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Study of Convection using the Kain-Fritsch Convective Scheme of WRF Numerical Model

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We have studied a convection from a convective cloud that brought damage to people and economy on 14-15 July of 2010 in the area of Ulaanbaatar city, using ARW, the third version of the WRF simulation program. The results have been compared to meteorological observed data and the reliability was 87%.

Key words: numerical model, convection, micro physical characteristics of cloud, droplet, Doppler radar

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I. INTRODUCTION

In a meteorological research, usage of numerical model is necessary. Using the simulation programs that compiled in the leading research centers of the world capable to calculate an atmosphere in the 3-4 dimensional space, one can save time and money in a study of physical phenomena in the atmosphere. It has been shown by many researchers that the results obtained using a computer with the high speed and accuracy are fairly good like the ones obtained in a laboratory as well as with a human hand method [3]. Studying the local convective cloud, its evolution, internal micro physical phenomena and meteorological phenomena occurring due to the convective cloud by means of the simulation has been started since 1940 [2]. Since then the method of describing convection with a simulation and the basic theoretical methods as well as the schemes have been invented and used. This work will further continue and it is clear that as the capacity of the computer has been improved the methods and the results will have been improved as well.

II. THE RESEARCH METHOD

In our research we have used the simulation program, ARW (Advanced Research WRF), which is the third version of WRF (Weather Research and Forecasting) that produced in the NOAA and NCAR.

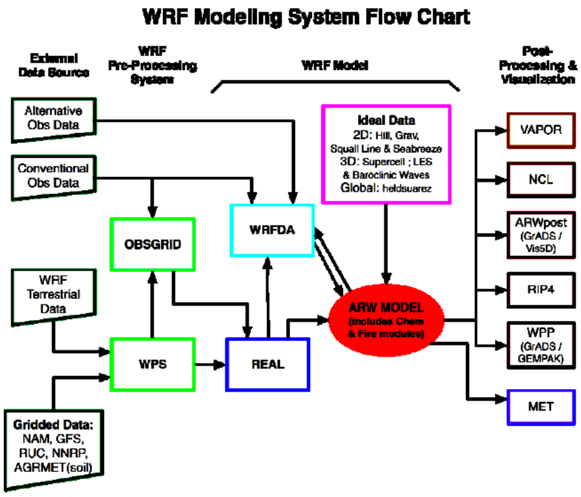

Figure.1. The block scheme of the WRF simulation program.

For now, more than 150 research centers and institutes around the world are using this system. Like the other meteorological simulation programs, the WRF requires a computer with good characteristics. In the table 1, we have listed the CPU's that the WRF simulation program can work with [5].

Table 1.

Vendor	Hardware	OS	Compiler
Cray	X1	UniCOS	vendor
Cray	AMD	Linux	PGI
IBM	Power Series	AIX	Vendor
SGI	IA64/Opteron	Linux	Intel Intel /PGI/
COTS	IA32	Linux	Intel /PGI/ gfortran /g95/

			PathScale
COTS	IA64/Opteron		Intel /PGI/ gfortran /g95/ PathScale
Mac	Power Series	Darwin	xlf / g95 / PGI /Intel
Mac	Intel	Darwin	g95 / PGI /Intel

The basic equation system of the simulation program consists of the following equations:

Momentum equation (x: zonal)

$$\frac{\partial u}{\partial x} = -\mathbf{u}\cdot\nabla u + 2\Omega \sin\phi v - \frac{1}{\rho}\frac{\partial p}{\partial x} + F_x \qquad (1)$$

Momentum equation (y: meridional)

$$\frac{\partial v}{\partial x} = -\mathbf{u}\cdot\nabla v - 2\Omega \sin\phi u - \frac{1}{\rho}\frac{\partial p}{\partial y} + F_y \qquad (2)$$

Momentum equation (z: vertical)

$$\delta\frac{\partial w}{\partial x} = -\frac{1}{\rho}\frac{\partial p}{\partial z} - g \qquad (3)$$

Mass conservation

$$\frac{\partial p}{\partial t} = -\mathbf{u}\cdot\nabla p - \rho\cdot\nabla\mathbf{u} \qquad (4)$$

Heat conservation

$$\frac{\partial \theta}{\partial t} = -\mathbf{u}\cdot\nabla\theta + H \qquad (5)$$

$$\theta = T\left(\frac{p_s}{p}\right)^{R/c_p} \qquad (6)$$

Conservation of water

$$\frac{\partial q}{\partial t} = -\mathbf{u}\cdot\nabla q + M \qquad (7)$$

State equation of gas

$$p = \rho R T \qquad (8)$$

The ARW simulation program uses the 3[th] order Runge-Kutta method (Figure 2) to calculate equations (1)-(8) numerically and calculates the motion by order 1, 2, 3, 4, 5 and 6 [5].

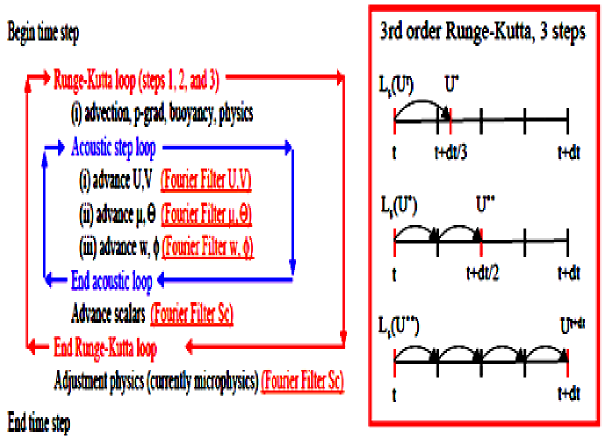

Figure 2. The 3[th] order Runge-Kutta method that used to integrate in the simulation program.

The basic dynamics of the simulation program is:

- Terrain representation
- Vertical coordinate
- Equations / variables
- Time integration scheme
- Grid staggering
- Advection scheme
- Time step parameters
- Filters
- Boundary conditions
- Nesting
- Map projections

III. THE KAIN-FRITSCH CONVECTIVE SCHEME

One of the widely used convective schemes since 1990 by the researchers is the Kain-Fritsch convective scheme. The main feature of the scheme is that it is considered that the convective thermic obtains the potential from the initial point of motion that is enough to pass a level not under 60 kPA in the vertical direction when it lifts off by dry adiabat till the condensation level [4]. The motion continues by an inertia of this potential

$$\delta T_{vv} = k(w_g - c(z))^{1/3} \qquad (9)$$

where k is a dimension and its unit is $[s^{1/3}\cdot cm^{-1/3}]$ and $w_g$is a vertical velocity that varies by grid spacing and its unit is $[cm\cdot s^{-1}]$ and $c(z)$ is a threshold vertical velocity given by

$$c(z) = \left\{\begin{pmatrix} w_0\cdot(Z_{LCL}/2000), & Z_{LCL}\le 2000 \\ w_0, & Z_{LCL}<2000\end{pmatrix}\right\}, \qquad (10)$$

where Z_{LCL} is the lifting condensation level and its unit is $[m]$, $w_0 = 2\ cm\cdot s^{-1}$.

Thus, according to the equations (9) and (10), the thermic lifts off as a dry adiabatic and as it does an exchange with a comparatively cold medium on its lifting way it reaches the bottom of the convective cloud or the condensation level. Total sweeping of the convective motion is

$$M_{ee} \ge 0.5\cdot\delta M_e\ , \qquad (11)$$

where $\delta M_e$is a mixing ratio and its unit is $[kg\cdot s^{-1}]$.

$$\delta M_e = M_{u0}\frac{(-0.3\cdot\delta p)}{R}. \qquad (12)$$

Here M_{u0} is a lifting mass flux and its unit is $[kg\cdot s^{-1}]$ and δp is a pressure grid spacing of the simulation model and its unit is $[Pa]$.

Here R is a radius of a cloud and is described as with the form

$$R = \begin{bmatrix} 1000, & W_{KL} < 0 \\ 2000, & W_{KL} > 10 \\ 1000 + \frac{W_{KL}}{10}, & 0 \le W_{KL} \le 10 \end{bmatrix}, \quad (13)$$

where $W_{KL} = w_g - c(z)$ and its unit is $[cm \cdot s^{-1}]$.

In the Kain-Fritsch convective scheme the possible width of a convective cloud has been described by equation (14). In generally, for the simulation model with eta vertical coordinate, it is considered the minimum width is 2 km [4].

$$D_{min} = \begin{bmatrix} 4000, & T_{LCL} > 20^0C \\ 2000, & T_{LCL} < 0^0C \\ 2000 + 100 \cdot T_{LCL}, & 0 \le T_{LCL} \le 20 \end{bmatrix}. \quad (14)$$

Here T_{LCL} is a lifting condensation level and its unit is [℃].

IV. THE RESULTS

The study has been done on the convection observed on 14-15 July of 2010 about Ulaanbaatar city. The results have been compared with those obtained by meteorological Doppler radar in the Morin-Uul. This convection process created a thunderstorm and heavy rain which caused a serious damage to people and economic entities. The thunderstorm directly influenced to the running of the research and training center located in Uvurzaisan.

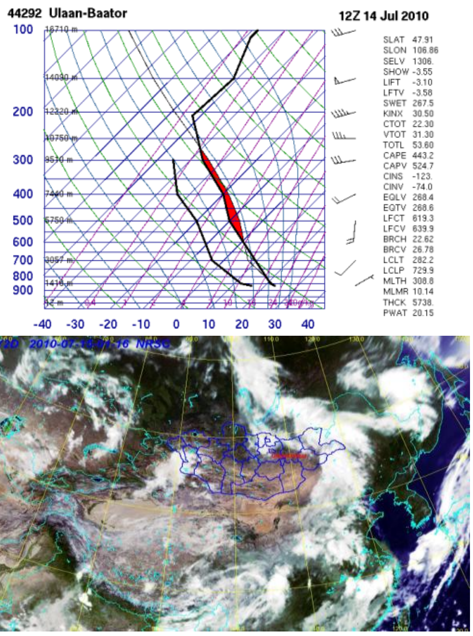

Figure 3. The aerological diagram and the satellite picture for that time [6].

By the simulation program we have calculated totally 8 convective characteristics which have the spacing of one hour and plotted them using Grid Analysis and Display System (GrADS).

A. Cloud water

Amount of water per volume of cloud is called cloud water. It has the shape of water drop and ice crystal.

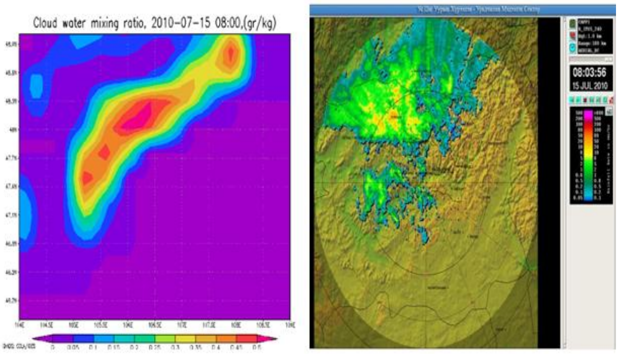

Figure 4. Comparison of the results of cloud water with the weather radar data. Left: The results obtained using by the simulation program.

B. Rain water

Amount of droplets that largened to a size of a precipitation stored in a cloud is called rain water.

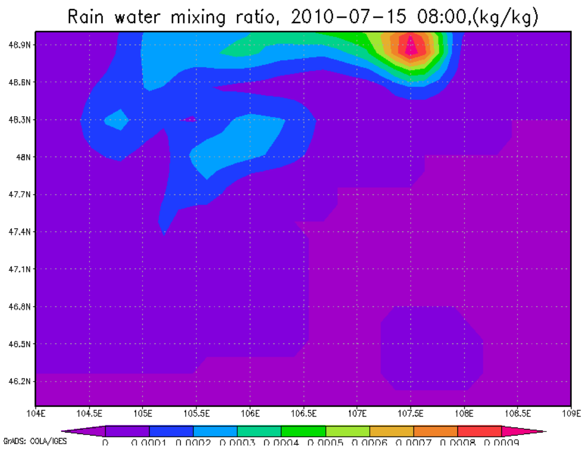

Figure 5. Rain water mixing ratio that is computed using the simulation program..

C. Amount of water vapor in the atmosphere

Amount of mass of water vapor stored per mass of the atmosphere is called individual humidity. Its physical value is the vapor mass divided by air mass, although it does not have a unit.

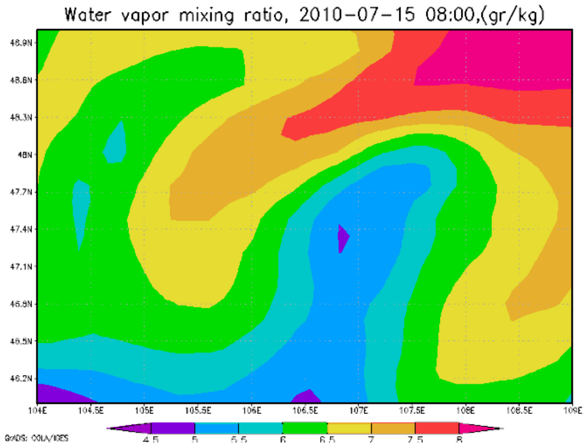

Figure 6. Water vapor mixing ratio that is computed using the simulation program.

CAPE Convective available potential energy

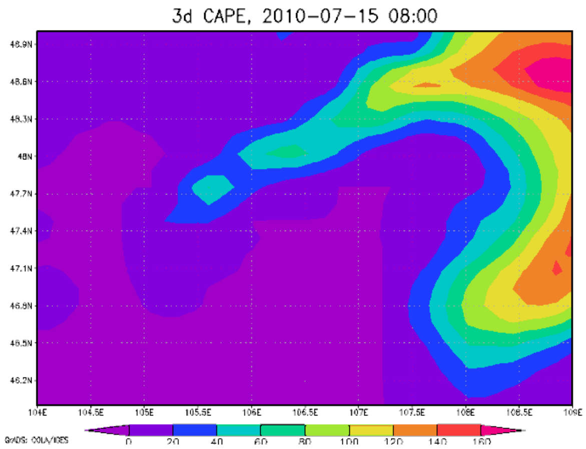

Figure 7. CAPE that is computed using the simulation program.

CIN Convective inhibition

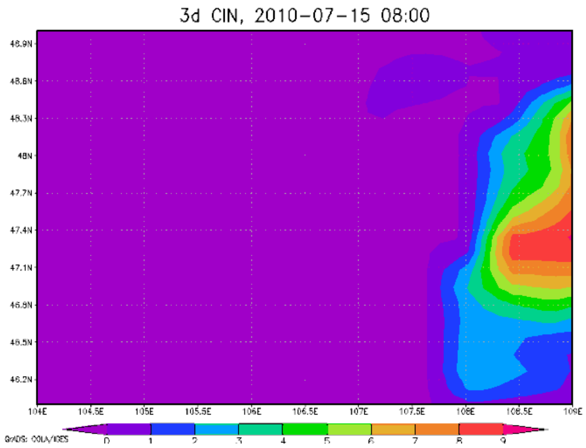

Figure 8. CIN that is computed using the simulation program.

dbz Radio echo of cloud that is calculated using the simulation program

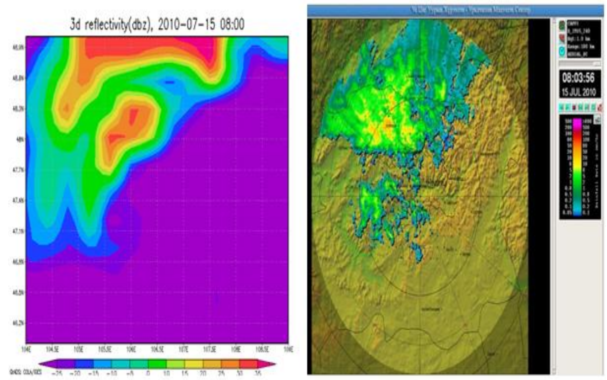

Figure 9. Comparison of cloud results with the radar data. Left: The results obtained using by the simulation program.

D. Precipitation

Liquid precipitation the radius of droplet of which is greater than 0.25 mm is called rain. It mainly consists of the droplets with the radius of 2.5-3.2 mm and forms wide-spread circles when it falls down on the ground and forms clear wet spots on a dry object [1].

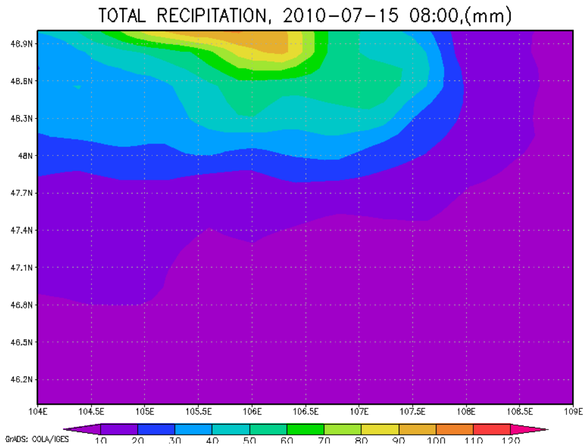

Figure 10. Precipitation that is computed by the simulation program.

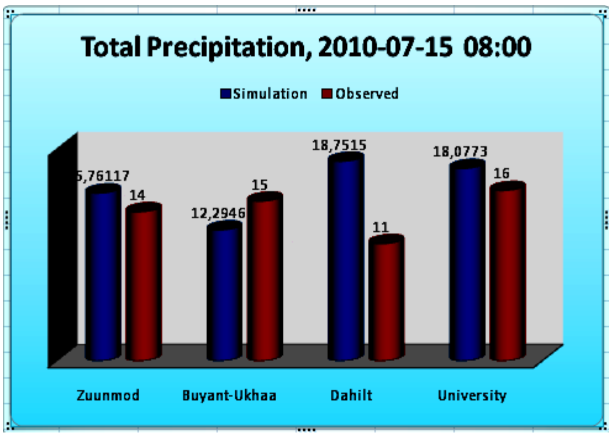

Figure 11. Comparison of the results obtained using by the simulation program with the real weather observation.

E. *Lifting condensation level (LCL)*

It is a level where a dry adiabat lifted air starts to saturate. From this point air starts to lift off by wet adiabat.

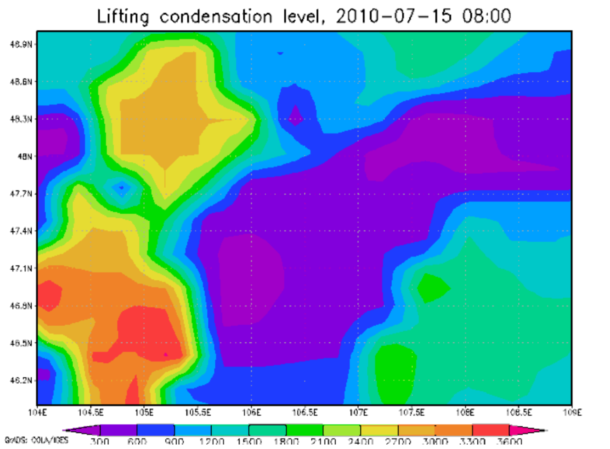

Figure 12. Condensation level that is computed by the simulation program.

F. *Level of free convection(LFC)*

It is a level where a wet adiabat lifting starts to saturate.

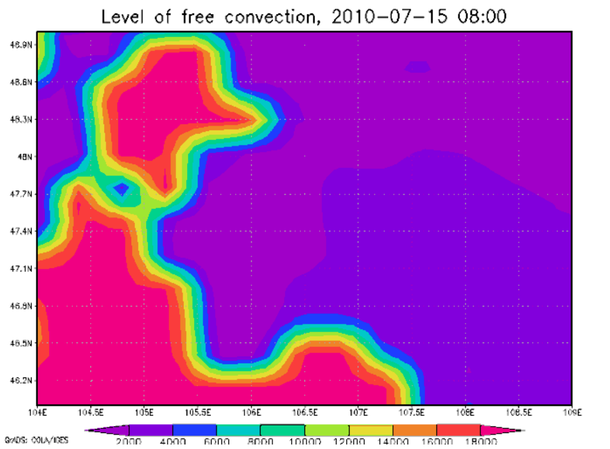

Figure 13. Level of free convection that is computed by the simulation program.

V. DISCUSSION

As we have seen from the study, although one can compare the results obtained using by Kain-Fritsch convective scheme of WRF numerical model with radar data, confidence level changes depending on the emergence of the numerical model. Confidence level increases when the emergence increases. That means in order to improve the confidence level we need more powerful computer.

VI. CONCLUSION

The results obtained using by the WRF numerical model match with weather Doppler radar data with the reliability more than 85%. Therefore we conclude that we can use the Kain-Fritsch convective scheme in Mongolia.

The amount of precipitation computed by the scheme matches with those of real weather observation with the reliability of 87%.

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