Sonoma Technology, Inc.
1360 Redwood Way, Suite C
Petaluma, CA 94954-1169
707/665-9900
FAX 707/665-9800
www.sonomatech.com

WEEKDAY/WEEKEND OZONE OBSERVATIONS IN THE SOUTH COAST AIR BASIN: RETROSPECTIVE ANALYSIS OF AMBIENT AND EMISSIONS DATA AND REFINEMENT OF STUDY HYPOTHESES

DRAFT FINAL REPORT
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Paul T. Roberts
Tami H. Funk
Clinton P. MacDonald
Hilary H. Main
Lyle R. Chinkin
Sonoma Technology, Inc.
1360 Redwood Way, Suite C
Petaluma, CA 94954-1169

Prepared for:
National Renewable Energy Laboratory
1617 Cole Blvd., MS 1633
Golden, CO 80401-3393

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PROJECT PERSONNEL ROLES

Principal Investigator:	Paul T. Roberts
Project Manager:	Hilary H. Main
Task Co-Leaders,	
Emissions-Related Data Issues (Section 2):	Tami H. Funk and Lyle R. Chinkin
Task Leader,	
Upper-Air Meteorological and Air Quality Analysis (Section 3):	Clinton P. MacDonald
Task Leader,	
Synthesis of Phase I Analyses (Section 4)	Paul T. Roberts

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1. INTRODUCTION

1.1 BACKGROUND AND OBJECTIVES

Since the mid-1970s, ozone concentrations in California's South Coast Air Basin (SoCAB) have been higher on weekends than on weekdays, and this tendency has been more pronounced in the western SoCAB. This occurs despite assumed lower emissions on weekends than on weekdays. The objective of the National Renewable Energy Laboratory (NREL) weekend effect project is to conduct a study of the possible cause(s) of higher weekend ozone compared to weekday ozone in the SoCAB. Co-contractors Sonoma Technology, Inc. (STI) and the Desert Research Institute (DRI) were selected by NREL to perform this work. The project consists of three phases (each including several tasks) conducted over a period of 30 months. Specific objectives of Phase I are (1) to acquire emissions activity, meteorological, and air quality data in order to establish data needs and priorities for Phase II field study data acquisition and measurements and (2) to refine hypotheses for further testing in Phases II and III. A field measurement program is proposed in Phase II to collect and assemble air quality, emissions, and meteorological data required to help verify or disprove our weekend effect hypotheses. Phase III will consist of analysis of all data collected under Phases I and II.

The weekend effect has generated strong interest because of its potential implications on ozone control strategies. Much of the difficulty in addressing the ozone problem is related to ozone's complex photochemistry in which the rate of ozone production is a non-linear function of the mixture of volatile organic compounds (VOC) and nitrogen oxides (NO_x) in the atmosphere. Depending upon the relative concentrations of VOC and NO_x and the specific mix of VOC present, the rate of ozone formation can be most sensitive to changes in VOC alone, to changes in NO_x alone, or to simultaneous changes in both VOC and NO_x. Understanding the response of ozone concentrations to specific changes in VOC or NO_x emissions is a fundamental prerequisite to developing less costly and more effective ozone abatement strategies.

Results of previous studies in the SoCAB indicate that, in general, air quality on weekends is significantly different from weekdays, and this difference is probably not due to weather phenomena. Therefore, it has been postulated that the observed weekend effect in the SoCAB arises from day-of-week variations in the temporal and spatial patterns of VOC and NO_x emissions, coupled with the complex interactions of physical and chemical processes.

1.2 IMPORTANT PHENOMEMA THAT MAY INFLUENCE THE WEEKEND EFFECT

In assessing the weekend effect, three general topics need to be addressed: atmospheric chemistry, meteorology, and emissions. It is the interaction of these phenomena that influence local ozone concentrations. The increase in intensity of the weekend effect has occurred during the same years in which changes in emissions have generally decreased ambient VOC and NO_x concentrations and ambient 0600-0900 local time (LT) VOC/NO_x ratios. The result has been generally lower ozone concentrations. Although VOC and NO_x concentrations are both lower on weekends compared to weekdays, data show that the decrease is relatively greater for NO_x, which results in higher VOC/NO_x ratios on weekend mornings relative to weekday mornings.

Greater VOC/NO_x ratios increase the rate of ozone formation; whereas, lower VOC and NO_x concentrations decrease the rate of ozone formation. The combination of these two factors may enhance or retard the weekend effect. The lower NO_x concentrations observed on the weekends also decrease the removal of ozone via titration. This lower titration rate on the weekend may contribute to increased ozone concentrations on weekends compared to weekdays. Finally, the time of day and location of the emissions in the SoCAB on weekdays also differ from weekends, adding to the complexity of this issue.

Understanding the meteorology is also important in assessing the weekend effect. It is well known that vertical mixing and horizontal advection have a large impact on local ozone concentrations. Although, on a time scale of several years, the average meteorology may be the same on weekends and weekdays, the daily evolution of meteorology and air quality still influences the weekend affect. Therefore, meteorology must be included in the effort to understand the weekend affect.

1.3 PRELIMINARY HYPOTHESES AND APPROACH

The following hypotheses have been formed regarding weekend ozone concentrations:

1. VOC/NO_x ratios are higher on weekends than on weekdays due to changes in emissions, resulting in greater weekend ozone forming potential despite lower VOC and NO_x concentrations on weekends.

2. The weekend effect is more pronounced in the western and central areas of the SoCAB where the largest decrease in NO_x is assumed to occur on weekends, compared to weekdays.

3. Higher VOC/NO_x ratios are observed in aged air as emissions are transported toward the eastern side of the SoCAB, due to more rapid removal of NO_x than VOC.

4. The magnitude of the weekend effect is a function of the ozone formation rate, precursor concentrations, and the time available for ozone formation before dilution by wind or vertical mixing.

5. Overnight carryover of ozone, VOC, and NO_x from Friday and Saturday nights is greater than on other days of the week. Carryover is greater for VOC than for NO_x. This affects the ozone forming potential of the ambient air.

The testing of these hypotheses involves an evaluation of emissions activity data in conjunction with ambient air quality data and meteorology. Specific weekend emissions activity changes to be investigated include:

- Increased refueling of gasoline-fueled vehicles (including Friday).
- Decreased number of trips of gasoline-fueled vehicles.
- Increased home-related activity (e.g., lawn and garden equipment, surface coatings, paints, backyard barbecues, etc.).

- Decreased commercial-related activity (e.g., lawn and garden equipment, surface coatings, paints, etc.).
- Increased recreational activities (boating and other off-road mobile sources).
- Decreased industrial activity.
- Decreased diesel (truck, bus, and train) activity.
- Decreased commuter activity (shifts time and location of on-road mobile source emissions).
- Increased use of utility vehicles for personal use.
- Decreased trip chaining.

Because each of the activities listed above potentially emits different hydrocarbons, it should be possible to trace these expected changes with ambient data as well as to estimate the changes. Possible ambient parameters that might change include VOC/NO_x ratios, NO_x and VOC concentrations, VOC speciation, and VOC reactivity (ozone formation potential). When evaluating the ambient data on weekends compared to weekdays, the influence of meteorology on the observed concentrations must be considered.

1.4 STI'S PHASE I TASK OBJECTIVES AND APPROACH

1.4.1 Review of Available Emissions Data (Section 2 of this report)

Everyday observations and common sense suggest that aggregate variations in human activities, which follow a weekend-weekday pattern, are the most likely cause of the observed differences in weekend-weekday air quality. These human behavioral patterns directly govern weekend-weekday patterns of anthropogenic pollutant emissions. Logically, we then hypothesize that the observed differences in air quality directly result from anthropogenic emissions patterns. The objectives of this task are twofold: 1) develop a comprehensive list of emissions-related hypotheses and prioritize the list for further study, and 2) identify existing sources of emissions data and assess the feasibility of gathering adequate data to refute or support each hypothesis. In order to formulate and prioritize a list of hypotheses, literature reviews were conducted, discussions with various government agencies were held, and potential sources of data were identified. Further study efforts were prioritized by examining each hypothesis, assessing the potential impact of each hypothesis on air quality, and determining the availability of existing data or the feasibility of collecting data to refute or support each hypothesis.

1.4.2 Analysis of SCOS97 Upper-Air Meteorological and Three-Dimensional Ozone Data (Section 3 of this report)

The SoCAB has complex meteorology and air quality processes that result in large day-to-day variations in ozone concentrations. A large portion of the variations in ozone concentrations is attributable to day-to-day variations in meteorology and not to the day-to-day (or weekday-to-weekend) variations in emissions. In the absence of a large data set of weekend and weekday ozone episodes to compare, one must account for meteorology in any analyses comparing weekend and weekday episodes. Even with a modest size data set from which to perform a statistical comparison, it is not likely that the weekend or weekday episodes are meteorologically similar enough to ignore the influence of meteorology. Furthermore, it is important to perform case study analyses along with any statistical analysis, and meteorology must be taken into account in case study analyses.

Of all the different parameters that represent meteorology, winds and mixing heights have the strongest day-to-day influence on ozone concentrations. There are two ways that these meteorological characteristics might help us understand the variations in ozone concentrations between weekend and weekdays. First, if we find selected weekend and weekday episode days with very similar meteorology, then we can compare them and attribute differences in the ozone concentrations to air quality processes and emissions, and not to meteorological processes. Second, because it is not likely that there are many days to compare with very similar meteorology, we will need to directionally quantify how mixing heights and winds might influence ozone concentrations. Then, using this directional influence information, we can use a modest size data set to perform a statistical comparison that takes meteorology into account.

To complete the described analyses, we must first be sure that we accurately represent the meteorology and second we must understand how the meteorology influences ozone concentrations. Furthermore, in addition to meteorology and emissions, aloft ozone also has some influence on surface ozone concentrations. Therefore, we need to understand the importance of its influence and decide if it needs to be taken into account in the comparison effort. With these issues in mind, we set out to answer the following questions:

- Are there both weekend and weekday intensive operating period (IOP) days from the 1997 Southern California Ozone Study (SCOS97) that we can compare?
- Is the meteorology on these IOP days similar enough to do a fair comparison of the air quality and emissions?
- How similar are the SCOS97 episode days to Southern California Air Quality Study (SCAQS) 1987 episode days, based on the characteristics of the aloft ozone layers?
- What is the influence of mixing heights and wind patterns on ozone concentrations?
- What is the regional representativeness of the temporal and spatial variations in wind and mixing heights that can be obtained from the Photochemical Assessment Monitoring Station (PAMS) profilers at Los Angeles International Airport (LAX) and Ontario (ONT) alone, since only these two continue to operate?

These questions were assessed and this report contains recommendations for additional meteorological measurements needed to enhance the upcoming Phase II field study and to improve our overall understanding of the hypotheses listed above.

1.4.3 Synthesis of Phase 1 Analyses (to be added as Section 4 of this report)

During the same time frame in which STI was performing the emissions activity and meteorological representativeness tasks, DRI was performing a retrospective analysis of ozone concentrations, ozone precursor concentrations, and ozone episodes as well as a review of source apportionment analyses. The results from each contractor are intended to guide the selection of the types and locations of measurements for the field campaign in Phase II. Clearly, the results from both contractors need to be considered and synthesized into a cohesive strategy. For this draft of the report, we have prepared an outline of the topics that we will discuss after the contractors have reviewed the Phase I investigations and discussed the results.

- *Summarize the results of Phase I data analysis.* A summary of the conclusions of each main task will be presented. The implications of the conclusions for the hypotheses will be discussed.
- *Compare results from each task.* The synthesis of conclusions from each task also includes a comparison of findings from related tasks. For example, examination of the time series of pollutants by DRI also provides corroboration of emission inventory results discussed in Section 2 of this report. The detailed analysis of a few SCOS97 IOP days performed by STI (Section 3) can be compared to the more general conclusions drawn from many more days as assessed by DRI in its report.
- *Update hypotheses.* The task results will be used to evaluate the candidate hypotheses. Those hypotheses that are most viable will be retained and those that are least likely to be important will be demoted or dropped altogether.
- *Revise conceptual model.* Based on the new set of hypotheses, we will revise the conceptual model of the weekend effect.
- *Finalize field measurement program.* Based on the Phase I task results, DRI and STI will recommend a final configuration for the field measurement program.

2. EMISSIONS-RELATED DATA ISSUES

2.1 BACKGROUND AND OBJECTIVES

Everyday observations and common sense suggest that aggregate variations in human activities, which follow a weekend-weekday pattern, are the most likely cause of the observed differences in weekend-weekday air quality. These human behavioral patterns directly govern weekend-weekday patterns of anthropogenic pollutant emissions. From this, we hypothesize that the observed differences in air quality directly result from anthropogenic emissions patterns. The overall objectives of the emissions tasks are (1) to identify the weekend-weekday variations in anthropogenic emissions patterns that are most likely to impact air quality, (2) to quantify these emissions variations, and (3) to combine these results with air quality and meteorological data in an analysis that tests our hypotheses. This section presents the findings of Phase I, Task 1: Review of Available Emissions Data.

The objectives of Phase I, Task 1 were twofold: 1) develop a comprehensive list of emissions-related hypotheses and prioritize the list for further study and 2) identify existing sources of emissions data and assess the feasibility of gathering adequate data to refute or support each hypothesis. In order to formulate and prioritize a list of hypotheses, literature reviews were conducted, discussions with various government agencies were held, and potential sources of data were identified. Further study efforts were prioritized by examining each hypothesis, assessing the potential impact of each hypothesis on air quality, and determining the availability of existing data or the feasibility of collecting data to refute or support each hypothesis.

The SoCAB covers an area of approximately 6,500 square miles and has a population of more than 14 million. The California Air Resources Board (CARB) and the South Coast Air Quality Management District (SCAQMD) routinely publish emission inventories for the SoCAB. Daily average 1996 emissions of important ozone precursors, reactive organic compounds (ROG), NO_x, and carbon monoxide (CO) are shown in **Table 2-1** (California Air Resources Board, 1998). Table 2-1 lists total emissions by pollutant and broken down by major source categories (stationary, area, on-road mobile, and other mobile), and subcategories (e.g., gasoline vehicles). Examples of stationary source emissions include industrial fuel combustion, cleaning and surface coating operations, petroleum production, and petroleum marketing. Area source emissions include, for example, consumer and other solvent evaporation, residential fuel combustion, waste burning, and utility equipment.

The emissions in Table 2-1 show that the on-road mobile source category is the single largest source category for ozone precursor pollutants, accounting for about 45, 64, and 69 percent of average daily ROG, NO_x, and CO, respectively. Most of the on-road emissions are due to gasoline vehicles, but diesel vehicles contribute substantially to NO_x emissions. Second to on-road mobile sources, stationary and area-wide sources are significant sources of ROG, while other mobile sources are currently a less important source of ROG. In contrast, other mobile sources generate relatively large emissions of NO_x, while stationary and area-wide sources are less important NO_x contributors. The vast majority of CO emissions are associated with on-road and other mobile sources. While CO emissions are not a major contributor to ozone formation they may serve as a tracer for mobile source emissions since they are primarily associated with mobile source fuel combustion.

2.2 SPATIAL AND TEMPORAL EMISSIONS ISSUES

The magnitude and spatial extent of the weekend effect is a function of the amount of time available for ozone formation to proceed before ventilation occurs and the rate at which VOC/NO_x ratios increase (due to more rapid removal of NO_x than VOC) as the emissions are transported to the eastern side of the SoCAB. Spatially, the weekend effect is less pronounced far downwind and more pronounced in regions where the ozone formation is more VOC-limited on weekdays and more NO_x-limited on weekends. Temporally, the 0600-0900 LT VOC/NO_x ratios are higher on weekends in the central portion of the SoCAB and more constant in the eastern SoCAB where the weekend effect is less pronounced.

Because the weekend effect appears to be partly a function of spatial and temporal characteristics of ozone precursor emissions, it is important to examine emissions in the SoCAB in the context of their spatial and temporal characteristics. In order to assess emissions on a day-of-week basis, emissions activity data must be obtained for both weekdays and weekends. Because ozone formation is dependent on precursor emissions emitted during the early part of the day, emissions activities occurring in the morning should be considered. Also, the diurnal differences in emissions activities between weekdays and weekends should be examined. For example, traffic patterns are likely to vary by both day-of-week and time-of-day. Because the extent of the weekend effect varies in different regions of the SoCAB, it is of interest to assess emissions activities on both a basin-wide level and a site-specific level.

As part of the field study to be conducted during the summer of 2000, DRI will investigate detailed, time-resolved chemistry to test hypothesized relationships between emissions sources, VOC/NO_x ratios, and ozone. Ambient measurements of hydrocarbons, NO_x, and CO will be collected at Photochemical Assessment Monitoring Stations (PAMS) and other ambient monitoring sites in the SoCAB. In addition to routine ambient data, several sites will be equipped with supplemental monitors in order to obtain the required chemical speciation and measurement sensitivity. In order to test hypothesized relationships between emissions sources, VOC/NO_x ratios, and ozone measurements, the emissions sources surrounding each ambient monitoring site were assessed as part of Phase I, Task 1. In order to collect emissions activity data that are relevant to each ambient monitoring site, emissions sources surrounding each site were identified, including unique sources (i.e., stadiums, parks, recreation areas) that may have different impacts on the ambient monitors on weekdays and weekends.

2.3 DEVELOPMENT AND PRIORITIZATION OF EMISSIONS-RELATED HYPOTHESES

In order to support the general hypothesis that the differences between weekday and weekend air quality are related to differences between weekday and weekend anthropogenic emissions patterns, anthropogenic emissions sources that are likely to show significant variations between weekdays and weekends were identified. A number of changes in emissions by day-of-week, time-of-day, and location in the SoCAB can be postulated. **Table 2-2** summarizes these emissions-related hypotheses and relevant emissions source categories. Each of the hypotheses have been assigned one of the following confidence levels based on the judgment of the principal investigators regarding the probability that the experimental approach proposed will achieve a definitive conclusion. The confidence levels are defined as follows:

- High confidence: There is low uncertainty in the data or data analysis approach or the conclusion can be supported by more than one independent analysis approach, each of which has moderate uncertainty.
- Medium confidence: There is moderate uncertainty in the data or data analysis approach and an independent analysis approach will not be available.
- Low confidence: There is large uncertainty in the data or data analysis approach and independent analysis approaches will not be applied.

Because the contributions from each of the source categories listed in Table 2-2 vary by pollutant and because the directional emissions changes are not correlated, the changes postulated in Table 2-2 are difficult to verify. Therefore, in formulating our hypotheses, we have combined the expected emissions changes into what we believe are independently verifiable and quantifiable impacts. **Table 2-3** lists the individual source categories that are likely to exhibit specific emissions changes on weekends and their relative contributions to total ROG and NO_x in Los Angeles County. **Figure 2-1** shows the contributions of the source categories listed in Table 2-3 to ROG and NO_x emissions in Los Angeles County.

As shown in Table 2-3 and Figure 2-1, the emissions source categories identified are responsible for about 80-90 percent of total ROG and NO_x emissions in Los Angeles County. Emissions from light-duty vehicles and light- and heavy-duty trucks account for about half of total ROG and NO_x emissions in the county.

2.4 IDENTIFICATION OF EXISTING DATA

As part of this work effort, sources of emissions activity data were pursued for the emissions categories listed in Table 2-3. In order to identify existing sources of emissions activity data, literature reviews were conducted and discussions with several government agencies and industry experts were held.

STI staff met with CARB staff to discuss existing data sources for all emissions source categories. At this meeting emissions activity data were identified for several important source categories. In addition to meeting with CARB staff, similar phone discussions with staff at the California Department of Transportation (Caltrans), the U.S. Census Bureau, the U.S. Marine Exchange, the U.S. Department of Energy, and the U.S. Department of Transportation Bureau of Transportation Statistics (DOT-BTS) were held. Literature reviews were conducted to identify recent studies regarding emissions activity patterns for all sources including the service industry, the manufacturing sector, and consumer products. **Table 2-4** summarizes the emissions activity data identified for each source category listed in Table 2-3. Refer to Appendix A for a detailed description of the data sets listed in Table 2-4.

As shown in Table 2-4, there are multiple sources of activity data for most mobile source categories. However, weekend activity data for industry and consumer product use is scarce. Discussions with CARB staff revealed that although temporal activity profiles are assigned to all industrial, manufacturing, and consumer product emissions categories, these profiles do not reflect differences between weekday and weekend activity patterns. Furthermore, there has been little, if any, work done to assess day-of-week activity patterns.

As part of Phase II, we will continue to gather and compile existing information and data that will support weekend-weekday comparisons of emissions. Our efforts will be focused on identifying and obtaining additional activity data for industrial, manufacturing, residential, and consumer sources, since considerable data for on-road mobile sources have already been identified for analysis.

2.5 CHARACTERIZATION OF EMISSIONS ACTIVITY SURROUNDING SELECTED AMBIENT MONITORING SITES IN THE SOCAB

As part of the field study to be conducted during the summer of 2000, DRI will collect ambient measurements for use in Phase III to test hypothesized relationships between emissions sources and VOC/NO_x ratios and ozone. In order to identify these relationships, emissions sources surrounding each ambient monitoring site were characterized in order to identify sources that may impact ambient measurements. Unique sources of emissions within 5 km of each site were identified, including stadiums, parks, and recreation areas that may have different impacts on ambient measurements on weekdays and weekends.

There are six ambient PAMS sites located throughout the SoCAB. These sites are listed in **Table 2-5**. In addition to the PAMS sites in the SoCAB, there is a monitoring site located in Los Angeles (Los Angeles North Main) that would be considered a Type 2 site under the PAMS classification scheme. **Figure 2-2** shows the locations of the six PAMS sites and the Los Angeles North Main long-term trend site. **Figures 2-3 through 2-9** depict each of the ambient monitoring sites and land features located within a 5-km radius of each site.

Because the SoCAB is dense with freeways and road networks, all of the sites are heavily influenced by motor vehicle emissions. Emissions sources within 5 km of all of the monitoring sites (with the exception of Banning) consist of many service facilities (i.e., gas stations, restaurants, dry cleaners, and auto body shops). The following provides a summary of the unique emissions sources surrounding each of the ambient monitoring sites for which data may be pursued further in Phase II. As part of the PAMS Data Analysis for Southern California Project (Main et al., 1999) conducted in 1999, all of the ambient monitoring sites in the SoCAB were assessed in terms of how well the PAMS measurement systems represent the ambient SoCAB air. In addition to normal on-road vehicular traffic on surface streets and highways unique characteristics of the selected monitoring sites are discussed below.

- Hawthorne. Unique emissions sources near the Hawthorne site include Los Angeles International Airport, Hawthorne Municipal Airport, and the Chevron El Segundo Refinery. Based on historical analyses of ambient hydrocarbon data collected at Hawthorne, VOC concentrations, composition, and ratios are consistent with Hawthorne's PAMS Type 1 designation (Main et al., 1999).

- Burbank. Unique emissions sources near the Burbank site include the Burbank-Glendale-Pasadena Airport and three major parks and recreation areas. Based on historical analyses of ambient hydrocarbon data collected at Burbank, it was determined that nearby hydrocarbon sources may dominate many of the samples collected at Burbank (Main et al., 1999).
- Pico Rivera. Unique emissions sources near the Pico Rivera site include the Whittier Narrows Recreation Area and a bag printing company. Based on historical analyses of ambient hydrocarbon data collected at Pico Rivera, it was discovered that a nearby source of toluene appears in the daytime data (Main et al., 1999).
- Banning. Banning is located in the eastern region of the SoCAB in Riverside County. There appear to be no unique emissions sources near the monitoring site. Banning is designated as a PAMS Type 2 site (as listed in the Environmental Protection Agency's Aerometric Information Retrieval System [EPA AIRS]), however, the concentration, composition, and ratio data are more characteristic of a Type 4/1 site for the greater Los Angeles area (Main et al., 1999).
- Azusa. The Azusa monitoring site is located near the Santa Fe Dam Recreation Area and appears to be more suburban than the other sites. The VOC data show characteristics of both fresh emissions and aged, transported emissions (Main et al., 1999).
- Upland. There are three colleges and a small airport located within the 5-km radius of the Upland site. It appears to be a fairly urban site with many service facilities nearby. Based on historical analyses of ambient hydrocarbon data collected at Upland, VOC concentrations, composition, and ratios are consistent with Upland's PAMS Type 3 designation (Main et al., 1999).
- Los Angeles North Main. The Los Angeles North Main long-term trend site is located near the intersection of two major freeways: the Pasadena and the Hollywood freeways. Dodger Stadium and Elysian Park are located slightly north of the site. VOC data are consistent with CBD emissions.

2.6 DISCUSSION OF PHASE II DATA COMPILATION

The objectives of the Phase III data analyses will be (1) to quantify the weekend-weekday variations in anthropogenic emissions patterns that are most likely to impact air quality, and (2) to combine these results with air quality and meteorological data to test our hypotheses. Mobile sources, estimated to be the most important contributor of ozone precursor emissions in the SoCAB, are known to follow pronounced weekday-weekend patterns of activity; thus, they will receive a more in-depth focus in Phase II.

There are many measures of on-road travel activity and several ways to compare them between weekdays and weekends. A few examples are listed below.

- Vehicle miles traveled (VMT)
- Vehicle Speeds
- Fleet mix (trucks vs. cars)

- Cold/warm engine starts
- Trips (frequency, length, and geographic pattern)
- Trip chaining
- Cars [sports utility vehicles (SUVs) versus commuter cars]
- Diurnal patterns

Figure 2-10, reproduced here from the Highway Capacity Manual, illustrates the traditional view of weekend vs. weekday travel activity patterns. Urban freeway (UF) traffic builds gradually from Monday through Friday, drops off on Saturday, and drops even further on Sunday. Rural (MR) and recreational (RA) routes have minimum traffic volumes mid-week, with pronounced peaks on Friday and Sunday. This result has been repeated for numerous urban centers, especially for Los Angeles. In a 1993-1995 study of Los Angeles vehicles equipped with data loggers, Magbuhat and Long (1996) showed that the frequency of cold starts follows the same general pattern as the urban traffic volumes illustrated in Figure 2-10 (see **Figure 2-11**). Additionally, several EPA reports document weekend-weekday activity information. Two recent EPA publications (Glover and Brzezinski, 1998a,b), reflect the results of instrumented vehicle studies in Spokane and Baltimore. **Figures 2-12 through 2-14** illustrate Glover and Brzezinski's conclusions that weekend urban travel levels are lower than weekday travel levels. Additionally, the data illustrate that most weekend travel tends to begin at a later hour of day than weekday travel and that it continues to be relatively uniform throughout the day (Glover and Brzezinski, 1998a,b).

Traditionally, travel diaries have not collected weekend travel data so there are relatively few comparisons illustrating the differences between weekday and weekend travel activity. Several efforts are currently underway to better evaluate the relative importance of weekend versus weekday activity. For example, the Georgia Institute of Technology has gathered commercial vehicle data for Atlanta and plans to gather personal vehicle activity data during an upcoming survey (Guensler, 1999). In another example, the Texas Transportation Institute (TTI) has collected data for several counties in the Houston Metropolitan Statistical Area (MSA), where TTI counted and classified vehicles for Sunday, Monday-through-Thursday, Friday, and Saturday during the non-school year. TTI has used these data to distribute VMT by hour and by day-of-week into these four-day groups (Dresser, 1999). In addition, work is ongoing in southern California to evaluate the relative importance of weekend vs. weekday travel in this area. Dr. Debbie Niemeier with the University of California at Davis recently completed analyses for the CARB that will help further the knowledge base of weekend vs. weekday travel in southern California (Niemeier et al., 1999). The SCAQMD is also studying these same weekend vs. weekday issues (Hsiao, 1999).

One illustration of the growing importance of weekend vs. weekday activity involves data from southern California. Several years ago, staff from the SCAQMD in Los Angeles used Caltrans traffic count data to contrast average weekday vs. average weekend traffic counts for all vehicle types. They found that weekend travel counts were approximately 96 percent of weekday travel counts and that weekend travel occurred more uniformly throughout the day, as opposed to the pronounced peak periods which are characteristic of weekday travel. More recently, SCAQMD staff have attempted to use truck traffic counts to better understand weekend vs. weekday heavy-duty vehicle activity. They have roughly estimated weekend truck traffic counts to be approximately 40 percent of the truck traffic observed during an average weekday

(Hsiao, 1999). Similar observations have been documented by the Transportation Research Board (**Figure 2-15**). The opposite phenomenon is observed for recreational boating patterns in California. Weekend recreational boating activity levels are six to eight times higher than weekday activity levels (**Figure 2-16**).

Historically, most detailed ozone photochemical modeling has focused on weekday ozone exceedance events. Furthermore, most emission control programs have focused on stationary sources and on reducing home-to-work related emissions. Thus, it should not come as a surprise that very little attention has been paid to the development of accurate weekend emissions. Some adjustment factors to scale weekday emissions for use in modeling weekend days have been developed by CARB and the EPA. However, these scaling factors are based on limited data and result in weekend emissions that are slightly lower than weekday emission totals and very slightly alter the diurnal emissions pattern.

As uncertain as weekend emissions appear, weekday emission estimates are also under considerable doubt. A number of researchers have shown that published average daily weekday emissions may underestimate real-world hydrocarbon emissions by as much as a factor of two or more (see, for example, Fujita et al., 1992, 1994; Korc et al., 1993, 1995; Gertler and Pierson, 1996; and Haste et al., 1998a,b). These results are fairly consistent throughout the country and throughout California. A top-down approach, wherein ambient measurements of air quality, either from existing air quality monitoring sites or from special monitors placed in roadway tunnels, has been used in many studies. Comparisons between the measured concentrations and predicted emissions show that the inventory for weekdays consistently underpredicts hydrocarbons, mostly, but not exclusively, from on-road mobile sources.

Because of the underestimates in the published weekday emission inventories, one cannot reliably use published estimates of differences in weekday and weekend emissions. Systematic discrepancies between observed and predicted emissions on weekdays may not apply to weekend emissions. Thus, in this study, ***independent and verifiable differences*** in emissions must be identified.

Detailed analyses of the differences between predicted emissions and observed hydrocarbon data show that the standard speciated emission inventories are not representative of ambient air quality data. This discrepancy can in part be attributed to outdated or unrepresentative profiles used to speciate total hydrocarbon emissions into individual chemical compounds measured in the ambient air. Particularly noteworthy is the lack of speciation profiles for recently introduced reformulated gasoline and reformulated solvents, inks, and surface coatings. The use of unrepresentative speciation profiles complicates the identification of differences between weekday and weekend day emissions from source types contributing significant hydrocarbon emissions. In Phase III, we plan to use the most recent source speciation profiles available to improve the success of this study.

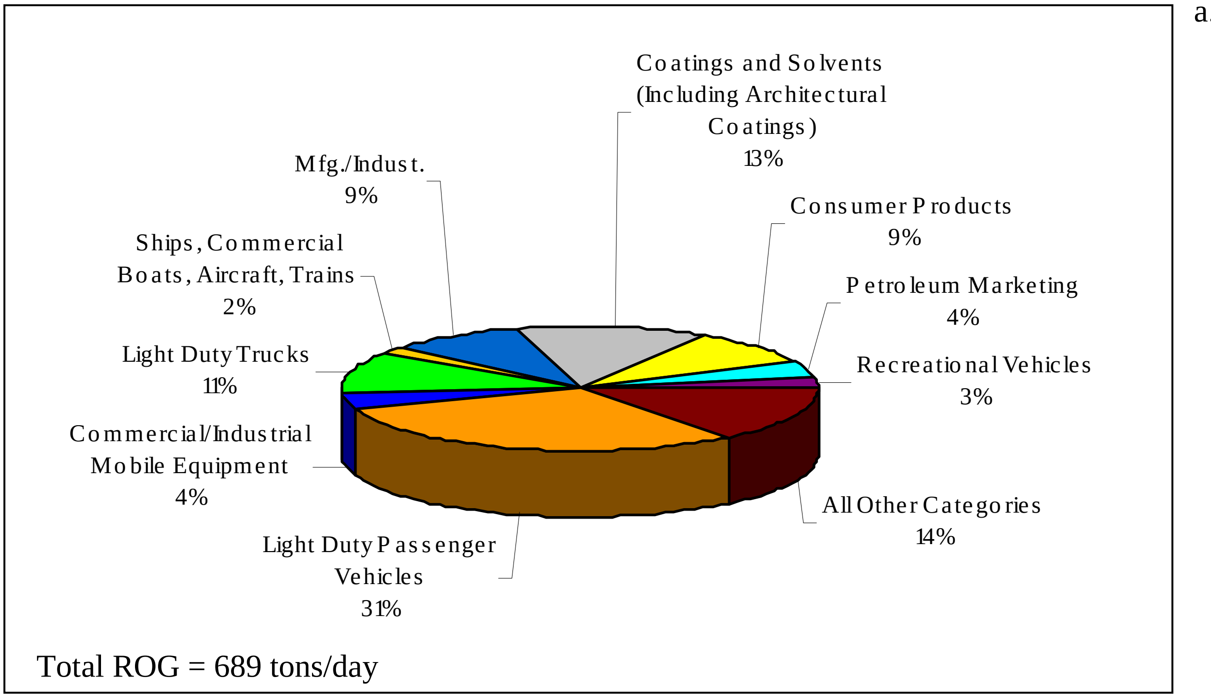
Specific emissions changes on weekends may include the following:

- Increased refueling of gasoline-fueled vehicles (including Friday)
- Decreased number of trips of gasoline-fueled vehicles

- Increased home-related activity (e.g., lawn and garden equipment, surface coatings, paints, backyard barbecues, etc.)
- Decreased commercial-related activity (e.g., lawn and garden equipment, surface coatings, paints, etc.)
- Increased recreational activities (boating and other off-road mobile sources)
- Decreased industrial activity
- Decreased diesel (truck, bus, and train) activity
- Decreased commuter activity (shifts time and location of on-road mobile source emissions)
- Increased use of utility vehicles for personal use
- Decreased trip chaining

Because each of the activities listed emits different hydrocarbons, it should be possible to trace these types of changes with ambient data as well as estimate the changes through information gathered using limited telephone surveys.

During Phase II of this study, we will compile data that can be used to assess possible weekend effects. We will compile data for the year 2000 as well as historical data for 1997. To the extent that data can be obtained, we will produce graphics and statistics such as those shown in the examples above for emissions-related activity differences between weekdays and weekends. Our priorities in compiling emissions-related activity data are collecting (1) monitoring site-specific data, (2) SoCAB-specific data, (3) California-specific data, and (4) typical data from locations throughout the country where available.



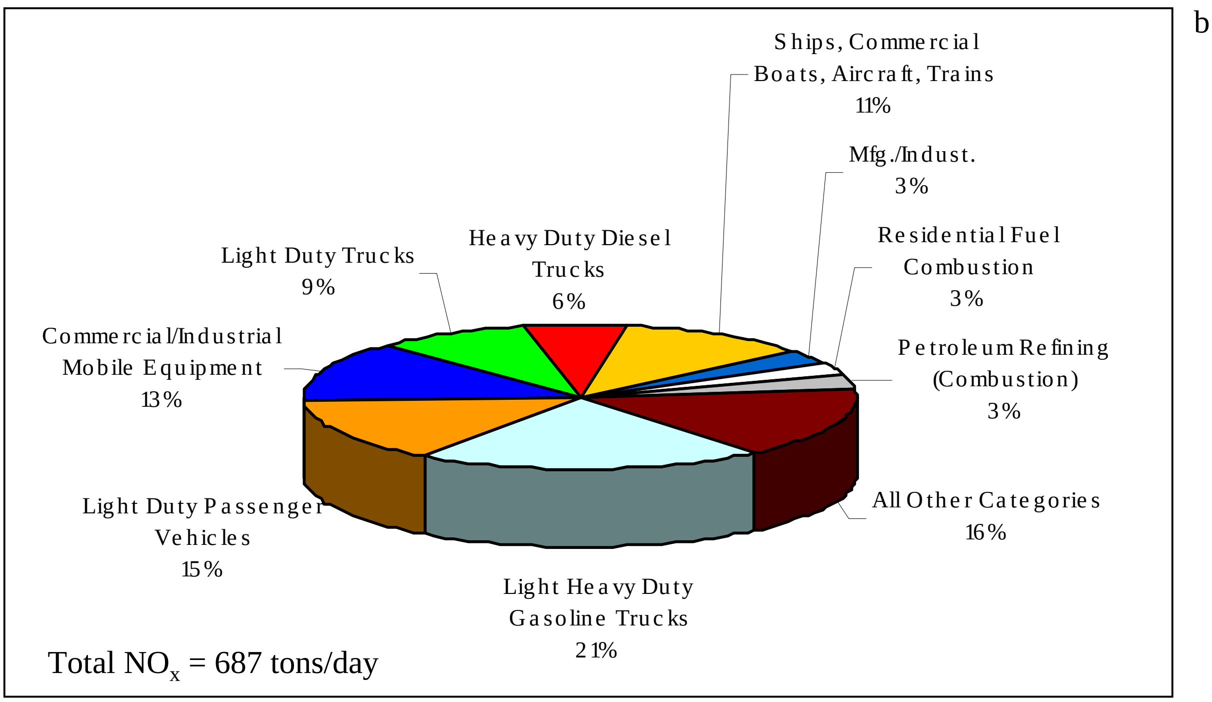


Figure 2-1. Emissions source category contributions to total (a) ROG and (b) NO_x in Los Angeles County.

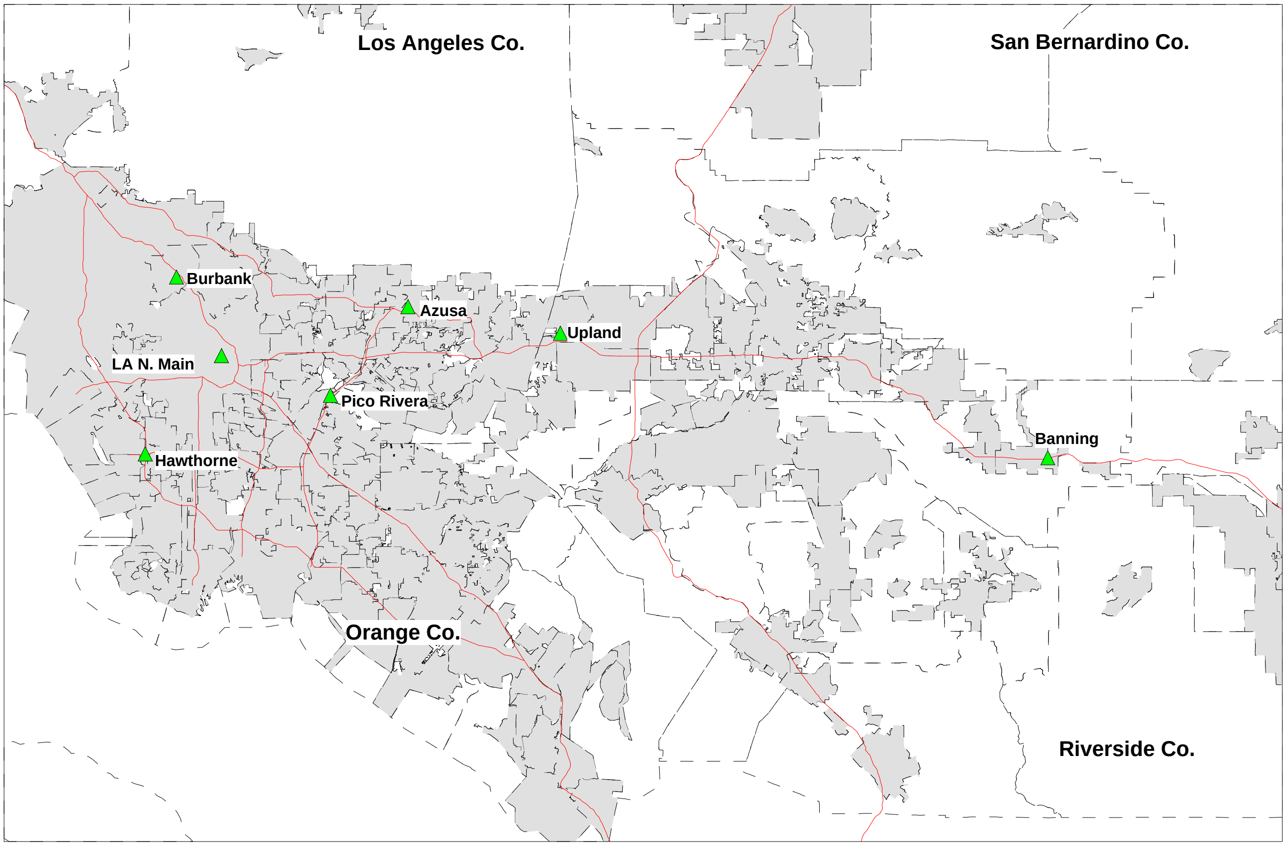
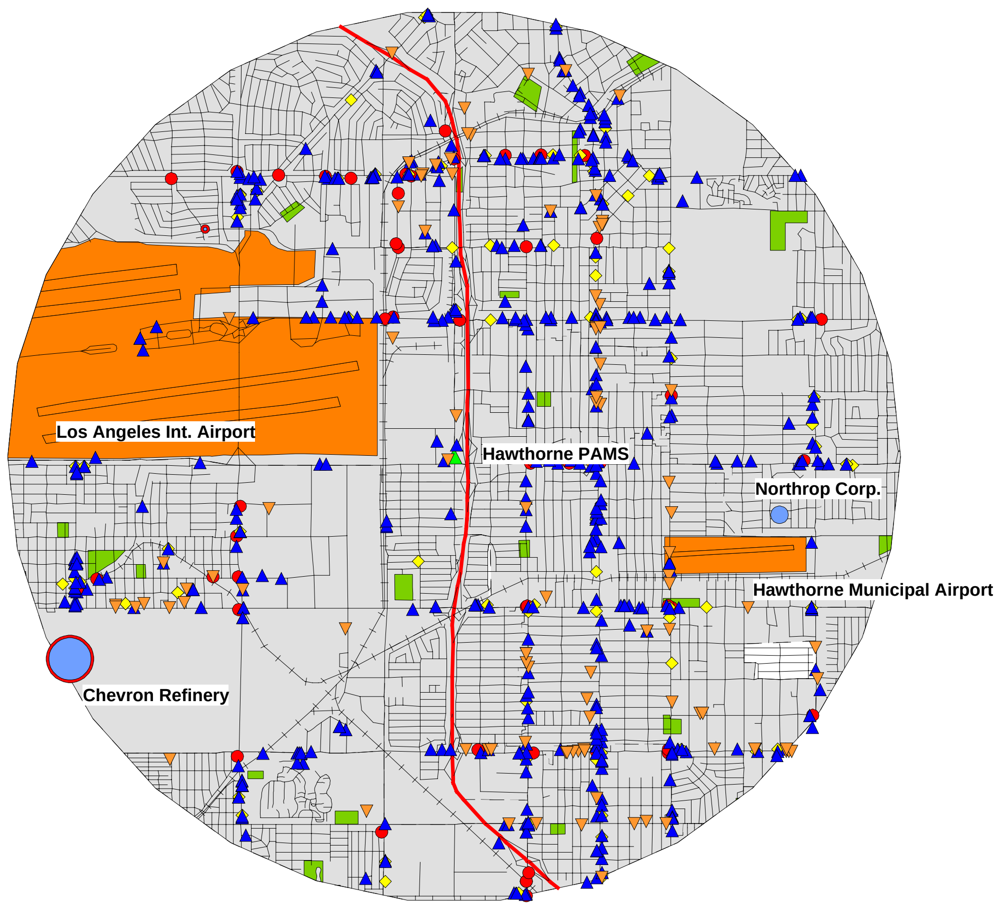


Figure 2-2.   Locations of selected PAMS and PAMS-like ambient monitoring sites in the South Coast Air Basin.

Hawthorne



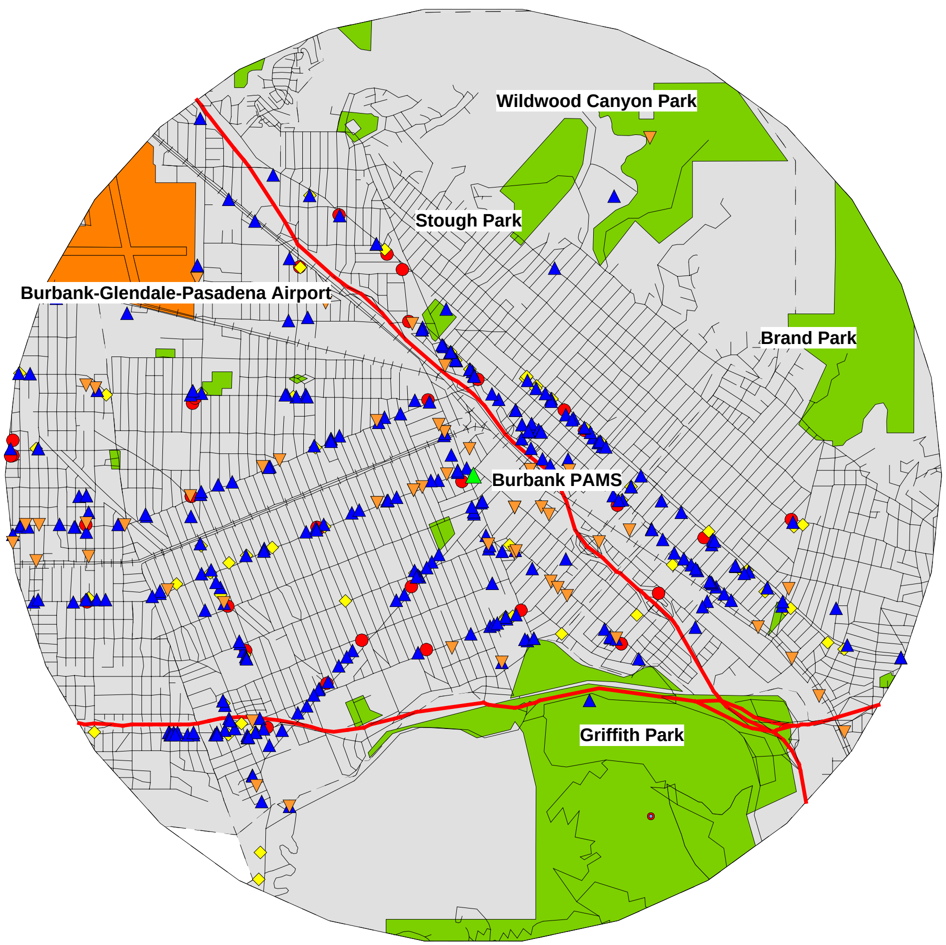
- Gasoline Service Stations
- Restaurants/Bakeries
- Dry Cleaning Facilities
- Automotive Repair Shops

<u>Unique Emissions Sources</u>

- Los Angeles International Airport
- Hawthorne Municipal Airport
- Chevron El Segundo Refinery

Figure 2-3. Depiction of the Hawthorne PAMS site including land features within a 5-km radius of the site.

Burbank

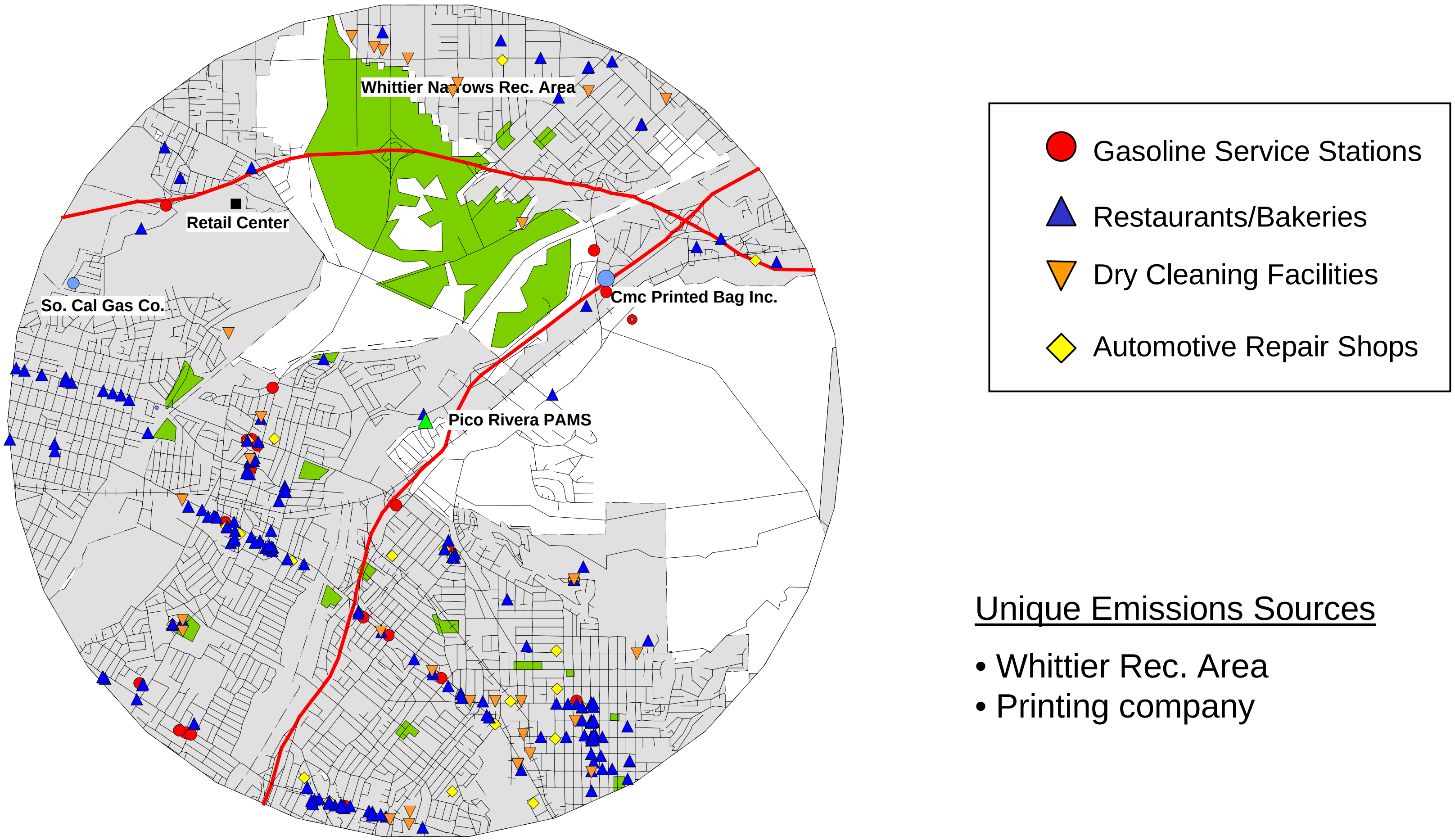


Unique Emissions Sources

- Airport
- Several Parks and Recreation Areas

Figure 2-4. Depiction of the Burbank PAMS site including land features within a 5-km radius of the site.

Pico Rivera



<u>Unique Emissions Sources</u>

- Whittier Rec. Area
- Printing company

Figure 2-5. Depiction of the Pico Rivera PAMS site including land features within a 5-km radius of the site.

Banning

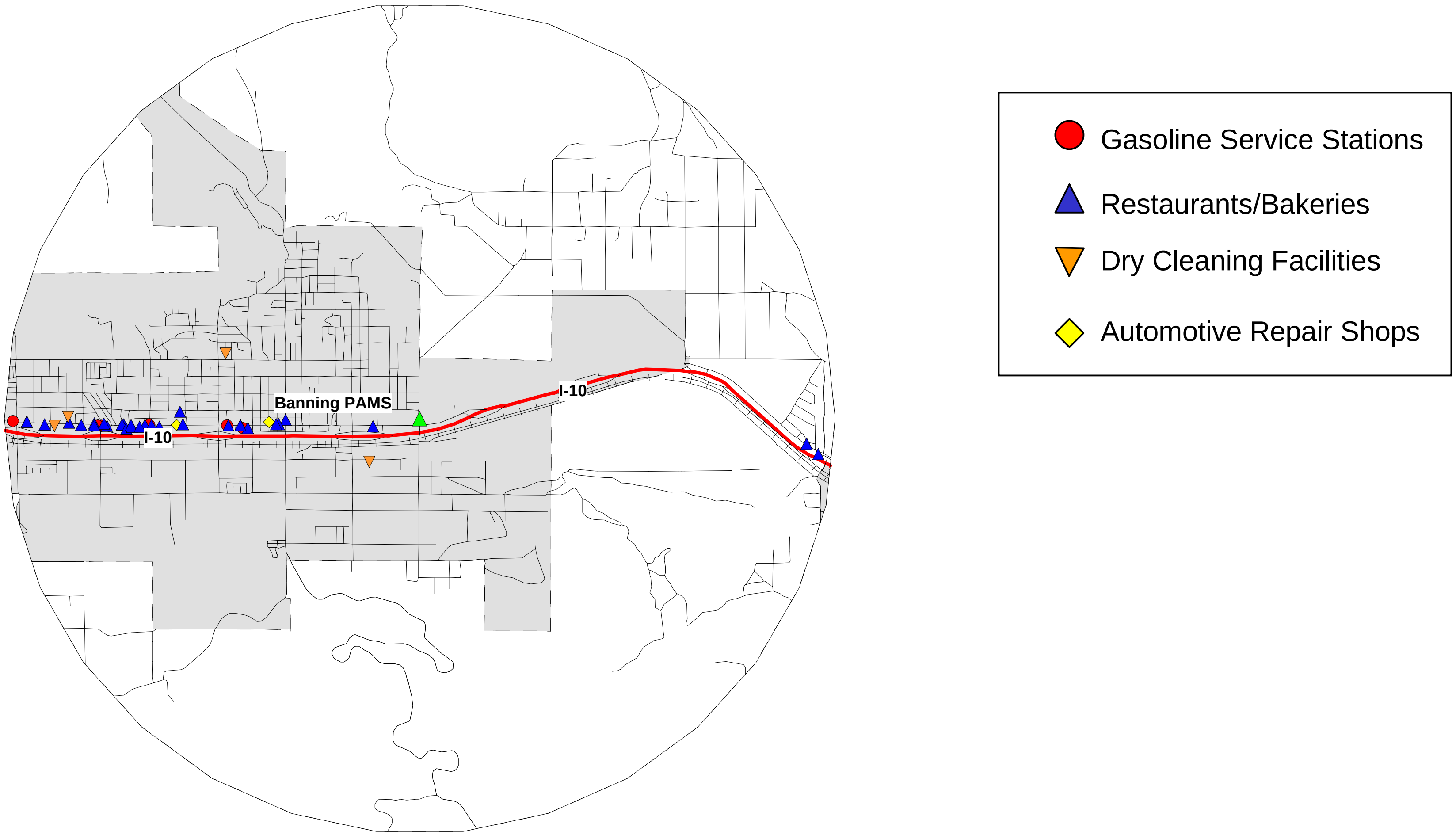
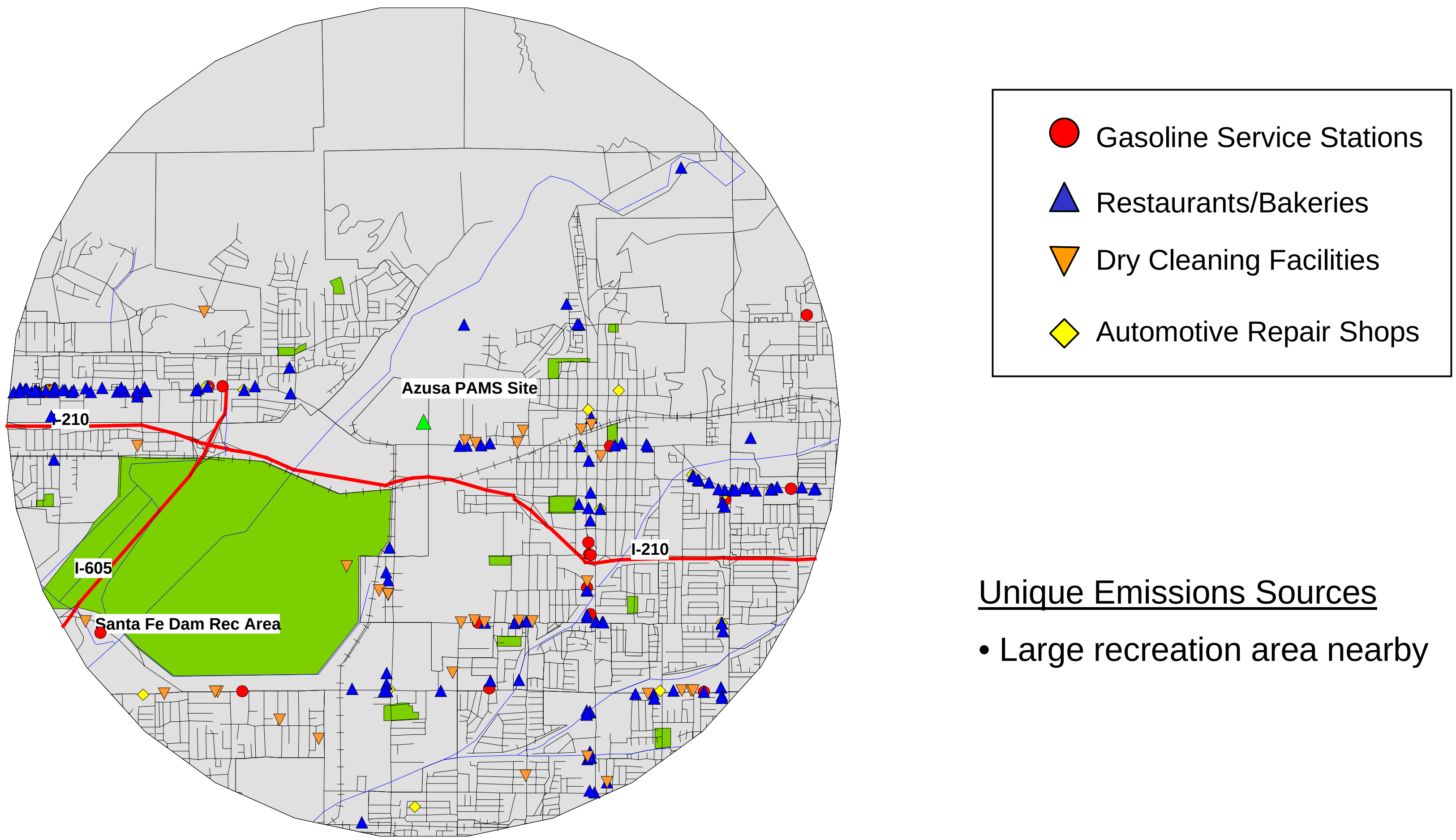


Figure 2-6. Depiction of the Banning PAMS site including land features within a 5-km radius of the site.

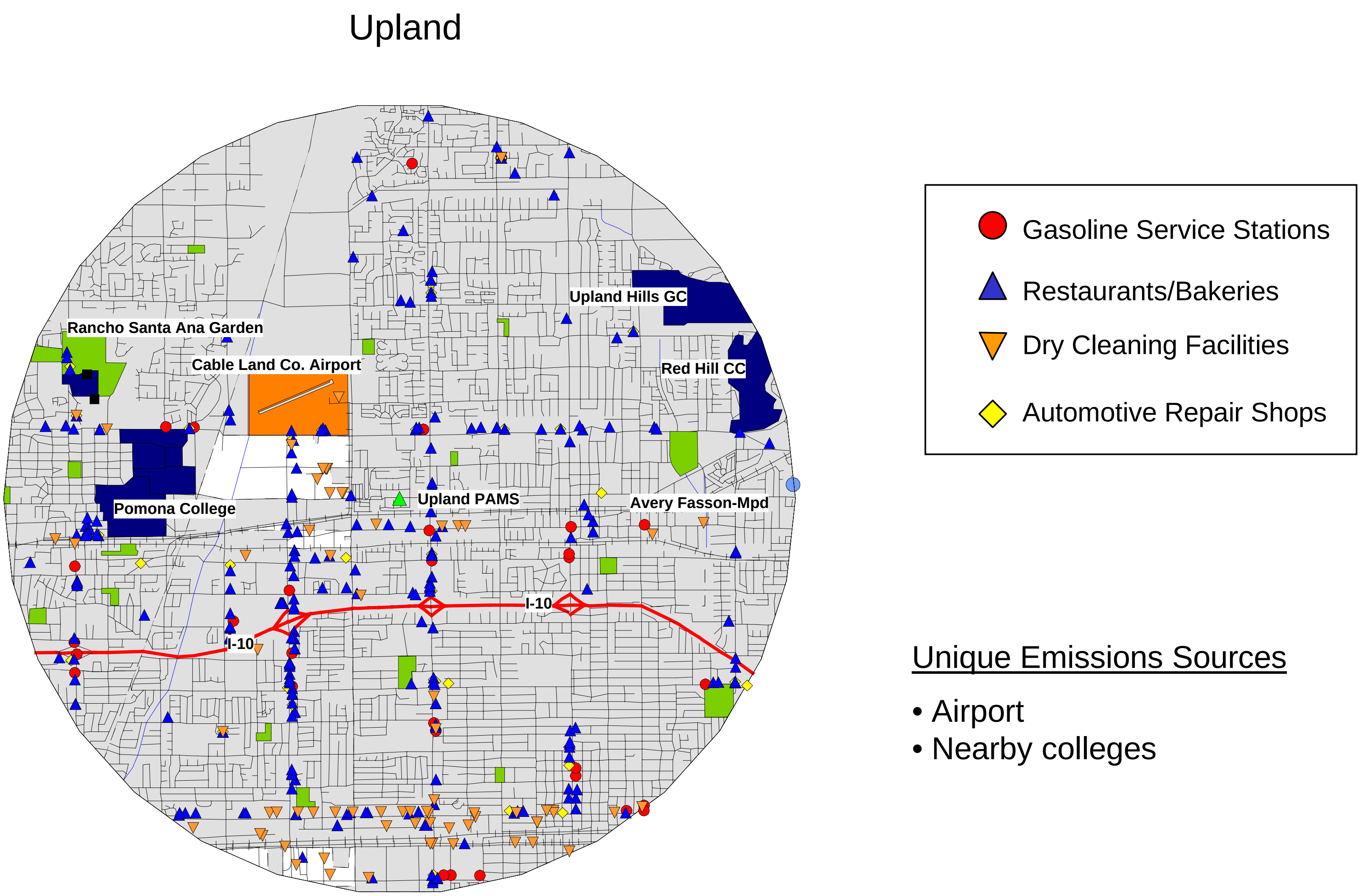
Azusa



Unique Emissions Sources

• Large recreation area nearby

Figure 2-7. Depiction of the Azusa PAMS site including land features within a 5-km radius of the site.

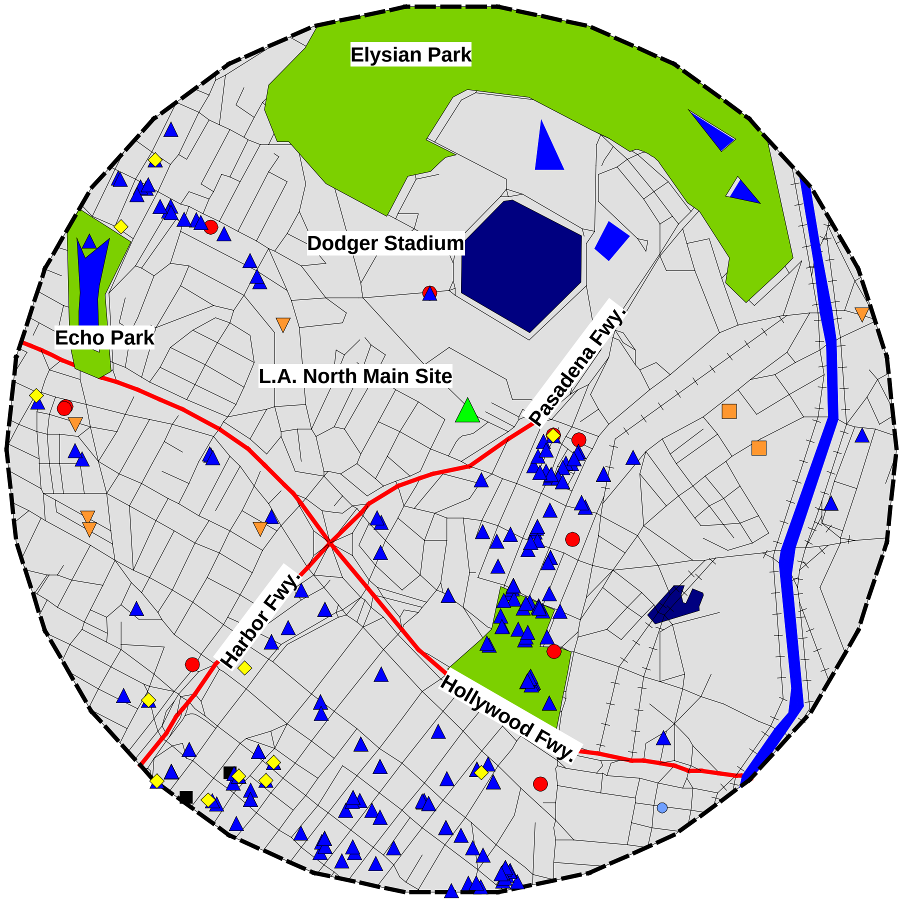


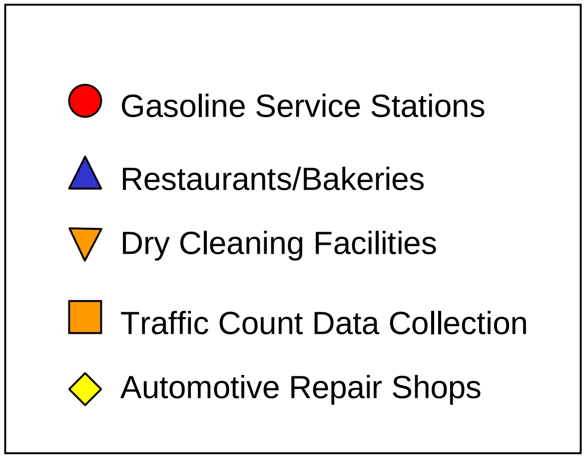
Unique Emissions Sources

- Airport
- Nearby colleges

Figure 2-8. Depiction of the Upland PAMS site including land features within a 5-km radius of the site.

Los Angeles North Main





Unique Emissions Sources

- Dodger Stadium
- Elysian Park

Figure 2-9. Depiction of the Los Angeles North Main long-term monitoring site including land features within a 5-km radius of the site.

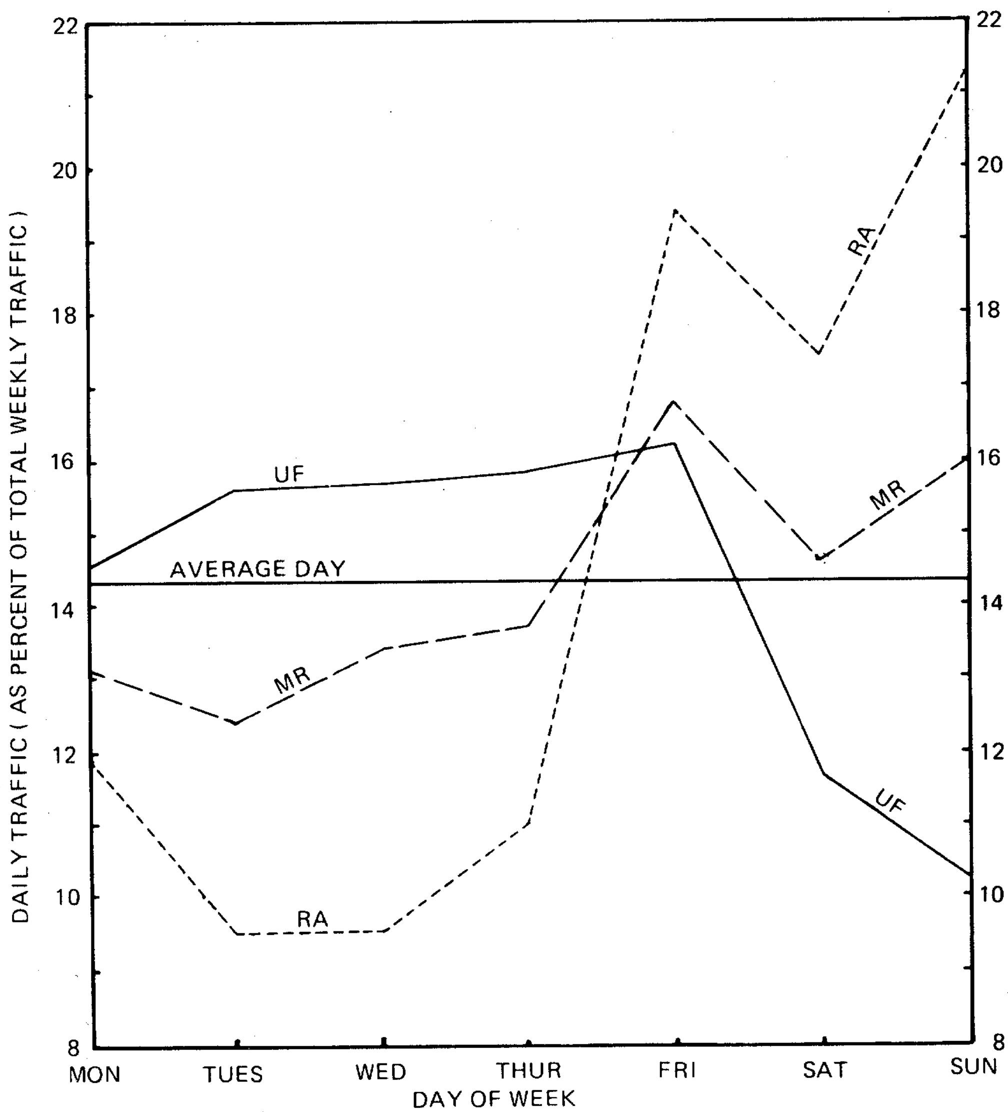


Figure 2-10. Examples of daily traffic variation by type of route. Legend: MR curve represents main rural route I-35, Southern Minnesota, AADT 10,823, four lanes, 1980; RA curve represents recreational access route MN 169, North-Central Lake Region, AADT 3,863, two lanes, 1981; UF curve represents urban freeway, four freeways in Minneapolis-St. Paul, AADTs 75,000-130,000, six to eight lanes, 1982. (Source: Transportation Research Board, 1994)

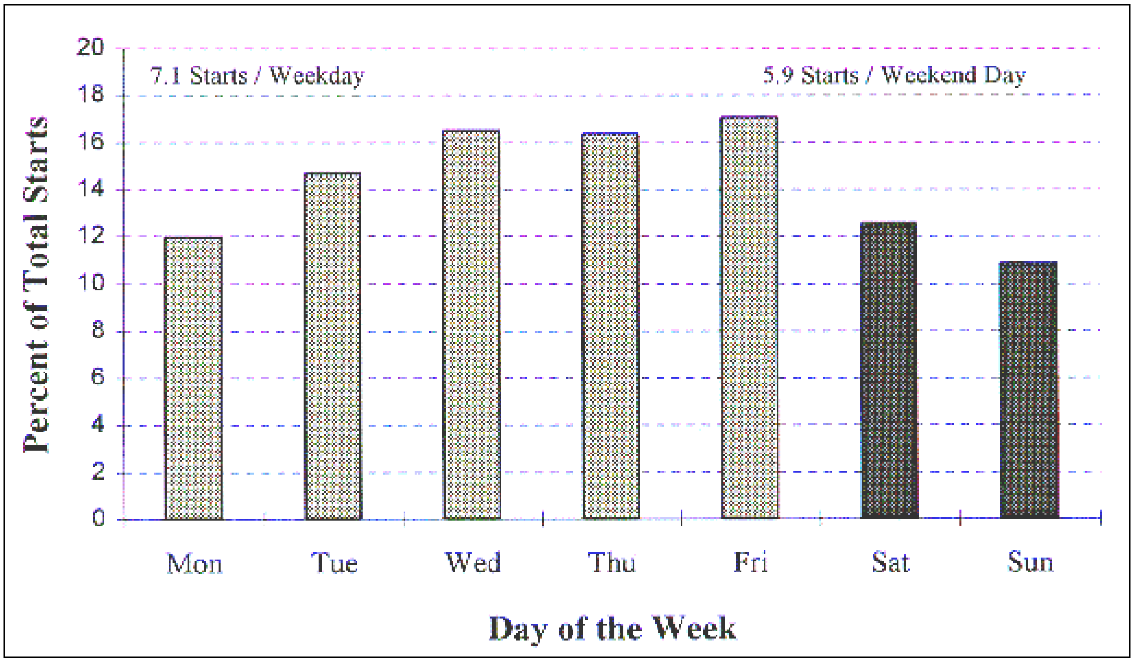


Figure 2-11. Frequency of cold engine starts observed from 1993-1995 during a study of instrumented vehicles in Los Angeles (Magbuhat and Long, 1996).

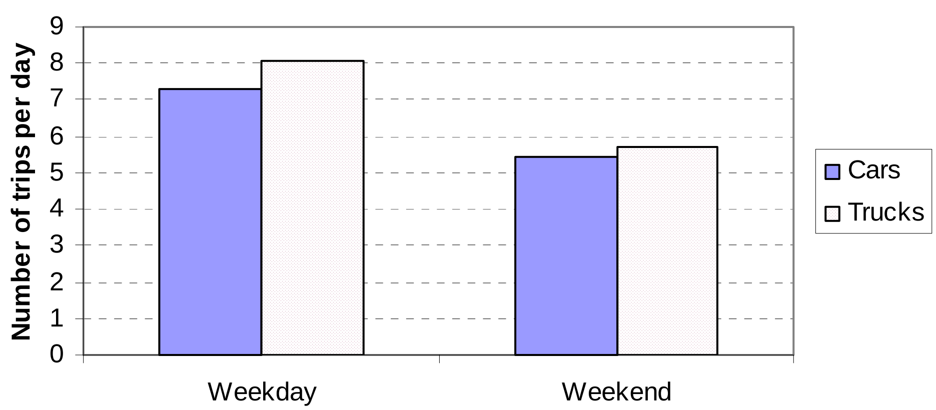


Figure 2-12. Average weekend and weekday trip frequencies (Glover and Brzezinski, 1998a).

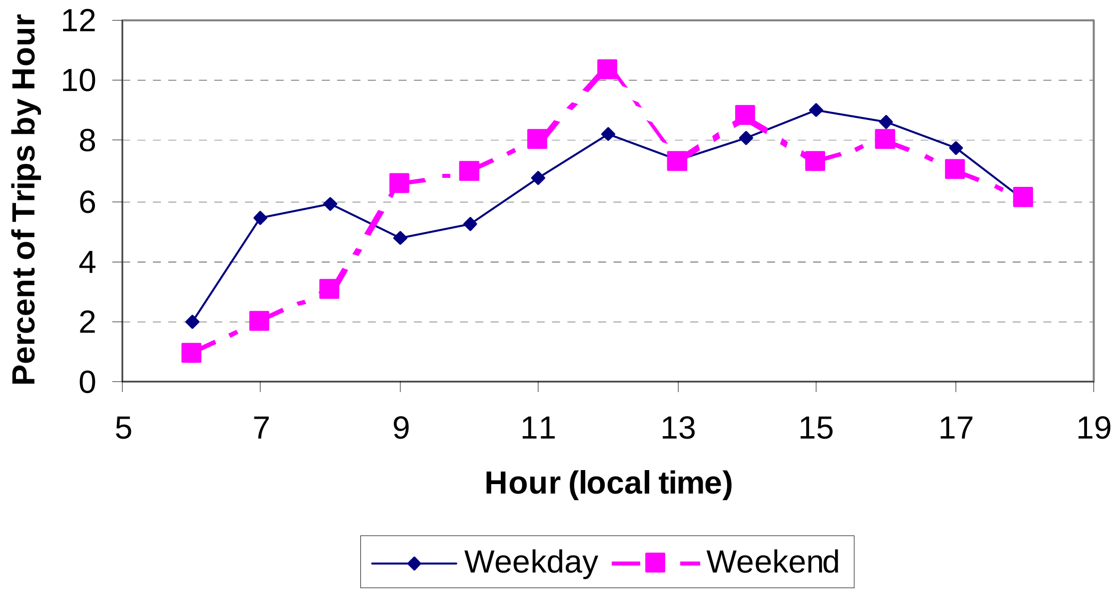


Figure 2-13. Diurnal weekend and weekday distributions of trip frequencies, expressed as a percent of total weekend or weekday trips (Glover and Brzezinski, 1998a).

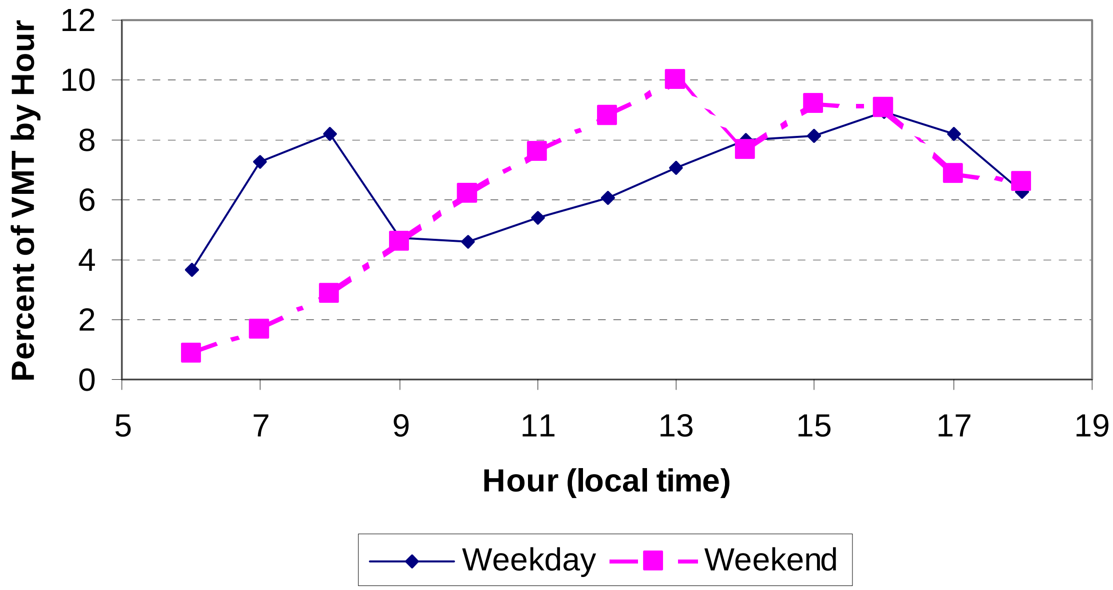


Figure 2-14. Diurnal weekend and weekday distributions of vehicle miles traveled expressed as a percent of total weekend or weekday VMT (Glover and Brzezinski, 1998a).

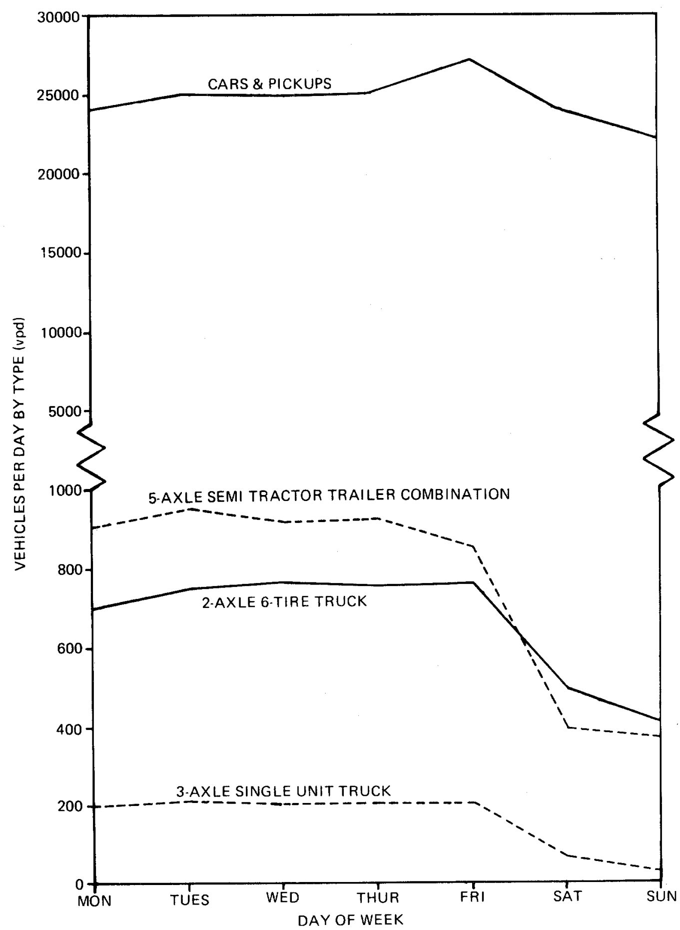


Figure 2-15. Daily variation in traffic by vehicle type. (Source: Transportation Research Board, 1994)

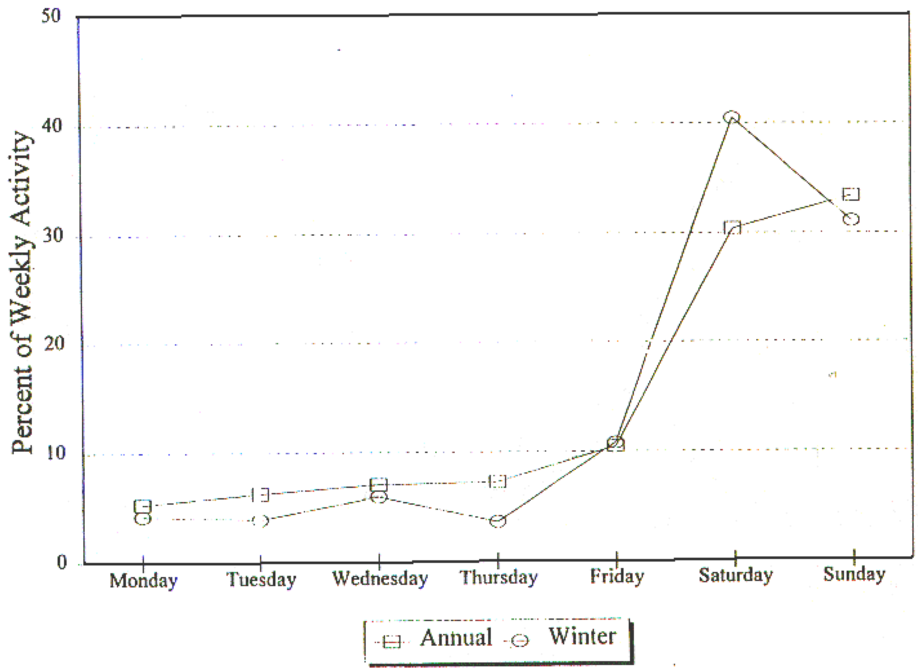


Figure 2-16. Estimated daily variation in recreational boating activity (based on fuel sales) for California. (Source: California Air Resources Board, 1995)

Table 2-1. 1996 average daily emissions in the SoCAB (California Air Resources Board, 1998).

Emissions Source	ROG (tons/day)	NO_x (tons/day)	CO (tons/day)
Total – All Sources	1,100	1,100	6,100
Stationary Sources	300	130	60
Area-wide Sources	210	34	430
On-Road Mobile Sources	500	700	4,200
Gasoline Vehicles	478	503	4,077
Diesel Vehicles	22	197	123
Other Mobile Sources	99	250	1,200
Industrial Vehicles	39	160	870
Recreational Vehicles	38	4	223
Non-road (Trains & planes etc.)	22	86	107

Table 2-2. Summary of emissions changes hypothesized for weekdays versus weekend days and relevant source categories.

Emissions Source	Spatial Pattern	Diurnal Pattern	Daily Total Emissions	Confidence Level
All Sources	Spread out	Spread out	Lower	Medium
Stationary Sources	Lower in CBD[a]	Spread out	Mixed	High
Area-wide Sources	Higher in suburbs	Higher in afternoon	Higher	Medium
On-Road Mobile	Spread out	Spread out	Lower	High
Gasoline Vehicles	Higher in suburbs	Lower in a.m.	Lower	
Diesel Vehicles	Lower in CBD	Spread out	Lower	
Other Mobile	Spread out	Spread out	Mixed	Medium
Industrial	Lower in CBD	Spread out	Lower	
Recreational	Higher in suburbs	Higher in afternoon	Higher	
Non-road (trains, airplanes, etc.)	Lower in CBD	Spread out	Lower	

[a] CBD is the central business district, i.e., downtown Los Angeles and the surrounding area of highest weekday emissions and commerce.

Table 2-3. Emissions source categories hypothesized to exhibit changes in emissions between weekdays and weekends in Los Angeles County and their contributions to total NO_x and ROG emissions.

Emissions Source Category	Percent of Total ROG Emissions	Percent of Total NO_x Emissions	Emissions Change on Weekend
Light Heavy-Duty Gasoline Trucks	<1%	20%	• Decreased truck activity (delivery trucks etc.) • Shifts in time and location of on-road mobile source emissions • Decreased number of trips of gasoline-fueled vehicles
Light-Duty Passenger Vehicles	30%	15%	• Decreased commuter activity (shifts in time and location of on-road mobile source emissions) • Increased refueling of gasoline vehicles (including Friday evening) • Decreased number of trips of gasoline-fueled vehicles
Commercial Industrial Mobile Equipment	4%	13%	• Decreased industrial activity
Light-Duty Trucks	11%	9%	• Decreased truck activity (delivery trucks etc.) • Decreased number of trips of gasoline-fueled vehicles
Heavy-Duty Diesel Trucks	<1%	6%	• Decreased diesel truck activity
Ships, Commercial Boats, Aircraft, Trains	2%	11%	• Differences in diurnal activity patterns
Manufacturing Combustion Degreasing Industrial	9%	3%	• Decreased industrial activity
Coatings and Solvents (Including Architectural Coatings)	13%	N/A	• Decreased industrial activity • Increased consumer/residential activity
Consumer Products	9%	N/A	• Increased residential activity
Petroleum Marketing	4%	<1%	• Differences in diurnal activity patterns
Recreational Vehicles	3%	<1%	• Increased recreational activity

Source of Data: California Air Resources Board Emission Inventory for Los Angeles County, 1996.

Table 2-4. Summary of emissions-related activity data identified in Phase I, Task 1.

Emissions Source Category	Type(s) of Activity Data Identified	Reference (see Appendix A)
Light-, Medium-, and Heavy-Duty Trucks	• Caltrans WIM data for freeways • Vehicle counts on surface streets • Truck population, activity and usage patterns report • Heavy-duty diesel truck activity data collected by Battelle • A&WMA paper – fuel based emission inventory for heavy-duty trucks • Off-road heavy-duty diesel vehicle activity	A B K C D E
Light Duty Passenger Vehicles	• Caltrans WIM data for freeways • Vehicle counts on surface streets • Driving behavior characteristics • Traffic counts collected during SCOS97 on freeways	A B F L
Commercial/Industrial Mobile Equipment	• Nothing identified	
Ships, Commercial Boats, Aircraft, Trains	• Marine activity data for Los Angeles and Long Beach harbors • Report - California locomotive activity data • Airport activity data for LAX	J I H
Manufacturing/Industrial	• Nothing identified	
Coatings and Solvents (Including Architectural Coatings)	• Activity profiles for auto-body refinishing, industrial/commercial adhesives and sealants, and metal products coating • Nothing identified for architectural coating	E
Consumer Products	• Nothing identified	
Petroleum Marketing	• Internal CARB Document	
Recreational Vehicles	• Activity profiles for recreational boating	G

Table 2-5. PAMS sites in the South Coast Air Basin.

Site	Type of Site
Hawthorne	Type 1
Burbank	Type 1/2
Pico Rivera	Type 2
Banning	Type 2
Azusa	Type 3
Upland	Type 4/1

Type 1 – Upwind background.
Type 2 – Maximum precursor emissions, typically located immediately downwind of CBD.
Type 3 – Maximum ozone concentration.
Type 4 – Extreme downwind transported ozone area.

3. UPPER-AIR METEOROLOGICAL AND AIR QUALITY ANALYSES

This section discusses meteorological and air quality analyses designed to improve the summer of 2000 field study and future analyses.

3.1 OVERVIEW

The SoCAB has complex meteorology and air quality processes that result in large day-to-day variations in ozone concentrations. A large portion of the variations in ozone concentrations are attributable to day-to-day variations in meteorology and not to the day-to-day (or weekday to weekend) variations in emissions. Therefore, in the absence of a large data set of weekend and weekday ozone episodes, one must account for the effects of meteorology in analyses that compare weekend and weekday episodes. Even with a modest size data set from which to perform a statistical comparison, it is not likely that the weekend or weekday episodes are, on average, meteorologically similar enough to ignore the effects of meteorology. Furthermore, it is important to perform case study analyses along with any statistical analysis and meteorology must be taken into account in case study analyses.

Of the different parameters that represent meteorology, two that have a strong day-to-day influence on ozone concentrations are winds and mixing heights. There are two ways that these meteorological characteristics might help us understand the variations in ozone concentrations between weekend and weekdays. First, if we find selected weekend and weekday episode days with very similar meteorology, then we can compare and attribute differences in the ozone concentrations to air quality processes and emissions and not to meteorological processes. Second, because it is not likely that there are many days to compare with very similar meteorology, we will need to directionally quantify how mixing heights and winds might influence ozone concentrations. Then, using directional influence information, we can use a modest size data set from which to perform a statistical comparison that takes into account meteorology.

To complete the described analyses, we must first be sure that we accurately represent the meteorology and, second, we must understand how the meteorology influences ozone concentrations. Furthermore, besides meteorology and emissions, aloft ozone also has some influence on surface ozone concentrations. Therefore, we need to understand the importance of the influence of aloft ozone and decide if it needs to be taken into account in the comparison effort. With these issues in mind, we set out to answer the following questions:

- What is the regional representativeness of the temporal and spatial variations in wind and mixing heights that can be obtained from the two Photochemical Assessment Monitoring Stations (PAMS) radar wind profilers (RWPs) at Los Angeles International Airport (LAX) and Ontario (ONT) alone? (Sections 3.2 and 3.3)
- Does the 1997 Southern California Ozone Study (SCOS97) field study have both weekend and weekday Intensive Operating Period (IOP) days that can be compared with one another? (Section 3.4)

- Is the meteorology on these IOP days similar enough to do a fair comparison of the air quality and emissions? (Section 3.4)
- How similar are the SCOS-97 episode days to Southern California Air Quality Study (SCAQS) 1987 episode days, based on the characteristics of the aloft ozone layers? (Section 3.5)
- What is the influence of the mixing heights and wind patterns on ozone concentration? (Section 3.5)

The results of analyses performed to address these questions are discussed in the following sections.

3.2 REPRESENTATIVENESS OF MIXING HEIGHTS

This section evaluates the regional representativeness of the temporal and spatial variations in mixing heights that can be obtained from the two PAMS profilers at LAX and ONT alone. Evaluation of the representativeness helps us determine whether the 2000 field study for Phase II of this project will require any additional radar profilers to accurately represent the mixing heights at selected monitoring sites in order to understand the differences between weekend and weekday ozone concentrations.

Conceptually, we believe that information about winds and mixing heights are particularly important in the middle and eastern part of the SoCAB (i.e., El Monte, Ontario, and Riverside) for understanding the weekend effect. It is in these areas where mixing heights and winds can be either marine layer dominated or convective boundary layer dominated; and the timing, evolution, and interaction of these phenomena can have a large impact on ozone concentrations.

In summary, we found that LAX and ONT do not spatially represent the temporal and spatial variations in mixing heights at two important areas in the SoCAB. On most episode days, neither LAX or ONT represent the mixing heights in the middle of the basin (i.e., EMT) or in the east basin (i.e., Riverside and Norton). Based on these results, we recommend that a radar wind profiler and radio acoustic sounding system (RASS) be operated in the vicinity of EMT and in the vicinity of Riverside (RSD) or Norton (NTN) during the 2000 field study. These two profilers, in addition to the LAX and ONT profilers, should produce the necessary mixing height data to represent areas throughout the basin, and, thus, allow us more complete data for an evaluation of the weekend effect.

To derive the representativeness conclusions, we performed a variety of data analyses using products from radar wind profiler and RASS data collected at 16 sites that operated throughout Southern California during the SCOS97 field study (see **Figure 3-1**). In particular, we used CALMET wind fields, site observation of winds, and hourly mixing heights. The CALMET wind fields and hourly mixing heights were produced as part of a work effort that we performed for the South Coast Air Quality Management District (SCAQMD) (MacDonald et al., 2000 a,b) and were available for three high-ozone episodes (August 3-7, 1997; September 3-6, 1997; and September 26-29, 1997).

3.2.1 Surface-Based Mixing Heights

In studies in several locations across the country (such as the northeastern United States and Houston and El Paso, Texas), the hourly diurnal profile of rising mixing heights in the morning and the peak mixing heights had a significant influence on maximum ozone concentrations (Dye et al., 1994, 1998; Lindsey et al., 1994; Roberts et al., 1997, MacDonald et al., 1998). Only since the installation of the two PAMS RWPs with RASS at LAX and ONT and during SCOS97 have hourly mixing heights been available for the SoCAB.

In this work, the mixing height defines the top of the surface-based mixed layer. The surface-based mixed layer is the portion of the planetary boundary layer (PBL) above the surface through which vigorous vertical mixing of heat, moisture, momentum, and pollutants occurs (Holtzworth, 1972). During the daytime at inland sites, the mixing height is defined as the altitude of a stable layer, or an inversion capping a well-mixed convective boundary layer (CBL). At night, identification of the top of the mixed layer is more complicated because often several stratified layers exist below the base of a well-defined inversion and vertical mixing is confined to the lowest tens or hundreds of meters. At coastal sites, the surfaced-based mixing height is defined as the top of the marine boundary layer.

The RWP measures, as a function of height, wind speed and direction and the radar signal-to-noise ratio, which can be used to estimate mixing height. The RASS portion of the system measures temperature as a function of altitude; the temperature data can also be used to estimate mixing heights. The mixing height data can be used to help understand the processes that might influence weekend/weekday differences in ozone concentrations and evaluate the meteorological similarity of weekend and weekday days.

As discussed in MacDonald et al. (2000b), RASS virtual temperature data coupled with surface temperature data were used to estimate hourly surface-based mixing heights when the mixing height was below the maximum height of the RASS profile [at about 1000 m above ground level (agl)]. This typically meant that RASS data were used to estimate the mixing heights at night and during the early morning hours at all sites. Furthermore, RASS data were often used to estimate the mixing heights all day at coastal sites where mixing heights are strongly influenced by the marine boundary layer and where the marine boundary layer rarely exceeded the maximum height of the RASS virtual temperature profile. At inland sites, when the convective boundary layer exceeded about 1000 m agl, the refractive index structure parameter (C_n^2) and vertical velocity data were used to estimate the mixing heights. C_n^2 indicates the fluctuations of the index of refraction, which are primarily due to fluctuations in the water content of air. Fluctuations in water content are strongest near boundaries, such as at the top of the CBL. Both theoretical and empirical studies have shown that C_n^2 peaks at the inversion located at the top of the CBL due to warm, dry, aloft air entraining into cooler, moister air below the inversion (for example, Wyngaard and LeMone, 1980). Generally, C_n^2 estimated from RWPs will not resolve low-level inversions below 200 to 300 m agl.

3.2.2 Mixing Height Characteristics

There are several characteristics of mixing heights that have been shown to be important to peak ozone concentrations and may be important in understanding differences between weekend and weekday air quality, and there are others that we hypothesize may be important. The following mixing height characteristics were considered in our evaluation of representativeness.

Peak daytime mixing height

Perhaps the most important and the most commonly assessed characteristic of mixing height is the peak daytime mixing height. The peak mixing height often occurs in the early afternoon around the time of the daily peak ozone concentration. The peak mixing height controls the maximum vertical dilution of ozone and its precursors. If the peak mixing height is high, then the vertical dilution of surface ozone at this time is large and ozone concentrations will probably be lower compared to when the peak mixing height is low and the vertical dilution of ozone is small. Obviously, as the mixing height grows during the day, it entrains aloft air. The chemical composition of this aloft air can affect the surface ozone concentration. If the aloft air is clean, then rising mixing heights will dilute surface ozone and precursor concentrations. If aloft air is polluted, surface concentrations may not show a significant change.

Mixing growth rate

Another characteristic of the mixing height that has received recent attention is the mixing growth rate (MGR) (Dye et al., 1994, 1998; Lindsey et al., 1994; Roberts et al., 1997; MacDonald et al., 1998). The MGR often characterizes the morning transition of the mixed layer from the nocturnal boundary layer to the convective boundary layer prior to the peak mixing height. In coastal areas, the MGR may represent the evolution of the marine boundary layer. For this project the MGR has been chosen to be the rate of growth from 0700 to 1200 PST. During this time, important ozone forming chemistry takes place, and the vertical dilution of ozone and ozone precursors may result in peak ozone concentrations that are different, even if the peak mixing heights are similar. The mixing growth rate may be an important key to understanding how weekend and weekday emission differences can result in different ozone concentrations. If the weekend emissions are more reactive compared to weekday emissions, then a day with a fast mixing growth rate may result in different ozone concentrations on a weekend compared to a weekday.

Mid-morning average mixing height

A mixing height characteristic similar to the MGR is the mid-morning average mixing height. For this project, the mid-morning average mixing height was chosen to be the average mixing height from 0900 to 1100 PST. This parameter may be an important characterization of mixing height for evaluating the weekend effect because during the mid-morning important ozone forming chemistry occurs. Differences in the vertical dilution of ozone and ozone precursors in the mid-morning may result in peak ozone concentrations that are different, even if the peak mixing heights are similar.

Time of peak mixing

The time of peak mixing height may also be another important characterization of mixing height for evaluating the weekend effect. If the convective boundary layer grows quickly and peaks early in the day, then the maximum vertical dilution of ozone precursors and ozone also occurs early. Again, if weekend emissions have a different ozone production rate, then a weekend day with an early peak in mixing height may produce different ozone concentrations compared to a weekday with similar meteorology.

Early morning mixing height

The early morning mixing height gives information on the state of the system at the start of the day, when ozone-producing chemistry begins. If the early morning mixing height (0200 to 0600 PST average mixing height for this project) is high, then the overnight emissions were diluted into a larger volume than if the mixing height is low. The resulting differences in chemical concentrations within the mixed layer at the start of the day could have an influence on the peak ozone concentration. Therefore, early morning mixing heights may need to be accurately represented to understand the weekend effect.

3.2.3 Method for Evaluating Mixing Representativeness

Using the hourly mixing heights from the 16 RWP/RASS stations (see **Table 3-1**) within the SoCAB, we performed a variety of objective and subjective data analyses to evaluate the representativeness of the LAX and ONT hourly mixing heights. The coastal sites include PHE, LAS, LAX, CBD, SCE, SCL, and TTN; mid-basin sites include USC, EMT, VNS, SMI, and VLC; and east-basin sites include ONT, NTN, RSD, and TCL. Figure 3-1 shows the locations of all sites, and Table 3-1 lists the site names, three-letter identifier, position, and elevation information. We performed the following:

- For each site for each of the 13 episode days, we calculated the peak daytime mixing height, the 0700 to 1200 PST mixing growth rate, the 0900 to 1200 PST mid-morning average mixing height, the time of peak mixing, and the 0200 to 0600 PST early morning mixing height. Using these data, we performed cluster analyses to determine how the sites group by each of these variables. We also performed cluster analyses on three subsets of days including a westerly sea breeze (day type 1), a southerly sea breeze (day type 2), and an offshore flow (day type 3).
- We calculated how often the hourly mixing heights from each site are within the greater of 200 m or 25 percent of the hourly mixing heights at LAX or ONT. These criteria were chosen because past studies comparing profiler- and RASS-derived mixing heights to rawinsonde-, aircraft pollutant-, and turbulence-derived mixing heights had root mean square differences of 200 m. Because mixing heights have different nighttime and daytime characteristics, we divided the data by daytime only, nighttime only, and all time and performed the calculations.
- We calculated the correlation coefficients for the hourly mixing height data between LAX and all other sites and between ONT and all other sites. We also created a dataset of "binned" mixing heights to remove the noise associated with uncertainties in the

mixing height estimates. These binned mixing heights were created by setting the hourly mixing heights at a candidate site equal to the mixing heights at LAX or ONT if the hourly mixing heights at the candidate site were within the greater of 200 m or 25 percent of the hourly mixing heights at LAX or ONT. Again, we divided the frequency of occurrence by daytime only, nighttime only, and all time.

- We created scatter plots of hourly mixing heights at LAX and other coastal sites and ONT and mid- and east-basin sites.
- We plotted and subjectively analyzed time-series plots of mixing heights at the 16 RWP/RASS stations.
- We plotted and subjectively analyzed hourly spatial contour plots of mixing heights using data from stations throughout the SoCAB and surrounding areas.
- We plotted the east-basin, mid-basin, and coastal sites' daily average peak afternoon mixing heights. We then compared the daily average peak mixing height of each region to the daily peak mixing height at LAX, EMT, ONT, and RSD.

3.2.4 Mixing Results and Conclusions

Neither LAX or ONT spatially represent the temporal and spatial variations of mixing heights at two important areas in the SoCAB. On most episode days, neither LAX nor ONT represent the mixing heights in the middle of the basin, including the mixing heights at USC, EMT, VNS, SMI, and VLC or in the far east basin including NTN, RSD, and TCL. Furthermore, the analyses suggest that EMT and RSD are representative of the mid-basin and east basin, respectively. Examples of the analyses from which these conclusion were derived are presented below.

Subjective review

Time-series plots and spatial contour plots of hourly mixing heights indicate that the mixing heights derived from the radar profiler and RASS data are conceptually reasonable. Mixing heights at coastal sites show little diurnal variability indicating a marine layer-dominated boundary layer. Whereas, the far inland sites show a strong diurnal cycle from the nocturnal boundary layer to the convective boundary layer, with little apparent marine influence. Finally, the mid-basin sites have more diurnal variability than the coastal sites, but the height of the convective boundary layer growth is only half as much as the inland sites. The limited CBL growth at these sites is likely due to cool marine air suppressing the convective mixing.

In terms of representativeness, the time-series plots indicate that mixing heights at LAX are representative of the mixing heights at coastal sites and not the mid-basin sites, as expected. For example, the time-series plots of hourly mixing heights on September 3-4, 1997, shows that mixing heights at LAX ranged from 250 m agl to only 600 m agl (Figure 3-2). Despite the hourly variability in mixing heights, the relatively steady mixing height at LAX are similar and representative of other coastal sites such as CBD, SCE, SCL, and PHE but are not representative of mid-basin sites such as USC, EMT, VNS, and SMI.

ONT, which has a diurnal cycle from the nocturnal to convective boundary layer, with some indications of a marine influence, has a diurnal pattern similar to those of the mid-basin and east-basin sites; however, the maximum mixing heights do not represent any site often enough to be representative. For example, on some days, such as September 26, 1997, ONT is somewhat representative of a mid-basin site such as EMT; whereas, on other days, such as August 4, 1997, ONT is not similar to EMT, but is similar to an inland site such as RSD.

The average coastal, mid-basin, and east-basin regions each have distinct daily peak mixing heights (**Figure 3-3**). Comparing the three regions daily average peak mixing heights to other sites further illustrates that LAX represents coastal sites, and ONT waivers between representing a mid-basin site and east-basin sites. As shown in Figure 3-3, the peak mixing heights at coastal sites are about 500 m and show little day-to-day variability. The peak mixing heights at mid-basin sites are about 800 m during the August episode and about 1400 m during the September episodes. The peak mixing heights at east-basin sites have the greatest variability, ranging from about 900 m on August 7 to about 2900 m on September 3 and 4. Comparison of the daily peak mixing heights at LAX to the coastal and mid-basin average peak mixing heights indicates that peak mixing heights at LAX are representative of the coastal average, but are not representative of the mid-basin average (**Figure 3-4**). Comparison of the daily peak mixing heights at ONT to the mid-basin and east-basin averages indicates that peak mixing heights at ONT are sometimes representative of the mid-basin average and sometimes representative of the east-basin average (**Figure 3-5**). Comparison of the daily peak mixing heights at EMT to the daily peak mixing heights in the mid-basin indicates that the peak mixing heights at EMT are representative of the mid-basin average (**Figure 3-6**). Finally, comparison of the daily peak mixing heights at RSD to the daily peak mixing heights in the east basin indicates that the peak mixing heights at RSD are generally representative of the east-basin average (**Figure 3-7**).

Cluster analyses

Cluster analyses were performed using the peak daytime mixing height, the mixing growth rate, the mid-morning average mixing height, the time of peak mixing, and the early morning mixing height. Results show that LAX grouped well with all coastal sites for all parameters except for the average early morning mixing height and the time of peak mixing. Whereas, ONT grouped poorly with all sites for all parameters. For example, as shown in Figure 3-8, for the peak mixing height cluster, LAX grouped well with SCE, SCL, PHE, and CBD [Euclidean (root mean square) distances less than 200 m], fair with TTN, LAS, VLC, USC, and EMT (Euclidean distances between 200 and 250 m), and poor with the east-basin sites (Euclidean distances greater than 400 m). ONT, on the other hand, did not group well with any site (Euclidean distances greater than 400 m for this parameter).

For the most part, the cluster analyses by day type showed results similar to those of the all day's cluster analyses, with a few exceptions. For all parameters, except the early morning mixing height and time of peak, there were better groupings among coastal sites on day types 2 and 3 (southerly sea breeze and offshore days, respectively) compared to day type 1 (westerly sea breeze). Also, the peak mixing height at mid-basin sites grouped best on day type 2 (Euclidean distances less than 200 m). Furthermore, the mid-basin site, EMT, grouped very well with LAX (Euclidean distances of 80 m) on day type 2.

Correlations, scatter plots, and frequency bins

The correlation coefficients (r) of hourly mixing heights and frequency of equal mixing height are summarized in Table 3-2 for ONT and Table 3-3 for LAX. In these tables, correlation coefficients greater than 0.6 are bold and frequencies greater than 0.7 are bold for mixing heights that are within the greater of 200 m or 25 percent of LAX or ONT. Scatter plots were used in the analysis to allow for a more robust interpretation of the correlations.

LAX correlated poorly with all sites, day or night. Despite LAX's poor correlation, the mixing heights were within 200 m or 25 percent of the coastal sites at least 60 percent of the time during the day and even more often at night. The higher frequency of agreement at night makes sense because there is much smaller spatial variation in mixing heights at night compared to during the day. These analyses indicate that despite a poor correlation with other sites, the mixing heights at LAX reasonably represent the mixing heights at coastal sites during the day and at night.

Mixing heights at ONT correlated fair to good with mixing heights at mid-basin and east-basin sites and poorly with coastal sites. The correlation coefficients between ONT and RSD, NTN, and Simi Valley were about 0.7 for all times. Despite the high correlation with these sites, the frequency of the mixing heights being within the greater of 200 m or 25 percent was only around 50 percent during the day for the mid- and east-basin sites. At night, the frequencies were much higher. The positive correlation during the day and the relatively poor frequency numbers during the day mean that although the hourly mixing heights at ONT have similar daily cycles, the magnitudes of the cycles are not similar. Furthermore, as the scatter plot of hourly mixing heights between ONT and RSD shows (**Figure 3-9**), the good correlation between these sites is driven by mixing heights below 1000 m. When mixing heights at RSD are 2000 to 4000 m agl, the correlation between mixing heights at RSD and ONT sites is poor. Therefore, without a site near RSD, this important information that indicates high mixing heights east of ONT would be unavailable.

3.3 REPRESENTATIVENESS OF WINDS

As part of a work effort for the SCAQMD, MacDonald et al. (2000a) used wind data collected by the 16 RWP during three high-ozone episodes in 1997 (August 3-7, September 3-6, and September 26-29) to develop three-dimensional CALMET diagnostic wind fields. The locations of the RWP are shown in Figure 3-1. Using the wind fields, we prepared hourly CALMET wind-field plots for each episode day for three elevations:

- 40 m agl (level 1), 486 m agl (level 5), 1671 m agl (level 15) representing the surface layer;
- a layer within the midday mixed layer (e.g., 400 or 600 m agl); and
- a layer above the mid-basin midday mixed layer (e.g., 1000 to 2000 m agl).

Using these CALMET wind fields, in conjunction with the observed wind profiles at the 16 sites shown in Table 3-1, we subjectively evaluated the regional representativeness of the temporal and spatial variations in wind that can be obtained from profiler data collected at LAX and ONT alone.

In summary, we found that the aloft winds measured at LAX are reasonably representative of winds at other surrounding coastal sites including USC, LAS, TNN, and PHE, and are often not representative of winds at mid- or east-basin sites such as EMT, ONT, RSD, and NTN. Also, we found that the winds measured at ONT are reasonably representative of winds at other surrounding inland sites including RSD and NTN and are often not representative of mid- basin or coastal sites such as EMT and LAX. Particular observations from the analyses are presented below.

During the three 1997 ozone episodes, a variety of meteorological conditions were characterized by the synoptic weather pattern, wind fields and mixing heights. A more detailed comparison of these episodes is presented in Section 3-4. Of importance to our wind representative analysis are the varying wind-flow patterns. These patterns included strong westerly sea breeze flow, moderate southerly sea breeze flow, light offshore easterly flow, and strong offshore northerly flow. The representativeness of the aloft winds measured at LAX and ONT depended on these flow types and flow strength. In general, the stronger the winds, the more representative the winds at LAX and ONT were of the winds in the rest of the SoCAB. Under light flow patterns, when local forcing tends to dominate the winds, LAX and ONT were less representative of the winds in the rest of the SoCAB.

Because there are many surface monitors throughout the basin that represent the lower level winds (i.e., 40 m agl) and because the winds at 1671 m agl are often above the boundary layer, we focused our observations on the 486 m agl boundary-layer winds. Note that the figures described next are spatial plots of wind fields; the CALMET diagnostic wind fields are displayed as narrow arrows and the observations are displayed as bold fat arrows. Observations of boundary-layer winds during the three SCOS97 episodes include the following:

- Under sea breeze conditions, there was no obvious timing delay in the start of onshore flow during the day between the coastal sites and inland sites.
- Under strong sea breeze conditions, winds at LAX were representative of the winds in the entire basin including winds at RSD, ONT, and NTN. For example, **Figure 3-10** shows the wind field on September 4, 1997, at 1500 PST.
- Under moderate sea breeze conditions, winds at LAX were representative of the winds at USC, TTN, LAS and often EMT. For example, **Figure 3-11** shows the wind field on September 26, 1997, at 0300 PST.
- Under light wind conditions, winds at LAX were often representative of the winds at USC.
- Under westerly sea breeze conditions at LAX, the winds at TTN and LAS tended to be more northwesterly.
- Under northerly or northeasterly flow in most of the mid- and east basin, winds at LAX were generally not representative of the winds at most sites. For example, **Figure 3-12** shows the wind field on September 28, 1997, at 0900 PST.

- Under strong sea breeze flow, winds at ONT were representative of the winds at NTN and RSD; however, winds at RSD were, at times, northwesterly when winds at ONT and NTN were westerly. For example, **Figure 3-13** shows the wind field on September 28, 1997, at 1500 PST.
- Under offshore flow, wind direction at ONT was usually representative of wind direction at NTN and RSD, but the wind strength was sometimes lighter at ONT than at NTN and RSD. Winds at ONT were generally not representative of winds at EMT or coastal sites under the offshore flow pattern.

3.4 EVALUATION OF THE METEOROLOGY DURING THE SCOS97 OZONE EPISODES

The wealth of both air quality and meteorological data collected during the SCOS97 field study provides an excellent opportunity to add to our understanding of the weekend ozone effect. This section discusses the possibility of taking advantage of this episodic data set. To do so, we must first determine if there were both weekend and weekday IOP days to compare. Second, if there were weekend and weekday IOP days, we must determine if the meteorology on these IOP days is similar enough to do a fair comparison of the air quality and emissions.

In summary, there were two weekend episodes and three weekday episodes. In our analyses, we did not consider one of these weekday episodes (July 14) because we did not have the necessary data readily available to complete our analyses. Of the four episodes, there were three distinct synoptic meteorological patterns. Of the two episodes with similar synoptic meteorology, one was a weekend episode and the other was a weekday episode; therefore, these episodes are candidates for comparison of weekend and weekday air quality. Finally, because the meteorology of the ozone episodes is significantly different on some days, modeling of the weekend and weekday effect should be done using different meteorological patterns and not just one pattern.

To derive these conclusions, we analyzed the daily National Weather Service synoptic weather charts, Eta Data Assimilation System (EDAS) archive, hourly mixing heights throughout the SoCAB, hourly CALMET wind fields for three elevations (40 m agl , 486 m agl, and 1671 m agl), and ozone data for each episode day. As mentioned previously, the hourly mixing heights and CALMET wind fields were developed as part of a work effort for the SCAQMD (MacDonald et al., 2000 a,b). As part of this project, we produced mixing heights for a fourth episode (August 22 and 23, 1997) at LAX, EMT, ONT, and RSD. These sites were chosen because Section 3-1 showed that mixing heights at these sites generally represent mixing heights throughout the basin.

During the SCOS97 field program there were four major IOP ozone episodes in the SoCAB including August 4-7 (Monday through Thursday), August 22-23 (Friday and Saturday), September 3-4 (Wednesday and Thursday), and September 26-27 (Saturday and Sunday). The peak 1-hr and 8-hr ozone concentrations for these episodes are shown in **Table 3-4**.

The August 4-7 episode was characterized by a strong upper-level ridge that built in from the east over Southern California **(**e.g., **Figure 3-14)**. This resulted in weak offshore flow in the east basin, light variable flow in west basin at night. and weak onshore flow during the day. The strong upper-level ridge also resulted in low mixing heights throughout the mid-basin (about 750 m agl) and coastal sites (about 500 m agl) throughout the episode. The east basin also had low mixing heights on August 4 and 7, but had relatively high mixing heights in the middle of the episode. A summary of the peak mixing heights for all episodes can be found in Figure 3-3 for the area averages and in Figure 3-15 for LAX, EMT, ONT, and RSD. Figure 3-15 was added because the area averages were unavailable for the August 22-23 episode.

The August 22-23 episode was characterized by a “battle” between an upper-level high-pressure system east of southern California and an upper-level trough of low pressure located off the coast of northern California. With the trough offshore, and the ridge being unable to build in over southern California as it did during the August 4-7 episode, the sea breeze was stronger during August 22-23 than during August 4-7. Also, the peak mixing heights at the mid-basin site (EMT) were slightly higher during August 22-23 than during August 4-7 but were similar at the coast (LAX) and east basin (ONT and RSD) (e.g., Figure 3-15). These meteorological differences and their likely influence on ozone concentrations between the two August episodes would probably overwhelm any signal from the differences in emissions between the weekday episode (August 4-7) and weekend episode (August 22-23). Therefore, these two August episodes are not the best cases for comparison to understand the weekend effect.

Similar to the August 22-23 episode, the September 3-4 episode was characterized by a “battle” between an upper-level high-pressure system east of southern California and an upper-level trough of low-pressure located off the coast of northern California. However, the trough was not quite as dominant in the September 3-4 episode as during the August episode. Because of the weaker trough, the onshore flow during this episode was slightly weaker than the onshore flow, and the offshore flow at night in the east basin was slightly stronger, compared to the August 22-23 episode. As shown in Figure 3-15, the peak mixing heights between the September 3-4 episode and the August 22-23 episode were similar at LAX and EMT but lower during the August 22-23 episode at ONT and RSD. Despite the differences in onshore flow strength and inland peak mixing heights, these two episodes probably have similar enough meteorology to be good candidates for a more detailed weekend and weekday analysis.

The September 27-29 episode was characterized by a strong surface high-pressure system over the intermountain west (between the Sierra Nevada and Rocky Mountain ranges) with a thermal trough along the coast. This pattern resulted in northerly flow at night that reached the coast and weak onshore flow during the day, with the exception of offshore flow through Simi Valley. Mixing heights were very similar to the September 3-4 episode, being low at the coast, moderate in the mid-basin, and relatively high in the east basin. Unlike September 3-4, however, there was strong offshore flow at the 850-mb level during September 27-29. This episode does not have meteorology similar enough to any of the other episodes to be a candidate for a more detailed weekend and weekday analysis.

3.5 MIXING HEIGHTS, WINDS, AND ALOFT OZONE

Previous analyses of aloft ozone data from SCAQS have shown the presence of deep layers (about 500 m) of high ozone concentrations over a wide portion of the SoCAB (e.g., Roberts and Main, 1992). The aloft ozone can contribute to the surface ozone concentrations when mixed to the surface during the day. During SCOS97 a Lidar located at EMT collected aloft ozone data from 90 m agl to about 2500 m agl during IOPs. Aloft wind and mixing height data were also collected at EMT. Using these data we evaluated the variability of the characteristics of these aloft ozone layers during ozone episodes and evaluated the similarity of the SCOS97 episode days to SCAQS 1987 episode days, based on the characteristics of the aloft ozone layers and investigated the influence of the mixing heights and wind pattern on ozone concentrations.

We created time-height cross sections of ozone data (collected by the Lidar), mixing heights, and winds for four 1997 episode days. The episode days included August 4-5 (Monday and Tuesday) and August 22-23 (Friday and Saturday). Originally, we wanted to use September 3-4 instead of August 4-5 because, as discussed in the previous section, September 3-4 and August 22-23 had similar synoptic meteorology and were week days and weekend days, respectively. However, Lidar data were unavailable for September 3-4. We also created time-series plots of surface ozone and mixing heights at Upland/Ontario and Rubidoux/Riverside for August 3-7, August 22-23, September 3-6, and September 26-29, 1997. For the evaluation of the similarity of the SCOS97 episode days to 1987 episode days, we reviewed aloft ozone data collected at EMT on four 1987 episode days and compared these data to the aloft ozone data collected on four 1997 episode days.

In summary, we found that the interaction among winds, mixing heights, and ozone concentrations is too complex to form any definitive conclusions (in this preliminary analysis) about their relationship and how their relationship might influence differences in ozone concentrations between weekdays and weekends. We recommend a more detailed investigation of mixing heights, winds, and ozone concentrations in Phase II. Also, we found that the morning aloft ozone concentrations at EMT for selected 1997 episodes were about half the aloft ozone concentrations observed during selected 1987 episodes. Although only a few days were compared, the observation does suggest that contribution of aloft ozone to surface ozone may not be as significant now as it was in 1987. Some details of our observations are presented below.

Although the relationship among the vertical structure of ozone, mixing heights, and winds is too complex to form any definitive conclusions from these preliminary analyses, important observations were made. Several of these observations refer to **Figures 3-16 through 3-19**. These figures show time-height cross sections of ozone data (collected by the Lidar), mixing heights, and winds at EMT during 1997.

- Mixing heights are lower at EMT in the afternoon than during midday hours on all four case-study days. The lowering of the mixing heights appears to be associated with the intrusion of marine air undercutting the CBL.
- On August 4, despite the lowering of the inversion, boundary layer ozone concentrations decreased from about 100 ppb at 1400 PST to 60 ppb at 1600 PST (Figure 3-16). The decrease in ozone over this period is probably associated with clean marine air. A similar pattern was observed on August 5 (Figure 3-17). On the other hand, on August 23, ozone concentrations did not decrease at EMT when the afternoon mixing heights lowered, even with apparent marine intrusion (Figure 3-19).

- On August 5, there was a layer of high ozone concentrations between 500 and 1000 m agl during 1400 to 1700 PST (Figure 3-17). The high ozone concentrations were above the mixed layer at EMT. It is not clear where this pool of high ozone concentrations came from. The winds prior to this time were light easterly in the morning and strong westerly during the time of high ozone concentrations. Given the mixing height and the location of the high ozone concentrations above the boundary layer, it appears that the high ozone did not contribute to the surface ozone concentrations at EMT on this day.
- On August 4, there were no high concentrations of aloft ozone above the mixed layer. The winds above the mixed layer were from the northwest during the morning and afternoon (Figure 3-16).
- On August 23, there were three distinct layers of high ozone concentrations aloft (Figure 3-19). There was a thick layer of high ozone concentrations (130 to 150 ppb) between about 600 and 1000 m agl; this layer was above the mixed layer. Winds in this layer were from the southeast until 1400 PST. At 1500 PST, when the plume appeared, the 1000 m agl wind was from the north. Below the mixed layer, there were two other pools of high ozone concentrations: one at about 500 m agl and one at about 100 m agl.
- Time-series plots of surface ozone and mixing heights at Upland/Ontario and Rubidoux/Riverside show no distinct relationship. For example (see **Figure 3-20**), on August 7, the peak mixing height at RSD was only 1000 m agl, and the peak surface ozone concentration was about 105 ppb; whereas, on August 5, the peak mixing height was 2500 m agl, yet the peak surface ozone concentration was about 190 ppb.
- For selected case-study comparisons, aloft ozone concentrations observed in 1997 were less than those observed in 1987, and the peak surface ozone concentrations were much less in 1997 compared to 1987. The aloft ozone data collected at EMT during the four episode days in 1997 show a layer of aloft ozone ranging from 60 ppb to about 100 ppb at about 0800 PST on all four days (Figures 3-16 to 3-19). Whereas, the SCAQS aircraft flights over EMT on episode days show aloft morning ozone concentrations ranging from 100 to 200 ppb (Roberts and Main, 1992). This could mean that the ozone system in 1997 was different from that in 1987, or the particular case studies were different, or there was a combination of both of these points.

3.6 CONCLUSIONS AND RECOMMENDATIONS

We have investigated several important meteorological and air quality questions formulated to improve the design of the 2000 field study and to guide future analyses. Below are the questions that we investigated, our conclusions, and our recommendations.

- *What is the regional representativeness of the temporal and spatial variations in wind and mixing heights that can be obtained from the two PAMS profilers at Los Angeles International Airport (LAX) and Ontario (ONT)?*

  Conclusion. Winds and mixing heights at LAX and ONT do not spatially represent the temporal and spatial variations in wind and mixing heights at two important areas in the SoCAB. On most episode days, neither LAX nor ONT represents the mixing heights in the middle of the basin (i.e., EMT) or in the far east basin (i.e., RSD and NTN). On some episode days, neither LAX nor ONT represents the mid-basin winds.

Recommendation. We recommend that a radar profiler and RASS system be operated in the vicinity of EMT and in the vicinity of RSD or NTN during the 2000 field study. The addition of these two profilers to the LAX and ONT profilers should produce the necessary wind and mixing height data to properly evaluate the weekend effect.

- *Does the SCOS97 field study have both weekend and weekday IOP days that can be compared with one another? Is the meteorology on these IOP days similar enough to do a fair comparison of the air quality?*

  Conclusion. There were two weekend IOP episodes and three weekday IOP episodes during SCOS97. In our analyses, we did not consider one of the weekday episodes (July 14) because we not have the necessary data readily available to complete our analyses. Of the four episodes, there were three distinct synoptic meteorological patterns. Of the two episodes with similar synoptic meteorology, one was a weekend episode (August 22-23) and the other was a weekday episode (September 3-4); therefore, these episodes are candidates for comparison of weekend and weekday air quality.

  Recommendation. Because the meteorology of the ozone episodes is significantly different on some days and because the different meteorological conditions may enhance or degrade the weekend effect, modeling that attempts to understand the weekend effect must be completed based on a number of meteorological conditions.

- *What is the influence of the mixing heights and wind patterns on ozone concentrations? How similar are the SCOS97 episode days to the SCAQS 1987 episode days based on the characteristics of the aloft ozone layers?*

  Conclusion. The interaction among winds, mixing heights, and ozone concentrations is too complex to form any definitive conclusions in this preliminary analysis about their relationship and how their relationship might influence the weekend effect. We found that the morning aloft ozone concentrations at EMT on selected 1997 episodes were about half the aloft ozone concentrations observed during selected 1997 episodes. Although the comparison was done with only a few days, the observation suggests that contribution of aloft ozone to surface ozone may not be as significant now as it was in 1987

  Recommendation. We recommend a more detailed investigation of mixing heights, winds, and ozone concentrations in Phase II..

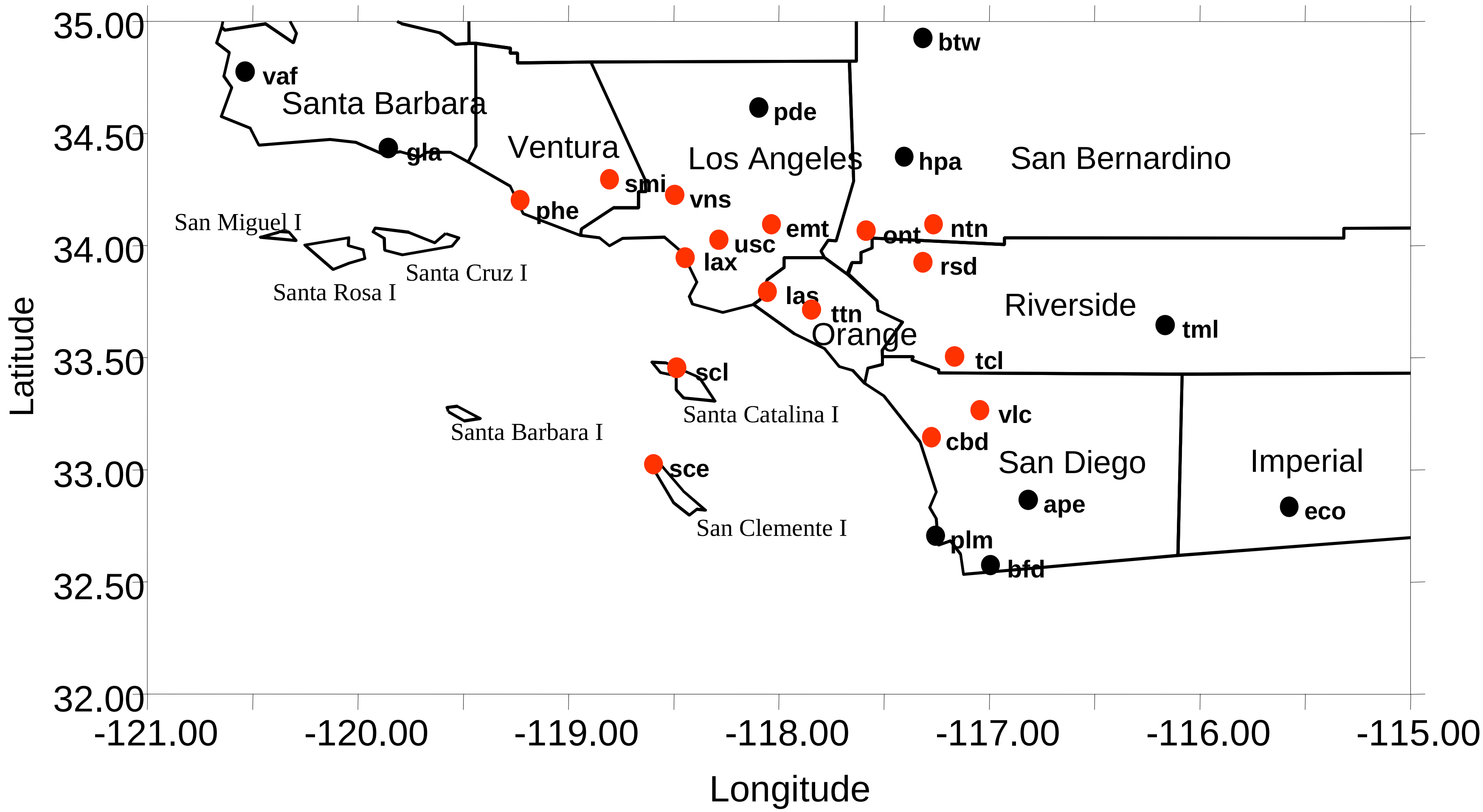


Figure 3-1. RWP/RASS sites operated during the SCOS97 field study. The 16 sites considered in this work are shown in red.

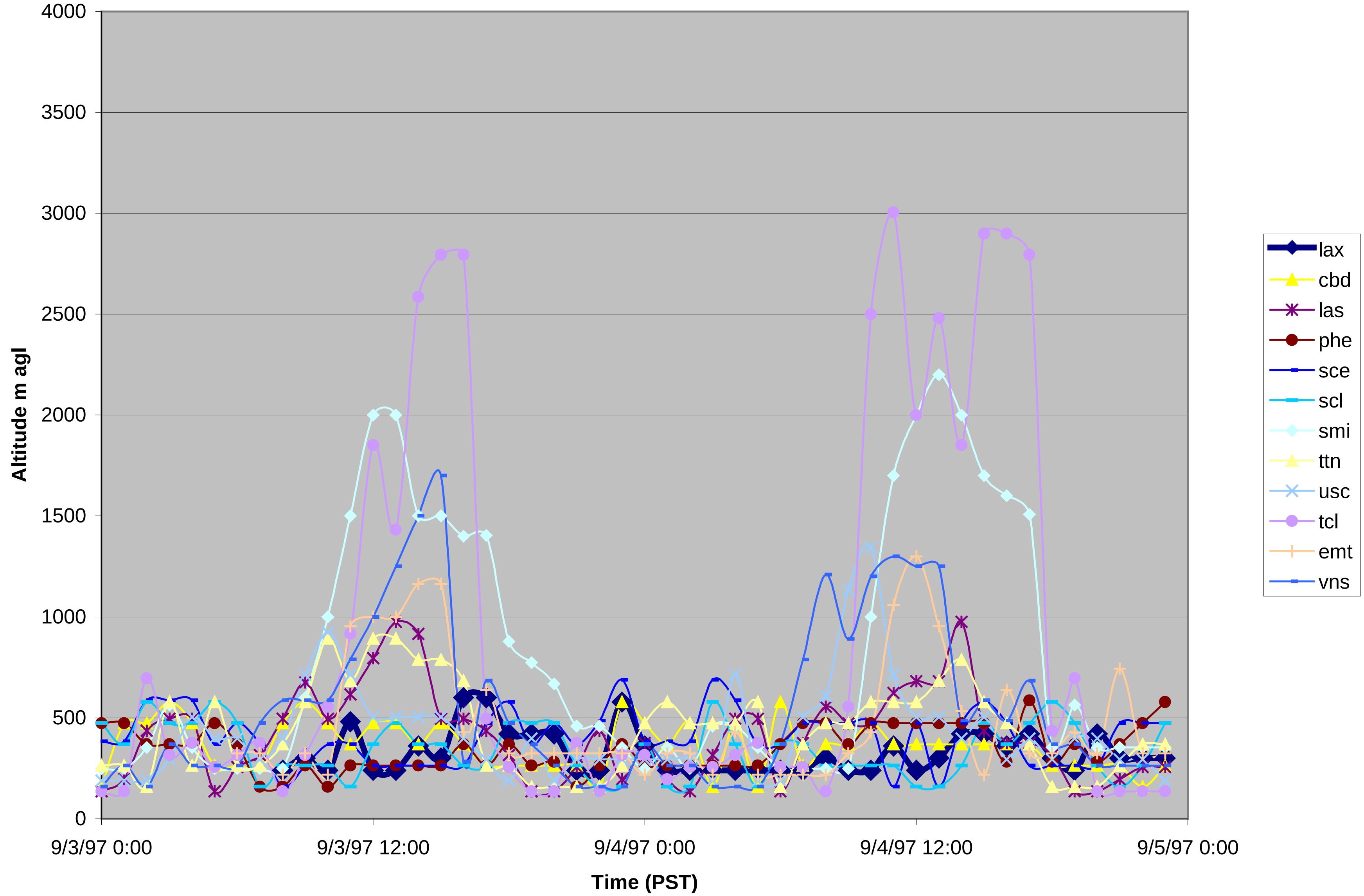


Figure 3-2. Mixing height time-series plot for coastal and mid-basin sites in the SoCAB on September 3- 4, 1997. Coastal sites include LAX, CBD, SCE, and PHE.

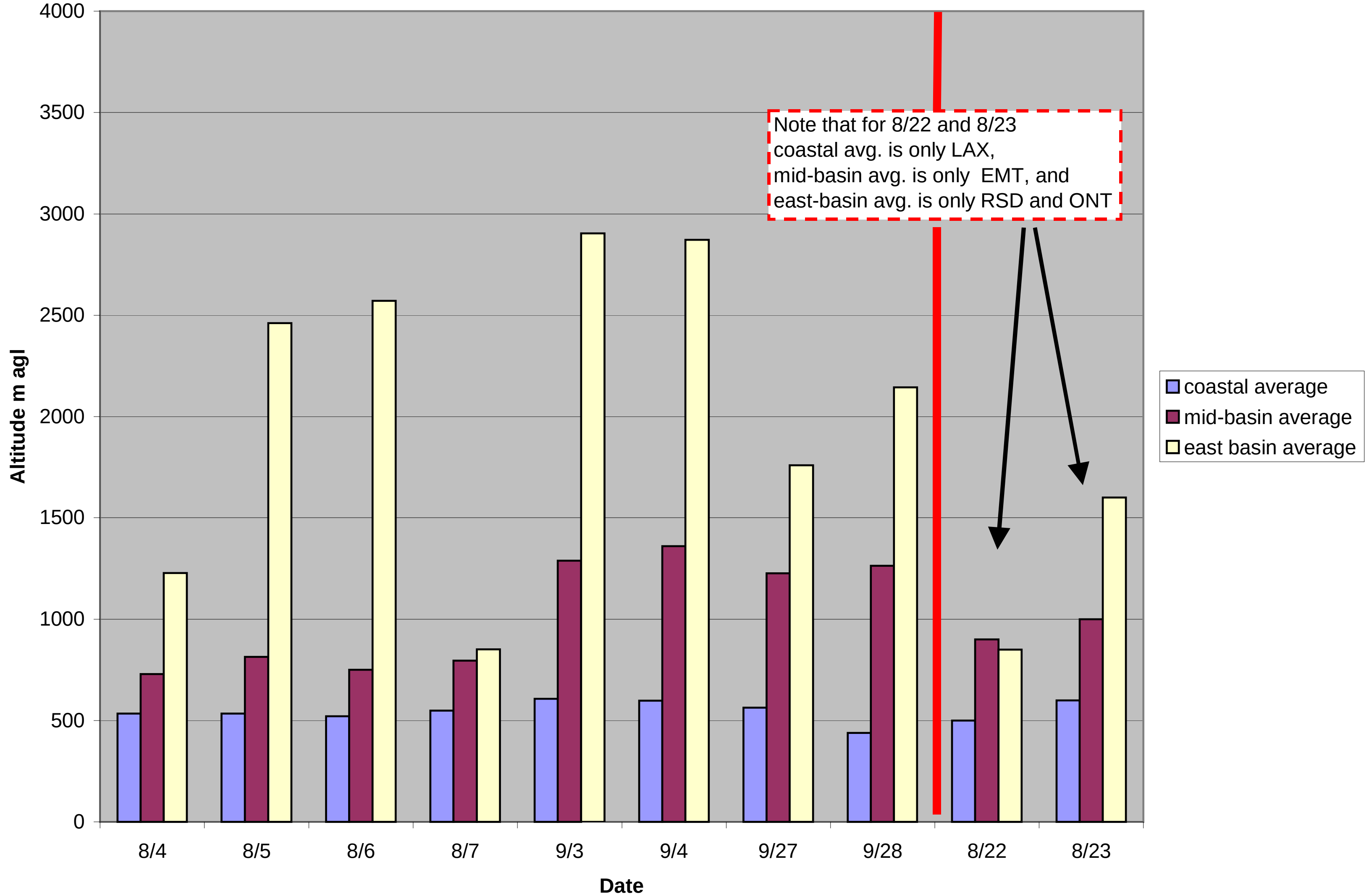


Figure 3-3. Daily average peak mixing heights for coastal sites, mid-basin sites, and east-basin sites during four SCOS97 episodes.

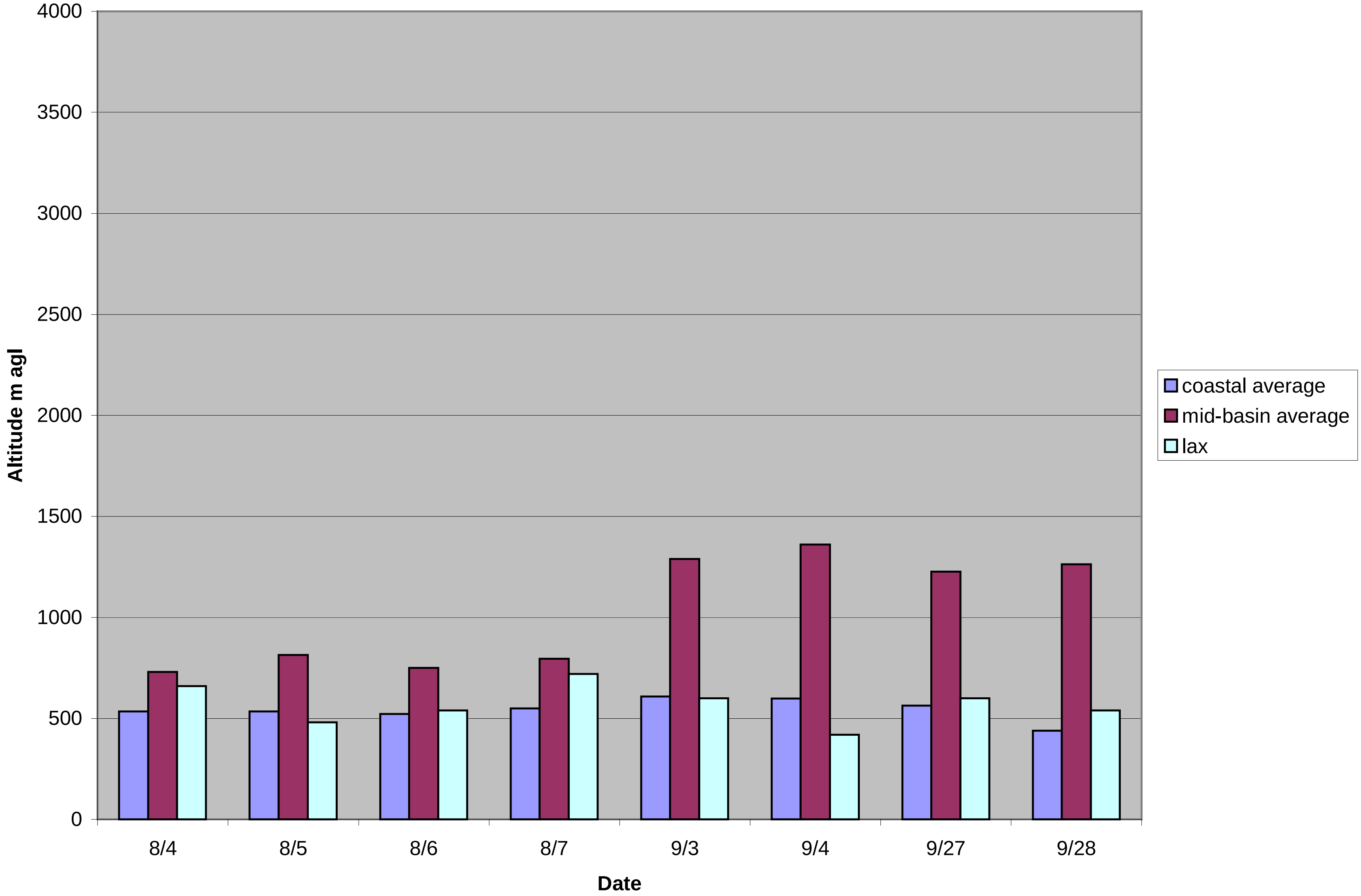


Figure 3-4. Daily average peak mixing heights for coastal sites, mid-basin sites, and LAX during three SCOS97 episodes.

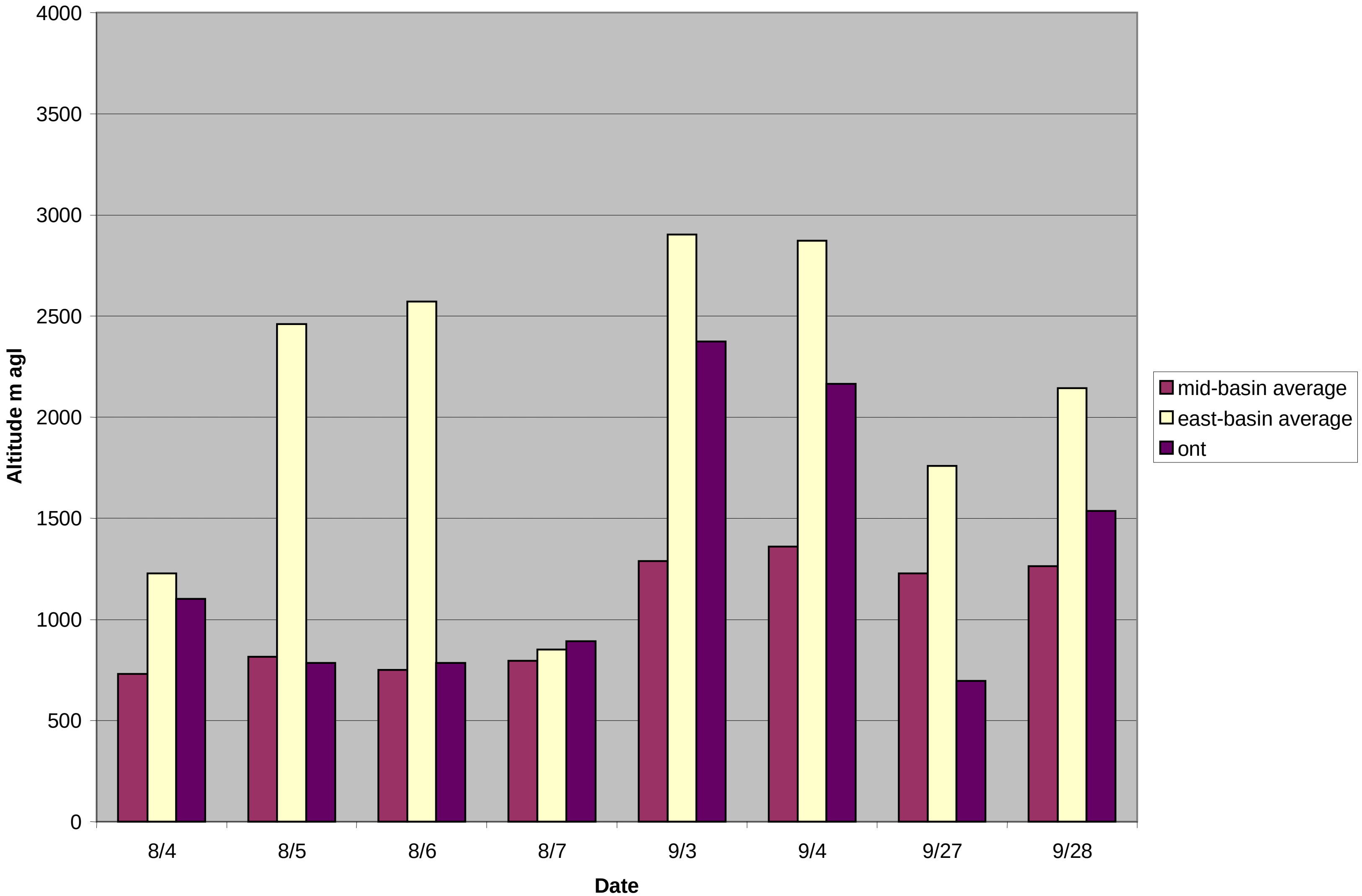


Figure 3-5. Daily average peak mixing heights for mid-basin sites, east-basin sites, and ONT during three SCOS97 episodes.

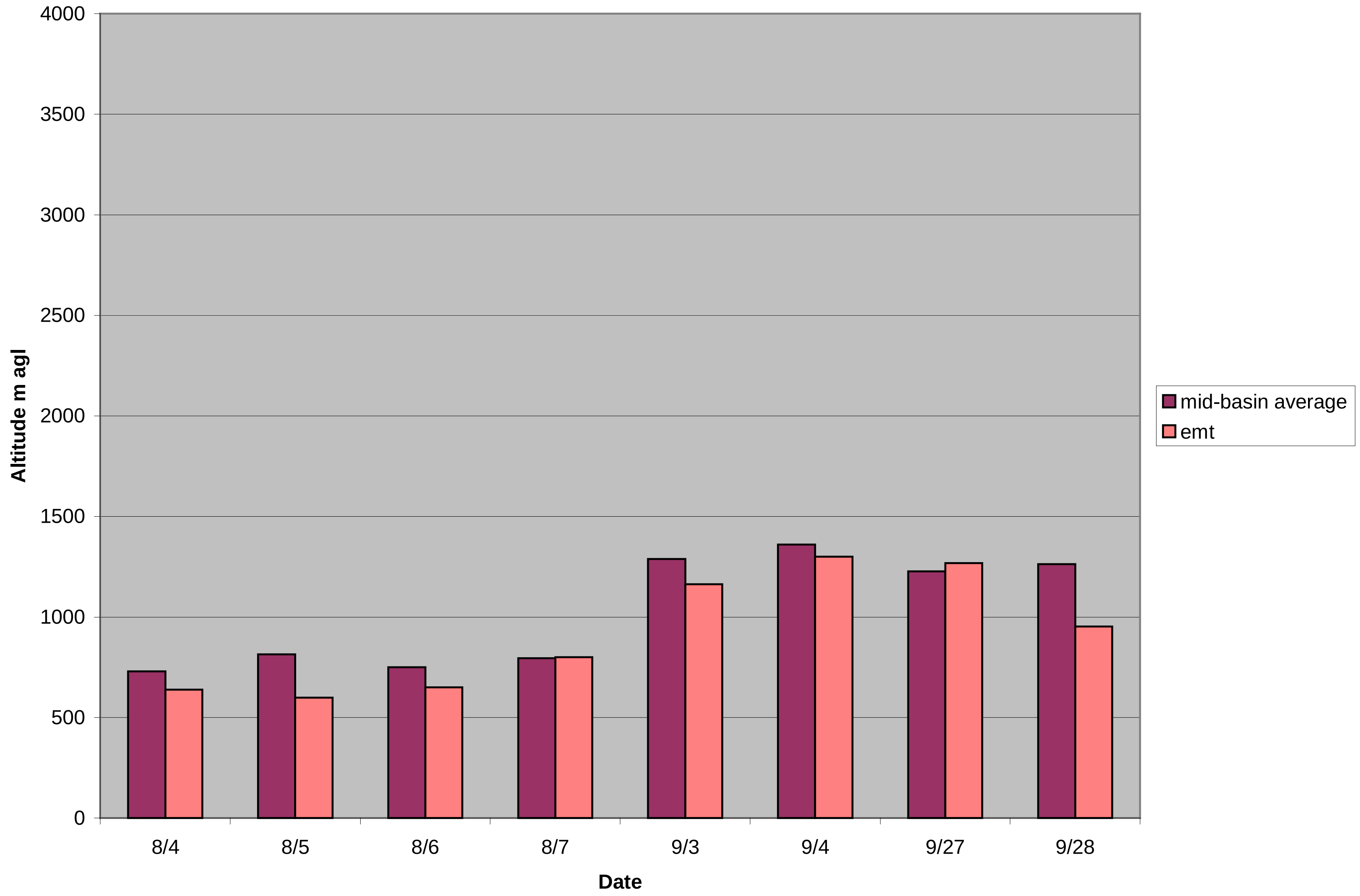


Figure 3-6. Daily average peak mixing heights for mid-basin sites and EMT during three SCOS97 episodes.

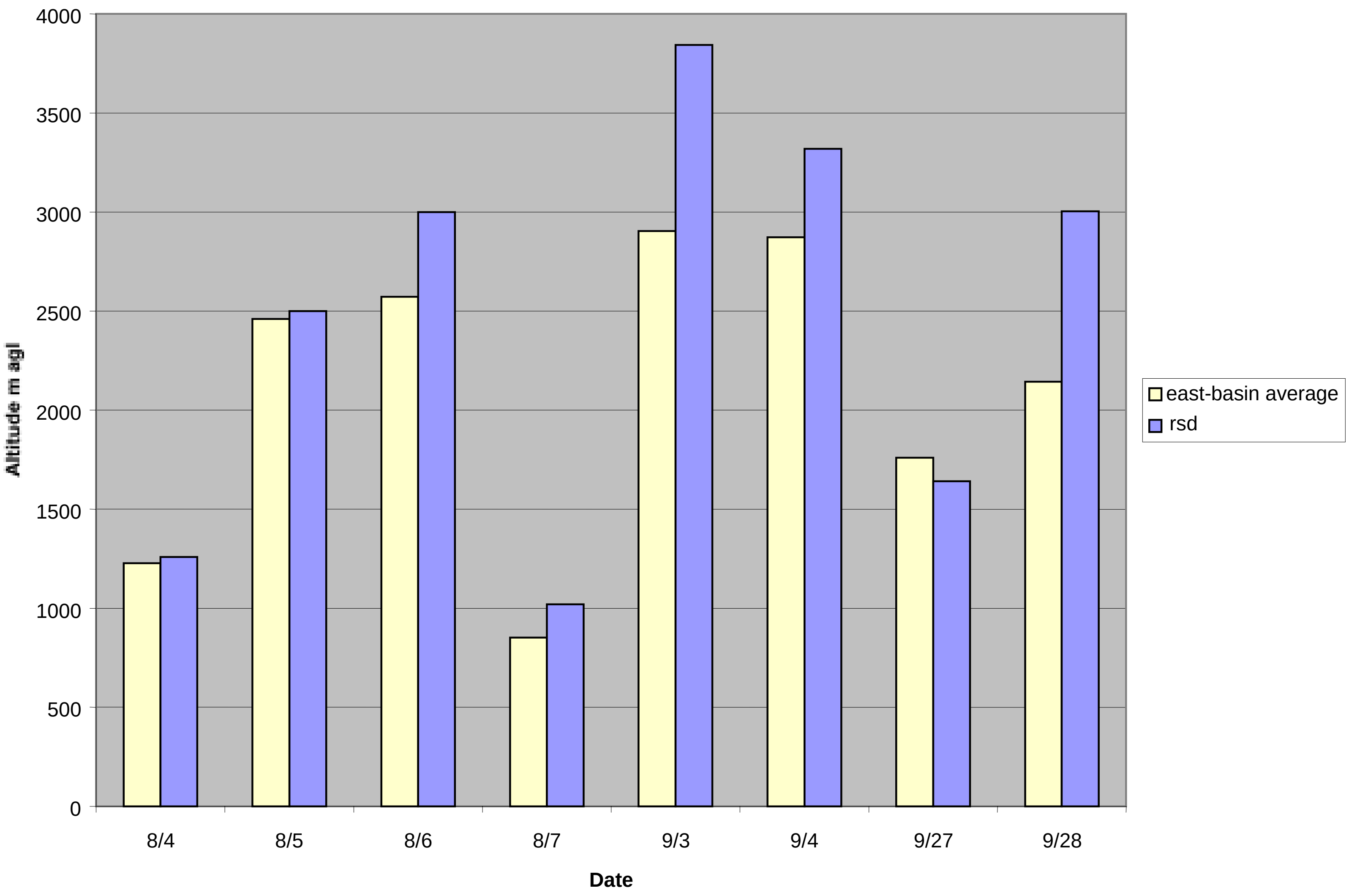


Figure 3-7. Daily average peak mixing heights for east-basin sites and RSD during three SCOS97 episodes.

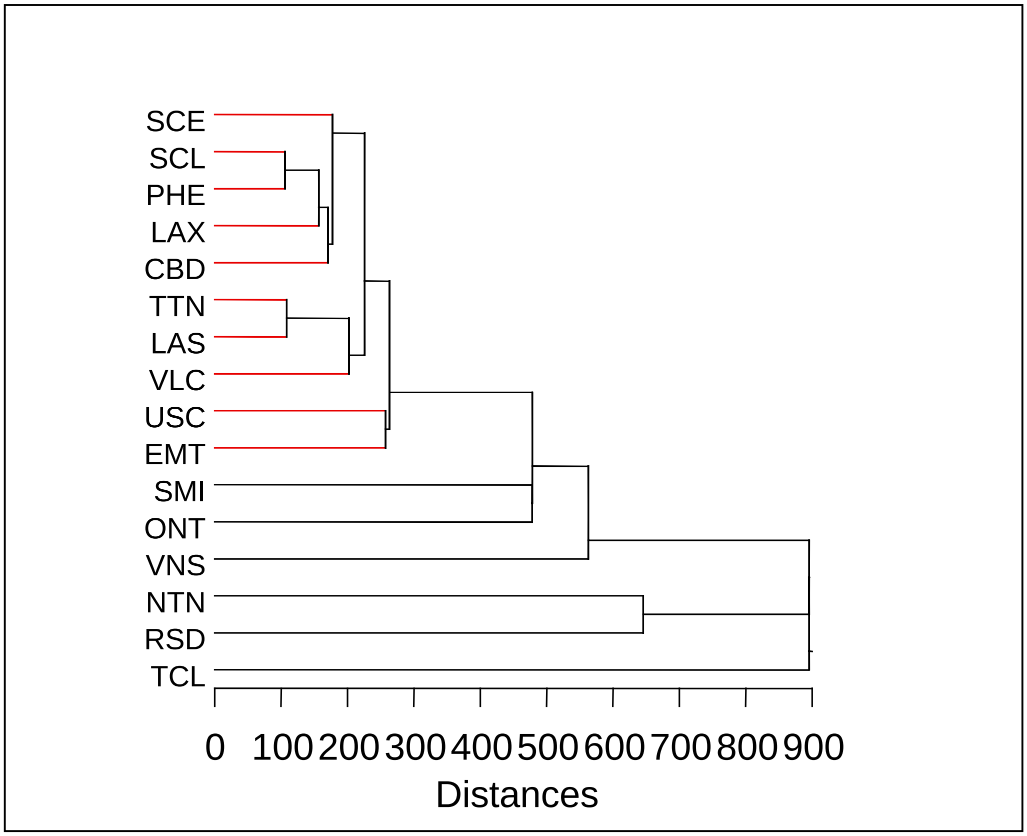


Figure 3-8. Cluster analysis of daily peak mixing heights. Euclidean distances shown are in meters.

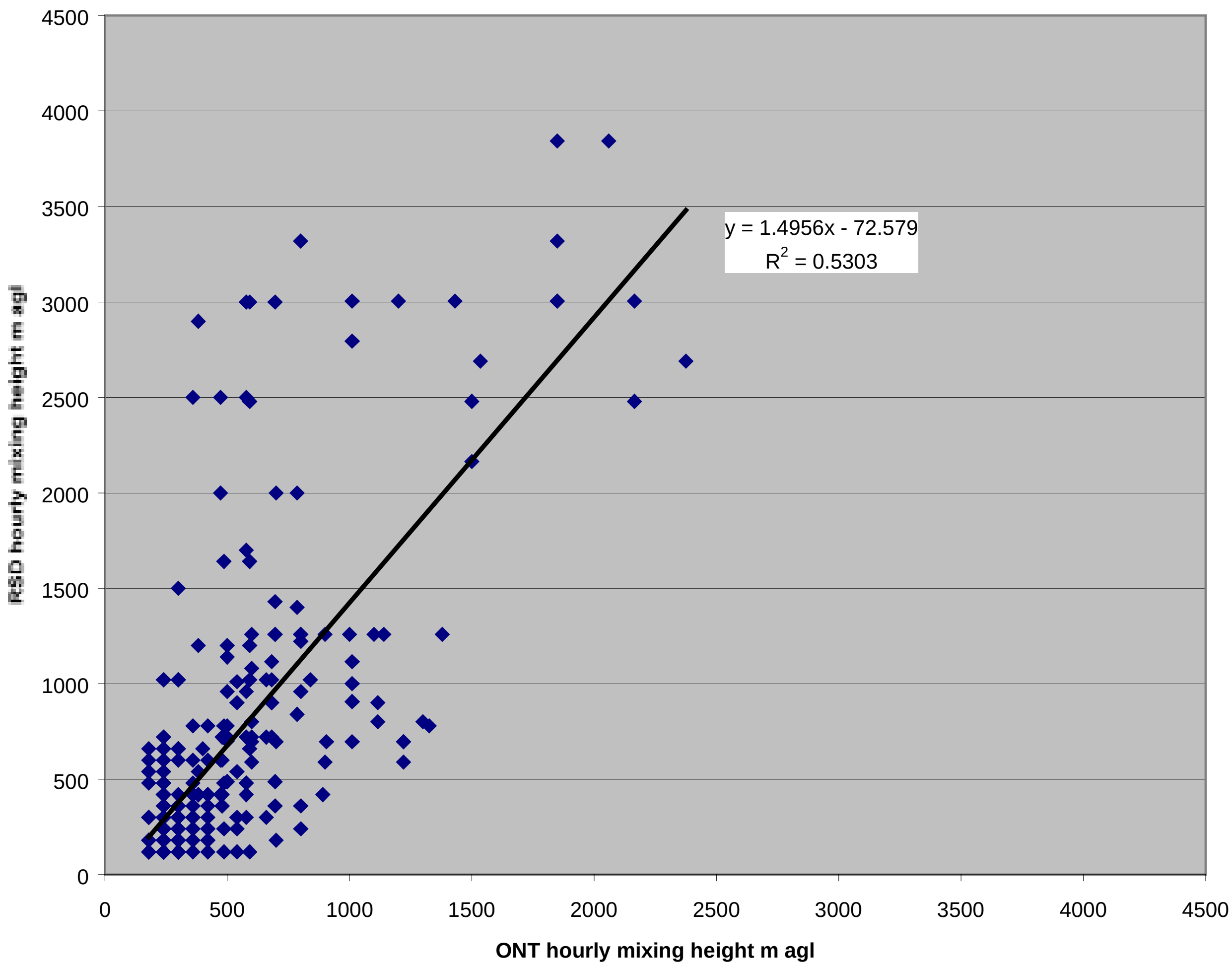


Figure 3-9. Scatter plot of hourly mixing heights from ONT and RSD during three SCOS97 episodes.

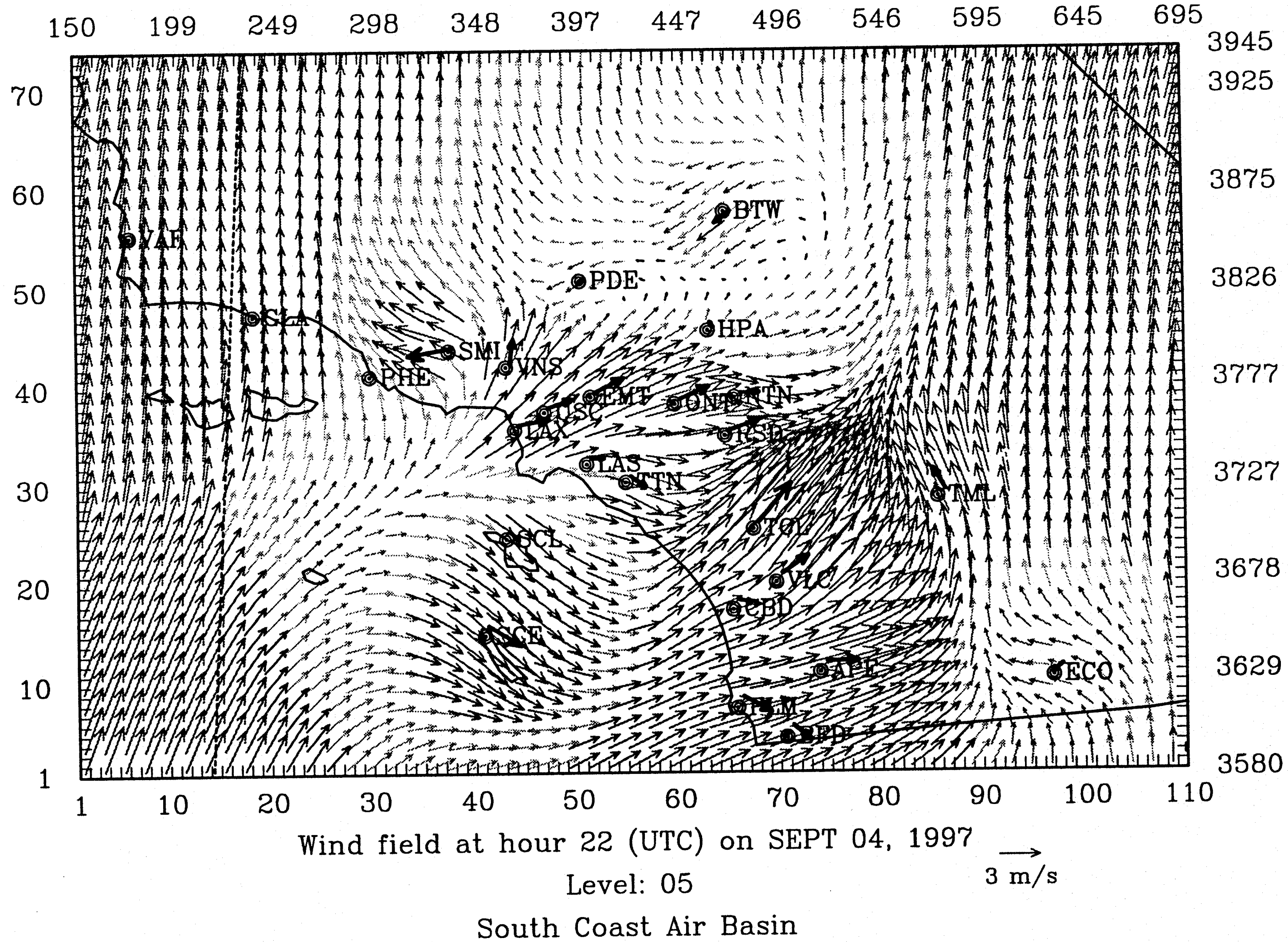


Figure 3-10. CALMET-derived winds (narrow arrows) and profiler-observed winds (bold arrows) at 500 m agl on September 4, 1997, at 1500 PST.

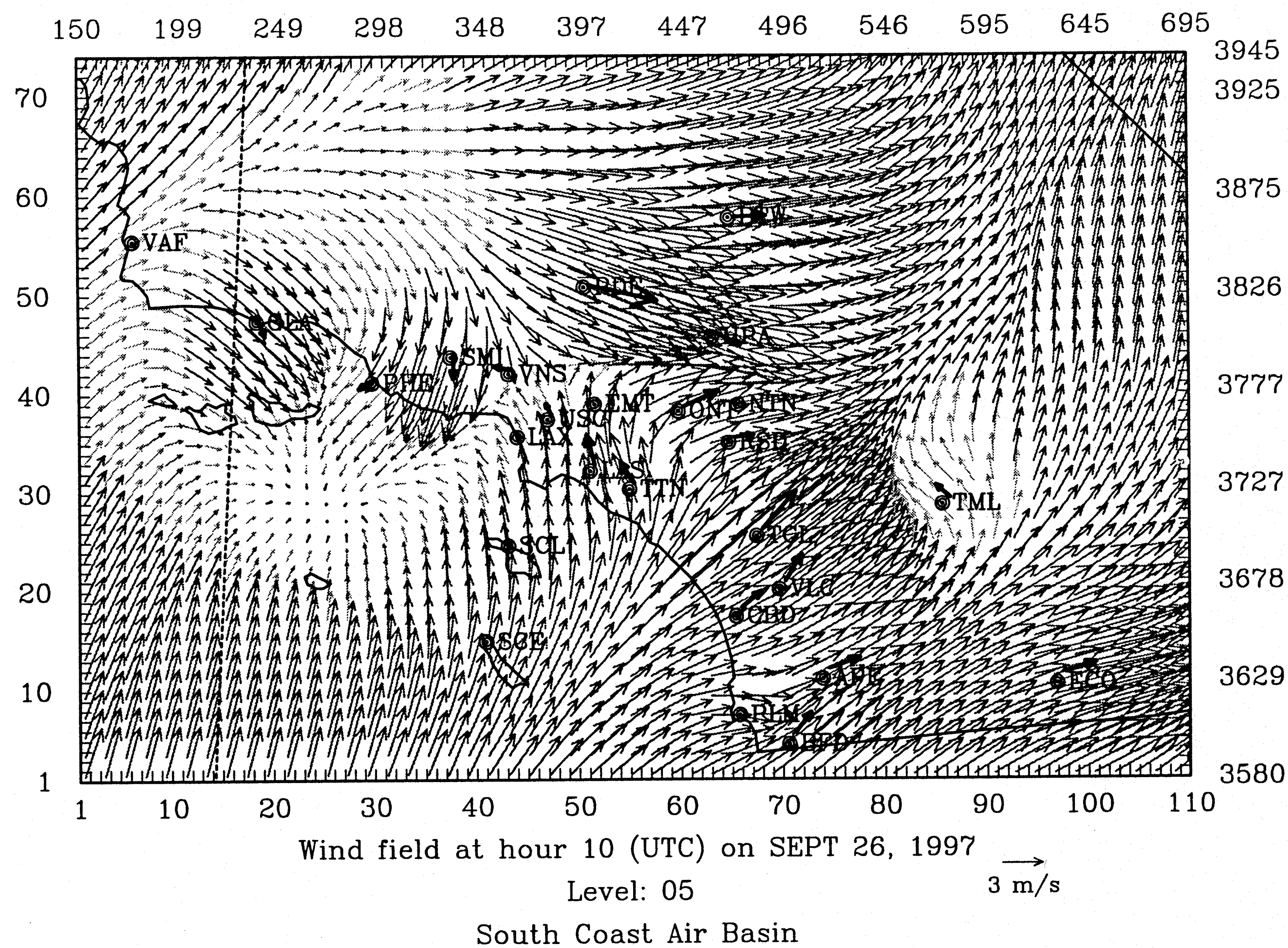


Figure 3-11. CALMET-derived winds (narrow arrows) and profiler-observed winds (bold arrows) at 500 m agl on September 26, 1997, at 0300 PST.

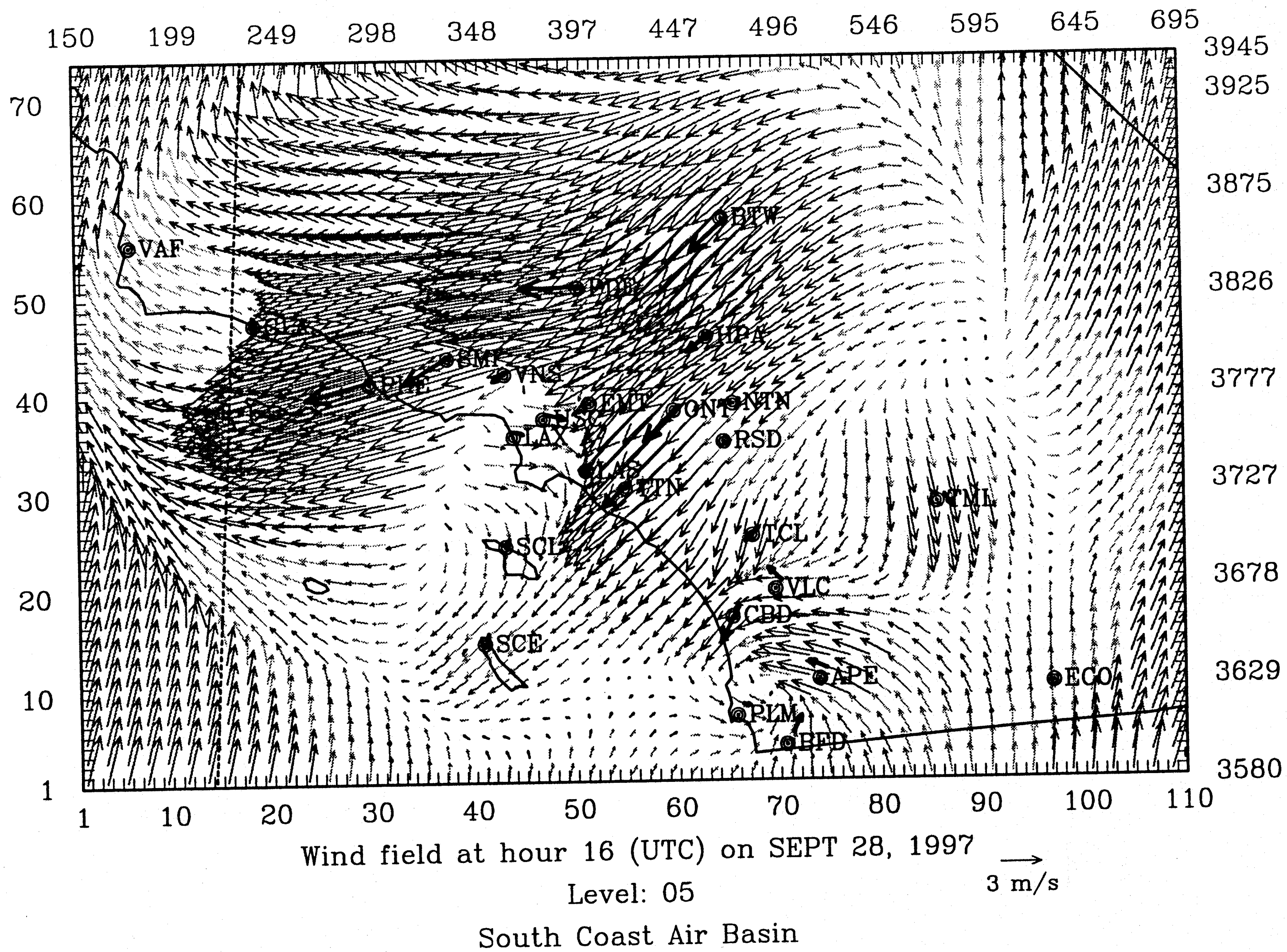


Figure 3-12. CALMET-derived winds (narrow arrows) and profiler-observed winds (bold arrows) at 500 m agl on September 28, 1997, at 0900 PST.

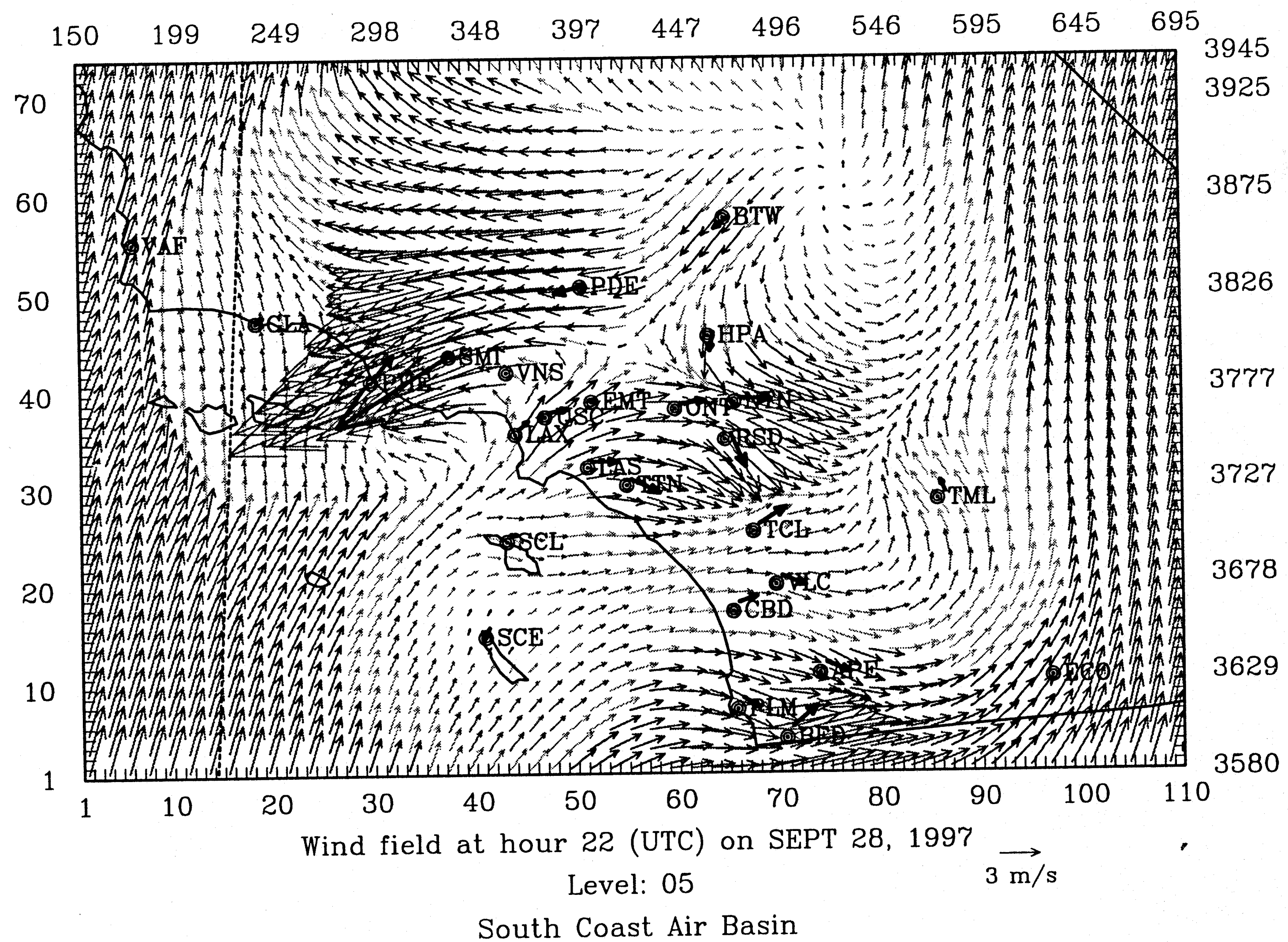


Figure 3-13. CALMET-derived winds (narrow arrows) and profiler-observed winds (bold arrows) at 500 m agl on September 28, 1997, at 1500 PST.

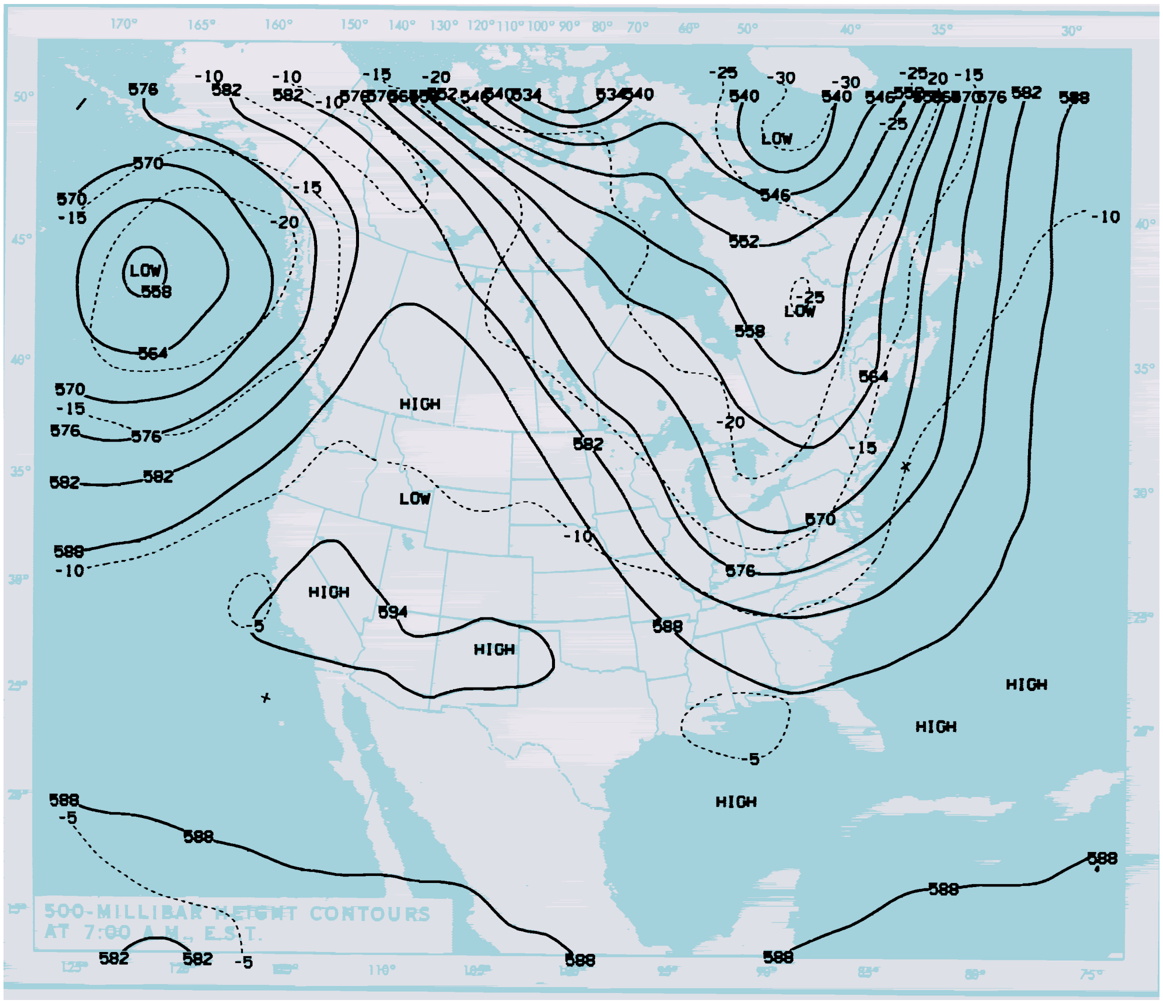


Figure 3-14. National Weather Service daily weather map of 500-mb heights on August 5, 1997, at 0400 PST.

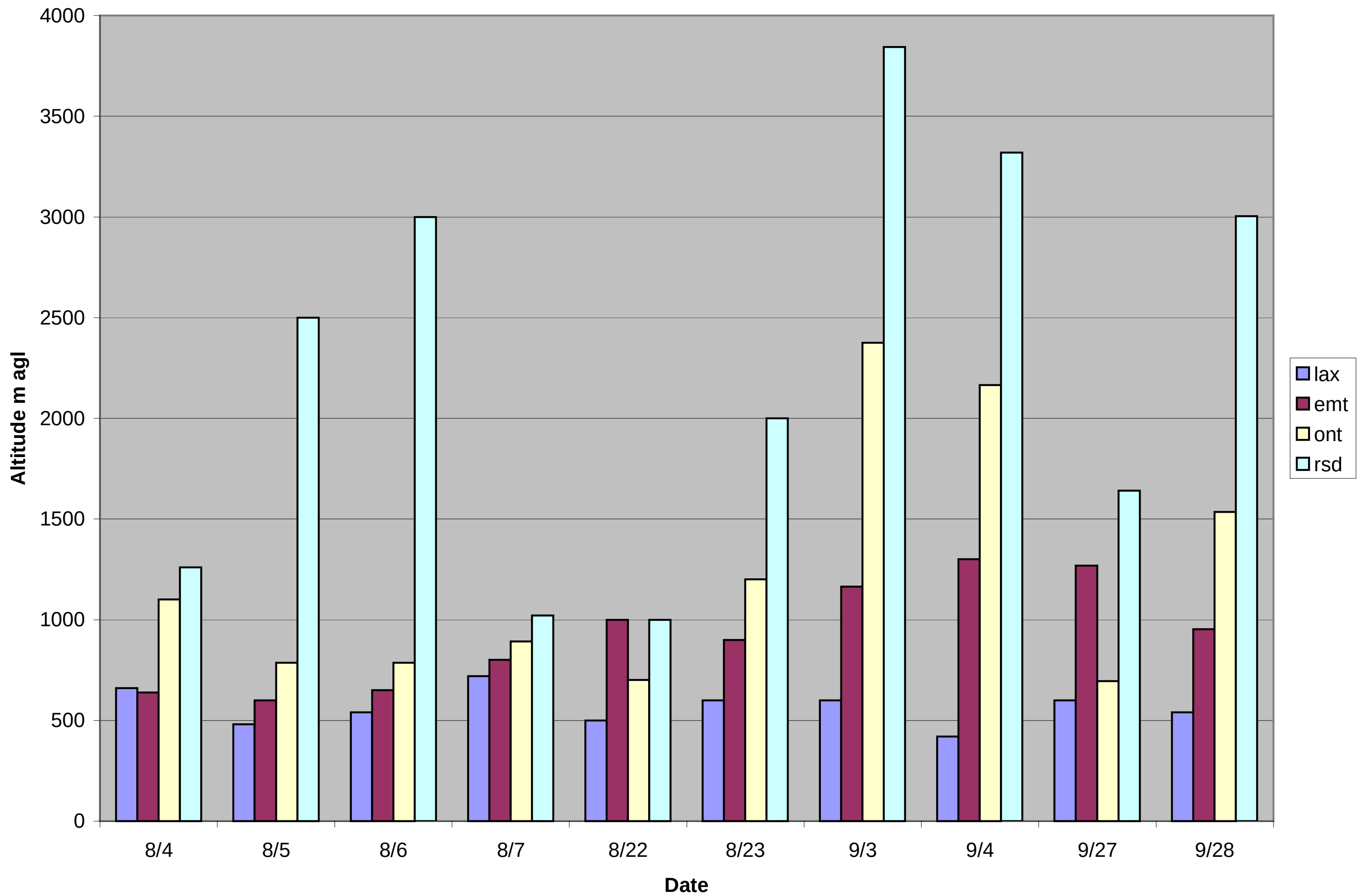


Figure 3-15. Daily average peak mixing heights for LAX, EMT, ONT, and RSD during four SCOS97 episodes.

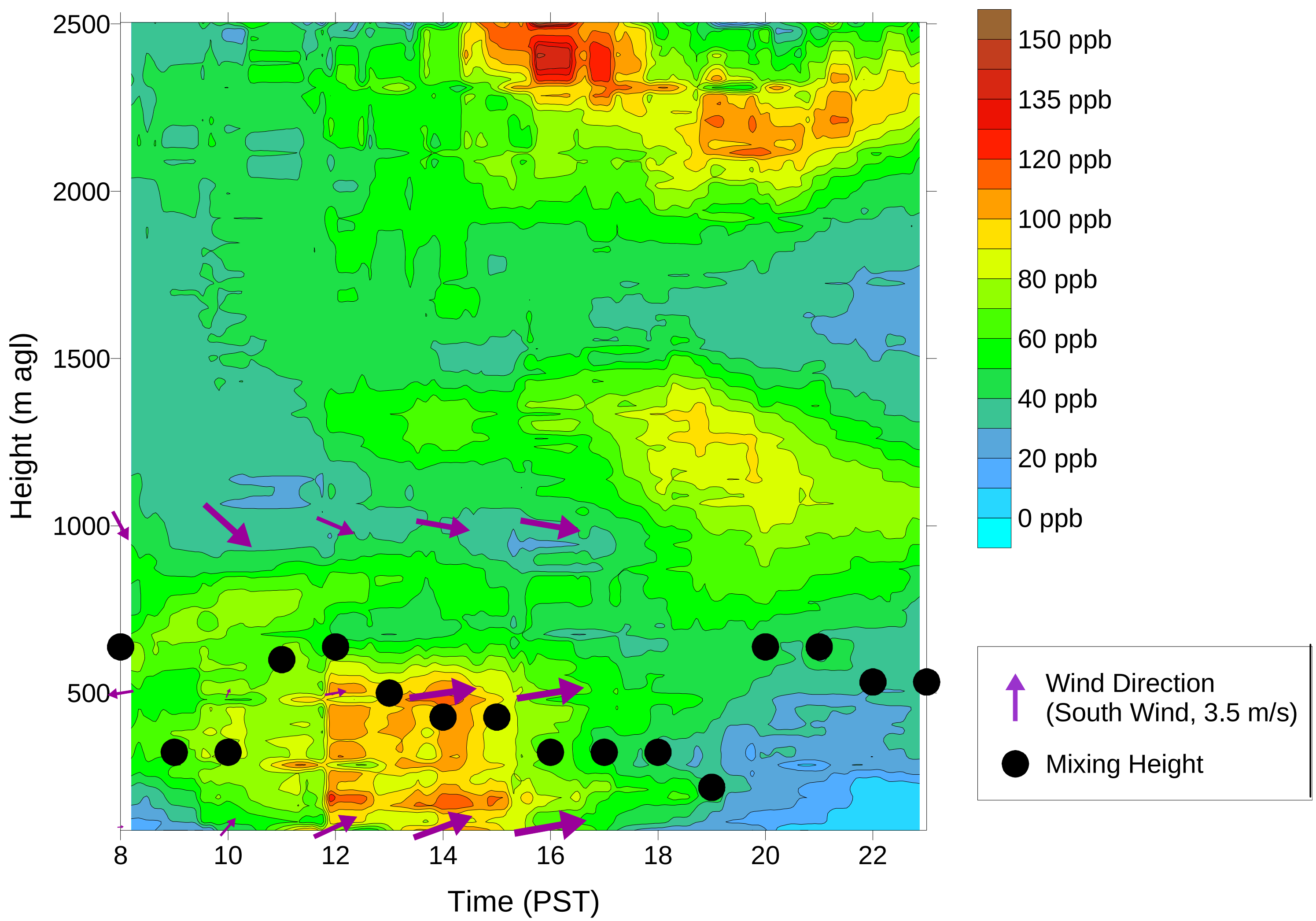


Figure 3-16. Time-height cross section of ozone concentrations by Lidar, profiler winds, and mixing heights at EMT on August 4, 1997.

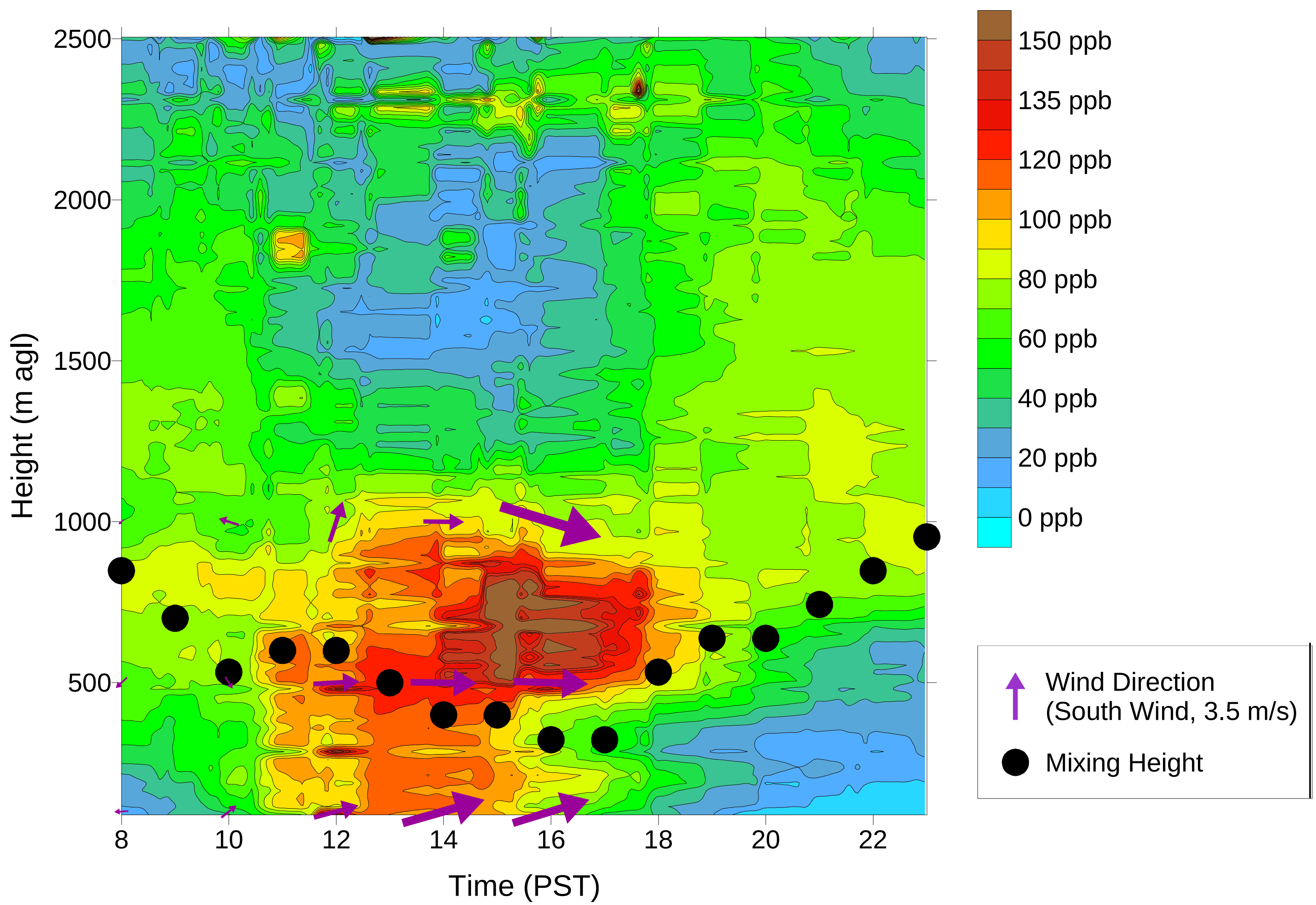


Figure 3-17. Time-height cross section of ozone concentrations, profiler winds, and mixing heights at EMT on August 5, 1997.

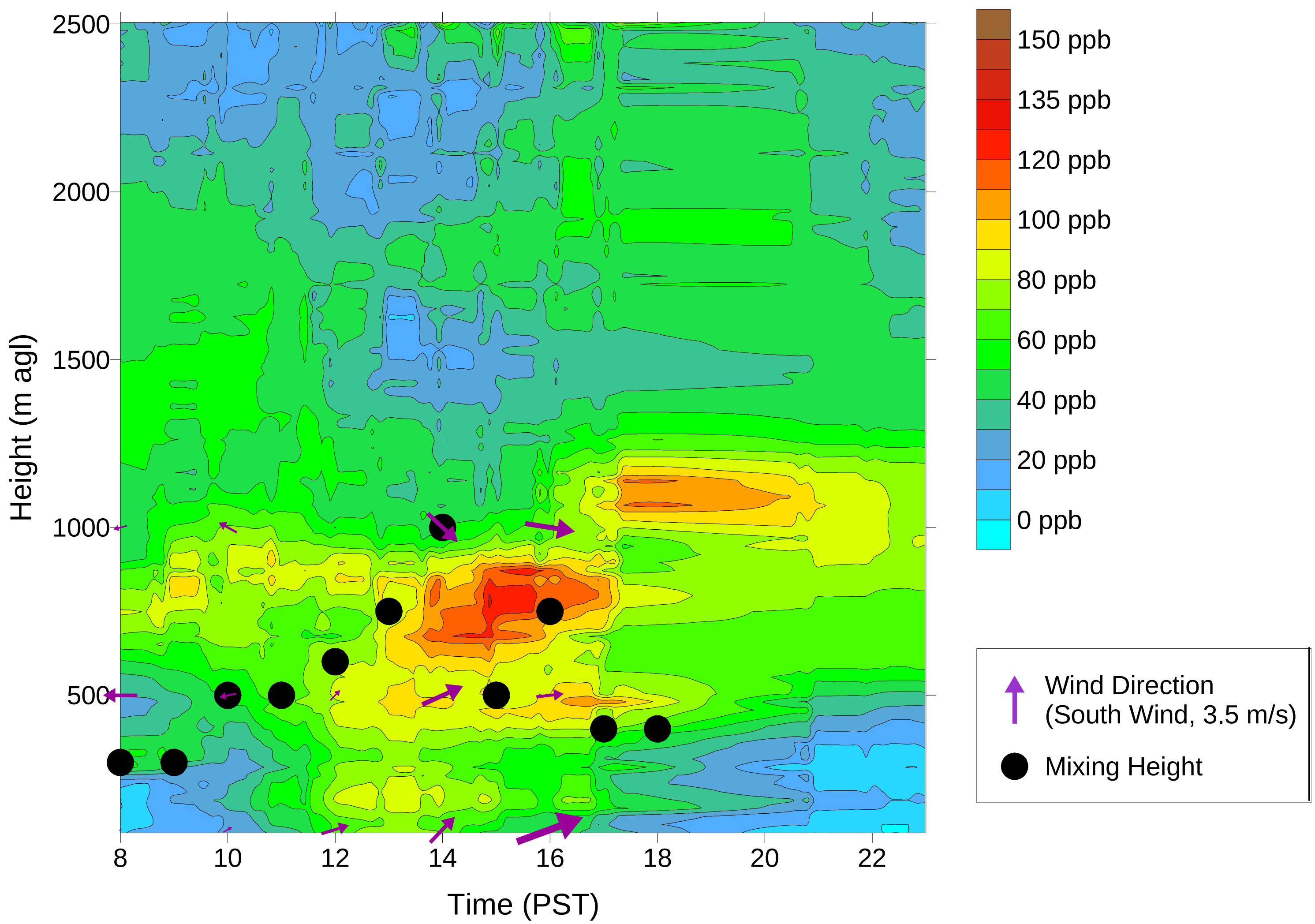


Figure 3-18. Time-height cross section of ozone concentrations, profiler winds, and mixing heights at EMT on August 22, 1997.

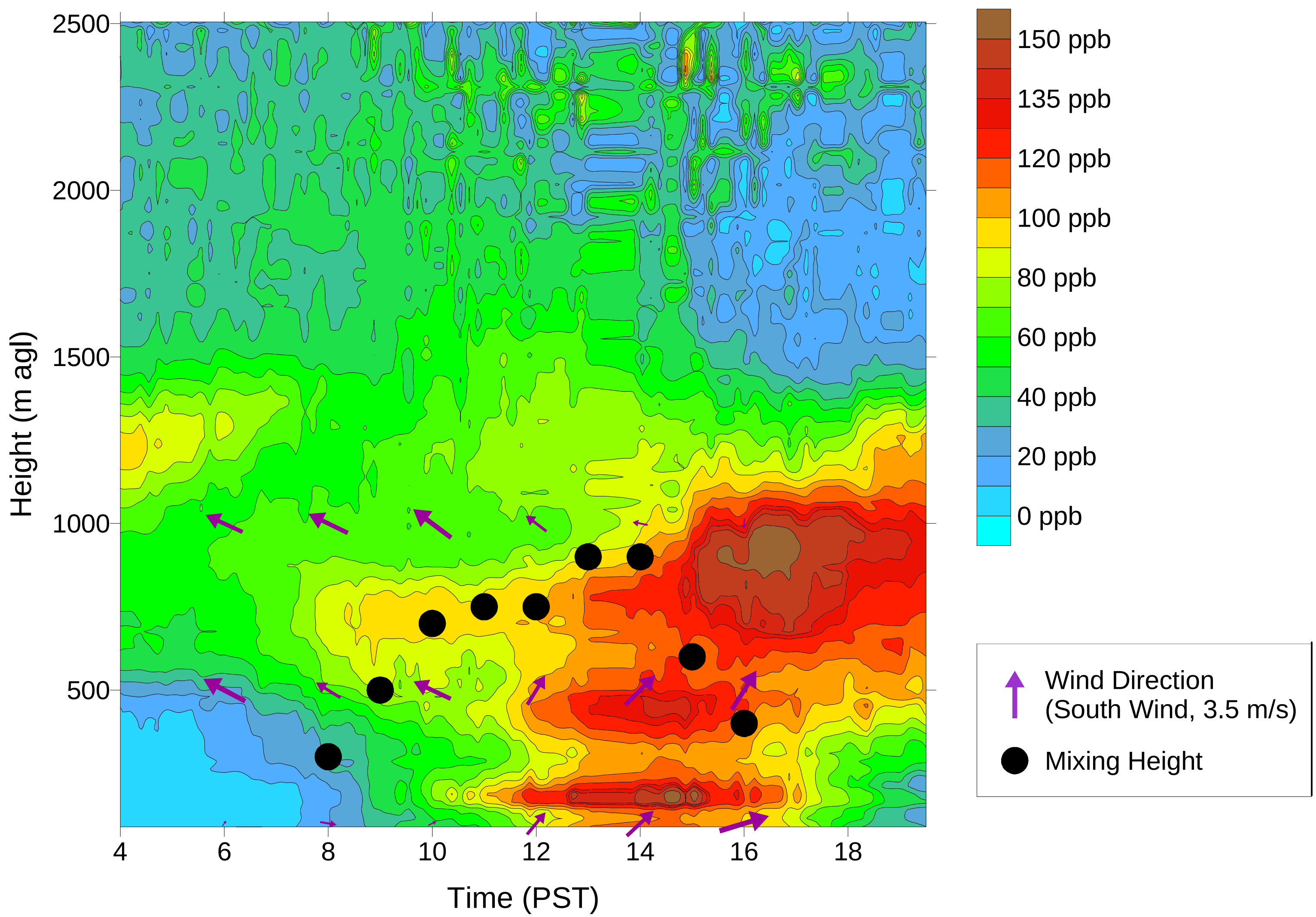


Figure 3-19. Time-height cross section of ozone concentrations, profiler winds, and mixing heights at EMT on August 23, 1997.

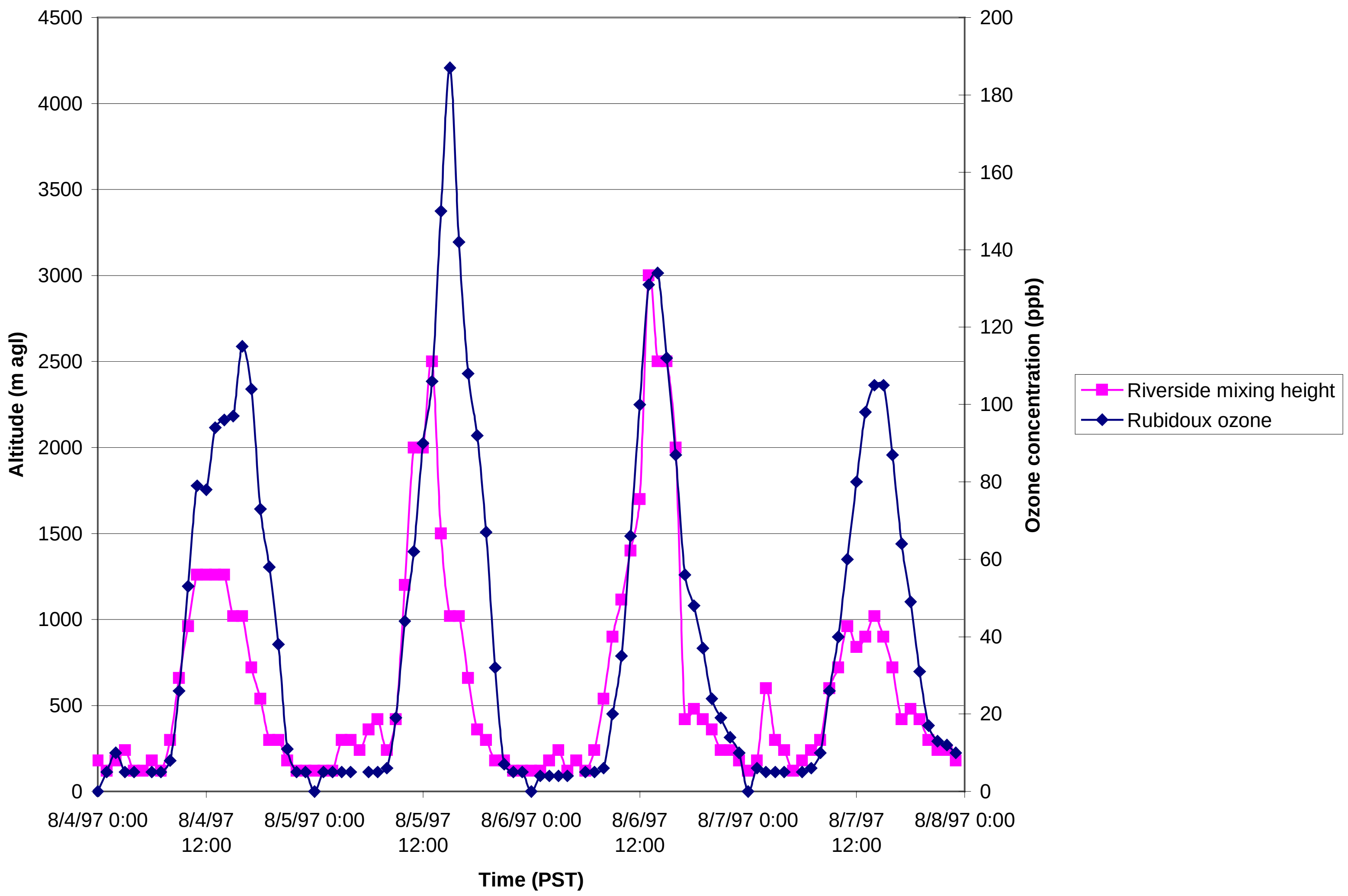


Figure 3-20. Time-series plot of mixing heights at Riverside and surface ozone concentrations at Rubidoux on August 4-7, 1997.

Table 3-1. Radar wind profiler/RASS sites operated during the SCOS97 field study. The 16 sites considered in this work are shown in bold.

Site Name	Site ID	Latitude	Longitude	Elevation m msl[a]
El Monte	**emt**	**34.09**	**118.03**	**95**
Norton	**ntn**	**34.09**	**117.26**	**318**
Alpine	ape	32.86	116.81	463
Brown Field	bfd	32.57	116.99	158
Carlsbad	**cbd**	**33.14**	**117.27**	**110**
El Centro	eco	32.83	115.57	-18
Goleta	gla	34.43	119.85	4
Los Alamitos	**las**	**33.79**	**118.05**	**7**
Palmdale	pde	34.61	118.09	777
Port Hueneme	**phe**	**34.17**	**119.22**	**2**
San Clemente Island	**sce**	**33.02**	**118.59**	**53**
Santa Catalina Island	**scl**	**33.45**	**118.48**	**37**
Tustin	**ttn**	**33.71**	**117.84**	**16**
Central Los Angeles	**usc**	**34.02**	**118.28**	**67**
Van Nays	**vns**	**34.22**	**118.49**	**241**
Los Angeles Int.	**lax**	**33.94**	**118.44**	**47**
Ontario	**ont**	**34.06**	**117.58**	**280**
Point Loma	plm	32.70	117.25	23
Valley Center	**vlc**	**33.26**	**117.04**	**415**
Barstow	btw	34.92	117.31	694
Hesperia	hpa	34.39	117.40	975
Riverside	**rsd**	**33.92**	**117.31**	**488**
Temecula	**tcl**	**33.50**	**117.16**	**335**
Thermal	tml	33.64	116.16	-36
Vandenberg AFB	vaf	34.77	120.53	149
Simi Valley	**smi**	**34.29**	**118.80**	**279**

[a] msl = mean sea level

Table 3-2. Correlation coefficients (r) and percent of time within the same bin between the hourly mixing heights at ONT and the hourly mixing heights at each of the other 15 sites. Values greater than 0.6 and frequencies greater than 0.7 are shown in bold.

	ALL TIME			DAY			NIGHT		
Site	Correlation (r) no bin	Correlation with bin	Percent of time in bin	Correlation no bin	Correlation with bin	Percent of time in bin	Correlation no bin	Correlation with bin	Percent of time in bin
ONT	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
lax	-0.01	0.06	0.63	-0.07	-0.07	0.39	0.01	0.28	**0.86**
cbd	0.06	0.11	0.51	0.14	0.15	**0.54**	-0.14	-0.01	0.54
emt	0.44	0.47	0.57	0.47	0.54	0.50	-0.06	0.06	0.61
las	0.45	0.52	0.65	0.33	0.46	0.53	0.19	0.40	**0.84**
ntn	0.69	**0.67**	0.60	**0.61**	**0.65**	0.52	0.08	0.08	**0.76**
phe	0.05	0.10	0.52	0.10	0.08	0.47	-0.08	0.07	0.62
rsd	0.75	**0.74**	0.65	**0.68**	**0.72**	0.47	0.20	0.26	**0.89**
sce	-0.12	0.00	0.58	-0.06	-0.08	0.53	-0.02	0.27	**0.70**
scl	-0.13	-0.09	0.47	-0.08	-0.14	**0.48**	-0.11	-0.06	0.51
smi	0.67	**0.70**	0.61	**0.66**	**0.75**	0.58	0.05	0.09	0.68
tcl	0.56	0.56	0.66	0.44	0.47	0.58	-0.06	0.12	**0.79**
ttn	0.35	0.40	0.54	0.35	0.47	0.49	-0.01	0.08	0.65
usc	0.24	0.27	0.60	0.09	0.11	0.36	0.05	0.23	**0.77**
vlc	0.66	**0.70**	**0.71**	0.58	**0.68**	0.57	0.05	0.51	**0.90**
vns	0.55	0.55	0.61	0.32	0.31	0.31	0.22	0.38	**0.82**

Table 3-3. Correlation coefficients (r) and percent of time within the same bin between the hourly mixing heights at LAX and the hourly mixing heights at each of the other 15 sites. Values greater than 0.6 and frequencies greater than 0.7 are shown in bold.

	ALLTIME			**DAY**			**NIGHT**		
Site	Correlation (r) no bin	Correlation with bin	Percent of time in bin	Correlation no bin	Correlation with bin	Percent of time in bin	Correlation no bin	Correlation with bin	Percent of time in bin
LAX	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
ont	-0.01	0.04	0.63	-0.07	-0.06	0.40	0.01	0.41	**0.87**
cbd	-0.04	0.12	0.67	-0.27	0.07	**0.65**	0.12	0.22	0.69
emt	0.07	0.12	0.63	-0.04	0.03	0.59	0.23	0.29	0.66
las	0.01	0.08	0.68	-0.14	0.03	0.59	0.11	0.08	**0.77**
ntn	-0.04	-0.02	0.43	-0.12	-0.10	0.24	0.06	0.15	0.66
phe	0.06	0.21	**0.71**	0.07	0.32	**0.76**	0.07	0.13	0.67
rsd	0.05	0.04	0.52	0.02	0.01	0.27	-0.04	-0.09	**0.76**
sce	-0.11	0.10	0.69	-0.08	0.12	**0.71**	-0.13	0.10	0.67
scl	0.04	0.09	0.64	0.01	0.13	**0.67**	0.10	0.09	0.62
smi	-0.01	0.04	0.58	-0.04	0.00	0.52	-0.04	0.14	0.62
tcl	0.09	0.11	0.60	0.07	0.07	0.38	0.25	0.53	**0.80**
ttn	-0.05	0.01	0.59	-0.13	-0.02	0.53	-0.01	-0.01	0.65
usc	0.01	0.06	0.59	-0.16	-0.09	0.47	0.17	0.23	**0.71**
vlc	-0.04	0.05	0.65	-0.09	-0.03	0.53	-0.14	0.20	**0.77**
vns	0.03	0.07	0.51	-0.03	-0.03	0.22	0.00	0.32	**0.79**

Table 3-4. SCOS97 IOP days used in this project (from Fujita et al., 1999).

Date	Day of Week	Maximum 1-hr ozone concentration (ppb) in the SoCAB	Maximum 8-hr ozone concentration (ppb) in the SoCAB
August 4	Monday	140	105
August 5	Tuesday	190	119
August 6	Wednesday	160	125
August 7	Thursday	150	122
August 22	Friday	130	90
August 23	Saturday	140	106
September 3	Wednesday	130	90
September 4	Thursday	160	99
September 5	Friday	120	91
September 6	Saturday	120	94
September 27	Saturday	140	102
September 28	Sunday	170	107
September 29	Monday	110	89

4. SYNTHESIS OF PHASE 1 ANALYSES (TO BE COMPLETED)

During the same time frame in which STI was performing the emissions activity and meteorological representativeness tasks, DRI was performing a retrospective analysis of ozone concentrations, ozone precursor concentrations, and ozone episodes as well as a review of source apportionment analyses. The results from each contractor are intended to guide the selection of the types and locations of measurements for the field campaign in Phase II. Clearly, the results from both contractors need to be considered and synthesized into a cohesive strategy. For this draft of the report, we have prepared an outline of the topics that we will discuss after the contractors have reviewed the Phase I investigations and discussed the results.

- *Summarize the results of Phase I data analysis.* A summary of the conclusions of each main task will be presented. The implications of the conclusions for the hypotheses will be discussed.
- *Compare results from each task.* The synthesis of conclusions from each task also includes a comparison of findings from related tasks. For example, examination of the time series of pollutants by DRI also provides corroboration of emission inventory results discussed in Section 2 of this report. The detailed analysis of a few SCOS97 IOP days performed by STI (Section 3) can be compared to the more general conclusions drawn from many more days as assessed by DRI in its report.
- *Update hypotheses.* The task results will be used to evaluate the candidate hypotheses. Those hypotheses that are most viable will be retained and those that are least likely to be important will be demoted or dropped altogether.
- *Revise conceptual model.* Based on the new set of hypotheses, we will revise the conceptual model of the weekend effect.
- *Finalize field measurement program.* Based on the Phase I task results, DRI and STI will recommend a final configuration for the field measurement program.

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APPENDIX A

DESCRIPTION OF EMISSIONS ACTIVITY DATA

A. **Dataset:** Caltrans Weight In Motion (WIM) Database
Source: Caltrans maintained database
Description: Contains hourly and day-of-week vehicle counts for several vehicle classes traveling on freeways
Vintage: 1998, Can request data for specific time period
Spatial Coverage: 4 sites located in Los Angeles county and 16 other sites throughout the SoCAB
Relevant Source Categories: All vehicle types
Limitations: Data collected on freeways only

B. **Dataset:** Vehicle counts on surface streets
Source: Collected by Deb Niemeier
Description: Contains hourly and day-of-week vehicle counts for several vehicle classes on surface streets collected over a two-week time period (Sept. 30 – Oct. 13, 1997). CARB is currently obtaining electronic versions of all data.
Vintage: 1997, Historical
Spatial Coverage: Several sites, one located near L.A. North Main monitoring site, other locations unknown at this time
Relevant Source Categories: All vehicle types
Limitations: Data collected on surface streets only, two-week sampling period

C. **Dataset:** Heavy-duty diesel truck activity data
Source: Collected by Battelle/CARB
Description: Contains heavy-duty diesel activity data and route information. Approximately 140 heavy-duty diesel trucks fitted with GPS devices and tracked for specified time periods in the state of California.
Vintage: 1998, Historical
Spatial Coverage: Includes regions of SoCAB but trucks travel in and out of SoCAB throughout California
Relevant Source Categories: Heavy-duty diesel trucks
Limitations: Limited data may not be spatially adequate

D. **Dataset:** A&WMA paper reporting the development of a fuel-based emissions inventory for heavy-duty diesel trucks
Source: David Dreher and Robert Harley
Description: Reports development of a fuel-based emission inventory for heavy-duty diesel trucks in the San Francisco Bay Area. Contains anecdotal discussion of truck activity on weekends versus weekdays.
Vintage: 1998, Historical
Spatial Coverage: Study conducted in San Francisco Bay Area
Relevant Source Categories: Heavy-duty diesel trucks
Limitations: Anecdotal only

E. **Dataset:** Temporal, Spatial, and Ambient Temperature Effects in the Sacramento Modeling Region
Source: Study conducted by David Rocke and Daniel Chang at U.C. Davis
Description: Contains day-of-week and diurnal temporal profiles for select emissions categories
Vintage: 1998
Spatial Coverage: Emissions activity based on California
Relevant Source Categories: Heavy-duty diesel construction equipment, autobody refinishing, industrial and commercial adhesives and sealants, metal products and coatings.
Limitations: Study done in Sacramento, but useful for representative profiles

F. **Dataset:** Driving behavior characteristics on weekdays and weekends
Source: Analyses done by Mark Carlock at CARB
Description: Summarizes driving behavior on weekdays and weekends including: VMT, vehicle speed distributions by day of week, gasoline sales by day-of-week, and fleet mix
Vintage: 1998
Spatial Coverage: South Coast Air Basin
Relevant Source Categories: Light-duty passenger vehicles
Limitations: None

G. **Dataset:** Improved emission inventory for pleasure craft in California
Source: Study done by Systems Applications International
Description: Contains day-of-week and diurnal temporal profiles for pleasure craft in California.
Vintage: 1995
Spatial Coverage: California
Relevant Source Categories: Recreational boats
Limitations: None

H. **Dataset:** Los Angeles International Airport Flight Schedules
Source: LAX World Airport Center
Description: Day-of-week flight activity for all flights arriving and departing at LAX
Vintage: Can obtain by request for specific time period
Spatial Coverage: LAX

Relevant Source Categories: Airplanes
Limitations: Limited to total flights

I. **Dataset:** Locomotive Emission Inventory, Supplement to the Locomotive Emission Study (April 1991)
Source: Study done by Booz-Allen & Hamilton for CARB
Description: Contains average activity profiles by month and day-of-week for trains in California
Vintage: 1992
Spatial Coverage: California averages
Relevant Source Categories: Trains
Limitations: Slightly out of date, only contains California averages

J. **Dataset:** Ship data
Source: Marine Exchange L.A.-L.B. Harbor
Description: Contains arrival and departure logs for all ships traveling into and out of Long Beach and Los Angeles harbors by day-of-week and hour
Vintage: Can request for specific time period
Spatial Coverage: Los Angeles and Long Beach harbors
Relevant Source Categories: Marine vessels
Limitations: May have to pay for the data, approximately $50/month

K. **Dataset:** Heavy-duty Truck Population, Activity, and Usage Patterns
Source: Report by Jack Faucett Associates for CARB
Description: Contains average heavy-duty diesel truck activity patterns such as VMT and speed distribution. Also includes light-heavy and medium-heavy truck activity.
Vintage: 1998
Spatial Coverage: California average data
Relevant Source Categories: Heavy-, medium-, and light-duty diesel trucks
Limitations: California average data, and nothing by day of week

L. **Dataset:** Hourly traffic count data collected during SCOS97
Source: Study by Dr. Deb Niemeier
Description: Hourly traffic count data by day of week collected during SCOS97 for many sites throughout the SoCAB. Larry Larsen of CARB currently processing and analyzing the data.
Vintage: 1997
Spatial Coverage: Many sites throughout SoCAB, Larry Larsen processing for relevant locations
Relevant Source Categories: On-road vehicles
Limitations: Reports total vehicles only