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Before the House, Science, Space, and Technology Committee
House of Representatives
Washington, D.C.
September 26, 2019

Madam Chair, Ranking Member Lukas, and Members of the Committee, thank you for inviting me to participate in this morning's hearing on extreme weather. I am Adam Sobel, a professor and atmospheric scientist at Columbia University's Lamont-Doherty Earth Observatory and School of Engineering.

Introduction

In this testimony I will cover three topics:

- A brief overview of the relationship of different extreme weather events to climate change;
- In the case of hurricanes in particular, some of the complexities of their relationship to climate, the sources of uncertainty, and the challenges this poses for communicating and acting on our understanding of the risks they pose; and
- Recommendations for future research, with an emphasis on an expanded view of what the insurance industry calls "catastrophe modeling".

My testimony is based on the peer-reviewed literature, including reports from the Intergovernmental Panel on Climate Change, the National Climate Assessments, and others, as well as being informed by my own research and that of my colleagues at Columbia. I was one of the authors of a 2016 National Academy of Sciences Report *Attribution of Extreme Weather Events in the Context of Climate Change,* which also informs my views.

How extreme weather is affected by climate change: An overview

Extreme weather is changing as a consequence of human-induced climate change. How it is changing, how quickly, and how well we can detect those changes varies across different kinds of extreme weather events. In my view, there are multiple answers to the question "how are extreme weather events changing"?

Let us first establish some basic concepts. Weather is the instantaneous state of the atmosphere and its evolution over short time scales – days, say. Climate, to take the simplest definition, is the average of the weather over long periods of time. The climate is strongly influenced by external factors, some of which are predictable and act over long periods of time: the position of the earth in its orbit around the sun, the slow circulation of the oceans, and the concentrations of greenhouse gases in the atmosphere. While these factors may control the climate, the internal chaotic dynamics of the atmosphere still give the weather much freedom to fluctuate about that climate. So every weather event, including an extreme one, has many proximate causes, and most of those causes are natural. (Chaos theory teaches us, in fact, that we cannot trace these paths of causality very far back in time in the atmosphere.) So it is never accurate to say that climate change "caused" a single weather event without further qualification. But a change in climate can still change the *probability* that a given type of weather event will occur, or the severity of events in a given class when they do occur. (Event attribution studies, such as described in the 2016 National Academy report, assess those changes in probability or severity for individual events, and investigate to what extent – always much less than 100% - climate change can be held responsible for a given event.) We need to understand those causal links in order to know how to best respond to the reality of human-induced climate change.

Our understanding rests on three distinct sources: observations of the events; numerical models that allow us to simulate and predict them in the context of the larger climate within which they occur; and "theory". By theory, I mean our well-grounded and tested understanding of the first principles that govern the events and their relationship to climate, principles that can be expressed without resorting to numerical models. When observations, models and theory yield similar answers about how some type of event is related to climate, we become more confident in our understanding of the relationship. If one or more of the three is inadequate, or they are inconsistent with one another, we are much less confident.

Heat waves are the best example of a case where observations, models, and theory converge. Observations show heat waves increasing in frequency and intensity in most parts of the world; we understand well how heat waves are related to the climate in which they occur; and because climate models predict that they should be increasing in frequency and intensity. At this point in history, when a heat wave occurs, one can almost say with confidence that global warming made it *more likely*, *more intense* or *both*, even without doing a formal attribution study.

To take the other extreme, we know relatively little about how tornadoes are changing. The observations do show some changes in statistics of tornado occurrence – especially, increasing tendency for them to be bunched into large outbreaks, rather than spaced out more in smaller clusters. But the observations themselves are imperfect; and beyond that, we do not have the necessary theoretical understanding of how tornadoes are related to climate to be able to say with confidence that these changes are caused by warming, and climate models at this point provide only weak guidance.

Most kinds of extreme weather fall in between these extremes of understanding and ignorance.

We have good confidence that heavy rain events are increasing in many parts of the world: again observations, theory and models are all broadly consistent. Droughts and wildfires are both to some degree influenced directly by temperature, so we have good confidence that global warming increases either the frequency or intensity of these events under some conditions, although other factors that influence them may sometimes be more important.

In the case of wildfires such as those that have devastated the American west in recent years, warming and drying are the primary causes. Pre-historical evidence stored in tree rings and charcoal buried in lakes tell us that for thousands of years, periods of warming have coincided with periods of increased wildfire activity in this region. While fire is very complex and affected by much more than just climate, the data from recent decades indicate the same thing today as in the past: the hot years are the years with the most wildfire, and as temperatures have increased, burned areas have increased in step. It is entirely possible that on-the-ground human factors such as land management and accidental ignitions have set the stage for an especially potent fire response to warming in some areas, but the relationship between annual burned areas and temperature has nonetheless been strong and stable over the past few decades. We should plan for continued increases in western U.S. wildfire activity due to continued warming.

We have relatively little understanding of how winter storms are changing, except we know that warming makes some storms produce rain when they would have produced snow in the past (though when it remains cold enough to snow, warming can under some conditions increase the amount of snow).

In-depth example: Hurricanes

Of all types of extreme weather, hurricanes do the most damage. Hurricane Dorian's absolute devastation of the Bahamas is fresh in our minds; the U.S. was fortunate to escape major impacts from Dorian, but was not so fortunate with Hurricanes Michael and Florence last year, or Hurricanes Harvey, Irma, or Maria in 2017. Hurricanes are also the focus of my own research, and the issues around interpreting their relationship to climate are to some extent representative of those with other kinds of events. Hurricanes illustrate some broader issues around communicating and acting on our scientific understanding of the risk, as well as for their own intrinsic importance.

What we know about changes in hurricanes

What do we know about how hurricanes are changing with climate? We can give the most precise answer if we break it down into different aspects.

The most certain way in which hurricane risk is increasing due to climate is that, because of sea level rise, coastal flooding due to hurricane storm surge is becoming worse. Storm surge occurs when the winds from a storm push the ocean onto the land. The total flooding is determined by the surge (the part produced by the wind), the tide, and the background average sea level. As sea level has risen – about a foot in New York City, for example, of which about eight inches is related to climate - for any given combination of storm and tides, the flooding is exacerbated by that amount. There is no doubt about this. The flooding Hurricane Sandy produced, for example, was due to nine feet of storm surge plus a high tide that was five feet above low tide. So the eight inches of additional water due to sea level rise was a small fraction of that, but still a significant one. There is no question this number will increase in the future; sea level rise projections are uncertain in magnitude, but certain in sign: sea level will only go up, not down.

Also the rain hurricanes produce is increasing. Rain-driven flooding from storms like Harvey and Florence is becoming exacerbated, perhaps somewhere between five and twenty percent per degree Celsius (or per 1.8 degrees Fahrenheit) of warming.

In the case of Harvey – and also Dorian in the Bahamas, though its damage was more due to wind and surge than rain – the disaster was made much worse by the slow forward motion of the storm, so that it stayed in one place for a long time. Several recent studies show that storms on average have been slowing down, and suggest that this is a consequence of climate change. These are relatively new findings, not fully understood or digested by the scientific community yet, so this conclusion is particularly uncertain. But the studies are of high quality, and their implications are very serious, so they should be taken into consideration as part of our overall assessment of risk.

Another fairly certain consequence of warming is that hurricane winds are strengthening. Again there is support for this conclusion from observations, theory, and numerical models. The evidence is particularly strong for the north Atlantic – the source of the hurricanes that threaten the United States. The magnitude of the increases in intensity we can attribute to warming is not clear; it may only be a few percent, but even that is significant. The strongest storms do by far the most damage, and increases in intensity at the high end mean more category four and five storms. Because damage is proportional to wind speed cubed, or perhaps even a higher power, we see that for a given small percentage increase in wind, the damage increase is three or more times greater.

In contrast, some aspects of changes in hurricanes are almost entirely uncertain. In particular, we can say very little about how hurricane frequency – the total number of storms that occur each year – will change with warming. Because all other aspects of changes in hurricanes only matter if, where and when a hurricane occurs in the first place, this uncertainty about hurricane frequency limits our ability to assess overall hurricane risk in a changing climate.

We do not have a good understanding of what controls the overall number of tropical cyclones (tropical storm intensity and higher) on the earth presently, which is around 90 per year for the whole earth, around 11 for the Atlantic. Additionally, and we do not have any physical theory for how this should change as climate does. The observations lack any clear indication, mostly showing large fluctuations year to year and decade to decade that make it difficult to discern clear trends. Until recently, numerical simulations tended to show that hurricane frequency should decline with warming, but in the last few years simulations with a couple of the best models have instead produced increases. This produces a large uncertainty in our overall assessment of hurricane risk; if each storm on average produces stronger winds, heavier rains, and worse coastal flooding, but the total number of storms were to decrease enough, the total hazard - the probability of an event of a given magnitude at any given location – might still stay constant, or even decrease. But if the number of storms increases along with the intensities of their wind and rains, then we are in even bigger trouble.

With hurricanes we have the following complex situation: Some aspects are certainly becoming worse with warming; others are likely becoming worse, but with some uncertainty; and other aspects are very uncertain, such that changes in the overall hazard are also uncertain. This situation is broadly representative of other kinds of extreme weather events. The degree of uncertainty varies, but is usually substantial. Yet it would be a grave mistake to interpret this uncertainty as license to ignore the problem and postpone action on climate. There are at least two reasons for this.

Uncertainty is not our friend

Uncertainty about how the risk is changing means we have to accept some possibility of the worst outcome, namely that the risk is increasing at the upper bound of plausible scientific estimates. This is sometimes known as the “precautionary principle”, and it is consistent with how human beings rationally deal with other kinds of risks in life, particularly when the worst outcomes would be truly serious.

Much of the uncertainty in our understanding of changes in extreme weather is due to the fact that our observational record is short while natural variability is large, so that it is difficult to separate the contribution of human influence from that natural variability. The climate fluctuates naturally from year to year, decade to decade, and even century to century. The gradual trends due to human-induced climate change are superimposed on these large fluctuations. With extreme events, the fluctuations are even larger because the events are - by definition – rare, so that the statistics are less conclusive.

To understand this, just flip a coin some number of times, and calculate the fraction of the time it comes up heads. Repeat with different numbers of coin flips, and notice that the more flips you have, the closer your average generally gets to 0.5. When we look at extreme events compared to regular weather, it’s like having fewer coin flips. Now to understand the role of climate change, try to imagine that we are trying to determine whether the coin is fair, or whether the probability of heads has become, say, slightly greater than 0.5, though it was 0.5 in the past. This will be more difficult the fewer flips we have; that example is similar to the situation with hurricanes, since there are few of them compared to days with normal weather.

Further, climate scientists traditionally apply criteria for detecting and attributing trends that are very conservative: they are designed to minimize the risk of a so-called type 1 error (claim of a change when none is actually present, or "false alarm") but in doing so they maximize the probability of type 2 errors (failure to detect a change when one actually is present).

NOAA makes the public statement, as is currently visible on one of its web pages maintained at the Geophysical Fluid Dynamics Laboratory: "In the Atlantic, it is premature to conclude with high confidence that human activities–and particularly greenhouse gas emissions that cause global warming–have already had a detectable impact on hurricane activity." A few sentences later: ""Human activities may have already caused other changes in tropical cyclone activity that are not yet detectable due to the small magnitude of these changes compared to estimated natural variability, or due to observational limitations."

What NOAA is trying to say, in my view, is "there are changes, but we cannot show at 95% confidence that those changes could not have occurred in the absence of human-induced climate change". That may be true, but I would argue that that is not the right question to ask. We know that human-induced climate change is present. The right question is: what is our best estimate of what the changes are, with what confidence? How wide is the range of possibilities that are reasonably consistent with the data, and what is the worst-case scenario?

The most important thing to understand here is: when it comes to disaster risk, uncertainty is not our friend.

When faced with risks we can't assess precisely, but where we have some evidence that they may be increasing, choosing to ignore that evidence because of uncertainty is not prudent. Imagine you want to cross a highway. There are few cars on this highway, but they drive fast, and you can't see around a sharp corner. You don't know the probability that a car is coming, and none have come by for a for a while. Do you assume it's fine and walk across? Or, if there were an action you could take that would reduce your risk, even at some cost – say, walking to somewhere with a better view in both directions, even if it makes you late to where you need to be – wouldn't you do it?

Or, we can make the analogy a little closer using another risk that is hard to quantify: terrorism.

Imagine that a U.S. intelligence agency has some evidence that some bad people somewhere in the world may be planning an attack. The evidence is inconclusive, but strong enough to warrant concern. These bad people are having a meeting somewhere, and it is suspected that their agenda at that meeting is to plan the attack. U.S. agents are not present at the meeting, but have managed to plant a microphone in the room, connected to a transmitter so that they can hear the sound in the room at their offices in the U.S. But the room is noisy and the bad people are speaking quietly, so it is impossible to make out what they are saying, and thus impossible to be sure if they are really planning the attack or not. Would we want the U.S. agents to interpret this uncertainty as meaning everything is fine and no action needs to be taken? Or would we want them to take whatever measures they have at their disposal to prevent the attack, given whatever incomplete information they do have? In this analogy, the possible terrorist attack represents the possibility that hurricane frequency is increasing - along with hurricane wind intensity, rain, and coastal flooding – representing the greatest possible increase in risk. The "noise" is natural variability.

In this example, I think most of us would want to take action and the same is true, in my view, with respect to extreme weather and climate.

Changes in the future will be greater than in the past or present

In addition to taking inappropriate comfort from uncertainty, another fallacy is to assess the human influence on extreme weather risk using only data from the present, while ignoring *the likely greater increases in the future*.

Human-induced climate change has already caused changes in some kinds of extreme weather events. Attribution studies are now done in real time to assess to what extent any given event that just happened may have been influenced by global warming. These studies are important in helping the public to understand the links between climate and extreme weather, because they capture attention during the teachable moments right after major disasters.

But by focusing attention on the present, when the warming is less than it will be in the future, they can actually give the impression that climate change is less serious than it is, once we accept some responsibility to future generations. With many kinds of events – including hurricanes – event attribution studies give inconclusive results, because of the large natural variability and short, imperfect historical records (and sometimes also because numerical models are not quite good enough to do such studies). If an attribution study gives inconclusive results, as some do, that might leave the impression that climate is not changing that kind of event, and that this is one less reason for action now. Perhaps it would make more sense to wait until we see clearer indications of human influence in extreme events, and then take action. The problem here is that there is a long lag between action and result when it comes to greenhouse gas emissions. We need action now if we hope to reduce the impacts of climate change in the future.

The greenhouse gases already emitted by human activity have committed us to some additional warming beyond what has already been realized, due to the time it takes for the ocean to warm. We are almost certainly committed to additional warming beyond that due to the commitment baked into our current economic and energy systems – that is, absent much stronger and more immediate commitments to decarbonization than currently appear likely, greenhouse gas emissions will continue at sufficient rates to drive further warming for some time. If the climate were a ship, it would be a very large aircraft carrier or ocean liner – it can't be turned around quickly. As further warming proceeds, the changes in extreme weather will continue to grow.

We cannot wait until all the uncertainties have resolved themselves. To take the case of hurricanes, by the time we know with precision how much hurricane risk increases with each degree of warming, the risk will have increased quite a lot – that is how we will be sure, because only then will the data show it conclusively – and by then we will have baked in yet much more warming, warming that we could have avoided with earlier action.

Future Research Challenges

There are several different areas where additional research on extreme weather is urgently needed.

Short-term forecasts directly save lives and property. Weather forecasts, including those for extreme weather, have continuously improved from decade to decade since the mid-20th century. The three-day hurricane track forecast today, for example, is as good as the one-day forecast was 30 years ago --- and two extra days of warning makes an enormous difference in emergency managers' abilities to save lives and property. This increase in forecast skill is an amazing success story of science and technology, even if the public doesn't always recognize it, and it has been largely driven by federal investment in research – much of which was authorized by this Committee. Such improvements will continue as long as the government sustains its support of the research into the observations, numerical models, data assimilation, and high-performance computing that form the backbone of the modern weather, water and climate enterprise --- and the Congress continues to exercise constructive oversight on weather and climate research as it has done via the Weather Research and Forecasting Innovation Act of 2017.

On the longer time scale, an exciting development of the last decade or so has been the emergence of some skill in numerical models on the "subseasonal to seasonal" time scale – especially the subseasonal, meaning roughly 2-4 weeks ahead. This new capability is making it possible to produce forecasts of some phenomena on that time scale. But these forecasts remain mostly experimental and have only a very small amount of skill. The challenges are not just to figure out what can be usefully predicted and to make the predictions better, but also to figure out *how to communicate and use forecasts when they are only slightly better than no forecast at all.* You can make money if you bet on such a forecast over a long time, but much of the time it will still be wrong. Under what circumstances is such a forecast useful, and how can one make sure users understand its limitations and do not develop unrealistic expectations that are sure to be disappointed? For example, there might be moves that could be taken to begin pre-positioning people or materials well in advance of a wildfire or hurricane that appears possible in two weeks, due to a subseasonal forecast, such that the response to a disaster later will be more effective, but that are sufficiently inexpensive that there will be little regret if the event does not materialize.

For more accurate detection and attribution of changes in extreme weather events due to human-induced climate change several things are needed. First, as in all climate research, *the observational network must be sustained over time*, or better, strengthened, so that we can maintain the long-term records that are necessary to document climate change, including its manifestation in extreme events. Second, *climate models need to be continuously improved* -- the US should maintain and build on its strength in climate modeling. Third, and perhaps least appreciated but equally important, *fundamental understanding of the relationship between climate and extreme weather events must be improved*. This is essential to our confidence in our interpretations of the observations and the models. In the case of hurricanes, we lack a plausible candidate theory that might explain the number of hurricanes on the planet each year and how that should change. This makes us totally reliant on numerical models which, though rapidly improving, are still not adequate to answer the question on their own. The Federal agencies that support climate research should more explicitly prioritize work whose goal is to achieve such basic understanding, as much as it prioritizes work whose goals are to improve models or observations.

Perhaps most urgently needed, though, in my view, is *research that quantifies the risks from extreme weather, and their changes as the climate warms, in terms of their impacts on human society: economic losses, fatalities and human health impacts, harm to ecosystems, etc*.

For most of the past decade, I have been interacting closely with colleagues in the insurance industry. They use tools called "*catastrophe models*" to assess the risks from extreme weather events. These industry catastrophe models are designed to solve the problem that most disaster losses come from a few large events, those events are rare, and often modern recorded history has no analog. Before Hurricane Sandy, the last comparable event in New York City occurred in 1821. There were neither good measurements, nor did the city have anywhere near its size or population in 2012. Understandably, the impacts were not comparable. How could one have assessed the risk, pre-Sandy, lacking good, recent historical analogs? Catastrophe models generate large numbers of synthetic events – virtual storms, say, that are realistic, but fill such gaps in history. The models calculate not only the storms' geophysical dimensions but also the impacts they would have on buildings and infrastructure. Essentially, catastrophe models produce synthetic histories from which more representative estimates of risk can be produced.

Such catastrophe models have served the insurance industry well until now, but they have significant limitations in the new environment we face today, where climate change is an established fact and the industry, along with most of the rest of the private and public sector, needs to understand how extreme weather risk is changing. Because of the way catastrophe models have been developed, based closely on historical data, they implicitly assume that the present and near future will be similar to the past, and thus do not adequately capture climate change. The most influential and widely used models are also proprietary, meaning the details of their construction and output are not subject to open scientific debate and peer review. Finally, they are designed to be used in places and for assets where the insurance industry has significant exposure, but tend to be less accurate or nonexistent elsewhere. Thus for calculating property damage risk due to hurricanes in the U.S. they may be pretty good, while they basically can't be used to calculate human health risks from hurricanes in Mozambique, for example.

Some public, academic and nonprofit catastrophe models do exist, but these largely share the weaknesses of the private sector ones, or have even more severe limitations in some respects. The science of climate-aware catastrophe modeling is in its infancy. Yet with the rapidly increasing pressure for climate-related financial disclosure in the private sector, and for increased resilience and adaptation to extreme weather risk at the state, local and federal level in the public sector, there is a rapidly growing need to overcome these limitations.

It is time for the Federal science agencies to invest in a set of open-source tools to assess changing extreme weather risk in a way that is practically useful for real decisions, accounts for climate change, and whose methodologies and assumptions can be debated openly, in the peer-reviewed literature and elsewhere. This will highlight their strengths, weaknesses, and appropriate uses – including the best way to quantify the uncertainties, which will be even larger when climate change is accurately integrated into models and forecasts. They would be available for the insurance industry, and the rest of the private sector, to use (alongside the existing proprietary models, which should and would remain in place) but also be available for use by the governments, such as to inform cost-benefit calculations for building physical flood defenses or any other measure being designed to increase resilience.

The private sector would benefit greatly from the existence of such tools, but for them to be trusted it is important that no company or other private interest "own" them, thus the funding needs to come from the government, or perhaps a public-private partnership. A federal research program in such a direction could be guided, for example, by a steering group with representatives from the private sector, government, and academia.

Concluding Remarks

Thank you for the opportunity to participate in today's hearing. I also want to thank this Committee and your colleagues on both sides of the aisle and both sides of the Capitol for your steadfast support for the Nation's research enterprise. I suspect you have many difficult decisions to make on where to allocate the public's resources. Your support for research and education has helped this Nation maintain its competitive edge and allowed science to contribute to the nation's national, economic and environmental security. I would be pleased to answer any questions or provide additional follow up information that may be useful to the Committee.

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Dr. Adam Sobel is a professor at Columbia University's Lamont-Doherty Earth Observatory and Fu Foundation School of Engineering and Applied Sciences. He is an atmospheric scientist who specializes in the dynamics of climate and weather, particularly in the tropics, on time scales of days to decades.

A major focus of his current research is extreme events - such as hurricanes, tornadoes, floods, and droughts, and the risks these pose to human society in the present and future climate. He leads the Columbia University Initiative on Extreme Weather and Climate. Together with colleagues in both academia and the insurance industry, Sobel has also been developing models to assess the risk of rare but extremely damaging extreme weather events, particularly tropical cyclones, tornadoes, and hail.

Sobel holds a Bachelor's degree in Physics and Music from Wesleyan University, and a Ph.D. in Meteorology from the Massachusetts Institute of Technology. In the last few years, he has received the Meisinger Award from the American Meteorological Society, the Excellence in Mentoring Award from the Lamont-Doherty Earth Observatory of Columbia University, an AXA Award in Extreme Weather and Climate from the AXA Research Fund, and an Ascent Award from the Atmospheric Sciences Section of the American Geophysical Union. Sobel is author or co-author of over 125 peer-reviewed scientific articles, and his book about Hurricane Sandy, *Storm Surge*, published in October 2014 by Harper-Collins, received the 2014 Atmospheric Science Librarians International Choice Award in the popular category and the 2016 Louis J. Battan Award from the American Meteorological Society.

September 2019

Curriculum Vitae - Adam H. Sobel

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Education

- B.A., Wesleyan University, Middletown, CT, Double Major in Physics and Music, Honors in Music, 1989.
- Extension Courses in Physics, Mathematics and Computer Science, University of California at Berkeley, Berkeley, CA, 1991-92.
- Ph.D. in Meteorology, Massachusetts Institute of Technology, Cambridge, MA. Thesis defended September 1997, formal degree date February 1998. Thesis title: Quantitative Diagnostics of Stratospheric Mixing.

Positions

- August 1992 - August 1993: Research Assistant, Nuclear Science Division, Lawrence Berkeley Laboratory, Berkeley, CA.
- September 1993 - September 1997: Graduate Research Assistant, Massachusetts Institute of Technology, Cambridge, MA, faculty advisor R. A. Plumb.
- September 1997 - December 1999: Postdoctoral Research Associate, University of Washington, Seattle, WA.
- January 2000 - July 2003: Assistant Professor, Department of Applied Physics and Applied Mathematics and Department of Earth and Environmental Sciences, Columbia University, New York, NY.
- July 2003 – June 2010: Associate Professor (tenured since 2006), Department of Applied Physics and Applied Mathematics and Department of Earth and Environmental Sciences, Columbia University, New York, NY.
- 2013-2015: Consultant, World Bank. Lead technical author of a report on tropical cyclone and storm surge forecasting for Bangladesh.
- July 2010 – present: Professor, Department of Applied Physics and Applied Mathematics and Department of Earth and Environmental Sciences, Columbia University, New York, NY.

Courses Taught

- Earth's Environmental Systems – The Climate System, EESC W2100
- Partial Differential Equations, APMA E3102
- Atmospheric Science Seminar, EESC G9910
- Tropical Meteorology, EESC G6928
- Partial Differential Equations, APMA E4200
- Climate Thermodynamics and Energy Transfer, EESC W4040
- Physics of Fluids, APPH E4200
- Geophysical Fluid Dynamics, APPH E4210
- Geophysical Fluid Dynamics Seminar, EESC G9815

Fellowships and Awards

- Phi Beta Kappa, Wesleyan University, 1989.
- NASA Group Achievement Award, for participation in the Airborne Southern Hemisphere Ozone Experiment and Measurements for Assessing the Effects of Stratospheric Aircraft (ASHOE/MAESA) field program, February - November 1994.
- NASA Graduate Student Fellowship for Global Change Research, September 1994 - September 1997.
- NOAA/UCAR Postdoctoral Fellowship in Climate and Global Change Research, September 1997 - September 1999.
- Packard Fellowship in Science and Engineering, 2000.
- NASA New Investigator Award, 2001.
- AMS Editor's award for *Journal of the Atmospheric Sciences*, 2009.
- AMS Clarence Leroy Meisinger Award, 2010.
- Lamont-Doherty Earth Observatory Award for Excellence in Mentoring, 2010.
- AXA Award from the AXA Research Fund, 2013.
- AGU (Atmospheric Sciences Section) Ascent Award, 2014.
- Atmospheric Science Librarians International Choice Award (Popular Category) for *Storm Surge* (see publications), 2014.
- AMS Louis J. Battan Author's Award for *Storm Surge*, 2016.
- AMS Fellow, 2020

Service

- *Community*
  - American Meteorological Society Council, 2017-present (elected for 3-year term).
  - National Academy of Sciences Committee on Extreme Weather Events and Climate Change Attribution, 2015-16.
  - Editorial Board, *Current Climate Change Reports,* 2016-present.
  - Section Editor, *Current Climate Change Reports* (section on Extreme Events), 2014-2016.
  - World Meteorological Organization, Chapter Lead Author, Report of the 8th International Workshop on Tropical Cyclones, 2014.

  - World Climate Research Program Grand Challenge on Clouds, Circulation, and Climate Sensitivity, Steering Group member, 2013-present.
  - Co-organizer (with Michael Tippett, Suzana Camargo, and Harold Brooks) Workshop on Severe Convection and Climate, at Lamont-Doherty Earth Observatory of Columbia University, March 2013.
  - US-CLIVAR Working Group on Hurricanes and Climate, 2011-2012.
  - Co-organizer, International Centre for Theoretical Physics Workshop on Hierarchical Modeling of Climate, July 2011, Trieste, Italy.
  - Scientific Steering committee for the Dynamics of the Madden-Julian Oscillation (DYNAMO) field program, 2010-present.
  - Committee on Atmospheric and Oceanic Fluid Dynamics, American Meteorological Society (2005-2010); chair of committee 2007-2010.
  - Associate Editor, *Journal of the Atmospheric Sciences*, 2003-2006.
  - Associate Editor, *Monthly Weather Review*, 2002.
  - Steering Committee, NOAA/UCAR Global Change Postdoctoral Fellowship Program (2005-2007).
  - Program Committee, American Meteorological Society 27th Meeting on Hurricanes and Tropical Meteorology (2005-2006).
  - Co-organizer (with Michela Biasutti, Alessandra Giannini, Isaac Held, and John Chiang), Workshop on Sahel climate change, at Columbia, March 2007.
  - Co-organizer (with Suzana Camargo), Workshop on Tropical Cyclones and Climate, at Lamont, March 2006.
  - Co-organizer (with Tapio Schneider), Conference on the Global Circulation of the Atmosphere, November 4-6, 2004, Pasadena, CA.
  - Organizing committee, Japanese-American Frontiers of Science meeting, organized by U. S. National Academy of Sciences and Japanese Society for the Promotion of Science, December 2003, Shonan Village, Japan.
- *Columbia (APAM=Dept. of Applied Physics & Applied Mathematics; DEES=Dept. of Earth & Environmental Sciences)*
  - Director, Columbia Initiative on Extreme Weather and Climate (see extremeweather.columbia.edu).
  - Science advisor and consultant, Columbia's Alfred P. Sloan Foundation Short Film and Screenwriting Grant.
  - Columbia University – NASA GISS Advisory Committee, 2013-2014
  - Vice Chair, APAM, 2012-2013.
  - APAM applied physics faculty search committee, 2011-2012.
  - Faculty Advisory Committee, Fu Foundation School of Engineering and Applied Science, 2009-2010.
  - DEES atmospheric science faculty search committee (chair), 2008-2009.
  - APAM graduate admissions committee, 2001-2003, 2008-2010, 2014-15.
  - DEES graduate admissions committee, 2001-2009, 2014-15.
  - NSF IGERT program in Applied Mathematics and Earth & Environmental Science, steering committee, 2002-2009.
  - DEES physical oceanography faculty search committee, 2004-2005.
- *Referee*

- Manuscripts: *Journal of the Atmospheric Sciences*, *Journal of Climate, Monthly Weather Review*, *Journal of Geophysical Research*, *Geophysical Research Letters*, *Quarterly Journal of the Royal Meteorological Society*, *Nature*, *Chaos, Multiscale Modeling and Simulation*, *Science*, *Tellus*, *Journal of Advances in Modeling the Earth System*, *Earth Interactions*, *Proceedings of the National Academy of Sciences.*
- Proposals: NSF, NASA, NOAA, DOE, Canadian Foundation for Climate and Atmospheric Science, Israel Science Foundation.

Academic Advising

- *Postdocs*
  - Guojun Gu (now at NASA Goddard Space Flight Center)
  - Joseph Galewsky (now Professor at University of New Mexico)
  - Cristina Perez (now Research Scientist at UK Meteorological Office, Reading, UK)
  - Michela Biasutti (now Lamont Research Professor at Lamont-Doherty Earth Observatory of Columbia University)
  - Gilles Bellon (now Senior Lecturer at University of Auckland, New Zealand)
  - Jonathon Wright (now Associate Professor, Center for Earth System Science, Tsinghua University, Beijing, China)
  - Hamish Ramsay (now at CSIRO, Aspendale, Australia)
  - Lei Zhou (now at Second Institute of Oceanography, Hangzhou, China)
  - Daehyun Kim (now Assistant Professor at University of Washington)
  - John Allen (co-advised with Michael Tippett, now Assistant Professor at Central Michigan University)
  - Allison Wing (co-advised with Suzana Camargo, now Assistant Professor at Florida State University)
  - Shuguang Wang (now Associate Research Scientist, APAM)
  - Chia-Ying Lee (co-advised with Michael Tippett and Suzana Camargo, now Lamont Assistant Research Professor, Lamont-Doherty Earth Observatory, Columbia)
  - Ji Nie (now Assistant Professor, Peking University)
  - Ding Ma (current)
  - Jeffrey Strong (current, co-advised with Suzana Camargo)
  - Spencer Hill (current, co-advised with Michela Biasutti)
  - Jane Baldwin (current, co-advised with Suzana Camargo)
- *Graduate Students*
  - Sam Burns (PhD 2006; now Research Scientist at Johns Hopkins University)
  - Deborah Herceg (PhD 2006)
  - Francesca Terenzi (PhD 2009; academic advisor, research advisor T. Hall; now at Risk Management Solutions, London)
  - Abby Swann (MS 2005; now Associate Professor at University of Washington)
  - Casey Burleyson (MS 2008; now Scientist at Pacific Northwest National Laboratory)
  - Bo Zhou (MS 2002; ABD)
  - Kirk Knobelspiesse (PhD 2010; academic advisor, research advisor B. Cairns/B. Carlson)

  - Kyle Krouse (PhD 2010)
  - Nick Mykins (MS 2011)
  - John Dwyer (PhD 2014, now in private sector)
  - Usama Anber (PhD 2015, now postdoc at Brookhaven National Laboratory)
  - Dan Shaevitz (PhD 2016, now in finance industry)
  - Melanie Bieli (current)
  - Zane Martin (current)
- *Graduate Student Committees, at present*
  - Bernard Lipat (APAM)
- *External Graduate Student Committees*
  - Sarah Kang (Princeton), thesis defense committee, defense May 2009.
  - Carl Schreck (SUNY Albany), advisory committee, 2008-2011, defense 2011.
  - Juliana Dias (Courant Institute, NYU), thesis defense committee, spring 2010.
  - Allison Wing (MIT), defense October 2014.
  - Yee Man Au-Yeung (City University of Hong Kong), defense July 2015.
- *Undergraduate Research Advising*
  - Dan Shaevitz
  - Pearl Flath
  - Martin Kang
  - Alicia Wagner
  - Emmi Yonekura
  - Allison Wing (Cornell; summer intern at Columbia in 2006 and 2007)
  - Marla Schwartz
  - Earle Wilson
  - Nathan Dadap
  - Julio Herrera-Estrada
  - Deanna Tufano
  - Lucas Zeppettello (co-advised by postdoc Chia-Ying Lee, 2014-15)
  - Lingxiang Yu (co-advised by postdoc John Allen, Fall 2014)
  - Zachary Shaw (co-advised by postdoc Chia-Ying Lee, fall 2015)
  - Kevin Gong (summer 2016)
  - Alek Anichowski (co-advised by Prof. Michael Tippett and Dr. Shuguang Wang, summer and fall 2016)
  - Patrick Chi (co-advised with Shuguang Wang, summer 2017)
  - Sawal Acharya (co-advised with Chia-Ying Lee, summer 2017)
  - June Yang (co-advised with Suzana Camargo, summer 2017-spring 2018)
  - Helena Rios (co-advised with Suzana Camargo, spring and summer 2018)

Peer-Reviewed Journal Articles

1. Goody, R. M., and A. H. Sobel, 1996: A graduate radiation course based upon numerical methods. *Bull. Amer. Meteor. Soc.,* **77**, 2919-2924.
2. Sobel, A. H., R. A. Plumb, and D. W. Waugh, 1997: Methods of computing transport across the polar vortex edge. *J. Atmos. Sci.,* **54**, 2241-2259.
3. Wieman, H., E. Anderssen, A. Banerjee, W. Betts, R. Bossingham, V. Ghazikhanian, W. Gong, D. Greiner, G. Harper, H. Huang, E. Hjort, L. Kotchenda, A. Lebedev, I.

Sakrejda, D. Shuman, M. Smith, A. Sobel, N. Stone, B. Stringfellow, T. Trainor, S. Trentalange, R. Wells, 1997: STAR TPC at RHIC. *IEEE Trans. Nucl. Sci.,* **44**, 671-678.

4. Sobel, A. H., and R. A. Plumb, 1999: Quantitative diagnostics of mixing in a shallow-water model of the stratosphere. *J. Atmos. Sci.*, **56**, 2811-2829.
5. Sobel, A. H., 1999: Diffusion vs. nonlocal models of stratospheric mixing, in theory and practice. *J. Atmos. Sci*., **56**, 2571-2584.
6. Sobel, A. H., and C. S. Bretherton, 1999: Development of synoptic-scale disturbances over the summertime tropical northwest Pacific. *J. Atmos. Sci*., **56**, 3106-3127.
7. Gettelman, A., and A. H. Sobel, 2000: Direct diagnoses of stratosphere-troposphere exchange. *J. Atmos. Sci*., **57**, 3-16.
8. Sobel, A. H., and T. Horinouchi, 2000: On the dynamics of easterly waves, monsoon depressions, and tropical depression type disturbances. *J. Meteor. Soc. Japan*, **78**, 167-173.
9. Sobel, A. H., and G. R. Flierl, 2000: Cross-channel advective-diffusive transport by a monochromatic traveling wave. *Phys. Fluids,* **12**, 1377-1381.
10. Sobel, A. H., and E. D. Maloney, 2000: Effect of ENSO and the MJO on western north Pacific tropical cyclones. *Geophys. Res. Lett*., **27**, 1739-1741.
11. Sobel, A. H., and C. S. Bretherton, 2000: Modeling tropical precipitation in a single column. *J. Climate,* **13**, 4378-4392.
12. Sobel, A. H., J. Nilsson, and L. M. Polvani, 2001: The weak temperature gradient approximation and balanced tropical moisture waves. *J. Atmos. Sci*., *58*, 3650-3665.
13. Polvani, L. M., and A. H. Sobel, 2002: The Hadley circulation and the weak temperature gradient approximation. *J. Atmos. Sci*., **59**, 1744-1752.
14. Sobel, A. H., I. M. Held, and C. S. Bretherton, 2002: The ENSO signal in tropical tropospheric temperature. *J. Climate*, **15**, 2702-2706.
15. Chiang, J. C.-H., and A. H. Sobel, 2002: Tropical temperature variations caused by ENSO and their influence on the remote tropical climate. *J. Climate*, **15**, 2616-2631.
16. Bretherton, C. S., and A. H. Sobel, 2002: A simple model of a convectively coupled Walker circulation using the weak temperature gradient approximation. *J. Climate,* **15**, 2907-2920.
17. Sobel, A. H., 2002: Water vapor as an active scalar in tropical atmospheric dynamics. *Chaos*, **12**, 451-459.
18. Bretherton, C. S., and A. H. Sobel, 2003: The Gill model and the weak temperature gradient approximation. *J. Atmos. Sci.,* **60**, 451-460.
19. Sobel, A. H., and C. S. Bretherton, 2003: Large-scale waves interacting with deep convection in idealized mesoscale model simulations. *Tellus*, **55A**, 45-60.
20. Sobel, A. H., 2003: On the coexistence of an evaporation minimum and precipitation maximum in the warm pool. *J. Climate*, **60**, 1003-1009.
21. Gildor, H., A. H. Sobel, M. A. Cane, and R. N. Sambrotto, 2003: A role for ocean biota in tropical intraseasonal atmospheric variability. *Geophys. Res. Lett.,* **30**, 1460, 10.1029/2002GL016759.
22. Sobel, A. H., and H. Gildor, 2003: A simple model of SST hot spots. *J. Climate,* **16**, 3978-3992.
23. Sobel, A. H., S. E. Yuter, C. S. Bretherton, and G. N. Kiladis, 2004: Large-scale meteorology and deep convection during TRMM KWAJEX. *Mon. Wea. Rev.*, **132**, 422-444.

24. Camargo, S. J., and A. H. Sobel, 2004: Formation of tropical storms in an atmospheric general circulation model. *Tellus*, **56A**, 56-67.
25. Shaevitz, D. A., and A. H. Sobel, 2004: Implementing the weak temperature gradient approximation with full vertical structure. *Mon. Wea. Rev.*, **132**, 662-669.
26. Maloney, E. D., and A. H. Sobel, 2004: Surface fluxes and ocean coupling in the tropical intraseasonal oscillation. *J. Climate*, **17**, 4368-4386.
27. Gu, G., R. F. Adler, and A. H. Sobel, 2005: The eastern Pacific ITCZ during the boreal spring. *J. Atmos. Sci*., **62**, 1157-1174.
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29. Camargo, S. J., and A. H. Sobel, 2005: Western north Pacific tropical cyclone intensity and ENSO. *J. Climate,* **18**, 2996-3006.
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32. Biasutti, M., A. H. Sobel, and Y. Kushnir, 2006: GCM precipitation biases in the tropical Atlantic. *J. Climate*¸ **19**, 935-958.
33. Swann, A., A. H. Sobel, S. E. Yuter, and G. N. Kiladis, 2006: Observed radar reflectivity in convectively coupled Kelvin and mixed Rossby-gravity waves. *Geophys. Res. Lett.*, **33**, doi:10.1029/2006LG025979.
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37. Zhou, B., and A. H. Sobel, 2006: Nonlinear shallow water solutions using the weak temperature gradient approximation. *Theor. Comp. Fluid Dyn.*, **20**, 469-484.
38. Herceg, D., A. H., Sobel, L. Sun, and S. Zebiak, 2006: The big brother experiment with the NCEP regional spectral model. *Climate Dyn*., **27**, 69–82.
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45. Bellon, G., and A. H. Sobel, 2008a: Poleward-propagating intraseasonal monsoon disturbances in an intermediate-complexity axisymmetric model. *J. Atmos. Sci.*, **65**, 470-489.
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50. Biasutti, M., I. M. Held, A. H. Sobel, and A. Giannini, 2008: SST forcings and Sahel rainfall variability in simulations of the 20th and 21st centuries. *J. Climate*, **21**, 3471-3486.
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53. Sobel, A. H., and G. Bellon, 2009: The effect of imposed drying on parameterized deep convection. *J. Atmos. Sci.*, **66**, 2085-2096.
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83. Dwyer, J. G., M. Biasutti, and A. H. Sobel, 2012: Projected changes in the seasonal cycle of surface temperature. *J. Climate,* **25**, 6359-6374.
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116. Anber, U., P. Gentine, S. Wang, and A. H. Sobel, 2015b: Fog and rain in the Amazon. Proc. Nat. Acad. Sci., doi: 10.1073/pnas.1505077112.
117. Nie, J., and A. H. Sobel, 2015: Responses of tropical deep convection to the QBO: cloud-resolving simulations. *Journal of the Atmospheric Sciences*, **72**, 3625-3638.
118. Yokoi, S., and A. H. Sobel, 2015: Seasonal march and intraseasonal variability of the moist static energy budget over the eastern Maritime Continent during CINDY2011/DYNAMO. *Journal of the Meteorological Society of Japan*, doi:10.2151/jmsj.2015-041.
119. Walsh, K., and many coauthors (incl. Sobel), 2015b: Tropical cyclones and climate change. *WIREs Climate Change*, DOI: 10.1002/wcc.371.
120. Wang, S., A. Fridlind, A. H. Sobel, Z. Feng, J. M. Comstock, P. Minnis, and M. L. Nordeen, 2015b: Simulations of cloud-radiation interaction using large-scale forcing derived from the CINDY/DYNAMO northern sounding array. *Journal of Advances in Modeling the Earth System*, DOI: 10.1002/2015MS000461.
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122. Daleu, C. L., S. J.Woolnough, R. S. Plant, S. Sessions, M. J. Herman, A. H. Sobel, S. Wang, D. Kim, A. Cheng, G. Bellon, P. Peyrille, F. Ferry, A. P. Siebesma, and B. van Ulft, 2015: Intercomparison of methods of coupling between convection and large-scale circulation. Part I: Comparison over uniform surface conditions. *Journal of Advances in Modeling the Earth System,* 7, doi:10.1002/2015MS000468.
123. Nie, J., and. A. H. Sobel, 2016: Modeling the interaction between quasi-geostrophic vertical motion and convection in a single column. *Journal of the Atmospheric Sciences*, **73**, 1101-1111.
124. Camargo, S. J., A. H. Sobel, A. D. Del Genio, J. Jonas, M. Kelley, Y. Lu, D. A. Shaevitz, and N. Henderson, 2016: Tropical cyclones in the GISS ModelE2. *Tellus A*, **68**, 31494, http://dx.doi.org/10.3402/tellusa.v68.31494.
125. Anber, U., S. Wang, and A. H. Sobel, 2016: Response of atmospheric convection to vertical wind shear: Cloud resolving simulations with parameterized large-scale circulation. Part II: Effect of interactive radiation. *Journal of the Atmospheric Sciences*, **73**, 199-209.
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127. Lee, C.-Y., M. K. Tippett, A. H. Sobel, and S. J. Camargo, 2016b: Auto-regressive modeling for tropical cyclone intensity climatology. *Journal of Climate,* **29**, 7815-7830.
128. Wang, S., A. H. Sobel, and J. Nie, 2016: Modeling the MJO in a cloud-resolving model with parameterized large-scale dynamics: Vertical structure, radiation, and horizontal advection of dry air, *Journal of Advances in Modeling the Earth System,* **8**, 121–139, doi:10.1002/2015MS000529.

129. Wing, A. A., S. J. Camargo, and A. H. Sobel, 2016: Role of radiative-convective feedbacks in spontaneous tropical cyclogenesis in idealized numerical simulations. *Journal of the Atmospheric Sciences*, **73**, 2633-2642.
130. Daleu, C. L., S. J.Woolnough, R. S. Plant, S. Sessions, M. J. Herman, A. H. Sobel, S. Wang, D. Kim, A. Cheng, G. Bellon, P. Peyrille, F. Ferry, A. P. Siebesma, and B. van Ulft, 2016: Intercomparison of methods of coupling between convection and large-scale circulation. Part II: Comparison over non-uniform surface conditions. *Journal of Advances in Modeling the Earth System*, **8**, 387-405, DOI: 10.1002/2015MS000570.
131. Walsh, K., and many coauthors (including Sobel), 2016: Tropical cyclones and climate change. *WIREs Climate Change*, **7**, 65-89, DOI: 10.1002/wcc.371
132. Sobel, A. H., S. J. Camargo, and A. Barnston, 2016: Northern hemisphere tropical cyclones during the quasi-El Niño of late 2014. *Natural Hazards*, doi:10.1007/s11069-016-2389-7.
133. Sobel, A. H., S. J. Camargo, T. M. Hall, C.-Y. Lee, M. K. Tippett, and A. A. Wing, 2016: Human influence on tropical cyclone intensity. *Science*, **353**, 242- 246, DOI: 10.1126/science.aaf6574.
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135. Nie, J., D. A. Shaevitz, and A. H. Sobel, 2016: Forcings and feedbacks on convection in the 2010 Pakistan flood: Modeling extreme precipitation with interactive large-scale ascent, *Journal of Advances in Modeling the Earth System*, **8**, 1055–1072, doi:10.1002/2016MS000663.
136. Hsiang, S., and A. H. Sobel, 2016: Potentially extreme population displacement and concentration in the tropics under non-extreme warming. *Scientific Reports*, **6**, 25697.
137. Waugh, D. W., A. H. Sobel, and L. M. Polvani, 2017: What is the polar vortex, and how does it influence weather? *Bulletin of the American Meteorological Society*, **98**, 37-44.
138. Adames, A., D. Kim, A. H. Sobel, and A. D. Del Genio, 2017a: Changes in the structure and propagation of the MJO with increasing CO2. *Journal of Advances in Modeling Earth Systems*, **9**, doi:10.1002/2017MS000913.
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142. Nakamura J., S. J. Camargo, A. J. Sobel, N. Henderson, K. A. Emanuel, A. Kumar, T. LaRow, H. Murakami, M. J. Roberts, E. Scoccimarro, P. L. Vidale, H. Wang, M. F. Wehner, and M. Zhao, 2017: Western north Pacific tropical cyclone model tracks in present and future climates. *Journal of Geophysical Research,* doi:10.1002/2017JD027007.

143. Wang, S. and A. H. Sobel, 2017: Factors controlling rain on small tropical islands: diurnal cycle, large-scale wind speed, and topography. *Journal of the Atmospheric Sciences*, doi:10.1175/JAS-D-16-0344.1.
144. Anber, Wang, and Sobel 2017: Coupling with ocean mixed layer leads to intraseasonal variability in tropical deep convection - evidence from cloud-resolving simulations. *Journal of Advances in Modeling Earth Systems***,** **9**, 616-626, doi:10.1002/2016MS000803.
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146. Lee, C., M. K. Tippett, A. H. Sobel, and S. J. Camargo, 2018a: An environmentally forced tropical cyclone hazard model. *Journal of Advances in Modeling Earth Systems*, DOI: 10.1002/2017MS001186.
147. Kim, D., Y. Moon, S. J. Camargo, A. A. Wing, A. H. Sobel, H. Murakami, G. A. Vecchi, M. Zhao, and E. Page, 2018: Process-oriented diagnosis of tropical cyclones in high-resolution GCMs. *Journal of Climate*, doi:10.1175/JCLI-D-17-0269.1.
148. Tandon, N., X. Zhang, and A. H. Sobel, 2018: Understanding the dynamics of future changes in extreme precipitation intensity. *Geophysical Research Letters*, DOI: 10.1002/2017GL076361.
149. Wang, B., S.-S. Lee, D. E. Waliser, C. Zhang, A. H. Sobel, E. D. Maloney, T. Li, X. Jiang, and K.-J. Ha, 2018: Dynamics-oriented diagnostics for the Madden-Julian Oscillation. *Journal of Climate*, **31**, 3117-3135.
150. Biasutti, M., et al., 2018: Global energetics and local physics as drivers of past, present and future monsoons. *Nature Geoscience*, **11**, 392-400.
151. Lee, C.-Y., S. J. Camargo, A. H. Sobel, F. Vitart, and M. K. Tippett, 2018b: Sub-seasonal tropical cyclone genesis prediction and MJO in the S2S dataset. *Weather and Forecasting*, doi:10.1175/WAF-D-17-0165.1.
152. Sobel, A. H., P. Pillai, et al., 2018: *Improving Lead Time for Tropical Cyclone Forecasting: Review of Operational Practices and Implications for Bangladesh*. World Bank, Washington, DC, 56 pp.
153. Nie, J., A. H. Sobel, D. A. Shaevitz, and S. Wang, 2018: Dynamic amplification of extreme precipitation sensitivity. *Proceedings of the National Academy of Sciences*, doi:10.1073/pnas.1800357115.
154. Wang, S., D. Ma, A. H. Sobel, and M. K. Tippett, 2018: Propagation characteristics of BSISO indices. *Geophysical Research Letters*, **45**, 9934-9943, doi: 10.1029/2018GL078321.
155. Wang, S., A. H. Sobel, M. K. Tippett, and F. Vitart, 2018: Prediction and predictability of tropical intraseasonal convection: seasonal dependence and the Maritime Continent prediction barrier. *Climate Dynamics*, doi: 10.1007/s00382-018-4492-9.
156. Martin, Z. K., S. Wang, J. Nie, and A. H. Sobel, 2019: The influence of the quasi-biennial oscillation on the Madden-Julian oscillation in idealized cloud-resolving simulations. *Journal of the Atmospheric Sciences*, **76**, 669-688.
157. Bieli, M., S. J. Camargo, A. H. Sobel, J. L. Evans, and T. M. Hall, 2019a: A global climatology of extratropical transition, Part I: Characteristics across basins. *Journal of Climate*, **32**, 3557-3582.

158. Bieli, M., S. J. Camargo, A. H. Sobel, J. L. Evans, and T. M. Hall 2019b: A global climatology of extratropical transition, Part II: Statistical performance of the cyclone phase space. *Journal of Climate*, **32**, 3583-3597.
159. Sobel, A. H., S. J. Camargo, and M. Previdi, 2019: Aerosol vs. greenhouse gas effects on tropical cyclone potential intensity and the hydrologic cycle. *Journal of Climate*, 5511–5527.
160. Sobel, A. H., C.-Y. Lee, S. J. Camargo, K. Mandli, K. A. Emanuel, P. Mukhopadhyay, and M. Mahakur, 2019: Tropical cyclone hazard to Mumbai in the recent historical climate. *Monthly Weather Review*, **147**, 2355-2366.
161. Ma, D., A. H. Sobel, Z. Kuang, M. Singh, and J. Nie, 2019: A moist entropy budget view of the South Asian summer monsoon onset. *Geophysical Research Letters*, **46**, doi:10.1029/2019GL082089.

Books

1. T. Schneider and A. H. Sobel, Eds., 2007: *The Global Circulation of the Atmosphere*, Princeton University Press, 400pp.
2. L. M. Polvani, A. H. Sobel, and D. W. Waugh, Eds., 2010: *The Stratosphere: Dynamics, Transport, and Chemistry*, American Geophysical Union, Geophysical Monograph Series, **190**, 220pp.
3. A. H. Sobel, 2014: *Storm Surge: Hurricane Sandy, Our Changing Climate, and Extreme Weather of the Past and Future,* Harper-Collins, published October 2014. (Popular science.)

Book Chapters

1. Sobel, A. H., C. S. Bretherton, H. Gildor, and M. E. Peters, 2004: Convection, cloud-radiative feedbacks and thermodynamic ocean coupling in simple models of the Walker circulation. *Earth's Climate: The Ocean-Atmosphere Interaction.* C. Wang, S.-P. Xie, and J. Carton, Eds., AGU Geophysical Monograph **147**, 393-405.
2. Sobel, A. H., 2007: Simple models of ensemble-averaged precipitation and surface wind, given the SST. *The Global Circulation of the Atmosphere*, T. Schneider and A. H. Sobel, Eds., Princeton University Press.
3. Camargo, S. J., A. H. Sobel, A. G. Barnston, and P. Klotzbach, 2009: The influence of natural climate variability, and seasonal forecasts of tropical cyclone activity. *Global Perspectives on Tropical Cyclones*, 2nd edition, J. Chan and J. D. Kepert, Eds., World Scientific, 325-360.
4. Sobel, A. H., 2009: Going to extremes. *Climate Change: Picturing the Science,* G. Schmidt and J. Wolfe, Eds., Norton. (Popular science, not peer reviewed).
5. Sobel, A. H., 2010: R. Alan Plumb: A brief biographical sketch, and personal tribute. *The Stratosphere: Dynamics, Transport, and Chemistry*, AGU, Geophys. Monogr. Ser., **190**, L. M. Polvani, D. W. Waugh, A. H. Sobel, Eds. (Foreword chapter, not peer reviewed.)
6. Sobel, A. H., and M. K. Tippett, 2018: Extreme events: trends and risk assessment methodologies. *Resilience: The Science of Adaptation to Climate Change.* K. Alverson and Z. Zommers, Eds., Elsevier. 3-12.

7. Adames, A., D. Kim, E. D. Maloney, and A. H. Sobel, 2019: The moisture mode framework of the Madden-Julian oscillation. *The Global Multiscale Monsoon System*, C.-P. Chang, Ed., World Scientific, in press.

Meeting Summaries

1. Schneider, T., and A. H. Sobel, 2006: Global circulation of the atmosphere (2004). *Bull. Amer. Meteor. Soc.*, **87**, 807-809.
2. Camargo, S. J., and A. H. Sobel, 2007: Workshop on tropical cyclones and climate. *Bull. Amer. Meteor. Soc.*, **88**, 389-391.
3. Biasutti, M., A. Giannini, A. H. Sobel, I. M. Held, and J. C.-H. Chiang, 2007: Sahel climate change. *EOS*, **88**, (29), 295.
4. Allen, J., M. Tippett, A. Sobel, and C. Lepore, 2016: Understanding the drivers of variability in Severe Convection: Bringing together the scientific and insurance communities. *Bull. Amer. Meteor. Soc.*, **97**, ES221–ES223, doi:10.1175/BAMS-D-16-0208.1
5. Sobel, A. H., S. J. Camargo, W. Debucquoy, G. Deodatis, M. Gerrard, T Hall, R. Hallman, J. Keenan, U. Lall, M. A. Levy, B. Orlove, C. Rosenzweig, R. Seager, J. Shaman, and M. K. Tippett, 2016: Extreme Weather and Climate: Workshop Report. *Journal of Extreme Events*, **3**, DOI: 10.1142/S2345737616710019.
6. Robertson, A. W., S. J. Camargo A. H. Sobel, F. Vitart, and S. Wang, 2018: Summary of workshop on sub-seasonal to seasonal predictability of extreme weather and climate. *npj Climate and Atmospheric Science* **1**, doi:10.1038/s41612-017-0009-1

Op-Eds

CNN, "What we didn't learn from Superstorm Sandy." Oct. 26, 2013.
CNN, "How deadly storms claim a bigger toll." Nov. 10, 2013.
Los Angeles Times, "Monitoring a climate epidemic." Nov. 15, 2013 (with Naomi Oreskes).
CNN, "Record cold doesn't disprove global warming." Jan. 7, 2014.
CNN, "Is China climate deal the best we can get?" Nov. 18, 2014.
Salon, "Forget the 'polar vortex' backlash: How I learned to love an overused media buzzword." Nov. 22, 2014.
Los Angeles Times, "Flood, drought risks must be managed, with or without climate change." December 18, 2014 (with Richard Seager).
CNN, "Wrong but right about winter storm." January 27, 2015.
CNN, “Did climate change cause California drought?” April 8, 2015.
WXshift, “Joaquin? There’s no perfect forecast, so stay tuned, be prepared.” September 30, 2015.
CNN, “Patricia shows need for better hurricane forecasting.” October 24, 2015.
Times of India, “All at sea – what Mumbai needs to learn from Superstorm Sandy.” December 2, 2015.
CNN, “Why the freakishly warm December?” December 25, 2015.
The Conversation, “Why are hurricanes forming in January?” January 21, 2016
Washington Post, “Links between climate change and extreme weather are increasingly clear and present.” March 11, 2016.
New York Times, “Where are the hurricanes?” July 15, 2016.

CNN, "Why Harvey's devastation is so severe." August 28, 2017.
Fortune, "Climate change didn't cause Hurricane Harvey, but it made it worse." August 29, 2017 (with Suzana Camargo).
CNN, "Are we ready for Hurricane Irma?" September 7, 2017.
CNN, “Who really paid to protect us from Florence.” September 16, 2018 (with Sean Solomon).
CNN, “Climate scientists aren’t in it for the money but the truth.” November 27, 2018.
CNN, “Scientist: Why do so many Americans ask me about nuking a hurricane?” August 26, 2019.
New York Times, “A Storm expert’s view: Dorian’s damage remains impossible to predict.” September 1, 2019.
New York Times, “What will turn Hurricane Dorian? How wide is the eye? Your questions answered.” September 3, 2019.

Talks (since 2002)

Invited

1. Yale University, Dept. of Geology and Geophysics, New Haven, CT, March 2002.
2. American Geophysical Union Spring Meeting, Washington, DC, May 2002.
3. Stockholm University, Dept. of Meteorology, Stockholm, Sweden, June 2002.
4. Japanese-American Frontiers of Science Symposium, Irvine, CA, December 2002.
5. UCLA Dept. of Atmospheric & Oceanic Sciences, Los Angeles, CA, January 2003.
6. 1st Northeast Tropical Meteorology Workshop, Rhinebeck, NY, June 2003.
7. Kyoto University, Radio Atmospheric Science Center, Uji, Japan, December 2003.
8. Oregon State University, College of Oceanic and Atmospheric Sciences, Corvallis, OR, December 2003.
9. University of Maryland, Dept. of Meteorology, College Park, MD, March 2004.
10. MIT Atmospheric Science Seminar Series, Cambridge, MA, April 2004.
11. University of Washington, Dept. of Atmospheric Sciences, Seattle, WA, March 2005.
12. Courant Institute of Mathematical Sciences, New York University, CAOS seminar, New York, NY April 2005.
13. Global Chemistry and Climate Summer School, Banff, Canada, May 2005 (3 invited lectures).
14. California Institute of Technology, Dept. of Earth and Planetary Sciences, Pasadena, CA, May 2005.
15. 2nd Northeast Tropical Meteorology Workshop, Rensselaerville, NY, June 2005.
16. National Center for Atmospheric Research, Institute for Mathematics Applied to Geosciences’ Workshop on Emerging Mathematical Strategies for Multi-Scale and Stochastic Modeling of the Atmosphere and Climate, Boulder, CO, November 2005.
17. CIMMS/IPAM Worskhop on Multiscale Modeling and Computation: Basic Theory and the Geosciences, Pasadena, CA, November 2005.
18. Colorado State University, Dept. of Atmospheric Sciences, Fort Collins, CO, April 2006.
19. Massachusetts Institute of Technology, Dept. of Earth, Atmospheric, and Planetary Sciences, Cambridge, MA, May 2006.
20. Workshop on Geophysical Fluid Dynamics and Fluid dynamics in the Tropics, Singapore National University, Singapore, November 2006 (2 invited lectures).
21. NASA Goddard Institute for Space Studies, New York, NY, Feburary 2007.
22. Australian Bureau of Meteorology, Melbourne, Australia, September 2007.

23. Australian Bureau of Meteorology Northern Territory Regional Office, Darwin, Australia, September 2007.
24. National Taiwan University, Dept. of Atmospheric Sciences,Taipei, Taiwan, November 2007.
25. National Central University, Taipei, Taiwan, November 2007.
26. University of Tokyo, Center for Climate Systems Research, Chiba, Japan, November 2007.
27. University of Melbourne, Dept. of Meteorology, Melbourne, Australia, November 2007.
28. National Institute for Water and Atmosphere, Lauder, New Zealand, January 2008.
29. National Institute for Water and Atmosphere, Wellington, New Zealand, January 2008.
30. Australian Bureau of Meteorology Northern Territory Regional Office, Darwin, Australia, February 2008.
31. Australian Defense Force Academy, Canberra, Australia, May 2008.
32. Stony Brook University, School of Marine and Atmospheric Sciences, Stony Brook, NY, September 2008.
33. Princeton University, Department of Geosciences, Princeton, NJ, October 2008.
34. NOAA Geophysical Fluid Dynamics Laboratory, Princeton, NJ, October 2008.
35. Cornell University, Department of Earth and Atmospheric Sciences, Ithaca, NY, November 2008.
36. University of Toronto, Department of Physics, Toronto, Canada, April 2009.
37. University of Chicago, Department of Geosciences, Chicago, IL, May 2009.
38. Princeton Center for Theoretical Science, Workshop on Fundamental Problems in Climate Dynamics, Princeton, NJ, May 2009.
39. Northeast Tropical Meteorology Conference, Rensselaerville, NY, June 2009.
40. Workshop on Climate Monitoring and Modeling, Korean Ocean Research and Development Institute, Seoul, South Korea, June 2009.
41. IAMAS-IAPSO-IACS Joint Assembly “MOCA 2009”, Session on “Advances in Theoretical Dynamics”, Montreal, Canada, July 2009.
42. Workshop on Large-Scale Circulations in Moist Convecting Atmospheres, Harvard University, Cambridge, MA, October 2009.
43. Wesleyan University, Physics Department, Middletown, CT, October 2009.
44. Pennsylvania State University, Dept. of Meteorology, February 2010.
45. Harvard University, Dept. of Earth and Planetary Sciences, March 2010.
46. Split Workshop in Atmospheric Physics and Oceanography, Split, Croatia, May 2010.
47. MJO workshop, Busan, Korea, June 2010.
48. US-Korea workshop on seasonal climate prediction, Busan, Korea, June 2010.
49. Max Planck Institute for Meteorology, Hamburg, Germany, June 2010.
50. IFM-GEOMAR, Kiel, Germany, July 2010.
51. “Fighting for Survival: The Vulnerability of America’s Gulf Coast and the Caribbean Basin”, conference at Tulane University, New Orleans, LA, August 2010.
52. University of Arizona, Department of Atmospheric Sciences, September 2010.
53. Association of Small Island States/CARIBSAVE Losses and Damages Workshop, Oxford, UK, November 2010.
54. California Institute of Technology, Pasadena, CA, March 2011.
55. Rosenstiel School of Marine and Atmospheric Sciences, University of Miami, March 2011.

56. Max Planck Institute for Meteorology, Hamburg, Germany, August 2011.
57. University of California, Berkeley, Center for Atmospheric Science seminar, October 2011.
58. Geophysical Fluid Dynamics Laboratory, Princeton, NJ, December 2011.
59. CLIVAR Tropical Cyclone Working Group Workshop, New Orleans, LA, January 2012.
60. NCAR Advanced Study Program Summer Colloquium, June 2012.
61. First Pan-Global Atmospheric System Study Meeting, Boulder, CO, September 2012.
62. University at Albany, Earth and Atmospheric Sciences Department seminar, November 2012.
63. Secret Science Club, The Bell House, Brooklyn, NY, November 2012.
64. Lamont Public Lecture, AppNexus, New York, NY, April 2013.
65. Federal Emergency Management Agency (FEMA) Joint Field Office, Forest Hills, NY, April 2013.
66. New York Public Library, New York, NY, June 2013.
67. Workshop on the Nature of MJO, George Mason University, Fairfax, VA, June 2013.
68. Laboratoire Meteorologie Dynamique, Ecole Normale Superieur, Paris, France, June 2013.
69. EUCLIPSE Summer School on Clouds and Climate, Les Houches, France, July 2013.
70. Workshop on Fluid Dynamics in Earth and Planetary Sciences (FDEPS), Kyoto, Japan – sole lecturer, 17 hours of lectures over 4 days, December 2013.
71. AGU Fall Meeting, December 2013.
72. Workshop on Tropical Dynamics and the MJO, Honolulu, HI, January 2014.
73. World Climate Research Program Grand Challenge Workshop on Clouds, Circulation, and Climate Sensitivity, Rottach-Egern, Germany, March 2014.
74. University of Oklahoma School of Meteorology, Norman, OK, May 2014.
75. Brooklyn School for Collaborative Studies, June 2014 (high school class).
76. Latsis Symposium on Atmosphere and Climate Dynamics, Zurich, Switzerland, June 2014.
77. Geophysical Fluid Dynamics Program, Woods Hole Oceanographic Institute, Woods Hole, MA, July 2014.
78. Yale University, Geology & Geophysics Department, September 2014.
79. WCRP Climate Symposium, Darmstadt, Germany, October 2014.
80. Northeast Risk and Resilience Leadership Forum, October 2014.
81. 8th International Workshop on Tropical Cyclones, Jeju, Korea, December 2014.
82. Tel Aviv University, Department of Geosciences (3 lectures), Tel Aviv, Israel, January 2015.
83. Hebrew University, Jerusalem, Israel, January 2015.
84. Weizmann Institute, Rehovot, Israel, January 2015.
85. Rutgers University, Department of Environmental Sciences, January 2015.
86. Reinsurance Association of America Catastrophe Modeling Conference, Orlando, FL, February 2015.
87. TEDx Broadway, New York, NY, February 2015.
88. Simon Fraser University, Vancouver, BC, March 2015.
89. University of Washington, Seattle, WA, March 2015.
90. Reed College, Portland, OR, March 2015.
91. Portland State University, Portland, OR, March 2015.

92. New York Public Library (Mid-Manhattan Branch), New York, NY, April 2015.
93. American Museum of Natural History, New York, NY, June 2015.
94. Northeast Tropical Meteorology Conference, Dedham, MA, June 2015.
95. Society for Wetlands Scientists Annual Meeting, Providence, RI, June 2015.
96. Speaking tour through eastern Canada (7 cities between Newfoundland and Ontario), organized by the MEOPAR network, August-September 2015.
97. American Institute of Aeronautics and Astronautics, Long Island Chapter, Bethpage, NY, September 2015.
98. University of Connecticut, Groton, CT, October 2015.
99. The Union Club, New York, NY, October 2015.
100. Guy Carpenter Conference on Enterprise Risk Management, Las Vegas, NV, October 2015.
101. 6th Maritime Risk Symposium, Stevens Institute of Technology, Hoboken, NJ, November 2015.
102. Stony Brook University, Stony Brook, NY, November 2015.
103. El Nino Conference, IRI, Palisades, NY, November 2015.
104. AGU Fall Meeting, San Francisco, CA, December 2015 (two invited talks).
105. New York City Transit Museum, New York, NY, March 2016.
106. New York State Flood Risk Symposium, Hyde Park, NY, April 2016.
107. Koshland Science Museum, Washington, DC, April 2016.
108. University of Wisconsin, Madison, WI, May 2016.
109. University of Illinois, Urbana-Champaign, IL, May 2016.
110. Princeton University, Dept. of Geosciences, May 2016.
111. Science Speaks! Series for New York City science teachers, New York, NY, May 2016.
112. National Center for Atmospheric Research, Mesoscale and Microscale Meteorology Division, Boulder, CO, July 2016.
113. International scientific seminar on "Storylines as an alternative way of representing uncertainty in climate change", Chicheley Hall, UK, November 2016.
114. Department of Meteorology, Reading, UK, November 2016.
115. National Institute of Oceanography, Goa, India, January 2017.
116. University of Texas Institute of Geophysics, Austin, TX, January 2017.
117. Nevis Laboratories, Columbia University, Science-on-Hudson series, Irvington, NY, February 2017.
118. American Physical Society March Meeting, New Orleans, LA, March 2017.
119. Lotos Club, New York, NY, March 2017.
120. Forum on Near-term Impacts of Climate Change on Investors, Kohlberg, Kravis & Roberts, New York, NY, May 2017.
121. Northeast Tropical Meteorology Conference, Rensselaerville, NY, June 2017.
122. Sixth International Summit on Hurricanes and Climate Change, Heraklion, Greece, June 2017.
123. Webinar for Swiss Re & clients on *Hurricane Risk: 25 years after Andrew*, August 2017.
124. International Society of Catastrophe Managers Education Seminar, New York, NY, September 2017.
125. Webinar for NOAA Modeling, Analysis and Prediction Program, September 2017.
126. Joint SPARC Dynamics & Observations Workshop, Kyoto, Japan, October 2017.
127. University of Toronto, Toronto, Canada, November 2017.

128. Lotos Club, New York, NY, November 2017.
129. India Institute of Technology Bombay, Mumbai, India, December 2017.
130. Tata Institute of Social Sciences, Mumbai, India, December 2017.
131. India Institute of Tropical Meteorology, Pune, India, December 2017.
132. India Meteorological Society, Pune Chapter, Pune, India, December 2017.
133. Columbia University Alumni Club, Portland, Oregon, January 2018.
134. George Mason University, Fairfax, VA, January 2018.
135. Jewish Community Center of Manhattan, February 2018.
136. Symposium on Awe and Attention, University of Utah, Salt Lake City, UT, February 2018.
137. New Mexico Institute of Mining and Technology, Socorro, NM, February 2018.
138. University of New Mexico, Albuquerque, NM, February 2018.
139. Reinsurance Association of America Cat Risk Management 2018 Conference, Orlando, FL, February 2018.
140. Mission Earth, A Fundraiser for Off the Hook Arts Summer Festival 2018, National Sawdust, Brooklyn, NY, April 2018.
141. Workshop on the Future of Earth System Models, California Institute of Technology, Pasadena, CA, May 2018.
142. National Taiwan University, Taipei, Taiwan, May 2018.
143. Academia Sinica, Taipei, Taiwan, May 2018.
144. UnisonSteadfast Independence Day Conference, Havana, Cuba, June 2018.
145. Long Island Hurricanes Symposium, Hofstra University, Hempstead, NY, September 2018.
146. Pennsylvania State University, State College, PA, October 2018.
147. Understanding and Modeling the Earth's Climate: A Symposium in Honor of Isaac Held, Princeton, NJ, October 2018.
148. AGU Fall Meeting, Washington, DC, December 2018.
149. PISTON Science Team Workshop, La Jolla, CA, January 2019.
150. Workshop on Oil and Gas Company Engagement on Climate Change, Center for Strategic & International Studies, Washington, DC, February 2019.

Contributed

1. AGU Fall Meeting, San Francisco, CA, December 2002.
2. Tropical Biases Workshop, Geophysical Fluid Dynamics Laboratory, Princeton, NJ, May 2003.
3. 14th AMS Conference on Atmospheric and Oceanic Fluid Dynamics, San Antonio, TX, June 2003.
4. Lamont-Doherty Earth Observatory, Ocean and Climate Physics Seminar, Palisades, NY, April 2004.
5. 26th AMS Conference on Hurricanes and Tropical Meteorology, Miami, FL, May 2004.
6. Western Pacific Geophysics Meeting, Honolulu, HI, August 2004.
7. 15th AMS Conference on Atmospheric and Oceanic Fluid Dynamics, Cambridge, MA, June 2005.
8. 27th AMS Conference on Hurricanes and Tropical Meteorology, Monterey, CA, April 2006.
9. AGU Fall Meeting, San Francisco, CA, December 2006.

10. 16th Conference on Atmospheric and Oceanic Fluid Dynamics, Santa Fe, NM, June 2007.
11. Australian Meteorological and Oceanographic Society Annual Meeting, Geelong, Australia, January 2008.
12. AMS Conferences on Air-Sea Interaction and Climate Variability and Change, AMS Annual Meeting, Phoenix, AZ, January 2009.
13. AGU Fall Meeting, San Francisco, CA, December 2010.
14. 18th Conference on Atmospheric and Oceanic Fluid Dynamics, Spokane, WA, June 2011.
15. Workshop on Hierarchical Modeling of Climate, International Centre for Theoretical Physics, Trieste, Italy, July 2011.
16. 30th AMS Conference on Hurricanes and Tropical Meteorology, Ponte Vedra, FL, April 2012.
17. AGU Fall Meeting, San Francisco, CA, December 2012.
18. AGU Fall Meeting, San Francisco, CA, December 2013.
19. AMS Annual Meeting, Atlanta, GA, February 2014.
20. AGU Fall Meeting, San Francisco, CA, December 2014.
21. AMS Conference on Weather, Analysis and Forecasting, Chicago, IL, July 2015.
22. 32nd AMS Conference on Hurricanes and Tropical Meteorology, San Juan, Puerto Rico, April 2016.
23. Model Hierarchies Workshop, Princeton, NJ, November 2016.
24. AMS Annual Meeting, Seattle, WA, January 2017.
25. Sea Level Changes 2017 Conference, Columbia University New York, NY, July 2017 (poster presentation).
26. Super Storm Sandy: Five Years Later Conference, Meadowlands Environmental Research Institute, Lyndhurst, NJ, October 2017.
27. AMS Annual Meeting, Austin, TX, January 2018.
28. AMS Annual Meeting, Phoenix, AZ, January 2019.