Initialization, prediction and diagnosis of the rapid intensification of tropical cyclones using the Australian Community Climate and Earth System Simulator, ACCESS

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Award Number: N000141010139
http://www.cawcr.gov.au. Address of the site(s) most closely related to this effort

LONG-TERM GOALS

The Bureau of Meteorology has recently shifted to using ACCESS (the Australian Community Climate and Earth Simulation System), which is based around the assimilation and prediction systems from the U.K. MetOffice, as its numerical weather prediction system for operations and research. A re-locatable run-on-demand version specifically for tropical cyclones (ACCESS-TC) has been developed and is presently in transition to operations, where it will join the already operational global, regional, tropical and mesoscale versions. The goals for ACCESS-TC are to: (i) support operational TC forecasting in the Australian region, (ii) support tropical cyclone research within Australia, and (iii) support operational TC forecasting in neighbouring states such as Fiji and the Philippines. ACCESS-TC features a state-of-the science atmospheric model, several options for vortex specification, and is one of the very few tropical cyclone NWP systems worldwide to utilize 4D-Var assimilation.

OBJECTIVES

(a) To develop and apply ACCESS-based numerical systems to perform nested, high-resolution data assimilation, initialization and forecast experiments for rapid and slow intensification events.

(b) To use the outcomes from (a) to investigate assimilation, prediction and dynamics of environmental influences and internal structure change during rapid intensification events.

(c) To explore advanced hybrid ensemble-4DVAR data assimilation techniques to better initialize and validate TC structures (including the intense inner core and storm asymmetries) consistent with the large scale environment (LSE) of TCs.

(d) To use sensitivity experiments and ensemble techniques to (i) understand the variability in simulations of RI, and (ii) estimate the highly anisotropic, flow dependent error covariances required for effective TC data assimilation.

(e) To use idealised, synthetic TC structures in initial conditions, to investigate the sensitivity of RI prediction to vortex structure.

(f) To investigate the use of additional data sources and new assimilation techniques for initialization of intense TC vortices without the use of a synthetic vortex.

APPROACH AND WORK PLAN

1. The approach will centre on the simulation of significant tropical cyclones from around the world, and the detailed analysis of a number of interesting cases. These cases will be chosen for their interesting meteorology and for the availability of high-quality data, and will include storms measured during field programs including PREDICT, ITOP, T-PARC and TCS-08. The purpose for simulating these storms is two-fold: firstly to investigate the NWP systems capabilities and to improve these through better vortex specification, data assimilation, and choice of physical parameterizations, and secondly to improve our understanding of tropical cyclone dynamics through the detailed analysis of a few significant case studies.

2. The key individuals involved are (i) Michael Reeder, Monash University, expert in atmospheric dynamics, (ii) Noel Davidson, CAWCR, expert in the numerical prediction of tropical cyclones and in tropical cyclone dynamics, (ii) Jeff Kepert, CAWCR, expert in tropical cyclone dynamics and data assimilation, (iii) Peter Steinle, CAWCR, expert in data assimilation especially at the mesoscale, (iv) Kevin Tory, CAWCR, expert in tropical cyclone dynamics, and (v) Craig Bishop, NRL, expert in data assimilation.

3. Our work plans for the current year are to simulate a number of notable storms, both within the Australian region and that occurred in field experiments PREDICT, ITOP, T-PARC and TCS-08. Analysis of these events will proceed on several fronts: (i) verifying the ability of ACCESS-TC to produce good forecasts on a statistically significant number of storms, (ii) detailed analysis of cases where the forecasts were relatively poor, and (iii) detailed analysis of case studies of interesting events, particularly rapid intensification. Testing will include the tuning of the vortex specification within the ACCESS system, and the use of field experiment data to validate the bogus when possible. In addition, a graduate student will be engaged at Monash University to work on the relationship between inner core vacillations and rapid intensification.

WORK COMPLETED

The main focus of the project to date has been recruitment of suitable scientists to perform the work. A merit-based recruitment campaign has resulted in the appointment of two staff: Dr Yimin Ma has commenced work and is presently learning to use ACCESS-TC. His initial focus is on simulating storms from the ITOP and TCS-08 experiments. Dr Richard Dare is presently engaged on a separate project and will commence work on this project in June 2011. Both scientists have previous experience with NWP systems and with tropical cyclone research, including with the Bureau's previous NWP suite.

Progress to date has been slower than anticipated. One issue was the initial delay in setting up the transfer arrangements for the funds; unfortunately recruitment could not commence until all arrangements were in place (April). There were significant delays in the recruitment process, due to a backlog in the Bureau of Meteorology's human resources section caused by some large recruitment exercises earlier in the year. The final cause of the slow progress is the delayed start for the second appointment (Dr Dare). Our initial choice for that position withdrew his application, necessitating a further search, and unfortunately there were no suitably qualified scientists available earlier than Dr Dare. Nevertheless, with these startup issues behind us, we are confident of making strong progress over the coming year.

RESULTS

We present a sample of two early results from the ACCESS-TC system. These have not been studied in detail at present, but indicate the strong capabilities of the system.

North Atlantic Hurricane Danielle produced a near-perfect 72-hour forecast, capturing not only the track and intensification as detailed in table 1, but also the expansion in size of the storm (Fig. 1). Size changes of tropical cyclones have considerable operational significance, since the greater fetch leads to a much greater ocean response in both waves and storm surge.

Northwest Pacific Typhoon Fanapi produced good guidance for the landfall of Typhoon Fanapi on Taiwan and China, although the modeled movement was somewhat faster than observed. The leftwards displacement of the track as Fanapi passed over Taiwan was well captured. Fanapi was a significant storm, with reports of 33 dead and 42 missing in China's Guangdong province.

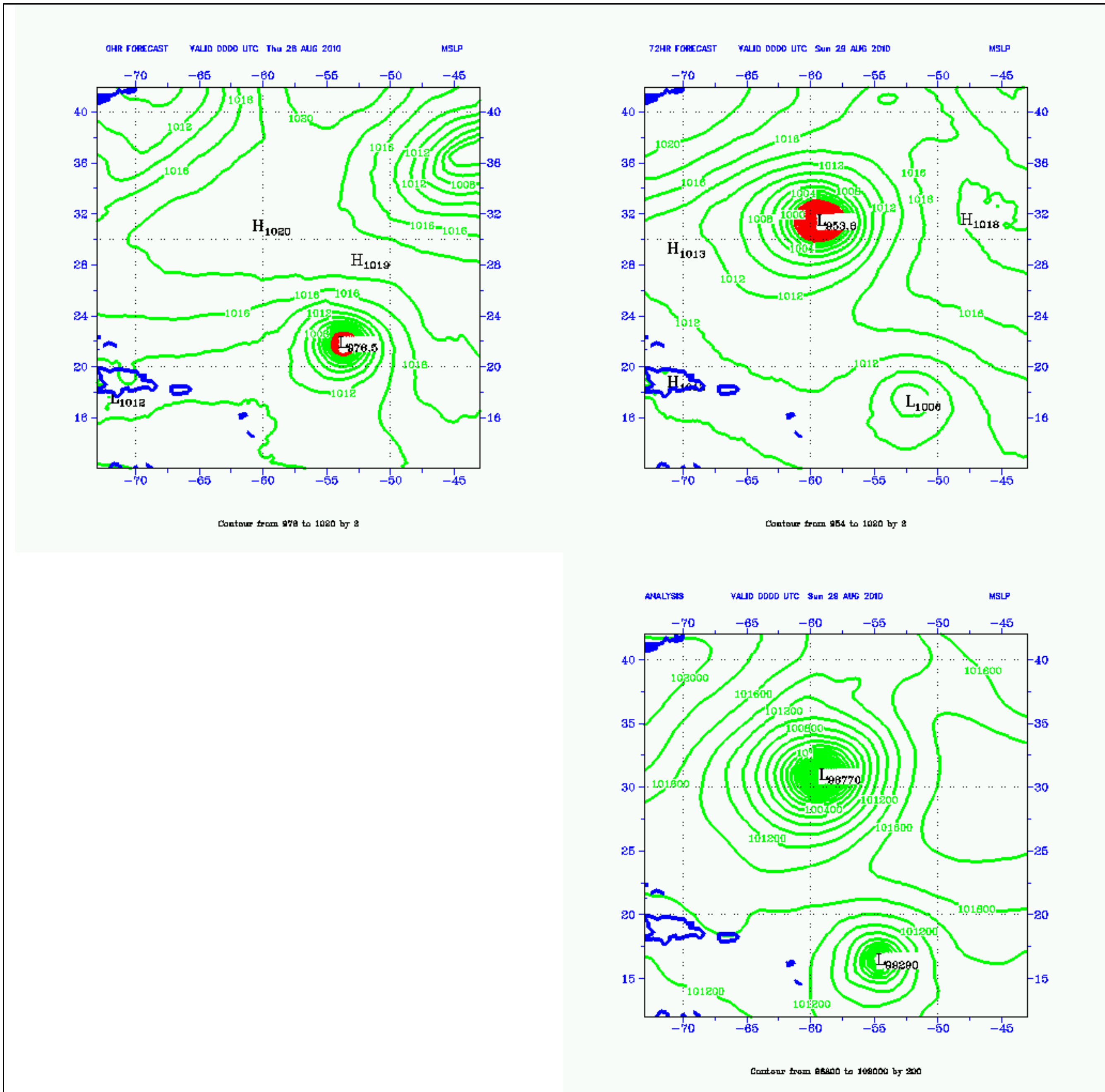

Fig 1: Initial condition on 28 August 2010 (top left), forecast at +72 hours (top right) and verifying analysis (lower right) for Hurricane Danielle. Note the excellent forecast of storm position, intensity and size.

	Lat	Long	Central pressure (hPa)
Observed Danielle 26 Aug 00UTC	22.0	306.4	975
ACCESS-TC initialization	21.9	306.2	975
Observed Danielle 29 Aug 00UTC	30.9	300.8	958
ACCESS-TC forecast	31.5	300.9	953

Table 1: Position and intensity details for ACCESS-TC forecast of Hurricane Danielle.

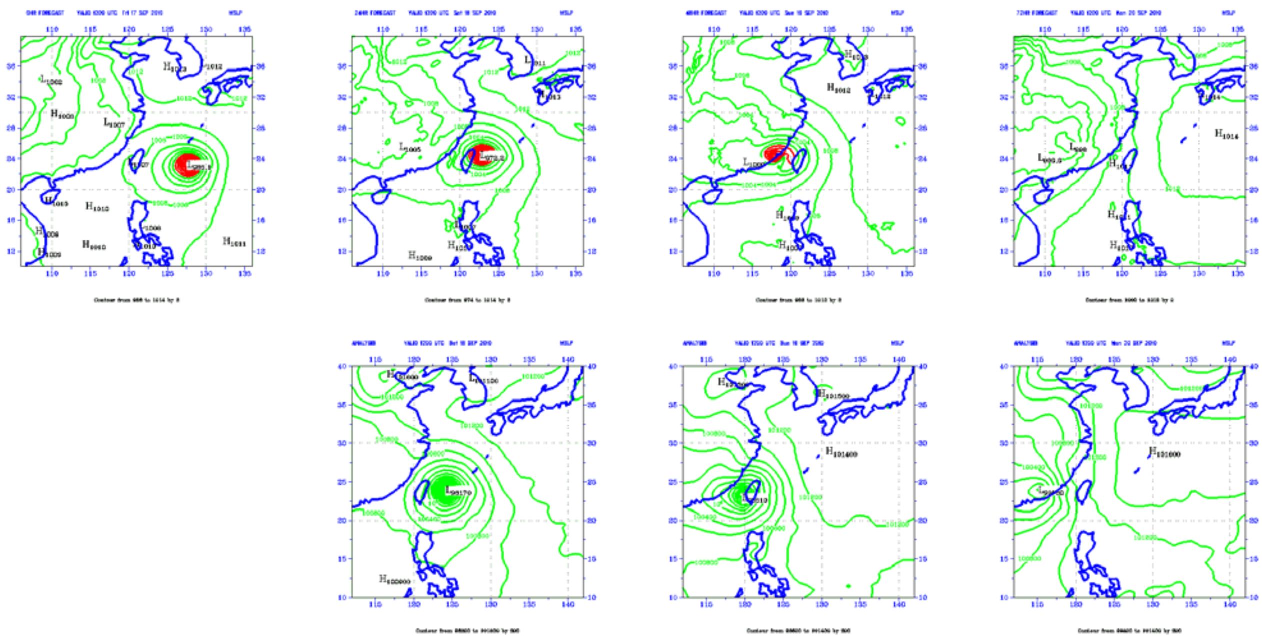

Fig 2: Top row, initial condition valid at 12UTC 17 Sept 2010 and forecasts at 24, 48 and 72 hours, for Typhoon Fanapi. Bottom row, verifying analyses at the same times.

A study of the impact of vortex initial structure on forecast performance in the previous TC-LAPS system is presently under revision at Monthly Weather Review (Ma et al. 2010, Davidson and Ma 2010). This study focused mainly on North Atlantic hurricanes, to take advantage of aircraft reconnaissance data, and found that correct specification of the initial structure had a large impact on the prediction of both structure and intensity in some cases, including Hurricane Katrina. In contrast, track forecast was largely insensitive to the initial structure of the vortex. The model forecasts tended to preserve the initial vortex structure, indicating that correct initialization of vortex size (for example) will improve forecasts of this parameter. This is illustrated in Fig. 3, which shows the model initial condition (i.e. following vortex specification, data assimilation and diabatic initialization) and 48-hour forecast for three cases.

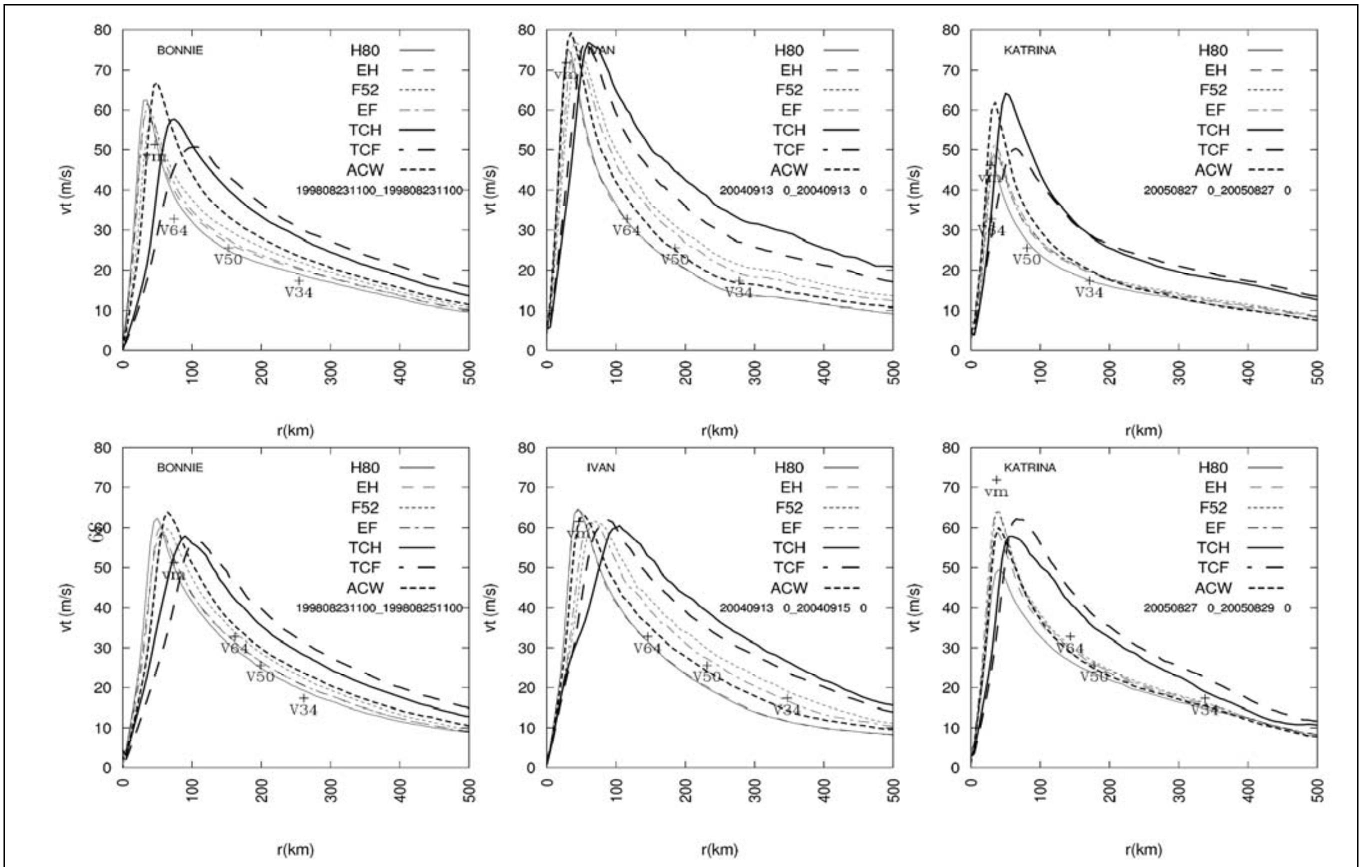

Fig 3: The top row shows the initialized radial profiles of tangential wind at 975 hPa, and the bottom row the corresponding 48-hour forecasts, for Hurricanes Bonnie (left column), Ivan (middle column) and Katrina (right column). Each curve represents a different analytical profile used in the vortex initialization scheme in TC-LAPS: H80 (Holland 1980), EH (Enhanced Holland 1980), F52 (Fujita 1952), EF (Enhanced Fujita 1952), TCH (TC-LAPS version of Holland 1980), TCF (TC-LAPS version of Fujita 1952), ACW (Amended Chan and Williams 1987).

IMPACT AND APPLICATIONS

Economic Development

Tropical cyclones are a major class of natural disaster, which cause significant loss of life and economic damage. Improved NWP and understanding will contribute to better forecasts and warnings, which are a major part of the effort to mitigate the effects of tropical cyclones. In addition, more accurate forecasts can also reduce the costs of preparation, for example by reducing the area that needs to be evacuated.

Quality of Life

Tropical cyclones worldwide cause significant loss of life, ecological damage, and loss of amenity. Improved predictions and understanding contribute directly to better forecasts. More accurate and precise forecasts lead to more efficient preparation, a lower chance of a significant impact not being forecast, and a reduction in the extent of over-warning.

TRANSITIONS

National Security

ACCESS-TC is presently being made operational by the Australian Bureau of Meteorology for use in the coming cyclone season (southern summer). Subsequent work will extend operational running into neighboring regions, including the vicinities of Fiji and the Philippines. Track and intensity forecasts from the system will be supplied to the U.S. Joint Typhoon Warning Center and other international agencies.

Economic Development

The operational transition of ACCESS-TC will start to realize the economic benefits noted in the previous section.

Quality of Life

The operational transition of ACCESS-TC will start to realize the quality of life benefits noted in the previous section.

RELATED PROJECTS

Several projects within CAWCR are closely related to the present project. These fall within the Earth System Modelling program (http://www.cawcr.gov.au/research/esm/index.php) and relate to the development and operational implementation of the ACCESS system. The initial operational implementation, known as APS0, is largely complete. The follow-up APS1 project will bring increased resolution, use of some additional satellite data in the assimilation, updates of the assimilation and model software, and some rationalization of the model domains. Other related projects include the research implementation and testing of an ensemble prediction system based on that at the MetOffice and using the Ensemble Transform Kalman Filter method, and the development of a coupled atmosphere-ocean tropical cyclone model in collaboration with the Oceanography program within CAWCR.

PUBLICATIONS

At this early stage, there are no publications directly attributable to this project. The following list is of related publications from the project personnel over the present year. These publications demonstrate the strong scientific capabilities of the project partners, and will help lay the foundation for the postdoctoral fellows and graduate students who are or will be funded by the NOPP.

Bishop C.H., Hodyss D., Steinle, P., Sims, H., Clayton, A.M., Lorenc, A.C., Barker, D.M. and M. Buehner, 2010: Efficient ensemble covariance localization in variational data assimilation. *Mon. Wea . Rev*. In press

Bishop, C.H. and D. Hodyss, 2010: Adaptive ensemble covariance localization in ensemble 4D-VAR state estimation, *Mon. Wea . Rev.* In Press.

Bougeault P, Toth Z, **Bishop C.H.**, Brown B, Burridge D, et al., 2010: The Thorpex Interactive Grand Global Ensemble (TIGGE). *Bull. Amer. Meteor. Soc.*, **91**, 1059–1072.

Campbell,W.F., **C.H. Bishop,** and D. Hodyss, 2010: Covariance Localization for Satellite Radiances in Ensemble Kalman Filters. *Mon. Wea. Rev.*, **138**, 282–290.

Chan, J. C. L. and **J. D. Kepert**, (Eds.), 2010: *Global Perspectives on Tropical Cyclones – From Science to Mitigation*. World Scientific Publishing, 444 pp.

Dare, R.A. and J.L. McBride, 2010: Sea surface temperature response to tropical cyclones, *Submitted to Monthly Weather Review*.

Davidson, N.E., 2010: On the intensification and recurvature of Tropical Cyclone Tracy (1974). *Australian Meteor. Ocean. J.*, **60,** 169-177

Davidson, N.E. and **Y.M. Ma**, 2009: Surface Pressure Profiles and Initialization for Hurricane Prediction. Part II: Numerical Simulations of Track, Structure and Intensity. In revision, *Mon. Wea. Rev.*

Harper, B. A., J. D. Holmes, **J. D. Kepert**, L. M. Mason, and P. J. Vickery, 2010: Comments on "Estimation of Tropical Cyclone Wind Hazard for Darwin: Comparison with Two Other Locations and the Australian Wind-Loading Code". *J. Appl. Met. Clim.*, Submitted.

Kepert, J. D., 2010: Balance-aware localisation for atmospheric and oceanic ensemble Kalman filters. Comp. Geosci. doi:10.1007/s10596-010-9188-0.

Kepert, J. D., 2010: Comparing slab and height-resolving models of the tropical cyclone boundary layer. Part I: Comparing the simulations. *Quart. J. Roy. Meteor. Soc*., **136**, 1689-1699, doi:10.1002/qj.667.

Kepert, J. D., 2010: Comparing slab and height-resolving models of the tropical cyclone boundary layer. Part II: Why the simulations differ. *Quart. J. Roy. Meteor. Soc*., **136**, 1700-1711, doi:10.1002/qj.685.

Kepert, J. D., 2010: Tropical cyclone structure and dynamics. *Global Perspectives on Tropical Cyclones – From Science to Mitigation*, Chan, J. C. L. and J. D. Kepert, Eds., World Scientific Publishing, 3–53

Leroux, M.-D., **N. E. Davidson**, **Y. Ma**, and **J. D. Kepert**, 2010: Prediction and diagnosis of the motion and rapid intensification of Typhoon Sinlaku during TCS08 (Tropical Cyclone Structure Experiment, 2008). *Mon. Wea. Rev*., submitted.

Ma, Y.M., M. Kafatos and **N.E. Davidson**, 2009: Surface Pressure Profiles and Initialization for Hurricane Prediction. Part I: Analysis of Observed and Synthetic Structures. In revision, *Mon. Wea. Rev.*

McLay, J., **C. H. Bishop**, and C. A. Reynolds, 2010: A local formulation of the ensemble-transform (ET) analysis perturbation scheme. *Wea. Forecasting*., **25,** 985-993.

Nguyen, M., **M. J. Reeder**, **N. E. Davidson**, R. K. Smith and M. T. Montgomery. 2011. Inner-core vacillation cycles during the rapid intensification cycles of Hurricane Katrina. *Quart. J. Roy. Meteor. Soc*., (Submitted)

Powell, M. D., **J. D. Kepert**, and E. W. Uhlhorn, 2010: Reply. *Wea. Forecasting*, Submitted.

Tory, K. T., and W. M. Frank, 2010: Tropical cyclone formation. *Global Perspectives on Tropical Cyclones – From Science to Mitigation*, Chan, J. C. L. and J. D. Kepert, Eds., World Scientific Publishing, 55–91

Walsh, K. J. E., P. Sandery, G. B. Brassington, M. Entel, C. Siegenthaler-LeDrian, **J. D. Kepert**, and R. Darbyshire, 2010: Constraints on drag and exchange coefficients at extreme wind speeds. *J. Geophys. Res. (Oceans)*, **115**, C09007, doi:10.1029/2009JC005876.

Wang, X., T.M. Hamill, J.S. Whitaker, and **C.H. Bishop**, 2009: A Comparison of the Hybrid and EnSRF Analysis Schemes in the Presence of Model Errors due to Unresolved Scales. *Mon. Wea. Rev.*, **137**, 3219–3232.