EXPLAINING EXTREME EVENTS OF 2015

From A Climate Perspective

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EXPLAINING EXTREME EVENTS OF 2015 FROM A CLIMATE PERSPECTIVE

Editors

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

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COVER CREDIT:

©Photo by Joe Raedle/Getty Images—A vehicle drives through flooded streets caused by a combination of the lunar orbit which caused seasonal high tides and what many believe is the rising sea levels due to climate change on September 30, 2015, in Fort Lauderdale, Florida. South Florida is projected to continue to feel the effects of climate change, and many of the cities have begun programs such as installing pumps or building up sea walls to try and combat the rising oceans.

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This fifth edition of explaining extreme events of the previous year (2015) from a climate perspective continues to provide evidence that climate change is altering some extreme event risk. Without exception, all the heat-related events studied in this year's report were found to have been made more intense or likely due to human-induced climate change, and this was discernible even for those events strongly influenced by the 2015 El Niño. Furthermore, many papers in this year's report demonstrate that attribution science is capable of separating the effects of natural drivers including the strong 2015 El Niño from the influences of long-term human-induced climate change.

Other event types investigated include cold winters, tropical cyclone activity, extreme sunshine in the United Kingdom, tidal flooding, precipitation, drought, reduced snowpack in the U.S. mountain west, arctic sea ice extent, and wildfires in Alaska. Two studies investigated extreme cold waves and monthly-mean cold conditions over eastern North America during 2015, and find these not to have been symptomatic of human-induced climate change. Instead, they find the cold conditions were caused primarily by internally generated natural variability. One of these studies shows winters are becoming warmer, less variable, with no increase in daily temperature extremes over the eastern United States. Tropical cyclone activity was extreme in 2015 in the western North Pacific (WNP) as measured by accumulated cyclone energy (ACE). In this

report, a study finds that human-caused climate change largely increased the odds of this extreme cyclone activity season. The 2015 Alaska fire season burned the second largest number of acres since records began in 1940. Investigators find that human-induced climate change has increased the likelihood of a fire season of this severity.

Confidence in results and ability to quickly do an attribution analysis depend on the “three pillars” of event attribution: the quality of the observational record, the ability of models to simulate the event, and our understanding of the physical processes that drive the event and how they are being impacted by climate change. A result that does not find a role for climate change may be because one or more of these three elements is insufficient to draw a clear conclusion. As these pillars are strengthened for different event types, confidence in the presence and absence of a climate change influence will increase.

This year researchers also link how changes in extreme event risk impact human health and discomfort during heat waves, specifically by looking at the role of climate change on the wet bulb globe temperature during a deadly heat wave in Egypt. This report reflects a growing interest within the attribution community to connect attribution science to societal impacts to inform risk management through “impact attribution.” Many will watch with great interest as this area of research evolves in the coming years.

9. THE 2015 EXTREME DROUGHT IN WESTERN CANADA

KIT SZETO, XUEBIN ZHANG, ROBERT EDWARD WHITE, AND JULIAN BRIMELOW

Analysis results indicate that the 2015 extreme drought in western Canada was likely an outcome of anthropogenically influenced warm spring conditions and naturally forced dry weather from May to July.

Introduction. Although drought is common over western Canada (Bonsal et al. 2011), the drought that affected the area during the spring and summer of 2015 (Fig. 9.1a) was unusual in terms of its severity, extent, and impacts. British Columbia (B.C.) and Alberta were the most severely affected provinces. Vast areas in southern B.C. were assigned the highest possible (Level-4) drought rating by the B.C. government, several extreme-low streamflow advisories, and extreme wildfire risk ratings. Stringent water restrictions were in place by the end of June (AFCC 2016). In Alberta, conditions were even drier, and the Alberta government declared the province an Agricultural Disaster Area by early August. The extreme dry and warm conditions also created one of the most active and longest wildfire seasons for western Canada, and some rivers ran at their lowest recorded flows since measurements began 80 to 100 years ago (CMOS 2016). The extreme heat and dryness the region experienced in 2015 have raised concerns as to whether or not anthropogenic climate change (ACC) has increased the risk of extreme droughts in the area; this is the question we attempt to address in this paper.

Hydrometeorological conditions. Because the drought affected a vast area that includes regions characterized by different climate conditions, this study focuses on southern B.C., among the worst-affected regions. Three critical factors need to exist for severe drought to occur in southern B.C.: 1) low snowpack near the end of winter, 2) dry spring (May–June), and 3) dry summer (July–August) conditions (BCMOE 2016). The winter preceding the drought was characterized by near-normal precipitation. Apart from the

extremely low snowpack that was observed in southwestern B.C. throughout the winter, near-normal to slightly below-normal snowpacks were present near the end of winter across most of the province (BCRFC 2015a). However, due to anomalously warm temperatures in March and April (MA; Fig. 9.2a), record low snow water equivalent (SWE) was observed over most of southern B.C. by 1 May (BCRFC 2015b). A persistent upper ridge off the west coast of North America (Fig. 9.1b) resulted in extraordinary warm and dry conditions from May through July (MJJ; Fig. 9.1c). The low SWE was compounded by the extreme dry conditions to create one of the worst droughts in the region. Time series of region-averaged standardized precipitation and evapotranspiration index (SPEI; Vicente-Serrano et al. 2010) for MJJ shows that the value for 2015 was the second lowest for the 1950–2015 period (Fig. 9.1d), reflecting the significant surface moisture deficit in the area.

Methods. Attribution for the 2015 event is carried out using CMIP5 results (Taylor et al. 2012). It is well-known that coarse-grid climate models have very limited skills in simulating precipitation or SWE at regional scales. The preceding discussion suggests that it is justifiable to simplify the attribution analysis by limiting the drivers to the warm MA temperature (T_{34}) that caused the enhanced and earlier than normal melt and subsequent low summer runoff, and the hot and dry MJJ weather that aggravated the conditions during the growing season. In addition, the intensity of the upper ridge, which is physically linked to the variability of both precipitation (P) and temperature (T) during MJJ, is used as proxy for both variables.

It is evident from the point correlation map of region-averaged MJJ P with geopotential heights (Z) at 500 hPa (Fig. 9.1e) that dry (wet) conditions are related to positive (negative) upper-level height anomalies off the west coast. A parameter (H) is formulated to quantify the intensity of the upper-level ridge (see

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FIG. 9.1. (a) Jul 2015 drought conditions over western Canada (adapted from AAFC 2016). The rectangle over southern B.C. shows the study area where spatial averages of parameters are calculated. (b) MJJ height anomalies at 500 hPa from NCEP reanalysis (Kalnay et al. 1996). (c) 1950–2015 time series of normalized area-average MJJ precipitation and temperature anomalies computed from Environment and Climate Change Canada’s homogenized CANGRD monthly dataset (Vincent et al. 2015). (d) Time series (blue) and linear trend (red) of area-average MJJ SPEI obtained from the SPEI Global Drought Monitor (<http://sac.csic.es/spei/map/maps.html>). (e) Map of correlations between the P' time series in (b) and MJJ NCEP height at 500 hPa. Also shown are the region D and cross-sections used in the computation of H with Eq. (1). (f) Map of correlations between the time series of H computed from NCEP reanalysis with MJJ GPCP precipitation (Adler et al. 2012).

the online supplemental information for details):

$$H = 3\langle Z' \rangle_D - \langle Z' \rangle_{AA'} - \langle Z' \rangle_{BB'} - \langle Z' \rangle_{CC'} \quad (1)$$

where the anomalies are relative to the 1971–2000 climatology. Locations of the region D and transects used in the calculation of H are shown in Fig. 9.1e. H exhibits statistically significant correlations with precipitation over western Canada in general

(Fig. 9.1f). Contemporaneous correlations between detrended H and P , T , and SPEI averaged over southern B.C. are -0.68 , 0.74 , and -0.76 , respectively. Time series of H computed from reanalysis data (Fig. 9.2c) shows that years of extreme positive values of H (e.g., above the 95th percentile— $H_c = 60$ m) also correspond well with extreme dry and warm years. In particular, both the driest and hottest MJJ and largest H occurred in 1958, and the value for 2015 is the third

largest over the period. The other two high H years (1969 and 1992) were also exceptionally warm and dry, but the conditions improved in July, resulting in less extreme seasonal averages.

To determine how greenhouse gas (GHG) forcing influences T_{34} and the H -index, we compare the trends and other statistics of these variables as computed from observed or reanalysis data and ensembles of CMIP5 historical simulations with natural (NAT) or all (ALL) forcings. The list of 19 CMIP5 models used in the analysis is given in the online supplemental information. The change in likelihood of extreme droughts in southern B.C. from GHG forcing is assessed by evaluating how the exceedance probabilities for these variables differ between the ALL and NAT

ensembles. This is achieved by calculating the fraction of attributable risk (FAR; Allen 2003), as detailed in the supplemental information.

Results. We first investigate if ACC has increased the risk of reduced snowpacks at the end of winter. There is no detectable trend of December–March precipitation in either the observations or CMIP5 results (not shown). There are, however, significant warming trends for T_{34} in both the observed and CMIP5-ALL ensemble-mean data, but not for the NAT runs (Fig. 9.2a). No significant increasing trend is evident in the ensemble maximum T_{34} for either ALL or NAT. The best estimate (median) FAR calculated by using thresholds corresponding to the 96th percentiles of

FIG. 9.2 (a) Time series of MA temperatures (T_{34}) computed from CANGRD (blue) dataset and the ensemble mean T_{34} for experiments ALL (red) and NAT (green), along with linear trends for the corresponding series. Also shown are the time series of ensemble maximum for ALL (dashed black) and NAT (blue dashed). (b) Empirical distribution of FAR computed with thresholds set as the 96th percentiles of T_{34} from the individual ALL runs. (c) 1950–2015 time series of the MJJ H -index computed from NCEP reanalysis (blue) and the ensemble minimum (green), median (black), and maximum (orange) of H for experiment ALL. Gray shading indicates the range between the 25th and 75th percentiles. The CMIP5 historical simulations end at 2005 and ensemble statistics for H from 2006 to 2015 are computed from the RCP4.5 projection results. (d) As in (b) but for the MJJ H -index and computed with thresholds set as the 96th percentiles of H from the ALL runs.

T_{34} in ALL runs (i.e., the same percentile for the T_{34} observed for 2015) is about 0.49 (Fig. 9.2b). This suggests that external forcing (mainly anthropogenic forcing) may have doubled the risk for the occurrence of the recent extreme high T_{34} that resulted in the early snowmelt, as evidenced by the early peak flows in the streamflow data (BCRFC 2015b). We note, however, that the FAR estimate has a large spread.

How ACC might have affected the MJJ conditions is examined next. Figure 9.1c shows that both T and P increased between 1950 and 2015. Given that there is no trend in the area-average SPEI (Fig. 9.1d), it is likely that the effects of increasing P on surface water balance could have been offset by the increase in evapotranspiration due to the warming temperatures during this time. Regardless of whether the increases in T and P were the result of ACC, the results suggest they currently do not have detectable influence on surface water balance in MJJ and thus drought risk in the region.

Next we assess whether GHG forcing has affected the upper ridge that creates the meteorological conditions (i.e., low P and high T) that are critical for the development of extreme drought. The bounds of H computed from either the ALL or NAT ensembles are comparable to those exhibited in the H -index derived from the NCEP reanalysis, suggesting that the “observed” variability of H was reproduced by the models in these two experiments. No significant trend (at 5% level) is detected for either the NCEP H or ensemble statistics (median, extrema, etc.) for the two CMIP5 experiments (Fig. 9.2c; results are not shown for NAT), suggesting that GHG forcing has not produced detectable change in the intensity of the west coast upper ridge and the attendant increase in the risk of drought in the area.

Lastly, we examine if ACC has increased the risk of extreme H that are associated with extreme droughts. Results show that the exceedance probability for extreme H in ALL runs is similar to and perhaps somewhat smaller than that in NAT runs (Fig. 9.2d), suggesting that GHG forcing has not resulted in detectable increase in the risk of extremely high H , and consequently the occurrence of intense stationary upper ridge and associated extreme warm and dry conditions. Similar results are also obtained for a parallel analysis that was carried out by constructing H based on the Z' composited over the three driest MJJ during the 1950–2015 period.

Concluding remarks. The multifaceted characteristics and forcings of droughts render attribution analysis

of their causes a challenging task, particularly for a region where both cold- and warm-season processes are critical for drought development. Results from this study indicate that ACC likely played a role in causing the warm late-winter temperatures and the associated reduction in snowpack that set the stage for the 2015 drought. On the other hand, there is no detectable evidence that GHG forcing influenced the intensity or the likelihood of occurrence for the strong and persistent upper-air ridge off the west coast that brought the record heat and dryness in MJJ, which escalated the drought to an extreme event. The results thus suggest that the extreme drought was likely an outcome of anthropogenic effect that has increased the occurrence of extreme warm spring temperatures and natural climate variability that caused the persistent upper ridge. The climate of western Canada is known to be influenced strongly by key Pacific climate variability modes on sub-seasonal to multi-decadal time scales (Gan et al. 2007). For instance, the developing intense 2015–16 El Niño could have contributed to the extreme summer conditions. However, the question of whether or not El Niño played a role does not alter the conclusion that the extreme MJJ conditions were mainly a result of natural variability. Lastly, it is noteworthy that analysis of CMIP5 projections suggests that both late-winter warming and the west coast upper ridge could be enhanced in response to GHG forcing during the latter part of this century. As such, effects of changes in warm-season precipitation and temperature on the surface water budget might not offset each other, or may even reinforce each other in the future. The collective effects of these projected changes on future extreme droughts in western Canada are being investigated and the results will be reported elsewhere.

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Table 28.I. Summary of Results

ANTHROPOGENIC INFLUENCE ON EVENT			
	INCREASE	DECREASE	NOT FOUND OR UNCERTAIN
Heat	Global Temperature (Ch. 2) South India & Sri Lanka (Ch. 2) Central Europe (Ch. 11) Europe (Ch. 12) Ethiopia and Southern Africa (Ch. 15) N.W. China (Ch. 19) W. China (Ch. 20) Japan (Ch. 21) Indonesia (Ch. 22) S. Australia (Ch. 23) Australia (Ch. 24)		Central Equatorial Pacific (Ch. 2)
Cold		Northeastern U.S. (Ch. 7)	Mid-South Atlantic U.S. (Ch. 7) N. America (Ch. 8)
Heat & Humidity	Egypt (Ch. 14) India & Pakistan (Ch. 16)		
Dryness	Indonesia (Ch. 22) Tasmania (Ch. 25)		
Heavy Precipitation	China (Ch. 18)		Nigeria (Ch. 13) India (Ch. 17)
Sunshine	United Kingdom (Ch. 10)		
Drought	Canada (Ch. 9) Ethiopia and Southern Africa (Ch. 15)		
Tropical Cyclones	Western North Pacific (Ch. 26)		
Wildfires	Alaska (Ch. 4)		
Sea Ice Extent		Arctic (Ch. 27)	
HIGH TIDE FLOODS	SOUTHEASTERN U.S. (Ch. 6)		
SNOWPACK DROUGHT	WASHINGTON U.S. (Ch. 5)		
TOTAL	23	2	5

	METHOD USED	Total Events
Heat	Ch. 2: CMIP5 modeling Ch. 11: Observations; weather@home modeling Ch. 12: HadGEM3-A modeling Ch. 15: CMIP5 modeling Ch. 19: CMIP5 modeling with ROF; FAR Ch. 20: CMIP5 modeling with ROF; FAR Ch. 21: MIROC5-AGCM modeling Ch. 22: Observations; CMIP5 modeling Ch. 23: weather@home modeling; FAR Ch. 24: BoM seasonal forecast attribution system and seasonal forecasts	12
Cold	Ch. 7: Observations; CMIP5 modeling Ch. 8: AMIP (IFS model) modeling	3
Heat & Humidity	Ch. 14: weather@home modeling Ch. 16: Non-stationary EV theory; C20C+ Attribution Subproject	2
Dryness	Ch. 22: Observations; CMIP5 modeling Ch. 25: Observations; Modeling with CMIP5 and weather@home	2
Heavy Precipitation	Ch. 13: Observations; Modeling with CAM5.1 and MIROC5 Ch. 17: Observations; Modeling with weather@home, EC-Earth and CMIP5 Ch. 18: HadGEM3-A-N216 modeling; FAR	3
Sunshine	Ch. 10: Hadley Centre event attribution system built on the high-resolution version of HadGEM3-A	1
Drought	Ch. 9: Observations; CMIP5 modeling; Trend and FAR analyses Ch. 15: CMIP5 modeling, land surface model simulations, and statistical analyses	2
Tropical Cyclones	Ch. 26: GFDL FLOR modeling; FAR	1
Wildfires	Ch. 4: WRF-ARW optimized for Alaska with metric of fire risk (BUI) to calculate FAR	1
Sea Ice Extent	Ch. 27: OGCM modeling	1
HIGH TIDE FLOODS	Ch. 6: TIDE-GAUGE DATA; TIME-DEPENDENT EV STATISTICAL MODEL	1
SNOWPACK DROUGHT	Ch. 5: OBSERVATIONS; CESM1 MODELING	1
		30

ACRONYMS:

AMIP: Atmospheric Model Intercomparison Project

BoM: Bureau of Meteorology, Australia

BUI: Buildup Index

CAM: Community Atmosphere Model, <http://www.cesm.ucar.edu>

CESM: Community Earth System Model

CMIP: Coupled Model Intercomparison Project

FAR: Fraction of Attributable Risk

EC-EARTH: <https://verc.enes.org/>

EV: Extreme Value

GFDL FLOR: Geophysical Fluid Dynamics Laboratory Forecast version Low Ocean Resolution

GHCN: Global Historical Climatology Network

IFS: Integrated Forecast System

MIROC5-AGCM: Model for Interdisciplinary Research on Climate-Atmospheric General Circulation Model

OGCM: Ocean General Circulation Model

ROF: Regularized Optimal Fingerprinting

weather@home: <http://www.climateprediction.net/weatherathome>

WRF-ARW: Advanced Research (ARW) version of the Weather Research and Forecasting (WRF) model