Initialization of Tropical Cyclone Structure for Operational Application

PI: Tim Li
IPRC/SOEST, University of Hawaii at Manoa
1680 East-West Road, POST Building 409B
Honolulu, Hawaii 96822
Phone: (808) 956-9427, fax: (808) 956-9425, e-mail: timli@hawaii.edu

Co-PI: Melinda S. Peng
Naval Research Laboratory
Monterey, CA 93943-5502
Phone: (831) 656-4704, fax: (831) 656-4769, e-mail: melinda.peng@nrlmry.navy.mil

Award Number: N000141010774

LONG-TERM GOAL

The long-term goal of this project is to improve the prediction of tropical cyclone (TC) genesis, structure and intensity changes through improved representation of 3-dimensional TC structure at the initial time. The accurate prediction of TC genesis, structure and intensity changes is critical to Navy missions and civilian activities in coastal areas. Significant gains have been made in the TC track prediction over the past decades. The genesis and intensity forecast, however, has shown very little progress during the same period. A main factor contributing to lack of skill in the prediction of TC genesis and intensity is the inadequate representation of initial axisymmetric and asymmetric TC dynamic and thermodynamic structures. TC initialization is a universal problem in nearly all current operational weather forecast systems, as indicated in a recent HFIP workshop. By conducting both idealized Observation System Simulation Experiments (OSSE) and real-case TC forecast experiments, we intend to tackle the weaknesses faced in current operational weather forecast models.

OBJECTIVE

The objective of this project is to develop a new initialization scheme to improve the representation of 3-dimensional TC structures in operational weather forecast models.

APPROACH

We propose a combined TC dynamic initialization-3DVar data assimilation approach. The key component of this new scheme is a TC dynamic initialization (TCDI) package. The TCDI package includes three steps. The first step is the decomposition of the TC vortex from its environmental field. The second step is a dynamic initialization with the full nonlinear dynamics and physics, which forces the first guess field toward the observed central minimum pressure, given realistic asymmetric heating profiles. The third step is to add the newly generated TC field into the environmental field and used it

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2012**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Initialization of Tropical Cyclone Structure for Operational Application**	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) **IPRC/SOEST, University of Hawaii at Manoa 1680 East-West Road, POST Building 409B Honolulu, Hawaii 96822**	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
The original document contains color images.

14. ABSTRACT

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**	**SAR**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

in the subsequent 3DVar assimilation. After the TCDI is completed, the 3Dvar assimilation further follows. A preliminary OSSE study was conducted and the result showed that this new approach greatly improved both TC symmetric (such as TC intensity and warm core structure) and asymmetric dynamic and thermodynamic patterns.

WORK COMPLETED

Observation System Simulation Experiments with aid of the NCAR WRF model and its 3DVAR assimilation system have been done to demonstrate the usefulness of the combined TC dynamic initialization-3DVar scheme. A manuscript entitled "A 3DVAR-based Dynamical Initialization Scheme for Tropical Cyclone Predictions" was published in 2012 in the AMS journal *Weather and Forecasting*.

Collaborated with NRL scientists (Dr. Eric Hendricks, Dr. Melinda Peng), we have implemented this new initialization strategy to the Navy operational TC forecast model, COAMPS-TC. A test run with either a cold start or a warm start for 2008-2009 summer TCs has been conducted and the result shows that the new methodology improved TC intensity forecast skill.

RESULTS

1. A 3DVAR-based Dynamical Initialization Scheme for Tropical Cyclone Predictions

A combined three-dimensional variational assimilation/tropical cyclone dynamic initialization scheme (3DVAR/TCDI) is proposed. The specific procedure for the new initialization scheme is described as follows. Firstly, a first-guess vortex field derived from a global analysis will be spin up in a full-physics mesoscale regional model in a quiescent environment. During the spin-up period, the weak vortex is forced toward the observed central minimum sea-level pressure (MSLP). The so-generated balanced TC vortex with realistic MSLP and warm core is then merged into the environmental field and used in the subsequent 3DVAR data assimilation.

The observation system simulation experiments (OSSE) demonstrate that this new TC initialization scheme leads to a much improved initial MSLP, warm core and asymmetric temperature patterns, compared to that from the conventional 3DVAR scheme.

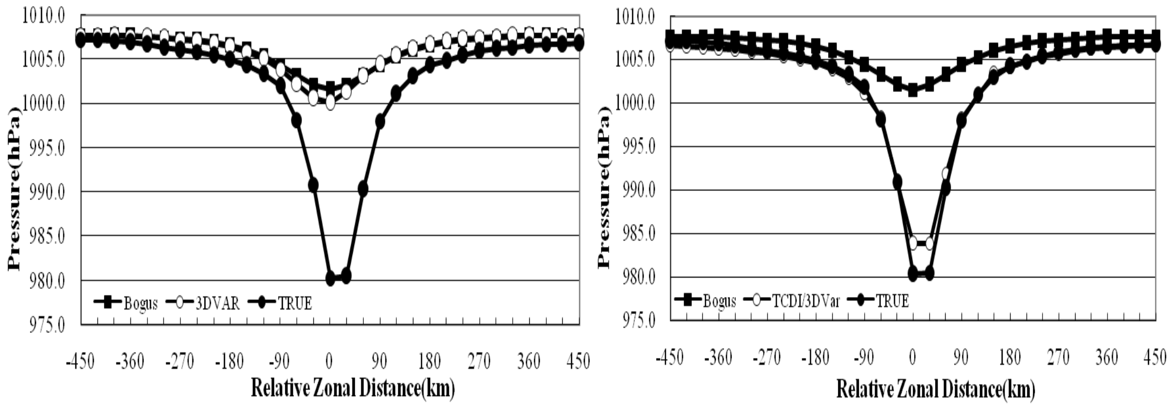

Fig. 1 Zonal profiles of the surface pressure across the vortex center derived from the first guess (close square), the conventional 3DVAR scheme (open circle in the left panel), the new TC initialization scheme (open circle in the right panel), and the "observation"(close circle).

The left panel of Figure 1 shows the result using the conventional 3DVAR assimilation. Comparing with the "observations", we note that the winds are in general well assimilated. For the temperature profile, however, both the pattern and amplitude of the warm core have serious errors. The warm core in the upper level is less than a half of the "observed" magnitude, and the warm core is split into two centers, one in the upper troposphere at 250 hPa and the other in the lower troposphere around 800 hPa. The assimilated geopotential height also is much weaker. Accompanying the large temperature and geopotential biases is the much weaker sea-level pressure. The assimilated MSLP is 1000 hPa, which is very close to the first-guess value (left panel, Fig. 1).

A marked difference appears in the assimilated surface pressure field using the new approach, as shown in the right panel of Fig. 1. The assimilated MSLP is now 983 hPa, much closer to the "observed" MSLP value. In addition, the combined TCDI/3DVAR initialization scheme also significantly improves initial TC dynamic and thermodynamic structures, compared to the conventional 3DVAR scheme.

A forecast of TC intensity with the new initialization scheme is further conducted, and the result shows that the new scheme is able to predict the "observed" evolution of TC intensity, compared to runs with the conventional 3DVAR scheme. Sensitivity experiments further show that the intensity forecast with the knowledge of initial MSLP and wind fields appears more skillful than the case when the knowledge of initial MSLP, temperature and humidity fields are known. The numerical experiments above demonstrate the potential usefulness of the proposed new initialization scheme in the operational application.

2. Application of the new initialization scheme to COAMPS 2008-2009 TC forecast

A dynamic initialization scheme for tropical cyclone structure and intensity in numerical prediction systems is tested. The procedure involves the removal of the analyzed vortex, and then insertion of a new vortex which is dynamically initialized to the observed surface pressure, into the numerical model initial conditions. This new vortex has the potential to be more balanced, and to have a more realistic boundary layer structure than by adding synthetic data to represent the tropical cyclone in a model. The dynamic initialization scheme was tested on multiple tropical cyclones during the 2008 and 2009 hurricane seasons in the North Atlantic and Western North Pacific basins using the Navy tropical cyclone version of the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS-TC). The use of this initialization procedure yielded significant improvements in intensity forecasts (Hendricks et al. 2011). Mean absolute errors in the maximum sustained surface wind were reduced by approximately 5 knots for all lead times up to 72 h. The primary reason for the reduction in intensity error is due to the TC vortex being initialized very close to the best track intensity. Meanwhile, the dynamic initialization method also produces a self-consistent, balanced vortex, with realistic boundary and outflow layers, potentially helping to improve the TC forecast.

3. Dependence of tropical cyclone intensification on the Coriolis parameter

The dependence of tropical cyclone (TC) intensification on the Coriolis parameter was investigated in an idealized hurricane model. By specifying an initial balanced vortex on an *f* plane, we observed faster TC development under lower planetary vorticity environment than under higher planetary vorticity environment. The time evolutions of the center minimum sea level pressure (CMSLP) and maximum tangential winds (V_{max}) in the eight experiments are shown Fig. 2. In all the experiments, the initial weak vortex develops into the typhoon strength within 5 days. Note that, however, the timing of rapid intensification depends on the Coriolis parameter. The rapid intensification is referred to as the rapid drop of CMSLP or rapid increase of maximum tangential wind. TC develops earlier under lower planetary vorticity environment than under planetary vorticity environment. For instance, the CMSLP starts to drop rapidly shortly after hour 24 in the F05 experiment, and it reaches a quasi-steady state around hour 60. As the Coriolis parameter value increases, the timing of RI is delayed. For instance, the RI of TC in F30 starts after hour 48 and reaches a mature state after hour 84.

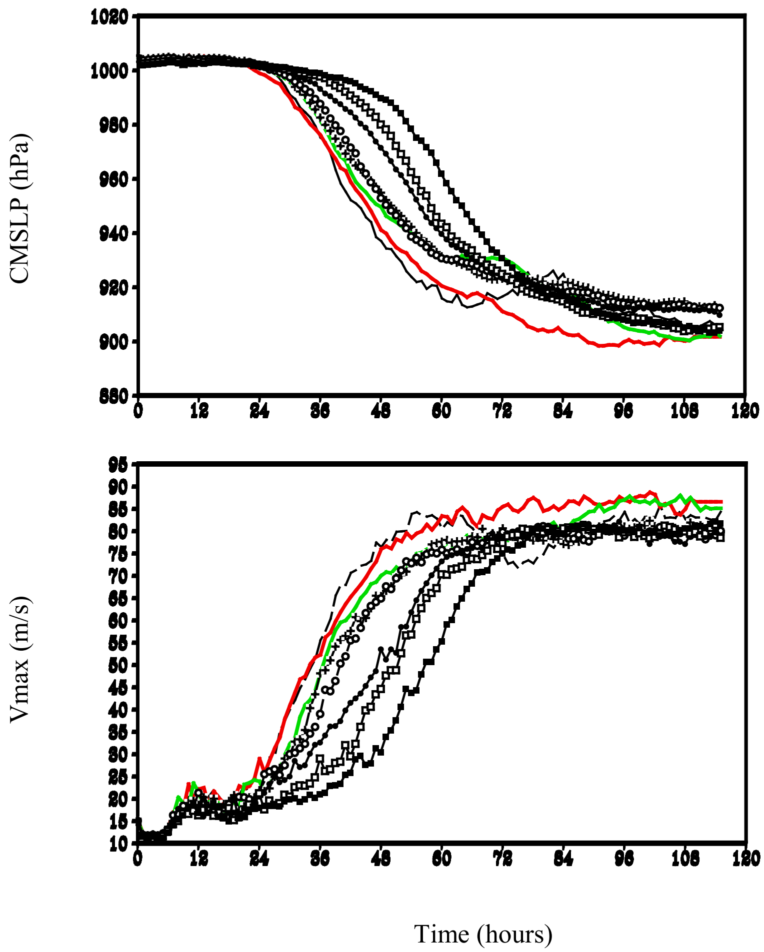

Fig. 2 Time evolution of the center minimum sea level pressure (unit: hPa, top panel) and V_{max} (unit: ms^{-1}; bottom panel) in F05 (f at 5N, dashed), F075 (f at 7.5N, red), F10 (f at 10N, green), F125 (f at 12.5N, solid curve with plus mark), F15 (f at 15N, open circle), F20 (f at 20N, filled circle), F25 (f at 25N, open square) and F30 (f at 30N, filled square).

The diagnosis of the model outputs indicates that the distinctive evolution characteristics arise from the extent to which the boundary layer imbalance is formed and maintained in the presence of surface friction. Under lower planetary vorticity environment, stronger and deeper sub-gradient inflow develops due to Ekman pumping effect, which leads to greater boundary layer moisture convergence and condensational heating. The strengthened heating further accelerates the inflow by lowing central pressure further. This positive feedback loop eventually leads to distinctive evolution characteristics.

The outer size (represented by the radius of gale-force wind) and the eye of the final TC state also depend on the Coriolis parameter. TC tends to have larger (smaller) outer size and eye under higher (lower) planetary vorticity environment. Whereas the radius of maximum wind or the eye size in the current setting is primarily determined by inertial stability, the TC outer size is mainly controlled by environmental absolute angular momentum.

IMPACT/APPLICATIONS

The improved representation of initial TC state may lead to a more skillful prediction of TC genesis and intensity change.

TRANSITIONS

The proposed TC initialization scheme has been transferred to NRL for intensive offline test using the NOGAPS and COAMPS-TC models. Once proved to be useful, the TC dynamic initialization scheme will be transitioned into the navy operational systems.

RELATED PROJECTS

This project is complimentary to the ONR funding entitled "Analysis and high-resolution modeling of tropical cyclone genesis during the TCS-08 field campaign" in which we investigate the dynamics of TC genesis using a cloud resolving model and conduct western Pacific TC reanalysis during the period of TCS-08 observational campaign.

PUBLICATIONS

The following are papers that are partially or fully supported by this grant:

Hendricks, E.A., M. S. Peng, X. Ge, and T. Li, 2011: Performance of a Dynamic Initialization Scheme in the Coupled Ocean Atmosphere Mesoscale Prediction System for Tropical Cyclones (COAMPS-TC). *Wea. Forecasting*, **26**, 650–663.

Li, T., 2012: Synoptic and climatic aspects of tropical cyclogenesis in western North Pacific. in *Cyclones: Formation, triggers and control, edited by K. Oouchi and H. Fudevasu, Noval Science Publishers*, in press.

Li, T., X. Ge, M. Peng, and W. Wang, 2012: Dependence of tropical cyclone intensification on the Coriolis parameter. *Tropical Cyclone Research and Review*, 1 (2), 242-253, doi:10.6057/2012TCRR02.04.

Zhang, S.-J., T. Li, X. Ge, M. Peng and N. Pan, 2012: A 3DVAR-based Dynamical Initialization Scheme for Tropical Cyclone Predictions. *Wea. Forecasting*, 27, 473-483.