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Spatial Variation of WRF Model Rainfall Prediction over Uganda

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***Abstract*—Rainfall is a major climatic parameter affecting many sectors such as health, agriculture and water resources. Its quantitative prediction remains a challenge to weather forecasters although numerical weather prediction models are increasingly being used for rainfall prediction. The performance of six convective parameterization schemes, namely the Kain-Fritsch scheme, the Betts-Miller-Janjic scheme, the Grell-Deveny scheme, the Grell-3D scheme, the Grell-Fretas scheme, the New Tiedke scheme of the weather research and forecast (WRF) model regarding quantitative rainfall prediction over Uganda is investigated using the root mean square error for the March-May (MAM) 2013 season. The MAM 2013 seasonal rainfall amount ranged from 200 mm to 900 mm over Uganda with northern region receiving comparatively lower rainfall amount (200–500 mm); western Uganda (270–550 mm); eastern Uganda (400–900 mm) and the lake Victoria basin (400–650 mm). A spatial variation in simulated rainfall amount by different convective parameterization schemes was noted with the Kain-Fritsch scheme over estimating the rainfall amount over northern Uganda (300–750 mm) but also presented comparable rainfall amounts over the eastern Uganda (400–900 mm). The Betts-Miller-Janjic, the Grell-Deveny, and the Grell-3D underestimated the rainfall amount over most parts of the country especially the eastern region (300–600 mm). The Grell-Fretas captured rainfall amount over the northern region (250–450 mm) but also underestimated rainfall over the lake Victoria Basin (150–300 mm) while the New Tiedke generally underestimated rainfall amount over many areas of Uganda. For deterministic rainfall prediction, the Grell-Fretas is recommended for rainfall prediction over northern Uganda while the Kain-Fritsch scheme is recommended over eastern region.

***Keywords*—Convective parameterization schemes, March-May 2013 rainfall season, spatial variation of parameterization schemes over Uganda, WRF model.

I. Introduction

PRECIPITATION (e.g. rainfall) is one of the key climatic parameter that impacts many sectors e.g. agriculture [1], [2], health [3], electricity generation [4] and water resources [5], [6] among others. Rainfall over Uganda is normally influenced by the Inter–Tropical Convergence Zone, the El Niño/La Niña episodes, the Indian Ocean Dipole and extra-tropical weather systems [7], [1] and has large spatial and temporal variability which complicates its prediction [1], [8] but it can be predicted quantitatively up to 7 days [5], [9].

There are a couple of scientific ways of quantitatively predicting rainfall such as using the radar which is superior at now–casts due to better spatial representation and assimilation of initial precipitation estimates but their accuracy deteriorates with time due to their inability to resolve growth and decay of precipitation for long lead times [5]; the Numerical Weather Prediction (NWP) models which have higher skill for longer lead times because they solve the dynamics and physics of the atmosphere [5] and statistical models such regression which describe the relationship between the predictant and predictor [8].

Due to large spatial and temporal variability of precipitation, errors normally arise introducing uncertainty. This limitation can be partly addressed by statistically correcting the models [10]. An additional improvement in spatial performance can be obtained by applying ensemble prediction [11]. Ensembles members can be obtained by perturbing model physical parameterization schemes [12], running the models at the different time (time–lagged) [9], combining output from different models (multi–model ensemble) [9], [13] or a combination of all the methods.

Although ensemble prediction, radar tools and statistical correcting predictions from numerical weather prediction (NWP) models can attempt to address the problems in spatial performance of NWP models, it is more important to have a thorough knowledge regarding the performance of a given model in any given region. In the study we employed the weather research and forecasting (WRF) model and assessed the spatial performance of six convective schemes. The rest of the paper is presented as Section II describes the data and methods, Section III presents the results and discussion while Section IV gives the summary and conclusions.

II. Data and Methods

A. Data Sources

The study used observed March–May (MAM) 2013 rainfall data from 21 weather stations of Uganda (i.e. Fig. 1) which was obtained from the Uganda National Meteorological Authority (UNMA). The rainfall data was compared to the simulated rainfall data by the WRF model over the same period. The input data to initialize the deterministic WRF model was obtained from the National Centers for Environmental Prediction (NCEP) final reanalysis [14] at a resolution of $1^o \times 1^o$, covering the period of study.

B. Rainfall of the Study Area

Rainfall over Uganda exhibits large spatial and temporal variations with the first rains starting late in northern region. Generally Uganda experiences two rainy season

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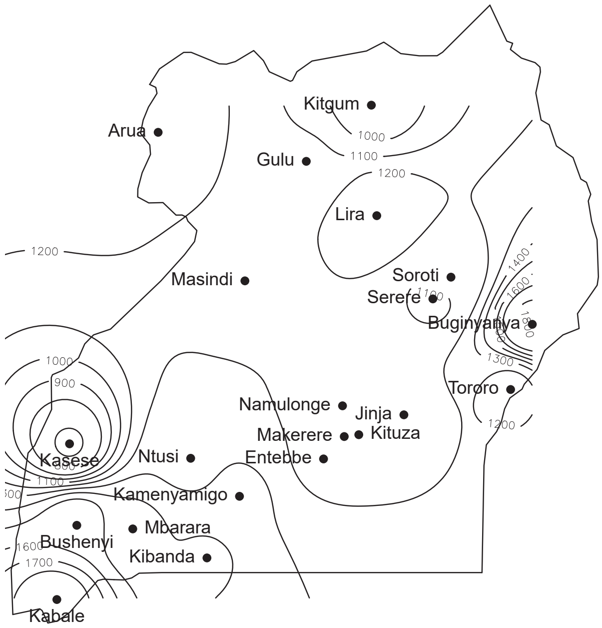

Fig. 1 Study region and contours in meters over the Uganda

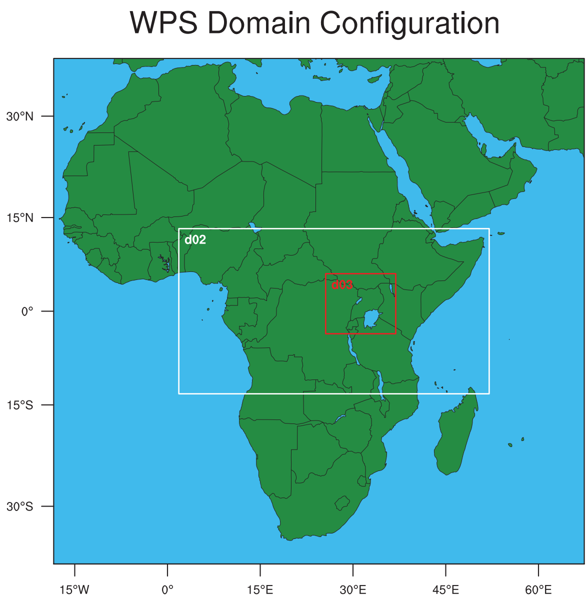

Fig. 2 The domains used in running WRF model

(i.e. March–May and September–November/December). The MAM seasonal rainfall over Uganda is generally influenced by the Inter–Tropical Convergence Zone (ITCZ) [1], [2]; the monsoon winds of East Africa [15], [16]; the Indian ocean dipole; the humid Congo airmass [6]; the tropical cyclones, semi–permanent subtropical anticyclones and easterly waves [1], [7]; the complex topography [16], vegetation and inland water bodies which modulate local rainfall [1], [17].

The ITCZ migrates north and southwards over the equator twice in a year which makes the region to experience two major rainfall seasons (March–May and September–November). Our study considered the MAM 2013 season due to the heavy rainfall that was generally experienced over Uganda that also caused destruction of infrastructure and loss of lives in western Uganda.

C. Experiment Design

In this study, the spatial performance of six convective parameterization schemes (i.e. Kain–Fritsch (**KF**); Betts–Miller–Janjić (**BMJ**); Grell–Fretas (**GF**); Grell 3D ensemble (**G3**); New–Tiedke (**NT**) and Grell–Devenyi (**GD**)) is assessed. Three domains (Fig. 2) are used with the first domain at 90Km horizontal resolution sufficiently covering Africa to capture the large scale synoptic systems (e.g. the sub–tropical high pressure systems) important for rainfall over equatorial region; the second domain at 30 Km horizontal resolution covering a major part of equatorial region to cater for influx of moisture over Uganda especially the Congo air mass and the moist currents from Mozambique channel; and the third domain at 10 Km resolution containing Uganda. For all the schemes, the integration is done over MAM 2013 with same initial conditions. The cumulus parameterization schemes are used because of their significant effect on precipitation simulation [18].

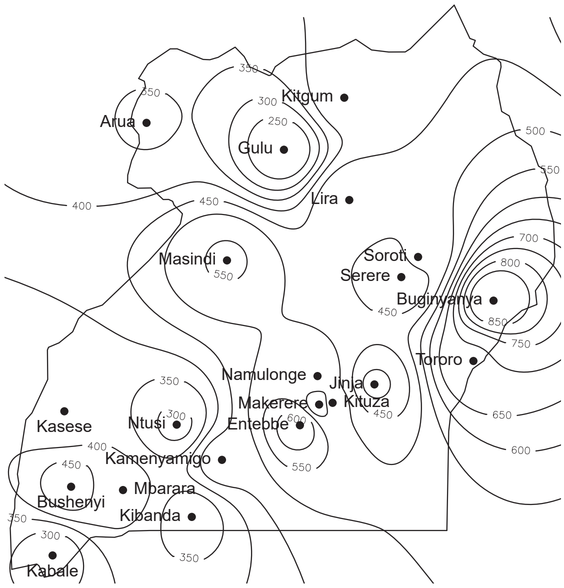

Fig. 3 Study stations and isohytes in mm over Uganda

D. Methods

1) Model Performance: The model performance was assessed by comparing the simulated rainfall using the convective schemes and observed rainfall. Two statistical scores: the root mean square error (RMSE) and the mean error (Bias) were employed to assess the spatial performance of the schemes. These performance measures have been discussed by Mugume et al. [19].

The RMSE is obtained from the square root of the mean square differences between predicted (i.e. P) and observed (i.e. O) when paired. It is computed mathematically as:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left[P_i - O_i\right]^2} \tag{1}$$

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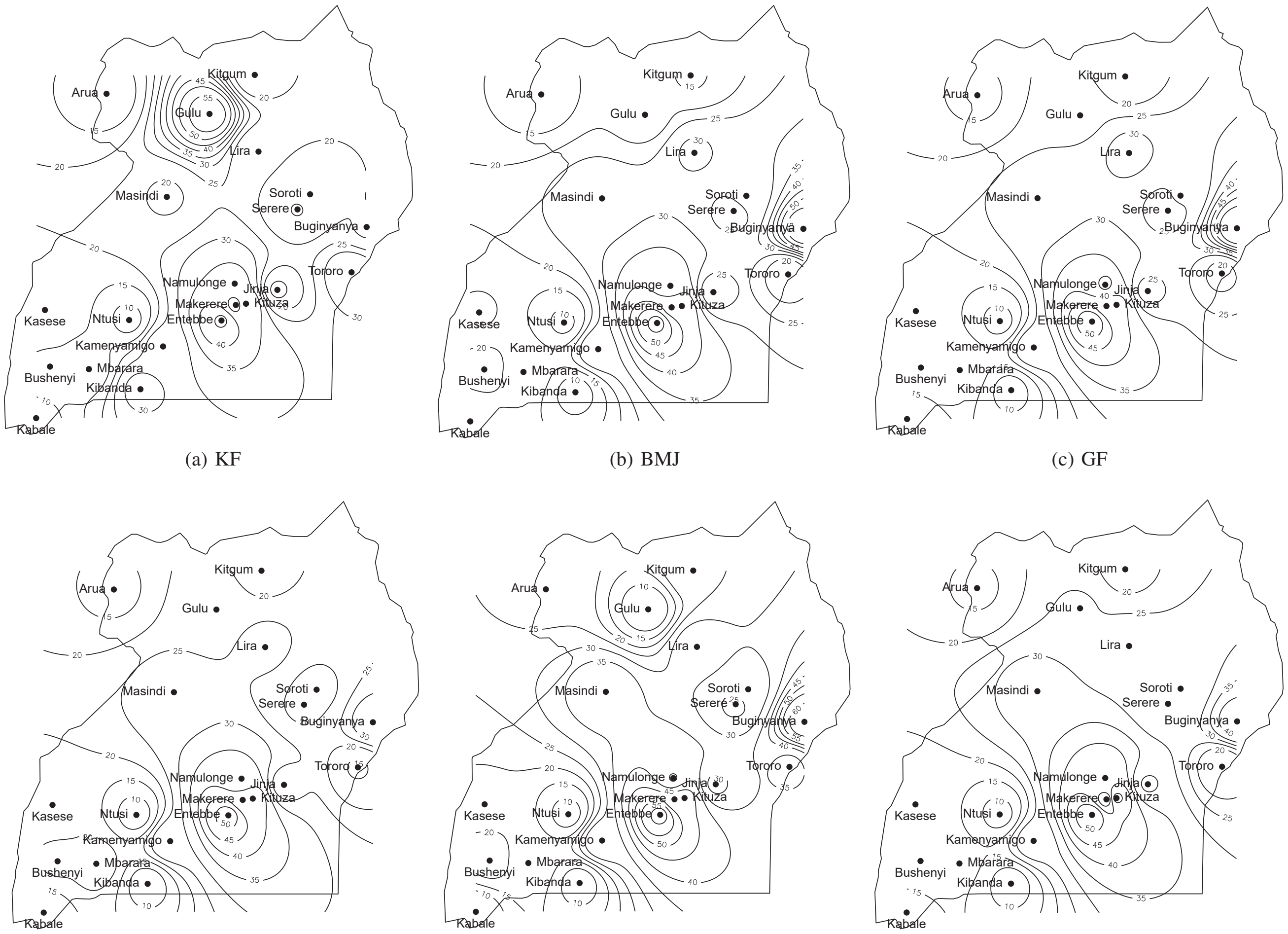


(a) KF (b) BMJ (c) GF

(d) G3 (e) NT (f) GD

Fig. 4 The root mean square error of different areas over Uganda presented by the six convective schemes of WRF model

and Bias is the mean of the differences (i.e $P_i - O_i$) which is computed as:

$$Bias = \frac{1}{n}\sum_{i=1}^{n}[P_i - O_i] \tag{2}$$

where i is the i^{th} data point ordered in time.

2) Spatial Interpolation: To represent results spatially, we employed the inverse distance weighted method (IDW). The description of the IDW is given by Franke [20]. According to Franke [20], given f_i a partial derivative of a bivariate function $F(x, y)$ with distance, d_i defined as

$$d_i = \sqrt{(x - x_i)^2 + (y - y_i)^2}$$

$F(x, y)$ becomes:

$$F(x, y) = \frac{\sum_{i=1}^{n} w_i(x, y) f_i}{\sum_{i=1}^{n} w_i(x, y)} \tag{3}$$

with the weight w_i defined as

$$w_i = \left[\frac{R - d_i}{R d_i}\right]^2$$

for $d_i \neq 0$; $i = 1, 2, \cdots, n$ and R is a radius of some disk centered at (x_i, y_i).

III. Results and Discussion

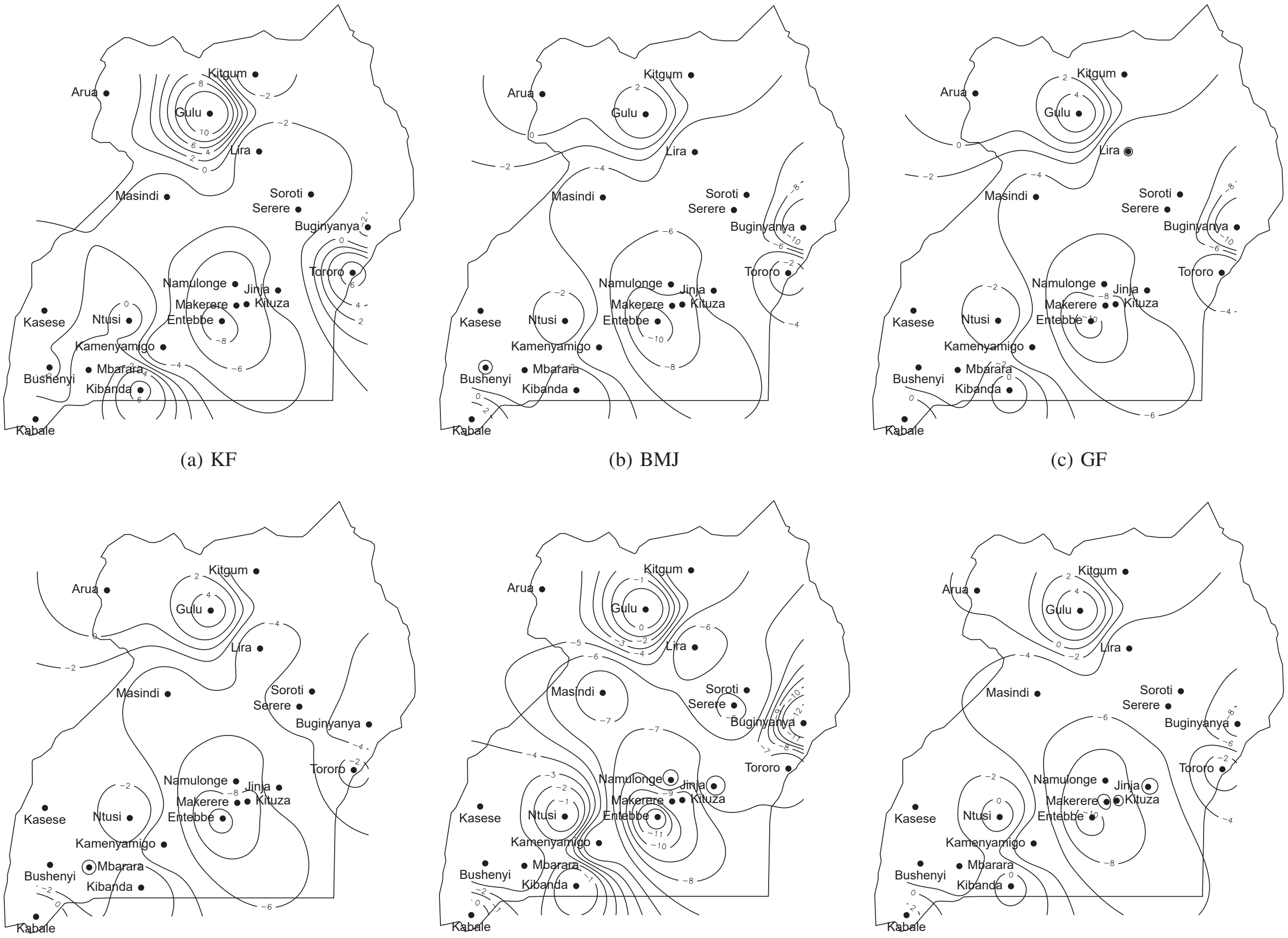
A. Overview of Rrainfall over the Study Period

The study region and isohytes representing the total rainfall of stations considered in study is shown by Fig. 3. We observed that the total MAM 2013 rainfall amount was generally in the range: 200–900 mm. Stations in northern Uganda received comparatively lower rainfall amount (i.e. 200–500 mm) which is expected because this region normally receives a unimodal rainfall distribution with rainfall onset around April/May peaking around July/August. Over western Uganda, the rainfall amount was in the range: 270–550 mm; rainfall over Eastern Uganda was in the range: 400–900 mm while the lake Victoria basin received rainfall in the range: 400–650 mm.

B. Spatial Performance of the Convective Schemes

The performance of the convective schemes as indicated by the RMSE and the Bias is presented using Figs. 4 and 5, respectively.

The results of RMSE show that the **KF** scheme gave the highest RMSE over northern region (i.e. 25–60) while the other schemes gave RMSE of 20–30. With exception of **KF**



(a) KF (b) BMJ (c) GF

(d) G3 (e) NT (f) GD

Fig. 5 The mean error (Bias) of different areas over Uganda presented by the six convective schemes of WRF model

scheme, all the other schemes presented poor performance over eastern Uganda. Additionally, the performance over the lake Victoria basin was equally poor in the 30–60. The RMSE of the schemes over western Uganda was in the range 10–25.

The results of Bias show that the **KF** scheme had positive Bias over the northern region (Bias: 2 to 10) and a negative Bias over the eastern region (Bias: -4 to 0). The **NT** scheme gave the largest negative bias (Bias: -12 to -7) over the lake Victoria basin. The schemes also presented negative bias over the lake victoria basin (generally in the range: -8 to 0) and Bias: -4 to 0 over western Uganda.

IV. Summary and Conclusion

The study assessed the performance of six convective parameterization schemes of WRF model over Uganda using the MAM 2013 rainfall that was in the range 200–900 mm. The cumulus schemes presented varied results over different regions of Uganda with the **KF** scheme over estimating rainfall over northern Uganda; the **BMJ**, the **GD** and the **G3** schemes underestimating rainfall amount over most parts of the country especially the eastern region; the **GF** scheme capturing rainfall amount over the northern region while the **NT** scheme generally underestimating rainfall amount over most of the areas.

The schemes generally presented a RMSE in the range of 10 to 30 with poor performance notable over the northern region. A negative Bias is generally noted over most parts of Uganda with exception of the northern region. These results confirm that you can not find a perfect convective scheme for all the areas in Uganda. The study proposes using ensemble methods to improve performance of the schemes over Uganda.

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