# 4. MEASUREMENT APPROACH

This section specifies study design principles, measurement periods, the study domain, and the locations and purposes of sites for the different networks and study periods. Sections 5, 6, and 7 elaborate on the specific measurements taken within these networks during the long-term, winter, and fall experiments.

Additional details are tabulated in the CRPAQS Reference Tables, which are available on the study website at http://www.arb.ca.gov/airways/crpaqs/lookups.htm. The Reference Tables include detailed measurement information such as site coordinates, instrument model numbers, and instrument ranges.

## 4.1 Study Design Principles

The selection of measurement locations, observables, averaging times, and frequencies was guided by the following principles:

- $PM_{10}$ is driven by $PM_{2.5}$ during winter. Solving the wintertime $PM_{2.5}$ problem also solves the wintertime $PM_{10}$ problem. The wintertime study therefore focused on $PM_{2.5}$ measurements.

- $PM_{10}$ is driven by both the $PM_{2.5}$ and coarse fractions during fall in the central to southern San Joaquin Valley. The fall study focused on the coarse fraction that is predominantly suspended dust.

- Excessive $PM_{10}$ and $PM_{2.5}$ situations due to nearby activities and windblown dust are relatively rare, random occurrences that are often of short duration and cannot be predicted. These situations can only be captured by very frequent sampling throughout the year.

- The statistical nature of the $PM_{10}$ and $PM_{2.5}$ NAAQS minimizes the influence of a few high concentrations and requires three years of data to determine compliance status. Although elevated PM concentrations are sought during winter and fall, these are only of value to the extent that they can be extrapolated to similar occurrences during the three-year period needed to determine $PM_{2.5}$ and $PM_{10}$ standard compliance.

- $PM_{2.5}$ standards are most likely to be exceeded in Fresno and Bakersfield. $PM_{10}$ standards are most likely to be exceeded in the Corcoran/Hanford region. These areas were more intensively examined than other parts of central California.

- Wintertime secondary ammonium nitrate, ammonium sulfate, and organic aerosol result from regional-scale transport and mixing of emissions from urban and non-urban areas.

- Wintertime transport of secondary $PM_{2.5}$ and its precursors occurs above the surface, often at night or early morning, and reaches the ground-level during afternoon mixing. Measurements to verify this hypothesis and to determine the nature of this transport and mixing were emphasized in the winter study.

- Existing or previously used measurement sites are preferred. When they serve the purpose, measurement sites from compliance networks, IMS95, VAQS, and SJVAQS/AUSPEX were selected. These have been surveyed and documented before. Several have existing infrastructure and trained technicians available. Previously used or existing sites offer an opportunity to contrast new measurements with those acquired in other studies.

- More detailed and costly measurements at a smaller number of anchor locations were complemented by less detailed and costly measurements at many satellite locations. Satellite measurements were used to understand the zone of representation, and changes that occur, between a few well-instrumented anchor sites with high time resolution for a number of observables.

- More frequent and more complete aerosol chemistry is preferable to a larger number of locations with only mass concentrations. Without the chemical composition, elevated mass concentrations cannot be explained and remain anomalies.

- The Fresno First Street and Bakersfield California sites represent community exposure for those urban areas. Large numbers of micro-scale and middle-scale saturation studies around those sites were not needed.

- Detailed understanding of one or two urban areas can be translated to other urban areas that are not as intensively monitored. The sources are similar, although not identical, in most central California urban areas, and there is evidence of only small transport of primary particles between them. The exceptions are Bakersfield and the eastern Bay area, where several large sulfur dioxide emitters are located.

- Sulfate concentrations are much lower than other $PM_{2.5}$ components; its sources are well identified and probably the most accurate in the emissions inventory. Understanding ammonium nitrate formation and sources or precursors takes precedence over understanding ammonium sulfate formation and sources. The ammonium/nitrate/sulfate chemical system is inter-related, so sulfate is not ignored.

## 4.2 Study Periods

The long-term annual average study took place from December 1, 1999 to January 31, 2001. This period was intended to achieve at least one representative of each conceptual model at one or more of the measurement sites. This requires daily continuous aerosol sampling and meteorological measurements at some of the sites, especially to capture the high wind situation. Annual average measurements continued through the shorter winter, summer, and fall studies. The annual study period included two complete wintertime periods, with the detailed measurements made during the second winter. This schedule allowed the ARB backbone network to attain full operational capability during 2000 and permitted further evaluation and testing of new measurement systems to be deployed in the second winter.During the two month winter study period from December 1, 2000 to February 3, 2001, three to four day episodes, for a total of 15 episode days, were selected by forecast for enhanced measurements. Episodes were forecast by meteorologists based on satellite photos that indicate at least four-days between Pacific storms and on NGM model forecasts of a Great Basin high pressure system that is conducive to PM buildup. A forecast team created a forecast protocol and practiced it during winters of 1998/1999 and 1999/2000. In addition to measurements conducted on the forecast episode days, a number of continuous measurements were added during the two-month winter period to enhance the annual network.

The fall study occurred from October 9 to November 14, 2000, corresponding to harvesting and land preparation in the Corcoran area in the central San Joaquin Valley. Special measurements taken during the summer occurred between June 20 and September 1, 2000.

## 4.3 Study Domain and Long-Term Measurement Locations

The study domain includes all of central California, as shown Figure 4.3-1. The meteorological and air quality modeling domain is regional (lat/lon coordinates [33.8788,-124.2708] [33,8203,-117.1484] [39.7733,-116.7238] [39.8385, -124.5415]). The northern boundary extends through Chico and provides a sufficient representation of areas upwind of Sacramento. The western boundary extends approximately 200 km west of San Francisco and allows the meteorological model to use mid-oceanic values for boundary conditions. The southern boundary extends below Santa Barbara and into the South Coast Air Basin. The eastern boundary extends past Barstow and includes a large part of the Mojave Desert and all of the southern Sierra Nevada.

This large domain is represented for aerosol measurements by the ARB $PM_{2.5}$ "backbone" monitoring network also shown by the small dots in Figure 4.3-1. This is a large network that will be operated for years to come and will provide the measurements used to determine compliance with the 24-hour and annual standards. Each of these locations operates a Federal Reference Method (FRM) monitor that acquires $PM_{2.5}$ deposited on a 47 mm Teflon membrane filter that is submitted to gravimetric analysis; with appropriate handling and storage these filters can also be used for elemental and ionic analyses. Several of the backbone compliance sites are also designated in Figure 4.3-1 as chemical speciation sites that acquired elemental, ionic, and carbon concentrations every sixth day during the annual study period.

Figure 4.3-2 shows the sampling frequency at each of the backbone network sites, ranging from every day to every sixth day sampling.

Figure 4.3-3 shows the ARB backbone $PM_{10}$ network, much of which has been operated since 1987 within central California. This network has provided most of the information concerning suspended particle concentrations and chemical compositions that resulted in the conceptual models presented in Section 3. Many of these are collocated with the $PM_{2.5}$ sites identified in Figure 4.3-1. Existing $PM_{10}$ sites substantially outnumber $PM_{2.5}$ compliance sites. The small domain indicated in Figure 4.3-3 shows where the fall $PM_{10}$ study was conducted.

## 4.4 Measurement Network Enhancements During CRPAQS

The long-term $PM_{10}$ and $PM_{2.5}$ networks were enhanced during the CRPAQS field study with respect to variables measured, sampling frequency and averaging time, and spatial distribution. Sampling sites were classified as follows:

- **Community exposure (COmmunity REpresentative, CORE):** CORE sites are intended to represent $PM_{2.5}$ concentrations experienced by large populations that live, work, and play within 5 to 10 km surrounding the site. These sites are most affected by regional and urban scale contributions with relatively small neighborhood scale source contributions to $PM_{2.5}$.

- **Background**: Background sites intend to measure concentrations that are not influenced by central California emissions. There is no location in central California that is completely uninfluenced by manmade emissions in the state. CRPAQS background sites were located at Bodega Bay along the west coast, at Yosemite in the Sierra Nevadas, and at Olancha in the Owens Valley. The concentrations and compositions measured at these sites, coupled with examination of concurrent meteorology, will be examined to determine the extent to which samples at these sites can be used to represent global and continental scale concentrations.

- **Interbasin transport:** These sites are intended to evaluate concentrations along established or potential transport pathways between the Bay Area, the south central coast, the SJV, the South Coast Air Basin, and the Mojave Desert. Interbasin transport sites are typically at mountain passes. During winter, these may also double as background sites, as they will sometimes be above and sometimes be below the valleywide mixed layer.

- **Intrabasin gradient:** These sites are located in non-urban areas between backbone network sites. They are intended to evaluate the extent to which one urban area affects PM concentrations in another urban area, as well as the extent to which urban contributions arrive at non-urban locations. These sites are also located in areas that may be affected by nearby dust emissions raised by undocumented activities or wind erosion.

- **Vertical gradient:** These sites are located at higher elevations on tall towers or hillsides to evaluate vertical mixing by comparison with ground-level measurements.

- **Source:** Source sites are located right next to, and downwind of, representative and identifiable emitters. Where practical, these were located within 1 km of gradient or CORE sites to further evaluate the zone of influence of these source emissions on measurements at those sites. Source sites are intended to quantify near-maximum contributions from individual emitters and, when coupled with measurements from nearby sites, estimate the zone of influence of these emitters.

- **Receptor zone of representation:** Receptor sites are intended to examine medium or neighborhood scale spatial variability around CORE sites. Their data are used to determine the extent to which the CORE site represents community exposure at increasing distances from the CORE site.

- **Visibility:** Visibility sites are intended to estimate the amount of light scattering or light extinction, and sometimes the contributions of atmospheric constituents to scattering and extinction. Many of the sites located for other purposes can serve these purposes, but a few sites were located specifically for these purposes, especially during the summer in and near the Mojave desert.

Sites meeting these classifications are distributed among three different networks:

- **ARB backbone network:** ARB, in collaboration with the California air quality management districts, has established the $PM_{2.5}$ monitoring sites shown in Figure 4.3-1. The IMPROVE visibility sites in National Parks and Wilderness Areas are also backbone sites. This network acquires samples with the frequencies shown in Figure 4.3-2. The $PM_{10}$ network shown in Figure 4.3-3 acquires filter samples every sixth day. Several of the $PM_{10}$ sites have continuous monitors that measure hourly $PM_{10}$ everyday. Most of these $PM_{2.5}$ and $PM_{10}$ sites have been selected to be community representative and will be used for determining compliance with the $PM_{2.5}$ and $PM_{10}$ NAAQS. These monitors will operate for many years, well beyond the duration of the CRPAQS field study. Additional measurements are made at these backbone sites, as well as at other locations that represent the classifications described above.

- **CRPAQS anchor network:** Anchor sites were more highly instrumented than other sites, especially with monitors that acquire mass and chemical measurements continuously at high time resolution. Two sites were collocated with $PM_{2.5}$ backbone network sites for the annual program: Bakersfield-California Avenue (BAC) and Fresno-First Street (FSF). An additional non-urban anchor site operated all year at Angiola (ANGI). The Edwards Air Force Base (EDW) site was made an anchor site during the summer to evaluate the properties of visibility-reducing atmospheric constituents in the Mojave Desert, and the Corcoran site (COP) was upgraded to anchor status during the fall $PM_{10}$ study. The anchor network was substantially augmented during the winter with additional measurements at the Bethel Island (BTI), San Jose (SJ4), Sacramento Del Paso (SDP), Sierra Nevada Foothills (SNFH), and Walnut Grove Tower (WAG) sites. Both surface and elevated monitors were located on the Angiola and Walnut Grove towers to evaluate vertical gradients. Also during the winter, aethalometers were added at the Bodega Bay and Modesto sites. The original study plan had called for five annual anchor sites and winter additions at six additional sites. The reductions from these plans were due to limitations in funding and in the availability of new-model instruments, such as continuous sulfate monitors.

- **CRPAQS satellite network:** The satellite network consisted of portable filter-based and continuous light scattering measurement systems that do not require complicated infrastructure. Instruments were often mounted to existing power poles or similar structures. This type of network offered substantial flexibility with respect to site selection and site type. Most of the interbasin transport and intrabasin gradient sites were in this category. Most of the satellite sites used $PM_{2.5}$ inlets on the sampling systems owing to the relatively low number of backbone $PM_{2.5}$ sites compared to $PM_{10}$ sites. Seven $PM_{10}$ satellite sites at which historically high $PM_{10}$ concentrations have been measured were collocated with backbone sites at the Bakersfield-Golden State (BGS), Corcoran (COP), Fresno-Drummond (FSD), Hanford (HAN), Modesto (M14), Oildale (OLD), and Visalia (VCS) sites. These $PM_{10}$ satellite sites were operated every six days, but three days behind the regular six-day schedule applied to $PM_{10}$ and $PM_{2.5}$ sampling at these sites.

Figure 4.4-1 shows the combined backbone, anchor, and satellite site network for $PM_{2.5}$ by site type, while Figure 4.4-2 shows the types of measurements that were acquired at each site, both as part of long-term monitoring and as part of CRPAQS.

Table 4.4-1 describes the backbone air quality network that was operated in the CRPAQS study domain by ARB and local districts. This table summarizes the location of each site and the measurements that are conducted. Where noted, $PM_{2.5}$ backbone network sites were equipped with Federal Reference Method (FRM) samplers that acquire $PM_{2.5}$ mass deposits on Teflon membrane filters that can be analyzed for mass and elemental concentrations, and on quartz filters that can be analyzed for carbon concentrations. As part of long-term monitoring, the speciation monitors operate every twelfth day and undergo chemical characterization for elements, ions, and carbon. Complete descriptions of each of these monitoring sites, including site coordinates and addresses, can be found on the ARB website at: http://www.arb.ca.gov/aqdas/sitelist.php3.

For the most part, the backbone network sites follow the summertime transport pathway from the Bay Area, through the SJV, and out into the Mojave Desert. The SJV backbone sites are primarily located on the eastern side of the valley, along SR 99, within population centers. One exception is the Corcoran site, which is in a rural area that has registered elevated $PM_{10}$ in the past and has served as a design location for the $PM_{10}$ State Implementation Plan. The larger urban areas have more than one $PM_{2.5}$ monitor, so that $PM_{2.5}$ spatial homogeneity can be determined and spatial averages can be calculated. These sites have undergone substantial scrutiny and they pass the tests for urban-scale, community exposure site described by Watson et al., (1997) and summarized in Section 8.

The following tables provide details regarding the CRPAQS measurement network. Tables 4.4-2 through 4.4-4 provide descriptions of the site locations. Table 4.4-2 describes sites that were established by and for CRPAQS, where no site existed previously. Table 4.4-

3 describes existing sites at which CRPAQS equipment was added. Most of these were sites operated by the ARB or by local districts. More detailed descriptions of the CRPAQS sites, including coordinates, addresses, photographs, site diagrams, and maps, can be found in the CRPAQS Site Documentation Reports (McDade, 2002).

Table 4.4-4 lists the CRPAQS meteorological sites. Many of these sites (those which also house air quality instruments) were also listed in the previous two tables, but they are repeated here for completeness. Table 4.4-4 includes only sites which were part of the CRPAQS network. It does not include meteorological measurements made at many, many backbone and other sites throughout California.

Tables 4.4-5 through 4.4-7 list the measurements conducted by CRPAQS at each site. The three tables list the measurements for the newly-established CRPAQS sites, for the sites adapted from existing sites, and for the meteorological sites, respectively. Tables 4.4-8 and 4.4-9 provide the letter and number codes used in Tables 4.4-5 through 4.4-7. Appendix A (Tables A1 through A3) contains additional details concerning each measurement, including diurnal measurement frequencies and the beginning and ending dates for each measurement at each site.

The CRPAQS anchor sites used in the annual program were carefully considered to represent the following characteristics:

- **Fresno First Street CORE site (FSF):** This long-term site in a residential/commercial area receives a broad mixture of neighborhood, urban, and regional scale $PM_{2.5}$ contributions. Although it is near neighborhoods where wood is burned during winter, it is not overly influenced by this local source.

- **Bakersfield California Street CORE site (BAC):** This site is also in a residential/commercial area with a broad mixture of sources from various scales that is not overly influenced by microscale sources. Refineries and oilfield operations provide an increment of sulfur emissions from well-defined directions that are above those found at other CORE sites in the SJV.

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- **Angiola intrabasin gradient site (ANGI):** This new site was located in a non-urban setting approximately ten miles south of Corcoran, outside the influence of SR 99 and its population centers. The surrounding area was open farmland, planted principally in cotton and wheat. The immediate surroundings (a square approximately 225 meters on each side) was uncultivated during the CRPAQS period. A 100 m tower was erected to acquire micrometeorological measurements all year and to permit elevated measurements during winter to determine vertical fluxes between the surface and valleywide layer.

During summer an anchor site was operated at:

- **Edwards Air Force Base (EDW):** This site on the base has long been used to evaluate light extinction and its chemical constituents. The only nearby sources are suspended desert dust and roadway emissions from lightly traveled paved roads within the base.

During winter, the annual anchor sites were enhanced by measurements at:

- **Bethel Island interbasin transport site (BTI):** This established air quality site in the Sacramento Delta is in a transition zone between the Bay Area and SJV. It is along the summertime transport pathway between the two basins, but during winter it experiences secondary nitrate concentrations that are more typical of the SJV than of other Bay Area PM monitoring sites. It is isolated from local sources, but is directly east of the Benicia/Martinez, Pittsburg, Antioch industrial corridor where much of central California's point source emissions are located.

- **Sierra Nevada Foothills vertical gradient site (SNFH):** This site was located east of Fresno at 589 m above mean sea level, between the towns of Prather and Auberry. The location was selected following testing during the winter of 1998-99, when light scattering measurements showed the area to be typically near or above the top of the wintertime valley haze layer, thereby allowing assessment of the vertical extent and composition of the haze. There were minimal terrain obstructions between the site and the valley.

- **San Jose-Fourth Street CORE site (SJ4):** This site is in a residential/commercial area with mostly traffic-dominated emissions nearby. Wood smoke has been found as a significant contributor during winter. This site represents the climate and source mix in the Bay Area Air Quality Management District

- **Sacramento Del Paso Street CORE site (SDP):** This site is in a residential/commercial area with mostly traffic-dominated emissions nearby. This site provides a contrast with other sites in the central and lower San Joaquin Valley.

- **Walnut Grove interbasin transport and vertical gradient site (WAG):** This site was established during winter to take advantage of the ability to locate instruments at the base of and at an elevated point (260 m agl) of the Walnut Grove tower. This site is located near the transition point between the Sacramento and San Joaquin Valleys and will evaluate transport between these valleys as well as the vertical evolution of pollutant concentrations.

- **Angiola vertical gradient site (ANGI):** In addition to the ground-based measurements acquired throughout the year, continuous measurements of secondary particles and their precursors were made near the top (~90 m agl) of the 100 m Angiola tower during winter.

Anchor sites require substantial infrastructure to support the detailed, high time resolution measurements to be acquired both throughout the year and during the intensive monitoring campaigns.

Many of the satellite sites were intrabasin gradient monitors to determine what happens between the backbone sites, especially between the major cities. The Bethel Island and Altamont Pass sites were intended to monitor transport between the Bay Area and the San Joaquin Valley. The Pacheco Pass site monitored transport between the north central coast and the SJV. The Tehachapi site monitored transport between the SJV and the Mohave Desert. Transport can go in both directions, and these interbasin transport sites are collocated with meteorological monitors. The source-oriented sites are intended to be near and downwind of source types identified in Section 2. Two urban source monitors were targeted for residential areas near the anchor sites in Fresno and Bakersfield to determine incremental amounts of exposure that might be contributed by neighborhood-scale contributions such as woodburning. The fall campaign operated additional satellite sites for $PM_{10}$ that are described in greater detail in Section 7.

**Surface Meteorological Network**

The existing meteorological network in central California is extensive, but uncoordinated among the different agencies. Figure 4.5-1 shows the locations of surface meteorological monitoring sites from the Air Resources Board (ARB), the Bay Area Air Quality Management District (BAAQMD), the National Oceanic and Atmospheric Administration (NOAA), the California Irrigation Management Information Service (CIMIS), Interagency Monitoring of PROtected Visual Environments (IMPROVE), the National Weather Service (NWS), Pacific Gas and Electric Company (PG&E), the U.S. Coast Guard, Remote Automated Weather Stations (RAWS) for firefighting, and a few miscellaneous monitors. CRPAQS surface stations are located on this map along transport pathways, at anchor sites, and at upper air measurement sites to supplement this network.

Figure 4.5-2 shows the surface meteorological observables measured at each monitoring location, regardless of the network from which they are derived. Wind speed and direction, temperature, and relative humidity are the most common measurements. The network or surface pressure and solar radiation measurements is also extensive. Three sites measure ultraviolet radiation in the Sacramento Valley, in the San Joaquin Valley, and along the south coast in Santa Barbara County.The existing networks report hourly average wind speed and direction, temperature, relative humidity, solar radiation, and pressure measurements.

Thuillier et al. (1994) document the methods used to acquire and report data in most of these networks with their similarities and differences. Wind speed measurements are taken at heights ranging from 2 m to 10 m agl at most sites and temperatures are measured by aspirated and unaspirated thermometers. The major limitations of existing network instrumentation are: 1) wind thresholds of ~1 m/s for most instruments, which is adequate for non-winter periods, but not for low winds in the surface layer during winter; 2) relative humidity sensors that are inaccurate at high (<90%) humidities; and 3) insufficient temporal resolution (i.e. on the order of minutes) to detect wind gusts that might suspend dust.

The existing meteorological network was supplemented with the CRPAQS sites shown in Figure 4.5-1 and described in Tables 4.4-4 and 4.4-7. Ten meter meteorological towers were equipped with low threshold (~0.3 m/s) wind sensors and high sensitivity relative humidity sensors. Section 10 describes the monitors used for these measurements. Five-minute average measurements were acquired so that the data can be interpreted with respect to wind gusts that might raise dust, short-term shifts and wind direction that might correspond to pulses measured by continuous particle monitors, and short duration clouds and fogs that cause rapid changes in the 90% to 100% RH interval. With these supplemental measurements and surface measurements at the upper air sites, the existing surface monitoring network provided adequate coverage for the central California study domain.The surface and upper air meteorological networks for CRPAQS were similar to, but not identical to, the networks proposed in the original study plan. The actual network design was based on budget and logistical concerns, and it covered a somewhat smaller number of sites, some in different locations. In some instances site placement was coordinated with the summer 2000 Central California Ozone Study (CCOS), so that both studies could make use of shared resources.

**Upper Air Meteorological Network**

Section 2 showed substantial decoupling between surface meteorological conditions and those aloft for all but the afternoon periods. This situation occurs during both winter and non-winter months. The decoupling endures for a larger number of hours per day during winter when days are shorter. Non-winter meteorology has been documented in several prior studies, but little is known about conditions aloft during winter. As a result, the long-term upper air network was supplemented with additional sites and special studies during winter.

Figure 4.6-1 shows the locations of types of upper air meteorological monitors deployed for the long-term campaign and Figure 4.6-2 shows how this network was augmented for the winter campaign. Tables 4.4-4 and 4.4-7 describe the upper air sites, their measurements and operators. Radar profilers, doppler sodars, and RASS were used at many sites because they acquire hourly average wind speed, wind direction, and temperature by remote sensing without constant operator intervention. Sodars were collocated with profilers at several locations because they provide greater vertical resolution in the first 100 m agl. This is especially important near terrain features and during winter. Rawinsondes are needed to determine changes in relative humidity and to quantify conditions at elevations above ~2000 m agl. They are also the only practical means of acquiring upper air measurements in cities where the noise and siting requirements of remote sensing devices make them difficult to operate. NEXRAD radar sites are also located in Figures 6.5-1 and 6.5-2. While these are primarily used to identify precipitating clouds, algorithms are being constructed to deduce upper air wind speeds and directions from their output. Relevant output from these established sites will become part of the CRPAQS data base.

Several radar profilers have been installed to acquire a multi-year data base, and one of the important functions of the CRPAQS supplements to this network is to relate these relatively sparse measurements to the detailed meteorological patterns determined during CRPAQS. The backbone profiler network includes Travis AFB, Visalia, Sacramento, and Monterrey. Profilers may become operational at Vandenberg and Edwards Air Force bases before the end of 1999. These profilers are operated by different entities, and equivalent methods of data evaluation and reporting needs to be established among these entities prior to CRPAQS field campaigns.

Rawinsondes are routinely launched through the year at 0400 and 1600 PST from Oakland, Vandenberg, Edwards, and Pt. Mugu. None of these locations are within the central valley, so these were supplemented by launches at Fresno and Bakersfield on the 15 episodic days during winter. Figure 2.4-1 showed an information deficiency between 1000 and 1600 PST when substantial vertical mixing is believed to occur. For the 15 episodic days during winter, four rawinsondes per day were launched at 0400, 1000, 1600, and 2200 PST at the Oakland site (supplementing the twice per day launches), and at the Fresno and Bakersfield sites.

**Micrometeorological Towers**

The 100 m tower at the Angiola site supportted year-long micrometeorological measurements as well as other vertical experiments. For the long-term measurements, the tower was instrumented at five elevations with high precision anemometers, relative humidity, and temperature measurements, and recorded five minute averages of wind speed, wind direction, temperature, and relative humidity as well as average cross-products in the vertical and horizontal directions. These micrometeorological measurements will be used to create a diurnal and seasonal climatology for surface layer evolution, describe turbulent mixing and dispersion at the sub-grid scale level, and to determine micrometeorological conditions near the surface that affect suspension and deposition of dust, gases, and fine particles.

In addition to supporting continuous micrometeorological measurements, the tall tower provided a platform for measurements above the surface layer during nighttime and morning periods during winter. These uses included:

- Continuous measurements of black carbon, nitrate, light scattering, particle size distribution, ozone, and $NO_y$ at the top level and surface to determine mixing and transport concentrations above the surface layer.

- Fog water size and chemistry measurements at several levels to determine differences with elevation above ground level.

The Walnut Grove tower between Stockton and Sacramento was instrumented in a similar manner (black carbon, nitrate, and light scattering only) during the winter campaign to evaluate difference between the Sacramento and San Joaquin Valleys.

A second tower, approximately 20 m tall, was installed at Angiola in the spring of 2000. It operated beyond the end of CRPAQS, until the end of 2001. Micrometeorological measurements were conducted at seven level on this tower. Further details of these measurements are provided in Section 10.