Final Report

1. General Information

Project Title: **Understanding Changes in the Regional Variability of U.S. Drought**
PIs: Scott J. Weaver & Monika Barcikowska
Institutions: Environmental Defense Fund, Inc. (EDF)
Grant#: NA16OAR4310200
Date: 9/28/18

2. Summary

Recurrent regional drought over the U.S. has massive socioeconomic impacts prompting the need to understand recently observed changes in the variability of warm season regional precipitation and its primary focusing mechanism, the North American low level jet (NALLJ). To improve our understanding of the variations in regional precipitation and the associated physical mechanisms, we analyzed two sets of data. Reforecast simulations from the NOAA Climate Forecast System (CFS) helped us understand shifts in the statistical properties of recent global precipitation extremes. We also analyzed superensemble climate model experiments from a new initiative designed to better understand changes in extreme events in a 1.5°C and 2°C warmer world. This analysis allowed us to (1) provide insight into the changes in the Great Plains low level jet (GPLLJ) variability and related summertime drought and pluvial; and (2) understand changes in global extreme events under various global temperature scenarios.

3. Cumulative net outcomes and impacts of the project

Our research revealed insight into shifts in present-day global precipitation patterns compared to a few decades ago, as well as future projected changes in atmospheric circulation patterns over North America that can have large consequences to precipitation. Collaboration with European scientists helped in the development of a useful storm tracking algorithm that could eventually be applied to analyzing current and future drought characteristics over North America as a function of potential storm track changes. This research also revealed significant changes in severe European winter storms, including increased precipitation and higher wind speeds as the world warms from 1.5°C to 2°C.

The PIs have presented results of this work in numerous conferences, workshops, and stakeholder/committee meetings. The research has resulted in two published paper and one book chapter that are referenced below. The results have also been colloquially used in various interactions with NGO's, media, and general public education about the relative roles of internal variability and external climate forcing in the context of climate attribution.

4. Main goals of the project, as outlined in the funded proposal

(1) Advance the understanding of the physical mechanisms linking changes in NALLJ fluctuations and regional precipitation variability,

(2) Determine the ability of the current generation of global climate models to simulate and predict NALLJ variability and its related precipitation impacts,

(3) Examine the roles of internal climate variability and external climate forcing to recent changes in regional precipitation and NALLJ variability.

5. Results and Accomplishments

To achieve the main goals of the project, the PI's have engaged on the following areas of research and development:

(1) Analysis targeting a seasonal comparison of shifts in global and regional precipitation distributions in the CFSv2.

(2) Analysis of new superensemble of multi-institutional AMIP runs to provide improved insight into the changes in Great Plains low-level jet variability and related summertime drought and pluvial.

(3) Understand the statistical difference in global extreme events under various global temperature scenarios.

Here, we briefly describe results from these three tasks.

3.1 Analysis targeting a seasonal comparison of shifts in global and regional precipitation distributions in the CFSv2

Building off of the methodology in Weaver et al. 2014, which used over one thousand reforecast simulations from the NOAA Climate Forecast System (CFS) to understand statistical properties of the recent (1983-2012) shifts in the probability density function (PDF) of global and regional temperatures, the PI's have extended the analysis to investigate the nature of changes in precipitation extremes. The potential link is that regardless of the cause, if the atmosphere warms it will become more moist which can potentially lead to larger extremes in precipitation on account of there being more water vapor available for processing. However, the expectation is that unlike for temperature, changes in precipitation extremes may be smaller and/or harder to detect because of the strong influence of atmospheric circulation when compared with the aforementioned thermodynamic influence – especially when both external and internal influences are at play.

Unlike global temperature, whose PDF didn't change shape over the 30 year period of study but exhibited positive shifts in the global mean (Weaver et al. 2014), the winter global precipitation PDF (Figure 1) does shift toward the positive side, but also exhibits a wider and flatter distribution. This is indicative of changes in variability in addition to that of the mean. Conversely, the summertime PDF shift is indicative of only a mean increase in the globally averaged precipitation.

Interesting differences also arise when analyzing the globally averaged land surface-only precipitation (Figure 2). The positive winter land surface precipitation PDF shift appears to retain a similar magnitude and shape, but in summertime, there is an indication of a drying trend over the global land surface – completely at odds with the global (i.e., ocean + land) tendency for increased precipitation. So the trend in the land surface-only precipitation is opposing that which is found in the global mean. The extent to which these mean and variability changes in precipitation are due to natural internal variations is an important question as such influences cannot be ruled out easily.

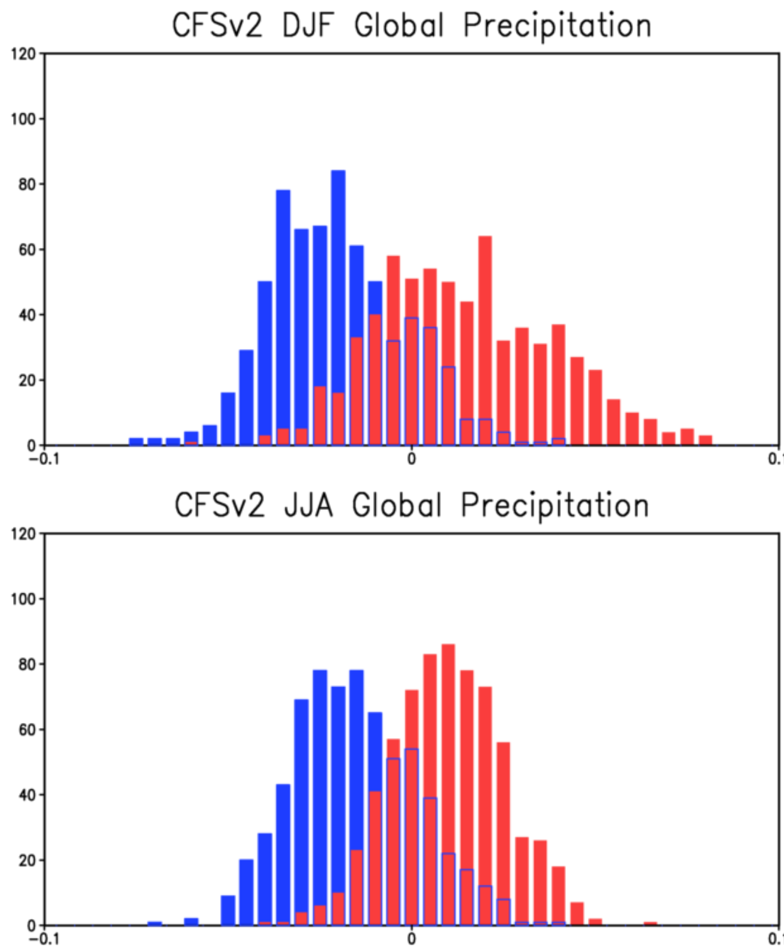

Figure 1. Global precipitation anomaly histograms as a function of the early (1983–1986 blue) and late (2009–2012 red) periods in the CFSv2 for (top) DJF and (bottom) JJA. Each period has 672 seasonal realizations. Precipitation units are in mm day^{-1}.

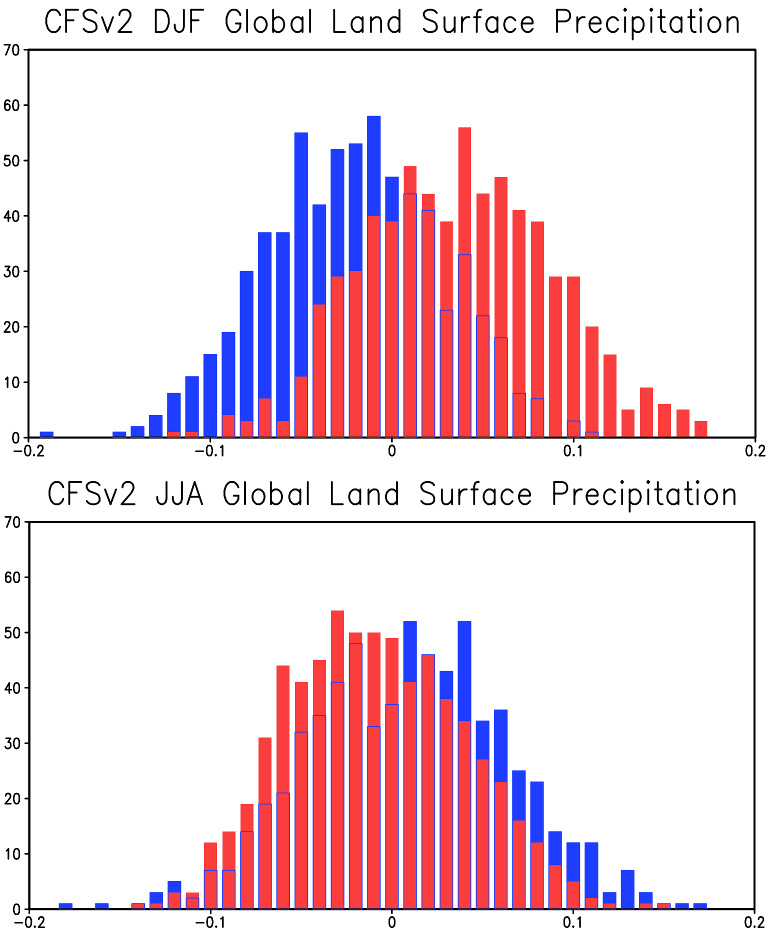

Figure 2. Global land surface precipitation anomaly histograms as a function of the early (1983–1986 blue) and late (2009–2012 red) periods in the CFSv2 for (top) DJF and (bottom) JJA. Each period has 672 seasonal realizations. Precipitation units are in mm day^{-1}.

3.2 Analysis of new superensemble of multi-institutional AMIP runs to provide improved insight into the changes in Great Plains low-level jet variability and related summertime drought and pluvial

A new set of unique multi-institutional superensemble AMIP simulations have been conducted to better understand extreme events, including drought, and their causes on daily to interannual timescales. The Half a degree of Additional Warming, Prognosis and Projected Impacts (HAPPI) effort provides a very high number (100 members per model) of multi-model ensembles that can be used to characterize the statistical properties of important weather and climate variables (precipitation, temperature, winds, etc.) in the current climate (Mitchell et al. 2017).

We conducted preliminary analyses to understand their utility in applications to drought-related physical mechanisms over both the U.S. Great Plains in summer, and the western U.S. states in winter. Figures 3 and 4 show the seasonal cycle of the 850 hPa mean winds (i.e., marker for GPLLJ) in the NCEP-DOE Reanalysis 2 (Figure 3) and the MIROC5 100 member ensemble average AMIP simulation for 2006-2015. Despite some minor biases, the MIROC5 reproduces well the mean GPLLJ. Benchmarking other aspects of the various models is currently underway with an eye toward more robust analyses for understanding U.S. drought.

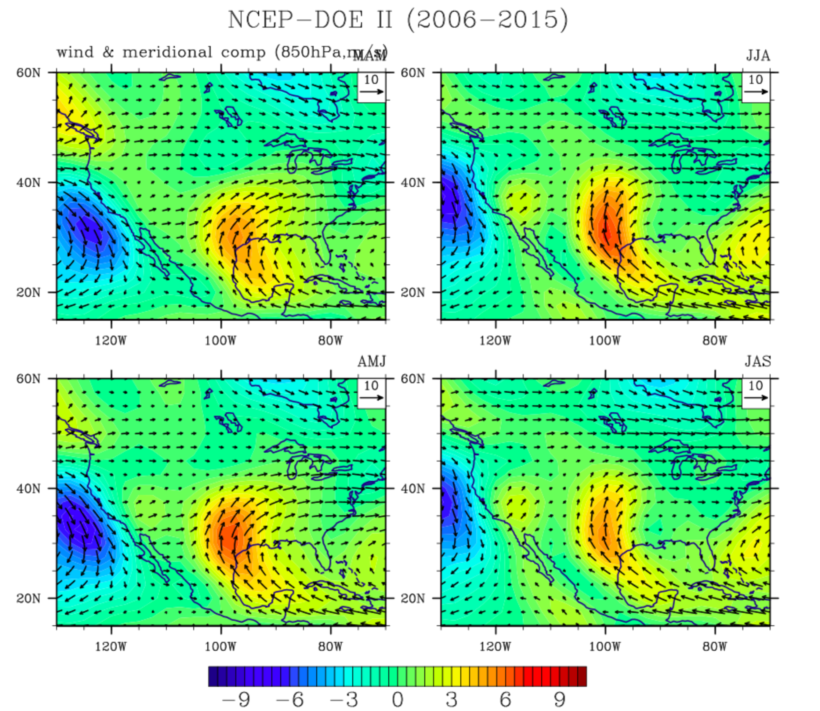

Figure 3. Seasonal evolution of the GPLLJ as diagnosed from the NCEP-DOE R2 850 hPa winds for 2006-2015. Meridional wind is shaded and the arrows indicate total vector winds. Units are in m s^{-1}.

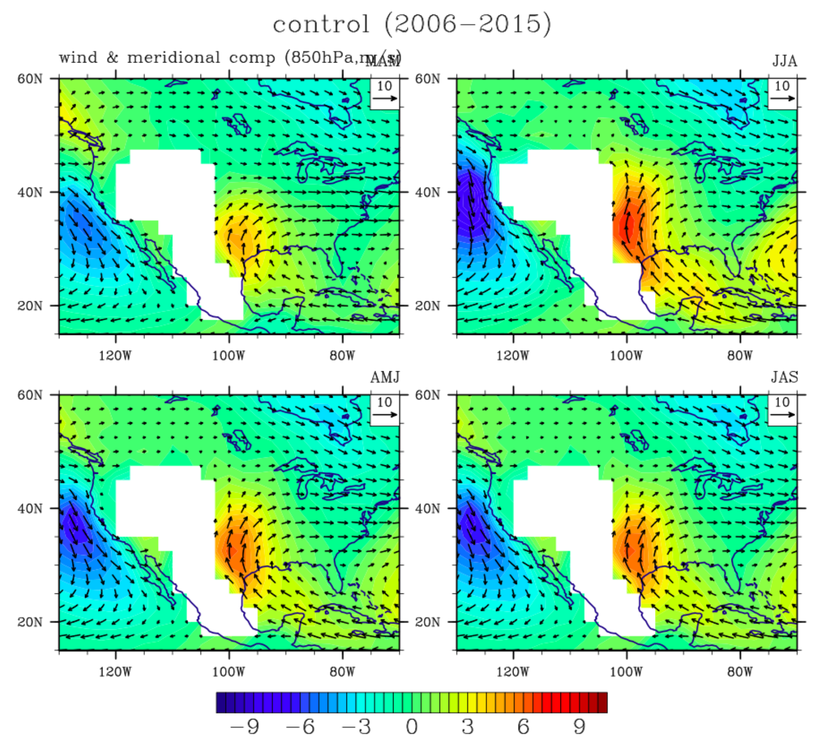

Figure 4. Seasonal evolution of the GPLLJ as diagnosed from the AMIP MIROC5 simulated 850 hPa winds for 2006-2015. Meridional wind is shaded and the arrows indicate total vector winds. Units are in m s^{-1}.

However, while the superensemble AMIP experiments add to the understanding of physical mechanisms of regional precipitation variability over the U.S. and the world, most simulations could not be used for this analysis as they were deficient in capturing properly the summer climate. On the other hand, the CAM5 simulations were sufficient, but were not completed until January 2018, delaying this work. However, we have been able to analyze the CAM5 simulations, with the following results.

In the first part of the analysis we investigated the performance of the CAM5 model in capturing the mean large scale circulation features over North America at different horizontal resolutions. The analysis points to the benefits of using higher resolution simulations. For example, spatial patterns of the mean summer SLP are more accurately represented at 1° and 0.25° resolution. This includes a reduction of a pronounced positive SLP bias over the eastern coasts of North America. This improvement is manifested in the representation of the zonal gradient of the SLP over the continent, and associated with the location of the Great Plains Low Level Jet (GPLLJ). Additionally, the intensity of the SLP gradient is refined at the 0.25° resolution, which increases intensity of the jet. These conclusions were corroborated by an additional comparison with other low-resolution models (e.g. CAN4, MIROC5), provided by the HAPPI experiment. These results increase our confidence in using only the subset of HAPPI simulations, provided by high-resolution CAM5 model, as it provides the most plausible representation of the GPLLJ and this will presumably improve the representation of associated precipitation extremes and their changes in future scenarios (Figure 1).

The analysis of the HAPPI experiment, which includes stabilization scenarios at the 1.5°C and 2°C levels doesn't indicate any fundamental changes in the mean atmospheric circulation over North America, neither in the mean summer pattern and intensity of the GPLLJ, compared with the present-day climate runs. However, the analysis of the variability of the GPLLJ in April-June suggests a possibility of modest changes associated with the additional half a degree warming. For example, analysis of the first mode of variability suggests an intensification and south-eastward shift of the jet. A second component of GPLLJ variability (April-June) indicates a modest intensification confined towards the north-east coasts of United States. Nevertheless, the derived changes are small and in many regions not statistically significant. It is likely that the anthropogenic signal associated with the additional half a degree warming may be much smaller than the contribution of internal climate variations. Thus the very small subset of the HAPPI ensemble, which constitutes CAM5 simulations, limits the feasibility of ruling out the contribution of noise to the derived changes.

However it is important to acknowledge that seemingly subtle shifts in the loading pattern of these modes can have large consequences to precipitation (and even tornadoes), including the increased prevalence of drought and flood years. Hence it is worth continuing this analysis and verify the derived results, using either a bigger ensemble of 1.5 and 2C runs, or using stabilization scenarios (e.g. 3 and 4°) with more radical forcing. These findings from the NOAA/MAPP sponsored research have laid the foundation for our new future efforts. As such, we will continue the analysis using the new simulations, and this will be expanded also on the analysis of not only seasonal changes but also associated daily and 3-hrly precipitation extremes.

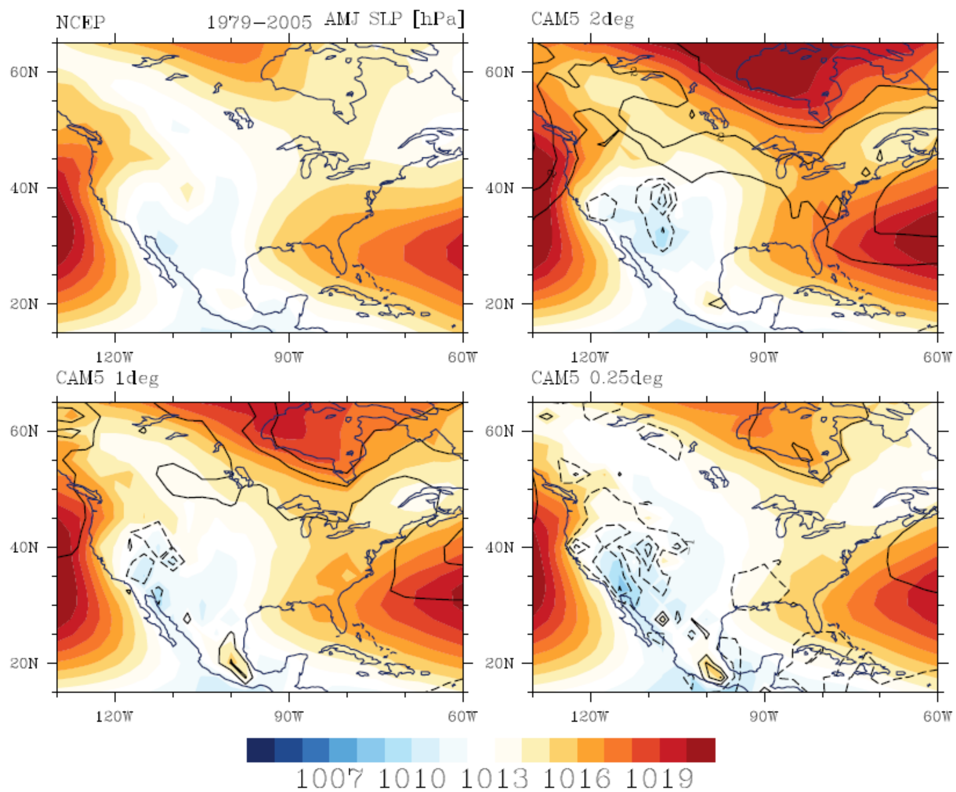

Figure 5. Mean circulation (SLP in 1979-2005) for observations (NCEP) and CAM5 at different (2°, 1° and 0.25°) resolutions. The low resolution deteriorates the large scale circulation (and therefore pattern and intensity of the jet). High resolution reduces the bias significantly (but also produces other local features and intensity, which low res NCEP(obs) cannot resolve). This should presumably produce more plausible representation of future changes of the mean summer circulation, GPLJJ and associated precipitation extremes and drought.

3.3 Understand the statistical difference in global extreme events under various global temperature scenarios.

As the world considers the implications of temperature targets at either 1.5°C or 2°C, it is important to know whether risks from extreme weather will change in a significant way with the additional half a degree of warming.

As a first step to understanding U.S. and global changes in extreme events, we collaborated with European scientists to conduct a regional analysis of changes in extratropical storms over Europe. This was because they were working on a useful storm tracking algorithm that could eventually be applied to analyzing current and future drought characteristics over North America as a function of potential storm track changes.

Indeed, these storms also affect the eastern coast of the U.S. Extratropical storms which origin over the North Pacific impact the northwest U.S.; however, the CMIP5-based future projections show rather contrasting changes, when compared with storms over the North Atlantic, suggesting a dominace of different factors. Hence we decided to conduct the analysis separately for these two regions.

By analyzing data from the HAPPI initiative, we found statistically significant changes in severe European winter storms, including increased precipitation and higher wind speeds as the world warms from 1.5°C to 2°C (Figures 6, 7, and 8). These changes are due to the intensification and northeastward shift of both atmospheric circulation and the mid-latitude westerly winds over the North Atlantic, which are responsible for transporting storms towards Europe. As the mid-latitude westerly winds shift to the northeast, they transport storms further towards the northeastern parts of Europe. This manifests in the increase of stormy weather and extreme wind and precipitation, concentrated between the British Isles and Iceland, and over the Norwegian Sea, and Scandinavia. This work was recently published in the journal Earth System Dynamics.

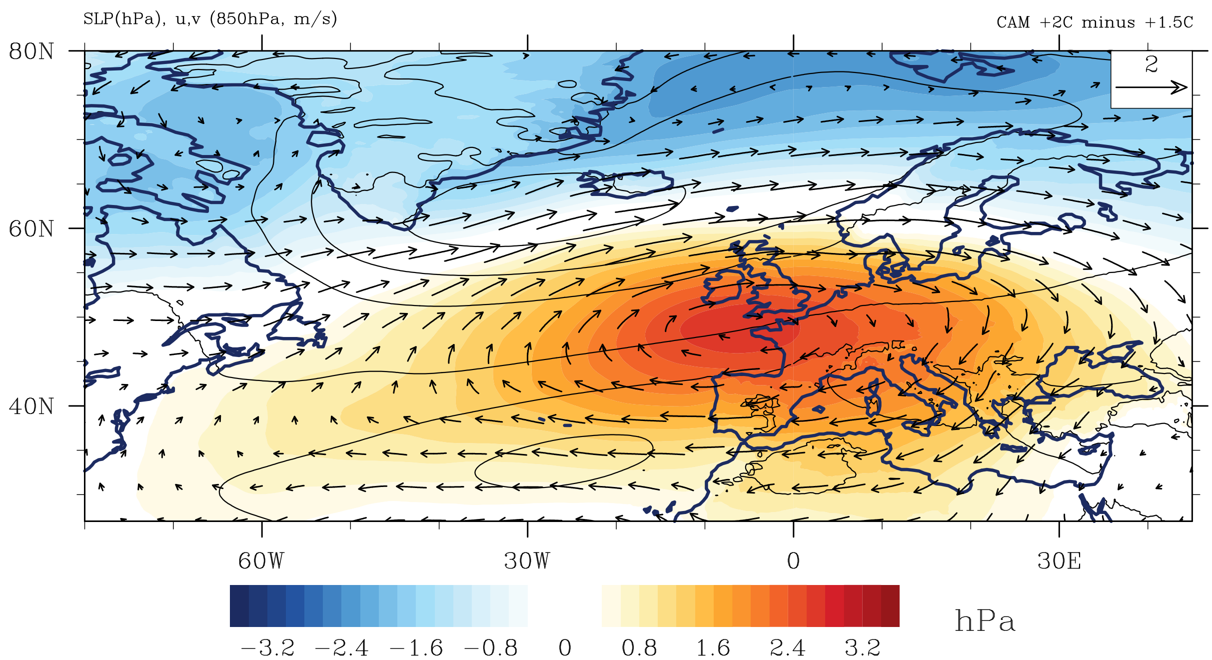

Figure 6. Intensification of westerly winds over Northern Europe. Difference between +2°C and 1.5°C ensembles in winter a) sea level pressure [shaded, hPa] and wind vector at 850hPa [m s–1]. Contours show sea level pressure in present climate, with a local maximum in the vicinity of Azores and minimum in the vicinity of Iceland.

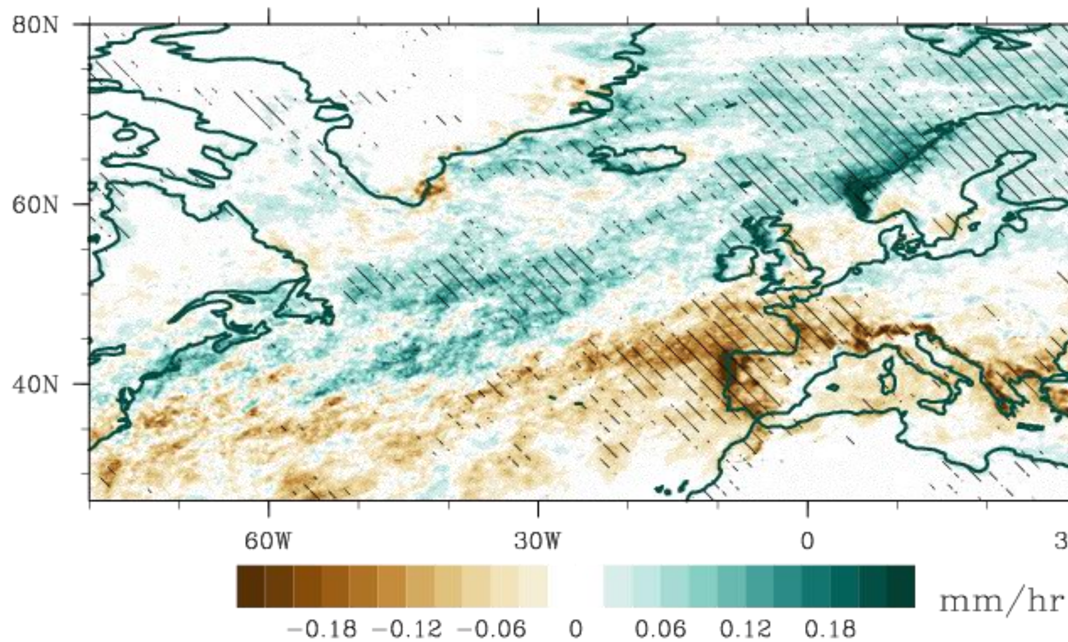

Figure 7. Intensification of extreme precipitation over Northern Europe. Difference between +2°C and +1.5°C ensemble experiments for winter GEV, 10-yr 3hr precipitation.

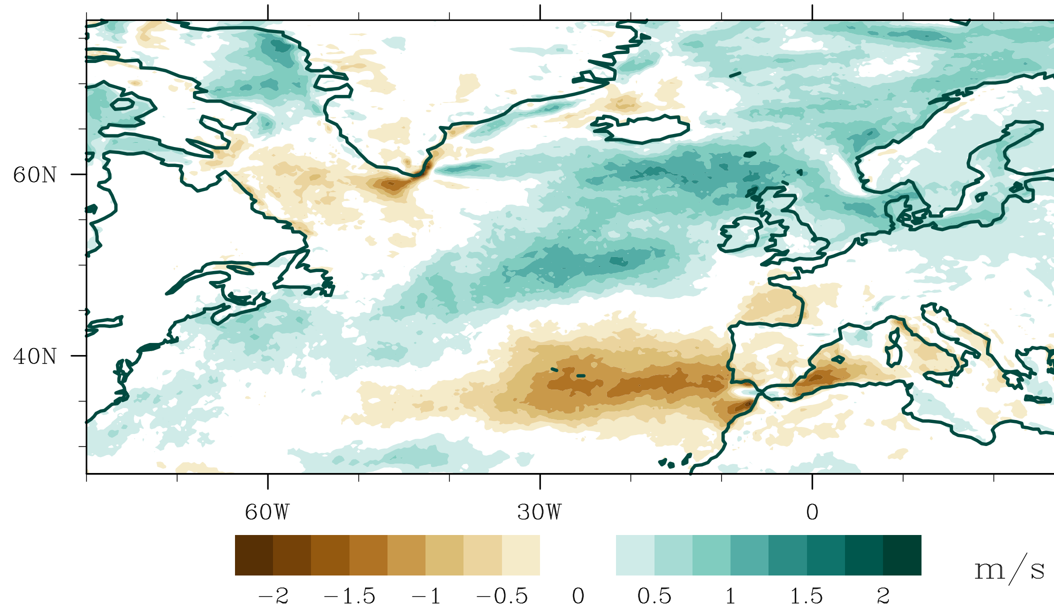

Figure 8. Intensification of extreme winds over Northern Europe. Difference between +2°C and +1.5°C ensemble experiments for winter GEV, 10-yr 3hr wind.

6. Highlights of Accomplishments

The highlights of our research are listed below.

1) We have presented research results at 5 large scientific conferences: two annual American Geophysical Union (AGU) meetings in December 2016 and 2017, the American Meteorological Society (AMS) meeting in January 2018, and two European Geophysical

Union (EGU) meetings in April 2017 and 2018. We also participated in a press conference at EGU 2018.

2) We have expanded the analysis framework of Weaver at al. 2014 to include precipitation.

3) Analysis of new superensemble of multi-institutional AMIP runs provided insight into projected changes in Great Plains low-level jet variability and related summertime drought and pluvial for different future warming levels.

4) We have begun to look into changes in global extremes in a warming world, with a first step of collaborating with European scientists to employ a storm tracking algorithm that could be applied to analyzing drought characteristics over North America.

5) Through analyzing changes in winter storms in Europe, we found important implications for international temperature targets in that they justify pushing for a more stringent target. We recently published a paper on this in Earth System Dynamics, and the results were discussed in a press conference at EGU 2018.

6) The European study forms a sold methodology and foundation for ascertaining the changes in storminess over the Pacific Ocean, which will be used for other analyses on North American climate impacts such as the California drought.

7. Publications

Dr. Weaver co-authored a chapter on extreme temperatures for the book, "Climate Extremes: Patterns and Mechanisms," which published in summer of 2017. Dr. Barcikowska, along with Dr. Weaver, published a paper entitled "Euro-Atlantic winter storminess and precipitation extremes under 1.5°C versus 2°C warming scenarios" in the refereed journal Earth System Dynamics.

Weaver, S. J., A. Kumar, and M. Chen, 2016: Recent increases in extreme temperature occurrence over land. AGU book Climate Extremes: Patterns and Mechanisms.

Barcikowska, M. J., S. J. Weaver, F. Feser, S. Russo, F. Schenk, D. A. Stone, and M. Zahn: Euro-Atlantic winter storminess and precipitation extremes under 1.5 °C versus 2 °C warming scenarios. Earth Syst. Dynam., 9, 679-699, 2018.

8. PI Contact Information

Dr. Scott J. Weaver
Environmental Defense Fund
1875 Connecticut Avenue NW
Washington, DC 20009
sweaver@edf.org
(202) 572-3328

PI Weaver is no longer with EDF. Amanda Lichtenberg is now the primary contact.

Monika Barcikowska

Enironmental Defense Fund
257 Park Avenue South
New York, NY 10010
mbarcikowska@edf.org
(212) 616-1413
Aministrative contant:

Amanda Lichtenberg,
Senior Government Grants Officer
alichtenberg@edf.org
(212) 616-1213

References

Mitchell, et al., 2017: Half a degree of additional warming, prognosis and projected impacts (HAPPI): background and experimental design. Geosci. Model Dev., **10**, 571–583.

Weaver, S. J., A. Kumar, and M. Chen, 2014: Recent increases in extreme temperature Occurrence over land. Geophys. Res. Lett., 41, 4669–4675, doi:10.1002/2014GL060300.