1 of 1

LA-UR-94- 94-0229

Conf-931251--1

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36.

TITLE: PERFORMANCE OF A NEW WIND UPDATING SYSTEM FOR A PROGNOSTIC METEOROLOGICAL MODEL IN THE ENVIRONS OF MEXICO CITY

AUTHOR(S): Michael D. Williams

SUBMITTED TO: IMP, MEXICO CITY, MEXICO, DECEMBER, 1993

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

By acceptance of this article, the publisher recognized that the U S Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution or to allow others to do so for U S Government purposes.

The Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U S Department of Energy.

Los Alamos

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

FORM NO. 836 R4
ST. NO. 2629 5/81

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Performance of a New Wind Updating System for a Prognostic Meteorological Model in the Environs of Mexico City

Michael D. Williams
Los Alamos National Laboratory
Group A-4
Mail Stop B299
Los Alamos, NM 87545

INTRODUCTION

Los Alamos National Laboratory and Instituto Mexicano del Petroleo are completing a joint study of options for improving air quality in Mexico City. The US Department of Energy supported the efforts of the Los Alamos investigators, while PEMEX supported the efforts of the Mexican researchers. One of the first steps in the process was to develop an understanding of the existing air quality situation. In this context we have modified a three-dimensional, prognostic, higher order turbulence model for atmospheric circulation (HOTMAC) to treat domains which include an urbanized area. This sophisticated meteorological model is required because of the complexity of the terrain and the relative paucity of meteorological data. Mexico City lies at an elevation of approximately 7500 feet above sea level in a "U" shaped basin which opens to the north. The city occupies a major part of the southwest portion of the basin. Upper level winds are provided by rawinsondes at the airport, while low-level winds are measured at several sites within the city. Many of the sites have obstructed upwind fetches for a variety of directions. During the wintertime when the worst air quality episodes occur, the winds are frequently light, and out of the northeast at lower levels, while above 1000 meters above the surface they are usually from the southwest. This means the winds are light within the city, but significant slope winds develop which influence the behavior of the pollutants.

Frequently, the winds in the basin change as a seabreeze penetrates the basin from the northeast. The seabreeze produces a much different wind regime after its arrival in the late afternoon or early evening. This makes it important to update the winds in a realistic fashion.

THE METEOROLOGICAL MODEL HOTMAC

Model Description

HOTMAC is a three-dimensional time-dependent model (Yamada,1981,Mellor and Yamada, 1982, Yamada, 1985). It uses the hydrostatic approximation and a terrain following coordinate system. HOTMAC solves conservation relations for the horizontal wind components, potential temperature, moisture, turbulent kinetic energy, and the turbulence length scale. HOTMAC describes advection, Coriolis effects, turbulent transfer of heat, momentum, and moisture. It also describes solar and terrestrial radiation effects, turbulent history effects, and the drag and radiation effects of forest canopies. The lower boundary conditions are defined by a surface energy balance and similarity theory. The soil heat flux is obtained by solving a heat conduction equation in the soil which ignores lateral heat transfer. In an urban context the surface energy balance requires an additional term which represents the heat released by man's activities. The additional heat, along

with differences in thermal and albedo properties between urban and non-urban surfaces, produces the urban heat island.

At the start of this project, HOTMAC used two major sets of inputs: (1) topography and (2) a single vertical profile of winds, temperatures, and relative humidity. The topography consisted of terrain heights at half grid intervals over the domain and indices that showed which computational cells were covered with water and which had trees. In the case of trees, the fraction of the area of the cell which was covered by trees was also required. In the instance of cells covered by water, the ground temperature is fixed and the air at the surface is saturated.

The meteorological profile is used to describe the synoptic (large-scale) conditions of winds, temperatures, and moisture. The model is initialized with the potential temperature assumed to be the same in every location for any given height above mean sea level. Potential temperature is the temperature of a parcel of air adiabatically compressed to sea-level pressure. On the lateral boundaries the winds, moisture, and temperatures are the result of solving a one-dimensional form of the model in which parameters vary only in the vertical direction. The placement of the boundaries is normally chosen so that all the major terrain influences on the region of interest are included within the computational grid.

Mesoscale models are designed for circumstances in which the local terrain influences are significant and make the meteorology more predictable than might otherwise be the case. The top boundary of the model is fixed at a constant height above sea-level and is a no flow boundary. The model uses a vertical grid which is linear for a specified number of cells, but then increases parabolically to the top. The horizontal grid is staggered so that the east-west and north-south wind components are calculated at points that are off-set one-half grid in the corresponding directions. The model uses the alternating-direction implicit differencing technique which provides high accuracy and stability. The model uses a nested grid system so that areas of importance can be treated in much greater detail. In the current version, the innermost grid is one third the scale of the next larger grid. The computational time is dominated by the requirements of the innermost grid so that the outer grids require little computational time.

Model Development

Early in this project, three days, representing poor, good, and normal air quality were chosen for detailed modeling. All of the days were in the winter of 1987-88.

Meteorological inputs were based on the afternoon rawinsonde of the preceding days which was used to estimate synoptic scale wind and temperature profiles. We used a nested grid system to model the valley of Mexico and its surrounding terrain. The outer grid has a 6 km spacing and covers the major terrain influences as shown in Figure 1. The inner grid is shown enclosed in the rectangle of Figure 1; it embraces the city and the immediately adjacent slopes. The individual characters plotted on the Figure are monitoring sites operated by the Mexican Urban Development and Ecology Secretariat. The symbol "Y" for instance represents the hangares station at the airport, while "X" represents at station in the downtown area. The higher terrain to the north of the city in the inner grid is Pico de Tres Padres. The high volcanoes are in the southeast corner of the outer grid. The inner grid has a resolution of 2 km.

The original version of HOTMAC developed the large scale winds from the winds used to initialize the model. Essentially, a single wind speed and direction aloft are used to produce the effects of varying large scale pressure systems. In order to have a wind shear above the lowest levels, the model allows the user to specify two wind levels. The result of the coding is to add additional factors in the conservation equations for the two horizontal components so that the winds are nudged toward the desired winds at the specified levels. The first alteration for time-varying winds was to permit the input winds aloft to be variable with time. The winds nudged to at any given hour would be interpolated in time between the input values at the two nearest times for which measured winds were available.

This approach, however, suffers from two deficiencies: (1) the low-level driving winds are not changed unless the specified levels are quite low and (2) the differences between the measured wind and the large-scale wind are not considered. The lack of low-level wind changes was solved by nudging the lowest level winds to the average wind for the lowest 500 meters of the atmosphere. The measured wind normally reflects both the large scale wind and the local influences of topography and surface features.

The procedure to adjust for the difference between the local and large scale wind was based on using the model to estimate the local wind in the lowest 500 meters. Essentially two model runs are made. In the first run average upper level conditions are used and the low level winds are nudged to very low values to represent no large scale forcing. Typically this model run is for one and a half days with one-half day to spin the model up and one day to provide hourly local wind estimates. The local winds are then subtracted from the

measured winds and the nudging is done to the difference in the full simulations. This procedure permits the model to reproduce the measurements and make good estimates for other points. It also shows good performance over many days without reinitializing the model.

COMPARISON WITH MEASUREMENTS

Model Application

Measurements are very important to provide model inputs and to help understand the limitations and performance of the models. For the meteorological model there were six types of measurements which were available to provide insight into the model's performance. The measurements are: (1) surface station winds, (2) Rawinsonde profiles, (3) tethersonde profiles, (4) aircraft meteorological profiles, and (5) aircraft elevated winds. It is important to realize that the model and the measurements are not necessarily attempting to represent the same item. For example, the surface winds are measured at a single site and represent one hour scalar averages of the wind direction and wind speed. At the same time, the model provides one hour ensemble mean vector averages of the wind over a 2 kilometer by 2 kilometer grid with a vertical depth appropriate to the grid cell. The model takes the ground level as the street level and includes the buildings as the above ground canopy. The measurement sites are usually chosen to be in more open areas, but they may be influenced by nearby buildings or trees.

There were two periods in which detailed comparisons were made with a variety of measurements. The first period was February 21 through February 22, 1991 which was a period with a good scope of measurements and was also a period in which high ozone concentrations occurred in the southwest portion of the city on February 22. This period represents a classical pollution episode. The second period is from February 25 through February 28, 1991. There were fewer measurements available during this period, and the highest ozone occurred in the downtown region on February 28.

During the first period, the simulations were begun with information from the late afternoon and early evening rawinsonde measurements at the airport. In the Mexico City work, the data were available at increments of about 75 meters in height. About 7 rawinsondes were made each day. During both periods, the upper level winds at 2000 and 3000 meters above the surface were based on the rawinsonde measurements.

During the first period, the low-level winds were obtained by averaging the winds between 250 meters and 750 meters from the tethersonde which was made at the polytechnic site.

The tethersonde measurements were made with a tethered balloon. Wind speeds, wind directions, pressure, and wet bulb and dry bulb temperature were measured at each height. Typically, the cable is slowly reeled out, a measurement made and the cable is released to make a new measurement. The tethersonde spends a short time at each height and it takes most of an hour to cover the atmosphere up to the maximum height. In contrast the rawinsonde takes a much shorter time to traverse the same height and produces data at much larger intervals. The model requires an ensemble mean wind and thus the tethersonde provides a better approximation of the required input. For the second period where relatively few tethersonde profiles were available the rawinsonde profiles were used.

The model begins with the temperature being horizontally uniform; this situation is best approximated by an afternoon situation in which the atmosphere is well-mixed. Normally, the profile taken about 5 p.m. at the start of the simulation was used. The temperature and relative humidity profiles were used to define an approximate profile which was used.

Comparison to surface station winds

The model produces volume averaged, ensemble mean vector winds. These winds are interpolated between grid cells to the monitoring locations. The measurements, which were provided by SEDESOL, represent scalar averaged wind speeds and directions. In the scalar averaging of the directions the previous wind direction is considered. For example, if the wind were from 350 degrees one minute and 5 degrees the next; 360 degrees would be added to the 5 degrees to make 365 degrees for averaging purposes. In addition to the averaging techniques, stations may have local influences which would be too fine scale for the model.

There are two kinds of displays which were developed to help understand the model performance: (1) hourly plots in which the model wind vectors are shown along with the measured winds and station locations, and (2) daily time profile plots in which either the wind direction or the wind speed is shown in comparison to the measurements.

In both cases the terrain is also shown as well as the locations of the sites. Figures 2 through 5 show hourly comparisons for the morning, afternoon, morning transition and evening for February 25. The symbol Y represents the hangers station of the SEDESOL network, which is located at the airport. The mountains in the upper central area are Pico de Tres Padres which are north of the city center. The arrows at regular intervals show the modeled wind speeds and directions while the arrows near the letters show the measured

wind speeds and directions. The modeled values are for 26 meters in the terrain following coordinate system which corresponds to about 40 meters above the ground. This height was chosen because it is the first height above the highest point of the canopy for which calculations were made.

The 7 a.m. slope winds as evidenced by stations U and T which are closest to the mountains are well represented. Station B is not well represented, but it generally seems to show anomalous behavior. The city stations such as X and Y show a somewhat different behavior which is not what might be expected because of the likely local effects. There is also some suggestion in the data that there is more wind convergence over the city than the model shows, as seen by winds from the west on the west side of the city and winds from the east on the east side of the city. The transition to upslope flows occurs at about 10 a.m. and the model is showing a less developed transition than are the measurements. At 2 p.m., Figure 4 shows the afternoon flows with fully developed slope winds. At 6 p.m., winds out of the west dominate the flow fields and there is fair agreement between the model and the measurements. This wind is likely the result of a coupled see-breeze and valley breeze from the Gulf of Mexico. Model simulations with RAMS model and a large enough domain to include both oceans predict the occurrence of these winds. These four Figures demonstrate the variety of wind conditions which can occur in the valley. They also show that the model does a reasonably good job of representing the major features.

Figure 6 shows the time profiles of wind directions at all sites on February 25, while Figure 7 shows the time profile of wind speeds at all sites on February 25. In Figure 6, the entire model domain is shown so that the two dark areas on the lower right hand side are the two 17,000 ft plus volcanoes, the central splotch is Pico de Tres Padres, while the Y is the airport. The model shows good behavior for stations U and T, although there are some large fluctuations in the measurements which may be the result of afternoon clouds which are not represented in the model.

The wind speeds shown in Figure 7 underestimate the increase in the late morning and afternoon winds. Part of this difference may be related to the difference between vector averaged winds and scalar averaged speeds. For an extreme example, suppose that the wind for one minute was from the north at 2 meters per second and then it shifted to the south for the next minute. The vector averaged wind for the two minutes would be zero while the scalar averaged winds would be 2 meters per second. Actual experiments as

reported by Dr. Hector G. Riveros R. of the Instituto de Fisica at UNAM show that the scalar averages can be much greater than the vector averages during circumstances where the mean winds are light and the turbulent fluctuations are large. From an air transport point of view the vector average is the more relevant because the critical question is how long does the same air mass remain near the source and experience increased concentrations.

Figures 8 through 10 show the comparisons between measured and modeled wind direction profiles for February 26 through February 28 respectively. While Figures 11 through 13 show the comparisons for wind speeds. The simulations show relatively good agreement despite the fact that the winds were driven with rawinsondes and the fact that the simulation extends for a relatively long period. The wind speed comparisons show a similar behavior to that found on February 25.

Comparison to Rawinsonde Measurements

Figures 14 through 18 report the comparison between the winds speeds and directions reported by the rawinsondes and the model representation. The model only uses the average of the rawinsonde winds over the lowest 500 meters and the rawinsonde winds at 2000 meters and 3000 meters. The model generally does a reasonable job of representing the rawinsondes although there are several instances in which the model gives lower wind speeds. The technique of using averaged wind components over the lower 500 meters would tend to give lower wind speeds. An example of this performance is found on Figure 14 for the set at 8 am on the 25th. The winds vary from 90 degrees to 340 degrees in the lowest 500 meters and the model under predicts winds speeds by almost a factor of two.

There is one feature of the wind speed measurements which the model does not replicate. In Figure 15 the hours of 11, 14, and 17 on the 26th all show high wind speeds near the surface at times when the atmosphere should be well mixed. These winds probably represent either a very local effect or, perhaps the balloon launching is at a slightly different point than that assumed. In Figure 11 we note that the model exhibited a better agreement with measurements of wind speeds than on most other days, so that the failure to predict high near surface winds as shown by the rawinsonde measurements did not adversely affect the overall model performance.

Some of the worst model performance occurs late in the afternoon of the 27th as shown in Figure 12. Figure 17 sheds some light on this problem. The rawinsonde wind profile at

hour 17 on the 27th shows that the measured winds are much higher at lower levels. Since the model uses only the lowest 500 meters and the 2000 and 3000 meter winds, it has no information on the higher winds between 500 meters and 1000 meters. Consequently it gives lower wind speeds than it should.

Performance Summary

Researchers (Tesche et al., 1990) funded by the California Air Resources Board, have suggested procedures for evaluating the performance of photochemical models. They suggested many graphical outputs and a suite of statistical measures. Included among the statistical measures are: (1) model means, (2) mean observation, (3) standard deviation of model estimates, (4) standard deviation of observations, (5) least squares regression statistics, (6) root means square error (7) systematic root means square error (8) unsystematic root mean square error (9) index of agreement,(10) skill error, and (11) skill variance Many of these terms are well understood, but some may require explanation. Specifically the regression is of the form:

$$\hat{\emptyset}_{pi} = a + b\,\emptyset_{oi}$$

so that the predictions, $\hat{\emptyset}_{pi}$ are regressed against the observations, $\emptyset_{oi}$ with intercept a and regression coefficient b. The systematic root mean square error is then defined as:

$$RMSE_s = \left[\frac{1}{N}\sum_{i=1}^{N}|\hat{\emptyset}_{pi} - \emptyset_{oi}|^2\right]^{\frac{1}{2}}$$

while the unsystematic root mean square is:

$$RMSE_u = \left[\frac{1}{N}\sum_{i=1}^{N}|\hat{\emptyset}_{pi} - \emptyset_{pi}|^2\right]^{\frac{1}{2}}$$

The index of agreement is given by:

$$I = 1 - \left[\frac{N\,(RMSE)^2}{\sum_{i=1}^{N}(|P'_i| + |O'_i|)^2}\right]$$

with $P'_i = \emptyset_{pi} - \bar{\emptyset}_o$, and $\emptyset'_i = \emptyset_{oi} - \bar{\emptyset}_o$. The range of I is from 0 to 1 with 1 representing perfect agreement. The skill error is given by:

$$SE = \frac{RMSE_u}{\sigma_o}$$

while the skill variance is given by:

$$SV = \frac{\sigma_p}{\sigma_o}$$

The computation of these statistical parameters is straight forward for the wind speeds and mixing layer heights, but wind directions pose a more difficult problem. Because of the difficulty with circular data, techniques developed by Mardia (Mardia, 1972) were used to calculate a regression relationship which is analogous to the standard regression on a line.

Table I summarizes the statistics for wind speeds at the monitoring stations for six days:

Wind Speed Statistics	
Model mean	2.4
Observation mean	4.8
Standard deviation of predictions	1.2
Standard deviation of observations	3.0
Regression intercept	1.8
Regression coefficient	0.14
Correlation coefficient	0.32
Root mean square error	3.7
Systematic root mean square error	3.5
Unsystematic root mean square error	1.2
Index of agreement	0.49
Skill error	0.40
Skill variance	0.42

Note that the bulk of the disagreement is represented by the systematic error.

Table II summarizes the statistics for wind directions at the monitoring stations for six days:

Wind Direction Statistics	
Model mean	161.
Observation mean	203.
Standard deviation of predictions	74.
Standard deviation of observations	94.
Regression intercept	79.
Regression coefficient	.42
Correlation coefficient	xx

Root mean square error	87
Systematic root mean square error	80.
Unsystematic root mean square error	72.
Index of agreement	0.73
Skill error	0.96
Skill variance	0.79

The correlation coefficient is not shown, since it is not calculated for circular data. Generally the model captures the major meteorological features; the winds respond well to major changes in forcing winds. The slope winds develop appropriately and couple well with the large scale conditions. There are some areas, however, which could be improved. For instance, the model does not have quite as much convergence over the city as it should, and it also looks as though the temperatures do not drop as much at night as they should. The wind speeds seem to be a little low. The light wind speeds could be a function of the way layer averaged winds are used as input, or they may reflect the fact that the model is currently not using some of the information from the soundings in the range from 750 meters to 2000 meters above ground. In a layer where winds are turning with heights averaging over 250-750 meters, the wind speeds may actually be artificially reduced.

Generally, the model is able to incorporate the changing winds and produce good simulations of the winds. There are areas which could stand further improvement such as the use of averaged winds which probably tends to produce lower wind speeds than are measured.

CONCLUSIONS

A new wind updating system has been developed and applied to air quality studies in the Mexico City region. The model takes into account the local winds and makes the appropriate adjustment to provide a good representation of the changes in the winds over time. The modeling system could probably be further improved by using representative wind speeds in the lower 500 meters rather than speeds derived from vector averages over the lowest 500 meters.

REFERENCES

Yamada, T., 1985, ``Numerical Simulation of the Night 2 Data of the 1980 ASCOT Experiments in the California Geysers Area," Archives for Meteorology, Geophysics, and Bioclimatology, Ser. A34, pp 223-247.

Yamada, T., 1981,``A Numerical Simulation of Nocturnal Drainage Flow," J. Meteor. Soc., Japan, vol. 59, pp 108-122.

Mellor, G. I. and T. Yamada, 1982, ``Development of a Turbulence Closure Model for Geophysical Fluid Problems," Rev.Geophys. Space Phys., vol. 20, pp 851-875 .

Tesche, T.W., P. Georgopoulus, J.H. Seinfeld, G. Cass, F. L. Lurmann, P.M. Roth, 1990, "Improvement of Procedures for Evaluating Photochemical Models", final report contract No. A832-103, prepared for the California Air Resources Board, Radian Corporation, DCN:90-264-069-05-02.

Mardia, K.V.,1972, "Statistics of Directional Data", Academic Press Inc., Orlando, Florida, pp 127-128.

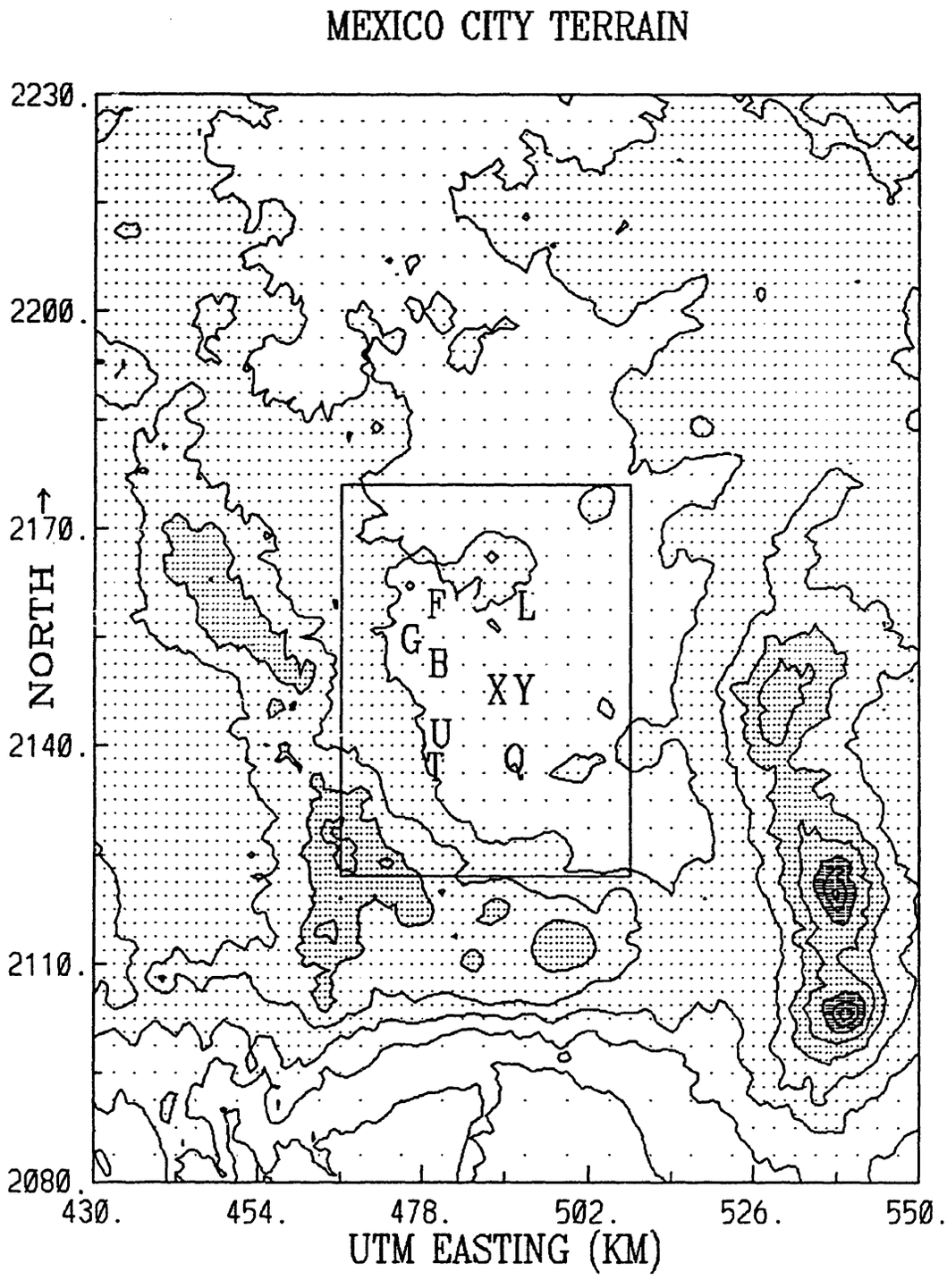

Figure 1. Meteorological model domains for the Mexico City simulations. Inner grid is enclosed by the box in the center.

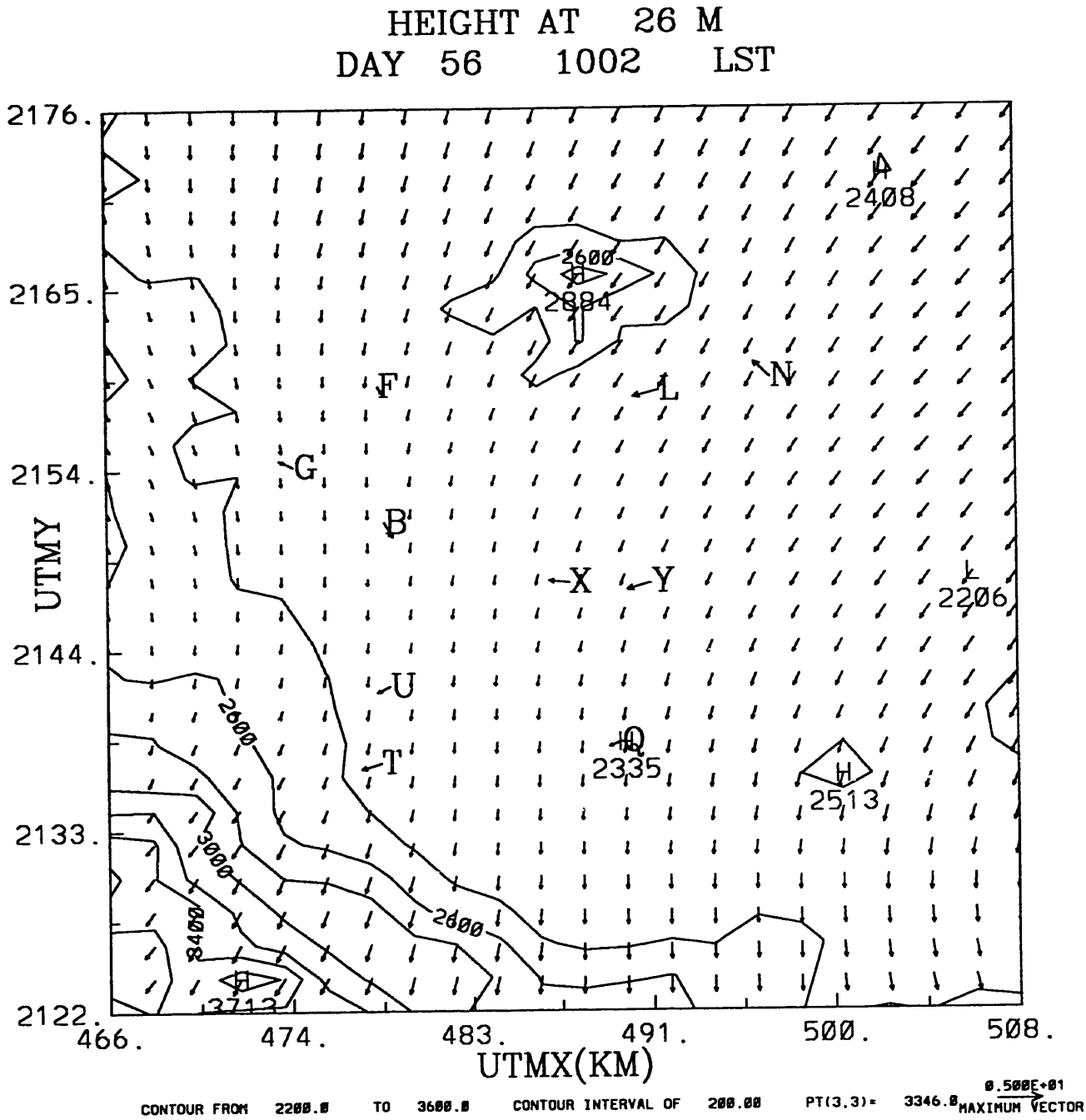

Figure 3. Measured and modeled winds at 10 am on February 25, 1991.

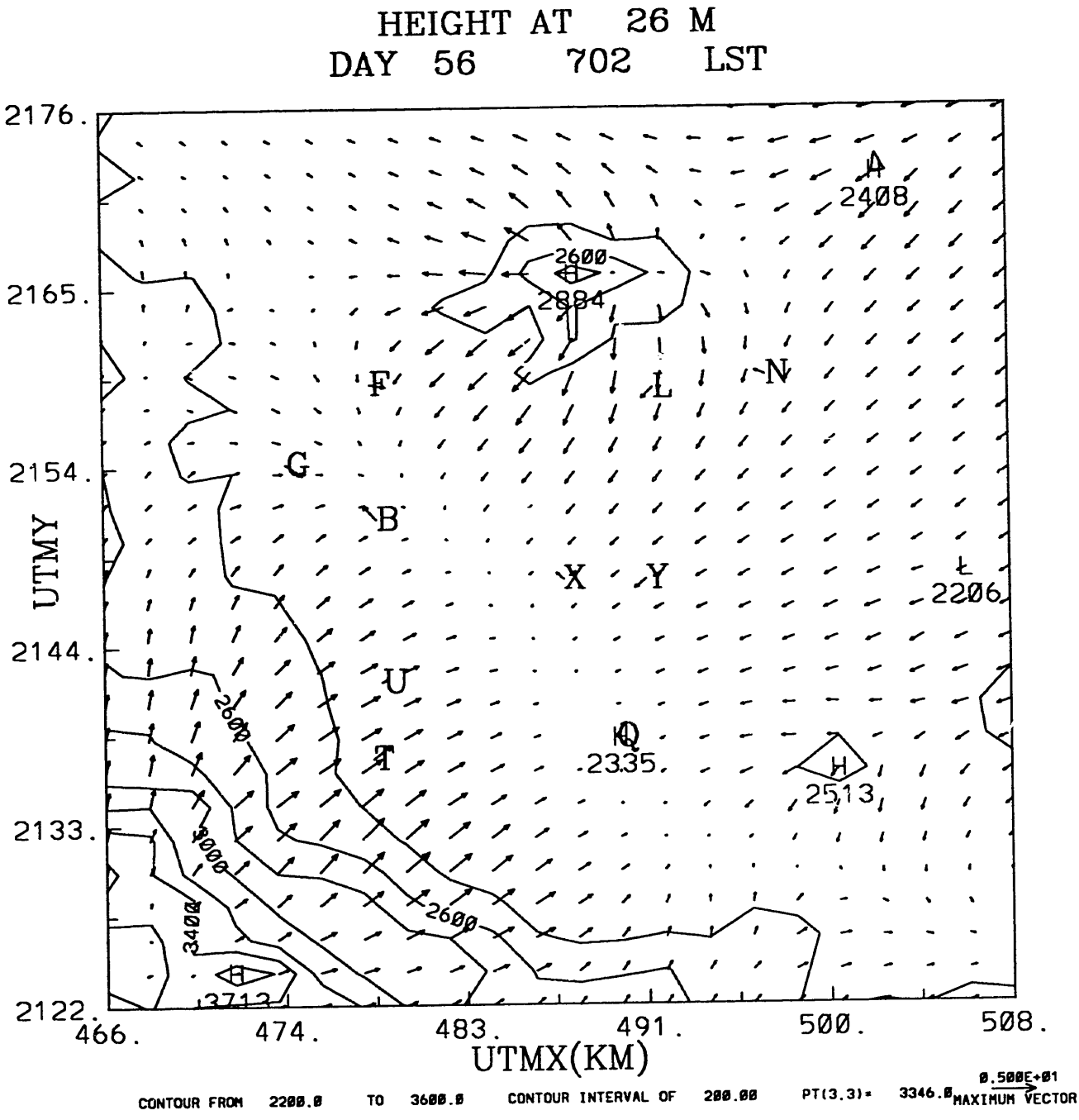

Figure 2. Measured and modeled winds at 7 am on February 25, 1991.

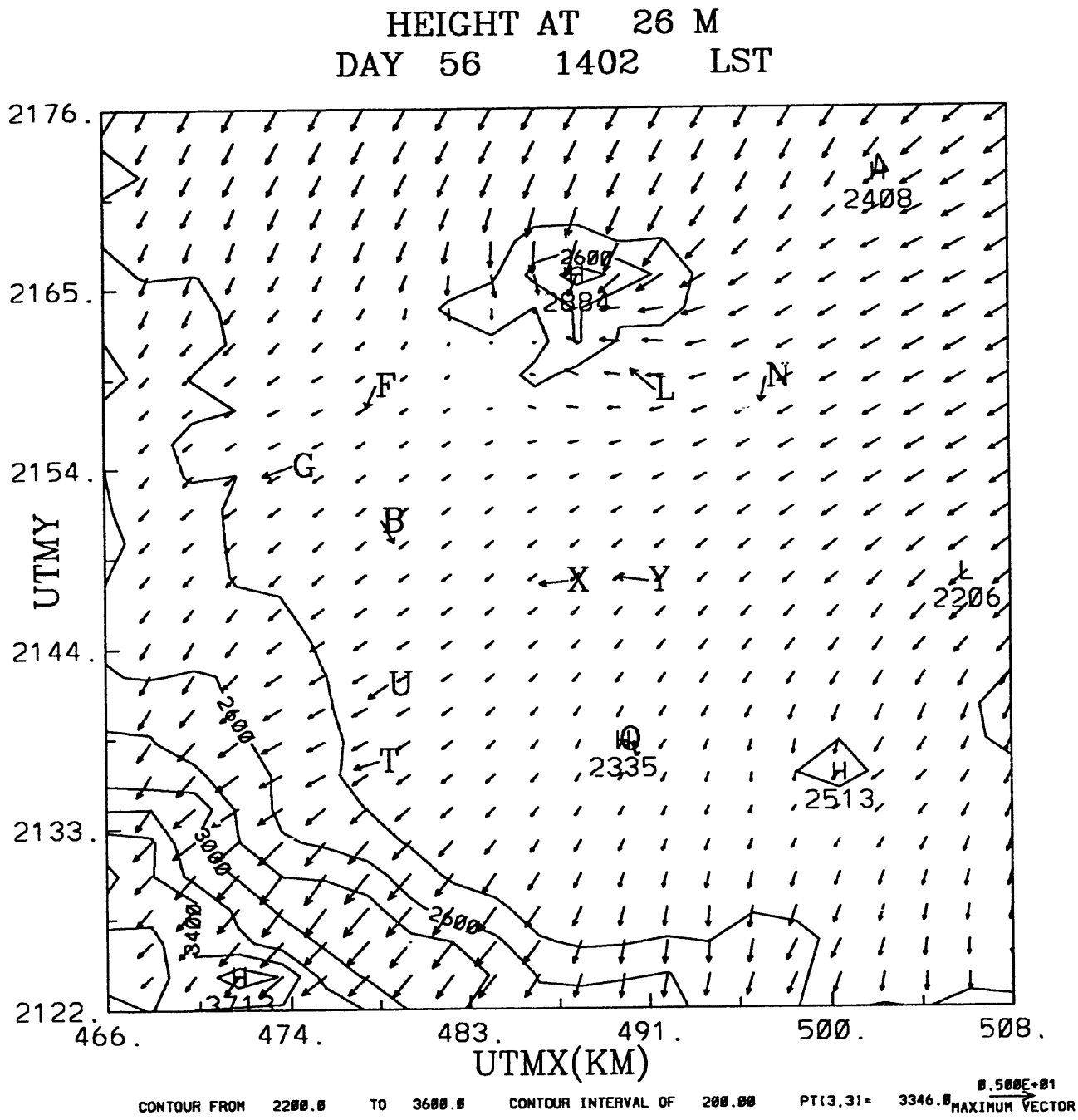

Figure 4. Measured and Modeled winds at 2 pm onf February 25, 1991

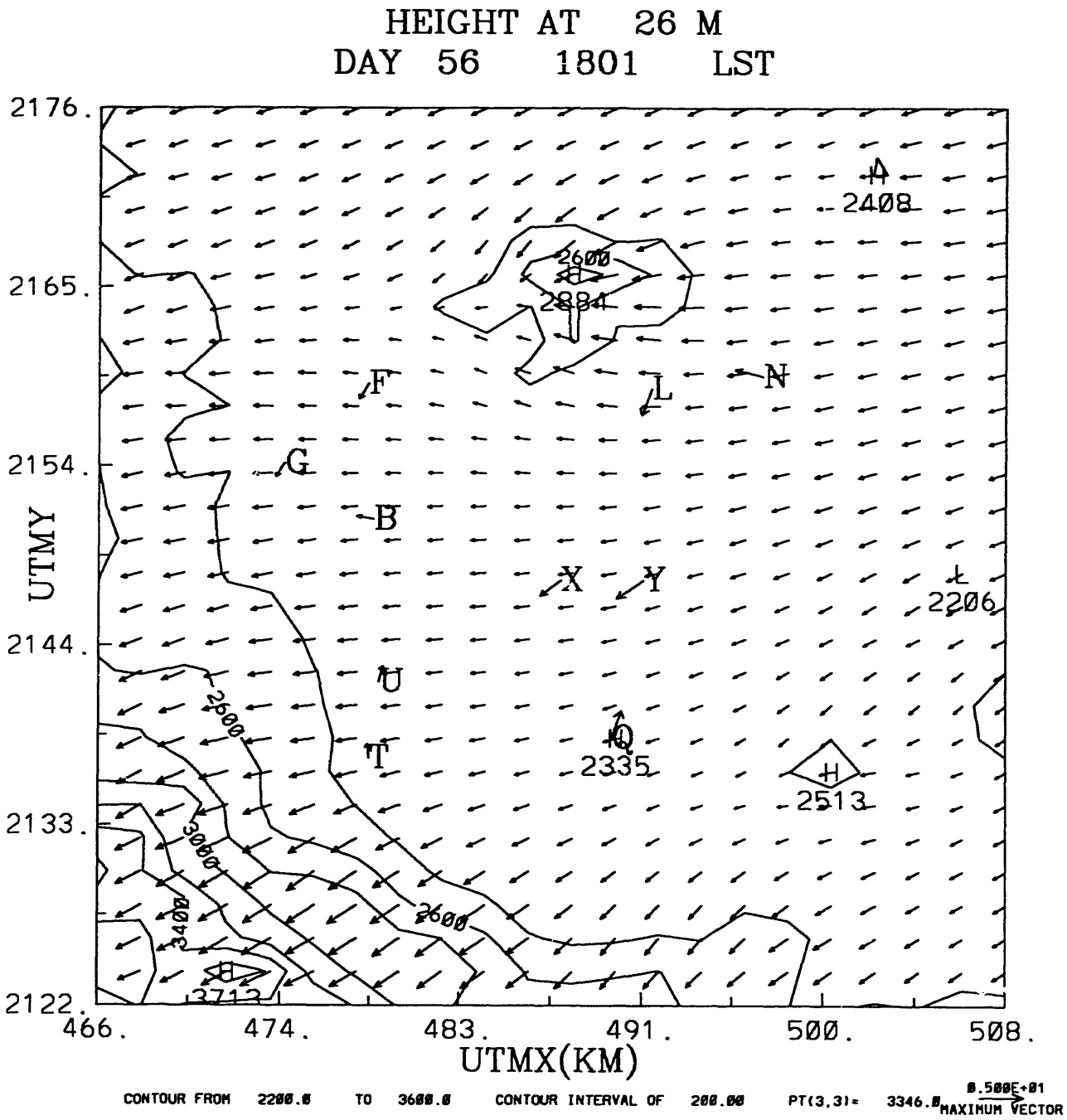

Figure 5. Measured and Modeled winds at 6 pm on February 25, 1991.

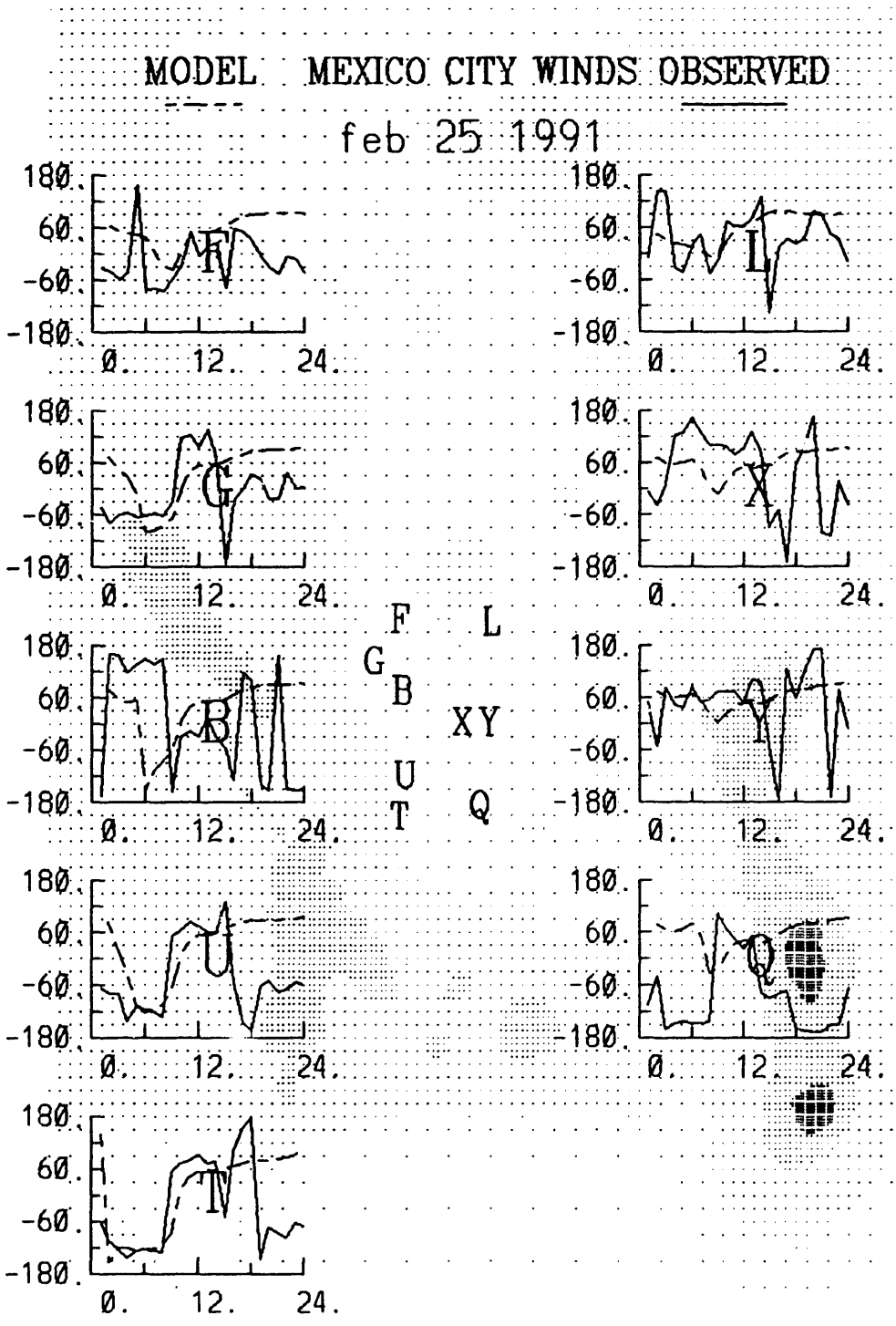

Figure 6. Comparison between the modeled and measured wind direction time profiles on February 25, 1991.

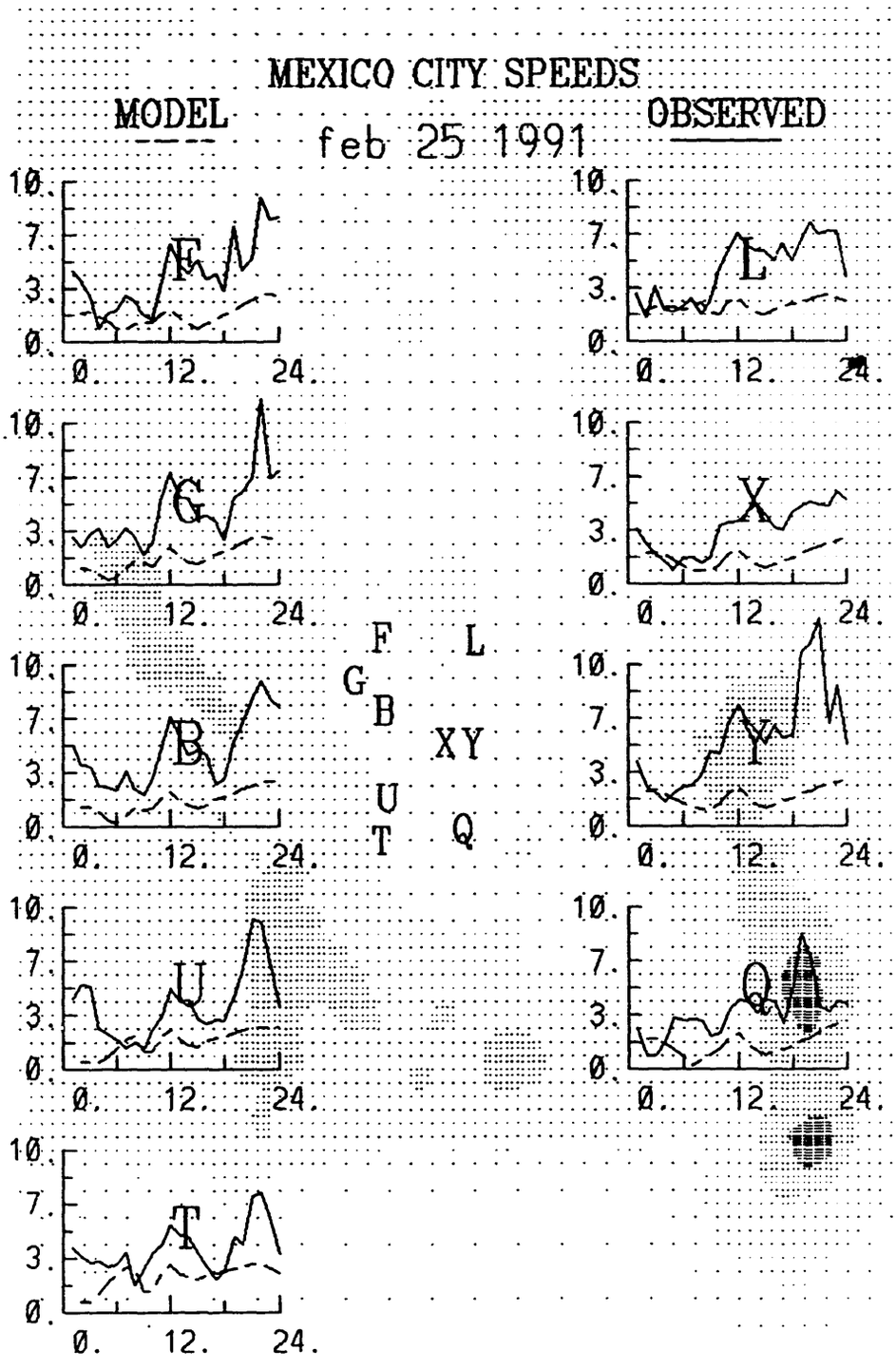

Figure 7. Comparison between the modeled and measured wind-speed time profiles on February 25, 1991.

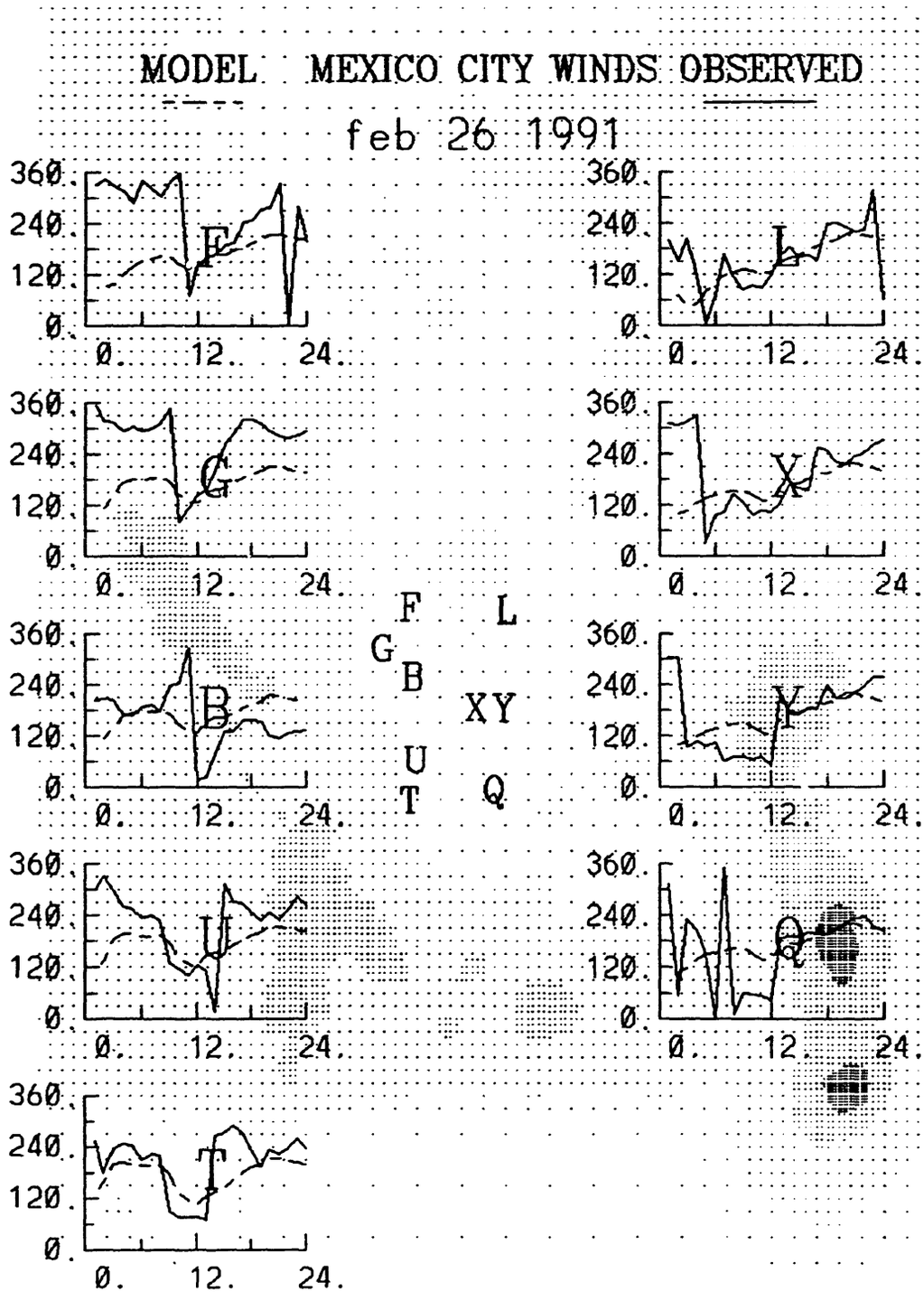

Figure 8. Comparison between the modeled and measured wind-direction time profiles on February 26, 1991.

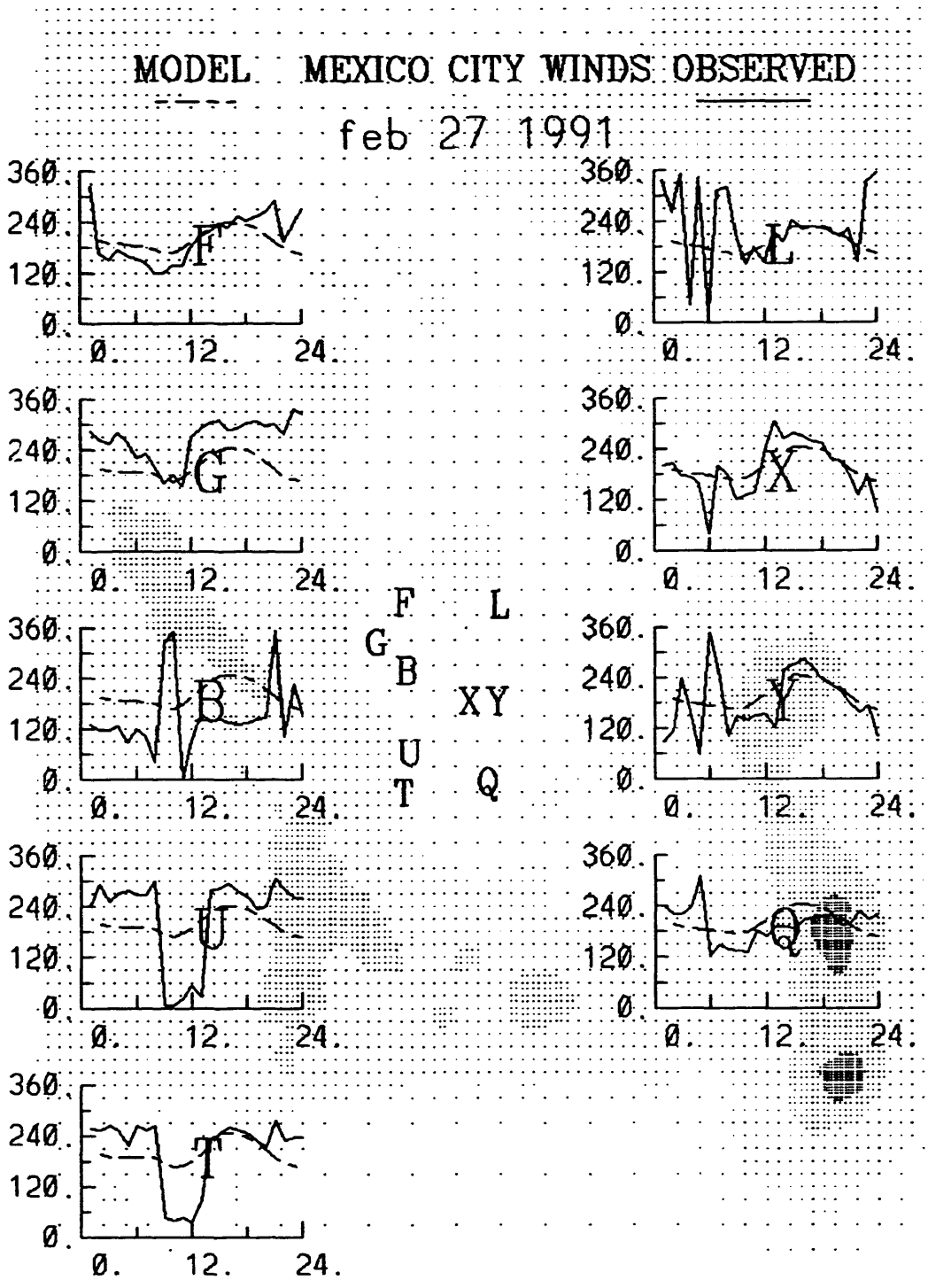

Figure 9. Comparison between the modeled and measured wind-direction time profiles on February 27, 1991.

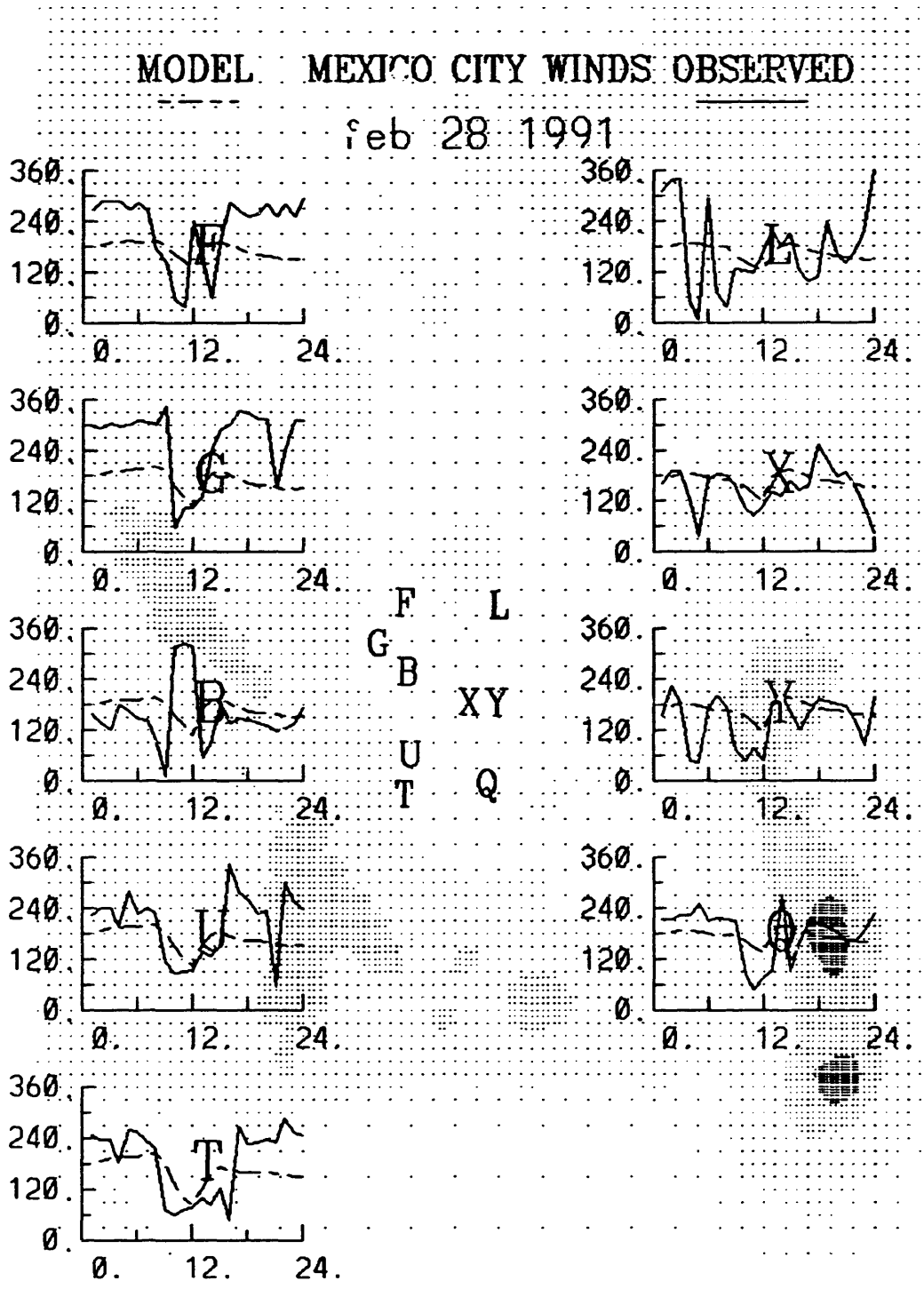

Figure 10. Comparison between modeled and measured wind-direction time profiles on February 28, 1991.

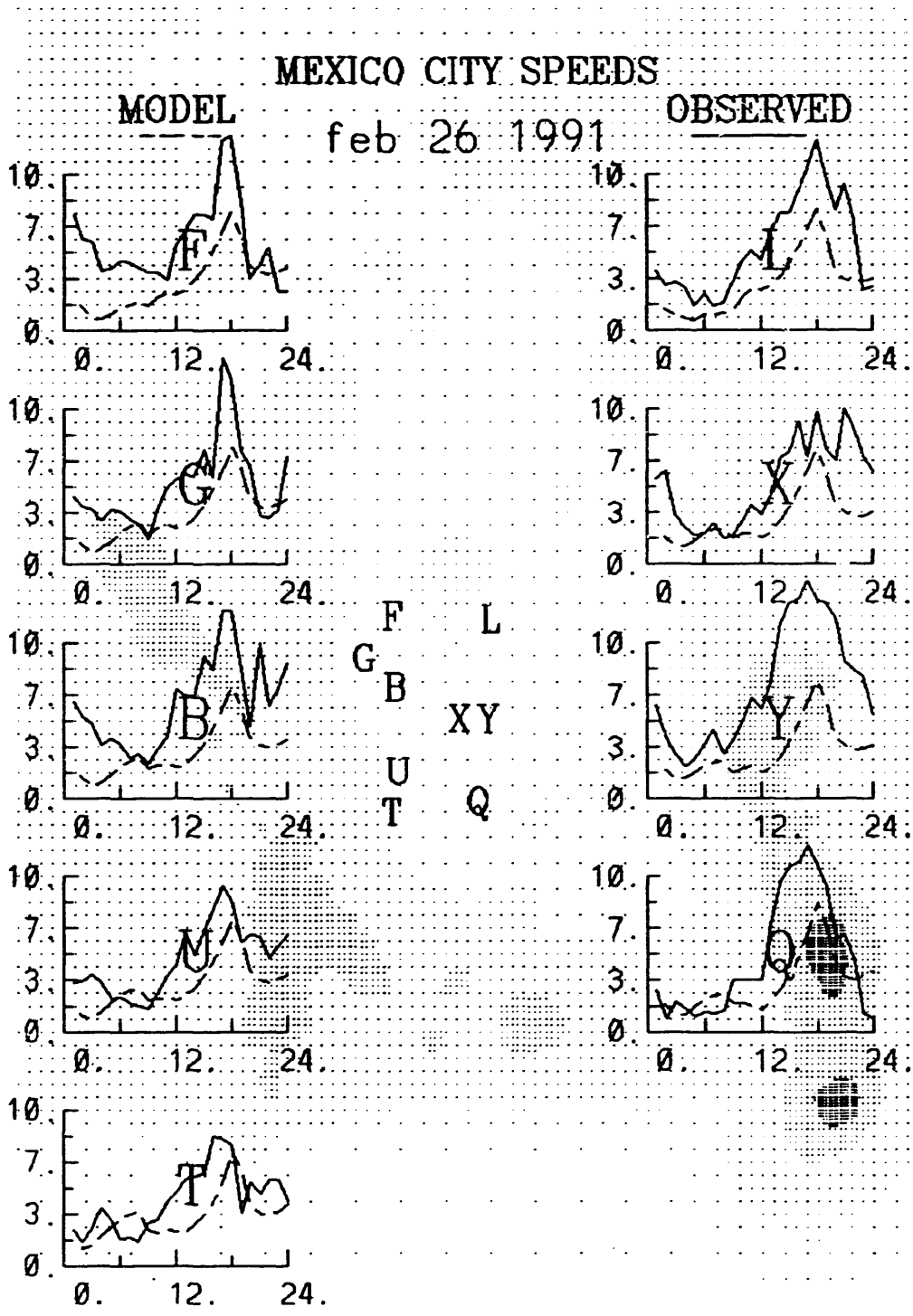

Figure 11. Comparison between modeled and measured wind-speed time profiles on February 26, 1991.

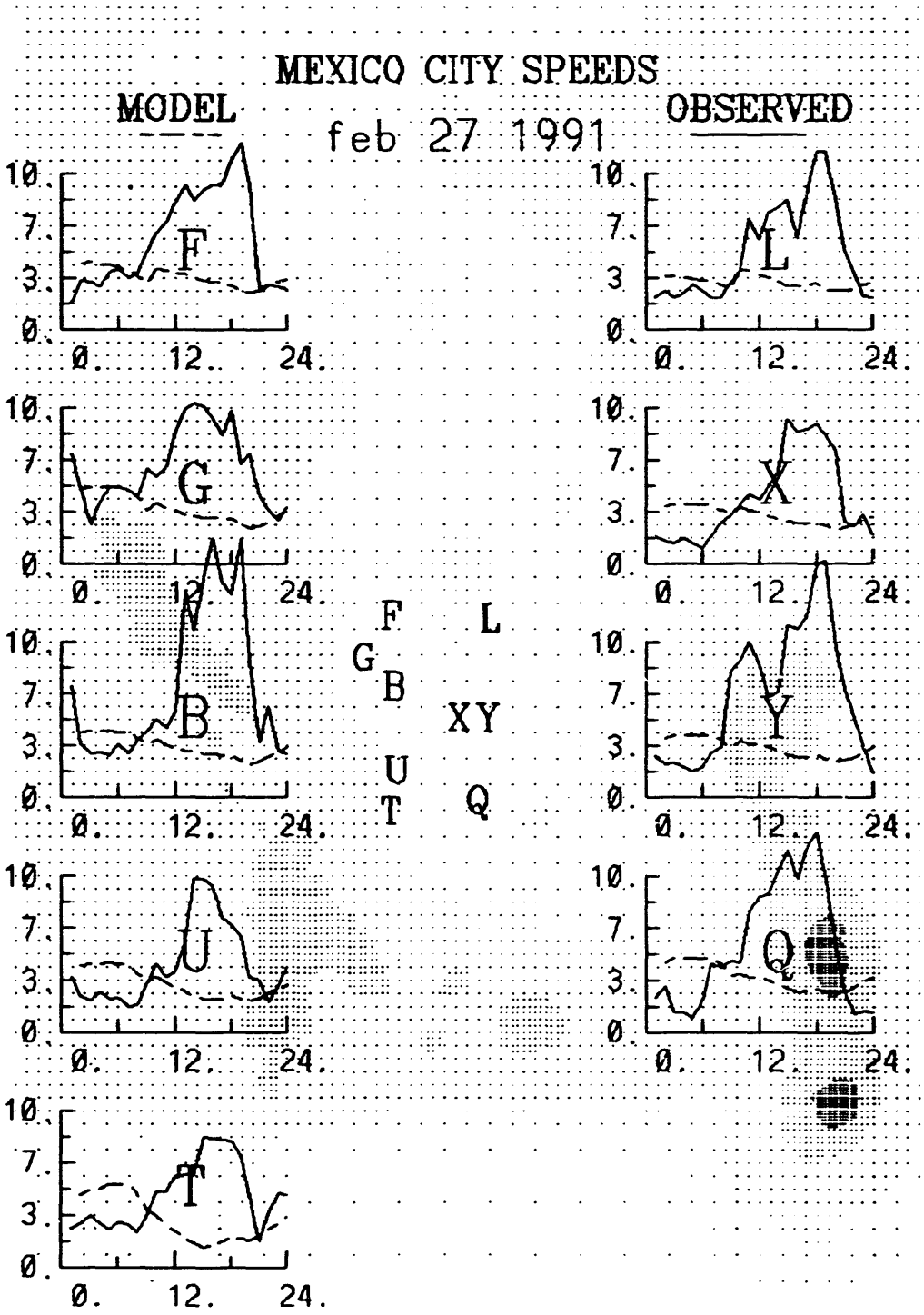

Figure 12. Comparison between the modeled and measured wind-speed time profiles on February 27, 1991.

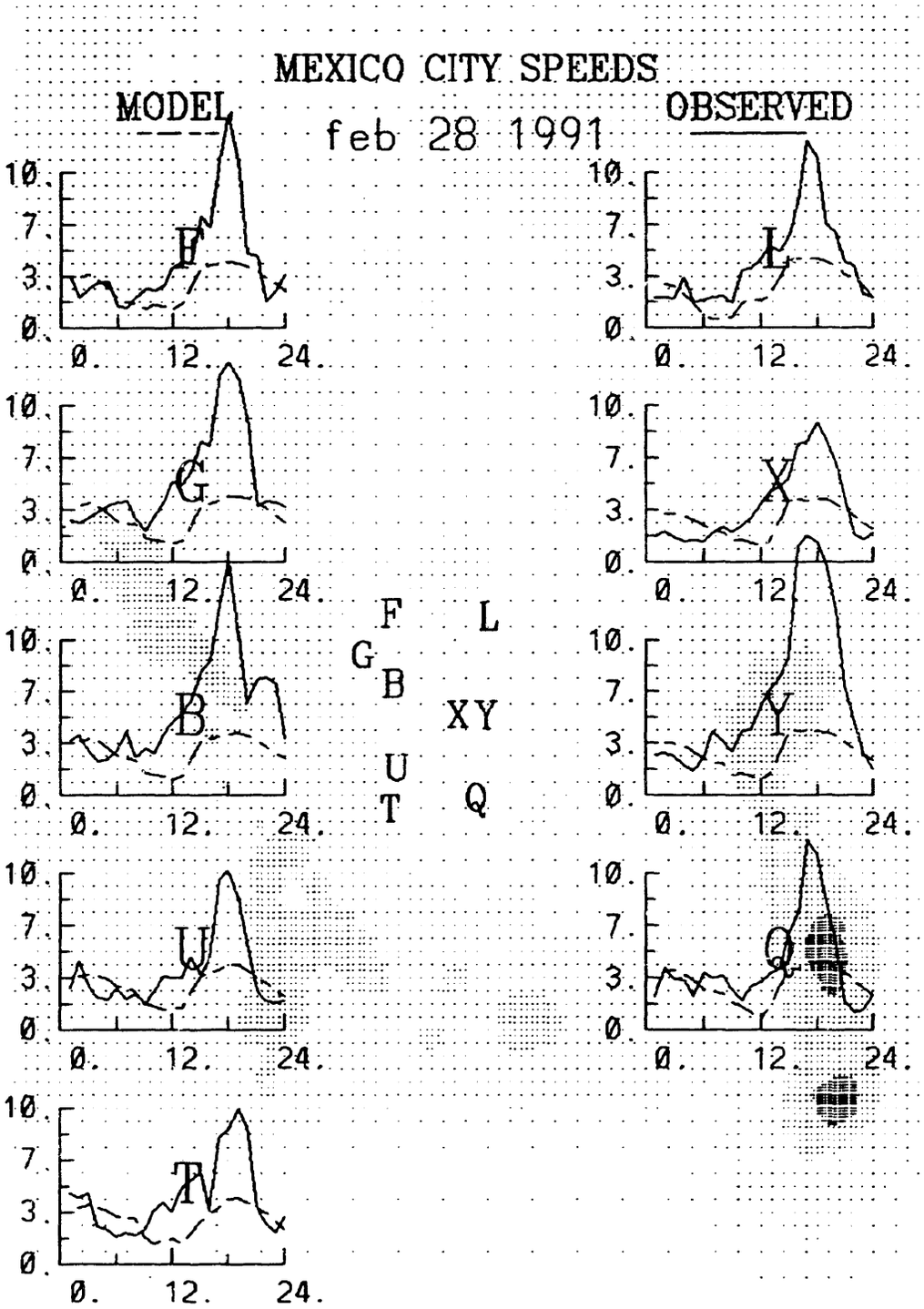

Figure 13. Comparison between the modeled and measured wind-speed time profiles on February 28, 1991.

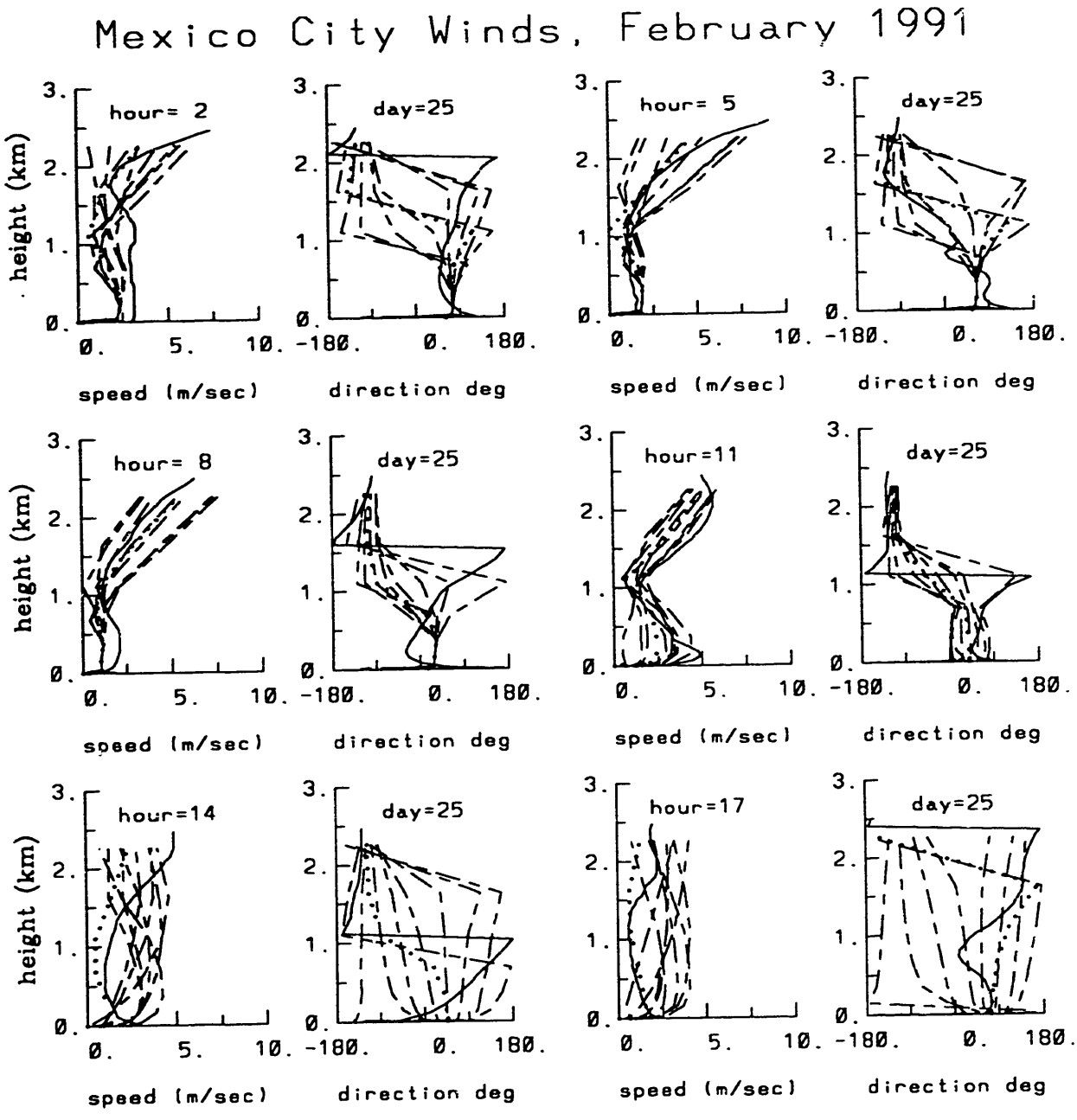

Figure 14. Comparison between modeled (dashed lines) and measured vertical wind profiles at the Mexico City airport on February 25, 1991.

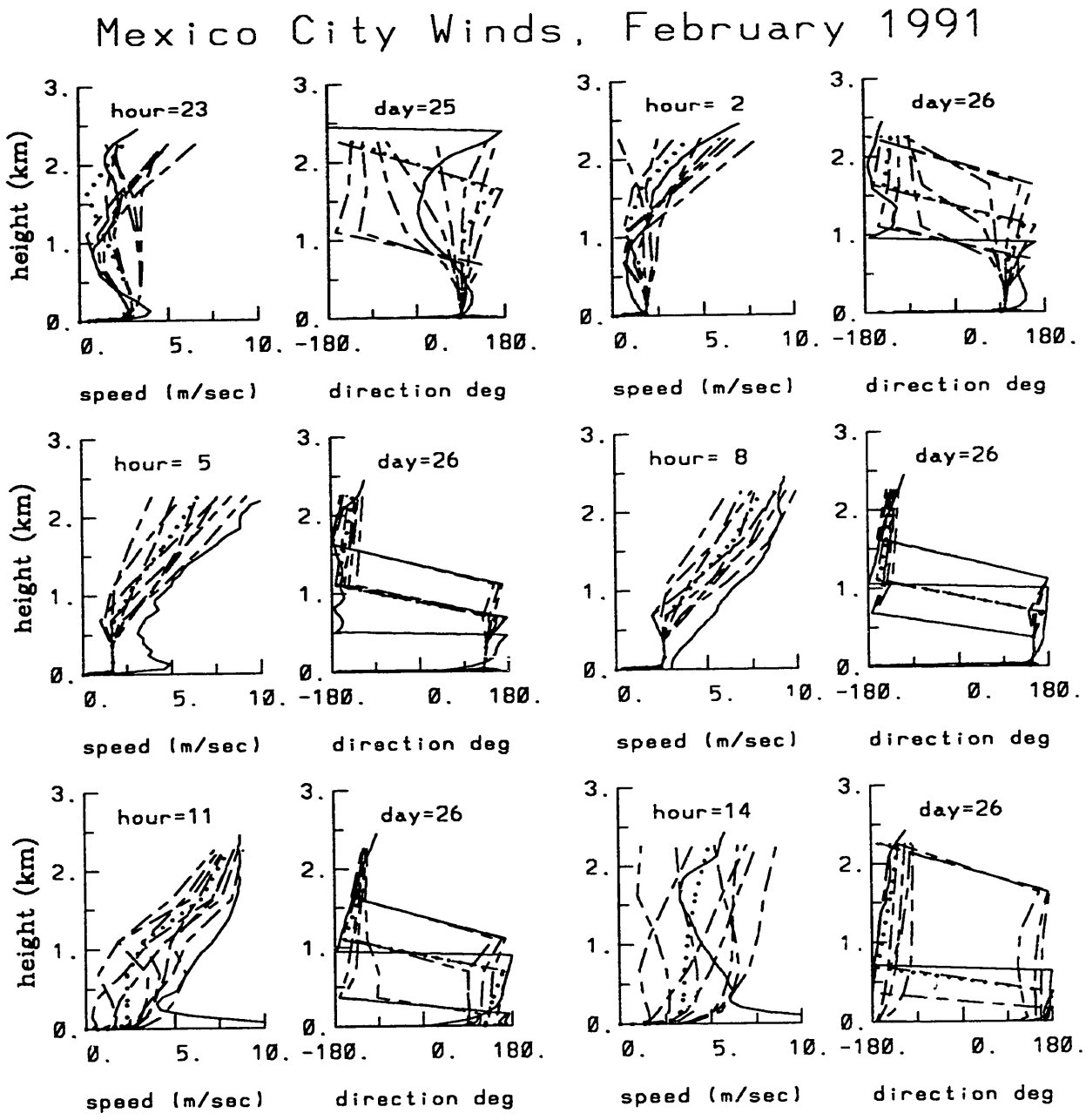

Figure 15. Comparison between modeled (dashed lines) and measured vertical wind profiles at the Mexico City airport on February 25 and 26, 1991.

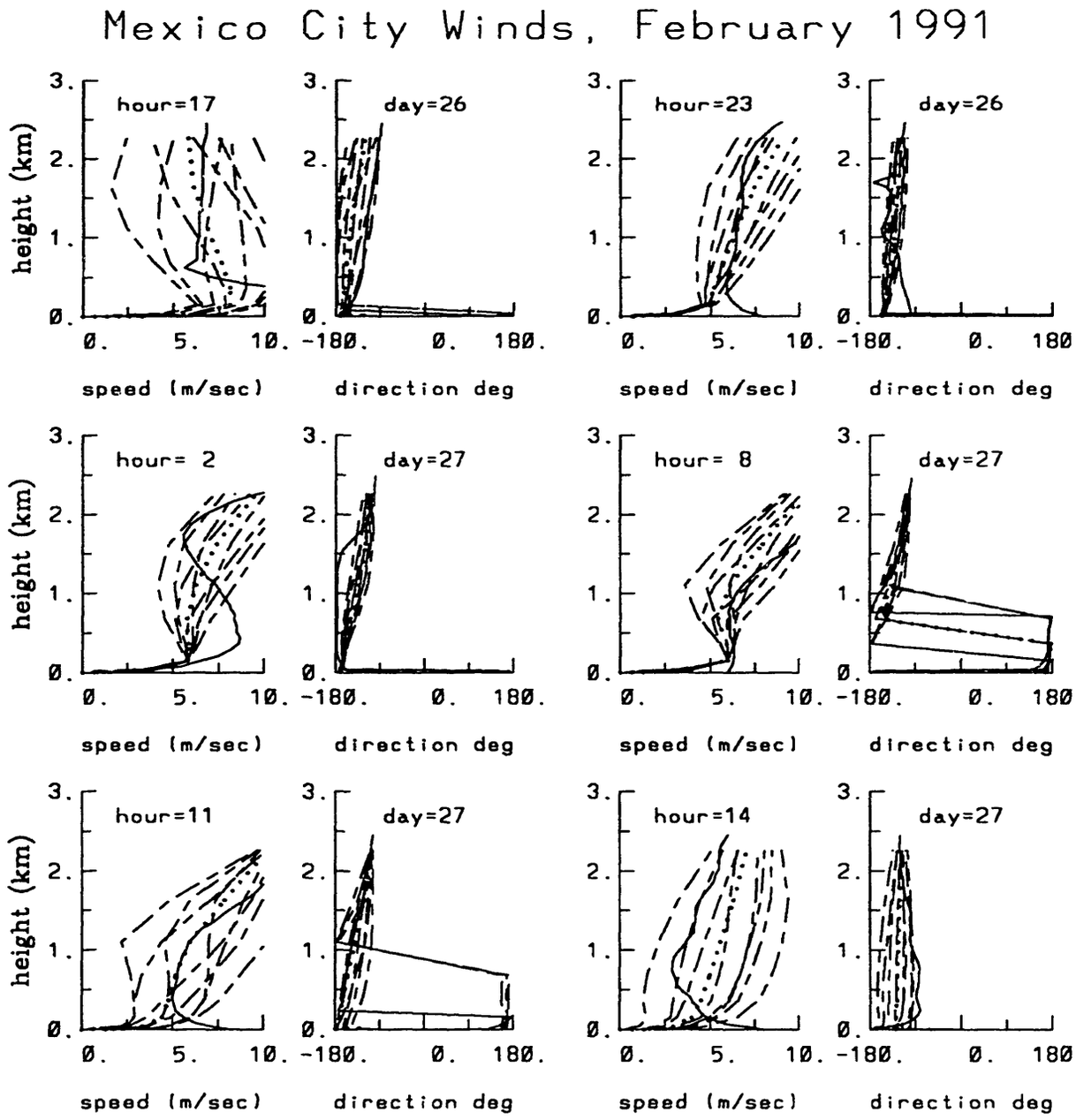

Figure 16. Comparison between modeled (dashed lines) and measured vertical wind profiles at the Mexico City airport for February 26 and 27, 1991.

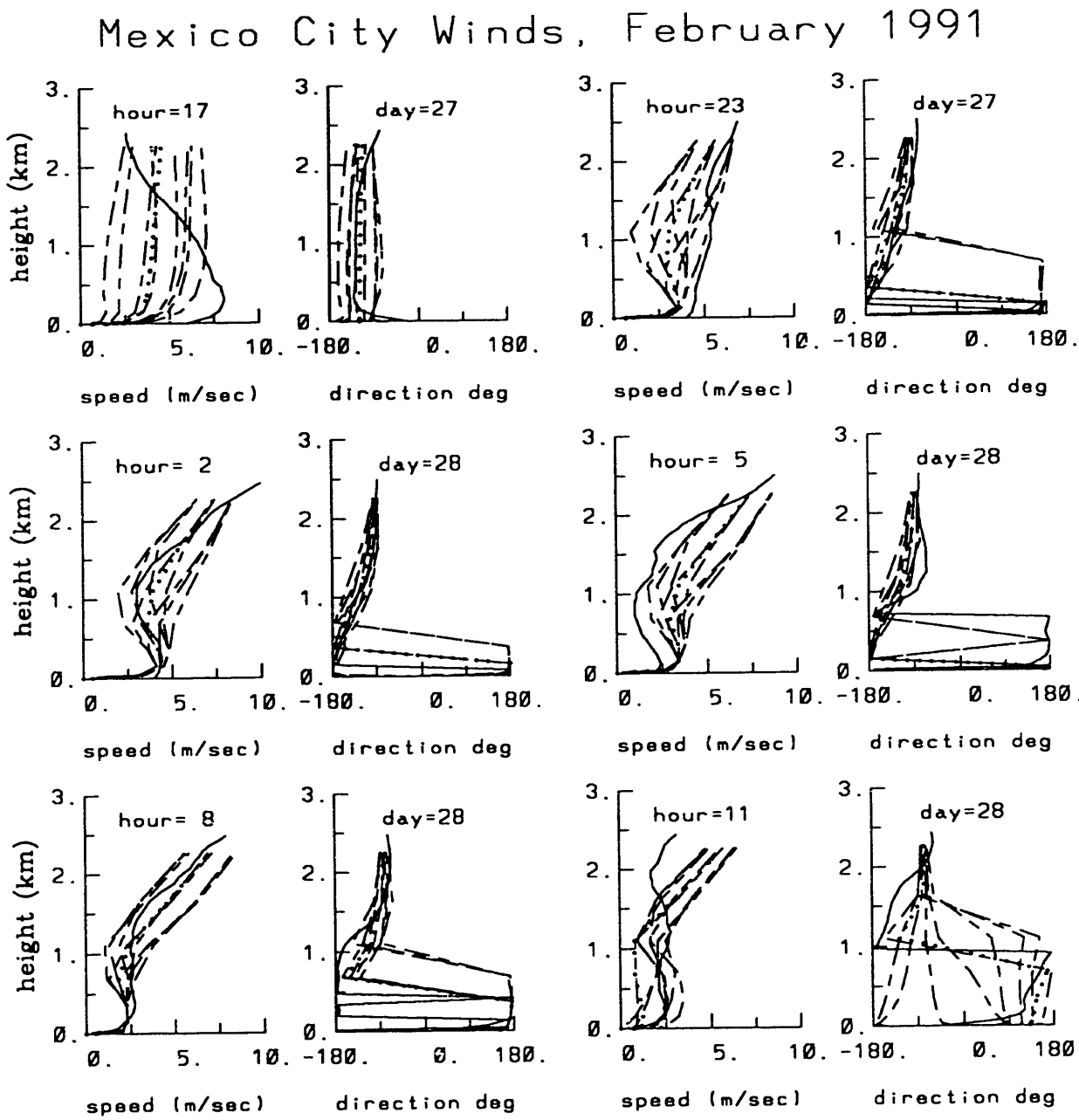

Figure 17. Comparison between modeled (dashed lines) and measured vertical wind profiles at the Mexico City airport for February 27 and 28, 1991.

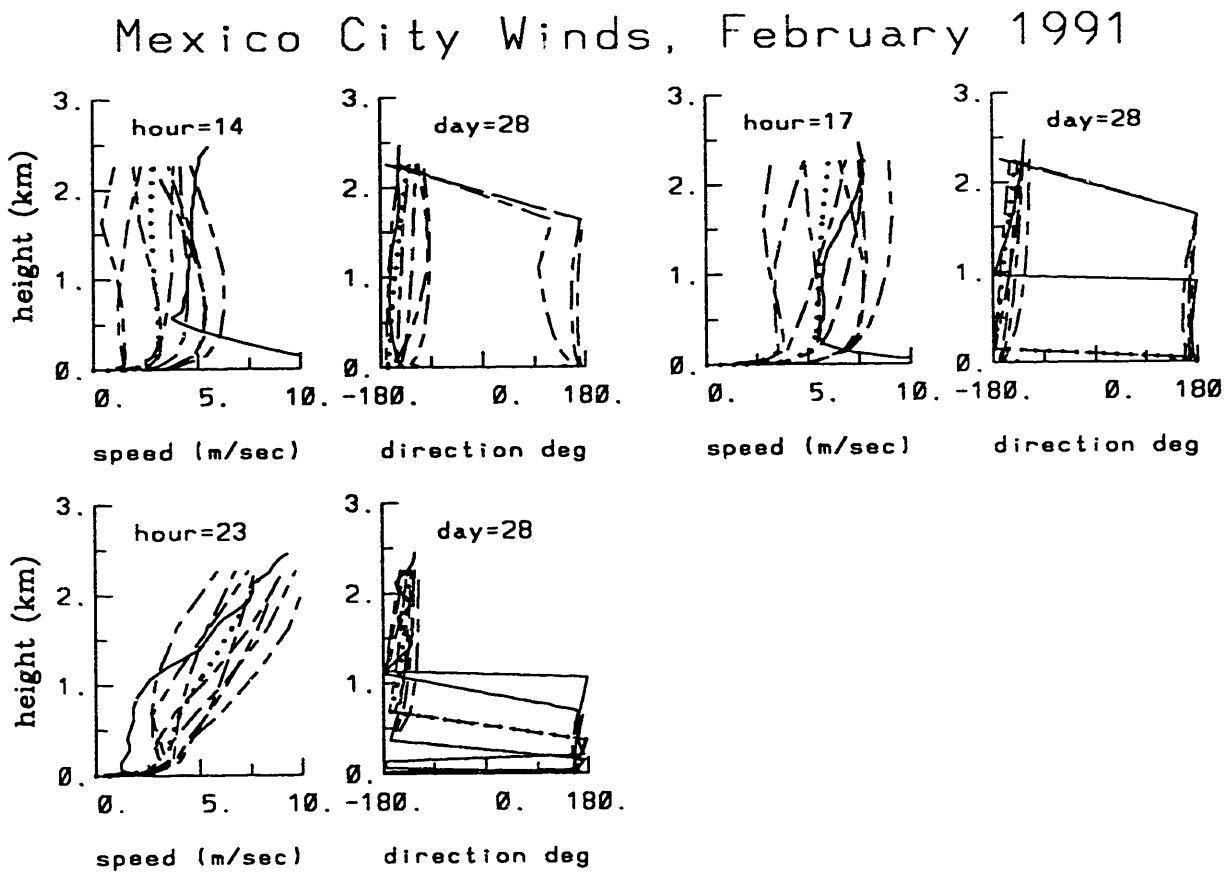

Figure 18. Comparison between modeled (dashed lines) and measured vertical wind profiles at the Mexico City airport for February 28, 1991.

DATE
FILMED
4/11/94

END