

Data Analysis and Modeling to Support NOWCAST and Forecast Activities at the Fallon Naval Air Station

Darko Koracin
Desert Research Institute
2215 Raggio Parkway, Reno, NV 89512
phone: (775) 674-7091 fax: (775) 674-7060 email: Darko.Koracin@dri.edu

Melanie Wetzel
Desert Research Institute
2215 Raggio Parkway, Reno, NV 89512
phone: (775) 674-7024 fax: (775) 674-7060 email: Melanie.Wetzel@dri.edu

John Lewis
Desert Research Institute
2215 Raggio Parkway, Reno, NV 89512
phone: (775) 674-7077 fax: (775) 674-7060 email: John.Lewis@dri.edu

Award Number: N00014-06-1-0028
<http://www.dri.edu>

LONG-TERM GOALS

The goals of this project are to increase our understanding of weather predictability and to develop capabilities to provide more accurate forecasts and nowcasts in complex terrain using ensemble modeling techniques and special observations including remote sensing.

OBJECTIVES

The main objectives of the study are: 1) To develop and test a mesoscale forecasting system with sub-kilometer horizontal resolution to support the NOWCAST system at the Fallon Naval Air Station (NAS); 2) To improve the accuracy of the forecasts and nowcasts by assimilating asynchronous data into the forecasting system; 3) To provide short-term accurate predictions of cloud structure, especially for the clouds such as the stratus cloud decks and fog, that are relevant to visibility for the Navy's aircraft operations in the complex terrain; and 4) To develop methods of mesoscale ensemble forecasting to improve the applicability of the forecasts and nowcasts.

APPROACH

A self-sustained MM5 real time forecasting system to support NAS Fallon was fully developed and tested. The system is now in continuous operation on a multi-processor computer located in the Division of Atmospheric Sciences at the Desert Research Institute (DRI). The system results - 24 hour forecasts updated every 12 hours - are posted on the dedicated web site with password protection [URL: <http://www.adim.dri.edu/>]. The forecasts are provided for five interactive domains with the highest sub-kilometer resolution (330m) on the innermost domain centered on the NAS Fallon runway.

Report Documentation Page

*Form Approved
OMB No. 0704-0188*

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE 30 SEP 2008	2. REPORT TYPE Annual	3. DATES COVERED 00-00-2008 to 00-00-2008			
4. TITLE AND SUBTITLE Data Analysis And Modeling To Support NOWCAST And Forecast Activities At The Fallon Naval Air Station		5a. CONTRACT NUMBER			
		5b. GRANT NUMBER			
		5c. PROGRAM ELEMENT NUMBER			
6. AUTHOR(S)		5d. PROJECT NUMBER			
		5e. TASK NUMBER			
		5f. WORK UNIT NUMBER			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Desert Research Institute, 2215 Raggio Parkway, Reno, NV, 89512		8. PERFORMING ORGANIZATION REPORT NUMBER			
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)			
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)			
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES Code 1 only					
14. ABSTRACT The goals of this project are to increase our understanding of weather predictability and to develop capabilities to provide more accurate forecasts and nowcasts in complex terrain using ensemble modeling techniques and special observations including remote sensing.					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 12	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

To increase accuracy of the forecasts, three types of data assimilation were incorporated into the operational forecasting system

- Assimilation of data from four meteorological stations that were set up in the NAS Fallon area during a previous ONR project.
- Assimilation of WSR 84 Fallon radar data.
- Assimilation of satellite data and use of these data as input to a new methodology of improving model initial conditions in the vicinity of the NAS Fallon area, and the initial boundary layer height over the entire model domain (Vellore et al. 2007).

The major testing of the forecasting system included sensitivity studies using various optional physical parameterizations, varying horizontal and vertical resolution, and efficiency with respect to number of processors used for the operational forecasting.

We have tested the efficiency of the real-time forecasting system on a multi-processor computer and this has provided guidance on which aspects of the model structure the execution time is most sensitive.

Ensemble forecasts provide human forecasters with a range of possible solutions whose average is generally more accurate than a single deterministic forecast. It also provides a quantitative basis for probabilistic forecasting (Lewis 2005; Lewis et al. 2006) for the operational weather forecasting sectors. Our approach is to conduct an investigation on the potential effectiveness of ensemble forecasting for the Fallon real-time forecasting system using a 'Lagged Average Forecasting (LAF) method' following Hoffman and Kalnay (1983) by creating ensemble members of different ages (i.e., at different initial times, not by different set of initial perturbations at a specific time as in the Monte Carlo approach). For evaluation, we selected a case study of high winds and a dust storm event during February-March 2002 in western Nevada. Reno and Fallon surface observations indicated a sudden gusty spell of wind, rising to more than 10 m s^{-1} on 28 February 2002. These conditions are faced by the Fallon NAS staff and pilots – creating significant issues related to wind forecasting and visibility as they affect aircraft operations.

WORK COMPLETED

To support real-time forecasting and nowcasting at the Fallon Naval Air Station, surface meteorological stations were operational during the project period. The location specifications of these sites are:

- Fallon 31ESE [NAS B17] at Centroid in Fairview Valley (39°19'27" N, 118°13'22" W, 4235' MSL). Location from NAS Fallon: 23 miles range at 99 degrees azimuth.
- Fallon 23SSE [NAS B19] at Blowing Sand Mountains (39°08'31"N, 118°40'01"W, 3886' MSL). Location from NAS Fallon: 16 miles range at 164 degrees azimuth.
- Fallon 36NE [NAS B20] at Carson Sink (38°54'40" N, 118°23'14" W, 3881' MSL). Location from NAS Fallon: 31 miles range at 13 degrees azimuth
- Fallon NAS EW71 Complex at Edwards Creek Valley (39°31'57" N, 117°44'50" W, 5192' MSL). Location of EW Complex: 11 miles NE of Cold Springs, NV

We have provided maintenance on these stations and additionally installed a sonic anemometer at the B17 station. The sonic anemometer has been in continuous operation since February 2007. The high

frequency (20 Hz) flux and turbulence data from the sonic anemometers allow us to evaluate various turbulence parameterizations that are widely used in mesoscale models (MM5, COAMPSTM, and WRF). This will aid towards finding the optimally best turbulence parameterization that can be used for real-time forecasting in the Fallon area. Currently, we are comparing the sonic anemometer data against the MM5 results; however, in the future, similar methods can be applied to verify COAMPSTM forecasts of the turbulence kinetic energy (TKE) at the NAS Fallon.

The real-time MM5 system was developed and installed on an XD1 Cray computer at the Desert Research Institute. To account for synoptic processes and also to resolve the characteristics of the mesoscale processes, coarse and nested grids were set up to cover a large portion of the western U.S. The coarsest grid has a horizontal resolution of 27 km and encompasses most of the eastern Pacific Ocean and western United States; it has 103 x 103 grid points (23 synoptic sounding stations in the western and the central U.S. fall in this domain). The next grid has 103 x 103 points with a horizontal resolution of 9 km and covers Nevada and most of California, while the subsequent grids are each centered on Fallon, with resolutions of 3, 1, and 1/3 km. The third grid was of horizontal dimensions 103 x 103, while grids 4 and 5 were both comprised of 49 x 49 points. Each model domain consists of 40 layers where 23 layers were designated in the lowest 3 km for forecasts that are significant to aircraft operations.

The Four Dimensional Data Assimilation (FDDA; Stauffer and Seaman 1990) technique was applied to the data from the four special-network weather stations installed by DRI. The data from the stations are continuously transmitted to DRI's Western Regional Climate Center (WRCC) network and processed through the main quality assurance software. These data were set up as input to the 12-hr pre-forecasting time or model adjustment time in order to provide better initial conditions and subsequent improvement in the short-term forecasts (1-6 hrs) that are essential to the nowcasting objectives.

A version of this procedure modified for application to the Fallon Naval Air Station region of complex land surface has been developed and demonstrated (Vellore et al. 2006). Satellite data were provided by the Naval Research Laboratory (Monterey) in SeaSpace TeraScan TDF digital format.

Analysis of the model assimilation procedure and simulation results related to cloud cover can be accomplished using several output fields and derived parameters. Graphics of three-dimensional cloud field representations are produced and used for time-lapse animation that are directly compared with satellite image loops in multiple imaging channels (visible, infrared, near-infrared, and water vapor) and satellite composite products. Model predicted fields such as relative humidity provide information on the ability of the model to simulate vapor flux in the boundary layer. Model-generated vertical profiles of cloud mass concentration have been essential in previous studies to interpret the influences of model resolution and initial conditions on thermodynamic evolution, particularly in the presence of temperature inversions. Vertically-integrated cloud and ice concentration, as computed column parameters, allow subjective and quantitative validation of critical conditions for restricted visibility in stratus, fog and ice fog events. Evaluation of these conditions also benefits from the availability of the turbulence kinetic energy observations and model results, for verification of the development of turbulent mixing as solar radiation transmittance through low cloud allows surface warming.

RESULTS

Regarding the efficiency of the real-time forecasting system, two situations were considered. One with respect to the number of processors, and the other is the selection of various physical parameterizations and model options. A series of model forecasts were conducted for evaluation. Figure 2 shows the clock time speed-up as a function of the number of processors.

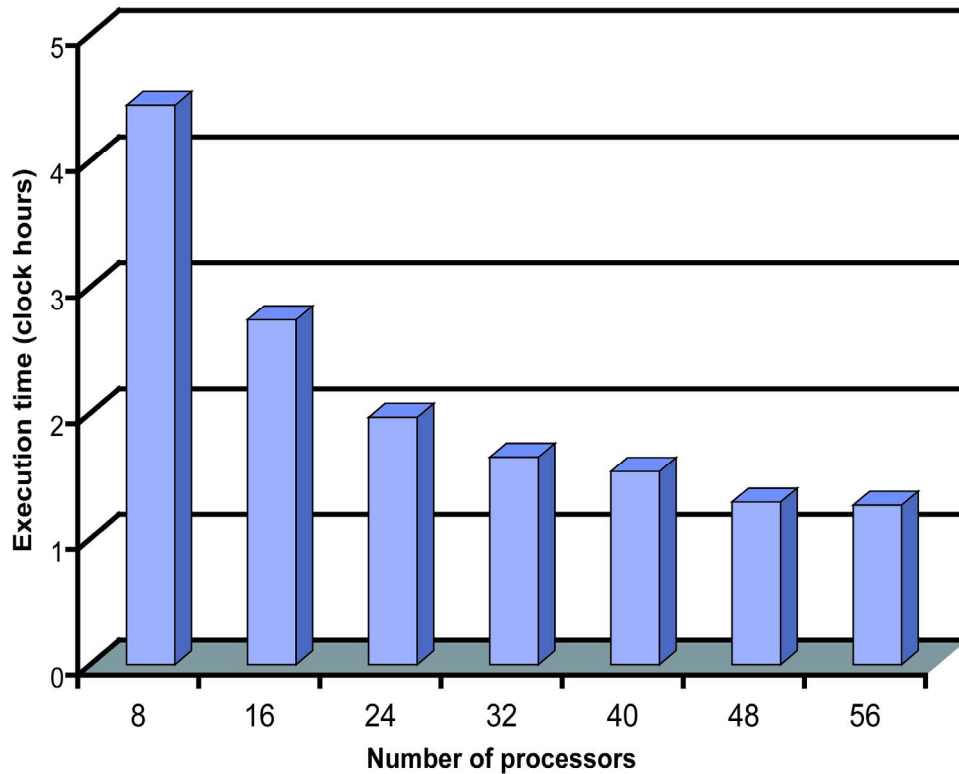


Figure 2. The execution time of a 24-hr real-time forecast as a function of number of processors (8-56).

Most of the benefit was gained by increasing the number of processors from 8 to 16 and then to 24. For the second case (sensitivity to various model parameterizations), we have run a baseline case (shown in Table 1) and then varied options related to the physical parameterizations of shallow convection, cumulus formation, two microphysical packages, three turbulence transfer schemes, and a radiation scheme (Fig. 3).

Table 1. Physical parameterizations used in the model base configuration

Cumulus parameterization	Grell scheme (only on 27 and 9 km grids)
Cloud microphysics	Reisner's simple explicit microphysics (five hydrometeors) (water vapor, cloud water, rain water, cloud ice, and snow)
PBL physics	Gayno-Seaman scheme
Radiation	Dudhia scheme (shortwave and longwave)
Two-way nesting	Feed back with strong smoothing

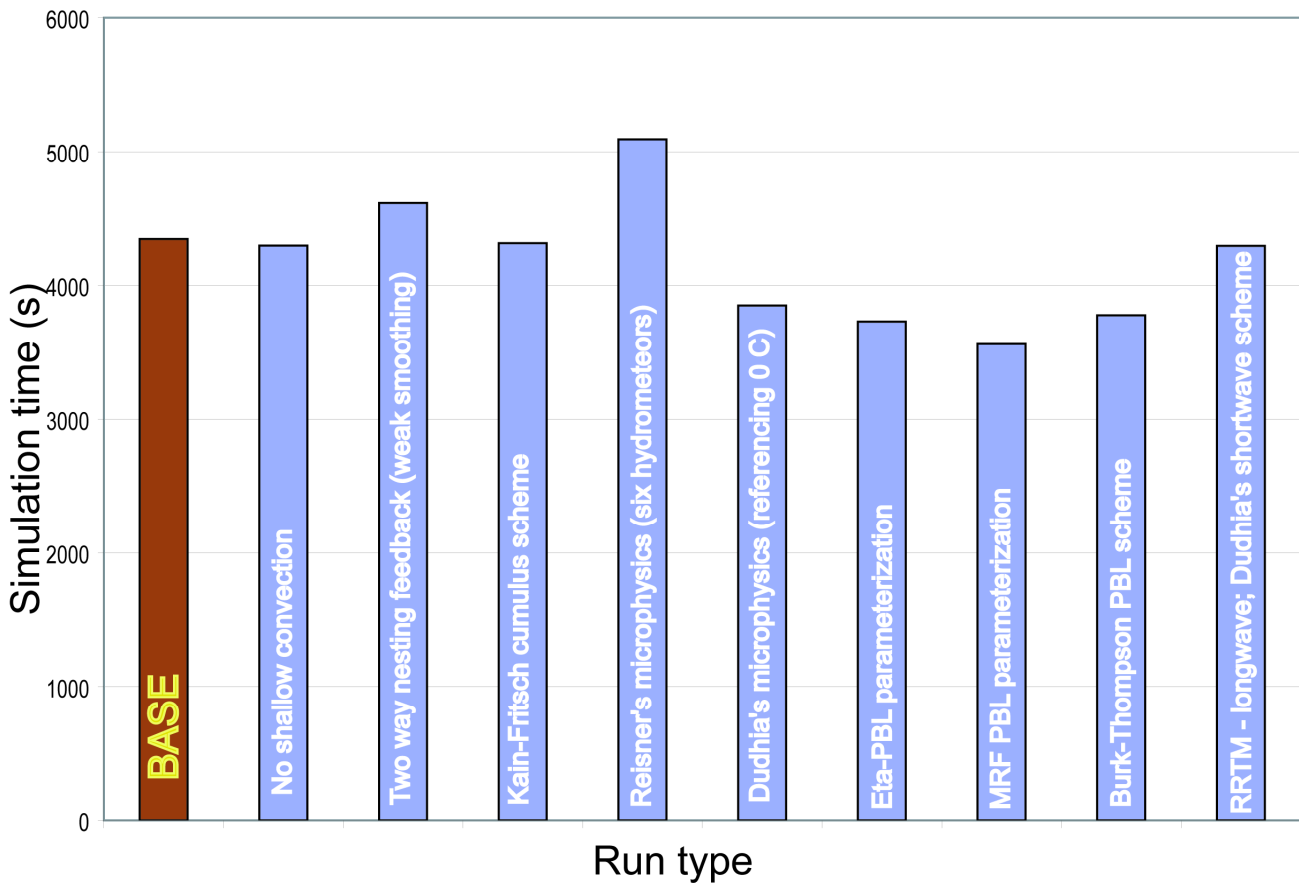


Figure 3. Real-time forecasting execution time with respect to the optional parameterizations.

Figure 3 shows that the choice of the microphysical parameterizations significantly influences the execution clock time, while the optional turbulence parameterizations show similar weight on the execution time. This behavior is due to the extra computational time used by the complex calculations in the additional prognostic computations of hydrometeors and number concentration. The options of turbulence parameterizations, either local or non-local, 1.5 order Mellor-Yamada type (the Eta-PBL scheme; used in the operational NCEP Eta model) or schemes that include second order moments (the Burk-Thompson scheme; used in COAMPSTM) showed similar weight on the execution time. Also, complex radiation modules such as the Rapid Radiative Transfer Model (RRTM) based radiative

computations rates did not significantly alter the simulation time with reference to the base run which used a simple type of radiative scheme for the longwave radiation. Strong or weak smoothing in the nesting feedback of dynamical variables did not show significant difference from the base run; however, it is suggested by the MM5 community users that we use the nesting feedback with strong smoothing in combination with MPI for better performance (mesouser@ucar.edu).

Regarding a new method of satellite data assimilation, we show two products: determination of cloud types, and improvement in the surface temperature forecasts as a consequence of more realistic initial boundary layer structure. An example of the satellite data assimilation evaluation for the 24 April 2006 forecast is shown in Figs. 4 and 5. This case was characterized by scattered cloudiness and mainly clear-sky conditions at the NAS Fallon airport area. As indicated by Fig. 5, the difference between the cloud top temperature and the measured surface temperature indicates that the clouds were generally absent at the time for which the simulated contours of the integrated liquid water path are shown in Fig. 4. Without assimilating satellite data, the model significantly overestimated cloudiness and underestimated the surface temperature (Fig. 5). The satellite data assimilation definitely improved the forecasts of cloudiness and consequently air temperature in the boundary layer.

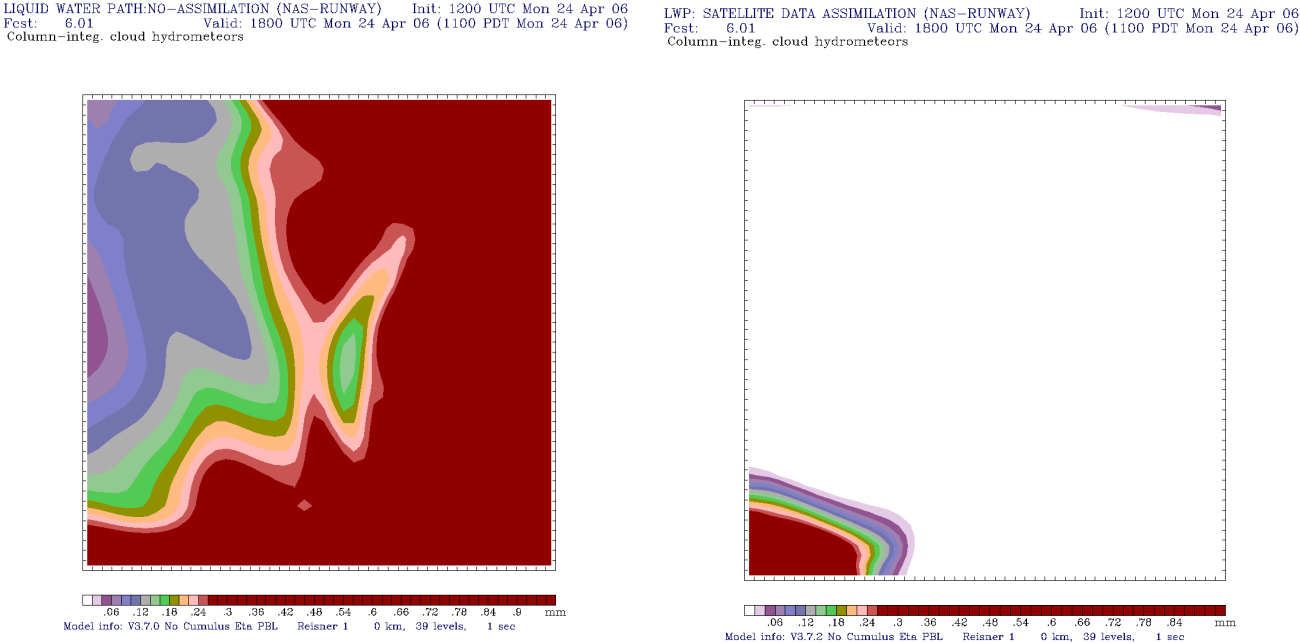


Figure 4. Contour plots of the integrated liquid water path for 1800 UTC on 24 April 2006 without (left panel) and with (right panel) satellite data assimilation in the real-time forecasting system.

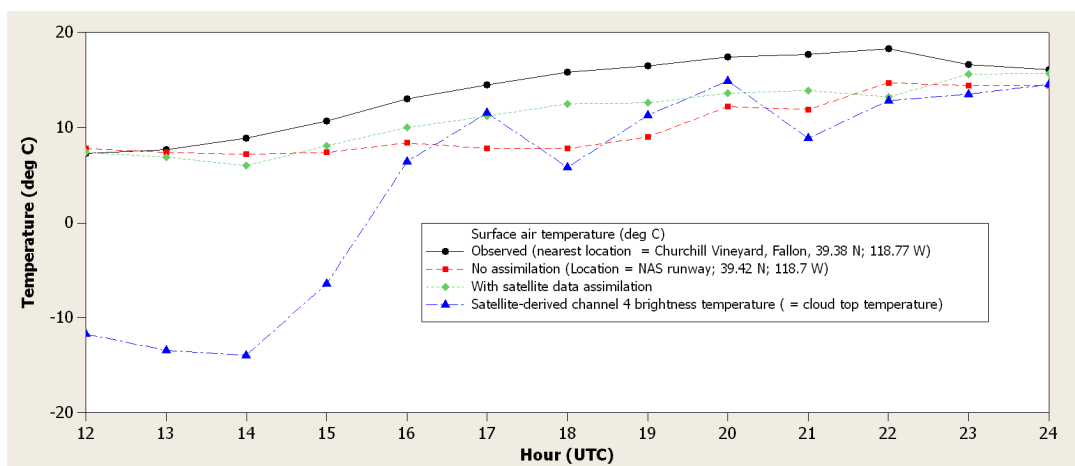


Figure 5. Observed surface temperature, satellite-measured cloud top temperature, and simulated time series of air temperature at the surface for the simulations initialized at 1200 UTC on 24 April 2006.

Installation of the sonic anemometer at the NAS Fallon station B 17 allowed us to evaluate turbulence parameterizations that are used in MM5 and other models. MM5 employs three turbulence parameterizations that predict the evolution of TKE. Figure 6 shows a comparison of the measured and simulated TKE for a period of 3 days (April 3-6, 2007). We tested three commonly used turbulence parameterizations, namely Gayno Seaman (widely tested and applied in the study of low clouds and fog, Vellore et al. 2007), the Eta-PBL scheme, and the Burk-Thompson parameterization.

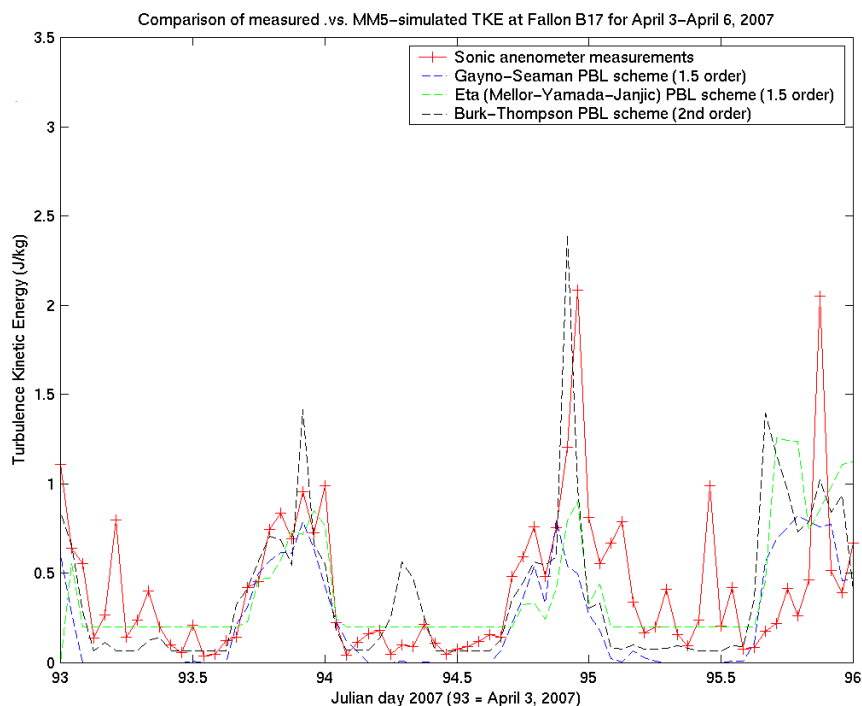


Figure 6. Turbulence kinetic energy (TKE) as measured by the sonic anemometer and simulated by MM5 (3 km grid) using the Gayno Seaman, Eta-PBL and Burk-Thompson PBL schemes at Fallon station B17 for the period from 3-6 April 2007 (Julian day 93 refers to April 3, 2007 at 0000 UTC).

Besides sharp peaks, mainly as a consequence of sonic's high sampling rate (20 Hz), both schemes show reasonable resemblance to the data. For this limited sample the model shows quite good agreement generally for all schemes; however, this needs to be evaluated for longer time samples during various weather conditions.

Regarding the predictability study, we set up a sequence of the lag-forecasting runs (Fig. 7) for a dust storm case in February 2002 to address the principal question of how close the ensemble members are with respect to measurements.

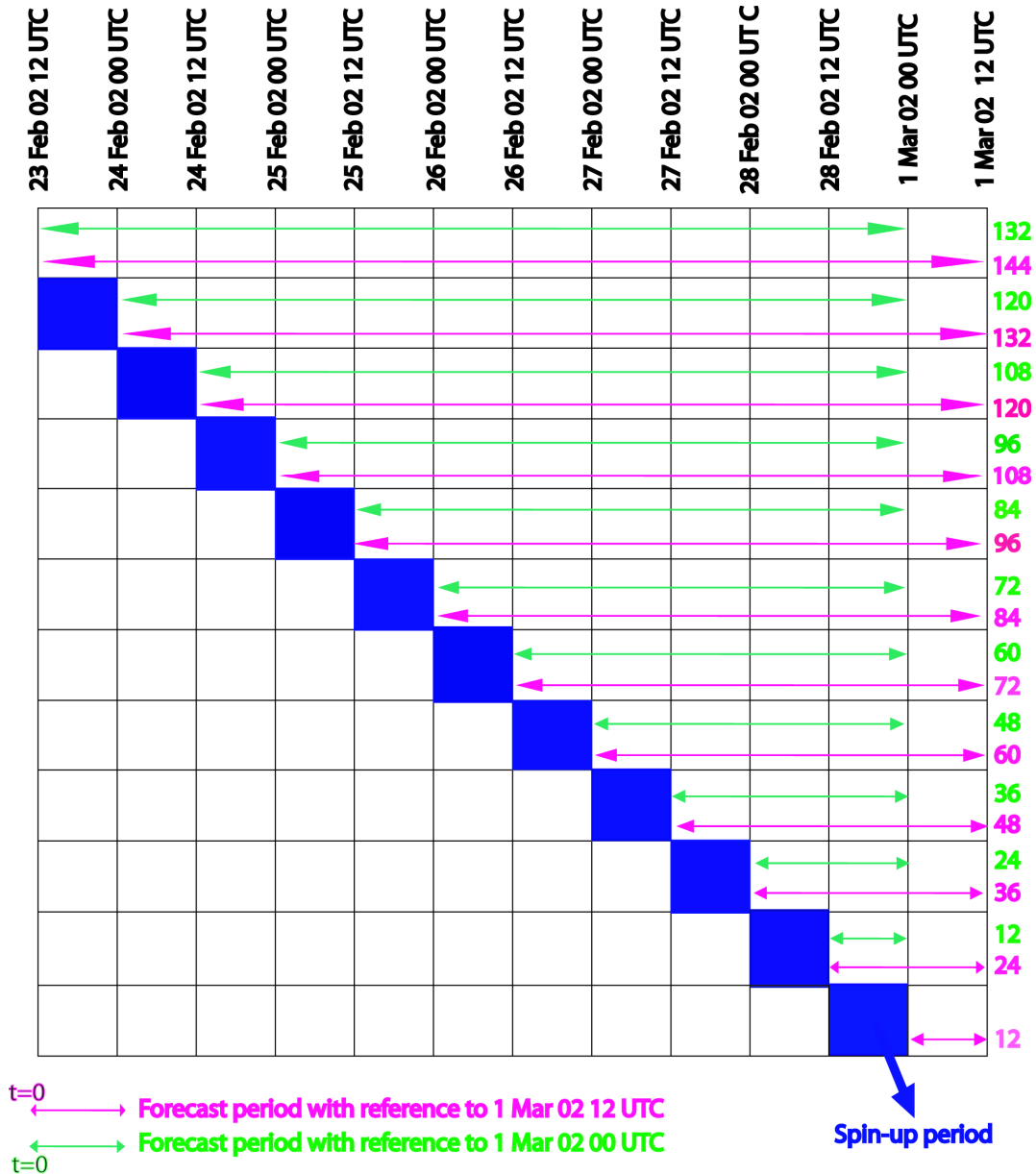


Figure 7. Schematic of the lag-forecasting setup to provide forecasts on 1 March 2002 at 1200 UTC. Each run includes a 12 hr spin-up (pre-forecast) period.

Figure 8 shows the spread of the ensemble members composed from the lag-forecasting runs for the temperature at 700 hPa and 500 hPa levels.

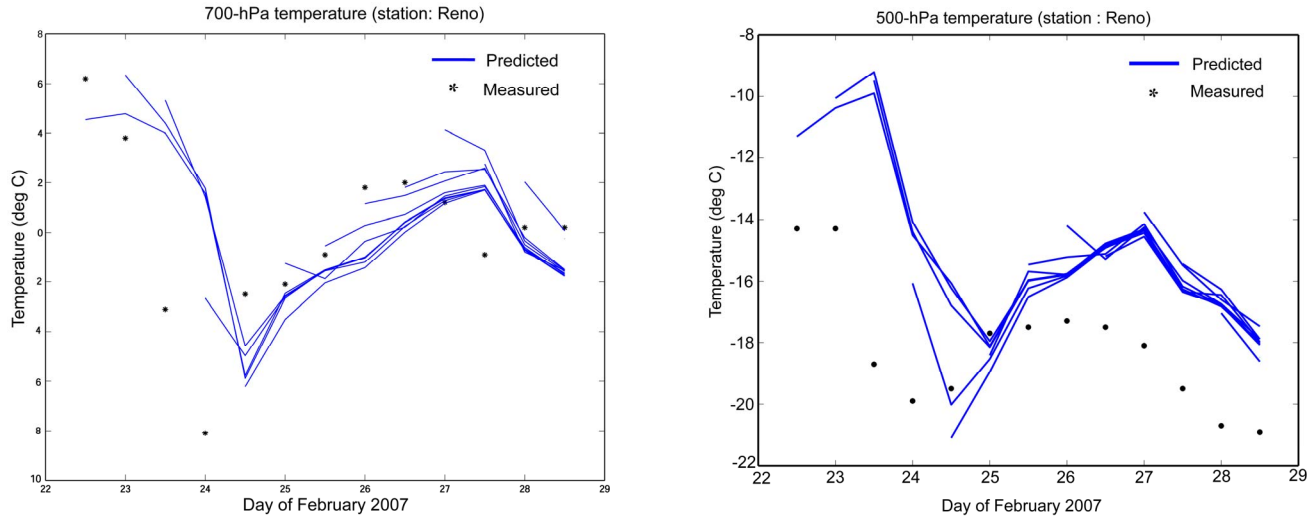


Figure 8. Measured (symbol) and predicted (using the lag-forecasting runs) (solid line) air temperature at 700 hPa (left panel) and 500 hPa (right panel) at the Reno radiosonde location. The left end of the each forecast line is a start time of the forecast and the right end of the line is the end of that particular run.

The figure shows that the lag-forecasting runs provided a useful spread that allows the ensemble average to come close to the measurements. To compare with standard methods of examining model's behavior at the 500 hPa level, we selected 23 radiosonde stations in the western U.S. and computed the root-mean-square error (RMSE) and index of agreement (IA) (Willmott 1982; Fig. 9). Future studies should focus on developing new methods for creating a viable set of initial perturbations for mesoscale simulations in combination with the LAF method to provide probabilistic forecasting for longer forecast lead time for the Fallon area.

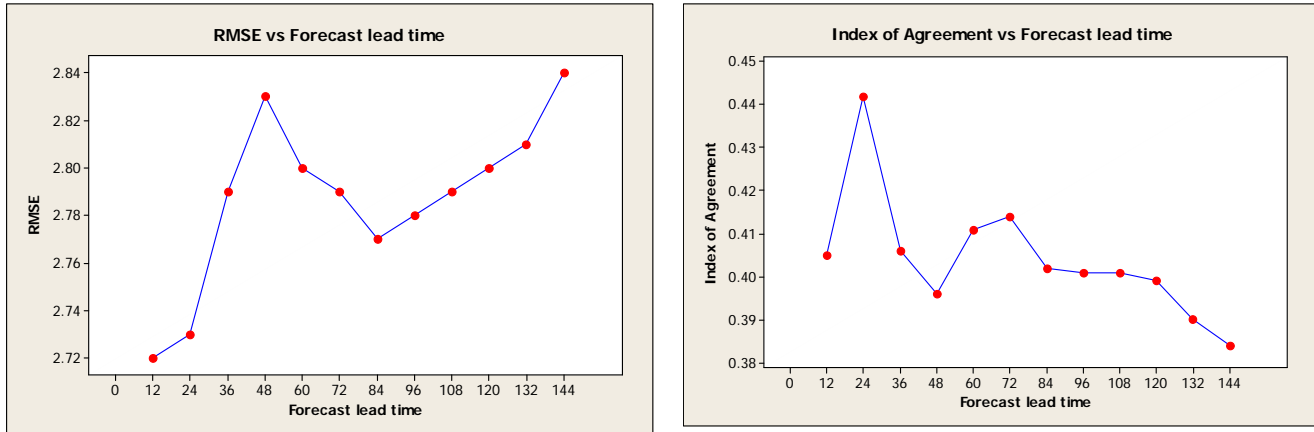


Figure 9. Root-mean-square error (left panel) and the index of agreement (right panel) of the simulated temperature at the 500 hPa level vs. forecast lead time as computed from the 23 radiosonde stations' data in the western U.S. The range of the index of agreement is 0 for a no-skill forecast and 1 for a perfect forecast.

Figure 9 shows that, although the RMSE shows a general trend of increasing values for greater lead time (as would be expected), the variations in the mid range lead time (essential for the conventional forecasting time scale; 24-48h) indicate characteristics that need to be explored further. It is possible that the mesoscale models need more time to capture the complete evolution of complex weather storm systems (as also seen in Fig. 8). The IA indicates that the highest model accuracy is within the first 24 hrs, but there is again an increase in the IA in the mid range before decreasing for greater lead time.

Bearing in mind the complexity of 4-D forecast models, we additionally provided the first attempt to find better and faster ways of interpreting and searching forecast results by using advanced methods of model visualization. An example is shown in Fig. 10. This visualization system can be a useful tool for a time-efficient and perception-rich search through large forecast outputs in particular areas of interest and flight patterns by personnel (pilots, meteorological support staff, etc.) who do not need to have any technical knowledge of the forecast or/and visualization technical aspects.



Figure 10. Visualization of the real-time forecasts of turbulence and cloudiness over the runway for the Fallon NAS in the CAVE (Cave Automatic Virtual Environment). A person in the CAVE can interactively probe forecast results with respect to various model domains, times, and forecasted parameters. For this visualization, white represents cloud, while cyan represents areas of high turbulence kinetic energy.

RELATED PROJECTS

Dr. Koracin is a P.I. on a project supported by another ARO grant that is focusing on visualization and virtual reality applications of the Fallon NAS high-resolution mesoscale forecasts. Dr. Koracin is a co-P.I. on ARO Project entitled “Forecasting of Desert Terrain” where real-time experience and expertise is facilitating an interdisciplinary project linking dust emission modeling, atmospheric predictions and Lagrangian Random Particle Dispersion modeling. Drs. Wetzel and Koracin are also co-P.I.s on a multi-institutional NSF-EPSCoR Project on Cognitive Information Processing: Modeling and Inversion where they are developing new methods of satellite data assimilation and investigation of predictability and chaos in numerical weather and climate forecasting.

REFERENCES

- Hoffman, R. N., and E. Kalnay, 1983: Lagged average forecasting, an alternative to Monte Carlo forecasting. *Tellus*, **35A**, 100-118.
- Lee, T. F., F. J. Turk, and K. Richardson, 1997: Stratus and fog products using GOES-8-9 3.9 μm data. *Weather and Forecasting*, **12**, 664-677.
- Lewis, J., 2005: Roots of ensemble forecasting. *Mon. Wea. Rev.*, **133**, 1865-1885.
- Lewis, J., S. Lakshminarayanan, and S. Dhall, 2006: *Dynamic Data Assimilation: A Least Squares Approach*. Cambridge Univ. Press, 648 pp.
- Stauffer, D. R., and N. L. Seaman, 1990: Use of four-dimensional data assimilation in a limited area model. Part I: Experiments with synoptic scale data. *Mon. Wea. Rev.*, **118**, 1250-1277.

Vellore, R., D. Koracin, and M. Wetzel, 2006: A method of improving cloud predictions for real-time weather forecasting and visualization. *Advances in Visual Computing, Lecture Notes in Computer Science 4292*, G. Bebis et al. (Eds.), Part II, Springer-Verlag, 544-553.

Vellore, R., D. Koracin, M. Wetzel, S. K. Chai, and Q. Wang, 2007: Challenges in mesoscale predictions of nocturnal stratocumulus-topped marine boundary layer and implications for operational forecasting. *Weather and Forecasting*, **22**, 1101-1122.

Willmott, C. J. 1982: Some comments on the evaluation of model performance. *Bull. Amer. Met. Soc.*, **63**, 1309-1313.

PUBLICATIONS AND PRESENTATIONS

Bebis, G., R. Boyle, B. Parvin, D. Koracin, P. Remagnino, A. Nefian, G. Meenakshisundaram, V. Pascucci, J. Zara, J. Molineros, H. Thiesel, and T. Malzbender, Eds., 2006: *Advances in Visual Computing. Lecture Notes in Computer Science*, LNCS 4291, Vol. I, 916pp, Springer, Berlin.

Bebis, G., R. Boyle, B. Parvin, D. Koracin, P. Remagnino, A. Nefian, G. Meenakshisundaram, V. Pascucci, J. Zara, J. Molineros, H. Thiesel, and T. Malzbender, Eds., 2006: *Advances in Visual Computing. Lecture Notes in Computer Science*, LNCS 4292, Vol. II, 906pp, Springer, Berlin.

Isakov, V., A. Venkatram, J. Touma, D. Koracin, and T. L. Otte, 2007: Evaluating the use of outputs from comprehensive meteorological models in air quality applications: A case study in Wilmington, CA. *Atmos. Environ.*, **41**, 1689-1705.

Koracin, D., A. Panorska, V. Isakov, J. S. Touma, and J. Swall, 2007: A statistical approach for estimating uncertainty in dispersion modeling: an example of application in southwestern U.S. *Atmos. Environ.*, **41**, 617-628.

Lewis, J., S. Lakshmivarahan, and S. Dhall, 2006: *Dynamic Data Assimilation: A Least Squares Approach*. Cambridge University Press, 648 pp.

Lewis, J., 2007: Use of a mixed-layer model to investigate problems in operational prediction of return flow. *Mon. Wea. Rev.*, **135**, 2610-2628.

McAlpine, J.D., D. Koracin, K. Veropoulos, D. Boyle, G. Lamorey, and E. McDonald, 2007: Determining atmospheric dust concentrations during strong flow perturbations using a digital-optical technique. *Lecture Notes in Computer Science (in press)*.

Vellore, R., D. Koracin, and M. Wetzel, 2006: Improvements in cloud predictions through modeling and visualization of the satellite imagery. *Lectures in Computer Science*, LNCS 4292, Vol. II, 544-553.

Vellore, R., D. Koracin, M. Wetzel, S. K. Chai, and Q. Wang, 2007: Challenges in mesoscale predictions of nocturnal stratocumulus-topped marine boundary layer and implications for operational forecasting. *Weather and Forecasting*, **22**, 1101-1122.