GPC Newsletter

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APS TOPICAL GROUP ON THE PHYSICS OF CLIMATE

IN THIS ISSUE

Message from the Editor

This is the fourteenth 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.

Message from the GPC Chair

William Collins, Lawrence Berkeley National Laboratory

Welcome to the Fall 2020 Newsletter of the APS Topical Group on the Physics of Climate (**@APS_GPC**)!

This year is shaping up to be an exceptional one in the climate record. 2020 will likely be the warmest or 2nd warmest year on record. The first half of 2020 saw record heat events over many parts of the world, with exceptionally high temperatures in Siberia (reaching as high as 100 degrees Fahrenheit) and a heatwave baking Australia from late 2019 to early 2020. As a climate modeler, I suppose I can take some grim satisfaction in the close agreement between the global temperature data and the models from the 6th Coupled Model Intercomparison Project we are assessing as part of the 6th IPCC (Intergovernmental Panel on Climate Change) Assessment (AR6). The entire schedule of the AR6 has been radically altered by COVID – discussions that

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2021 APS March Meeting

The 2021 March Meeting will take place March 15-19. A decision regarding a virtual or in-person March Meeting will be made in October. GPC is planning two Focus Sessions, described below, each with three invited presentations.

Contributed abstract submission deadline is October 23, 2020. It is emphasized that although abstracts consistent with the Focus Session topics are certainly desired, *any climate physics related contribution will be welcomed.*

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ARTICLE: A more confident view of Earth's climate sensitivity

Mark D. Zelinka, Program for Climate Model Diagnosis and Intercomparison, Lawrence Livermore National Laboratory
Maria A. A. Rugenstein, Department of Atmospheric Sciences, Colorado State University
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How much will Earth warm in response to increasing concentrations of greenhouse gases in the atmosphere? Answering this question has been an abiding goal of climate science for decades, as the severity of climate change increases in direct proportion to global surface warming. A common measure is equilibrium climate sensitivity (ECS) – the equilibrated global surface temperature response to a doubling of atmospheric CO_2 concentrations. Despite measuring the climate response to a highly idealized step change in CO_2, it turns out that ECS is highly correlated in models with projected warming over the next several decades under more realistic forcing scenarios **[1]**. Higher ECS implies greater urgency in reducing emissions to avoid crossing highly disruptive climate change thresholds, like 2˚C warming since preindustrial times **[2]**.

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Message from the GPC Chair – *continued from p. 1*

would have occurred in dense but compact Lead Author Meetings have been spread over months of zoom calls, with heroic work by the IPCC Technical Support Units to juggle time zones and a whole new way of working together. Working Group 1 on the Physical Science Basis will turn in its final governments draft on April 21, 2021 and will engage with government representatives during the final approval session on July 26-30, 2021. July 30 will truly be a day for celebrating the hard work by hundreds of authors and reviewers to see this report through to completion in the face of exceptional logistical headwinds.

I am thankful for the GPC membership's the strong interest in the 2020 APS March Meeting. In light of the timely and prudent decision by the APS to cancel the in-person meeting literally the weekend before, we have elected to focus our energies on future conferences. For the 2021 March Meeting GPC will be sponsoring two focus sessions. "Rare events, tipping points, and abrupt changes in the climate system" will be co-organized by Mary Silber and myself, and "Statistical and nonlinear physics of Earth and its climate" is co-organized by Mary and Justin Burton and jointly sponsored with the APS Group on Statistical and Nonlinear Physics (GSNP). Both sessions will feature invited and contributed talks. Freddy Bouchet (CNRS and ENS de Lyon), Morgan O'Neill (Stanford University), and Juan Restrepo (Oak Ridge National Laboratory) are invited speakers for the first session, and Alison Banwell (University of Colorado Boulder), Rebecca Jackson (Rutgers University), and Dan Rothman (MIT) are invited speakers for the second. For both sessions, we strongly encourage you to submit contributed talk abstracts (deadline October 23). Submissions need not match the session focus -- all climate physics related topics will be welcomed. As the APS abstract submission site notes, the "APS March Meeting will be either hybrid (part in-person/part virtual) or fully virtual. This decision will be announced by early October."

In other APS activities, the APS Division of Fluid Dynamics (DFD) annual meeting will be held in Chicago, Illinois on November 22-24, 2020 with live-streamed parallel tracks of invited talks and award lectures on the first two days. These will be also be recorded for viewing at participants' convenience. As at previous DFD meetings, the Geophysical Fluid Dynamics and Turbulence topical areas feature many specialized sessions that are great fits with GPC themes. Later this year, the American Geophysical Union Fall Meeting is planning a mostly virtual Fall Meeting in San Francisco, CA spread over two weeks from December 1-17, 2020 to help maximize global participation. Much of the content will be recorded or online for attendees to view at times convenient for their locales. Also, the American Meteorological Society will host its 101st AMS Annual Meeting in New Orleans, from January 10-14, 2021. The theme of the 101st Annual Meeting is "*Strengthening Engagement with Communities through our Science and Services.*" It looks like all oral and poster sessions, panel discussions, and exhibits are transitioning to a virtual format, although AMS is still exploring options for a smaller in-person meeting in New Orleans for those that would like to gather assuming it is safe to do so. The DFD, AGU, and AMS Meetings will be great places to share your research on the Physics of Climate.

In closing, first, I would like to thank the GPC Executive Committee for all their work and guidance this past year and particularly the help of Raymond Shaw as the Treasurer/Secretary. I would like to thank prior chair Chris Forest for his helpful leadership and also welcome Mary Silber as the next GPC Chair starting in January. Please follow us on twitter at @APS_GPC for key research findings, occasional announcements, and general items of interest. Finally, we look forward to seeing you (virtually or in person) at the 2021 March Meeting!

2019 APS March Meeting – *continued from p. 1*

Focus session 1: Organized by Mary Silber and Bill Collins, GPC chair: *Rare events, tipping points, and abrupt changes in the climate system*

The Earth system has strong internal variability on many timescales. Large-scale transitions can occur due to tipping points in components of the climate system, and in many cases these depend on complex interactions between different sub-systems. However, the role of small-scale processes in inducing these transitions is not well understood for many important tipping points. These issues have been elevated in importance since Earth's climate is currently experiencing an unprecedented transition under non-stationary anthropogenic radiative forcing and is far out of equilibrium with this forcing. This session aims at connecting fluctuations and responses for the climate system with a focus on issues involving abrupt climate change, climatic hysteresis, tipping points, and climate extremes as rare events. General approaches and novel measures to quantify the climate response to non-stationary forcing in the climate system are encouraged. We also seek talks on complex interactions between the different components and subcomponents of the Earth system that illuminate how these interactions can induce rapid, large-scale transitions in its major components. Submissions which are focused on the study of reasons and mechanisms of the emergent behavior are especially welcome.

Invited speakers:

(1) Freddy Bouchet, CNRS and ENS de Lyon, "Large deviation theory, extreme events and abrupt changes in the climate system."

(2) Morgan O'Neill, Stanford University, "Feedbacks between the worst storms on Earth and lower stratospheric water vapor."

(3) Juan M. Restrepo, Oak Ridge National Laboratory, "Data assimilation and Uncertainty Quantification in the Geosciences."

Focus session 2: organized By Mary Silber and Justin Burton, GPC member-at-large; jointly sponsored by the APS Group on Statistical and Nonlinear Physics (GSNP): *Statistical and nonlinear physics of Earth and its climate*

Observations of natural processes on Earth, including those driven by its changing climate, present challenging applied problems that have potential to advance research in statistical and nonlinear physics. These phenomena are not observed in a pristine laboratory setting, and come not only with environmental heterogeneities, but also with enormous uncertainties about the underlying physical models. This session is aimed at bringing together researchers investigating Earth, its landscape and ecosystems, and its climate, all through a lens of statistical and nonlinear physics. We envision a broad set of topics, from critical phenomena associated with river networks, melt ponds on Arctic sea ice, and vegetation pattern formation in drylands, to the distribution of lakes on Earth's surface and the fracture mechanics of ice shelves in the Antarctic. How might we use satellite and terrestrial observational data to constrain models and test predictions? What is the potential for table-top experiments to probe physical processes that usually operate on a very large scale? What is an appropriate pairing of conceptual theoretical physics models with large scale computational ones to advance understanding of Earth in a changing climate? This session will facilitate an exchange of ideas and pressing questions between physicists and Earth scientists, and explore how modern methods of statistical and nonlinear physics can have an impact on these problems, and what new physics can be learned by studying Earth's many physical processes.

Invited speakers:

(1) Alison Banwell, University of Colorado Boulder, "Impacts of surface hydrology on Antarctic ice-shelf dynamics and break-up."
(2) Rebecca Jackson, Rutgers University, "Melting and mixing at the ocean-glacier interface."
(3) Dan Rothman, MIT, "Characteristic Excitations of Earth's Carbon Cycle."

We look forward to your contributions and interacting you in March.

2020 APS Fluid Dynamics Meeting

The 73nd Annual Meeting of the APS Division of Fluid Dynamics will take place virtually November 22-24, 2020. GPC will be a co-sponsor of a mini-symposium on the topic of *Fluid dynamics of atmospheric clouds*, organized by Sisi Chen from the National Center for Atmospheric Research, Rama Govindarajan from the Tata Institute of Fundamental Research, Steve Krueger from University of Utah, Eckart Meiburg from UC Santa Barbara, and Raymond Shaw from Michigan Technological University. It is also part of the "Fluids Next" effort by Physical Review Fluids.

Representing clouds in computational models used for weather forecasting and climate science is an enduring challenge. Due to their multi-phase and multi-scale nature, the challenge is not only that clouds are not resolved, but also that the underlying physics of some empirically observed phenomena is not fully understood. Cloud turbulence interactions involve buoyancy-driven flows in which processes such as internal latent heating and coupling between scalar fields and a discrete, particulate phase are all relevant. The multi-faceted nature of these flows has encouraged a wide and interdisciplinary range of fluid dynamicists, including atmospheric scientists, mechanical engineers, and physicists, to contribute to the field. Current understanding and open issues will be covered in the mini-symposium.

Speakers have been selected to represent a variety of scales and approaches, as well as to illustrate the interdisciplinary nature of the latest research:

(1) Toshiyuki Gotoh, Nagoya Institute of Technology, Nagoya, Japan, on "Numerical simulation of cloud droplets and turbulence."
(2) Fabian Hoffmann, Ludwig-Maximilians-University, Munich, Germany, on "Inhomogeneous mixing processes in clouds: toward mixed-phase clouds."
(3) Sonia Lasher-Trapp, University of Illinois, Urbana-Champaign, USA, on "Entrainment in a simulated supercell thunderstorm."
(4) Prasanth Prabhakaran, Michigan Technological University, Houghton, USA, on "Cloud-turbulence interactions: insights from moist Rayleigh-Benard convection experiments."
(5) S. Ravichandran, Nordita and Stockholm University, Stockholm, Sweden, on "Numerical simulation of cumulus and mammatus clouds."
(6) Xiyue (Sally) Zhang, National Center for Atmospheric Research, Boulder, USA, on "Seasonal cycle of idealized polar clouds: large eddy simulations driven by a GCM."

ARTICLE: A more confident view of Earth's climate sensitivity –

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Unfortunately the range of likely ECS values has remained stubbornly wide for decades, with the most recent IPCC assessment report placing the likely range at 1.5 - 4.5˚C **[3]**, essentially the same range provided in a landmark report from 1979 **[4]**. Recently, however, a World Climate Research Programme (WCRP) commissioned assessment by Sherwood and colleagues **[5]** has considerably narrowed this range to 2.6 - 3.9 ˚C (illustrated in **Figure 1**), providing a major advance on this holy grail of climate science.

ECS is governed by how strongly the Earth is directly heated by the additional CO_2 – the radiative forcing – and by the subsequent response of the system as it warms in order to restore planetary energy balance. Whereas the radiative forcing for a doubling of CO_2 is fairly well-known from spectroscopic measurements and radiative transfer calculations to be around 4 W/m^2 globally **[6]**, the response to that forcing is more complicated and therefore less certain. Warming allows the planet to shed infrared heat to space through the basic blackbody response, but it also causes changes throughout the climate system that weaken this radiative damping. For example, warming causes decreases in the area covered by highly reflective snow and ice as well as increases in the concentration of water vapor, a greenhouse gas. These, together with several other feedback mechanisms, actually make a larger contribution than CO_2 itself to the warming that the planet ultimately experiences.

How do climate scientists determine Earth's climate sensitivity? Since nature has not provided us with a step change in CO_2 to analyze, a commonly-used approached is to simulate the climate response to a doubling of CO_2 in Earth system models. While this directly addresses the question at hand, models are approximations of the Earth system requiring numerous simplifications and assumptions with varying degrees of justification. Indeed, the answers that they give span an even wider range than the aforementioned 1.5-4.5˚C, owing primarily to differences in how clouds respond to warming **[7-10]**.

The approach taken by Sherwood *et al.*, in contrast, is to take three semi-independent lines of evidence and bring them together in a Bayesian framework to determine more confidently the Earth's climate sensitivity. This is analogous to a crime investigation in which all available pieces of evidence are collected, scrutinized, and weighed against each other such that the culprit can be identified more confidently than if only one piece of evidence were considered in isolation. Sherwood *et al.* systematically evaluated all the evidence from these disparate components spanning a huge range of disciplines, space scales, time scales, and data sources (some examples are shown here **[11]**) – a novel and groundbreaking approach that brought clarity to the ECS problem that has been elusive to date.

The first line of evidence considered comes from estimates of individual forcing and feedback processes derived using a combination of observations, high-resolution models, and theory. For example, satellite observations of how clouds respond to changing environmental conditions from one year to the next can be used to infer the cloud feedback. Quantitative estimates of each forcing and feedback process, along with their attendant uncertainties, can then be combined to estimate a probable range of ECS consistent with this evidence.

Secondly, Sherwood *et al.* analyzed the instrumental record of Earth's climate since the late 1800s. During this period, greenhouse gas concentrations have increased, causing warming at the Earth's surface and through the depths of the ocean. Given estimates of radiative forcing along with instrumental measurements of warming at Earth's surface and in the ocean, one can infer ECS.

The paleoclimate record provides the third line of evidence. Proxy data – including that taken from bubbles trapped in ice cores – indicates periods deep in Earth's past where global temperatures were much colder or much warmer than today. Together with coincident proxy measurements of radiative forcing, these ancient temperature estimates allow for yet another ECS estimate.

Each of these three lines of evidence comes with its own set of advantages and disadvantages. For example, process studies directly quantify the terms that actually govern the climate response to doubled CO_2, but observational uncertainty can be substantial. Evidence from the historical record capitalizes on high quality observations of real-world warming, but the exact radiative forcing

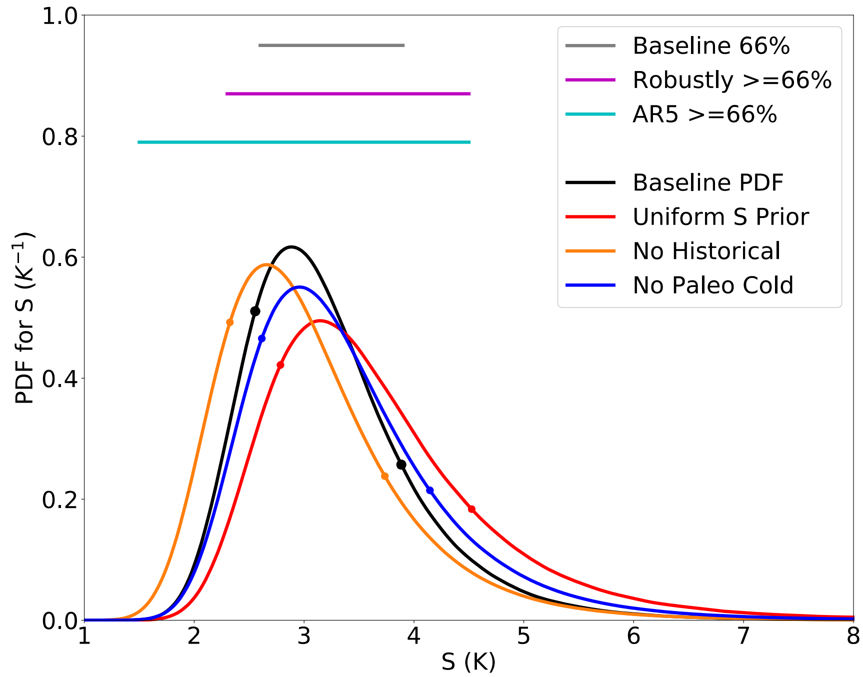

Figure 1: ***Estimates of climate sensitivity derived in Sherwood et al (2020). The primary calculation is shown in the black curve, with the values spanned by the central 66% of the distribution indicated by the horizontal gray line near the top. Other estimates derived with different assumptions are shown in red, orange, and blue curves, and their 66% range is indicated by the horizontal magenta line. For comparison, the likely ECS range of 1.4-4.5 ˚C from IPCC AR5 is indicated by the horizontal cyan line.***

Earth experienced remains uncertain, and there are difficulties in distinguishing between internal variability and the forced response, which ECS measures. Finally, paleoclimate evidence uniquely comes from states in which the temperature is actually equilibrated with the forcing, but has to contend with increasingly uncertain radiative forcing as one peers deeper into the geological record and uncertainties in how exactly radiative feedback strengths differ, for example, between an ice age and a hothouse climate.

Despite all the uncertainties, the three lines of evidence yield ECS estimates that are in substantial agreement with each other. This close corroboration among multiple sources, when combined in a Bayesian framework, allows for tighter constraint on ECS than has ever been achieved previously. The basic calculations illustrated in **Figure 1** indicate that ECS is likely between 2.6 and 3.9 ˚C, a much narrower range than provided in the IPCC AR5. The result is quite resilient, with the likely range remaining within 2.3 - 4.5 ˚C even when fairly drastic tests are performed, like ignoring entire lines of evidence. Notably, the lower bound of the likely ECS range has shifted upwards markedly, meaning that the large volume of consistent evidence now makes it very unlikely that ECS is below 2˚C. On the high end, while ECS values in excess of 4.5˚C are not ruled out in this analysis, they are deemed very unlikely.

In sum, Sherwood *et al.* has provided a more confident assessment of Earth's climate sensitivity than was ever achieved previously, particularly by ruling out very low sensitivity values. This means that it is increasingly unlikely that substantial warming in excess of 2˚C since preindustrial times can be avoided if humanity follows a high-emissions scenario into the future. At the same time, the unlikelihood of extremely high ECS means that the future warming trajectory is not out of human control; rather emissions reductions can stave off dangerous climate change.

Acknowledgements

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References

[1] M. R. Grose, J. Gregory, R. Colman, and T. Andrews. What Climate Sensitivity Index Is Most Useful for Projections? *Geophysical Research Letters* **45**, 1559-1566 (2018); doi:10.1002/2017gl075742.

[2] UNFCC. Adoption of the Paris Agreement Tech. Rep. (2015); FCCC/CP/2015/L.9/Rev.1.

[3] *IPCC Climate Change 2013: The Physical Science Basis*. (Cambridge University Press, 2013).

[4] J. G. Charney, *et al. Carbon Dioxide and Climate: A Scientific Assessment*. 22 (National Academy of Sciences, 1979).

[5] S. Sherwood, *et al.* An assessment of Earth's climate sensitivity using multiple lines of evidence. *Reviews of Geophysics* **n/a**, e2019RG000678 (2020); doi:10.1029/2019RG000678.

[6] C. J. Smith, *et al.* Effective radiative forcing and adjustments in CMIP6 models. *Atmos. Chem. Phys.* **20**, 9591-9618 (2020); doi:10.5194/acp-20-9591-2020.

[7] R. D. Cess, Interpretation of Cloud-Climate Feedback as Produced by 14 Atmospheric General Circulation Models. *Science* **245**, 513-516 (1989); doi:10.1126/science.245.4917.513.

[8] S. Bony and J. L. Dufresne, Marine boundary layer clouds at the heart of tropical cloud feedback uncertainties in climate models. *Geophys. Res. Lett.* **32**, (2005); doi:10.1029/2005GL023851.

[9] P. M. Caldwell, M. D. Zelinka, K. E. Taylor, and K. Marvel, Quantifying the Sources of Intermodel Spread in Equilibrium Climate Sensitivity. *Journal of Climate* **29**, 513-524 (2016); doi:10.1175/jcli-d-15-0352.1.

[10] M. D. Zelinka, *et al.* Causes of Higher Climate Sensitivity in CMIP6 Models. *Geophysical Research Letters* **47**, (2020); doi:10.1029/2019gl085782.

[11] R. Knutti, M. A. A. Rugenstein, and G. C. Hegerl, Beyond equilibrium climate sensitivity. *Nature Geoscience* **10**, 727 (2017); doi:10.1038/ngeo3017.

GPC Elections

The upcoming GPC election features openings for Vice Chair, and two regular Members-at-Large. The election is to be held in October and elected candidates would begin their terms in January 1, 2021. We strongly encourage you to help shape your GPC by voting.

The nominating committee is chaired by Past Chair Chris E. Forest, with additional members Brad Marston, Dan Rothman, Katie Dagon, and Hope Michelsen. Prospective candidates will be considered for their scientific standing and activity, their history of involvement with GPC and the APS, their perspective on the activities of the Group, and their likelihood of service to GPC if elected. Diversity in the GPC leads to vitality and innovation.

The position of the Vice Chair of GPC (currently held by William Newman) is a four-year commitment: after a year as vice chair the officer becomes in successive years the chair-elect (currently Mary Silber), chair (currently William D. Collins), and then past chair (currently Chris E. Forest) – each with distinct duties. The chair officers play a crucial role in providing leadership in organizing the scientific content of the March Meeting and other meetings and in representing climate physics within the American Physical Society. The position of Secretary-Treasurer (currently held by Raymond A. Shaw) is a three year position, plus an additional year to aid in the transition of duties. The duties are to maintain the records of the GPC, and have responsibility for all GPC funds.

The members-at-large (two regular positions, replacing Barbara Levi and Isabel McCoy) serve a three-year term; they constitute the fellowship committee, help select the invited symposia and invited talks for the March Meeting and provide advice on issues important to the GPC.

Identifying excellent candidates who can provide a broad view of the diverse field that is climate physics is key to maintaining the vitality of GPC.

GPC Students and Early Career Investigators Prizes

Last year, GPC created a scholarship for young GPC members to attend the APS March Meetings and participate in the GPC sessions.

This year we will make two awards of $500 to a graduate student and an early career investigator. In future years, the GPC may expand the award if the Physics of Climate community grows and continues its success.

The first award will be "The GPC Students Prize" and will be given to a graduate student member of the APS that is pursuing work related to the GPC mission. The second award will be "The GPC Early Career Investigators Award" and will be given to an early career investigator (less than 5 years out of Ph.D.) and be a member of the APS GPC. Both awards will help cover the costs to attend and participate at the March Meeting in a GPC related session.

To apply for the scholarship, applicants should submit a CV, an abstract for a contributed (10 minute) talk, and a short summary (200-300 words) of how their work fits with the GPC mission.

Please send these items to msilber@uchicago.edu with the heading: "APS GPC Scholarship Application 2020"

Deadline for applications: December 13, 2020

The scholarship committee consists of the GPC Vice Chair (currently, William Newman) as the committee chair and three additional members.

For additional information, please contact Dr. Newman if needed.

Other News Links of Interest and Upcoming Events Calendar

1. Interview with Michael Gil on "The Complex Variability of Climate," APS Physics Magazine (July 31, 2020). The interview was motivated by the publication of the first review on climate physics for Reviews of Modern Physics: "Climate variability and climate change," by Michael Ghil and Valerio Lucarini, Rev. Mod. Phys. 92, 035002.

2. 101st American Meteorological Society Annual Meeting, New Orleans, LA, January 10-14, 2021.
3. 34th Conference on Hurricanes and Tropical Meteorology, New Orleans, LA, May 9-14, 2021
4. AMOS 2021, February 8-12, 2021, Melbourne, Australia.
5. AGU Fall meeting, Dec. 1-17, 2020, San Francisco, CA.
6. 2022 Ocean Sciences Meeting, February 27-March 4, Honolulu, HI
7. European Geosciences Union General Assembly 2021, April 25-30, Vienna, Austria.