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Storm Initialization of Hurricane Bonnie Using SSM/I Brightness Temperatures: Preliminary Results

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1 INTRODUCTION

The skill of hurricane prediction depends strongly on the accuracy of the initial vortex. Due to the lack of observation data over the tropical oceans, where tropical storms are generated and spend most of their lifetime, the initial vortices in large scale analyses are often too weak and misplaced. Hurricane initialization, a procedure which uses limited observational data to generate a dynamically consistent and conceptually correct initial vortex of all model variables, is often needed to improve the initial storm vertex. The bogus data assimilation (BDA) scheme was found to be a promising method for initialization (Zou and Xiao 2000). BDA fits the forecast model to a set of specified bogus data such as sea level pressure (SLP) within a circular region. BDA generated fields of all model variables are dynamically and physically consistent.

Furthermore, due to its variational formulation, new observations can be incorporated into BDA. Using satellite-derived water vapor wind vectors (WVWVs), rain rates, brightness temperatures, and ozone, as well as radar radial velocity and reflectivity data, a more realistic initial field can be obtained by BDA. In this study brightness temperatures (TBs) obtained from the Special Sensor Microwave Imager (SSM/I) are used (i) to evaluate the performance of the BDA scheme, and (ii) to improve the initial vortex of Hurricane Bonnie through direct assimilation of SSM/I brightness temperature observations.

2 CASE DESCRIPTION

The case chosen for this study is Hurricane Bonnie 1998, which originated from a tropical wave that moved over Dakar, Senegal on 14 August 1998. Bonnie became a hurricane at 06 UTC 22 August. It obtained maximum winds of 100 kt and a minimum pressure of 954 mb at 03 UTC 24 August. After a slight weakening, Bonnie made land-fall near Wilmington, NC as a Category 2 hurricane (based on the Saffir/Simpson Hurricane Scale) at 0330 UTC 27 August.

At 12 UTC 23 August, observations from the SSM/I covered the area in which Hurricane Bonnie was located. Therefore, numerical experiments for the hurricane initialization are carried out at this time. A general overview of the performance of the BDA scheme is provided in the following section, which will be used as a benchmark for our new experiment.

2.1 A DIAGNOSTIC STUDY

In BDA, Fujita's formula (1952) is used to formulate the bogused surface low data. The SLP is expressed as a function of radial distance from the cyclone center (r) as follows:

$$P_{bogus}(r) = P_{inf} - \frac{(P_{inf} - P_c)}{(1 + (r/{R_0}^2))^{1/2}} \qquad (2.1)$$

where P_c and P_{inf} are the value of the central pressure of the hurricane and an estimation of the SLP at an infinite distance, respectively. The parameter R_0 has a dimension of length and is defined as the radius of maximum gradient of the SLP multiplied by $\sqrt{2}$.

The observed parameters, which are currently provided operationally by the Tropical Prediction Center (TPC), are central pressure(P_c), direction and speed of past motion, the radius of the outermost closed isobar(R_{out}), the maximum wind(V_{max}), the radius of the maximum wind(R_{max}), and the

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radii of 35, 50 and 65 knot winds (R_{35kt}, R_{50kt}, R_{64kt}) by quadrants. All the parameters are supposed to represent the surface estimates.

Since BDA scheme use only sea level pressure generated by Fujita's formula to specify the initial vortices, it is interesting to compare the main features of the corresponding observed storm to the bogused SLP. These features include all the TPC observed parameters.

Four cases of initial vortices generated by BDA are examined. They are hurricane Bonnie at 0000 UTC 24 August (Bonnie A), and at 1200UTC 23 August (Bonnie B) 1998, hurricane Felix at 0000 UTC 16 August 1995, and hurricane Opal at 1200UTC 2 October 1995. The intensities of Bonnie, Felix, and Opal are within the category of Hurricane 3, 2, and 1 respectively at the selected initialization times. The grid system and input parameters of Fujita's formula are summarized in Tables 1 and 2. Except the central pressure, other input parameters were determined empirically. The assimilation window is 10 minutes for Bonnie B, and 30 minutes for other cases.

Table 1: Grid system and assimilation window.

Case	Resolution (km)	Dimension	Assim. window (min)
BonnieA	18	57x53x27	30
BonnieB	9	136x136x27	10
Felix	30	76x85x27	30
Opal	30	76x85x27	30

Table 2: Input parameters of Fujita's formula.

Case	Central Pressure (mb)	SLP at infinity distance (mb)	Radius of the max. SLP gradient (km)
BonnieA	954	1022	42
BonnieB	958	1016	40
Felix	963	1035	106
Opal	973	1030	124

The observed model parameters corresponding to TPC parameters are calculated and compared with each other.

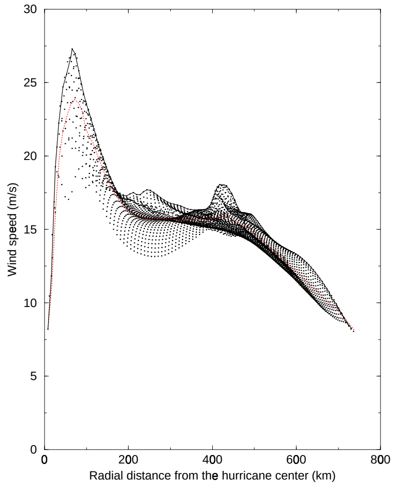

Figure 1: Radial wind profile of north-east quadrant of Bonnie B case. Thick and thin lines are the radial profile of the maximum and averaged wind speeds, respectively.

Figure 1 shows the horizontal wind speed with respect to the radial distance for all grid points in north east quadrant of Bonnie B. The wind data are divided into n subsets. The data, whose radial distance from the storm center is between $n$ds and (n-1)ds, belong to the nth subset. The radial profile of the maximum wind is defined as the set of the maximum wind of each subset. That is, we can get n data of the maximum wind from n subsets, and these n data construct the radial profiles (thick solid line). Wind data averaged in each subset are used to construct the radial profile of average wind (thin solid line).

The radial profile of the maximum and average wind profiles show similar a pattern. Thus, in this study the wind radii are determined from the profile of the maximum wind.

The outermost closed isobar can be estimated by using the radial profile of the minimum pressure, which is defined as the minimum pressure of each subset (similar to the construction of the radial profile of the maximum wind). The outermost closed isobar is assumed to be located where the gradient of the radial profile with respect to r is zero. Due to the discrepancy between the specified initial vortex and the environment field, there are usually several local maximum values in the profile. Thus the largest local maximum value, whose ratio between the longest and the shortest radius for a given value of an isobar is less than 2, is chosen as the value of the outermost closed isobar. The shortest and the longest radius are obtained from the radial profile of the minimum and the maximum pressure profile. The radius of the outermost closed isobar is calculated as (shortest R_{out}+longest R_{out})/2.

The numerical model has 27 vertical layers, and the data in the lowest 7 layers (below 850mb) are analyzed. All the parameters of each layer are calculated for the four quadrants, and the averaged values are shown in Tables 3 and 4.

The maximum wind speed and its radius are smaller than observations in all cases except the Opal case. Higher resolution seems to give better agreement with observations. Wind radii have larger errors than other parameters, but those of the Bonnie B case are very close to observations.

Table 3: Comparison of model and TPC observed parameters (BonnieA and BonnieB). Pressures are in mb and radii in km.

Case	BonnieA		BonnieB	
	Model	Obs.	Model	Obs.
P_c	954	953	961	955
P_{out}	1011	1009	1009	1009
R_{out}	553	420	360	370
V_{max}	40	51	23	51
R_{max}	40	46	38	46
R_{35kt} NE	358	324	187	278
R_{35kt} SE	374	324	243	278
R_{35kt} SW	414	185	182	185
R_{35kt} NW	200	278	255	278
R_{50kt} NE	164	185	70	139
R_{50kt} SE	163	185	56	139
R_{50kt} SW	235	139	xxx	139
R_{50kt} NW	127	139	xxx	139
R_{64kt} NE	76	139	xxx	74
R_{64kt} SE	93	139	xxx	74
R_{64kt} SW	79	74	xxx	74
R_{64kt} NW	96	74	xxx	74

3 EXPERIMENT DESIGN

Fujita's formula requires values of three input parameters, the central pressure, the pressure at infinite distance, and the radius of the maximum SLP gradient. The observed TPC parameters are the most useful information for the determination of these input parameters. The central pressure can be directly obtained from the observation. The radius of the maximum SLP gradient is determined from the radius of the observed maximum wind (R_{max}) based on the gradient wind relation. That is, the radius of the maximum gradient wind is assumed to be the radius of the observed maximum wind. Since we know the central pressure and the radius of the SLP maximum gradient, the pressure at an infinity distance is obtained by using the pressure value outside the radius of the outermost closed isobar.

Table 4: Comparison of model and TPC observed parameters (Felix and Opal).

Case	Felix		Opal	
	Model	Obs.	Model	Obs.
P_c	966	963	973	973
P_{out}	999	1010	1004	1008
R_{out}	280	550	499	194
V_{max}	34	36	20	33
R_{max}	121	167	297	74
R_{35kt} NE	577	463	297	370
R_{35kt} SE	747	463	398	278
R_{35kt} SW	455	324	553	278
R_{35kt} NW	464	324	490	278
R_{50kt} NE	425	278	xxx	167
R_{50kt} SE	434	278	xxx	93
R_{50kt} SW	205	231	482	93
R_{50kt} NW	321	231	178	93
R_{64kt} NE	228	222	xxx	56
R_{64kt} SE	227	139	xxx	56
R_{64kt} SW	xxx	46	469	56
R_{64kt} NW	xxx	46	xxx	56

The input parameters of Fujita's formula are obtained by using above method for Hurricane Bonnie at 12 UTC 23 August 1998. The central pressure, the radius of the maximum SLP gradient, and the pressure at infinity distance are 958mb, 34.3 km, and 1014.2mb respectively. BDA was performed in a 30 minute assimilation window.

4 RESULTS FROM BDA

After BDA, the location and the intensity are improved (Fig. 3). One of the interesting features of BDA is the wind field. Since the initial weak vortex is adjusted by BDA, the upper (lower) level wind becomes more divergent (convergent) after BDA (see Figure 3).

The model parameters corresponding to the TPC observed parameters, are calculated from BDA results. (Table 5). The model parameters are closer to the observations than previous BDA results.

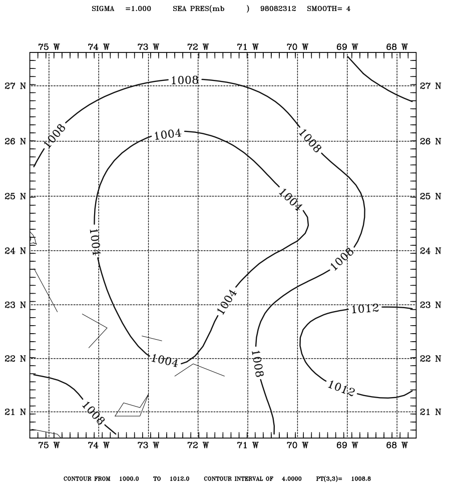

Figure 2: Sea level pressure before BDA.

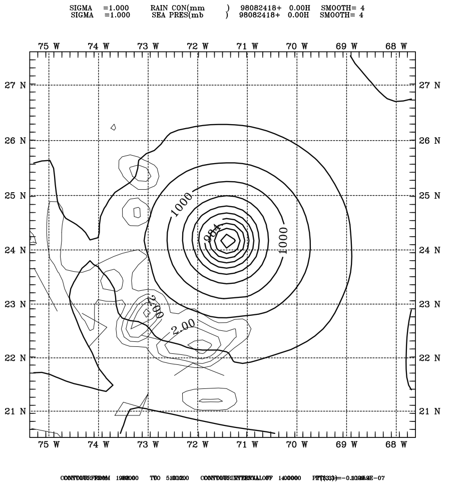

Figure 3: Sea level pressure (thick solid line) and the initial half-hour convective rainfall (thin solid line) after BDA.

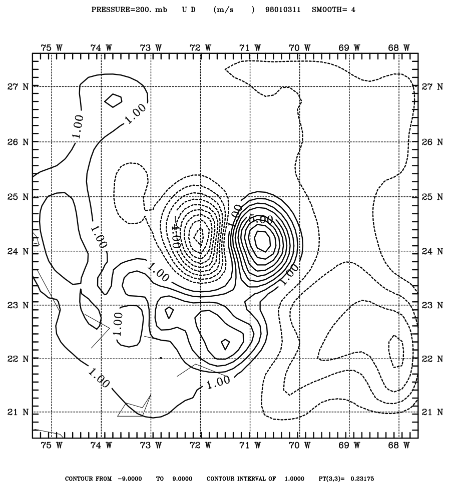

Figure 4: The adjustment in the zonal wind (Du).

Table 5: Comparison of model and TPC observed parameters (at t=0 and 30min).

	Model	Obs.
P_c	969	958
P_{out}	1009	1009
R_{out}	309	370
V_{max}	39	51
R_{max}	32	46
R_{35kt} NE	239	278
R_{35kt} SE	177	278
R_{35kt} SW	73	185
R_{35kt} NW	62	278
R_{50kt} NE	97	167
R_{50kt} SE	81	167
R_{50kt} SW	48	139
R_{50kt} NW	68	139
R_{64kt} NE	74	74
R_{64kt} SE	56	74
R_{64kt} SW	xxx	74
R_{64kt} NW	49	74

5 COMPARISON OF OBSERVED AND SIMULATED BRIGHTNESS TEMPERATURES

A fast and accurate four-stream radiative transfer model (RTM) is used to calculate TBs from model fields, i.e., pressure, temperature, and moisture variables. These calculated TBs are compared with observed TBs in an effort to better represent the initial state of the hurricane. The use of this particular RTM is beneficial in the data assimilation process because of its relative accuracy and inexpensive computational costs. This model makes use of a 4-stream scattering source term as well as a simplification to the Mie scattering phase function which drastically reduces the computational time relative to more complicated models, while adding an acceptable decrease in the accuracy of the calculated TBs (Liu 1998).

SSM/I TBs are helpful in hurricane initialization because of the ability of microwave radiation to penetrate non-precipitating clouds. Often upper level clouds shield hurricane structures in the lower layers to visible and infrared sensing instruments. However, microwaves are able to pass through these upper level clouds relatively unaltered so that features of the hurricane, such as the eye wall and rain bands, can be detected. Locating these structures is an essential part of the initialization process.

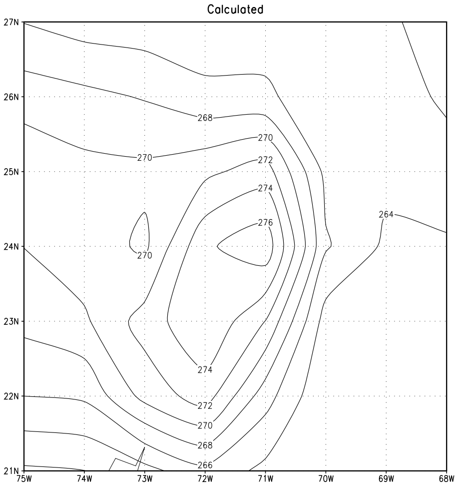

Figure 5: Simulated TBs for 12 UTC August 23, 1998 at 85 GHz.

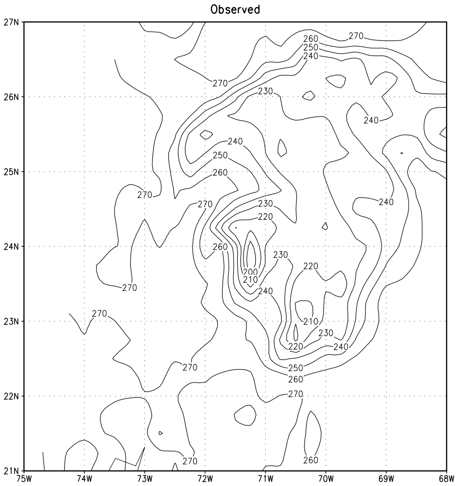

Figure 6: Observed TBs for 12 UTC August 23, 1998 at 85 GHz.

Figures 5 and 6 show the calculated and observed TBs at 12 UTC Aug 23, 1998 at 85 GHz (horizontal polarization). The 85 GHz channel is unique because microwaves at this frequency come from both the emission from liquid water scattering from ice particles. Whereas, at other frequencies emission creates a warmer scene than the surrounding oceans, the scattering at 85 GHz acts to cool the scene. The figure shows that the model derived TBs are much warmer than the observations at this frequency. The colder areas in the observations are due to the formation of ice in the areas of deep convection that causes scattering (see Fig. 3). The simulated TBs didn't capture these features. This could be attributed to the zero ice input to the radiative tranfer model. It is suggested that the forecast model constraint used in the hurricane initialization scheme include the ice variable to which the TBs at 85 GHz channel are most sensitive.

Errors associated with the observed and calculated TBs must be considered for the direct assimilation of TBs. The root mean square (RMS) error for the observed TBs is roughly 1 K for each channel. While the RMS error associated with the RTM is 5 K for the 85 GHz channels and 3 K for all other channels (Liu 1998). Any bias between the observations and the RTM can be removed by comparing values over clear-sky ocean scences.

6 CONCLUSIONS

The BDA generated an initial vortex which compared favorably with the observed parameters from TPC for hurricane Bonnie. The model prediction from this initial vortex produced an initial convective rainfall on the west side of the hurricane, consistent with the TB observations from the SSM/I. However, quantitative agreement between simulated and observed TBs is still rather poor. Further refinement of the BDA scheme and/or direct assimilation of SSM/I brightness temperatures within the BDA framework may produce a more realistic initial vortex and thus an improved prediction of Hurricane Bonnie. These results will be presented at the conference.

Acknowledgment

The first author is supported by the Office of Naval Research under the project N00014-99-1-0022, and the second author is supported by the National Science Foundation under the project ATM-9908939.

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