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USING THE COAMPS^{TM*} ADJOINT MODELING SYSTEM TO FORECAST A TROPICAL CYCLONE

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1 INTRODUCTION

The Coupled Ocean-Atmosphere Mesoscale Prediction System (COAMPS) was developed by the Naval Research Laboratory (Hodur 1997) for prediction of atmospheric phenomena on scales as small as a few meters to as large as hundreds of kilometers. Hong et al. (2000) and Liu et al. (2002) have utilized the COAMPS model in the prediction of tropical cyclones. In Hong et al. (2000) the COAMPS atmospheric component was linked to an ocean model to study the interaction between Hurricane Opal (1995) and a warm core ring in the Gulf of Mexico. The atmospheric initial condition was obtained from a multivariate optimum interpolation (MVOI) procedure performed on the Navy Operational Global Atmosphere System (NOGAPS) analysis field. Before the MVOI procedure, an initial bogus vortex representing the circulation of Opal was inserted in the analysis field. The forecasts which resulted from this experiment compared quite well with observations of the track and intensity of Opal. However, the point was also made that a number of different initial bogus vortices were examined and each resulted in a different intensity forecast. Furthermore, no discernible relationship between the specified initial intensity and the forecasted maximum intensity could be obtained.

Liu et al. (2002) utilized the COAMPS atmospheric model to investigate the orographic influences on rainfall and tropical cyclone track deflection associated with the passage of Supertyphoon Bilis (2000) over the Central Mountain Range of Tawain. As in Hong et al. (2000), the initial condition was obtained by performing an MVOI procedure on the NOGAPS analysis field, except that an initial bogus vortex was not inserted in the NOGAPS analysis. The forecasts produced from this analysis followed the observed track of Bilis well, but were poor in terms of intensity as the forecasted storm was always much weaker than the observed storm.

The goal of this study is to use the Bogus Data Assimilation (BDA) procedure (Zou and Xiao 2000; Xiao et al. 2000; Zou et al. 2001; Park and Zou 2003) to objectively produce an initial vortex for the COAMPS model that will lead to improved tropical cyclone track and intensity forecasts. In order to apply the BDA procedure with the COAMPS model, the tangent linear and adjoint of the COAMPS atmospheric model were developed, as was a 4D-Var assimilation system utilizing the adjoint COAMPS model.

2 MODELING SYSTEM

2.1 COAMPS Adjoint Modeling System

An adjoint modeling system based on the COAMPS atmospheric model is currently under development at Florida State University. The tangent linear and adjoint models based on the dynamical core and turbulent kinetic energy (TKE) parameterization scheme of the COAMPS atmospheric model have been developed and tested for correctness in multiprocessor distributed memory computing environments. For more information on how these models are tested see Zou et. al. 1997. The tangent linear and adjoint models of the COAMPS moisture microphysics scheme have also been developed and tested using the Tangent Linear and Adjoint Model Compiler (Giering and Kaminski 1998) and will soon be incorporated into the modeling system. In addition to the tools mentioned above, a limited memory quasi-Newton minimization software package (the LBFGS algorithm, Liu and Nocedal 1989) has also been included in the system so that 4-dimensional variational (4D-Var) minimization experiments can be conducted.

2.2 BDA

In the BDA scheme, a bogus SLP field is assimilated as an observational field in a short assimilation window in a four-dimensional variational 4D-Var assimilation framework. The resulting analysis produces

[*] COAMPS^{TM} is a trademark of the Naval Research Laboratory

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a more realistic tropical cyclone structure in all model fields than the original analysis procedure did (Zou and Xiao 2000). In the BDA scheme, Fujita's formula (1952) is used to compute the SLP field,

$$P_{bogus}(r) = P_\infty - \frac{(P_\infty - P_c)}{(1 + (\frac{r}{2R_0^2}))^{1/2}}, \qquad r \leq R_{out} \quad (1)$$

where P_c and P_∞ are the central SLP and an estimation of the SLP at an infinite distance, respectively, R_{out} is the radius of the outermost closed isobar, and R_0 is the radius of the maximum gradient of the SLP. The bogus SLP field is confined to a circular region specified by R_{out}. The values of P_c and R_{out} can be taken directly from observations recorded by the the National Oceanographic and Atmospheric Administration's Tropical Prediction Center (TPC). R_0 is determined from an empirical formula provided by Park and Zou (2003),

$$R_0 = 0.37R_{34kt} + 1.9 \quad (2)$$

where R_{34kt} is the averaged 34 kt wind radius (an observed parameter provided by the TPC). The value of P_∞ can then be estimated by solving (1) for P_∞ and setting r to R_{out} and P_{bogus} to P_{out} (P_{out} is the pressure of the outermost closed isobar, another TPC observed parameter). Equation 1 can then be rewritten as

$$P_\infty = \frac{P_{out}(R_{out})(1 + (R_{out}/R_0^2))^{1/2} - P_c}{((R_{out}/R_0^2) - 1)^{1/2}}. \quad (3)$$

Until now, the BDA scheme had been used exclusively with the MM5 Adjoint Modeling System. Now it also available with the COAMPS Adjoint Modeling System. Results from COAMPS hurricane forecasts initialized with the BDA procedure will be presented at the conference. The next section contains some preliminary results of this study.

3 PRELIMINARY RESULTS

To date the COAMPS adjoint modeling system has only one physics package available for BDA experiments, the TKE parameterization scheme. Previous studies involving the BDA scheme have conducted the minimization procedure with a cumulus parameterization as well as a parameterization that deals with the physics of the planetary boundary layer (PBL). However, we propose, that performing the minimization with only a PBL (MM5) or TKE (COAMPS) scheme will be adequate. To test this, two BDA experiments were conducted with the MM5 for Hurricane Bonnie (1998), one with both a cumulus and a PBL scheme turned on (APHY), and the other one with a PBL scheme turned on, but with the cumulus scheme as well as all other physical parameterizations turned off (1PHY). For both of the resulting analyses, a forecast was conducted to see how the lack of a cumulus parameterization in the analysis scheme effects the forecast. The forecasts were performed on a grid with 6 km horizontal spacing. The physics options for both forecasts were identical. Figure 1 shows the 24 hr forecast of SLP for both experiments. The difference in the minimum central SLP is 8 mb between the two forecasts, which is within the forecast uncertainty of central SLP for a hurricane. In fact, the observed central SLP at the forecast time was 962 mb, meaning the 1PHY forecast (957 mb) was better in terms of intensity. The centers of both forecasted hurricanes were close to one another, but the center of the APHY forecast was slightly closer to the observed center of Bonnie, giving it a better track forecast. From these results, we are confident that using the BDA scheme with the COAMPS Adjoint Modeling System with only the TKE parameterization scheme will produce satisfactory forecasts. Results from the COAMPS system will be presented at the conference.

4 FUTURE WORK

In addition to the continuing system development mentioned above, we also plan to test the effectiveness of incorporating different types of observations into the assimilation scheme. Specifically, we hope to directly assimilate Special Sensor Microwave/Imager (SSM/I) brightness temperatures in a hurricane environment using the COAMPS Adjoint Modeling System. With the recent development of the adjoint of a radiative transfer model which can be used in areas of precipitation (Amerault and Zou 2003) along with the adjoint of the complex COAMPS moisture micorphysics scheme, assimilation of SSM/I brightness temperatures is possible in rainy environments; whereas, previously such observations had mainly been assimilated in clear atmospheric conditions surrounding areas of disturbed weather. The ability to directly assimilate such observations will hopefully lead to improved hurricane forecasts.

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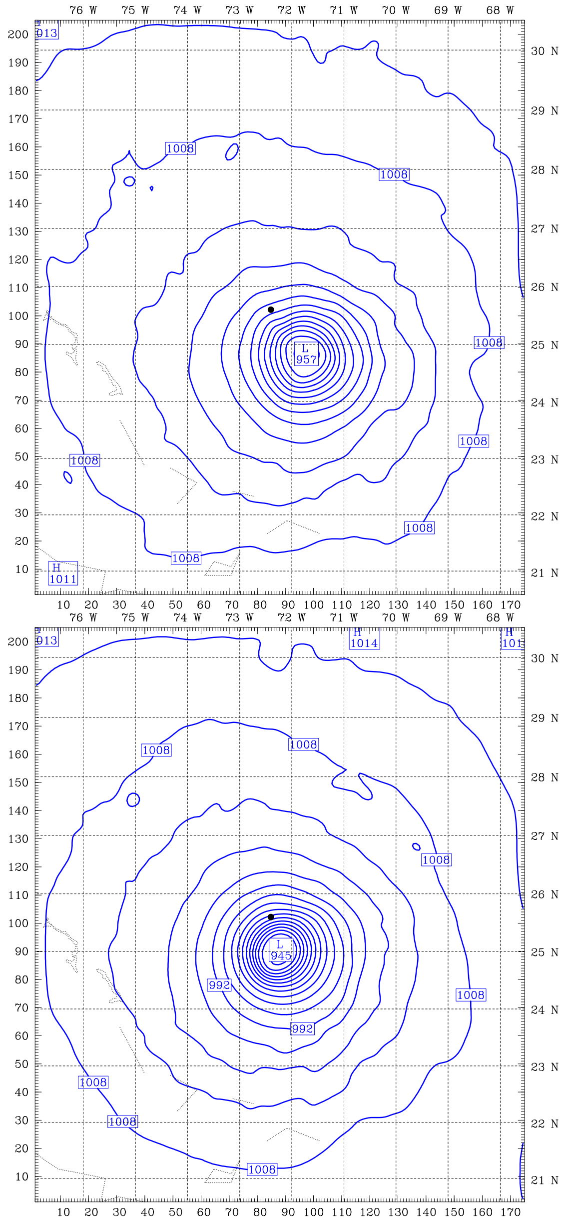

Figure 1: 24 hr forecast of SLP for Hurricane Bonnie valid at 1200 UTC August 1998. The filled circle indicates the observed center of Bonnie. The top panel is a forecast result from a BDA analysis in which no cumulus parameterization was used, the bottom panel is the resulting forecast when the cumulus parameterization is added.

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