Verification of Taiwan-Area AOAWS MM5 Forecasts

James F. Bresch and Hui-Chuan Lin
National Center for Atmospheric Research
Boulder, CO, USA

Abstract

For the past five years, the Taiwan Civil Aeronautics Administration has been running high-resolution numerical weather forecasts using the Penn State / NCAR mesoscale model (MM5) as part of its Advanced Operational Aviation Weather System (AOAWS). MM5 is run 8 times daily in cooperation with the Central Weather Bureau to support aviation weather forecast needs. In this study, an objective verification of the forecasts is made using conventional sounding and surface observations. The verification results may be used by forecasters to interpret and improve forecasts based on the AOAWS MM5. The results can also serve as a benchmark with which to compare modifications or enhancements to the AOAWS modeling system.

Key word: Taiwan, numerical weather prediction, MM5, verification

1. Introduction

The Advanced Operational Aviation Weather System (AOAWS) of Taiwan's Civil Aeronautics Administration (CAA) includes as a major component high-resolution numerical weather forecasts. The forecasts are produced by the Penn State/NCAR Mesoscale Model Version 5 (MM5, Grell et al., 1994). MM5 is run 8 times per day on the Central Weather Bureau's (CWB) Fujitsu VPP5000 supercomputer. The forecasts are made available to aviation weather forecasters and pilots on dedicated display workstations as well as web-based products.

While MM5 was configured to produce the best possible forecasts over the Taiwan region, no systematic quantitative verification of the forecasts has been done. In this study we will compare AOAWS MM5 forecasts with conventional sounding and surface observations. The goals of this verification are to 1) obtain a quantitative estimate of model performance, 2) determine if there are any systematic biases which the forecasters may take into account, and 3) determine if forecasts initialized between the synoptic times (0 and 12 UTC) have more skill than those initialized at older, synoptic times. In addition, forecasts from the Central Weather Bureau's Nonhydrostatic Forecast System (NFS) are also analyzed with the verification system to provide a benchmark comparison with the MM5 forecasts.

2. Methodology

The AOAWS MM5 consists of 4 nested domains with grid spacing of 135, 45, 15, and 5 km as shown in Figure 1. At the standard synoptic times (00 and 12 UTC) MM5 is initialized using the CWB Global Model (CWBGM) as a first guess field. At the other initial times (3, 6, 9, 15, 18, and 21 UTC) MM5 is initialized with the previous 3-hour MM5 forecast. The CWBGM provides the lateral boundary conditions for the outermost domain for all runs. MM5 3DVAR is run on domains 1, 2, and 3 for each initial time. The observations are obtained from the CWBGM Optimum Interpolation system. These observations are also used for the verification after the removal of large errors.

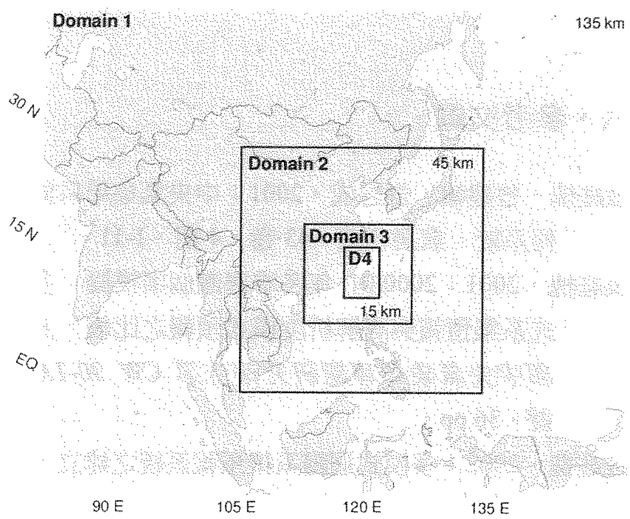

Figure 1. MM5 domains used in AOAWS.

Model verification is performed by first interpolating MM5 output from sigma levels to pressure levels and then horizontally interpolating to the observation locations. Databases are created consisting of time series of observations and model output. These databases are then combined into one database of model and observation pairs. In addition to the standard variables on the mandatory levels (temperature, dewpoint, geopotential height, and U and V wind components), sounding diagnostics are also computed. These diagnostics include tropopause height, low-level inversion height, level of maximum wind, CAPE, and CIN. Finally, a plotting and analysis program computes biases, mean absolute errors (MAE), and root-mean-square errors (RMSE). User-selectable plots are then created and are easily displayed over the world-wide-web.

Statistics are computed for the 15 km domains of both the MM5 and NFS. Twenty-seven sounding sites are verified along with 13 surface stations. So far, verification has been done for February, April, and June 2005. Additional periods will also be verified and it is planned that in the future, the verification will be run in real-time. Experience with the verification of MM5 forecasts over the United States performed at NCAR has shown that a one-month verification period is sufficient to reveal model biases.

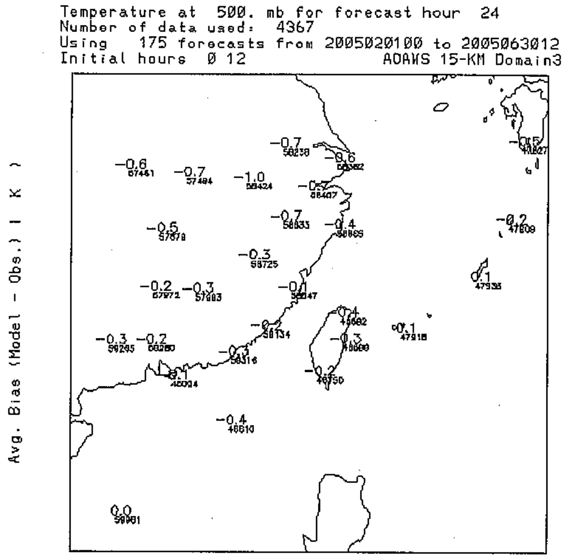

Figure 2. Average 500 hPa temperature bias (degrees K) for a 24-h MM5 forecast on AOAWS domain 3.

3. Results

Figure 2 shows the 24-h forecast 500 hPa temperature biases over the 15-km MM5 domain for the 27 verification sounding sites during February, April, and June 2005. A slight cold bias (< 1 deg K) is found at most stations with the largest values in the northwest part of the domain. The temperature bias as a function of height average over all stations is shown in Figure 3. The biases are less than 1 degree at all levels with near zero bias at initial time. MM5 exhibits its typical cold bias at 300 hPa and below with the 24-h forecast slightly colder than the 12-h forecasts. The mean absolute error (MAE) of temperature as a function of height is shown in Figure 4. Largest errors are at 925 hPa and decrease slightly up to 500 hPa. MAE is less than 1.7 K at all levels. RMS errors (which tend to emphasize the largest errors) are similar to MAE, but are about 0.5 K larger at all levels (not shown).

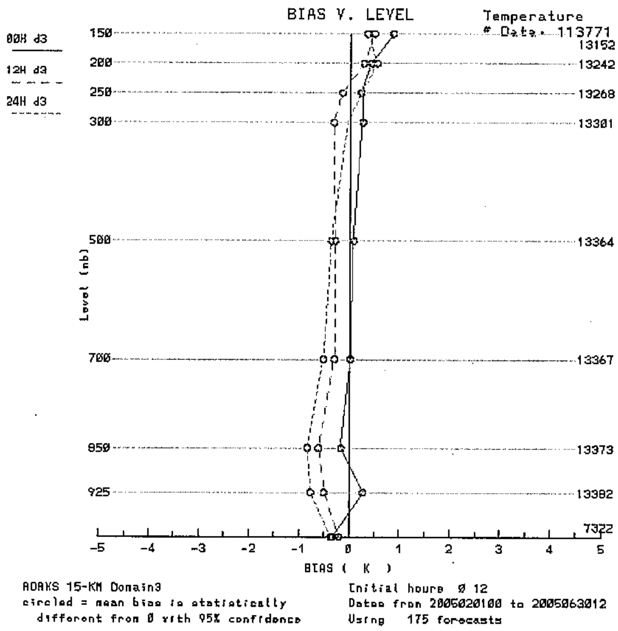

Figure 3. Temperature bias (deg K) as a function of pressure for all stations in domain 3. The number of data points for each level are shown on the right side of the figure. The circles represent biases statistically different than zero.

Wind speed bias as a function of height is shown in Figure 5. At initial time, MM5 has a slight negative bias at all levels below 300 hPa. For the 12- and 24-h forecasts, MM5 shows a positive bias of 1 to 1.5 m/s in the boundary layer (1000 and 925 hPa) decreasing with height to a minimum at 700 hPa. At typical aircraft cruising altitudes (from 500 to 250 hPa) MM5 exhibits near zero bias. The wind speed MAE is shown in Figure 5. At initial time, MAE is around 1.5 m/s at all levels. The MAE increases with forecast duration having values around 3 m/s in the lower troposphere, increasing to about 5 m/s at jet stream level. Error values are similar for both the U and V components (not shown).

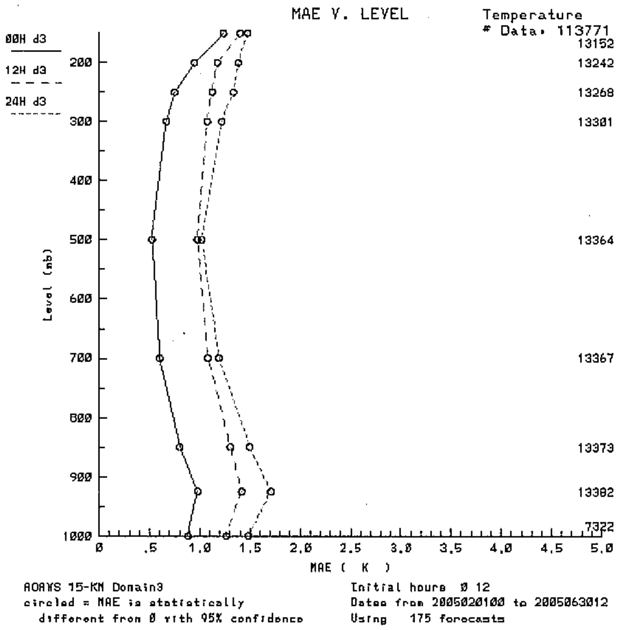

Figure 4. Mean Absolute Error as a function of pressure for temperature (deg K).

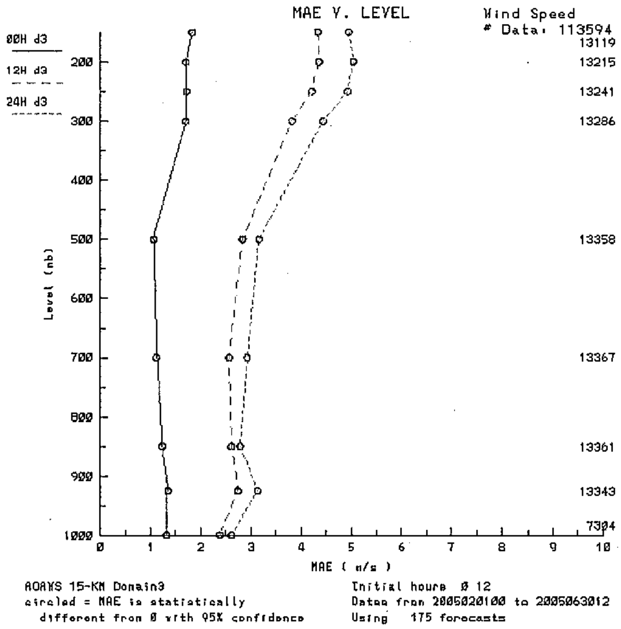

Figure 6. Mean Absolute Error as a function of pressure for wind speed (m/s).

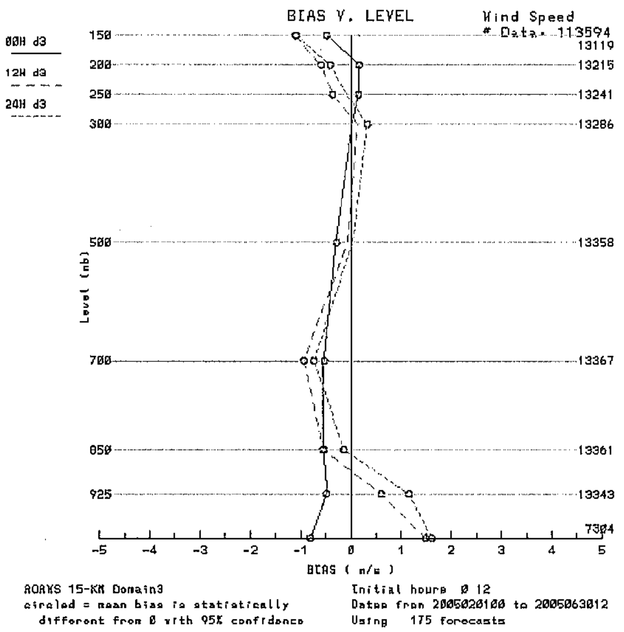

Figure 5. As in Fig. 3, but for wind speed (m/s)

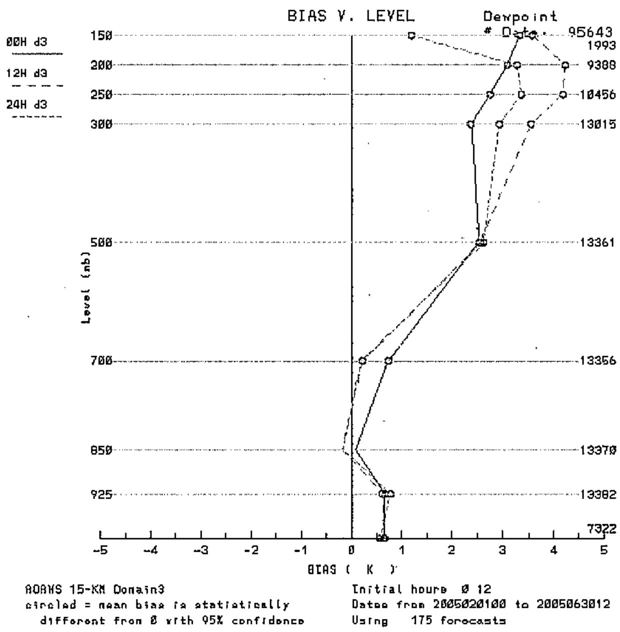

Figure 7. As in Fig. 3, but for dewpoint (deg K).

Dewpoint bias as a function of height is shown in Figure 7. MM5 exhibits a positive bias at all levels except for 850 hPa. The biases at initial time are almost as large as during the forecast. Largest biases (4 degrees K) are found at cirrus level.

The temperature bias as a function of height from NFS forecasts for the same 3-month period as the MM5 results is shown in Figure 8. The NFS shows a warm bias in the boundary layer (1000 and 925 hPa) with a cold bias from 850 to 250 hPa. Biases are slightly larger for the NFS compared to MM5, but are less than 1 degree K.

The NFS wind speed bias is shown in Figure 9. Values are less than 1 m/s at most levels and, like MM5, near zero bias at aircraft cruising altitudes. In general, the model biases and errors for the MM5 and NFS 15 km forecasts are very similar with MM5 having slightly less bias and errors for all variables except wind.

While combined error statistics provide an indication of overall model performance, it is also helpful to look at errors for individual stations. The temperature biases for Panchiao (46692) are shown in Figure 10. Here, MM5 has a stronger cold bias than in the overall domain with the 12-h forecast colder than the 24-h forecast. The temperature MAE is also larger at 12-h than at 24-h for most levels (not shown). The dewpoint bias (not shown) is also cold, in contrast to the positive bias in the overall domain. Also, the Panchiao dewpoint is consistently missing above 300 hPa. Wind speed bias for 46692 is shown in Figure 11. MM5 shows a positive bias at 500 hPa and above which is again in contrast to the overall domain average bias.

Verification results also show that the wind quality from stations 46750 and 46810 is often poor. For example, the wind speed bias for station 46750 during February is shown in Figure 12. At 300 hPa and above there is a large (25 m/s) positive bias. This bias is caused by observed wind speeds that are too low when compared to the expected gradient flow and the winds reported by Hualien and Panchiao. The time series of 300 hPa wind speed bias shown in Figure 13 suggest that as the westerlies decreased during the spring, the apparent bias also decreased.

4. Summary

A verification of AOAWS forecasts was performed for three months during 2005. MM5 forecasts on a 15-km grid were verified using conventional sounding data. Also, forecasts from CWB's NFS 15-km model were verified. It was found that, on average, both models performed well with MM5 slightly better than the NFS for most variables except wind speed. MM5 exhibited a cold temperature bias and a warm dewpoint bias as has been found in other studies. While the overall average results were good, results from individual sounding sites sometimes showed large errors. Results from station 46750 indicate problems with the observations, while at 46692, forecast errors were different than the domain mean.

Future work includes expanding the verification to all seasons, and eventually running the forecasts verification system verify in real-time so that forecasters can have access to the latest statistics. It is also planned to verify precipitation forecasts. These results will then provide a benchmark with which to compare future modeling system enhancements including a switch to the WRF model.

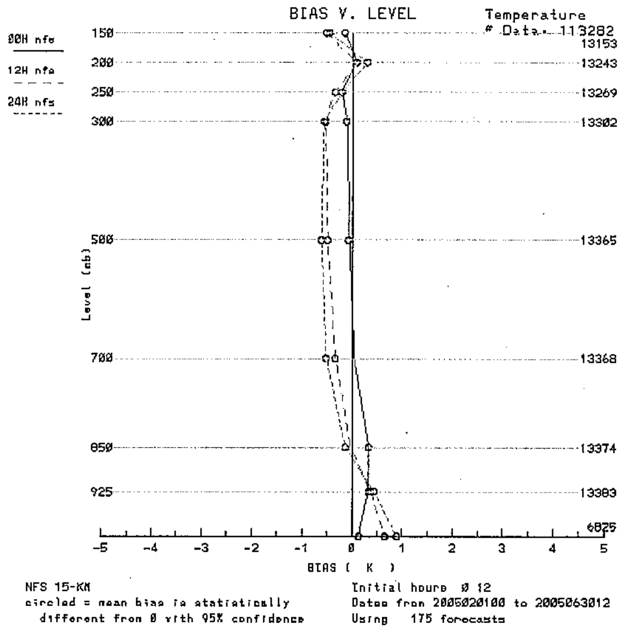

Figure 8. As in Fig. 3, but for the NFS 15-km forecasts.

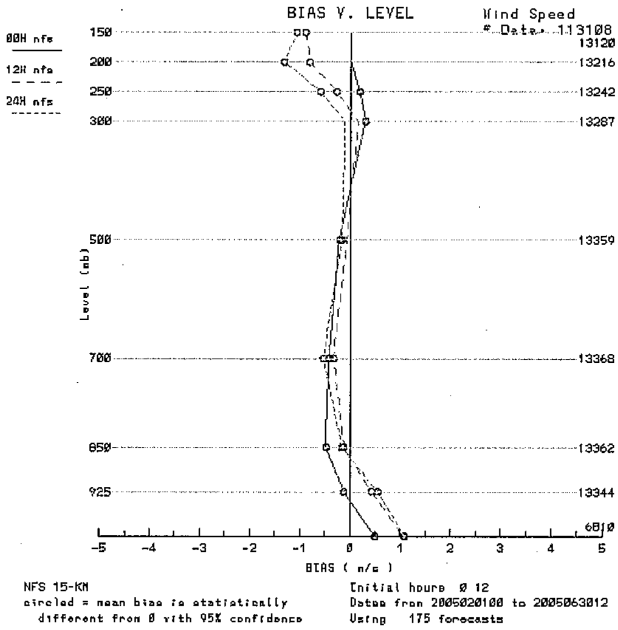

Figure 9. As in Fig. 8, but for wind speed (m/s).

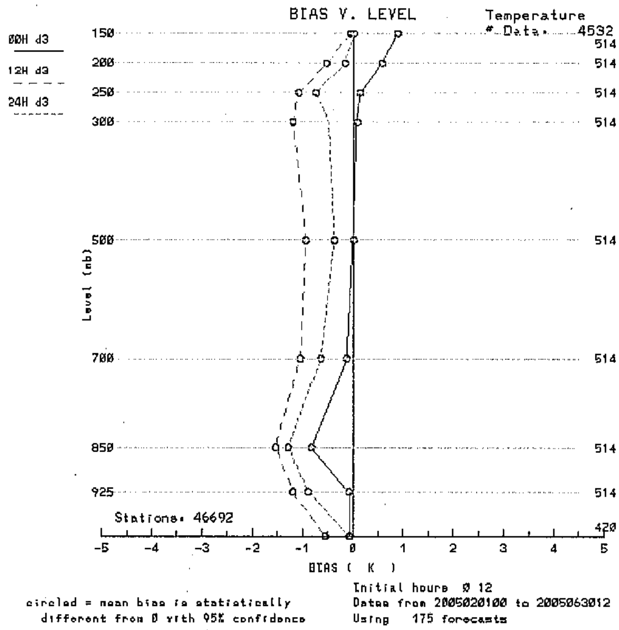

Figure 10. As in Fig. 3, but for MM5 forecasts at station 46692.

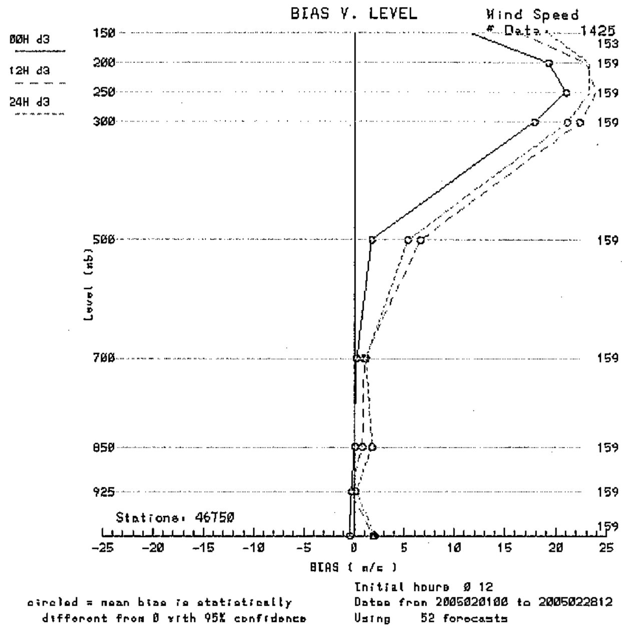

Figure 12. As in Fig 11, but for station 46750.

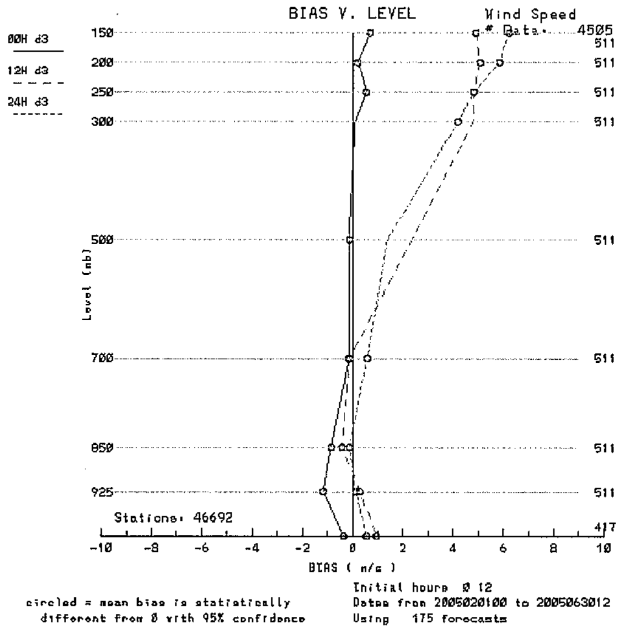

Figure 11. As in Fig 9, but for wind speed (m/s).

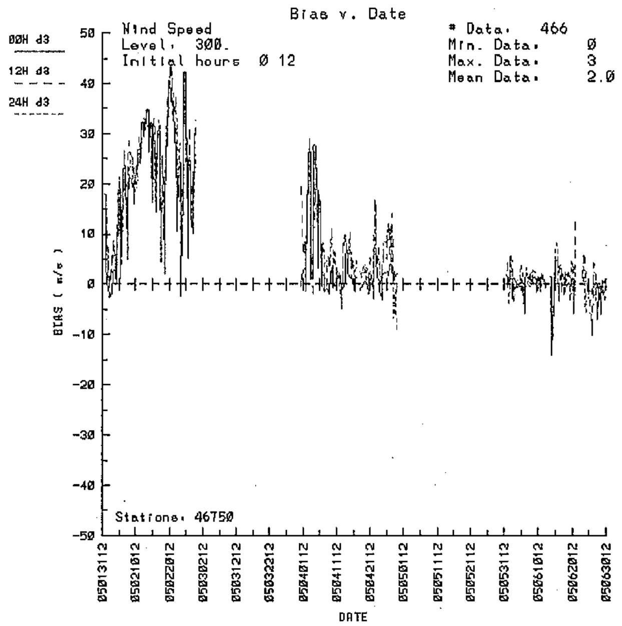

Figure 13. Time series of the 300 hPa wind speed bias (m/s) for station 46750.

Acknowledgements.

Portions of this work were funded by the Civil Aeronautics Administration of Taiwan and the Central Weather Bureau. We thank Michael Duda for valuable contributions to the verification system.

References

Grell, G. A., J. Dudhia and D. R. Stauffer, 1994: A description of the fifth-generation Penn State / NCAR mesoscale model (MM5). NCAR Tech. Note, NCAR/TN-398+STR, National Center for Atmospheric Research, Boulder, CO, 138 pp.