GPC Newsletter

Issue #7

February 2017

IN THIS ISSUE

APS TOPICAL GROUP ON THE PHYSICS OF CLIMATE

Message from the Editor

This is the seventh 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 Chair

Brad Marston, GPC Chair

The upcoming March APS Meeting in New Orleans will feature two formal scientific sessions sponsored by the Topical Group on the Physics of Climate (GPC), both on Tuesday March 14. Beginning at 11:15 am, Mary Silber will chair Focus Session F12 on "Natural Pattern Formation and Earth's Climate System" featuring two invited speakers and 8 contributed talks on a diverse range of components of the climate system. The Focus session will be held in room 271. At 2:30 pm our Invited Session H21 on "Extreme Events in a Changing Climate" will be held in room 281-282. Speakers Eric Vanden-Eijnden, Karen McKinnon, Michael Mann, Adam Sobel, and Jennifer Francis will approach the title subject from the perspectives of mathematics, paleoclimatology, statistics, and climate dynamics. More details about the two scientific sessions can be found inside this Newsletter. The GPC Business Meeting (session J19) will follow at 5:45 pm, in room 278-279. All GPC members are invited to participate. I hope to see you in New Orleans.

I would like to thank colleagues whose terms on the Executive Committee finished at the end of 2016 for their hard work. John Wettlaufer, past GPC chair, put together an impressive slate of candidates for our election in his capacity as chair of the Nominations Committee. Morgan O'Neill (member-at-large), has helped out in numerous ways, including the organization of the Invited Session next month.

Professor Tim Palmer of Oxford University has been working on sources of sensitivity and uncertainty in weather forecasting and climate prediction for several decades. He has also pioneered work in ensemble forecasting and stochastic parameterization of unresolved processes. Tim's PhD training in the theory of general relativity has informed his interests and the path he has taken in climate science. I am delighted that Tim has contributed an essay in this Newsletter. "Simulating Earth's Climate — Drawing on the Vision and Talent of the High Energy Physics Community" invites other physicists to contribute to climate science. Physicists have a unique way of thinking and solving problems and climate science would benefit from more of it. Read on below!

Simulating Earth's Climate – Drawing on the Vision and Talent of the High-Energy Physics Community

Tim Palmer, Atmospheric, Oceanic and Planetary Physics Clarendon Laboratory, University of Oxford

The goal of simulating our global climate system accurately is as challenging as that of finding the Higgs boson or searching for supersymmetry, and should be treated with the same level of ambition. Moreover, post-PhD theoretical physicists have the right numerate background to help advance climate science to the next level.

I recently attended a public lecture given by an eminent theoretical physicist from Princeton. What, the speaker asked, if the Large Hadron Collider finds no evidence of supersymmetry? For him, the answer was simple: build an even larger collider! His next slide showed plans for a

(Continued on p. 2)

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Simulating Earth's Climate – Drawing on the Vision and Talent of the High-Energy Physics Community

(Continued from p. 1)

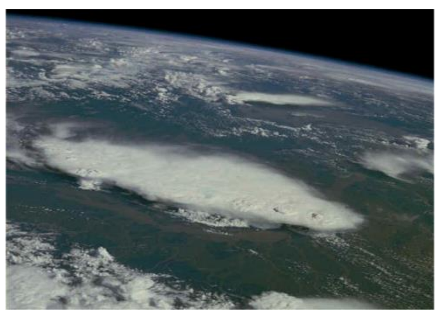

Figure 1: ***With the advent of exascale computing, it will be possible to run global climate models where deep convective cloud systems, such as illustrated, are represented by the basic laws of physics, and not by semi-empirical closure formulae as is currently the case. From https://eol.jsc.nasa.gov.***

possible next-generation accelerator – the particles travelling around a 100 km circumference ring going underneath Lake Geneva. Expensive for sure, the theoretician noted, but surely worth it if we wish to truly understand the nature of our universe. I really admired this guy's chutzpah. It made me think about my field – climate physics. How I would love just one of the billions of dollars needed to build this next-generation collider. What would I do with it? I would create the type of international institute first advocated by Einstein and colleagues Marie Curie and Heinrich Lorentz! Bear with me, I will explain!

Discovering the fundamental building blocks of the universe may sound a lot sexier than trying to answer the more utilitarian question of how our ongoing emissions of carbon into the atmosphere will affect humanity. But if temperatures and humidities together rise to the point where humans living in large parts of the world cannot avoid overheating [1], debates about supersymmetry may seem rather moot. However, frustratingly, we don't know how bad climate change is going to be in the coming century and beyond, and whether humanity will be faced with such existential challenges.

There are two key reasons for this. The first is that there is uncertainty about the extent to which clouds will amplify, or even damp, the direct radiative effect of enhanced CO_2. Available evidence suggests they are amplifiers (bad news) but because individual cloud systems are too small to be simulated *ab initio* in current-generation climate models, they must be represented by highly simplified, partially empirical closure equations. The dependence of projections of global temperature rise on these approximate closure equations makes such projections especially uncertain. Hence, for example, based on current understanding, the equilibrium response of climate to a doubling of CO_2 could be anything from a little over a degree, to 6 or more degrees [2,3]. If the lower temperature change prevails, climate change may not be the world's most pressing problem; if the high change materializes, then it is.

The second reason for uncertainty is that current-generation climate models do a relatively poor job in simulating regional climate extremes (e.g., long-lived drought) [4,5]. The reason is again related to an inability to simulate the small-scale elements of atmosphere and ocean circulations, which are believed to play a crucial role in the nonlinear dynamics of these extremes. For example, drought-forming anticyclones are believed to be partially maintained over long periods by internal Rossby wave-breaking processes associated with individual weather systems as they travel around the flanks of these anticyclones. These effects can in principle be simulated using high-resolution regional climate models, embedded into global models. However, these regional models inherit the deficiencies of the low-resolution global models through the regional models' lateral boundaries.

In climate science we are unable to go into the lab to do an experiment to find out what will happen to climate if we double atmospheric CO_2. We need complex *ab* *initio* models of climate as surrogates of the lab experiments, and with which we can compare our theoretical understanding of climate. Traditionally such models have been developed at the institute level, and quasi-independent models have proliferated around the world as a result. We can continue along this path, but progress is likely to be very slow: individual institutes are now finding they have neither the computational power nor the human resources needed to progress climate modelling science adequately. Consistent with this, evidence suggests that improvement in the quality of global climate models over the last decade has been rather minimal [6,7]. By any measure, this is an unsatisfactory state of affairs.

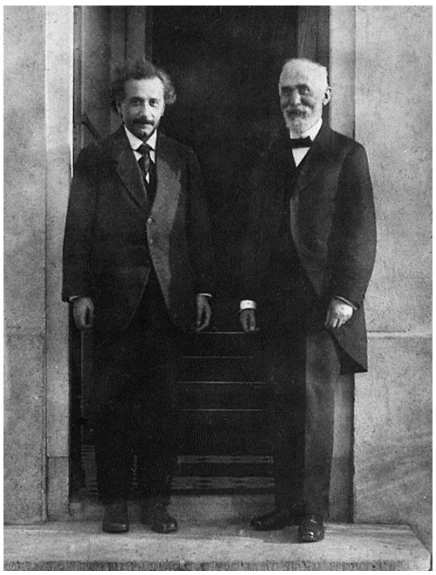

Figure 2: *Albert Einstein and Heinrich Lorentz were deeply committed Internationalists. Together with colleague Marie Curie, they proposed, in 1926, the establishment of an international institute for meteorology. With the climate threat looming, the need for such an institute has never been greater. (Source: Museum Boerhaave, Leiden)*

It is time, in my view, to pool resources, human and computational, to develop a new class of ultra-high-resolution global climate models, where deep convective cloud systems and mesoscale eddies in the atmosphere and oceans can be simulated *ab initio,* i.e., with the basic laws of physics (Fig. 1) [8][1]. To enable this to be done as quickly as possible, we need to start planning for some of the first available exascale computers – expected to come on the market in the early part of the next decade – to be completely dedicated to climate prediction; experience has shown that a supercomputing resource shared with other users just won't be adequate for the task.

My own belief is that an exascale climate computing center will be most successful if it has international governance; most importantly this will enable resources to be made available that may be neither affordable nor even available at the national level. CERN provides an outstandingly successful example of what can be achieved by international collaboration. In meteorology, an equivalently successful example is the European Centre for Medium-Range Weather Forecasts (ECMWF)[10]: from its inception in the 1970s, this center has provided the world's most skillful global weather forecasts (and has provided the basis for many media stories, particularly in the US, asking why Europe is so far ahead in the field of weather prediction). A key reason for this success does indeed arise from an ability of ECMWF's supporting countries, 34 at the latest count, to pool resources – human, computational and financial. As far as I am aware, the first scientists to advocate the establishment of an international institute for meteorology were Albert Einstein, Marie Curie and Heinrich Lorentz (Fig. 2) [11] – themselves committed Internationalists! We need these great scientists' vision to move forward.

However, to make such centers fly (I am not necessarily advocating a single such center), we also need highly numerate scientific talent. It's not just about simulating the nonlinear fluid dynamics of the atmosphere and oceans, there's also the land surface, the cryosphere and the multiple biogeochemical processes that, for example, determine Earth's carbon cycle. It's not just about solving known deterministic partial differential equations, it's about developing and incorporating new sets of stochastic equations, e.g., for uncertain cloud microphysical and aerosol processes. It's not about running individual integrations, but rather about running large ensembles of integrations which properly explore and indeed predict the inevitable uncertainties arising from solving the equations of an infinite-dimensional nonlinear system using finite-dimensional computational representations. It's not just about forecasting the future, it's about exploring and understanding our past climatic regimes. Developing a modelling system in which all this can be achieved efficiently on power-hungry massively parallel supercomputers will be exceptionally challenging mathematically. (Some of my own research in this latter area revolves around the question of how many of the billions of bits which represent the many variables in a partially stochastic climate model, contain real information. Computer resources can be deployed much more efficiently by only moving, inside the supercomputer, those bits which contain real information [12]).

Finally, as well as providing new understanding of the mechanisms and processes at play, output from such a climate modelling system will be crucial for driving a range of impact models from health and energy to transport and food security, in much more reliable ways than are currently possible. Where do we find the human resources to do all this work? Climate science and applied mathematics departments are traditional sources. However, I want to suggest a largely overlooked area: post-Ph.D. talent in theoretical physics (not just in high-energy physics, but in other branches such as condensed matter, astrophysics and so on) and in pure mathematics. The people that do Ph.D.s in String Theory or in Number Theory do so because, as undergraduates or earlier, they have become completely beguiled by foundational problems in physics and mathematics and feel a deep yearning to explore basic questions arising in these fields. At this stage in their careers they are simply not interested in doing research in environmental science (I know this because I was one of them – my Ph.D. was in General Relativity theory). However, having done their Ph.D.s and maybe a few years of postdoc research and having made some contributions to these foundational questions, these same people may start to feel it is time to apply their scientific talents to problems of more societal relevance. In a world where we are all living longer, it seems completely crazy to view our research careers as essentially set in stone by the time we have completed our Ph.D.s. I strongly believe that someone who has completed a Ph.D. in theoretical physics, and is sufficiently motivated, can pick up what is needed to become a credible researcher in climate physics in about a year. However, for such an idea to be viable, we must fund post-Ph.D. accelerated-training programs to allow such talent to move seamlessly between fields.

Governments around the world will shortly have to make major investment decisions on the types of infrastructure needed to make society more resilient to our changing climate: this is an essential part of the climate adaptation program. Investment in the basic science underpinning climate will provide a clearer vision of the world we are heading for, allowing more informed decisions to be made and hence money to be better spent, with costs that are, relatively speaking, trivial. Importantly, it should be recognized that improving our ability to understand and anticipate future climate change is quite independent of the stance we may have on the politics of climate mitigation. It is time to recognize that the goal of simulating our global climate system accurately is as challenging as that of finding the Higgs boson or searching for supersymmetry, and should be treated with the same level of ambition. Theoretical physicists are well placed to make major contributions, should they so wish.

These issues are discussed in more detail in a personal-perspective paper [13] which appeared in the Royal Society's Proceedings A journal in 2016.

Notes

[1] The full benefit of increased resolution will only be seen when such models are coupled to data assimilation technology. Data assimilation is the (optimization) process by which observational data can be ingested into the models. Data assimilation provides a powerful method for constraining poorly known parameters in sub-grid closure formulae [9].

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[13] T. N. Palmer, 2016: A personal perspective on modelling the climate system. Proc. R. Soc. A **472**: 20150772. (doi:10.1098/rspa.2015.0772)

GPC Executive Committee Members-at-Large and Newsletter Editor:

Left to right: Douglas Kurtze (12/2019), Sharon Sessions (12/2019), Mary Silber (12/2018), Robert Ecke (12/2018), Mark Boslough (12/2017), Raymond Shaw (12/2017), Douglas Peter Weichman (Newsletter Editor, 12/2018).

MARCH MEETING 2017

MARCH 13 – 17, 2017
NEW ORLEANS, LOUISIANA

GPC Climate Café

(8:00-10:00 pm, Tuesday March 14)

You are cordially invited to the GPC Climate Café!

The cafe will take place immediately following the **GPC business meeting (Session J19, 9:00-10:00 pm, Tuesday March 14, Rm. 278-279).** This is an informal meeting where, over drinks and food, you can meet the March Meeting GPC speakers, as well as fellow GPC and other APS members. We'll discuss climate science, network, and chat with the Executive Committee members about GPC concerns. In keeping with the informal nature of the cafe, we will announce the venue for this year's Climate Cafe at the Tuesday sessions.

All APS members are welcome to attend!

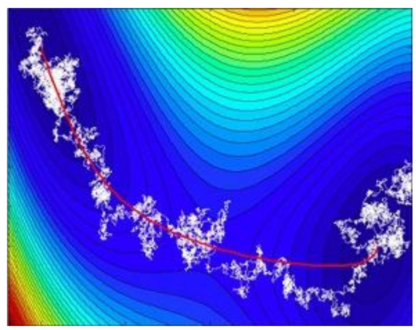
GPC Invited Session: Extreme Events in a Changing Climate

(Session H21, 2:30 pm – 5:30 pm, Tuesday, March 14, Rm. 281-282)

ERIC VANDEN-EIJNDEN
Courant Insititute of Mathematical Sciences
New York University

Title: Extreme events, tail statistics, and large deviation theory in geophysical flows

Synopsis: The talk will give an overview of analytical and numerical methods that have been recently introduced to characterize the pathway, rate, and likelihood of rare but important events observed in the context of geophysical flows. These methods build on large deviation theory, which indicates that the way



such events occur is often predictable and offers way to compute them via solution of an optimization problem for their most likely path. These concepts and ideas will be illustrated via examples ranging from transitions between metastable patterns in atmospheric flows to rogue waves.

KAREN MCKINNON
National Center for Atmospheric Research
Boulder, CO

Title: The signal and the noise: forced and unforced changes in temperature distributions and the probability of extremes

Synopsis: Recent observed trends in climate variables are a combination of a forced climate change signal and unforced internal variability, or noise. To gain insight into important climate parameters such as climate sensitivity and make reasonable projections into the future, it is necessary to separate the forced signal from the random sampling of variability. Here, I focus on this goal in the context of the changing shape of daily temperature distributions. Because daily temperature distributions tend to be non-Gaussian, I will first introduce a non-parametric method based on quantile regression which summarizes changes in the shape of seasonal temperature distributions with a small set of basis functions. Next, I will explore the relative roles of circulation and the land surface in controlling the trends in daily temperature distributions in both the observations and the NCAR CESM1 Large Ensemble. In the context of the Large Ensemble, it is then possible to determine which trends -- and which physical mechanisms associated with the trends -- are the signal, and can reasonably be expected to continue into the future.

MICHAEL MANN
Department of Meteorology and Atmospheric Science
Pennsylvania State University

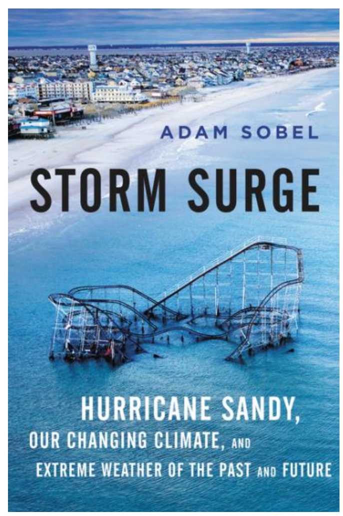
Title: Influence of Anthropogenic Climate Change on Planetary Wave Resonance and Extreme Weather Events

Synopsis: Persistent episodes of extreme weather in the Northern Hemisphere summer have been shown to be associated with the presence of high-amplitude quasi-stationary atmospheric Rossby waves within a particular wavelength range (zonal wavenumber 6-8) [1]. The underlying mechanistic relationship involves the phenomenon of quasi-resonant amplification (QRA) of synoptic-scale waves with that wavenumber range becoming trapped within an effective mid-latitude atmospheric waveguide[1-3]. Recent work suggests an increase in recent decades in the occurrence of QRA-favorable conditions and associated extreme weather, possibly linked to amplified Arctic warming[4] and thus a climate change influence[5]. Here, we isolate a specific fingerprint in the zonal mean surface temperature profile that is associated with QRA-favorable conditions. State-of-the-art (``CMIP5") historical climate model simulations subject to anthropogenic forcing display an increase in the projection of this fingerprint that is mirrored in multiple observational surface temperature datasets. Both the models and observations suggest this signal has only recently emerged from the background noise of natural variability.

ADAM SOBEL
Department of Applied Physics and Applied Mathematics
Columbia University

Title: Human influence on tropical cyclone intensity

Synopsis: Recent assessments agree that tropical cyclone intensity should increase as the climate warms. Less agreement exists on the detection of recent historical trends in tropical cyclone intensity. We interpret future and recent historical trends by using the theory of potential intensity, which predicts the maximum intensity achievable by a tropical cyclone in a given local environment. Although greenhouse gas--driven warming increases potential intensity, climate model simulations suggest that aerosol cooling has largely canceled that effect over the historical record. Large natural variability complicates analysis of trends, as do poleward shifts in the latitude of maximum intensity. In the absence of strong reductions in greenhouse gas emissions, future greenhouse gas forcing of potential intensity will increasingly dominate over aerosol forcing, leading to substantially larger increases in tropical cyclone intensities.



GPC Program Committee:

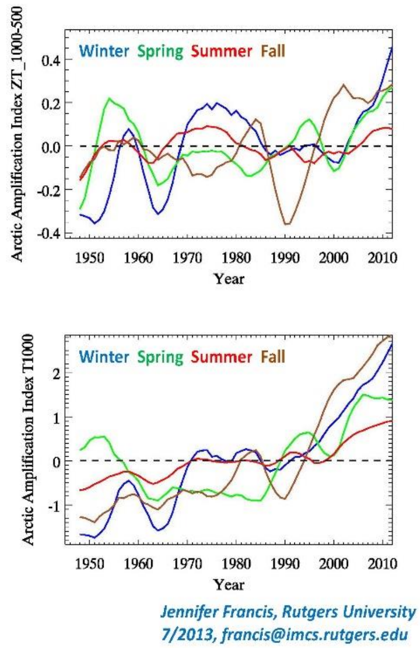
Left to right: Brad Marston (Chair), James Cho, Michael Mann, Ken Minschwaner, and Morgan O'Neill.

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.

JENNIFER FRANCIS
Institute of Marine and Coastal Sciences
Rutgers University

Title: Crazy Weather and the Arctic Meltdown: Emerging Connections

Synopsis: *The issue:* In recent decades, the pace of Arctic warming was at least double that of the globe. A growing body of research suggests this differential warming will increase the frequency of extreme weather events in the northern hemisphere. *Why it matters:* Extreme weather events cause billions of dollars in damage, scores of deaths and injuries, and thousands of disrupted lives each year. The frequency of these events is increasing, and certain types have clear links to climate change. Rapid Arctic warming is expected to cause more persistent weather regimes that can lead to devastating drought, prolonged heat waves, extreme fire seasons, stormy winters,



and heavy flooding, many of which have been prominent weather headlines across the U.S. in recent years. *State of the Science:* The dramatic Arctic warming during recent decades is reducing the temperature difference between the Arctic and mid-latitudes, which is weakening the jet stream's west-to-east winds. Instead of a coherent river of strong winds, a weaker jet tends to waver, split, and wander north and south on its path around the northern hemisphere. These wavier jet streams are responsible for a variety of extreme weather events, which have become more frequent in the U.S., Canada, Europe, and Asia.

GPC Focus Session: Natural Pattern Formation and Earth's Climate System

(Session F12, 11:15 am – 2:15 pm, Tuesday, March 14, Rm. 271)

Invited talks:

B. CAEL BARRY
Department of Earth, Atmospheric, and Planetary Sciences
Massachusetts Institute of Technology

Title: The Volume of Earth's Lakes

Synopsis: How much water do lakes on Earth hold? Global lake volume estimates are scarce, highly variable, and poorly documented. We develop a mechanistic null model for estimating global lake mean depth and volume based on a statistical topographic approach to Earth's surface. The volume-area scaling prediction is accurate and consistent within and across lake datasets spanning diverse regions. We applied these relationships to a global lake area census to estimate global lake volume and depth. The volume of Earth's lakes is 199,000 km^3 (95% confidence interval, 196,000-202,000 km^3). This volume is in the range of historical estimates (166,000-280,000 km^3), but the overall mean depth of 41.8 m (95% CL 41.2-42.4 m) is significantly lower than previous estimates (62 - 151 m). These results highlight and constrain the relative scarcity of lake waters in the hydrosphere and have implications for the role of lakes in global biogeochemical cycles. We also evaluate the size (area) distribution of lakes on Earth compared to expectations from percolation theory.

PEDRAG POPOVICH
Department of Geophysical Sciences
The University of Chicago

Title: **Arctic sea ice melt pond fractal dimension – explained**

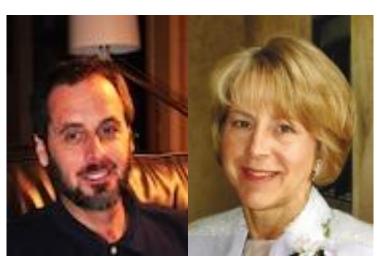
Synopsis: As Arctic sea ice starts to melt in the summer, pools of melt water quickly form on its surface, significantly changing its albedo, and impacting its subsequent evolution. These melt ponds often form complex geometric shapes. One characteristic of their shape, the fractal dimension of the pond boundaries, *D*, when plotted as a function of pond size, has been shown to transition between the two fundamental limits of $D = 1$ and $D = 2$ at some critical pond size. Here, we provide an explanation for this behavior. First, using aerial photographs, we show how this fractal transition curve changes with time, and show that there is a qualitative difference in the pond shape as ice transitions from impermeable to permeable. Namely, while ice is impermeable, maximum fractal dimension is less than 2, whereas after it becomes permeable, maximum fractal dimension becomes very close to 2. We then show how the fractal dimension of a collection of overlapping circles placed randomly on a plane also transitions from $D = 1$ to $D = 2$ at a size equal to the average size of a single circle. We, therefore, conclude that this transition is a simple geometric consequence of regular shapes connecting. The one physical parameter that can be extracted from the fractal transition curve is the length scale at which transition occurs. We provide a possible explanation for this length scale by noting that the flexural wavelength of the ice poses a fundamental limit on the size of melt ponds on permeable ice. If this is true, melt ponds could be used as a proxy for ice thickness.

Contributed talks:

Darin Comeau, Elizabeth Hunke, Adrian Turner	Spatial distribution of Antarctic mass flux due to iceberg transport
John Wettlaufer , Srikanth Toppaladoddi	Statistical Mechanics and the Climatology of the Arctic Sea Ice Thickness Distribution
Srikanth Toppaladoddi, John Wettlaufer	Patterned surfaces pattern convection
Juan Restrepo , Jorge Ramirez	Stochastic Wave Breaking Dynamics
Brad Marston, Antoin Venaille	Are Geophysical Jets Protected Topologically?
David Raymond, Zeljka Fuchs	The Madden-Julian Oscillation of the Earth's Atmosphere
Punit Gandhi , Karna Gowda , Sarah Iams , Lucien Werner , Mary Silber	Topographic influences on vegetation patterns in semi-arid regions
Isabel McCoy , Robert Wood , Jennifer Fletcher	Identifying Meteorological Controls on Open and Closed Mesoscale Cellular Convection as Associated with Marine Cold Air Outbreaks

GPC Communications Committee

Left to right: Peter Weichman (Chair), Barbara Levi



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.

Upcoming Events and Other Links of Interest

1. European Geosciences Union General Assembly 2017, Vienna, Austria, April 23-28, 2017.
2. PAGES 3rd Young Scientists Meeting (YSM), Morillo de Tou, Spain, May 7-9, 2017.
3. Climate, Oceans and Society Challenges & Opportunities, Busan, Korea, May 30-June 2, 2017.
4. AMS AOFD meeting, Portland, OR June 26-30, 2017.
5. MPIPKS Dresden meeting, "Climate Fluctuations and Non-equilibrium Statistical Mechanics: An Interdisciplinary Dialogue," Dresden, Germany, July 9-August 5, 2017.
6. Aspen Center for Physics "Vorticity in the Universe: From Superfluids to Weather and Climate, to the Universe," Aspen CO, August 27 to September 17, 2017 (organized by James Cho, Brad Marston, and Juan Restrepo).
7. Fourth International Conference on Earth System Modelling (4ICESM), Hamburg, Germany, August 28-September 1, 2017.
8. KITP Program on "Planetary Boundary Layers in Atmospheres, Oceans, and Ice on Earth and Moons", UC Santa Barbara, CA, April 2-June 22, 2018.

Image Credits

p. 5: http://cims.nyu.edu/~eve2/rare_events.htm

p. 6: https://www.harpercollins.com/9780062304766/storm-surge