P2.5A NUMERICAL SIMULATIONS OF HURRICANE BRET (21−23 AUGUST 1999) OBSERVED BY TRMM

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1. INTRODUCTION

Although[€] tropical cyclones are one of the most fascinating and impressive meteorological phenomena, they have often dramatic consequences at their landfall causing loss of properties and human lives through extreme winds, torrential rain, or storm surge. Since the advent of Doppler radar, important fine−scale processes associated with the internal kinematic, thermodynamic and microphysical structure of tropical cyclones have been highlighted. Meanwhile, numerical simulations permitted to study mechanisms controlling their different stages of their existence (cyclogenesis, mature development, landfall,...). However one major drawback of these numerical studies is the spin−up time necessary for the ill−defined, too weak, and sometimes misplaced initial vortices provided by large−scale analyses from operational meteorological models to become a tropical cyclone. In this study, we intend to show that it is possible to simulate realistic characteristics of Hurricane Bret through an original initialization technique based on the introduction of information derived from Doppler radar data in the first steps of the simulation.

2. HURRICANE BRET (21−23 AUGUST 1999)

a. Hurricane Bret

The 1999 hurricane season was a very active one as compared to the means values for 1950−1990 with 12 named storms of which five reached category−4 on the Saffir/Simpson scale. Bret was among these intense hurricanes but, fortunately, it made landfall along a sparsely−populated section of the south Texas coast. Both a tropical wave, which moved from Africa to the tropical Atlantic Ocean on 5 August, and an upper−level low over the northwest Caribbean contributed to the formation of a disturbance on the 18th. As a closed circulation was observed during a reconnaissance mission, the system was upgraded to a tropical depression at 1800 UTC on the 18th over the Bay of Campeche.

Due to strong vertival shear caused by an upper−level trough over the extreme western Gulf of Mexico, the depression did not strengthen rapidly. But once the trough moved away toward the east, Bret reached tropical storm strength late on the 19th while beginning to move slowly northwards. With the decrease of the vertical wind shear, it became more organized and then steadily strengthened to a 125−kt and 944−hPa category 4 hurricane on the Saffir/Simpson scale on the morning of the 22nd , while approaching the southern Texas coast near Brownsville. In response to a weak mid−tropospheric ridge over the northwest Gulf of Mexico and to a mid−tropospheric cyclonic circulation over the Rio Grande valley, Bret turned northwestwards. It made landfall over the Texas coast between Brownsville and Corpus Christi at 0000 UTC on 23 August and finally dissipated on the 25th over the high terrains of north central Mexico.

b. The airborne Doppler observation

During the hurricane season, the NOAA's annual hurricane field program aims at improving the understanting of the structure and behaviour of hurricanes. Different airborne experiments are conducted within tropical cyclones, among which the objective of the Hurricane Synoptic−Flow Experiment is to gather vertical profiles of wind, temperature, and humidity typically within 1,000 km from hurricanes centers over the data−sparse oceanic regions of the western Atlantic or Gulf of Mexico. Such an experiment was conducted with the NOAA G−IV and WP−3D aircraft in Hurricane Bret on 21−22 August 1999 from 1751 to 0143 UTC. While the WP−3D aircraft performed a « rotated figure−4 » pattern in the inner−core of the disturbance, the G−IV released GPS−sondes over the whole Gulf of Mexico (Fig. 1).

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We show in this study that it is possible to initialize a mesoscale numerical model with small and meso−scale fields derived from these data.

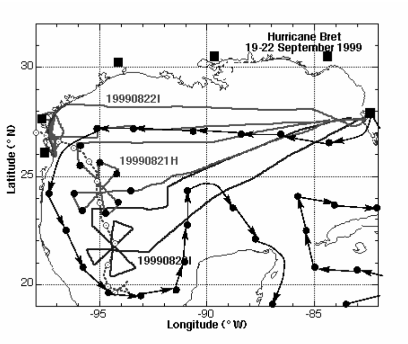

Figure 1. The successive NOAA aircraft missions within Hurricane Bret (20−21−22 August 1999). Storm track is shown by the dash line. The points and the squares indicate locations of G−IV dropwinsondes and operational rawinsondes at 00 UTC on 22 August, respectively.

3. METHODOLOGY

With a variational analysis technique developped for FASTEX data by Moine et al. (2001), which permits to retrieve three−dimensionnal fields from a series of vertical measurements from dropwinsondes and rawinsondes, tangential, radial and vertical winds, temperature and humidity fields have been derived and utilized to initialize the numerical model.

a. The model

A three−dimensionnal, two−way interactive, nested−grid version of the French « Meso−NH » nonhydrostatic mesoscale numerical model was used for the present study. The Meso−NH Atmospheric Simulation System is a joint effort of Centre de Recherches Météorologiques (Météo−France) and Laboratoire d'Aérologie (CNRS) (Lafore et al. 1998). The basic atmosphere variables are temperature, pressure, density of the dry fraction of the air and total density of moist air. The prognostic variables of the model are the three Cartesian components of velocity, the dry potential temperature and the different water mixing ratios. The Meso−NH model is initialized with ECMWF analysis at 00 UTC on 21 August. In order to take large−scale conditions and storm−environment interaction into account, three nested−grids were used: the outermost domain A with a 50−km resolution (Fig. 2a), the intermediate domain B with a grid size of 10 km (Fig. 2b), and the finest domain C with a 2−km resolution (Fig. 2c).

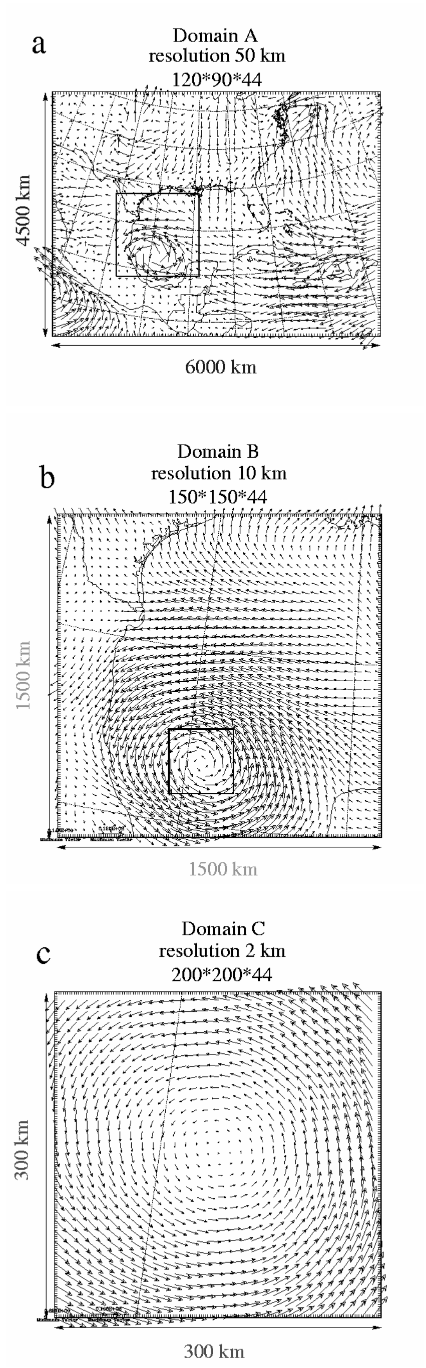

Figure 2 : Design of model domains and horizontal wind analysis from ECMWF−analysis at 00 UTC on 21 August.

b. The necessary ingredients

Although the large−scale analysis estimated the position of Hurricane Bret with a good approximation, it was unable to capture the correct intensity of the tropical cyclone. An EVTD (Extended Velocity Track Display) (Roux and Marks 1996) analysis of airborne Doppler data revealed a small intense hurricane with a radius of maximum wind at 20−25 km from the center whereas the ECMWF−analysis rather depicted a large and diffuse low−level cyclonic circulation. Moreover the analyzed mid−troposphere was too dry to enable help the development of an intense hurricane like Bret. Figure 5 shows mean relative humidity values between 700 and 400 hPa as low as 40 % in the vicinity of the storm while the dropsondes information rejected both dry areas further inland northwestwards and northwards (Figs. 3 and 4).

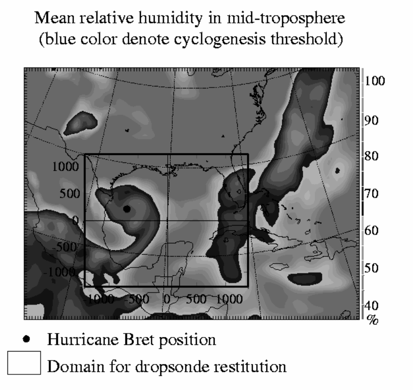

Figure 3: Relative humidity in mid−troposphere from ECMWF−analysis.

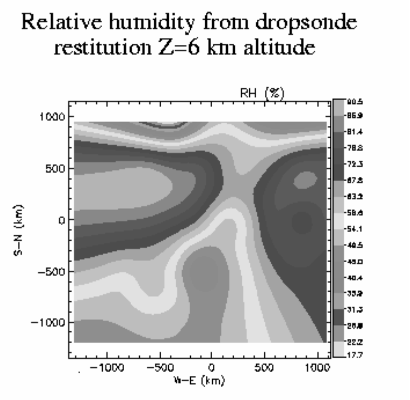

Figure 4: Relative humidity in mid−troposphere from dropwinsondes analysis.

Based on these three−dimensional fields derived from airborne Doppler radar and GPS−dropsondes within Bret in 21 August 1999 and in order to correct the initial vortex, the dynamic and thermodynamic values from the ECMWF−analysis were modified to force more realistic initial conditions. This was done through an additional forcing on the initial three components of wind, temperature and humidity so as to minimize the deviation with respect to the observed fields. The perturbation was applied only throughout the first time step (during 10 s).

In the inner core region the forced wind and temperature fields are expressed through analytical formulations, derived from symmetric EVTD−derived tangential wind and potential temperature fields in thermal wind equilibrium. The secondary circulation has an inflow in the low levels, upward motions in the eyewall region and outflow in the upper levels. It has been showed in Nuissier et al. (2001) that such a balanced vortex embedded in an ideal environmental conditions (initially neutral conditions and no large−scale wind) permitted to obtain realistic structures of mature tropical cyclones with the Meso−NH numerical model.

4. PRELIMINARY RESULTS

After being initialized with the above described fields, the model was integrated for a period of 12 hours of simulated time with a double nested−grid configuration, then for a period of 2 hours with a triple nested−grid one. We present here only the results for the last two hours in the finest domain C where most of the kinematic, thermodynamic and explicit microphysical perturbations associated with the inner−core of the disturbance occured.

Although the fields used for small−scale forcing in the initial analysis were symmetric ones, asymetric features similar to those observed on the satellite images of Hurricane Bret could be found in the preliminary results. Although the simulated reflectivity values are slightly stronger than the observed ones, it is encouraging to remark that the model very well reproduces the small echo−free eye of Bret with a radius near 15 km with more intense precipitation in the northwestern quadrant of the eyewall. Also well reproduced is the intense precipitation associated with the cellular deep convection embedded along the spiral rainbands with reflectivities values as high as 50 dBZ.

Fig. 8 shows a vertical cross−section of the simulated radar reflectivity where the strong asymmetry in the precipitation field is quite obvious. The maximum activity extends up to 90−100 km from the center with very intense rainfall (near 50 dBZ). This strong radar reflectivity can also be observed on the airborne radar fields as well as on the TRMM ones (Figs. 6 and 9). The model reproduces the typically sharp increase of the simulated reflectivity values below 5 km altitude, resulting from the « bright−band » effect due to the melting of iced hydrometeors into liquid ones, with a higher dielectric constant. The graupel content distribution (not shown) reveals a large production of particles just above the maximum of precipitation and the melting of these iced−hydrometeors seems to be directly correlated with intense rainfall in the lowest levels. In addition, the possible interaction between a secondary outflow pattern near 12 km altitude, related to an outer rainband, with the main updraft within the northwestern eyewall could produce a large area of iced hydrometeors which then is advected downwards (Fig. 8). It might be that the resulting aggregation in this region creates an increase of graupel production locally. The southeastern part of the eyewall depicts a less complex organization (Fig. 8) with intense upward motions (> 4 to 8 $m.s^{-1}$) between 5 and 10 km altitude and a large outflow near 15 km altitude as high as 15 $m.s^{-1}$.

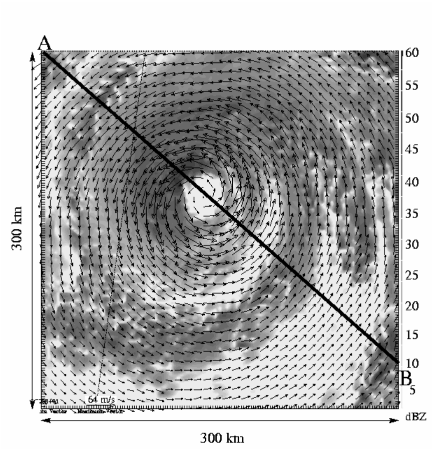

Figure 5 : Simulated radar reflectivity at Z=2.5 km altitude after the final 2−h integrations of Hurricane Bret (i.e at 1400 UTC 21 August 1999).

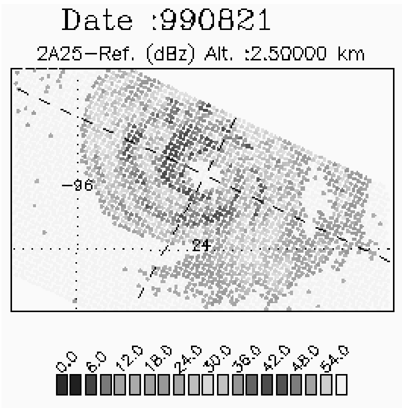

Figure 6 : Observed radar reflectivity from TRMM−Precipitation Radar at Z=2500 km altitude on 21 August 1999 at 2246 UTC .

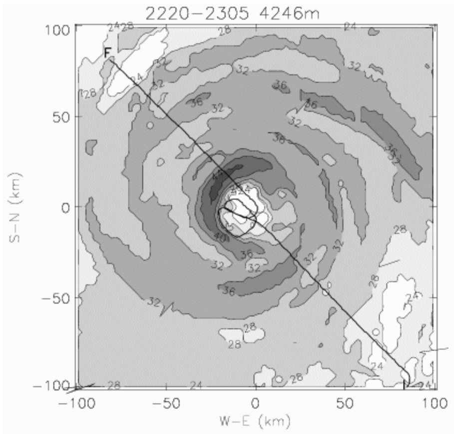

Figure 7: Horizontal reflectivity composite at flight level (4246 m) from the lower fuselage radar data on 21 August 1999 from 2220 till 2305 UTC. The solid line indicates the aircraft track (I: initial location at 2220, F: final location at 2305).

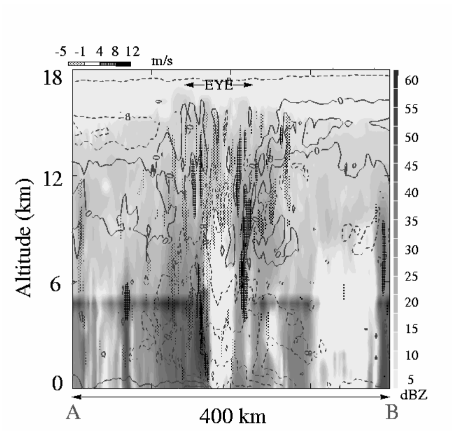

Figure 8: Vertical cross−section of the simulated radar reflectivity with gray scales along line AB in Fig. 5 at the final 2−h integrations of Hurricane Bret (i.e at 1400 UTC on 21 August 1999). Solid (dashed) lines denotes a radial motion toward B (A) at intervals of 8 $m.s^{-1}$. The vertical motions is superposed with shaded areas.

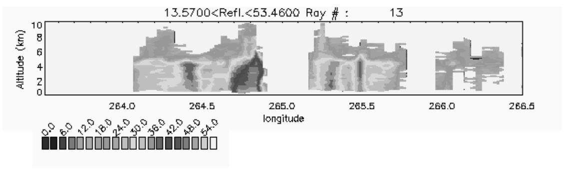

Figure 9: Northwest−southeast vertical cross−section of observed radar reflectivity from TRMM−Precipitation on 21 August 1999 at 2246 UTC.

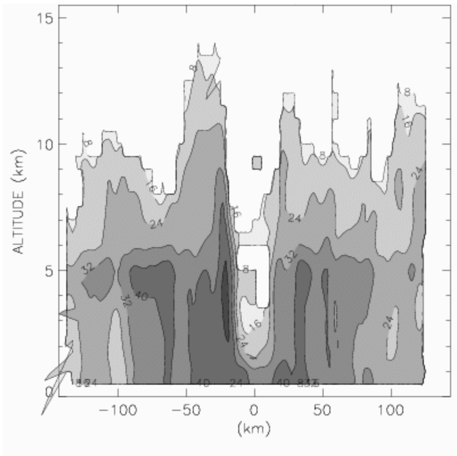

Figure 8: Vertical reflectivity composite along the flight track from the Tail Doppler radar data on 21 August 1999 from 2225 till 2310 UTC. Left of the figure is northwest, right is southeast.

5. CONCLUSIONS

We have shown that it is possible to efficiently simulate a tropical cyclone with a minimum spin−up time of the numerical model by adding a very simple description of the inner vortex circulation in an operational analysis. It is however to be outlined that an appropriate description of the synoptic scale environment of the cyclone, especially with regard to humidity, is a necessary condition for a correct simulation. In these conditions, the numerically simutated reflectivity fields show striking similarities with those derived from both airborne and spaceborne observations. A next step is to study the evolution and propagation of the simulated cyclone, and to compare them witn the observations relative to Hurricane Bret, especially during landfall.

6. REFERENCES

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