CHARACTERIZATION OF OZONE EPISODES IN THE SOUTH COAST AIR BASIN: EFFECTS OF AIR PARCEL RESIDENCE TIME AND WEEKEND/WEEKDAY DIFFERENCES

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ABSTRACT

To date, airshed modeling for control strategy evaluations has typically involved simulations of only a few air pollution episodes, which may not represent either the complete range of meteorological conditions over which high ozone episodes can occur, or differences in ozone concentrations resulting from variation in precursor emissions by day-of-the-week. The present project focused on the California South Coast Air Basin (SoCAB) "smog season" of 1 May to 31 October for the years 1986-1993, and had the following primary objectives: to better characterize the range of meteorological conditions associated with high ozone episodes in the SoCAB; to assess the variation in, and influence of, transport and residence time on the occurrence of high concentrations of ozone; to isolate and examine relationships between day-of-the-week and ozone levels; and to examine sub-regional air quality trends over the past decade, including degree of correlation between ozone and NO_2 ambient air concentrations. Fulfillment of these research objectives necessitated the development of comprehensive, critically evaluated air quality and meteorological databases for the SoCAB. In addition to their utility for the present research project, these databases should be of benefit to future air quality research concerning the SoCAB.

Results of this project suggest the need for further investigation of the longstanding view of the importance of air parcel transport across the SoCAB. Specifically, better correlations between NO_2 and ozone concentrations were observed within sub-regions than between them. This finding (while not establishing causality) is consistent with the fact that although the Coastal and Metropolitan subregions were formerly much more densely populated than other regions of the Basin, over the past two decades the major growth in the SoCAB has occurred in the middle and eastern parts of the Basin, producing a commensurate change in emission patterns.

These results are also consistent with those from a comparative analysis of the surface meteorological conditions associated with the days of highest SoCAB peak ozone and days associated with average peak-ozone concentrations. Examination of the vector-mean hourly-average resultant winds throughout the SoCAB for each hour of the day for the high ozone days, along with an analysis of the average time at which the peak ozone value was reported at each station, indicated surface transport on the time scale of a day was of a subregional scale. (However, determination of the actual transport would require wind data aloft which were not available in the present project.) Also of interest was that both average- and highest-ozone days were associated with very similar vector-mean hourly-average resultant winds throughout the SoCAB. Thus, it did not appear differences in transport, at least as far as this was indicated by the surface winds, played a generally significant role in determining the magnitude of the Basin-peak ozone value.

Significant relationships were found, however, between Basin-peak ozone values and both the 850 mb temperature, and the Basin-wide values of maximum surface air temperature. Consistent with earlier studies, temperatures tended to be significantly higher on the high ozone days than on the middle ozone days. Some relationship was also found between the characteristic form of the synoptic-scale weather pattern and corresponding ozone concentrations: specifically, high ozone days tended to occur more

often in association with an "established ridge" aloft (characterized by high mid-tropospheric geopotential heights, a warm lower- and mid-tropospheric air mass, and light winds aloft), while a synoptic-scale pattern with lower heights and stronger and more zonal flow aloft was more typical for middle-ozone days.

Trend analyses were performed by comparing the mean Basin-maximum ozone values of the various CART nodes for 1986-1989 with those for 1990-1993; results indicated that regardless of the meteorological conditions, generally lower peak ozone values were observed in the latter four years than in the first four years.

A further trend analysis was performed by examining the means of the ten-highest hourly-average concentrations for each of the four-year periods. These "worst ozone days" trends showed the most pronounced percentage decrease in these highest ozone concentrations occurred in the western or middle portion of the Basin, corresponding generally to the area of maximum percentage decrease in early morning NO_x ambient concentrations for these same highest ozone days.

Both cumulative hourly ozone exposure above the federal standard of 12 pphm and number of first stage alerts were also found to decrease over the eight-year period of interest for each day of the week for the stations at Central Los Angeles, Azusa, and Riverside (chosen as representative of the western, middle and eastern portions of the urbanized area of the Basin). Higher daily peak ozone concentrations remained more common on weekend days, though, while lower daily maximum concentrations occurred more frequently on weekdays.

Although there was a lack of evidence for NO_2 or NO_x carry-over influencing next-day peak ozone, further investigation of the effect of carry-over of weekday precursor emissions on weekend high ozone episodes is needed. Better correlation of peak ozone with morning NO_2 than with morning NO_x ambient air concentrations was observed.

Implications of all of these results for NO_x and VOC control strategies will remain unclear until more accurate emissions data become available for the SoCAB as a function of day of the week, and by sub-region.

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GLOSSARY OF TERMS, ABBREVIATIONS, AND SYMBOLS

AFB	Air Force Base
AQMD	Air Quality Management District
AQMP	Air Quality Management Plan
ARB	Air Resources Board
CART	Classification and Regression Tree
DI	Deviation Index
FAA	Federal Aeronautical Association
GEMPAK	General Meteorology Package
GMT	Greenwich Mean Time
IV	Inland Valley
LAX	Los Angeles International Airport
MDL	minimum detectable level
MM5	NCAR Mesoscale Model Version 5
mph	miles per hour
NCAR	National Center for Atmospheric Research
NMC	National Meteorological Center
NMHC	non-methanated hydrocarbon
NO_2	nitrogen dioxide
NO_x	nitrogen oxides
PM-10	particulate matter less than 10 μm in diameter
PDT	Pacific Daylight Time

PST	Pacific Standard Time
ROG	reactive organic gases
SCAQMD	South Coast Air Quality Management District
SCAQS	Southern California Air Quality Study
SGV	San Gabriel Valley
SoCAB	South Coast Air Basin
TPD	ton per day
TSP	total suspended particulate
UAM	Urban Airshed Model
UCLA	University of California, Los Angeles
VOC	volatile organic compound
WD	weekday
WE	weekend

1.0 EXECUTIVE SUMMARY

1.1 Introduction

Despite empirical evidence from long-term trend data, for both emission inventories and ambient air quality, that reductions in oxides of nitrogen (NO_x) (simultaneous with volatile organic compound (VOC) reduction) have been beneficial in reducing peak levels of ozone in the SoCAB, and our understanding that photolysis of nitrogen dioxide remains the only significant pathway to ozone formation in the troposphere, predictions obtained through the use of the Urban Airshed Model (UAM) continue to suggest (AQMP Task Force 1994) that further NO_x control will be counterproductive in reducing ozone over most of the SoCAB. The contradiction between UAM predictions and observed air quality trends has led to suggestions that UAM inputs may not represent high ozone episode conditions over a sufficiently wide range of meteorological conditions to adequately model such episodes. For example, much of the regional modeling for the SoCAB has been conducted for a few air pollution episodes, from the Southern California Air Quality Study (SCAQS) conducted in 1987 (SCAQS 1993) or earlier field programs in the SoCAB. In addition, relatively little attention has been given to distinctions between weekend and weekday episodes, yet the fraction of total ozone standard violations which occur on weekends has been increasing over the past decade (Cassmassi 1994).

Clearly, there is a need to better characterize the range of meteorological conditions associated with high air pollution episodes and to assess the influence of air parcel residence time within the SoCAB and weekday/weekend effects on such episodes. Moreover, it is important to carefully analyze air quality trends in the SoCAB over the past decade on a sub-regional basis, and to evaluate correlations between NO_2 and NO_x precursor concentrations and subsequent ozone levels, in order to better evaluate the effects of earlier emission control programs for NO_x and VOC.

1.2 Objectives

The principal overall objectives of this project were to analyze recent air quality trends in the SoCAB on a subregional basis, to examine the relationship between ozone levels and NO_2/NO_x concentrations, and to investigate the influence of air parcel residence time and weekday/weekend effects on conclusions drawn concerning the relative benefits of VOC vs. NO_x control in California's South Coast Air Basin. The specific objectives were:

- To characterize recent (*i.e.*, past decade) air quality trends in the SoCAB on a sub-regional basis, including correlations (or lack thereof) between ozone and NO_2 ambient air concentrations.

- To examine the potential importance of distinguishing meteorologically similar high ozone episodes on the basis of whether the occurrence was on a weekend day or a weekday.

- To characterize days above the California state ozone standard by "residence time" and relate this assessment to the meteorological categories developed by South Coast Air Quality Management District (SCAQMD) meteorologists.

- (Exploratory) To evaluate further the meteorological representativeness of the August 1987 SCAQS episode which has been and will be used for urban airshed modeling in support of development of VOC/NO_x control strategies and future air quality management plans.

- (Exploratory) To explore multiple linear regression relationships between meteorological parameters and ozone.

1.3 Database Development

Comprehensive data for the criteria pollutants NO_2, CO, O_3, and PM-10 and for key meteorological parameters (Table 1-1) were acquired for the years 1986-93.

Table 1-1. Air quality and meteorological databases (1986-93) acquired for the South Coast Air Basin.

Criteria Pollutants	Meteorological Parameters
Ozone	Upper air data
Carbon Monoxide	Resultant wind speed & direction
Nitrogen Dioxide	Temperature
PM-10	Relative Humidity
TSP	Dewpoint
Nitrogen Oxides	FAA data*

* The FAA data (meteorological data from FAA stations in the region of the SoCAB) were available only for 1987-89.

The data set obtained from the ARB was used to generate a new data set containing the daily-maximum hourly-average ozone concentration and the time(s) of occurrence for each day for each station. The completeness of each of these ozone data sets was computed for each station for each smog season in the period 1986-93. For each smog season, the resulting data completeness for each of the stations used in our analyses of daily maximum hourly-average ozone concentrations in the region of the SoCAB, with two exceptions, was 89% or greater.

The ARB data for ambient concentrations of NO_x and NO_2 for the SoCAB from the various air monitoring stations for the eight-year period 1986-93 were subjected to data completeness checks. The morning 5-8 am Pacific Standard Time (PST) (6-9 am Pacific Daylight Time (PDT)) hours generally had greater than 95% data completeness with numerous cases of 98% and 99% completeness.

For the eight smog seasons, various sets of surface and upper-air meteorological data were used to generate a new data base which contained the meteorological data needed to bin the days according to the Classification and Regression Tree (CART) developed by Horie in 1987. Prior to this application, however, careful examination of the data base was undertaken to identify periods of missing data. To the degree possible, these gaps were filled using computer archives of meteorological data in the UCLA Department of Atmospheric Sciences (for the period 1990-93) and CD-ROM meteorological archives available through the UCLA Library. The resulting completeness of the meteorological data set used in applying the CART scheme was 97% or greater for each of the eight smog seasons in the period 1986-93 (with the exception that for five of the eight years, El Toro wind data were available from the AQMD site but not from the desired FAA site).

1.4 Correlations of Ozone Concentrations With NO_2 and NO_x Ambient Concentrations as a Function of Day of Week and Subregion

Various experimental and modeling studies over the past several decades indicated that transport of ozone-precursor pollutants from the upwind "source" regions of the SoCAB (*e.g.*, West Los Angeles) played a significant and even dominant role in the occurrence of high daily Basin ozone maximum concentrations in the downwind "receptor" regions (*e.g.*, the San Gabriel Valley) of the Basin (National Research Council 1991). However, although the Coastal and Metropolitan subregions have been relatively more densely populated compared to other regions of the Basin, over the past two decades the major growth in the SoCAB has occurred in the middle and eastern portions of the Basin resulting in changing emissions patterns. This raises the possibility that the traditional view of the critical importance of air parcel transport across the SoCAB may no longer be entirely valid. Investigation of the relationships between evening NO_x/NO_2 concentrations and next day ozone maximum concentrations is also relevant to the issues of "residence time" and "carry-over" effects.

To investigate the relationship between daily Basin ozone maxima and morning NO_x emissions on a subregional basis, the correlations between daily hourly-average maximum ozone concentration and average morning 6-9 am Pacific Daylight Time (PDT) NO_2 and NO_x concentrations were examined for the subregions of the Basin shown in Table 1-2. The correlations were calculated for each day of the week for both 1986-89

Table 1-2. Subregions of the SoCAB employed in this study and air monitoring stations within each subregion for which air quality data were employed.

Subregion	Stations
Coastal	[a,b]Hawthorne [a,b]Long Beach [b]Los Alamitos [a,b]West Los Angeles
Metropolitan	[a,b]Anaheim [b]Burbank [a,b]Central Los Angeles [b]El Toro [a,b]La Habra [b]Lynwood [b]Pico Rivera [b]Reseda [b]Whittier
San Gabriel Valley	[a,b]Azusa [a,b]Glendora [a,b]Pasadena [a]Pomona
Inland	[a,b]Norco [b]Pomona [a,b]Upland
Inland Valley	[b]Banning [a,b]Fontana [b]Hemet [b]Perris [a,b]Riverside [a]San Bernardino
Mountain	Crestline

[a] Stations used in analyses discussed in Chapter 4.
[b] Stations used in analyses discussed in Chapter 6.

(defined in this study as "period I") and for 1990-93 ("period II").

As in many earlier studies, the morning 6-9 am PDT period was chosen because commuter traffic is at a maximum, and these hours typically exhibit low solar insolation and low wind speeds. Under these conditions, average morning ambient air NO_x and NO_2 concentrations can, to a good approximation, be assumed to be representative of morning NO_x and NO_2 emissions, respectively, for the various subregions of the Basin.

1.4.1 Daily Basin O_3 Maximum Concentrations vs. Morning NO_2 and NO_x Concentrations

For all subregions of the Basin and all days of the week, the correlations between morning NO_2 concentration and Basin ozone maximum were better than the correlations between morning NO_x concentration and Basin ozone maximum.

The correlations between the daily Basin ozone maxima and the average morning NO_x and NO_2 concentrations in the "source" region (*i.e.*, the Coastal/Metropolitan subregions) were relatively poor, but were better for period I than for period II. For both periods, correlations were found to be lower on weekdays than on weekend-days.

In the San Gabriel Valley, the correlations for both NO_2 and NO_x with the daily basin ozone maxima were better for period I than for period II for all days of the week, except Monday and Tuesday. The effect that correlations were better for weekend-days than for weekdays, as yet unexplained, was most pronounced for the 1986-89 period for both NO_2 and NO_x. However, good correlations were found for NO_2 for both periods and for all days of the week. In the Inland Valley, NO_2 correlations with the daily Basin ozone maxima were better for weekend-days than for weekdays with the best correlation coefficient found for Sunday.

1.4.2 Daily Subregion O_3 Maximum Concentrations vs. Morning NO_2 and NO_x Concentrations

To further explore the influence of morning NO_x emissions within a given subregion on afternoon peak ozone concentrations within the same subregion, correlation coefficients between these quantities were calculated for all days of the week for both periods. The ozone concentration maxima within a given subregion were found to be highly correlated with the early morning NO_2 concentrations (and hence emissions) in the same subregion on the same day.

The correlations between average morning Coastal/Metropolitan NO_2 and NO_x concentrations and Coastal/Metropolitan ozone concentration maxima are given in Table 1-3. Reasonably good correlations were found for NO_2 concentrations for all days of the week for both periods.

Table 1-3. Correlation coefficients between daily Coastal/Metropolitan ozone maximum concentration and average morning NO_2 and NO_x concentrations in the Coastal/Metropolitan subregion.

	NO_2		NO_x	
	1986-89	1990-93	1986-89	1990-93
Monday	0.65	0.62	0.32	0.34
Tuesday	0.54	0.67	0.28	0.40
Wednesday	0.52	0.52	0.36	0.31
Thursday	0.57	0.50	0.25	0.21
Friday	0.63	0.49	0.30	0.23
Saturday	0.65	0.61	0.41	0.42
Sunday	0.66	0.64	0.48	0.50

In contrast, the Basin ozone maximum was poorly correlated with the average morning Coastal/Metropolitan NO_2 concentration for all days of the week. This suggests that morning NO_x emissions in the Coastal/Metropolitan subregions may not play as dominant a role in the occurrence of high ozone concentrations in the downwind regions like the San Gabriel Valley and Inland Valley as in the past (prior to the large population growth in these subregions), but contribute significantly to peak ozone concentrations in the Coastal/Metropolitan subregion.

Good correlations between average morning San Gabriel Valley NO_2 and NO_x concentrations and San Gabriel Valley ozone concentration maxima were found for both periods and for all days of the week for NO_2; correlations were highest for Friday through Sunday for period I. The correlation coefficients for NO_2 ranged from 0.63 to 0.75 for period I, and from 0.56 to 0.70 for period II.

The correlations between average morning Inland Valley NO_2 and NO_x concentrations and Inland Valley ozone maxima are given in Table 1-4. Good correlations were found for both periods and for all days of the week for NO_2; correlations were somewhat better for weekend days and Friday than for the other weekdays.

Table 1-4. Correlation coefficients between daily Inland Valley ozone maximum concentration and average morning NO_2 and NO_x concentrations in the Inland Valley subregion.

	NO_2 1986-89	NO_2 1990-93	NO_x 1986-89	NO_x 1990-93
Monday	0.57	0.62	0.26	0.38
Tuesday	0.57	0.66	0.22	0.42
Wednesday	0.61	0.54	0.20	0.25
Thursday	0.63	0.62	0.22	0.29
Friday	0.72	0.66	0.42	0.36
Saturday	0.69	0.67	0.47	0.44
Sunday	0.72	0.67	0.52	0.54

1.4.3 Daily O_3 Maximum vs. Previous Evening's NO_2 and NO_x Concentrations

Significant NO_x emissions occur in the SoCAB during evening hours from commuter traffic; in the western portion of the Basin stationary sources (*e.g.*, electric utilities and oil refineries) can also produce significant NO_x emissions during the evening and night-time hours. The degree to which carryover of NO_x emissions might influence early-morning ambient NO_2 and NO_x concentrations is dependent upon meteorological factors which control the dispersion and transport of pollutants. Fujita et al. (1992) found that carryover of emissions from the previous day may affect early morning ambient concentrations more during Fall months than during the summer months investigated in the present study.

To investigate whether transport of evening NO_x emissions from the Coastal/Metropolitan subregions influenced the peak ozone concentration in the Basin on the following day, the evening (6-9 PDT) Coastal/Metropolitan average NO_2 and NO_x concentrations were correlated with the following day Basin ozone maximum for Tuesday/Wednesday and for Friday/Saturday. Tuesday evening/Wednesday was assumed to be representative of typical weekdays, while Friday evening/Saturday was assumed to be representative of weekend-days.

The evening NO_x emissions within a given subregion might also contribute to the next day's early morning NO_x concentration in the same subregion. To investigate this possibility, correlations between the daily subregion ozone maxima and the previous evening's average NO_x and NO_2 concentrations in that subregion were also investigated for Tuesday/Wednesday and Friday/Saturday.

The correlations between the Coastal/Metropolitan average Tuesday evening NO_x concentration and the Wednesday Basin ozone maximum and the Wednesday Coastal/Metropolitan ozone maximum were both quite small, suggesting little relationship between weekday evening NO_x and following day maximum ozone. The correlations between Friday evening average Coastal/Metropolitan NO_x concentration and Saturday Basin ozone maximum and Coastal/Metropolitan ozone maximum were also poor. These results suggest that carryover of evening NO_x emissions from the Coastal/Metropolitan subregion may not have significantly influenced the daily ozone maximum either in the Coastal/Metropolitan subregion or in the Basin as a whole for the May-October months during the eight-year period investigated in the present study.

The correlations between the daily Basin ozone maximum, the San Gabriel Valley ozone maximum, and the previous evening average San Gabriel Valley NO_x or NO_2 concentrations were also poor.

Assuming the average evening (5-8 pm PST) ambient NO_x concentration was representative of the evening NO_x emissions from on-road mobile sources, these results suggest carryover of evening NO_x emissions from mobile sources in the San Gabriel Valley may not have influenced the daily ozone maximum in the Basin (and hence typically the San Gabriel Valley ozone maximum) to a significant extent during the period of this study.

1.5 Examination of Air Parcel Residence Time and Other Meteorological Parameters

Various previous observational and modeling studies have indicated there is a relationship between the ambient meteorological conditions and the occurrence of high concentrations of ozone in the SoCAB. In order to facilitate identification of those meteorological factors associated with the occurrence of high ozone values, we took the approach of examining the difference in meteorological conditions between those days on which a very high ozone value was reported somewhere in the SoCAB and those days on which the ozone value was simply average. A significant limitation of this analysis was the lack of adequate upper air meteorological data. More robust examination of the important issue of air parcel residence time would require the implementation of a mesoscale upper air meteorological network in the SoCAB.

In undertaking this analysis, we first ranked each smog season day for the years 1990-93 on the basis of the highest hourly-average ozone values reported in the SoCAB. It quickly became apparent, however, that virtually all of the highest ozone values occurred at one of the following four locations: Riverside, Crestline, Fontana, and Glendora. Since our objective was a description of the meteorological conditions associated with the typical occurrence of very high ozone values within the SoCAB, we limited our analyses to those days on which the peak ozone report came from one of these four sites.

The middle day in the ranked distribution had a peak ozone value of 15 pphm; there were 28 days during the 4-year period for which this was the Basin-maximum ozone value reported. In order to have comparably-sized groups of days for comparison, the high ozone days were defined as the first 28 days in the distribution; maximum values for these days ranged from 33 pphm to 25 pphm.

1.5.1 Surface Meteorological Conditions: High Ozone Days vs. Middle Ozone Days

Vector average 1-hour resultant winds were calculated from 0700 PDT to 1800 PDT for each station in the SoCAB for the set of high ozone days and for the set of middle ozone days. For both the high and middle ozone days, 1-hour resultant winds were generally 1 knot or less prior to 0900 PDT. Then weak ventilation of the Basin appeared for both sets of days, with general surface flow from coastal regions towards the interior. As the time of day progressed into the early afternoon, the strength of the surface flow towards the interior increased, but little difference appeared between the high ozone days and the middle ozone days. Wind speeds for both groups of days decreased in the late afternoon. Implications of these results include the following: westerly-southwesterly ventilation begins throughout the SoCAB at approximately the same time, rather than showing the eastward propagation of a discrete sea breeze front; significant surface transport between coastal areas and the far inland portions of the SoCAB is unlikely to occur in a single day; and variation in surface transport does not significantly influence the peak SoCAB ozone level. However, only surface wind data were available to us for the SoCAB and the actual transport will be determined by the three dimensional wind field.

Further understanding of the roles of transport and residence time was obtained from examination of the foregoing resultant wind analyses in conjunction with an analysis of the average initial hour of occurrence of the daily ozone maximum at each SoCAB station for the 28 high ozone days. This analysis revealed little variation in the average time of initial occurrence of the peak ozone value throughout a large part of the western SoCAB. Progressively later times of first occurrence of peak ozone at stations farther to the east suggests that at these locations transport from the west is important, but details of the analysis indicate the transport pattern is complex, with transport perhaps significant only within a particular subregion and between adjacent subregions.

A similar analysis for the 28 middle ozone days also suggests transport is perhaps only of significance within limited sub-domains of the SoCAB and not across the entire horizontal extent of the Basin. However, details of both this analysis and the aforementioned resultant wind analysis suggest surface transport is somewhat more from the west on high ozone days and somewhat more from the south on middle ozone days.

Additional examination of the roles of transport and residence time was enabled by examining the SoCAB resultant surface winds as a function of time of day along with the average initial hour of occurrence of the daily ozone maximum at each SoCAB station for just the 19 out of the 28 high ozone days that the ozone maximum occurred at Glendora, and for just the 6 out of the 28 high ozone days that the ozone maximum occurred at Crestline. Results of the former analyses suggest the precursor pollutants responsible for the highest hourly ozone occurrences in Glendora might originate from only a relatively short distance to the west, while results of the latter suggest two possible routes of transport to Crestline on the worst ozone days at that location: one from the San Bernardino area to the south, and the other along the southern base of the San Gabriel Mountains to the west-southwest (but not from as far west as the Coastal/Metropolitan subregions).

These analyses were then extended through determination of backward surface trajectories from Glendora (for the Glendora high ozone days) and from Crestline (for the Crestline high ozone days). These were found using the corresponding resultant surface wind analyses for each of these two groups of days, with parcels "started" at Glendora and Crestline at the respective mean initial times of occurrence of the daily maximum ozone value. Results are consistent with the findings noted above.

A limitation of the foregoing resultant wind analyses is that the resultant wind speeds and directions do not necessarily well-represent the individual reports they comprise. To directly examine the variation in wind speeds and directions among selected groups of wind observations, wind roses were constructed for the resultant 0800-0900 PDT wind and the resultant 1400-1500 PDT wind for both West Los Angeles and Glendora and for both the 28 high ozone days and the 28 middle ozone days. At the earlier time (0800-0900 PDT) on the high ozone days, the winds at West Los Angeles were predominantly very light and out of the south, while the predominant wind direction at Glendora was southwesterly but with a typical wind speed of less than 0.5 mph. Quite similar results were found for the middle ozone days, except the wind direction at West Los Angeles tended to be less predominantly southerly and instead more southwesterly (primarily) or easterly (secondarily). Striking similarity between middle and high ozone days was also apparent in the afternoon (1400-1500 PDT) wind roses. At both locations and for both the high ozone days and the middle ozone days, the flow is predominantly from the southwest. In summary, then, these wind rose analyses also imply that variation in surface transport in itself is not a dominant factor in determining the daily SoCAB peak ozone level for the period 1990-93.

In contrast to the apparent similarity in low-level wind flow between the high and middle ozone days, the average maximum surface (air) temperatures were significantly different between the two groups of days. At all of the stations in the SoCAB with temperature data (with the exception of Hawthorne), the decrease in average maximum surface temperature was 9 °F or greater between the high ozone and middle ozone days. The implication is thus that surface heating is a significant factor in determining the daily SoCAB peak ozone level for the period 1990-93.

1.5.2 850 mb Meteorological Conditions: High Ozone Days vs. Middle Ozone Days

Data at the 850 mb pressure level (approximately 5000 feet above sea level) are provided by balloon-borne radiosondes, routinely launched at 1200 GMT (0500 PDT) and 0000 GMT (1700 PDT) from rather widely-spaced stations. The two closest radiosonde sites to the SoCAB that have daily reports throughout the period are San Diego to the south and Vandenberg Air Force Base (AFB) to the northwest. Temperature and wind data from these two sites were utilized.

An approximate 850 mb temperature for the SoCAB was defined by averaging the values simultaneously reported by the San Diego and Vandenberg AFB sites. At both 0500 PDT and 1700 PDT, the average SoCAB 850 mb temperature for the 28 high ozone days was significantly greater than that for the 28 middle ozone days. At the latter time, none of the 850 mb temperatures for high ozone days were lower than the highest 850 mb temperature for a middle ozone day.

Vector-average 850 mb winds were found separately for Vandenberg AFB and San Diego at both 0500 PDT and 1700 PDT for both middle and high ozone days. In general, differences between the two sets of days were fairly small. It did appear, though, that the

850 mb winds were somewhat stronger and more northerly on high ozone days than on middle ozone days.

Further examination of the 850 mb winds was enabled by the construction of wind roses for the 1700 PDT 850 mb radiosonde wind observations at Vandenberg AFB and San Diego. At both locations and for both middle and high ozone days, a variety of wind directions were evident. Winds did tend to be somewhat more northerly at Vandenberg AFB and northwesterly at San Diego on high ozone days than on middle ozone days.

1.5.3 Pattern Number: High Ozone Days vs. Middle Ozone Days

Five different synoptic patterns, described by the contour signature at the 500 mb level, were defined by Cassmassi (1987) for ozone prediction stratification. Among the data received from the SCAQMD for the present study was a number indicating the classification of each day according to this set of synoptic patterns.

The pattern number distribution for the 28 high ozone days was compared with that for the 28 middle ozone days. All but three of the high ozone days were associated with pattern number 4 (a high pressure ridge over California, with 500 mb heights approaching or exceeding 5880 m throughout the study area), while the majority of the middle ozone days were associated with pattern number 3 (zonal flow or a "building" high pressure ridge, characterized by a moderate pressure gradient and 500 mb heights somewhat higher to the southwest). The implication is that the highest ozone values occurred in association with very high 500 mb heights and thus warm troposphere-mean temperatures, while lower ozone days tended to be associated with lower 500 mb heights and thus cooler troposphere-mean temperatures, and stronger flow aloft. However, since a not insignificant number of middle ozone days had the same pattern number as did most of the high ozone days, the pattern number as defined by Cassmassi (1987) cannot fully account for the difference in characteristic synoptic-scale meteorological conditions between high and middle ozone days.

1.5.4 Application of the CART Scheme

Horie (1987) developed a Classification and Regression Tree (CART) scheme which was used to separate each day of the 3-year period 1983-85 into ten different categories (nodes) based on meteorological conditions. In the present study, this CART scheme was used to bin the smog season days from the 8-year period 1986-93 into the 10 nodes of the tree in 4 different ways. First, the smog season days for each of the years 1986-93 were individually binned using the CART scheme. Then, all of the smog season days for 1986-89 were treated as one group for binning and those for 1990-93 were treated as a second group. Next, the 28 high ozone days and the 28 middle ozone days for the smog seasons of 1990-93 were binned according to their associated node in the CART scheme. Finally, the weekdays (here represented by Tuesday and Wednesday) and the weekend days (Saturday and Sunday) were separately binned for the two four-year periods 1986-89 and 1990-93.

When the smog season days for each of the years 1986-93 were individually binned using the CART scheme, it was found for each of the 8 years that the highest Basin-maximum ozone concentration was associated with node 10. This node is characterized by very warm temperatures at 850 mb and 900 mb (and thus probably very high inversion temperatures) and morning winds at El Toro ranging from west-southwesterly to northwesterly. However, Basin-maximum ozone values associated with this node were significantly less in the latter four years than in the earlier four years, and were lower for all years of our study than the 1983-85 average for this node of 28.9 pphm reported by Horie. Thus, under similar meteorological conditions conducive to ozone formation, peak ozone values appear to have decreased and have thus apparently decreased for other than meteorological reasons.

When all of the smog season days for 1986-89 were binned together by node of the CART scheme and then compared with the smog season days for 1990-93, it was found the Basin-maximum ozone value for each of the 8 CART nodes into which the days were distributed was lower for the latter group of years than for the earlier 4-year period. The implication is thus that regardless of the meteorological conditions, generally lower peak ozone values were observed in the latter four years than in the earlier four years. However, the magnitudes of the reductions were comparatively small, and thus attribution to other than meteorological influences, while likely, is not definitive.

Finally the 28 high ozone days and the 28 middle ozone days for the smog seasons of 1990-93 were binned according to their associated nodes in the CART tree. While sixteen of the high ozone days were classified as node 10 and four as node 9, none of the middle ozone days were associated with either of these nodes. Nodes 9 and 10 are distinguished by having the warmest temperatures at both 850 and 900 mb.

1.6 Characterization of Weekday/Weekend Effects

The ozone database (1986-93) was analyzed for differences in daily ozone maxima on weekdays vs. weekend days for the air pollution season (May-October). As simple averages of daily ozone maxima were not found to be a useful metric for distinguishing weekday/weekend differences, other indices of weekday vs. weekend differences were investigated.

1.6.1 Daily Maximum Ozone Distributions for Weekdays vs. Weekend Days

For the 1986-93 period, ozone daily maximum data for stations at Central Los Angeles (L.A.), Azusa, and Riverside were analyzed for weekday/weekend differences in the distribution of ozone concentrations. Many of the higher daily maximum ozone concentrations occurred on weekend days while the lower daily maximum concentrations were more frequent on the weekdays. Enhancement of this difference appeared to occur in the later years of the period studied.

1.6.2 Ozone First Stage Alerts and Cumulative Hourly Exceedance for Weekdays vs. Weekend Days

As defined by the SCAQMD, a first stage alert for ozone is declared if the hourly-average ozone concentration equals or exceeds 20 pphm at any station in the SoCAB. A computer program was developed to compare the number of ozone first stage alerts on weekdays and weekend days for the air monitoring stations at Central LA, Azusa, and

Riverside.

For the entire eight-year period 1986-93 a greater number of ozone first stage alerts occurred on Saturday/Sunday than on weekdays for the Azusa station but not for the Riverside station. The number of ozone first stage alerts for each day of the week for each year between 1986 and 1993 for the same two stations was also plotted and a general decline in the number of ozone first stage alerts was observed for all days of the week over the eight-year period. The Azusa station and Central L.A. station appear to have experienced greater declines over the eight-year period in the number of ozone first stage alerts on weekend days than did the Riverside station.

The cumulative hourly ozone exceedance above the federal standard of 12 pphm was also computed for each day of the air pollution season for each of the eight years of interest for the Central L.A., Azusa and Riverside stations. In general, the cumulative ozone exceedance decreased over the eight-year period (1986-93) for all days of the week at all three stations. These data also indicated that although in general ozone exceedances for Central LA and Azusa were higher on weekend days as compared to weekdays, this was not necessarily true for Riverside, consistent with the finding for first stage alerts.

1.6.3 Weekday/Weekend Analyses Using the CART Scheme

The CART scheme developed by Horie (1987) was used to bin the smog season days into the 10 different nodes of the tree. Weekdays (here represented by Tuesday and Wednesday) and weekend days (Saturday and Sunday) were separately binned for the two four-year periods 1986-89 and 1990-93.

A general increase was observed in mean (daily-maximum hourly-average) ozone value with node number in Horie's CART scheme. On average, the worst ozone days were defined by node 10, characterizing 6%-8% of the smog season days. However, the standard deviations were sufficiently large that many of the CART nodes cannot be considered as statistically distinct from each other.

1.6.4 Examination of Ten Days with Highest Hourly-Average Ozone Concentrations: 1986-89 vs. 1990-93

To further investigate the trends noted from application of the CART scheme, we examined the means of the ten highest daily hourly-average ozone concentrations for each of the four-year periods for each of the stations for which data were available. In other words, we examined the trends as seen on the worst ozone days at each station. As shown in Figure 1-1, we found the most significant ozone decreases between the two four-year periods occurred in the western and middle portions of the SoCAB for the worst ozone days, corresponding generally to the area of maximum percentage decrease in early morning NO_x ambient concentrations for these same highest ozone days, as shown in Figure 1-2.

For the period 1986-89, the mean of the ten highest daily ozone values on weekend days was higher than the mean for those on weekdays (here taken to be Tuesdays and Wednesdays) for all Coastal subregion stations considered, and for most (7 out of 9) of the Metropolitan subregion stations. However, the reverse was true for all of the Inland Valley subregion stations (as well as the one Mountain station), and for 2 out of 3 stations in both the San Gabriel Valley subregion and the Inland subregion.

For the period 1990-93, the mean of the peak concentrations on the weekend days was higher than that on the weekdays for all stations in all subregions, with the exception of two stations in the far eastern end of the SoCAB (Crestline, and Banning) where the weekday mean was only very slightly higher than that for weekend days.

1.6.5 Weekday/Weekend Differences in Ambient NO_2, NO_x, and NO_2/NO_x

WD vs. Saturday: Taking the means of NO_2, NO_x and the NO_2/NO_x ratio for the combined Coastal and Metropolitan subregions for the period 1986-89, Saturdays had 18% lower NO_2 levels, 32% lower NO_x levels, and 17% higher NO_2/NO_x ratios than the weekday average. Similar results were found for the period 1990-93.

WD vs. Sunday: Again, combining the data for the Coastal and Metropolitan subregions, for the period 1986-89, Sunday had 26% lower NO_2 levels, 43% lower NO_x levels, and 28% higher NO_2/NO_x ratios than the weekday average. Corresponding values

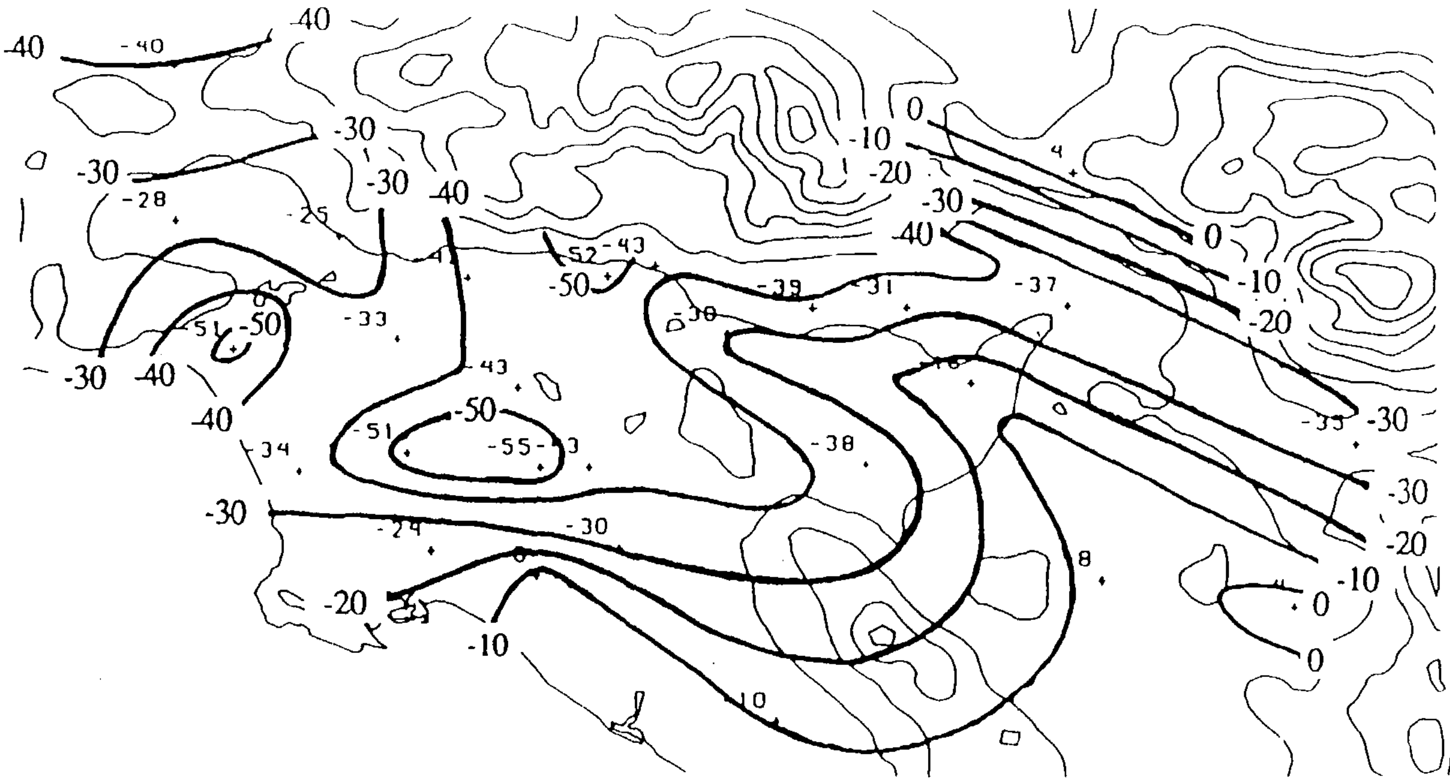


Figure 1-1. Changes in means of the ten highest daily ozone concentrations (ppb) between 1986-89 and 1990-93 by station within the SoCAB. Negative values indicate lower ozone values in the latter period.

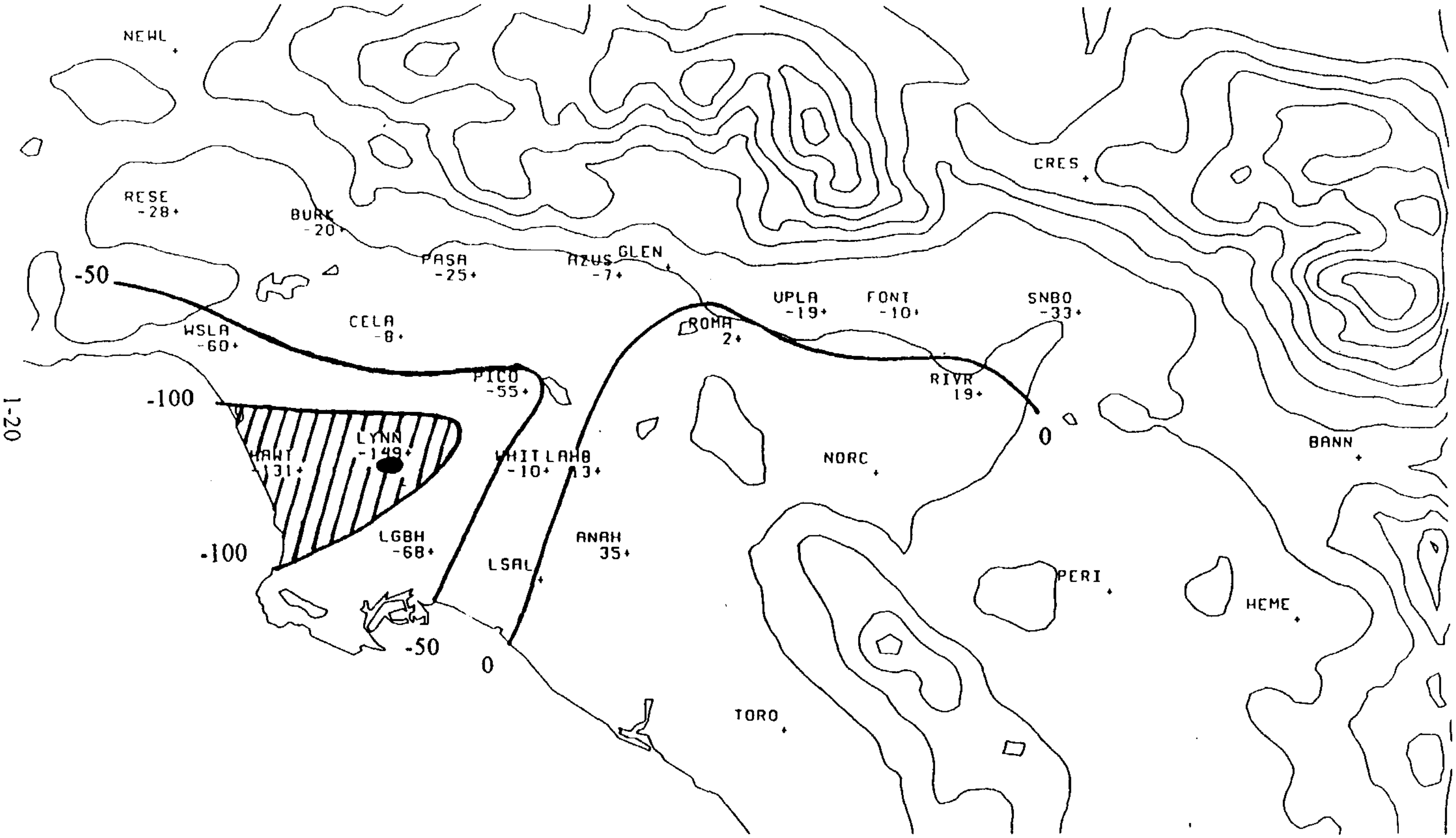


Figure 1-2. Isopleth diagram for change in ambient 5-8 am (PST) NO_x concentration (ppb) from 1986-89 to 1990-93 for top ten O_3 days in those periods.

for the period 1990-93 were 27%, 52%, and 36%, respectively.

In general, these early morning ambient air concentration data suggest that only a modest decrease in emissions of NO_x occurred in the Coastal/Metropolitan subregions between the two four-year periods under study here. Specifically, combining the NO_x data for the two subregions, weekdays (as represented by Wednesday/Thursday) and Saturday experienced only a 3% decrease in NO_x concentrations between 1986-89 and 1990-93, while Sunday and Monday experienced an 18% decrease in NO_x concentrations for the combined subregions. The change in NO_2 concentrations varied less by day of the week, with a decrease of 14% for Weekdays, 12% for Saturday, 16% for Sunday, and 18% for Monday.

1.7 Principal Findings

The principal findings of this study were as follows.

- Peak ozone concentrations in the SoCAB were generally much better correlated with NO_2 concentrations than with NO_x concentrations.

- In general, the highest correlations between morning NO_2 and peak ozone concentrations occurred on weekend days and Fridays.

- High intra-subregion, same day correlations between morning NO_2 and peak ozone were observed throughout the Basin, particularly in the San Gabriel Valley and Inland Valley subregions.

- Correlations were weak between evening NO_2 or NO_x and the next day's Basin peak ozone during the smog season months for the 1986-93 period investigated here.

- Significant differences in these correlations were observed between the 1986-89 and 1990-93 periods, suggesting continuing changes in the spatial distribution of emissions in the Basin over this period and/or the influence of different multi-year meteorological patterns.

- Little difference in surface wind field was evident between high ozone days a n d average ozone days.

- Differences in 850 mb winds between high ozone days and average ozone days were relatively small.

- Maximum surface air temperatures, and both early morning and late afternoon 850 mb temperatures, were significantly higher on high ozone days than on average ozone days.

- Application of the CART scheme to each of the 8 years of the study showed that the highest Basin-maximum ozone concentration was associated with node 10, which is characterized by very warm temperatures at 850 mb and 900 mb, as well as morning onshore flow at El Toro.

- Basin-maximum ozone values associated with CART node 10 were significantly lower in the latter four years than in the first four years covered by this study, and were lower for all years of the present study than the 1983-85 average for this node of 28.9 reported by Horie. Lower Basin-maximum ozone values were also found for the other seven CART nodes for the second four years.

- As well documented earlier by ARB, SCAQMD and others, substantial reductions in peak ozone concentrations occurred in all regions of the Basin and across all days of the week between 1986-89 and 1990-93, although the percentage reductions were greatest in the western and middle portions of the Basin. On average there were greater reductions on weekdays than on weekends and hence the differences in WD vs. WE daily ozone maxima increased in the 1990-93 period over the 1986-89 period.

- An examination of the worst ozone days, specifically the ten highest daily hourly-average ozone concentrations for each of the two four-year periods for each station for which data were available, showed the most pronounced percentage decrease in these highest ozone concentrations occurred in the western and middle portions of the Basin, corresponding generally to the area of maximum percentage decrease in early morning NO_x ambient concentrations for these same highest ozone days.

- The distribution by day-of-the-week of the ten highest ozone concentrations in the Basin for each year for each station in the period 1986-93, showed these episodes occurred significantly more often on Saturdays than on Sundays through Wednesdays.

- Similarly, for the period 1990-93, the means of the peak ozone concentrations for the top ten days were higher on weekend days than on weekdays for all stations in all subregions (with the exception of Crestline and Banning).

- On average, early morning ambient concentrations of NO_2 and NO_x during the eight year period studied were lower by approximately 20-25% and 30-50%, respectively on weekend days than on typical weekdays in the Coastal/Metropolitan subregions.

- Significantly more comprehensive upper air data are required to better characterize air parcel transport and carry-over effects.

2.0 INTRODUCTION, BACKGROUND AND OBJECTIVES

2.1 Introduction

More than two decades of systematic and effective control in California of the precursors to photochemical smog has resulted in a remarkable reduction in ozone concentrations in the South Coast Air Basin, despite an enormous increase in both population and vehicle miles travelled. By any common metric---including peak ozone concentrations, number of first or second stage violations, and seasonal total station hours above the ozone air quality standards---ozone levels in the SoCAB have declined markedly over the past fifteen years (AQMP 1994, Cassmassi 1994).

These improvements in air quality are the result of stringent control programs for both stationary and mobile emission sources mandated by the California Air Resources Board (ARB) and implemented by local air quality management districts such as the South Coast Air Quality Management District (SCAQMD). The dramatic gains made in southern California, particularly over the past decade, stand in sharp contrast to the lack of improvement in ambient ozone concentrations throughout most of the rest of the country (which has generally followed the strategy of controlling only volatile organic compounds (VOC) as advocated by the U.S. Environmental Protection Agency during the 1970's and 1980's). The lack of progress in the eastern U.S. has prompted a reexamination of Federal policy and a call for greater emphasis on control of oxides of nitrogen in other regions of the nation (National Research Council 1991), as well as attention to the role of biogenic hydrocarbons in establishing a potential limit to the effectiveness of anthropogenic VOC control.

Empirical evidence from long-term trend data, for both emission inventories and ambient air quality, indicates that reduction in oxides of nitrogen (NO_x) has been beneficial in reducing peak levels of ozone in the severely impacted downwind regions of the SoCAB. In addition, it is our understanding that photolysis of nitrogen dioxide remains the only significant pathway to ozone formation in the troposphere. Nonetheless, predictions obtained through the use of the Urban Airshed Model (UAM) continue to suggest (AQMP Task Force 1994) that further NO_x control will be counterproductive in reducing ozone over most of the SoCAB. The contradiction between UAM predictions and observed air quality trends has led to suggestions that UAM inputs may not represent high ozone episode conditions over a sufficiently wide range of meteorological conditions.

Specifically, much of the regional modeling for the SoCAB has been conducted for one or two pollution episodes, from the Southern California Air Quality Study (SCAQS) conducted in 1987 (SCAQS 1993) or earlier field programs in the SoCAB. It is possible, for example, that reliance on only one or two episodes may lead to difficulties in properly representing the importance of air parcel "residence time" in the SoCAB in the UAM predictions. Moreover, earlier studies of this issue have not accounted for distinctions between weekend and weekday episodes, yet the fraction of total ozone standard violations which occur on weekends has been increasing over the past several years (Cassmassi 1994).

In particular, in recent years, Saturday has been one of the highest ozone days, despite apparently lower VOC and NO_x precursor concentrations (ARB 1993). Because the NO_x inventory is believed to be relatively more reduced on weekends vs. weekdays than is the VOC inventory, it has sometimes been concluded that reductions in NO_x emissions increase ozone, at least in the western portion of the SoCAB. However, it is possible that inclusion of "residence time" in such analyses may show that carry-over effects are largely responsible for the observation of "high" Saturday and "low" Monday ozone levels.

Clearly, there is a need to better characterize the range of meteorological conditions associated with high air pollution episodes and to assess the influence of residence time and weekday/weekend effects on such episodes. Moreover, it is critical to carefully analyze air quality trends in the SoCAB over the past decade on a sub-region basis, and to evaluate correlations between NO_2 and NO_x precursor concentrations and subsequent ozone levels. As described in the following section, such characterizations and assessments have employed as their departure point the important earlier investigations by researchers at Valley Research Corporation (Horie 1987), InstaWeather Inc. (1989), and Systems Applications International (Rosenbaum and Pehling 1991, Stoeckenius 1991), as well as the accumulated knowledge of meteorologists at the ARB and SCAQMD.

2.2 Background

The history of urban airshed modeling for the California South Coast Air Basin is one in which the meteorological conditions of a single ozone episode have been used to forecast the impacts of proposed emission control programs for VOC and NO_x, and to draw fundamental conclusions about the relative efficacy of VOC vs. NO_x control for reducing ozone levels in the SoCAB. For example, Air Quality Management Plans (AQMPs) developed by the SCAQMD in the 1980's generally used a single two-day episode on 26-27 June 1974 as the base case modeling episode. For the AQMP prepared in 1994, the 27-29 August 1987 episode which occurred during SCAQS was used, and several other episodes were also considered.

Reliance on no more than a few episodes is largely a consequence of the complexities and expense of running the Urban Airshed Model in extensive scenario testing and control program evaluations. However, such reliance has raised questions concerning the representativeness of the meteorology of a single episode, given that ozone air quality standard violations in the SoCAB still occur on more than 100 days of the year under a wide range of meteorological conditions. Thus, the SCAQMD's regional modeling and air quality planning efforts have been criticized on this issue (Horie 1987).

In an attempt to address this criticism, a study by Horie (1987) was commissioned by the SCAQMD to develop a set of statistically determined meteorological conditions (*i.e.*, "met classes") that were representative of the long-term meteorology of the Basin. In this study, a Deviation Index (DI) was defined separately for each met class and computed for every individual day during the period from January 1983 through December 1985, in order to systematically measure the suitability of individual days for ozone modeling (Horie 1987). This index was designed to measure a deviation of a particular day's meteorological condition from the average condition for the met-class to which the day belonged.

By examining the emissions, air quality data, and meteorological conditions of the thirteen days having the lowest DI values in each met-class, four candidate days that appeared to be best suited for regional ozone modeling in the SoCAB were selected from approximately 400 days that were found to belong to one of the four met-classes with basin-maximum ozone concentrations exceeding the Federal ozone air quality standard. Using the same selection procedure, the suitability of three ozone episodes used for regional modeling (26-27 July 1974; 30 August-2 September 1982; 7-8 August 1984) was also evaluated. None of these episode days were found to be representative of any of the four met-classes defined by Horie (1987).

In research building upon the work of Horie, Zeldin conducted a study entitled "A Meteorological and Air Quality Assessment of the Representativeness of the 1987 SCAQS Intensive Days" (Instaweather 1989). In this study, each of the five summer SCAQS episodes and three fall/winter intensive periods were examined with respect to meteorology and air quality. Surface streamlines and sea level pressure were analyzed for three daytime periods, and maps of ozone, nitrogen dioxide, and PM-10 were plotted.

Climatological statistics were found for key meteorological and air quality parameters. These were then compared with the conditions on SCAQS days. Zeldin evaluated the representativeness of the SCAQS summer intensive periods with the methodology developed by Horie. These analyses, along with a special evaluation of intensive day uniqueness, were used to develop a ranking of the SCAQS intensive periods with respect to their suitability for modeling applications.

Zeldin found that only 28 August 1987 had a "reasonable central met-class tendency." None of the other days corresponding to SCAQS intensive episodes had central met-class characteristics. As a consequence of the need to have two consecutive days suitable for modeling, Zeldin ranked the 24-25 June 1987 episode higher than the 27-29 August episode in terms of "overall representativeness" as only the middle day of the three day August episode was judged suitable for modeling.

These findings reinforce the need for further investigations of episode representativeness, and of the influence of factors such as residence time and carry-over as manifest, for example, in weekday/weekend effects.

2.3 Objectives

2.3.1 Overall Objective

The primary overall objectives of this project were: (1) to analyze recent air quality trends in the SoCAB on a sub-regional basis; (2) examine the relationship between ozone levels and NO_2/NO_x concentrations; and (3) to investigate the influence of air parcel residence time and weekday/weekend effects on conclusions drawn concerning the relative benefits of VOC vs. NO_x control in California's South Coast Air Basin.

2.3.2 Specific Objectives

The specific objectives of this project were:

- To characterize recent (*i.e.*, past decade) air quality trends in the SoCAB on a sub-regional basis, including correlations (or lack thereof) between ozone and NO_2 ambient air concentrations.

- To examine the potential importance of distinguishing meteorologically similar high ozone episodes on the basis of whether the occurrence was on a weekend day or a weekday.

- To characterize days above the California state ozone standard by "residence time" and relate this assessment to the meteorological categories developed by South Coast Air Quality Management District (SCAQMD) meteorologists.

- (Exploratory) To evaluate further the meteorological representativeness of the August 1987 SCAQS episode which has been-and will be-used for urban airshed modeling in support of development of VOC/NO_x control strategies and future air quality management plans.

- (Exploratory) To explore multiple linear regression relationships between meteorological parameters and ozone.

3.0 DATABASE DEVELOPMENT

3.1 Database Acquisition

3.1.1 Air Quality Database

Comprehensive data for the criteria pollutants NO_2, CO, O_3, and PM-10 and for key meteorological parameters (Table 3-1) were acquired for the years 1986-93. These data were acquired electronically from two different sources: the ARB and the SCAQMD. The data files were transferred to the UCLA Department of Atmospheric Sciences computer system via the Internet, with backup copies of the data files made on an 8 mm data cartridge.

Table 3-1. The air quality and meteorological databases (1986-93) acquired for the South Coast Air Basin.

Criteria Pollutants	Meteorological Parameters
Ozone	Upper air data
Carbon Monoxide	Resultant wind speed & direction
Nitrogen Dioxide	Temperature
PM-10	Relative Humidity
TSP	Dewpoint
Nitrogen Oxides	FAA data*

* The FAA data (meteorological data from FAA stations in the region of the SoCAB) are available only for 1987-89.

The criteria pollutant data were obtained as hourly-average observations reported from all air monitoring stations in the SoCAB. The air quality data received from the ARB for criteria pollutants O_3, NO_2, and PM-10 for 1986-93 were in a single computer file. Using a FORTRAN program, the ozone data were extracted from this large data file and stored as eight individual files, one for each year. The criteria pollutant data from the AQMD were received as multiple files with each file containing one year of data for each pollutant. Hence the partitioning of the ARB ozone data allowed for an efficient cross-check between the ARB ozone data and the AQMD data as described below.

3.1.2 Meteorological Database

The meteorological data were also received electronically via the Internet from the AQMD and backup copies of these computer files were stored on an 8 mm data cartridge.

3.2 Comparison of ARB and SCAQMD Databases

The hourly ozone data obtained from the ARB were compared with those received from the AQMD. A computer program identified days on which at least one hour exhibited a difference of greater than or equal to 2 pphm. A difference of 1 pphm was not considered to be significant as different rounding procedures were used by the ARB and the AQMD (Cassmassi 1994).

An analysis of the data indicated that less than 10% of the days in 1986-93 exhibited a difference of 2 pphm or greater. Further analysis of the time intervals of disagreement revealed that the ARB data set was more complete than that from the AQMD. This appears to reflect effort undertaken by the ARB to fill in data missing from the original record (*e.g.*, as a result of telemetry problems). Hence the ARB ozone data were used in all further analysis.

3.3 Database Completeness

3.3.1 Initial Completeness Analysis

The ARB hourly-average ozone concentrations for the 1986 through 1993 smog seasons (*i.e.*, 1 May to 31 October) all stations (30+) in the SoCAB were used to generate a new data set containing the daily-maximum hourly-average ozone concentration and the time(s) of occurrence for each day for each station. However, a number of multi-hour intervals of missing data were found in the ARB data set; as a result it was necessary to examine whether there were sufficient ozone reports from a given station on a given day to determine the maximum value. This assessment was made through development and application of data "tests" as described below.

The completeness of each of these ozone data sets was computed for each station for each smog season in the period 1986-93. Table 3-2 shows the fraction of days for each station for each of these eight smog seasons with two or more consecutive hours of

Table 3-2. The fraction of days during the smog season with gaps in ozone data of two or more hours in length. Missing data are denoted by '-----'.

Station/Year	1986	1987	1988	1989	1990	1991	1992	1993
Anaheim	0.09	0.01	0.02	0.02	0.04	0.03	0.02	0.02
La Habra	0.01	0.03	0.04	0.08	0.02	0.03	0.01	0.02
El Toro	0.02	0.02	0.04	0.01	0.02	0.04	0.02	0.02
Los Alamitos	0.02	0.02	0.10	0.01	0.01	0.01	0.03	0.02
Costa Mesa	0.02	0.01	0.27	-----	-----	-----	-----	-----
Costa Mesa	-----	-----	-----	-----	0.03	0.03	0.02	0.01
Palm Springs	0.07	0.01	0.02	0.01	0.03	0.01	0.18	0.03
Indio	-----	-----	-----	-----	-----	-----	-----	-----
Hemet	0.00	0.04	0.01	0.03	0.03	0.07	0.01	0.01
Riverside	0.01	0.03	0.05	0.01	0.02	0.01	0.02	0.06
Perris	0.01	0.03	0.04	0.01	0.03	0.01	0.01	0.02
Banning	0.01	0.02	0.03	0.08	0.01	0.04	0.03	0.05
Norco	0.04	0.02	0.03	0.02	0.03	0.04	0.02	0.01
3300157	-----	-----	-----	0.02	0.05	0.04	0.02	0.05
3300158	0.22	0.78	-----	0.72	0.61	0.34	-----	0.75
Temecula or Lake Elsinore	-----	-----	-----	0.02	0.01	0.01	0.01	0.07
3300160	-----	-----	-----	-----	-----	0.84	0.08	0.04
Blythe	-----	-----	-----	-----	-----	0.84	0.05	-----
Barstow	0.43	0.30	0.18	0.10	0.10	0.37	0.15	0.07
Upland	0.10	0.05	0.05	0.04	0.01	0.02	0.01	0.01
Crestline	0.02	0.04	0.01	0.03	0.01	0.02	0.02	0.03
Trona	0.73	0.80	0.61	0.05	0.51	0.17	0.29	0.14
3600190	-----	-----	-----	-----	0.28	-----	-----	-----
Adobe	0.18	0.63	0.02	0.03	0.02	0.03	0.05	0.54
Redlands	0.24	-----	-----	-----	-----	-----	-----	-----
Fontana	0.03	0.02	0.03	0.04	0.01	0.02	0.01	0.01
Chino	0.01	-----	-----	-----	-----	-----	-----	-----
Hesperia	0.35	0.32	0.18	0.18	0.13	0.20	0.07	0.11
Victorville	0.18	0.11	0.12	0.04	-----	-----	-----	-----
San Bernardino	0.17	0.04	0.05	0.03	0.02	0.02	0.02	0.02
Redlands	-----	0.01	0.01	0.01	0.01	0.01	0.02	0.02
Phelan	-----	-----	0.14	0.48	0.08	0.11	0.03	0.08

Table 3-2. The fraction of days during the smog season with gaps in ozone data of two or more hours in length. Missing data are denoted by '------'. (continued)

Station/Year	1986	1987	1988	1989	1990	1991	1992	1993
Victorville	-----	-----	-----	-----	-----	0.30	0.08	0.04
Trona	-----	-----	-----	-----	-----	-----	-----	0.15
Azusa	0.02	0.03	0.03	0.02	0.02	0.02	0.01	0.00
Burbank	0.02	0.07	0.03	0.03	0.03	0.04	0.02	0.01
Long Beach	0.08	0.05	0.04	0.02	0.04	0.03	0.01	0.06
Reseda	0.01	0.09	0.04	0.07	0.04	0.04	0.03	0.02
Pomona	0.02	0.03	0.02	0.01	0.01	0.00	0.03	0.03
Whittier	0.02	0.02	0.03	0.02	0.01	0.01	0.01	0.00
Lancaster	0.09	0.10	0.04	0.02	-----	-----	-----	-----
Lynwood	0.08	0.04	0.05	0.04	0.02	0.02	0.03	0.03
Pico Rivera	0.03	0.04	0.05	0.02	0.03	0.01	0.01	0.05
Los Angeles	0.02	0.04	0.04	0.04	0.03	0.04	0.03	0.01
Pasadena	0.05	0.02	0.06	0.06	0.03	0.09	0.08	0.16
Newhall	0.02	0.04	0.04	0.02	0.07	0.02	0.03	0.01
West LA	0.02	0.08	0.06	0.04	0.11	0.01	0.02	0.02
Hawthorne	0.05	0.04	0.02	0.01	0.03	0.05	0.02	0.01
Santa Clarita	-----	-----	-----	0.07	-----	-----	-----	-----
7000096	-----	-----	-----	-----	0.03	0.01	0.01	0.02
Avalon	-----	-----	-----	-----	0.27	-----	-----	-----
Glendora	0.04	0.03	0.06	0.04	0.03	0.01	0.03	0.02

missing ozone data. Here we include all stations with hourly ozone data in the ARB data set; we note that some of these stations lie outside the present study area but may be of interest to the ARB and future researchers.

Generally, less than 15% of the days at a particular station and during a given smog season were missing two or more consecutive hours of ozone data. Application of our "tests" (see Section 3.3.2) to eliminate only those days with data gaps that precluded reasonable assessment of the daily-maximum ozone value (rather than all days with two or more consecutive missing hours) resulted in some improvement (approximately 1 to 5%) in data completeness. For each smog season, the resulting data completeness was 89% or greater for all but two of the stations used in our analyses of daily maximum hourly-average ozone concentrations in the region of the SoCAB. The two exceptions were Redlands, with all ozone data missing for the period 26 September 1986 to 31 October 1986, and San Bernardino, with all ozone data missing for May 1986.

The ARB data for ambient concentrations of NO_x and NO_2 for the SoCAB from the various air monitoring stations for the eight-year period 1986-93 were electronically received as a single file. This file was then divided into sixteen new files, each containing data for one species for a single year. Attention was focused on the three stations in the "Coastal" subregion (West Los Angeles, Hawthorne, and North Long Beach) and the three stations in the "Metropolitan" subregion (Central Los Angeles, La Habra, and Anaheim) used in a previous weekday/weekend (WD/WE) analysis by Horie (1987). For each of these stations, the 4-10 am Pacific Standard Time (PST) NO_x data for the smog season (May 1- Oct 31) were subjected to data completeness checks; the results are shown in Tables 3-3 and 3-4 for the Coastal and Metropolitan subregions, respectively.

Note that beginning in 1988, the morning 4-5 am (PST) hour was used by the ARB for instrument calibration; therefore in most cases no data were recorded for this hour after 1987 (King 1995). Otherwise, the morning 5-8 am PST (6-9 am Pacific Daylight Time (PDT)) hours generally had greater than 95% data completeness, with numerous cases of 98% and 99% completeness. The lowest percentage of data completeness for any hour in any year during the study period was 88% for 6-7 am PST

Table 3-3. The fraction of NO_x data available for morning (4-10 am PST) observations for the summer months (May 1 - Oct 31) for 1986-93 for the Coastal subregion.

	Hour					
Station/Year	4-5 am	5-6 am	6-7 am	7-8 am	8-9 am	9-10 am
West Los Angeles						
1986	1.00	1.00	1.00	0.99	0.96	0.96
1987	0.95	0.95	0.93	0.93	0.93	0.93
1988	0.16	0.98	0.97	0.94	0.96	0.92
1989	0.08	0.99	0.89	0.97	0.99	0.98
1990	0.00	0.93	0.90	0.90	0.91	0.90
1991	0.00	1.00	1.00	0.98	0.98	0.98
1992	0.00	0.98	0.96	0.98	0.98	0.97
1993	0.00	0.99	0.97	0.99	0.99	0.99
Hawthorne						
1986	0.98	0.98	0.97	0.93	0.96	0.95
1987	1.00	1.00	0.99	0.97	1.00	0.98
1988	0.00	0.98	0.96	0.98	0.98	0.96
1989	0.00	0.92	0.90	0.92	0.91	0.91
1990	0.00	0.94	0.89	0.93	0.93	0.93
1991	0.00	0.99	0.96	0.98	0.98	0.97
1992	0.00	0.97	0.95	0.97	0.95	0.96
1993	0.00	0.99	0.96	0.99	0.99	0.99
North Long Beach						
1986	0.96	0.96	0.96	0.96	0.94	0.93
1987	1.00	1.00	0.99	0.99	0.96	0.92
1988	0.00	0.99	0.99	0.98	0.97	0.92
1989	0.00	1.00	1.00	0.98	0.97	0.95
1990	0.00	0.99	0.99	0.98	0.98	0.91
1991	0.00	0.99	0.99	0.99	0.99	0.98
1992	0.00	1.00	1.00	0.99	0.99	0.99
1993	0.00	0.98	0.98	0.98	0.97	0.95

Table 3-4. The fraction of NO_x data available for morning (4-10 am PST) observations for the summer months (May 1 - Oct 31) for 1986-93 for the Metropolitan subregion.

	Hour					
Station/Year	4-5 am	5-6 am	6-7 am	7-8 am	8-9 am	9-10 am
Anaheim						
1986	1.00	1.00	0.97	1.00	0.98	0.97
1987	0.99	0.99	0.93	0.97	0.97	0.96
1988	0.00	0.99	0.96	0.96	0.98	0.97
1989	0.00	0.98	0.88	0.95	0.98	0.96
1990	0.00	0.96	0.95	0.95	0.94	0.94
1991	0.00	1.00	0.99	0.99	0.99	0.98
1992	0.00	0.97	0.97	0.96	0.95	0.94
1993	0.00	0.99	0.99	0.99	0.99	0.98
La Habra						
1986	0.98	0.98	0.98	0.98	0.97	0.97
1987	0.99	0.99	0.99	0.98	0.97	0.97
1988	0.00	0.99	0.99	0.98	0.98	0.97
1989	0.00	0.94	0.98	0.98	0.96	0.95
1990	0.00	0.98	0.98	0.98	0.97	0.97
1991	0.00	1.00	0.99	0.98	0.98	0.98
1992	0.00	0.99	0.99	0.97	0.98	0.97
1993	0.00	0.99	0.99	0.98	0.97	0.96
Los Angeles, Central						
1986	0.98	0.98	0.96	0.92	0.94	0.96
1987	0.96	0.96	0.96	0.93	0.89	0.96
1988	0.00	0.99	0.99	0.94	0.96	0.98
1989	0.09	0.97	0.95	0.95	0.90	0.92
1990	0.00	1.00	1.00	1.00	1.00	0.99
1991	0.00	0.91	0.90	0.90	0.89	0.89
1992	0.00	0.99	0.99	0.98	0.97	0.97
1993	0.00	0.95	0.95	0.93	0.92	0.93

in 1989 at the Anaheim station.

As noted earlier, various sets of surface and upper-air meteorological data were acquired from the SCAQMD for the period 1986-93. These were used to generate a new data base for the eight smog seasons which contained the meteorological data needed to bin the days according to the Classification and Regression Tree (CART) developed by Horie in 1987. Prior to this application, however, careful examination of the data base was undertaken to identify periods of missing data. To the degree possible, these gaps were filled using computer archives of meteorological data in the UCLA Department of Atmospheric Sciences (for the period 1990-93) and CD-ROM meteorological archives available through the UCLA Library. The resulting completeness of the meteorological data set used in applying the CART scheme was 97% or greater for each of the eight smog seasons in the period 1986-1993 (with the exception that for five of the eight years, El Toro wind data were available from the AQMD site but not from the desired FAA site).

3.3.2 Additional Completeness Tests

For days with incomplete data, the data gaps were tested for significance. A data gap was considered significant if the daily-maximum hourly-average ozone concentration was likely to have occurred during the period of missing data. If a data gap of two or more consecutive hours in length was found to be insignificant, then the day on which that gap occurred was included for that station in subsequent air quality analyses. Almost all stations were missing at least one hourly ozone observation per day due to daily calibration requirements, but the calibrations were generally conducted at a time of day (*e.g.*, 5 am PST) when the daily maximum ozone value was very unlikely to have occurred. Hence data gaps where only one hourly ozone observation was missing were considered to be insignificant.

Three tests were used to determine the significance of the remaining data gaps. For the first test, a data gap was considered insignificant if the gap comprised hours judged very unlikely to have contained the maximum ozone value for the day. This was determined as follows. First, for each station for each smog season, the highest ozone value reported for each hour of the day was determined. Then the largest of these values for the hours of missing data on a given day were compared with the maximum ozone value determined from the non-missing hours for that day. If the latter was larger that the former, the maximum ozone value for the day was considered unlikely to have occurred during hours of the data gap and these days were then included in the analyses.

Those data gaps failing the first test were subjected to a second test. This test can perhaps best be illustrated by consideration of the following hypothetical sequence of hourly data, where hourly-average pollutant concentrations before and after the data gap are represented by a, b and c, d respectively, and the missing observations are represented by a minus one: a b -1 -1 c d. Here, a data gap was considered insignificant in determining the maximum ozone value of the day if the data gap was not longer than 4 consecutive hours and if one or more of the following three conditions was true:

(1) $a \leq b$, $b \leq c$, and $c < d$.

(2) $a > b$, $b \geq c$, and $c \geq d$.

(3) $a > b$, and $c < d$.

Those data gaps failing both of the first two tests were subjected to a third and final test. Here it was assumed that the ozone value was unlikely to change at a rate exceeding 2 pphm/hr. A hypothetical maximum ozone value during the hours of the gap could then be calculated and compared with the maximum ozone value determined from the non-missing hours. This test was only applied to days with data gaps not longer than 4 consecutive hours.

For a given observing station, the days on which gaps were found to be significant after being subjected to all three tests were eliminated from subsequent statistical analyses utilizing daily maximum ozone values. Finally, stations were not included if the data were not available for each year of the 1986-93 period; stations were also excluded for years where more than 19 days (*i.e.*, 10%) had significant data gaps during the smog season. Ozone concentrations from all other smog season days in the data set were used.

4.0 CORRELATIONS OF OZONE CONCENTRATIONS WITH NO_2 and NO_x AMBIENT CONCENTRATIONS AS A FUNCTION OF DAY OF WEEK AND SUBREGION

Various experimental and modeling studies over the past several decades indicated that transport of ozone-precursor pollutants from the upwind "source" regions of the SoCAB play a significant and even dominant role in the occurrence of high daily Basin ozone maximum concentrations in the downwind "receptor" regions of the Basin (National Research Council 1991). In a historical context, "source region" was typically taken to mean roughly the western one-third, and "receptor region" roughly the middle and eastern thirds, of the geographical region comprising the SoCAB. However, although the Coastal and Metropolitan subregions constituting a significant portion of the western third of the SoCAB were initially much more densely populated than other regions of the Basin, over the past two decades the major growth in the SoCAB has occurred in the middle and eastern portions of the Basin with the result of changing emissions patterns (AQMP 1994). Moreover, these trends are projected to continue (AQMP 1994). This raises the possibility the canonical view of the importance of air parcel transport across the SoCAB may no longer be entirely valid, and may become even less so in the future. Accordingly, it is important to investigate relationships between daily Basin morning NO_x emissions and ozone maxima on a subregional basis. Investigation of relationships between evening NO_x/NO_2 concentrations on a sub-regional basis and next day ozone maximum concentrations is also relevant to the roles of "residence time" and "carry-over" effects.

The correlations between daily hourly-average maximum ozone concentration and average morning 6-9 am Pacific Daylight Time (PDT) NO_2 and NO_x concentrations were examined for the subregions of the Basin shown in Figure 4-1 and Table 4-1. The grouping of air monitoring stations into these subregions followed the approach of Horie (1988) in order to permit comparison with his results for 1984-86. The correlations were calculated for each day of the week for the smog season (May 1 to October 31) days of both 1986-89 (defined in this study as "period I") and for 1990-93 (period II).

As in many earlier studies, the morning 6-9 am PDT period was chosen because commuter traffic is at a maximum (St. Denis *et al.* 1994), and these hours typically

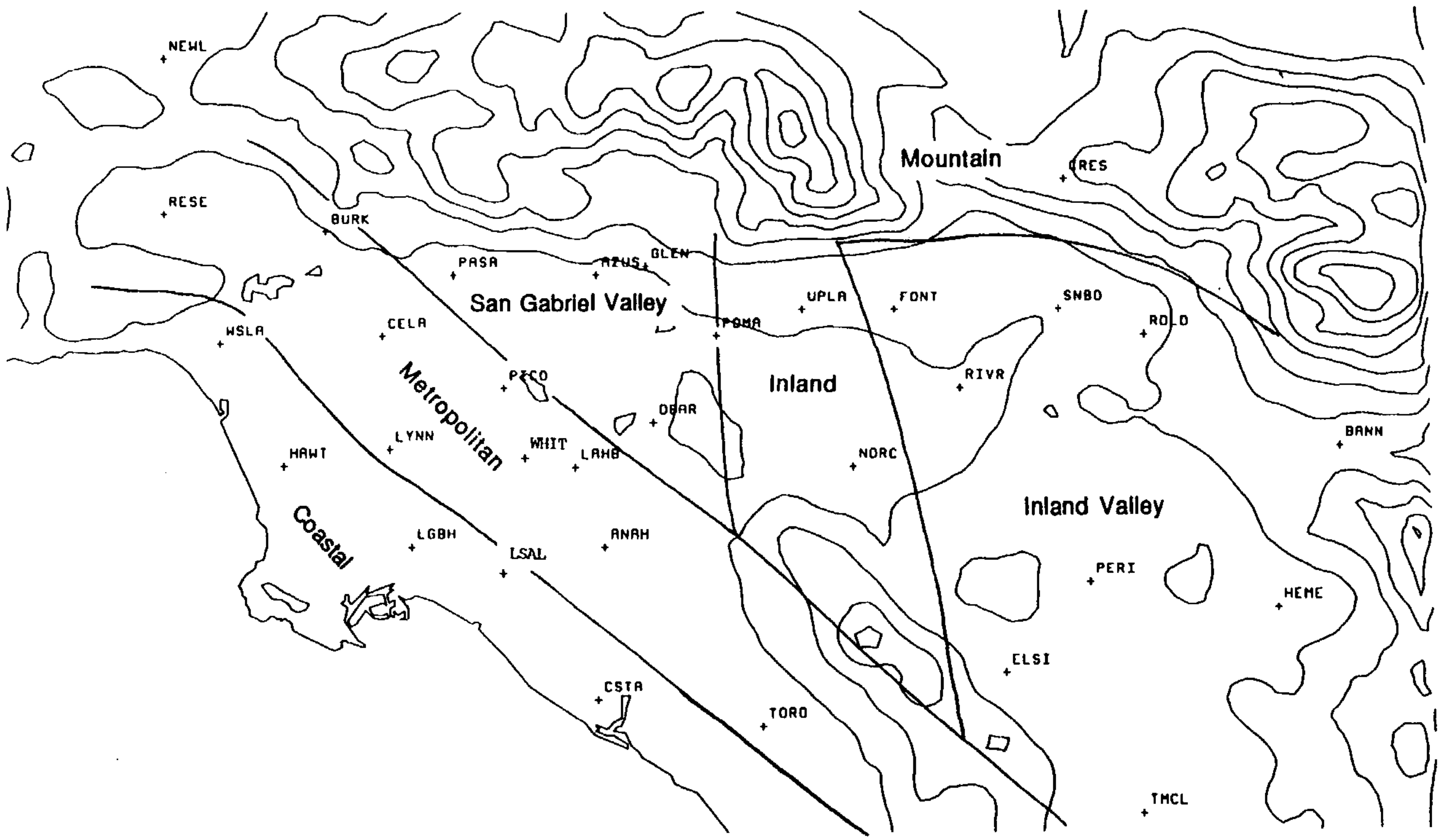


Figure 4-1. Major portion of the SoCAB, with locations of air quality monitoring stations and subregions employed in this study indicated. Solid lines indicate surface elevation at 1000 foot intervals.

Table 4-1. Subregions of the SoCAB and selected air monitoring stations within each subregion.

Subregion	Stations
Coastal	[a, b]Hawthorne [a, b]Long Beach [b]Los Alamitos [a, b]West Los Angeles
Metropolitan	[a, b]Anaheim [b]Burbank [a, b]Central Los Angeles [b]El Toro [a, b]La Habra [b]Lynwood [b]Pico Rivera [b]Reseda [b]Whittier
San Gabriel Valley	[a, b]Azusa [a, b]Glendora [a, b]Pasadena [a]Pomona
Inland	[a, b]Norco [b]Pomona [a, b]Upland
Inland Valley	[b]Banning [a, b]Fontana [b]Hemet [b]Perris [a, b]Riverside [a]San Bernardino
Mountain	Crestline

[a] Stations used in analyses discussed in Chapter 4.

[b] Stations used in analyses discussed in Chapter 6.

exhibit low solar insolation and low wind speeds. Under these conditions, average morning ambient air NO_x and NO_2 concentrations can be assumed to be representative of morning NO_x and NO_2 emissions, respectively, for the various subregions of the Basin. Examination of time periods other than 6-9 am might well prove useful in analyzing carry-over effects but this was beyond the scope of the present project.

We recognize the inherent limitations in making simple correlations, and the importance of augmenting correlation analyses with more sophisticated modeling approaches. However, we believe correlation analyses can provide an important first step in examining these relationships.

4.1 Daily Basin O_3 Maximum Concentrations vs. Morning NO_2 and NO_x Concentrations

As discussed in the following subsections, for all subregions of the Basin and all days of the week, the correlations between morning NO_2 concentration and Basin ozone maximum were higher than the correlations between morning NO_x concentration and Basin ozone maximum. This is attributed to the fact that NO_2 is the direct precursor for ozone whereas NO_x comprises both NO and NO_2, and NO titrates ozone (to form NO_2 and O_2) (Finlayson-Pitts and Pitts 1986).

4.1.1 Coastal and Metropolitan Subregions

The correlations between the daily Basin ozone maxima and the average morning NO_x and NO_2 concentrations in these combined subregions are shown in Table 4-2. In general, for both NO_2 and NO_x, correlations were relatively poor, but were better for period I than for period II. For period I, the correlation coefficients ranged from -0.04 to 0.36 for NO_x, and from 0.27 to 0.51 for NO_2, while for period II, they ranged from -0.07 to 0.30 for NO_x, and from 0.15 to 0.46 for NO_2. Also, for both periods, correlations were found to be lower on weekdays than on weekend-days. It should be noted that for the Coastal and Metropolitan subregions, ozone concentrations were generally substantially lower than for the rest of the Basin; except in very rare instances, daily Basin ozone maxima did not occur in either the Coastal or Metropolitan subregions.

Table 4-2. Correlation coefficients between daily Basin ozone maximum concentration and average morning NO_2 and NO_x concentrations in the Coastal and Metropolitan subregions.

	NO_2 1986-89	NO_2 1990-93	NO_x 1986-89	NO_x 1990-93
Monday	0.38	0.38	0.03	0.08
Tuesday	0.27	0.36	-0.04	0.07
Wednesday	0.28	0.15	0.06	-0.07
Thursday	0.34	0.17	0.01	-0.13
Friday	0.42	0.22	0.10	-0.05
Saturday	0.51	0.40	0.21	0.20
Sunday	0.51	0.46	0.36	0.30

These relatively poor correlation coefficients suggest the possibility transport of NO_2 and NO_x from the Coastal and Metropolitan subregions was relatively less important in causing the subsequent Basin ozone maximum on the same day.

4.1.2 San Gabriel Valley Subregion

The correlations between the daily Basin ozone maxima and the average morning NO_2 and NO_x concentrations in the San Gabriel Valley are shown in Table 4-3. The correlations for both NO_2 and NO_x were better for period I than for period II for all days of the week, except Monday and Tuesday. Also, correlations for both were better for weekend-days than for weekdays; this as yet unexplained result was most pronounced for 1986-89. However, good correlations were found for NO_2 for both periods and for all days of the week; correlation coefficients ranged from 0.61 to 0.77 for period I and from 0.57 to 0.67 for period II. Correlation coefficients for NO_x were significantly lower, except for period I from Friday through Sunday, when they ranged from 0.58 to 0.67.

The relatively strong correlation observed between morning NO_2 concentrations and daily Basin ozone maxima is consistent with the frequent occurrence of the daily Basin ozone maximum in the San Gabriel Valley subregion. These results also suggest, however, that NO_2 emitted or formed in the 6-9 am period in the San Gabriel Valley subregion led to elevated ozone levels later in the day in that same subregion a substantial fraction of the time.

Table 4-3. Correlation coefficients between daily Basin ozone maximum concentration and average morning NO_2 and NO_x concentrations in the San Gabriel Valley subregion.

	NO_2 1986-89	NO_2 1990-93	NO_x 1986-89	NO_x 1990-93
Monday	0.65	0.67	0.34	0.43
Tuesday	0.61	0.57	0.33	0.42
Wednesday	0.61	0.58	0.35	0.38
Thursday	0.67	0.65	0.38	0.35
Friday	0.75	0.58	0.58	0.38
Saturday	0.76	0.65	0.61	0.48
Sunday	0.77	0.66	0.67	0.53

4.1.3 Inland Valley Subregion

The correlations between Basin ozone maxima and the average morning NO_2 and NO_x concentrations in the Inland Valley are given in Table 4-4. As in the previous analyses, correlations were better for NO_2 than for NO_x. The correlations for both NO_2 and NO_x were better for period I than for period II for days later in the week, and particularly for weekend days. For both periods, correlations were better for weekend-days than for weekdays with the best correlation coefficient found for Sunday.

A plot of Sunday Basin ozone maximum as a function of average Sunday morning

Inland Valley NO_2 concentration for period I is shown in Figure 4-2. A high correlation coefficient of 0.78 was found; the remaining scatter can be attributed to the influence of meteorological variability. The scatterplots for NO_2 for the other days of the week were found to be similar to that for Sunday. Over the seven days of the week, correlation coefficients ranged from 0.62 to 0.78 for period I and from 0.62 to 0.72 for period II. As noted earlier, correlation coefficients for NO_x were significantly lower than those for NO_2, especially on weekdays.

As in the case of the San Gabriel Valley subregion, the robust correlation coefficients for the Inland Valley subregion can be attributed both to the fact that a substantial fraction of the daily Basin ozone maxima occurred in the Inland Valley subregion, and that morning NO_2 emitted or formed in that subregion may have led to intrasubregion ozone formation. The latter hypothesis is investigated further in the following sections.

Table 4-4. Correlation coefficients between daily Basin ozone maximum concentration and average morning NO_2 and NO_x concentrations in the Inland Valley subregion.

	NO_2 1986-89	NO_2 1990-93	NO_x 1986-89	NO_x 1990-93
Monday	0.62	0.66	0.32	0.37
Tuesday	0.67	0.70	0.33	0.49
Wednesday	0.64	0.62	0.26	0.35
Thursday	0.65	0.64	0.23	0.30
Friday	0.75	0.68	0.49	0.36
Saturday	0.76	0.72	0.57	0.49
Sunday	0.78	0.69	0.59	0.54

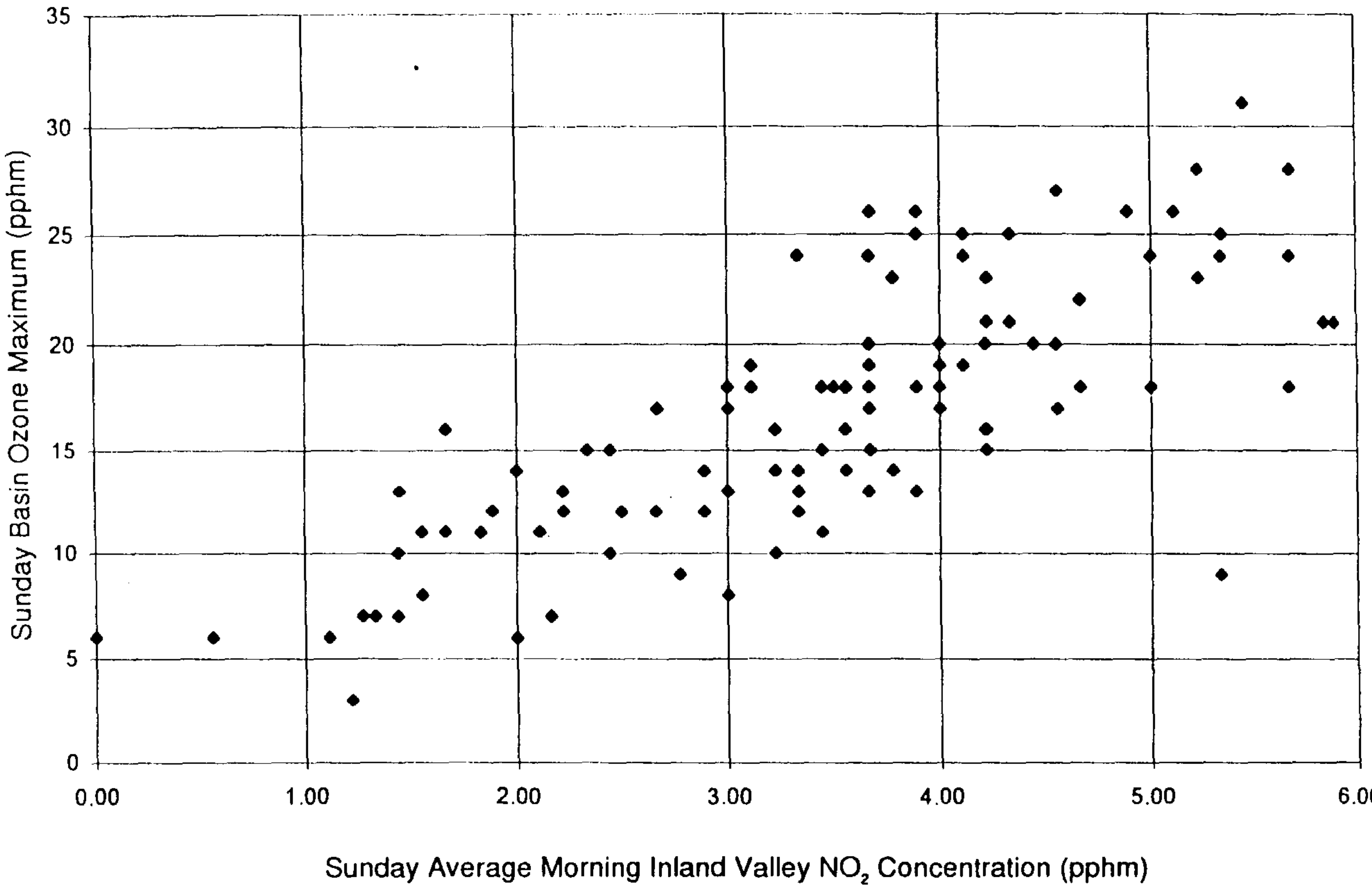


Figure 4-2. Sunday Basin ozone maximum vs. Sunday morning Inland Valley NO_2 for period I (1986-89), Correlation Coefficient = 0.78.

4-8

4.2 Daily Subregion O_3 Maximum Concentrations vs. Morning NO_2 and NO_x Concentrations

As discussed above, early morning NO_2 concentrations in the Coastal/Metropolitan subregions were poorly correlated with the Basin ozone maxima on both weekdays and weekend-days, while early morning NO_2 concentrations in the San Gabriel Valley and Inland Valley subregions correlated well with the Basin ozone maxima, especially on weekend-days. To explore further the influence of morning NO_2 and NO_x emissions within a given subregion on the afternoon peak ozone concentrations within the same subregion, correlation coefficients between these quantities were calculated for all days of the week for both periods. As discussed below, the ozone concentration maxima within a given subregion were found to be highly correlated with the early morning NO_2 concentrations (and hence emissions) in the same subregion on the same day.

4.2.1 Coastal and Metropolitan Subregions

The correlations between average morning Coastal/Metropolitan NO_2 and NO_x concentrations and Coastal/Metropolitan ozone concentration maxima are given in Table 4-5. Reasonably good correlations were found for NO_2 concentrations for all days of the week for both periods. For NO_2 for period I, the correlation coefficients ranged from 0.52 to 0.66; for period II the corresponding range was 0.49 to 0.67. In contrast, as seen in section 4.1.1, the Basin ozone maxima were poorly correlated with the average morning Coastal/Metropolitan NO_2 concentrations for all days of the week. This suggests that morning NO_2 and NO_x emissions in the Coastal/Metropolitan subregions may not play as dominant a role in the occurrence of high ozone concentrations in subregions to the east, or downwind under typical prevailing daytime wind conditions, (*e.g.*, San Gabriel Valley and Inland Valley) as in the past (prior to the large population growth in these subregions). These emissions may contribute more significantly to peak ozone concentrations in the Coastal/Metropolitan subregion.

Table 4-5. Correlation coefficients between daily Coastal/Metropolitan ozone maximum concentration and average morning NO_2 and NO_x concentrations in the Coastal/Metropolitan subregion.

	NO_2 1986-89	NO_2 1990-93	NO_x 1986-89	NO_x 1990-93
Monday	0.65	0.62	0.32	0.34
Tuesday	0.54	0.67	0.28	0.40
Wednesday	0.52	0.52	0.36	0.31
Thursday	0.57	0.50	0.25	0.21
Friday	0.63	0.49	0.30	0.23
Saturday	0.65	0.61	0.41	0.42
Sunday	0.66	0.64	0.48	0.50

4.2.2 San Gabriel Valley Subregion

The correlations between average morning San Gabriel Valley NO_2 and NO_x concentrations and San Gabriel Valley ozone concentration maxima are given in Table 4-6. Good correlations were found for both periods and for all days of the week for NO_2 (correlation coefficients ranged from 0.63 to 0.75 for period I, and from 0.56 to 0.70 for period II); correlations were highest for Friday through Sunday for period I. A plot of ozone maximum vs. morning NO_2 for this subregion for Fridays in period I is shown in Figure 4-3. In Section 4.1.2, it was also shown that the Basin ozone maximum was well correlated with the average morning San Gabriel Valley NO_2 -- as expected since on many days of the smog season during this eight year period the Basin ozone maximum occurred in the San Gabriel Valley. Correlation coefficients between morning NO_x and San Gabriel Valley ozone maxima were significantly lower, though still reasonably high, for period I weekend-days (0.58-0.64).

Table 4-6. Correlation coefficients between daily San Gabriel Valley ozone maximum concentration and average morning NO_2 and NO_x concentrations in the San Gabriel Valley subregion.

	NO_2 1986-89	NO_2 1990-93	NO_x 1986-89	NO_x 1990-93
Monday	0.68	0.70	0.39	0.50
Tuesday	0.63	0.56	0.38	0.48
Wednesday	0.63	0.63	0.40	0.44
Thursday	0.67	0.67	0.39	0.40
Friday	0.75	0.59	0.59	0.42
Saturday	0.71	0.64	0.58	0.49
Sunday	0.75	0.67	0.64	0.53

4.2.3 Inland Valley Subregion

The correlations between average morning Inland Valley NO_2 and NO_x concentrations and Inland Valley ozone maxima are given in Table 4-7. Good correlations were found for both periods and for all days of the week for NO_2; correlations tended to be highest for Friday through Sunday. The correlation coefficients for period I ranged from 0.57 to 0.72; the corresponding range for period II was 0.54-0.67. Correlations for NO_x were much lower for Monday through Thursday for period I (*i.e.*, 0.20-0.26), but moderate for the weekend-days in both periods I and II (0.44-0.54). As for the San Gabriel Valley subregion, these results for the Inland Valley subregion indicate that intrasubregion morning NO_2 concentrations may be responsible for subsequent afternoon ozone peaks within that subregion.

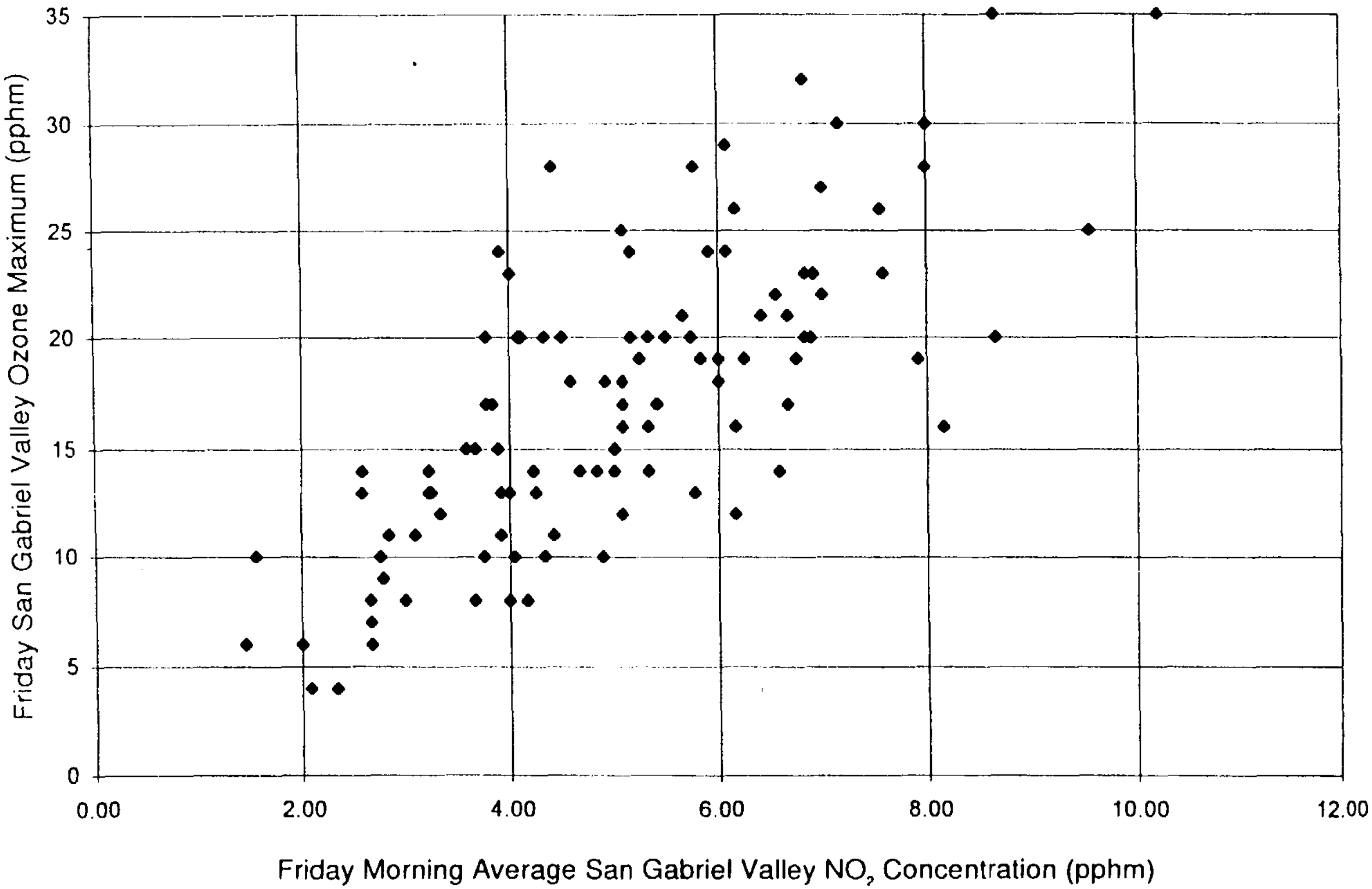


Figure 4-3. Friday San Gabriel Valley ozone maximum and Friday morning San Gabriel Valley NO_2 for period I (1986-89), Correlation Coefficient = 0.75.

Table 4-7. Correlation coefficients between daily Inland Valley ozone maximum concentration and average morning NO_2 and NO_x concentrations in the Inland Valley subregion.

	NO_2 1986-89	NO_2 1990-93	NO_x 1986-89	NO_x 1990-93
Monday	0.57	0.62	0.26	0.38
Tuesday	0.57	0.66	0.22	0.42
Wednesday	0.61	0.54	0.20	0.25
Thursday	0.63	0.62	0.22	0.29
Friday	0.72	0.66	0.42	0.36
Saturday	0.69	0.67	0.47	0.44
Sunday	0.72	0.67	0.52	0.54

4.3 Daily O_3 Maximum vs. Previous Evening's NO_2 and NO_x Concentrations

Significant NO_x emissions occur in the SoCAB during evening hours from on-road mobile sources (commuter traffic); in the western portion of the Basin stationary sources (*e.g.*, electric utilities and oil refineries) can also produce significant NO_x emissions during the evening and night-time hours (AQMP 1994). The degree to which carryover of NO_x emissions might influence early morning ambient NO_2 and NO_x concentrations is dependent upon meteorological factors which control the dispersion and transport of pollutants. Fujita et al. (1992) found that carryover of emissions from the previous day may affect early morning ambient concentrations more during fall months (October-December) than during the annual period (May-October) investigated in the present study.

To investigate whether transport of evening NO_2 or NO_x emissions from a given subregion influenced the peak ozone concentration in the Basin on the following day, the average 6-9 pm PDT NO_2 and NO_x concentrations in the subregion were correlated for all eight years with the following day Basin ozone maximum; this was done for Tuesday/Wednesday and for Friday/Saturday. Tuesday evening/Wednesday was assumed to be representative of typical weekdays, while Friday evening/Saturday was assumed to be representative of weekend-days.

The evening NO_2 and NO_x emissions within a given subregion might also contribute to the next day's early morning NO_2 and NO_x concentration in the same subregion. To investigate this possibility, correlations were calculated between the daily subregion ozone maxima and the previous evening's average NO_x and NO_2 concentrations in that subregion for Tuesday evening/Wednesday and Friday evening/Saturday.

4.3.1 Coastal and Metropolitan Subregions

The correlations between the Coastal/Metropolitan average Tuesday evening NO_x concentration and the Wednesday Basin ozone maximum and the Wednesday Coastal/Metropolitan ozone maximum are given in Table 4-8. Correlation coefficients for both were quite small, suggesting little relationship between weekday evening NO_x and following day maximum ozone. The correlations between Friday evening average Coastal/Metropolitan NO_x concentration and the Saturday Basin ozone maximum and the Saturday Coastal/Metropolitan ozone maximum are given in Table 4-9. Here, too, correlations were poor.

Table 4-8. Correlation coefficients between Tuesday evening (6-9 PDT) NO_x concentration and Wednesday ozone maximum.

	Coastal/Metropolitan	San Gabriel Valley
Tuesday evening NO_x vs. Wednesday Basin ozone maximum	-0.01	0.12
Tuesday evening NO_x vs. Wednesday subregion ozone maximum	0.20	0.14

Table 4-9. Correlation coefficients between Friday evening (6-9 PDT) NO_x concentration and Saturday ozone maximum.

	Coastal/Metropolitan	San Gabriel Valley
Friday evening NO_x vs. Saturday Basin ozone maximum	-0.03	0.05
Friday evening NO_x vs. Saturday subregion ozone maximum	0.13	0.04

These results suggest that carryover of evening NO_x emissions from the Coastal/Metropolitan subregion may not have significantly influenced the daily ozone maximum either in the Coastal/Metropolitan subregion or in the Basin as a whole during the eight- year period investigated in the present study.

4.3.2 San Gabriel Valley Subregion

The correlations between the daily Basin ozone maximum, the San Gabriel Valley ozone maximum and the previous evening average San Gabriel Valley NO_x concentration were investigated for Tuesday/Wednesday and Friday/Saturday; the results are given in Tables 4-8 and 4-9. The correlation coefficients ranged from 0.04-0.14, indicating poor correlation. The correlations between daily Basin and San Gabriel Valley ozone maxima and the previous evening average NO_2 concentration in the San Gabriel Valley subregion were also investigated; the results are given in Table 4-10. The correlation coefficients ranged between -0.01 and 0.20, again indicating poor correlations.

Table 4-10. Correlation of previous evening's (6-9 PDT) San Gabriel Valley subregion NO_2 and daily ozone maximum in the Basin and in the San Gabriel Valley.

	Basin ozone Maximum	San Gabriel Valley ozone maximum
Tuesday/Wednesday	-0.01	0.12
Friday/Saturday	0.20	0.14

To the extent the average evening (6-9 pm PDT) NO_2 and NO_x concentrations were representative of the evening NO_2 and NO_x emissions from on-road mobile sources, these results suggest carryover of evening NO_2 and NO_x emissions from on-road mobile sources in the San Gabriel Valley may not have influenced the daily ozone maximum in the Basin (and hence typically the San Gabriel Valley or Inland Valley ozone maxima) to a significant extent during the period of this study.

4.4 Summary

Several observations concerning correlations between peak ozone and concentrations of oxides of nitrogen in the SoCAB during the eight years investigated in this study can be derived from the data presented in the preceding sections. The most significant findings include the following:

- Peak ozone concentrations in the SoCAB were generally much better correlated with NO_2 concentrations than with NO_x concentrations.

- In general, the highest correlations between morning NO_2 and peak ozone concentrations occurred on weekend-days and Fridays.

- High intra-subregion same-day correlations between morning NO_2 and peak ozone were observed throughout the Basin, particularly in the San Gabriel Valley and Inland Valley subregions.

- Correlations were weak between evening NO_2 or NO_x and the next day's Basin peak ozone during the summer smog season months for the 1986-93 period investigated here.

- Significant differences in these correlations were observed between the 1986-89 and 1990-93 periods, suggesting continuing changes in the spatial distribution of emissions in the Basin over this period and/or the influence of different summer season meteorological conditions.

In summary, our analyses suggest ozone peaks observed in inland subregions are significantly dependent on local precursor emissions and may be less dependent on transport of precursors from the Central and Metropolitan subregions than in years prior to the present study period. This observed behavior is presumably due to changing emission patterns in the SoCAB as the result of large population growth in the central and eastern portion of the Basin.

A portion of the subregional behavior we observed may also be related to the spatial heterogeneity of vehicle emissions resulting from the influence of high-emitting vehicles. Present mobile source emissions models effectively provide basin average inventories and do not reflect such potential spatial variations.

5.0 EXAMINATION OF AIR PARCEL RESIDENCE TIME AND OTHER METEOROLOGICAL PARAMETERS

5.1 Surface Meteorological Conditions: High Ozone Days vs. Middle Ozone Days

In this chapter we systematically examined the difference in meteorological conditions between those days on which a very high ozone value is reported somewhere in the SoCAB and those days on which the ozone value is simply average. This comparison facilitated identification of those meteorological factors associated with occurrences of high ozone. (Note that this would not be the case if we were instead to compare the days with highest ozone values with those with lowest ozone values; these results would be ambiguous as to whether the difference in associated meteorological conditions was identifying meteorological features associated with occurrences of high ozone concentrations, low ozone concentrations, or a combination of the two. For example, a finding that the surface temperature was greater for high ozone days than for low ozone days could indicate: (a) unusually low surface temperatures on low ozone days while surface temperatures were average on high ozone days; (b) average surface temperatures on low ozone days while surface temperatures were unusually high on high ozone days; or (c) unusually low surface temperatures on low ozone days and unusually high surface temperatures on high ozone days.) To our knowledge, no previous analysis of this kind has appeared in the published literature.

The first step in the analysis was to rank each smog season day for the years 1990-1993 on the basis of the highest hourly-average ozone values reported in the SoCAB. It quickly became apparent, however, that virtually all of the highest ozone values occurred at one of the following four sites: Riverside, Crestline, Fontana, and Glendora. The few exceptions occurred at rather disparate locations. Since our goal was to describe the meteorological conditions associated with the typical occurrence of very high ozone values within the SoCAB, we limited our analysis to those days on which the peak ozone report came from one of these four sites.

The middle day in the ranked distribution of smog season days for the four-year period had a peak ozone value of 15 pphm; there were 28 days during the 4-year period for which this was the Basin-maximum ozone value reported. In order to have comparably-sized groups of days for comparison, we then defined the high ozone days as the first 28 days in the distribution; maximum ozone values for these days ranged from 33 pphm to 25 pphm.

5.1.1 Resultant Surface Winds

Vector-average 1-hour resultant winds were calculated from 0700 PDT to 1800 PDT for each station in the SoCAB for the set of high ozone days and for the set of middle ozone days. The wind data used in this analysis were those acquired from the SCAQMD: 1-hour resultant winds (instantaneous and 5-minute average wind data were not available). Note that the vector-averaging process used to calculate the resultant winds makes the resultant wind speed less than that of the individual winds used in the averaging. Nonetheless, the reduction in magnitude is generally less than a factor of 2.

For 0700-0800 PDT and 0800-0900 PDT for both high and middle ozone days, average 1-hour resultant winds throughout the SoCAB are 1 knot or less (not shown), except for Crestline for middle ozone days where winds at both times are from the southeast at 2 knots. Resultant wind speeds for the following hour (0900-1000 PDT) are slightly greater, and for both high ozone days (Figure 5-1) and middle ozone days (Figure 5-2), indicated weak ventilation of the Basin with general surface flow from coastal regions towards the interior, as channeled by the orography (*e.g.*, the southeasterly mean flow at Burbank and the northwesterly mean flow at Norco seen in both plots). Very little difference is evident between the two groups of days. At most stations, resultant wind vectors for high ozone days were similar in magnitude and direction to those for middle ozone days. To the degree that there was any difference, winds in the southwestern part of the SoCAB were slightly more southerly on middle ozone days and slightly more westerly on high ozone days.

The high degree of similarity between the two groups of days was also seen for 1000-1100 and 1100-1200 PDT (not shown) and 1200-1300 PDT (Figures 5-3 and 5-4). Again, the slight difference that does appear lies in the slightly more southerly orientation to the flow for middle ozone days in the southwestern part of the SoCAB (*e.g.*, 190° vs.

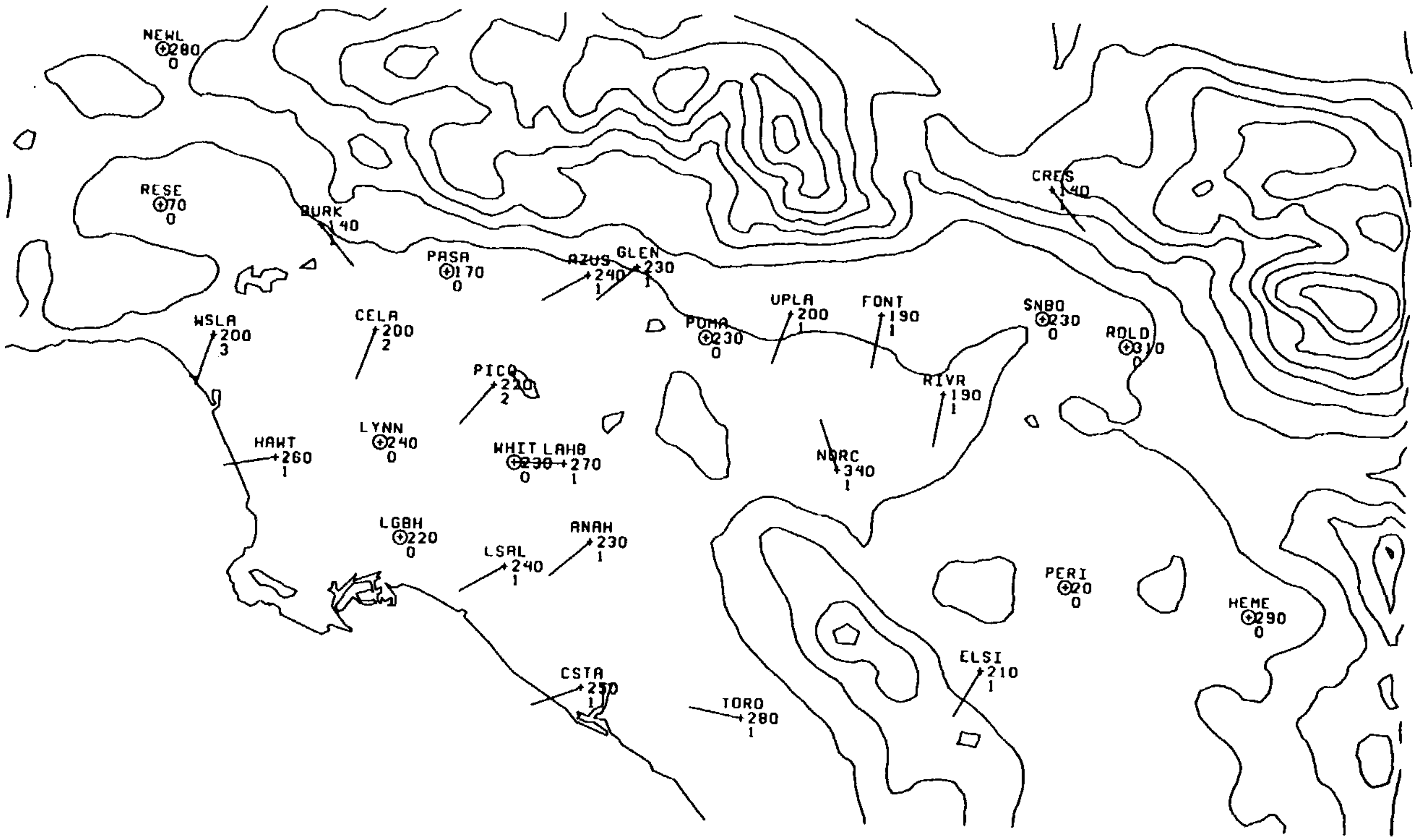


Figure 5-1. 0900-1000 PDT resultant winds for 28 high ozone days. Wind direction (degrees) and wind speed (knots) are indicated.

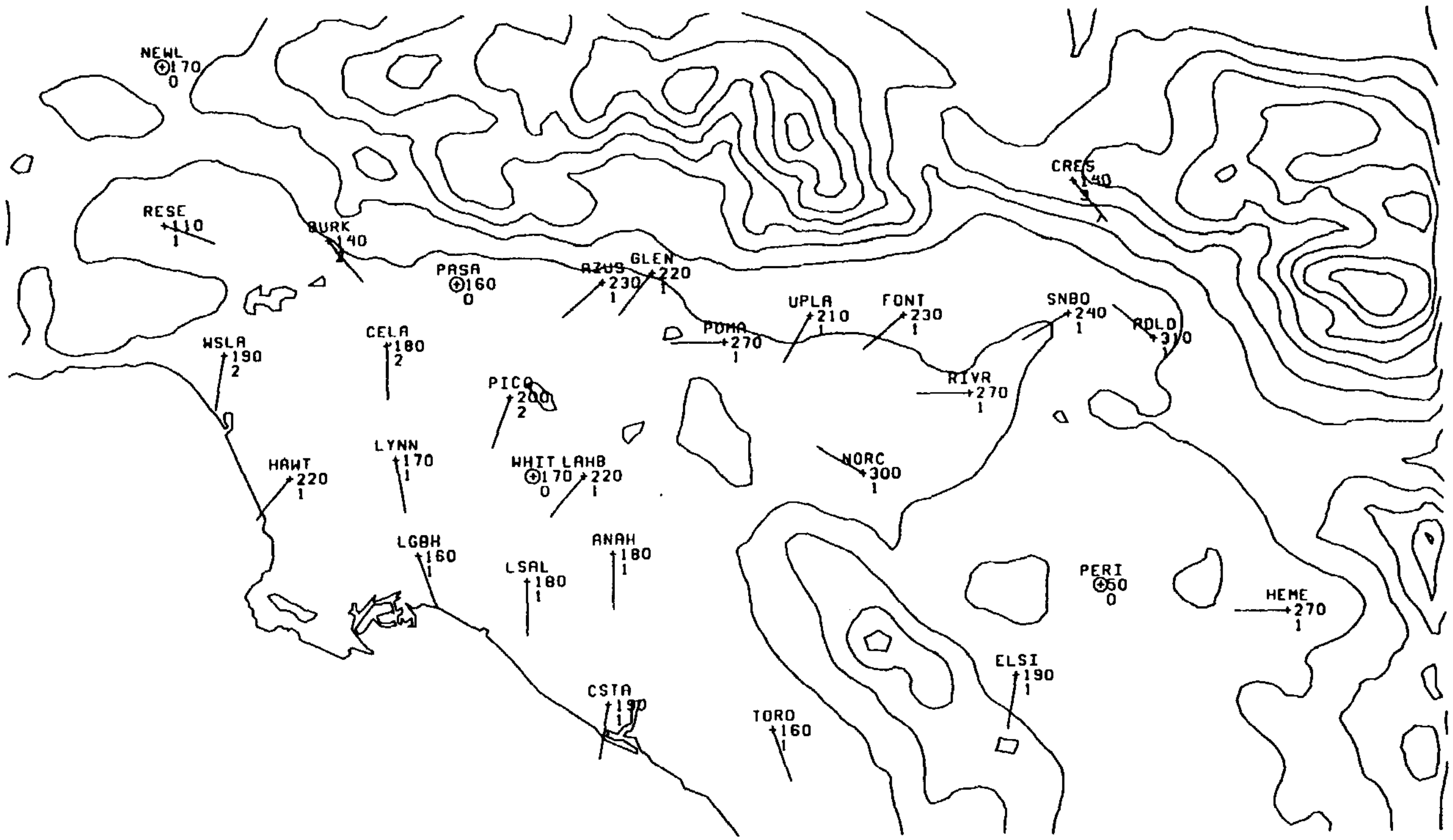


Figure 5-2. 0900-1000 PDT resultant winds for 28 middle ozone days. Wind direction (degrees) and wind speed (knots) are indicated.

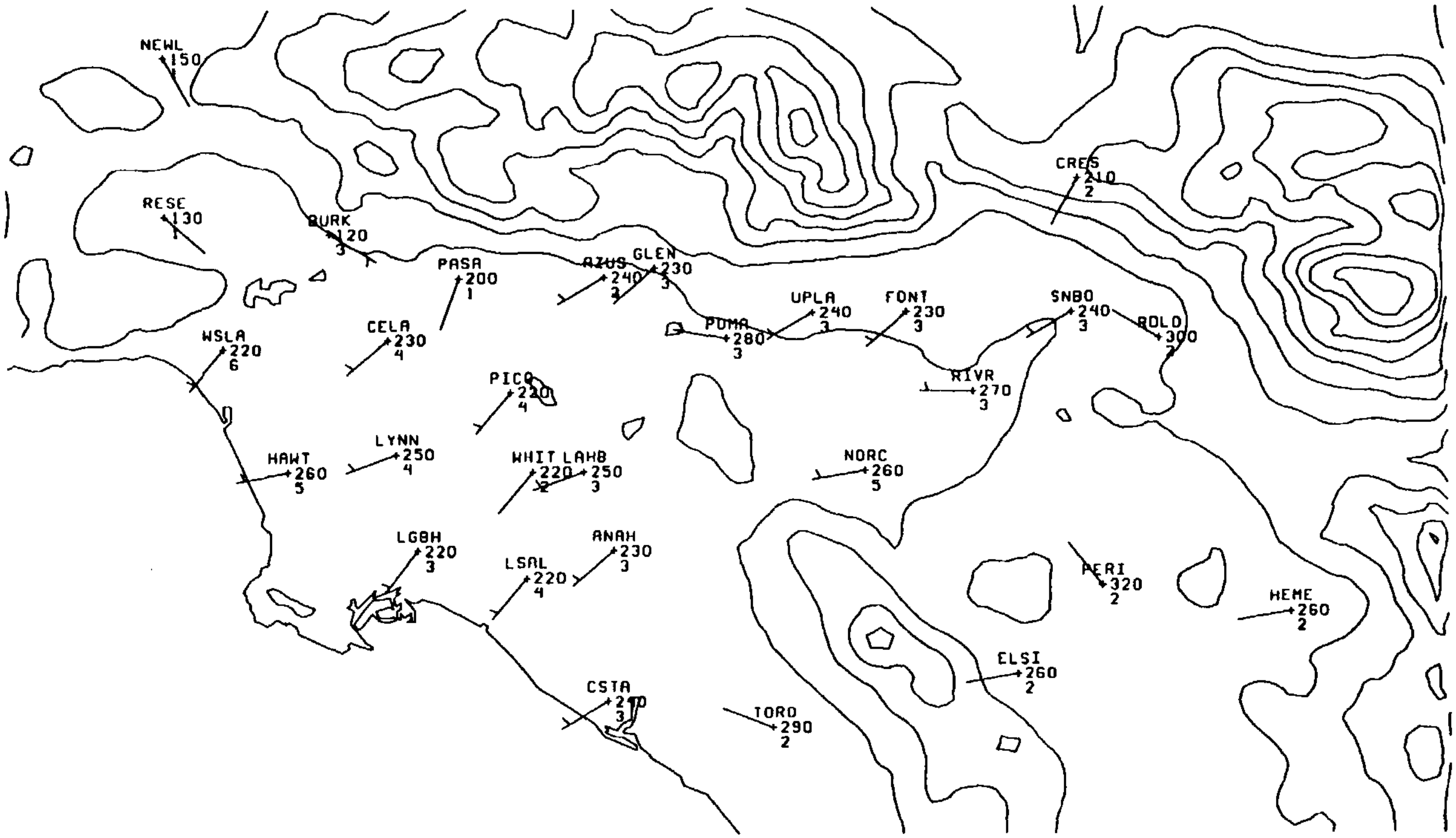


Figure 5-3. 1200-1300 PDT resultant winds for 28 high ozone days. Wind direction (degrees) and wind speed (knots) are indicated.

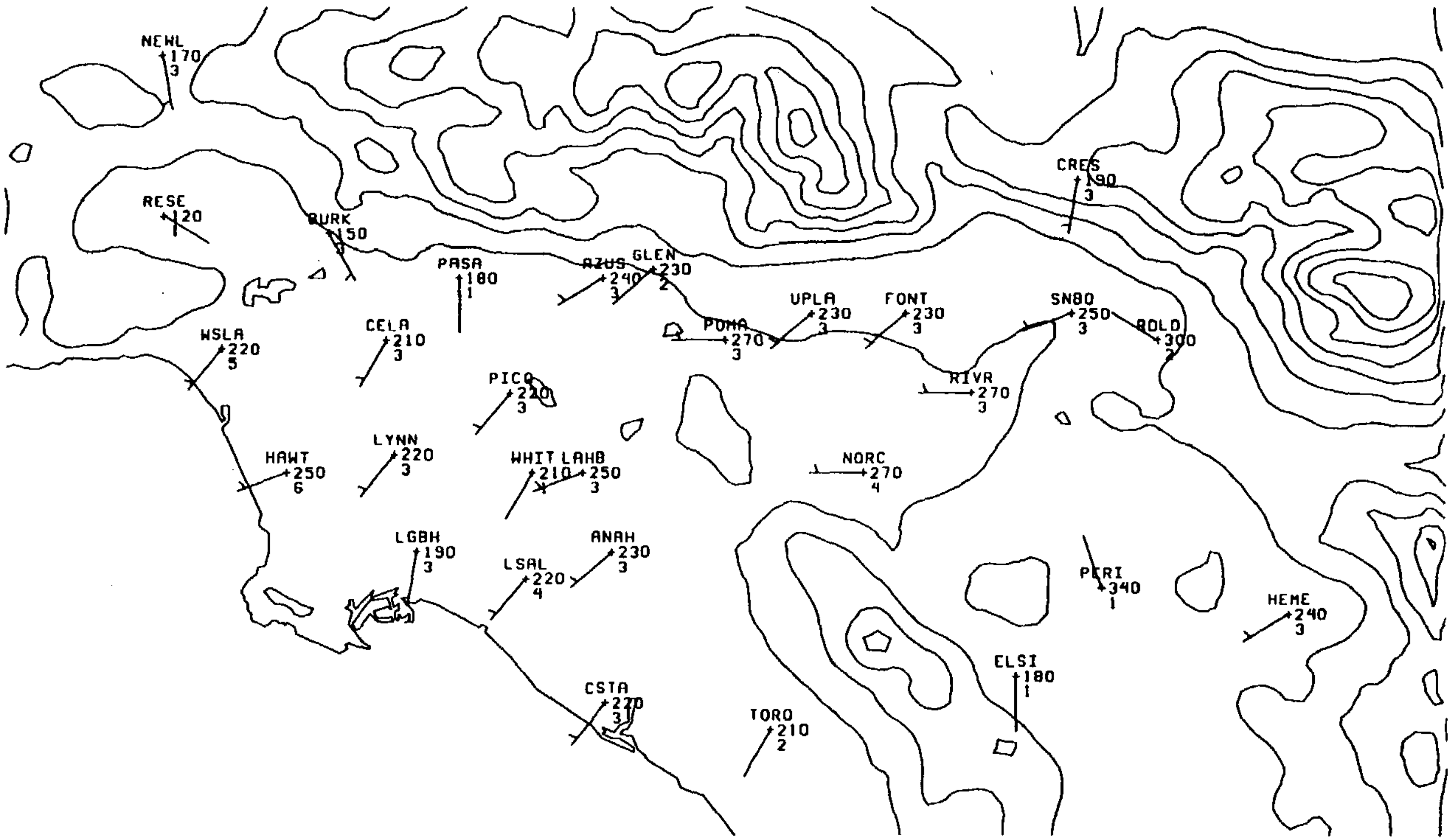


Figure 5-4. 1200-1300 PDT resultant winds for 28 middle ozone days. Wind direction (degrees) and wind speed (knots) are indicated.

220° at Long Beach, 220° vs. 250° at Lynwood, 220° vs. 240° at Costa Mesa). Resultant wind speeds were greater for both groups of days for 1300-1400 PDT (not shown), especially at stations closer to the coast. By 1400-1500 PDT, resultant wind speeds increased to 10 knots at Norco, and to 8 knots at Central Los Angeles, for the high ozone days (Figure 5-5). Resultant wind directions and wind speeds for middle ozone days (Figure 5-6) were quite similar. Very little change appeared for either 1500-1600 PDT (not shown) or 1600-1700 PDT (Figures 5-7 and 5-8). Wind speeds then generally began to diminish slightly by the 1700-1800 PDT hour (not shown).

There are several interesting implications of these results. First, resultant surface winds indicated that general westerly-southwesterly ventilation began throughout the SoCAB at approximately the same time, rather than showing the eastward propagation of a discrete boundary such as a sea breeze front. This interpretation is subject to the effects of the averaging process used in the wind analysis, but is nonetheless consistent with the modeling results of Lu and Turco (1994a,b), which show that ventilation of the SoCAB was driven more by mountain-slope heating effects than by diurnal differences in heating between land and water (aside, perhaps, for the portion of the SoCAB closest to the coast). A second significant implication of these results is that the surface resultant wind speeds were, in themselves, too small to indicate significant transport between coastal areas and the far inland portions of the SoCAB in a single day. However, only surface wind data were available to us for the SoCAB and the actual transport will be determined by the three dimensional wind field. Additionally, the high degree of similarity in the resultant winds for middle and high ozone days implies that variation in low-level transport did not, in itself, significantly influence the peak SoCAB ozone level.

5.1.2 <u>Time of Peak Ozone Occurrence</u>

Additional insight into intrabasin transport can be gleaned from examining the resultant wind analyses together with an analysis of the average initial hour of occurrence of the daily ozone maximum at each SoCAB station for the 28 high ozone days (1990-93) in the SoCAB (Figure 5-9). Several interesting features were apparent. First, throughout a large part of the western SoCAB, there was little variation in the average time of initial occurrence of the peak ozone value. The stations of Reseda, Burbank, Pasadena, West

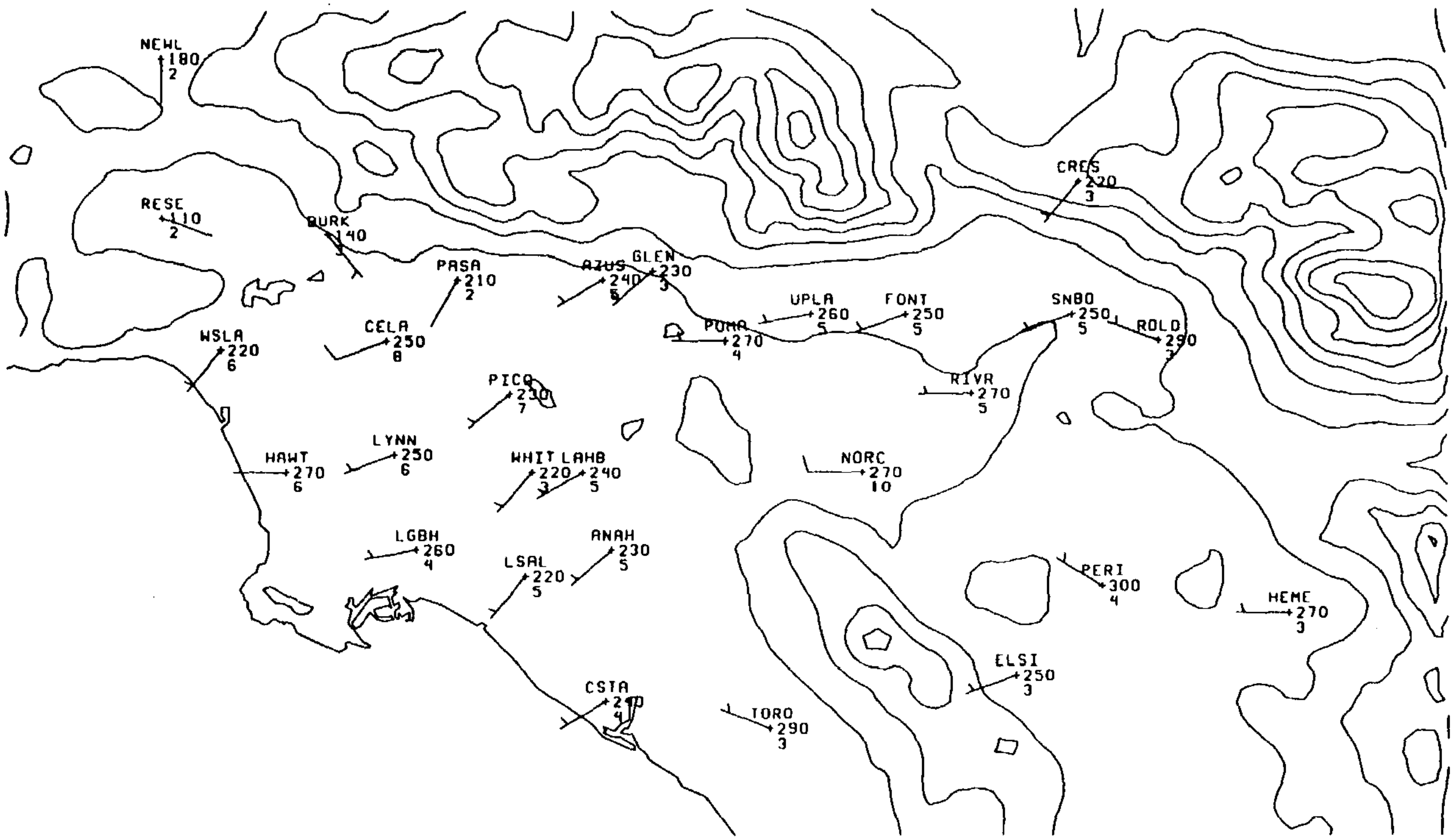


Figure 5-5. 1400-1500 PDT resultant winds for 28 high ozone days. Wind direction (degrees) and wind speed (knots) are indicated.

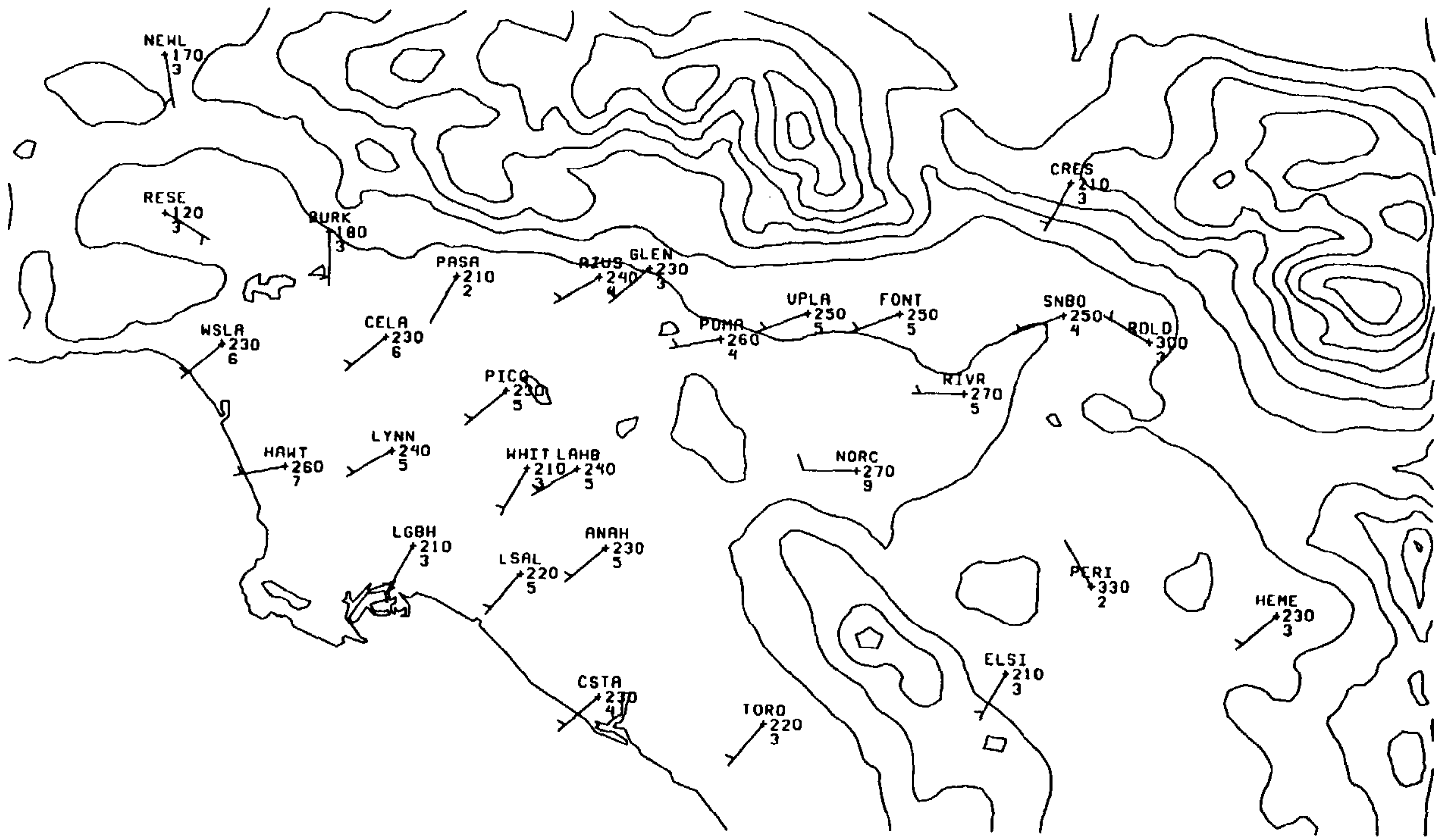


Figure 5-6. 1400-1500 PDT resultant winds for 28 middle ozone days. Wind direction (degrees) and wind speed (knots) are indicated.

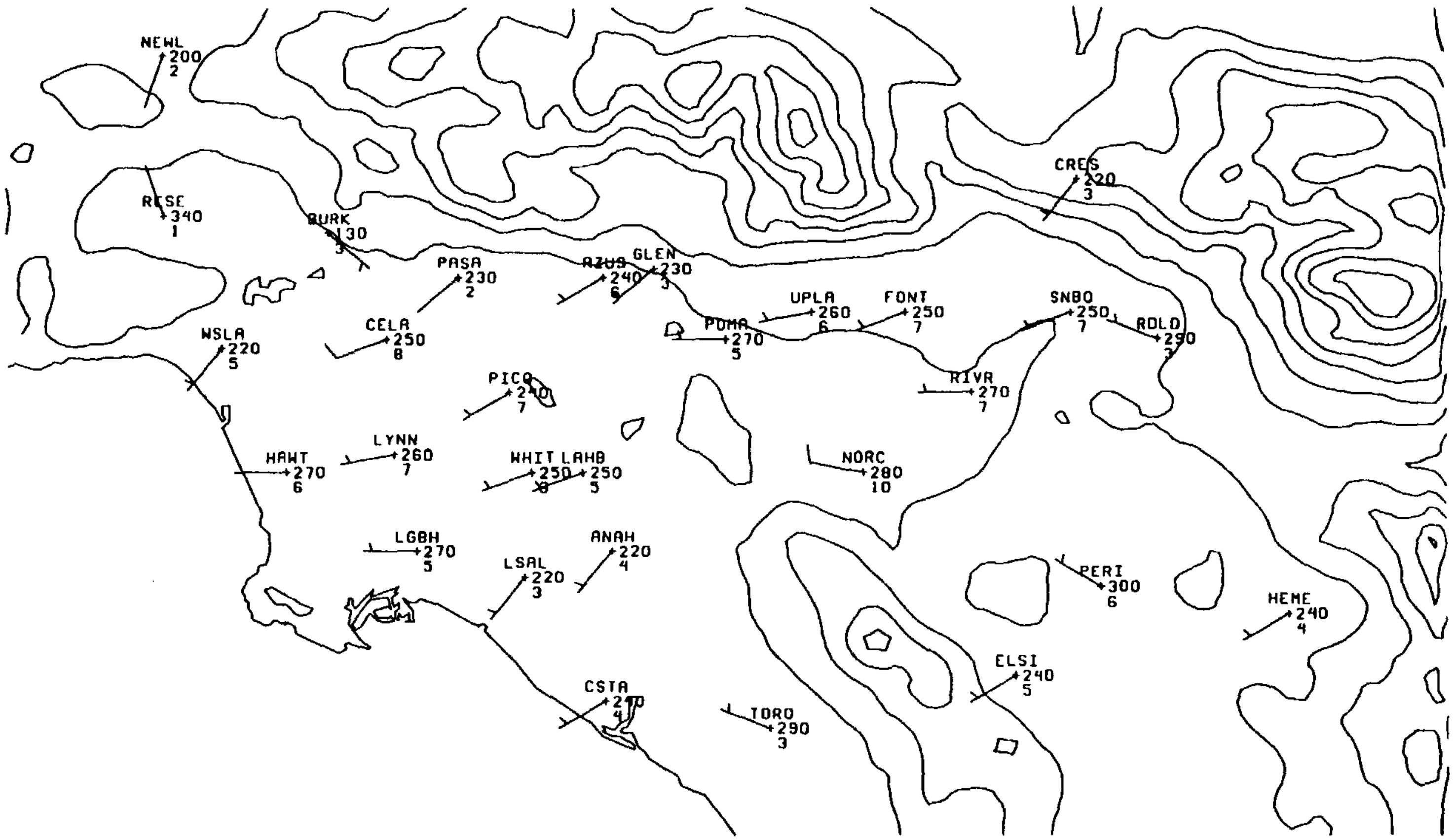


Figure 5-7. 1600-1700 PDT resultant winds for 28 high ozone days. Wind direction (degrees) and wind speed (knots) are indicated.

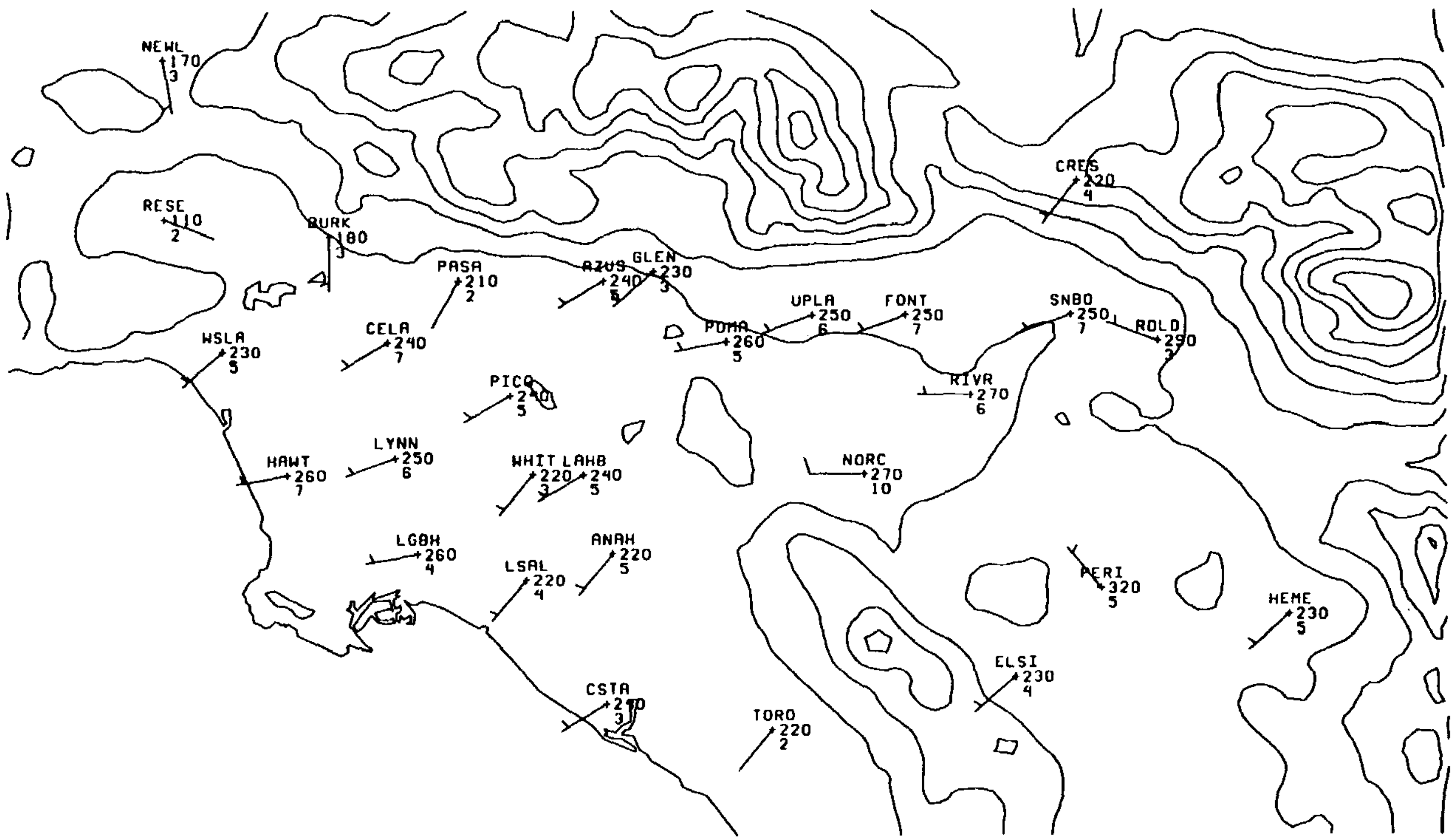


Figure 5-8. 1600-1700 PDT resultant winds for 28 middle ozone days. Wind direction (degrees) and wind speed (knots) are indicated.

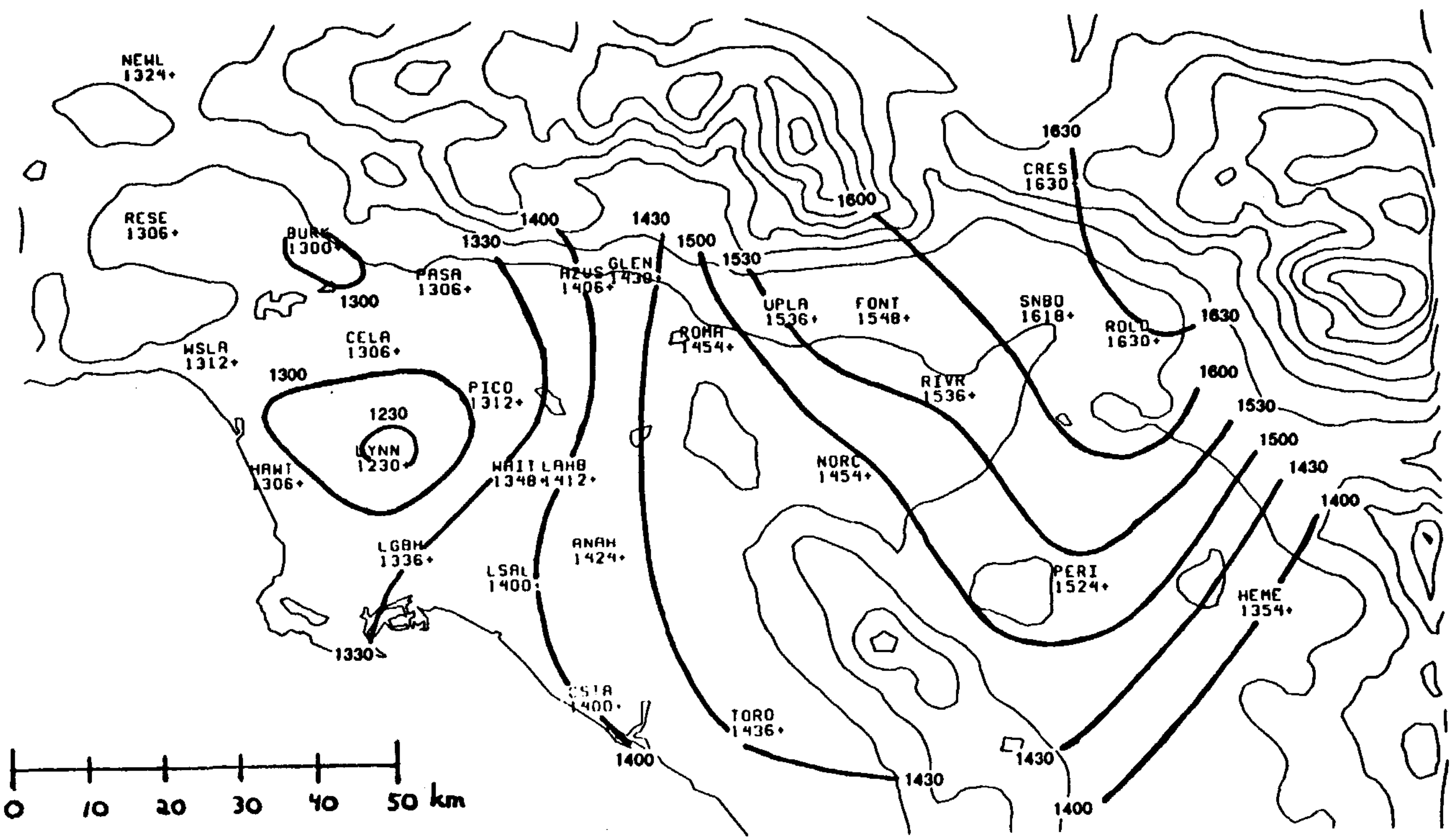


Figure 5-9. Mean initial time of occurrence (PDT) of peak ozone for 28 high ozone days. Plotted times represent average of beginning times of first hour of occurrence. Distance scale (km) indicated in lower left hand corner of figure.

L.A., Downtown L.A., Hawthorne, and Pico Rivera all experienced approximately the same mean first hour of occurrence of their daily peak ozone values for the group of high ozone days. The progressively later times of first occurrence of peak ozone at stations successively farther to the east suggests that transport from the west was important. Even here, though, the simple transport paradigm that the western part of the SoCAB acts as the source region fails to explain the variation seen. The non-uniform spacing of the isochrones of mean first hour of peak ozone occurrence (except right along the base of the San Gabriel Mountains) may indicate separate regions of significant eastward transport: one in part of the central SoCAB, and another in a portion of the inland and far inland regions. The mean first hour of occurrence at Crestline, for example, was less than 1 hour later than at the typically upwind locations of Upland (40 km to the west-southwest) and Riverside (30 km to the southwest). Note that surface wind speeds were far too low to account for such rapid propagation of pollutants. The implication is that, on high ozone days, transport may have been of greatest significance on a subregional scale.

Some similar features appear in an analysis of the average initial hour of occurrence of daily ozone maxima for the 28 middle ozone days (Figure 5-10). As for the high ozone days, little difference appeared across a broad swath of the western SoCAB. For example, Long Beach, Pico-Rivera, Pasadena, and Norco had nearly identical average first times of occurrence despite the wide variation in distance inland from the coast. Also similar to the high ozone days was the difference of only about an hour between the first hour of occurrence at Upland and that at Crestline much farther to the east. In fact, for the middle ozone days, the average first hour of occurrence at Upland was exactly the same as that at Redlands, also much farther to the east. Again, these data suggest transport may be more significant within limited sub-domains of the SoCAB.

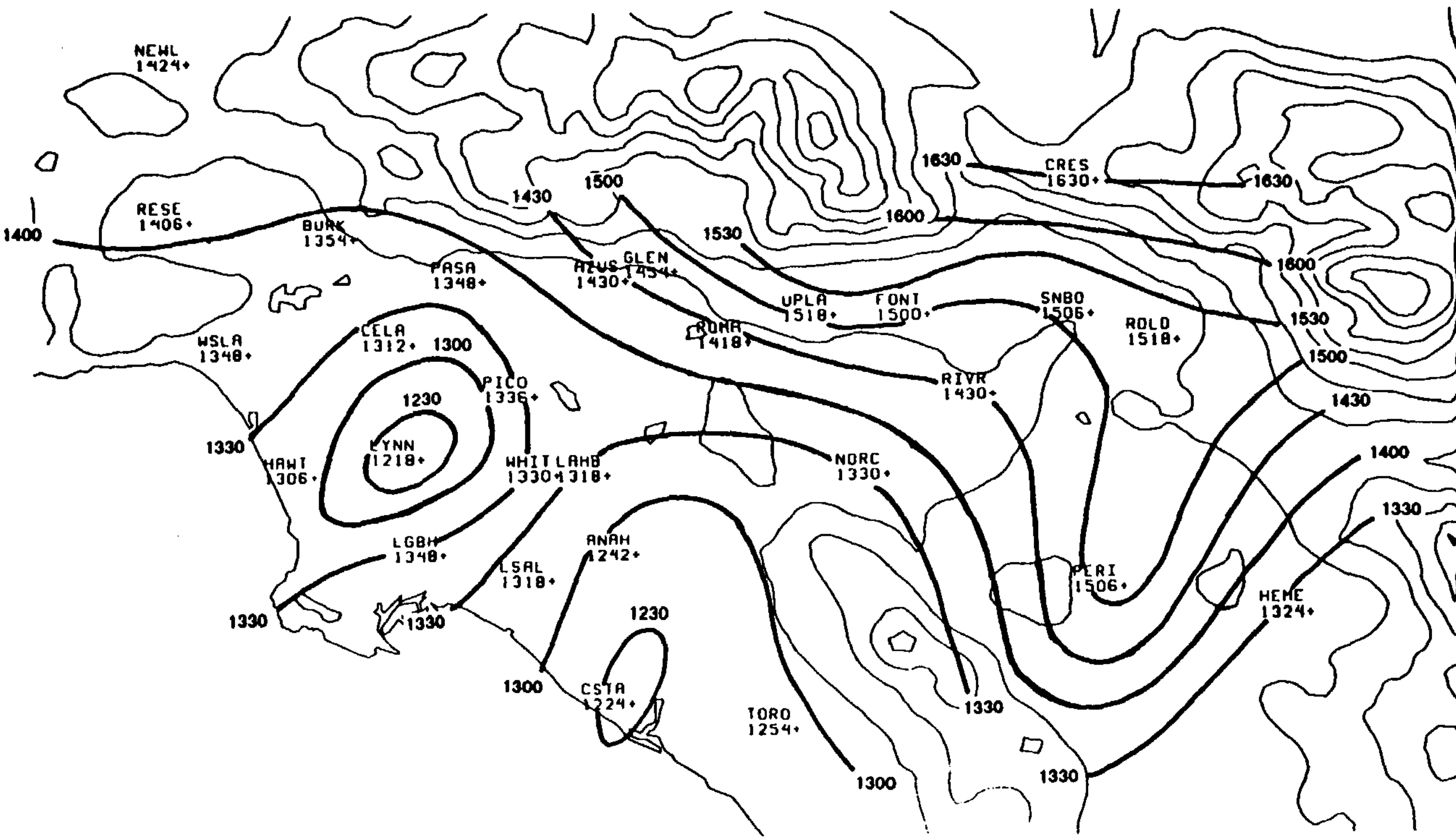


Figure 5-10. Mean initial time of occurrence (PDT) of peak ozone for 28 middle ozone days. Plotted times represent average of beginning times of first hour of occurrence. For distance scale, see Figure 5-9.

One difference that does appear between the middle and high ozone days is in the general orientation of the isochrones. On high ozone days, isochrones appear to have had more of a north-south orientation (Figure 5-9), while their orientation was more east-west on middle ozone days (Figure 5-10). The implication is that transport was somewhat more from the west on high ozone days and somewhat more from the south on middle ozone days. This was consistent with the differences in resultant surface wind directions between Figures 5-3 and 5-4, and Figures 5-5 and 5-6, though magnitudes of these differences was quite small.

Further insight into the role of transport may be acquired from examination of the average initial hour of occurrence of daily ozone maximum at each SoCAB station for just the 19 out of the 28 high ozone days that the ozone maximum occurred at Glendora (Figure 5-11). Here, with the exception of Lynwood, all stations in a broad portion of the northwestern SoCAB had almost exactly the same initial time of occurrence (1312 PDT). With increasing distance east of Pasadena, ozone maxima occurred at progressively later times. At Glendora, the average initial hour of occurrence was 1442 PDT, or 1.5 hours later than in Pasadena and 20 minutes later than at Azusa. It may be, then, that the precursor pollutants responsible for the highest hourly ozone occurrences in Glendora originated from only a relatively short distance to the west (*i.e.*, within the San Gabriel Valley). This was consistent with the low resultant surface wind speeds for these 19 high ozone days at Glendora (Figure 5-12), evident in the region just to the west of Glendora just prior to the occurrence of the ozone maximum at this location. (As noted earlier, however, the vector-averaging process used to calculate the resultant winds did make the resultant wind speed less than that of the individual winds used in the averaging. Nonetheless, as also noted earlier, the individual wind speeds (not shown) rarely appear to be more than twice the corresponding resultant wind speeds -- with the difference often smaller than this. We also note that no routine site-specific above-surface wind data were available to us.)

Similar analyses were performed for the 6 out of the 28 high ozone days that the ozone maximum occurred at Crestline. Here, again, much of the western SoCAB experienced similar times of peak ozone occurrence (Figure 5-13), with progressively later

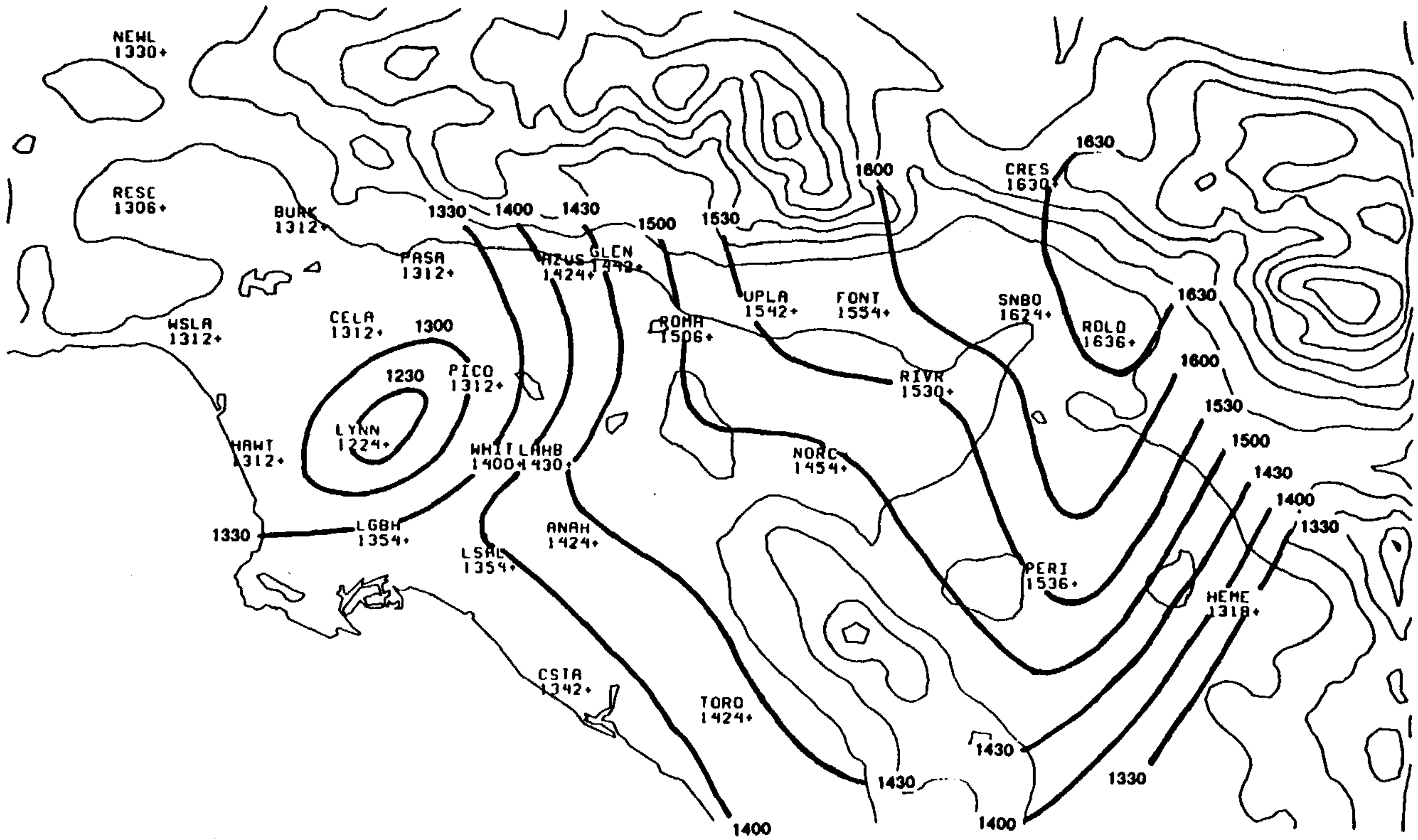


Figure 5-11. Mean initial time of occurrence (PDT) of peak ozone for subset of high ozone days (N=19) on which peak ozone value within the SoCAB occurred at Glendora. Plotted times represent average of beginning times of first hour of occurrence. For distance scale, see Figure 5-9.

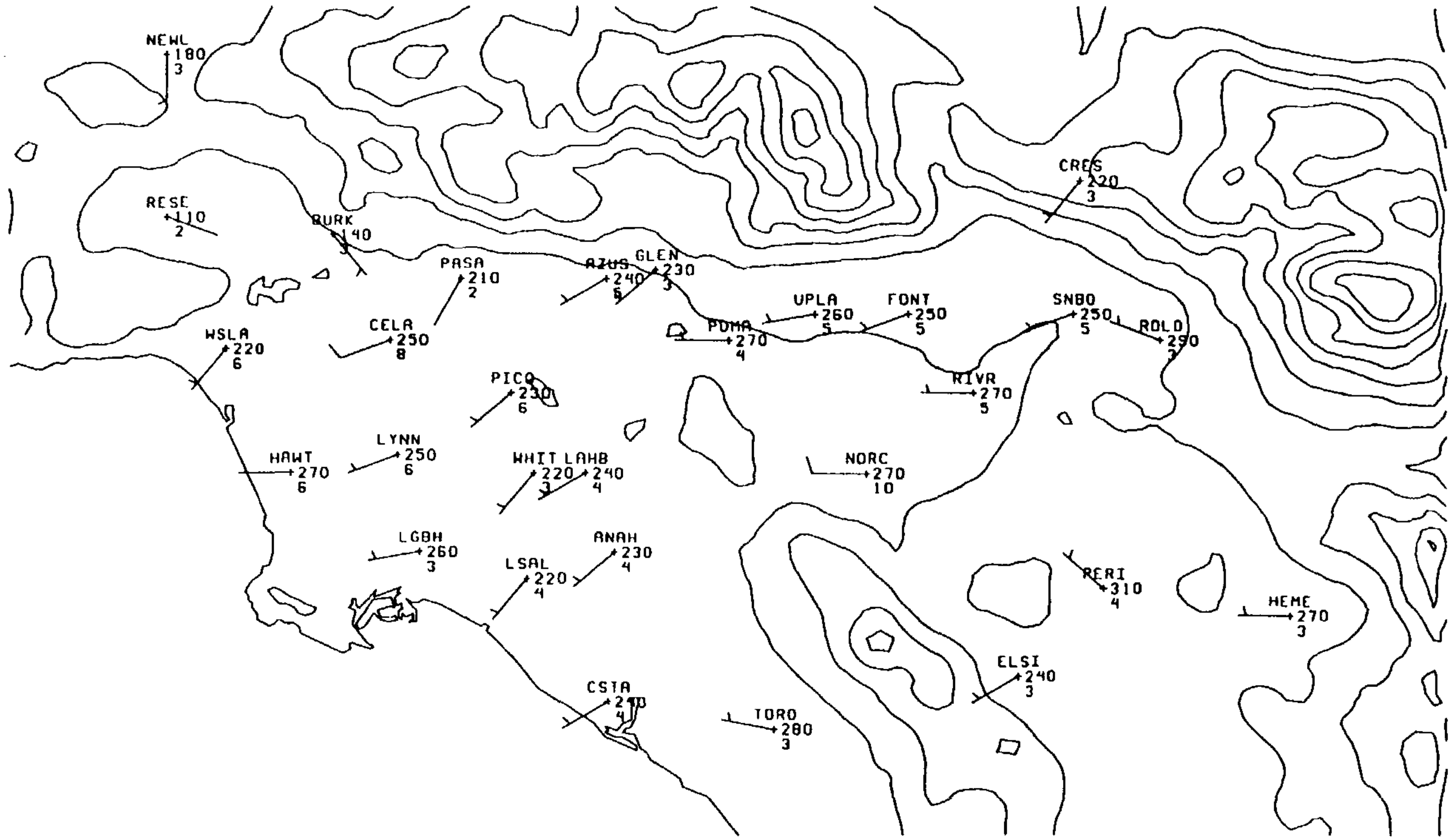


Figure 5-12. 1400-1500 PDT resultant winds for subset (N=19) of high ozone days on which Glendora reported the highest SoCAB ozone value. Wind direction (degrees) and wind speed (knots) are indicated.

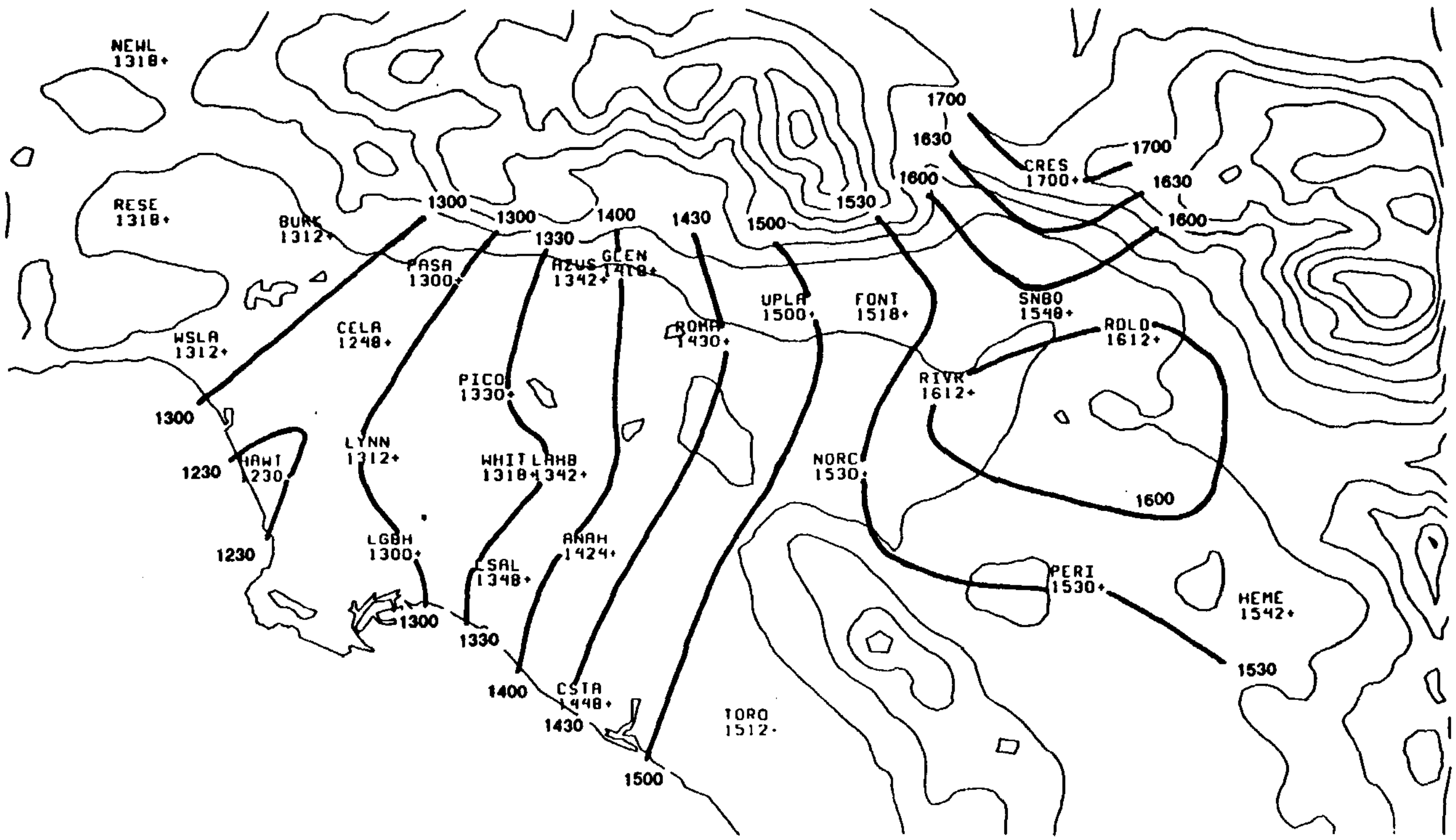


Figure 5-13. Mean initial time of occurrence (PDT) of peak ozone for subset of high ozone days (N=6) on which peak ozone value within the SoCAB occurred at Crestline. Plotted times represent average of beginning times of first hour of occurrence. For distance scale, see Figure 5-9.

times of occurrence farther eastward. The isochrone analysis alone appeared to indicate two possible routes of transport to Crestline on the worst ozone days at that location: one from the San Bernardino area to the south and the other along the southern base of the San Gabriel Mountains to the west-southwest. Here isochrones were relatively evenly spaced from Pasadena eastward, with average eastward progression of the ozone maximum of about 18-20 km per hour (10-12 knots). This was faster than would be consistent with the typical magnitude of the resultant winds for this same set of six days (Figure 5-14), but not by more than a factor of two. It is difficult, then, from just this analysis to estimate from exactly how far to the west significant transport to Crestline is occurring on those days that Crestline reports its highest ozone values.

5.1.3 Backward Surface Trajectories

To further examine the role of transport, backward surface trajectories were determined for two of the four stations reporting the highest ozone values (Glendora and Crestline). Note that as 19 of the 28 high ozone days occurred at Glendora and 6 occurred at Crestline, these two stations together account for 25 of the 28 high ozone days (though on a few of these days an equally high hourly-average peak ozone value was also reported at another SoCAB station). The relevant procedure will be explained for Glendora; a precisely analogous process was used for Crestline.

First, resultant surface winds as a function of the time of day were found and plotted for each station in the SoCAB for the subset of the 28 high ozone days that the peak ozone value within the SoCAB occurred at Glendora. A sample of such a plot for the 1400-1500 PDT hour is shown in Figure 5-12. Next, the time of the mean initial hour of occurrence of the daily maximum ozone values at Glendora and for this set of days was found (see Figure 5-11). A trajectory could then be calculated by "starting" a parcel at Glendora at this time (1442 PDT), and first advecting it backwards a distance equal to the 1-hr resultant wind speed for Glendora multiplied by the number of minutes after the start of the hour of the average time of occurrence, and in the direction the resultant wind at Glendora is blowing from. At this new location, a resultant surface wind speed and direction at the first even-hour earlier time (1400 PDT) were estimated from the resultant

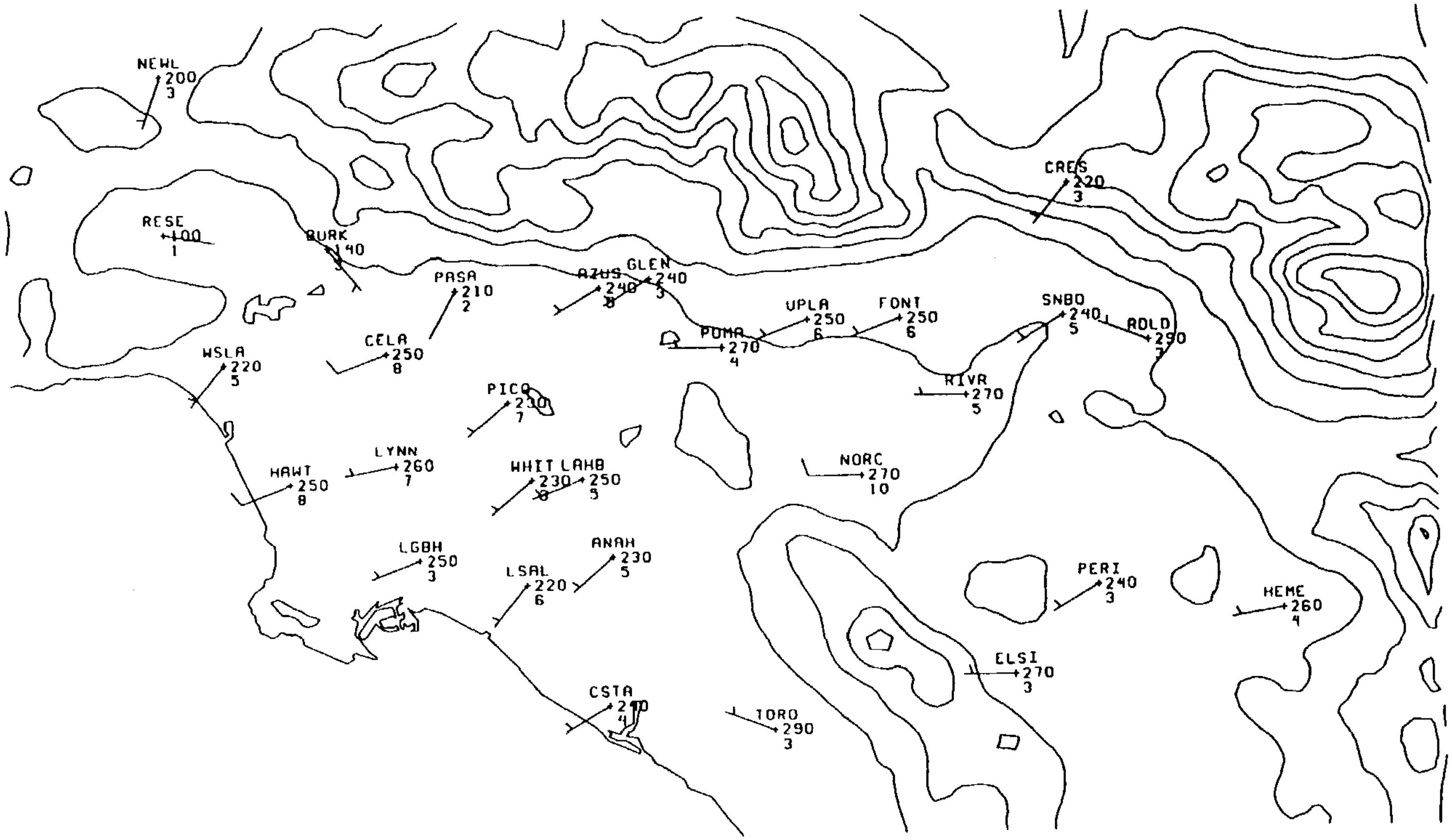


Figure 5-14. 1400-1500 PDT resultant winds for subset (N=6) of high ozone days on which Crestline reported the highest SoCAB ozone value. Wind direction (degrees) and wind speed (knots) are indicated.

winds at surrounding stations and then used to advect backwards to the next previous even-hour time (1300 PDT). This process was continued until a morning hour at which winds were calm at the parcel location (0900 PDT).

Trajectories found in this manner for both Glendora and Crestline are shown in Figure 5-15. The greater transport distance for Crestline than for Glendora was consistent with the later average time of day of the peak ozone values at Crestline. Trajectories for both of these stations as calculated here should be considered no more than qualitatively representative of the actual transport that occurs on the respective individual high ozone days. A more accurate estimate of the transport could be obtained by finding and then examining the set of individual trajectories for each of the high ozone days at a particular station. As there are 19 such days for Glendora and 6 for Crestline, however, and as determination of these trajectories is a time-consuming process, such a calculation was considered beyond the scope of this project (and would still fail to account for pollutant transport at above-surface levels). (Note that a computer program could be developed to do such a calculation but proper treatment of the topography and above-surface flow would be problematic. Essentially, though, this represents the development of a simple 1-level advective model; an exercise of seemingly limited utility as far-more sophisticated three-dimensional prognostic models including both topography and three-dimensional atmospheric structure and motion already exist (*e.g.*, Lu and Turco 1994a,b; Grell et al. 1995) and could readily be used to make far more accurate estimates of this sort of transport. We recommend that such an effort be undertaken as part of a future research project.)

5.1.4 Surface Wind Roses

A limitation of the resultant wind analyses discussed above is that the resultant wind speeds and directions do not necessarily well-represent the individual reports. For example, consider 2 hypothetical sets of 2 observations each: (1) wind reports of 270 degrees (from the west) at 30 knots and 270 degrees at 10 knots; and (2) 270 degrees at 50 knots and 90 degrees (from the east) at 10 knots. Both would yield the same resultant (vector-average) wind direction (270 degrees) and speed (20 knots)! Understanding of the

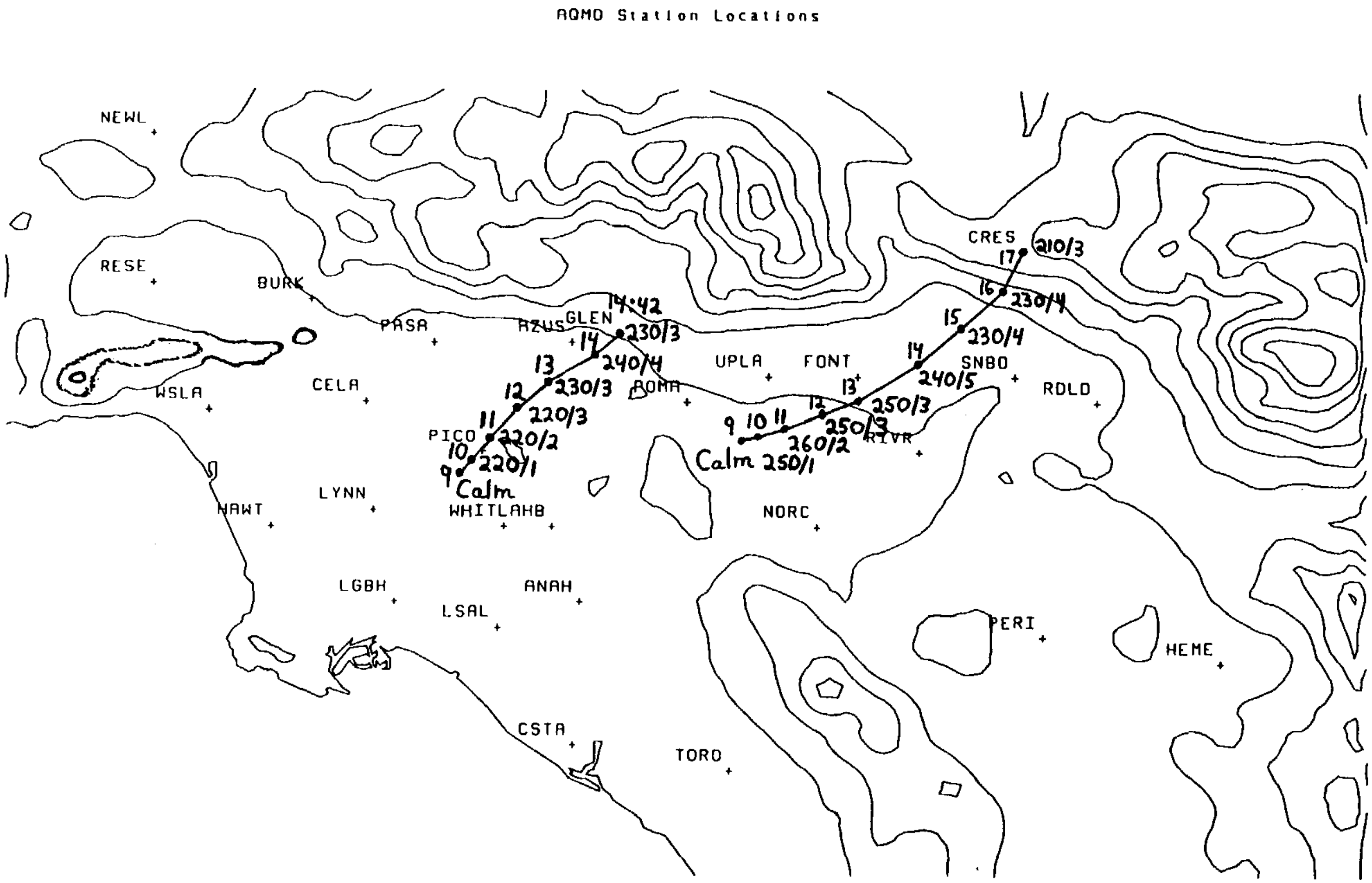


Figure 5-15. Backward trajectories based on hourly resultant winds at SoCAB stations for Glendora high ozone days and Crestline high ozone days (see text for details). Times (PDT) at start of each segment of backward trajectory, and interpolated wind direction (degrees) and wind speed (knots) used for determining parcel movement for that hour, are plotted. For distance scale, see Figure 5-9.

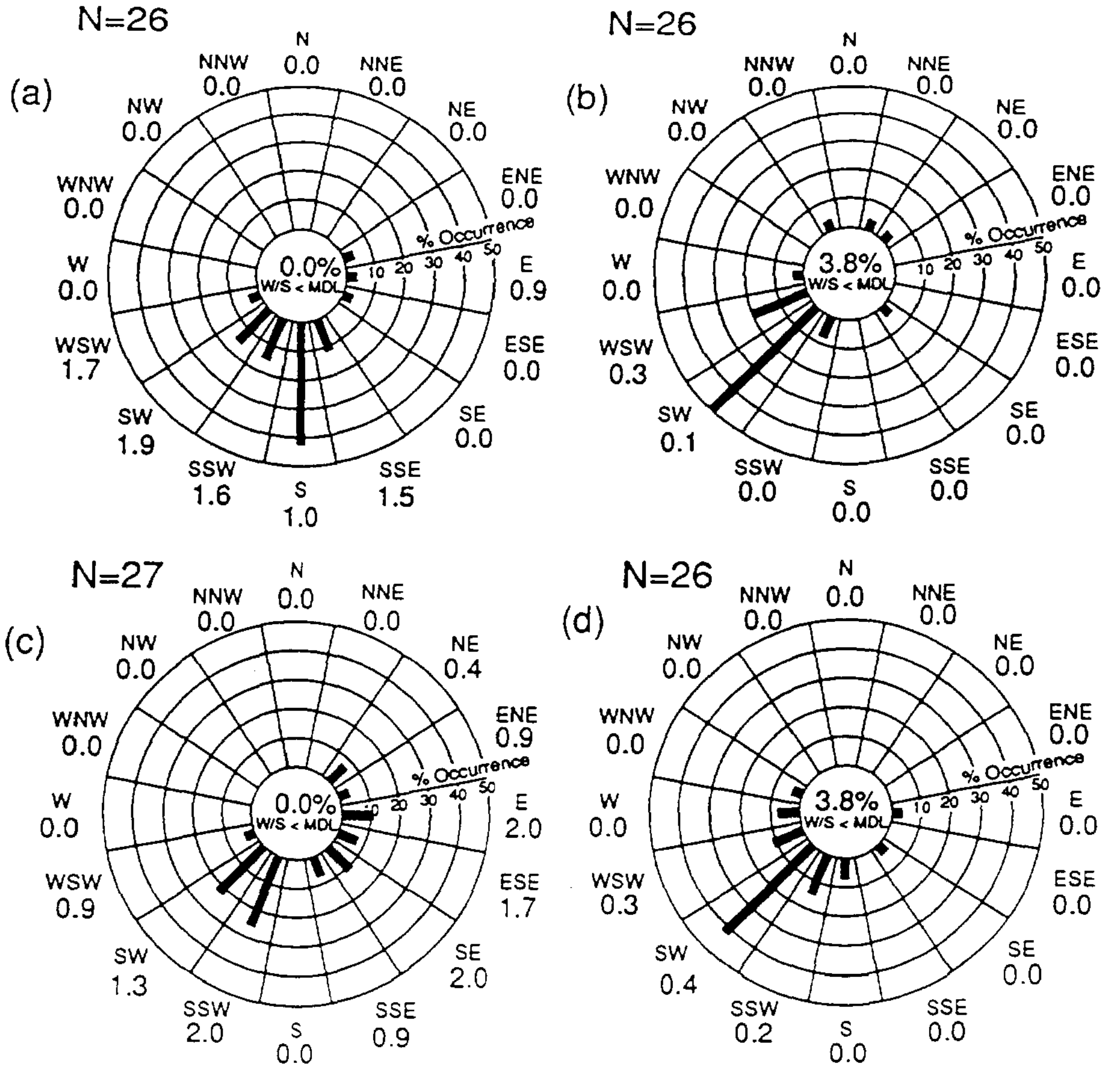
variation between the individual wind observations used in calculating the resultant winds plotted in Figures 5-1 through 5-8 thus requires further analysis of the wind data.

One technique for displaying the variation in wind speeds and directions among a group of observations is through the construction of wind roses. A wind rose depicts the frequency of occurrence of each wind direction (typically partitioned into 16 categories) and the average speed for each of these directions. As in the preceding wind analyses, the wind data used were those acquired from the SCAQMD: 1-hour resultant winds. (As noted above, instantaneous and 5-minute average wind data were not available.)

In order to facilitate interpretation of this form of wind analysis, the wind rose plotted in the upper-left-hand corner of Figure 5-16 will be discussed in detail. This wind rose gives an analysis of the 0800-0900 PDT West Los Angeles wind reports (*i.e.*, of the 1-hour resultant winds reported at 0900 PDT) based on the 26 of the 28 high ozone days that the requisite data were available. In the wind rose, the frequency of occurrence of a particular wind direction is indicated by the length of the associated bar (note the % Occurrence scale), with the average wind speed (knots) given numerically. For example, the aforementioned West Los Angeles wind rose shows that on high-ozone days, the resultant 0800-0900 PDT wind was out of the south 43% of the time, with an average speed of 1.0 knots. The number in the center of the wind rose indicates the percentage of time that the wind speed was less than the minimum detectable level (MDL), which is 0.44 knots (0.5 mph). Since wind speeds were reported only to the nearest whole mile per hour (note that 1 mph = 0.87 knots), there were some cases where a wind direction was reported with a wind speed of zero. This accounts for the presence of average wind speeds of zero for some wind directions with a nonzero frequency of occurrence.

In summary, then, the wind rose for West Los Angeles determined from the 0800-0900 PDT resultant winds for the high ozone days (as defined above) showed the predominance of very light flow out of the south -- wind directions with a frequency of occurrence exceeding 10% extend from SSE through SW. For the same time of day in Glendora, the predominant wind direction was SW -- this one wind direction captured 50% of the wind reports; the only other wind direction with a frequency of

West Los Angeles (high ozone days) Glendora (high ozone days)



West Los Angeles (middle ozone days) Glendora (middle ozone days)

Figure 5-16. West Los Angeles and Glendora wind roses for 0800-0900 PDT for high ozone concentrations days and middle ozone concentration days during the 1990-93 smog seasons. N=number of days (out of 28) with available wind observations. Wind speed in mph; MDL=0.5mph (see text for details).

occurrence exceeding 10% was WSW. Here, though, these morning winds on high ozone days were exceedingly light; in fact; all but one of the wind reports from the SW had a wind speed of zero mph (*i.e.*, less than 0.5 mph).

Wind roses were then constructed for the same locations at the same morning hour for middle ozone days. In general they looked quite similar to those for the high ozone days, except the wind direction at West Los Angeles tended to be less predominantly southerly and instead more southwesterly (primarily) or easterly (secondarily). Wind speeds appeared to be comparably small for this mid-morning hour at both stations for both middle and high concentration days.

Striking similarity between middle and high ozone days was also apparent in the afternoon (1400-1500 PDT) wind roses at these same two locations (Figure 5-17). At both locations and for both the high ozone days and the middle ozone days, the predominance of flow out of the southwest was evident -- wind directions with a frequency of occurrence exceeding 10% extended only from SSW through WSW. In Glendora, the predominant wind direction was SW -- in fact this one wind direction captured over 75% of the wind reports for both middle and high ozone days. The wind did tend to slightly more often have more of a westerly component on the middle ozone days than on the high ozone days, otherwise resultant wind speeds and directions were very similar at both locations for both groups of days.

Noting the *caveat* that this analysis is limited in that it only considers two stations at two different times, it would appear (as in Section 5.1.1) that the surface flow was not significantly different between SoCAB high ozone days and SoCAB middle ozone days. The implication is thus that low-level transport in itself may not be a dominant factor in determining the daily SoCAB peak ozone level for the period 1990-93. This is consistent with the low correlation coefficients obtained between morning NO_2 and NO_x concentrations in the Coastal and Metropolitan subregions and daily SoCAB maximum hourly-average ozone concentration (see Section 4.1.1). It is also consistent with the light resultant wind speeds shown in Figures 5-1 through 5-8, which appear too low to produce significant surface air parcel transport between the Coastal/Metropolitan subregion and the Inland Valley subregion within a single day.

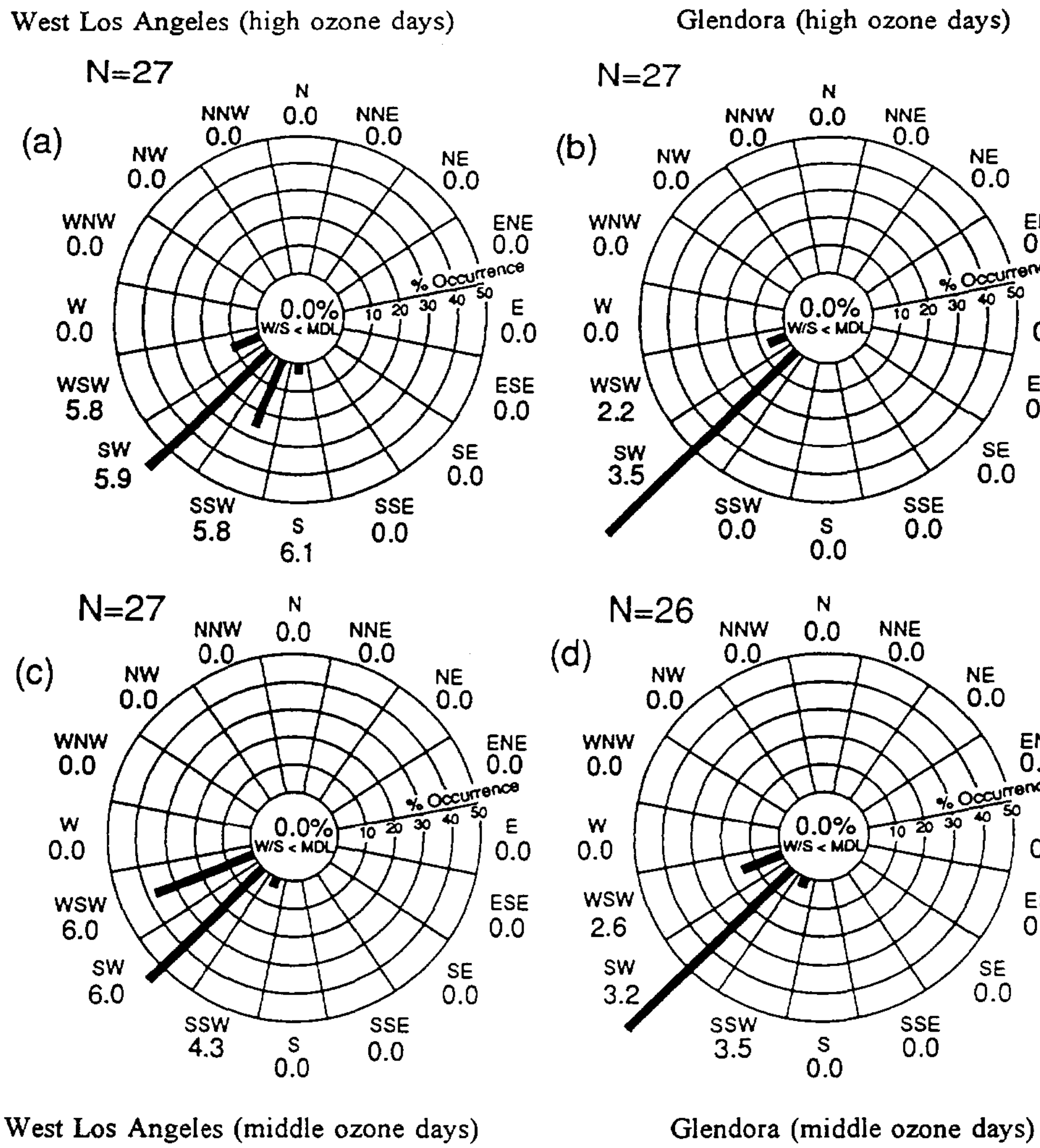


Figure 5-17. West Los Angeles and Glendora wind roses for 1400-1500 PDT for high ozone concentration days and middle ozone concentration days during the 1990-93 smog seasons. N = number of days (out of 28) with available wind observations. Wind speed in mph; MDL = 0.5 mph (see text for details).

5.1.5 Surface Temperatures

Average daily maximum surface (air) temperatures were calculated at each station in the SoCAB for the set of 28 high ozone days and for the set of 28 middle ozone days. Results of the former are shown in Figure 5-18. Here maximum temperatures were seen to vary from 77 °F at Hawthorne to 101 °F at San Bernardino and 104 °F at Newhall. In general, average maximum temperatures were much lower for the 28 middle ozone days (Figure 5-19), where values ranged from 74 °F at Hawthorne to 89 °F at San Bernardino and 90° F at Newhall. Thus the peak average daily maximum SoCAB surface temperature (*i.e.*, at Newhall) was 14 °F lower on the middle ozone days than on the high ozone days. Additionally, at all of the stations in the SoCAB with temperature data (with the exception of Hawthorne), the decrease in average maximum surface temperature was 9 °F or greater between the high ozone and middle ozone days. The implication was thus that surface heating was a significant feature associated with the daily SoCAB peak ozone level for the period 1990-93.

5.2 850 mb Meteorological Conditions: High Ozone Days vs. Middle Ozone Days

In this section we provide an examination of the difference in meteorological conditions at the 850 mb pressure level (approximately 5000 feet above sea level) between the high ozone days and the middle ozone days. Such data are provided by balloon-borne radiosondes, which are routinely launched at 1200 GMT (0500 PDT) and 0000 GMT (1700 PDT) from rather widely spaced locations. Unfortunately, there were no radiosonde stations in the SoCAB that regularly operated 7 days per week during the period 1990-93. The two closest radiosonde sites that had daily reports throughout this period were San Diego to the south and Vandenburg Air Force Base (AFB) to the northwest (locations indicated in Figure 5-20). Thus we were limited to data from these sites for our analyses.

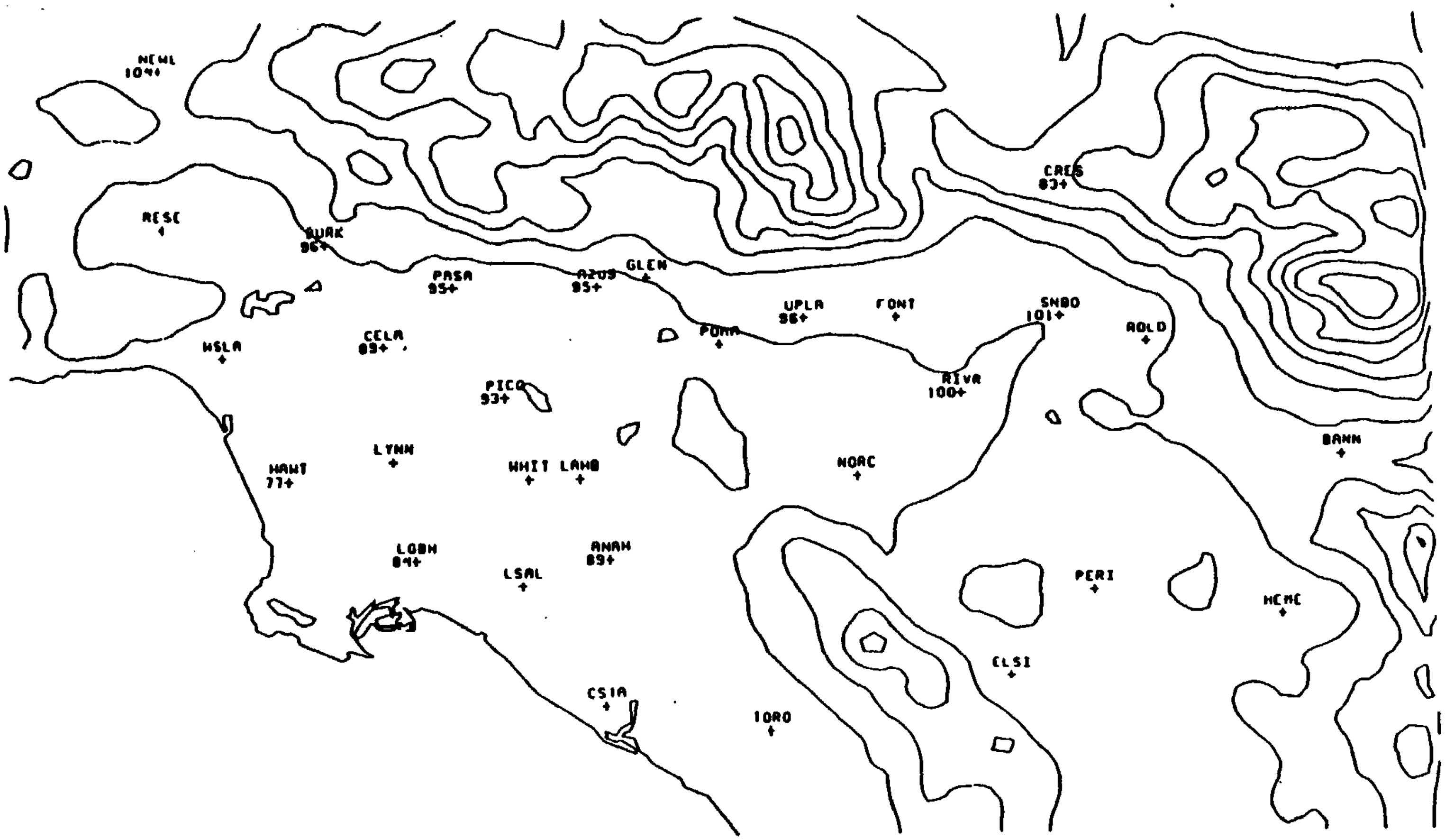


Figure 5-18. Mean daily maximum surface temperature (°F) for 28 high ozone days.

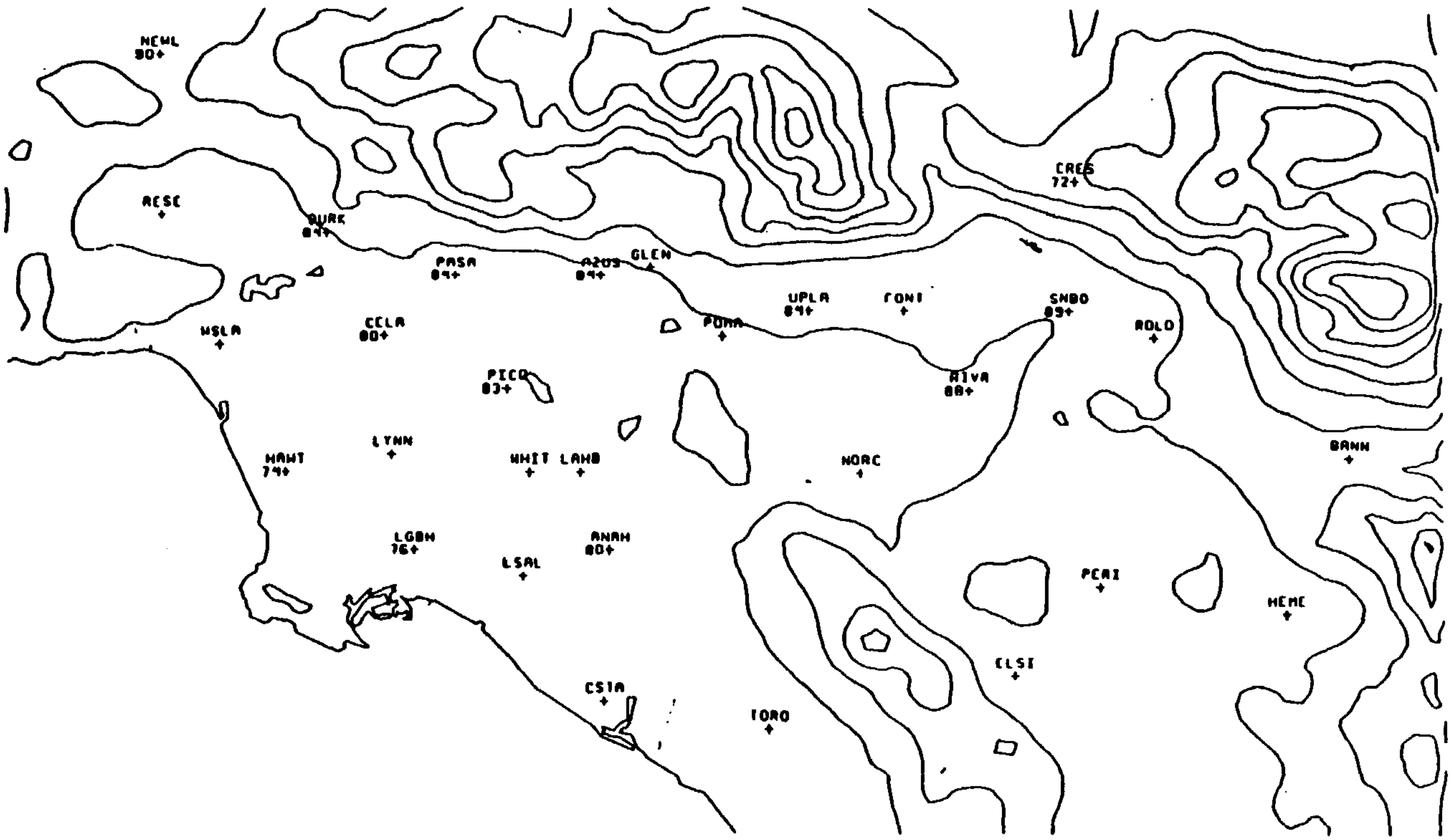


Figure 5-19. Mean daily maximum surface temperature (°F) for 28 middle ozone days.

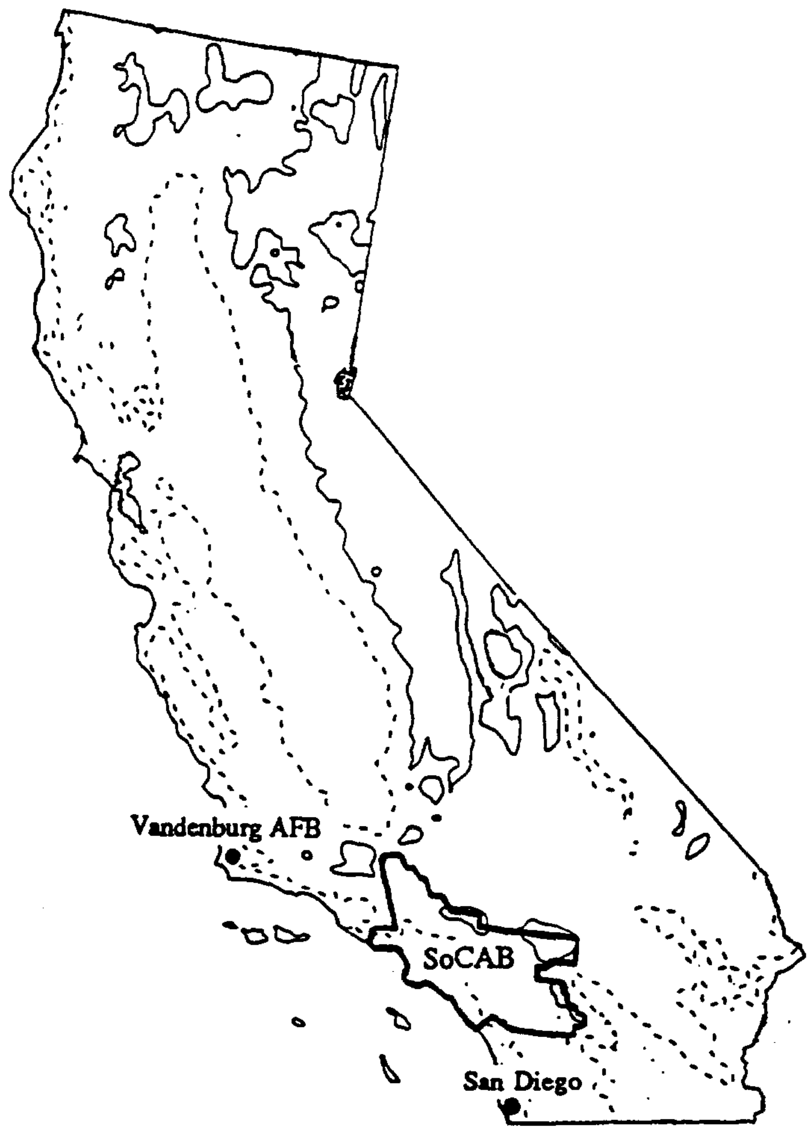


Figure 5-20. Map of California, indicating area of SoCAB. The dashed (solid) line represents the 300-m (1500-m) surface elevation contour. Locations of San Diego and Vandenberg AFB upper-sir sounding sites are shown.

5.2.1 850 mb Temperatures

It has long been established that there is a high correlation between the 850 mb temperature and the Basin-maximum ozone value (*e.g.*, Davidson et al. 1985); therefore differences in the 850 mb temperatures between the two groups of days were examined. In our analysis of the 850 mb temperatures, we defined an approximate 850 mb temperature for the SoCAB by averaging the values simultaneously reported by the San Diego and Vandenberg AFB sites (as the distances to these stations are similar, and since the 850 mb temperature gradient in the region of Southern California during the smog season tends to be fairly weak).

Significant effort was required in order to assemble the requisite data set. Neither the ARB nor the SCAQMD archives site-specific radiosonde data. Thus, in order to examine 850 mb temperatures, a new data set had to be assembled. Most of the data were acquired from archives of radiosonde reports in GEMPAK file format assembled by the Department of Atmospheric Sciences at UCLA, but a significant number of missing days remained. Some of these were filled from plotted reports on NMC 850 mb analyses maintained by the Department. In order to obtain the others in a timely manner, our only readily available option was to use a preprocessor program normally used to incorporate radiosonde data into the initial structure of the atmosphere as represented in supercomputer mesoscale model simulations using the NCAR MM5.

As Table 5-1 shows, the mean 0500 PDT 850 mb temperature for the middle ozone days was 18.7 °C with a standard deviation of 2.8 °C, while that for the high ozone days was 23.8 °C with a standard deviation of 2.1 °C. The significance of the difference in the means (5.1 °C) is indicated by its exceedance of the sum of the standard deviations (4.9 °C). A similarly significant result was found for the 1700 PDT 850 mb temperatures. Here the mean for the middle ozone days was 19.5 °C with a standard deviation of 1.9 °C while that for the high ozone days was 25.0 °C with a standard deviation of 1.8 °C. Again the difference in the means (5.5 °C) exceeds the sum of the standard deviations (3.7 °C). Hence it can be concluded that 850 mb temperatures are significantly higher on high ozone days than on more typical ozone days. The dramatic difference in 850 mb temperature is clearly evident in the plots shown in Figures 5-21 and 5-22. At 1700 PDT, there are no 850 mb temperatures for high ozone days that are lower than the highest 850 mb temperature for a middle ozone day. These results were consistent with the higher average maximum surface temperatures on high ozone days.

Table 5-1. Vandenberg AFB/San Diego mean 850 mb temperatures for 0500 PDT (1200 GMT) and 1700 PDT (0000 GMT) for the 28 high ozone concentration days and the 28 middle ozone concentration days during the 1990-93 smog seasons (see text for details).

Vandenberg/ San Diego	Middle days at 0500 PDT	Middle days at 1700 PDT	Highest days at 0500 PDT	Highest days at 1700 PDT
850 mb temperature (°C)	18.7	19.5	23.8	25.0
Standard Deviation (°C)	2.8	1.9	2.1	1.8
Number of Observations (28 maximum)	28	28	27	26

5.2.2 850 mb Winds

Data for examination of the difference in 850 mb winds between high ozone days and middle ozone days were compiled in the same manner as described above for the 850 mb temperatures, except that we considered winds at Vandenburg AFB and San Diego individually, rather than averaging them as with temperatures. Unlike with the temperature gradient, the difference in 850 mb winds between the two sites can be significant, and the variation nonlinear in the horizontal.

Vector-average wind directions and speeds at Vandenburg AFB and San Diego for both middle and high ozone days, and for both 0500 PDT and 1700 PDT, are shown in Table 5-2. In general there were fairly small differences in these average 850 mb winds between the two sets of days. It does appear, though, that the 850 mb winds were somewhat stronger and somewhat more northerly on high ozone days than on middle

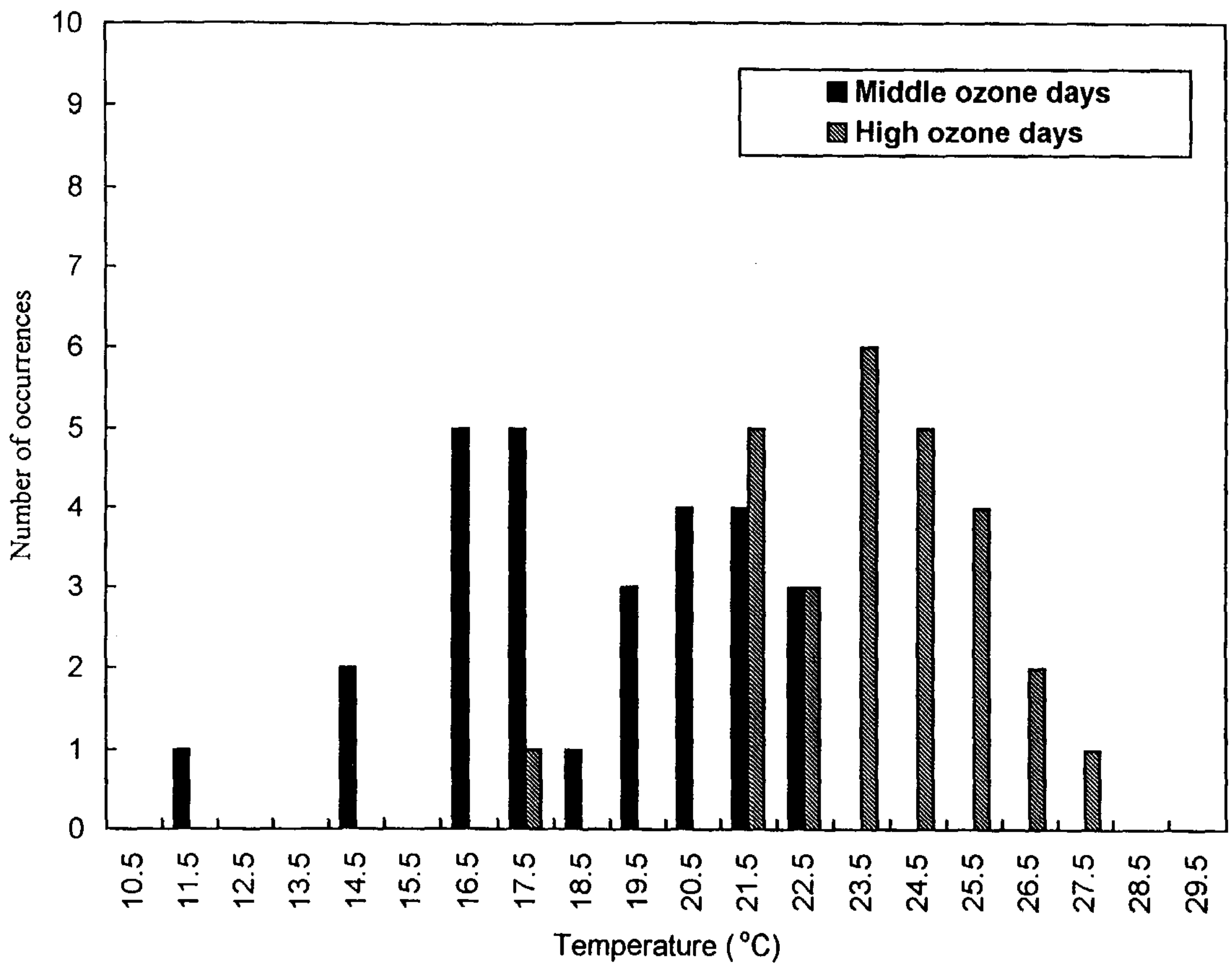


Figure 5-21. Distribution of mean (San Diego + Vandenberg AFB) 0500 PDT (1200 GMT) 850 mb temperatures for both 27 (out of 28) high ozone days (hatched) and 28 middle ozone days (solid). Temperature interval = 1 °C.

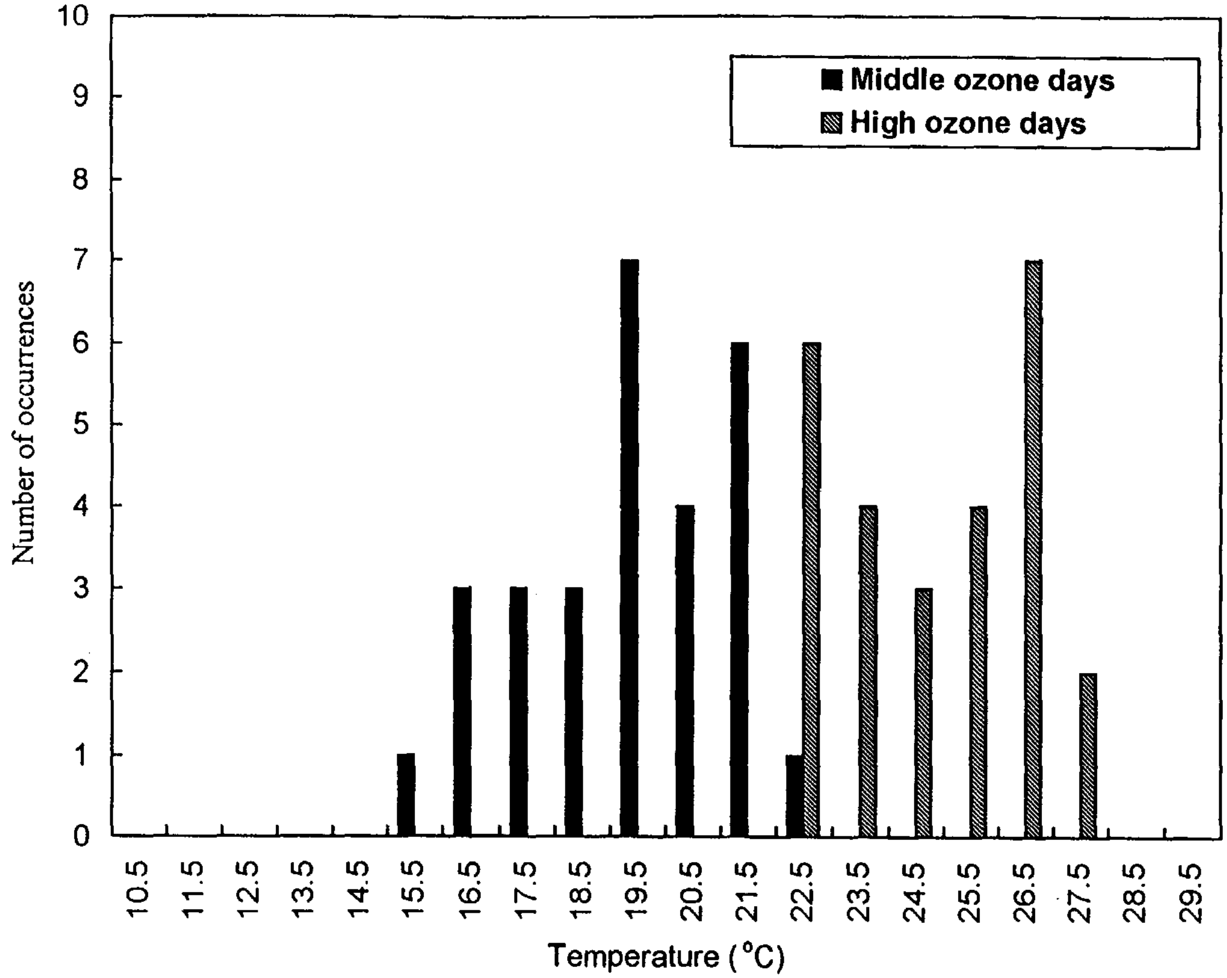


Figure 5-22. Distribution of mean (San Diego + Vandenberg AFB) 1700 PDT (0000 GMT) 850 mb temperatures for both 26 (out of 28) high ozone days (hatched) and 28 middle ozone days (solid). Temperature interval = 1 °C.

ozone days. Given the transverse (east-west) mountain ranges that lie to the north of the SoCAB, more northerly flow could result in stronger subsidence and warmer temperatures at lower levels in the atmosphere. This result thus appears not inconsistent with the higher average maximum surface and 850 mb temperatures on high ozone days than on middle ozone days.

Table 5-2. Vandenberg AFB and San Diego 850 mb resultant wind speeds and directions for 0500 PDT (1200 GMT) and 1700 PDT (0000 GMT) for the 28 high ozone concentration days and the 28 middle ozone concentration days during the 1990-93 smog seasons (see text for details).

	Middle days 0500 PDT	Middle days 1700 PDT	High days 0500 PDT	High days 1700 PDT
Vandenberg				
Speed (knots)	4.3	2.2	8.0	6.3
Direction (deg)	1.7	337.0	3.4	358.9
Number of observations (28 maximum)	28	28	28	26
San Diego				
Speed (knots)	2.2	2.0	4.5	3.5
Direction (deg)	289.6	235.7	324.5	300.7
Number of observations (28 maximum)	28	28	27	28

5.2.3 <u>850 mb Wind Roses</u>

Further examination of the 850 mb winds was enabled by the construction of wind roses (as in Section 5.1.4) for the 1700 PDT 850 mb radiosonde wind observations at Vandenburg AFB and San Diego; these are shown in Figure 5-23. At both locations and for both middle and high ozone days, a variety of wind directions were evident. Consistent with the results shown in Table 5-2, however, the Vandenburg wind tended to

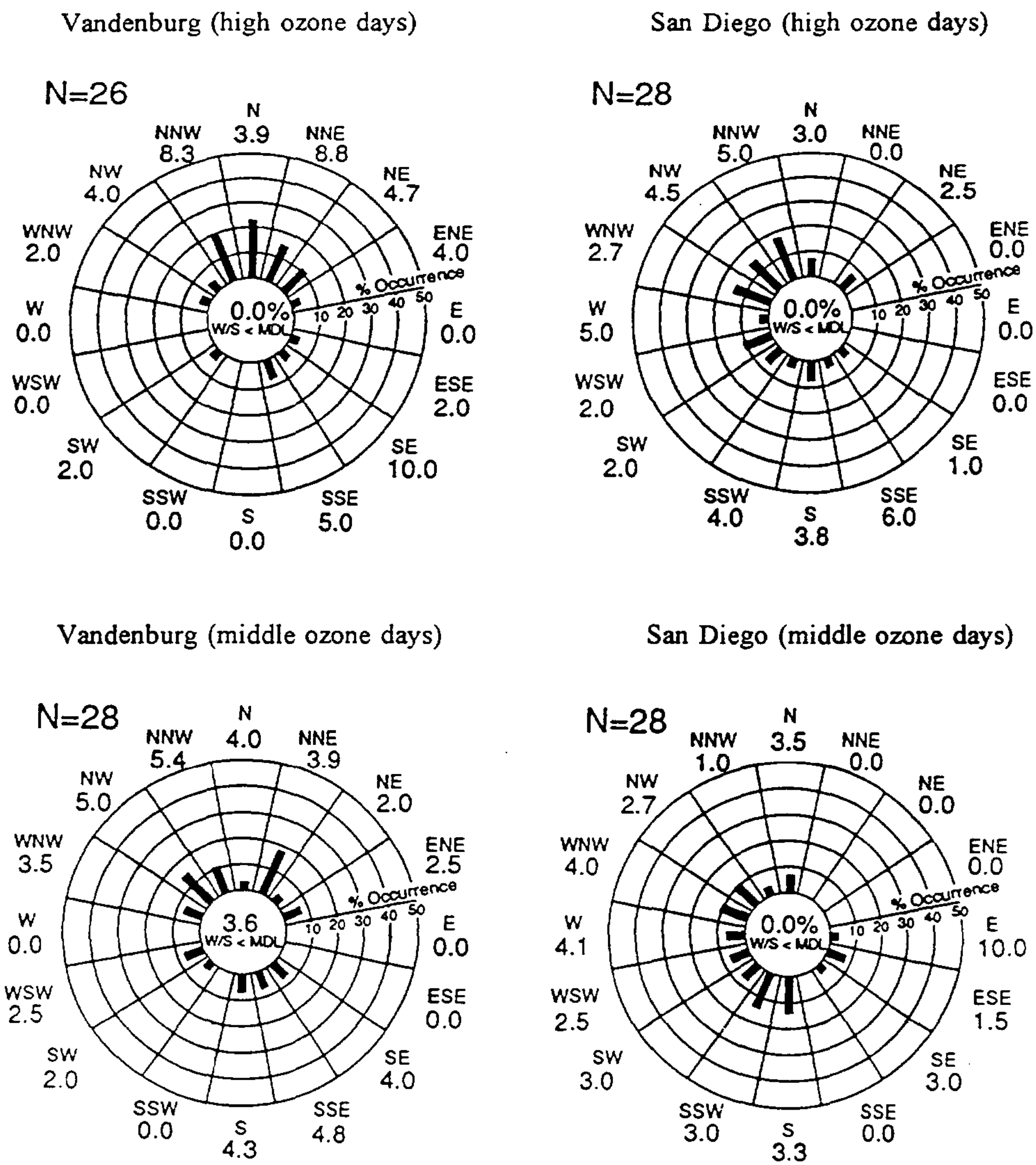


Figure 5-23. Vandenburg and San Diego wind roses at 850 mb for 0000 GMT (1700 PDT) on high ozone concentrations days and middle ozone concentration days during the 1990-93 smog seasons. Wind speed in knots; MDL=2knots (see text for details).

more often be from more northerly directions and overall at slightly higher wind speeds than on middle ozone days. As above, results were not inconsistent with the warmer low-level temperatures observed on high ozone days as these are wind directions more likely to be associated with orographically-induced subsidence warming. Nonetheless, it is apparent that high ozone values can occur in the SoCAB under a variety of 850 mb wind directions.

5.3 Pattern Number: High Ozone Days vs. Middle Ozone Days

Five different synoptic regimes, described by the contour signature at the 500 mb level, were defined by Cassmassi (1987) for ozone prediction stratification. The five patterns that emerged from the classification (shown in Figure 5-24) include: (1) a low pressure trough over California characterized by a large north-south pressure gradient; (2) a low pressure trough approaching California from the west or "breakdown" of a ridge of high pressure over the state; (3) zonal flow or a "building" high pressure ridge, characterized by a moderate pressure gradient and 500 mb heights somewhat higher to the southwest; (4) a high pressure ridge over California, with 500 mb heights approaching or exceeding 5880 m throughout the study area; and (5) a cut-off upper-level low centered over the central California-Nevada state line. Among the data received from the SCAQMD for the present study was the classification of each day according to this set of pattern numbers.

Here we compared the pattern number distribution for the 28 high ozone days with that for the 28 middle ozone days (Table 5-3). All but three of the high ozone days were ascribed to pattern number 4, while the majority of the middle ozone days were associated with pattern number 3. The implication was that highest ozone values occurred in association with very high 500 mb heights and thus warm troposphere-mean temperatures (and thus 850 mb temperatures as well). Such conditions are likely to be associated with very weak flow aloft, while diurnally-driven circulations dominate near the surface in the Basin. In contrast, lower ozone days are more likely to be associated with lower 500 mb heights and thus cooler troposphere-mean temperatures, and stronger flow aloft. A not insignificant number of middle ozone days, however, did have the same pattern number

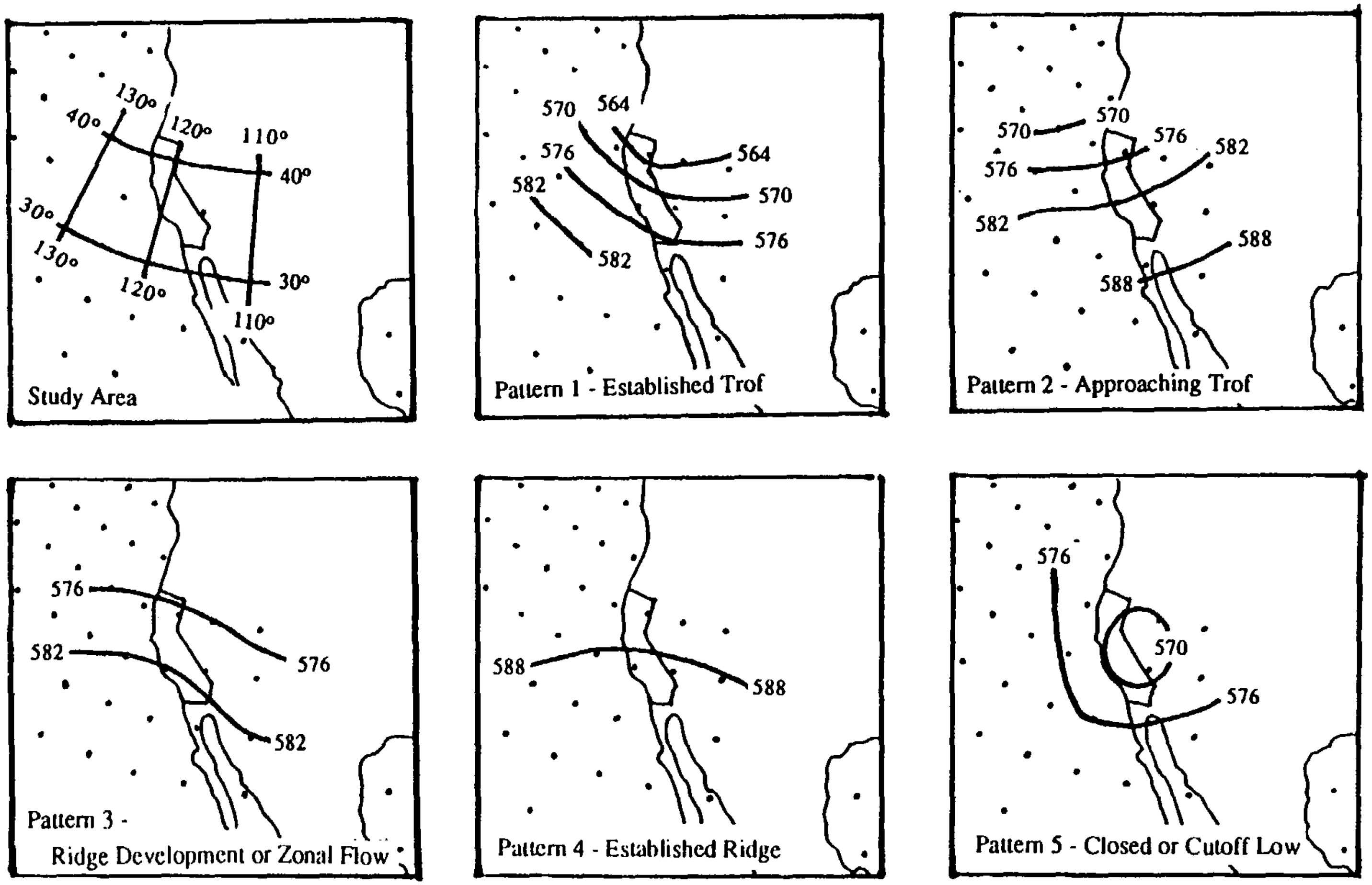


Figure 5-24. 500 mb flow patterns defined by Cassmassi (1987) for ozone prediction stratification.

as most of the high ozone days. Thus the pattern number as defined by Cassmassi (1987) could not fully account for the difference in characteristic synoptic-scale meteorological conditions between high and middle ozone days.

Table 5-3. The number of occurrences of the pattern numbers for the 28 middle and 28 high ozone days.

Pattern Number	High Ozone Days	Middle Ozone Days
1	0	2
2	0	2
3	3	16
4	25	7
5	0	1

5.4 Application of the CART Scheme

Horie (1987) developed a Classification and Regression Tree (CART) scheme which was used to separate each day of the 3-year period 1983-85 into ten different categories (nodes) based on meteorological conditions (Figure 5-25). The total number of days within a category indicates the frequency of occurrence of the associated meteorological conditions during the period of investigation. The average value of the Basin-maximum ozone concentrations for the days in a particular category can reveal important relationships between the meteorological conditions and the daily peak ozone concentrations.

In the present study, we applied the CART scheme developed by Horie to the period 1986-93. Unlike Horie, however, we only considered days during the smog season, and we did not distinguish days with less than 10.8 hours of daylight (as this is only marginally true for the last few days of October).

The data used in the application of the CART scheme to the 1986-93 smog season days included the daily SoCAB-maximum hourly-average ozone concentrations, the morning (0600-1200 PST) resultant wind directions at Los Angeles International Airport

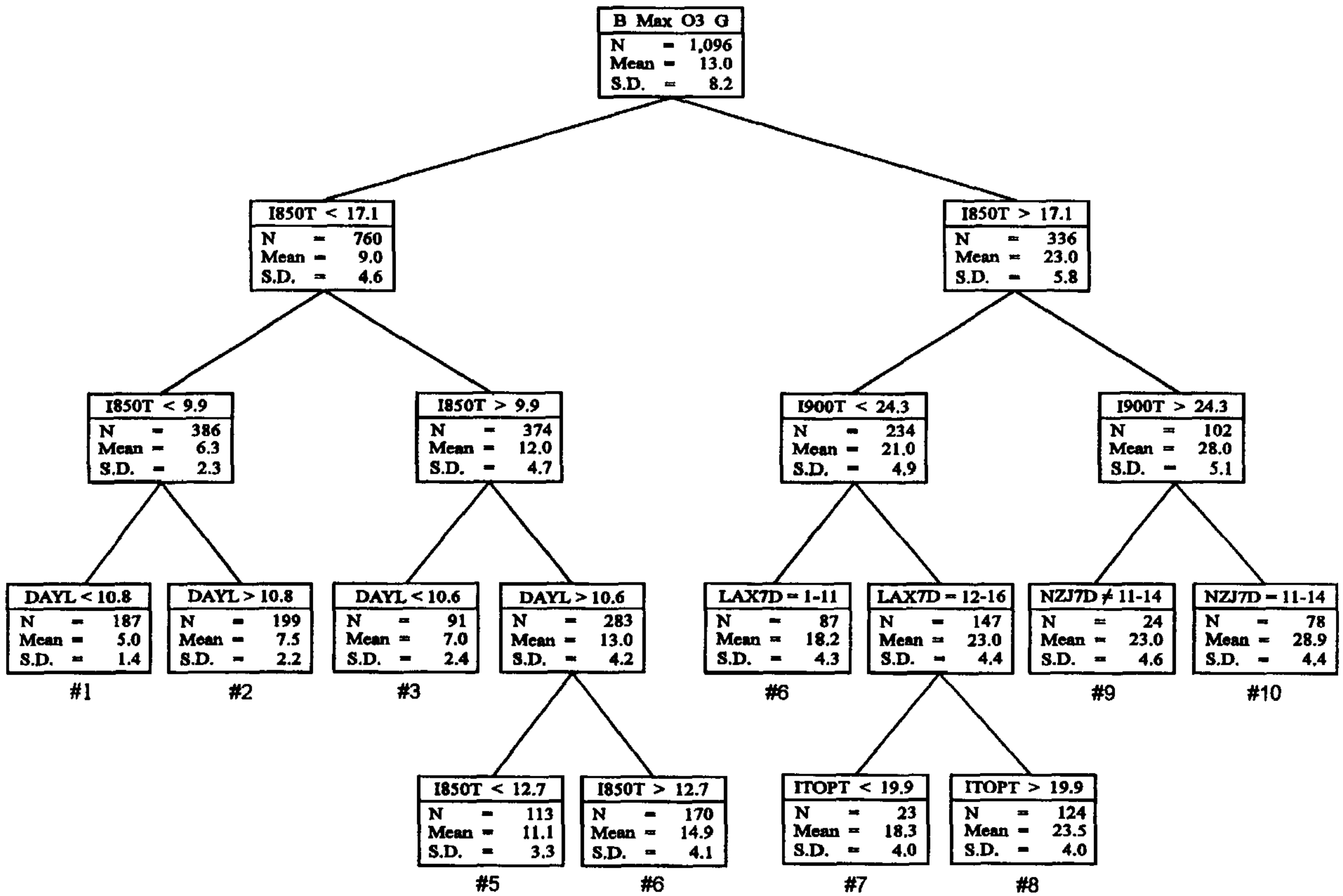


Figure 5-25. CART decision tree for daily SoCAB maximum ozone concentrations (including those measured at Glendora). Following Horie (1987).

(LAX) and El Toro, the inversion top temperature, the 850 and 900 mb temperatures in the region of the SoCAB, and the number of daylight hours.

The SoCAB-maximum ozone concentrations were obtained from the ARB ozone data set, which was subjected to the rigorous quality control checks described in Section 3.3.2. The LAX wind data for 1986-93 were obtained from the CD-ROM meteorological data archive at the UCLA Geology Library. These wind observations were 1-minute averages taken 10-15 minutes before the hour. The LAX morning resultant wind directions were derived from these 1-minute averages. The El Toro wind data for 1986-87 were obtained from the same source and were of the same form as the LAX wind data. However, the El Toro wind data for 1988-93 were obtained from the AQMD hourly-average resultant wind directions. Thus there is some inconsistency between the winds used for El Toro for the first two years covered by this study, which were 1-minute averages taken at the Federal Aviation Administration (FAA) site, and those used for the remaining 6 years, which were 1-hour averages taken at the AQMD site. Ideally, winds would have been used from the FAA site for all 8 years (to be entirely consistent with Horie's CART scheme), but the requisite data were unavailable to us. Although it was suspected that the impact on the resulting distribution of days by CART node would be small -- as the El Toro wind only affects the separation of days between nodes 9 and 10 and as there would seemingly be little difference in the overall morning (0600-1200 PST) resultant wind direction -- calculations were performed to further examine this issue. For the 1991 and 1992 smog season days, the CART scheme was applied using wind data from each of the El Toro sites (as data completeness for both sites was excellent for those two years). When the winds from the FAA site were used for 1991, 5.4% of the days were classified into Node 9 and 7.6% into Node 10; respective mean peak SoCAB hourly-average ozone values were 18.9 and 22.6 pphm, respectively. When the winds from the AQMD site were used for 1991, 7.6% of the days were classified into Node 9 and 5.4% of the days into Node 10, with corresponding mean ozone values of 19.9 and 22.7 pphm, respectively. When the FAA site winds were used for 1992, 3.3% of the days were classified into Node 9 and 12.0% into Node 10; respective mean peak SoCAB hourly-average ozone values were 18.2 and 21.0 pphm, respectively. When the AQMD site winds were used for 1992, 3.8% of the days were classified into Node 9 and 12.0% into Node 10, with corresponding mean ozone values of 19.4 and 21.0 pphm, respectively. (In each of the 1991 applications of the CART scheme, there were 2 days with insufficient data; in the 1992 applications of the CART scheme, there were 2 days with insufficient data when the FAA site winds were used, and no days with insufficient data when the AQMD site winds were used.) Thus our use of the El Toro data from the FAA station rather than from the AQMD station appears likely to have had no more than a modest impact on the distribution of days between nodes 9 and 10 and (potentially) on the respective mean Basin-peak ozone values for each of these nodes.

The inversion top temperatures and 850 and 900 mb temperatures were also obtained from the AQMD. Data files they provided to us contained these observations, extracted once daily, from the local morning upper-air sounding taken at one of the following stations: LMU, UCLA, MYF, NKX, VBG, NTD, or NSI. According to Cassmassi (1994), the majority of the soundings were from either LMU or UCLA, but no information on the actual sounding location was contained in the data files. The morning soundings at LMU and UCLA were taken at approximately 1300 GMT (0500 PST), while those from the other sites were taken at approximately 1200 GMT (0400 PST).

The CART scheme was used to bin the smog season days into the ten nodes of the tree in 3 different ways. First, the smog season days for each of the years 1986-93 were individually binned using the CART scheme. Then, all of the smog season days for 1986-89 were treated as one group for binning and those for 1990-93 were treated as a second group. Finally, the weekdays (here represented by Tuesday and Wednesday) and the weekend days (Saturday and Sunday) were separately binned for the two four-year periods 1986-89 and 1990-93. Before proceeding with the results of these analyses, however, a *caveat* should be noted. As indicated by Instaweather (1989), if one were to develop a new CART tree for the period of years presently being examined, it is likely that the nodes would be defined differently than in the CART tree developed by Horie using meteorological data from 1983-85. Such a task would represent a substantial undertaking, though, and is beyond the scope of the present project.

5.4.1 Individual Years: 1986-93

The distribution of smog season days by node of the CART decision tree for each of the individual years between 1986 and 1993 is shown in Table 5-4. Sufficient data existed to bin all smog season days for each of these years, except for one day in 1989 and two days in 1992. Each terminal node of the tree represents a different set of meteorological conditions with respect to the potential for ozone formation. No days were classified into nodes 1 or 3 as the former is associated with less than 10.8 hours of daylight and the latter with less than 10.6 hours of daylight. In the present study, the number of daylight hours was taken to be greater than 10.8 throughout the smog season (which is true, except for the last several days of October).

For each of the 8 years, the highest mean Basin-maximum ozone concentration was associated with node 10. According to Figure 5-25 and Horie (1987), node 10 is characterized by very warm temperatures at 850 mb and 900 mb (and thus probably very high inversion temperatures) and morning winds at El Toro ranging from west-southwesterly to northwesterly. However, Basin-maximum ozone values associated with this node were significantly less in the latter four years than in the earlier four years, and were lower for all years of our study than the 1983-85 average for this node of 28.9 pphm reported by Horie. Thus, under similar meteorological conditions highly conducive to ozone formation, peak ozone values appear to have decreased and have thus apparently decreased for other than meteorological reasons.

In each of the eight years of the present study, the next highest mean Basin-maximum ozone values were associated with nodes 8 and 9. The only meteorological difference between nodes 9 and 10 was in the morning El Toro wind direction, while node 8 was characterized by cooler 900 mb temperatures than nodes 9 and 10 (though also by a warm inversion-top temperature and a resultant morning wind direction between west-southwesterly and north-northwesterly at LAX). In general, as temperatures at the 850 and 900 mb levels cooled, Basin-peak ozone levels diminished. This is consistent with the results shown in Section 5.2.1.

Table 5-4. Distribution of smog season days by node of the CART decision tree for each year in the period 1986-93.

1986				
Node	# Days	Mean $[O_3]$ pphm	Standard Deviation	% Days
1	0	-1.0	-1.0	0.0
2	26	9.3	2.7	14.1
3	0	-1.0	-1.0	0.0
4	16	11.6	2.7	8.7
5	39	14.9	3.8	21.2
6	47	20.0	4.2	25.5
7	5	16.4	2.7	2.7
8	30	21.7	5.1	16.3
9	2	26.0	5.7	1.1
10	19	26.5	3.3	10.3

1987				
Node	# Days	Mean $[O_3]$ pphm	Standard Deviation	% Days
1	0	-1.0	-1.0	0.0
2	24	8.2	3.2	13.0
3	0	-1.0	-1.0	0.0
4	7	8.3	4.5	3.8
5	48	13.7	3.7	26.1
6	38	18.2	3.7	20.7
7	11	18.3	3.1	6.0
8	36	22.4	3.7	19.6
9	5	21.4	2.3	2.7
10	15	24.8	5.6	8.2

Table 5-4. Distribution of smog season days by node of the CART decision tree for each year in the period 1986-93. "-1.0" indicates no data. (continued)

1988

Node	# Days	Mean [O_3] pphm	Standard Deviation	% Days
1	0	-1.0	-1.0	0.0
2	15	8.0	2.5	8.2
3	0	-1.0	-1.0	0.0
4	10	10.1	2.6	5.4
5	30	14.4	2.8	16.3
6	40	18.5	3.8	21.7
7	14	18.2	2.6	7.6
8	51	20.9	3.5	27.7
9	10	22.7	4.5	5.4
10	19	25.9	4.7	7.6

1989

Node	# Days	Mean [O_3] pphm	Standard Deviation	% Days
1	0	-1.0	-1.0	0.0
2	27	7.3	2.5	14.7
3	0	-1.0	-1.0	0.0
4	11	9.7	3.2	6.0
5	35	13.5	3.2	19.0
6	31	16.6	4.0	16.8
7	12	17.3	3.8	6.5
8	49	20.1	4.1	26.6
9	11	21.9	4.8	6.0
10	7	27.6	5.0	3.8

Table 5-4. Distribution of smog season days by node of the CART decision tree for each year in the period 1986-93. "-1.0" indicates no data. (continued)

1990				
Node	# Days	Mean $[O_3]$ pphm	Standard Deviation	% Days
1	0	-1.0	-1.0	0.0
2	20	8.6	3.4	10.9
3	0	-1.0	-1.0	0.0
4	18	9.8	1.5	9.8
5	40	11.5	3.1	21.7
6	35	15.7	4.4	19.0
7	5	15.0	2.2	2.7
8	45	18.7	3.2	24.5
9	8	21.1	2.4	4.3
10	13	24.2	4.6	7.1

1991				
Node	# Days	Mean $[O_3]$ pphm	Standard Deviation	% Days
1	0	-1.0	-1.0	0.0
2	33	8.0	3.1	17.9
3	0	-1.0	-1.0	0.0
4	12	11.7	1.8	6.5
5	38	13.5	3.0	20.7
6	29	17.0	4.2	15.8
7	9	18.3	2.8	4.9
8	37	18.9	4.1	20.1
9	14	19.9	4.5	7.6
10	10	22.7	6.1	5.4

Table 5-4. Distribution of smog season days by node of the CART decision tree for each year in the period 1986-93. "-1.0" indicates no data. (continued)

1992				
Node	# Days	Mean $[O_3]$ pphm	Standard Deviation	% Days
1	0	-1.0	-1.0	0.0
2	15	7.8	3.0	8.2
3	0	-1.0	-1.0	0.0
4	15	9.7	2.7	8.2
5	48	13.0	4.1	26.1
6	36	15.7	3.4	19.6
7	9	14.7	2.5	4.9
8	32	17.9	4.5	17.4
9	7	19.4	2.7	3.8
10	22	21.0	4.6	12.0

1993				
Node	# Days	Mean $[O_3]$ pphm	Standard Deviation	% Days
1	0	-1.0	-1.0	0.0
2	17	87.5	3.1	9.2
3	0	-1.0	-1.0	0.0
4	21	9.0	2.8	11.4
5	54	11.6	3.0	29.3
6	31	15.8	3.3	16.8
7	11	15.2	2.4	6.0
8	29	17.3	3.5	15.8
9	10	20.2	2.0	5.4
10	11	21.3	3.8	6.0

5.4.2 1986-89 vs. 1990-93

Here all smog season days for 1986-89 were binned together by node of the CART decision tree, as were all smog season days for 1990-93 (Table 5-5). The mean Basin-maximum ozone value for each of the 8 CART nodes into which days were distributed was lower for 1990-93 than for 1986-89. The implication was that regardless of the meteorological conditions, generally lower peak ozone values were observed in the latter four years than in the earlier four years. However, given the magnitudes of the associated standard deviations, the reductions in most cases were comparatively small, and thus attribution to other than meteorological influences, while likely, was not definitive. The largest reduction in peak ozone values (both in magnitude and percent) occurs for node 10. Thus the largest ozone decreases generally occurred under the meteorological conditions most conducive to occurrence of a very high ozone concentration in the SoCAB.

In the previous section the significant influence of the temperatures at 850 and 900 mb and at the inversion top on the potential for ozone formation was noted. Wind variables were also selected by the CART software Horie applied; the morning resultant wind direction at LAX separates node 6 from nodes 7 and 8, while the morning resultant wind direction at El Toro separates node 9 from node 10. In the case of the former, more westerly morning winds were associated with higher peak ozone values if inversion top temperatures are >19.9 °C. With regards to the latter, more westerly morning winds at El Toro, on days with warm 850 and 900 mb temperatures, were associated with higher peak ozone values. The implication was that morning transport in the direction of the interior of the SoCAB was of some significance with respect to the peak ozone levels observed on days with warm temperatures aloft.

5.4.3 High Ozone Days vs. Middle Ozone Days

In Table 5-6, the 28 high ozone days and the 28 middle ozone days for the smog season during the period 1990-93 (as defined in Section 5.1) were binned according to their associated nodes in the CART tree. Results were generally consistent with those seen in the previous section: 16 of the high ozone days were classified as node 10, while

Table 5-5. Distribution of smog season days by node of the CART decision tree for each of the two four-year periods 1986-89 and 1990-93.

1986-89				
Node	Sum	Mean	Standard Deviation	Percent
1	0	--	--	0.0
2	92	8.2	2.8	12.5
3	0	--	--	0.0
4	44	10.3	3.2	6.0
5	152	14.1	3.4	20.7
6	156	18.5	4.1	21.2
7	42	17.8	3.1	5.7
8	166	21.1	4.1	22.6
9	28	22.4	4.3	3.8
10	55	26.0	4.5	7.5
1990-93				
Node	Sum	Mean	Standard Deviation	Percent
1	0	--	--	0.0
2	85	8.0	3.1	11.5
3	0	--	--	0.0
4	66	9.8	2.5	9.0
5	180	12.4	3.4	24.5
6	131	16.0	3.9	17.8
7	34	15.9	2.9	4.6
8	143	18.3	3.8	19.4
9	39	20.2	3.2	5.3
10	56	22.1	4.8	7.6

Table 5-6. Distribution of the 28 high ozone days and the 28 middle ozone days by node of the CART decision tree.

Node	Middle Ozone Days	High Ozone Days
1	0	0
2	1	0
3	0	0
4	1	0
5	9	0
6	9	3
7	2	0
8	6	5
9	0	4
10	0	16

4 were classified as node 9; none of the middle ozone days were associated with either of these nodes. Nodes 9 and 10 are distinguished by having the warmest temperatures at both 850 and 900 mb.

5.5 Summary

In order to study the relationship between air parcel residence time (and various other meteorological parameters) and the occurrence of high ozone in the SoCAB, a basic methodology was followed of comparatively examining those days on which the Basin peak ozone value was very high and those days on which the ozone value was merely average. Such an approach facilitated the identification of those meteorological parameters and conditions explicitly associated with high ozone. Several significant results emerged.

First, it was found that although horizontal advection of pollutants evidently occurs in the San Gabriel Valley and farther inland regions of the SoCAB, transport by surface winds is typically of only subregional scale (on the time-scale of a single day). Additionally, little difference in transport was evident between high ozone days and average ozone days. The implication of this result was that variations in surface wind flow within the SoCAB may not, in themselves, have played a significant role in determining the peak ozone level in the inland part of the SoCAB. Differences in 850 mb winds were also relatively small.

In contrast, significant evidence was found for a direct relationship between surface air and lower-tropospheric temperature and the magnitude of the Basin-peak ozone values. Maximum surface air temperatures and both early morning and late afternoon 850 mb temperatures were significantly higher on high ozone days than on average ozone days.

Application of the CART scheme to each of the 8 years of this study showed that the highest mean Basin-maximum ozone concentration was associated with node 10. This node is characterized by very warm temperatures at 850 mb and 900 mb (and thus probably very high inversion temperatures), as well as morning onshore flow at El Toro. Interestingly, though, Basin-maximum ozone values associated with this node were significantly less in the latter four years than in the first four years covered by this study, and are lower for all years of the present study than the 1983-85 average for this node of 28.9 pphm reported by Horie (though, of course, application of a CART tree explicitly developed for the years 1983-85 to later years is potentially problematic, as discussed earlier in this chapter). Thus, under similar meteorological conditions highly conducive to ozone formation, peak ozone values appear to have decreased for other than meteorological reasons.

Results of the meteorological analyses of the present chapter, taken in conjunction with the correlations of ozone concentrations with the NO_2 and NO_x ambient concentrations presented in Chapter 4, suggest that residence times for surface parcels within the SoCAB (but not within a particular subregion of the SoCAB) are greater than one day (for both high and middle ozone days). In contrast, however, correlations between evening NO_2 and NO_x concentrations and following day peak ozone concentration, both within the same subregion and farther downwind, were generally weak. Further understanding of the residence time, and its day-to-day variation, will require a network of routinely-operating above-surface wind monitoring platforms (*e.g.*, a network of profilers) and/or simulations with a high-resolution three-dimensional mesoscale model. Finally, we note there are other approaches to characterizing "residence time," for example by investigating chemical aging of hydrocarbons as determined by changes in VOC composition through speciated hydrocarbon analyses of ambient air parcels.