Simulate Heavy Rainfall During 19th to 28th December 2014 Using WRF for Different Atmospheric Physics

D.W.T.T. Darshika
K.H.M.S.Premalal
Department of Meteorology
Colombo 07

ABSTRACT

Quantitative Precipitation Estimation (QPE) plays an important role in predicting extreme rainfall events. Many scientific methods are using to estimate heavy rainfall event and common methods are using Doppler Weather Radar, Satellites and Numerical Weather Prediction. Different kind of numerical models are used for this purpose and Weather Research Forecasting (WRF ARW) is the commonly use numerical mode for the research community. Therefore many scientists are now engaging to investigate the possibility for estimating heavy rainfall events using WRF model.

Tuning up the model with various micro physics and cumulus parameters are the important parts of capturing the heavy rainfall. Different combinations of micro physics and cumulus parameters are now using and the Anthes-Kuo, Betts-Miller, Betts-Miller-Janjic (BMJ), Grell (GR) and the Kain-Fritsch scheme (KF) are better schemes according to many research.

This study was carried out to identify the suitable micro physics and cumulus parameters for Sri Lanka for the WRF model to estimate the heavy rainfall events. Heavy rainfall occurred during the period 18 to 27 December 2014, resulted in the worst flooding event in the island. To capture the event 6 experiments were carried out with the different combinations of micro physics and cumulus parameters for the WRF model.

Combinations of Kain–Fritsch, Betts–Miller–Janjic Cumulus parameters and Kessler, WSM5, WSM6 micro physics were used to identify the best combination to simulate the heavy rainfall event in December 2014. However, all the experiments underestimated the rainfall distribution on 25th December,which fairly widespread heavy rainfall occurred over most parts of the island except in the northern part of the island. During all 4 days (19, 20, 25, and 26 December 2014) EXP1 (Kessler and Kain–Fritsch), EXP3(WSM5 and Kain–Fritsch) and EXP6(WSM6 and Betts–Miller–Janjic) were able to capture the rainfall distribution occurred over northeast coastal areas and adjoining interior parts along the coastal belt, and north central and northwestern parts of the island, but those experiments were unable to capture rainfall distribution elsewhere. Part of the rainfall distribution, occurred outside the northeastern parts were able to capture by EXP2 (Kessler and Betts–Miller–Janjic) and EXP5 (MSM6 and Kain–Fritsch).

1 Introduction

The numerical prediction of extreme weather systems remains one of the most challenging problems in the field of meteorology. Most of the global models developed far generally underestimate the total rainfall produced in any heavy precipitation event, and also contain errors in terms of their prediction on the timing and location of the event. For a better prediction of flash floods, it is necessary to understand the dynamics and physics associated with isolated heavy precipitation and the dynamic features associated with thunderstorms and tornados etc. (Wang 2002; Lin et al. 2006; Lei et al 2008).

The nine consecutive days of widespread torrential rains that occurred over Northeastern, Eastern and Southeastern parts of Sri Lanka in Eastern, Central, Uva, North-Central, Northern and Northwestern provinces from 18 to 27 December 2014 resulted in one of the worst flooding event in the island.

According to Disaster Management Centre 1.1 million people were affected by floods, landslides, and high winds since 19 Dec 2014 in 22 out of 25 districts. Deaths were reported with 20 people injured and 2 people were missing.

The Government of Sri Lanka announced that sluice gates had to be opened in the affected provinces, as hundreds of water reservoirs (300 only in Anuradhapura district) were exceeded their danger levels. North-Central and Eastern Provinces appear to be worst affected.

Figure 1 shows daily rainfall distribution from 19th to 28th December 2014. It is evident that during 19th December to 21st December, heavy rainfall was confined in to the Eastern, and North Central provinces and spread to Southern, Uva and Central provinces during the period from 24 to 25th. Again fairly heavy rainfall confined in to the Eastern and northeastern parts on 26th and 27th December.

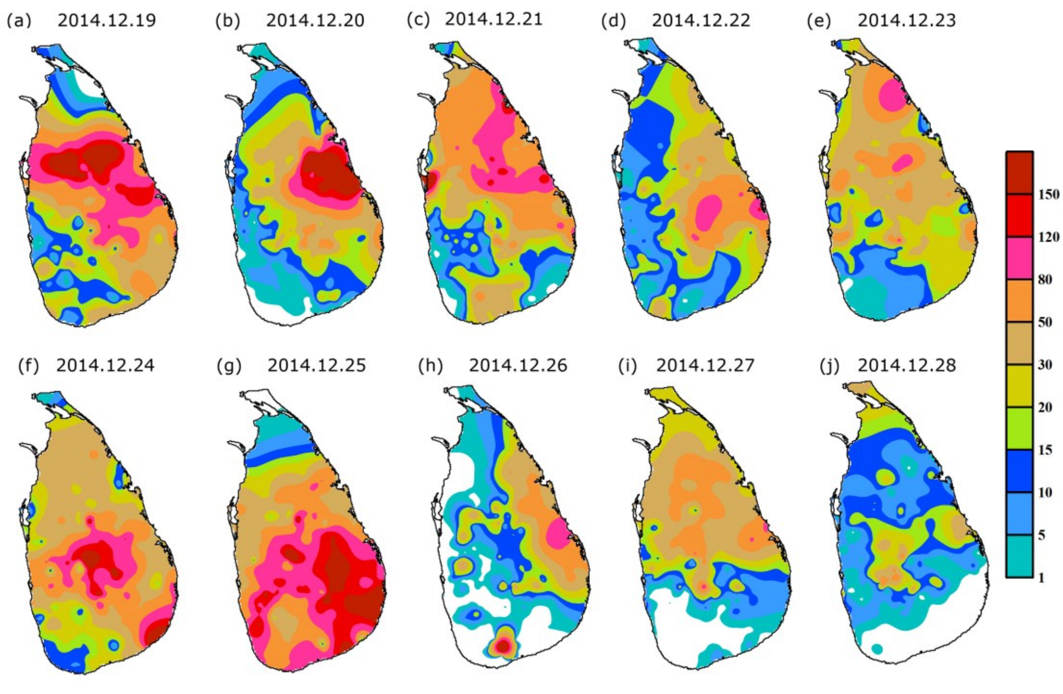

Figure 1 : Daily rainfall (mm) distribution from 19th to 28th December 2014

During this period more than 100mm of total rainfall received from the most parts of the island and more than 300mm rainfall received in Eastern, North Central, Uva and Central provinces (Fig 2) with some areas in Polonnaruwa district received more than 1000mm rainfall which is nearly 2/3 of the annual rainfall of the district.

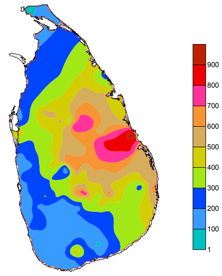

Fig 2. Total Rainfall distribution from 19th to 30th December 2014

Department of Meteorology predicted rainy conditions for the period in the daily weather forecast mentioning the possibility of isolated heavy rainfalls. Generally it is not easy to predict quantitative weather forecast by using the conventional methods alone. However objective methods have some capability to predict quantitative rainfall amount. Many scientists are now conducting research on "Quantitative Precipitation Estimation (QPE), to estimate the possible rainfall amount to minimize the hazards due to heavy rainfall events. There are different kinds of micro physics and cumulus parameterization schemes have found by many scientist for better prediction of rainfall amount for the numerical model.

Widely used CP schemes in high resolution models are: Anthes-Kuo (Anthes,1997), Betts-Miller, Betts-Miller-Janjic (BMJ) (Betts and Miller, 1986; Janjic, 1994), Grell scheme (GR) (Grell,1993; Grell et al., 1994) and the Kain-Fritsch scheme (KF) (Kain and Fritsch,1993).

Sarkar and Debsarma, 2012, simulated heavy rainfall event at Bhur in Bhutan on 18th July 2010, using Advanced Research Weather Research Forecast model (WRF ARW) developed at the National Center for Atmospheric Research (NCAR) in the USA. They compared the model output rainfall with the rainfall data distributed by Tropical Rain Measuring Mission (TRMM) and it showed a good agreement. It was able to predict even 60 mm rainfall using the combination of Kian-Fritsch (KF) scheme and Grell-Devenyi (GD) ensemble scheme.

Kirtsaeng et. al, 2010, simulated heavy rain event at Mumbai in India on 26th July 2005. WRF ARW (version 3.0.1), were used for this study. Kian-Fritsch (KF), Betts–Miller–Janjic (BMJ) and Grell–Devenyi ensemble (GD) was used for this study as cumulus parameterization schemes across three nested domain and default micro physics WRF single-moment 6-class Graupel (WSM-6) was used. In addition, many modification were done for the model and the heavy rainfall estimated as 32 cm from TRMM had been simulated satisfactory.

Kumar et. al 2010, evaluated Physics options of the WRF Model to simulate high impact heavy rainfall events over the Indian Monsoon region. The study shows that WRF model is sensitive to the type of convective scheme. They found that Betts-Miller-Janjic (BMJ) cumulus scheme can produce better results compared to other cumulus schemes for the Indian monsoon region. Kumar et. al 2012 , simulated the heavy rainfall events during Retreat Phase of Summer Monsoon Season over Parts of Andhra Pradesh on 2009, using the WRF ARW model, and toward that Kain-Fritsch (KF) scheme than Betts-Miller-Janjic (BMJ) and Grell-Deveneyi (GD) scheme were the best parameters to capture the event.

Nasrin et. al. 2012 also simulated the heavy rainfall event associated with Hurricane "Rita" in 2005 using WRF for different micro physics. The study also investigated the performance of the WRF in forecasting precipitation, hurricane track, and landfall time using various microphysics and cumulus schemes. A total of 20 combinations of microphysics and cumulus schemes were used, and the model outputs were validated against ground-based observations. According to the results no any single combination can be considered ''ideal'' for modeling all characteristics of a hurricane, including precipitation amount, areal extent, hurricane track, and the time of landfall. Betts–Miller–Janjic´ (BMJ) cumulus parameterization in combination with the WRF single-moment five-class microphysics scheme has the ability to simulate precipitation and also WSM5–BMJ, WSM3 -BMJ, and Ferrier microphysics in combination with the Grell–Devenyi cumulus scheme were the best combinations for simulation of the landfall time.

The purpose of this study was to simulation of heavy rainfall event in Sri Lanka from 19^{th} to 28^{th} December 2014, using two cumulus parameterization schemes and 3 micro physics in the WRF model.

2 Materials and Method

2.1 Model

Weather Research and Forecasting (WRF) (Skamarock, et al.2008) is a state-of-the-art atmospheric modeling system, applicable for both meteorological research and numerical weather prediction. Also the WRF is a limited area, non-hydrostatic primitive equation model, with multiple options for various physical parameterization schemes. WRF model was used for the heavy rainfall simulation from 19^{th} to 28^{th} December 2014, in this study. Model configuration in this study is shown below.

Model Feature	Configuration
Horizontal spatial resolution	30 km
Grid points	265X187
Vertical Levels	27
Topography	USGS
Dynamics	
Time Integration	Semi Implicit
Time Steps	180 seconds
Vertical Differencing	Arakawa's Energy Conserving Scheme
Horizontal Diffusion	2nd order over Quasi-pressure, surface, scale selective
Physics	
PBL	YSU scheme
Surface Layer	Monin-Obukhov (Janjic Eta) sheme
Radiation	RRTM (LW), Dudhia (SW)
Land Surface Process	Noah Land Surface Model

2.2 Experimental Design

Following micro physics and cumulus parameterization combinations were selected to run the model to simulate the rainfall. Three microphysics schemes including Purdue Lin (LIN; Lin et al. 1983), Kessler (KES; Kessler 1969), Ferrier (FER; see Ferrier 1994), Rapid Radiative Transfer Model WSM3 (Hong et al. 2004), and the WRF single moment six-class microphysics scheme (WSM6; Honget al. 2004) were utilized. In addition, the following cumulus parameterization schemes were used, Kain–Fritsch(KF; see Kain 2004; Kain and Fritsch 1993; Kain and Fritsch 1990) and Betts–Miller–Janjic´ (BMJ; see Janjic´ 1994). Six experiments were carried out and the micro physics and cumulus parameterization schemes used for the study are tabulated in the table 1.

Experiment name	micro physics	Cumulus Parameterization
EXP1	Kessler(mp1)	Kain–Fritsch(cu1)
EXP2	Kessler(mp1)	Betts–Miller–Janjic(cu2)
EXP3	WSM5(mp4)	Kain–Fritsch(cu1)
EXP4	WSM5(mp4)	Betts–Miller–Janjic(cu2)
EXP5	WSM6(mp6)	Kain–Fritsch(cu1)
EXP6	WSM6(mp6)	Betts–Miller–Janjic(cu2)

Table 1: Model Configuration

1.0 x 1.0 degree resolution 6 hour interval grid data from the Global Data Assimilation System (GDAS) of the National Weather Service National Center for Environmental Prediction (NCEP) was used as initial boundary condition to run the WRF model.

Various terrestrial datasets for terrain, land-use, soil type, soil temperature, vegetation fractions etc. were taken from the WRF user website. To verify the results from the model, ground -based rainfall data from the Department of Meteorology was used.

3 WRF simulation comparison and discussion

Figures 3 to 7 show the simulated 24 hour cumulative rainfall over Sri Lanka from 19th, 20th, 25th and 26th December 2014 from 6 different model simulation using different cumulus parameterization schemes and micro physics schemes tabulated in the table 1.WRF simulation from the EXP1, EXP2 EXP3 and EXP6 (Figure 3a, 3b, 3c and f) were able to capture observed rainfall maxima over north central, eastern and southeastern parts of the island. However none of the simulation was able capture the rainfall maxima over northwestern parts completely. Part of the rainfall maxima over northwestern part capture by EXP2 but for southwestern parts, the rainfalls were over estimated. EXP4 was able to capture the rainfall maxima over northwestern part but it underestimated the rainfall over rest of the island. EXP1, EXP2 EXP3 and EXP6 were able to simulate the rainfall amount over eastern and north central parts of the island.

The reason for such heavy rainfall situation was the development of vortex at the vicinity of Sri Lanka. All WRF outputs were able to produce the vortex located to the southeast of Sri Lanka (Fig 4). Location of vortex was very close to Sri Lanka in EXP1.

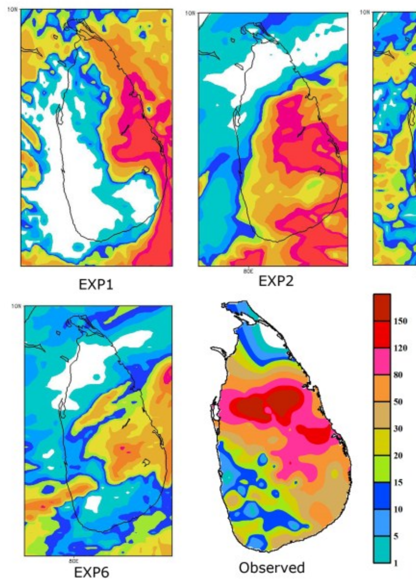

Fig 3. Simulated 24-hour cumulative rainfall (mm) for 19th December 2014 from the WRF experiments and Observed rainfall-: a) EXP1, b) EXP2, c) EXP3, d)EXP4, e)EXP5, f)EXP6 and g)Observed Rainfall. Details of the experiments are listed in Table 1

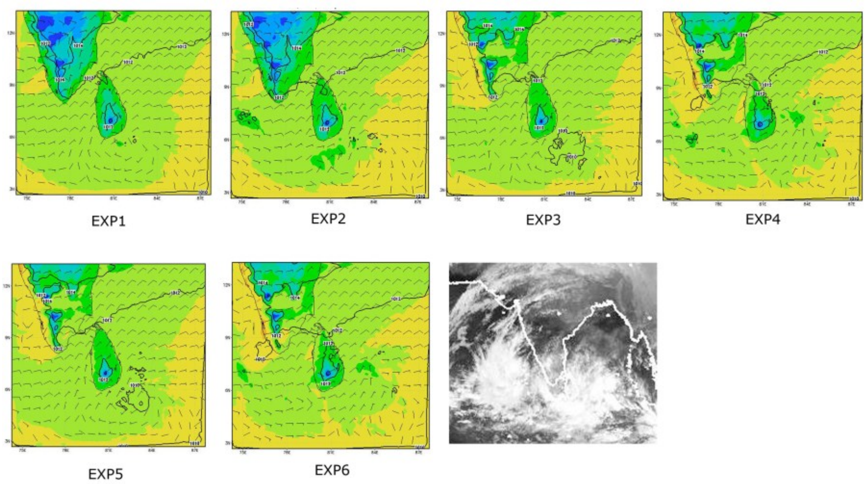

Fig 4. Simulated Surface Wind for 1200 UTC 0n 19th December 2014 from the WRF experiments and Dundee Satellite image -: a) EXP1, b) EXP2, c) EXP3, d)EXP4, e)EXP5, f)EXP6 and g)Satellite image. Details of the experiments are listed in Table 1

According to figure 5, all the experiments except EXP2 provides an indication of the heavy rainfall occurred in the eastern part of the Sri Lanka on 20th December 2014. All the experiments except EXP1 overestimated the rainfall occurred in the southwestern part of the island. The quantum of rainfall predicted in EXP5 that provides information about the rainfall distribution more accurate than other experiments.

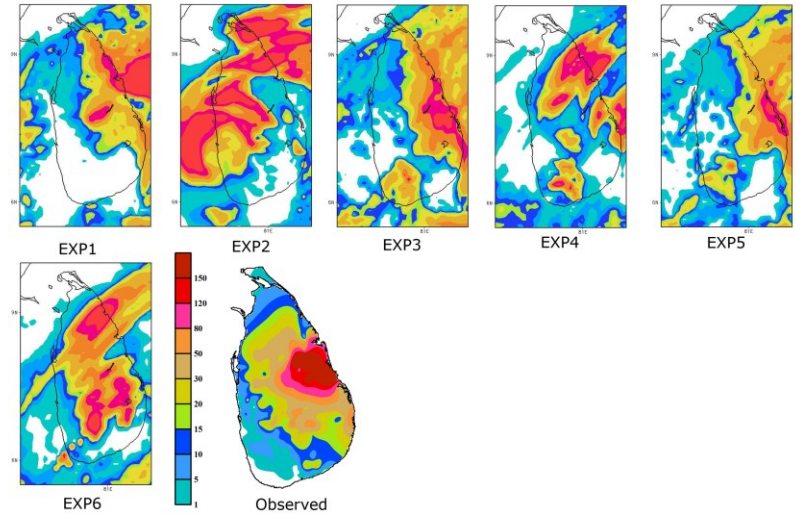

Fig 5. Simulated 24-hour cumulative rainfall (mm) for 20th December 2014 from the WRF experiments and Observed rainfall

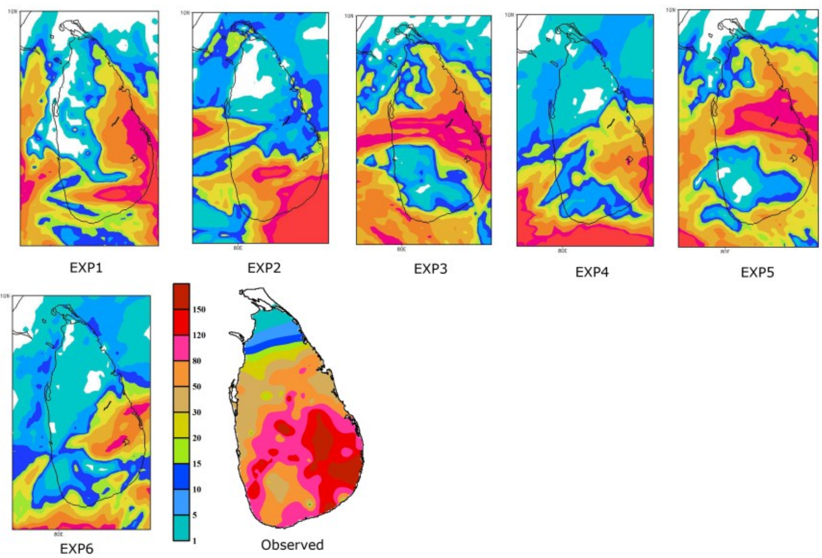

Fig 6. Simulated 24-hour cumulative rainfall (mm) for 25th December 2014 from the WRF experiments and Observed rainfall

On 25th December 2014, fairly widespread heavy rainfall occurred over most parts of the island except in the northern part (Fig 6). All the experiments were unable to capture this widespread heavy rainfall completely.

Rainfall occurred in northeastern coastal areas and neighborhood was captured accurately by EXP1, EXP3 and EXP6 but it was not able to predict the rainfall occurred in southwestern parts. The maximum rainfall occurred in the south western part was predicted from the experiment EXP2 (fig 6) was able compared with the observed position and amount of rainfall.

On 26th December 2014, rainfall was mostly confined to the northeast coastal areas and interior parts along the coastal belt with isolated heavy rainfall patch over southern part (Fig 7). Most of the simulations were able to capture the rainfall occurred in northeastern coastal areas with either overestimating (EXP2, EXP4 and EXP5) or underestimating (EXP1, EXP3 and EXP6) the area of rainfall. The particular location of the heavy precipitation patch in the southern part of the Island was very well simulated with the EXP5 (Fig 7) though the magnitude of rainfall was a little higher than the actual observation.

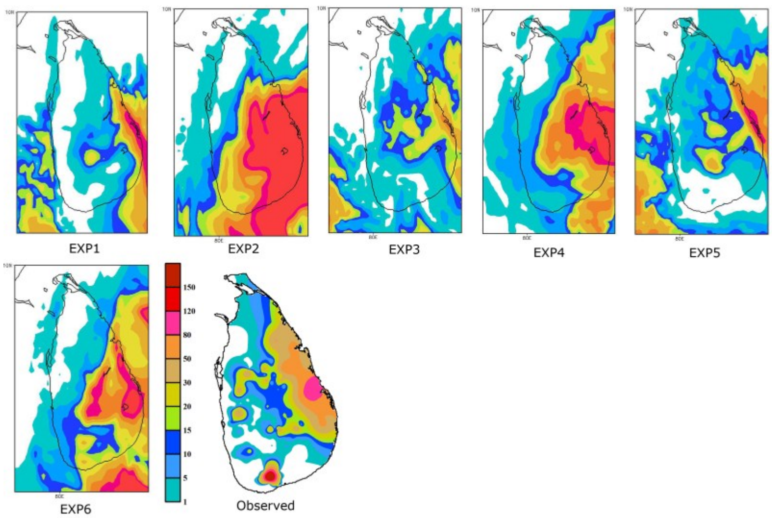

Fig 7. Simulated 24-hour cumulative rainfall (mm) for 26th December 2014 from the WRF experiments and Observed rainfall

4 Conclusion

A quantitative assessment of the simulation of a heavy rainfall event occurred from 19th to 28th December 2014, in Sri Lanka was attempted with WRF model version 3.0.1, using two cumulus parameterization schemes (Kain–Fritsch and Betts–Miller–Janjic) and 3 micro physics schemes (Kessler, WSM5 and WSM6). All the simulation of the 850mb level winds were able to produce the synoptic- scale circulation features such as votex located to the southeast of Sri Lanka on 19th December 2014. However all the experiments underestimated the rainfall distribution with fairly widespread heavy rainfall occurred over most parts of the island except in the northern part on 25th December. During all 4 days (19, 20, 25, and 26 December 2014), EXP1 (Kessler and Kain–Fritsch), EXP3 (WSM5 and Kain–Fritsch) and EXP6(WSM6 and Betts–Miller–Janjic) were able to capture the rainfall occurred over northeast coastal areas and adjoining interior parts along the coastal belt over north central and northwestern parts of the island but those experiments were unable to capture rainfall elsewhere. Part of the rainfall occurred outside the northeastern parts captured by EXP2 (Kessler and Betts–Miller–Janjic) and EXP5 (MSM6 and Kain–Fritsch).

This is a very preliminary attempt to use the WRF model (version 3.0.1), and it is recommended that further testing using more case studies, as well as an improved version of the model plus the incorporation of different satellite data and Doppler Radar data, through use of the WRF data assimilation system, be carried out. Although the above conclusions are based on a very limited number of experiments, this study provides some insights for WRF model users in the tropics and may prompt the modeling community to pursue and evaluate real-time quantitative precipitation forecasting.

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