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The impact of dropsonde data on forecasts of Hurricane Debby by the Met Office global model

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1. Introduction

The Met Office global model was used to do a series of experiments to understand how the forecasts of the track of Hurricane Debby in August 2000 depended on the different elements of dropsonde data.

1.1 Forecast History

Hurricane Debby formed east of the Lesser Antilles and moved west-north-westwards whilst strengthening. Forecasts from the global model suggested the hurricane would continue strengthening and track just north of the Greater Antilles towards the Bahamas and southern Florida. However, there was a major change in the forecast from 00UTC 23 August which tracked a weakening system south of Cuba into the Gulf of Mexico. The following forecast from 12UTC 23 August reverted to a more northerly track. However, the forecast from 00UTC 24 August took the weakening hurricane south of Cuba towards the Yucatan Peninsula. Four successive forecast tracks up to 00UTC 24 August are shown in Figure 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 00UTC 23 August. This co-incided with the deployment of dropsondes from the NOAA G-IV jet in the vicinity of the hurricane between the hours of 18UTC 22 August and 01UTC 23 August and again between 18UTC 23 August and 02UTC 24 August.

1.2 Dropsonde Data

The NOAA Gulfstream-IV jet undertakes 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^{nd} August. Between 18UTC and 01UTC 23^{rd} a total of 25 dropsondes were deployed. Eleven of these were assimilated into the 18UTC run of the model (marked by "•" in Figure 2) and the remaining 14 into the 00UTC run (marked by "✳"). The distribution of these can be seen relative to the centre of the hurricane at 00UTC 23^{rd} (marked by "★").

It is only possible to undertake one mission per day. Hence, the next reconnaissance flight was started on 23^{rd} August. Between 18UTC and 02UTC 24^{th} a total of 23 dropsondes were deployed. Nine of these were assimilated into the 18UTC run of the model (marked by "•" in Figure 3) and the remaining 14 into the 00UTC run (marked by "✳"). The distribution of these can be seen relative to the centre of the hurricane at 00UTC 24th (marked by "★") .

1.3 Experiment Definitions

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 Met Office global model was rerun 10 times starting at 12UTC 22 August and running forward to 00UTC 24 August. Five-day forecasts were produced at 00UTC and 12UTC 23 August and 00UTC 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 rejected during the data assimilation process. Experiments 08 and 09 were just run for time 00UTC 23 August and rejected all dropsondes to the north-east (north of 16°N, east of 69°W) and south-west of the hurricane. Details of the experiments are found in Table 1.

Table1. Dropsonde data usage in rerun experiments

Experiment	Dropsonde data usage
Control	All dropsondes data is included
01	All dropsondes data is rejected
02	Wind data only is rejected
03	Temperature data only is rejected
04	All data above (and including) 500hPa is rejected
05	All data below 500hPa is rejected
06	Humidity data only is rejected
07	Wind and humidity data is rejected
08	All data north-east of TC is rejected (00UTC 23 August only)
09	All data south-west of TC is rejected (00UTC 23 August only)

It must be pointed out that Hurricane Debby was declared dissipated south of Cuba at 06UTC 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.

2. Analysis of the Experiment Forecast Tracks

2.1 00UTC 23rd 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 of all these 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 indicates 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 had modest impacts on the forecast track (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 forecast track is achieved by the data below 500hPa 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 Figure 2). This bears out results seen in previous impact experiments. On occasions the model does not represent the strength of the ridge on 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 00UTC 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. 00UTC 23 August. The hurricane centre position differences between the experiments and the Control.

Positive values indicate experiment position further north and west than Control.

	T+24		T+48		T+72		T+96		T+120		AAE		AAE
Expt.	°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 12UTC 23rd August

There were no further dropsonde data available to the model prior to the 12UTC 23 August run and as Figure 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 00UTC to 12UTC 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 Figure 4 and Table 2. These results again showed that Experiment 01 (without all dropsondes) produced the most significantly different track to the Control with a greater northerly and easterly component in forecasts. However, the positional differences were only about one third of those seen in the 00UTC run. This shows that a relatively small proportion of the positive impact of the dropsonde data assimilated into the 00UTC run was carried forward to the next run at 12UTC.

There are some interesting contrasts in the results for the individual experiments when compared with those for the forecast 12 hours earlier. The results for Experiments 03, 04 and 05 show that data below 500hPa had a large impact, but temperature data and data above 500hPa did not have a large impact; this is consistent with what was seen in the 00UTC run. However, contrary to the 00UTC run, in the 12UTC run humidity data is 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, whilst not so instant, is retained into the next model run.

Table 3. 12UTC 23 August. The hurricane centre position differences between the experiments and the Control.
Positive values indicate experiment position further north and west than Control.

	T+24		T+48		T+72		T+96		T+120		AAE		AAE
Expt.	°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 00UTC 24th August

Dropsondes were again deployed around Hurricane Debby in the hours leading up to the 00UTC 24 August forecast (see Figure 3). Although the impact of these data was not so great as 24 hours previously, the trend in the results was very similar as is seen in Figure 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 forecast times. Analysis of the experiment tracks shows that wind data had the largest impact on the forecast followed by humidity. Temperature again had relatively little impact on the forecast track. Data below 500hPa was more important than that above, but not to the same degree as in the forecast 24 hours previously.

Table 4. 0UTC 24 August. The hurricane centre position differences between the experiments and the Control.
Positive values indicate experiment position further north and west than Control.

	T+24		T+48		T+72		T+96		T+120		AAE		AAE
Expt.	°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. Analysis of Model Fields

The T+0 00UTC 23rd August model fields were examined and some comparisons made between the Control and experiment analyses.

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, but 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 500hPa excluded), 05 (data below 500hPa excluded), 06 (RH excluded), 07 (RH and wind excluded), 08 (data to the north-east excluded), 09 (data to the south-west excluded).

Figure 7(a) shows that when all dropsondes were rejected the 500hPa RH field was reduced by up to 60% to the north-east of the hurricane and increased by up to 30% to the south-west. The impact at 850hPa was less with a reduction of up to 30% to the north-east 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 north-east of the hurricane and higher RH to the south-west.

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

Figures 7(d) and (e) show that excluding just RH and excluding RH and wind together has a similar impact on RH fields to Experiment 01 which excluded all dropsonde data.

Finally, Figures 7(f) and (g) show the difference between the Control and experiments which exclude data to the north-east and south-west of the hurricane centre. These results indicate the 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 has reduced the northerly wind component on the east side of the hurricane at 500hPa and 850hPa by more than $8ms^{-1}$. The westerly component of wind is also strengthened near to the hurricane at 850hPa and the easterly component is strengthened well to the north of the hurricane. At 250hPa 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 north-east and south-west rejected). 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 here than on the equatorwards side. This contrasts with results for relative humidity data which impacted the model analysis on both sides of the hurricane.

4. Summary of Results

- Dropsondes deployed and used in the 00UTC 23 and 24 August runs of the model vastly improved hurricane track forecasts compared to previous runs of the model.
- The wind component of the dropsonde data had the greatest impact on forecasts from the 00UTC runs (when dropsonde data were directly assimilated into the model run).
- The relative humidity component of the dropsonde data (assimilated 12 hours earlier) had the greatest impact on the forecast from the intermediate 12UTC run of the model (when no additional dropsonde data was available to the model).
- The temperature component of the dropsonde data did not contribute much to the improvement of hurricane forecast track.
- Dropsonde data at lower levels (below 500hPa) made a more significant impact on forecast hurricane track than higher level data.
- 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 equatorwards side of the hurricane, since

the sub-tropical ridge strength has a great bearing on the recurvature of the hurricane.

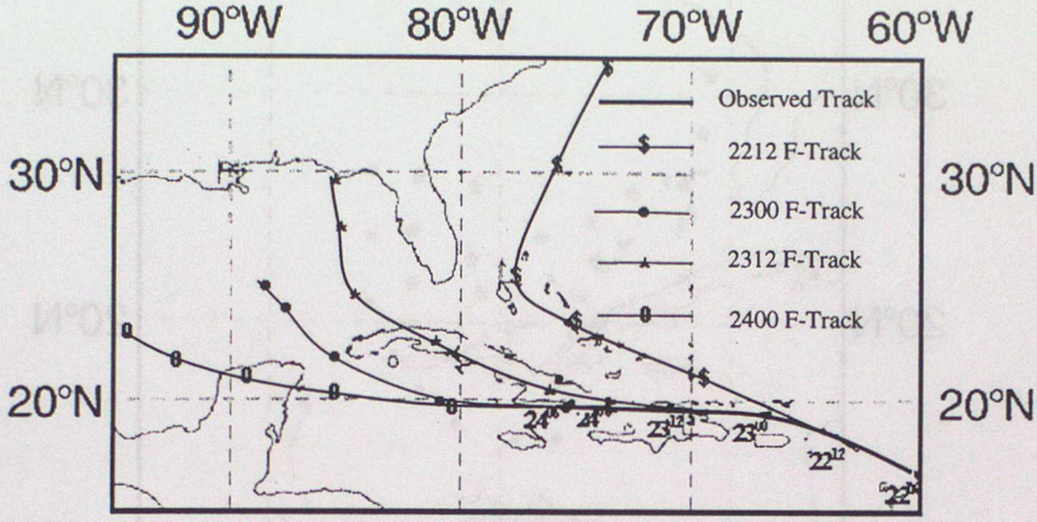


Figure 1 Observed track of Hurricane Debby and forecast tracks from 12UTC 22 August 2000, 00UTC, 12UTC 23 August 2000 and 00UTC 24 August 2000

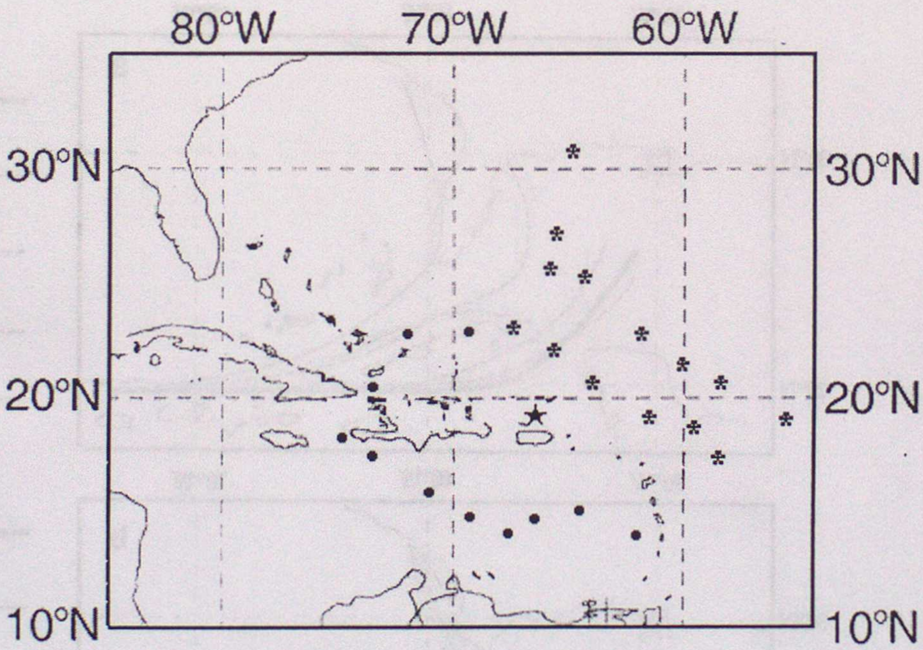


Figure 2 Dropsonde distribution for 00UTC 23 August 2000

- • Assimilated in 18UTC 22 August model run
- * Assimilated in 00UTC 23 August model run

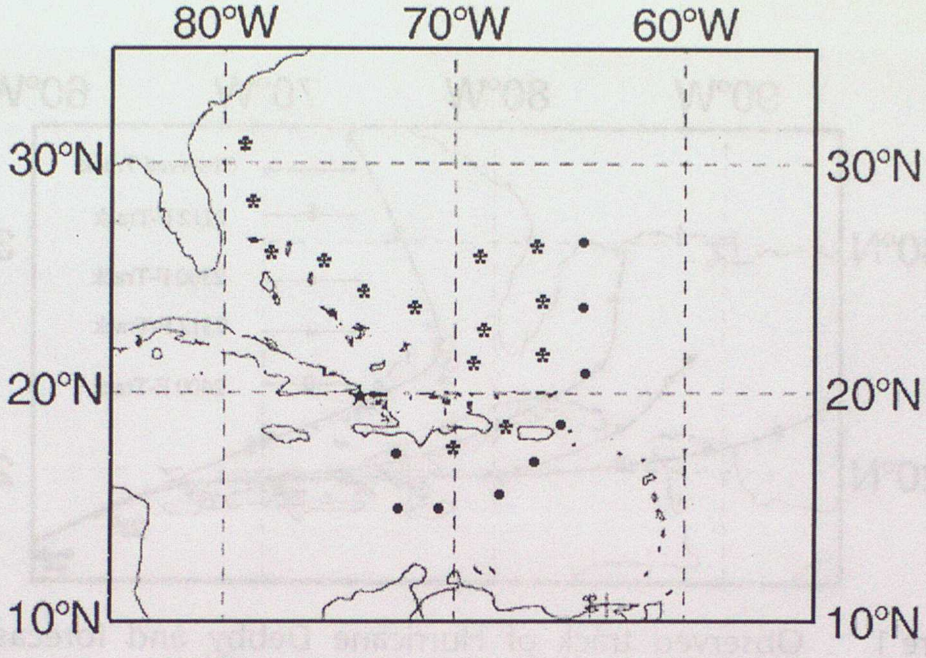


Figure 3 Dropsonde distribution for 00UTC 24 August 2000
● Assimilated in 18UTC 23 August model run
* Assimilated in 00UTC 24 August model run

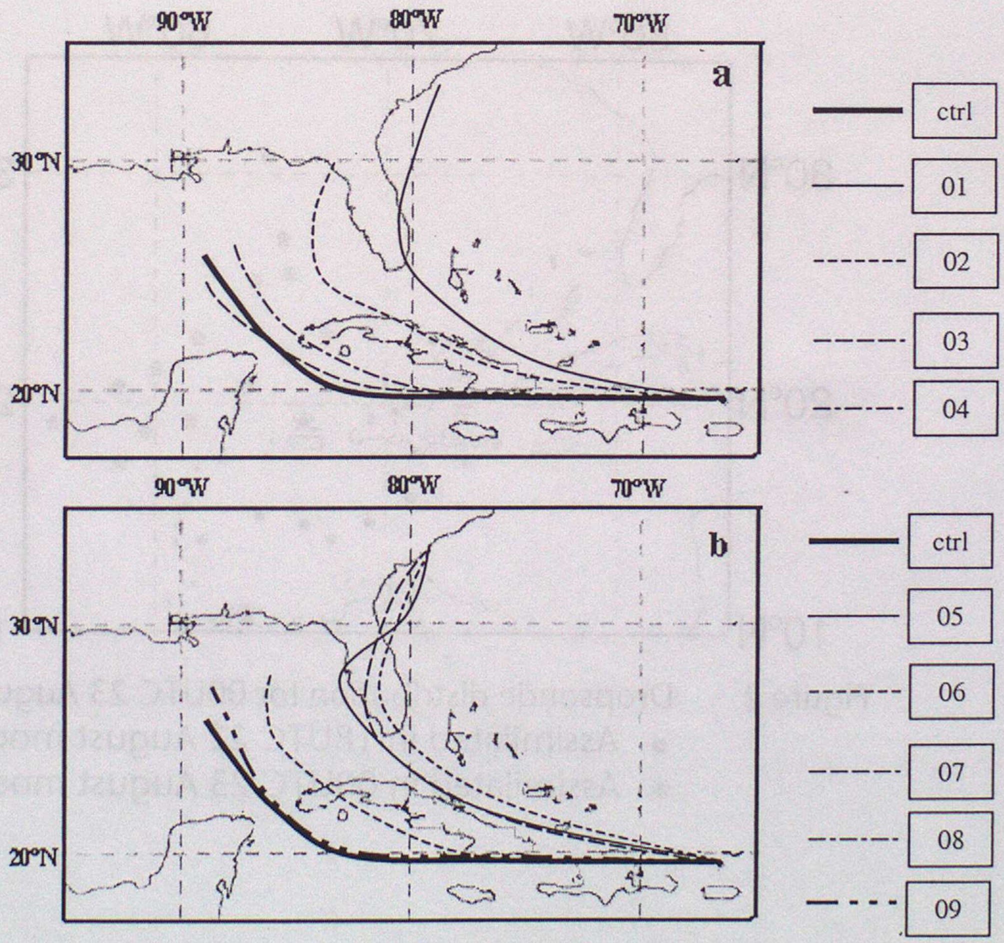


Figure 4 Experiment forecast tracks from DT 00UTC 23 August 2000
(a: control and Experiment 01-04, b: control and Experiment 05-09)

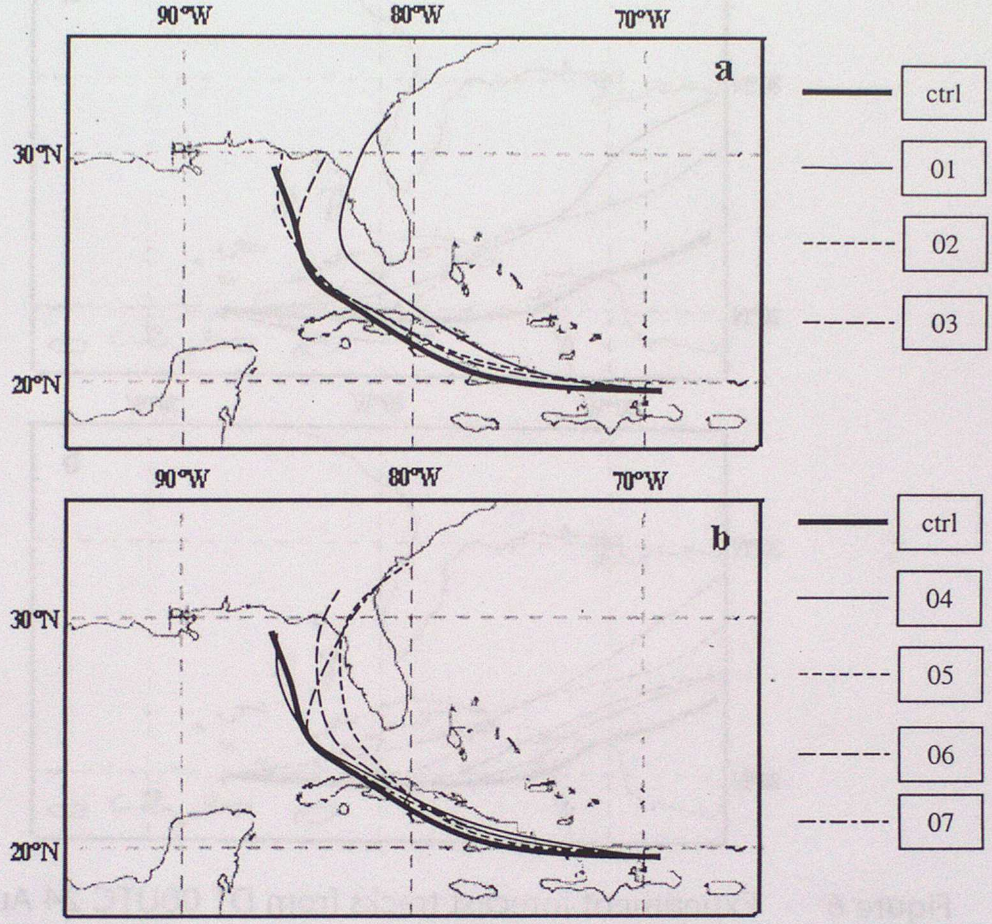


Figure 5 Experiment forecast tracks from DT 12UTC 23 August 2000 (a: control and Experiment 01-03, b: control and Experiment 04-07)

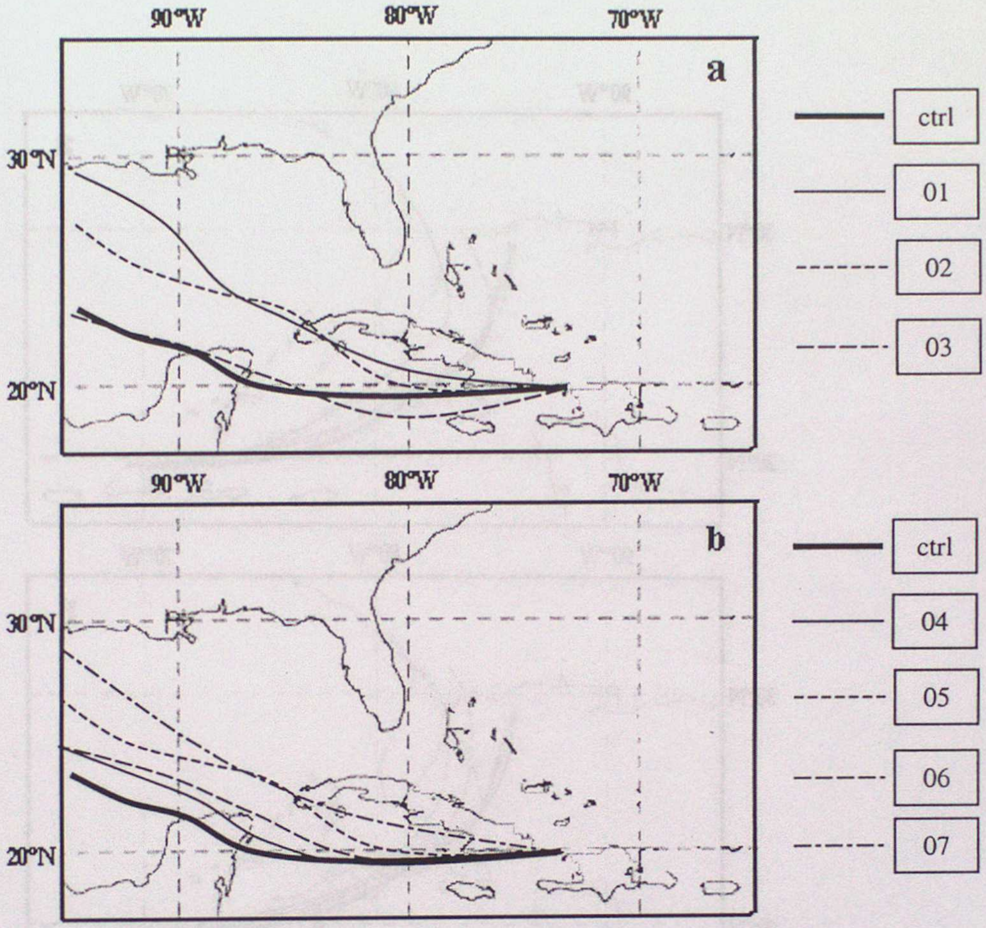
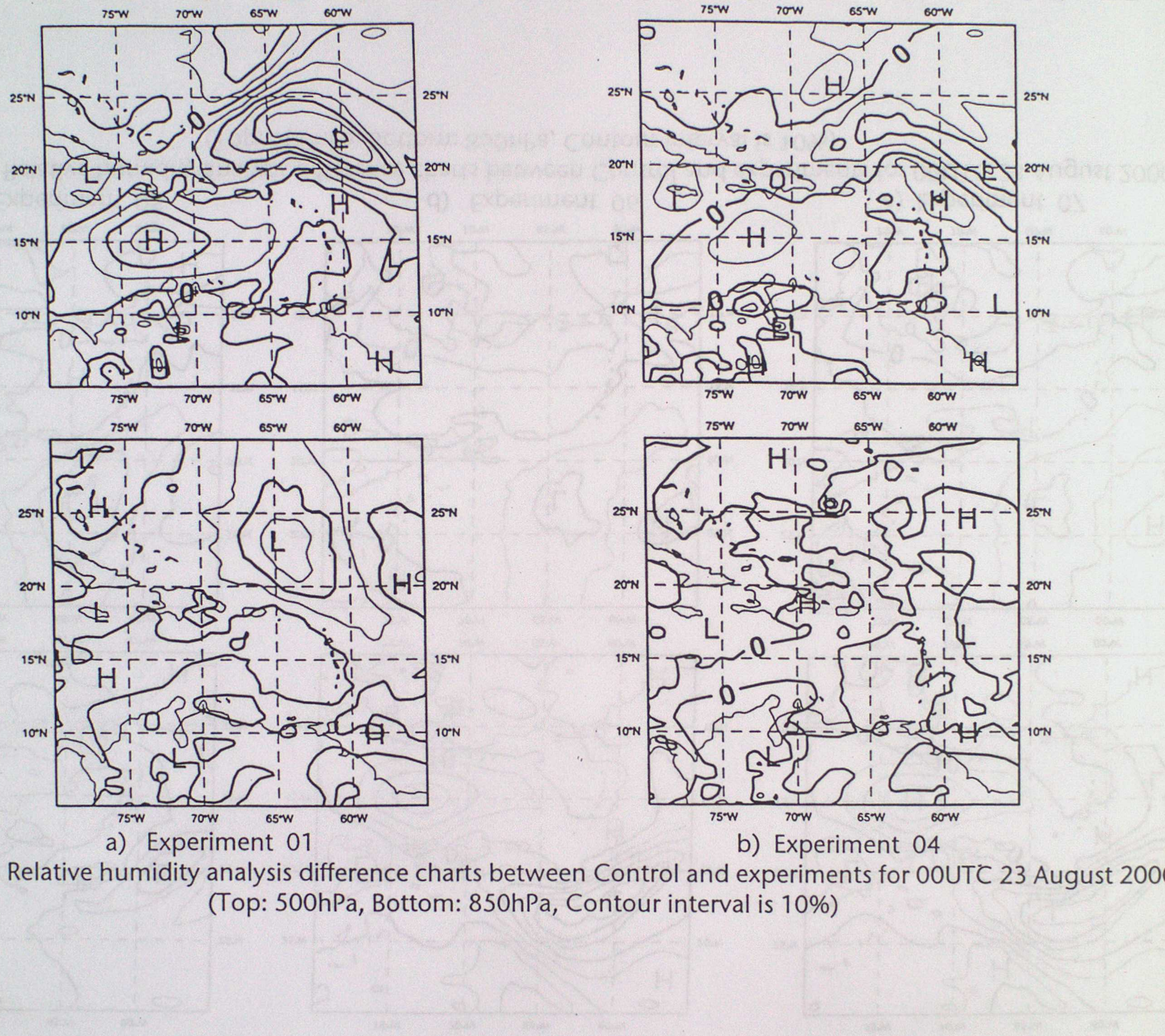


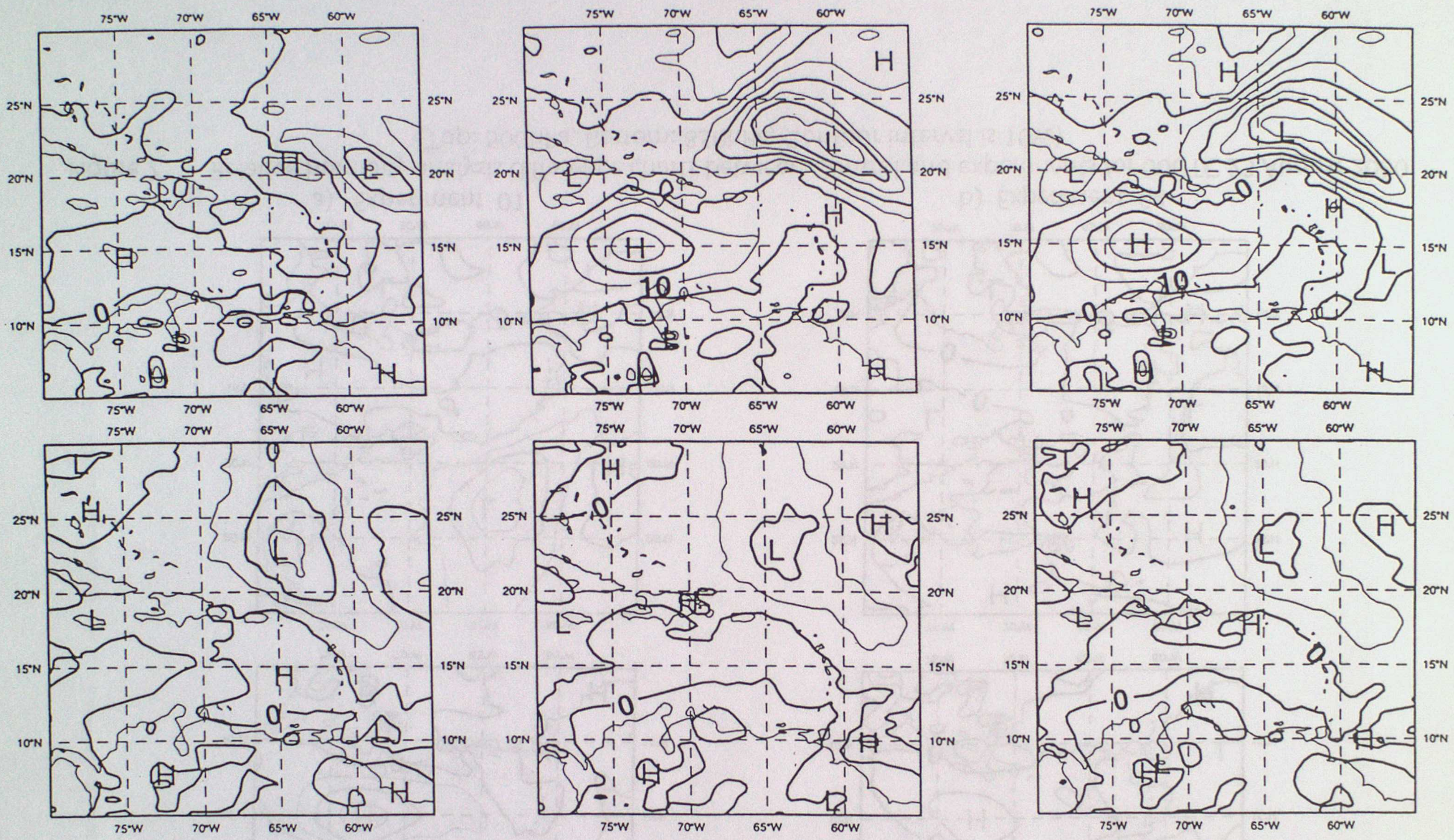
Figure 6 Experiment forecast tracks from DT 00UTC 24 August 2000
(a: control and Experiment 01-03, b: control and Experiment 04-07)



a) Experiment 01

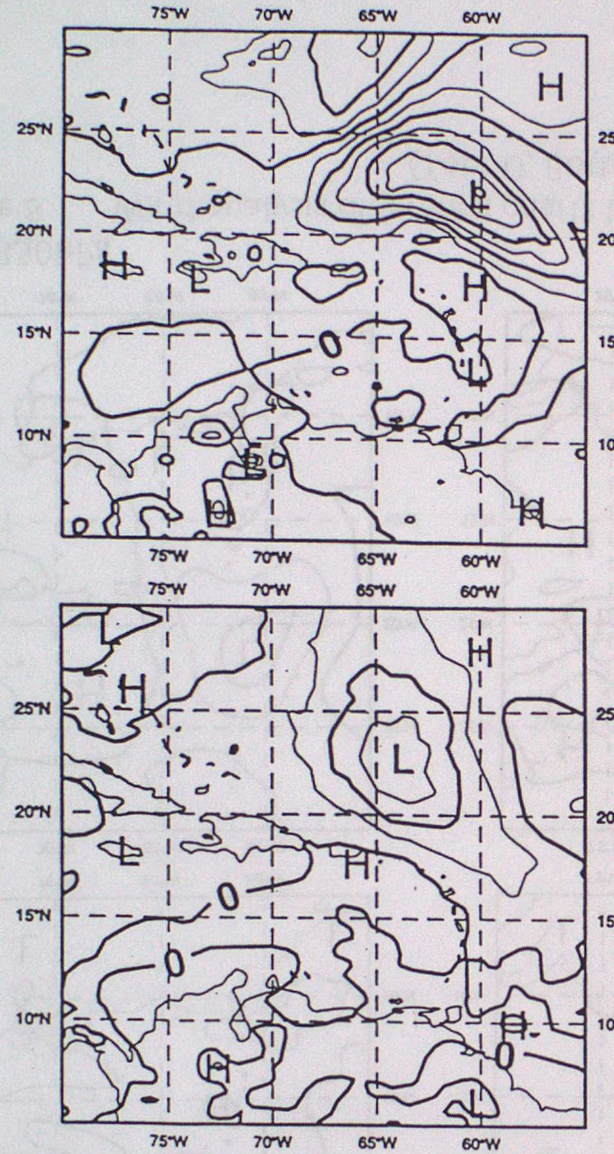
b) Experiment 04

Figure 7 Relative humidity analysis difference charts between Control and experiments for 00UTC 23 August 2000
(Top: 500hPa, Bottom: 850hPa, Contour interval is 10%)

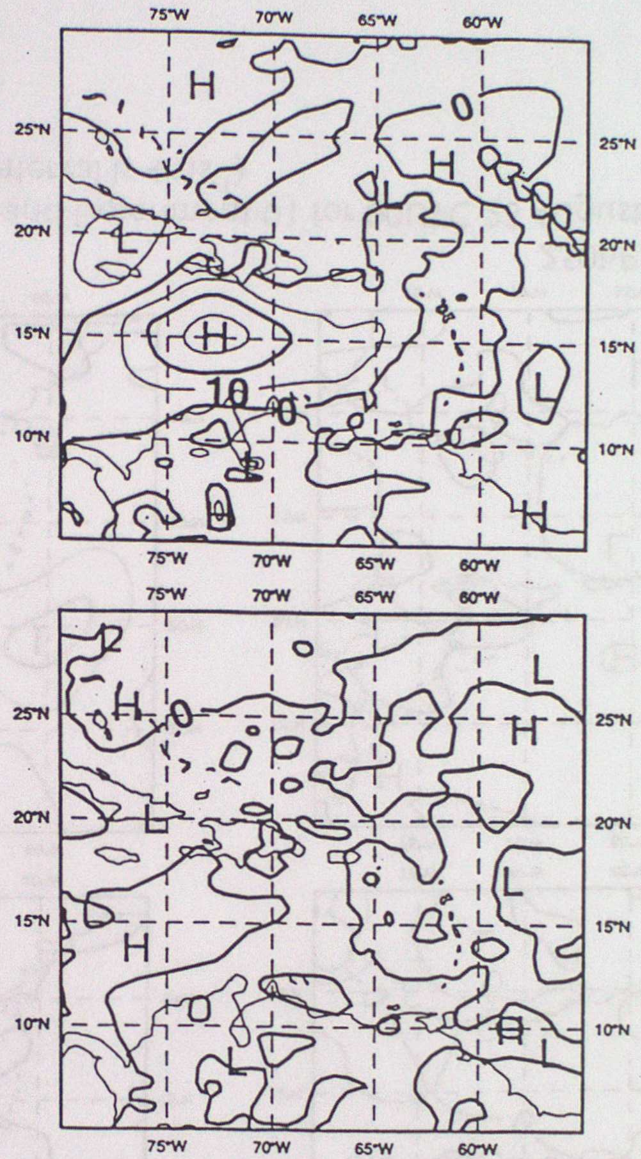


c) Experiment 05 d) Experiment 06 e) Experiment 07

Figure 7 Relative humidity analysis difference charts between Control and experiments for 00UTC 23 August 2000 (Top: 500hPa, Bottom: 850hPa, Contour interval is 10%)



f) Experiment 08



g) Experiment 09

Figure 7 Relative humidity analysis difference charts between Control and experiments for 00UTC 23 August 2000 (Top: 500hPa, Bottom: 850hPa, Contour interval is 10%)

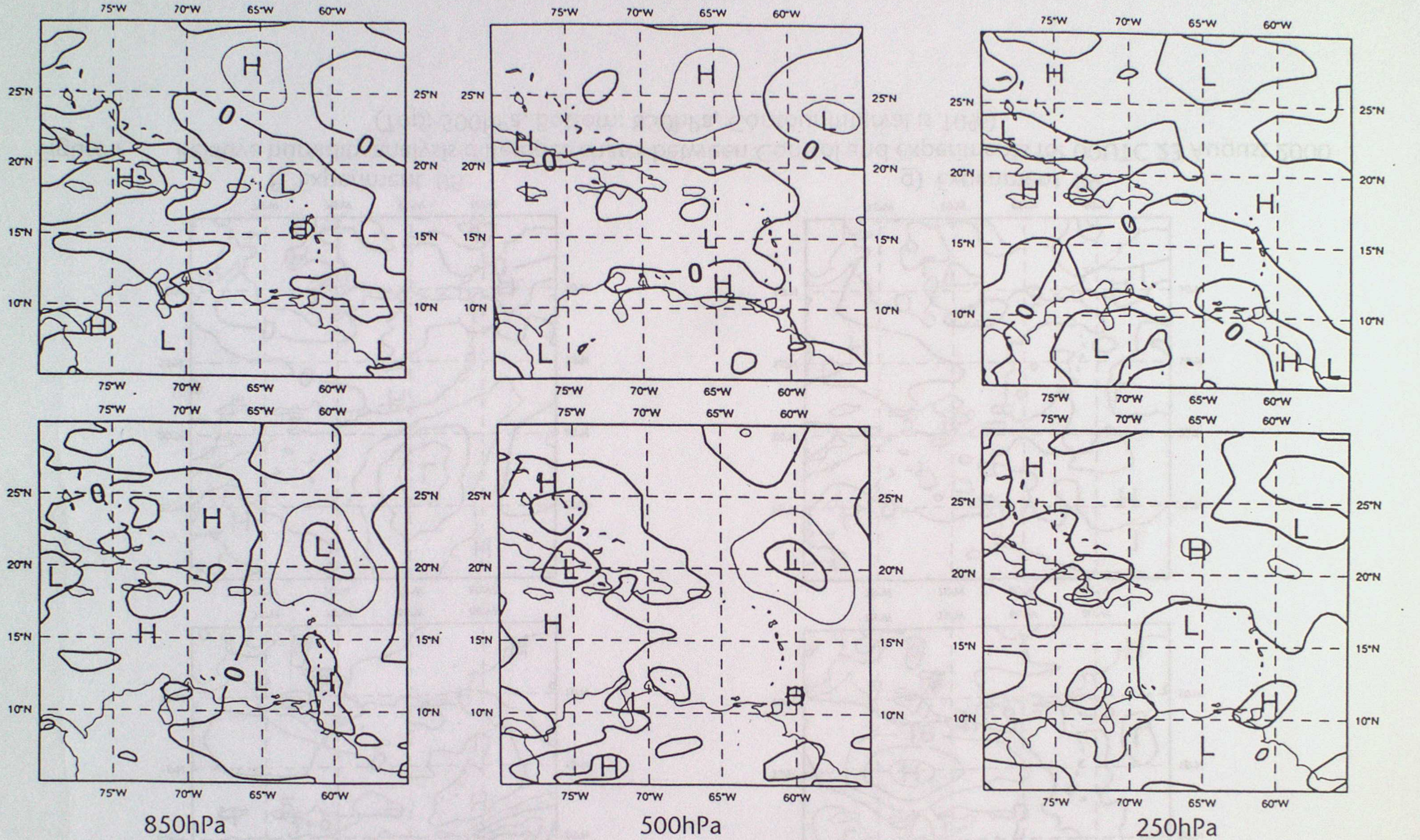


Figure 8 Wind analysis difference charts between Control and Experiment 01 for 00UTC 23 August 2000 (Top: U, Bottom: V, Contour interval is $4ms^{-1}$)

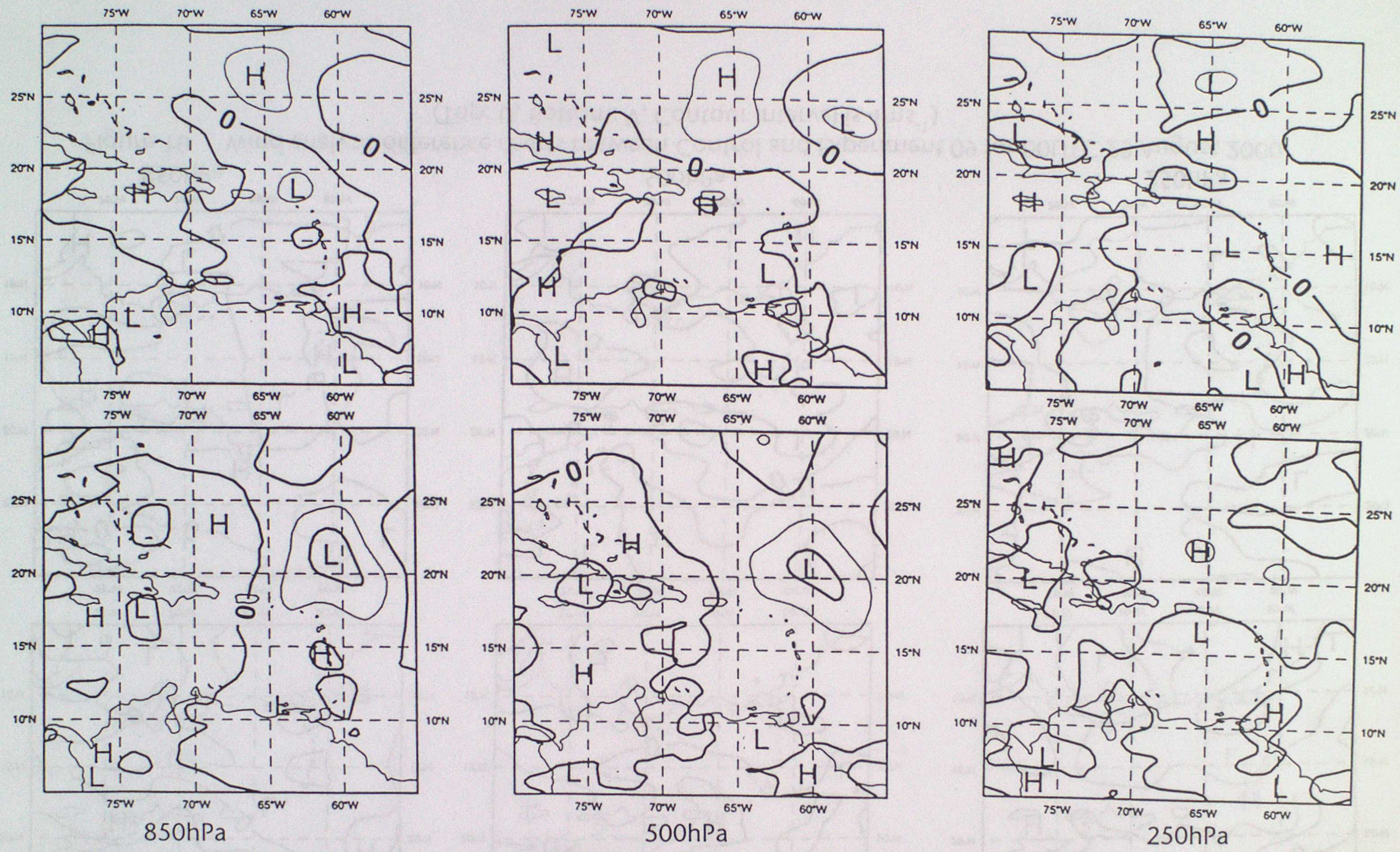


Figure 9 Wind analysis difference charts between Control and Experiment 08 for 00UTC 23 August 2000 (Top: U, Bottom: V, Contour interval is $4ms^{-1}$)

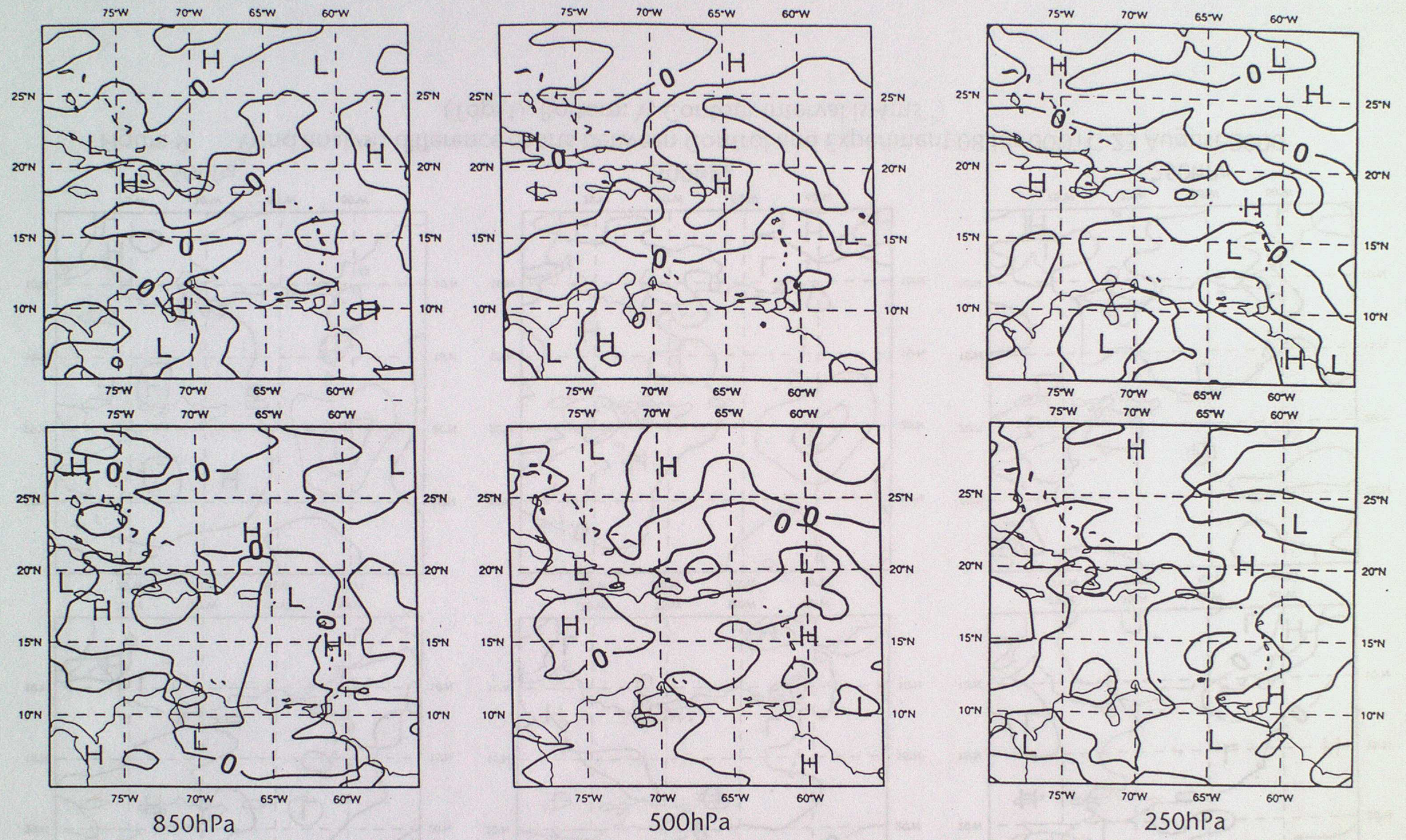


Figure 10 Wind analysis difference charts between Control and Experiment 09 for 00UTC 23 August 2000
(Top: U, Bottom: V, Contour interval is $4ms^{-1}$)