Atmospheric Research 135–136 (2014) 172–192

Contents lists available at ScienceDirect

Atmospheric Research

journal homepage: www.elsevier.com/locate/atmos

Verification of the WRF model for simulating heavy precipitation in Alberta

Clark Pennelly *, Gerhard Reuter, Thomas Flesch

Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, Canada

ARTICLE INFO

Article history:
Received 25 April 2013
Received in revised form 19 August 2013
Accepted 3 September 2013

Keywords:
Weather Research and Forecasting model
WRF
Precipitation simulation
Cumulus parameterization scheme
Precipitation verification

ABSTRACT

The Weather Research and Forecasting (WRF) model was used to simulate precipitation for three flooding events in Alberta, Canada. A detailed comparison was made between the 48 hour spatial distribution of model rainfall and observations obtained from rainfall gauges. Verification was evaluated in terms of Probability of Detection, False Alarm Ratio, BIAS, and Equitable Threat scores from over 120 observation stations. Evaluation was also performed using the root-mean-squared-error at each model grid box as well as integration over the major river basins of Alberta. Simulations with 15 km grid resolution were compared using five different cumulus parameterization schemes: Explicit, Kain–Fritsch, Betts–Miller–Janjić, Grell–Dévényi and Grell 3D ensembles.

The Kain–Fritsch and explicit cumulus parameterization schemes were found to be the most accurate when simulating precipitation across three summer events. The model simulations using the Kain–Fritsch scheme often overestimated precipitation, resulting in higher Probability of Detection values. Combined with low False Alarm Ratio values, this typically yielded the highest Equitable Threat scores. Greater precipitation accuracy was generally observed when the horizontal resolution of the model was increased to 6 km. Model simulations performed without using a cumulus parameterization scheme (i.e. explicit precipitation only) performed with similar accuracy as simulations using a cumulus parameterization scheme at 6 km resolution.

1. Introduction

The Rocky Mountains form the Continental Divide extending some 2500 km from northern Canada to southern Texas. This mountain barrier strongly affects the weather and precipitation for the province of Alberta, Canada. The orographic effects are particularly evident during the summer due to differential slope heating which gives rise to convergence, triggering convective outbreaks (Smith and Yau, 1987). The summer season can experience extreme rainfall events associated with the passage of an upper air cutoff low and lee cyclogenesis over the Alberta Foothills Region (Reuter and Nguyen, 1993). The transport of water vapor to Alberta often occurs in moist warm conveyer belts originating from the Gulf of Mexico (Brimelow and Reuter, 2005). These extreme rainfall events can lead to flash flooding in southern Alberta.

In June 2005, extensive rainfall caused flooding in southern Alberta (Ou, 2008). Sixteen municipalities declared states of emergency. Thousands of people were forced to leave their homes along the rivers. The floods claimed four casualties and the estimated damage was 400 million Canadian dollars. The precipitation fell from four distinct storms with similar tracks. The dates and recorded maximum rainfall amounts were: 1–5 June (140 mm), 5–9 June (248 mm), 16–19 June (152 mm), and 27–29 June (90 mm). This paper focuses on numerical simulation of two of these extreme events: 5–9 June (Storm A) and 16–19 June (Storm B).

Storm A showed synoptic conditions that are typical for large Alberta rain storms (Ou, 2008). On 5 June 2005, an upper-air blocking high was stationed over Alberta. With an upper-air trough approaching from the west, a surface low

* Corresponding author at: 1-26 Earth Sciences Building, University of Alberta, Edmonton, Alberta, Canada, T6G 2E3. Tel.: +1 805 242 3146.
E-mail address: Pennelly@ualberta.ca (C. Pennelly).

0169-8095/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.atmosres.2013.09.004

pressure center developed over Montana, forming a trough of low pressure extending into Alberta. A secondary low formed in this trough in southeastern Alberta late on 6 June. This low moved slowly to the northwest on 8 June, causing heavy precipitation across southern Alberta. The most intense precipitation fell from 00 UTC 06 June to 12 UTC 08 June. The intense radar echoes were organized in a precipitation band that approached Alberta from the southwest pushing northeastwards across the province. Heavy precipitation fell over the foothills of the Rocky Mountains, while lighter precipitation occurred throughout the southern part of Alberta. The Oldman River basin received an average precipitation amount of 107 mm during a 48 hour period which started at 06 UTC 06 June. The southeastern border between Alberta and Saskatchewan had precipitation amounts around 50 mm, considerably smaller than the accumulation over the Oldman River basin. The northern part of the domain, above 52°N, received relatively low precipitation amounts.

Storm B followed a common pattern for heavy rainfall over Alberta. A cutoff cold low supported a well developed surface low pressure center. The vertically stacked system slowly moved northwards from Montana into southern Alberta. During the early stage, the system was quite convective and contained lightning, hail and squall lines across southern Alberta. Storm B produced an observed 48 hour maximum rainfall accumulation of 152 mm at Springbank, about 25 km northwest of Calgary, and it was estimated that an area of about 50,000 km^2 received $\geq$50 mm of rain (Ou, 2008).

A third modeling case (Storm C) was added to have an example of a highly convective event. Storm C occurred on 12–13 July 2010, with maximum recorded rainfall of 110 mm. On 12 July 2010, the metropolitan city of Calgary suffered the most damaging hailstorm in Canada's recent history. The maximum hail size was 4 cm in diameter, and damages were assessed at 400 million Canadian dollars in insurance claims (Phillips, 2010). Storm C developed in the exit region of the 250 mb jet in southern Alberta. The cold front aligned northeast to southwest, and produced numerous thunderstorms across central and southern Alberta, which caused significant damage. The Strathmore Radar recorded reflectivity values above 55 dBZ passing over the metropolitan city of Calgary, which indicated heavy precipitation with large hail (Smith, 2011). These large hail stones produced damage to structures, vehicles, trees, and crops. This storm also produced heavy precipitation over the North Saskatchewan River basin, with an average of 47 mm of rainfall. While this amount is far less than the precipitation which Storm A and Storm B produced for the river basin with the heaviest precipitation, the North Saskatchewan River basin was the largest basin we studied, and a lower precipitation value would be expected when sampled over a much larger area.

Hydrological models estimating water flow for rivers in Alberta need a high spatial and temporal resolution of precipitation data. Rain gauge measurements alone do not provide adequate resolution, particularly in the orographic regions of south west Alberta. Weather radar imagery can estimate rainfall rate, but not over mountainous terrain because ground clutter distorts radar echoes. In addition, radar images have limited forecast skill, as they cannot be produced prior to the precipitation event. In recent years there have been efforts to use precipitation estimates from Numerical Weather Prediction (NWP) models as an input for hydrological models.

With the advances of computing power and data assimilation, it is possible to run NWP models as a tool for flood forecasters. An important issue is to assess the skillfulness of these models in predicting the spatial distribution of rainfall to obtain reliable estimates of the total water mass falling over the catchment areas of the river systems. One of the standalone NWP models used for mesoscale precipitation forecasting is the Weather Research and Forecasting model (WRF). Flesch and Reuter (2012) used WRF to simulate heavy precipitation events over Alberta and examined the role of the topography in simulating and organizing the precipitation. Specifically, they performed simulations using the actual topographic grid and other simulations with reduced mountain elevations. They concluded that a reduction of mountain elevation decreases maximum precipitation by about 50% over the mountains and foothills.

NWP models often use cumulus parameterization schemes (CPS) to mimic the effects of cumulus clouds which are not resolved as they are smaller than individual model grid cells. These schemes attempt to trigger the convection and modify the temperature and moisture profiles within a model column based on the grid-scale (i.e. resolved) meteorological information. Some common cumulus parameterization schemes are: Betts and Miller (1986), Kain and Fritsch (1990), and Grell (1993). How cumulus parameterization schemes operate in NWP models is particularly important for hydrological applications, because the total volume of rainwater is sensitive to the cumulus parameterization scheme (Wang and Seaman, 1997). Kerkhoven et al. (2006) compared different cumulus parameterization schemes for an intense monsoon rainfall event in China and Japan and found that the Grell scheme was the most robust, performing well at different rainfall intensities. The Grell scheme was also used by Litta et al. (2012) to simulate severe storms over east India using the WRF model.

The results of a NWP model can be quite dependent on the spatial resolution of the numerical grid. Intuitively, one would expect that simulations using the highest spatial resolution would provide the most accurate model simulation. Wang and Seaman (1997) and Done et al. (2004) indeed found that a finer grid resolution yielded the most accurate results, but Grubišić et al. (2005) and Roberts and Lean (2008) showed cases for which the finer grid spacing did not improve simulation accuracy. Furthermore, the finer grid spacing requires significantly more computation time and resources when performing simulations.

The purpose of this paper is to simulate intense Alberta summer rainstorms with the emphasis on evaluating the skillfulness of the model to accurately predict the spatial distribution of rainfall. A secondary objective is to determine the optimum choice of cumulus parameterization schemes for grid resolution of 15 km and 30 km. Furthermore, we investigate whether a fine grid resolution of 6 km yields more accurate precipitation amounts. An inter-comparison between model precipitation and rain gauge observations will be performed on the model grid and also integrated across the watershed basins. Three storms will be simulated using the Weather Research and Forecasting model. The model output will be examined for accuracy of location and amounts of precipitation by comparing the simulated