Shipboard Data Assimilation System/Doppler Radar

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LONG-TERM GOALS

Our goal is to develop a short-term high-resolution data assimilation capability that can provide the Navy with improved analyses and forecasts of atmospheric conditions with sufficient detail and accuracy for supporting the Navy mission in threat detection, weapons development, and weather safe operations. The data assimilation system will utilize all available weather data, such as Doppler radar, in situ, and remotely sensed observations. The system will run efficiently and generate a detailed analysis of the atmosphere with sufficient accuracy to predict Electro-Magnetic/Electro-Optical (EM/EO) propagation and target area weather conditions. This information can then be fed back to SPY-1 radar and other weapon system operators to improve detection capabilities.

OBJECTIVES

The objective of this research is to build a set of comprehensive data assimilation algorithms for the on-scene (OS) version of the Coupled Ocean/Atmospheric Mesoscale Prediction System (COAMPS®), and at the same time, investigate the impact of high-resolution data assimilation on short-term mesoscale numerical weather prediction. This data assimilation scheme will be able to analyze mesoscale weather by applying sophisticated analysis procedures capable of ingesting the information from Doppler radar, satellite, and other remote sensors. The primary focus of this effort will be to design a system that optimally utilizes the available weather data such as DoD Doppler radar data for initializing COAMPS-OS® .

APPROACH

The Naval Research Laboratory (NRL) and the University of Oklahoma (OU) are jointly developing a high-resolution data assimilation system. The system includes a three-and-half dimensional variational (3.5dVar) approach for Doppler radial velocity data assimilation. This 3.5dVar system uses the background fields provided by atmospheric predictions from COAMPS at non-synoptic times and/or analyses from the newly developed NRL Atmospheric Variational Data Assimilation System (NAVDAS) at synoptic times. Simplified adjoint methods are used to achieve the high computational efficiency needed to assimilate high-resolution data from Doppler radars (including DoD radars on ships and at forward-deployed locations). The analysis increment fields are expressed by B-spline basis functions to optimally filter noise while the analysis is performed directly on the COAMPS grid. The assimilation time window is synchronized with COAMPS integration time steps and radar

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volumetric scans to enhance the coupling of the model with the data. To compliment the radar assimilation system, a separate cloud analysis package was adapted for COAMPS from the OU Advanced Regional Prediction System (ARPS). The ARPS Data Analysis System (ADAS) is used to analyze high-resolution geostationary satellite observations (such as the infrared and visible imagery), and surface cloud observations. An algorithm has also been developed recently and added to the system to assimilate radar reflectivity data into COAMPS to initialize the model's precipitation fields.

WORK COMPLETED

Research efforts for this project in the fiscal year of 2006 have been focused on studying the impact of radar reflectivity and Doppler radial velocity data assimilation on mesoscale NWP model forecasts. The high-resolution data assimilation system was further improved by adding a new algorithm recently developed for radar reflectivity data assimilation. A variational approach is used in the new algorithm for the retrieval of rain, snow and graupel mixing ratios from radar observations of reflectivity, with COAMPS forecasts used as background fields. Four steps are taken during the data assimilation processes, namely,

1. Forward: Computing reflectivity from hydrometeors in the model background fields (Atlas 1954; Brown and Braham 1963; Douglas 1964):

$$Z_b = 10 * \log(a_r q_{rb}^{b_r} + a_s q_{sb}^{b_s} + a_g q_{gb}^{b_g})$$

Where q_{rb}, q_{sb} and q_{gb} are rain, snow and graupel water content from the background fields, Z_b is the background reflectivity in dBZ, a_r, a_s, a_g, b_r, b_s, b_g are constants.

2. Analysis: minimizing the costfunction to get the reflectivity analysis field, $\mathbf{Z}_a$,

$$J = \| w_b(\mathbf{Z}_a - \mathbf{Z}_b) \| + \| w_o(\mathbf{Z}_a - \mathbf{Z}_o) \|$$

3. Backward: updating the model microphysical fields

$$q_{rb}^{new} = c^{\frac{1}{b_r}} q_{rb} \qquad q_{sb}^{new} = c^{\frac{1}{b_s}} q_{sb} \qquad q_{gb}^{new} = c^{\frac{1}{b_g}} q_{gb}$$
$$where \quad c = 10^{(\frac{Z_a - Z_b}{10})}$$

4. Temperature and moisture adjustment: computing temperature changes from the increments in q_r, q_s and q_g; keeping observed storm regions saturated and reducing relative humidity to below 80% in regions without observed storms.

The new reflectivity data assimilation algorithm has been tested both separately and along with the three-dimensional Doppler radial velocity data assimilation to study the individual and combined impacts of the data assimilation components on the very short-term prediction of severe storms and other hazardous weather events. Several experiments have been conducted. To quantify the impact of data assimilation on model forecasts, two verification systems have been developed to verify model forecasts against radar observations. The first one is the NRL 3D Radar Mosaic System. By integrating volumetric scans of radar reflectivity from each of individual radars in a storm region into one three-dimensional reflectivity field on a Cartesian grid, this system provides ground truth data that are not available anywhere else for the validation of model forecasts of the three-dimensional microphysical fields (cloud liquid water, cloud ice water, rain, snow, and graupel) with a nearly complete coverage of large storm systems (for example, a hurricane). In addition to model verification, this system can also be used for storm studies and radar data assimilation. The second verification system is the NRL three-dimensional radar wind analysis system. This system calculates radial velocities from model forecasts of three-dimensional winds (u, v, w) at radar observational grid points and then compares the calculated radial velocities with radar observations. Statistics are computed during the verification. This is the first system we know of that is capable of verifying three-dimensional wind forecasts with the ability of showing model forecast errors both in phase and in magnitude. It has showed its usefulness in mesoscale model verification.

Efforts also continue for radar data processing and quality control (QC). Software has been developed and implemented to ingest and display Doppler radar data stored in Universal Format (UF). This paves the way to use DoD radar data for NOWCAST and data assimilation applications. A comprehensive radar data quality control suite is under development that will merge the National Center for Atmospheric Research (NCAR) Radar Echo Classifier (REC) algorithm, the MIT/Lincoln Laboratory Data Quality Assurance system, the National Severe Storms Laboratory (NSSL) radar data quality control system with the algorithms developed at NRL Monterey to provide a complete radar quality control for the radial velocity and reflectivity data from the WSR-88D radars, the Supplemental Weather Radar (SWR), the SPS-48 air control radar, and other DoD radars. This will further improve the radar data quality in the data assimilation and consequently the impact on model prediction.

RESULTS

The data assimilation system has been extensively tested with case studies. To fully examine the contribution from each data assimilation component and the overall effect, three radar data assimilation experiments plus a control run were conducted with several severe weather cases, including a squall line case and Hurricane Isabel 2003. Table 1 lists all the experiments conducted. Figure 1 illustrates the procedures in which data assimilation was cycled to assimilate the retrieved wind, thermodynamic, and microphysical fields into COAMPS every hour during the data assimilation period. At the end of the final data assimilation cycle, forecasts were launched.

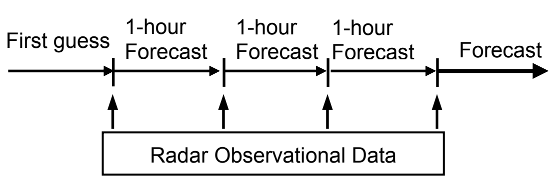

Fig. 1. Illustration of data assimilation procedures

Table 1. Data assimilation experiments

CNTL	No data assimilation
Reflectivity DA	Radar reflectivity data assimilation
Radial velocity DA	Radar radial velocity data assimilation
Combined DA	Radar reflectivity and radial velocity data assimilation

Figure 2a shows the equitable threat scores of the storm forecasts (storm areas were defined by 0 dBZ in radar composite reflectivity) as a function of forecast hour from all the experiments tested with the squall line case on 9 May 2003 along the East Coast of US. Figure 2b gives correlation coefficients between the model-predicted radial velocities and radar observations for the same case. All three data assimilation experiments improved storm prediction over the control run. The newly developed algorithm for radar reflectivity data assimilation showed improvements not only on storm location prediction, but also on the 3D wind forecasts. Detailed study also indicated that the latent heat and moisture adjustments in the algorithm played an important role in improving wind prediction. It is also interesting to notice that the improvements from the combined data assimilation experiment lie atop of those from the other two individual data assimilations at most forecast times, an indication that consistently updating the model fields will perform the best in improving storm prediction.

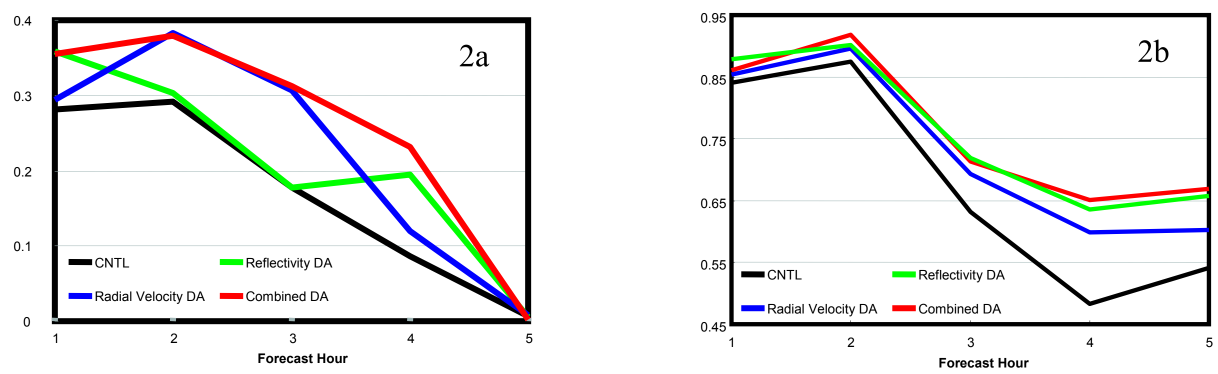

Fig. 2 Equitable Threat Scores (a) of storm location prediction (storm areas were defined by the 0 dBZ in radar composite reflectivity) and correlation coefficients (b) between the model-predicted radial velocities and radar observations at radar scan tilt angle of 1.49^o as a function of forecast hour.

As mentioned earlier, Hurricane Isabel 2003 was also selected for studying the impact of radar data on prediction of large storms such as hurricanes. Figure 3 presents correlation coefficients, as a function of radar scan tilt angles, between model-predicted radial velocities of Hurricane Isabel during the four-hour landfall period and those observed by the WSR-88D radar at Morehead City, North Carolina. Figure 4 gives the sea level pressure and surface wind forecasts from the control run and the combined data assimilation experiment. Figure 5 shows the predicted sea level pressures at hurricane center and maximum surface wind speed verified against National Hurricane Center (NHC) observations. Obviously, radar data have very significant impacts on hurricane prediction. This can be seen not only in the statistical scores given in Fig. 3 but also by comparing the hurricane center structures in Fig. 4. The difference in hurricane center sea level pressure forecasts between the control run and the data assimilation experiment reached about 14 hPa, a huge improvement that is generally not seen from other data assimilation studies. More importantly, the data assimilation experiment also forecasted the weakening tendency in hurricane strength during landfall hours. Although this study was aimed at testing the high-resolution data assimilation system with a large-scale storm system, the successful data assimilation experiments with Hurricane Isabel 2003 also encourages us to study the possibility of initializing high-resolution hurricane models with radar data, especially when hurricanes are near landfall, during which the rapid changes in hurricane intensity and internal structures are usually very difficult to predict. The availability of large amount of radar observations on hurricanes from airborne radars in field experiments and from the land-based WSR-88D network along the East Coast of the U.S. provides us with such an opportunity.

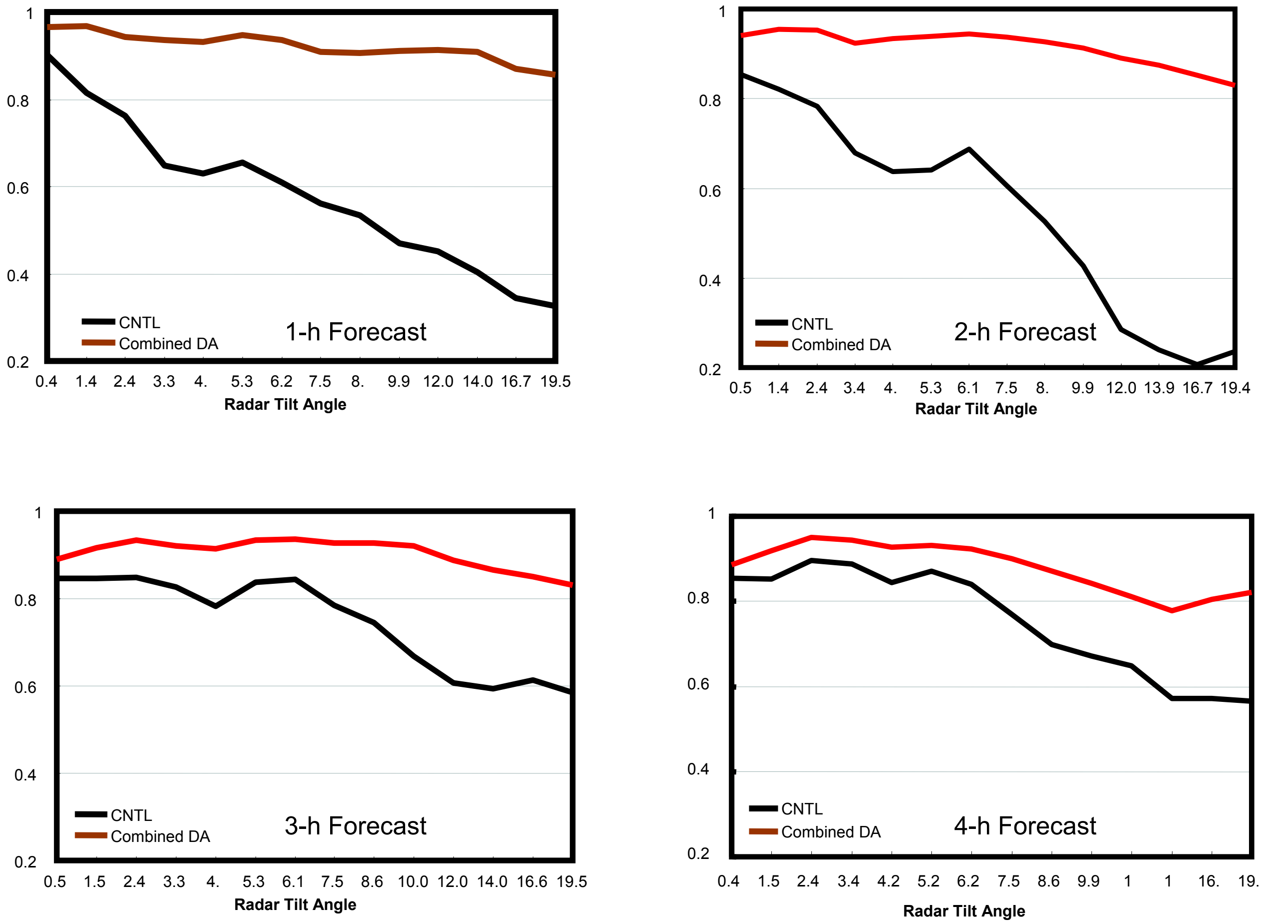

Fig. 3 Correlation coefficients between the model-predicted radial velocities during the four-hour landfall of Hurricane Isabel 2003 and the radar observations from the WSR-88D radar at Morehead City, North Carolina.

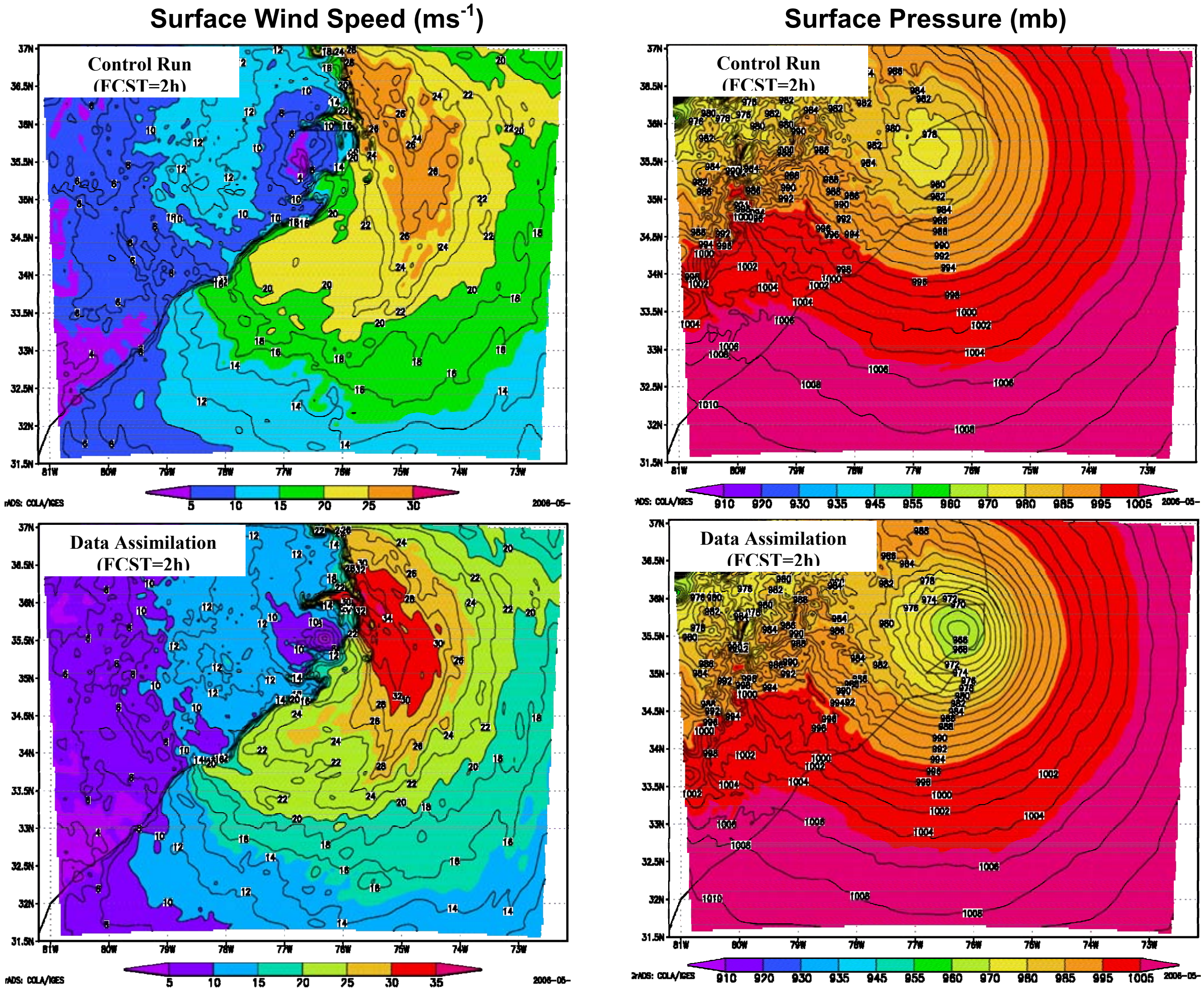

Fig. 4 Two-hour forecasts of surface wind (m/s) and sea level pressure (hPa) from the control run and the radar data assimilation experiments.

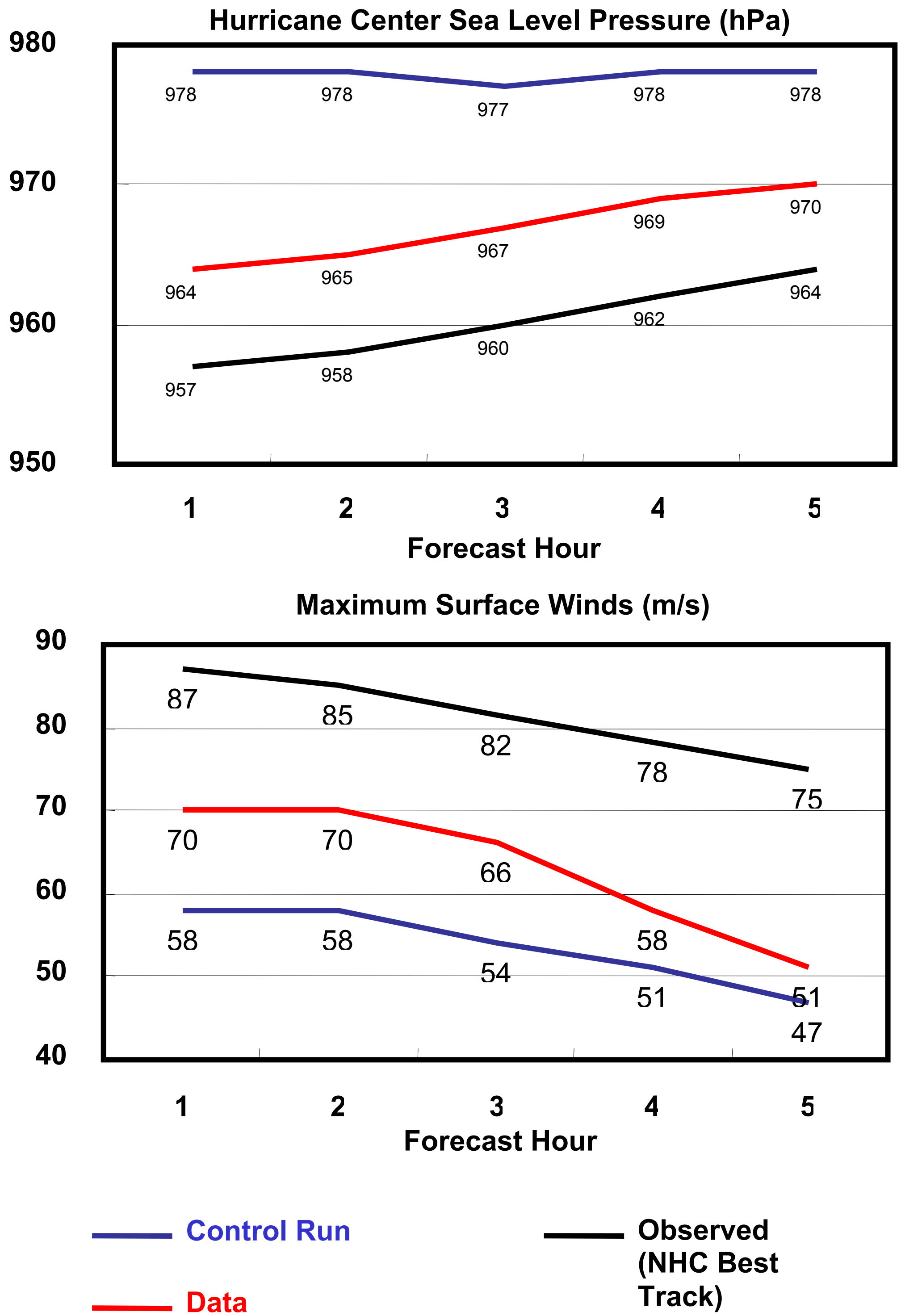

Fig. 5 Verification of hurricane center sea level pressure (hPa) and maximum surface wind (m/s) forecasts from the control run and the radar data assimilation experiments against NHC observations.

IMPACT/APPLICATIONS

The hourly-cycled high-resolution data retrieval and assimilation system developed at NRL for radar, satellite and surface observations for the COAMPS model will provide the Navy, through the NRL NOWCAST system, with near real-time, three-dimensional cloud and wind analyses and very short-term (0-6 hours) theater-scale weather forecasts in any region of interest to support the Navy's mission. The technology was demonstrated during Fleet Battle Experiment – Juliet with products providing up-to-date, detailed information to tactical decision makers about the three-dimensional atmospheric battlespace conditions. The high-resolution winds from both the data assimilation system and the COAMPS model forecast are also used to drive chemical/biological (CB) dispersion models, which are used for assessing contamination avoidance and decontamination strategies. While focusing on battlespace environmental applications, this work also establishes a scientific framework for utilizing radar-derived meteorological information in nowcasting and numerical weather prediction applications.

TRANSITIONS

The ADAS cloud analysis and cloud verification system has been successfully transited to COAMPS-OS V1.3 in 6.4 programs (PE 0603207N). The ADAS cloud verification algorithms and associated source codes have also been adapted by COAMPS Verification System for cloud forecast verification. The 3.5dVar Radar Wind Analysis System is being implemented to run real-time for NOWCAST at the Naval Strike and Air Warfare Center at Fallon, Nevada. The NRL 3D Radar Mosaic system originally developed for radar data assimilation is also transitioned to NRL NOWCAST for processing real-time radar data for TITAN (a storm nowcasting system).

PATENTS

NRL Three-Dimensional Radar Reflectivity Mosaic System has been plied for.

RELATED PROJECTS

Related NRL base projects include BE-235-001, Optimum Use of DoD Radar Data in Battlespace Environmental Prediction and BE 35-2-19, Data Assimilation for Mesoscale Prediction. Other related projects at NRL include METOC Battlespace Characterization FY 04 RTP (ONR, N0001406WX20250).

PUBLICATIONS

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