Development of the COAMPS™[1] Adjoint Modeling System and Its Application to Storm Initialization Using SSM/I Observations

Xiaolei Zou
Dept. of Meteorology, Florida State University
404 Love Building, Tallahassee, FL 32306-4520
phone: (850) 644-6025 fax: (850) 644-9642 email: zou@met.fsu.edu

Award number: N000140110375

LONG-TERM GOALS

Our long-term goal is to develop a 4-dimensional variational (4D-Var) data assimilation system using the COAMPS™ (Coupled Ocean/Atmosphere Mesoscale Prediction System) atmospheric model, which could be used for many applications in mesoscale numerical weather prediction. Once completed, the system can be used to assess the impact of remote-sensing observations (e.g., SSM/I (Special Sensor Microwave/Imager) microwave radiances and QSCAT (QuikSCAT) surface winds) on mesoscale and storm-scale prediction. Adjoint sensitivity studies can also be conducted with this system in analyzing model forecasts. The system can potentially be used operationally at the Naval Research Laboratory (NRL) if there is an appropriate level of computing power available.

OBJECTIVES

1. This ONR-related research focuses on three primary objectives:
2. Developing the COAMPS™ Adjoint Modeling System, which includes a 4D-Var data assimilation system component, - an effective, well-documented and user-friendly adjoint modeling system using the COAMPS™ atmospheric model,
3. Applying the new system (once it is fully developed) to hurricane initialization using TPC (Tropical Prediction Center) observed parameters, and
4. Assimilating SSM/I brightness temperature observations in a hurricane initialization scheme using the COAMPS™ 4D-Var system.

APPROACH

The technical approach involves conducting 4D-Var data assimilation experiments and adjoint sensitivity studies with the COAMPS™ atmospheric model, as well as a radiative transfer model (RTM), which calculates brightness temperatures from COAMPS™ model data. The 4D-Var experiments assess the impact of various types of data on weather prediction while the adjoint sensitivity calculations provide insights into the key components for model prediction.

Dr. Xiaolei Zou, Dr. Qiang Zhao, Mr. Zheng Yang, and Mr. Clark Amerault have all worked on the development of the COAMPS™ tangent linear and adjoint models, which includes both coding and testing. Furthermore, Clark Amerault has developed the tangent linear and adjoint models of a fast RTM, and performed an analysis of the numerical results of the model.

[1] COAMPS™ is a trademark of the Naval Research Laboratory

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
30 SEP 2003		**00-00-2003 to 00-00-2003**

4. TITLE AND SUBTITLE	
Development of the COAMPSâ ¢1 Adjoint Modeling System and Its Application to Storm Initialization Using SSM/I Observations	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Dept. of Meteorology, Florida State University,,404 Love Building,,Tallahassee,,FL,32306**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Our long-term goal is to develop a 4-dimensional variational (4D-Var) data assimilation system using the COAMPS??? (Coupled Ocean/Atmosphere Mesoscale Prediction System) atmospheric model, which could be used for many applications in mesoscale numerical weather prediction. Once completed, the system can be used to assess the impact of remote-sensing observations (e.g., SSM/I (Special Sensor Microwave/Imager) microwave radiances and QSCAT (QuikSCAT) surface winds) on mesoscale and storm-scale prediction. Adjoint sensitivity studies can also be conducted with this system in analyzing model forecasts. The system can potentially be used operationally at the Naval Research Laboratory (NRL) if there is an appropriate level of computing power available.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a REPORT	b ABSTRACT	c THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**4**	

WORK COMPLETED

The tangent linear and adjoint models of the dynamical core and parameterization scheme for the planetary boundary layer (PBL) of the COAMPS™ atmospheric model have been developed and tested. Furthermore, both the tangent linear and adjoint models have been verified for correctness on multiple processors, meaning these models can function in a highly scalable distributed memory-computing environment.

At the request of researchers at NRL, the tangent linear and adjoint models of the newest explicit moisture scheme in the COAMPS™ atmospheric model has been developed and tested. Work is ongoing to update our original version of the COAMPS™ system to include this new scheme in the original forward nonlinear model, as well as the tangent linear and adjoint atmospheric models.

Also, the tangent linear and adjoint models of a fast RTM have been written and verified for correctness. An adjoint sensitivity study was conducted to determine which input variables to the RTM have the largest effect on the calculated brightness temperature. The errors associated with some of the simplifications in the model were also quantified. These are all steps, which are important in assimilating SSM/I brightness temperatures in a hurricane initialization scheme.

RESULTS

In developing the parallel and scalable tangent linear and adjoint COAMPS™ models, several important considerations arose during the code development. In a 4D-Var system the forecast model is run forward in time and the output at each time step is written to a disk. The adjoint model then runs backward in time reading in the output from the forecast model at the corresponding time step. For a multiple processor environment, the I/O (input/output) operations become a concern. Even though the 4D-Var system has not been completed, these I/O operations were needed when verifying the correctness of the adjoint COAMPS™. For our purposes, each processor wrote out its own portion of the forecast domain in the forward model to a separate file, which was then read by the same processor when it was running the adjoint model backwards for the same portion of the forecast domain. However, this may not be the most efficient method of I/O and may need to be altered in the future. For example, Ruggiero et al. (2001) wrote all the data for the entire forecast domain to a single file during the forward model execution in their scalable 4D-Var system which was based on another mesoscale model. In addition to the I/O considerations, the difference in communication between processors in the forecast and adjoint models was also an important issue. This meant that the adjoint of the communication routines had to be written. If, for example, processor A sent information to processor B in the forward model, then in the adjoint model the communication of information has to be from processor B to processor A.

Furthermore, the benefit of using an automatic tangent linear and adjoint code generator was realized in the development of tangent linear and adjoint of the COAMPS™ explicit moisture scheme. The newest scheme developed by researchers at NRL contains on the order of a few thousand lines of code which estimates the source and sink terms of cloud droplets, rain, ice crystals, snowflakes, and graupel particles. Writing the tangent linear and adjoint routines for this scheme by hand would take many man-hours. However, to accomplish this task, we experimented with the Tangent Linear and Adjoint Model Compiler (TAMC, Giering 1998) and found it to be very effective in generating correct tangent linear and adjoint code. The use of this tool has saved many hours that would have been spent writing computer code. We are currently updating our version of the COAMPS™ forecast model to include this newest parameterization scheme. Once completed, the adjoint and tangent linear code of the dynamical core as well as the PBL and explicit moisture schemes of the model will all be part of the COAMPS™ adjoint modeling system. Furthermore, because TAMC has proven to be an effective tool, it could be used to add additional schemes to the system should the need arise with minimal man-hours required for coding.

Finally, work has also been performed to improve the performance of the RTM. In a study published by Amerault and Zou (2003), the brightness temperatures produced by the RTM used in this effort tended to be unrealistically low in areas of high ice production by the numerical weather prediction (NWP) model. The difference in the brightness temperature between the model and the observations was as great 100 K in the 85 GHz channels. The magnitude of these differences had to be reduced in order for the RTM to be used effectively in a data assimilation scheme. By including the Maxwell-Garnet mixing formula in the calculation of the dielectric function for ice-air mixtures, the discrepancy between the model and the observations was significantly reduced. Further improvements were realized when values for certain microphysical parameters were given the same value in both the RTM and the NWP model. Figure 1 below shows brightness temperatures from Hurricane Bonnie calculated from the RTM (left) using NWP model data as input and observed by the SSM/I (right) at 00 UTC 25 August 1998 over the tropical Atlantic Ocean. The difference now between the lowest observed and calculated brightness temperature is about 20 K.

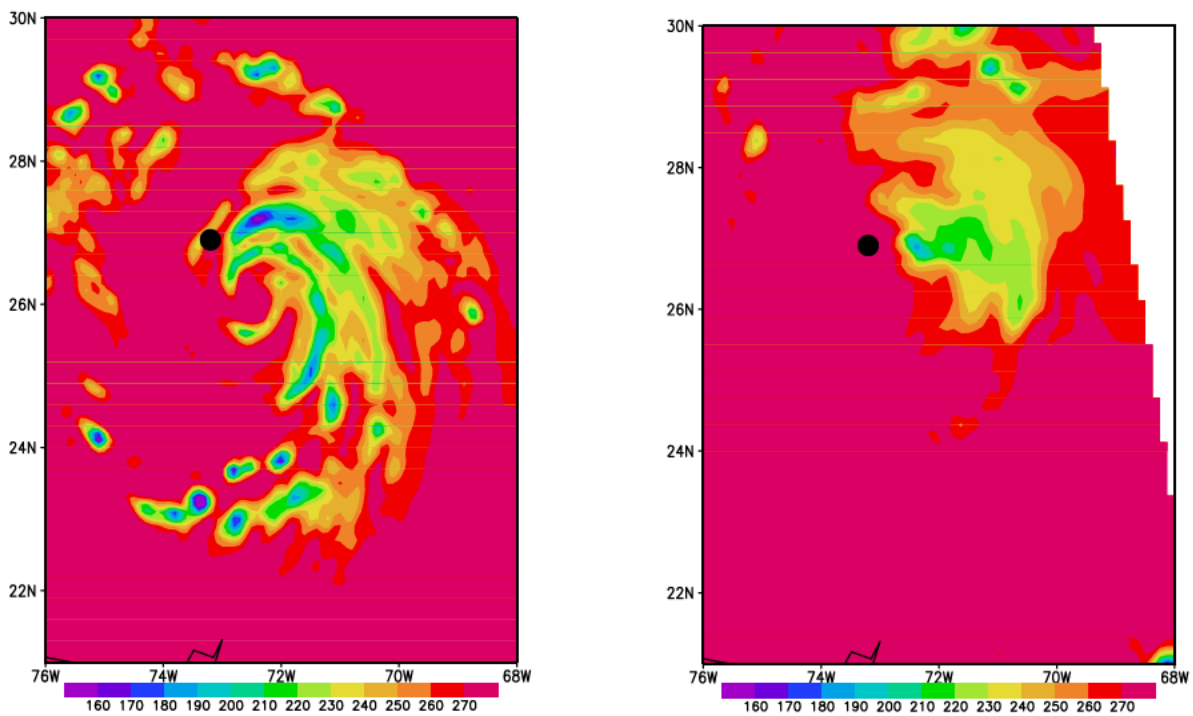

Figure 1. Calculated (left) and SSM/I observed (right) 85 GHz (vertical polarization) brightness temperatures for Hurricane Bonnie at 00 UTC 25 August 1998. The black circle is located at the observed center of Hurricane Bonnie.
[The difference between the lowest calculated and observed brightness temperature is roughly 20 K]

IMPACT/APPLICATIONS

The COAMPS™ 4D-Var system is expected to improve mesoscale weather prediction using the COAMPS™ atmospheric model and observations, both conventional and non-conventional. Assimilation of SSM/I brightness temperatures will be possible within weather disturbances such as hurricanes, not just rain-free areas, using the adjoint RTM developed from this work. These advancements will hopefully lead to improved hurricane track and intensity forecasts as well as improved skill of prediction of other weather phenomena.

RELATED PROJECTS

"Impact of radar, satellite and targeted *in situ* data on hurricane forecasts near landfall," funded by NSF-USWRP under the project number ATM-9908939.

REFERENCES

Giering R., and T. Kaminski, 1998: "Recipes for adjoint code construction." *ACM Trans. On Math Software*, 24, 437-474.

Ruggiero, F., G. Modica, T. Nehrkorn, M. Cerniglia, J. Michalakes, and X. Zou, 2001: "Development of an MM5-based four-dimensional variational analysis system for distributed memory multiprocessor computers. *Preprints, HPCMP 2001 User's Group Conference*. Biloxi, MS, June 18-22 2001.

PUBLICATIONS

Amerault C., and X. Zou, 2003: "Preliminary steps in assimilating SSM/I brightness temperatures in a hurricane prediction scheme." *J. Atmos. Ocean. Tech.*, 20, 1154-1169. [published, refereed]

Amerault C., and X. Zou, 2003: "Using the COAMPS™ adjoint modeling system to forecast a tropical cyclone." *20th Conference on Weather Analysis and Forecasting/16th Conference on Numerical Weather Prediction*. Seattle, Washington. [submitted, non-refereed]

Amerault C., and X. Zou, 2003: "Evaluating the performance of explicit moisture schemes using satellite microwave radiances in the prediction of a tropical cyclone." *Eighth Symposium on Integrated Observing and Assimilation Systems for Atmosphere, Oceans, and Land Surface*. Seattle, Washington. [submitted, non-refereed]

Amerault, C., Y. Zheng, and X. Zou: 2003. User's Guide to the COAMPS™ Adjoint Modeling System. *Data Assimilation Group Tech Note*. 20 pp. [published, non-refereed]