WRF simulations of future changes in rainfall IFD curves over Greater Sydney

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Abstract

The Weather Research and Forecasting (WRF) model has been used at convection-permitting resolution (2km) to simulate the future climate of the greater Sydney region with a focus on precipitation extremes at durations from 1 hour to 1 day. Overall, the simulations project temperature increases of 1 to 2°C, with larger increases in autumn and winter compared to spring and summer. In terms of precipitation most of the domain is projected to see annual increases of up to 40%. These increases occur mostly in autumn, with little change in summer. Extreme precipitation (higher than 95th percentile) is projected to contribute a larger proportion of this precipitation total.

While the model can reasonably reproduce medium extremes (like the 95th percentile), annual maxima precipitation time-series contains significant over-estimation for much of the area of interest. Given this model limitation, the area-averaged rainfall Intensity-Frequency-Duration (IFD) curves are simulated reasonably well at large Annual Exceedence Probabilities (AEPs) (50%) and show progressively larger errors for rarer AEPs. Future projections show rainfall depths increasing for all durations and AEPs considered here. This future increase is larger for rarer AEPs, but relatively consistent across durations.

1. INTRODUCTION

Projecting future climate change impacts on precipitation, particularly extreme precipitation, remains a significant challenge for the climate modelling community due to the many non-linear processes involved and the high spatial variability. Projections of extremes such as annual maxima at sub-daily durations, as required for IFD curves, are particularly difficult for current climate models (Westra et al. 2014). Applying some kind of downscaling and bias correction to future climate projections are necessary steps to overcome the climate model shortcomings in this regard.

Several previous studies have investigated future changes in IFDs using regional climate models (RCMs) with a number using data from the North American Regional Climate Change Assessment Program (Mirhosseini et al. 2013, 2014; Wang et al. 2013; Zhu et al. 2013). These simulations use relativity coarse spatial resolution (50km). Studies that used station based observations applied various bias corrections to account for both model errors and the spatial scale mismatch between model grid cells and station locations (Mirhosseini et al. 2013; Wang et al. 2013). This correction was applied to the precipitation depths within the IFDs so that the correction applied directly to the most extreme rainfall intensities. Biases of 50% or more were often found (Liew et al. 2014; Mirhosseini et al. 2013; Wang et al. 2013; Zhu et al. 2013) in the model results for the recent past. Several studies also applied a regional frequency analysis to increase the sample size and hence the robustness of the results (Kuo et al. 2015; Zhu et al. 2013). Kuo et al. (2015) applied an RCM at convection-permitting resolution (3km), reducing the scale mismatch and the dependence on a convection parametrization. This resolution had previously been found to be required to capture small-scale convective precipitation events. While attempts to explicitly quantify uncertainty led to wide ranges (Kuo et al. 2015 often found ±50%), studies generally found increases in rainfall depths in the future though this varied across AEPs, durations and locations, emphasizing the difficulty in generalizing these results more broadly.

This study reports the projected IFD curves at 2050 for the greater Sydney region produced using a convection-permitting resolution Regional Climate Model (RCM).

2. EXPERIMENT DESIGN

The RCM used is based on the Weather Research and Forecasting (WRF) modelling system. WRF is developed as a collaborative partnership between the National Center for Atmospheric Research (NCAR), the National Oceanic and Atmospheric Administration's Centers for Environmental Prediction (NCEP) and the Forecast Systems Laboratory, the Air Force Weather Agency, the Naval Research Laboratory, Oklahoma University, and the Federal Aviation Administration in the USA, as well as the wider research community. The version used in this study is the Advanced Research WRF (ARW) version 3, maintained at NCAR (Skamarock et al. 2008).

The boundary conditions for the 2km simulation were taken from the previously performed and evaluated 10km simulation (Evans and McCabe 2010, 2013). The model used the following physics schemes: WRF Single Moment 5-class microphysics scheme; the Rapid Radiative Transfer Model (RRTM) longwave radiation scheme; the Dudhia shortwave radiation scheme; Monin-Obukhov surface layer similarity; Noah land-surface scheme; the Yonsei University boundary layer scheme and the Kain-Fritsch cumulus physics scheme.

For the 2km simulation no cumulus physics scheme is required, and the cloud microphysics scheme

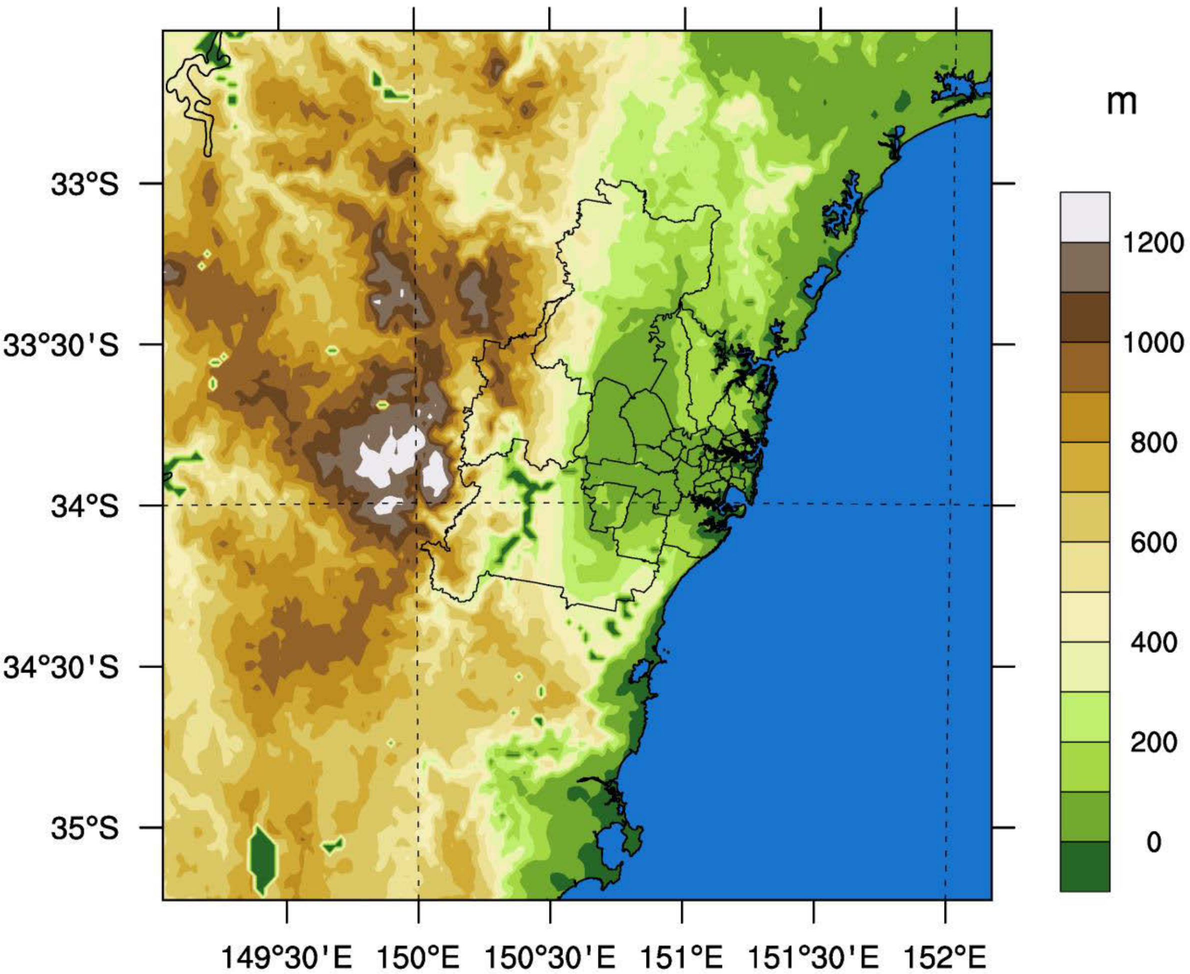

Figure 1 High resolution simulation domain with topography. Black lines indicate the Sydney council regions.

plays a more important role warranting the use of a more complex scheme. Several microphysics scheme were run for 1990 conditions and then evaluated against gridded and station based observations. The chosen scheme is the Thompson microphysics scheme (Thompson et al. 2004). There are 40 vertical atmospheric levels in the 2km simulation.

The model domain is shown in Figure 1. Land use data was derived primarily from NSW statewide Land Use data and translated in to the 24 class USGS classification. The future land-use map contains minor changes to the present map based on data from the NSW Department of Planning that indicate areas of urban expansion.

These simulations were performed using global boundary conditions from the CSIRO Mk3.5 Global Climate Model (GCM) simulation (Gordon et al. 2002) using the SRES A2 (high) emissions scenario. Simulations for both the recent past (1990-2009) and a future time slice (2040-2059) were performed.

A bias-correction technique is applied to the temperature and precipitation time series (Argüeso et al. 2013). This technique combines the fitting of theoretical functions (Gamma for precipitation, Gaussian for temperature) to the cumulative distribution functions at each grid point and correcting these based on observations from nearby stations. The technique is designed to correct for biases in the lower order moments of the distribution.

The Bureau of Meteorology has produced new design rainfall IFD curves (http://www.bom.gov.au/water/designRainfalls/ifd/) using a database comprising rainfall data from the Bureau's rain gauge network and data from rainfall recording networks operated by other organisations across Australia. The quality controlled rainfall data was used to fit Generalised Extreme Value (GEV) distributions using the technique of L-moments for the rainfall frequency analysis; Bayesian Generalised Least Squares Regression for deriving sub-daily rainfall statistics from daily rainfall values; GIS-based methods for gridding data; and an 'index rainfall procedure' for regionalisation of point data. The derived grids of parameters for the GEV distribution were used to derive rainfall IFD curves for the Greater Sydney domain.

3. RESULTS

The present-day WRF model precipitation contains a general overestimation bias that can be seen in Figure 3. After applying the bias correction this over-estimation bias is substantially reduced but not eliminated. An overestimation remains in the bias-corrected model precipitation output, partly due to errors in the fitting of theoretical gamma functions.

At each land grid point within the model domain the annual maximum precipitation time series for durations 1, 3, 6, 12 and 24 hours was calculated. To these time series GEV distributions are fitted using the same L-moments procedure used by the Bureau of Meteorology to derive the observations-based GEV. Rainfall depths are then averaged over the domain to produce the rainfall IFD curves shown in Figure 3.

WRF is able to reproduce the 50% AEP very well but is progressively worse at rarer AEPs. The error is largest in the 3 – 12 hour rainfall durations for the rarer AEPs, and reaches ~60% for the 6-hour duration rainfall depth for the 1% AEP. WRF does a good job at simulating the 1 hour rainfall depths for all AEPs. It can be seen that the observations display a near linear response across durations while the model has a non-linear response with increases being more rapid at short durations than at long durations.

The change in IFDs estimated by the bias-corrected present day (1990-2009) WRF and the bias-corrected future WRF (2040-2059) is shown in Figure 4. Increases in rainfall depths can be found across all durations and AEPs. These increases are larger in rarer flood events and with increasing event duration. They reach ~50% for 12 hour durations for the 1% AEP.

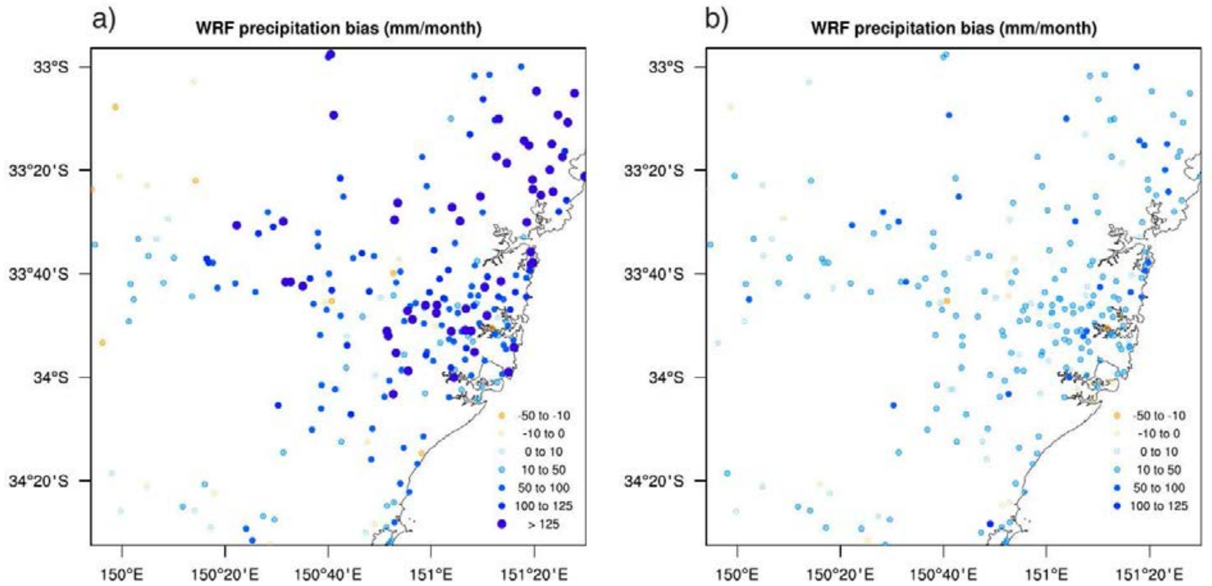

Figure 3 Annual precipitation biases with respect to Bureau of Meteorology stations. a) Non-corrected present-day WRF simulation driven by CSIRO-MK3.5. b) bias-corrected present-day WRF simulation driven by CSIRO-MK3.5.

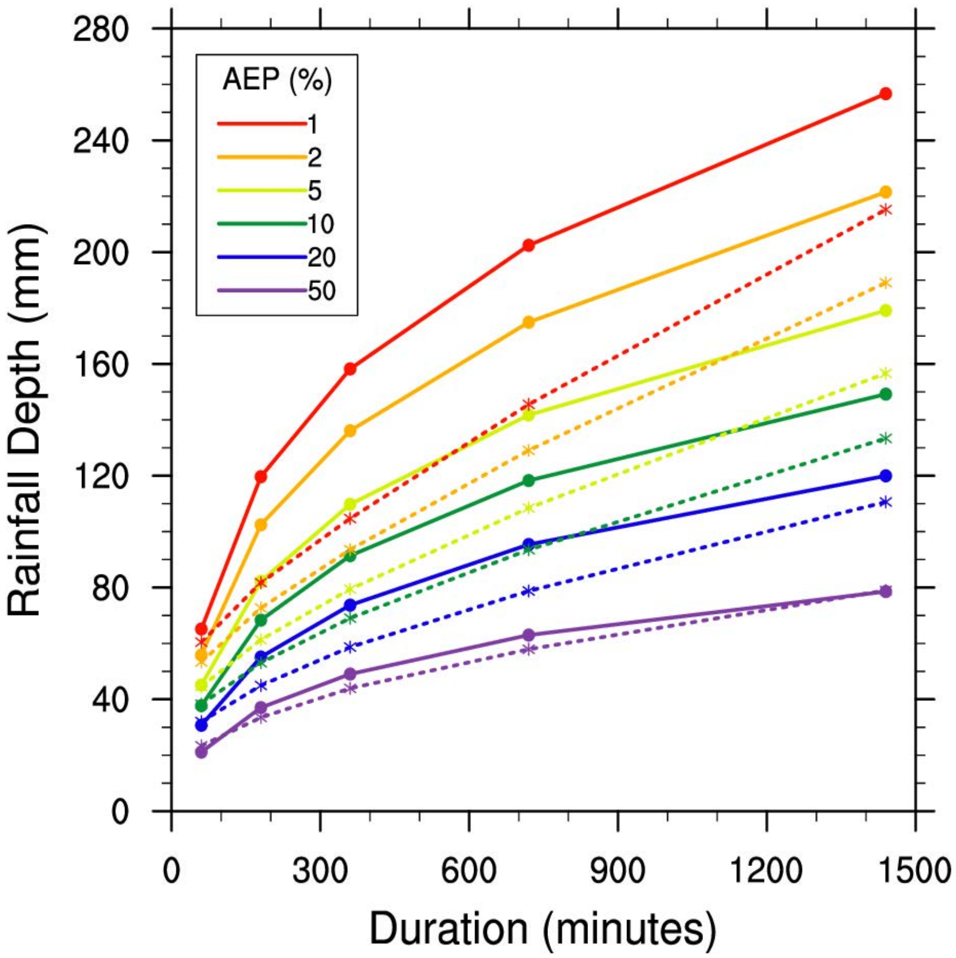

Figure 2 Domain average IFD curves for bias corrected WRF (solid lines) and Bureau of Meteorology observational estimates (dashed lines).

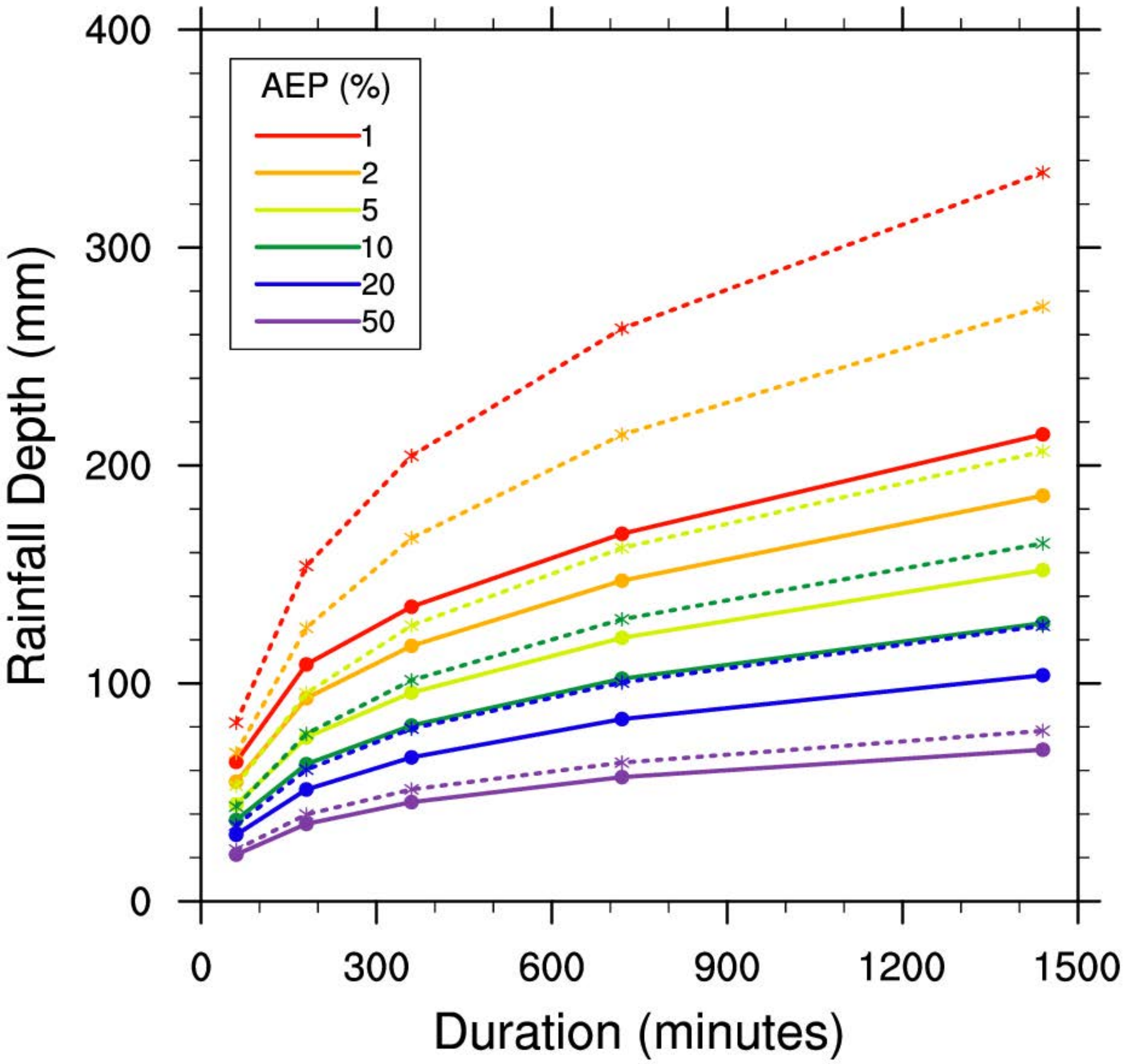

Figure 4 Domain average IFD curves for bias corrected WRF: 1990-2009 (solid lines) and 2040-2059 (dashed lines).

4. CONCLUSIONS

The precipitation modelled by the CSIRO Mk3.5-driven WRF simulation overestimates the observed field in summer and autumn and to a lesser extent in spring. Statistical bias correction has been performed using station data as the model grid is at a higher resolution than the AWAP observational grid. This correction dramatically improves the model performance compared to the station data but some bias remains when compared to the AWAP gridded data. The bias corrected precipitation data shows improved performance across all time scales though over-estimations remain.

Overall, the simulations project temperature increases of 1 to 2°C, with larger increases in autumn and winter compared to spring and summer. In terms of precipitation most of the domain is projected to see annual increases of up to 40%. These increases occur mostly in autumn, with little change in summer.

The simulated rainfall IFD curves are reasonably good at large AEPs (50%) and show progressively larger errors for rarer AEPs. Future projections show rainfall depths increasing for all durations and AEPs considered here. This future increase is larger for rarer AEPs, but relatively consistent across durations.

5. ACKNOWLEDGMENTS

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