DRAFT PROPOSAL

Quantifying the Origins of Residual Layer Ozone and its Contribution to Surface Exceedances in the Southern San Joaquin Valley

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ABSTRACT

This research contract proposes to extensively sample the lower 1500 m of the atmosphere, all the way to the surface, throughout the diurnal cycle spanning four different three consecutive day periods with the use of a very well instrumented scientific research aircraft operated by Scientific Aviation, Inc. The sampling days will include four periods in the Southern San Joaquin Valley at which time an ozone exceedance of the National Ambient Air Quality Standard is forecast. By using two teams of pilot and flight scientist, the missions will provide nearly 10 hours of research data spread out over each 24-hour period (140 flight data hours in total) that will range across a 150 km domain from Fresno to Bakersfield. Data to be collected and quality assured include horizontal winds, humidity, temperature, ozone (O_3), nitrogen dioxide (NO_2), methane (CH_4), and ethane (C_2H_6), all at 2-second (~125 m in the horizontal, 5 m in the vertical) resolution or better. This very unique data set will provide unprecedented observational constraints to support high precision modeling of ozone concentrations and its spatial distribution pattern throughout the region. Furthermore, the experiment is designed to allow for an explicit empirical estimation of the vertical mixing of ozone between the residual layer aloft and the shallow boundary layer overnight in the presence of the region's low level nocturnal wind maximum, and during the morning hours when the mixed layer grows up rapidly through the residual layer. Moreover, the budgeting techniques used with the data set can quantify the midday photochemical production of ozone for comparison with a full chemistry air quality model. In this way the experiment is optimized to constrain modeling efforts across the entire diurnal ozone cycle, and provides a detailed paradigm with which to improve air quality modeling efforts. By measuring the explicit terms of the ozone budget equation this experiment can test specific model components (both transport and photochemistry) and definitively quantify the ultimate contribution of residual layer O_3 to the following day's afternoon maximum.

INTRODUCTION

The San Joaquin Valley (SJV) has become the locus of one of the more vexing air quality challenges in the nation, and consequently is classified as an extreme ozone nonattainment area for the 8-hour ozone NAAQS. One of the difficulties of fully understanding the causes of degraded air quality of the SJV is its long and deep geography, running approximately 400 km (Stockton to Arvin) to the south-southeast, spanning an average of ~100 km across, and bordered by a rim that rises to over 3 km on its eastern flank and ~1 km to its west. Because of the topographic isolation of the SJV, air quality along its surface is strongly dependent on the exact nature of the mixing aloft, as the air that naturally feeds into it from the gap in the Pacific Coast Range around the San Francisco Bay Area stagnates as it approaches the cul-de-sac of the Southern SJV (SSJV) and the Tehachapi Mountains. Attaining air quality standards in the SSJV thus requires a much better understanding of the dynamical influences on the vertical mixing at the top of the boundary layer.

Generally speaking, surface ozone in the SSJV is dependent on horizontal transport (from sources throughout the state), vertical mixing with air in the lower free troposphere above the valley boundary layer, and local in-situ photochemical production. From regions as distant as the San Francisco Bay, there are many sources of ozone precursors (VOCs and NO_x), and under the north-northwesterly up-valley daytime wind flow that is prevalent during summer days, these precursors generate ozone levels that increase as the air mass moves south, often reaching a peak at the southern edge of the valley near Arvin. However the horizontal pattern is not always so straightforward (Jin et al., 2011). Present research being conducted by our group under the auspices of the San Joaquin Valley Air Pollution Control District (SJVAPCD) is working towards explicit quantification of the individual terms in the daytime ozone budget. Preliminary data from this airborne study, focusing on the region downwind of Bakersfield, indicate that, although it varies substantially from day to day, the entrainment mixing of ozone is on average greater than 20% as large as that due to in-situ photochemical production. During the daytime, when the surface ozone builds to over 40-60 ppb, the vertical entrainment mixing tends to dilute the boundary layer concentrations, so this term works to slow the buildup. Nevertheless, because of the non-linearity of ozone photochemistry, the eventual daytime maximum can be strongly influenced by the initial conditions established in the early morning. The ozone levels found at the surface in the middle of the morning, as daytime mixing strengthens abruptly, are most strongly determined by the instantaneous vertical mixing. Therefore, although vertical mixing may only be one-fifth as strong during midday photochemical production, it dominates earlier on before the photochemistry has taken off and can be unduly influential in establishing the initial conditions upon which that photochemistry feeds.

Because near surface ozone is titrated by fresh emissions of NO in the absence of sunlight (and removed entirely by dry deposition), and because it is not well-mixed into a very deep layer due to nocturnal stable stratification, the vertical O_3 gradient becomes large and positive overnight. Then as the morning solar heating develops, rapid mixing down of ozone gives rise to an abrupt increase observed at surface monitoring sites. This sequestration of ozone aloft is plainly evident in the aircraft profile in Figure1, taken during the first of the CALGEMS project deployments around Bakersfield in November 2013. The elevated layer between ~500 – 1000 m is the residual layer (RL), marked by elevated moisture (RH = relative humidity, %), ozone (O_3), and methane

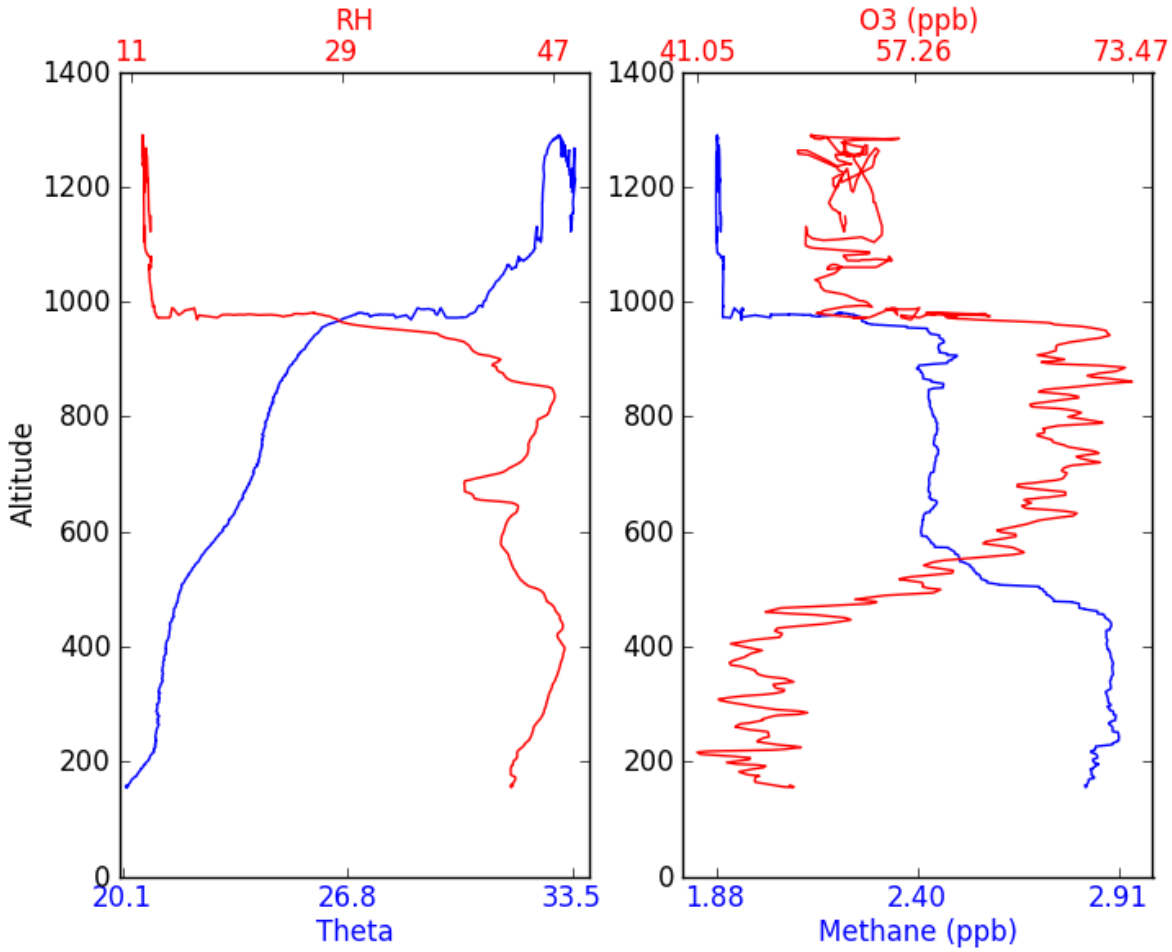

Figure 1. Vertical profiles measured near Bakersfield on Nov. 12, 2013. Ozone (and methane, and potential temperature, theta) all rise sharply in the residual layer between 500-1000 m as the mixed layer grows upward from the surface.

(CH_4) delivered there by vertical mixing from the day before. However, because the residual layer flow tends to be relatively decoupled from that near the surface, tracking the origin of this layer can be difficult and depends heavily on the ability of any particular model to reproduce very small scale wind features in complex terrain under stable stratification – a tall order indeed. Measurements of the breadth and timing proposed in this research contract will be invaluable in validating the wind flow and pollutant concentration under these circumstances.

Figure 2 shows the average time derivative of ozone measured at 5 CARB air quality monitoring stations spanning a transect from upwind to downwind across Bakersfield, CA during June-September of 2012. These data indicate that the large burst of ozone that appears in the mid-morning during the rapid growth of the convective boundary layer up through the approximately neutrally stratified residual layer has made the majority of its contributions to surface ozone by about 09:00 Pacific Standard Time (PST). All four sites show the greatest rise in ozone occurring at 07:00 PST with a shoulder that typically extends out to about 09:00 or 10:00 PST. It is important to note that different sites experience very different rates of ozone injection from the residual layer. Part of this is due to the fact that some sites (e.g., Shafter & Bakersfield) have

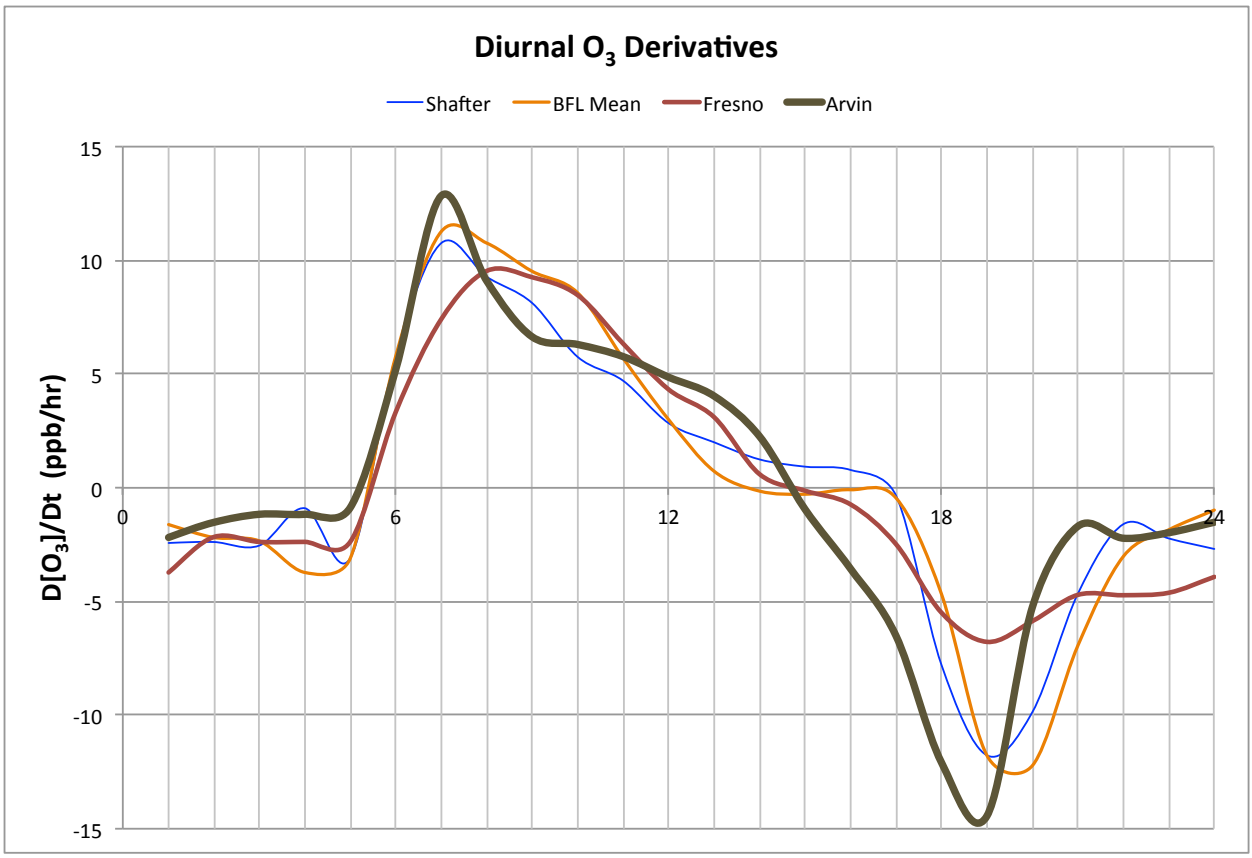

Figure 2. Average time derivative of surface ozone concentrations from June-September, 2012 from 5 sites in the CARB air quality monitoring network in the SSJV. The 'BFL mean' is the average of two Bakersfield sites (California Ave. and the airport) and the hour is PST.

lower overnight O_3 lows (presumably due to greater NO titration.) But this fact also points towards geographical variations of residual layer contributions to daytime O_3.

While the importance of this residual layer down-mixing mechanism has been noted by many authors (Neu et al., 1994; Mckendry et al., 1997; Aneja et al., 2000; Morris et al., 2010), there is no simple way to treat it because the residual layer ozone can be modified by differential advection, shear-induced turbulent mixing stimulated by low level nocturnal jets (Zaveri et al., 2010), and nitrate radical production (Brown et al, 2003). A recent study of residual layer O_3 in Houston conducted by Morris et al. (2012) using ozonesondes, found a good relationship between yesterday afternoon's maximum O_3 levels and the peak in the residual layer, but the profiles were complex and the authors could not explain the strong variability in the residual layer aside from possible differential advection from a variety of hypothetical areas throughout the chemically variegated region. Hu et al. (2013) studied this problem in a field experiment in Maryland and concluded that models such as WRF/Chem required improved numerical algorithms to properly account for nocturnal vertical mixing.

The studies of Zhong et al. (2004), Bao et al. (2008), and Bianco et al. (2011) present evidence of a strong and persistent low level wind maximum (jet) in the Southern San Joaquin Valley that appears to peak in the late evening (~23:00 PST). Figure 3 reproduces the data from the 2000 ozone season of two radio acoustic sounding systems at Visalia and Angiola from Zhong et al.,

(2004), both indicating a clear surge in north-northwesterly (up-valley) winds below 300 m just before midnight. Such flows surely enhance horizontal advection as well as shear-induced vertical mixing, thereby strongly influencing the evolution of the regional residual layer. In a WRF study conducted by Bao et al. (2008) this low level wind feature of the SSJV was over predicted by the model with a 2-3 m/s bias, and a 4 m/s root-mean-square error (see their figure 10). Another unique strength of the proposed research is the direct measurement of these nocturnal flows, which can be used to validate model processes that are very difficult to simulate *ab initio*.

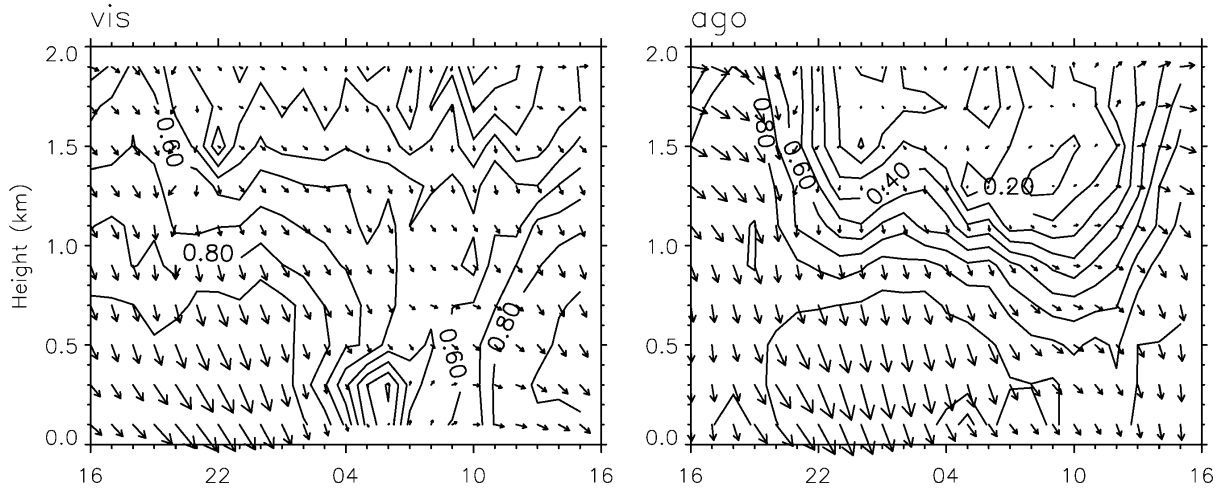

Figure 3. Time-height vector averaged horizontal winds observed in Visalia and Angiola in the Southern San Joaquin Valley. The hour is PST, contours are wind persistence, and largest vectors are approximately 10 m/s. Data is from the four summer months of 2000 as reported in Zhong et al. (2004). Wind vectors are drawn relative to north directed towards the top of the page.

Identifying the advection of ozone in the residual layer over the SSJV region is a crucial component of this study and one that is very difficult to achieve without an airborne platform. Most previous studies of residual layer pollutants have relied on back trajectories or mesoscale models to investigate the chemical origins and evolution of the residual layer. These methods are dubious in the complex terrain of the Central Valley, and the process can be very significant in magnitude. For example, Figure 4 shows a horizontal ozone and wind pattern observed in the residual layer during our recent airborne ozone study near Bakersfield. The observed wind speeds (~10 km/hr) and ozone gradients (~30 ppb over ~25 km) indicate horizontal advection strengths of greater than 12 ppb/hr near the center of the region. Note that this rate of change of ozone is comparable to the largest values observed at the surface any time of day (see Figure 2). By measuring the horizontal O_3/NO_2 gradients and the in-situ winds, this investigation will be able to directly quantify the importance of advection in determining the composition of the following morning's residual layer, and by so doing will provide powerful checks on the requisite accuracy of low level, nocturnal winds in air quality models.

Two current projects that our group is executing under the aegis of the SJVAPCD have direct bearing on the proposed work, and will serve as value-added support to the research. The first is an airborne ozone budget study being investigated in the Arvin area whose objective is to quantify the vertical mixing of ozone at the top of the daytime valley boundary layer and apportion its importance to surface concentration maxima. The methods developed in this

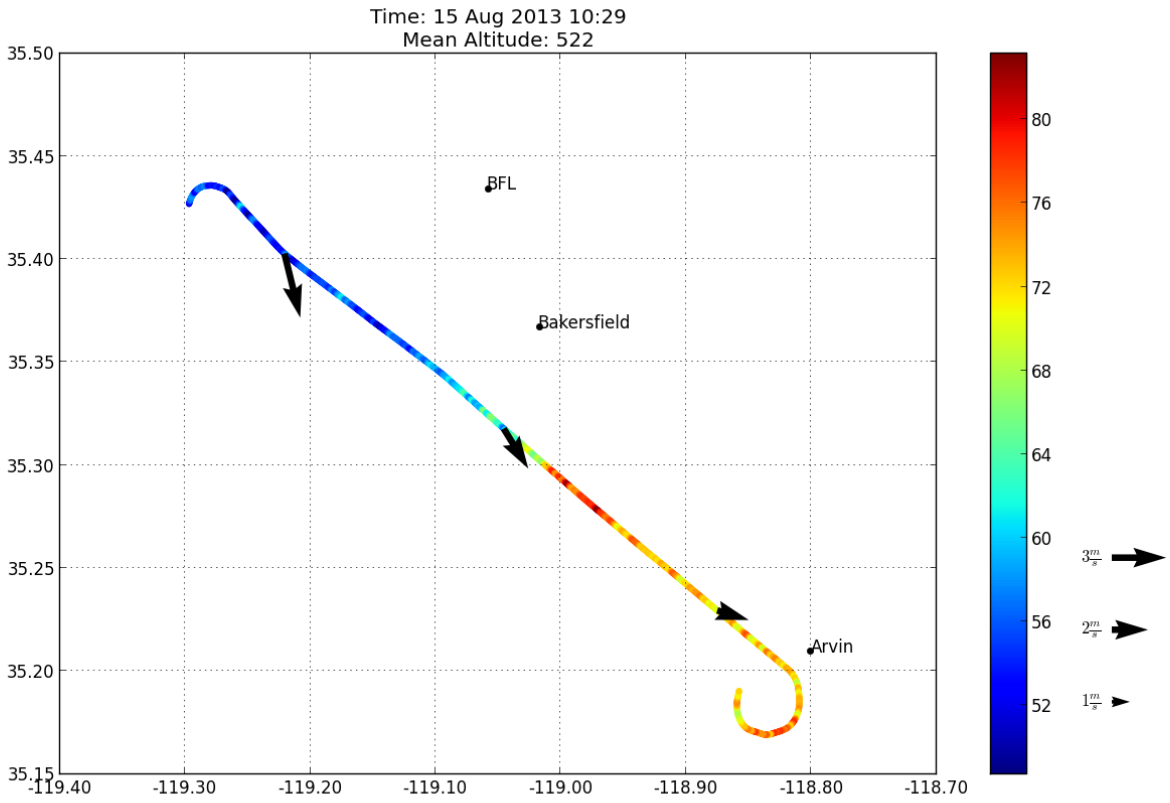

Figure 4. Longitude and latitude pattern of ozone (colorbar, ppb) and winds observed in the residual layer near Bakersfield.

project, although focused on the mid-afternoon period of maximum ozone, will assist in planning and execution of the proposed work. The second project is the continuous monitoring of free tropospheric ozone underway on Chews Ridge (1500 m) in the Santa Lucia mountain range ~30 km east of Pt. Sur in Monterey county. A second phase of monitoring is being contracted present to continue its operation through the summer of 2015. Analysis of these data indicate a substantial correlation between the mountain observations and ozone levels found near the top of the daytime maximum boundary layer over Fresno, and even surface ozone measured at Arvin, albeit to a smaller degree. Thus it appears that continuous monitoring at the high elevation site can provide crucial boundary conditions to ozone modeling for the SSJV.

OBJECTIVES

This research contract will deploy a wide array of airborne instrumentation to characterize the physical and chemical conditions of the lower layers of the atmosphere of the SSJV with the aim of improving ARB's modeling of ozone concentrations throughout the region. The project is designed to obtain the greatest spatial and temporal coverage during episodes of ozone NAAQS violations, by utilizing a dual crew system deployed to Bakersfield for three day periods. By flying concerted sorties to the same area repeatedly, budgets can be applied to the data set in order to precisely track its movement and chemical evolution throughout the diurnal cycle.

The measurements will be used to validate the model's ability to capture the chemical and physical processes leading to elevated ozone concentrations aloft, and to determine to what extent the ozone aloft contributes to photochemistry and high ozone concentrations on subsequent days. If the model is not able to accurately capture these processes, then the measurements will be used as a foundation for improving ARB's ozone modeling and will provide a detailed dataset for validating future updates to the modeling.

By performing focused sorties that span a total of 12 entire 24-hour day periods, the project will be able to use precise budgeting techniques for each ~2.5 hour flight. By measuring the principal terms of the ozone budget equation (horizontal advection and temporal trend), analysis of the flight data can be performed that will estimate photochemical production during the daytime and vertical mixing at night, processes that are not usually readily observed. These measurements thus provide a deeper level of model validation by investigating specific physical mechanisms that are critical to accurate air quality modeling.

TECHNICAL PLAN

I. Observational Techniques

UC Davis personnel will monitor the synoptic meteorological conditions on a semi-weekly basis throughout the summer with an eye on poor air quality forecasts for the SSJV. In the absence of a good air quality forecast model that is run several days out, the forecasts will seek to identify periods of maximum temperature and air mass stagnation conditions. We will aim at calling for a deployment (3 total days) at least 24-48 hours in advance, approximately one each month of the ozone season (June-September). It is anticipated that our team will work closely with appropriate members of CARB, or NWS-Hanford colleagues, who may be running air quality forecasts, or may have extensive experience with forecasting in the SSJV.

When ozone is forecast to meet a certain threshold (e.g. exceed the NAAQS standard), the aircraft will be moved to Bakersfield (KBFL) during the afternoon preceding the first 6AM sampling sortie. Over the next three days, we will conduct 4 flights per day with each flight being long enough to estimate horizontal and temporal gradients (necessary for estimation of the terms in the ozone budget equation). The four flights per day will be conducted with approximate sampling intervals on station from 06:00-08:00, 12:00-14:00, 17:00-19:00, and 22:00-24:00 (all times PST.) Including taxi and transit time, this will total approximately 2.5 hours per flight, 10 hours over the course of each sampling day.

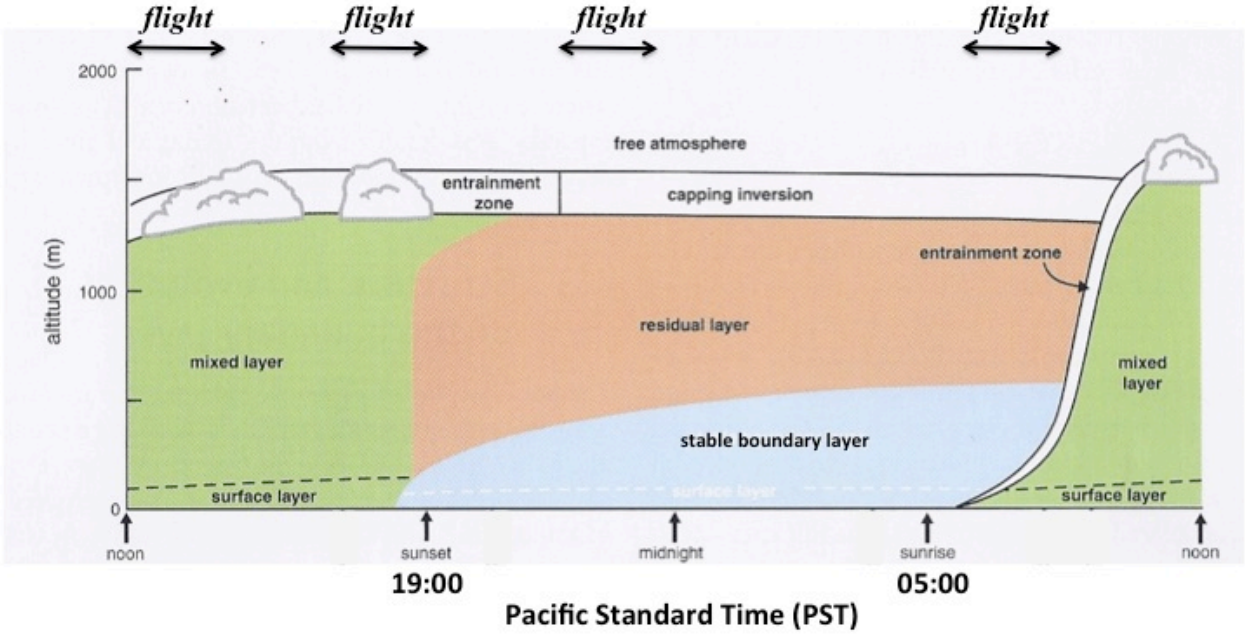

Figure 5. Timeline depiction of the layers of the lower atmosphere under investigation. The proposed 2-2.5 hour sorties are shown along the top of the figure spanning the diurnal cycle. Figure modified from Stull via Markowski & Richardson (2005).

Most of the motivation for the intervals listed above comes from inspection of the average surface ozone depicted as a time derivative (see Figure 2). The morning interval will capture the maximum rise in ozone, corresponding to the peak input from mixing down from the residual layer. The midday flight will sample the peak in the photochemical production when the mixed layer is almost fully developed. Climatologically the peak in the ABL depth is observed to be at 15:00 PST (Bianco et al., 2011). The early evening flight will monitor the period of maximum ozone decay at the surface, which coincides with the rising edge of NO_2 (data not shown.) And finally the midnight flight will observe the features of the nocturnal low-level wind maximum. Because of the high winds, this period should consist of strong horizontal advection and vertical turbulent mixing.

We can get a general sense of the mean vertical ozone distribution from a collection of aircraft data collected above Fresno during the ozone seasons (June-September) of 2012 and 2013, generously provided by Dartanion Sims of the California ARB. Figure 6 shows the mean profiles (and ± 1 standard deviation) from all flights (200 early a.m. and only 3 late p.m. soundings) combined into 50 m altitude bins. The data indicates that above 1500 m there is no consistent vertical gradient, and the observed ozone concentrations over Fresno correspond to averages (as well as variances) observed at a similar elevation 120 km to the west on Chews Ridge in Monterey County where our group has been monitoring ozone and other pollutants for two continuous years. We believe therefore that high elevation monitoring sites can successfully track this free tropospheric boundary condition upwind. The observed aircraft soundings further evince the structure of the typical residual layer and its diurnal evolution. The daytime convective boundary layer reaches to 850 m above ground level during June-September (Bianco et al. 2011). This level thus marks the top of what would be traditionally considered the residual layer, and ozone does not deviate much from the concentrations at these altitudes in the top part

of the layer. Below about 600 m the effects of overnight ozone loss are readily apparent, and yet there appears to be a more well-mixed layer below about 200 m. This lowest ozone layer is likely a marker of the nocturnal stable boundary layer, which is actively mixed despite its thermal stratification due to strong wind shear. The strongly mixed character of this layer may be additional evidence of the importance of the nocturnal low level wind maximum that has been observed in this region (Zhong et al., 2004; Bao et al., 2008) and that is enhanced by the sloping terrain (Markowski & Richardson, 2010) adjacent to Fresno.

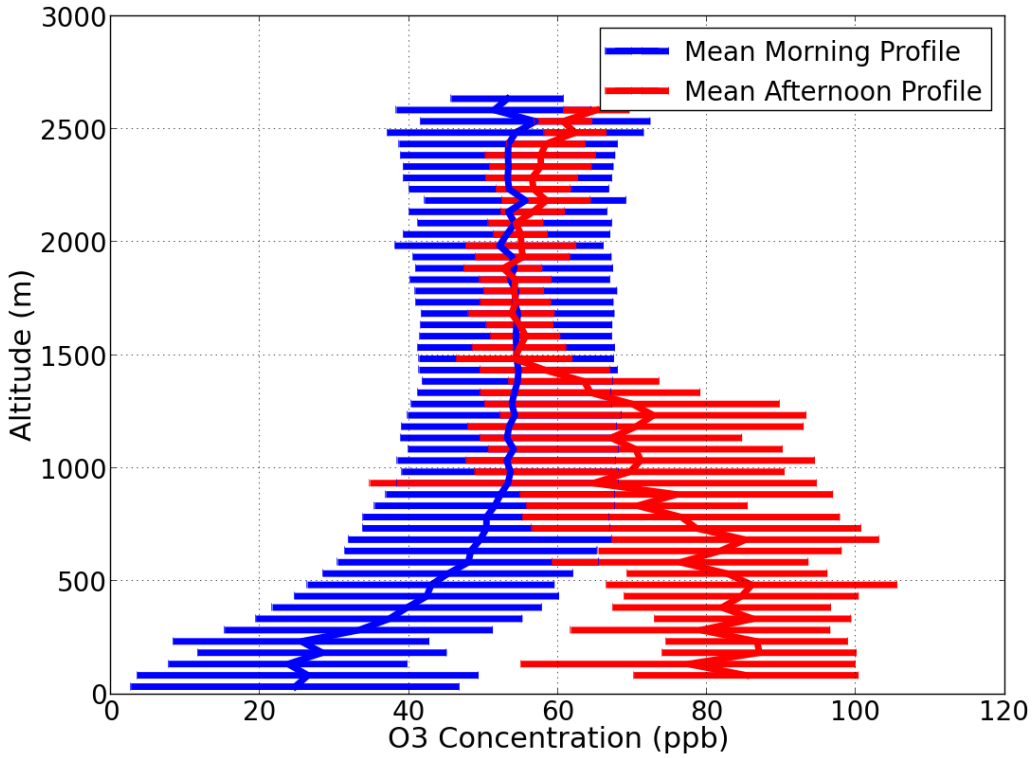

Figure 6. Average O_3 profiles observed by CARB's Fresno aircraft soundings during the ozone seasons of 2012/2013. The horizontal bars represent ±1 standard deviation about the mean in each 50 m altitude bin.

Because the late afternoon mixed layer air that seeds the residual layer typically contains less than 5 ppb (CARB AQIMS data, not shown), in an average sense across the region the fall off of ozone from ~50 ppbv at the top of the residual layer to ~25 ppbv in the nocturnal boundary layer must be dominated by vertical mixing between the two layers. This mixing process, occurring within a stably stratified atmosphere, is difficult to simulate using LES let alone a parameterized air quality model and traditional surface networks can only be used to test the final net result on the ground, but cannot easily monitor the residual layer component. The proposed experiment, utilizing a budget analysis, has the ability to greatly improve the constraints on the models, as well as deliver estimates of the mixing rate directly. Such investigations are exactly what have been recommended by other researchers (Salmond & McKendry, 2005) working on this problem.

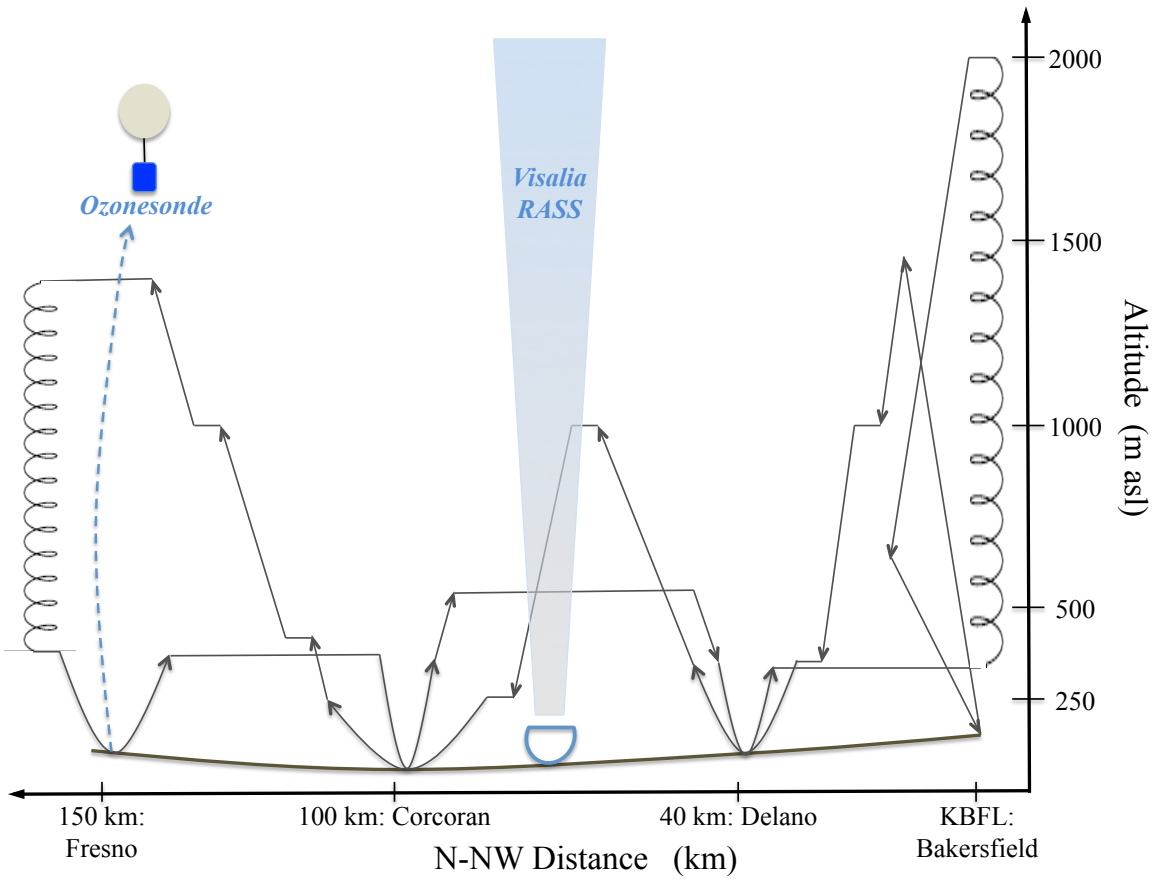

Figure 7. Flight plan cross-section along the valley axis. Touch and go approaches are planned at the three airports (KDLO, DCRO, KFAT) upwind of Bakersfield. Support measurements include ozonesondes launched from Fresno and the NOAA RASS profiler at Visalia.

Figure 7 is a representation of a typical flight pattern proposed for each ~2:15 hour sortie. To maximize vertical profile data collection, each flight will contain an outbound pass from Bakersfield and Fresno (~150 km), here consisting mostly of profiling, punctuated by 1 minute level legs, which are necessary for an accurate measurement of the winds. Then a return pass will be more directed at sampling extended level legs at altitudes below 500 m (agl). Along the way during each transit we will make a touch-and-go, or 'missed approach' landing at the airports in Delano, Corcoran, and Fresno in order to sample all the way to the ground. Moreover, at the end points in Fresno and Bakersfield we will fly tight spirals (radius ~1.2 km) to obtain deep vertical profiles up to 1500-2000 m depending on the available time. The spirals allow for a sounding that is minimally influenced by horizontal gradients. While Figure 7 captures the general spirit of the sampling strategy, each flight will randomly shuffle the elements (e.g., outbound level leg pass, KDLO-DCRO connected by 150 m level leg, etc.) in order to minimize the chance of a systematic bias in sampling the structure of the lower layers of the atmosphere. Also, missed approach landings may be omitted during the midday flight due to air traffic constraints and the well-mixed nature of the convective boundary layer.

For validation of the aircraft ozone measurements, we plan to launch two ozonesondes per deployment. The ozonesondes provide a profile of ozone, temperature and humidity for the entire troposphere, with samples roughly every 100 meters. These redundant data should be able to provide a level of confidence that the gradients observed in the airplane are similar to those observed by the sonde. Additionally, NOAA's ESRL Physical Science Division has been operating a radio acoustic sounding system (RASS) in Visalia since March, 2010 with no present intention of removing it. The RASS is able to measure (virtual) temperature and winds with height at a resolution of ~50 m every hour, and can be very useful in serving as another check on the airborne data collection systems.

II. Data Analysis Techniques

Build-up of a chemical species in the atmospheric boundary layer is affected by turbulent transport, advection by the mean wind and in-situ net chemical production. Thus, in a sense, the chemical reactivity and the dynamics of the medium are equally important in understanding the evolution of a trace gas. Our group has been working for a decade to shine light on the coupling of these two processes in order to better understand both.

The details of the proposed methodology are found in our work on the NSF C-130 aircraft over the Pacific Ocean (Conley et al., 2011). Briefly, the mean budget equation for a vertically averaged scalar (S) in a turbulent medium can be described as:

$$\frac{\partial S}{\partial t} = \frac{\langle w's' \rangle_0 - \langle w's' \rangle_{z_i}}{z_i} - U\frac{\partial S}{\partial x} - P$$

where S is the vertically averaged concentration throughout the layer, <$w's'$> represents a turbulent flux at the bottom, 0, or top, z_i, of the layer, U is the mean wind (x aligned in the direction of the mean surface wind), and P is the net chemical production (or loss) of species S. In words, the ozone trends can be attributed to three processes: a) delivery from other parts of the valley by the wind, b) mixing from above (daytime) or below (nighttime) the layer by turbulent motion, and c) local photochemical production (daytime).

Remaining in the same airspace during each sortie provides an opportunity to directly measure the (Eulerian) time rate of change (left hand side), while flying upwind/downwind during the transits provides the advection term (2nd term on right hand side). For species without significant photochemical production/loss on the timescale of a flight (e.g., H_2O, CH_4, and C_2H_6), this leaves only the fluxes at the surface and top of the layer to close the budget. During the daytime evapotranspiration rates can be readily estimated from the CIMIS (California Irrigation Management Information System) network, or NCEP/NARR high-resolution reanalysis data, and can then be used as a well-constrained surface flux for water vapor.

A common parameterization for entrainment is to use the observed jump across the boundary layer top (ΔS) in conjunction with a transfer velocity known as the entrainment velocity, w_e, which can be solved for in the governing budget equation (see above) for a non-reactive species like water vapor:

$$\langle w's' \rangle_{z_i} = w_e \Delta S = \langle w's' \rangle_0 - z_i\left(\frac{\partial S}{\partial t} + U\frac{\partial S}{\partial x}\right)$$

This equation provides the means to measure the entrainment velocity for a well-constrained scalar such as water vapor (in the absence of precipitation), and then use it in concert with observed mean jumps to infer elements of other budget equations for any other chemical species (viz: ozone, NO_2, C_2H_6, and CH_4.) For instance, the budget equation can be inverted to solve for the regional surface fluxes of the greenhouse gases C_2H_6 and CH_4 (negligible P terms), and can be used to infer the net photochemical production of ozone (using a deposition velocity parameterization to estimate the surface flux.) During the night when most of the chemical terms shut off, we will be able to use the budget equation to solve for the vertical turbulent fluxes of the compounds between the nocturnal boundary layer and the residual layer (as long as we assume that the mixing at the top of the residual layer is minimal.)

The instrumented aircraft, operated by Scientific Aviation, Inc. will make seven measurements that are central to air quality meteorology at the cost of $650 per flight hour. The measurements and their time resolution, vendor, and method include:

T, RH:	Temperature and relative humidity (1-2s response, Vaisala probe on wing)
U,V:	Horizontal wind speed and direction (~1s, dual GPS developed in-house)
O_3:	Ozone (~2s, 2B Technologies UV absorbance)
NO_2:	Nitrogen dioxide (~1s, Los Gatos Research cavity enhanced spectroscopy)
CH_4:	Methane (~0.2s, Picarro CaRDS airborne flux model)
C_2H_6:	Ethane (~0.2s, Aerodyne QCL mini monitor)

Of course the temperature and relative humidity measurements are crucial for determining the thermodynamic structure and layering of the atmosphere, which strongly controls vertical motions. Moreover, the high-precision measurement of the horizontal winds is critical for tracking the strength of advection and any changes of this term with height. NO_2 is a trace gas that is intimately tied to ozone production, as it is photolysis of its labile N-O bond that provides the atomic oxygen to form ozone from molecular oxygen in the lower troposphere. But beyond that NO_2 is the main reservoir of NO_x overnight in the residual layer, so knowing both the O_3 and NO_2 levels will allow for the direct calculation of O_3 loss due to nitrate radical production ($NO_2 + O_3 \rightarrow NO_3$) which can then lead to irreversible losses in further reaction with various hydrocarbons or with NO_2 leading to N_2O_5 and hydrolysis. It turns out that because of its relatively short lifetime (~1-2 days), NO_2 also serves as an excellent tracer of anthropogenically influenced boundary layer air. Figure 8 illustrates the clear demarcation of the afternoon convective boundary layer by NO_2 and corroborated by ozone, water vapor and potential temperature (theta). Although ozone appears to be well-mixed, NO_2 shows a distinct layer of cool, moist air that has been advected into the area. Nevertheless, notice the sharp jump to near zero concentrations that occurs at the top of the convective boundary layer. Further analysis from that project showed that a large source of the ozone photoproduction on that afternoon in Arvin was fueled by a strong horizontal advection of NO_2 from upwind near Bakersfield, illustrating how beneficial these combined measurements can be.

The other key ingredients in ozone production are reactive hydrocarbons that provide the organic peroxy radical substrate for conversion of NO to NO_2. Although the first two (C1 & C2) saturated hydrocarbons, which are proposed to be measured in this project, are not thought to be

significant contributors to direct ozone production, they can be used as important proxy species for understanding the origins of the hydrocarbons that are present (and that will need to be modeled.) Generally speaking methane appears to have two main sources in the San Joaquin

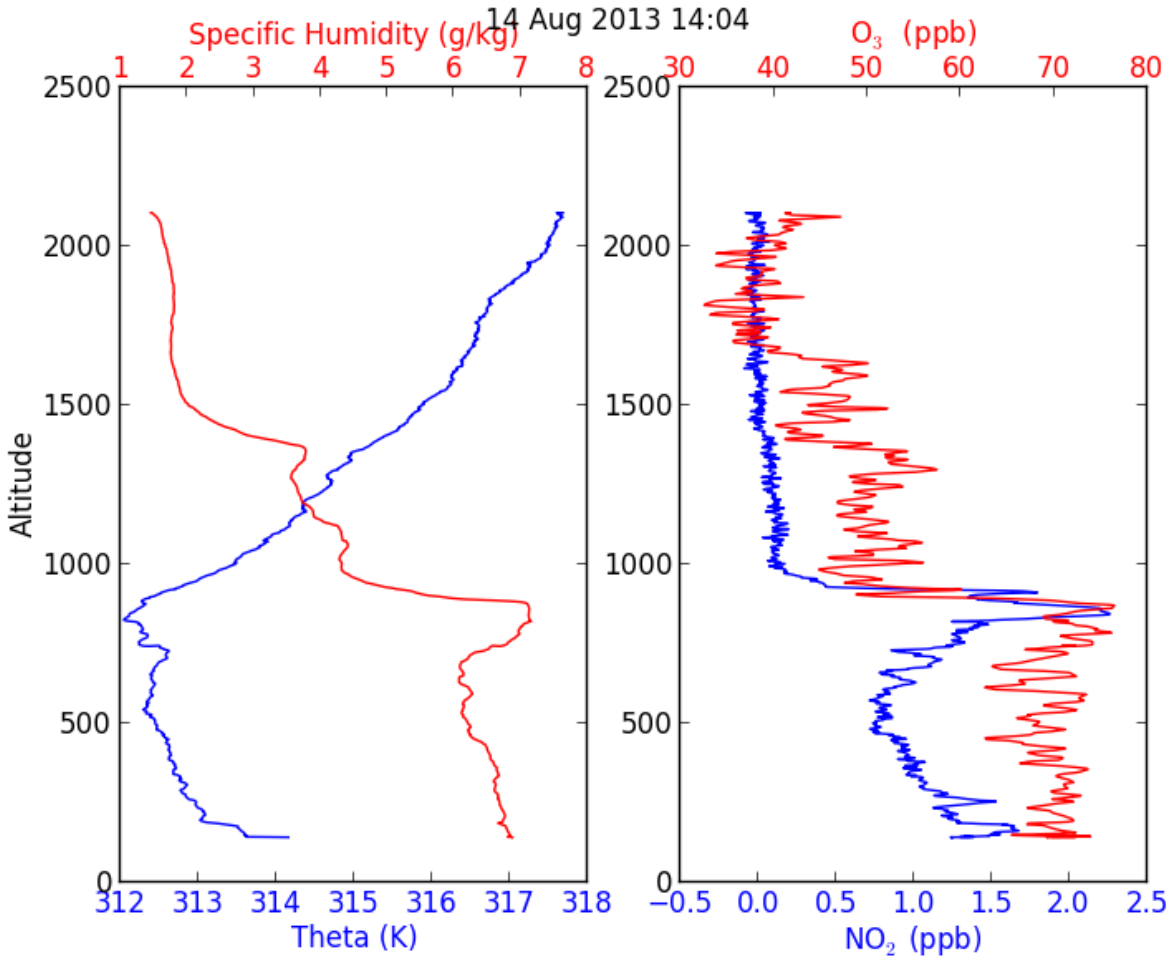

Figure 8. Afternoon aircraft profiles observed in the SJVAPCD Arvin ozone study.

Valley: oil and natural gas and dairy operations. Based on our group's work on leak detection in natural gas transmission lines, ethane is an excellent tracer of fossil fuel derived hydrocarbons. Thus ethane concentrations can be used in some measure to differentiate between methane from dairy operations (and the attendant oxygenated reactive VOCs) and methane from petroleum sources (with their own attendant reactive VOCs). Thus this project provides yet another inroad into testing air quality models by constraining the blend of hydrocarbons present in the SSJV.

III. Major Tasks

1. Flights – A total of 140 flight hours including 4-flights per day with roughly 2 – 2.25 hours on station per flight.

2. Data Collection – All data collected during flights will be quality checked and transmitted electronically to ARB. In addition to ozone, the aircraft, subcontracted from Scientific Aviation, Inc. will collect methane (CH_4), ethane (C_2H_6), CO_2, NO_2, temperature, humidity, and wind speed and direction.

3. Post Flight Analysis – In flight data will be combined with other sources (e.g. CIMIS stations, nearby airports, Visalia RASS, ozonesondes, ARB network air quality monitors) to estimate the relevant terms in the atmospheric ozone budget. For each flight, we will estimate the contributions from horizontal transport, vertical mixing, photochemical production and surface deposition to the overall ozone budget.

4. Instrument Calibration – Ozone (2B Technologies Model 205) analyzer will be calibrated directly against a 2B Model 306 Ozone calibration source prior to and after each experimental deployment to track any changes in instrument performance. Similar calibration schedules will be maintained for NO_2 with a NIST traceable gas blend provided commercially (e.g. Scott-Marin). The methane and ethane instruments are routinely calibrated in flight at least monthly by comparison to collocated whole air samples that are analyzed via GC-MS in Boulder by NOAA ESRL Global Monitoring Division's aircraft program.

IV. Data Management Plan

The aircraft will monitor accurate horizontal winds (Conley et al., 2014), temperature, humidity, ozone (O_3), nitrogen dioxide (NO_2), methane (CH_4), and ethane (C_2H_6). A data management system is currently in use that collects measurements from all of the onboard instruments, applies a common time stamp, displays key values in real-time and stores all measurements for post-flight analysis. The files are stored in comma delimited ASCII format, and in addition to the system time, the official UTC time provided by the GPS is included for synchronization with other data systems.

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Hu, X.-M., D.C. Doughty, K.J. Sanchez, E. Joseph, J.D. Fuentes, Ozone variability in the atmospheric boundary layer in Maryland and its implications for vertical transport model, *Atmospheric Environment* **46**, 354-364, 2012.

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Zhong, S., C.D. Whiteman, and X. Bian, Diurnal Evolution of Three-Dimensional Wind and Temperature Structure in California's Central Valley, *Journal of Applied Meteorology*, 1679-1699, 2004.

PROJECT SCHEDULE

Task 1: Project planning
Task 2: Aircraft deployments/flights
Task 3: Instrument calibrations
Task 4: Data quality assurance
Task 5: Data analysis
Task 6: Draft final report
Task 7: Amend final report

Task/Quarter	JFM-2015	AMJ-2015	JAS-2015	OCN-2015	JFM-2016	AMJ-2016	JAS-2016	OCN-2016	JFM-2017
1	XXX	XXX	XXX						
2		X	XXX				?		
3		X	XXX	X			?		
4		X	XXX	XXX	XXX		?		
5			XXX	XXX	XXX	XXX	XXX	XXX	
6								XXX	XXX
7									X
	m	p	m	p	m	p	m	d	f

m – meet with ARB staff
p – quarterly progress report
d – deliver draft final report
f – deliver final report

CURRICULUM VITAE OF KEY SCIENTIFIC PERSONNEL

IAN C. FALOONA
University of California Davis
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EDUCATION

Postdoctoral Fellow, Chemistry/Microscale Meteorology 2003
The National Center for Atmospheric Research
Research Topics: *Airborne instrumentation development, eddy correlation measurements of chemical fluxes, turbulent dynamics of stratocumulus clouds*

Ph.D., Meteorology 2000
The Pennsylvania State University
Thesis Topic: *Studies of Atmospheric Oxidation Using Measurements of OH and HO_2 Radicals*

B.A., Chemistry 1991
University of California, Santa Cruz
Thesis Topic: *Energy Transfer in Molecular Collisions of He and DABCO*

EMPLOYMENT EXPERIENCE

Department of Land, Air, & Water Resources, University of California Davis
Job Description: Associate Professor/Bio-micrometeorologist 2010-present
Job Description: Assistant Professor/Bio-micrometeorologist 2004 - 2010

National Center for Atmospheric Research 2000 - 2003
Job Description: Advanced Study Program Postdoctoral Fellow

The Pennsylvania State University 1995 - 2000
Job Description: NASA Global Change Graduate Student Fellow

SECOR International, Fort Collins, CO 1991 - 1994
Job Description: Data Analyst/Field Engineer

Los Alamos National Laboratory 1988 - 1989
Job Description: Undergraduate Research Assistant

TEN RECENT REFEREED PUBLICATIONS

O'Brien, T.A., L.C. Sloan, P.Y. Chuang, I.C. Faloona, & J.A. Johnstone, Multidecadal simulation of coastal fog with a regional climate model, *Climate Dynamics*, *40, 2801-2812, 2013*.

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Choi, W.S.-, I. C. Faloona, M. McKay, A. H. Goldstein, and B. Baker, Estimating the atmospheric boundary layer height over sloped, forested terrain from surface spectral analysis during BEARPEX. *Atmos. Chem. & Phys.*, **11**, 6837-6853, 2011.

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Faloona, I., Sulfur processing in the marine atmospheric boundary layer: A review, and critical assessment of modeling uncertainties, *Atmospheric Environment*, **43**, 2841–2854, 2009.

Day, D. A., and I. Faloona, Carbon monoxide and chromophoric dissolved organic matter cycles in the shelf waters of the northern California upwelling system, *J. Geophys. Res. - Oceans*, **114**, C01006, doi:10.1029/2007JC004590, 2009.

Petters, M. D., J. R. Snider, B. Stevens, G. Vali, I. Faloona, and L. Russell, Accumulation Mode Aerosol, Pockets of Open Cells, and Particle Nucleation in the Remote Subtropical Pacific Marine Boundary Layer, *J. Geophys. Res.*, 111 (D2): Art. No. D02206, 2006.

Dr. Stephen A. Conley

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Profile:

I recently completed my Ph.D in Atmospheric Science at the University of California, Davis. My research focused on processes controlling transport of traces gasses in the planetary boundary layer, with heavy emphasis on turbulent motions. I am interesting in continuing my research into these processes and developing techniques to use small aircraft in atmospheric sampling. I currently have the NOAA contract for airborne sampling off the coast of California and perform these flights in a Mooney TLS.

Employment:

University of California, Davis **9/2004 – Present**

Position: **Posdoctoral Researcher**
Duties: Performed analysis of boundary layer data collected during the Pacific Atmospheric Sulfur Experiment (PASE). Presented findings at project data meetings and the annual American Geophysical Union meeting.

Scientific Aviation, Inc. **04/2010 – Present**

Position: **Pilot**
Duties: Perform airborne atmospheric sampling between the surface and 25,000 feet off the northern coast of California. Test sampling systems for leaks and troubleshoot anomalous values.

Sourcewise Data Engineering, Inc. **06/1998 - 09/2004**

Position: **President/Owner**
Duties: Developed software applications for banking clients including Wells Fargo, Norwest Mortgage, The Money Store, Nehemiah Corporation. Systems included work flow, underwriting, web automation and interactive voice response systems.

CP Automation, Inc. **04/1992 – 06/1998**

Position: **President/Owner**
Duties: Developed billing software and provided billing service to approximately 500 martial arts schools around the country. Developed the first real-time web based credit card authorization system for the Electronic Payment Exchange.

United States Navy **04/1990 – 04/1992**

Position: **Lieutenant/Electronics Readiness Officer**
Duties: Served aboard the USS Lewis B. Puller during the Gulf War.

Managed a team of 25 electronics technicians responsible for ship's communications and radar equipment. Also developed database application for training that was shared with and used by all ships stationed at Long Beach Naval Station.

Education:

Ph.D. Atmospheric Science **2010**
University of California, Davis

Thesis Topic: **The dynamics of the tropical marine boundary layer**

B.S. Physics **1987**
California State University, Chico

Publications:

Faloona, I.C., S.A. Conley, B. Blomquist, A. Clarke, S. Howell, V. Kapustin, and A. Bandy, *Sulfur dioxide in the tropical marine boundary layer: Dry deposition and heterogeneous oxidation observed during the Pacific Atmospheric Sulfur Experiment*, *J. Atm. Chem.*, **63**(1), 13-32, 2010.

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Stephen A. Conley, Ian C. Faloona, Donald H. Lenschow, Teresa Campos, Clifford Heizer, Andrew Weinheimer, Christopher A. Cantrell, Roy L. Mauldin III, Rebecca S. Hornbrook, Ilana Pollack & Alan Bandy, *A complete dynamical ozone budget measured in the tropical marine boundary layer during PASE,* Journal of Atmospheric Chemistry, 2011

Conley, S.A., I.C. Faloona, D.H. Lenschow, A. Karion, and C. Sweeney, A Low-Cost System for Measuring Horizontal Winds From Single-Engine Aircraft, submitted to the *Journal of Atmospheric and Oceanic Technology*.

Certifications:

Licensed commercial pilot with instrument rating

Amateur Radio License (Extra)

BUDGET

CARB: Quantifying the Origins of Residual Layer Ozone and its Contribution to Surface Exceedances in the Southern San Joaquin Valley	
Budget	
A. PERSONNEL	
1. Project Scientist (25% x 2years)	$39,700
2. Graduate Student Researcher (100% x 2years)	$56,827
3. Undergraduate summer	$0
Total Wages & Salaries	$96,527
B. FRINGE BENEFITS	
A1 (@40.4%)	$16,039
A2 (@1.3%)	$739
Student Fees (in-state, 2 years)	$30,774
Total Fringe plus Fees	$47,552
C. TRAVEL	
1. Domestic	
Hotel + per diem (4 people Bakersfield) 3 days, 4 deployments	$8,400
2. Transport ($0.51/mi x 300 mi)	$1,224
Total Travel	$9,624
D. EQUIPMENT	
1. Ozonesondes ($1200 * 8)	$9,600
Total Equipment	$9,600
E. OTHER DIRECT COSTS	
1. Materials & Supplies (lab expendables: cal gases, tubing, valves, fittings)	$4,000
2. SUBCONTRACT: Aircraft Sampling by Scientific Aviation	
(140 Flight Hours Total @ $650/hr)	$91,000
3. Publication & Conference Registration Fees	$3,000
Total Other Costs	$94,000
Total Other Direct Costs	$98,000
F. TOTAL DIRECT COSTS	$261,302
G. INDIRECT COSTS (State Rate)	
Total Indirect Costs (25%)	$38,732
H. TOTAL Project (=DIRECT AND INDIRECT) COSTS	$300,034

ESTIMATED COST BY TASK

Task	Task Name	Labor	Employee Fringe	Education /Tuition	Sub-contract	Equipment	Travel	Materials, Supplies	Misc. (conferences)	Overhead	Total
1	Planning	$9,653	$1,678	$3,077	$0	$0	$0	$800	$0	$3,873	$19,081
2	Deployment	$33,784	$5,872	$10,771	$91,000	$9,600	$9,624	$800	$0	$13,556	$175,008
3	Calibrations	$4,826	$839	$1,539	$0	$0	$0	$1,400	$0	$1,937	$10,541
4	Data QA	$6,757	$1,174	$2,154	$0	$0	$0	$0	$300	$2,711	$13,097
5	Data Analysis	$24,132	$4,194	$7,694	$0	$0	$0	$1,000	$2,700	$9,683	$49,403
6	Draft Report	$14,479	$2,517	$4,616	$0	$0	$0	$0	$0	$5,810	$27,422
7	Final Report	$2,896	$503	$923	$0	$0	$0	$0	$0	$1,162	$5,484
TOTALS:		$96,527	$16,778	$30,774	$91,000	$9,600	$9,624	$4,000	$3,000	$38,732	$300,034