Performance of the WRF Model in simulating the Tropical Temperate Troughs over southern Africa

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1. Introduction

Southern Africa receives most of its rainfall during the austral summer (December to February, DJF). The dominant weather systems contributing to the spatial and temporal distribution of the rainfall during this season are the Tropical Temperate Troughs (TTT). Often a significant amount of summer rainfall (about 30-60 %) over southern Africa is attributed to the occurrence of such TTTs (Harrison, 1984). The TTTs form due to the interactions among the tropical convective systems and the extratropical transient eddies. TTTs often extend from northwest to southeast; from the southern African landmass to the southwest Indian Ocean (SWIO). Understanding and modeling of the TTTs is important for improving the predictability of these systems. The regional models such as the Weather Research and Forecasting (WRF) are useful tools which help us in understanding the regional features associated with such synoptic systems. However, the regional models are to be first evaluated for their fidelity in simulating the TTTs. In this study we evaluated the WRF model in simulating the TTT events observed over southern Africa during January 1998 and January 2011. During 1-6 January1998, two TTT systems formed in succession leading to heavy rainfall over southern Africa. The rainfall during these events contributed to more than 40 % of the 1997/98 November-February season's rainfall over much of South Africa (Hart et al., 2010). Similarly, during January 2011 the TTT events caused flooding over Southern Africa. As the regional model simulations are sensitive to the cumulus parameterization schemes used in the regional models, we carried out the simulations with four different cumulus schemes viz Kain-Fritsch scheme (KF; Kain, 2004), Betts-Miller-Janjic scheme (BMJ; Janjic, 1994; Betts and Miller, 1986), and two Grell schemes (Grell and Devenyi, 2002) namely Grell-Devenyi ensemble (GDE) and Grell-3D ensemble (G3DE).

2. Model, Data and Methodology

Weather Research and Forecasting (WRF) model (Skamarock, et al. 2008) is used to simulate two extreme rainfall events observed over southern Africa during (i) 1-6 January 1998 and (ii) 20-23 January 2011. Two way interacting nested domains with a horizontal resolution of 27 and 9 km was used for this study. To test the sensitivity of the results to the cumulus parameterization scheme used in the model, we made the model runs with four different cumulus schemes. For the first case the model was run for ten days starting from 00 UTC 30 Dec 1998 initial conditions. The second event was initiated from the initial conditions of 00 UTC 18 Jan 2011 and the model was run for 6 days. The initial 3-dimensional atmospheric fields and time varying boundary conditions were taken from the NCEP Reanalysis II available at 2.5 degree resolution and at 6 hours interval. The wind, temperature and humidity fields from NCEP reanalysis were used to compare the model derived atmospheric fields. The model simulated rainfall is compared with TRMM 3B42 daily estimates.

3. Results and Discussion

3.1 Case Study I: 1-6 January 1998

During 1-6 Jan 1998, two TTT events occurred in succession with first event producing heavy rainfall on 1st Jan 1998 and the second event on 6th Jan 1998 (Fig 1a). No rainfall was observed in between these two events.

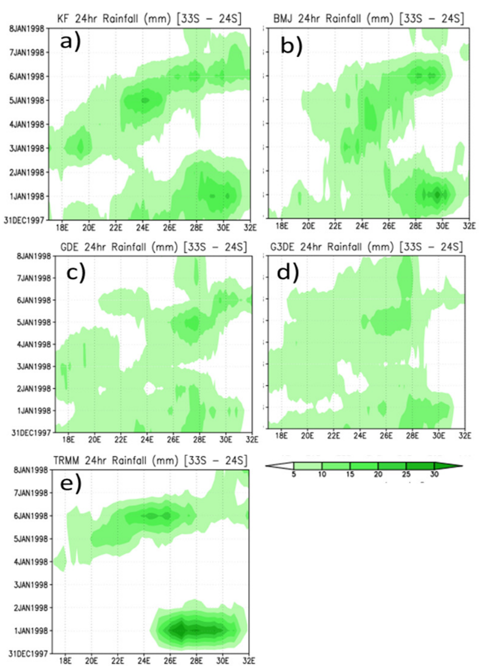

Fig. 1: Time-Longitude section of daily Rainfall (mm) averaged over the latitude zone 33^0S – 24^0S.

The KF simulated rainfall (Fig 1a) captures the heavy rainfall events of 1st and 6th Jan though the intensity of the rainfall is less compared to the observed. The model also successfully captured the lull in the rainfall during 2nd to 5th Jan 1998. The model with the BMJ scheme (Fig 1b) could also capture the events though with less intensity. However, the model could not capture the break in the rainfall. The Grell schemes had (Fig 1c, 1d) difficulty in simulating the heavy rainfall during both the events.

To make a quantitative estimate of the model simulated rainfall, we plot the area averaged (over 24^0E - 30^0E and 32^0S – 25^0S) rainfall over the period of the events (Fig. 2). The maximum rainfall during this rainfall episodes occurred over this region. From the figure it can be seen that the KF scheme simulated rainfall are comparable to observations throughout the period. However, the KF scheme along with all the other schemes had difficulty in simulating heavy rainfall event of 1st Jan 1998.

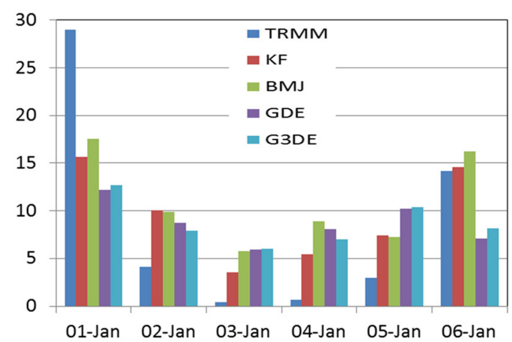

Fig. 2: Model simulated and TRMM obtained Rainfall (mm) averaged for the region 24^0E – 30^0E and 32^0S – 25^0S.

To understand the possible causes for the differences in the rainfall simulated by the different cumulus schemes in the model, we plotted the vertical profiles of the error in the simulated values of temperature, specific humidity, and equivalent potential temperature of 1 Jan 1998. The values are area averaged for the region (24^0E – 30^0E, 32^0S – 25^0S) corresponding to heavy rainfall (Fig. 3). All the schemes simulated a warmer middle atmosphere with BMJ being closer to the observations. The specific humidity simulated by KF and BMJ schemes are comparable to observations. However, the GR scheme simulated a dryer middle atmosphere. The GR simulated equivalent potential temperature profile error becomes more negative with height in the middle levels, indicating a more unstable atmosphere compared to observations. The reason for the GR scheme to simulate more unstable atmosphere and less rainfall maybe due to the infrequent triggering of the scheme.

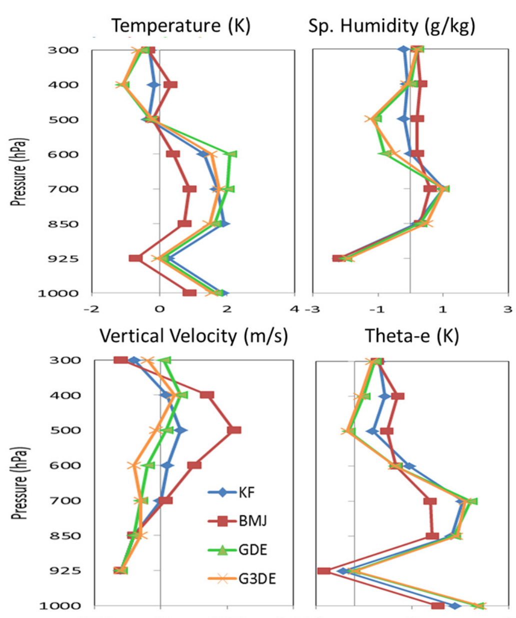

Fig. 3: Vertical profiles of the differences of Model-NCEP for Temperature (K), Specific Humidity (g/kg), Vertical velocity (m/s) and Equivalent potential temperature (K) averaged over the domain 24^0E – 30^0E and 32^0S – 25^0S for 1 January 1998.

3.2 Case Study II: 20-23 January 2011

Fig.4 shows four days accumulated rainfall (mm/day) for the heavy rainfall event of 20-23 January 2011. All the schemes simulated the heavy rainfall zones over Southern Africa though weaker in magnitude. Area averaged rainfall (Figure not shown) shows that the rainfall simulated by KF scheme is closer to observations compared to other schemes. The KF and BMJ simulated vertical profiles of the temperature, specific humidity and equivalent potential temperature are closer to the observations.

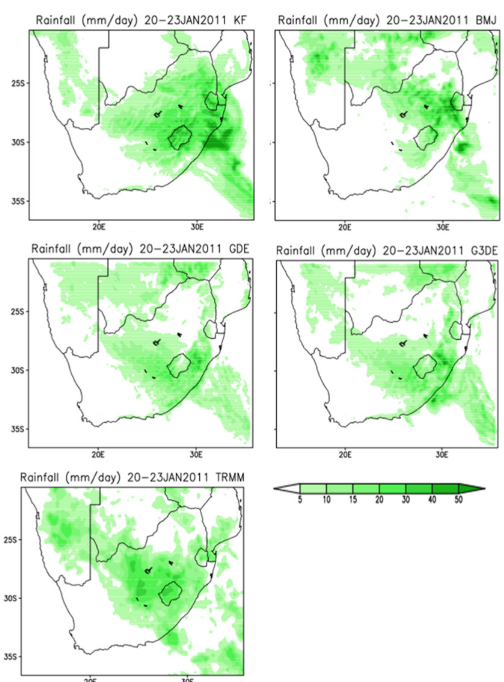

Fig. 4: Four days accumulated rainfall (mm/day) for the heavy rainfall event that occurred during 20-23 January 2011

4. Conclusion

In this study we tried to validate the WRF model for the simulation of TTTs and to test the sensitivity of the model results to four different cumulus parameterization schemes. We chose two case studies for the study. The first case study was for the period 1-6 January 1998, during which two TTT events occurred successively and the second case 20-23 January 2011 that produced heavy rainfall over Southern Africa. The results show that all the schemes are able to simulate the large scale features of the heavy rainfall events. However, large differences were seen in the temporal and spatial rainfall distribution. It is seen that the KF scheme simulated the regional rainfall most-accurately among all the cumulus schemes. The difference in the simulated regional rainfall was due to the differences in the simulation of the vertical profiles of specific humidity, temperature and equivalent potential temperature. The Grell scheme simulated a more unstable atmosphere compared to other schemes but produced less rainfall. This may be due to less frequent triggering of the scheme.

References

Betts, A.K. and M.J. Miller, 1986: A new convective adjustment scheme. Part II: single column tests using GATE wave, BOMEX, ATEX and arctic air-mass data sets. Q J R Meteorol Soc 112:693–709.

Grell, G.A. and D. Devenyi, 2002: A generalized approach to parameterizing convection combining ensemble and data assimilation techniques. Geophys. Res. Lett. doi:10.1029/2002GL015311.

Harrison, M. S. J., 1984: A generalized classification of South African summer rain-bearing synoptic systems. J. Climatol., 4, 547-560.

Hart, N. C. G., C. J. C. Reason, N. Fauchereau, 2010: Tropical–Extratropical Interactions over Southern Africa: Three Cases of Heavy Summer Season Rainfall. Mon. Wea. Rev., 138, 2608–2623.

Janjic, Z.I., 1994: The step-mountain eta coordinate model: further developments of the convection, viscous sublayer, and turbulence closure schemes. Mon Weather Rev 122, 927–945.

Kain, J.S., 2004: The Kain–Fritsch convective parameterization: an update. J Appl Meteor 43,170–181.

Skamarock, W. C., J. B. Klemp, J. Dudhia, D. O. Gill, D. M.Barker, M. G. Duda, X-Y. Huang, W. Wang, and J. G. Powers, 2008: A description of the Advanced Research WRF version 3. NCAR Tech.Note, NCAR/TN-475STR, 113 pp.