EXPLAINING EXTREME EVENTS OF 2016

From A Climate Perspective

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EXPLAINING EXTREME EVENTS OF 2016 FROM A CLIMATE PERSPECTIVE

Editors

Stephanie C. Herring, Nikolaos Christidis, Andrew Hoell, James P. Kossin, Carl J. Schreck III, and Peter A. Stott

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©The Ocean Agency / XL Catlin Seaview Survey / Chrisophe Bailhache—A panoramic image of coral bleaching at Lizard Island on the Great Barrier Reef, captured by The Ocean Agency / XL Catlin Seaview Survey / Christophe Bailhache in March 2016.

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ABSTRACT—Stephanie C. Herring, Nikolaos Christidi, Andrew Hoell, James P. Kossin, Carl J. Schreck III, and Peter A. Stott

This sixth edition of explaining extreme events of the previous year (2016) from a climate perspective is the first of these reports to find that some extreme events were not possible in a preindustrial climate. The events were the 2016 record global heat, the heat across Asia, as well as a marine heat wave off the coast of Alaska. While these results are novel, they were not unexpected. Climate attribution scientists have been predicting that eventually the influence of human-caused climate change would become sufficiently strong as to push events beyond the bounds of natural variability alone. It was also predicted that we would first observe this phenomenon for heat events where the climate change influence is most pronounced. Additional retrospective analysis will reveal if, in fact, these are the first events of their kind or were simply some of the first to be discovered.

Last year, the editors emphasized the need for additional papers in the area of "impacts attribution" that investigate whether climate change's influence on the extreme event can subsequently be directly tied to a change in risk of the socio-economic or environmental impacts. Several papers in this year's report address this challenge, including Great Barrier Reef bleaching, living marine resources in the Pacific, and ecosystem productivity on the Iberian Peninsula. This is an increase over the number of impact attribution papers than in the past, and are hopefully a sign that research in this area will continue to expand in the future.

Other extreme weather event types in this year's edition include ocean heat waves, forest fires, snow storms, and frost, as well as heavy precipitation, drought, and extreme heat and cold events over land. There were a number of marine heat waves examined in this year's report, and all but one found a role for climate change in increasing the severity of the events. While humancaused climate change caused China's cold winter to be less likely, it did not influence U.S. storm Jonas which hit the mid-Atlantic in winter 2016.

As in past years, the papers submitted to this report are selected prior to knowing the final results of whether human-caused climate change influenced the event. The editors have and will continue to support the publication of papers that find no role for human-caused climate change because of their scientific value in both assessing attribution methodologies and in enhancing our understanding of how climate change is, and is not, impacting extremes. In this report, twenty-one of the twenty-seven papers in this edition identified climate change as a significant driver of an event, while six did not. Of the 131 papers now examined in this report over the last six years, approximately 65% have identified a role for climate change, while about 35% have not found an appreciable effect.

Looking ahead, we hope to continue to see improvements in how we assess the influence of human-induced climate change on extremes and the continued inclusion of stakeholder needs to inform the growth of the field and how the results can be applied in decision making. While it represents a considerable challenge to provide robust results that are clearly communicated for stakeholders to use as part of their decision-making processes, these annual reports are increasingly showing their potential to help meet such growing needs.

10. EXTREME CALIFORNIA RAINS DURING WINTER 2015/16: A CHANGE IN EL NIÑO TELECONNECTION?

Xiao-Wei Quan, Martin Hoerling, Lesley Smith, Judith Perlwitz, Tao Zhang, Andrew Hoell, Klaus Wolter, and Jon Eischeid

Failure of heavy rain in Southern California during the 2016 strong El Niño compared to flooding rains during the 1983 strong El Niño does not constitute a climate change effect.

Introduction. This is a story of two extreme events one that was expected *but failed to occur* and the other that actually *did occur* but was not anticipated. The one that failed was extreme wetness over Southern California (SCAL) during winter 2015/16, which was predicted by seasonal forecasts. The extreme event that did occur was dryness whose considerable magnitude exacerbated one of the worst droughts on record over SCAL.

Ranked among the three strongest historical El Niño events, the 2015/16 event fueled apprehensions for flooding rains over California. Analogs were drawn from abundant winter rain during the strong El Niño events of 1982/83 and 1997/98. NOAA's winter outlook indicated a greater than 60% probability that rain totals over SCAL would be in the upper tercile of the historical distribution (www.cpc.ncep.noaa.gov /products/archives/long_lead/llarc.ind.php).

December 2015–February 2016 precipitation over SCAL was 112 mm, which ranked in the lower tercile of the historical distribution of winter precipitation since 1895 (Fig. 10.1). While not unusual from a historical perspective (Fig. ES10.1a), this dryness was an extreme event when taking account of precipitation likelihoods during strong El Niño conditions (e.g., Hoell et al. 2016). We pose the attribution question whether a transformation of El Niño teleconnections has occurred due to climate change, the effect of which may have made such an extreme dry outcome during 2015/16 more likely than during 1982/83 and 1997/98. Such a transformation could arise from changes in atmospheric circulation that mediates

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A supplement to this article is available online (10.1175 /BAMS-D-17-0118.2) trajectories of tropically forced waves (e.g., Diaz et al. 2001; Meehl and Teng 2007), or from shifts in the intensity and longitude of equatorial Pacific rainfall during El Niño events (e.g., Kug et al. 2009; Wang et al. 2015; Zhou et al. 2014). In this study, we explore whether SCAL rainfall sensitivity to a strong El Niño occurring in 2016 has changed compared to a comparably strong El Niño in 1983.

Datasets and methods. Observed monthly precipitation for 1901–2016 is from the GPCC gridded 1° resolution analysis (Schneider et al. 2013). Monthly atmospheric circulation for 1948–2016 is from the NCEP/ NCAR Reanalysis (Kalnay et al. 1996). Monthly sea surface temperature (SST) and sea ice concentration (SIC) data are based on Hurrell et al. (2008).

Two ensemble suites of climate simulations are analyzed. The first is a 40-member historical transient simulation of the NCAR Community Earth System Model version 1 (CESM1; Kay et al. 2015). These "All-Forcings" simulations span 1920-2005, and use RCP8.5 for 2006-2100. The second is a 20-member ensemble of atmospheric model simulations (AMIP) generated from the atmospheric component of CESM1, named Community Atmospheric Model version 5 (CAM5; Neale et al. 2012). In these AMIPstyle experiments spanning 1871-2016, observed time evolving lower boundary conditions (SSTs and SIC) are prescribed globally, while time varying external radiative forcings identical to those used in CESM1 are also specified. The atmospheric model uses horizontal resolution of $0.94^{\circ} \times 1.25^{\circ}$ and 30 vertical levels for all simulations.

While the historical AMIP ensemble size is 20-members, the ensemble size was increased to 50 members for the strong El Niño cases of 1982/83 and 2015/16. A parallel set of 50-member AMIP-style runs were conducted for these two strong El Niño events in which SST forcing over an El Niño-core region (15°N– 15°S, 175°E–South America) only was specified, while



FIG. 10.1. Rows: Dec-Feb (DJF) total precipitation anomalies (mm) in observation (top), CAM5 AMIP (middle), and CESMI (bottom) simulations. Shadings indicate difference between DJF of 2015/16 (left column), 1982/83 (middle column) and 1981–2010 climatological mean. Differences between the two strong El Niño winters are shown in right-side panels. Percentage values in each panel indicate departure of area mean of DJF total relative to observed and simulated 1981–2010 climatology of area mean, respectively. Red region denotes SCAL domain used for area averaging.

climatological SSTs were specified over the remaining world oceans. These experiments address how differences in the "flavor of El Niño" alone affected SCAL precipitation in 2016 versus 1983. Further, we address how SSTs over the "rest-of-the-world" affected SCAL precipitation by first calculating differences between the globally forced runs and the El Niño core-region runs, and then comparing these residual estimates for 2016 and 1983.

To test the effect of climate change on the response to strong El Niño, we construct composites of strong El Niño events occurring around 1983 and 2016 by subsampling the 40-member CESM1 ensemble. Hurrell et al. (2013) demonstrate that the CESM1 realistically simulates the magnitude of the observed rise in global surface temperature during recent decades. Using a 15-year period centered in 1983 or 2016, we select all December–February warm events that exceed 1.5 times the standard deviation of the model's Niño3.4 SST variability (1981–2010 reference). This yields strong El Niño composites having about 30–40 members for each period. Our results are robust to an alternate method in which El Niño occurrences are calculated relative to each 15-year climatology rather than from the single 1981-2010 climatology.

Results. a. Observations. Across all regions of California, less precipitation fell during winter (December-February) 2016 compared to 1983 (Fig. 10.1, top row). For SCAL (Fig. 10.1, red outline), 2016 precipitation was 35% below the 1981-2010 mean, compared to 48% above the mean in 1983. Owing to the positive skew of SCAL climatological winter rainfall, the 2016 total was only 22% below the climatological median. It was thus not particularly extreme when assessed in an unconditional framework. However, winter rainfall statistics derived from the CAM5 AMIP simulations indicate that the observed dryness was an extreme event when conditioned upon the particular global boundary forcing of strong El Niño (Fig. ES10.1b).

The immediate cause for the drastic distinction in SCAL rainfall between 2016 and 1983 atmospheric circulations. Both

winters exhibit features of the well-known canonical El Niño teleconnection pattern (e.g., Horel and Wallace 1981). A key distinction, however, is that the North Pacific 200-hPa negative height anomaly is weaker and shifted farther north into the Gulf of Alaska during 2016 (Fig. 10.2, top row). The circulation difference between those two winters (Fig. 10.2, top right) consists of an anticyclonic anomaly across the central North Pacific which reduced the frequency of storms over SCAL during 2016.

b. Atmospheric model simulations. The ensemble mean of CAM5 experiments indicates a SST-forced wet signal over SCAL in 2016 (Fig. 10.1, middle row), consistent with aforementioned forecast guidance. The dryness in 2016 was therefore unlikely due to boundary forcing.



FIG. 10.2. As in Fig. 10.1, but for the 200-hPa geopotential height anomalies (gpm). Contour interval is 15 m for left and middle columns, and 10 m for right column. High and low anomaly centers are denoted by H and L, reis the difference in North Pacific spectively. Colored shadings indicate SST anomalies (°C).

The magnitude of the CAM5 wet signal was diminished in 2016 when compared to 1983, however. Note especially that the simulated difference in ensemble mean California precipitation between these two winters is remarkably similar to the difference in observations. Also, comparison of the model probability density function (PDF) of SCAL precipitation in 2016 versus 1983 (Fig. ES10.1b) indicates increased likelihood for dryness in 2016; the two distributions are significantly different at the 5% level according to a Kolmogorov-Smirnov test. Nonetheless, the magnitude of observed dryness was a low probability within both ensembles.

The dynamical basis for this weaker SCAL wet signal in CAM5 is a weakened and northward displaced North Pacific low pressure in the model's circulation pattern during 2016 (Fig. 10.2, middle row). The model, whose El Niño driven upper tropospheric wave train agrees well with observations (Fig. 10.2, top and middle rows), indicates that upper tropospheric heights are higher across the entire Pacific basin in 2016 compared to 1983. Importantly for SCAL rainfall, differences between the height patterns of the two events consist of an anomalous anticyclonic circulation across the mid-Pacific basin which steers storms northward in 2016 relative to 1983.

Results from the El Niño core-region experiments confirm that distinct El Niño flavors (e.g., stronger far east Pacific SST warmth in 1983 but stronger central Pacific SST warmth in 2016) did not cause the Pacific– North American differences in the fully forced CAM5 simulations. Rather, the principal climate sensitivity distinguishing these two strong El Niño winters arises from the rest-of-the-world boundary conditions. In 2016 relative to 1983, these drive widespread increases in Pacific basin heights whose main feature is an anticyclonic circulation across the mid-Pacific basin (Fig. ES10.2, bottom right).

c. Coupled model simulations. To understand the AMIP results in the context of climate change, we compare CESM1 strong El Niño impacts on western U.S. precipitation for 2016 and 1983 (Fig. 10.1, bottom row). No statistically significant difference in their El Niño-related composite rainfall occurs over SCAL, even though El Niño events circa 2016 are immersed in a warmer ocean. Consistent with a warmer ocean, CESM1 indicates that climate change increases upper level heights across the entire Pacific basin (Fig. 10.2, bottom row). Importantly, however, these height increases are relatively uniform across the Pacific; there is thus no meaningful shift in the model's El Niño-related teleconnection and hence little change in the SCAL winter precipitation. The PDF of CESM1 SCAL winter precipitation for El Niño events circa 2016 versus 1983 are statistically indistinguishable according to a Kolmogorov-Smirnov test (Fig. ES10.1c).

Conclusion. Based on transient coupled climate simulations, no transformation of El Niño teleconnections has occurred since 1983 that would materially alter the remote sensitivity of Southern California precipitation to strong El Niño forcing. Both composites of strong El Niño in CESM1 experiments circa 1983 versus 2016 show wet signals over SCAL, with no significant difference in the probability distributions for either extreme wet or extreme dry winters. We conclude that the failure of heavy rains in SCAL during the strong El Niño of 2016, compared to the flooding rains of 1983, does not constitute a climate change effect.

Our analysis of atmospheric simulations does indicate, however, that the actual global boundary forcing in 2016 (especially the rest-of-the-world boundary forcing outside of the El Niño core-region) was significantly less favorable for wet SCAL in 2016 than in 1983. Additional experiments are required to better understand the nature of these rest-of-world boundary conditions that operated in 2016. More research is especially needed to reconcile those conditions with plausible modes of internal natural variability (Berg and Hall 2015; Kumar and Chen 2016).

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Table I.I. SUMMARY of RESULTS

ANTHROPOGENIC INFLUENCE ON EVENT							
	INCREASE	DECREASE	NOT FOUND OR UNCERTAIN				
Heat	Ch. 3: Global Ch. 7: Arctic Ch. 15: France Ch. 19: Asia						
Cold		Ch. 23: China Ch. 24: China					
Heat & Dryness	Ch. 25: Thailand						
Marine Heat	Ch. 4: Central Equatorial Pacific Ch. 5: Central Equatorial Pacific Ch. 6: Pacific Northwest Ch. 8: North Pacific Ocean/Alaska Ch. 9: North Pacific Ocean/Alaska Ch. 9: Australia		Ch. 4: Eastern Equatorial Pacific				
Heavy Precipitation	Ch. 20: South China Ch. 21: China (Wuhan) Ch. 22: China (Yangtze River)		Ch. 10: California (failed rains) Ch. 26: Australia Ch. 27: Australia				
Frost	Ch. 29: Australia						
Winter Storm			Ch. II: Mid-Atlantic U.S. Storm "Jonas"				
Drought	Ch. 17: Southern Africa Ch. 18: Southern Africa		Ch. 13: Brazil				
Atmospheric Circulation			Ch. 15: Europe				
Stagnant Air			Ch. 14: Western Europe				
Wildfires	Ch. 12: Canada & Australia (Vapor Pressure Deficits)						
Coral Bleaching	Ch. 5: Central Equatorial Pacific Ch. 28: Great Barrier Reef						
Ecosystem Function		Ch. 5: Central Equatorial Pacific (Chl- a and primary production, sea bird abun- dance, reef fish abundance) Ch. 18: Southern Africa (Crop Yields)					
El Niño	Ch. 18: Southern Africa		Ch. 4: Equatorial Pacific (Amplitude)				
TOTAL	18	3	9				

	METHOD USED			
		Events		
Heat	 Ch. 3: CMIP5 multimodel coupled model assessment with piCont, historicalNat, and historical forcings Ch. 7: CMIP5 multimodel coupled model assessment with piCont, historicalNat, and historical forcings Ch. 15: Flow analogues conditional on circulation types Ch. 19: MIROC-AGCM atmosphere only model conditioned on SST patterns 			
Cold	Ch. 23: HadGEM3-A (GA6) atmosphere only model conditioned on SST and SIC for 2016 and data fitted to GEV distribution Ch. 24: CMIP5 multimodel coupled model assessment			
Heat & Dryness	Ch. 25: HadGEM3-A N216 Atmosphere only model conditioned on SST patterns			
Marine Heat	 Ch. 4: SST observations; SGS and GEV distributions; modeling with LIM and CGCMs (NCAR CESM-LE and GFDL FLOR-FA) Ch. 5: Observational extrapolation (OISST, HadISST, ERSST v4) Ch. 6: Observational extrapolation; CMIP5 multimodel coupled model assessment Ch. 8: Observational extrapolation; CMIP5 multimodel coupled model assessment Ch. 9: Observational extrapolation; CMIP5 multimodel coupled model assessment 			
Heavy Precipitation	 Ch. 10: CAM5 AMIP atmosphere only model conditioned on SST patterns and CESMI CMIP single coupled model assessment Ch. 20: Observational extrapolation; CMIP5 and CESM multimodel coupled model assessment; auto-regressive models Ch. 21: Observational extrapolation; HadGEM3-A atmosphere only model conditioned on SST patterns; CMIP5 multimodel coupled model assessment with ROF Ch. 22: Observational extrapolation, CMIP5 multimodel coupled model assessment Ch. 26: BoM seasonal forecast attribution system and seasonal forecasts Ch. 27: CMIP5 multimodel coupled model assessment 			
Frost	Ch. 29: weather@home multimodel atmosphere only models conditioned on SST patterns; BoM seasonal forecast attribution system			
Winter Storm	Ch. II: ECHAM5 atmosphere only model conditioned on SST patterns			
Drought	 Ch. 13: Observational extrapolation; weather@home multimodel atmosphere only models conditioned on SST patterns; HadGEM3-A and CMIP5 multimodel coupled model assessent; hydrological modeling Ch. 17: Observational extrapolation; CMIP5 multimodel coupled model assessment; VIC land surface hdyrological model, optimal fingerprint method Ch. 18: Observational extrapolation; weather@home multimodel atmosphere only models conditioned on SSTs. CMIP5 multimodel coupled assessment 			
Atmospheric Circulation	Ch. 15: Flow analogues distances analysis conditioned on circulation types			
Stagnant Air	Ch. 14: Observational extrapolation; Multimodel atmosphere only models conditioned on SST patterns including: HadGEM3-A model; EURO-CORDEX ensemble; EC-EARTH+RACMO ensemble			
Wildfires	Ch. 12: HadAM3 atmospere only model conditioned on SSTs and SIC for 2015/16			
Coral Bleaching	Ch. 5: Observations from NOAA Pacific Reef Assessment and Monitoring Program surveys Ch. 28: CMIP5 multimodel coupled model assessment; Observations of climatic and environmental conditions (NASA GES DISC, HadCRUT4, NOAA OISSTV2)			
Ecosystem Function	Ch. 5: Observations of reef fish from NOAA Pacific Reef Assessment and Monitoring Program surveys; visual observations of seabirds from USFWS surveys. Ch. 18: Empirical yield/rainfall model			
El Niño	Ch. 4: SST observations; SGS and GEV distributions; modeling with LIM and CGCMs (NCAR CESM-LE and GFDL FLOR-FA) Ch. 18: Observational extrapolation; <i>weather@home</i> multimodel atmosphere only models conditioned on SSTs, CMIP5 multimodel coupled model assessment			
		30		