EXPLAINING EXTREME EVENTS OF 2016
From A Climate Perspective

Special Supplement to the Bulletin of the American Meteorological Society
Vol. 99, No. 1, January 2018
# TABLE OF CONTENTS

Abstract ................................................................................................................................................ ii

1. Introduction to Explaining Extreme Events of 2016 from a Climate Perspective ......................... 1
2. Explaining Extreme Ocean Conditions Impacting Living Marine Resources ............................. 7
3. CMIP5 Model-based Assessment of Anthropogenic Influence on Record Global Warmth During 2016 .................................................................................................................................. 11
4. The Extreme 2015/16 El Niño, in the Context of Historical Climate Variability and Change ........................................... 16
5. Ecological Impacts of the 2015/16 El Niño in the Central Equatorial Pacific ........................................ 21
6. Forcing of Multiyear Extreme Ocean Temperatures that Impacted California Current Living Marine Resources in 2016 ........................................................................................................... 27
7. CMIP5 Model-based Assessment of Anthropogenic Influence on Highly Anomalous Arctic Warmth During November–December 2016 ........................................ 34
8. The High Latitude Marine Heat Wave of 2016 and Its Impacts on Alaska ............................................ 39
9. Anthropogenic and Natural Influences on Record 2016 Marine Heat waves .................................. 44
11. Was the January 2016 Mid-Atlantic Snowstorm ”Jonas” Symptomatic of Climate Change? 54
12. Anthropogenic Forcings and Associated Changes in Fire Risk in Western North America and Australia During 2015/16 ........................................................................................................... 60
13. A Multimethod Attribution Analysis of the Prolonged Northeast Brazil Hydrometeorological Drought (2012–16) .................................................................................................................. 65
14. Attribution of Wintertime Anticyclonic Stagnation Contributing to Air Pollution in Western Europe ................................................................................................................................................. 70
15. Analysis of the Exceptionally Warm December 2015 in France Using Flow Analogues ........ 76
16. Warm Winter, Wet Spring, and an Extreme Response in Ecosystem Functioning on the Iberian Peninsula .............................................................................................................................................. 80
17. Anthropogenic Intensification of Southern African Flash Droughts as Exemplified by the 2015/16 Season ........................................................................................................................................... 86
18. Anthropogenic Enhancement of Moderate-to-Strong El Niño Events Likely Contributed to Drought and Poor Harvests in Southern Africa During 2016 ................................................................. 91
19. Climate Change Increased the Likelihood of the 2016 Heat Extremes in Asia ................................. 97
20. Extreme Rainfall (R20mm, RX5day) in Yangtze–Huai, China, in June–July 2016: The Role of ENSO and Anthropogenic Climate Change ........................................................................................................ 102
22. Do Climate Change and El Niño Increase Likelihood of Yangtze River Extreme Rainfall? .... 113
23. Human Influence on the Record-breaking Cold Event in January of 2016 in Eastern China .......................................................................................................................................................... 118
25. The Hot and Dry April of 2016 in Thailand .................................................................................... 128
26. The Effect of Increasing CO₂ on the Extreme September 2016 Rainfall Across Southeastern Australia ........................................................................................................................................ 133
27. Natural Variability Not Climate Change Drove the Record Wet Winter in Southeast Australia ......................................................................................................................................................... 139
28. A Multifactor Risk Analysis of the Record 2016 Great Barrier Reef Bleaching ............................ 144
29. Severe Frosts in Western Australia in September 2016 .................................................................. 150
30. Future Challenges in Event Attribution Methodologies .................................................................. 155
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 human-caused 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.
16. WARM WINTER, WET SPRING, AND AN EXTREME RESPONSE IN ECOSYSTEM FUNCTIONING ON THE IBERIAN PENINSULA


A warm winter 2015/16 followed by a wet spring enabled exceptionally high ecosystem gross primary productivity on the Iberian Peninsula. Climate-ecosystem model simulations show warming winters and increased CO₂ availability benefit ecosystem productivity, but no increase in spring precipitation.

Introduction. The Iberian Peninsula (IP) experienced unusual meteorological conditions in winter and spring 2015/16 (WS15/16) with a warm winter followed by wet conditions in late winter and spring (Figs. 16.1a–c). The unusual succession of these events coincided with an extremely positive anomaly in vegetation productivity on local and regional scales over the IP with unusually high regional vegetation greenness (Figs. 16.1d–f; a proxy for ecosystem productivity) and high crop yields (JRC MARS Bulletins 2016, https://ec.europa.eu/jrc/en/research-topic/crop-yield-forecasting).

Climatic changes can affect the intensity and frequency of extreme events (Seneviratne et al. 2012), and these changes are widely recognized to impose substantial impacts on terrestrial ecosystems (Reichstein et al. 2013). However, interpreting and quantifying climate-induced ecosystem impacts such as the vegetation productivity on the IP in WS15/16 remains challenging as continuous site-level measurements that span over a decade are generally rare, and even the longest site measurements are only available for the last 25 years (http://fluxnet.fluxdata.org/data/fluxnet2015-dataset/).

While long-term climatic changes impose fundamental impacts on terrestrial ecosystems (Parmesan and Yohe 2003; Walther et al. 2002), cause–effect chains under climatic extremes are often highly nonlinear (Frank et al. 2015) and typically include instantaneous and lagged effects (Arnone et al. 2008). Ecosystem responses to climate extremes are specific to the ecosystem type affected (Teuling et al. 2010), depend on nutrient status, ecosystem health, and pre-exposure; and extreme climatic events can lead to little ecosystem responses while moderate events can trigger large responses. Similarly, ecosystem responses can be mitigated or amplified across seasons (Wolf et al. 2016). For example, higher spring carbon uptake due to higher spring temperatures could compensate for carbon losses under drought conditions over the contiguous United States in summer 2012 (Wolf et al. 2016).

To improve our understanding of extreme responses of ecosystem productivity, the concept of compound events is particularly useful. A compound event is a combination, or in our case succession, of events in which the single drivers are not necessarily extreme themselves but lead to an extreme impact (Field et al. 2012; Leonard et al. 2014). A warm winter followed by wet spring in a Mediterranean ecosystem is one example of a compound event in which single drivers (winter temperature and spring precipitation) are not record-breaking extremes themselves, but this favorable combination of meteorological variables can lead to highly positive impacts on ecosystem productivity if other stressors are absent. In particular, for the ecosystem studied, other stressors could include, but are not limited to, short but intense cold spells in

* S.S. and T.S.E.-M contributed equally to the manuscript.
In this paper, we: 1) analyze the extreme ecosystem productivity anomaly of WS15/16 at the regional scale and 2) investigate the factors that contributed to this anomaly, including winter temperature, spring precipitation, and the carryover of stress from previous seasons. The figure below illustrates the time series of temperature and precipitation, as well as scatter plots of winter temperature and spring precipitation, and maps showing the relative anomaly in FAPAR.

Fig. 16.1. (a),(b) Time series of (a) temperature (°C) and (b) precipitation (mm month⁻¹) over IP in 2015/16 (gray shading indicates ±2σ range, w.r.t. 1981–2010). (c),(d) Scatter plot of (c) winter temperature (°C) and spring precipitation (mm month⁻¹), and (d) winter and spring fraction of FAPAR. Ellipse denotes quantile of 95% in multivariate normal distribution (Santos-Fernández 2012). (e),(f) Map of relative anomaly in FAPAR in (e) winter and (f) spring 2015/16 w.r.t. 2001–16 (black dot indicates study site Majadas del Tietar; rectangle denotes model domain).

In winter, moisture stress carried over from previous seasons, fires, pests, or legacy effects thereof.
and with site-level measurements, including a process interpretation, and 2) assess, based on an ensemble of process-oriented ecosystem model simulations, how the odds of extremely positive vegetation productivity events [measured in gross primary productivity (GPP) and net ecosystem productivity (NEP)] in winter and spring are changing in response to climate change.

**Winter 2015/16 and spring 2016: Meteorological drivers and extreme ecosystem impacts.**

a. Regional-scale analysis of vegetation productivity. Strong and persistent anticyclonic conditions prevailed from November to mid-January over the Mediterranean basin, leading to the advection of very mild air into the IP and, in fact, into large parts of western Europe. For example, December 2015 was among the warmest months ever recorded in a range of European countries, such as Spain (2nd; Fig. 16.1a; www.aemet.es/documentos/es/serviciosclimaticos/vigilancia_clima/resumenes_climat/mensuales/2015/res_mens_clim_2015_12.pdf), France (1st; http://actualite.lachainemeteo.com/actualite-meteo/2015-12-26-06h09/décembre-2015---historiquement-chaud-et-sécher-séc-29466.php), and Germany (1st; www.dwd.de/DE/presse/pressemitteilungen/DE/2015/20151230_deutschlandwetter_dezember_news.html), among others; and combined December and January temperatures exceeded the previous IP area-average record value by 0.72°C in the EOBS-dataset (Haylock et al. 2008). In late winter, however, the synoptic situation changed with temperatures returning to near normal, and abundant above-average precipitation over the IP continuing from January through May (Fig. 16.1c). Hence, high winter temperatures were followed by high late winter and spring precipitation, exceeding a bivariate 95th percentile (Fig. 16.1c; see online supplement for details).

Continuously high temperatures during winter enable better functioning of plant enzymes used in the photosynthetic machinery (Sage and Kubien 2007) and prevent plants from damage through cold stress. The availability of water during spring prevents soils from drying out and the plants from experiencing drought stress. The 2015/16 meteorological conditions thus provided the basis for the highest area averaged IP fraction of absorbed photosynthetically active radiation (FAPAR, a proxy for ecosystem productivity observed from space that is related to the state and greenness of vegetation canopies; Gobron et al. 2010) in both winter and spring (Fig. 16.1d), using the Tip–FAPAR dataset (Pinty et al. 2011) in the MODIS era (2001–16); and positive FAPAR anomalies prevailed in both seasons across most of the IP except its southeastern parts (Figs. 16.1e,f).

A correlation analysis of concurrent and lagged meteorological variables and FAPAR at the seasonal time scale shows that IP FAPAR (as a regional-scale ecosystem productivity proxy) is mainly temperature-limited in winter, which gradually transcends toward water limitation in spring (Table ES16.1). While we focus only on the individual 2015/16 event, in fact out of the four years (i.e., 25% of the 16-year FAPAR record) that showed the highest December–May IP FAPAR, all four years were among the warmest 30% of IP winters in the EOBS—dataset, and three out of four among the wettest 30% of IP springs (and all four within the wettest 35% of springs on record). Nonetheless, FAPAR in IP ecosystems is also sensitive to precipitation in the previous season both in winter and spring (Table ES16.1), which highlights the role of lagged effects. Hence, the dependence on contemporaneous meteorological conditions should not be mistaken as the sole driver of positive ecosystem productivity events.

b. Site-scale analysis of vegetation productivity. In Spain, 2.16 million hectares of the vegetation used for livestock production consists of a mosaic of at least 20% oak woodlands plus grass- and shrublands, so-called dehesas. Over a quarter of this vegetation type is located in Extremadura (Campos et al. 2013) in which the study site, Majadas del Tietar (39.9415°N, −5.7734°E), is located (Casals et al. 2009).

The site was established in 2003 with meteorological measurements and eddy covariance flux measurements of energy, water vapor, and carbon dioxide, thus a 13-year record is available for analysis.

At site-level, the meteorological variables largely mirrored the regional-scale patterns, that is high temperatures in winter (2.5°C above site average in winter) and wet conditions in spring [57 mm (~25%) above site average precipitation in spring]. During the warm winter and wet spring, GPP exceeded the respective seasonal averages by 29 grams of carbon (gC) m⁻² month⁻¹ (~45%) and 43 gC m⁻² month⁻¹ (~30%). In addition, ecosystem respiration (Reco, the release of carbon by the ecosystem), is coupled to temperature and also increased during the warm winter by 29 gC m⁻² month⁻¹ (70%) as compared to the average winter. The absence of water stress during the wet spring 2016 also led to increased Reco by 40 gC m⁻² month⁻¹ (42%; Fig. ES16.1). Therefore, despite the fact that ecosystem productivity was high in WS15/16 as measured by FAPAR (Figs. 16.1e,f; Pearson correlation between FAPAR and GPPsite, RDec-May = 0.84), the
simultaneous increase of GPP and Reco meant that NEP (the net sequestration of carbon) was not unusually high (Fig. 16.2b). This means, that an increase in ecosystem productivity does not necessarily lead to the ecosystem functioning as a larger carbon sink.

**How do climatic changes affect regional-scale ecosystem productivity extremes?** We provide an estimate of changes in the likelihood of ecosystem productivity extremes such as in 2015/16 based on a process-oriented ecosystem model over the time period of 1986–2010. To do so, we evaluate an ensemble of process-oriented ecosystem model simulations over
the IP (500 members in each year in 1986–2010), using the Lund–Potsdam–Jena managed Land (LPJmL) ecosystem model (Bondeau et al. 2007; Sitch et al. 2003). The simulations are driven by (i) a bias corrected regional climate model ensemble (Massey et al. 2015), and (ii) ERA-Interim reanalysis data (Dee et al. 2011) as a transient simulation reflecting observed meteorology (Pearson correlation between FAPAR and GPP\textsubscript{LPJmL–ERAI}, $R_{\text{Dec–May}} = 0.83$). Further, the ecosystem model is run in two setups, that is, in standard mode with transient (i.e., observed) CO\textsubscript{2} concentrations, and a second setup with CO\textsubscript{2} values held constant at 1986 values (CONSTCO\textsubscript{2}) in order to isolate direct CO\textsubscript{2} effects on ecosystem functioning. The climate model is driven by observed sea surface temperatures in the weather@home setup (Massey et al. 2015). A detailed methodological description of the HadRM3P–LPJmL ensemble approach is available in Sippel et al. (2017) and is summarized in the online supplement.

Overall, the ecosystem model simulations driven by ERA-Interim indicate that 2015/16 had been an extreme event in regional-scale GPP consistent with site-scale measurements (Fig. 16.2c), and to a lesser degree in NEP (Fig. 16.2d), which differs from site observations that do not indicate anomalous conditions. Contrasting the bivariate distribution of an earlier (1986–95) and a more recent period (2001–10) reveals that the odds for high winter GPP associated with high spring GPP have indeed increased, and the model indicates that the odds for an event similar to 2015/16 have more than doubled (Fig. 16.2c). These changes can be attributed to higher winter temperatures, consistent with anthropogenic climate change, in combination with CO\textsubscript{2} fertilization effects in the ecosystem model. Long-term meteorological observations show a strong trend in winter temperatures over the IP (Fig. ES16.2), which is reproduced by the climate model that drives the ecosystem model (both for the 2001–10 vs. 1986–95 decade, but also if the 2001–10 decade is compared to a hypothetical preindustrial 2001–10 ensemble; see Fig. ES16.2 and online supplement text for details). In contrast, there is no significant trend in IP spring precipitation neither in observations nor in the climate model (Fig. ES16.2). Thus increased odds for high spring GPP events that follow high winter GPP events (Fig. 16.2c) cannot be attributed to changes in spring precipitation. Instead, the increased odds in high spring GPP events arise from direct CO\textsubscript{2} effects in the ecosystem model, because these changes disappear in the CONSTCO\textsubscript{2} scenario (cf. Fig. ES16.3 and Fig. 16.2c). However, crucially, the ecosystem model ensemble simulations also indicate that net ecosystem carbon sequestration, that is after ecosystem respiration is accounted for, has not increased (Fig. 16.2d). This might be due to the fact that higher temperatures are associated with increased Reco (as consistently observed at site scale in Majadas in 2015/16).

**Conclusion.** Our study shows that the 2015/16 positive GPP anomaly on the Iberian Peninsula, which was enabled by a compound warm winter and wet spring event, is indeed consistent with recent observed climate change, as diagnosed in site and regional scale observations and model simulations. While the increase in winter GPP can be attributed to increasing temperatures, the increase in spring GPP cannot be attributed to changes in spring precipitation, but these changes result from increased CO\textsubscript{2} fertilization. However, these warming and CO\textsubscript{2}-induced effects are largely canceled in terms of net ecosystem carbon sequestration in 2015/16, as carbon uptake and release intensified in tandem, which is consistent with expectations in a changing climate as indicated by the ecosystem model ensemble. This study presents and discusses a novel inquiry into the attribution of ecosystem impacts to extreme climate events and the underlying drivers. However, because it uses only one combination of climate–ecosystem models, and a relatively short observational record, its conclusions should be regarded as contingent on these limitations.

**ACKNOWLEDGMENTS.** S. S., M. D. M., and M. F. thank the European Space Agency for funding the STSE project CAB-LAB. T. S. E.-M., M. M. and M. R. thank the Alexander von Humboldt Foundation for supporting this research with the Max Planck Research Award to Markus Reichstein. We thank the two reviewers and the editor for their valuable comments and ideas to enhance the quality of this manuscript.
REFERENCES


### Table 1.1. SUMMARY of RESULTS

<table>
<thead>
<tr>
<th>ANTHROPOGENIC INFLUENCE ON EVENT</th>
<th>INCREASE</th>
<th>DECREASE</th>
<th>NOT FOUND OR UNCERTAIN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat</td>
<td>Ch. 3: Global</td>
<td></td>
<td>Ch. 23: China</td>
</tr>
<tr>
<td></td>
<td>Ch. 7: Arctic</td>
<td></td>
<td>Ch. 24: China</td>
</tr>
<tr>
<td></td>
<td>Ch. 15: France</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ch. 19: Asia</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cold</td>
<td></td>
<td></td>
<td>Ch. 25: Thailand</td>
</tr>
<tr>
<td>Heat &amp; Dryness</td>
<td>Ch. 26: Australia</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marine Heat</td>
<td>Ch. 4: Central Equatorial Pacific</td>
<td></td>
<td>Ch. 4: Eastern Equatorial Pacific</td>
</tr>
<tr>
<td></td>
<td>Ch. 5: Central Equatorial Pacific</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ch. 6: Pacific Northwest</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ch. 8: North Pacific Ocean/Alaska</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ch. 9: North Pacific Ocean/Alaska</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ch. 9: Australia</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heavy Precipitation</td>
<td>Ch. 20: South China</td>
<td></td>
<td>Ch. 10: California (failed rains)</td>
</tr>
<tr>
<td></td>
<td>Ch. 21: China (Wuhan)</td>
<td></td>
<td>Ch. 26: Australia</td>
</tr>
<tr>
<td></td>
<td>Ch. 22: China (Yangtze River)</td>
<td></td>
<td>Ch. 27: Australia</td>
</tr>
<tr>
<td>Frost</td>
<td>Ch. 29: Australia</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winter Storm</td>
<td></td>
<td></td>
<td>Ch. 11: Mid-Atlantic U.S. Storm &quot;Jonas&quot;</td>
</tr>
<tr>
<td>Drought</td>
<td>Ch. 17: Southern Africa</td>
<td></td>
<td>Ch. 13: Brazil</td>
</tr>
<tr>
<td></td>
<td>Ch. 18: Southern Africa</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atmospheric Circulation</td>
<td></td>
<td></td>
<td>Ch. 15: Europe</td>
</tr>
<tr>
<td>Stagnant Air</td>
<td>Ch. 12: Canada &amp; Australia (Vapor Pressure Deficits)</td>
<td></td>
<td>Ch. 14: Western Europe</td>
</tr>
<tr>
<td>Wildfires</td>
<td>Ch. 5: Central Equatorial Pacific</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ch. 28: Great Barrier Reef</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ch. 28: Great Barrier Reef</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ecosystem Function</td>
<td>Ch. 5: Central Equatorial Pacific (Chl-a and primary production, sea bird abundance, reef fish abundance)</td>
<td></td>
<td>Ch. 4: Equatorial Pacific (Amplitude)</td>
</tr>
<tr>
<td></td>
<td>Ch. 18: Southern Africa</td>
<td></td>
<td></td>
</tr>
<tr>
<td>El Niño</td>
<td>Ch. 18: Southern Africa</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>18</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>METHOD USED</td>
<td>Total Events</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------</td>
<td>--------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat</td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cold</td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat &amp; Dryness</td>
<td>18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marine Heat</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heavy Precipitation</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frost</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winter Storm</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drought</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atmospheric Circulation</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stagnant Air</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wildfires</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coral Bleaching</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ecosystem Function</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>El Niño</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**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: CAMS AMIP atmosphere only model conditioned on SST patterns and CESM1 CMIP single coupled model assessment
- Ch. 20: Observational extrapolation; CMIP5 and CESM multimodel coupled model assessment; auto-regressiv models
- Ch. 21: Observational extrapolation; HadGEM3-A atmosphere only model conditioned on SST patterns; CMIP5 multimodel coupled model assessment with ROF
- 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. 11: ECHAMS 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 assessment; hydrological modeling
- Ch. 17: Observational extrapolation; CMIP5 multimodel coupled model assessment; VIC land surface hydrololgical model, optimal fingerprint method
- Ch. 18: Observational extrapolation; weather@home multimodel atmosphere only models conditioned on SSTs, CMIP5 multimodel coupled model 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 atmosphere 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; weather@home multimodel atmosphere only models conditioned on SSTs, CMIP5 multimodel coupled model assessment