Evaluation of regional climate models for simulating sub-daily rainfall extremes

by

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Glossary

2-CC or super-CC	twice the Clausius-Clapeyron rate
4AR	the Fourth Assessment Report from the IPCC
AEP	annual exceedance probability
ARF	areal reduction factor
BMJ	the Betts-Miller-Janjić scheme
CAPE	the convective availability potential energy
C-C	the Clausius-Clapeyron rate
CFSR	Climate Forecast System Reanalysis
CMIP5	Coupled Model Intercomparison Project Phase 5
DC	the diurnal cycle
ESRL	Earth System Research Laboratory
ETCCDI	the Expert Team on Climate Change Detection and Indices
GCM(s)	General circulation model(s)
GEV	the Generalized Extreme Value distribution
GHGs	greenhouse gases
IPCC	Intergovernmental Panel on Climate Change
KF	the Kain-Fritsch scheme
MIROC 3.2	Model for Interdisciplinary Research on Climate version 3.2
MMM	Mesoscale and Microscale Meteorology Division
MSLP	mean sea level pressure
MTSR	mean of the temperature scaling rate
MYJ	the Mellor-Yamada-Janjić scheme
NARCCAP	North American Regional Climate Change Assessment Program
NARCliM	NSW/ACT Regional Climate Modelling
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NNRP	NCEP–NCAR reanalysis project
NOAA	the National Oceanic and Atmospheric Administration's
NWP	numerical weather prediction
OBS	the observations
PBL	the planetary boundary layer
PMF	probable maximum flood
PMP	probable maximum precipitation
Q-Q	the quantile-quantile plots
RCM(s)	Regional climate model(s)
RRTM	Rapid Radiative Transfer Model
SC	Seasonal cycle
WDM5	WRF Double Moment 5-class
WRF	Weather Research and Forecasting
YU	the Yonsei University scheme

Abstract

Over the last decade, observational and modelling studies have both indicated that the intensity and frequency of rainfall extremes have increased. This increase has been linked to the human emissions of greenhouse gases that cause the climate to warm. There is increasing evidence that the largest changes in rainfall extremes are likely to occur for short duration events (less than a day), enhancing the potential for flash flooding over urban catchments and fast responding rural catchments. The economic, social and environmental effects of flash flooding are often catastrophic, resulting in substantial damage to properties and fatalities due to its sudden onset with little or no warning.

The understanding of changes in sub-daily rainfall extremes is of paramount importance to help society in planning decisions about future flood risk resulting from climate change. Short duration rainfall is important for urban catchments where there is substantial investment in infrastructure. For instance, the design of urban water infrastructure for protection from stormwater requires information on rainfall extremes at short temporal (minutes to hours) and spatial (hundreds to thousands of meters) scales.

Although observational studies are valuable for exploring historical changes to extreme rainfall patterns, future projections are usually obtained through the use of climate models to explore how rainfall patterns will respond to future greenhouse gases concentrations. General circulation models (GCMs) are sometimes used for estimating the effect of climate change on the intensity and frequency of rainfall extremes under different greenhouse gases emission scenarios. However, their coarse resolution fails to capture regional features of rainfall extremes such as the size of convective storms (1-10 km^2) that are usually smaller than the spatial resolution of GCMs. By contrast, nested regional climate models (RCMs) are able to simulate the interactions between large-scale circulation systems and local scale weather patterns and topography. RCMs have proven to adequately simulate the statistical properties of rainfall extremes at daily and longer durations; while for sub-daily durations, model simulations are often improved by applying bias correction methods to match the observations. However, the evaluation of RCMs based on extreme rainfall statistics do not provide insight into whether the model gets the right answers (statistics of rainfall extremes) for the right reasons (correct representation of the underlying physical mechanism leading to rainfall extremes) and whether it is recommended to use the model simulations after applying any bias correction approach.

The purpose of the research reported in this thesis was to explore the use of physically meaningful metrics to evaluate the capacity of regional climate models to simulate sub-daily rainfall extremes. The research metrics will complement the standard suite of statistical metrics that are commonly used for model evaluation studies. The physically meaningful metrics focus on the skill of RCMs in reproducing (i) the diurnal cycle of rainfall extremes, (ii) the seasonal

cycle of extreme rainfall events and (iii) the observed relationship between sub-daily rainfall extremes with respect to the atmospheric temperature.

The research began with the evaluation of the capacity of three versions of the Weather Research and Forecasting (WRF) regional climate model to reproduce observed sub-daily rainfall extremes. First, the statistics of sub-daily rainfall extremes were estimated and compared with observations at 69 locations across the Greater Sydney region. The main results indicate underestimations in the intensity of rainfall extremes for 1-hour duration and overestimations in the intensity for longer durations (e.g. 3-hour, 6-hour and 12-hour), overestimations in the trend of the annual maxima of rainfall for sub-daily durations and overestimations in the annual maxima over high elevation areas and underestimations over coastal parts.

Despite these apparent biases, the ability of the three RCMs to reproduce the underlying physical processes of sub-daily rainfall extremes was reasonable. The diurnal cycle of hourly rainfall extremes was realistically captured by the RCMs with a late evening peak in agreement with the observations. The seasonality was also captured and better simulated for short durations (1-hour and 3-hour) and during summer months. The intensification of sub-daily rainfall extremes with temperature was well captured by the RCMs, particularly at hourly durations when rainfall extremes approximately followed the Clausius-Clapeyron scaling rate.

The overall capacity of the three RCMs provided the confidence to investigate likely changes in sub-daily rainfall extremes over Greater Sydney, considering two future periods in simulation (2020-2039 and 2060-2079) under the A2 emissions scenario of climate change. Future changes in sub-daily rainfall extremes were explored in (i) the intensity of sub-daily rainfall extremes, (ii) the diurnal cycle of rainfall extremes, (iii) the seasonality of sub-daily rainfall extremes, and (iv) the intensification of sub-daily rainfall extremes with temperature. The results from the two future periods were compared with the historical simulation period (1990-2009). The main findings indicated an overall increase in the intensity of rainfall extremes over inland areas for long durations (e.g. 6-hour and 12-hour), especially found in the long-term future period in the simulations.

No significant changes were found for future projections of the diurnal cycle of rainfall extremes, which was fairly consistent with the historical period. Surprisingly, the greatest changes were found in the seasonality of sub-daily rainfall extremes with an increase in the occurrence of sub-daily rainfall extremes during summer accompanied by a decrease during winter over the region. Future projections also indicated an intensification of rainfall extremes with temperature that followed a scaling rate close to the C-C rate for all sub-daily durations. In contrast, an analysis into the temperature scaling relationship revealed that the historical scaling relationship in simulations was not valid for future projections, with significant changes in the scaling rate. This has significant implications for the use of the Clausius-Clapeyron (C-C) scaling relationships for developing future climate projections, which are explored in the final part of this thesis.

Statement of Originality

I, Virginia Edith Cortes Hernandez, hereby declare that this work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint-award of this degree.

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Salmos 23