

## Evaluation of different convective schemes on simulation of thunderstorm event over Delhi by ARPS Model

KULDEEP SRIVASTAVA, S. K. ROY BHOWMIK and H. R. HATWAR

*India Meteorological Department, New Delhi, India*

*(Received 12 September 2006, Modified 9 February 2009)*

**e mail : kuldeep.nhac@gmail.com**

**सार** – इस शोध पत्र में दिल्ली में हुई संवहनी वर्षा से संबंधित गर्ज के साथ तूफानों की दो घटनाओं को दर्शाने के लिए उन्नत क्षेत्रीय पूर्वानुमान माडल (ए. आर. पी. एस.) से तीन भिन्न भिन्न प्रकार की कपासी प्राचलीकरण पद्धतियों नामतः केन-फ्रिस्क, न्यू केन-फ्रिस्क और दि बिट्टस-मिलर-जैन्जीक को उपयोग किया गया है प्रत्येक संवहन पद्धति में अनुकृति वर्षा मॉडल की वास्तविक रूप से प्रेक्षित वर्षा आँकड़ों के साथ तुलना की गई है। इस अध्ययन से पता चला है कि केन-फ्रिस्क पद्धति दिल्ली में आए गर्ज के साथ तूफान वाली घटनाओं के अधिक सही परिणाम देती है। यह पद्धति वर्षा के कालिक वितरण और नियत समय पर गर्ज के साथ तूफान आने की सूचना उपलब्ध कराने जैसी दोनों की स्थितियों की जानकारी देने में सक्षम रही है जबकि अन्य दो पद्धतियाँ इन स्थितियों को बताने में विफल रही हैं। तथापि केन-फ्रिस्क पद्धति में वर्षा की मात्रा को अधिक आँका गया है।

**ABSTRACT.** Three difference cumulus parameterization schemes namely, Kain-Fritsch, New Kain-Fritsch and the Betts-Miller-Janjic are used to simulated convective rainfall associated with two thunderstorm events over Delhi by Advanced Regional Prediction Model (ARPS). An inter comparison of model simulated precipitation in respect of each convection scheme is made with reference to observed precipitation. The study shows that for the Delhi thunderstorm events, the Kain-Fritsch scheme provides more realistic results. This scheme is able to capture the temporal distribution of rainfall and the timely development of thunderstorm in both the cases. While the other two schemes fail to capture these features. However, the Kain-Fritsch scheme is found to overestimate the rainfall amount.

**Key words** – Thunderstorm, Convection, Cumulus parameterization, ARPS model.

### 1. Introduction

Cumulus convection is an important physical process that influences the dynamic and thermodynamic state of the tropical atmosphere. During the south west monsoon season (June to September) Delhi (northern parts of India) often experiences severe thunderstorm activity due to convective instability which triggers deep convection giving rise to convective rainfall. The cumulus convection schemes can be categorized into three groups, the moisture convergence scheme (Kuo 1974), the mass flux type scheme (Arakawa and Schubert, 1974) and the moist convective adjustment scheme. Cumulus parameterization schemes in models are responsible for the sub-grid-scale effects of convective clouds. The schemes are intended to represent vertical fluxes due to unresolved updrafts and downdrafts and compensating motion outside the clouds. They operate only on individual columns where the

scheme is triggered and provide vertical heating and moistening profiles. Some schemes additionally provide cloud and precipitation field tendencies in the column, and future schemes may provide momentum tendencies due to convective transport of momentum. The schemes all provide the convective component of surface rainfall. Cumulus parameterizations are theoretically only valid for coarser grid sizes, (e.g., greater than 10 km), where they are necessary to properly release latent heat on a realistic time scale in the convective columns. While the assumptions about the convective eddies being entirely sub-grid-scale break down for finer grid sizes, sometimes these schemes have been found to be helpful in triggering convection in 5–10 km grid applications. Generally, they should not be used when the model can resolve the convective eddies it self (e.g.,  $\leq 5$  km grid). Since convective elements have a horizontal scale of the order of 0.1 to 10 km, fine horizontal resolution is required in

**TABLE 1**  
**Configuration of the Experiment**

Central Latitude (Delhi)	28.58° N
Central Longitude (Delhi)	77.20° E
Dimension Size (No of Grids) in X, Y & Z direction	37, 37, 25
Grid spacing (meters) in X, Y & Z direction	10000, 10000, 500
Run mode	3-D run
Model Initialization Option	Initialize using analytic function
Time step for model integration	12 second
Boundary Conditions	Zero gradient (east, west and top), Periodic (north and south)
Turbulent Mixing Option	1.5 TKE turbulent mixing
Moist processes Option	Moist processes are activated
Microphysics Option	Kain - Fritsch warm rain microphysics
Surface physics Option	Surface fluxes are calculated from the constant surface drag coefficients, and predicted surface temperature and surface volumetric water content.

numerical model for a realistic treatment of the convective processes.

In order to deal with the mesoscale convective events, recently various non hydrostatic mesoscale models (such as MM5, RAM, ARPS, etc.) were developed by various institutes. To deal exclusively with the mesoscale systems like thunderstorms, a nonhydrostatic model known as Advanced Regional Prediction System (ARPS) was developed (Xue *et al.*, 2000, 2001) by Center for Analysis and Prediction of Storms (CAPS) at Oklahoma University U.S.A. Many Indian researchers has evaluated the effect of different convective scheme for forecasting of rainfall associated with thunderstorm over Indian stations using different Meso-Models but the results varied in each case (Vaidya *et al.*, 2004, 2006 & 2007, Mukhopadhyay *et al.*, 2003, etc.).

The ARPS Model includes inbuilt package for data ingest, quality control and objective analysis. Main speciality of this model is that this model can be run for a particular station by using radio sonde sounding for that station and artificial triggering mechanism. Also Radar data, Satellite data and Surface data can be ingest in the

model. Hence this is very useful for small station to predict thunderstorm events (Srivastava *et al.*, 2008)

In this paper the effect of, three different cumulus parameterization schemes in ARPS Model, on convective rainfall have been investigated for two thunderstorm events, which occurred over Delhi on 4 August and 9 September 2005. The detailed description of the model is documented by Xue, *et al.* (2000, 2001).

## 2. Data sources and design of experiment

Data used for this study are:

(i) Radio sonde (RS/RW) and rainfall observations of Delhi (Lat. 28.58° N, Long. 77.20° E) for 5 August and 9 September 2005.

(ii) Terrain field of 5 minutes (~ 10 km) resolution.  
(Source: CAPS, Oklahoma  
Website +ftp://<ftp.caps.ou.edu>/ARPS)

The experiment was initiated by a 4° C bubble shaped perturbation with radii 10 km in *x* and *y* direction and 1.5 km in vertical direction. This was used to give artificial triggering mechanism. Model is run for these

two thunderstorm events, using the following three different parameterization schemes.

Kain-Fritsch (KF) Cumulus parameterization scheme

Betts-Miller-Janjic (BMJ) Cumulus parameterization scheme.

New Kain-Fritsch (New KF) Cumulus parameterization scheme.

The configurations used in these experiments are as given in Table 1.

### 3. The parameterization schemes

Brief descriptions of the different cumulus parameterization schemes used in this experiment are described below:

#### 3.1. *Kain-Fritsch (KF) Cumulus parameterization scheme*

This scheme is designed to rearrange mass in a column so that CAPE is consumed. The following conditions must be met for the scheme to trigger convection:

- (i) The sounding has CAPE for source parcels from a low-level layer 50 to 100 hPa thick.
- (ii) The CAPE is small enough for a parcel to penetrate given a boost of a few m/s (a function of large-scale vertical motion at LCL).
- (iii) The convective cloud depth exceeds a threshold.

Changes to the sounding result from cloud detrainment, environmental subsidence, and evaporatively driven downdrafts dumping into the convecting source layer. In addition, these effects are based on cloud properties determined in a one-dimensional cloud model. Clouds of only one height (the tallest cloud that the sounding permits) are assumed to exist and entrain and detrain at many levels. Instead of a single mixture of cloud and environment, entrainment is assumed to produce many different mixtures, which have different buoyancy properties and thus detrain at different levels. This allows the scheme to be even more responsive and sensitive to different soundings than others. It also allows more realistic detraining of hydrometeors to a complex. Precipitation is produced in the cloud model, with some precipitation evaporating in the downdraft and some instantly falling as precipitation. This scheme has mass-

flux approach of accounting for the fundamental grid-scale effects of convection (cloud detrainment, downdrafts, and environmental subsidence).

Main Strengths of this scheme is that it is suitable for mesoscale models and coupling with other schemes that use clouds. The assumption about consuming CAPE is appropriate for short time and space scales. It accounts for microphysical processes in convection and hence may perform better in cases of severe convection.

#### 3.2. *Betts - Miller - Janjic (BMJ) Cumulus parameterization scheme*

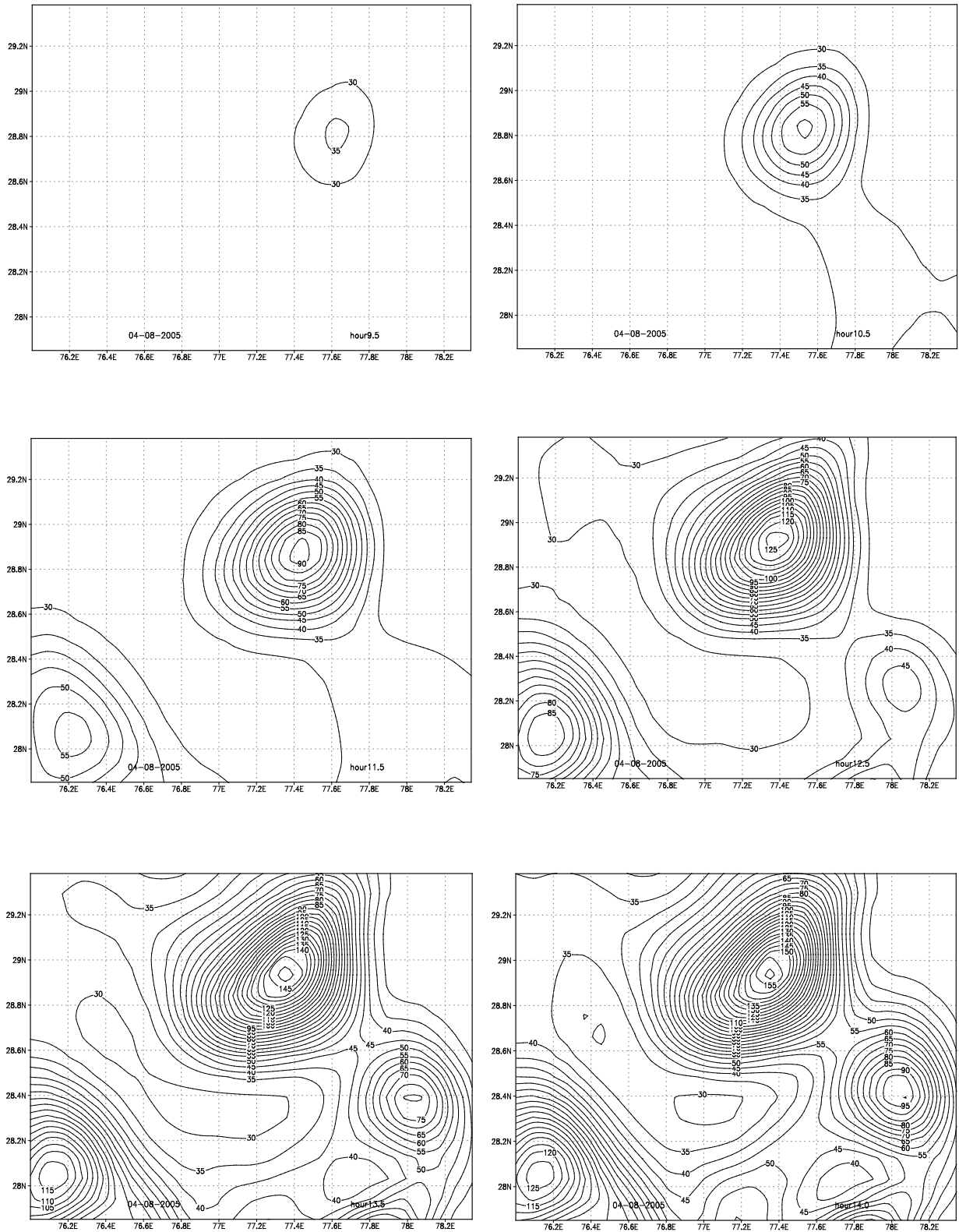
The Betts-Miller-Janjic (BMJ) scheme (Janjic, 1994, 2000) was derived from the Betts-Miller (BM) convective adjustment scheme (Betts, 1986; Betts and Miller, 1986). However, the BMJ scheme differs from the Betts-Miller scheme in several important aspects. The deep convection profiles and the relaxation time are variable and depend on the cloud efficiency, a non-dimensional parameter that characterizes the convective regime (Janjic, 1994). The cloud efficiency depends on the entropy change, precipitation, and mean temperature of the cloud. The shallow convection moisture profile is derived from the requirement that the entropy change be small and non-negative (Janjic, 1994). Recently, attempts have been made to refine the scheme for higher horizontal resolutions, primarily through modifications of the triggering mechanism in particular.

- (i) A floor value for the entropy change in the cloud is set up below which the deep convection is not triggered;
- (ii) In searching for the cloud top, the ascending particle mixes with the environment; and
- (iii) The work of the buoyancy force on the ascending particle is required to exceed a prescribed positive threshold.

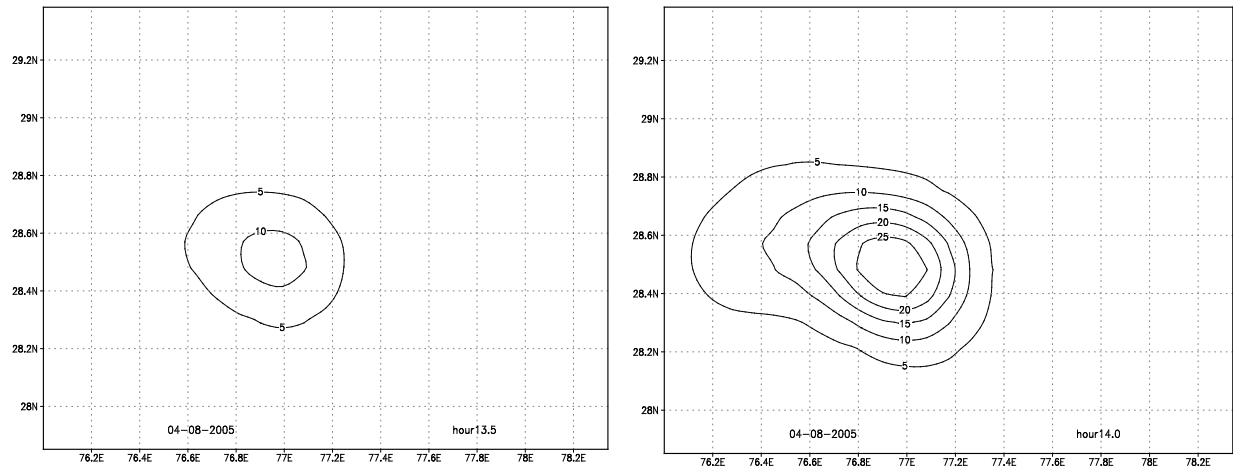
#### 3.3. *New Kain - Fritsch (New KF) Cumulus parameterization scheme*

The modified version of the Kain-Fritsch scheme (New KF) is based on Kain and Fritsch (1990) and Kain and Fritsch (1993). As with the original KF scheme, it utilizes a simple cloud model with moist updrafts and downdrafts, including the effects of detrainment, entrainment, and relatively simple microphysics. It differs from the original KF scheme in the following ways:

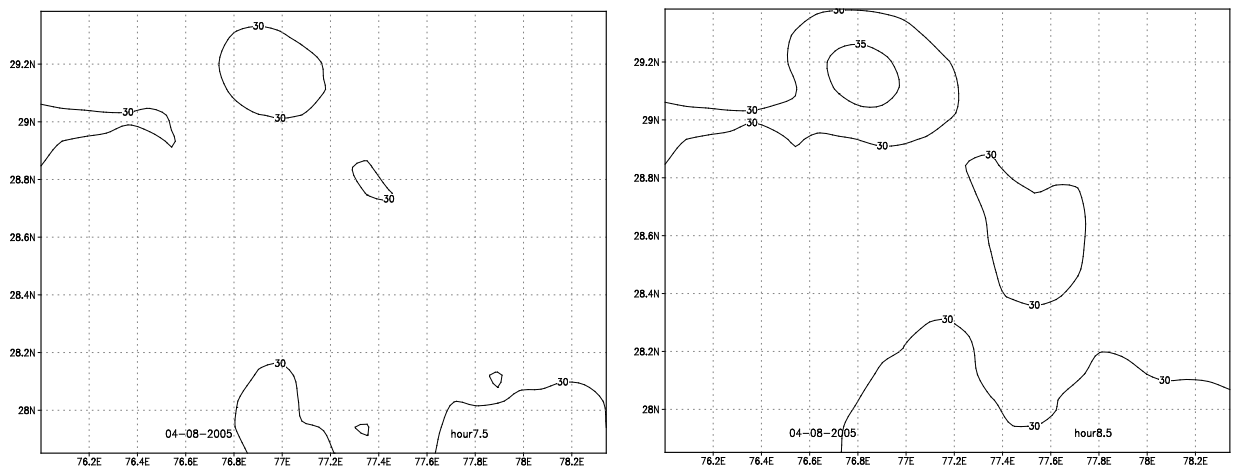
- (i) A minimum entrainment rate is imposed to suppress widespread convection in marginally unstable, relatively dry environments.



**Fig. 1.** Latitude longitude section of rainfall (mm) by Kain-Fritsch scheme (KF) (04 August 2005)



**Fig. 2.** Latitude longitude section of rainfall (mm) by New Kain-Fritsch scheme (new KF) (04 August 2005)



**Fig. 3(a).** Latitude longitude section of rainfall (mm) by Betts-Miller-Janjic (BMJ) scheme (04 August 2005)

(ii) Shallow (non precipitating) convection is allowed for any updraft that does not reach minimum cloud depth for precipitating clouds; this minimum depth varies as a function of cloud-base temperature.

(iii) The entrainment rate is allowed to vary as a function of low-level convergence.

(iv) Downdraft changes:

- Source layer is the entire 150–200 MB deep layer just above cloud base.

- Mass flux is specified as a fraction of updraft mass flux at cloud base. Fraction is a function of source

layer RH rather than wind shear or other parameters, *i.e.*, old precipitation efficiency relationship not used.

- Detrainment is specified to occur in updraft source layer and below.

#### 4. Results and discussion

Two cases selected for this study are, the thunderstorms events of 4 August and 9 September 2005, which occurred over Delhi. Model has been run using 0000 UTC RS/RW observations of the particular date for the 24 hour forecast using three different convective parameterization schemes. A comparison between hourly

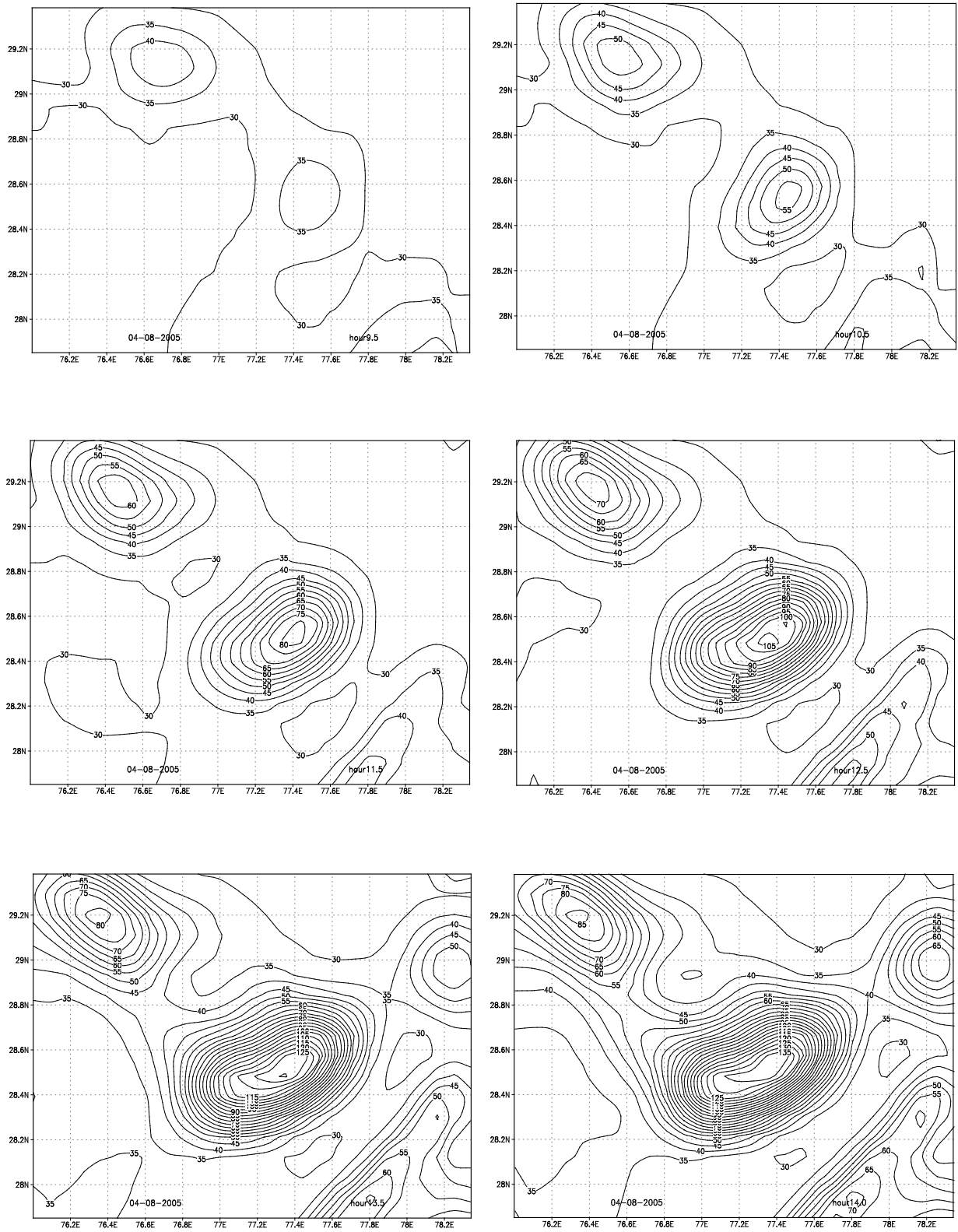
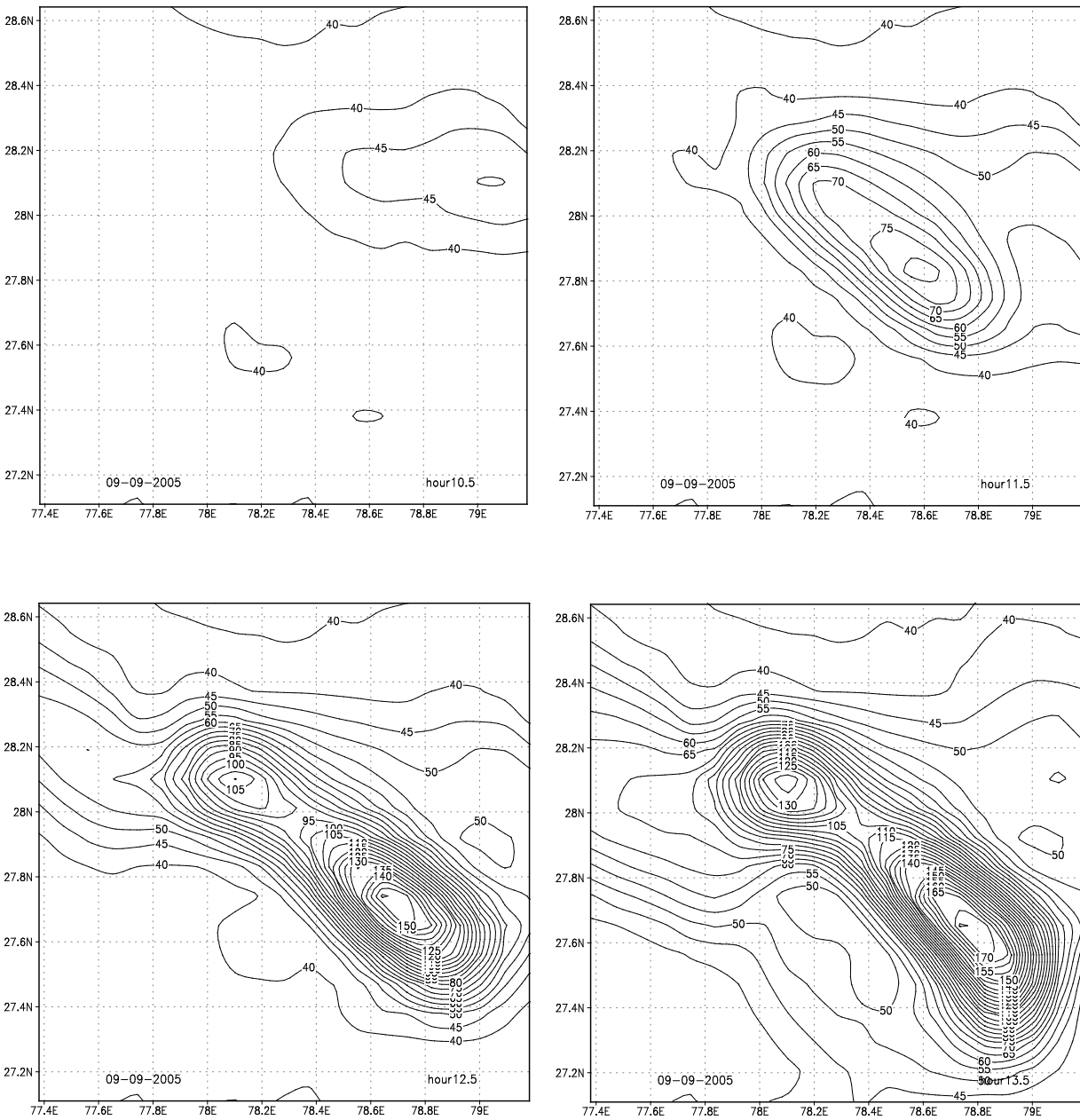


Fig. 3(b). Latitude longitude section of rainfall (mm) by Betts-Miller-Janjic (BMJ) scheme (04 August 2005)



**Fig. 4.** Latitude longitude section of rainfall (mm) by Kain-Fritsch scheme (KF) (09 September 2005)

convective precipitation simulated in the coarse domain with the Kain-Fritsch, New Kain-Fritsch and the Betts-Miller-Janjic (BMJ) schemes have been made. The hourly forecast fields of rainfall in all three schemes are compared with the actual observations. The temporal

distribution of rainfall has also been analyzed and compared with the time of actual occurrence of thunderstorm 24 hour forecast of updraft and downdraft (vertical velocity) by Kain-Fritsch scheme in both the cases has been analyzed.

TABLE 2

## One hourly SRRG rainfall observations of 4 August 2005

S. No.	Date	Rainfall recorded between Time interval Time in hrs (IST)	Rainfall (mm) Safdarjung	Rainfall (mm) Palam	Rainfall (mm) Lodi Road
1	04 Aug 2005	1130 – 1230	0.0	0.0	0.0
2	04 Aug 2005	1230 – 1330	0.0	0.0	0.0
3	04 Aug 2005	1330 – 1430	0.0	0.0	0.0
4	04 Aug 2005	1430 – 1530	0.0	0.0	0.0
5	04 Aug 2005	1530 – 1630	35.0	0.0	2.0
6	04 Aug 2005	1630 – 1730	0.0	0.7	18.0
7	04 Aug 2005	1730 – 1830	0.0	0.3	0.0
8	04 Aug 2005	1830 – 1930	0.0	0.0	0.0
		Total	35.0	1.0	20.0

TABLE 3

## One hourly SRRG rainfall observations of 9 September 2005

S. No.	Date	Rainfall recorded between Time interval Time in hrs (IST)	Rainfall (mm) Safdarjung	Rainfall (mm) Palam	Rainfall (mm) Lodi Road
1	09 Sep 2005	1130 – 1230	0.0	0.0	0.0
2	09 Sep 2005	1230 – 1330	0.0	0.0	0.0
3	09 Sep 2005	1330 – 1430	0.0	0.0	0.0
4	09 Sep 2005	1430 – 1530	0.0	0.0	0.0
5	09 Sep 2005	1530 – 1630	10.0	0.0	23.0
6	09 Sep 2005	1630 – 1730	14.0	5.3	13.0
7	09 Sep 2005	1730 – 1830	0.6	0.1	0.0
8	09 Sep 2005	1830 – 1930	0.0	0.0	0.0
		Total	24.6	5.4	36.0

## 4.1. Case-I (4 August 2005)

## (i) Synoptic condition

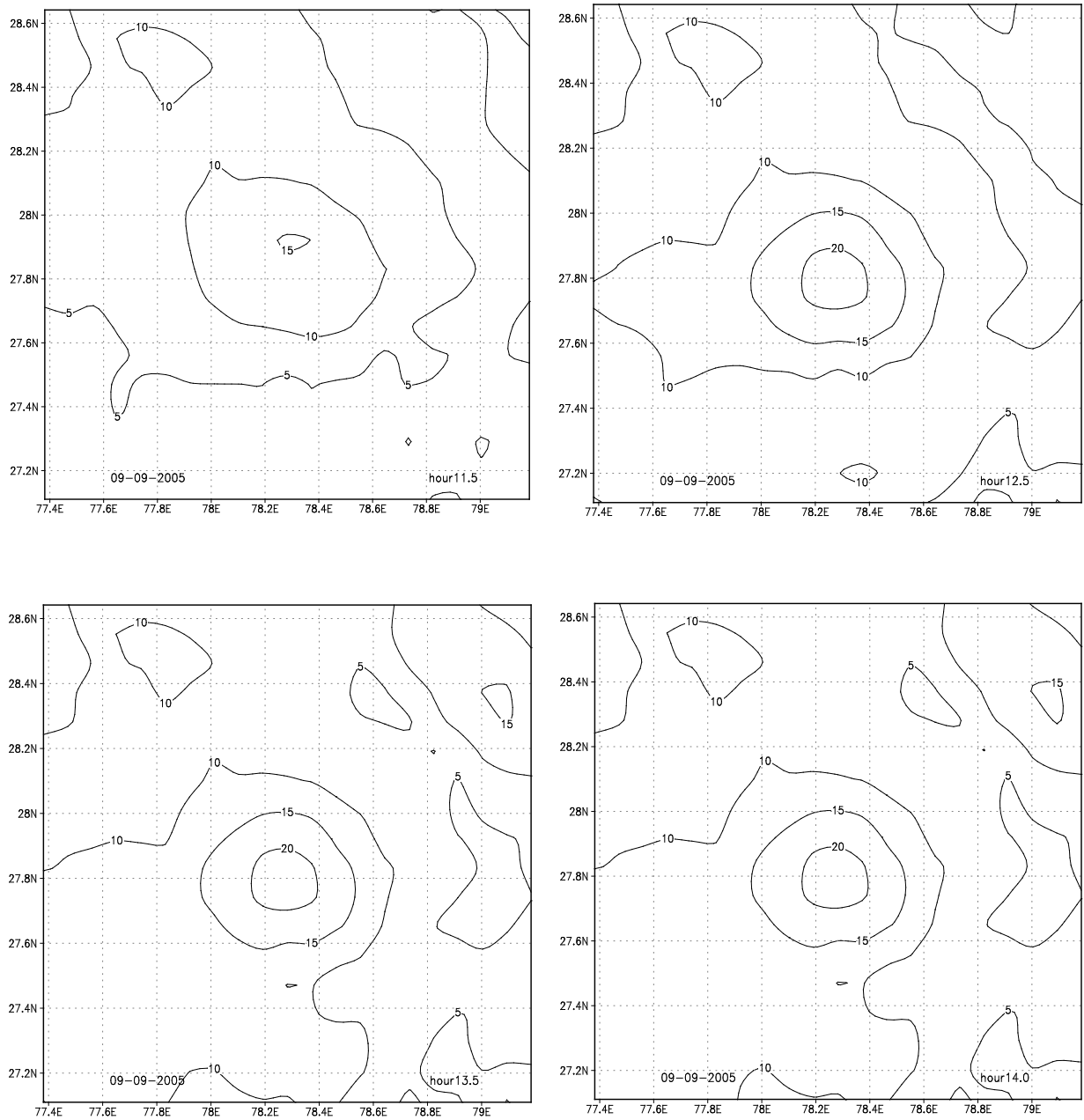
On 4 August 2005, a well mark low-pressure area was lying over Chhattisgarh & neighbourhood and associated upper air cyclonic circulation extending up to mid tropospheric levels. Another upper air cyclonic circulation was lying over southwest Rajasthan & neighbourhood extending between 1.5 & 4.5 km asl. The

off-shore trough was running from Goa to Karnataka coast. The axis of monsoon trough at sea level passes through Anupgarh, Kanpur, center of low-pressure area, Balasore and thence southwest wards to north Andaman Sea.

## (ii) Quantitative rainfall

A comparison between hourly convective precipitation simulated in the coarse domain with the





**Fig. 5.** Latitude longitude section of rainfall (mm) by New Kain-Fritsch scheme (new KF) (09 September 2005)

Kain-Fritsch (Fig. 1), New Kain-Fritsch (Fig. 2) and the Betts-Miller-Janjic (BMJ) schemes [Figs. 3(a&b)] have been made. This shows how the Kain-Fritsch scheme produces significant more convective precipitation than the other two scheme. Simulated rainfall in Kain-Fritsch, New Kain-Fritsch and the Betts-Miller-Janjic (BMJ)

schemes are 16.0 cm, 2.5 cm and 13.5 cm respectively. While observed rainfall is 3.7 cm, 0.1 cm & 2.5 cm over three different observatories, namely Safdarjung, Palam, Lodi Road, over Delhi, respectively (Table 2). Kain-Fritsch scheme and Betts-Miller-Janjic (BMJ) scheme is overestimating the rainfall.

**TABLE 4**  
**Cloud Top Temperature on 04 August 2005**

Time in hrs (IST)	Direction of cloud patch	Cloud top temperature in Degree Centigrade	Direction of cloud patch	Cloud top temperature in Degree Centigrade
0930	NE	-20		
1030	NE	-21		
1130	NE	-24		
1230	NE	-26	N	-31
1330	NE	-31	N	-41
1430	NE	-37		
1530	NE	-40	C	-41
1630	C	-38		
1730	C	-31		
1830		Cloud patch moved westward		

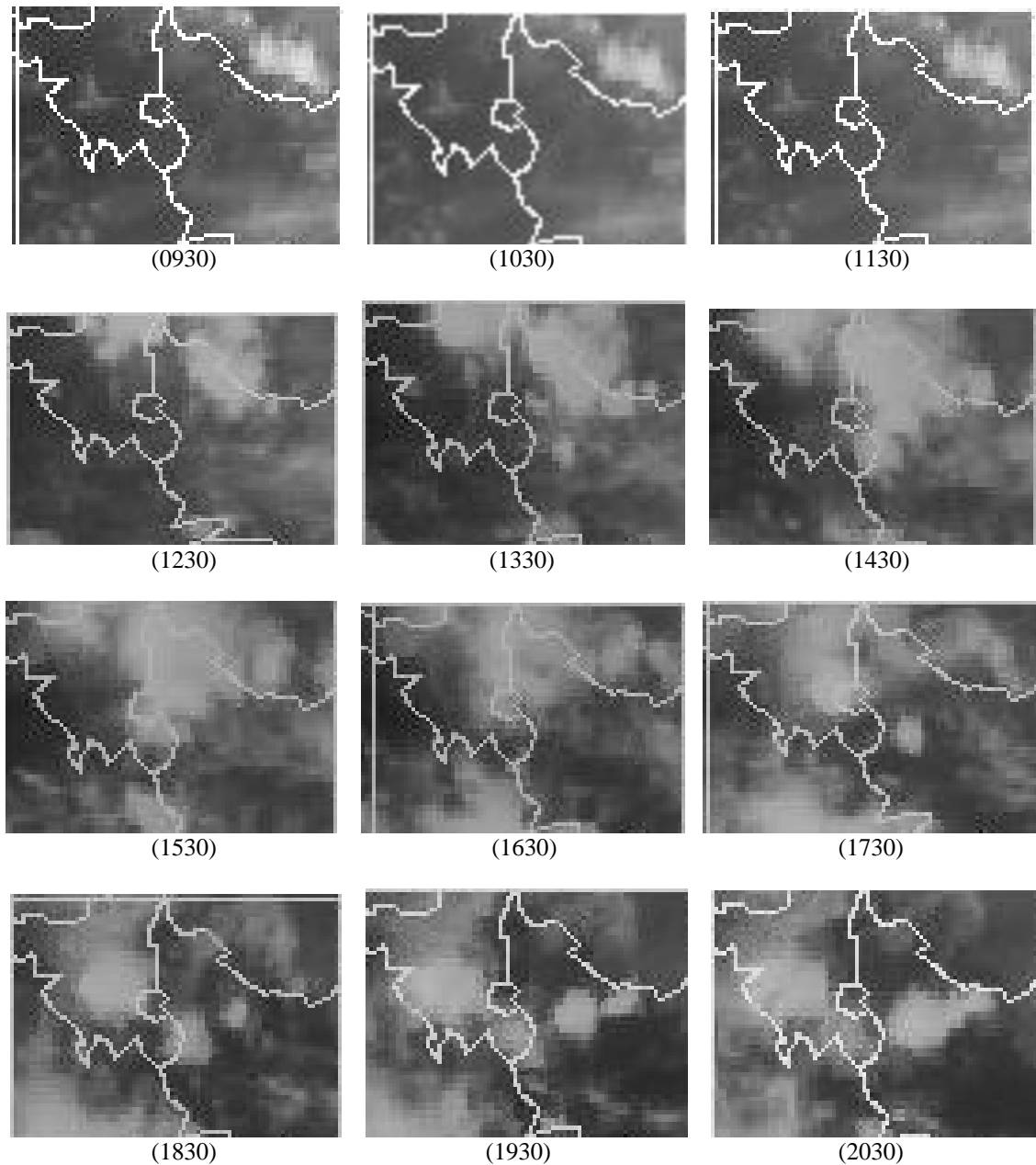
**TABLE 5**  
**Cloud Top Temperature on 09 September 2005**

Time in hrs (IST)	Direction of cloud patch	Cloud top temperature in Degree Centigrade	Direction of cloud patch	Cloud top temperature in Degree Centigrade
1130	NW	-43		
12:30	NW	-45		
1330	NW	-46		
1430	NW	-51	West-NW	-47 & -48
1530	NW	-51	West-NW	-47 & -48
1630	C	-47	West-NW	-40 & -45
1730	C	-43		
1830	C	-40		
1930	C	-40		

*(iii) Temporal distribution of rainfall*

Table 2 shows that rainfall has occurred between 1530 – 1730 hrs (IST). Satellite picture is also showing that thunderstorm has occurred between 1530 – 1730 hrs (IST) (Fig. 6). Cloud top temperatures corresponding to convective clouds in Satellite picture are given in Table 4. This shows that minimum cloud top temperature was -40 degree Celsius at 1530 hrs (IST). This is suitable for occurrence of intense thunderstorm with rain. Kain-

Fritsch scheme has started giving rainfall from 9.5 hrs [1500 hrs (IST)] onwards. While New Kain-Fritsch scheme and the Betts-Miller-Janjic (BMJ) scheme are predicting rainfall from 1330 UTC and 0730 UTC onwards respectively. We see that Kain-Fritsch scheme is able to produce thunderstorm rainfall timely. Actually it is matching nearly with the time of observed rainfall (Table 2). While New Kain-Fritsch scheme is predicting rainfall much later & Betts-Miller-Janjic (BMJ) scheme is predicting rainfall earlier than the time of observed



**Fig. 6.** Satellite pictures of 4 August 2005

Thunderstorm. We see that Kain-Fritsch is able to produce thunderstorm rainfall timely and is matching nearly with the time of actual occurrence of thunderstorm (Fig. 8).

So far as quantitative rainfall is concern Kain-Fritsch scheme is overestimating but temporal distribution of rainfall, is matching nearly with time of actual occurrence of thunderstorm.

#### 4.2. Case-II (9 September 2005)

##### (i) Synoptic condition

On 9 September 2005, there was a low-pressure area over west central Bay of Bengal off Coastal Andhra Pradesh and associated cyclonic circulation extends up to mid-tropospheric levels. An upper air cyclonic circulation

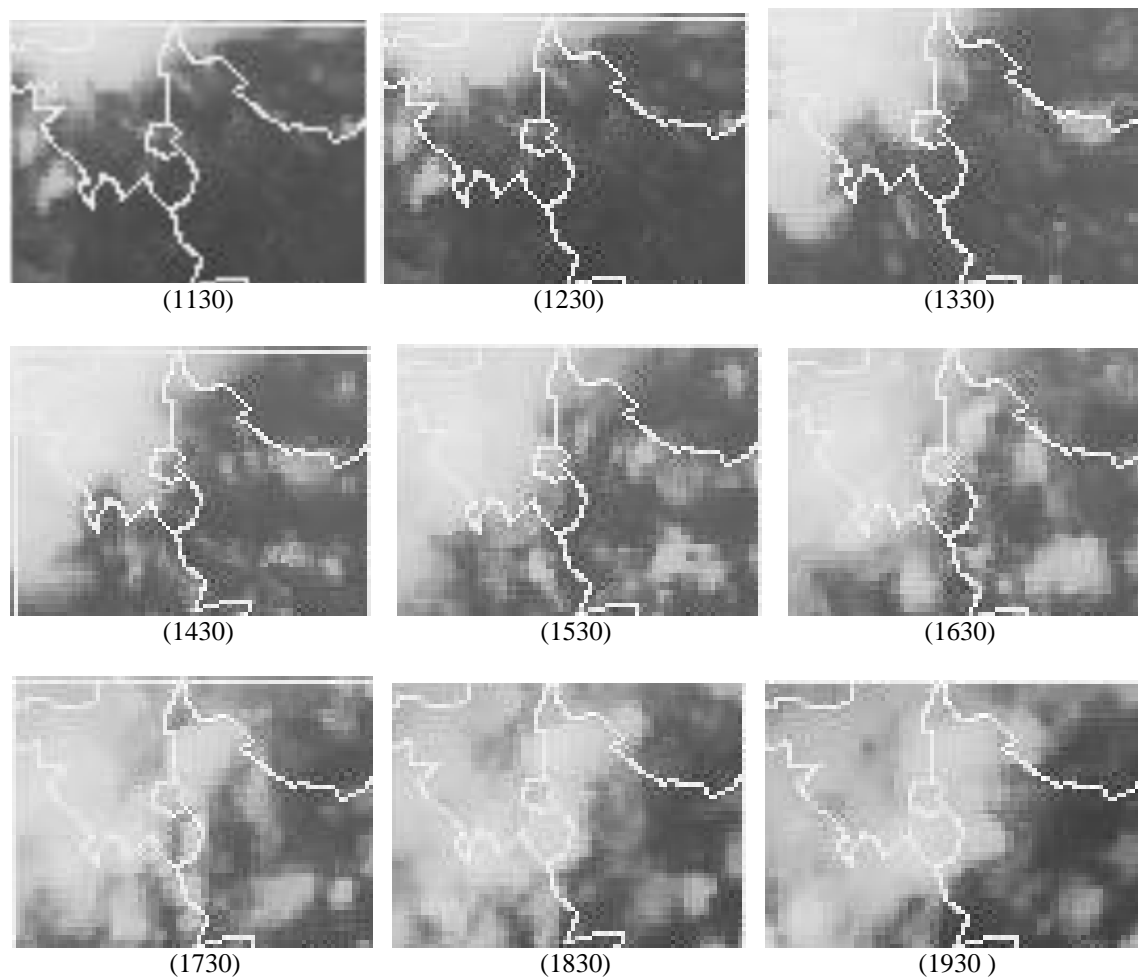


Fig. 7. Satellite pictures of 9 September 2005

extending up to mid-tropospheric levels lies over south Madhya Maharashtra and neighbourhood. Another cyclonic circulation lies over Pakistan and adjoining northwest Rajasthan extending up to 1.5 asl.

(ii) *Quantitative rainfall*

A comparison between hourly convective precipitation simulated in the coarse domain with the Kain-Fritsch (Fig. 4), New Kain-Fritsch (Fig. 5) and the Betts-Miller-Janjic (BMJ) schemes have been made. This shows how the Kain-Fritsch scheme produces significant more convective precipitation than the other two schemes. In this case even Betts-Miller-Janjic (BMJ) scheme is not able to initiate the rainfall. Simulated rainfall in Kain-Fritsch & New Kain-Fritsch schemes are 17.0 cm and 2.0 cm respectively and Betts-Miller-Janjic (BMJ) is not able to produce any rainfall in course domain. The observed rainfall by SRRG is 2.5 cm, 0.58 cm & 4.6 cm

over three different observatories, namely Safdarjung, Palam, Lodi Road over Delhi, respectively are given in Table 3. So Kain-Fritsch scheme is overestimating the rainfall and New Kain-Fritsch scheme is giving slightly less amount of rainfall as compared to observed.

(iii) *Temporal distribution of rainfall*

Table 3 shows that rainfall has occurred between 1530 – 1830 hrs (IST). Satellite picture is also showing that thunderstorm has occurred from 1530 – 1830 hrs (IST) (Fig. 7). Cloud top temperature corresponding to convective clouds in Satellite picture is given in Table 5. This shows that minimum cloud top temperature was -51 degree Celsius between 1430 & 1530 hrs (IST) which is suitable for occurrence of thunderstorm. Kain-Fritsch scheme has started giving rainfall from 1030 UTC [1600 hrs (IST)] onwards. While New Kain-Fritsch scheme is predicting rainfall from 1030 UTC and the

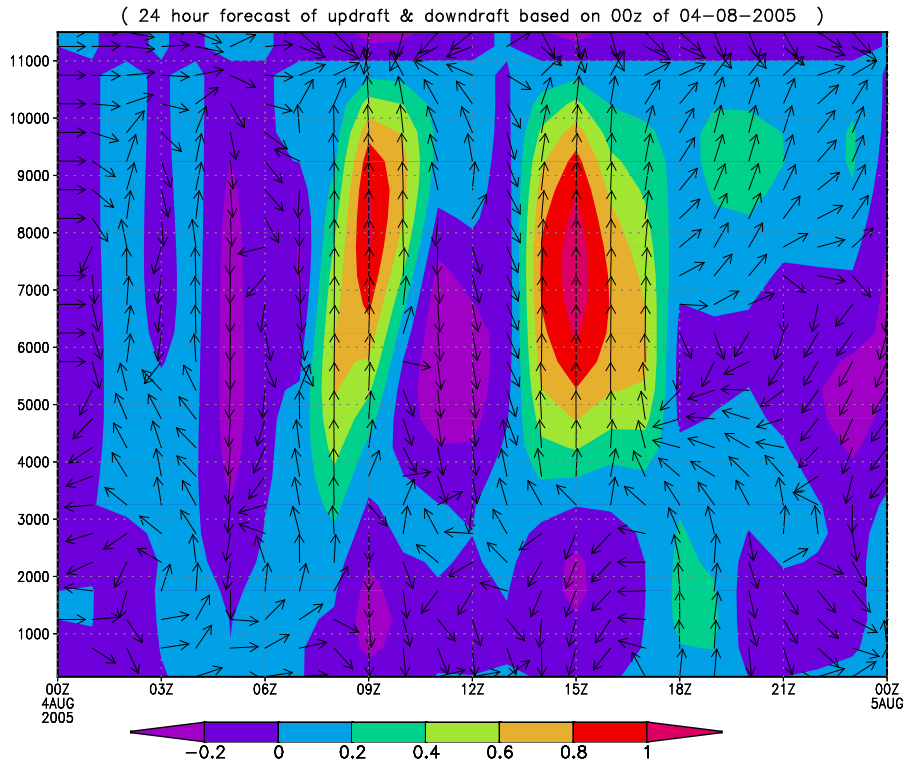


Fig .8. 24 hour forecast of updraft and downdraft based on 0000 UTC of 04 August 2005

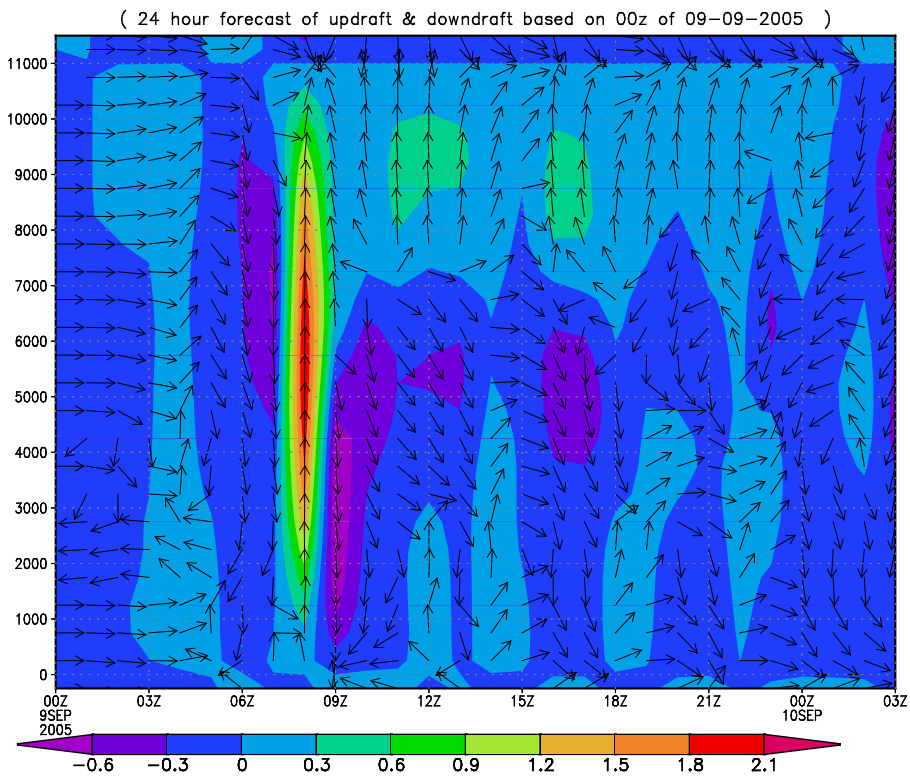


Fig .9. 24 hour forecast of updraft and downdraft based on 0000 UTC of 09 September 2005

Betts-Miller-Janjic (BMJ) scheme is not able to initiate the rainfall. We see that Kain-Fritsch is able to produce thunderstorm rainfall timely and is matching nearly with the time of actual occurrence of thunderstorm (Figs. 8& 9).

So similar to case (1), in this case also Kain-Fritsch scheme is overestimating the quantitative rainfall but temporal distribution of rainfall is matching nearly with observed rainfall.

## 5. Conclusions

The effect of cumulus convection on the thunderstorm rainfall has been investigated using ARPS Model. The convection schemes compared in the experiments are the Kain-Fritsch, New Kain-Fritsch and the Betts-Miller-Janjic (BMJ) scheme. The model simulated precipitation is compared with the observed precipitation. The result shows that change in convection parameterization has significant impact on the simulation on thunderstorm rainfall. In both the case studies it has been observed that Kain-Fritsch scheme generates more convective rainfall than the other two schemes. Also KF scheme is able to capture convective rainfall in both the cases while rest of the schemes are not able to capture both events properly. It has also been observed that KF scheme is overestimating the rainfall in both the cases. This scheme is also able to capture the temporal distribution of rainfall. In both the cases it is showing the development of thunderstorm timely while other two schemes are not able to do so.

## Acknowledgements

The authors are thankful to Director General of Meteorology, India Meteorological Department (IMD), New Delhi for rendering all facilities. The authors also gratefully acknowledge Mr. A. K. Mitra, Meteorologist Gr-II, Satmet Division, I.M.D. New Delhi, for providing necessary Satellite images to carry out this study.

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