Energetics of Hurricane Bonnie (1998)

Wallace Hogsett

whogsett@atmos.umd.edu

Department of Atmospheric and Oceanic Science, University of Maryland, College Park, MD USA

Introduction

In 1998, Hurricane Bonnie developed in the tropical Atlantic Ocean and eventually made landfall on the Eastern coast of the United States. The asymmetry of the eyewall and the varied rate of intensification make Bonnie a particularly interesting case study. Zhu et al. (2004) presented a numerical simulation of Bonnie, in which the developmental stages were captured as observed.

Soon after being classified as a hurricane, Bonnie underwent rapid intensification for a two-day period, followed by a relatively steady maintenance period for the three days prior to landfall (Figure 1). Superimposed upon this intensity trend is an evolution of the eyewall structure (Figure 2). Early on, the eyewall was characterized by a wavenumber-1 asymmetry in reflectivity due to the large scale wind shear that suppressed convection in the western half of the storm. Later, during the maintenance period, the shear subsided, and the reflectivity pattern became more axisymmetric.

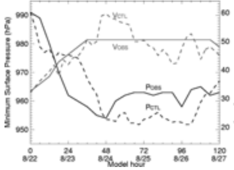

Figure 1: Time series of the minimum central pressure (P) and maximum surface winds (V) from the best analysis and the model simulation, from Zhu et al (2004). Note the early, rapid intensification followed by a steady maintenance period.

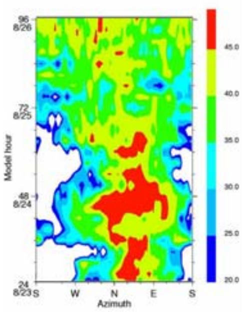

Figure 2: A time-azimuth cross section of the simulated radar reflectivity along the updraft core at z = 5km, from Zhu et al. (2004). Note the transition from a partial eyewall (high intensity) to a full eyewall (low intensity).

Objectives

This study will use analyses of kinetic and latent energy to provide answers to the questions:

- ***Why is convection so intense before hour 66 and weaker after this time?***
- ***Why does the eyewall structure evolve from a half to full eyewall?***

Method

Using a real data, 4-km resolution MM5 simulation of Hurricane Bonnie, we chose the 24-96 hour window for analysis, because this timeframe captures both the intensity and structural fluctuations. At each 3-hour timestep, we chose a domain defined as a cylinder of radius 200km, centered at the location of minimum pressure, and integrated various budget terms over the volume. The domain was moved with the storm every 3-hour timestep. Below are the budget equations for Latent and Kinetic energy, respectively.

$$\frac{d}{dt}(L_v q_v) = -L_v(Q_{con} - Q_{ev}) + OceanFlux + BoundaryFlux$$

$$\frac{d}{dt}\left(\frac{\vec{V}\bullet\vec{V}}{2}\right) = \boxed{-\frac{1}{\rho}\vec{V}_H \bullet \nabla p'} - gw(q_c + q_r + q_i + q_s + q_g) - \vec{V}\bullet\vec{F} + BoundaryFlux$$

Results

Presented below is the budget of kinetic energy. Of note is the positive tendency throughout the 24-96 hour integration. In the 66-78 hour period, while the storm is transitioning from a partial eyewall to a full eyewall, the tendency decreases to nearly zero, which is consistent with Figure 1. Kinetic energy production will be analyzed further in Figure 5.

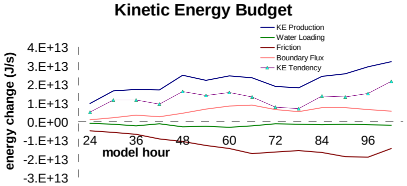

Figure 3: Kinetic energy budget for a domain with radius of 200 km that is centered on and moves with the storm.

The latent energy input (fuel for the heat engine) into the storm is examined below in Figure 4, and it can be seen by a comparison with Figure 2 that there is a high correlation between the quadrant of maximum latent energy input and the quadrant of greatest radar reflectivity. ***In the first half of the integration, all of the latent energy input into the storm comes from the southeast and northeast quadrants, while late in the integration, there is a more equal azimuthal input of latent energy.*** **This is also consistent with the transition from a partial eyewall to a full eyewall.**

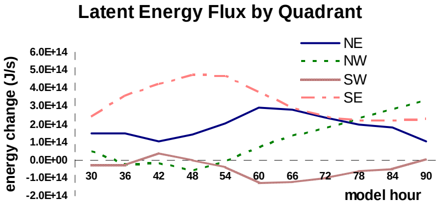

Figure 4: Latent energy flux into the domain, divided into quadrants. Note the unequal partitioning among the four quadrants transitions into a more evenly divided input.

Results, cont.

Figure 5 provides a look at kinetic energy (KE) production inside the storm at hour 48 (partial eyewall) and hour 96 (full eyewall). At hour 48, the environmental shear from west to east is evident in the flow vectors, and this suppresses the convection and minimizes the KE production in the western half. However, the shear evidently aids in ventilating the eastern half of the storm, which is vigorously convective at this time. At hour 96, the environmental flow is calm and the hurricane is characterized by a full eyewall but significantly less vigorous convection and less widespread KE production.

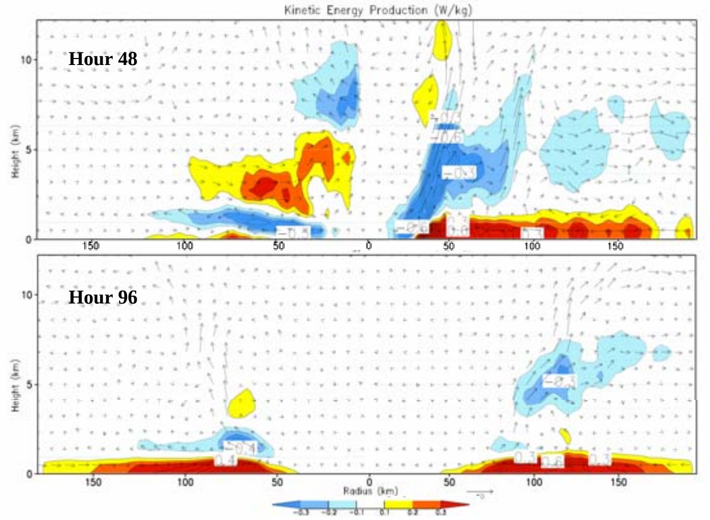

Figure 5: West-east vertical cross sections of one-hour averaged kinetic energy production through the center at hours 48 (top) and 96 (bottom). Superimposed are the in-plane flow vectors. colorsssss

Conclusions

Using energy analyses, the structural and intensity variations of Hurricane Bonnie are explained in terms of kinetic energy production, latent energy input, and environmental wind influence. Environmental winds account for the asymmetric structure early in the integration, as well as the extreme intensity of the eastern half of the eyewall.

Acknowledgements

I would like to thank my advisor, Dr. Da-lin Zhang, as well as Chanh Q. Kieu who provided many helpful comments.