Paper No. 8

A MESOSCALE NUMERICAL MODEL AND THE DEVELOPMENT OF A SEVERE STORM PREDICTION SYSTEM

M. L. Kaplan, *Management and Technical Services Company, Langley Research Center, Hampton, Virginia*

ABSTRACT

This paper deals with the use of a mesoscale numerical model for predicting preferred zones of severe storm development. A 60 consecutive day real-time test of the prediction system during the spring of 1978 proved useful in determining the problems and potentialities of such a system. A case study of severe storm development from this test period is described and compared to the model forecast fields.

INTRODUCTION

During the period from mid-April to mid-June 1978, a 60 consecutive day test of a mesoscale numerical model was performed. This was done to determine the feasibility of its use in a real-time environment for the prediction of preferred zones of severe local storm development. This test was run at NASA Langley Research Center, and all model integrations were performed on the CDC STAR-100 computer system. Initial data were received daily from the National Meteorological Center through the Bureau of Reclamation in Denver, Colorado. This initial data consisted of 1200 G.m.t. Limited Area Fine Mesh (LFM) analyses of geopotential height, temperature, and dewpoint at 190 km grid mesh intervals. These data were then interpolated to a 60 x 48 x 12 level three-dimensional matrix of 38 km grid mesh interval. After running a numerical 24-hour forecast (typically requiring 20 minutes of "wall-clock" time on the STAR-100 computer), a mesoscale severe storm index was disseminated for daily use and evaluation to the National Severe Storms Laboratory, Air Force Global Weather Central, and Goddard Space Flight Center.

The numerical hydrostatic (primitive equation) model utilizes sixth-order space advection, the Euler backward time marching scheme, and a sixth-order spatial diffusion operator. The system is presently adiabatic and ignores surface friction. For the spring test period, vertical levels ranged from 1150 to 12,000 m elevation. The boundary conditions were fixed in time with respect to the lateral boundaries.

The 60-Day Real-Time Test-The 60-day test period during the spring of 1978 permitted the achievement of several goals for the mesoscale numerical model: (1) The model was run in real-time with a standard meteorological data base on a daily basis for the first time; (2) the model simulated the development of and interaction between sub-synoptic and mesoscale waves with reasonable fidelity; (3) the model provided a useable forecast of the preferred mesoscale areas of convective activity; and (4) problem areas where the model could be improved were revealed. Before discussing these problems and future plans for dealing with them, we shall present an example of a model forecast.

Example of Forecast-Severe weather erupted over southwestern Oklahoma and northwestern Texas during the late afternoon and evening of May 18, 1978. At approximately 6 p.m. c.s.t. (0000 G.m.t. May 19, 1978), Post, Texas, reported 2 cm hail. During the next 2 hours (0000 to 0200 G.m.t.), a 19 km swath from southwest of Grassland, Texas, to near Post, Texas, received hail up to 4.5 cm in diameter and nearly 6.4 cm of rain. In addition, at approximately 6:30 p.m. c.s.t. (0030 G.m.t.), Hollis, Oklahama, reported hail as large as 7 cm in diameter.

Later in the night, the severest convective activity shifted slightly to the southwest. At 1:24 a.m. c.s.t. May 19, 1978 (0724 G.m.t.), Slaton, Texas, reported hailstones up to 4.5 cm in diameter.

The 1200 G.m.t. May 18, 1978, surface weather situation presents a familiar pattern for the central and western plains. A north-south trough extends from eastern Montana southward to western Texas. A cold front is placed along the trough axis over the Oklahama Panhandle eastward to Georgia. Warm, very moist air is found to the east of the cold front and south of the stationary front. Surface dewpoints near 24°C (75°F) were observed over southeastern Texas with 21°C (70°F) dewpoints extending as far north as Dallas, Texas. Meanwhile, to the west of the cold front, surface dewpoints were mostly below -1°C (30°F) over extreme western Texas, New Mexico, and Colorado.

The 1200 G.m.t. May 12, 1978, 500 mb flow exhibits the characteristics of an omega blocking pattern over the United States. A difluent pattern in the wind field and height field is present over the central and southern plains. By 1200 G.m.t. May 19, 1978, the surface and 500 mb flow patterns show little change throughout this region. Integrating the numerical model with increased vertical resolution in the lower troposphere yields a very impressive forecast when one compares the 750 m σ_E (moist static stability) and 400 m divergence fields with the radar summaries presented in figs. 1-4.

By 10 hours into the forecast (2200 G.m.t.), the model has organized a zone of convergence from central Kansas southwestward through west central Oklahoma into west central Texas. A moderately strong convergence maximum ($-4 \times 10^{-5}s^{-1}$) is located over central Kansas at this time. The forecasted σ_E distribution also has an axis of moderately low values from central Kansas southward to north central Texas.

Over the next 2 hours (2200 to 0000 G.m.t. May 19, 1978), the area of maximum convergence is forecasted to move to the southwest and increase in magnitude to -5.6×10^{-5} s^{-1}. The minimum σ_E axis is also forecasted to increase in strength and shift slightly to the west during this 2 hour period. Thus, by 12 hours (0000 G.m.t.), the maximum 400 m convergence and minimum 750 m σ_E are nearly superimposed over southwestern Oklahoma. It was at about this time that the first reports of severe weather were received from Hollis, Oklahoma, and Post, Texas.

During the next 2 hours (0000 G.m.t. to 0200 G.m.t.), the model forecasts a southwestward movement and growth of the convergence band. The area of maximum convergence has moved into the vicinity of Childress, Texas, and Hobart, Oklahoma. The magnitude has reached nearly -10^{-4} s^{-1}. The minimum values of σ_E have again decreased in response to the low level moisture convergence associated with the zone of wind velocity convergence. The 0135 G.m.t. radar summary shows a southwest to northeast squall line which is nearly coincident with the model's band of superposition of strong low level convergence and minimum σ_E values. In fact, the area of maximum convergence between 12 and 14 hours of the model forecast is also the location of the most intense radar-observed activity. For example, the highest radar-reported echo (18.9 km) is located just to the southwest (toward lower σ_E) of the model-forecasted convergence maximum.

By 16 hours (0400 G.m.t.) the model-forecasted convergence maximum has moved southwestward into the vicinity of Lubbock, Texas. During the 2 hours from 0200 G.m.t. (14 hours) to 0400 G.m.t. (16 hours), the low level moisture convergence has continued to force a decrease in the 750 m σ_E values over southwestern Oklahoma and extreme north central Texas. One should note that by the 16 hour mark, a portion of the western flank of the convergence band has become superimposed upon high values of σ_E ($\sigma_E > 1.0$). Thus one would expect the majority of the convective activity to occur on the northeastern side of the convergence band, and this is observed on the late evening radar summaries.

The 10 to 16 hour convergence forecasts have clearly indicated a southwestward movement in the preferred zone of convective development, and the same trend is observed in the real world. The convective activity in southwestern Oklahoma diminishes during the night while the activity in northwestern Texas continues through 1035 G.m.t.

Problems Encountered-Several technical problems were encountered during the test: (1) The limited size of the model domain prevented the proper handling of synoptic wavelengths greater than 2000 km for time periods in excess of 8 hours; (2) poor initial low level data over high terrain regions due to the fictitous build-down of data to the lower boundary caused the model to erroneously create or amplify areas of convergence or potential instability near these high terrain regions; (3) the geostrophic initialization of momentum often caused unrealistic wave developments during the first few hours of the forecast; (4) the model

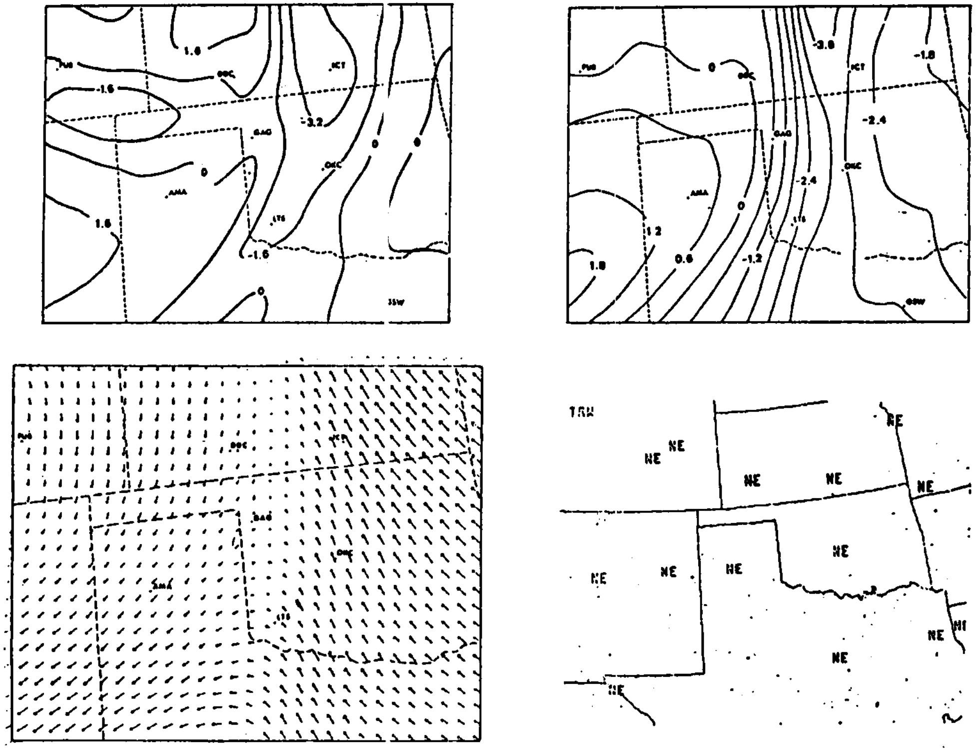

Fig. 1– Ten hour 400 m model forecast valid at 2200 GMT 18 May 1978.
Upper left: Divergence at intervals of 1.6 x 10^{-5} s^{-1}.
Upper right: 750 m σ_l at intervals of 0.6.
Lower left: Wind vectors.
Lower right: National Weather Service radar summary for 2035 GMT 18 May.

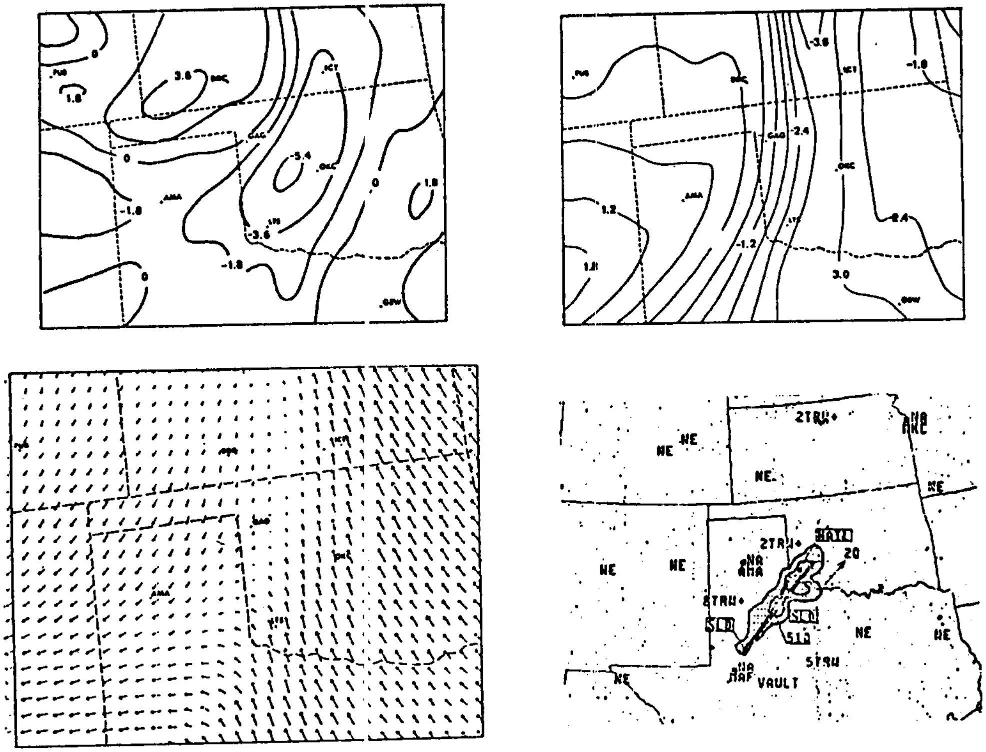

Fig. 2- Twelve hour 400 m model forecast valid at 0000 GMT 19 May 1978.
Upper left: Divergence at intervals of 1.8×10^{-5} s^{-1}.
Upper right: 750 m σ_E at intervals of 0.6.
Lower left: Wind vectors.
Lower right: National Weather Service radar summary for 2335 GMT 18 May.

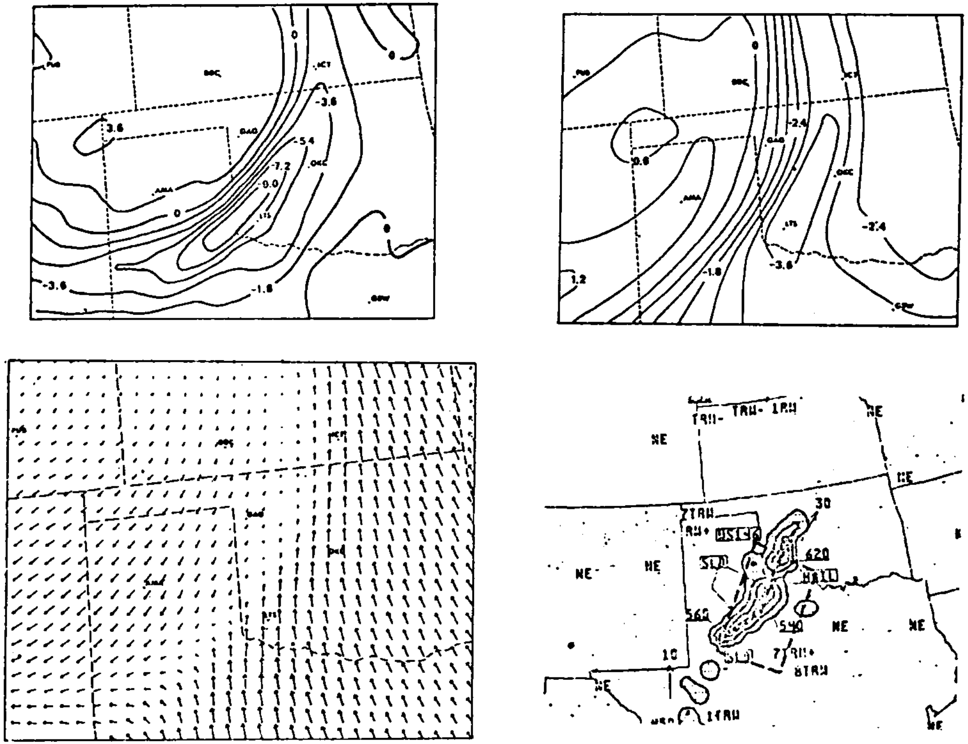

Fig. 3- Fourteen hour 400 m model forecast valid at 0200 GMT 19 May 1978.
Upper left: Divergence at intervals of $1.8 \times 10^{-5}\ s^{-1}$.
Upper right: 750 m σ_E at intervals of 0.6.
Lower left: Wind vectors.
Lower right: National Weather Service radar summary for 0135 GMT 19 May.

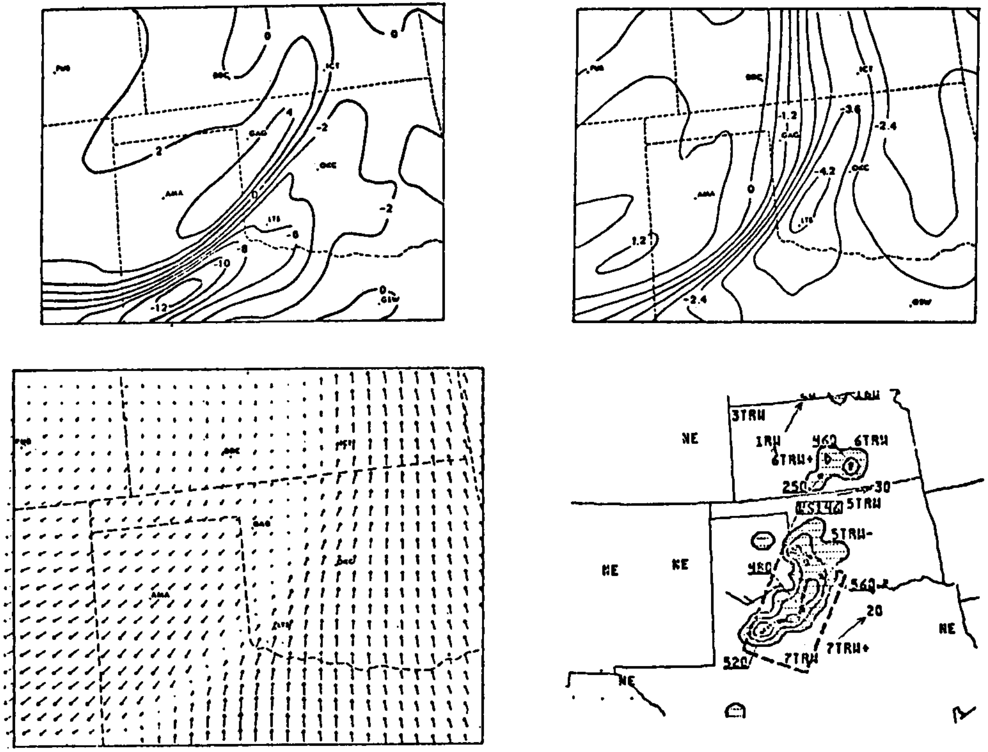

Fig. 4– Sixteen hour 400 m model forecast valid at 0400 GMT 19 May 1978.
Upper left: Divergence at intervals of 2 x 10^{-5} s^{-1}.
Upper right: 750 m σ_E at intervals of 0.6.
Lower left: Wind vectors.
Lower right: National Weather Service radar summary for 0335 GMT 19 May.

vertical resolution in the lower troposphere may have been insufficient to capture the complete dynamical process associated with the generation and amplification of the mesoscale convergence zones; and (5) because of telecommunications limitations, only the distribution of a preliminary index (with values 0 to 10) could be made available to users on a real-time basis, and much information was lost by condensing the entire model forecast into this index.

Improvements Being Implemented-The following improvements are expected to alleviate these problems and substantially improve the forecasts: (1) Because of available improvements in STAR system software and hardware, the model horizontal domain will be expanded from 60 x 48 to 90 x 64 points in 1979, and by 1980, a horizontal matrix size of 134 x 84 will be possible; (2) terrain-following lower levels will be incorporated into the model to eliminate the build-down problem in the mountains; (3) additional vertical resolution will be added to the lower tropospheric region of the model (several cases (e.g., May 18, 1978) have already been rerun using levels at 400, 750, 1150, 1650, and 2275 m instead of the 1150, 2275, and 3400 m levels used during the spring 1978 test period); (4) the geostrophic initialization scheme will be replaced by a dynamical balancing scheme which will represent the initial wind field with greater realism without distorting the observed pressure field; (5) additional scales of motion will be simulated by employing several smaller scale nested grids in addition to the 38 km grid; and (6) if increases become available in telecommunications hardware, future disseminated forecasts will include actual dependent variables of the model in order to give the users a more comprehensive picture of the model forecast.

SUMMARY

A mesoscale numerical model was run in real-time for a 60 consecutive day test period during the spring of 1978. Model output parameters were used to predict preferred zones of severe storm potential. The test revealed that the model captured a substantial number of subsynoptic and mesoscale dynamical processes with fidelity. However, problem areas were also noted, and corrective measures are being implemented to improve the performance of the model for the spring 1979 severe storm season.