

1. STUDY OVERVIEW

Central California is a complex region from an air quality and meteorological perspective, owing to its proximity to the Pacific Ocean, its diversity of climates, and its complex terrain. As a result of progressively more stringent controls on emissions of reactive organic gases and oxides of nitrogen, the frequency and intensity of excessive ozone concentrations in central and northern California have been significantly reduced despite rapid increases in population, commercial activities and vehicle miles traveled. For example, the average annual maximum hourly ozone concentrations have declined by 40, 21, and 30 percent from 1980 to 1997 in the San Francisco Bay Area, Sacramento Valley, and San Joaquin Valley air basins, respectively. The average annual exceedances of the federal 1-hour ozone standard (0.12 ppm) in the San Francisco Bay Area declined from 11 in 1980 to 4 in 1997, from 21 to 10 in the Sacramento Valley Air Basin and from 58 to 41 in the San Joaquin Valley Air Basin. While progress has been made toward attainment of the 1-hour ozone standard, it continues to be exceeded frequently in central California, and the prediction of attainment for the San Joaquin Valley by 1999, based on modeled forecast of emissions in 1994 (SJVUAPCD, 1994), has fallen far short of expectations.

Retrospective analyses of O₃ data (details in Section 2) have also shown disparate progress toward attainment of ozone standards within northern and central California with greater reductions in ozone within coastal urban areas than in the Central Valley. In addition, the data show larger downward trends in 1-hour-average peak O₃ concentrations¹ and less progress in reducing the frequency of exceedances of the state 1-hour standard (0.09 ppm) and the pending federal 8-hour ozone standard². In addition to areas that are currently in nonattainment of the 1-hour ozone standard, several areas in central and southern Sierra Foothills and northern Sacramento Valley that are now in compliance of the 1-hour standard are also expected to become nonattainment for the 8-hour standard. The state 1-hour and pending federal 8-hour ozone standards will require a reappraisal of past strategies that have focused primarily on addressing the urban/suburban ozone problem to one that considers the problem in a more regional context. Although the recent court action prohibits EPA from enforcing the 8-hour ozone standard, the ruling did not remove the standard. Pending the likely appeal by EPA and its ultimate outcome, the current 1-hour ozone standard continues to apply in areas that have not attained the standard.

1.1 Introduction

The Central California Ozone Study (CCOS) is intended to provide another milestone in the understanding of relationships between emissions, transport, and ozone standard exceedances, as well as to facilitate planning for further emission reductions needed to attain state and federal ozone standards. The CCOS is being proposed to gather aerometric and emissions databases for modeling and to apply air quality models for the attainment demonstration portion of the SIP for the federal 8-hour and state 1-hour ozone standards. The modeling domain for CCOS will cover all of central California and most of northern California,

¹ In this report, the term concentration refers to mixing ratios by volume.

² The new standard will be attained when the 3-year average of the annual 4th highest daily maximum 8-hour concentration is less than or equal to 0.08 ppm.

extending from the Pacific Ocean to east of the Sierra Nevada and from Redding to the Mojave Desert. CCOS is an integrated effort that includes air quality and meteorological field measurements, emissions characterization, data analysis and air quality modeling.

The CCOS field measurement program will be conducted in the summer of 2000 in conjunction with the California Regional PM₁₀/PM_{2.5} Air Quality Study (CRPAQS), a major study of the origin, nature and extent of excessive levels of fine particles in central California (Watson et al, 1998). The CRPAQS includes air quality and meteorological field measurements, emissions characterization, data analysis and air quality modeling. The CRPAQS field study will consist of a long-term campaign from 12/1/99 through 1/31/01, a winter intensive study within the period of 11/15/00 through 1/31/01, and a fall intensive study within the period of 9/1/00 through 10/31/00. Several experiments will be conducted during the summer period of 7/1/00 through 8/31/00. These include chemical characterization of PM_{2.5} at the Fresno site to estimate the fraction of fine particles that is attributable to secondary organic aerosol and source contributions of directly-emitted fine particles. Other experiments will examine the timing and intensity of light extinction in the San Joaquin Valley and the Mohave Desert. The baseline measurements for CRPAQS, which will begin in December 1999 and continue to the end of the study, are incorporated and leveraged into the CCOS field program. These include six upper-air meteorological measurement sites within the CCOS domain. Opportunities for cost sharing also exist for purchases of instruments that are needed for both CCOS and the CRPAQS winter intensive study (e.g., NO₂, PAN, and NO_y³ and continuous particulate nitrate). CCOS will also benefit from measurements that are available throughout the study region from existing federal, state, local, and private air quality and meteorological monitoring programs.

The CCOS is directed by a technical committee that comprises staff from the California Air Resources Board (ARB), the California Energy Commission (CEC), local air pollution control agencies, industry, and other sponsoring organizations with technical input from a consortium of university researchers in California and the Desert Research Institute (DRI). The CCOS program plan consists of this conceptual program plan (Volume I) and an operational program plan (Volume II), which will be available by April, 2000. These documents correspond to the two phases of the planning process for CCOS. Parallel efforts are also underway to develop a broad conceptual model of ozone formation in central California based on SARMAP and other relevant studies and a “comprehensive” study plan that addresses the long-term research needs related to the ozone problem in central California (Roth, 1999a and 1999b).

The CCOS conceptual program plan describes the goals and technical objectives that will be addressed by the study and describes alternative experimental, modeling, and data analysis approaches for addressing the study objectives. This introductory section provides an overview of the study, which includes the background and rationale for the proposed study, statements of study goals and technical objectives, and a summary of the proposed field measurement program. Chapter 2 presents a summary of the current knowledge of the relationship between meteorology, emissions, chemical and physical transformation, and ozone concentrations in northern and central California. It also reviews the results from prior SAQM modeling, and

³ Reactive oxidized nitrogen (NO_y) include nitric oxide (NO), nitrogen dioxide (NO₂), nitrous acid (HONO), peroxyacetic acid (HNO₄), nitrate radical (NO₃), nitrate aerosol (NO₃-), dinitrogen pentoxide (N₂O₅), nitric acid (HNO₃), peroxyacetylnitrate (PAN) and other PAN analogues, and organic nitrates (ORNI).

identifies the remaining uncertainties and their implications for the design of the CCOS field measurement program. Section 3 describes the requirements for the modeling and data analysis approaches that are proposed to address CCOS technical objectives. Section 4 specifies the base and optional CCOS measurements that are recommended to meet the requirements of modeling and data analysis. It considers the merits of alternative measurement approaches and explains the rationale and criteria for measurement decisions. Details of the measurements are contained in three appendices. Appendix A describes the existing meteorological and air quality measurement networks and details of the supplemental measurements proposed for CCOS (e.g., measurement method, precision, and accuracy). Appendix A1 provides a list of volatile organic compounds that are recommended for identification and quantification as part of the chemical characterization of ozone precursors. Appendices B and C describe the required quality assurance and data management activities for the study, respectively. Section 5 provides the corresponding budget estimates and Section 6 defines the program management and schedule.

1.2 CCOS Goals

The CCOS has the following goals.

1. Obtain suitable aerometric and emission databases to update, evaluate, and improve model applications for representing urban and regional-scale ozone episodes in central and northern California to meet the regulatory requirements for the state 1-hour and pending federal 8-hour ozone standards.
2. Determine the contributions of transported and locally generated ozone and the relative benefits of volatile (VOC) and nitrogen oxide (NO_x) emission controls in upwind and downwind areas. Assess the relative contributions of ozone generated from emissions in one air basin to federal and state exceedances in neighboring air basins.

These goals are to met through a process that includes analysis of existing data; execution of a large-scale field study to acquire a comprehensive database to support modeling and data analysis; analysis of the data collected during the field study; and the development, evaluation, and application of an air quality simulation model for northern and central California. Although air quality simulation modeling may be used to address both CCOS goals, past experience has demonstrated the need for thorough diagnostic analyses to assess the reliability of model outputs.

Despite efforts to improve models during the past two decades, significant questions remain in both model formulation and input data. Uncertainties in the estimation of emissions are believed to be the major limitation to producing reliable air quality model results. Studies during the past twelve years have shown that on-road reactive organic gases (ROG) and CO emissions have been historically underestimated (e.g., Ingalls, 1989; Pierson et al., 1990; Fujita et al., 1992). Sensitivity studies also showed that model performance was greatly improved when the base on-road motor vehicle ROG emissions were increased by substantial margins (Wagner and Wheeler, 1993; Chico et al., 1993; Harley et al., 1993). Gaps in model formulation that fail to treat certain chemical and physical processes adequately are additional limitations. Boundary-layer parameterizations that determine the rates of dilution and mixing, and the origin and evolution of ozone layers aloft are examples of such gaps. Other limitations include insufficient spatial and temporal data to adequately specify boundary conditions and photolytic

rate parameters. Despite the limitations imposed by model uncertainties, air quality models remain the only acceptable tools available for quantitatively estimating the effect of control measures on future air quality.

The reliability of model outputs is assessed through operational and diagnostic evaluations and application of alternative diagnostic tools. Operational evaluations consist of comparing concentration estimates from the model to ambient measurements. The level of confidence that can be developed from this type of evaluation increases with the number and variety of episodes and chemical species that are examined. Measurements of the three-dimensional variations in ozone and ozone precursors also enhance the utility of the evaluations. Diagnostic evaluations determine if the model is estimating ozone concentrations correctly for the right reasons by assessing whether the physical and chemical processes within the model are simulated correctly. Examples of diagnostic tests include examining ratios of chemical species that are sensitive to specific processes within the model such as O_3/NO_y , O_3/NO_z , examining the flux of ozone and ozone precursor across interbasin transport corridors, and comparing concentration changes from weekdays to weekends.

One of the most important tests of model simulations is the ability to simulate accurately weekday-weekend differences in precursors and ozone. Since the mid-1970's it has been documented that ozone levels in California's South Coast Air Basin (SoCAB) are higher on weekends than on weekdays, in spite of the fact that ozone pollutant precursors are lower on weekends than on weekdays (Elkus and Wilson, 1977; Horie et al., 1979; Levitts and Chock, 1975; Zeldin et al., 1989; Blier and Winer, 1998; and Austin and Tran, 1999). Similar effects have been observed in San Francisco (Altshuler et al., 1995) and in the northeastern cities of Washington D.C., Philadelphia, and New York (SAIC, 1997). While a substantial "weekend effect" has been observed in these cities, the effect is less pronounced in Sacramento (Austin and Tran, 1999), and is often reversed in Atlanta (Walker, 1993) where VOC/NO_x ratios are typically higher. Several of the above studies show that the "weekend effect" is generally less pronounced in downwind locations where ambient VOC/NO_x ratios are higher.

In past air quality modeling performed in Southern California and elsewhere, the measured 6 to 9 a.m. ambient VOC/NO_x ratios were substantially higher than the corresponding ratios derived from the modeling inventory. Such discrepancies have important implications for model predictions for the consequence of VOC versus NO_x controls. Depending upon the relative concentrations of VOC and NO_x and the specific mix of VOC present, the rate of O₃ formation can be most sensitive to changes in VOC alone or to changes in NO_x alone or to simultaneous changes in both VOC and NO_x. Understanding the response of ozone levels to specific changes in VOC or NO_x emissions is a fundamental prerequisite to developing a cost-effective ozone abatement strategy. The varying emissions that occur between weekday and weekend periods provide a natural test case for air quality simulation models. At the same time, the model performance and evaluation must be accompanied by an evaluation of the accuracy of the temporal and spatial patterns of precursor emissions. With the questions that still remain regarding the accuracy of emission inventories, the "weekend effect" emphasizes the need for observation-based data analysis to examine the relationship between ambient O₃ and precursor emissions. The results of corroborative data analyses need to be reconciled with model outputs taking into consideration the various sources of uncertainties associated with both approaches.

1.3 CCOS Technical Objectives

The study design and experimental approach for CCOS are defined in terms of specific technical objectives. These objectives fall into four categories: (A) planning and preparation; (B) emission inventory development, (C) modeling, and (D) data analysis. A number of tasks are required to meet each of the technical objectives. These tasks are listed in this section and are described in greater detail in Section 3 (data requirements) and Section 4 (field measurement program).

1.3.1 Objectives A - Planning and Preparation for the CCOS Field Study

Objective A-1. Develop a technically and scientifically defensible experimental design based on the goals and objectives of the sponsoring organizations and current conceptual understanding of the chemical and meteorological conditions that are conducive to violations of the state 1 hour and federal 8-hour ozone standards in central California.

- a. Update current bibliography, and review and summarize the literature on emissions, meteorology, ozone formation, and transport in central California and identify gaps in current knowledge with respect to the questions posed.
- b. Summarize existing monitoring data in central California with respect to locations and frequency of exceedances of the threshold value for the state 1-hour and pending federal 8-hour ozone standards.
- c. Review and evaluate past SIP modeling projections of air quality for the San Francisco Bay Area, the San Joaquin Valley, and the Sacramento Valley to ascertain the causes of biases in estimates of air quality improvements. Estimate the contributions to biases in air quality projections.
- d. Formulate specific questions to be answered by the CCOS field measurement program. Prioritize these questions according to their importance in meeting the objectives of compiling a database for grid-based modeling and improving understanding of the atmospheric processes that affect surface and aloft ozone mixing ratios.
- e. Identify meteorological scenarios related to exceedances of the 8-hour ozone standard and specify the characteristics of episodes for which monitoring would be sought as part of CCOS, and outline a strategy for forecasting these episodes based on existing data acquisition.
- f. Survey existing and planned quantitative modeling and data analysis approaches and determine the additional information needed to improve, evaluate, and apply them.
- g. Summarize and evaluate existing, long-term measurement networks in central California consider the need for supplemental measurements of surface and aloft concentrations of ozone, ozone precursors and reaction products and reactive intermediates to adequately characterize their three-dimensional distribution within the CCOS modeling domain.

Consider alternative measurement methods with respect to temporal and spatial resolution, precision and accuracy, and cost.

- h. Review and determine the applicability of existing surface and upper-air meteorological measurements (e.g., ARB, APCD, and military) and planned CRPAQS meteorological measurements toward achieving the technical objectives of CCOS. Consider supplemental surface and upper-air meteorological measurements needed to adequately characterize the main air flow patterns in the CCOS domain.
- i. Evaluate potential measurement methods with respect to required averaging times, duration, detection limits, accuracy, precision, validity, and cost-effectiveness. Determine which observables can be measured continuously and which require integrated samples that are submitted to off-site laboratory analysis. Relate each measurement to its intended use in a modeling and/or data analysis activity.
- j. Define steps for appropriate quality control/quality assurance in order to produce data of specified completeness, validity, accuracy and precision. Articulate the appropriate levels of funding required for the necessary components of quality control/quality assurance (QC/QA), database management and data archival.
- k. Estimate costs for each element of the conceptual plan and summarize the rationale and justification for their inclusion in the final network design in order to facilitate consideration by the CCOS Technical Committee of program options and tradeoffs.
- l. Prepare and post the conceptual program plan, in PDF format, to the CCOS web site.

Objective A-2. Prepare the CCOS operational program plan and field operations protocol, make contractual arrangements with measurement groups, and conduct preliminary evaluations of measurement methods and forecast protocol.

- a. Prepare and issue requests for proposals for CCOS field measurements, as necessary, and make contractual arrangements with measurement groups. Identify coordinators for quality assurance and data management.
- b. Evaluate the accuracy, precision and validity of measurement methods that have not been sufficiently tested under either laboratory or field conditions. Such methods include continuous NO₂ and PAN measurement by gas chromatography (GC)/Luminol and continuous HCHO measurements. Assemble and evaluate the accuracy and precision of an automated GC/ion trap mass spectrometry (MS) and develop a calibration library for identification and quantitation of VOC species of interest. These preparations should begin by fall, 1999.
- c. Set up a forecast system to identify potential study days that meet preselected criteria and maintain daily contact with the study management for selection of sampling days. Design a protocol for handling the scheduling of intensive measurement periods. Specify the episode forecasting method that will be implemented and identify how go/no go decisions will be made and disseminated to project participants.

- d. Arrange for the acquisition of new air quality measurement sites. Ensure compliance with applicable siting criteria in the network design plan. Document the site with GPS data, digital images, and perform a video survey of each new site and enter site information into the field operations protocol. Determine the needs and costs for permits, indemnification/insurance requirements, compliance with environmental and safety laws, water, power, air conditioning, and sanitary facilities, and additional structures to accommodate added sampling equipment.
- e. Prepare an operational program plan and field operations protocol that specifies the details of the field measurement program that will allow the study plan to be executed with available resources. It identifies measurement locations, observables, and monitoring methods. It specifies data management and reporting conventions and outlines the activities needed to ensure data quality. The field operations protocol is a short document that serves as the guide for those in the field. It is a concise overview of the field study, enumerating the most pertinent information needed by those conducting the measurements. Post the operational plan and field operations protocol, in PDF format, to the CCOS web site by April 2000.
- f. Conduct a workshop in May 2000 in Sacramento with ARB and district staff, measurement contractors, and other study participants to orient them to the elements in the plan and their responsibilities as members of the project team. Review the draft field operations protocol with the project team, and reconcile any discrepancies between the protocol and measurements planned by study participants. Ensure that potential cross-contamination between measurements is eliminated. Confirm schedules and protocols, and identify potential logistical problems and develop appropriate action plans for their resolution.

1.3.2 Objectives B - Emission Inventory Development

The emission inventory needed to support the CCOS modeling will be a series of day-specific, hourly, gridded emission inventories that cover each day of the ozone episodes captured during the field study. There are about 30 districts in the CCOS modeling domain. Each local air district in the state updates a portion of the emission inventory for their area. To help coordinate this effort, the Emission Inventory Coordination Group (EICG) has been established to determine the process for preparing the emission inventories needed to support air quality modeling for CCOS. Participants in the group include many local air districts, several local councils of government, Caltrans, California Energy Commission, and the ARB. Local air districts participating to date include San Joaquin Valley Unified APCD, Bay Area AQMD, Sacramento Metropolitan AQMD, Mendocino County AQMD, Northern Sierra AQMD, Yolo-Solano AQMD, Placer County APCD, San Luis Obispo County APCD, and Monterey Bay Unified APCD. Other local air districts will also be participating. See Section 3.1.2 for details.

Objective B-1. Prepare day-specific, hourly, gridded emission inventories that cover each day of the ozone episodes captured during the CCOS field study.

- a. Develop a “fast-track” spatially and temporally resolved inventory of emission estimates of ROG, NO_x, and CO for the CCOS domain for summer 2000 for preliminary modeling.

- b. Update the “fast-track” with day-specific information collected during the CCOS study (see Objective B-2).
- c. Project the effects of future activity and alternative controls on emission estimates and develop a spatially and temporally resolved inventory for future year simulation.

Objective B-2. Collect day-specific emissions data to update the “fast-track” inventory to more accurately determine the spatial and temporal distribution of emissions from motor vehicles and other area sources.

- a. Integrate transportation data for CCOS domain and run DTIM for entire modeling domain. Create gridded, hourly emission estimates of NO_x, TOG, CO and PM for on-road mobile sources.
- b. Develop base year and future year gridding surrogates for spatial distribution of stationary area source categories.
- c. Compile biomass and emission factor data for major plant species in the Central Valley and Bay Area for use in GIS-based biogenic inventory for the CCOS modeling domain.
- d. Collect day-specific emission data for wildfires, controlled burns, and agricultural burns.
- e. Develop point and area source emission inventories for smaller air pollution districts.

Objective B-3. Evaluate the validity of emission inventory estimates. See objective D-4 under data analysis and Section 3.2.2 for descriptions of related tasks.

1.3.3 Objectives C - Preparation, Execution and Evaluation of Air Quality Simulation Models

ARB will analyze the data collected during the CCOS field measurement program and will select a minimum of three ozone episodes to simulate. This work will be conducted by ARB staff (in-kind resources). Assistance will be sought from air districts to develop day-specific emission inventory as well as additional simulation days. See Section 3.2 for details.

Objective C-1. Apply air quality models for the attainment demonstration portion of the SIP for the proposed 8-hour and state 1-hour ozone standards.

- a. Select the most suitable model(s) for representing photochemical air pollution in central and northern California.
- b. Specify model domain boundaries, boundary conditions, initial conditions, chemical mechanisms, grid sizes, layers, and surface characteristics.
- c. Identify performance evaluation methods and performance measures, and specify methods by which these will be applied.

- d. Evaluate the results of the meteorological model (see Section 3.2.1 for list of evaluation checks).
- e. Perform operational evaluation of the air quality model (see Section 3.2.3)
- f. Apply simulation methods to estimate ozone concentrations at receptor sites and to test potential emissions reduction strategies. Evaluate and improve the performance of emissions, meteorological, and air quality simulations.
- g. Identify the limiting precursors and assess the extent to which reductions in volatile organic compounds and nitrogen oxides, would be effective in reducing ozone concentrations.

Objective C-2. Determine the relative contributions of ozone generated from emissions in one basin to federal and state exceedances in neighboring air basin.

- a. Characterize the structure and evolution of the boundary layer and the nature of regional circulation patterns that determine the transport and diffusion of ozone and its precursors in northern and central California.
- b. Identify and describe transport pathways between neighboring air basins, and estimate the fluxes of ozone and precursors transported at ground level and aloft under differing meteorological conditions.
- c. Determine the contribution of ozone generated from emissions in one basin to federal and state exceedances in neighboring air basin through emission reduction sensitivity analysis.

Objective C-3. Provide improve understanding of the role of thermal power plant plumes in contributing to regional air quality problems in central California.

- a. Provide operational evaluation of a state-of-the-science reactive plume model component using data collected during the CCOS field study.
- b. Using the modeling system developed by CCOS, provide a technical analysis appropriate to support the development of interbasin/interpollutant offset rules that could be applied to the central California region.
- c. Run model simulations to estimate the air quality implications of different energy policies.

Objective C-4. Assess the reliability associated with air quality model inputs and formulation, and reconcile model results with observation-based and other data analysis methods.

- a. Perform diagnostic evaluation of model results (see Section 3.2.3)
- b. Quantify the uncertainty of emissions rates, chemical compositions, locations, and timing of ozone precursors that are estimated by emission models.

- c. Quantify the uncertainty of meteorological and air quality models in simulating atmospheric transport, transformation, and deposition.

1.3.4 Objectives D - 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. Section 3.3 provide details of tasks that address data analysis objectives.

Objective D-1. Determine the accuracy, precision, validity, and equivalence of CCOS field measurements.

- a. Evaluate the precision, accuracy, and validity of PAMS and CCOS supplemental VOC measurements.
- b. Evaluate the precision, accuracy, and validity of equivalence of nitrogenous species measurements.
- c. Evaluate the precision, accuracy, validity, and equivalence of surface and upper-air meteorological data.
- d. Evaluate the precision, accuracy, validity, and equivalence of solar radiation data.

Objective D-2. Determine the spatial, temporal, and statistical distributions of air quality measurements to provide a guide to the database and aid in the formulation of hypotheses to be tested by more detailed analyses.

- a. Examine average diurnal changes of surface concentration data.
- b. Examine spatial distributions of surface concentration data.
- c. Examine statistical distributions and relationships among surface air quality measurements.
- d. Examine vertical distribution of concentrations from airborne measurements.
- e. Examine the spatial and temporal distribution of solar radiation.

Objective D-3. Characterize meteorological transport phenomena and dispersion processes. Examine the mechanisms for the movement of air into, out of, and between the different air basins in both horizontal and vertical directions. Determine occurrence, spatial extent, intensity, and variability of phenomena affecting horizontal transport (low-level jet, slope flows, eddies, coastal meteorology and bifurcation) and vertical transport (convergence and divergence zones).

Characterize the depth, intensity, and temporal changes of the mixed layer and characterize mixing of elevated and surface emissions.

- a. Determine horizontal transport patterns and intensities into, out of, and within the air basins.
- b. Determine vertical transport patterns and intensities within the modeling domain.
- c. Characterize the depth, intensity, and temporal changes of the mixed layer and characterize mixing of elevated and surface emissions.

Objective D-4. Reconcile emissions inventory estimates with ambient measurements and “real-

- a. Compare proportions of species measured in ambient air and those estimated by emission inventories for reactive and nonreactive species.
- b. Estimate source contributions by Chemical Mass Balance using measured and predicted ambient VOC composition.
- c. Conduct on-road remote sensing measurements of CO, HC, NO_x and (PM if available) in Sacramento, Fresno, and the San Francisco Bay Area, and evaluate the effects of cold-starts, grade and geographic distribution of high-emitting vehicles.
- d. Determine effects of meteorological variables on emissions rates.
- e. Determine the detectability of day-specific emissions (e.g., fires) and variations in emissions between weekday and weekend.

Objective D-5. Characterize pollutant fluxes between upwind and receptor areas. Examine the orientations, dimensions, and locations of flux planes by using aircraft spiral and traverse 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.

- a. Define the orientations, dimensions, and locations of flux planes.
- b. Estimate the fluxes and total quantities of selected pollutants transported across flux planes. Test following hypotheses: 1) whether there is significant local generation of pollutants; 2) whether there is significant dilution within or turbulent exchange through the top of the mixed layer; and 3) whether there is substantial transport or dilution owing to eddies, nocturnal jets, and upslope/downslope flows.

Objective D-6. Characterize chemical and physical interactions in the formation of ozone.

- a. Examine VOC and nitrogen budgets as functions of location and time of day.
- b. Reconcile the spatial, temporal, and chemical variations in ozone, precursor, and end-product concentrations with expectations from chemical theory.

- c. Apply observation-based methods to determine where and when ozone concentrations are limited by the availability of NO_x or VOC.

Objective D-7. Characterize episodes in terms of emissions, meteorology, and air quality and determine the degree to which each intensive episode is a valid representation of commonly occurring conditions and its suitability for control strategy development.

- a. Describe each intensive episode in terms of emissions, meteorology, and air quality.
- b. 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.

Objective D-8. Reformulate the conceptual model of ozone formation in the study domain using the results yielded by the foregoing data analyses. Examine the formulation, assumptions, and parameters in mathematical modules in the air quality model with respect to their consistency with reality.

1.4 Summary of the Preliminary Conceptual Explanation of Ozone Exceedance in Central and Northern California

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 Sections 2.3, 2.5 and 2.7). 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 the development of this study 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 has been formed to generate, at a minimum, a small set of qualitative scenarios to aid in the development of the CCOS study plan, and to link these scenarios to objective analysis.

The identification of meteorological scenarios is an on-going task of the CCOS Meteorological Working Group. Progress to date is summarized here and in Section 2.5. Ozone season days, May 1 – October 31, have been classified for three recent seasons, 1996-1998, using two complementary approaches. The first is a top-down approach using inspection of 500-mb weather maps to establish gross features and to classify all 552 subject days into eight categories, including 2-4 subcategories for six of the eight scenarios. These are presented here in the approximate order of decreasing ozone impact:

1. Western U.S. Hi – Upper-level high centered over the Western U.S.
2. Eastern Pacific Hi – Upper-level high centered off the Western U.S. coast

3. Monsoonal Flow – Upper-level high centered in the south-western U.S. or in northern Mexico such that southerly flow brings moisture north
4. Zonal Flow – West-to-East
5. Pre-Frontal – Front approaching from northwest brings southwesterly flow
6. Trough Passage – Upper-level trough moves through California, usually ventilating Central California.
7. Continental Hi – Northerly wind with no marine component, more typical in winter
8. El Nino Cut-off Lo – A special class for 1997 where a cut-off low sat just off the southern California coast for several days.

The Western U.S. High accounts for proportionately the greatest number of exceedances. As shown in Table 2.5-3, 97% of days with highs centered over southern California have 8hr exceedances in the Central San Joaquin Valley, where the frequency of exceedances on all 1996-98 ozone season days is 42%. The Western U.S. High contributes to stagnation conditions throughout central California by fostering an off-shore gradient which weakens (and in some cases even reverses) the usual sea breeze. Compared to a more vigorous sea breeze scenario like the Eastern Pacific High, this tends to keep pollutants longer within respective source regions, although some transport can still occur with the delayed and/or weakened sea breeze, the reversed flow, or other thermally driven mesoscale features. The SFBA has 8hr exceedances on 29% of days when the Western U.S. High is centered over the Pacific Northwest, while the frequency of 8hr exceedances on all 1996-98 ozone season days is only about 4%. This scenario also provides abundant sunlight and the greatest subsidence inversion to reduce mixing heights and trap pollutants vertically all over central California. Monsoonal flow can have both mitigating and exacerbating impacts on SJV air quality. Some monsoonal days are identified (e.g., 9/3/98), where SJV air quality is lower relative to the rest of Central California, but on other days, the southerly monsoonal flow can weaken the SJV exit flow through Tehachapi Pass. Zonal flow tends to increase synoptic forcing, and less ozone impact is seen in the northern portion of the study area, but the topography surrounding the SJV helps decouple the valley from the upper level winds, and many exceedances are observed in SJV for this scenario. The last four scenarios all help ventilate the Central Valley. There were no 1hr exceedances during any of the 142 out of 552 days studied (26%), although some 8hr exceedances are observed in the SJV and the Mountain Counties (MC) even with a trough passage.

While these results are conceptually helpful, interpretation and application of the top-down approach is limited due to the large scale of the eight classes that does not allow for adequate consideration of day-to-day atmospheric variability and of smaller mesoscale effects. Additionally, during the Western U.S. High, when synoptic forcing over central California is weakest, ozone concentrations are greatest, and mesoscale features which re-distribute ozone and precursors become most important. Subtle synoptic differences, fostering the formation and/or amplification of these features, are difficult to identify and classify.

The second approach uses a more objective technique of cluster analysis. Ozone data from the same three ozone seasons is employed to determine groupings of spatial patterns on

several very high ozone days selected by the local air quality districts. Despite some differences in the 8hr and 1hr results that are still being examined in the Meteorological Working Group, three clusters are found for both 1-hour and 8-hour exceedances:

Cluster 1 - The San Francisco Bay Area has its highest basin-wide ozone values, though still less in absolute magnitude than San Joaquin Valley. This cluster is characterized by the weakest sea breeze (lowest west-to-east component through Carquinez Strait), and the lowest Oakland inversion base heights. Among the cluster days, North Central Coast ozone is also highest during Cluster 1.

Cluster 2 - The San Joaquin Valley (SJV) has its highest basin-wide values while the Bay Area and Sacramento Valley are relatively cleaner. A stronger sea breeze, relatively to Cluster 1, keeps the pollutants moving through the Bay Area and the Sacramento Valley, but may increase transport into the SJV. Among the cluster days, Mountain Counties ozone is lowest during Cluster 2

Cluster 3 – Sacramento Valley has its highest basin-wide ozone values, as does the Mountain Counties Air Basin. As with Cluster 2, a stronger sea breeze is present, relative to Cluster 1, but surface temperatures in Sacramento Valley are significantly higher, indicating less and/or later intrusion of the sea breeze, allowing more time for photochemistry before evening transport to the Mountain Counties.

Figure 1.4-1 shows the average ozone for each clusters and for all 42 cluster days (Cluster 1- 22 days, Cluster 2 – 12 days, and Cluster 3 – 8 days). Days were selected from 1996-98 high-ozone episodes identified by local districts (see Section 2.5.4.3). Differences for SFBA are statistically significant for all three clusters and each is different from the mean. Differences for SV are statistically significant for all three clusters, but only 2 and 3 statistically differ from the mean. None of the clusters are significant for SJV due to less sea breeze penetration over the surrounding topography. This analysis shows the importance of the sea breeze in determining spatial distribution of ozone accumulation. When the sea breeze is inhibited, higher ozone levels occur throughout the study area, including the coastal regions. The San Joaquin Valley shows the least variation among the clusters owing to the combined effect of topography and greater distance from the coast, while Sacramento Valley shows more variation due to potential for greater influence of the marine intrusion.

Figures 1.4-2 through 1.4-7 illustrate the differences in the spatial patterns of ozone concentrations for these three clusters, for both 1hr (Figures 1.4-2, 4 and 6) and 8hr (Figures 1.4-3, 5, and 7) ozone maximums. Each figure displays the daily ozone maximum from 126 monitoring stations throughout the entire study region. More discussion is presented in Sections 2.3, 2.5 and 2.7, but some features are noted here.

- The SFBA had ozone on a par with the SJV (147 ppb at Concord and 145 ppb at Clovis in the SJV) on August 12, 1998, a Cluster 1 day. The hexagon and large circles represent exceedances of the 1hr standard. The upper Sacramento Valley was relatively clean with no state 1-hr or Federal 8-hr exceedances.

- On August 30, 1996, a Cluster 2 day, the SFBA and Sacramento Valley (SV) were relatively clean, but San Andreas registered a 138 ppb on the southeastern edge of the clean zone, whereas the northern Mountain Counties was clean like the SV. Arvin and Edison experienced 156 and 163 ppb respectively.
- An interesting feature on August 14, 1998, a Cluster 3 day, is the high 8-hr ozone values in the north Sacramento Valley. There were 8-hr exceedances downwind of Sacramento, but even higher 8-hr values of 110 ppb were present in Redding. An objective of this study is to determine the extent to which transport and local sources contribute to these increasingly frequent northern Sacramento Valley 8-hr exceedances.

1.5 Overview of CCOS Field Measurement Program

The CCOS 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.

The CCOS field measurement program will be conducted during a four-month period from 6/1/00 to 9/30/00 (*study period*). This period corresponds to the majority of elevated ozone levels observed in northern and central California during previous years. Continuous surface and upper-air meteorological measurements and surface 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. These 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.

Additional continuous surface air quality measurements will be made at up to three “research” sites during a shorter two-month study period from 7/1/00 to 8/31/00 (*primary study period*). These additional measurements include continuous, hourly surface air quality measurements include nitrogen dioxide (NO₂), peroxyacetylnitrate (PAN) and other peroxyacetylnitrates (PACN), particulate nitrate (NO₃⁻), formaldehyde (HCHO), volatile organic compounds. These measurements allow detailed examination of the day-to-day and day-of-the-week variations in carbon and nitrogen chemistry at a downwind location in San Francisco Bay Area, Sacramento, and Fresno where ozone formation may wither be VOC or NO_x limited depending upon time of day and pattern of pollutant transport. These data are needed to support emission evaluations and observation-based data analyses.

Additional data will be collected during ozone episodes (*intensive operational periods, IOP*) to better understand the dynamics and chemistry of the formation of high ozone concentrations. The base budget for CCOS allows for up to 18 days total for episodic measurements with option for 2 additional days of episodic measurements. With an average

episode of three to four days, five to six episodes are likely. These measurements include instrumented aircraft, speciated VOC, and radiosonde measurements, which are labor intensive and require costly expendables or laboratory analyses. IOPs will be forecast 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. These intensive measurements will be made on days leading up to and during ozone episodes and during specific ozone transport scenarios. The additional measurements are needed for operational and diagnostic model evaluation, to 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.

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 because boundary conditions, particularly for formaldehyde, can significantly affected model outputs. Boundary measurements will be made during both episode and non-episode days. Measurements are also needed to characterize the pollutant fluxes between upwind and receptor areas and the effects of elevated NO_x plumes on regional ozone problem.

1.5.1 Surface Air Quality and Meteorological Monitoring Sites (Section 4.4)

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, interbasin transport, intrabasin transport and source. Background sites intend to measure concentrations that are not influenced by northern and central California emissions. Interbasin transport sites are intended to evaluate concentrations along established or potential transport pathways between basins, including the Bay Area, the south central coast, the Sacramento Valley, the San Joaquin Valley, Mountain counties, the South Central Coast Air Basin, and the Mojave desert. Intrabasin gradient sites are located in non-urban areas between routine network sites. They are intended to evaluate the extent to which one urban area affects ozone concentrations in another urban area, as well as the extent to which urban contributions arrive at suburban and rural locations. Source sites are located 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.

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. 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.

Supplemental air quality measurement are required at several existing monitoring sites to increase the extent of chemical speciation and in key areas of the modeling domain where monitoring data does not exist. The measurements to be made at each of the supplemental monitoring sites are listed in Table 1.5-1.

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 18 IOP days (with option for 2 additional days) 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 18 IOP days (with option for 2 additional days) for C₁-C₇ carbonyl compounds by HPLC with UV detection.

Measurements of speciated volatile organic compounds (VOC) made under CCOS supplement the 11 existing Photochemical Assessment Monitoring Stations in the study area (four in Sacramento, four in Fresno, and three in Bakersfield. 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) are designed to determine whether ozone precursors immediately upwind of Redding are largely transported or are attributable to local sources. Similar transport issues are address by measurements in the foothill communities near Grass Valley and Sonora. One additional type 1 site is proposed at San Jose depending on available funding.

CCOS Type 2 Supplemental Monitoring Sites

Type 2 supplemental sites are located at the interbasin transport and intrabasin gradient sites. These sites are located near the downwind edge of the urban center 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 (e.g., TEI 42S) for new sites and with TEI42CY for existing monitoring sites with a NO/NO_x analyzer. Nitric acid can be estimated by difference between the signals with and without a NaCl impregnated fiber denuder.
4. Continuous NO₂ and peroxyacetyl nitrate (PACN) during primary 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 primary 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 18 IOP days (with option for 2 additional days) 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 18 IOP days (with option for 2 additional 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. One additional type 2 site is proposed downwind of Fresno at the Mouth of the Kings River and north of the Carizo Plain (between San Luis Obispo and the San Joaquin Valley) depending on available funding.

CCOS Research Sites

Research sites have the same site requirements as Type 2 supplemental sites. The sites are intended to measure a representative urban mix of pollutants, and must be carefully selected to minimize the potential influence of local emission sources. As with Type 2 supplemental monitoring sites, 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. Data will be collected during a minimum period of two months. 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 (e.g., TEI 42S) for new sites and with TEI42CY for existing monitoring sites with a NO/NO_x analyzer. Nitric acid can be estimated by difference between the signals with and without a NaCl impregnated fiber denuder.
4. Continuous NO₂ and PAcN during primary 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 primary 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 during primary study period 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. Semi-continuous particulate nitrate during primary study period by Aerosol Dynamics Inc. (ADI) automated particle nitrate monitor. The monitor uses an integrated collection and vaporization cell whereby particles are collected by a humidified impaction process, and analyzed in place by flash vaporization with quantitation of the evolved gases by chemiluminescent analyzer. A commercial unit is anticipated by next summer.
10. Continuous total light absorption by aethalometer and total light scattering by ambient integrating nephelometer during primary study period.
11. Continuous NO₂, HNO₃, HCHO and H₂O₂ on twenty IOP days by dual tunable diode laser absorption spectrometers at one of the research site.

12. Semi-continuous measurements of multi-functional carbonyl compounds on twenty IOP days by derivatization and analysis by GC/MS at one research site. (Contingent upon available funding)
13. Continuous HONO by Differential Optical Absorption Spectroscopy on twenty IOP days at one research site. (Contingent upon available funding).
14. Four 3-hour Tenax cartridge samples for up to 18 IOP days (with option for 2 additional days) for analysis C₈-C₂₀ hydrocarbons.

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 CCOS and thereafter.

Atmospheric chemistry measurements made at the University of Michigan Biological Research Station (UMBS) near Pellston, Michigan, under the Program for Research on Oxidants: PHotochemistry, Emissions and Transport (PROPHET) provide measurements that are highly complementary to CCOS (Carroll et al., 1998 <http://aoss.engin.umich.edu/PROPHET/>). Data were collected in summer 1997 and 1998, and a third field study is planned for 2000. The data set includes: continuous measurements of meteorological parameters, ultraviolet radiation, ozone, CO, peroxyacetyl nitrate (PAN), peroxypropionyl nitrate (PPN), peroxymethacrylic nitric anhydride nitrate (MPAN); simultaneous measurements of nitrogenous species, NO_x, NO_y, HONO, HNO₃ and organic nitrates; measurements of volatile organic compounds and organic peroxy radicals (RO_x); HO and HO₂ radicals; peroxides, and the physical properties and chemical composition of aerosol (Carroll et al., 1998). The PROPHET study provides a very complete data set from one site that can be used to develop and evaluate the chemical mechanisms used air quality models. CCOS, on the other hand, provides greater spatial coverage.

1.5.2 Surface Meteorological Network (Section 4.5)

The existing meteorological network in central California is extensive, but uncoordinated among the different agencies. Surface meteorological monitoring networks includes those operated by 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. Wind speed and direction, temperature, and relative humidity are the most common measurements. The network of 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 meteorological network will be augmented with the CCOS supplemental sites described above. 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. 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.

1.5.3 Upper Air Meteorological Network (Section 4.6)

Table 1.5-2 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.

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 ARB operates two profilers (with RASS) in the San Joaquin Valley, and the San Joaquin Unified APCD and Sacramento Metropolitan AQMD operate one profiler/RASS each as part of their PAMS monitoring program. Military facilities with operational profilers include Travis AFB, Vandenberg AFB, and the Naval Post Graduate School in Monterey. Because these profilers are operated by different entities, equivalent methods of data evaluation and reporting need to be established among these entities prior to CCOS field study. Six profiles/RASS will be installed and operational during summer 2000 as part of the CRPAQS. In addition, nine profilers/RASS and 5 sodars will be installed for the CCOS summer 2000 field study.

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. Radiosondes are routinely launched through the year at 0400 and 1600 PST from Oakland, with additional launches at Vandenberg, Edwards, and Pt. Mugu according to military mission requirements. None of these locations are within the Central Valley, so these will be supplemented by launches at Sacramento and in the southern San Joaquin Valley on 20 episodic days during summer with six radiosondes (with ozonesonde) releases per day. The 490 MHz RWP will be placed in the Fresno area to provide higher vertical sounding in the southern portion of the Central Valley.

1.5.4 Aloft Air Quality (Section 4.7 and 4.8)

In addition to the existing aloft measurements on fixed platforms that are part of the routine monitoring network (e.g., ozone on the Walnut Grove radio tower and Sutter Buttes) and the ozonesonde releases mentioned in the previous section, the following airborne platforms are recommended.

Instrumented aircraft will be used to measure the three dimensional distribution of ozone, ozone precursors, and meteorological variables. The aircraft will provide information about boundary concentrations, vertical concentration gradients, the mixed layer depth, and the spatial extent of some 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. Four aircraft are included in the base program.

Three 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. One aircraft is needed for the Bay Area and the northern San Joaquin Valley, a second aircraft for the Sacramento Valley and northern Sierra Nevada, and a third aircraft the San Joaquin Valley and southern Sierra Nevada. Onboard air quality instruments should have high sensitivity and fast response (e.g., modified TEI 42S for NO 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 may 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. One of these aircraft will also participate in characterizing flux-planes. This aircraft should have the capability to measure wind direction and speed.

A larger multi-engine aircraft is needed to document the horizontal and vertical gradients along the offshore boundaries of the modeling domain. This plane carries the same instrumentation as the smaller planes with the capability to measure wind direction and speed. 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 likely 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 western, overwater 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 during several spirals for the shoreline legs. Boundary measurements will be made during both non-episode and episode days. This plane will also participate in flux plane measurements.

Hydrocarbon samples are collected in stainless steel canisters and carbonyl samples are collected in Tedlar bags and transferred to dinitrophenyl hydrazine impregnated 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 and carbonyl samples are analyzed in the laboratory by HPLC with UV detection. The budget allows for collection and analysis of three sets of hydrocarbon and carbonyl samples per flight.

The specific flight plans will be developed over the next several months for the four aircraft under different meteorological scenarios. The above general description of flight patterns and objectives of each flight will be specified in the operational program plan. Aircraft that are available during the summer 2000 field study include two single-engine Cessna from UCD, twin-engine Aztec and up to two additional single engine aircraft by STI, NOAA Long EZ, and the NOAA Twin Otter.

1.5.5 Special Studies

In addition to the measurement described above, data are also needed to develop day-specific emissions data and to evaluate the validity of emission estimates as described under CCOS technical objectives B-2 and D-4, respectively. The following experiments are also required to address specific technical issues that cannot be fully address by the proposed CCOS monitoring program.

Contribution of Transported Pollutants 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.

In order to quantify pollutant transport and to provide data for modeling and data analyses, surface and aloft measurements are needed at locations where transport can occur and at the times when transport is occurring. These monitoring locations include in and near mountain passes, along coastlines, offshore, and at various locations in the downwind air basin. Aloft measurements made by instrumented aircraft are used to calculate transport across flux planes. Vertical planes, intersecting the profiler sites downwind of and perpendicular to the transport path, can be defined and provide estimates of transport through these passes using surface and aircraft measurements of pollutant concentrations and surface and wind profiler data for volume flux estimations.

Contributions of Elevated NO_x Sources to Downwind Ozone

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, question 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 ozone in downwind areas.

It is not clear that the treatment of plumes by state-of-the-art models is adequate. Vertical transport (e.g., plume rise and fall the plume during downwind transport) may not be adequately described. Recent power plant plumes 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. This

aircraft was considered as a study option, but budget constraints will prevent its use during CCOS. However, aircraft measurements of NO_x, ozone and VOC concentrations made in plumes are required to test the validity of the treatment of plume dispersion and chemistry and the procedures for terminating the plume into the regular model grid by plume-in-grid parameterizations.

Deposition Studies

During the California Ozone Deposition Experiment (CODE) in 1991, aircraft and tower-based flux measurements were taken over different types of San Joaquin Valley crops, irrigated and non-irrigated fields, and over dry grass. Estimates of ozone deposition velocities are 0.7-1.0 cm/s (Pederson et al. 1995). Order of magnitude calculations by Pun et al. show that dry deposition can be a few percent (~3-5%) of the total ozone budget in the San Joaquin Valley. However, modeling studies (Glen Cass, personal communication) have shown that dry deposition can play a more significant role in the budget of an important ozone precursor, NO₂. Three alternative deposition studies are described in this conceptual plan. Two are tower-based and could take advantage of the 100-m tower at Angiola planned for CRPAQS. The third is an aircraft flux measurement and could be used for a variety of different terrain types. The consensus view of the CCOS Technical Committee was that a proper study of atmospheric deposition would require far more funds than available within CCOS. Rather than dilute the CCOS effort, the Committee recommended that separate funding be sought for a comprehensive deposition study in the year 2001.

1.6 Funding

Cost estimates have been prepared for each element of the base and optional programs based on a consensus of the CCOS Technical Committee. Cost estimates are summarized in Table 5-1 for major components of the proposed measurement plan. The total contract costs for CCOS is \$6,100,000 for the base program and \$1,00,000 for optional elements for a total combined contract costs of \$7,100,000.

In addition to the above contract costs, the ARB and the local APCD's are committing in-kind resources for planning and execution of CCOS. In-kind costs include additional efforts that are specifically required during CCOS and does not include data collection and analysis associated with normal daily operations (e.g., PAMS and other aerometric monitoring programs). The in-kind costs total \$1,369,000, which does not include substantial leveraging of resources that will be available from CRPAQS.

**Table 1.5-1
Supplemental Surface Air Quality and Meteorological Measurements**

Site	Type *	Ozone & Surf Met	J _{NO2} and J _{O1D}	NO, NOx	NO, NOy TEI 42S	NOy, NOy-HNO ₃ TEI 42CY	NO ₂ , PAcNs by GC - Luminol	NO ₃ by flasher	NO ₂ , HNO ₃ TDLAS	H ₂ O ₂ , HCHO TDLAS	HCHO by AnalTech 9902P	CO, CO ₂ , CH ₄ , C ₂ -C ₁₂ can/GC-FID	C ₁ -C ₇ carbonyls DNPH-HPLC/U V	VOC by Auto-GC/Ion Trap MS	CO, CO ₂ TEI 48C	PM2.5 babs aeth	PM2.5 bscat neph
Point Arena	S1	a										c1	c1			CRPAQS	CRPAQS
South Central Coast	S1	a			a							c1	c1				
Anderson	S1	Shasta		Shasta	a							c1	c1				
Colusa	S1	ARB		ARB	a							c1	c1				
Turlock	S1	SJVU		SJVU	a							c1	c1				
Near Grass Valley	S1	N. Sierra		N. Sierra	a							c1	c1				
Sonora	S1	ARB		ARB	a							c1	c1				
Bethel Island	S2	BAAQMD		BAAQMD		a	b1				b1	c1	c1			CRPAQS	CRPAQS
Pacheco/Santa Nella	S2	a			a		b1				b1	c1	c1				
Altamont/Tracy	S2	a			a		b1				b1	c1	c1				
Angiola	S2	CRPAQS		CRPAQS		a	b1				b1	c1	c1			CRPAQS	CRPAQS
Edison	S2	ARB		ARB		a	b1				b1	c1	c1				
DW Fresno	R	a	a	SJVU?		a	b1	b1	b1	b1	b1	c2	c2	b2	a	CRPAQS	CRPAQS
DW Sacramento	R	a	a	ARB?		a	b1	b1			b1	c2	c2	b2	a	a	a
UW of Livermore	R	a	a	BAAQMD?		a	b1	b1			b1	c2	c2	b2	a	a	a
Optional																	
Mouth Kings River	S2	a			a		b1				b1	c1	c1				
Carizo Plain	S2	a			a		b1				b1	c1	c1				
San Jose	S1	BAAQMD		BAAQMD	a							c1	c1				

* Type 1 supplemental sites are located in background and emission source areas for boundary and initial conditions, transport assessment, and operational evaluation.

* Type 2 supplemental sites are located in interbasin transport and pollutant gradients areas for initial conditions, transport assessment, operational evaluation, and observation-based analysis of NOx and VOC limitations.

* Research sites are located at downwind edge of urban areas, and provide high time-resolution data at exposure, transport, and gradient sites for diagnostic evaluation of PAQSM and evaluation of emission inventory estimates.

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 (80 samples/site)

c2. Limited number of samples for comparison with automated GC/MS (10 samples/site).

**Table 1.5-2
CCOS Upper-Air Meteorological Measurements**

Name	Purpose	Operator ^a	Radar ^b	RASS ^b	Sodar ^{b,c}	Sonde ^{b,d}	
ABK	Arbuckle	Intrabasin Transport, Represents Predominant Summer Flow through Sacramento Valley	CCOS	SC	SC		
ABU	N. of Auburn, S. of Grass Valley	Upslope/Downslope Flow, Downwind of Major Source Area	CCOS	SC	SC		
ACP	Angel's Camp	Upslope/Downslope Flow, Complex Terrain for Challenging Model Evaluation	CCOS			SC	
ANGI	Angiola	Intrabasin Transport, Vertical Mixing, Micrometeorology	CRPAQS/ CCOS (sodar)	AC	AC	SC	
CRG	Corning	Northern Valley Barrier and Convergence Cone	CCOS	SC	SC		
EDI	Edison	Interbasin Transport through Tehachapi Pass	CRPAQS	AC	AC		
EDW	Edwards AFB	Interbasin Transport through Tehachapi Pass, Desert Mixed Layer, Synoptic Conditions, Downwind of	EAF			AS	
FAT	Fresno Air Terminal	Intrabasin Transport, Fresno Eddy, Major Source Area	CCOS	SC	SC	SC	
FSF	Fresno-First Street	Urban Heat Island, Intrabasin Transport, Synoptic Conditions. Major Source Area	CCOS			SE	
HUR	Huron	Intrabasin Transport, SJV Nocturnal Jet	ARB	AC	AC		
LGR	Lagrange	Upslope/Downslope Flow, Mariposa River Valley exit jet	CCOS	SC	SC	SC	
LHL	Lost Hills	Intra&Interbasin Transport across Carizo Plain	CRPAQS	AC	AC		
LIV	Livingston	Intrabasin Transport, mid-SJV Valley Axis Flow	CRPAQS/ CCOS (sodar)	AC	AC	SC	
MJD	Mojave Desert	Interbasin Transport, Downwind of southern SJV	CRPAQS	AC	AC		
MKR	Mouth Kings	Upslope/Downslope Flow	CRPAQS	AC	AC		
MON	Monterey	Onshore/Offshore Transport	USNPGS	AC	AC		
NTD	Point Mugu USN	Onshore/Offshore Transport, Synoptic Conditions	USN			AS	
OAK	Oakland airport	Onshore/Offshore Transport, Synoptic Conditions	NWS			AS	
POR	Point Reyes	On-Shore Flow, Along Coast Flow	CCOS	SC	SC		
RIC	Richmond	Onshore/Offshore Transport	CCOS/	SC	SC	AC	
SAC	Sacramento	Intrabasin Transport	SMAQMD/ CCOS (sondes)/ ARB (launches)	AC	AC	SE	
SMM	SanMartin	Intra&Interbasin Transport, Flow Through Santa Clara Valley	CCOS	SC	SC		
SNA	Santa Nella, E of I-5 to Los Banos	Interbasin Transport through Pacheco Pass	ARB	AC	AC		
TRA	Travis AFB	Interbasin Transport between Valley and Bay Area	TAF	AC			
TRC	Tracy, W of Tracy, S of I-205, W of I-580	Interbasin Transport through Altamont Pass	CCOS	SC	SC		
VBG	Vandenberg AFB	Onshore/Offshore Transport, Synoptic Conditions	VAF	AC		AS	
VIS	Visalia	Intrabasin Transport	SJVUAPCD	AC	AC		
Totals by Operator:			CCOS	9	9	5	2
			CRPAQS	6	6		
			ARB/Districts	4	4	1	
			Military/U.S.	3	1		4
			Grand Totals:	22	20	6	6

Footnotes

Optional RWP sites: Livermore, Salinas Valley, and Pleasant Grove (N of Sacramento).

^aCCOS=Central California Ozone Study (this study) ARB=Air Resources Board, 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; SMAQMD=Sacramento Metropolitan Air Quality Management District, CRPAQS=California Regional PM10/PM2.5 Air Quality Study; VAF=Vandenberg Air Force Base, TAF=Travis Air Force Base, EAF=Edwards Air Force Base, USN=U.S. Navy.

^bAC=Annual continuous measurements; AS=Annual sporadic measurements, SC=Summer continuous, 7/1/2000-9/30/2000;

SE=Summer episodic measurements on forecasted days.

^cSummer campaign sodar added at some sites are part of CCOS, except at RIC.

^dBalloon launch on episode days. Frequency should be 4-8 times per day but include 0700 and 1900 PST.

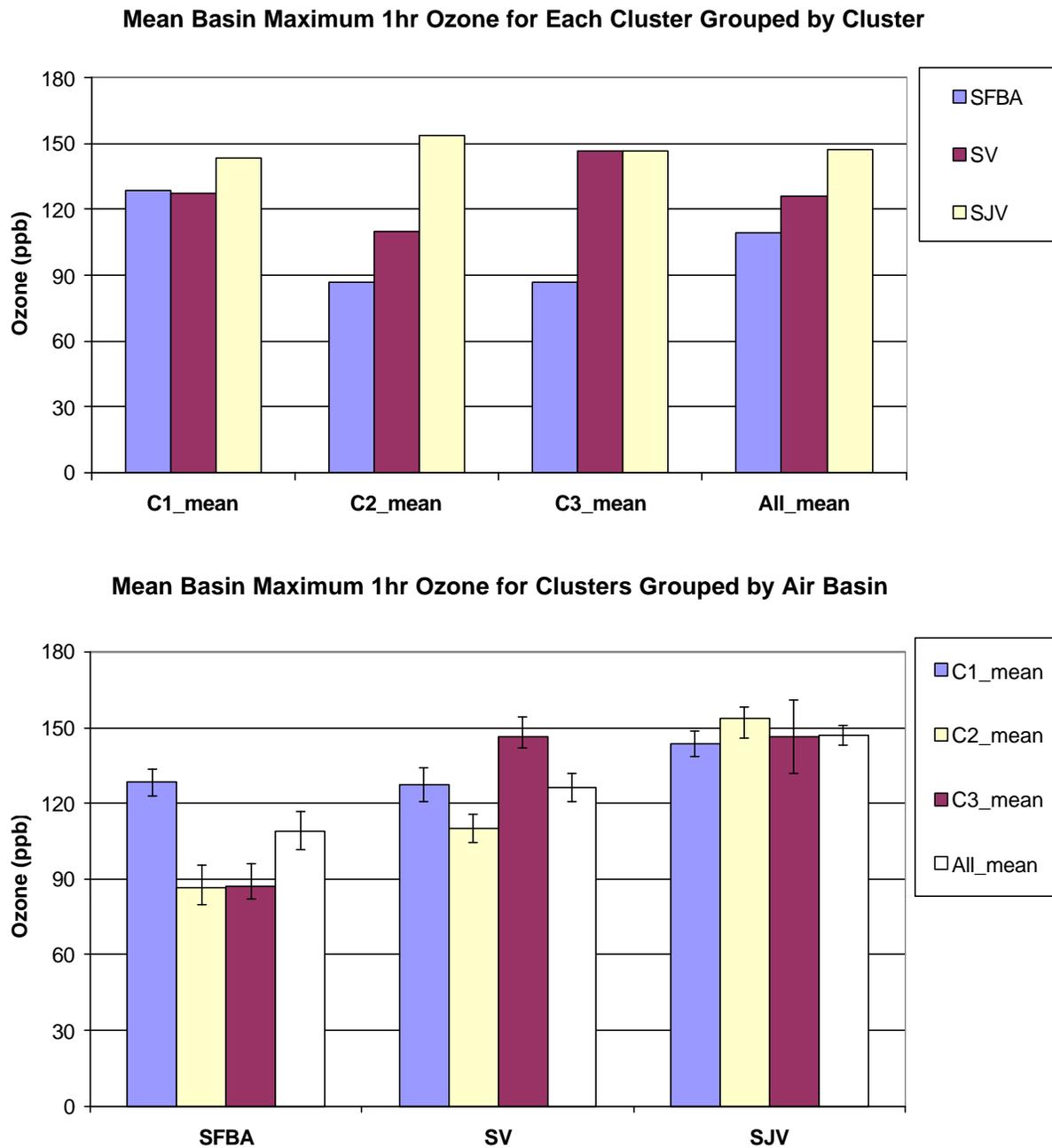


Figure 1.4-1. Mean basin maximum⁴ 1-hour ozone for each cluster grouped by cluster and grouped by air basin.

⁴ Average ozone for clusters and for all 42 cluster days (Cluster 1- 22 days, Cluster 2 – 12 days, and Cluster 3 – 8 days). Days were selected from 1996-98 high-ozone episodes identified by local districts (see Section 2.5.4.3). Differences for SFBA are statistically significant for all three clusters and each is different from the mean. Differences for SV are statistically significant for all three clusters, but only 2 and 3 differ from the mean. None of the clusters are significant for SJV due to less sea breeze penetration over the surrounding topography.

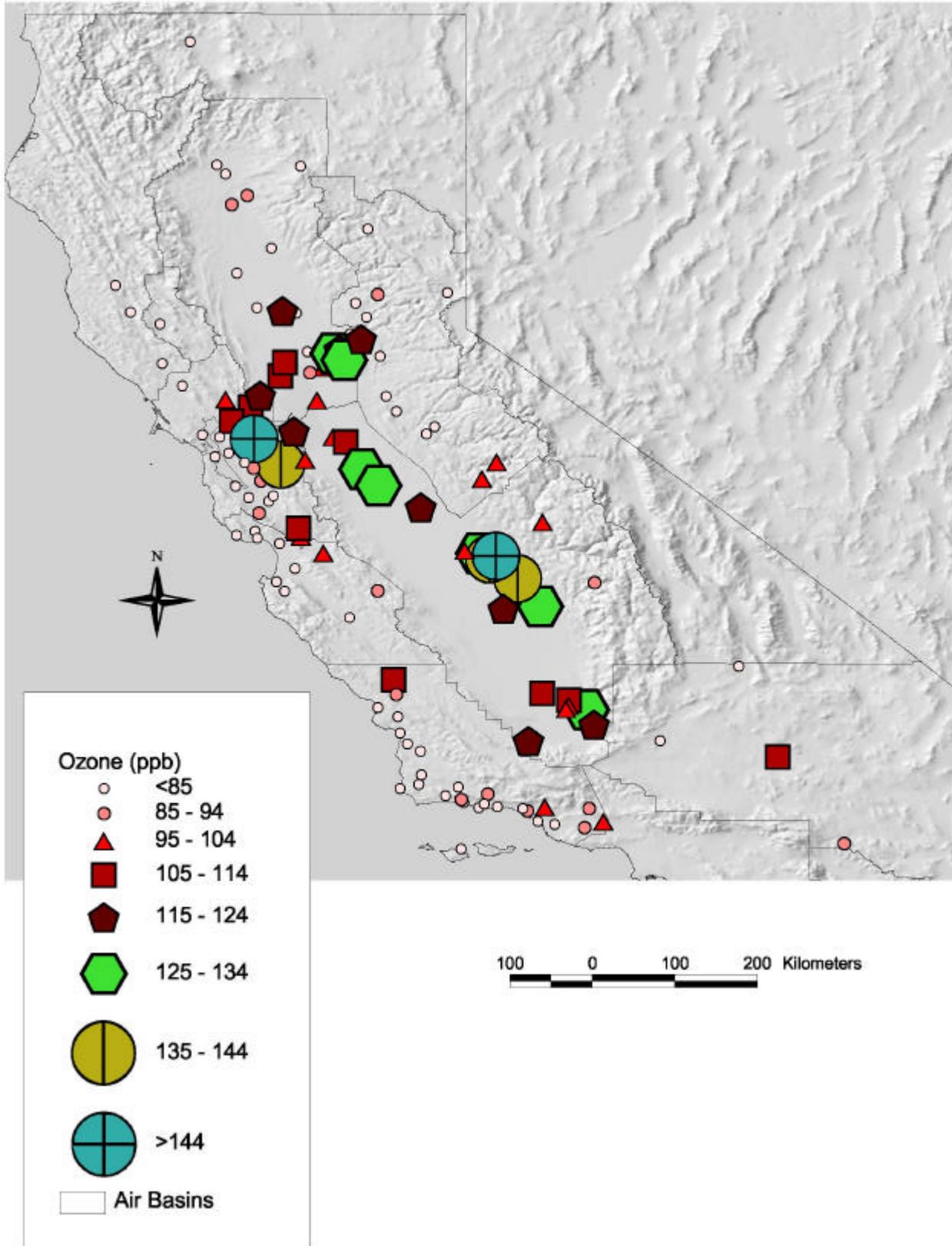


Figure 1.4-2. Maximum 1hr ozone for 126 monitoring stations on 8/12/98, a Cluster 1 Day.

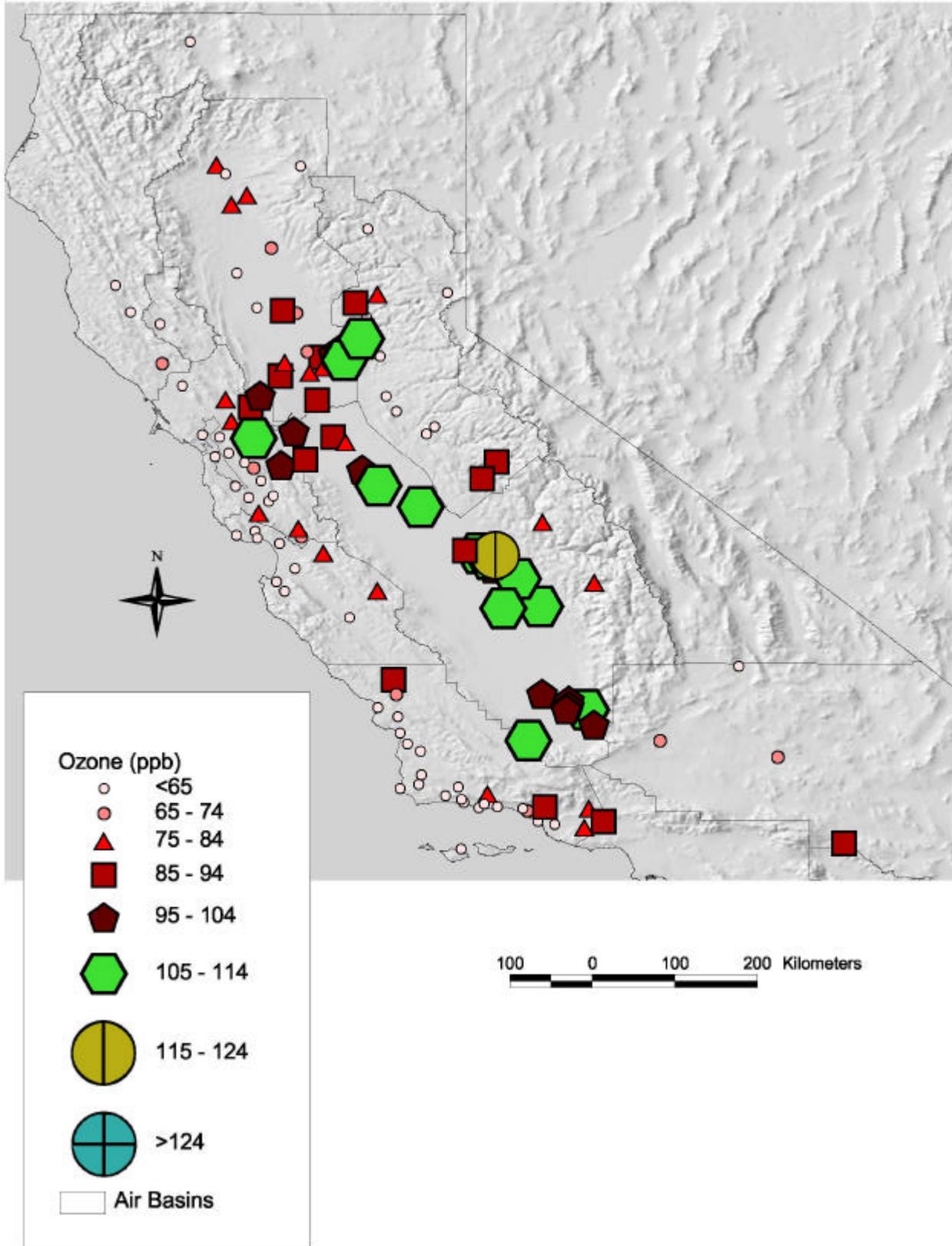


Figure 1.4-3. Maximum 8hr ozone for 126 monitoring stations on 8/12/98, a Cluster 1 Day.

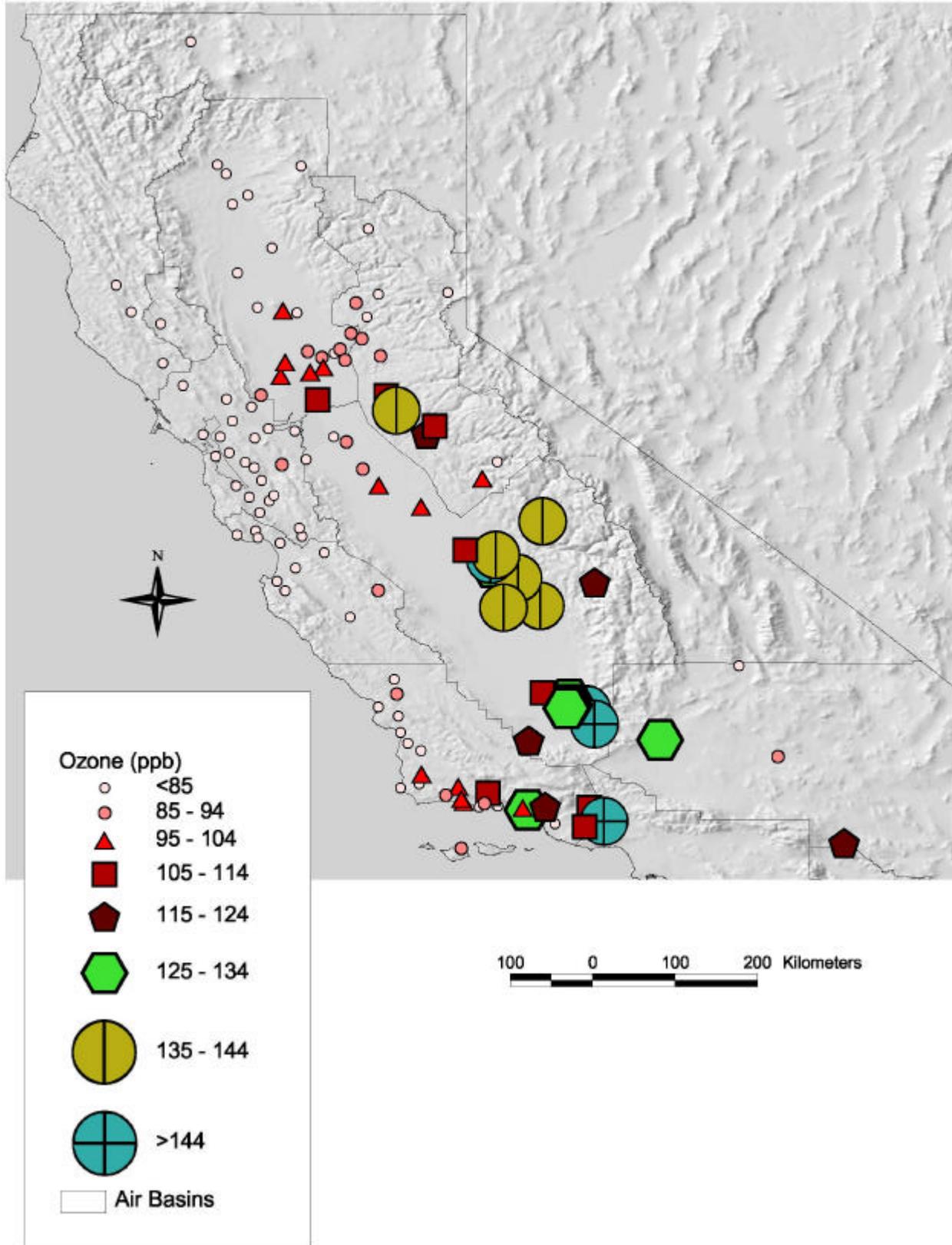


Figure 1.4-4. Maximum 1hr ozone for 126 monitoring stations on 8/30/96, a Cluster 2 Day.

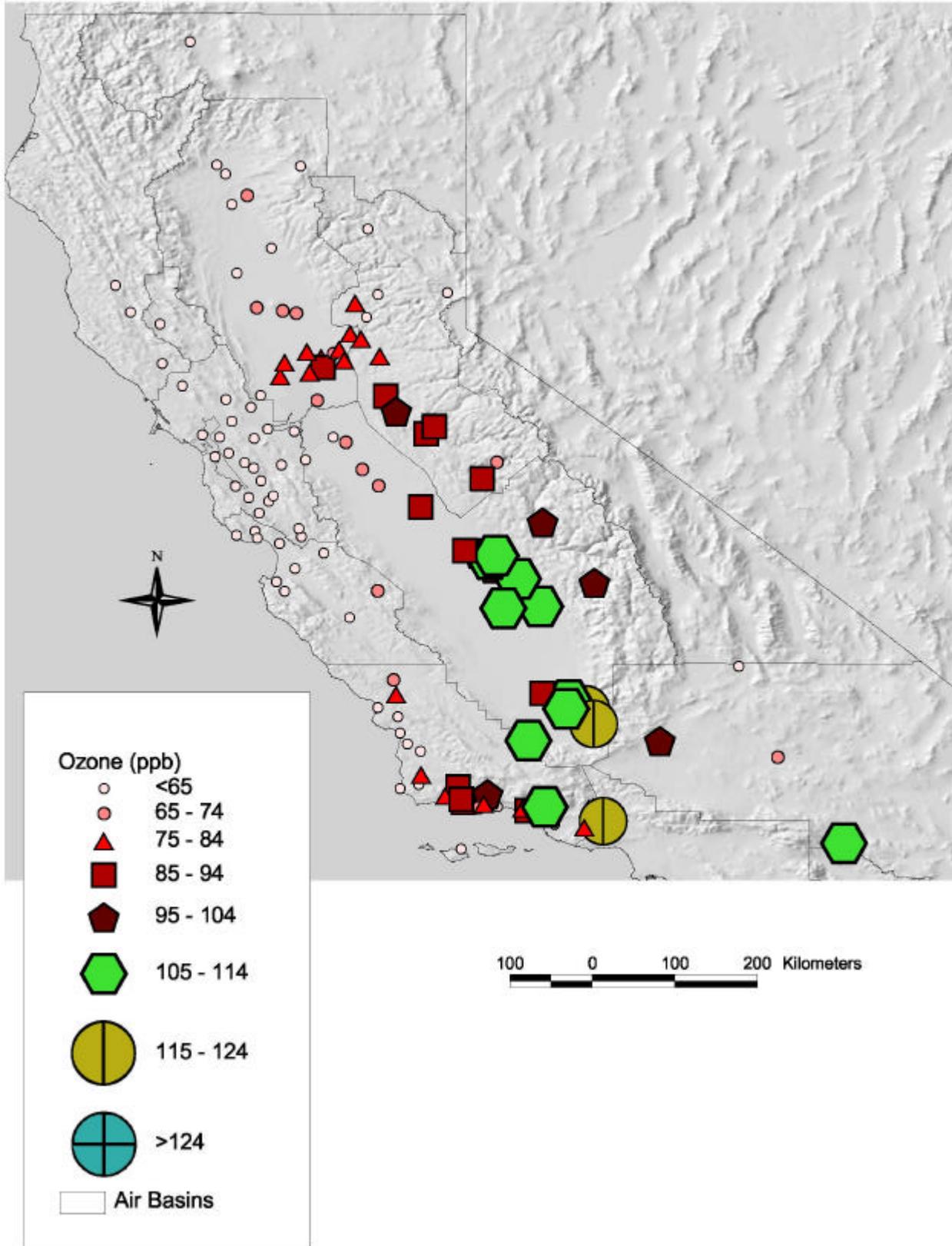


Figure 1.4-5. Maximum 8hr ozone for 126 monitoring stations on 8/30/96, a Cluster 2 Day.

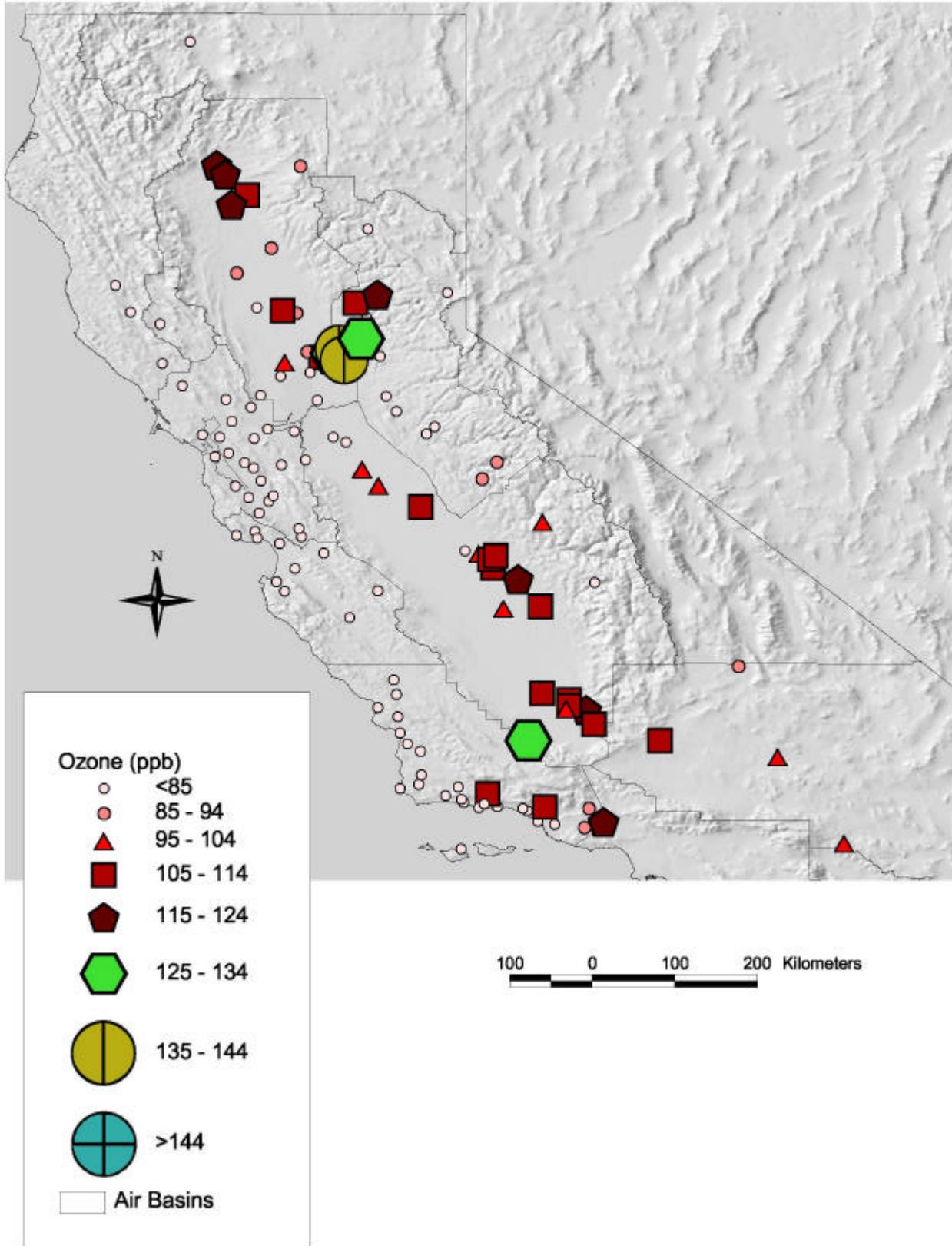


Figure 1.4-6. Maximum 1hr ozone for 126 monitoring stations on 8/14/98, a Cluster 3 Day.

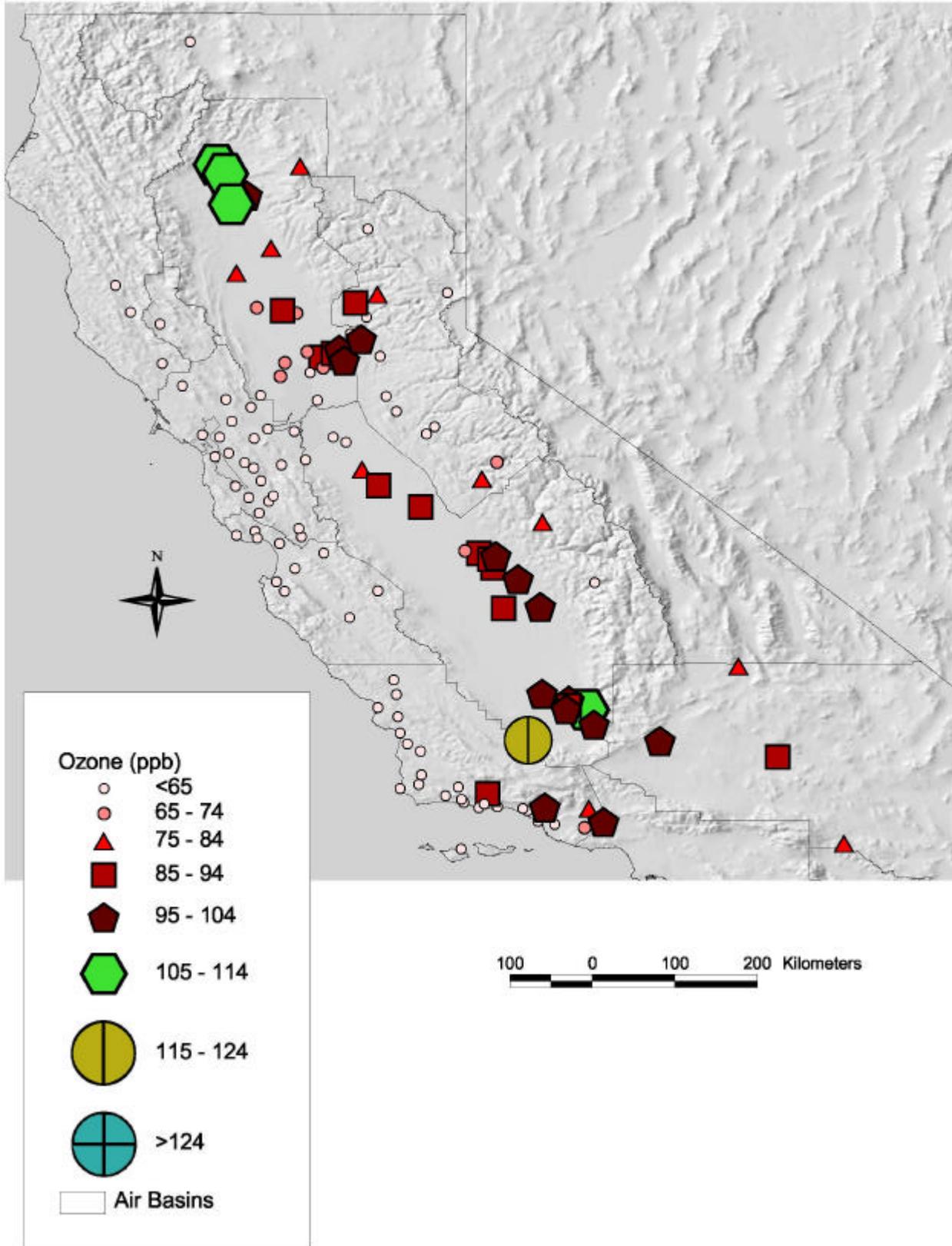


Figure 1.4-7. Maximum 8hr ozone for 126 monitoring stations on 8/14/98, a Cluster 3 Day.