THE ORIGIN AND FATE OF AIRBORNE POLLUTANTS WITHIN THE SAN JOAQUIN VALLEY

VOLUME 2 - EXTENDED SUMMARY AND SPECIAL ANALYSIS TOPICS

by

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ABSTRACT

An extensive air quality and tracer observational program was carried out in four phases from November 1978 to October 1979 in the San Joaquin Valley. Purpose of the program was to determine the transport routes into and out of the valley, to investigate the chemical composition of particulates and determine their sources and to acquire a data base for use in developing regional models.

The program consisted of three field studies of about three weeks each in November-December 1978, July 1979 and September 1979. These studies were supported by surface and airborne air quality measurements, by meteorological observations including a network of pibal stations and by a total of 17 SF_6 tracer releases. Two additional tracer releases were carried out in February-March 1979 but with limited meteorological and air quality support.

A very large amount of data was collected during the program. Time has not permitted as complete an analysis as the data warrant. The present volume (Volume 2) is an attempt to integrate some of the more important results concerning ventilation, mixing and transport in the valley. Also included is an overview of the meteorological and air quality environment as well as comments on emission sources. Further details on the three field studies are included in Volumes 3-5.

Most of the ozone exceedances in the valley are associated with urban centers and do not occur on a valley-wide basis. Significant downwind impact occurs, however, as evidenced by frequent exceedances in the Sierra Foothills.

Air flux is directed into the valley from the northwest on a mean 24-hour basis during all months except January and February. During the summer the flux is into the valley at all hours of the day. Summer fluxes are considerably greater than those observed in winter.

Under typical summer conditions, northwesterly winds enter the valley and flow in a continuous manner past Bakersfield and over the Tehachapi Mountains. During the afternoon this constitutes the main transport mechanism out of the valley, assisted in a minor way by upslope flows in the southern part of the valley.

At night, during the summer, the flux continues into the northern end of the valley but with somewhat diminished velocities after midnight. In order to maintain continuity a comparable mass of air is exhausted from the southern part of the valley by a complex mechanism in which the Fresno Eddy plays a major role.

During the winter, occasional frontal or trough passages provide an effective scouring mechanism for removal of pollutants in the valley. Between trough passages, however, the flux into the valley decreases significantly. Transport over the Tehachapis frequently occurs during the afternoon but to a lesser degree. Slope flows become relatively more important in removing pollutants from the edge of the valley. At night, in the absence of frontal passages, the only viable removal mechanism results from southerly, low-level winds at the northern end of the valley.

Cross-valley transport is aided by low-level drainage winds which flow into the valley, creating a convergent zone near the center. Evidence was obtained after west-side releases of surface concentrations on the east side appearing shortly after sunrise in spite of the convergence zone which occurred during the night. During the following day, the convergence zone disappeared, northwesterly winds prevailed throughout the valley and the tracer material was mixed across the valley and carried out to the southeast.

Attempts to model the San Joaquin Valley on a regional basis must contend with the dynamic, non-steady state flow fields which are typical of wide areas in the valley. In addition, there are frequent low velocity, meandering winds during extensive stagnation periods which tend to mix the pollutants laterally but without much evidence of organized transport.

A manuscript which describes transport of material out of the San Joaquin Valley into the Mojave Desert is included as an Appendix.

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1. Introduction

The San Joaquin Valley is characterized by unique terrain and meteorological conditions which contribute to a significant air pollution potential. In view of the value of the agricultural crops in the valley and the future population growth, serious consideration needs to be given to the development of a control strategy to assure favorable directions of growth in the area. This requires an adequate understanding of the sources, transport, transformation and ultimate fate of pollutants in the valley.

A study was initiated in 1978 to acquire the data and understanding necessary for the development of this strategy. Specific objectives of the study were to:

1. Identify the transport routes into, within and out of the Central Valley into the Sierra Nevada Mountains and adjacent air basins.
2. Determine the chemical compositon of the particulate matter in the Central Valley and trace the sources of this material.
3. Acquire an aerometric data base that can be used in air quality model simulation of the photochemical formation and transport in the valley.

The study consisted of three intensive field programs, each of about three weeks duration. Field programs were carried out in November-December, July and September in order to examine seasonal variations in the valley characteristics. A total of seventeen tracer tests were conducted during these field programs. Two additional tests were carried out by CalTech during February and March 1979. In addition to the tracer releases, each field program included extensive meteorological and air quality sampling.

Participants in the study included Meteorology Research, Inc., California Institute of Technology, Rockwell International (EMSC) and Environmental Research and Technology (ERT). The Atmospheric Testing Branch of the CARB at El Monte obtained and analyzed hydrocarbon samples several times daily at various locations in the valley during the July and September field programs.

The final report of the study has been divided into a number of volumes. These are summarized below:

Volume 1 - Executive Summary
2 - Extended Summary and Special Analysis Topics
3 - Winter Field Study
4 - Summer Field Study
5 - Fall Field Study
6 - Rockwell International Final Report
7 - Environmental Research and Technology Final Report

Appendix - Volume 3: Data Volume for Winter Field Study
Appendix - Volume 4: Data Volume for Summer Field Study
Appendix - Volume 5: Data Volume for Fall Field Study

In addition to these volumes, aircraft and pibal data have been furnished to the CARB on magnetic tape.

The present volume (Volume 2) is a limited attempt to integrate the findings of the various field programs into a more coherent picture of the valley characteristics. Portions of Volumes 3-7 have been used in the preparation of this volume.

2. Emissions in the San Joaquin Valley

2.1 Sources of Data

Various forms of CARB emission data form the basis for the data used in this report. The Preliminary 1976 Emissions Inventory is the primary source of information on local sources. It was noted that significant increases in emissions are estimated between 1973 and 1976 for all pollutants. This was especially true for particulates in the San Joaquin Valley, which showed a 66 percent increase between the inventories, presumably due to the more complete inclusion of agricultural sources, and fugitive dust emissions.

Also, a October 16, 1978 summary printout of the CARB Emissions Inventory System (EIS) was used to provide geographical information of the primary stationary point sources in the Central Valley. This inventory contains all point sources emitting greater than 25 tons/year.

2.2 Comparison with Adjacent Basins

Table 2.2.1 provides a comparison of recently available emissions data for the areas expected to impact Central Valley particulate concentrations. The total magnitude of each of the gaseous emissions from the nine bay area counties is very similar to the total for each gas in the Sacramento to Bakersfield region. However, the particulate emissions in the Central Valley are 15 times as great as the bay area due to the dominance of agricultural operations.

Table 2.2.1

COMPARISON of BAY AREA, SACRAMENTO COUNTY and SAN JOAQUIN VALLEY TOTAL EMISSIONS

Emissions (tons/day)

	Year	TOG	NO_x	SO_2	PART	CO
Bay Area*	1975	1023	731	219	169	4331
Sacramento County**	1976	126	79	5	167	643
San Joaquin Valley**	1976	828	510	332	2578	2020

Sources: * ABAG et al. 1977

** CARB 1979

2.3 Comparison of Stationary and Mobile Sources

Table 2.3.1 presents the stationary and mobile source breakdown of 1976 emissions in the Central Valley by county. The major source categories of the overall San Joaquin Valley emissions are listed in Table 2.3.2.

In addition, for comparison, the county totals from the point source EIS are indicated in parenthesis. Since the stationary point source inventory includes several 1978 updates, it appears greater than the 1976 stationary total on occasion. These stationary source data were plotted on a 10 x 10 km grid square basis and are shown in Figures 2.3.1 to 2.3.3. Mr. Larry Landis of Kern Couty APCD provided Universal Transverse Mercator (UTM) coordinates of specific oil field locations for the major sources in Kern County from the detailed EIS printout, since the summary printout often listed business office locations instead of source locations.

The comparison of these tables and figures illustrates many interesting features of the San Joaquin Valley Air Basin (SJVAB) emissions:

- Kern County point sources emissions are concentrated in the oil fields and Bakersfield refineries. They constitute 87 percent of the SO_2 and 29 percent of the NO_x emissions in the entire San Joaquin Valley Air Basin (SJVAB). Most of the oil field emissions are from boilers used to inject steam into the wells. Thus, while moderate heat and plume rise are associated with these SO_2 surface emissions, they will probably always remain below inversions in the valley.
- Mobile NO_x emissions constitute 57 percent of the NO_x emissions and appear relatively evenly distributed throughout the SJVAB. Therefore, most NO_x emissions are from ground level, relatively nonbuoyant sources.
- About 40 percent of the total organic gases (TOG) are emitted from petroleum processing in the Kern County oil field areas.
- The remainder of TOG emissions are relatively evenly distributed throughout the basin as well as throughout stationary/mobile and urban/rural categories.

Table 2.3.1

PRELIMINARY 1976 EMISSION INVENTORY BY COUNTY FOR THE
SAN JOAQUIN VALLEY AIR BASIN
Emissions (tons/day)

	TOG (*)	NO_x (*)	SO_2 (*)	PART (*)	CO (*)
Fresno County	133	81	8	657	499
Stationary	77 (33)	15 (13)	3 (4)	649 (7)	199 (6)
Mobile	56	66	5	8	320
Kern County (AQCR31)	376	210	274	442	388
Stationary	338 (28)	165 (150)	271 (290)	437 (40)	133 (86)
Mobile	38	45	3	5	255
Kings County	30	35	21	268	94
Stationary	17 (4)	15 (14)	20 (19)	264 (5)	24 (11)
Mobile	13	20	2	4	69
Madera County	42	14	1	170	69
Stationary	35 (23)	2 (1)	<1 (.2)	169 (4)	22 (1)
Mobile	7	12	1	1	47
Merced County	46	40	4	247	170
Stationary	15 (.1)	2 (1)	<1 (.03)	240 (.2)	47 (.2)
Mobile	31	38	4	7	123
San Joaquin County	88	56	18	319	322
Stationary	50 (7)	12 (10)	15 (15)	314 (9)	67 (1)
Mobile	38	43	3	5	255
Stanislaus County	51	36	3	185	239
Stationary	23 (.1)	5 (4)	1 (1)	181 (4)	47 (.4)
Mobile	28	31	2	4	192
Tulare County	62	38	3	292	238
Stationary	35 (.7)	2 (.3)	<1 (.1)	288 (.6)	60 (7)
Mobile	27	36	3	4	178
San Joaquin Valley Air Basin	828	510	232	2578	2020
Stationary	590 (196)	218 (184)	310 (331)	2540 (70)	520 (113)
Mobile	238	292	22	38	1500

(*) Stationary Point Source Emissions from CARB Emission Inventory System

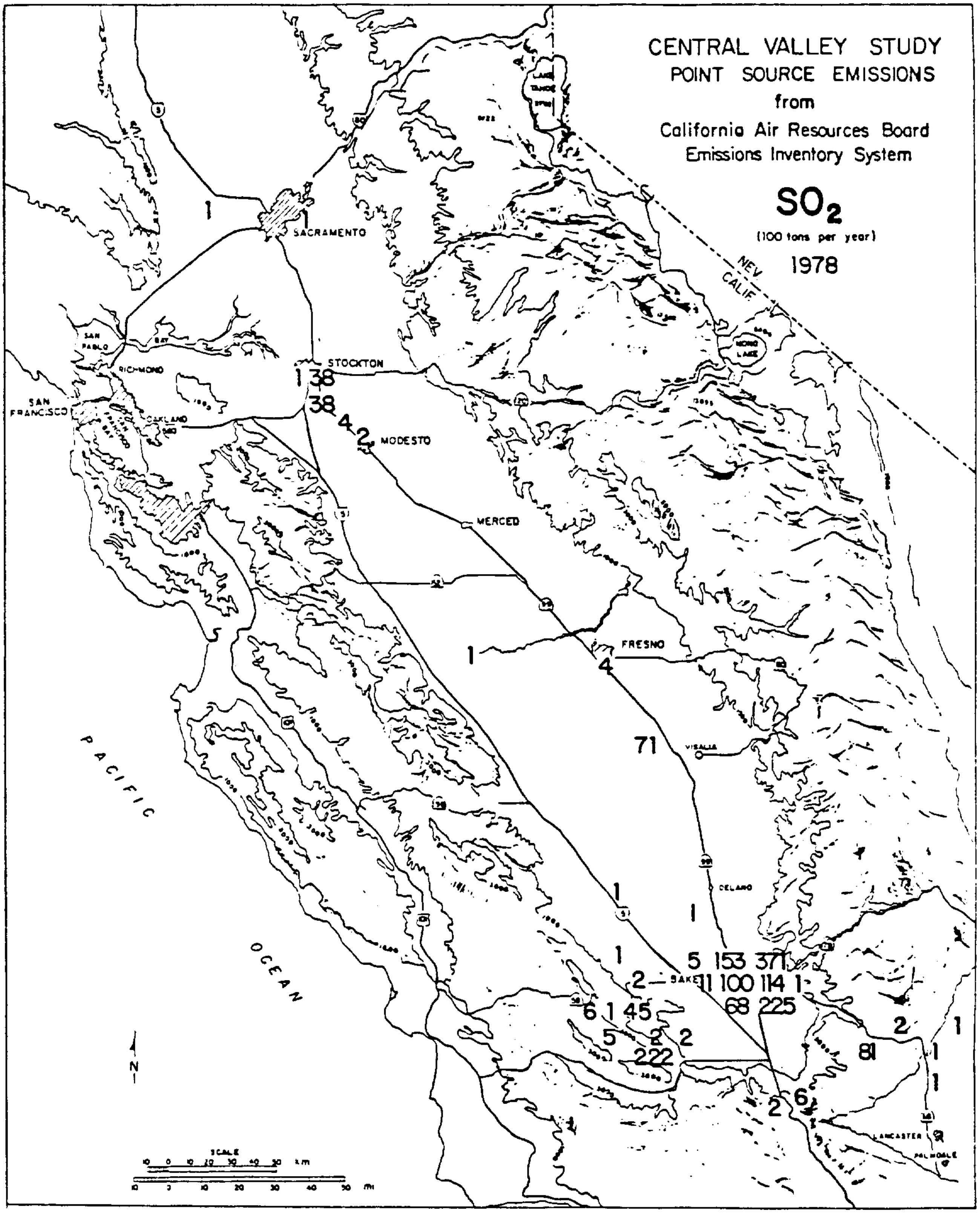
Table 2.3.2

1976 PRELIMINARY EMISSIONS INVENTORY FOR SAN JOAQUIN VALLEY AIR BASIN BY MAJOR SOURCE CATEGORY

Emissions (tons/day)

Major Source Category	TOG	NO_x	SO_2	PART	CO
Stationary Sources:					
Petroleum Processes	354	1	2	0	85
Organic Solvent Use	68	0	0	0	0
Industrial Processes	29	5	14	33	1
Pesticides	70	0	0	0	0
Combustion of Fuels	18	211	294	44	108
Waste Burning	41	0	0	38	246
Misc. Area Sources	9	1	0	2425*	80
Mobile Sources:					
On-Road Vehicles	184	155	8	17	1327
Other Mobile Sources	54	137	14	21	173
TOTALS:					
Stationary Sources	590	218	310	2540	520
Mobile Sources	238	292	22	38	1500
GRAND TOTAL	828	510	332	2578	2020

* These are primarily fugitive emissions (76% are due to farming operations and 21% are from paved and unpaved roads)



CENTRAL VALLEY STUDY
POINT SOURCE EMISSIONS
from
California Air Resources Board
Emissions Inventory System
SO2
(100 tons per year)
1978
SACRAMENTO
STOCKTON
MODESTO
MERCED
FRESNO
VISALIA
DELANO
LANCASTER
PALMDALE
SAN FRANCISCO
OAKLAND
RICHMOND
SAN PABLO BAY
MONO LAKE
NEV
CALIF
PACIFIC
OCEAN
N
SCALE

Figure 2.3.1

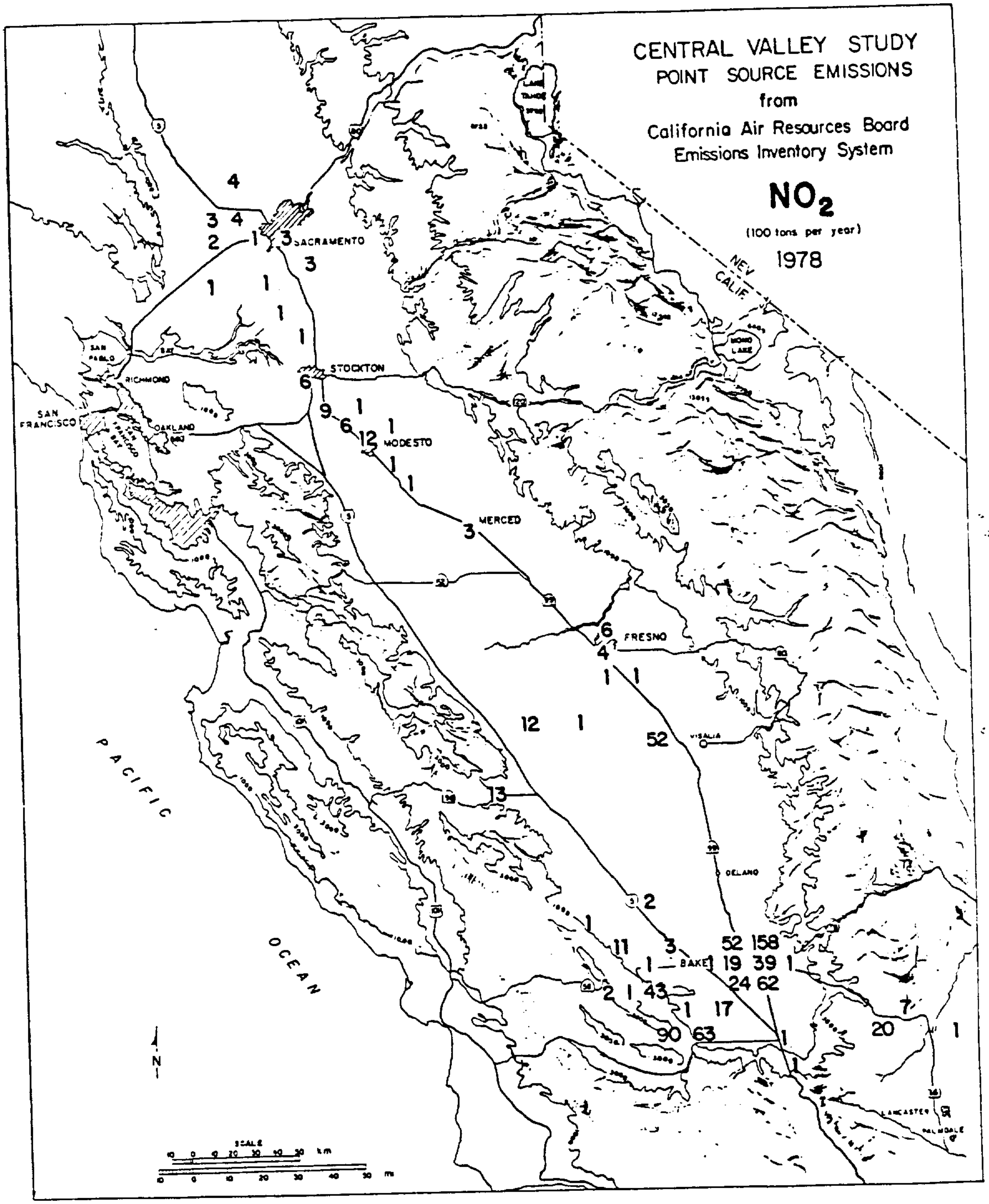

CENTRAL VALLEY STUDY
POINT SOURCE EMISSIONS
from
California Air Resources Board
Emissions Inventory System
NO2
(100 tons per year)
1978
NEV
CALIF
SACRAMENTO
STOCKTON
MODESTO
MERCED
FRESNO
VISALIA
DELANO
RICHMOND
OAKLAND
SAN FRANCISCO
SAN PABLO
LANCASTER
PALMDALE
PACIFIC
OCEAN
SCALE

Figure 2.3.2

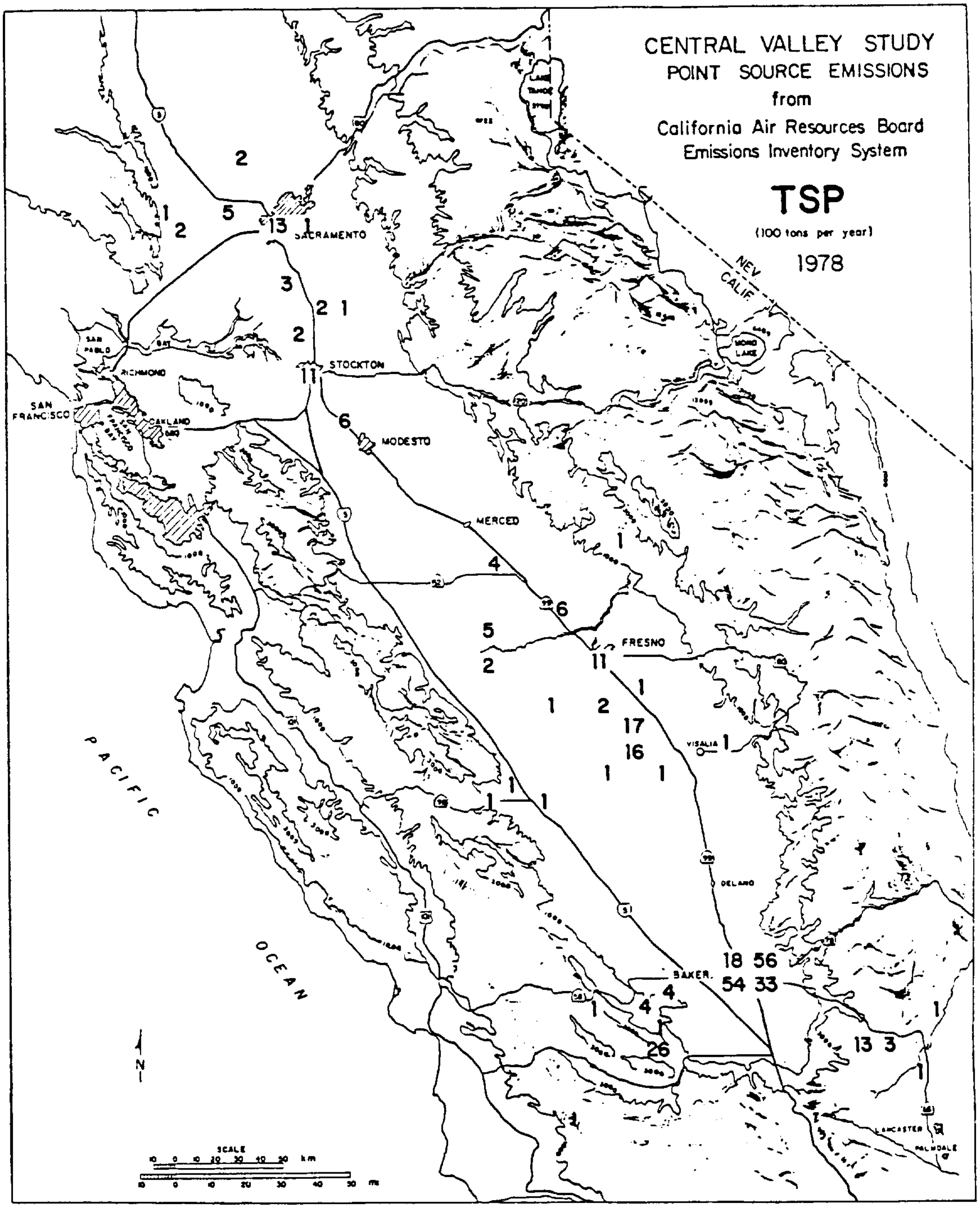

CENTRAL VALLEY STUDY
POINT SOURCE EMISSIONS
from
California Air Resources Board
Emissions Inventory System
TSP
(100 tons per year)
1978
NEV
CALIF
SACRAMENTO
STOCKTON
MODESTO
MERCED
FRESNO
VISALIA
DELANO
BAKER.
SAN FRANCISCO
OAKLAND
RICHMOND
SAN PABLO
MONO LAKE
LANCASTER
PALMDALE
PACIFIC
OCEAN
SCALE
km
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Figure 2.3.3

- Miscellaneous area sources are responsible for 94 percent of the total SJVAB particulate emissions. Of these, farming operations represent the vast majority of the burden. Point sources only result in 3 percent of particulate emissions in the entire basin. Thus, the overwhelming mass of particulates are expected to be in the large particle size range and have a short-range impact due to deposition and their non-buoyant ground level origin.

2.4 Seasonal Variations in Emissions

It is important to note that these emissions data do not reflect some of the large seasonal variations in many of the major agricultural operations. Pesticide applications occur continuously throughout the growing season, thus their actual source strength is about twice the annual-average numbers. Hydrocarbon emissions from cotton defoliants applied in Kern County are a significant source concentration only in the winter harvest period. Agricultural burns also contribute to the organic emissions, as well as a significant portion of small particle emissions. Their source strength is largely focused on burn days in the fall. Similarly the largest portion of the particulate burden, farming operations emissions, also has a strong seasonal dependence. While those emissions are largest during field preparation, planting, and harvest, fugitive emissions are greatest during the nongrowing season when fields are bare.

In summary, it appears that the Bakersfield and Bay areas have the greatest potential for local small particulate buildup from sulfates. Both urban areas have SO_2 emission densities on the order of 1 ton/day-km^2 over about 400 km^2 area. Also, both primary and secondary small particles due to conversion from gaseous emissions may contribute to impacts hundreds of kilometers away. Although these two major SO_2 source regions have similar emission densities, their regional sulfate impacts are quite different. Clearly, the meteorology dispersing these major SO_2 source regions is quite different in the Bay area than in the Bakersfield area.

2.5 Source Characterization

Source characterization has been previously determined in the Central Valley during the California Aerosol Characterization Experiment (ACHEX) of 1972 and 1973. While the emphasis was placed on the photochemical haze in the Los Angeles Basin, source characterizations were performed in Fresno as well. The reader is referred to Friedlander (1973) for details of the chemical element balance method used in the ACHEX and Watson (1979) for recent developments in the method. Sources which were characterized on September 1, 1972 in Fresno and traced to their ambient air contribution included: sea salt, soil dust, auto exhaust, cement dust, fly ash, diesel exhaust, tire dust, industrial and agricultural activities and aircraft (Hidy et al. 1974 or Gartrell and Friedlander 1975). Almost half of the aerosol mass was found attributable to large particle soil dust, industrial and agricultural activities. Almost half of the total mass was accounted for by source category. A carbon balance was not performed; thus, the organic contribution was not determined. Iron and calcium concentrations were quite high. The diurnal patterns of lead and bromine were not as well correlated as one would expect from these two primary auto emissions.

The particle volume distribution showed a well-developed bimodal distribution indicative of a well-aged, urban enriched aerosol. A peak in concentration at 0.5 μm was found to be due to nitrogen, carbon, lead, vanadium, bromine and sulfur oxide compounds of primary anthropogenic but secondary natural origin. This is also known as the accumulation mode and includes sulfates and nitrates at its upper end near 1 μm. The second mode, the coarse mode, peaks around 10 μm and is due to primary natural and quasi-natural sources. These are distinguished by silicon, titanium, aluminum, iron, sodium and chlorine elements.

Several more recent studies of the chemical composition and particle size distribution of specific sources in the Central Valley and California provide direct information for the chemical element balance approach. Sources which have been characterized include wind-blown soil, cattle feedlots, freeways, and agricultural burns. While much data on sources are available in the form of emission factors for the basic gas and particulate categories, what is needed for the chemical element balance is elemental composition. Ideally, each source may be characterized and traced using a particular element or ratio of elements which are unique to that source.

The work of Flocchini et al. (1976), Cahill et al. (1977), and Barone et al. (1979), have established chemical elements dominant in California soils. This research, conducted by the Air Quality Group, Crocker Nuclear Laboratory, University of California, Davis, was primarily funded by the CARB, U.S. Energy, Research and Development Agency, U.S. EPA, and National Science Foundation. Their samplers included the Lundgren-type multi-day impactor and stacked filter units with four or two stages to discriminate particle size. Elemental analyses were performed using ion-excited X-ray fluorescence in the Davis cyclotron. Results showed dominant elements including aluminum (Al), silicon (Si), calcium (Ca), potassium (K), and iron (Fe). It was found that soil-derived particulates in the Sacramento Valley (Sacramento and Davis sites) are predominately (over 80%) greater than 3 μm diameter. The two predominant elements found to give soils a unique signature were aluminum and silicon with a Al/Si ratio of 0.28. Emissions specifically from agricultural operations have not yet been categorized by size or composition. For this reason their source description is included as a part of this study.

Similarly, sea salt was found to be primarily a large particulate with obvious key elements of sodium (Na) and chloride (Cl) having a ratio of 0.56. Small amounts of manganese (Mn) and sulfur (S) are also shown to occur in sea salt.

The small particle sources are dominated by anthropogenic emissions. Barone et al. (1979) present two such categories. Automotive emissions in 1973 were characterized by a bromine (Br) to lead (Pb) ratio of around 0.3. Several studies have indicated a well-aged auto aerosol reaches a Br/Pb equilibrium ratio of about 0.25 (see Watson, 1979). Both elements were primarily submicron in size. Significant amounts of large soil-related particulates were also found to be emitted from road traffic such as freeways, Cahill and Fenney (1973), Fenney et al. (1975). Ter Haar et al. (1972)

show a negligible concentration of trace elements in unleaded auto exhaust and emission rates a factor of four less than those of leaded autos. The current source characterization may be significantly different due to the recent proportion of nonleaded gasoline autos and the catalytic converter. As a result, the freeway source characterization is included in this study.

The second major anthropogenic category distinguished by the U.C. Davis Group is fuel oil. Fuel oil is characterized by sulfur with small amounts of vanadium and nickel, which appear unique to this source. Chemical analysis of the fuel oil used in the Bakersfield oil fields, as well as the chemical element source characterization planned in this study, should establish a unique elemental tracer and its ratio to sulfur for the Bakersfield oil field emissions.

One agricultural operation that has been studied in great detail in California is the agricultural burn. However, while emission factors for the basic categories of particulates, carbon monoxide and hydrocarbons have been determined for a wide variety of weather, fuel moisture and ignition conditions (Darley, 1977), elemental source characterization has not yet been established with great certainty. It is important to note that agricultural burns generally emit over 90 percent submicron particles. Watson (1979) reports that chlorine and potassium are dominant elements in the fine mode accompanied by silicon and calcium (due to soils) in the coarse mode.

An agricultural particulate emission which has been categorized by elements is the beef cattle feedlot. Azevedo et al. (1974) found that high ratios of P, S, Cl, K and Ca to S distinguished feedlot emissions which were primarily large particles. Under the light-wind conditions in Tulare County on September 14, 1972, the day of measurements, the emissions were undetectable 750 m downwind. However, higher winds have been known to dry out the surface moisture and suspend feedlot emissions at greater distances.

3. San Joaquin Valley Environment - Background

3.1 Ambient Concentrations - Gases

Table 3.1.1 summarizes the peak hourly ozone concentrations measured in the San Joaquin Valley during 1979 (CARB Air Quality Data, Annual Summary, 1979). Peak concentrations in the center and eastern side of the valley were relatively uniform at all stations, ranging from .13 ppm to .18 ppm. Observed concentrations on the western side of the valley were consistently lower, particularly at Five Points, Taft and Los Banos. Two observing locations along the western slopes of the Sierra Nevadas (Shaver Lake and Miracle Hot Springs) show peak concentrations (.15 and .16 ppm, respectively) which are not appreciably different from the stations located closer to urban centers. The reactive nature of the ozone is indicated by these downwind receptor points.

The number of days during 1979 which exceeded the California ozone standard of .10 ppm is also shown in the table. Peak frequencies of occurrence were observed at Fresno-CSU, Shaver Lake and Miracle Hot Springs. As expected, the frequency of exceedances on the western side of the valley is relatively low. Average daily maximum ozone concentrations for the period July-September 1979 are shown in Figure 3.1.1.

Tables 3.1.2 and 3.1.3 give the peak hourly concentrations for NO_2 and SO_2, respectively, for 1979. No exceedances of the hourly California state standards occurred in the San Joaquin Valley for either pollutant. A peak concentration of .22 ppm was observed at Bakersfield while a maximum of .16 ppm of SO_2 was measured at Oildale.

Two detailed observational studies were carried out by CARB personnel near Fresno and Bakersfield for the purpose of determining the representativeness of the existing monitoring stations (CARB, Tech Services Div., 1977 and Duckworth and Crow, 1979).

The Fresno study documented the effect of the urban area on downwind ozone values. Increased ozone concentrations were found as far downwind as 35 miles in the Sierra foothills. The study at Bakersfield concentrated on the measurement of SO_2 and sulfate in and near Bakersfield and Oildale. Peak SO_2 and sulfate concentrations were found near Oildale with a strong tendency to decrease to the south toward Bakersfield. The data suggest the influence of local sources in the eastern Kern County oilfields.

Table 3.1.1

1979 OZONE DATA - SAN JOAQUIN VALLEY

Station	No. Days >.10 ppm	Peak Hourly Concentration (ppm)
Coalinga	10	.12
Firebaugh	37	.14
Five Points	0	.08
Fresno CSU	79	.18
Fresno-Olive	36	.17
Fresno-L Street	48	.17
Shaver Lake	63	.15
Bakersfield	36	.16
Miracle Hot Springs	77	.16
Oildale	60	.15
Taft	4	.11
Hanford	30	.14
Kettleman City	23	.16
Madera	27	.15
Los Banos	12	.11
Stockton	28	.14
Modesto	31	.17
Turlock	54	.16
Valley Home	22	.12
Fountain Springs	86	.13
Visalia	48	.15

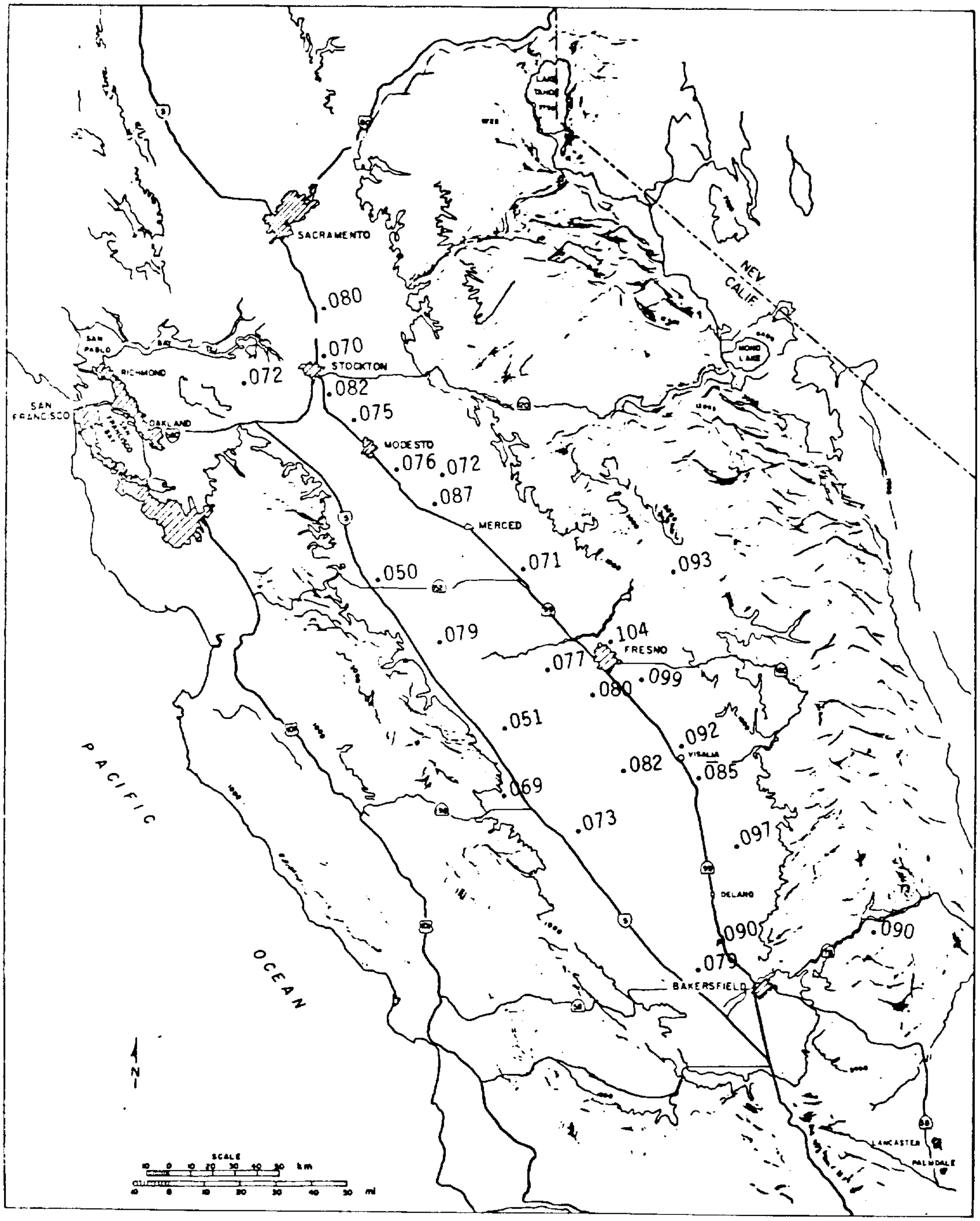


Figure 3.1.1 Average Daily Maximum Ozone (ppm) July-September 1979

Table 3.1.2

1979 NO_2 DATA - SAN JOAQUIN VALLEY

Station	No. Days >.10 ppm	Peak Hourly Concentration (ppm)
Coalinga	0	.08
Fresno-Olive	0	.16
Fresno - L Street	0	.13
Bakersfield	0	.22
Stockton	0	.17
Modesto	0	.15
Visalia	0	.11

Table 3.1.3

1979 SO_2 DATA - SAN JOAQUIN VALLEY

Station	No. Days >.10 ppm	Peak Hourly Concentration (ppm)
Fresno-Olive	0	.12
Bakersfield	0	.10
Oildale	0	.16
Modesto	0	.10
Visalia	0	.04

Several studies have been made of the impact of ozone on the western slopes of the Sierra Nevadas. These include Miller et al. (1972), Williams et al. (1977), Pronos, Vogler and Smith, (1978) and Smith, Lehrman and Gouze (1980). All studies document the ozone concentrations along the slopes in similar fashion. Pronos, Vogler and Smith (1978) show peak concentrations in 1977 of .15 ppm at Shaver Lake and Whitaker Forest in good agreement with the 1979 data. Smith, Lehrman and Gouze (1980) found somewhat decreased values at higher elevations along the slopes. A peak value of .11 ppm was measured at Huntington Lake (7000 ft msl) in 1979. The studies indicate the effectiveness of upslope transport from the valley floor.

3.2 Ambient Concentrations - Particulates

3.2.1 Total Suspended Particulates

TSP mass measured on glass fiber filters from 24-hour high-volume samples represent the only long-term record available of particulates in the Central Valley. An examination of the data indicates no evident trend from the mid-1960s to 1977, primarily due to the dominance of wind-blown soil dust. Kinosian et al. (1973) indicate TSP samples in the spring of 1972 contained 48 percent soil at Stockton, 54 percent at Visalia and 59 percent at Bakersfield, assuming the soil is 20 percent silicon and silicon entrainment is proportional to soil content.

A similar southward gradient occurs with the TSP annual geometric mean (AGM) measured in the urban areas of the San Joaquin Valley. The northern part of the valley from Stockton to Merced generally experiences AGMs of 60 to 100 $\mu g/m^3$, while the central part from Fresno to Visalia shows 100 to 140 $\mu g/m^3$, and the southern or Bakersfield urban area registers 120 to 150 $\mu g/m^3$ AGM. Urban TSP appears strongly dependent on meteorological and soil characterization and is enriched by local human activity. Comparison with more rural monitors along the valley reinforce this hypothesis with AGMs typically in the 60 to 80 $\mu g/m^3$ at Salida, Patterson, Los Banos, Three Rivers, Coalinga, and Kern Refuge.

The distribution of TSP data in the Central Valley is generally highly variable with mostly low values but some very high values. Maximum 24-hour TSP concentrations indicate their strong dependence on wind-blown soil dust. Wind erosion is optimum in the spring because of maximum exposure of dry soil to occasional high winds. Also, the ratio of precipitation to evaporation is another indicator of the soil erodibility. While evaporation is relatively uniform from Sacramento to Bakersfield (60 to 65 inches/year), precipitation decreases from about 16 inches in the north to 5 inches in the southern San Joaquin Valley (California Department Water Resources, 1975). Thus, one would expect higher suspended particulate concentrations due to soil erosion in the southern San Joaquin Valley. Maximum TSP concentrations measured throughout the valley confirm this. Generally maximum TSP values are around 200 $\mu g/m^3$ in the northern San Joaquin Valley and 300 to 500 $\mu g/m^3$ in the southern half from Fresno south. Seasonally the maxima are generally in the spring. Occasionally large concentrations do occur in the fall or winter during wind storms.

3.2.2 Sulfates

Particulate sulfates result from the homogeneous gas to particle conversion via oxidation of SO_2 or heterogeneous conversions via other aerosol particles. While water vapor, nitrogen oxides, hydrocarbons, carbon monoxide, aldehydes, and oxidants all affect the homogeneous oxidation, generally heavy metal ions, carbon particles and liquid water droplets control the heterogeneous reactions.

Analysis for sulfates on glass fiber filters collected in high-volume samplers for a 24-hour period comprise the majority of available data on sulfates in California. While numerous studies, including one funded by the CARB (Appel, et al. 1978) have shown a positive sulfate artifact due to SO_2 absorption and oxidation on the glass fiber media, the relative error is smallest on highly loaded filters (Grosjean, 1979). Since this study focuses on sulfate episodes, the effects of the $SO_4^=$ artifact will not be addressed in detail. The sulfate measurements were made on Teflon-coated glass fiber filters during the present study.

Sulfate data were analyzed from 1974 through 1978. The lack of continuous data with diurnal and size discrimination makes it difficult for source-receptor analysis, but several features of the geography and seasonality of the data are evident. Figure 3.2.1 shows quarterly urban sulfate data from Sacramento to Bakersfield for stations with the longest records. The most outstanding seasonal feature is that all cities report sulfate maxima during the fourth quarter (October to December). Peak concentrations take place either in December or January. This is in contrast to the distinct summertime sulfate maxima in the Los Angeles Basin and the San Francisco Bay area. A second feature of the urban data is a general gradient of increasing concentration as one travels southward from Sacramento to Bakersfield.

Occasional supplemental sulfate data taken from hi-vols in other urban and several nonurban locations enhance the geographical view of sulfates in the Central Valley. Generally, the highest sulfate of any San Joaquin stations occurs at Oildale on the north side of Bakersfield. Between Bakersfield and Fresno several stations are located on the west side of the valley. Taft and McKittrick Fire Station reflect large oil field emissions and show maxima greater than 25 $\mu g/m^3$ during the winter. Stations to the north (Kern Refuge, Coalinga and Five Points), all on the west side, generally have maxima in the 10 to 15 $\mu g/m^3$ range. Parlier, to the southeast of Fresno, about 20 miles, and the Cal State Fresno station, on the northeast edge of Fresno, show maxima around 10 $\mu g/m^3$. Special episode analyses for January 19, 25 and 31, 1977 by CARB (1979b) indicated regional sulfate events generally greater than 15 $\mu g/m^3$ can cover the majority of the San Joaquin Valley from Stockton to Bakersfield during winter stagnation.

The special continuous monitoring studies conducted by the U.C. Davis Air Quality Group have expanded the knowledge of total sulfur in ambient particulate matter in the Central Valley. Using three-stage Lundgren-type impactors, the Davis group established the seasonal size distribution of sulfur in suspended particulate matter for 1973. The coarse particle mode, Stage 1, ranged from 3.6 to 20 μm aerodynamic diameter, Stage 2, intermediate, was 0.65 to 3.6 and fine particles, Stage 3, ranged from 0.1 to 0.65 μm.

Figure 3.2.2, taken from Flocchini et al. (1978), shows the definite wintertime maximum sulfur particulate in the Central Valley. The bottom

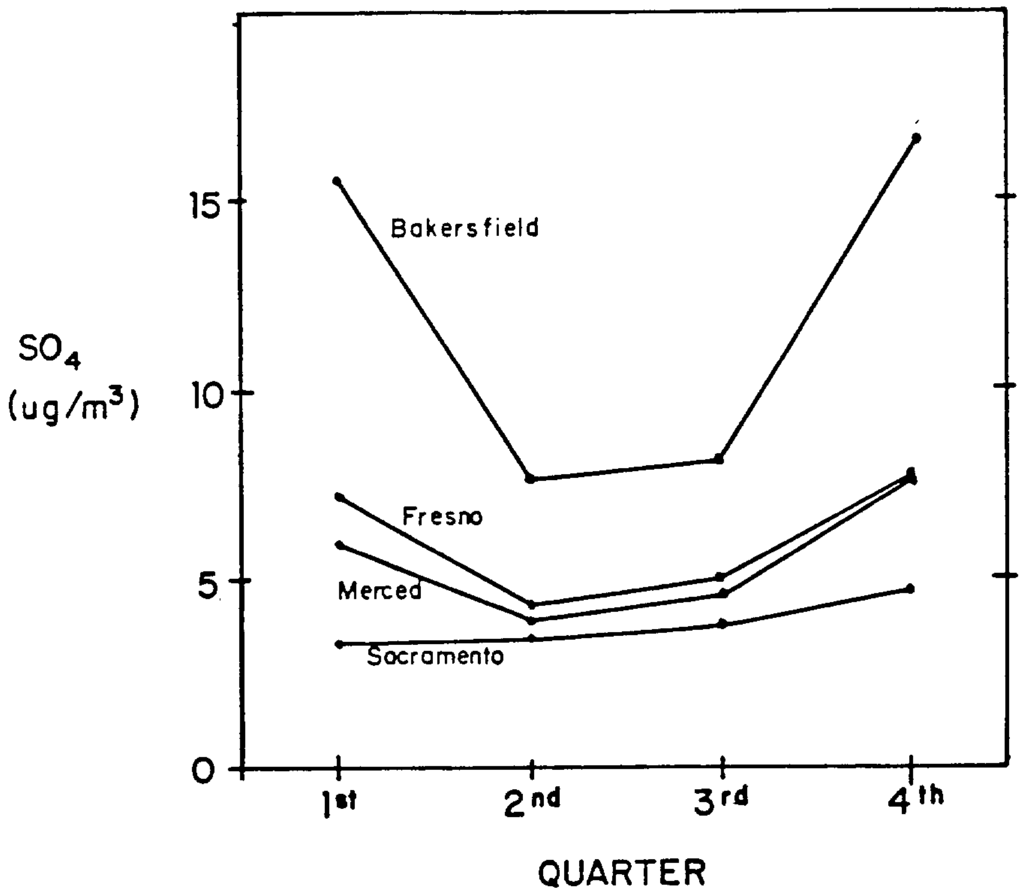


Figure 3.2.1 Quarterly Average Sulfate Concentrations in the Central Valley for April 1976 through September 1978

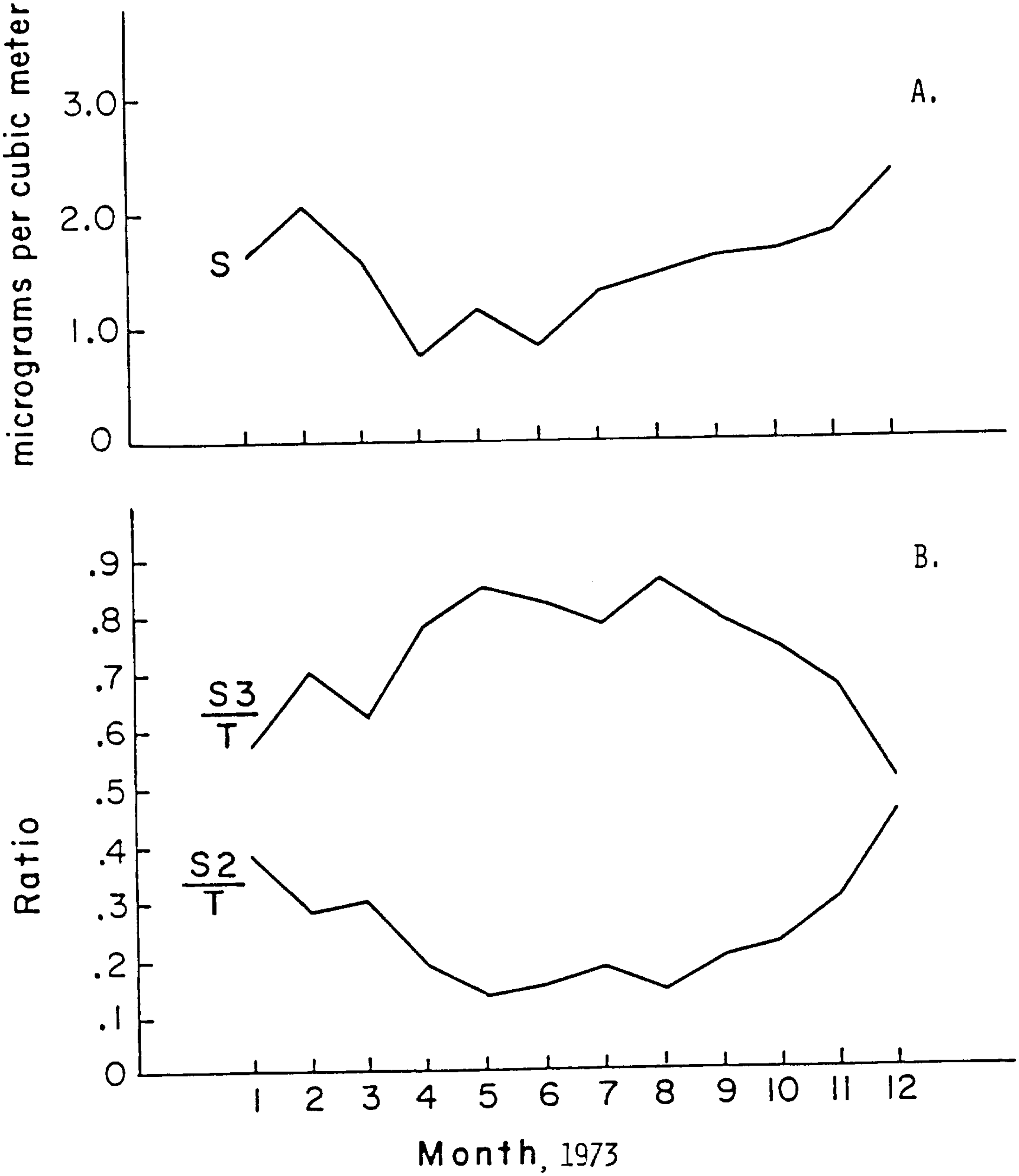


Figure 3.2.2 Monthly Average Particulate Sulfur Averaged at Bakersfield and Sacramento 1973. A. Sulfur concentration B. Ratios of fine (0.1-0.65 μm) particulate sulfur (S3) and intermediate (0.65-3.6 μm) particulate sulfur (S2) to the total particulate mass (T). (Flocchini et al. 1978)

figure illustrates the contribution of Stage 2 (0.65 to 3.6 μm) particles which also peak during the winter. Fine sulfur particulates are maximum in summer, but do not attain the mass concentrations of wintertime.

Further analysis by Flocchini et al. (1978) shows an inverse seasonal relationship between the Stage 2 sulfur particulate and oxidant and a direct seasonal relationship with relative humidity (see Figure 3.2.3). Because of rapid dispersion in the summer and low humidity, it appears that the gas-phase homogeneous reactions of SO_2 with oxidants are not effective in producing high sulfates. However, during poor dispersion conditions in winter, both homogeneous photochemical and heterogeneous reactions, with a possible strong influence of fog, appear to be the major mechanisms for effective SO_2 conversion to sulfate and particulate accumulation at Bakersfield.

Clearly, the Bakersfield and Kern County oil field areas show the greatest propensity for high-ambient sulfate concentrations during winter stagnation conditions. A CARB (1976) statistical analysis of 24 days at Bakersfield and Oildale concluded high-sulfate days (average was 33 $\mu g/m^3$) for November 1977 to March 1978 took place during low wind speed, low visibility, strong inversion, high humidity, and higher than average temperature conditions. The converse was true for lower sulfate days which averaged 8 $\mu g/m^3$.

3.2.3 Nitrates

Numerous papers (Witz and MacPhee, 1977, Spicer and Schumacher, 1977, and Stevens, 1978 for example) have summarized the aerosol nitrate ambiguity that has plagued air monitoring for years. Basically, three major problems have been identified:

- Filters may collect HNO_3 and NO_2 producing a NO_3^- artifact;
- Ammonium nitrate on the filter may evaporate during collection; and
- NO_3^- may be lost due to acid-aerosol reactions on the filter.

When glass fiber filters are compared with quartz, it was found that artifact nitrate was 10 to 20 times as much as particulate nitrate on the glass fiber media (Spicer and Schumacher, 1977). Hidy (1979) recommends the best use of

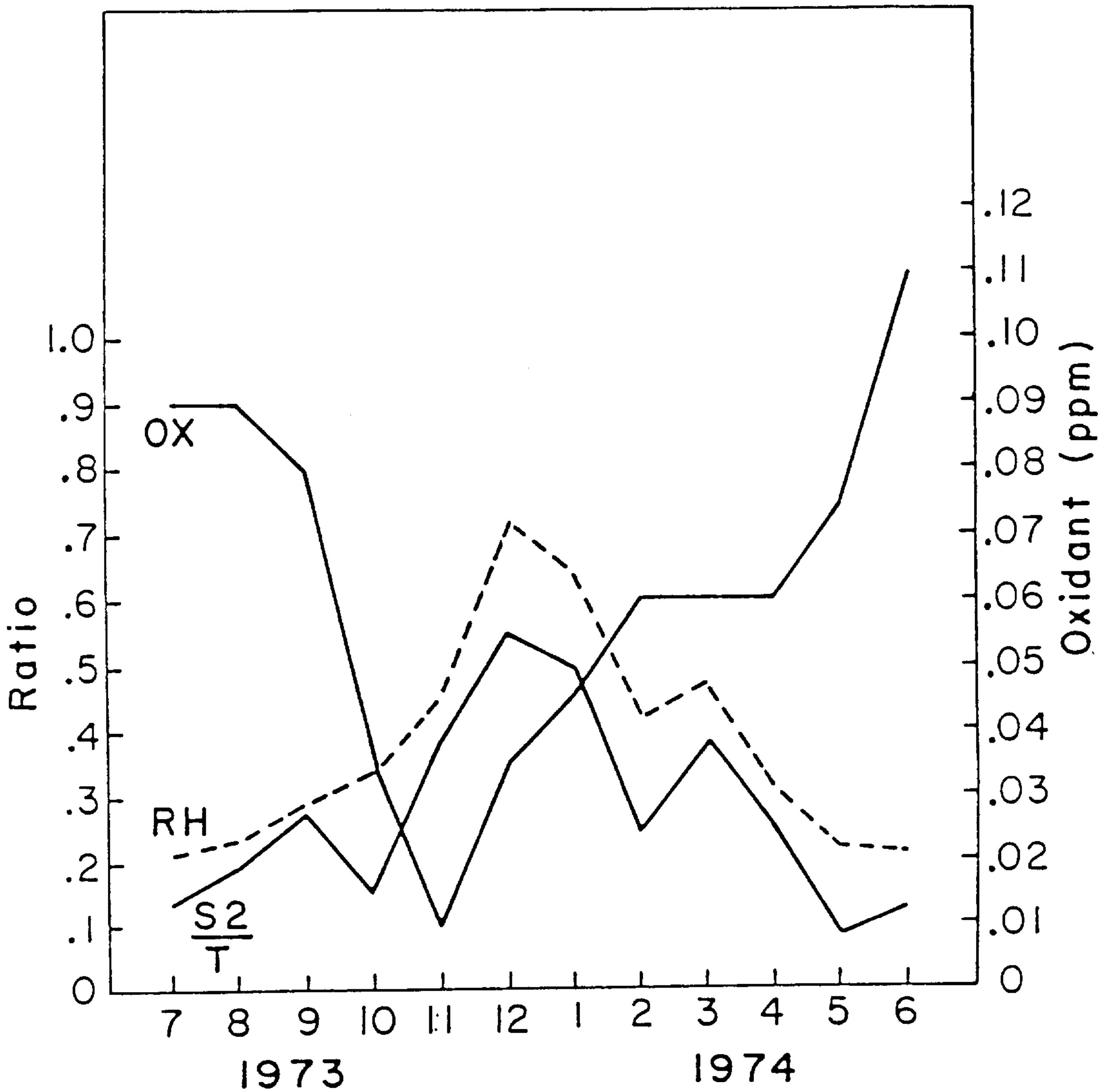


Figure 3.2.3 Monthly Average Oxidant, Relative Humidity, and the Relative Mass of Intermediate Sulfur Particulate (0.65-3.6 μm) for Bakersfield. (Flocchini et al. 1978)

current glass fiber nitrate data would be to make a sum of the nitrate and NO_x gas data and the result would be an indicator of total atmospheric nitrogen oxide. With this in mind, the ambient "nitrate" data collected to date cannot be taken as an actual measure of the particulate nitrate.

Seasonal averages of nitrates from glass fiber filters taken in the Central Valley are about double the sulfate concentrations. While the absolute values are not very meaningful alone, a clear seasonal and geographical picture is evident from the comparison of the data. It is the same southward gradient and winter time maxima which occurred in the sulfate data. The April to December frequency distribution for nitrates is also similar to sulfates (Twiss, 1977). Evidently, meteorological processes exert a dominant role over the buildup of both sulfate and nitrate in the Central Valley.

3.2.4 Lead

Ambient lead concentrations are also derived from the hi-vol filters. These data show a similar distribution to the secondary particulates. Lead concentrations solely reflect auto emissions as dispersed by the local meteorology. The monitoring data show Sacramento to be the lowest among the valley sites, with Bakersfield second and Fresno highest. Clear winter maxima are present at all stations due to limited dispersion of these primarily low-level emissions.

3.3 General Meteorological Environment

3.3.1 Introduction

The terrain surrounding the Central Valley dominates the meteorology of the valley with the exception of the influence of occasional cold air trough passages, primarily during the winter and spring. During the remainder of the year, and particularly during conditions of air pollution interest, local airflow currents control the air circulation in the valley, powered by slope heating effects and pressure gradient differences between the ocean, the valley, and the interior desert areas.

As in most areas of California west of the Sierras, inversion conditions are frequent. Because of the high terrain surrounding the valley, these inversion conditions lead to a trapping of the pollutants within the valley and to generally poor ventilation. The characteristic wind flow pattern brings air into the valley from the northwest each day. The distribution of this air in the valley and how the compensating losses from the basin occur have been a major part of the present study.

During the winter, the entrapment of low level air becomes particularly severe. This condition manifests itself frequently through the occurrence of persistent fog throughout the entire valley. Conditions favoring the formation of the fog occur following a general rain throughout the valley which provides an adequate source of moisture, followed by a stabilizing high pressure area. Under these conditions, the fog may persist for long periods until a major change in the synoptic weather pattern occurs.

3.3.2 Pressure Gradients

In the absence of strong frontal systems passing through Central California, the flow patterns in the San Joaquin Valley are dominated by local pressure gradients. A gradient from San Francisco to Las Vegas has been used to indicate the diurnal and seasonal variations in the pressure gradient influence. Since the pressure gradient changes reflect large scale variations in the surface pressure field, other point-to-point gradients could also be used.

Table 3.3.1 gives the seasonal variations for 15 PST for the 1975 air pressure gradients from San Francisco to Las Vegas. The average gradients are highest in June and lowest in December-January. In a general way, these averages reflect the seasonal variations in ventilation experienced by the San Joaquin Valley. June represents the month with the greatest ventilation potential while the highest stagnation potential will normally occur in December and January. A significant range in ventilation can, of course, occur in any month.

Table 3.3.2 shows the diurnal variations in pressure gradients in July and September 1979. The peak pressure gradients occur from 15 to 00 PST while a minimum generally occurs about 09 PST.

Table 3.3.1

SEASONAL VARIATIONS IN 15 PST PRESSURE GRADIENTS (1975)
(SFO-LAS VEGAS)

Month	Pressure Gradient (mbs)	Month	Pressure Gradient (mbs)
January	1.1	July	7.1
February	2.3	August	5.5
March	4.8	September	3.1
April	6.7	October	4.1
May	6.8	November	2.6
June	8.3	December	1.6

Table 3.3.2

DIURNAL VARIATIONS IN PRESSURE GRADIENT (1979)
(SFO-LAS VEGAS)

July 1979		September 1979	
Time (PST)	Pressure Gradient (mbs)	Time (PST)	Pressure Gradient (mbs)
00	6.0	00	3.7
03	5.6	03	3.0
06	4.6	06	1.8
09	4.4	09	1.4
12	5.2	12	2.5
15	6.3	15	3.7
18	6.7	18	3.4
21	6.2	21	3.5

This variation results primarily from the diurnal heating characteristics of the inland areas. The most effective ventilation of the valley occurs in the late afternoon and evening as a consequence.

3.3.3 Surface Wind Flow

Surface winds at Stockton have been examined in relation to the pressure gradient forces indicated in the previous section. For this purpose, wind flow at Stockton was divided into components along and across the valley axis and averaged by months for four periods of the day. These components along the valley axis for 1975 are shown in Table 3.3.3.

Table 3.3.3

1975 STOCKTON SURFACE WIND (m/s) ALONG VALLEY AXIS

Month	Time (PST)			
	03	09	15	21
January	-0.86	-0.35	+0.58	-0.81
February	-0.41	-1.01	-0.29	-0.38
March	+0.06	+0.08	+1.79	+1.50
April	+0.32	+1.94	+4.09	+2.02
May	+2.46	+3.52	+5.12	+3.38
June	+2.37	+3.78	+4.52	+3.50
July	+2.02	+2.71	+3.89	+3.50
August	+1.81	+2.26	+3.61	+3.30
September	+1.26	+2.58	+4.25	+3.11
October	+0.50	+0.76	+2.91	+1.84
November	+0.43	+0.82	+2.01	+0.68
December	-0.28	-0.47	+2.06	-0.03

(Positive values indicate flow from Stockton towards Bakersfield)

With the exception of January and February, the net flow for a 24-hour period is directed into the valley from the northwest for all months. Peak flow occurs in the afternoon and evening in correspondence with the pressure gradient variations. Seasonally, the strongest flows occur in May and June although moderate wind velocities are present from April through September.

From a mass continuity basis, the influx of air at Stockton must have a compensating exit mechanism at some other point in the valley. The implications of the data in Table 3.3.3 are that the valley is, on the average, well ventilated during the period April through September.

3.3.4 Stagnation Episodes

The component winds at Stockton provide a means for estimating the occurrence of stagnation episodes at any time during the year. For this purpose, the occurrence of 24-hour average component winds of less than 2 m/s (into or out of the valley) were tabulated. The results of this tabulation for 1975 appear in Table 3.3.4.

Table 3.3.4

OCCURRENCE OF 24-HOUR AVERAGE WINDS LESS THAN 2 m/s
STOCKTON (1975)

Month	Total Number of Days	Maximum Number of Consecutive Days
January	19	14
February	7	4
March	13	3
April	12	5
May	2	1
June	0	0
July	3	1
August	6	2
September	5	2
October	14	3
November	20	8
December	24	10

The number of days with low net transport into or out of the valley reaches a peak in November to January with a minimum during the May to July period. The maximum number of consecutive days with low wind transport is reached in December and January.

During the fall and winter months visibility is also a good indicator of stagnant conditions in the valley. Following the passage of troughs through the area the air in the valley stabilizes rapidly and the visibility drops dramatically, aided by moisture from previous rainfall or irrigation. For the purpose of the present analysis occurrences of low visibilities (less than 10 miles) for an entire 24-hour period were used to identify the days with potential stagnation. An eleven year period (1967-77) was examined with results shown in Table 3.3.5. Mean number of days per month together with maximum duration of consecutive days are shown for Stockton, Fresno and Bakersfield.

Table 3.3.5

OCCURRENCE OF 24-HOUR VISIBILITIES LESS THAN 10 MILES
(ELEVEN-YEAR AVERAGE 1967-77)

	Stockton		Fresno		Bakersfield	
Month	No. Days	Maximum Duration	No. Days	Maximum Duration	No. Days	Maximum Duration
September	1.2	2	0.5	1	1.9	5
October	8.3	8	11.8	17	7.9	7
November	14.4	10	20.6	19	16.6	14
December	19.3	16	20.0	19	18.9	18
January	16.9	26	20.7	30	15.6	30
February	9.9	9	9.4	7	9.7	11
March	1.8	2	3.7	5	2.5	3
April	0.3	1	0.5	2	0.3	1
May	0.1	1	0.4	1	1.0	1

As indicated in the previous paragraphs peak occurrences of stagnation periods occur from November through January. No days with 24-hour visibilities less than 10 miles were found in June through August. The duration of such episodes shows a clear maximum during January. Fresno shows a slight tendency for a higher frequency of low visibility days but the similarity among locations in the valley suggests that the stagnation is a valley-wide phenomenon.

3.3.5 Fog Occurrences

Dense fog is a frequent occurrence in the San Joaquin Valley during the winter months. Moisture for the fog is supplied by winter rainfall and by extensive irrigation. During the stable, stagnation periods between trough passages the fog may persist for many days. The importance of the fog from an air pollution standpoint is the probable participation of the water in the heterogeneous conversion of SO_2 to sulfate. Peak sulfate measurements in Bakersfield in 1978 occurred in December to February during the months when fog or high humidities were most prevalent.

Table 3.3.6 shows the distribution of fog occurrences at Bakersfield as a ten year average. Shown in the table are the mean number of days each month when visibility was reduced to less than 2 miles due to reported fog. Also given is the maximum number of consecutive days with fog for each month.

Table 3.3.6

OCCURRENCES OF FOG (<2 MILES VISIBILITY) BAKERSFIELD
(TEN YEAR AVERAGE 1970-79)

Month	Mean Number of Days	Maximum Number of Consecutive Days
January	10.0	21
February	5.6	11
March	1.2	7
April	0.1	1
May		
June		
July		
August		
September	0.5	3
October	0.3	2
November	3.6	10
December	10.9	19

As expected, the peak occurrences of fog are in January and December with as many as 21 consecutive days of fog being reported. Fog does not occur in the valley during the summer.

3.3.6 Mixing Heights

Mixing heights were measured from aircraft soundings in each of the intensive field programs. The maximum mixing heights measured during the afternoon are of interest in assessing the maximum dispersion potential. Morning inversions are generally surface based in all seasons.

Table 3.3.7 shows a summary of the range of mixing heights measured by the aircraft during the afternoon flights. Also shown are the peak frequencies of 1500 PST mixing heights at Fresno as given in the referenced publication for various seasons. There is good agreement between the two sets of data and the values shown can be considered as representative for the valley under typical conditions.

Table 3.3.7

SUMMARY OF AFTERNOON MIXING HEIGHTS

Field Programs	Mixing Height (m)
July	500-1300
September	500-1500
November-December	500-1000
Fresno Summary Data* (1500 PST)	
Summer	900-1500
Fall	500-600
Winter	500-600
Spring	900-1200

* From "Summary of California Upper Air Meteorological Data," (CARB 1979d)

During the night, a low-level temperature inversion frequently forms in the valley due to nocturnal radiation. An example observed by the aircraft on July 17, 1979 near Modesto is shown in Figure 3.3.1. This low-level inversion permits the accumulation of pollutants near the surface during the night and early morning hours and may contribute significantly to local ozone production in the valley.

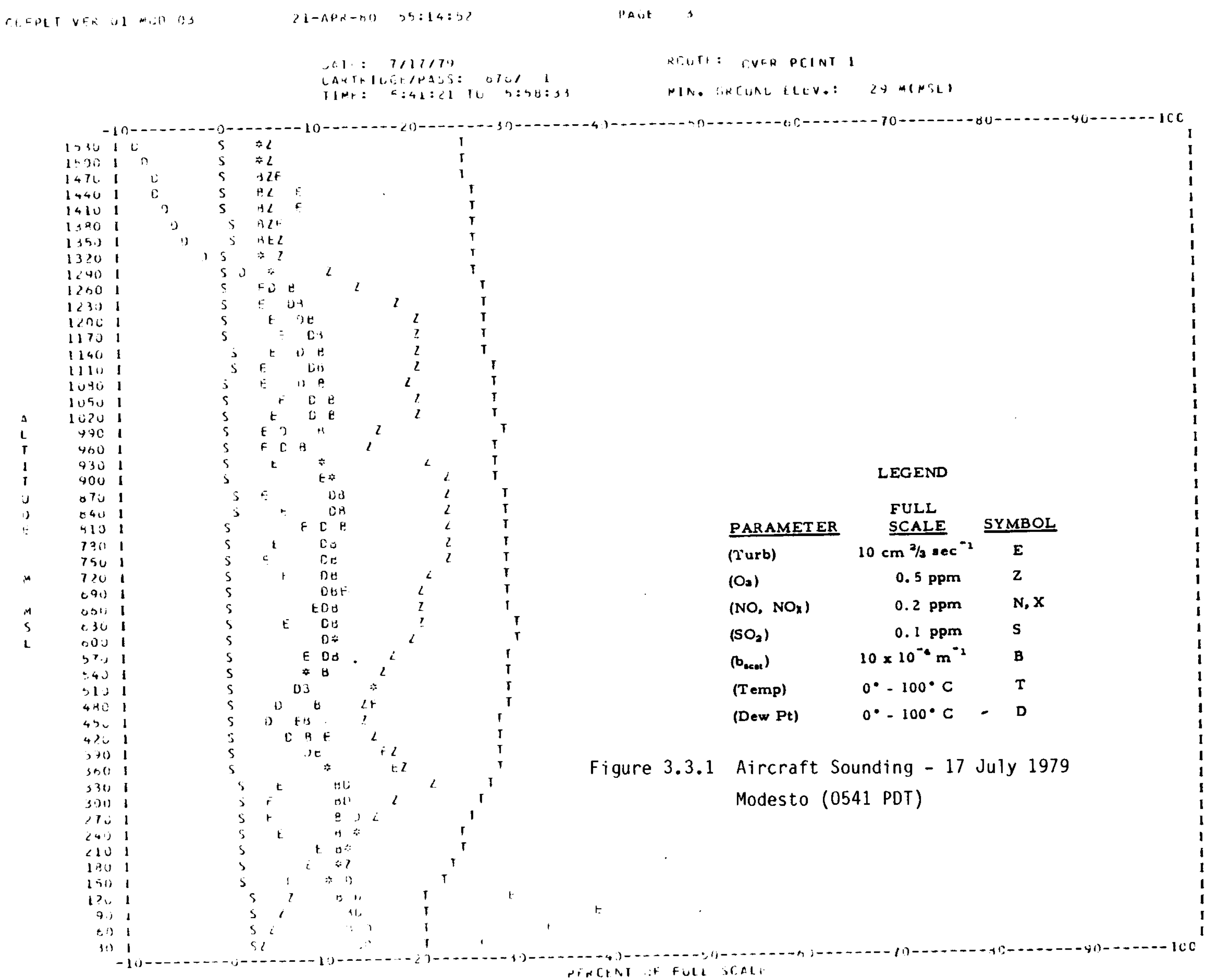


Figure 3.3.1 Aircraft Sounding - 17 July 1979
Modesto (0541 PDT)

3.4 Conceptual Model of Valley Ventilation

Based on the foregoing sections and some of the information obtained during the field programs portions of the conceptual ventilation model can be described.

On the average, air flows into the northern part of the San Joaquin Valley at low levels for all hours of the day during the period of March through November. During November through February the average flow direction is out of the valley for at least a part of the day. Peak influx occurs from May through September and, diurnally, during the late afternoon and evening.

The strong influx into the northern end of the valley must have a compensating flow out of the valley in order to maintain mass continuity. The most effective transport mechanism out of the valley is a northwesterly flow over the Tehachapis at the southeastern end of the valley. This flow represents an unrestricted continuation of the northwesterly flow which characterizes the entire valley in the afternoon.

Upslope flow occurs during the afternoon on both sides of the valley and a considerable volume of air is transported up the slopes. This flow, however, appears to have its source near the edges of the valley and does not appear capable of drawing significant quantities of air from the center of the valley. In addition, some of the upslope air which may have been moving up the slope in the late afternoon is returned to the valley by the nocturnal drainage wind.

Stabilization in the low levels of the valley tends to occur after 17-19 PST. In the southern end of the valley this tends to cut off the flow over the Tehachapis since the low-level air is not able to be lifted against the existing density forces. Air tends to pile up in the southern end of the valley in the form of a "Fresno Eddy," an example of which is shown in Figure 3.3.2. The development of the Fresno Eddy is covered in greater detail in a later section. The northwesterly flow is forced over the eddy and some of it is still able to exit from the valley over the Tehachapis. Surface heating on the following day serves to disintegrate the eddy and by afternoon the valley flow returns to a uniform northwesterly direction.

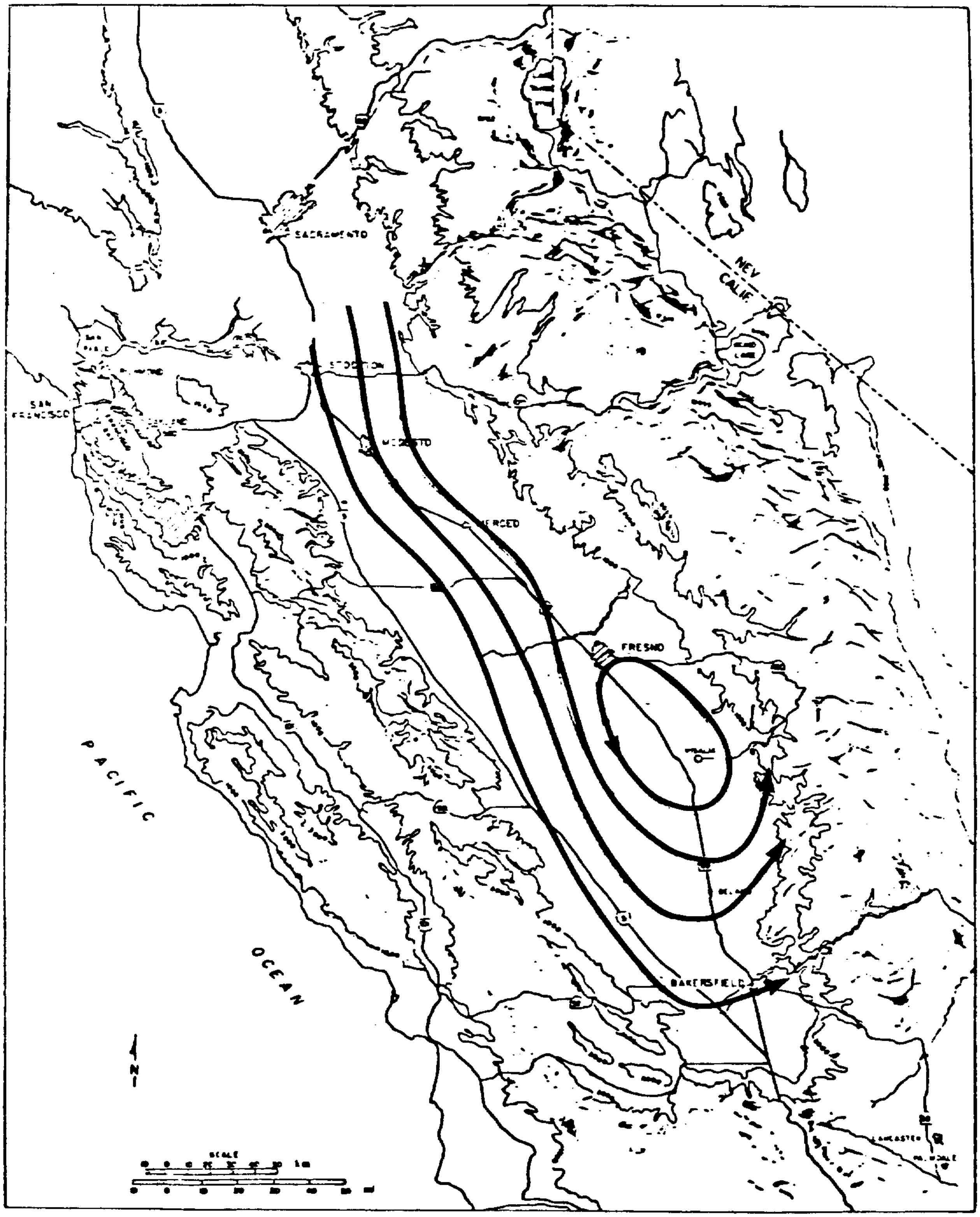


Figure 3.3.2 1000 Ft-agl Streamlines - 13 July 1979 (07 PDT)

Stagnant periods occur frequently, particularly during the winter months but seldom in the summer. Under these conditions the vertical stability is sufficiently strong and the pressure gradient forces are sufficiently weak to prevent significant ventilation in the manner described above. Slope winds due to heating and cooling probably provide much of the ventilation system under these conditions but appear to operate most effectively near the edges of the valley. The stagnation periods may occur for as long as 10-15 consecutive days during December and January before a major synoptic weather change flushes out the entire valley.

Mixing heights typically reach at least 500 to 900 m during the peak afternoon heating period, regardless of season. Dilution of the pollutants throughout the area within the mixing layer is therefore an effective means of keeping concentrations low in view of the large horizontal areas involved in the valley. Locally, high build-ups of pollutants can occur, however, during the night and early morning hours as a result of strong low-level temperature inversions.

The foregoing summary has been presented to provide overall guidance for the sections which follow where many of the topics described above are considered in greater detail.

4. Ventilation Characteristics of the Valley

4.1 Flux Estimates

4.1.1 Flux into the Valley

Introduction

Three test periods during the study were designed to provide meteorological and air quality data for the determination of air volume and pollutant fluxes into the San Joaquin Valley from the north. Winds aloft (pibal) observations were taken at three locations placed across the valley to determine vertical cross sections of the wind field (Figure 4.1.1). Observations were taken simultaneously from these locations every two hours. MRI airborne air quality sampling provided two-dimensional pollutant information along a similar cross section across the valley. The aircraft sampling typically consisted of two or three horizontal traverse times at different altitudes across the valley and a series of vertical soundings at intermediate points along the transect. Two sampling missions were flown in a 24-hour period. One measured conditions in the afternoon when vertical mixing was at a maximum and when photochemical reaction processes were active. The second measured conditions soon after daybreak when the atmosphere was stable and photochemistry was inactive.

The three test periods were 13-14 July 1979, 16-17 July 1979, and 21-22 September 1979. The sampling airplane did not support the flux study in September but flew an alternate mission.

Volume Flux Calculations

The rate or flux of air (V) passing through a cross section across the valley is given by the relationship

$$V = \int_{z_1}^{z_2} \int_{x_1}^{x_2} u\,dx\,dz$$

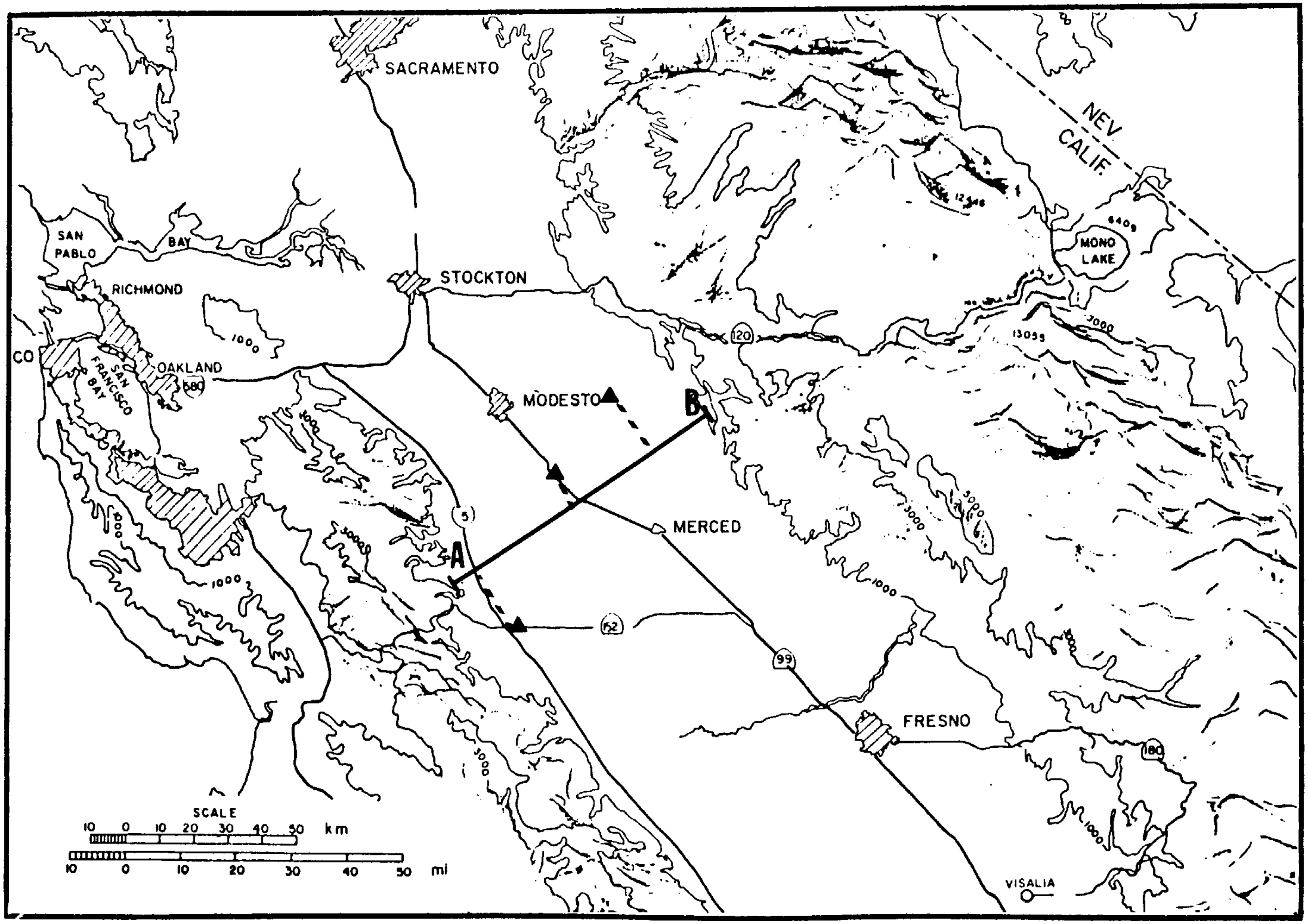


Figure 4.1.1 Pibal Locations and Valley Transect Used for Volume Flux Calculations

where x = horizontal position along the cross section

z = vertical position

u = component of the wind perpendicular to the cross section

For the calculations in this section, the pibal locations were projected onto the transect line shown on Figure 4.1.1, which is perpendicular to the valley axis through Livingston. The width of the valley was defined to be between the 1000 ft (msl) contour lines. The cross section was divided into roughly three equal sections and each pibal was assumed representative of the flow in one of those sections. The vertical increments for the calculations were defined by the 30-second measurement interval (roughly 90 m). Fluxes were computed from the surface to the top of the mixed layer. Results are shown in Figures 4.1.2 through 4.1.4. The meteorological conditions were different in each period for which flux measurements were made. The conditions which existed and the results of the flux determinations for each period are summarized below.

a. 16-17 July 1979

The meteorology during this period more nearly typifies conditions which exist in the San Joaquin Valley during the warmer months than any other periods studied. The vertical and temporal characteristics of the winds aloft are shown in the time-height cross section of the winds over Turlock (Figure 4.1.5). The pibal winds have been resolved into components parallel and perpendicular to the valley axis. The parallel component was used to develop the cross section.

A moderate to strong component transporting air up-valley persisted at low levels throughout the period. Maximum speeds within the northwest flow were observed in the nocturnal jet which formed during the evening of the 16th and persisted throughout the night. The jet developed across the width of the valley and is very much in evidence in the flux calculations shown on Figure 4.1.2. The period of high volume flow up-valley coincides with the maximum development of the nocturnal jet. The depth of the up-valley flow increased as the jet developed but remained about 800 m even as flow rates decreased. For the whole of the 24-hour period depicted on Figure 4.1.2, the estimated volume of air entering the valley was about 20.5×10^3 km^3. Assuming the

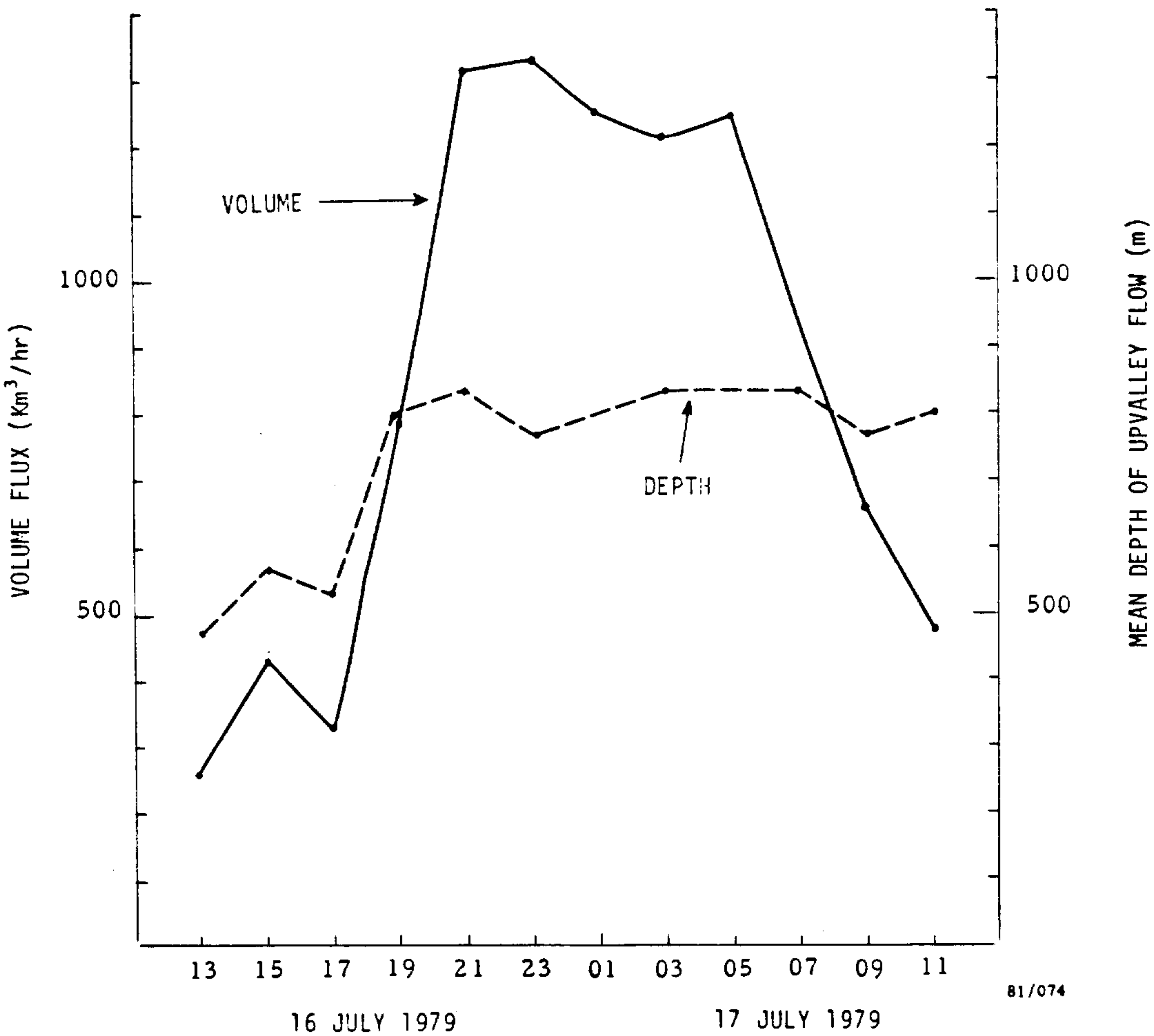


Figure 4.1.2 Volume Flux and Depth of Up-valley Flow 16-17 July 1979

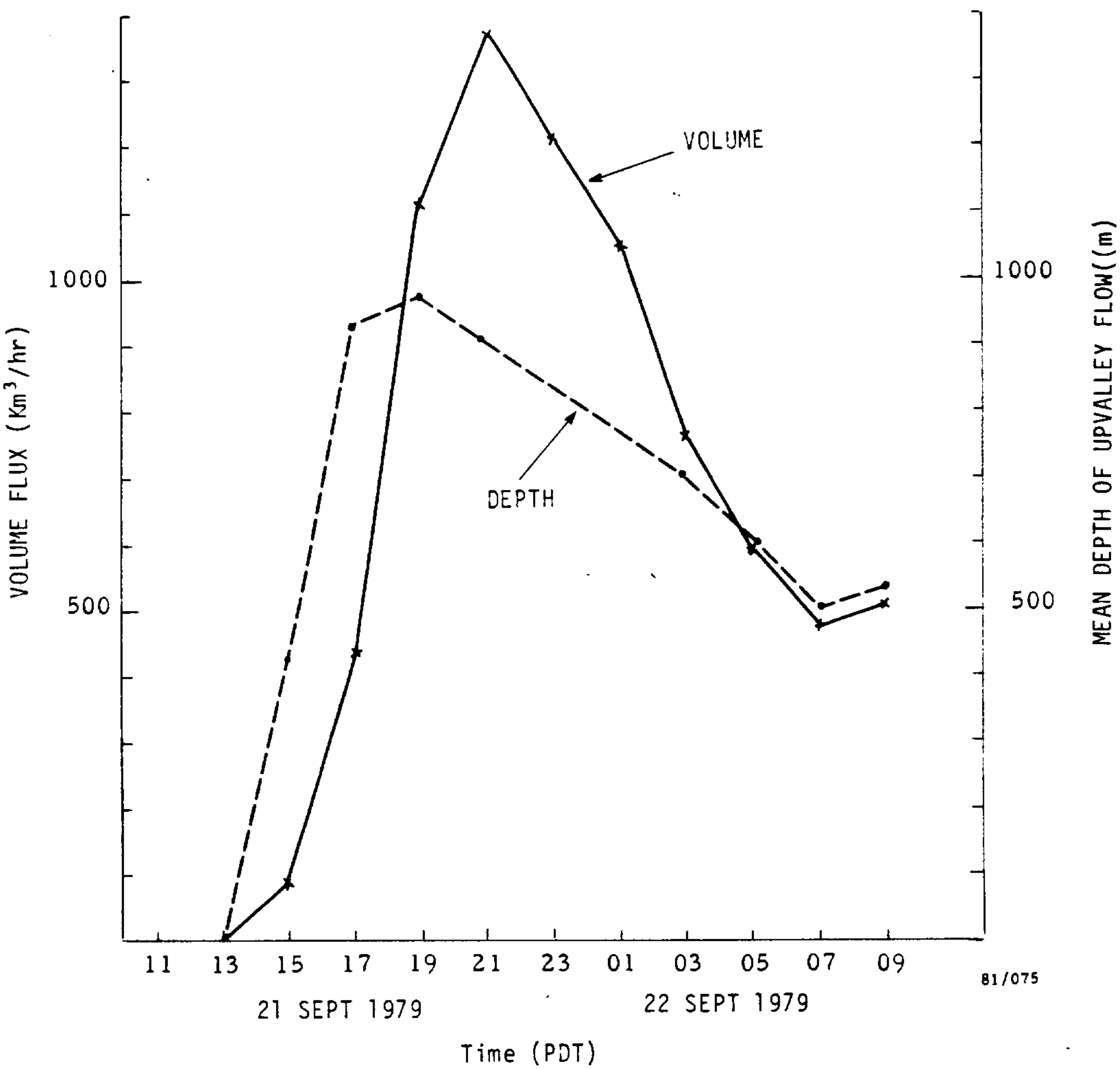
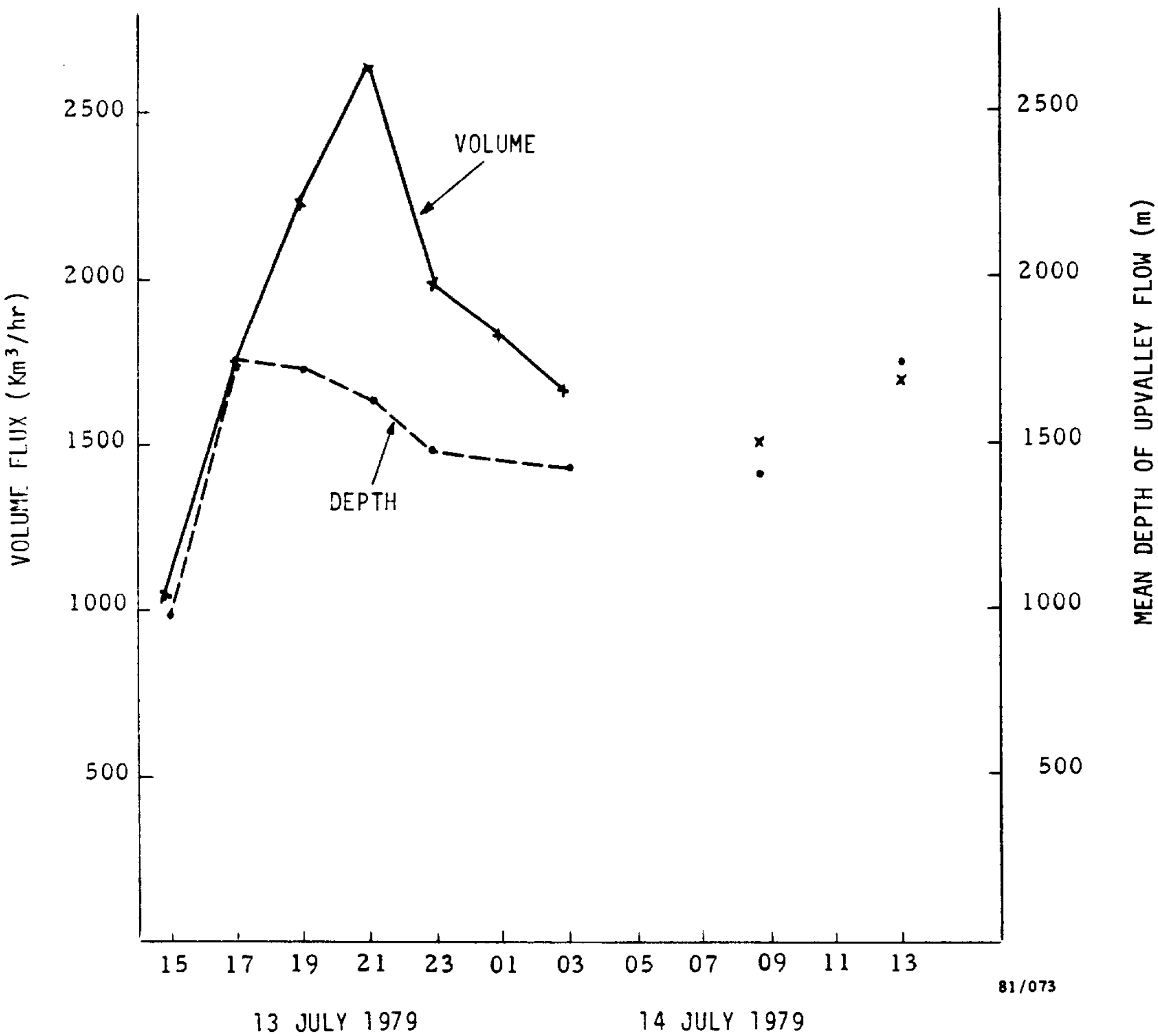


Figure 4.1.3 Volume Flux and Depth of Up-valley Flow 21-22 September 1979



Time (PDT)

Figure 4.1.4 Volume Flux and Depth of Up-valley Flow 13-14 July 1979

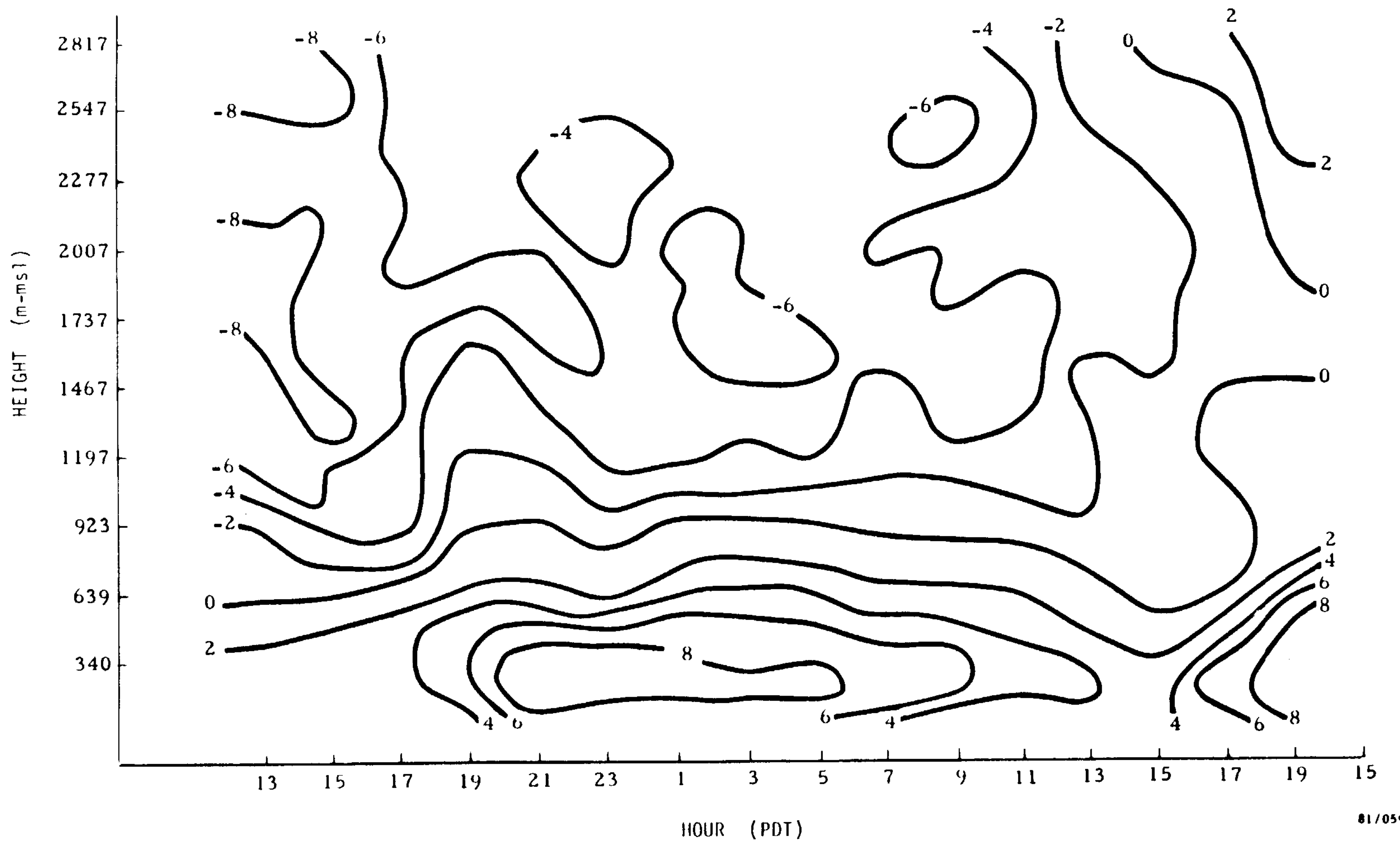


Figure 4.1.5 Component Wind (m/s) From Turlock - 16 July 1979
(Positive Represents Upvalley Flow)

valley to average 80 km wide and to extend 380 km in length (from Stockton south) and further assuming the 800 m deep flow is representative of the entire valley, the total basin volume within the mixed layer is about 24.3 x 10^3 km^3. These data suggest it would take approximately 28 hours to replace the air in the valley.

b. 21-22 September 1979

On the morning of the 21st, a weak pressure trough moved through California. The approaching trough appears to have had the effect of temporarily preventing the northwest flow into the valley which typically prevails 24 hours a day during the summer and early fall months.

Figure 4.1.6 gives the valley axis component flow for September 21-22. During the early part of the observational period the low-level flow was directed out of the valley. A northwest or up-valley component developed in the afternoon and persisted during the remainder of the period, ranging in depth between 500 and 1000 m. Within the northwest flow, a jet developed with speeds in excess of 8 m/s at about 20 PDT on the 21st and continued until approximately 03 PDT on the following morning. Again from the flux estimates, shown on Figure 4.1.3, the influence of the nocturnal jet is very much in evidence. Peak hourly flux of air into the valley was near 1400 km^3/hr, slightly larger than the 1300 km^3/hr on July 16. However, the large volume fluxes were not sustained throughout the night. An estimated 15.2 x 10^3 km^3 of air was transported into the San Joaquin Valley during the 24-hour period, about one-fourth less than during the 16-17 July period. A high flow rate continued over Turlock but the contribution from the other portions of the valley decreased substantially. Using the same basin volume as before, it would take approximately 39 hours to replace the air in the valley within the mixing layer under these conditions.

c. 13-14 July 1979

Flux determinations during this period were made difficult by an uncommon flow pattern which developed in the valley and doesn't lend itself well to this type of analysis. Figure 4.1.7 shows the streamlines constructed from

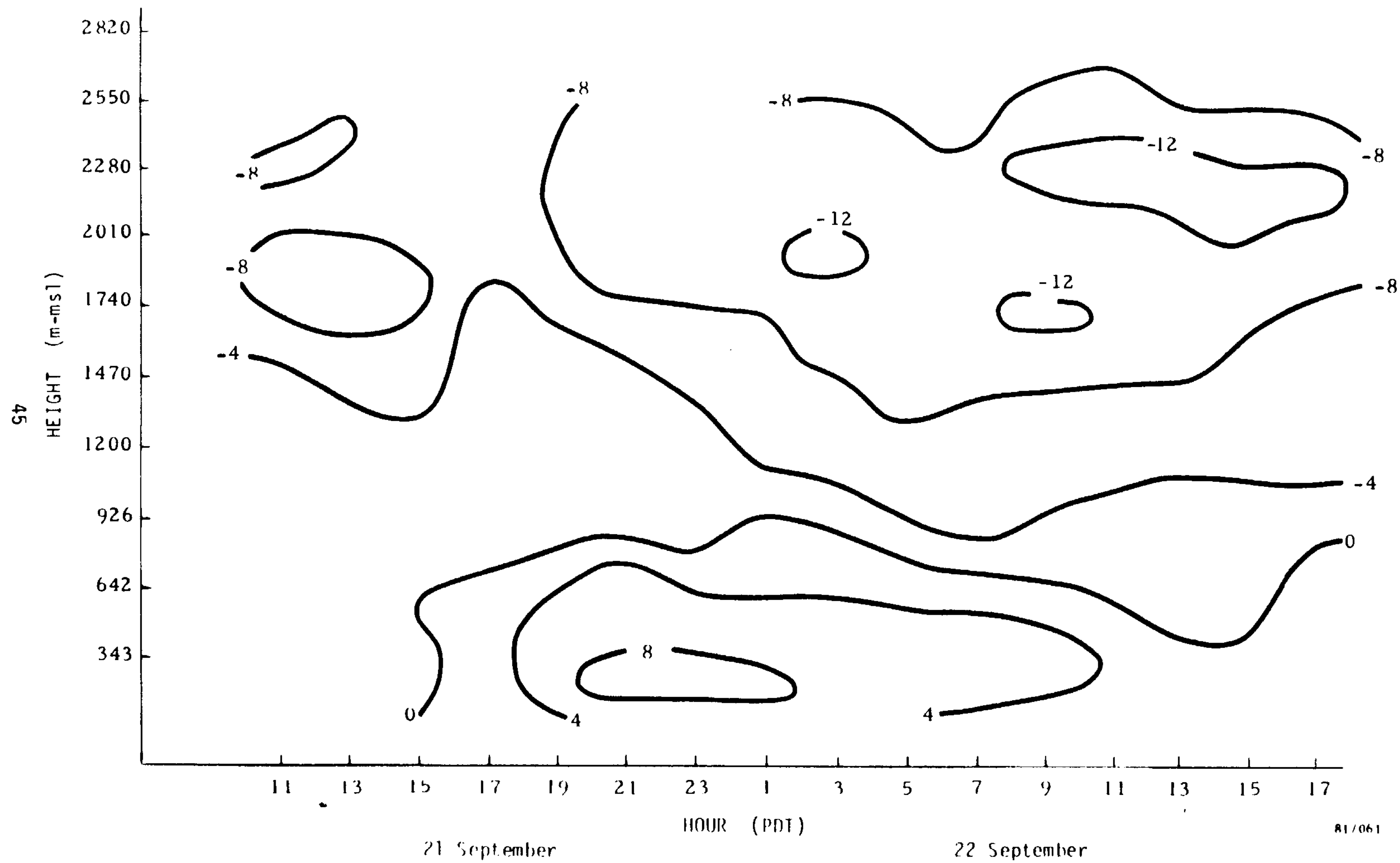


Figure 4.1.6 Time-Height Cross Section Component Winds (m/s) from Turlock - 21-22 September 1979

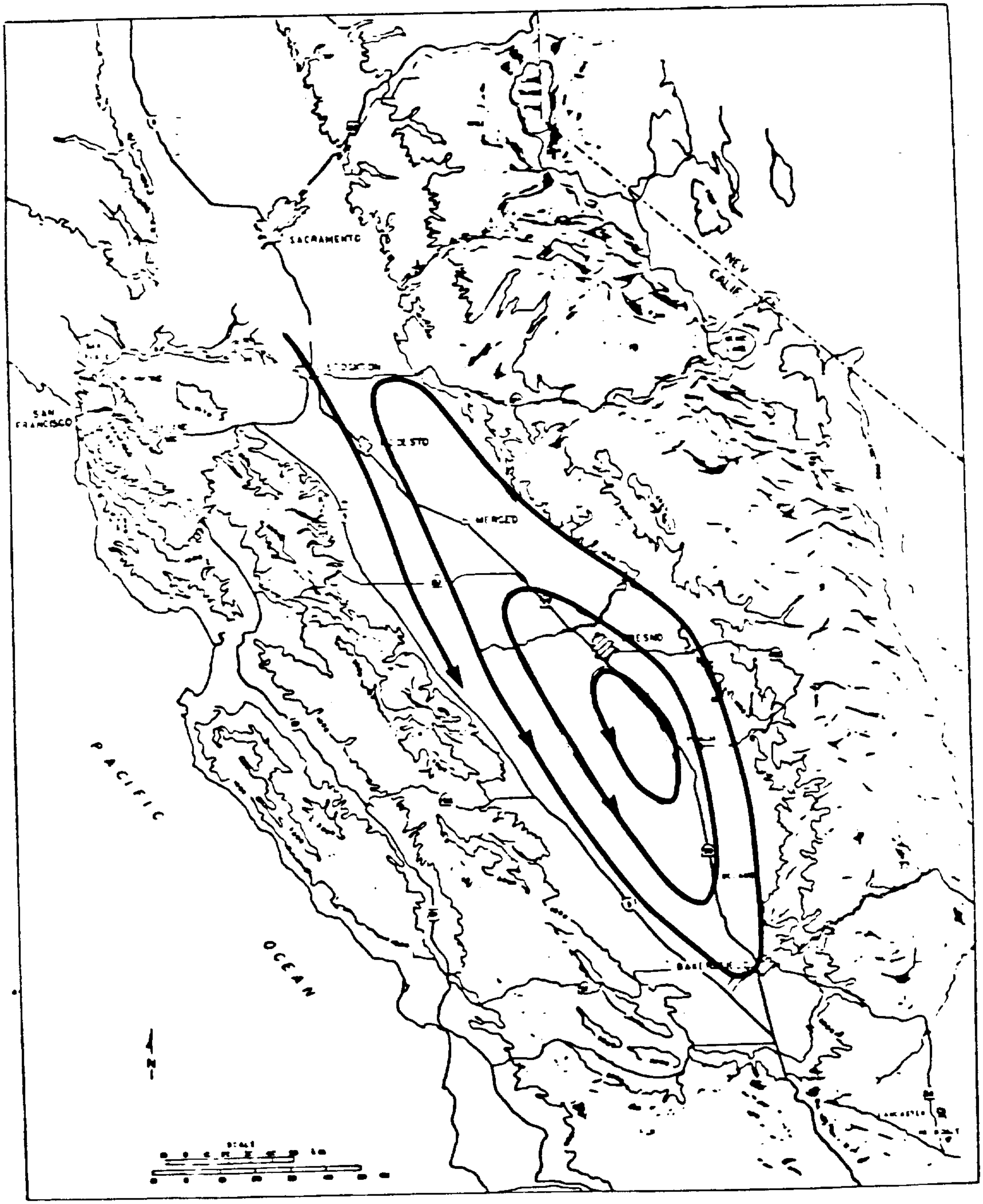


Figure 4.1.7 1000 Ft-agl Streamlines - 13 July 1979 (09 PDT)

the 1000 ft winds at 09 PDT on the 13th. A strong northwesterly flow extended the length of the valley on the west while on the east side, a return flow from the southeast also extended the length of the valley. The east-west shear of the opposing flows exceeded 24 m/s at times. The cross section of the up-valley component wind, shown on Figure 4.1.8, is typical of the conditions which persisted throughout the morning and early afternoon. By late afternoon, a general northwest flow had been established across the valley. The depth and strength of the up-valley flow remained variable and nonuniform through most of the period. The depth of the up-valley flow varied more than 1000 m across the valley.

Some flux calculations were made for the 24-hour period beginning when a northwest flow was first established across the width of the valley. These data are shown in Figure 4.1.4. Missing pibal measurements precluded flux calculations during periods on the 14th.

Volume fluxes were twice as large as those determined for the other periods studied but the temporal trend was nevertheless similar. The peak flux was measured at 21 PDT. The depth of the up-valley flow was correspondingly greater than those measured in the other two periods. Missing data prevented a reliable determination of a 24-hour total volume flow in the valley.

Ozone Flux Calculations

A relationship similar to the one used for the volume flow calculations was used to compute ozone flux (M) and is defined as follows

$$M = \int_{z_1}^{z_2} \int_{z_1}^{x_2} u X dx dz$$

where x, z, and u are the same as defined in the previous section, and X is the ozone concentration (mass per unit volume).

The ozone measurements acquired by the MRI sampling airplane along the transects shown on Figure 4.1.9 were plotted on vertical cross sections and isopleths of ozone concentration were constructed. The analyzed fields were digitized into a series of grids each measuring 5 x .1 km. The pibal data were projected onto the aircraft traverse routes and digitized in a similar manner as ozone. Fluxes for each box within the grid matrix were calculated and results are shown in Table 4.1.1.

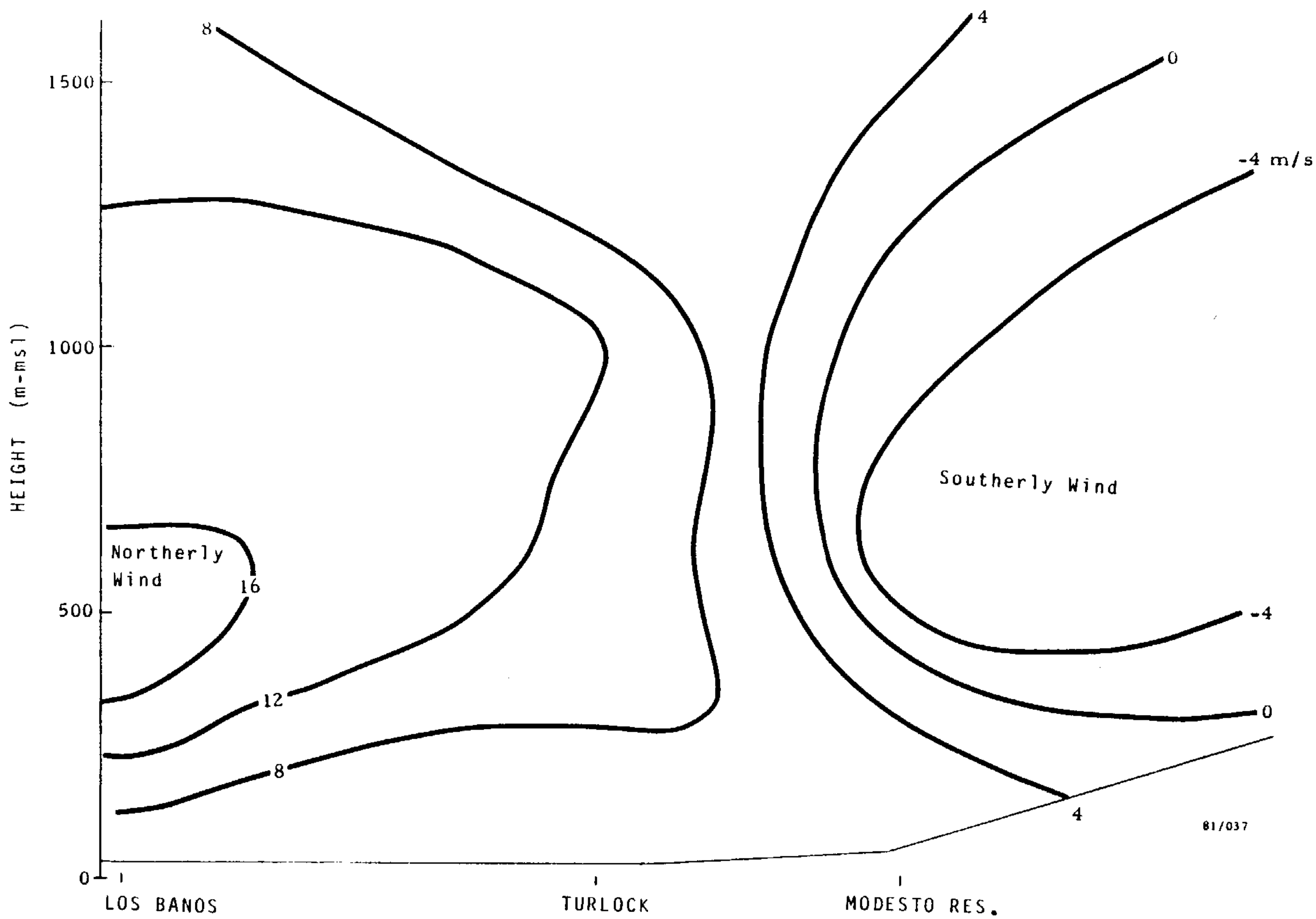


Figure 4.1.8 Vertical West-East Cross Section of Wind Component (m/s) Along Valley Axis (Positive Component into Valley) - 13 July 1979, 07 PDT

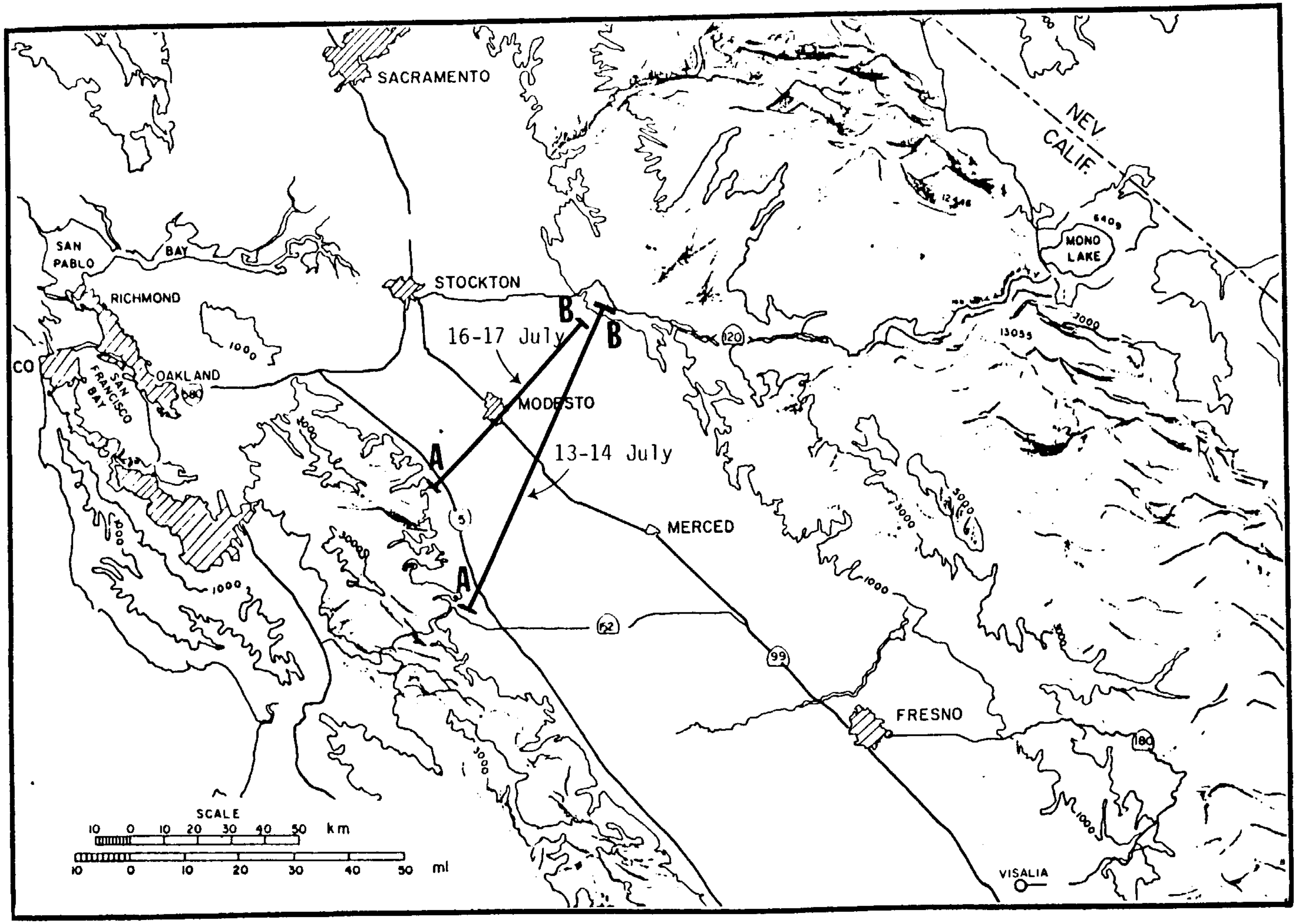


Figure 4.1.9 Valley Transect Used for Pollution Flux Calculations (Aircraft Traverse Routes)

Table 4.1.1

OZONE FLUX ESTIMATES

Date	Time (PDT)	Flux Direction	Depth of Layer (km)	Total O_3 Flux (metric tons/hr)	Flux Above Background* (metric tons/hr)
13 July	07	From SE	2.5	105	72
13 July	07	NW	2.5	384	233
13 July	19	NW	0.8	209	152
16 July	19	NW	0.8	158	119
17 July	07	NW	0.8	106	55

* 30 ppb background assumed

Total flux of ozone within the mixed layer is shown together with that portion of the flux which exceeded the background. Background levels of 30 ppb were used in the computations.

The ozone flux estimates for 13 July at 07 PDT reflect the existence of the southerly flow on the east side of the valley as shown in Figure 4.1.8. Ozone concentrations on the east side were in excess of 100 ppb while the values ranged from 60-80 ppb in the northwesterly flow on the west side of the valley. Nevertheless, the total flux on the west side was considerably greater due to the higher transport winds.

During the afternoon (19 PDT) the northwesterly flow had become more uniform across the valley and was confined to the lowest 800 m. Highest O_3 concentrations of over 180 ppb occurred on the east side of the valley. The total flux from the northwest was only slightly smaller than at 07 PDT in spite of the lower mixing depth.

The afternoon flux estimates on 16 July (19 PDT) were slightly lower than observed on 13 July. Highest O_3 concentrations of 170 ppb were observed on the west side of the valley. Above 1200 m on the west side (700 m - east) the flux was from the south and directed out of the valley.

On the morning of 17 July the ozone flux was homogeneous across the valley and considerably reduced from the previous afternoon. Effects of NO depletion in the low levels contributed to this reduction. The northwesterly flow was confined to the lowest 800 m and the ozone flux was directed out of the valley (from the south) above this level.

4.1.2 Urban Ozone Flux Estimates

On September 14 aircraft soundings were made both upwind and downwind of the Bakersfield area. Comparison of these soundings together with assumptions on their representativeness provide an opportunity to estimate the flux of ozone attributable to the Bakersfield urban area.

Locations of the ozone and temperature soundings both upwind (five miles north of Oildale) and downwind (Caliente) are shown on Figure 4.1.10. The soundings were made about one hour apart. The upwind and downwind temperature and ozone soundings are shown in Figure 4.1.11. Downwind concentrations within the surface mixing layer averaged more than 100 ppb greater than upwind. Both soundings exhibit well defined mixing layers of comparable depths. Upwind ozone concentrations near the surface were comparable to maximum ozone concentrations recorded at Oildale for that day. A nearly two-fold increase in ozone burden is observed between the two locations.

A partial definition of the urban plume downwind of the Bakersfield area was obtained from a horizontal traverse within the mixing layer across the southeastern end of the valley, terminating at Caliente. The map in Figure 4.1.10 shows the sampling route and the location of the plume which was distinguishable by increases in ozone, NO_x, b_{scat} and SO_2. From the winds aloft observation at Bakersfield, the average wind within the mixing layer was determined to be 290° at 3.1 m/sec. Based on that resultant vector, the trajectory of an air parcel over the upwind spiral location would pass a few miles north of Caliente.

An estimate of the ozone production net increase influx due to the Bakersfield urban area sources was made for the box defined by dashed lines in Figure 4.1.10. The box is oriented parallel to the average wind vector and defined horizontally by aircraft traverse measurements. It was evident that there was some plume impact to the north of Caliente so that our total flux estimates will be slightly conservative. The depth of the plume was defined by the ozone profiles and determined to be 1100 m. The sounding at Oildale was assumed to be representative of the incoming air mass. The ozone concentration measured on the horizontal traverse was judged to be more representative of the average downwind conditions than the sounding at Caliente.

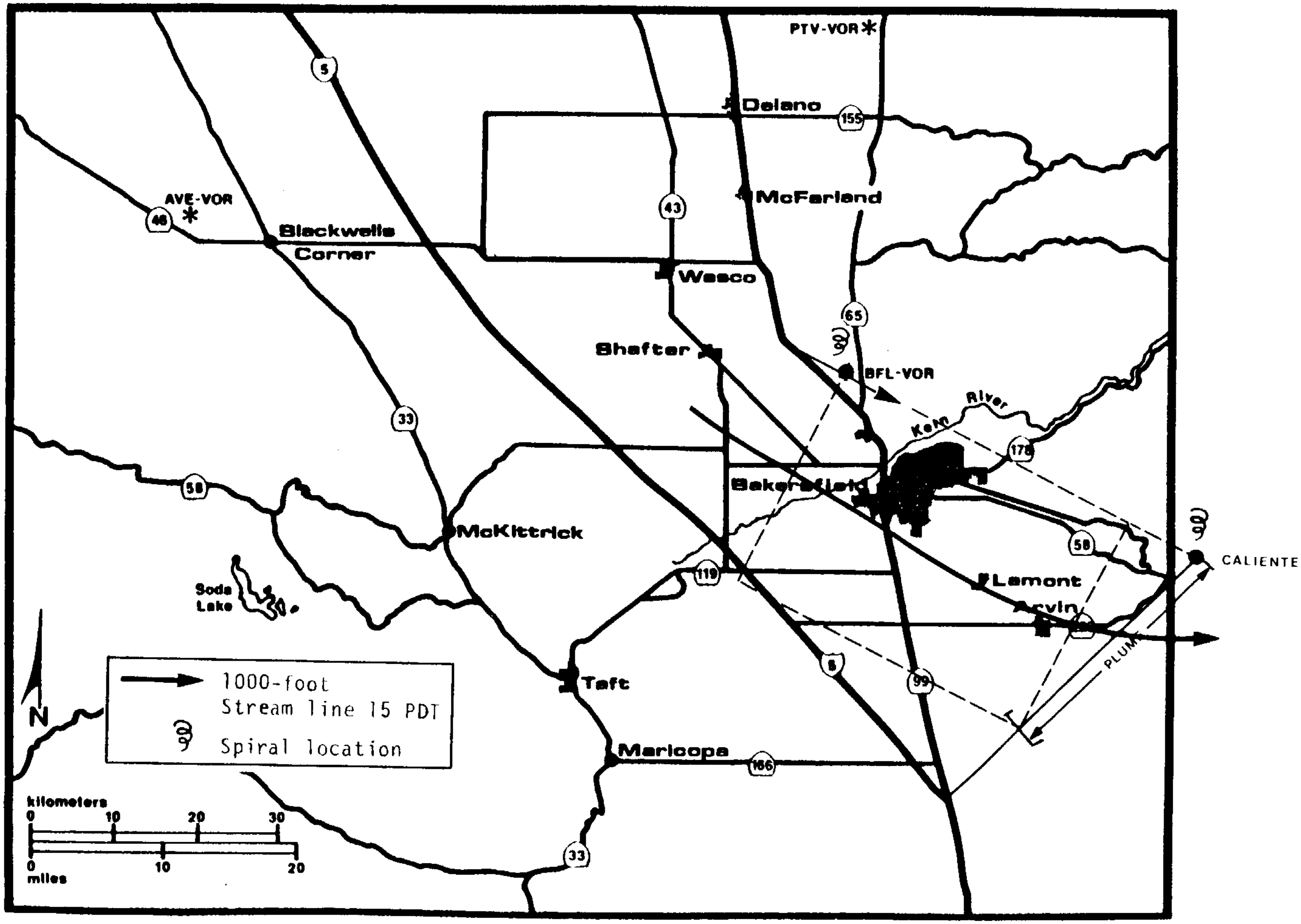


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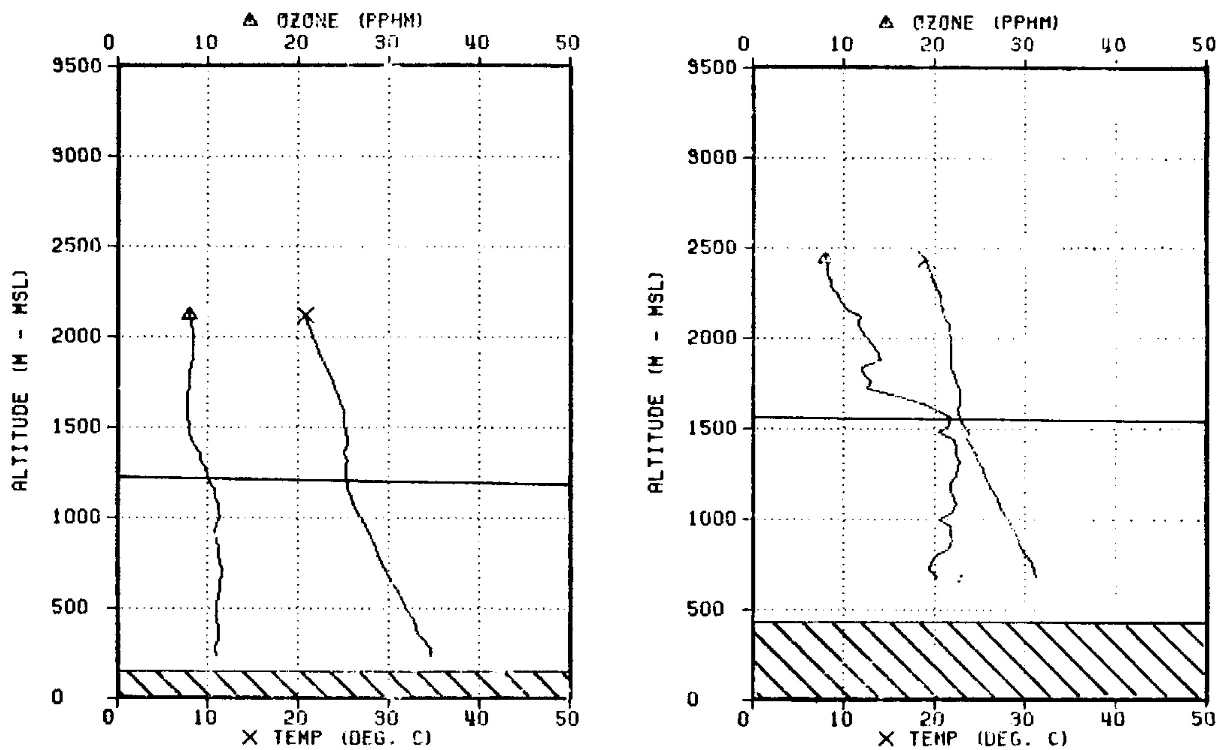
Figure 4.1.10 Aircraft Sampling Patterns (1430-1600 PDT - September 14, 1979). Broken Line Shows Box Dimensions for Flux Calculations.



Date: 9/14/79 Time: 14:36:46 (L)
Location: Bakersfield VOR

Date: 9/14/79 Time: 15:47:17 (L)
Location: Caliente

Figure 4.1.11 MRI Aircraft Soundings

Based on these plume characteristics, increased ozone flux downwind of Bakersfield was estimated at 57 metric tons/hour or, normalized to a unit of crosswind plume width, 2.1 metric tons/hour/km.

To put this increased pollution burden into some perspective, the afternoon flux calculations for air entering the valley from the north, which were discussed in Section 4.1.1 were also normalized. The results are shown in Table 4.1.2. The flux calculations on 13 and 16 July were based on an ozone excess (above background levels) of 30 ppb. It is seen from the table that ozone production from the east Kern County sources can be equal to or greater than the flux into the valley per unit of cross wind width.

Table 4.1.2

NORMALIZED FLUX CALCULATIONS

Date	Region	Flux Metric Tons/Hr/km
13 July	North End of San Joaquin Valley	1.7
16 July	North End of San Joaquin Valley	1.7
14 September	East Kern County	2.1

Significant concentrations of SF_6 were observed during the sounding at Caliente and during the horizontal traverse which terminated at Caliente. This tracer material was released from Fellows (01-07 PDT) and was strongly detected in Bakersfield between 10 and 14 PDT. The trajectory of the ozone burden observed near Caliente is therefore clearly established as having passed over the Bakersfield urban area.

4.2 Stagnation Potential of the San Joaquin Valley

The air pollution potential of a developing basin such as the San Joaquin Valley is directly related to the average residence time of a parcel of air within the basin. In a large basin with a diverse emissions inventory, the most significant air pollution problems can be due to multi-day episodes where pollutants accumulate over a period of time due to inadequate ventilation of the basin. Generally, it is very difficult to infer a ventilation rate from either pollutant or meteorological data. During some of the tracer experiments conducted during this program, however, it was possible to directly estimate the air exchange rate in the San Joaquin Valley by following the loss of tracer mass as a function of time after release. In the following sections the ventilation rate and stagnation potential of the valley during each of the three intensive experimental periods are described.

4.2.1 Winter

The first two tracer experiments during the winter field program were conducted in the northern half of the San Joaquin Valley, with releases from Chowchilla and Fresno. Very little dispersion of the tracer was noted during either of these experiments and essentially all of the tracer remained within the valley at least into the day following the tracer release. During the first experiment, it was estimated that a majority of the tracer released was accounted for within a 350 square mile area (less than 3 percent of the total valley area) a full 24 hours after the start of the release.

Somewhat more dispersion of the tracer was noted during the five tracer experiments conducted in the southern half of the valley. During each of these later experiments, however, essentially all of the tracer was detected within the valley on the day after the release. The average residence time of an air parcel within the San Joaquin Valley during the winter is clearly in excess of one day. As shown in Figure 4.2.1, SF_6 was detected at Old River during Test 7 (March release from Lost Hills) for at least 72 hours after the start of the release. The tracer concentrations at this location in the center of the southern valley decreased by only about a factor of two during each day subsequent to the release. It was estimated that about 50 percent +/- 25 percent

TEST SJV-7, OLD RIVER

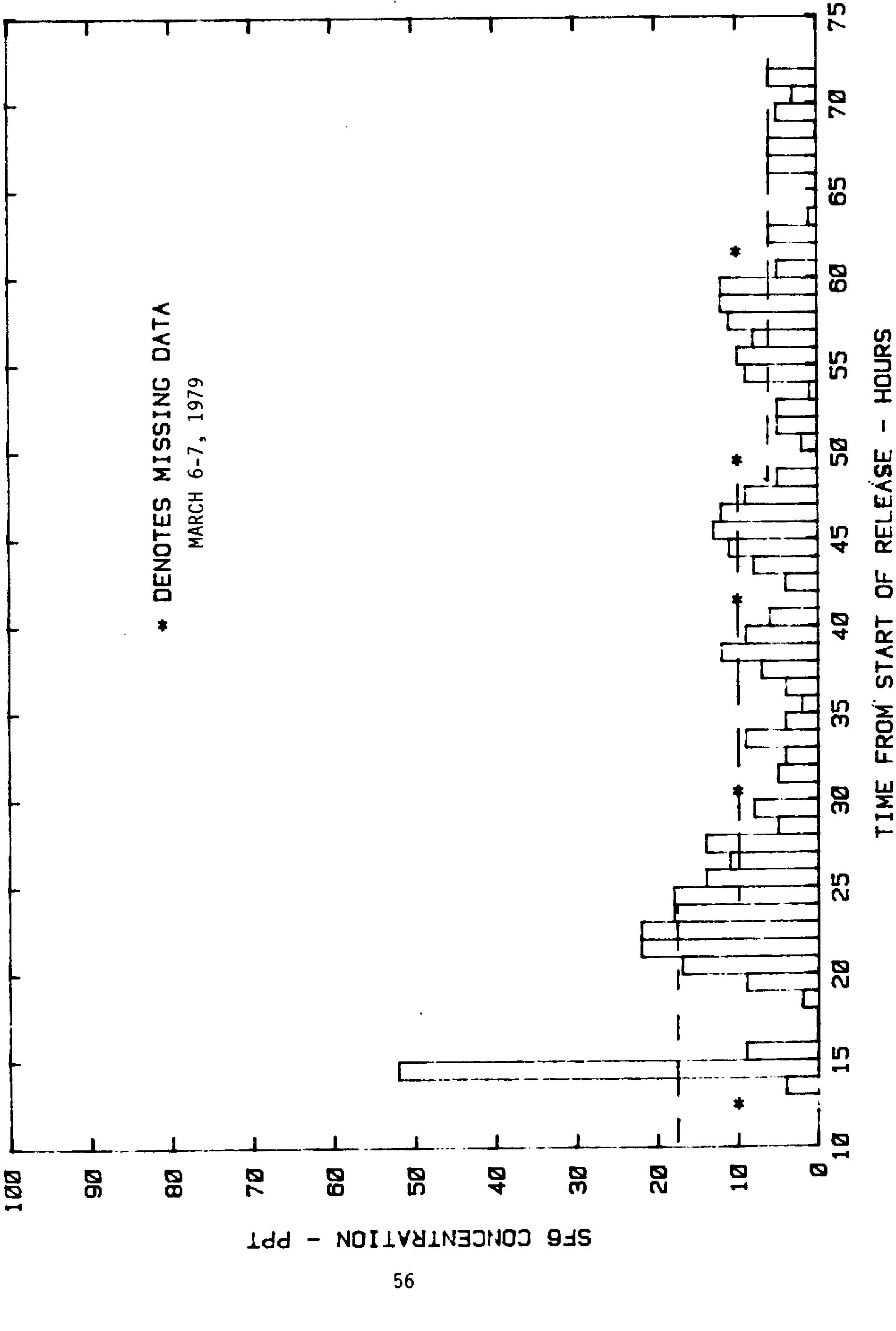


Figure 4.2.1

of the tracer remained within the valley about 60 hours after the start of the release. This calculation was based on an average tracer concentration of about 8 ppt that was detected over a 900 square mile area, 4000 ft deep. By considering the San Joaquin Valley as a well-mixed volume, a 50 percent loss rate in 2.5 days implies an average air parcel residence time of almost four days. Thus a well-mixed conserved pollutant would require almost four days for 63 percent (1-1/e) of the pollutant to be transported out of the valley under the atmospheric conditions of Test 7. Considering the uncertainties of this calculation, the average air parcel residence time under these conditions may be as short as two days or as long as eight days. Clearly, the potential exists for significant carryover of pollutants into days subsequent to their release.

4.2.2 Summer

The potential for stagnation during the summer is much reduced over that observed during the winter. Generally, atmospheric conditions during the day are less stable, and afternoon mixing heights and wind speeds are more conducive to pollutant dilution during the summer. The tracer was efficiently transported away from the release site during all tests. All releases during the summer field program were conducted from sites in the northern half of the San Joaquin Valley (north of Fresno). While the potential for stagnation during these tests was apparently minimal, very little net out-of-valley transport was noted until the second day. The afternoon upslope flow along the western slopes of the Sierra Nevada Mountains is potentially an important mechanism for ventilation of the valley. Its effectiveness was found to be limited, however, by the nighttime drainage flow which arrests the upslope movement of air and can transport air parcels back to the valley floor. The effectiveness of the afternoon upslope flow is also limited by its negligible influence on the center of the valley floor. The first three tracer releases led to impacts along the valley center and western side during transport to its southern end. Essentially no influence of an upslope or other out-of-valley flow was noted during these tests. Even during an afternoon release from Reedley, southeast of Fresno, a significant fraction of the released SF_6

remained on the slopes or in the valley throughout the night following the release. Thus while the stagnant winter conditions are not repeated during the summer, the average residence time of an air parcel initially in the northern half of the San Joaquin Valley is at least in excess of one day.

4.2.3 Fall

The early fall conditions investigated during the September field studies were very similar to mid-summer conditions in terms of stagnation potential. The tracer experiments during this period were all conducted from the southern San Joaquin Valley. Unlike the upslope flow in the northern half of the valley, the afternoon upslope flow over the Tehachapi Mountains at the extreme southern end of the valley leads to a significant efflux of air from the valley. About 85 percent of the tracer released during the morning at Oildale was transported up and over the Tehachapi Mountains and into the Mojave Desert. The average residence time of an air parcel in the southern San Joaquin Valley is thus probably about one day (the frequency of the afternoon upslope winds). Tracer released at the northern mouth of the valley took at least one or two days to arrive in the southern valley during the summer and early fall conditions. Thus the average residence time of an air parcel initially at the northern mouth of the valley is probably two or three days.

4.3 Slope Flows

4.3.1 Introduction

Upslope flows develop along the slopes of the mountains which surround the San Joaquin Valley as a result of a diurnal heating. The westward-facing slopes of the Sierra Nevadas are particularly well situated for this development since they are well exposed to the afternoon sun. At the south end of the valley the upslope flow is oriented in the same direction as the afternoon northwesterly flow in the valley and assists in the transport of air over the Tehachapis. The effectiveness of the upslope flows in removing pollutants from the valley has been examined in the next section.

4.3.2 Description of the Flows

Observational data for an examination of the slope flow come from pibal observations made during the present study. Additional data have been obtained from a U.S. Forest Service study (Lehrman, Smith and Gouze, 1980) whose observational program, in part, overlapped the period of the CARB San Joaquin Valley study.

Time cross sections of the upslope wind component at two locations in the Sierras are shown in Figure 4.3.1. The locations of Huntington Lake and Meadow Lakes are shown in Figure 4.3.2. Upslope components exist at both locations to a maximum depth of about 600 m (agl). The velocities at Huntington Lake, however, are significantly higher than at Meadow Lakes which is at a much lower elevation. It is typical of most upslope observations that a return flow (downslope) exists over the top of the upslope flow. This is shown in Figure 4.3.1 at both locations.

All available sequences of pibal observations which exhibited upslope characteristics have been summarized in Table 4.3.1. Locations of the observations are shown in Figure 4.3.2. Duration of each upslope flow example and average depth are given in the table. The average upslope velocity through the layer multiplied by the average depth of the layer gives an average, instantaneous flux of air carried by the upslope flow. This flux can be considered as representative of a volume flux (m^3/s) corresponding to each meter of horizontal width along the slope.

There is a clear trend in Table 4.3.1 for the fluxes to be higher at Huntington Lake (elevation about 7000 ft) compared to the valley locations (Fresno and Reedley) as well as the intermediate locations such as Meadow Lakes. Average depths of the upslope layer also appear to increase at higher elevations along the slope.

During the November-December period most of the locations along the edge of the valley show slightly smaller but significant fluxes compared to the summer observations. Bealville, at the southern end of the valley, reflects the superposition of the valley northwesterly flow with an upslope component resulting in a stronger flux component.

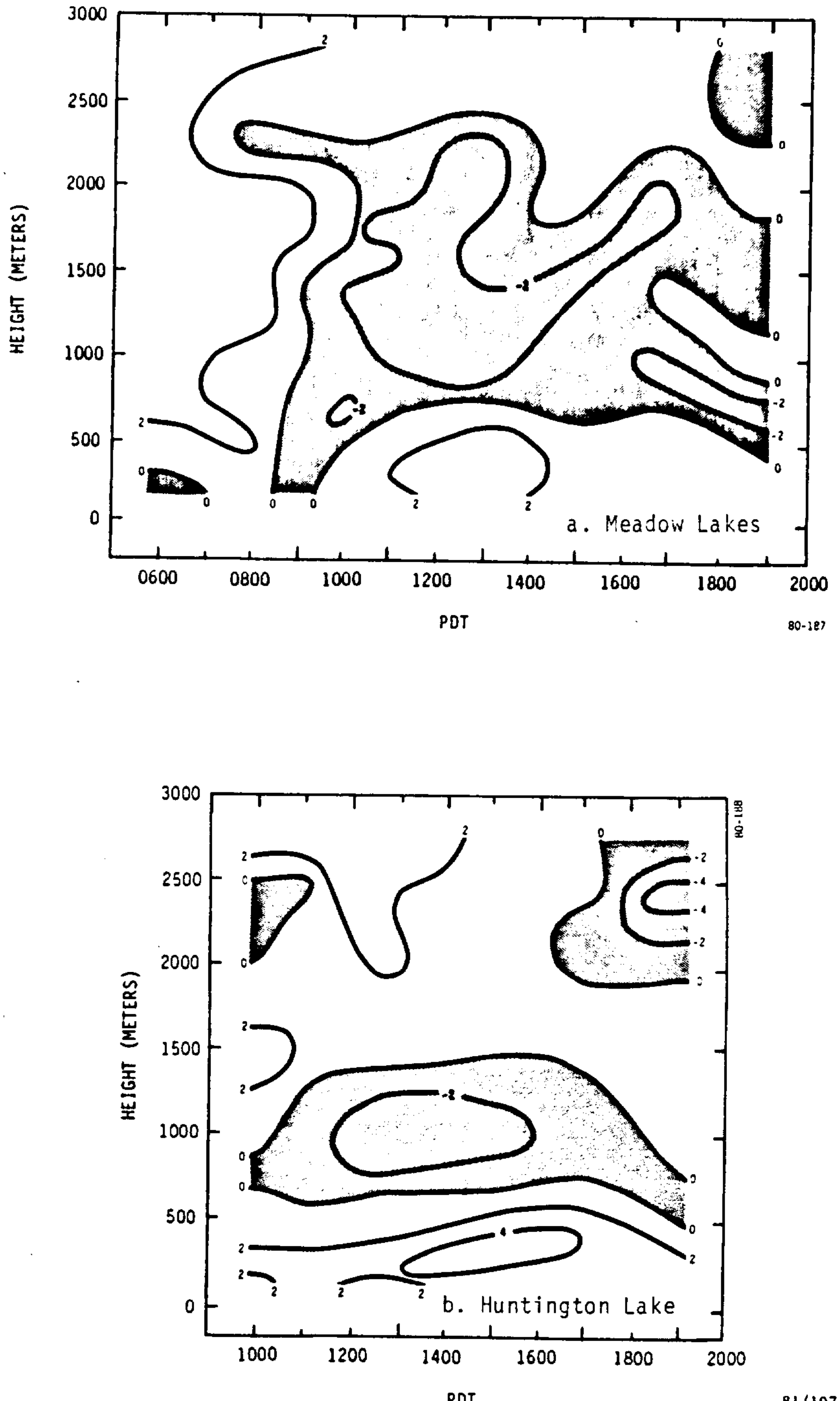


Figure 4.3.1 Time-Height Cross Section of Upslope Component of Wind (m/s) - 27 July 1979 (Shaded areas represent downslope winds)

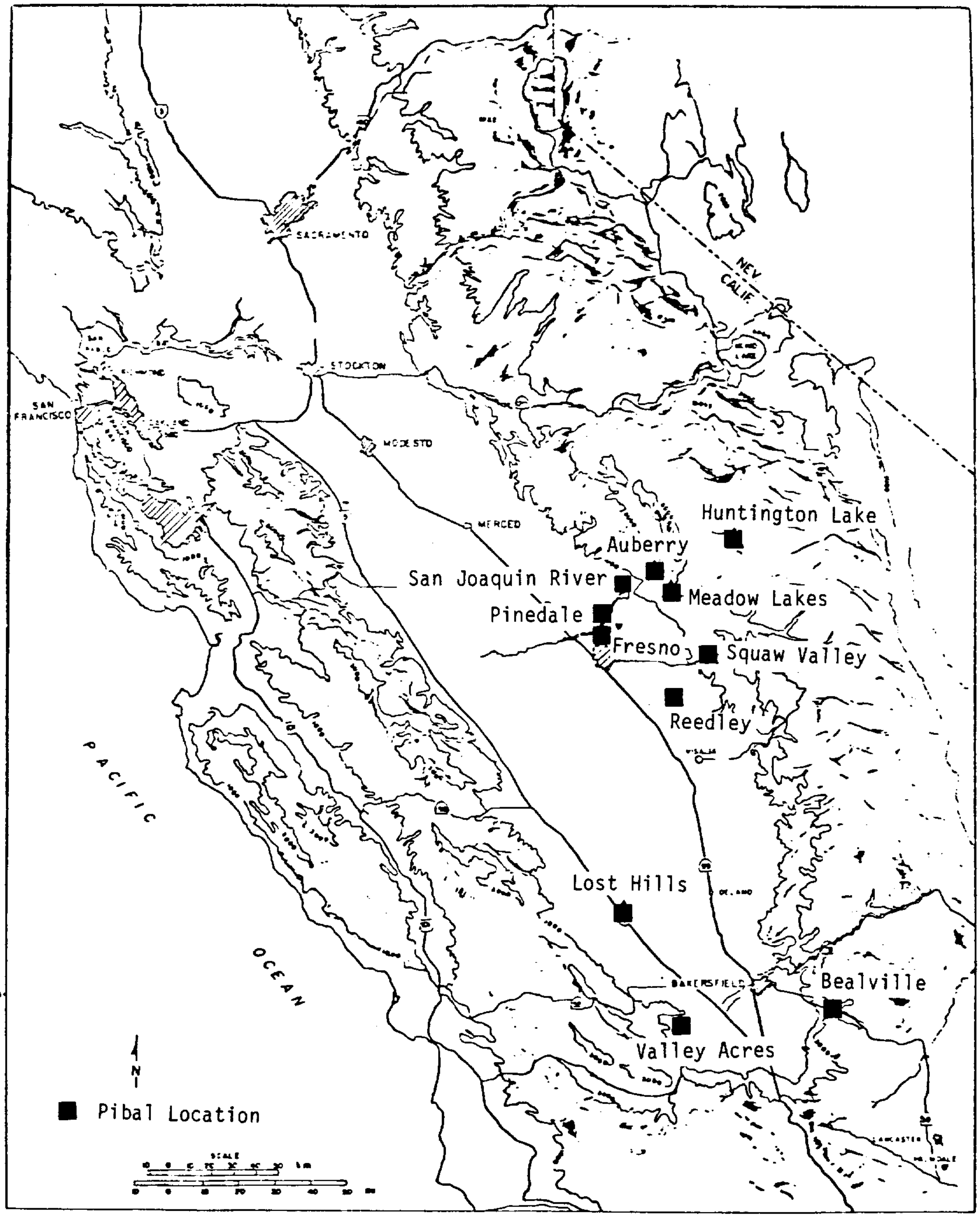


Figure 4.3.2 Location of Slope Flow Observations

Table 4.3.1

SLOPE FLUX CHARACTERISTICS

Date	- Location	Duration (PDT)	Average Depth (m)	Hourly Average Flux (m^2/s)
July 1979				
07/26	Meadow Lakes	12-19	420	1000
	Huntington Lake	12-19	650	2005
07/27	Meadow Lakes	10-19	415	565
	Huntington Lake	10-19	535	1205
07/25	Reedley	11-19	270	865
	Fresno	12-19	200	405
September 1979				
09/23	Huntington Lake	13-19	415	1355
	Auberry	13-19	325	790
November-December 1978				
11/15	San Joaquin River	13-17	375	615
11/18	Reedley-Pinedale	12-17	215	195
11/18	Squaw Valley	11-16	210	275
11/26	Bealville	09-17	530	1260
11/29	Valley Acres	15-18	330	465
12/08	Lost Hills	14-20	330	595

4.3.3 Pollutant Evidence of the Upslope Flow

During the U.S. Forest Service program (Lehrman, Smith and Gouze, 1980) an ozone monitor was operated at Huntington Lake (elevation 7000 ft). Another monitor was operated by the USFS at Whitaker Forest (elevation 5400 ft). Results of the observations from July-October 1979 are presented in Figure 4.3.3 in terms of diurnal variations in the median and maximum ozone values recorded at each location. A significant diurnal ozone peak is apparent at 14 PDT at Whitaker Forest with a somewhat lower peak at 18 PDT at Huntington Lake. In view of the time delay between the two sites and the lack of significant diurnal sources on the slopes, transport of ozone from the valley floor is clearly suggested.

4.3.4 Effects of Upslope Flow

The observations that the upslope flow increases in magnitude and depth at higher elevations is of considerable significance. These data suggest that increased heat and buoyancy is contributed by the slope as the air moves upward to higher elevations. The depth of the layer would therefore be expected to increase as will the buoyant forces which drive the upslope circulation. The ultimate result is for the upslope velocities and the layer depth to increase with increasing elevation. Air to satisfy the mass continuity must therefore be drawn in laterally from layers above the valley floor. This air, in general, is frequently lower in pollutant concentration and the air from the valley floor is consequently diluted.

The above discussion suggests that the slopes may not be as effective a pollutant removal mechanism for surface layer pollutants as heretofore assumed. Much of the slope air is drawn from elevations well above the valley floor. The flux from the valley floor may be only 20-30 percent of the slope flow at higher elevations (Table 4.3.1). This may serve, however, to help remove ozone-rich layers aloft which are carried over from the previous day.

Tracer observations, particularly in November-December, indicated that the slope flow did not draw effectively from the center of the valley. Tracer material was required to mix horizontally to the edges of the valley before significant loss of material up the slopes seemed to occur. During the summer and early fall, transport from the northwest during the daytime was a much more effective removal mechanism. It is concluded, therefore, that the effectiveness of the upslope flow in removing pollution from the valley is primarily confined to the immediate edges of the valley.

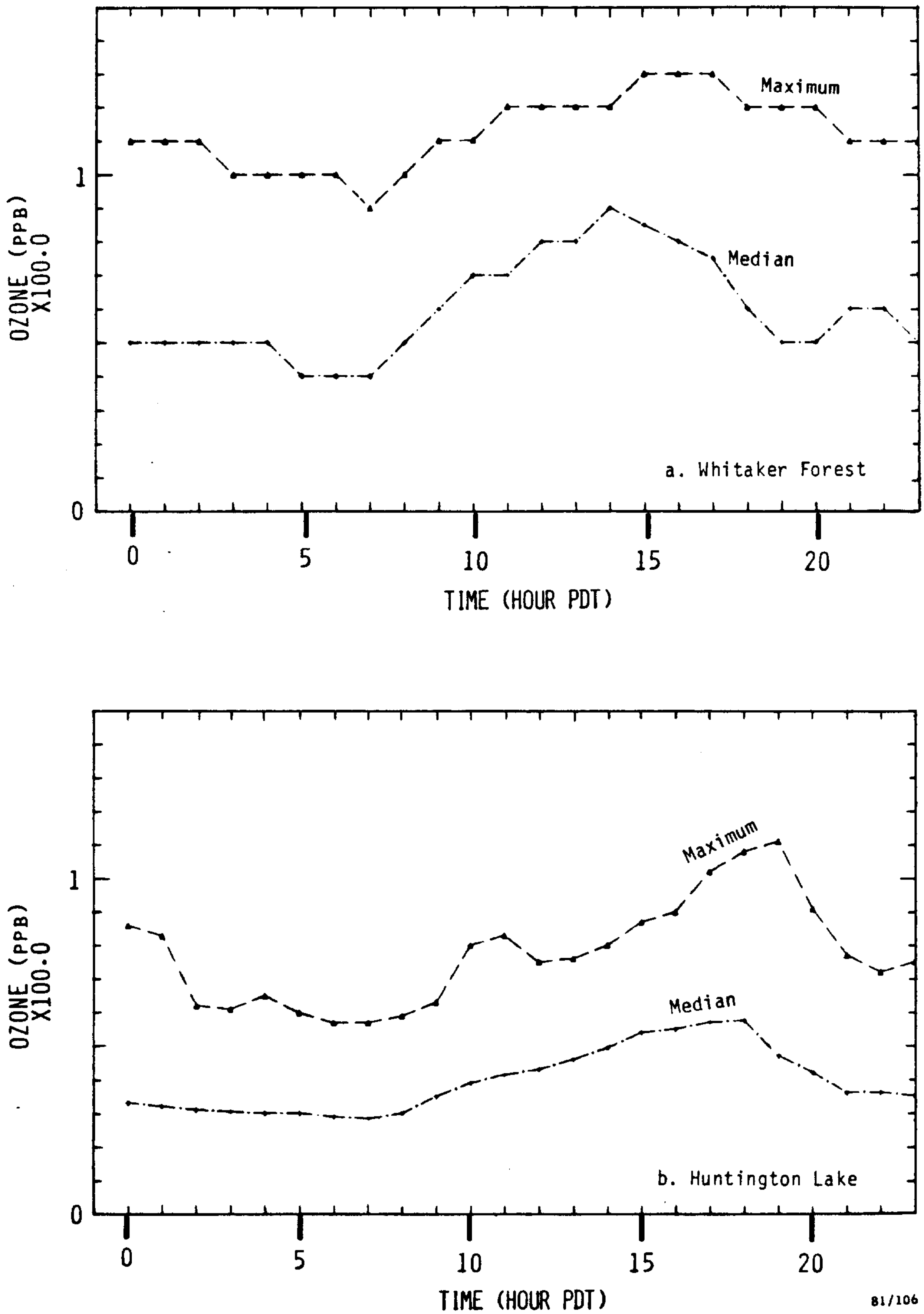


Figure 4.3.3 Diurnal Variation of Ozone - July Through October 1979

4.4 Ventilation Budget for the Valley

Pibal observations were taken routinely at five locations in the valley and at 05, 09, 13, 17 and 21 PDT daily at each location for about three weeks during the July and September field programs. These observations (from the surface to about 2700 m) were divided into components along and across the valley axis and averaged by levels to obtain a mean profile for each field program.

Mean profiles of the components along the valley axis are shown in Figures 4.4.1 to 4.4.5 for the July program. The profiles for 17 PDT (Figure 4.4.1) are similar for all stations, indicating relatively uniform transport from the northwest throughout the valley. By 21 PDT (Figure 4.4.2), however, winds in the low levels at Los Banos and Fresno show sizeable increases compared to Stockton, reflecting the development of the nocturnal jet (Section 5.2). The similarity between the profiles at Los Banos and Fresno suggests that the jet is a valley-wide phenomenon. At the same time, the mean profile at Bakersfield shows a marked decrease in velocity below 1200 m compared to Fresno and Los Banos but a marked increase in velocity above that level. This profile is created by blocking of the northwesterly flow by terrain at the southern end of the valley when nocturnal stability begins to inhibit the free transport of low-level air upward and over the Tehachapis. The increased flow aloft at Bakerfield serves to maintain part of the mass continuity for the northwesterly low-level flow approaching Bakersfield from Visalia and Fresno. The level of 1200 m represents the approximate height of the terrain at the southern end of the valley.

At 05 PDT (Figure 4.4.3) the terrain blocking appears at Visalia but not yet at Fresno. Negative winds (southerly) at Visalia reflect the development of the "Fresno Eddy" which is considered in greater detail in Section 5.3. By 09 PDT (Figure 4.4.4) the terrain blocking is felt as far north as Fresno with Bakersfield and Visalia continuing to exhibit reduced velocities below 1200 m and increased velocities above that level. Remnants of the wind blocking effect remain in the mean profiles for 13 PDT (Figure 4.4.5) compared to Los Banos and Stockton but with reduced magnitudes.

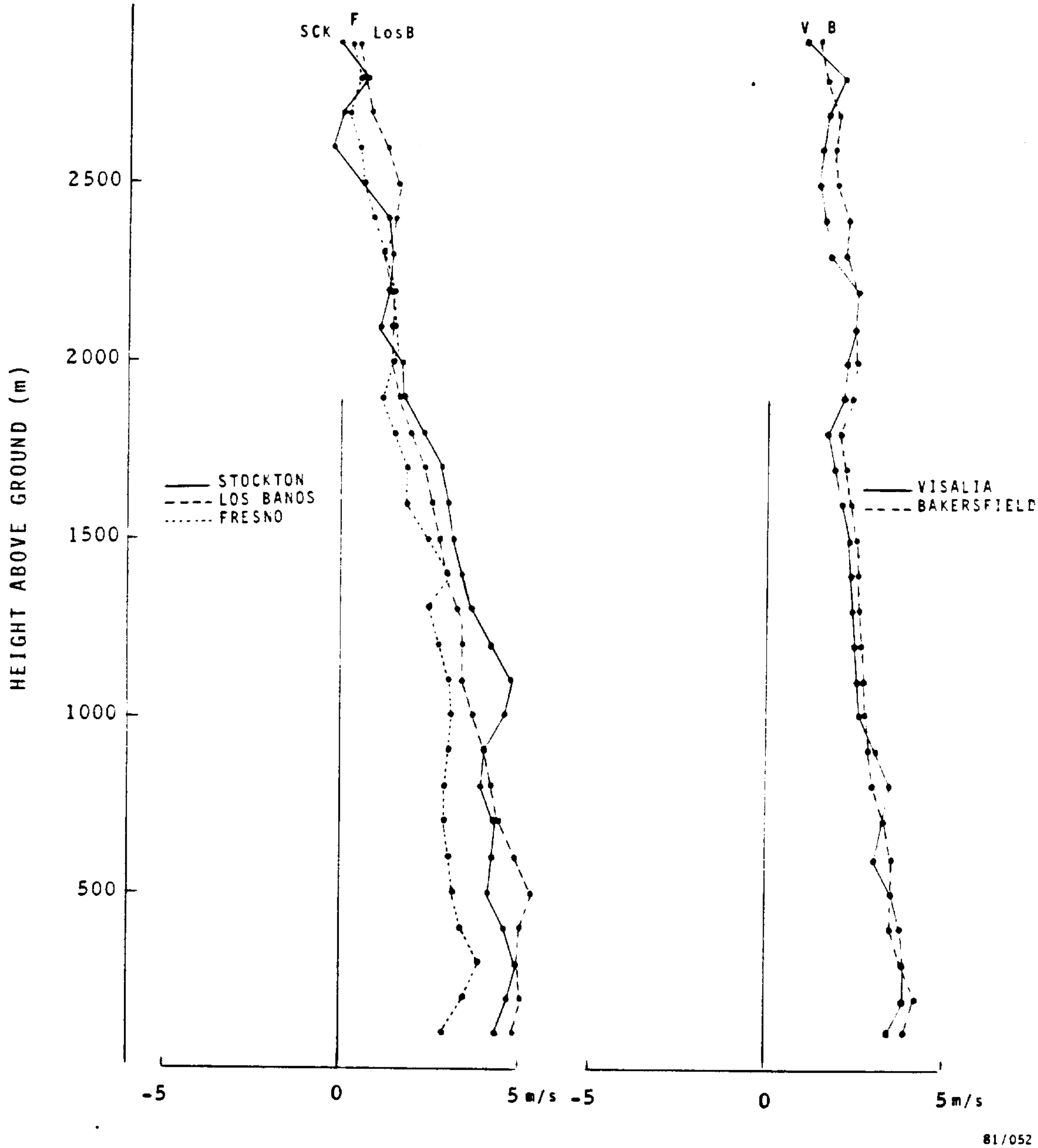


Figure 4.4.1 Average Wind Components Along Valley Axis
July 1979 (17 PDT)

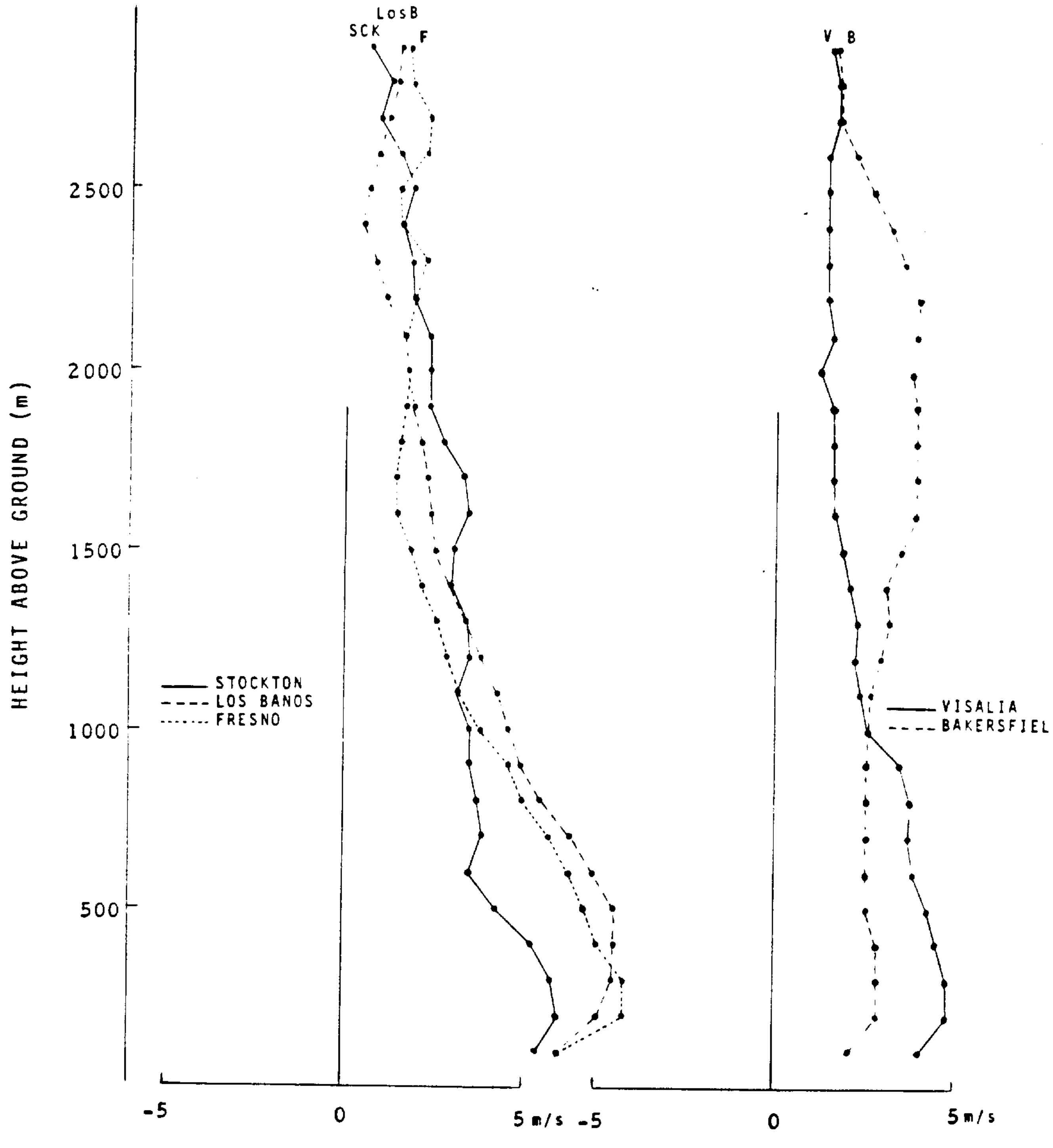


Figure 4.4.2 Average Wind Components Along Valley Axis
July 1979 (21 PDT)

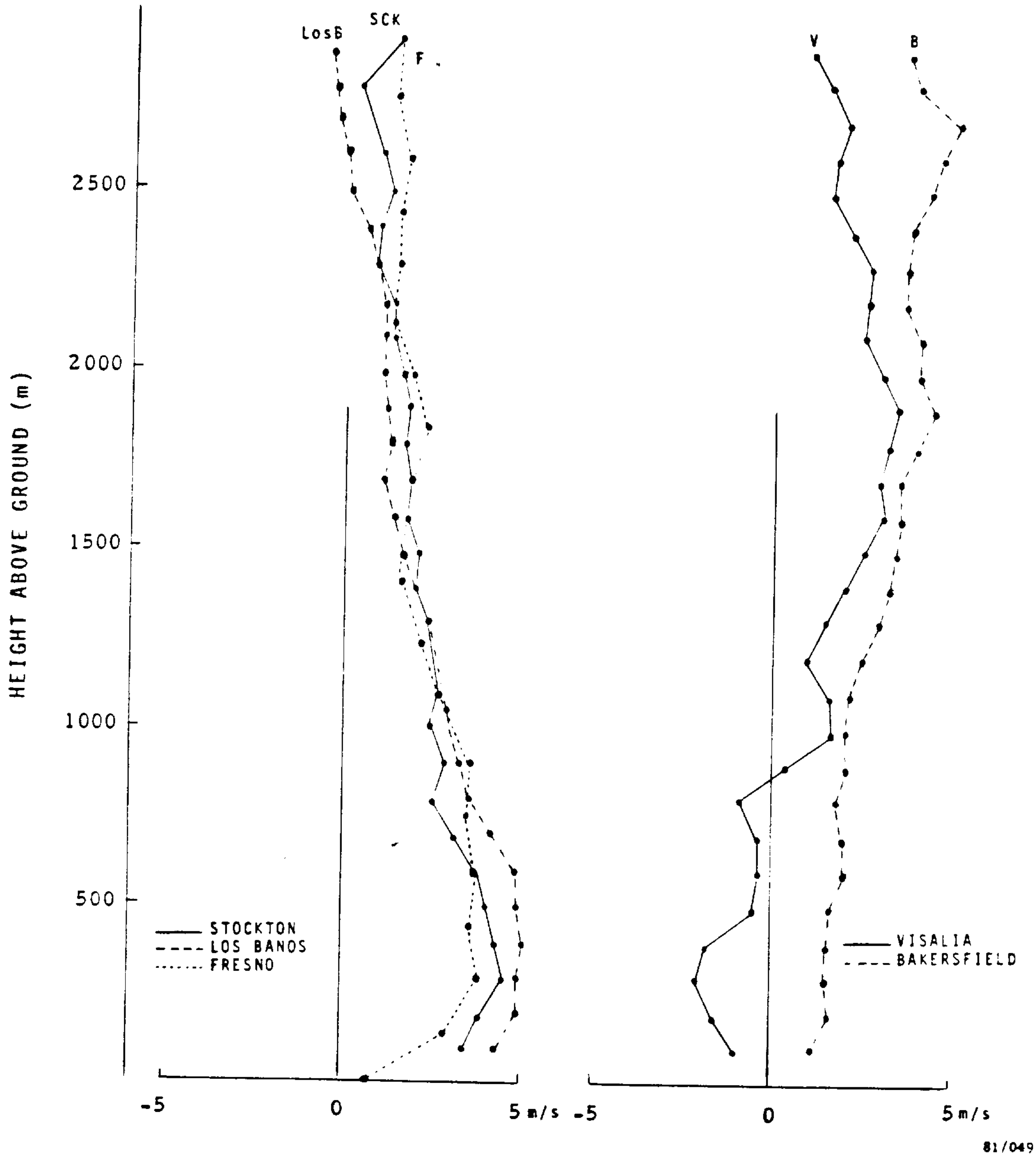


Figure 4.4.3 Average Wind Components Along Valley Axis
July 1979 (05 PDT)

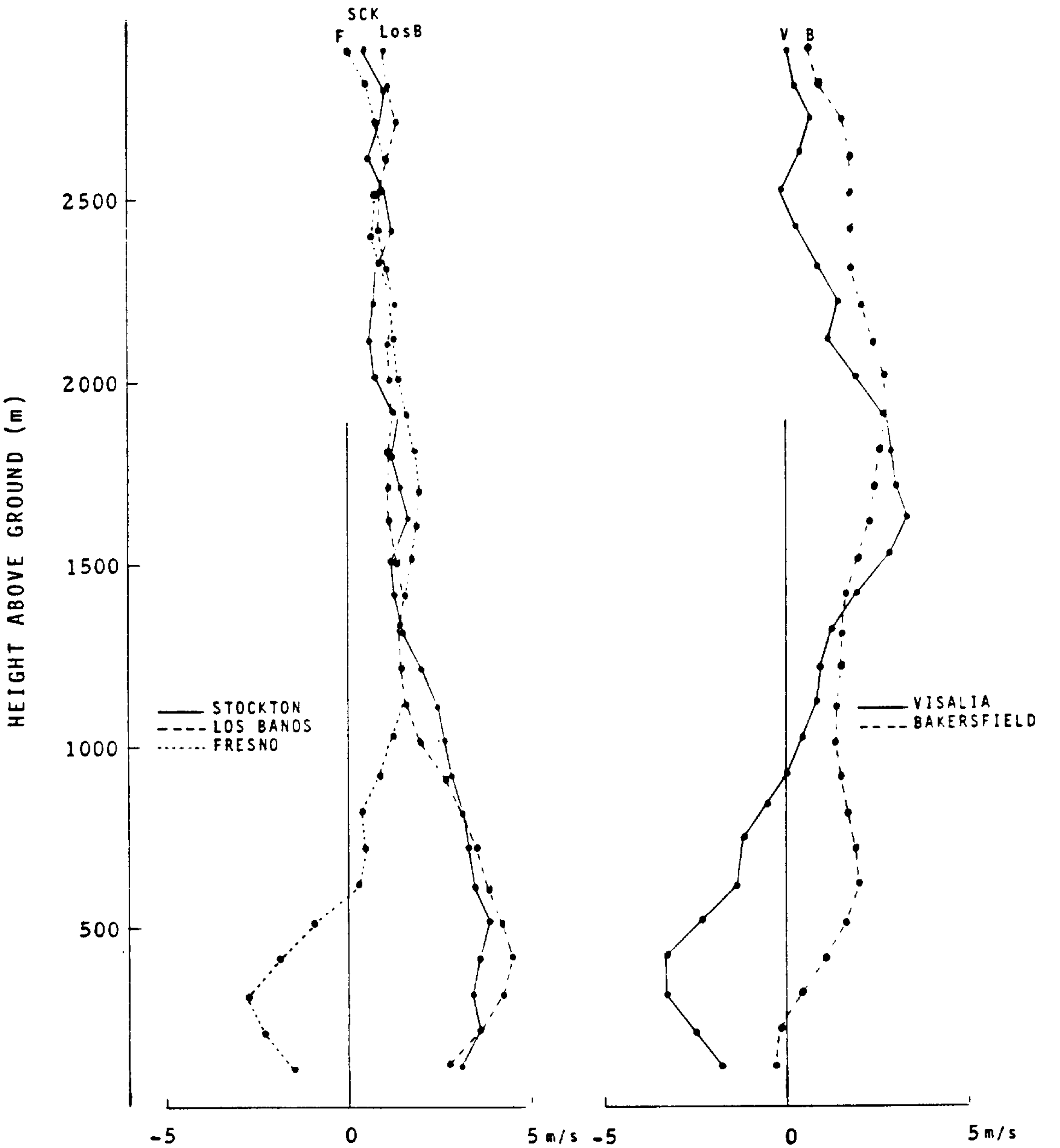


Figure 4.4.4 Average Wind Components Along Valley Axis
July 1979 (09 PDT)

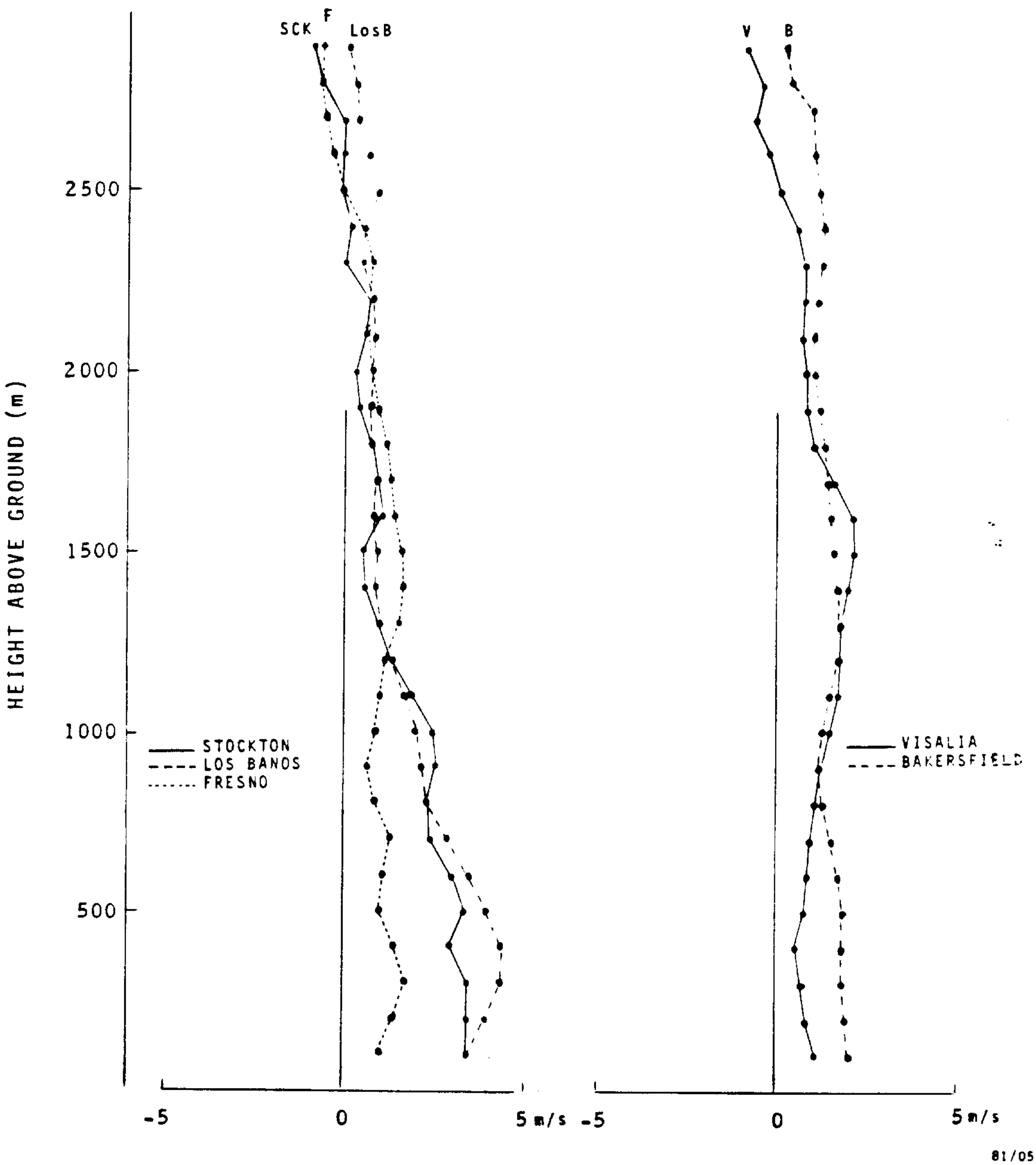


Figure 4.4.5 Average Wind Components Along Valley Axis
July 1979 (13 PDT)

Mean winds at 1000 feet for the July period were calculated for the five pibal stations. These mean vectors have been plotted for the various observational times in Figures 4.4.6 to 4.4.10. Streamlines were drawn to represent the mean July flow patterns for each observational time.

At 17 PDT (Figure 4.4.6) the mean wind directions and speeds are similar throughout the valley. By 21 PDT (Figure 4.4.7) the flow pattern at 1000 ft continues from a northwesterly direction but with substantially reduced speeds, particularly at Bakersfield. This represents the first manifestation of the terrain blocking on the valley wind field.

By 05 PDT (Figure 4.4.8) existence of the Fresno Eddy appears in the form of a mean wind from the south at Visalia. The eddy increases in strength and area by 09 PDT (Figure 4.4.9) and encompasses the entire southern end of the valley. Note the mean wind velocity of 3.5 m/s from the south at Visalia.

At 13 PDT (Figure 4.4.10) the remnants of the eddy are carried up the slopes of the Sierras and the flow within the valley becomes more northwesterly.

It is apparent from this discussion that air above the 4000-ft level (1200 m) moves readily out of the valley to the southeast on a mean flow basis in July. The interest in ventilation of the valley during summer, therefore, lies in the air volume below this level.

Mean velocities for the lowest 1200 m were calculated for each of the profiles in Figures 4.4.1 to 4.4.5. If these velocities are multiplied by the depth of the layer of interest (1200 m) and the width of the valley at each location, an estimate of the total volume flux below 1200 m can be made. An assumption is made that the airflow is uniform across the valley at the value given by the pibal observations. This appears to be a reasonable assumption generally in the northern half of the valley and probably for 13 and 17 PDT in the southern part of the valley. During the balance of the 24-hour period in the south, the existence of the Fresno Eddy assures a non-uniform horizontal wind distribution.

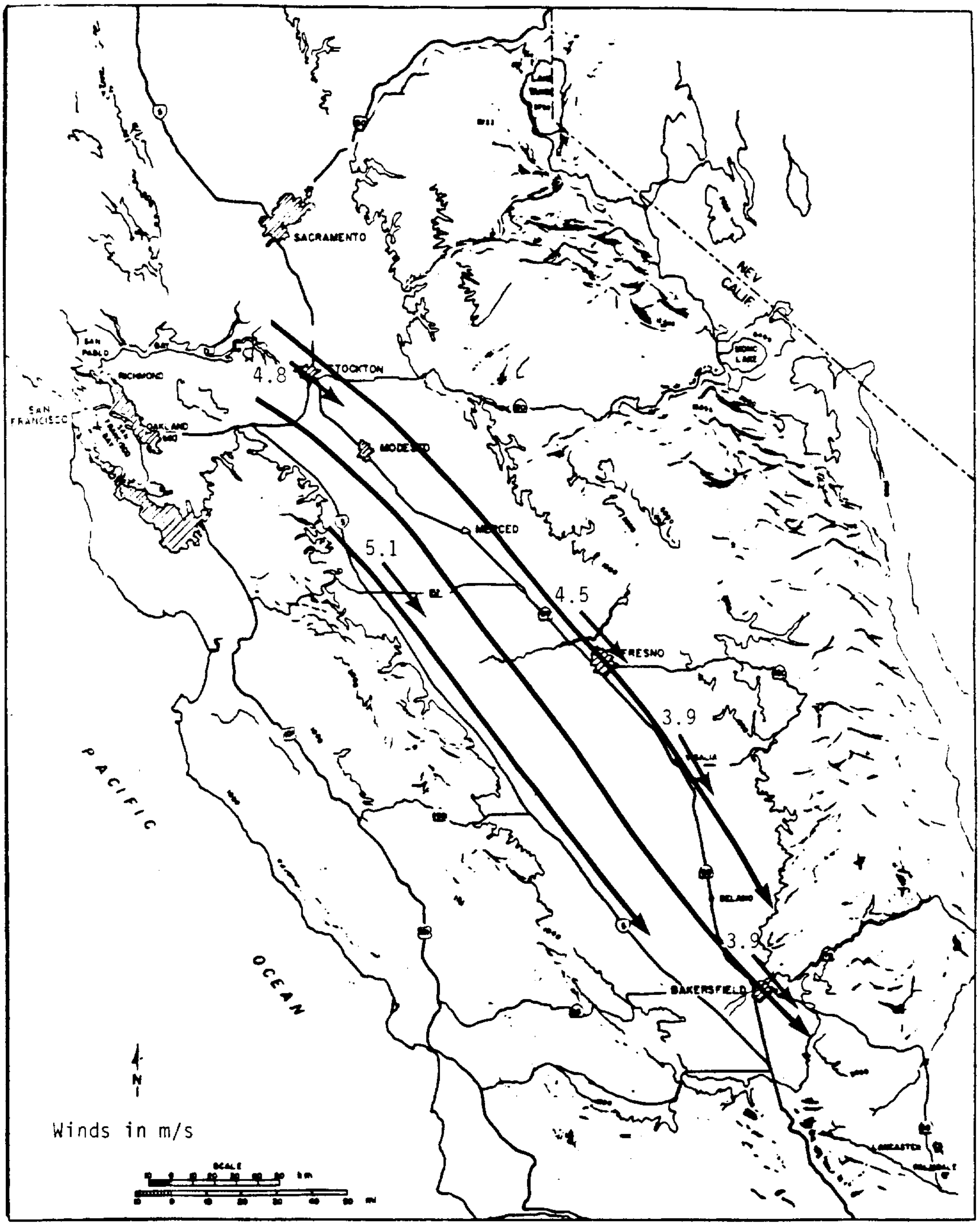


Figure 4.4.6 July Average Winds at 1000 Feet (17 PDT)

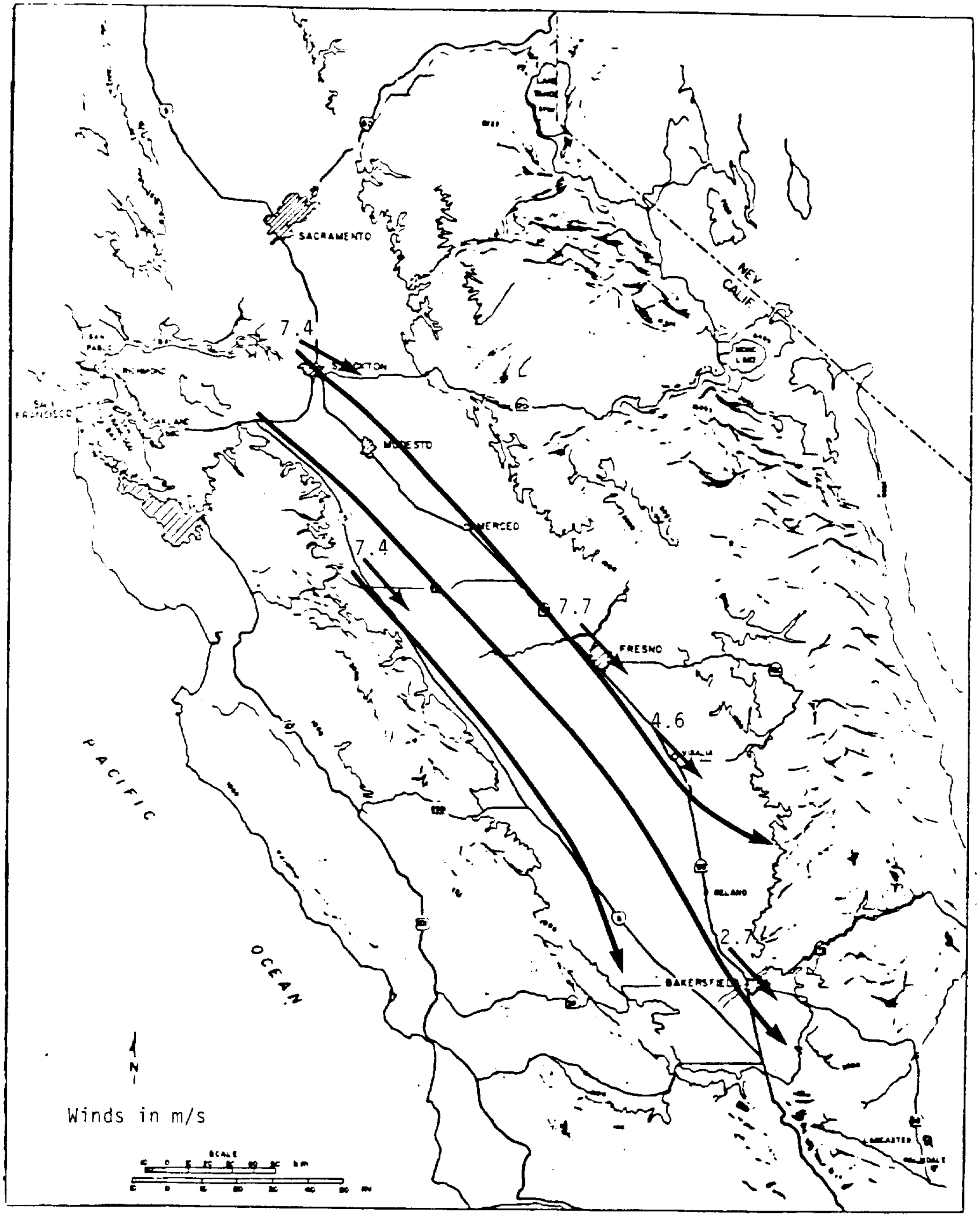


Figure 4.4.7 July Average Winds at 1000 Feet (21 PDT)

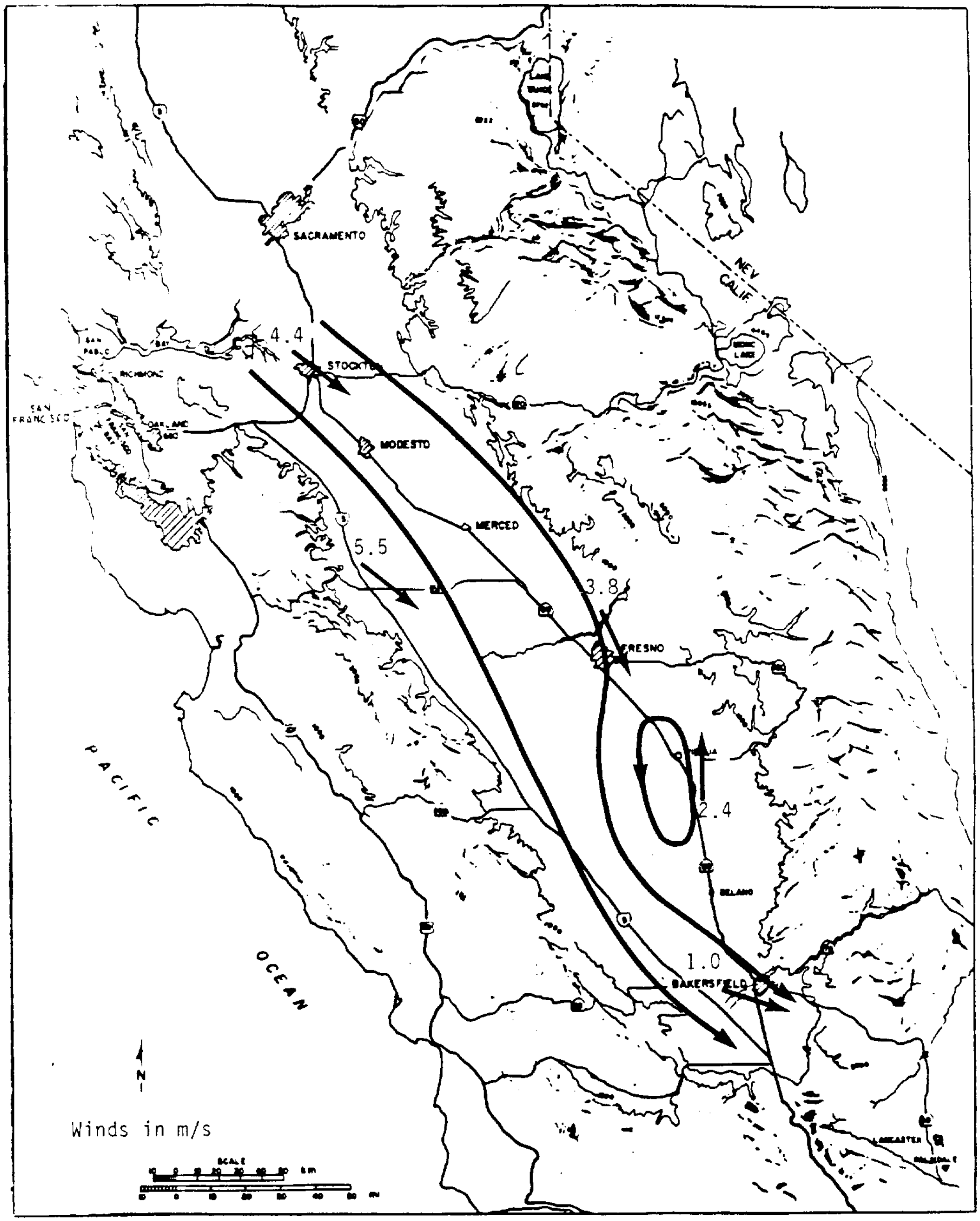


Figure 4.4.8 July Average Winds at 1000 Feet (05 PDT)

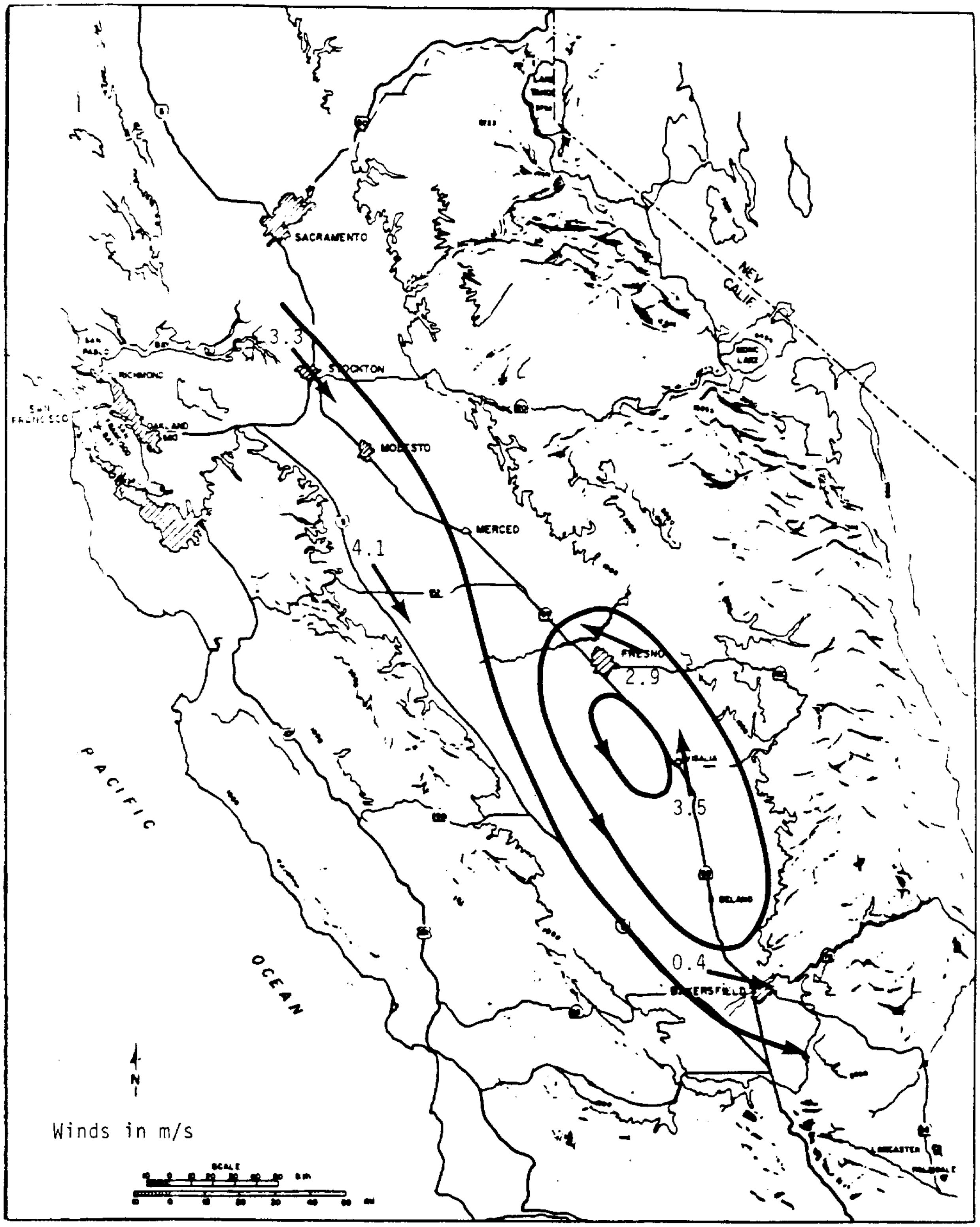


Figure 4.4.9 July Average Winds at 1000 Feet (09 PDT)

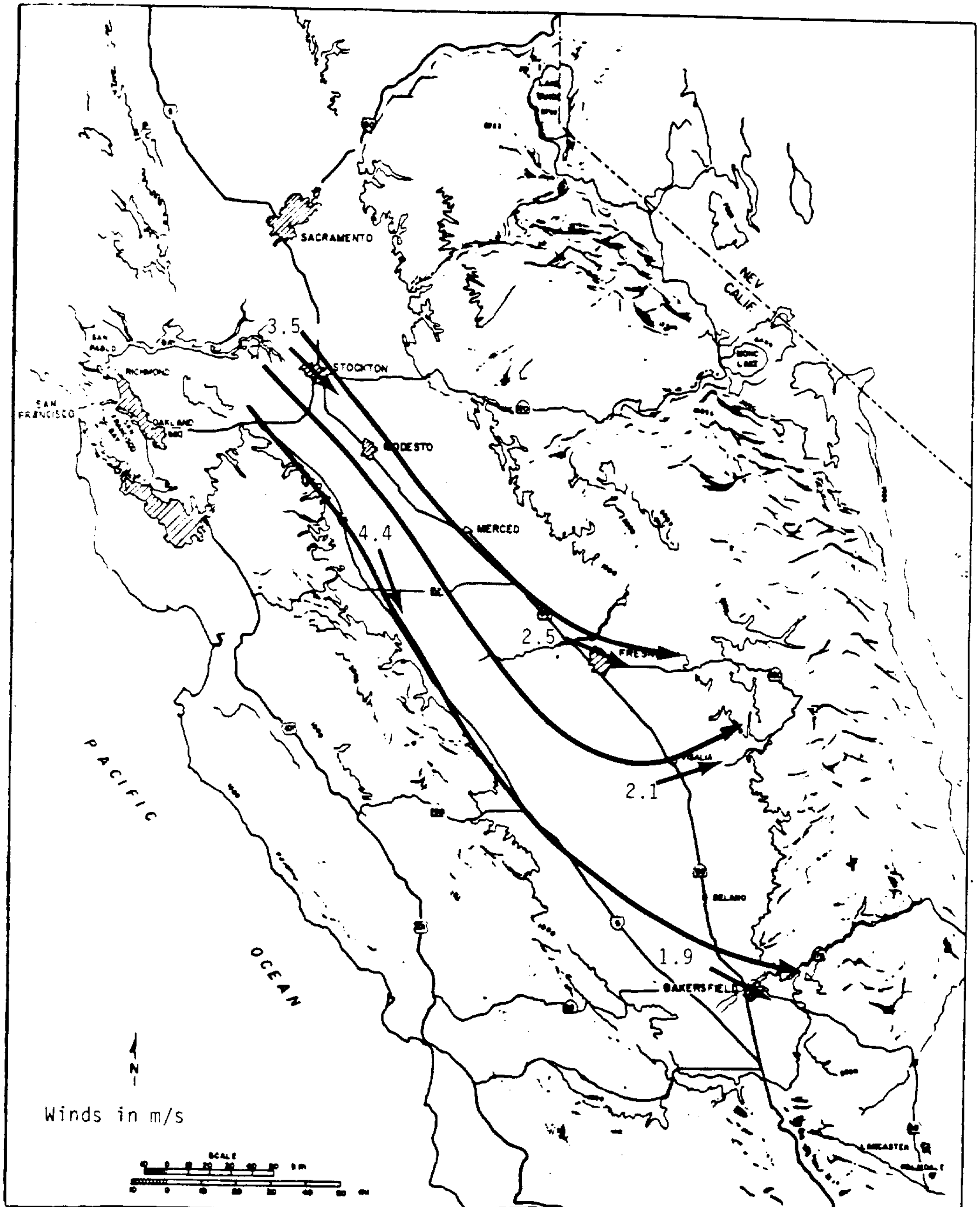


Figure 4.4.10 July Average Winds at 1000 Feet (13 PDT)

Table 4.4.1 gives the results of the estimated flux calculations. Note that Stockton and Los Banos show very similar fluxes with the exception of 21 and 05 PDT when both Los Banos and Fresno are influenced by the nocturnal jet while Stockton is not. The average flux at Stockton over a 24-hour period is 1.28 x 10^{12} m^3/hour. The total volume of the valley below 1200 m from Stockton southward is about 3.89 x 10^{13} m^3. Based on the average flux at Stockton a total of about 30 hours would be necessary to replace the air in the valley below 1200 m.

Table 4.4.1

ESTIMATED AIR FLUX BELOW 1200 m - JULY 1979

(all values x 10^{12} m^3/hour)

Time (PDT)	Stockton	Los Banos	Fresno	Visalia	Bakersfield
17	1.59	1.63	1.44	1.27	.95
21	1.54	2.16	2.44	1.61	.71
05	1.15	1.42	1.37	- .18	.47
09	1.10	1.12	- .14	- .50	.26
13	1.00	1.10	.50	.47	.45

Table 4.4.1 shows that the volume flux increases from Stockton to Fresno at 21 PDT and 05 PDT in association with the nocturnal jet. Since Los Banos and Fresno are on different sides of the valley this is believed to be a true increase in flux and not a horizontal division of the flow preferentially to one side of the valley. It is suggested that air is entrained from above the jet to maintain this increased flux.

In the northern part of the valley as far south as Fresno the flux estimates at the three observational locations are quite similar with the exception of the influence of the Fresno Eddy at 09 and 13 PDT. Given this uniformity there is only slight evidence of significant losses in flux due to slope flow effects between Stockton and Fresno. Carroll and Baskett (1979), however, found evidence of some ozone transport from the valley into such areas as Yosemite National Park.

From Fresno southward, particularly at 17 PDT when the most uniform flow exists in the valley, there are further indications of a decrease in air flux. Table 4.3.1 indicates that about 500 m^3/sec (1.8×10^6 m^3/hour) of flux may be transported out of the valley toward the foothills during the afternoon for each lateral meter along the slope. The distance from Fresno to Bakersfield is about 150 km, resulting in an estimate of 150 km x 1.8 x $10^6 = 2.7 \times 10^{11}$ m^3/hour of total flux up the east slopes of the valley. If a slightly lower estimate is made for the contribution of the western side of the valley, about 0.5×10^{12} m^3/hour of flux could be attributed to upslope flow between Fresno and Bakersfield. This corresponds to a decrease of 0.46×10^{12} m^3/hour as shown in Table 4.4.1.

It is therefore concluded that there is little evidence, from the mean profiles, of significant upslope losses between Stockton and Los Banos compared to the magnitude of the up-valley flux. Estimated losses from slope flows between Fresno and Bakersfield, however, are of a sufficient order of magnitude to account for the apparent decreases in flux observed at 17 PDT in the southern part of the valley.

Figure 4.4.3 shows the mean profile conditions at 05 PDT when the terrain blocking is active. Within the lowest 1200 m at Fresno a total flux of 1.4×10^{12} m^3/hour can be estimated from the data in the figure. Mean velocity profiles at Stockton and Los Banos would yield similar estimates.

This flux through the central part of the valley at 05 PDT must be removed from the southern part of the valley by some type of mechanism. The increased wind components at Bakersfield above 1200 m (Figure 4.4.3) represent one such mechanism. This increased flow at Bakersfield compared to Fresno (at the same levels) represents a net transport out of the valley toward the southeast. This excess flux (compared to Fresno) amounts to 0.7×10^{12} m^3/hour within the layers from 1200 m to 2740 m and represents about half of the total flux into the Fresno area below 1200 m.

It appears that the balance of the Fresno flux must be entrained into the development of the Fresno Eddy. This eddy increases in size during the night to finally encompass the entire valley south of Fresno. The eddy structure, in turn, is a cyclonic, convergent area where small, organized, upward motions must exist to accomodate the influx from Fresno. An incoming flux of 0.7×10^{12} m^3/hour can be balanced by an upward velocity of about one cm/sec if distributed over the southern part of the valley. Such a convergent flow would be compensated aloft by an area-wide divergent flow (above 1200 m) which would be superimposed on the valley axis component effect indicated in Figure 4.4.3.

The implications of such a conceptual model of the eddy structure are that pollutants can be transported during the night from the layers below the 1200 m level to levels where they can escape from the valley. Evidence of such transport is suggested in the aircraft sounding data from September 11-12 at Bakersfield in which clean air above 800 m during the evening of September 11 was replaced by polluted air to 1500 m by 07 PDT on September 12 (see Volume 5, Section 3). The eddy may also distribute ozone within the southern part of the valley in the form of layers aloft where it may be incorporated into the mixing layer during the following day.

During the winter the flux into the valley from the northwest decreases and the frequent existence of stable conditions reduces the effectiveness of transport over the Tehachapis. As indicated in Section 4.3, slope flows are active near the edges of the valley, however.

During the November-December program northwesterly winds were frequent during the afternoons. One series of pibal soundings at Bealville (Table 4.3.1) shows an upslope flow toward the southeast, averaging about 500 m deep for a period of eight hours. Assuming that the Bealville data represent the southern end of the valley the total flux out of the valley during this eight-hour period would amount to about 0.8×10^{13} m^3 or about one-fourth of the valley air below 1200 m.

The effectiveness of the winter slope flow in removing pollutants from the valley, in contrast to recirculating the valley air to higher levels within the valley, is unknown. Assuming a range of effects, depending on stability and effectiveness of the slope flow, it is reasonable to assume that the air in the valley below 1200 m could be replaced under the November conditions in one to four days. Under the conditions encountered during the February-March tests the exchange rate would probably be even slower.

4.5 Effects of Fronts and Trough Passages

An effective means of removing pollutants from the valley, occurs during the occasional passage of fronts and trough passages. Under the more unstable conditions accompanying these events, mixing occurs to greater depths and increased wind velocities frequently aid in scouring out the valley. The occurrence of stagnation episodes between trough or frontal passages was considered in Section 3.3.4. The following discussion focuses on the frequency of the events which terminate the stagnation episodes.

An example of the effect of frontal passages on visibility is given in Figure 4.5.1. Variations in the 13 PDT visibility at Bakersfield are plotted for the November-December 1978 period along with the daily 04 PST - 850 mb temperature values at Vandenberg AFB. A marked negative correlation is shown in the figure. High visibilities correspond to low 850 mb temperatures and represent the effectiveness of trough passages in removing particulate material from the valley. Stabilization occurs rapidly after trough passage and the visibility quickly drops below 10 miles.

Following the concepts shown in Figure 4.5.1, the 13 PDT visibility records at Bakersfield were examined for the 10-year period 1967-77. A visibility of 20 miles or more was considered to be a major cleansing of the valley. The number of such events per month for the 10-year period are tabulated in Table 4.5.1.

Another perspective on frequency of cleansing events is provided by examination of Stockton surface winds. For this purpose, surface winds of at least 5 m/s were considered to be associated with major pollutant removal events. The number of such separate events by months in 1975 is shown in Table 4.5.2.

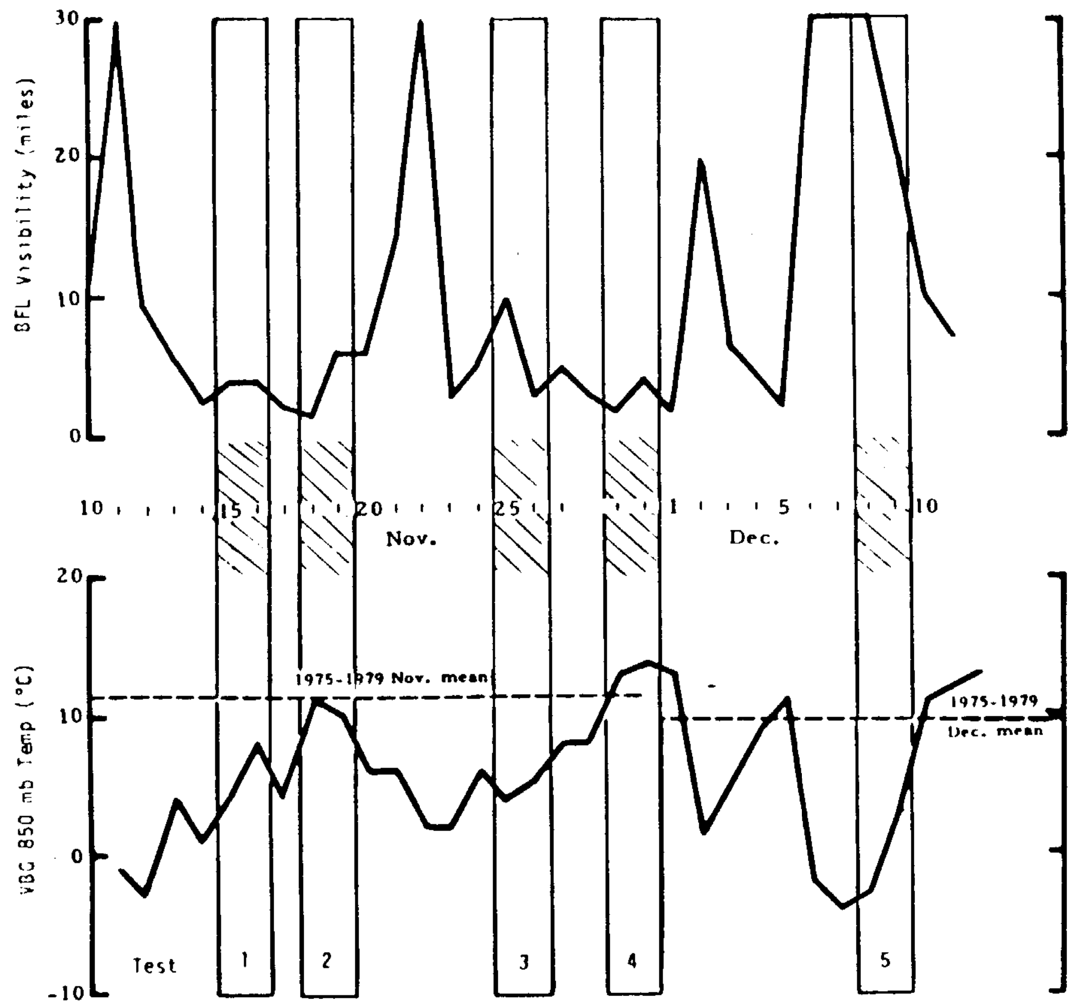


Figure 4.5.1 Visibilities and 850 mb Temperatures During the Winter Intensive Period

Table 4.5.1

FREQUENCY OF HIGH VISIBILITY EVENTS AT BAKERSFIELD (1967-77)

Month	Average Number of Events Per Month
September	2.7
October	1.9
November	2.1
December	2.4
January	2.4
February	3.0
March	4.4
April	4.9
May	4.4

Table 4.5.2

FREQUENCY OF MODERATE NORTHWESTERLY WIND EVENTS
AT STOCKTON (1975)

Month	No. Events	Month	No. Events
January	3	July	1
February	3	August	2
March	3	September	4
April	6	October	4
May	8	November	5
June	4	December	2

It is apparent from these data that significant frontal or trough passages occur in the valley on the order of 2-5 times per month but with variations ranging from one to eight events per month.