# 5. Mixing and Transport

## 5.1 Cross-Valley Transport

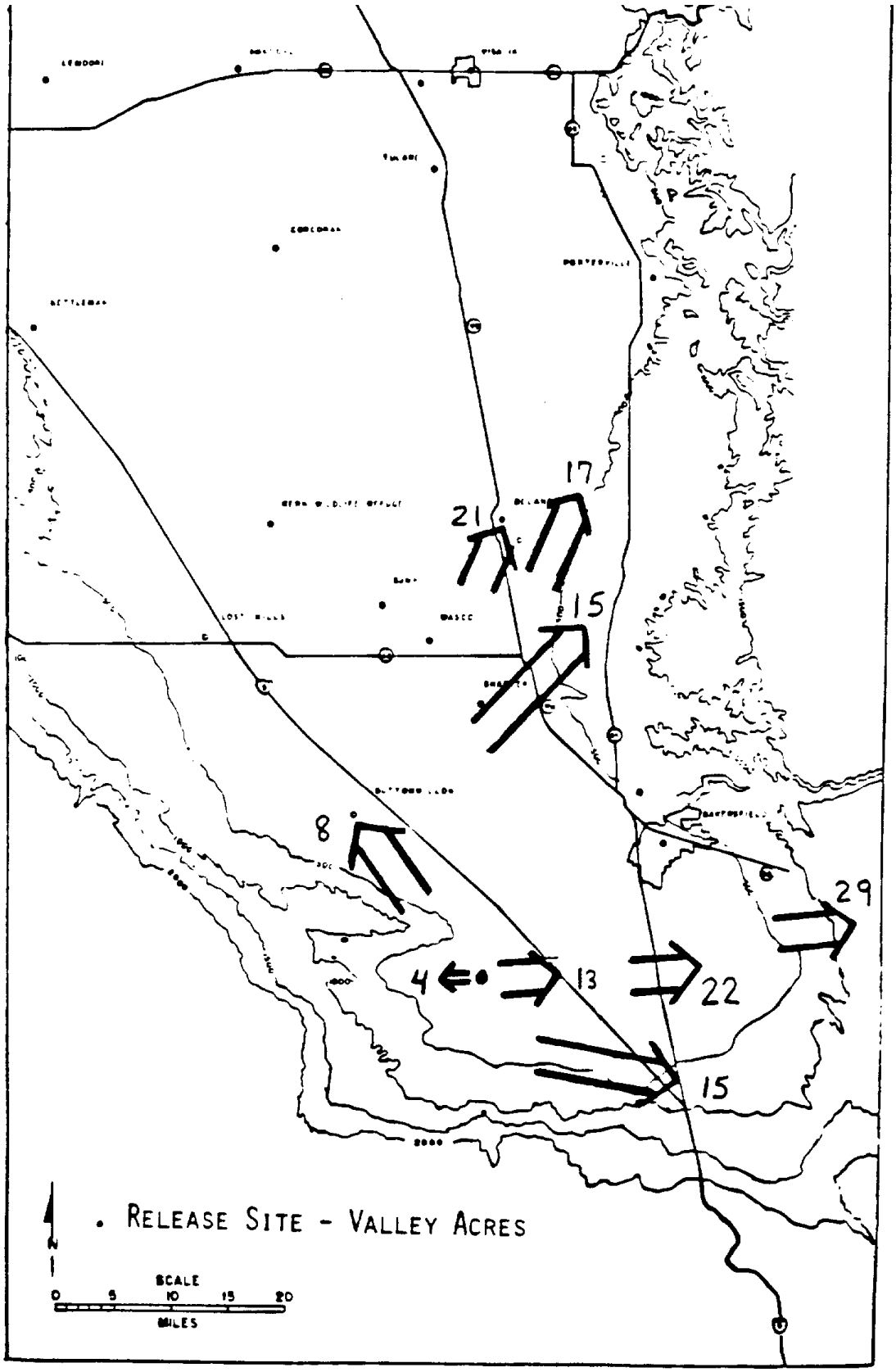
### 5.1.1 Introduction

Nighttime drainage winds from the mountain slopes on both sides of the San Joaquin Valley typically produce a convergence zone near the center of the valley. The implications of the converging flow on the transport of pollutants across the valley were addressed by a number of tracer studies during each of the three intensive periods.

### 5.1.2 Winter

During the first two tracer experiments of the winter field program ($SF_6$ releases from Chowchilla and Fresno in November, 1978), essentially none of the tracer was transported across the valley center to the western side. As described in Volume 3, the transport path of the tracer during these experiments was along the axis of the valley. During the subsequent five experiments, however, all conducted in the southern end of the San Joaquin Valley between November 1978 and March, 1979, the tracer was efficiently transported across the center of the valley.

Perhaps the best example of cross-valley transport is Tracer Test 4, conducted 11/29/78. On that date, about 416 lbs of $SF_6$ were released from Valley Acres, in the Elk Hills in the southwestern San Joaquin Valley. As shown in Figure 5.1.1, the tracer was transported to the eastern side of the valley by the early morning of 11/30/78. This transport occurred even though a well-defined convergence zone apparently existed near the center of the valley, as indicated by 2200 PDT streamlines (see Figure 5.1.2). At Greenfield, southeast of Bakersfield, the average impact of the tracer between 0900 and 1400 PDT on 11/30/78, was about 10 ppt/lb-mole of tracer released. Similarly, at Richgrove, about 25 miles north of Bakersfield, the average tracer concentration between 0600 and 1100 PDT was also about 10 ppt/lb-mole of tracer released. Clearly, the potential exists for transport across the center of the valley, even if a drainage flow convergence develops during the night. During the stagnant atmospheric conditions observed during Tracer Tests 6 and 7, conducted during February and March 1979, cross-valley transport led to efficient mixing of the tracer throughout that part of the San Joaquin Valley south of Wasco within 24 hours after the end of the release.




ARROW POINT INDICATES OBSERVED TRACER LOCATIONS
NUMBERS REFER TO HOURS AFTER RELEASE START (1200 PST)

Figure 5.1.1 Tracer Trajectories (11/29-30/78)

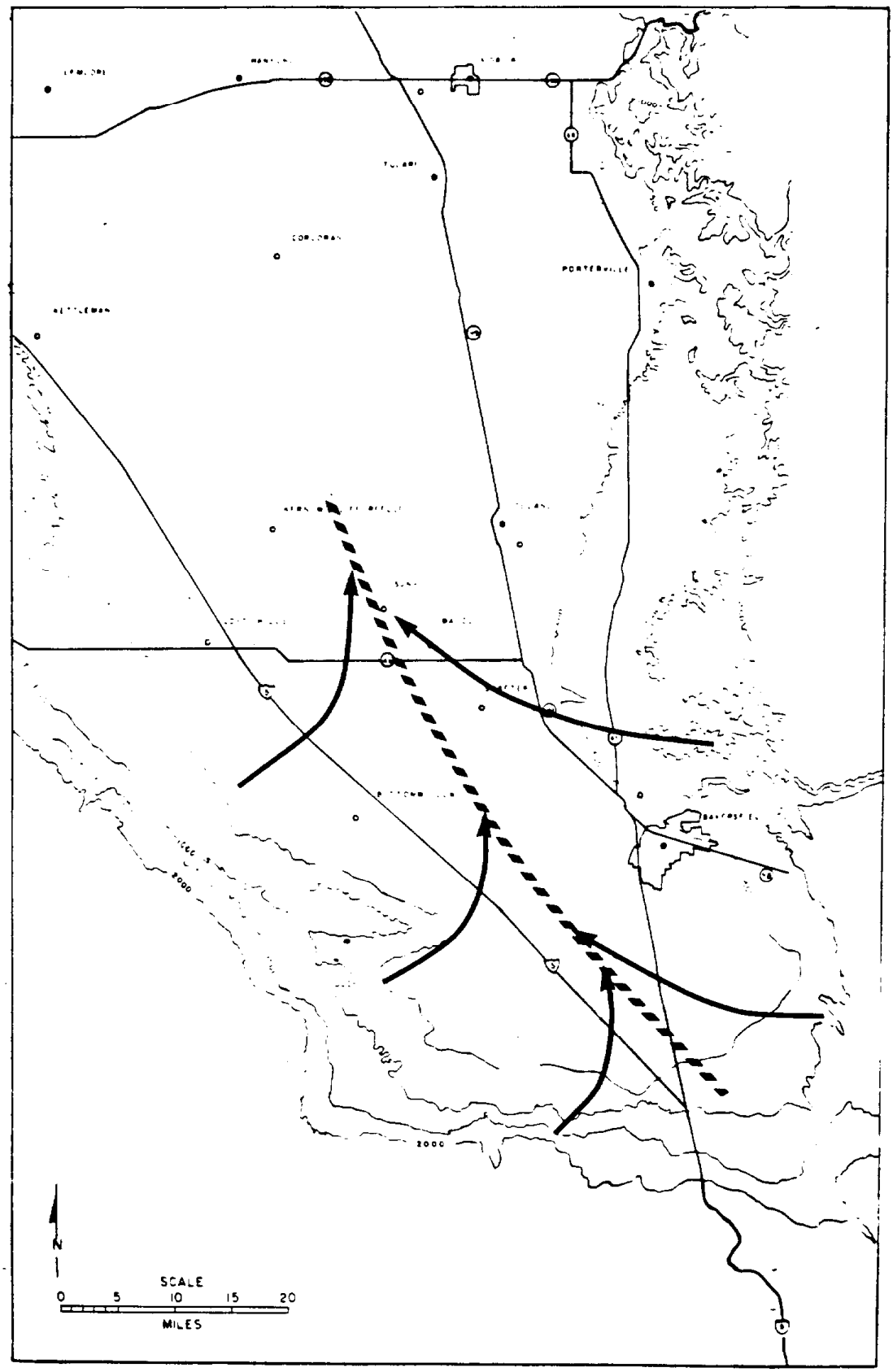



Figure 5.1.2 Surface Streamlines - 29 November 1978 (22 PST)

### 5.1.3 Summer

The July field program was concentrated in the northern half of the San Joaquin Valley. As in the winter experiments, the July experiments indicated that cross-valley mixing was limited in the northern part of the valley. For this purpose, the northern part of the valley is considered as that part of the valley north of Fresno. The southern part of the valley is assumed to include Visalia and all points south. During the first three experiments in the July program, the tracer was transported down the western side of the valley and essentially none was detected along the urban east side. Due to the presence of the Fresno Eddy with a southerly flow during the morning along the eastern side of the valley, it is apparently possible to transport pollutants from the western side of the valley to the east side, but pollutants must first be transported into the southern half of the valley. No direct transport from the west side to the east side or vice versa, in the northern half of the valley was observed under the test conditions encountered. In Test 4, during which $SF_6$ was released from Reedley, southeast of Fresno, some of the tracer was transported to Huron on the western side of the valley by early morning following the release. This cross-valley transport was apparently due to the eddy flow structure that developed during the night in the southern end of the valley and slowly grew toward the north, finally becoming the source of the southerly flow at Fresno during mid-morning. Again, the potential for cross-valley mixing by this flow structure appears to be limited in the northern half of the valley. During Test 1, a strong and persistent southerly flow was channelled to the east of the predominant northwesterly flow on the western side of the valley. The limited cross-valley mixing on this day is demonstrated by the generally lower maximum ozone concentrations observed on the west side than those on the opposite side of the valley (Figure 5.1.3).

### 5.1.4 Fall

The Fall experiment program (September 1979) was concentrated in the southern end of the San Joaquin Valley. Based on the information gleaned from the previous field programs, cross-valley mixing was expected to be an important dispersal mechanism during these experiments. The first, second

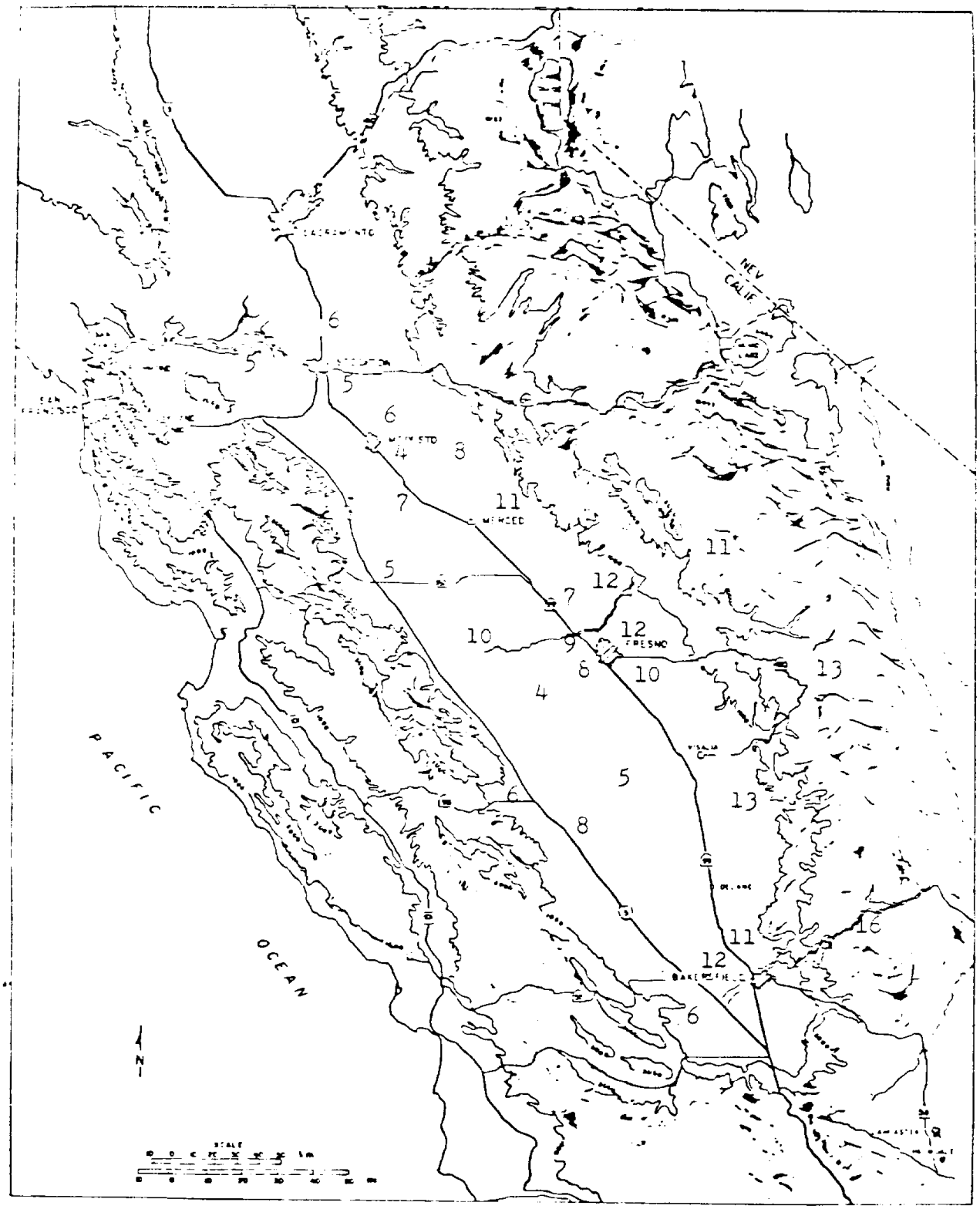



Figure 5.1.3 Maximum Hourly Ozone Concentrations (pphm) - 13 July 1979

and fifth tracer releases were conducted from Oildale, on the eastern side of the valley. During all three experiments, the tracer was initially transported by southeasterly drainage winds towards the center of the valley. Before detection of any significant amounts of the tracer on the western side of the valley, however, the afternoon northwesterly flow developed throughout the valley. These winds transported the tracer towards the southeast and in at least two of the three experiments, the majority of the tracer was transported into the Mojave Desert. Thus the strength of the northwesterly flow precluded any significant cross-valley mixing of the tracer released at Oildale during the Fall studies.

The third and fourth experiments during this intensive period, however, were conducted from the western side of the valley at Fellows. During Tracer Test 4, $SF_6$ was released between 01 and 07 PDT on 9/14/79, during a westerly drainage wind that conceivably could transport the tracer across the valley. As shown in Figure 5.1.4, the surface winds would predict that the tracer would be transported towards the northeast by the drainage flow from the western mountain slope. As shown in Figure 5.1.5, the winds at 1000 ft above ground level indicated a counterclockwise eddy structure of northerly winds in the center and western sides of the valley and southerly winds along the extreme eastern edge of the valley. The combination of these winds led to transport of the tracer to the eastern side of the valley. At Bakersfield, an hourly-averaged concentration of about 350 ppt/lb-mole of $SF_6$ released/hr was detected between 10 and 11 PDT. The concentrations detected at all hourly-averaged sampling sites are included in Figure 5.1.6 and the locations of these sites are shown in Figure 5.1.7. Automobile traverses at about 10 PDT indicated that the centerline of the tracer plume was at Bakersfield and Oildale. Low levels of tracer, however, were also detected at Mettler, south of Bakersfield. The tracer detected south of the plume centerline probably represents material that had mixed upward into the northerly flow aloft. The majority of the tracer, however, was apparently transported directly across the valley in the surface layer winds. During the afternoon, the strong northwesterly flows over the Tehachapi Mountains transported the tracer towards the Mojave Desert, as evidenced by the detection of $SF_6$ at Keene (included in Figure 5.1.6). Thus the transport of tracer from west to east during the morning was not repeated in the opposite direction during the subsequent evening.

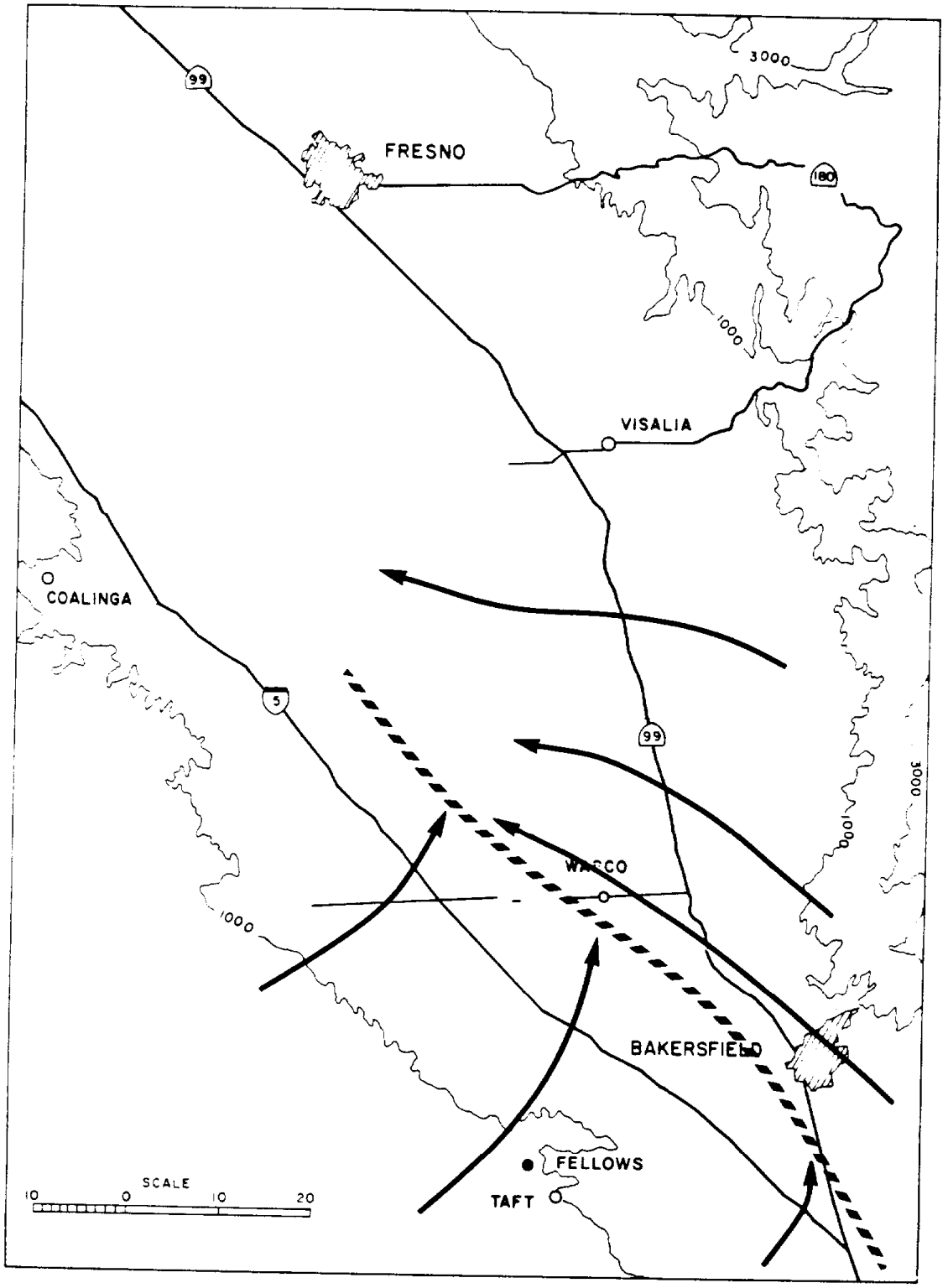



Figure 5.1.4 Surface Streamlines - 14 September 1979 (05 PDT)

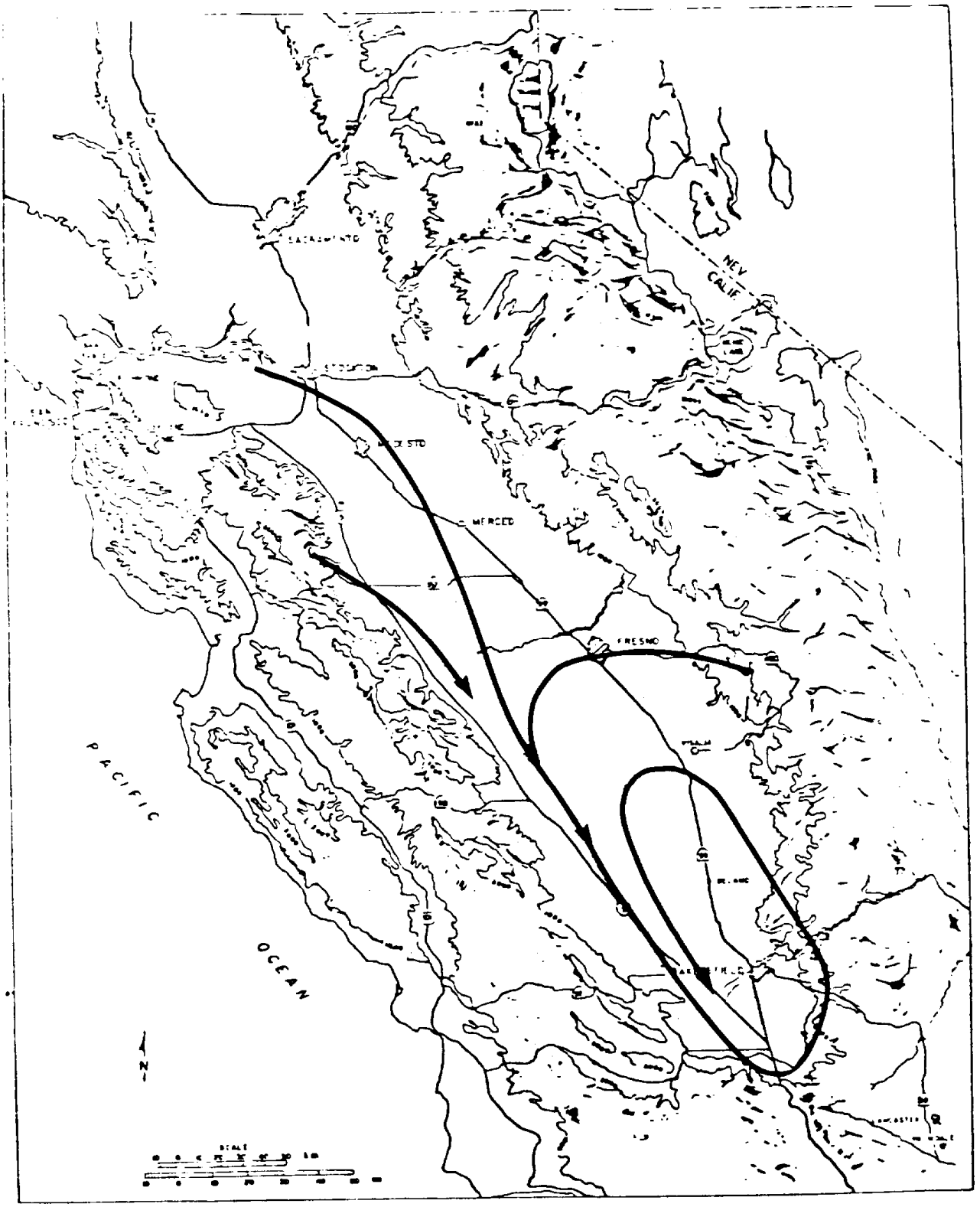
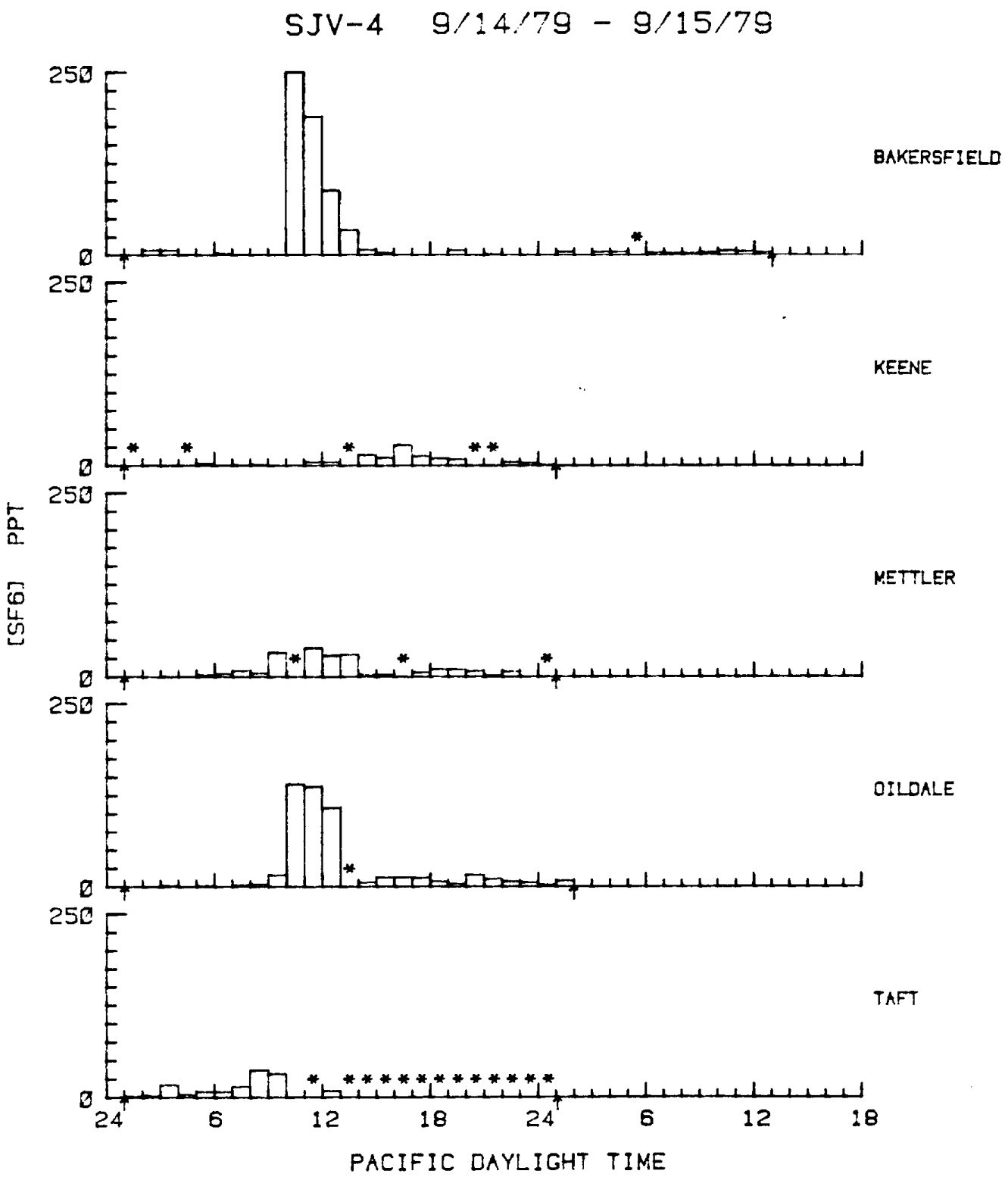


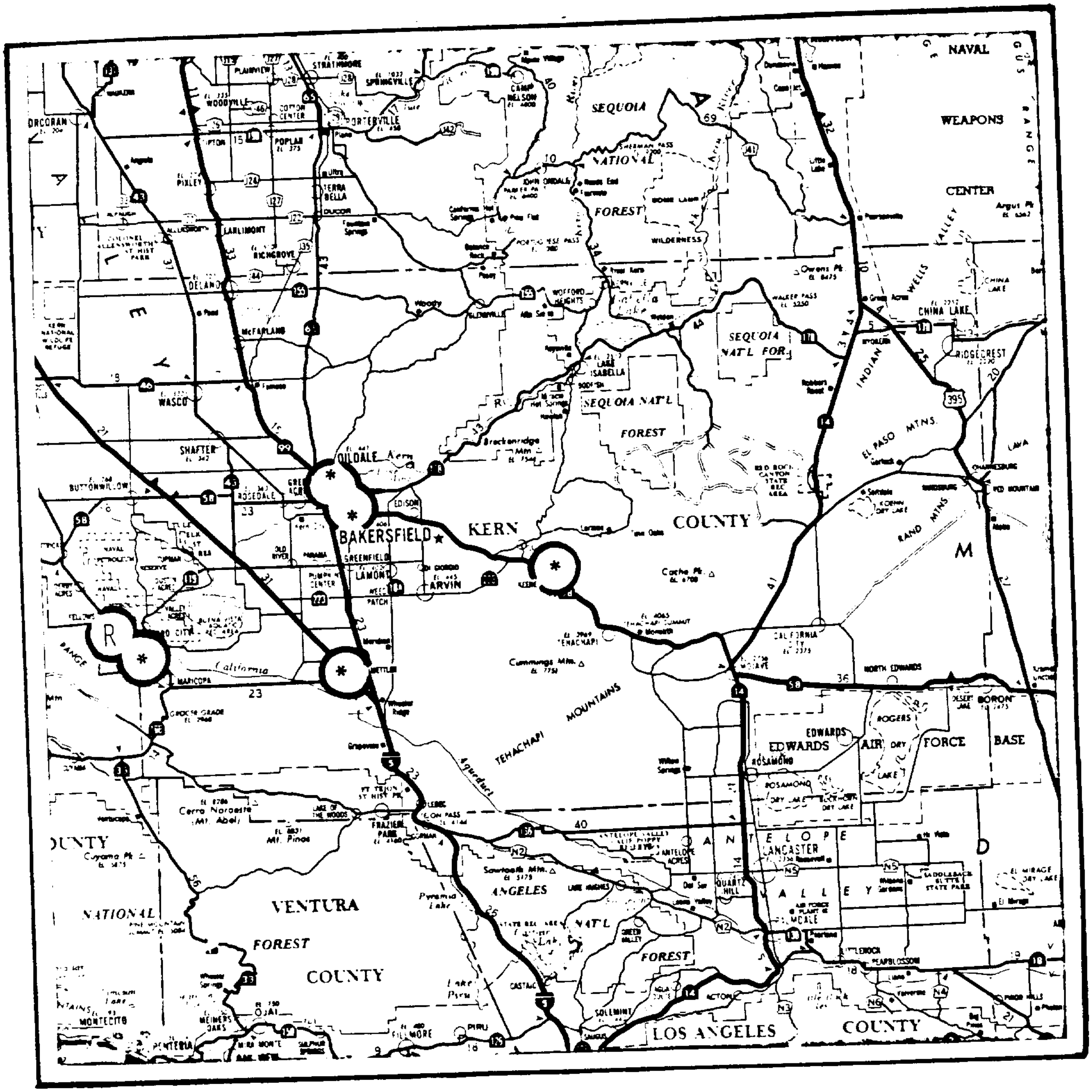

Figure 5.1.5 1000 Ft-agl Streamlines - 14 September 1979 (05 PDT)




RELEASE LOCATION: 615 # SF6 AT FELLOWS
RELEASE TIME: 0107-0647 PDT, 9/14/79

* INDICATES MISSING DATA
ARROWS INDICATE BOUNDS OF SAMPLING PERIOD

Figure 5.1.6




(*) INDICATES SAMPLER LOCATIONS
(R) IS THE RELEASE SITE

Figure 5.1.7

### 5.1.5 Summary

In summary, the southern end of the San Joaquin Valley appears to be much more efficiently mixed than its northern half throughout the year. During the winter, the mixing in the southern end of the valley is driven by the strength of the nighttime drainage flows from both sides of the valley. During the summer and early fall, however, the afternoon northwesterly flow throughout the valley dominates the transport within the southern valley. Transport from the western side of the valley towards the east occurred by early morning of the day following release. Subsequently the northwesterly flow mixes the material throughout the southern part of the valley by mid-day. The reverse transport direction was not observed due to the onset of the northwesterly flow. As mentioned previously, the afternoon upslope flow over the eastern boundary of the valley during the summer is the most efficient ventilation mechanism for the valley demonstrated during the entire test program.

## 5.2 Nocturnal Wind Jet

### 5.2.1 Introduction

The existence of a low-level wind jet in the San Joaquin Valley has been recognized for a number of years. Willis and Williams (1972) carried out a field study with eight pibal locations for a limited period during the summer of 1971. They found that the jet was centered at an average height of about 300 m above ground with highest wind speeds of about 20 mps. The jet was determined to be stronger in the northern part of the valley compared to the southern part. The driving force for the jet was indicated as a pressure gradient generally directed from the coast inland during the summer months. A deep mixing layer in the valley was found to inhibit the development of the jet.

Morgan (1974) carried out additional studies of the nocturnal jet occurrences. He found that the jet tended to develop slightly later in the southern part of the valley and at a slightly greater elevation above ground. Based on the occurrence of at least a 10 mph wind at 1600 ft msl near Fresno Morgan found jet occurrences on about 90 percent of the summer nights included in his study.

### 5.2.2 Description of the Nocturnal Jet

Figure 5.2.1 shows a vertical time-section of the wind components along the valley axis at Los Banos and Fresno for the period July 16-17, 1979. Positive components refer to flow directed from Stockton toward Bakersfield.

After a short afternoon sea breeze at 13 and 15 PDT, primarily at Los Banos, the development of the nocturnal jet starts abruptly at 19 PDT. Peak up-valley components occurred at 23 PDT at both locations. By comparison, peak flow occurred at 21 PDT at Stockton and Visalia. It is apparent that there is little time variation in development of the jet throughout the valley. Overall depth of the jet in Figure 5.2.1 was about 800 m at both locations. Peak velocities occur at about 300 m. The effect of the "Fresno Eddy" is shown in the time-section as negative component winds at Fresno in the lowest 900 m, beginning at 07 PDT.

Figure 5.2.2 shows the time variations in average wind velocity below 600 m for Fresno and Los Banos for July 16-17, 1979. The average wind velocity increases abruptly from 17 to 19 PDT, reaching a peak at 23 PDT. During the morning hours (07-13 PDT) the wind component at Fresno becomes negative as a result of the Fresno Eddy while the Los Banos component remains positive (northerly wind) but steadily decreases in magnitude. Peak velocities at the two locations were similar suggesting the wide horizontal extent of the flow.

Also included in Figure 5.2.2 is the time variation in surface pressure gradient between San Francisco and Las Vegas for July 16-17. This gradient was positive (San Francisco pressure higher) throughout the entire 24-hour period, reaching a diurnal peak at 21 PDT.

Following the discussion of Morgan (1974) and illustrated by the data in Figures 5.2.1 and 5.2.2 there are several factors which influence the development of the nocturnal jet:

1. Synoptic pressure gradient - As shown in the data for July 16-17, the pressure gradient is directed from the coast to the inland areas throughout the day. This provides the necessary driving force for the development of northwesterly winds in the valley.

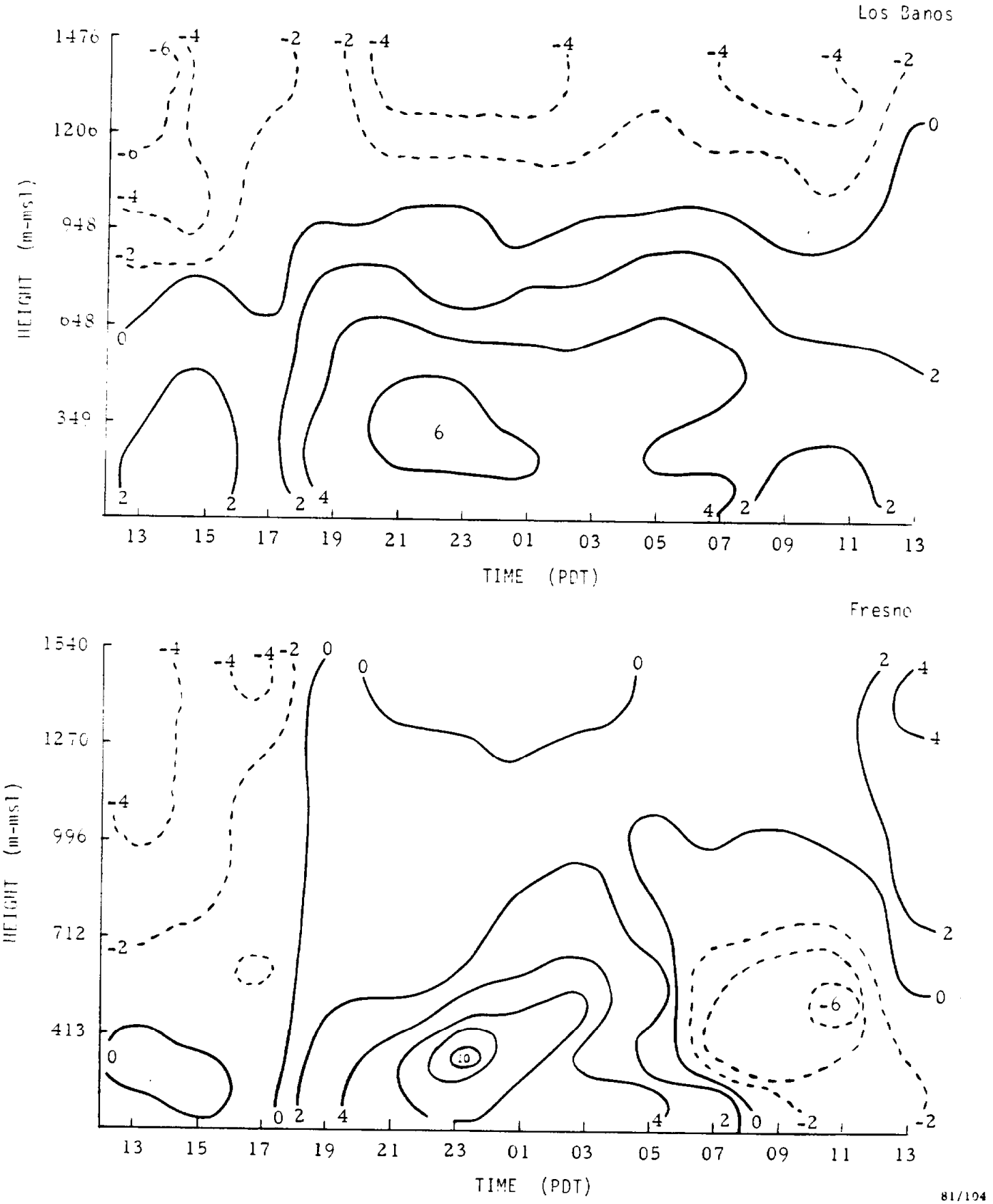



Figure 5.2.1 Valley Axis Wind Components (m/s) - July 16-17, 1979

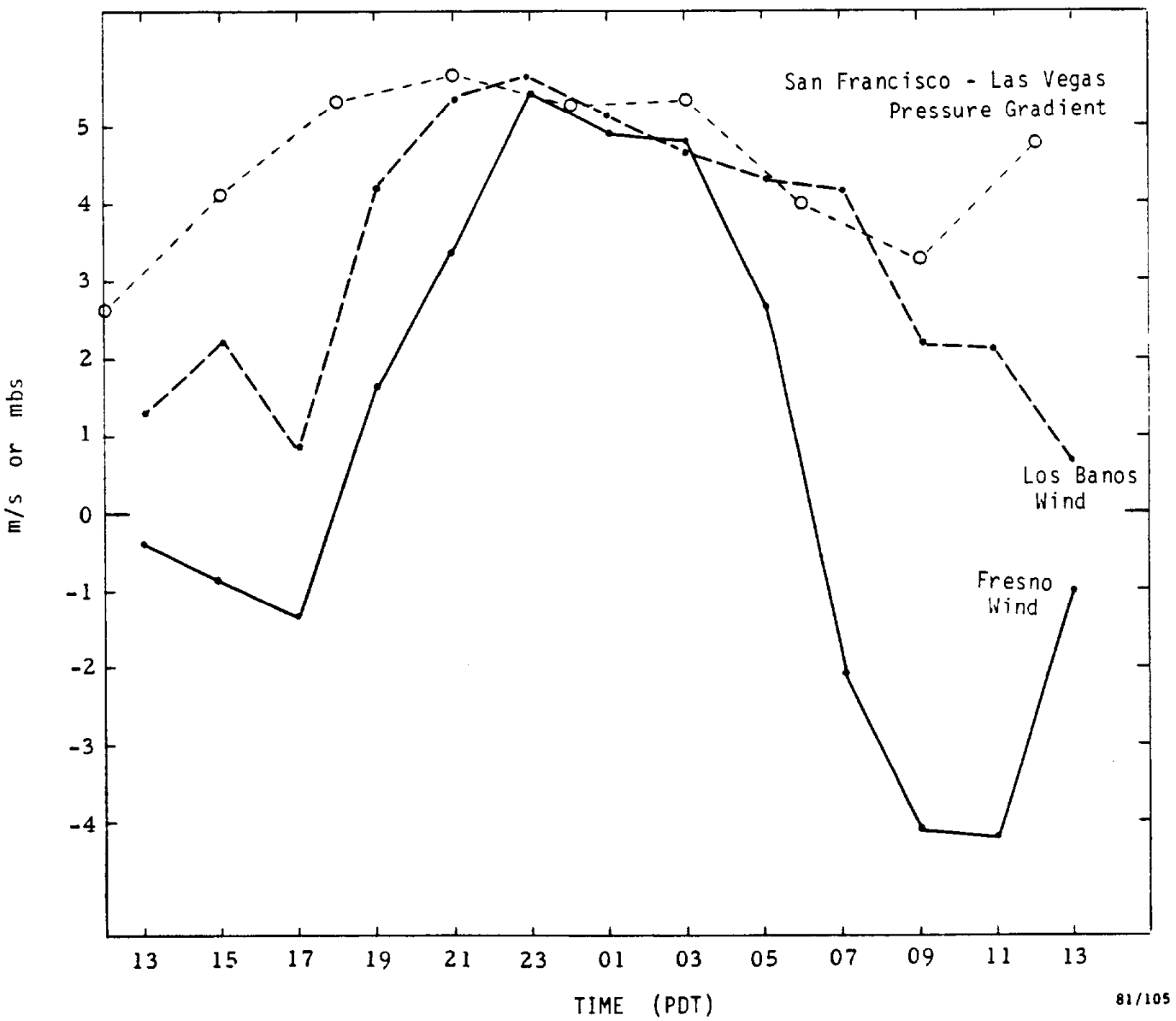



Figure 5.2.2 Comparison of Pressure Gradients and Valley Axis Flux in Lowest 600 m, July 16-17, 1979

2. Diurnal pressure gradient - There is a considerable diurnal variation in the pressure gradient which provides an additional impulse to develop the northwesterly winds during the evening.

3. Low-level stability - Coincident with the diurnal increase in the pressure gradient force, the low-level layers in the valley become more stable due to nocturnal cooling. This reduces the low-level frictional forces and permits the air aloft to accelerate relative to the afternoon velocities. The coincidence of the diurnal pressure gradient peak and the initiation of low-level stability reinforces this acceleration mechanism.

4. Stable layer aloft - Development of the nocturnal jet also requires that the mixing layer depth in the valley is relatively low so that the terrain channeling influences are effective (Morgan, 1974). Deep, nonstable layers preclude the development of the jet.

### 5.2.3 Frequency of Occurrence

The frequency of occurrence of the jet is highly dependent on the definition used to determine its existence. Indications of the jet in terms of velocity accelerations during the evening and/or profile characteristics are present on most nights during the summer. High velocity jets are present on only a limited number of nights.

A loose definition of jet occurrence was established as follows:

1. Velocity Profile - A peak low-level velocity was required at 21 PDT decreasing aloft by at least 25 percent from the maximum value.

2. Time Variation - Peak velocity at 21 PDT was required to be at least 25 percent greater than existing at 13 PDT.

Based on this definition the following jet-like occurrences were indicated:

Table 5.2.1

JET FREQUENCY OCCURRENCES

| | | |
|---|---|---|
| July 1979 | | |
| | Fresno | 75 percent |
| | Los Banos | 80 |
| September 1979 | | |
| | Fresno | 90 percent |
| | Los Banos | 81 |

The non-occurrences at Fresno and Los Banos did not necessarily occur on the same nights so that some tendency for jet formation was present on virtually all nights in the valley.

The existence of high velocity jets is summarized in Table 5.2.2:

Table 5.2.2

HIGH VELOCITY (>8 m/s) JET OCCURRENCES

| | | |
|---|---|---|
| July 1979 | | |
| | Fresno | 60 percent |
| | Los Banos | 50 |
| September 1979 | | |
| | Fresno | 70 percent |
| | Los Banos | 29 |

### 5.2.4 Effects of the Nocturnal Jet

The nocturnal jet provides a mechanism for effective transport of pollutants from north to south within the valley. During the tracer test of September 21 from Manteca, tracer material was transported rapidly to the Bakersfield area in about 25 hours after release. It appeared that this transport had been aided by the existence of the nocturnal winds.

The development of the jet requires that limited mixing exist between the surface and the elevation of the jet. Pollutants being transported southward therefore do not appear at the surface in significant concentrations until the following day when nocturnal heating deepens the mixing layer and destroys the remnants of the nocturnal jet. These mixing characteristics were observed in the tracer release of July 27-28 when tracer material was injected directly at jet level.

## 5.3 Fresno Eddy

### 5.3.1 Introduction

The frequent occurrence of southeast winds at Fresno during the early morning hours of the summer has been observed for several years. Unger has written several CARB memos concerning the phenomenon which has come to be known as the "Fresno Eddy." The availability of seven pibal stations during the summer and early fall field programs has made a more detailed description of the Eddy possible than heretofore.

### 5.3.2 Description of the Eddy

The formation of the Fresno Eddy is associated with the development of low level stability in the southern part of the valley. During the summer afternoon and early evening, temperature lapse rates in the valley (to 5000 ft msl or more) are usually near neutral in response to strong surface heating. Air flow over the Tehachapis (about 4500 ft msl) is relatively unimpeded under these conditions.

During the evening, surface temperatures decrease and the lapse rate in the layers below 4500 ft becomes relatively stable. Under such circumstances the movement of low-level air up the slope and over the Tehachapis is impeded by the opposing density forces. The low-level northwesterly flow existing in the valley at this time must therefore be deflected back toward the north in the form of an eddy. This sequence is shown in Figures 5.3.1 to 5.3.4 which illustrates the development of the eddy from 21 PDT on September 16, 1979 to 09 PDT on September 17. The figures represent 1000-foot (agl) streamlines which are sufficiently far above the surface layer to represent the basic low-level flow pattern.

Figure 5.3.1 at 21 PDT shows a characteristic northwesterly flow throughout the entire valley including the Bakersfield area. By 01 PDT (Figure 5.3.2) a eddy has formed in the southern part of the valley with moderate wind velocities from the northwest at Taft and an easterly wind at Visalia. In Figure 5.3.3 (05 PDT) the eddy has extended past Fresno with south to southeasterly winds along the east side of the valley. At 09 PDT the eddy center remained in the vicinity of Visalia-Fresno. The strength

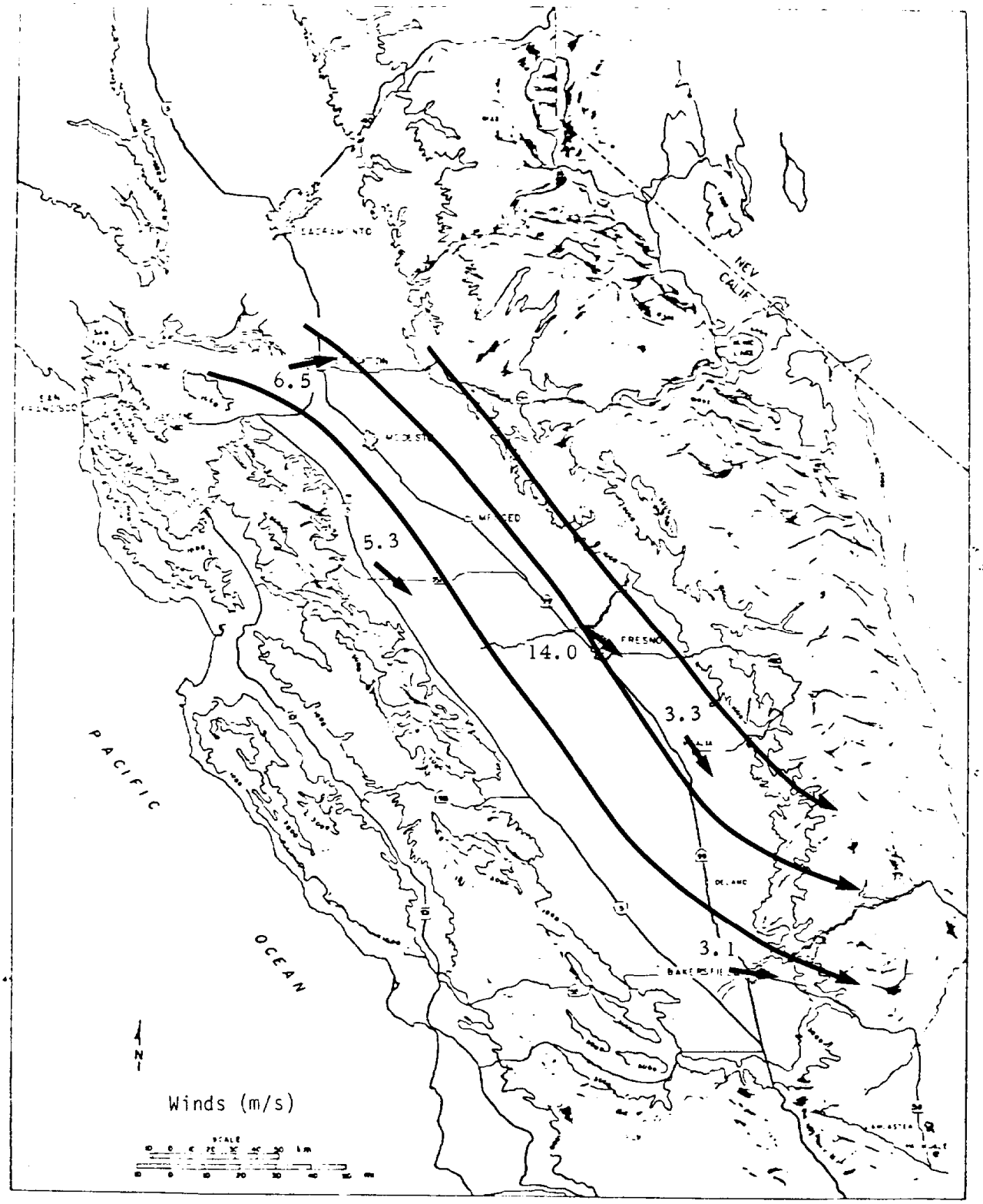



Figure 5.3.1 1000 Ft-msl Streamlines - September 16, 1979 (21 PDT)

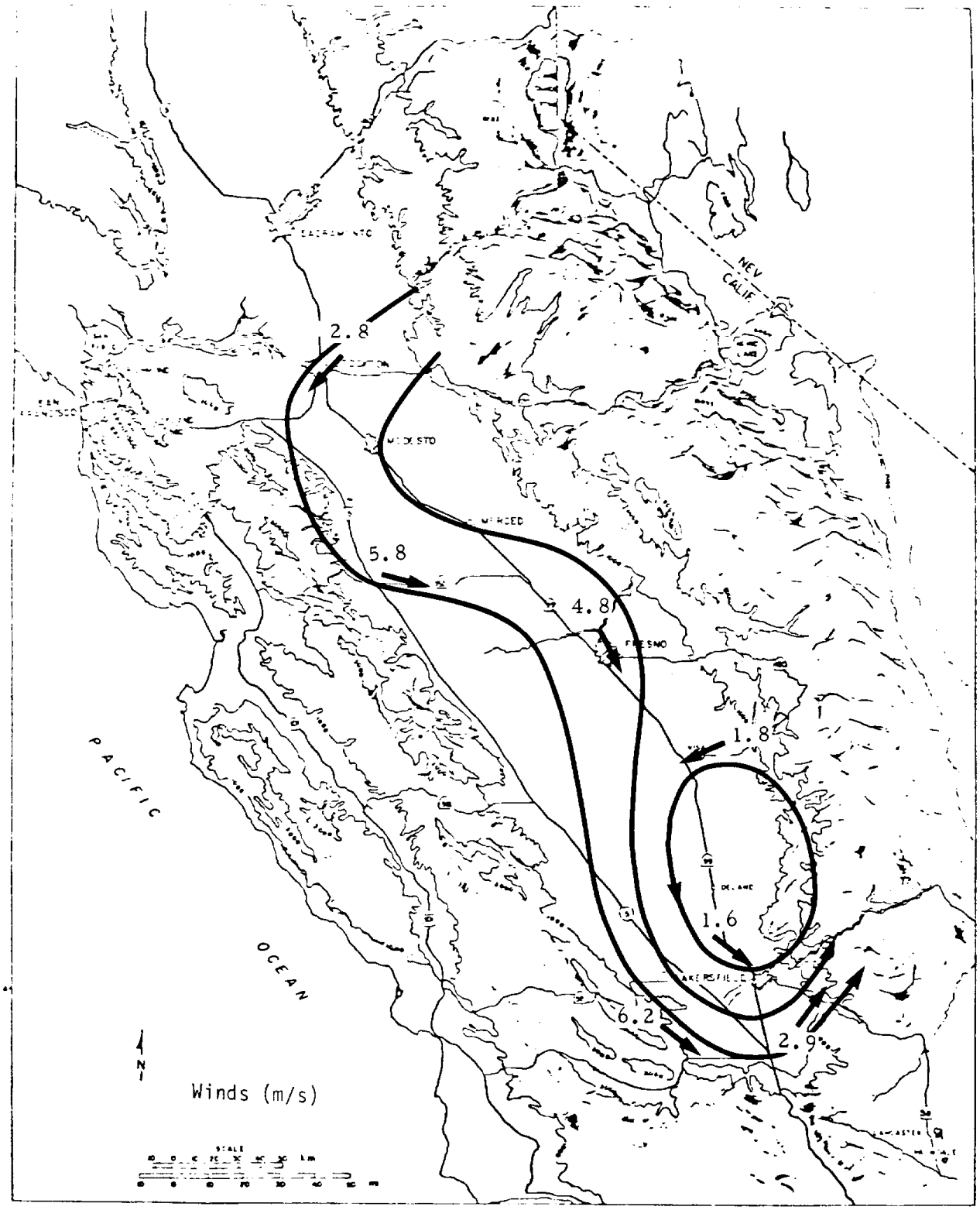



Figure 5.3.2 1000 Ft-msl Streamlines - September 17, 1979 (01 PDT)

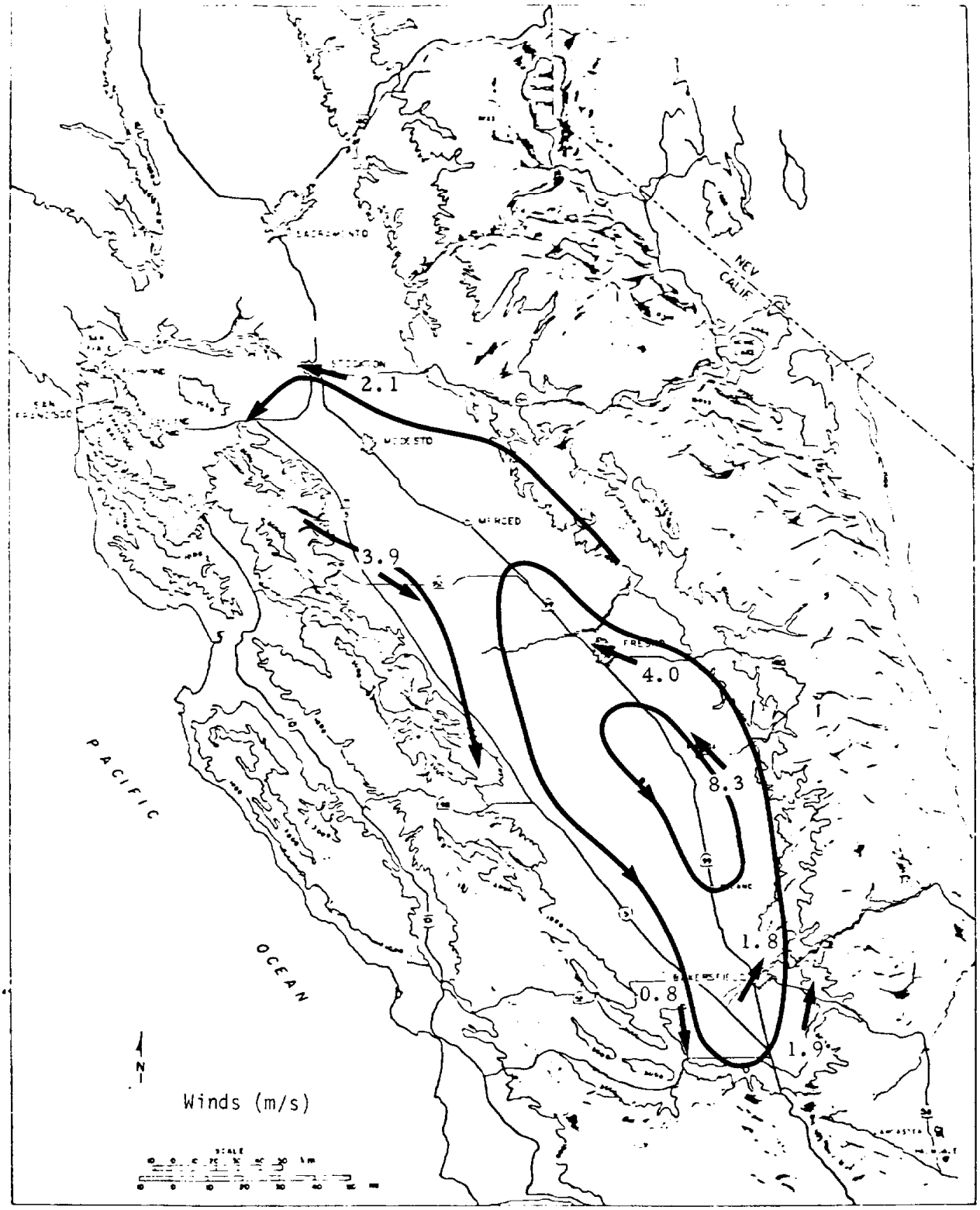



Figure 5.3.3 1000 Ft-msl Streamlines - September 17, 1979 (05 PDT)

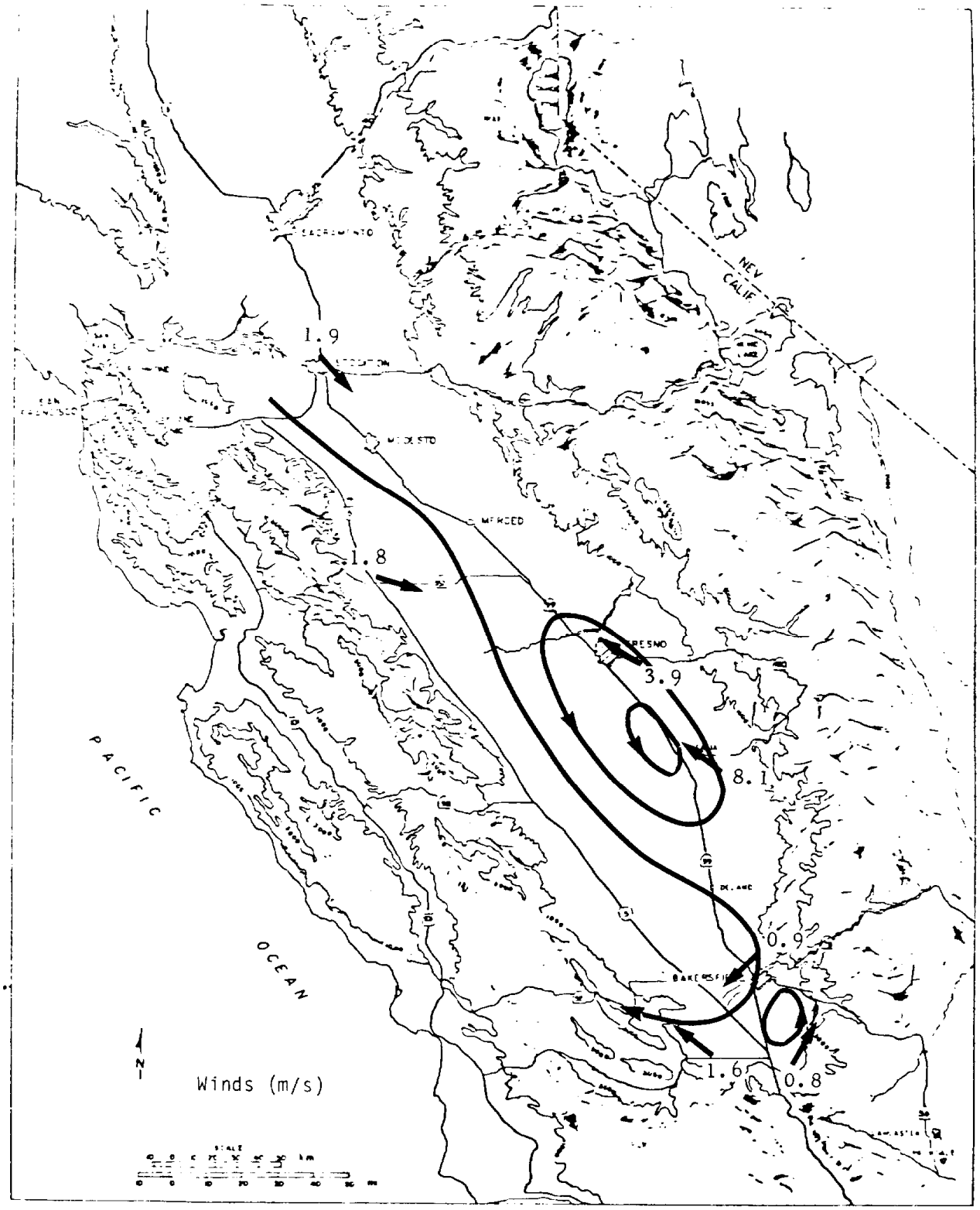



Figure 5.3.4 1000 Ft-msl Streamlines - September 17, 1979 (09 PDT)

of the eddy circulation is evidenced by 1000-foot winds of 8 m/s or more from the south-southeast at Visalia at 05 and 09 PDT. The eddy center moved to the north of Fresno by 13 PDT and the entire eddy structure disappeared by 15 PDT as the surface mixing layer deepened sufficiently to encompass the layers in which the eddy was embedded.

The movement of the eddy center to the north during the night and early morning is typical of the usual eddy development. It is apparent that this development is a dynamic, non-steady state process which will be difficult to model adequately.

Figure 4.4.1 gives the profiles at 17 PDT when all five locations show similar profiles, indicating flow in a direction from Stockton toward Bakersfield. By 21 PDT (Figure 4.4.2) the wind components at Los Banos and Fresno show increased velocities in the low levels accompanying the development of the nocturnal jet. At Bakersfield, however, the wind components are considerably reduced below 1200 m (agl) but increased above that height relative to the other locations. This deviation in the Bakersfield wind profile is interpreted as a terrain-blocking effect in the low levels and a deflection of some of the northwesterly flow over the top of the blocked region. The eddy, of course, forms in the layers being blocked by the terrain.

At 05 PDT (Figure 4.4.3) Stockton, Los Banos and Fresno show similar profiles, representing a uniform flow from the northwest, Visalia and Bakersfield however, show evidence of the terrain blocking again accompanied by the increased velocities aloft necessary to maintain mass continuity with the flow in the northern part of the valley. Increased flow at Visalia and Bakersfield occurs above about 1300 m (agl) in the figure.

Figure 4.4.4 shows the profiles for 09 PDT. At this time the low-level flows at Fresno, Visalia and Bakersfield are also reduced relative to Los Banos and Stockton. Very little increase in velocity aloft is evident, however, at Fresno. The 1300 m altitude again represents an approximate dividing line between increased and decreased wind components at Visalia and Bakersfield.

A vertical perspective on the eddy development has been given in Section 4.4. This description suggests that the blocked flow extends farther and farther upstream during the night so that all of the area from Fresno south is involved by 09 PDT. This vertical picture corresponds to the growth of the horizontal flow patterns indicated in Figures 5.3.1 to 5.3.4. The depth of the eddy agrees with the approximate elevation of the terrain at the south end of the valley. Above this level (about 4500 ft msl) the northwesterly flow in the valley can escape over the Tehachapis.

### 5.3.3 Frequency of Occurrence

The 09 PDT wind at Fresno at 1000-ft (agl) was used as a simple indicator of the existence of the Fresno Eddy. If the 09 PDT wind was from an easterly or southerly direction a Fresno Eddy was indicated to exist.

Of the 22 days in July for which 09 PDT pibals were available at Fresno, 18 showed evidence of an eddy. A total of 17 eddy days were found in the 22 available September days.

The following dates showed no eddy existence at Fresno under the definition chosen:

DATES OF NON-OCCURRENCE OF FRESNO EDDY

| July 1979 | September 1979 |
|---|---|
| 10 | 4 |
| 11 | 8 |
| 26 | 18 |
| 28 | 24 |
| | 25 |

Reference to the 850 mb temperatures (see Volumes 4 and 5) indicates that these days were characterized by cooler air temperatures aloft, usually lasting for one or two days as a cold air trough moved through the area.

The effect of the cold air aloft is apparently to lessen the nocturnal stability effects and to permit the northwesterly flow to pass over the Tehachapis more readily during most of the night.

### 5.3.4 Effects of the Eddy

The primary importance of the eddy from an air pollution standpoint lies in its ability to redistribute pollutants, primarily throughout the southern part of the valley. In an unusual case on the morning of July 13, the eddy was present throughout the entire valley as far north as Modesto. Ozone was being transported from the south to the north in this flow while the air in the northwest flow along the west side of the valley showed much lower ozone concentrations. Due to the extensive length of the valley, air can usually only be transported through about half of the valley length by the eddy before it disappears. Consequently, a thorough horizontal mixing process is not possible but significant transport can occur.

Such a pronounced cyclonic eddy would be expected to represent a convergent area characterized by small upward velocities throughout its wide horizontal extent. There is some evidence that pollution in the lower, blocked layers can be transported upward to regions above the eddy where escape by upper-level winds may be possible. This process has not been explored in detail as yet. The eddy may also redistribute ozone as layers aloft where it may be incorporated into the mixing layer on the following day.

## 5.4 Local Source Areas - Airborne Sampling

### 5.4.1 Introduction

During the three intensive field studies, the MRI aircraft sampled the air quality over a number of source and downwind receptor areas. In this section concentrations of $O_3$, $NO_x$ and $SO_2$ as measured by the aircraft are considered. The urban plumes from the two largest population centers in the valley, Fresno and Bakersfield, were each sampled under two different sets of meteorological conditions; fall and winter. The latter sampling was in conjunction with tracer releases within the urban center. The oil fields in Kern County are the major source of sulfur dioxide emissions in the San Joaquin Valley. For this reason, airborne measurements obtained while orbiting an oil field in East Kern County are included in the following discussion.

### 5.4.2 Sampling Aircraft Description

The MRI Cessna 206 was utilized as the sampling platform for this study. Air quality, meteorological, and position parameters listed in Table 5.4.1 were recorded at the rate of 2.4 times per second on computer-compatible magnetic tape. Tracer syringe samples were also collected for analysis by CalTech. During the winter intensive study, a Theta Sensor LS400 was used to measure $SO_2$ but was replaced by the Meloy 285 monitor for the remainder of the program.

The gas monitors were multipoint-calibrated in-situ on a routine basis after every two flights. The nephelometer was calibrated with Freon 12 two or more times during each intensive period. Prior to each flight, standard preflight checkouts were performed to insure that the equipment was functioning properly.

### 5.4.3 Fresno Urban Plume

Fall

The MRI airplane sampled in the Fresno area on 21 September 1979 when numerous exceedances of the California air quality standard for ozone (10 pphm) were experienced throughout the San Joaquin Valley. Maximum hourly average surface concentrations (14 pphm) were measured in the Fresno metropolitan area.

Table 5.4.1

MRI CESSNA 206 INSTRUMENT CONFIGURATION

- Sulfur Dioxide - Meloy 285 E
- Ozone - Bendix
- Oxides of Nitrogen - Monitor Labs 8440
- Integrating Nephelometer - MRI Model 1550
- Temperature - MRI Vortex-housed Thermister
- Dew Point - Cambridge Systems 137
- Turbulence - MRI 1120 UITS
- Condensation Nuclei - Environment One Rich 100
- Altitude, Indicated Airspeed - Validyne Pressure Transducers and Pitot Static Probe
- Position - Aircraft VOR/DME
- Data System - LSI 11 Computer System. One scan per sec logged on cassette recorder
- Chart Recorder - Linear Instruments Model #486 (2-channel)

The winds in the area were light and variable until late afternoon which contributes to the high oxidant concentrations within the city. An additional effect of the variability of the flow was the broad and diffuse nature of the urban plume as defined by the airborne sampling. Ozone and $NO_x$ were relatively evenly distributed on two traverses, each greater than 40 km in length. Mean ozone and $NO_x$ concentrations were 16-17 pphm and 2 pphm, respectively. The data are summarized in Table 5.4.2. On a traverse east of Fresno at the edge of the valley, sampling was extended until rural or background air was encountered. A plot of the data from this traverse is shown in Figure 5.4.1. From the table it is seen that within the urban air ozone and $NO_x$ levels were comparable for the first two traverses. Outside the plume, average ozone levels dropped 7 pphm and $NO_x$ 1 pphm. The maximum instantaneous concentration of ozone (20 pphm) was measured within the urban air during the last traverse approximately 8 miles east of Fresno.

DATE: 9/21/79
CARTRIDGE/PASS: 711/ 9
PASS START TIME : 18:20: 2

ROUTE: Friant Dam to Great Western Airport
ALTITUDE: 610 M(MSL)

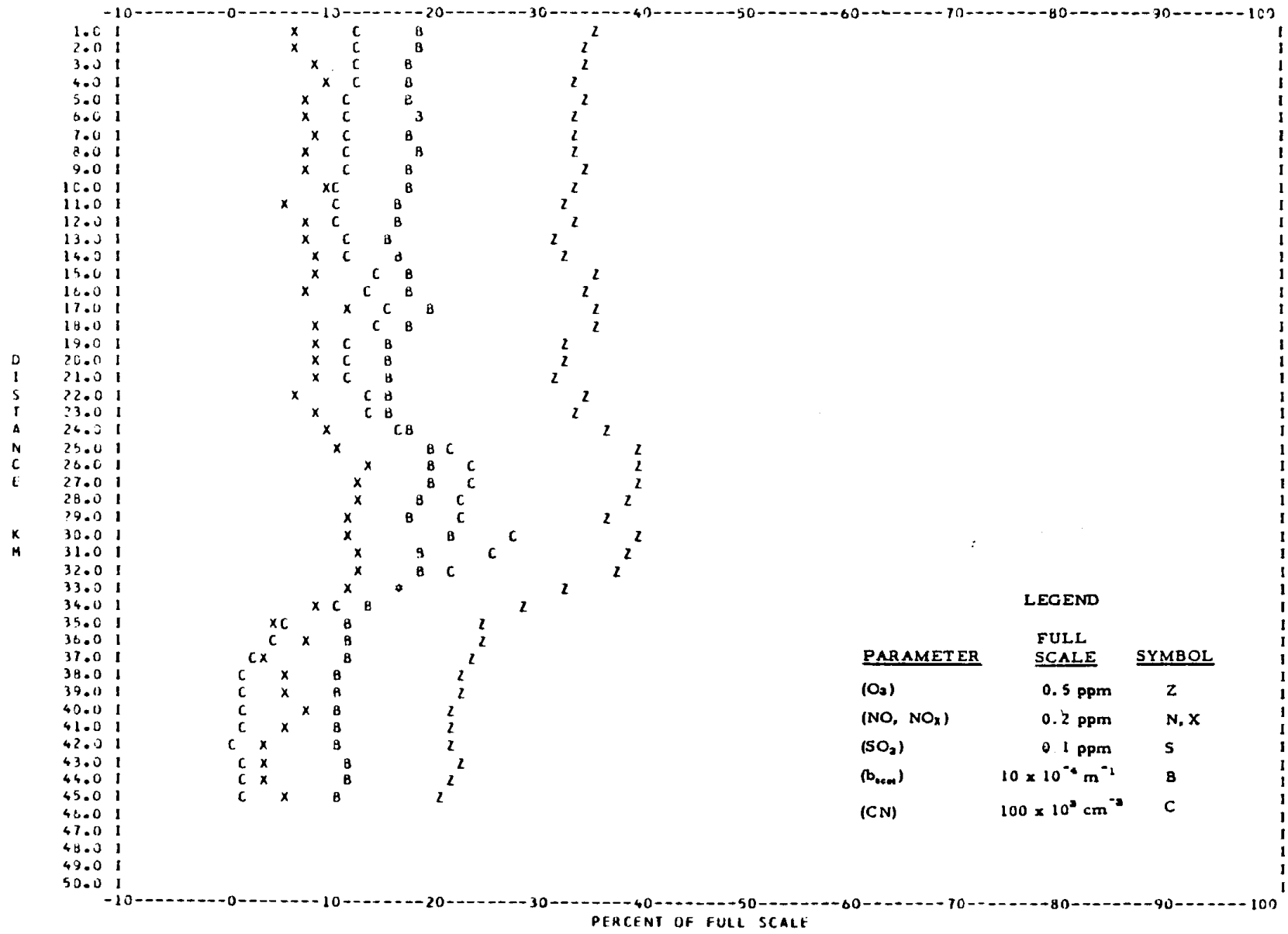



Figure 5.4.1 Horizontal Distribution of Selected Air Quality Parameters
Downwind of Fresno, 21 September 1979 - Altitude 2000 ft

Table 5.4.2

21 SEPTEMBER 1979 AIRCRAFT SAMPLING - FRESNO

| | Altitude (m-msl) | $O_3$ Mean* | $O_3$ Maximum* | $NO_x$ Mean* | $NO_x$ Maximum* |
|---|---|---|---|---|---|
| NW-SE Traverse Across Fresno | 457 | 16 | 18 | 2 | 6 |
| NE-SW Traverse Across Fresno | 457 | 17 | 19 | 2 | 4 |
| NW-SE Traverse E of Fresno | 610 | | | | |
| Within Plume | | 17 | 20 | 2 | 3 |
| Outside Plume | | 11 | 12 | 1 | 2 |

* Concentrations reported in pphm

Winter

In conjunction with a tracer release from the downtown area on 18 November 1978, the urban plume from Fresno was sampled with the MRI aircraft. The tracer was released between 1300-1700 PST and airplane sampling was conducted from 1430-1730 PST. In the afternoon, a general southeast flow developed and the urban air was transported to the north. The sampling airplane flew several traverses downwind of the city within the mixing layer and one upwind traverse. Figure 5.4.2 shows a typical distribution of pollutants along one of the downwind traverse routes at 457 m (msl). As can be seen the plume was well defined by the distribution of $O_3$, $NO_x$, and CN. The increase of condensation nuclei within the urban air is typical near the source area. The number of condensation nuclei decreased at farther downwind distances due to particle coagulation. In Table 5.4.3, $NO_x$ and $O_3$ concentrations measured upwind and downwind at 457 m (msl) are tabulated. The main points illustrated by the data in the table are:

- Background $NO_x$ and $O_3$ concentrations are approximately 2 pphm and 8 pphm, respectively.
- At 5 miles downwind (of the downtown area), $NO_x$ concentrations averaging 5 pphm were measured within the plume or 3 pphm in excess of the background. Average ozone deficits of 3 pphm were observed within the plume.

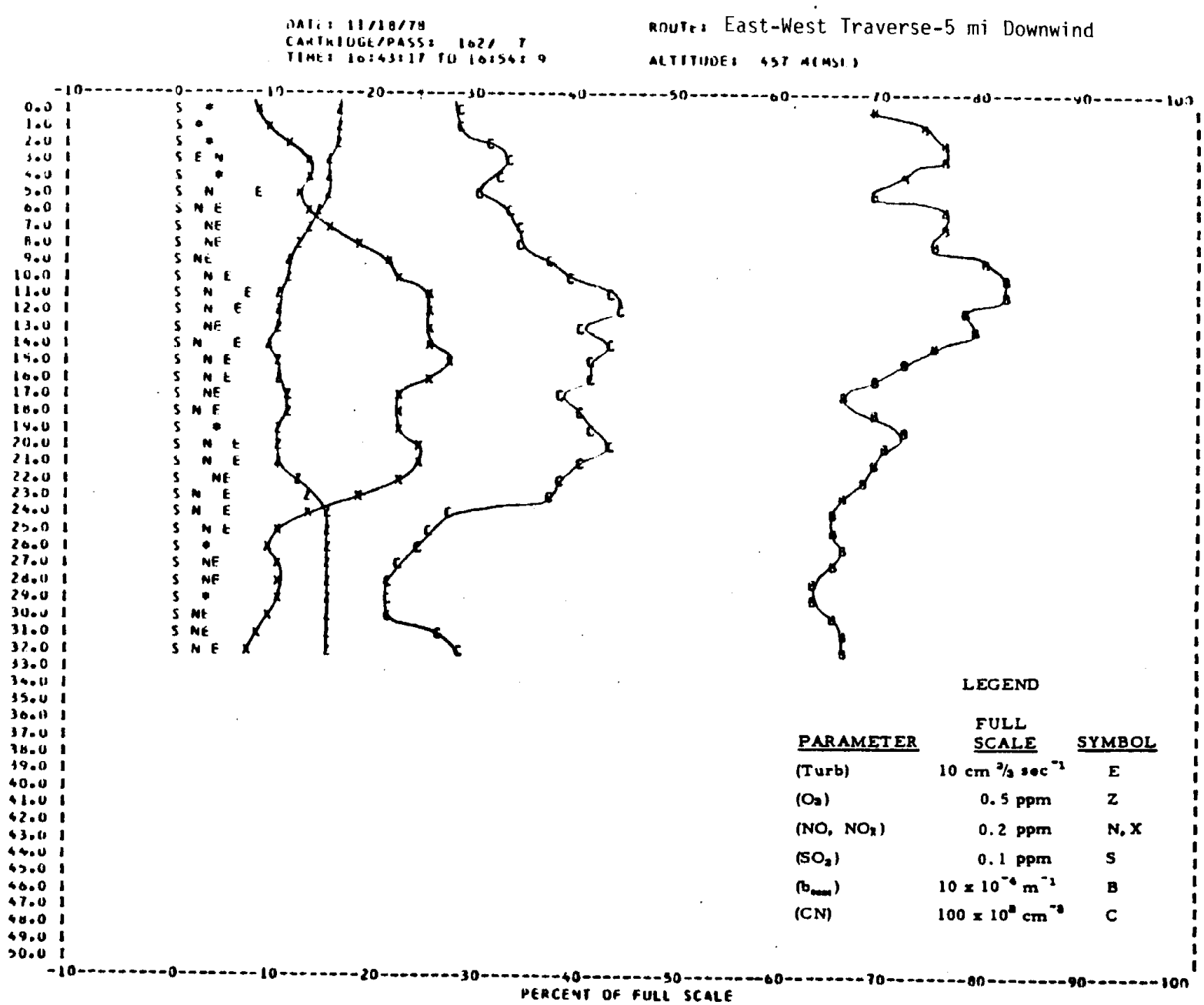



Figure 5.4.2 Horizontal Distribution of Selected Air Quality Parameters
5 Miles Downwind of Fresno, 18 November 1978 - Altitude 1500 ft

- At 10 mi downwind, $NO_x$ concentrations remained approximately 3 pphm in excess of background. However, a 1 pphm deficit of ozone suggests that reduction by NO was decreasing in effectiveness.
- At 15 mi downwind, the urban plume continued to be well defined by an approximate 2 pphm increase in $NO_x$ concentrations. Ozone showed a smaller but measurable deficit.
- No significant concentrations of $SO_2$ were measured in the Fresno area.

Table 5.4.3

18 NOVEMBER 1978 AIRCRAFT SAMPLING - FRESNO

| | Within Plume* | | | Background* | | |
|---|---|---|---|---|---|---|
| | $NO_x$ | $O_3$ | $SO_2$ | $NO_x$ | $O_3$ | $SO_2$ |
| Upwind (457 m-msl) | - | - | - | 2 | 8 | 0 |
| 5 Mi Downwind (457 m-msl) | 5 | 5 | 0 | 2 | 8 | 0 |
| 10 Mi Downwind (457 m-msl) | 4 | 7 | 0 | 2 | 8 | 0 |
| 15 Mi Downwind (457 m-msl) | 4 | 7.5 | 0 | 2 | 8 | 0 |

* Concentrations reported in pphm

$SF_6$ concentrations taken concurrently with the air quality sampling are shown on Figure 5.4.3. The tracer material having had the opportunity to disperse throughout the metropolitan area early in the release was transported downwind as an area source coincident with the polluted air mass.

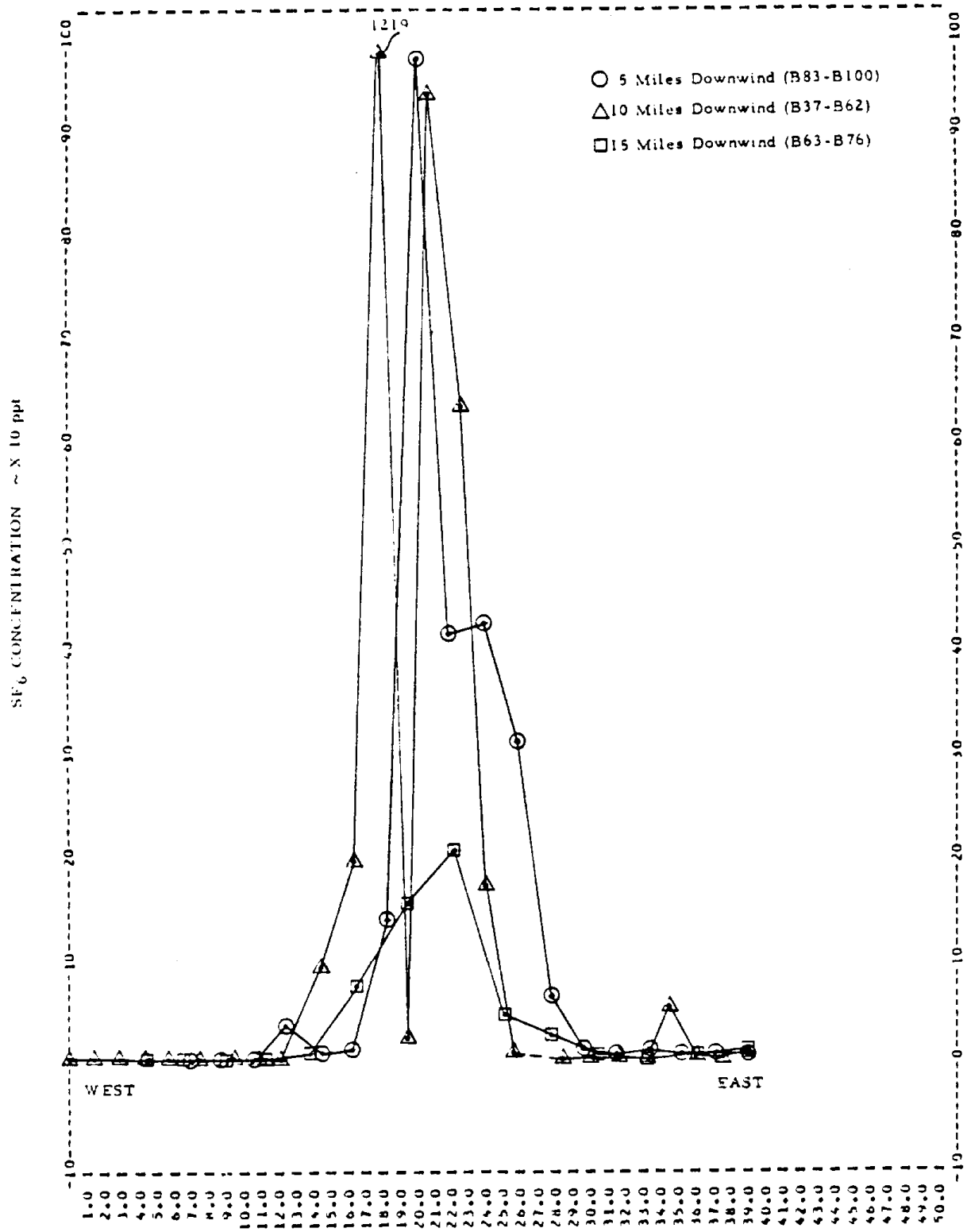



Figure 5.4.3 $SF_6$ Concentrations - 18 November 1978
Altitude 1500 Ft msl

### 5.4.4 Bakersfield Urban Plume

Fall

During September sampling in the southern San Joaquin Valley, the plume from the Bakersfield area was intersected on several different days approximately 20 mi downwind (from the downtown area) on a traverse from the intersection of I-5 and Highway 99, near Mettler, to Caliente. The region between Arvin and Caliente, southeast of Bakersfield was repeatedly shown to be a major downwind receptor area. It should be noted that the Bakersfield urban plume can frequently not be distinguished at downwind distances from adjacent oil field sources and as such the following discussion considers the area as one source.

A summary of the sampling on two days when the urban air was particularly well delineated from background air is shown in Table 5.4.4. Three sets of observed concentrations of $O_3$, $NO_x$, and $SO_2$ are tabulated in the table. The data associated with the location identified as the BFL VOR is from the vertical distribution within the mixing layer over a location approximately 7 mi northwest (or upwind) of the downtown area but adjacent to known major source regions such as the Kern Front and Poso Creek Oil Fields and downwind of the Wasco-Delano urban areas. For this reason, data from that part of the downwind traverse which was outside the plume boundary is also shown in the table and is referred to as rural air.

Table 5.4.4

AIRCRAFT SAMPLING - BAKERSFIELD

| | Upwind | | Downwind | | | |
|---|---|---|---|---|---|---|
| | BFL VOR | | Rural | | Urban | |
| | Mean | Maximum | Mean | Maximum | Mean | Maximum |
| 11 September 1979 (altitude 610 m-msl) | | | | | | |
| $O_3$ (pphm) | 19 | 20 | 10 | 18 | 24 | 26 |
| $NO_x$ (pphm) | 2 | 3 | 1 | 2 | 2 | 4 |
| $SO_2$ (ppb) | 4 | 5 | 1 | 4 | 8 | 11 |
| 14 September 1979 (altitude 762 m-msl) | | | | | | |
| $O_3$ (pphm) | 11 | 12 | 15 | 16 | 20 | 24 |
| $NO_x$ (pphm) | 1 | 3 | 1 | 2 | 2 | 4 |
| $SO_2$ (ppb) | 1 | 1 | 2 | 2 | 6 | 12 |

In the third column of the table concentrations within the urban air are listed. As shown in the table, increases in mean concentrations of ozone between rural and urban air were 14 pphm on one day and 5 pphm on the other. Increases of 5 and 9 pphm in ozone concentrations were observed between the upwind and downwind samplings. Although concentrations were low, the downwind urban air exhibits increases in $SO_2$ of at least 100 percent. Similar percentage increases in $NO_x$ were detected on the 14th.

Figure 5.4.4 shows an example of the horizontal distribution of pollutants along the downwind traverse route. The demarcation at the plume boundary is quite sharp. This case has been discussed in greater detail in Section 4.1.2.

Winter

In a manner similar to the Fresno urban plume study, the Bakersfield area was sampled also by the MRI aircraft on 25 November 1978. $SF_6$ tracer was released from the downtown area from 1200-1700 PST while the airplane sampled from 1350-1745 PST. In conjunction with the air quality sampling, the ambient air was sampled with syringes at 30-sec or 1-minute intervals for later analysis of $SF_6$ concentrations. At the beginning of the tracer release period, the winds at Bakersfield were from the west but by 1500 PST had shifted to northwest. The airplane flew a series of traverses at three downwind (based on a northwest flow) distances from the release location (2, 7, and 12 miles). At each downwind distance, sampling was conducted at three altitudes within the mixing layer; 457, 915 and 1372 m (msl). One traverse was also flown upwind of the city. The traverses, varying in length from 19-28 km, typically extended from west of Bakersfield east to the Sierra foothills and roughly perpendicular to the wind flow. Details on the sampling locations can be found in the test summaries contained in Volume 3 of this report.

Figure 5.4.5 is typical of the horizontal distribution of the air quality parameters $O_3$, NO, $NO_x$, $SO_2$ and $b_{scat}$ and of the tracer material. Unlike the Fresno test, where the tracer plume coincided with the maximum pollution, the tracer plume which originated in downtown Bakersfield was detected west of the area where maximum concentrations of $NO_x$ and $SO_2$ were measured. Oil recovery operations, a known major emission source in East Kern County, were most likely the source of this pollution. Concentrations

DATE: 9/11/79
CARTRIDGE/PASS: 706/ 12
PASS START TIME : 18:12:33

ROUTE: I-5 and 99 to Caliente
ALTITUDE: 610 M(MSL)

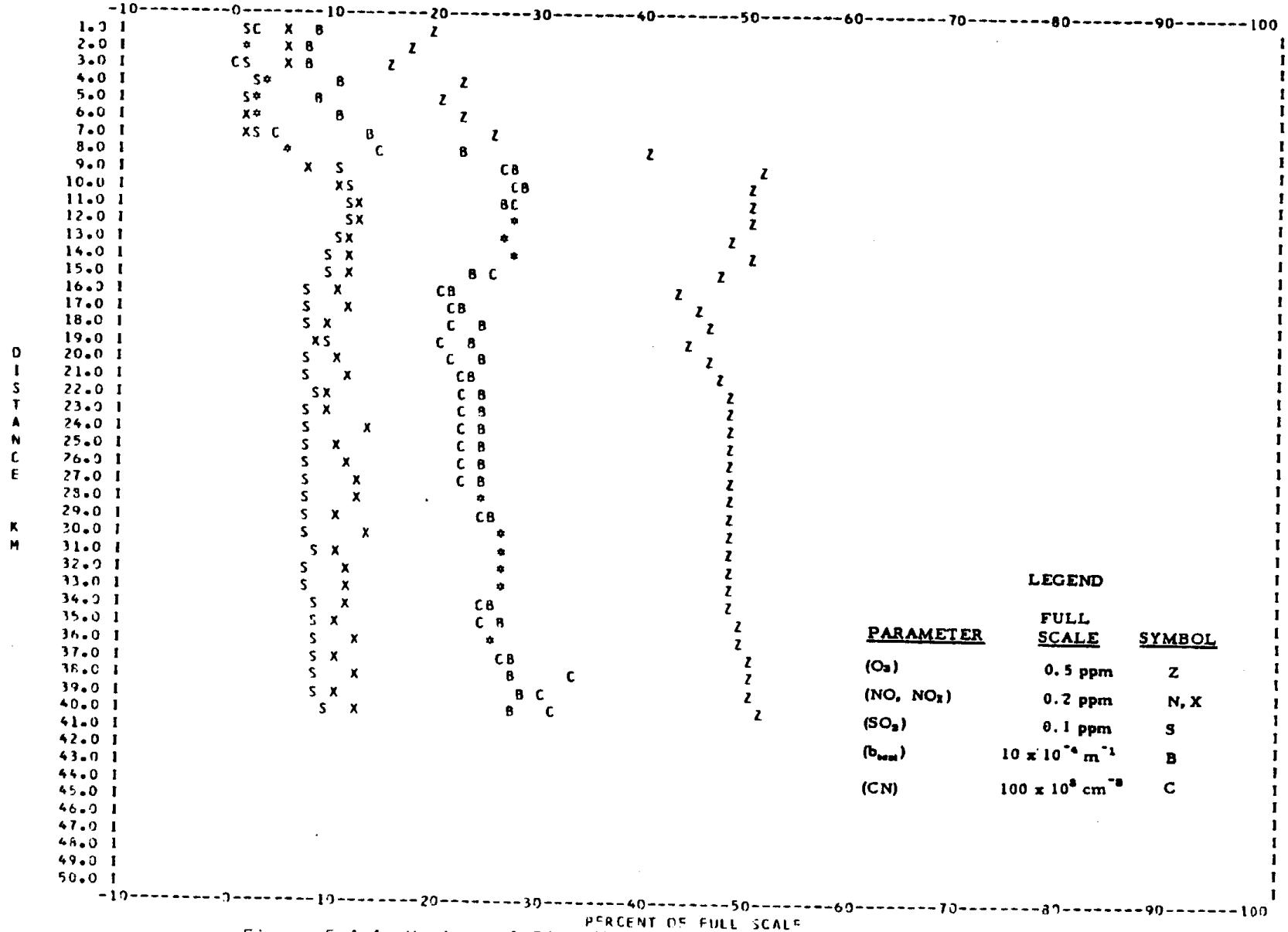



Figure 5.4.4 Horizontal Distribution of Selected Air Quality Parameters Downwind of Bakersfield, 11 September 1979 - Altitude 610 m (msl)

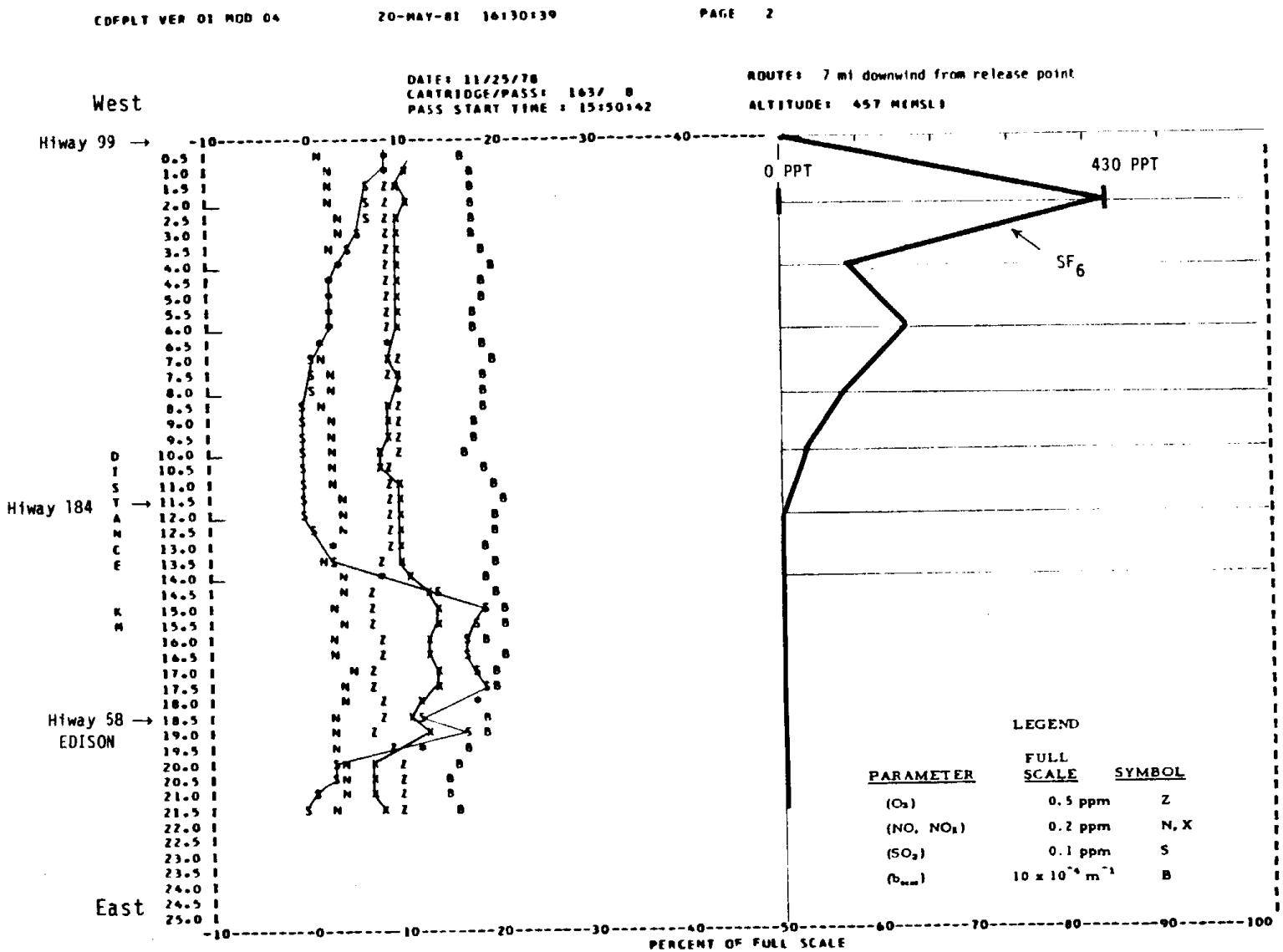



Figure 5.4.5 Horizontal Distribution of Selected Air Quality Parameters and $SF_6$ 7 mi Downwind from Release Point, Bakersfield, 25 November 1978 - Altitude 1500 Ft

of $O_3$, $NO_x$, and $SO_2$, measured at 1500 ft both upwind and downwind of downtown Bakersfield, are summarized below in Table 5.4.5. On the left side of the table mean concentrations measured within the plume defined by the tracer material are given. For the upwind sampling, mean concentrations for the complete traverse are tabulated. The maximum concentrations shown in the table include measurements along the entire traverse at all downwind distances as well as upwind.

Table 5.4.5

25 NOVEMBER 1978 AIRCRAFT SAMPLING AT BAKERSFIELD
ALTITUDE 457 m (msl)
BAKERSFIELD

| Location | Mean Concentration* (pphm) | | | Maximum Concentrations (pphm) | | |
|---|---|---|---|---|---|---|
| | $O_3$ | $NO_x$ | $SO_2$ | $O_3$ | $NO_x$ | $SO_2$ |
| Upwind | 4 | 1 | 0 | 5 | 2 | 1 |
| 2 Mi Downwind | 4 | 2 | 0 | 5 | 3 | 4 |
| 7 Mi Downwind | 4 | 2 | 0 | 5 | 3 | 2 |
| 12 Mi Downwind | 4 | 1 | 1 | 5 | 3 | 4 |

* Mean concentrations within tracer plume on downwind traverses

From the table it can be seen that small increases over the upwind concentrations of $NO_x$ were observed within the $SF_6$ plume on the 2 mile and 7 mile downwind distances. No significant increase in $SO_2$ was detected. The increase in $SO_2$ levels at 12 miles downwind was caused by a plume from a nearby source. With the exception of the aforementioned plume, the maximum $NO_x$ and $SO_2$ concentrations shown in the table were measured east of the tracer plume. As can be seen from Figure 5.4.5, an ozone deficit was associated with the oil field $NO_x$ and $SO_2$ plume.

Thus, the data suggest sources in East Kern County, namely oil recovery operations, should be considered major contributions to the air quality in the southern end of the valley.

### 5.4.5 East Kern County Oil Fields

Based on an ARB 1976 inventory about 84 percent of the sulfur oxides emitted in the eastern part of Kern County within the San Joaquin Valley air basin are from oil recovery operations. In these operations crude oil is burned to produce steam for tertiary oil recovery. Accordingly, during the September intensive study, the MRI aircraft orbited the oil fields near Oildale in East Kern County to measure the effect of that source. The sampling was conducted in the morning, approximately two hours after sunrise while the nocturnal inversion was still intact. The orbiting was carried out at 300 m and intersected plumes from several stacks in the area. Table 5.4.6 below summarizes the data obtained.

Table 5.4.6

12 SEPTEMBER 1979 AIRCRAFT SAMPLING - EAST KERN COUNTY OIL FIELD

| | Mean | Maximum |
|---|---|---|
| $O_3$ | 3 pphm | 12 pphm |
| $SO_2$ | 16 pphm | 22 pphm |
| $NO_x$ | 18 pphm | 38 pphm |
| $b_{scat}$ | $278 \times 10^{-6}\ m^{-1}$ | $1602 \times 10^{-6}\ m^{-1}$ |

Full scale values for the $SO_2$, $NO_x$, and $b_{scat}$ monitors were 10 pphm, 20 pphm, and $1000 \times 10^{-6}\ m^{-1}$, respectively. As can be seen from the table all three instruments over-ranged. It has been MRI's experience that the instrument calibrations remain generally linear at least to 150 percent of range. However above that point, the response is uncertain. Thus, the maximum levels measured which are greater than 150 percent of full-scale should be considered extrapolations and used with caution.

## 6. Comments Regarding Air Quality Modeling

One of the objectives of the study was to develop a data base for use in air quality modeling of the San Joaquin Valley. During the course of the study a number of concepts and questions were developed which should be taken under consideration during the modeling work:

1. The air flow characteristics of the valley are generally non-steady state, even on a regional basis. Both the nocturnal jet and the Fresno Eddy are dynamic events which change significantly from hour to hour. The large areal extent of the valley requires that these dynamic changes be taken into account in the regional modeling.
2. Interaction of the ground level air with the flow aloft - In any modeling effort, it is extremely difficult to evaluate the influence of the atmosphere above the surface layer on ground-level air quality. During the night, for example, the nocturnal jet can transport pollutants from the northern region to the southern region of the San Joaquin Valley. Although these pollutants are transported by the air aloft, they can fumigate downward and impact ground-level sites as the mixing layer grows during the subsequent afternoon. Clearly, air quality data above the morning mixing layer must be incorporated into the initial conditions of any model for the southern region of the valley.
3. The impact of the slope flows - The afternoon upslope flow can transport pollutants from the valley into mountainous regions (such as the Sierra National Forest). In order to model the impact of the upslope flow, the timing, strength and depth of the flow must be routinely monitored. This information is also required to model the impact of the night-time drainage flows upon the valley floor. Given an understanding of the basic flow structure, however, it is generally difficult to predict the dispersion of pollutants over complex terrain. It is also conceivable that the downslope flow will be relatively rich in hydrocarbon emissions that may modify the air chemistry within the valley.

The presence of the slope flows increases the importance of having an adequate description of the temporal variations of air quality and emissions along the foothills.

The influence of the nighttime drainage flows upon the structure of the mid-valley convergence zone, and the variation of the structure of the convergence along the axis of the valley should be investigated. Without an adequate description of the structure of the mid-valley convergence zone, it will not be possible to accurately model the cross-valley mixing of pollutants that occurs within the southern region.

4. Along-valley mixing by the Fresno Eddy - An adequate model of the "Fresno Eddy" is needed before the transport of pollutants from the south towards the north can be correctly included in the regional model.

5. Transport and mixing of the light and variable winds associated with wind reversals - Due to the diurnal nature of the winds within the San Joaquin Valley, a non-negligible portion of each day may be characterized by light and variable winds. The tracer experiments indicated that significant transport and mixing can occur under these conditions. In order to model this dispersive mechanism, it will be necessary to accurately characterize winds whose mean velocity may be less than the threshold velocities of commonly used anemometers.

6. Chemistry of the San Joaquin Valley atmosphere - A unique aspect of the atmosphere of the San Joaquin Valley is the extensive and persistent occurrence of fogs that develop during the winter. The influence of this condition on the chemistry of reactive pollutants within the atmosphere must be studied prior to the development of an accurate air quality model for the San Joaquin Valley air basin.

7. Complexity and reproducibility of valley flows - Although the characteristic patterns of transport and mixing are rather complex, they appear to be relatively reproducible within a season. Transport and dispersion of pollutants in the summer and in the fall appear to be similar in that there exist effective mechanisms for pollutant transport both within and out of the valley. During the stable winter conditions, a more limited ventilating mechanism normally exists and pollutants tend to become uniformly mixed throughout the southern region of the valley during the days subsequent to their release. Due to the complexity of the flow, it appears unlikely that a model can be easily formulated that predicts the daily variations in pollutant levels. It does appear possible, however, to take advantage of the basic reproducibility of the flow system to formulate seasonal models which can be used to analyze long-term trends in air quality.

## 7. Conclusions

1. Total emissions in the San Joaquin Valley are comparable to emissions from the nine Bay area counties. The primary exception is TSP where the valley emissions are 10-15 times the values reported for the Bay area counties.
2. Over 80 percent of the $SO_2$ and about 30 percent of the $NO_x$ are associated with the oil fields in Kern County and the Bakersfield refineries.
3. Nearly 60 percent of the $NO_x$ emissions in the valley are derived from mobile sources. Some 40 percent of the TOG emissions in the valley come from oil activities in Kern County.
4. Significant seasonal variations in emissions occur in association with agricultural practices. Anthropogenic sources of TSP and hydrocarbons appear during the growing season, agricultural burn operations contribute during the fall and fugitive emissions from cultivated and uncultivated land contribute during the winter.
5. Significant ozone concentrations are generally associated with urban areas and their downwind influences. Peak hourly concentrations over .10 ppm were exceeded on as many as 86 days in 1979. Pronounced surface stability during the early morning and strong solar radiation contribute to this problem.
6. Sulfate concentrations greater than 25 $\mu g/m^3$ appear principally near the oil fields (McKittrick and Oildale) and occur during stagnant, high moisture events in winter.
7. Surface wind flow is directed from Stockton to Bakersfield on a 24-hour mean basis for all months except January and February.
8. Stagnation episodes occur most frequently from November to January and may last as long as 20 days.
9. During the summer the total volume flux (below 1200 m) into the northern part of the valley averages about $3 \times 10^4$ $km^3$ for 24-hours. The total volume of the valley below 1200 m is approximately $3.9 \times 10^4$ $km^3$. This results in about 1.3 days for a replacement of the valley air on a mean basis.

10. Flux into the northern part of the valley (north of Fresno) continues throughout the 24-hour day during the summer with only modest diurnal decreases during the morning hours. During the daytime this flux continues down the valley and over the Tehachapis but with a small upslope contribution to the exit mechanism. At night, the flux into the valley continues and is balanced by a complex flow pattern in the southern part of the valley which provides the mechanism for injecting the air above 1200 m where escape from the valley becomes possible.
11. Evidence from the tracer studies indicates that the residence time of the tracer was 1-2 days during summer, depending on release location. In winter, the residence time increased to 2-8 days, depending on stability and release location.
12. Slope flux is found to increase with distance upward along the slope. This implies that much of the air transported to higher levels is entrained from mid-altitudes in the valley. This somewhat limits the effectiveness of the slopes for removing low-level pollutants from the valley.
13. Evidence of ozone transport from the valley was found as far up the slope as Huntington Lake (elevation 7000 ft).
14. Tracer material released from the west side of the southern part of the valley appeared on the east side by 09 PDT the following morning in spite of the presence of an apparent convergence zone in the center of the valley.
15. A nocturnal wind jet forms on most nights during summer and early fall. Peak velocities occur at about 300 m elevation in the central part of the valley (Fresno-Los Banos). The jet serves to transport pollutants rapidly from the northern part of the valley to the south.
16. A Fresno Eddy forms in the southern part of the valley on most summer and early fall nights. This eddy develops as a result of blocking of the northwesterly air flow by the terrain at the southern end of the valley. The effect of the Fresno Eddy is to transport pollutants from the south to the north along the east side of the valley.

17. Urban plume effects were observed downwind of Fresno and Bakersfield to distances of at least 15 miles.
18. Maximum ozone concentrations tend to occur along the eastern side of the valley and in the Sierra foothills. In response to the observed flow patterns, transport from the Bay area should lead to ozone impacts on the western side of the valley. It is therefore concluded that local emissions and local wind patterns appear to be relatively important in determining the spatial distribution of ozone in the San Joaquin Valley.
19. Efforts to model the San Joaquin Valley on a regional basis will be complicated by the dynamic, non-steady state nature of the regional flow patterns, by the upslope and drainage effects near the edges of the valley and by the frequent, meandering nature of the wind flows under stagnant, episode conditions.

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APPENDIX

# Atmospheric Transport of Visibility Degrading Pollutants Into the California Mojave Desert

by

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ABSTRACT

Three atmospheric tracer experiments using $SF_6$ and fine aerosol measurements were conducted in California to determine the relative impact of pollutant sources in the San Fernando Valley area of Los Angeles and the southern San Joaquin Valley on visibility in a portion of the Mojave Desert. Dilution ratios calculated for $SF_6$ and various gaseous and aerosol chemical species were used to indicate atmospheric transformation processes between source and receptor. The evolution of the aerosol sulfur mass distribution resulting from transport and transformation was measured. The $SF_6$ data were compared to predictions based upon the Gaussian dispersion model.

$SF_6$ released in the San Fernando Valley was found to impact the southern Mojave Desert including the towns of Palmdale and Adelanto during a test on July 20, 1978. $SF_6$ released at Oildale in the southern San Joaquin Valley was found to directly impact the northern Mojave Desert including the towns of Mojave and China Lake. Some $SF_6$ released in the San Joaquin Valley was also detected in the southern Mojave Desert. $SF_6$ was found to be diluted by factors of only 2 to 3 during passage over the mountains separating the source and receptor areas. The $SF_6$ dispersion during the San Fernando Valley experiment could be modeled with the Gaussian plume model if the experimentally determined mixing height, transport speed and plume trajectory were used, and the stability class was chosen to give good agreement with the data. A simple Gaussian plume model could not provide an adequate description of the San Joaquin Valley test because of the complexities of the wind reversal that occured during the transition from morning to afternoon flow conditions during this test.

Dilution ratios for conserved fine aerosols between Oildale and China Lake were found to be about 3, in excellent agreement with the $SF_6$ data.

The timing of the diurnal degradation in visibility at China Lake was found to coincide with the arrival of $SF_6$, thus indicating that the southern San Joaquin Valley was the source of visibility degrading aerosol. The aerosol sulfur mass distribution was found to be essentially conserved between Oildale and China Lake and substantially different from Los Angeles-Palm Springs sulfur mass distributions.

Our data indicate that pollutants from both the southern San Joaquin Valley and the Los Angeles Basin can both impact the Mojave Desert during their transport eastward by the predominantly westerly summertime winds; consequently, both "plumes" should be taken into account when considering the impact of southern California pollutants upon the southwestern United States.

## INTRODUCTION

It has become apparent in recent years that air pollution is not only a localized problem. Some aspects of air pollution have become regional and even global in scope. For example, emissions from urban sources can lower the pH of rain in rural areas downwind. Liljestrand (1979) concluded that more than half of the acids and bases released within the Los Angeles area are advected out into the California Desert. In addition to contributing to the acid rain problem, the long range transport of pollutants has been implicated in the visibility degradation in the southwestern United States.

The Mojave Desert of California (see Figure 1) appears to be a transition region between the heavily populated California coast and the sparsely populated Southwest. Although visibility in the arid Southwest is currently excellent in most locations, Trojinis (1979) has noted a 10-30% deterioration in visibility at some locations within this region from the middle 1950's to the early 1970's. Visibility degradation throughout the Mojave Desert appears to be associated with fine particles of anthropogenic origin (Charlson et al., 1978; Macias et al., 1979; Trijonis 1979, and Ouimette et al., 1980). Macias, et al. (1980) and Hering, et al. (1980) have found that pollutant sources in southern California contribute to the regional haze in the southwestern United States.

Substantial variations in the particle light scattering coefficient, $b_{sp}$, as measured with an integrating nephelometer, may take place both seasonally and diurnally at China Lake, California in the northern Mojave Desert (Ouimette, 1980). Afternoon visibility during summer and early fall is often as high as 100 miles. During the late evening and night-time hours, however, the visibility is typically reduced to about 30-50 miles. There are no significant local sources of pollutants that could cause this visibility reduction

(Ouimette, 1974). Based on typical wind flow patterns in California, the two most likely sources of airborne contaminants detected at China Lake are the western end of the Los Angeles air basin (e.g. the San Fernando Valley) and the southern San Joaquin Valley. The Los Angeles air basin is a large, densely populated urban area that is well known for its air pollution problems. The southern San Joaquin Valley is less densely populated but the area has a number of significant agricultural and industrial pollution sources. In 1976, 275 tons per day of $SO_2$ were emitted in the Kern County portion of the San Joaquin Valley (Duckworth and Crowe, 1979). The highest 24 hour average aerosol sulfate concentration to date in California, 80 $\mu g/m^3$, was found at Oildale in Kern County in 1978 (Duckworth and Crowe, 1979). It should be noted that the Mojave Desert is within the Southeast Desert Air Basin while the two suspected source areas are within separate air basins. The "air basin" is the basic organization of air pollution regulation and control in California.

The purpose of the present work was to determine the transport and dispersion of visibility-degrading pollutants from the San Fernando Valley area of the Los Angeles air basin and the Oildale-Bakersfield area of the San Joaquin Valley to the Mojave Desert, including China Lake, under typical summer conditions. The complexities of the pollutant transport and dispersion in complex terrain are such that no existing model can be expected to provide accurate estimates with the necessarily limited meteorological data available. For this reason, this work involved the use of atmospheric tracers to quantify the impact of the San Fernando Valley and the San Joaquin Valley on the Mojave Desert. The transport and dispersion of pollutants from the San Fernando Valley was investigated by employing sulfur hexaflouride ($SF_6$) as an atmospheric tracer. Fine aerosols of less than 2 micrometers ($\mu m$) diameter

and $SF_6$ were relied upon as quantitative tracers for the investigation into the impact of the San Joaquin Valley on the Mojave Desert.

## EXPERIMENTAL PROCEDURE

### A. Atmospheric tracer studies

During the first tracer test, 245 kg of an inert, non-toxic gas, sulfur hexaflouride ($SF_6$), were released continuously from Whiteman Airport in the San Fernando Valley of Los Angeles, California. The release took place on July 20, 1978 between 1030 and 1607 PDT (continuous release rate of 44 kg $SF_6$/hr). The San Fernando Valley is a densely populated region north of central Los Angeles. The release point was east of the San Fernando convergence zone described by Edinger (1961). Based on average wind trajectories (Demarris, Holzworth and Hosler, 1965), pollutant sources in this region can have an impact on the western Mojave Desert. As shown in Figure 1, 1-2 km peaks (San Gabriel Mountains) separate the valley from the desert. The second tracer test involved a continuous release of 245 kg of $SF_6$ from Oildale in the San Joaquin Valley of California between 0700 and 1200 PDT on September 5, 1979 (49 kg $SF_6$/hr). In a third test, 240 kg of $SF_6$ were released continuously from Oildale between 0200 and 0700 PDT on September 9, 1979 (48 kg $SF_6$/hr). The San Joaquin Valley is a large inland valley (400 km long by 80 km wide) bounded on the west by the California Coastal Mountains (elevations from 0.3 to 1.2 km), on the south by the Tehachapi Mountains (elevations of 1-2.5 km) and on the east by the Sierra Nevadas (elevations of 2 to 4 km). The Oildale area is a significant source of airborne pollutants in the southern San Joaquin Valley. Bakersfield, an urban area with a population in excess of 80,000, lies immediately to the south of Oildale, and a large oilfield lies north and east. During all tracer tests, the gaseous $SF_6$ was released at a constant rate from 6 cylinders, each containing about 45 kg of liquid $SF_6$. The cylinders were connected via 1.3 cm OD (1/2") copper manifolding. The $SF_6$ flowrate was

monitered with a high volume rotameter and verified by weighing the cylinders both before and after each release.

During each test, a series of automobile air sampling traverses were conducted using two person teams. During the automobile traverse, the passenger in each car took grab samples in 30 $cm^3$ plastic syringes. Samples were typically taken at 1.6 km intervals (1 mile) but during some traverses that passed close to the release site, the sampling interval was 0.8 km (0.5 miles). During the San Joaquin Valley release an airplane was used to obtain additional grab samples. Airplane traverse samples were generally taken every minute (every 3.2 km-2 miles). In addition, the vertical distribution of $SF_6$ was investigated by airplane spirals in which samples were taken at altitude intervals of about 150 m. Both airplane and automobile traverse paths were determined in the field based upon real time wind data and spot checking of samples with a portable electron capture gas chromatograph. Hourly averaged air samples were obtained during each test by automatic samplers at fixed locations. The samplers uniformly fill a 30 $cm^3$ syringe each hour for 12 hours. Two or more samplers were deployed at each location to provide continuous coverage for at least 24 hours. The locations of the hourly averaged sampling stations for the San Fernando release are shown in Figure 2. Also included are some of the hourly averaged sampling stations used during the San Joaquin Valley releases (a complete display of these sites is shown in Figure 7) and the major traverse routes for each test.

Air samples were analyzed for $SF_6$ using electron capture gas chromatography. Details of the analytical procedure and the experimental apparatus are described by Drivas (1974) and Lamb (1977). The gas chromatographs were calibrated using the exponential dilution method and checked between calibrations by comparison to a known standard. Calibration results showed that

concentrations as low as 10 parts $SF_6$ per trillion parts air (10 PPT) could be detected within about 20%. Concentrations between 1 and 5 PPT could be detected within a factor of two.

B. Aerosols

San Fernando Valley $SF_6$ Release of July 20, 1978:

During the San Fernando Valley test, the aerosol measurements were limited to continuously monitoring the particle light scattering coefficient, $b_{sp}$, at China Lake with a Meteorology Research Inc. (MRI) Model 1561 integrating nephelometer.

Oildale $SF_6$ Release of September 5, 1979:

Aerosol measurements were more complete during the Oildale-San Joaquin Valley test. The aerosol analysis was, however, limited to fine particles. This mode is linked closely to human influence, dominates light extinction through particle scattering and absorption, and is transported over long distances (Friedlander, 1977). To estimate aerosol dilution from source to receptor, fine aerosol was sampled at the Oildale $SF_6$ release site on September 5, 1979 from 0850-1302 PST. Similarly, aerosol was sampled at China Lake from 1000 PST September 5, 1979 to 1800 PST September 7, 1979.

At the Oildale site, the aerosol was sampled from a roof at a height of about 3 meters above the ground which was located about 20 meters from the $SF_6$ release point and about 10 meters from a monitoring trailer operated by the California Air Resources Board (CARB). Two calibrated cyclone separators were operated at a flowrate of about 23 liters per minute. These removed coarse particles from the airstream with efficiencies of 50% for 2 μm and 98% for 6 μm aerodynamic diameter (John and Reiche, 1978). The fine particle airstream from each cyclone was sampled by a total filter and a low pressure

impactor (LPI) operating in parallel. The calibrated LPI segregates aerosol into eight stages having 50% efficiency aerodynamic diameters of 4.0, 2.0, 1.0, 0.50, 0.26, 0.12, 0.075, and 0.05 μm respectively (Hering, et al., 1978 and Hering, et al., 1979). Immediately after collection, all samples were placed in petri dishes, sealed with parafilm, wrapped in a sealed ziplock bag, and placed in an ice chest or refrigerator. This was to prevent contamination and loss of volatile species.

The fine aerosol from cyclone #1 was collected by a Pallflex Tissuequartz filter which had been baked at 900 $^{o}$C for 1 hour. The Tissuequartz filters were subsequently analyzed for total carbon by proton induced gamma ray emissions (Macias et al., 1978) and graphitic carbon (soot) by optical reflectance at Washington University (Delumyea, et al., 1980). In parallel to the Tissuequartz filter, a LPI collected aerosol on vaseline coated stainless steel strips to determine sulfur mass distributions by the technique of flash volatization and flame photometric detection (Roberts and Friedlander, 1976).

The fine aerosol from cyclone #2 was collected by a 0.4 μm pore size Nuclepore polycarbonate filter. After determination of the average fine particle mass concentration by gravimetric analysis, the filters were cut into pieces for separate additional analyses. The time average particle absorption coefficient, $b_{ap}$, at a wavelength of 0.63 μm was measured with an He-Ne laser and phototransister using the opal glass technique (Lin, et al., 1973). Aerosol sulfate, nitrate, phosphate and ammonium ion mass concentrations were determined by liquid ion chromatography and calorimetry at Environmental Research and Technology, Inc. (ERT), Westlake Village, California. Elemental mass concentrations were were determined by particle induces c-ray emissions (PIXE) at Crocker Nuclear Laboratory, U.C. Davis, California (Cahill, 1975) and Florida State University.

To obtain time averaged gas phase $HNO_3$ and $NH_3$ concentrations, ambient air was filtered through, in succession, a Millipore 1 μm pore size teflon filter, a prewashed Ghia nylon filter, and 2 oxalic acid impregnated glass fiber filters. It was assumed that the $HNO_3$ and $NH_3$ would pass through the teflon filter and would be collected with 100% efficiency by the nylon and oxalic acid impregnated filters, respectively (Spicer, 1979; Richards, 1979). The average $HNO_3$ concentration was determined from the $NO_3^-$ extracted from the nylon filter and analyzed by liquid ion chromatography at ERT. The $NH_3$ concentration was determined from the $NH_4^+$ extracted from the oxalic acid filters by Rockwell International, Thousand Oaks, California and analyzed using colorimetry.

Aerosol at China Lake was sampled at about 3 meters above ground on top of an air-conditioned air monitoring trailer operated by the U.S. Naval Weapons Center, China Lake, California. The trailer was located about 5 miles north of Ridgecrest on restricted land away from any significant local sources. Aerosol sampling and analyses was accomplished for China Lake in a manner similar to that of Oildale. In addition, the aerosol scattering coefficient, $b_{sp}$, was continuously measured with two MRI Model 1561 nephelometers modified by Alan Waggoner at the University of Washington to provide automatic daily zeroing and an accuracy of $\pm$ 2.5 $(10^{-6})$ $m^{-1}$ from 0 to 250 $(10^{-6})$ $m^{-1}$. The submicron aerosol size distribution was obtained from a Thermo Systems Model 3030 Electrical Aerosol Analyzer. Temperature, dew point, solar intensity, wind speed, and direction were also continuously monitored.

## PRESENTATION AND DISCUSSION OF RESULTS

### San Fernando Valley Release of July 20, 1978

As described previously, 245 kg of $SF_6$ were released continuously from Whiteman Airport in the San Fernando Valley between 1030 and 1607 PDT on July 20, 1978. During the release period, winds in the eastern San Fernando Valley were generally from the southeast at 3 mps. Typical July wind flow patterns persisted in the San Fernando Valley throughout the test (Demarris, et al., 1965). Winds measured at Newhall (3 mps @ 130-170$^{o}$), north of the release site, and in the Mojave Desert (7-9 mps @ 220-250$^{o}$ at Palmdale) also corresponded to typical July wind flow patterns. Demarris, et al. (1965) found, for example, that July afternoon winds at Palmdale average about 6 mps and are from the southwest quadrant 83% of the time.

Figure 3 shows the time variation in the light scattering coefficient due to particles, $b_{sp}$, on July 20 and 21, 1978 at China Lake. Comparing this to the July composite average $\pm$ one standard deviation for 1978-1979 on the same figure, it is seen that $b_{sp}$ levels during this period were slightly higher than normal although a typical diurnal variation was observed (Ouimette, 1980). None of the $SF_6$ released in the San Fernando Valley was detected at China Lake during the sampling period (1300 PDT, July 20 to 1300 PDT, July 21, 1979). This would indicate that either the San Fernando Valley was not a significant source of visibility degrading aerosol at China Lake during this period, or that its plume was too dilute to detect by $SF_6$, but still optically significant.

Two main automobile traverse routes were followed during the test. These are shown as dotted lines in Figure 2. The arrow drawn from the San Fernando Valley release point in Figure 2 is a qualitative depiction of the experimentally determined tracer plume transport path. This line connects the locations of

the maximum traverse concentrations. A third traverse route showed that apparently none of the tracer was transported south or west of the release site.

Beginning at 1004 PDT on the day of the release, automobile traverse samples were taken along California Highway 126 and the Soledad Canyon Road between Piru and Acton (shown as a dotted line in Figure 2). This route lies about 19 km downwind of the release site. By traveling back and forth between the end points, this traverse was sampled six times between 1004 PDT and 1820 PDT. These traverses were designated as Traverses 1-1 through 1-6. The experimentally determined $SF_6$ concentration profiles for these traverses are shown in Figure 4. The first two traverses found essentially no $SF_6$. The third traverse, which began at the eastern end of the route, found a very sharply defined $SF_6$ plume spread over 12-16 km. Traverses 1-4 and 1-5 encountered $SF_6$ plumes of about the same width and location. During all three traverses the peak $SF_6$ concentration was between 250 and 320 PPT. The arrival of $SF_6$ occurred about 2 hours after the start of the release suggesting a transport time of about 2.5 mps for the plume. Traverse 1-6, which began about 1-1/2 hours after the end of the release, found essentially no $SF_6$.

The second traverse route was sampled nine times between 1318 and 2227 PDT. As shown in Figure 2, this route followed the eastern edge of the San Gabriel Mountains between Lake Hughes and Valyermo (shown as a dotted line in Figure 2). The experimental concentration profiles found during the second through the ninth traverse are shown in Figure 5. An $SF_6$ plume was found in the vicinity of Palmdale during Traverse 2-3 through 2-7. The peak $SF_6$ concentrations for Traverses 2-3 through 2-6 were between 100 and 200 PPT. The lower $SF_6$ concentrations measured during Traverse 2-7 imply that essentially all of the $SF_6$ had passed through the area by about 1900 PDT. Between 1500 and 1800 PDT (Traverses 2-4 through 2-6), the location of the maximum $SF_6$ concentration shifted

towards the southeast. This was presumably due to a slow shift in the prevailing wind direction. This conclusion could not be verified because of insufficient wind data. The detection of the plume at Palmdale suggested a transport speed of about 3 mps (65 km, 5.5-6 hours).

The automobile traverse data summarized above was used to estimate the vertical dispersion of the tracer in the slope flow over the San Gabriel mountains. In the absence of airborne sampling, it was assumed that the tracer was well-mixed over the height of the slope flow layer since this flow is typically only weakly coupled with the synoptic scale flow aloft (i.e. the flow above the slope flow layer). As mentioned previously, an automobile traverse showed that essentially no $SF_6$ was transported south or west of the release point. It was thus assumed that essentially all of the released $SF_6$ was in the plumes detected near Newhall and Palmdale. The height of the well-mixed layer above the surface can be estimated from the mean transport wind speed, the density of the air and the crosswind integrated tracer concentration:

$$H = \frac{q}{U_c \rho f_{rd} \cos\theta \int_{\ell} C(\ell)d\ell}$$

where,

- $H$ = height of the well mixed layer
- $q$ = tracer release rate per unit time (45 kg $SF_6$/hr)
- $U_c$ = mean transport wind speed
- $\rho$ = air density at sampling position (5.6 kg/m$^3$)
- $C$ = experimentally determined $SF_6$ concentration
- $f_{rd}$ = the ratio of the straight-line and along road distance between the points representing the limits of the integration ($f_{rd} \sim 0.85$ for both Trav Rt 1 and Trav Rt 2)
- $\theta$ = the average angle between the road and the tracer plume centerline (i.e. the mean wind direction). Together with $f_{rd}$, this term corrects for the fact that the road is not straight nor crosswind to the plume ($\theta \sim 45^o$ for both Trav Rt 1 and Trav Rt 2)
- $\ell$ = distance coordinate along road traversed

The integral in this equation was evaluated using the experimental concentration data and the trapezoidal rule. The calculated mixing height was 600 ± 100 m using Traverses 1-3, 4, 5 and 2-3, 4, 5. Thus, the average value of about 600 m appears to be a reasonable estimate of the slope flow depth above the San Gabriel Mountains on the test day.

The automobile traverse data was also compared to predictions of the Gaussian plume model. Traverses 1-3, 1-4 and 1-5 on the west side of the San Gabriel Mountains were fit to a Gaussian curve. The best-fitted curves had a peak of 300 ± 70 PPT and a crosswind standard deviation in concentration of 1.9 ± 0.3 km. The curve-fitting technique employed was that described by Reible, et al. (1981a). This technique involves evaluating the integral definitions of the necessary statistical quantities (such as the standard deviation). Because of the sensitivity of the standard deviation to the "tail" of the concentration data, the integrals are evaluated between the locations corresponding to 10% of the maximum detected concentration and then corrected for the neglected area under an exact Gaussian curve. The calculated standard deviations in concentration were corrected for crosswind distance along the traversed road (i.e. the crosswind distance was estimated to be about 60% of the along-road distance). Assuming stability class C, and by employing the calculated mixing height and mean transport wind speed, the Gaussian model predicts a centerline concentration of 210 PPT and a crosswind standard deviation in concentration of 1.5 km at this distance downwind (19 km). A similar curve fitting procedure for data from Traverses 2-3, 2-4, and 2-5, estimated a peak concentration of 135 ± 25 PPT with a crosswind standard deviation in concentration of 3.4 ± 1.0 km. The standard deviation was corrected for the fact that the crosswind distance was again about 60% of the along-road distance. Assuming stability class C, the Gaussian model

predicts a centerline concentration of 72 PPT and a crosswind standard deviation of about 4 km at this distance downwind (65 km). The downwind distances used in these calculations are along the plume trajectory as defined by the automobile traverse data. These calculations suggest that it is possible to describe the observed horizontal dispersion with a Gaussian model once the mean wind speed, the vertical mixing height, stability class, and trajectory have been accurately determined. Because of the complexities of pollutant transport and dispersion in mountain terrain, however, the Gaussian plume model may at times be the most cost-effective modeling approach, especially when experimental tracer data are available. However, Gaussian modeling in complex terrain cannot be relied upon to provide much more than an order of magnitude type of analysis, especially if experimental data are not available. Reible et al. (1981b) have outlined the use of the Gaussian plume model in worst case analyses of pollutant transport and dispersion in complex terrain.

Comparison of the average concentrations within the plume on the west and east sides of the San Gabriel Mountains shows that this value decreased by a factor of about 2.0 $\pm$ 0.5. The limits of the plume were again defined as the locations corresponding to $SF_6$ concentrations 10% of the peak concentration. Thus the tracer plume was diluted only by a factor of two during passage over about 50 km of mountainous terrain. This suggests that the boundaries normally used to separate various regulatory airsheds (e.g. mountains) are <u>not</u> barriers to significant pollutant transport under certain conditions, in that the dilution over these mountains can be relatively small.

The fixed site hourly averaged data shows the same basic tracer transport and dispersion as the grab sample automobile traverse data. Palmdale was the most highly impacted of the sites sampled (maximum $SF_6$ concentration - 65 PPT).

Good agreement between grab and hourly averaged concentrations was found in that the average ratio of the hourly averaged concentration to the corresponding traverse concentration was 0.77. This ratio is substantially higher than would be predicted by the Hino correction, (see Hino, 1968). The only other sampling site that showed a significant $SF_6$ concentration was the southern Mojave Desert sampling site of Adelanto in which three consecutive samples (1900-2200 PDT) showed $SF_6$ levels of about 10 PPT. For the purposes of this study, the southern Mojave Desert was defined as that part of the desert south of Highway 58 (as shown in Figure 2). Essentially no $SF_6$ was transported to the northern Mojave Desert sampling sites of Mojave, Ridgecrest and Boron. This suggests that airborne pollutants emitted in the eastern San Fernando Valley primarily impact the southern Mojave Desert under the meteorological conditions prevailing during this tracer test. It should be remembered, however, that typical wind flow patterns were observed throughout the study area (Demarus et al. 1965) and that the visibility at China Lake, as measured by $b_{sp}$, also showed typical diurnal variations (Ouimette, 1980).

San Joaquin Valley Release of September 5, 1979

During the second test, 245 kg of $SF_6$ were released continuously from Oildale, within the San Joaquin Valley of California, between the hours of 0700 and 1200 PDT on September 5, 1979. Southeasterly drainage winds predominated throughout most of the release period, transporting the $SF_6$ to the northwest at 2 mps. At about 1100 PDT, winds at about 4 mps from the west and northwest due to daytime heating of the surrounding mountain slopes and the resulting upslope flow. This upslope flow in the Bakersfield area persisted until about 1900 PDT. These conditions are typical late-summer wind flow patterns (Schultz, 1975).

Figure 6 shows the temporal $b_{sp}$ variation at China Lake on September 5 and 6, 1979. Comparison with the September composite average $\pm$ one standard deviation for 1978-1979 shows that $b_{sp}$ levels observed during this period were typical in both magnitude and diurnal variation. In contrast to the San Fernando Valley release, however, the $SF_6$ released from Oildale was detected in significant quantities at Ridgecrest, about 8 km south of the aerosol sampling location. The $SF_6$ levels detected at Ridgecrest are also included in Figure 6. It is clear that the temporal variation in $SF_6$ and $b_{sp}$ at China Lake were similar, indicating that the $SF_6$ adequately tagged the source of visibility degrading aerosol.

Automobile traverses during the first Oildale tracer release covered a very large area both within the San Joaquin Valley and in the Mojave Desert to the east of the release site. Initially the traverses showed the expected transport of the tracer via drainage winds to the northwest. Later traverses found $SF_6$ south and east of Bakersfield due to transport via the afternoon upslope winds. Airplane traverses at about 450 m (agl) showed similar concentration peaks at the same locations. An overview of the tracer transport is depicted in Figure 7 in which the hourly averaged fixed sampler data is shown. The Oildale and Bakersfield samplers did not show large $SF_6$ concentrations until after the upslope flow began in the early afternoon. Most of the $SF_6$ detected at these sites is thus the diluted reversed plume. The wind reversal caused the $SF_6$ to be spread over a large area as evidenced by its detection in Mettler, south of the release site, and Lake Isabella to the northeast. By midnight on the day of the release, an automobile traverse showed that $SF_6$ was well-mixed in the area south and east of Bakersfield at a concentration of about 14 $\pm$ 4 PPT. An area of approximately 370 sq km was

enclosed by this traverse. A 1200 m (agl) maximum mixing height over Bakersfield on the test day can be inferred from airplane traverse spirals. Assuming that the $SF_6$ was well-mixed over the entire volume and assuming a pure $SF_6$ density of about 5.9 kg/m$^3$, suggests that about 15% of the total $SF_6$ emitted could still be detected within the valley on the night following the release. Traverses on the first and second day after the release showed that the mass of $SF_6$ within the valley continued to decrease. On the second day after the release (9/7/79) a similar calculation on automobile traverse data showed that only about 5% of the $SF_6$ originally released could be accounted for within the San Joaquin Valley.

The balance of the tracer material was transported over the Tehachapi Mountains and the southern tip of the Sierra Nevada's into the Mojave Desert. This is clearly shown in Figure 7 by the $SF_6$ levels detected at the Mojave Desert hourly averaged sampling sites of Mojave and Ridgecrest. Maximum $SF_6$ concentrations measured at Ridgecrest were a factor of 3.1 lower than the early afternoon concentrations measured at Bakersfield and Oildale. The estimated dilution ratio was calculated by comparing the 1200-1600 PDT averages at Bakersfield and Oildale with the average resulting from three different averaging periods at Ridgecrest (2200, 7/20 - 0300, 7/21; 2200, 7/20 - 0900, 7/21; and 0100 - 0900, 7/21). The different average periods all gave dilution ratios within 30% of 3.1. $SF_6$ arrived at Mojave and Ridgecrest between 11 and 15 hours after the start of the release. The arrival times at the fixed sampling sites are in good agreement with arrival times suggested by the automobile traverses depicted in Figure 8. These automobile traverses sampled along California HWY 14 on the western edge of the Mojave Desert (shown as broken line in Figure 2). These traverses each consisted of three passes between Lancaster and the intersection of HWY 14 with HWY 395 on the night following the release. No $SF_6$ was detected until the sampling run begun at

1800 PDT at the HWY 395 intersection. During this traverse, a maximum of 81 PPT $SF_6$ was detected in the vicintiy of Red Rock Canyon State Recreation Area, directly east of Bakersfield. The average $SF_6$ concentration within this 30 km wide plume was about 27 PPT. The boundaries of the plume were defined as the locations where $SF_6$ levels corresponded to 10% or less of the measured maximum $SF_6$ level. This can be compared to an average of 68 PPT detected in a plume about 12 km wide in the San Joaquin Valley near Edison during an earlier traverse. The $SF_6$ detected near Edison was assumed to be the same material later encountered in the Red Rock Canyon Area. The ratio of the average concentrations within the plumes gives a dilution factor of 2.5 during passage over the mountains separating the Mojave Desert and the San Joaquin Valley. A traverse along a road near the ridgeline of the mountains encountered an $SF_6$ plume with an average concentration of 46 PPT over about 16 km (about 24 km as measured along the road). This gives a dilution factor for half of the distance over the mountains as roughly half the calculated dilution factor for the entire distance. During the traverse beginning at 2010 PDT from Lancaster, $SF_6$ was detected over the entire traverse route. The $SF_6$ encountered during the southern half of the traverse probably corresponds to $SF_6$ detected earlier in the southeastern San Joaquin Valley. Comparison of the average concentrations within the two plumes suggests a dilution factor of 2.1 for this distance. The detection of $SF_6$ throughout much of the western end of the Mojave Desert suggests that air pollutants from the San Joaquin Valley and those from the San Fernando Valley can jointly impact the eastern Mojave Desert and southern Nevada and Arizona. Our data suggest that both "plumes" should be taken into account when considering the impact of southern California pollutants upon the southwestern United States.

Table 1 summarizes the aerosol mass concentrations averaged over the times of the $SF_6$ release at Oildale and $SF_6$ detection at China Lake. Since $b_{sp}$ was not measured at Oildale, it was estimated from average 1 pm July-September visual range data by Barone et al., (1978) and Trijonis (1979), corrected for measured particle absorption. The table is divided into those species which may, in the absence of additional sources, be conserved, and those species which may undergo conversion. The amount of fine aerosol dilution from Oildale to China Lake may be estimated from the conserved chemical species data. The average dilution, from the ratios of Oildale to China Lake conserved species concentrations, is 3.0 $\pm$ 0.6. The fine aerosol dilution value compares favorably with that estimated from $SF_6$ dilution, 2.5-3.1. Just as in the San Fernando Valley release, the transport of tracer and/or pollutants over a mountain range does not result in dilution by a factor of much more than 2 to 3.

The effects of conversion and loss of aerosols during transport may be examined by comparing the dilution values of the unconserved species to 3.0. The sulfate and ammonium ratios are slightly less than average, and indicate the possibility of additional ammonium sulfate aerosol being produced enroute from Oildale to China Lake. Aerosol nitrate concentrations for both locations were close to, or within, the standard deviation of the Nuclepore filter blank ($NO_3^-$). Thus the nitrate ratio is the least precise of the values. In fact, at the temperatures sampled, the gas phase ammonia and nitric acid data indicate that no pure $NH_4NO_3$ should be in the aerosol phase (Stelson, et al., 1979). The small quantity of nitrate aerosol at Oildale was evidently volatized into its gaseous precursors by the time the air parcel reached China Lake. The lower dilution ratio for $NH_3$ indicates the possibility of a large area source for ammonia in addition to Oildale. The anomolously high value of the

TABLE 1 - TIME AVERAGED FINE AEROSOL AND SELECTED GASEOUS CONCENTRATIONS

A. Conserved Species

| Species | Mass Concentration, $\mu g/m^3$ Oildale | China Lake | Ratio |
|---|---|---|---|
| Total Carbon | 18.6 | 5.6 | 3.3 |
| Soot | 4.2 | 1.1 | 3.8 |
| Al | 0.68 | 0.21 | 3.2 |
| Si | 1.36 | 0.64 | 2.1 |
| K | 0.20 | 0.08 | 2.4 |
| Ca | 0.50 | 0.18 | 2.8 |
| Fe | 0.64 | 0.19 | 3.3 |
| $b_{ap}, 10^{-6} m^{-1}$ | 29. | 8.8 | 3.3 |
| | | | average = 3.0 ± 0.6 |

B. Other Species

| Species | Mass Concentration, $\mu g/m^3$ Oildale | China Lake | Ratio |
|---|---|---|---|
| $SO_4$ | 8.47 | 4.24 | 2.0 |
| $NO_3^-$ | 1.81 | 0.44 | 4.1 |
| $NH_4^+$ | 2.67 | 1.43 | 1.9 |
| $NH_3(g)$ | 2.45 | 1.9 | 1.3 |
| $HNO_3(g)$ | 10.1 | 1.2 | 8.4 |
| Total Mass | 44.9 | 19.7 | 2.3 |
| $b_{sp}, 10^{-6} m^{-1}$ | 150.(est.) | 49. | 3.1 (est.) |

Oildale average for 0951-1402 PDT, 9/5/79

China Lake average for 2210-0600 PDT, 9/5/79-9/6/79

$HNO_3$ dilution indicates that loss of $HNO_3$ likely took place enroute. Possible routes could include dry deposition to alkaline soil or by diffusion and adsorption on coarse alkaline aerosol which was not sampled.

The effect of transport on the distribution of aerosol sulfur with respect to aerodynamic diameter can be seen in Figure 9. Aerosol size was segregated by low pressure impactor (LPI) (Hering, et al., 1979) and analyzed by flash volatization and flame photometric detection (Roberts and Friedlander, 1976). Histograms are inverted distributions obtained from LPI calibration data and Twomey (1975) inversion algorithm (Ouimette, 1980). The Oildale sulfur aerosol mass was preferentially distributed between 0.1 and 0.2 μm diameter, consistent with the gas phase homogeneous oxidation of $SO_2$ to $H_2SO_4$ aerosol (Gelbard and Seinfeld, 1979; McMurry and Friedlander, 1978).

Earlier work by Drivas and Shair (1974), showed that under typical meteorological conditions, Palm Springs may be the recipient of polluted air from the Los Angeles Basin. Typical aerosol sulfur mass distributions at Palm Springs and Pasadena are plotted in Figure 10 (Hering, 1980 and Friedlander, 1978). It is seen that the sulfur distribution very likely preserves its shape in transit from the Los Angeles Basin to Palm Springs. However, in this case the sulfur is preferentially distributed at about 0.5 μm diameter, substantially larger than the Oildale-China Lake distribution. The larger Los Angeles sulfur aerosol is consistent with particle growth by heterogeneous droplet phase conversion of $SO_2$ (Friedlander, 1978; Friedlander, 1977). Mie calculations indicate that the Los Angeles-Palm Springs sulfate is distributed optimally for light scattering whereas the Oildale-China Lake sulfate is not, due to its distribution in smaller sizes (Ouimette, 1980). Because the Los Angeles and Oildale sulfur distributions are typical (Hering, 1980; Friedlander,

1978; Barone, et al., 1978) they may be used as qualitative aerosol tracers of each source in the absence of other sources in the Mojave Desert.

To ensure that the bulk of the tracer and pollutants from Oildale were transported to and detected in the Mojave Desert, a mass balance calculation on the tracer data was attempted. An airplane spiral during the afternoon on the day of the release above Caliente on the eastern edge of the San Joaquin Valley showed that $SF_6$ was relatively well-mixed to a height of about 1400 m (asl). Caliente lies in a small basin that has an average elevation around 6-800 m. Thus the mixing height above the mountain slopes is about 6-800 m (agl). This was roughly the mixing height calculated during the analysis of transport over the similar San Gabriel Mountain range during the first test. The mixing height on the desert side of the mountains were not measured. The travel time between Bakersfield and the Mojave Desert was about 6-8 hours which corresponds to a mean transport speed of about 4-5 mps. A mass balance calculation using the experimental concentration profiles, a 600 m mixing height and a 4.5 mps wind speed suggests that 70-80% of the $SF_6$ released at Oildale was transported eastward over the southern end of the Sierra Nevada Mountains into the northern Mojave Desert. About 10-20% of the $SF_6$ was transported to the southeast over the Tehachapi Mountains into the southern Mojave Desert. The town of Mojave appeared to be roughly the point separating the two transport paths and was used to separate the northern and southern Mojave Desert. For the mass balance calculations, a mass flowrate was calculated from each of the traverse passes and then multiplied by the time interval until the next traverse pass. Due to the uncertainty in vertical mixing height, the mass balance can merely suggest that most of the tracer not accounted for within the San Joaquin Valley on the night following the release was detected in the Mojave Desert.

Because of the complexity of the flow reversal during the transition from downslope to upslope flow at the release site, a simple Gaussian model cannot hope to provide a complete description of the tracer transport and dispersion during this test. The tracer was spread over a large area and significant amounts could be found throughout the western edge of the Mojave Desert and in the San Joaquin Valley. As described previously, however, the bulk of the tracer was transported directly east of the release point after the onset of the afternoon upslope winds. The peak concentrations within this plume, as measured by automobile traverses 1-8 and 1-12 on the western edge of the Mojave Desert, varied between 81 and 26 PPT. Assuming stability class C, the Gaussian model predicts a centerline concentration between 33 and 50 PPT, depending on whether the downwind distance is calculated along the reversed tracer trajectory or on a straightline from the release point. The concentration profiles along these traverses, however, are not Gaussian in shape and the crosswind spread of the tracer plume is not well described by the Gaussian model.

San Joaquin Valley Release of September 9, 1979

The results of the September 5, 1979 tracer study suggest that airborne pollutants released in and around Bakersfield and Oildale have a strong impact upon the northern Mojave Desert. The only effective mechanism of pollutant transport out of the southern San Joaquin Valley during summer and early fall appears to be afternoon upslope flows (Reible and Shair, 1981). Thus pollutants released at different times during the day from the industrial, agricultural and urban sources in the San Joaquin Valley probably impact the Mojave Desert at about the same time. Partially to test this hypothesis, an additional tracer study was conducted from Oildale involving the release of 240 kg of $SF_6$ between 0200 and 0700 PDT on September 9, 1979. The wind flow patterns during this test were

virtually indistinguishable from the first Oildale release. This test was primarily intended to detail transport within the San Joaquin Valley but one automobile traverse along the Tehachapi Mountains was extended into the town of Mojave. $SF_6$ levels around 20 PPT were detected in the vicinity of Mojave and 29 PPT was detected within the town at 2100 PDT. This can be compared to the 2000-2100 PPT hourly averaged $SF_6$ concentration of 20 PPT detected at Mojave during the first Oildale release (Figure 7). There thus appears to be little difference between the two Oildale releases in terms of impact on the Mojave Desert. No aerosol data were available, however, for an Oildale-China Lake comparison as in the first Oildale test.

## SUMMARY AND CONCLUSIONS

Three atmospheric tracer experiments using $SF_6$ and fine aerosol measurements were conducted in California to determine the relative impact of pollutant sources in the San Fernando Valley area of Los Angeles and the southern San Joaquin Valley on visibility in a portion of the Mojave Desert. Dilution ratios calculated for $SF_6$ and various gaseous and aerosol chemical species were used to indicate atmospheric transformation processes between source and receptor. The evolution of the aerosol sulfur mass distribution resulting from transport and transformation was measured. The $SF_6$ data were compared to predictions based upon the Gaussian dispersion model.

## CONCLUSIONS OF TRACER TEST FROM THE LOS ANGELES AIR BASIN

1) During a test conducted under apparently typical summer meteorological conditions, little or no impact of a tracer released in the San Fernando Valley of the Los Angeles air basin was detected in the northwestern Mojave Desert area of China Lake.

2) $SF_6$ released from a location east of the San Fernando convergence zone of the Los Angeles air basin was found to be transported towards the north and then transported eastward into Palmdale and the southern Mojave Desert.

3) The average concentrations within the tracer plume were reduced by a factor of 2 during passage over the San Gabriel Mountains, between Newhall and Palmdale, clearly demonstrating that these mountains are <u>not</u> barriers to significant pollutant transport.

4) Good agreement was found between the experimental concentration profiles and those predicted by the Gaussian plume model

(using experimental inputs) for the tracer transport and dispersion from the San Fernando Valley.

CONCLUSIONS OF TRACER TESTS FROM THE SAN JOAQUIN VALLEY

1) During apparently typical summer meteorological conditions, airborne pollutants released at Oildale in the southern San Joaquin Valley clearly impact the northern Mojave Desert. This conclusion is based upon a number of independent indicators:

   a) $SF_6$ tracer released at Oildale during mid-morning was detected in Ridgecrest (near China Lake) that night. The tracer transport path was verified by automobile traverses both in the San Joaquin Valley and in the Mojave Desert.

   b) Coincident with the detection of $SF_6$ at Ridgecrest, the visibility, as measured by $b_{sp}$ at China Lake, decreased from almost 200 km at 1600-1800 PDT to less than 60 km between 2200-2300 PDT.

   c) Both conserved fine aerosols and $SF_6$ levels detected in the Mojave Desert were a factor of 3 lower than the corresponding levels detected at Oildale.

   d) The aerosol sulfur mass distributions at Oildale and China Lake were quite similar, and both differed markedly from typical Los Angeles-Palm Springs sulfur mass distributions.

2) The average $SF_6$ concentration in the plume on the east side of the Tehachapi and Sierra Nevada Mountains was about $2.3 \pm 0.2$ lower than the average concentration in the plume on the west side of these mountains. When coupled with the dilution of aerosols and $SF_6$ between Oildale and China Lake, this again shows that mountains do not necessarily pose a barrier to significant pollutant transport.

3) Because of the wind reversal between drainage and upslope flow during the first $SF_6$ release from Oildale, the tracer plume was spread over a large area and was apparently bifurcated. The simple Gaussian plume model is inadequate to describe the assymmetry of the tracer plume, or even provide a rough estimate of its spread.

4) Because of the diurnal mountain-valley wind cycle, the maximum impact of sources in the southern San Joaquin Valley upon the Mojave Desert occurs during evening and night-time hours, apparently independent of the time of the release.

5) Even during relatively good ventilation of the San Joaquin Valley, carry-over of pollutants into the day following their release can be significant. During the first test from Oildale, at least 15% of the $SF_6$ released in the morning remained in the valley throughout the night.

6) There is indication that aerosol sulfate was created during transport between Oildale and China Lake, but that aerosol and gaseous nitrates were scavenged enroute.

7) The tracer data suggested that air pollutants released in the San Fernando Valley area of Los Angeles and the San Joaquin Valley can impact southern Nevada and Arizona.

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TABLE OF FIGURES

Figure 1 - Map of southwestern United States showing the region of study and its relationship to the surrounding area.

Figure 2 - Map of study area including $SF_6$ release points (▲), $SF_6$ fixed site sample locations (■), and main automobile traverse routes (...) for the San Fernando Valley release and the main automobile traverse routes (--) for the San Joaquin Valley release. Also included are arrows indicating the general direction(s) of $SF_6$ transport during each test. The width of the arrows for the San Joaquin Valley test is a qualitative indicator of the amount of mass transported in each direction and does not represent the width of the plume.

Figure 3 - Hourly average scattering due to particles, $b_{sp}$, at China Lake on July 20 and 21, 1978 (—). Also shown are the $b_{sp}$ levels within one standard deviation of the 1978, 1979 July composite mean $b_{sp}$ at China Lake (--).

Figure 4 - $SF_6$ concentrations detected during automobile traverses between Piru and Acton on the west side of the San Gabriel Mountains during the San Fernando Valley release.

Figure 5 - $SF_6$ concentrations detected during automobile traverses between Lake Hughes and Valermo on the east side of the San Gabriel Mountains during the San Fernando Valley release.

Figure 6 - Hourly average scattering due to particles, $b_{sp}$, at China Lake on September 5 and 6, 1979 (—). The $SF_6$ levels detected at Ridgecrest are shown in the bottom figure for comparison (—).

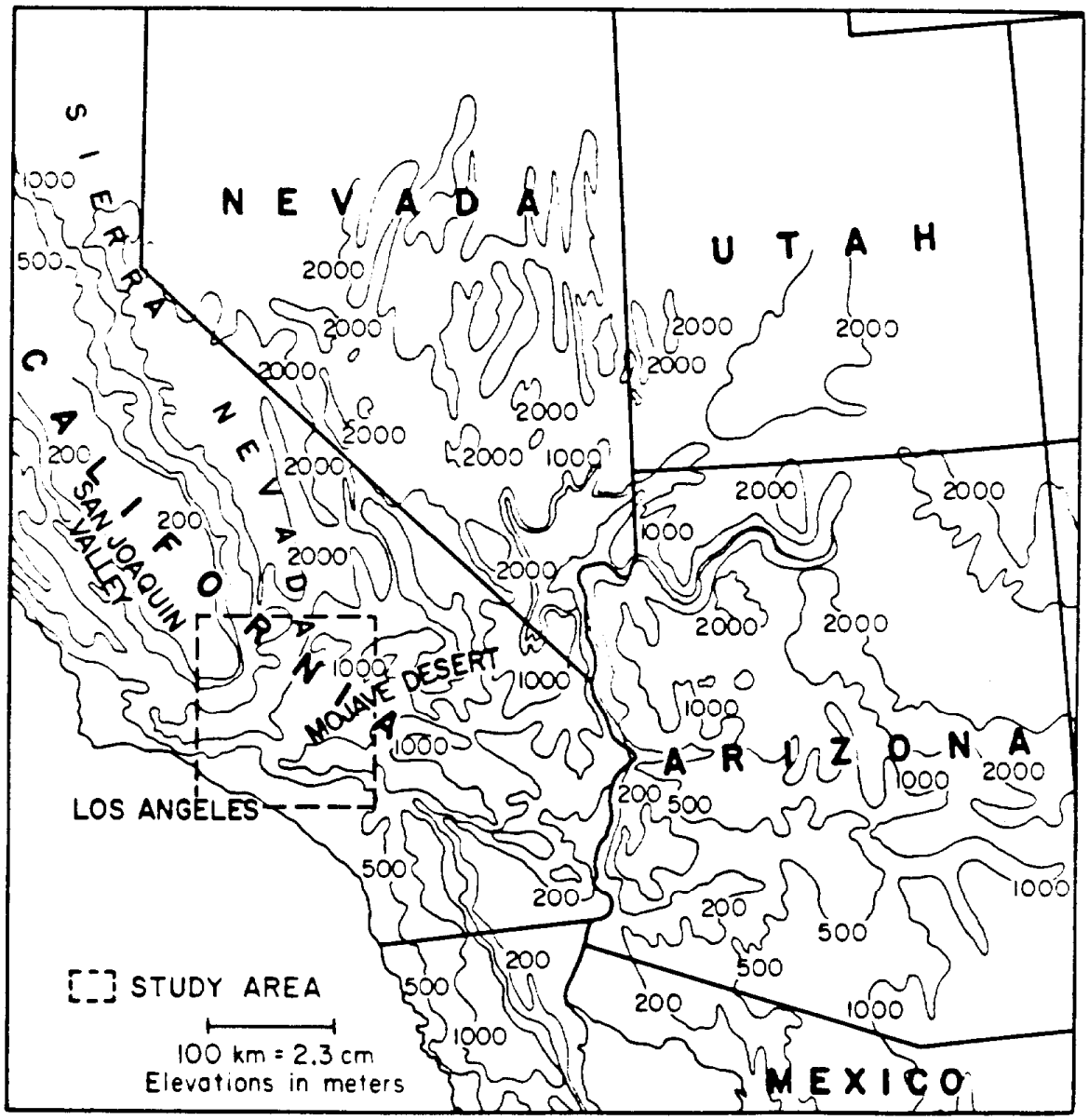
Also shown are the $b_{sp}$ levels within one standard deviation of the 1978, 1979 September composite mean $b_{sp}$ at China Lake (--).

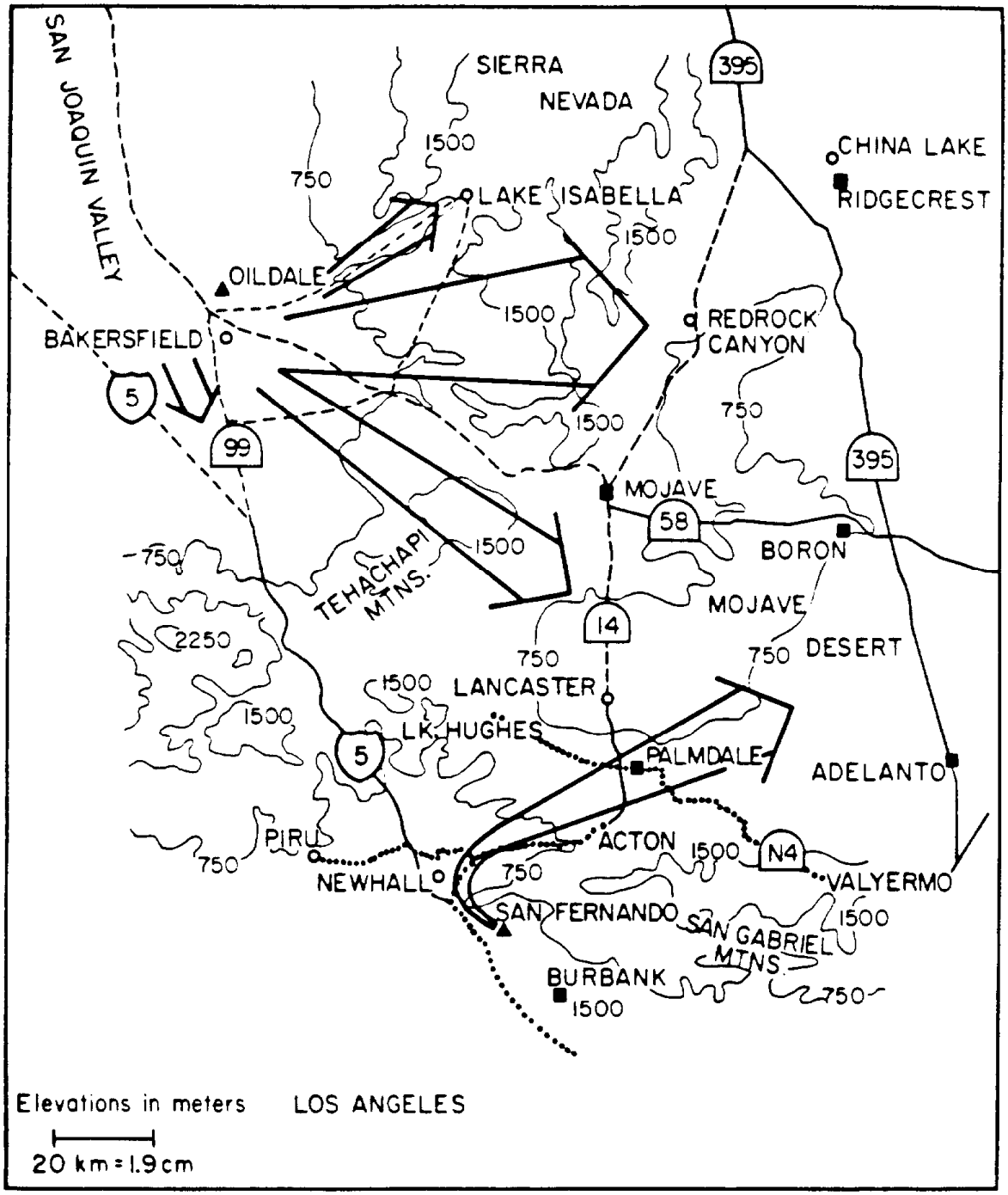
Figure 7 - Overview of $SF_6$ transport during San Joaquin Valley tests as shown by fixed site sample concentrations. Arrows denote end of sampling period.

Figure 8 - $SF_6$ concentrations detected during automobile traverses between Lancaster and the intersection of Ca. Hwy's 14 and 395 in the Mojave Desert during the San Joaquin Valley test.

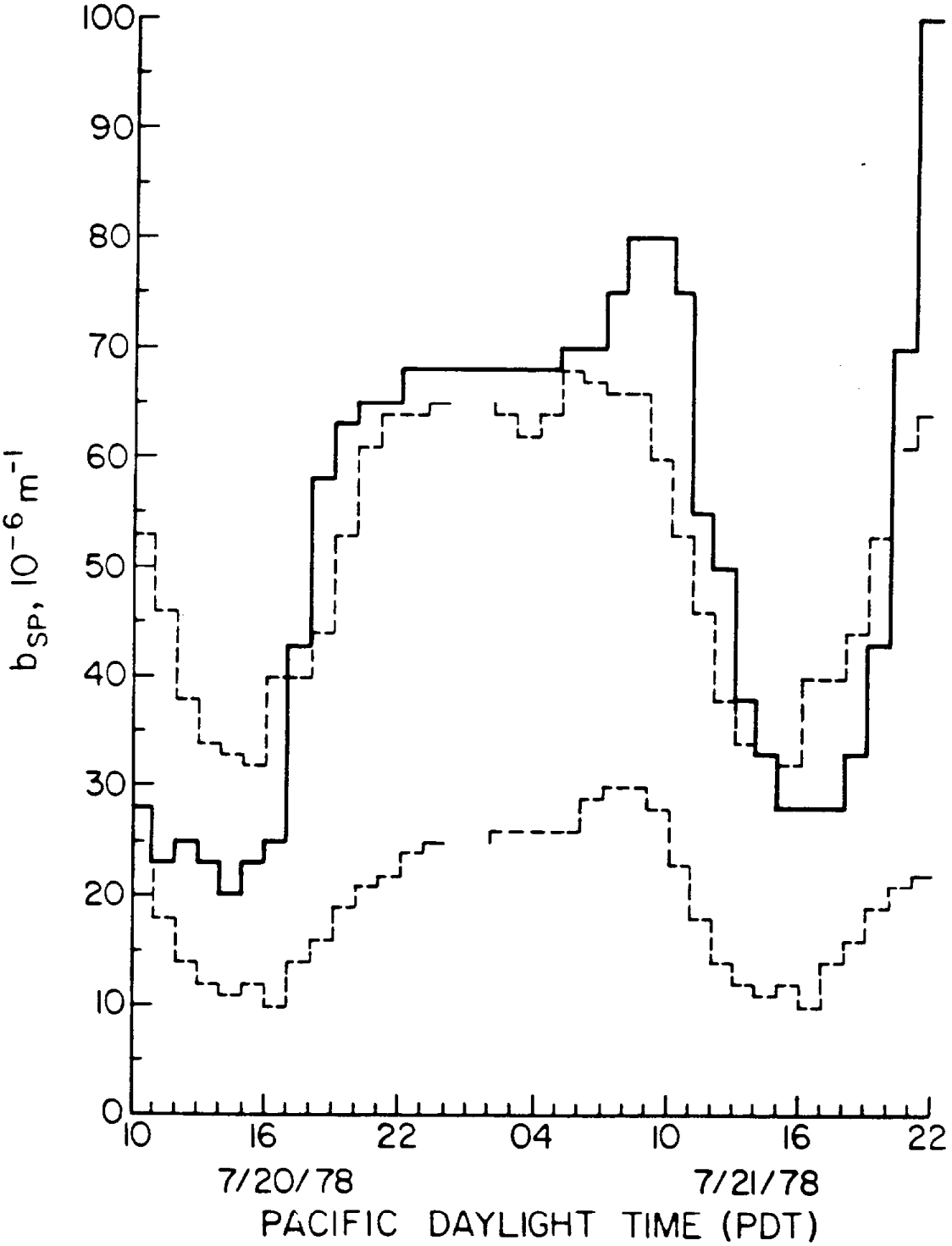
Figure 9 - Normalized ambient aerosol sulfur mass distributions. The solid histogram is the time average distribution measured at Oildale, Ca. from 1127-1215 PDT, September 9, 1979; M=3.48 $\mu g/m^3$. The dashed histogram is the time average distribution measured at China Lake from 2200-0130 PDT, September 9-10, 1979; M=1.15 $\mu g/m^3$.

Figure 10 - Normalized ambient aerosol sulfur mass distributions. The solid histogram is the time average distribution measured at Pasadena, Ca., from 1528-1728 PDT, December 26, 1978; M=10.6 $\mu g/m^3$. The dashed histogram is the time average distribution measured at Palm Springs, Ca., 1730-1830 PDT, August 3, 1979; M=2.1 $\mu g/m^3$.

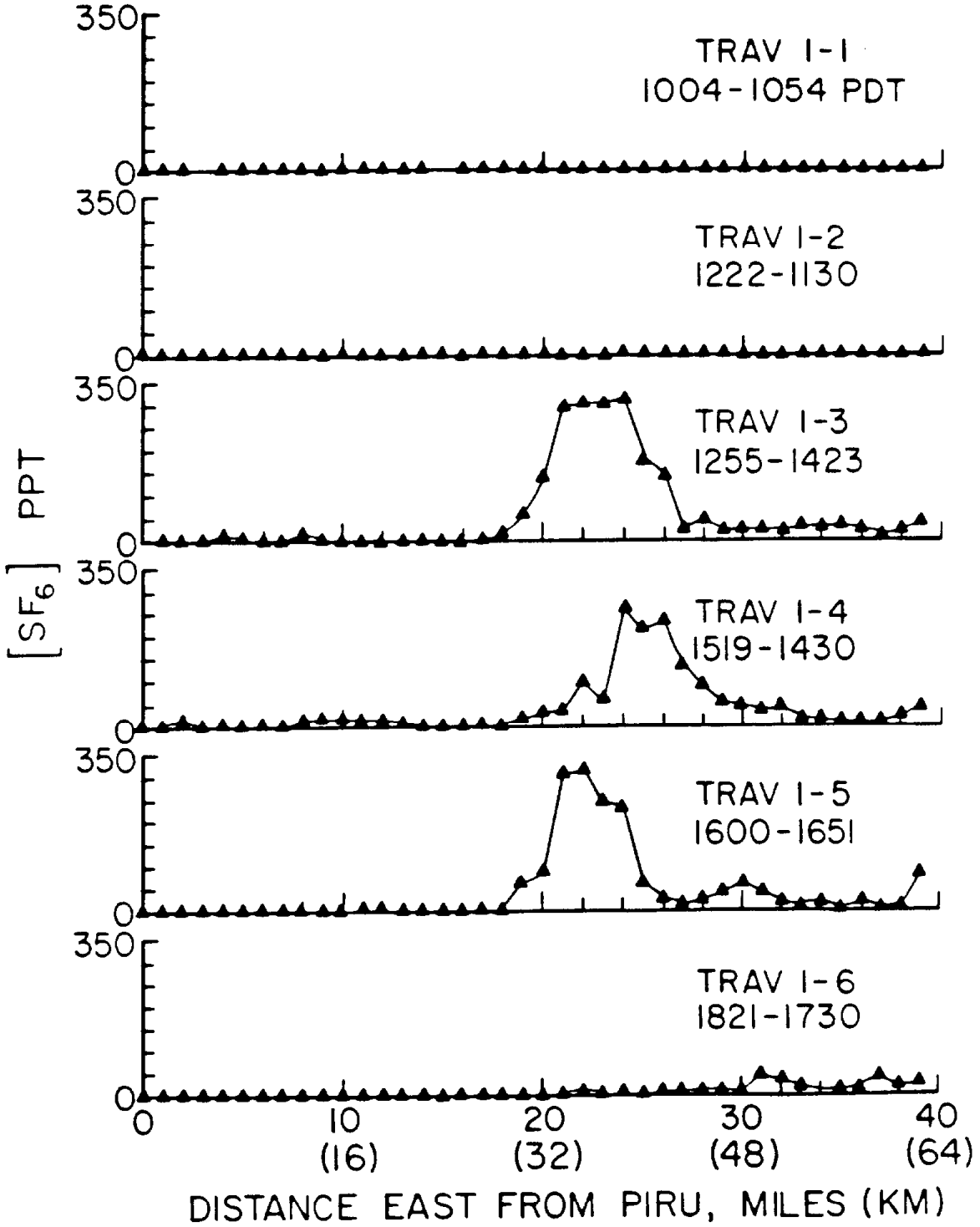

NEVADA
UTAH
ARIZONA
MEXICO
CALIFORNIA
SIERRA NEVADA
SAN JOAQUIN VALLEY
MOJAVE DESERT
LOS ANGELES
STUDY AREA
100 km = 2.3 cm
Elevations in meters


SAN JOAQUIN VALLEY
SIERRA
NEVADA
395
CHINA LAKE
RIDGECREST
1500
750
LAKE ISABELLA
1500
OILDALE
1500
REDROCK
CANYON
BAKERSFIELD
5
1500
750
99
395
MOJAVE
58
BORON
750
1500
TEHACHAPI
MTNS.
MOJAVE
14
DESERT
2250
750
750
1500
LANCASTER
1500
LK. HUGHES
5
PALMDALE
ADELANTO
PIRU
ACTON
1500
N4
750
750
NEWHALL
VALYERMO
SAN FERNANDO
1500
SAN GABRIEL
MTNS.
BURBANK
750
1500
Elevations in meters
LOS ANGELES
20 km = 1.9 cm

HOURLY AVERAGE SCATTERING DUE TO PARTICLES,
$b_{SP}$ CHINA LAKE 7/20/78 - 7/21/78



SAN FERNANDO VALLEY TEST 7/20/78



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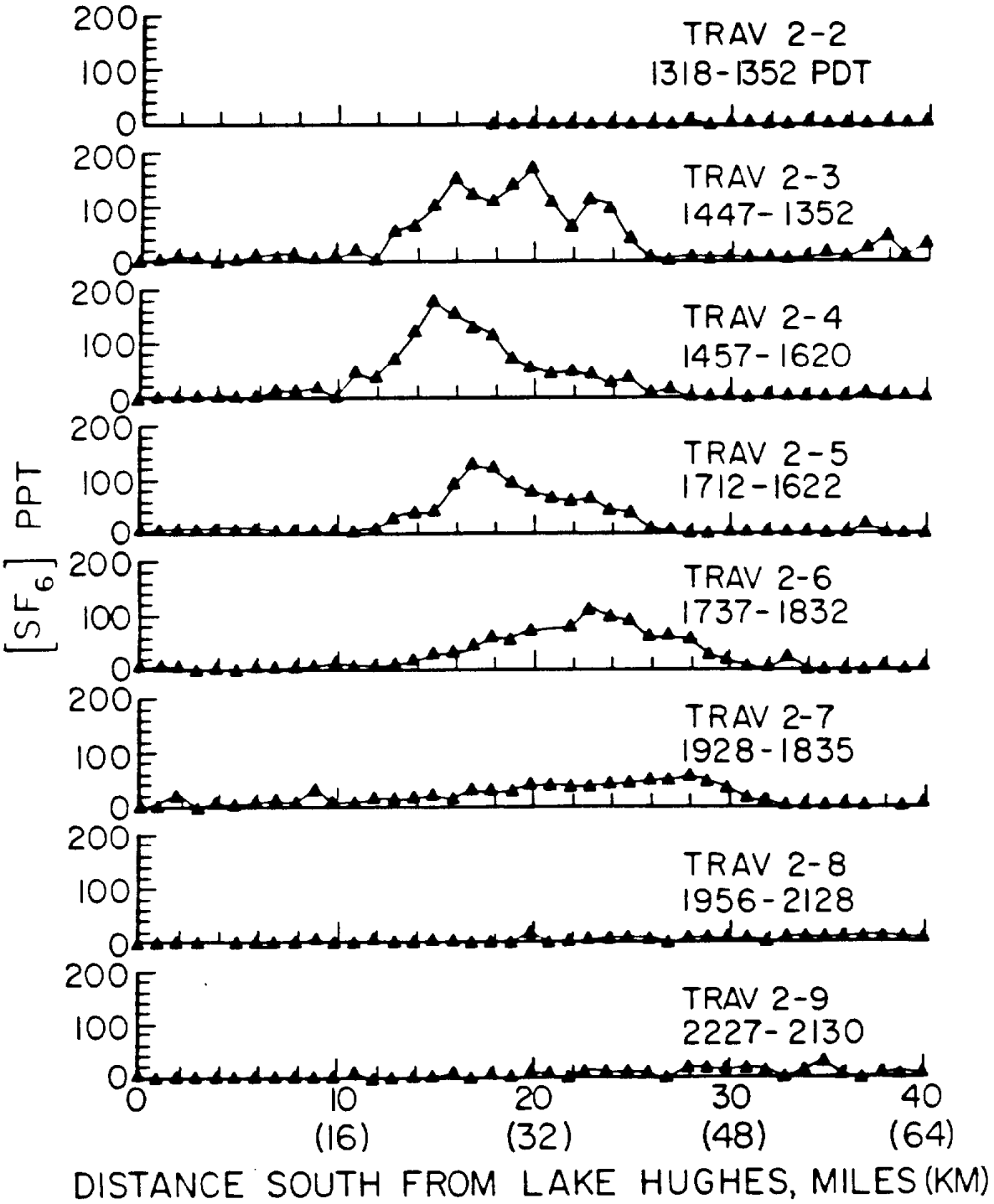
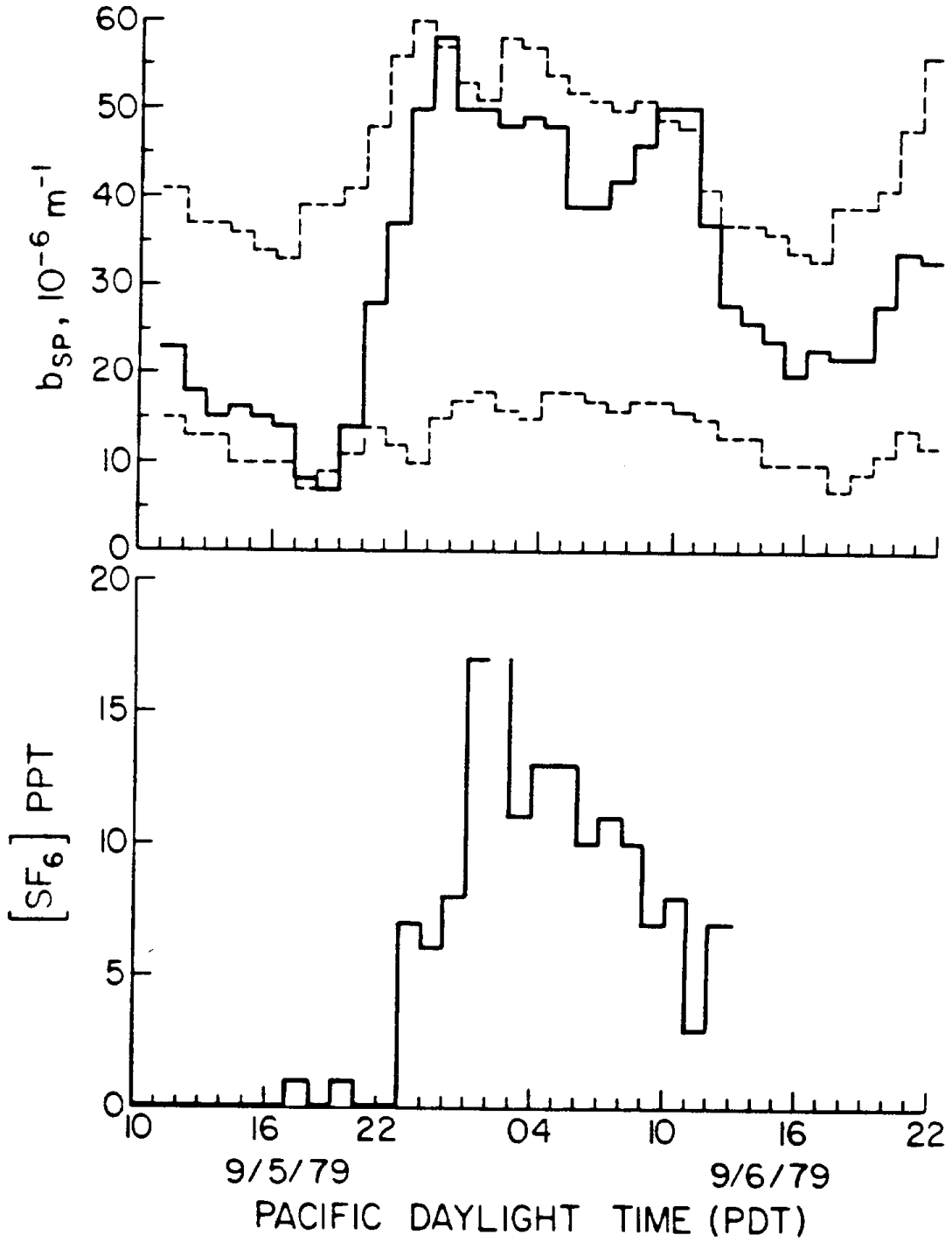
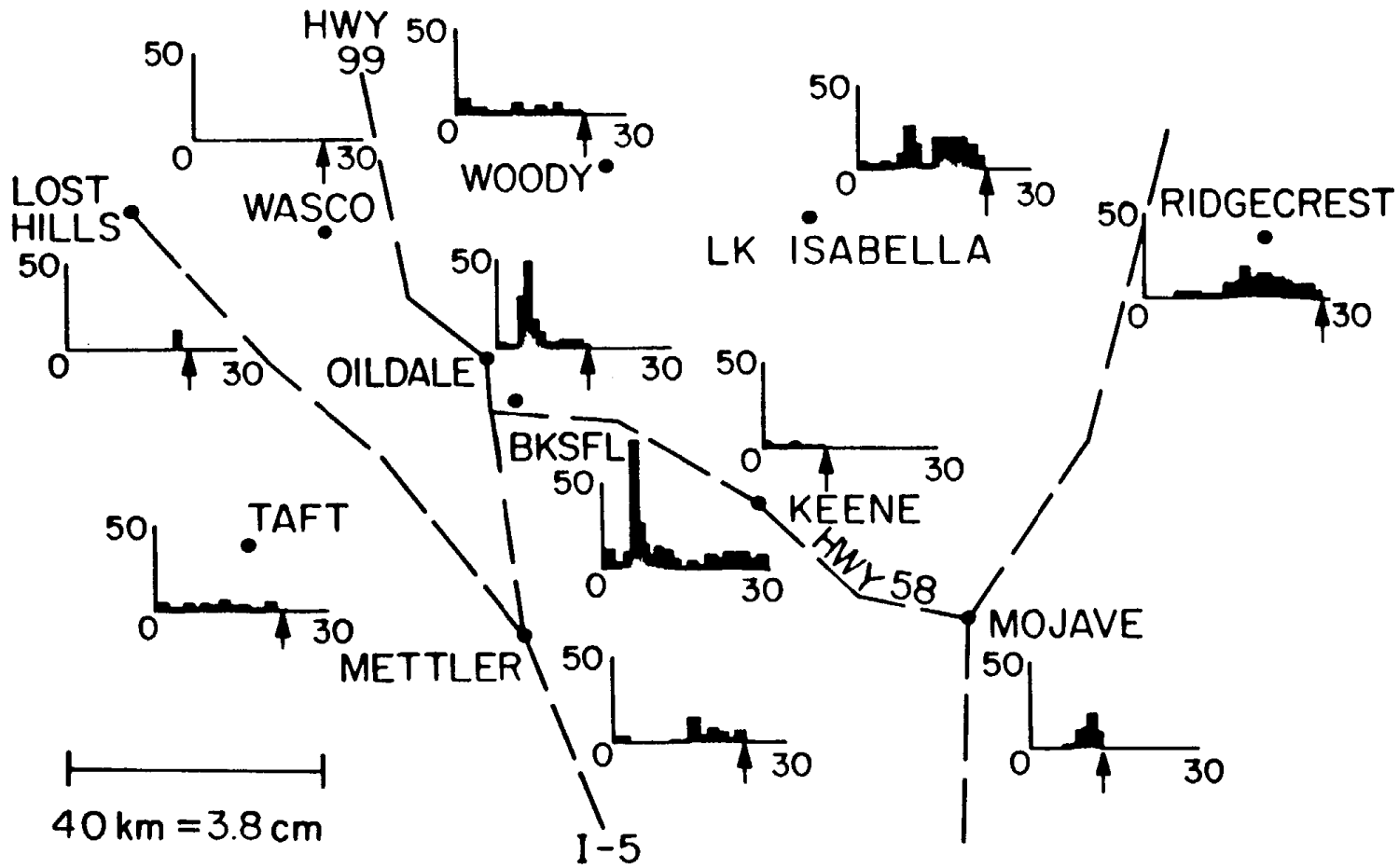


HOURLY AVERAGE SCATTERING DUE TO PARTICLES, $b_{SP}$, AT CHINA LAKE AND $[SF_6]$ AT RIDGECREST

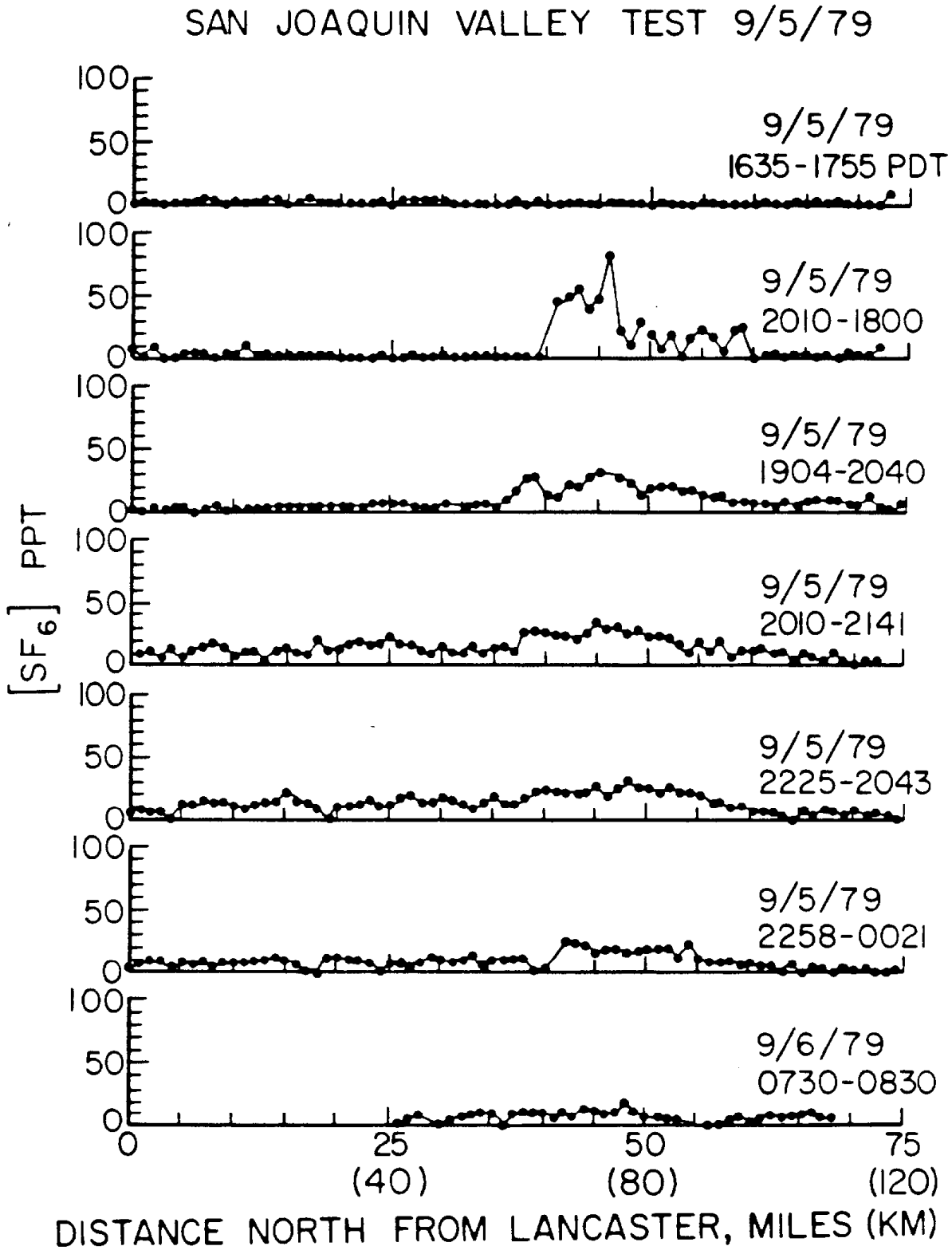
9/5/79 - 9/6/79

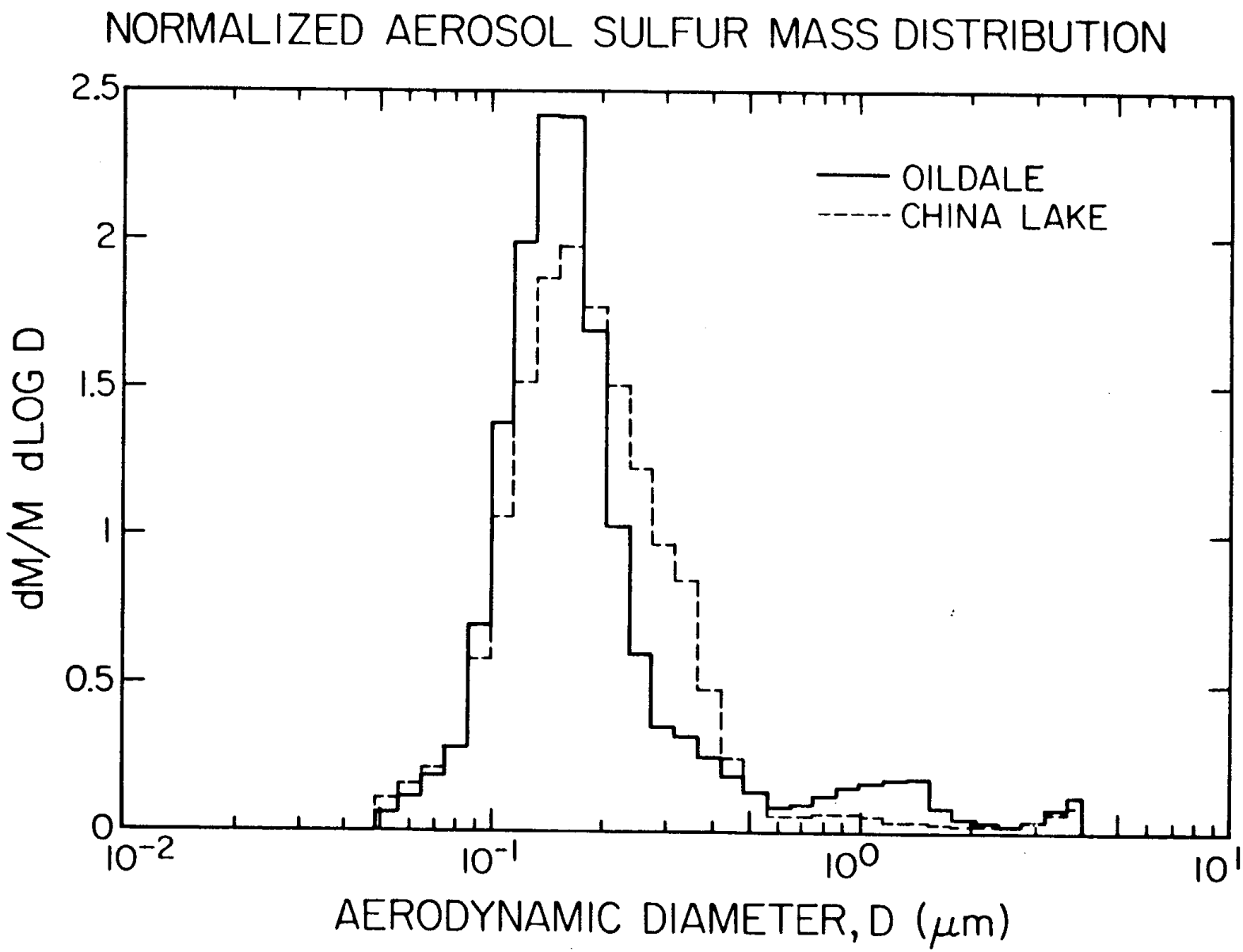


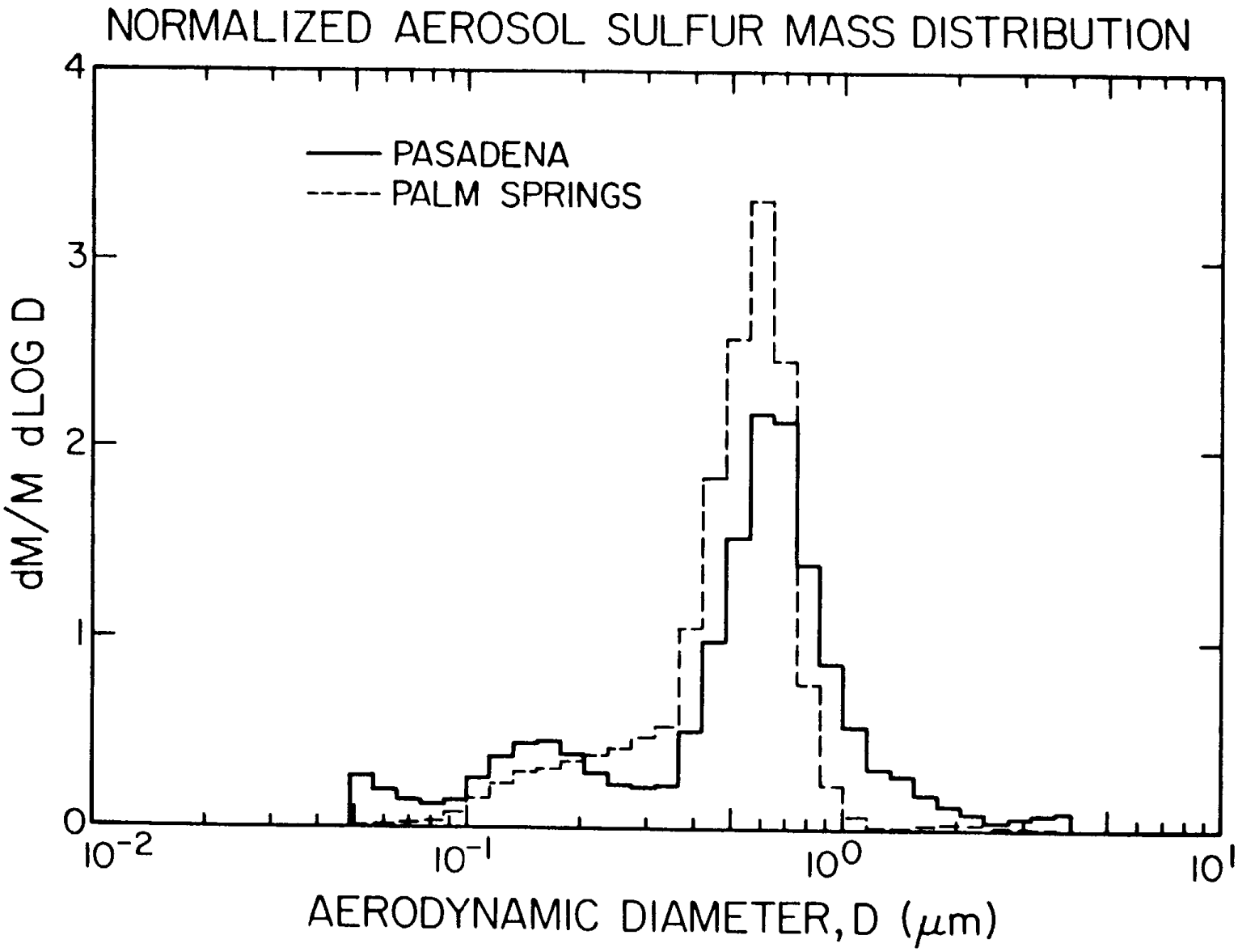
SAN JOAQUIN VALLEY TEST 9/5/79




HORIZONTAL AXIS – TIME AFTER START OF RELEASE (HOURS)
VERTICAL AXIS – $[SF_6]$ ppt


SAN JOAQUIN VALLEY TEST 9/5/79
[SF6] PPT
100
50
0
9/5/79
1635-1755 PDT
9/5/79
2010-1800
9/5/79
1904-2040
9/5/79
2010-2141
9/5/79
2225-2043
9/5/79
2258-0021
9/6/79
0730-0830
0
25
50
75
(40)
(80)
(120)
DISTANCE NORTH FROM LANCASTER, MILES (KM)


NORMALIZED AEROSOL SULFUR MASS DISTRIBUTION
OILDALE
CHINA LAKE
dM/M dLOG D
2.5
2
1.5
1
0.5
0
$10^{-2}$
$10^{-1}$
$10^{0}$
$10^{1}$
AERODYNAMIC DIAMETER, D ($\mu$m)


NORMALIZED AEROSOL SULFUR MASS DISTRIBUTION
PASADENA
PALM SPRINGS
dM/M dLOG D
0
1
2
3
4
$10^{-2}$
$10^{-1}$
$10^{0}$
$10^{1}$
AERODYNAMIC DIAMETER, D ($\mu$m)