Seven-Year Plan (FY08-14)
Submitted by the
Product Development Team for

Model Development and Enhancement

FAA Aviation Weather Research Program

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Table of Contents

Appendices

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I. Introduction and role of MDE in AWRP

Improving forecasts of aviation weather hazards requires a combination of

- improved model guidance, and
- development of algorithms to convert from explicit model variables and model post-processing (generally run at NCEP) into enhanced post-processing products.

This sequence reflects the relationship between the MDE PDT and other AWRP PDTs, the latter developing enhanced post-processing products for turbulence, icing, convective weather, ceiling and visibility. This relationship has evolved from that in the 1990s to the current status as of March 2007. Explicitly output fields from a prediction model and enhanced aviation hazard products (AHPs) are both of direct interest to decision-makers such as pilots, dispatchers, and air traffic controllers. As prediction models have become more sophisticated and accurate, the enhanced AHPs have become increasingly accurate. The AHP algorithms have and will continue to evolve, with the accuracy of the enhanced AHPs becoming even more critically dependent upon the accuracy of the model output. Currently and in the future, even the best AHP algorithm cannot remedy a poor model prediction; thus the emphasis herein is on developing, testing, and implementing the best possible models and data assimilation.

The Federal Aviation Administration (FAA) and National Weather Service (NWS) investments in new observing systems[1] over the years have improved the detection and the potential for avoidance of a number of aviation hazards over the U.S. For flight planning and routing, however, mere detection is not enough. Major strides in model accuracy, resolution, and realism have occurred during the past ten years. Even so, operational models today continue to lack, in some aspects, the sophistication needed to extend the benefit of these new observations many hours into the future. **Moreover, the requirements for accurate aviation forecasts continue to tighten with increasing automation and air traffic using the National Airspace System.**

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[1] Recent observing systems:

- WSR-88D radar (reflectivity for inferring precipitation intensity, radial velocities, Velocity-Azimuth Display (VAD) winds, Vertically Integrated Liquid (VIL) within clouds)
- Ascent/descent/enroute data from commercial aircraft (AMDAR – Aircraft Meteorological Data Relay), experimental data from regional aircraft with ascent/descent from regional airports, moisture observations are slowly being added to wind/temperature data through the Water Vapor Sensing System (WVSS-II) and TAMDAR (Tropospheric AMDAR)
- From satellites: cloud-drift winds, vapor-drift winds, estimates of precipitable water, infrared and microwave radiometers, and cloud-top pressure/temp data
- Ground-based moisture measurements inferred by analyzing signals from the Global Positioning System (GPS) satellites
- Automated observations of clouds made from the ground (also visibility)
- Returned power and velocity variance data (related to turbulence and useful for quality control) from wind profiling radars.

For example, a noticeable improvement in forecasts of icing and turbulence (both convective and non-convective) requires more accurate and detailed analyses and forecasts of wind, humidity, and clouds. This, in turn, requires improvements in:

- Model initial conditions to reflect current observations (especially the distribution of clouds, moisture, and precipitation),
- Vertical and horizontal model resolution (to more closely match the scale of the hazardous phenomena), and
- Specification of the physical processes within the model (for example, the formation of cloud).

This plan, submitted by the Product Development Team (PDT) for Model Development and Enhancement, focuses on model development and enhancement (including data assimilation) that will contribute to more accurate analyses and predictions of wind/temperature/moisture as well as those of AHPs, especially, turbulence, icing, convective storm development, cloud ceiling, and visibility.

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There are no extended participants in the Model Development and Enhancement PDT.

Planning Summary Chart B
Model Development and Enhancement PDT

The priority number for funding is to the left of each amount for FY08-10. The full requested funding, in thousands of dollars, is listed at the bottom of each column.

Task #	Task Description	Priority	FY08-D		FY09		FY10	FY11	FY12	FY13	FY14
5.1	Infrastructure support for operational running of the RUC at NCEP	1	185	1	110						
5.17	Infrastructure support for running WRF RR, NAM, and HRW models	2	175	2	280	1	390	390	390	390	390
5.4	Develop, test, and implement the Rapid Refresh configuration of the WRF model (WRF-RR)	3	365	3	315	2	315	350	350	350	350
5.5	Develop, test, and implement improvements to the operational 3DVAR for WRF Rapid Refresh and WRF-NAM	4	440	4	380	3	380	360	360	360	360
5.8	Improve physics in the WRF model, especially including those that affect aircraft icing	5	140	5	215	4	215	250	250	250	250
5.15	Develop improved methods for analyzing clouds and water substance for use in the WRF modeling system	6	125	6	330	6	330	300	300	300	300
5.6	Develop, test, and evaluate the performance of the nonhydrostatic WRF modeling system	7T	60	7	60	7	60	60	60	60	60
5.24	Test WRF Rapid Refresh model at 3km resolution toward HRRR	7T	230	8	230	8	230	350	350	350	350
5.19	Develop ability to assimilate WSR-88D radial velocity and reflectivity data into the WRF modeling system	8	470	9	470	5	470	500	400	400	400
5.20	Examine utility of ensembles for conveying probability and confidence to aviation users	9	185	10	185	10	185	250	250	350	350
5.9	Assimilate turbulence observations (EDR data) directly into the WRF model	10	180	11	180	11	180	200	200	200	200
5.21	Develop, test, and implement advanced 4DDA capability for the WRF model	11	320	12	320	12	320	300	250	250	250
5.11	Develop adjoints for physical processes in the WRF model	12	210	13	210	13	210	200	200	200	200
5.23	Develop advanced numerical models for aviation	13	150	14	150	9	150	150	250	350	350
			3235		**3435**		**3435**	**3660**	**3610**	**3810**	**3810**

II. Summary of Research Program and Objectives

For more timely and precise forecasts of aviation-specific weather hazards, these improvements to systems for operational numerical weather prediction are essential:

A. Exploit available observations, many still not used operationally, to improve analyses of wind, temperature, cloud, and moisture fields – a prerequisite to better cloud and other aviation-hazard forecasts (a data assimilation problem)
B. Define the detailed wind, temperature, and cloud features required to forecast turbulence, icing, convection, and cloud ceiling (a grid resolution and modeling problem)
C. Improve the model's internal representation of cloud development, including convective storms (a physics problem)

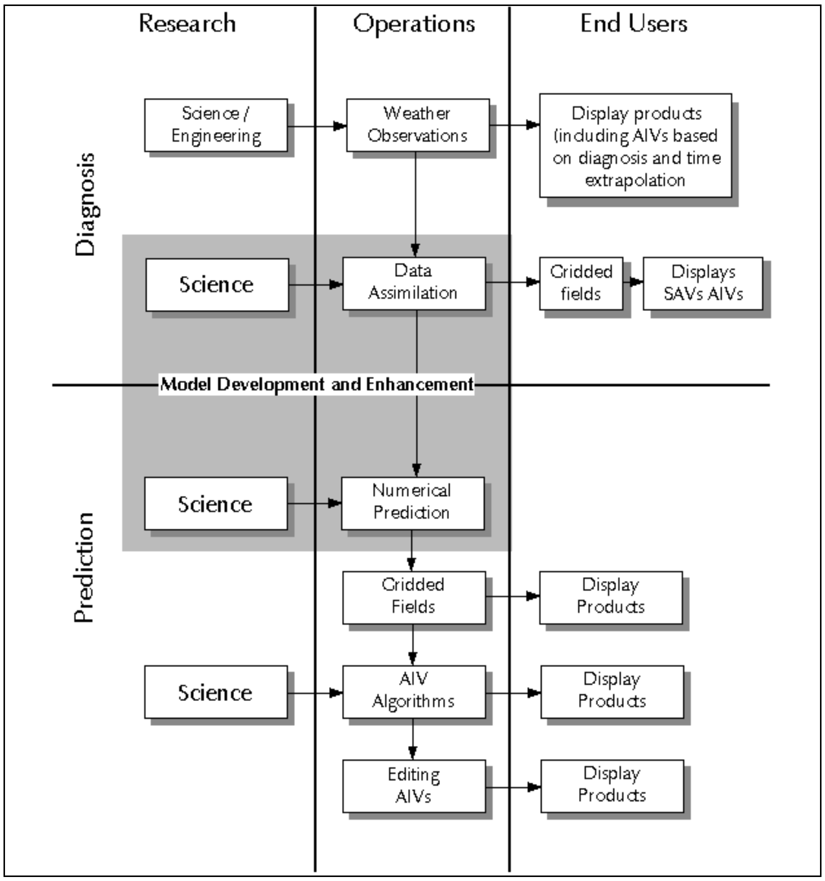
MDE efforts over the years have focused on all three of these areas to produce required gains in the accuracy of aviation-hazard products (AHPs) for turbulence, icing, convective storms, ceiling and visibility. Because these model enhancements will largely determine the possible gains in AHP accuracy, the targets for accuracy can be taken directly from the PDT plans for these AHPs. Figure 1 illustrates how Model Development and Enhancement fits into the overall Aviation Weather Research Program. The columns of the matrix shown in Fig. 1 describe the progression of aviation weather information from researchers (who discover it) through operational meteorologists (who use it in numerical prediction and for advisories, watches, and warnings) to the end users (who require it tailored in the form of specific products). The rows of the matrix represent the chronological use of weather information, first in the form of raw observations or analyses (diagnosis) and then as input for numerical forecasts (prediction). The arrows represent the direction of information flow. Model Development and Enhancement activities lie within the shaded region. Except for a few products that can be generated from observations alone, the entire aviation weather enterprise depends upon analyses and forecasts from computer models. Models and their associated data assimilation systems are the *foundation* of the aviation weather enterprise.

The centrality of MDE efforts within aviation weather has been underscored since 2005 by the FAA announcement of Next Generation Air Transportation System, now called NextGen, a Congress-mandated interagency planning through the Joint Planning and Development Office (JPDO) toward future versions of the Air Transportation System. NextGen will be based on **4-D weather information gridded data including physically consistent AHP information**. This is not a new idea, but emphasizes further the dependency on *continued increase in accuracy and frequently updated aviation weather models using latest observations*. Toward this goal, MDE places emphasis this year in this 7-year plan on focusing its efforts on:

- Model development for *aviation* needs, specifically *0-12h* forecasts
- Developments with a *well-defined path into operational NOAA numerical weather prediction* at the National Centers for Environmental Prediction (NCEP), currently via the RUC (or Rapid Refresh) and the NAM (North American Mesoscale) models.
- Improvements for 10-13km resolution, since the RUC/RR (hourly updating) and NAM (6h updating) will be running at this resolution out to at least 2010.
- A higher-cost option is provided to begin work toward a hourly-updated convection-resolving 3-km model to start over the Northeast Corridor area of the U.S. (*High-*

Resolution Rapid Refresh, or *HRRR*)

- *Increased interactions with other PDTs dependent on MDE development*, including those for turbulence, icing, convective weather, ceiling and visibility, and winter weather.



Overall MDE objectives with RUC, WRF, Rapid Refresh, and NAM models

The goals for MDE are to **improve initial conditions** for weather forecasts models including use of new observing systems ("A" in last section) and to **improve weather models**, in both dynamics (B) and physics (C).

Improving initial conditions through intelligent assimilation (including QC) of the new observing systems on p.3 have been especially important for the short-range forecasts used for aviation.   This trend will only continue with new deployments being planned for new observing systems (e.g., dual-polarization radar, phased-array radar, new satellites, regional aircraft). GSD, NCEP, and CAPS have all emphasized work in this area for MDE.

Improving weather forecast models with a specific emphasis on aviation requirements has driven MDE efforts over the past 12 years, with developments in the RUC and Eta models, and now the WRF model.   Modifications to physics have often been driven by requirements from aviation forecast users for better gridded data for upper-level winds, clouds and especially supercooled liquid water, surface conditions (particularly for airports), and many others.   GSD, NCEP, and NCAR have all had major contributions in this area, including NCAR's contribution to cloud microphysics in the RUC.

Key modeling requirements from the aviation weather forecasting community were identified at a 1999 meeting convened by the MDT PDT with representatives from the other PDTs. The outcome of this meeting is the set of requirements listed in **Appendix B**, still an important reference document for MDE as of March 2007. These requirements have guided development of the RUC, Eta (now NAM), and the WRF models since that time. Interaction between MDE and other PDTs has increased for RUC and WRF-RR testing in recent years and must be continued via adequate funding for MDE in FY08.

These same aviation requirements to improve forecasts of weather hazards have contributed strongly to the overall motivation for community development of the Weather Research and Forecasting (WRF) modeling system. The WRF nonhydrostatic mesoscale model has been under development since 1998. A version of the WRF model has already been implemented within the North American Mesoscale (NAM) model application, and development is well underway toward the Rapid Refresh to replace the current Rapid Update Cycle (RUC) model.

The effort to develop WRF has been a collaborative partnership, principally among the NCAR, NOAA [(NCEP and Global Systems Division (GSD) within the Earth System Research Laboratory (ESRL)], the Air Force Weather Agency (AFWA), the Naval Research Laboratory, the University of Oklahoma/Center for the Analysis and Prediction of Storms (CAPS), and the Federal Aviation Administration (FAA).

The common modeling infrastructure underlying WRF was designed to facilitate a faster infusion of research advancements into operational forecast models, and an easier transition for personnel moving between university research and the operational modeling and forecast centers. A mass-coordinate version dynamic core option within the WRF prediction model, termed the Advanced Research WRF (ARW), was developed by NCAR. A second dynamical core, the Nonhydrostatic Mesoscale Model (NMM), has been adapted to the WRF framework by NCEP/EMC.

Recent efforts, especially in FY06 for the WRF Rapid Refresh Core Intercomparison Test (http://ruc.noaa.gov/coretest2) have focused on developing interoperability of physics packages with different dynamic cores and on testing these variations. Mature versions of the WRF model and the WRF-GSI assimilation package replaced the North American Mesoscale (NAM) run of the MesoEta Model and its Eta Data Assimilation (EDAS) in June 2006. The release of WRF version 2.2 in December 2006, including pervasive physics interoperability upgrades developed for the WRF-RR coretest, was an important milestone for the WRF community and by the MDE collaborators. By June 2009, a WRF-based version of the RUC (to be called the 'Rapid Refresh', or 'RR') is planned to take on the function of rapid updating now served by the current hydrostatic RUC model. The development and testing specifically related to this 'Rapid Refresh' application of the WRF, to serve as the high-frequency cycle replacing the RUC, is, in FY08, an increasingly sharper focus of the MDE PDT, along with the NAM WRF. WRFv2.2 was an important accomplishment toward the Rapid Refresh, since WRFv2.2 now includes all of the RUC-like physical parameterizations. Transition of all regional and mesoscale applications at NCEP to WRF is planned for FY 2008, when the Short Range Ensemble Forecast (SREF) system will be composed entirely of WRF members. It is hoped that this ensemble effort will be extended into rapid updating using high-resolution members from the RR and NAM-WRF.

The transfer of new numerical weather prediction (NWP) science and technology from research into operations, the goal of the MDE PDT driven by aviation requirements, is now aided by the Developmental Testbed Center (DTC), a facility run jointly by NOAA/ESRL/GSD and NCAR where the research and operational communities interact to accelerate testing and evaluation of new modeling techniques for research applications and operational implementation, without interfering with current operations.

The long-term WRF community goals continue to coincide with those of the aviation weather community. The WRF working group efforts continue to contribute to the capabilities of the WRF model, to the benefit of its applications at NCEP for the Rapid Refresh and NAM. These working groups include:

1. Dynamical model framework - numerical design and construction
2. Model shell - parallel implementation, nesting, coding standards
3. Standard initialization procedures - using gridded analyses from other models
4. Three-dimensional variational (3DVAR) data assimilation system
5. Model physics - standard interfaces, adapting existing parameterizations, new physics
6. Post processing - display, diagnostic analyses, statistics
7. Applied testing, verification, and real-time implementation
8. Community support - documentation, web site, workshops, tutorials, consulting
9. Operational implementation - adapting/ streamlining for operational environment
10. 4DVAR data assimilation system - adjoint and tangent linear models
11. Atmospheric chemistry - chemical transport and reacting species
12. Data handling and archive - observed data processing and quality control required for data assimilation systems and operational archive functions

13. Ensemble forecasting **-** optimal ensemble techniques for mesoscale forecasting
14. Land surface modeling **-** advanced models for surface physics and fluxes
15. Operational forecaster training **-** Forecaster interpretation of high-resolution WRF forecasts.

For information on the management of WRF, one may go to the WRF Web Page at http://wrf-model.org and click on "Development Teams" and from there, to "Working Groups".

The following sections describe each organization's overall role and proposed work in FY 2008.

Global Systems Division (GSD) within NOAA Earth System Research Laboratory (ESRL)

GSD will continue to contribute to development of both assimilation and WRF-model components specific to the Rapid Refresh (RR-WRF) application. It will also conduct real-time and retrospective testing and performance comparisons for the RR with the current hydrostatic RUC model and assimilation system. Into 2007, GSD has been the focal point for developing improved assimilation techniques for the RUC system and developing and transferring model code into the RUC model. GSD has also been responsible for 'research-quality' testing of the RUC and now, with the Rapid Refresh and RR-version of the WRF model also. Finally, GSD is responsible for recommending and transferring codes for both RUC and RR-WRF to NCEP/EMC for its real-time and retrospective testing. These continued tasks by GSD will contribute to the overall WRF effort but specifically toward the goal of implementing the WRF into the operational RR-WRF cycle at NCEP planned by June 2009, replacing the current RUC system. The assimilation development work at GSD will be aviation-related enhancements to the Gridpoint Statistical Interpolation (GSI) 3DVAR analysis system discussed under NCEP/EMC in the next section.

FY08 work for GSD will focus on end-to-end testing of the Rapid Refresh, cycling with a version of the WRF model using the ARW core (per Sept 07 NCEP-GSD decision) and a version of the WRF-GSI assimilation system. Both components will include RUC-specific software, from enhancement to GSI for RR application to model physics and digital filter initialization for the WRF model. The RR GSI will include RUC-developed components in its cloud/hydrometeor assimilation, including GOES cloud-top, METAR cloud/visibility/current weather data, and 3-d radar reflectivity data. The RR GSI will also include of boundary-layer depth to determine spatial representativeness of surface observations.

GSD will develop and test a method to assimilate 3-d radar reflectivity in the WRF model by specifying latent heating in a diabatic DFI, a highly successful technique developed and incorporated into the RUC model in FY07. An effort will continue in FY2008 on testing and revision of physical parameterizations, including the mixed-phase bulk cloud microphysics and convective parameterization schemes, similar to those used in the RUC model. This task will include an extensive evaluation of the complicated interaction of all of these RR-WRF components (assimilation, model dynamics, model physics, post-processing) via extensive case studies and real-time and retrospective statistical evaluation periods over the new RR-WRF domain covering all of North America.

GSD also has proposed to lead development of radar assimilation for the High-Resolution Rapid Refresh (HRRR), a 3-km hourly-updated model starting with a regional domain over the northeast United States. Ultimately, the HRRR would run operationally at NCEP as a nest within the Rapid Refresh. GSD has begun with some initial HRRR tests in FY07 using interpolated 13km RUC grids including 3-d hydrometeor fields as HRRR initial conditions, including the radar-enhanced RUC13 running experimentally at GSD. Under this proposal, GSD would be joined by CAPS and NCAR in this development, and would collaborate closely with the Convective Weather PDT.

NCEP/Environmental Modeling Center

NCEP's activities for the WRF modeling system span these areas: DTC support, GSI development, physics development, and implementation of WRF components into NCEP's operational Production Suite of model runs. NCEP staff form the core of lecturers at the DTC's twice yearly WRF-NMM Tutorials. NCEP will remain the primary source of support to add the capability to support the NMM core into the WRF Pre-processing System and WPS and real codes. With new SI and real codes coming out of NCAR in 2006, this activity will be a major aspect of implementations for the remainder of FY2007. Peripheral WRF code development and support are also included for observation processing, post-processing, product generation and verification. In the remainder of FY2007, NCEP will concentrate on improving performance of WRF-NMM and its Gridpoint Statistical Interpolation (GSI) 3DVAR running in the North American Mesoscale (NAM) slot.

NCEP has embarked on a transition to using the Earth System Modeling Framework 9ESMF) in all of its future systems from global to regional to local scale. These efforts will not impact any short-term activity but will in the out years.

NCEP is the source of processed observations for 3DVAR analysis and verification codes. In FY 2004, NCEP/EMC decided to adapt its state-of-the-art Gridpoint Statistical Interpolation (GSI) version of 3DVAR to WRF (initially NMM followed by ARW). The GSI provides the most capable platform for a 3DVAR analysis capability that NCEP could use for all its global, regional and mesoscale applications, and could also share with its partners in the Joint Center for Satellite Data Assimilation (JCSDA). Radiances from multiple channels and multiple satellite platforms and the full Level II data stream from the WSR-88D Doppler radar network are just two examples of extremely high volume data sources that are available in their entirety at NCEP and that must be made available to users of WRF and the DTC.

NCAR

Mesoscale and Microscale Meteorology (MMM) Division

NCAR/MMM will continue to advance the WRF system through its hosting of the annual WRF Users' Workshop and its organization of an ARW tutorial. For the development of the Rapid Refresh, MMM will also address the incorporation of new physical schemes and physics improvements. This is necessary to advance the basic capability of the RR as improvements from both the MDE PDE and the broader community are made. NCAR/MMM will transfer physics improvements from GSD and NCEP into RR WRF (ARW core) and perform the necessary testing for code commitment. The RR system ultimately delivered to the FAA will thus benefit from the leveraging of the work of a wider array of scientists working on WRF model physics improvements. MMM will collaborate with MDE team members GSD and RAL as their developments for the RR are ready for inclusion.

NCAR/MMM also will work with GSD toward a digital filter initialization (DFI) capability for the Rapid Refresh (assuming an ARW core is selected). This is a method to reduce noise early in RR integrations, which is important for improving the performance and usefulness of frequent, cycled forecasts. MMM will also address the implementation of the initial DF capability from the RR development into the WRF repository. In following years MMM would pursue testing and evaluation of the DFI capability in the RR.

Given that the goal of the WRF model applications in the Rapid Refresh is ultimately to resolve convection explicitly, NCAR/MMM, budget permitting, would work toward the ultimate RR applications at such scales. These are envisioned by the proposed High-Resolution Rapid Refresh (HRRR), estimated to run at 3 km. In collaboration with GSD, MMM would perform selected RR simulations at 3-km grid scales and evaluate the results to identify strengths and weakness of the model at high resolution. MMM would work with GSD in this preparation of the system for such application.

Research Applications Laboratory (RAL)

NCAR/RAL will develop improved physical parameterizations applicable to the WRF model, especially for the Rapid Refresh application. NCAR/RAL will also work with GSD and CAPS in developing and testing strategies for assimilation of radar reflectivity data.

Center for the Analysis and Prediction of Storms

CAPS views their FAA support as a critical component in realizing the technology transfer of research findings supported by NSF, FAA, NASA, NOAA and other sources of funding into operations. CAPS will continue to play to its strength in the retrieval, analysis and assimilation of WSR-88D radar and other high-resolution data into storm-scale nonhydrostatic models. Radar is ideally suited to sample the atmosphere at resolutions high enough to resolve convective clouds. Radar is also a valuable source of observations on mesoscale precipitation systems, and with proper quality control, the clear air wind observations can also be very beneficial. Significant progress has been made in recent years in assimilating radar data into mesoscale and storm-scale NWP models.

Since radar data are indirect observations, in that the observed quantities (radial velocity and radar reflectivity) are not prognostic variables of NWP models, variational methods or other advanced methods based on estimation theories are most effective. The 3DVAR, 4DVAR and ensemble Kalman filter are leading examples of such methods. While 4DVAR and ensemble Kalman filter (EnKF) methods have clear advantages, and even more so for radar data because they offer the important links among the model variables which are usually not directly observed by radar, 3DVAR is the current method used by US operational models, mainly because of its lower computational cost. While active research continues at CAPS with EnKF and 4DVAR methods, mainly under the support of NSF grants, the work at CAPS on radar data assimilation under the support of FAA AWRP has recently been focusing on and will continue to emphasize more practical methods, including 3DVAR (based on the GSI system), and the complex cloud analysis, and their near future implementation into the Rapid Refresh and NAM and also in the future High-Resolution Rapid Refresh (HRRR) model. To this end, CAPS has been actively collaborating with GSD and NCEP, and with leverage from the DTC visitor's program, in implementing and testing radar data assimilation capabilities within the GSI and WRF framework, and in performing radar data impact studies. The work also takes advantage of various radar data processing and analysis capabilities originally developed within the ARPS framework.

The assimilation of reflectivity data in the 3DVAR framework for the purpose of defining cloud microphysics fields requires additional information because otherwise the problem is underdetermined and/or nonunique. A well behaved analysis should take into account the air temperature and model microphysics. The results of EnKF obtained so far in assimilating simulated reflectivity data are very encouraging because EnKF provides flow-dependent error correlations among observations and all model variables. Eventually, methods like EnKF or 4DVAR are necessary to most effectively assimilate radar data. Before 4DVAR or EnKF method is implemented operationally, the physics-based complex cloud analysis procedure is still the most effective way for assimilating the reflectivity observations. Several published papers have carefully documented the positive impact of reflectivity data assimilation via cloud analysis, in a 3DVAR framework, for several different types of convective systems. This has been demonstrated for a case of a cluster of storms at 9 km resolution. The GSI background analysis was combined with the ARPS cloud analysis to produce an initiation condition for WRF-ARW. Much improved forecast was obtained during the 6 hour forecast period examined. Collaborating with GSD, work is underway in building a unified cloud analysis system within GSI using GSI's realtime data stream, by combining the best attributes of the ARPS and RUC cloud analysis packages, which emphasize convective and stratiform precipitation types, respectively. The new generalized system is designed to handle both stratiform and convective precipitation, and will be tuned for 8-13 km grid spacing for implementation in Rapid Refresh and WRF high-res windows. The system needs to work well with a combination of cumulus parameterization and explicit microphysics at ~10 km resolution, and needs to be consistent, e.g., in terms of the hydrometeor types represented, with the specific microphysics scheme to be used in operations.

Another component of radar data assimilation work focuses on radial velocity data, including its superobbing and their impact on short-range forecasting. The optimal degrees of superobbing, the background-error decorrelation scales that should be used for analyzing radar data, and the data quality control are among the issues needing careful examination.

In addition, CAPS contributes to the general evaluation and testing of the WRF model, through real time high-resolution forecast experiments, and through detailed case studies. Such work leverage on other sources of support. Recently, CAPS is funded by the NOAA CSTAR (Collaborative Science, Technology and Applied Research) Program for three years to conduct realtime storm-scale ensemble and high-resolution deterministic forecast experiments using the WRF model, at part of the NOAA Hazardous Weather Testbed Spring Experiments. In the spring of 2007, the ensemble forecasts are designed to provide an opportunity to examine different physics options in the WRF, while the overall ensemble examines the value of both initial/boundary condition and physics perturbations, and the value of 4-km ensemble as compared to a 2-km deterministic forecasts. In the future years, the radar assimilation capabilities developed under the support of this and other projects will be tested in realtime.

Developmental Testbed Center (DTC)

The DTC was established to help bridge the ‘valley of death’ between research and operations for WRF applications. DTC consists of staff primarily from NCAR and GSD, but with assistance from NCEP and other organizations as needed. DTC has conducted training courses in FY07 for the NMM dynamic core, including additional training to GSD personnel working on AWRP MDE development. DTC has also worked especially with GSD in the FY06 test program to determine the best WRF dynamical core for the Rapid Refresh application.

III. Specific Tasks for the Period FY 2008 through FY 2010

Background: GSD and NCEP will use the following terminology for many of the MDE subtasks and deliverables that reflects a sequence of four stages of transitioning new or upgraded systems into NCEP Operations:

1. Chronologically, the first deliverable will be designated "*Research Quality*" and will reflect the point in the overall process when development efforts produce code that is stable and reflects the new capability or effects the desired changes. Efforts then switch from development to periodic case study testing and fine-tuning. It is at this time that the implementation process is invoked – i.e. a charter is written and submitted to NCEP Central Operations (NCO) and a schedule of subsequent events is laid out. Developers work with NCO throughout the remaining steps until the process culminates in an implementation in NCEP Operations or, if results don't merit it, cancellation of the particular upgrade.

2. The second deliverable will be designated "*Experimental*" and will reflect the point at which refinements performed during case study testing have produced a stable code whose results warrant that the level of testing is elevated to a parallel status. Parallel testing includes both retrospective testing and extensive case studies usually involving cycled data assimilation but in each category the testing is over extended periods of at least 3 weeks duration. All of the testing to this point has involved single changes.

3. The third deliverable is designated "*Pre-Implementation*" and indicates that experimental / parallel testing has produced consistent results that are positive/stable enough to justify elevation of the code to pre-implementation status. This status normally involves real-time testing at full resolution or at the resolution targeted for implementation. This testing also involves combination with other mature upgrades to both the prediction model and the assimilation system into a single package or bundle of changes that are tested together. This phase of testing is used to perform timing tests to assure the bundle/package will fit into the prescribed production time window at NCEP. It is during this stage that results are made available for customers to evaluate usually for roughly a 30-day period. This stage includes major preparation steps to prepare documentation of the changes included in the bundle, summaries of the objective (internal only) and subjective (internal and external) evaluations of the pre-implementation parallel runs, composition and distribution of advance notices, briefings to the EMC and NCO Directors followed by a final briefing to the NCEP Director.

4. The fourth and final deliverable designated "*Operational*" signifies the culmination of the overall process with the new or upgraded codes being implemented into the NCEP operational production suite. Typically (but not exclusively), this final stage is used as a traceable deliverable, whereas stages 1-3 are used for subtasks.

It is now customary to expect one major implementation (package of upgrades) each year for each major modeling system. With the extent and intricacies of NCEP's current production suite, EMC and NCO are no longer able to schedule these whenever the packages become mature. The opportunity to update a major AWRP related system now follows a schedule (give or take a month on either side): NAM in March, RUC in June, HiResWindow in September and SREF in November. This plan will attempt to be consistent with these major implementation targets. While the separation between stages can vary considerably, applying the four-stage process to a 12-month period between each major upgrade for each modeling system leads to:

Month \ System	NAM	RUC/RR	HiResWindow	SREF
October	Stage 3			
November		Stage 2	Stage 1	**Stage 4**
December				
January			Stage 2	Stage 1
February		Stage 3		
March	**Stage 4**			
April				Stage 2
May	Stage 1		Stage 3	
June		**Stage 4**		
July	Stage 2			Stage 3
August		Stage 1		
September			**Stage 4**	

In the following description of activities for each fiscal year, the tasks are listed in priority order. The numbering system is as follows: *ww.x.y.Ez*, where

- *ww* are the last two digits of the year.
- *x* designates the PDT; for example, "5" refers to Model Development and Enhancement.
- *y* is the task number, which stays with the task until completed. The task number identifies the task but gives no information about its priority. For example, in this plan Task 6 pertains to the development of the WRF model.
- *E denotes a trackable "Event" or deliverable.*
- *The absence of an E denotes subtask z, where z* is the subtask or milestone number.

1 April 2007

MDE budget options for FY08

Option A - $1070K, level funding

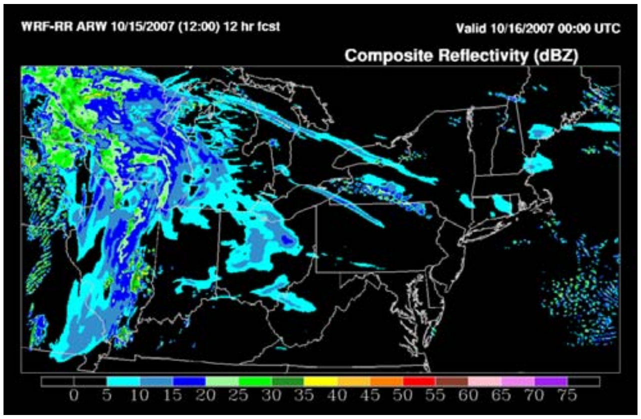
- **Rapid Refresh implementation at NCEP in June 2009, consistent with FY07 plan.**

Option B

- **Preliminary experiments toward 3-km High-Resolution Rapid Refresh (HRRR)**
- **$481K increment over Option A, total $1551 funding required**

Option C

- **Accelerated work toward 3-km High-Resolution Rapid Refresh (HRRR). Essential for Consolidated Convective Weather Product (Convective Weather PDT, also required by Turbulence and Icing PDTs).**
- **Probabilistic aviation forecast development using ensembles including very-short-range forecasts from the RUC/RR and NAM.**
- **$929K increment for labor over Option B, total $2295K.**



Experimental 12h reflectivity forecast from 3km HRRR initialized with radar-enhanced RUC – valid 00z 15 Oct 07. Over preliminary HRRR domain over NE Corridor.

Option D

- **Full funding for long-term development consistent with planning toward the Next-Generation Air Transportation System.**
- **Also includes all tasks recommended in Option A, B1/B2 and C**
- **Only this funding level for Task 5.17 is sufficient for EMC to begin transitioning**

Icing and Turbulence PDT algorithms / capabilities into its Central Computing Centers.

Option A - Budget Summary of FY 2008 Tasks - **RR in Jun 09**

Task #	Task Description	Priority	Funding NCAR	NCEP	GSD	CAPS	DTC	Total	Running Total
08.5.1	Infrastructure support for operational running of the RUC at NCEP	1		65	120			185	185
08.5.17	Infrastructure support for running WRF RR, NAM, and HRW models	2		95				95	280
08.5.4	Develop, test, and implement the Rapid Refresh configuration of the WRF model (WRF-RR)	3		35	170		40	245	525
08.5.5	Develop, test, and implement improvements to the operational 3DVAR for WRF Rapid Refresh and WRF-NAM	4		120	170	40		330	855
08.5.8	Improve physics in the WRF model, especially including those that affect aircraft icing	5	40		60			100	955
08.5.15	Develop improved methods for analyzing clouds and water substance for use in the WRF modeling system	6			60	30		90	1045
08.5.6	Develop, test, and evaluate the performance of the nonhydrostatic WRF modeling system	7	25					25	1070
08.5.19	Develop ability to assimilate WSR-88D radial velocity and reflectivity data into the WRF modeling system	8						0	1070
08.5.20	Examine utility of ensembles for conveying probability and confidence to aviation users	9						0	1070
08.5.9	Assimilate turbulence observations (EDR data) directly into the WRF model	10						0	1070
08.5.21	Develop, test, and implement advanced 4DDA capability for the WRF model	11						0	1070
08.5.11	Develop adjoints for physical processes in the WRF model	12						0	1070
08.5.23	Develop advanced numerical models for aviation	13						0	1070
			65	**315**	**580**	**70**	**40**	**1070**	**1070**

[blank from table deleted in Oct 2007 from 1 April 2007 version]

Option B - Budget Summary of FY 08 Tasks, **HRRR init exps**

Task #	Task Description	Priority	Funding NCAR	NCEP	GSD	CAPS	DTC	Total	Running Total
08.5.1	Infrastructure support for operational running of the RUC at NCEP	1		65	120			185	185
08.5.17	Infrastructure support for running WRF RR, NAM, and HRW models	2		95				95	280
08.5.4	Develop, test, and implement the Rapid Refresh configuration of the WRF model (WRF-RR)	3		35	170		40	245	525
08.5.5	Develop, test, and implement improvements to the operational 3DVAR for WRF Rapid Refresh and WRF-NAM	4		120	170	40		330	855
08.5.8	Improve physics in the WRF model, especially including those that affect aircraft icing	5	60		60			120	975
08.5.15	Develop improved methods for analyzing clouds and water substance for use in the WRF modeling system	6			60	65		125	1100
08.5.6	Develop, test, and evaluate the performance of the nonhydrostatic WRF modeling system	7	46					46	1146
08.5.24	Test WRF Rapid Refresh model at 3-km resolution toward High-Resolution Rapid Refresh (HRRR)	7	55		100			155	1301
08.5.19	Develop ability to assimilate WSR-88D radial velocity and reflectivity data into the WRF modeling system	8	75		100	75		250	1551
08.5.20	Examine utility of ensembles for conveying probability and confidence to aviation users	9						0	1551
08.5.9	Assimilate turbulence observations (EDR data) directly into the WRF model	10						0	1551
08.5.21	Develop, test, and implement advanced 4DDA capability for the WRF model	11						0	1551
08.5.11	Develop adjoints for physical processes in the WRF model	12						0	1551
08.5.23	Develop advanced numerical models for aviation	13						0	1551
			236	**315**	**780**	**180**	**40**	**1551**	**1551**

Option C - Budget Summary of FY 08 Tasks, **Accelerated HRRR +ensemble**

Task #	Task Description	Priority	Funding NCAR	NCEP	GSD	CAPS	DTC	Total	Running Total
08.5.1	Infrastructure support for operational running of the RUC at NCEP	1		65	120			185	185
08.5.17	Infrastructure support for running WRF RR, NAM, and HRW models	2		95				95	280
08.5.4	Develop, test, and implement the Rapid Refresh configuration of the WRF model (WRF-RR)	3		75	250		40	365	645
08.5.5	Develop, test, and implement improvements to the operational 3DVAR for WRF Rapid Refresh and WRF-NAM	4		150	250	40		440	1085
08.5.8	Improve physics in the WRF model, especially including those that affect aircraft icing	5	80		60			140	1225
08.5.15	Develop improved methods for analyzing clouds and water substance for use in the WRF modeling system	6			60	65		125	1350
08.5.6	Develop, test, and evaluate the performance of the nonhydrostatic WRF modeling system	6	60					60	1410
08.5.24	Test WRF Rapid Refresh model at 3-km resolution toward High-Resolution Rapid Refresh (HRRR)	7	80		150			230	1640
08.5.19	Develop ability to assimilate WSR-88D radial velocity and reflectivity data into the WRF modeling system	8	100	50	200	120		470	2110
08.5.20	Examine utility of ensembles for conveying probability and confidence to aviation users	9		85	100			185	2295
08.5.9	Assimilate turbulence observations (EDR data) directly into the WRF model	10						0	2295
08.5.21	Develop, test, and implement advanced 4DDA capability for the WRF model	11						0	2295
08.5.11	Develop adjoints for physical processes in the WRF model	12						0	2295
08.5.23	Develop advanced numerical models for aviation	13						0	2295
			320	**520**	**1190**	**225**	**40**	**2295**	**2295**

Option D - Budget Summary of FY 08 Tasks, Option C + **Advanced Development**

Task #	Task Description	Priority	Funding					Total	Running Total
			NCAR	NCEP	GSD	CAPS	DTC		
08.5.1	Infrastructure support for operational running of the RUC at NCEP	1		65	120			185	185
08.5.17	Infrastructure support for running WRF RR, NAM, and HRW models	2		175				175	360
08.5.4	Develop, test, and implement the Rapid Refresh configuration of the WRF model (WRF-RR)	3		75	250		40	365	725
08.5.5	Develop, test, and implement improvements to the operational 3DVAR for WRF Rapid Refresh and WRF-NAM	4		150	250	40		440	1165
08.5.8	Improve physics in the WRF model, especially including those that affect aircraft icing	5	80		60			140	1305
08.5.15	Develop improved methods for analyzing clouds and water substance for use in the WRF modeling system	6			60	65		125	1430
08.5.6	Develop, test, and evaluate the performance of the nonhydrostatic WRF modeling system	6	60					60	1490
08.5.24	Test WRF Rapid Refresh model at 3-km resolution toward High-Resolution Rapid Refresh (HRRR)	7	80		150			230	1720
08.5.19	Develop ability to assimilate WSR-88D radial velocity and reflectivity data into the WRF modeling system	8	100	50	200	120		470	2190
08.5.20	Examine utility of ensembles for conveying probability and confidence to aviation users	9		85	100			185	2375
08.5.9	Assimilate turbulence observations (EDR data) directly into the WRF model	10		80	100			180	2555
08.5.21	Develop, test, and implement advanced 4DDA capability for the WRF model	11	80	80	80	80		320	2875
08.5.11	Develop adjoints for physical processes in the WRF model	12		80	80	50		210	3085
08.5.23	Develop advanced numerical models for aviation	13			150			150	3235
			400	**840**	**1600**	**355**	**40**	**3235**	**3235**

Tasks for FY 2008

Task 08.5.1
FY 2008, Priority 1: Infrastructure Support Related to Operational Running of the non-WRF Rapid Update Cycle System in NCEP Operations

Description

This task assures the reliable and timely running of the RUC modeling system in the NCEP Operational Suite and providing output grids (SAVs and AIVs/AHPs) to aviation users. RUC together with NAM constitute the principal guidance tools for aviation users that are supported by the AWRP and feed into the Aviation Digital Data Service (ADDS) at the Aviation Weather Center as well. Comprehensive information about the RUC is available and frequently updated at http://ruc.noaa.gov/. GSD carefully monitors RUC performance, corrects any malfunctions in the code as they occur, administers configuration management (maintaining a well-documented code and, together with NCEP Central Operations, strict control over changes). Most activity of this sort is immediately documented on a "Forum" page for the RUC on the World Wide Web: http://ruc.noaa.gov/forum/eval. A log of changes made to the operational RUC processing (13km and 20km versions) is also available at http://ruc.noaa.gov/RUC20.changelog.html. Changes in the experimental RUC running at GSD, queued toward the operational RUC, as described in http://ruc.noaa.gov/13km_RUC.changelog.html . The current status of operational model runs at NCEP, including the RUC can be tracked at http://www.nco.ncep.noaa.gov/pmb/nwprod/prodstat/.

GSD's work on real-time support for the operational high-frequency aviation model (currently the RUC) takes priority overall other MDE tasks, as it is also for the NCEP/EMC RUC liaison. Monitoring of RUC performance by GSD and EMC is essential, often leading to code changes that prevent future problems. GSD/EMC resolution on crisis situations (usually related to some kind of unanticipated observation problem) takes particularly high priority when it is needed and provoked by some kind of problem. On average, there are a dozen or so incidents each year where RUC performance issues have required GSD & EMC to investigate the operational problem. In this area, GSD provides 24h/7day/week availability for any problem (along with EMC), unlike other tasks. GSD takes the primary responsibility for diagnosing each problem and designing and testing a solution. NCEP/EMC performs pre-implementation testing at NCEP and coordinates the implementation process with NCO. Since 2-5 GSD personnel have been involved with these events in the past, this had been a substantial task at GSD.

The milestones are generally the same as in prior years. Deliverable 08.5.1.3 was added in FY2006 to better describe the bulk of the work done for infrastructure support at GSD.

This is the last full year when infrastructure support is requested solely for the RUC since the implementation activity with the RUC system is winding down as efforts are concentrated on the RR-WRF implementation now planned for June 2009. Critical infrastructure support of WRF configurations running in NCEP Operations (NAM, High Resolution Window and SREF) is covered under Task 08.5.17. The following activities continue throughout the year.

Subtasks

October 2007 through September 2008

08.5.1.1 Maintain hourly RUC runs and provide grids of SAV and AIV guidance products.

08.5.1.2 Provide vendors with gridded model data via Family of Services and the FAA Bulk Weather Data Telecommunications Gateway.

08.5.1.3 Provide full grids from RUC runs on NCEP and NWS/OPS servers.

08.5.1.4 Maintain access to model verification data.

Deliverables:

08.5.1.E1 Perform ingest, quality control and preparation of both existing and new observations in support of the operational RUC runs. (NCEP, GSD)

08.5.1.E2 Perform configuration management for RUC, including thorough documentation, and respond promptly to any code malfunctions or performance issues. (GSD)

08.5.1.E3 Monitor RUC performance, respond to any problems detected by GSD, NCEP, or any RUC users, diagnose cause, develop solution to RUC software, test changes and coordinate with NCO on implementation. (GSD, NCEP)

<u>Task 08.5.17</u>
FY 2008, Priority 2: Infrastructure support for operational running of WRF-based modeling system in North American Mesoscale and HiResWindow at NCEP. (Rapid Refresh to be added in FY09)

Description

This task has a high priority to assure uninterrupted running of the models, continued availability of model datasets at highest resolution and smooth incorporation of incremental enhancements to the systems (configuration management). This is the third year for operational WRF infrastructure support and will cover NAM and HiResWindow (SREF also has WRF components). In FY2010, this task will completely replace Task 1 which covers similar activities except for the legacy non-WRF RUC modeling system.

This task ensures reliable and timely running of the WRF-based North American Mesoscale

(NAM) and HiResWindow components of the NCEP Operational run suite. The model runs provide gridded guidance to forecasters at NCEP's Aviation Weather Center (AWC) and Storm Prediction Center (SPC), to FAA end-users via the FAA Bulk Weather Data Telecommunications Gateway (FBWDTG), to aviation users in general and in particular to aviation users supported by the AWRP, and to those obtaining guidance through the AWC ADDS. The current non-WRF RUC is critically dependent on the NAM-WRF for its lateral boundary conditions as will be the WRF-based Rapid Refresh in 2009. The NAM and RUC constitute the principal guidance tools for aviation users that are supported by the AWRP and feed into the Aviation Digital Data Service (ADDS) at the AWC as well. This task has high priority to assure uninterrupted running of the models, continued availability of model datasets at highest resolution and smooth incorporation of incremental enhancements to the systems (configuration management).

A new development in FY2008 will be the task of transitioning other AWRP PDT product generation systems into NCEP's operational environment. Currently, these systems are being run on a set of redundant Linux boxes at AWC which, in addition to performing data ingest, simulate the NCAR environment under which the AIV algorithms and product generation software was developed and tested. A recent dictum from higher management says that all components of NCEP's operations must be running at its Central Computer System by end of FY2008. While the details are still being worked out, it is certain that this new strategy will add to the transition tasks that NCEP Central Operations and EMC personnel have to perform. Therefore, subtask 08.5.17.6 has been added and the amount of support requested under this task has been increased (this amount is just an estimate at this time). For those prediction products based on model data, algorithms will be incorporated into NCEP's unified post-processor.

Information about the four-per-day runs of the 12-km / 60-level NAM Model and cycled NDAS can be found through http://www.emc.ncep.noaa.gov/mmb/mesoscale.html. All model changes made to the operational version of the model and assimilation are logged at http://www.emc.ncep.noaa.gov/mmb/mmbpll/eric.html#TAB4. The current status of model runs can be tracked at http://www.nco.ncep.noaa.gov/pmb/nwprod/prodstat/.

The following activities continue throughout the year.

Subtasks

08.5.17.1 Maintain four-per-day North American Mesoscale runs and provide SAV and AIV guidance. (NCEP)

08.5.17.2 Maintain four-per-day HiResWindow runs and provide SAV and AIV guidance. (NCEP)

08.5.17.3 Provide vendors with gridded model data via Family of Services and the FAA Bulk Weather Data Telecommunications Gateway. (NCEP)

08.5.17.4 Provide full grids from NAM, and HiResWindow on NCEP and NWS/OPS servers. (NCEP)

08.5.17.4 Maintain access to model verification data. (NCEP)

OPTION D ONLY
08.5.17.5 Provide assistance to Inflight Icing, Turbulence, Convective Weather, Ceiling and Visibility and Oceanic Weather PDTs when their algorithms and product generation systems are ready to transition into NCEP's operational Production suite. (NCEP)

Deliverables

08.5.17.E1 Perform ingest, quality control and preparation of both existing and new observations in support of the operational WRF runs. (NCEP)

08.5.17.E2 As requested by other PDTs, incorporate new AIV calculations into Operational WRF Model post-processor and product generator (NCEP).

Task 08.5.4
FY 2008, Priority 3: Develop, test, and implement Rapid Refresh configuration of the WRF modeling system.

Description

A focused effort will continue in FY 2008 to configure the WRF model and the Gridpoint Statistical Interpolation (GSI) analysis for the Rapid Refresh (RR) replacing the RUC assimilation/model system. The transition from the RUC to the RR will be evolutionary, not revolutionary, by using model physics and assimilation techniques in the RR similar to those in the RUC that have proven beneficial to aviation weather forecasting. As of September 2007, NCEP and ESRL/GSD have agreed that the initial Rapid Refresh in 2009 will use the WRF model with the ARW dynamic core.

The Rapid Refresh includes a major increase in domain coverage from the current CONUS RUC domain to a North American domain, not quite as large as the NAM domain, but still covering Alaska, Canada, Puerto Rico, and the Caribbean region. The consequential trade-off in resolution by configuring the RR in the enhanced North American domain is not drastic, with an estimated resolution that is essentially the same as for the 13-km RUC CONUS domain.

A version of the WRF-GSI system will be at the heart of the rapid updating system, serving as the Rapid Refresh analysis code, in the RR operational implementation planned in FY 2009. GSD will complete real-time and limited retrospective runs with the full WRF model in an hourly assimilation cycle. This testing will be the primary task for the work at GSD with the WRF and Rapid Refresh application this year, in anticipation of planned implementation at NCEP in 2009.

During FY2006, work commenced on transferring RUC-specific capabilities into the WRF-GSI: these include the cloud/hydrometeor assimilation, including GOES cloud-top data and METAR cloud/visibility/current weather data, use of full surface observational data including use of inferred PBL depth, and soil temperature/moisture adjustment. By the start of FY2008 and somewhat earlier, we hope, a dynamical core will have been selected for the WRF model to be used for the RR application. In FY2008, work must be completed on transferring all RUC-specific capabilities into the WRF post-processor and testing them with the selected dynamic core and physics. A major effort for all of FY2008 will be focused on final testing and revision of physical parameterizations, including the mixed-phase bulk cloud microphysics, similar to that used in the RUC model. This task will include an extensive evaluation of the complicated interaction of all of these RR components (assimilation, model dynamics, model physics, post-processing) via extensive case studies and real-time and retrospective evaluation periods.

By the end of FY 2008, much of the final testing, both retrospective and real-time, will be completed. A rigorous field test with RUC and Rapid Refresh (RR) users will need to occur for such a significant implementation. GSD will make available experimental RR products in FY2008 and interact extensively with RUC/RR users, **including other AWRP PDTs**, on its performance. Currently, GSD already provides WRF-RUC data over the current RUC CONUS domain via ftp to allow early evaluation by collaborating institutions in AWRP. Considerable effort will be necessary to communicate information on the WRF-RR system to users in the FAA, NWS, and specifically at AWC and SPC. This will include documentation (papers, web forums, and in-person presentations).

Subtasks

08.5.4.1 30 Dec 2007 (GSD, NCEP)
Begin real-time hourly cycling of RR model with GSI over RR domain with availability at GSD of hourly prepBUFR files from NCEP having begun on 12 October 07.

08.5.4.2 1 March 2008 (GSD)
Begin collaborative evaluation with planned NOAA Rapid Refresh users, including AWC, SPC, NWS in Alaska and Puerto Rico. Arrange to have GSD RR grids available to examine and solicit feedback on RR performance.

08.5.4.3 1 March 2008 (GSD)
Begin collaborative evaluation of Rapid Refresh with Inflight Icing, Turbulence, National Ceiling/Visibility, and Convective Weather PDTs. Arrange to have GSD RR grids available to examine and solicit feedback on RR performance.

08.5.4.4 30 May 2008 (GSD, NCAR, NCEP)
Report on status of tactical planning for making RR-WRF code for 2012 in compliance with Earth System Modeling Framework (ESMF) in agreement with the Sept 2007 Rapid Refresh MOU between NCEP and GSD .

08.5.4.5 Ongoing (GSD)
Further enhancement to WRFpost version for Rapid Refresh application, including modifications

for generation of RUC-specific fields.

08.5.4.6 Ongoing (GSD, DTC later)
Ongoing evaluation of performance of real-time and retrospective runs of RR system for SAVs, AHPs.

Deliverables

08.5.4.E1 30 Aug 2008 (GSD)
Have available for delivery to NCEP initial 'experimental level' WRF Rapid Refresh code for start of EMC testing toward 2009 Rapid Refresh implementation.

Task 08.5.5
FY 2007, Priority 4: Develop, test, and implement improvements to the operational WRF 3DVARs for Rapid Refresh and North American Mesoscale runs.

Description

The Gridpoint Statistical Interpolation (GSI) package is currently used for the North American Model (NAM) and has been selected for use with the WRF Rapid Refresh (scheduled to replace the RUC in June 2009). This task provides the necessary continued development for the 3DVAR-based GSI analysis capability, the critical analysis component of data assimilation, for implementation and improvement in both the Rapid Refresh and North American Mesoscale components of the NCEP operational run suite. In FY 2008, GSD and NCEP will continue development of the WRF-GSI assimilation system. GSD will have primary responsibility for adaptation of the WRF-GSI to the Rapid Refresh application, including existing RUC-specific 3DVAR capabilities, such as the cloud and hydrometeor analysis, use of surface observations, and soil temperature/moisture adjustment. GSD tasks during this year will also include full testing of the WRF-GSI over the extended Rapid Refresh domain covering all of North America.

Assimilation of satellite radiances and Doppler radar data will be part of the WRF-GSI. Previous development for cloud and land-surface analysis in the RUC assimilation (particularly the RUC13 version) will be further developed within the WRF-GSI in preparation for the RR. The treatment of these variables will be further improved as more advanced versions of the WRF-GSI are developed. To properly perform the analysis of these new types of data and to take advantage of the information in new or existing observations, new assimilation capabilities for observations types such as satellite imagery, advanced sounders, surface cloud, snow and ice observations will be incorporated into the assimilation system.

NCEP is the primary organization responsible for the overall coordination of the GSI development (done jointly with many partners including GSD, JCSDA etc), including change management, testing, and distribution of new releases to users in the community. In FY2007, NCEP upgraded the GSI roughly every 6-months. At NCEP, there is typically one major implementation each year for each major component of the model runs – e.g., one for the NAM-WRF and one for the Rapid Refresh WRF. Changes to the forecast model are combined with changes to the analysis and assimilation into a single change package or bundle. As progress is made, the most mature capabilities will be incorporated in the March 2008 NAM-WRF changes package and the RR parallel development version. The following enhancements to the WRF-GSI will be considered in FY 2008 (if not previously implemented):

1. Expand use of anisotropic background error covariance (used now for 2D surface temperature, wind and moisture).
2. Improve quality control modules for Level II 88D radar data by integrating radial velocity module (from Qin Xu's group at NSSL) with reflectivity (NSSL's reflectivity mosaic).
3. Implement and test use of CAPS forward model for Level II radial winds and/or reflectivity.
4. Retune unbalanced portion of temperature and limit vertical influence of surface data.
5. Implement/improve use of digital filter (requires changes to WRF model and/or infrastructure).
6. Implement/improve use of R.J. Purser's recursive filters in covariance model.
7. Converge/incorporate modules together with NCAR's WRF 3DVAR.
8. Implement/improve 2DVAR component of WRF-GSI applied only at the surface.
9. Improve diagnostic files and the ability to monitor data usage and guess fit/innovation.
10. Improve background error covariance
11. Expand/complete dynamic constraint term
12. Improve data usage; use original reported height or pressure to locate the observation, test and implement boundary layer model for assimilation of surface data
13. Add ability to read and process new satellite data.
14. Introduce/add time dimension to the 3D-Var: 4D-Var, Kalman Filtering or through constraint.
15. Cloud analysis using cycled background fields and METAR and satellite cloud-top information
16. Assimilation of 3D national radar reflectivity mosaic data and lightning data
17. Assimilation of imagery data from GOES and POES data
18. Use of anisotropic covariance formulation control vertical influence length for surface observations
19. Improved treatment horizontal influence length for surface observations near land/water boundaries and in complex terrain.
20. Improved matching of vertical structures in rawinsonde observations.

The major objective for GSD in FY08 will be to adapt RUC-specific analysis components to the WRF-GSI framework to create a Rapid-Refresh specific WRF-GSI suitable for use with 1-h cycling with surface and other observation types. Specific RUC capabilities include 1) cloud/hydrometeor analysis for stratiform clouds and parameterized convective clouds including use of METAR cloud/weather/visibility information and NESDIS cloud top pressure data (see also task 5.15), 2) use of surface observations including specification of appropriate horizontal and vertical correlation length scales, and 3) appropriate balancing for the RR mesoscale 1-h cycling application yielding forecast improvement down to 1-h lead time.

Testing of an initial cycling version of the RR-GSI began in Fall 2006. In 2008, comparisons against the current RUC analysis/forecast system over CONUS will continue as refinements are made to the RR-GSI formulation. In addition, detailed evaluation of the experimental forecast system will also be conducted over OCONUS regions with a particular emphasis on Alaska and Puerto Rico. Ensuring a close analysis fit and short-term forecast skill for surface observations will be a significant challenge in the arctic regions, where unique land surface challenges exists (glaciers, tundra, arctic night, etc.). An extended period of testing and evaluation in collaboration with Alaskan NWS forecasters will occur during the winter of FY08. The other anticipated major challenge will be in achieving an appropriate overall mesoscale mass/wind balance within the RR-GSI, resulting in acceptable short-term wind errors (equal to present skill of RUC over CONUS). Additional interrelated development work described in other tasks includes: 1) radar radial velocity and reflectivity assimilation (task 5.19) and diabatic Digital Filter Initialization (5.15)

CAPS will work with NCEP and GSD in further refining the radial velocity data assimilation capabilities in the GSI system, for the planned resolutions of operational implementation, and examine the impact of the data on cloud and precipitation forecasts. The optimal choice of the error correlation scale for radar data analysis will be further refined, in the context of generally improved definition of the background error covariance, with the use of a multi-pass analysis framework. The latter is necessitated by the very different scales represented by the radar data versus those represented by large-scale observational networks.

Subtasks

Option A

08.5.5.1 31 December 2007 (GSD and CAPS)
Progress report on testing and evaluation of the generalized cloud/hydrometeor assimilation (including GOES cloud-top data and METAR cloud/visibility/weather data) within a cycled GSI on the full Rapid-Refresh domain.

08.5.5.2 31 December 2007 (NCEP and GSD)
Report on testing of 2DVAR GSI assimilation of high spatial and temporal mesonet surface data using analysis grids with 5-km or finer resolution.

08.5.5.3 31 January 2008 (NCEP and CAPS)
Further refine the radial velocity analysis component of GSI in response to model resolution changes. Examine data impact at higher assimilation frequencies and higher spatial resolutions. Consider issues on data quality, super-obbing, and optimal decorrelation scales.

08.5.5.4 28 February 2008 (GSD)
Report on statistical evaluation of Rapid Refresh forecasts initialized with the GSI, including examination of upper-level winds, surface fields, and precipitation.

08.5.5.5 31 July 2008 (NCEP)

Based on case-study testing and refinement of the research quality code, deliver result in an 'experimental' code for an upgrade package (e.g. improved use of WSR-88D data and satellite radiances and covariances) to the WRF-GSI for FY2009 change package to the NAM-WRF.

Deliverables

08.5.5.E1 30 March 2008 (NCEP)
Subject to NCEP Director approval implement upgrades to WRF-GSI used in NAM/NDAS.

08.5.5.E2 30 August 2008 (GSD)
Rapid Refresh code delivery date to NCEP/EMC for initial testing of RR version of GSI.

08.5.5.E3 30 September 2008 (NCEP and CAPS)
Deliver enhancement package for radial velocity data analysis for further implementation testing.

<u>Task 08.5.8</u>
FY 2007, Priority 5: Improve physics in the WRF model, especially that bearing on prediction of aircraft icing.

Description

The FY2008 activities at NCEP will be toward improving the physics and their nonlinear interactions with dynamics, particularly at higher resolution, as more of the details of mesoscale circulations are explicitly resolved. In FY2008, the possibility of explicitly advecting each hydrometeor category will be examined in explicit, high-resolution (4-5 km) runs where no parameterized convection is called, together with evaluating new microphysics packages now available in the WRF NMM. By FY2008, this will become an area of active development as EMC prepares to run the NAM as a nested model by FY2009, where the inner nest may be run at sufficiently high resolution to eliminate the need for using parameterized convection, or at least greatly reduce its forecast impact. As always, practical considerations are forefront in model evaluation, in which changes are made based forecast performance and computational efficiency.

Work will continue at NCAR to improve microphysical parameterizations and other physics packages in the WRF system in response to research findings from case studies (those proposed from field programs), comprehensive cloud verification systems being developed within EMC, and other sources of information from the research and operational meteorological communities. Focus at NCAR will be on improving forecasts of icing associated with stratocumulus clouds and the impacts of aerosol particles on the formation of freezing drizzle. In order to take advantage of the information from aerosol particles, the current one moment scheme will be expanded to two moments.

Consideration will be given to splitting the prognostic variable for rain into the portion of rain formed by droplet coalescence and rain formed by melting ice, the reason being that the former is typically associated with drizzle and small raindrop sizes and the latter is associated with larger drops. Of particular importance will be whether the models are able to correctly represent the partitioning of ice species into the forms of snow, graupel, frozen drops (sleet), or hail. This determination could be better served as we get more experience looking at the forecast simulated radar reflectivities from the WRF models. The number concentrations of rain and various types of ice can also important, because they determine the mean size, fall speed characteristics, and rates of conversion between various forms of liquid (e.g., tiny cloud droplets, small drizzle drops, and large rain drops) and ice (e.g., small ice crystals, unrimed and rimed snow, heavily rimed graupel, frozen drops and sleet, and large hail).

GSD will continue evaluation of physics parameterizations in the GSD developmental RR cycle, and in collaboration with the Developmental Testbed Center. Discussions with NWS forecasters and others in Alaska have helped GSD identify matters of particular concern. As in the past, particular attention will be given to the microphysics and its interaction with radiation and convection and will include collaboration with microphysics experts outside of GSD.

Another matter of GSD concern for the RR arising from discussions with Alaska forecasters is the handling of snow cover in Land-surface Models, as well as the description of the low-level profiles of temperature, moisture and wind under very stable conditions. We have gleaned from our discussions with Alaska modelers in March 2007 that having at least 2 layers of snow in the land-surface model is important to obtain reasonable forecasts of near-surface conditions. This aspect of the WRF version of the RUCLSM is considered a strength of that scheme. A separate issue is that neither the RUC LSM nor the Noah LSM has any provision for tiling (i.e., handling areas covered by snow differently than areas of bare ground within the same grid box, and then using a weighted combination of the heat and moisture fluxes from bare ground and from snow-covered areas to determine the predicted grid-box area average temperature). This deficiency leads to too cold temperature forecasts at the lowest few model levels when there is predicted snow cover surmounted by a strong low-level flow of warm air. Testing of tiling procedures for intense ablation periods will be required.

An initiative to unify physics packages between the Regional and Global Branches within EMC was started in 2004, but has since been put on hold to focus on the WRF NMM implementation in the operational NAM, as well to fix forecast issues found in the modeling system since it was put into production. Although much progress has been made over the past year, more work is needed to "iron out all the kinks in the system", some of which involve improving model physics as they impact forecasts, leaving little time to focus on cloud microphysics. Although microphysics plays a crucial role in the forecasts of icing, ceiling, and visibility, these conditions depend critically on capturing the larger scale conditions as accurately as possible. The large scale conditions, as well as forecasts of surface conditions so important in mesoscale forecasts, are determined in large part by what NCEP has termed the "physics wheel of pain", involving interactions between parameterizations of microphysics, boundary-layer processes, radiation, convection, land surface processes, and subgrid effects of flow over and around topography. EMC plans to resume physics unification after most of the forecast issues in the NAM have been resolved, which is likely to be in the latter half of 2007. The motivation for unifying the physics in NCEP models is driven by plans to unify the Global and Regional models, in which a higher resolution grid centered over North America is nested within a global model sharing the same dynamic core.

The evolution and development of short-range ensemble systems will continue based in part on what we will learn during the intervening years. It is mentioned under this task (see also Task 08.5.20) because some of this development will involve the diversification and improvement of model physical parameterizations. At NCEP this will all be performed in the context of a Short Range Ensemble Forecast (SREF) system that is entirely based on WRF components (2 dynamic cores and various suites of physics). Incorporating more realistic growth of forecast errors may include ideas currently being evaluated at ECMWF and UKMO concerning stochastic physics, and other currently novel approaches that attempt to incorporate probabilistic uncertainty within physical parameterizations. This is an area that will likely involve continued interactions between experts in many different areas of NWP.

Since parameterization of precipitation-producing deep convection will continue to be necessary in the RR for several more years, GSD will continue to develop and test new designs for improving the Grell-Devenyi convection scheme, as has been found necessary each of the past 4 years through FY07.

Subtasks

All Option A unless noted otherwise.

08.5.8.1 31 Dec 2007 (GSD)
Begin systematic GSD evaluation of physics performance in GSD 1-hour RR cycle and address issues that arise in preparation for 2009 RR implementation. Particular attention will be given to microphysics and interactions between microphysics and the other parameterized physical processes.

08.5.8.2 15 May 2008 (NCEP)
Development efforts produce a 'research quality' code of physics upgrades for consideration in the 2009 NAM-WRF change package.

08.5.8.3 1 July 2008 (NCAR)
Expand the current one moment microphysical scheme to two moments and add a variable for aerosol particles in order to improve forecasts of freezing drizzle and icing. Computer storage and run time considerations will be considered as a constraint on the development.

08.5.8.4 15 July 2008 (NCEP)
Based on case-study testing and refinement of the research quality code, deliver an "experimental" code of physics upgrades for the 2009 NAM-WRF change package.

08.5.8.5 31 Mar 2008 (DTC, GSD)
Report on GSD-DTC RR retrospective testing of land-surface model formulations for snow, and,

as appropriate, other physics.

08.5.8.6 1 August 2009 (GSD)
Begin to explore possibilities for enhancing treatment of sea ice and tundra (including spring-time pooling) in Rapid Refresh domain.

08.5.8.7 1 September 2008 (NCAR) **Option B**
Upgrade the microphysics and boundary layer scheme to appropriately simulate freezing drizzle and icing in stratocumulus clouds.

08.5.8.8 30 September 2008 (NCAR) **Option C**
Implement the above upgrades into the WRF model and test on IMPROVE, AIRS-II and stratocumulus case studies. The evaluation will include supercooled liquid water, freezing drizzle, as well as snowfall rate and precipitation type and ceiling and visibility.

Deliverables

08.5.8.E1 30 March 2008 (NCEP)
Subject to NCEP Director approval, the physics upgrades become Operational at NCEP as part of the 2008 change package for WRF-NMM. (Will supplement physics progress toward Rapid Refresh.)

08.5.8.E2 30 Aug 2008 (GSD, NCEP)
Have available for delivery to NCEP initial 'experimental level' WRF Rapid Refresh code, including physics routines, for start of EMC testing toward 2009 Rapid Refresh implementation.

08.5.8.E3 30 September 2008 (NCAR)
Provide an improved microphysics scheme to GSD for evaluation in WRF Rapid Refresh.

Task 08.5.15
FY 2007, Priority 6 Develop improved methods of cloud and moisture analysis for use in the WRF Modeling System.

Description
Aviation needs for improved cloud/hydrometeor assimilation are for three different cloud situations:

- Stratiform cloud
- Convective cloud at parameterized scale (~10-13km)
- Convective cloud at explicit scale (<4 km)

Under this task (5.15), we focus on work associated with improving the first two cloud situations, stratiform cloud and parameterized convection, and related moisture assimilation issues. The 3rd task on this list (radar assimilation at explicit 3-km scale) is treated separately for task 5.19.

Aside from improving operational mesoscale models themselves, a key data assimilation development that will spur improvements in the prediction of icing, ceiling and visibility, and convective storms is *better initial cloud and moisture fields*. All operational permutations of the WRF Model (the North American Mesoscale, Rapid Refresh and HiResWindow) predict clouds and precipitation, and they need detailed information on the water vapor field, the location, coverage, and hydrometeor composition of observed clouds and observed precipitation at the start of the forecast period--thus the need for cloud and moisture (and precipitation) analyses.

The focus of this task will be on the analysis and assimilation needs of the three WRF runs listed above *specifically for stratiform clouds and parameterized convection* (distinguished from Task 5.5 focused on GSI 3DVAR development for the Rapid Refresh application and Task 5.19 on assimilation of radar data). Within this task, research and development on the use of radar data will be restricted to the use of reflectivity data to improve hydrometeors fields and specify latent heating fields.

The present RUC uses both GOES and METAR cloud observations (in the RUC13), within a variational outer loop to interact with the assimilation of in-situ and precipitable water moisture data. The assimilation of observed precipitation for the NAM (a.k.a. diabatic initialization) is currently performed with an adjustment (nudging) approach that actually takes place in the prediction model component of the NAM Data Assimilation System.

This task will focus on improvements that will result in better moisture and cloud fields for initializing the WRF prediction model. It will be accomplished by working to improve the analysis algorithms and through continued efforts to improve the utilization of observations of clouds, hydrometeors and precipitation using satellite, surface, and radar observations.

GSD made considerable progress in FY04-06 on its assimilation of METAR cloud data and a much improved technique for GOES cloud-top assimilation. In FY06, GSD and NCEP implemented a diabatic digital filter initialization (DFI) (without radar reflectivity assimilation) into the experimental RUC13. In FY07, GSD has developed a procedure for applying radar reflectivity-based and lightning-based latent heating during the diabatic DFI. This technique has shown promising results in real-time parallel RUC tests at GSD and is now in testing at NCEP toward an early 2008 RUC NCEP operational implementation bundle. GSD has also tested a further extension to the RUC cloud/hydrometeor assimilation by assimilating radar reflectivity using simple reflectivity-to-hydrometeor mixing ratio relationships.

NCEP has currently put only a bare-bones version of diabatic initialization into its NAM-WRF. Observed precipitation (based on our Stage 2 and Stage 4 precipitation analyses http://wwwt.emc.ncep.noaa.gov/mmb/ylin/pcpanl/) is only used to directly drive the surface energy balance. There is no nudging in the NDAS to this field or the GOES cloud top pressure fields we had been using in the non-WRF-era in with Eta and its EDAS. In FY2008, NCEP would like to implement in full this diabatic initialization (and improvements thereto) in the NAM-WRF. Special emphasis will be placed on evaluating the impact of the one-sided approach used in the EDAS of only deleting model cloud above GOES sounder cloud-top pressures since this may be systematically depleting moisture. NCEP will also work with GSD on possible use of the RR cloud fields in NAM diabatic initialization.

Efforts at NCEP will also focus on the use of Level II reflectivity in the diabatic initialization. These efforts were postponed in prior years due to delays in the arrival of the Level II 88D data. The routine transmission to NCEP of the national collection of archive Level II 88D radar data began 3rd Quarter FY2005. In FY2006, NCEP took advantage of an NSSL-NCEP partnership (funded outside of AWRP) in which NCEP acquired code to quality control Level II 88D reflectivity. This code was part of a larger product generation capability that produces a national mosaic of reflectivity. NCEP's initial approach will be based on a simple reflectivity-to-precipitation rate (Z-R) scheme designed specifically for the Ferrier microphysics used in the WRF-NMM. This is the Z-R scheme that generated simulated reflectivity from WRF-NMM runs for the first time in the winter 2005 DWFE. It will be used initially to directly convert the reflectivity "error" (difference between mosaic and model predicted values of Z) to "corrections" to be applied directly to the model's hydrometeor fields. Efforts will be begun in FY2008 to investigate use of this relationship as a forward model so that its Tangent Linear Model could be used in a more general (and less direct but more powerful) way to project corrections onto the model's state variables.

Following initial implementation of just the bare bones use of analyzed precipitation in the land-surface physics in WRF-NMM in NAM in June 2006, NCEP will continue efforts during FY2008 to improve the use of cloud, precipitation and reflectivity data and all aspects of the diabatic initialization. Efforts will also concentrate on methods to improve use of cloud (satellite and surface) observations in the diabatic initialization and use of moisture observations, especially those from the WVSS-2 ACARS, in the WRF-GSI. Early FY2008 will include implementation of the March 2008 upgrade package for NAM while during the remainder of FY2008, development efforts will target the upgrade package to be applied to NAM in March FY2009.

Before 4DVAR or EnKF method is implemented operationally, the physics-based complex cloud analysis procedure is still the most effective way of assimilating the reflectivity observations. Several published papers, mainly by the CAPS group, have carefully documented the positive impact of reflectivity data assimilation via cloud analysis, in a 3DVAR framework, for several different types of convective systems. More recently, CAPS linked its complex cloud analysis package with WRF GSI and used the final analysis to initialize WRF-ARW for an individual case. A very good prediction of a cluster of convective systems is obtained with this initial condition for the entire life cycle of the system, and the forecast at 9 km resolution is far superior to that obtained without radar data starting from the initial time. However, this is a strong convective case, and the generalization of the cloud analysis technique for other types of precipitation systems and clouds, combined with other cloud observations, is needed.

GSD and CAPS will continue to work together on further developing a generalized cloud analysis for the Rapid Refresh GSI. This will include improved use of GOES satellite cloud data and METAR cloud data, especially for estimating cloud depth, currently set as fixed in the RUC cloud analysis. GSD will also investigate special considerations regarding initialization of clouds over Alaska and other arctic regions using satellite data (possibly POES data) and

METAR data.   GSD will also review the possibility of including the GOES fog / low-level 3.9 micron product, which may help to improve the horizontal definition of low cloud coverage in important low-ceiling/visibility conditions.

GSD will further test the use of radar data to specify latent heating within the diabatic digital filter initialization (DDFI) for the WRF model to be used in the Rapid Refresh.   Specifically, GSD will evaluate and improve the performance of the DDFI to ensure that it produces effective initial 3-D cloud and hydrometeor fields.   All work on using the radar-enhanced DDFI for the 3-km HRRR is covered under task 5.19.

Collaboration will continue between CAPS and GSD in building a unified cloud analysis system within the GSI framework, using GSI's realtime data stream. An initial version has been developed based on the ARPS and RUC cloud analysis systems. The cloud analysis is designed to handle both stratiform and convective precipitation, and will initially be tuned for 8-13 km grid spacing for implementation in Rapid Refresh and NAM, and later WRF high-res windows. The system needs to work well with a combination of cumulus parameterization and explicit microphysics at ~10 km resolution, and make use of all available sources of cloud observations, including radar reflectivity, METAR multi-layer cloud observations, and satellite cloud data, and lightning data, using the same structure as the RUC13 cloud/hydrometeor analysis technique. Further refinements of this generalized system include modifications of the reflectivity equations to be compatible with the microphysics scheme likely to be used within the Rapid Refresh (the new NCAR/RAL Thompson scheme), and optimization of the in-cloud temperature adjustment scheme for target resolutions of the RR. The cloud analysis procedure will also include the removal of spurious precipitation in the analysis background. Improvement to clouds, ceiling and visibility and convective forecasts will be the emphasis.

Subtasks

08.5.15.1   31 October 2007 (NCEP)
Based on parallel testing and refinement of the experimental code, deliver the 'pre-implementation' code to NCO including improved diabatic initialization (e.g. nudging to analyzed precipitation and GOES cloud-top) for the March 2008 NAM change package.

08.5.15.2   30 Jan 2008 (GSD)
Develop and evaluate performance of diabatic digital filter initialization (DDFI) in the RR WRF model without use of radar data

08.5.15.3   30 March 2008 (GSD and CAPS)
Further refine the generalized cloud analysis for the target RR resolution, model physics scheme and use of additional data. Perform forecast test evaluations to document the impact of the cloud analysis refinenents.

08.5.15.4   30 May 2008 (NCEP)
Based on development efforts, deliver 'research quality' diabatic initialization upgrades (e.g. initial use of Level II reflectivity) for consideration in the March 2009 change package for NAM.

08.5.15.5 30 Mar 2008 (GSD)
Include radar reflectivity-based latent heating within diabatic digital filter initialization (DDFI) in the RR WRF model

08.5.15.6 30 July 2008 (NCEP)
Based on case-study testing and refinement of the research quality code, an 'experimental' WRF code is delivered with diabatic initialization upgrades (e.g. initial use of Level II reflectivity) for the March 2008 change package for NAM.

Deliverables

08.5.15.E1 30 March 2008 (NCEP)
Subject to NCEP Director approval, the WRF-NMM code with upgraded diabatic initialization capability (e.g. nudging to analyzed precipitation and GOES cloud-top) becomes Operational at NCEP as part of the March 2008 change package to NAM.

08.5.15.E2 30 Aug 2008 (GSD)
Complete testing of GSI generalized cloud analysis for Rapid Refresh and deliver code to NCEP as part of Rapid Refresh package delivered to EMC, pending availability of NCEP testing capability.

Task 08.5.6
FY 2008, Priority 7: Develop, test, and evaluate the performance of the nonhydrostatic WRF modeling system.

Description

In June 2006, the WRF-NMM and WRF-GSI were implemented in the operational NAM/NDAS by NCEP. The support infrastructure for the operational running of this model is covered under Task 08.5.17. NCEP and GSD are planning continued development efforts of the WRF-GSI under Tasks 08.5.5 (GSI), 08.5.9 (Turbulence assimilation) and 08.5.19 (Level II 88D radar assimilation).

GSD has decided to use the WRF-GSI for the Rapid Refresh WRF but the decision on dynamic core awaits a final decision in Spring 2007. Development efforts for WRF-GSI in the Rapid Refresh are necessary. NCEP is planning continued development efforts for GSI (see Task 08.5.5). A major component of change for analyses and assimilation systems is the continued evolution of the available satellite data sets. The satellite platforms evolve constantly, as satellites with new or different instrument capabilities are launched or existing satellites have their instruments fail or become unstable / unreliable. Assimilation techniques are also expected to improve (e.g., the ability to assimilate satellite imager data is likely to become feasible). To minimize the considerable effort needed to incorporate these changes, close coordination with the Joint Center for Satellite Data Assimilation (JCSDA) will need to be sustained.

In addition to the WRF-GSI, NCEP is responsible for development and maintenance of all NMM-specific capabilities within the end-to-end WRF modeling system. In this, NCEP is aided by Beth Weekley and Jamie Wolff at the DTC. This includes primarily the WPS and real codes, the NMM prediction model, the NMM physics options (and interfaces), the nesting capabilities in NMM. NCEP also supports BOTH dynamic cores through its WRF post-processing, product generation and verification codes all of which are used at DTC for objective model evaluation. Further, NCEP operational requirements necessitate use of machine-binary rather than NetCDF and it has been solely responsible for these capabilities in the WPS and “real” programs. NCEP is also responsible for the suite of WRF physics contributed from NCEP’s Global Forecast System (GFS). In FY2008, NCEP will concentrate development efforts on nesting, digital filtering, implementing latest WRF versions including the new WPS and real codes issued by NCAR in FY2006 to which NCEP will add the NMM capabilities, improvements to the non-cycled WRF-based components of the NCEP operational suite (the HiRes Window and Fire Weather/IMET Support runs) and exploratory research on the use of NMM nesting in NAM and to perform the Fire Weather/IMET Support and Homeland Security runs.

The goal of the WRF model applications in the Rapid Refresh and North American Mesoscale versions is ultimately to resolve convection explicitly, which is considered possible at resolutions finer than 5 km. This will require an additional 12-15-fold computational increase to move from the initial WRF-RR and WRF-NAM implementations in 2008-2009. It will not be possible to treat convection explicitly prior to 2013 in the WRF-RR or WRF-NAM.

However, the proposed High-Resolution Rapid Refresh (HRRR, Tasks 08.5.24, also partially under 08.5.19) is an initial step toward hourly-updating 3-km convection resolving model forecasts. Also, in FY2005, NCEP was able to push the resolution of its HiResWindow runs close enough to the 5-km limit to turn off convective parameterizations. In 2007, resolution and domain size will both have been increased. These runs are made four-times per day for six different domains. These runs are considered a promising testing ground for improvements to explicit cloud and precipitation modeling.

These runs are also considered a promising testing ground for attempts to better initialize convective areas and precipitation in general. While there is no current HiResWindow initialization other than through WRF SI or WPS, NCEP is willing to consider performing a brief WRF-GSI data assimilation as part of these runs. Data from a three hour period would be assimilated and would allow a shift in the nominal model start times from 00z, 06z, 12z and 18z to 03z, 09z, 15z and 21z. The mini-assimilation period would take advantage of observational data arriving in the roughly 4 hours between their nominal start times (0,6,12 & 18z) and their actual (clock) start times (4,10,16 and 22z).

Doppler radial velocity and reflectivity should be assimilated into the model in a way consistent with the model resolution and model physics, and spurious or mislocated storms in the model background should either be removed or corrected by shifting in space so as to retain information about the model storm structure. The cloud microphysical variables should be initialized consistent with microphysics parameterization, and research in assimilating dual-polarization data should begin, as the operational WSR-88D radars will start to be upgraded in 2009 to include these measurements.

As it has in the past, NCAR/MMM will organize and put on the annual WRF Users' Workshop. It will also conduct an ARW tutorial. In support of the development and enhancement of the Rapid Refresh, MMM will address the incorporation into WRF of new physical schemes and physics improvements. This is necessary for the ongoing advancement of the base capability of the RR and to ensure that it is benefiting from the advancements made in the research community. This will include collaboration with MDE team members GSD and RAL as appropriate as their developments for the RR are ready for inclusion. MMM will perform the necessary code testing for the implementation of new code in the WRF repository.
Working with GSD, NCAR/MMM also shall begin analysis of a digital filter initialization (DFI) capability for the Rapid Refresh (ARW core). By way of background, imbalances between mass and wind in the initial conditions can trigger spurious high-frequency oscillations (i.e., noise) in RR integrations. For data assimilation cycles, the noise can degrade the subsequent analyses. MMM shall collaborate with GSD on evaluation of a DFI scheme for the ARW to remove such noise, considering prototypes at both NCAR and GSD.

Subtasks

08.5.6.1 15 May 2008 (NCEP)
Commit to WRF Repository the changes embodied in operational WRF codes used in NAM upgrade package of March 2008.

08.5.6.3 30 July 2008 (NCEP)
Maintain and further develop WRF Preprocessing System (WPS) and Land-Surface Model static fields, including updates to all documentation, in response to community requirements.

08.5.6.5 1 September 2008 (NCEP)
Maintain and further develop WRF Post-processing system including necessary RUC capabilities and updates to all documentation, in response to community requirements.

08.5.6.6 30 June 2008 (NCAR/MMM and DTC)
Deliver a WRF Users' Workshop and a tutorial on the ARW core (NCAR) and a tutorial on the NMM core (DTC) for the user community.

Deliverables

Option A

08.5.6.E1 30 June 2008 (NCAR/MMM and DTC)
Deliver a WRF Users' Workshop and a tutorial on the ARW core (NCAR) and a tutorial on the NMM core (DTC) for the user community.

08.5.6.E2 30 September 2008 (NCAR/MMM)
Incorporate physics improvements from the user community, GSD, and NCEP into the WRF software infrastructure for use in the Rapid Refresh model. Perform code testing to permit implementation into WRF repository. In collaboration with GSD, assist in the evaluation of those physics schemes for the RR that may be tested using the ARW.

Task 08.5.24 (Task 5.6a in Sept 06 FY07 plan)
FY 2007, also Priority 7:
Test WRF Rapid Refresh model at 3-km resolution toward High-Resolution Rapid Refresh

Task 5.24 specifically treats development and testing of the 3-km HRRR model itself. Development and testing work on assimilation of radar data at the 3-km scale is under Task 5.19.

Requirement for HRRR
Accurate, rapidly updated (at least hourly) forecasts of convective storms are probably the greatest need for improvement in aviation weather services. Summertime convection is the foremost weather-related problem for U.S. aviation weather and the National Airspace System.

How to fulfill the requirement
Improved forecasts of convective storms, critical for aviation and many other national needs, require

- Horizontal resolution in the **1-3km range** to resolve convective storms. Resolution of 5 km is borderline, and resolution of 8-13km is clearly inadequate.
- **Hourly updating** using current conditions, including radar data, since convective time scales are less than 1h.
- New forecasts produced within 30-45 minutes of initial time.

Limitations of current and planned NOAA models
Currently, NOAA and NCEP support models toward convection forecasts toward aviation needs, but with critical shortcomings for each:

- Rapid Update Cycle (RUC) and upcoming WRF-based Rapid Refresh (RR)
  - Advantage: Hourly updating
  - Shortcoming: Inadequate horizontal resolution (13km with current RUC and 13km with initial Rapid Refresh)
- North American Mesoscale (NAM) model
  - Shortcomings:
    - Inadequate horizontal resolution (currently 12km, down to only 8-10km by 2008)
    - Updated only once every 6 hours

- Hi-Res Window (HRW)
    - Advantage: Run at about 4.5 km resolution
    - Shortcomings:
        - Run only once daily

<u>Proposed High-Resolution Rapid Refresh (HRRR) characteristics / evolution</u>
(in addition to those shown above under "How to fulfill the requirement"):

- Start with limited eastern U.S. domain initially from 95 W to 65 W. Subsequent westward extensions to 110 W and 130 W.
- Perform data assimilation focusing on 3-d radar reflectivity, probably using current Rapid Refresh analysis as background (already incorporating data including all other observations on a coarser resolution)
- Cycle frequency: Run HRRR cycle at least hourly, increase to 30 min
- Forecast duration: at least 6h every hour.
- Output frequency: at least every 15 min.
- Complete HRRR assimilation and 6h forecast within 30 min.
- Increase domain size westward over all of CONUS, increase forecast duration to 12h hourly.
- Enhancements after initial version in subsequent years.
    - Horizontal domain buildout from northeast corridor domain to include central/southern US and full CONUS coverage, contingent on NCEP/CCS enhancement funding.
    - Increase frequency from every 60min to every 30min.
    - Increase forecast duration from 6 h to 12h (and longer), again dependent on targeted CCS augmentations for the HRRR.

GSD and NCAR/MMM will collaborate with running experimental versions of the HRRR as shown in the tasks below. The goal of the WRF model applications in the Rapid Refresh is ultimately to resolve convection explicitly, which is considered possible at resolutions finer than 5 km. The 3-km resolution chosen for the HRRR was based on previous experiments at 3-5km by NCAR/MMM, CAPS, and NCEP. As has been learned by NCAR through its analysis of the developing WRF model in such regimes, model behavior, and how to improve it at convection-permitting scales, is not well understood. Thus, in collaboration with GSD, NCAR will perform selected RR simulations at 3-km grid scales and evaluate the results to identify strengths and weakness of the model at high resolution. The goal is to work toward the preparation of the system and its users for that advanced application.

OPTION B, C.

Subtasks
08.5.24.1 30 October 2007 (GSD)

Begin regular experimental tests of 3-km HRRR using radar-enhanced RUC or Rapid Refresh initial conditions.

08.5.24.2 15 August 2008 (NCAR/RAL and NCAR/MMM)
Evaluate techniques for convection-permitting (e.g., 3-km) forecasting by the ARW core in preparation for development of high-resolution RR (HRRR). Perform and evaluate convection-permitting forecasts on test cases using radar-enhanced RUC or Rapid Refresh (13-km) grids from GSD for initial condition fields to identify strengths and weakness of model at high resolution. Perform fully-explicit tests and include evaluation of short-term forecast results.

08.5.24 30 September 2008 (NCAR/RAL and NCAR/MMM)
Collaborate with GSD on analysis of convection-permitting tests. Draft and deliver summary of results.

Option B – Tests every 2h during warm-season test periods.
Option C – Tests every 2h during cold-season (for Winter Weather application) and warm-season test periods.

Deliverables

08.5.24.E1 30 July 2008 (NOAA/ESRL/GSD)
Option B - Complete FY08 test with small NorthEast U.S. domain with 3-km High-Resolution Rapid Refresh running every 2 h.
Option C – Add cold-season near-real-time experiments for winter period and extended summer test period along with improved interaction with Convection Weather PDT and Winter Weather PDT.

08.5.24.E2 15 August 2008 (NCAR/RAP and NCAR/MMM) **-** Option B2, C
Evaluate techniques for convection-resolving (e.g., 3-km) forecasting by the Rapid Refresh (ARW core) in preparation for development of high-resolution RR (HRRR). Perform and evaluate RR convection-resolving forecasts on test cases using radar-enhanced RUC or Rapid Refresh grids from GSD to identify strengths and weakness of model at high resolution. Evaluate effects of transition from 13-km parameterized convection to 3-km resolved convection in 0-3h forecasts and in lateral boundary conditions from the RUC or Rapid Refresh using the Grell-Devenyi parameterization.

08.5.24.E2 30 September 2008 (NCAR/RAP and NCAR/MMM)
Collaborate with GSD on analysis of results. Draft and deliver summary of results.

Task 08.5.19

FY 2008, Priority 8: Develop ability to assimilate WSR-88D radial velocity and reflectivity data through GSI and Rapid Refresh toward High-Resolution Rapid Refresh.

OPTIONS B and C only

Description

As described previously under Task 08.5.15, the aviation needs for improved cloud/hydrometeor assimilation are for three different cloud situations:

- Stratiform cloud
- Convective cloud at parameterized scale (~10-13km)
- Convective cloud at explicit scale (<4 km)

This task (05.19) includes development for convective cloud assimilation for explicit horizontal scales using radar reflectivity data.

GSD, CAPS, NCAR, NCEP

In FY2008, GSD will start work on a 3+ year effort, in collaboration with CAPS, NCAR, and NCEP, toward a demonstration ***High-Resolution Rapid Refresh (HRRR)*** to run at **3-km** resolution with **hourly updating** in continuing cycling and assimilation of 3-d radar reflectivity and radial wind data. The HRRR will initially be tested over a regional area covering the NorthEast Corridor area including Chicago through New York City and Boston, on a GSD/ESRL computing environment. FY08 will be an initial year for HRRR design and development, although it will incorporate techniques already considered and tested in the research community.

Task 5.19 treats the radar assimilation development and testing specifically for the 3-km HRRR. The HRRR will finally allow a plunge into full explicit convection modeling with real-time hourly assimilation. The HRRR is necessary to frontally attack the convection problem, currently identified as the foremost weather problem for aviation in general and for the National Airspace System (NAS) in particular. Both the **3-km resolution** and **continuing refreshing on at least an hourly basis** are essential in order to bypass the pitfalls associated with convective parameterizations to be used for the RR and NAM into the next decade. The hourly (or less) assimilation is critical especially considering the short time scale typical of convection (~1-3 h or less). The HRRR will be also built on a version of the WRF model and GSI (similar to that for the Rapid Refresh) but operating at 3-km horizontal resolution and using new techniques for radar assimilation. While the HRRR could not be fit into current NCEP CCS plans for computer power, a demonstration limited-area version will be developed over the next 2 years at GSD led by GSD in collaboration with CAPS, NCEP, and NCAR.

In FY07, GSD has successfully developed an initial technique for assimilation of 3-d radar reflectivity data (from NSSL mosaic) through the diabatic digital filter initialization (DFI), which allows latent heat nudging during the forward part of the DDFI step. This radar-DDFI technique is currently running in the experimental devRUC13 cycle at GSD with considerable success. In FY08, GSD (with help from NCAR/MMM) would test the radar-DDFI technique in the WRF-Rapid Refresh model at the HRRR 3-km resolution.

Active collaboration is under way between CAPS and GSD in building a unified cloud analysis system within the GSI framework, using GSI's PrepBUFR data stream as used currently in the RUC (under 5.15).

CAPS will also work on the variational assimilation of Level-II reflectivity data in GSI, including development of more accurate forward operators and their adjoint for reflectivity data, and the derivation of statistical relations among microphysical and thermodynamic variables as needed to unambiguously determine hydrometeor species from reflectivity data. Physics-based relations currently used in complex cloud analysis may also be needed.

NCEP

In FY 2008, NCEP will continue the efforts it began in FY2006 to refine use of Level II 88D radar data in its WRF-GSI analysis system. In June FY2006, the NAM-WRF and its GSI were the first NCEP operational data assimilation system to use Level II 88D data directly within the variational solver. Unfortunately, attempts to get significant additional positive impact from the use of Level II radial velocity in the NAM were largely unsuccessful. This was considered a minor setback since modest positive impact had been demonstrated from the use of the so-called Level 2.5 (superob winds computed on site) in 2005 and use of the Level II winds directly was expected to yield additional benefit.

Efforts in FY2008 will be directed to improving our ability to extract useful information from the Level II radial winds. The impact of vertical velocity will be considered in the forward model of radial wind in GSI, the forward model will be more accurate and therefore improve the analysis. The radar radial wind quality control package will also be further improved, especially for the velocity aliasing problem. Radar reflectivity assimilation work will also begin based initially on the NSSL reflectivity mosaic and will include development of unified treatment for both radar reflectivity and other cloud/hydrometeor observations compatible with NCEP's GSI.

In 2006, NCEP built a small domain high-resolution data-assimilation system that could provide initial conditions for the HiResWindow runs of WRF-ARW and WRF-NMM at ~5 km resolution. The plan is to perform analyses and 1 hour forecasts from the current start times of 00z, 06z, 12z and 18z to 03z, 09z, 15z and 21z and then start the free forecast. This system would bring in the latest arriving observations and take advantage of the high resolution. By assimilating hourly, more of the radar data will be used than is being used in the NAM where updates in the data assimilation are every 3 hours. By assimilating at the 5 km resolution, more of the radar data will be used than would be used in the 13 km RUC / Rapid Refresh and the higher resolution would require less superobbing in space and time. While NCEP is a year or two away from implementing this capability, this has proven to be an ideal test system for GSI-based use of Level II data in the meantime.

Hourly assimilation using present methods requires substantial I/O data transfer. The largest file associated with WRF is its restart file. For a single analysis update this file must be read or written four times: write out of the model, read into the analysis, write out of the analysis and read back into the model. It is NCEP's intention to eliminate all of this data motion during data assimilation by incorporating the GSI analysis as a subroutine call in the WRF model.

Subtasks

OPTION B.

08.5.19.1 30 November 2007 (GSD, NCAR/RAL, CAPS)
Select initial case studies from summer 2007 for 3-km HRRR data assimilation case studies.

08.5.19.2 28 Feb 2008 (GSD)
Develop and test 3-km version of radar-reflectivity-based diabatic digital filter initialization (DDFI) and perform initial tests on cases. Revise during FY09 based on GSD tests and associated testing to be performed by NCAR/RAL.

08.5.19.3 30 March 2008 (NCAR/RAL)
Provide wind/temperature/moisture profiles for HRRR case studies using VDRAS for case studies. Provide these profiles to CAPS for GSI data assimilation experiments for 3-km HRRR.

08.5.19.4 30 June 2008 (NCAR/RAL)
Complete case study tests using radar-DDFI-enhanced WRF-HRRR model at 3-km. Report on effect on 0-3h forecasts using 3-km radar-DDFI assimilation.

08.5.19.5 31 August 2008 (CAPS)
Complete 3-km GSI data assimilation experiments for potential application within the HRRR assimilating radial wind and RAL-provided VDRAS profiles. Evaluate impact using 3-km HRRR-WRF model configuration as used by GSD.

08.5.19.6 January 2008 (NCEP)
Prepare for the expected doubling of Level II data volume due to the modified and additional VCP strategies.

08.5.19.7 15 July 2008 (NCEP)
Report on progress towards incorporating Level II reflectivity through the GSI analysis into the WRF model runs.

Option C addition.

08.5.19 30 August 2008 (GSD, CAPS, NCAR/MMM)
Data assimilation development and testing as described in Option B2 are also conducted for winter cases to provide an improved data assimilation capability ready for real-time application by this date.

08.5.19 30 March, 30 Sept 2008 (GSD)
Develop two versions at each of these dates of radar reflectivity-based latent heating within

diabatic digital filter initialization (DDFI) in initial test version of 3-km HRRR. The first version will be used for summer 2008 real-time experiments, and the second will be ready for winter 08-09 experiments and spring 2009 experiments.

08.5.19 30 September 2008 (GSD, CAPS)
Exploratory work on ensemble Kalman filter from time-lagged HRRR

08.5.19 15 September 2008 (NCEP)
Demonstrate mini-data assimilation system using HRRR design from 1 March plan constructed to precede HiResWindow runs using hourly updates with GSI.

Deliverables
OPTION B.
08.5.19.E1 31 August 2008 (GSD, CAPS, NCAR, MIT/LL)
Report on radar assimilation results for HRRR from summer 2008 test under the lead of GSD with contributions from each organization.

08.5.19.E2 30 March 2008 (NCEP)
Subject to NCEP Director approval, implement upgrade package to WRF-GSI (e.g. improved use of Level II radial velocity) in the NAM and NDAS runs.

OPTION C only.
08.5.19.E3 31 July 2008 (GSD, CAPS, NCAR, MIT/LL)
Provide additional report on radar assimilation results for HRRR from winter 2007-08 case studies under the lead of GSD with contributions from each organization.

<u>Task 08.5.20</u>
FY 2008, Priority 9: Develop ensemble-based probabilistic products for aviation users.

OPTION C only.

Description

This task will continue efforts to improve the Short-Range Ensemble Forecast (SREF) system at NCEP with its annual upgrade and continued development of both grid-based and site-specific SREF products for aviation interests in accord with recommendations and suggestions by AWC and the AWRP. In early FY2006, 6 WRF members were added the operational SREF running at NCEP. Three each were based on WRF-ARW and the other three on WRF-NMM. Each set of three consisted of a control run with no initial condition perturbation plus a pair of runs using Bred Mode perturbation applied with positive and negative sign. The primary challenge of this implementation was getting the WRF (version 2.0) members to fit into the designated runslot and, eventually, coarser resolutions were chosen to accomplish this.

Despite the lack of FAA funding in FY2006 and FY2007, it is felt that results to this point establish the fundamental utility of the SREF approach for aviation interests. Clearly, funding this task ensures that the value of this approach is refined and enhanced as the component forecast models improve and especially as ensemble strategies become more optimal. The goal is the highest possible skill in providing reliable probability distributions of the parameters relevant to aviation on the temporal and spatial scales required. Effectively, that translates to maximizing the ability to reliably specify confidence limits of aviation-relevant parameters on the smallest space and shortest time scales possible.

Thus, improving SREF depends very much on continued model development. A NWS goal is to produce a SREF made up entirely of different WRF members utilizing diversity in WRF dynamic cores and physics. Improvement is expected from enhanced ensembling in the context of increasing ensemble size, higher model resolution, perturbing model physics (as well as initial conditions), and including additional model configurations. Much effort will be required to weigh the relative merits of these and other options, and ultimately to decide on tradeoffs that will be required as a function of available computer resources. Also, as the SREF system evolves, so too will the ability to generate new products and improve upon the old, e.g., more reliable and more highly resolved probabilities through statistical post processing.

FY2008 will begin by completing the implementation of developments accomplished in FY2006 (without AWRP funding): a bias correction scheme for SREF, upgrade WRF to version 2.1.2 (or higher), higher resolution for 6 WRF members (closer to Eta members' 32 km), aviation/AWC demanded grid 221, and ensemble BUFR soundings.

The remainder of FY2008 will find NCEP seeking the optimal WRF-based SREF configuration in order to determine whether configurations of WRF members (dynamic cores, physics, initial and lateral boundary conditions) provide sufficient diversity of solution ("spread") and the same quality of probabilistic guidance to replace the multi-model approach used now with Eta, RSM and WRF, and RUC. It is NCEP's strong desire to utilize physics suites – packages of physics that have been run in one environment or another for many realizations and which have been found to work well together. It is highly likely that the following physics suites will be available for consideration: ARW physics from NCAR, NMM physics from NCEP, Rapid Refresh physics from GSD, GFS physics from NCEP and COAMPS physics from NRL. Lateral boundary diversity is plentiful at NCEP coming as they do from the Medium Range Ensemble Forecast System. Initial condition uncertainty can be sampled via the current bred-mode approach or through the new Ensemble Transform method going into the MREF in May 2006 but this latter approach must be adapted from the global context into the WRF limited area context.

GSD will develop an initial component of an aviation-targeted Very Short-Range Ensemble Forecast (VSREF), updated hourly with members from hourly RUC forecasts, recent NAM and GFS forecasts, and even longer-range SREF members. VSREF will extend the SREF structure toward rapid-updated probabilistic aviation products. A first component of the VSREF will be to adapt the RUC/NAM Convective Probabilistic Forecast (RCPF). Consistent with the initial GSD/EMC work toward the VSREF, the NWS Science and Technology Infusion Plan speaks of supporting 6-dimensional databases: a variable; 3-D space; time; and with probabilistic bounds.

Subtasks

08.5.20.1 15 January 2008 (NCEP)
Complete 'research quality' version of upgrade to SREF (e.g. higher resolution, more WRF members and more physics diversity) for consideration in November 2008 SREF upgrade package.

08.5.20.2 15 February 2008 (NCEP)
NCEP visits AWC to conduct continued training and education on SREF applications, receive feedback on existing guidance, and to acquire new requirements (fully depending on FAA funding).

08.5.20.3 15 April 2008 (NCEP)
NCEP develops and delivers a new fog algorithm used in the SREF product for aviation (fully depending on FAA funding, $60K requested).

08.5.20.4 31 August 2008 (NCEP)
Based on case-study testing and refinement of the research-quality code, deliver the upgrade SREF codes to NCO for November 2008 SREF upgrade package.

08.5.20.5 31 March 2008 (GSD and NCEP)
Develop a preliminary procedure appropriate for aviation users from Very Short-Range Ensemble Forecast (VSREF) system using high-resolution RUC and NAM existing runs.

08.5.20.6 1 July 2007 (GSD and NCEP)
Further calibrate probabilities and potential echo-top (improve statistical reliability) ensemble cumulus information.

Task 08.5.9 (not funded in previous years)
FY 2008, Priority 10: Assimilate turbulence observations directly into the WRF systems running in Rapid Refresh and NAM.
Description

As of 2007, two different kinds of automated real-time turbulence observations from commercial aircraft are now available, eddy dissipation rate (EDR) using the NCAR algorithm (flying on United Airlines 757s), and now additional EDR data via TAMDAR. Additional automated turbulence reports using derived equivalent vertical gust (DEVG) data are being made by European and Australian commercial carriers.

MDE proposes for FY08 to conduct initial comparisons the EDR observations between RUC gridded EDR and TKE observations using a database similar to that developed by Bill Moninger for monitoring aircraft wind, temperature, and relative humidity and their systematic differences (bias, mean absolute) with RUC 1-h forecasts from different versions of the RUC. This work will be coordinated with the work of the Turbulence PDT, where ongoing comparison evaluations of EDR observations vs. GTG grid values continue.

NCEP continues to routinely receive and process aircraft turbulence data from all the equipped aircraft that report through ACARS. These data pass through ARINC and are put into the MDCRS format, which has space for turbulence as well as moisture (WVSS-II). Data assimilation is an essential tool for extracting useful information from these reports. NCEP can monitor these data and their correspondence to model fields by adding a turbulence metric to its verification package. In order to better reflect the model environment, the WRF-POST must be expanded to include the various turbulence diagnostics (see 5.17 also).

These proposed observation-model comparisons proposed above are a prerequisite for attempting assimilation of turbulence observations, requiring a forward model from multivariate 3-d model fields to EDR (or DEVG) and their adjoint. We propose to leave this work until FY09, should this task become important enough to finally allow funding from AWRP.
GSD and NCEP must connect the observed turbulence observations, which NCEP has been ingesting since 2003, to the GSI assimilation code (being used for the RR and NAM) as a passive two-dimensional variable for updating.

Subtasks

08.5.9 30 March 2008 (GSD)
Work toward initial capability to compare TAMDAR and other EDR measurements with RUC gridded data via aircraft-model data base similar to that used previously for monitoring aircraft wind/temperature/moisture observations broken out by aircraft tail number.

08.5.9.1 15 March 2008 (NCEP)
Connect observed turbulence metrics to the processed PREPBUFR file used by the GSI analysis.

08.5.9.2 15 August 2008 (NCEP. GSD)
Incorporate turbulence metric as passive 2D variable in GSI analysis.

Deliverables

08.5.9.E1 31 July 2008 (GSD)
Complete initial capability to compare TAMDAR and other EDR measurements with RUC gridded data via aircraft-model data base similar to that used previously for monitoring aircraft wind/temperature/moisture observations broken out by aircraft tail number.

<u>Task 08.5.12</u>
FY 2008, Priority 11: Develop adjoints for physical processes in forecast models

Development of the adjoint model for each of the physics packages in WRF is a major undertaking that is essential to achieve a fully functional 4DVAR data assimilation system. In addition, a number of physical parameterizations contain switches whereby different physical process are invoked depending on the value of certain model parameters. These switches introduce fundamental nonlinearities and discontinuities in gradients in the system that cannot be represented within the adjoint model. Consequently, research is needed to replace these switches with processes that produce continuous variation while maintaining the accuracy of the parameterized physics. As the physics adjoints are written, they must also be adapted to the parallel version of the WRF 4DVAR system to achieve computational efficiency.

It is necessary to develop adjoints of physical parameterizations for mixed phase (water and ice) stable precipitation and for convective precipitation for the NAM-WRF and WRF Rapid Refresh models (including the Thompson/RUC microphysics and Grell/Devenyi convection). The purpose of the physical adjoints is for improved initialization of all fields in the model related to precipitation processes in either a 3DVAR or 4DVAR setting. The adjoints allow a much more sophisticated adjustment in the model fields consistent with the parameterizations so that there will be more accurate retention of precipitation observations.

Deliverable

08.5.11.E1 15 January 2007 (EMC)
Report on progress of community to produce reliable automatic adjoint compilers.

Task 08.5.21

FY 2008, Priority 12: Develop, test, and implement advanced data assimilation techniques for aviation versions of the WRF model.

Description

The 4DVAR method is able to account for the dynamics embodied in the model equations and to assimilate data distributed through time, but it requires the development of the adjoint code of the entire prediction model. An alternative method that may perform as well as or better than 4DVAR is the ensemble Kalman filter (EnKF) method, which uses a suite of ensemble forecasts to estimate flow-dependent background error covariances. Recent work at NCAR and at CAPS with simulated and limited real radar data has shown great promise for the EnKF method. Being a method that evolves the background error in time, it falls into the general category of Kalman filter, which is considered theoretically optimal. The EnKF is attractive because no adjoint model is necessary (adjoints require much resource to develop and are difficult to maintain), and a full nonlinear model is used to evolve the background errors. It has the added advantage of being able to provide uncertainties about the model forecast, the most important goal of an ensemble forecast. However, the EnKF method is not as mature as the 4DVAR method. It is still unknown how many ensemble members are required to adequately represent error correlations in the background or whether coexisting correlations at vastly different scales can be effectively estimated and used. The overall efficiency compared to 4DVAR is still unknown.

Work so far has been based mostly on simple models and simulated data, and EnKF performance may suffer in significant ways from model biases. Further research is therefore still needed.

Many years of basic research will be required before 4DVAR becomes a mature and affordable capability in the WRF modeling system. Operational implementation at NCEP/EMC is consequently many years away. Nonetheless, work should commence on this very critical task and interim solutions of a more affordable nature. NCEP, GSD, and CAPS will develop Ensemble Kalman Filter (EnKF) and simple 4DVAR capabilities that have the potential to be applied operationally toward aviation-relevant forecasts. As the adjoints for the model physics are developed (Task 07.5.11), they must be integrated into the overall WRF 4DVAR code and parallelized to provide computational efficiency, which is essential for these time-consuming computations. As the basic 4DVAR system becomes functional, comprehensive testing will be needed to determine both the value and computational cost of 4DVAR in comparison to the more mature 3DVAR system and the EnKF approach. To receive serious consideration for operational use, the timing of 4DVAR as compared to 3DVAR must be consistent with expected operational computing resources. Also, the impact of assimilating storm-scale Doppler radar data must also be assessed, particularly as the feasibility of convection-resolving NWP is investigated.

The EMC Director (Stephen Lord) has written a White Paper strategy for evolving 4DDA capability at EMC into the future. This plan includes investigations of 4DVAR as well as EnKF techniques in the longer term while concentrating on incremental improvements to the GSI in the short term. The Earth System Modeling Framework (ESMF), to which NCEP is committed, will contain a “coupler” between the two major components of a data assimilation cycle – the prediction model and the analysis update. Once built, this capability will need to be applied to the Operational data assimilation system and be used for both regional and global applications.

As an alternative to full 4DVAR, the current emphasis at NCEP with the GSI 3DVAR is to first add a term for incremental minimization of divergence tendency, using a generic terrain following adiabatic dynamics model (neither ARW nor NMM). This would be a grid-point version of the same model used in the operational Spectral Statistical Interpolation (SSI). If properly functioning, the incremental minimization of divergence tendency should eliminate the need for a digital filter and at the same time improve the fit to observed data. Using the tendencies, it is trivial (and at no significant extra expense) to add time extrapolation for assimilating off-time observations in the analysis time window. Using this in combination with the NCEP flow dependent background error covariance should result in an easily manageable, competitive, cost effective alternative to full 4DVAR.

The ensemble Kalman filter data assimilation capabilities for WRF will be further developed. As part of the testing for convection-resolving forecasts, the incorporation of radar data using the EnKF approach will be evaluated by CAPS and NCAR to determine their value in enhancing storm-scale initialization of the model. CAPS will also work on the problem of correcting erroneously placed features in the analysis background, such as the location of thunderstorm outflow boundaries. Correcting such analysis errors is very important when convective systems are explicitly initialized in model rapid refresh cycles.

Deliverables

08.5.21.E1 01 June 2008 (GSD, NCEP, CAPS)
Submit report on first tests of 4DVAR assimilation with the WRF model without physics.

08.5.21.E2 01 August 2008 (NCEP)
Report on initial tests using incremental minimization of divergence tendency in WRF-GSI as alternative to 4DVAR.

08.5.21.E3 30 September 2008 (NCEP)
Report on progress towards advanced assimilation in the ESMF era.

08.5.21.E4 15 September 2008 (CAPS)
Report results of EnKF assimilation of radar data with WRF.

Task 08.5.23
FY 2008, Priority 13: Develop advanced numerical models for aviation

Description

The current era of aviation modeling is focused on the RUC model (an isentropic-sigma hydrostatic model) and the WRF model dynamic cores (NMM and ARW) both non-hydrostatic and both using non-isentropic vertical coordinates. This task considers more advanced versions beyond these current models. The advantage of the isentropic-sigma vertical coordinate used in the RUC model (improved jet dynamics, upper-air turbulence, moisture transport, etc.) is being laid aside for the current WRF implementations in the NAM and the Rapid Refresh.

NCEP has proposed that a modification of the current ARW sigma-pressure formulation into an isentropic-sigma variation is possible and have collaborated toward this with an outside scientist in the WRF community. GSD has introduced the RUC isentropic-sigma vertical coordinate into a new global model formulation using an icosahedral grid (advantageous since global model grid points can be equally spaced) and finite-volume numerics (excellent conservation properties). This model is called the FIM (Flow-following finite-volume Icosahedral Model). GSD and NCEP are working toward including the FIM dynamic core as an alternative dynamic core in a new ESMF-based global model infrastructure being developed at NCEP.

Subtasks

08.5.23.2 15 May 2008 (GSD)
Continue work on GSD Flow-following Finite-volume Icosahedral Model (FIM) development. GSD and NCEP will continue to coordinate this work as a possible alternative dynamic core.

Specifically, GSD will provide preliminary isentropic FIM data to the Turbulence PDT and other PDTs for experimental evaluation, as required.

Deliverable

08.5.23.E1 30 Sept 2008 (GSD)
Submit report on development of the isentropic FIM models.

Tasks for FY 2009

Tasks for FY09 (and FY10) are in order of task number, <u>not</u> in order of priority.

<u>Task 09.5.1</u>
FY 2009, Priority 1: Infrastructure Support Related to Operational Running of the RUC.

Description

This task assures the reliable and timely running of the RUC in the NCEP Operational Suite and providing grid output (SAVs and AIVs) to aviation users. This activity is expected to be needed for only part of FY2009 – just until the Rapid Refresh WRF replaces the RUC.

Subtasks

October 2008 through date of implementation of RR-WRF:

09.5.1.1 Maintain hourly RUC runs and provide grids of SAV and AIV guidance products.

09.5.1.2 Provide vendors with gridded model data via Family of Services and the FAA Bulk Weather Data Telecommunications Gateway.

09.5.1.3 Provide full grids from RUC runs on NCEP and NWS/OPS servers.

09.5.1.4 Maintain access to model verification data.

Deliverables:

09.5.1.E1 Perform observation ingest, quality control and preparation in support of the operational RUC runs (NCEP, GSD).

09.5.1.E2 Perform configuration management for RUC, including thorough documentation, and respond promptly to any code malfunctions (GSD).

09.5.1.E3 Monitor RUC performance, respond to any problems detected by GSD, NCEP, or any RUC users, diagnose cause, develop solution to RUC software, and coordinate with EMC and NCO on testing. (GSD)

<u>Task 09.5.4</u>
FY 2009, Priority 3: Develop, test, and implement Rapid Refresh configuration of the WRF modeling system.

Description

Implementation of the Rapid Refresh application of the WRF is currently scheduled for FY 2009, assuming that most of the development work toward WRF and its focus toward the Rapid Refresh application that is critical for aviation interests was accomplished last year. However, a considerable number of additional changes are expected in FY2009 during the NCEP pre-implementation testing. In addition, considerable work will be necessary to communicate information on the WRF-RR system to users in the FAA, NWS, and specifically at AWC and SPC. This will include documentation in the form of papers, a technical procedures bulletin-like document, web forums, and in-person presentations.

Following the implementation, careful monitoring of operational RR performance by GSD will occur.

Subtasks

09.5.4.1 Ongoing (GSD, NCEP)
Ongoing evaluation of performance of real-time and retrospective runs of RR system for SAVs, AIVs,

09.5.4.2 1 Nov 2008 (GSD)
Continue to solicit input from other PDTs and NWS forecasters in Alaska and Puerto Rico, as well as AWRP PDTs, on performance of pre-implementation Rapid Refresh.

09.5.4.3 30 May 2009 (GSD, NCEP)
Complete evaluation of Rapid Refresh in accordance of NCEP pre-implementation checklist for major implementations. Respond to evaluation questions, present information on Rapid Refresh pre-implementation testing and evaluation results in various forums, as required.

09.5.4.4 30 June 2009 (GSD and NCEP)
Pending EMC, NCO, and NCEP recommendations, operational implementation of WRF-based Rapid Refresh.

Deliverables

09.5.4.E1 20 Dec 2008 (GSD)
Report on Rapid Refresh testing to NCEP Operational Model Suite Performance Review meeting.

09.5.4.E2 1 May 2009 (GSD, NCEP)
Complete documentation (in Technical Procedures Bulletin-like document) of WRF Rapid Refresh model.

09.5.4.E3 30 June 2009 (GSD, NCEP)
Implement WRF Rapid Refresh into operations pending favorable NCEP recommendations, and

operational capabilities and availability.

Task 09.5.5

FY 2008, Priority 4: Develop, test, and implement improvements to the operational GSI 3DVAR for Rapid Refresh and North American Mesoscale runs.

Description

NCEP will be incorporating its GSI into the NCEP ESMF. This will be done such that data assimilation can be accomplished without reading and writing large files between distinct analysis and prediction components. This is likely to be accomplished via the concept of ESMF "couplers".

A complete replacement of the operational systems with a WRF assimilation system will have commenced in FY 2006 with the substitution of the Eta 3DVAR by the WRF-GSI in the NAM-WRF and it will be completed this year with the replacement of the RUC 3DVAR by a WRF-GSI in the RR-WRF. In addition, there will be continued attention to the details of WRF-GSI treatment of the advanced satellite datasets. The most likely improvements in 3DVAR will come with new strategies for assimilating selected data sources, for example, GPS signal delay, radiances from new satellites, and WSR-88D radar data. Improvements may also be expected in quality control procedures, efficient minimization of the cost function, which is at the heart of variational analysis, improved or more efficient recursive filters, and improved use of anisotropic background error covariances.

GSD will continue enhancements to the WRF-GSI for the effective treatment of surface observations and background error in the 1-h Rapid Refresh cycle, which will include running a time-phased ensemble to evaluate the background error covariance. The primary objective of doing so is to have the diabatic initialization operating fully within a 3DVAR framework. The result of this development will be to increase the utility of 0–3 h forecasts by initializing with existing clouds and precipitation in a manner fully consistent with the model dynamics, as discussed more fully under task 08.5.15.

CAPS will work with GSD and NCEP on further testing and operational implementation of radial velocity assimilation. The proposed use of a multi-scale multi-pass strategy will be finalized, with appropriate spatial correlations of the background error for different passes and scales. For FY2009 and beyond, more emphasis in the area of radar data assimilation will be shifted towards higher resolutions where most convective-scale motion is explicitly resolved. This shift is linked to the proposed 3-km high-resolution rapid refresh (HRRR, see 5.24 and 5.19) testing. At the 3-km resolution, direct assimilation of level-II radial velocity data, perhaps thinned only for the reason of data volume, will be performed. The need for and the impact of superobbing will be assessed for such resolutions.

Subtasks

09.5.5.1 30 November 2008 (CAPS, NCEP)
Refine the radial velocity analysis component of GSI and determine the optimal decorrelation scales for different analysis passes.

09.5.5.2 30 January 2009 (GSD/ NCEP)
Provide code changes for Rapid Refresh GSI package to EMC/NCO for final pre-implementation testing at NCEP (for 3Q FY09 implementation).

09.5.5.3 15 May 2009 (NCEP)
Development efforts produce a 'research quality' code for an upgrade (e.g. improved filters and covariances, integration into ESMF)) to the GSI.

09.5.5.4 30 July 2009 (GSD, CAPS, NCEP)
Test version of GSI appropriate for 3-km High-Resolution Rapid Refresh (HRRR) configuration, including use of radar data.

09.5.5.5 30 September 2009 (CAPS, HRRR)
Work on ensemble Kalman filter from time-lagged HRRR

09.5.5.6 30 Sept 2009 (NCEP)
Based on case-study testing and refinement of the research quality code, deliver an "experimental" code for an upgrade (e.g. improved filters and covariance) to the WRF-GSI for the 2009 NAM-WRF change package.

09.5.5.7 30 August 2009 (CAPS, GSD, NCEP)
Finalize the multi-scale multi-pass configuration for analyzing radial velocity and other data. Report initial results with HRRR testing.

Deliverables

09.5.5E1 15 November 2008 (NCEP)
Based on parallel testing and refinement of the experimental code, deliver the 'pre-implementation' code to NCO for the 2009 upgrade (improved use of 88D and satellite radiances) to the GSI for the 2009 NAM change package.

09.5.5E2 30 March 2009 (NCEP)
Subject to NCEP Director approval, implement in NCEP Operations the 2009 upgrade (improved use of 88D and satellite radiances) to the WRF-GSI became Operational at NCEP as part of the 2009 NAM-WRF change package.

09.5.5.E3 30 June 2009 (GSD)
Pending EMC, NCO, and NCEP directors' approval and NCEP operational capabilities, implement Rapid Refresh version of GSI as part of the Rapid Refresh package.

09.5.5E4 1 September 2009 (CAPS and NCEP)
Deliver enhancement package for radial velocity data analysis for further implementation testing.

Task 09.5.6

FY 2009, Priority 7: Develop, test, and evaluate the performance of the nonhydrostatic WRF modeling system.

Description

The development of different aspects of the WRF system has been distributed into other tasks to a considerable extent. Thus, this task now retains some remaining development activities, but makes a transition toward support of the DTC / OTC, the code repository and contributions to it. Following the various operational implementations of WRF at NCEP in 2004 - 2009, the WRF models will fall into the normal upgrade sequence at NCEP. Twice each year, roughly in the spring for NAM-WRF and fall for Rapid Refresh-WRF, upgrade bundles are implemented into the NCEP model suites. This task will cover those activities whose focus will be incremental improvements to the WRF infrastructure components and support of DTC. At NCEP, nesting in the WRF-NMM is likely to be mature enough to be made part of operations in FY2009. This capability will be used to make 4 km nests within the NAM-WRF and to consider running the Fire Weather / IMET Support runs inline, making NCEP's production suite more streamlined.

In addition, increasing emphasis will be placed on the research required to adapt WRF to higher resolution forecast applications, in which convective processes are resolved instead of relying on cumulus parameterization. These forecasts will have the ability to produce *realistic* high-amplitude, small-scale features in evolving weather systems, many of which have important impacts on aviation weather. Careful evaluation will be required to determine how the greatest *accuracy* can be obtained in these forecasts. The sensitivity of forecast fields to changes in grid resolution, model physics, and small-scale structure in assimilated observations will be explored to determine how best to design a convection-resolving version of WRF. In evaluating the quality of these very high-resolution forecasts, it must be recognized that even small errors in phase, displacement, or time lag will produce very large differences between forecast and observed scalar variables at specific locations. Despite these uncertainties, WRF predictions that contain spatial structures similar to those that are observed, albeit with phase/displacement errors, may be of considerable value to certain users. However, the value of forecasts that contain realistic features will probably not be accurately expressed when using traditional methods of verifying forecast accuracy. New verification methods, designed to complement traditional techniques, must be developed and tested.

In FY09 and FY10 NCAR/MMM will continue to organize and put on the annual WRF Users' Workshop. It will also conduct an ARW tutorial. In support of the development and enhancement of the Rapid Refresh, MMM will address the incorporation of new physical schemes and physics improvements into WRF. This is necessary for the ongoing advancement of the base capability of the RR and to ensure that it is benefiting from the advancements made in the research community. This will include collaboration with MDE team members GSD and RAL as appropriate as their developments for the RR are ready for inclusion. MMM will perform the necessary code testing for the implementation of new code in the WRF repository.

NCAR/MMM also shall continue work with GSD on digital filter initialization (DFI) capability for the Rapid Refresh (ARW core). By way of background, imbalances between mass and wind in the initial conditions can trigger spurious high-frequency oscillations (i.e., noise) in RR integrations. For data assimilation cycles, the noise can degrade the subsequent analyses. MMM shall implement the digital filter initialization scheme (DFI) to the ARW to remove such noise. In this approach a digital filter (DF) is applied on a time series of model states to remove the high frequency oscillations. A standard DFI implementation requires a backward integration of the adiabatic version of the dynamic model, followed by a forward integration of the full model, and the filter can be applied during both integrations. For FY09, NCAR/MMM will test the digital filter (DF) capability implemented into ARW core for the Rapid Refresh. It will make modifications as necessary and will evaluate the DF behavior and performance and impact of DFI on RR forecasts for selected cases. It will work with GSD in analysis and interpretation of results. This would be for the regular-resolution RR. With the emergence of High-Resolution Rapid Refresh (HRRR) model development, in FY10 MMM will pursue such work in that context. It would test and evaluate the DF capability for the HRRR, looking at its behavior in selected cases. This work seeks to contribute to the advancement of the HRRR capability and its performance.

The goal of the WRF model applications in the Rapid Refresh is ultimately to resolve convection explicitly, which is considered possible at resolutions finer than 5 km. As has been learned by NCAR through its analysis of the developing WRF model in such regimes, model behavior, and how to improve it at convection-permitting scales, is not well understood. NCAR/MMM will continue to work toward the ultimate High-Resolution Rapid Refresh (HRRR) applications at such scales, where HRRR is estimated to run at 3 km. Thus, in collaboration with GSD, NCAR will perform selected RR simulations at 3-km grid scales and evaluate the results to identify strengths and weakness of the RR model at high resolution. The goal is to work toward the preparation of the HRRR system and its users for such applications.

Subtasks

09.5.6.1 15 May 2009 (NCEP)
Commit to WRF Repository the changes embodied in operational WRF codes used in NAM upgrade package of March 2009.

09.5.6.3 30 July 2009 (NCEP)
Maintain and further develop WRF Preprocessing System (WPS) and Land-Surface Model static fields, including updates to all documentation, in response to community requirements.
Report on status of adaptation to ESMF.

09.5.6.5 1 September 2009 (NCEP)
Maintain and further develop WRF Post-processing system including necessary RR capabilities and updates to all documentation, in response to community requirements. Report on status of adaptation to ESMF.

09.5.6 30 June 2009 (NCAR/MMM and DTC)
Deliver a WRF Users' Workshop and a tutorial on the ARW core (NCAR) and a tutorial on the NMM core (DTC) for the user community.

09.5.6 30 September 2009 (NCAR/MMM)
Incorporate physics improvements from the user community, GSD, and NCEP into the WRF software infrastructure for use in the Rapid Refresh model. Perform code testing to permit implementation into WRF repository. In collaboration with GSD, assist in the evaluation of those physics schemes for the RR that may be tested using the ARW.

09.5.6 31 August 2009 (NCAR/MMM)
Using Rapid Refresh model, test digital filter (DF) capability implemented into ARW core. Evaluate DF behavior and performance and impact of DFI on RR forecasts for selected cases. Modify DF code as necessary. Work with GSD in analysis and interpretation of results. Draft and deliver summary of results.

09.5.6 30 September 2009 (NCAR/MMM)
Through testing and evaluation, investigate potential RR enhancements for improving high-resolution Rapid Refresh (HRRR) agreement with very-high-resolution (e.g., o(100 m)) model simulations that display converged results. Investigate cycled data assimilation initialization and/or modifications to parameterizations and microphysics. Collaborate with GSD on analysis of results. Draft and deliver summary of results.

Task 09.5.8
FY 2009, Priority 5: Improve physics in the WRF model, especially including those that affect aircraft icing.

Description

NCEP will incorporate mature enhancements into the operational implementation process from its efforts with WRF physics that affect icing, focusing in particular on resolving remaining issues related to explicit (no convection) forecasts from the 4-5 km inner domain of the newly configured nested NAM model, targeted for implementation in FY2009. Work will include aerosol concentrations as a predicted variable in FY2009, where it is expected to lead to improved concentrations of cloud condensation nuclei and ice nuclei, which are very important to microphysics. This development will lead to improved forecasts of aircraft icing and visibility. NCEP is leveraging aerosol work from its partnership with EPA for Air Quality Forecasting. Improved representations of the size distributions of drizzle drops may also be incorporated into the model, and possibly simplified two-moment schemes, depending on the availability of computational resources.

Work at NCAR will focus on improving the treatment of ice in the NCAR microphysics based on results from the ICE-L field program. Ice crystals are the main factor impacting the lifetime of freezing drizzle and supercooled liquid water in clouds. The current scheme does not adequately treat the formation and depletion of ice nuclei. The depletion of ice nuclei has in particular been shown to be critical to the formation of in-flight icing and freezing drizzle. ICE-L is focused on the formation processes in wave clouds and upslope clouds in the Colorado Front Range using a suite of aircraft and other instruments. The two moment microphysical scheme developed in FY08 will be upgraded on the basis of the field program results. A key addition to the scheme will be a variable to account for the formation and depletion of ice nuclei. The new upgraded scheme will be tested in the WRF model and transferred to GSD and NCEP as appropriate.

Early in FY2009 GSD will be concentrating on ensuring that physics schemes are producing acceptable results in RR pre-implementation testing. The latest version of the NCAR microphysics will be given consideration based on efficacy and computer demands of the scheme. Later in the year GSD anticipates beginning testing of updated physics packages that are considered candidates for the FY2010 RR change bundle. Among possible upgrades are the following: introduction of explicit prediction of aerosol to provide explicit CCN input to the next version of RR microphysics, shortwave radiation scheme that incorporates radiative effects of aerosol and more accurate radiative effects of clouds, and improved capability to describe stratocumulus-topped mixed layers with the goal of improving prediction of Stratocumulus icing. Some of this work will be leveraged from GSD WRF-Chem developments.

Subtasks

09.5.8.1 15 November 2008 (NCEP)
Based on parallel testing and refinement of the experimental code, deliver the 'pre-implementation' code to NCO of physics upgrades for the 2009 NAM change package.

09.5.8.2 15 May 2009 (NCEP)
Development efforts produce a 'research quality' code of physics upgrades for consideration in the 2010 NAM change package.

09.5.8.3 1 July 2009 (NCAR)
Analyze data from the ICE-L field program related to the formation, advection and depletion of ice nuclei in clouds. Case studies will be chosen based on their relevance to ice formation processes related to supercooled liquid water and freezing drizzle formation.

09.5.8.4 15 July 2009 (NCEP)
Based on case-study testing and refinement of the research quality code, deliver an

“experimental” code of physics upgrades for the 2010 NAM change package.

09.5.8.5 31 August 2009 (GSD, NCAR/MMM)
Begin testing at GSD of latest version of microphysics for Rapid Refresh upgrade in FY2010.

09.5.8.6 1 September 2009 (NCAR)
Use the ICE-L and other case studies as a basis for upgrading the current two moment microphysics to include improved ice nuclei formation, advection and depletion processes.

09.5.8.7 30 September 2009 (NCAR)
Implement the above upgrades into the WRF model and evaluate on previous case studies from IMPROVE II, AIRS II, WISP, and NASA Lewis field data. The evaluation will include supercooled liquid water, freezing drizzle, as well as snowfall rate and precipitation type and ceiling and visibility.

Deliverables

09.5.8.E1 30 March 2009 (NCEP)
Subject to NCEP Director approval, implement in NCEP Operations the physics upgrades of the 2009 NAM-WRF change package.

09.5.8.E2 30 June 2009 (GSD, NCEP)
Implement WRF Rapid Refresh, including physics designed to meet the needs of aviation, into NCEP operations pending favorable NCEP recommendations, and operational capabilities and availability.

09.5.8.E3 30 September 2009 (NCAR)
Deliver an improved ice nuclei tracking scheme in the two-moment microphysics scheme to GSD for real-time testing in the WRF Rapid Refresh.

Task 09.5.9
FY 2009, Priority 11: Assimilate turbulence observations directly into the WRF model.

If this work is started in FY08 for observation-model comparisons, work in FY09 can concentrate on actual data assimilation experiments with turbulence observations from both United Airlines and TAMDAR with the intent of improving 1-6h model forecasts of turbulence.

As discussed under task 08.5.9, if expected progress by the Turbulence PDT group and AirDAT (TAMDAR) is realized for reasonably accurate EDR observations, then development of assimilation of these data (using 3DVAR methodology in GSI) can proceed. As discussed under 08.5.9, this will require forward algorithm from model variables to EDR, adjoint of same, reasonable estimates of EDR errors for background and model including representativeness error) needing to be addressed before an operational EDR data assimilation could be possible.

Subtasks

09.5.9.1 15 Jan 2009 (NCAR Turbulence PDT and GSD)
Evaluate the usability of the NCAR quality-assured EDR data for assimilation purposes.

09.5.9.2 30 March 2009 (GSD)
Produce the adjoint of the forward model calculation for EDR to allow initial assimilation tests turbulence observations in the GSI for use in WRF Rapid Refresh.

09.5.9.3 15 May 2009 (NCEP, GSD)
Development efforts result in delivery of a "research quality" version of GSI that is capable of assimilating turbulence observations.

<u>Task 09.5.11</u>
FY 2008, Priority 13: Develop adjoints for physical processes in forecast models.

Description

Development of the adjoint model for each of the physics packages in WRF is a major undertaking that is essential to achieve a fully functional 4DVAR data assimilation system. In addition, a number of physical parameterizations contain switches whereby different physical process are invoked depending on the value of certain model parameters. These switches introduce fundamental nonlinearities and discontinuities in gradients in the system that cannot be represented within the adjoint model. Consequently, research is needed to replace these switches with processes that produce continuous variation while maintaining the accuracy of the parameterized physics. As the physics adjoints are written, they must also be adapted to the parallel version of the WRF 4DVAR system to achieve computational efficiency.

Subtasks

09.5.11.1 15 June 2009 (CAPS)
Perform land surface state retrieval experiments using the WRF 4DVAR system. Evaluate the performance and impact on forecast, particularly of precipitation.

09.5.11.2 01 September 2009 (GSD, NCEP, CAPS)
Begin work toward new physics packages with switches replaced by continuous processes, to be available for testing in FY10.

Deliverables

09.5.11.E1 15 June 2009 (GSD, NCEP, CAPS)
Coordination plans developed between GSD, NCEP, and CAPS for development of adjoint codes for a number of physics options supported in the research and operational configurations

of the WRF Model.

09.5.11.E2 1 August 2009 (NCEP)
Conduct testing, analysis, and debugging of ESMF-NMM core adjoint code.

Task 09.5.15
FY 2009, Priority 6: Develop improved methods of cloud and moisture analysis for use in the WRF Modeling System.

Description

The emphasis at GSD for this year will be the implementation of techniques developed over the previous few years to improve cloud/hydrometeor analysis for the WRF Rapid Refresh. Likewise, NCEP will be concentrating on implementing the most mature improvements to the GSI assimilation and diabatic initialization using cloud, precipitation and other moisture observations. New sources will be tested with mini-impact tests to ensure that no harm will occur when the new data are turned on in NAM or RR assimilation systems based on GSI. Also included in improvements to be considered for implementation will be quality control procedures and algorithms. NCEP will also be investigating the replacement of the current nudging approach to precipitation assimilation with a “2DVAR” approach, in which the model’s temperature, moisture and hydrometeor fields in each single column are adjusted by integrating the fields in the column forward/backward in time (hence “2DVAR”) in order that the fields would be consistent with the observed precipitation field and then the wind field would be adjusted for the entire domain.

Collaboration between CAPS and GSD in further developing and refining the cloud analysis package with emphasis on Rapid Refresh will continue. More cloud observations, including those from satellite, will be utilized. The emphasis in FY2009 will continue to be on improving the generalized cloud analysis package at the convective parameterization scale (~13 km resolution) for use by Rapid Refresh. The cloud analysis package will be tuned to work optimally with initialization procedures including the diabatic digital filtering (DFI), to minimize the initial adjustment in the cloud fields and to improve the cloud/ceiling/visibility forecast from model time zero. The cloud analysis package also seeks to make effective use of the convective-scale vertical velocity information obtainable with the assimilation of radial velocity data. By FY09, we will also have developed at least a “research quality” version of the cloud analysis with a specific improvement for use in high-latitude regions using GOES and polar-orbiter imager data. Previously, the RUC and RR cloud analysis procedures have used sounder-based NESDIS-produced cloud-top data, limited up to only 45-50 deg N.

Efforts will also be made to use hydrometeor classification algorithms to help better define and analyze precipitation hydrometeors and cloud fields in the cloud analysis package. The information on DSD will also helpful for more accurately specifying the cloud mixing ratios. Initial development will start in this year. Data from the prototype polarimetric WSR-88D radar operated by NSSL and ROC (Radar Operation Center) in Norman as well as polarimetric radar data from CASA (a multi-institution NSF Engineering Research Center for the Ming Xue is the Oklahoma campus PI) Oklahoma Testbed radars (4 of them right now) will be used for testing the algorithms.

Subtasks

09.5.15.1 30 December 2008 (GSD and CAPS)
Complete final testing of revised version of generalized cloud analysis in combination with diabatic digital filter initialization procedure in the 13-km RR.

09.5.15.2 30 April 2009 (GSD)
Develop improved version of RR cloud analysis (within GSI) applicable to high-latitude regions including Alaska.

09.5.15.3 15 May 2009 (NCEP)
Development efforts produce a 'research quality' upgrade (improved WRF-GSI and/or diabatic initialization for cloud, precipitation and moisture) to WRF code for consideration in the 2010 NAM-WRF change package.

09.5.15.4 30 May 2009 (CAPS and GSD)
Start porting polarimetric radar hydrometeor classification algorithms and utilize the hydrometeor classification information within the generalized cloud analysis package.

09.5.15.5 15 July 2009 (NCEP)
Based on case-study testing and refinement of the research quality code, deliver an "experimental" upgrade (improved GSI and/or diabatic initialization for cloud, precipitation and moisture) to code for the 2010 NAM change package.

Deliverables

09.5.15.E1 15 November 2008 (NCEP)
Based on parallel testing and refinement of the experimental code, deliver to NCO the 'pre-implementation' upgrade (improved GSI and/or diabatic initialization for cloud, precipitation and moisture) to code for the 2008 NAM change package.

09.5.15.E2 30 January 2009 (GSD)
Provide code changes for revised version of generalized cloud analysis (within RR GSI) to EMC/NCO for final pre-implementation testing at NCEP (for 3Q FY09 implementation).

09.5.15.E3 30 March 2009 (NCEP)
Subject to NCEP Director approval, implement in NCEP Operations the upgrade (improved GSI and/or diabatic initialization for cloud, precipitation and moisture) to code for the 2009 NAM change package.

09.5.15.E4 30 September 2009 (CAPS)
Initial testing of the cloud analysis using polarimetric radar information completed.

Task 09.5.17

FY 2009, Priority 2: Infrastructure support for running operational WRF model in Rapid Refresh, North American Mesoscale and HiResWindow modes at NCEP.

Description

As in FY 2008, this high priority task assures the reliable and timely running of the North American Mesoscale and HiResWindow versions of the WRF model in NCEP operations and in providing gridded output (SAVs and AIVs) to aviation users. The major changes this year include the expected start of the Rapid Refresh WRF in the latter half of FY09 and delivery of NCEP's new CCS computer system. Conversion and optimization are now covered under this task rather than having its own task (e.g. Task 5.12 in prior plans).

The current agreement between IBM and NCEP for support of the Central Computer System (CCS) at NCEP is embodied in a 5-year option period covering FY2007 through FY2011 and including two major computer upgrade replacements. The first upgrade was installed in latter half of 2006 with NCEP's Operations moving to it in late January 2007. The second and final upgrade under this agreement is scheduled for installation in Quarter 2 2009 with NCEP Operations switching over in October 2010.

NCEP will begin testing version of NMM model running in ESMF against version of NMM model running in operations in WRF in anticipation of replacing WRF-based components in NAM and HiResWindow beginning FY2010.

Subtask 09.5.17.8 covers the porting of operational codes that support the FAA in general and the FAA AWRP in particular, to the new platform. The operational components of interest to the FAA are the Rapid Refresh, North American Mesoscale and HiResWindow modeling systems. While each of these systems is made up of many components: data preparation, data assimilation, prediction model, post processor, product generation and product dissemination, they are all now WRF-based providing a substantial economy compared to previous conversion efforts.

Porting involves several steps: design, compile, debug, optimize, and implement. The first computer upgrade's architecture is very similar to the clustered Symmetric Multi-Processor (SMP), upon which previous CCS's (frost/snow, blue/white and dew/mist) were based. Code conversion should be relatively straightforward, but issues with a new generation of processor (Power-6 will be replacing Power-5) and a new version of the Fortran compiler have in the past (2006-2007) resulted in substantial challenges.

Subtasks

October 2008 through September 2009:

09.5.17.1 Maintain hourly Rapid Refresh (RR-WRF) runs with gridded output and provide SAV and AIV guidance products, starting in June 2009.

09.5.17.2 Maintain four-per-day North American Mesoscale (NAM-WRF) runs and provide SAV and AIV guidance.

09.5.17.3 Maintain four-per-day HiResWindow WRF runs and provide SAV and AIV guidance.

09.5.17.4 Provide vendors with gridded model data via Family of Services and the FAA Bulk Weather Data Telecommunications Gateway.

09.5.17.5 Provide full native-resolutions grids from RR-WRF, NAM-WRF, and HiResWindow WRF on NCEP and NWS/OPS servers.

09.5.17.6 Maintain access to model verification data.

09.5.17.7 Provide assistance to Inflight Icing, Turbulence, Convective Weather, Ceiling and Visibility and Oceanic Weather PDTs when their algorithms and product generation systems are ready to transition into NCEP's operational Production suite. (NCEP)

09.5.17.8 Working with NCO, complete the design, compilation, debugging, test runs and parallel testing of RR, NAM and HiResWindow codes on new CCS computer.

Deliverables

09.5.17.E1 Perform ingest, quality control and preparation of both existing and new observations in support of the operational WRF runs. (NCEP, GSD)

09.5.17.E2 As requested by other PDTs, incorporate new AIV calculations into Operational WRF Model post-processor and product generator (NCEP, GSD).

09.5.17.E3 Perform configuration management for Rapid Refresh, including thorough documentation, and respond promptly to any code malfunctions (GSD).

09.5.17.E4 Monitor RUC performance, respond to any problems detected by GSD, NCEP, or any RUC users, diagnose cause, develop solution to RUC software, test changes and coordinate with NCO on implementation. (GSD, NCEP)

09.5.17.E5 30 September 2009 (NCEP, GSD)
Provide NCO with ported/converted/tested/accepted codes for operational

running of RR, NAM and HiResWindow on new CCS.

Task 09.5.19

FY 2009, Priority 9: Develop ability to assimilate radar radial velocity and reflectivity data into the GSI assimilation system.

Description

In FY09, MDE will further develop further improvements in radar assimilation for the initial version of the High-Resolution Rapid Refresh (HRRR) as described under 08.5.19.

Development and testing work toward building a 3-km HRRR cloud analysis and radar-based diabatic digital filter initialization capabilities will continue this year. These capabilities will already exist in the Rapid Refresh and porting the code to the HRRR will be straightforward. Important research will be needed to adapt and optimize the algorithms for explicitly resolved convection. GSD, NCAR/MMM, and CAPS will develop and test more advanced versions of the 3-km radar-DDFI, and the 3-km cloud analysis (within GSI) for stable clouds at this resolution. GSD, CAPS, and NCEP will all work toward 3-km assimilation of radar radial wind data.

NCEP will have already implemented direct use of the Level II radial winds and a diabatic initialization (for NAM) of the Level II reflectivity mosaic. NCEP will be concentrating on implementing the most mature improvements to Level II data assimilation. New sources and techniques will be tested with mini-impact tests to ensure that no harm will occur when the new data / technique are turned on in NAM assimilation system. Also included in improvements to be considered for implementation will be quality control procedures and algorithms. NCEP will have decided which of its alternative schemes for advanced 4DDA of radar data show the most promise and will be working to refine that approach.

The current National Weather Service plan is to start upgrading the WSR-88D network to include dual-polarization (DP) capabilities in FY2009. Hydrometeor types can be identified with much less ambiguity from DP than from conventional radar reflectivity fields. For stratiform or winter-type precipitation, an important way in which DP may help with hydrometeor classification is that, together with appropriate independent measurements at the ground (such as disdrometer measurements) and aircraft measurements, DP radar measurements will give feedback to modelers that they can use to improve the bulk, mixed-phase microphysics parameterization in the WRF model, notably the drop size distributions, leading to more accurate prediction of precipitation type. Another advantage of DP lies with the better precipitation rate estimates that could be used in diabatic initialization of the WRF-NAM and Rapid Refresh modeling systems. At present, drop (or particle) size distributions for rain, snow, and graupel are assumed to be of the form of either exponential or gamma distribution, with their parameters such as intercept and slope specified. DP data can help define these parameters on case by case basis. As models gain access to more powerful computing resources, the microphysics schemes used in the models will increase in complexity so the ability to actually use 2-moment microphysics schemes may be realized within a few years; in that case, the initialization of the additional prognostic moments (e.g., the first moment total number concentration in addition to the third moment mixing ratio) will also become necessary. DP data provide such a possibility. Furthermore, DP data are very helpful in distinguishing ground cluster, biological targets etc. from meteorological targets, and therefore, may be able to help improve radar data quality control (by removing e.g., ground, bird and insect contaminations).

CAPS proposes to start working in FY09 on the assimilation of polarimetric radar data using the ensemble Kalman filter method and through the cloud analysis. Data from the dual-polarization-upgraded WSR-88D radar in Norman (KOUN) will be used for the testing. The work will include the development of forward observation operators for the additional polarimetric parameters observed, such as differential reflectivity and differential phase. These forward operators will need to be compatible with some of the more sophisticated microphysics schemes used in the prediction model. Efforts will also be made to use hydrometeor classification algorithms to help better define and analyze precipitation hydrometeors and cloud fields in the cloud analysis package. The information on DSD will also helpful be for more accurately specifying the cloud mixing ratios.

Subtasks

09.5.19.1 15 March 2009 (CAPS)
Start developing forward operators for polarimetric radar measurements and implement them inside an EnKF system for WRF. Explore the use of hydrometeor classification algorithms in cloud analysis.

09.5.19.2 15 January 2009 (NCEP)
Report on progress of affordable alternative strategies for assimilating Level II data.

09.5.19.4 15 May 2009 (NCEP)
Development efforts produce a 'research quality' upgrade (improved GSI and/or diabatic initialization of Level II radial winds & reflectivity) to NAM code for consideration in the 2008 change package.

09.5.19.5 15 July 2009 (NCEP)
Based on case study testing and refinement of the research quality code, deliver an "experimental" upgrade (improved GSI and/or diabatic initialization of Level-II radial winds and reflectivity) to NAM code for the 2010 change package.

Deliverables

09.5.19.E1 15 November 2008 (NCEP)
Based on parallel testing and refinement of the experimental code, deliver to NCO the 'pre-implementation' upgrade (improved GSI and/or diabatic initialization of Level II radial winds and reflectivity) to NAM code for the 2009 change package.

09.5.19.E2 30 March 2009 (NCEP)
Subject to NCEP Director approval, implement in NCEP Operations the upgrade (improved GSI and/or diabatic initialization of Level II radial winds and reflectivity) to NAM code for the 2009 change package.

09.5.19.E3 01 September 2008 (CAPS)
Report initial results assimilating dual-polarization data via EnKF.

09.5.19.E4 15 September 2009 (GSD)
Deliver progress report on development and testing of revised radar reflectivity assimilation using DDFI in the 3-km HRRR version of the RR-WRF model.

Task 09.5.20
FY 2009, Priority 10: Develop ensemble-based probabilistic products for aviation users.
Description:

In FY2009, routine upgrades to the SREF will be accompanied by pre-implementation testing of the WRF-based SREF and NCEP will begin testing "equivalent" configurations within ESMF. It is likely that ESMF members will be added in 2009 rather than staying with a SREF made up exclusively of WRF members. NCEP and GSD must determine whether various configurations of WRF (dynamic core, physics) provide sufficient diversity of solution (spread) and the same quality of probabilistic guidance to replace the multi-model approach being currently employed with the Eta and RSM models. NCEP and GSD will also continue to develop the aviation-oriented VSREF using the now-operational Rapid Refresh runs. GSD will also continue to develop and test a WRF core with a generalized coordinate for consideration in the WRF-based SREF context.

GSD will also develop statistical post-processing algorithms from the diabatically-initialized WRF Rapid Refresh model in order to provide 6-dimensional databases (a given variable for a specified time, in 3D space, with probabilistic bounds). The diabatic initialization consists of the radar-DDFI procedure in the WRF Rapid Refresh model, as described under task 5.15.

Subtasks:

09.5.20.1 15 January 2009 (NCEP)
Deliver "research quality" version of upgrade (e.g., 20 km resolution, improved IC perturbation generating scheme) to SREF for consideration in November 2009 SREF upgrade package.

09.5.20.2 15 February 2009 (NCEP)
NCEP visits AWC to conduct continued training and education on SREF applications, to get feedback on current guidance and to acquire new requirements (fully depending on FAA funding).

09.5.20.3 31 March 2009 NCEP)
Expansion of bias correction to derived fields related to aviation users (fully depending on FAA funding, $60K requested).

09.5.20.4 31 August 2009 (NCEP)
Based on case-study testing and refinement of the research-quality code, deliver an “experimental” upgrade (e.g. 20 km resolution, improved IC perturbation generating method) to SREF code for November 2009 SREF upgrade package.

Deliverables

09.5.20.E1 30 November 2008 (NCEP)
Subject to approval from the NCEP Director, implement in NCEP Operations the SREF upgrades (25 km resolution, add ESMF members, more physics diversity).

09.5.20.E2 31 August 2009 (NCEP)
Deliver bias correction codes of aviation-related derived field to NCO for November 2008 implementation (fully depending on FAA funding, $60K requested).

09.5.20.E2 31 August 2009 (NCEP)
Based on parallel testing and refinement of the experimental code, deliver the “pre-implementation” SREF upgrade code to NCO (with 20 km resolution, improved IC perturbation generating method) for the November 2009 SREF change package.

<u>Task 09.5.21</u>
FY 2008, Priority 12: Develop, test, and implement advanced data assimilation techniques for aviation versions of the WRF model.

Description

Acknowledging that it will take many years of basic research to achieve a mature and affordable 4DDA capability for insertion into the WRF components running operationally, we suggest that FY 2008 or FY2009 should see accelerated efforts on this critical task. GSD, CAPS, and NCEP will continue to develop Ensemble Kalman Filter (EnKF) and simple 4DVAR capabilities that have the potential to be applied operationally toward aviation-relevant forecasts, especially in the Rapid Refresh application. The WRF 4DVAR capability will be expanded to include moist physics. The performance of the 4DVAR, 3DVAR, and EnKF will be compared as well as their computational requirements. A significant problem in ensemble forecasting and ensemble-based assimilation techniques is the difficulty of incorporating uncertainty in the limited area NWP forecast boundary conditions. We will develop techniques to address this problem within both the mesoscale and cloud-scale applications of the WRF-based EnKF.

In FY2008, many of the investigative steps in Steve Lord’s 4DDA plan will be concluding. The

Earth System Modeling Framework (ESMF), to which NCEP is committed, may actually contain the analysis-model “coupler” between the two major components of a data assimilation cycle. This capability will applied to the NCEP Operational data assimilation system and be used for both regional and global applications.

Subtasks

09.5.21.1 15 June 2009 (CAPS, GSD)
Complete case study testing of Ensemble Kalman Filter technique applicable to hourly or sub-hourly Rapid Refresh assimilation.

09.5.21.2 01 June 2009 (GSD, CAPS, and NCEP)
Complete adjoint codes consistent with the microphysics used in the forward model of WRF, and use for the retrieval of microphysics variables for convection and cloud initialization problems.

09.5.21.3 30 June 2009 (CAPS)
Compare results of 4DVAR with EnKF assimilation.

09.5.21.4 01 July 2009 (NCEP)
Complete adaptation of WRF data assimilation using ESMF coupler.

Deliverables

09.5.21.E1 15 September 2009 (NCEP, GSD and CAPS)
Submit report on testing results of 4DDA technique based on Ensemble Kalman Filtering.

09.5.21.E2 30 September 2009 (NCEP & JCSDA)
Report on investigations comparing advanced 3DVAR, 4DVAR & EnKF techniques for 4DDA surrounding EMC Data Assimilation in ESMF Era plan

Task 09.5.23
FY 2009, Priority 14: Develop advanced numerical models for aviation

Description

Work on the isentropic global FIM model and the isentropic version of WRF will continue. GSD and NCAR/MMM will re-evaluate common points in these efforts, including participating in the ongoing Isentropic Modeling Workshops last held in August 2004. GSD and MMM will provide experimental grids to other PDTs as needed.

Subtasks

09.5.23 15 May 2009 (GSD)

Further work on GSD Flow-following Finite-volume Icosahedral Model (FIM) development. GSD will continue to coordinate this work as a possible alternative dynamic core but should be nested within EMC's Global Model Framework by this time. GSD will be producing regular global model runs initialized with GFS initial conditions by this time, and will continue to provide preliminary isentropic FIM data to the Turbulence PDT and other PDTs for experimental evaluation.

Deliverable
09.5.23 30 Sept 2008 (GSD)
Submit report on development and relevance for aviation-impact variables for isentropic FIM models.

<u>Task 09.5.24</u>
FY 2007, Priority 8: Test WRF Rapid Refresh model at 3-km resolution toward High-Resolution Rapid Refresh

[As stated earlier, Task 5.24 specifically treats development and testing of the 3-km HRRR model itself. Development and testing work on assimilation of radar data at the 3-km scale is under Task 5.19.]

Description

MDE will continue an effort toward development of the 3-km hourly updating, radar-reflectivity assimilating High-Resolution Rapid Refresh (HRRR). Tests will continue over the NE Corridor domain, but with advanced versions of the RR-WRF model and data assimilation methods (work under 5.19) based on experimental results from testing in FY08.

Accurate, rapidly updated (at least hourly) forecasts of convective storms are probably the greatest need for improvement in aviation weather services. Summertime convection is the foremost weather-related problem for U.S. aviation weather and the National Airspace System. The multi-year HRRR effort is designed to specifically address this problem.

See additional text from FY08 for task 5.24.

Subtasks

09.5.24 30 July 2009 (GSD, NCAR/MMM, CAPS)
Test advanced FY09 version of 3-km High-Resolution Rapid Refresh (HRRR) configuration, including use of radar data.

Deliverable
09.5.24 31 August 2009 (GSD, CAPS)
Complete summer test of advanced FY09 version of 3-km High-Resolution Rapid Refresh (HRRR) configuration, including assimilation of radar data.

Budget Summary of FY 09 Tasks

Task #	Task Description	Priority	Funding: NCAR	NCEP	GSD	CAPS	DTC	Total	Running Total
08.5.1	Infrastructure support for operational running of the RUC at NCEP	1		55	55			110	110
08.5.17	Infrastructure support for running WRF RR, NAM, and HRW models	2		175	105			280	390
08.5.4	Develop, test, and implement the Rapid Refresh configuration of the WRF model (WRF-RR)	3		75	200		40	315	705
08.5.5	Develop, test, and implement improvements to the operational 3DVAR for WRF Rapid Refresh and WRF-NAM	4		120	200	60		380	1085
08.5.8	Improve physics in the WRF model, especially including those that affect aircraft icing	5	80	75	60			215	1300
08.5.15	Develop improved methods for analyzing clouds and water substance for use in the WRF modeling system	6		90	140	100		330	1630
08.5.6	Develop, test, and evaluate the performance of the nonhydrostatic WRF modeling system	6	60					60	1690
08.5.24	Test WRF Rapid Refresh model at 3-km resolution toward High-Resolution Rapid Refresh (HRRR)	7	80		150			230	1920
08.5.19	Develop ability to assimilate WSR-88D radial velocity and reflectivity data into the WRF modeling system	8	100	50	200	120		470	2390
08.5.20	Examine utility of ensembles for conveying probability and confidence to aviation users	9		85	100			185	2575
08.5.9	Assimilate turbulence observations (EDR data) directly into the WRF model	10		80	100			180	2755
08.5.21	Develop, test, and implement advanced 4DDA capability for the WRF model	11	80	80	80	80		320	3075
08.5.11	Develop adjoints for physical processes in the WRF model	12		80	80	50		210	3285
08.5.23	Develop advanced numerical models for aviation	13			150			150	3435
			400	**965**	**1620**	**410**	**40**	**3435**	**3435**

Tasks for FY 2010

Tasks for FY10 (and FY09) are in order of task number, not in order of priority.

Task 10.5.4__
FY10, Priority 2: Develop, test and implement the Rapid Refresh modeling/assimilation system in an ESMF configuration.

Description

At GSD, development will continue on all aspects of the RR, including upgrades to the GSI analysis, improved diabatic initialization including hydrometeors, and upgrades to model physics. A 2010 change bundle will be evaluated at GSD and then transferred to NCEP for operational implementation.

In anticipation of continued growth in trans-oceanic air transport between North America, Europe and eastern Asia, GSD will also begin testing an hourly RR on an expanded domain including the North Atlantic, North Pacific, western Europe, and eastern Asia.
A target implementation, pending availability of computing resources, would occur in FY2011 or 12. It is envisioned that this expanded version of the RR would use some version of the ESMF regional model and in many other respects will look much like an upgraded version of the RR that preceded it, except for the expanded domain.

Another aspect of the anticipated changes toward the FY11 RR upgrade will be a likely transition (based on 30 March 2007 "thinking") from the current WRF infrastructure toward an ESMF-based infrastructure.

Subtasks

Comment [jb1]: I noticed that there were no subtasks or deliverables for FY10, and that, indeed, I had forgot to provide any. So, here they are. Note that I made refrence to ESMF compliance. Up to Stan to decide what to do about these.

10.5.4.1 1 October 2009 (GSD, NWS-AR, NCAR)
Begin real-time and retrospective evaluation of next RR upgrade, including NCEP-ESMF-compliant code, revised or new physics packages and other RR assimilation/model changes, including possible increase in resolution, in hourly RR development cycle at GSD. This will include providing grids to the NWS Alaska Region and the AWRP PDTs for their evaluation and feedback.

10.5.4.2 1 April 2010 (GSD)
Begin tests of expanded domain RR at GSD.

Deliverables

10.5.4.E1 1 February 2010 (GSD)
Make available to NCEP revised ESMF-compliant RR code with other upgrades for pre-implementation testing in preparation for NCEP implementation, pending EMC, NCO and

NCEP recommendations, later in 2010.

Task 10.5.5
FY 10, Priority 3: Develop, test, and implement improvements to the operational GSI 3DVAR for Rapid Refresh and North American Mesoscale runs.

Description

By 2010, the WRF-GSI based Rapid Refresh should have replaced the operational RUC at NCEP and a GSI upgrade package for the NAM should have occurred..

GSD will focus its work toward the GSI version appropriate for the 3-km High-Resolution Rapid Refresh (HRRR). CAPS, NCAR, and NCEP will contribute to the HRRR demonstration project. In FY10, a working version will be running over a northeastern U.S. area with hourly updating and a 3-km WRF (evolving to ESMF infrastructure) model running out to at least 6h duration every hour.

CAPS will work with GSD and NCEP in evaluating the operational performance of level-II radial velocity data and the variational analysis of reflectivity data within GSI, and on improving radar data quality control. Emphasis in the area of radar data assimilation will be given to convection-resolving resolutions, and the target grids of the 3-km High-Resolution Rapid Refresh (HRRR, see 07.5.6a).

Subtasks

10.5.5.1 28 February 2010 (GSD)
Development efforts produce a set of revisions to GSI needed for application to Rapid Refresh based on latest changes from NCEP and GSD.

10.5.5.2 30 May 2010 (NCEP)
Development efforts produce a "research quality" code for an upgrade (e.g., improved use of WSR-88D and new radar data and satellite radiances) to the GSI.

10.5.5.3 30 June 2010 (GSD)
Complete initial case study tests of advanced version of WRF (or ESMF version) for the Rapid Refresh model.

10.5.5.4 30 July 2010 (NCEP)
Based on case-study testing and refinement of the research quality code, an 'experimental' code is delivered for an upgrade (improved use of 88D and satellite radiances) to the GSI for the 2010 NAM change package.

10.5.5.6 30 September 2010 (GSD, CAPS, NCEP)

Complete revised version of GSI appropriate for advanced Rapid Refresh update in FY11 and High-Resolution Rapid Refresh (HRRR) running experimentally at GSD. This will include improved versions diabatic initialization using radar and precipitation data.

10.5.5.7 1 August 2010 (CAPS)
Start testing trial-analysis-based method for determining background error structure, and study its impact realized through anisotropic recursive filter.

Deliverables

10.5.5E1 30 November 2009 (NCEP)
Based on parallel testing and refinement of the experimental code, the "pre-implementation" code to NCO is delivered for the 2010 upgrade (improved filters and covariances) to the GSI for the 2009 NAM change package.

10.5.5E2 30 March 2010 (NCEP)
Subject to NCEP Director approval, implement in NCEP Operations the 2009 upgrade (improved filters and covariances) to the GSI became Operational at NCEP as part of the 2009 NAM-WRF change package.

10.5.5E3 30 July 2010 (GSD)
Provide software for WRF Rapid Refresh GSI update for "experimental" testing to EMC.

Task 10.5.6
FY 2010, Priority 7: Develop, test, and evaluate the performance of the nonhydrostatic WRF modeling system.

Description

By this time, NCEP will be well underway toward use of an ESMF-based infrastructure in the NMM. NCEP and GSD will likely be committed to make similar changes to the version of the WRF model used in the Rapid Refresh.

Also by this time, the development of different aspects of the WRF system will have been distributed among other tasks to a considerable extent. Thus, this WRF development task makes an even stronger transition toward support of the DTC/OTC, maintaining and updating the WRF code repository there, and testing and transition to operations of contributions from it. Since the first operational implementation of WRF beginning in 2004, the WRF model configurations at NCEP have fallen into the normal upgrade sequence at NCEP. Twice each year, roughly in the spring for NAM-WRF and fall for RR-WRF, upgrade bundles have been implemented into the NCEP model suites. This task will cover those activities whose focus will be incremental improvements to WRF infrastructure components and support of DTC with the addition of well-tested enhancements from the community outside of NCEP via the DTC.

In addition, emphasis will continue to be placed on the research required to adapt WRF to higher resolution forecast applications, in which cumulus processes are resolved instead of relying on parameterized physics. These forecasts will have the ability to produce *realistic* high-amplitude, small-scale features in evolving weather systems, many of which have important impacts on aviation weather. Careful evaluation will be required to determine how the greatest *accuracy* can be obtained in these forecasts. In evaluating the quality of these very high-resolution forecasts, it must be recognized that even small errors in phase, displacement, or time lag will produce very large differences between forecast and observed scalar variables at specific locations. Despite these uncertainties, WRF predictions that contain spatial structures similar to those that are observed, albeit with phase/displacement errors, may be of considerable value to certain users. However, the value of forecasts that contain realistic features will probably not be accurately expressed when using traditional methods of verifying forecast accuracy. New verification methods, designed to complement traditional techniques but applicable to mesoscale phenomena with high temporal variability, will be developed, tested, and implemented by the DTC and applied to evaluation of the WRF Rapid Refresh model.

NCAR – Same as for FY09.

Subtasks

10.5.6.1 15 May 2010 (NCEP)
Commit to WRF Repository the changes embodied in operational WRF codes used in NAM upgrade package of March 2010.

10.5.6.3 30 July 2010 (NCEP)
Maintain and further develop WRF Preprocessing System (WPS) and Land-Surface Model static fields, including updates to all documentation, in response to community requirements.

10.5.6.5 1 September 2010 (NCEP)
Maintain and further develop WRF Post-processing system including necessary Rapid Refresh capabilities and updates to all documentation, in response to community requirements.

10.5.6 30 June 2010 (NCAR/MMM and DTC)
Deliver a WRF Users' Workshop and a tutorial on the ARW core (NCAR) and a tutorial on the NMM core (DTC) for the user community.

10.5.6 30 September 2010 (NCAR/MMM)
Incorporate physics improvements from the user community, GSD, and NCEP into the WRF software infrastructure for use in the Rapid Refresh model. Perform code testing to permit implementation into WRF repository. In collaboration with GSD, assist in the evaluation of those physics schemes for the RR that may be tested using the ARW.

10.5.6 31 August 2010 (NCAR/MMM)

Using High-Resolution Rapid Refresh (HRRR) model, test digital filter (DF) capability implemented into ARW core. Evaluate DF behavior and performance and evaluate impact of DFI on HRRR forecasts for selected cases. Modify DF code as necessary. Work with GSD in analysis and interpretation of results. Draft and deliver summary of results.

Task 10.5.8

FY 2010, Priority 4: Improve physics in the WRF model, especially including those that affect aircraft icing.

Description

NCEP and NCAR will incorporate the most mature enhancements into the operational implementation process from its efforts with WRF physics that affect icing. NCEP will continue working on refinements of cloud and microphysics and inclusion of aerosol concentrations as a predicted variable in FY2010. This effort could lead to improved prediction of cloud condensation nuclei and ice nuclei, of critical importance to microphysics and visibility. Improved representations of the size distributions of drizzle drops will be incorporated into the model, and possibly simplified two-moment schemes, depending on the availability of computational resources.

Work will continue on improving microphysical parameterizations and other physics packages in the WRF system in response to research findings from case studies (those proposed by NCAR from field programs), comprehensive cloud verification systems being developed within EMC, and other sources of information from the research and operational meteorological communities. It is anticipated that convection will remain a problem to be addressed through various avenues of research, including high-resolution numerical modeling within WRF. The findings from these studies could yield improvements in cloud parameterizations at coarser scales in the NCEP operational forecast models.

GSD will continue to test updated physics packages, including the latest version of the NCAR microphysics, for the FY2010 RR change bundle and for later RR upgrades. Among possible upgrades for FY2010 are the following: introduction of explicit prediction of aerosol to provide explicit CCN input to the next version of RR microphysics, shortwave radiation scheme that incorporates radiative effects of aerosol and more accurate radiative effects of clouds, and an improved capability to describe stratocumulus-topped mixed layers. Some of this work will be leveraged from GSD WRF-Chem developments.

Subtasks

10.5.8.E1 15 November 2009 (NCEP)
Based on parallel testing and refinement of the experimental code, a “pre-implementation” code is delivered to NCO with physics upgrades for the 2010 NAM-WRF change package.

10.5.8.1 15 May 2010 (NCEP)

Development efforts produce a ‘research quality’ code of physics upgrades for consideration in the 2011 NAM-WRF change package.

10.5.8.2 15 July 2010 (NCEP)
Based on case-study testing and refinement of the research quality code, deliver an “experimental” code of physics upgrades for the 2011 NAM-WRF change package.

10.5.8.3 31 Jan 2010 (GSD)
Development efforts produce a set of physics upgrades important for aviation as part of the 2010 RR change package.

Deliverables

10.5.8.E1 30 March 2010 (NCEP)
Subject to NCEP Director approval, the physics upgrades become Operational at NCEP as part of the 2010 change package for WRF-NMM.

10.5.8.E2 30 June 2010 (GSD, NCEP)
Implement WRF Rapid Refresh 2010 change package, including upgrades to physics designed to meet the needs of aviation, into NCEP operations pending favorable NCEP recommendations, and operational capabilities and availability.

Task 10.5.9
FY 2010, Priority 11: Assimilate turbulence observations directly into the WRF model.

Description

By FY10, work on this area would be inclusion of turbulence assimilation in experimental tests with the Rapid Refresh, applicable also to the NAM model.

Subtasks

10.5.9.1 15 November 2009 (NCEP and GSD)
Report on results of monitoring made possible by tracking capability built into the existing turbulence report processing at EMC.

10.5.9.2 15 May 2010 (NCEP, GSD)
Development efforts produce a “research quality” code for upgrades (including assimilation of turbulence observations) to the GSI for consideration in the 2011 change package.

10.5.9.3 15 July 2010 (GSD)
Conduct parallel tests at EMC of upgrades to the Rapid Refresh with assimilation of turbulence observations.

Task 10.5.11
FY 2009, Priority 13: Develop adjoints for physical processes in forecast models.

Description

Development of the adjoint model for each of the physics packages in WRF is a major undertaking that is essential to achieve a fully functional 4DVAR data assimilation system. In addition, a number of physical parameterizations contain switches whereby different physical process are invoked depending on the value of certain model parameters. These switches introduce fundamental nonlinearities and discontinuities in gradients in the system that cannot be represented within the adjoint model. Consequently, research is needed to replace these switches with processes that produce continuous variation while maintaining the accuracy of the parameterized physics. As the physics adjoints are written, they must also be adapted to the parallel version of the WRF 4DVAR system to achieve computational efficiency.

Subtasks

10.5.11.1 15 June 2010 (CAPS)
Perform land surface state retrieval experiments using the WRF 4DVAR system. Evaluate the performance and impact on forecast, particularly of precipitation.

10.5.11.2 01 September 2010 (GSD, NCEP, CAPS)
Complete development and testing of new physics packages with switches replaced by continuous processes.

Deliverables

10.5.11.E1 15 June 2010 (GSD, NCEP, CAPS)
Adjoint coding completed for the full spectrum of physics options supported in the research and operational configurations of the WRF Model.

10.5.11.E2 01 August 2010 (NCEP)
Complete testing, analysis, and debugging of WRF-NMM core adjoint code.

Task 10.5.15
FY 2010, Priority 6: Develop improved methods of cloud and moisture analysis for use in the WRF Modeling System.

Description

The emphasis at GSD for this year will continue to be the implementation of techniques developed over the previous few years to improve cloud/hydrometeor analysis for the WRF Rapid Refresh. However, a new research thrust will be to investigate methods for assimilating cloud and moisture data into higher-resolution versions of the 3-km High-Resolution Rapid

Refresh (HRRR). This effort will include adaptation of Rapid Refresh algorithms (generalized cloud analysis and radar reflectivity-based diabatic digital filter initialization) to explicit convection resolving scales. In addition a fresh appraisal of other methods (EnKF, 4DVAR, etc.) will be conducted.

NCEP will be concentrating on implementing the most mature improvements to WRF-GSI assimilation and diabatic initialization using cloud, precipitation and other moisture observations. New sources will be tested with mini-impact tests to ensure that no harm will occur when the new data are turned on in NAM-WRF or RR-WRF assimilation systems based on WRF-GSI. Also included in improvements to be considered for implementation will be quality control procedures and algorithms.

Investigations into the "2DVAR" approach, in which the model's temperature, moisture and hydrometeor fields in each single column are adjusted by integrating the fields in the column forward/backward in time, will have been coded by this time (if it proves promising). Testing in earnest will begin this year and will determine if this approach does indeed yield model fields that are more dynamically consistent than those from the current nudging approach.

CAPS will continue to work with GSD in refining the cloud analysis package with emphasis on Rapid Refresh in quasi-operational settings. Additional data from e.g. Aqua satellites will be used. The emphasis in FY2010 will shift towards the explicit convective scale. The cloud analysis scheme will be upgraded to be consistent with the improved microphysics scheme used in the prediction model and to include polarimetric radar data.

Subtasks

10.5.15.1 30 December 2009 (GSD, CAPS)
Refine the Rapid Refresh/GSI cloud analysis package by adding additional satellite data, especially for polar-orbiter data. Emphasis will be placed on use in arctic environment, especially Alaska.

10.5.15.2 30 April 2010 (GSD)
Capability for real-time hourly cycled 3-km HRRR experimental forecasts in place (code, scripting, observation feed).

10.5.15.3 1 May 2010 (CAPS)
Further refine the use of dual-polarimetric data in the cloud analysis package and study their impact on forecast, using data from upgraded WSR-88D radars when available.

10.5.15.4 15 May 2010 (NCEP)
Development efforts produce a "research quality" upgrade (improved WRF-GSI and/or diabatic initialization for cloud, precipitation and moisture) to WRF code for consideration in the 2010 NAM-WRF change package.

10.5.15.5 01 June 2010 (CAPS)

Develop sophisticated observation operator for dual polarimetric radar measurements for improved microphysics and implement them into the EnKF system.

10.5.15.6 15 July 2010 (NCEP)
Based on case-study testing and refinement of the research quality code, deliver an 'experimental' upgrade (improved WRF-GSI and/or diabatic initialization for cloud precipitation and moisture) to WRF code 2009 change package.

10.5.15.7 30 September 2010 (GSD and CAPS)
Deliver improved Rapid Refresh cloud analysis package to NCEP ready for testing toward FY11 operational upgrade.

Deliverables

10.5.15.E1 15 November 2009 (NCEP)
Based on parallel testing and refinement of the experimental code, deliver to NCO a "pre-implementation" upgrade (improved WRF-GSI and/or diabatic initialization for cloud, precipitation and moisture) to WRF code for the 2010 change package.

10.5.15.E2 30 March 2010 (NCEP)
Subject to NCEP Director approval, implement in NCEP Operations the upgrade (improved WRF-GSI and/or diabatic initialization for cloud, precipitation and moisture) to WRF code as part of the 2010 NAM-WRF change package.

10.5.15.E3 15 September 2010 (CAPS)
Report on new results with polarimetric radar data assimilation.

10.5.15.E4 30 September 2010 (GSD)
Report on real-time hourly cycled HRRR tests to AWRP and NOAA.

Task 10.5.17
FY 2010 Priority 1: Infrastructure support for running Rapid Refresh, North American Mesoscale and HiResWindow modeling systems in operations at NCEP.

Description

As in FY 2009, this high priority task maintains the reliable and timely running of the Rapid Refresh, North American Mesoscale and HiResWindow modeling systems in NCEP operations and in providing gridded output (SAVs and AIVs) to aviation users. The activities are the same as in FY 2009. This is the first year that this operational infrastructure support is at full level, as activity with the RUC and MesoEta have ceased. The following activities continue throughout the year. In 2010, NCEP will replace the WRF-based NMM in NAM with an ESMF-based

NAM.

Subtasks

10.5.17.1 Maintain hourly Rapid Refresh (RR-WRF) runs with gridded output and provide SAV and AIV guidance products.

10.5.17.2 Maintain four-per-day North American Mesoscale (NAM-WRF) runs and provide SAV and AIV guidance.

10.5.17.3 Maintain four-per-day HiResWindow WRF Ensemble runs and provide SAV and AIV guidance.

10.5.17.4 Provide vendors with gridded model data via Family of Services and the FAA Bulk Weather Data Telecommunications Gateway.

10.5.17.5 Provide full native-resolutions grids from RR-WRF, NAM-WRF, and HiResWindow WRF Ensemble on NCEP and NWS/OPS servers.

10.5.17.6 Maintain access to model verification data.

10.5.17.7 Provide assistance to Inflight Icing, Turbulence, Convective Weather, Ceiling and Visibility and Oceanic Weather PDTs when their algorithms and product generation systems are ready to transition into NCEP's operational Production suite. (NCEP)

Deliverables

10.5.17.E1 Perform ingest, quality control and preparation of both existing and new observations in support of the operational WRF runs. (NCEP, GSD)

10.5.17.E2 As requested by other PDTs, incorporate new AIV calculations into Operational WRF Model post-processor and product generator. (NCEP, GSD)

10.5.17.E3 Perform configuration management for Rapid Refresh, including thorough documentation, and respond promptly to any code malfunctions (GSD).

10.5.17.E4 Monitor RUC performance, respond to any problems detected by GSD, NCEP, or any RUC users, diagnose cause, develop solution to RUC software, test changes and coordinate with NCO on implementation. (GSD, NCEP)

<u>Task 10.5.19</u>
FY 2010, Priority 5: Develop ability to assimilate WSR-88D radial velocity and reflectivity

data into the Rapid Refresh and NAM modeling systems.

Description

NCEP and GSD should have implemented direct use of the Level II radial winds and diabatic initialization of the Level II reflectivity mosaic in FY2009, but additional improvements to Level-II data assimilation will continue to be implemented. New sources and techniques will be tested with mini-impact tests to ensure that no harm will occur when the new data / techniques are turned on in RR and NAM assimilation systems. Also included in improvements to be considered for implementation will be improved quality control procedures and algorithms. NCEP will have decided which of its alternative schemes for advanced radar data 4DDA show the most promise and will be working to refine that approach. This refinement will by this time involve adaptation to the new ESMF.

Subtasks

10.5.19.1 15 January 2010 (EMC)
Begin preparations for the expected quadrupling of Level II data volume due to the dual polarization upgrade to 88D system.

10.5.19.3 15 January 2010 (EMC)
Submit a summary report on progress of affordable alternative strategies for assimilating Level II data in the ESMF era.

10.5.19.4 01 March 2010 (GSD, CAPS, NCAR, NCEP)
Begin 2010 testing of HRRR 3-km resolution 1-h cycling including current radar assimilation.

10.5.19.5 15 May 2010 (NCEP)
Development efforts produce a ‘research quality’ upgrade (improved GSI and/or diabatic initialization of Level II radial winds & reflectivity) to ESMF-based code for consideration in the 2010 NAM change package.

10.5.19.6 15 July 2010 (NCEP)
Based on case study testing and refinement of the research quality code, deliver an ‘experimental’ upgrade (improved GSI and/or diabatic initialization of Level II radial winds & reflectivity) to ESMF-based code for the 2010 NAM change package.

Deliverables

10.5.19.E1 15 November 2009 (NCEP)
Based on parallel testing and refinement of the experimental code, deliver to NCO the ‘pre-implementation’ upgrade (improved WRF-GSI and/or diabatic initialization of Level II radial winds and reflectivity) to code for the 2010 NAM change package.

10.5.19.E2 30 March 2010 (NCEP)
Subject to NCEP Director approval, implement in NCEP Operations the upgrade (improved GSI and/or diabatic initialization of Level II radial winds & reflectivity) to code as part of the 2010 NAM change package.

<u>Task 10.5.20</u>
FY 2010, Priority 10: Develop ensemble-based probabilistic products for aviation users.

Description:

In FY2010, the routine upgrades to the SREF will include implementation of a SREF made up entirely of WRF-based and ESMF-based members and an improved IC perturbation generating method. Developments will include planning for transition of SREF and its components in ESMF. These upgrades to the SREF will be accompanied by pre-implementation testing. NCEP and GSD must determine whether various configurations of these members (dynamic core, physics) provide sufficient diversity of solution (spread) and the same quality of probabilistic guidance to replace the multi-model approach with Eta and RSM.

NCEP and GSD will also continue to develop the aviation-oriented VSREF using the operational Rapid Refresh and North American Mesoscale WRF runs.

Subtasks

10.5.20.1 15 January 2010 (NCEP)
Deliver “research quality” version of upgrade (e.g., more members and stochastic physics) to SREF for consideration in November 2010 SREF upgrade package.

10.5.20.2 15 February 2010 (NCEP)
NCEP visits AWC to conduct continued training and education on SREF applications, obtain feedback on current guidance and to acquire new requirements (fully depending on FAA funding).

10.5.20.3 31 March 2010 (NCEP, GSD)
Downscaling aviation-related fields to 5-km resolution (using variant of RTMA downscaling) becomes available (fully dependent on FAA funding, $60K requested).

10.5.20.3 31 August 2010 (NCEP)
Based on parallel testing and refinement of the experimental code, deliver the ‘pre-implementation’ to NCO upgrade to SREF (e.g. more members and stochastic physics) for the November 2010 SREF change package.

10.5.20.4 15 July 2010 (GSD and NCEP)
Complete improved version of VSREF.

Deliverables

10.5.20.E1 30 November 2009 (NCEP)
Subject to approval from the NCEP Director, implement in NCEP Operations the SREF upgrades (20 km resolution, improved IC perturbation generating method).

10.5.20.E2 31 August 2010 (NCEP, GSD)
Deliver downscaling codes of aviation-related fields to NCO for November 2010 implementation (fully depending on FAA funding, $60K requested).

10.5.20.E3 31 August 2010 (NCEP)
Based on parallel testing and refinement of the experimental code, deliver the "pre-implementation" SREF upgrade code to NCO (more members and stochastic physics) for the November 2010 SREF change package.

10.5.20.E4 31 August 2010 (NCEP and GSD)
An initial version of the VSREF is also delivered to NCO as part of the Nov 2010 SREF change package.

Task 10.5.21
FY 2009, Priority 12: Develop, test, and implement advanced data assimilation techniques for aviation versions of the WRF model.

Description

Acknowledging that it will take many years of basic research to achieve a mature and affordable 4DDA capability for insertion into the WRF components running operationally, we suggest that FY 2007 should see accelerated efforts on this critical task. GSD, CAPS, and NCEP will continue to develop Ensemble Kalman Filter (EnKF) and simple 4DVAR capabilities that have the potential to be applied operationally toward aviation-relevant forecasts, especially in the Rapid Refresh application. The WRF 4DVAR capability will be expanded to include moist physics. The performance of the 4DVAR, 3DVAR, and EnKF will be compared as well as their computational requirements. A significant problem in ensemble forecasting and ensemble-based assimilation techniques is the difficulty of incorporating uncertainty in the limited area NWP forecast boundary conditions. We will develop techniques to address this problem within both the mesoscale and cloud-scale applications of the WRF-based EnKF.

In FY2007, the investigative steps in Steve Lord's 4DDA plan were concluded and adaptation to the Earth System Modeling Framework (ESMF) was completed. FY2009 will be spent in testing that new capability within ESMF. This ESMF capability, as applied in NCEP's Operational data assimilation system, must be used for BOTH regional and global applications.

Subtasks

10.5.21.1 01 June 2010 (GSD, CAPS, and NCEP)
Complete adjoint codes consistent with the microphysics used in the forward model of WRF, and use it for the retrieval of microphysics variables for convection and cloud initialization problems.

10.5.21.2 15 June 2010 (GSD, CAPS)
Complete case study testing of Ensemble Kalman Filter technique applicable to hourly or sub-hourly Rapid Refresh assimilation.

10.5.21.3 30 September 2010 (CAPS)
Conduct further refinement and testing of the WRF EnKF system.

Deliverables

10.5.21.E1 15 August 2010 (NCEP and GSD)
Submit report on testing results of 4DDA technique based on Ensemble Kalman Filtering.

10.5.21.E2 10 September 2009 (NCEP & JCSDA)
Report on testing of advanced 4DDA technique in ESMF.

<u>Task 10.5.23</u>
FY 2009, Priority 9: Develop advanced numerical models for aviation

Description

By this time, there should be extensive discussions with AWRP PDTs and NCEP on these developments and their relevance for aviation forecasting. Assuming positive answers to these questions, work on the isentropic global FIM model will continue. GSD will continue provide experimental grids to other PDTs as needed.

Subtasks

10.5.23 30 September 2010 (NCAR/MMM)
Continue development of the generalized vertical coordinate for WRF.

10.5.23 15 May 2010 (GSD)
Further work on GSD Flow-following Finite-volume Icosahedral Model (FIM) development. GSD will continue to coordinate this work as a possible alternative dynamic core but should be nested within EMC’s Global Model Framework by this time. GSD will be producing regular global model runs initialized with GFS initial conditions by this time, and will continue to provide preliminary isentropic FIM data to the Turbulence PDT and other PDTs for experimental evaluation.

Deliverable
10.5.23 30 Sept 2010 (GSD)
Submit separate reports on development and relevance for aviation-impact variables for isentropic WRF core and isentropic FIM models.

<u>Task 10.5.24</u>
FY 2010, Priority 8: Test WRF Rapid Refresh model at 3-km resolution toward High-Resolution Rapid Refresh

[As stated earlier, Task 5.24 specifically treats development and testing of the 3-km HRRR model itself. Development and testing work on assimilation of radar data at the 3-km scale is under Task 5.19.]

Description

In FY10, if funding is available for additional computer resources at NCEP for the HRRR, plans for a transfer to NCEP will be developed and the transfer itself will commence for FY11 testing at NCEP.

MDE will continue its effort toward HRRR development. Tests will continue at GSD over the NE Corridor domain, but with further improvements to the RR-WRF model and data assimilation methods (work under 5.19) based on experimental results from testing in FY09.

Subtasks

10.5.24 30 July 2010 (GSD, NCAR/MMM, CAPS)
Test FY10 version of 3-km High-Resolution Rapid Refresh (HRRR) configuration, including use of radar data.

Deliverable
10.5.24 31 August 2010 (GSD, CAPS)
Complete summer test of advanced FY10 version of 3-km High-Resolution Rapid Refresh (HRRR) configuration, including assimilation of radar data.

Budget Summary of FY 09 Tasks

Task #	Task Description	Priority	Funding: NCAR	NCEP	GSD	CAPS	DTC	Total	Running Total
08.5.17	Infrastructure support for running WRF RR, NAM, and HRW models	1		230	160			390	390
08.5.4	Develop, test, and implement the Rapid Refresh configuration of the WRF model (WRF-RR)	2		75	200		40	315	705
08.5.5	Develop, test, and implement improvements to the operational 3DVAR for WRF Rapid Refresh and WRF-NAM	3		120	200	60		380	1085
08.5.8	Improve physics in the WRF model, especially including those that affect aircraft icing	4	80	75	60			215	1300
08.5.15	Develop improved methods for analyzing clouds and water substance for use in the WRF modeling system	5		90	140	100		330	1630
08.5.6	Develop, test, and evaluate the performance of the nonhydrostatic WRF modeling system	5	60					60	1690
08.5.24	Test WRF Rapid Refresh model at 3-km resolution toward High-Resolution Rapid Refresh (HRRR)	6	80		150			230	1920
08.5.19	Develop ability to assimilate WSR-88D radial velocity and reflectivity data into the WRF modeling system	7	100	50	200	120		470	2390
08.5.20	Examine utility of ensembles for conveying probability and confidence to aviation users	8		85	100			185	2575
08.5.9	Assimilate turbulence observations (EDR data) directly into the WRF model	9		80	100			180	2755
08.5.21	Develop, test, and implement advanced 4DDA capability for the WRF model	10	80	80	80	80		320	3075
08.5.11	Develop adjoints for physical processes in the WRF model	11		80	80	50		210	3285
08.5.23	Develop advanced numerical models for aviation	12			150			150	3435
			400	**965**	**1620**	**410**	**40**	**3435**	**3435**

IV. Out-year Research Planning, FY 2011 through FY 2014

The following trends guide planning for the years FY 2011 through FY 2014.

- *Increase model resolution commensurate with increasing computing capacity and capability at NCEP, leading to more realistic model physics.*

Some version of the High-Resolution Rapid Refresh (1-3km grid and updating at least hourly and including radar and all other observations) will continue to be a major focus for FY11-14.

To parameterize a physical process is to approximate the effects of a process too small to be resolved by the computational grid. For example, a parameterization of convection may approximate the effects of growing cumulus towers with updrafts hundreds of meters across on a single grid square 10 km on a side. As the grid points become closer together, the approximations become more exact, but only to the extent that we understand how the atmosphere actually behaves and can describe that behavior in precise mathematical terms. We can expect more realism and more detail in our recipes for model physics. As convection-resolving model forecasts are tested and enhanced, increased scrutiny will be placed on cloud microphysics, sub-grid turbulence, and boundary-layer physics. Continued improvements in these model physics will be required to achieve the desired advances in model forecast accuracy. We can also expect better predictions of airflow in complex terrain, as more of the smaller topographic features are resolved. Much more work with the physics will be required as models begin to resolve features and more complete and complex processes have to be treated explicitly. In seeking to forecast significant weather features in ever-greater detail, new observing systems that capture the fine-scale structure of the atmosphere must also be identified and evaluated in the WRF 4DDA systems. These observations can serve to validate improvements in model physics and enhance the quality of model initializations. This will be an ongoing process as new observing systems are developed and advancing computer technology allows ever-higher model resolution.

- *Increased emphasis more sophisticated physics in aviation models and assimilation, especially for air chemistry.*

Since aerosols, both natural and anthropogenic, have a significant effect on precipitation, clouds, and visibility, treatment of these chemical processes and interaction with clouds and precipitation will become an increasing focus. Summertime problems with slant visibility in haze situations can be treated by gridded model forecasts by including aerosols and an initial treatment of air chemistry.

Assimilation of chemical variables using satellite and surface-based observations will also be a critical component of this direction in the FY11-14 time period. This means that aerosol/chemistry prognostic variables in aviation models of this era will need to be cycled through the 1-h assimilation cycle in the Rapid Refresh..

- *Greater emphasis on ensemble techniques*

In March 2004, EMC, GSD, and NCAR agreed that the first operational application of WRF in the HiResWindow runs at NCEP would be in the form of an ensemble forecast with three members drawn from each of the two WRF dynamical cores. Current AIV tools are based upon deterministic forecasts. In the out years, AIV products will be associated with probabilities (confidence limits), and aviation users will be able to quantify the risk of making specific decisions. It is anticipated that ensemble-based forecasts will be developed in research and operations for 3-h and even 1-h forecast frequency. This would mean, for instance, that the Rapid Refresh run might well be based on multiple forecasts initialized hourly.

We also envision the following changes in ensemble forecasts for aviation needs:

- Use of high-resolution ensemble data, taking advantage of deterministic high-frequency models from the RR, NAM and possibly even the HRRR, as members of this "Very Short-Range Ensemble Forecast".
- All current AWRP aviation products for icing, turbulence, ceiling, visibility, convection, and other hazards, will be produced out of a VSREF data base. Obviously, the VSREF design and aviation-product post-processing will be a driving factor in the future work of the AWRP team.
- Goals of NGATS will drive these developments.

- *Greater emphasis on advanced four-dimensional data assimilation*

Three-dimensional variational (3DVAR) data assimilation had become operational at several NWP centers by the turn of the century. Inclusion of the time dimension in variational assimilation has been difficult primarily because of the huge computational demand but also because the improvement of 4DVAR over 3DVAR or other operational analysis techniques is not always easy to demonstrate, especially on the mesoscale. The ability to assimilate any atmospheric observation relevant to prediction and to alter physical processes in the model based upon current and past observations is an attractive idea but very difficult to implement. Nevertheless, the European Centre for Medium-Range Weather Forecasts made 4DVAR assimilation operational before the turn of the century. WRF efforts will include making advanced four-dimensional data assimilation techniques operational at NCEP, either 4DVAR or Ensemble Kalman filters (EnKF), or other variations of these techniques. Nevertheless, new observing systems will always challenge the ingenuity of modelers to assimilate the data. Projections indicate that global data volumes will increase by *five* orders of magnitude by 2010. It is likely that some mesoscale applications will remain intermittent and be based on 3DVAR, for which observational data may support 15-30 min updates.

FY 2011

- Complete conversion / development and begin testing of a Short Range Ensemble Forecasting system based entirely on ESMF.
- Revisit strategies for the analysis of atmospheric moisture and clouds in light of changes in observing systems.
- Work on more site-specific snow forecasts for airport operations.
- Develop a scheme to more accurately simulate the vertical velocities observed in stratocumulus clouds in order to reproduce supercooled liquid water more realistically.
- An ensemble-based hourly Rapid Refresh cycle will be run in a test mode at GSD and/or NCEP.
- A 15-30-min Rapid Refresh cycle or HRRR cycle can begin testing, aimed toward improved forecasts of convective storms and surface conditions.
- Move Rapid Refresh toward global implementation with a 1-h update cycle using GSI and extending other Rapid Refresh modeling and assimilation capabilities, to better meet AWRP Oceanic PDT and global requirements for aviation.
- The FIM isentropic-based global model based on current GSD and EMC efforts may be appropriate for aviation products in the future.

FY 2012

- Pending computing resources at NCEP, implement a version of the 3-km hourly updating High-Resolution Rapid Refresh (HRRR) into operations.
- GSD and NCEP will work to adapt the Rapid Refresh components (GSI, model) to the ESMF-based data assimilation structure.
- Make appropriate modifications to assimilation of cloud and moisture observations, direct and proxy.
- Begin to use coupled atmospheric-chemistry version of WRF model in version of Rapid Refresh.
- Implement assimilation of air chemistry variables including volcanic ash, smoke, and natural and anthropogenic aerosols in Rapid Refresh version.
- Consider focused program for fog prediction and dissipation. A very high-resolution model, horizontally and vertically, is needed for this application.
- Implement a three-moment scheme for rain, snow, and graupel in the NCAR microphysics scheme and test on well observed cases.
- An hourly update cycle for global forecasting will be considered, possibly with an isentropic-based global model,, most likely the FIM model within the NCEP ESMF global model infrastructure.

FY 2013

- With the exception of having sufficient computing power to run convection-resolving forecasts over the whole continental U.S., further refinements to the model physics will be developed and tested for the purpose of enhancing the prediction of critical aviation weather parameters. These high-resolution forecasts should provide accurate terminal-area forecasts for all airports as part of the national forecast.

- Improve cloud microphysical scheme based on comparison to observations.

FY 2014

- Consider implementation of a version of the WRF as a global model ensemble component.
- With the exception of having sufficient computing power to run convection-resolving forecasts over the whole continental U.S., further refinements to the model physics will be developed and tested for the purpose of enhancing the prediction of critical aviation weather parameters. These high-resolution forecasts should provide accurate terminal-area forecasts for all airports as part of the national forecast.
- Improve cloud microphysical scheme based on comparison to observations.
- Develop a 5-10-min-updated national high-resolution grid monitoring capability with full atmospheric variables including aviation hazards – icing, turbulence, low ceiling/visibility.

Appendix A

Budget Tables for FY 2008, by Task and Organization

PDT for Model Development and Enhancement
Detailed FY 2008 Costs for Task 5.1 – all OPTIONS
Title: Infrastructure support for operational running of the RUC and NAM (formerly called the Meso-Eta) model systems

Organization	**FY 2008**	
NCEP/EMC	Staff Months	Cost ($K)
Labor[1] Senior Researcher Mid-Level Researcher Technician	 3.5 1.5	 45 9.9
Travel		1
Other Direct Costs Hardware (describe) Software (describe) Publication		
Additional Overhead[2]		9.1
Totals		65

[1] This footnote pertains to labor charges at NCEP/EMC and is not repeated later. Labor charges are fully encumbered, i.e. they include the benefits and overhead charges levied by either UCAR (about 88%) for visiting scientists (researcher) and our support services contractor (about 75%) for scientists (researcher) and programmers (technician).

[2] This footnote pertains to NCEP/EMC overhead charges and is not repeated later. The additional overhead charge is for EMC overhead and covers desktop computing software, support, and maintenance; supplies and administrative support. The charge in FY2007 will be 14%.

PDT for Model Development and Enhancement
Detailed FY 2008 Costs for Task 5.1 – all OPTIONS
Title: Infrastructure support for operational running of the RUC model systems

Organization	**FY 2008**	
GSD	Staff Months	Cost ($K)
Labor[1] Senior Researcher Mid-Level Researcher Technician	 1.0 4.1	 20 52.4
Travel		2
Other Direct Costs Hardware (describe) Software (describe) Publication		
Additional Overhead[1]		45.6
Totals		120

[1] This footnote pertains to GSD overhead charges and is not repeated later. The labor charges are for fully loaded labor. The additional overhead charges are for the GSD Internal Resources Allocation (IRA), which covers computing facility support and maintenance; hardware, software, and network upgrades; and administrative support. The IRA charge was modified in FY 2000 to be more equitable across all classes of employees (government, Cooperative Institute, and contractor). The charge in FY2006 is 38.65% applied to the fully loaded allocation, and it does fluctuate slightly from year to year.

PDT for Model Development and Enhancement
Detailed FY 2008 Costs for Task 5.4 - OPTION B1
Title: Develop, test, and implement Rapid Refresh configuration of the WRF model.

Organization	**FY 2008**	
GSD	Staff Months	Cost ($K)
Labor Senior Researcher Mid-Level Researcher Technician	3.0 6.7	60 85
Travel		8
Other Direct Costs Hardware (describe) Software (describe) Publication		2
Additional Overhead		95
Totals		250

PDT for Model Development and Enhancement
Detailed FY 2008 Costs for Task 5.4 – OPTION A
Title: Develop, test, and implement Rapid Refresh configuration of the WRF model.

Organization	**FY 2008**	
NCEP/EMC	Staff Months	Cost ($K)
Labor Senior Researcher Mid-Level Researcher Technician	1.5 1.5	21 9.1
Travel		
Other Direct Costs Hardware (describe) Software (describe) Publication		
Additional Overhead		4.9
Totals		35

PDT for Model Development and Enhancement
Detailed FY 2008 Costs for Task 5.4 – OPTION A, B1
Title: Develop, test, and implement Rapid Refresh configuration of the WRF model.

Organization	**FY 2008**	
DTC (50% each to GSD, NCAR)	Staff Months	Cost ($K)
Labor Senior Researcher Mid-Level Researcher Technician	 0.5 1.5	 8.2 15.6
Travel		1
Other Direct Costs Hardware (describe) Software (describe) Publication		
Additional Overhead		15.2
Totals		40

PDT for Model Development and Enhancement
Detailed FY 2008 Costs for Task 5.5 – OPTION B1
Title: Develop, test, and implement improvements to the operational 3DVAR for WRF Rapid Refresh and North American Mesoscale runs

Organization	**FY 2008**	
GSD	Staff Months	Cost (K)
Labor Senior Researcher Mid-Level Researcher Technician	 3.6 8	 56 94
Travel		5
Other Direct Costs Hardware (describe) Software (describe) Publication		
Additional Overhead		95
Totals		250

PDT for Model Development and Enhancement
Detailed FY 2008 Costs for Task 5.5 – OPTION A
Title: Develop, test, and implement improvements to the operational 3DVAR for WRF Rapid Refresh and North American Mesoscale runs

Organization	**FY 2008**	
NCEP/EMC	Staff Months	Cost ($K)
Labor Senior Researcher Mid-Level Researcher Technician	5 2	88 13
Travel		1.5
Other Direct Costs Hardware (describe) Software (describe) Publication		0.7
Additional Overhead		16.8
Totals		120

PDT for Model Development and Enhancement
Detailed FY 2008 Costs for Task 5.5 – OPTION A
Title: Develop, test, and implement improvements to the operational 3DVAR for WRF Rapid Refresh and North American Mesoscale runs

Organization	**FY 2008**	
OU/CAPS	Staff Months	Cost (K)
Labor (including fringe benefits at University standard rate of 37.4%) Senior Researchers Mid-Level Researchers	 1 3.6	 11.3 17.4
Travel 1 Domestic trips to visit NCEP or GSD or to attend conference		1
Other Direct Costs Telephone, supplies, computer network connection charges; Publication		0 2
Additional Overhead (IDC 26%)		8.3
Totals		40

Note: Salaries are based on current rates plus 5%. All items except for hardware are charged by the University of Oklahoma at a reduced indirect cost (IDC) rate of 26% based on CIMMS Cooperative Agreement. Regular IDC rate is 48%. This note will not be repeated again.

PDT for Model Development and Enhancement
Detailed FY2008 Costs for Task 5.6 – OPTIONS A, B1

Title: Develop, test and evaluate the performance of the WRF Modeling System

Organization	**Option A**		**Option B1**	
NCAR (MMM)	Staff Months	Cost ($K)	Staff Months	Cost ($K)
Labor[1] Mid-Level Researcher Senior Level	 1.25	 15.1	 1.25 1.25	 15.1 12.6
Travel				
Other Direct Costs Hardware (describe) Software (describe) Publication				
Additional Overhead				
NCAR Indirect Cost		7.9		14.4
Computer Services Cost		1.3		2.4
UCAR Fee		0.7		1.3
Totals	1.25	25	2.5	45.8

[1] NCAR Labor is direct labor costs plus benefits. The "Additional Overhead" category includes (i) overhead on the labor, travel, and other direct costs and (ii) the direct and indirect computing service center cost, which is based on the staff months worked.

PDT for Model Development and Enhancement
Detailed FY 2008 Costs for Task 5.8 – OPTION C
Title: Improve model physics that affect icing in RUC and NAM models; transferable to WRF model.

Organization	**FY 2008**	
NCAR (RAL)	Staff Months	Cost (K)
Labor		
Student		
Senior Researcher	1	13
Mid-Level Researcher	2.5	19
Technician		
Travel		2
Other Direct Costs		
Hardware (describe)		
Software (describe)		
Publication		3
Additional Overhead		
Benefits and indirect charges		37
NCAR computer use charges		6
Totals	3.5	80

PDT for Model Development and Enhancement
Detailed FY 2008 Costs for Task 5.8 - OPTION A
Title: Improve model physics that affect icing in RUC and NAM models; transferable to WRF model.

Organization	**FY 2008**	
GSD	Staff Months	Cost ($K)
Labor Senior Researcher Mid-Level Researcher Technician	 0.6 1.5	 13.2 18.0
Travel		4
Other Direct Costs Hardware (describe) Software (describe) Publication		 2
Additional Overhead		22.8
Totals		60

PDT for Model Development and Enhancement
Detailed FY 2008 Costs for Task 5.15 – OPTION A
Title: Develop new methods for analyzing clouds and water substance for use in the WRF modeling system.

Organization	**FY 2008**	
GSD	Staff Months	Cost ($K)
Labor Senior Researcher Mid-Level Researcher Technician	0.5 1.5	10 23.2
Travel		2
Other Direct Costs Hardware (describe) Software (describe) Publication		2
Additional Overhead		22.8
Totals		60

PDT for Model Development and Enhancement
Detailed FY 2007 Costs for Task 5.15 - OPTIONS B2 / C
Title: Develop new methods for analyzing clouds and water substance for use in the WRF modeling system.

Organization	**FY 2007**	
OU/CAPS	Staff Months	Cost ($K)
Labor Senior Researcher Mid-Level Researcher	0.5/0.5 2.5/6.0	8.2/14.3 13.8/33.2
Travel		1.0/1.5
Other Direct Costs Hardware (describe) Software (describe) Publication		0.8/2.6
Additional Overhead		6.2/13.4
Totals		30/65

PDT for Model Development and Enhancement
Detailed FY 2008 Costs for Task 5.17 - OPTION D
Title: Infrastructure support for running WRF Rapid Refresh, North American Mesoscale and HiResWindow models in NCEP Operations.

Organization	**FY 2008**	
NCEP/EMC	Staff Months	Cost ($K)
Labor Senior Researcher Mid-Level Researcher Technician	 .5 8 8	 8 92 50
Travel		0.5
Other Direct Costs Hardware (describe) Software (describe) Publication		
Additional Overhead		24.5
Totals		175

PDT for Model Development and Enhancement
Detailed FY 2008 Costs for Task 5.19
Title: Develop ability to assimilate WSR-88D radial velocity and reflectivity data into the WRF modeling system.

Organization	**FY 2008(B2/C)**	
OU/CAPS	Staff Months	Cost ($K)
Labor Senior Researcher Mid-Level Researcher Technician	1 / 2.5 8.25 / 12 0	10.3 / 25.6
Travel		1.5 / 1.2
Other Direct Costs Hardware (describe) Software (describe) Publication		2.1 / 2.0
Additional Overhead		15.5 / 24.8
Totals		75 / 120

PDT for Model Development and Enhancement
Detailed FY 2008 Costs for Task 5.19 – OPTION B2
Title: Develop ability to assimilate WSR-88D radial velocity and reflectivity data into the WRF modeling system.

Organization	**FY 2008**	
GSD	Staff Months	Cost ($K)
Labor Senior Researcher Mid-level Researcher	 1.0 3.2	 19 38
Travel		2
Other Direct Costs Hardware (describe) Software (describe) Publication		 3
Additional Overhead		38
Totals		100

PDT for Model Development and Enhancement
Detailed FY2007 Costs for Task 5.19 – OPTION C
Title: Develop ability to assimilate WSR-88D radial velocity and reflectivity data into the WRF modeling system.

Organization	**FY2007**	
NCAR (MMM)	Staff Months	Cost ($K)
Labor[1] Mid-Level Researcher (2)	8	72.5
Travel		
Other Direct Costs Hardware (describe) Software (describe) Publication		
Additional Overhead		
NCAR Indirect Cost		36.7
Computer Services Cost		7.2
UCAR Fee		3.5
Totals	8	120

[1] NCAR Labor Cost is a fully burdened number and includes benefit costs. The "Additional Overhead" category includes (i) overhead on the labor, travel, and other direct costs and (ii) the indirect computing service center fees, which are based on the staff months worked.

PDT for Model Development and Enhancement
Detailed FY 2008 Costs for Task 5.19 – OPTION C
Title: Develop ability to assimilate WSR-88D radial velocity and reflectivity data into the WRF modeling system.

Organization	**FY 2008**	
NCEP/EMC	Staff Months	Cost ($K)
Labor Senior Researcher Mid-Level Researcher Technician	 1 1.5 1	 17.5 17.5 6
Travel		2
Other Direct Costs Hardware (describe) Software (describe) Publication		
Additional Overhead		7
Totals		50

PDT for Model Development and Enhancement
Detailed FY 2007 Costs for Task 5.20
Title: Examine utility of ensembles for conveying probability and confidence to aviation users

Organization	**FY 2008**	
NCEP/EMC	Staff Months	Cost ($K)
Labor Senior Researcher Mid-Level Researcher Technician	 2 2.5 1	 35 29 6.5
Travel		2
Other Direct Costs Hardware (describe) Software (describe) Publication		.6
Additional Overhead		11.9
Totals		85

PDT for Model Development and Enhancement
Detailed FY 2008 Costs for Task 5.20
Title: Examine utility of ensembles for conveying probability and confidence to aviation users

Organization	**FY 2008**	
GSD	Staff Months	Cost ($K)
Labor Senior Researcher Mid-Level Researcher Technician	 0.5 4.3	 8 52
Travel		2
Other Direct Costs Hardware (describe) Software (describe) Publication		
Additional Overhead		38
Totals		100

PDT for Model Development and Enhancement
Detailed FY2008 Costs for Task 5.24 – OPTION B2

Title: Test WRF Rapid Refresh Model at 3-km Resolution Toward High-Resolution Rapid Refresh

Organization	**FY 2008**	
GSD	Staff Months	Cost ($K)
Labor Senior Researcher Mid-level Researcher	 1.0 3.2	 19 38
Travel		2
Other Direct Costs Hardware (describe) Software (describe) Publication		 3
Additional Overhead		38
Totals		100

PDT for Model Development and Enhancement
Detailed FY2008 Costs for Task 5.24

Title: Test WRF Rapid Refresh Model at 3-km Resolution Toward High-Resolution Rapid Refresh – Option B2

Organization	**FY2008**	
NCAR	Staff Months	Cost ($K)
Labor[1] Mid-Level Researcher (2)	3.25	32.9
Travel		
Other Direct Costs Hardware (describe) Software (describe) Publication		
Additional Overhead		
NCAR Indirect Cost		17
Computer Services Cost		3
UCAR Fee		1.6
Totals	3.25	54.5

[1] NCAR Labor is direct labor costs plus benefits. The "Additional Overhead" category includes (i) overhead on the labor, travel, and other direct costs and (ii) the direct and indirect computing service center cost, which is based on the staff months worked.

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Appendix B

Summary of Aviation Model Requirements in Future Years as of 1999

A meeting of AWRP Product Development Team representatives was held in February 1999 in Boulder, Colorado to discuss requirements for MDE PDT efforts from all of the other PDTs. The purpose of the meeting was two-fold: 1) to bring those requirements to the attention of the MDE PDT, and 2) to present current MDE efforts and plans and explore opportunities for improved interaction between the MDE and other PDTs. The requirements for MDE efforts set at this meeting, ***still relevant as of March 2007***, are listed below.

- One- to twelve-hour forecasts of snow, freezing rain, ice pellets, freezing fog, snow pellets, and frostBall ground-based winter aviation hazards are a high priority within the aviation weather community.
- New ways of verifying mesoscale forecasts, based upon a user perspective of skill, must be developed.
- Mesoscale forecasts should have an element of probability in them. Decision makers need to weigh the probability of an event against the potential damage it might cause.
- Tests with high-resolution models have indicated that resolutions *at a minimum* of 10 km in the horizontal and 500 m in the vertical are necessary to adequately capture the scales of motion producing turbulence. Need proof that the more sophisticated algorithms actually perform better when used in higher resolution models.
- For improved icing forecasts, the need exists to predict the height and strength of inversions more accurately (partly a matter of vertical resolution), and to predict supercooled water more accurately (cloud droplets and especially drizzle droplets). Droplet depletion mechanisms, especially the presence of ice particles in a cloud of droplets, are not handled well. Predicting cloud field details is still a major problem.
- Line convection is a major problem en route because it can force major deviations from the flight path. Single-cell convection is a problem around approach and departure paths at airports. Current operational model resolution is insufficient for adequate treatment of either of these phenomena, particularly the latter. The mesoscale model that solves this problem will need frequent updates (presumably through assimilation of radar and satellite data) at a frequency approaching ten minutes.
- Formation of ground fog is a delicate balance between infrared radiation, the wind close to the ground, and the moisture content of the air. After the initial formation of fog, the interaction of radiation with fog droplets also becomes important. Adequate treatment of these processes requires higher resolution than is likely to be available nationally. Either post-processing of national model output must be improved or, alternately, process models must be run at the local level. Predicting the time of dissipation of low stratus is a high priority. A combination of statistical and physical/dynamical modeling approaches is likely to be useful.
- The model needs to make quantitative use of cloud information from the ground and from satellite. The treatment of stratocumulus clouds must be improved. Icing frequently occurs in stratocumulus clouds.

Plans for development of the RUC, Eta, and WRF systems were also presented at this meeting, including staged changes to higher resolution as NCEP computer upgrades allow. Also, improvements in data assimilation are planned, especially regarding assimilation of satellite and radar data, which are important for the other PDTs and their work. The requirements stated above are generally consistent with the MDE plans for operational model improvements, but identify the specific areas where progress is needed for other PDTs. The meeting was also successful in identifying areas where improved collaboration can take place between MDE and other PDTs, in particular ceiling/visibility and convective weather. A significant amount of interaction is already occurring between MDE and the icing and turbulence PDTs, which should continue and also increase.