Developmental Testbed Center Annual Operating Plan
1 April 2016 – 31 March 2017

The Developmental Testbed Center (DTC) is a distributed facility with components residing at the National Center for Atmospheric Research (NCAR) and the National Oceanic and Atmospheric Administration's (NOAA) Earth System Research Laboratory (ESRL). The fundamental purpose of the DTC is to serve as a coordinating mechanism that acts as a bridge between research and operations, thereby facilitating the activities of both communities in pursuit of their own objectives. The DTC Annual Operating Plan (AOP) for 2016 was developed based on recommendations from the DTC's Science Advisory Board (SAB) and the priorities of NCEP's Environmental Modeling Center (EMC) as articulated by the EMC team leads, as well as the priorities expressed by the DTC sponsors through their DTC Management Board (MB) members.

Director's Office Staff and Non-Salary Expenses

Motivation

The Developmental Testbed Center (DTC) is a distributed facility with components residing at the National Center for Atmospheric Research (NCAR) and the National Oceanic and Atmospheric Administration's (NOAA) Earth System Research Laboratory (ESRL). In addition to a distributed staff, all DTC activities involve extensive interactions with external partners in both the research and operational communities. The DTC Director is responsible for the overall coordination of DTC activities and maintaining strong ties with the community. The DTC Assistant Director helps the DTC Director with this overall coordination. Due to the distributed nature of the DTC, the Director must rely on staff at the respective institutions to oversee the staffing, budgets and reporting to assure accountability. The DTC external management structure also requires administrative support for external meetings that goes beyond the day-to-day administrative support for staff contributing to DTC activities.

Project Description

The DTC Director's Office provides administrative and management support for all DTC activities. This support includes: (i) overseeing and coordinating the annual planning process (both internally and externally), (ii) managing and coordinating all DTC tasks, (iii) conducting DTC workshops and tutorials, (iv) interacting with DTC partners [e.g., NOAA's National Centers for Environmental Prediction (NCEP) Environmental Modeling Center (EMC), NCAR's Mesoscale and Microscale Meteorology (MMM) Laboratory, and the Air Force] on collaborative efforts, (v) creating and maintaining the DTC web site, (vi) coordinating the preparation and distribution of a quarterly DTC newsletter, and (vii) providing administrative support for DTC management meetings. A detailed breakdown of the costs of operating the DTC that are included under this activity is included below:

Project Deliverables

- Quarterly reports to EC
- Reports to sponsors
- Quarterly DTC newsletter

DTC Visitor Program

Motivation

Maintaining strong ties to both the research and operational NWP communities is critical to the success of the DTC's mission. The DTC Visitor Program provides an opportunity for the DTC, as well as our operational partners, to develop stronger ties with the research community, as well as serving as a mechanism to make research innovations available for considering by the DTC's operational partners.

Project Description

The DTC Visitor Program supports visitors to work with the DTC to test new forecasting and verification techniques, models, model components, and DA approaches for NWP and to perform diagnostic evaluations of the current operational systems. It also offers an opportunity for visitors to introduce new NWP and verification techniques into the community codes supported by the DTC. The goal of this program is to provide the operational weather prediction centers (i.e., NCEP and Air Force) with options for near term advances in operational weather forecasting and to provide researchers with NWP codes that represent the latest advances in technology. The DTC offers the opportunity for two types of projects: 1) projects undertaken by the Principal Investigator (PI), and 2) projects undertaken by a graduate student under the direction of the PI. Successful applicants for the first type of project are offered up to two months of salary compensation, and travel and per diem, where the two months could be distributed over several weeks during a one-year period. Successful applicants for the second type of project are offered up to one year of temporary living per diem stipend and travel expenses for the graduate student to work with the DTC in Boulder, Colorado, or with DTC operational partners, and travel and per diem for up to two two-week visits to the DTC by the project PI. Researchers have a year to complete their project. The proposal is to allocate $81 K from the DTC's NOAA funds to support visitor project and submit a proposal to NSF to match this $100 K. The additional $19 K in the budget for this activity covers computing support costs for the visitors.

Project Deliverables

- Visitor project reports and transition of new NWP technology to community codes, as appropriate

WRF Users Workshop

Motivation

Maintaining strong ties to both the research and operational NWP communities is critical to the success of the DTC's mission. Workshops are one mechanism for bringing together a broad range of people working on a similar problem together to share information and ideas. The annual WRF Users Workshop is a forum that brings together researchers from around the world to share ideas and discuss future NWP development.

Project Description

The DTC proposes to continue to provide funding to MMM to invest in the organization of the 2015 WRF Users Workshop. This funding provides salary support for staff tasked with organizing the workshop. Expenses related to food and beverages provided at the workshop are covered by the workshop registration fee. In the past, this workshop has provided a productive forum for bringing together researchers and the operational community to discuss model strengths/weaknesses and potential new innovations for operational consideration. Topics discussed at this workshop include from model physics, data assimilation, ensembles systems and verification techniques.

Project Deliverables

- Co-host WRF Users Workshop

Data assimilation system (GSI and EnKF) code management and user support

Motivation

Recent research indicates positive forecast impacts when introducing ensemble information to traditional variational data assimilation algorithms. Many operational centers have implemented such

an algorithm through a hybrid ensemble-variational (EnVar) data assimilation system. The NCEP hybrid system uses two separate data assimilation systems for its Global Forecast System (GFS): the Gridpoint Statistical Interpolation (GSI) system, which updates the deterministic analyses, and the Ensemble Kalman Filter (EnKF) system, which updates the ensemble perturbations. For regional hybrid applications, potential uses of model specific ensembles, updated through EnKF, are still under investigation. Supporting GSI and EnKF to the community will help focus the research community on further development of EnVar data assimilation capabilities and encourage direct research transitions to these two operational systems and, therefore, the hybrid data assimilation system for both global and regional applications.

Project Description

For AOP 2016, the DTC is proposing to continue providing code management and user support for NCEP's two operational data assimilation systems: GSI and EnKF. The DTC will continue to maintain the code management framework through the joint GSI and EnKF Data Assimilation Review Committee (DRC). This code management framework facilitates close collaboration among active system developers (e.g., NOAA, NASA, NCAR, etc) and avoids code divergence among operational agencies and the research community. As chair of the DRC, the DTC hosts development meetings and implements code review procedures. The DTC also fulfills committee member duties (reviewing proposed code changes, testing proposed changes, and providing feedback and suggestions to code development). Under this activity, the DTC will also collaborate with EMC and JCSDA to examine the current state of the GSI code and provide suggestions and advice toward the GSI refactoring effort.

The DTC will continue to provide community support for the GSI and EnKF data assimilation systems. The DTC will provide a helpdesk service, which provides timely answers regarding the systems and their usage and development. In addition, the DTC will provide technical and operational contingency support for maintaining and troubleshooting Air Force Weather applications of GSI, as needed. For AOP 2016, the DTC proposes one code release. The code release effort will include documentation and webpage updates, code pre-release tests, and code/utility updates, if necessary. Documentation covers all aspects of the individual data assimilation systems, as well as the combined EnVar capability when using EnKF together with GSI. Updates to the webpage will include a new online tutorial covering the new capabilities included in the release. The DTC will continue to maintain the DTC Community repository and provide code access to community developers for various applications (e.g. developers for HWRF, NCAR MPAS, etc). This work will include syncing the DTC repository with the EMC repository (which is not publically accessible) and maintaining the community tools/utilities. The DTC will also work with NCEP/EMC on unifying the build systems for GSI and EnKF among agencies and providing a modern and portable build system to both internal and external developers. In addition, the DTC will work with potential contributors from the community to bring code from the community back to the trunk of the data assimilation repository.

Project Deliverables

- GSI and EnKF code releases
- Data assimilation community user support service

High resolution (3 km) EnVar testing and evaluation

Motivation

NCEP's transition from the GSI three-dimensional (3D) variational data assimilation (DA) system to the GSI-EnKF 3D hybrid DA system for its Global Forecast System (GFS) produced significant improvements in forecast skill. Following on the global application success, a number of regional applications have transitioned to one-way 3D hybrid ensemble-variational systems that use the GFS ensemble (e.g., NAM,

HWRF, RAP). A number of operational centers (e.g., UK Met Office, Environment Canada) have implemented four-dimensional Ensemble-Variational (4D EnVar) DA toward further improved initial conditions for their global models. Such a DA system is slated to be included in NCEP's 2016 GFS implementation. The DTC Science Advisory Board (SAB) recommended the DTC continue to work with operations on 4D EnVar (including 4D hybrid EnVar), as this work is needed to support R2O transitions. Conducting EnVar DA tests is critical to DTC staff being able to make effective contributions to this effort. Such testing and evaluation (T&E) activities have the potential to provide critical insight into future operational applications at NCEP/EMC and NOAA/ESRL. Given the DTC's current focus on DA for regional applications and NCEP's goal to move toward high-resolution regional guidance, focusing its DA T&E activities on convective-scale NWP and ensembles provides the best alignment with its operational partners.

Project Description

The DTC proposes to test and evaluate 4D hybrid EnVar capabilities for high-resolution regional DA. This work will begin with a benchmark system based on the operational HRRR system, which uses global ensembles (~30 km) for its hybrid DA system and one-hour ARW forecasts from interpolated RAP analyses (13 km) for its 3-km initial conditions.

The first objective of this activity will be to demonstrate whether 4D hybrid EnVar system improves upon the performance of the benchmark HRRR system. The DTC will set up an experimental 4D hybrid EnVar system, including setting up a workflow based on the operational NOAA HRRR system. Then the DTC will test hourly cycled 4D hybrid EnVar for comparison to the control runs using the 3D hybrid system with current HRRR DA configuration. The DTC will verify the results and demonstrate the performance of 4D hybrid EnVar.

The second objective of this activity will be to estimate feasibility and then impacts of fast cycling of 4D hybrid EnVar. Based on the above-mentioned system and experiments, the DTC will increase the analysis update frequency from hourly to sub-hourly. The DTC will collect and adapt appropriate observation and background files for such a fast cycling system and perform experiments to evaluate its performance and the impacts of increasing update frequency on analysis and forecasts.

The DTC will work closely with the HRRR and EnVar developers on the experiment design and result evaluation. A reduced domain size may be adopted, if needed, due to computational constraints. Verification metrics accepted for operational relevancy will be used.

Project Deliverables

- Project reports
- Conference presentations to share outcome of tests with community
- Publication in referred journal

NEMS software support & community engagement

Motivation

The NOAA Earth Modeling System (NEMS) framework is an important communication component in coupled operational models for both global and regional applications. Current operational NWP systems using the NEMS framework are a subset of the full capabilities contained within the entire framework. This framework is based on software systems that are a shared resource with distributed development. Ongoing development within NEMS is maintained under version control. To serve as a bridge between operations and research, the DTC must have the capability to run targeted NWP systems within the NEMS framework [e.g., North American Mesoscale (NAM) model].

Project Description

The critical elements undertaken for the NEMS software support activity within the DTC will include maintaining a connection to the operational NEMS repository and external libraries and enhancing portability of the targeted software systems within NEMS to DTC platforms. The DTC will be responsible for checking out a tag from the operational NEMS repository at EMC twice a year to ensure that the system is still portable to DTC testing platforms. Focus will be placed on ensuring the framework is portable to the NCAR supercomputer, Yellowstone. Select regression tests for regional applications will be conducted on Yellowstone to ensure the code is robust and portable. Any issues that arise during the regression testing will be investigated and reported back to NEMS developers for inclusion in the repository. Small test cases using targeted operational systems (e.g., NAM) will be conducted to ensure the DTC maintains a minimum level of fluency with these systems. In addition, the DTC will maintain a version of each of the external libraries required for NEMS. These libraries are tags from the EMC repository and will be shared among other DTC supported software packages to the greatest extent possible.

Project Deliverables

- Targeted operational software ported and tested on DTC testing platforms
- Feedback provided to NEMS developers on any issues that arise during testing

WRF software support & community engagement

Motivation

The Weather Research and Forecasting (WRF) model is a community code with distributed development and centralized support. Though NCAR's Mesoscale and Microscale Meteorology (MMM) Laboratory already contributes to the WRF modeling system for the community in many areas (including dynamics and physics development, WRF framework development, model system testing, and user support) additional activities are not well funded that are critical to the overall success of the WRF package and offer great benefits to WRF users around the world. Hence, DTC funding is an important source to enable these additional support and development tasks.

Project Description

The DTC works in collaboration with NCAR's MMM to maintain the WRF repository and make certain that robust software packages are distributed to the user community. As part of this process, regression testing of the WRF repository is performed on a weekly basis. The regression test suite currently includes 274 ARW real-data tests, 150 ARW idealized tests, 19 WRF-Chem tests, 42 NMM tests, and 2 HWRF tests. The regressions tests are run using three compilers on NCAR's supercomputer, Yellowstone: PGI, Intel, and GNU. Any issues that arise during the regression testing are resolved in a timely manner. Ongoing maintenance and enhancement of the regression test script to exercise new options and capabilities available in the latest code is conducted, as necessary, throughout the year.

A major WRF release is typically distributed to the user community on an annual basis, occurring in April. A minor bug-fix release often follows in July or August. In the three months leading up to the major release and one month leading up to the minor release, various tasks are conducted to ensure the quality of the released code, including maintenance of the WRF infrastructure, updates to the WRF Preprocessing System (WPS) to support the latest functionality in WRF, and packaging the code for distribution.

Project Deliverables

- (1) Major and (1) Minor WRF code release

UPP software support & community engagement

Motivation

To serve as a bridge between operations and research, the DTC provides a framework for the two communities to collaborate in order to accelerate the transition of new scientific techniques into operational weather forecasting. This framework is based on software systems that are a shared resource with distributed development. The current operational systems are a subset of the capabilities contained in these software systems. Ongoing development of these systems is maintained under version control with mutually agreed upon software management plans. The Unified Post Processor (UPP) is one such system the DTC supports to the community in order to facilitate operations to research (O2R) and research to operations (R2O) transitions. Currently, UPP is used in operations with the Global Forecast System (GFS), the North American Mesoscale (NAM) model, the Weather Research and Forecasting (WRF) Rapid Refresh (RAP) and High Resolution Rapid Refresh (HRRR) models, and the Hurricane WRF (HWRF) model.

Project Description

The DTC is proposing to continue to collaborate with EMC to make the UPP tool available to the user community. UPP provides the capability to compute a variety of diagnostic fields, interpolate to pressure levels, de-stagger grids and interpolate to specified grids. These grid manipulations produce GRIB output files that can be used directly by a number of plotting packages and the Model Evaluation Tools (MET) verification package. The community UPP repository will be maintained in a manner such that updates and enhancements may be contributed by, and shared between, both the operational and research communities. A new community release of UPP will be distributed annually. Associated with each release, extensive testing will be performed. Both NetCDF and binary WRF output file formats will be tested in serial and parallel (using mpi) environments to ensure that a broad range of model output formats are compatible with the UPP software. The full suite of tests will be run on all of the computing platforms available to the DTC using a variety of compilers. Documentation updates will be made available to the user community with each release and user support will be provided by the DTC through help desk email support and presentations during the Basic WRF Tutorials.

Project Deliverables

- Code release
- UPP presentation at the Basic WRF Tutorials in Boulder, CO
- Documentation updates (User Guide, webpage)

HRRR ensemble code maintenance and Rocoto end-to-end workflow

Motivation

For the purpose of testing and evaluation activities, it is critical to have diligent code management in place. One proposed testing and evaluation activity for AOP 2016 uses the High Resolution Rapid Refresh (HRRR) system in an ensemble mode. The HRRR system consists of various software components including the GSI and hybrid ensemble data assimilation systems, the WRF Preprocessing System (WPS), WRF-ARW dynamic core, and the Unified Post Processor (UPP). To ensure coordinated research, development, and transition of new or enhanced techniques to operations for the various system components, it is critical to maintain a traceable history of the software used in the testing.

Workflow management systems make executing large testing and evaluation activities more efficient through managing complex interdependencies and requirements. An HRRR-based ensemble system is one such complex system that requires workflow management to effectively execute the large number of tasks. When factoring in pre-processing, including data assimilation, running the model itself, post-

processing, calculating verification scores, and visualizing the results, one "run" of an ensemble modeling system can entail hundreds of individual calls to different software system components and scripts. The complexity of the system makes the process of running an ensemble system onerous for an operational center and extremely hard for the research community to emulate.

Project Description

For the purpose of supporting testing and evaluation activities in AOP 2016, it will be necessary to establish a mechanism for HRRR code maintenance. The DTC proposes using the existing HRRR code repository with branches to capture code changes/additions associated with a particular DTC testing activity.

GSD staff have access to the deterministic HRRR system that utilizes the Rocoto workflow. This workflow will be used as a starting point for development of a Rocoto workflow for an HRRR-based ensemble system. An expanded version of the workflow will also include visualization, MET verification, and probabilistic product generation adopted from the Short Range Ensemble Forecast (SREF) post-processing package. For AOP 2106, the workflow will be designed to run on the Theia (NOAA) and Yellowstone (NCAR) supercomputers, providing the DTC with options to perform experiments on either of the two supercomputers.

Project Deliverables

- Branches within the existing HRRR repository with code modifications related to this year's testing (e.g. stochastic physics parameterizations).
- HRRR ensemble Rocoto-based workflow established on Theia and Yellowstone supercomputers.

MMET

Motivation

To assist the research community with conducting detailed case study testing of newly developed techniques, the DTC established and is maintaining the Mesoscale Model Evaluation Testbed (MMET). The motivation for MMET is to assist the research community in efficiently demonstrating the merits of new developments that could positively impact an operational configuration in the future. Researchers have the ability to perform comparisons between previous baseline configurations established by the DTC or operational model output provided by the DTC through MMET. It is believed that by providing the research community with information on current operational model shortfalls or relevant research topics of interest, a stronger collaboration among the NWP community as a whole can be realized, ultimately resulting in more accurate and reliable operational NWP forecasts.

Project Description

In the past, as new versions of the WRF and NEMS code were released, MMET cases were rerun to provide current, baseline results for the user community. For AOP 2016, the DTC proposes to evaluate operational model output for several NWP systems (both deterministic and probabilistic) and provide the objective verification scores to the research community through MMET as baseline results for comparison with the forecast performance of their innovation. Depending on the native model resolution, model output will be regridded to either a 12- or 3-km CONUS domain. Operational systems will include North American Mesoscale (NAM), Rapid Refresh (RAP), High-Resolution Rapid Refresh (HRRR), and Hurricane WRF (HWRF) models for deterministic forecasts and the Storm Scale Ensemble of Opportunity (SSEO) for probabilistic forecasts. For each deterministic model, MMET cases with high relevance will be determined (some current MMET cases may be aged off and replaced with new cases) and operational data will be obtained. To address the needs for other regions of operational consideration, a case over Alaska will also be established with available deterministic models. For the

probabilistic forecasts, a multi-week period during the 2016 Hazardous Weather Testbed (HWT) Spring Experiment will be gathered and distributed.

Cases of interest and/or persistent operational model issues will be identified throughout the year by leveraging a direct link to EMC's Model Evaluation Group (MEG). A table identifying which MMET cases could be used to investigate particular issues will be established and publicized to the research community. This table will also include recommendations on what to investigate further and/or what remedies have already been investigated.

Through enhanced collaborations with community users, improvements to operational physics suites can be realized in a more efficient manner. The research community will be encouraged to interact with the DTC on MMET cases through a variety of forums. One avenue for enhancing collaborations is through the DTC Visitor Program. Direct communication with potential candidates will be established to encourage future proposal submissions to the DTC Visitor Program. Another avenue is through community outreach events. The DTC proposes to offer an instructional session to raise awareness of the tools available to the community-at-large through MMET. Opportunities to join with other regional workshops or tutorials to expand the target audience will be explored. It is expected that these outreach approaches will establish and enhance connections with future community collaborators and promote the use of MMET datasets.

Project Deliverables

- Deterministic and probabilistic operational model data and verification statistics available through MMET as baselines
- New cases of interest identified through collaboration with MEG and list of operational cases of interest and/or persistent model weaknesses maintained and publicized on the MMET webpage
- Presentation at a relevant workshop/conference
- Community outreach: instructional session

Addressing model uncertainty through stochastic parameter perturbations within the HRRR ensemble

Motivation

In most existing regional ensemble systems, model-related uncertainty is addressed by using multiple dynamic cores, multiple physics suites, or a combination of these two approaches. While these approaches have demonstrated potential, it is time-consuming and costly to maintain such systems, especially in operations. In order to move toward a more sustainable and unified system, the DTC proposes to test an option based on an extensively tested physics suite combined with stochastic parameter perturbations on a set of physics parameterizations within that suite.

There has been considerable work on introducing stochastic physics into large-scale models, particularly for long-range and seasonal forecasts, but use of a similar approach in high-resolution, short-range models has been somewhat limited. The proposal for AOP 2016 is to investigate the impact of a stochastic physics parameter perturbation approach within a convection-resolving ensemble at 3-km grid spacing.

Project Description

The latest version of the WRF-ARW core includes an option to generate a field of random perturbations that can be applied to parameters in physics schemes. This option was developed and implemented by Judith Berner of NCAR. The stochastic pattern is centered on zero and has a user-prescribed standard

deviation. With this option, the user can specify the random perturbation length-scale, temporal de-correlation of the randomly perturbed field, and the vertical structure of the random perturbations.

During AOP 2015, the DTC ensemble team worked closely with the Rapid Refresh (RAP) physics developers to implement stochastic perturbations into several RAP physics parameterizations. Multiple experiments were performed comparing performance between a RAP ensemble created using stochastic parameter perturbations in a variety of RAP physics schemes and a RAP ensemble that involved mixed physics. To this end, stochastic parameter perturbations were applied to parameters within the Grell-Freitas convective scheme, MYNN Planetary Boundary Layer (PBL) scheme, and the RUC Land Surface Model (LSM). In addition, the impact of stochastic perturbation approaches such as SKEB and SPPT were explored. Results are very encouraging and motivate a continuation and expansion of this work.

To facilitate a similar effort at storm-scale resolutions for a rapid refresh ensemble (planned for implementation into operations at NCEP in 2017), the DTC proposes to test stochastic parameter perturbations, as well as the impact of the SKEB and SPPT approaches, within the High-Resolution Rapid Refresh (HRRR) framework. The focus for this testing will be on PBL and LSM processes. Once again, the team will work in close collaboration with the developers of the physical parameterizations. This collaboration will facilitate the process of identifying parameters of interest and adequate perturbation ranges. Performance of the HRRR ensemble with stochastic parameter perturbations will be evaluated in terms of bias, skill, accuracy, reliability, and sharpness.

Project Deliverables

- Report on the experiment results
- Results presented at relevant conferences/workshops
- Journal article on outcome of testing

Test and evaluation of smoothed terrain-following coordinate in WRF

Motivation

The terrain-following sigma coordinate (Phillips, *J. Meteor.* 1957) has been widely used in NWP models with considerable success for many years. However, because the horizontal component of the pressure-gradient force as expressed in sigma coordinates consists of two terms of opposite sign, numerical truncation errors can be exaggerated in areas of steep terrain, introducing spurious small horizontal scale accelerations into the model solutions.

In recognition of this well-known problem with the pure sigma coordinate, various remedial procedures have been developed. One specifically applicable to WRF was recently developed by Joe Klemp of NCAR (2011, *Mon. Wea. Rev.*), with test results on idealized cases showing a considerable reduction of small-scale spurious features. Through current DTC funding, the implementation of Klemp's proposed smoothed terrain-following (STF) coordinate into the current version of WRF should be completed by March 2016. The proposed work for AOP 2016 is to rigorously test this implementation on a variety of cases, including real-time forecast application with data assimilation.

Project Description

The DTC proposes to thoroughly test and evaluate the new STF coordinate option in WRF by pursuing two types of testing: 1) the DTC's NCAR node will evaluate the performance of the STF coordinate using several retrospective MMET cases that include a variety of weather systems from different seasons, and 2) the DTC's GSD node will test the STF coordinate in the WRF-ARW-based Rapid Refresh (RAP) and High Resolution Rapid Refresh (HRRR) systems for real-time experimental runs. The purpose of this testing is to vet this major WRF enhancement for both the larger WRF user community and within the most

important WRF-ARW operational forecast applications. A thorough evaluation is necessary to ensure that this major WRF enhancement is working correctly and that provides measurable improvement in overall forecast quality over the present WRF vertical coordinate, particularly in areas where terrain influences are large. Performance with respect to the standard variables of wind, temperature and dew point (or relative humidity), as well as for precipitation location and amount will be examined. In the case of GSD, the impact of the new coordinate will be evaluated in the context of hourly cycling; both real-time parallel testing and retrospective testing will be performed and evaluated for suitability of introducing this new WRF feature into the operational RAP and HRRR at NCEP.

Based on past experience with new model features, the DTC anticipates issues may arise that will require assistance from the WRF developers at NCAR. Hence, the budget for this activity includes a small amount of funding for the NCAR WRF developers so they will be able to assist the DTC in addressing these matters in a timely and effective manner.

Project Deliverables

- Reports on the performance of the STF coordinate in WRF-ARW
- Publication in referred journal
- Presentation at a relevant workshop/conference

Containers for UPP, MET, and MMET datasets

Motivation

Many times the biggest hurdle to running a new software system is getting it set up and compiled on the intended computer platform. Building complex systems that require a number of external libraries can be a large issue for users to overcome. To relieve some of this difficulty, a new technology referred to as a "container" has been developed that allows for the complete software system to be bundled and shipped to users. The containers include everything that is needed to run the software component, including the operating system (tools and libraries) and code - thus allowing for the user to quickly produce output without being delayed by technical issues.

Project Description

With non-DTC funding, containers have been set up for portions of an end-to-end NWP system, including WPS, WRF, and NCL. The proposed DTC activity for AOP 2016 is to develop containers for the Unified Post Processor and Model Evaluation Tools (MET) software systems. In addition, datasets that make up two Mesoscale Model Evaluation Testbed (MMET) cases will also be bundled in a container. By establishing these additional containers, the DTC will be assisting the user community (especially students) with efficiently running NWP components and making connections with future collaborators.

Project Deliverables

- Containers for UPP, MET, and two MMET cases

7th Ensemble User's Workshop

Motivation

The 7th Ensemble User Workshop is scheduled to take place at the NOAA Center for Weather and Climate Prediction (NCWCP) 14-17 June 2016. This workshop is expected to attract 100-150 participants representing a broad cross-section of expertise ranging from ensemble developers to the end users of ensemble products. Starting in 2011, the DTC has co-sponsored these semi-annual ensemble user workshops with NCEP. The upcoming 7th Ensemble User Workshop will have a specific focus on how to support the NWS as it moves toward a seamless operational ensemble forecast system at storm- to global-scales, from short-term to seasonal time scales, and from atmosphere-only to ocean-wave

coupled ensemble prediction systems. Given the future direction of NCEP's modeling suite, it will be important for the DTC to continue its engagement with ensemble systems and potentially expand its work in this area. Maintaining strong ties to both the research and operational NWP communities is critical to the success of the DTC's mission. Workshops like this ensemble user workshop serve as an excellent mechanism for bringing together a broad range of people working on a similar problem to share information and ideas.

Project Description

The DTC proposes to once again co-sponsor with NCEP the upcoming 7th Ensemble User Workshop. Traditionally, DTC has contributed to the development of the workshop agenda, provided a summary presentation on the DTC's ensemble related infrastructure development and testing activities, led one of the discussion breakout groups, and contributed to the preparation of a meeting report. In addition, the DTC is proposing to provide logistical support for the workshop, as well as travel support for two invited speakers.

Project Deliverables

- Report on the 7th Ensemble User Workshop recommendations

HWRF User Support

Motivation

The state-of-the-art HWRF end-to-end system currently has over 1100 registered users. By supporting the HWRF system to the community at large, it is expected that NCEP will receive more feedback on the model's performance, which will lead to model improvements. In addition to its use by the community at large, several recipients of the HFIP grants rely on the public release HWRF code and/or documentation to conduct their research. The HWRF system undergoes substantial annual upgrades that are making great strides towards improving its forecast skill. For the community to provide useful feedback on the strengths and weaknesses of this system, it is important for them to have timely access to the current capabilities, which requires an annual code release and updates to the accompanying documentation and training materials. Given the rapidly evolving HWRF system and complexity of the system, providing in-person tutorials is an essential mechanism for engaging the HWRF user community.

Project Description

For AOP 2016, the DTC proposes to continue its HWRF user support activities. These activities will include an HWRF v3.8a release that will contain updates included in the 2016 operational HWRF, plus additional research capabilities (such as the idealized modeling capabilities and alternate physics options). Prior to this public release, the DTC will test the new HWRF capabilities (e.g. GFS upgrades, *basinscale* configuration, alternate physics, updated GFDL Vortex Tracker, etc.) on multiple platforms, enabling users around the world to benefit from a range of scientific options valuable for tropical cyclone research and forecasting. Revised support documents will be prepared to accompany the public release: HWRF scientific documentation, HWRF Users' Guide, datasets and an online tutorial. The HWRF FAQ and Known Issues webpages will be updated. Bug fixes will be posted as they become available. The HWRF release and support will include a set of running scripts and eight (potentially nine) updated components: WRF atmospheric model, WRF preprocessing system (WPS), GSI data assimilation, *hwrf-utilities* (which includes a vortex relocation package), atmosphere-ocean coupler, MPIPOM-TC (or HYCOM, with backwards compatibility for use with MPIPOM-TC) ocean model, WAVEWATCH III (pending planned 2016 implementation), UPP, and GFDL Vortex Tracker. The planned transition from

MPIPOM-TC to HYCOM and inclusion of WAVEWATCH III, as well as the inclusion of the *basinscale* configuration will require increased testing and further documentation.

An HWRF tutorial is proposed for College Park, MD. The tutorial will consist of lectures by EMC and DTC staff, as well as invited speakers from URI, GFDL, and HRD. In the event the DTC is invited to participate in an international HWRF tutorial, staff time for this event will be supported by allocations for HWRF User Support, but travel would need to be provided by the host country.

As part of its HWRF user support activities, the DTC will also continue to maintain a helpdesk to support users in troubleshooting compilation and running issues using a ticketing system to track requests.

Project deliverables

- HWRF v3.8a public release with updated documentation and HWRF Users' Page
- User support helpdesk with ticketing system
- In-person HWRF tutorial in College Park, MD

HWRF Developer Support

Motivation

Distributed HWRF development is being facilitated through funding provided by the Hurricane Forecast Improvement Project (HFIP). To avoid divergence of these development efforts and assure new development can be easily integrated into the centralized HWRF repository, it is imperative that these developers work on the same code base. To assure these developers work within the repository framework, it is important to provide training on the HWRF code management tools and provide assistance using these tools when necessary. Providing access to non-operational aspects of HWRF, such as candidate new components, and a mechanism for developers to share tools also enhances the inter-developer collaborations, which will lead to timelier model advancement.

Project Description

The DTC currently hosts the HWRF code repository, which is composed of a sophisticated set of scripts plus eight components: WRF atmospheric model, WRF Preprocessing System (WPS), GSI data assimilation, *hwrf-utilities* (which includes several libraries and a vortex initialization package), ocean-atmosphere coupler, MPIPOM-TC ocean model, UPP postprocessor, and vortex tracker. For AOP 2016, the DTC proposes to continue to maintain the HWRF code repository and coordinate the links to all external source code components. This work will include updating the main HWRF development branches with all developments in the trunk of the community repositories, assuring that the main HWRF development and the community codes remain synchronized. The HWRF repository will also be affected by a potential transition of the WRF repository from SVN to Git. The DTC will continue to communicate with the WRF team and assess the impact to HWRF and apply the most appropriate repository structure for all HWRF components. Additionally, if the planned operational implementation of two new components, HYCOM ocean model (replacing MPIPOM-TC as the ocean component) and WAVEWATCH III, is successful the DTC will update the code management plan accordingly and implement it for these components. The HWRF repository integrity will be regularly tested through consistency checks, which are tests to ascertain that code changes not intended to alter the answer of the operational HWRF configuration indeed do not do so. For AOP 2016, the DTC will also undertake work towards enhancements to the consistency check procedure to expedite this process.

The DTC will facilitate the use of code management tools to HWRF developers external to EMC. This facilitation will be done through training and repository assistance to developers, as well as through conducting regression tests and consistency checks on the developments, as applicable. In response to developer feedback, the DTC plans to provide additional specialized training in AOP 2016. This focused training will be held through remote sessions or in conjunction with another scheduled event. In addition, the DTC will enhance computational platform interoperability by working with developers to make sure their code is portable and usable by the broader community. Particular emphasis will be given to supporting the HFIP principal investigators in accomplishing the development funded by their grants. Development deemed high priority by EMC for inclusion in the operational HWRF (particularly involving scripting developments) will be addressed within the scope of the resources allocated to this activity. Finally, the DTC will continue to host the HWRF Developers Committee meetings, maintain the mailing lists used by the HWRF developers, and centralize the overall communication among HWRF developers.

The DTC will continue to maintain and enhance *hwrf-contrib*. Note that DTC will maintain the *hwrf-contrib* code repository and support access to it, but maintenance, documentation and support of the codes in *hwrf-contrib* is the responsibility of the contributors. In addition, DTC will continue to maintain the HWRF build system, a set of tools designed to efficiently compile and install the HWRF source code.

Project deliverables

- Unified HWRF scripts and code with additional developments ready for testing by EMC.
- Code integrity tested through regression and consistency checks, as applicable.
- Code repository *hwrf-contrib* maintained and protocols for contributing code well documented.

HWRF Physics Advancement

Motivation

The HFIP community has invested a substantial amount of effort over the last five years to investigate and improve the representation of physical processes in HWRF. The planetary boundary layer (PBL) parameterization in HWRF was improved with the addition of the *alpha* parameter (AOML/HRD) and dependency on the critical Richardson number (EMC). These two innovations lead to forecasts that are more physically consistent with observations. Through Prof. R. Fovell's (Univ. Albany) participation in the DTC Visitor Program, additional changes to the PBL height specification were implemented in the 2015 operational HWRF.

The effects of the PBL parameterization on the forecast fields cannot be easily separated from those of cloud-radiative forcing (CRF). Work by Bu et al. (2014) and R. Fovell (Fovell and co-authors, 2015) showed that both the PBL scheme and cloud radiative feedback (CRF) impact storm size, which in turn influences storm motion through the beta effect. To improve CRF in HWRF, a scale-aware partial cloudiness scheme in RRTMG was added by the DTC, which compensated for the lack of stratus cloud representation in the HWRF parent domain. This innovation was tested by DTC and transitioned to EMC for consideration. Tests indicated forecast improvement, resulting in operational implementation of RRTMG and the scale-aware partial cloudiness scheme in 2015.

Multi-metric, process-based diagnostics such as those performed in the above testing and evaluation (T&E) work provides a deeper understanding of the physical processes representation in *any* modeling system. The process-based diagnostic work outlined above (Fovell, Bu) allows for identification of

misrepresentation of physical processes in parameterizations, which is key to identifying situations of getting the "right answer for the wrong reason" (e.g. CRF compensating for excessive PBL mixing). This type of information leads to improvements to the physical representations in the schemes themselves, rather than tuning model parameters for a specific model configuration, which have lasting impacts on model parameterizations and are a more model agnostic approach to improving forecast skill.

Project Description

For AOP 2016, the DTC proposes to pursue physical process diagnostics directed at improving the representation of physical processes in HWRF. The DTC proposes to run HWRF retrospective forecasts for multiple PBL and microphysical schemes and compare the results of near-surface winds, PBL structure (e.g. mixing profiles), Quantitative Precipitation Forecasts (QPF), clouds, and radiation against observations of the same variables or available proxies, including satellite images. These diagnostics will complement the usual track and intensity verification to provide input on the representation of physical processes in the various PBL and microphysical parameterizations tested.

There are several ongoing efforts by community Subject Area Experts (SAEs) to improve physical parameterizations that can be applied across modeling systems to improve model fidelity, and the DTC is in a unique position to coordinate and test innovations, and to provide EMC with information and codes that can be transferred into the operational system. Current proposed DTC Visitor projects by M. Iacono (AER) on the treatment of cloud radiative transfer in the RRTMG and Prof. R. Fovell (Univ. Albany) on the impact of PBL assumptions on HWRF forecast skill (pending successful proposal) will be leveraged to foster further collaborations. Based on the results obtained from the proposed physics-based sensitivity study and diagnostic work, the DTC will collaborate with an appropriate SAE to work toward improvements in the operational HWRF physics. The focus will be on exploration of the direct and indirect role of PBL in model skill and gaining better understanding of how and why model physics alterations act to change tropical cyclone structure, motion, and intensity. The DTC will facilitate the R2O transition through effective communication with EMC concerning controlled diagnostics, sensitivity experiments, and multi-storm testing of any improved parameterizations from the above work. Any advancement deemed viable will be made available to EMC for pre-implementation testing.

Project deliverables

- Report on results of sensitivity experiments to various PBL and microphysics parameterizations.
- Assessment of improved parameterizations in the context of the operational HWRF system with new capabilities in HWRF physics made available to EMC for testing.
- Results presented at relevant conferences/workshops
- Publication in referred journal

MET development and community support

Motivation

The Model Evaluation Tools (MET) verification package is comprised of a series of tools designed to help users with pre-processing, data inspection, and calculation of both traditional and spatial statistics. Aggregation of those statistics and attributes can be performed using the MET analysis package or through the METViewer database and display system. MET is a community-supported software package with over 2900 users from a wide variety of universities (48%), government (27%), non-profit organizations (14%), and private companies (11%). Following its October 2015 release, 40 new users registered and 150 downloads were requested. Besides helping the research community refine numerical weather prediction through objective evaluation, MET and specifically MODE (Method for

Object-based Diagnostic Evaluation) are being used either operationally or to make operational decisions at NCEP's Environmental Modeling Center (EMC) and Weather Prediction Center (WPC), the UK Met Office, and the South African Weather Bureau. Supporting MET and METViewer to the community is necessary to meet the DTC mission of connecting the research and operational communities by using common tools with repeatable results directed toward assessing forecast skill and informing the model development process.

Project Description

The MET helpdesk responds to approximately 2-5 emails per day, resulting in approximately 200 tickets closed per year. This support requires approximately $90 K per year to maintain. The remainder of the community support funds are generally used for the MET release and documentation. Decisions regarding what to include in the next software release are made via requirements assessment based on input from the community and other DTC task areas, which are recorded in our features tracking and bug-fix package (JIRA). Areas of critical development for the next annual MET release include:

- Adopting the NetCDF4 data model to better support the use of satellite data and other relevant data sources.
- Completing the inclusion of and developing unit tests for advances made through other projects
- Extending METViewer capability to support new statistics added during the release cycle
- Completing documentation for the next MET release and adding critical descriptive METViewer documentation.
- Improving user support via an enhanced online tutorial and more usage examples.
- Enhancing support for evaluations directed at obtaining critical feedback on forecast system performance that can be obtained from information provided by the data assimilation system (see below)

During AOP 2015, among the many new capabilities bundled in the METv5.1 release was initial support for data assimilation (DA), in particular support for reading the GSI diagnostic file and computing statistics. For AOP 2016, the verification team is proposing to continue to work with the DTC Data Assimilation team, and others in the community (e.g. JCSDA, NCAR MMM, NOAA ESRL, and Air Force staff) to identify and complete 1-2 major enhancements to MET/METViewer in order to provide critical support for this discipline. To facilitate the discussion, the Verification team proposes to host, at a university, a verification workshop focused on two topics: data assimilation and a topic complementary to data assimilation of interest to the host university. The verification workshop, which is being proposed based on SAB recommendations, will be the first one held since 2010. Continuing work focused on data assimilation would also leverage the cloud verification work being performed for the Air Force.

Project Deliverables

- MET release with 2-4 new capabilities, with a focus on the needs of the data assimilation community.
- Updated MET documentation and newly created METViewer documentation.
- Expanded online user support.
- Report on verification workshop recommendations.

NOAA-DTC verification unification

Motivation

Over the past two years, the number of NOAA users has tripled and now represents 2% of the 2,900+ registered users and 11% of the registered users affiliated with a government organization. These

numbers are likely under-representative because MET is now installed in a public location on a number of NOAA computing platforms (i.e., WCOSS, Theia, and Jet). In response to requests from NOAA partners, METViewer is now available for developmental use by EMC on the NCEP Central Operations (NCO) virtual machine farm and for use by GSD on the HIWPP computing platform.

During AOP 2014 and 2015, the DTC Verification Team undertook a concerted effort to engage users within the NOAA to understand and document their verification capabilities and needs to inform MET development decisions. These discussions brought to light a significant number of verification packages within and across organizations with overlapping capabilities, but also a fair number of differences. For example, EMC has at least 3-4 separate gridded verification packages, each supported by different staff. EMC has recognized the need to reduce redundancy and move toward a unified package. ESRL is also reviewing several on-going verification efforts to determine how to streamline and become more efficient. The need for NCEP to unify its verification systems was identified in the recent UMAC report. The UMAC report includes numerous references to "evidence driven decision making" and "improved verification and diagnostic methods ." In particular, "We recommend that NCEP unify its verification systems, and migrate toward a community verification system, based on infrastructure such as MET and METViewer, with comprehensive and regionally specific statistics." (see page 26 of report). The need to unify verification tools has also been identified by the NGGPS Verification Team as a key priority.

Project Description

The DTC proposes to accelerate the verification unification effort within NOAA by working with its NOAA partners to complete a requirements analysis for verification unification within NOAA, continuing to leverage the pre-existing community software package, MET, and augmenting the METViewer database and display system to handle big data needs and support. The requirements analysis will be the basis of a white paper outlining a roadmap for verification unification. To make strides towards a unified package, two to three critical EMC and ESRL capabilities will be integrated into MET. Three candidates have already been identified: use of binned climatologies for both global and ensemble verification, the ability to derive additional fields from PrepBUFR observations, and methods to automatically generate 2-dimensional plots of verification scores. Other candidates will be identified through discussions with stakeholders and capabilities will be added in a prioritized order. To assure METViewer will be able to meet the needs of NCEP and ESRL, a new database schema able to hold multiple years of data from the NOAA production suite and GSD testing environment (~500GB) will be developed and tested. To be most useful, it will be important for this database to be available to the public, which will require close coordination with EMC, NCO and ESRL/GSD. In addition to these new capabilities, the DTC is proposing to provide a 3-day in-house tutorial at NCWCP and prioritized user support through the MET helpdesk. In-house training and discussions with ESRL staff will occur by including GSD staff in the Verification Team. This proposed work is critical to efforts already funded at ESRL and EMC. If funded, these activities would accelerate the verification unification efforts, which, in turn, would increase the effectiveness of Research-to-Operations (R2O) endeavors within the DTC, NOAA and the broader community.

Project Deliverables

- 2-3 critical capabilities added to MET (several listed above).
- Improved database design to handle "big data" and many users (i.e. the public).
- Tutorial at NCWPC and prioritized user support of NOAA staff.
- Development of MET/METViewer expertise at ESRL/GSD.
- White Paper on roadmap for verification unification.

Cloud verification

Motivation

Skillful numerical guidance for forecasting cloud properties is critical to Air Force (AF) operations, as well as a broad range of other applications (e.g., renewal energy, others?). Advanced cloud-centric verification metrics focused on the properties of clouds most critical to AF operations are needed by the AF to inform decisions regarding their future implementation of cloud forecasting systems. Due to the complex non-linear interactions between clouds and other physical processes in the atmosphere, accurate representation of cloud processes is also critical to the overall performance of numerical weather prediction (NWP) models. Hence, advanced cloud-centric verification metrics provided to the community through the Model Evaluation Tools (MET) would provide tools needed to perform in-depth model evaluations geared toward informing the model development process.

Project Description

The DTC proposes to enhance and implement, based on information gathered from the 557th Weather Wing, advanced cloud-centric verification metrics that can be used to inform decisions regarding the implementation of cloud forecasting systems as part of the AF operational guidance. These metrics will focus on the cloud properties that are most critical to AF operations, within the limitations of what observations are available for conducting an evaluation. These metrics will enhance the limited capabilities that were identified during AOP 2105. In addition, the DTC will implement the new capabilities developed through AOP 2015 in a formal released version of the Model Evaluation Tools (MET) verification package, and will make available prototype versions of newly developed capabilities. Examples of enhancements to be considered (in collaboration with the 557th Weather Wing) include extensions to MET to include quantile thresholding (for model comparisons), methods for three-dimensional variables (e.g., cloud layers), inclusion of additional observation systems (e.g., from polar orbiting satellite systems), and application of spatial-temporal verification methods. The DTC will also provide a report outlining potential avenues for development of more advanced capabilities that take advantage of more advanced verification approaches and focus on additional relevant cloud variables.

Project Deliverables

- Cloud-centric verification metrics developed through AOP 2015 added to formal released version of MET
- New or enhanced cloud-centric verification metrics implemented and made available through prototype versions of MET.