2C.1 THE EFFECTS OF VERTICAL WIND SHEAR ON THE FORMATION OF HURRICANE GABRIELLE (2001)

Kate Musgrave[1], C. A. Davis[2] and M. T. Montgomery[3]

[1]UCAR/SOARS and Colorado State University, Fort Collins, CO
[2]National Center for Atmospheric Research, Boulder, CO
[3]Colorado State University, Fort Collins, CO

INTRODUCTION

Over the past half-century, research in the area of tropical cyclogenesis has established several factors necessary for tropical cyclone formation (Gray 1968). More recently, some studies have challenged the role of vertical wind shear as one of those factors (Bosart and Bartlo 1991; Bracken and Bosart 2000). The present study examined the formation of Hurricane Gabrielle (2001), including the effects of vertical wind shear on the developing storm.

Gabrielle formed in the Gulf of Mexico within a few hundred miles of Florida's west coast. The National Hurricane Center (NHC) began officially tracking Gabrielle on 11 September 2001 (Lawrence and Blake 2001), and she made landfall near Venice, FL on 14 September 2001 as a tropical storm. Gabrielle did not gain hurricane status until after crossing the Florida peninsula and entering the Atlantic Ocean. Gabrielle is an interesting case to study because she formed outside the tropics in an area of significant vertical wind shear.

METHODOLOGY

The formation of Gabrielle was simulated using the fifth-generation Pennsylvania State University-National Center for Atmospheric Research mesoscale model version 3.5 (MM5). The time period chosen for the simulation was from 1200 UTC 9 September 2001 to 1200 UTC 13 September 2001. The end of this period corresponds to the time when NHC declared Gabrielle a tropical storm.

A control run and two sensitivity experiments were performed to examine Gabrielle's formation. The first sensitivity experiment removed the initial disturbance (a mid-tropospheric vortex), while the second sensitivity experiment lessened the vertical wind shear in the initial conditions in the vicinity of the developing storm. The second sensitivity experiment will be the focus of this discussion.

The simulations used two domains nested within a coarse domain (Domain 1) of dimensions 91 x 91 and with a grid spacing of 111 km. Domain 2 had a grid spacing of 37km, with 79 x 73 grid points. Domain 3 had a grid spacing of 12km, with 91 x 91 grid points. All three domains had 38 vertical levels from surface level to 50 mb, with more closely spaced levels near the surface.

[1] *Corresponding Author Address:* Kate Musgrave, Department of Atmospheric Science, Colorado State University, Fort Collins, CO 80523-1371; email: kate@atmos.colostate.edu

Domains 1 and 2 were run for 96 hours – from 1200 UTC 9 September 2001 until 1200 UTC 13 September 2001. Domain 3 was added to the model 48 hours into the simulation; running from 1200 UTC 11 September 2001 until 1200 UTC 13 September 2001. Domain 3 was run only for the last 48 hours to reduce computations and to allow the larger mesoscale features to develop. The time step used for Domain 1 was 180 seconds, while decreasing by a factor of three for each successive inner domain. The model produced output every three hours for Domains 1 and 2 and every hour for Domain 3.

In the second sensitivity experiment the vertical wind shear profile was altered over a large area around the initial disturbance. The alterations were based on the fact that horizontal gradients in potential vorticity (PV) are inversely related to velocity through the invertibility principle (Hoskins et al. 1985). Thus removal of PV gradients over a deep layer will tend to weaken the velocity at all layers and hence decrease the shear. In practice, local alterations of PV are effective for decreasing the shear within a sub-synoptic-scale region, while retaining a significant barotropic component of the flow associated with PV features on larger scales.

In the present case, the shear is reduced between 900 and 300 hPa. The step-wise process first removes the PV attributed to the initial disturbance as described by Davis and Bosart (2002). This required averaging PV horizontally over a scale of a few hundred km. Next, PV was averaged over a larger-scale box, roughly 1100 km on a side (11x10 grid points on Domain 1). This domain was chosen so that the PV on the boundaries was approximately uniform. To reduce the remaining vertical wind shear, a positive PV anomaly was added in the upper atmosphere and a negative temperature anomaly was added to the lower atmosphere over the western Gulf of Mexico. Finally, the PV anomaly of the disturbance was added back to the modified PV. This new PV field was inverted to compute balanced wind and temperature increments associated with the PV modifications. These were added to the model initial condition (interpolated vertically to model levels) and a new simulation was integrated.

RESULTS

The model output was compared with several sets of observations, including the NHC best track data, NCEP final operational analyses, available ship and buoy data (provided by UCAR/Unidata), the National Oceanic and Atmospheric Association (NOAA)

Hurricane Research Division's (HRD) experimental surface wind analyses, and radar and satellite imagery provided by NCAR. Minimum central pressure, maximum sustained winds, and surface wind contours were examined to compare the strength of the pre-Gabrielle disturbance as well as trends in intensification. Satellite infrared imagery was compared to cloud-top temperatures produced by the model, which confirmed that the convective features of the control run were in general agreement with the observed organization of convection.

Figure 1 shows the maximum sustained winds as determined by the NHC best track data and the simulations. The control run and the NHC best track both indicate maximum sustained winds holding steady from 48 hours until 60 hours into the simulation (the data is shown starting at 48 hours into the simulation). At this point, the control simulation maximum sustained winds increase steadily for approximately 18 hours. During this time less increase is seen in the NHC best track, leading to larger values of maximum sustained winds in the simulation than in the NHC best track. The data sets approach each other again at the end of the time period. One reason for the difference between the simulation and the NHC best track maximum sustained winds is that the measurements of the winds were taken at different levels. NHC best track surface winds were taken at 10 m above the surface, while the model surface winds were predicted at 40 m above the surface. Taking friction into account would reduce the predicted winds by 15%-20% over water, yielding a better agreement with observations. Also the NHC best track is based off of very limited data, and in the case of Gabrielle reconnaissance flights did not begin until the last day of the time period. In situ measurements indicate that NHC may have underestimated Gabrielle's winds towards the end of the simulation.

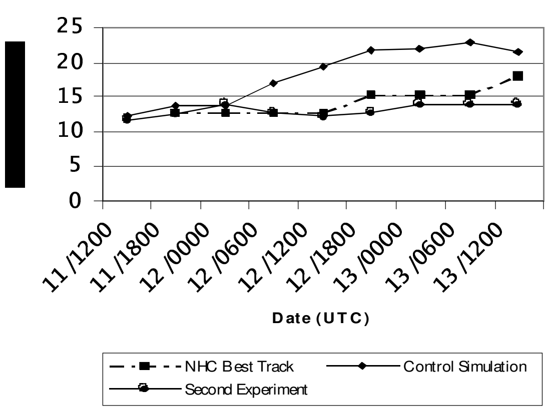

Figure 1. Maximum sustained wind speed as determined by NHC best track and the simulations. NHC best track data did not start until 1800 UTC 11 September.

Figure 2 shows the magnitude of the vertical wind shear for the control simulation and the second sensitivity experiment. This figure shows that the vertical wind shear was significantly reduced throughout the simulation.

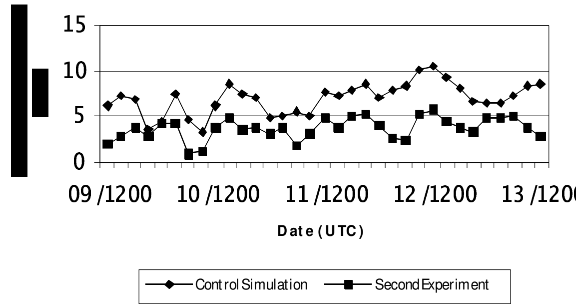

Figure 2. Magnitude of vertical wind shear for entirety of four-day simulation, plotted in 3-hour increments for both the control simulation and the second sensitivity experiment. Shear was calculated using the average over a box measuring 25x25 grid points (Domain 3) centered about Gabrielle.

Gabrielle's formation was affected by reducing the vertical wind shear. While a system that could be identified as Gabrielle formed, the formation occurred at a slower pace than in the control simulation and produced a much weaker version of Gabrielle by the end of the four-day simulation. As shown in Figure 1 the maximum sustained wind speed does not increase in the case with lessened wind shear, remaining nearly constant throughout the last 48 hours of the simulation. This is perhaps the first direct evidence of a positive influence of vertical wind shear on tropical cyclogenesis, supporting the assertions of Bracken and Bosart (2002).

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