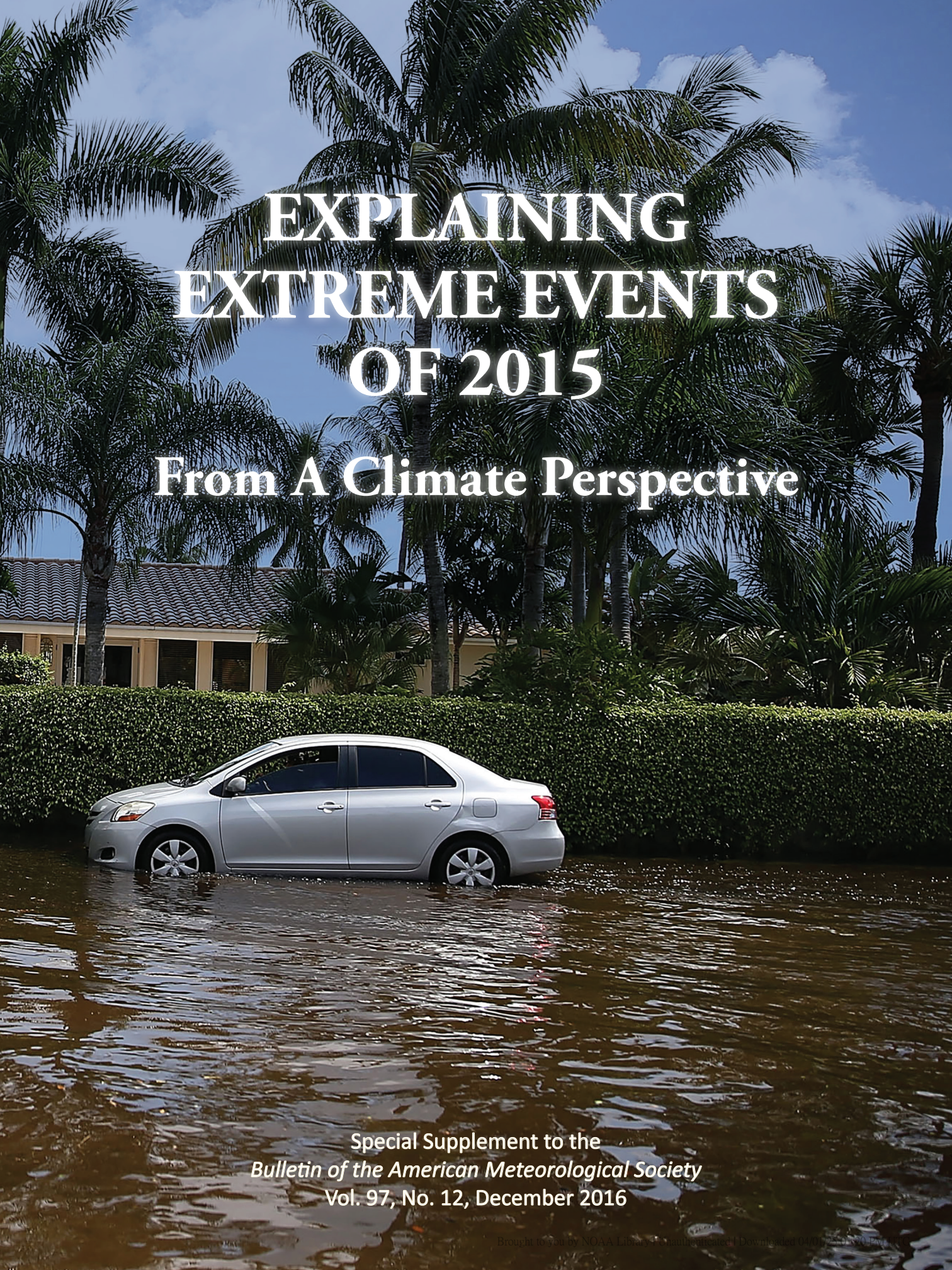

EXPLAINING EXTREME EVENTS OF 2015

From A Climate Perspective

Special Supplement to the
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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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ABSTRACT—Stephanie C. Herring, Andrew Hoell, Martin P. Hoerling, James P. Kossin, Carl J. Schreck III, and Peter A. Stott

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.

1. INTRODUCTION TO EXPLAINING EXTREME EVENTS OF 2015 FROM A CLIMATE PERSPECTIVE

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

In the first years of this report, we answered questions such as: "What is event attribution?" and "Is it even possible to address the effects of long-term changes on extreme events using event attribution?" The science has now advanced to the point that we can detect the effects of climate change on some events with high confidence (e.g., especially those linked to temperature), although results are necessarily probabilistic and not deterministic. The growing popular interest in event-attribution is feeding back to the science, for example by requiring it to more carefully consider the impacts of various interpretations and framings of the causation question. We thus now ask: "What is the confidence of the results?" and "How should the results be interpreted?" We are conscious of the importance of the precise question being asked, for instance "What are long-term contributions to event frequency?" versus "What are long-term contributions to event intensity?" (e.g., Dole et al. 2011). There remains an ongoing need to reconcile attribution results pertaining to different aspects of extreme event behavior (e.g., Otto et al. 2012).

To state that event attribution is complex, especially for extreme rainfall and related storm systems including tropical cyclones, is obvious. Yet, such complexities mean that the analytic work to pull numerous pieces together to establish probable cause continues to require considerable time, even as computers become more powerful to aid the effort. Thus, the reliability and realism of "real time" attribution for which there is great public appetite, continues to be an open question. The scope of information demand is also multifaceted, not only to explain "why the event happened," but also "how well the event was anticipated." These new questions are far more challenging to address and are increasingly relevant to the concerns of society. Attribution science has made progress in answering these questions, though considerably more work needs to be done.

This last year has been exciting for attribution science, as the U.S. National Academy of Sciences released its report on the topic (NAS 2016). To date, it is the most comprehensive look at the state of event attribution science, including how the framing of attribution questions impacts the results. For example, in a complex event such as drought, a study of precipitation versus a study of temperature may yield different results regarding the role of climate change. The report also addresses how attribution results are presented, interpreted, and communicated. It provides the most robust description to date of the various methodologies used in event attribution and addresses the issues around both the confidence of the results and the current capabilities of near-real time attribution. No single methodology exists for the entire field of event attribution, and each event type must be examined individually. Confidence in results of an attribution analysis depends on what has been referred to as 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 recently published paper (Mitchell et al. 2016) marks the beginning of an important new undertaking for the event attribution field by providing an example of how to apply event attribution science to understanding and preparing for impacts. For many years, the scientific community has discussed linking event attribution to the impacts of these events and the role climate change has played in altering those impacts. This year, for the first time, attribution scientists partnered with public health officials to assess the role climate change played in increased mortality from a specific event—the 2003 European heatwave (Mitchell et al. 2016). Their results concluded that in the summer of 2003, "out of the estimated ~315 and ~735 summer deaths directly

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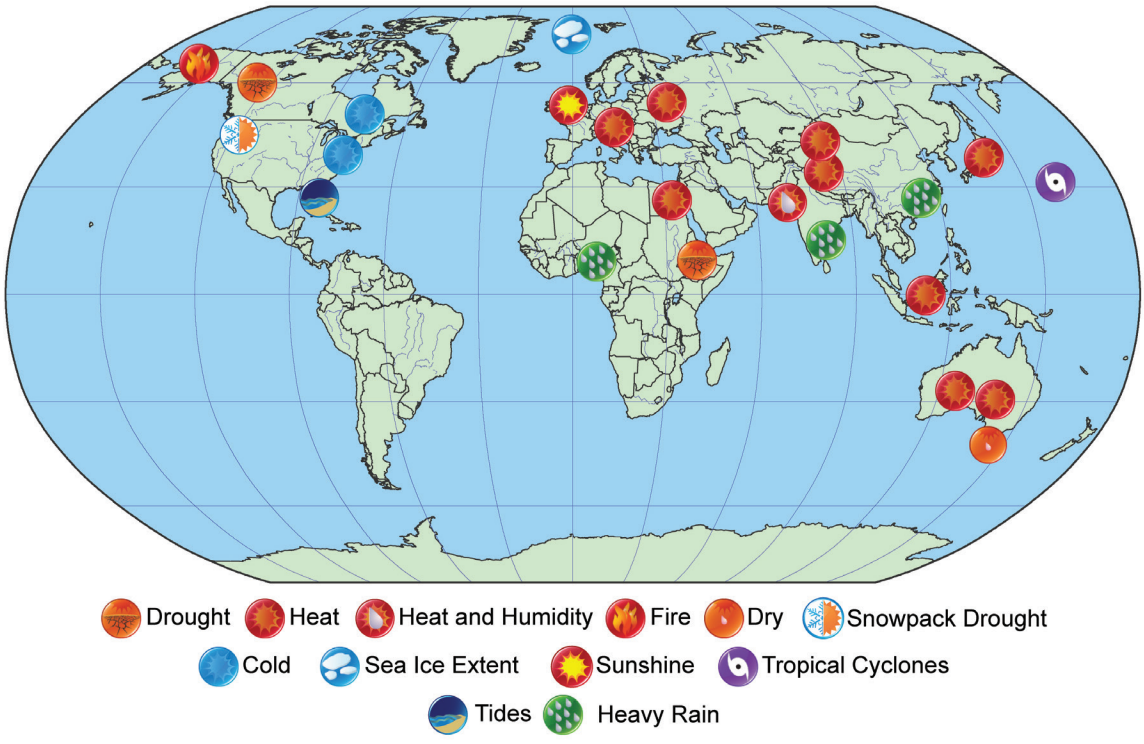

Fig. 1.1. Location and types of events analyzed in this publication.

attributed to the heatwave event in Greater London and Central Paris, respectively, 64 (± 3) deaths were attributable to anthropogenic climate change in London, and 506 (± 51) in Paris." While the numbers for this heat wave are noteworthy, especially for Paris, the paper makes a larger contribution than just its analysis of the 2003 event. It lays out a methodology for linking the role of climate change on an extreme heat event and, subsequently, the impacts of that event on human health. Clearly, multiple approaches could be taken to address these questions, and the paper by Mitchell et al. lays out just one. Also, it is no accident that this work addresses a heat event, where the climate change signal is strongest and confidence in attribution results is highest.

Even so, it would be premature to regard this result—that 506 (± 51) deaths in Paris in summer 2003 are attributable to anthropogenic climate change—as the last word on the matter. Unquantified uncertainties need to be further explored owing to different observational, modeling, and methodological strategies for both climate attribution and health sciences. And the confidence with which a linkage can be made between anthropogenic emissions and impacts is different for other event types. However, as the science advances we hope to see more papers connecting a line between climate change and impacts, not only for heat but also for other event types. Friederike Otto put it well in a recent paper where she wrote, "The event attribution community has come a long way towards applying different methodologies and combining meteorological variables to indices of relevance to people, making impact attribution the challenge for the coming years" (Otto 2016). Mitchell's paper begins to address this challenge.

Meaningful connections between weather and climate events and impacts will require that the event attribution community collaborate with the impacts community. Furthermore, event attribution would be most useful to the impacts community if potential users engage closely with scientists in the co-production of knowledge relevant to decision-making. The European Climate and Weather Events: Interpretation and Attribution (EUCLEIA) project has engaged with such stakeholders and found that different sectors often have different uses for such information and different requirements (Stott et al. 2015). For example, the insurance industry may value robustness over speed in the assessment of climate risks. By contrast, the World Weather Attribution project has worked with Red Cross/Red Crescent

which require information on faster time scales. They find value in rapid assessments of recent disastrous weather and climate events during the relatively short window of opportunity when resources may be available to enable communities to become more resilient to such shocks in the future (https://www.climatecentral.org/about/partners/).

A common characteristic for all these impact attribution efforts is that they have been cross disciplinary. In support of the IPCC's 1.5°C impacts report, collaborations between science disciplines have been established that will hopefully continue to increase the applicability of event attribution science in decision-making.

In addition to the literature, Mother Nature also made this year an interesting one because of the strong El Niño. Although we had anticipated that we would focus on event types other than heat in this year's report, the heat proposals we received put an interesting twist on the heat attribution question. With the presence of a strong El Niño in 2015, these papers asked whether attribution could effectively disentangle the effects of El Niño from longer-term human-caused warming. Without exception, the analyses in this report were successfully able to do this. All investigations of heat events found an increased risk from human-caused climate change separate from the role of El Niño and other drivers from natural variability.

As we look back at five years of this BAMS *Explaining Extreme Events from a Climate Perspective* report, we are excited to see the overall progress made to date. That progress is not merely in the climate science, but also in the growth of capabilities to share that information with others and to communicate that knowledge clearly. Also, the range of event types being examined with a focus on attribution has broadened over the years, and the ability of analyses to distinguish between natural and human-caused drivers continues to increase. It is also worth noting that this publication does not discriminate between papers that do and do not find a role for climate change. A large number of papers published in this report over the past five years (~35%) did not find any role for climate change on the risk of the event, and we expect to continue receiving and publishing similarly-themed manuscripts in the future.

Looking ahead, over the next half decade there is certainly a great deal of work still to be done in improving the reliability of event attribution results and how they are communicated. We will be closely watching to see how the effort to meet the challenge of "impact attribution" advances in the coming years. We are seeing the start of bridges being built between the disciplines of climate attribution, the practice of weather forecasting, and socioeconomic science, which are each truly essential next steps in using attribution analysis to inform risk management decisions. However, progress in managing risks from extreme events can only be made if the foundational pillars of observations, modeling, and our understanding of the physical processes that drive extreme events and their relationship to climate change also continue to improve. Continued investments in climate science at all levels are crucial not only in the next five years, but for the foreseeable future.

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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