Episode Selection

Report on Episode Selection for the Baltimore/ Washington Domain

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14 May 1992

Summary

Objective and subjective meteorological analyses of conditions characteristic of high ozone concentrations ([O_3]) in the Baltimore-Washington (B/W) metropolitan area are carried out for the purpose of selecting multi-day episodes for three-dimensional photochemical modeling using the Urban Airshed Model (UAM). These analyses are consistent with EPA guidance on episode selection with divergences noted in Section 1.A. The focus of the episode selection analyses is to identify local and regional weather patterns "resulting in distinctly different source-receptor configurations" (*EPA, 1991*). The subjective analysis, discussed in Section 1, identifies regional transport regimes, while the objective analysis, discussed in Section 2, uses the Classification and Regression Tree (CART) approach to investigate local conditions. The final selection of cases includes a consideration of issues related to expected model performance and is discussed in Section 3.

The cases selected for UAM simulations in the B/W domain are given in Table 1. Two episodes and one alternate are chosen for each of three major meteorological regimes characteristic of severe O_3 events in the region. Each episode is ranked by severity and pervasiveness of [O_3]. The severity measure is the maximum [O_3] monitored at any station in the B/W domain and the pervasiveness measure is the mean maximum [O_3] for all sites within the domain. The cases are ranked for 1987-1990.

Section 1: Subjective Analysis

A) Discussion of Techniques and Data

The purpose of the episode selection process is to select cases for modeling "that have a high probability of covering different sets of meteorological conditions corresponding with high O_3 concentrations" (*EPA, 1991*). The prime consideration for distinguishing these different sets, or meteorological regimes, is different source-receptor relationships. This emphasis on the effects of transport of O_3 and its precursors on local air quality, along with the use of regional models, such as the Regional Oxidant Model (ROM), for boundary conditions, will allow for better analyses of regional air quality issues.

Appendix B of the EPA Guidelines recommends the use of surface wind roses to determine the strongest source-receptor relationships. Ideally, discrete weather regimes associated with severe O_3 episodes can be identified by distinct surface wind distributions. This approach proved less than satisfactory for the B/W domain. Results of the surface wind rose analysis are given in Table 2. The resultant, or vector mean, wind direction for days with O_3 violations for the period 1987-1990 are fairly evenly distributed about the west-southwest (WSW, or 225°-270°). The major difference in the wind rose distribution for non-O_3 violation days is a strong increase in winds from the north and east. This is to be expected because those wind directions are often found in cool, post-frontal environments which are not conducive to O_3 production. Given the fairly even distribution of winds about the WSW, which is approximately the prevailing wind direction at BWI during the summer months (*NOAA, 1988*), the wind rose analysis does not appear to provide a simple means to identify meteorological regimes. The alternative conclusion, of course, is that all O_3 events in the B/W domain are associated with one transport regime (WSW).

There are several possible reasons for the lack of insight provided by surface wind rose distributions alone. First, surface winds are often affected by local topographical conditions that may not be consistent with domain-wide wind flow (*Yoshini, 1975*). Second, ozone episodes are strongly correlated with stagnant, or slow moving, surface anticyclones (*Vukovich et al., 1977; Vukovich and Fishman, 1986*). Surface conditions associated with slow-moving or stationary anticyclones include light and variable winds that may not be well resolved by surface wind rose analysis. In addition, weak surface wind flow near the center of a surface anticyclone can allow mesoscale effects, such as bay breezes, to dominate the diurnal wind patterns. For the B/W domain, wind fields in anticyclonic conditions are strongly affected by the diurnal bay breeze cycle (*Scofield and Weiss, 1977; Segal et al., 1982*). In general, then, surface wind conditions are not always a reflection of domain-wide transport.

With this in mind, an additional subjective analysis of surface conditions and upper air wind fields was carried out. The data set for the subjective analysis consisted of National Weather Service (NWS) surface synoptic charts, at three hour intervals, and 850 mb constant pressure charts upper air charts, available twice daily, for all multi-day ozone events in the B/W domain for the period 1983-1990. The ozone data set consisted of measured one-hour O_3 concentrations from stations in Maryland, District of Columbia and northern Virginia. For most days, 20-24 monitors reported. A list of monitors is given in Table 3.

The ozone problem in the B/W region occurs primarily in the summer months (June, July and August, or JJA), with a peak in July, as shown in Figure 1. In all, 85% of monitored O_3 violations occurred during the JJA period with a peak in July. In addition, O_3 violations tend to occur in multi-day episodes. For *all* O_3 exceedances during 1983-1990, 76% occurred in multi-day events. For severe events, defined as having 5 or more violations, 83% occurred in multi-day episodes. For the period of interest for episode selection, 1987-1990, 19 of the top 20 severe cases were part of multi-day events. The remaining case, July 19, 1990, was included in the multi-day episode selection analysis in the interest of completeness. Ozone violations appear to be fairly independent of day-of-week position with the exception of reduced severe events on Sunday (Figure 2).

The subjective analysis of the multi-day events consisted of three parts. First, surface charts were analyzed for the position of the center of the nearest anticyclone at 1200 GMT (0800 EDT) and the general wind field as inferred from station reports and the orientation of isobars for the mid-Atlantic region (including the UAM domain). Second, the position of nearby surface frontal zones was noted. Finally, the orientation of the wind field in the mid-Atlantic region at 850 mb (approximately 1500-1800 m above ground), was determined from station reports and the alignment of isoheight lines. For the purposes of determining the transport pattern affecting the domain, the region from 32°-47° N and 70°-85° W was scanned.

Because wind flow is generally clockwise around the center of the anticyclone, and O_3 events are climatologically associated with nearby anticyclone centers, the location of the center of the anticyclone is a good indicator of domain-wide air flow at levels just above the surface. The location of frontal zones is important both for considerations of wind flow along frontal boundaries as well as issues, discussed further below, of expected model performance. Regional transport can be inferred from the height field at 850 mb based on the geostrophic wind approximation. The conditions at 850 mb are less affected by the surface and can provide information regarding the source of transport into the domain at the top of the model. Ideally, a slightly lower level would be a better indictor but 850 mb is the lowest level routinely charted by the NWS.

B) Results of Subjective Analysis

The subjective analysis identified four distinct transport regimes, or classes, associated with high O_3 events. A listing of cases, taken from the group of multi-day events and separated by class, is given in Table 4. The success rate of this classification scheme, which measures the degree to which the episodes could be assigned to any particular class, was approximately 86%. Table 5 summarizes the ability of the four class structure to classify all cases.

A description of the four classes follows:

Class 1 (Northerly Transport). This class is identified by a surface anticyclone centered south and west of the domain, typically in western Virginia or West Virginia. Surface winds are light and variable with little coherency of flow. Winds at 850 mb, however, are northerly, including northeast and northwest. Surface pressure and wind conditions from an illustrative case (July 6, 1988) are given in Figure 3a. Geopotential heights and wind direction at 850 mb are presented in Figure 3b. There are several sub-groups that are common within the northerly transport regime. Often, a surface anticyclone west of the domain is coupled with an offshore low pressure center (Subset C). The counter-clockwise circulation associated with the low pressure center combine with the anticyclonic circulation to the west to drive strong northerly winds. In addition, many cases, including the July 5-7, 1998 episode, feature retrograde, or westward-moving, surface and upper air high pressure centers (Subset A). The persistence of these unusual conditions for several days results in the recirculation of air throughout the eastern United States.

Class 2 (Westerly Transport): In terms of surface conditions, this class is nearly identical to Class 1. Class 2 is distinguished, however, by a strong westerly component in the upper air wind field. Surface and upper air conditions for an illustrative case (July 10, 1988) are given in Figures 3c and d. As in Class 1, a surface anticyclone is centered west of the domain in western Virginia or West Virginia. A sub-group of this class (Subset A) contains cases in which a frontal zone is located just north of the domain. Convergence along the frontal zone contributes to the westerly component of upper level winds.

One condition common in most Class 2 cases is the presence of a lee trough in or near the domain at some period during the episode. A lee trough is an area of low pressure located downwind, or east, of a mountain range. This effect is most common in the region east of the Rockies but has been identified as a frequent characteristic of high ozone episodes in the northeastern U.S. (*Pagnotti, 1987*). The connection between lee troughs and high O_3 is most likely due to converging winds along a trough axis that is often oriented parallel to the northeastern U.S. urban corridor. In the absence of deep convection, which is generally suppressed in anticyclonic conditions, this convergence will increase concentrations of O_3 and its precursors.

On surface synoptic charts, the lee trough is identified by a southward dip in the generally east-to-west oriented isobars. The response of the wind field to the presence of the trough is a discontinuity, or wind shift, across the trough axis with west or northwest winds to the west of the trough axis and south or east winds to the east. The lee trough is often not well analyzed on NWS surface charts due to the subjective nature of manual analysis and because the effect is often on too small a scale to be resolved by the standard synoptic-scale network of stations (*Pagnotti, 1987*). As a result, the presence of a lee trough is not an effective tool for discriminating between classes but does appear to be more strongly associated with Class 2 cases (But see Figure 2a for an example of a lee trough in a Class 1 case).

Class 3 (Along-Corridor): A surface anticyclone center is located south and east of the domain, often along the North Carolina coast. Wind fields are consistently south and southwest, or along the Atlantic coast corridor, at the surface and west to southwest at 850 mb. Surface and upper air conditions for an illustrative case (July 20, 1990) are given in Figures 3e and f. In terms of typical summer weather, this is the most consistent surface wind pattern (*NAVAIR, 1966; ESSA, 1968*). This class of cases is perhaps more typical of O_3 exceedances in the northeastern United States, due to transport of O_3 and its precursors from metropolitan centers along the coast, but is associated with weaker O_3 events in the B/W region due to weaker sources to the south. Because the movement of weather systems in the mid-latitudes is generally west-to-east, this class often occurs near the end of a longer episode characteristic of Classes 1 or 2. As in the previous classes, there are several sub-groups within Class 3. In one sub-group, a cold front advances from the Midwest and transport is southwesterly, or along-corridor (Subset A). Winds are often strong in these cases and this results in less local stagnation and generally lower O_3. In a second group (Subset B), a surface anticyclone over or southeast of the domain is associated with a strong off-shore anticyclone (Bermuda High). Upper air flow is south or southeast in these cases and very light.

Class 4 (Frontal Zone): In this class of cases, a cold or stationary frontal zone is analyzed in or just south of the domain. Upper air wind flow is typically west or northwest as in Class 2. High O_3 concentrations associated with frontal zones may be due to strong convergence of surface winds along the frontal zone, thus resulting in increasing local levels of O_3 and its precursors, or to very stable conditions in the wake of the front which traps local emissions beneath an inversion associated with the frontal zone. The O_3 events in this class are generally not as strong as the previous classes. Surface and upper air conditions for an illustrative case (July 18, 1988) are shown in Figures 3g and 3h. As will be discussed in more detail below, the simulation of strong local discontinuities in temperature, wind and moisture that are characteristic of frontal zones are difficult for grid-based three-dimensional models to carry out accurately (*Seinfeld, 1988*).

Section 2: Objective Analysis

A) Discussion of Techniques and Data

In addition to the subjective analysis, which concentrated on the effects of regional transport on local conditions, an objective analysis of conditions within the domain was carried out. The O_3 problem in the B/W domain is likely a combination of local concentrations of O_3 and emissions of O_3 precursors as well as transport of O_3 and its precursors into the region. The subjective analysis is helpful for understanding the transport patterns associated with high O_3 events but does not resolve local or thermodynamic effects, such as atmospheric stability, on O_3 production. To analyze local effects, a Classification and Regression Tree (CART) analysis was used (*California Statistical Software, 1991*). This type of analysis has been used for general weather forecasting (*Burrows, 1991*) and has been recommended for use in O_3 studies (*Horie, 1987; Seinfeld, 1988; EPA, 1990; National Research Council, 1991*).

The CART technique operates by a binary splitting of data into groups that are more homogeneous (*Breiman, et al., 1984*). A succession of binary splits results in a "tree" whose final "branches", or terminal nodes, represent distinct classes, or categories of data. CART is non-parametric, that is, no assumptions are made regarding the statistical distribution of the predictors. It can accommodate single predictors and linear combinations of predictors.

CART begins with a "learning data sample" consisting of a predictand value and predictor values. It then makes a "best" decision tree that separates events into categories of the predictand based on predictor values. In this case, the predictand is the domain mean maximum O_3 for the B/W domain for the period JJA 1983-1990. The predictors consisted of a primary set of surface (BWI) and upper air (Dulles) observations and a secondary set of variables derived from the upper air observations. The observed surface values are: pressure, temperature, moisture (dew point temperature), wind velocity and total opaque sky cover for 0600, 1000, 1400 and 1800 EDT. The observed upper air variables are: temperature, moisture (dew point temperature converted from relative humidity), wind velocity (expressed as vector components) and geopotential height for 50 mb intervals between 950 and 650 mb.

Virtual potential temperature (θ_v) is derived for each 50 mb level from 950-650 mb and gradients between levels are computed to give information about the local stability of the atmosphere. The stability analysis, in turn, can provide information on the strength and height of local inversions that tend to trap emissions and increase O_3 production. By definition, θ_v is the potential temperature a parcel of dry air would have if its pressure and density were equal to that of moist air. Virtual temperature is calculated by altering the equation of state for air by the addition of terms that account for the partial pressure of water vapor. A related variable, potential temperature (θ), is used by the UAM to determine the height of the mixed layer of the model (*Kelly, 1981*). This approach is useful in dry environments and in situations where bouyancy forces, driven by the earth's heating, dominate over larger scale forces, such as convergence associated with approaching fronts, which can also induce upward motion. In general, the eastern United States is quite moist in the summer months and the mixing ratio of water is not constant with altitude. In these cases, θ_v, which accounts for the presence of moist air, is more useful (*Stull, 1991*). Strong increases of θ_v with altitude reflect an atmosphere that is resistant to convective overturning and thus more likely to trap local emissions.

As will be discussed below, a number of CART runs were carried out. In all runs, the optimum number of classes, or terminal nodes, is that set which contains the minimum "cost" for misclassification. The cost is determined by holding out a portion of the data to use as a "test" set. The remainder of the data is used to create the binary decision tree and each terminal node is assigned to a particular class. In our case, each class is identified by a characteristic maximum mean O_3 concentration. The test cases are then run down the tree and their final position, or terminal node, is determined by the various splits. For example, in most O_3 trees, the first split is on maximum surface temperature. The extent to which the test cases are misclassified is determined by the difference between the predictand value characteristic of the terminal node (maximum mean O_3 in our example) and the predictand values of the test cases.

In situations, such as the present, where the data set is limited in number and cannot support the creation of a large test set, a variation on the misclassification test, termed the "cross-validation" test, is used. In this process, a series of test sets are created by dividing the learning sample iteratively. For example, in a "ten-fold" cross-validation test, the learning sample is cut into 10 groups. A series of 10 learning samples are created using 9 of the groups as a learning sample and the remaining group set aside as a test case. Each group is used once as a test set. A set of decision trees are created by this approach, called "auxiliary" trees, each containing the same number of teminal nodes. The cost of misclassification for a given number of terminal nodes is determined by running the test cases down the auxiliary trees. In the present example, there would be ten auxiliary trees for each given number of terminal nodes. The number of possible terminal nodes is usually quite large so that extensive computation is demanded. The misclassification costs are determined for each number of terminal nodes by averaging across the ten trees. The lowest average cost determines the optimum number of terminal nodes.

Given the present data set and method of analysis used by CART, a number of differences are expected from the subjective analysis. First, wind data at a specific point will not necessarily resolve transport, or source-receptor, relationships on a regional scale. As an example, Figure 4 shows how an instantaneous wind observation at a station can be associated with more than one regional transport regime. At a more basic level, wind observations from radiosondes are instantaneous meaurements and subject to a great deal of variability. Second, the subjective analysis did not resolve the thermodynamic structure of the lower tropsophere. The CART analysis, however, can resolve this, at least to 50 mb levels. Because strong low-level inversions can trap pollutants and raise O_3 concentrations, the thermodynamic structure of the lower atmosphere can be a strong factor in O_3 production.

B) Results of CART Analysis

The initial CART runs utilized the full data set for the JJA 1983-1990 period. The most successful run (Run 5B) utilized the linear combination option of the CART software which allows cases to be split on combinations of variables rather than a single variable. Using the linear combination option, with ten-fold cross validation, reduces the number of outlying (< 5 cases) nodes. Statistics relating to the success of the major runs in isolating O_3 events, along with values for important variables, is given in Table 7a-c.

In Run 5B, the majority of the strong O_3 cases are grouped in terminal nodes 4 and 5 (TN4 and TN5). In fact, 96% of the extreme O_3 cases, defined as having greater than 8 NAAQS violations), are grouped in these two nodes. Because the criteria for episode selection seeks to choose from only the strongest episodes, this statistic is quite important. The non-O_3 nodes, TN1-TN3, are easily filtered out by mid-day surface temperature of less than 86°F. A smattering of weak O_3 events occur in TN3 based on warm temperature (82 °F mean), warm upper air temperature (950 mb), and low mid-day sky cover. The distinction between the two high O_3 nodes (TN4 and TN5) is based on a linear combination dominated by midday temperature. Other variables that contribute to the distinction are high surface pressure and low morning temperature (characteristic of clear nights). The cases in TN5 are characterized by lower morning temperature, higher pressure and higher afternoon temperatures.

Wind directions are highly variable within each node and do not contribute significantly to differences at this level. Winds at the surface in the strong O_3 nodes are generally west (W) with west-northwest (WNW) winds aloft.

When the top fourteen episodes (Table 6) are grouped by terminal nodes, 28 of the 34 total episode days fall into TN5 along with 16 of the 18 days of greater than eight NAAQS violations. In terms of episode selection, the results of Run 5B are able to separate the non-O_3 or weak O_3 days based mainly on temperature. Run 5B is unable, however, to further distinguish within the high O_3 cases.

In order to investigate the structure within the high-O_3 cases, a second series of runs was undertaken using a subset of cases containing NAAQS violations or mean maximum O_3 greater than 90 ppbv. A total of 195 cases for the period JJA 1983-1990 were selected. Of these, fourteen contained mean $[O_3]$ greater than 90 ppbv but no NAAQS violations.

The most successful of this series of runs is Run 6B for which summary statistics are found in Table 7b. The basic split in Run 6B is between TN1 and the three remaining nodes (TN2-TN4). The key variables responsible for the split between TN1 and the remainder of the cases are upper air temperature and the total θ_v gradient from 950-650 mb. TN1 is characterized by high θ_v at 950 and 900 mb but a much smaller gradient in θ_v so that θ_v for all nodes are equal by approximately 700 mb (Table 7b). An inference that may be drawn from this distinction is that TN1 represents "hot" cases in which high temperature, and low sky cover, drive local O_3 chemistry to the maximum possible extent while TN2-TN4 represent cases in which stable lower tropospheric conditions trap emissions into a smaller volume and so increase local $[O_3]$.

Within the "cooler" nodes, there are further distinctions of interest. TN2 is proportionally the strongest with 45% of its cases in the severe or extreme categories compared to 17% for TN4. TN2 is characterized by nearly clear conditions, though surface temperatures are lower (88°F), and nearly stagnant conditions with weak NW winds aloft. TN3 contains no strong O_3 cases due to very strong WNW winds aloft that serve to ventilate the domain. TN4 appears to be a "catch-all" category. Sky cover is fairly high, westerly winds are moderate between the stagnant conditions of TN2 and the strong westerlies in TN3.

In terms of the top O_3 episodes, 15 of the 34 top episode days group into TN1 and 10 in TN4. If only the strongest O_3 days within the episodes are analyzed (Table 6), the strongest cases are almost unanimously clustered in TN1.

A final series of runs investigated only the wind fields in an attempt to distinguish O_3 regimes based on local wind patterns. The most successful run (Run 8) used the full dataset and only surface and upper air wind components. Summary statistics are given in Table 7c. The severe and extreme O_3 events are grouped into three nodes (TN4-TN6). Of these, TN5 is proportionally strongest with 44% of its cases containing greater than 5 violations compared to 19% for TN4 and 5% for TN6. TN5 is characterized by W winds at the surface backing slightly to the SW by 1800 EDT. Winds aloft are light NW. As was noted earlier, there is a large degree of variability in the wind data. TN4 also has W surface winds in the morning but there is a strong backing of the wind to the S by 1800 EDT. This may be a reflection of bay effects. The upper air winds contain a stronger westerly component than TN5 and are generally WNW. TN6 is characterized by WSW surface winds and strong WNW wind aloft. In all, the differences between nodes are based mainly on surface wind direction and upper air wind magnitude.

The connections between the Run 8 terminal nodes and the top O_3 cases are given in Table 6. The scattering of nodes about the top cases is better than in Run 6B and there is a slight correspondence between Class 3 and

TN4 based on more southerly winds.

Section 3: Selection of Cases

A) Additional Considerations

Because source-receptor relationships are the prime consideration, the four-class structure of the subjective analysis is used as the initial classification. Within the four classes, each episode is ranked by the sum of the severity and pervasiveness measures defined in Section 1. The most severe candidates in each class form the pool for final selection. CART terminal nodes are assigned to each episode based on the most successful CART runs and an effort is made to ensure that distinct CART classes are included within the group of six selected episodes. Then, issues of data availability, emphasizing availability of additional upper air data, are addressed. As noted in earlier reports, the B/W domain is very short on upper air data with only one NWS upper air station within the domain (Dulles). In practice, this leads to the selection of cases from 1989 and 1990 due to the availability of radiosonde data from Aberdeen Proving Grounds, Maryland (APG).

Finally, a series of "model tractability" issues are investigated. Model tractability refers to the known ability of the UAM to simulate certain types of meteorological conditions with a high degree of success. In particular, previous studies have shown that the UAM is sensitive to variations in wind fields. Thus, cases with well-defined and more or less invariant wind fields are to be favored. The UAM is also sensitive to variations in boundary conditions of air quality data. This favors episodes in which the initial model day is not a strong O_3 event and there is consistent day-to-day O_3 buildup. The presence of frontal zones poses a particular problem. Frontal zones are defined as containing horizontal and vertical discontinuities in temperature, wind velocity, moisture and cloud cover. The UAM is sensitive to variations in all these parameters (*Seinfeld, 1988*). As a result, cases containing frontal zones are not favored for model selection.

B) Discussion of Selected Cases

The list of ozone episodes selected for UAM evaluation are given in Table 1. The remainder of this section briefly summarizes, by class, the reasons for selecting certain cases and deleting others.

Class 1: July 5-7, 1988 This case is the highest ranked case in Class 1 and second overall for the 1987-1990 period. It is also a strong regional ozone event. The 850 mb wind field is coherent throughout the period and a steady day-to-day buildup of O_3 is observed. The only shortcoming of this episode is the presence of a meso-scale low pressure center which develops along a lee trough on Day 3 (July 7th). Although not the best of the top three cases in Class 1, it is usable and a considerable body of knowledge regarding this episode is already available from the initial ROM-NET research effort. In addition, additional surface data has already been collected for this episode.

Class 1: June 13-14, 1988 This case is ranked second in Class 1 and fourth overall. It is characterized by coherent and generally invariant surface and upper air wind fields and a uniform day-to-day O_3 increase and ,as a result, is likely to be well-modeled by the UAM. In terms of the CART analysis, both TN2 (June 13th) and TN1 (June 14th) are represented in this case so that both stability regimes are included.

Class 1: May 28-30, 1987 This case is ranked third in Class 1 and eighth overall and is a good candidate for modeling although it is preceeded by two stronger cases. It may be of interest if problems develop with the either of the two first choices.

Class 2: July 29-30, 1988 This case is ranked second in Class 2 and sixth overall. It is one of the selected episodes due to coherent wind fields and steady day-to-day buildup of O_3. It is clustered into the strongest CART nodes (TN1 in Run 6B and TN5 in Run 8).

Class 2: June 20-22, 1988 This case is ranked nominally slightly lower than the July 29-30, 1988 episode (third in Class 2 and seventh overall) but is essentially equal in terms of severity and pervasiveness. It also has consistent winds although a lee trough is present on Day 3. It is a longer episode with two very strong O_3 days (June 21 and 22). For the CART analysis, this episode includes a case from TN6 in the wind analysis (Run 8) which is characterized by stronger winds.

Class 2: July 29-31, 1987 This episode is ranked fourth in Class 2 and ninth overall. It has a difficult surface and upper air wind field on Day 1 (July 29th) but is fairly consistent thereafter. The difficulties on Day 1 and the lower O_3 values are enough to relegate this episode to alternate status.

The strongest episode in this class (July 10-11, 1988) is not included in these choices. There are several reasons for its exclusion. First, the day prior to the event is a very strong O_3 event associated with a frontal zone. In fact, $[O_3]$ actually falls during the 10th and 11th. Thus, there is no gradual O_3 buildup to simulate and a very difficult boundary and initial condition problem is posed. In addition to the frontal zone on the preceding day (July 9th), a strong lee trough is present on July 10th with a very complicated wind field. For these reasons, and the fact that the previous Class 2 episodes are also strong events, this episode can be passed over.

Class 3: July 19, 1990 This episode is the only single-day O_3 event ranked in the top twenty (13th) for the 1987-1990 period and is ranked third in its class. Although multi-day events are preferred, there are several considerations that strengthen the case for this episode. First, all CART runs grouped this case separately from the bulk of the severe O_3 episodes. In Run 6B, it is grouped in TN4 and in Run 8 it is grouped in TN4 with the cases that have a stronger southerly wind component. Thus, this episode is favored in order to include distinct local meteorological regimes in addition to regional transport regimes. Second, this is the only post-1988 episode and, as such, benefits from additional upper air data. Third, trajectory analyses, using the HYSPLIT trajectory model (*Draxler et al., 1991*) are available at the University of Maryland for 1990 and will be useful in analysis of UAM results. Additionally, this case scores well on considerations of coherent upper air fields and strong daily build-up of O_3. Finally, the remaining cases in this class are not very well posed for UAM analysis.

Class 3: August 10-12, 1988 This episode is ranked second in Class 3 and 17th overall. There are several problems with this episode that make it less than optimum for UAM simulation. First, a weak frontal zone drifts into the region on Day 2 (August 11th) with attendant shifts in wind direction at the surface and at 850 mb. Additionally, there is a strong O_3 event on August 9th that will make the initial and boundary condition problematic.

The O_3 build-up is steady through the period, however, and the wind fields are coherent on Day 3, the strongest O_3 day. The CART analysis tends to group this case with the July 19, 1990 case above but it also provides an additional episode from TN2 in Run 6B.

Class 3: June 15-16, 1988 This event is the strongest O_3 episode in Class 3 and is ranked third overall. However, it follows immediately after the episode of June 13-14th and will present significant initial and boundary condition problems. The CART analysis tends to group this episode with the nodes most heavily represented in the strong cases above (TN1 in Run 6B and TN6 in Run 8) and the addition of this episode would tend to duplicate regimes.

Finally, none of the Class 4 frontal zone cases are selected for further analysis. This is based mainly on the difficulties in simulating discontinuities along frontal zones. The two strongest cases, July 14-18, 1988 and August 16-17, 1988, are ranked fifth and eleventh respectively and the selection of a number of stronger cases makes their deletion less of a difficulty.

Conclusion

Objective and subjective meteorological analyses of conditions characteristic of high ozone concentrations in the Baltimore-Washington (B/W) metropolitan area were carried out and a selection of six multi-day episodes, plus three alternates, made for UAM simulations. The subjective analysis expanded on the wind rose analysis recommended by the EPA to include considerations of regional transport in the upper model layers. The results of the subjective analysis identified four major meteorological regimes characterized generally by differences in upper air wind fields. A subsequent objective analysis, using the Classification and Regression Tree (CART) approach, investigated local stability and wind conditions and identified two basic temperature and stability profiles characteristic of O_3 events and several wind patterns. The episodes selected from the major classes determined in the subjective analysis above were chosen to include cases from all major CART regimes. The final selection of cases was then based on consideration of additional issues related to expected model performance.

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Table 1. Episode Selection for Baltimore-Washington UAM Domain

Date	Peak Ozone	Number of Violations	Domain Mean Max Ozone	Episode Rank
		Class 1		
July 5-8, 1988	194	20	150	2
June 13-14, 1988	183	17	137	4
May 28-31, 1988*	165	8	116	12
		Class 2		
July 29-30, 1988	172	11	127	6
June 20-22, 1988	178	14	124	7
July 29-31, 1987*	170	7	115	9
		Class 3		
July 18-20, 1990	150	11	119	13
August 10-12, 1988	159	7	112	17
June 15-16, 1988*	196	14	133	3

Table 1 contains the episodes selected for UAM simulations. Two episodes from each of three classes are selected along with one alternate marked by an asterisk. The peak O_3 concentrations ($[O_3]$, in ppbv) for the episode, the domain mean maximum $[O_3]$ and the number of monitors measuring $[O_3]$ in excess of the NAAQS are given for the most severe day within each regime. The episode rank is the sum of two sets of rankings based on severity and pervasiveness of O_3 violations for multi-day episodes in the 1987-1990 period. The severity rank is determined by the peak ozone concentration within the domain and the pervasiveness rank is determined by the domain-wide average maxima $[O_3]$. The final selection criteria included additional elements as described in Section 3 of the text.

Table 2. Wind Rose Data for BWI

Wind Direction	Non-Ozone Days (%)	Ozone Days (%)	Severe Ozone Days (%)
NNE	14.5	6.4	7.1
ENE	11.0	3.2	2.4
ESE	4.4	2.1	0.0
SSE	4.6	0.0	0.0
SSW	8.9	18.9	16.7
WSW	19.5	31.9	40.5
WNW	14.5	20.2	23.8
NNW	9.6	2.1	0.0
Calm	12.9	16.0	9.5
Number of Days	518	94	42

Table 2 contains the results of the wind rose analysis for BWI. The wind direction is based on resultant, or vector mean, wind summed over the hourly reports at BWI from 0700-1000-EDT for the period May-September 1987-1990. Mean wind magnitudes of less than 3 kts are considered calm. "Ozone Days" refers to those days in which at least one monitor within the B/W domain registered an hourly mean ozone concentration in excess of the National Ambient Air Quality Standard (NAAQS) of 120 ppbv. "Severe Ozone Days" refers to days in which greater than five monitors recorded NAAQS violations.

Table 3. Domain Ozone Monitors

Domain Ozone Sites			
EPA Number	Location	County	Remarks
24-003-0014	Davidsonville	Anne Arundel	
24-003-0019	Fort Meade	Anne Arundel	
24-005-0003	Garrison	Baltimore	
24-005-0010	Perry Hall	Baltimore	< 1989
24-005-1007	Cockeysville	Baltimore	
24-005-3001	Essex	Baltimore	
24-013-0001	Winfield	Carroll	
24-017-0010	Hughesville	Charles	
24-025-1001	Edgewood	Harford	
24-025-9001	Aldino	Harford	> 1988
24-029-0002	Millington	Kent	> 1988
24-031-3001	Rockville	Montgomery	
24-033-0002	Greenbelt	Prince George's	
24-033-8001	Suitland	Prince George's	
24-045-1004	UM Farm	Wicomico	
24-510-0018	Baltimore	Baltimore	
24-510-0036	Fort Holabird	Baltimore	> 1989
51-013-0020	Arlington	Arlington	
51-059-1004	Fairfax	Fairfax	
51-061-0002	Fauquier	Fauquier	
51-510-0009	Alexandria	Alexandria	
51-600-0005	Fairfax	Fairfax	
11-001-0017	D.C.		
11-001-0025	D.C.		

Table 3 contains the ozone monitors included in the subjective and objective episode selection analysis. Because the density of monitors in Fairfax County, Virginia exceeded those of other localities, only two of the four available Fairfax stations were included. The excluded stations are: 51-059-0018 and 51-059-5001. In addition, the model domain was expanded while this analysis was in progress to include portions of Delaware and Pennsylvania. These stations are not included in the present analysis.

Table 4. Classifications for 1983-1990

Date	Peak Ozone	Domain Mean Max Ozone	Numberof Violations	Subset
Class 1				
July 5-8, 1988	194	150	20	A
June 13-14, 1988	183	137	17	B
May 28-30, 1987	199	113	11	A
June 11-14, 1983	170	129	14	B
July 22-25, 1987	171	114	7	B
May 28-31, 1988	165	116	8	C
July 15-16, 1983	152	116	7	B
August 7-9, 1988	149	98	2	C
August 14-15, 1983	138	98	3	C
July 18-19, 1984	137	103	5	C
July 25-27, 1989	141	89	2	A
June 17-18, 1990	137	93	2	C
August 6-7, 1983	131	97	2	C
July 7-8, 1986	136	88	3	A
Class 2				
July 10-11,1988	218	147	17	B
June 20-22, 1988	178	124	14	A
July 29-30, 1988	172	127	11	B
July 11-12, 1983	189	121	9	A
July 2-3, 1983	195	115	8	B
July 19-21, 1983	168	123	10	A
August 8-9, 1983	173	113	5	A
July 29-31, 1987	170	115	7	A
July 20-21, 1985	152	108	4	A
July 2-3, 1983	195	115	8	B
August 4-5, 1987	150	98	3	A
June 27-29, 1990	145	101	5	A
Class 3				
June 15-16, 1988	196	133	14	A
July 28-31, 1983	171	122	9	A

August 14-15, 1985	188	106	5	B
June 26-27, 1983	176	106	4	A
August 10-15, 1988	159	112	7	B
July 19, 1990	150	119	11	B
August 16-18, 1983	151	109	6	A
August 8-9, 1987	159	104	4	A
June 5-10, 1984	165	97	4	B

Class 4

July 14-18, 1988	181	121	7
August 16-17, 1988	167	115	10
July 13-14, 1984	187	103	3
June 12, 1984	150	116	8
August 10-11, 1983	152	104	4
August 13, 1985	157	100	5
July 28-29, 1986	160	94	4
July 15-17, 1986	131	104	7
August 2-3, 1984	141	98	4
July 7-9, 1987	137	82	1
August 3-4, 1986	121	90	1

Unclassified

July 9, 1988	190	138	13
July 27, 1983	164	105	7
May 17-18, 1987	155	108	7
July 17-19, 1987	161	104	4
June 15-17, 1983	149	124	9
June 22-23, 1983	157	102	5
June 11, 13, 1984	151	100	5
August 25-27, 1983	150	87	1
August 15, 1983	138	98	3
July 23-24, 1989	141	89	2

Cases With Unavailable Data

September 9-12, 1984	169	144	8
May 17-18, 1987	155	108	7
September 18-20, 1985	141	104	3
May 29-31, 1986	143	103	3
September 5-6, 1984	129	68	1
September 9-10, 1989	126	81	1

Table 5. Classification of Multi-Day Ozone Episodes

Sets	All Days	Episode Days	Classified Days
Total Cases	208	159	123
Severe Cases	72	60	55
Extreme Cases	30	26	22

Table 5. This table shows the propensity of ozone exceedance days to occur in episodes of greater than one consecutive day and the ability of the four-class subjective analysis structure to categorize these episodes. The All Days column gives the number of ozone exceedance days in the B/W domain for the period May-September of 1983-1990, the number of severe cases (greater than 5 monitors measuring ozone in excess of the NAAQS), and the number of extreme cases (greater than 8 monitors measuring ozone in excess of the NAAQS). The Episode Days column gives the same data only for those cases of greater than one consecutive day of ozone violations. The Classified Days column refers to cases able to be classified into meteorological regimes for the purposes of episode selection. Only the episode days were classified. Of the 36 unclassified cases, 16 were unclassified due to the unavailability of upper air charts. As a result, the overall success rate for classification of those cases with a full data set is 123 of 143 or 86%. Of the five severe cases that are not classified, three are unclassified due to missing data. Finally, two of the four unclassified extreme cases are due to missing data.

Table 6. Ranking of Severe Ozone Events with CART Terminal Node Results

Dates	Peak Ozone	Domain Ozone	CART Node Run 6B	CART Node Run 8
July 10-11,1988	218	147	1	4
July 5-8, 1988	194	150	1	5,4
June 15-16, 1988	196	133	1	5,6
June 13-14, 1988	183	137	2,1	5
July 16-18, 1988	181	121	1	4
July 29-30, 1988	172	127	1	5
June 20-23, 1988	178	124	1,4	6,5
May 28-30, 1987	199	113	NA	NA
July 29-31, 1987	170	115	1	6
July 22-25, 1987	171	114	4,2	5,4
August 16-17, 1988	167	115	4	6
May 28-31, 1988	165	116	NA	NA
July 19, 1990	150	119	4	4
August 9-15, 1988	159	112	2	4

Table 8 contains a ranking of the top multi-day O_3 events, based on the sum of the ranking of the peak O_3 and domain mean O_3 maximum, along with the terminal node membership from two CART runs discussed in the text.

Table 7a. Summary Statistics for Run 5B

CART Node	Number of Cases	Ozone Days (%)	Number of Extreme Ozone Days	T (1400)	Sky Cover (1400)
1	211	2	0	78.2	7.0
2	69	0	0	71.1	9.8
3	179	23	7	82.4	3.3
4	168	30	13	88.3	4.3
5	109	78	41	92.8	2.2

Table 7b. Summary Statistics for Run 6B

CART Node	Number of Cases	Number of Severe Ozone Days	Number of Extreme Ozone Days	θ_v 950 mb (deg K)	θ_v 750 mb (deg K)	Sky Cover in tenths (1400)
1	43	11	16	304.5	308.0	2.8
2	38	12	5	300.7	308.5	0.4
3	13	0	0	301.0	309.4	0.5
4	101	13	4	301.7	308.3	4.2

Table 7c. Summary Statistics for Run 8

CART Node	Number of Cases	Number of Severe Ozone Days	Number of Extreme Ozone Days
1	102	0	0
2	46	0	0
3	37	1	0
4	110	12	9
5	58	13	13
6	204	9	3
7	43	0	0
8	136	0	0

Tables 7a-c provide summary statistics on several CART runs. Ozone days are categorized as "severe" if greater than 5 but less than 8 monitors measure O_3 in excess of the NAAQS and as "extreme" if greater than 8 monitors are in excess of the NAAQS.

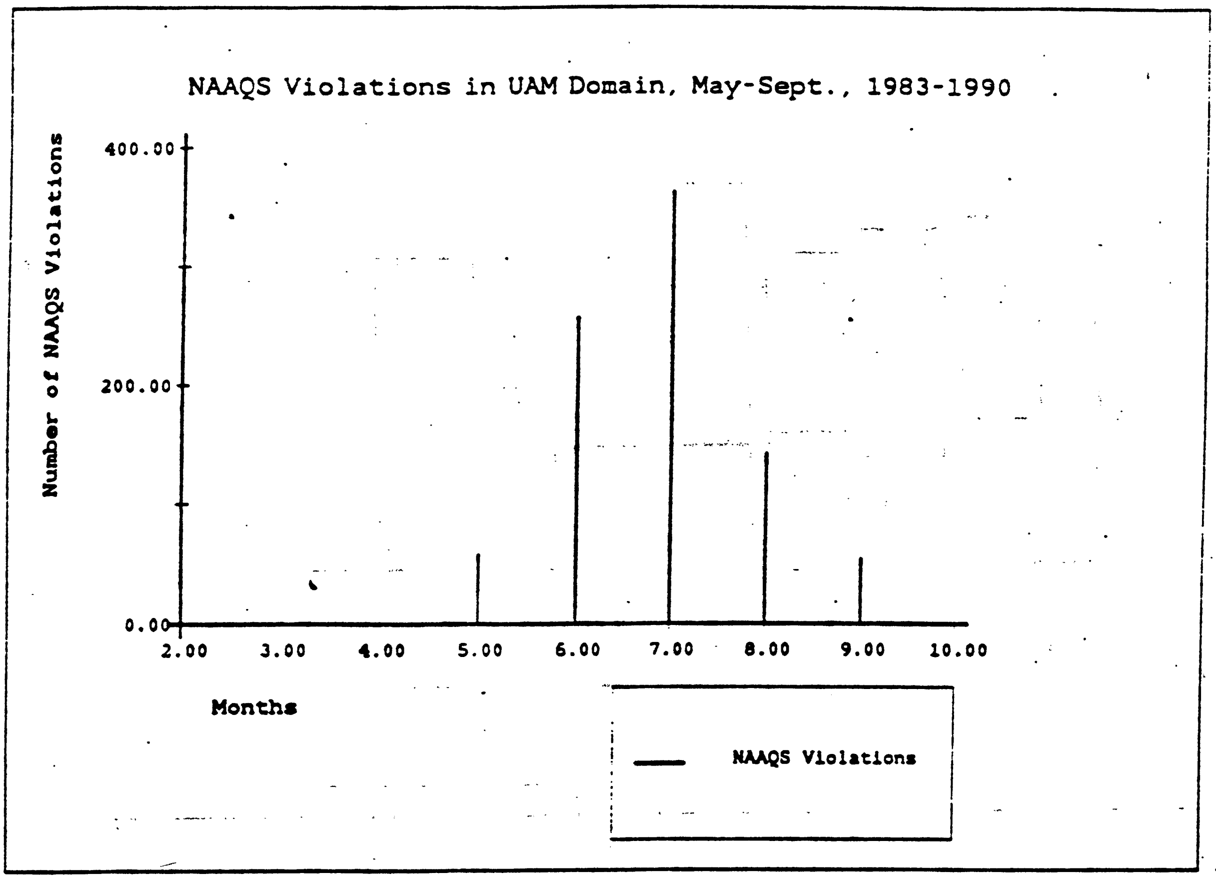


Figure 1. Monthly distribution of NAAQS O_3 violations for the B/W domain for the 1983-1990 period. Months of the years are given on the ordinate in standard numeric values.

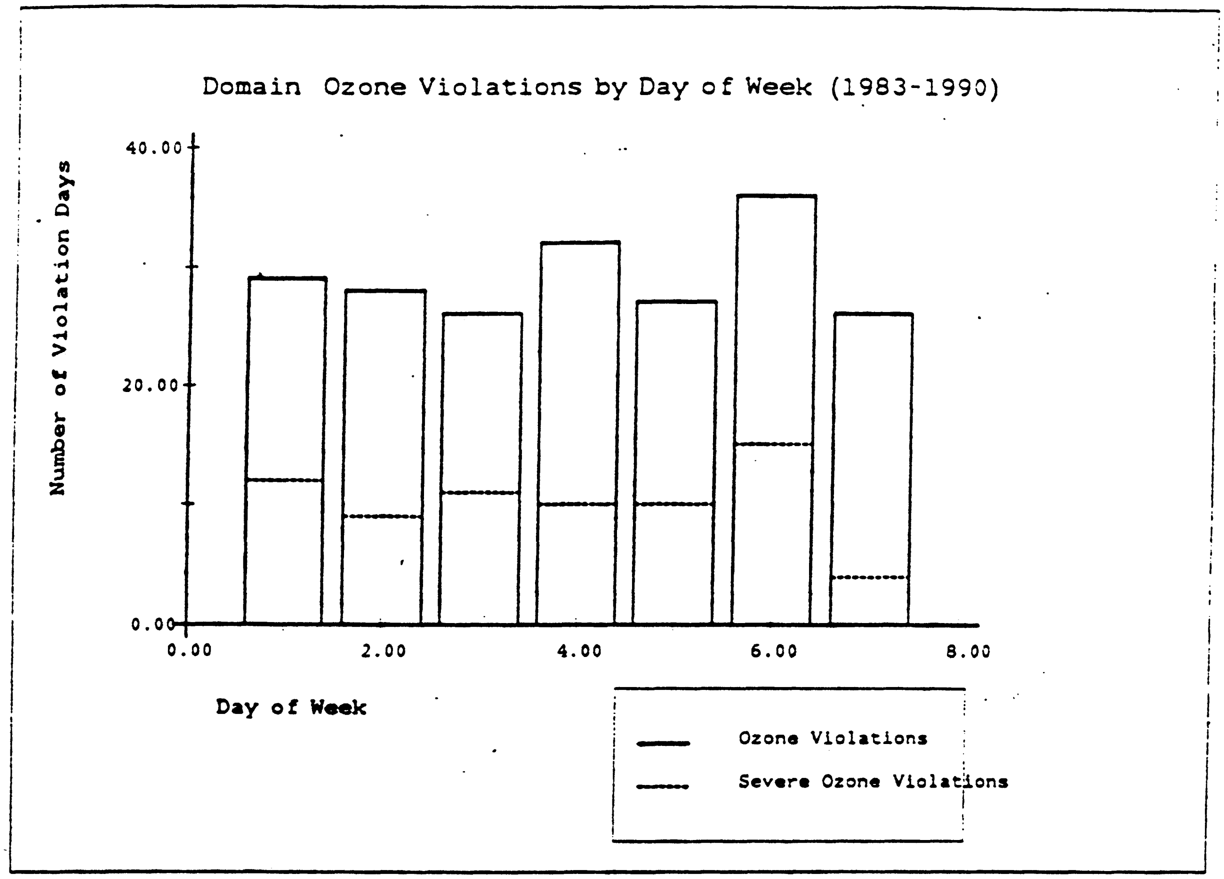


Figure 2. Day-of-week distribution of days with NAAQS O_3 violations, and severe O_3 violations, for the B/W domain in the 1983-1990 period. Severe O_3 events are defined as days in which 5 or more monitors recorded NAAQS violations. Day-of-week is given on the ordinate with Day 1 assigned to Monday.

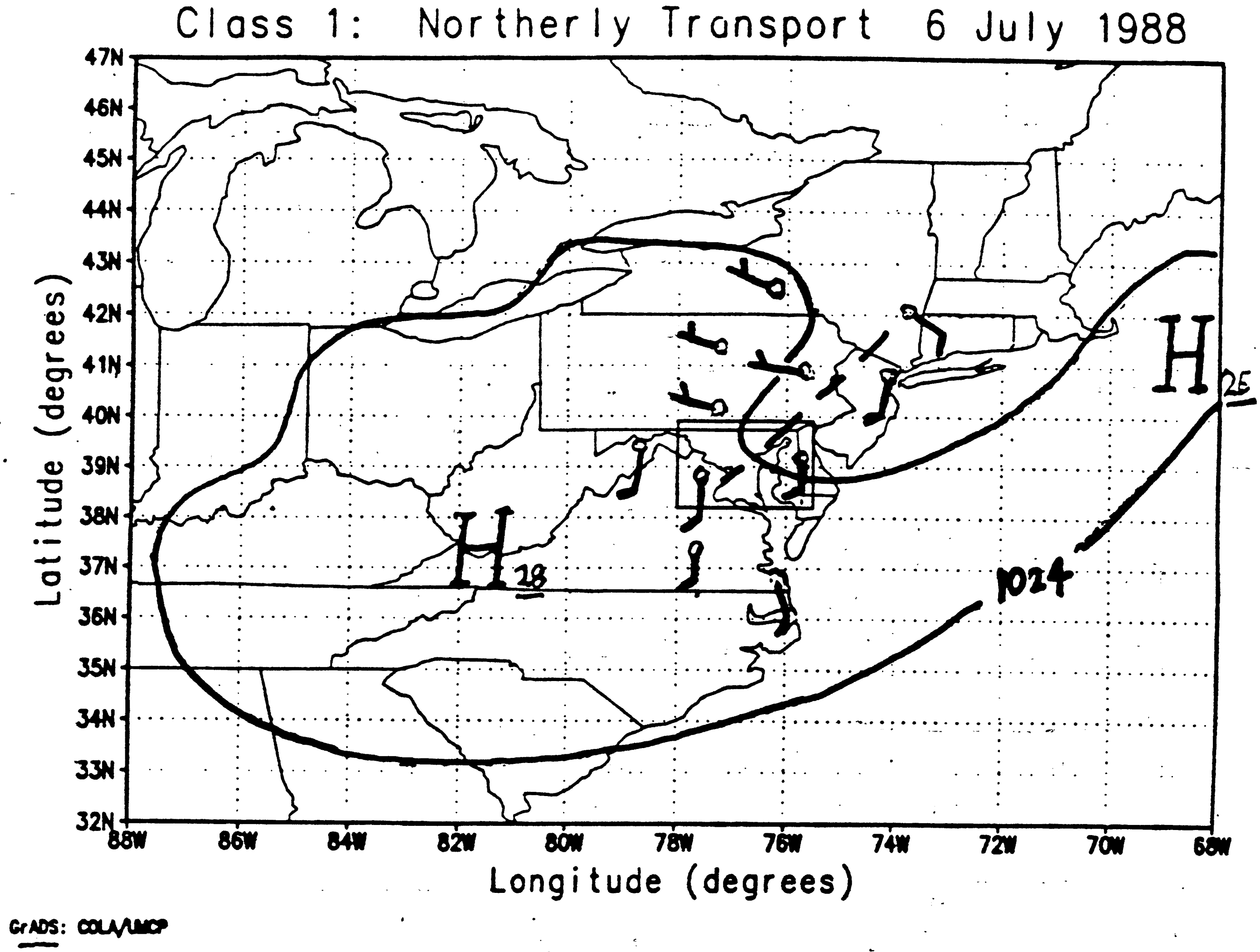
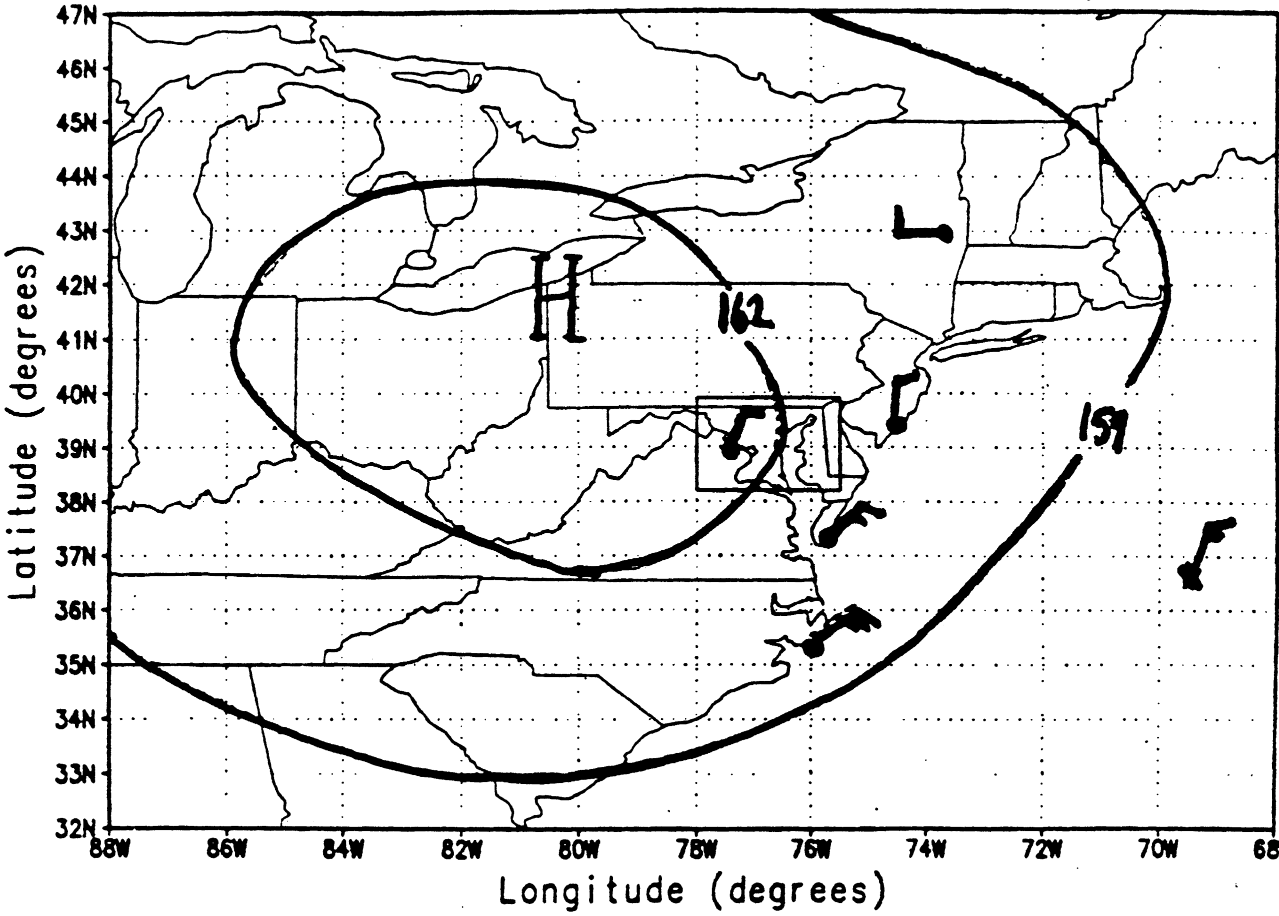


Figure 3a. Surface conditions adapted from NWS surface synoptic charts for July 6, 1988. Contours are in millibars with the central pressure of local maximum or minimum pressure centers given in tens of millibars. Surface pressure troughs are denoted by dashed lines and fronts (none shown in Figure 3a) are denoted by thick lines using standard meteorological symbols for cold fronts (triangles), warm fronts (semi-circles) and stationary fronts (alternating triangles and semi-circles). Wind direction and speed at selected stations are denoted by arrows which "fly" with the prevailing wind direction. Full terminal strokes denote 10 knots and half-strokes denote 5 kts. The UAM domain for the B/W metropolitan area is enclosed within a box.

Class 1: Northerly Transport 6 July 1988



GrADS: COLA/UMCP

Figure 3b. Conditions at 850 mb, adapted from NWS constant pressure upper air charts, for July 6, 1988. Contours of geopotential height are in decameters. Wind direction and speed at selected upper air stations are denoted by arrows which "fly" with the prevailing wind direction. Full terminal strokes denote 10 knots and half-strokes denote 5 kts. The UAM domain for the B/W metropolitan area is enclosed within a box.

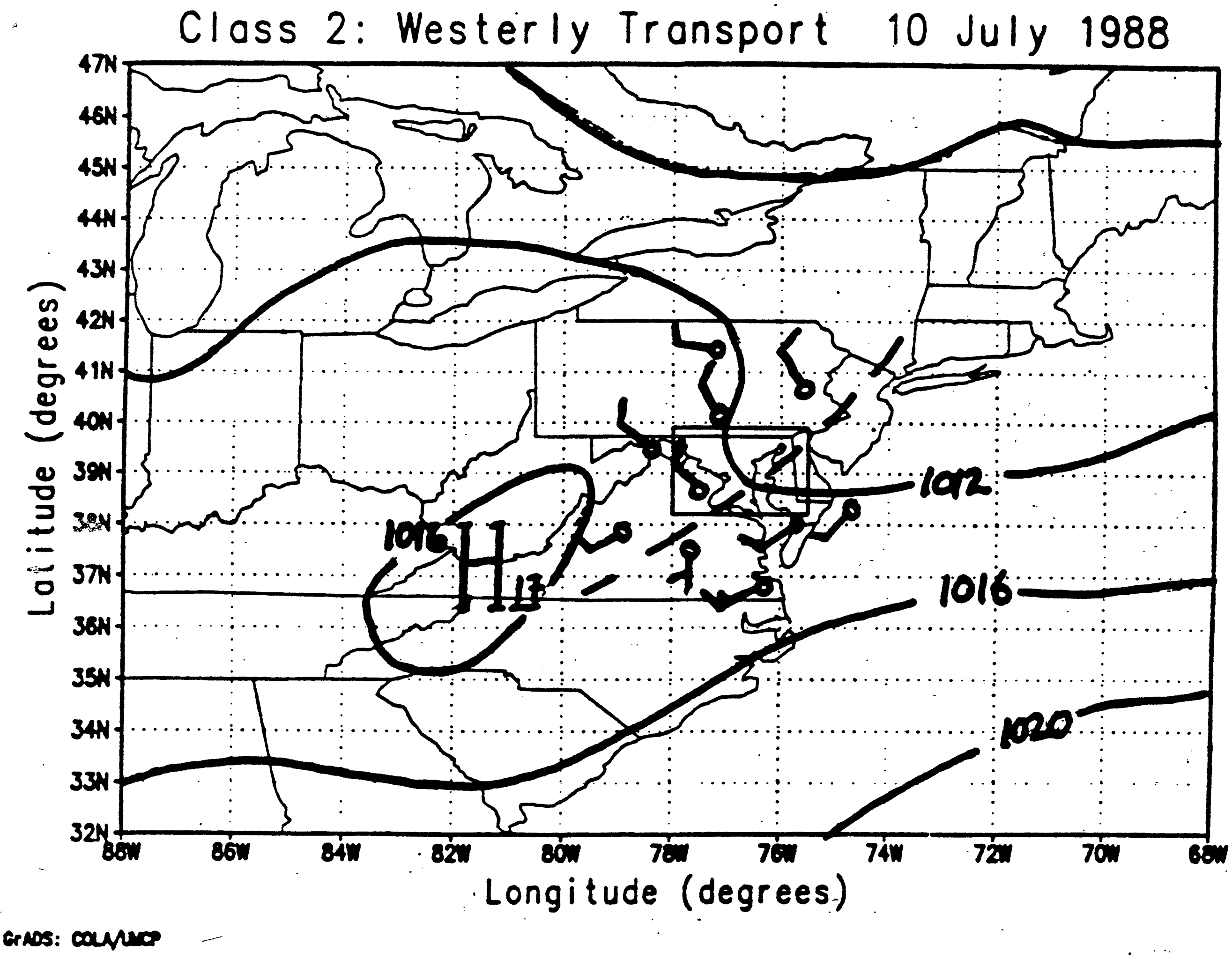


Figure 3c. Surface conditions, as in Figure 3a, except for July 10, 1988.

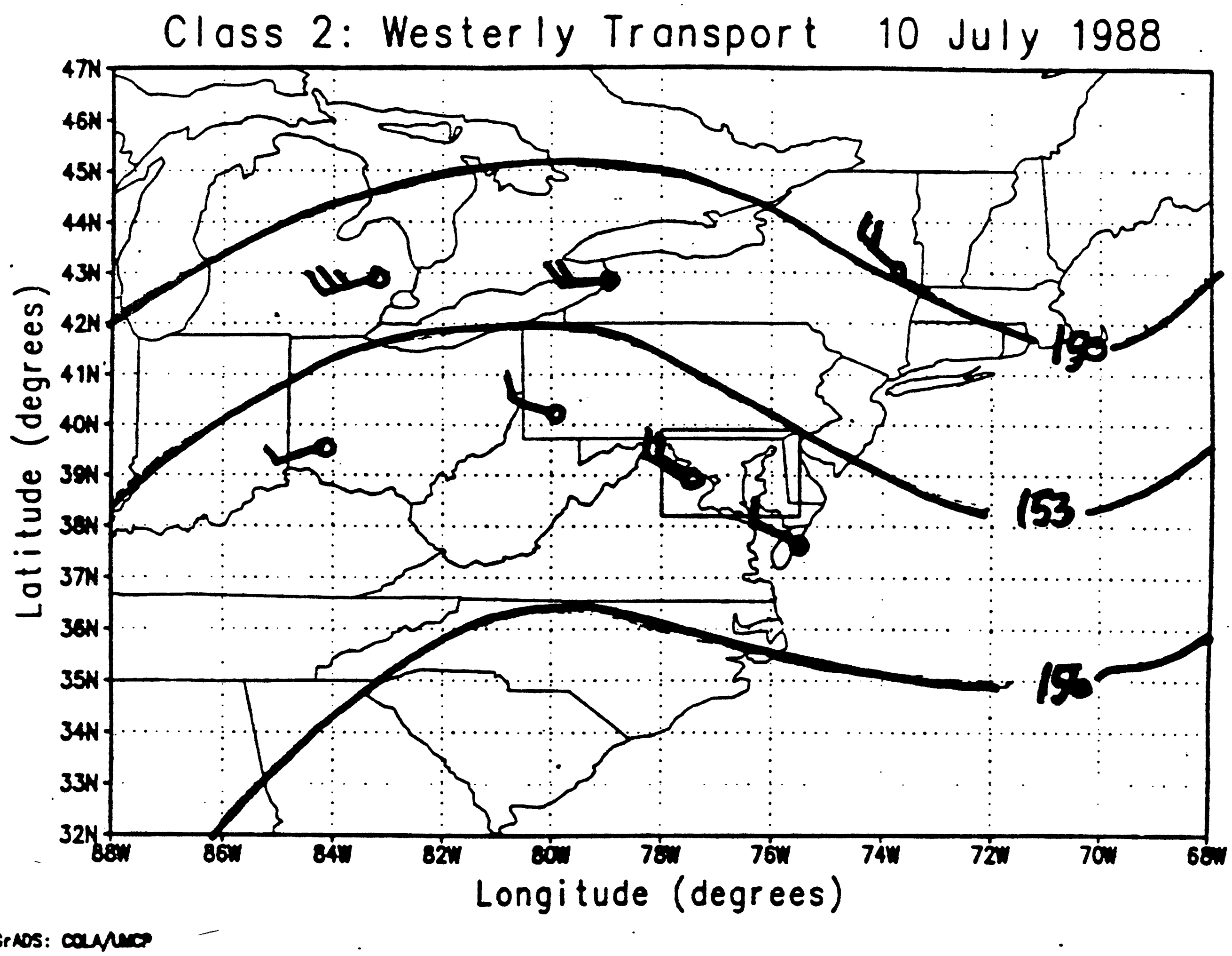


Figure 3d. Conditions at 850 mb, as in Figure 3b, except for July 10, 1988.

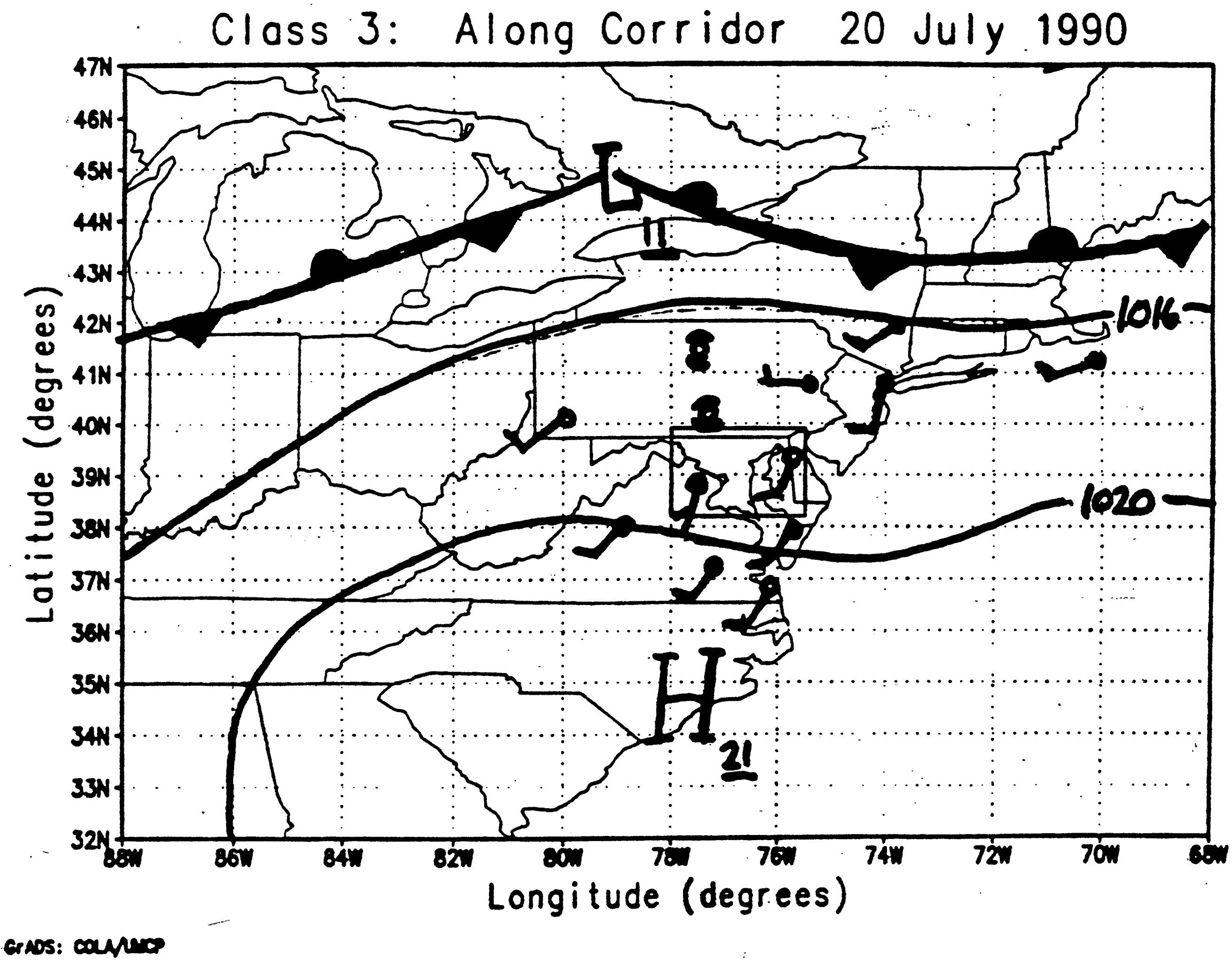


Figure 3e. Surface conditions, as in Figure 3a, except for July 20, 1990.

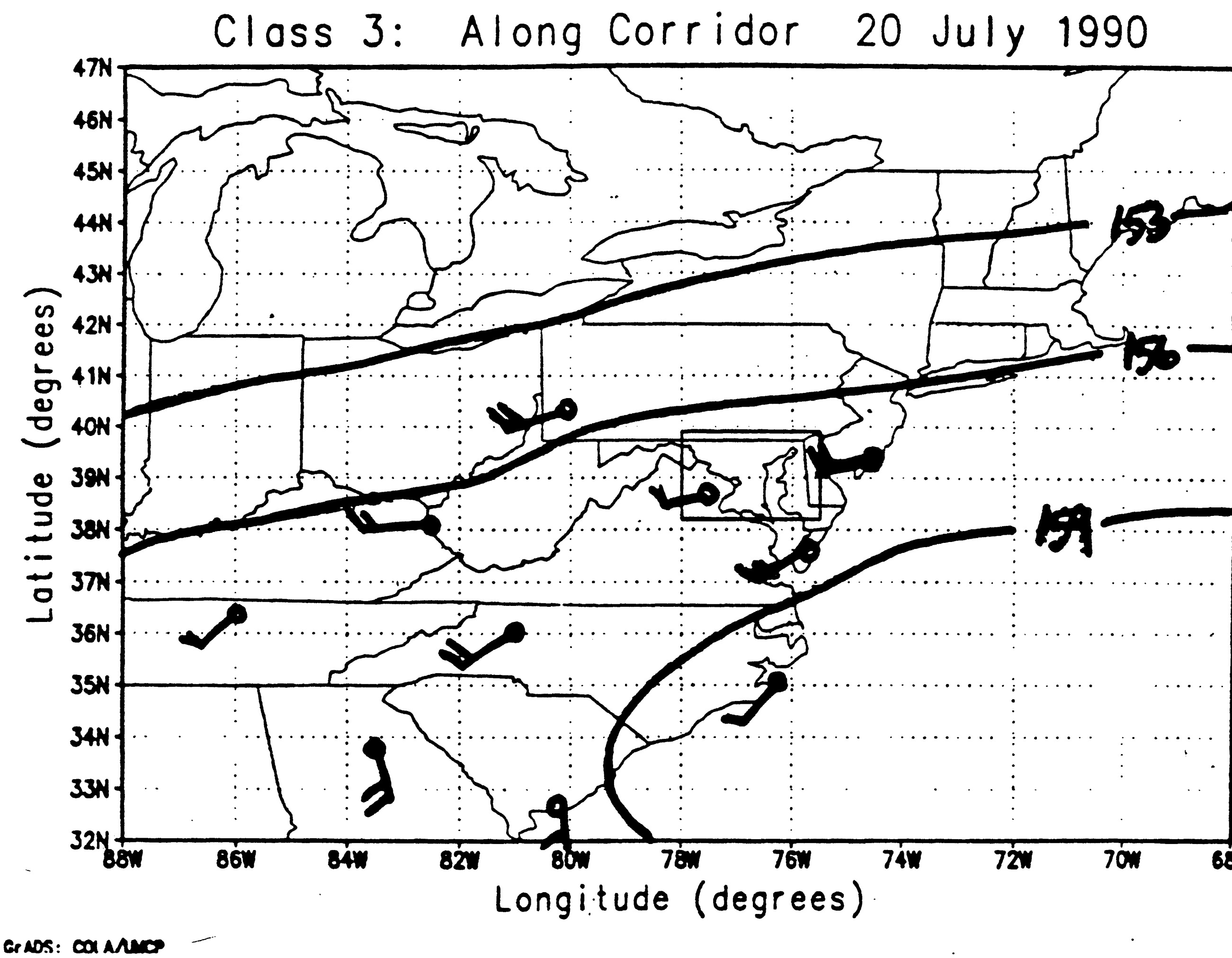


Figure 3f. Conditions at 850 mb, as in Figure 3b, except for July 20, 1990.

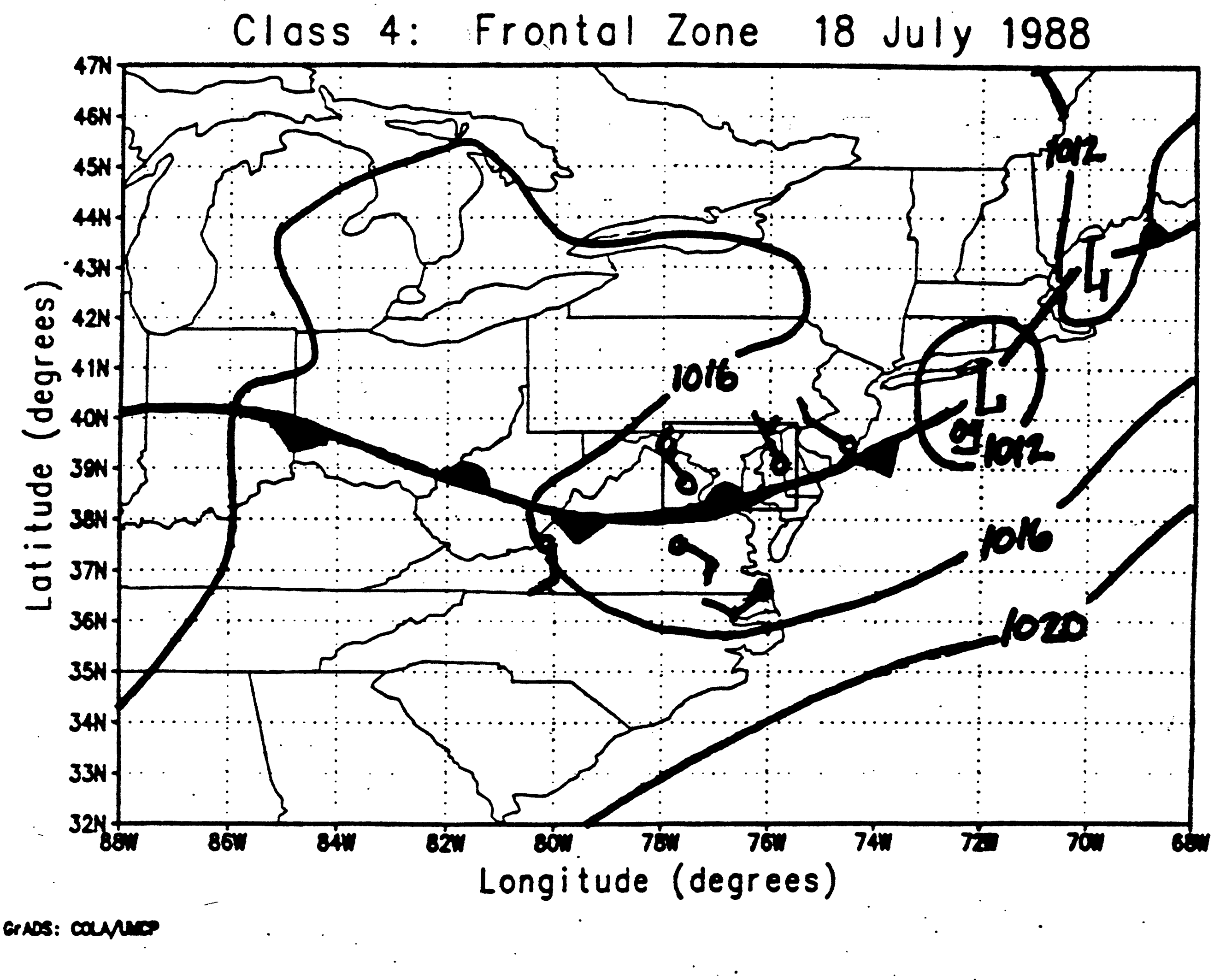


Figure 3g. Surface conditions, as in Figure 3a, except for July 18, 1988.

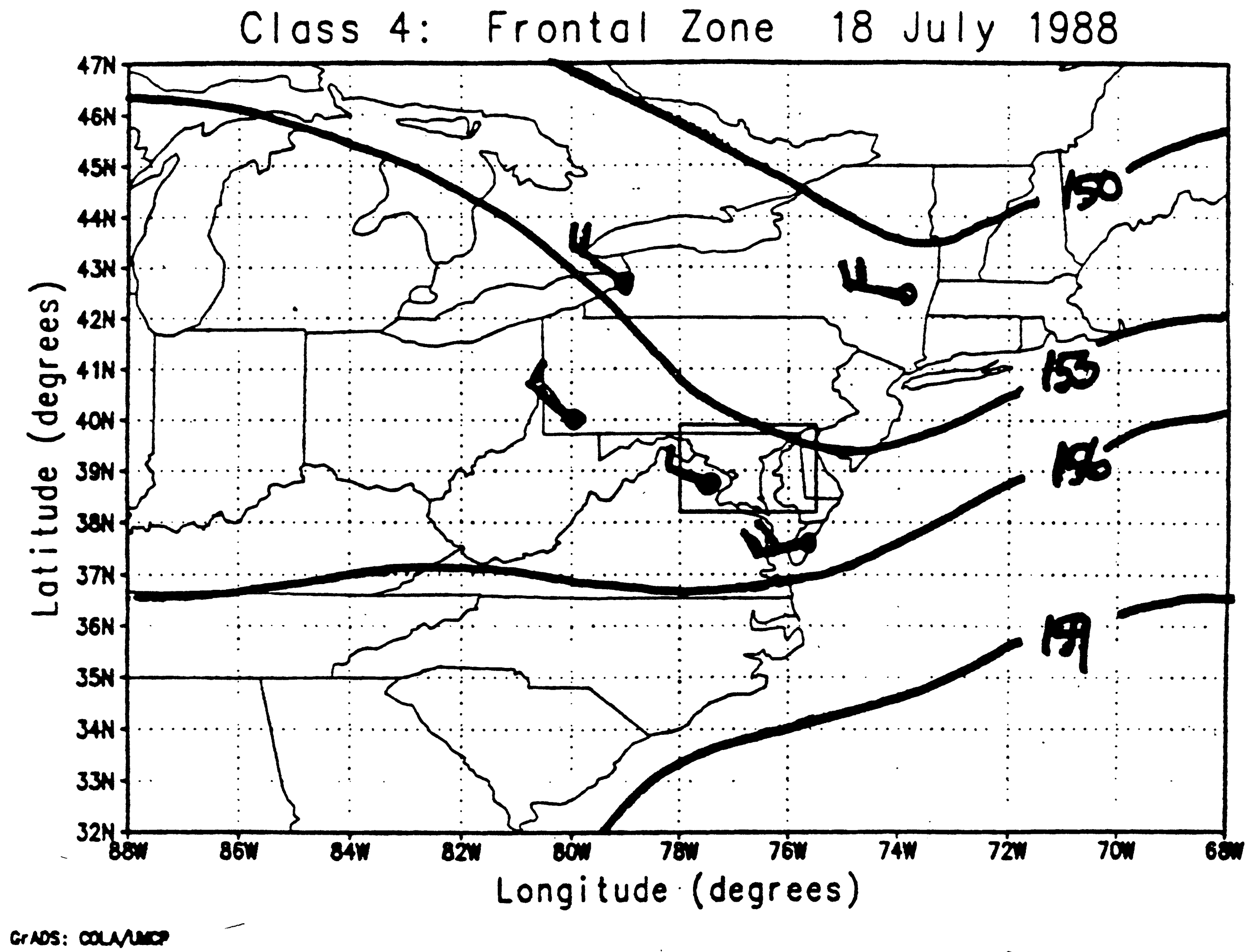


Figure 3h. Conditions at 850 mb, as in Figure 3b, except for July 18, 1988.

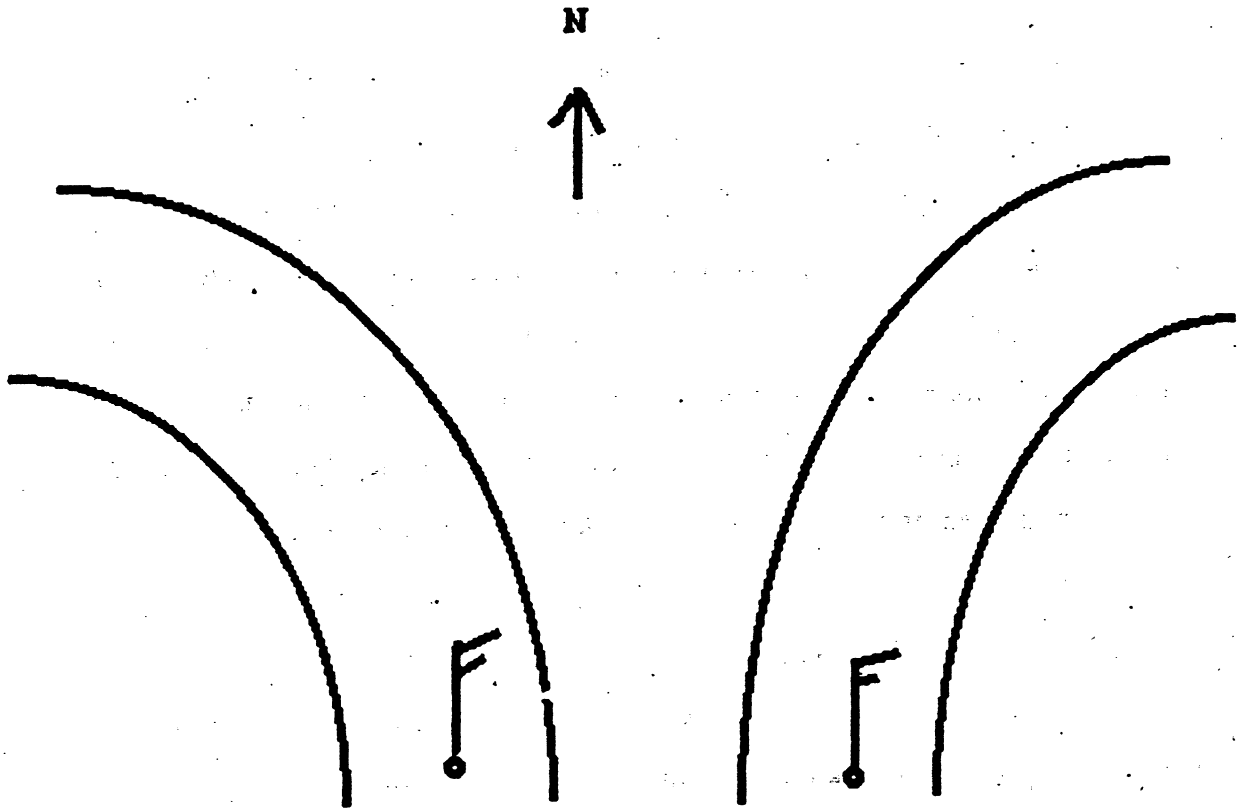


Figure 4. Idealized version of differences in transport regimes associated with similar point wind directions. In both cases, winds are locally north while the source region for air parcels passing the stations are markedly different.

Appendix A

This Appendix contains additional work on the episode selection question using cluster analyses and expands on the brief discussion contained in *Ryan [1992]* (A copy is attached).

EPA has recommended that several groups of historical O_3 episodes be modeled with each group representative of a "distinctly different source-receptor relationship" (*EPA, 1991*). Identifying discrete transport regimes in the context of severe O_3 episodes is a difficult process. Severe O_3 events in the eastern U.S. are typically associated with slow-moving, or stagnant, surface anticyclones (*Vukovich et al., 1977; Vukovich and Fishman, 1986*). Light and variable surface winds are associated with anticyclonic flow, especially near the center of the anticyclone. As a result, the presence of strong surface wind signals for distinct types of O_3 events are not expected. In the B/W domain, there is an additional complicating factor in the strong bay breeze signal associated with weak synoptic forcing (*Scofield and Weiss, 1977*). This effect is often not resolved by the synoptic-scale observation network.

When wind rose calculations are carried out as suggested by the EPA, there is a strong WSW signal in all cases *(Figure 1)*. This suggests that there is only one transport regime associated with strong O_3 events or that this method is not effective.

In order to determine if there are any useful classification strategies, three approaches were undertaken: (1) Cluster analysis; (2) Classifcation and Regression Tree (CART) analysis (discussed in the main report above), and; (3) Subjective analysis of severe O_3 events (also discussed above). The cluster analysis utilizes the standard synoptic climatological approach to determine weather patterns with a set of meteorological data from a single location in a particular season (*Kalkstein and Corrigan, 1986*). The shortcoming of this approach is that weather patterns, expressed in terms of meteorological variables, are generally homogeneous and categorization results in a loss of information as cases are forced into a Procrustean bed of clusters. In this study, summer season (June, July and August) data at Baltimore-Washington International Airport (BWI) for the period from 1983-1990 was used. Surface data consist of four times daily (10, 14, 18 and 2200 Z) pressure, temperature, dew point temperature, wind velocity and sky cover. Upper air data from the closest upper air station, Dulles (IAD) was also included and consisted of 12Z temperature, moisture (expressed as dew point temperature) and wind velocity at 850 and 700 mb. All wind data is expressed in vector components (u,v).

The cluster analysis consisted of two steps: First, principal components analysis (PCA) was applied to the original data matrix (*Kalkstein and Corrigan, 1986*). PCA is a type of factor analysis in which the observed meteorological data is re-written into a set of linearly independent "components". The weights, or "loadings", for each variable within each component are determined and each day is assigned a "score" for each component based on the observed data. The cluster analysis is performed on the matrix of component scores. For this analysis,the average linkage method is used (*Kalkstein et al., 1987*). This is an average of the complete and single linkage methods and compares the squared Euclidean distance between pairs of data. The SYSTAT statistical package was used to carry out the PCA analysis. Because the subsequent cluster analysis is computationally demanding, the IMSL cluster package was used.

The results from the first pass through all the data is shown in *Figure 2*. As expected, the bulk of the total variance is determined by temperature, pressure and sky cover. Two clusters contain the bulk of the most severe cases. In terms of source-receptor relationships, both clusters exhibit light WNW upper air winds. They are generally distinguished by the hot and moist conditions in Cluster 3 and stagnant conditions in Cluster 9.

In order to investigate smaller scale variations sufficient to reach a conclusion regarding source-receptor relationships, a second pass was made through the 195 cases in which domain mean O_3 exceeded 90 ppbv or in which the NAAQS was violated (*Figure 3*). The major components are essentially the same as in the initial run except that three additional components are added that include combinations of surface and upperair winds, afternoon sky cover and upper air temperatures. The two strongest O_3 clusters are similar to the major clusters above: C6 is extremely hot and moist with WNW winds aloft but afternoon southerly surface winds. The remaining clusters, which have less severe average O_3, but contain a smattering of severe cases, are variants on the strongest cluster (C6), with differences mainly relating to wind direction. C2 contains WNW winds aloft but stead WSW surface winds without any southerly afternoon component. C1 is extrememly hot and muggy like C6 but with a more northerly component to surface and upper air winds. The remaining strong O_3 cluster is cooler and drier with a stronger southerly wind component.

When the subjective classifications are compared to the second run cluster analysis for the fifteen strongest O_3 episodes, from which the final selection must be made, there is some overlap. In general, Cluster 2 (C2) is represented in all subjective classes. C1 (northerly flow) and C3 (stagnant) are associated with Class 1 in the subjective analysis. C2 (hot with WNW upper air and WSW surface) is associated with Class 2. C4 (southwesterly winds) is associated with Class 3. A similar comparison with the CART terminal nodes is less successful. The cases from Classes 1 and 2, which exhibit similar surface conditions, are typically grouped together by the CART analysis. Class 3 is separated into another node by CART. If all multi-day events are compared, there is very little coherence between the cluster, CART and subjective anlaysis.

Table 2. Wind Rose Data for BWI

Wind Direction	Non-Ozone Days (%)	Ozone Days (%)	Severe Ozone Days (%)
NNE	14.5	6.4	7.1
ENE	11.0	3.2	2.4
ESE	4.4	2.1	0.0
SSE	4.6	0.0	0.0
SSW	8.9	18.9	16.7
WSW	19.5	31.9	40.5
WNW	14.5	20.2	23.8
NNW	9.6	2.1	0.0
Calm	12.9	16.0	9.5
Number of Days	518	94	42

Table 2 contains the results of the wind rose analysis for BWI. The wind direction is based on resultant, or vector mean, wind summed over the hourly reports at BWI from 0700-1000-EDT for the period May-September 1987-1990. Mean wind magnitudes of less than 3 kts are considered calm. "Ozone Days" refers to those days in which at least one monitor within the B/W domain registered an hourly mean ozone concentration in excess of the National Ambient Air Quality Standard (NAAQS) of 120 ppbv. "Severe Ozone Days" refers to days in which greater than five monitors recorded NAAQS violations.

Figure 1

Cluster Analysis (1)

Component	Variable	%Variance
1	Surface T and T_d	27.0
2	Pressure, Height	19.3
3	Sky Cover	15.2
4	Surface v-Component	8.0
5	Upper Air u-Component	4.8
6	Stability Criteria	3.3
Total		77.6

Two Strong O_3 Clusters (C3 & C9): 83% of Extreme Cases

Cluster	Mean Ozone	Surface WD	Upper Air WD °F	T 18Z °F	T_d 18Z
C1	62.8	SE	W	79	66
C2	48.2	ENE	W-	75	66
C3	88.4	W/SW	WNW	89	67
C4	71.3	NW+	NW+	85	63
C5	64.7	NW+	NW+	82	54
C6	84.5	SSW	WNW	82	57
C7	58.4	WNW+	WNW	77	49
C8	76.7	NW-	NNW	80	54
C9	84.5	Calm/WNW-	NW-	86	64
C10	61.9	SW	WSW	82	67

Figure 2

Cluster Analysis (2)

High Ozone Days (N= 195)

Component	Variable	%Variance
1-6	Same as Cluster (1)	69.5
7	v-Surface, v-Upper Air	3.4
8	u-Upper Air, 22Z Sky Cover	3.2
9	Upper Air T, p.m. Sky Cover	3.0
Total		79.0

Similar Mix of Major Components

Three Additional Components

Cluster	Mean Ozone	Surface WD	Upper Air WD °F	T 18Z °F	T_d 18Z
C1	98.0	WNW	NW	92	65
C2	100.0	WSW	WNW	90	65
C3	103.5	Calm	NNW-	88	66
C4	96.0	Calm/SSW	WNW	85	62
C5	92.0	W	WNW+	87	72
C6	107.3	WSW/S	WNW	92	69

Figure 3

Episode 3B
"Average" Ozone Episode
July 14-16, 1991

The selection of episodes for photochemical modeling has focused on the identification and selection of the most ozone (O_3) events in the Baltimore-Washington region. These severe episodes have posed problems for modeling and control strategy development. In particular, the severe episodes are often characterized by complex meteorological fields that are difficult for the standard UAM preprocessors to handle. This apears to be the case for Episode 1 (July 5-7, 1988). In addition, matrix runs with severe episodes suggest that extreme control measures are necessary to reduce O_3 to the NAAQS.

At the request of the UAM Policy Committee, we have reviewed alternative episodes that are less severe in terms of peak O_3. The selection process was initially limited to already available ROM episodes so that the episode could be worked up as soon as possible.

Within the ROM episodes, which typically contain severe O_3 events, the Baltimore-Washington domain experienced some less severe episodes. We identified three possible less severe episodes within ROM:

June 16-18, 1987
July 31-August 2, 1988
July 14-16, 1991

Basic statistics for these epsides are contained in Table 1. In terms of single station peak O_3, all episodes are in the 90th percentile of peak O_3. The 1988 episode contains the highest peak (157 ppbv) though the mean of all monitor peaks is lowest (64 of 1140). The 1991 episode is the most pervasive event with 6 violations and ranks 55 of 1140 in terms of mean peak O_3.

The 1991 episode was selected as the best less severe episode. This was based on the following criteria:

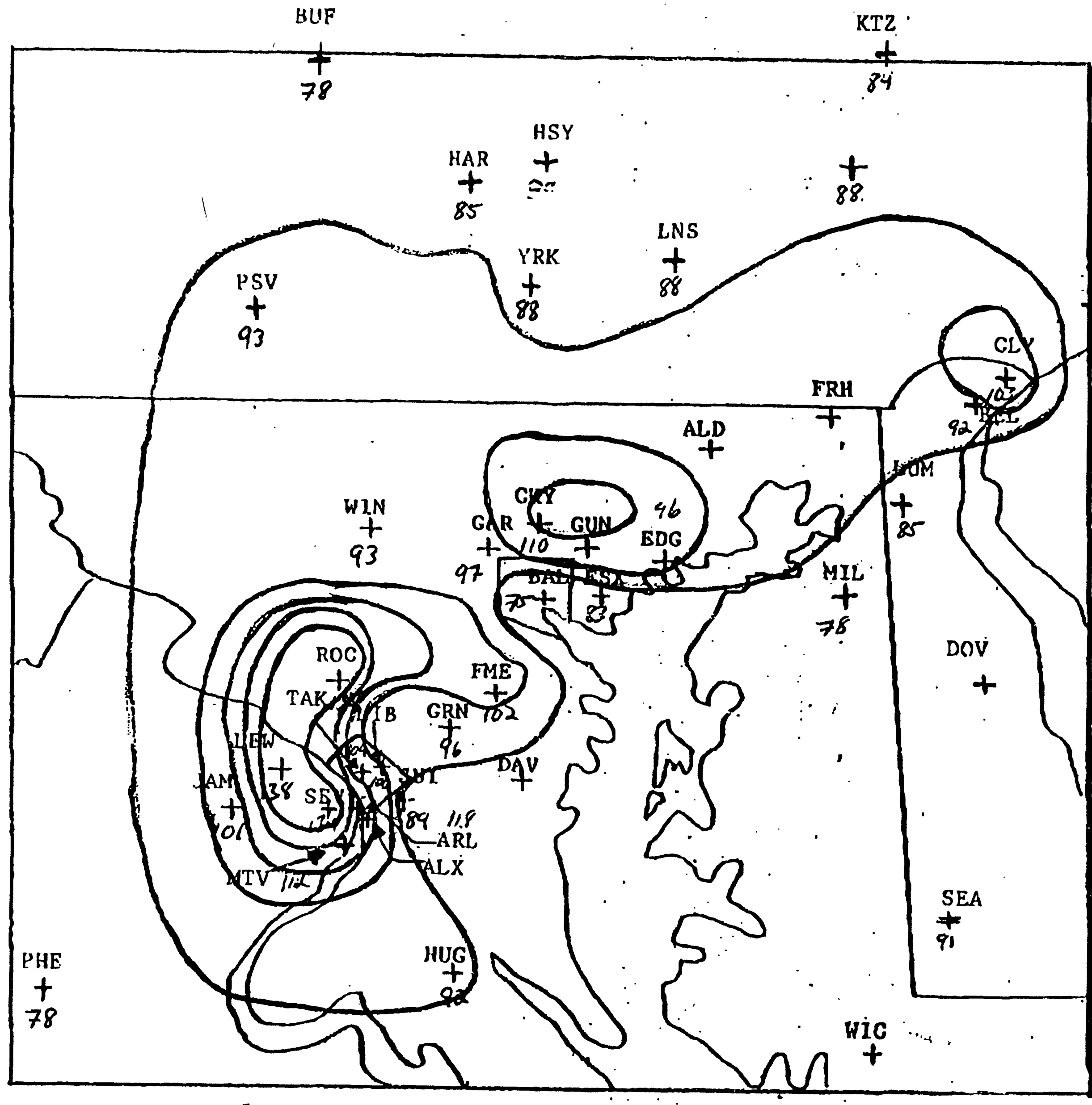
1. Emissions files for Episode 3 (July 18-20, 1991) could be easily converted for use with this episode.
2. The 1991 episode occurs early in the ROM episode when ROM performance is better.
3. OTC Strategy C2 and E are already available for this episode and not for the others.
4. Upper air data from Aberdeen Proving Ground is available for the 1991 episode only.

The meteorological conditions associated with the 1991 episode appear to be model tractable. The episode begins with a frontal passage on the 14th. This front stalls south of the domain and eventually dissipates. The overall advection pattern is northerly and northwesterly at 850 mb with high pressure moving almost directly overhead early on the 16th with light and variable winds. During the day on the 16th, winds at 850 mb become southerly. Winds near the surface also become southeasterly around mid-day on the 16th and the high O_3 plume that day is advected to the west of both Washington and Baltimore. The highest O_3 is recorded west of Washington (Rockville) and the Baltimore and Washington plumes appear to merge further northwest later that day.

Table 1

Alternative Ozone Episodes (ROM)					
Date	Peak Ozone (ppbv)	Mean Peak Ozone (peak)	Peak Rank (out of 1140)	Mean Rank (out of 1140)	Number of NAAQS Violations
June 16-18, 1987					
June 16	98	76	474	616	0
June 17	111	88	299	225	0
June 18	140	108	23	62	4
July 31-August 2, 1988					
July 31	91	77	580	440	0
August 1	117	92	220	173	0
August 2	157	107	36	64	5
July 14-16, 1991					
July 14	82	67	726	627	0
July 15	102	78	425	419	0
July 16	137	108	97	55	6

FROM:410 6'1 3202 TO: 061 301 314 9482 APR 13 '95 08:42AM APR 13, 1995 8:47AM P.01

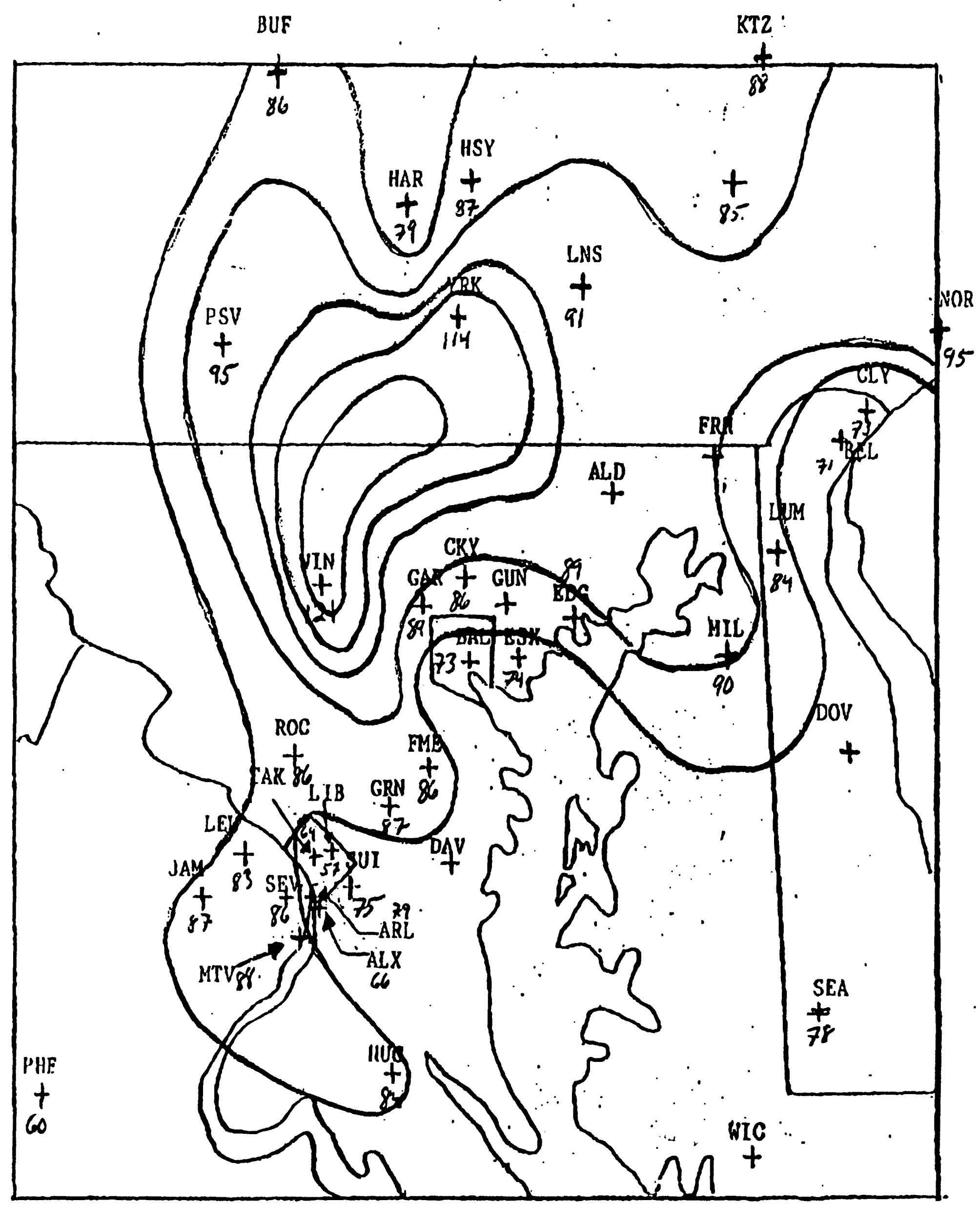


zone in parts per billion (ppb) Date: July 16, 1991 Time 1500

Fax Transmittal Memo 7672

To Bill Ryan
Company UMCP
Location
Fax # 301-314-9482
Telephone #
Comments

No. of Pages 4 + cover
Today's Date 4-13-95
Time
From Chuck Kimmick
Company MDE
Location
Dept. Charge
Fax #
Telephone #
Original Disposition: ☐ Destroy ☑ Return ☐ Call for pickup



Ozone in parts per billion (ppb) Date: July 16, 1991 Time 1800

Modeling Inventory Preparation and Quality Assurance

APPENDIX C. Quality Assurance/Quality Control of UAM Modeling Inventory for the Washington Nonattainment Area

Successful simulations of ozone formation and credible UAM attainment demonstration rely heavily on the accuracy and representativeness of UAM modeling emission inventories. Good modeling inventories are accurate translation of emission estimates from paper format as contained in the SIPs into electronic format as used by the UAM.

In the Washington ozone nonattainment area, much effort has been made to develop "The Phase I Attainment Plan for the Washington Metropolitan Nonattainment Area." The plan contains official base year and future year emission estimates, and information on growth and control measures for the nonattainment area. In order to produce a credible modeling demonstration, it is imperative that (1) emission estimates in the 1990 base year UAM modeling inventory match that documented in the Phase I Attainment Plan, (2) emission increases due to economic growth and reductions due to control strategies are accurately reflected in the 1999 UAM modeling inventory.

1. QA/QC of 1990 base year modeling inventory

The quality of 1990 base year UAM modeling inventory produced with EPS2.0 depends on the quality of the data in the input AFS and AMS workfiles. The QA/QC procedures in this section ensure that emissions produced by the AFS and AMS workfiles for modeling purposes match that reported in the Phase I Attainment Plan. During the preparation of the Phase I Attainment Plan, several revisions have been made to the 1990 base year emissions inventory. But not all corresponding changes have been made to emission files in AIRS which produces the AFS and AMS workfiles, especially for area and non-road sources. In cases where updates were not made in the AIRS according to the Phase I Attainment Plan, separate correction files were prepared in the UAM emissions modeling system. These correction files were compiled based on the revisions made to the 1990 base year inventory in the Phase I Attainment Plan. By applying the correction files to the EPS2.0 CNTLEM module, changes were made directly to the modeling inventory.

Table 1.1 is a list of area and non-road source categories for which correction files have been prepared. After corrections were made to the base year modeling inventory, the EPS2.0 RPRTEM module was run to generate emission reports for the 1990 base year modeling inventory. Emission estimates reported by RPRTEM were compared to that documented in the Phase I Plan.

Tables 1.2 through Table 1.5 provide comparison of EPS2.0 and Phase I Attainment Plan 1990 base year emission estimates. It can be seen that emission differences between EPS2.0 and Phase I Attainment Plan are within two percent.

Table 1.1 List of Area and Non-Road Source Categories with Corrections

SCCs	DC	MD	VA	Source Category Description
2102002000	X	X	X	Industrial Fuel Combustion/Coal
2102004000	X	X		Industrial Fuel Combustion/Distillate Oil
2102005000	X	X		Industrial Fuel Combustion/Residual Oil
2103002000	X	X	X	Commercial/Institutional Fuel Combustion/Coal
2103004000	X	X		Commercial/Institutional Fuel Combustion/Distillate Oil
2103005000	X	X		Commercial/Institutional Fuel Combustion/Residue Oil
2103006000	X	X		Commercial/Institutional Fuel Combustion/Natural Gas
2103007000	X			Commercial/Institutional Fuel Combustion/Liquified Petroleum Gas
2104004000	X			Residential Fuel Combustion/Distillate Oil
2104005000	X			Residential Fuel Combustion/Residual Oil
2104006000	X	X		Residential Fuel Combustion/Natural Gas
2104007000	X			Residential Fuel Combustion/Liquified Petroleum Gas
2401001000	X			Surface Coating/Architectural Coatings
2401005000	X			Surface Coating/Auto Refinishing
2401008000	X			Surface Coating/Traffic Markings
2401055000	X			Surface Coating/Machinery & Equipment
2401200000	X	X		Surface Coating/Special Purpose Coatings
2420000000		X		Dry Cleaning/All Processes
2420010055	X			Dry Cleaning/Commercial/Industrial Cleaners

Table 1.1 Continued.

SCCs	DC	MD	VA	Source Category Description
2425000000	X	X		Graphic Arts
2461800000		X		Pesticide Application
2302050000		X		Bakery Products
2260xxxxxx	X	X	X	Off-Highway Vehicles Gasoline, 2-Stroke
2265xxxxxx	X	X	X	Off-Highway Vehicles Gasoline, 4-Stroke
2282xxxxxx	X	X	X	Marine Vessels, Recreational

Table 1.2. Comparison of 1990 Base Year Point Source Emission Estimates

VOC Estimates (Tons/Day)

Jurisdiction	Phase I	EPS2.0	Difference
District of Columbia	1.0	1.0	0.0
Maryland	5.5	5.6	0.1
Virginia	8.1	7.7	-0.4
Total	14.6	14.3	-0.3

NO_x Estimates (Tons/Day)

Jurisdiction	Phase I	EPS2.0	Difference
District of Columbia	7.6	7.6	0.0
Maryland	267.4	266.7	-0.7
Virginia	59.8	58.4	-1.4
Total	334.8	332.7	-2.1

Table 1.3. Comparison of 1990 Base Year Area Source Emission Estimates

VOC Estimates (Tons/Day)

Jurisdiction	Phase I	EPS2.0	Difference
District of Columbia	20.0	19.5	-0.5
Maryland	94.2	92.8	-1.4
Virginia	77.0	77.0	0.0
Total	187.1	185.7	-1.9

NO_x Estimates (Tons/Day)

Jurisdiction	Phase I	EPS2.0	Difference
District of Columbia	3.4	3.0	-0.4
Maryland	15.8	15.8	0.0
Virginia	28.1	28.2	0.1
Total	47.3	47.0	-0.3

Table 1.4. Comparison of 1990 Base Year Non-Road Source Emission Estimates

VOC Estimates (Tons/Day)

Jurisdiction	Phase I	EPS2.0	Difference
District of Columbia	5.5	5.8	0.3
Maryland	32.1	31.7	-0.4
Virginia	32.8	32.9	0.1
Total	70.4	70.4	0.0

NO_x Estimates (Tons/Day)

Jurisdiction	Phase I	EPS2.0	Difference
District of Columbia	5.5	5.6	0.1
Maryland	43.5	44.0	0.5
Virginia	36.0	35.3	-0.7
Total	85.0	84.9	-0.1

Table 1.5. Comparison of 1990 Base Year Mobile Source Emission Estimates

VOC Estimates (Tons/Day)

Jurisdiction	Phase I	EPS2.0	Difference
District of Columbia	32.6	32.9	0.3
Maryland	108.4	109.6	1.2
Virginia	110.1	110.0	-0.1
Total	251.1	252.5	1.4

NO_x Estimates (Tons/Day)

Jurisdiction	Phase I	EPS2.0	Difference
District of Columbia	25.8	26.0	0.2
Maryland	129.1	127.6	-1.5
Virginia	106.8	108.4	1.6
Total	261.7	262.0	0.3

2. QA/QC of 1999 attainment year modeling inventory

2.1 Area and Non-Road Sources

The 1999 attainment year area and non-road modeling emission inventory was developed through two steps. In the first step, the 1990 base year inventory was grown to 1999 using growth factors based on the Round 5.3 Cooperative Forecasts. These growth factors are the same growth factors that were used in the final Phase I Attainment Plan. This step generates the 1999 uncontrolled projection inventory. In the second step, source category specific control factors were applied to the uncontrolled 1999 projection inventory. This step generates the 1999 attainment year modeling inventory which includes both growth and various control strategies contained in the Phase I Attainment Plan. The remainder of this section discusses in detail procedures involved in the two steps mentioned above.

Step 1: Generation and QA/QC of the 1999 uncontrolled projection inventory

The EPS2.0 CNTLEM module was used to generate the 1999 uncontrolled projection inventory. The county and source category specific projection/growth factors file was compiled by the Virginia DEQ based on the Round 5.3 Cooperative Forecasts. This file was carefully checked and used as an input to the CNTLEM module which applies the growth factors to the 1990 base year emissions and generates future year emissions.

The EPS2.0 RPRTEM module was used to process binary emissions output produced by CNTLEM and prepare emissions report in text format. Emission estimates reported by RPRTEM were then compared with the 1999 uncontrolled projection inventory emission estimates reported in the Phase I Attainment Plan.

The comparison process was the primary QA/QC tool and revealed a major error in the growth factors file. The error involved Solvent Utilization/Degreasing category with 2415xxxxxx SCC codes for Maryland counties in the Washington Nonattainment Area. A negative growth factor was used for this category. This error resulted in 5 tons less of VOC emissions from Maryland counties. The error was corrected by replacing the wrong growth factor with correct factor.

The above mentioned procedures ensure the accuracy of the growth factors file and representativeness of the UAM modeling inventory produced with the EPS2.0. Tables 2.1 through 2.4 show area and non-road sources emission estimates produced by EPS2.0 and as reported in the Phase I Attainment Plan for 1990 and 1999 for the three jurisdictions in the Washington Nonattainment Area. It can be seen that the emission estimates generated by the growth factors file compare very well with that documented in the Phase I Attainment Plan.

Table 2.1 Comparison of Area Source VOC Estimates produced by EPS2.0 and as reported in the Phase I Attainment Plan (Tons/Day)

	1990 Base Year Emissions Estimates			1999 Projected Emissions Estimates (Uncontrolled)		
	Phase I	EPS2.0	Diff.	Phase I	EPS2.0	Diff.
DC	20.0	19.5	-0.5	18.1	17.6	-0.5
MD	94.2	92.8	-1.4	103.7	104.2	0.5
VA	77.0	77.0	0.0	90.1	90.0	-0.1
Total	191.2	189.3	-1.9	211.9	211.8	-0.1

Table 2.2 Comparison of Area Source NO_x Estimates produced by EPS2.0 and as reported in the Phase I Attainment Plan (Tons/Day)

	1990 Base Year Emissions Estimates			1999 Projected Emissions Estimates (Uncontrolled)		
	Phase I	EPS2.0	Diff.	Phase I	EPS2.0	Diff.
DC	3.4	3.0	-0.4	3.1	2.7	-0.4
MD	15.8	15.8	0.0	18.5	18.4	-0.1
VA	28.1	26.3	-1.8	34.1	34.2	0.1
Total	47.3	45.1	-2.2	55.7	55.3	-0.4

Table 2.3 Comparison of Non-Road Source VOC Estimates produced by EPS2.0 and as reported in the Phase I Attainment Plan (Tons/Day)

	1990 Base Year Emissions Estimates			1999 Projected Emissions Estimates (Uncontrolled)		
	Phase I	EPS2.0	Diff.	Phase I	EPS2.0	Diff.
DC	5.5	5.8	0.3	5.2	5.4	0.2
MD	32.1	31.7	-0.4	37.4	37.6	0.2
VA	32.8	32.9	0.1	40.5	41.0	0.5
Toatl	70.4	70.4	0.0	83.1	84.0	0.9

Table 2.4 Comparison of Non-Road Source NO_x Estimates produced by EPS2.0 and as reported in the Phase I Attainment Plan (Tons/Day)

	1990 Base Year Emissions Estimates			1999 Projected Emissions Estimates (Uncontrolled)		
	Phase I	EPS2.0	Diff.	Phase I	EPS2.0	Diff.
DC	5.5	5.6	0.1	5.2	5.4	0.2
MD	43.5	44.0	0.5	50.4	48.6	-1.8
VA	36.0	35.3	-0.7	43.8	43.7	-0.1
Total	85.0	84.9	-0.1	99.4	97.7	-1.7

Step 2: Generation and QA/QC of the 1999 attainment year modeling inventory

The 1999 attainment year modeling inventory was created by applying source category specific control factors to the 1999 uncontrolled projection inventory. This was achieved by running EPS2.0's CNTLEM module using a user specified control factors file. The control factors file was basically a direct translation of control regulations and emission reductions adopted in the Phase I Attainment Plan into appropriate source categories/SCCs and control percentages, respectively. This file was originally prepared by the MWCOG and was examined and modified by the Virginia DEQ.

After the EPS2.0 CNTLEM module was executed, the EPS2.0 RPRTEM module was run to process binary emissions output produced by CNTLEM and generate emissions report in text format. Emission reduction benefit from each regulation was calculated by comparing emissions from source categories affected by the regulation with emissions before the control measures were applied. In cases where emission reduction from a certain regulation did not match that as documented in the Phase I Attainment Plan, control factors for that regulation were carefully checked and corrected when mistakes were found. The following is a list of regulation-specific mistakes detected from the control factors file and corrections made:

Stage I Expansion (Tank Truck Unloading):
(1) wrong SCC was used for Maryland counties in the file; wrong code was replaced by correct one.
(2) This rule does not apply to Washington DC; control factor for DC was removed.

Stage II Vapor Recovery Nozzles:
(1) no SCC was assigned to this category for Maryland counties; SCC 2501060050 was assigned for Maryland counties.

Graphic Arts Controls:
No errors were found.

Seasonal Opening Burning Restrictions:
No errors were found.

Landfill Regulations:
(1) wrong SCC was used for all jurisdictions; wrong SCC was replaced by correct one.
(2) wrong VOC control percentage of 22% was used; wrong percentage was replace by correct control percentage of 63%.

Autobody Refinishing:
No errors were found.

Surface Cleaning/Degreasing for Machinery/Automobile Repair
(1) wrong SCCs were used for Virginia counties; wrong SCCs

were replaced by correct ones.

Reformulated Consumer Products:

(1) wrong SCCs were used for DC and Virginia counties; wrong codes were replaced by correct codes.

Reformulated Surface Coating:

(1) Not enough SCCs were used for DC; Missing SCCc for this category were added.

EPA Non-Road Gasoline Engines Rule

(1) Many SCCs were missing for this category; about 124 missing SCCs were added.

Table 2.5 and Table 2.6 compare VOC and NOx reductions in UAM modeling inventories with that listed in the Phase I Attainment Plan.

Table 2.5 VOC Reductions from Area and Non-Road Sources Produced by EPS2.0 and as listed in the Phase I Attainment Plan

	VOC Reductions in DC		VOC Reductions in Maryland		VOC Reductions in Virginia		Total VOC Reductions	
	Phase I	EPS2	Phase I	EPS2	Phase I	EPS2	Phase I	EPS2
Stage I Expansion	0.0	0.0	0.9	0.9	1.1*	0.5	2.0	1.4
Stage II Vapor Recovery Nozzles	0.0	0.0	8.9	8.8	7.9	7.8	16.8	16.6
Graphic Arts Controls	0.5	0.5	1.0	1.0	1.5	1.5	3.0	3.0
Seasonal Open Burning Restrictions	0.0	0.0	3.7	3.7	2.6	2.6	6.3	6.3
Landfill Regulations	0.0	0.0	1.2	1.2	1.1	1.0	2.3	2.2
Autobody Refinishing	0.5	0.4	3.2	3.2	2.8	2.8	6.5	6.4
Surface Cleaning/ Degreasing/Automobile Repair	0.1	0.1	1.2	1.5	1.6	1.9	2.9	3.5
Reformulated Consumer Products	0.6	0.6	2.2	2.2	1.9	1.9	4.7	4.7
Reformulated Surface Coatings	1.6	1.4	6.6	6.9	5.6	5.6	13.8	13.9
EPA Non-Road Gasoline Engines Rule	0.9	0.7	6.3	6.1	6.8	5.6	14.0	12.4
Total	4.2	3.7	35.2	35.5	32.9	31.2	72.3	70.4

* This number in the Phase I document is questionable. The Counties of Stafford and Loundon where this rule applies have a combined VOC emission of 0.7 TPD from Stage I category. VOC reductions from this category can not exceed total emission itself.

Table 2.7 NOx Reductions from Area and Non-Road Sources Produced by EPS2.0 and as listed in the Phase I Attainment Plan

	NOx Reductions in Washington, D.C.		NOx Reductions in Maryland		NOx Reductions in Virginia		Total NOx Reductions	
	Phase I	EPS2	Phase I	EPS2	Phase I	EPS2	Phase I	EPS2
EPA Non-Road Diesel Engines Rule	0.4	0.4	3.7	3.5	3.2	3.1	7.3	7.0
EPA Non-Road Gasoline Engines Rule	-0.1	-0.2	-0.4	-0.4	-0.5	-1.1	-1.0	-1.7
Seasonal Opening Burning Restrictions	0.0	0.0	0.8	0.8	0.6	0.6	1.4	1.4
Total	0.3	0.2	4.1	3.9	3.3	3.6	7.7	6.7

2.2 Point Sources

The procedures used in the previous section were also used for point source emissions. Tables 2.8 and Table 2.9 show point source emission estimates produced by EPS2.0 and as reported in the Phase I Attainment Plan for 1990 and 1999 for the three jurisdictions in the Washington Nonattainment Area. It can be seen that the emission estimates generated by the growth factors file compare well with that documented in the Phase I Attainment Plan.

Table 2.8 Comparison of Point Source VOC Estimates produced by EPS2.0 and as reported in the Phase I Attainment Plan (Tons/Day)

	1990 Base Year Emissions Estimates			1999 Projected Emissions Estimates (Uncontrolled)		
	Phase I	EPS2.0	Diff.	Phase I	EPS2.0	Diff.
DC	1.0	1.0	0.0	1.1	1.0	-0.1
MD	5.5	5.6	0.1	5.5	5.5	0.0
VA	8.1	7.7	-0.4	9.9	9.6	-0.3
Total	14.6	14.3	-0.3	16.5	16.1	-0.4

Table 2.9 Comparison of Point Source NOx Estimates produced by EPS2.0 and as reported in the Phase I Attainment Plan (Tons/Day)

	1990 Base Year Emissions Estimates			1999 Projected Emissions Estimates (Uncontrolled)		
	Phase I	EPS2.0	Diff.	Phase I	EPS2.0	Diff.
DC	7.6	7.6	0.0	7.6	7.6	0.0
MD	267.4	266.7	-0.7	267.4	266.7	-0.7
VA	59.8	58.4	-1.4	59.9	59.9	0.0
Total	334.8	332.7	-2.1	334.9	334.2	-0.7

Table 2.10 and Table 2.11 compare VOC and NOx reductions in UAM modeling inventories with that listed in the Phase I Attainment Plan. Total VOC and NOx reduction in the UAM modeling inventory match reasonably well with that listed in the Phase I Plan.

Table 2.10 VOC Reductions from Point Source Produced by EPS2.0 and as listed in the Phase I Attainment Plan

	VOC Reductions in Washington, D.C.		VOC Reductions in Maryland		VOC Reductions in Virginia		Total VOC Reductions	
	Phase I	EPS2	Phase I	EPS2	Phase I	EPS2	Phase I	EPS2
Non-CTG RACT to 50 tpy and Expanded State Point Source Regulations to 25 tpy	0.0	0.0	0.7	1.4	0.9	0.3	1.6	1.7
Total	0.0	0.0	0.7	1.4	0.9	0.3	1.6	1.7

Table 2.11 NOx Reductions from Point Source Produced by EPS2.0 and as listed in the Phase I Attainment Plan

	NOx Reductions in Washington, D.C.		NOx Reductions in Maryland		NOx Reductions in Virginia		Total NOx Reductions	
	Phase I	EPS2	Phase I	EPS2	Phase I	EPS2	Phase I	EPS2
State NOx RACT Requirements	2.1	2.1	67.9	67.7	12.0	10.6	82.0	80.5
Phase II NOx Requirements	1.8	1.8	68.2	77.0	0.0	0.0	70.0	78.0
Total	3.9	3.9	136.1	144.7	12.0	10.6	152.0	159.2

2.3 Mobile Sources

The on-road mobile source emission inventory was QA/QC against hard copy traffic data and mobile control information provided by either the Virginia Department of Transportation (VDOT), Maryland Department of Transportation (MDOT), or the Metropolitan Washington Council of Governments (COG) for input transcription errors throughout the mobile emission factors modeling and activity level development. For repetitive input file generations for use in the Mobile5a emission factor modeling, errors were minimized by using common jurisdictional-specific base files with modification to mobile control program parameter files, as needed. The base and projected inventories were generated into a UAM-ready EPS2.0 file format. For each jurisdiction, the source category codes (SCC), VMT mix, and VMT figures assignments were consistent with the functional road classifications and mix for that jurisdiction, as provided by the transportation agencies. A dump program was developed using C-Programming to read in the Mobile5a emission factors from the electronic output files into the EPS2.0 formatted files. This procedure enables fast and accurate transcription of data. Additional QA/QC was performed from the EPS2.0 runs to check the emissions calculated against emission inventories developed under the SIP 1990 emission inventory, Reasonable Further Progress inventory, 15% Reduction Plan, or Phase 1 Attainment Plan, whichever was appropriate.

Air Quality and Meteorological Data Preparation

Meteorological Fields for Episode 3B (July 14-16, 1991)

Last Revised: November 13, 1995

William F. Ryan
University of Maryland
Department of Meteorology

General Overview

Episode 3B consists of three days with O_3 violations occurring only on the third day. The initial day (July 14th) is characterized by a stationary front across the southern portion of the domain with a series of weak and dissipating cold fronts to the northwest. Cool high pressure is centered over Wisconsin and the cool air associated with this system pushes the fronts well offshore by the evening of the 14th. At 850 mb, a low pressure system associated with the frontal zones is over the Bay of Fundy and exiting rapidly to the northeast. This drives fairly strong north and northwest winds over the domain weakening late in the day.

On the 15th (Day 2), the surface high pressure moves rapidly east to the vicinity of Detroit. Surface temperatures in the vicinity of the high pressure center are relatively cool with highs in the upper 70's and low 80's. Local maximum temperatures are in the mid-80's. Surface winds are north in the morning becoming more variable as the center of the surface high approaches. The 850 mb ridge is generally in phase with the surface high and, as it remains west of the domain, 850 mb winds remain north and northwest.

On the 16th (Day 3), surface high pressure moves into north-central PA. Surface winds become more variable finally settling into the southeast as the high pressure center continues to move eastward and away from the domain. During the day on the 16th, however, the center of the surface high is nearly overhead. At 850 mb, the center of the ridge is overhead at 1200 Z with geopotential heights of greater than 1600 m (quite high in climatic terms) and essentially no winds. By later in the day the center of the ridge drops southward slightly.

Surface Meteorological Data

The most outstanding feature of this episode is the rapid rise in pressure as the surface high pressure center, initially in the Midwest, moves over and past the region. A time series of three-hourly surface pressure at BWI is given in Figure 1.

The surface wind data at the first order stations reflects the fairly rapid passage of a summer high pressure system. Wind begin from the NW and become more N and NE as the high center approaches finally becoming calm as high pressure is overhead. As the center of high pressure moves past the region (east), the winds become SE and then SW after the episode.

Mean wind direction at three domain first-order stations is given below:

BWI -

7/14/91	NW in am then variable late
7/15/91	NW in am then veering NE and finally variable E late
7/16/91	SW in am then calm winds becoming variable E then SE

ADW -

7/14/91	NW around 5 kts becoming SE late in the day
7/15/91	NW in early am becoming NE by afternoon and ESE late in the day
7/16/91	Calm until mid-morning then SE around 5 kts
7/17/91	Steady SW through the day at 5-10 kts

IAD -

7/14/91	NW and NNW through the day
7/15/91	NW becoming NNE by mid-morning then SE late
7/16/91	Calm or light W in the am then becoming steady SE in the afternoon

Wind direction and speed are fairly uniform across these sites in the center of the domain though during the period from the evening of July 15th to late morning on July 16th these is high variability both at individual stations and between stations.

Quality of Meteorological Data

As noted in earlier reports (see, *"Wind Data Input to the DWM", W. F. Ryan, 1994* and *"Documentation for Meteorological Fields (Episode 3)", W. F. Ryan, 1995*), data for the first and second order meteorological stations are quality assured at the National Climate Data Center (NCDC) and the stations are well sited to insure that they reflect more than local conditions. Other meteorological sites are addressed on a case-by-case basis. For Episode 3B, data from the MDE monitor sites are discussed below:

MDE Air Monitor Data:

Davidsonville - Missing data all days.

Suitland - As in previous episodes wind data from Suitland is of questionable quality. This is probably due to station siting (see, Reports by Sally Campbell for DNR). When compared to observations from the nearby site at ADW, there is a consistent bias in direction. This was also observed during Episode 3 (July 18-20, 1991). The average wind direction difference (in degrees) is 93° for a 3-hourly comparison of non-calm conditions between SUI and ADW. Of the 19 data points compared, 16 have SUI backing from ADW, similar to Episode 3.

Because of the consistent directional bias and existing concerns about station siting, the SUI data was not used in this simulation.

Rockville - Because Rockville is not close to any particular first order station, it can be compared to both IAD and BWI. In general, Rockville compares fairly well with BWI with average directional difference of 48° (only 33° on Day 3 which is the most important day) and evenly split between back and veer differences (11 back, 9 veer, 3 identical).

Essex - Because there are questions about the siting of the Essex wind monitor relative to local obstructions, the presumption is that this data should be used only with caution. In Episode 3B, however, there is only one available Aberdeen Proving Ground site (unlike 3 sites in Episode 3B) and no other local MDE sites (as in Episodes 1 and 2). In this case, therefore, the Essex data becomes more valuable and since it compares generally well with BWI during the episode (NNE winds on 7/14, NNE early on 7/15 then veering to SE later and on 7/16, calm and then southerly) we will use the Essex data.

Edgewood - Also very similar to BWI and Essex with NW winds early on 7/14 becoming variable in afternoon, on 7/15 variable easterly and on 7/16 variable E becoming SE.

Other Data

Due to hardware problems at APG, the full suite of APG surface data is not available for this episode. Only the hard copy for Spesutie Island is available. That will be entered manually and is not a part of the current data base. The Martins State Airport data is also available only in hard copy and will be entered. The bay data from Martin and APG will form part of a sensitivity run.

Upper Air Data

The upper air wind and height data reflect the passage of the high pressure center from west to east with high pressure overhead on the 16th and then moving east. Tables 1a-1f show wind speed and direction at various levels for Episode 3B.

Soundings are available at APG for portions of this event. The soundings on 7/14 appear to have data quality problems as all winds are reported calm in a fairly strong NW flow synoptic situation. Data from the surrounding upper air sites are consistently NW during this period so that this data was not used in the simulation. No soundings are available on 7/15 but three sounding are available on 7/16 which appear to be in good shape.

Boundary Layer Preprocessor: MIXEMUP

The MIXEMUP preprocessor was run in the standard mode. A sample input file is attached as Appendix A. Note that MIXEMUP requires a fairly full time series of data for each station. Many of the stations used in earlier episodes (1988) were converted to 3-hourly observations by 1991. This limits the number of available stations with full data sets. For the base field used only those stations with complete hourly data. A future sensitivity run can include interpolated data for these stations.

MIXEMUP requires that surface stations be paired with upper air stations. The standard pairings are given below:

SV2 (Sterling, VA): IAD, NYG, DCA, CXY, BWI, ADW
WAL: DOV, SBY, NHK
ACY: PHI, NXX

The ILG station is about equidistant from all three sites. Have typically included with SV2.

Day 1 (July 14): The WAL-paired stations (SBY, NHK, DOV) are 50-80% lower than general domain heights and heights if paired with SV2. Check of 1200 Z sounding at WAL shows very warm lowest layer at WAL that is transient and disappears by the 0000 Z sounding (Figure 2). In addition, WAL mixes locally to 1528 m on the 14th which is well in excess of the MIXEMUP results. While the wind field does not show large vertical sheer on this day, intense mixing height gradients can cause some odd variations in the DWM. For this reason, matched SBY, NHK, DOV with SV2 on Day 1.

Mixing height maxima across the domain on this day are generally 1.6-1.8 km reflecting cool, cloudy conditions in the morning and early afternoon as the frontal zones move east and northwest flow becomes developed.

In previous applications have seen late afternoon instability in MIXEMUP results with rapid 1-2 hours rises around sunset. For this day, only DOV showed characteristic early evening MIXEMUP glitch, this was corrected with 1 h linear interpolation.

Day 2 (July 15): Average domain peak mixing height is in the 1.5-2.5 km range with the highest heights in the NE quadrant. Surface stations paired with WAL still lower than SV2 pairings though the difference is much less than on Day 1. Kept these stations paired with SV2 to be consistent though see Day 3 below.

Day 3 (July 16): To complicate matters, there is a reversal of the results on the first two days. The Eastern Shore sites are now very low if matched to SV2 (Figure 3). Matched stations with WAL for this day. Domain mean mixing heights peak at the 2.2-2.3 km range which is close to climatological levels for SV2.

The ILG results are very odd this day. Peak mixing height is reached in the late morning and afternoon heights are much lower than surrounding sites. This results in an intense local mixing height gradient. past experience has shown that the DWM has problems with this steep a gradient. For now, have replaced ILG results for midday hours with domain mean mixing height (Table 3).

Other adjustments to MIXEMUP output:

a. July 16, 1995: CXY hour 1900-2000, domain mean @ 500 m and CXY at 2208 m. Set CXY to 700 m.

b. July 15, 1995: SBY hour 1700-1800 696 m, reset to average of BWI, DOV, NHK at 1375 km.

DIFFBREAK

As in Episode 3, have added hours 0000-0100 and 0100-0200 at the end of the episode to allow DWM to complete the final day without crashing on the last hour. This done manually at dfsnbk.in step by repeating last hour twice. The final field was smoothed with a 4 pass filter.

A selection of output files for each day are included in Figures 4a-4f. The control file for DIFFBREAK is included as Appendix B.

Diagnostic Wind Model: DWM

The DWM contains many parameters that can be adjusted to accommodate the user. In general, have used the same parameter setup as in Episode 3 which is consistent with other local domains, particularly NJ and NC. A list of the stations used in the simulations is attached as Appendix C. Parameters setting are given in Appendix D and controls for the DWM/UAM interface is given in Appendix E.

One difference from many DWM simulations is setting I3DCTW off. This runs the DWM in the objective mode only and dispenses with the domain mean wind concept. This parameter caused considerable problems in strongly sheared environment in Episodes 1 and 2. Shear is less in this case but still present in this episode. Also, July 16th contains a period of light and variable winds. Choosing a domain mean wind in this case will be difficult. At a later date a sensitivity run will be made with the DWM in the full diagnostic mode.

The Pasquill-Turner categories, included in DWM as the ISTAB parameter, were computed manually using BWI as a proxy for the domain. The main problem with stability classes in the DWM is around times of sunrise and sunset where stability class can vary quite quickly. This large stability change can introduce odd discontinuities in the wind fields as seen in Episodes 1 and 3. As a result, have smoothed stability class changes across these hours. This becomes more of a problem later in the episode when skies clear and winds are quite light. As in previous episodes, must keep ISTAB < = 4 for hours 1900-2000 or DWM reacts badly.

On the initial run of the DWM the wind fields are blank from 2100 on Day 1 until 0300 on Day 2. On investigation, the problem is the lack of wind data in the 600-700 m range. None of the four upper air stations reports data in this range in the evening sounding - due to no significant levels reported in a fairly smooth early evening boundary layer sounding. To combat this problem we are forced to insert bogus data in the sounding gap. The bogus data adjustments are given in Table 5. There is very little shear between the layers into which the bogus data were inserted which makes this less of a difficulty.

As noted above, data from two stations (MTN and APG-Spesutie) were acquired late and are not included in this simulation. These will be included in a later sensitivity run along with any data from utility-operated stations.

The base wind fields are contained in files: WIND.bin.265 (July 14), WIND.bin.266 (July 15) and WIND.bin.263 (July 16). Plots of selected wind fields are contained in Figure 5.

Temperature Preprocessor: TEMPERATUR

The temperature preprocessor also requires a full hourly data set. It also appears to replace missing hourly data with a default to the domain maximum value. The base temperature field was run with a 14 station group with the addition of a downtown Baltimore pseudo-station using BWI data. A later sensitivity run will utilize a warmer downtown temperature. A list of parameters for the TEMPERATUR preprocessor is given in Appendix F. Stations not used include: RDG, MIV, LNS, HGR, DAA, ACS, ABE, TPT. Sample temperature plots are included in Figure 6.

Tables 1a-f

Tables 1a-f give selected upper air wind observations at the local upper air wind stations. Wind observations are given for mandatory (every 50 mb) levels from 950 mb to 750 mb. Approximate geopotential heights are given for each pressure level. Wind direction is given in full degrees and wind speed in meters per second (ms^{-1}). Observations are from Sterling, VA (SV2) which is located west of Washington DC near Dulles International Airport (IAD) and from Wallop's Island, VA which is located on the Eastern Shore of Virginia. Soundings are also reported on July 16, 1991 for Aberdeen Proving Ground (APG) which is along the Chesapeake Bay northeast of Baltimore.

Table 1a

July 14, 1991 - 1200 Z Upper Air Winds			
Pressure	Height (± 100 m)	IAD	WAL
SFC		330/3	270/1
950	500	337/6	321/7
900	100	325/10	287/6
850	1500	299/12	270/8
800	2000	283/12	261/11
750	2500	261/11	267/10
		NW > W	W

Table 1b

July 15, 1991 - 0000 Z Episode 3B			
Pressure	Height (± 100 m)	SV2	WAL
SFC		340/3	080/2
950	500	352/6	332/4
900	100	349/7	331/4
850	1500	349/7	307/5
800	2000	351/8	274/9
750	2500	336/9	273/10
		NW	NW > W

Table 1c

July 15, 1991 - 1200 Z Episode 3B			
Pressure	Height (± 100 m)	SV2	WAL
SFC		030/2	350/1
950	500	035/7	022/4
900	100	062/4	024/3
850	1500	332/4	001/3
800	2000	289/7	334/3
750	2500	290/9	319/4
		NE > NW	NNE > NW

Table 1d

July 16, 1991 - 0000 Z Episode 3B			
Pressure	Height (± 100 m)	SV2	WAL
SFC		020/2	070/3
950	500	039/2	071/3
900	100	025/2	355/2
850	1500	349/4	320/5
800	2000	346/5	311/6
750	2500	348/3	312/4
		NE > NW	ENE > NW

Table 1e

July 16, 1991 - 1200 Z Episode 3B				
Pressure	Height (± 100 m)	SV2	APG (1400 Z)	WAL
SFC		000/0	083/3	340/1
950	500	153/1	002/2	015/2
900	100	147/2	109/1	340/2
850	1500	127/3	117/5	102/5
800	2000	072/1	304/3	038/2
750	2500	348/3	023/6	027/3
		ESE	VAR	NE

Table 1f

July 17, 1991 - 0000 Z Episode 3B			
Pressure	Height (± 100 m)	SV2	WAL
SFC		190/3	170/3
950	500	190/4	145/4
900	100	197/3	043/3
850	1500	208/4	010/5
800	2000	222/3	022/1
750	2500	268/2	323/1
		SW	SE > NE

Table 2

July 14, 1991 Maximum Mixing Height		
Surface Station	WAL	SV2
SBY	658	1665
NHK	305	1525
DOV	798	1545
ADW	-	1665
BWI	-	1805

Table 2 gives MIXEMUP results when Eastern Shore surface stations are matched with various upper air station data on July 14, 1991.

Table 3

Episode 3B: July 16, 1995 Adjustments to dfsnbk.in		
Hour	Domain Mean Mixing Height	ILG MIXEMUP Output
10	1709	600
11	1895	700
12	2053	1000
13	2103	1000
14	2118	876
15	2095	786
16	2056	766
17	1881	750

Table 3 shows adjustments made to MIXEMUP output for the ILG (Wilmington, DE) station for July 16, 1991. The MIXEMUP data were replaced by the domain mean mixing height for the hours specified.

Table 4

Stability Classes (ISTAB Parameter) for DWM (Episode 3B)						
Hour (EST)	July 14		July 15		July 16	
	Old	New	Old	New	Old	New
Morning Hours						
0500	6	5	5	5	6	5
0600	3	4	3	4	2	4
0700	3	3	3	3	2	3
Evening Hours						
1800	3	3	2	3	2	3
1900	3	3	3	4	3	4
2000	3	4	3	5	3	5
2100	5	5	6	6	6	6

Table 4 shows adjustments made to the calculated stability parameters prior to use in the DWM.

Table 5

Bogus Data for 0000 Z Soundings July 15, 1991					
Pressure (mb)	Height (m)	Temperature (°C)	RH (%)	Wind Direction (degrees)	Wind Speed (ms^{-1})
Sterling, VA (SV2)					
950.0	577	23.9	49	352	6
940.0	**690**	**22.9**	**50**	**351**	**6**
928.0	**790**	**21.9**	**52**	**350**	**7**
916.0	**890**	**20.9**	**54**	**349**	**7**
903.8	1009	19.7	55	349	7
Wallop's Island, VA (WAL)					
950.0	573	21.5	81	332	4
940.0	**666**	**20.8**	**78**	**331**	**4**
930.0	**759**	**20.1**	**75**	**329**	**5**
920.0	851	19.4	72	327	5
Atlantic City, NJ (ACY)					
950.0	560	21.6	65	341	6
946.8	590	21.3	66	342	6
939.0	**648.5**	**21.0**	**63**	**344**	**6**
931.1	707	20.6	60	345	6

Table 5 shows data inserted into the observed upper air soundings in order to prevent the DWM from crashing during the evening hours of July 14, 1991. Inserted, or "bogus" data are given in **bold face**.

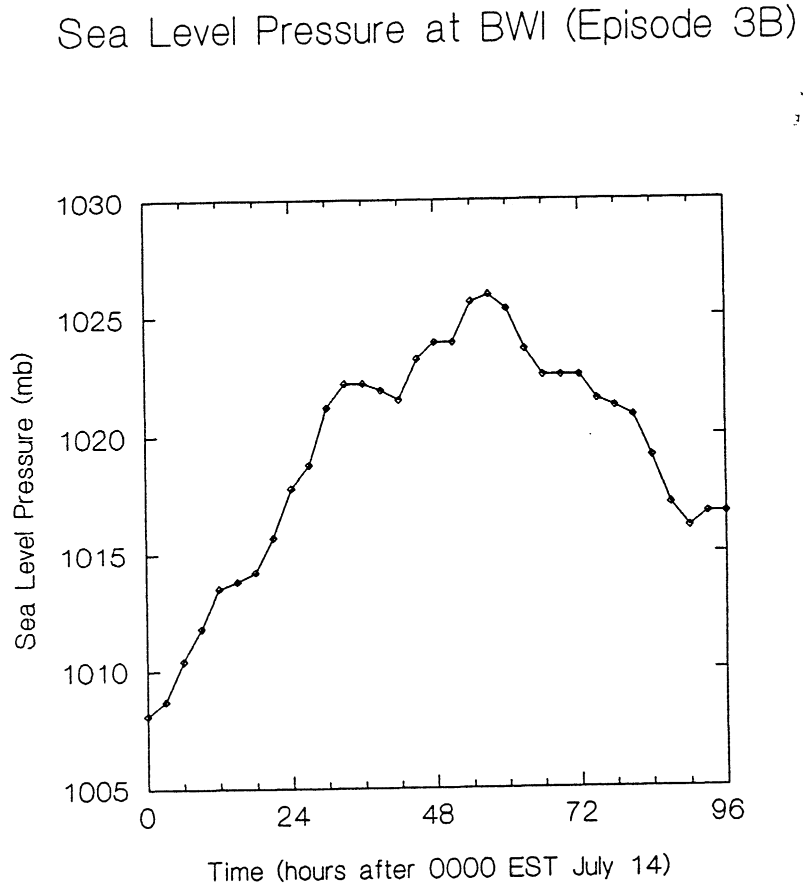


Figure 1. Time series of sea level pressure at BWI for July 14-17, 1991. Time is expressed as hours after 0000 EST on July 14th. The highest O_3 concentrations are observed on July 16th (hours 72-96).

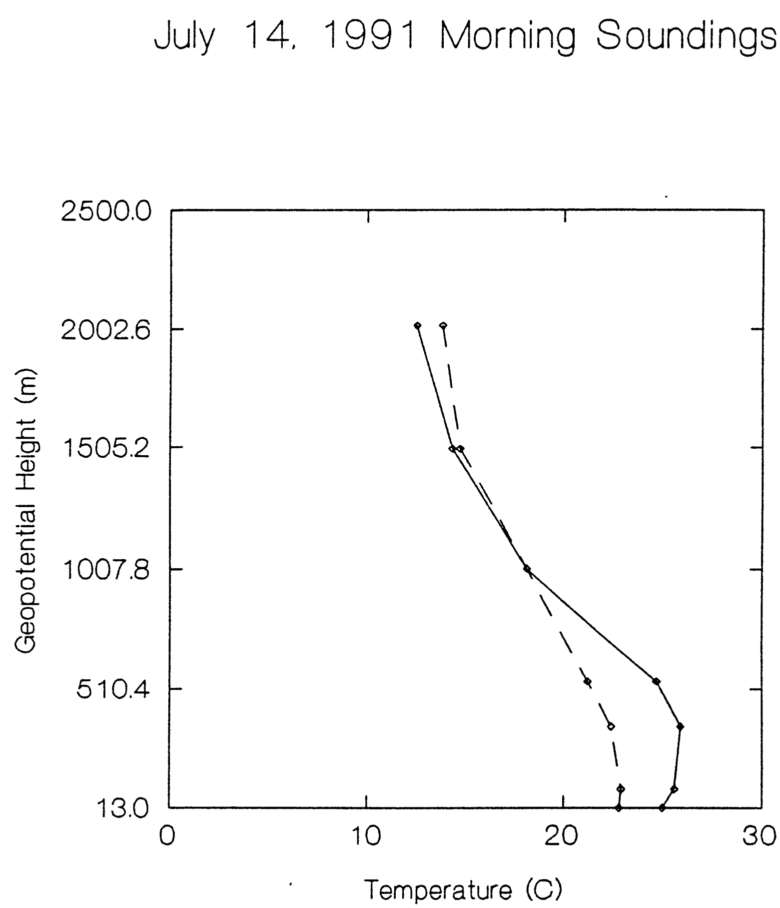


Figure 2. Temperature soundings for selected heights at WAL (straight line) and SV2 (Sterling, VA, dashed line) at 1200 Z on July 14, 1991

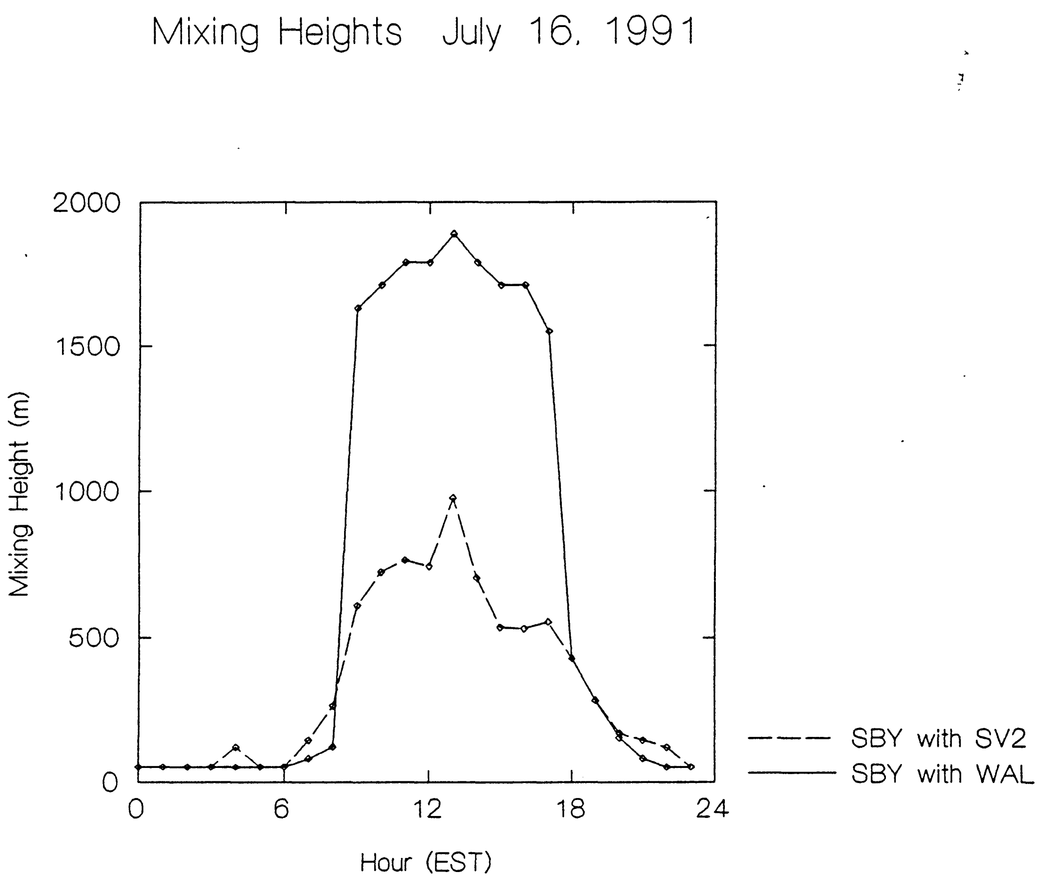


Figure 3. Mixing heights for Eastern Shore sites on July 16, 1991

Figures 4a-4f

Figures 4a-4f contain output from the DIFFBREAK preprocessor for Episode 3B. All figures show contoured mixing heights in meters.

Figure 4a. Mixing height at 1200 EST on July 14, 1991 (Julian Day 195).

Figure 4b. Mixing height at 1600 EST on July 14, 1991 (Julian Day 195).

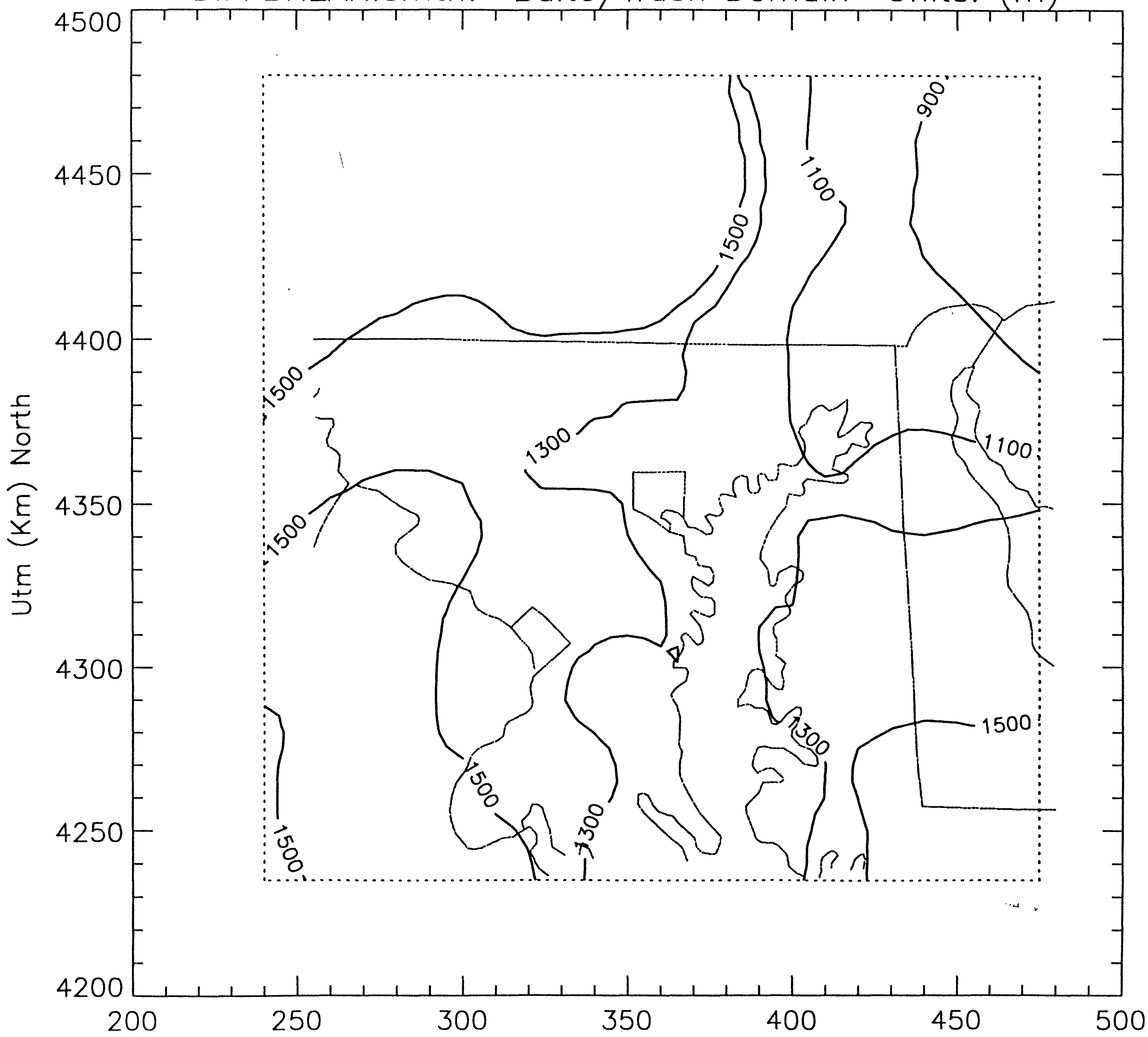
Figure 4c. Mixing height at 1200 EST on July 15, 1991 (Julian Day 196).

Figure 4d. Mixing height at 1600 EST on July 15, 1991 (Julian Day 196).

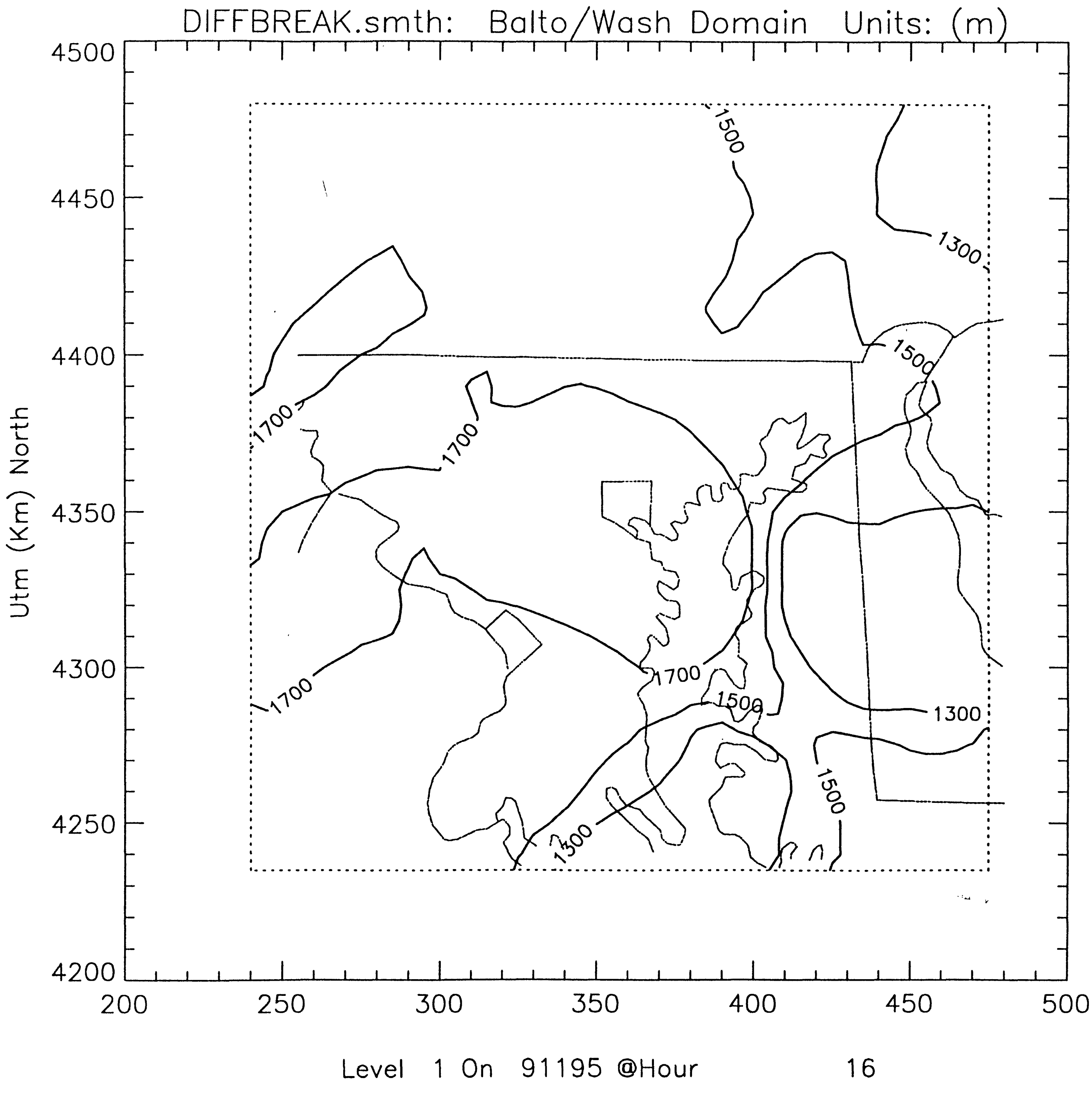
Figure 4e. Mixing height at 1200 EST on July 16, 1991 (Julian Day 197).

Figure 4f. Mixing height at 1600 EST on July 16, 1991 (Julian Day 197).

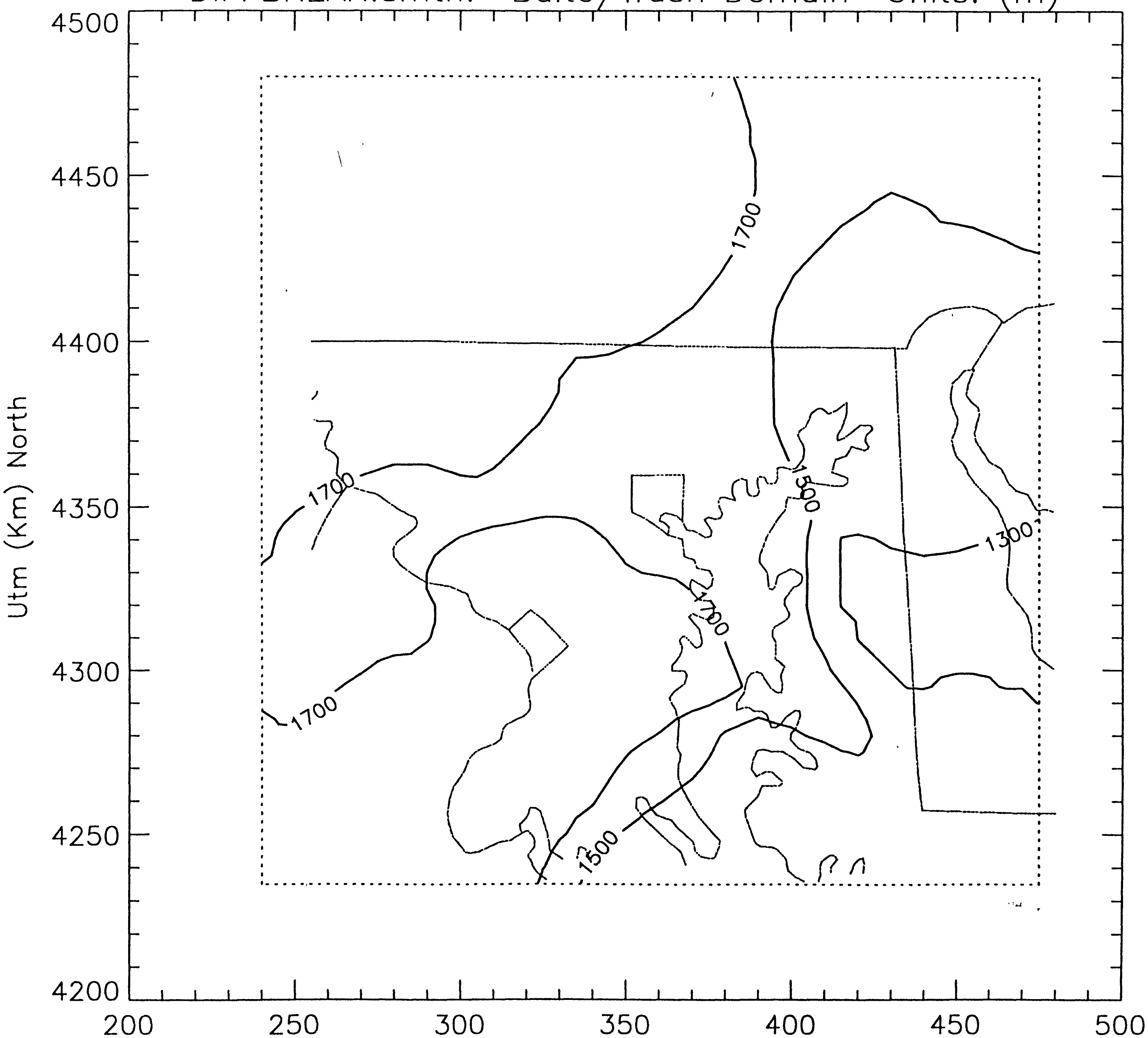
DIFFBREAK.smth: Balto/Wash Domain Units: (m)



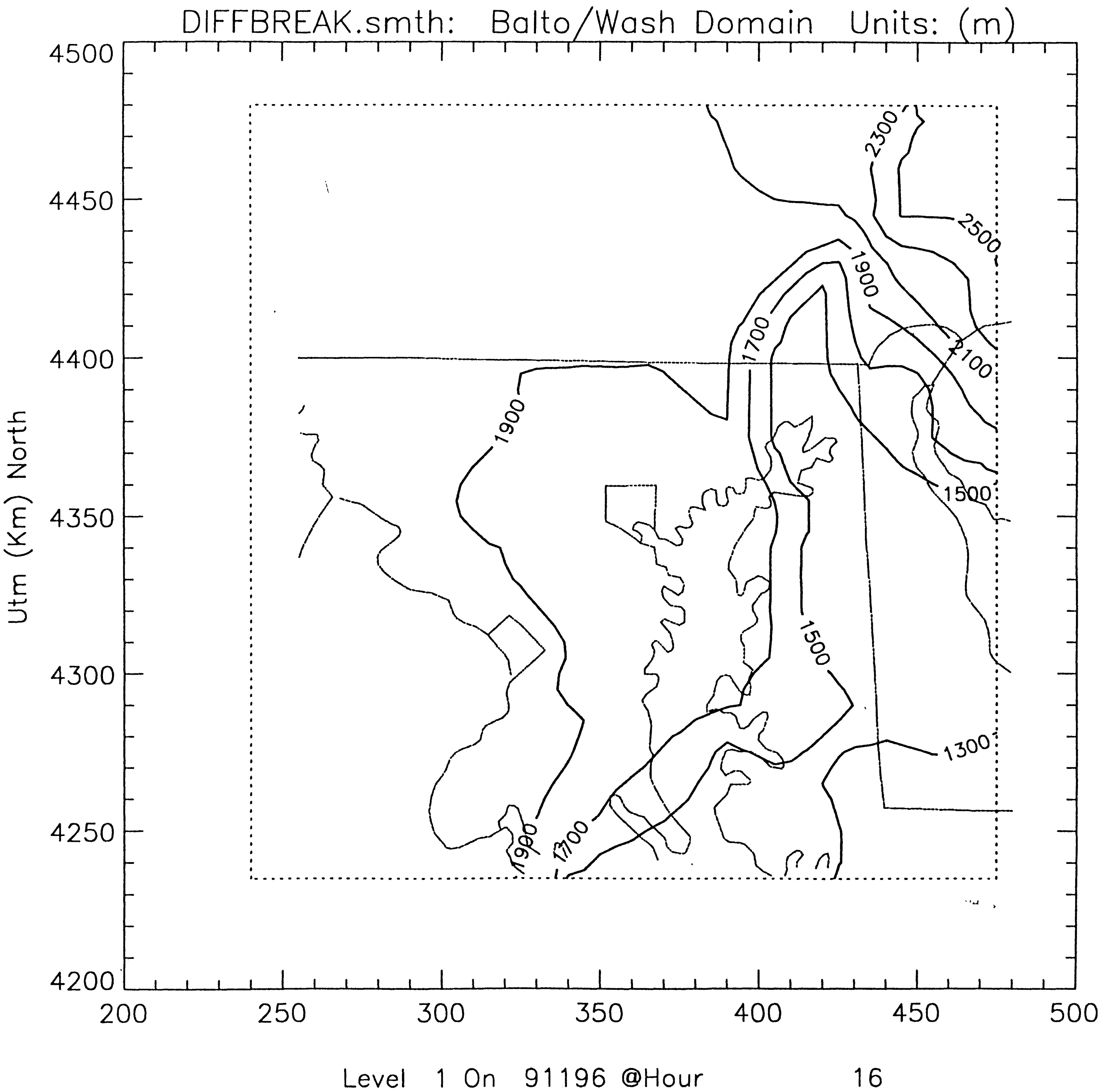
Level 1 On 91195 @Hour 12


DIFFBREAK.smth: Balto/Wash Domain Units: (m)
Utm (Km) North
Level 1 On 91195 @Hour 16
4500
4450
4400
4350
4300
4250
4200
200
250
300
350
400
450
500
1300
1500
1700

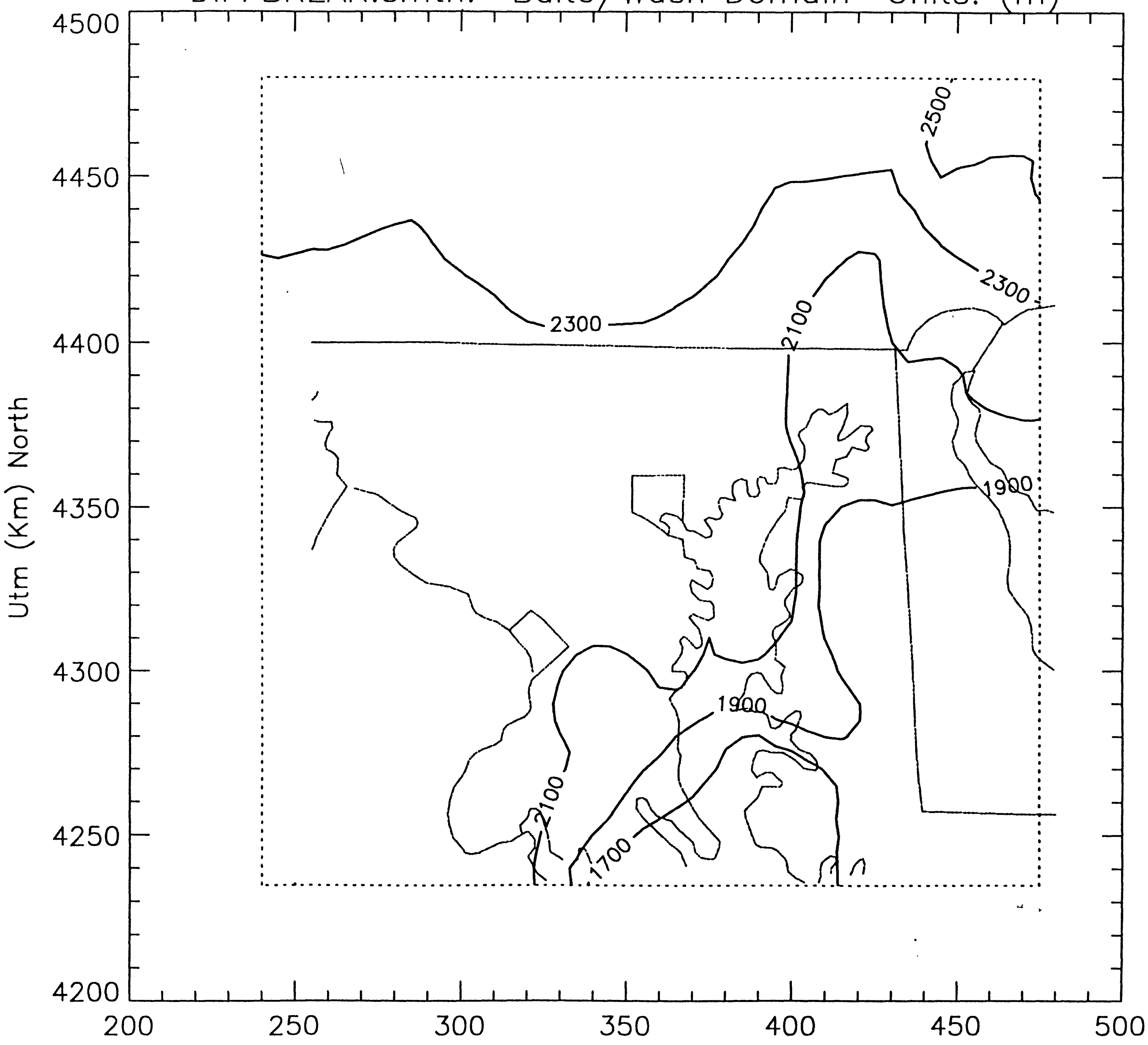
DIFFBREAK.smth: Balto/Wash Domain Units: (m)



Level 1 On 91196 @Hour 12

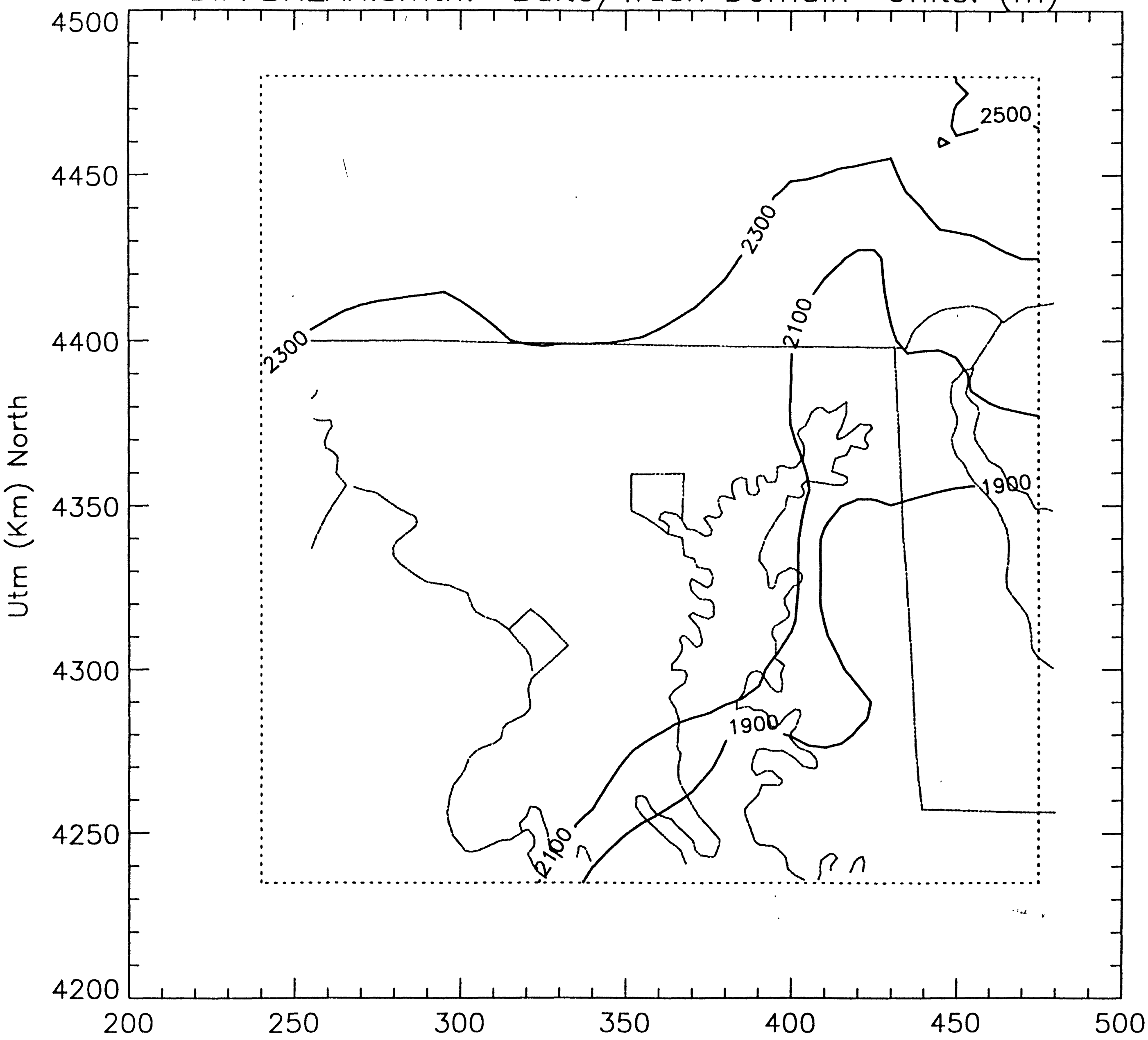

DIFFBREAK.smth: Balto/Wash Domain Units: (m)
Utm (Km) North
4500
4450
4400
4350
4300
4250
4200
200
250
300
350
400
450
500
2300
2500
1900
2100
1700
1500
1300
1900
1500
1900
1700
Level 1 On 91196 @Hour 16

DIFFBREAK.smth: Balto/Wash Domain Units: (m)



Level 1 On 91197 Hour 12

DIFFBREAK.smth: Balto/Wash Domain Units: (m)



Level 1 On 91197 Hour 16

Figures 5a-5f

Figures 5a-5f contain output from the DWM for various UAM model layers during Episode 3B. All figures show wind vectors and contoured wind speeds in meters per second.

Figure 5a. DWM output for Level 1 at 1600 EST on July 14, 1991 (Julian Day 195).

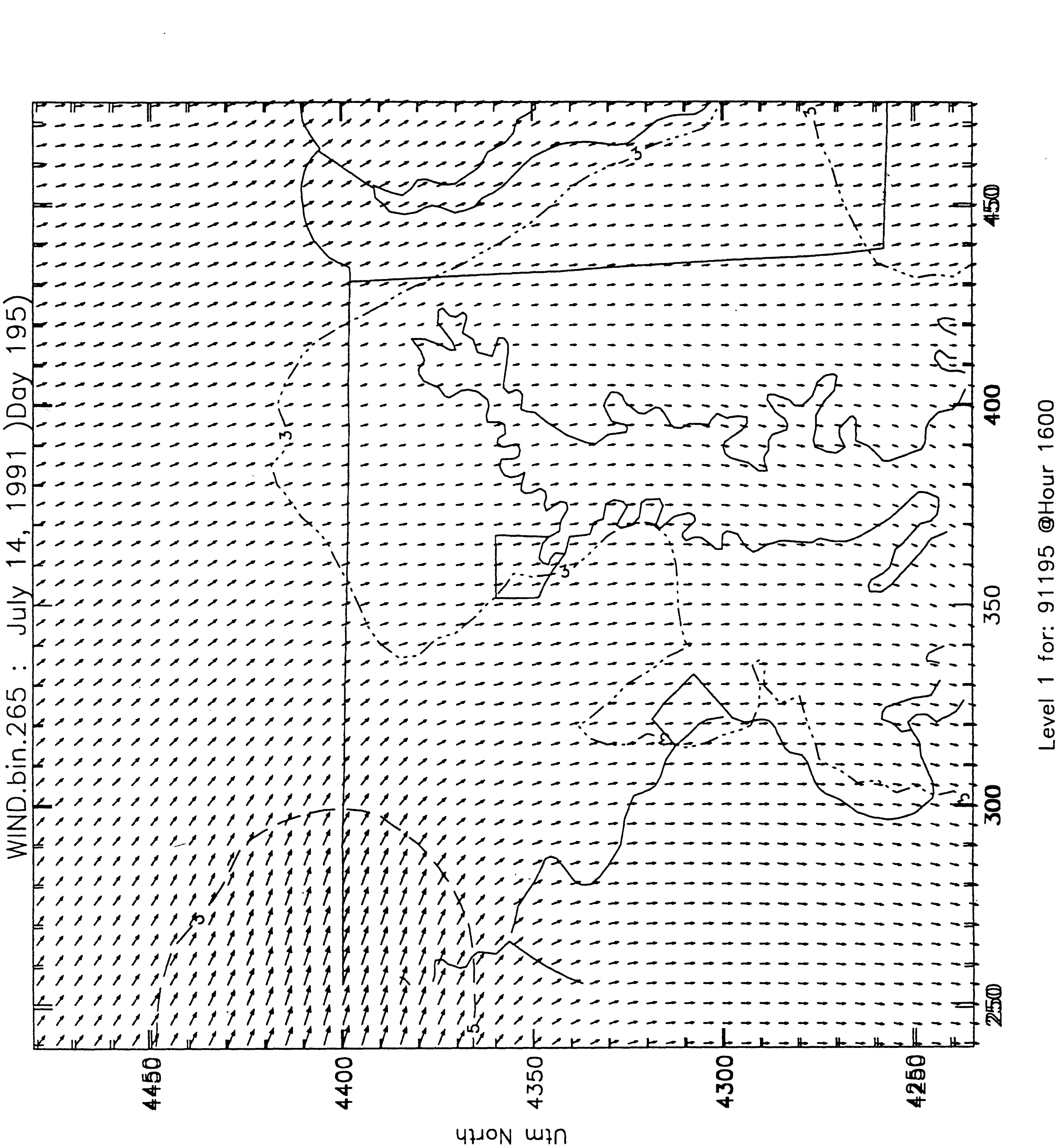
Figure 5b. DWM output for Level 3 at 1600 EST on July 14, 1991 (Julian Day 195).

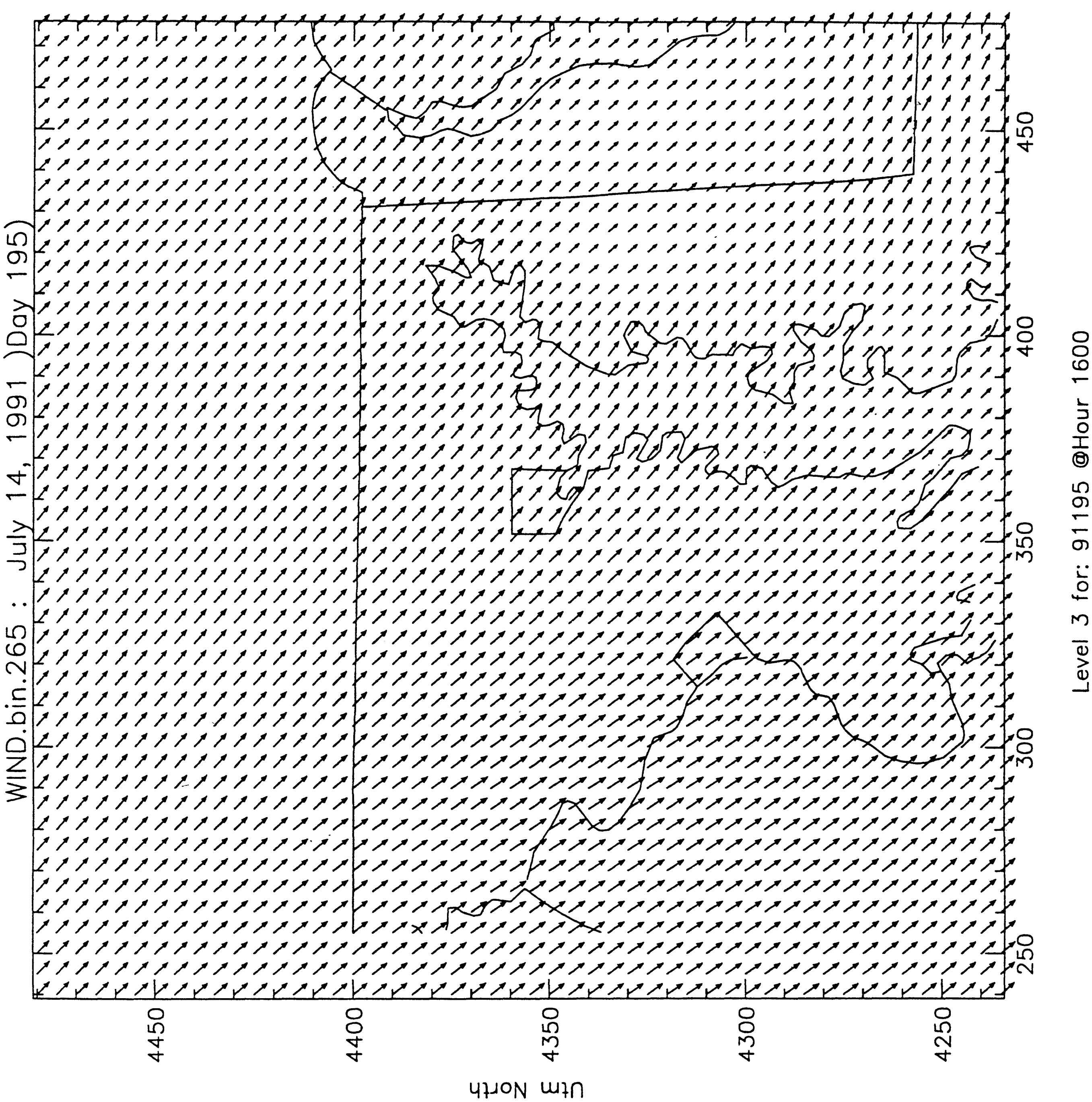
Figure 5c. DWM output for Level 1 at 1600 EST on July 15, 1991 (Julian Day 196).

Figure 5d. DWM output for Level 3 at 1600 EST on July 15, 1991 (Julian Day 196).

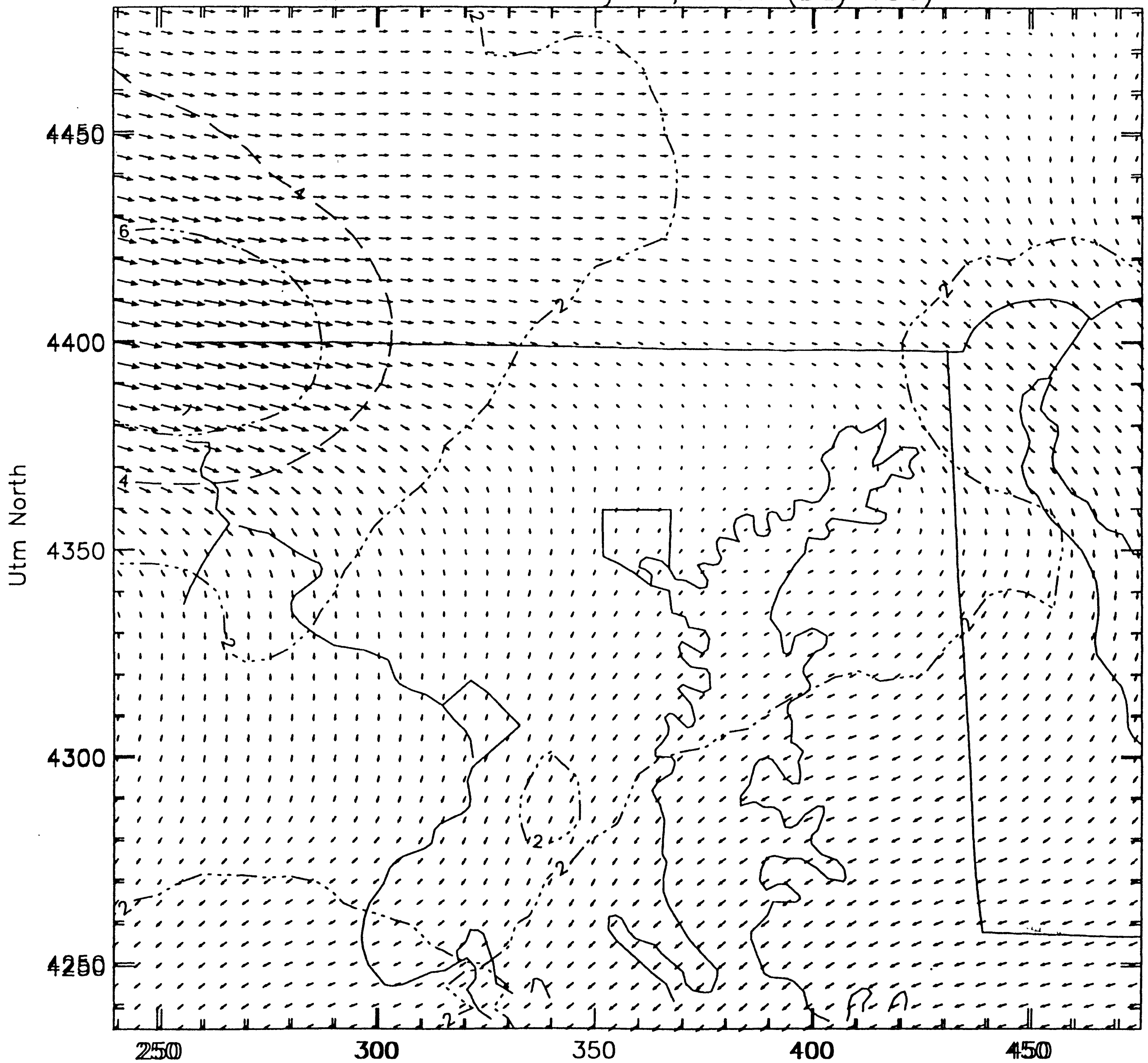
Figure 5e. DWM output for Level 1 at 1600 EST on July 16, 1991 (Julian Day 197).

Figure 5f. DWM output for Level 3 at 1600 EST on July 16, 1991 (Julian Day 197).


WIND.bin.265 : July 14, 1991)Day 195)
Level 1 for: 91195 @Hour 1600
Utm North
4450
4400
4350
4300
4250
250
300
350
400
450
3
5

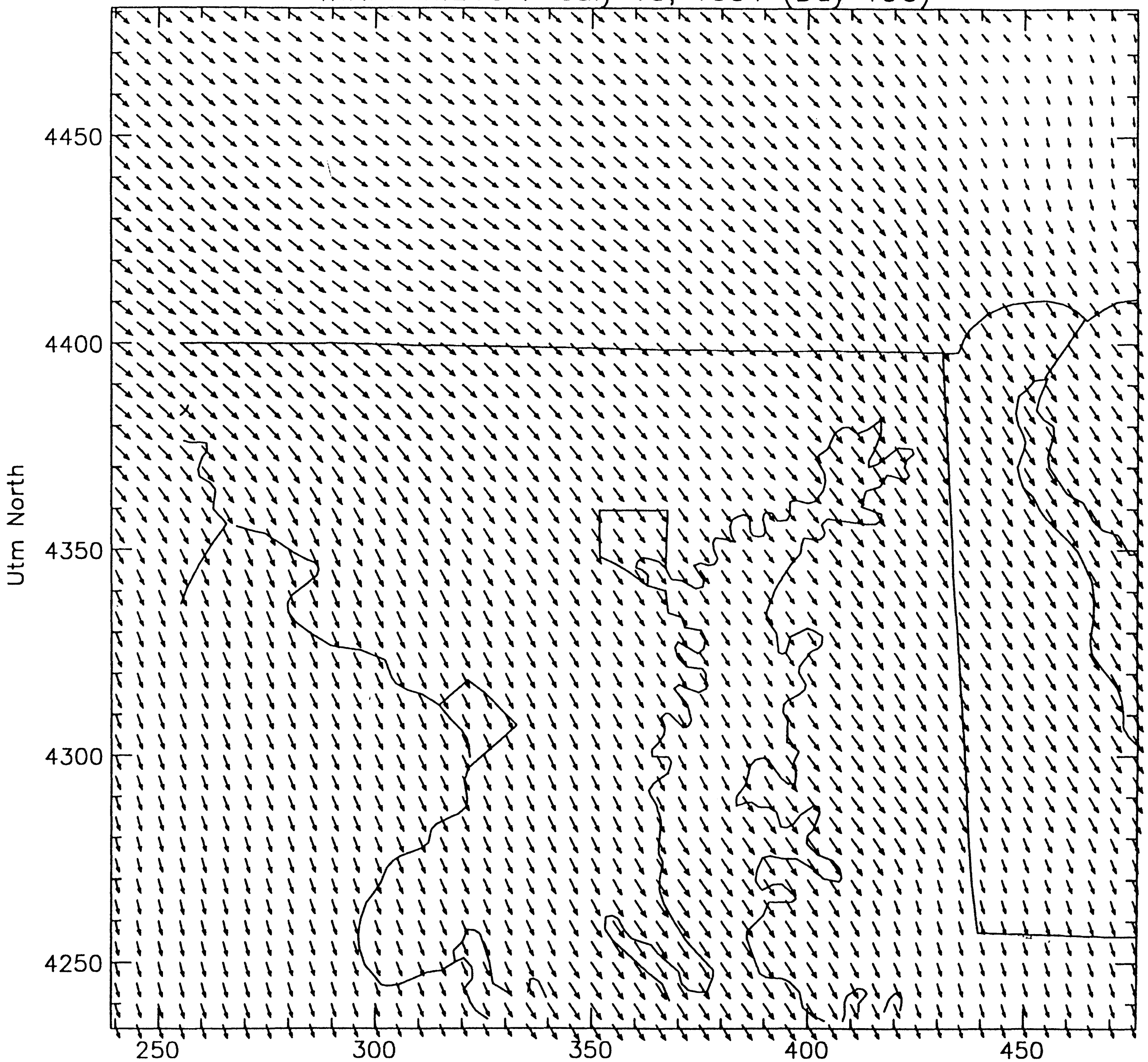

WIND.bin.265 : July 14, 1991)Day 195)
Level 3 for: 91195 @Hour 1600
Utm North
4450
4400
4350
4300
4250
250
300
350
400
450

WIND.bin.266 : July 15, 1991 (Day 196)

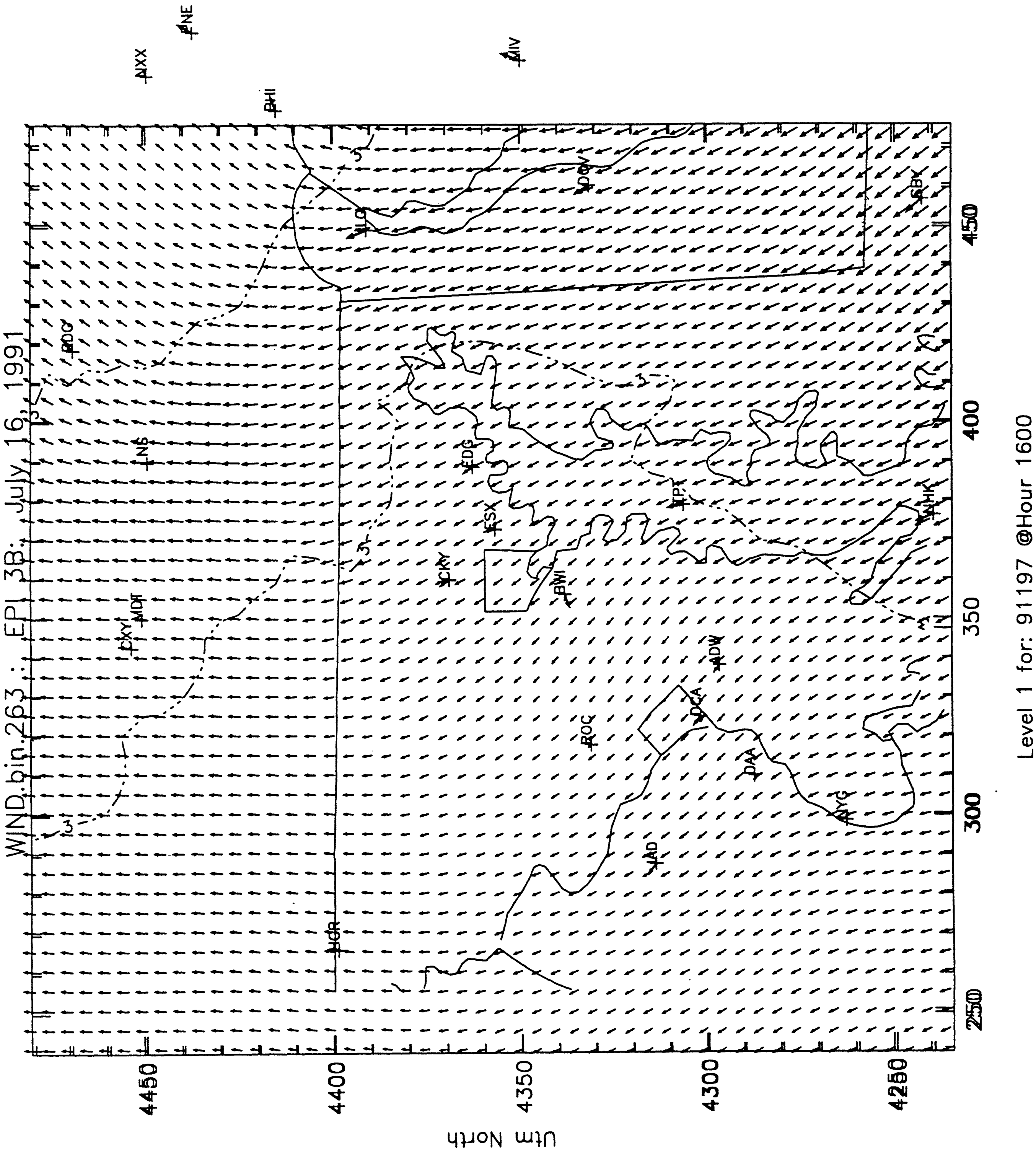


Level 1 for: 91196 @Hour 1600

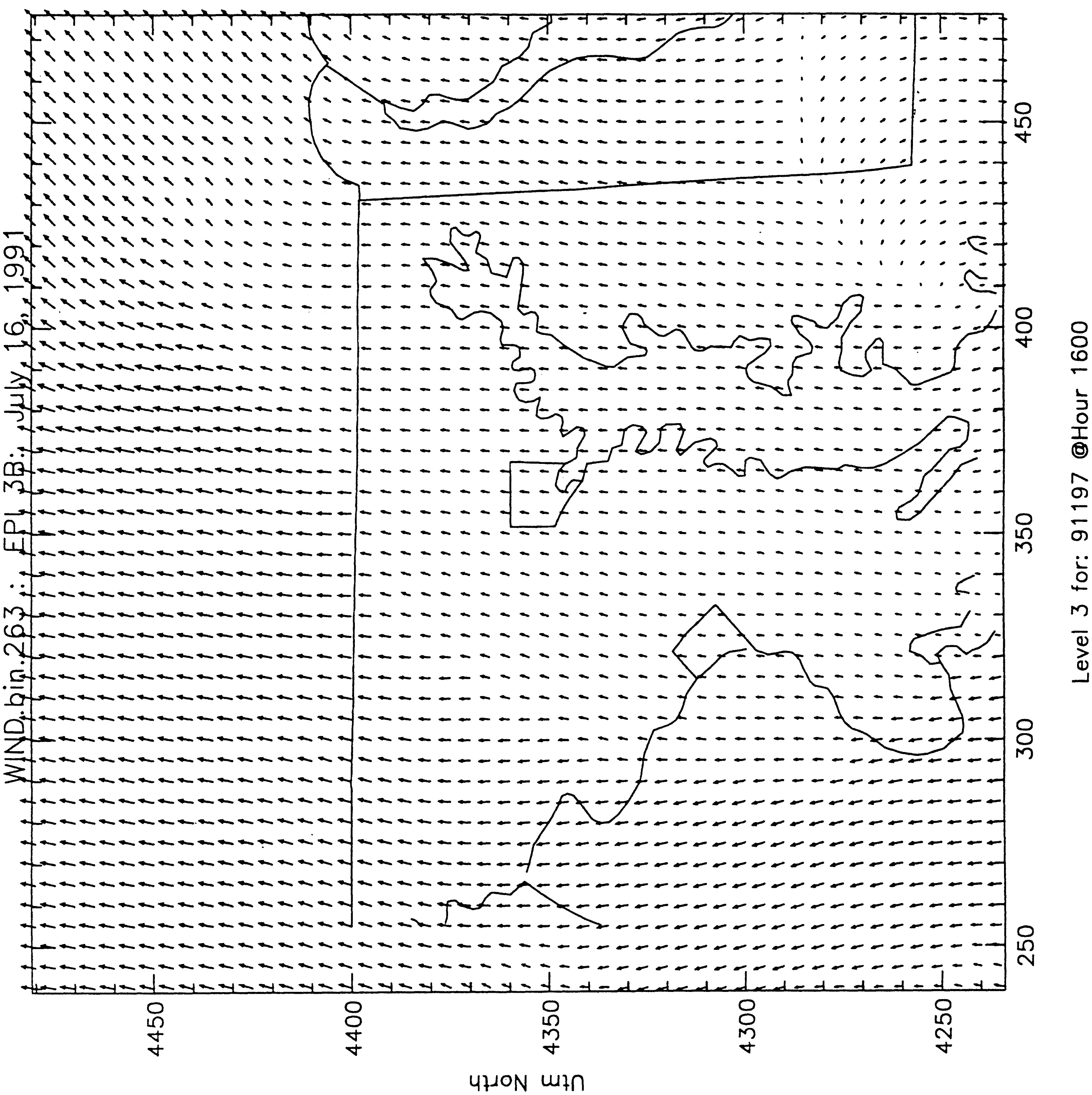
WIND.bin.266 : July 15, 1991 (Day 196)



Level 3 for: 91196 @Hour 1600



WIND.bin.263 : EPI 3B: July 16, 1991
Level 1 for: 91197 @Hour 1600
Utm North
4450
4400
4350
4300
4250
250
300
350
400
450
NXX
PNE
MIV
PHI
DOV
GBY
DOG
NS
EDG
ESX
CKY
BWI
MDT
CXY
HGR
IAD
ROC
DCA
ADW
DAA
NYG
WHK


WIND.bin.263 : EPI 3B: July 16, 1991
Level 3 for: 91197 @Hour 1600
Utm North
4450
4400
4350
4300
4250
250
300
350
400
450

Figures 6a-6f

Figures 6a-6f contain output from the TEMPERATUR preprocessor for various times and days during Episode 3B. All figures show temperatures in degreees Kelvin.

Figure 6a. TEMPERATUR output for 1200 EST on July 14, 1991 (Julian Day 195).

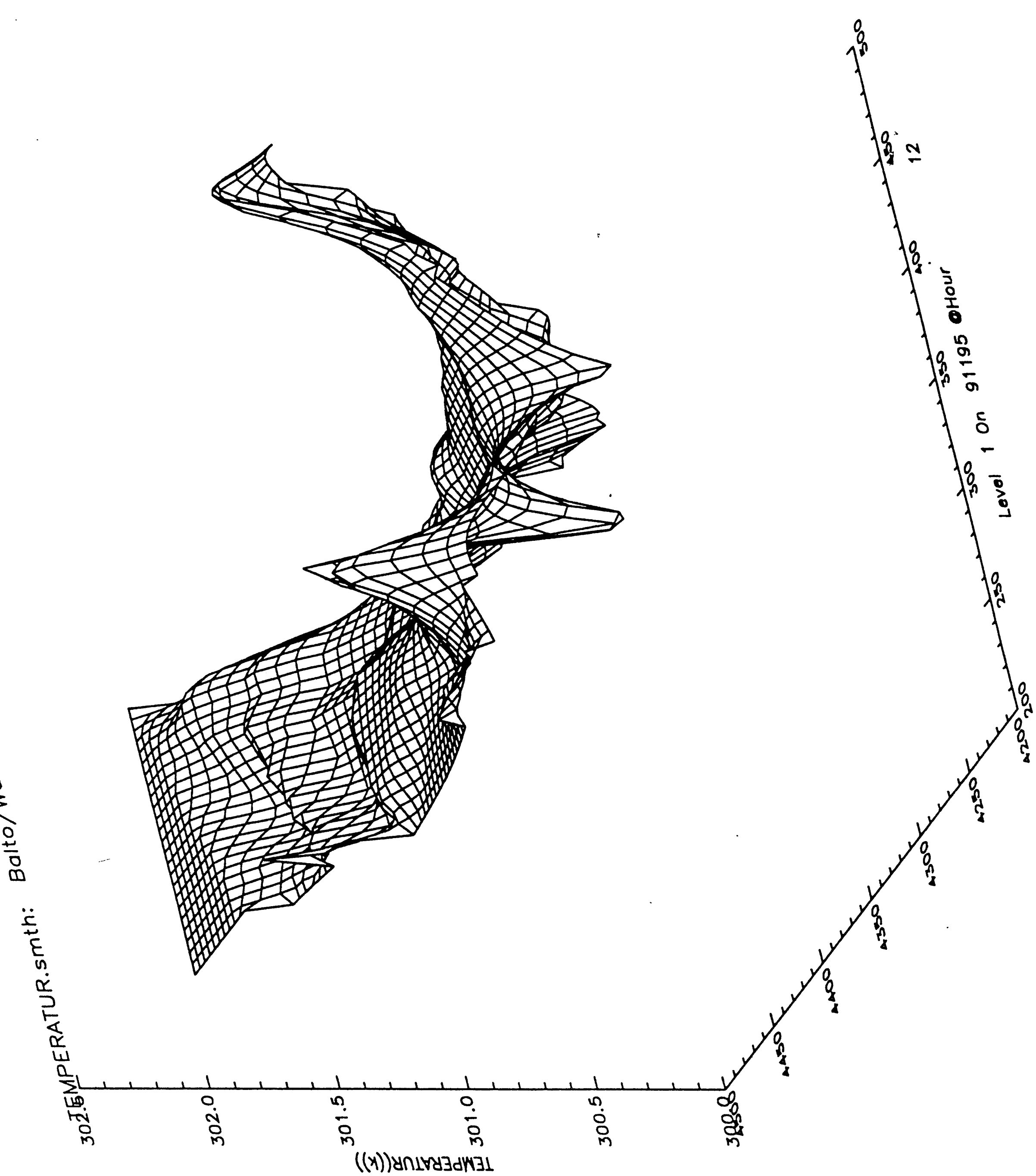
Figure 6b. TEMPERATUR output for 1600 EST on July 14, 1991 (Julian Day 195).

Figure 6c. TEMPERATUR output for 1200 EST on July 15, 1991 (Julian Day 196).

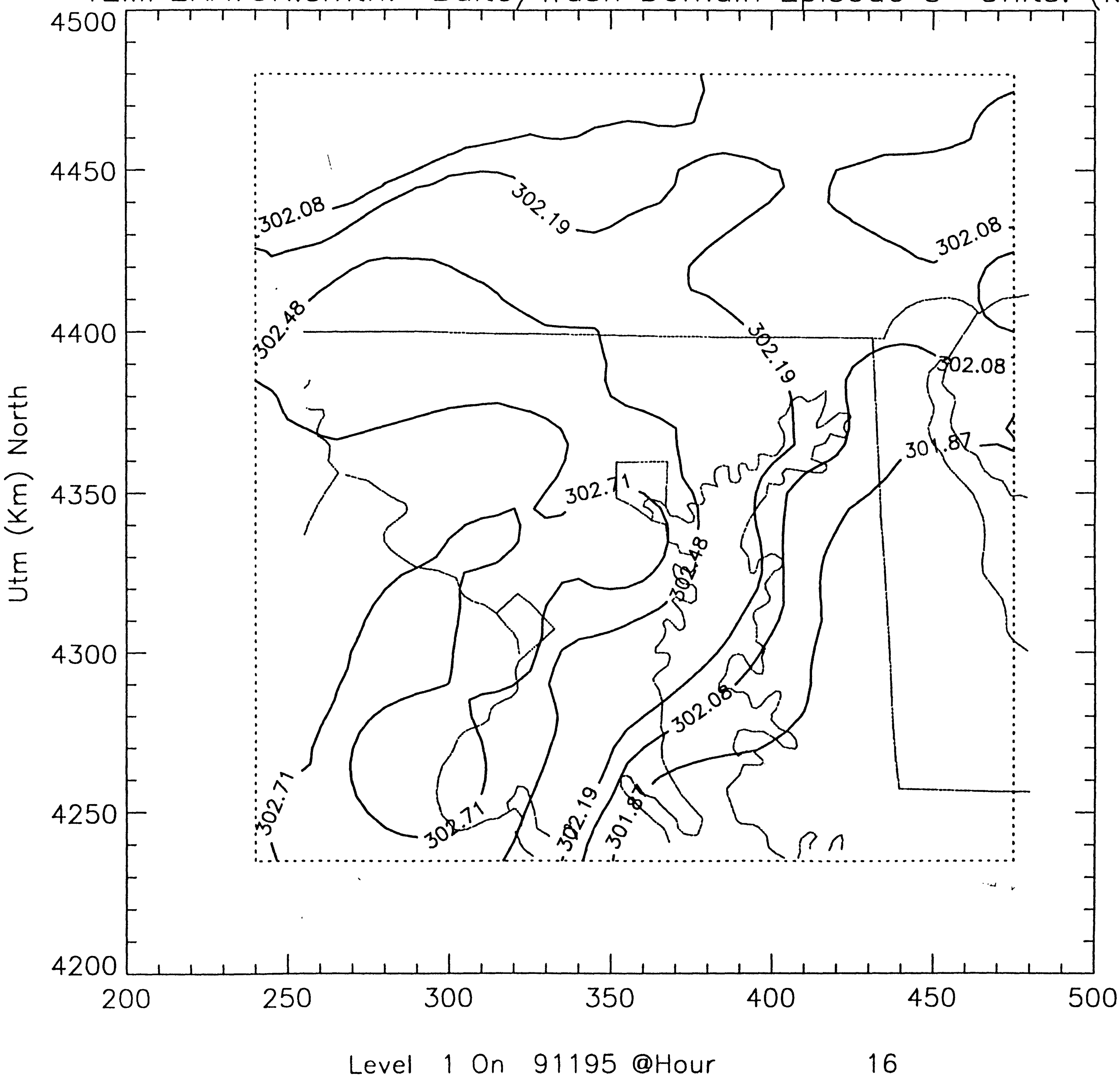
Figure 6d. TEMPERATUR output for 1600 EST on July 15, 1991 (Julian Day 196).

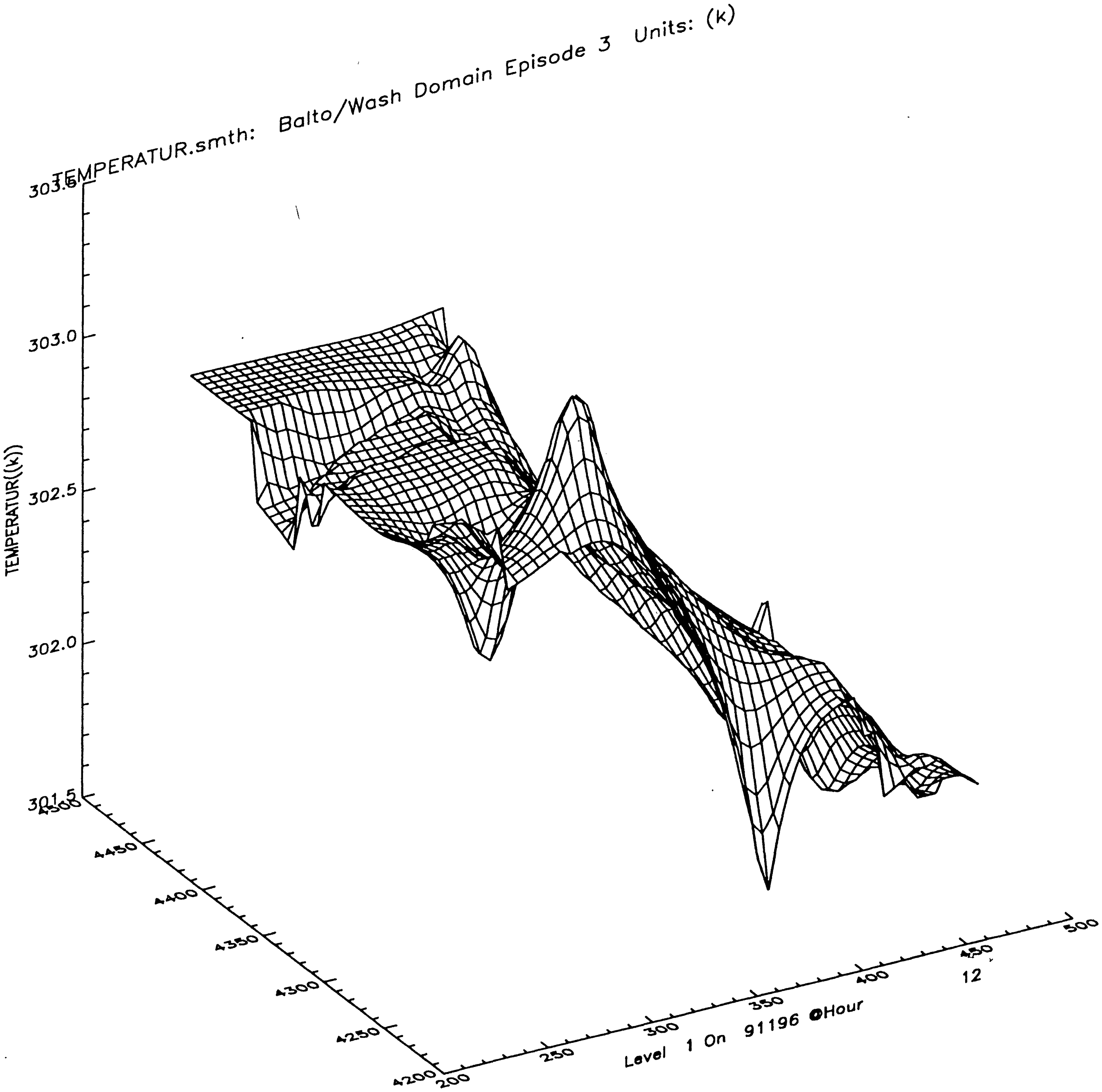
Figure 6e. TEMPERATUR output for 1200 EST on July 16, 1991 (Julian Day 197).

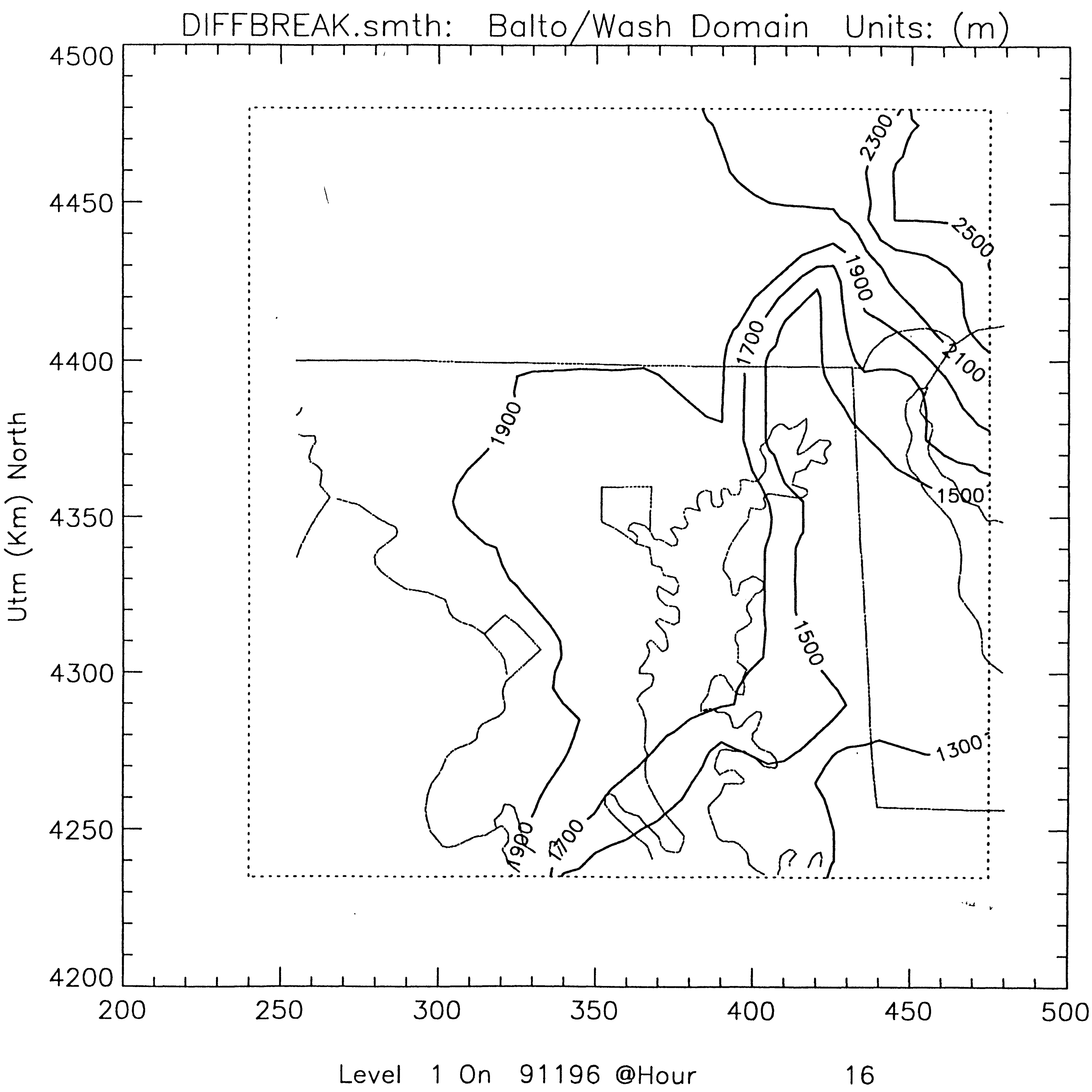
Figure 6f. TEMPERATUR output for 1600 EST on July 16, 1991 (Julian Day 197).

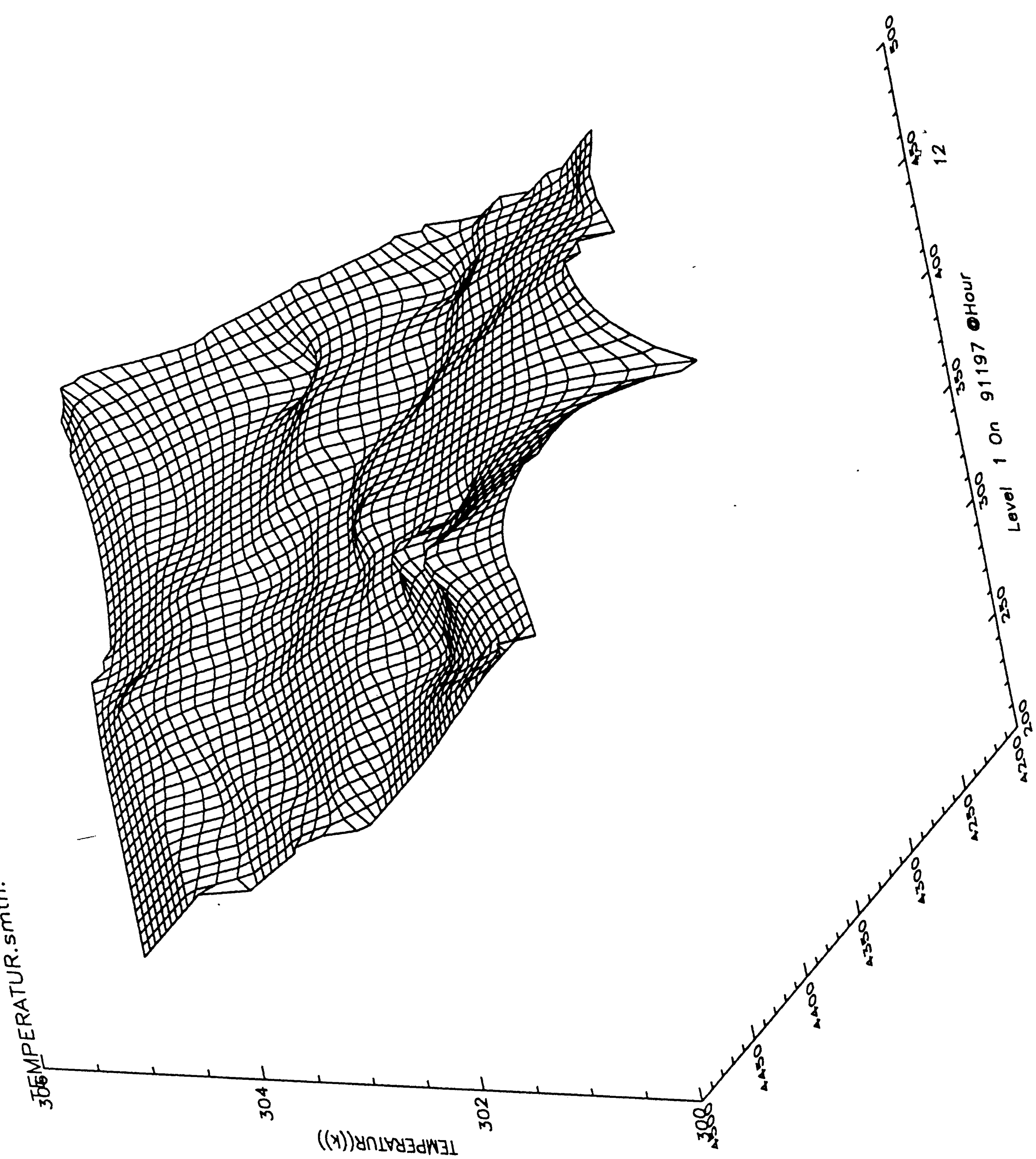

TEMPERATUR.smth: Balto/Wash Domain Episode 3 Units: (k)
TEMPERATUR((k))
302.5
302.0
301.5
301.0
300.5
300.0
Level 1 On 91195 @Hour 12

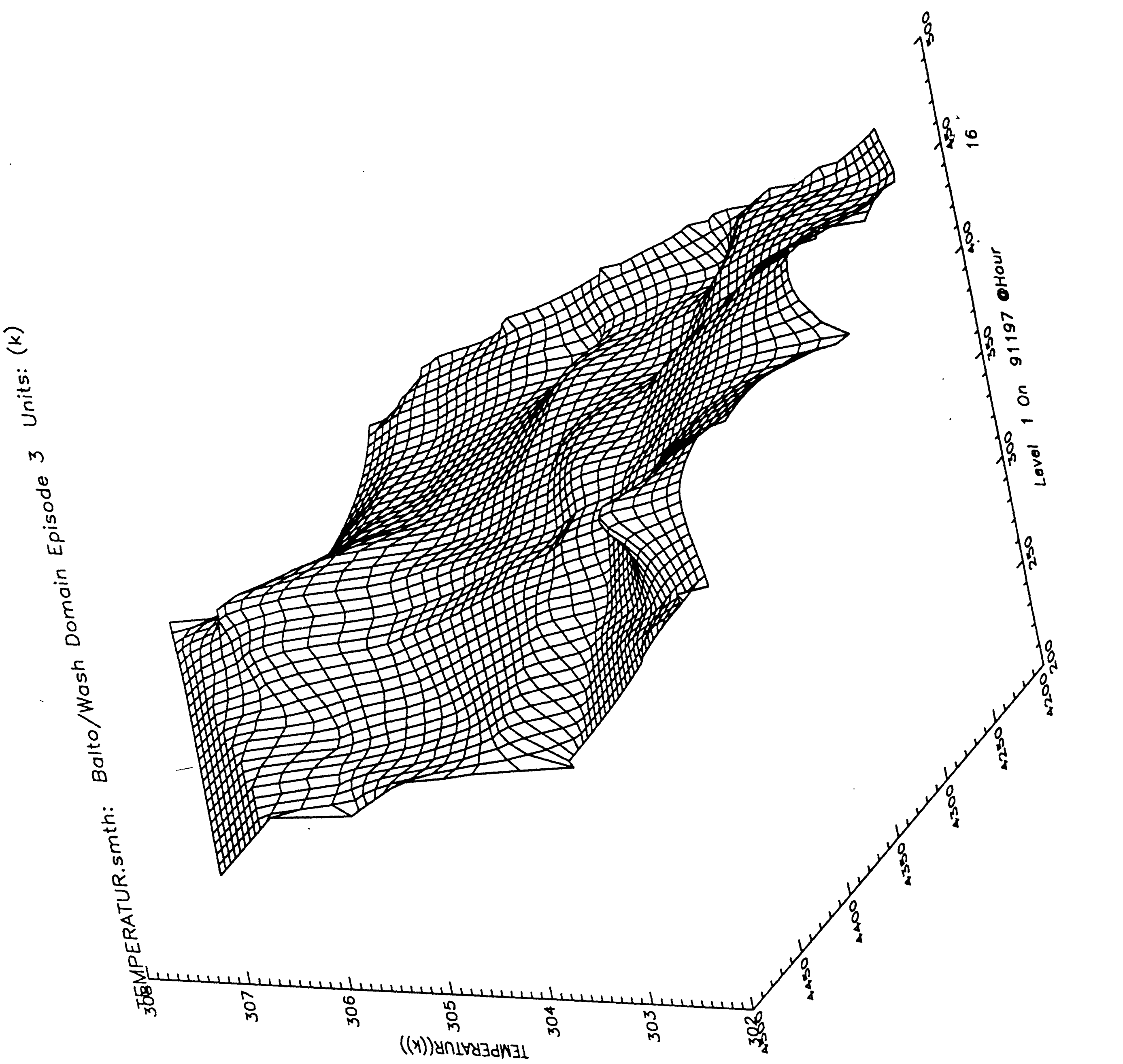
TEMPERATUR.smth: Balto/Wash Domain Episode 3 Units: (k)




TEMPERATUR.smth: Balto/Wash Domain Episode 3 Units: (k)
TEMPERATUR((k))
303.5
303.0
302.5
302.0
301.5
4500
4450
4400
4350
4300
4250
4200
200
250
300
350
400
450
500
Level 1 On 91196 @Hour 12


DIFFBREAK.smth: Balto/Wash Domain Units: (m)
Utm (Km) North
4500
4450
4400
4350
4300
4250
4200
200
250
300
350
400
450
500
2300
2500
1900
2100
1700
1500
1900
1500
1300
1900
1700
Level 1 On 91196 @Hour 16


TEMPERATUR.smth: Balto/Wash Domain Episode 3 Units: (k)
Level 1 On 91197 @Hour 12
TEMPERATUR((k))
306
304
302
300
200
250
300
350
400
450
500


TEMPERATUR.smth: Balto/Wash Domain Episode 3 Units: (k)
Level 1 On 91197 @Hour 16
TEMPERATUR((k))
302
303
304
305
306
307
308
200
250
300
350
400
450
500

Appendix A

Sample Control File for MIXEMUP Preprocessor
(Episode 3B)

NSTAU	: 3		
NAV	: 1		
LALLST	: WAL	ACY	SV2
KSTAT	: ACY		
LEVELS	: 30		
NSTASW	: 12		
IDSFCW	: ILG		
NSTAT	: 12		
IDSFCT	: ILG		
KYEAR	: 91		
KMONTH	: 07		
KDAY	: 16		
LSUNUP	: 487		
LSUNDW	: 1940		
SMINHM	: 50.		
SMAXHM	: 2586.		
LDELAY	: 3		
IDMIX	:BENSCH		
C1	: 125.		

Appendix B

Sample Control File for the DIFFBREAK preprocessor
(Episode 3B)

```
CONTROL
DIFFBREAK
Balto/Wash Domain
         0          0         12          1         10
        20          0          0
         0          1          0          0          1


     91195          0      91198       0200
END
REGION
       0.0        0.0         18
  240000.0  4235000.0
    5000.0     5000.0
        48         50          5
         2          3        0.0       50.0      400.0
END
STATIONS
93755PHI     478622.0 4414659.0        1.5                          2
93755NXX     487516.0 4449016.0       94.2                          1
93734SBY     456296.0 4242737.0       18.3                          1
93734NHK     376116.0 4239868.0       11.6                          1
93734DOV     459663.0 4331497.0        8.5                          1
93734BWI     356040.0 4338262.0       45.1                          2
93734ILG     448531.0 4390754.0       22.6                          2
93734NYG     298692.0 4263242.0        6.7                          2
93734DCA     324987.0 4301879.0        3.0                          2
93734CXY     342571.0 4453265.0       36.9                          1
93734ADW     338058.0 4296767.0       24.4                          2
93734IAD     287680.0 4313896.0       98.5                          2
END
TIME INTERVAL
     91195          0      91195        100
SUBREGION
A                   1          1         -1
END
METHOD
A         DIFFBREAK STATINTERP        0.0     5000.0          4
EXTENT     0.0
INITRADIUS   10.0
RADIUSINCR   15.0
MAXRADIUS  500.0
END
```

DIFFUSION BREAK CONTROL PARAMETERS FOR EPISODE 3B (JULY 14-16, 1991)

Appendix C

List of Stations Used in DWM Simulation
(Episode 3B)

Last Revised: November 2, 1995

```
NSTA:          %
NSTRHR:        0
NENDHR:        24
TDIF:         1.0
KYEAR:         91
KMONTH:        07
KDAY:          16
STATIONS
BWI
DCA
IAD
ILG
NHK
PHI
ADW
CXY
DAA
DOV
HGR
LNS
MDT
MIV
NXX
NYG
PNE
RDG
SBY
TPT
CKY
ROC
EDG
ESX
END
@ surface data will be included here
```

STATIONS USED FOR PRELIMINARY DWM FIELDS
FOR EPISODE 3B (JULY 14-16, 1991)

APG01:A01:Aberdeen Soundings:39.5:76.07:407994:4372630:16.4:2: Military
13701:ABE:Aberdeen:39.5:76.1:404894:4376524:58:1: Military
93730:ACS:Atl City Surf:39.75:74.667:528560:4399884:64:1: NWS
93755:ACY:Atlantic City:39.75:74.667:528560:4399884:64:1: NWS
74594:ADW:Andrews:38.8:76.9:338058:4296767:80:2: Military
30002:BAL:Baltimore pseudo:39.3:76.6:360556:4349283:10:1: Pseudo
30001:BL1:FrederickX:39.5:77.02:340000:4380000:148:1: Pseudo
MD997:BLT:Baltimore,245100011: 39.2: 76.6: 363251:4344028:36:1: MDE
93721:BWI:Balto.Wash.Intl:39.18:76.67:356040:4338262:148:2: NWS
30003:CAT:Catoctin Mt sudo:39.6:77.5:286926:4391673:491:2: Pseudo
40006:CCL:Calvert Cliffs:38.4:76.5:374600:4254700:38:1: Private
MD849:CKY:Cockeysville,240051007: 39.5: 76.6: 359673:4369009:413:1: MDE
24026:CRS:Crisfield :37.9:75.8:423705:4203236:13:2: CoastGuard
14751:CXY:Capitol City Arprt:40.2:76.8:342571:4453265:121:1: NWS
72403:DAA:Fort Belvior:38.7:77.2:310000:4287500:79:2: Military
71777:DAH:DAhlgren Naval:38.33:77.08:324989:4239873:2:Military
MD007:DAV:Davidsonville,240030014: 38.9: 76.5: 356679:4307078:13:2: MDE
13743:DCA:Wash.Natl:38.85:77.02:324987:4301879:10:2: NWS
40001:DIC:Dickerson surface:39.18:77.45:289100:4342800:270:1: Private
40007:DIK:Dickerson Sodar:39.18:77.45:289100:4342800:270:1: Private
72408:DOV:Dover AFB:39:75.47:459663:4331497:28:1: Military
MD005:EDG:Edgewood,240251001:39.3:76.2:388317:4362839:6:2 : MDE
90008:EGW:Edgewater:38.93:76.58:365000:4312500:49:1: SmitSon
30004:EMM:Emmitsburg sudo:39.6:77.3:302750:4394956:127:2: Pseudo
MD191:ESX:Essex,240053001: 39.3: 76.3: 372358:4356794:16:1: MDE
93735:FAF:Fort Eustis:39.1:76.6:361000:4328910:12:2: Military
13730:FRD:Frederick:39.4:77.4:294771:4363654:134:1: FAA
30005:FRE:Frederick sudo:39.4:77.5:290515:4365656:116:2: Pseudo
24093:GRG:Georgetown:38.6:75.7:460830:4276004:24:1: FAA
93711:HGR:Hagerstown:39.8:77.9:266064:4398551:704:1: FAA
93738:IAD:Wash.Dulles:38.95:77.45:287680:4313896:323:2: NWS
13781:ILG:Wilmington:39.667:75.6:448531:4390754:74:2: NWS
24046:IND:Indian River:38.5:75.1:495639:4261114:10:2: CoastGuard
13702:LFI:Langley AFB:37.1:76.3:384469:4106571:10:2: Military
40005:LMK:Limerick:40.1:75.6:450000:4452500:50:1: Private
14752:LNS:Lancaster:40.1:76.3:389648:4449016:270:1: FAA
40008:MCR:Martins Creek:40.8:75.1:488600:4515200:320: 2: Private
14711:MDT:Harrisburg:40.2:76.8:349890:4450496:316:1: FAA
13735:MIV:Millville:39.3:75.1:491377:4349894:67:1: Military
40002:MOR:Morgantown:38.5:77.02:326700:4253200:22:1: Private
90009:MTN:Martin StAP:39.30:76.42:377500:4354000:22:2: FAA
13721:NHK:Patuxent NAS:38.3:76.42:376116:4239868:38:1: Military
13769:NTU:Oceana:36.8:76.0:410781:4072967:20:2: Military
14793:NXX:Willow Grove:40.2:75.1:487516:4449016:309:1: Military
13773:NYG:Quantico MAS:38.5:77.3:298692:4263242:22:2: Military
13796:OCY:Ocean City:38.4:75.14:488000:4250000:10:1: FAA
40004:PCH:Peach Bottom:39.7:76.3:391000:4401600:50:1: Private
13739:PHI:Phil.Int:39.88:75.25:478622:4414659:5:2: NWS
24085:PNE:Philadelphia NE:40.1:75.0:498579:4436827:37:1: ???
40003:PSP:Possum Point:38.6:77.3:301100:4269100:22:1: Private
14712:RDG:Reading:40.3:75.9:417922:4468723:104:1: FAA
13740:RIC:Richmond:37.5:77.34:293733:4152710:164:2: NWS
MD406:RIV:Rivera Beach,240032002: 39.1: 76.5: 369390:4335381:46:1: MDE
MD234:ROC:Rockville,240313001:39.11:77.11:317810:4331259:126:1: MDE
93720:SBY:Salisbury:38.33:75.5:456296:4242737:60:1: FAA
07607:SPE:Spesutie, apg:39.5:76.12:407994:4372630:16:2: Military
MD740:SUI:Suitland,240338001: 39.0: 76.7: 332354:4302067:39:1: MDE
93734:SV2:Sterling,UAU:38.98:77.47:286336:4317635:276:2: NWS
25000:THM:Thomasville:39.9:76.8:340454:4419994:148:2: FAA
07646:TIP:Tipton, apg:39.05:76.46:347186:4327327:150:2: Military
99998:TPT:Thomas Point:38.9:76.4:378589:4306429:59:1: Coast Guard
07613:TRE:Trench Warefare, apg:39.78:76.22:402793:4369636:40:2: Military
93739:WAL:Wallops Is.:37.93:75.48:457522:4198346:40:1: NWS
07619:WOR:Worton Pt, apg:39.5:76.32:397909:4350556:30:2: Military

Appendix D

Control File for DWM Simulation
(Episode 3B)

```
Balt/Wash7/5/88-7/7/88
NX        :48
NY        :50
NZ        :14
DXK       :  5.0
DYK       :  5.0
CELLZB    :    0.0   50.0 100.0 200.0 300.0 400.0 500.0 600.0 700.0 800.0
           1000.01500.02000.02500.03000.0
UTMXOR    :240.0
UTMYOR    :4235.0
TSTART    :    0
TEND      : 2300
TINC      :1.
NWIND     :28
NUPPER    :4
ZSWIND    :10.
RMIN      :20.
RMAX1     :500.
RMAX2     :500.
RMAX3     :500.
R1        :25.
R2        :300.
NINTRP    :     8     4     4     4     4     4     4     4     4     4
                4     4     4
NZPRNT    :1
IPR0      :-1
IPR1      :-1
IPR2      :-1
IPR3      :-1
IPR4      :-1
IPR5      :-1
IPR6      :-1
IPR7      :-1
ICALC     :1
IOUTD     :1
HTFAC     :1.
NITER     :50
DIVLIM    :1.0E-6
IOBR      :0
NUMBAR    :0
I3DCTW    :0
NSMTH     :1
IEXTRP    :1
FEXTRP    :    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
               0.0    0.0    0.0
```

DWM PARAMETERS FOR EPISODE 3B (JULY 14-16, 1991)

Appendix E

Control Files Used in DWM-UAM Interface
(Episode 3B)

```
DWM WIND FIELDS - Balto/Wash
TOP:        3000.,3000.,3000.,3000.,3000.,3000.,3000.,3000.,
3000.,3000., 3000.,3000.,3000.,3000.,3000.,3000.,3000.,3000.,
3000.,3000., 3000.,3000.,3000.,3000.
NZD:            14
HGT:             0., 50., 100., 200., 300., 400., 500., 600.,
700., 800.,1000., 1500.,2000.,2500.,3000.
NSMTH:           2
IDATEW:    %idatew  # for July 14, 1991
BEGTIW:     %bgn
JDATEW:    %jdatew
ENDTIW:     %end
ISTAB:           5,    5,    6,    5,    6,    5,    4,    3,    3,    3,
2,   2,    2,    2,    2,    1,    2,    3,    3,    4, 5,    6,    6,  6
Z0:         1.20
NXT:           23
NYT:           25
```

```
DWM WIND FIELDS - Balto/Wash
TOP:        3000.,3000.,3000.,3000.,3000.,3000.,3000.,3000.,
3000.,3000., 3000.,3000.,3000.,3000.,3000.,3000.,3000.,
3000.,3000.,3000., 3000.,3000.,3000.,3000.
NZD:          14
HGT:           0., 50., 100., 200., 300., 400., 500., 600.,
700., 800.,1000., 1500.,2000.,2500.,3000.
NSMTH:         2
IDATEW:   %idatew    # for July 15, 1991
BEGTIW:    %bgn
JDATEW:   %jdatew
ENDTIW:    %end
ISTAB:         5,    5,    6,    5,    6,    5,    4,    3,    3,    3,
2,   2,   2,   2,    2,    1,    2,    3,    3,    4, 5,    6,    6,   6
Z0:         1.20
NXT:          23
NYT:          25
```

```
DWM WIND FIELDS - Balto/Wash
TOP:        3000.,3000.,3000.,3000.,3000.,3000.,3000.,
3000.,3000.,3000., 3000.,3000.,3000.,3000.,3000.,
3000.,3000.,3000.,3000.,3000., 3000.,3000.,3000.,3000.
NZD:          14
HGT:           0., 50., 100., 200., 300., 400., 500.,
600., 700., 800.,1000., 1500.,2000.,2500.,3000.
NSMTH:         2
IDATEW:    %idatew  # for July 16, 1991
BEGTIW:     %bgn
JDATEW:    %jdatew
ENDTIW:     %end
ISTAB:         6,   5,   6,   6,   6,   5,   4,   3,   2,
2,1,   2,   1,   1,   2,   2,   2,   2,   3,   4,
5,  6,   6,  6
Z0:         1.20
NXT:          23
NYT:          25
```

Appendix F

Control File Used for TEMPERATUR Simulation
(Episode 3B)

```
CONTROL
TEMPERATUR
Balto/Wash Domain Episode 3
         0         0        15         1        10
        20         0         1
         0         0         0         0         1


     91195         0     91197      2400
END
REGION
       0.0       0.0        18
  240000.0 4235000.0
    5000.0    5000.0
        48        50         5
         2         3       0.0      50.0     400.0
END
UNITS
TEMPERATUR     DEGF
END
STATIONS
SBY         456296.0 4242737.0      18.3                                  1
PNE         498579.0 4436827.0      11.3                                  1
PHI         478622.0 4414659.0       1.5                                  2
NYG         298692.0 4263242.0       6.7                                  2
NXX         487516.0 4449016.0      94.2                                  1
NHK         376116.0 4239868.0      11.6                                  1
MDT         349890.0 4450496.0      96.3                                  1
ILG         448531.0 4390754.0      22.6                                  2
IAD         287680.0 4313896.0      98.5                                  2
DOV         459663.0 4331497.0       8.5                                  1
DCA         324987.0 4301879.0       3.0                                  2
CXY         342571.0 4453265.0      36.9                                  1
BWI         356040.0 4338262.0      45.1                                  2
BAL         360556.0 4349283.0       3.0                                  1
ADW         338058.0 4296767.0      24.4                                  2
END
TIME INTERVAL
     91195         0     91195       100
SUBREGION
A                    1         1        -1
END
METHOD
A         TEMPERATURSTATINTERP50.0        120.0       4
EXTENT    0.0
INITRADIUS 5.0
RADIUSINCR10.0
MAXRADIUS 70.0
END
STATION READINGS
SBY       TEMPERATUR       75.0
PNE       TEMPERATUR       69.0
PHI       TEMPERATUR       72.0
NYG       TEMPERATUR       76.0
NXX       TEMPERATUR       69.0
NHK       TEMPERATUR       80.0
MDT       TEMPERATUR       76.0
ILG       TEMPERATUR       73.0
IAD       TEMPERATUR       70.0
DOV       TEMPERATUR       76.0
DCA       TEMPERATUR       83.0
CXY       TEMPERATUR       75.0
BWI       TEMPERATUR       74.0
BAL       TEMPERATUR       74.0
ADW       TEMPERATUR       76.0
END
```

TEMPERATURE CONTROL FILE FOR EPISODE 3B (JULY 14-16, 1991)

Documentation for Meteorological Fields
(Episode 3, July 18-20, 1991)

prepared by:

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Last Revision: 1/12/95

This document contains information regarding the creation of meteorological fields for the July 18-20, 1991 ozone episode in the Baltimore-Washington domain. This episode has been named "Episode 3" and reflects a transport regime (Class 3) that is characteristic of high ozone in this domain.

The Class 3 episodes, of which Episode 3 is a member, is characterized by the presence of surface high pressure (anticyclone) centered south and east of the domain. This results in a southerly or southwesterly low level wind flow. This is in contrast to the other classes of ozone episodes in which high pressure is centered to the west or northwest of the region and winds are generally northwest or north in the boundary layer (excepting the surface).

At the beginning of the episode (July 18, 1991), a stationary front lies well south of the region with a weak lee trough lingering along a line from NYC-PHI-HGR. This trough is a persistent feature of this episode and will drift back and forth across the domain from the west (near HGR) to the east (near SBY). At 850 mb (approximately 1.5 km), high pressure is located southeast of the domain (30° N, 70° W) with a secondary, weaker center over Missouri. A mid-level trough is exiting the New England region and the net effect of this pattern is to drive moderate west winds across the domain.

At the surface on the morning of the 18th, winds are light southerly with fog and haze. The stationary front to the south dissipates throughout the morning hours and, at 850 mb, the offshore high pressure center drifts slightly north. Winds at this level are light W and WSW. By 1100 EST, the surface lee trough is analyzed across the Chesapeake Bay. This trough is not particular strong in either the wind, pressure or density fields and the analysis of its position at any particular hour is subject to dispute. In general, the identification and placement of a weak lee trough can be highly variable from analysis to analysis. This is due in part to the mesoscale nature of the lee trough phenomena which is often inadequately resolved by synoptic scale observations. What can be stated about this episode is that the surface isobars are widely spaced (weak pressure gradients) and generally aligned WSW to ENE with a weak trough east of the Appalachians.

By evening of the 18th, the two-high pattern at 850 mb drifts slightly east with the weatern center now over Indiana. The winds at this level back to the south and southwest and tend to erase the lee trough though it is re-analyzed by early morning of the 19th. By mid-morning on July 19th, the western high pressure center is no longer evident at 850 mb. Wind along the coast (ACY, WAL) are strong SW while the inland stations (IAD, PIT) report weaker WSW winds. This is a more typical Bermuda High pattern and ozone concentrations on the 19th, though high, are not extreme.

By the evening of July 19th a subtle shift in the upper air pattern occurs. A short wave trough rotating around a closed low in southern Canada drops into the northern tier states. Although the cooler and drier weather associated with this system does not directly affect the model domain, the trough does "squeeze" into the high pressure circulation from the north. This serves to detatch a lobe of high pressure from the offshore anticyclone and drive it westward into the NC/SC coast. This shifts the winds at 850 mb more westerly.

On the morning of July 20th (the highest ozone day), the lobe of high pressure (1590$^+$ m) has moved further westward into eastern TN and AL. The effect of this building ridge to the SW of the domain, coupled with the trough to the north, is to shift the 850 mb winds further to the NW. At the surface, the cold front associated with the upper level trough reaches the northern Great Lakes. The pressure field in the domain, however, remains diffuse with isobars widely spaced and oriented west to east. A lee trough is again analyzed along the Eastern Shore in the moring and drifts west during the day. For a brief period in the late morning, there is a pulse of NW winds west of the Bay. This is replaced by southerly flow in the afternoon.

The high ozone on July 20th is related to several factors. First, light winds and clear skies drive strong photochemistry. In addition, the pulse of northerly winds in the morning, with southerly winds returning in the afternoon, serves to recycle the emissions plume. That is, the morning emissions are briefly advected southward and then backed up over the cities in the afternoon. This lack of ventilation concentrates the emissions plume and further enhances photochemical activity. A similar "backwash" effect was observed during the summer forecast programs in 1993 and 1994. The final factor driving high ozone is the presence of a strong low level inversion assocaited with the retrograding 850 mb high pressure lobe. This limits the volume into which the emissions are mixed. The net result is high ozone despite the fact that the 20th is a Saturday.

Mixing Height Field

The MIXEMUP preprocessor in standard form was used to create the mixing height field. Because MIXEMUP requires a full complement of data (temperature, wind and station pressure), with no missing data allowed, the selection of stations to be used as part of the MIXEMUP field was limited to some extent. In some cases, editing of the data base was necessary in order to create a fairly comprehensive mixing height field. This editing was not carried over to the wind field which can operate with missing data. In addition, the amount of editing of data was kept to the minimum possible.

Input Data:

A list of all surface and upper air stations in the B/W domain is attached as Appendix A. A list of those stations used in the Episode 3 MIXEMUP field is attached as Appendix B. A list of those stations for which some data was available but which are not used in the MIXEMUP field is listed below.

Surface Stations Not Used in Episode 3 MIXEMUP	
Station	Remarks
Aberdeen, MD (ABE)	Missing 8 h data on 7/18/-19, missing all data 7/20
Reading, PA (RDG)	Missing 8 h data each day, missing station pressure
Hagerstown, MD (HGR)	Missing 9 h data each day, missing station pressure
Middletown, PA (MDT)	Missing station pressure
Ocean City Coast Guard (OCY)	Only 3 reports daily
Lancaster, PA (LNS)	Missing 8 h data each day, missing station pressure
Millville, NJ (MIV)	Missing 16 h data each day

In addition, data from Thomas Point Light Station (TPT) on the Chesapeake Bay was not used to create the MIXEMUP field for this episode. The station at TPT is the only source of Chesapeake Bay data and the decision to not use this data is an important one. The reason for deleting the station is the extreme gradients that are produced in the MIXEMUP field when it is used. As will be noted in more detail below, a difference of a few degrees in temperature will drive very large differences in mixing height. TPT is routinely 10°F or more cooler than the land stations that surround it. The net result is a circular area of very low mixing height in the center of the domain. If the wind field has any vertical shear, which is usually the case for ozone episodes, the effect of these strong gradients in the mixing height can be severe.

As documented in previous reports, many attempts were made in Episode 1 to contain this effect or fully simulate the Bay effect using alias stations. None of these attempts were successful. The other possible method is to strongly smooth the field to contain the effect. It was felt that over-smoothing the mixing height field to add one station was not necessary in this case.

As noted above, MIXEMUP requires station pressure as input. The data set acquired from the National Climate Data Center for July 1991 does not include pressure data for several stations although the remainder of the data types (temperature, wind) are complete. In an attempt to include as many sources of data as possible, station pressure from nearby stations, at approximately (within 80 m) the same elevation, were used. These stations are: Salisbury, MD (SBY), using BWI pressure, North Philadelphia (PNE), using Philadelphia (PHI) data, and Dover AFB (DOV), using Wilmington (ILG) data. Because the pressure gradients are fairly weak during this episode, the difference should not be large. Pressure data was not supplied to Middletown (MDT) as the station at Harrisburg (CXY) is closely located.

Alterations to MIXEMUP field:

The MIXEMUP field contains some shortcomings which required limited adjustment of the model output. The areas of concern are listed below.

(1) MIXEMUP will predict large variations in late afternoon mixing heights based on slight cooling at the stations. In these cases the cooler temperature lasted only 1-2 hours before recovering. The huge drop in the mixing height in those hours does result in unusual spatial effects when the MIXEMUP field is interpolated into the DIFFBREAK field. When the DIFFBREAK field is then used to create the wind field, very odd effects are created that are model artifacts.

Episode 3: Short Term MIXEMUP Variations			
Station	Date	Time	1 hour Change in height (m)
ILG	7/19/91	1600	150
BWI	7/20/91	1600	630
NHK	7/20/91	1500-1600	650
DOV	7/20/91	1500-1600	660
PNE	7/19/91	1700	970
SPE	7/20/91	1400'	450

At all stations, the temperature fell 2-5°F at the hour (or hours) of lower mixing heights and then recovered, as did the mixing heights, to heights at or above those that preceded the brief cooling. To modulate the effects of these brief glitches, the final field was edited to interpolate between the hours prior to and succeeding the time of cooling.

(2) Extremely high mixing height values at higher elevation stations. This effect is related to some degree to higher temperatures at the higher elevation sites but also appears to be a function of the use of station pressure as the starting point for the stability analysis. That is, higher elevation stations have lower station pressure. When the lower station pressure is inserted into the applicable upper air sounding the effect is higher levels of buoyancy lifting. As in (1) above, dry static stability analysis, when used to predict mid-day mixing heights, is strongly sensitive to slight changes in temperature or surface pressure of the ascending parcel. This effect was documented also for the RAMMET preprocessor.

The elevation effect occurred at two stations for Episode 3: CXY and NXX. The table below gives an example of the differences that occur between stations.

Episode 3: Elevation and MIXEMUP			
Surface Station	Upper Air Station	Maximum Mixing Height (and Temperature) July 19, 1991	Maximum Mixing Height (and Temperature) July 20, 1991
PHI	ACY	1400 m (93° F)	900 m (97° F)
CXY	ACY	2700 m (101° F)	2600 m (100° F)
NXX	ACY	3000 m (96° F)	1900 m (98° F)

The NXX and PHI stations are located fairly close to one another though they differ in elevation by approximately 300 m. On July 19th a 3°F difference in maximum temperature results in a maximum mixing height difference of 1600 m. This occurs again on July 20th with only a 1°F difference in temperature. If both stations are retained, an extreme mixing height gradient is present along the northeastern boundary. As noted above, this can have unusual effects on the wind field, and is a particular problem near the boundary. To avoid this situation, which can have an adverse impact on the wind field, the NXX data was not used for this episode. It should be noted that the general transport is from the west and southwest during this episode which makes the northern boundary less critical in this episode than in Episode 1.

The CXY data is more critical since the surrounding stations (LNS, MDT and RDG) do not have complete data in order to apply MIXEMUP at their locations for this episode. However, the extremely high mixing heights near CXY are interpolated well southward due to the lack of other data in this area. Thus, an extreme mixing height gradient is found north of BWI. To reduce this effect, the mixing height at CXY is reduced to +200 m of the local domain maximum mixing height (usually IAD or BWI). This occurred during two periods (1100-2200 on July 19th and 1500-1700 on July 20th). The correction was generally in the range of 200-500 m.

The solution of limiting a station to an envelope of maximum heights is not perhaps the optimal solution. In previous episodes, other techniques were applied including the use of alias stations to limit the spatial interpolation of the station and the use of off-domain soundings (e.g. Pittsburgh sounding used in certain fields prepared by SAI). The net result of each approach is the same, to reduce an unrealistic model-generated value to a more reasonable level.

(3) Occasional large changes in mixing height at single stations. In Episode 3, this occurs at a number of locations. The only critical effect is at BWI on July 18, the first day of the simulation. Between 1000-1100 EST BWI mixing height rises from 500 m to 2500 m. None of the surrounding stations have nearly the same change so that the mixing height field is highly skewed during the hours 1100-1200 EST. This is another example of the extreme sensitivity of static stability analysis to small changes in surface temperature. The solution is to lower the mixing heights at BWI to be consistent with IAD and DCA heights for the hours 1000-1200. The difference generated in the wind field from this change is shown in Figure 1.

Matching of surface and upper air stations:

In order to create a mixing height field, each surface station must be matched with an upper air observation. Because there are so few upper air sites in or near the B/W domain. The matching of stations can be difficult. This is compounded in the B/W domain by the fact that 2 of the 3 available stations are at coastal locations (ACY, WAL). The thermodynamics of the boundary layer are much different at coastal stations than nearby inland locations. Thus, odd results can occur when a sounding from a coastal station is grafted on to an inland location. This was a considerable problem with Episode 1 but is less problematic in this case.

The matching of stations is given in Appendix B (*file: MUdfbk.skl.2*). The criteria for matching stations is based initially on climatological values. As noted in *Holzworth [1972]*, mixing heights along the eastern seaboard tend to increase with distance from the coast. As a result, the presumption for matching of surface and upper air stations is that inland surface stations should be matched with inland upper air stations. The difficulty is that there is only one inland upper air station (IAD). The matching of inland stations in the northern portion of the domain (CXY, ILG, PHI) to a very distant sounding at IAD becomes less attractive. Additionally, some stations, such as DOV, are equal distance from both coastal stations.

The matching in Appendix B follows the initial criteria of matching inland surface stations with inland upper air stations. Thus, CXY as well as the northern Bay stations (SPE, TRE, WOR) are matched to IAD. The stations on the Eastern Shore and lower Bay (SBY, DOV and NHK) are matched with WAL. The Philadelphia area stations are a problem because, although inland, they are considerably closer to ACY. In this case, they were matched to ACY. The most difficult station to match was ILG. ILG can be reasonably matched to any of the three upper air stations. The final decision was to match the station to IAD to preserve continuity to the north of Baltimore. Differences between stations are noted in the table below.

Differences in Maximum Mixing Height due to Upper Air Matching			
Surface Station	Upper Air Station	July 19, 1991	July 20, 1991
DOV	IAD	1.8	1.6
DOV	WAL	2.0	2.2
DOV	ACY	1.5	0.8
ILG	IAD	1.2	1.7
ILG	WAL	1.6	2.2
ILG	ACY	1.0	1.1
NHK	IAD	1.0	0.6
NHK	WAL	1.4	1.3
TPT	IAD	0.9	0.5
TPT	WAL	0.9	0.5
CXY	IAD	3.0	2.6
CXY	ACY	2.7	2.6

The final mixing height field was smoothed (4 passes) with a standard smoothing routine (see MDE documentation on the smoothing routine used). The Diagnostic Wind Model (DWM) requires data to 0100 on July 21, 1991 to complete the last hour of the last day of the run. Because the data base did not include a number of stations for July 21st, the mixing heights from 0000 on the 21st were repeated for the following hour. The mixing height is at its minimum value at these hours so this interpolation is an accurate representation of MIXEMUP results.

Discussion of Final Field (File: ***DIFFBREAK.smth.7*****):**

July 18, 1991: Very high mixing heights generally on July 18th. The afternoon maxima are in the 2.5-2.8 km range (Figure 2). Heights are considerably lower in the southeastern portion of the domain which gives an overall slope from northwest to southeast to the field. The field becomes very irregular during the period 1500-2000 as temperatures fall at the northern Bay stations. As a result, there is a strong gradient in mixing heights from north of Baltimore (low heights) to the center of the domain (Figure 3).

July 19, 1991: The lower temperatures at the northern bay sites are seen again early in the afternoon (Figure 4) but by mid-afternoon the field is fairly uniform with maximum mixing heights on the order of 1.5-2.1 km

July 20, 1991: Mixing height are again quite low this day with maxima on the order of 1.5-1.7 km. The lower northern Bay heights are again present at 1600 and later (Figure 5). In general, the low level inversion becomes stronger throughout the three-day episode with ozone concentrations increasing accordingly.

Summary: Compared to Episode 1, the mixing height field is much more uniform. The heights are generally much lower as well which raises the possibility of overprediction.

Wind Fields

The DWM was used to create the wind fields for Episode 3. No changes (from Episode 1) were made to the settings for the various DWM parameters. The DWM parameters are given in Appendices C and D.

Episode 3 has the advantage of additional wind data at critical locations. In particular, the meso-net at the Aberdeen Proving Ground provides data at three locations in the upper Bay (TRE, SPE, WOR) as well as some additional upper air soundings.

Additional Upper Air Data

Additional upper air data is available from two stations: Dahlgren Naval Weapons Center southeast of Washington D.C. (DAH) and Aberdeen Proving Grounds northeast of Baltimore (APG01). The APG01 location has been visited and the quality assurance program there is excellent. The morning soundings at APG01 data are used by the NWS for its weather analysis. Dahlgren has no specific quality assurance program but a review of the data showed it to be consistent with other observations during the period.

Additional Upper Air Data for Episode 3	
Date	Time (UTC)
Aberdeen Proving Grounds (APG01)	
July 18, 1991	1000
July 18, 1991	1400
July 19, 1991	1100
July 19, 1991	1700
Dahlgren Naval Weapons Center (DAH)	
July 19, 1991	1400
July 19, 1991	1500
July 19, 1991	1600

Missing or Poor Quality Upper Air Data

The upper air data set is fairly complete. The only changes to the data set are noted in the following table. Most of the changes (except IAD at 1200 Z on July 19th) were necessary to allow the MIXEMUP preprocessor to operate properly. Since these changes were minor in nature and none occurred on the high ozone day (July 20th), these changes were maintained for the DWM run (Input file: *uaodwm.out.44*).

Missing or Poor Quality Upper Air Episode 3			
Station	Date	Time	Comment
IAD	7/17/91	1200 Z	Level 1 calm, set equal to Level 2
IAD	7/19/91	0000 Z	Level 4 missing, interpolated from Levels 3-5
IAD	7/19/91	1200 Z	Poor quality data* between 900-750 mb, replace with weighted average of DAH, APG 1400 Z data
ACY	7/19/91	1200 Z	Missing above 620 mb, replaced with 620 mb at 50 mb intervals

* For IAD at 1200 Z on 7/19/91, wind data between 900-750 mb were consistently NW to NE at 1 ms^{-1}. The other local stations (ACY, WAL, APG01, DAH) have WSW winds at much higher speeds and airflow from the W and SW was consistent along the eastern seaboard. The NWS apparently considered the winds to be inaccurate as they did not use IAD data to prepare the 850 mb chart for that date. The IAD data was therefore considered flawed and replaced with weighted (by distance from IAD) vector mean winds from Dahlgren and Aberdeen (both at 1400 Z).

Stability data

The interpolation routine that fits the 14-level DWM field to the 5-level UAM wind field requires hourly stability data. The stability category can affect the extent to which surface winds are interpolated upward. For Episode 3, data from BWI and Pasquill's Stability Categories was used to create the hourly stability parameters. As discovered during Episode 1, wind fields in the late afternoon (1800-1900 EST) can become highly irregular if the stability is greater than 4 (of 6). In most cases, stability was 4 or less at these hours but was corrected to that category when necessary.

Surface Stations

The surface wind stations used in the DWM are listed in Appendix D. There are many more wind stations used than MIXEMUP stations. This is because the DWM can accept missing data. The data received from NCDC, which includes NWS as well as local airway stations, was of high quality. The data from the Aberdeen meso-net undergoes quality assurance at the site and was also checked carefully for consistency with other nearby stations before inclusion in the DWM.

The MDE monitor data was also checked carefully. The Suitland (SUI) station, as in previous episodes, showed quality problems. In general, the wind direction at SUI is stuck in the 350-360° range for all of July 18-19th. It shifts out of the north for some hours during July 20th. This persistent northerly flow is not noted at the nearby Andrews AFB (ADW) station. Problems with wind data at SUI also occurred in Episode 1 and may be due to siting problems (*S. A. Campbell, personal communication*). The SUI data was not used.

The MDE Essex (ESX) site suffers from local obstructions to the southeast and was not used in Episode 1. However, two additional stations (Riviera Beach, Chesapeake & Sun) nearby were available for Episode 1 which reduced the necessity of using this data. In 1991, however, these stations were not in operation and ESX was the only surface site to the north and east of Baltimore. As a result, this data was used.

As in Episode 1, the data from Martin State Airport (MTN) was not used. As outlined in a previous report, the data at MTN is collected at a non-standard height (the top of the control tower) and in heterogeneous surface conditions that make determining an appropriate correction for height arbitrary.

Discussion of DWM Wind Fields

Input files: *presfc.skl.1*
uamwnd.skl.163-165
DIFFBREAK.smth.7
uaodwm.out.44

Output files: *WIND.bin.241* (July 18, 1991)
WIND.bin.242 (July 19, 1991)
WIND.bin.243 (July 20, 1991)

The DWM is run in the objective interpolation mode so that surface and upper air observations are fairly well represented in the final fields. The most important smaller scale effect, the burst of northerly winds on July 20th, is fairly well represented in the DWM fields.

July 18, 1991: Level 1 winds are light WSW in the early morning and then back to SSW through the day. Speeds are generally around 3-5 ms^{-1} during the mid-day hours. The wind field is fairly consistent across the domain with the exception of more westerly winds in the northern regions and light southerly winds near Baltimore in the mid-afternoon.

At Level 3, winds are steady westerly throughout the day with a slight backing to the SW in the evening. Wind speeds are approximately 5 ms^{-1}. At level 5, winds are W with a slight veer to the WNW beginning in early afternoon.

The observed data for July 18th are well replicated in the DWM field. The only unusual observation is a more strongly sheared environment at IAD at 0000 Z on the 19th with winds more southwesterly up to 1544 m (850 mb) then shifting rather rapidly to the

NNW. This abrupt shift is not seen at WAL.

July 19, 1991: Level 1 winds are SW at 2-4 ms^{-1} in the early morning and then back slightly to the S through the day. The more southerly flow is first seen along the bay (TPT) as early as 1000 EST (Figure 6) and becomes general across the domain by 1400 EST. The NW quadrant of the domain has calm or very light winds throughout the day.

As on July 18th, winds veer smoothly with height. At Level 3, winds are WSW winds in the morning hours (Figure 7) becoming W by afternoon. There is a hint of a lee trough west of Baltimore at 1600 EST with winds more NW in the NW quadrant. At Level 5, winds veer from WSW in the morning to NW by 1900 EST.

July 20, 1991: In the early morning winds are generally SW but light (2 ms^{-1}) and even lighter near Baltimore. Later in the morning, beginning at 0900 EST in central PA and continuing through 1100 EST across Baltimore there is a pulse of northerly winds (Figure 8). This is quickly replaced by light southwesterly winds by 1300 EST. Later in the afternoon winds become SE along the Bay and near Baltimore (Figure 9). By 1900 EST winds are SW. At all hours winds are very light (2 ms^{-1}).

Observed winds are SW to 0900 EST then flop around from NW to NE for several hours before settling into the SE at 1500 EST and then to the S and SW after 1900 EST. The monitor at CKY has a more persistent NW to NE through the morning hours before shifting to SW.

Again, winds veer gradually with height with WSW winds at Level 3 and WNW winds are Level 5.

In general, the observed winds are well represented by the DWM fields. This reflects both the increased data density for this episode as well as the relatively slight vertical wind shear.

Appendix A

List of Stations

Appendix A contains the master list of stations in the Baltimore-Washington UAM domain. Not all stations are availabe for each episode. The data in Appendix A is listed as follows:

Column 1: Station number (generally WBAN number0
Column 2: Three letter station identifier
Column 3: Station name
Column 4: Latitude (decimal)
Column 5: Longitude (decimal)
Column 6: UTM East (m)
Column 7: UTM West (m)
Column 8: Elevation (feet)
Column 9: RAMMET code for rural (1) or urban (2)
Column 10: Type of station

APG01:A01:Aberdeen Soundings:39.5:76.07:407994:4372630:16.4:2: Military
13701:ABE:Aberdeen:39.5:76.1:404894:4376524:58:1: Military
93730:ACS:Atl City Surf:39.75:74.667:528560:4399884:64:1: NWS
93755:ACY:Atlantic City:39.75:74.667:528560:4399884:64:1: NWS
74594:ADW:Andrews:38.8:76.9:338058:4296767:80:2: Military
30002:BAL:Baltimore pseudo:39.3:76.6:360556:4349283:10:1: Pseudo
30001:BL1:FrederickX:39.5:77.02:340000:4380000:148:1: Pseudo
MD997:BLT:Baltimore,245100011: 39.2: 76.6: 363251:4344028:36:1: MDE
93721:BWI:Balto.Wash.Intl:39.18:76.67:356040:4338262:148:2: NWS
30003:CAT:Catoctin Mt sudo:39.6:77.5:286926:4391673:491:2: Pseudo
40006:CCL:Calvert Cliffs:38.4:76.5:374600:4254700:38:1: Private
MD849:CKY:Cockeysville,240051007: 39.5: 76.6: 359673:4369009:413:1: MDE
24026:CRS:Crisfield :37.9:75.8:423705:4203236:13:2: CoastGuard
14751:CXY:Capitol City Arprt:40.2:76.8:342571:4453265:121:1: NWS
72403:DAA:Fort Belvior:38.7:77.2:310000:4287500:79:2: Military
71777:DAH:DAhlgren Naval:38.33:77.08:324989:4239873:2:Military
MD007:DAV:Davidsonville,240030014: 38.9: 76.5: 356679:4307078:13:2: MDE
13743:DCA:Wash.Natl:38.85:77.02:324987:4301879:10:2: NWS
40001:DIC:Dickerson surface:39.18:77.45:289100:4342800:270:1: Private
40007:DIK:Dickerson Sodar:39.18:77.45:289100:4342800:270:1: Private
72408:DOV:Dover AFB:39:75.47:459663:4331497:28:1: Military
MD005:EDG:Edgewood,240251001:39.3:76.2:388317:4362839:6:2 : MDE
90008:EGW:Edgewater:38.93:76.58:365000:4312500:49:1: SmitSon
30004:EMM:Emmitsburg sudo:39.6:77.3:302750:4394956:127:2: Pseudo
MD191:ESX:Essex,240053001: 39.3: 76.3: 372358:4356794:16:1: MDE
93735:FAF:Fort Eustis:39.1:76.6:361000:4328910:12:2: Military
13730:FRD:Frederick:39.4:77.4:294771:4363654:134:1: FAA
30005:FRE:Frederick sudo:39.4:77.5:290515:4365656:116:2: Pseudo
24093:GRG:Georgetown:38.6:75.7:460830:4276004:24:1: FAA
93711:HGR:Hagerstown:39.8:77.9:266064:4398551:704:1: FAA
93738:IAD:Wash.Dulles:38.95:77.45:287680:4313896:323:2: NWS
13781:ILG:Wilmington:39.667:75.6:448531:4390754:74:2: NWS
24046:IND:Indian River:38.5:75.1:495639:4261114:10:2: CoastGuard
13702:LFI:Langley AFB:37.1:76.3:384469:4106571:10:2: Military
40005:LMK:Limerick:40.1:75.6:450000:4452500:50:1: Private
14752:LNS:Lancaster:40.1:76.3:389648:4449016:270:1: FAA
40008:MCR:Martins Creek:40.8:75.1:488600:4515200:320: 2: Private
14711:MDT:Harrisburg:40.2:76.8:349890:4450496:316:1: FAA
13735:MIV:Millville:39.3:75.1:491377:4349894:67:1: Military
40002:MOR:Morgantown:38.5:77.02:326700:4253200:22:1: Private
90009:MTN:Martin StAP:39.30:76.42:377500:4354000:22:2: FAA
13721:NHK:Patuxent NAS:38.3:76.42:376116:4239868:38:1: Military
13769:NTU:Oceana:36.8:76.0:410781:4072967:20:2: Military
14793:NXX:Willow Grove:40.2:75.1:487516:4449016:309:1: Military
13773:NYG:Quantico MAS:38.5:77.3:298692:4263242:22:2: Military
13796:OCY:Ocean City:38.4:75.14:488000:4250000:10:1: FAA
40004:PCH:Peach Bottom:39.7:76.3:391000:4401600:50:1: Private
13739:PHI:Phil.Int:39.88:75.25:478622:4414659:5:2: NWS
24085:PNE:Philadelphia NE:40.1:75.0:498579:4436827:37:1: ???
40003:PSP:Possum Point:38.6:77.3:301100:4269100:22:1: Private
14712:RDG:Reading:40.3:75.9:417922:4468723:104:1: FAA
13740:RIC:Richmond:37.5:77.34:293733:4152710:164:2: NWS
MD406:RIV:Rivera Beach,240032002: 39.1: 76.5: 369390:4335381:46:1: MDE
MD234:ROC:Rockville,240313001:39.11:77.11:317810:4331259:126:1: MDE
93720:SBY:Salisbury:38.33:75.5:456296:4242737:60:1: FAA
07607:SPE:Spesutie, apg:39.5:76.12:407994:4372630:16:2: Military
MD740:SUI:Suitland,240338001: 39.0: 76.7: 332354:4302067:39:1: MDE
93734:SV2:Sterling,UAU:38.98:77.47:286336:4317635:276:2: NWS
25000:THM:Thomasville:39.9:76.8:340454:4419994:148:2: FAA
07646:TIP:Tipton, apg:39.05:76.46:347186:4327327:150:2: Military
99998:TPT:Thomas Point:38.9:76.4:378589:4306429:59:1: Coast Guard
07613:TRE:Trench Warefare, apg:39.78:76.22:402793:4369636:40:2: Military
93739:WAL:Wallops Is.:37.93:75.48:457522:4198346:40:1: NWS
07619:WOR:Worton Pt, apg:39.5:76.32:397909:4350556:30:2: Military

Appendix B

Surface and Upper Air Matching for DIFFBREAK
Episode 3

This file contains the matching of surface and upper air stations for the DIFFBREAK preprocessor as well as the parameters for the DIFF job. The station numbers refer to upper air stations (see Appendix A) and the station identifiers to surface stations.

```
@ Please follow these instruction when editing this control file.
@ Make changes to fields following the colons.
@ Use vi's c, C, r, or R change command; avoid using insert mode.
@ Do NOT delete or add lines by pressing return in insert mode.
@ for more info see Vol. II pp.
@
CONTROL
DIFFBREAK
Balto/Wash Domain
Num_Specs:              0
Num_User_Vars:          0
Num_Stations:          16
Num_Sub_Rgns:           1
Num_Vars:              10
Out_Unit_Num:          20
Prnt_Data:            0
Prnt_Out:             0
Prnt_Units :          0
Prnt_Sta_Loc:         1
Rgn_Packet:           0
Prnt_Methods:         0
Prnt_Sta_Vals:        1
%Time
END
REGION
END
STATIONS
93734IAD
93734ADW
93734CXY
93734DCA
93734NYG
93734SPE
93734TRE
93734WOR
93734ILG
93734BWI
93739DOV
93739NHK
93739SBY
93755ACS
93755PHI
93755PNE
END
TIME INTERVAL
SUBREGION
A                  1         1        -1
END
METHOD
A         DIFFBREAK STATINTERP      0.0     5000.0        4
EXTENT    0.0
INITRADIUS  10.0
RADIUSINCR  15.0
MAXRADIUS  500.0
END
STATION READINGS
END
ENDTIME
```