19. AN ATTRIBUTION STUDY OF THE HEAVY RAINFALL OVER EASTERN AUSTRALIA IN MARCH 2012

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Introduction. Heavy rains at the end of summer 2012 across eastern Australia (Bureau of Meteorology 2012) led to swollen rivers and widespread flooding that swamped agricultural land, caused loss of life, and forced tens of thousands of people to evacuate their homes. The event came only a year after the catastrophic floods in Queensland, when the largest part of the north-eastern state was declared a disaster zone. In the aftermath of two major floods in consecutive years, the question arises whether the odds of heavy rain in eastern Australia are set to increase under the synergy between internal climate variability and externally forced climate change. Here we investigate the possible contributions of the ENSO and the long-term effect of human influences on the climate to the heavy rainfall in March 2012 over eastern Australia (10°S–45°S, 140°E–160°E). The anthropogenic contribution is estimated with a new state-of-the-art system for Attribution of extreme weather and Climate Events (ACE; Christidis et al. 2013), built on HadGEM3-A, the latest atmospheric model from the Hadley Centre. We concentrate on March, as the main flooding occurred in the beginning of that month and the total rainfall in the region was exceptionally high in comparison with the summer months (Fig. 19.1a). In fact, March 2012 ranks as the third wettest after 2011 and 1956 in the Global Historical Climatology Network (GHCN) dataset used to provide rainfall observations for this study (Peterson and Vose 1997). Although the heavy rainfall event examined here is not unprecedented, the adverse impacts associated with two consecutive wet years in the region make it an interesting case to study.

The influence of ENSO. A correlation between the phase of ENSO and rainfall in Australia has long been identified (McBride and Nicholls 1983). La Niña episodes, characterized by warm SST anomalies over the West Pacific are associated with wetter-than-normal conditions over eastern Australia. While La Niña conditions prevailed at the end of 2011 and beginning of 2012, they had considerably weakened by March, and ENSO changed phase in April. Figure 19.1b illustrates the relationship between March precipitation in the region and the Southern Oscillation Index (SOI) from summer to early autumn. An increase in rainfall with the SOI is evident, and the slope of the least-square fit is found to be significantly different

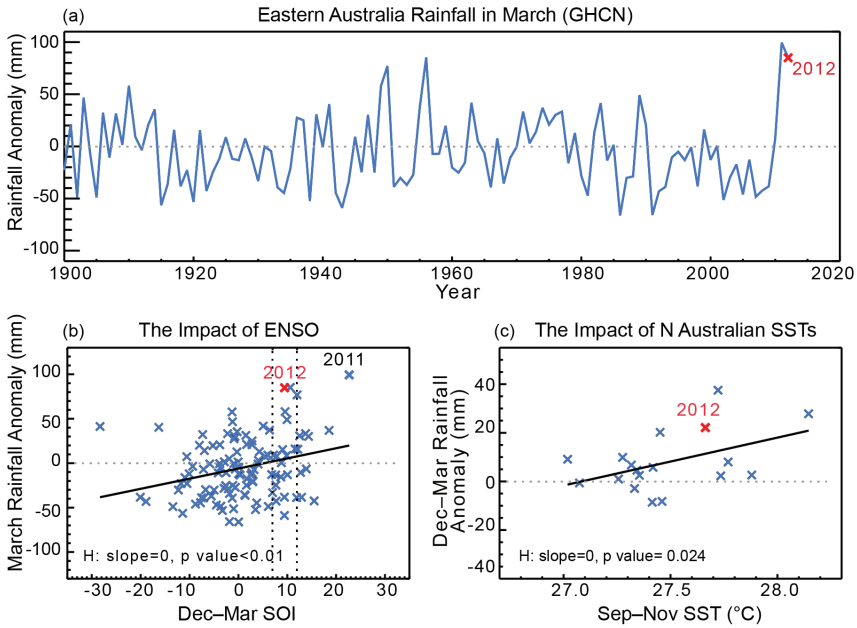

Fig. 19.1. GHCN observations of rainfall anomalies relative to 1961–1990 over eastern Australia. (a) 1900–2012 Mar rainfall time series; (b) the relationship between Mar rainfall and the Dec–Mar mean value of the Southern Oscillation Index (from http://www.bom.gov.au/climate/current/soi2.shtml); (c) the relationship between Dec–Mar rainfall and spring north Australian SST anomalies (from HadISST) for years with 7< SOI <12 (marked by the vertical dotted lines in panel b). The year 2012 is highlighted in red. The p-values (panels b and c) refer to testing of the hypothesis that the least square fit (plotted in black) has a zero trend.

from zero. While the La Niña episode early in the year is likely to increase the chances of a wet March, the extremely high rainfall amount (marked with a red cross in Fig. 19.1b) is unlikely to be attributable solely to ENSO.

SST warming to the north of Australia. Australian rainfall is also influenced by the SSTs to the north of the country, and it is found that warm anomalies during spring are associated with heavy summer rainfall across eastern Australia (Nicholls 1984; Evans and Boyer-Souchet 2012). Figure 19.1c depicts the relationship between summer-to-early-autumn rainfall and the spring SSTs around northern Australia (0°–22°S, 94°E–174°E) taken from the HadISST dataset (Rayner et al. 2003). Both external forcings and variability may contribute to warm SSTs. In order to minimize the effect of variability due to ENSO (Catto et al. 2012) we examine only years with SOI between 7 and 12 (marked by the vertical dotted lines in Fig. 19.1b), i.e., similar conditions to the event we consider here. We find a significant increase in rainfall with SST, which could explain wetter conditions in December–March 2012 given the warm ocean temperature. The observations suggest an increase in the SSTs north of Australia by 0.1 K decade^{-1} over the last 50 years, consistent with the multidecadal anthropogenic global ocean warming (Glecker et al. 2012; Pierce et al. 2006). While the SST warming is indicative of more wet summers over eastern Australia, which could also be exacerbated by La Niña conditions, it is important to assess whether the occurrence of extreme rainfall also becomes more frequent. So far, we have only assumed that long-term externally forced climate change might have contributed to the heavy rainfall in 2012 through the warming of the ocean. We next attempt to investigate the overall contribution of human influences in more detail and examine how they may have changed the odds of above average and extreme rainfall in March 2012.

Anthropogenic influence. The new Hadley Centre ACE system has already been employed to study several high-impact extreme events in recent years (Christidis and Stott 2012; Christidis et al. 2013; Lott et al. 2013). We carried out a new experiment that comprises ensembles of 600 simulations with HadGEM3-A over the period September 2011–August 2012. We have one ensemble that represents the actual climate where the effect of all external forcings is accounted for and two ensembles that provide two possible representations of a hypothetical "natural" climate without the effect of human influences. In simulations of the natural climate, an estimate of the anthropogenic change in the SSTs has been subtracted from the prescribed observations and the sea ice has been adjusted accordingly. The estimate of the change in the SST comes from two Earth System models, HadGEM2-ES (Jones et al. 2011) and CanESM2 (Gillett et al. 2012), hence, we have two different representations of the natural climate without human influences. Details on the ACE experimental setup are given in Christidis et al. (2013). We assessed the model skill in reproducing high rainfall during March over eastern Australia on the basis of reliability diagrams, as in previous work. Using GHCN observations and a five-member

ensemble of multidecadal simulations of the actual climate, we find that the forecast probability is consistent with the observed frequency of heavy rainfall in the reference region, which suggests the model can represent well drivers of high rainfall events and is therefore a reliable tool for our analysis.

Figure 19.2 illustrates the regional rainfall distributions for March 2012 with and without anthropogenic effects as well as the change in the odds of above average, heavy, and extreme precipitation (defined in the figure caption) due to human influences. Note that the observed rainfall in March 2012 was three standard deviations above the climatological average, i.e., well above the extreme threshold. Our results (Figs. 19.2a and 19.2c) indicate a small but statistically significant (as inferred from a Kolmogorov-Smirnov test) shift in the rainfall distribution towards wetter conditions under the effect of anthropogenic forcings. For the calculation of the change in the odds, the probabilities of exceeding a threshold are computed using the generalized Pareto distribution if the threshold lies at the tails, and a Monte Carlo bootstrap procedure is employed to estimate the sampling uncertainty (Christidis et al. 2013). Figures 19.2b and 19.2d show that the uncertainty in our estimate of the change in the odds increases as the threshold becomes more extreme, which implies that larger samples would be required to estimate small probabilities with greater precision. Our analysis provides evidence for increasing odds of above average rainfall relative to the natural climate. Therefore, although there is no evident trend in rainfall observations (Fig. 19.1a), once we constrain the SSTs and thus minimize the effect of natural variability, we begin to see an emerging signal of wetter months under the influence of anthropogenic forcings, as also indicated in Fig. 19.1c. The odds of heavy and extreme precipitation also seem to increase, as the largest part of the corresponding distributions in Figs. 19.2b and 19.2d lies over positive values, but the uncertainty in these cases is much larger. The results for these higher thresholds are also more sensitive to the SSTs prescribed in the simulations of the natural climate with the CanESM2 version providing a much stronger indication of an increase in heavy and extreme rainfall. It should be noted that the anthropogenic warming in north Australian SSTs computed with CanESM2 is 0.54 K higher than the HadGEM2-ES estimate, indicative of a greater separation between the rainfall distributions with and without the effect of human influences.

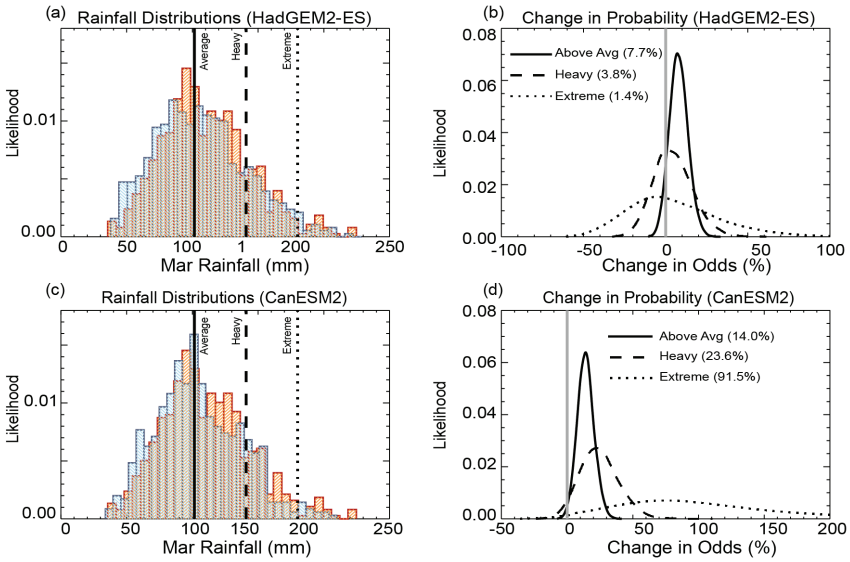

Fig. 19.2. Normalized distributions of the rainfall over eastern Australia in Mar 2012 (panels a and c) constructed with the ACE ensembles with (red histograms) and without (blue histograms) the effect of human influences. Simulations of the natural climate use estimates of the change in the SST and sea ice due to anthropogenic forcings from HadGEM2-ES and CanESM2 (blue histograms in panels a and c respectively). The normalized distributions of the change in the odds of above average, heavy, and extreme rainfall in the region in Mar 2012 due to anthropogenic forcings are shown in panels (b) and (d) for the two versions of the natural climate. The thresholds for average, heavy, and extreme rainfall correspond to the 1960–2010 climatological mean and the rainfall levels of one and two standard deviations above the mean. The best estimate of the change in the odds, approximated by the median of the distribution, is also noted in panels (b) and (d).

Conclusions. The La Niña episode in early 2012 is unlikely to entirely explain why March 2012 was the third wettest in the observational record in eastern Australia. Warm north Australian SSTs, however, are expected to result in wetter conditions and given the continuing warming trend of the ocean, increased rainfall over the eastern part of the country could become more common. Using the ACE methodology we find that the overall long-term effect of human

influences on the climate increases the chances of above-average rainfall by 5%–15% (best estimate), although the impact on extreme precipitation is much more uncertain. Even when all climatic forcings are accounted for, the observed rainfall in March 2012 lies in the far tail of the expected rainfall distribution from the ACE ensembles. Therefore, despite the potential contribution of all factors examined here, the extreme magnitude of the event appears to arise mainly from unforced internal climatic variations.