024), Ching-Yao Lai (3/2024), Steve Tobias (3/2024), Assigned Council Representative (DFD) Howard A. Stone, Peter Weichman (Newsletter Editor, 12/2024).



GPC Program Committee:

Left to right: Valerio Lucarini (Chair), Hussein Aluie, Mara Freilich, Ching_Yao Lai

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.

APS March Meeting

This year's in-person March Meeting will take place March 3-9 in Minneapolis, Minnesota. There will be a separate virtual meeting March 11-13.

There will be three **GPC Focus Sessions**, detailed below, taking place sequentially on Monday, March 4. There will be two additional **DSOFT Focus Sessions**, Soft Earth Geophysics, co-sponsored by GPC, taking place Tuesday, March 5, and Soft and Living Matter in Geophysical Flows, cosponsored by GPC, DBIO and DFD, taking place Wednesday, March 6.

The **GPC Business Meeting** will take place 6:15-7:15 pm in the evening of Monday, March 4. The "Climate Café" will take place following this meeting.

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

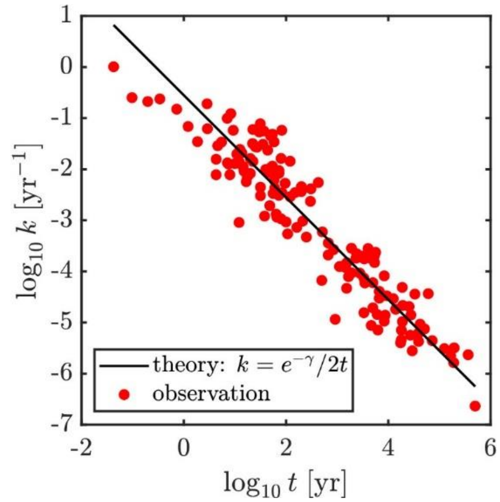
Session A64, 8:00 –11:00 am CST, Monday, March 4

Invited Talks:

DANIEL H. ROTHMAN
Dept. Earth, Atmospheric, and Planetary Sciences
MIT

Title: Aging and Slow Dynamics in Earth's Carbon Cycle

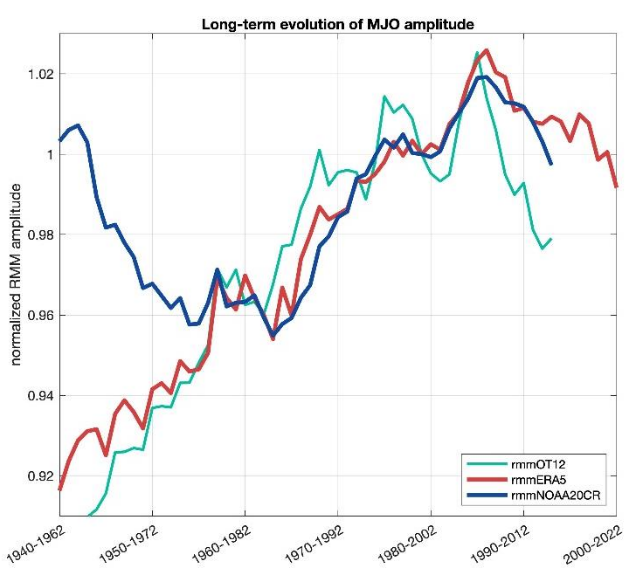
Synopsis: Carbon near the Earth's surface cycles between the production and consumption of organic carbon; the former sequesters carbon dioxide while the latter releases it. Microbes attempt to close the loop, but the longer organic matter survives, the slower microbial degradation becomes. This aging effect leaves observable quantitative signatures: organic matter decays at rates that are inversely proportional to its age, while microbial populations and concentrations of organic carbon in ocean sediments decrease at distinct powers of age. Yet mechanisms that predict this collective organization remain unknown. I show that these and other observations follow from the assumption that the decay of organic matter is limited by progressively rare extreme fluctuations in the energy available to microbes for decomposition. The theory successfully predicts not only observed scaling exponents, but also a previously unobserved scaling regime that emerges when microbes subsist on the minimum energy flux required for survival. The resulting picture suggests that the carbon cycle's age-dependent dynamics are analogous to the slow approach to equilibrium in disordered systems. The impact of these slow dynamics is profound: they preclude complete oxidation of organic carbon in sediments, thereby freeing molecular oxygen to accumulate in the atmosphere.



The rate at which marine sedimentary organic matter decays to CO_2 is proportional to the inverse of its age. The plot compares observations of the effective first order decay constant $k(t)$ in marine sediments of age t (red dots) to the theoretical prediction $k = e^{-\gamma}/2t$, where γ is the Euler-Mascheroni constant. The data were compiled by Middelburg [Geochim. Cosmochim. Acta 53, 1577–1581 (1989)]; the theory derives from a model of fluctuation-limited decay [Rothman, PNAS 121, e2310998121 (2024)].

JULIANA DIAS
NOAA Physical Sciences Laboratory (PSL)

Title: Understanding long-term variability of the Madden-Julian Oscillation leveraging in-situ observations



Time series of the Madden-Julian Oscillation (MJO) amplitude using a 22-year running mean. MJO indices are based on the Real-time Multivariate MJO (RMM) methodology (Wheeler and Hendon, 2004). RMM ERA5 (red) and RMM NOAA20CR (blue) follow the same methodology but the input data in the first includes all atmospheric observations available at the time, whereas the second estimate uses only surface pressure observations. The RMM OT12 (green) is a surface pressure reconstruction of RMM based on multilinear regression applied to a training period extending from 1979 to 2010 (Oliver and Thompson, 2012).

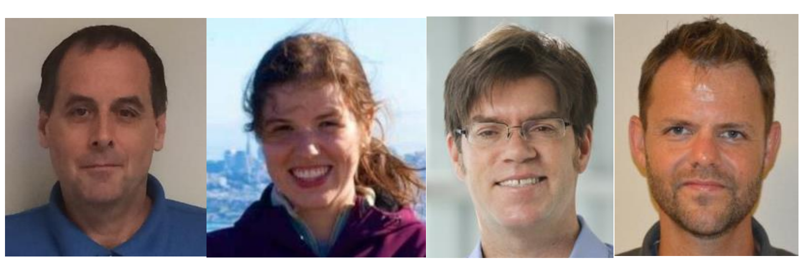
Synopsis: The Madden-Julian Oscillation (MJO) is a phenomenon characterized by a cloudy planetary scale (~10,000 km) coherent structure in the tropical atmosphere that primarily moves from west to east at about 5 m/s, with a period of about 40 days. The MJO associated convective heating is balanced by upward motion leading to upper-level divergent flow. This low altitude divergence anomaly interacts with the subtropical jets through vortex stretching and vorticity advection by the divergent horizontal flow generating Rossby waves. These Rossby waves then propagate away from the tropics modulating the higher latitude atmospheric flow. Even though the MJO was discovered over 50 years ago, and much progress has been made in its theoretical understanding as well as MJO global impacts, both issues remain significant outstanding problems in climate research. This presentation focuses on understanding potential changes in the MJO over the last hundred years. Long-term variability of the MJO is an important topic of research because changes in MJO propagation and amplitude characteristics could alter its role as a source of predictability within the tropics and at higher latitudes via the tropical-to-extratropical teleconnections described above. While there have been a few studies suggesting that the MJO amplitude has been increasing over the last century, there are also substantial uncertainties surrounding these estimates. Understanding long-term variability of the MJO is challenging because characterizing its behavior outside of the satellite era lacks detailed information about its observed state, and or relies on climate models' typically poor MJO representation. In this presentation, we discuss the contrast between long-term variability of the MJO derived from (imperfect) climate model products with the MJO behavior inferred from (sparse) tropical in-situ observations during the same period.

Contributed Talks:

Balu Nadiga, Kaushik Srinivasan	Climate Prediction in Reduced Dimensions: A Comparative Analysis of Reservoir Computing and Attention-based Transformers
Nadir Jeevanjee	The proportionality of temperature to forcing in transient climate change
Richard M. Kriske	The Thermodynamics of Trees may be helpful in controlling the Climate
A. K. M. Sadman Mahmud, Alison Macdonald, Gregory Johnson	Antarctic Bottom Water Warming in Eastern Pacific Southern Ocean
Karan Jakhar, Rambod Mojgani, Yifei Guan, Ashesh K. Chattopadhyay, Pedram Hassanzadeh	Learning Stable and Generalizable Closed-form Equations for Geophysical Turbulence
Rambod Mojgani, Daniel Wälchli, Yifei Guan, Petros Koumoutsakos, Pedram Hassanzade	Multi-agent reinforcement learning for subgrid-scale modeling of environmental turbulence
Nisha Chandramoorthy, Youssef Marzouk, Anant Gupta	Learning and using scores for efficient Bayesian filtering
Milkessa G. Homa, Gizaw M. Tsidu, Tamirat A Desta	The First Ground-Based Measurement of Atmospheric Carbonyl Sulphide over Addis Ababa (Ethiopia)
Abiola O. Ilori, Naven Chetty	An Empirical Study on Climate Change in Africa and the Role of Physics in its Mitigation

GPC Communications Committee

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



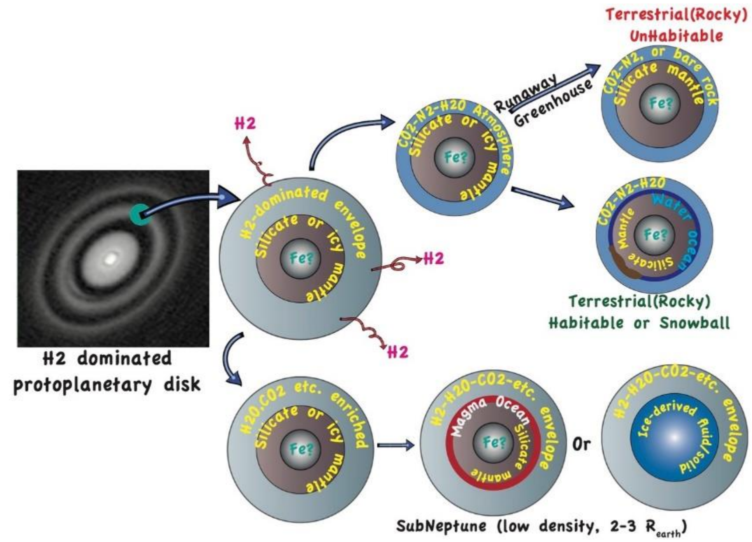
The role of the Communications Committee is to have oversight of the Newsletter and any other publications that may be established by the GPC. The Communications Committee shall also be responsible for keeping the physics community and other interested communities informed about climate physics issues,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

GPC Invited Session: Diversity of Planetary Circulation Regimes: Our Solar System and Beyond

Session B64, 11:30 am – 1:18 pm CST, Monday, March 4

RAYMOND PIERREHUMBERT
Dept. of Physics
University of Oxford

Title: Diversity of Planetary Climates: New revelations in the era of the James Webb Space Telescope



From the hydrogen dominated protoplanetary disk two distinct classes of relatively small planets emerge, which together make up probably the most common kind of planet in the Universe. While both likely start with a primordial hydrogen-rich atmos[phere, the rocky planet branch undergoes nearly complete hydrogen loss, leaving a high molecular weight atmosphere behind which is a small proportion of the total mass of the planet, or perhaps even a bare rock. The other branch loses some hydrogen and enriches the fluid envelope in higher molecular weight constituents, but leaves behind an extensive fluid envelope making up a significant proportion of the total mass of the planet. These are the "subNeptunes," characterised observationally by their comparatively low densities.

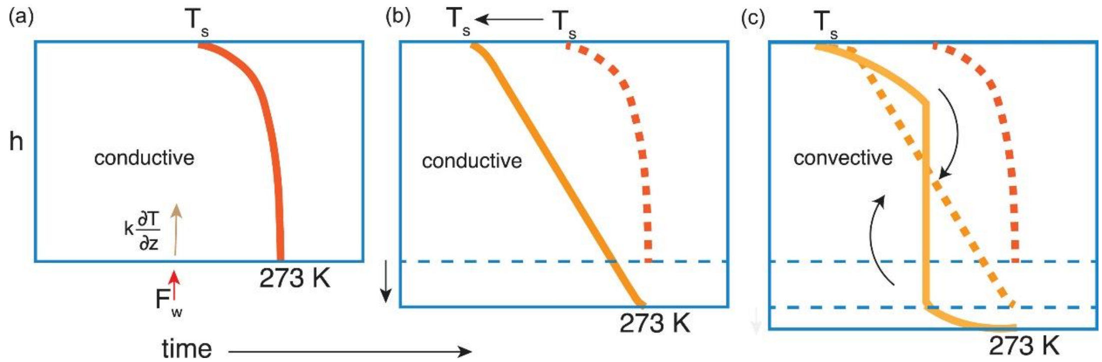
Synopsis: The new frontier of exoplanet discovery and characterization has revealed to us a Universe teaming with planets. It appears that it is quite hard to make a star without leaving enough material behind in a protoplanetary disk to form planets. The bounty of new planets (5500 and counting) has offered up many types of planets and associated climate phenomena unknown in our own solar system. Nonetheless, these novel planetary climates can be explored in terms of the building blocks of fundamental physics that have long been used to build an understanding of the climates of Earth and other Solar System planets, and their evolution over deep time. This talk will focus on the smaller range of planets, ranging up to 3 Earth radii. This class of planets includes both rocky planets, including super-Earths somewhat larger than Earth, and low density gaseous subNeptunes.

The James Webb Space Telescope has opened a revolutionary new capability to characterize atmospheres of the smaller range of planets. While subNeptunes, by virtue of their low density, must of necessity have extensive volatile envelopes, it was not known where the atmospheres sat on the continuum between Jupiter-like hydrogen-helium atmospheres and higher molecular weight volatiles such as H_2O, NH_3, CO_2 and CH_4. For rocky planets, one of the key questions has been whether rocky planets around low-mass M stars could retain atmospheres; since M stars are by far the most common (and long lived) stars in the Universe, if their rocky planets can retain atmospheres, the Universe is surely teeming with habitable territory. I will discuss what has been learned so far, and highlight a few key novel climate phenomena. These include climates of tide-locked planets, of lava planets with thin rock-vapor atmospheres, of water-rich subNeptunes involving a mix of hydrogen and supercritical water, and the key importance of characterizing atmospheric CO_2 and testing theories of its geochemical control on rocky planets.

NICOLE C. SHIBLEY
Princeton Center for Theoretical Science
Princeton University

Title: Ice-ocean interactions in the Solar System

Synopsis: Several ice-covered moons with underlying liquid-water oceans are thought to exist in the Solar System. In both Earth and planetary systems, the ocean below the ice is critical for understanding ice thickness and dynamics. However, unlike for Earth's polar oceans, in-situ measurements of ocean properties below an ice cover are not available for icy satellites. In this talk, I will describe how insights from polar research may help us understand ocean properties on icy satellites. We will largely focus on Europa, a moon of Jupiter, thought to have an ice shell overlying a global liquid-water ocean. How does this ice shell grow and move? What can the thermodynamics and dynamics governing this growth and movement tell us about the evolution of Europa and help us infer about its subsurface ocean? We will discuss how idealized models of Europa's ice shell, adapted from considerations of Earth's cryosphere, give us insight into this mysterious planetary body.

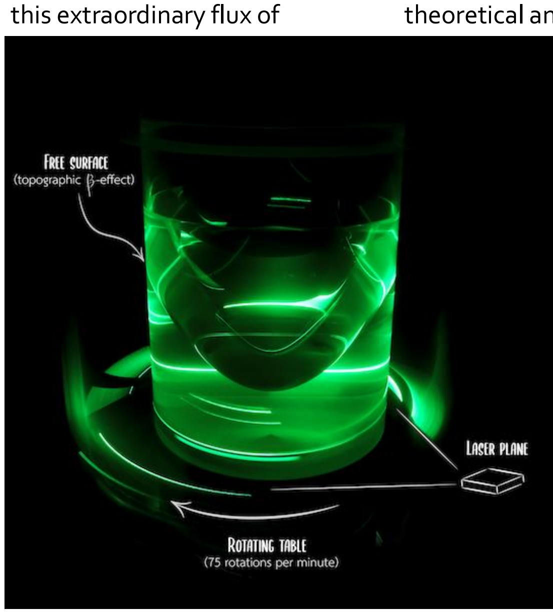


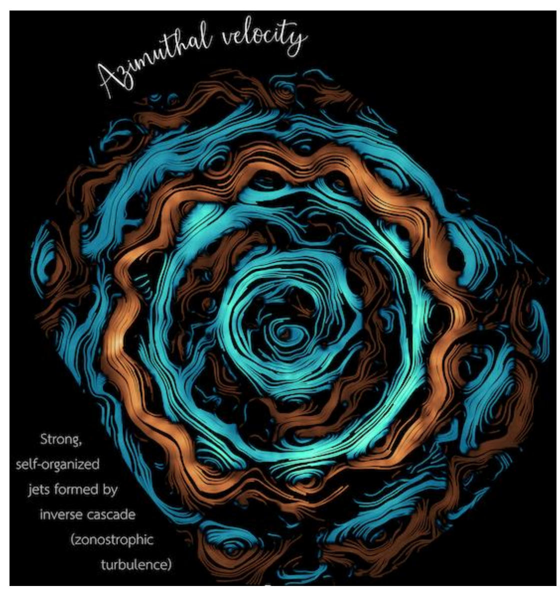
Schematic indicating changing heat-transport mechanisms in a growing Europan ice shell. Image from Shibley & Goodman, 2024, Europa's coupled ice-ocean system: Temporal evolution of a pure ice shell (https://www.sciencedirect.com/science/article/pii/S0019103523004517), © 2023 The Authors, under a CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

MICHAEL LE BARS
CNRS

Title: Fluid Dynamics of Jupiter in the Lab: Deep Jets and Floating Vortices

Synopsis: Jupiter's dynamics shapes its clouds but remains largely unknown below this natural observational barrier. Unravelling the underlying three-dimensional flows is one of the goals of NASA's ongoing Juno mission. In order to make the most of this extraordinary flux of new data, we have addressed the Jovian dynamics using idealized laboratory experiments complemented by theoretical and numerical analyses. I will present some recent results and ongoing works. I will describe the generic force balance responsible for the





three-dimensional pancake-like shape and surprising stability of the Great Red Spot. I will explain the mechanism of formation of the observed large Jovian jets, and compare their spectral properties to measurements from our experimental set-up that has reached, for the first time in the lab, the so-called zonostrophic turbulence regime. Finally, I will describe the suitable conditions to produce stable clusters of floating vortices at Jupiter's poles. This talk will illustrate the benefits of a constructive, multi-method, and interdisciplinary approach of challenging open questions in planetary fluid dynamics.

Left: Experimental set-up used to reproduce Jovian jets in the lab. A cylindrical tank, 1 m in diameter and 1.6 m high, is filled with 600 l of water and fixed on a table rotating at 75 rpm. The fluid free surface takes a paraboloidal shape due to the centrifugal force. Small-scale turbulent forcing is performed by circulating water through 128 small holes in the bottom plate. Time-resolving particle image velocimetry (PIV) measurements are performed on a horizontal plane using a side green laser and a top-view camera. Right: Example PIV measurement from an experiment in the zonostrophic regime. The streamlines are colored according to the sign of their azimuthal velocity to highlight the formation of successively prograde/retrograde Jovian-like zonal jets.

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

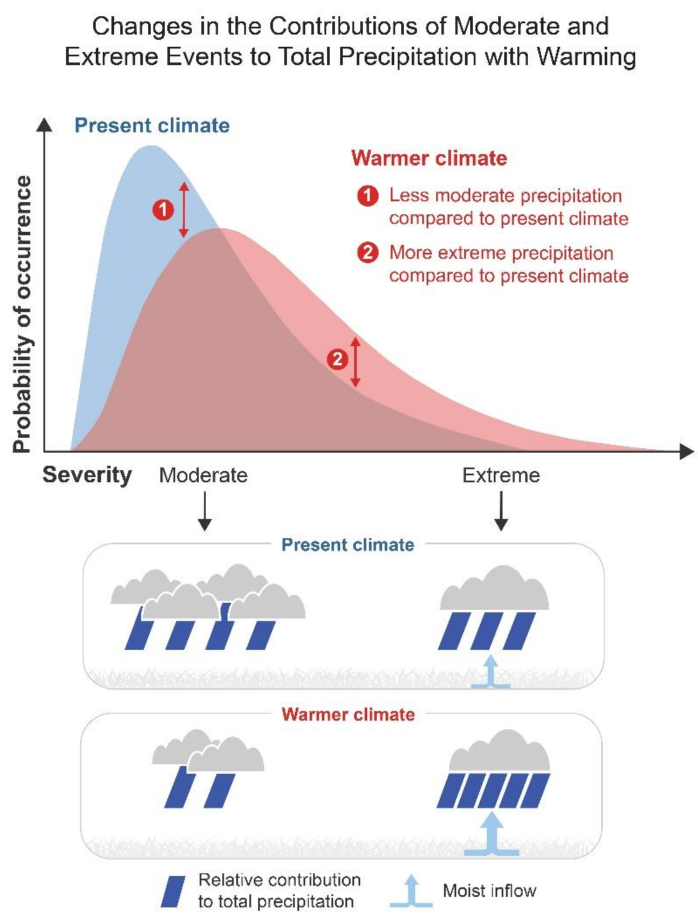
Session D64, 3:00 – 6:00 pm CST, Monday, March 4

Invited Talks:

ANGELINE PENDERGRASS
Dept. Earth and Atmospheric Science
Cornell University

Title: Extreme precipitation in a changing climate

Synopsis: As greenhouse gas concentrations increase and the world warms, not only temperature but also precipitation is changing. Governments, and more recently courts and businesses, are demanding information about what impacts they will face in the coming years and decades. Providing this information is challenging for any aspect of future climate because of the diverse sources of uncertainty – including natural variability, structural differences among climate models and their projections, and the range of trajectories society might choose to follow. Precipitation varies strongly in space and time, integrates over many physical processes unfolding at many different scales, and is highly non-gaussian. In this talk I will discuss work to advance our understanding of changes in precipitation, using climate models as well as observations and developing new approaches to quantify precipitation change, along the way rethinking what we mean by precipitation variability and its extremes.

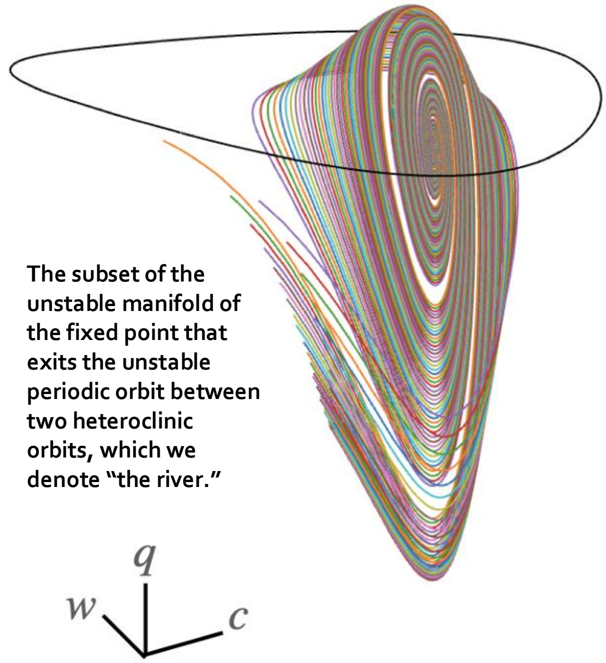


As the climate warms, extreme precipitation events become more intense and make up a larger fraction of total precipitation, while moderate events become less common. Citation: 5th National Climate Assessment, Figure 3.7

KATHERINE SLYMAN
Dept. Applied Mathematics
Brown University

Title: An investigation of tipping mechanisms in a carbon cycle model

Synopsis: Rate-induced tipping (R-tipping) occurs when a ramp parameter changes rapidly enough to cause the system to tip between co-existing, attracting states, while noise-induced tipping (N-tipping) occurs when there are random transitions between two attractors of the underlying deterministic system. We investigate R-tipping and N-tipping events in a carbonate system in the upper ocean, in which the key objective is understanding how the system undergoes tipping away from a stable fixed point in a bistable regime. While R-tipping away from the fixed point is straightforward, N-tipping poses challenges due to a periodic orbit forming the basin boundary for the attracting fixed point of the underlying deterministic system. Furthermore, in the case of N-tipping, we are interested in the case where noise is away from the small noise limit, as it is more appropriate for the application. We compute the most probable escape path (MPEP) for our system, resulting in a firm grasp on the least action path in an asymmetric system of higher scale. Our analysis shows that the carbon cycle model is susceptible to both tipping mechanisms.



The subset of the unstable manifold of the fixed point that exits the unstable periodic orbit between two heteroclinic orbits, which we denote "the river."

Contributed Talks:

Valerio Lucarini	Typicality of the 2021 Western North America summer heatwave
William Collins, Ankur Mahesh, Travis A. O'Brien, Karthik Kashinath, Michael Pritchard, Peter Harrington	Studies of Extreme Weather using Huge Ensembles of Machine-Learning-based Climate Emulators
Matthew Oline, Punit Gandhi, Mary Silber	A Modeling Framework to Investigate Impact of Increased Storm Variability on Self-Organized Vegetation Patterns in Drylands
Pedram Hassanzadeh, Ashesh K Chattopadhyay	Long-term instabilities and unphysical drifts of AI weather models: Challenges of learning multi-scale dynamics
Mara Freilich, Luc Lenain, Sarah Gille	Observations of localized submesoscale kinetic energy fluxes
Gang Chen, Guangxin Lv, Yaodong Tu, James H Zhang, Caterina Grossi, Briana Cuero	Cloud Absorption and Fog Heating by Visible Light due to Photomolecular Effect

Other News Links of Interest and Upcoming Events Calendar

1. The next Gordon conference on Radiation and Climate entitled *Theoretical and Observational Constraints on Climate System Behavior* will take place July 20-25, 2025 at Bates College, Lewiston, Maine.
2. The Les Houches School of Physics, France has two climate-adjacent programs in 2024: Physics of Complex Systems and Global Change, March 10-15, and Physics of Wave Turbulence and Beyond : Celebrating the 6th Birthday of Sergey Nazarenko, September 1-6, 2024.
3. The next International Conference on Clouds and Precipitation will take place July 14-19 2024 in Jeju, South Korea. The above will be preceded, July 13-14, by a Workshop on Scientific Directions for Cloud

Chamber Research with focus on recent progress and future opportunities in this area.

4. The Kavli Institute for Theoretical Physics will run a workshop on "The Physics of Changing Polar Climate" from May 13-July 18, 2025, with an associated conference June 23-26. KITP workshops are research-focused and highly interactive, aimed at researchers (including postdocs) and faculty, although there is some graduate student participation. A fuller description of the program may be found here.