REPORT DOCUMENTATION PAGE

AFRL-SR-BL-TR-01-

0615

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPO
		14 Nov 97 - 13 Apr 01

4. TITLE AND SUBTITLE
Determining the Accuracy and Limits of Predictability of Numerical Weather Prediction for Regional Tactical Military Operations

5. FUNDING NUMBERS
F49620-98-1-0121

6. AUTHOR(S)
John Scott Greene
Mark L. Morrissey

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of Oklahoma
OK Climatology Survey
Norman, Oklahoma, 73019

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
AFOSR/NM
801 N. Randolph Street Room 732
Arlington, VA 22203-1977

F49620-98-1-0121

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION AVAILABILITY STATEMENT
APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The U.S. Department of Defense aims to develop capabilities for the numerical prediction of small-scale weather as part of its Theatre Battle Management project. This is accomplished at research centers run by each branch of the military. Perhaps the most significant unknown at this point is the specific accuracy of the short-term, high-resolution models and the extent to which the forecasts can provide the guidance needed for tactical military operations. This report provides a detailed description of the research carried out under an Department of Defense Experimental Program to Stimulate Competitive Research (DEPSCoR) grant funded by the Air Force Office of Scientific Research. The overall objectives of this research project were to perform basic research into development of statistical methods for model validation, produce research quality data sets that could be used for operational verification, examine issues in uncertainty characterization, and to identify and examine the accuracies and uncertainties in the operational models currently being run by the Air Force Global Weather Center and the Army Research Laboratory using the Oklahoma Mesonet and other data sets. These research efforts have been carried out through the interdisciplinary Environmental Verification and Analysis Center (EVAC) at the University of Oklahoma which was established to develop and apply geostatistical methods to utilize point measurements of geophysical data to verity model and remote sensing output. Below is a short list of initial objectives, a summary of the key findings and results, and list of the research publications and presentations produced as a result of this grant.

14. SUBJECT TERMS	15. NUMBER OF PAGES
	9
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT

DETERMINING THE ACCURACY AND LIMITS OF PREDICTABILITY OF NUMERICAL WEATHER PREDICTION FOR REGIONAL TACTICAL MILITARY OPERATIONS

BY

John Scott Greene
Mark L. Morrissey

Final Report Submitted to Air Force Office of Scientific Research, Major Paul Bellaire,

Determining the accuracy and limits of predictability of numerical weather prediction for regional tactical military operations

EXECUTIVE SUMMARY OF FINAL REPORT

The U.S. Department of Defense aims to develop capabilities for the numerical prediction of small-scale weather as part of its Theatre Battle Management project. This is accomplished at research centers run by each branch of the military. Perhaps the most significant unknown at this point is the specific accuracy of the short-term, high-resolution models and the extent to which the these forecasts can provide the guidance needed for tactical military operations. This report provides a detailed description of the research carried out under an Department of Defense Experimental Program to Stimulate Competitive Research (EPSCoR) grant funded by the Air Force Office of Scientific Research. The overall objectives of this research project were to perform basic research into development of statistical methods for model validation, produce research quality data sets that could be used for operational verification, examine issues in uncertainty characterization, and to identify and examine the accuracies and uncertainties in the operational models currently being run by the Air Force Global Weather Center and the Army Research Laboratory using the Oklahoma Mesonet and other data sets. These research efforts have been carried out through the interdisciplinary Environmental Verification and Analysis Center (EVAC) at the University of Oklahoma which was established to develop and apply geostatistical methods to utilize point measurements of geophysical data to verify model and remote sensing output. Below is a short list of initial objectives, a summary of the key findings and results, and list of the research publications

d presentations produced as a result of this grant.

nitial Research Objectives

- Develop statistical methods to quantify uncertainties in surface validation fields, and investigate ways to develop improved uncertainty characterization and model validation techniques.
- Produce validation data products at scale comparable with model output with known error characteristics.
- Determine the errors associated with spatial averaging of surface and upper-level meteorological variables.
- Provide validation information for two DoD modeling groups (the Artillery Meteorology Branch of the Army, White Sands, NM and the Air Force Global Weather Center, Offutt AFB) via examination of their operation models over the Oklahoma Mesonetwork.
- Evaluate the operational models in areas of complex and mountainous terrain (as a simulation for areas of strategic military interest).

General Summary of Results

The following list provides a brief overview of the key findings of research undertaken for this project. For a more detailed description of the methods and results, including accompanying figures, please refer to the main body of the report.

Brief list of accomplishments and achievements:

- Publication of seven referred journal papers related to issues of statistical model development, uncertainty characterization, and model validation
- Presented several invited and conference presentation on these themes (see list below for a more detailed description).
- As stated in the abstract of our proposal: "The first goal is to produce the validation data products at scales comparable with model output.... This information will then

be used for a validation exercise of the models currently being used in an operational mode." These goals have been accomplished,, as we have used the Mesonet (and other available data) to identify the errors associated with spatial averaging. Thus, we have now produced a valuable dataset with gridded areal-averaged values of standard surface meteorological variables (e.g., temperature, precipitation, etc.) with known error characteristics. We have also archived a variety of atmospheric sounding and profiler data, which we are using for the validation of the Army Research Lab's Battlescale Forecast Model (BFM). This has been done both at the scale of the BFM and the Air Force Global Weather Center's MM90 models.

- Completed a series of operational tests. Results are quite promising in their ability to further improve weather prediction at increasingly smaller temporal and spatial scales (see figures described in main report below as well as http://www.evac.ou.edu/jmpbac for details)

- In year two, we sponsored a several-months long visit from a visiting scientist from Australia, Dr. Bill Lyons, who is an expert in statistical methodology and visualization of model and error analysis via use of Geographic Information Science (GIS) technology. Dr. Lyons allowed us to develop a visualization and GIS applications component to our model validation research.

- Developed a method to analyze the impact of model errors on the displacement of artillery shells (developed in collaboration with the Army Artillery Meteorology Branch.) The results show the types of weather conditions that provide problems for the BFM, and have been useful in examining the effectiveness of the model for use as a artillery-directing tool.

- Performed a series of model simulations and intercomparisons between the BFM and the MM-90 (run with the same configuration as the Air Force operational model). Results illustrate the relative strengths and weaknesses of the two models for the time periods and spatial domains selected. The information produced from these evaluation periods will assist the modeling groups to develop improvements to their operational models. (See main text below for a full description of the model intercomparison efforts).

Future Directions

Our plans for the future include ongoing collaboration with the Army Research Laboratory at White Sands, NM. Our intent is to leverage our existing research and EVAC resources, and to further strengthen and expand the scientific links between the Army Research Laboratory and EVAC

We are currently working on the development and testing of new and innovative hypotheses related to assessing the spatial variation of uncertainty in the prediction of mesoscale weather. In addition, the model intercomparisons that we have planned, using surface error analysis and producing statistically significant and meaningful interpretations, will assist the Army in choosing their weather forecast model of the future. Over the past three years, we have developed a strong and close link with the Army, and we plan to use this solid foundation for the future in order to pursue research into issues of importance for operational military forecasts.

Results from Research Associated with Project

Publications

Published in Peer Reviewed Journals and Books

Greene, J.S., W.E. Cook, D. Knapp, and P. Haines, An Examination of the Uncertainty in Interpolated Winds and their Effect on the Validation and Intercomparison of Forecast Models, *Journal of Atmospheric and Oceanic Technology*, in press (to be published March, 2002)

Greene, J.S., M.D. Klatt, W.E. Cook, and H.J. Johnson, 1999: Weather Modification on the Great Plains (pp. 37-50), in *The Ogallala Aquifer, Steps to Sustainability*, Lori Triplett, ed., Great Plains Foundation, Overland Park, KS.

Greene, J.S., and M.L. Morrissey, 1998: Evaluation and Validation of Simulated and Observed Climate Data, in *Climate Prediction for Agricultural and Resource Management*, L. Leslie and R. Munro, eds., Australian Academy of Sciences, Canberra.

Greene, J.S., and M.L. Morrissey, 2000: Validation and Uncertainty Analysis of Satellite Rainfall Algorithms, *The Professional Geographer, 52,* 247-257.

Morrissey, M.L., and J. S. Greene, 1998: Using the Oklahoma Mesonet to Develop and Test a Sampling Error Statistic for Meteorological Time Series, J*ournal of Geophysical Research,* Vol. 103, D8: 8979-8984.

Morrissey, M.L., and J.S. Greene, 1998: Uncertainty Analysis of Satellite Rainfall Algorithms over the Tropical Pacific, *Journal of Geophysical Research*, 103: 19569-19576.

Morrissey, M.L., and J. S. Greene, 1998: Using the Oklahoma Mesonet to Develop and Test a Sampling Error Statistic for Meteorological Time Series, J*ournal of Geophysical Research,* 103, D8: 8979-8984.

Morrissey, M.L., and J.S. Greene: *Validation of Remotely Sensed Estimates of Geophysical Variables using Surface Observations*, Book in progress to be published by Springer-Verlag

Published in Unreviewed Publications (proceedings, tech. reports, etc.)

"Evaluation of the Battle Scale Forecast Model over Oklahoma with an Emphasis on Artillery Accuracy", Greene, et al., *Proceedings of the 8th conference on Aviation, Range and Aerospace Meteorology*, January, 1999.

"An Examination of Battlescale Forecast Model Initializations over Complex Terrain," Greene, et al., *Proceedings of the 9th conference on Aviation, Range and Aerospace Meteorology*, January, 2000.

Accepted/Submitted for Publication

N/A

Invention Disclosures and Patents Granted

N/A

Invited Lectures, Presentations, Talks, etc.

Invited Lectures:

"Statistical approaches to determining the accuracy and limits of predictability of mesoscale meteorological models", Army Research Laboratory, White Sands, NM, February, 1998.

"Evaluation and Validation of Numerical Weather Prediction", AMS local chapter meeting, Las Cruces, NM, Oct., 1999.

"Evaluation and Validation of Simulated and Observed Climate Data", Center for the Analysis and Prediction of Storms, University of Oklahoma, December, 1998.

Conference Presentations:

"Verification of a PC-Based Mesoscale Model", presented at the 1998 National Weather Association Annual Meeting, Oct. 1998

"Evaluation of the Battle Scale Forecast Model over Oklahoma with an Emphasis on Artillery Accuracy", presented at the Annual Meeting of the American Meteorological Society, January, 1999

"A Comparison of Two Methods for Estimating Verification Ballistic Conditions", presented at the 1999 National Weather Association Annual Meeting, Oct. 1999.

"An Examination of Battlescale Forecast Model Surface Initialization over Mountainous Terrain", presented at the Annual Meeting of the American Meteorological Society, January, 2000.

"Evaluation of mesoscale weather prediction for regional tactical military operations with an emphasis on artillery accuracy assessment", presented at the Annual Meeting of the Association of American Geographers, March, 2001.

Extended Scientific Visits From and To Other Laboratories:

Visit to Air Force Global Weather Center, January, 1998;

Visits to Army Research Laboratory, White Sands, NM, February, 1998 October 1998; April 1999; October 1999.