OZONE TRANSPORT IN THE NORTH CENTRAL COAST AIR BASIN

Final Report

Executive Summary

February 1983

By: Walter F. Dabberdt, Deputy Director
Atmospheric Science Center

Prepared for:

California Air Resources Board
1131 S Street
Post Office Box 2815
Sacramento, California 95812

Contract A9-143-31

Projects 1898 and 4637

SRI International
333 Ravenswood Avenue
Menlo Park, California 94025
(415) 859-6200
TWX: 910-373-2046
Telex: 334 486

OZONE TRANSPORT IN THE NORTH CENTRAL COAST AIR BASIN

Final Report

Executive Summary

February 1983

By: Walter F. Dabberdt, Deputy Director
Atmospheric Science Center

Prepared for:

California Air Resources Board
1131 S Street
Post Office Box 2815
Sacramento, California 95812

Contract A9-143-31

Projects 1898 and 4637

Approved:

Warren B. Johnson, Director
Atmospheric Science Center

Earle D. Jones, Vice President
Advanced Development Division

DISCLAIMER

ABSTRACT

SRI conducted an experimental study during the period 17 September to 8 October 1980 to examine the transport of air pollutants (principally ozone) into and within the North Central Coast Air Basin (NCCAB). Ozone conditions during the study were the highest ever recorded in the NCCAB. The study employed two inert, nontoxic gaseous tracers (sulfur hexafluoride and bromotrifluoromethane) released at different locations or times on each of eight test days. Up to 1000 measurements of each tracer were made on each test day using aircraft, vehicle, and stationary sampling. Aerometric measurements were made by the airplane and two surface monitoring stations. In addition to the tracer tests, two airborne ozone mapping tests were conducted off the coast from Monterey to San Francisco. The measurements documented significant ozone transport from San Francisco to the NCCAB over the coastal waters and onshore in Monterey Bay. Transport was also documented from San Jose to Hollister through the Santa Clara Valley, although less dramatic than the offshore transport. The Santa Clara Valley transport pattern is impeded and complicated by the complex terrain and meteorology. Significant ozone transport was not observed over the Santa Cruz Mountains between Los Gatos and Scotts Valley, although transport of the tracer did occur. The strong marine inversion over the coast on the two relevant test days inhibited elevated emissions from Moss Landing from dispersing to the surface within the NCCAB. Other prevailing meteorological regimes may result in different impacts than those observed during the eight tests. Recommendations are provided for more quantitative and more detailed analyses of the data.

CONTENTS

ACKNOWLEDGMENTS

The support and assistance of several organizations and many people is sincerely and gladly acknowledged: Mr. Charles Unger, Research Division, California Air Resources Board, Sacramento, was the project officer and provided valuable direction, encouragement, and assistance. Mr. Tim MacHold and Ms. Janet Wainright, CARB, Berkeley, collected most of the mobile ozone measurements and many tracer samples. Mr. Lew Robinson and Mr. Jim Sandberg and the staff of the Bay Area Air Quality Management District provided daily weather and air quality data and forecasts. Mr. Larry Odle, APCO, and Mr. Harold Hillman, Deputy APCO, Monterey Unified Air Pollution Control District, provided support personnel and encouragement throughout the study.

Many people from SRI contributed to the experimental and data reduction tasks: Albert Smith, Eugene Shelar, Charles Flohr, Louis Salas, Robin Stiles, Bruce Cantrell, Janet Lee, Hisao Shigeishi, and Russell Trudeau. The aircraft was skillfully piloted by Thomas Freitas.

I INTRODUCTION

The basic objective of the study was to collect atmospheric data to resolve and quantify the origin and fate of the high surface oxidant concentrations occasionally monitored within the North Central Coast Air Basin (NCCAB). An experimental program was conducted during the period 17 September through 8 October 1980 to measure ambient aerometric parameters as well as the dispersion of two inert tracer gases released at various locations both within and outside the basin.

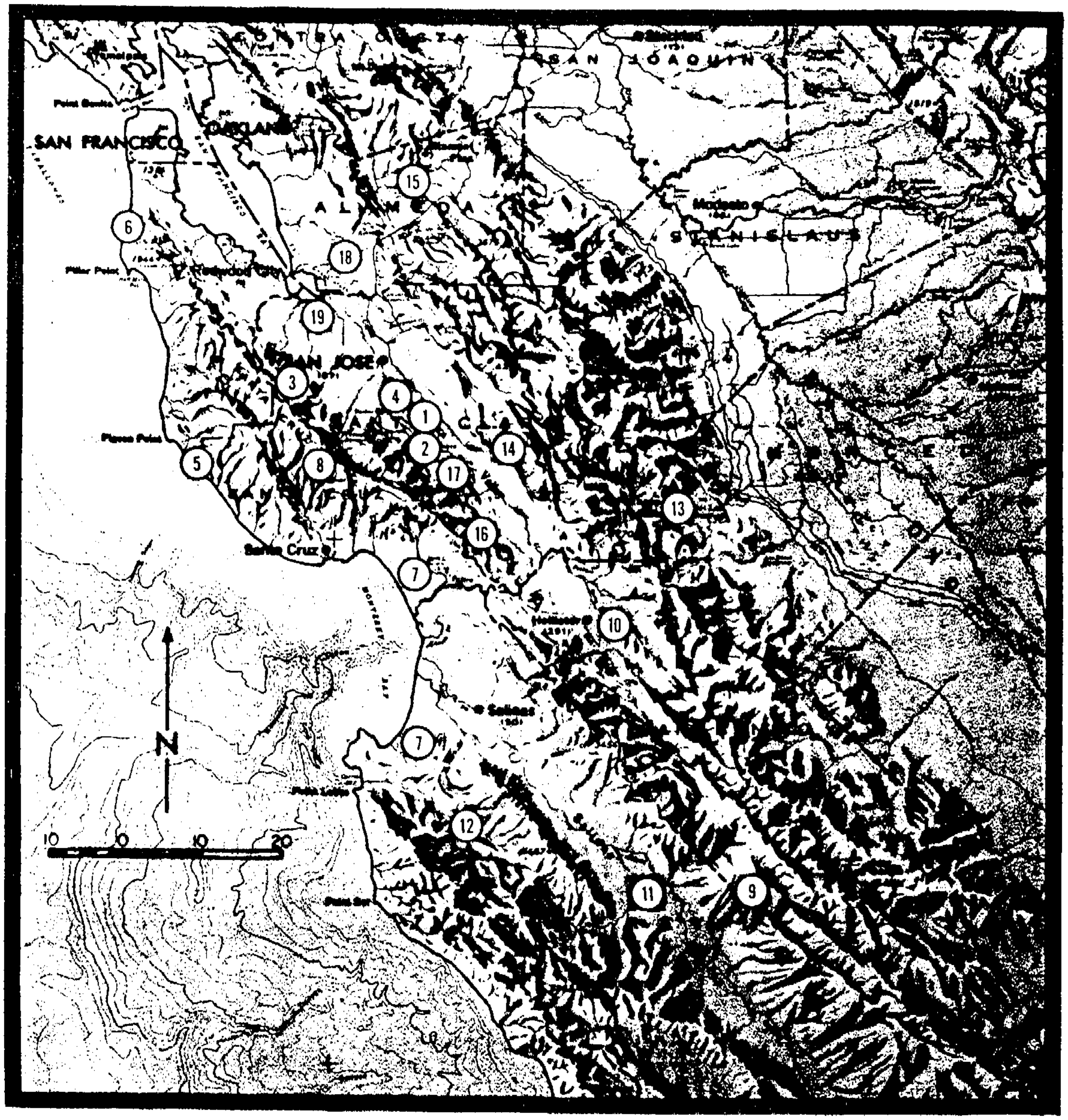
The NCCAB comprises Santa Cruz, Monterey, and San Benito counties. Four mountain ranges influence atmospheric transport and residence patterns throughout the basin. Figure 1 shows the location of the mountain ranges and valleys within the air basin.

Prior to this study, three principal routes had been postulated for atmospheric transport from the San Francisco Bay Area into the NCCAB; these are shown in Figure 2. An additional three transport routes that had been identified within the basin are illustrated in Figure 3. The most frequently discussed interbasin transport route is through the Santa Clara Valley (Number 1 in Figure 2). The northern end of the route is known to be an effective funnel of oxidant and oxidant-precursors into the Morgan Hill area, although a convergence zone in the Gilroy-Hollister area has been postulated to impede or retard the southward transport in that region. The mountain pass that parallels Highway 17 between Los Gatos and Santa Cruz has been identified as another, though less effective, transport route (Number 2). Lastly, there has also been speculation that occasionally high oxidant concentrations along the Monterey Bay from Scotts Valley and Santa Cruz to Monterey and Carmel have been the result of over-water transport down the coast from the San Francisco Area (Number 3).

Five routes had also been postulated as significant to oxidant advection within the NCCAB. First, there is transport from Moss Landing to Hollister and Gilroy (Number 4 in Figure 3); this route can converge with the Santa Clara Valley transport route to produce the convergence zone referenced earlier. Second, there is ozone transport down the Salinas Valley toward King City (Number 5). Third, the on- and offshore transport between Monterey Bay and the adjacent coastal plain (Number 6) is in response to the combined effects of the diurnal land and sea breezes and the prevailing synoptic flow. The fourth route (Number 7) is from the Santa Cruz area inland to Scotts Valley, and last, the postulated route (Number 8) inland from Monterey to Carmel Valley.

GENERALIZED TOPOGRAPHY

NORTH CENTRAL COAST
AIR BASIN



(1) SANTA TERESA HILLS
(2) CALERO RESERVOIR
(3) LEXINGTON RESERVOIR
(4) ALMADEN
(5) ANO NUEVO RESERVE
(6) SAN PEDRO POINT
(7) PAJARO COASTAL PLAIN
(8) SANTA CRUZ MOUNTAINS
(9) SAN LORENZO VALLEY
(10) SAN BENITO VALLEY
(11) SALINAS VALLEY
(12) CARMEL VALLEY
(13) PACHECO PASS
(14) ANDERSON RESERVOIR
(15) LIVERMORE VALLEY
(16) HECKER PASS
(17) UVAS RESERVOIR
(18) MISSION SAN JOSE
(19) MOFFETT FIELD

FIGURE 1 TOPOGRAPHY OF THE NORTH CENTRAL COAST AIR BASIN
(See Appendix for area/road maps)

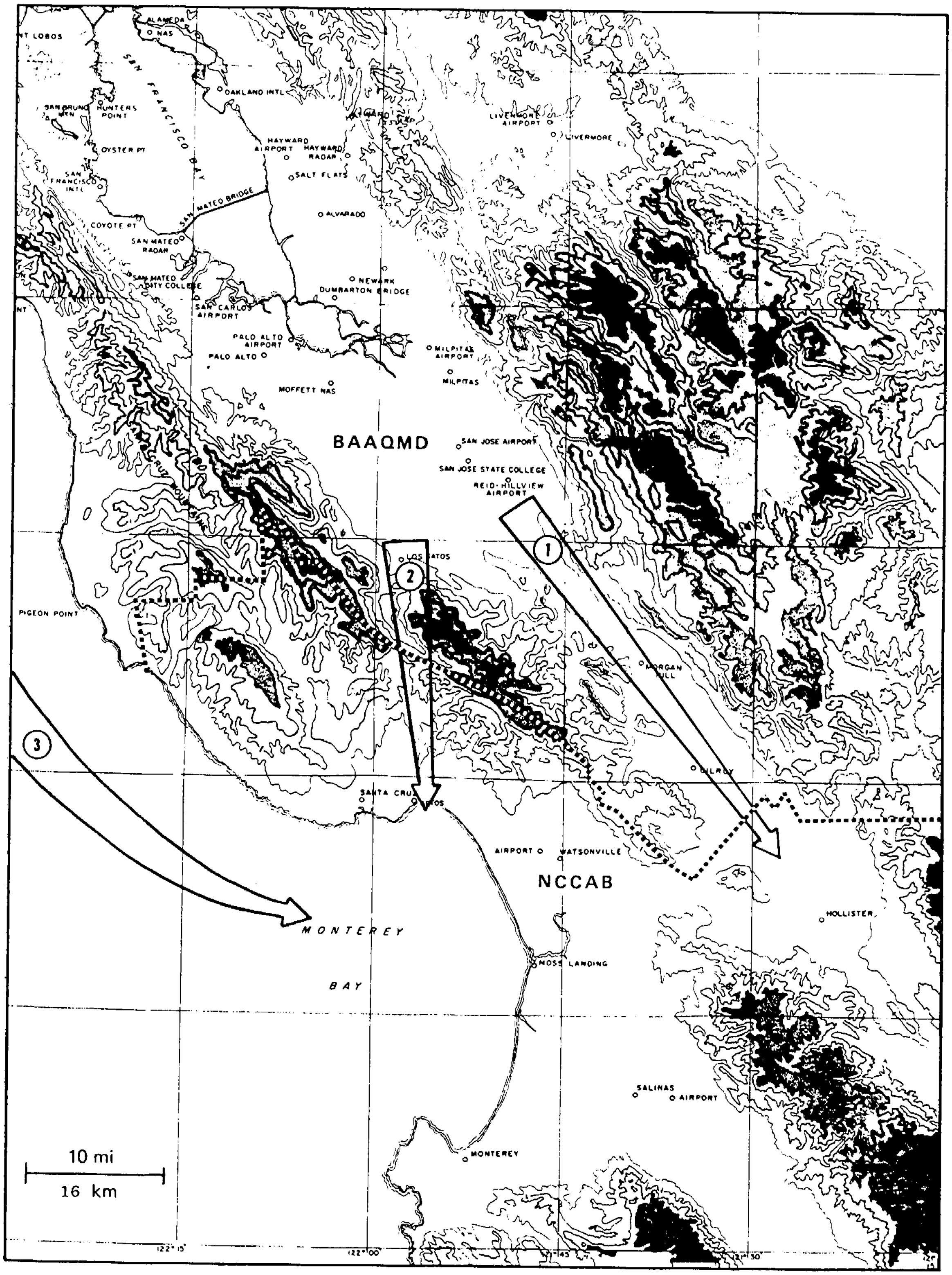


FIGURE 2 POSTULATED TRANSPORT ROUTES FROM SAN FRANCISCO BAY AREA INTO THE NORTH CENTRAL COAST AIR BASIN

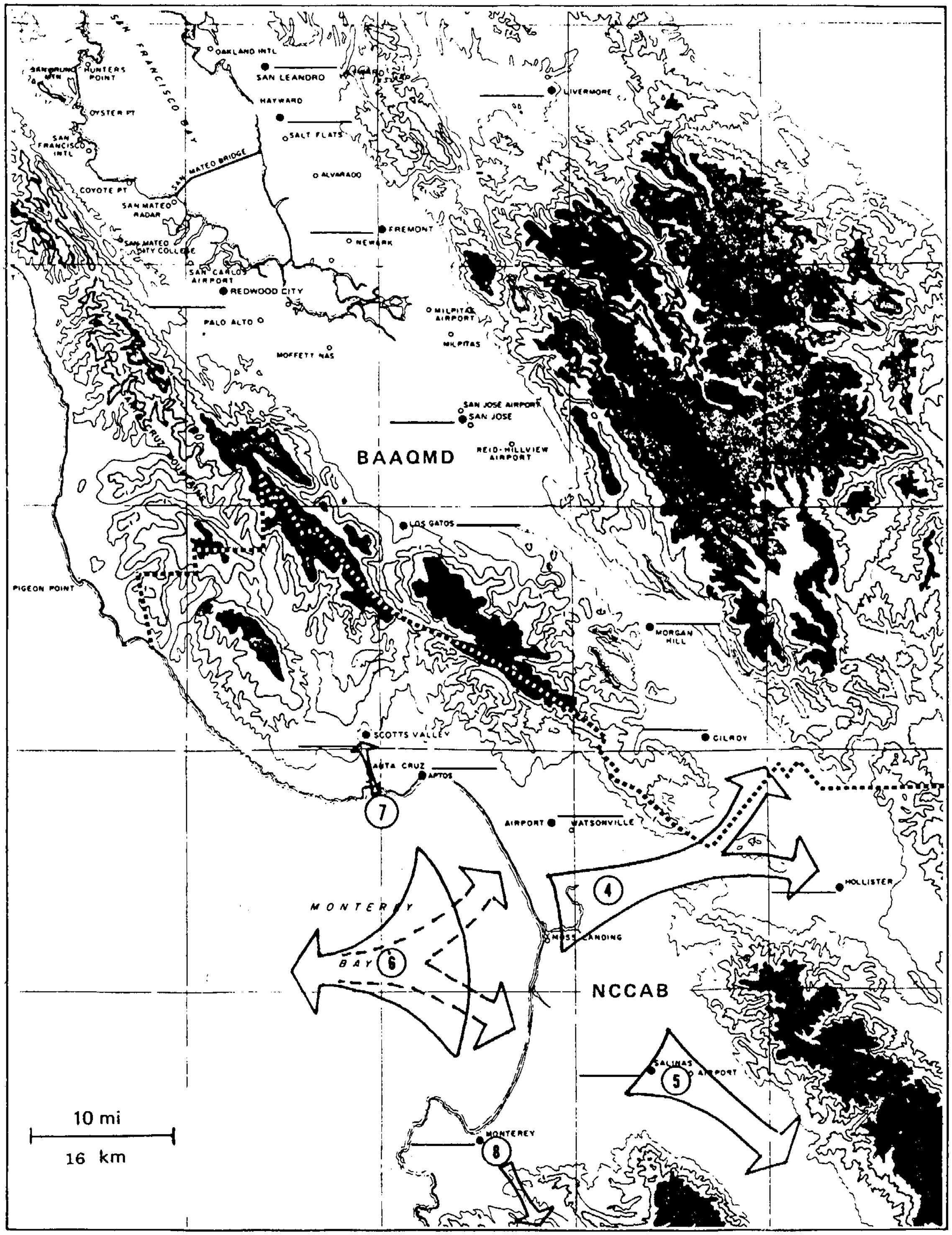


FIGURE 3 POSTULATED TRANSPORT ROUTES WITHIN THE NORTH CENTRAL COAST AIR BASIN

Prior to this study, the highest oxidant levels on record in the NCCAB occurred during several closely spaced periods in September and October 1976. Peak concentrations in Hollister and Aptos were 14 pphm, while Scotts Valley had the all-time maximum of 21 pphm on 9 September 1976.

A total of eight dual-tracer atmospheric tests were conducted over the period 17 September through 8 October 1980. Table 1 summarizes the characteristics of the tracer release times and locations for the various tests.

Meteorological conditions were ideal for the study insofar as they helped to create what perhaps has been the severest ozone concentrations recorded up to that time within the NCCAB. Four of the test days had ozone concentrations equal to or exceeding the national ambient standard;* four different stations within the basin had these high readings on at least one of the four days. The Watsonville station had high readings on three of the four days and was inoperative on the afternoon of the fourth day. Additionally, five neighboring BAAQMD stations recorded above-standard ozone levels on all four of these days plus two additional days. For orientation purposes, peak-hour concentrations are summarized in Table 2 for each of the test days for all stations in the NCCAB and those that are nearby but within the BAAQMD.

Figure 4 illustrates the day-to-day variation of several key meteorological and air quality parameters throughout the period. The ozone concentration in the illustration is the peak hourly value at Gilroy, which is representative of maximum concentrations in the study region (see Table 2). Temperature is the 12Z (05 PDT), 850-mb value on the Oakland RAOB, and winds are the 850-mb winds from the 00Z Oakland sounding (i.e., 17 PDT); westerly and southerly wind components are denoted as positive values. Surface pressure differences (12Z) are those between San Francisco (SFO) and Reno (RNO).

Data from 14 existing air quality monitoring stations were obtained and analyzed for each test day. Six of the stations are located in the NCCAB: Scotts Valley, Aptos, Salinas, Monterey, Carmel Valley, and Hollister. The remaining eight are in the BAAQMD: Gilroy, Los Gatos, San Jose, Redwood City, Fremont, Hayward, Livermore, and San Leandro.

---

*The national ambient air quality standard for ozone requires the daily peak-hour average concentration not to exceed 12 pphm (240 $\mu g\ m^{-3}$) more than once per year.

Table 1

SUMMARY OF TRACER TESTS

Date (1980)	Type of Test	Tracer Release Points*	
		SF_6 †	F13B1 ‡
17 September	Simultaneous, surface, dual-tracer release	Newark (0931–1131)	Cupertino (0936–1136)
22 September	Simultaneous, surface, dual-tracer release	Newark (0900–1100)	Cupertino (0900–1100)
24 September	Simultaneous, surface, dual-tracer release	Fairgrounds, San Jose (0900	Vasona Park, Los Gatos (0900
25 September	Carryover study--surface and aircraft measurements	—	—
26 September	Simultaneous, surface, dual-tracer release	Coyote Park, San Jose (1000–1200)	Vasona Park, Los Gatos (1000–1200)
30 September	Sequential, surface, dual-tracer release	San Jose City College (0900–1100)	San Jose City College (1030–1230)
1 October	Coastal air quality mapping with aircraft	—	—
2 October	Simultaneous, surface, dual-tracer release	Santa Cruz (1030–1230)	Monterey (1015–1215)
6 October	Simultaneous surface and elevated dual-tracer release	Moss Landing, PG&E stack (1049–1249)	Moss Landing, surface (1030–1230)
7 October	Carryover study--surface and aircraft measurements	—	—
8 October	Simultaneous surface and elevated dual-tracer release	Moss Landing, PG&E stack (1100–1300)	Moss Landing, surface (1100–1300)

*Release period (PDT) shown in parentheses

†SF_6 release rate: 26 kg h^{-1} for surface releases
52 kg h^{-1} for elevated releases

‡F13B1 release rate: 34 kg h^{-1} for all tests

Table 2

PEAK-HOUR OZONE CONCENTRATION (pphm)

Underscores indicate concentrations $\geq$ ambient standard

Station	Date (1980)										
	17 Sep	22 Sep	24 Sep	25 Sep	26 Sep	30 Sep	1 Oct	2 Oct	6 Oct	7 Oct	8 Oct
Scotts Valley[a]	5	*	8	7	4	*	*	10	7	9	10
Aptos[a]	5	5	8	4	4	11	11	9	6	10	7
Carmel Valley[a]	5	6	6	5	4	10	10	$\underline{14}$	7	6	5
Hollister[a]	7	7	8	8	3	$\underline{14}$	10	11	10	$\underline{12}$	8
Monterey[a]	*	*	*	*	*	*	*	*	6	5	4
Salinas[a]	5	5	7	5	4	9	9	$\underline{12}$	6	6	4
Gilroy[b]	8	9	9	10	5	$\underline{18}$	$\underline{20}$	$\underline{19}$	$\underline{14}$	$\underline{13}$	11
Los Gatos[b]	7	6	11	9	6	$\underline{16}$	$\underline{16}$	$\underline{>15}$†	11	*	$\underline{12}$
San Jose (4th Street)[b]	5	7	8	8	5	$\underline{15}$	$\underline{16}$	$\underline{17}$	8	9	5
San Jose (Piedmont Road)[b]	5	9	11	10	6	$\underline{19}$	$\underline{19}$	$\underline{19}$	9	10	7
Watsonville[c]	7	8	10	6	6	$\underline{12}$	$\underline{15}$	$\underline{17}$	9	*	10
Morgan Hill[c]	6	7	9†	*	*	$\underline{18}$	$\underline{20}$	$\underline{19}$	$\underline{13}$	*	$\underline{12}$

*Missing.

†Some missing afternoon hours.

[a]NCCAB station.

[b]BAAQMD station.

[c]Special, study station.

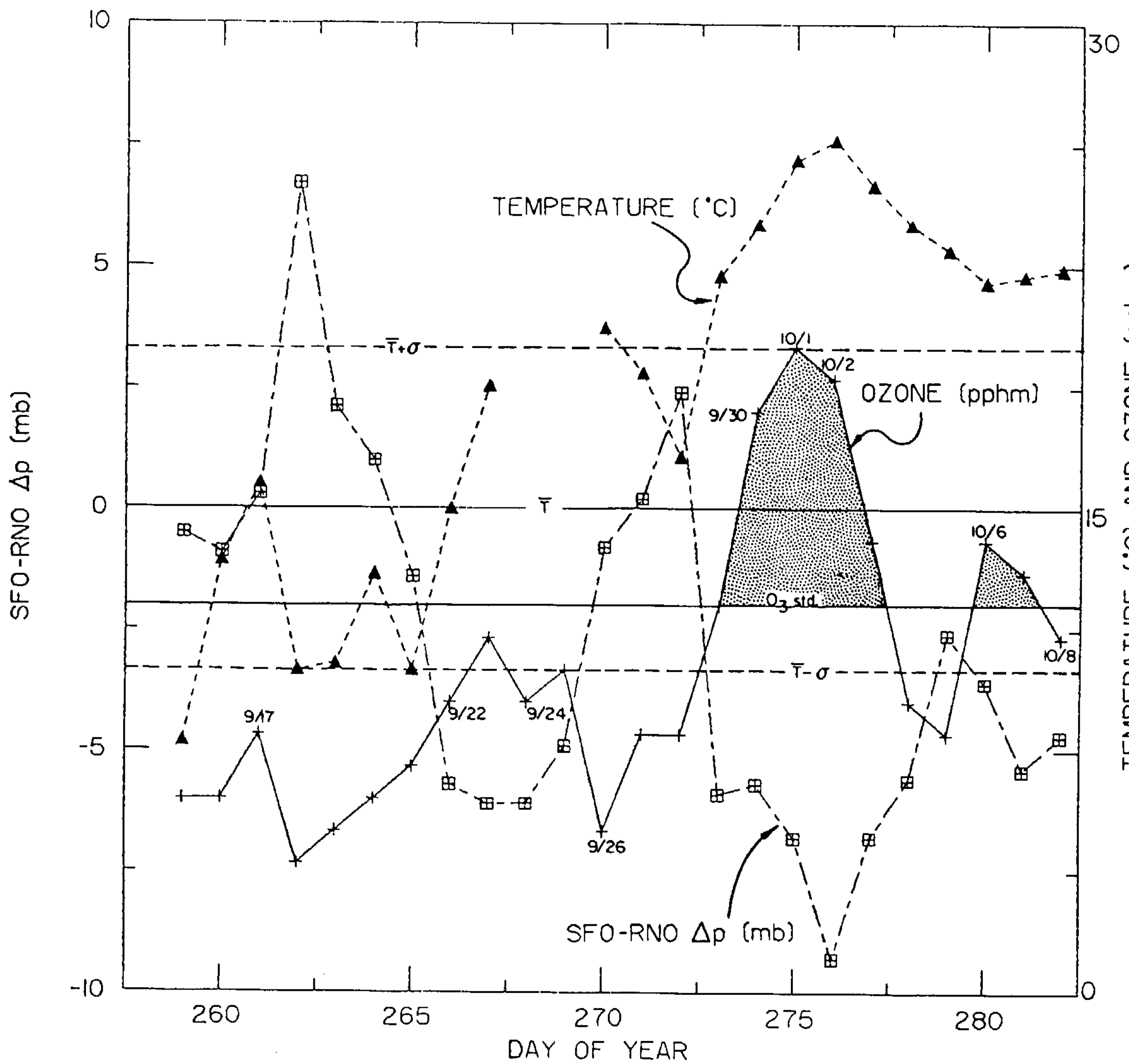


FIGURE 4(a) SYNOPTIC AEROMETRIC SUMMARY: TEMPERATURE, OZONE, AND PRESSURE DIFFERENCE (continued)

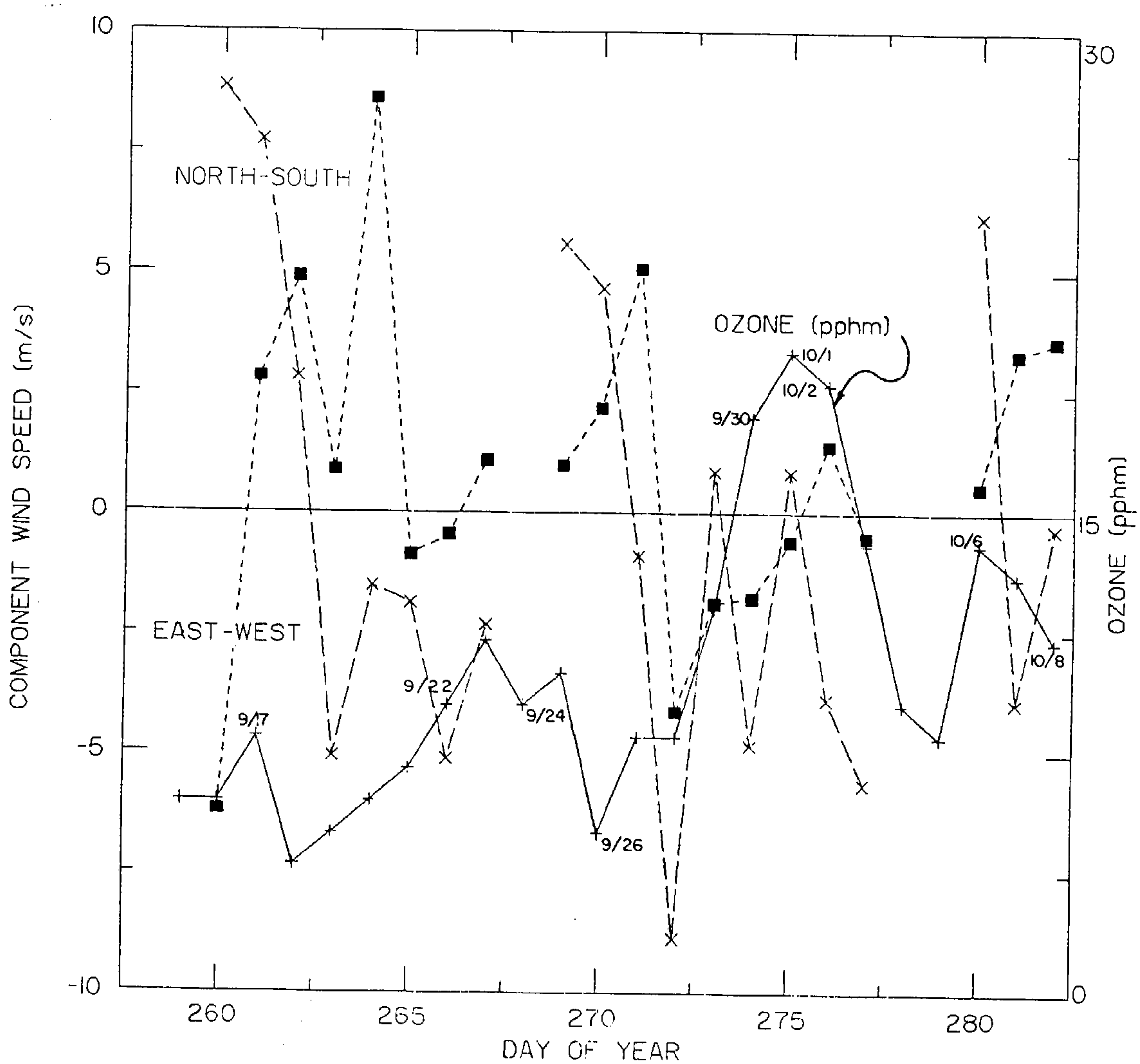


FIGURE 4(b) SYNOPTIC AEROMETRIC SUMMARY: OZONE AND COMPONENT — WINDS (concluded)

Two special air quality monitoring stations were established for this study: one in Morgan Hill* to fill the gap between Gilroy and San Jose; the other in Watsonville* to fill the void between Aptos, Hollister, and Salinas. The following measurements were made at both stations: ozone, oxides of nitrogen, wind speed and direction (10-m height), ambient temperature, and solar radiation (Watsonville only).

As discussed earlier, the principal objective of this study was to quantify the origin and fate of ozone and its precursors into and within the North Central Coast Air Basin. To meet this objective, a quasi-controlled atmospheric sampling program was conducted, including

- Controlled release of two gas tracers: sulfur hexafloride (SF_6) and bromotrifluoromethane (F13B1).
- Concurrent release of constant density-altitude balloons.
- Mobile (both aircraft and vehicular) and fixed site sampling for the tracer gases.
- Aircraft aerometric measurements.
- Surface aerometric measurements.

Sulfur hexafluoride (SF_6) and bromotrifluoromethane (F13B1) were released at different locations or times early on each of the eight tracer test days. The gases were released at a constant rate over a two-hour period. In all, 10 different tracer release points were used (summarized in Table 1).

Tetroons were launched at each tracer release location midway through the gas release period. The position of the tetroons was determined in two ways: visual observation by light aircraft (Cessna 152) of one tetroon, and visual tracking plus radar fixes from SRI's Beechcraft Queen Air aircraft (used primarily for aerometric and tracer sampling).

Tracer concentrations at ground level were determined by collecting air samples in the field and subsequently analyzing them in a laboratory set up for this purpose adjacent to the Watsonville Airport. Two types of samples were collected:

- Hourly samples collected automatically in 5-liter Tedlar bags at 25 locations by portable, programmable samplers.
- Instantaneous grab samples collected manually in 20-cm^3 disposable syringes by up to four automobiles that traversed the region.

---

*The Watsonville station was located about 0.4 km south of the airport and about 1.5 km east of Highway 1. The Morgan Hill station was on the eastern portion of the State Department of Forestry facility, near the intersection of Watsonville Road and Highway (Business) 101.

Figure 5 illustrates the 44 sampler locations that were used for one or more of the eight tests. Each sampler collected 12 one-hour samples in sequence, commencing within an hour or so of the end of the two-hour period. Instantaneous grab samples were collected in 20-cm^3 disposable syringes by each of up to four sampling crews traversing the area in automobiles.

Airborne tracer and aerometric sampling used the SRI twin-engine Beechcraft A-80/8800 Queen Air to provide three general types of measurements:

- Meteorological--temperature, dewpoint, turbulence, altitude.
- Air quality--ozone, nitric oxide, oxides of nitrogen, light-scattering aerosols, and cannister samples for hydrocarbon speciation.
- Tracer--20-cm^3 syringe grab samples for SF_6 and F13B1 analysis.

Approximately three cannisters were filled on each test day while flying over the San Jose portion of the San Francisco Bay Area; the cannisters were subsequently turned over to the Bay Area Air Quality Management District for analysis by Washington State University. The samples were taken as a courtesy to the District for use in their hydrocarbon speciation study.

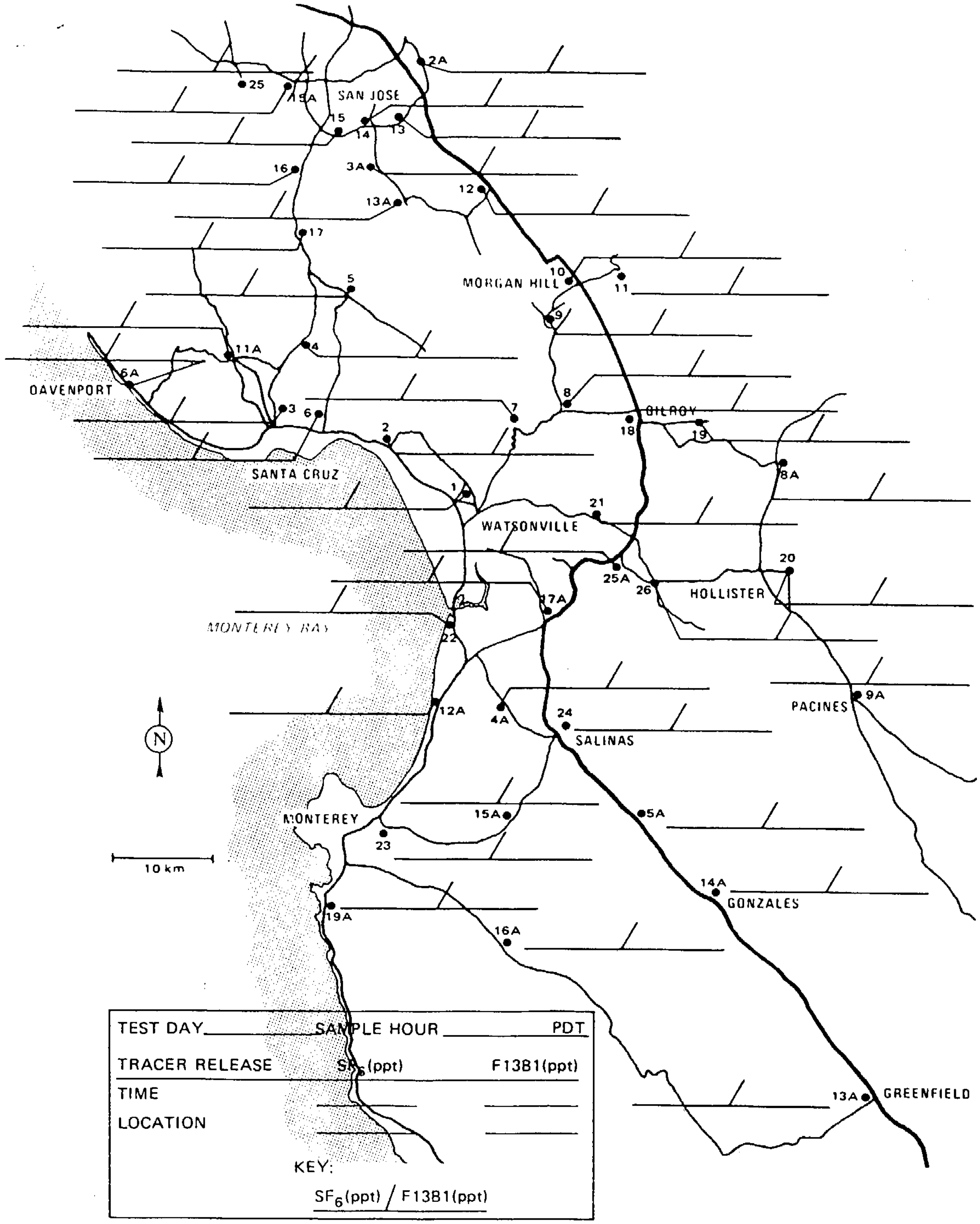
Two basic sampling procedures were used by the sampling aircraft:

- Horizontal traverses through the plume at multiple levels
- Spirals through the planetary boundary layer.

Typically, each test day began with a series (usually three) of spirals at area airports; ascent rates were about 150 m min^{-1} to/from a maximum altitude of 1500 m. The lower height of the spiral was restricted on several flights because of early-morning stratus. These flights generally were conducted between 0630 and 0800 PDT, and served two purposes:

- To define ambient background meteorological and air quality conditions prior to the onset of the daytime photochemistry.
- To provide temperature structure information with which to determine the height at which the tetroons would be flown, and to specify the required free lift and superpressure.

Spirals were also flown around midday at two or three locations and again in the late afternoon. The primary purpose of these spirals was to document meteorological and air quality conditions, although syringe samples were taken when the spiral location was within the area of the tracer plume(s).



(a) MAP DISPLAY OF SITE NUMBERS

FIGURE 5 LOCATION OF STATIONARY TRACER SAMPLERS (continued)

NO.	LOCATION	TEST DAYS* 1	2	3	4	5	6	7	8
1	Watsonville Base, Airport Boulevard at Hangar Way	x	x	x	x	x	x	x	x
2	Freedom Boulevard and Highway 1, Aptos	x	x	x			x	x	x
2A	Capitol Expressway (G21) at Cunningham, San Jose				x	x			
3	Highway 17 at Pasatiempo Drive, Santa Cruz	x	x	x		x	x	x	x
3A	Almaden Expressway at Redmond, San Jose				x	x			
4	Santa's Village at Highway 17, Scotts Valley	x	x	x	x	x	x	x	
4A	Cooper Road at Watsonville Highway (183), between Salinas and Castroville								x
5	Summit Road, 1 mile NW of Soquel-San Jose Road, Laurel	x	x	x	x	x	x	x	
5A	101 at Somavia Road, between Salinas and Gonzales								x
6	Soquel-San Jose Road, north of Soquel	x	x	x	x	x			
6A	Highway 1 at Lone Star Industries, Davenport							x	x
7	Mount Madonna	x	x	x	x		x	x	x
8	Highway 152 at G8 (Watsonville Road)	x	x	x	x	x			
8A	Highway 156 at Highway 152						x	x	x
9	Edmundson at Glen Avenue, Morgan Hill	x	x	x	x	x			
9A	Highway 25 at Panoche Road, Pacines						x	x	x
10	Dunne Avenue at Highway 101, Morgan Hill	x	x	x	x	x	x	x	x
11	Dunne Avenue at Anderson Reservoir, Morgan Hill	x	x	x	x	x			
11A	Felton Empire Road at Highway 9, Felton						x	x	
12	Bailey Avenue at Monterey Road, San Jose	x	x	x	x	x			
12A	Reservation Road at Highway 1, Marina						x	x	x
13	Highway 82 at Capitol Expressway, San Jose	x	x	x	x				
13A	McKean Road at Almaden Road, San Jose					x			
13A	Highway 101 at Thorne Avenue, Greenfield						x	x	x
14	Capitol Expressway at Almaden Expressway, San Jose	x	x	x	x	x			
14A	Highway 101 at Johnson, Gonzales						x	x	x
15	Camden at Union, San Jose	x	x						
15A	Highway 280 at Saratoga Avenue, Cupertino			x	x	x			
15A	Highway 68 at Toro Park Estates, between Salinas and Monterey						x	x	x
16	Blossom Hill Road at Vasona Park, Los Gatos	x	x	x	x	x			
16A	Carmel Valley Road at Ford Road, Carmel Valley						x	x	x
17	Highway 17 at Fire Station near Lexington Reservoir	x	x	x	x	x	x	x	
17A	Highway 101 at G12 (San Miguel Canyon Road), Prunedale								x
18	Monterey Road at Highway 152 (Hecker Pass Road), Gilroy	x	x	x	x	x	x	x	x
19	Canada Road east of Highway 152, Gilroy	x	x	x	x	x			
19A	Point Lobos, SW of Entrance to Highway 1						x	x	x
20	Fairview at Sunnyslope, Hollister	x	x	x	x	x	x	x	x
21	Highway 129 at Soda Lake (Riverside Drive)	x	x	x	x	x	x	x	x
22	Moss Landing	x	x	x	x	x	x	x	x
23	Highway 68 just east of Highway 1, Monterey	x	x	x	x	x	x	x	x
24	Natividad Road near East Laurel, Salinas	x	x	x	x	x	x	x	x
25	DeAnza College at Stevens Creek Boulevard, Cupertino				x	x			
25A	Highway 101 at Highway 156, near San Juan Bautista							x	x
26	San Juan Road at Highway 156, San Juan Bautista							x	x

*Test Day	Date (1980)
1	9/17
2	9/22
3	9/24
4	9/26
5	9/30
6	10/2
7	10/6
8	10/8

FIGURE 5 LOCATIONS BY TEST DAY (concluded)

Horizontal traverses were (usually) made at up to three heights, at roughly equidistant height intervals up to the marine inversion. The traverses consisted of the collection of 12 syringe samples at equal time (and distance) intervals perpendicular to the plume's transport direction when it could be determined. Additional samples were taken when longer traverses were made. When the plume transport was ill-defined, traverses were made along routes perpendicular to each other.

Flight maps were prepared for each day, indicating the location of traverses and spirals made on that day. Corresponding tables indicated the time, altitude, and number of syringe samples for each maneuver.

II SUMMARY OF THE TEST-DAYS

A. Test 0917: 17 September 1980

The western states were dominated by a broad, flat high-pressure region; a weak thermal trough was centered in extreme southwestern Arizona, but was restricted to southern California on its northern end. At the 850-mb level, winds in the test area were strong (8 m s^{-1}) from the SSW and the temperature (16°C) was nearly equal to the climatic norm for the period (15.3°C). The peak hourly ozone concentrations occurred during the hour 13-1400 PDT, with the maximum value of 80 ppb recorded at the Gilroy station. The release of SF_6 was from 0931-1126 PDT in Newark, about 1.5 km east of the Dumbarton Bridge, and the F13B1 was released from 0936-1129 PDT at DeAnza College in Cupertino.

F13B1 tracer gas was transported: (1) through the Santa Clara Valley, and (2) along and over the ridge line between Los Gatos and Watsonville and into the Pajaro coastal plain. Transport to Moss Landing was observed on the surface around 1800 PDT, while the leading edge of the F13B1 at 300 m agl was detected around 1530 PDT in the vicinity of Gilroy. Significant F13B1 concentrations persisted at the Watsonville sampling site until midnight when sampling ceased. Very little of the SF_6 tracer released from Newark was present in the air samples. Aircraft traverses indicated some SF_6 aloft on the eastern side of the northern end of the Santa Clara Valley (near Alum Rock). Although the transport pattern was not detected from the tracer measurements, the mid-morning streamline analysis suggests the possibility of transport into the Livermore Valley.

B. Test 0922: 22 September 1980

Ozone concentrations at Gilroy peaked at 90 ppb during the hour 16-1700 PDT, the highest this day throughout the study area. The 850-mb temperature reached the period norm, and was up 5°C from the previous calendar day, while the Gilroy peak-hour ozone also increased (20 ppb) above the September 21 peak. The SFO-RNO pressure difference decreased significantly from -1.4 mb on September 21 to -5.7 mb on this day. The drop was in response to the thermal troughing over California. Except for a wet frontal system in northwestern Washington State and British Columbia, the synoptic map was devoid of weather in the western states. Similar to the previous test, SF_6 was released from 0900-1100 PDT in Newark and F13B1 from 0900-1053 in Cupertino.

Summarizing the transport patterns depicted by the tracer measurements: There are different patterns for each of the two tracers. The SF_6, released in late-morning from Newark, is detected along two "corridors" in the afternoon and evening. (Because of the topography, the sampling was done along geographic corridors. In reality, it is not possible from the data to determine the lateral extent of these corridors or if they are indeed separate transport routes rather than a larger, contiguous transport pattern.) One corridor extends along Highway 17 from Los Gatos to the summit and then generally southward along and over the ridge line to Scotts Valley and Watsonville. Movement along this western corridor results in transport to Moss Landing at 21-2200 PDT, about 12 hours after initiation of the tracer release in Newark--a net transport rate of 2.9 m s^{-1}. The southern corridor extends through the Santa Clara Valley. SF_6 transport was first observed around 1300 near San Jose Municipal Airport by one of the mobile sampling vehicles; the next significant observation was for the hour 15-1600 PDT at Morgan Hill. Both the mobile and fixed-network samples indicated a relatively compact plume. By early evening, a broad plume was observed in the Morgan Hill-Gilroy area with higher concentrations. The plume persisted, varying in size and intensity, throughout the evening. This sudden onset of high concentrations over a broad area of the Valley suggests that more than one trajectory transported SF_6 from Newark to the upper Santa Clara Valley. Several alternative trajectories are possible for the evening transport; for example, horizontal transport through the Bay Area, and vertical transport to the mountain ranges during daytime and return flow to the valley floor with evening drainage winds. No SF_6 was observed beyond (i.e. south) of Gilroy,* indicating transport into the NCCAB did not occur on this day through the Santa Clara Valley.

The F13B1 observations indicate transport occurred primarily along the western corridor. By mid-afternoon, concentrations measured bythe fixed network were near-zero throughout the region, although the mobile sampling vehicles continued to detect isolated and widely scattered F13B-pockets. However, a significant F13B1 sample (32 ppt) was observed for the hour 18-1900 in Salinas. Mobile samples taken around 1900 in this area did not detect F13B1 in Salinas, but similar concentrations were detected between Castroville and Moss Landing.

C. Test 0924: 24 September 1980

The surface synoptic weather pattern for virtually all of California and Arizona was dominated by a well-established thermal trough centered in northwestern Mexico. The SFO-RNO pressure difference decreased an additional 0.4 mb from September 22 to a value of -6.1 mb. The Gilroy peak-hour ozone reached 90 ppb at 15-1600 PDT; Watsonville had a corresponding ozone level of only 63 ppb. However, during the preceding

*A single syringe sample (33 ppt) containing SF_6 was collected at 1833 PDT in Hollister; however, the isolated nature of the SF_6 sample suggests it is not indicative of a broad transport pattern.

hour (14-1500 PDT), Watsonville recorded a daily maximum hourly concentration of 101 ppb. The area-wide maxima for the day were observed at Los Gatos (110 ppb at 13-1400 PDT) and Fremont (130 ppb at 16-1700 PDT). By comparison, Hollister peaked for the day at 80-ppb ozone during the hour 15-1600 PDT. The F13B1 tracer was released from 0900-1100 in Vasona Park in Los Gatos to study the effectiveness of Transport Route 2 (Figure 2), also denoted here as the western corridor. SF_6 was released simultaneously from the Santa Clara County Fairgrounds in south San Jose. Tetroons were launched at 1000 PDT from both locations. On release, the Vasona Park tetroon become entangled in a tree and was unable to work itself free; the Fairgrounds tetroon headed north over downtown San Jose but could not be located visually or by radar. The San Jose surface winds indicated light downvalley flow from the SE and SSE throughout most of the morning with a reversal during 11-1200 PDT and NW-NNW until 1900 PDT. At Morgan Hill, the winds were crossvalley out of the east until mid-afternoon when there was an apparent shift to an upvalley flow (several missing values in the afternoon preclude a definitive analysis). In Hollister the winds were also variable, blowing from the NW from 1000 to 1400 PDT and then increased in speed out of the west from 1400 to 1700 PDT; during the period 17-2100, the winds varied between northwest, west and variable. Summarizing, the surface winds in the Santa Clara and San Benito Valleys did not reflect either a strong or consistent transport pattern; instead, they suggested a situation dominated by local effects that vary throughout the day.

The fixed-sampling network detected F13B1 dispersion from Vasona Park, Los Gatos, into and over the Santa Cruz Mountains. Beginning at 1200 PDT, when all fixed samples were operating, moderate F13B1 concentrations continued to be observed at Lexington Reservoir, while hour-average concentrations were very low in Watsonville and south San Jose. The 13-1400 PDT tracer map indicated F13B1 transport to Soda Lake (midway between Hollister and Watsonville), while a trace was measured at 14-1500 in Monterey. Later in the afternoon, F13B1 traces were observed at various locations throughout the study region, including Morgan Hill, Gilroy, and Santa Cruz. In the evening, the F13B1 continued to be observed at low concentrations in various isolated locations. Carry-over measurements the following morning (06-0900 PDT) continued to show concentrations in the 5-ppt range at Lexington Reservoir and the ridge line station, Santa Cruz, Morgan Hill, and south San Jose.

The SF_6 released from 09-1100 PDT at the County Fairgrounds in San Jose exhibited a more systematic transport pattern than did the F13B1 (released in Los Gatos). The first trace detected by the fixed network was 11-1200 at Lexington Reservoir; trace-values were subsequently observed throughout the day at this and surrounding stations. This suggests either a continuous transport into the area throughout the day or an initial transport from the release point with long-term residence in the small air basin that partially envelops Los Gatos and the immediate areas to the west and south. Of the two, the latter mechanism is more likely in view of the relatively short duration of the release. The more significant transport feature is movement down and up the Santa Clara Valley. From late morning to early afternoon, the SF_6 first moved

NW and then SE in response to the wind reversal in the area. By 14-1500, the tracer cloud had moved SE with a peak concentration of 75 ppt at south San Jose and 10-17 ppt values in Morgan Hill. Transport continued SE during 15-1600; an 81-ppt peak in Morgan Hill indicated movement to the SSE at a speed of about 3.7 m s^{-1}. The mobile data for this hour indicated the plume had an 8-km length along Highway 101, centered just north of San Martin. However, there continued to be no significant SF_6 levels farther south until the next two hours when Gilroy recorded very low (5-6-ppt) levels; the central portion of the cloud was not detected at this time by either the fixed or mobile samples. The 19-2000 tracer map indicated a second cloud entered the northern end of the Santa Clara Valley where 25 ppt SF_6 was measured at Site 14. The cloud moved SE at 2-4 m s^{-1} for the next 1-2 hours, but did not progress beyond south San Jose which had concentrations of 87 and 35 ppt for the hours 20-2100 and 21-2200, respectively. The precise mechanism that produced the second SF_6 cloud is unknown, but it appears likely that a bifurcation accompanied the wind reversal during the morning hours.

D. Test 0926: 26 September 1980

The thermal trough that had persisted over California the previous two test days was present only in the extreme southern portion of the state. A weak, surface low-pressure area was off the Washington coast and the eastern edge of the Pacific high extended into south-central California. Th SFO-RNO surface pressure difference had all but disappeared (-0.8 mb), although the 850-mb temperature exceeded the climatic average by more than one standard deviation. Winds at 850 mb were SSW at 10 m s^{-1}. The maximum hourly surface ozone concentration at Gilroy was very low (50 ppb), and the maximum at any of the fixed monitors in the basin was similarly low (60 ppb). Mobile ozone-sampling, however, did measure a short-term peak of 113 ppb in the foothills near Uvas Reservoir, west of Morgan Hill.

Both tracers were released during the two-hour period 10-1200 PDT, SF_6 from Coyote Park (10 km NNW of Morgan Hill and 2.5 km SSE of sampling Site 12) and F13B1 from Vasona Park in Los Gatos. Tetroons were launched at 1000 PDT from both sites. The trajectory of the Vasona Park tetroon indicated a slow movement (1 m s^{-1}) nearly due south into the mountain pass surrounding the Lexington Reservoir; the tetroon became entangled in trees as it attempted to rise over the 600-m western edge of the pass opposite the reservoir. The Coyote Park tetroon drifted erratically for about two hours, first north and then south, within 2 km of the launch site maintaining an altitude of 500 m. At 1203 PDT, when it was about 1 km WSW of the launch site, it began a systematic movement past San Jose Municipal Airport (1304 PDT), Milpitas Airport (1345), and into the Livermore Valley; about 1530 PDT it reversed direction to the SSW and was last observed at 1730 PDT near Mission Peak (4 km NE of Milpitas Airport).

The 0700-PDT aircraft sounding at San Jose indicated a slightly stable layer ($-0.65^{o}C/100$ m) from the surface to 420 m, capped by a very stable layer ($+5.3^{o}C/100$ m) to 650 m with isothermal and slightly stable layers above. Ozone was uniformly low (25 ppb) in the near-surface layer and peaked at 110 ppb in the isothermal layer at 900 m. Fog and low clouds at Hollister extended to 600 m at 0730 PDT; between 600 and 1500 m, ozone was nearly uniform around 80 ppb except for a narrow 150-ppb peak at 900 m.

The tracer transport pattern is diverse and complex, reflecting the morning variability of the surface winds. The 12-1400 F13B1 measurements from the fixed network indicated a high concentration remained in the Los Gatos release area. Otherwise, traces were measured in various locations: Scotts Valley, Cupertino-San Jose, Gilroy, and Hecker Pass. Southeastward transport was observed into San Jose during 15-1600. The next two hours (16-1800) had F13B1 transport up the Santa Clara Valley as far south as Morgan Hill. Then, F13B1 levels decreased abruptly at 18-1900 and remained low at scattered locations throughout the evening.

The SF_6 released from Coyote Park was first detected at 12-1300 PDT at the sampling site (Number 12), about 2 km NNW of the release point. The 33-ppt is very low considering the proximity to the release point, the low air movement during the late morning, and the short transport time from release; the implication is that only the edge of the tracer cloud passed over the site during the hour. Other locations detected only very low-level SF_6 traces during the hour. Conditions were relatively unchanged the following hour (13-1400). The trend continued from 14-1500 with SF_6 at Site 12 up to 111 pt; the only other significant measurement was west of Gilroy where a 42 ppt was observed. The 15-1600 pattern again showed the maximum concentration (40 ppt) in south San Jose, but no other significant values at any of the fixed sampling sites. The following hour (16-1700), east Morgan Hill had the only significant concentration (38 ppt) and from 17-1800 there was no measurement greater than 6 ppt. The samples obtained up to this time account for only a very small fraction of the total SF_6 mass released. Recalling the tetroon trajectory, it appears likely that the main SF_6 cloud was transported northward out of the sampling grid, and the measurements from south San Jose, west Gilroy and east Morgan Hill are indications of one or more secondary plumes that bifurcated away from the main cloud. There is some evidence to support the hypothesis in the evening tracer measurements. At 19-2000 PDT, the Cupertino sampling Site 25 measured an SF_6 concentration of 851 ppt while west Gilroy measured 21 ppt for the hour. Site 25 missed the next 3 hours; however, west Gilroy decreased to zero while Hecker Pass increased to 20 ppt during 20-2100 PDT. The following hour had no measurements above a trace, but during 22-2300 Morgan Hill (Site 10) registered 357 ppt; the origin of this very high concentration 10 hours after cessation of the tracer release is unknown. Even more unusual are some of the 23-2400 observations: one, Site 10 was missing, yet none of the adjacent stations registered any concentrations greater than a trace; and two, Site 25 in Cupertino recorded a daily high of 2059 ppt for the hour.

In summary, it appears that large percentages of the two tracers were initially transported northward out of the sampling grid and were subsequently transported southward later in the afternoon and evening. Some of the tracer did, however, move southward throughout the day although none was transported into the NCCAB.

E. Test 0930: 30 September 1980

Test 0930 (30 September) was the first test day where ambient ozone concentrations in the study region exceeded the one-hourly standard of 120 ppb; Watsonville peaked at 120 ppb (hour average) and Hollister at 140, while San Jose, Los Gatos, Gilroy, and Morgan Hill recorded maxima ranging from 150 to 190 ppb. Peak hourly readings were up from 40 to 80 ppb over peak values measured the preceding day. Maximum surface temperatures along the central California coast rose about 6°C from 28 to 29 September, in response to light airflow out of the Central Valley; a thermal trough centered in Baja California began to develop in the western half of the state. On 30 September the trough persisted, with the pressure pattern in Northern and North-Central California appearing very similar to the previous day's. The SFO-RNO pressure difference decreased markedly from the previous test (26 September) to -5.7 mb. The maximum surface temperature at San Francisco International Airport increased 9°C from the preceding calendar day to 30°C (87°F). At 850 mb, the temperature of 23.8°C was 8.5°C (or 1.7 standard deviations) above the climatic norm for the period. Afternoon 850-mb winds were from the NNE at 10 m s^{-1}. Winds on 30 September were very light at the surface in the interior portions of the study region.

Both tracer/tetroon releases were made at the San Jose City College; SF_6 was released from 0900 to 1100 PDT and F13B1 from 1030 to 1230. The 1000 tetroon drifted slowly to the ESE at a speed of about 1.1 m s^{-1} for approximately two hours when it grounded on a hill near the County Fairgrounds. The 1130 tetroon drifted SE at about 2 m s^{-1} before grounding in the Santa Teresa Hills northwest of the Calero Reservoir on the western edge of the Santa Clara Valley.

The SF_6 tracer measurements indicate there was organized transport both along the southern corridor (Route 1) and the western corridor (Route 2) in addition to some poorly organized dispersion of secondary elements of the main tracer plume. At 12-1300 PDT, the principle SF_6 measurement was a 136-ppt concentration in south-central San Jose. However, there were also trace measurements (5-10 ppt) from Morgan Hill to Hollister. The SF_6 core moved southward during the next hour with 228- and 375-ppt concentrations observed in the Almaden-Santa Teresa Hills region indicating slow transport at 1-2 m s^{-1}; trace values continued along the southern corridor as well as in Santa Cruz. Transport accelerated from 14-1500 along the southern corridor: the peak hourly average of 149 ppt was located in Morgan Hill, equivalent to SSE transport at 5-6 m s^{-1}. Also, the first significant indication of transport into the western corridor was the 82-ppt SF_6 concentration in Los Gatos. During the ensuing hours, some transport continued along the western corridor although the concentrations were small and erratic, and the rate of movement could not be estimated. The principal trace cloud continued movement down the southern corridor, and was detected in the Hecker Pass-Gilroy area by the 15-1600 measurements; the inferred transport speed for the hour was about 3 m s^{-1}. Beginning with the 16-1700 hour and continuing throughout the evening, there were no further SF_6 measurements above trace level. With strong late-afternoon WNW winds at Hollister, it is assumed that the plume was diluted by the 5-7 m s^{-1} winds and transported in the general direction of Pacheco Pass.

The 12-1300 F13B1 samples located the tracer core in south-central San Jose and low-to-moderate traces ($\leq$27 ppt) in east and west San Jose and up the Santa Clara Valley to Gilroy. A broader pattern is reflected by the 13-1400 PDT samples (nominally, two hours after the release). The F13B1 plume had spread throughout most of San Jose; the peak value of 1230 ppt occurred in the Almaden section. Traces continued to be found in the Santa Clara Valley as well as in Santa Cruz. By 15-1600, the plume had spread throughout virtually all of the Santa Clara Valley south of the release point; concentrations ranged from 17-82 ppt as far south as Gilroy. However, neither the San Benito Valley nor the Pajaro Coastal Plain measured any of the tracer. There was some evidence of transport into the western corridor with 31- and 16-ppt samples in Los Gatos and Lexington Reservoir, respectively. During the next hour, 16-1700, moderate-to-high concentrations persisted throughout the Santa Clara Valley, and a small concentration was first observed in Hollister. In contrast to some of the other tests, there was no discernible core of F13B1 that dispersed up the valley. Instead, the tracer was well mixed throughout the entire 50-km length of the Santa Clara Valley. Concentrations in the western corridor essentially doubled from the previous hour, although only low-level traces were observed at the summit and farther south. Transport into Scotts Valley occurred during the 17-1800 hour and persisted through 22-2300. Santa Cruz and Soquel did not measure tracer until 22-2300.

Significant tracer concentrations first occurred in Hollister during the hour 1900-2000 PDT, although the two preceding hours at that station had missing data. The mobile tracer measurements indicate a slow dispersion of tracer from San Jose down the Santa Clara Valley at an effective transport speed of about 11 km h^{-1} or 3 m s^{-1}. There appears to be little transport out of the Hollister area or dilution within the area from the time the tracer first arrived until cessation of sampling at 2300-2400.

Contrary to expectation, the highest surface ozone concentrations in the region during the late morning hours were centered in the NCCAB between Moss Landing and Hollister. This high-ozone zone expanded throughout the afternoon, linking up with rising concentrations in San Jose. However, the core of the afternoon ozone maximum shifted only slightly northward into Gilroy and Morgan Hill, where O_3 values were higher than those in San Jose, Los Gatos, and Fremont every hour. The afternoon SE transport indicated by the tracer data are reflected in the ozone pattern. From 1400-1500 PDT onward, there is first a stagnant situation, followed by a slow progression of the high-ozone core toward Hollister.

The high ozone readings at the Watsonville base station continued with the arrival there of the sea breeze around 1300 PDT. This suggested either a local pollution reservoir over the Monterey Bay (perhaps due to nocturnal offshore transport) or the occurrence of long-range transport. To evaluate these hypotheses, the aircraft broke off its inland tracer sampling in mid-afternoon and initiated an aerometric mapping survey at 150 m altitude over the Monterey Bay and up the coast to San Francisco, before returning along the coast to Watsonville.

The offshore mapping flight provided the following observations of ozone structure over Monterey Bay and along the coast from Monterey to San Francisco:

- Flying at 150 m msl from Moss Landing due west 24 nmi (39 km) toward the coastal Air Defense Intercept Zone (ADIZ), ozone concentrations oscillated for the first 24 km between about 40 and 120 ppb with an effective wavelength about 4 km; oscillations continued to the west end of the traverse, but with lower peaks (approximately 60 ppb). No similar variations occurred in the NO_x records, which remained nearly uniform around 10 ppb.
- Fifteen kilometers due west of Santa Cruz, ozone concentrations rose steeply to about 175 ppb and remained at this magnitude to a point about 22 km WxS of the Año Nuevo State Reserve, where they decreased to the 80- to 110-ppb range. Heading northeast to Pescadero, ozone levels again increased to above 200 ppb. Along the ensuing northwesterly leg, ozone varied from 50 ppb to 200 ppb. The subsequent NNE leg had near-uniform ozone around 140 ppb.
- From the Half Moon Bay waypoint northward to San Francisco, ozone concentrations were uniformly low--70 ppb.
- The return flight from San Francisco to Santa Cruz (same 150-m altitude) displayed a similar spatial variation of ozone, except the areas of high ozone had increased concentrations.
- Areas marked by high ozone showed similar increases in air temperature, oxides of nitrogen, and particulates. NO_x concentrations were around 20 ppb in these regions with $NO:NO_x$ ratios in the 15- to 20-percent range.
- The 1830 PDT aircraft sounding at Watsonville showed an inversion from the surface to 350 m msl. Ozone in this layer varied from 40 ppb near the surface to about 90 ppb at the top of the

inversion layer. Immediately above, ozone decreased slightly and then increased markedly to an average value near 150 ppb. This ozone reservoir consisted of two parts:

- A primary layer from 400 to 900 m msl
- A secondary layer of lower concentration from 900 to 1200 m msl.
- Above 1200 m, concentrations dropped rapidly from 125 ppb in the upper layer to 50 ppb above it; 50 ppb is typical of ambient background concentrations above clean environments.

- The evening's two-level flight pattern over Monterey Bay from Moss Landing to a point 24 nmi due west verified the continued presence of moderate ozone levels over the Bay.

The observations indicate a transport down the coast of ozone and ozone precursors (i.e., NO_x) from the San Francisco Bay Area (south of Half Moon Bay) to the Monterey Bay, where the secondary wind circulation over the bay and the afternoon sea breeze transport the air into the interior valleys (e.g., Hollister). However, the tracer and ambient pollution measurements also indicate a SE transport down the Santa Clara Valley from the greater San Jose area to Hollister.

F. Test 1001: 1 October 1980

Ozone peak-hourly concentrations were very nearly identical to the previous day's; Hollister decreased slightly (4 pphm, from 14 to 10), while Gilroy, Morgan Hill, and Watsonville increased 2 to 3 pphm. The 0500 PDT surface weather map is a near replica of the previous morning's map with pressure changes less than 2 mb throughout the state. The SFO-RNO pressure difference decreased further to -6.8 mb and the 850-mb temperature increased $2^{o}C$ to $25.8^{o}C$ (2 standard deviations above the climatic norm). No tracer releases were made this day; however, extensive aerometric mapping over the coastal waters was undertaken to identify more accurately the extent and magnitude of the ozone reservoir off the coast between San Francisco and Monterey.

The day began much like Test 0930: A late-morning ozone maximum around 100 ppb was seen at Watsonville, while a secondary maximum extended from Morgan Hill to Hollister but with lower concentrations (60 to 70 ppb); at this hour, the San Jose area was still reporting very low concentrations around 30 ppb. The sea breeze was observed to penetrate to the Watsonville base station at 1410 PDT; ozone concentrations increased nearly 30 pphm from the previous hour (in fact, ozone was nearly constant at 100 to 115 ppb for the previous four hours). With the persistence of the sea breeze, concentrations remained high for the next few hours, peaking at 150 ppb in Watsonville at 1500-1600 PDT. With the retreat of the sea breeze, concentrations dropped 40 ppb in one hour and decreased erratically into the evening. At 2100-2200 PDT, Watsonville ozone was only 36 ppb.

In contrast to the previous day, Hollister exceeded 100 ppb only one hour (1300-1400 PDT, 110 ppb). However, Morgan Hill and Gilroy exceeded 100 ppb seven and five hours, respectively, and they peaked around 200 ppb, as did Fremont further north. In contrast to the morning hours that suggest the significance of ozone transport from offshore, the late evening hours suggest no such influence. This is consistent with the surface wind flow at Watsonville in the evening when a persistent offshore land breeze was observed.

The offshore aircraft flight pattern resulted in the following features:

- A significant ozone reservoir persisted offshore. Over Monterey Bay, concentrations were about 90 ppb over the eastern portions while the western portions reached 125 ppb and did not decrease out to the 30-nmi waypoint. Further south and east, there was a steady decrease to the 85-ppb level in Monterey.
- A marked increase in ozone concentration was observed offshore (both on the outgoing and return traverses) in the vicinity of the Año Nuevo Reserve. Concentrations increased rapidly from 110 to 125 ppb south of this boundary to 175 ppb and higher to the north. Near-uniform concentrations up to 200 ppb were observed from just offshore to a point about 18 nmi offshore; further west, measured concentrations remained above 100 ppb.
- Elevated concentrations 175 ppb and higher were present as far north as San Pedro Point. Farther north, there was a gradual decrease to 125 ppb at the Marin headlands west of the Golden Gate (i.e., Point Diablo).
- On the southerly return traverse, the north-south ozone distribution was observed again except that concentrations were about 5 to 10 percent lower. However, this may reflect ozone destruction by the land surface in that the return flight paralleled the coastline at a distance of 3 to 4 nmi.

The distribution of ozone offshore and the diurnal cycle of surface concentrations inland provide the basis for postulating the importance of the southerly transport of ozone and its precursors during high-ozone episodes in the NCCAB. The apparent origin of this ozone-rich air is likely the San Francisco urban area, although the dynamics that lead to its transport from the interior out over the coastal waters are not understood at this time. Indeed, Test 0930 and 1001 may provide an excellent case study and data base for understanding this phenomenon.

From a purely subjective analysis, the data imply that the polluted interior air is transported from the San Francisco Bay area to the coast in the Half Moon Bay to Pacifica Region, and is then transported down the coast during the daytime when surface winds are strongest.

G. Test 1002: 2 October 1980

The weather pattern of the preceding two days presisted through 2 October. The thermal trough through California elongated and the 1012-mb core moved off the coast. The SFO-RNO pressure difference decreased substantially to -9.3 mb, while the 850-mb temperature reached 26.4^{o}C, or 2.4^{o}C above the climatic maximum for October. Hourly ozone peaks throughout the region are comparable to Tests 0930 and 1001, except that Salinas and Carmel Valley recorded peaks of 120 and 140 ppb, respectively, while Watsonville recorded 170 ppb. Scotts Valley reached a peak of 100 ppb, and was oriented downwind of the Santa Cruz Lighthouse tracer (SF_6) release point. The other release point, Fisherman's Wharf in Monterey, was upwind of the Carmel Valley station on this day.

The peak ozone hour in the NCCAB is 1600-1700 PDT with Watsonville at 167 ppb, Carmel 130 ppb, Salinas 120 ppb, Scotts Valley 100 ppb, and Hollister 110 ppb. Throughout the day, the distribution of ozone in the NCCAB appeared to be independent of conditions in the Santa Clara Valley where Morgan Hill and Gilroy peaked at 190 ppb, while Los Gatos registered 150 ppb at 1200-1300 PDT before going off-line for the remainder of the day. Moreover, ozone levels in the NCCAB appear to be augmented or dominated by transport down the coast from the San Francisco urban area to Monterey Bay and environs. In addition to the offshore measurements of the two preceding days and the shape of the surface (interior) ozone contours, there are also three other independent sets of measurements that support this hypothesis:

- Tetroon trajectories from Santa Cruz and Monterey
- Offshore ozone mapping from Monterey to Big Sur
- Vertical ozone profiles in the NCCAB.

The midday trajectories originating in Santa Cruz and Monterey confirm the general northerly flow along the coastline and the onshore transport in the Monterey Bay resulting from the so-called Santa Cruz hook in the prevailing flow pattern. The "hook" refers to the cyclonic curvature induced by the shape of the coastline relative to the normal northwesterly flow. Under high-ozone conditions as were observed 30 September through 2 October, the circulation is an effective mechanism for transporting coastal, ozone-rich air onshore; the effect is enhanced by the sea breeze under clear-sky conditions. Further south, the Monterey trajectory substantiates the downcoast transport.

The midday Salinas ozone profile shows concentrations not far above background except for a layer between 250 and 400 m that peaks at 100 ppb; the profile-average ozone is only 57 ppb. Seven hours later, however, the profile-average concentration has increased to 104 ppb with multiple peaks of 160, 175, and 195 ppb through a layer that extends from the surface to 1150 m msl. It is unlikely that such a large and rapid increase in ozone could result from local production. Transport is more reasonable, and the likely transport route is from the coastal waters under the influence of the sea breeze and prevailing flow.

Hollister shows a similarly dramatic increase of ozone aloft from 1300 to 1900 PDT, although the transport route(s) cannot be implied easily (i.e., down the Santa Clara Valley or inland from the coast, or both).

SF_6 was released from 1030 to 1230 PDT at the Santa Cruz Lighthouse, while F13B1 was released from 1015 to 1215 PDT at the Fisherman's Wharf parking lot in Monterey. From 1200-1300 PDT, Felton and Scotts Valley (Santa's Village) registered SF_6 peaks of 354 and 177 ppt, respectively, while Gilroy and Morgan Hill were at 7 and 6 ppt. The following hour, Felton had decreased to 72 ppt and Scotts Valley to 54 ppt. Santa Cruz (Site 3, Highways 1 and 17) had an SF_6 concentration of 328 ppt for the hour (1300-1400 PDT). The tetroon was nearly stationary above Scotts Valley after 1300 PDT. Santa Cruz concentrations continued at 252 ppt and Scotts Valley at 66 ppt, while Lexington Reservoir measured 10 ppt. From 1500-1600 PDT onward, Scotts Valley and Felton showed a steady decline in tracer concentration. However, there is an indication of transport into the Santa Clara Valley as a result of an increase in SF_6 seen during the evening, starting with 2100-2200 PDT and persisting until the last sampling hour (2300-2400 PDT).

The major features of the transport away from Santa Cruz are further substantiated by the instantaneous tracer samples collected in the three vans. Perhaps most intersting are the 10-ppt surface SF_6 concentrations detected around 1430 PDT between Salinas and Chualar along Highway 101--a distance of 15 km. Similar concentrations were detected later (1611 to 1741 PDT) from Gonzales to King City--30 km. In contrast, the afternoon (1430-1800 PDT) sampling route that surveyed the area between Santa Cruz, Watsonville, Hollister, Morgan Hill, and Redwood Estates detected no traces of SF_6.

Very little of the F13B1 released at midday in Monterey was detected by either the surface network, airplane, or vehicles. Sporadic traces (1 to 3 ppt) were seen at Moss Landing, Aptos, Hecker Pass, Hollister, and Salinas; these were observed starting at 1400 PDT. Grab samples from the vans indicate a discontinuous plume of F13B1 between Castroville and Gonzales; the measurements, which peak at 25 ppt, were taken between 1338 and 1500 PDT. Later in the day (1700-1840 PDT) F13B1 concentrations around 10 ppt were observed from Salinas to King City. The tracer sampling vans also detected isolated traces of F13B1 in the midafternoon in the 5- to 10-ppt range between Santa Cruz, Watsonville, Hollister, and Morgan Hill; they do not appear to indicate any organized transport.

In summary, it appears that transport away from Santa Cruz is a complicated phenomenon, while little was learned of transport out of Monterey. Two transport routes can be identified for Santa Cruz: one to the north into the mountain valleys of Scotts Valley and the San Lorenzo Valley; the other to the southeast down the Salinas Valley. The initial structure of the Salinas route is not known, though it may entail transport over Monterey Bay. The northerly route is probably complicated by terrain effects. However, the lack of tracer found in the Watsonville-Aptos area does suggest some bifurcation of the puff over the two-hour period of the release.

H. Test 1006: 6 October 1980

A thermal trough was aligned NW-SE through central California. The SFO-RNO surface pressure difference increased from Test 1002 to -3.6 mb. The 850-mb temperature (22°C) was 1.4 standard deviations above the period norm, while the 850-mb wind was from the south at 12 m s^{-1}. Surface winds at Watsonville varied considerably throughout the test period: from 09-1300 PDT, winds were SE-SSE at 1-2 m s^{-1}; 13-1600 winds generally were WSW at about 4 m s^{-1}; then SSW at 1.5-3 m s^{-1} from 16-1900; and approximately SW at 0.5-1 m s^{-1} until 2100 PDT when they began veering to the NW while staying light. Stratus was widespread in the morning; Hollister and Watsonville had tops of 400 m msl in the early morning. Insolation dissipated the stratus around noon at the coastline, and earlier inland. The hourly ozone peak for the day occurred at 15-1600 PDT at Gilroy with a value of 140 ppb. However, the peak was rather isolated and short-lived, particularly in contrast with the preceding week's ozone episode. Peaks within the NCCAB included 100 ppb at Hollister, 90 ppb at Watsonville, and 60 ppb at Salinas and Gilroy. The Hollister peak-value occurred abruptly at 13-1400 PDT; the preceding hour had only 50 ppb ozone and the following hour, 60 ppb. The explanation for the short-lived peak is in the Santa Clara-San Benito Valley transport pattern. The wind backed abruptly to WSW at Hollister beginning at 14-1500 PDT.

Both tracers were released during late morning at Moss Landing. SF_6 was emitted from 1030-1230 PDT at a rate of 54 kg h^{-1} from one of the 150-m stacks at the PG&E Moss Landing Power Plant. F13B1 was released at the surface at 35 kg h^{-1} from 1049-1245 PDT at a location about 400 m NW of the SF_6 release. The tetroon was launched at 1140 PDT from the PG&E yard. At 1215 PDT the tetroon was only 50 m offshore at an altitude of 400 m southwest of the launch. At 1254 PDT, the tetroon was at 660 m, 1.5 km due south-southwest of the launch site. An hour later (1347 PDT), the tetroon was up to 945 m, 2.5 km north-northeast of the power plant. The tetroon continued its erratic movement throughout the afternoon. At 1516 PDT, it was 3 km southwest of the town of Aromas near Pajaro Gap; at 1554 PDT it was still heading north-northeast (altitude, 840 m). However, around 1800 PDT the tetroon was still at 760 m, but was now 0.8 km west of Fremont Peak (essentially midway between Hollister and Salinas).

The F13B1 data indicate either a bifurcation or spread of the plume into the Salinas and San Benito Valleys. Transport occurred into the Hollister-Paicines area by late afternoon, reflecting a net transport rate of 5.5 km h^{-1} (1.5 m s^{-1}). However, the fixed Hollister site measured F13B1 during only one hour, inferring that the measurement reflected either transport of a secondary fragment of the plume or a measurement along the edge of a broad plume. Transport up the Salinas

Valley was more systematic: The plume was transported at a rate of about 2.8 m s^{-1}, and after 4-5 hours had diffused in the longtitudinal direction to 40-km in length.

The SF_6 tracer data reflect an equally complex transport pattern. First, a 25- to 30-ppt pocket persisted at the Marina site for the first three hours of sampling (12-1500 PDT), but did not appear on any subsequent measurements at that site. Transport occurred into the Salinas Valley with the 13-1400 hour: the Toro Park Estates fixed site (midway between Salinas and Carmel Valley) registered 9 ppt while numerous sites detected 2- to 3-ppt trace levels. Transport to Gonzales was first observed at 14-1500 and SF_6 continued to be observed there the next three hours. At 15-1600, the plume extended to Greenfield on the south and Carmel Valley to the west of the Valley. The plume passed south of Greenfield during 17-1800 when only a trace was measured. However, transport up the surface of the Pajaro Coastal Plain began at 16-1700 with 6- to 20-ppt measurements in Aptòs, Santa Cruz, Felton, and Scotts Valley. Transport continued during the next hour northward to Lexington Reservoir and eastward to Morgan Hill and Soda Lake. SF_6 persisted in the Santa Clara Valley until 2000 PDT and in the Santa Cruz-Scotts Valley area until 2100 PDT. Only trace-values were detected at 21-2200 PDT, but scattered hourly measurements up to 17 ppt were observed from 22-2400 in Scotts Valley, Felton, Gilroy, and Hollister.

Backing of the wind during the release period probably resulted in multiple "puffs" of tracer being transported in several directions. The low-to-moderate hourly tracer concentrations at the surface are the result of a strong elevated temperature inversion that dominated the region.

The temperature structure this day was typical of onshore flow conditions where cool marine air is capped by a subsidence inversion at 500-1000 m. During clear, daytime conditions, surface heating creates a thermal internal boundary layer (TIBL) that grows during the day and in proportion to the fetch from the coastline. Pollutants emitted aloft do not mix to the surface until the TIBL has extended to the effective height of their release. In this respect, Test 1006 is quite typical of summertime coastal conditions.

I. Test 1008: 8 October 1980

Test 1006 and 1008 were designed to study transport of surface and elevated sources at Moss Landing. During Test 1008, F13B1 was released from 1100-1300 PDT from the same ground-level location; the release rate was maintained at the earlier value of 35 kg h^{-1}. SF_6 was released over the same period at a rate of 54 kg h^{-1} through one of the 150-m PG&E stacks. A single tetroon was launched at 1200 PDT from the power plant site.

The thermal trough over California that was so pronounced the previous week was still present but was less intense in the northern half of the state. The SFO-RNO pressure difference was still -4.7 mb and the 850-mb temperature a very warm 22.4°C. Coastal stratus were present through noon in Moss Landing, though slightly inland (0.5 km) skies were clear and temperatures warm. The highest hourly ozone concentrations in the NCCAB were 100 ppb in Watsonville and Scotts Valley, while Salinas peaked at 40 ppb, Hollister at 80 ppb, and Monterey at 40 ppb.

The height of release from the PG&E stacks, plus the nominal plume rise in view of the strong inversion at and well above the top of the stack, would have placed the initial height of the tracer at 300 m or less, well within the 500-m inversion top measured at Moss Landing during the tracer release period. None of the afternoon soundings show the presence of a neutral or unstable layer from plume height to the surface. Therefore, it is consistent that no significant SF_6 concentrations were detected either by the sampler network or the vans.

The surface F13B1 plume was transported through Prunedale and San Juan Bautista in the early afternoon and Paicines down the San Benito Valley in the middle afternoon. No concentrations were detected aloft except for sporadic trace measurements (≤5 ppt). The five vehicles collecting grab samples on this day provided details of the surface transport pattern. From 1315-1400 PDT, large concentrations (100 to 870 ppt) were detected along a 13-km segment of Highway 101 between Prunedale and the San Juan Bautista exit. Lower concentrations (around 10 ppt) were observed along the coast highway from Watsonville to Castroville during the same hour. Large concentrations were again encountered the following hour (150 to 325 ppt) from Gilroy to Prunedale. From 1440 PDT to 1530 PDT, an elongated plume 32 km long was observed between San Juan Bautista and Paicines. From 1300-1400 PDT, moderate concentrations (<100 ppt) were also detected as far south as Salinas. Around 1630 PDT, sporadic low levels of 10 to 20 ppt were detected in the vicinity of Greenfield.

In summary, surface transport from Moss Landing followed at least two identifiable routes. The primary route having the highest concentrations (≤1000 ppt) passed through Prunedale, San Juan Bautista, Tres Pinos, and Paicines in the San Benito Valley. The secondary route with lower concentrations (around 50 ppt) passed down the Salinas Valley with tracer detected as far south as King City (the southern extent of our sampling). No transport or diffusion was observed to the north.

III CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

A detailed qualitative analysis of the tracer, air quality, and meteorological measurements has provided the following primary conclusions:

- Ozone transport from the San Francisco Bay Area to the North Central Coast Air Basin was evaluated along each of three proposed transport routes with the following results: One, transport up the Santa Clara Valley to Hollister--Route one--was observed to occur, though ineffectively and sporadically; the intrusion of marine air from Monterey Bay apparently sets up a convergence zone in the northern San Benito Valley that generally inhibits transport south of Gilroy. However, this flow regime was observed during the tests to break down for short periods, enabling transport to Hollister from the NW. Two, significant ozone transport was not observed along proposed Route two from Los Gatos to Scotts Valley and Aptos. Three, significant amounts and concentrations of ozone were transported on several days along offshore Route three, resulting in exceedances of the ambient standard at several locations in the NCCAB. The mass of ozone discovered offshore during two tests extended about 50-km off the coast from the vicinity of San Francisco on the north to (at least) Monterey on the south; concentrations increased rapidly from about 100 ppb at the coast to nearly 250 ppb and decreased very gradually. Similar concentrations were observed offshore on a third test, extending southward to Big Sur where they decreased rapidly. The atmospheric dynamics of the phenomenon and the proportions of advected and locally generated ozone in the NCCAB remain to be determined.

- Transport of the gaseous tracers from the Bay Area to the NCCAB was evaluated on five test days, only one of which had ozone peaks in excess of the ambient standard. Transport to Hollister along Route one generally reinforced the conclusions of the ozone analysis above. Tracer transport along Route two was complex and sporadic, although transport was observed on several occasions as far south as Moss Landing, Salinas and Monterey. However, the actual transport pattern does not appear to confirm effective transport through the mountain passes. Rather, the measurements suggest transport up the heated slopes and then along the ridge line of the Santa Cruz Mountains with subsequent dispersion into both the Santa Clara-San Benito Valley and the Pajaro Plain.

- Tracers released in the morning in the San Jose area documented complicated flow patterns associated with the transition from early-morning downvalley flow out of the Santa Clara Valley to midday conditions characterized by upvalley and upslope flow. On one occasion tracer was transported first northward from San Jose to Fremont and eastward into the Livermore, and then later southward entering the lower portion of the Santa Clara Valley in the early evening. Tracer emitted at Los Gatos showed a similar overall pattern with significant transport measured up the peninsula as far north as Portola Valley (where sampling terminated). These thermal-orographically driven flows prevent morning emissions from the Bay Area from being initially transported (until afternoon) to the NCCAB on days with light synoptic winds and clear skies.

- On two days, large tracer concentrations (from releases in Newark and San Jose) were observed to occur abruptly during the late evening in the San Jose area. These represent situations where emissions from a given source region may have contaminated twice the same air mass or parcel, e.g., once in the late morning and again in the evening. The sudden onset and localized extent of the high evening concentrations also indicate little dispersion had taken place. The transport mechanism causing this recirculation is unknown. One possibility is transport first up the valley walls during midday and afternoon, and subsequent transport to the valley floor with nocturnal drainage flows. Other possibilities include strictly horizontal transport along closed trajectories.

- Tracer material transported from San Jose to Hollister was observed during one test to disperse slowly in the Hollister area, where the rate of dilution in the evening and night followed an exponential decay of the form $X = X_0 \exp - 6t^2$, where X is the concentration, t is time in hours following the time of peak concentration in Hollister, and b has a value calculated to be 0.029 h^{-2}. This suggests that the Hollister area may on occasion be a reservoir of pollutants that remains to contribute to the succeeding day's ozone levels.

- Intrabasin transport within the NCCAB was documented on three of the tests using the tracers. Tracers released at ground level indicated: moderate transport along postulated Route four from Moss Landing to Hollister; significant, long-range transport from Moss Landing down the Salinas Valley and limited transport into the Carmel Valley (Route eight); and some transport up the Pajaro Plain to the Santa Cruz-Scotts Valley area.

- Morning tracer emissions from Monterey on a day with high ozone concentrations in the NCCAB were observed to be transported first offshore and then down the coast (although not inland), as a result of the combined effects of the residual land breeze and the synoptic flow. Santa Cruz emissions on the same day were bifurcated with transport observed both into the Scotts Valley area (Route seven) and southeastward into the Salinas Valley.

- A strong, elevated marine temperature inversion was present on the two tests with releases at Moss Landing. During one test, surface heating was only able to generate a surface, near-adiabatic boundary layer up to 200 m. The elevated tracer plume was embedded in the elevated inversion above and virtually none of the elevated tracer was dispersed to the surface over the broad extent of the sampling area. In the other test, an adiabatic layer extended to nearly 400 m through part of the day and diffused the elevated tracer to the surface. The resultant horizontal transport occurred in two directions. First, one segment moved up the Salinas Valley during early afternoon and then a second segment moved northward during mid afternoon through evening into the Pajaro Coastal Plain, the Santa Cruz Mountains, and parts of the Santa Clara Valley. Corresponding surface-released tracer was transported into the Santa Clara, San Benito, and Salinas Valleys.

B. Recommendations

The present study was designed to measure the transport of ozone and precursors into and within the NCCAB, and to archive and analyze subjectively the tracer, air quality, and meteorological data. These objectives have been satisfied completely. Because of the adverse nature of air quality conditions during the test period, the measurements provide a unique and valuable data base with which to better understand the structure of ozone episodes in Northern California, in general, and to develop an improved implementation plan for the MUAPCD, in specific. However, to achieve these two objectives, there is a continuing need to design and implement a systematic, objective analysis program using the special measurements from this study and other available meteorological and air quality data from the study period. Below are three recommendations that are an initial attempt to specify the types of analyses that would be valuable; others need to be developed in response to the needs of local and state agencies.

- Transport and diffusion of contaminants from the San Jose portion of the BAAPCD to the Hollister portion of the NCCAB should be analyzed objectively using the meteorological, ozone, and tracer data from this program and the routine measurements of oxides of nitrogen, hydrocarbons, and winds. Trajectory analyses should be performed and chemical kinetics models applied to estimate the percentage of ozone observed in Hollister that can be attributed to NCCAB sources and to BAAPCD sources.

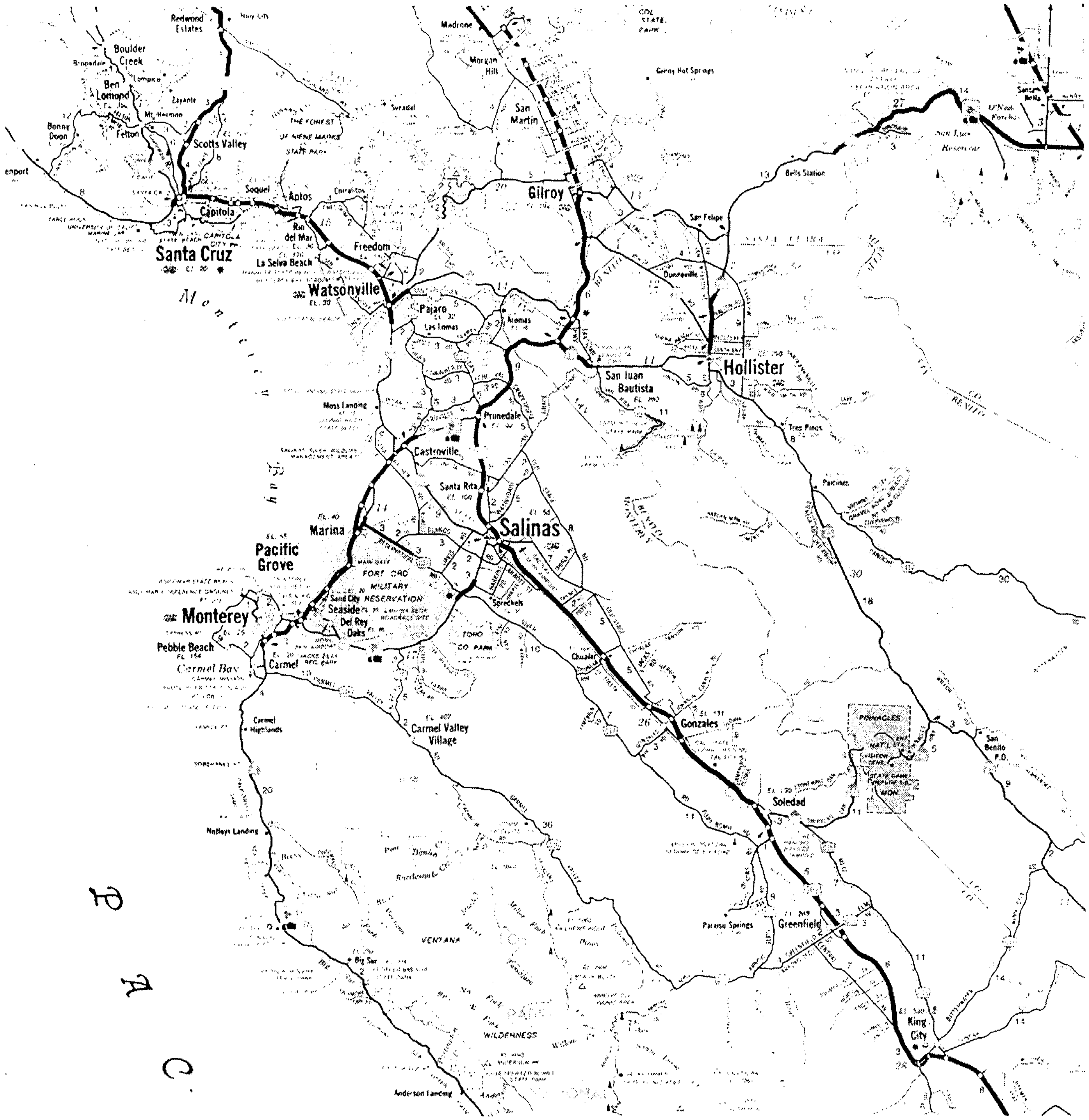
- Similar analyses should be undertaken of the offshore ozone measurements to quantify the magnitude of the impact of transported ozone/precursors on ozone levels in Monterey, Watsonville, Santa Cruz, and Hollister. There is a need to understand the residence, formation, and destruction characteristics of this offshore ozone reservoir.

- Additional effort is required to understand better the contribution of Moss Landing emissions on air quality in the NCCAB in the presence of a strong marine inversion. This analysis should examine available ambient SO_2 and NO_x measurements, in addition to the measurements collected in the current study.

Appendix

LOCATOR MAPS OF THE NCCAB-BAY AREA STUDY REGION

BASE MAP REPRODUCED WITH PERMISSION OF THE CALIFORNIA STATE AUTOMOBILE ASSOCIATION, COPYRIGHT OWNER.



BASE MAP REPRODUCED WITH PERMISSION OF THE CALIFORNIA STATE AUTOMOBILE ASSOCIATION, COPYRIGHT OWNER.