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Future changes in Extreme East Coast Lows

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Low pressure systems affecting the east coast of Australia are known as East Coast Lows (ECLs). Severe ECLs are responsible for the majority of damaging storm events in this region. How these severe ECLs may change in a future warmer climate is a major question for the area. The NSW ACT Regional Climate Modelling (NARClIM) project downscaled four global climate models with three regional climate models to produce a 12-member ensemble of high-resolution (50 km and 10 km) climate projections for southeast Australia. Using these projections, and several objective methods for identifying and tracking ECLs, future changes in severe ECLs are examined. The use of both a 12-member regional climate projection ensemble, and a range of ECL identification methods with different strengths and sensitivities, allows an assessment of robustness for these future changes in severe ECLs.

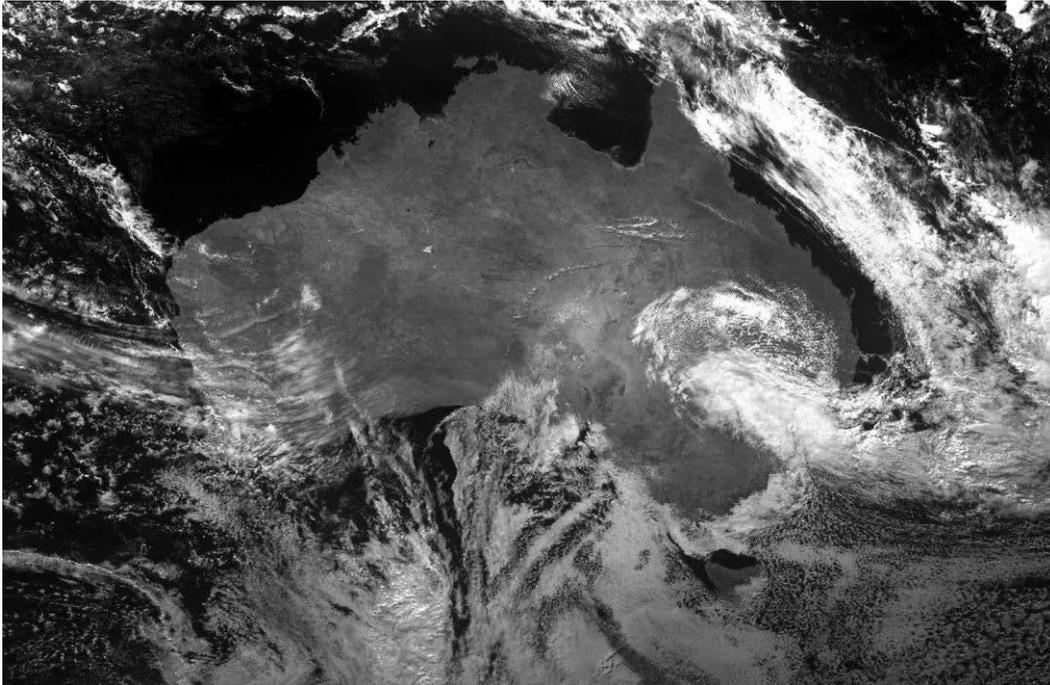


Figure 1: Geostationary satellite image of the 8 June 2007 East Coast Low event that flooded Newcastle and beached the Pasha Bulker.

1. INTRODUCTION

The east coast of Australia from north-east Victoria to south-eastern Queensland is subject to heavy rain, strong winds and large waves resulting from low pressure systems adjacent to the Tasman Sea that develop from a variety of synoptic and mesoscale systems (Speer et al. 2009). These systems, referred to as “East Coast Lows”, cause a significant amount of damage along the east coast each year (see Figure 1). They are also a major source of water for the reservoirs serving coastal communities, and thus are both vital to, and dangerous for, human activities in the area. Understanding the likely future changes in ECLs is therefore a major policy-relevant concern for our project partners.

It has been known for some time that ECLs produce large precipitation events on the east coast of Australia (e.g. Holland et al. 1987; McInnes et al. 1992). Formation of ECLs generally requires an upper level cutoff low or short-wave trough moving over an area of strong low-level baroclinicity (Holland et al. 1987; Hopkins and Holland 1997). Thus while the right large scale atmospheric circulation conditions are necessary for these very large ECL events, the speed of development and final intensity are still dependant on relatively small scale features such as the size and strength of the southerly jet streak and the low level atmospheric conditions (McInnes and Hess 1992). ECLs have the capacity for rapid intensification (Holland et al. 1987), with many satisfying the “Bomb” criterion of Sanders and Gyakum (1980).

However, ECLs are often storms with relatively small spatial scales and short lifetimes (Holland et al. 1987). Their pressure centres may develop or intensify offshore making them difficult to study using standard in situ observations. While Global Climate Models (GCMs) have been found to significantly under-predict their frequency and their residence time near the coast (Katzfey and McInnes 1996). In this project we use Regional Climate Models (RCMs) to simulate the climate around the east coast at high enough spatial and temporal resolutions to capture ECL development and intensification. These RCMs should allow the detailed study of ECL systems (Evans et al. 2012; Ji et al. 2014) and the testing of hypotheses concerning how important various physical processes are to their development. The RCMs have also been ‘nested’ in Global Climate Model simulations to produce high resolution projections of the future East coast climate, including any changes in the development and intensity of

ECLs.

Future changes in ECLs due to global warming has been considered explicitly in few studies to date. Due to the known inability of GCMs to capture the distribution of ECLs, Dowdy et al. (2013b,a) applied a diagnostic of ECL activity based on an upper-level vorticity measure to a small number of GCM projections. This study projected a 30% decrease in future ECL frequency, and associated this with a decrease of 8 to 25% in heavy rainfall events on the eastern seaboard. Dowdy et al. (2014) used the same GCM based vorticity measure to also estimate a future decrease in wave heights, with similar projected declines. A similar decrease in storm wave energy was also found by Hemer et al. (2013), although they first physically downscaled the GCM data to ~60km resolution using a regional climate model. Recently Ji et al. (2015) used the same regional climate projection ensemble investigated here, along with the vorticity measure of Dowdy et al. (2013a) to show that the modelled decrease in ECL frequency also arise when using higher resolution models and that this decrease occurs largely in winter. However, at this point there are no projections available for ECLs when explicitly identified through their synoptic features at the surface.

The main impact ECLs have on the coastal areas is in producing rainfall, often extreme rainfall that leads to flooding. Climate change impact studies performed for Eastern Australia (e.g. CSIRO 2007; CSIRO and Bureau of Meteorology 2015) indicate large uncertainty in future rainfall projections. Rainfall statistics are substantially harder to simulate than other meteorological variables due to 1. uncertainties in convection parameterisations and cloud processes as well as spatial resolution; 2. regional variability and strong spatial complexity; 3. the statistical volatility of rainfall given its non-normal distribution requiring sophisticated analysis techniques particularly for extreme events in the distribution tails. The use of regional climate models to dynamically downscale the GCM data to higher resolution helps to address each of these points, including improving the simulation of the tail of the distribution (Tapiador et al. 2009).

The study reported here investigates future changes to extreme ECLs as modelled within a regional climate model ensemble.

2. DATA AND METHODS

2.1. The NARCLiM Ensemble

The New South Wales / Australian Capital Territory Regional Climate Modelling (NARCLiM) project produced a 12-member ensemble of dynamically downscaled climate projections for south-east Australia (Evans et al. 2014). The ensemble was created by downscaling four Global Climate Models (GCMs) from the CMIP3 dataset (Meehl et al. 2007) with three Regional Climate Models (RCMs) created using different configurations of the Weather Research and Forecasting (WRF) model. These GCMs were chosen based on their performance, level of model independence (Evans et al. 2013; Bishop and Abramowitz 2013), and the ability to capture the full ensemble spread of future changes in temperature and precipitation. The RCMs were chosen based on their performance (Evans et al. 2012) and model independence. This model selection process ensures that the regional climate projection ensemble spans much of the uncertainty present in the full GCM ensemble. The NARCLiM model domains are shown in Figure 2.

2.2. Low detection methods

Four different automated low detection methods have been applied to identify and track ECLs in recent years (Dowdy et al. 2013a; Browning and Goodwin 2013; Pepler and Coutts-Smith 2013). The Laplacian based method of cyclone identification and tracking described in Murray and Simmonds (1991) was applied in Pepler and Coutts-Smith (2013) and here is referred to as LAPv1. An updated version of this scheme, referred to as LAPv2, has also been used (Lim and Simmonds 2007). Browning and Goodwin (2013) identified East Coast Lows based on the presence of a closed low in the surface pressure field as determined using 2D pressure gradients (referred to as PG). Dowdy et

al. (2013a) presented an alternative method (here referred to as ULGV) of identifying ECL-favorable conditions that has been optimized for studies using low-resolution global climate models, described above. Rather than seeking to identify an ECL in the pressure field, Dowdy's approach calculates the 500 hPa geostrophic vorticity and assumes an ECL is present if the vorticity is larger than a predetermined threshold, typically chosen to identify a certain number of ECLs per year in the current climate

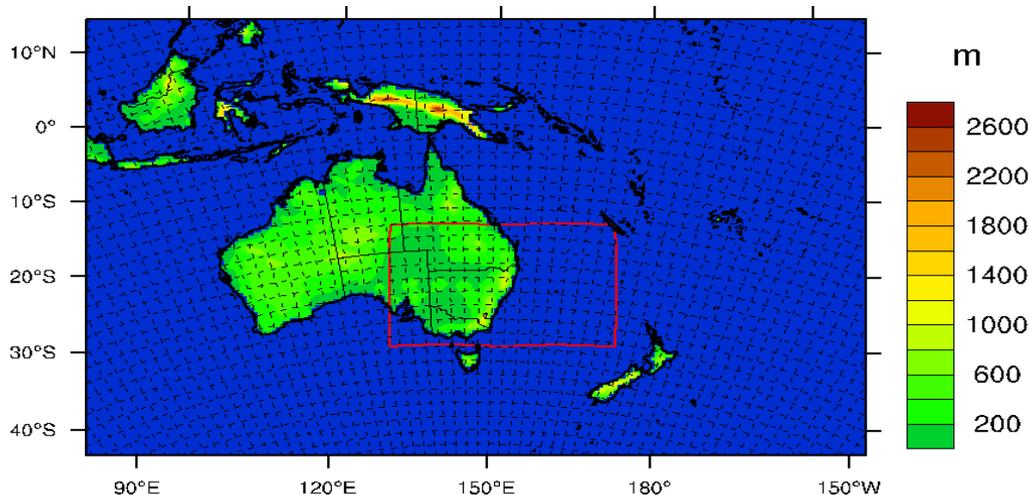


Figure 2: NARCLiM model domains. The whole area was modelled at 50km resolution while the inner red box was modelled at 10km resolution.

In a recent paper, Pepler et al. (2014) investigated the sensitivity of ECL identification based on these methods using reanalysis data (see Figure 3) in comparison to a manual ECL database, and found large differences between identification methods when considering all ECLs. However, there was much larger agreement between all methods when considering only the more extreme events based on high wind gusts, significant wave heights or explosive development. Thus, when only considering extreme ECLs the identification methods are largely interchangeable. The two LAP versions were particularly similar, with only the superior LAPv2 method retained for further analysis.

3. FUTURE CHANGES TO EXTREME ECLS

Figure 4 shows the future change in ECL frequency for moderately intense ECLs. For each ECL identification method and NARCLIM ensemble member, an event maximum intensity threshold is identified that gives five ECLs per year on average in the 1990-2009 period, and changes assessed for ECLs exceeding that intensity threshold in 2060-2079. The whiskers indicate the NARCLiM ensemble range, the box contains the 25th to 75th percentile and the median is given by the central line. Three different ECL identification methods are shown (i.e., ULGV, LAP and PG) with both the LAP and the PG methods applied at two different resolutions. The future change in the number of ECLs in the cool season shows a consistent decrease, while the warm season change is less certain with zero change falling within the ensemble range in each case.

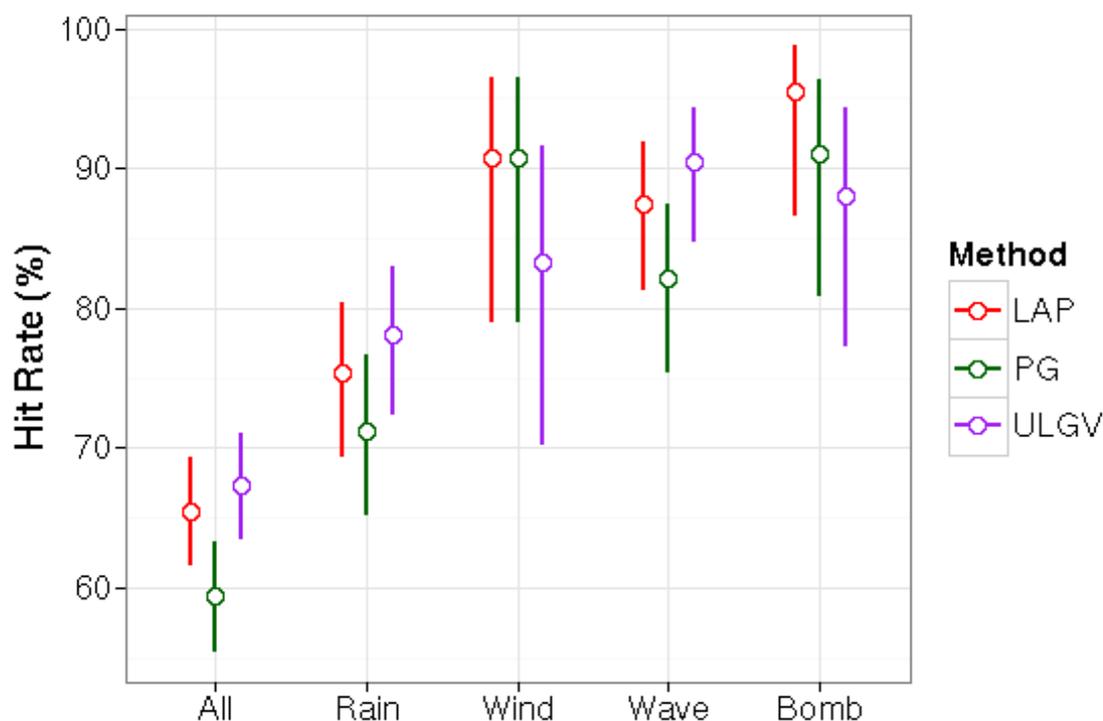


Figure 3: Hit rates (within 1 day) for the four ECL identification methods (section 2) when detecting ECL events in the Maritime Low Database (Speer et al. 2009) , with bars indicating the 95% confidence interval from a using the bias-corrected accelerated bootstrap test (10,000 samples). Hit rates for subcategories of ECL are also indicated, including those associated with an east coast rainfall cluster, wind gusts $> 90 \text{ km h}^{-1}$ or significant wave heights $> 4 \text{ m}$, and explosive events. Reproduced from Pepler et al. (2014).

The use of a wind speed threshold of 17ms^{-1} allows for the selection of those intense ECL that have wind speeds equivalent to that of a tropical storm. Figure 5 shows wind speed and mean sea level pressure composites for winter (JJA) and summer (DJF) ECLs satisfying this wind speed threshold criteria for both the present-day (1990-2009) and the far future (2060-2079) simulations. These composites were constructed by selecting, for each individual simulation, ECLs that satisfy the wind speed criteria, and then averaging across the members of the NARClIM ensemble. Little overall change in the wind fields for these events is evident in winter, while there is a small intensification in summer ECLs. There is also a decrease in the number of these storms in winter (from 52 to 46) and an increase in summer (104 to 115). Compared to the results for all ECLs given in Figure 4, we can see that the winter decrease in the number of intense ECLs is smaller than the overall winter decrease, and that the summer increase is larger than is expected based on results for all ECLs.

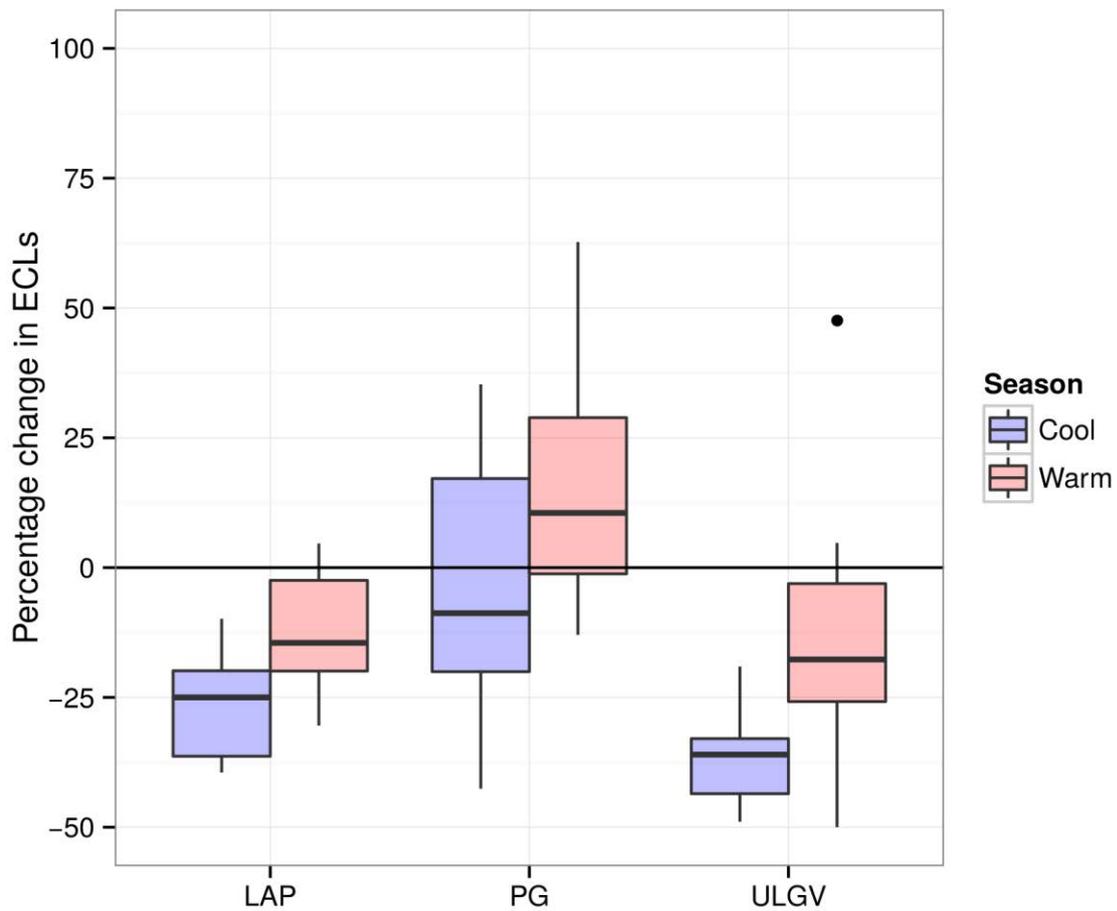


Figure 4: Percent change in ECLs from 2000 to 2070 with intensity threshold designed to give 5 ECLs p.a. Note that one member for ULGV projects warm season increases greater than 100% and is not shown in the figure.

4. CONCLUSIONS

In general ECLs are projected to decrease in frequency in the future with most of this decrease occurring in winter. This overall decreasing trend does not hold for the most intense ECLs that are projected to decrease only a little in winter but to increase in summer. Further work is required to determine the spatial variability of these changes as it is suspected that the summer increase is related to an increased frequency of tropical systems entering the northern part of the domain. The causes behind the overall decreasing frequency of future ECLs remains to be investigated.

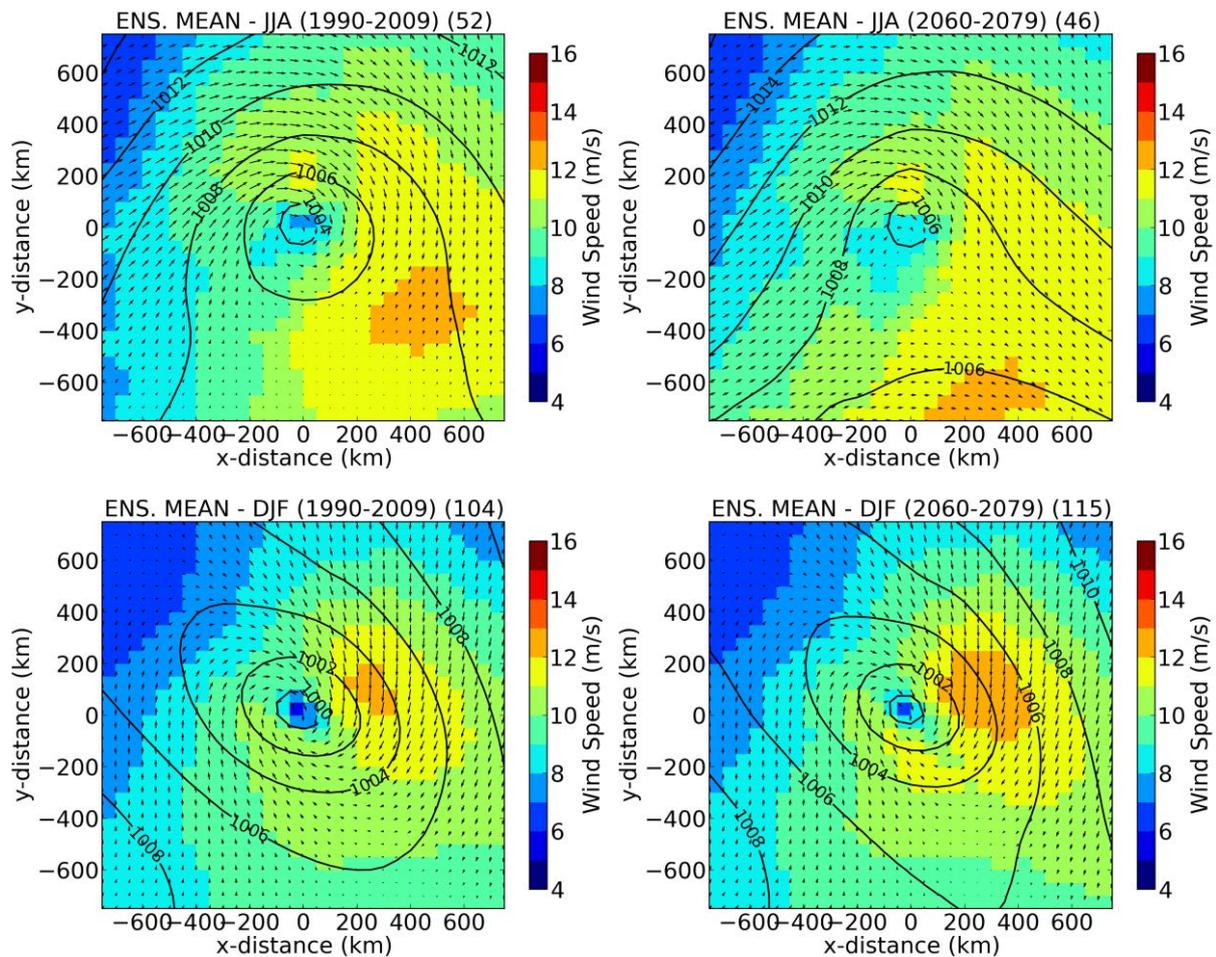


Figure 5: Ensemble composite of ECLs with wind speeds greater than 17m s^{-1} . Line contours indicate the sea level pressure. Coloured contours indicate the wind speed and vectors indicate the direction. The number to the top right of each panel indicates the number of events in each composite.

5. ACKNOWLEDGMENTS

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6. REFERENCES

- Bishop, C. H., and G. Abramowitz, 2013: Climate model dependence and the replicate Earth paradigm. *Clim Dyn*, **41**, 885–900, doi:10.1007/s00382-012-1610-y.
- CSIRO, 2007: *Climate Change in Australia*. CSIRO, 148 pp. <http://www.climatechangeinaustralia.gov.au/index.php>.
- , and Bureau of Meteorology, 2015: *Climate Change in Australia Projections for Australia's NRM Regions*. CSIRO and Bureau of Meteorology, Australia,.
- Dowdy, A. J., G. A. Mills, and B. Timbal, 2013a: Large-scale diagnostics of extratropical cyclogenesis in eastern Australia. *Int. J. Climatol.*, **33**, 2318–2327, doi:10.1002/joc.3599.

- , ——, ——, and Y. Wang, 2013b: Changes in the Risk of Extratropical Cyclones in Eastern Australia. *Journal of Climate*, **26**, 1403–1417, doi:10.1175/JCLI-D-12-00192.1.
- , ——, ——, and ——, 2014: Fewer large waves projected for eastern Australia due to decreasing storminess. *Nature Clim. Change*, **4**, 283–286, doi:10.1038/nclimate2142.
- Evans, J., M. Ekström, and F. Ji, 2012: Evaluating the performance of a WRF physics ensemble over South-East Australia. *Climate Dynamics*, **39**, 1241–1258, doi:10.1007/s00382-011-1244-5.
- Evans, J. P., F. Ji, G. Abramowitz, and M. Ekström, 2013: Optimally choosing small ensemble members to produce robust climate simulations. *Environ. Res. Lett.*, **8**, 044050, doi:10.1088/1748-9326/8/4/044050.
- Evans, J. P., F. Ji, C. Lee, P. Smith, D. Argüeso, and L. Fita, 2014: Design of a regional climate modelling projection ensemble experiment – NARClIM. *Geosci. Model Dev.*, **7**, 621–629, doi:10.5194/gmd-7-621-2014.
- Hemer, M. A., K. L. McInnes, and R. Ranasinghe, 2013: Projections of climate change-driven variations in the offshore wave climate off south eastern Australia. *Int. J. Climatol.*, **33**, 1615–1632, doi:10.1002/joc.3537.
- Holland, G., A. Lynch, and L. Leslie, 1987: Australian east-coast cyclones .1. Synoptic overview and case-study. *Monthly Weather Review*, **115**, 3024–3036.
- Hopkins, L., and G. Holland, 1997: Australian heavy-rain days and associated east coast cyclones: 1958-92. *Journal of Climate*, **10**, 621–635.
- Ji, F., M. Ekström, J. P. Evans, and J. Teng, 2014: Evaluating rainfall patterns using physics scheme ensembles from a regional atmospheric model. *Theor Appl Climatol*, **115**, 297–304, doi:10.1007/s00704-013-0904-2.
- , J. P. Evans, D. Argueso, L. Fita, and A. D. Luca, 2015: Using large-scale diagnostic quantities to investigate change in East Coast Lows. *Clim Dyn*, 1–11, doi:10.1007/s00382-015-2481-9.
- Katzfey, J., and K. McInnes, 1996: GCM simulations of eastern Australian cutoff lows. *Journal of Climate*, **9**, 2337–2355.
- McInnes, K. L., and G. D. Hess, 1992: Modifications to the Australian region limited area model and their impact on an east coast low event. *Australian Meteorological Magazine*, **40**, 21–31.
- , L. M. Leslie, and J. L. McBride, 1992: Numerical simulation of cut-off lows on the Australian east coast: sensitivity to sea-surface temperature. *International Journal of Climatology*, **12**, 783–795.
- Meehl, G. A., C. Covey, T. Delworth, M. Latif, B. McAvaney, J. F. B. Mitchell, R. J. Stouffer, and K. E. Taylor, 2007: The WCRP CMIP3 multimodel dataset - A new era in climate change research. *Bull. Amer. Meteor. Soc.*, **88**, 1383–1394.
- Pepler, A. S., A. Di Luca, F. Ji, L. V. Alexander, J. P. Evans, and S. C. Sherwood, 2014: Impact of Identification Method on the Inferred Characteristics and Variability of Australian East Coast Lows. *Mon. Wea. Rev.*, **143**, 864–877, doi:10.1175/MWR-D-14-00188.1.
- Sanders, F., and J. Gyakum, 1980: Synoptic-dynamic climatology of the bomb. *Monthly Weather Review*, **108**, 1589–1606.
- Speer, M., P. Wiles, and A. Pepler, 2009: Low pressure systems off the New South Wales coast and associated hazardous weather: establishment of a database. *Australian Meteorological and Oceanographic Journal*, **58**, 29–39.