How Does Extreme Weather Change with Global Warming?

Miller Fellow Focus: Yi Zhang

Full of uncertainty and disorder, the Earth’s climate system is a unique subject in complex systems science. Reducing complex phenomena to simple laws is fascinating to me as a scientist. However, climate science also involves a practical mission -- to better prepare societies worldwide for the impact of climate change. A most dangerous impact of climate change is the increased risk of extreme weather, and accurately predicting future changes in extreme weather requires a fundamental understanding of the dynamics and thermodynamics of the atmosphere.

Atmospheric dynamics is the study of atmospheres on the Earth or other planets, treating them as Newtonian fluids. A unique aspect of the atmosphere compared to laboratory fluids is that it flows on a rotating sphere. The Earth’s rotation gives rise to swirling motions in the middle and high latitudes but not so much in the tropics, forming two distinct regimes of atmospheric dynamics (Figure 1). This is because the tropical atmosphere feels less of the Earth’s rotation than higher latitudes: The ground at one of the poles rotates at the same angular velocity as the Earth, while the ground in lower latitudes rotates at a slower angular velocity, which is the component of the Earth’s angular velocity perpendicular to the local ground. This is the same effect demonstrated by the Foucault pendulum.

Ignoring the Earth’s rotation effect can be a useful approximation in some aspects of tropical atmospheric dynamics. Supporting evidence is that the tropical atmospheric temperature is roughly uniform in the horizontal direction from about 2 km above the surface till the top of the troposphere (the troposphere is the lowest 80-90% of the atmosphere’s mass, where weather happens). Another characteristic of the tropical atmosphere is frequent deep convection, the strong vertical motions in cumulus clouds that produce intense rainfall. Deep convection brings a humid air mass from the surface to above 10 km in just a few hours while condensing the air mass’ water vapor to rainfall. This process is much faster than...
other processes that heat or cool the air mass. The air mass thus conserves its moist static energy during convection, which is the sum of the sensible, latent, and potential energy. With these pieces of information, we can describe the tropical atmospheric dynamics using a two-layer model (Figure 2) – The uniform temperature in the upper layer (about 2-15 km in altitude) acts as a uniform bar to the non-uniform lower layer (the bottom 2 km). Whenever and wherever the moist static energy in the lower layer reaches the threshold put in place by the upper layer, the whole tropospheric column becomes unstable. This results in convection that exports energy away from this column and prevents the local moist static energy from increasing. This conceptual picture has been long-standing, but my work crystallized these ideas and provided additional observational evidence.

Application of this conceptual picture is the spatial distribution of tropical rainfall. With global warming, the troposphere would hold more water vapor, and these H2O molecules interact with radiation strongly. The troposphere thus radiates away more energy which must be compensated by latent heat release of condensation. Detailed calculation suggests that the global mean precipitation will increase by about 2% per degree of global warming. However, this increase in rainfall is distributed in different ways across the globe. In the tropics, which locations get the additional rain is a competition of moist static energy of surface air. Many studies, including mine, have found that regions that are already humid and energetic will become comparatively more so with global warming, and the unevenness of precipitation distribution in the tropics will amplify.

Highlight of my graduate research has been using the dynamics described above to project the changes in tropical extreme heat stress – the additive health impact of temperature and humidity in hot weather. We use wet-bulb temperature as a metric for heat stress, which is, by definition, tightly related to moist static energy. The dynamics that control the maximum moist static energy also make the maximum wet-bulb temperature in the tropics relatively uniform, both on land and on the ocean. This finding allowed us to work around the land's varying topography and surface types by calculating how climate change would affect the wet-bulb temperature over the homogenous surface of the ocean — which would play out similarly on land. What climate change does is raise the bar on the wet-bulb temperature. The tropospheric column stabilizes itself according to this new upper limit, and extreme wet-bulb temperatures across the tropics rise. With this reasoning, we

Figure 1: Wind at 500-hPa pressure level (about 5.5 km above sea level) showing the tranquil tropics and the swirling motions in higher latitudes.

Figure 2: A two-layer picture for the tropical atmosphere. The troposphere keeps the annual-maximum moist static energy and the wet-bulb temperature (TW) roughly uniform on land and on the ocean. (Picture source: https://www.princeton.edu/news/2021/05/05/simple-atmospheric-dynamics-foretell-dangerously-hot-future-tropics)
project that annual maximum wet-bulb temperatures in the tropics would increase by 1 degree Celsius with every degree of mean warming. Though many studies have suggested potential surprises in extreme weather that climate change could bring, we do not think extreme wet-bulb temperatures in the tropics are one of these cases. This work brings a positive message regarding climate mitigation – if we mitigate the mean warming, we also reduce the most extreme heat stress episodes throughout the tropics.

At the Miller Institute, I have ventured into the midlatitudes, where the effect of the Earth’s rotation (Figure 1) forbids a simple migration of tropical theories. Along with my faculty host, Dr. William Boos, I have developed a theory for the upper bound of surface temperature over midlatitude land. We are currently applying this theory to heat waves in the midlatitudes, where many regions are not adapted to high temperatures. I will strive to enhance our physical understanding of extreme weather phenomena and take advantage of the interdisciplinary community at the Miller Institute to develop new tools for a better understanding and more accurate projections of future changes in extreme weather.

Yi Zhang is a second-year Miller Fellow in the Earth and Planetary Science Department, advised by Professor William Boos. She received her PhD in Atmospheric Science from Princeton University, advised by Professor Stephan Fueglistaler, and her BS in Physics from Peking University.

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In the News

(see more current & past Miller Institute news: miller.berkeley.edu/news)

The Nobel Prize in Physiology or Medicine 2022

Svante Pääbo
Visiting Miller Professor 2013

“For his discoveries concerning the genomes of extinct hominins and human evolution.”


Sho Takatori (Miller Fellow 2017-2020) has been selected as a 2022 Packard Fellow.

Omar Yaghi (Visiting Miller Professor 2009) was appointed as the scientific leader of the Bakar Institute of Digital Materials for the Planet (BIDMaP). The institute’s work to help limit the planet’s warming and adapt to climate impacts is urgent. It will capitalize on Berkeley’s first-rate faculty and new faculty hires to create a novel field and interdisciplinary solutions that help solve society’s most intractable problems.

Ting Xu (Miller Professor 2022-2023) and her work on compostable plastic by embedding enzyme won the Breakthrough of the year in Engineering and Technology by the German Falling Walls Foundation. She also led the development of a fully recyclable and biodegradable printed circuit. The advance could divert wearable devices and other flexible electronics from landfill, and mitigate the health and environmental hazards posed by heavy metal waste.

Aaron Joiner (Miller Fellow 2021-2024) was awarded a 2022 Hanna Gray Fellowship. He’s among 25 exceptional postdoctoral scientists who represent a promising and more diverse future for biomedical science.

F. Dean Toste (Miller Professor 2014) and James Olzmann (Miller Professor 2020-2021) are part of a UC Berkeley team that works with their peers at Novartis Institutes for BioMedical Research to find new cures for debilitating illnesses.

Yi Cui (Miller Fellow 2003-2005, Somorjai Visiting Miller Professor Spring 2022) is leading the brand new Stanford postdoctoral program in energy, the Stanford Energy Postdoctoral Fellowship.

Karen Winey (Visiting Miller Professor 2014) received the 2023 ACS Award in Polymer Chemistry.
On November 29, 2022, the Advisory Board of the Miller Institute met to select next year’s Professorship awards. The Board is comprised of four advisors external to UCB: Scott Edwards (Evolutionary Biology, Harvard), Anna Gilbert (Math, Statistics & Data Science, Yale), Feryal Özel (Physics, Georgia Institute of Technology) and Tim Stearns (Graduate and Postgraduate Studies, The Rockefeller University); and four internal Executive Committee members: Executive Director Marla Feller (Molecular & Cell Biology), Jeffrey Long (Chemistry and Chemical & Biomolecular Engineering), Chung-Pei Ma (Astronomy & Physics) and Yun Song (EECS/Statistics/IB). The Board is chaired by Chancellor Carol Christ.

The Miller Institute is proud to announce the awards for Professorship terms during the Academic Year 2023-2024. These outstanding scientists pursue their research, following promising leads as they develop. The Visiting Miller Professors join faculty hosts on the Berkeley campus for collaborative research interactions.

### Miller Professorship Awards

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<td>Hillel Adesnik</td>
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<td>Nicholas Swanson-Hysell</td>
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<td>Junqiao Wu</td>
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### Visiting Miller Professorship Awards

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<td>Ran Nathan</td>
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<td>Michael Yartsev</td>
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<td>Jure Zupan</td>
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<td>Benjamin Safdi</td>
<td>University of Cincinnati</td>
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The Miller Institute is a program of the University of California, Berkeley.
Recent Publications

Jillian Banfield (Miller Professor 2006-2007) and Jennifer Doudna (Miller Senior Fellow 2017) are co-authors of the paper "Borgs are giant genetic elements with potential to expand metabolic capacity" published in Nature.


Jennifer Doudna (Miller Senior Fellow 2017) & Daniel Fletcher (Miller Professor 2019-2020) are co-authors of the paper, "Rapid detection of SARS-CoV-2 RNA in saliva via Cas13", published in Nature Biomedical Engineering.


In 2022, the Miller Institute named its first Kathryn A. Day Miller Postdoctoral Fellow, Dr. Raul Ramos! This award, established in 2019 and named for the Institute’s long-time administrator, is intended for an early-career scientist who, in addition to excelling in their research, has also demonstrated efforts towards community building and outreach in support of science. Learn more about Raul, his research and outreach efforts at his website: ramosneuro.com
Gifts to the Miller Institute

The Miller Institute gratefully acknowledges the following contributors to our programs in 2022 (received as of November 30, 2022). With your generosity, the Miller Institute is able to continue to support basic research in science at UC Berkeley.

Kathryn A. Day Miller Postdoctoral Fellowship Fund

The Kathryn A. Day Miller Postdoctoral Fellowship was established with a generous gift by Nobel Laureate Professor Randy Schekman and Professor Sabeeha Merchant to honor Kathy Day, who served as the Chief Administrative Officer at the Miller Institute for Basic Research in Science from 1989 - 2019. The purpose of the Fund is to provide an annual stipend, benefits and a research fund to a postdoctoral researcher at the Miller Institute who has demonstrated efforts towards community building and outreach in support of science.

Rachel Akeson
Anonymous
Justin Brown
John Clarke
Kathryn Day (2)
Dmitry Dolgopyat
Marla Feller
Alexei Filippenko
Eric & Christina Ford
Suzanne Peshette McKee & Christopher Fulton McKee
Iswar Hariharan
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Miller Institute for Basic Research in Science General Fund

The Miller Institute for Basic Research in Science is dedicated to the encouragement of creative thought and the conduct of research and investigation in the field of pure science. Contributions to this fund will support the four programs of the Miller Institute: the Miller Research Fellowship, the Miller Professorship, the Visiting Miller Professorship, and the Miller Senior Fellowship.

Anonymous
Anonymous - In Memory of Edward Steinhaus
Norman Yao

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2022 Miller Institute Mementos

New Fellows Retreat

L-R: Chief Administrative Officer Hilary Jacobsen, Miller Fellows Lijie Chen, Georgios Varnavides, Chadi Saad-Roy, Elena Zavala, Kelian Dascher-Cousineau, Shashank Gandhi, Carly Schissel, Mengshan Ye, Executive Committee member Jeffrey Long, Executive Director Marla Feller, Miller Fellow Boryana Hadzhyska, Executive Committee member Yun Song and Miller Fellow Lingfu Zhang

Miller Fellow Georgios Varnavides

L-R: Executive Director Marla Feller, Miller Fellows Mengshan Ye and Kelian Dascher-Cousineau, Chief Administrative Officer Hilary Jacobsen, Miller Fellows Carly Schissel and Chadi Saad-Roy, Executive Committee member Yun Song and Miller Fellow Shashank Gandhi

Miller Fellows Lijie Chen and Lingfu Zhang

Miller Fall Reception

Miller Senior Fellow Ken Ribet, Executive Committee Member Chung-Pei Ma & former Miller Fellow Yasunori Nomura

Former Miller Fellow Danqing Wang, Miller Fellows Nayeli Rodriguez Briones and Dimitrios Fraggedakis

Miller Fellow Yao Yang, guest Amy Davis and Miller Fellow Emily Davis
Clara Duman joined the Miller Institute staff team in August 2022 as our new Events Specialist. Clara has supported diverse communities through events management since 2018. She shares that “her empathetic and organized approach to events reflects her steadfast commitment to providing inclusive and engaging experiences for attendees.” Clara has a bachelor’s degree in Environmental and Urban Studies from Bard College. Prior to moving to Berkeley in May 2022, she has lived in Arizona, New York, Costa Rica, and Vermont. You can contact Clara at: millerevents@berkeley.edu.