Model Output Applications and Model Diagnostics

Introduction

The Applications Development and Diagnostics Team (ADD) will develop applications of the HFIP numerical model forecasts, including deterministic and ensemble runs. These applications include (1) advanced diagnostic techniques to better understand model performance and to provide guidance for model improvement to other HFIP teams, and (2) post-processing applications that optimize use of HFIP advances by operational forecast offices (e.g., National Hurricane Center), and can lead to greater effectiveness of end-user products. While these two activities are closely linked, it is useful to describe them separately.

Current Status

Diagnostic work

An initial diagnostics workshop was held in May of 2009 (see http://rammb.cira.colostate.edu/research/tropical_cyclones/hfip/workshop_2009/ ) to help establish the scope of the diagnostics effort. It includes regional and global models, and both operational models such as HWRF, COAMPS-TC and GFDL and experimental models such as HWRFx, ARW and FIM that are run as part of the annual HFIP model demonstration. It also includes the analysis of single deterministic runs of these models and ensemble forecasts, as well as the atmosphere and ocean components of the coupled regional models.

The main purpose of the diagnostic effort is to identify sources of model biases and errors so that the models can be improved. The diagnostic studies range from the calculation of fairly simple large-scale parameters such as vertical wind shear and steering flow for statistical analysis, to more in-depth analysis such as energetic and potential vorticity budgets.

Another aspect of the diagnostics effort is the incorporation of observations. These include aircraft data, such as airborne radar observations for use in evaluation of the statistical properties of the model-generated convection, and satellite observations. Procedures are under development for using model forecast fields as input to radiative transfer algorithms to generate synthetic satellite observations that can be compared with the real satellite data. This will aid model evaluations in regions such as near the cloud top or below the ocean surface, where in situ data are not usually available.

An example of the use of satellite data for model evaluation is shown in Fig. 7. The top panel shows the Oceanic Heat Content (OHC) from the HyCOM ocean model, which is part of an experimental version of the coupled HWRF system. The 72 hr HyCOM forecast of OHC is from a case for Hurricane Ike. The bottom panel shows the OHC estimated from satellite altimetry and sea surface temperature data. This type of comparison will help to establish the reliability of the coupled ocean forecasts provide guidance for improvements.

Another function of the diagnostics effort is to provide a means to collect model output from the operational and demonstration forecast systems at common location for later analysis by the participating groups. The DTC/TCMT has taken on this role. In the first year three tiers of data were identified. Tier 1 includes the tracks and intensity estimates from the various models in the Automated Tropical Cyclone Forecast (ATCF) system format, which can be used for model inter-comparison and basic verification studies. Tier 2 data includes subsets of model fields for basic diagnostic studies, and
tier 3 includes the full model fields. The tier 3 data are too large to be housed at a common location, but specific forecasts can be made available as needed.

**Applications Development work**

The applications development component of the work serves three user groups: Hurricane Specialists (forecasters) at the National Hurricane Center (NHC), other HFIP teams, and “end users” comprising mainly emergency managers, the media and the public.

Forecasters can access numerical guidance products from several operational global and regional models on display systems like N-AWIPS, AWIPS, the ATCF system and the web. Data and display options are very limited at this time, however, for viewing information from some models (e.g., ensembles), in certain configurations (e.g., high resolution data; cross-sections), and observing some key features (e.g., inner core and convective-scale and mesoscale structures).

To help guide the applications development, forecasters provided the ADD team with a prioritized list of new or enhanced guidance products to improve model utility. Table 8 shows a subset of that list with the highest priority. A part-time contractor hired in late 2009 has already started work on some of the forecasters’ requirements in Table 8. Fig. 7 shows preliminary examples of products generated from model forecasts. Another goal of HFIP is to extend tropical cyclone forecasts from 5 to 7 days. Work has begun to modify the ATCF system to accommodate the longer forecasts, as shown in Fig. 9. One of the more challenging aspects of application development is the utilization of ensemble forecasts. An ensemble product development workshop was held in April, 2010 (see [http://www.ral.ucar.edu/jnt/tcmt/events/2010/hfip_ensemble_workshop](http://www.ral.ucar.edu/jnt/tcmt/events/2010/hfip_ensemble_workshop)) to provide guidance for these activities. Preliminary work has begun to modify the ATCF to display large numbers of forecasts from ensemble modeling systems. Fig. 10 shows an example of this capability for storm tracks generated from NHC’s existing statistically based wind probability model.

**Focus Areas for the Next Five Years**

**Diagnostics**

In the short term, the emphasis will be the determination of a standard set of basic large-scale diagnostics for the operational and experimental models that will be run during the next hurricane season. The use of standard procedures will allow for model inter-comparison. Preliminary versions of the synthetic satellite imagery will also be developed, including infrared (IR) and microwave channels. Development of more advanced diagnostic techniques will begin, including the incorporation of aircraft data for comparison. Diagnostics for the ocean component of coupled models will also be developed, including incorporation of satellite-derived ocean parameters such as OHC, and in situ ocean profiles where available. The establishment of the model output distribution capabilities that were started in 2009 will be expanded. Diagnostics for a regional model ensemble will build on preliminary results from 2009. Work will also begin on embedding statistically based intensity forecast models within global modeling systems.

Similar to the application development described below, the longer-range plans will evolve as experience is gained after each hurricane season, and through interactions with other HFIP teams. The initial diagnostic efforts described above will evolve over the next 5 years to include more sophisticated techniques, including methods specifically designed to understand the behavior of physical parameterizations, especially cloud microphysics and the boundary layer. These studies will
need to include observed quantities such as vertical velocity and hydrometeor measurements from aircraft and particle size estimates from satellite algorithms. On the storm scale, Lorenz-type energetic studies modified to include non-hydrostatic effects and angular momentum budgets will be performed to better understand model evolution. Also in the longer term, adjoint techniques will be applied to better understand model sensitivities to initial conditions and parameters used in physical parameterizations. The synthetic satellite data techniques will also be refined, with the possibility of developing more general methods for visible channels with more accurate representations of cloud scattering.

Enhanced Diagnostics and Coordination

To augment the general diagnostics plan, the DTC can provide an organizational framework to support a dedicated and ongoing diagnostics effort for continuous and effective feedback to the model developers of HWRF, COAMPS-TC and the AHW. This effort would require several full time dedicated people investigating different aspects of model behavior to include past seasons to establish model climatology and help provide feedback on potential upgrades on model performance to model developers.

In support of this effort for HWRF, the DTC is developing a parallel EMC testing environment so that proposed annual upgrades to the HWRF system can be effectively evaluated on model performance. This is preseason preliminary diagnostics and require working very closely with HWRF model developers. The constancy of this effort is particularly time critical to assess impending upgrades as the operational HWRF evolves each year with upgrades to the system prior to the start of hurricane season. For both operational and research models, it is also imperative to assess ongoing model improvements and assess potential new enhancements that would impact model performance. Over the course of several years, it is likely that new benchmarks for performance will have to re-established with the operational HWRF system, as well as the research models at NRL and MMM. As the COAMPS-TC nears transition to operations, careful benchmarking of model performance will be imperative.

This effort will require substantial coordination between the different levels of diagnostics. The enhanced effort will depend on the delivery of time critical studies of preliminary diagnostics as described above in order to target specific case studies. Also, model climatology will be altered with various system upgrades. The intent of this effort is to provide feedback to support time critical model developments especially as model complexity increases. Specific scientists will need to be identified working on these various levels. This is critical to properly manage this effort. Expertise must be identified as well as capability to deliver useful diagnostic information and meet needed timelines.

Application Development

In the short term, the emphasis of the application development will be on the first few items from Table 8. Work will also begin on applications recommended at the ensemble product development workshop. These include new displays that combine track and intensity information from ensembles, and that couple dynamical ensemble model output with statistically based products. In the longer term, the applications development will be an iterative process that will depend on experience gained with experimental applications and display, the evolution of the operational display capabilities at NHC (for example, the transition from N-AWIPS to AWIPS-II), improvements in the operational and HFIP demonstration modeling systems, and interactions with other HFIP teams. Also in the longer term, the possibility of replacing NHC’s probabilistic products that currently use statistical methods for estimating uncertainty with similar products based on ensembles will be investigated. Results from a
separate HFIP effort intended to identify new or enhanced NHC products for end users will be folded into ADD in future years.

**Milestones and Deliverables**

Listed below are milestones and deliverables, along with estimated completion dates, through 2014 for the diagnostic and application development efforts. Similar to the tropical cyclone forecasts themselves, the longer-range items have greater uncertainty.

**Diagnostics**

- Aug 2010 - First version of synthetic satellite imagery from tropical cyclone models
- Aug 2010 – Establishment of first generation HFIP data service
- Sep 2010 – Common large-scale diagnostic dataset from NCEP and Navy operational models (HWRF, COAMPS-TC, GFDL, GFS) and selected set of HFIP demo models
- Sep 2010 – Initial capability to use aircraft data in diagnostic studies
- Sep 2010 – Initial capability to embed statistical intensity models in the FIM global model forecasts
- 2011 – First capability for routine ocean model diagnostic capabilities
- 2011 – Evaluation of large-scale diagnostic study from 2010 season, provision of feedback to modeling groups, adjustment of diagnostics as needed
- 2011 – Upgraded HFIP model/data service
- 2012 – Generalization of diagnostics with focus on physical parameterizations
- 2012 – Lorenz-type energetic analysis
- 2013 – Angular momentum studies
- 2013 – Refinement of synthetic satellite imagery, better treatment of visible channels
- 2014 - Adjoint-based sensitivity studies
- 2014 – Mature system for utilization of all available in situ data for diagnostics, including in situ, aircraft, satellite and oceanic measurements

**Application Development**

- Aug 2010 – First version of at least two forecaster applications for NHC
- Sept 2010 – Prototype version of web-based ATCF to enhance HFIP-NHC interaction
• 2011 – First ensemble product for NHC forecasters
• 2011 – Mutual product development with other HFIP teams
• 2012 – new or prototype products for each of the 14 forecaster requirements listed currently;
• 2012 – First test of replacing statistical input with ensemble input to NHC probabilistic products several operational ensemble model products;
• 2013 – Completion or re-evaluation of the set of 14 forecaster products in Table 8
• 2013 – Development of new set of forecaster priorities based on experience from previous hurricane seasons and new HFIP developments
• 2014 – Adaptation of more sophisticated diagnostic applications to real time environment
• 2014 – 3 to 5 new or enhanced NHC public products.
Table 8  NHC product development priorities as of fall 2009.

- Shear analysis for user-specified layers
- User-selectable (e.g., point and click) vertical cross sections of any field or combination of fields
- Genesis probabilities derived from global model ensembles and possibly high resolution pre-TC models (capability to record probabilistic information in ATCF
- Magnitude and location of maximum 1-minute sustained surface (10 m) wind speed for each minute of integration (for operations and diagnostics); full surface wind field at hour intervals
- Probability distribution of intensity change (including RI)
- Guidance on the best locations for additional observations, e.g., supplemental soundings, G-IV dropsondes, C-130 data.
- Ensemble-based probabilistic guidance for track, intensity, wind structure, storm surge, rainfall, as well as support for existing products.
- Structural analyses using the mass and motion forecast fields to help diagnose tropical, subtropical and extratropical stages (e.g., phase space)
- Capability to make model comparisons (contemporary and sequential runs of any combination of models)
- Global model tropical cyclone (TC) formation index/indicator and verification methods.
- Model originated simulated radar/microwave imagery.
- Center locations at multiple vertical levels and depiction of vertical coherence
- Ensemble mean track (high priority; a near-default output)
- Surface map of accumulated forecast rainfall
Figure 7 Oceanic Heat Content (OHC, kJ/cm$^2$) from a 72 h forecast of the experimental HyCOM-HWRF modeling system for Hurricane Ike initialized at 00 UTC on 8 September 2008 (upper panel) and the corresponding OHC fields from a satellite retrieval (lower panel). The full track of Hurricane Ike is also shown. Ike was just east of Cuba at the model initialization time.

Figure 8 Examples of prototype forecast products generated from model output. The left panel shows a vertical cross section through tropical cyclone Omais and the right panel shows a wind and moisture display from model-simulated soundings, included a Hovmoller format for Dakar.
Figure 9 Capability for hurricane forecasters to generate 6 and 7 day forecasts under development as part of combined HFIP and JHT effort.

Figure 10 New capability for hurricane forecasters to display tracks of one thousand or more ensemble members as part of combined HFIP and Joint Hurricane Testbed (JHT) effort.