Precipitations Prediction by Different Physics of WRF Model

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Abstract: - In this article we have configured the nested grid WRF v.3.6 model for the Caucasus region. Computations were performed using Grid system GE-01-GRENA with working nodes (16 cores+, 32GB RAM on each). Two particulate cases of unexpected heavy showers were studied. Simulations were performed by two set of domains with horizontal grid-point resolutions of 6.6 km and 2.2 km. The ability of the WRF model in prediction precipitations with different microphysics and convective scheme components taking into consideration complex terrain of the Georgian territory was tested. Some results of the numerical calculations performed by WRF model are presented.

Key-Words: - WRF modeling, heavy showers, different microphysics and convective schemes.

1 Introduction

As known the global weather prediction models can well characterize the large scale atmospheric systems, but not enough the mesoscale processes which mainly associated with regional complex terrain and land cover. For modeling these smaller scale atmospheric processes and its characterizing features it is necessary to take into consideration the main features of the local terrain, its heterogeneous surfaces and influence of large scale atmosphere processes on the local scale processes. The Weather Research and Forecasting (WRF) models are widely used by many operational services for short and medium range weather forecasting [1]. As a matter of fact the Advanced Research Weather Research and Forecasting Model (WRF-ARW) is a convenient research tool, as it offers multiple physics options and they can be combined in many ways [2]-[9]. Indeed in WRF-ARW model the main categories of physics parameterizations (microphysics, cumulus parameterizations, surface physics, planetary boundary layer physics and atmospheric radiation physics) mutually connected via the model state variables (potential temperature, moisture, wind, etc.) by their tendencies and via the surface fluxes [1]-[5]. Taking into account this broad availability of parameterizations it is not easy to define the right combination that better describes a meteorological phenomenon dominated above the investigated region. Many works have been dedicated to the problem of identification the best combination of parameterizations in WRF model that better represents the atmospheric conditions above the investigated region [2]-[26]. Three main combination of the microphysics parameterization schemes (WRF Single-Moment 3-class (WSM3) scheme[11], Eta Ferrier scheme [12], Purdue Lin scheme [13]) and 3 cumulus schemes (Kain-Fritsch [7], Betts-Miller-Janjic [14]-[15], Grell-Devenyi ensemble [16]) were chosen for identification which combination in WRF model was better simulated the atmospheric lightning conditions in the Brazil southeastern [5]. The sensitivity of quantitative precipitation forecasts to various modifications of the KF scheme and determination at which grid spacing values the KF scheme may no longer be needed on simulated precipitation was studied in [17]. By the way the Kain-Fritsch scheme [7],[18],[19] is frequently used to improve forecasts for convective parameterization at grid spacing below 20 km, likely because it has been shown that KF scheme perform better convective parameterization than other CPSs such as the Betts-Miller-Janjic and Grell-Devenyi schemes [8], [9], [10]. Also the KF scheme outperformed others for the 4 km simulation that used no convective scheme, so KF scheme can be used to improve forecasts even at such high resolutions [8],[17],[20]. Atmosphere processes and parameterization of physics for the Caucasus territory have been tested by the WRF model using the following schemes: WSM 3-class simple ice scheme, RRTM scheme, Dudhia scheme, unified Noah and-surface model, Yonsei University scheme, Kain-Fritsch (new Eta) scheme and Noah land-surface model scheme [25], [26].

2 Problem Formulation

In this study, WRF v.3.6 model is using for prediction heavy showers and hails for different set of physical options over the regions characterized with the complex topography. Namely Mesoscale Convective Systems (MCS) is studied using real data and WRF simulations are based on grid spacing in the range from 2.2 km to 19.8 km with an emphasis on 2.2 km. The ability of the WRF model in prediction precipitations with different microphysics and convective scheme components taking into consideration complex terrain of the Georgian territory is tested.

2.1 Data and Methodology

At present air quality monitoring in Georgia performs by National Agency of Environment and under his jurisdiction are 7 observation stations distributed in the 5 cities of Georgia: Tbilisi, Rustavi (eastern Georgia) Kutaisi, Zestafoni and Batumi (western Georgia). Each city has only 1 or 2 observation stations and only exception is capital city of Georgia Tbilisi were for the last ten-year period the observation were carried out in 8 posts, located in different districts of Tbilisi. It is obvious that these numbers of stations are not enough for assessment of hydro-atmosphere statement over the territory of Georgia. In fact we have hydro-meteorological information only for separated areas were the stations are located. For analyzing two particulate cases of unexpected heavy showers which took place on 13-14 June and 20-21 August 2015 in Tbilisi we were supported by scant information on air temperature, wind (speed, direction), humidity and amount of precipitation. All data were obtained from Hydro-meteorology Department of Georgia and from the meteorological post of Tbilisi State University. Also we were supported by radar's information on clouds structure. The whole set of those data have been used for assessment WRF model calculations results.

2.1.1 Observed convective events

Weather on the night of 13 to 14 June 2015 in Tbilisi was terrible with showers, thunderstorms and lights. According to the official data there were transfer of heat from the south by wave and it stipulated high temperature and showers with thunderstorms and lights in Tbilisi. Namely late on 13 June 2015 during 1.5-2 hours there was heavy shower and following of the heavy rainfall, a landslide was released above the village of Akhaldaba, about 20 km southwest of Tbilisi. The collapsed 1 million m^3 of land, mud, rocks and trees moved down from the Akhaldaba mountain into Tbilisi and dammed up the Vere river. A big wave (constructed by mass of slush, rocks and trees) run across the Vere canyon and washed everything away until the square of Heroes. The resulting flood inflicted severe damage on the Tbilisi Zoo, Heroes' Square and nearby streets and houses. Unfortunately this process has been resulted in at least 20 deaths, including three zoo workers and leaving half of the Tbilisi Zoo's animal inhabitants either dead or on the loose.

The another case of convective events was observed on 20-21 August 2015. It was dominated western atmospheric processes above the territory of Georgia from 19 to 21 August 2015. There were developed inner massive processes above the territory of Tbilisi and it was hailed in the evening of 19th August 2015. Also on 20th of August 2015 a heavy rainfall was observed above the Kakheti region (Kakheti is famous wine-making region in eastern Georgia) of Georgia. Downpours with hail cause destruction to some regions of Kakheti and resort suburbs of Tbilisi Kojori and Kiketi, where ground floors of many houses were flooded in the evening of 20th of August 2015. Namely, caused by the violent weather the rain with hail lasted for half an hour and in some settlements of the Gurjaani, Lagodekhi and Kvareli districts broke roofs and even walls of houses.

According to radar's allocated in the Kakheti region at 19:00 o'clock of 20th August from south-west of radar system there was outbreak of cloud systems having atmospheric front appearance which was moving towards to north-east direction. At 19:20 a new clod systems were formed and began moving from north-west to the town Akhmeta and 19:49 it achieved Akhmeta and the atmospheric column over the region has 15km height with maximal reflection 60dB. At 20:18 the cloud system with height 15km and maximal reflection 60dB from the territory of Akhmeta continued moving towards south-east direction and at 21:13 it reached territory of Kvareli with height 16km and maximal reflection 60dB. The cloud system continued migration and at 23:07 it shifted to the Lagodekhi territory the height and reflection of the cloud system began depletion. At 01:59 were formed a new clod system and it began moving from north-west to the north-east direction and at 02:19 it has 10km height, maximal reflection 50dB at 02:42 it achieved Akhmeta territory continued moving toward to the north-east direction and leaved investigated region.

2.1.2 WRF model simulation design

In our study we have used one-way nested domains centered on the territory of Georgia. The coarser domain (resolutions of 6.6km) has a grid of 94x102 points which covers the South Caucasus region, while the nested inner domain (resolutions 2.2 km) has a grid size of 70x70 points mainly territory of Georgia. Both use the 54 vertical levels including 8 levels below 2 km. A time step of 10 seconds was used for the nested domain. The WRF model contains a number of different physics options such are micro physics, cumulus parameterization physics, radiation physics, surface layer physics, land surface physics, and planetary boundary layer physics. Microphysics contains a number of microphysics modules and in our study we have chosen WSM6, Thompson, Purdue Lin, Morrison 2 Moment and Goddard schemes. Cumulus parameterization schemes are responsible for the sub-grid-scale effects of convective and/or shallow clouds and theoretically valid only for coarser grid sizes [1]. We have chosen Kain-Fritsch, Betts – Miller - Janjic and Grell – Devenyi ensemble schemes for our experiments. The planetary boundary layer (PBL) is responsible for vertical sub-grid-scale fluxes due to eddytransports in the whole atmospheric column [1]. Parameterization of the PBL directly influences on vertical wind shear, as well as precipitation evolution [21],[22]. In [23] summarized the main characteristics that explain the differences among WRF PBL schemes and also there was investigated how the PBL evolves within the ARW using 4-km grid spacing. There are number of PBL schemes but according to [23] we have chosen Yonsei University scheme. The land-surface models use atmospheric information from the surface layer scheme, radiative forcing from the radiation scheme, and precipitation forcing from the microphysics and convective schemes, together with internal information on the land's state variables and landsurface properties, to provide heat and moisture fluxes over land points and sea-ice points[2]. We have chosen Noah Land Surface Model. After considering various combinations of microphysics, Cumulus parameterization schemes, Land surface-physics and planetary boundary layer physics its combination for our experiments are given in the Table 1.

Table 1. Five set of the WRF parameterizations used in this study.

WRF Physics	Set1	Set 2	Set 3	Set 4	Set 5
Micro physics	WSM 6	Thom pson	Purdu e Lin	Morrison 2-Moment	Goddard
Cumulus Paramet erization	Kain-Fritsc h	Betts-Miller Janjic	Kain-Fritsc h	Grell-Devenyi ensemble	Kain-Fritsch
Surface Layer	MM5 Simil.	MM5 Simil.	MM5 Simil	(PX) Similarity	MM5 Similarit
Planet. Boundar y Layer	YSU PBL	YSU PBL	YSU PBL	ACM2 PBL	YSU PBL
Land-Surface	Noah LSM	Noah LSM	Noah LSM	Noah LSM	Noah LSM
Atmosph eric Radiat.	RRT M/Du dhia	RRT M/Du dhia	RRT M/Du dhia	RRTM/D udhia	RRTM/ Dudhia

3 Results and Discussion

Results of numerical calculation have showen that not one of the combinations listed in the Table 1 were able to model true atmospheric event which took place on the 13^{th} of June 2015. Namely results of numerical calculations showed that 24h predictions by these schemes were not in satisfactory quality as they were not able to account of the small-scale processes that lead to the development of deep convection. For example on the Fig.1 and Fig.2 are presented predicted fields of the relative humidity on the 850 hPa for 13 June (21UTC) and 14 June (00UTC) 2015, respectively, which were simulated by WRF Physics Options set1 (it gave a better result than others). The calculated amounts of water vapor presented on the Fig.2 and Fig.3 (nested domain with 6.6 km resolution) at the accidental moments when atmospheric event were in full swing are not in satisfactory agreement with real situation which took place in Tbilisi and surroundings on 13 June 2015.

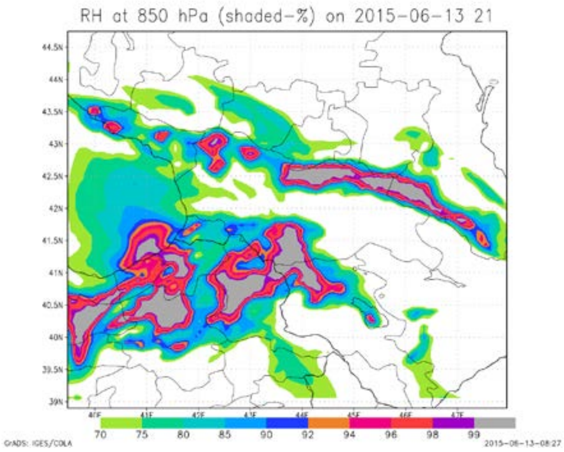

Fig.1 Map of the relative humidity at the 850 hPa for 13 June 2015 (21UTC) simulated for the nested domain with 6.6 km resolution.

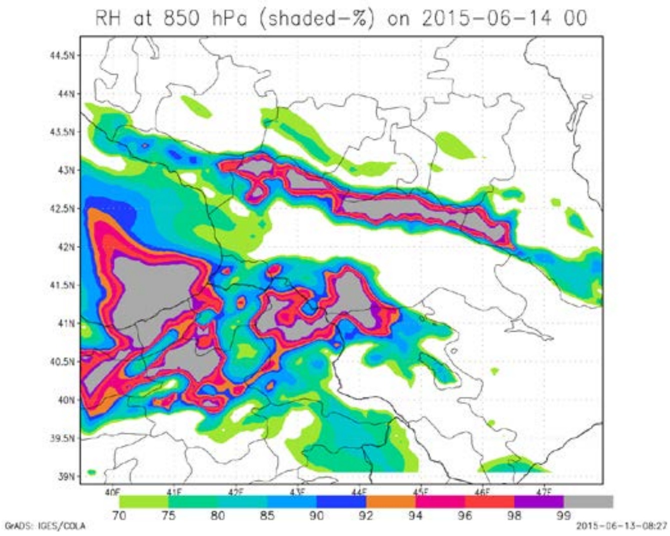

Fig.2 Map of the relative humidity at the 850 hPa for 14 June 2015 (00UTC) simulated for the nested domain with 6.6 km resolution.

On the figures 3 and 4 are presented forecasted precipitation fields on the 850 hPa height for 13 June 2015 (21UTC) and for 14 June 2015 (00UTC) respectively. Both of the figures demonstrate 24 h WRF-ARW forecast failure and especially in the investigated region where the both nested models predicted almost dray conditions (insignificant precipitations). Namely comparison Fig.3 with Fig.4 shows that considerably increased amount of accumulated precipitations at the coastal area of the Black Sea nearby of the Poti city, but there is diffuse spectrum of accumulated precipitations on the Fig.4 in comparison with Fig.3 in the investigated area. Unfortunately for this case study, all of the precipitation simulated in the region of interest (Tbilisi and suborbs) was not convective in nature, only small amount of precipitation was produced by the model. As it is known the CPSs are producing precipitation, not the microphysics [8], so this indicates that the set of choices of CPSs were not producing precipitation for this mesoscale case study. An important deduction from all simulation results was that quite accurate reproductions of lower tropospheric temperature and wind profiles but these were not necessary for the successful simulation mesoscale deep convection which took place on 13 June 2015 in Tbilisi and suburbs. In our opinion, it is necessary to strengthen initial and boundary conditions through data assimilation, and to improve the physical linkages between the radiation physics, surface layer physics, land surface physics.

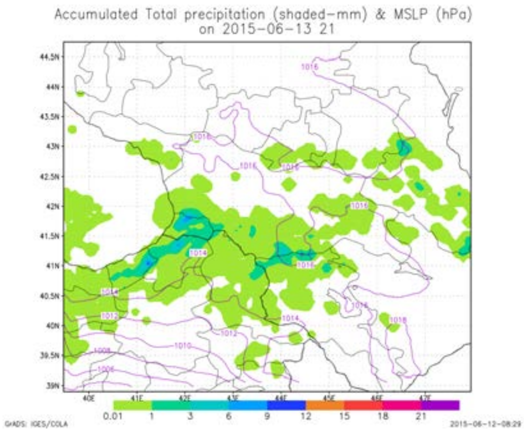

Fig.3 Forecasted (13 June 00 UTC) accumulated precipitation 12 h sum simulated for the nested domain with 6.6 km resolution.

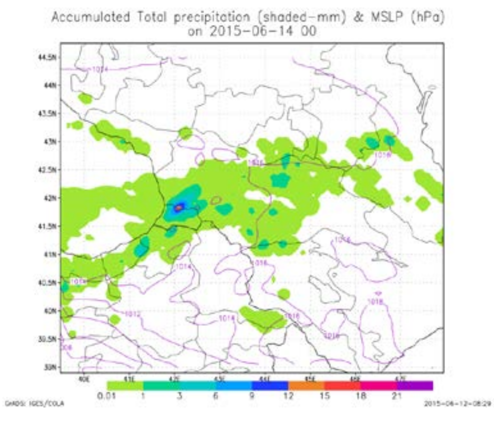

Fig.4 Forecasted (14 June 00 UTC) accumulated precipitation 12 h sum for nested domain with 1-way nesting method and 6.6 km resolution.

Numerical calculations fulfiled for simulation shower which took place on 20 August (with 5 different combinations of physical schemes) have shown that in all cases, orographic forcing plays an important role in the localization and intensification of precipitation in and nearby of complex terrain. Numerical calculations have shown that combination of the Purdue Lin scheme with Kain-Fritsch scheme and MM5 Similarity Surface Layer (Set 3) and Goddard scheme with Kain-Fritsch scheme and MM5 Similarity Surface Layer scheme (Set 5) gave the better results than others. Selected convective cases for Set3 and Sey5are shown in Fig.6 and Fig.7 respectively. Numerical calculations have shown that there are indeed 'natural' scales of activity for the convective parameterization within WRF.

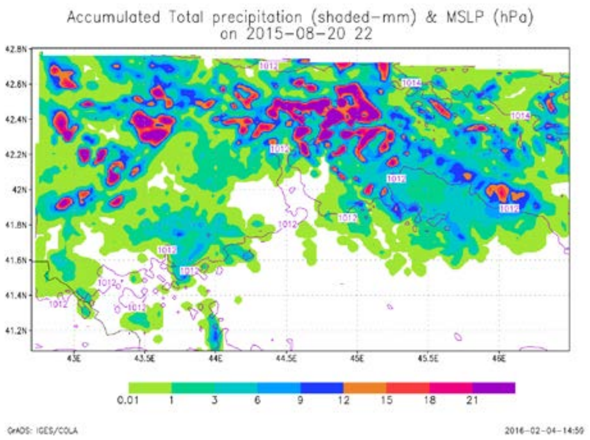

Fig.5 Forecasted (Set-3, 20 August 21 UTC) accumulated precipitation 12 h sum for nested domain 2.2 km resolution.

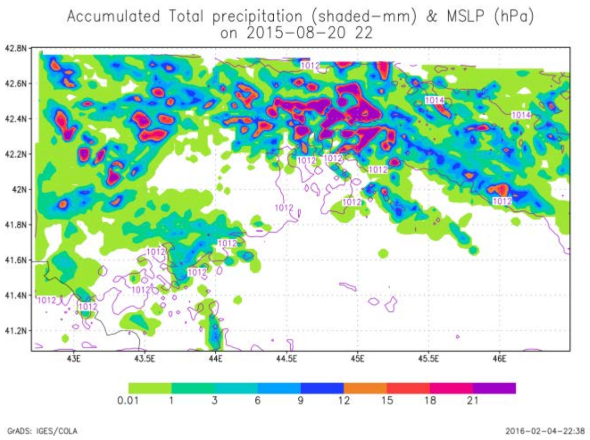

Fig.6 Forecasted (Set-5, 20 August 21 UTC) accumulated precipitation 12 h sum for nested domain 2.2 km resolution.

Comparison Fig.5 with Fig.6 shows that the main features of accumulated precipitations are predicted almost similarly, but accurate study of the dynamics and its comparison with the data of observations have shown that Set 3 was able to model that true atmospheric event which took place on the 20 -21 August 2015. In summary it can be said, that above mentioned model can be successfully used for local weather extremes prediction for western type synoptic processes such was 19-21 August atmospheric circulation above the Georgian territory.

4 Conclusion

In these study comparisons between WRF forecasts allowed verifying that in general the set of combinations of Purdue Lin scheme with Kain-Fritsch scheme and MM5 Similarity Surface Layer (Set 3) and Goddard scheme with Kain-Fritsch scheme and MM5 Similarity Surface Layer scheme (Set 5) gave the better results than others for western atmosphere processes dominated above the territory of Georgia. Also for evolution and improvement of model skill for different time and spatial scale the verification and assimilation methods should be used for further tuning and fitting of model to local conditions.

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