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The Impact of Dropsonde Data on Forecasts of Hurricane Debby by the Meteorological Office Unified Model

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ABSTRACT

The numerical product of hurricane tracks vastly depends on initial observation fields. However, the forecast error is very large because of lack of observational data, especially when hurricanes are over the sea. This paper shows that extra non–real–time data (dropsonde data) can improve hurricane track forecasts compared with real–time observational data, and that the wind and relative humidity components of the dropsonde data have the greatest impact on the track forecasts.

Key words: dropsonde, hurricane, *track forecast, experiment*

1. Introduction

Hurricanes are very important synoptic systems. According to their scale, they belong to the class of subsynoptic systems, and their characteristics such as genesis, development, structure, and motion, are effected by the larger scale circulation fields (Chen and Ding 1979; Chen and Luo 1995a). Hurricane track forecasting is very difficult, especially when a hurricane is far from land and observational data are lacking. So it is very important that non–real–time observational data are used in analysis and forecasting. The asymmetric structure has very important meaning when the forecasts of intensity and motion of the hurricane are issued, which has been proved by many numerical experiments (Williams and Chan 1994; Chen and Luo 1995b, 1996, 1998). The results of Zhu et al. (1999) show that intensive observational data from ground stations can greatly improve the forecasts of the numerical weather prediction (NWP) system of the National Meteorological Center (NMC) of China. In this paper, the Unified Model (UM) was used to do a series of experiments to understand how the forecasts of the track of Hurricane Debby in August 2000, which appeared in Caribbean Sea, depended on the different elements of dropsonde data used to improve hurricane track forecasts.

1.1 *Forecast history*

The UM is the Meteorological Office Global Model. It is the sole grid model which is being used in operational forecasting in the world. The UM's horizontal latitude–longitude grid spacing is 0.554° × 0.883° and the number of vertical levels is 30.

Hurricane Debby formed east of the Lesser Antilles and moved west–north–westwards while gaining strength. Forecasts from the UM suggested the hurricane would continue strengthening and track just north of the Greater Antilles towards the Bahamas and southern

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Florida at 1200 UTC 22 August 2000. However, there was a major change in the forecast at 0000 UTC 23 August, which tracked a weakening system south of Cuba into the Gulf of Mexico. The following forecast at 1200 UTC 23 August reverted to a more northerly track. However, the forecast from 0000 UTC 24 August took the weakening hurricane south of Cuba towards the Yucatan Peninsula. These three successive forecast tracks are shown in Fig. 1. In reality the hurricane sheared apart rapidly as it turned westwards, crossing south–eastern Cuba on 24 August. The remnants eventually dissipated in the Gulf of Mexico. Clearly, early forecasts for the track and strength of the hurricane were poor, but were suddenly improved at 0000 UTC 23 August. This coincided with the deployment of dropsondes from the NOAA G–IV jet in the vicinity of the hurricane between the hours of 1800 UTC 22 August and 0100 UTC 23 August and again between 1800 UTC 23 August and 0200 UTC 24 August. Comparing to the observed tracks within 24 hours, the forecasts at 0000 UTC 23 and 0000 UTC 24 August are very good while the forecasts at 1200 UTC 23 August are poorer.

1.2 *Dropsonde data*

The NOAA Gulfstream–IV jet makes reconnaissance missions into the environment of hurricanes which develop in the western North Atlantic, Caribbean Sea, and Gulf of Mexico. The missions normally last about 9 hours with more than 20 dropsondes usually deployed in all quadrants of the hurricane if possible.

In the case of Hurricane Debby, the first mission started on 22 August 2000. Between 1800 UTC 22 August and 0100 UTC 23 August, a total of 25 dropsondes were deployed. Eleven of these were assimilated into the 1800 UTC 22 August run of the model and the remaining 14 into the 0000 UTC 23 August run. The distribution of these relative to the centre of the hurricane at 0000 UTC 23 August can be seen in Fig. 2.

It is only possible to make one mission per day. Hence, the next reconnaissance flight was started on 23 August. Between 1800 UTC 23 August and 0200 UTC 24 August, a total of 23 dropsondes were deployed. Nine of these were assimilated into the 1800 UTC 23 August run of the model and the remaining 14 into the 0000 UTC 24 August run. The distribution of these relative to the centre of the hurricane at 0000 UTC 24 August can be seen in Fig. 3.

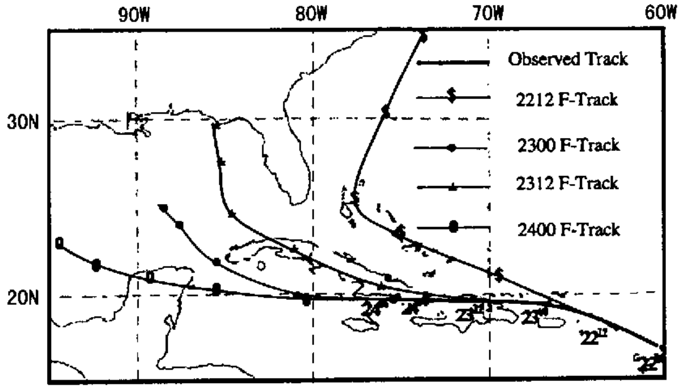


Fig. 1. Observed track of Hurricane Debby and forecast tracks from 1200 UTC 22 August 2000, 0000 UTC, 1200 UTC 23 August 2000, and 0000 UTC 24 August 2000.

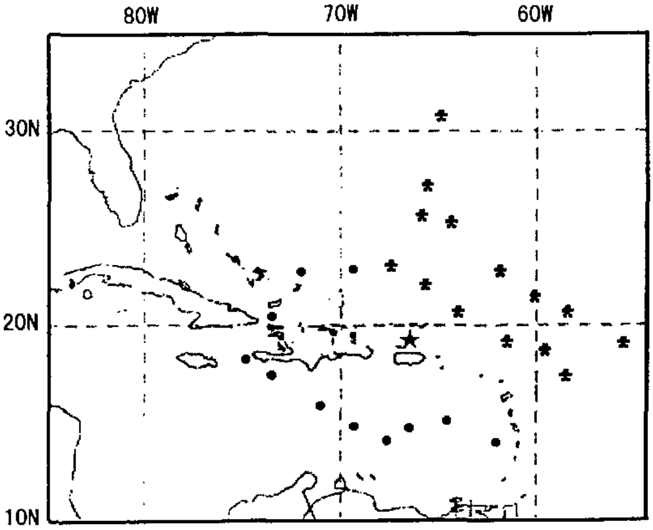


Fig. 2. Dropsonde distribution for 1800 UTC 22 August, and 0000 UTC 23 August 2000. (●: assimilated in 1800 UTC 22 August model run, ✱ assimilated in 0000 UTC 23 August model run, ★: the centre of the hurricane at 0000 UTC 23 August).

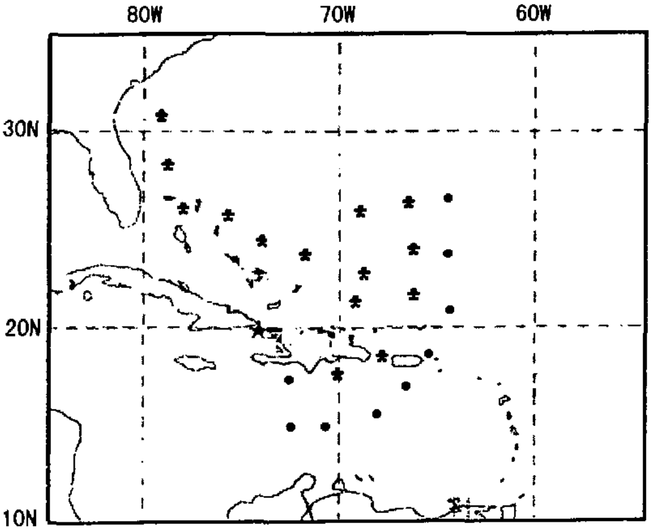


Fig. 3. Dropsonde distribution for 1800 UTC 23 and 0000 UTC 24 August 2000. (●: assimilated in 1800 UTC 23 August model run, ✱ assimilated in 0000 UTC 24 August model run, ★: the centre of the hurricane at 0000 UTC 24 August).

1.3 *Experiment definitions*

The UM uses the 3DVAR scheme to assimilate non–real time data in real time (Lorenc 1996). A ' bogus' scheme is generated which is assimilated into the model along with other observational data to define the structure of the tropical cyclone (TC) in the initial fields (He ming et al. 1995). The scheme which devises the bogus data effectively generates an asymmetric vortex.

Experiments were undertaken to evaluate the impact of the dropsonde data as a whole during this period and also to assess the relative importance of the various elements of the data. The UM was rerun 10 times starting at 1200 UTC 22 August and running forward to 0000 UTC 24 August. Five–day forecasts were produced at 0000 UTC 23 August, 1200 UTC 23 August, and 0000 UTC 24 August.

A control run, which includes all dropsonde data used operationally, is considered to be the benchmark forecast in this investigation. Experiments 01 to 07 had various elements of the dropsonde data excluded during the data assimilation process. Experiments 08 and 09 were only run for 0000 UTC 23 August in addition to excluding all dropsondes to the northeast (north of 16°N, east of 69°W) and southwest of the hurricane. Details of the experiments are found in Table 1.

It must be pointed out that Hurricane Debby was declared dissipated south of Cuba at 0600 UTC 24 August. Hence, forecast tracks (which retained a circulation centre well beyond this time) cannot be verified against observed positions. However, the purpose of these experiments is to evaluate the various forecast tracks against the control run track.

Table 1. Dropsonde data usage in rerun experiments

Experiment	Dropsonde data usage
Control	All dropsonde data are included
01	All dropsonde data are excluded
02	Wind data are excluded
03	Temperature data are excluded
04	All data above (and including) 500 hPa are excluded
05	All data below 500 hPa are excluded
06	Humidity data are excluded
07	Wind and humidity data are excluded
08	All data northeast of TC are excluded (0000 UTC 23 August only)
09	All data southwest of TC are excluded (0000 UTC 23 August only)

2. Analysis of the experiment forecast tracks

2.1 0000 *UTC* 23 *August*

Figure 4 shows the forecast tracks of the various experiments. Table 2 shows these positions relative to the position in the control forecast. The first thing to note is that in virtually all cases, the experiment position was to the north and east of the control position and the most extreme was Experiment 01 (no dropsonde data included at all). Since the control forecast was correct in producing a strong westerly component in the steering (compared to previous forecasts), this indicates that the forecast without dropsondes was the worst of all the experiment forecasts, and the other experiments (which rejected various parts of the dropsonde data) fell somewhere in between.

The absolute average error (AAE) in Table 2 is defined as the change in forecast track for each experiment relative to the control forecast averaged over all forecast periods. Experiment 03 shows the smallest differences in forecast track from the control, which suggests that the temperature component of dropsonde data has a very small impact on the quality of the forecast track. Wind (Experiment 02) and humidity (Experiment 06) data have modest impacts on the forecast track (with that of wind greater than humidity). Experiment 07 shows that their combined impact is more or less a linear combination of their individual impacts. The results for Experiment 04 and Experiment 05 show that over 90% of the impact of all dropsonde data on the forecast track is achieved by the data below 500 hPa in this case.

Examination of Experiment 08 and Experiment 09 indicates that almost all the impact of dropsonde data in this run is achieved by the dropsondes deployed to the north of the hurricane (see dropsonde distribution in Fig. 2). This bears out results seen in previous impact experiments. On occasions, the model does not represent the strength of the ridge on

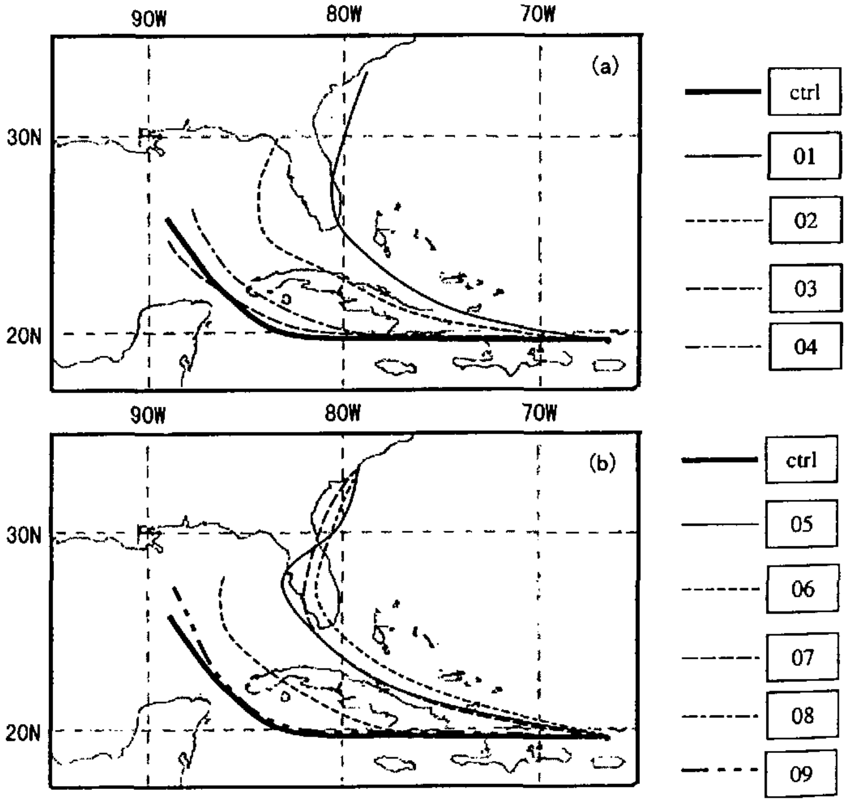


Fig. 4. Experiment forecast tracks from DT 0000 UTC 23 August 2000, (a) control and Experiments 01–04, (b) control and Experiments 05–09.

the poleward side of the hurricane correctly, which results in premature recurvature of the hurricane in the forecast. This is what happened in forecasts prior to 0000 UTC 23 August, but the dropsondes in this run depicted a stronger ridge than had previously been analysed, and forced the hurricane on a more westward track in the forecast.

Table 2. The hurricane centre position differences between the experiments and the control at 0000 UTC 23 August. Positive values indicate experiment position further north and west than control. AAE is absolute average error

	T+24		T+48		T+72		T+96		T+120		AAE		AAE
Experiment	°N	°W	°N	°W	°N	°W	°N	°W	°N	°W	°N	°W	Direct
01	2.3	−2.0	4.5	−2.6	5.0	−5.7	6.9	−7.7	7.3	−9.5	5.2	5.5	7.6
02	1.1	−1.6	3.1	−1.9	3.1	−3.7	3.6	−4.9	4.2	−6.5	3.0	3.7	4.8
03	0.3	−0.2	0.0	0.4	0.4	−0.5	0.3	0.3	0.0	−0.3	0.2	0.3	0.4
04	0.2	−0.1	0.1	−1.3	0.9	−2.0	1.6	−1.5	1.3	−2.4	0.8	1.5	1.7
05	2.2	−1.5	3.9	−3.0	5.0	−3.7	6.6	−7.6	7.7	−9.6	5.1	5.1	7.2
06	0.6	−1.4	1.5	−0.3	2.0	−1.8	2.3	−2.9	1.6	−4.3	1.6	2.1	2.7
07	1.7	−1.6	4.6	−2.5	4.6	−4.4	6.6	−6.7	7.3	−9.6	5.0	5.0	7.0
08	2.2	−1.6	4.5	−3.0	5.0	−5.1	6.4	−7.0	7.3	−9.4	5.1	5.2	7.3
09	0.4	0.1	0.0	0.1	0.3	0.4	0.6	0.0	0.4	−0.4	0.3	0.2	0.4

2.2 1200 *UTC* 23 *August*

There were no further dropsonde data available to the model prior to the 1200 UTC 23 August run and, as Fig. 5 shows, the control forecast track reverted to a much poorer solution, steering the hurricane further north and east of its previous forecast track. Experiments 01 to 07 were run forward from 0000 UTC to 1200 UTC 23 August and forecast tracks produced. Figure 5 and Table 3 show the tracks and positions of the centre of hurricane Debby in the various forecast experiments relative to the position in the control forecast, in the same way as Fig. 4 and Table 2. These results again show that Experiment 01 (without any dropsondes) produced the most significantly different track from control with a greater northerly and easterly component in forecasts. However, the positional differences were only about one third of those seen in the 0000 UTC run. This shows that a relatively small proportion of the positive impact of the dropsonde data assimilated into the 0000 UTC run was carried forward to the next run at 1200 UTC.

There are some interesting contrasts in the results for the individual experiments when compared with those from the forecast 12 hours earlier. The results for Experiments 03, 04, and 05 show that data below 500 hPa had a large impact, but temperature data and data above 500 hPa did not have a large impact; this is consistent with what was seen in the 0000 UTC run. However, contrary to the 0000 UTC run, the 1200 UTC run humidity data are found to have more of an impact than wind from examination of Experiments 02, 06, and 07. This suggests the impact of wind data on forecasts is instant, but not carried forward to the next model run. However, the impact of humidity data, while not so instant, is retained in the next model run.

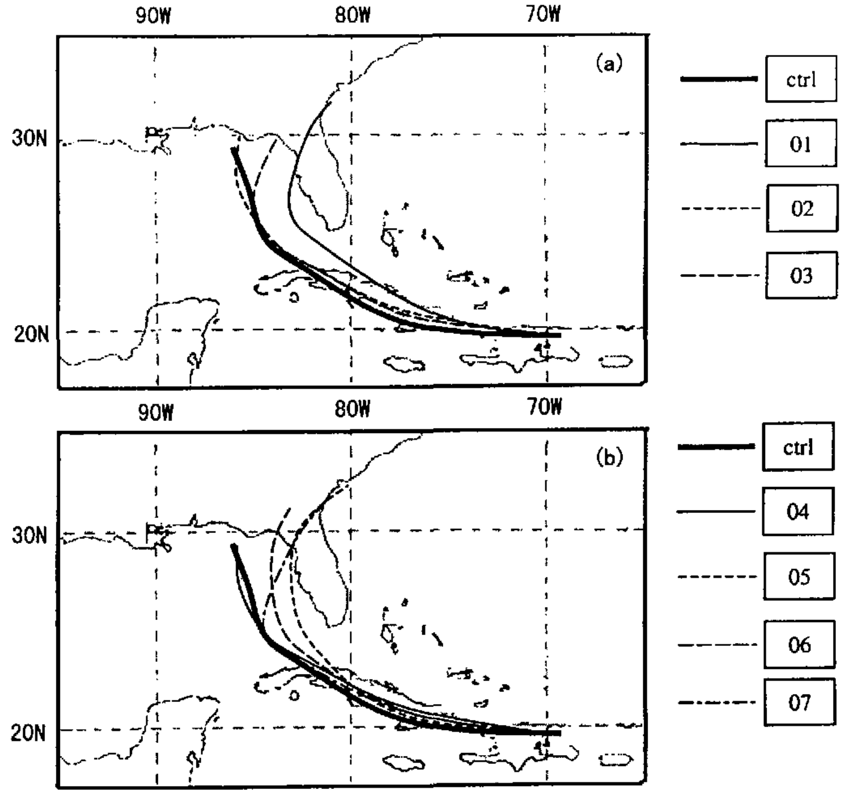


Fig. 5. Experiment forecast tracks from 1200 UTC 23 August 2000, (a) control and Experiments 01–03, (b) control and Experiments 04–07.

Table 3. The hurricane centre position differences between the experiments and the control at 1200 UTC 23 August. Positive values indicate experiment position further north and west than control. AAE is absolute average error

	T+24		T+48		T+72		T+96		T+120		AAE		AAE
Expteriment	°N	°W	°N	°W	°N	°W	°N	°W	°N	°W	°N	°W	Direct
01	1.1	−1.3	1.0	−1.2	0.9	0.5	−1.5	−2.5	−2.4	−5.5	1.4	2.2	2.6
02	0.6	0.4	0.5	−0.2	0.6	0.3	−0.1	0.5	−0.0	−0.9	0.4	0.5	0.6
03	0.4	−0.2	0.6	−0.5	1.0	−0.5	−0.2	−0.8	−0.0	−1.4	0.4	0.7	0.8
04	0.5	0.2	0.2	−0.6	0.6	0.0	−0.1	0.5	−0.7	−0.7	0.4	0.4	0.6
05	0.2	0.1	1.0	−0.8	1.9	−1.0	−1.7	−2.4	−2.6	−5.5	1.5	2.0	2.5
06	0.4	0.2	0.6	−1.0	0.9	−0.4	−0.8	−1.1	−2.0	−3.3	0.9	1.2	1.5
07	0.2	−0.1	1.0	−1.0	1.6	−0.5	−1.2	−2.2	−2.6	−4.2	1.3	1.6	2.1

2.3 0000 *UTC* 24 *August*

Dropsondes were again deployed around Hurricane Debby in the hours leading up to the 0000 UTC 24 August forecast (see Fig. 3). Although the impact of these data was not so great as 24 hours previously, the trend in the results is very similar, as seen in Fig. 6 and Table 4.

The control forecast took a track which was more to the south and west of most of the experiment tracks at most of the forecast times. Analysis of the experiment tracks shows that wind data have the largest impact on the forecast, followed by humidity. Temperature again had relatively little impact on the forecast track. Data below 500 hPa were more important than those above, but not to the same degree as in the forecast 24 hours previously.

3. Analysis of model fields

The T+0 0000 UTC 23 August model fields were examined and some comparisons were made between the control and experiment analyses.

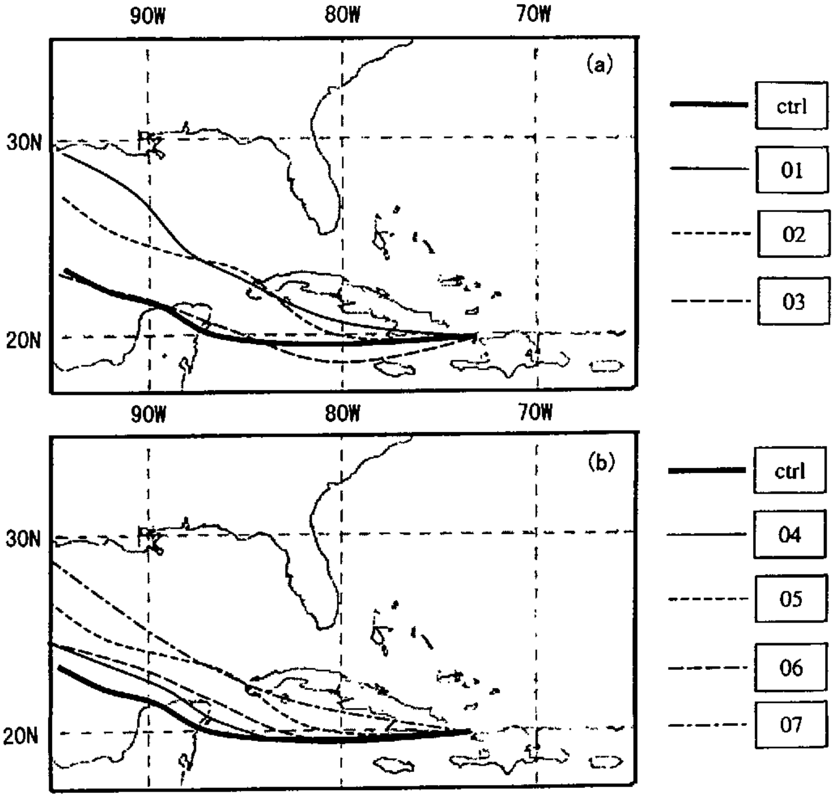


Fig. 6. Experiment forecast tracks from 0000 UTC 24 August 2000, (a) control and Experiments 01–03, (b) control and Experiments 04–07.

Table 4. The hurricane centre position differences between the experiments and the control at 0000 UTC 24 August. Positive values indicate experiment position further north and west than control. AAE is absolute average error

	T+24		T+48		T+72		T+96		T+120		AAE		AAE
Expteriment	°N	°W	°N	°W	°N	°W	°N	°W	°N	°W	°N	°W	Direct
01	−1.5	−0.3	−2.8	−0.9	3.7	−1.6	4.9	−1.5	5.8	0.4	3.7	0.9	3.9
02	−0.4	0.0	−2.3	−3.2	2.9	−0.9	4.2	−1.1	4.5	0.7	2.9	1.2	3.1
03	−0.2	0.0	−0.3	−0.2	0.4	−0.1	0.4	0.2	0.4	0.5	0.3	0.2	0.4
04	−0.3	0.0	−0.4	−1.2	1.1	−0.6	2.4	−1.2	2.1	0.4	1.3	0.7	1.4
05	−0.5	0.1	−3.0	−0.5	3.0	−0.3	4.5	−1.2	4.8	0.6	3.2	0.5	3.2
06	−0.3	0.1	−1.1	0.5	1.9	0.5	2.5	0.6	1.9	2.0	1.5	0.7	1.7
07	−2.2	0.2	−3.1	−0.2	3.1	−0.2	4.6	−1.4	5.6	0.2	3.7	0.4	3.7

3.1 *Height and temperature fields*

The results already discussed have shown that the humidity and, particularly, wind components of dropsonde data had a large impact on the hurricane track, whereas temperature data did not. Hence, it is not a surprise to find that in a comparison of the control and experiment analysis (T+0) fields, differences are very small in the temperature and geopotential height fields (not shown). Even in the case of Experiment 01 (all dropsonde data excluded) there were no significant differences between the analysis and that from the control run (with all data included).

3.2 *Relative humidity (RH) field*

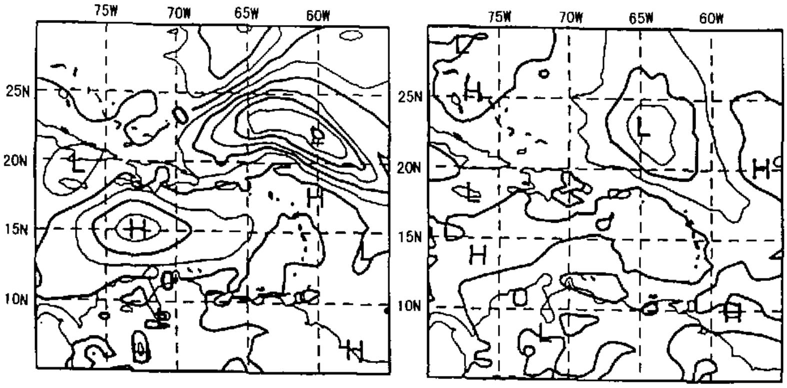
Figure 7 shows the differences between the control and the following experiments: 01 (all data excluded), 04 (data above 500 hPa excluded), 05 (data below 500 hPa excluded), 06 (RH excluded), 07 (RH and wind excluded), 08 (data to the northeast excluded), 09 (data to the southwest excluded).

Figure 7a shows that when all dropsondes were excluded, the 500 hPa RH field was reduced by up to 60% to the northeast of the hurricane and increased by up to 30% to the southwest. The impact at 850 hPa was less, with a reduction of up to 30% to the northeast of the hurricane. Examination of the dropsonde data shows that this was a fair reflection of the increments supplied. The data generally showed much lower RH at mid–tropospheric levels than the model's background field to the northeast of the hurricane and higher RH to the southwest.

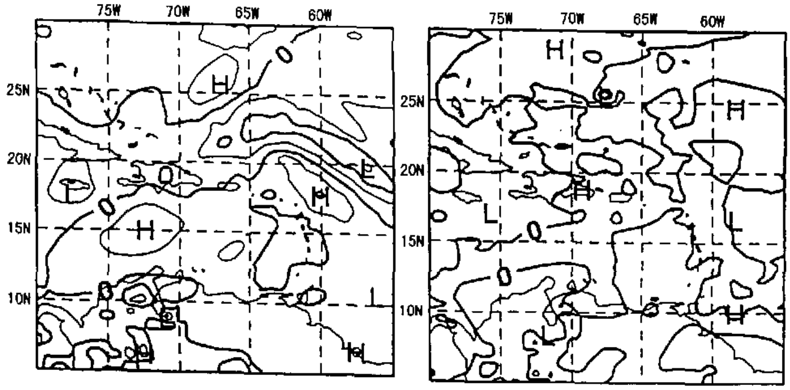
Figures 7b and 7c show the difference between the control and experiments with data excluded above and below 500 hPa. The results are very much as expected. They show that the dropsonde data above and below 500 hPa have a similar magnitude of impact on the 500 hPa RH field. However, the data below 500 hPa have a greater impact on the 850 hPa RH field than the data above 500 hPa.

Figures 7d and 7e show that excluding just RH and excluding RH and wind together have a similar impact on RH fields as Experiment 01, which excluded all dropsonde data.

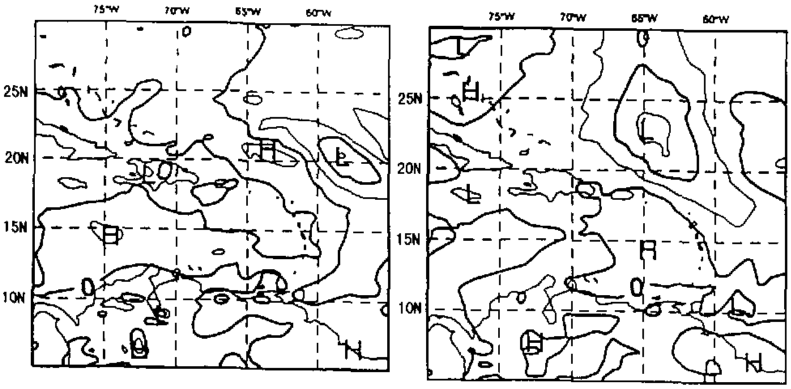
Finally, Figs. 7f and 7g show the difference between the control and experiments which exclude data to the northeast and southwest of the hurricane center. These results indicate the



(a) Experiment 01

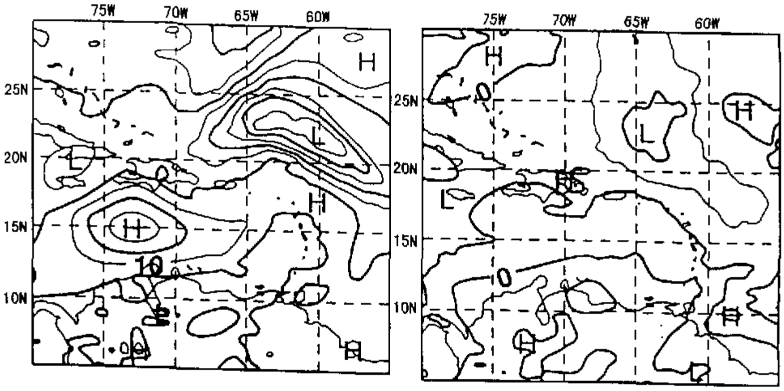


(b) Experiment 04

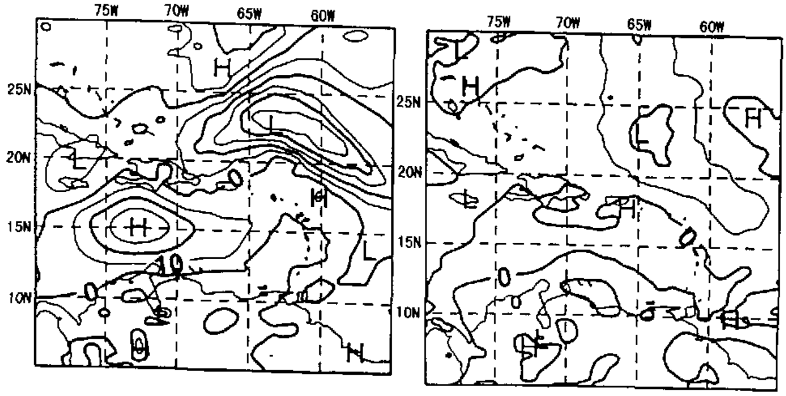


(c) Experiment 05

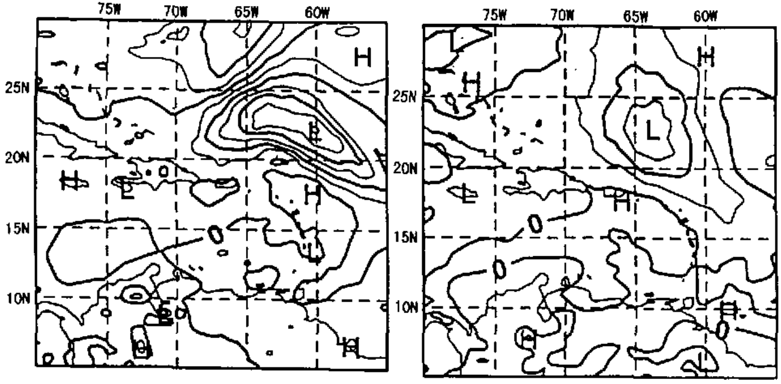
Fig. 7. Relative humidity analysis difference charts between Control and Experiments for 0000 UTC 23 August 2000 (Left: 500 hPa, right: 850 hPa, contour interval is 10%).



(d) Experiment 06

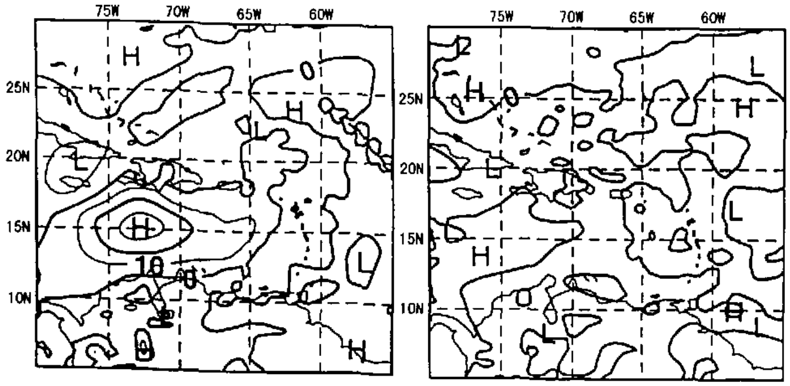


(e) Experiment 07



(f) Experiment 08

Fig. 7. (Continued).



g) Experiment 09

Fig. 7. (Continued).

impact of the data on model analyses is confined to the immediate geographical area of the data.

3.3 *Wind field*

Figure 8 shows the difference in wind analysis between the control and Experiment 01 (all data excluded). This indicates that the dropsonde data have reduced the northerly wind component on the east side of the hurricane at 500 hPa and 850 hPa by more than 8 m s^{-1}. The westerly component of wind is also strengthened near to the hurricane at 850 hPa and the easterly component is strengthened well to the north of the hurricane. At 250 hPa, the differences are very small. These results are consistent with the forecast track taking a more westerly and less northerly track when dropsonde data are included. The other experiments with dropsonde data excluded show similar results to Experiment 01.

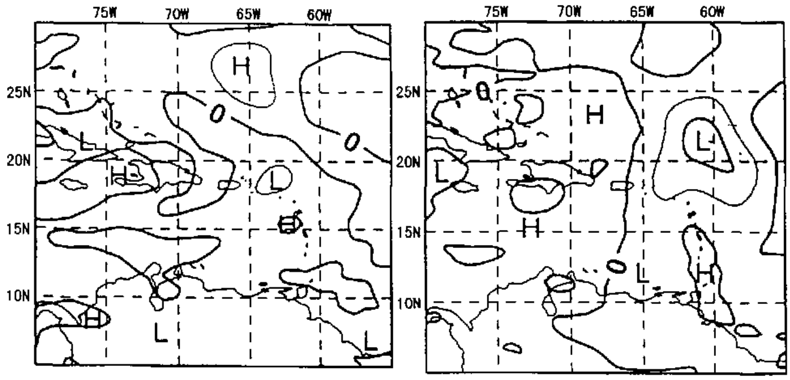
Figures 9 and 10 show the results for Experiments 08 and 09 (data to the northeast and southwest excluded). These indicate that the impact of wind data on the model analysis is greatest on the poleward side of the hurricane. This is to be expected since wind speeds will be stronger there than on the equatorward side. This contrasts with results for the relative humidity data, which impacted the model analysis on both sides of the hurricane.

4. Summary of results

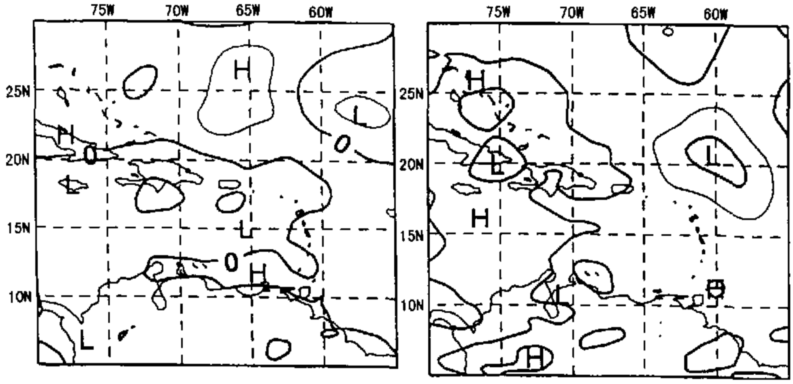
(1) Dropsondes deployed and used in the 0000 UTC 23 and 24 August runs of the model vastly improved hurricane track forecasts compared to previous runs of the model. The asymmetric structure of hurricanes greatly affects hurricane track forecasts.

(2) The wind component of the dropsonde data had the greatest impact on forecasts from the 0000 UTC runs (when dropsonde data was directly assimilated into the model run).

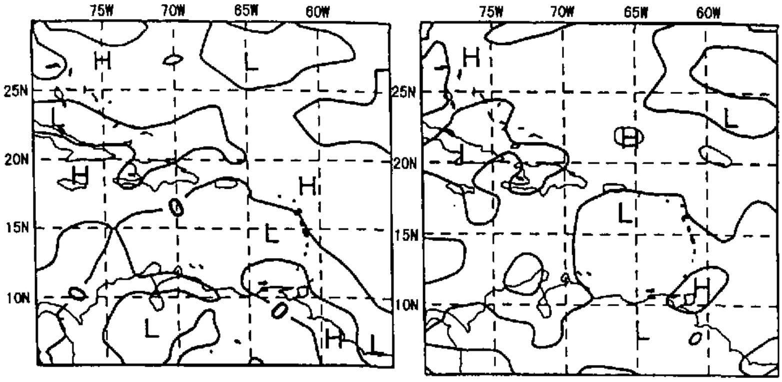
(3) It is not only the wind component but also the relative humidity component of the dropsonde data (assimilated 12 hours earlier) that had the greatest impact on the forecast



850 hPa

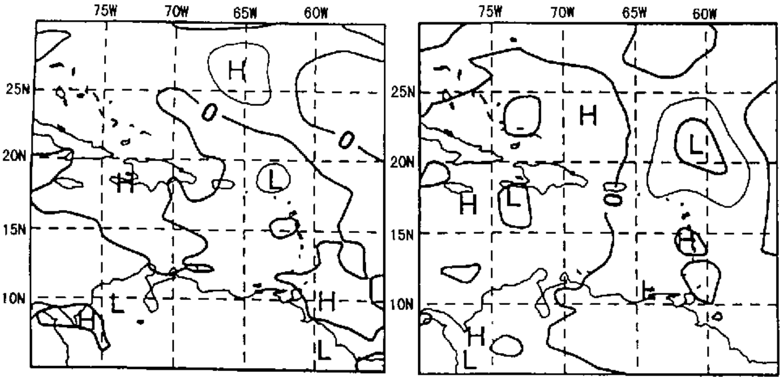


500 hPa

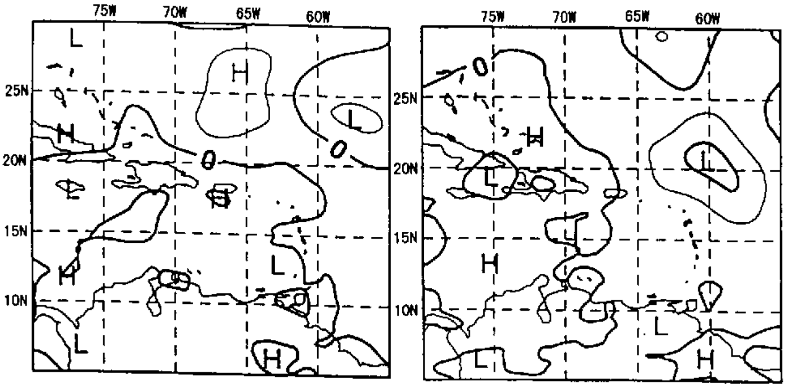


250 hPa

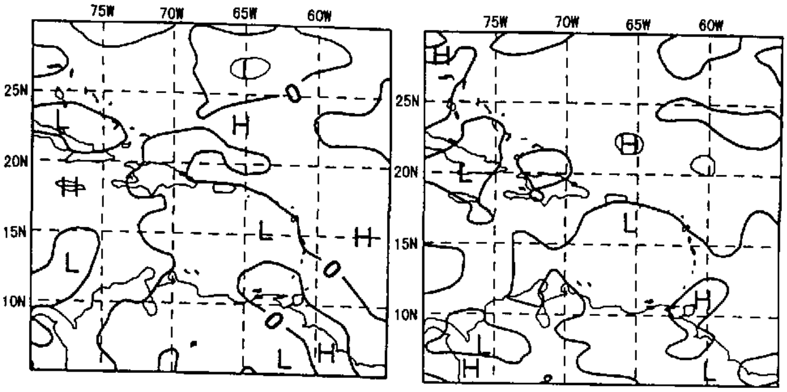
Fig. 8. Wind analysis difference charts between Control and Experiment 01 for 0000 UTC 23 August 2000 (Left: *U*, right: *V*, contour interval is 4 m s^{-1}).



850 hPa

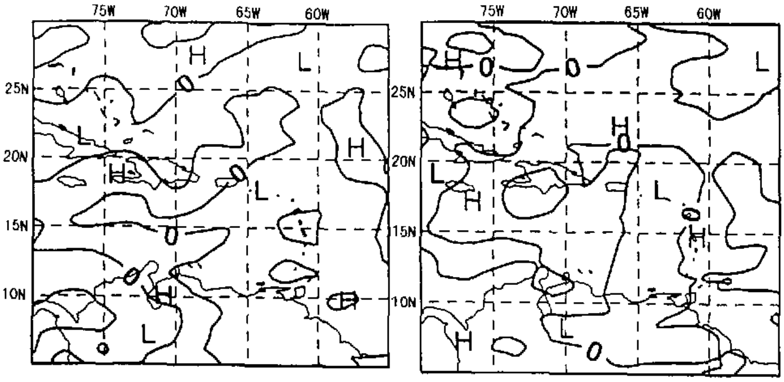


500 hPa

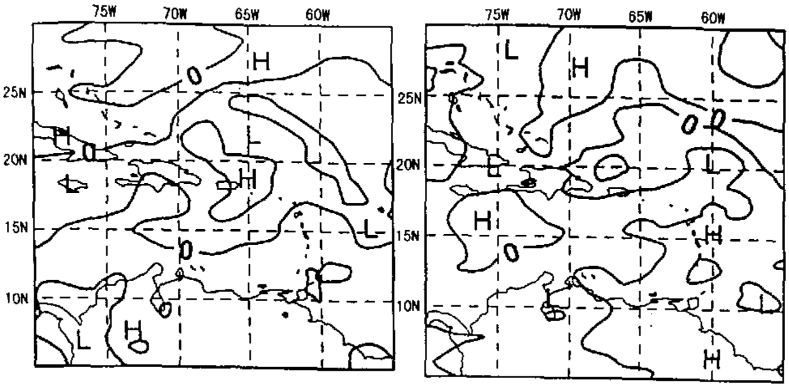


250 hPa

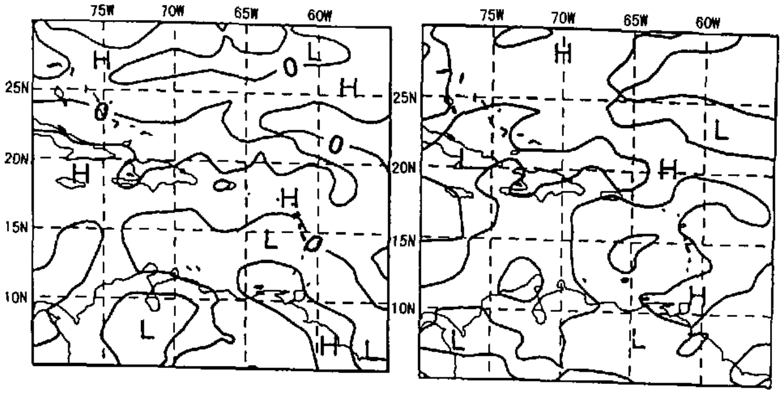
Fig. 9. Wind analysis difference charts between Control and Experiment 08 for 0000 UTC 23 August 2000 (Left: U, right: V, contour interval is 4 m s^{-1}).



850 hPa



500 hPa



250 hPa

Fig. 10. Wind analysis difference charts between Control and Experiment 09 for 0000 UTC 23 August 2000 (Left: U, right: V, contour interval is 4 m s^{-1}).

from the intermediate 1200 UTC run of the model (when no additional dropsonde data was available to the model).

(4) The temperature component of the dropsonde data did not contribute much to the improvement of the forecast hurricane track.

(5) Dropsonde data at lower levels (below 500 hPa) made a more significant impact on the forecast hurricane track than higher–level data.

(6) Dropsonde data on the poleward side of the hurricane, which helped define the sub–tropical ridge structure, were more important to the forecast than data on the equatorward side since the sub–tropical ridge strength has a great bearing on the recurvature of the hurricane.

(7) The experiments in this paper show it is useful to decide the key regions for deploying dropsondes.

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下投式探空资料对 Debby 飓风路径预报影响的数值试验

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摘 要

在飓风路径的数值预报中,对于初始场的要求很高。然而,由于初始资料的缺乏,经常导致路径预报的误差较大,尤其是当飓风处于远离陆地的海上时,这种误差更大。通过利用UM模式在Debby飓风活动期间,对下投式探空仪所获取探空资料,采用不同使用方案的三个时次共计10次数值试验的结论分析,给出一些有意义的结论,即非实时资料对实时资料的有效补充,能够提高飓风路径预报精度,而在众多气象要素场中,风场和湿度场对飓风路径预报的影响更大.

关键词: 下投式探空资料,飓风,路径预报,数值试验