28. SUMMARY AND BROADER CONTEXT

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This year's event types include tropical cyclones, extreme sunshine, nuisance tidal flooding, snowpack drought, forest fires, and Arctic sea ice extent in addition to heat, cold, precipitation, and drought. The Summary Table (Table 28.1) is provided to give readers a general overview of the results. However, it is a highly simplified categorization of the results and does not include information about the size of the signal detected or the confidence in the results. This information is found within each individual report and provides essential context for understanding and interpreting results for any individual event. Also, while these reports may be the first analysis for many of these events, they may not be the last. Additional research on any of these events may uncover new information that helps provide a more complete understanding for the role of climate change.

Over the years, authors contributing to this report have also taken on the challenge of quantifying the impacts of climate change. We have increasingly emphasized this because to make attribution results informative to adaptation decisions, scientists must take on the questions of whether the risk or magnitudes of such events have increased or decreased, by how much, and what level of confidence supports the claims. Going forward, report authors will continue to clearly state not only the magnitude and nature of the impacts, but the confidence in their conclusions. While we have made great strides in communicating the exact role of climate change, we still struggle with ensuring that the confidence in the conclusions is also conveyed. This year we also added a methods column to the Summary Table 28.1. While we have limited data at this time, it will be interesting to see what methodological approaches are being applied for different event types and regions as the science evolves.

It was also exciting to see that even after five years and over 100 events examined, investigators are still finding new event types with which to explore the role of climate change. This year we had contributions on novel event types including extreme sunshine in the United Kingdom, "sunny day" flooding in the south-eastern United States, and snowpack drought in the U.S. mountain west. What might be a bright spot for the United Kingdom is that investigators found that extreme winter sunshine there, as observed in the record high 2014/15 season, has become more than 1.5 times more likely to occur under the influence of human-caused climate change. The southeastern United States has a less positive outlook when it comes to sunny day coastal flooding. Even without a cloud in the sky or a storm on the horizon, the Miami, Florida, region is more likely to experience tidal flooding because of long-term sea level rise caused by global warming. In the U.S. Cascade Mountains, a 2015 "snowpack drought" resulted from unprecedented warmth that caused cold-season precipitation to fall as rain rather than snow on the mountains. Investigators found that because of climate change this event could be recurrent in the future.

As observed in years past, all the papers that looked at heat events around the world—from Egypt, Australia, Europe, Indonesia, Asia, India, and Pakistan—all found that climate change played a role in increasing the severity of the event. In addition, many of these events were influenced by both El Niño and natural variability, and in all cases researchers were able to distinguish between these drivers. For example, while El Niño conditions normally have a cooling impact on Japan in July–August, the 2015 summer was still unexpectedly hot. Authors isolated the various influences and showed that intraseasonal disturbances including tropical cyclones were the main drivers, but that human-caused warming increased the likelihood by 1.5 to 1.7 times.

The results of individual event attribution studies can be put into context by looking at the broader

Table 28.1. 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 Equitorial 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

literature. For example, investigators find that human-induced climate change has increased the likelihood of a fire season as extreme as the one that occurred in 2015 in Alaska, which is consistent with numerous studies in recent years that indicate climate change is increasing fire risk in parts of the United States (Melillo et al. 2014). The 2015 Alaska fire season burned the second largest number of acres since records began in 1940.

Another example was the extreme tropical cyclone activity in 2015 in the western north Pacific (WNP) as measured by accumulated cyclone energy (ACE). In this report, a study finds that warm sea surface temperatures associated with El Niño played a major role, but human-caused climate change substantially increased the odds of the extremely active 2015 WNP tropical cyclone season. The observed extreme ACE was mostly due to the anomalously high frequency of category 4–5 storms, which is consistent with projections of increased category 4–5 storms in the WNP region under anthropogenic warming (Walsh et al. 2016).

Five years in review. In this fifth year of the Special Supplement on *Explaining Extreme Events from a Climate Perspective*, we have hit an exciting milestone of over 100 papers examining extreme events over half a decade. Approximately 65% of these papers have shown that human-caused climate change influenced an event's frequency and/or intensity in a substantial and measurable manner. Around 35% did not find an influence for climate change. While these reports represent a small and non-random sampling of extreme events from around the world, these results add to the preponderance of evidence that climate change is influencing extreme events (Field et al. 2012; Melillo et al. 2014).

It is worth commenting on some patterns we have started to see after five years. For example, of the 104 papers published in this report over the last five years, the event types most studied are overwhelmingly heat (29 papers, 28%), precipitation (24 papers, 23%) and drought (17 papers, 16%). In total, these three event types comprise approximately two-thirds of all submissions.

Of the 29 papers that looked at heat events, only one did not find a role for climate change. In contrast, over the past five years this supplement has published 24 attribution studies on precipitation, and the majority (~62%) did not find human influences on the event. This more divided set of precipitation results indicates that either the ability to detect a climate change signal is more challenging for precipitation events because of observational or modeling limitations, or that the impact of climate change on precipitation is more complex or less pronounced than it is for heat. The ~62% of "no signal" found in these precipitation papers is also influenced by the broad variety of questions authors asked for precipitation events. For example, Tett et al. (2013) asked, "Are recent wet northwestern European summers a response to sea ice retreat?" They concluded the answer was no, but given the numerous ways climate change could influence precipitation in this region, a no result for the role of arctic sea ice should not be interpreted as an absence of any role at all for climate change. In general, precipitation analyses have looked at a small subset of the possible physical drivers. Also, the geographic location of each event must be taken into consideration when considering the confidence of a yes or no result. This is because changes in precipitation trends are anticipated to vary by location (Field et al. 2012), and the strength of the observational record, the ability of models to reproduce extremes, and the understanding of physical processes also can vary regionally.

Analyses of drought are also split with about 50% finding and 50% not finding a role for climate change, and again this overall percentage does not tell the full story. For example, multiple reports on the 2013 California drought looked at many variables. Swain et al. (2014) found an influence on geopotential heights that were associated with blockage of storms off the California coast, but the influence on actual changes in precipitation or temperature remain uncertain. Funk et al. (2014) found the long-term sea surface temperature warming did not contribute to the California drought risk. Wang and Schubert (2014) identified increases in anomalies that divert storms away from California (increase drought risk) but also found increases in humidity (decrease drought risk). These conflicting influences resulted in no *net* impact from climate change. So while these papers were neatly binned into the "no influence" category for the purposes of the Summary Table 28.1, a clear picture of how long-term climate change impacted the 2013 California drought is yet to emerge.

The overall message to our readers remains that when interpreting the results of individual event attribution assessments the binary yes or no answer may not tell the full story. Readers must have a clear understanding of the exact nature of the question the researchers were asking in their study and the areas

of uncertainty to fully understand the implications of the results.

A look ahead. As we look ahead to the future of this report, a few very exciting opportunities are evident to the editors. On the attribution science front, the National Academy report (NAS 2016) on event attribution had several recommendations that this supplement could help implement. For example, the NAS report notes that standards have not yet been established for presenting results. They suggest that event attribution could be improved by the development of transparent, community standards for attributing classes of extreme events. That development would be an interesting discussion for future attribution community meetings. While community standards are under discussion, this report will continue to encourage authors to include an assessment of model quality in relation to the event class, use multiple lines of evidence, and clearly communicate the sensitivities of the result to how event attribution questions are framed. This information could be useful in developing these community standards.

In addition to improving event attribution science, we see opportunities for event attribution to become increasingly relevant to society through impacts attribution. This will include both intersecting with other scientific disciplines to apply attribution results to risk management in sectors such as human health, and including other aspects of human influence in understanding the causes of events. For example, flooding in the Canadian prairies in 2014 was more likely due to human impacts on precipitation along with land use changes that affect drainage mechanisms (Szeto et al. 2015). These types of mechanical factors reemphasize the various pathways beyond climate change by which human activity can increase regional risk of extreme events.

A look ahead would not be complete without acknowledging that the continued success and relevance of this report is dependent on the attribution science community. The editors would like to thank all of our contributing authors to date, because without the voluntary contributions of literally hundreds of authors from around the world this report would not be possible. From our beginnings in 2011 with just six papers to the over 100 published to date, no part of this journey has been more enjoyable for the editors than our engagement with the authors. Over the years this report has evolved in large part from both criticism and praise from contributors. The editors are grateful for the authors' thoughtful input and

hope this dialog continues. Looking ahead we hope for their continued engagement as we work together to advance this exciting frontier of science.

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