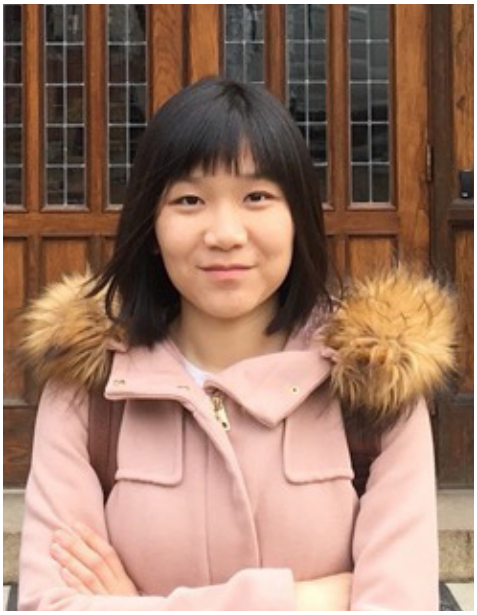
The Adolph C. and Mary Sprague
MILLER INSTITUTE
for Basic Research in Science

Newsletter
Winter 2023

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

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The Miller Institute is "dedicated to the encouragement of creative thought and the conduct of research and investigation in the field of pure science and investigation in the field of applied science in so far as such research and investigation are deemed by the Advisory Board to offer a promising approach to fundamental problems."

"In principle, I could have accomplished all that I achieved in my research without leaving home. In practice, the time and mental space afforded by the Miller Visiting Professorship allowed me to have what feels like one of my most productive months of the last decade."

- David Weinberg
Department Chair,
Distinguished University Professor
Ohio State University
Miller Fellow 1990 - 1991
VMP Spring 2022

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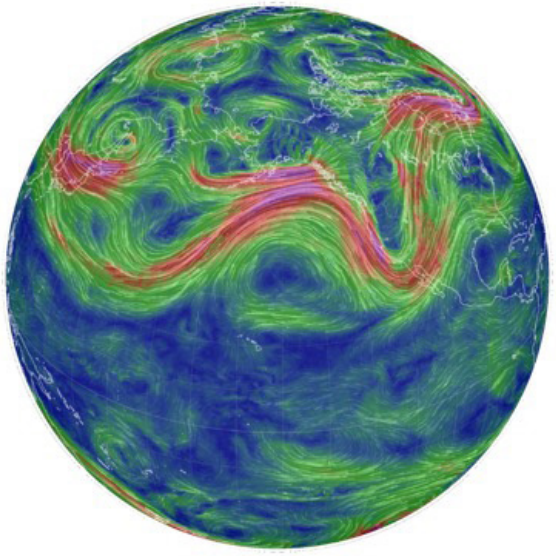

Figure 1: Wind at 500-hPa pressure level (about 5.5 km above sea level) showing the tranquil tropics and the swirling motions in higher latitudes.

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.

An 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.

A 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

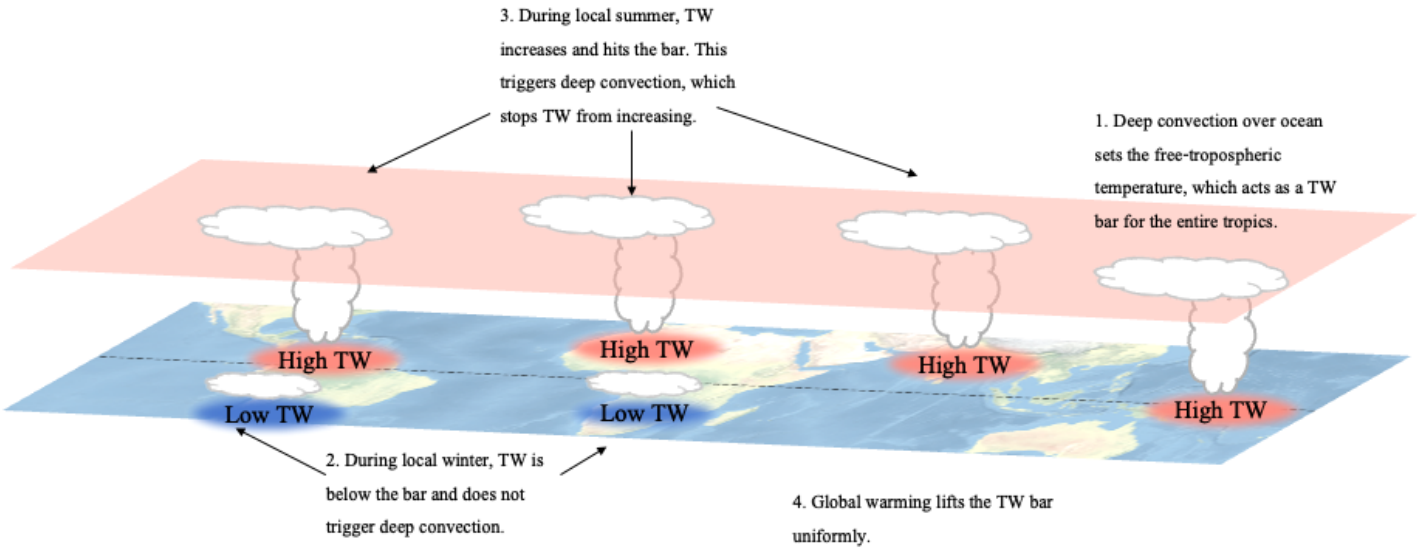

Figure 2: A two-layer picture for the tropical atmosphere. The troposphere keeps the annual-maximum moist static energy and the wet-bulb temperature (TW) roughly uniform on land and on the ocean. (Picture source: https://www.princeton.edu/news/2021/05/05/simple-atmospheric-dynamics-foretell-dangerously-hot-future-tropics)

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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.

Contact: y-zhang@berkeley.edu

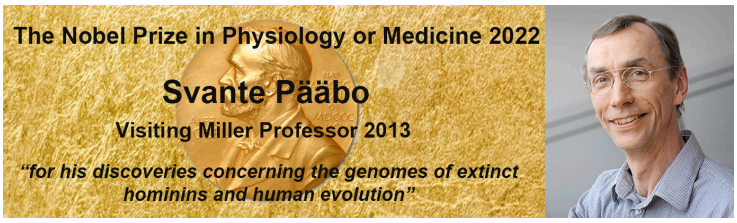
Make a Gift

Private donations are becoming an increasingly significant resource for the Miller Institute. Your personal investment in support of the future of the Miller Institute will be greatly appreciated.

Join Miller friends and alumni in contributing to this important endeavor by logging on to ***miller.berkeley.edu/gift*** to help support the independent research of the Miller Institute members.

In the News

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



Michael Jordan (Miller Professor 2008, 2017-2018, Miller Senior Fellow 2019-2021) won the **inaugural World Laureates Association Prize** *"for fundamental contributions to the foundations of machine learning and its application."*

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 a 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.**

Miller Research Competitions: Awards

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

Hillel Adesnik
MCB

Joshua Bloom
Astronomy

Nicholas Swanson-Hysell
EPS

Junqiao Wu
MSE

Visiting Miller Professorship Awards

Vilhelm Bohr
NST
Host: Danica Chen
Home Institution: National Institute on Aging, NIH

R. David Britt
Chemistry
Host: Michael Marletta
Home Institution: UC Davis

Jose Fuentes
ESPM
Host: Dennis Baldocchi
Home Institution: Penn State University

Mihaela Ifrim
Mathematics
Host: Daniel Tataru
Home Institution: University of Wisconsin, Madison

Philip Kim
Physics
Host: Feng Wang
Home Institution: Harvard University

Harm-Anton Klok
MSE
Host: Ting Xu
Home Institution: Ecole Polytechnique Fédérale de Lausanne (EPFL)

Nicolas Mathevon
Psychology
Host: Frederic Theunissen
Home Institution: University of Saint-Etienne & Institut Universitaire de France

Ran Nathan
Bioengineering
Host: Michael Yartsev
Home Institution: The Hebrew University of Jerusalem (HUJI)

Donna Nelson
Chemistry
Host: Anne Baranger
Home Institution: University of Oklahoma

Alec Wodtke
Somorjai Visiting Miller Professor
Chemistry
Host: Daniel Neumark
Home Institution: MPI for Multidisciplinary Sciences

Jure Zupan
Physics
Host: Benjamin Safdi
Home Institution: University of Cincinnati

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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.*

John Harte (Miller Professor 2006) was a co-author of two recent publications, "Information Theory: A Foundation for Complexity Science", published in PNAS & "An Equation of State Unifies Diversity, Productivity, Abundance and Biomass", published in *Communications Biology*.

Danqing Wang (Miller Fellow 2019-2022), **Feng Wang** (Miller Fellow 2005-2008, Miller Professor 2021-2022) & Alex Zettl (Miller Professor 1995, 2007) are co-authors of the paper, "Correlated interlayer exciton insulator in heterostructures of monolayer WSe2 and moiré WS2/WSe2" published in *Nature Physics*.

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*.

Soonwon Choi (Miller Fellow 2018-2021), **Umesh Vazirani** (Miller Professor 1999-2000, 2018-2019) & **Norman Yao** (Miller Fellow 2014-2017) are co-authors of the paper, "Classically verifiable quantum advantage from a computational Bell test," published in *Nature Physics.*

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

2022 Annual Fall Dinner

Miller Fellows Alfred Zong and Mengshan Ye, Executive Committee member Jeffrey Long, guest Gen Li, Miller Fellow Lingfu Zhang and Miller Professor Ting Xu

Advisory Board member Feryal Özel and Executive Committee member Chung-Pei Ma

Guest Young-Eun Choi, Executive Committee member Yun Song, Symposium Chair Michael Manga and Advisory Board member Scott Edwards

Guest speaker Professor Christopher Hendon, University of Oregon, presents his talk, "Chemical and Physical Principles of Coffee Production."

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
Yu He
John Hunter III
Daniel Ibarra
Thomas MC Juenger
Vyacheslav Krushkal
Michael Manga
Frederick Matsen
Vijay Pande
Ken Ribet
Patricia Rosen - In Honor of Andrew Rosen
Dustin Rubenstein
Stephen Suh (2)
Jesse Thaler
Peter & Gloria Yu

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

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 Hadzhiyska, 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

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Please send address corrections to:
miller_adm@berkeley.edu

New Staff Welcome

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.

Next Steps

Iwnetim Abate
Assistant Professor
Department of Materials Science and Engineering
MIT

Emeritus Miller Institute Members!

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