27. NATURAL VARIABILITY NOT CLIMATE CHANGE DROVE THE RECORD WET WINTER IN SOUTHEAST AUSTRALIA

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Warmth in the east Indian Ocean increased the likelihood of the record wet July–September in southeast Australia by at least a factor two. The role of climate change was minimal.

Introduction. In July–September 2016, southeast Australia suffered from record-breaking wet conditions (Fig. 27.1a). This three-month wet period featured several significant extratropical low pressure systems culminating in a major system crossing the region that resulted in a power blackout across South Australia. While this wet period had many negative consequences, including multiple flood events, it also provided much-needed rainfall for farmers in a region of Australia home to a large volume of the country's food supply.

The 2016 wet extreme is not part of a trend towards wetter conditions (Fig. 27.1a). The event was associated with large quantities of moisture being advected from the eastern Indian Ocean, a region that was experiencing well-above average sea surface temperatures (Fig. 27.1b). This moisture interacted with extratropical weather systems crossing the south of the country (Bureau of Meteorology 2017). There was lower surface pressure than normal over southeast Australia (Fig. 27.1c), reflecting an equatorward movement in the storm track, and the moisture content of the atmosphere was higher than normal (Fig. 27.1d) in July–September 2016.

This study examines the roles of both human-induced climate change and natural climate variability in this event. The influences of these two factors on the circulation patterns conducive to unusually wet seasons and moisture availability are considered.

Data and methods. The observed precipitation anomalies (1961–90 baseline) are derived from the Australian Water Availability Project product (AWAP; Jones et al. 2009). Over regions of the continent with relatively dense station coverage, like southeast Australia (SEA; 33°–45°S, 135°–155°E), AWAP performs well in capturing extreme rainfall variability and trends (King et al. 2013). The sea surface temperatures (SSTs) over the east Indian Ocean (EIO) region (0°–20°S, 90°–120°E) were extracted from HadISST (Rayner et al. 2003), and anomalies were also calculated from 1961–90. For both SEA rainfall and EIO SSTs the anomalies are calculated from the area-averaged time series for the July–September (JAS) period.

The mean sea level pressure (MSLP) and total column water vapor (TCWV) anomalies associated with the 2016 event were both calculated from the ERA-Interim reanalysis (Dee et al. 2011) with a 1981–2000 baseline period. The MSLP and TCWV anomalies were also calculated from the SEA-region area-average, over both land and sea grid boxes, whereas the rainfall anomalies were for land-only boxes. To estimate trends in these indices over a longer period, the ERA-20C reanalysis (Poli et al. 2016), which extends back to 1900, was used.

To assess the influence of anthropogenic climate change and natural climate variability from the EIO region, CMIP5 models (Taylor et al. 2012) were used. Simulations under both natural and anthropogenic forcings for the past (historical; 1860–2005) and future (RCP8.5; 2006–2100), and model simulations including only natural forcings (historicalNat; 1860–2005) were analyzed. Sixteen climate models, with at least three historical simulations, were analyzed initially (Table ES27.1). After evaluation (see online supplement information), nine of 16 CMIP5 models remained for further analysis (Table ES27.1).

The role of climate change was estimated through calculating the change in likelihood of wet JAS periods like 2016 (using a threshold of +30% rainfall anomaly) between the current world (2006–26 in RCP8.5 simulations) and a natural world (1901–2005 in historicalNat simulations). This is a relatively weak

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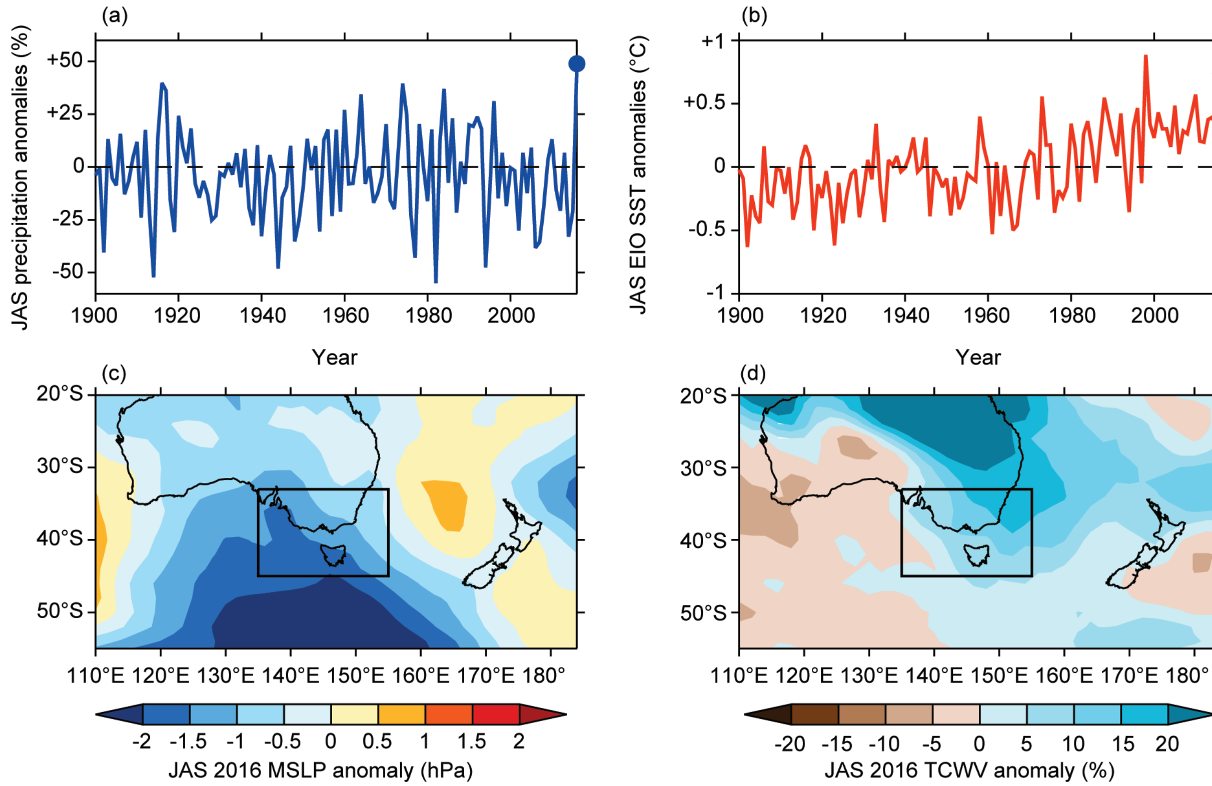

Fig. 27.1. Time series of Jul–Sep (a) SEA rainfall anomalies (%), and (b) EIO SST anomalies (°C), from a 1961–90 baseline with 2016 marked by a dot. Maps of Jul–Sep 2016 (c) mean sea level pressure anomalies (hPa), and (d) TCWV anomalies (%), from a 1981–2000 baseline (due to the length of ERA-Interim). Boxes indicate SEA region.

threshold chosen to increase statistical power. Uncertainties on the estimated change in likelihood were calculated by bootstrap resampling half of the simulations in each ensemble 10 000 times. Future changes in rainfall anomalies under a high greenhouse gas emissions scenario were also investigated (2040–60 in RCP8.5). This period was chosen to represent a near-future scenario with a little more than 2°C of global warming.

The influence of the warmth in the EIO SSTs was estimated by comparing the likelihood of wet JAS periods like 2016 (same threshold as previously) in seasons of above- and below-average detrended EIO SST anomalies in the current world ensemble (2006–26 in RCP8.5). Again, uncertainties on this change in likelihood were estimated through bootstrapping.

Due to a lack of TCWV model data, the climate change and EIO SST relationships with MSLP and TCWV over SEA and the surrounding region were investigated using ERA-20C instead. Correlations (Spearman rank) between EIO SSTs and SEA-average MSLP and TCWV were calculated and subsequent relationships with precipitation anomalies were assessed. The influence of climate change on these variables was examined through trends over 1900–2010 while the effect of warm EIO SST anomalies was investigated by compositing MSLP and TCWV detrended anomalies under warm EIO SST conditions (above +0.2°C detrended) and all other EIO SST values. Note that this does not constitute an attribution of changes in circulation and moisture to climate change and Indian Ocean SSTs, but it provides an indication of these relationships.

There is a warming trend in the EIO (Fig. 27.1b), but I focus on detrended EIO anomalies since these have a stronger relationship with SEA rainfall. The likely reason is due to the EIO being a source of Rossby waves influencing circulation over SEA (van Rensch and Cai 2014), so the EIO SST relative to other equatorial regions is of greater importance than the absolute EIO SST.

Results: a) The role of anthropogenic climate change. Human-induced climate change does not appear to be having a significant influence on the likelihood of wet JAS periods in SEA (Fig. 27.2a). High uncertainty exists even in the sign of the change in likelihood of wet JAS periods between the natural world and the

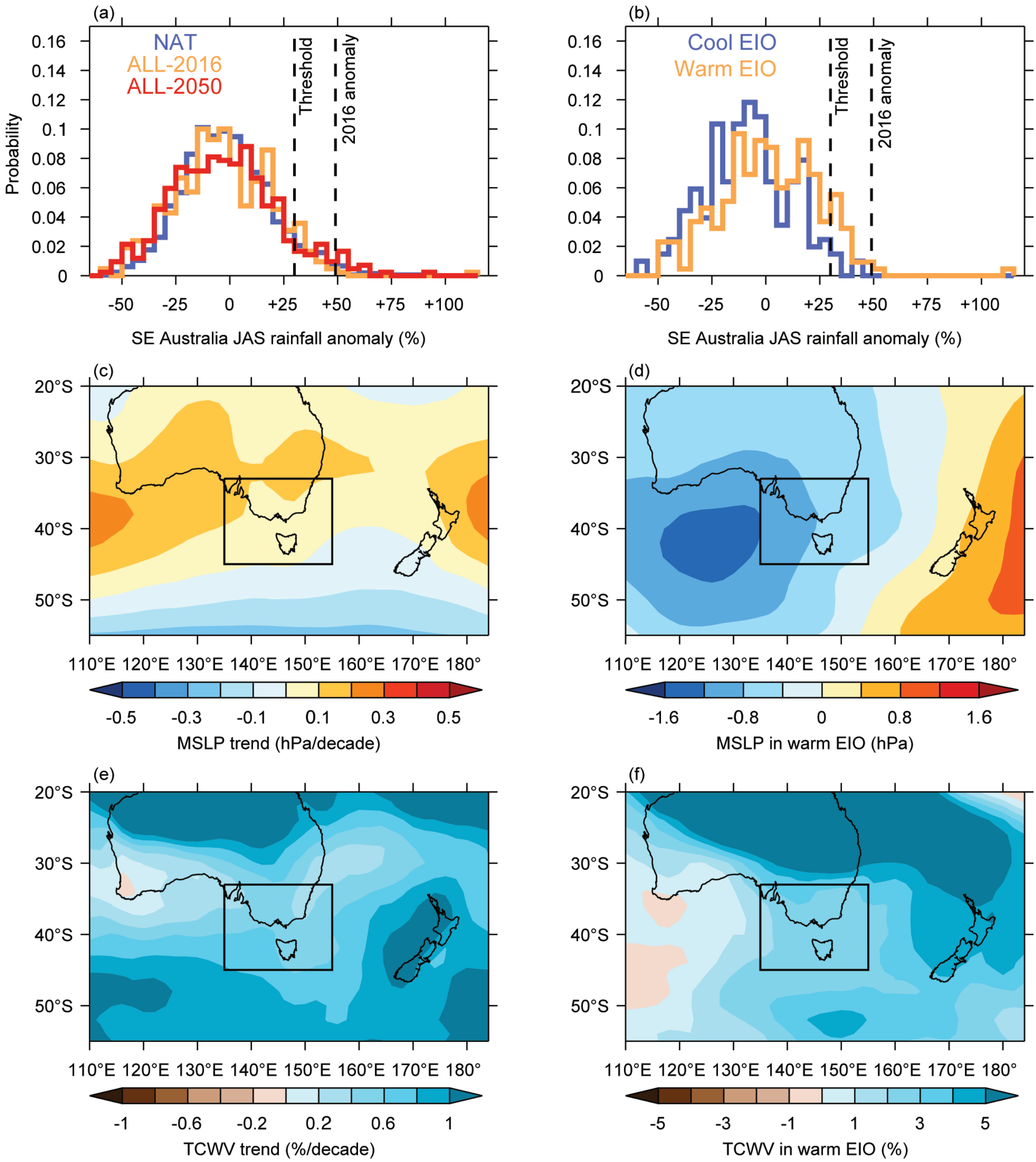

FIG. 27.2. (a) Probability distributions of Jul–Sep SEA rainfall anomalies (%) under natural climate influences only (blue), all climate influences in the current world (orange), and all climate influences in the world of 2050 under continued high greenhouse gas emissions (red). (b) Probability distributions of Jul–Sep SEA rainfall anomalies (%) under cool EIO conditions (blue) and warm EIO conditions (orange) in the current world. Dashed lines in (a) and (b) indicate the 2016 anomaly and the +30% threshold used in FAR calculations. (c) MSLP trend (hPa decade^{-1}) and (d) MSLP average anomalies (hPa) in warm EIO conditions. (e) TCWV trend (% decade^{-1}) and (f) TCWV average anomalies (%) in warm EIO conditions. Boxes indicate the SEA region.

current world based on the 10 000 bootstrapped subensembles. The probability distributions of rainfall anomalies in the natural world and current world are not significantly different. The future world distribution is slightly wider (Fig. 27.2a) due to weak opposing trends in different models (not shown).

The influence of climate change appears to be toward an increase in MSLP (Fig. 27.2c; conducive to a decrease in JAS rainfall in SEA) and an increase in TCWV (Fig. 27.2e; conducive to an increase in JAS rainfall). These effects appear to be largely canceling each other out as demonstrated by the lack of a trend in observed (Fig. 27.1a) and simulated (Fig. 27.2a) rainfall over SEA. The tendency towards higher pressure over southern Australia is well-documented and is related to a poleward movement in the extratropical storm track during austral winter that is predominantly due to greenhouse gas emissions (e.g., Arblaster and Meehl 2006; Delworth and Zeng 2014), although it may, in part, also be related to stratospheric ozone depletion. Over the coming decades the storm track is expected to continue to move polewards due to increased greenhouse gas emissions, even as ozone levels recover (e.g., Bengttson et al. 2006).

Human-induced climate change is also increasing the ability of the atmosphere to hold water vapor through the Clausius–Clapeyron effect. I do not consider shorter-term extreme rainfall for which the moisture availability and circulation changes may be less balanced.

b) The role of the east Indian Ocean. There is a shift in the probability distributions between SEA rainfall associated with cool and warm EIO SST anomalies whereby warmer conditions favor wetter JAS periods. The warmth in the EIO increased the likelihood of the record wet JAS period in SEA by at least a factor two using the +30% rainfall anomaly threshold (Fig. 27.2b). No events under cool EIO conditions reach the observed JAS 2016 anomaly, and there were just five events above the +30% threshold in that ensemble.

Unlike the climate change influence, the effect of warm conditions in the EIO is to enhance conditions associated with wetter periods. Warmer conditions in the EIO tend to be associated with lower MSLP over the Great Australian Bight (Fig. 27.2d; conducive to higher JAS rainfall in SEA), and higher TCWV (Fig. 27.2f; also conducive to higher JAS rainfall). The water vapor relationship with SST anomalies in the EIO is stronger than the MSLP response to the SSTs (Fig. ES27.1). The EIO is a source region for an equivalent-barotropic Rossby wave train which influences MSLP to the south of Australia (van Rensch and Cai 2014), thus affecting atmospheric circulation in the region. In addition, moisture is advected over the continent during warm episodes in the EIO through northwest cloud bands and these often reach southern Australia and interact with frontal systems.

Conclusions. While the effect of human-induced climate change on this event appears to be minimal, it is estimated that the anomalous warmth in the EIO increased the likelihood of the wet July–September in southeast Australia by at least a factor two. Warmth in the EIO tends to both increase moisture availability and decrease surface pressure, resulting in rainfall increases. In contrast the effects of climate change on circulation and moisture largely cancel each other out.

It is interesting to note that a "mis-attribution" statement was possible in this study if the analysis had been designed more simplistically. I found a positive correlation between EIO SSTs and SEA rainfall, and I also show that EIO SSTs are increasing. Given that this trend is in part related to anthropogenic climate change (e.g., Roxy et al. 2014), an incorrect attribution of the record high rainfall in SEA to human influences could have been made. Also, a simplistic argument that human-caused climate change increases atmospheric water vapor, thus increasing the likelihood of wetter events, would have also been incorrect in this case. The circulation response to anthropogenic climate change is reducing the likelihood of high rainfall over SEA and counteracting the effect of increasing water vapor content. This study highlights the need for carefully designed attribution analyses.

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