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DEFINING UNCERTAINTIES THROUGH COMPARISON OF ATMOSPHERIC RIVER TRACKING METHODS

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Atmospheric rivers (ARs) are a weather phenomenon associated with long, narrow bands of atmospheric moisture transport from the tropics to higher latitudes (Zhu and Newell 1998). ARs are broadly recognized for their global significance in mediating energy and water cycles and for their regional importance for providing water supply but also as a source of hazard. There is a large body of literature that explores ARs from both global and regional perspectives and from time scales spanning hourly to centennial. Despite this broad literature, the consensus definition of ARs remains essentially qualitative (Ralph et al. 2018), so diverse methods have been developed to track ARs, leading potentially to an important source of uncertainty in understanding ARs and their myriads of impacts.

THE SECOND ATMOSPHERIC RIVER TRACKING METHOD INTERCOMPARISON PROJECT

What: A two-day workshop with participants from various U.S. federal agencies/programs, national and international universities, and U.S. national laboratories met to discuss progress with the Atmospheric River Tracking Method Intercomparison Project (ARTMIP). ARTMIP aims to quantify the uncertainty in AR climatology, precipitation, and related impacts that arise from a wide range of AR tracking methods developed by the community and how these AR-related metrics may change in the future.

When: 23–24 April 2018

Where: Gaithersburg, Maryland

ARTMIP is a grassroots effort initiated by U.S. Department of Energy (DOE) and National Oceanic and Atmospheric Administration (NOAA) scientists to understand and quantify the implications of the diverse set of AR identification and tracking methods

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found in the literature. The second Atmospheric River Tracking Method Intercomparison Project (ARTMIP) workshop, sponsored by the U.S. Department of Energy, built upon the framework established by the first ARTMIP workshop (held in May 2017 in San Diego, California). The goal of ARTMIP is to understand and quantify uncertainties in atmospheric river science based on choice of identification and/or tracking methodology (i.e., AR algorithms) and communicate this to the AR research and stakeholder communities. More information on ARTMIP's goals, framework, and experimental design is available in Shields et al. (2018). The climatological characteristics of ARs, such as AR frequency, duration, intensity, and seasonality, are all strongly dependent on the method used to identify ARs. Understanding the uncertainties and how the choice of detection algorithm impacts quantities such as precipitation is imperative for stakeholders such as water managers, city and transportation planners, agriculture, or any industry that depends on global and regional water cycle information for the near term and into the future. Understanding and quantifying AR algorithm uncertainty is also important for developing metrics and diagnostics for evaluating model fidelity in simulating ARs and their impacts. ARTMIP launched a multitiered intercomparison effort designed to fill this community need. The first tier of the project is aimed at understanding the impact of AR algorithm on quantitative baseline statistics and characteristics of ARs, and the second tier of the project includes sensitivity studies designed around specific science questions, such as reanalysis uncertainty and climate change.

The second ARTMIP workshop provided a forum for the AR community to

1) discuss analyses of the tier 1 dataset,
2) synthesize the results and implications of the tier 1 analyses,
3) use this information to define the experimental designs for the various tier 2 experiments,
4) work toward developing a set of recommendations regarding the advantages and disadvantages of different AR algorithms for various scientific questions, and
5) discuss gaps and emerging opportunities for advancing the tracking and science of ARs.

ARTMIP SCIENCE QUESTIONS. The driving question guiding ARTMIP is to understand how the uncertainties, and the implications for uncertainties associated with algorithmic choice for AR identification, affect our scientific understanding of ARs. Many science questions follow from this basic goal and have been discussed among the ARTMIP participants in depth. A sample of these questions include the following: How do metrics such as frequency, duration, intensity, and precipitation associated with ARs differ among the AR tracking algorithms? Which algorithms are best suited for addressing AR impacts? Can AR tracking methods be equally useful for forecasts versus climate projections? How do algorithmic choices impact the representation of AR dynamics? How and why do different algorithm choices change our understanding of ARs now and into the future? Do global models represent AR characteristics and processes accurately, and how do AR tracking methods influence this assessment? What are the drivers for AR genesis based on ARs tracked using different methods? What forecast variables and forecast skill are most useful for stakeholders? Do AR tracking methods affect assessment of forecast skill and hence communication of the usefulness of AR forecasts to stakeholders?

TIER 1 ANALYSIS, STATUS, PLANS. The second ARTMIP workshop began with a discussion of results from the first tier of the project. Previously, many scientists ran their own AR identification and tracking methods over different regions, using different datasets, and during different periods of record. With ARTMIP tier 1, each participant runs their respective method on the same global data, from the Modern-Era Retrospective Analysis for Research and Applications (MERRA), version 2, from January 1980 through June 2017 (Gelaro et al. 2017) and provides their results using the same format to facilitate intercomparison. An example of a comparison across the ARTMIP algorithms identifying ARs for 0600 UTC 7 February 2017 is shown in Fig. 1.

AR metrics and a sample of discussion points follow:

AR frequency and seasonality. Given that the diverse algorithms produce a range of frequencies, visualizing and comparing these methodologies can be done most effectively by grouping, or clustering, the algorithms into different categories. "Clustering" (e.g., by absolute thresholds, relative thresholds, length requirements) reduces the amount of data shown and facilitates interpretation. The spread in AR frequency can be explained, in part, by the different algorithmic choices and by identifying what part of the AR, spatially and temporally, the algorithms are targeting.

AR duration. Quantifying and visualizing the key metric of AR duration among the different AR algorithms can be a challenge. Direct comparison among the different algorithms can be accomplished by examining the overlap between AR detection methods for AR cases at certain locales. Alternatively, computing duration climatologies for predefined time intervals allows for comparison of clustered categories.

AR intensity. Diagnosing and comparing AR intensity can be tricky when comparing the different algorithms. In some regards, the intensity of the ARs described by a particular method will be inherent in the definition of the algorithm itself, specifically for those that use moisture and/or moisture transport thresholds. For example, a method that requires a limit of 500 kg (m s^{-1})$^{-1}$ vertically integrated vapor transport will inherently represent more "intense" ARs than those that allow for lower thresholds, such as 250 kg (m s^{-1})$^{-1}$. Nonetheless, AR intensity is an important metric to evaluate. Initial attempts at defining and comparing "intensity" across the algorithms were discussed.

Precipitation attributable to ARs will be the next metric to be tackled with tier 1 data. Ultimately, tier 1 data and publications will aim to quantify the uncertainty in AR climatology (e.g., frequency, duration, and intensity), precipitation, and related impacts that arise because of different AR tracking methods. This will provide a baseline for comparison to results of tier 2 analyses, some of which are based on climate model runs, and an assessment of how AR climatology and AR-related impacts may change in the future.

TIER 2 STATUS AND PLANS. Tier 2 has just begun and will focus on climate change as its first topic. The purpose of the second day of the workshop was to flesh out the details and framework for tier 2 topics. To reduce the burden of creating catalogs from a variety of datasets all at once, each topic will be initiated sequentially, starting with climate change and followed by reanalysis sensitivity. The goal of tier 2 is to generate data and perform analysis that delves into topical science questions important to research groups and stakeholders. Tier 2 topics were discussed at length both in plenary and in breakout groups, and a timeline was created for accomplishing tier 2 goals, including 1) generating the necessary datasets and 2) analysis of datasets focused on specific questions.

It is our hope to provide the community with a suite of publications as well as a data repository and easy access to all ARTMIP datasets with the goal of encouraging AR science advancement.

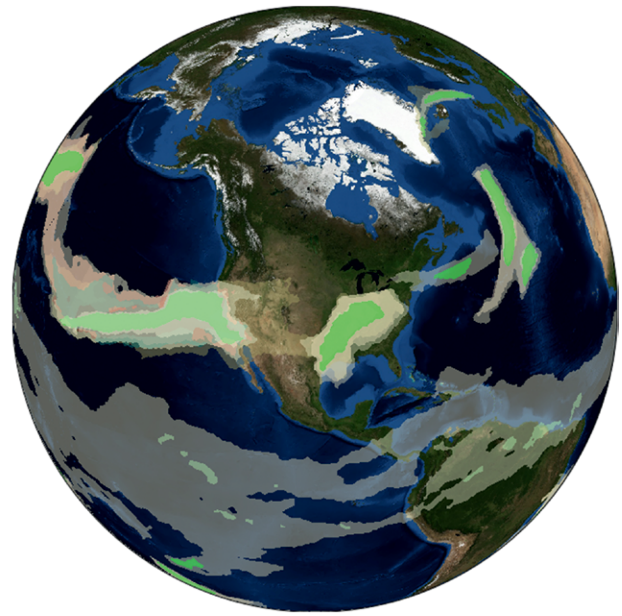

Fig. 1. A visual representation of multiple atmospheric river detections at 0600 UTC 7 Feb 2017. Values are shaded where an individual ARTMIP algorithm detects an AR, and each ARTMIP algorithm is randomly assigned a distinct color with a low opacity. Areas with all algorithms agreeing on AR detection appear perfectly opaque, areas with all algorithms agreeing on a lack of AR presence simply show the background "blue marble" image, and areas with some amount of algorithm disagreement on AR presence appear semitranslucent.

BEYOND ARTMIP: EMERGING NEEDS AND OPPORTUNITIES. The plenary session on the second day of the workshop was dedicated to a discussion of emerging needs and opportunities for AR research. A number of topics were discussed, including the needs of both weather and climate communities, observational research, and AR impacts.

The importance of ARTMIP to the end user was emphasized. Economic growth and vitality of the western United States is dependent on the effective and efficient use of the existing water supplies. In the Pacific Northwest, the Columbia and Willamette Rivers have been controlled and diverted to support navigation interest in the region but constitute the main water supply for nearly 8 million people. The state of California, one of the largest states in the west, developed its water resources with the California State Water Project, plus water from the Colorado River, to meet its water supply demands for nearly 39 million people. All of these rivers are driven by precipitation in the form of rain and snow that have a moisture source from the Pacific Ocean. This moisture is driven inland by storm systems frequently linked to ARs that have a wide range of intensity and storm track from year to year. The ability to make optimum use of the existing water supplies is greatly dependent on our ability to forecast the tracks of these storm systems and associated moisture throughout the year. Forecasting the intensity of the wet season, up to two years in advance, would greatly improve water managers' abilities to better operate control structures on the primary rivers and provide a more consistent water supply for multiple users from recreation, navigation, agriculture, and human consumption.

Predictability on subseasonal, decadal, and longer time scales were also highlighted as key emerging needs for AR climate research. What are the meteorological conditions needed for AR initiation and how do ocean, land, and atmosphere contribute to predictability for those large-scale conditions on various time scales? Delving deeper into the hydrological aspects associated with ARs was also noted. In addition to diagnosing and analyzing the relationship between AR and precipitation, quantities such as soil moisture, snowpack, and streamflow are all critical components of the local water cycle. How will these important quantities be affected on different climatic time scales? Polar ARs, in particular, those connected to extreme events such as anomalous snowfall, or rapid glacier mass loss, were noted as a relatively new area for AR research. ARs in the paleoclimate record were discussed as well as an area to be more fully explored. Understanding and identifying ARs in the paleoclimate and historical record and their meteorological context could emerge as a key to understanding future changes in ARs.

In both weather and climate science, the how, why, and where of AR landfall ultimately leads to impacts for local communities. Improving our communication geared toward, for example, the general public or water resource managers is critically important. Impacts due to extreme precipitation and flooding, wind damage, and/or prolonged exposure to AR conditions can have economic consequences. The group discussed ways to better communicate AR metrics making them understandable outside of the AR research community. Taking a more interdisciplinary approach and pairing with different scientific communities, such as hydrologists, was also seen as a needed activity.

MORE INFORMATION: WEBSITE AND CONTACTS. More information can be found in Shields et al. (2018) and on the ARTMIP website (www.cgd.ucar.edu/projects/artmip/).

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