FALL 2022

GFDL BULLETIN

Research Highlights from the Geophysical Fluid Dynamics Laboratory Community

Advancing the Modeling, Understanding, and Prediction of Weather and Climate

A SIMPLE CONCEPTUAL MODEL FOR THE SELF-SUSTAINED MULTIDECADAL AMOC VARIABILITY

Geophysical Research Letters *Xinyue Wei[1], Rong Zhang[2]*

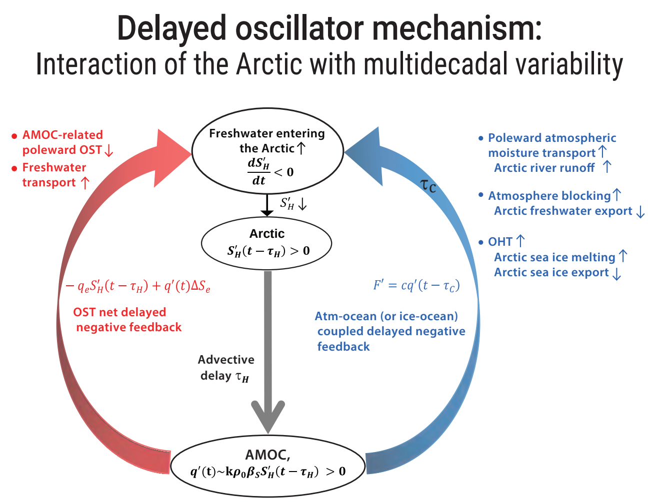
DOI: 10.1029/2022GL099800

Multidecadal variability of Atlantic Meridional Overturning Circulation (AMOC) has enormous societal and economic impacts, including Sahel and Indian monsoons, Atlantic hurricanes, Arctic sea ice, and it affects the climate in general over Europe, North America, and Asia.

The authors constructed a simple conceptual model to understand the two-way interaction of the Arctic with multidecadal AMOC variability through a delayed oscillator mechanism. Their model suggests an important role of Arctic salinity and delayed negative freshwater feedback in multidecadal AMOC variability.

AMOC has been reconstructed by various proxies, simulated in climate models, and linked to multidecadal Arctic salinity variability. However, the mechanisms of the multidecadal AMOC variability and its two-way interaction with the Arctic salinity anomaly, as well as the factors affecting the periods and amplitudes of the variability, are not well understood using simple conceptual models. Stommel's Two-Box Model provides a pioneering and powerful theoretical framework but even Stommel's Two-Box Model does not include a self-sustained multidecadal AMOC oscillation solution.

GFDL scientists have revised Stommel's Two-Box model by considering the delayed oceanic advective time lag for the Arctic density/salinity anomalies to reach the subpolar North Atlantic, as well as the dependence of the freshwater flux entering the Arctic on the AMOC strength. The revised model is able to obtain the AMOC delayed oscillator at multidecadal time-scales and suggests the important role of the Arctic salinity anomalies and associated delayed negative feedback in the multidecadal AMOC variability.



Schematic diagram of the AMOC delayed oscillator. A positive Arctic salinity anomaly takes an advective time delay (grey arrow) to induce a positive AMOC anomaly across the subpolar North Atlantic. Both the ocean salt transport (OST) anomaly (red arrow) and the AMOC-induced atmosphere-ocean (or ice-ocean) coupled freshwater feedback (blue arrow) increase the freshwater flux entering the Arctic and cause a negative salinity tendency there, i.e., delayed negative feedback for the Arctic salinity anomaly.

Using a simple conceptual model, this research provides a novel framework to understand the mechanisms of reconstructed and simulated multidecadal AMOC variability, and its two-way interaction with the Arctic salinity variability, in climate models. This understanding will help to predict future variations in the AMOC and associated climatic, ecological, and economic impacts.

OAR Goals: Detect Changes in the Ocean and Atmosphere and Drive Innovative Science

[1]Program in Oceanic and Atmospheric Sciences, Princeton University, Princeton, NJ; [2]NOAA/Geophysical Fluid Dynamics Laboratory, Princeton, NJ

GFDL SCIENTISTS IN THE SPOTLIGHT

Noemi Vergopolan, *Postdoctoral Research Associate*

Vergopolan was given the **2022 AGU Science for Solutions Award,** given annually to a student or postdoctoral scientist in recognition of significant contributions in the application and use of the Earth and space science to solve societal problems.

She also won the **2022 Paul F. Boulos Excellence in Computational Hydraulics/Hydrology Award** from the American Academy of Environmental Engineers and Scientists for her work on hyper-resolution land surface modeling.

A WEAKENED AMOC MAY PROLONG GREENHOUSE GAS-INDUCED MEDITERRANEAN DRYING EVEN WITH SIGNIFICANT AND RAPID CLIMATE CHANGE MITIGATION

Proceedings of the National Academy of Sciences *T. L. Delworth[1], W. F. Cooke[1], V. Naik[1], D. Paynter[1], L. Zhang[1,2]*

DOI: 10.1073/PNAS.2116655119

A decline in winter precipitation over the Mediterranean is a robust response to global warming across climate models, with significant impacts on agriculture and water resources. This study used a suite of simulations with the GFDL SPEAR climate model to explore whether the precipitation decline could be reversed in response to a hypothetical decline in greenhouse gas emissions after 2040. In a surprising result, this study shows that the precipitation decline might not be reversed, but could persist despite greenhouse gas reductions.

This seemingly contradictory behavior is related to changes in Atlantic Ocean circulation. The Atlantic Meridional Overturning Circulation (AMOC) weakens in response to increasing greenhouse gases and stays in a weakened state through the year 2100, even with greenhouse gas reductions. The persistently weakened AMOC impacts atmospheric circulation in important ways that lead to prolonged Mediterranean drying in the winter. This result highlights the risk that some important climate changes may not be easily reversed even with substantial reductions in greenhouse gas emissions.

The study also explores the extent to which other changes in the climate system resulting from global warming could be reversed. Some elements of the climate system, such as global mean temperature, global mean precipitation, and Arctic sea ice, respond rapidly and directly to changes in greenhouse gas concentrations, and thus show signs of recovery when greenhouse gas emissions decline. Other elements have more complex behavior, with long delay times and possible threshold-like behavior. A better understanding of such results will facilitate climate change adaptation and mitigation.

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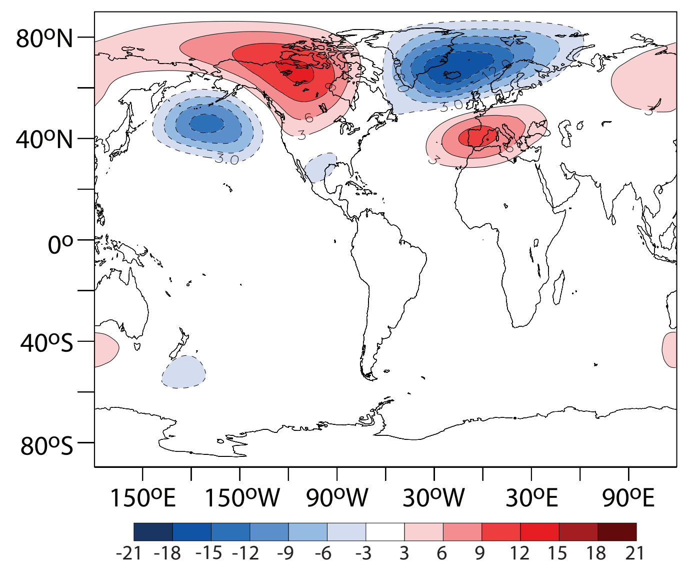
Atmospheric circulation changes helping to prolong Mediterranean drying, despite reductions in greenhouse gas emissions



Changes in winter upper atmosphere (500 hPa) geopotential height for years 2081-2100 minus years 2041-2060 in a simulation with declining greenhouse gas emissions after 2040. An increase in geopotential height (in meters) is seen over the Mediterranean (red shading), which tends to deflect storms and reduce Mediterranean rainfall, along with a decrease in geopotential height (blue shading) over the subpolar North Atlantic. This pattern of atmospheric circulation changes is related to a persistent weakening of the Atlantic Meridional Overturning Circulation in the North Atlantic, and helps to prolong the Mediterranean drying despite reductions in greenhouse gas emissions.

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RECENTLY HONORED SCIENTISTS AT GFDL

Ming Zhao, *Senior Physical Scientist*

For his “growing research accomplishments and leadership in climate model development”, Ming Zhao has been recognized with the **2022 AGU Ascent Award.** He successfully led a team that developed GFDL's latest atmospheric model (AM4). AM4 is at the core of GFDL models that are considered world-leading models for climate predictions and applications.

Yujin Zeng, *Postdoctoral Research Associate*

Is the recipient of the **2022 Robert H. Socolow Carbon Mitigation Initiative Best Paper Award for Postdoctoral Researchers at Princeton University** for his paper, “Possible anthropogenic enhancement of precipitation in the Sahel-Sudan Savanna by remote agricultural irrigation.”

IMPACT OF WARMER SEA SURFACE TEMPERATURE ON THE GLOBAL PATTERN OF INTENSE CONVECTION: INSIGHTS FROM A GLOBAL STORM RESOLVING MODEL

Geophysical Research Letters

K.-Y. Cheng[1,2], L. Harris[1], C. Bretherton[3], T. Merlis[2], M. Bolot[2], L. Zhou[1,2], A. Kaltenbaugh[4], S. Clark[1,3], S. Fueglistaler[2]

DOI: 10.1029/2022GL099796

Intense convection is a major source of weather hazards associated with heavy rain, damaging winds, and large hail. Worldwide, the daily economic loss related to intense convection was about $108 million dollars from 1970 to 2019. Intense convection is also an important component in Earth's energy balance.

This study employed GFDL's new ultra-high-resolution global model to conduct year-long simulations under present-day and warmed-ocean conditions, to investigate the impact of a warmed climate on intense convection. The authors found that intense convection becomes more frequent globally in a warmed climate. Notably, some regions have less intense convection. Spatial and seasonal responses of intense convection are associated with the changed planetary circulation. Results also indicated that increases in convective available potential energy do not necessarily enhance intense convection frequency.

Previously, changes to intense convection in a warmed climate were poorly understood. Traditional climate models cannot resolve these convective events because they have too coarse a grid to simulate intense convection explicitly. While high-resolution regional dynamical downscaling can simulate intense convection explicitly, those regional studies cannot reveal the full global distribution of intense convection. This study overcomes these limitations by using a global storm resolving model, GFDL's new eXperimental System for high-resolution prediction on Earth-to-Local Domains (X-SHiELD), with 3.25 km horizontal resolution that can resolve individual convective storms.

The novel simulations produced for this study offer a better understanding of how intense convection changes in a warming climate, helping to reduce the uncertainty in cloud feedback. This opens many opportunities for weather and climate research.

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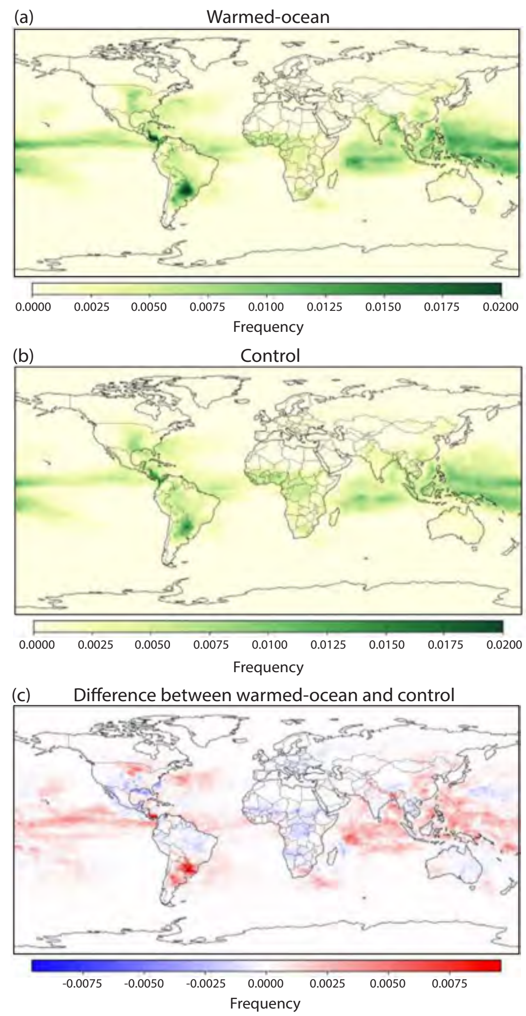
Impact of sea surface temperature on the global pattern of intense convection



Annual frequency of intense convection for (a) Warmed-Ocean Condition and (b) Control (normal climate); (c) is the difference between (a) and (b).

[1]NOAA/Geophysical Fluid Dynamics Laboratory, Princeton, NJ; [2]Program in Oceanic and Atmospheric Sciences, Princeton University, Princeton, NJ
[3]Allen Institute for Artificial Intelligence, Seattle, WA, [4]University Corporation for Atmospheric Research, Boulder, CO

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The bibliography contains professional papers by GFDL scientists and collaborators from 1965 to present day. You can search by text found in the document title or abstract, or browse by author, publication, or year.

REDUCTION IN NEAR-SURFACE WIND SPEEDS WITH INCREASING CO_2 MAY WORSEN WINTER AIR QUALITY IN THE INDO-GANGETIC PLAIN

Geophysical Research Letters *F. Paulot[1], V. Naik[1], L.W. Horowitz[1]*

DOI: 10.1029/2022GL099039

The Indo-Gangetic Plain (IGP), stretching from Pakistan to Bangladesh across Northern India, and home to over 800 million people, experiences among the most elevated concentrations of fine particulate matter in the world. Such high levels of air pollution are estimated to reduce average life expectancy by nearly a decade.

Using 26 models from the Climate Model Intercomparison Project (CMIP6) the authors show that increasing carbon dioxide emissions will cause a reduction in surface wind speed in the IGP. This study indicates that such a reduction in wind speed will result in higher wintertime airborne fine particulate matter concentration, and more frequent high pollution events.

High local anthropogenic emissions associated with waste and crop residue burning, transportation, industry, and power generation are the primary cause for the poor air quality in the region. Air quality in the IGP is especially poor in wintertime, in part due to meteorological conditions that encourage air stagnation. Unlike other major population centers in Europe, the United States, and China, air pollution has been worsening in the IGP over the last two decades. This suggests that meteorological changes associated with global warming may require stronger reductions in anthropogenic emissions than expected, to achieve lasting improvements in air quality in the IGP.

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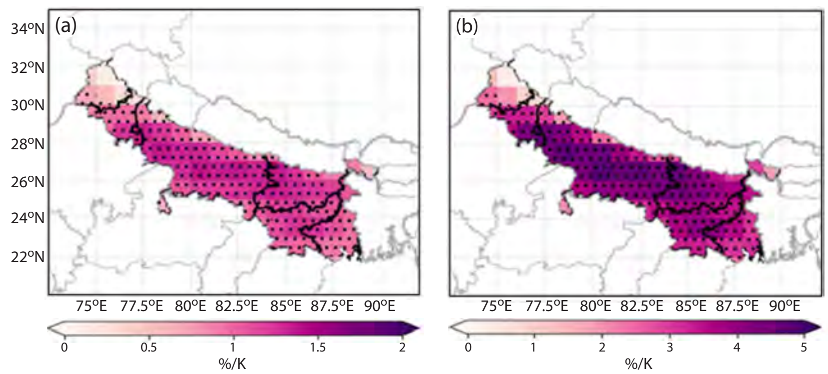
Change in wintertime fine particulate airborne matter concentration over the Indo-Gangetic Plain



Change in surface fine particulate matter (a) and probability of exceeding the present-day 75th percentile in fine particulate matter (b) estimated from the changes in surface wind speed in the 1pct CO_2 experiment. All changes are normalized by the global surface temperature change. Stippling indicates regions where changes are statistically significant ($p < 0.01$) and agree on the sign for at least 70% of the models.

[1]NOAA/Geophysical Fluid Dynamics Laboratory, Princeton, NJ

GFDL Scientists' Service for Professional Societies and External Organizations

Ram Ramaswamy
- WMO Executive Council Panel on Polar and High Mountain Observations, Research, and Services (EC-PHORS)
- Research Advisory Council, Indian Institute of Tropical Meteorology, Pune, India
- Chair, External Advisory Council for Climate Modeling, Allen Institute of Artificial Intelligence (AI2)

Charles Stock
- U.S. Ocean Carbon and Biogeochemistry (OCB) Scientific Steering Committee
- Project Advisory Board for the European Climate Change and Future Marine Ecosystem Services and Biodiversity project (FutureMARES)
- Scientific Advisory Board for the Centre for Ocean Life, Denmark Technical Univ.

Andrew Wittenberg
- International CLIVAR Pacific Region Panel (PRP) Working Group on Conceptual Models of ENSO

Baoqiang Xiang
- U.S. CLIVAR Panel on Predictability, Predictions, and Applications Interface

Liping Zhang
- U.S. CLIVAR Process Study and Model Improvement Panel

Rong Zhang
- Science Advisory Board for the Bjerknes Climate Prediction Unit, Bergen, Norway
- CLIVAR AMOC Task Team

Ming Zhao
- U.S. CLIVAR Process Study and Model Improvement Panel
- American Meteorological Society, Committee on Tropical Meteorology

Youtong Zheng
- Dept. of Energy, Atmospheric Radiation Measurements User Executive Committee

(Continued from GFDL Scientists' Service list part 1 in the Summer 2022 Issue.)