# 2. EPISODE SELECTION

Any future ozone air quality planning to be undertaken by the BAAQMD must include an evaluation of the effectiveness of emission control measures by simulating their effects on ambient ozone air quality during specific multi-day pollutant episodes. A three-dimensional air quality model, the Comprehensive Air Quality Model with extensions (CAMx), will be used for these simulations. Air quality models require time- and space-varying inputs of emission and meteorological fields over the episodes to be considered. These fields significantly influence the results of the simulations and are the most relevant to the SIP analysis.

The general modeling approach for evaluating control measures is to simulate one or more historic episodes (periods that violated the air quality standard) using inputs that best approximate the physical conditions that prevailed during each episode. This simulation defines a base-year reference or "base" case. If the performance of the historic base case simulation is acceptable, meaning that all evidence suggests that the model is operating correctly and appropriately reproducing the causes for high ozone where and when it was observed, then a simulation is performed using emissions that incorporate best-estimate growth projections and adopted control programs into a future year (usually the attainment year). This "future base" case is then analyzed to indicate if any additional controls are necessary to ensure attainment of the ozone standard. If necessary, then simulations are performed using emissions that introduce proposed new emission control measures ("future control" case). The differences between the "future base " and "future control" simulations represent the air quality impacts of the proposed new emission control measures.

Episodes used for this analysis need to be selected carefully so that the analysis has the maximum credibility and generality. The criteria for episode selection are:

- The episode must have had an ozone measurement that exceeded the federal ambient air quality standard. The 1-hour standard for ozone is 124 ppb averaged over one hour, while the new 8-hour ozone standard is 84 ppb averaged over eight hours. Ozone observations above these standards may influence the calculation of the "ozone design value", which is the regulatory measure of ozone levels in each air basin.

- The episode must be representative of a class of episodes that occur frequently so that the simulation will presumably have greater generality to the analysis of predicted changes in the design value. Incorporating multiple episodes into the analysis will further broaden its generality. EPA guidance recommends the examination of three or more episodes, unless sufficient evidence can be provided to suggest that fewer are technically acceptable.

- The episode must have sufficient observations to determine the physical conditions that contribute to the ozone exceedances. Furthermore, the observations must provide data that satisfy model input needs and that can be used to evaluate model performance.

Furthermore, the CARB and other Districts will be conducting regional transport assessments as a means for controlling ozone levels throughout the state. It is therefore beneficial to the BAAQMD to identify and consider the modeling episodes to be used by the CARB and other districts to specifically support the District's own evaluation of pollutant transport into and out of the Bay Area.

This chapter summarizes the episode selection process undertaken early in this project to support revised photochemical modeling in the Bay Area. Note that at the time of episode selection, the District was tasked with developing a revised SIP to attain the 1-hour ozone standard; hence, the language in this chapter revolves around analyses of historic 1-hour ozone patterns and trends in the Bay Area. While we believe that the episodes ultimately chosen for the current effort would provide an adequate base for initial 8-hour ozone assessments as well, the BAAQMD will be cognizant of more recent ozone episodes that have occurred in the 2001-2003 8-hour designation period (and later) to update their modeling library.

BAAQMD staff have investigated the categorization of 1-hour ozone exceedances in the Bay Area for the period 1995 through September 2002 in order to find representative exceedance days to be used for SIP modeling. Two main categories of exceedance patterns were found: (1) when high ozone values occurred at isolated individual sites; and (2) when high values occurred at several sites and in many regions. This is discussed further in the following section.

## EPISODE REPRESENTATIVENESS

### Criteria For Modeling Episode Representativeness

A key question that emerges from modeling a small set of ozone exceedance days is whether the physio-chemical dynamics are adequately similar to the broader set of episodes that the conclusions derived from modeling would apply in general. That is, can the modeled days be considered *representative* of other exceedance days. One important aspect of this question is whether episode days fall into more than one clear-cut category. Do the dynamics vary sufficiently so that the modeled results of a day in one category cannot be extrapolated to days in the other category?

We are not aware of a single omnibus approach to address these issues. This analysis looks at various approaches, including simple tabulations; frequencies of episode days by day of week, month, and area; an analysis of trends by site; and a cluster analysis. The ultimate choice of modeling days necessarily involves judgment based on our experience with previous modeling, and on our conceptual understanding of ozone dynamics in the Bay Area.

### Definitions

It is often a good idea to attempt to pin down the definitions of key words in an analysis. It can lead to a clarification of thought. The word “representative” is frequently used, but is a difficult one to define in this context. Let's try to answer the following: representative *of what*? Are we talking about representative *days* or representative *episodes*?

When we say “representative,” it seems reasonable to assume we mean “representative *of Bay Area days exceeding to the 1-hour standard*.” Because the focus of the Bay Area's ozone problem is in the east, Livermore specifically, we may want to restrict this to “representative *of eastern Bay Area days exceeding the 1-hour standard*,” excluding the few days where peak ozone occurred elsewhere. We may also determine that there is more than one category of days we wish to consider, e.g., two sets of days with distinctly different dynamics. Then, we could define a day as “representative *of days exceeding the 1-hour standard that fall into category x*.”

Modeling is done on episodes rather than individual days. However, episodes are more complicated because the number of days can vary, making episode to episode comparisons difficult. Also, the standard is written in terms of days, not episodes. Thus, it may be preferable to consider representative *days*. When an episode is being considered for modeling, then, we look at the days it contains to see which, if any, are "representative."

Thus, this analysis focused on days that exceeded the 124 ppb national 1-hour ozone standard somewhere in the District. To obtain a large enough sample, we used data back to 1995. Going back further would have increased the sample size, but it is unclear whether the emissions patterns back then would be sufficiently similar to current patterns.

Tables 2-1 through 2-3 present features of the 36 days from 1995 through September 17, 2002 that exceeded the national 1-hour ozone standard of 124 ppb. Table 2-2 shows numbers of exceedances by site. One feature that stands out is Livermore, which had exceedances on 27 of the 36 days, and had the highest ozone on 20 of those days. Concord was a distant second with exceedances on 10 days and the highest ozone on 6. These sites, along with Bethel Island and Fairfield, account for all but seven of the highest ozone values.

Table 2-3 shows that at least one eastern site had an exceedance on 33 out of the 36 episode days. Santa Clara County had 11 such days. The other regions – North Counties, Central Bay sites and South Central Bay sites -- have few exceedances by comparison. Table 2-3 also shows that most exceedance days (26 out of 36) occurred only in one region. Nevertheless, there were 10 days where exceedances occurred in more than one region, that is, more than once a year on average. Finally, the table shows that both 1-day and multi-day episodes are common: 16 of the 1-hour exceedances are 1-day events, the rest are 2-day or 3-day events.

**Exceedances By Day of Week**

Recent history suggests that ozone exceedances occur more frequently on weekend days than weekday days – a so-called "weekend effect." Figure 2-1 shows a histogram of exceedance frequencies by day of week. The average frequency is 36/7 = 5.1, so that the weekend exceedances are somewhat more frequent than average. The differences are not statistically significant, however, and in fact, Monday has been the most common exceedance day.

The weekend effect appears strongest for inner-bay sites. Blanchard and Fairley (2001) showed that sites ringing the bay had statistically significant weekend effects whereas sites further east did not. Note that the three days when Fremont and San Jose recorded the District's maximum were weekend days and eight of the nine exceedance days for San Jose, Fremont and Alum Rock occurred on weekends. In contrast, many of Livermore's and Concord's exceedances occurred during weekdays (16 in Livermore), so weekday exceedances cannot be ignored. Eleven of Livermore's exceedances occurred on the weekends, an event that would occur only about 12% of the time by chance if the probability of a weekend exceedance was equal to that for weekdays, based on a binomial distribution. Thus, Livermore may indeed have a greater probability of an exceedance on a weekend day than a weekday.

**Table 2-1.** Ozone (ppb) by site on District days exceeding the national 124 ppb 1-hour ozone standard, 1995 through September 2002. Exceedances in bold; District max underlined. Successive episodes shown by alternating shading/no shading.

| | d | Eastern | | | | | | North | | | | Central Bay | | | South Central Bay | | | | | Santa Clara Valley | | | | | BA | SJV | SAC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| m/d/yr | o w | bi | ff | pt | cc | li | lv | np | va | st | sr | oa | sf | ri | mv | rc | sl | fr | ha | lg | gi | sm | ar | sj | Max | Max | Max |
| 6/23/95 | Fr | 86 | 95 | 96 | 90 | **130** | | 81 | | 53 | 60 | 36 | 26 | 49 | | 68 | 77 | 108 | 88 | 89 | 118 | 113 | **127** | 100 | **130** | **142** | 116 |
| 6/24/95 | Sa | 76 | 109 | 87 | 98 | **142** | | 74 | | 67 | 84 | 84 | 74 | 81 | | 116 | **150** | **153** | **145** | **130** | 107 | 115 | **127** | 121 | **153** | **133** | 106 |
| 6/25/95 | Su | 98 | **129** | 121 | **128** | 120 | | **130** | | 84 | 88 | 75 | 71 | 78 | | 114 | **131** | 117 | 119 | 97 | 92 | 91 | 113 | 114 | **131** | **132** | **125** |
| 7/14/95 | Fr | 79 | 95 | 91 | 86 | 106 | | 80 | 82 | 61 | 57 | 33 | 53 | 52 | 97 | 88 | 67 | 92 | 102 | 101 | **130** | **128** | 113 | 108 | **130** | **128** | 111 |
| 7/15/95 | Sa | 84 | 87 | 93 | 99 | 98 | | 90 | | 88 | 82 | 70 | 88 | 87 | 116 | **140** | **144** | **149** | **138** | **128** | 108 | 107 | **145** | **134** | **149** | **140** | 117 |
| 7/27/95 | Th | 124 | 113 | 119 | **152** | **155** | | 105 | 91 | 97 | 59 | 26 | 40 | 47 | 79 | 58 | 87 | 107 | 88 | **141** | 96 | 102 | 106 | 102 | **155** | **156** | **131** |
| 7/31/95 | Mo | 104 | 104 | 104 | 121 | **138** | | 78 | 71 | 73 | 54 | 30 | 40 | 62 | 90 | 69 | 82 | 87 | 94 | **135** | 86 | 93 | 113 | 98 | **138** | **149** | **154** |
| 8/14/95 | Mo | 107 | 98 | 113 | **147** | **134** | | 95 | 99 | 73 | 68 | 34 | 42 | 57 | 66 | 60 | 87 | 100 | 88 | 85 | 81 | 88 | 105 | 98 | **147** | **139** | 111 |
| 8/19/95 | Sa | 74 | 88 | 86 | 92 | **147** | | 90 | 100 | 76 | 73 | 75 | 58 | 79 | 84 | 103 | 100 | 99 | 101 | 107 | 90 | 86 | 102 | 97 | **147** | **129** | 123 |
| 8/20/95 | Su | 73 | 63 | 71 | 75 | **130** | | 53 | 43 | 52 | 30 | 27 | 37 | 36 | 60 | 56 | 59 | 75 | 64 | 101 | 57 | 69 | 94 | 90 | **130** | **140** | 116 |
| 9/795 | Th | **128** | 95 | 124 | 92 | 78 | | 92 | 61 | 66 | 47 | 21 | 42 | 53 | 52 | 48 | 69 | 68 | 77 | 63 | 90 | 91 | 80 | 59 | **128** | 118 | 114 |
| 6/3/96 | Mo | | 81 | 75 | 87 | **128** | | 73 | 83 | 53 | 51 | 21 | 20 | 27 | 42 | 32 | 38 | 71 | | 72 | 91 | 82 | 73 | 59 | **128** | **126** | 113 |
| 6/30/96 | Su | 79 | 100 | 92 | 115 | **131** | | 90 | 100 | 66 | 80 | 85 | 51 | 73 | 94 | 69 | 107 | 89 | | 113 | 90 | 114 | 88 | 90 | **131** | **137** | 114 |
| 7/1/96 | Mo | **137** | 113 | 117 | **127** | **133** | | 83 | 93 | 83 | 56 | 30 | 47 | 44 | 80 | 49 | 79 | 90 | | **129** | 95 | 94 | 102 | 88 | **137** | **143** | **126** |
| 7/21/96 | Su | 86 | 74 | 69 | 85 | **126** | | 62 | 54 | 68 | 53 | | 27 | 36 | 69 | 34 | 44 | 74 | | 91 | 78 | 83 | 86 | 81 | **126** | 115 | **126** |
| 7/28/96 | Su | 77 | 89 | 91 | 95 | **129** | | 86 | 69 | 61 | 46 | 27 | 25 | 33 | 68 | 41 | 55 | 75 | | 92 | 84 | 103 | 74 | 72 | **129** | 121 | 93 |
| 8/8/96 | Th | 90 | 67 | 87 | 99 | **133** | | 76 | 60 | 48 | 37 | 22 | 30 | 33 | 47 | | 30 | 53 | | 57 | 104 | 99 | 57 | 61 | **133** | **150** | 110 |
| 8/9/96 | Fr | 113 | 101 | 94 | 101 | **138** | | 78 | 81 | 60 | 55 | 36 | 31 | 42 | 71 | 46 | 71 | 76 | | 96 | 98 | 109 | 62 | 88 | **138** | **144** | **150** |
| 8/10/96 | Sa | | 76 | | 97 | **137** | | 69 | | 45 | | 21 | 23 | 31 | 50 | 32 | | 50 | | 77 | 92 | | 51 | | **137** | **148** | 113 |
| 7/18/98 | Sa | 97 | 102 | 95 | 115 | **146** | | 91 | 79 | 63 | 69 | 43 | 26 | 58 | 97 | 54 | 73 | 106 | 99 | **133** | **132** | **135** | **129** | **147** | **147** | **158** | 104 |
| 8/3/98 | Mo | 91 | 98 | 75 | 84 | 124 | | 72 | 63 | 67 | 73 | 43 | 29 | 56 | 95 | 66 | 90 | 96 | 94 | | **135** | **142** | 98 | 109 | **142** | **143** | **151** |
| 8/4/98 | Tu | 101 | 121 | 97 | 119 | **134** | | **125** | 119 | 67 | 74 | 34 | 29 | 47 | 85 | 43 | 101 | 115 | 104 | | 118 | **144** | 120 | 110 | **144** | **153** | **148** |
| 8/12/98 | We | 123 | 106 | 95 | **147** | **139** | | 101 | 106 | 68 | 63 | 20 | 19 | 49 | 81 | 42 | 77 | 89 | 92 | 92 | 97 | 112 | 72 | 76 | **147** | **145** | **130** |
| 8/29/98 | Sa | 88 | 70 | 63 | 88 | **131** | | 66 | 59 | 44 | 42 | | 30 | 36 | 56 | 36 | 37 | 63 | 63 | 68 | 91 | 98 | 61 | 66 | **131** | **154** | 111 |
| 9/2/98 | We | 113 | 87 | 70 | 98 | **139** | | 72 | 59 | 56 | 39 | | 21 | 29 | 50 | 32 | 45 | 61 | 59 | 76 | 96 | 92 | 47 | 56 | **139** | **153** | **145** |
| 9/3/98 | Th | 120 | 110 | 96 | **130** | 113 | | 101 | 104 | 66 | 57 | | 23 | 38 | 81 | 36 | 111 | 98 | 116 | 60 | 63 | 72 | 86 | 101 | **130** | 119 | **151** |
| 9/13/98 | Su | 94 | 90 | 68 | 87 | **136** | | 88 | 75 | 62 | 52 | | 36 | 56 | 83 | 55 | 86 | 102 | 98 | 92 | 88 | 94 | 96 | 88 | **136** | 124 | **127** |
| 7/11/99 | Su | 99 | 117 | 88 | **126** | **146** | | 105 | 113 | 76 | 92 | 76 | 52 | 67 | 109 | 69 | 113 | **133** | 123 | 116 | 104 | **125** | 116 | 103 | **146** | **142** | **137** |
| 7/12/99 | Mo | 112 | 120 | 98 | **156** | **144** | | 115 | 95 | 76 | 61 | 27 | 50 | 47 | 95 | 47 | 89 | 98 | 83 | | 101 | 115 | 107 | 109 | **156** | **132** | **140** |
| 8/25/99 | We | **128** | **129** | 95 | 109 | 94 | | 103 | 98 | 73 | 81 | 34 | 26 | 63 | 100 | | 52 | 70 | 68 | 117 | 105 | 110 | 89 | 109 | **129** | **144** | **160** |
| 5/22/00 | Mo | 115 | 82 | 107 | **138** | 84 | 82 | 70 | 65 | 43 | 48 | 30 | 21 | 47 | | 29 | 43 | 55 | 50 | 46 | | 77 | 61 | 58 | **138** | **139** | **134** |
| 6/15/00 | Th | 85 | 66 | 78 | 86 | **137** | **152** | 57 | 36 | 37 | 32 | 31 | 30 | 36 | | 36 | 35 | 44 | | 63 | | 64 | 56 | 52 | **152** | **139** | 124 |
| 7/31/00 | Mo | 93 | 79 | 84 | 81 | **126** | 124 | 63 | 46 | 48 | 25 | 15 | 17 | 23 | | 25 | 20 | 56 | 51 | 62 | | 48 | 46 | 46 | **126** | 118 | 103 |
| 7/3/01 | Tu | **130** | 102 | 118 | **134** | | 113 | 99 | 82 | 86 | 68 | 38 | 58 | | 55 | 45 | 80 | 91 | 76 | 90 | 90 | 95 | 77 | 84 | **134** | **134** | 110 |
| 7/9/02 | Tu | 97 | | 87 | 84 | | **135** | 76 | 82 | 50 | 57 | 34 | 35 | 54 | 70 | 54 | 65 | 84 | 69 | 92 | 121 | 116 | 76 | | **135** | **133** | **145** |
| 7/10/02 | We | 111 | 101 | 111 | 102 | | **160** | 78 | 73 | 67 | 60 | 29 | 29 | 51 | 67 | 48 | 75 | 67 | 70 | 106 | 75 | 90 | 67 | | **160** | **163** | **137** |

| Sites | |
|---|---|
| **bi** | Bethel Island |
| **ff** | Fairfield |
| **pt** | Pittsburg |
| **cc** | Concord |
| **li** | Livermore – old 1st st |
| **lv** | Livermore – Rincon |
| **np** | Napa |
| **va** | Vallejo |
| **st** | Santa Rosa |
| **sr** | San Rafael |
| **oa** | Oakland |
| **sf** | San Francisco |
| **ri** | Richmond/San Pablo |
| **mv** | Mountain View/ Sunnyvale |
| **rc** | Redwood City |
| **sl** | San Leandro |
| **fr** | Fremont |
| **ha** | Hayward |
| **lg** | Los Gatos |
| **gi** | Gilroy |
| **sm** | San Martin |
| **ar** | Alum Rock |
| **sj** | San Jose |

**Table 2-2.** Number of 1-hour exceedances (District maximum) by site, 1995 through September 2002.

| North Counties (NC) | | Eastern (E) | | South Central Bay (SCB) | | Santa Clara County (SCC) | | Central Bay (CB) | |
|---|---|---|---|---|---|---|---|---|---|
| Napa | 2(0) | Bethel Isl. | 4 (2) | Fremont | 3(2) | Alum Rock | 4(0) | Oakland | 0 |
| San Rafael | 0 | Concord | 10(6) | Hayward | 2(0) | Gilroy | 3(1) | SF | 0 |
| Santa Rosa | 0 | Fairfield | 2(1) | Mountain View | 0 | Los Gatos | 6(0) | San Pablo /Richmond | 0 |
| Vallejo | 0 | Livermore | 27(20) | Redwood City | 1(0) | San Jose | 2(1) | | |
| | | Pittsburg | 0 | San Leandro | 3(1) | San Martin | 5(2) | | |

**Table 2-3.** Number of 1-hour exceedances by year, subregion, number of areas, and episode length, 1995 through September 2002.

| | | Exceedances by subregion | | | | | No. of days with n regions exceeding std | | | Episode length | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | District | NC | CB | E | SCB | SCC | n=1 | n=2 | n=3 | 1 day | 2 days | 3 days |
| 1995 | 11 | 1 | 0 | 9 | 3 | 6 | 5 | 4 | 2 | 4 | 2 | 1 |
| 1996 | 8 | 0 | 0 | 8 | 0 | 1 | 7 | 1 | 0 | 3 | 1 | 1 |
| 1997 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1998 | 8 | 1 | 0 | 7 | 0 | 3 | 6 | 1 | 1 | 4 | 2 | 0 |
| 1999 | 3 | 0 | 0 | 3 | 1 | 1 | 2 | 0 | 1 | 1 | 1 | 0 |
| 2000 | 3 | 0 | 0 | 3 | 0 | 0 | 3 | 0 | 0 | 3 | 0 | 0 |
| 2001 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 |
| 2002* | 2 | 0 | 0 | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 1 | 0 |
| All | 36 | 2 | 0 | 33 | 4 | 11 | 26 | 6 | 4 | 16 | 7 | 2 |

*Through September 17, 2002

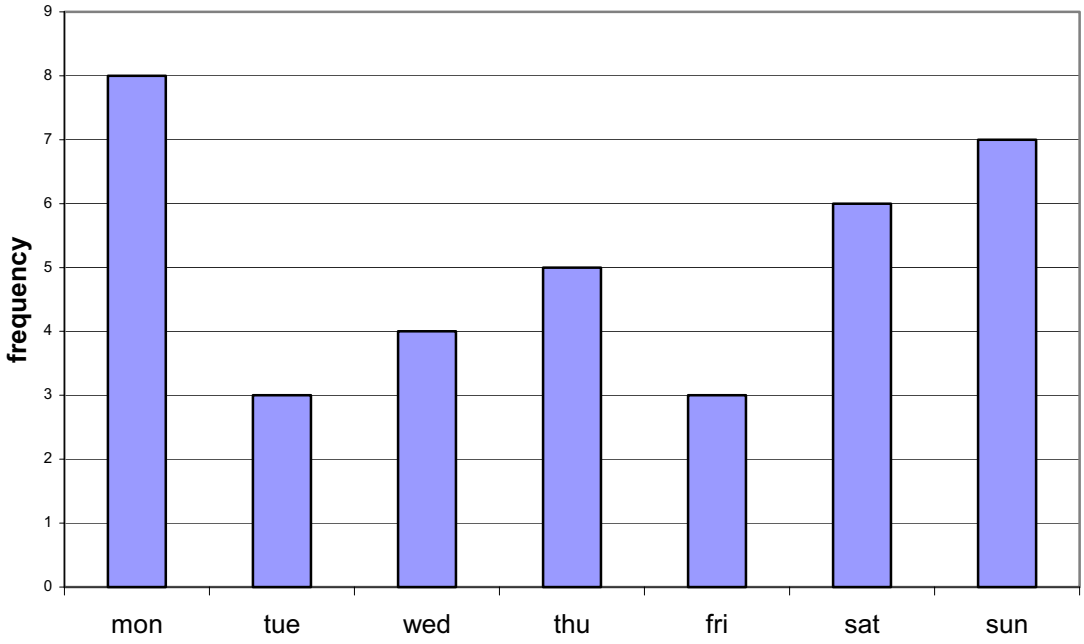



**Figure 2-1.** Numbers of exceedances by day of week, 1995 through September 2002.

Another way to compare the importance of weekends vs. weekdays is to compare design values. For this, seven years were used, 1996-2002, so that there would be five years of weekdays and two years of weekend days. Design values can be estimated from the 6th and 3rd largest values respectively. Typically, the design value is the 4th highest value from 3 years of data. The 7 years of data include 5 years of weekdays and 2 years of weekends. Thus, it seems reasonable to estimate the weekday design value by the 6th highest weekday value, and the weekend design value by the 3rd highest weekend value. For Livermore, these were 138 ppb for the weekdays vs. 137 ppb for the weekends.

Ninety percent confidence intervals can be constructed based on the binomial distribution.[1] They are 134 ppb to 152 ppb for weekdays, compared with 136 ppb to 146 ppb for the weekends. Thus, there is no evidence that Livermore's weekend design value is higher or lower than its weekday design value. By way of contrast, Fremont has a strong weekend effect. Its weekday and weekend design values are 98 ppb and 109 ppb respectively, with confidence intervals of (96, 106) for weekdays, and (106, 133) for weekends. This difference is statistically significant.

**Month of Exceedance**

In the Bay Area, ozone exceedances are most frequent in July and August (Figure 2-2). In fact, all but two of the 36 exceedances in 1995 through September 2002 occurred between June 15 and September 15.

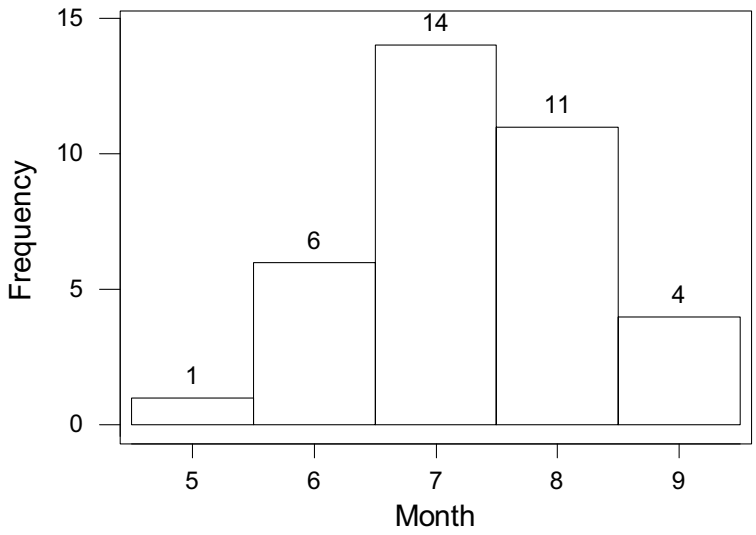



**Figure 2-2.** Numbers of exceedances by month, 1995 through September 2002.

[1] Here a confidence interval for the upper 1/365th percentile is shown. This is not identical to the design value however. With three years of data, this would usually be estimated as the 3rd largest value, whereas the design value is estimated as the 4th largest. Also, technically, the binomial distribution is assuming that the days are statistically independent, whereas in reality, ozone values are serially correlated. This makes the confidence intervals narrower than they would be if we could take this correlation into account.

This suggests that, to ensure representativeness, modeling days should be selected from this period. However, it is not clear that the dynamics are necessarily different at other times; the main reason for the fewer exceedances may simply be that there tend to be more hot days between mid-June and mid-September. Nevertheless, since ozone production depends on sunlight, the dynamics of ozone production in September and October may be different from earlier summer months. September exceedance days in recent years experienced localized ozone, with only one station exceeding the standard on each day.

**Trends and Representative Days**

Figure 2-3 shows numbers of exceedances by decade (1982-1991 vs. 1992-2001) for long-running BAAQMD sites. Livermore was the hot spot in both decades, but during the 1980's there were other sites that competed with it, Los Gatos in particular. What is apparent from the figure is that there has been a dramatic improvement in the south bay area, but marginal if any improvement in the east (Livermore, Concord, Bethel Island). The point is, as more previously adopted controls are implemented, one would expect more of the same, namely further improvement in the south bay, but not necessarily in the eastern part of the district. This implies that the regulatory focus should be on reducing ozone in the eastern part of the district, and hence modeling also needs to be focused on days when ozone is high in the east.

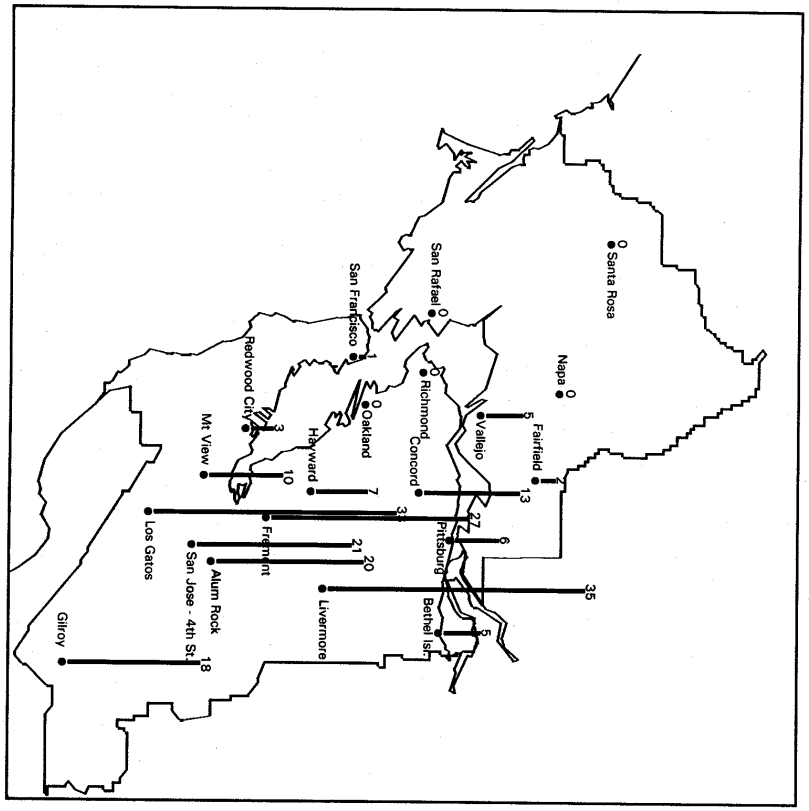
**Cluster Analysis**

Another way to assess representativeness is through cluster analysis. This analysis finds groups of days that are similar, based on some numeric variables. The variables used here are the 1-hour ozone maxima from the various BAAQMD sites. Two days are "similar" if the patterns of high ozone are similar. In this analysis there were 36 episode days with ozone measurements from 21 BAAQMD sites.[2]

Figure 2-4 presents the results of the analysis. Pairs of days connected by short lines are most similar. For example, 8/8/96 and 8/10/98 have lines connecting them with a distance of about 7 ppb (representing the average difference between the 1-hour values on the two days from the 21 sites). The cluster of those two days is similar to 8/29/96. The cluster containing those three days is similar to 9/2/98, and so on.

The analysis shows two days that are very different from the rest, 6/24/95 and 7/15/95, denoted as cluster 3 in the figure. These were days when the maximum ozone occurred at Fremont and there was high ozone at other sites near San Francisco Bay. We can break the remaining days into two clusters, denoted in the figure by 1 and 2. Comparing cluster 2 days with Table 2-1, we note that in every case, the maximum occurred at just one eastern site, with relatively low values everywhere else. Cluster 1 days contain all days where there was ozone at multiple sites and regions, thus representing more widespread high ozone.

[2] Missing values were filled in using a combination 2-way ANOVA to provide initial estimates, then assuming the values for a particular day came from a multivariate normal distribution, estimating the parameters using the E-M algorithm, then using the MVN to predict the missing values.



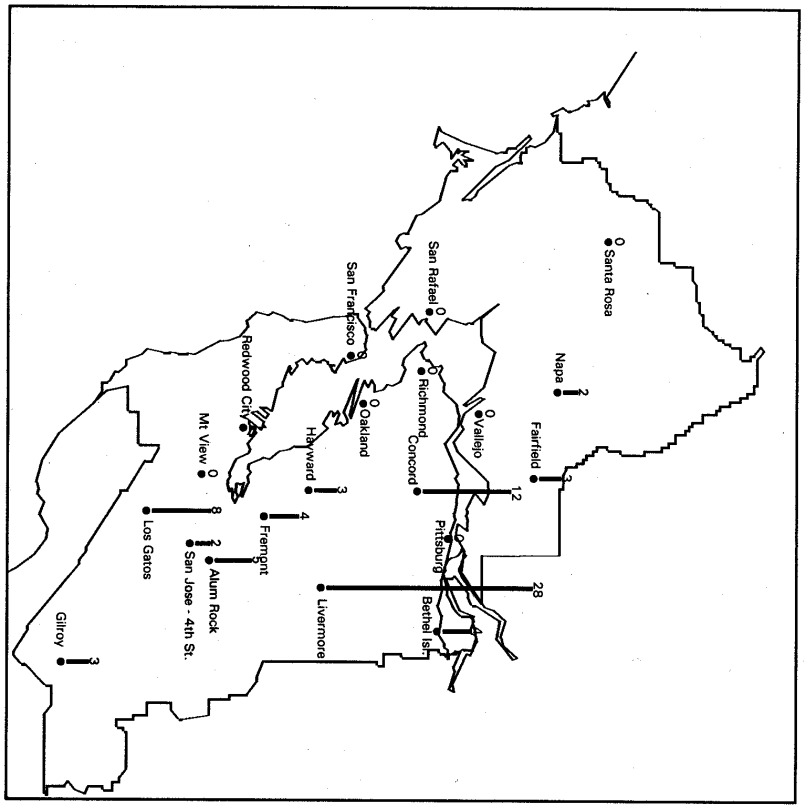




**Figure 2-3.** Trends in exceedances of the federal 1-hour ozone standard 1982-91 vs. 1992-2001. Vertical bars represent numbers of exceedances at long-running BAAQMD sites.

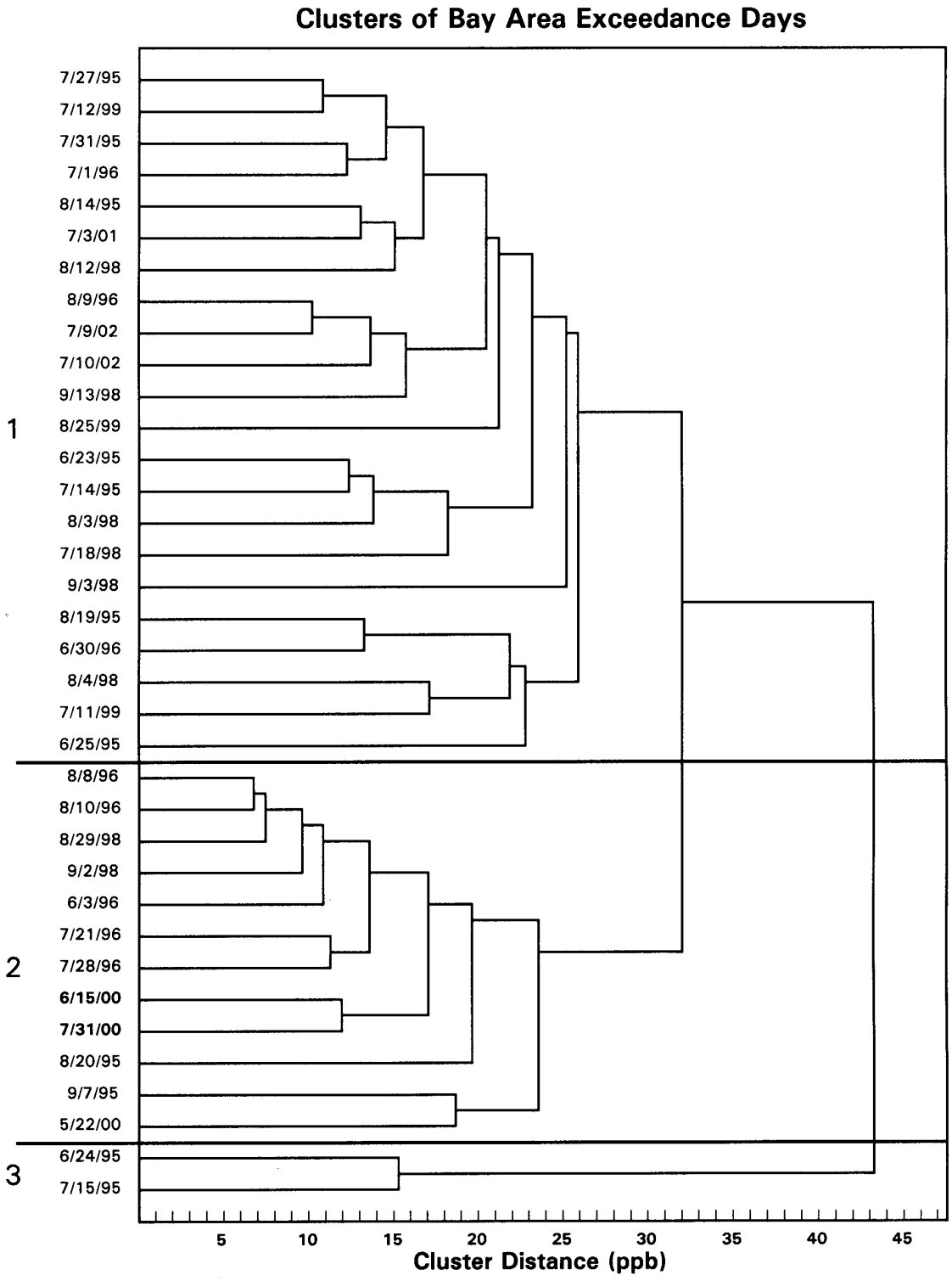



**Figure 2-4.** Clustering of Bay Area days exceeding the national 1-hour ozone standard, 1995 through September 2002. Thick, horizontal lines divide the three main clusters.

Table 2-4 shows that Cluster 1 District peak ozone values were somewhat higher than Cluster 2's. From Figure 2-5, however, there was considerable overlap. Cluster 3's peaks were among the highest, but the paucity of data makes statistical inference difficult – the differences are not statistically significant.

In contrast, the means of the daily 1-hour maximum ozone values from BAAQMD sites show dramatic differences. There is no overlap between the three clusters (see Figure 2-6), with Cluster 2 having the lowest mean values, Cluster 1 in the middle, and Cluster 3 the highest. Among the six selected days shown in Table 2-4, the mean ozone values for the two from Cluster 2, 6/15/00 and 7/31/00, show the lowest mean ozone. The two 2002 days have mean ozone that is substantially below the Cluster 1 average, whereas the 1999 days are above the Cluster 1 average.

Table 2-4 also shows the daily 1-hour maximum ozone for the Sacramento (SV) and San Joaquin Valley (SJV) districts. For SJV, there is no statistical difference between the clusters. For Sacramento, however, Cluster 1 days have substantially higher ozone than Cluster 2 days. Note that among the six days shown in Table 2-4, SV exceeded the 1-hour standard on all the Cluster 1 days and neither of the Cluster 2 days.

Comparisons of Meteorological Variables by Cluster

A number of meteorological variables were chosen for comparison between clusters. The basis for the choice was previous experience – variables that had been shown to be useful for predicting high ozone. These included daily maximum temperatures and midday wind speeds at several Bay Area surface meteorological monitoring sites and various RAOB measurements collected at Oakland at 4 AM and 4 PM daily. Among the temperature variables, there was some difference between Clusters 1 and 2 at Livermore, but still considerable overlap. The 850 mb temperatures exhibited no significant difference between the clusters. For San Jose maximum temperature, however, there was a clear-cut, highly statistically significant difference, with 75 percent of the Cluster 1 temperatures greater than 75 percent of the Cluster 2 temperatures.

The Cluster 1 midday winds at Travis AFB and San Martin were somewhat lighter than for Cluster 2. The 850 mb wind speeds showed no difference, nor did the 850 mb 4 AM wind direction. The 850 mb 4 PM wind direction did show clear-cut differences (Figure 2-7). On over half of the Cluster 1 days the 4 PM winds had an easterly component. In contrast, only one of the 12 Cluster 2 days (and 1 out of 2 Cluster 3 days) had an easterly component.

In summary, there are indeed differences between the clusters for some meteorological variables. Cluster 2 days tended to be cooler, especially in the south bay. Cluster 2 days had somewhat stronger winds. Almost all Cluster 2 days had westerly 850 mb winds at 4 PM, whereas over half the 850 mb winds at 4 PM for Cluster 1 had an easterly component.

**Table 2-4.** Ozone and meteorological summary statistics: medians by cluster and values by key exceedance day.

| Cluster: | 1 | 2 | 3 | Cluster | 7/11/99 | 7/12/99 | 6/15/00 | 7/31/00 | 7/9/02 | 7/10/02 |
|---|---|---|---|---|---|---|---|---|---|---|
| n: | 22 | 12 | 2 | Diffs* | Clust 1 | Clust 1 | Clust 2 | Clust 2 | Clust 1 | Clust 1 |
| District Max $O_3$ (ppb) | 138 | 131 | 151 | 2<1 | 146 | 156 | 152 | 126 | 135 | 160 |
| District Avg $O_3$ (ppb) | 89 | 65 | 107 | 2<<<1 | 102.8 | 92.5 | 52.7 | 56.7 | 77.3 | 78.5 |
| Livermore max T (F) | 103 | 99 | 102 | 2<1 | 104 | 105 | 102.8 | 101.4 | 103.8 | 105.9 |
| SJ max T (F) | 98 | 92 | 103 | 2<<<1 | 95 | 101 | 90 | 93 | 101 | 99 |
| 850 mb 4am T (F) | 77 | 75 | 71 | 1≈2 | 77 | 78 | 79 | 77 | 77 | 85 |
| 850 mb 4 pm T (F) | 77 | 74 | 74 | 1≈2,3 | 78 | 81 | 81 | 79 | 80 | 85 |
| Travis 10-4 WS (mph) | 6.7 | 7.7 | 6.7 | 1<2 | 5.4 | 8.6 | 11.9 | 8.6 | | |
| S Martin 10-4 WS (mph) | 8.0 | 9.9 | 7.9 | 1<2 | 6.5 | 7.9 | 10.2 | 9.5 | 8.4 | 7.8 |
| 850 mb 4 am WS (mph) | 6 | 6 | 5 | 1≈2 | 14 | 6 | 18 | 5 | 5 | 2 |
| 850 mb 4 pm WS (mph) | 7 | 6 | 3 | 1≈2 | 12 | 5 | 11 | 2 | 3 | 10 |
| 850 mb 4 am WD (deg) | 150 | 235 | 78 | 1≈2 | 345 | 160 | 10 | 310 | 75 | 360 |
| 850 mb 4 pm WD (deg) | 170 | 252 | 260 | 1<<2 | 25 | 245 | 255 | 280 | 175 | 300 |
| SJV max $O_3$ (ppb) | 142 | 139 | 137 | 1≈2 | 142 | 132 | 139 | 118 | 133 | 163 |
| SAC max $O_3$ (ppb) | 131 | 114 | 112 | 1<2 | 137 | 140 | 124 | 103 | 145 | 137 |

* This column shows the extent to which the clusters differed for the selected ozone and met. variables. A ≈ indicates that there was no statistically significant difference. One < sign indicates statistical significance ($p < .05$). Two < signs indicate significance at the .01 level. Three < signs indicates cognizance at the .001 level. Because Cluster 3 had only 2 values, it was not reasonable to test for statistical significance.

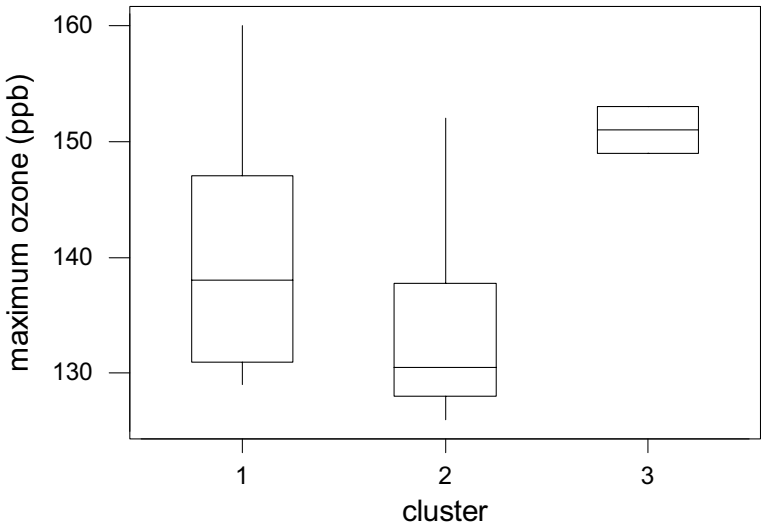



**Figure 2-5.** Boxplots of daily maximum ozone by cluster. Boxes (rectangles) show 25th and 75th percentiles. Horizontal lines in the boxes are medians. Vertical lines above and below the boxes indicate the range of the data unless there are outliers. Outliers are shown with asterisks (see Figure 2-6).

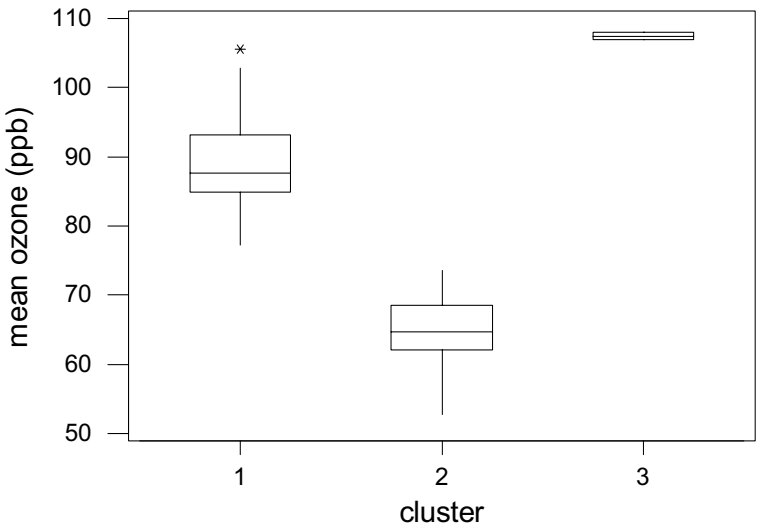



**Figure 2-6.** Boxplots of mean 1-hour ozone maxima for the 21 sites, by cluster, 1995 through September 2002.

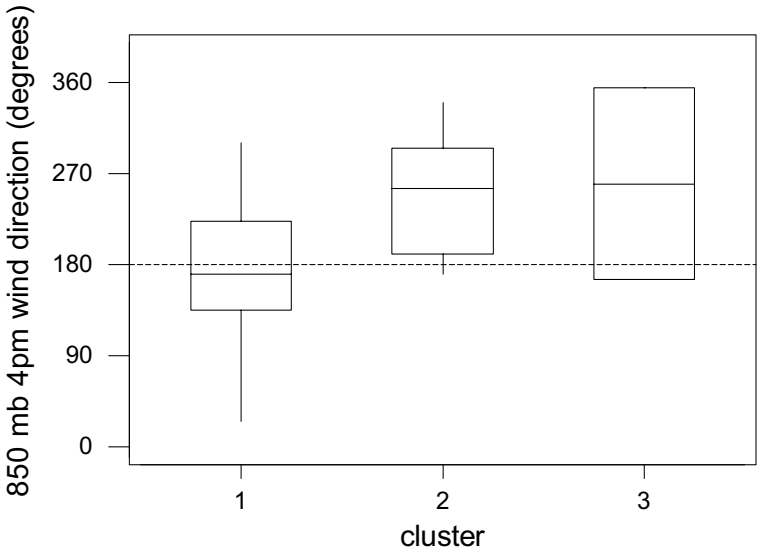



**Figure 2-7.** 850 mb 4 PM wind directions at Oakland by cluster, 1995 through September 2002. A line is drawn at 180° for reference.

## Analysis of Meteorological Conditions

The cluster analysis in the previous section produced two distinct ozone episode clusters: Cluster 1 with ozone exceedances in several regions of the Bay Area and Cluster 2 with ozone exceedances mostly in the Concord and Livermore areas. The previous section also examined the influence of meteorological variables for 6 episode days (7/11-12/1999, 6/15/2000, 7/31/2000, and 7/9-10/2002) that were potential candidates for the Bay Area modeling work. The June 15 and July 31, 2000 episodes, both Cluster 2 episode days, had originally been selected as the first 2 episodes to be modeled since they were part of the CCOS field study. A third episode was to be selected from the Cluster 1 episodes of July 11-12, 1999 or July 9-10, 2002. The representativeness of these episodes were examined by analyzing available meteorological data.

A cursory analysis of the weather maps showed that all the 6 episode days were characterized by a high 500 mb geopotential height and high 850 mb temperature, indicating strong downward motion. This downward motion created a strong inversion layer in the Oakland sounding. The surface weather maps also showed thermal lows or troughs over California for each of the 6 days. There was no clear distinction in the weather patterns between Cluster 1 episode days and Cluster 2 episode days.

### Trajectory Analysis

Another way to characterize the meteorological conditions is to analyze back trajectories from various points in the Bay Area to identify transport routes and possible source areas of ozone precursors. Figures 2-8 and 2-9 show back trajectories from Livermore and San Martin ending at 2 PM PST on July 11, 1999, computed by HYSPLIT using the EDAS (Eta Data Assimilation System) wind fields. The surface trajectory arriving at Livermore came from the North Bay area. The surface trajectory arriving at San Martin came from the Peninsula and the Central Bay Area. Both of the trajectories passed through areas rich in ozone precursors and could be linked to the high ozone observed at Livermore and San Martin on this day.

As a matter of fact, the surface trajectories reaching Livermore at 2 PM for each of the 6 days (the other 5 days not shown) all came from the west, passing through the areas surrounding the San Francisco Bay; high ozone was observed at Livermore for all days. The surface trajectories at San Martin passed through the San Francisco Bay area on 5 of the 6 days (the other 5 days not shown). High ozone was observed at San Martin in 4 of these 5 days. July 31, 2000 was the only exception, when the observed ozone maximum was 46 ppb. On June 15, 2000, the surface trajectories at San Martin passed through the Santa Cruz Mountains and the observed ozone maximum at San Martin was 56 ppb.

Note also the vastly different trajectory paths for the three different end-point elevations (surface, 500 m, and 1000 m). This shows that a high degree of vertical shear is present during July 11. Certainly, this opens up the possibility for contributions of ozone and precursors reaching the eastern Bay Area from the Central Valley, particularly Sacramento. While the 1000 m trajectory is probably higher than the 2 PM mixing depth in Livermore, the 500 m trajectory should be near the top of boundary layer, indicating that some pollutants could be arriving in Livermore from the north and east.

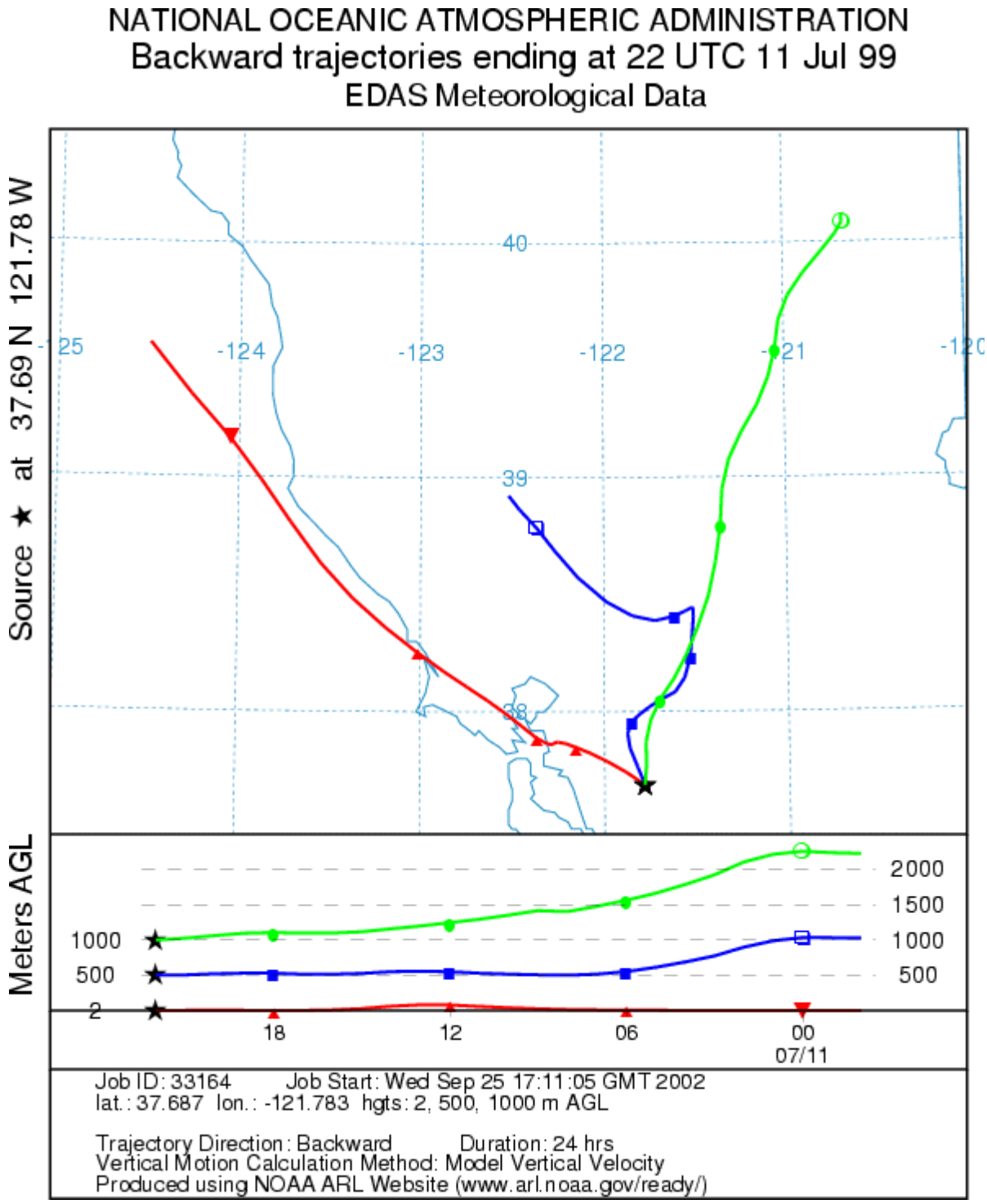



**Figure 2-8.** Back trajectories ending at Livermore at 2 PM July 11, 1999. The red line (with triangles) is the surface trajectory at 2 m. The blue line (with square) is the trajectory at 500 m. The green line (with circle) is the trajectory at 1000 m. The time is shown in UTC. To convert to PST, subtract 8 hours from UTC.

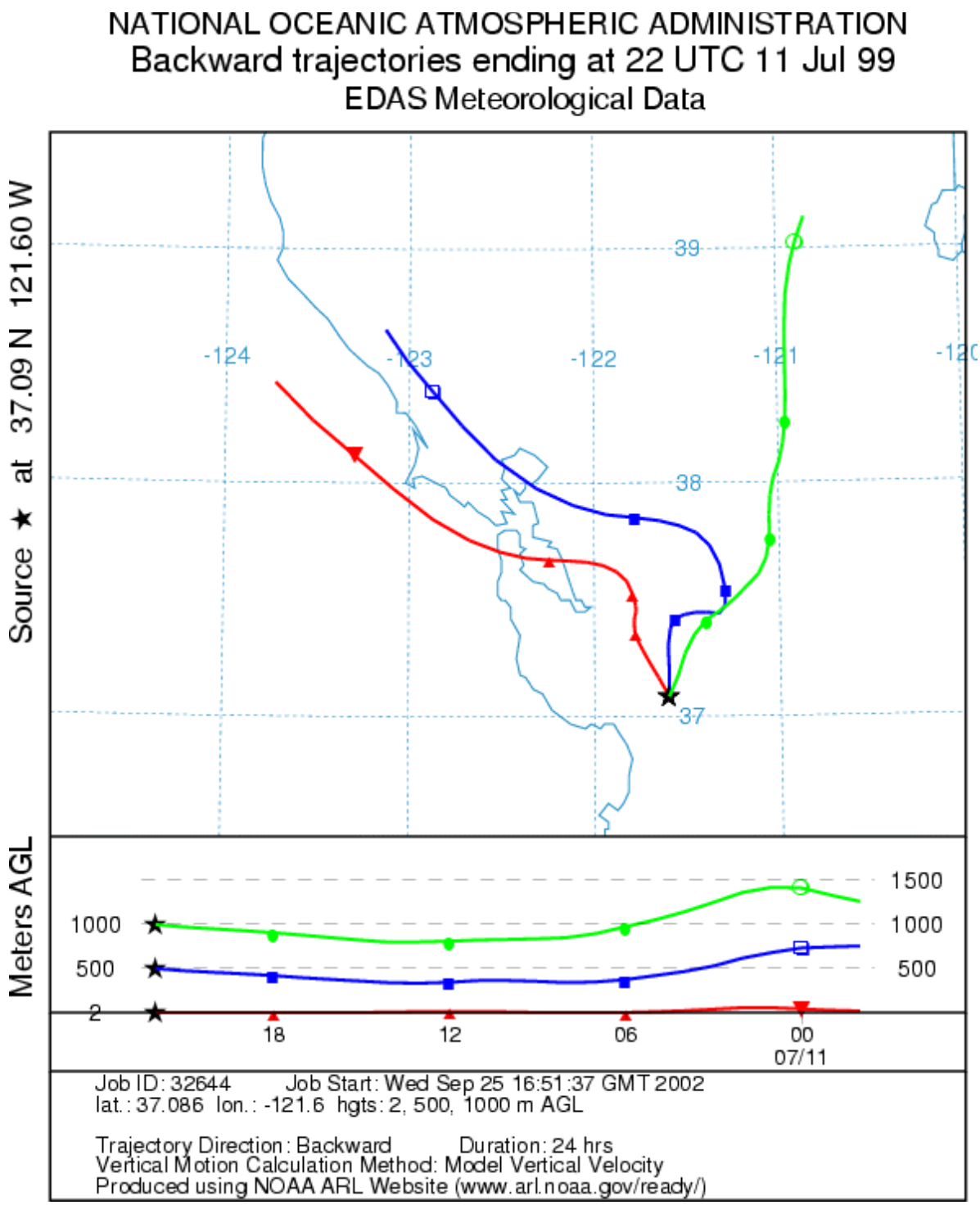



**Figure 2-9.** Same as Figure 2-8 except for San Martin.

We must be cautious in drawing conclusions purely based on the trajectory analysis for the following two reasons:

1. Individual trajectories vary greatly with time and height. Since the trajectories in Figures 2-8 and 2-9 are the back trajectories ending at 2 PM, when the sea breeze penetrated into the Livermore and Santa Clara Valley, the trajectories are most likely to be from the ocean. Some of the trajectories computed for the early morning hours, when the wind at Livermore was weak or from the east, originated from the Central Valley.

2. The EDAS data, having a 40 km resolution, do not resolve the intricate topography of the Bay Area. Specifically, the EDAS data may not resolve the Tri-Valley area, which is important in the assessment of transport to Livermore, as discussed in the next section.

Surface Observations

Figures 7-10 through 7-21 show surface wind observations in the Bay Area at 7 AM and 2 PM PST for the 6 episode days.

The wind patterns at 7 AM, a heavy commuting hour, are generally light and variable, but differ quite a bit among the 6 episode days. For example, the two CCOS 2000 episode days are characterized by strong winds; north-northwest winds of 8-10 MPH had already been established by this hour in the Martinez area. There were also south-southwest winds between Livermore and San Jose, forming a clear convergence in the Tri-Valley area. During the other 4 episode days, the morning winds were weak. Northwest winds existed on July 11, 1999, and on both July 9 and 10, 2002. The winds in the Martinez and Pittsburg areas funneled into the San Ramon Valley. However, on July 12, 1999, morning winds in the Martinez area were in general from the west (northerly at only one station). By 9 AM on July 12, north-northwest winds were also established in the Martinez area.

The afternoon wind patterns of the 6 days were amazingly similar in all areas except in the Santa Clara Valley. One consistent feature was the northwest to north-northwest wind near Martinez; yet another feature was the strong afternoon westerly flow at Pleasanton. The northwest wind near Martinez either persisted throughout the previous night or started in the early morning. This wind may transport ozone precursors from this area down to the Tri-Valley area over a long period of time. The wind at Pleasanton was weak in the morning; the westerly wind usually did not start until after 10 AM, and sometimes started as late as 1 PM. This sea/bay breeze could transport ozone precursors from areas surrounding the San Francisco Bay into the Livermore area via the Castro Valley-Dublin gap. Therefore, high ozone in Livermore may be due to a convergent inflow from two areas of ozone precursors. The similarities in the wind pattern on these 6 days and the occurrence of ozone at Livermore may indicate that the mechanism for ozone production in Cluster 1 and Cluster 2 days are similar. Resolving the topography and winds in the Tri-Valley area may be necessary for proper modeling of Livermore ozone formation.

The afternoon wind at San Martin was northerly for half of the 6 days and southerly for the other half. Of the 4 high ozone days at San Martin, 2 days showed north wind and 2 days showed south wind. Of the 2 low ozone days at San Martin, 1 day showed north wind and the

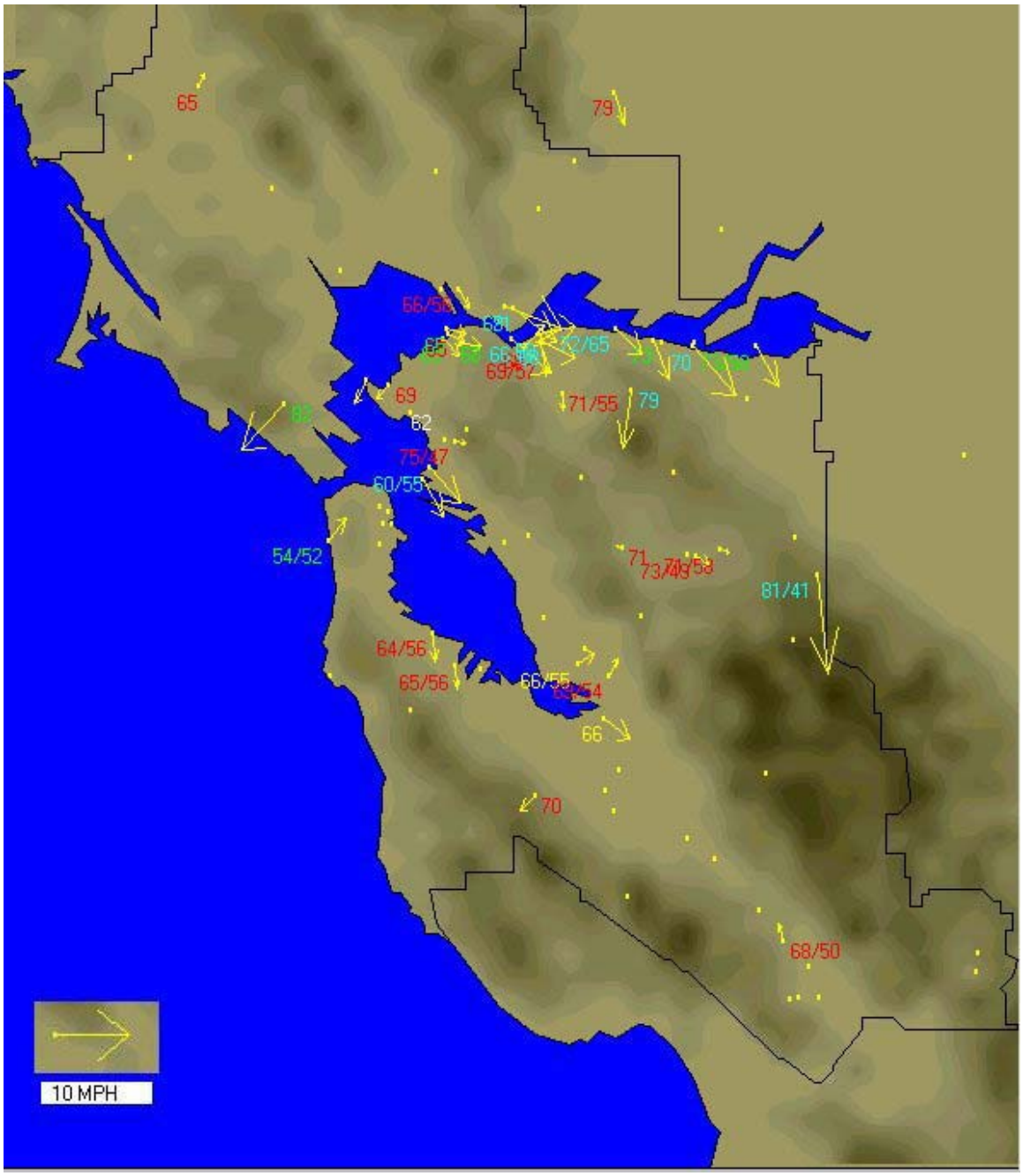



**Figure 2-10.** Bay area surface-wind observations at 7 AM PST, July 11, 1999. The numbers are temperature and dew point temperature.

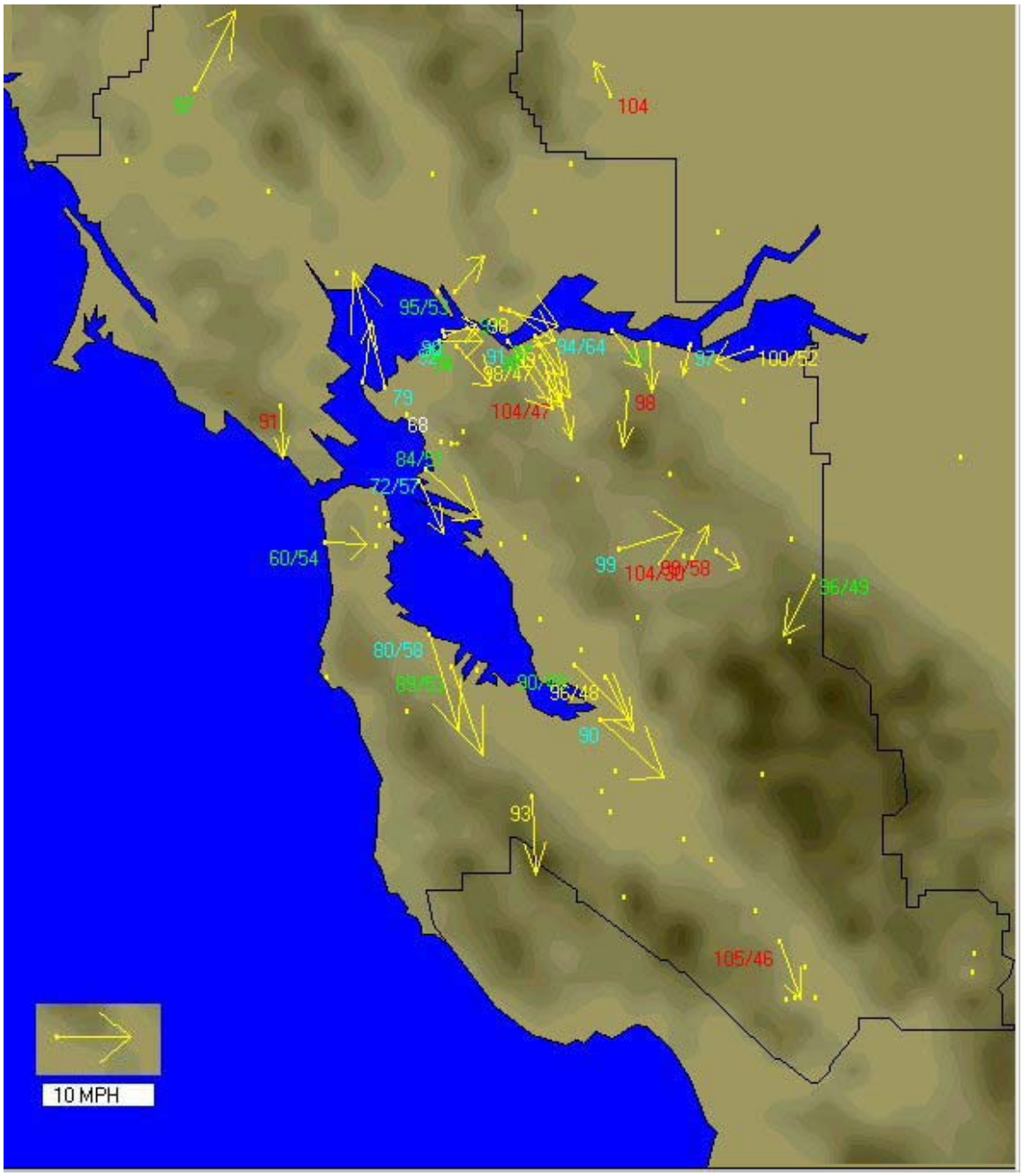



**Figure 2-11.** Bay area surface-wind observations at 2 PM PST, July 11, 1999. The numbers are temperature and dew point temperature.

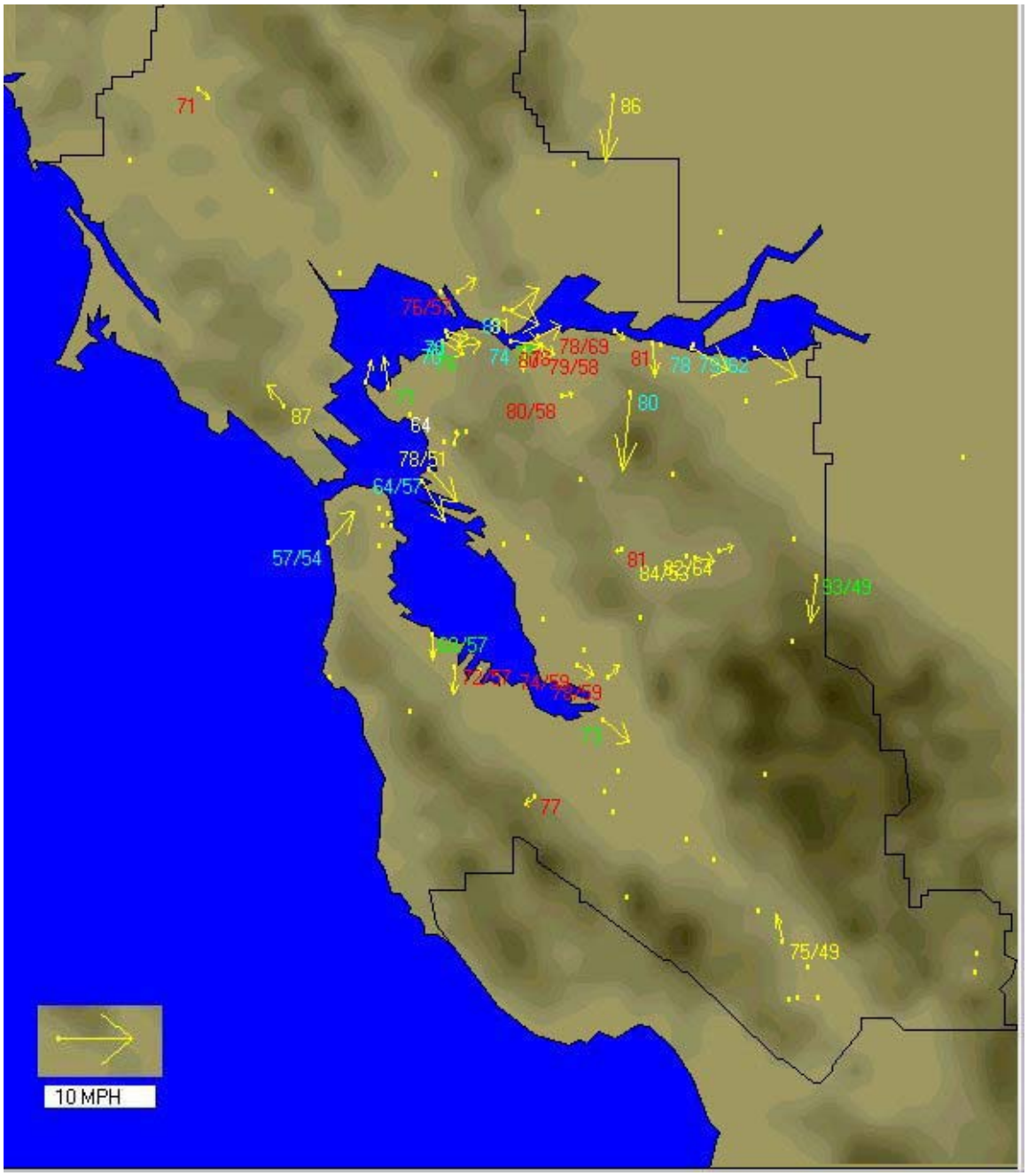



**Figure 2-12.** Bay area surface-wind observations at 7 AM PST, July 12, 1999. The numbers are temperature and dew point temperature.

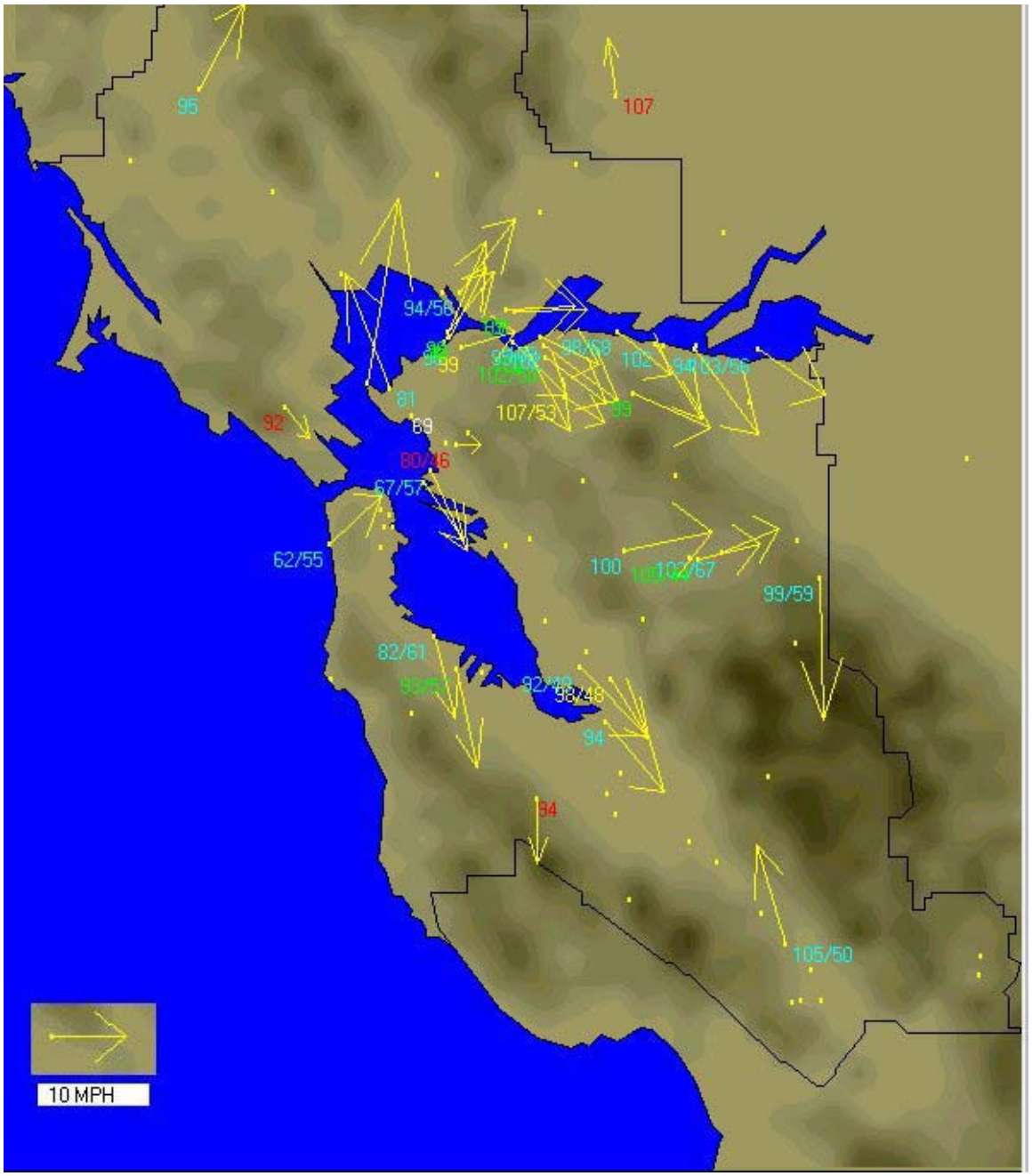



**Figure 2-13.** Bay area surface-wind observations at 2 PM PST, July 12, 1999. The numbers are temperature and dew point temperature.

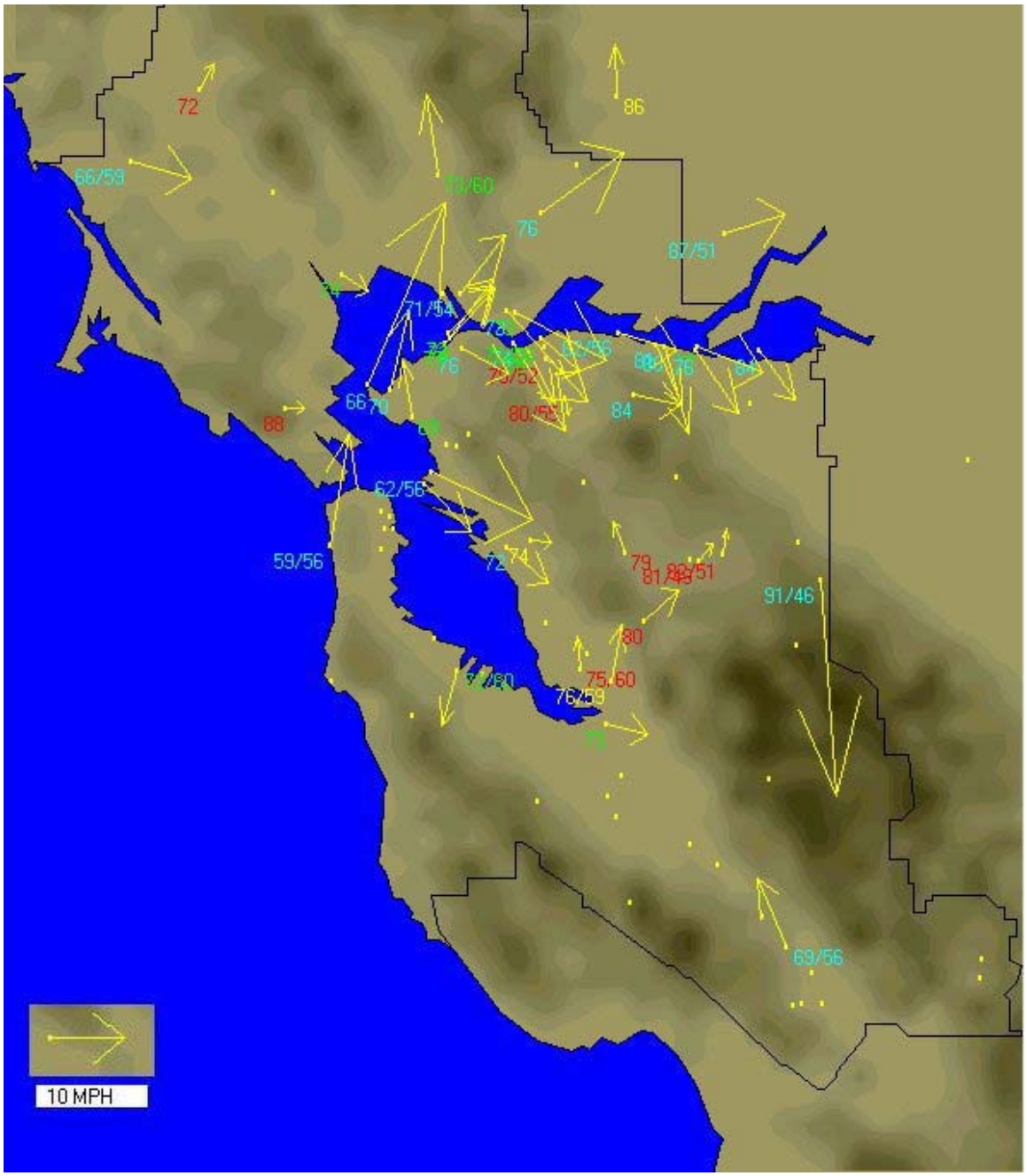



**Figure 2-14.** Bay area surface-wind observations at 7 AM PST, June 15, 2000. The numbers are temperature and dew point temperature.

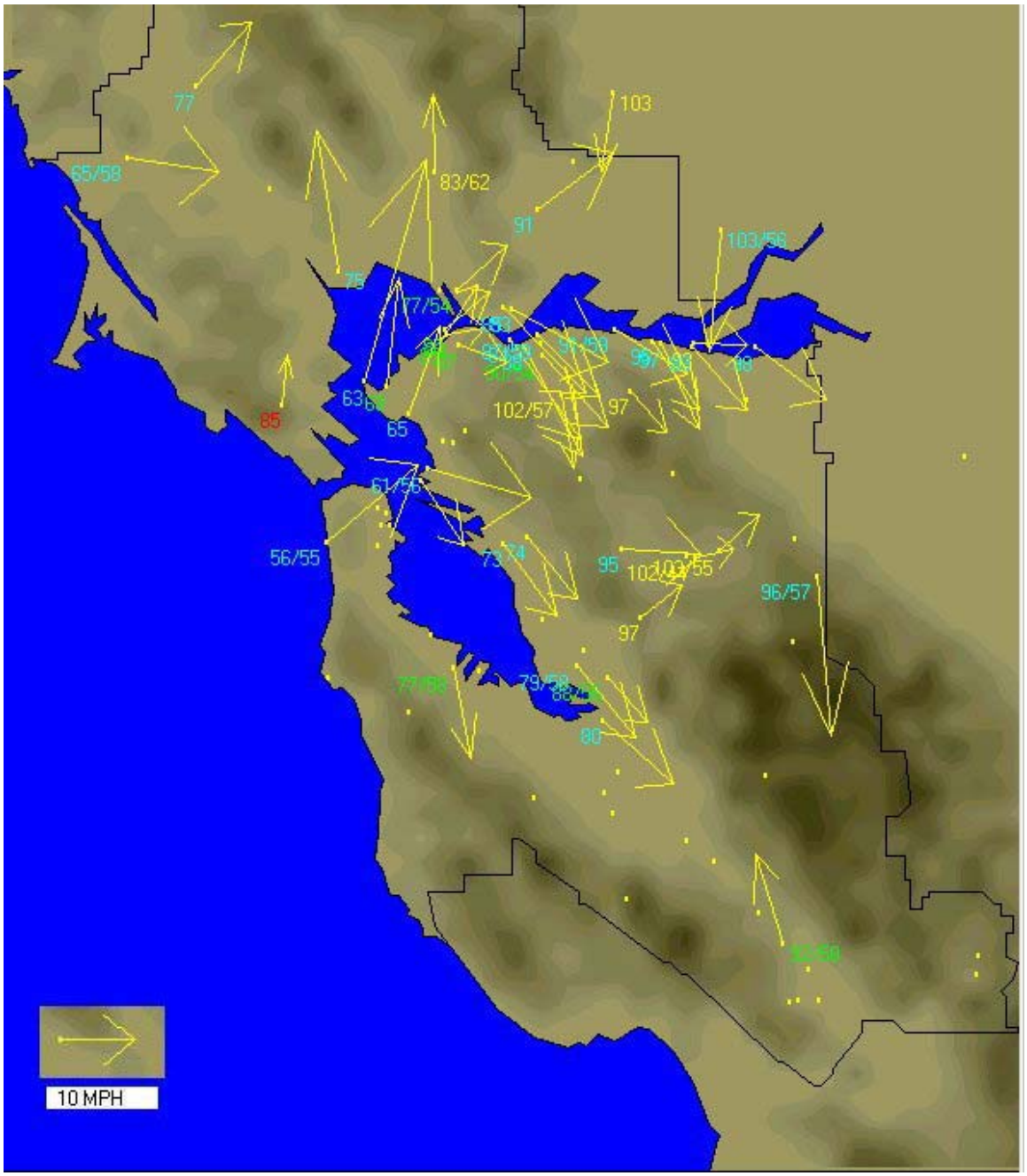



**Figure 2-15.** Bay area surface-wind observations at 2 PM PST, June 15, 2000. The numbers are temperature and dew point temperature.

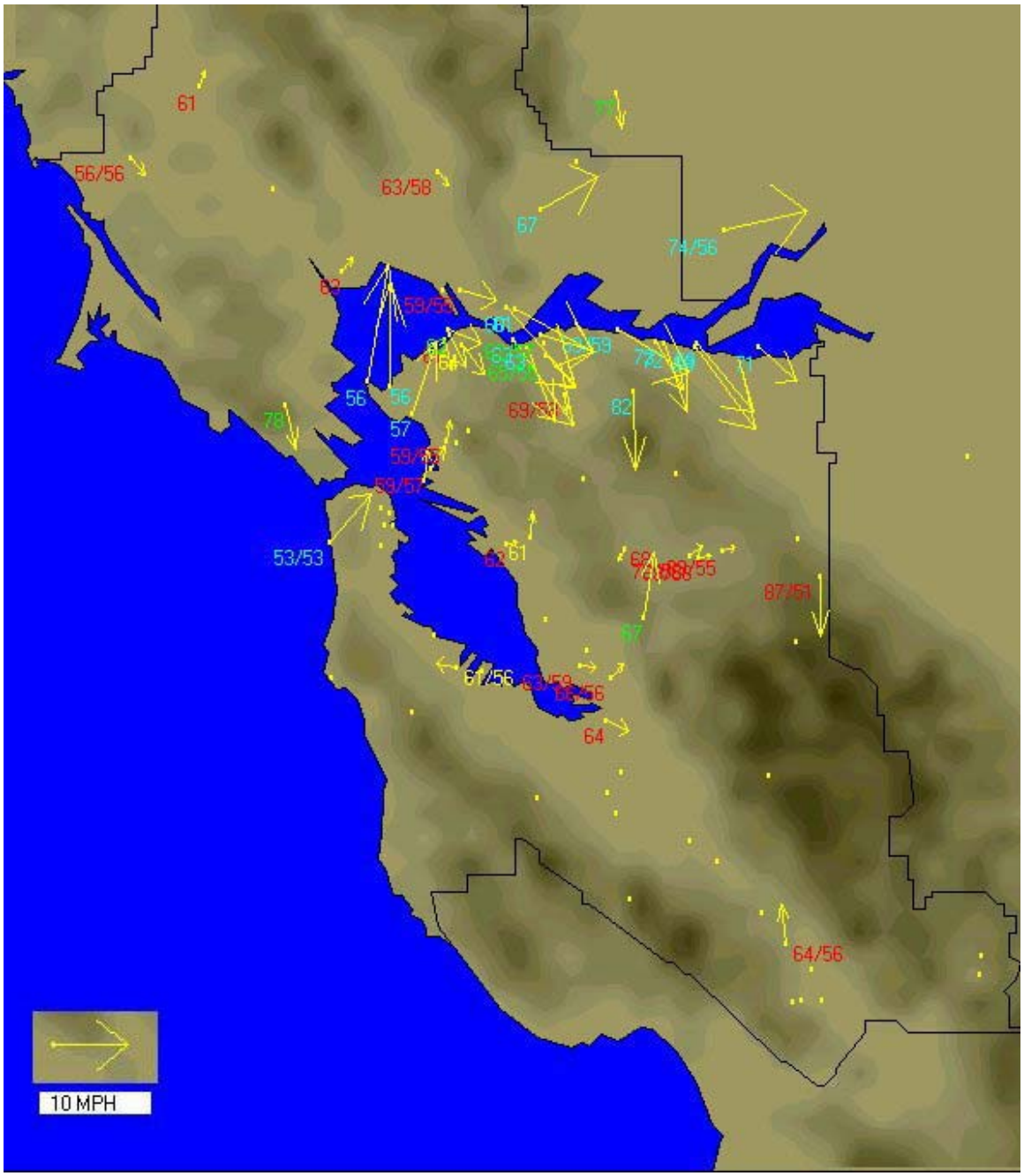



**Figure 2-16.** Bay area surface-wind observations at 7 AM PST, July 31, 2000. The numbers are temperature and dew point temperature.

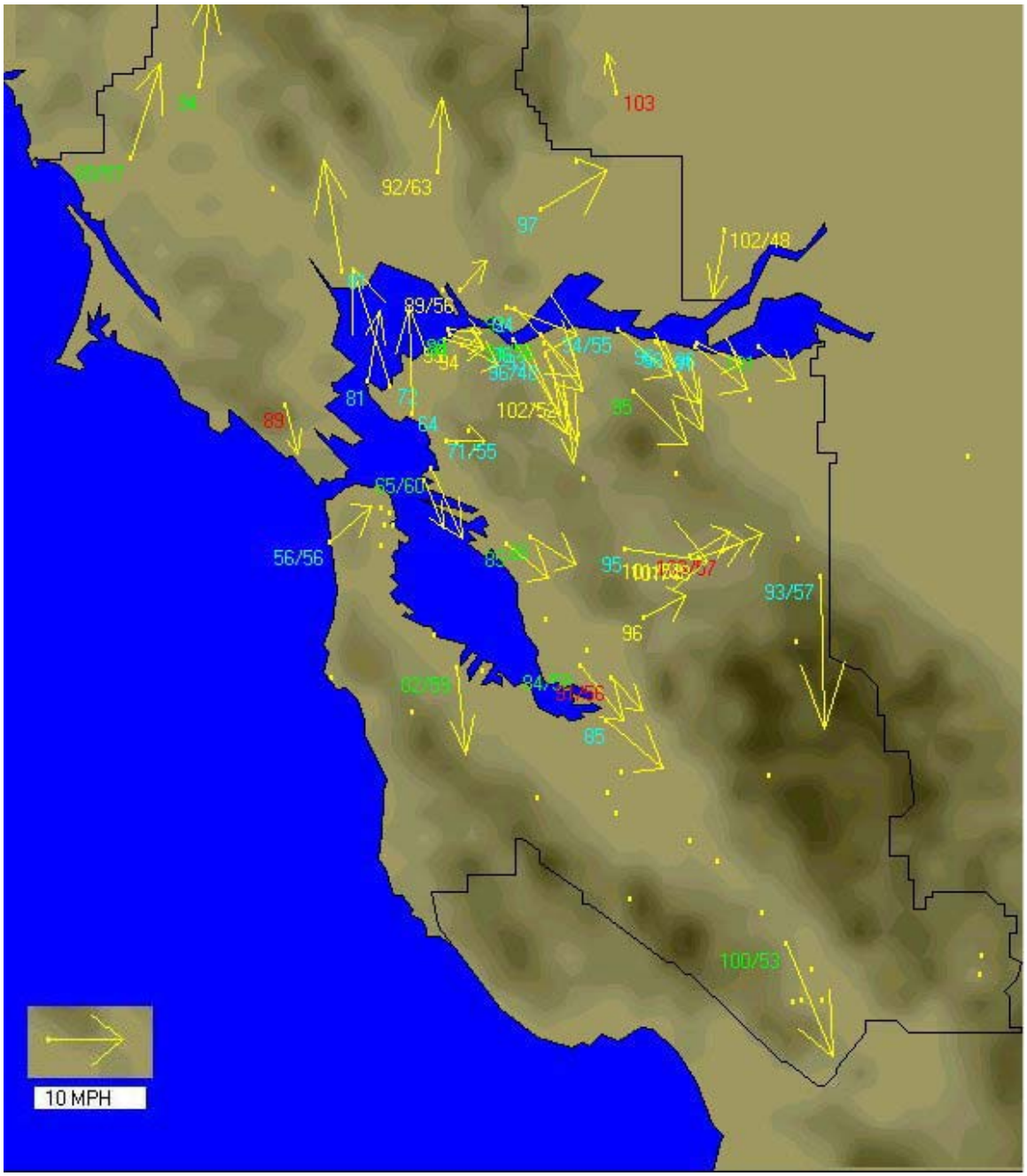



**Figure 2-17.** Bay area surface-wind observations at 2 PM PST, July 31, 2000. The numbers are temperature and dew point temperature.

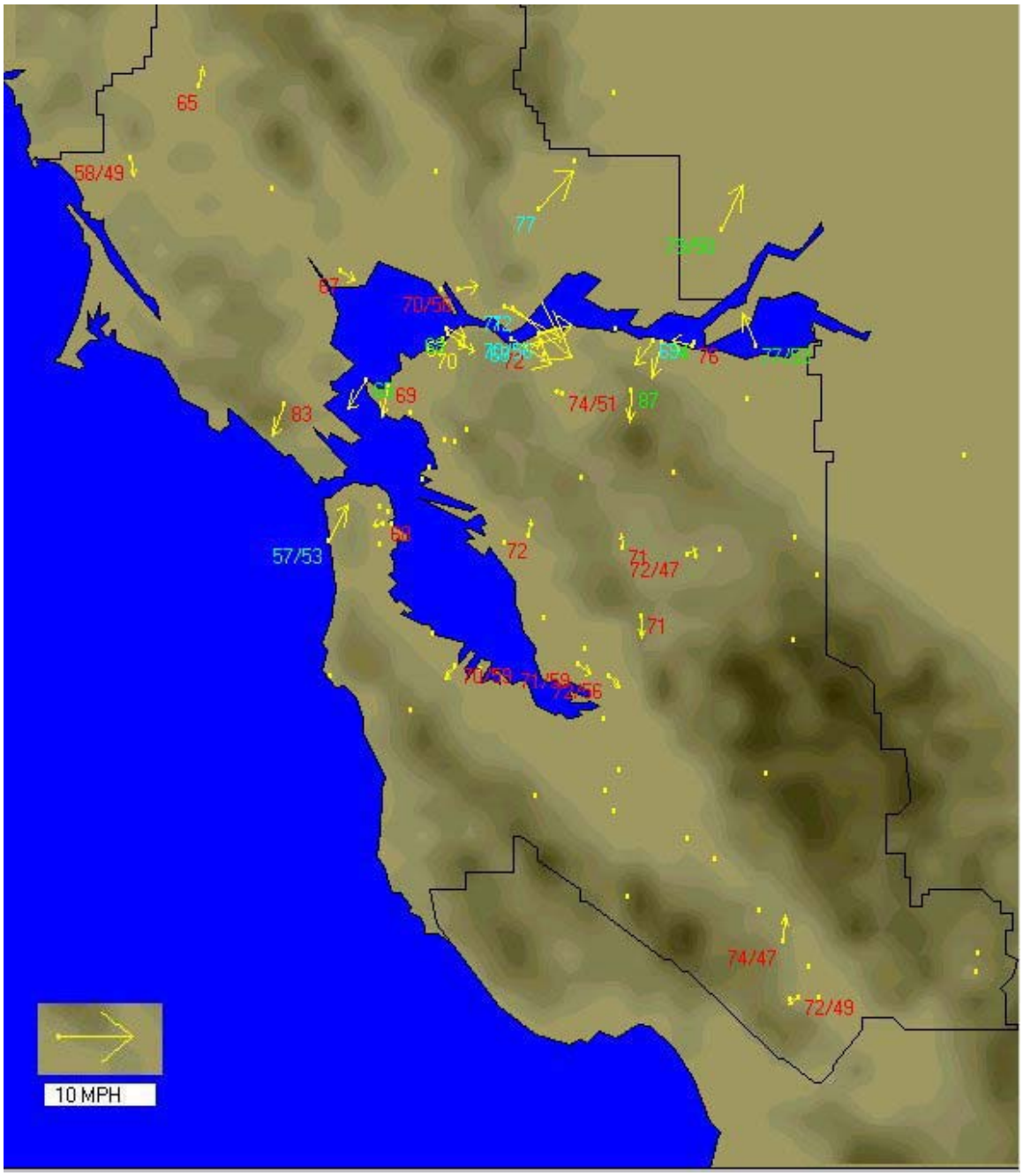



**Figure 2-18.** Bay area surface-wind observations at 7 AM PST, July 9, 2002. The numbers are temperature and dew point temperature.

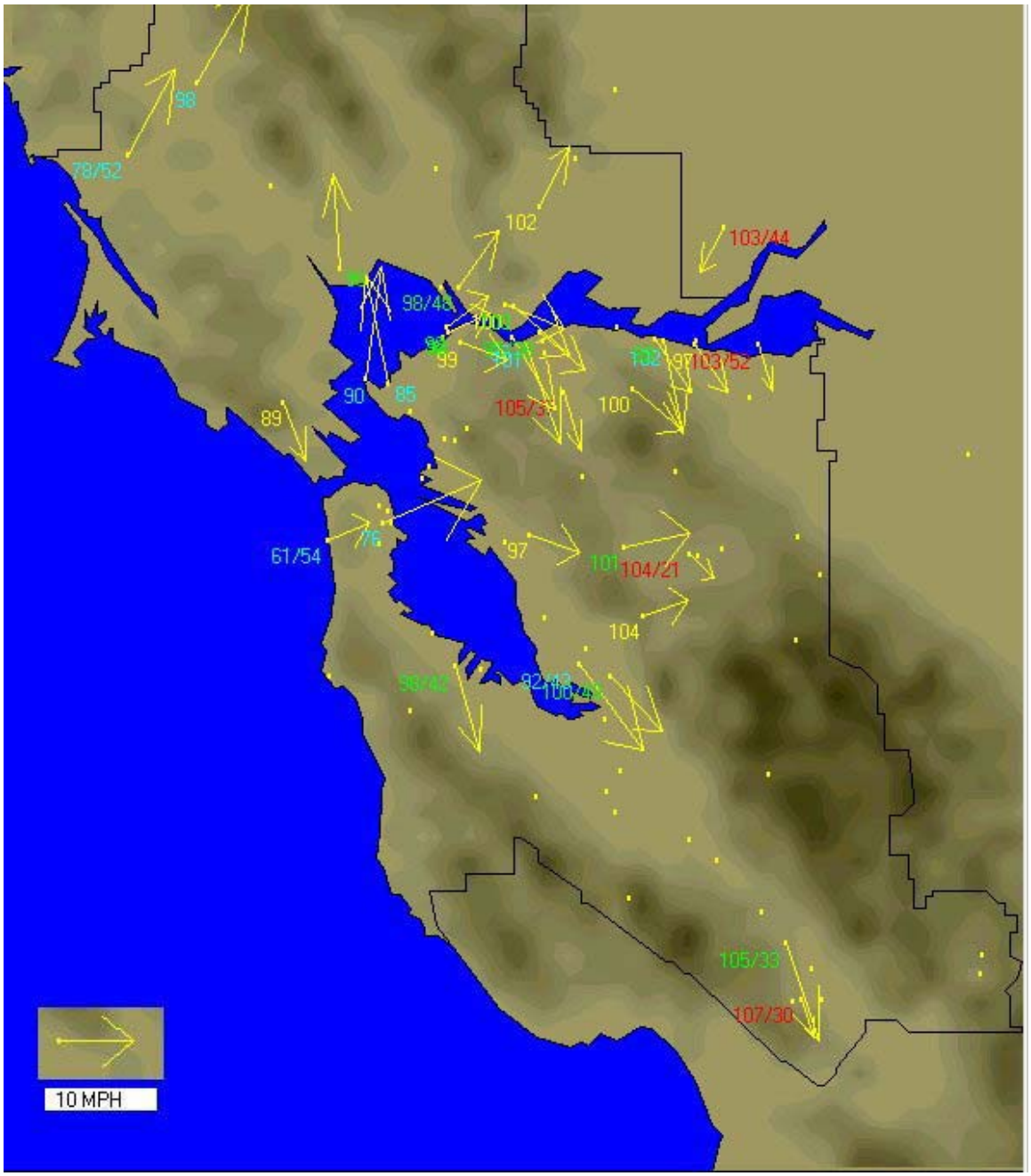



**Figure 2-19.** Bay area surface-wind observations at 2 PM PST, July 9, 2002. The numbers are temperature and dew point temperature.

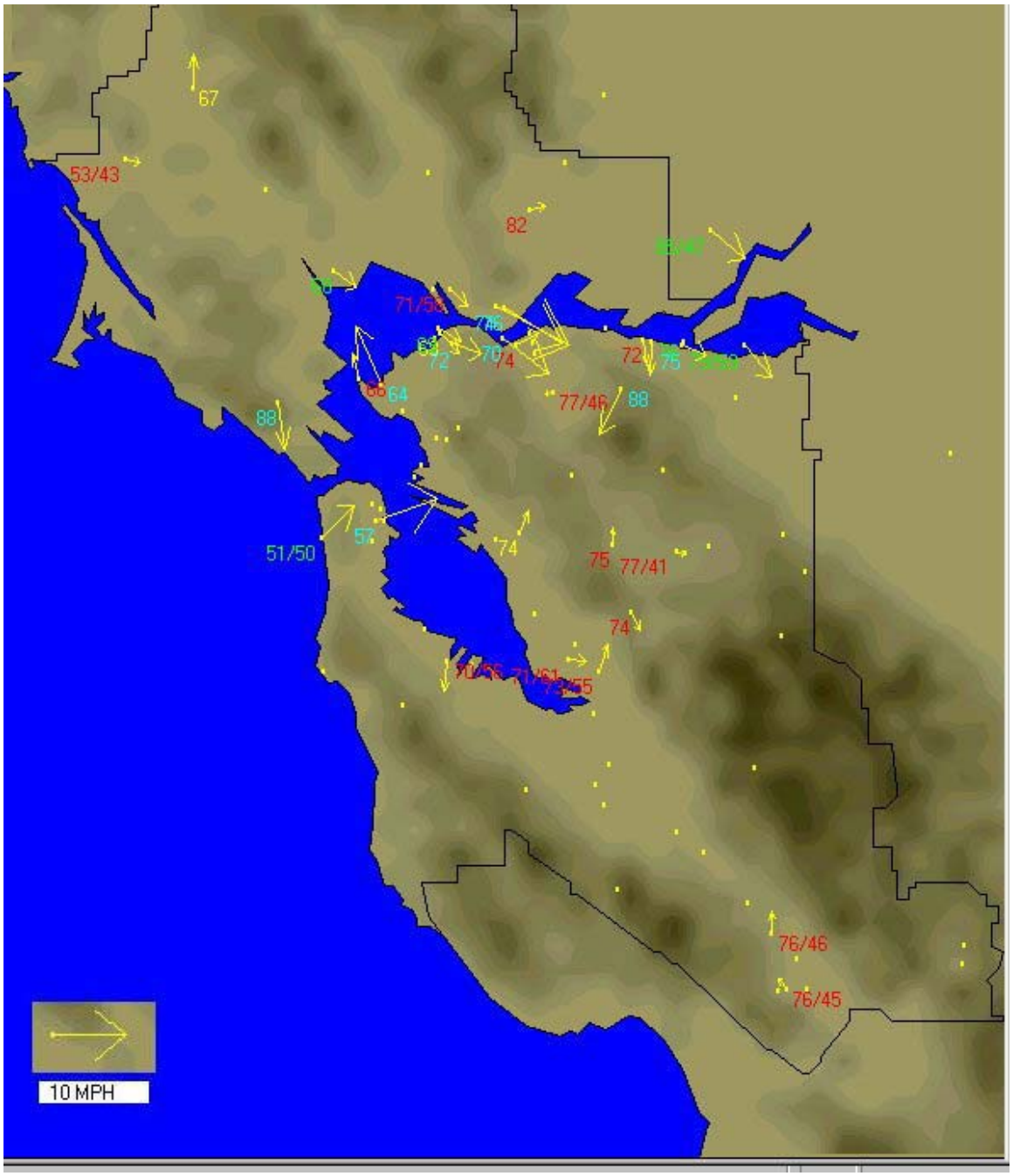



**Figure 2-20.** Bay area surface-wind observations at 7 AM PST, July 10, 2002. The numbers are temperature and dew point temperature.

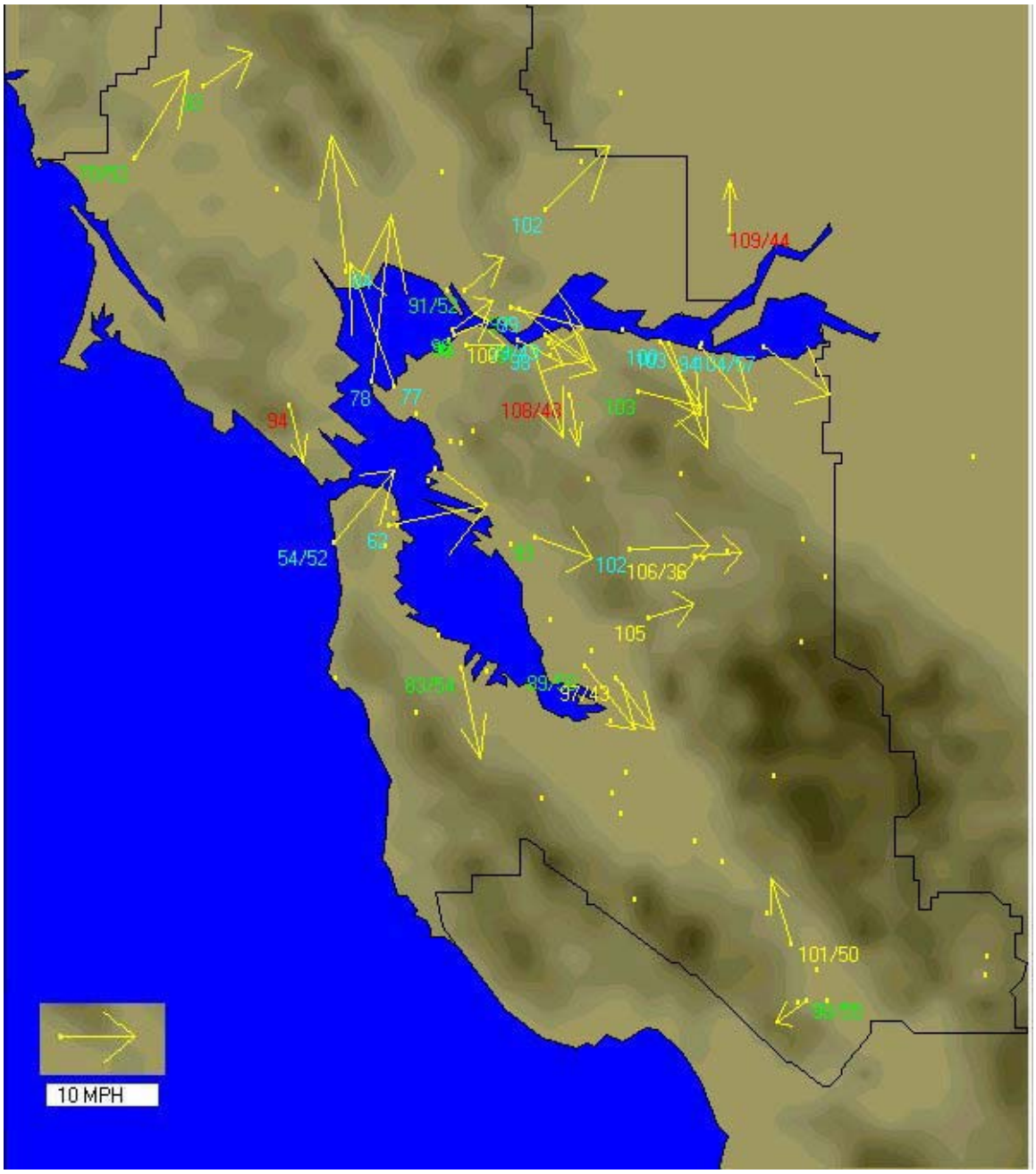



**Figure 2-21.** Bay area surface-wind observations at 2 PM PST, July 10, 2002. The numbers are temperature and dew point temperature.

other day showed south wind. It poses a challenge to explain the source of ozone precursors at San Martin during high ozone days, especially when the wind is from the south. Perhaps a flow reversal associated with a horizontal shift of the sea breeze front in the southern Santa Clara Valley is a culprit. This front often shifts in response to differing sea/bay breeze strengths between the southern San Francisco Bay and the northern Monterey Bay.

**An Evaluation of Transport Potential from the Bay Area**

The airborne transport of pollutants is of continuing interest because it affects every region and air basin. This SIP modeling effort originally focused on attainment planning for the San Francisco Bay Area, but will provide information on transport patterns during the selected ozone episodes. This section considers transport of pollutants from the Bay Area to selected sites in the Central Valley and Monterey area for four candidate episode periods (June 11-12, 1999, June 15 and July 31, 2000 and July 9-10, 2002).

Pollutant transport potential between two areas can be assessed by back trajectory analysis, where simulated particles are released at specified times and locations and are transported by winds back in time. The path that the particle takes defines the back trajectory and defines a transport connection between any two points on the back trajectory. For this analysis back trajectories were computed on a NOAA Air Resources Laboratory web site using the HYSPLIT software. However, we must recognize the limitations of this analysis. The back trajectories computed by HYSPLIT used meteorological data with a 40 km grid spacing, which does not resolve wind variations due to narrow mountains, valleys, and gaps in and around the Coastal Ranges. Hence, we have more confidence in the accuracy of these back trajectories in the Central Valley where the terrain is relatively smooth than in the San Francisco Bay and Monterey areas where the terrain is more rugged. The back trajectories in this report were selected as follows:

1. For each of the four candidate episodes, we expanded the date range by 2 days before and 2 days after the episode period. The modeling work included these additional dates for the July/August 2000 period, and thus, we are able to broaden the analysis of transport.
2. For each expanded episode day, we identified all stations in the Central Valley and Monterey area with ozone exceedances. There were no ozone exceedances in the Monterey area in any of the episode periods. The highest ozone in the Monterey area was 115 ppm observed at Pinnacles at 1700 PST on July 10, 2002. The back trajectory from this Pinnacles observation station is included.
3. For each of these stations, we identified the hour of maximum ozone. These station locations and times defined the initial points for each back trajectory.
4. For all of these initial points, 24- and 48-hour back trajectories were computed.

Figures 2-22 through 2-25 show the composites of all 24-hour back trajectories for each of the four candidate episodes and these are discussed for each episode below.

<u>Transport for July 11-12, 1999</u>

Figure 2-22 shows 17 back trajectories for the 1999 episode. The Sacramento area has definite Bay Area transport connections. Eight of the back trajectories from the Sacramento area passed

through the North Bay Area. As noted earlier, the 40 km resolution wind data may not sufficiently resolve the detailed wind variations generated by important topographic features, such as the Carquinez Strait, an ostensible transport corridor. In reality, such features may cause the true back trajectories to be located south of those indicated in Figure 2-22, putting them over the densely populated North Bay Area. Three additional back trajectories ending just north of Sacramento did not reach the Bay Area within 24 hours. Two of these eventually traversed the North Bay Area 24- to 48-hours earlier. The influence of any Bay Area emissions on the Sacramento area will be diluted significantly after traverse times greater than 24 hours.

The six San Joaquin Valley 24-hour back trajectories all had a northwest to southeast orientation. One back trajectory from the Modesto area traversed the Bay Area. The other Modesto area back trajectory and the two Fresno back trajectories traversed the Stockton area 24-hours earlier and traversed the Bay Area 24- to 48-hours earlier. The back trajectory from Bakersfield and one from near the Sequoia National Park did not show any Bay Area connections.

Transport for June 15, 2000

Figure 2-23 shows six back trajectories for the June 15, 2000 episode. All back trajectories ended in the Sierra. There were no Bay Area connections even up to 48 hours.

Transport for July 31, 2000

Figure 2-24 shows five back trajectories for the July 31, 2000 episode. The Fresno back trajectory traversed the Bay Area. The two 24-hour Bakersfield back trajectories did not traverse the Bay Area but the 48-hour back trajectories did. The two back trajectories from the Sacramento area traversed the North Bay Area.

Transport for July 9-10, 2002

Figure 2-25 shows 19 back trajectories for the July 9-10, 2002 episode. Three of the four Sacramento area back trajectories traversed the North Bay Area. The fourth one had no Bay Area connection. The three back trajectories from Merced County had clear Bay Area connections, with two passing through the central Bay Area and the other passing through the North Bay Area. Of the eight back trajectories from Fresno, only one traversed the Bay Area within 24 hours, and two others traversed the North Bay Area within 48-hours. The three back trajectories from Bakersfield passed over Fresno within 24 hours and two of these reached the central Bay Area within 48-hours. The back trajectory from the Pinnacles meandered through the Santa Clara Valley and East Bay Area before reaching the North Bay Area 24 hours later.

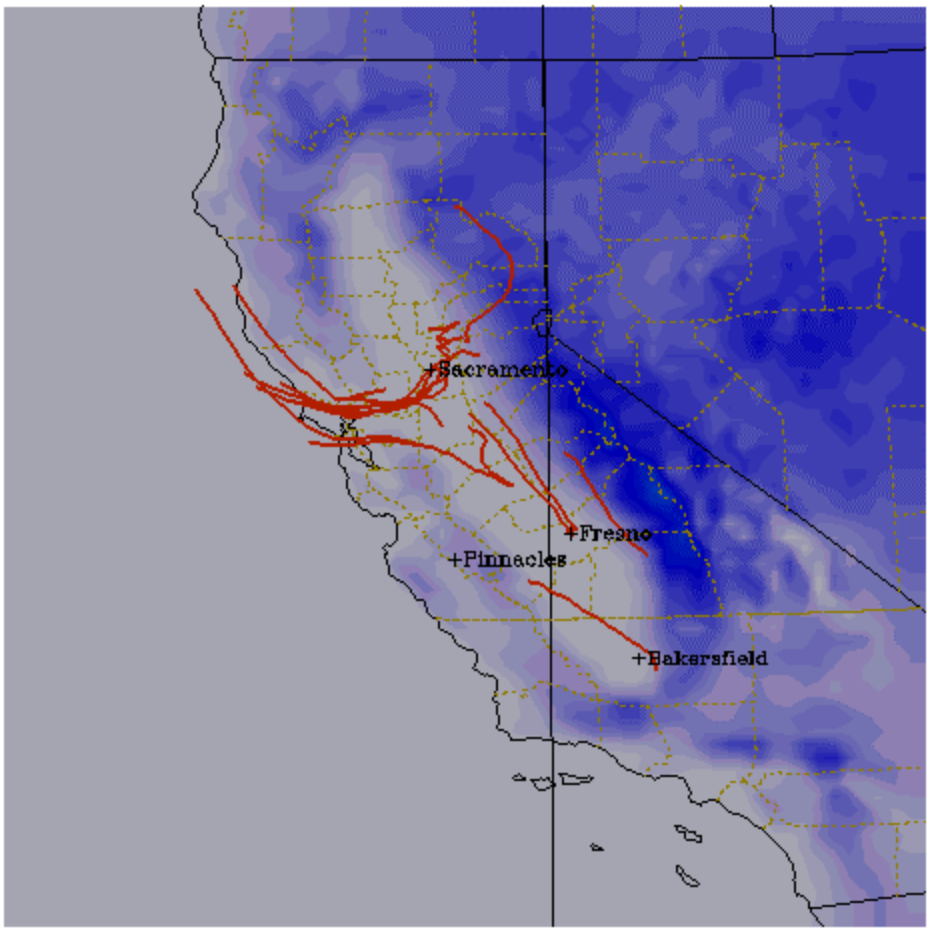



**Figure 2-22.** The 24-hour back trajectories for the July 11-12, 1999 episode.

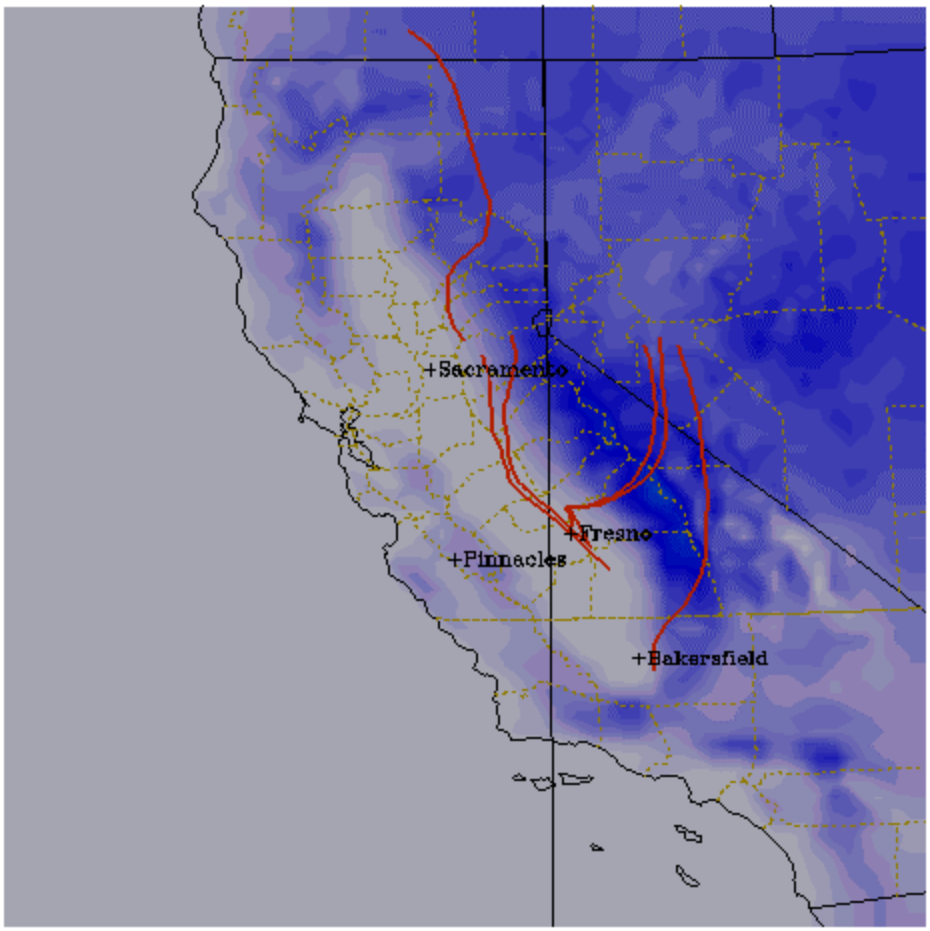



**Figure 2-23.** The 24-hour back trajectories for the June 16, 2000 episode.

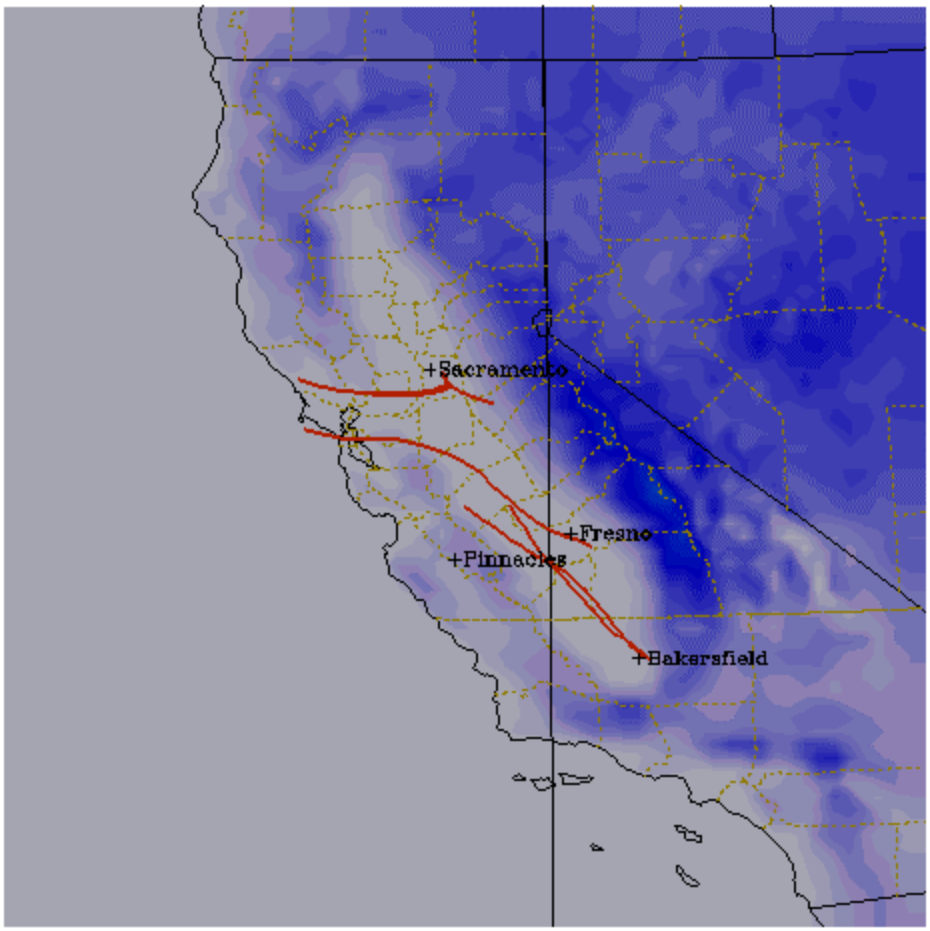



**Figure 2-24.** The 24-hour back trajectories for the July 31, 2000 episode.

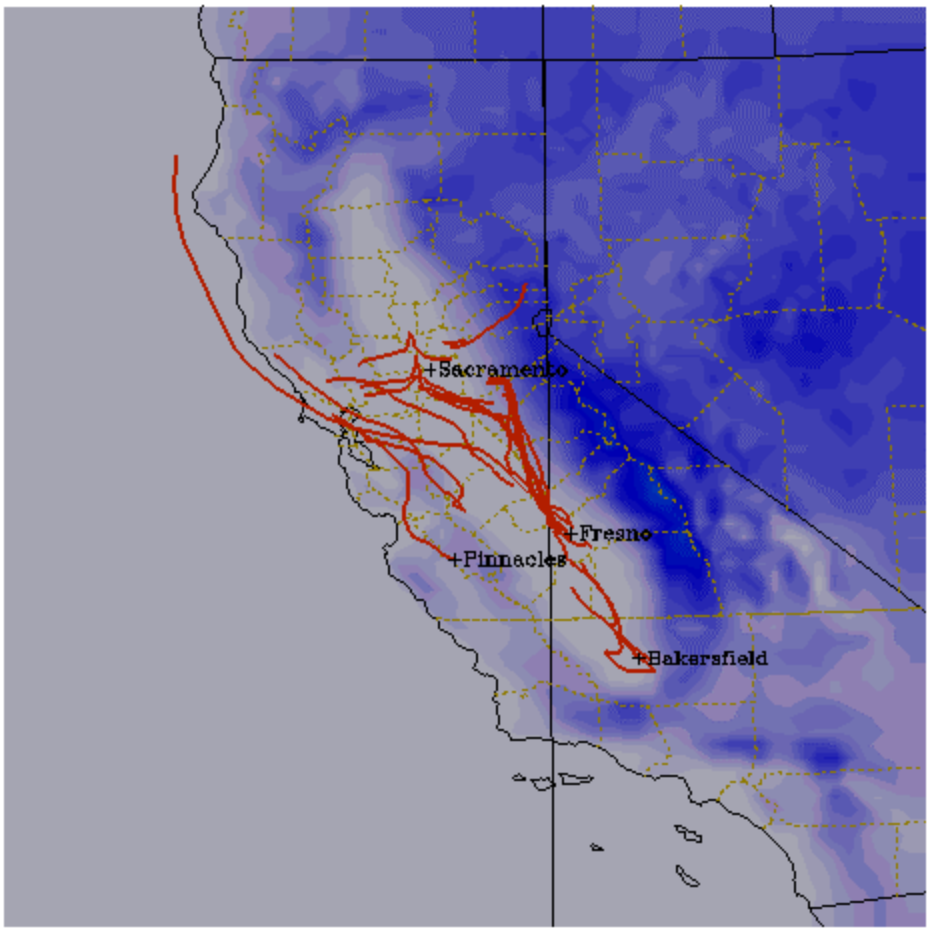



**Figure 2-25.** The 24-hour back trajectories for the July 9-10, 2002 episode.

Summary

The potential for transport of pollutants from the Bay Area to the Central Valley and Monterey areas for four candidate Bay Area SIP episodes were assessed using the HYSPLIT back trajectory analysis. The results are summarized in Table 2-5. More than 70% of the Sacramento Valley 24-hour back trajectories pass through the Bay Area. For San Joaquin Valley, this ratio is less than 25%. This is understandable because most high ozone days occur during stagnant or weak wind conditions. Hence, pollutants from the Bay Area will not be able to reach Fresno or Bakersfield within 24 hours. If the back trajectory computation is extended to 48 hours, this ratio increases to 80% in the Sacramento Valley and to 55% in the San Joaquin Valley. The one back trajectory computed for the Monterey area does show a clear Bay Area transport connection.

**Table 2-5.** The ratios of the number of back trajectories passing through the Bay Area to the total number computed. The 24- and 48-hour columns indicate the ratios for the 24- and 48-hour back trajectories, respectively. Sacramento Valley includes Stockton area. San Joaquin Valley includes Merced County area.

| Episode | Sacramento Valley | | San Joaquin Valley | | Monterey Area | |
|---|---|---|---|---|---|---|
| | 24-hour | 48-hour | 24-hour | 48-hour | 24-hour | 48-hour |
| 7/11-12/99 | 7/10 | 9/10 | 2/7 | 5/7 | 0/0 | 0/0 |
| 6/15/00 | 0/1 | 0/1 | 0/5 | 0/5 | 0/0 | 0/0 |
| 7/31/00 | 2/2 | 2/2 | 1/3 | 3/3 | 0/0 | 0/0 |
| 7/9-10/02 | 3/4 | 3/4 | 4/14 | 8/14 | 1/1 | 1/1 |
| Total | 12/17 | 14/17 | 7/29 | 16/29 | 1/1 | 1/1 |

We rank these episodes for suitability of use in transport analyses as follows:

1. The July 11-12, 1999 episode.
2. The July 31, 2000 or the July 9-10, 2002 episodes. The July 9-10, 2002 episode includes the only Pinnacles high ozone case.

No back trajectories during the June 15, 2000 episode showed any transport connection from the Bay Area to the Central Valley or the Monterey area.

**Discussion and Conclusions**

The statistical analysis has looked at representativeness from several points of view and suggests the following points:

1. There has been substantial progress in reducing ozone in the south bay region. In contrast, there has been little progress for eastern sites. Almost all exceedance days include high ozone at eastern sites. Thus, it seems reasonable that any modeled day should include high ozone from eastern sites.

2. The cluster analysis suggests that the days with high ozone at Fremont (6/24/95 and 7/15/95) are substantially different from other exceedance days. This, coupled with the fact that the emissions leading to high ozone at Fremont may well be different from those at eastern sites,

and the discussion in (1) suggests that these days be excluded from modeling and be considered a category that is not represented in the modeling analysis.

3. High ozone occurs at eastern sites on both weekdays and weekends. The emissions patterns will clearly differ for these two periods. Thus, ideally, modeling should include both weekend and weekday exceedances.

4. The cluster analysis found two main categories of clusters: days with exceedances at isolated individual sites where the rest of the District was relatively clean; and days with exceedances at several sites and regions. Cluster 2 days have much lower mean ozone than Cluster 1 and differ with respect to several meteorological variables. In particular, Cluster 2 days are cooler in the south bay and have somewhat stronger winds through the Carquinez Strait and Santa Clara Valley. In addition, Cluster 2 afternoon 850 mb winds almost all contained a westerly component, whereas over half the Cluster 1 winds contain an easterly component. It is not unreasonable to assume the dynamics of ozone formation on these two types of days could be different. Thus, it seems reasonable to model days from within both of these categories.

5. Both potential CCOS modeling days fell into Cluster 2, the cluster representing an isolated high ozone event. Thus, these days may be acceptable to model Cluster 2 days, but another episode is necessary to cover Cluster 1 days. Also, since both CCOS days fell on weekdays and both were single day episodes in the Bay Area, it is valuable for the additional episode to cover include a multi-day episode and at least one weekend day.

The meteorological analysis of the 6 candidate ozone episode days identified from the statistical representativeness evaluation leads to the following conclusions:

1. The weather patterns of the 6 ozone episode days were similar, with high 500 mb contour heights, high 850 mb temperatures and low inversion layers.

2. The 2 PM PST surface wind patterns are similar on all 6 days in all regions except in the Santa Clara Valley. One source area of ozone precursors at Livermore is likely the Martinez area, where northwest winds prevail. Another source area of ozone precursors at Livermore may be the area surrounding the San Francisco Bay. Precursors from this area arrive via the sea breeze through the Castro Valley-Dublin gap, which starts after 10 AM.

3. The afternoon wind patterns at Livermore are similar for all 6 ozone episode days. The mechanism for ozone production at Livermore in Clusters 1 and 2 may also be similar. Based on this analysis, it would appear that any of these 6 days are as good as another for modeling ozone at Livermore.

4. There is no clear relation between the wind direction and the observed ozone at San Martin. Therefore, it poses a challenge to determine the source of ozone precursor at San Martin during high ozone days, especially during south wind days.

**Selected Episodes for Modeling**

The table below summarizes the six episode days described above.

| Episode Dates | Days of Week | Peak ozone (ppb) | # Exceedances | Cluster Category | PM Wind Pattern |
|---|---|---|---|---|---|
| July 11-12, 1999 | Sun, Mon | 156 Concord | 6 | 1 | Similar |
| June 15, 2000 | Thurs | 152 Livermore | 1 | 2 | Similar |
| July 31, 2000 | Mon | 126 Livermore | 1 | 2 | Similar |
| July 9-10, 2002 | Tues, Wed | 160 Livermore | 2 | 1 | Similar |

Based upon the review above, and the criteria for data availability, we initially elected to model four exceedance days for the SIP modeling, in the following order:

1) July 31, 2000
2) June 15, 2000
3) July 11 and 12, 1999.

The June and July 2000 days occurred during the Central California Ozone Study (CCOS), a field monitoring program that collected extensive meteorological and aerometric measurements for use in the analysis and the modeling of ozone throughout central California. Both of the 2000 days fell into one of the two main episode categories described above.

The 1999 days represent the other frequently occurring ozone pattern category. July 11 was a Sunday and July 12 was a Monday, which should satisfy the need to evaluate weekend-weekday issues. Data for this period was quality assured and archived by various agencies, while data for July 9-10, 2002 was not readily available at the time of episode selection. Also, this episode experienced more wide-spread Bay Area exceedances than other periods (3 per day).

## DESCRIPTION OF EPISODES

Histories of daily maximum observed ozone inside and outside the SFBA for the 1999 and 2000 seasons are presented in Figures 2-26 and 2-27, respectively. Figure 2-26 shows that the largest 1999 SFBA exceedance occurred on 7/12/1999. Exceedances over this season were infrequent and peak values varied significantly from the generally clean levels around 60 ppb. The ozone observations outside the SFBA were consistently around the 120 ppb level.

Figure 2-27 shows that the 2000 SFBA exceedances (6/15/2000 and 7/31/2000) also occurred infrequently and that the exceedance values varied significantly from the generally clean values of 60 ppb. During this season the daily maxima inside and outside the SFBA were better correlated than they were during the 1999 season.

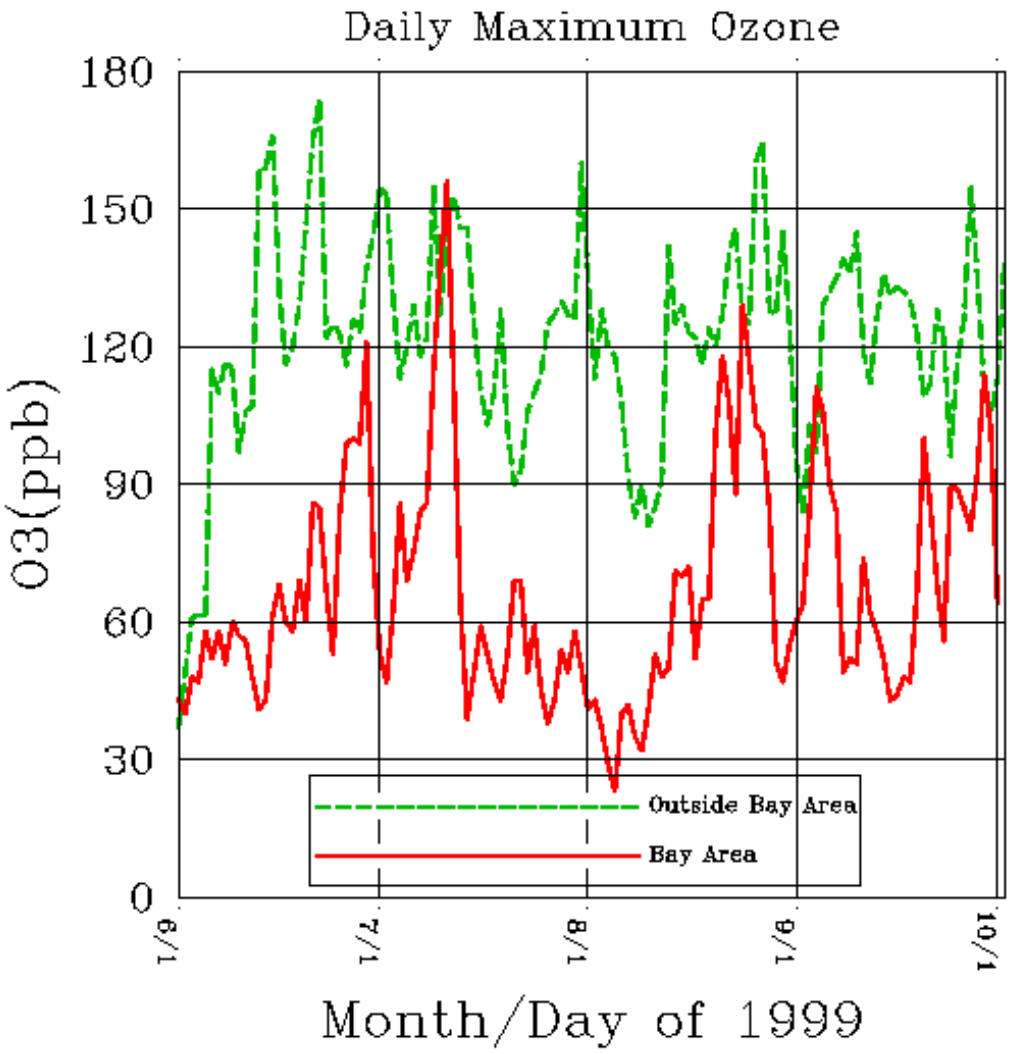



**Figure 2-26.** Daily maximum observed ozone from 6/1/1999 to 10/1/1999.

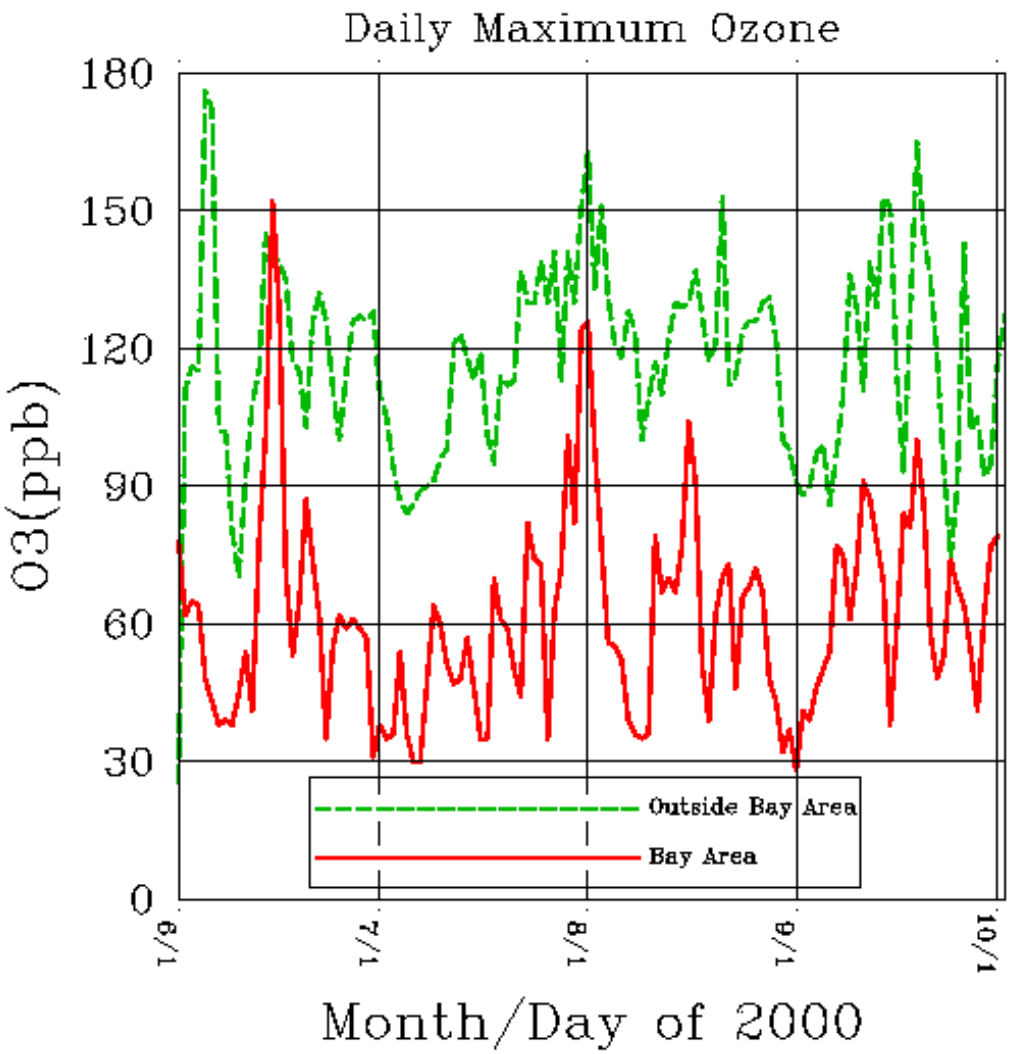



**Figure 2-27.** Daily maximum observed ozone from 6/1/2000 to 10/1/2000.

Figures 2-28 through 2-31 show the spatial distribution of daily maximum ozone for each of the four selected exceedance modeling days. Specific hourly values are listed in Table 2-6 for the July 11-12, 1999 episode, and in Table 2-7 for the July/August, 2000 episode. On 7/11/1999 the exceedances were wide-spread and include Sacramento, Fresno, and Los Angeles areas. On 7/12/1999 the high ozone values outside the SFBA diminished from the previous day, leaving the highest ozone observations in the SFBA. On 6/15/2000 isolated high ozone values were quite localized at Livermore, while clean conditions existed around Sacramento, and moderate values existed around Fresno. On 7/31/2000 ozone values just above the 1-hour standard were observed in Livermore and Fresno, while moderate values were observed around Sacramento.

**Table 2-6.** Hourly ozone concentration measured at sites recording at least one exceedance value during the July 11-12, 1999 episode. Yellow shading denotes 1-hour exceedances.

| Day | 7/11/1999 | | | | | | | | 7/12/1999 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| hour (pst) | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
| **SF Bay Area** | | | | | | | | | | | | | | | | |
| Concord | 113 | 115 | 126 | 120 | 126 | 99 | 102 | 81 | 134 | 156 | 149 | 129 | 104 | 93 | 99 | 91 |
| Livermore | 88 | 94 | 96 | 138 | 145 | 146 | 128 | 93 | 117 | 144 | 133 | 128 | 111 | 94 | 86 | 73 |
| Fremont | 79 | 111 | 133 | 117 | 101 | 66 | 43 | 14 | 93 | 98 | 90 | 88 | 80 | 73 | 59 | 53 |
| San Martin | 112 | 121 | 124 | 125 | 97 | 62 | 56 | 45 | 115 | 96 | 90 | 74 | 65 | 55 | 46 | 37 |
| **Sacramento** | | | | | | | | | | | | | | | | |
| Folsom | 125 | 132 | 133 | 137 | 125 | 107 | 98 | 90 | 109 | 108 | 100 | 89 | 89 | 92 | 107 | 79 |
| Vacaville | 96 | 97 | 99 | 122 | 118 | 101 | 82 | 62 | 108 | 127 | 140 | 115 | 95 | 74 | 65 | 59 |
| Auburn | 85 | 90 | 91 | 93 | 111 | 133 | 118 | 112 | 89 | 93 | 90 | 89 | 99 | 95 | 82 | 71 |
| Sloughhouse | 125 | 131 | 116 | 109 | 105 | 103 | 100 | 83 | 108 | 106 | 110 | 103 | 96 | 105 | 91 | 72 |
| Roseville | 108 | 120 | 128 | 128 | 119 | 108 | 100 | 81 | 96 | 90 | 82 | 78 | 78 | 81 | 108 | 74 |
| Rocklin | 99 | 115 | 128 | 123 | 119 | 111 | 105 | 92 | 99 | 96 | 85 | 79 | 80 | 82 | 104 | 87 |
| **San Joaquin** | | | | | | | | | | | | | | | | |
| Clovis | 124 | 140 | 142 | 125 | 105 | 110 | 81 | 58 | 112 | 124 | 108 | 102 | 98 | 96 | 90 | 66 |
| Fresno - 1st St | 128 | 130 | 132 | 135 | 124 | 114 | 99 | 63 | 114 | 115 | 108 | 95 | 88 | 87 | 75 | 60 |
| Tracy | 84 | 94 | 91 | 97 | 97 | 97 | 95 | 94 | 102 | 106 | 117 | 118 | 132 | 121 | 113 | 99 |
| Stockton - Hazelton | 107 | 122 | 130 | 122 | 108 | 113 | 91 | 62 | 100 | 96 | 95 | 90 | 86 | 102 | 95 | 75 |
| Merced | 111 | 115 | 118 | 116 | 112 | 110 | 110 | 100 | 121 | 125 | 117 | 115 | 102 | 108 | 118 | 116 |

Figures 2-32 through 2-34 present hourly ozone time series ("histories") for the SFBA sites that measured exceedances during these four episode days. Figure 2-32 presents ozone time series for 7/11-12/1999 at the Livermore (Old First Street) and Concord sites. The ozone observations were similar for these two locations indicating that high levels of ozone were widespread over the East Bay. Figure 2-33 presents the time series at the two Livermore sites for 6/15/2000. These sites were approximately one mile from each other, and so their time series were quite similar; no other sites measured ozone exceedances. Figure 2-34 presents the ozone time series at the two Livermore sites for 7/31/2000l; these were similar (but lower) to 6/15/2000.

**Table 2-7.** Hourly ozone concentration measured at sites recording at least one exceedance value during the July 31- August 2, 2000 episode. Yellow shading denotes 1-hour exceedances.

| Day | 7/31/2000 | | | | | | | | 8/1/2000 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hr | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
| **SF Bay Area** | | | | | | | | | | | | | | | | |
| Livermore - Old 1st | 68 | 88 | 116 | 123 | 126 | 73 | 53 | 34 | 73 | 86 | 92 | 81 | 68 | 65 | 52 | 37 |
| **Sacramento** | | | | | | | | | | | | | | | | |
| Sloughhouse | | 100 | 92 | 87 | 78 | 74 | 66 | 80 | 88 | 112 | 133 | 126 | 119 | 112 | 95 | 82 |
| **San Joaquin** | | | | | | | | | | | | | | | | |
| Edison | 115 | 110 | 106 | 94 | 81 | 74 | 38 | 19 | 113 | 109 | 93 | 102 | 102 | 96 | 83 | 73 |
| Turlock | 75 | 91 | 104 | 105 | 96 | 88 | 64 | 52 | 100 | 101 | 97 | 104 | 86 | 85 | 73 | 61 |
| Modesto - 14th | 74 | 87 | 94 | 90 | 84 | 81 | 60 | 41 | 80 | 84 | 99 | 87 | 94 | 91 | 70 | 53 |

| Day | 8/2/2000 | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Hr | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
| **SF Bay Area** | | | | | | | | |
| Livermore - Old 1st | 88 | 93 | 98 | 84 | 69 | 57 | 49 | 46 |
| **Sacramento** | | | | | | | | |
| Sloughhouse | 98 | 102 | 101 | 103 | 98 | 66 | 77 | 69 |
| **San Joaquin** | | | | | | | | |
| Edison | 129 | 151 | 139 | 121 | 76 | 51 | 45 | 39 |
| Turlock | 98 | 95 | 114 | 117 | 116 | 131 | 106 | 79 |
| Modesto - 14th | 90 | 94 | 95 | 113 | 131 | 128 | 85 | 64 |

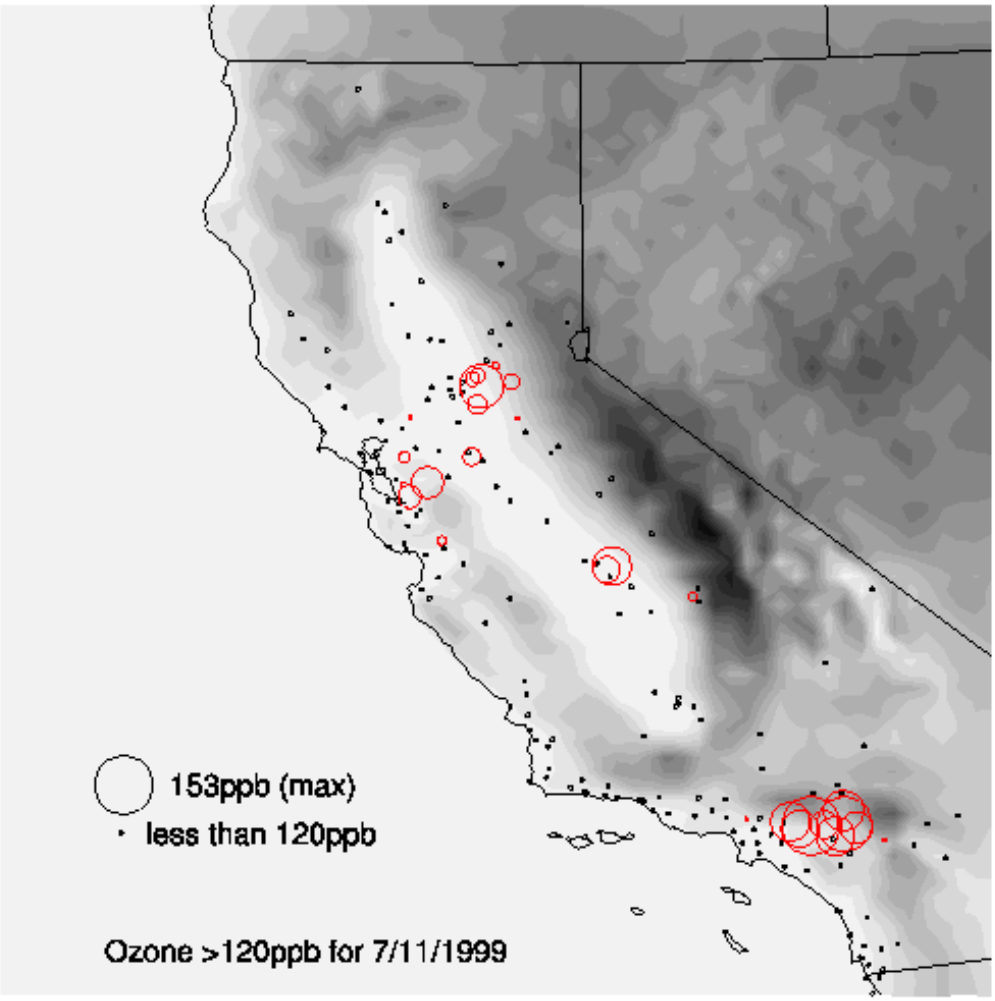



**Figure 2-28.** Spatial distribution of daily maximum ozone observations greater than 120 ppb (red) for 7/11/1999.

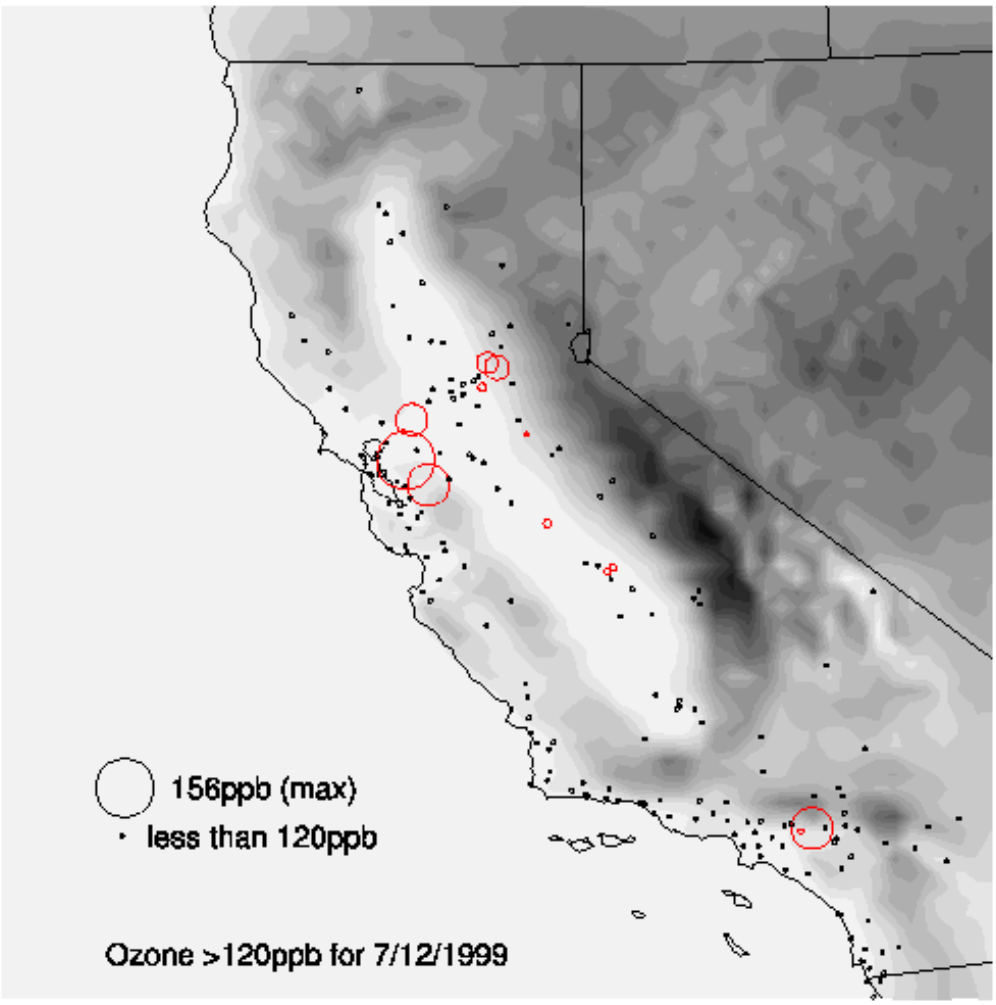



**Figure 2-29.** Spatial distribution of daily maximum ozone observations greater than 120 ppb (red) for 7/12/1999.

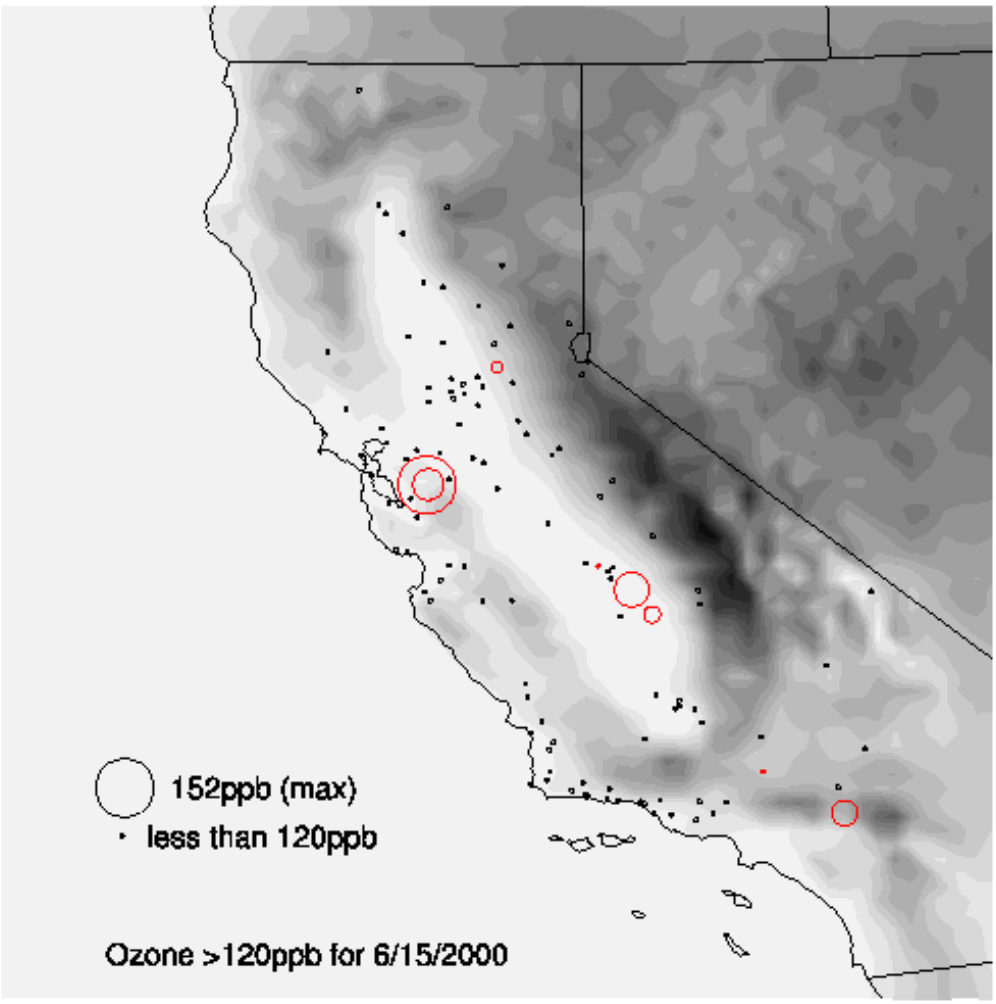



**Figure 2-30.** Spatial distribution of daily maximum ozone observations greater than 120 ppb (red) for 6/15/2000.

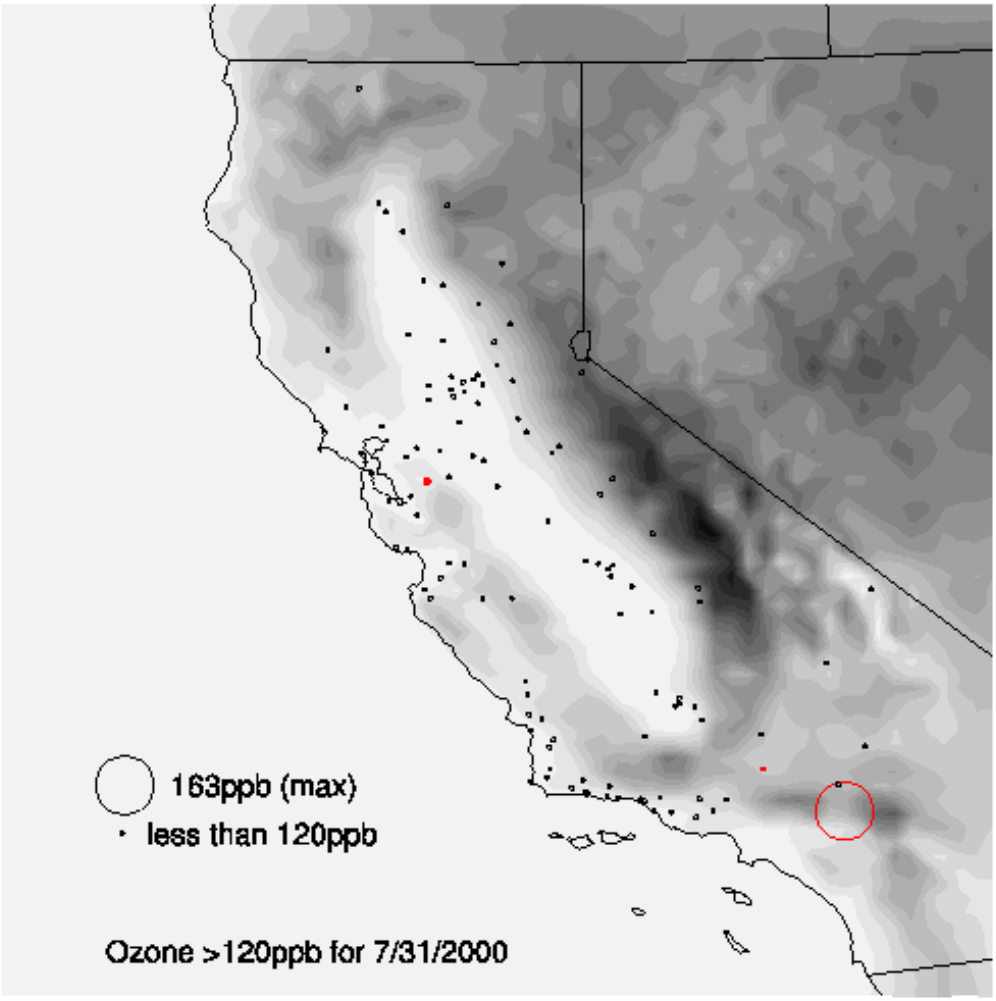



**Figure 2-31.** Spatial distribution of daily maximum ozone observations greater than 120 ppb (red) for 7/31/2000.

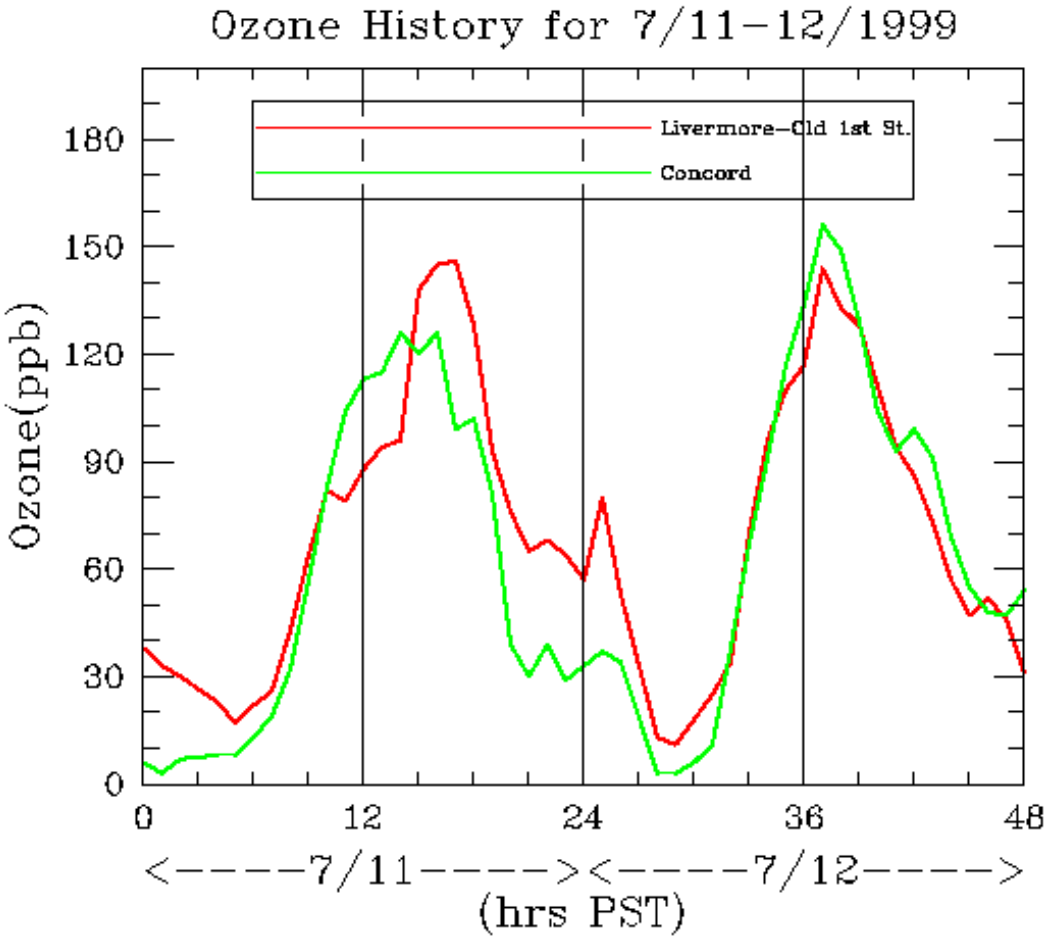



**Figure 2-32.** Ozone time series at the two SFBA stations with the highest ozone observations during 7/11-12/1999.

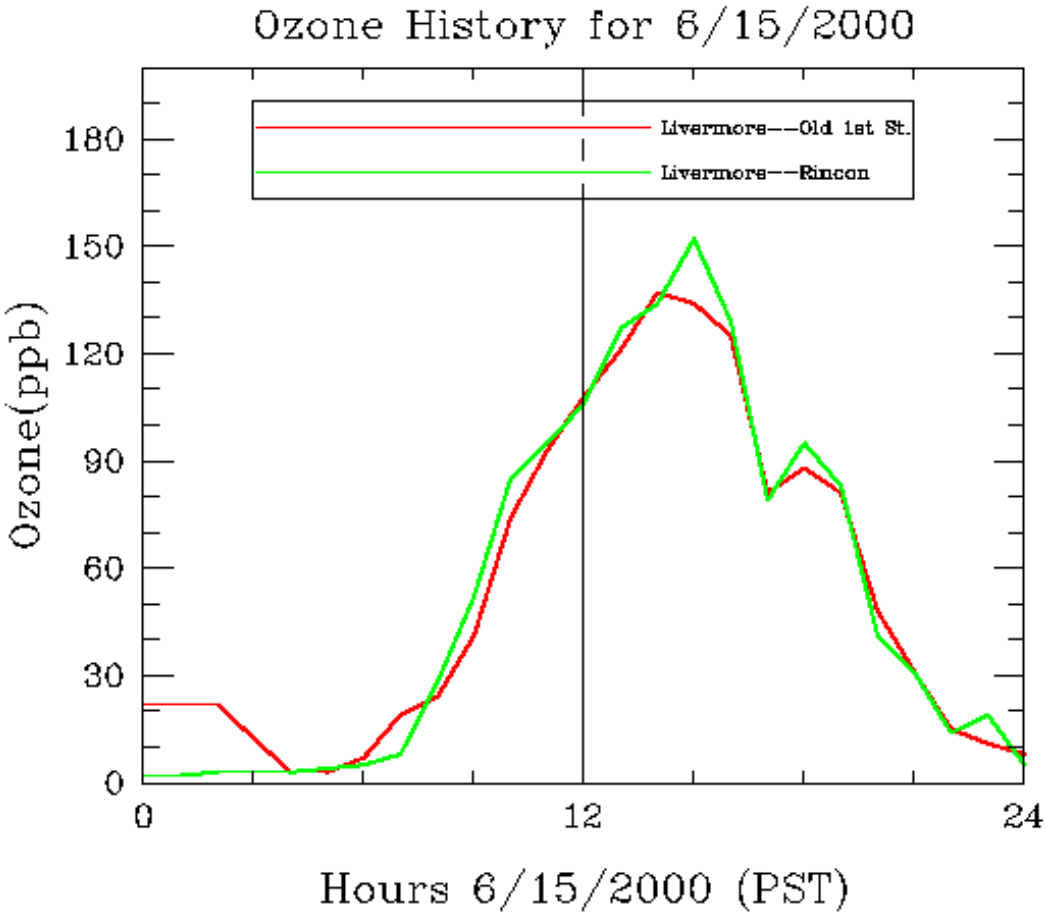



**Figure 2-33.** Ozone time series at the two SFB stations with the highest ozone observations during 6/15/2000.

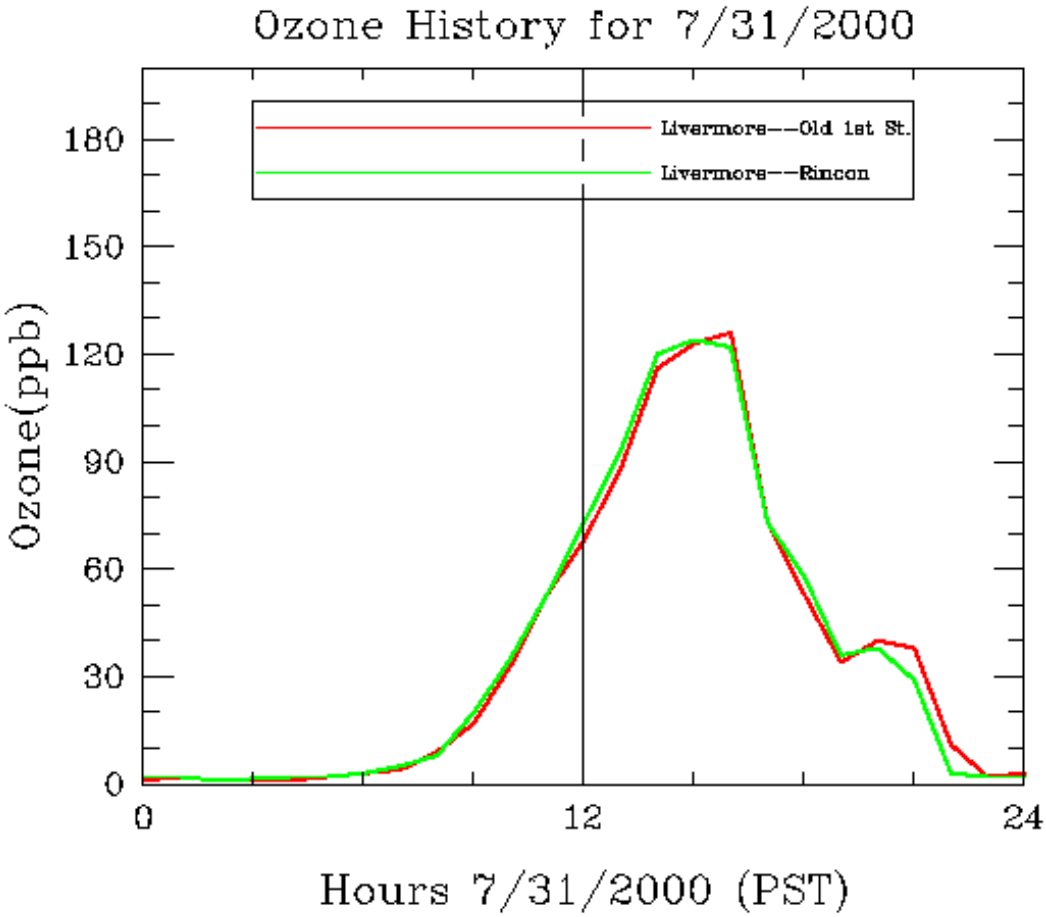



**Figure 2-34.** Ozone time series at the two SFB stations with the highest ozone observations during 7/31/2000.

**Summary of Meteorology**

Lehrman et al. (2001) describe the CCOS meteorological conditions and their relationship to ozone values:

"The relationship between the dispersion of ozone and ozone precursors in California and large-scale synoptic weather patterns is well known. During the summer ozone season, the extension of the eastern Pacific high over the western US effectively blocks the influx of cyclonic weather systems into California from the Gulf of Alaska, and allows the entrenchment of large static air masses which are typically warm, stable, and poorly mixed. The strength and persistence of the resultant boundary layer mixing and transport patterns affects the magnitude and duration of ozone events in Central California. High-pressure ridges and low-pressure troughs in the mid to upper atmosphere are particularly efficient indicators of ozone formation conditions. ... Two synoptic scale meteorological parameters, which historically have correlated well with ozone formation and fate in California, are the height of the 500 mb surface and the temperature at the 850 mb level. The time history of 500 mb heights at a fixed location is a general indicator of the behavior of the 500 mb surface indicating pressure ridges and troughs. The 850 mb temperature

is a measure of large-scale subsidence, which produces stable layers in the atmosphere and limits vertical dispersion of ozone and precursors."

Figures 2-35 and 2-36 show the variation of the 850 mb temperature and 500 mb heights at Oakland for the 1999 ozone season from 6/1/1999 to 9/30/1999. The 500 mb height at the beginning of the season dipped to as low as 5470 m on 6/3/1999. It increased rapidly and varied over a much narrower range over the entire ozone season afterwards. The few days leading to 7/11/1999 were characterized by the gradual building of the 500 mb heights from 5760 m on 7/4/1999 to a high of 5950 m on 7/10/1999. The 500 mb heights stayed at 5940 for 7/11-12/1999 and there were closed height contours over Northern California over this two-day period. The building of the 500 mb height can be easily seen on the weather maps (not shown), where the 5880 contour line moved from Central California to Washington State during this period of time. The 850 mb temperature increased from 9.6 $^{o}$C on 7/4/1999 to a high of 27.2 $^{o}$C on 7/12/1999 during the building of the 500 mb height. The peak 850 mb temperature was reached two days after the peak 500 mb height and this can be easily explained by the continued warming from the downward motion in a high pressure area. The highest surface temperature reached 113$^{o}$F on 7/11/1999 and 115$^{o}$F on 7/12/1999, both at Redding. The highest temperature in the San Joaquin Valley was 106$^{o}$F at Fresno for both days.

Figures 2-37 and 2-38 show the variation of the 850 mb temperature and 500 mb heights at Oakland for the 2000 ozone season from 6/1/2000 to 9/30/2000. The peak 500 mb height and the peak 850 mb temperature correlated well with the high SFBA ozone observations during this season. Lehrman et al. (2001) describe the synoptic conditions leading up to 6/15/2000:

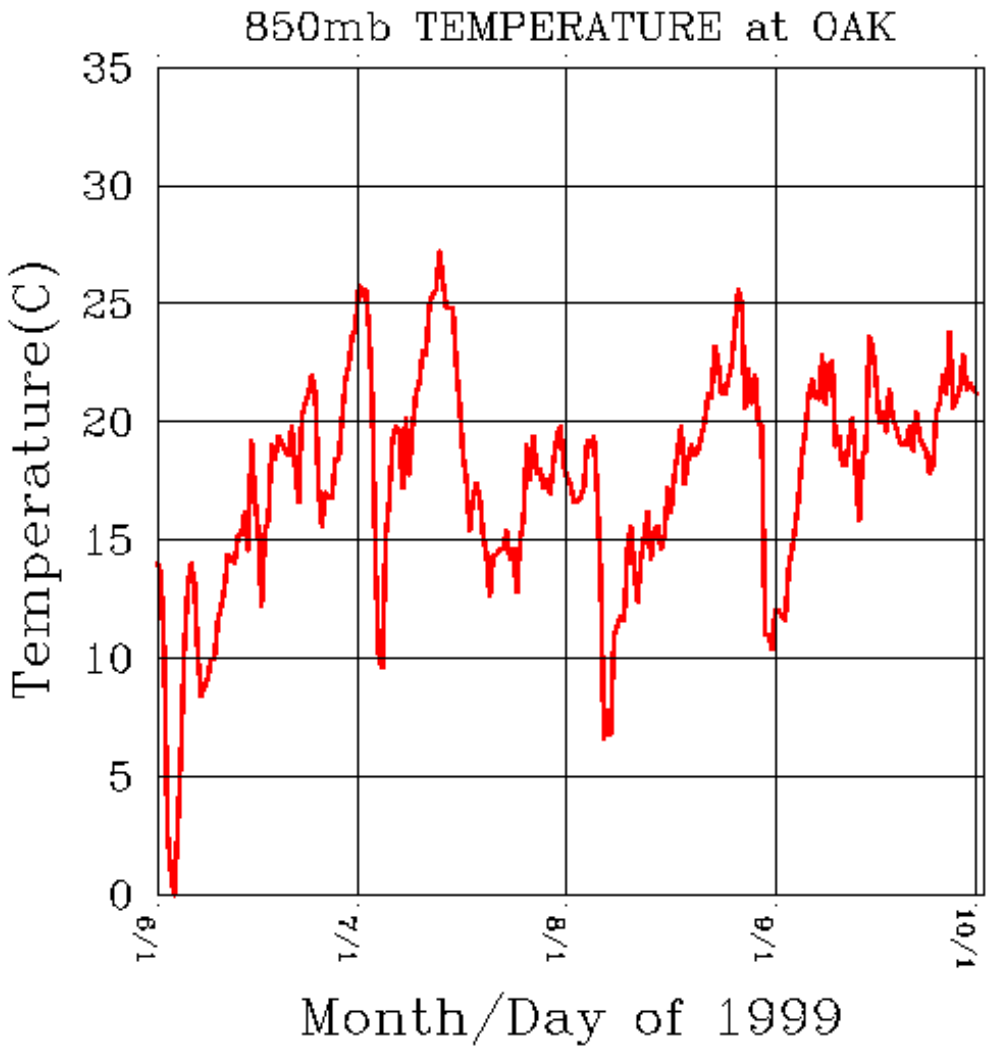



**Figure 2-35.** 850 mb temperatures at Oakland from 6/1/1999 to 10/1/1999.

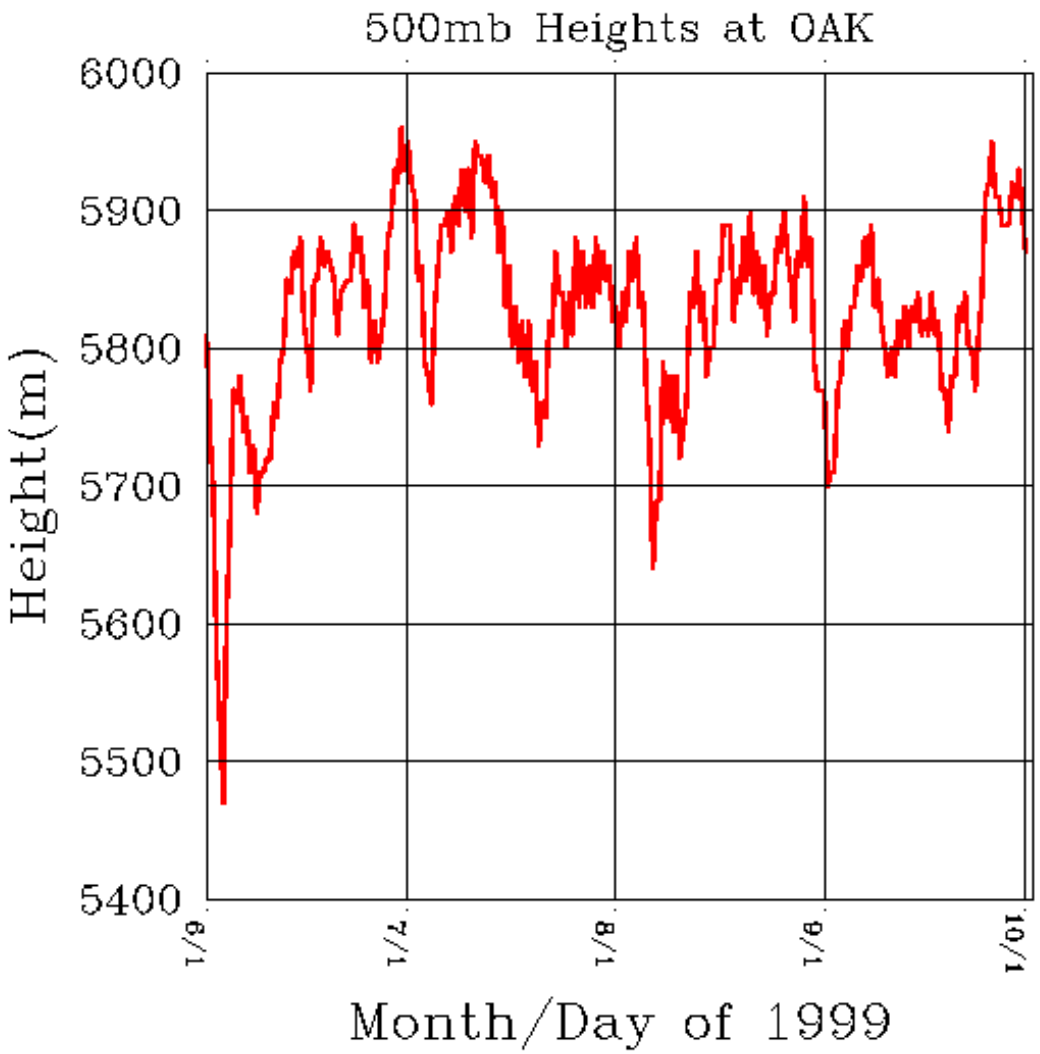



**Figure 2-36.** 500 mb heights at Oakland from 6/1/1999 to 10/1/1999.

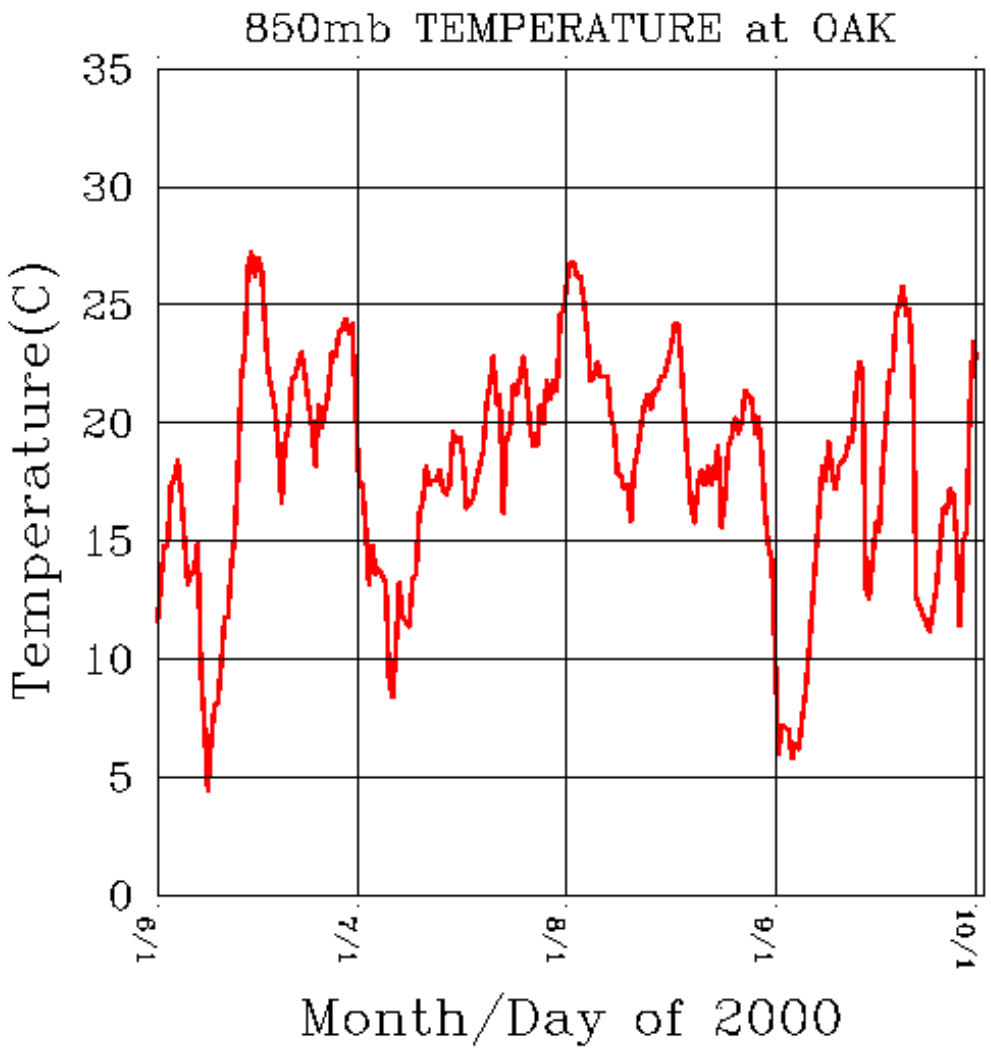



**Figure 2-37.** 850mb temperatures at Oakland from 6/1/2000 to 10/1/2000.

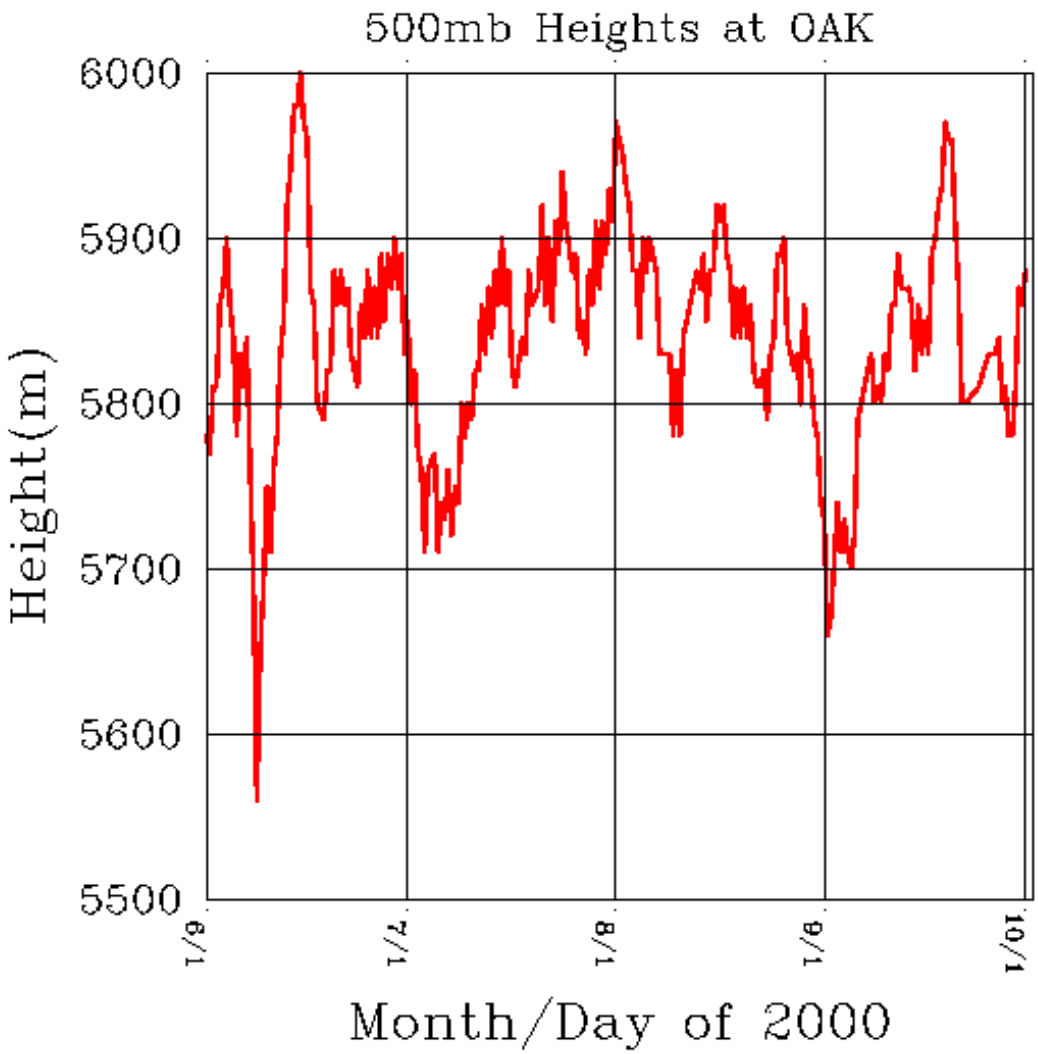



**Figure 2-38.** 500 mb heights at Oakland from 6/1/2000 to 10/1/2000.

"The OAK (Oakland) 500 mb height had increased from a low of 5,650 m on June 8 to a maximum of 6,000 m on June 14. During that same period, the OAK 850 mb temperature increased from 7°C on June 8 to a high of 27°C on June 14. As the ridge progressed towards the east-southeast, flow aloft remained from the north throughout the period. This slowly encouraged the onset of offshore flow across the project area during that time. Ozone concentrations increased steadily as the ridge approached with peak ozone values in excess of the Federal and State Standards..."

They also describe conditions for the 7/31/2000 episode:

"By July 25, the ridge had weakened slightly and dropped southeastward into eastern New Mexico and a trough developed along the West Coast from Point Conception to British Columbia. This resulted in the lowering of 500 mb heights and 850 mb temperatures somewhat during July 25 and 26. However, on the 27th, the high-pressure ridge once again regressed

towards the west and strengthened somewhat to become centered once again in the Four Corners area. With this regression of the ridge, the 850 mb temperature and 500 mb heights at OAK once again rose during that period and continued to rise through July 30 ... During the IOP of July 30 through August 2, the ridge remained strong and continued to slowly regress towards the west until it was centered near Reno, Nevada by July 31. The OAK 850 mb temperature during the IOP reached as high as 27$^{o}$C and the 500 mb height topped at 5,970 m ... Elevated ozone concentrations persisted in the project area for several days after the IOP, which ended on August 2."

## DATABASES FOR THE EPISODES

### Data for the 1999 Episode

Data to support the modeling and analysis of the 1999 episode was taken from routine sources. During summer 1999, the CARB and the districts operated over 150 surface-based air quality monitoring stations throughout northern and central California. Many of these sites routinely measured $O_3$, $NO_x$, CO and hydrocarbons. Existing PM10 measurements acquired filter samples every sixth day. A few of the PM10 sites had continuous monitors that measured hourly PM10 everyday. A few routine PM2.5 measurements sites were also in operation. Districts in the Sacramento and San Joaquin Valleys are required to routinely operate photochemical assessment monitoring stations (PAMS) as part of their State Implementation Plans. Each PAMS station measures speciated hydrocarbons and carbonyl compounds, $O_3$, $NO_x$, and surface meteorological data. Additionally, each area must monitor upper-air meteorology at one representative site.

An extensive but uncoordinated network of surface meteorological monitoring sites is routinely operated by the CARB, BAAQMD, SJVAPCD, SMAQMD, the National Weather Service (NWS), the California Irrigation Management Information Service (CIMIS), Remote Automated Weather Stations (RAWS), and a few additional agencies. Wind speed and direction, temperature, and humidity are the most common measurements. Surface pressure and solar radiation measurements are also common. A few sites measured ultraviolet radiation in the Sacramento and San Joaquin Valleys, and in Santa Barbara County.

The CARB operated two profilers (with RASS) in the San Joaquin Valley, and the San Joaquin Unified APCD and Sacramento Metropolitan AQMD operate one profiler/RASS each as part of their PAMS monitoring program. The SJVAPCD also operated a profiler at Tracy during the 2000 CCOS. Military facilities with operational profilers include Travis AFB, Vandenberg AFB, and the Naval Post Graduate School in Monterey. Radiosonde measurements of winds, temperatures, and humidity aloft are routinely made twice per day at Oakland and, according to military base requirements, at Vandenberg, Edwards, and Pt. Mugu.

Finally, polar-orbiting and geostationary satellites collected an enormous amount of radiometric data that yield useful products, including the total ozone column, cloud cover, sea surface temperature, vegetative cover, and surface albedo throughout California.

Review of the CARB 1999 Meteorological Dataset

The CARB downloaded all available meteorological data for the July 1999 ozone episode from the California Irrigation Management Information System (CIMIS), the Remote Automated Weather Stations (RAWS), the Aerometric Information Retrieval System (AIRS), the Bay Area Air Quality Management District (BAAQMD), the National Weather Service (NWS), the Federal Aviation Administration (FAA), and the National Buoy Data Center. The CARB processed data from these sources having one single file with common format and units.

The BAAQMD downloaded the CARB-processed meteorological data file as well as the original files from ARB. It was immediately apparent that some problems existed with the CARB-processed data. In order to ensure that the data were reliable for the intended use, a systematic check of all the processed data was carried out. Time series plots of wind speed, direction, and temperature were created and evaluated for each station. Station locations were plotted on a terrain map of California. Station coordinates in the site list file were compared with the best available data. The processed data were also compared with the original data for time conversion to Pacific Standard Time (PST), unit conversions to metric values, and missing or zero-values. Corrections and additions to the ARB-processed data resulted in a new BAAQMD-processed file.

A significant number of corrections were made to the ARB-processed file in creating the BAAQMD-processed file as detailed below.

- To the extent possible, site latitudes and longitudes were checked against the Central California Ozone Study (CCOS) site list and with coordinates listed on official web sites for the CIMIS, RAWS, NWS, FAA, and buoy networks. A crosscheck with street address coordinates was also conducted. One hundred twenty five stations were inaccurate by a kilometer or more. One RAWS station (r118) was off by 869 km. Site coordinates that were more than 0.5 km from trusted values were changed to reflect the more accurate locations. Coordinates for a total of 184 stations were adjusted. Four stations with no coordinates in the CARB dataset were removed.
- The processed data were checked for proper conversion from Coordinated Universal Time (UTC) to PST and the consistent use of hour beginning for the averaging hour. The CARB-processed buoy data were in UTC. All buoy data were converted to PST.
- A significant amount of zero values in the CARB-processed file were actually missing data. Most of these errors were found in the RAWS stations. Incorrectly coded zero data were replaced with a missing data flag (–99.0).
- A filter was applied setting wind speeds greater than 20 m/s to missing. The more than thirty RAWS stations that reported sudden extreme increases in wind speeds for a single hour or a few consecutive hours prompted this. High wind speed values ranged from 21.4 to 57.2 m/s.
- A large number of stations reported sudden large wind speed drops to 0.0 m/s for a single hour. An empirical filter was applied to wind speeds, replacing zero values with -99.0 when speeds before and after the calm hour were greater than 2.0 m/s.
- Stations with either long periods of constant wind speed, wind direction, or temperature or many shorter periods of constant data were removed from the data set or had the constant values set to –99.0. One AIRS station exhibited a constant temperature curve that appeared to be from an indoor temperature probe.

- Processed CIMIS data had many hours of missing temperature on July 11 and 12. Also, all temperature data were 0.07 °C higher than reported on the CIMIS web site. In the CIMIS database, temperature data were flagged for being far out of historical range (rise or drop greater than 10 °C; outside the 99.8% confidence interval), for being moderately out of historical range (outside the 96% confidence interval), and for constant values (>4 hours). The CARB-processed data had all flagged data removed. The flagged raw CIMIS data were compared to nearby stations within the data set to determine if these data warranted being deleted in the processed file. The flagged data seemed reasonable and comparable to nearby non-CIMIS stations. It appears that some of the flags were inappropriate or in error. All raw data were reprocessed ignoring the flags. The 0.07 increases in temperature were corrected.
- Though not an error, only eleven NWS/FAA stations were included in the ARB-processed data. Raw NWS and FAA data were downloaded from the National Center for Atmospheric Research (NCAR) website. Seventy-one sites were identified within the modeling domain. The new data were quality assured and stations with bad or questionable data were removed from the BAAQMD-processed file. The existing data from the eleven stations original stations were replaced with the new data for consistency. Station call signs were used as site IDs.
- Stations with sudden large changes in temperature for short periods had those hours set to –99.0. The majority of these occurrences were at RAWS stations. The absolute maximum magnitude of these temperature changes was 15 °C.
- Redundant data were removed. One AIRS station was removed after it was discovered to have the same data as another AIRS station that was thirty meters away.

A final visual check via time series plots was made on the new BAAQMD-processed data set. The BAAQMD file is larger than the ARB data set due to the addition of newly processed NWS and FAA sites.

**Data for the 2000 Episodes**

Two of the 2000 episodes identified as candidates for this study occurred during the Central California Ozone Study (CCOS). Most of the data that used for air quality modeling and analysis – for generating model inputs, for model evaluation, and for corroborative studies – were therefore derived from the CCOS database. During CCOS, when high ozone episodes were forecast, an intensive operation period (IOP) was launched and additional special field study data were collected. The 7/31/2000 episode occurred within an IOP and therefore benefits from many special field-study observations. However, the 6/15/2000 episode occurred before most of the special study data from CCOS were being gathered, so this episode relied primarily on routine data within the CCOS database.

The CCOS data were archived and made available by the CARB. However, much of the data had not undergone a complete quality assurance analysis by the start of this project and, as such, required that they be analyzed as they were used.

This section provides a brief overview of the CCOS study and its database. The data available during both of the episode periods, both IOP and non-IOP, are described. A few additional data

sources will also be used for producing and evaluating modeling inputs. These sources are identified and briefly described in this section as well.

CCOS Field Study

The CCOS was a large-scale field program involving many sponsors and participants with a research budget of over $8 million for the summer 2000 field measurement campaign. In addition, the CARB and local Air Quality Management Districts (AQMDs) provided substantial in-kind contributions during the measurement campaign. The CARB was responsible on a day-to-day basis for management of the study.

The CCOS field measurement program covered a domain over much of northern California, extending north of Redding, and all of central California, including the San Francisco Bay Area and the San Joaquin Valley. A summary report on the CCOS field operations has been completed (DRI, 2001) and is available online: http://www.arb.ca.gov/airways/ccos/docs/ccosv3fdS0.zip. For background information, this section provides a brief overview of the data collected during CCOS. For more details, the reader should consult the summary report.

Study Period

The **primary study period** for CCOS extended from 7/6/2000 to 9/30/2000. During that period, continuous surface and upper-air meteorological measurements and surface air-quality measurements were made for ozone ($O_3$), nitric oxide (NO), oxides of nitrogen ($NO_x$), reactive oxidized nitrogen ($NO^*_y$), nitrogen dioxide ($NO_2$), peroxyacetylnitrate (PAN) and other peroxyacetylnitrates, particulate nitrate ($NO_3^-$), formaldehyde (HCHO), and speciated volatile organic compounds (VOC) from automated gas chromatography with ion-trap mass spectrometers (three research sites). At regular intervals, speciated VOC were also available during the primary study period from PAMS.

During the **intensive operation periods** (IOPs), additional measurements were collected including instrumented aircraft measurements, speciated VOC at more locations, and radiosonde and ozonesonde measurements. During the month of August only, an ozone LIDAR was deployed at Livermore, measuring vertical ozone profiles from 50 m to 2000 m with a 200 m-range resolution.

Routine Data

The routine data available during summer 1999 were also available during summer 2000. The data for 2000 were incorporated into the Central California Air Quality Study CCAQS database.

Field Study Data

The CCOS field measurement program consisted of four categories of surface measurement sites: “supplemental” (S) sites consisting of Type 0, 1, and 2 sites; and “research” (R) sites. The

measurements made at each type of supplemental monitoring site are tabulated below. One of the S1 sites was a mobile van operated in the vicinity of Livermore. The carbonyl measurements and the speciated HC measurements at all but the research sites were only collected during the IOPs.

- **Type S0 Sites:**
  - $O_3$, NO, $NO_y$
  - wind speed, wind direction
  - temperature, and relative humidity

- **Type S1 Sites:**
  - S0 measurements, plus CO, $CO_2$, speciated HC, carbonyls

- **Type S2 Sites:**
  - S1 measurements, plus $NO_2$, PAN

- **Research Sites (3):**
  - S2 measurements, CO, $CO_2$, $NO_y^*$, particulate nitrate,
  - light absorption, scattering, actinic flux

Six profilers with RASS were installed and operated during summer 2000 as part of the Central Regional Particulate Air Quality Study (CRPAQS). In addition, nine profilers with RASS and 5 sodars were installed for the CCOS summer 2000 field study. Another sodar was located in the vicinity of the Pittsburgh power plant stacks. During IOPs only, radiosondes and ozonesondes, one in the Sacramento Valley and one in the San Joaquin Valley, were deployed six times per day.

Four instrumented aircraft were used to measure the vertical and horizontal gradients of temperature, humidity, and pollutant concentrations in the study region during CCOS IOPs. These aircraft included a Cessna 172RG and a Cessna 182 operated by University of California, Davis (UCD), and a Cessna 182 and Piper Aztec operated by Sonoma Technology, Inc. (STI). One additional aircraft (Twin Otter), flown by the Tennessee Valley Authority (TVA), made measurements in power plant plumes. The TVA data were collected to evaluate the plume-in-grid parameterizations used in air quality models.

Supplemental Data

A number of supplemental data sources exist that may be useful to this study. For example, an on-road vehicle remote sensing special measurement study was conducted by CARB and coordinated with the CCOS study; the CARB also contracted UC Davis to conduct a vehicle traffic count study; and Districts supplied day-specific plant schedules and pollutant profiles, when and where available. Such data were used in the CCOS effort for checking the modeling emissions inventory estimates.

Other data sources were independent of CCOS and mostly the result of routine data collection and analysis efforts. These included synoptic-scale meteorological analysis products and satellite data from multiple platforms and sensors. The meteorological analysis products were used as inputs to the meteorological model; the satellite data yield products that provided inputs

to both the meteorological model and the photochemical model. The meteorological model requires surface vegetation amounts, and sea surface temperature; the photochemical model requires total ozone column and surface albedo. These inputs can be derived from satellite data products and/or standard information from the U.S. Geological Survey.

## CCOS 2000 FIELD STUDY DATA QA/QC AND PRELIMINARY ANALYSIS

### Surface-Based Measurements

Meteorological Data

The BAAQMD performed some QA/QC screening of the CCOS 2000 meteorological data surface wind, temperature, humidity data and the upper-air wind profiler and RASS data. This screening was not comprehensive, but performed as part of our qualitative comparisons of these data with both the RAMS and the MM5 meteorological fields. To assist with the surface data evaluations, the BAAQMD completed a web-based plotting program. The RASS and profiler evaluation was work undertaken in coordination with NOAA.

During this screening, we discovered that surface temperatures in the Monterey Bay Area were consistently too high. Closer examination of these temperature data revealed that there had been a processing error in converting from degrees Fahrenheit to Celsius. In addition, we found that the site location coordinates were incorrect for some of the surface stations. To fix these site-location problems, we reviewed all site coordinates and checked them against maps and site descriptions obtained from site operators. Both the temperature data and the site-location corrections were relayed to CARB. According to verbal communications with database manager Greg O'Brien at CARB, these corrections were incorporated into the official CCOS database.

Air Quality Data

The carbonyl measurements initially could not be extracted from the CCOS database as a group, nor were they included with the NMHC data. Greg O'Brien manually extracted the carbonyl measurements for us. Since then, a new "group" was added to the database that allows the carbonyl measurements to be extracted without specifying each species individually.

For all NMOC data, species names in the database were matched to species chemical names and CAS numbers. From these, molecular weight and carbon numbers were determined. Where we were uncertain, we consulted the database search utility at ChemFinder.com. Using molecular weights and carbon numbers, all species were converted to ppbC from either micrograms per cubic meter or from ppb. For developing model inputs and comparison to model output, the NMOC data were also converted to CBIV and SAPRC99 mechanism surrogates.

**Aircraft Measurements**

For the purpose of assisting in the development of boundary conditions for the photochemical modeling, the BAAQMD examined the far-offshore aircraft measurements of ozone, NO, NOy, and NMOC. Flights that collected pollutant data far offshore included 4 morning flights of the Sonoma Technologies Inc. (STI) Aztec aircraft and 1 afternoon flight of the Pacific Northwest National Laboratories (PNNL) G-1 aircraft (see Table 2-8). Our initial review of the aircraft data retrieved from the CCOS database revealed that some fights were missing height coordinate data and that the PNNL flight was missing NMOC data. All missing data were obtained from the appropriate contractors. We alerted Greg O'Brien to the problems and subsequent discussions have indicated that these omissions have been corrected in the CCOS database.

Aircraft pollutant data from all far-offshore flights were plotted from different perspectives to afford varying views, including plan and elevation views to help assess pollutant loading near the boundaries of the CCOS modeling domain. Plots derived from the aircraft pollutant measurements are shown in Figures 2-39 through2-46.

**Table 2-8.** Dates and times of offshore aircraft measurements used to estimate boundary conditions for photochemical modeling.

| Date | Aircraft | Start Time (PST) | End Time (PST) |
|---|---|---|---|
| July 8, 2000 | STI Aztec | 8:23 | 11:36 |
| July 8, 2000 | PNNL G1 | 12:54 | 17:12 |
| July 23, 2000 | STI Aztec | 6:46 | 10:57 |
| July 30, 2000 | STI Aztec | 4:59 | 9:02 |
| September 17, 2000 | STI Aztec | 4:56 | 9:11 |

Plots of flight paths immediately revealed that there were no data to assess pollutant levels along either the northern or the eastern boundary. Furthermore, the data showed a high level of variability in pollutant levels between the flights, which was somewhat surprising considering that we were examining only the offshore flights. Because of this variability, we decided to use all the data and try to derive average pollutant values at the levels where observations were collected. Even following this approach, it was still difficult to generate pollutant levels along the entire western and southern boundaries because of the sparsity of the data. In the end, we decided to use the data as a guide to update the boundary conditions used for the 1990 SARMAP modeling (DaMassa et al, 1990). Some vertical variability was derived from the ozone data; for the other pollutants, the data were used to determine representative values in approximately the first 1500 meters above sea level.

Figure 2-39 shows a plan view of ozone from all far-offshore flights. The plotted trace that extends furthest to the north and west is that for the afternoon PNNL flight. The dashed lines in Figure 2-39 mark the cutoff for data used for setting the boundary conditions. Note that no data were available that could be used specifically for determining the northern pollutant boundary conditions. Figure 2-40 plots a plan view of data west of the diagonal dashed line in Figure 2-39. Figure 2-40 shows the great variability between flights. Ozone levels range from about 20 to about 70 ppb. Much of the variability appears to be temporal, that is, due to the difference in flight dates. There were significant differences in the offshore cloud decks on the different days. But even given this variability, there does seem to be a tendency for lower ozone nearer the sea surface.

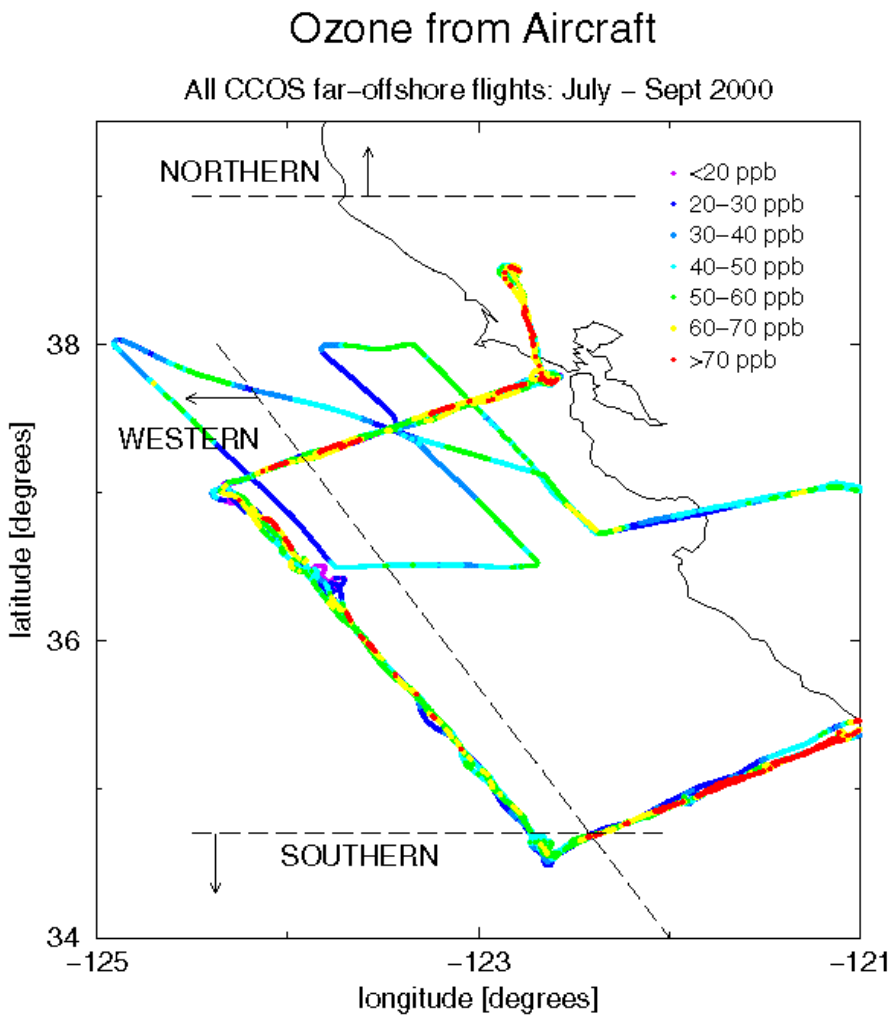



**Figure 2-39.** Plan view of ozone measurements from aircraft during July through September 2000. Dashed lines show the cutoff for data considered for setting the western and southern boundary conditions.

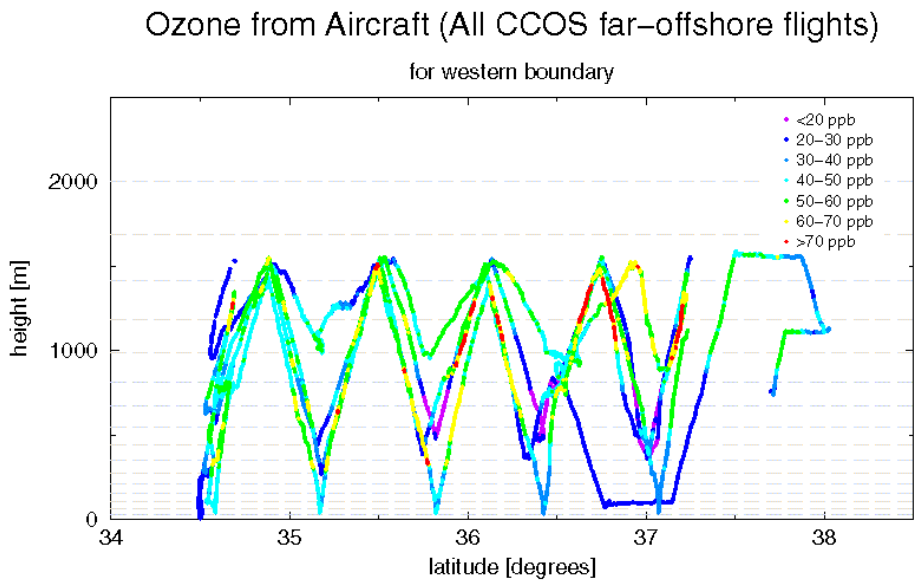



**Figure 2-40.** Elevation view (looking west) of all far-offshore ozone measurements sampled from aircraft during July through September 2000.

Plots similar to those for ozone were also generated for NOy (Figures 3-4) and NO (Figures 5-6). NOy data ranged from about 0.5 ppb to about 2 ppb. Even more variability between the different flights was found for the NOy data than for the ozone data. The NO data ranged from near zero to about 0.2 ppb. Many of the aircraft NO observations were near zero, but mixed in with these were relatively high values, suggesting that for some of these flights, NO may have been near the instrument detection limits.

The NMOC data (Figures 7 and 8) were speciated to the CB-IV chemical mechanism for plotting and analysis. These data, like the inorganic data, showed large variations among the different sampling times and locations. The large variability and sparsity of the data made it difficult to discern useful spatial relationships; instead, the median values among the samples were used to define representative values.

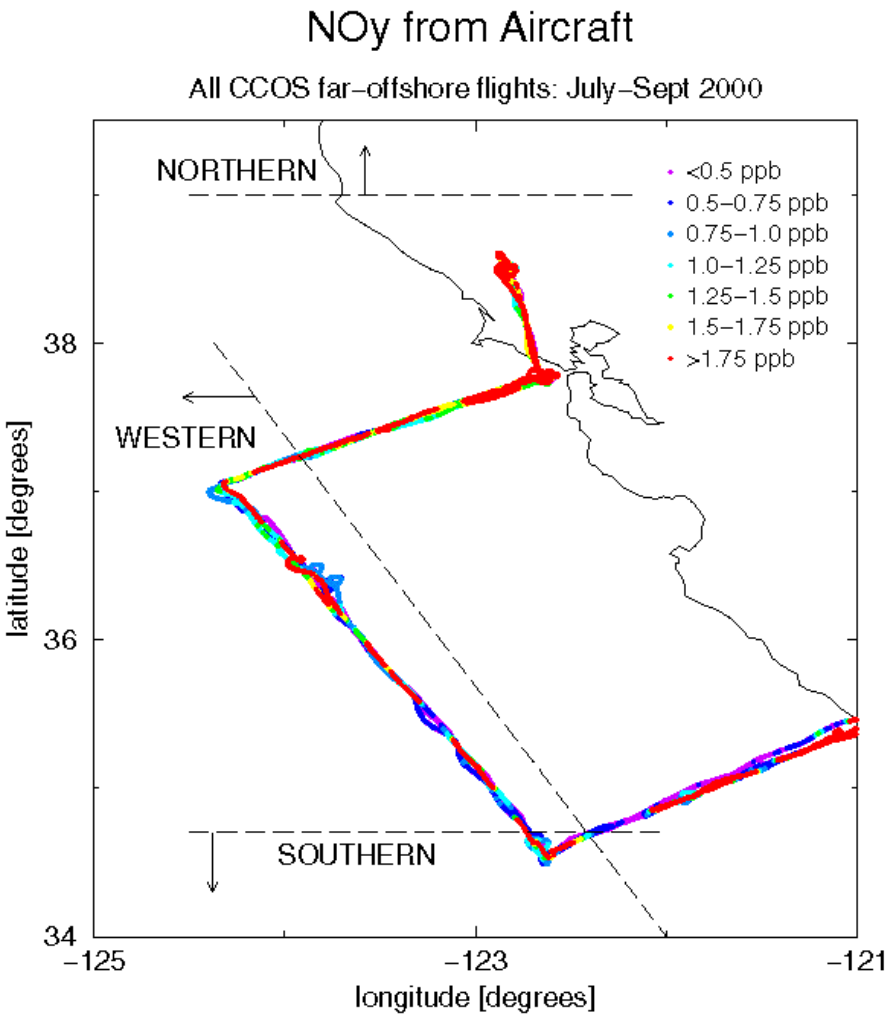



**Figure 2-41.** Plan view of NOy measurements from aircraft during July through September 2000. Dashed lines show the cutoff for data considered for setting the western and southern boundary conditions.

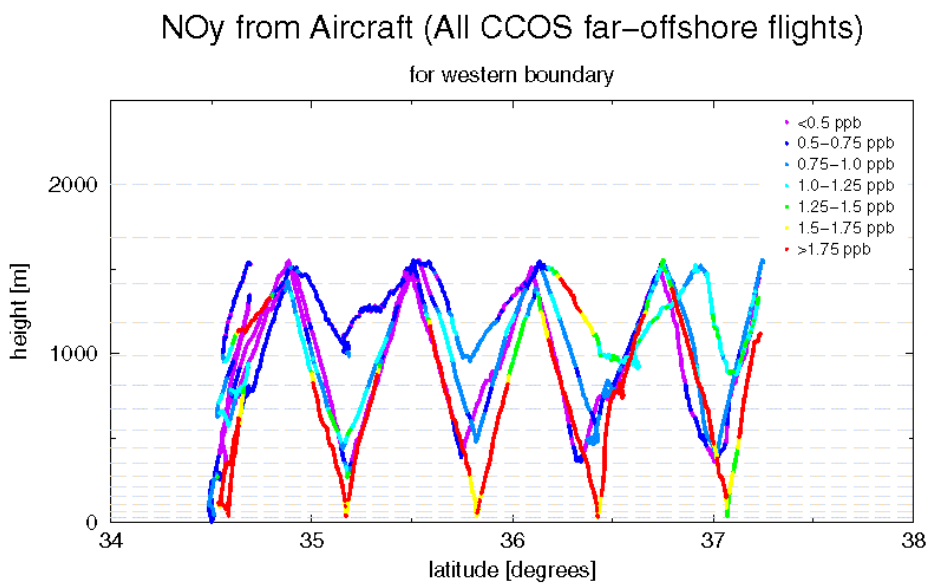



**Figure 2-42.** Elevation view (looking west) of all far-offshore NOy measurements sampled from aircraft during July through September 2000.

Table 2-9 shows the estimates derived for the CCOS 2000 far-offshore aircraft measurements and compares these with the SARMAP estimates. Major findings were that the CCOS flights suggested lower values than the SARMAP values for ozone along the western boundary, both near the surface (within the first few 100 meters) and at elevations of 1000 m. The CCOS values near the surface were about 25 ppb and about 50 ppb aloft, compared to 40 ppb and 70 ppb for the respective SARMAP estimates. The CCOS aircraft observations also suggested lower NO values than what was used for CCOS. We determined that 0.05 ppb was a representative value for NO compared to 0.5 from CCOS. NO2 was estimated by assuming that most of the NOy after subtracting off the NO was NO2. By this estimate, NO2 values were about half of the SARMAP values: 1 ppb for CCOS versus 2.5 ppb for SARMAP. NMHC values were found to be in approximate agreement with the SARMAP values. There were some important differences in the aldehyde estimates however. We found that a representative value for total aldehydes was about 7 ppb, which was consistent with the SARMAP values. The difference was that the CCOS measurements suggested a lower value for formaldehyde (2 ppb from CCOS versus almost 6 ppb from SARMAP) and a lower value for C2 and greater aldehydes (5 ppb from CCOS versus almost 2 ppb from SARMAP).

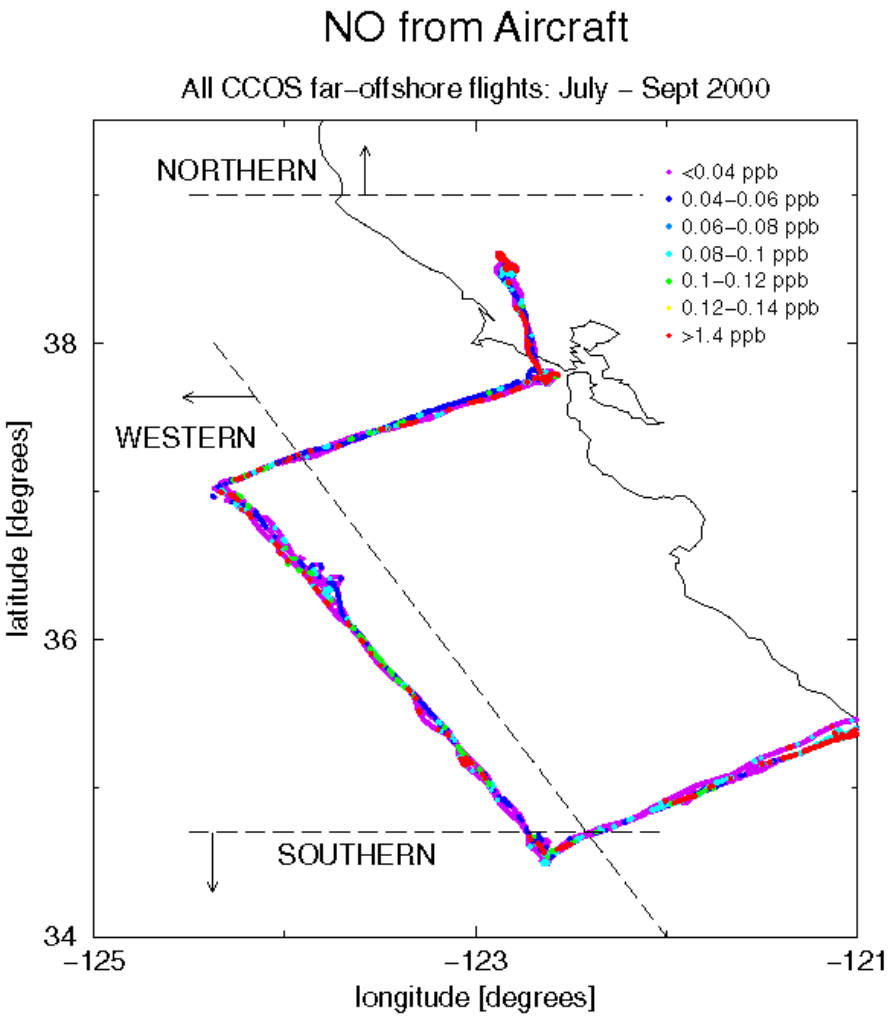



**Figure 2-43.** Plan view of NO measurements from aircraft during July through September 2000. Dashed lines show the cutoff for data considered for setting the western and southern boundary conditions.

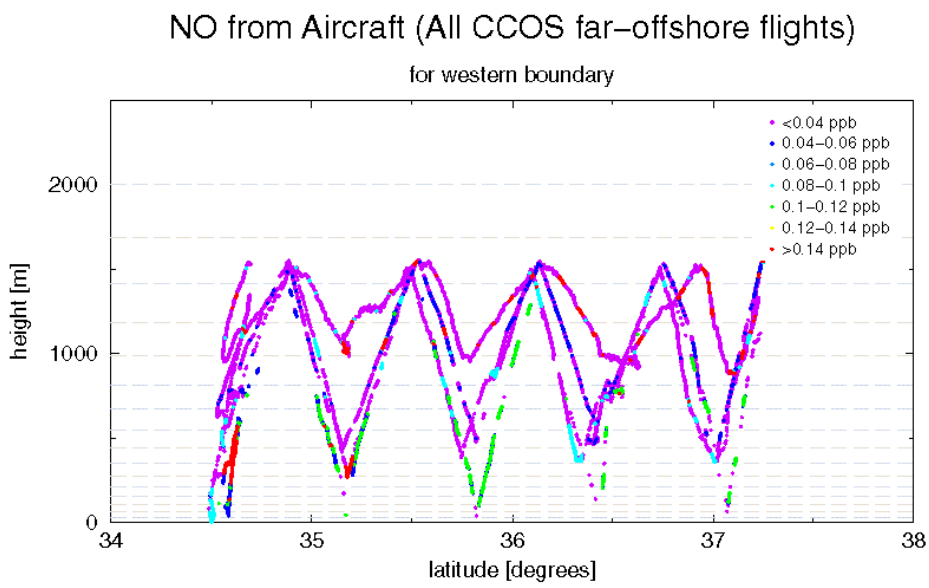



**Figure 2-44.** Elevation view (looking west) of all far-offshore NO measurements sampled from aircraft during July through September 2000.

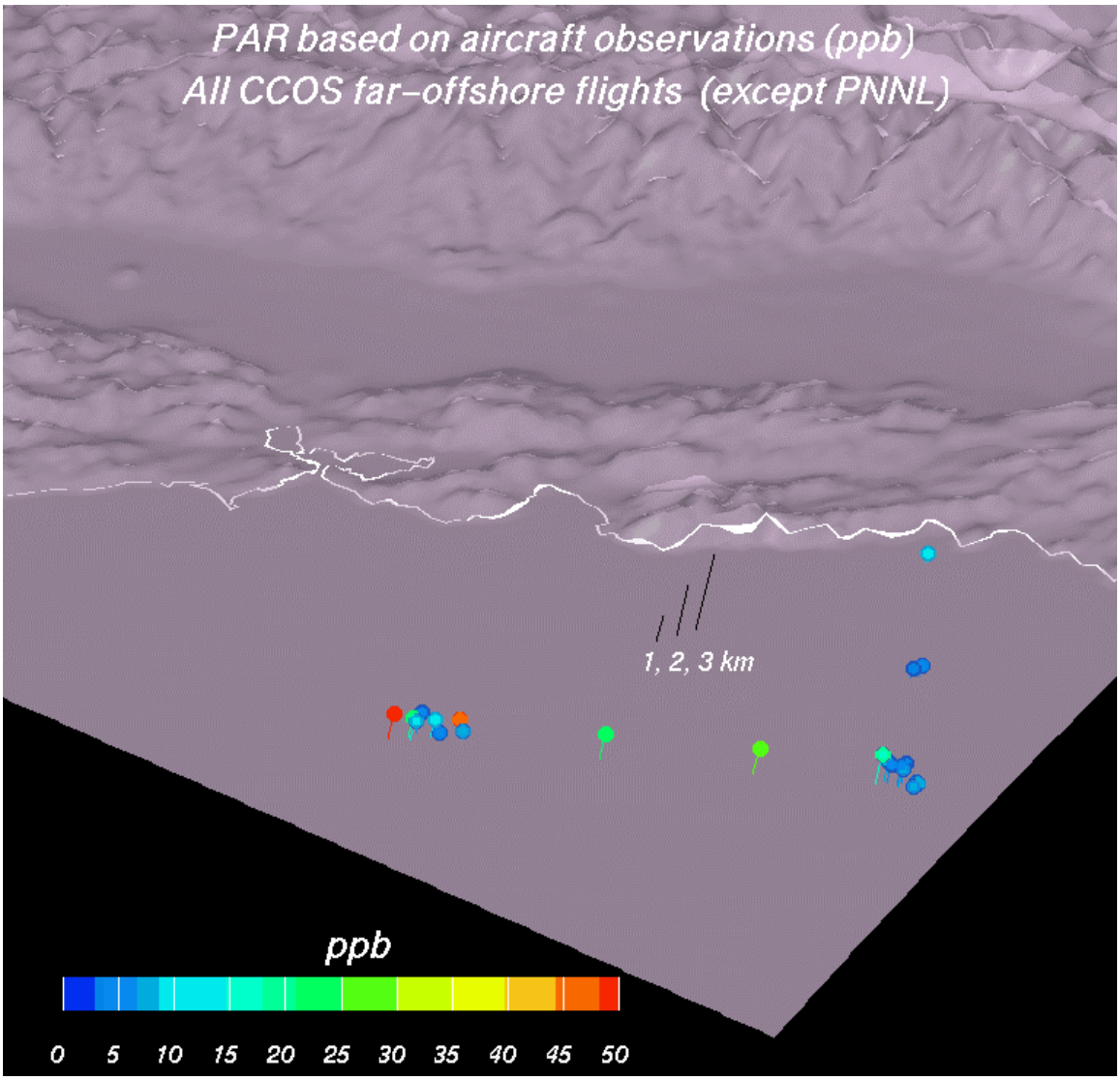



**Figure 2-45.** Oblique 3-D view of the paraffinic-bond (PAR) component of NMOC measurements from aircraft during July through September 2000. Black vertical lines show 1, 2, and 3 km heights for reference.

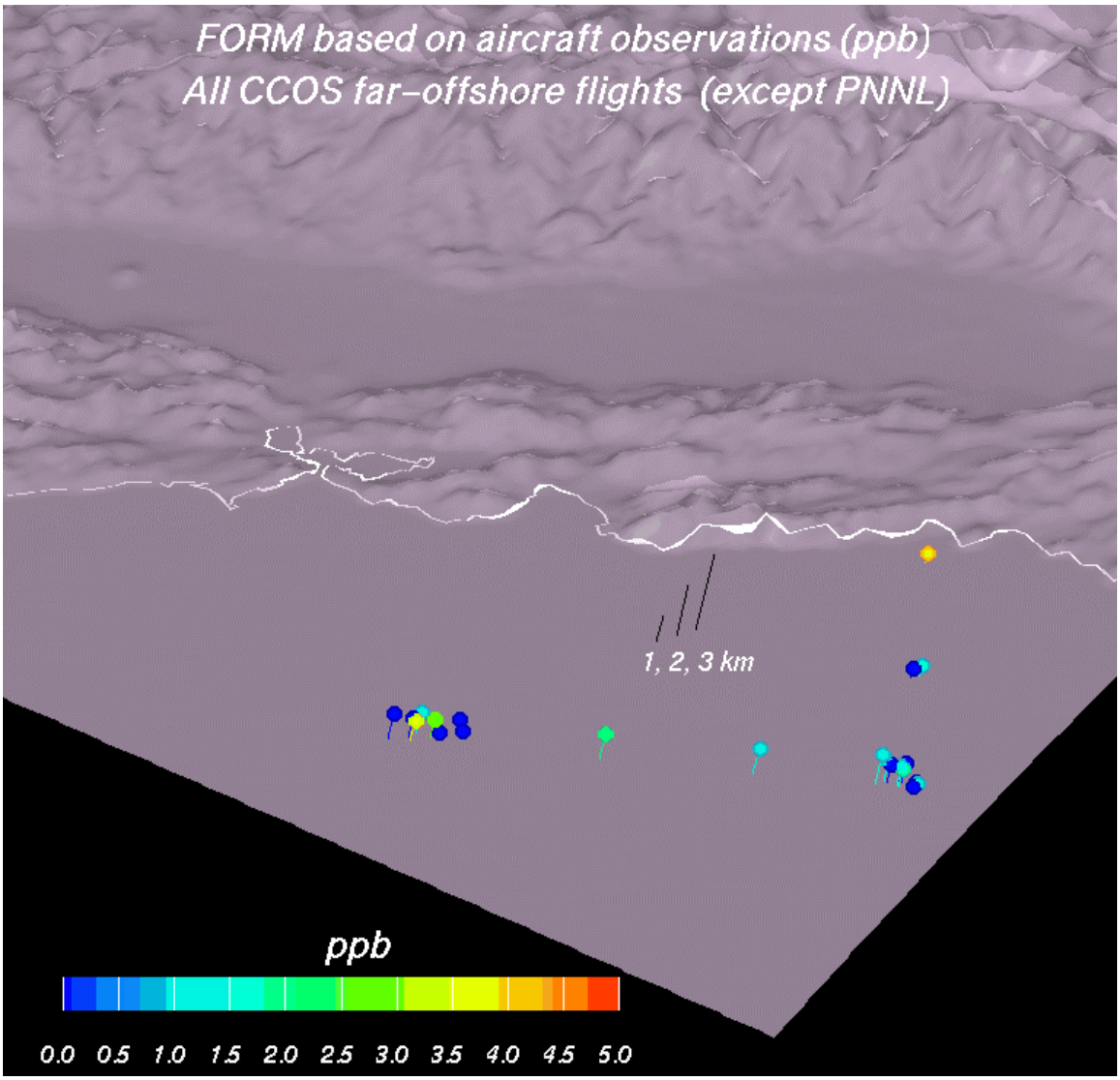



**Figure 2-46.** Oblique 3-D view of the formaldehyde (FORM) component of NMOC measurements from aircraft during July through September 2000. Black vertical lines show 1, 2, and 3 km heights for reference.

**Table 2-9.** Carbon-Bond IV mechanism representation of western boundary condition.

| Species | CCOS obs* (ppb) | SARMAP Based** (ppb) |
|---|---|---|
| O3 (@100m) | 25 | 40 |
| O3 (@1000m) | 50 | 70 |
| NO | 0.05 | 0.5 |
| NO2 | 1 | 2.5 |
| PAR | 20 | 20.5 |
| MEOH | 3 | - |
| ETOH | 1 | - |
| TOL | 0.1 | 0.246 |
| XYL | 0.05 | 0.135 |
| ETH | 0.5 | 0.702 |
| OLE | 0.5 | 0.414 |
| ISOP | 0.05 | 0.05 |
| FORM | 2 | 5.78 |
| ALD2 | 5 | 1.52 |

* Considers CCOS 2000 and SARMAP 1990 aircraft observations.
** Used for SARMAP modeling.