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Evaluation Study of an Operational Mesoscale Forecast Model Over Three Climatologically Different Areas

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This report describes the evaluation study of the forecast skill of the Battlescale Forecast Model (BFM) over three different regions with different terrain complexities and climates. The model computations are initialized with three different sets of initial conditions over Colorado, Washington, and Florida; forecast data are statistically compared with surface observation data.

Statistical results of the BFM are compared to those of the Navy Operational Global Atmospheric Prediction System and Navy Operational Regional Atmospheric Prediction System.

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Preface

The Battlescale Forecast Model (BFM) is statistically evaluated by comparing the forecast data to observed data. BFM was run for cases of a 30-day period over three different model domains having different terrain complexities and climate (Colorado, Washington, and Florida). The model calculations were initialized with three different sets of initial conditions:

(1) Navy Operational Global Atmospheric Prediction System (NOGAPS) + upper air + surface data,
(2) NOGAPS + upper air, and
(3) NOGAPS.

For all three model domains, the temperature fields of BFM initialized with (1) and (2) above are statistically better than those initialized with (3). For Colorado and Washington model domains, the BFM showed clear tendencies of forecasting dew point temperatures lower than those observed throughout the 24-h forecast period. However, for the Florida model domain, forecasts of dew point temperature are higher than observed. Three different types of initialization data did not produce significantly different wind fields throughout the 24-h forecast period.

For Colorado and Washington model domains where terrain is more complex than Florida, the use of the BFM improves temperature and wind forecasts over those of NOGAPS and Navy Operational Regional Atmospheric Prediction System (NORAPS). For the Florida domain, no significant improvements in temperature forecasts are found.

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Executive Summary

The Battlescale Forecast Model (BFM) is statistically evaluated by comparing the forecast data to observed data. BFM was run for cases of a 30-day period over three different model domains having different terrain complexities and climate (Colorado, Washington and Florida). The model calculations were initialized with three different sets of initial conditions:

(1) Navy Operational Global Atmospheric Prediction System (NOGAPS) + upper air + surface data,
(2) NOGAPS + upper air, and
(3) NOGAPS.

Forecast data for 24-h periods are statistically compared with surface observation data, by calculating parameters such as mean difference (MD), absolute difference (AD), root mean square error, and root mean square vector error.

For all three model domains, the temperature fields of BFM initialized with (1) and (2) above are statistically better than those initialized with (3). For Colorado and Washington model domains, the BFM showed clear tendencies of forecasting dew point temperatures lower than those observed throughout the 24-h forecast period. However for the Florida model domain, forecasts of dew point temperature are higher than observed.

Three different types of initialization data did not produce significantly different wind fields throughout the 24-h forecast period. The values of MD for wind speed are in the range of 0 to 1 m/sec, and those of AD are also between 0 and 1 m/sec for three model domains throughout the 24-h forecast period.

For Colorado and Washington model domains where terrain is more complex than Florida, the use of the BFM improves temperature forecasts over those of NOGAPS and NORAPS. For the Florida domain, no significant improvements in temperature forecasts are found. Similarly, the BFM produces better wind fields than NOGAPS and Navy Operational Regional Atmospheric Prediction System (NORAPS) over Colorado and Washington.

1.0 Introduction

The Battlescale Forecast Model (BFM) is an operational mesoscale forecast model, developed at the U.S. Army Research Laboratory (ARL). It has been extensively used to make short-range forecasts of atmospheric conditions as a component in both the Integrated Meteorology System (IMETS) and the Computer Assisted Artillery Meteorology (CAAM) System. The BFM uses, for prognostic calculation, the Higher Order Turbulence Model for Atmospheric Circulation (HOTMAC) developed by Yamada. Recently, the forecast skill of the BFM was compared with that of the Fifth-Generation National Center Atmospheric Research/Penn State Mesoscale Model (MM5), by applying the models to the domain of White Sands Missile Range (WSMR), NM, which covers an area size of 167 x 167 km (51 x51 grid points with grid spacing of 3.33 km). Meteorological parameters forecasted by the models were compared with observed data. The comparison study showed that the forecast skills of the BFM are comparable to those of the MM5—surface temperature forecasted by both the BFM and the MM5 agreed well with observed values. Both the BFM and the MM5 showed difficulties forecasting the relative humidity. For wind parameters, both models tend to predict wind speed less than observation, but the BFM calculations produce smaller wind speed than the MM5. For wind-direction forecast, the BFM resulted in better forecast than the MM5. [1]

The BFM in operational mode on the IMETS has been extensively used over the model domain of 500 x 500 km with grid spacing of 10 km. So far there has been no evaluation study of the BFM in operational mode, applying the model for an extended period and comparing model forecasted parameters with observations. In this study, the BFM was applied for 30-day periods to three different model domains, each having an area size of 500 x 500 km with 51 x 51 grid points and 10 km grid spacing.

The first purpose of the present report is to describe the results of evaluation studies of BFM forecast skill over three different areas with different terrain complexities and climates (Colorado, Washington, and Florida). In this study, the model calculations were initialized with three different sets of initial conditions of varying completeness, and model values were statistically compared with observed data. The second purpose is to compare the statistics of BFM forecast data to those of other models, such as the Navy Operational Global Atmospheric Prediction System (NOGAPS) and the Navy Operational Regional Atmospheric Prediction System (NORAPS). [2,3,4]

2.0 Model Domains

The following three model domains were chosen for the present study:

1. Colorado, centered at 38.8°N and 104.7°W,
2. Washington, centered at 46.8°N and 121.5°W, and
3. Florida, centered at 28.0°N and 81.0°W.

Each model domain covers 500 x 500 km area with horizontal grid spacing of 10 km and the horizontal grid number of 51 x 51. The vertical depth of model is 7 km above the highest point of the model domain with 16 vertical layers.

The complexities of the three model domains are summarized in table 1.

Table 1. Terrain complexities of the three model domains

	Colorado	Washington	Florida
Mean elevation (m)	2022	590	7
Max. height (m)	4053	4105	69
Min. height (m)	1001	0	0
Standard Dev. (m)	722	526	12

As seen in table 1, Colorado and Washington model domains are complex compared to the Florida model domain. Figures 1, 2, and 3 are the elevation contour maps of, respectively, Colorado, Washington, and Florida model domains. In these figures, the outside squares cover the NOGAPS analysis and data composite area of 800 x 800 km, and the inside square covers the model domain of 500 x 500 km. In these figures, the characters N, U, and S represent the locations of the input data used for initialization of the model calculation:

N - NOGAPS data,
U - upper-air sounding data, and
S - surface observation data.

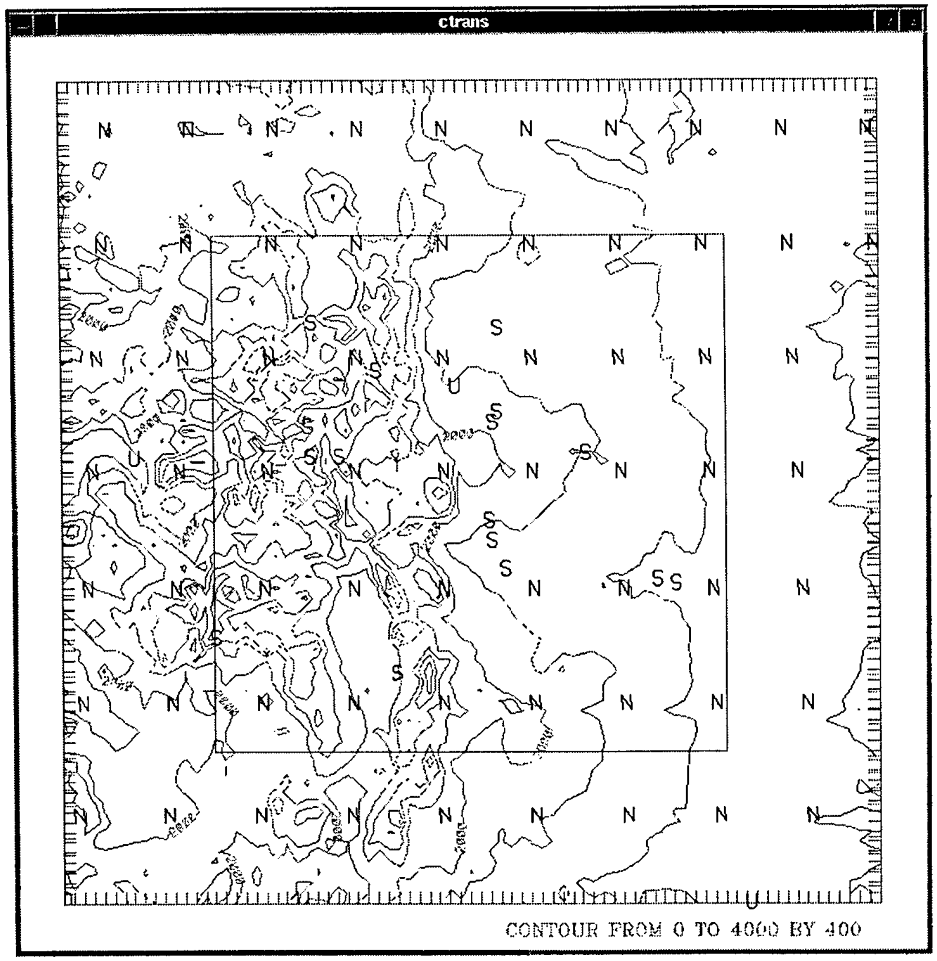


Figure 1. Elevation contours of the Colorado model domain.

Note: The outside area covers 800 x 800 km, and the inside area covers 500 x 500 km.

N = NOGAPS data points,
U = upper-air sounding locations, and
S = surface observation locations.

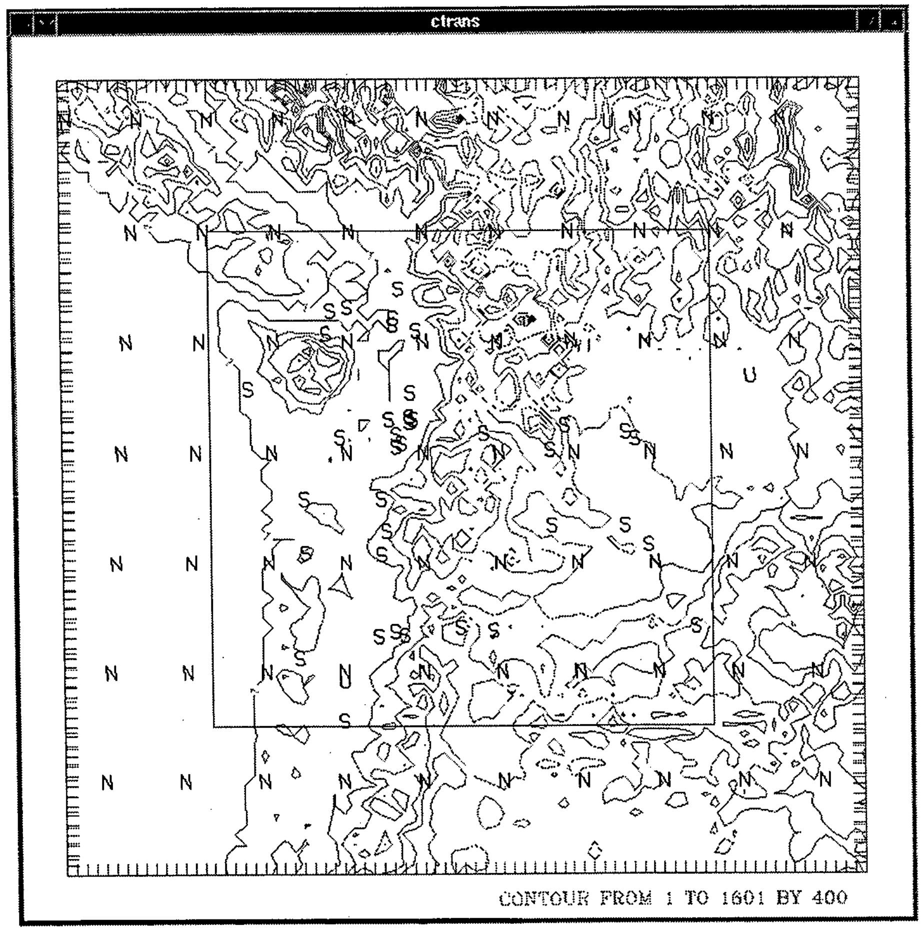


Figure 2. Elevation contours of the Washington model domain.

Note: The outside area covers 800 x 800 km, and the inside area covers 500 x 500 km.

N = NOGAPS data points,
U = upper-air sounding locations, and
S = surface observation locations.

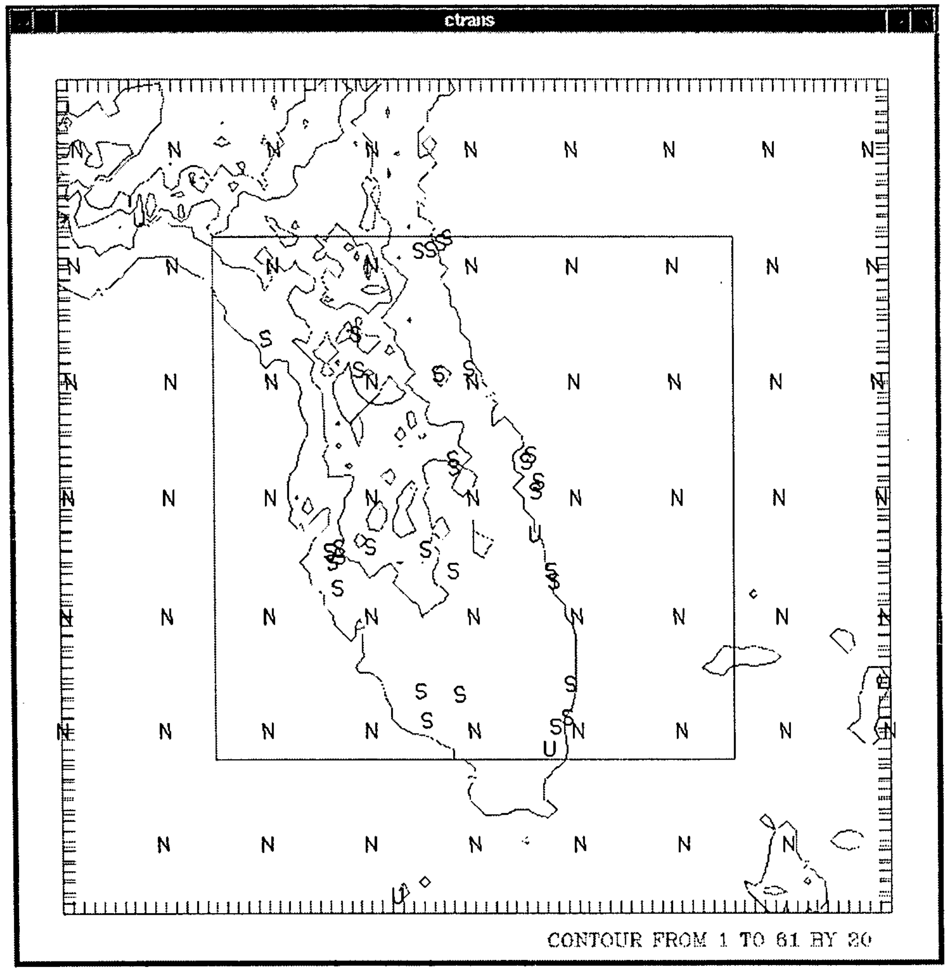


Figure 3. Elevation contours of the Florida model domain.

Note: The outside area covers 800 x 800 km, and the inside area covers 500 x 500 km.

N = NOGAPS data points,
U = upper-air sounding locations, and
S = surface observation locations.

3.0 Method

3.1 Data Used

The following data sets were obtained from the period of June 23 to July 22, 1998 from the indicated Internet home pages. NOGAPS and NORAPS data used for this study were obtained through the Internet home page of the Master Environmental Library (MEL) of the Defense Modeling and Simulation Office (DMSO) at: http://mel.dmso.mil.

NOGAPS forecast data were available at every 1° grid points over the entire earth, and NORAPS forecast data were available at every 0.5° grid points over the North America region. NOGAPS data were used for initialization and time-dependent lateral boundary conditions of BFM and, for comparison with BFM forecast data. The forecast data for the periods of 12, 24, and 36 h, initialized at 0000 UTC, were obtained at 13 pressure levels from 1000 mb to 100 mb. NORAPS data were used for statistical comparison with the BFM.

Upper-air sounding data are obtained from the University of Wyoming at the following Internet home page: http://www-das.uwyo.edu/upperair. Upper-air data observed at 1200 UTC were used for this study. Surface observation data were obtained from Ohio State University at the following Internet home page: http://geograf1.sbs.ohio-state.edu. The data are archived for 00, 03, 09, 12, 15, 18, and 21 UTC.

3.2 Initialization Methods

For all three model domains, BFM is initialized at 12 UTC with three different data sets as mentioned below, and forecasted data for 24-h period are compared with surface observation data:

(1) NOGAPS + upper air + surface data,
(2) NOGAPS + upper air data, and
(3) NOGAPS data only.

Details of the initialization method of BFM are described in reference 1. Briefly, for the three data sets, the 1° NOGAPS data valid for the forecast periods of 0, 12, and 24 h are spatially interpolated for the outside square areas of 800 x 800 km (see figures 1, 2, and 3). For initializations (1) and (2), the interpolated data from NOGAPS for the period of 0 h are composited with upper-air sounding data. For initialization (1), surface data of wind vector components, temperature, and mixing ratio at the 0-h period are assimilated into the model field by a nudging method. The nudging is done for 3 h from T_0-3 to T_0, where T_0 is the start of the forecast period. For the present study, T_0 is 12 UTC for all three model domains. [1,2]

3.3 Statistical Parameters

The following verification statistics were calculated using the data for the 30 day period between June 23 and July 22, 1999. Temperature, dew point temperature, wind speed, and vector components at the surface were compared by using these parameters at the forecast periods of 0, 3, 6, 9, 12, 15, 21, and 24 h.

3.3.1 Mean Difference

$$MD = \frac{\sum_{j=1}^{m}\sum_{i=1}^{n}(x_{p,i,j} - x_{o,i,j})}{m \cdot n} \quad (1)$$

Where

x = arbitrary meteorological parameter,
$_o$ = observation,
$_p$ = prediction,
$_i$ = i^{th} surface station,
$_j$ = j^{th} forecast day,
n = surface stations,
m = total number of forecast days, and
Nonzero = MD indicates bias.

For instance, if the mean difference (MD) is positive, it indicates that the model tends to overforecast.

3.3.2 Mean Absolute Difference

$$AD = \frac{\sum_{j=1}^{m}\sum_{i=1}^{n}\left|x_{o,i,j} - x_{p,i,j}\right|}{m \cdot n} \quad (2)$$

Because the absolute value of the difference is used, good agreements between observation and forecast are, in general, related to small values of absolute difference (AD).

3.3.3 Root Mean Square Error

$$rmse = \sqrt{\frac{\sum_{j=1}^{m}\sum_{i=1}^{n}(x_{o,i,j} - x_{p,i,j})^2}{m \cdot n}} \tag{3}$$

Usually, the values of root mean square error (RMSE) is proportional to those of AD. [2]

3.3.4 Root Mean Square Vector Error

$$RMSVE = \sqrt{\frac{\sum_{j=1}^{m}\sum_{i=1}^{n}\left[(u_{o,i,j} - u_{p,i,j})^2 + (v_{o,i,j} - v_{p,i,j})^2\right]}{m \cdot n}} \tag{4}$$

This parameter measures the difference of both the n-s and e-w components of the wind vector giving a result that effectively combines wind speed and direction. Again, good agreements of wind vectors are related to small values of the root mean square vector error (RMSVE).

3.3.5 Correlation Coefficient

$$CC = \frac{\sum_{j=1}^{m}\sum_{i=1}^{n} y_{o,i,j} \cdot y_{p,i,j}}{\sqrt{\sum_{j=1}^{m}\sum_{i=1}^{n} y^2_{o,i,j} \cdot \sum_{j=1}^{m}\sum_{i=1}^{n} y^2_{p,i,j}}} \tag{5}$$

Here $y_{o,i,j} = x_{o,i,j} - \overline{x_o}$, and $y_{p,i,j} = x_{p,i,j} - \overline{x_p}$. $\overline{x_o}$ and $\overline{x_p}$ are the means of observed and forecast values, respectively.

4.0 Results

4.1 Scatter Diagrams

The forecast data generated by the BFM runs using the NOGAPS + upper-air data (2) are used for the plotting. Scatter diagrams obtained for the model domains of Colorado, Washington, and Florida are shown in figures 4, 5, and 6, respectively. In these figures, (a) is for temperature, (b) for dew point temperature, (c) for wind vector components u and v, and (d) for wind speed. The correlation coefficients between forecasted and observed data are summarize in table 2.

Table 2. Correlation coefficients between forecast and observation for three model domains of Colorado, Washington, and Florida

	Colorado	Washington	Florida
Temperature	0.83	0.77	0.65
Dew point temp.	0.78	0.44	0.26
Wind speed	0.62	0.48	0.59
u	0.38	0.18	0.27
v	0.34	0.32	0.33

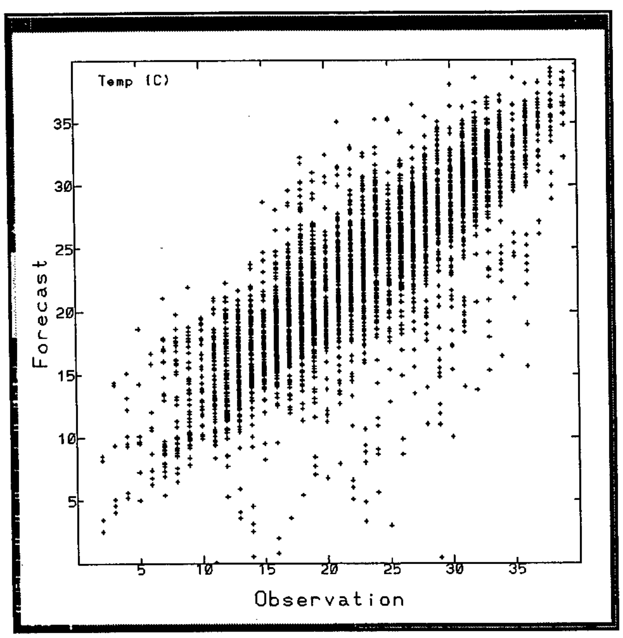


Figure 4a. Scatter diagram of model calculation versus observation of temperature, Colorado model domain.

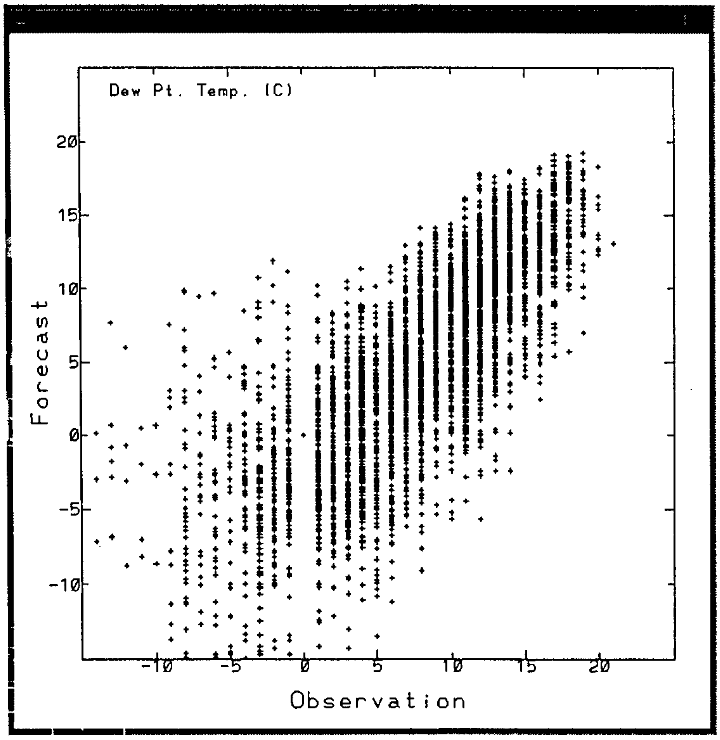


Figure 4b. Scatter diagram of model calculation vs. dew point temperature, Colorado model domain.

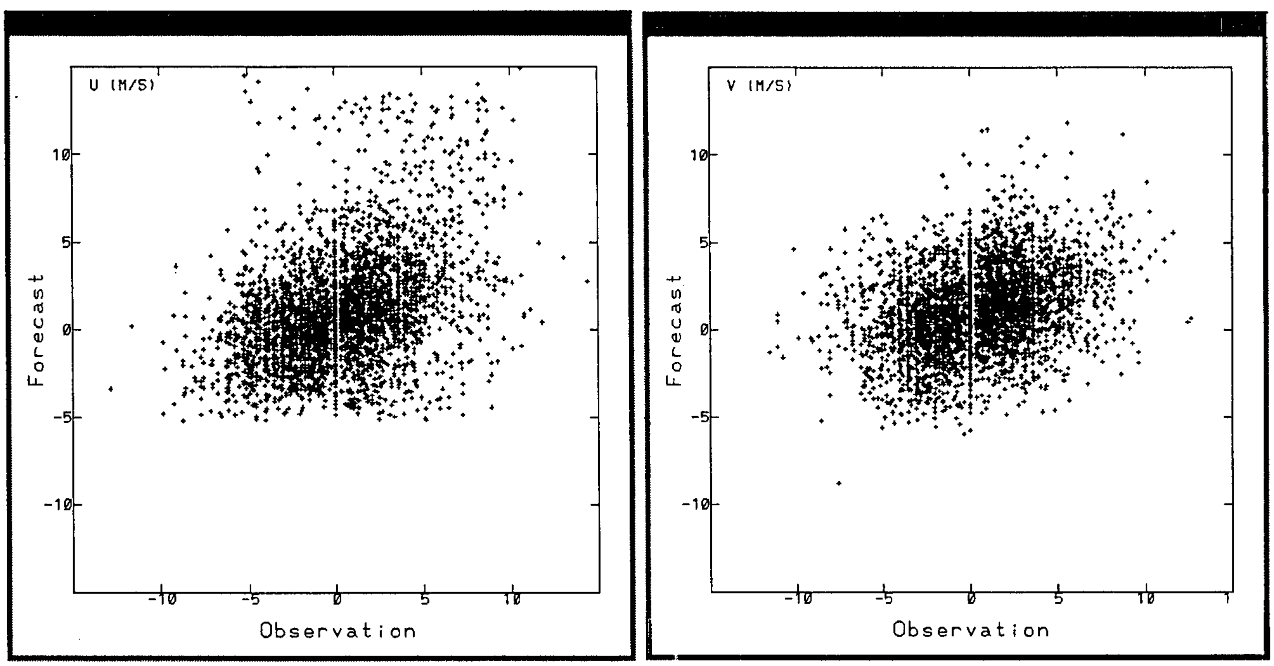


Figure 4c. Scatter diagram of model calculation versus wind vector components u (left-hand side) and v (right-hand side), Colorado model domain.

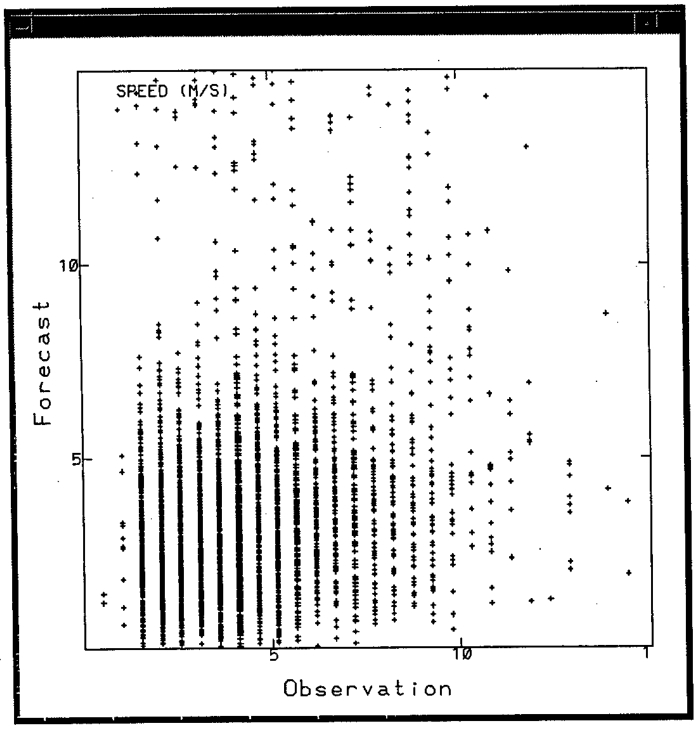


Figure 4d. Scatter diagram of model calculation versus wind speed, Colorado model domain.

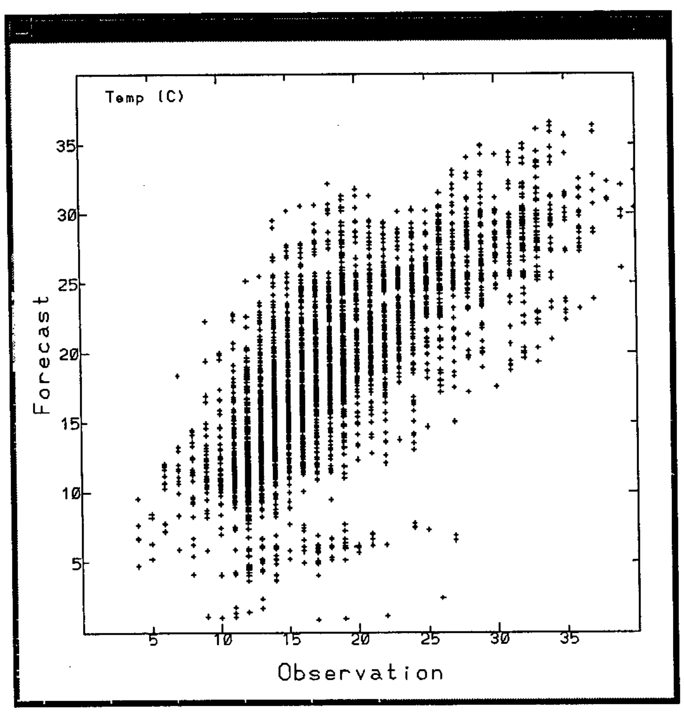


Figure 5a. Scatter diagram of model calculation versus observation of temperature, Washington model domain.

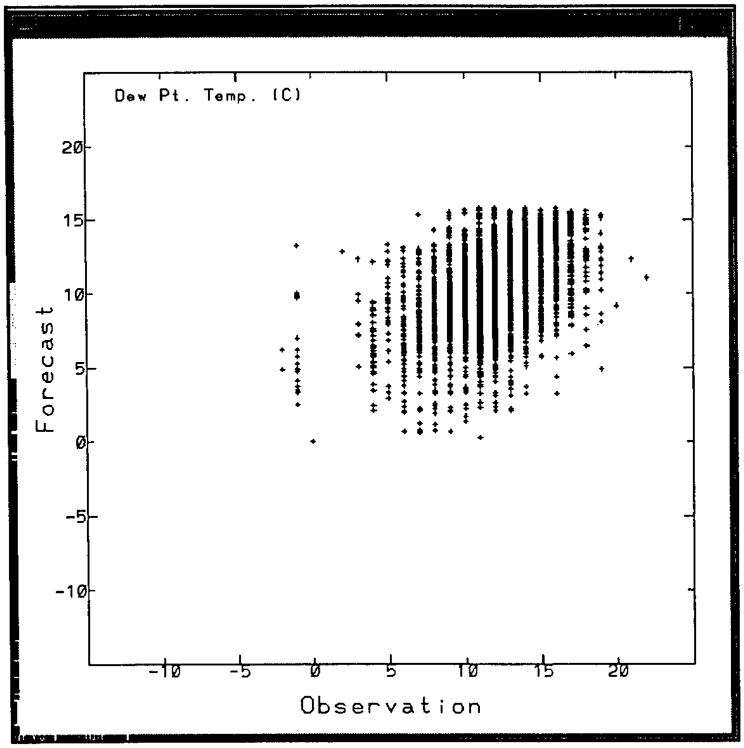
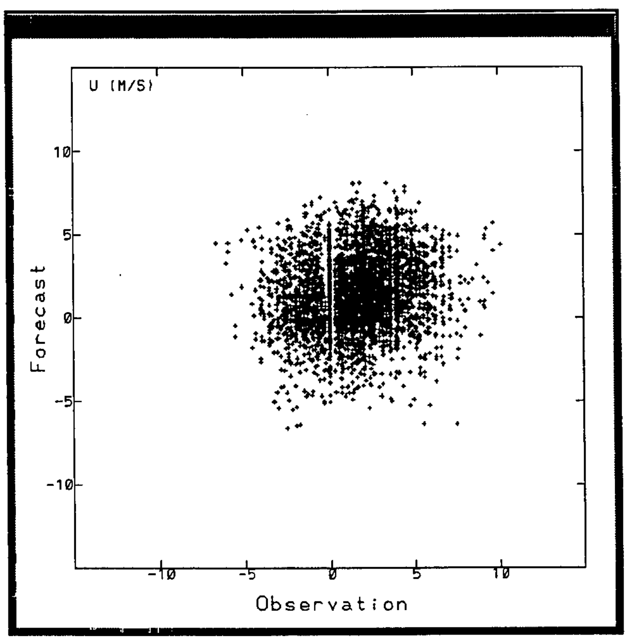


Figure 5b. Scatter diagram of model calculation vs. dew point temperature, Washington model domain.



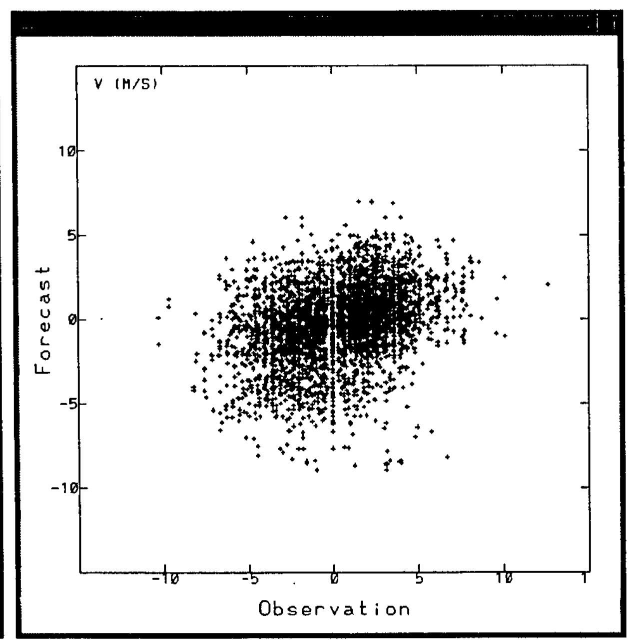


Figure 5c. Scatter diagram of model calculation versus wind vector components, u (left-hand side) and v (right-hand side), Washington model domain.

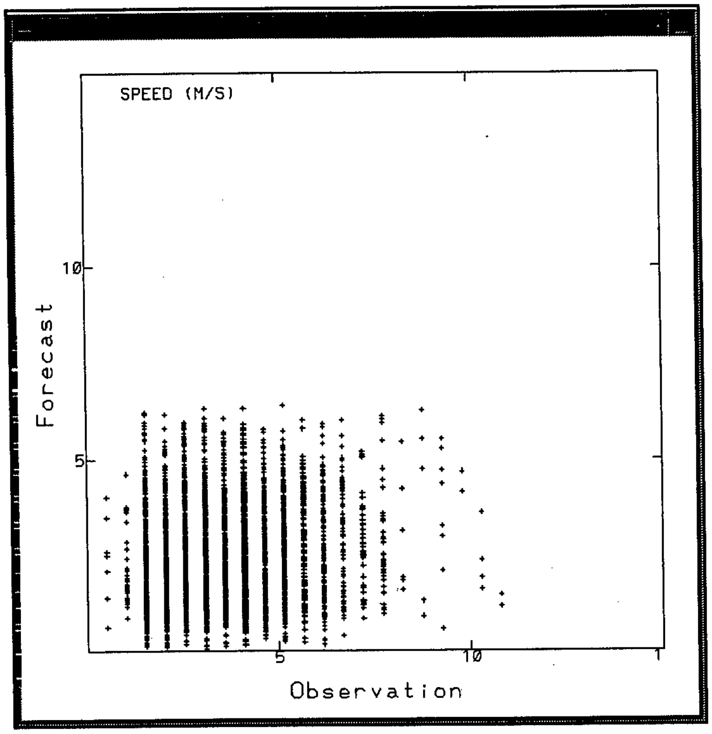


Figure 5d. Scatter diagram of model calculation versus wind speed, Washington model domain.

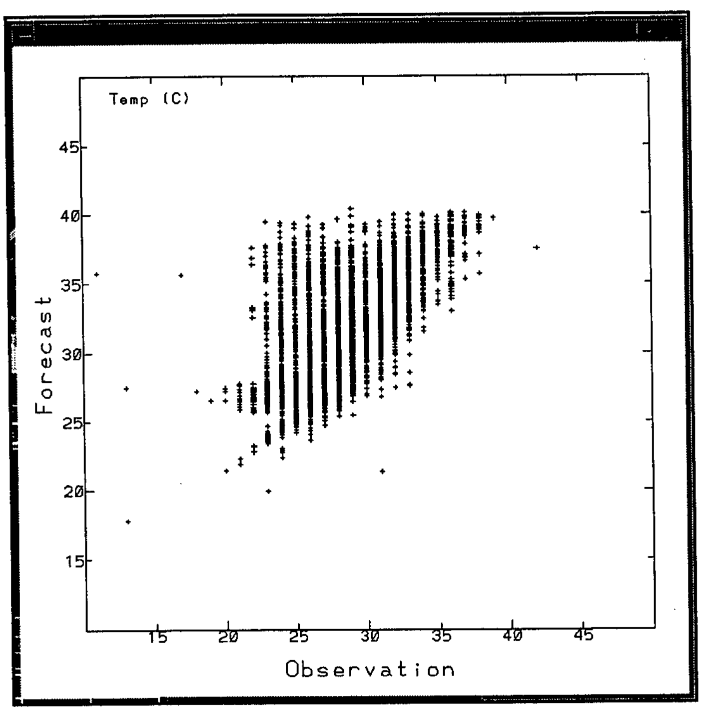


Figure 6a. Scatter diagram of model calculation versus observation of temperature, Florida model domain.

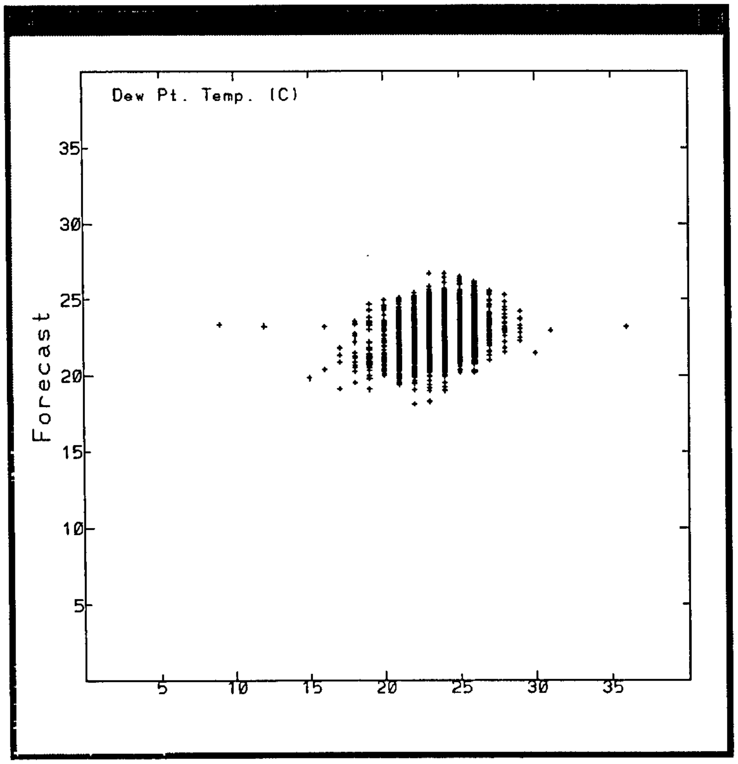


Figure 6b. **Scatter diagram of model calculation versus dew point temperature, Florida model domain.**

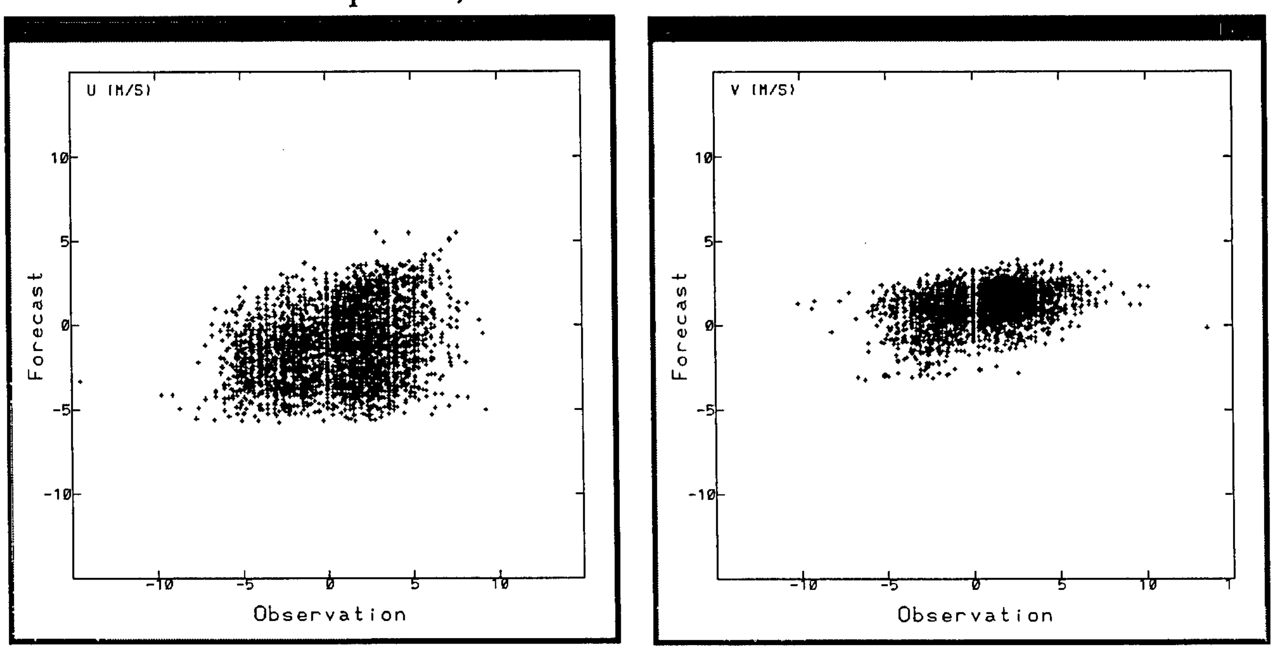


Figure 6c. Scatter diagram of model calculation versus wind vector components u (left-hand side) and v (right-hand side), Florida model domain.

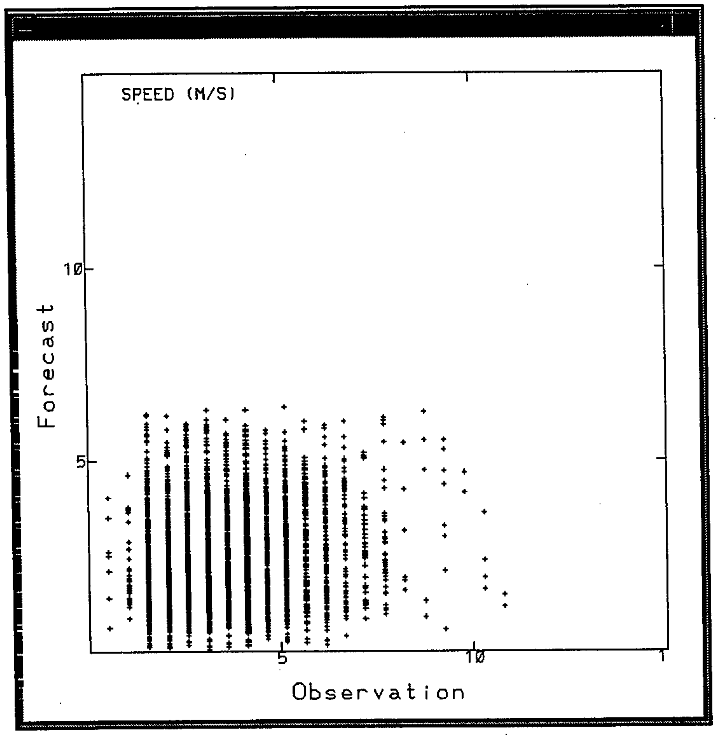


Figure 6d. Scatter diagram of model calculation versus wind speed, Florida model domain.

The ranges of variation of temperature and dew point temperature for the Florida domain are the narrowest among the three domains, reflecting the maritime climate, and those for the Colorado domains are the largest, reflecting the continental climate.

For temperature and dew point temperature, the correlation coefficients for the Colorado model domain are the largest, and those for the Washington domain follow. It is encouraging to see that the highest correlation values for temperature and dew point temperature are produced for the Colorado model domain by the BFM despite the large range of values.

For wind vector components u and v, and speed, the correlation coefficients are smaller than those for temperature and dew point temperature. The wind speed scatter diagram for the Colorado domain is the most scattered of the three domains, again reflecting the complex terrain. On the other hand, the wind speed scatter diagram for the Florida domain shows much less scattering distribution than the diagrams for the other two domains.

4.2 Time Series of the Statistical Parameters

MD, AD, RMSE, and RMSVE are calculated at the forecast periods of 0, 3, 6, 9, 12, 15, 21 and 24 h. Time 0 h corresponds to 12 UTC. Forecast calculations are performed three times with three different initial conditions. In figures 7 through 9, three curves are drawn:

K=1 represents the statistics of the BFM initialized with NOGAPS + upper air + surface data,

K=2 represents those initialized with NOGAPS + upper-air data, and

K=3 represents those initialized with NOGAPS data only.

In the figures, only MD and AD for all the meteorological variables, and RMSVEs for wind vector are shown in the figures. The RMSEs are calculated but are not shown in this report, because the RMSE usually varies proportionally to the AD.

4.2.1 Temperature

Figures 7, 8, and 9 are the MD and AD of temperature for Colorado, Washington, and Florida, respectively. It is clear from these three figures that the BFM initialized with NOGAPS + upper-air data (K=1 and K=2) produced better forecast than that with NOGAPS data only (K=3).

For the Colorado model domain, the initial data without upper-air data produced worse temperature forecast than those with upper-air data. The effect of using the surface data is seen at the forecast periods between 0 and 3 h. For very short-term forecast up to 3 h, the nudging of the surface data produces improved forecasts of surface temperature. After 3 h, the curves with K=1 and K=2 are very similar, implying that the effect of surface temperature nudging becomes insignificant. The curves of MD indicate that during daytime hours the temperatures forecasted by the BFM are lower than observed over the Colorado model domain.

For the Washington model domain, the use of upper-air data for the initial condition produced better temperature forecasts, but the influence of upper-air data is not as significant as over the Colorado model domain. The effect of surface temperature nudging in initialization is seen again in the first 3 h of forecast. There are no significant differences between the three MD curves, and the values of all three curves for K=1, 2, and 3 stayed around 0° C, indicating there is no significant bias. For the Florida model domain, similar to the results from the Colorado and Washington domains, the initial condition without upper-air data produced inferior forecast of temperature to those with upper-air data included. MD curves show that the surface temperature over the land of the Florida model domain was underpredicted during daytime hours and overpredicted during nighttime hours. The amplitude of daily temperature cycle forecasted by the BFM was not large enough to match that observed.

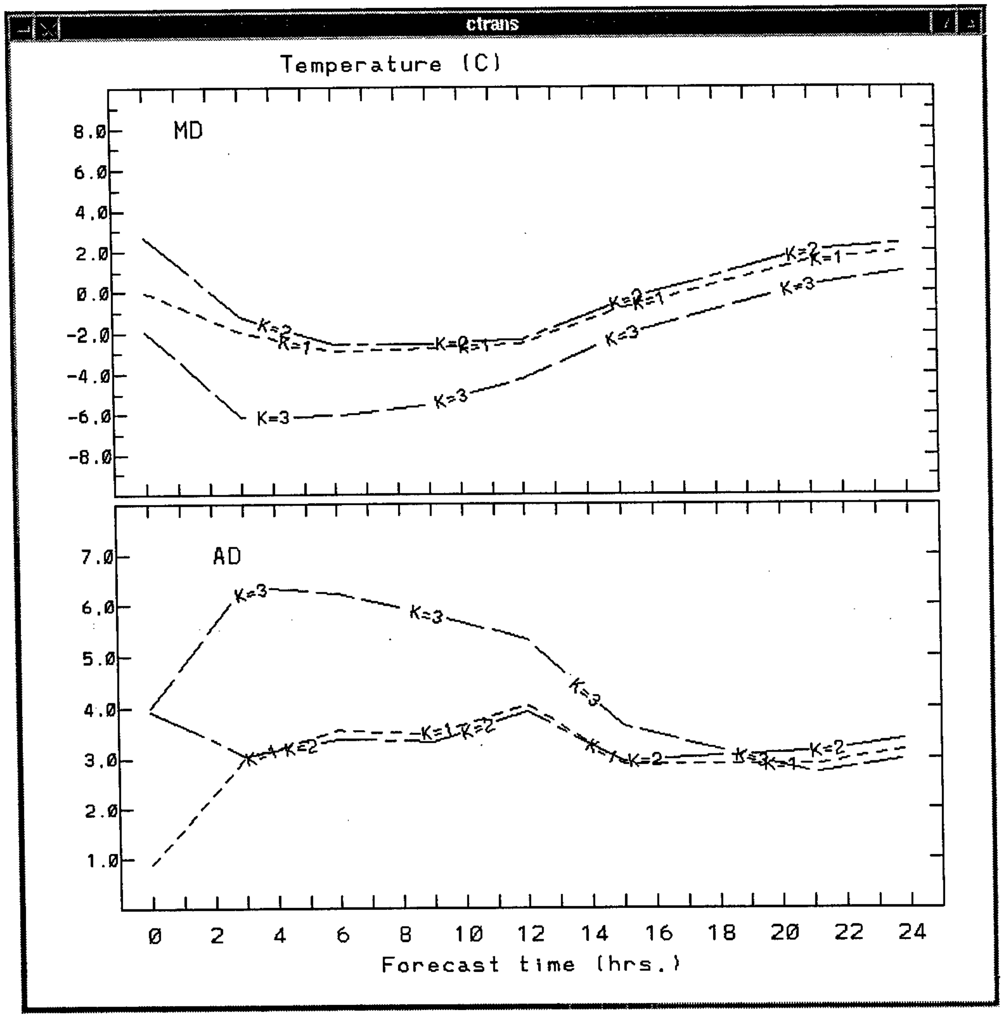


Figure 7. Time series of MD and AD of temperature, Colorado model domain.

Note:

K=1, for initialization with NOGAPS + upper air + surface data,
K=2, for initialization with NOGAPS + upper-air data, and
K=3, for initialization with NOGAPS data.

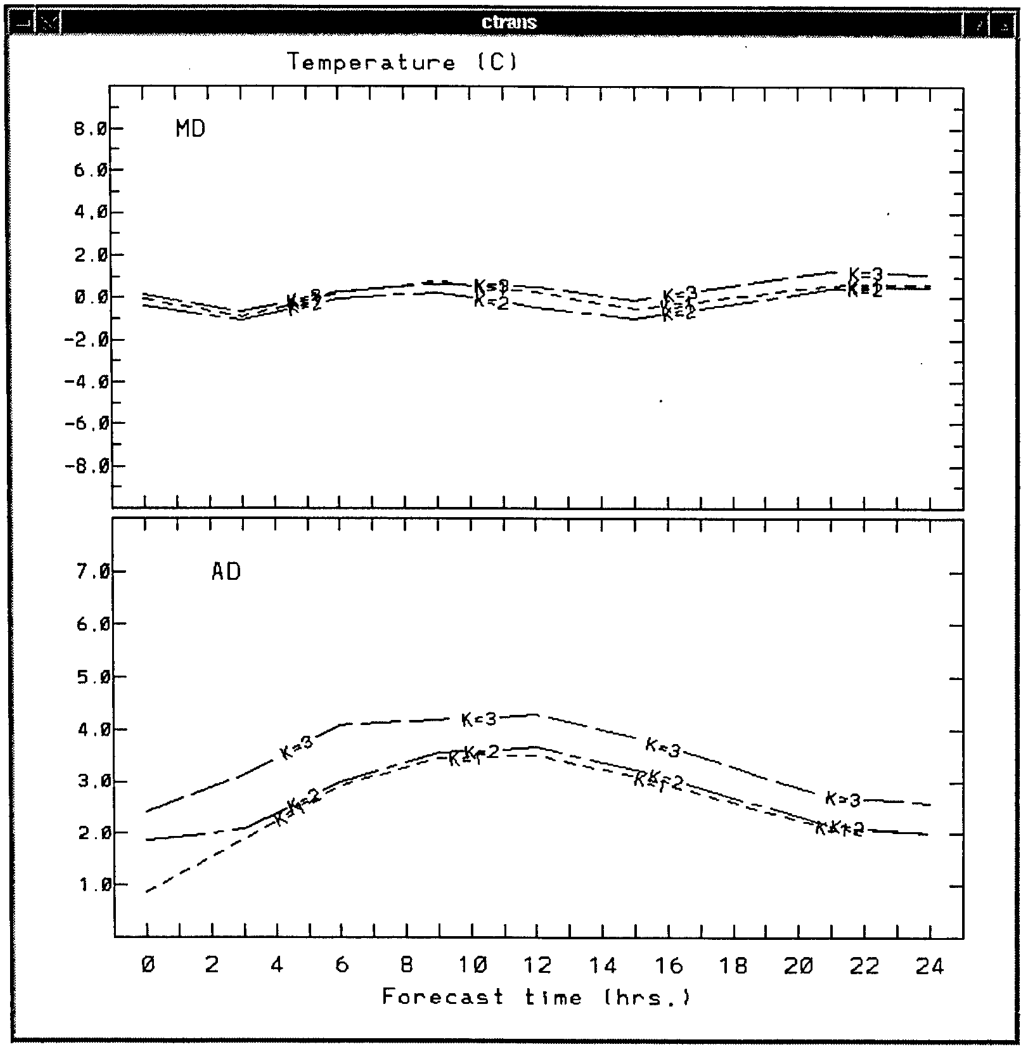


Figure 8. Time series of MD and AD of temperature, Washington model domain.

Note:

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K=2, for initialization with NOGAPS + upper-air data, and
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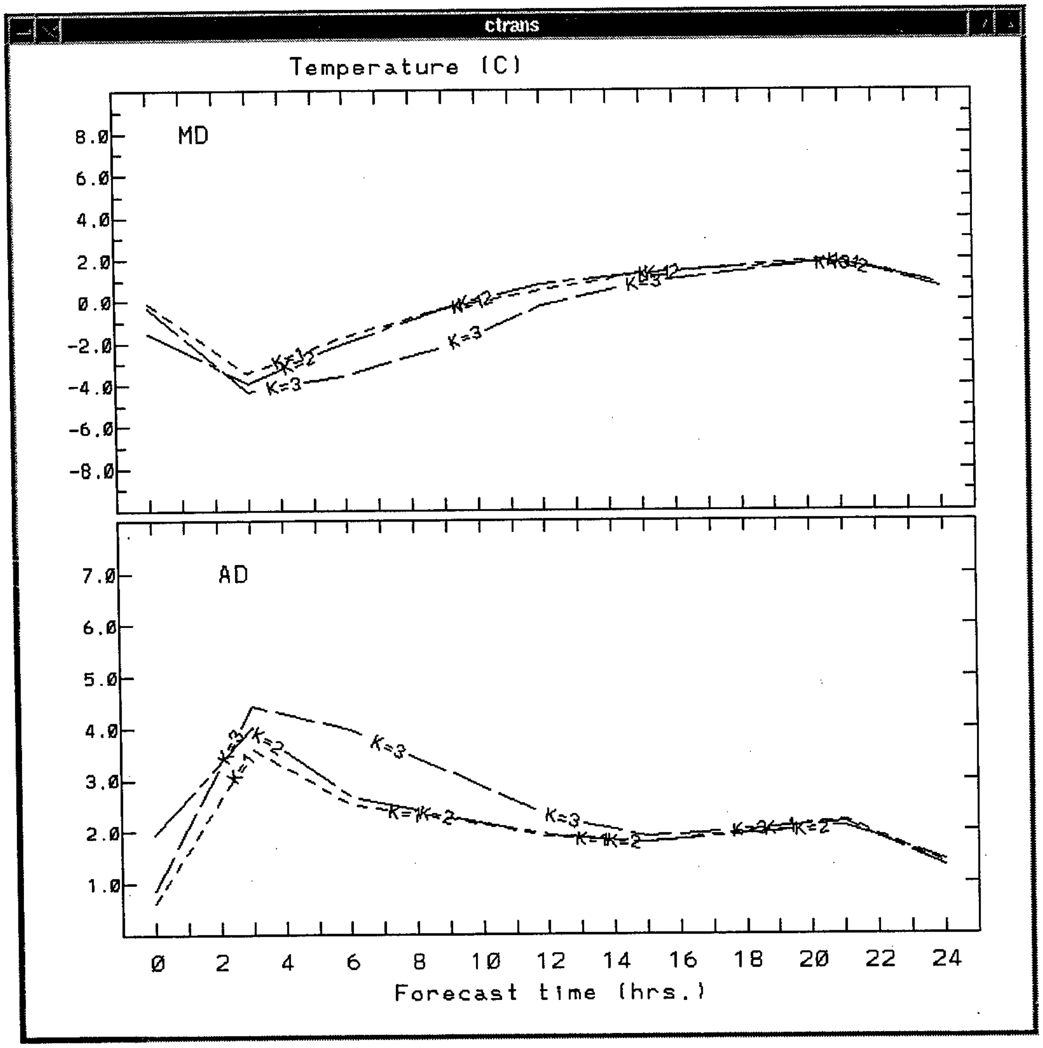


Figure 9. Time series of MD and AD of temperature, Florida model domain.

Note:

K=1, for initialization with NOGAPS + upper air + surface data,
K=2, for initialization with NOGAPS + upper-air data, and
K=3, for initialization with NOGAPS data.

4.2.2 Dew Point Temperature

Figures 10, 11, and 12 are the plotting of MD and AD time series for the three model domains. For the Colorado model domain (figure 10), the model forecast of dew point temperature averages more than 3° off from the observations. Among the three model domains, the AD values for the Colorado model domain are the largest. For daylight hours, the model forecasted the dew point temperature lower than observed. This is particularly significant with K=1 and 2, which represent the initial conditions with upper-air data. It is not clear why the initial conditions with upper-air data generated inferior forecasts of dew point temperature to those only with NOGAPS data.

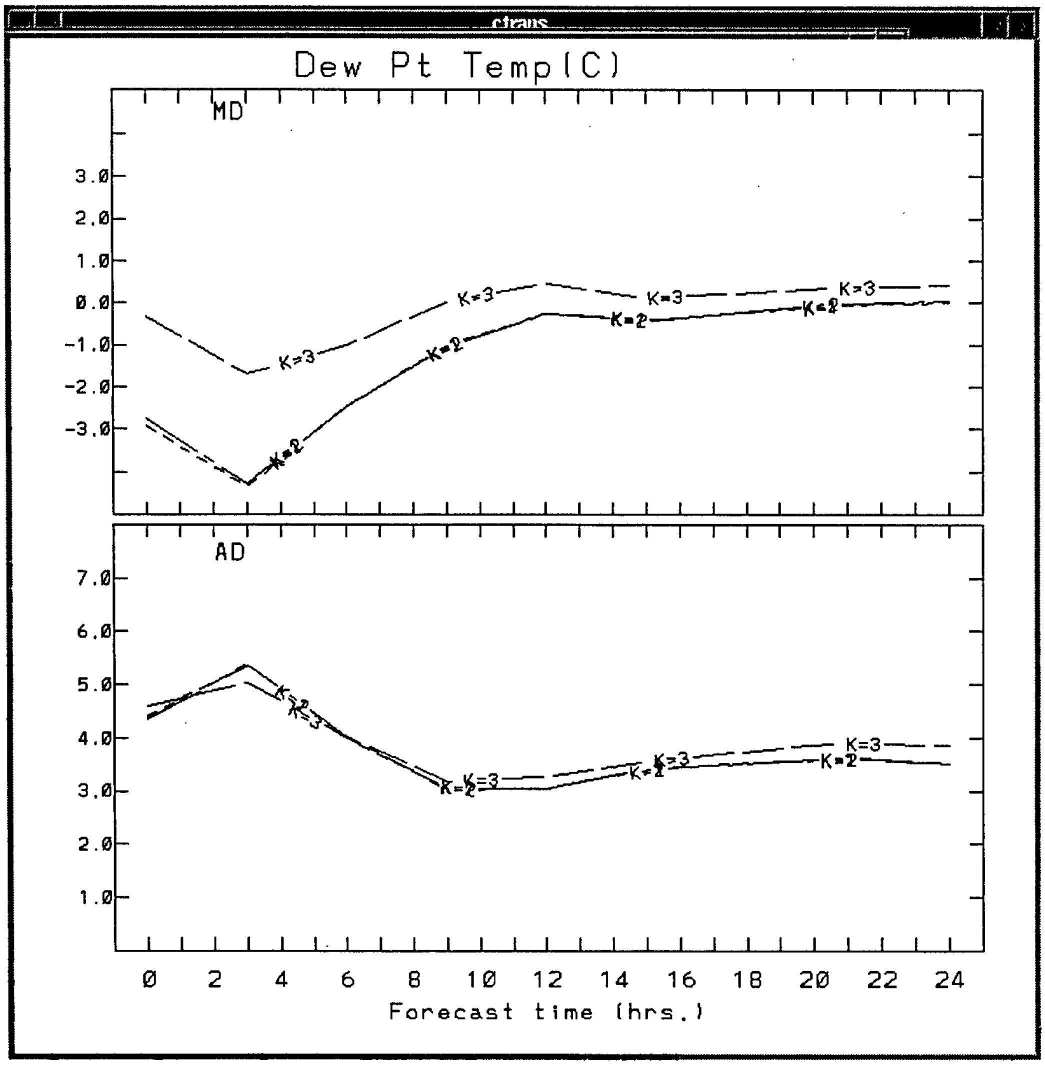


Figure 10. Time series of MD and AD of dew point temperature, Colorado model domain.

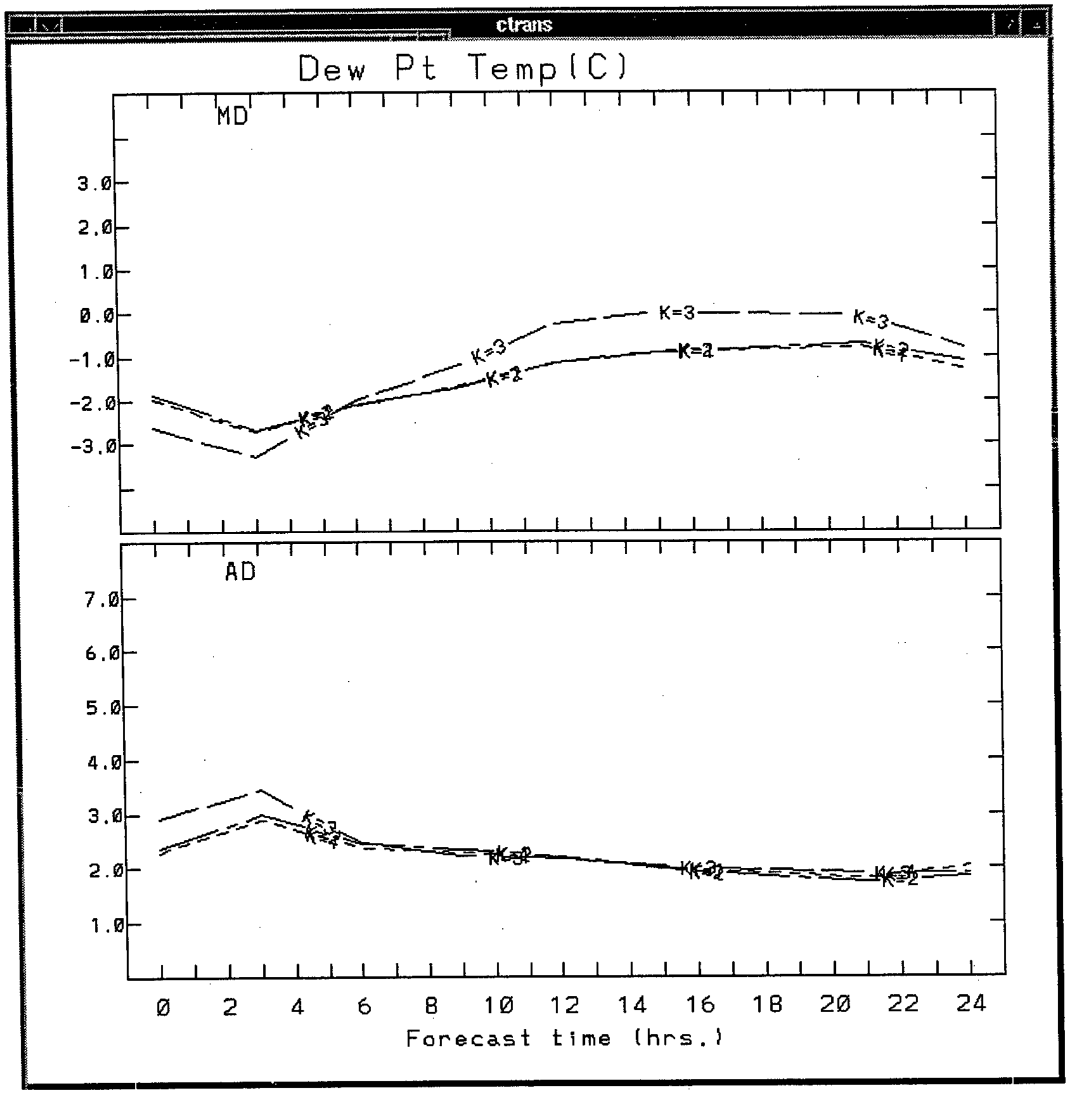


Figure 11. Time series of MD and AD of dew point temperature, Washington model domain.

For the Washington model domain, the model generated lower dew point temperatures than observed throughout 24-h forecast period. Similar to the Colorado model domain, the initial conditions with upper-air data produced lower dew point temperatures than those without upper-air data.

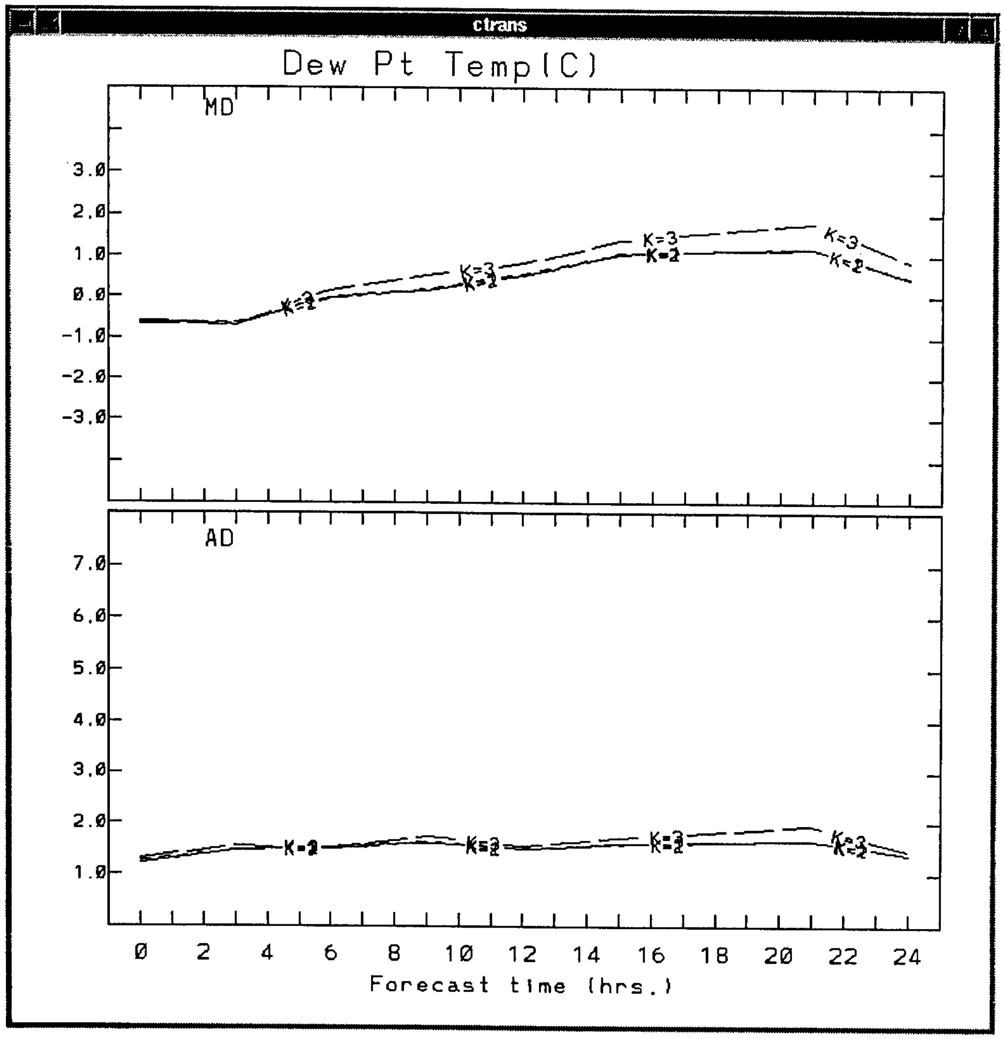


Figure 12. Time series of MD and AD of dew point temperature, Florida model domain.

For the Florida model domain, the model produced greater dew point temperatures than observed throughout the 24-h forecast period, except for the 0 and 3-h periods. The AD values are the smallest among the three model domains throughout the 24-h forecast period. There are no significant differences among the three forecasts with different initial conditions.

From the inspection of the moisture values of NOGAPS data, which is used for initial and boundary values of the BFM, it is suspected that NOGAPS tends to forecast drier atmosphere than observed. Therefore, the dew point temperatures by the NOGAPS are compared to the observed values.

Tables 3, 4, and 5 show MD and AD between NOGAPS data and observations for dew point temperature, respectively, for the Colorado, Washington, and

Florida model domains. The NOGAPS data used for the initialization and boundary conditions of the BFM at 0, 12, and 24 h are compared with the surface data.

Table 3. MD and AD at forecast periods of 0, 12, and 24 h between NOGAPS data and observation, Colorado model domain

Forecast hours	MD	AD
0 h	-2.2	3.6
12 h	-1.2	3.5
24 h	-1	3.5

Table 4. MD and AD at forecast periods of 0, 12, and 24 h between NOGAPS data and observation for Washington model domain

Forecast hours	MD	AD
0 h	-0.9	1.8
12 h	-0.2	2
24 h	-1.3	2

Table 5. MD and AD at forecast periods of 0, 12, and 24 h between NOGAPS data and observation for Florida model domain

Forecast hours	MD	AD
0 h	-0.7	1.2
12 h	0	1.2
24 h	0.8	1.3

From these tables, the MD indicates that dew point temperature fields of NOGAPS are lower than those observed throughout the 24-h forecast periods over the Colorado and Washington domains. For the Florida domain, they are lower than observed in the first 12 h. However, the magnitudes of the MD and AD between NOGAPS and observation at 0 h given in tables 3 and 4 are smaller than those shown in figures 10 and 11. Therefore, it is suspected that in the Colorado and Washington domains, the BFM's prognostic calculations might have numerically produced lower dew point temperatures than observed during the early stages of forecast periods.

Figures 13, 14, and 15 are time series of MD and AD of wind speed and RMSVE respectively, for Colorado, Washington, and Florida.

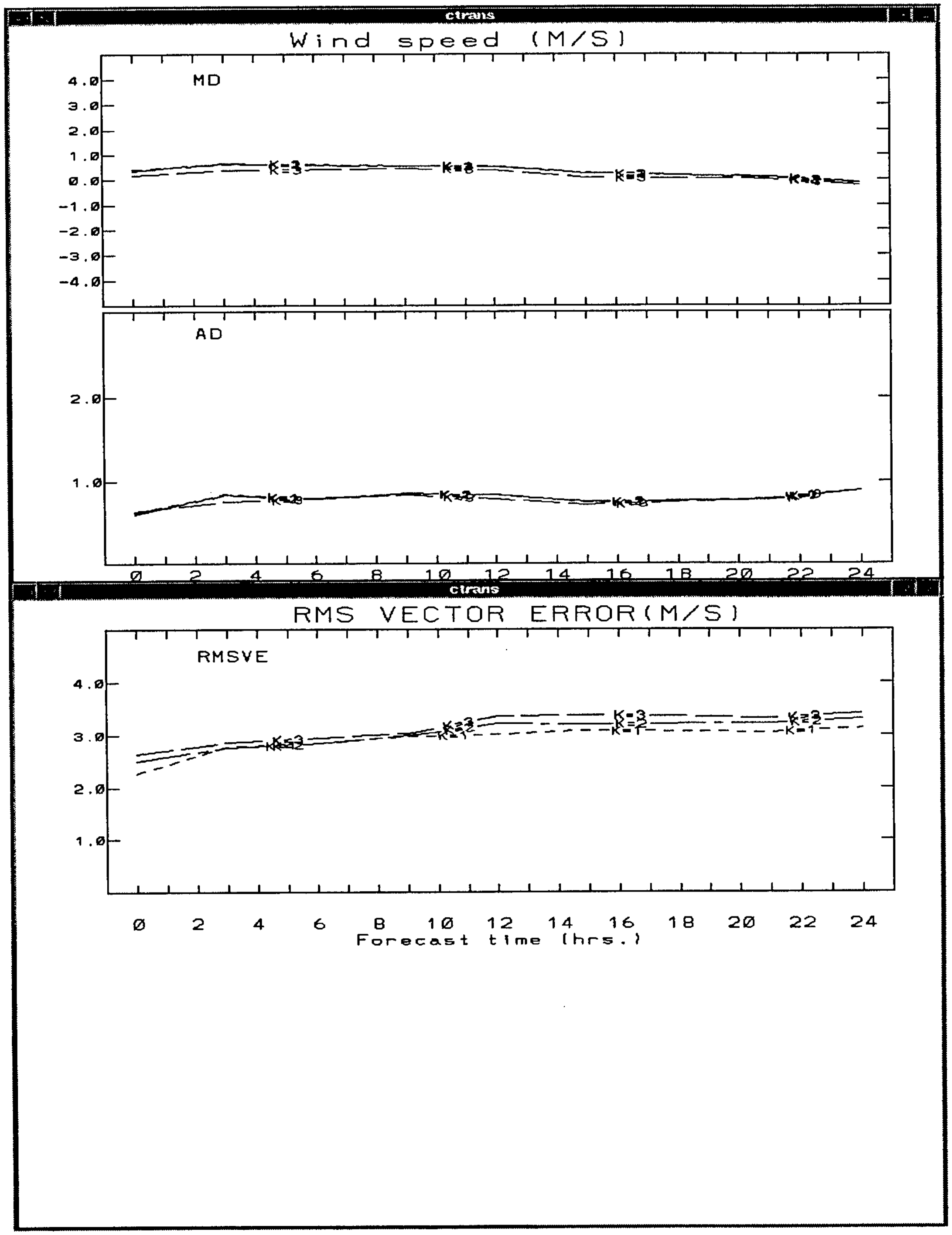


Figure 13. Time series of MD and AD of wind speed (top), and RMSVE (bottom), Colorado model domain.

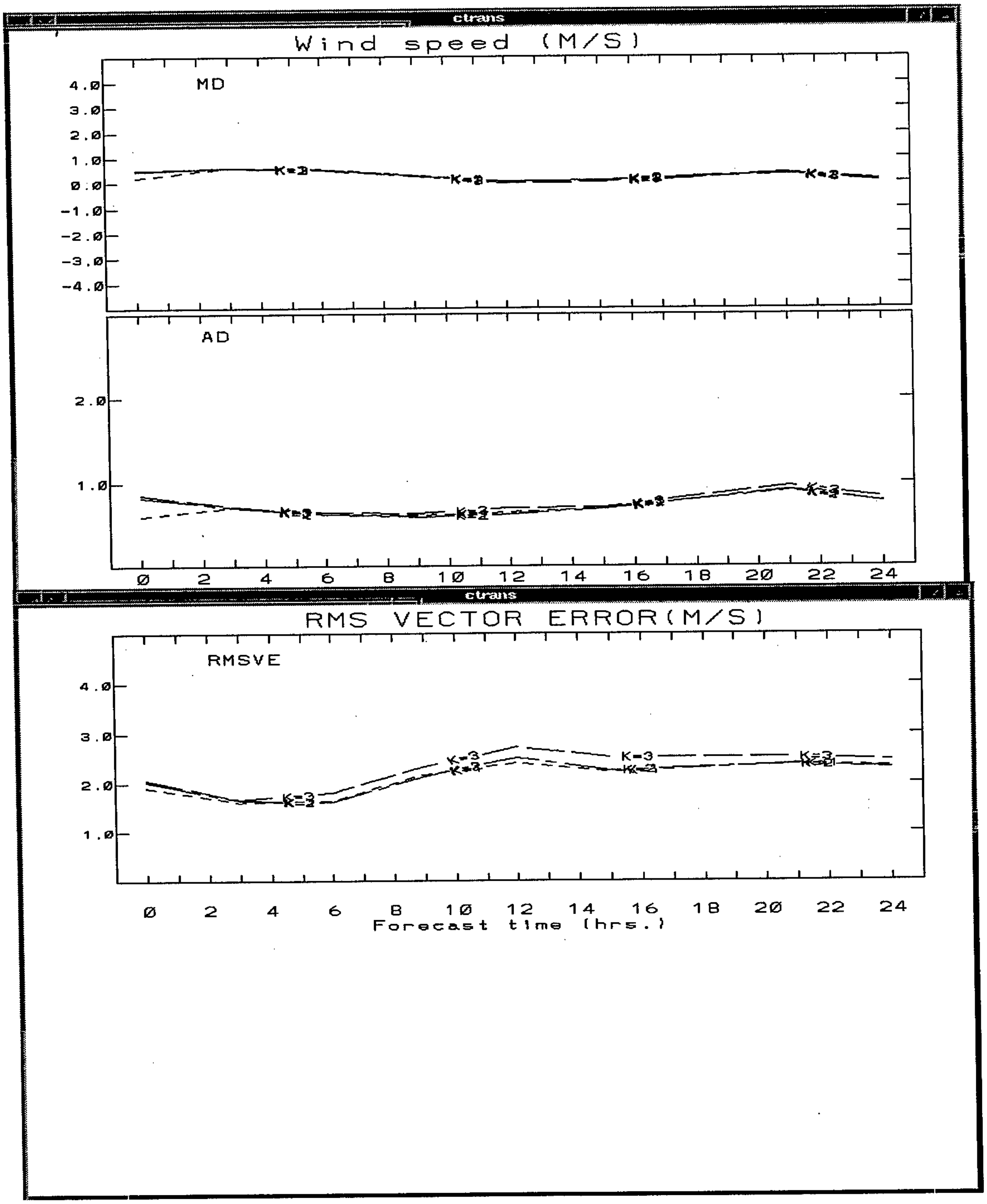


Figure 14. Time series of MD and AD of wind speed (top) and RMSVE (bottom), Washington model domain.

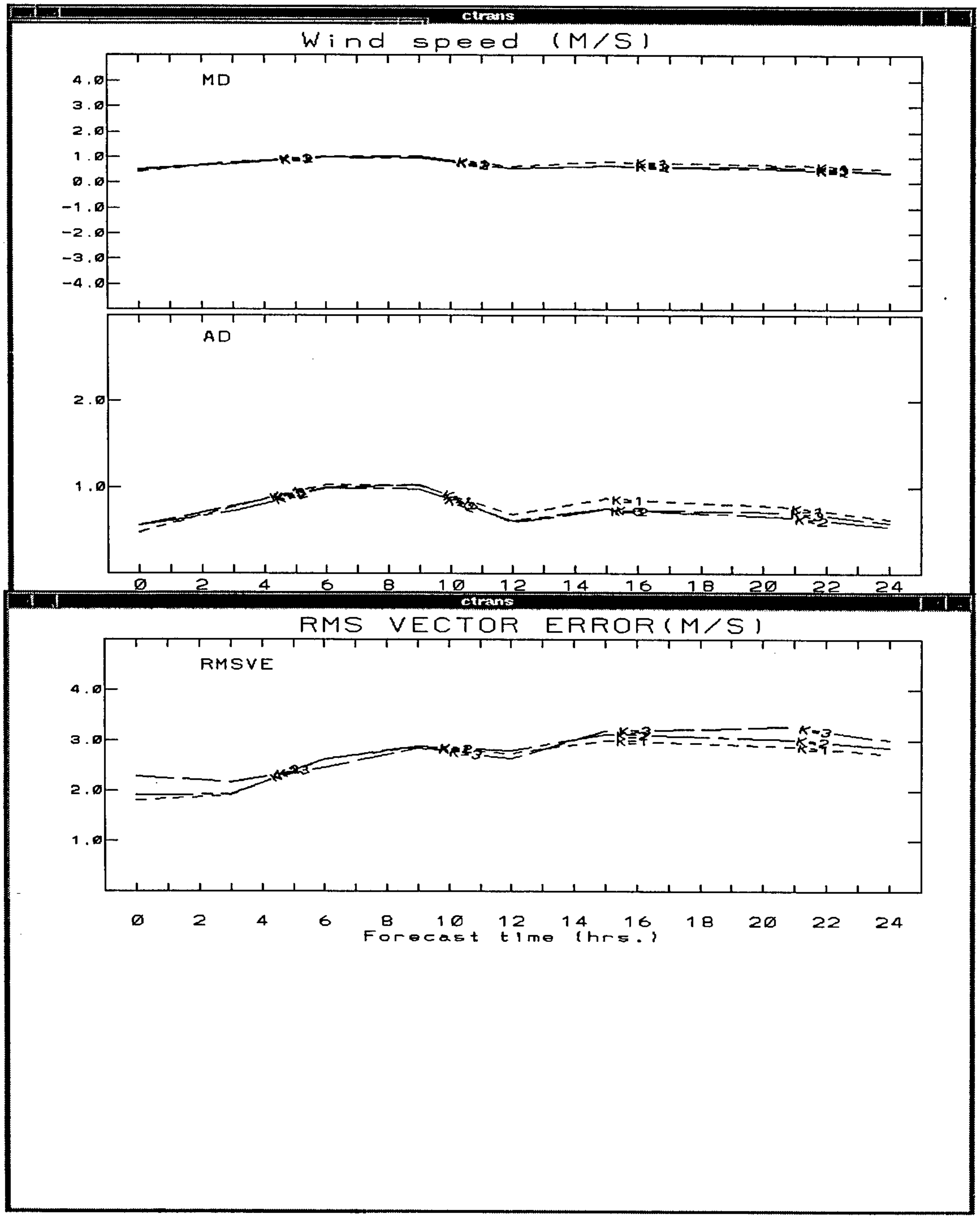


Figure 15. Time series of MD and AD of wind speed (top) and RMSVE (bottom), Florida model domain.

4.2.3 Wind Speed and Wind Vector

Unlike temperature and dew point temperature, there are no significant differences in MD, AD and RMSVE among the three different initialization methods for all three model domains. The values of MD are between 0 and 1 m/s for the three domains throughout the 24-h forecast period, implying that the BFM calculates the wind speeds slightly greater than those of observations. For all three domains, AD values are also between 0 and 1 m/sec. For wind speed forecasts, there are no significant differences among three different model domains. The AD values less than 1 m/sec are well within the weather forecast data criteria used by the U.S. Air Force, which requires that for observed wind speed less than 10 m/sec, AD is to be within 1 m/s, and for observed wind speed greater than 10 m/sec, AD is to be smaller than 2.5 m/sec. [5]

For wind vector forecasts, the RMSVE values for the Colorado model domain shows the greatest values among the three model domains, and those for the Washington model domain show the smallest.

In the comparison and evaluation study of the MM5 and the BFM over the WSMR with unit grid spacing of 3.33 km, the AD values for wind speed are between 2 and 3 m/sec for both MM5 and BFM. In a similar study over the National Training Center area in which BFM was run with unit grid spacing of 2.5 km, the AD values for wind speed were also between 2 and 3 m/sec. For both studies, the AD for wind speed are significantly greater than those for the current three model domains, which were run with unit grid spacing of 10 km. At this time, why the current study shows better results in wind speed forecast than these two studies is unknown. Further examination is needed to find the exact reasons for the differences and a few items to consider that are:

1. model performances in different grid spacing,
2. quality of observed data, and
3. model performances in different seasons. [1,6]

4.3 Comparison of the BFM with NOGAPS and NORAPS

The forecast results of the BFM are compared with those given by the NOGAPS and the NORAPS. For the NOGAPS and the NORAPS, data are given every 1° and 0.5°, respectively, and are interpolated bilinearly to the observation locations.

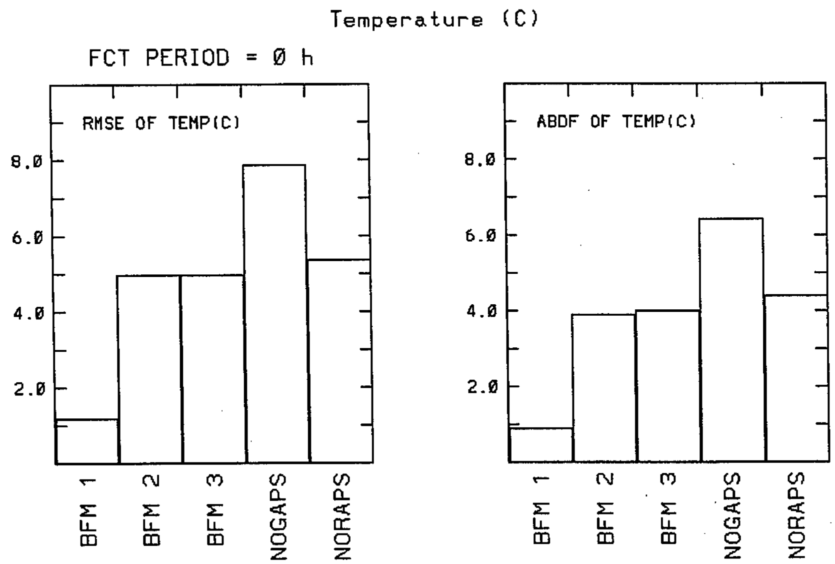
4.3.1 Temperature

Figures 16, 17, and 18 show the comparisons of temperature forecasts for the Colorado, Washington, and Florida model domains, respectively. The values of RMSE and AD are compared in the form of bar diagrams. In these figures, the comparisons for the forecast periods of 0, 6,12, and 24 h are shown in (a), (b), (c), and (d), respectively. The bar diagram at the left-hand side is for the RMSE, and that at the right-hand side is for the AD. In these figures, three BFM forecasts with the different initial conditions (see section 3.2) are shown, marked as BFM1, BFM2, and BFM3.

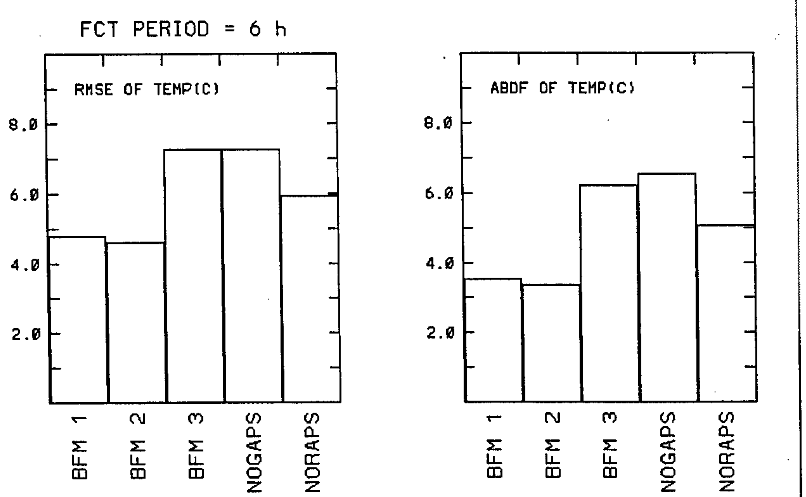
For all the model domains, the initial temperature fields predicted by the BFM are calculated best when the surface observed data are used, but at the forecast period of 6 h, the influences of use of surface temperature disappears. For Colorado and Washington model domains, where the terrain is more complex than Florida, the use of the BFM improves the temperature field forecast. However, for Florida model domain, the temperature fields forecast by the BFM do not significantly improve the comparison statistics over the forecasts by NOGAPS and NORAPS.

4.3.2 Wind Speed and Vector

Figures 19, 20, and 21 are the comparisons of wind speed and vectors, respectively, for the Colorado, Washington, and Florida model domains. In these figures, the RMSE is shown at the left-hand side, the AD at the middle, and the RMSVE at the right-hand side. For the Colorado and Washington model domains, the BFM calculations produced better wind fields than NOGAPS and NORAPS throughout the 24-h forecast period, but for the Florida model domain, the BFM does not improve the statistics over NOGAPS and NORAPS. A recent study by Dumais clearly shows that the ability of BFM to forecast local diurnal winds is largely determined by its horizontal resolution and treatment of the local surface feature data. In the present study, the horizontal grid spacing is 10 km, and constant values for surface albedo and soil heat conductivity are used over the land. Rao et al. for realistic simulation of sea breeze circulation, the horizontal resolutions of ~100 m for terrain elevation, and surface features such as soil type and soil moisture are needed. It is, therefore, suspected that the present forecast calculations by the BFM for the Florida domain had failed to simulate the effects of sea-land breeze circulation. BFM showed better forecast skills for predictions of wind fields over complex terrain than NOGAPS and NORAPS [7,8]



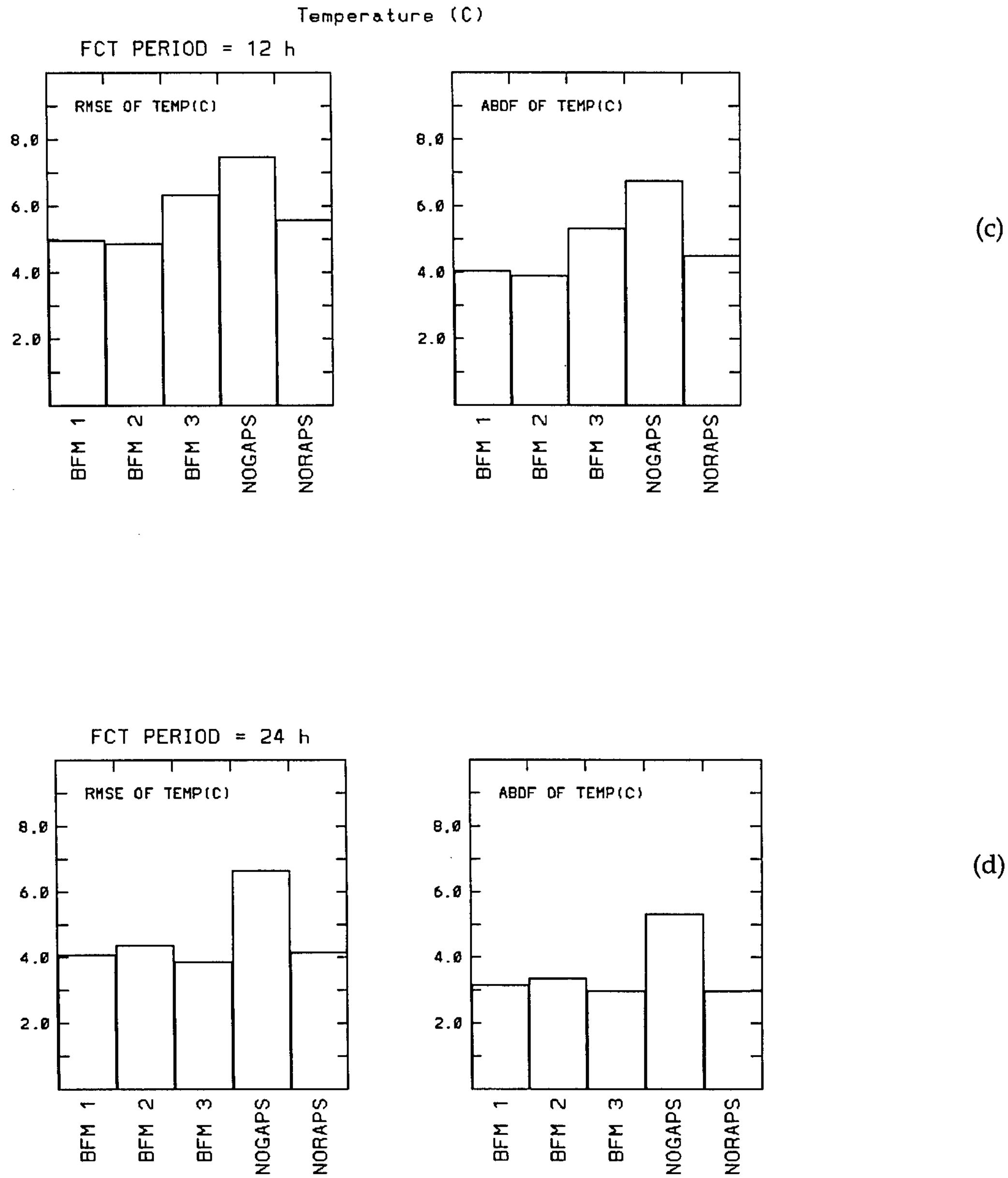
(a)



(b)

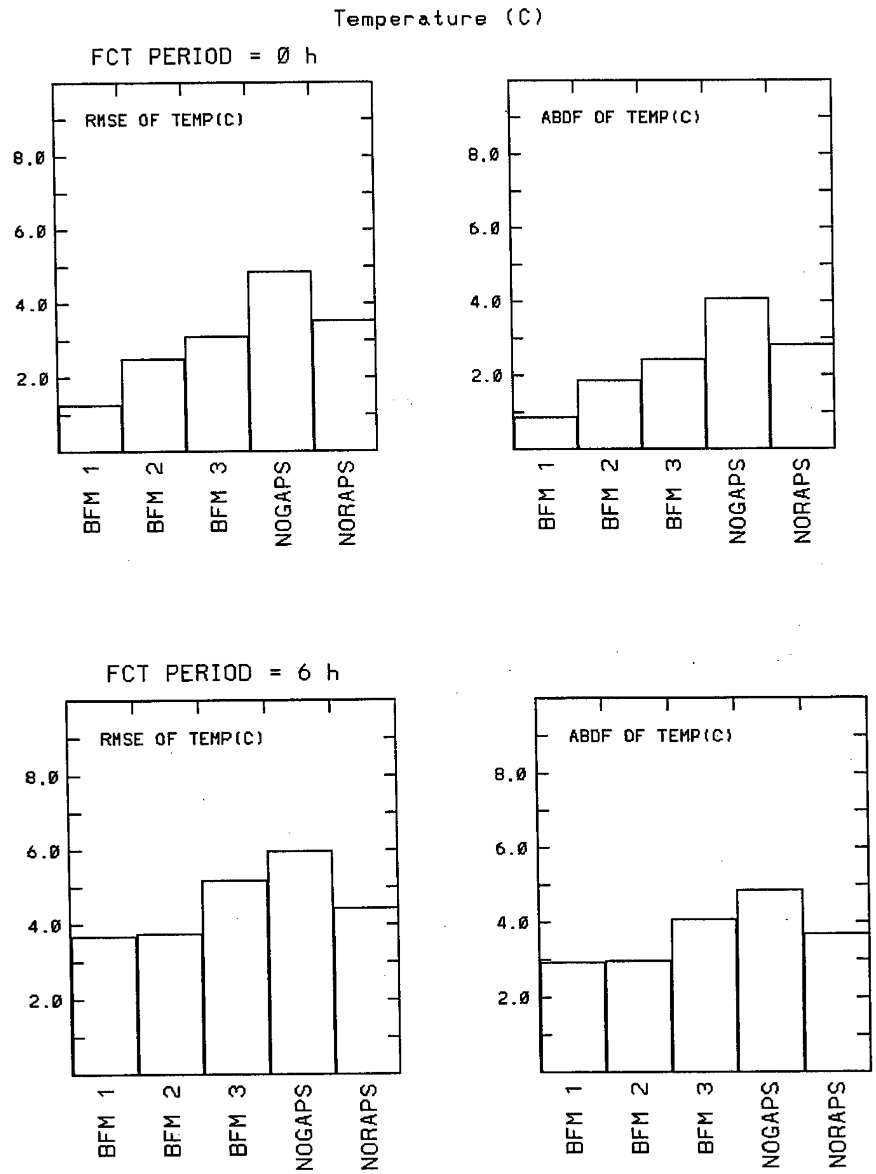
Figures 16(a) and (b). Comparison of BFM temperature forecast performance to NOGAPS and NORAPS, the Colorado model domain.

Note: (a) 0 h, and (b) 6-h forecast period. Left-hand side: RMSE, right-hand side: AD.



Figures 16(c) and (d). Comparison of BFM temperature forecast performance to NOGAPS and NORAPS, the Colorado model domain.

Note: (c) 12 h, and (d) 24-h forecast period. Left-hand side: RMSE, right-hand side: AD.

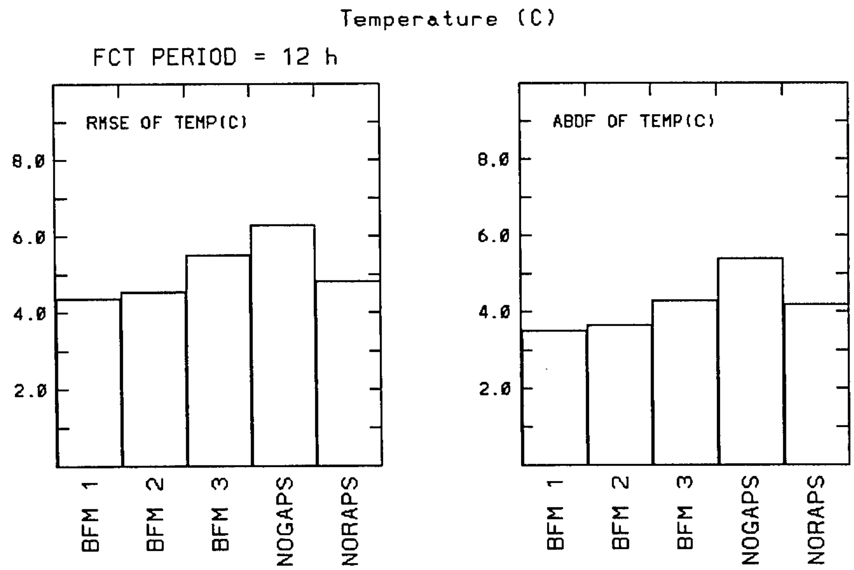


(a)

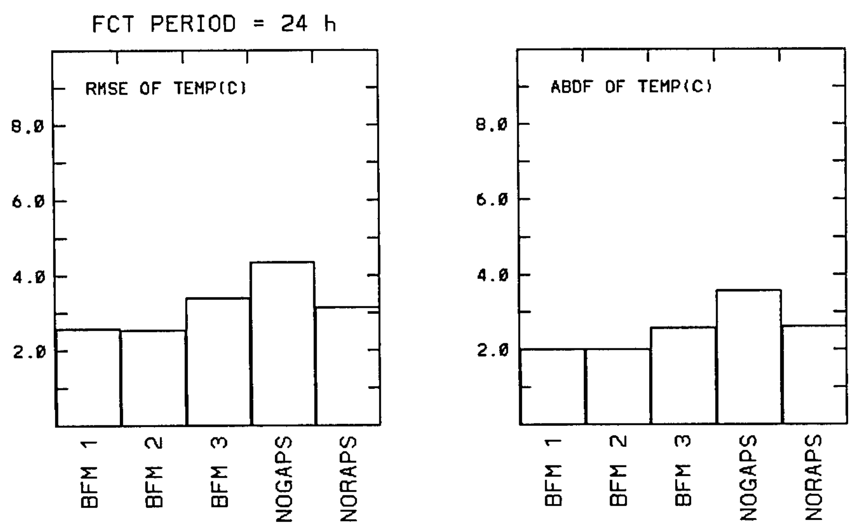
(b)

Figures 17(a) and (b). Comparison of BFM temperature forecast performance to NOGAPS and NORAPS, Washington model domain.

Note: (a) 0 h, and (b) 6-h forecast period. Left-hand side: RMSE, right-hand side: AD.



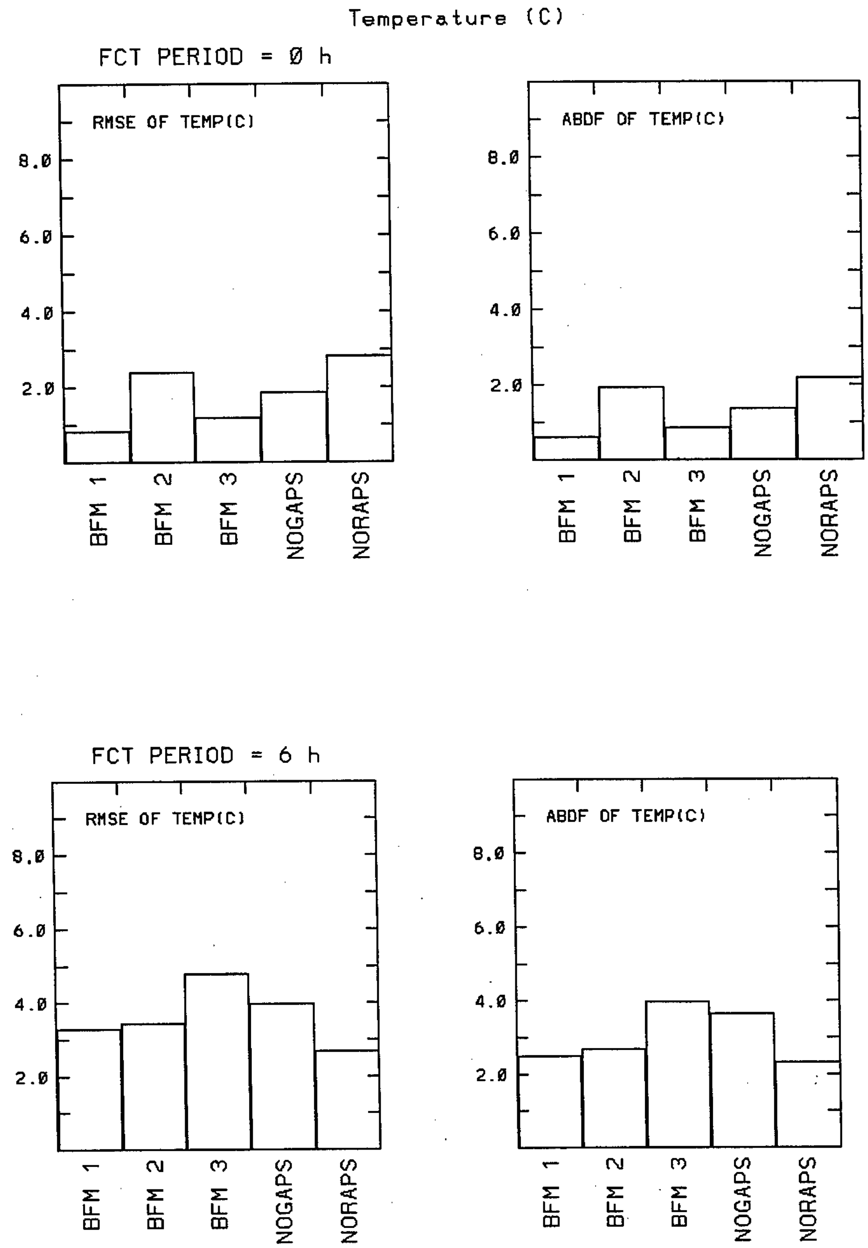
(c)



(d)

Figures 17(c) and (d). Comparison of BFM temperature forecast performance to NOGAPS and NORAPS, Washington model domain.

Note: (c) 12 h, and (d) 24-h forecast period. Left-hand side: RMSE, right-hand side: AD.

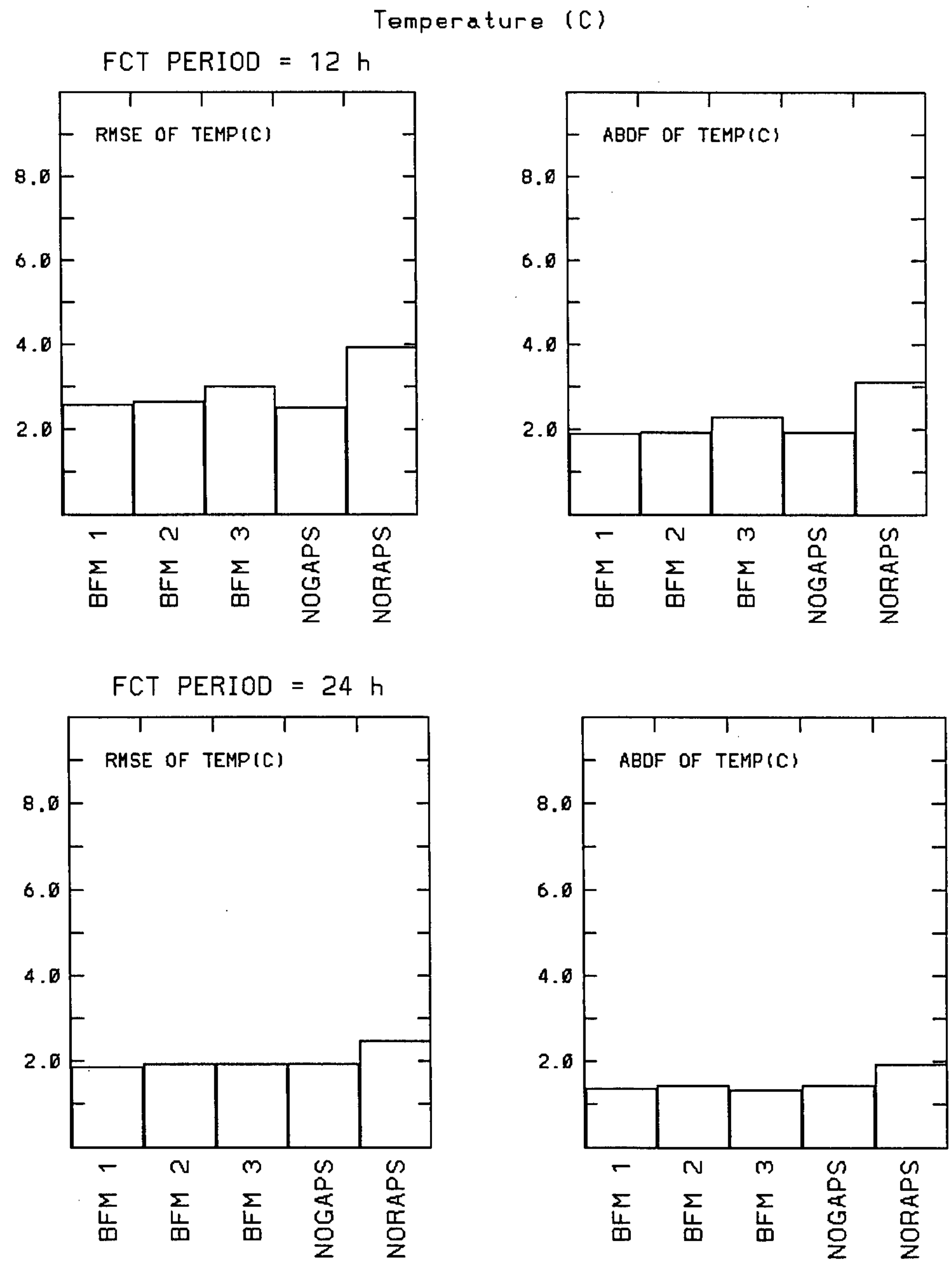


(a)

(b)

Figures 18(a) and (b). Comparison of BFM temperature forecast performance to NOGAPS and NORAPS, Florida model domain.

Note: (a) 0 h, and (b) 6-h forecast period. Left-hand side: RMSE, right-hand side: AD.

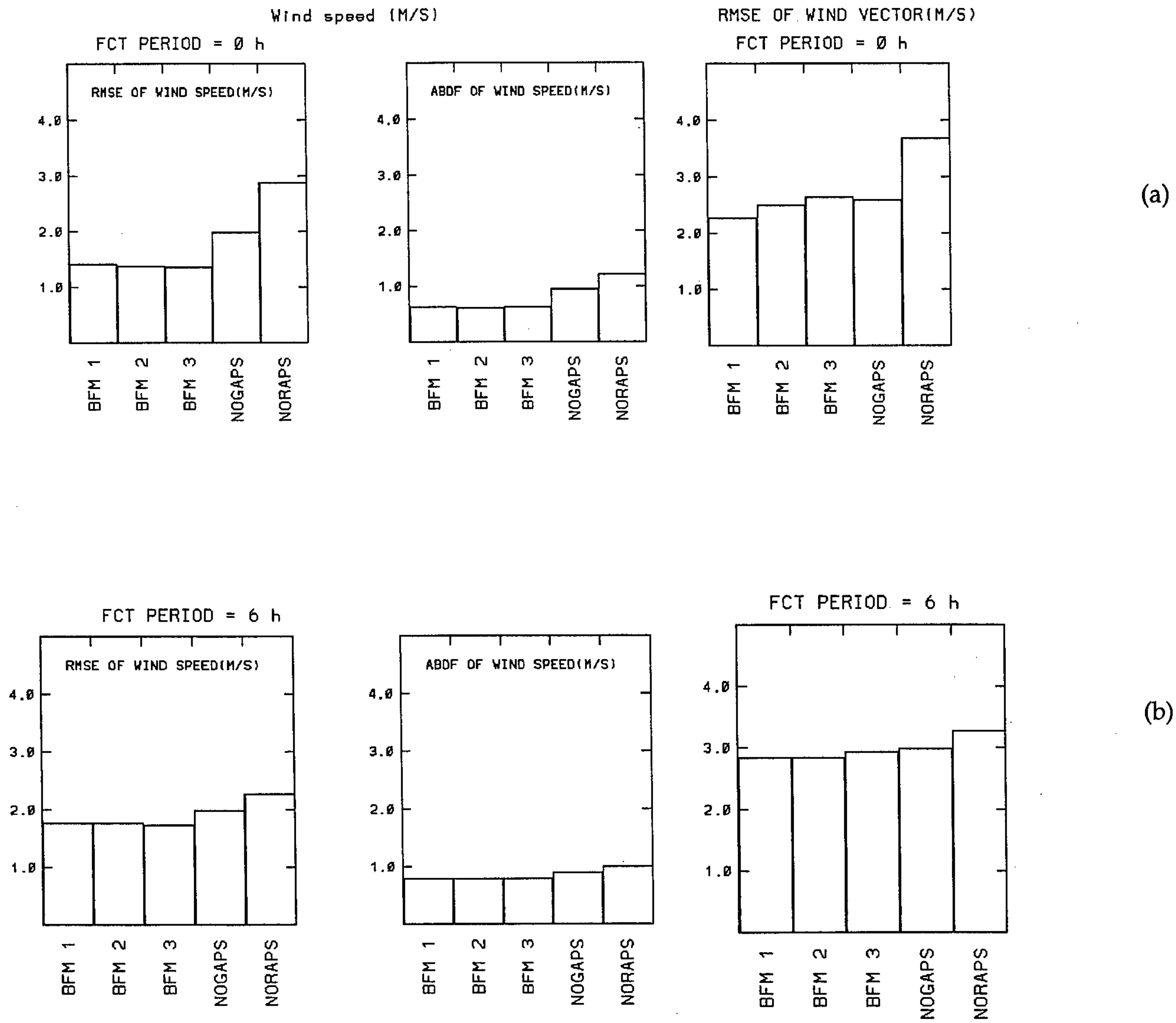


(c)

(d)

Figures 18(c) and (d). Comparison of BFM temperature forecast performance NOGAPS and NORAPS, Florida model domain.

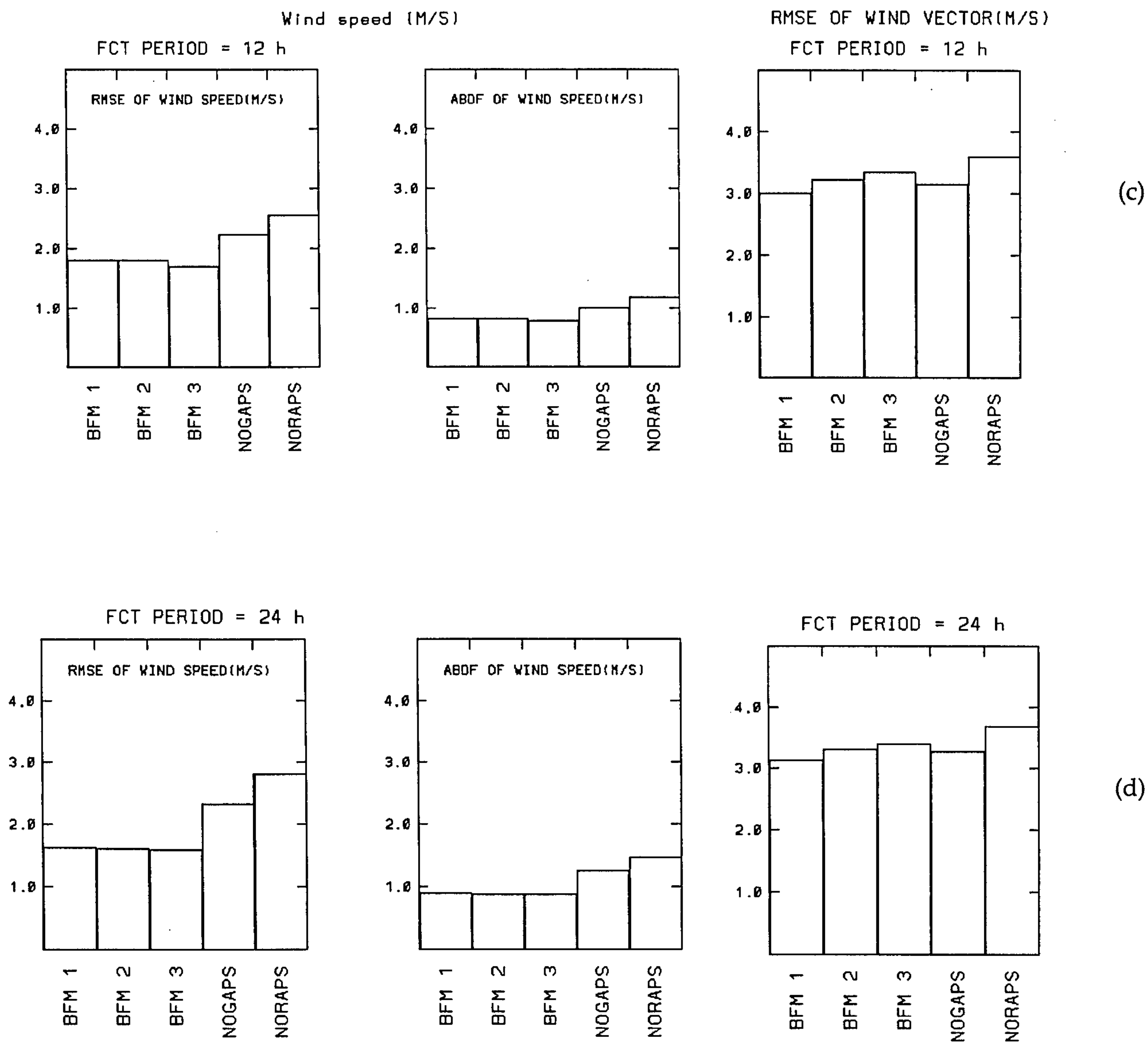
Note: (c) 12 h, and (d) 24-h forecast period. Left-hand side: RMSE, right-hand side: AD



Figures 19(a) and (b). Comparison of BFM performance to NOGAPS and NORAPS, for wind speed and vectors, Colorado model domain.

Note: (a) 0 h, (b) 6-h forecast periods. Left-hand side: RMSE of speed, Center: AD of speed, right-hand side: RMSVE.

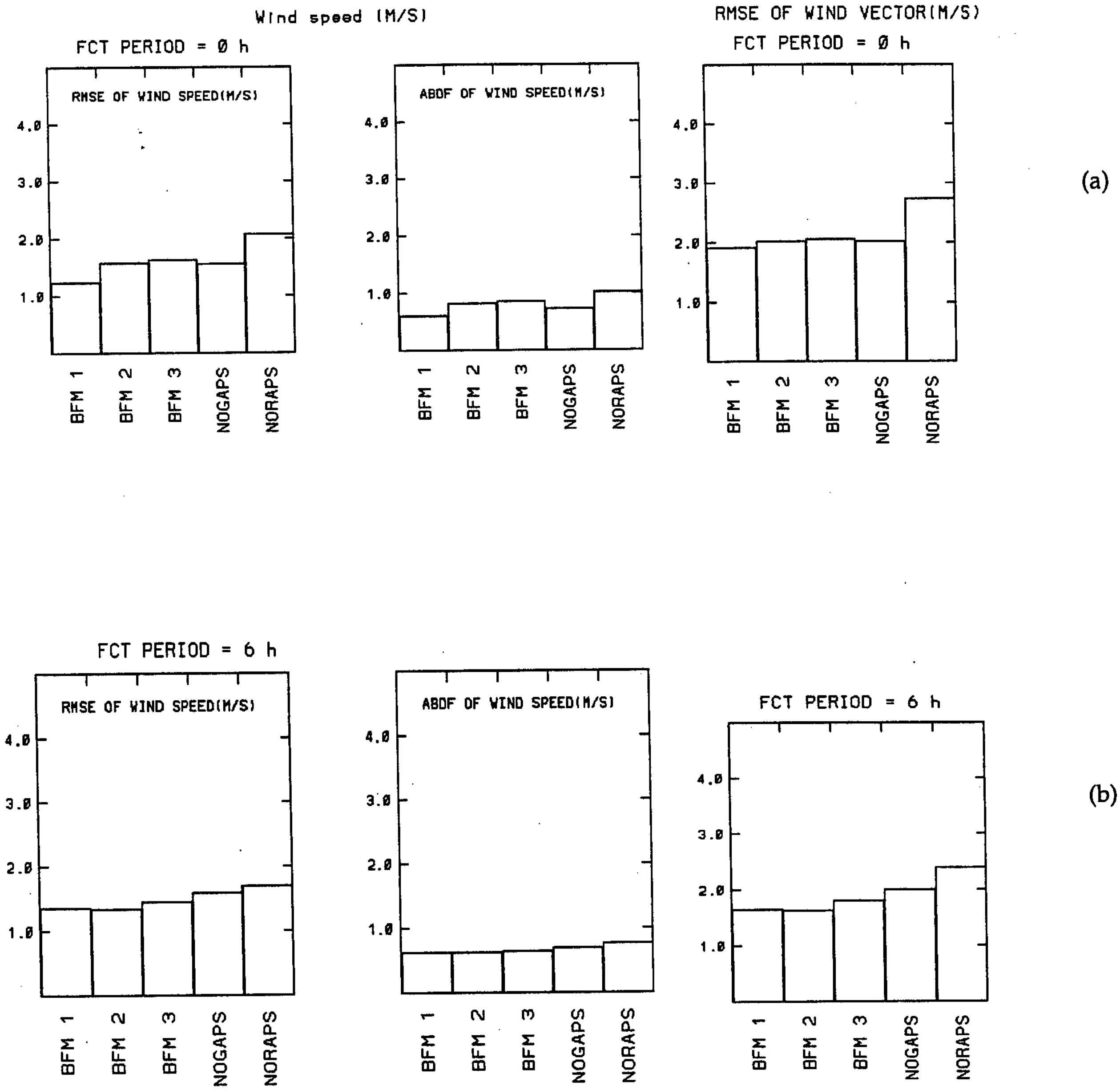
BFM1: initialized with NOGAPS + upper air + surface data,
BFM2: initialized with NOGAPS + upper-air data, and
BFM3: initialized with NOGAPS.



Figures 19(c) and (d). Comparison of BFM performance to NOGAPS and NORAPS, for wind speed and vectors, Colorado model domain.

Note: (c) 12 h, (d) 12-h forecast periods. Left-hand side: RMSE of speed, Center: AD of speed, right-hand side: RMSVE.

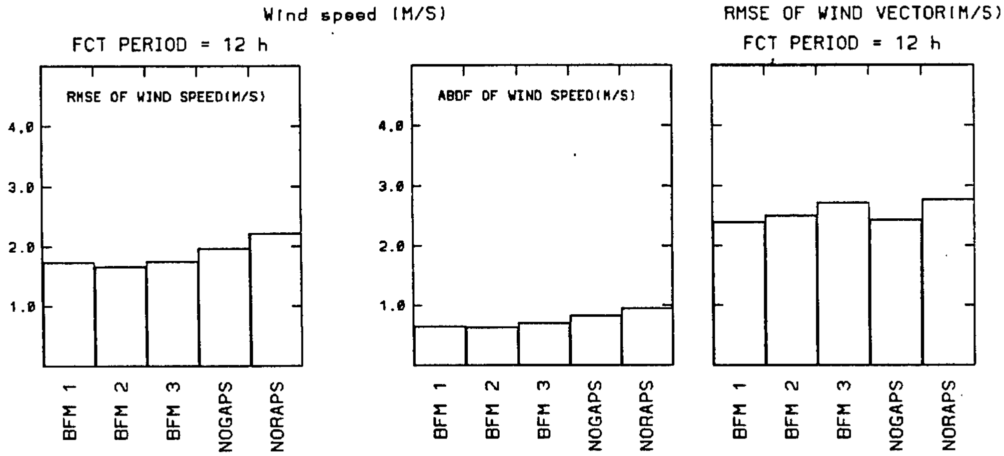
BFM1: initialized with NOGAPS + upper air + surface data,
BFM2: initialized with NOGAPS + upper-air data, and
BFM3: initialized with NOGAPS.



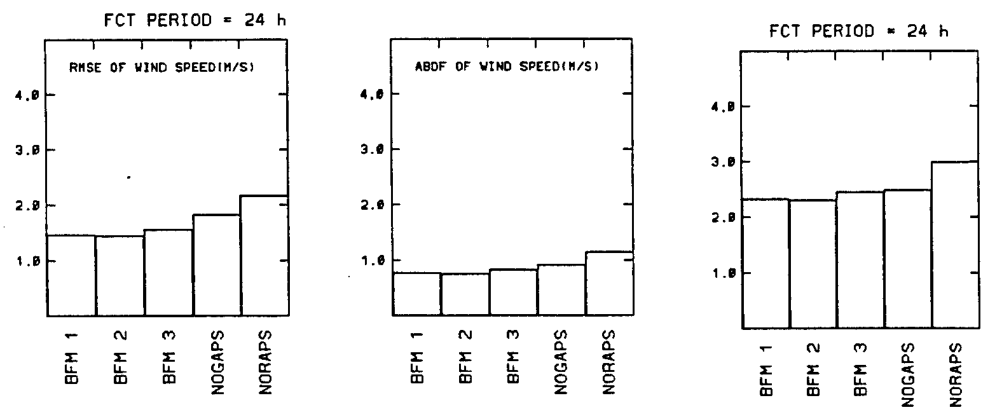
Figures 20(a) and (b). Comparison of BFM performance to NOGAPS and NORAPS for wind speed and vectors for Washington model domain.

Note: (a) 0 h, (b) 6-h forecast periods. Left-hand side: RMSE of speed, Center: AD of speed, right-hand side: RMSVE.

> BFM1: initialized with NOGAPS + upper air + surface data,
> BFM2: initialized with NOGAPS + upper-air data, and
> BFM3: initialized with NOGAPS.



(c)

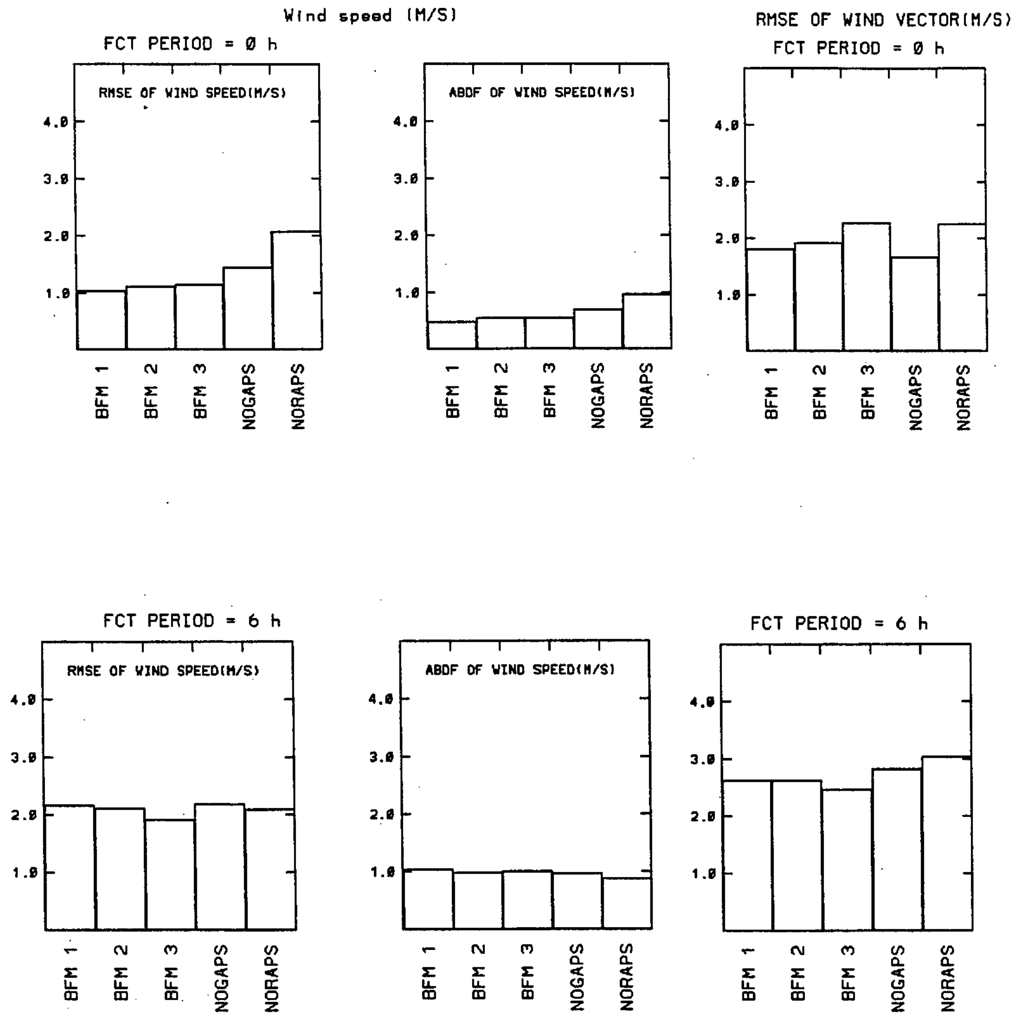


(d)

Figures 20(c) and (d). Comparison of BFM performance to NOGAPS and NORAPS for wind speed and vectors, Washington model domain.

Note: (c) 12 h, (d) 12-h forecast periods. Left-hand side: RMSE of speed, Center: AD of speed, right-hand side: RMSVE.

BFM1: initialized with NOGAPS +upper air + surface data,
BFM2: initialized with NOGAPS + upper-air data, and
BFM3: initialized with NOGAPS.



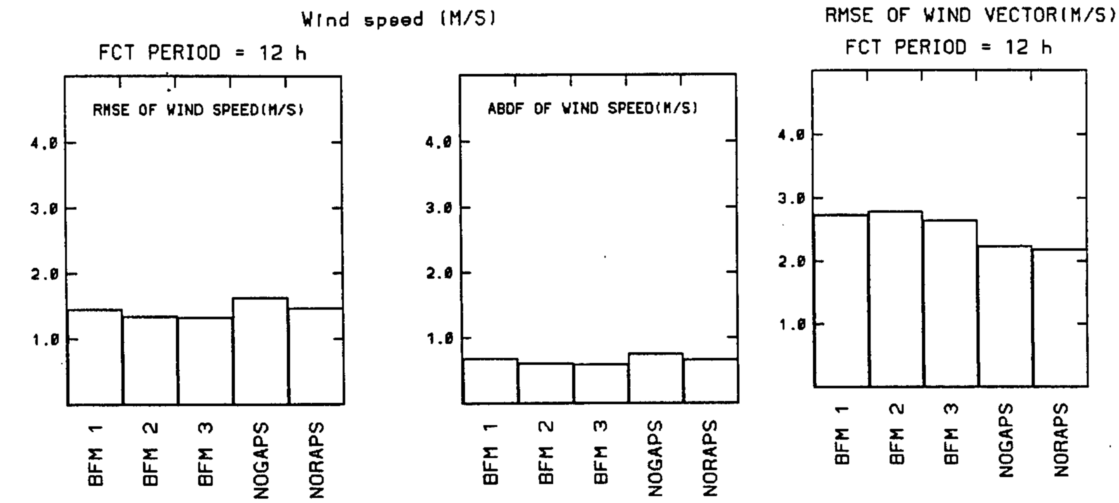
(a)

(b)

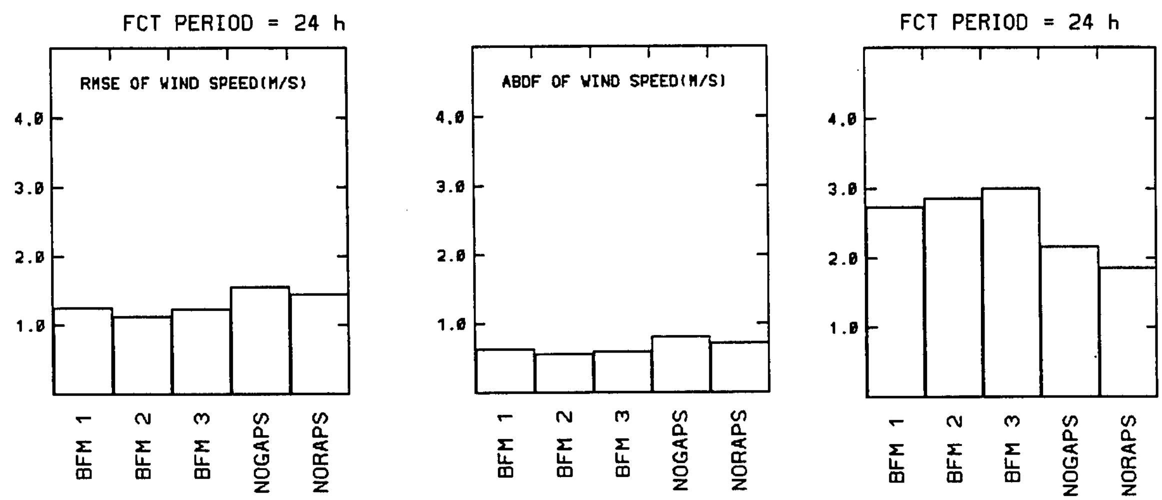
Figures 21(a) and (b). Comparison of BFM performance to NOGAPS and NORAPS for wind speed and vectors, Florida model domain.

Note: (a) 0 h, (b) 6-h forecast periods. Left-hand side: RMSE of speed, Center: AD of speed, right-hand side: RMSVE.

BFM1: initialized with NOGAPS +upper air + surface data,
BFM2: initialized with NOGAPS + upper-air data, and
BFM3: initialized with NOGAPS.



(c)



(d)

Figures 21(c) and (d). Comparison of BFM performance to NOGAPS and NORAPS, wind speed and vectors, Florida model domain.

Note: (c) 12 h, (d) 12-h forecast periods. Left-hand side: RMSE of speed, Center: AD of speed, right-hand side: RMSVE.

BFM1: initialized with NOGAPS +upper air + surface data,
BFM2: initialized with NOGAPS + upper-air data, and
BFM3: initialized with NOGAPS.

5.0 Summary

BFM forecast calculations were made over the different climatological and topographical model domains of Colorado, Washington, and Florida. Forecast calculations were made for a 30-day period from June 23 to July 22, 1998. Three different initial conditions were generated from the combination of:

(1) NOGAPS + upper air + surface observation data,
(2) NOGAPS + upper air, and
(3) NOGAPS only.

1. Scatter diagrams of forecast versus observed data showed the forecast data of temperature, dew point temperature, and wind speed and vector components u and v over the Colorado model domain correlated better with observations than those over Washington and Florida. The reasons why the Florida model domain did not produce better correlations than the other two model domains are not obvious. The Florida domain is much flatter than the Colorado and Washington domains, which implies simpler forecast problem. On the other hand, the Florida domain is surrounded by the sea. In the BFM on the IMETS, the sea surface temperature distribution is provided by the monthly average sea surface temperature data over the globe obtained from the U. S. Air Force Combat Climatological Center in 1994. To improve the temperature and dew point temperature distributions over the model domains surrounded by the sea, the daily sea surface temperature distribution may be needed. In the near future, the earth surface skin temperature by NOGAPS, which provides daily sea surface temperature based on satellite and buoy observations, will be incorporated in the BFM operational on the IMETS system.

2. For all three model domains, the forecast temperature fields initialized with (1) and (2) were statistically better than those initialized with (3). For the Colorado and Florida domains, the model produced surface temperatures lower/higher than observation during daytime/nighttime, indicating the daily amplitudes of temperature predicted by the model were smaller than what actually occurred. For the Washington model domain, no significant bias of temperature was found. The AD values for the 24-h forecast period for all three domains varied between 2° and 3° C for the BFM calculations using the initial conditions of (1) and (2). Forecast data accuracy criteria used by the U.S. Air Force for temperature is 2° C.

Therefore, the BFM produced slightly worse temperature values than those required by the U.S. Air Force criteria. [1]

3. For the Colorado and Washington domains, MD values of dew point temperature were negative during most of 24-h forecast periods. For the Colorado domain, this was more significant when the model was initialized with (1) and (2) in the above than when initialized with (3). The initial fields created by compositing NOGAPS data with upper-air data might have caused this numerical drying. Further studies are needed to find the exact reasons for this shortcoming of the BFM. For the Florida model domain, on the other hand, the values of MD for dew point temperature stayed positive throughout the 24-h period.

4. For wind fields, the three different data initializations combinations did not produce significantly different BFM wind fields throughout the 24-h forecast periods. There was little difference in the values of MD, AD and RMSVE among three different initialization methods for all three model domains. The values of MD for wind speed are between 0 and 1 m/sec, and the values of AD are also between 0 and 1 m/sec for the three model domains throughout 24-h forecast period. For wind vector forecasts, the values of RMSVE for Colorado domain were the greatest among the three model domains, and those for the Washington domains were the smallest.

5. For the Colorado and Washington model domains where the terrain is more complex than Florida, the use of the BFM improves temperature field forecast over those of NOGAPS and NORAPS. For the Florida model domain, there was not significant improvement in the temperature field forecast by the BFM over those of NOGAPS and NORAPS.

6. BFM calculations produced better wind fields than NOGAPS and NORAPS throughout the 24-h forecast periods for the Colorado and Washington model domains, but the BFM for the Florida domain, did not produce improved wind fields over those by NOGAPS and NORAPS. For the Florida domain, horizontal grid resolution of 10 km might have been too coarse to simulate sea and land breeze circulation.

Although the present study has shown some limitations of the BFM, the BFM is a valuable and useful tool for the short-range weather forecast over complex terrains when used with initial and time-dependent lateral values provided by a global scale forecast model such as NOGAPS and other available meteorological data.

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Acronyms

AD	absolute difference
ARL	U.S. Army Research Laboratory
BFM	Battlescale Forecast Model
CAAM	Computer Assisted Artillery Meteorology
HOTMAC	Higher Order Turbulence Model for Atmospheric Circulation
IMETS	Integrated Meteorological System
MD	mean difference
MEL	Master Environmental Library
NOGAPS	Navy Operational Global Atmospheric Prediction System
NORAPS	Navy Operational Regional Atmospheric Prediction System
RMSE	root mean square error
RMSVE	root mean square vector error
WSMR	White Sands Missile Range
MM5	Fifth-Generation National Center for Atmospheric Research/ Penn State Mesoscale Model

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ARMY RESEARCH LABORATORY AMSRL CI E COMP & INFO SCI DIR WSMR NM 88002-5501	1
DTIC 8725 JOHN J KINGMAN RD STE 0944 FT BELVOIR VA 22060-6218	1
US ARMY MISSILE CMND AMSMI REDSTONE ARSENAL AL 35898-5243	1
US ARMY DUGWAY PROVING GRD STEDP3 DUGWAY UT 84022-5000	1
USTRADOC ATCD FA FT MONROE VA 23651-5170	1
WSMR TECH LIBRARY BR STEWS IM IT WSMR NM 88002	1
US ARMY RESEARCH LAB AMSRL D DR D SMITH 2800 POWDER MILL RD ADELPHI MD 20783-1197	1
US ARMY CECOM INFORMATION & INTELLIGENCE WARFARE DIRECTORATE ATTN AMSEL RD IW IP FORT MONMOUTH NJ 07703-5211	1
ARMY RESEARCH LABORATORY AMSRL CI EW ATTN MR HEMNI COMP & INFO SCIENCES DIR WSMR NM 88002-5501	1
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TOTAL	58