

4.0 EXPERIMENTAL APPROACH

This section summarizes the major components of the field measurement program with consideration of alternatives, options, and tradeoffs. The air quality and meteorological measurement program includes measurements that can be performed continuously over several months and additional episodic measurements that are to be performed on a forecast basis during periods when ozone exceedances and transport are most likely. Cost estimates are itemized in Section 5. Measurement methods are described in Appendix A and requirements for quality assurance and data management are specified in Appendices B and C, respectively.

4.1 Study Design Principles

The proposed measurement program is designed to meet the goals and technical objectives of the sponsors and incorporates the following design guidelines that combine technical, logistical and cost considerations, and lessons learned from similar studies.

1. CCOS is designed to provide the aerometric and emission databases needed to apply and evaluate atmospheric and air quality simulation models, and to quantify the contributions of upwind and downwind air basins to exceedances of the federal 8-hour and state 1-hour ozone standards in northern and central California. While urban-scale and regional model applications are emphasized in this study, the CCOS database is also designed to support the data requirements of both modelers and data analysts. Air quality models require initial and boundary measurements for chemical concentrations. Meteorological models require sufficient three-dimensional wind, temperature, and relative humidity measurements for data assimilation. Data analysts require sufficient three-dimensional air quality and meteorological data within the study region to resolve the main features of the flows and the spatial and temporal pollutant distributions. The data acquired for analyses are used for diagnostic purposes to help identify problems with and to improve models.
2. Since episodes are caused by changes in meteorology, it is useful to document both the meteorology and air quality on non-episode days. For this reason, surface and upper air meteorological data as well as surface air quality data for NO_x and ozone will be continuously collected during the entire summer of 2000. The database will be adequate for modeling and a network of radar profilers will allow increased confidence in assigning qualitative transport characterization (i.e., overwhelming, significant, or inconsequential) throughout the study period.
3. Additional data will be collected during ozone episodes to better understand the dynamics and chemistry of the formation of high ozone concentrations. These measurements include instrumented aircraft, speciated VOC, and radiosonde measurements, which are labor intensive and require costly expendables or laboratory analyses. These intensive measurements will be made on days leading up to and during ozone episodes and during specific ozone transport scenarios. These additional measurements are needed for operational and diagnostic evaluation of model performance during particular meteorological scenarios leading to ozone exceedances within the study area.

4. Many of the transport phenomena and important reservoirs of ozone and ozone precursors are found aloft. CCOS is designed to include extensive three-dimensional measurements and simulations because the terrain in the study area is complex and because the flow field is likely to be strongly influenced by land-ocean interactions. Several upper air meteorological measurements are proposed at strategic locations to elucidate this flow field.
5. Although specific advances have been made in characterizing emissions from major sources of precursor emissions, the accuracy of emission estimates for mobile, biogenic and other area sources at any given place and time remains poorly quantified. Ambient and source measurements, with sufficient temporal and chemical resolution, are required to identify and evaluate potential biases in emission inventory estimates.
6. Past studies document that the differences in temporal and spatial distributions of precursor emissions on weekdays and weekends alter the magnitude and distribution of peak ozone levels. Measurements are needed to evaluate model performance during periods that include weekends.
7. Boundary conditions, particularly for formaldehyde, significantly affected model outputs in the SARMAP modeling resulting in over-prediction of ozone levels in the Bay Area. Measurements of documented quality and adequate sensitivity are needed along the western boundary of the modeling domain to adequately characterize the temporal and spatial distributions of ambient background levels of ozone precursors.
8. The measurements should be designed such that no single measurement system or individual measurement is critical to the success of the program. The measurement network should be dense enough that the loss of any one instrument or sampler will not substantially change analysis or modeling results. The study should be designed such that a greater number of intensive days than minimally necessary for modeling are included. This helps minimize the influence of atypical weather during the field program and decreases the probability of equipment being broken or unavailable on a day selected for modeling. Most measurements should be consistent in location and time for all intensive study days and during the entire study period (i.e., no movement of measurements). In this way, one day can be compared to another. Continuous measurements should be designed to make use of the existing monitoring networks to the extent possible.

4.2 Study Domain

The study domain includes most of northern California and all of central California. The northern boundary extends through Redding and provides representation of the entire Central Valley of California. 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.

4.3 Study Period

The CCOS field measurement program will be conducted during a four-month period from June 1, 2000 to September 30, 2000. This study period corresponds to the majority of elevated ozone levels observed in northern and central California during previous years. Continuous surface and upper air meteorological and air quality measurements will be made hourly throughout the study period in order to provide sufficient input data to model any day during the study period.

Additional continuous and intermittent measurements will be made during a shorter two-month intensive study period and during episodic periods of up to five consecutive days. Forecasts are prepared each day during the two-month period and episodic measurement groups are on standby. The current budget for CCOS allows for up to 20 days total for episodic measurements. With an average episode of three to four days, five to six episodes are likely. Intensive measurements will be made during periods that correspond to categories of meteorological conditions, called scenarios, which are associated with ozone episodes and ozone transport in northern and central California. In addition, detail chemical data will be collected continuously during the entire intensive study period to allow detailed examination of the day-to-day and day-of-the-week variations in carbon and nitrogen chemistry at intrabasin gradient sites.

The development of a conceptual model for ozone formation is aided by identification of meteorological scenarios that foster the formation, accumulation and transport of ozone (see Section 2.4 and 2.6). An idealized set of meteorological scenarios would be distinct from one another. Each scenario should be linked to a set of commonly measured observables, like routine meteorological and air quality data, to increase the success rate of go/no-go decisions based on weather forecasts.

In search of these scenarios for California air quality applications, several investigators have used techniques varying from subjective inspection of weather charts (Neff, 1992) and streamline plots (Hayes et al. 1984; Stoeckenius et al., 1994), to objective classification methods like linear regression (Roberts, 1992), multivariate regression (Stoeckenius, 1998), cluster analysis (Roberts et al. 1994; Smith 1994; Stoeckenius 1994; Fairley and De Mandel 1996), empirical orthogonal functions (Ludwig et al. 1995) and neural networks (Stoeckenius, 1998). In each of the cited cluster analyses, the number and nature of the clusters has varied. However, as summarized by Stoeckenius et al. (1994), certain key variables remain statistically, and perhaps more importantly, conceptually linked to ozone formation in central California. These are:

1. The 850-mb temperature (Oakland 0400 PST sounding)
2. Fresno and Sacramento maximum temperatures
3. San Francisco to Reno surface temperature gradient

In the development of this plan, an investigation is proceeding to analyze 1-hr and 8-hr ozone trends, identify important features of the diurnal and hebdomadal cycles in the emissions inventory, and then to objectively classify the observed meteorology and air quality data into meteorological scenarios. Toward this end, a meteorological working group is proposed to generate, at a minimum, a small set of qualitative scenarios akin to the successful SCOS97 effort.

These should ultimately be statistically linked to the Hayes et al. (1984) streamline charts, which have stood the test of time.

4.4 Supplemental Surface Air Quality and Meteorological Monitoring Sites

Field monitoring includes continuous measurements over several months and intensive studies that are performed on a forecast basis during selected periods when episodes are most likely to occur. The continuous measurements are made in order to assess the representativeness of the episode days, to provide information on the meteorology and air quality conditions on days leading up to the episodes, and to assess the meteorological regimes and transport patterns which lead to ozone episodes. The intensive study components are designed to provide a detailed aerometric database for operational and diagnostic model evaluation, and improve our conceptual understanding of the causes of ozone episodes in the study region and the contribution of transport to exceedances of federal and state ozone standards in downwind areas. This section describes the existing routine air quality and meteorological monitoring network in northern and central California, and the options for continuous and intensive air quality and meteorological measurements (surface and aloft) to be made during CCOS.

The long-term, routine aerometric measurement networks will be enhanced during the CCOS field study with respect to variables measured, sampling frequency and averaging time, and spatial distribution. Sampling sites are classified as follows:

- **Background:** Background sites intend to measure concentrations that are not influenced by northern and central California emissions. There is no location in the study domain that is completely uninfluenced by manmade emissions in the state. Several sites along the West Coast may best represent background atmospheric concentrations and composition much of the time. The concentrations and compositions measured at these sites, coupled with their temporal variations and 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 Sacramento Valley, the San Joaquin Valley, Mountain counties, the South Coast Air Basin, and the Mojave desert. Interbasin transport sites are typically at mountain passes.
- **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 ozone mixing ratios in another urban area, as well as the extent to which urban contributions arrive at suburban and rural locations.
- **Source:** Source sites are located right next to, and downwind of, representative and identifiable emitters. Where practical, these are located within existing monitoring 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.

Table 4.4-1 provides a summary of the proposed supplemental surface air quality and meteorological network that is to be installed during summer 2000. This table summarizes the location, purpose, measurement frequency, and routine chemical characterization that are currently envisioned for these sites. Figure 4.4-1 shows the locations of the existing monitoring stations measuring ozone and NO_x. Figure 4.4-2 shows the locations of existing monitoring stations measuring carbon monoxide and speciated hydrocarbons and carbonyl compounds in relation to proposed CCOS supplemental monitoring sites.

4.4.1 Existing Routine Monitoring Network

The California Air Resources Board and local air pollution control districts operate a network of sampling sites that measure ambient pollutant levels. There are 185 active monitoring stations in northern and central California. Table A.1-1 contains a list of the monitoring sites and the air quality parameters measured at each site. Of the active sites, 130 measure ozone and 76 measure NO_x. Carbon monoxide and total hydrocarbons are measured at 57 and 14 sites, respectively. Data from these sites are routinely acquired and archived by the ARB and Districts. This extensive surface air quality monitoring network provides a substantial database for setting initial condition for the model, and for operational evaluation of model outputs.

ARB, in collaboration with the California air quality management districts, is establishing the PM_{2.5} monitoring sites. The PM₁₀ acquires filter samples every sixth day. Several of the PM₁₀ sites have continuous monitors that measure hourly PM₁₀ everyday. The PM measurement network is described by Watson et al. (1998).

4.4.2 CCOS Type 1 Supplemental Monitoring Sites

Type 1 supplemental monitoring sites are suitable at the upwind boundaries of the modeling domain or at downwind rural sites. Type 1 sites establish boundary and initial conditions for input into air quality models. The following aerometric parameters are measured at Type 1 supplemental monitoring sites.

1. Continuous surface wind speed and direction and temperature during study period.
2. Continuous ozone during study period.
3. Continuous NO and NO_y during study period by high sensitivity chemiluminescence analyzer (e.g., TEI42S or equivalent) with the converter near the sample inlet.
4. Four 3-hour canister samples for up to 20 episode day for analysis of CO, CO₂, methane by gas chromatography, reduction of CO and CO₂ to CH₄, and analysis by flame ionization detection; and C₂-C₁₂ hydrocarbons and MTBE by gas chromatography with flame ionization detection.
5. Four 3-hour DNPH cartridge samples for up to 20 episode days for C₁-C₇ carbonyl compounds by HPLC with UV detection.

Measurements of speciated volatile organic compounds (VOC) made under CCOS supplement the 14 existing Photochemical Assessment Monitoring Stations in the study area

(four in Sacramento, four in Fresno, three in Bakersfield, and three in Ventura County). See section A.3.3 for details. The PAMS sites are generally located within and immediately upwind and downwind of major urban centers that are currently classified serious or worst with respect to attainment of the federal 1-hour ozone standard.

Type 1 sites are proposed for Pt. Arena and Pt. Arguello to obtain background data near the western boundary of the CCOS modeling domain. Colusa and Turlock sites provide characterization of ambient air transported into the upper Sacramento Valley and into the northern San Joaquin Valley as a function of the nature of the flow bifurcation downwind of the San Francisco Bay Area. Measurements at Anderson (located north of Colusa) is designed to determine whether ozone precursors immediately upwind of Redding is largely transported or attributable to local sources. Similar transport issues are address by measurements in the foothill communities near Grass Valley and Sonora.

4.4.3 CCOS Type 2 Supplemental Monitoring Sites:

Type 2 supplemental sites are located at the interbasin transport and intrabasin gradient sites. These sites are located downwind of the urban center where maximum ozone levels are expected, and where ozone formation may either be VOC or NO_x limited depending upon time of day and pattern of pollutant transport. Type 2 supplemental monitoring sites provide data for initial conditions and operation evaluations and some diagnostic evaluation of model outputs. The measurements also allow additional independent assessments of VOC- and NO_x-limitation by observation-driven methods during the entire two-month intensive study period. The following aerometric parameters are measured at Type 2 supplemental monitoring sites.

1. Continuous surface wind speed and direction and temperature during study period;
2. Continuous O₃ during study period;
3. Continuous NO and NO_y during study period by a high sensitivity chemiluminescence analyzer with dual converters (e.g., TEI42CY or equivalent), which are located near the sample inlet. Nitric acid can be estimated by difference between the signals with and without an in-line nylon filter or NaCl impregnated fiber denuder.
4. Continuous NO₂ and peroxyacetyl nitrate (PACN) during intensive study period by gas chromatography with Luminol detector. A second estimate of HNO₃ is obtained by the difference between NO_y and the sum of NO, NO₂, and PACN. This second estimate is an upper-limit because NO_y also includes other organic nitrates and particulate ammonium nitrate.
5. Continuous formaldehyde (HCHO) during intensive study period by an instrument that continuously measures the fluorescent, dihydrolutidine derivative formed by the reaction of formaldehyde with 1,3-cyclohexanedione and ammonium ion (Dong and Dasgupta, 1994; Fan and Dasgupta, 1994).
6. four 3-hour canister samples for up to 20 episode day for analysis of CO, CO₂, methane by gas chromatography, reduction of CO and CO₂ to CH₄, and analysis by flame

ionization detection; and C₂-C₁₂ hydrocarbons and MTBE by gas chromatography with flame ionization detection;

7. four 3-hour DNPH cartridge samples for up to 20 episode days for C₁-C₇ carbonyl compounds by HPLC with UV detection.

Type 2 sites are proposed at locations downwind of the three main passes connecting the Bay Area and the Central Valley, Bethel Island, Altamont/Tracy, and Pacheco/Santa Nella. Type 2 measurements are also proposed for the SJV regional site at Angiola, and downwind of Bakersfield at Edison, and downwind of Fresno at the Mouth of the Kings River.

4.4.4 CCOS Research Sites

Research sites are located several miles further downwind of the downwind edge of the urban area, and are intended to measure a representative urban mix of pollutants in an area of high ozone. The site must be carefully selected to minimize the potential influence of local emission sources. As with Type 2 supplemental monitoring site, research sites are located where ozone formation may either be VOC or NO_x limited depending upon time of day and pattern of pollutant transport. Research sites are intended to provide the maximum extent of high-quality, time-resolved chemical and other aerometric data for rigorous diagnostic evaluation of air quality model simulations and emission inventory estimates. The following aerometric parameters are measured at Research monitoring sites.

1. Continuous surface wind speed and direction and temperature during study period;
2. Continuous ozone during study period;
3. Continuous NO and NO_y during study period by a high sensitivity chemiluminescence analyzer with dual converters (e.g., TEI42CY or equivalent), which are located near the sample inlet. Nitric acid can be estimated by difference between the signals with and without an in-line nylon filter or NaCl impregnated fiber denuder.
4. Continuous NO₂ and PAcN during intensive study period by gas chromatography with Luminol detector. A second estimate of HNO₃ is obtained by the difference between NO_y and the sum of NO, NO₂, and PAcN. This second estimate is an upper-limit because NO_y also includes organic nitrates and particulate ammonium nitrate.
5. Continuous formaldehyde during intensive study period by an instrument that continuously measures the fluorescent, dihydrolutidine derivative formed by the reaction of formaldehyde with 1,3-cyclohexanedione and ammonium ion (Dong and Dasgupta, 1994; Fan and Dasgupta, 1994).
6. Semi-continuous hourly organic compound speciation data by gas chromatography with mass spectrometry. VOC speciation includes C₂ and higher volatile hydrocarbons, carbonyl and halogenated compounds. Collect up to 10 sets of canister and DNPH samples for measurement comparisons with GC/MS and continuous HCHO analyzer.

7. Continuous CO by TEI 48C or equivalent and continuous CO₂ by TEI 41C or equivalent during study period.
8. Continuous NO₂ and O₃ photolysis rates during study period by filter radiometer
9. Continuous turbulence during study period by sonic anemometers
10. Continuous total light absorption by aethalometer and total light scattering by ambient integrating nephelometer during intensive study period.
11. Continuous NO₂, HNO₃, HCHO and H₂O₂ by dual tunable diode laser absorption spectrometers at one of the research site during the intensive study period.

Up to three research sites are proposed. Potential locations include downwind of Sacramento and Fresno, and upwind of Livermore. The Bay Area AQMD has expressed an interest in acquiring an automated gas chromatograph for use during in CCOS and thereafter. The CCOS budget estimates assume that the auto-GC deployed in the Livermore area will be purchased from CCOS funds and will be operated by BAAQMD staff.

4.5 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. The specific measurements at each site and the networks they belong to are documented in Appendix C of Watson et al., (1998).

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 will be supplemented with the CCOS sites shown in Figure 4.4-2 and described in Table 4.4-1. Ten meter meteorological towers at each of these sites will be equipped with low threshold (~0.3 m/s) wind sensors and high sensitivity relative humidity sensors. Section 10 describes the monitors available for these measurements. Five-minute average measurements will be 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 provides adequate coverage for the northern and central California study domain.

4.6 Upper Air Meteorological Network

Figure 4.6-1 shows the locations of types of upper air meteorological monitors to be deployed for the summer 2000 field study. Table 4.6-1 describes the upper air sites, their measurements and operators. Radar profilers, doppler sodars, and RASS are used at most sites because they acquire hourly average wind speed, wind direction, and temperature by remote sensing without constant operator intervention. Sodars are 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. Radiosondes 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 4.6-1 and 4.6-2. 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 database.

Several radar profilers are being installed to acquire a multi-year database, and one of the important functions of the CCOS/CRPAQS supplements to this network is to relate these relatively sparse measurements to the detailed meteorological patterns determined during CCOS. The 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.

Radiosondes are routinely launched through the year at 0400 and 1600 PST from the Oakland, Vandenberg, Edwards, and Pt. Mugu. None of these locations are within the Central Valley, so these will be supplemented by lunches at Fresno and Bakersfield during episodic days during summer. For the 20 episodic days during summer, six radiosondes per day will be

launched at 0400, 1000, 1200, 1400, 1600, and 2200 PST at the Oakland and Edwards sites (supplementing the twice per day launches), and at the Fresno and Bakersfield sites.

4.7 In-Situ Aircraft Measurements

Instrumented aircraft will be used to measure the three dimensional distribution of ozone, ozone precursors, and meteorological variables. The aircraft will provide information at the boundaries and will document the vertical gradients, the mixed layer depth, and nature of elevated pollutant layers. The concentrations and (in conjunction with upper air wind soundings) the transport of pollutants across selected vertical planes will be measured to document transport of pollutants and precursors between offshore and onshore and between air basins. Redundancy and operational cross-checks can be built into the aircraft measurements by including overlapping flight plans for the various types of aircraft and by doing aircraft measurements near the ground over air quality monitoring sites. Three aircraft are included in the program and one additional aircraft is equipped with an ozone lidar.

Two small air quality aircraft are needed to document the vertical and horizontal gradients of ozone, NO_x, ROG, temperature, and humidity in the study region. These aircraft should be single- or twin-engine planes with an air speed of 150 to 200 kts and an endurance of four to five hours. They typically will be six-seat single-engine planes with 100 to 200 amps of 28 volt electrical power available. One aircraft is needed for the Bay Area and the Sacramento Valley and Northern Sierra Nevada and a second aircraft is needed for San Joaquin Valley, Southern Sierra Nevada.

Onboard air quality instruments should have high sensitivity and fast response (e.g., modified TEI 42S for NO₂ and NO_y). The small aircraft will make one flight in the early morning (0500 to 0900 PDT) to document the morning precursors and the carryover from the day before and a second flight in mid-afternoon (1300 to 1700 PDT) to document the resulting ozone distribution. An occasional third flight might be considered during the night to characterize the nocturnal transport regime and pollutant layers. Flights last between three to four hours and consist of a series of spirals (over fixed points on the ground) and traverses (at constant altitude from one point to another) throughout the mixed layer. The following are examples of the flight paths for these aircraft:

VOC samples are collected in the morning during downward spirals between 200 and 600 m AGL in order to characterize carryover of VOC from the previous day. VOC samples in the afternoon are collected in the mixed layer in the bottom 350 m of the downward spiral. Sample durations in these layers are approximately two minutes. Hydrocarbon samples are collected in stainless steel canisters and carbonyl samples are collected in Tedlar bags and transferred to dinitrophenyl hydrazine impregnated C₁₈ cartridges on the ground at the conclusion of the flight. Hydrocarbon samples are subsequently analyzed in the laboratory by gas chromatography with flame ionization detection per EPA Method TO-14 and carbonyl samples are analyzed in the laboratory by HPLC with UV detection per Method TO-11. The budget allows for collection and analysis of three sets of hydrocarbon and carbonyl samples per flight. Analytical laboratories must demonstrate the capability to achieve detection limits that are anticipated for these samples .

A larger multi-engine aircraft is needed to document the horizontal and vertical gradients offshore and across the shoreline. This plane carries the same instrumentation as the smaller planes plus the capability to measure wind direction and speed. The wind measurements should be precise to ± 1 m/s with a response time of 10 to 20 Hz. This measurement is typically made on research aircraft using an inertial navigation system and gust probe or comparable setup. With recent advances in instrumentation, UCD and STI have both acquired capabilities to reliably measure horizontal winds. A 10 seat, twin-engine airplane with the capability for extended overwater flights at sampling speeds of over 200 kts and an endurance of five to six hours is needed for this route. UCD's twin-engine Aztec and the NOAA Long EZ are able to fly over water while UCD's single-engine plane is less suitable for over water flights.

This long-range aircraft will make two flights per day, one in the early morning and one in mid-afternoon. The flights will take about four hours and will consist of a series of dolphin patterns (slow climbs and descents along the flight path) and traverses. During one leg of the morning flight of the first day of an IOP, this aircraft will measure the concentrations at the overwater (western) boundary of the study area. On the return leg, the aircraft will document the concentrations and fluxes across the shoreline. VOC samples are collected during constant-altitude traverses for the overwater boundary and channel legs and during several spirals for the shoreline legs. The specific flight plans will need to be developed over the next year for this aircraft under different meteorological scenarios.

Aircraft that are available during the summer 2000 field study include two single-engine Cessna from UCD, STI's twin-engine Aztec, NOAA Long EZ and the NOAA Twin Otter. The capabilities of these aircraft and associated personnel vary with each group. The data needs for CCOS can be met with three in-situ instrumented aircraft.

Item for discussion with CCOS Technical Committee.

4.8 Vertical Ozone Measurements (Lidars and Ozonesondes)

4.8.1 Airborne Lidar

The Atmospheric Lidar Division of NOAA's Environmental Technology Laboratory in Boulder is operating an airborne, downlooking UV-DIAL, which was originally developed by EPA's Environmental Monitoring Systems Laboratory – Las Vegas. This system is capable of measuring range resolved ozone concentrations and aerosol, nadir looking from its airborne platform to near the ground level.

The current measurement range for ozone is from about 0.8 km to 2.5–3 km, with the lower limit corresponding to the complete overlap of laser beams with the field of view of the telescope. The lower limit might be reduced somewhat in the future by applying the overlap correction in the data analysis and/or different alignment of the hardware. Generally, the DIAL data are analyzed for ozone concentrations down to about 90–150 m above ground.

Accuracy of the DIAL data is 4 ppbv from comparisons with in situ instruments. Precision is 3 ppbv at 1.5 km range from the lidar to 11 ppbv at 2.5 km range with 500 m

horizontal resolution (8 seconds at 65 m/s flight speed) and 90 m vertical resolution (Alvarez, 1999).

Cost Estimate: Cost estimate for NOAA's airborne ozone lidar including preliminary on-site data processing. Final data processing is included as separate item:

1 month deployment and 80 flight hours	\$300k
Additional week including additional 20 flight hours	\$ 70k
Final data processing, approximately	\$150k

Possible Scheduling Conflicts: The airborne system is currently scheduled to participate in the SOS 2000 experiment (Houston) from August 15 through September 15, 2000.

4.8.2 Ground-Based Lidar

The Atmospheric Lidar Division of NOAA's Environmental Technology Laboratory in Boulder has developed a transportable ozone and aerosol lidar specifically for the measurement of ozone in the boundary layer and the lower free troposphere. Ozone measurements can be obtained for a range of up to 3 km under moderate to high surface ozone concentrations (< 150 ppb) while, for extremely high concentrations, a range of 2 km can still be achieved. Aerosol profiles for a maximum range of about 10 km can be obtained with a range resolution of 15 m. The lower range limit is very good (\approx 50 m) due to the use of an innovative technique for the compression of the lidar dynamic range (Zhao et al., 1992). Using the 266/289 nm wavelengths pair, averaging 600-1200 pulses (5-10 min at 2 Hz or 1-2 min at 10 Hz), the retrieval of ozone concentrations has a range resolution from a few tens of meters in the lower boundary layer to 150-200 m at about 3 km. Range resolution decreases with height because the signal-to-noise ratio decreases with distance.

The NOAA ground-based lidar has the necessary range to make useful measurements further inland where the boundary layer height is larger. This lidar could be located at up to two of the CCOS research monitoring sites (with one move during the summer 2000 field study). The ground-base lidar will serve as an anchor site within a network of ozonesonde launch locations arrayed along the following transport routes: 1) west-east transport path between the Bay Area, Sacramento, and the Sierra Nevada foothills; and 2) north-south transport up the San Joaquin Valley. The measurement direction of the lidar system can be scanned in one dimension from 30° to 150° yielding a two dimensional ozone measurement. The vertical scanning capability provides a valuable internal system check, frequent calibration, and was desired for both monitoring and modeling studies. This system is being modified to add a new wavelength at 299 nm, to provide a longer maximum range of ozone measurements in a thick boundary layer.

Cost Estimate: Cost estimate for NOAA's ground based ozone lidar (OPAL):

1 month deployment including 150 hours of operation	\$230k
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4.8.3 Ozonesondes

Ozonesondes can be deployed at each of the ground-based lidar sites for quality assurance purposes and to obtain a higher vertical range of ozone distributions. Other ozonesondes will be released at during episodes at several sites along transport paths. Two configurations are proposed as described above.

4.9 Measurements for Special Studies

4.9.1 Micrometeorological Towers

As part of CRPAQS, a 100 m, walk-up, scaffold tower will be constructed and maintained at the Angiola site to support year-long micrometeorological measurements as well as other vertical experiments. For the long-term measurements, the tower will be instrumented at five elevations with high precision anemometers, relative humidity, and temperature measurements and will record 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.

A tower-based experiment using a DOAS lidar at three to five different heights could be employed to measure vertical O_3 , NO_2 , HONO, NO_3 , and HCHO concentration gradients. Optical fibers would distribute the laser pulse to each height, and a multi-pass cells could be used to increase the path length and thereby the accuracy. The O_3 and NO_2 measurement has an estimated accuracy on the order of 1.5 ppb for a five-minute averaging period over a 100-m pathlength (5 m folded 20 times). (Accuracy for any other species measured may be part of the investigation.) To get fluxes from the lidar gradient measurement, either an assumed form of eddy diffusivity would be required, or a modified Bowen ratio approach could be employed. The modified Bowen ratio and a direct eddy correlation measurement both require fast-response sonic anemometry (on the order of 10 Hz) to measure turbulent perturbations in the vertical velocity. With direct eddy correlation techniques, the species of interest must also be measured at the same rate to find the covariance with the vertical turbulent perturbations. This is the approach used in aircraft flux measurements. With the modified Bowen ratio technique, fast response measurements of a surrogate species (typically CO_2 or H_2O) are made and are then related to the species of interest via the ratio of vertical concentrations. Since fast response instruments are available for ozone (chemi-fluorescence) and for NO_x (chemi-luminescence), the two techniques could be directly compared, giving greater confidence in the HONO, NO_3 , and HCHO flux estimates.

Instrumented aircraft can also be a part of a wider study to investigate more diverse land types. For example, the NOAA Long-EZ operated by the NOAA Air Resources Lab is already instrumented with fast response O_3 and NO_x analyzers and has a wind probe providing 2 cm/s accuracy in turbulent perturbations. As was done in CODE, the aircraft could be periodically flown near the tower for crosscheck and QA purposes.

4.9.2 Contributions of Elevated NO_x Sources to Downwind O₃

Power plants and other sources with tall stacks are significant sources of NO_x, which in the presence of NMHC can lead to catalytic formation of ozone downwind of the source. However, close to the stack there is a temporary decrease in ozone levels due to “titration” by high levels of NO in the near field of the plume. Further downstream, ozone levels above the local background indicate net ozone production due to the reaction of plume NO_x with NMHC that are entrained into the plume in the dilution process. However, questions remain as to how much ozone is actually produced in the plume, how the ozone production efficiency depends on the chemical composition of the plume, and what the relative contributions of power plants are to high ozone episodes in downwind areas.

Recent power plant plume studies (Senff et al., 1998) utilized airborne ozone and aerosol lidar in conjunction with other instrumented aircraft. Because of its ability to characterize the two dimensional structure of ozone and aerosols below the aircraft, the airborne lidar is well suited to document the evolution of the size and shape of the power plant plume as well as its impact on ozone concentration levels as the plume is advected downwind.

Need additional details.

4.9.3 Emission Inventory Evaluation

Develop and Update Source Composition Profiles

On-Road Remote Sensing Study

4.10 Quality Assurance

See Appendix B

4.11 Data Validation and Data Management

See Appendix C

4.12 Data Analysis

Data analysis is an essential part of the database and model development components of CCOS. Measurements, by themselves, say nothing about the causes of air pollution and the likely effects of emission reductions. It is only when these measurements are interpreted that relationships can be observed and conclusions can be drawn. Similarly, mathematical models cannot be expected to explain phenomena that are not conceptually defined. "Conceptual

models" of pollutant emissions, transport, chemical transformation, and deposition must be formed so that the best mathematical formulations can be selected to describe them. The major goals of CCOS data analysis are:

- To evaluate the measurements for applicability to model input, parameterization, and verification.
- To describe the air quality and meteorology during the field study period and to determine the degree to which these measurements represent other summertime pollution levels.
- To further develop conceptual models of physical and chemical processes which affect ozone formation and transport in southern California.

While these goals provide guidance, concrete actions must be taken to attain them. These actions are described in the following data analysis plan. The plan is intended to:

- Identify data analysis objectives and hypotheses to be tested by applying data analysis methods.
- Specify data analysis work elements and the data to which they will be applied so that objectives may be met and hypotheses may be tested.
- Specify methods by which the data analysis tasks can be carried out and integrated into publications and reports to meet data analysis objectives.

Data analysis activities are defined here within the following topic areas: 1) measurement evaluation; 2) spatial, temporal, and statistical descriptions; 3) qualitative transport characterization; 4) dispersion characterization; 5) emission characterization; 6) quantitative transport characterization (pollutant fluxes); 7) ozone chemistry; 8) episode characterization; and 9) refinement of conceptual models. Activities are detailed in the following sub-sections.

4.12.1 Accuracy, Precision, Validity, and Equivalence of Field Measurements

There has never been a field study to date that did not require substantial examination and investigation of the measurements prior to their further use in data analysis and modeling. This first topic area is essential to all subsequent data analysis efforts, and needs to be performed as data are received into the database. Major concerns focus on: 1) accuracy of VOC peak identification, and proper, consistent quantification of total nonmethane hydrocarbons; 2) representativeness of meteorological measurements, especially those drawn from existing networks; 3) accuracy and precision of low-concentration measurements, especially NO_y and PAN; and 4) comparability of measurements taken from different networks with different procedures.

Evaluate the Precision, Accuracy, and Validity of Light and Heavy Hydrocarbon and Aldehyde Measurements

For sites and sampling periods which represent different expected mixtures of VOCs (e.g., background, fresh urban, aged urban, regional, forested, industrial), create scatterplots of

the sum of measured species vs. total nonmethane VOC. Calculate slopes, intercepts and correlations and compare these among different sites and sampling times. Estimate the range of values for unaccounted hydrocarbons and the degree to which these differ at different sites. Compare the sum of identified VOC concentrations to total nonmethane VOCs and identify significant differences among sampling sites and sampling periods. Plot hydrocarbon profiles (bar charts of percent composition for each carbon number and for the lumped parameter classes used in photochemical models) and compare these among different sampling periods and sampling sites.

Compare the detailed speciation of quality assurance samples with the routine speciation from normal network samples. Ascertain which species are not typically identified in normal network samples. Estimate the feasibility and effort required to reduce existing chromatograms with unidentified peaks for more complete speciation of normal network samples. Examine a selection of chromatograms from routine analyses and determine the feasibility and value of re-processing these chromatograms for more complete speciation. Use collocated and replicate analysis results to determine an overall precision for hydrocarbon measurements. Examine the discrepancies between different analyses as a function of aging time in the canisters and attempt to quantify the extent to which the gaseous contents change with time.

Evaluate sampling and analysis methods for aldehyde measurements by comparing collocated and replicate measurements. Determine the extent to which reactions take place in sampling bags used in aircraft from collocated measurements of bag and cartridge sampling. See Fung et al. (1993) for examples.

Evaluate the Precision, Accuracy, and Validity of Nitrogenous Species Measurements

Create scatterplots and calculate slopes, intercepts, and correlation coefficients for normal sensitivity chemiluminescent NO_x, high sensitivity chemiluminescent NO_y measurements sites, and spectroscopic measurements (e.g., TDLAS). Determine the equivalency of these different measurement methods by evaluating these plots and statistics. Examine differences among sites (along with calibration and performance test data) to attribute differences to instrument differences or to interferences in the sampled air streams (e.g. HNO₃ detected by chemiluminescence). Create scatterplots and statistics of collocated PANalyzer values. Explain differences in terms of measurement methods or environmental variables (e.g., interferences). Compare differences to propagated uncertainty intervals derived from performance tests and extrapolate the collocated uncertainties to other luminol PAN sampling sites in the network. Reconcile laboratory comparison data with field comparison data.

Evaluate the Precision, Accuracy, Validity, and Equivalence of Meteorological Data

Devise methods to compare upper air measurements of wind speed and direction from profilers, acoustic sounders, and surface wind towers and with corresponding measurements from radiosondes. Determine equivalent averaging layers and averaging times. Determine times of day (e.g., early morning, mid-day, and late-day) when these measurements are similar and when they are not. Draw conclusions regarding the equivalence of these methods. Compare

surface measurements of wind speed and direction with the lowest elevation values from collocated profile, sonde, and sounder measurements. Stratify comparisons by time of day to obtain well-mixed and layered vertical structures. Determine when surface measurements are an adequate estimate of upper air winds and when they are not, both with respect to elevation above ground level and time of day.

Evaluate the Precision, Accuracy, Validity, and Equivalence of Solar Radiation Data

Compare nearby measurements from the spectral radiation, ultraviolet radiation, and total solar radiation instruments. Determine the extent to which total solar radiation and spectral radiation are correlated with the ultraviolet wavelengths which are most influential in photochemistry. Determine the equivalence or difference between measurements taken in the CCOS and existing networks.

4.12.2 Spatial, Temporal, and Statistical Distributions of Air Quality Measurements

More data will be produced by field monitoring than can be examined by any data analysis plan. Summaries need to be created which can serve as a guide to the database and for the formulation of hypotheses to be tested by more detailed analyses. These summaries may be examples drawn from a data display package (such as that which was developed to display data in real-time during the study). The database and display software could then be used in other data interpretation projects to provide support for their findings.

Examine Average Diurnal Changes of Surface Concentration Data

Create diurnal box plots (which graphically show quartiles, median, mean, and extrema) for the entire sampling period and for each hour at each site of ozone, NO, NO₂, and PAN concentrations. Note differences in the timing and intensity of peak values as a function of sampling site, episode, and stratification. Group sites for which diurnal variations behave in a similar manner. Compare these with plots from selected sites in prior summers where ozone and NO_x data are available. Evaluate the extent to which the summer of 2000 is similar to or different from prior summers.

Create diurnal box plots for each hour at each site of ozone, NO₂, and PAN (where available) for each episode and the stratified intensive sampling days. Superimpose diurnal average total VOC, total aldehyde, nitric acid, and particulate nitrate boxes for specified sampling periods. Note differences in the timing and intensity of peak values as a function of sampling site and how these are similar to or different from those of the longer-term averages.

Create diurnal box plots of surface temperature, relative humidity, insolation, sigma theta, and scalar wind speed for each hour at each site for the entire monitoring period and for the intensive episodes. Identify similarities and differences among sites and between the intensive episodes and the entire study period.

Examine Spatial Distributions of Surface Concentration Data

Plot spatial isopleths corresponding to each intensive episode sample for total VOCs, selected VOC surrogates (selected to represent reactivity class, sources of precursors, or end

products), NO_x, NO₂, PAN, HCHO, NO/NO₂, VOC/NO_x, and O₃. Note similarities and differences in patterns with time of day, pollutant, and from episode to episode.

Examine Statistical Distributions and Relationships Among Surface Air Quality Measurements

Combine hourly averages of air quality measurements into sample averages corresponding to VOC and aerosol samples. For each site, calculate averages, standard deviations, first, second, third and fourth maxima (with date and time of occurrence), and minima (with date and time of occurrence) concentrations for each species measured. Identify differences between morning, afternoon and nighttime, sampling locations, episodes, and chemical observable. Give special attention to differences between rural vs. urban areas, central California vs. other air basins, morning vs. afternoon vs. nighttime.

Combine hourly averages of continuous measurements into sampling periods corresponding to VOC and aerosol samples. For each site, calculate the temporal correlation coefficients for all measured variables. Identify those variables that are highly correlated (negatively or positively) with each other and identify observables which might be represented by a single surrogate at each site. Combine these surrogates with meteorological variables and note positive or negative correlations among them.

Perform Principal Component Analysis (PCA) on VOC and nitrogenous species. Calculate eigenvectors of the correlation matrix and perform a varimax rotation to identify empirical factors which explain the variability in the data. Describe these factors in terms of physical phenomena, and examine factor scores to determine when each factor has much greater than or much less than average influence at each site.

Using selected species concentrations, calculate spatial correlations for the intensive episode samples. Examine correlations and identify which sites are highly correlated (positively or negatively) with each other. Calculate eigenvectors of this correlation matrix, perform a varimax rotation, and plot the empirical orthogonal functions that are deemed significant. Use these to select surrogate sites which can be used to represent neighboring sites for different observables (the surrogates and the area which they represent may not be the same for all observables).

Plot surface wind roses for all data at selected times of the day on a single map. Identify when flow reversals take place and when wind speeds increase or decrease. Note which areas have the highest frequencies of calms and when they occur. Perform these analyses for meteorologically stratified cases. Perform analyses for stations near sea-level as well as those located on higher terrain, and compare and explain differences.

Examine Vertical Distribution of Concentrations from Airborne Measurements

Plot VOC (total and selected species, aldehydes (total and selected species), NO₂, NO, O₃, and bscat as a function of altitude for each spiral. Note similarities and differences with respect to location, time of day, and chemical species. Give special attention to VOC speciation in morning samples (i.e., local emissions) over urban (motor vehicle), non-urban (biogenic), and industrial (oil-field) areas. Compare canister and cartridge samples of VOC and aldehydes taken in spirals with those taken in circles at the top of the spiral.

Plot spatial distributions of VOC (total and selected species, aldehydes (total and selected species), NO₂, NO, O₃, and bscat along aircraft traverses (within the mixed layer). Note similarities and differences with respect to location, time of day, chemical species, and the spatial distributions derived from surface-based measurements. Compare concentrations along boundaries (long-range aircraft) with those measured at locations within the study domain and note similarities and differences.

Examine the Spatial and Temporal Distribution of Solar Radiation

From the radiometer data, estimate the photosynthetically active radiation (needed for deposition and biogenic emissions), direct beam solar radiation, diffuse solar radiation, visible radiation (for light extinction), incident flux, and actinic flux (at frequencies relevant to photochemical reactions). Create spatial and temporal plots of these observables. Describe differences between sites and time-of-day in terms of measurement uncertainty, meteorological and air quality parameters. Note the effects of clouds and smoke on different types of radiation.

4.12.3 Meteorological Transport Phenomena

This topic addresses the major mechanisms for the movement of air into, out of, and between the different air basins in both horizontal and vertical directions. This requires an examination of conditions near sea level and also just below, within, and above the inversion layer.

Determine Horizontal Transport Patterns and Intensities Into, Out of, and Within the Air Basins

Plot 0500, 1100, 1700, and 2300 horizontal windfields at three different heights (surface, within the mixed layer, and above the mixed layer) using continuous and radiosonde data. Examine the consistency of these flow vectors with those predicted from synoptic weather maps and pressure gradients. Note similarities and differences with respect to time of day, elevation, and episode. Associate the directions with the expected phenomena of low-level jet, slope flows, eddies, coastal meteorology and bifurcation. Examine aircraft data to further describe the evolution of these phenomena. Determine the time of occurrence, spatial extent, intensity, and variability of these phenomena.

Plot detailed horizontal wind vectors as a function of height for the Carquinez, Altamont Pass, Pacheco Pass. Examine these to determine the intensity and duration of transport from the the Bay Area to the Sacramento and San Joaquin Valleys. Note similarities and differences with respect to time of day, elevation, and episode.

Plot back-trajectories for critical receptors (e.g., ozone hot-spots, forested sites, and transport corridors) for each intensive episode at three elevations. Start trajectories at the time of maximum ozone concentration. Identify general areas over which air masses might have passed to reach these receptors. Classify sampling periods into categories that are likely to be influenced by different types of source areas (e.g., industry, traffic, forest). Track horizontal pollution movements (e.g., visibility analyses) and determine if ozone values at stations downwind can be traced to photochemical changes on precursors upwind.

Determine Vertical Transport Patterns and Intensities within the Modeling Domain

Examine wind flow patterns to identify convergence and divergence zones. Examine acoustic sounder, profiler, and aircraft meteorological data for evidence of vertical exchanges in these regions. Determine the extent to which surface air is transported above the mixed layer, or air above is transported into the mixed layer at these locations. Verify this with vertical profiles of pollutant concentrations from onboard aircraft measurements. Examine and describe the intensity and duration of upslope flows to estimate the amount and frequency with which pollutants might be transported above the mixed layer. Verify this with onboard aircraft pollutant measurements. Plot the vertical velocity structure as a function of time. Examine monostatic sounder data and profiler data to determine the degree of layering in the atmosphere, especially during the morning. Identify the locations of wind shears and their effect on layering. Note the differences in layers at different locations throughout the study area.

4.12.4 Meteorological Dispersion Processes

Dispersion processes address the mixing of pollutants within the mixing layer, especially elevated and ground-level emissions, dispersion within and between modeling grid cells, and transport to the surface where deposition of pollutants may occur.

Characterize the Depth, Intensity, and Temporal Changes of the Mixed Layer and Characterize Mixing of Elevated and Surface Emissions

Plot the spatial distribution of expected mixing depths derived from temperature soundings at 0500, 1100, 1700, and 2300. Examine sounding, aircraft, and profiler data to determine the accuracy of interpolations of mixing depths between the 4 per day soundings. Examine aircraft and profiler data for evidence of other layers within the mixed layer, their time of formation and dissipation, and their typical duration and intensity. Describe the changes in layers as a function of time, especially during the morning when rapid changes are taking place with heating. Associate changes in layers with changes in surface temperature and solar radiation.

Examine vertical mixing as a function of location and time of day using aircraft data and continuous profiler and acoustic sounder measurements. Estimate the times of day on which pollutants emitted from stacks, and pollutants carried over from the previous day above the mixed layer, will combine with pollutants emitted at the surface. Verify this by examining aloft and surface level concentrations which are associated with aged emissions.

4.12.5 Characterize Emissions

Emission data will be acquired in separate projects. If ambient measurements and emission data are correct, consistent relationships between the spatial, temporal, and meteorological variability in emissions and ambient measurements should be found. The tasks associated with this objective will examine these relationships and will explain why they are observed or are not observed.

Determine the Consistency between Proportions of Species Measured in Ambient Air and those Estimated by Emission Inventories

Calculate the average VOC/NO_x and CO/NO_x ratios and ratios of selected species (e.g., acetylene/benzene, ethylene/acetylene, benzene/xylenes, carbon monoxide/selected VOCs, total aromatics/total VOC, total biogenic species/total VOC, >C₁₀/total VOC, benzene/VOC, MTBE/VOC) in source-dominated areas for samples which are expected to be dominated by fresh, local emissions (e.g., morning samples). Compare these ratios with those in emission inventory grid squares in the vicinity of the sampling site and with ratios in speciated profiles. If profiles are sufficiently speciated, perform Chemical Mass Balance modeling to apportion each species to a source type (e.g., evaporative emissions, solvents, refinery, tailpipe emissions, biogenics) and compare the ratios of source contributions to the ratios of total VOC emissions in nearby grid squares. Note consistencies and differences between ambient ratios and emission inventories and advance explanations for these differences. Define further investigations needed to reconcile the discrepancies (both further work on inventories and ambient/source sampling). Compare ratios from high ozone days with those on low ozone days and identify the presence or absence of different emissions at receptors on different types of days.

Calculate the average ratios of VOC/NO_x and ratios of selected species (e.g. homologous groups/total VOC, oxygenates/total VOC, methyl vinyl ketone and methyl acrolein/isoprene, other daughter products/precursors) for samples which are expected to contain end products of photochemical reactions. Compare these ratios with those in emissions inventory grid squares in the vicinity of the sampling site and with ratios in speciated profiles to determine the extent to which primary emissions and secondary products contribute to the entire VOC loading. Explain differences between inventoried and measured VOC/NO_x ratios in terms of chemical reactions, if possible.

Using existing VOC source profiles for the study region, calculate source contributions to VOC at selected receptor sites using a Chemical Mass Balance (Watson et al., 1984, 1990). Compare relative source contributions with the relative emission rates from these sources in grid squares in the vicinity of the sampling sites. Examine source contributions for consistency with the emission inventory with respect to geographic location and sampling times. See Fujita et al. (1992, 1994, 1995) for examples.

Determine the Effects of Meteorological Variables on Emissions Rates

Select representative sampling sites from major source regions (e.g., urban, industrial, biogenic, etc.) and examine concentrations of "marker" species for sources as functions of temperature, relative humidity, wind speed, and other environmental variables which are used to adjust emission factors. If possible, draw conclusions concerning the efficacy of current emission factors to respond accurately to changes in meteorological variables. Compare VOC source contributions when intermittent sources are known to operate and when they are known not to operate. Attempt to detect effects of different wind speeds, temperatures, solar radiation levels, and relative humidities on biogenic and industrial emissions.

Determine the Detectability of Day-Specific Emissions at Receptors

Examine day-specific emissions and identify sampling locations and times that correspond to fires, pesticide applications, spills, etc. From previous measurements of emission compositions, identify chemical species that are likely to be contributed by that source. Examine

transport and dispersion patterns to determine the likelihood of influence at nearby sites. Compare the ambient concentrations at likely impact sites with concentrations at that site when day-specific emissions do not exist. Examine nearby sites and draw conclusions about the region of influence of intermittent emitters. Draw conclusions regarding the importance of intermittent emissions for ozone formation.

4.12.6 Characterize Pollutant Fluxes

A "flux plane" is a rectangular cross-section that is perpendicular to the prevailing horizontal wind direction at a location between major emissions areas. The major transport pathways that are suspected of passing through these flux planes were specified in Section 2.

Define the Orientations, Dimensions, and Locations of Flux Planes

Examine windfields to identify areas in air that is transported across a boundary at vertical levels, especially at entry and exit points to the Central Valley. Specify the horizontal and vertical coordinates of these flux planes. Examine the usefulness of different conceptual definitions of flux (i.e., mass/unit area/time, mass/time, upwind/downwind concentrations along a wind vector). Estimate uncertainties due to: 1) mis-specifying the portion of ozone flux attributable to background vs. that generated in the upwind source area; 2) the effects of vertical and horizontal wind shears or reversals on the definition of the flux plane; 3) variations in wind speed and direction between measurements; 4) mis-specification of the boundary plane height; and 5) effects of wind speed and direction variability on flux estimates.

Estimate the Fluxes and Total Quantities of Selected Pollutants Transported Across Flux Planes

Using aircraft spiral and traverse data, lidar data, and ground-based concentration data for VOCs, NO_x, and O₃ coupled with average wind speeds that are perpendicular to the chosen flux planes, calculate the mg/m²-sec of each pollutant which crosses each plane as a function of time of day. Compare the fluxes for the different planes and assign downwind fluxes to a combination of fresh pollutant generation and contributions from the upwind flux plane. Examine fluxes at different layers, especially at night, if major differences are observed in vertical concentrations and wind speeds. Plot vertical cross-sections of concentrations, wind speed, and direction.

Compare the magnitudes of inflow to and outflow from regions which are bordered by flux planes. Advance explanations for major differences between inflow and outflow. Using all relevant field study data, test the hypotheses that: 1) there is significant local generation of pollutants; 2) there is significant venting through the mixed layer; and 3) there is substantial reverse or lateral transport owing to eddies, nocturnal jets, and upslope/downslope flows.

4.12.7 Characterize Chemical and Physical Interactions

Ozone, several nitrogenous species, and significant portions of the VOCs found in the study domain are not emitted directly from sources, but form from precursors. In particular, it is necessary to determine where or when ozone concentrations are limited by the availability of NO_x or VOC. These issues are addressed within this topic

VOC and Nitrogen Budgets

Plot pie charts of VOC speciation (with species expressed as mg/m³ carbon categorized into homologous groupings such as paraffins, olefins, aromatics, formaldehyde, other aldehydes, heavy hydrocarbons, unidentified peaks, and total nonmethane VOC minus sum of peaks and average carbon number for <C₁₀ and >C₁₀) maps for morning, afternoon, and evening sampling periods, with the size of the pie proportional to the total VOC. Select relatively inert compounds (e.g., ethane and acetylene) as well as reactive species to help identify sources. Determine the extent to which total VOCs are accounted for as a function of location and time of day. Advance hypotheses regarding the compositions of the unidentified peaks and the unaccounted-for VOC. Test these hypotheses by examination of example chromatograms from source-oriented and receptor-oriented sampling sites and from direct samples of source emissions. Draw conclusions regarding the effects of these unidentified and unknown fractions on chemical mechanisms used in air quality models.

Plot pie charts of the gaseous and particulate nitrogen (NO, NO₂, HNO₃, PAN, HONO, and NO₃-), and carbon (heavy and light VOCs, aldehydes, and organic aerosol carbon) as a function of location. Make the radius of each pie proportional to the total number of N, S, or C atoms, and make each wedge proportional to the number of N, S, or C atoms contributed by each species. Examine the distributions of these species among gaseous and particulate phases as a function of time and location.

Reconcile Spatial, Temporal, and Chemical Variations in Ozone, Precursor, and End-Product Concentrations with Expectations from Chemical Theory

Calculate pseudo-steady-state values of ozone using NO/NO₂ ratios (from maps generated in work element 2.2.1) and assumed photolysis rates. Compare the spatial distribution of these calculated values with the measured values plotted in earlier data analysis activities. Explain possible reasons for differences. Compare NO₂ plots to PAN plots to determine when NO₂ is less than PAN.

Calculate average VOC-OH reactivity and determine VOC vs. NO_x limitations. Estimate (from literature) typical VOC-OH rate constants for individual VOC species. Calculate an average VOC reactivity by weighting each rate constant by the proportion of total VOC represented by its corresponding species. Compare the resulting average rate constants at different types of sites (urban, rural, oilfield) and sampling times (morning, day, night) with the VOC-OH reactivity of a standard urban VOC mixture (~3500 ppm-1min⁻¹). Stratify data near elevated point sources to separate periods when plumes are above the mixed layer from periods for which elevated plumes are within the mixed layer. Note similarities and differences with respect to site-type and time of day. Calculate adjusted VOC/NO_x ratios by multiplying a reference value of VOC/NO_x (for typical urban areas) by the ratio of the adjusted reference rate constant. Relate the results to bands of demarcation on an EKMA-type diagram between regions of VOC, combined, and NO_x limitation in producing ozone. Use the results to classify areas of the study domain into ones for which the ozone-forming potential is limited by VOC or NO_x.

Simulate ozone-producing potential of ambient VOC samples using an accepted chemical mechanism (e.g., CBM-IV, RADM, SAPRC) in a simple box using a range of diurnal radiation

profiles from the radiometers. Artificially add NO_x concentrations and calculate time to formation of peak ozone and the amount of ambient carbon carried over or available for reaction the next day for an assumed radiation intensity and time. Define an "ozone-forming-potential" figure of merit and map these as a function of location, time, and VOC level. Estimate the effects of VOC, radiation, and other measurement uncertainties on ozone-forming potential. Identify differences in potential owing to changes in the model mechanisms (e.g., compare results from CBM-IV with SAPRC and RADM).

Stratify episodes by high and low photochemical potential days, and compare photochemical products along trajectories estimated by other data analyses. Further stratify these episodes by VOC/NO_x ratios in the western and northern parts of the study domain and estimate the extent to which this ratio affects the maximum ozone levels in the eastern and southern portions of the study domain. Performing the same analyses as above for ozone levels in central California air basins. Recalculate VOC/NO_x ratios for specific reactivity classes, especially aromatics, and examine receptor area ozone concentrations for cases of high and low ratios in the source areas. Examine the emission maps to compare the quantity of fresh hydrocarbon and NO_x injected along the trajectories, and determine the degree to which this might interfere with the conclusions drawn from the VOC/NO_x ratios in the source areas.

Examine aircraft traverses and compare ozone, NO_x, and VOC levels to simple equilibrium calculations. Examine nighttime concentrations of O₃ and precursors above the mixed layer and off the coastline to determine the degree of carryover from the previous day. Compare VOC/NO_x ratios above the mixed layer with those calculated from localized emissions grid squares near the northern and western boundaries of the study domain. Identify potential causes of discrepancies, if they are found.

Compare day-to-day changes in emission patterns (using day-specific inventories) with O₃ and VOC concentrations for otherwise similar meteorological conditions. Compare oxidant values in cases with high ambient aromatic VOC concentrations to values obtained when aromatic VOCs are low.

Apply and Evaluate Ozone Receptor Models to Determine VOC and NO_x Limitations

Several receptor-oriented models have been developed and applied to determining relationships between oxides of nitrogen, VOC, and ozone levels. In each case, evaluate and determine the applicability of these models to CCOS by evaluating their fundamental assumptions as part of applying them to appropriate measurements from the database.

Compute correlations and regression relationships between ozone, NO_x and NO_y for measurement locations with fresh and aged emissions. Determine the extent to which ozone increases in photochemically aged air when NO_y is less than 1 ppb and when it is higher than 10 ppb (e.g., Trainer et al., 1993; Jacob et al., 1995). Calculate Integrated Empirical Rates (e.g., Johnson, 1984, Blanchard et al., 1994; Chang et al., 1995) to determine at what downwind distances from major source regions NO_x reductions or VOC reductions would most affect ozone concentrations. Compare these distances with those determined by other methods. Examine ratios among ozone and nitrogenous species (e.g., Sillman et al., 1990; Sillman, 1995; Milford et al., 1994; Jacob et al., 1995; Watkins et al., 1995) to estimate when VOC and NO_x

limitations might apply. Apply the observation-based model (OBM) of Cardelino and Chameides (1995).

4.12.8 Characterize Episodes

Each of the episodes of two- to four-day duration has similarities and differences with respect to emissions, meteorology, transformation, deposition, and air quality levels. These episodes may be high for similar or for different reasons. Information derived the proceeding activities is synthesized to provide an anatomy of each episode. Conclusions are drawn with respect to which episodes are, for all practical purposes, the same, and which ones are substantially different.

Describe Each Intensive Episode in Terms of Emissions, Meteorology, and Air Quality

Prepare written overviews of each intensive sampling period. Describe the synoptic meteorology leading up the episode and summarize the forecasting rationale. Illustrate, with plots generated in other work elements, the general wind flows for the duration of the period and any deviations from these generalizations. Identify major emissions events, identified as significant in other work elements, which affected pollutant concentrations. Summarize the key pollutant concentrations at key times and key locations in the study domain. Summarize the completeness and validity of the data set from each episode with respect to modeling of ozone. Identify the transport and transformation mechanisms that are likely to be dominant in each episode. Evaluate each episode for its potential use in model testing and control strategy evaluation.

Determine the Degree to which Each Intensive Episode is a Valid Representation of Commonly Occurring Conditions and its Suitability for Control Strategy Development

Examine continuous meteorological and air quality data acquired for the entire study period, and determine the frequency of occurrence of days which have transport and transformation potential similar to those of the intensive study days. Generalize this frequency to previous years, using existing information for those years.

4.13 Reformulate the Conceptual Model

The conceptual model described in Section 2 must be revisited and refined using the results yielded by the foregoing data analyses. New phenomena, if they are observed, must be conceptualized so that a mathematical model to describe them may be formulated and tested. The formulation, assumptions, and parameters in mathematical modules which will be included in the integrated air quality model must be examined with respect to their consistency with reality.

4.13.1 Refine Conceptual Models of Pollutant Emissions

Specify motor vehicle emission model equations, assumptions, input data, and uncertainties. Reconcile the ambient species ratios found in ambient data (as studied in prior work elements) with ratios determined from emissions models in terms of model or measurement

biases. By stratifying samples, estimate the effects of different meteorological variables on emission rates. Pay special attention to the validity of models regarding vehicle age, maintenance, effects of hot and cold operating conditions, and vehicle-type distributions. Recommend improvements to emission models based on these observations.

Specify biogenic emission model assumptions, input data, and uncertainties. Reconcile ambient hydrocarbon species ratios at sites located in agricultural and forested areas with those determined from emission models in terms of model or measurement biases. By stratifying samples, estimate the effects of different meteorological variables, especially wind speed, on emission rates. Examine chemical speciation as a function of vegetation type. Examine total ammonia concentrations as a function of nearby soil types and fertilizer applications. Recommend improvements to emission models based on these observations.

Specify oilfield and refinery emission model assumptions, input data, and uncertainties for cogeneration systems, diesel-powered internal combustion engines associated with pumps, natural gas plants, drilling rigs, remote operations, spills, leaks from valves and flanges, evaporation from storage tanks, cyclic and non-cyclic well head vents, sumps, measuring stations, evaporation from tanker trucks and loading racks, pumping stations, and vacuum trucks, and gasoline stations. Evaluate how well these emissions estimates relate to reality, and which variables are not included in current methodology.

Reconcile ambient hydrocarbon species ratios at sites located near sewage plants and feedlots with those determined from emission models in terms of model or measurement biases. By stratifying samples, estimate the effects of different meteorological variables, especially temperature and relative humidity, on emission rates. Recommend improvements to emission models based on these observations.

Intermittent events include fires, entertainment and sporting events, and industrial upsets. Specify the models that treat intermittent events, their assumptions, and input data. Examine the magnitude of emissions from intermittent events with respect to other emissions to determine whether or not these emissions are significant. Recommend improvements to emission models based on these observations.

Examine the variability in emissions for intensive analysis days. Compare this variability to that assumed by point source models. Recommend improvements in emission models based on these observations.

4.13.2 Refine Models of Pollutant Transport and Dispersion

Thermal lows are caused by surface heating over the Mojave Desert and the Central Valley and are one of the major causes of flow between the Bay Area and the central coast to the Central Valley. Specify meteorological model assumptions and input data relevant to calculating the vertical profile of this transport pathway. For unidirectional flows, the mathematical formulation should show a minimum in turbulence or laminar flow occurring at the height of the wind maximum, and the width of the jet should be adequately estimated. The model formulation should allow this region of minimal turbulence to intensify the nighttime inversion in the vicinity of the flow and to inhibit vertical transport. Reconcile the model formulation with the location,

dimensions, intensity, duration, and frequency of the thermal low transport. Quantify and compare measurement and model uncertainties.

Upslope flows in the Sierra Nevada result from heating of the mountain sidewalls by the afternoon. The downslope flows commence after sunset when the slopes cool. When the intensity of these up-slope winds is large, pollutants are vented from the Central Valley into the air above the mixed layer, and possibly into neighboring air basins. Examine the assumptions and input data of the meteorological model, which relate to slope flows. Determine whether or not the intensity and timing of these flows corresponds to those observed in other data analysis work elements. Identify those cases in which upslope flows vent pollutants above the mixed layer or over the summit, and determine the extent to which the mathematical formulation can represent these cases. Identify areas of uncertainty in the modeling and measurement processes and attempt to quantify these uncertainties.

Marine airflows mix, age, and transport pollutants from coastal air basin to the Central Valley. These airflows develop primarily from strong coast-to-inland pressure gradients. The most visible artifact of these flows is the marine stratus that forms along the coastal areas. A stronger inversion, a feature of the subtropical high, is usually present above the marine stratus layer and may extend to heights of 100 to 1000 m ASL, sufficiently deep to extend over the coastal mountains. Examine the results of windflow analysis to determine where and when this transport phenomenon occurs. Determine the presence or absence of fogs and high humidity at night, with the intent of understanding whether or not NO_x transported off the coast can be rapidly transformed to particulate nitrate that could be advected on-shore during the next day. Examine meteorological model formulation for those features that will describe these flows. Identify uncertainty in the modeling and measurement processes and attempt to quantify these uncertainties. Compare different pollutants with diurnal/spatial variations in humidity, visibility, cloud cover, and solar radiation for the same air mass. Evaluate episodes using Leipper Inversion Based Statistics (LIBS) discussed in Section 2.6.

Identify the occurrence and thickness of different atmospheric layers from other data analysis work elements. Determine the modeled layer structure. Examine the extent to which layers can be assumed to be uniform, or must vary in depth as a function of location and time. Evaluate the uncertainty introduced to the modeling process by anticipated deviations from layering assumptions.

4.13.3 Evaluate Boundary Conditions for Models

VOC concentrations are usually assumed to be constant or negligible at the western and northern boundaries and at the top of the study domain. Boundary conditions, particularly for formaldehyde, significantly affected model outputs in the SARMAP modeling resulting in over-prediction of ozone levels in the Bay Area. Plot airborne measurements of VOCs (total VOC, homologous groups, and lumped VOC classes) along boundaries and above the mixed layer, then examine the magnitude and constancy of their concentrations in space and time. List assumptions and input data requirements for VOC boundary conditions, and estimate the effects of uncertainties caused by insufficient data on the ability of the model to represent reality.

Nitrogenous species concentrations are usually assumed to be constant or negligible at the western and northern boundaries and at the top of the study domain. Plot airborne measurements of NO, and NO_y along boundaries and above the mixed layer, then examine the magnitude and constancy of their concentrations in space and time. Specify the model assumptions for boundary conditions of nitrogenous species, and estimate the effect if deviations from those assumptions on chemical concentrations.

4.13.4 Evaluate Initial Conditions for Models

Each grid square and each layer in the modeling domain starts with a concentration for each chemical species. These must be estimated from a sparse network of ambient measurements. Examine the different methods by which initial conditions are estimated from surface and airborne measurements. State the equations, assumptions, inputs, and uncertainties for these methods. Determine which methods are most applicable to the single point and aircraft measurements. Determine which methods are most useful for approximating initial conditions for integrated air quality modeling.

4.13.5 Evaluate Chemical and Physical Transformation Models

State the equations, assumptions, and input data for ozone formation. Identify those species in these models which were measured during CCOS. Evaluate the uncertainties introduced by non-continuous, 2-hour VOC measurements, variations in solar radiation, and uncertainties in boundary and initial conditions.

4.13.6 Evaluate Pollutant Deposition Models

Specify the equations, assumptions, input data, and uncertainties for the deposition model. From the examination of micrometeorological data and vertical flux measurements, determine the extent to which these equations represent reality, and the degree to which assumptions are complied with. Evaluate the effects of input data uncertainties on deposition estimates.

4.13.7 Contribution of Transported Pollutant to Ozone Violations in Downwind Areas

In principle, well-performing grid models have the ability to quantify transport contributions. However, many of the interbasin transport problems involve complex flow patterns with strong terrain influences that are difficult and expensive to model. Upper-air meteorological and air quality data in critical transport locations is generally required in order to properly evaluate and use grid models for quantifying transport contributions. In combination with modeling, data analyses can improve the evaluation of modeling results and provide additional quantification of transport contributions.

**Table 4.4-1
Supplemental Surface Air Quality and Meteorological Measurements**

Site	Type	Purpose	Ozone & Surf Met	NO, NO _y , ~ TEI 42S	NO ₂ , PAcNs by GC - Luminol	HCHO by AnalTech Methanalyzer 9902P	CO, CO ₂ , CH ₄ , C ₂ -C ₁₂ HC, MTBE can/GC-FID	C1-C7 carbonyls DNP-HPLC/UV	CO, CO ₂ TEI 48C TEI 41C	VOC Automated GC/Ion Trap MS	NO ₂ , HNO ₃ by TDLAS	H ₂ O ₂ and HCHO by TDLAS	babs aeth
Point Arena	S1	boundary	a	a			c1	c1					
South Central Coast	S1	boundary	a	a			c1	c1					
Anderson	S1	intrabasin gradient	Shasta	a			c1	c1					
Colusa	S1	interbasin transport, intrabasin gradient	ARB	a			c1	c1					
Turlock	S1	interbasin transport, intrabasin gradient	SJVU	a			c1	c1					
Near Grass Valley	S1	interbasin transport, slope flow	Northern Sierra	a			c1	c1					
Sonora	S1	interbasin transport, slope flow	ARB	a			c1	c1					
Bethel Island	S2	interbasin transport	BAAQMD	a	b1	b1	c1	c1					
Pacheco/Santa Nella	S2	interbasin transport	a	a	b1	b1	c1	c1					
Altamont/Tracy	S2	interbasin transport	a	a	b1	b1	c1	c1					
Mouth Kings River	S2	interbasin transport, slope flow	a	a	b1	b1	c1	c1					
Angiola	S2	intrabasin gradient	CRPAQS	a	b1	b1	c1	c1					
Edison	S2	intrabasin gradient	ARB	a	b1	b1	c1	c1					
DW Fresno	R	intrabasin gradient	a	a	b1	b1	c2	c2	a	b2	b1	b1	x
DW Sacramento	R	interbasin transport, slope flow	a	a	b1	b1	c2	c2	a	b2			x
UW of Livermore	R	interbasin transport, intrabasin gradient	BAAQMD	a	b1	b1	c2	c2	a	b2			x

a. Continuous during study period (6/1/00 to 9/30/00).
 b1. Continuous during intensive period (7/1/00 to 8/31/00).
 b2. Semi-continuous (hourly) during intensive period (7/1/00 to 8/31/00).
 c1. Four, 3-hour samples during 20 episode days.
 c2. Limited number of samples for comparison with automated GC/MS.

**Table 4.1-1
Upper Air Meteorological Measurements for CCOS (Draft, May 31, 1999)**

Site ID	Name	Purpose	Justification	Operator ^a	Radar ^b	RASS ^b	Sodar ^{b,c}	Sonde ^{b,d}	Nexrad
ABK	Arbuckle	Intrabasin Transport	Location provides coverage of predominant summer flow through Sacramento Valley.	CCOS/ CRPAQS/ NOAA	SC	SC			
ABU	North of Auburn, South of Grass Valley	Upslope/Downslope flow, Downwind of Major Area Source	Site to monitor possible summer eddy flow, vertical temperature structure evolution, model input and evaluation data. Downwind of Sacramento area source.	CCOS/ NOAA	SC	SC			
ACP	Angel's Camp	Upslope/Downslope flow	Serve as site to capture eddy flow, mixing, vertical temperature structure, model input and evaluation data during SJVAQS/AUSPEX	CCOS/ CRPAQS/ NOAA			SC		
ANGI	Angiola	Intrabasin Transport, Vertical Mixing, Micrometeorology	Positioned to monitor transport up the valley, low level nocturnal jet flow, and Fresno eddy flow patterns. Collocated with tall tower.	CCOS/ CRPAQS/ NOAA	AC	AC	SC		
BBX	Beale AFB-Oro Dam Blvd West	Northern Boundary Transport, Synoptic Conditions	Fulfill needs of National Weather Service and Beale AFB flight operations; existing long-term site.	BAFB					AC
BHX	Humboldt County	Onshore/Offshore Transport	Fulfill needs of National Weather Service; existing long-term site	NWS					AC
CRG	Corning	Northern Valley Barrier, Characterize Northern SV convergence zone.	To observe southerly barrier winds along the Sierra Nevada which may be a transport mechanism. May characterize extent of northerly flow into SV for some scenarios.	CRPAQS/ NOAA	SC	SC			
DAX	Sacramento	Intrabasin Transport	Fulfill needs of National Weather Service; existing long-term site	NWS					AC
EDI	Edison	Interbasin Transport through Tehachapi Pass. Downwind of major source.	Site to observe possible divergence flow at southern end of the valley, low level jet flow, and eddy flows. Data from SJVAQS/AUSPEX taken at Oildale supports these observations. Downwind of Bakersfield area source.	ARB	AC	AC			

**Table 4.6-1 (continued)
Upper Air Meteorological Measurements for CCOS (Draft, May 31, 1999)**

Site ID	Name	Purpose	Justification	Operator ^a	Radar ^b	RASS ^b	Sodar ^{b,c}	Sonde ^{b,d}	Nexrad
EYX	Edwards AFB	Interbasin Transport	Fulfill needs of National Weather Service and Edwards AFB flight operations; existing long-term site	EAFB					AC
FAT	Fresno-Air Terminal	Intrabasin Transport	Capture the Fresno eddy, characterize urban mixing heights, transport from major Fresno area source.	CCOS/ CRPAQS/ NOAA	SC	SC	SC		
FSF	Fresno-First Street	Urban Heat Island, Intrabasin Transport, Synoptic Conditions. Characterize winds at major area source.	Site to monitor possible summer eddy flow, vertical temperature structure evolution, model input and evaluation data. Flow out of Fresno.	CCOS/ CRPAQS/ NOAA				SE	
HNX	Hanford-edge of town between the fairgrounds and the municipal airport	Intrabasin Transport	Fulfill needs of National Weather Service; existing long-term site	NWS					AC
HUR	Huron	Intrabasin Transport	This is to monitor daily transport from north to south with average surface winds during afternoons and early evening and the low level nocturnal jet on the western side of the SJV; models should do well with topographic channeling.	CRPAQS/ NOAA	AC	AC			
LGR	Lagrange	Upslope/Downslope flow	This site represents valley/Sierra interaction in northern SJV. Monitor possible upslope flow transport of pollutants during day and possible recirculation via Mariposa River Valley exit jet by night. Also completes the west to east transect across SJV from SNA to LIV sites.	CRPAQS/ NOAA	SC	SC	SC		
LHL	Lost Hills	Intra&Interbasin Transport across Carizo Plain	Situated east of the coastal range and represents uniform flow aloft at 1000m as opposed to a site on the Tremblor Range. Good position to detect the direction of flow between the Carrizo Plain and the SJV	ARB	AC	AC			

Table 4.6-1 (continued)
Upper Air Meteorological Measurements for CCOS (Draft, May 31, 1999)

Site ID	Name	Purpose	Justification	Operator ^a	Radar ^b	RASS ^b	Sodar ^{b,c}	Sonde ^{b,d}	Nexrad
LIV	Livingston	Intrabasin Transport	Representative of mid SJV flow since variation in flow is small along the valley's central axis	CCOS/ CRPAQS/ NOAA	AC	AC	SC		
MJD	Mojave Desert-between Tehachapi and Mojave	Interbasin Transport	Chosen to monitor interbasin flow out of the San Joaquin Valley to the desert via Tehachapi Pass. Previous monitoring studies have shown a clear exit jet out of the SJV in this region. The exact site is to be determined.	CRPAQS/ NOAA	AC	AC			
MKR	Mouth Kings River- Trimmer	Upslope/Downslope flow	The current suspicion is that the mountain exit jets flow along the axis of the valley over Trimmer. A site between Academy and Humphrey's Station is more likely to observe the flow than a site at Piedra.	CCOS/ CRPAQS/ NOAA	AC	AC			
MON	Monterey	Onshore/Offshore Transport	Existing long term site	USNPGS	AC	AC			
MUX	Santa Clara	Interbasin Transport	Fulfill needs of National Weather Service; existing long-term site	NWS					AC
NTD	Point Mugu USN	Onshore/Offshore Transport, Synoptic Conditions	Existing long term site	USN				AS,SE	
OAK	Oakland airport	Onshore/Offshore Transport, Synoptic Conditions	Fulfill needs of National Weather Service; existing long-term site	NWS				AS,SE	
PLE	Pleasant Grove (optional site if budget allows)			CCOS/ NOAA					
REV	Reno National Weather Service Office	Northern Boundary Transport, Synoptic Conditions	Fulfill needs of National Weather Service; existing long-term site	NWS				AS	
RGX	Washoe County- Virginia Peak	Northern Boundary Transport, Synoptic Conditions	Fulfill needs of National Weather Service; existing long-term site	NWS					AC
RIC	Richmond	Onshore/Offshore Transport	Monitor possible deeper mixed layer	CRPAQS/ NOAA	SC	SC	AC		

**Table 4.6-1 (continued)
Upper Air Meteorological Measurements for CCOS (Draft, May 31, 1999)**

Site ID	Name	Purpose	Justification	Operator ^a	Radar ^b	RASS ^b	Sodar ^{b,c}	Sonde ^{b,d}	Nexrad
SNA	Santa Nella, East of I-5 toward Los Banos	Interbasin Transport from Pacheco Pass, Model QA	May represents flow through Pacheco pass during some coastal valley intrusions; represents along-valley flow on western side at other times. Models should handle channeled, along-valley flow well at this point.	CCOS/NOAA	AC	AC			
SOX	Orange County	Onshore/Offshore Transport	Fulfill needs of National Weather Service; existing long-term site	NWS					AC
TRA	Travis AFB	Interbasin Transport between Valley and Bay Area	Existing long term site	TAFB	AC				
TRC	Tracy, West of Trace, South of I-205, West of I-580	Interbasin Transport through Altamont Pass	Monitor flow through Altamont Pass for San Francisco Bay Area to SJV transport in p.m.; also help monitor less frequent off-shore flow.	CCOS/NOAA	SC	SC			
VBG	Vandenberg AFB	Onshore/Offshore Transport, Synoptic Conditions	Existing long term site	VAFB	AC			AS,SE	
VBX	Orcutt Oil field-Vandenberg AFB	Onshore/Offshore Transport	Fulfill needs of National Weather Service and Vandenberg operations; existing long-term site	VAFB					AC
VIS	Visalia	Intrabasin Transport	Existing long term site	SJVUABPC	AC	AC			
VTX	Ventura County	Intrabasin Transport-Onshore/Offshore Transport	Fulfill needs of National Weather Service; existing long-term site	NWS					AC

^aCCOS=Central California Ozone Study (this study), CRPAQS=California Regional PM₁₀/PM_{2.5} Air Quality Study, ARB=Air Resources Board, USN=U.S. Navy, BAAQMD=Bay Area Air Quality Management District,USNPGS=U.S. Navy Post Graduate School, SJVUAPCD=SJV Unified Air Pollution Control District, NWS=National Weather Service, SMUAPCD=Sacramento Metro Unified Air Pollution Control District, VAFB=Vandenberg Air Force Base, TAFB=Travis Air Force Base, EAFB=Edwards Air Force Base, BAFB=Beale Air Force Base.

^bAC=Annual continuous measurements by CRPAQS or indicated sponsoring agency; AS=Annual sporadic measurements

SC=Summer continuous, 7/1/2000-9/30/2000

SE=Summer episodic measurements on IOP days.

^cSodars added at all sites as part of CRPAQS except at RIC.

^dBalloon launch frequency is augmented during IOP days. Normal frequency is twice per day at 0700 and 1900 PST.

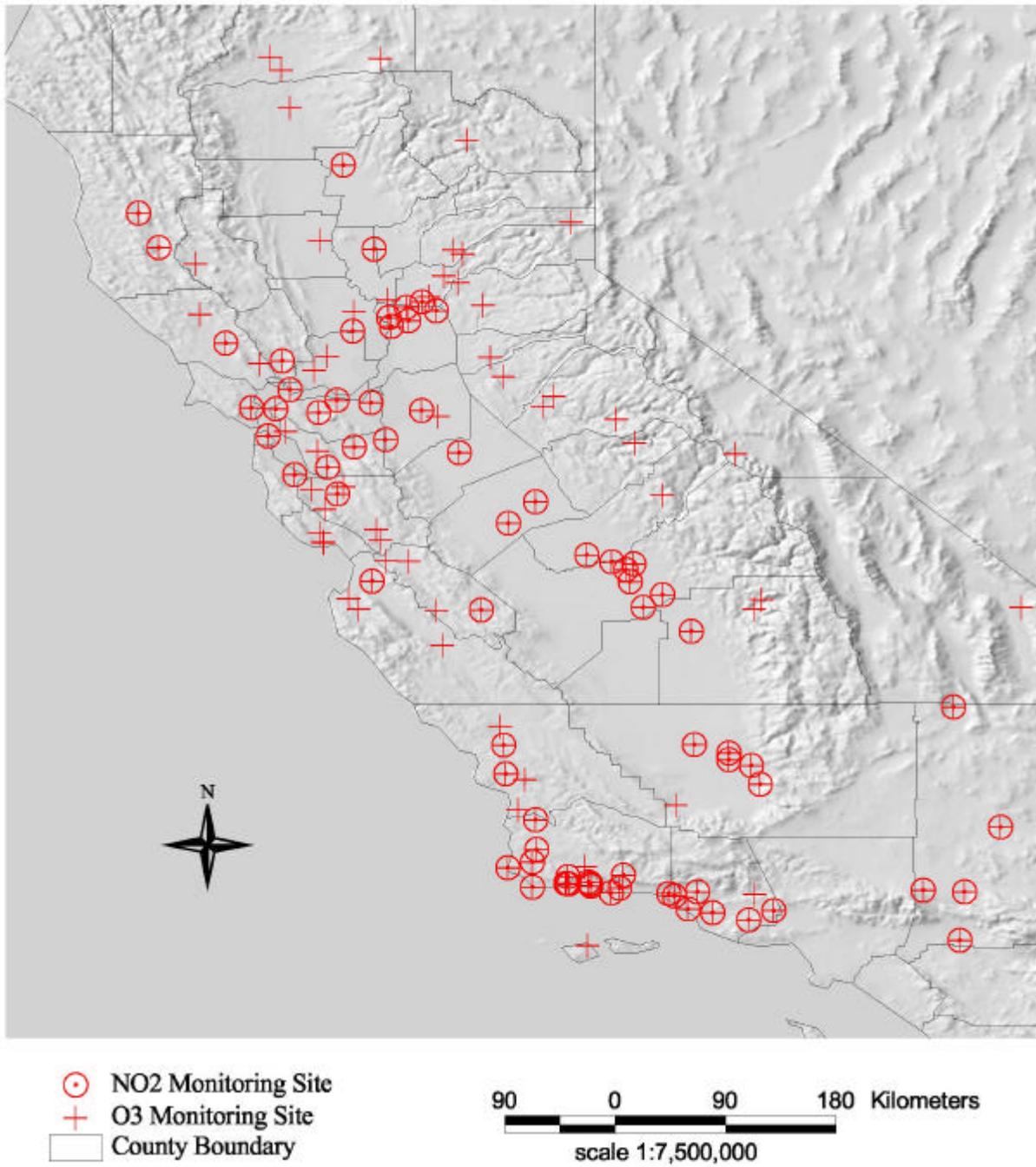


Figure 4.4-1. Existing routine O₃ and NO_x monitoring sites

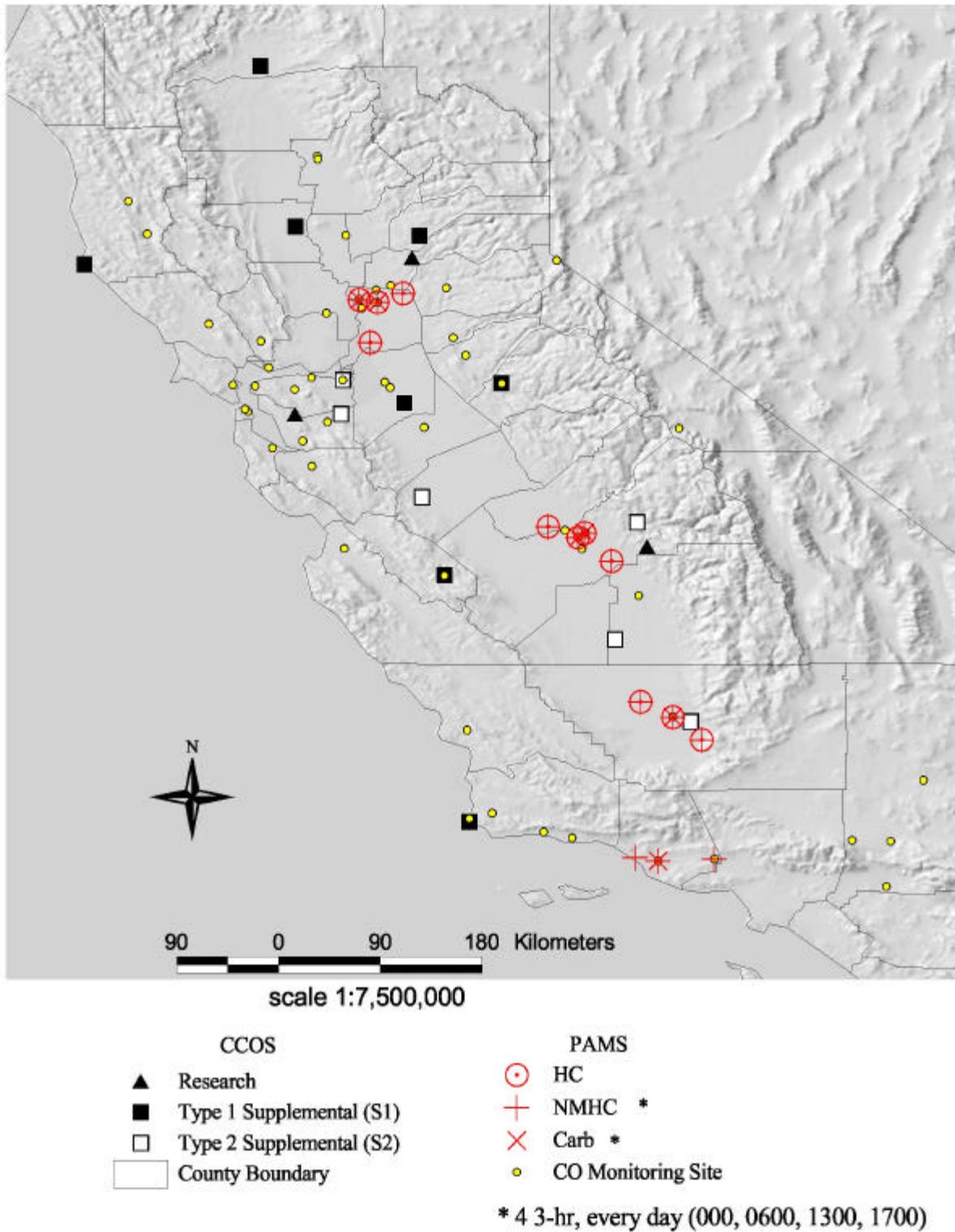
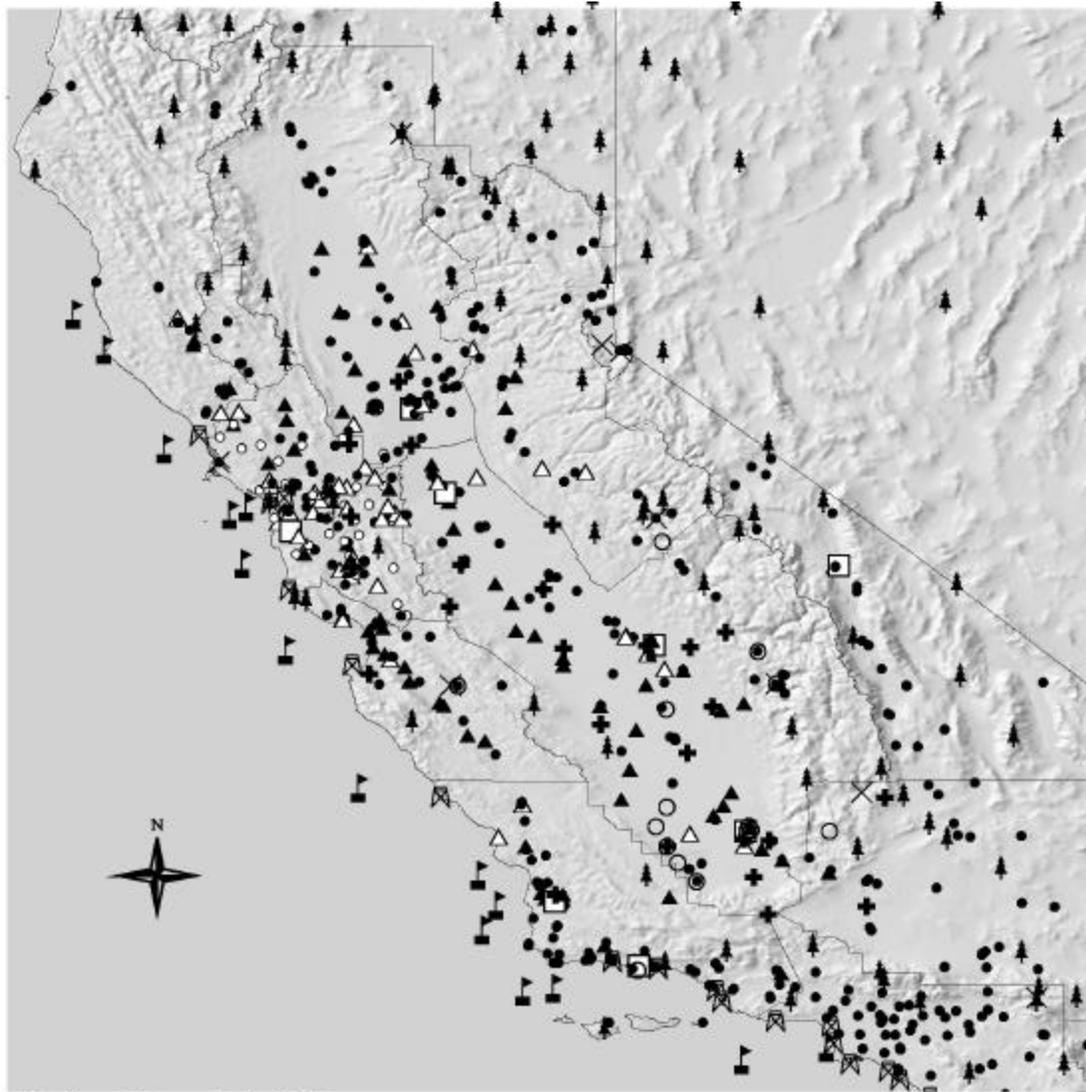


Figure 4.4-2. CCOS supplemental air quality and meteorological monitoring sites and Photochemical Assessment Monitoring Stations



Surface Meteorological Sites

- + CRPAQS
- ARB
- BAAQMD
- ▧ NOAA Buoy
- ▲ CIMIS
- × IMPROVE
- National Weather Service
- △ PG&E
- ⚓ US Coast Guard
- ♣ RAWS
- Other
- ▭ Air Basins

100 0 100 200 Kilometers

Figure 4.5-1. Central California surface meteorological networks and measurement locations.

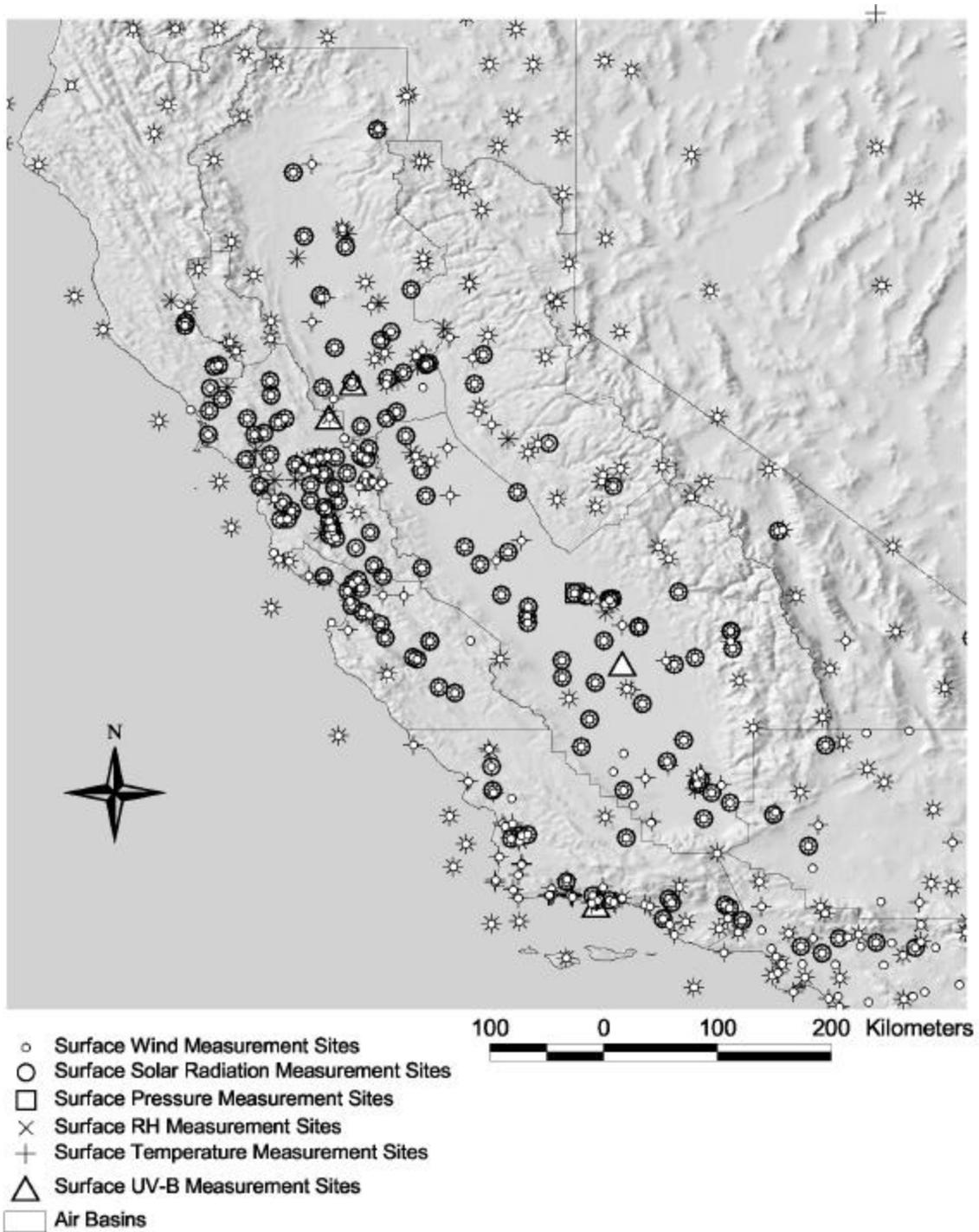


Figure 4.5-2. Surface meteorological observables measured in the combined central California meteorological network.

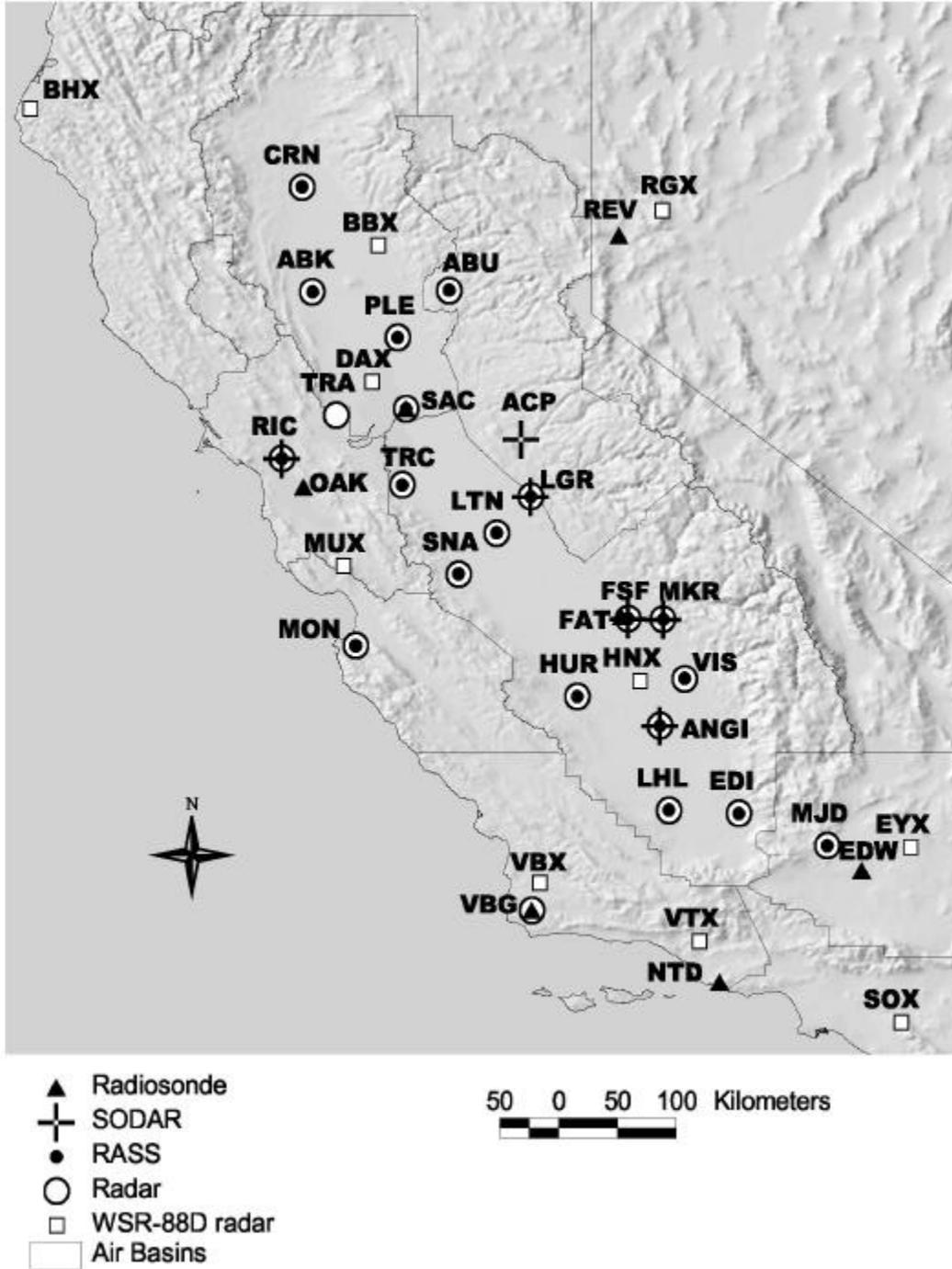
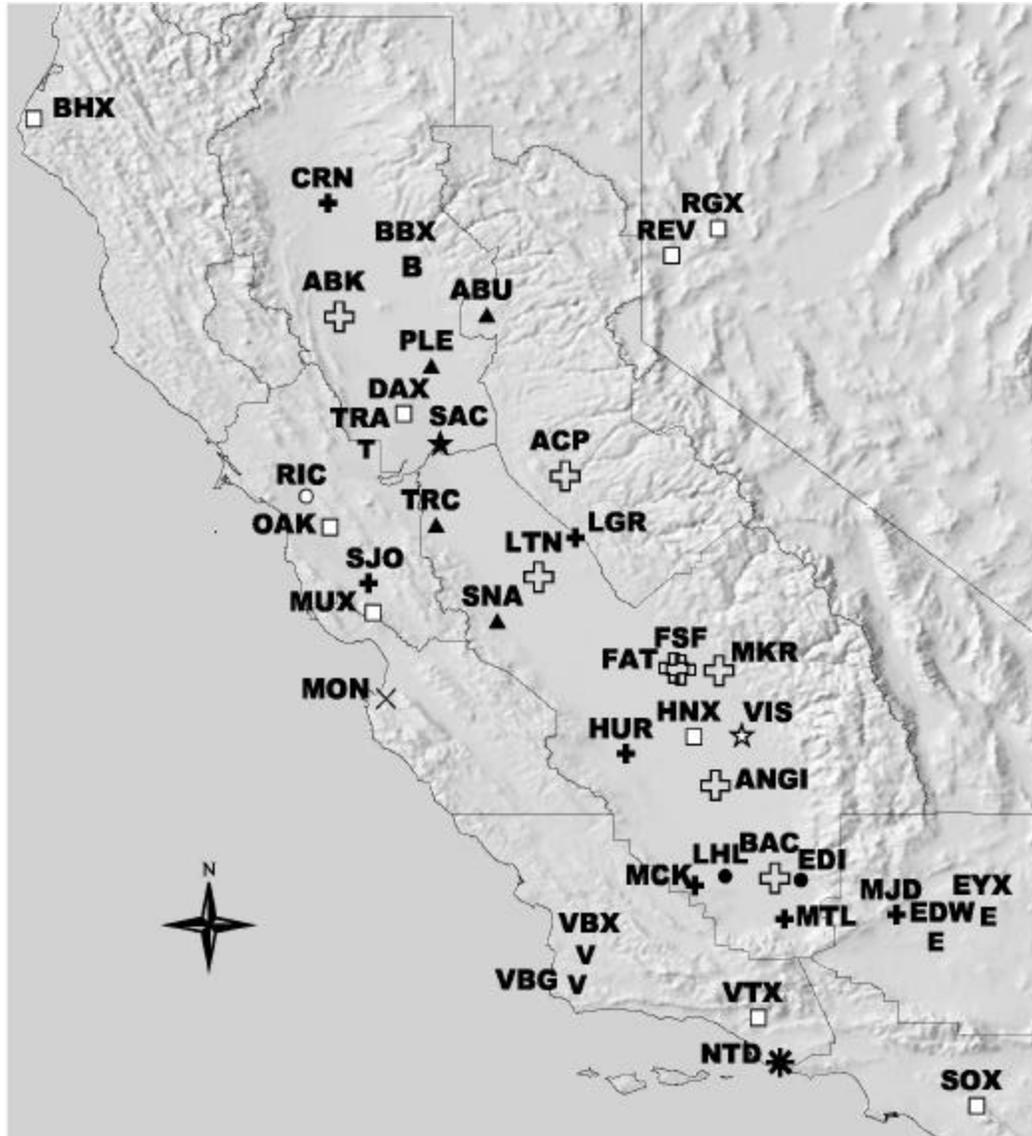


Figure 4.6-1. Upper air meteorological measurements during the summer campaign, including annual average study sites and NEXRAD (WSR-88D) profilers.



Upper Air Sites

- ARB
- BAAQMD/CCOS
- B** Beale AFB
- ▲ CCOS
- ⊕ CRPAQS
- ⊕ CRPAQS/CCOS
- E** Edwards AFB
- National Weather Service
- ☆ SJVUAPCD
- ★ SMUAPCD
- T** Travis AFB
- ✱ US Navy
- ✕ US Navy Post Graduate School
- V** Vandenberg AFB
- Air Basins

Figure 4.6-2. Upper air meteorological measurement network indicating operating agency.