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Research Highlights from the Geophysical Fluid Dynamics Laboratory Community

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

INCREASES IN EXTREME PRECIPITATION OVER THE NORTHEAST UNITED STATES USING HIGH-RESOLUTION CLIMATE MODEL SIMULATIONS

npj Climate and Atmospheric Science *B.-T. Jong[1,2], T. L. Delworth[2], W. F. Cooke[2], K.-C. Tseng[1,2,3], H. Murakami[2,4]*

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Extreme precipitation is among the most destructive natural disasters. Future projections with GFDL's high-resolution climate model, **S**eamless System for **P**rediction and **EA**rth System **R**esearch (SPEAR), show that by the mid-21st century, extreme precipitation events (i.e., top 1% of daily precipitation based upon historical climatology) will occur over the Northeastern United States 50% more often – driven by increasing anthropogenic forcing and distinguishable from natural variability.

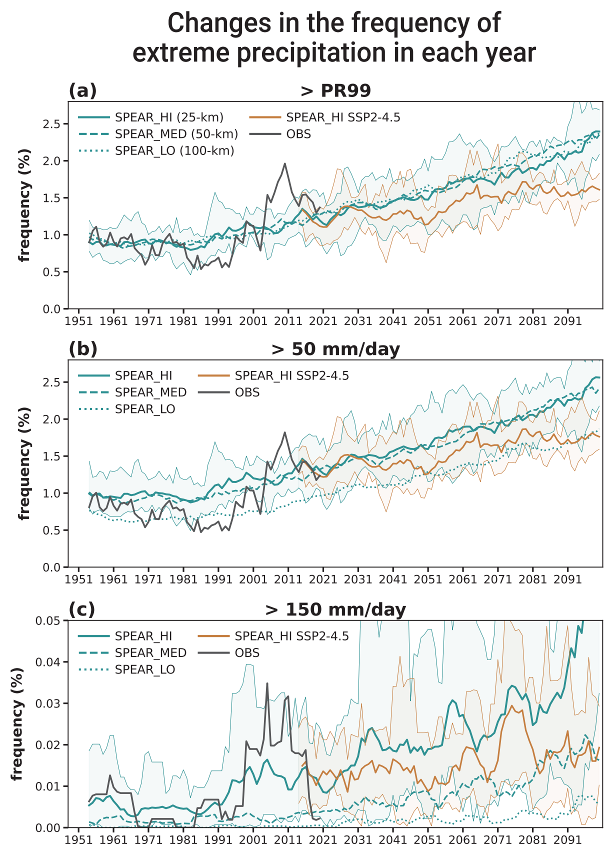
Very extreme events, such as heavy rainfall related to hurricanes, may be six times more likely by 2100 compared to the early 21st century, under the Shared Socioeconomic Pathway 5-8.5 (SSP5-8.5), high-end projection of future greenhouse gas emission.

Detecting and projecting changes in extreme precipitation on regional scales remain highly challenging and uncertain. Global climate models, typically with atmospheric resolution ranging from 100 to 200 km, are not sufficient to represent the most extreme precipitation events. Models with higher-resolutions permit the simulation of higher precipitation rates and better represent several physical processes related to extreme events such as tropical cyclones, extratropical transition, mesoscale processes, atmospheric rivers, and quasi-persistent weather regimes, compared to models with coarser resolutions.

For this study, the authors used an ensemble of simulations from SPEAR to study extreme precipitation over the Northeastern United States, where extremes have increased rapidly since the mid-1990s. The authors focused on September to November, as the fall season has the most robust trend. A variety of horizontal resolutions (from 100 to 25 km) in the atmosphere and land components of the model were tested to demonstrate that a finer resolution model facilitates a more realistic simulation of extreme precipitation frequency.

The 25-km SPEAR shows remarkable performance in simulating the observed extreme precipitation frequency and variability over recent decades compared to comparable models with 50 or 100 km resolution. This study enhances our understanding of how the frequency and amplitude of extreme precipitation events will change in the future, through the use of high-resolution global models.

OAR Goals: Make Forecasts Better, Drive Innovative Science



(a) *All the models simulate similar increasing trend since the 1980s when extreme events are defined as top 1% of daily precipitation based upon historical climatology from each dataset or model. Green lines show the ensemble mean from SPEAR_LO, SPEAR_MED, and SPEAR_HI historical simulations (1951-2014) and SSP5-8.5 projections (2015-2100). Projections under the lower-emission scenario, SSP2-4.5, from SPEAR_HI are also included (orange lines).*

(b),(c) *Models with coarser resolution underestimate the frequency, especially the ones with 100-km horizontal resolution, such as when using absolute thresholds, 50 mm/day and 150 mm/day, to define extreme events. For the very extreme events (>150 mm/day), only SPEAR_HI can simulate comparable frequency with the observations.*

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ASSESSMENT AND CONSTRAINT OF MESOZOOPLANKTON IN CMIP6 EARTH SYSTEM MODELS

Global Biogeochemical Cycles

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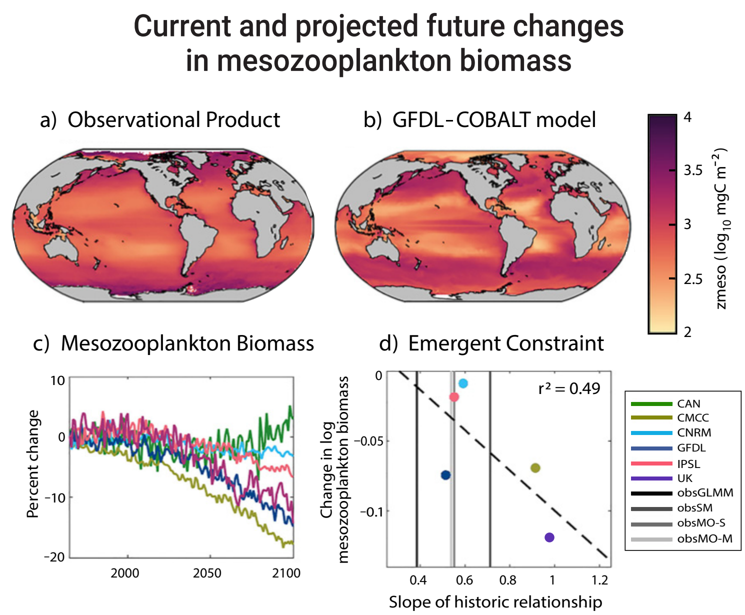
Zooplankton play a key role in transferring carbon from the atmosphere deeper into the ocean. They also serve as a crucial link in food chains between microscopic marine plants (phytoplankton) and predators like fish and whales. Yet, how well zooplankton is represented in Earth System models has not been adequately tested.

The authors first compared observations of zooplankton biomass to model estimates and found that five out of six models had similar patterns and comparable average biomasses across the global ocean as the observations. Additionally, they explored whether these models can reproduce an observed relationship between zooplankton biomass and chlorophyll concentration, a useful way to assess how well the models represent predator-prey relationships. For this metric, three models fell within the observed relationship. The strength of the relationships across all models was related to how much zooplankton biomass will decrease with climate change.



Comparison between ***(a)*** *a global observational dataset of mesozooplankton biomass and* ***(b)*** *the simulated mesozooplankton from the GFDL-COBALT model from 1965-2014.* ***(c)*** *Projected future changes in mesozooplankton biomass under a high emissions scenario (SSP5-8.5) in a range of CMIP6 models (colored lines), and* ***(d)*** *the historic chlorophyll-mesozooplankton relationship in CMIP6 models, constrained by observations (gray & black vertical lines) and contrasted with the future projected change in mesozooplankton biomass.*

GFDL's COBALT model ranked among the best performing models in this study, and typically had the lowest mean absolute error and smallest bias. COBALT represents bacteria and three size classes of zooplankton in addition to phytoplankton groups (small phytoplankton, large phytoplankton and diazotrophs). COBALT also advances the overall representation of the ocean carbon cycle, including the biological pump, which is a key mechanism for exporting carbon from the surface to the deep sea. As such, it is among the most comprehensive and skillful of its generation of ocean biogeochemical models.

The role of zooplankton in the biological pump is one of the largest uncertainties in ESM simulations of the marine carbon cycle, so constraining their biomass is important for understanding future climate. To improve the representation of zooplankton in models, we need better observations of the relationships between organisms. This would advance estimates of carbon transfer to the deep sea and carbon available to fish, and how they will change with climate change.

OAR Goals: Drive Innovative Science, Explore the Marine Environment

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FORCING, CLOUD FEEDBACKS, CLOUD MASKING, AND INTERNAL VARIABILITY IN THE CLOUD RADIATIVE EFFECT SATELLITE RECORD

Journal of Climate *Shiv Priyam Raghuraman[1], David Paynter[2], Raymond Menzel[2,3], V. Ramaswamy[1,2]*

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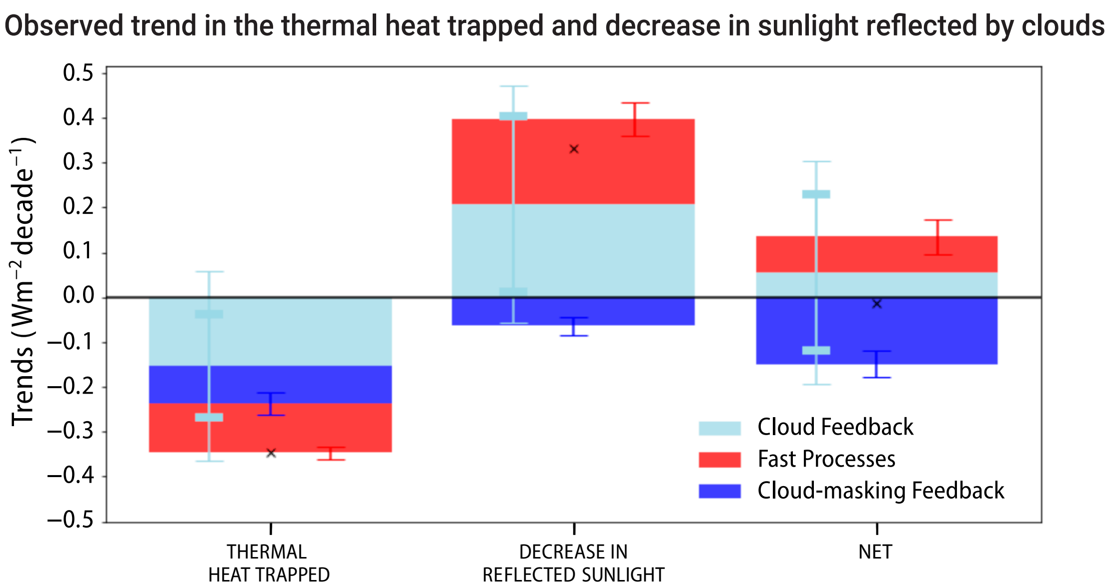
How clouds respond to human activities has been a major source of uncertainty in predicting future global warming. Clouds can influence the temperature of Earth through both trapping thermal heat and reflecting sunlight, which warm and cool the planet respectively. In this research, the authors show that over the last two decades, globally, both the thermal heat trapped and sunlight reflected by clouds has declined. The study reveals that these two countervailing forces, that are roughly equal, cancel each other — resulting in a net zero influence of clouds.

Climate feedback due to clouds is the process by which clouds change in response to the warming of the planet which, in turn, either enhances or reduces the magnitude of future warming. Over the past two decades, as the Earth has seen notable global warming, the flat net response of clouds could be seen as evidence for a near-zero feedback of clouds.

However, this study highlights that many changes in both thermal trapping and solar reflection could be due to "fast processes" which are driven directly by increased human emissions, and unlike feedbacks, not directly controlled by warming. The decreased thermal trapping of clouds is largely due to a phenomenon known as cloud masking; a direct consequence of increased carbon dioxide trapping heat that would have otherwise been trapped by clouds. While the change in reflective sunlight is consistent with decreasing aerosol making clouds less reflective, as well as increasing carbon dioxide absorption by the atmosphere which tends to reduce cloud cover.

The authors show that internal variability in the climate system plays an important role, too, and can have a notable impact on the magnitude of observed trends. Uncertainty in the contribution of fast processes along with the magnitude of internal variability makes it not possible to meaningfully constrain the sign of the net cloud feedback in the future using observations of the last two decades. However, improved process-level understanding and continued monitoring of the climate system over the next decade will help fill this gap.

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



The cross sign is the total observed trend between 2001 and 2020 in the thermal heat trapped and decrease in sunlight reflected by clouds. The net sum of the two is also shown. The contribution of fast processes (red), cloud masking of the feedback (dark blue) and cloud feedback (light blue) is shown. For cloud feedback, the error bar includes uncertainties in the observations and unforced variability. The two ranges on this error bar represents two methods of estimating observational uncertainty. Hence, the large light blue error bars highlight a large uncertainty in cloud feedback over the past twenty years.

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A MECHANISTIC SEA SPRAY GENERATION FUNCTION BASED ON THE SEA STATE AND THE PHYSICS OF BUBBLE BURSTING

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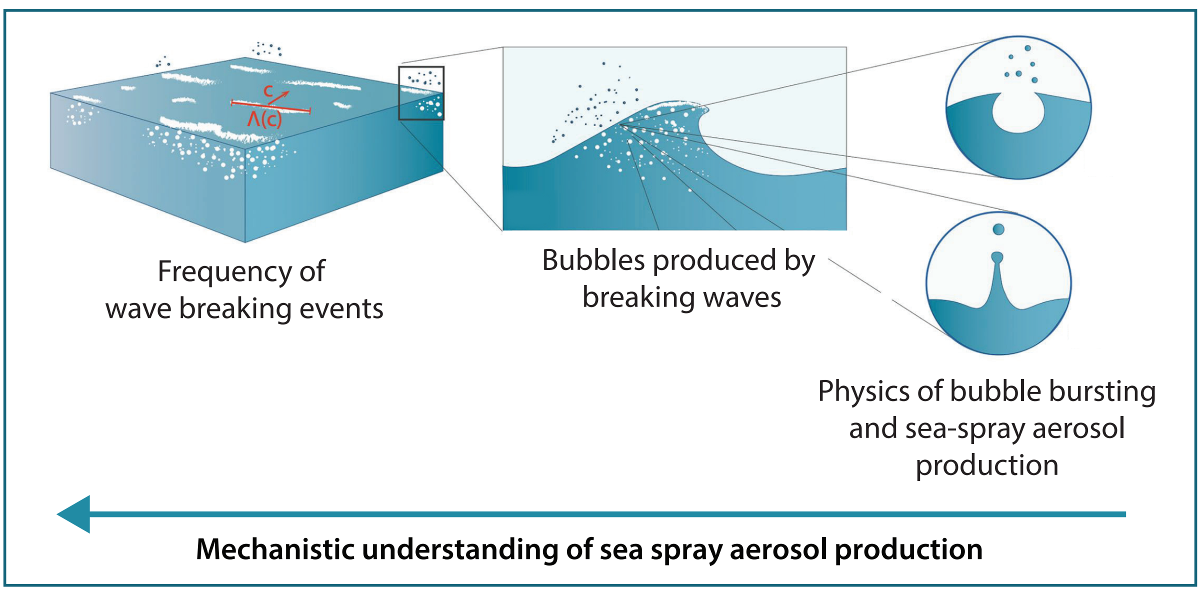
Bubbles bursting at the ocean surface are an important source of sea spray aerosols, contributing to atmospheric aerosols and playing a crucial role in radiative and cloud processes. Knowledge of the size distribution of primary sea spray aerosol particles and its dependence on meteorological and environmental variables is necessary for simulating clouds and the influence of aerosol on radiative processes. Currently, the extent and brightness of marine low clouds are poorly represented in Earth system models, and the response of low clouds to changes in atmospheric greenhouse gases and aerosols remains a major source of uncertainty in climate projections.

The authors propose a new mechanistic sea spray generation function for climate models that takes into account the sea state, wind, and temperature variability to address this challenge. This approach naturally integrates the role of wind, waves and temperature using the physics of bubble bursting. The resulting sea spray generation function does not require tuning to match any existing data sets, in terms of magnitude of sea salt emissions and recently observed temperature dependencies. The remarkable coherence between the model and observations of sea salt emissions strongly supports the mechanistic approach and the resulting sea spray generation function.

This represents a significant advancement over previous models and has the potential to improve our ability to predict the impact of sea spray aerosols on the climate and our understanding of their effects on the atmosphere and climate. This approach dovetails with efforts by several modeling centers to develop coupled oceanic and atmospheric wave models, moving toward coupled wave atmosphere-ocean Earth system models. Consequently, this could contribute to the development of more accurate climate model projections.

OAR Goals: Drive Innovative Science, Explore the Marine Environment

New mechanistic sea spray generation function for climate models



Schematic representation of processes encapsulated in the mechanistic sea spray generation function (arrow represents increasing scales). The function considers the frequency of wave breaking events from the sea state and the wind conditions, the characteristics of the wave breaking events determine the types of bubbles produced, and these bubbles and their bursting physics are used to predict the sea spray aerosol production.

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