ATMOSPHERIC RIVERS: POTENTIAL DROUGHT BUSTERS

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EXECUTIVE SUMMARY

Atmospheric rivers (ARs) are a subset of midlatitude storms that can have profound regional impact. This is particularly true in the western United States where ARs can make landfall and produce heavy rainfall events. Strong AR precipitation during the anomalously wet winter of 2016–2017 nearly eliminated the decade-long drought impacting most of California. In this project on Blue Waters, we use fully coupled high-resolution atmospheric and oceanic climate simulations to investigate how ARs on the West Coasts of the United States, United Kingdom, and Iberian Peninsula may change under a future high-emission warming scenario. Future change in AR behavior is linked to changes in the midlatitude jet. Our model results suggest more or stronger ARs on the California coast, the U.K., and Iberian Peninsula and fewer or weaker ARs in the Pacific Northwest. Precipitation associated with ARs is also projected to increase in intensity under global warming conditions.

RESEARCH CHALLENGE

An overarching objective of our research is to identify processes and mechanisms that characterize high-impact events and quantify how these events could change in the future. For this particular study, we focused on atmospheric rivers (ARs) that make landfall on the U.S. West Coast, the U.K., and Iberian Peninsula. Results indicate that AR properties are dependent on the location and strength of the subtropical and eddy-driven atmospheric jets [1] and that ARs using higher-resolution atmospheric models better match those found in observations [3]. In this study, we investigate the representation of ARs and their potential future change using a climate model configuration with a high-resolution atmosphere (0.25°) uncoupled and coupled to both a medium- (1°) and high- (0.1°) resolution ocean.

METHODS & CODES

For long climate integrations we use the Community Earth System Model (CESM), a coupled climate model for simulating the earth's climate system. Composed of six component models that simulate Earth's atmosphere, ocean, land surface, sea ice, land ice, and river transport, the CESM allows researchers to conduct fundamental research into the Earth's past, present, and future climate states. The experiments we conducted are at the highest resolution currently feasible within the CESM for century-scale climate studies in terms of both scientific fidelity and computational cost. They allow better quantification of long-term climate change projections at regional scales and enable a more accurate representation of important dynamical features. These features include realistic extreme precipitation events that compare better to observations in heavy precipitation categories as well as more realistic midlatitude and tropical storms. In this project, we investigated ARs—a subset of midlatitude storms. (The long, filamentous structures streaming from the tropics into the midlatitudes in both hemispheres in Fig. 1 are illustrations of ARs.) A tracking algorithm developed by Shields and Kiehl [2] was employed to obtain the number and properties of North Pacific (U.S. West Coast) and North Atlantic (United Kingdom and Iberian Peninsula) ARs.

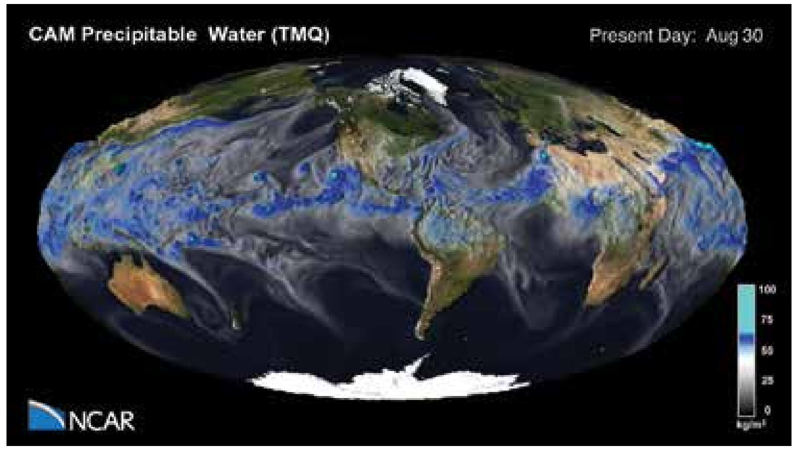

Figure 1: A snapshot of total precipitable water in the atmosphere on August 30, 1990, from a high-resolution (0.25°) simulation of the CESM. This illustrates the location of moisture in the atmosphere. (Figure courtesy of Computational and Information Systems Lab/NCAR)

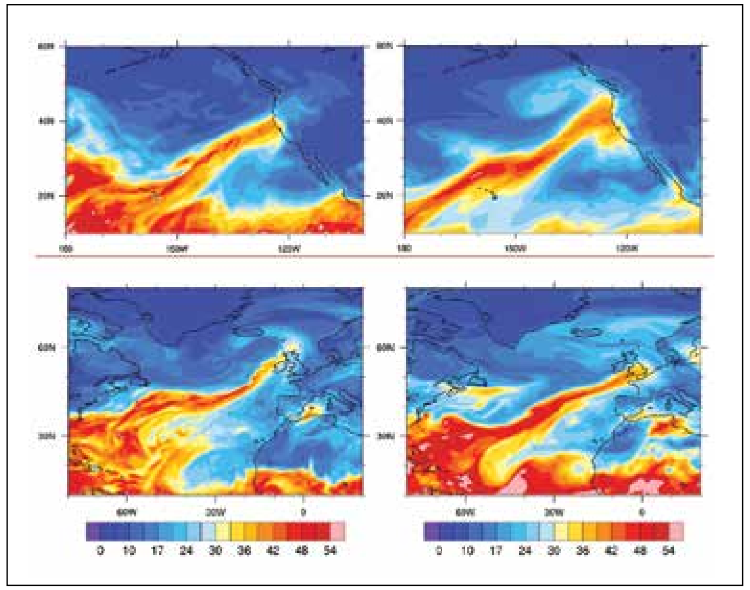

Figure 2: Snapshots of examples of ARs in the north Atlantic (bottom panels) and north Pacific (top panels) when using a standard 1° ocean configuration (right panels) and a high-resolution (0.1°) configuration (left panels). The high-resolution ocean provides significantly more detailed structure to the AR. (Figure courtesy of Christine Shields, NCAR)

RESULTS & IMPACT

We first compared the representation of ARs within the various model configurations using a previous study conducted by Shields and Kiehl [1,2] that examined simulations with a 0.5° atmosphere model and the simulations run on Blue Waters that use a 0.25° atmosphere. Results indicate that increasing resolution generally improves the AR count compared to observations. Increasing model resolution results in a decrease of AR counts along the California and U.K./Iberian Peninsula coasts whereas counts increase in the Pacific Northwest. We anticipate further improvement in the simulation using the 0.1° ocean, particularly in the North Atlantic where the latitudinal position of the underlying Gulf Stream leads to improvement in storm track location [4].

We next investigated changes in ARs that could occur by the mid-21st century under the future high-emission scenario (RCP8.5). Change in ARs are driven by changes in the subtropical and eddy-driven jets, with the U.S. West Coast and Iberian Peninsula ARs following the subtropical jet and the U.K. ARs following changes in both jets. In the North Pacific in the future scenario we anticipate a strengthening of the jet along its southern flank and a weakening along the northern flank, resulting in more or stronger ARs on the California Coast and fewer or weaker ARs in the Pacific Northwest. In the North Atlantic, strengthening of both jets results in more or stronger ARs for both the U.K. and the Iberian Peninsula.

AR research thus far has largely focused on the atmosphere [e.g., 1,2]. Our work investigated the ocean's role regarding AR development, intensity, and structure, and how this may change in future states of the earth system. High-resolution ocean models may resolve AR structure with much finer detail, in part by resolving the small-scale ocean eddies that sit below the AR transport path. More realistic ocean eddy structure could impact AR structure and its role as a vehicle for moisture transport. Fig. 2 illustrates the ability of the higher-resolution ocean to imprint smaller-scale features onto the structure of ARs compared to the lower-resolution model.

WHY BLUE WATERS

In order to determine model representation of climate processes and to project future changes, multiple century-long simulations are needed, including a long, stable preindustrial control, followed by historical and future scenarios. For investigation of climate extremes such as ARs, high-resolution simulations are necessary. Furthermore, multimember ensembles are needed to quantify and reduce uncertainty. The simulations we have conducted on Blue Waters this past year consist of a 0.25° atmosphere/land coupled to both a 1° and 0.1° ocean. These high-resolution simulations at a minimum require petascale computing resources and cannot be completed without a computational platform like Blue Waters. Because these simulations use a modest number of nodes for long periods of time, our project needs the help of the Blue Waters staff to achieve good throughput.