Uintah Basin 2012/13 Winter Ozone
Study Plan and Budget

Draft Version 1.2
Prepared for Utah Department of Environmental Quality

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1. Introduction

The Uintah Basin is an enclosed basin that lies in the northeast corner of Utah and is part of a larger area known as the Colorado Plateau. The Basin is bounded on the north by the Uinta Mountain range, on the south by the Book and Roan Cliffs, on the west by the Wasatch Range and on the east by elevated terrain separating it from the Pieance Basin in Colorado. The Green River runs diagonally through the area from northeast to southwest, exiting the Basin through the Book Cliffs (Desolation Canyon). The floor of the Basin is at approximately 4800 feet AMSL.

Duchesne and Uintah counties make up the majority of the Basin, with a small portion of Carbon county extending into the Basin from the southeast. The Uintah and Ouray Indian Reservation covers a significant portion of the Basin. Regulation of air quality on the Reservation and the surrounding “Indian Country” is administered by the EPA and tribe (Figure 1).

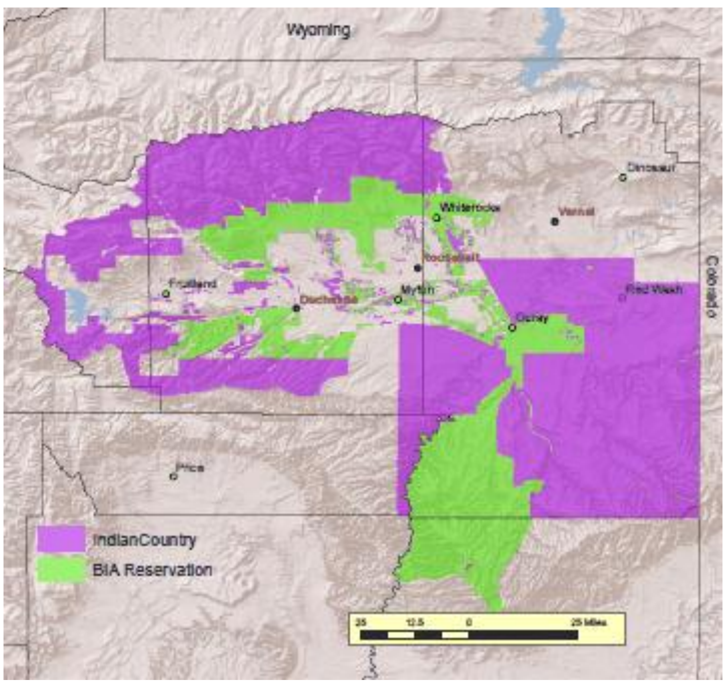


Figure 1. EPA and the Ute Tribe have air jurisdiction on the Reservation and Indian Country.

The Basin is rural with a population of about thirty thousand people located in three primary communities: Duchesne, Roosevelt, and Vernal. These towns lie along State Highway 40 running east-west through the Basin.

The economy of the Basin is driven by energy production due to the vast petro-resources located there. Oil and gas development (approximately 10,000 producing wells) is widely scattered throughout the Basin (Figure 2) with associated drilling, processing, compressing and piping facilities. There is also a 500-megawatt, coal-fired power plant operating in the Basin. There is some agricultural production in addition to energy development in the Basin.

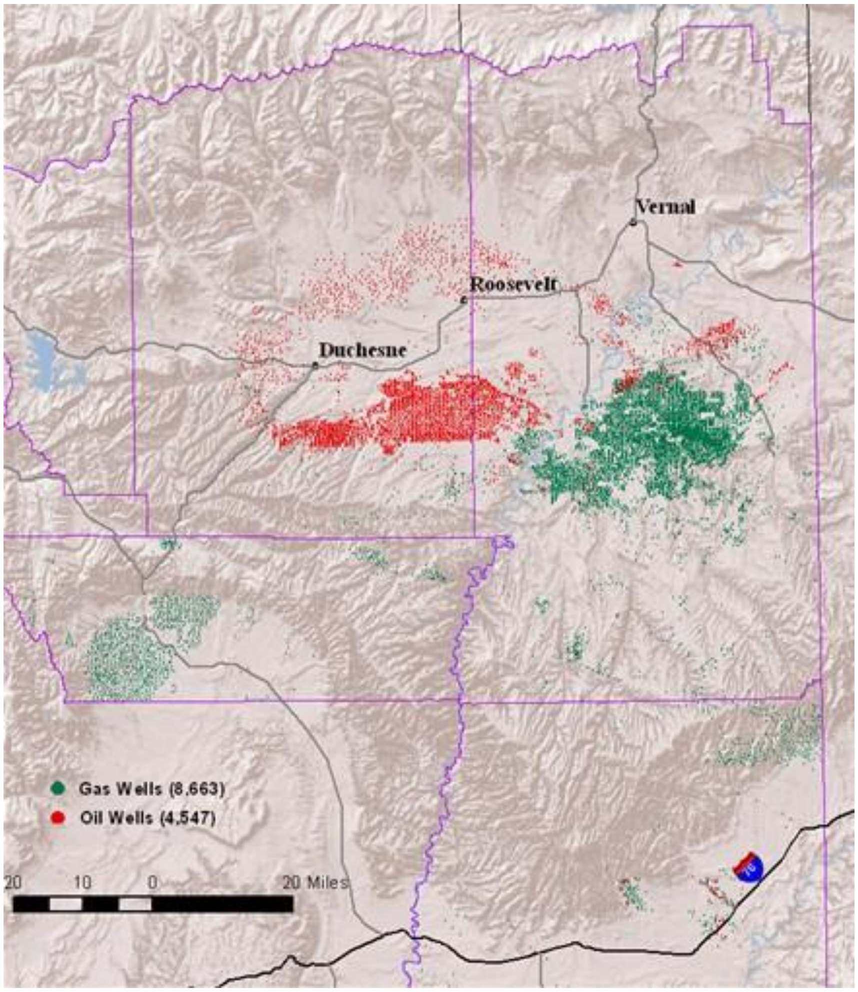


Figure 2. Oil and gas well sites as of 2010.

2. Monitoring in the Basin

2.1 Historical Monitoring Studies

High winter ozone levels were first observed in the Upper Green River Basin, Wyoming in 2005. Since that time, the Uintah Basin in Utah has also seen high ozone levels during the winter months. Neither of these occurrences is well understood and further information and evaluation are needed to understand the processes that cause the formation of winter ozone and determine sensitivities in particular environments to changes in VOC and NO_x levels relative to the formation of ozone.

Air quality monitoring in the Uintah Basin began in 2006 when the UDAQ installed monitors in Vernal to measure fine particulate ($PM_{2.5}$), ozone, and oxides of nitrogen (NO_x). Data were collected from February 2006 through December 2007. Higher 8-hour ozone averages were found in the summer, with the highest being 81 ppb, below the 85 ppb NAAQS at that time. No elevated ozone was noted in the winter months.

Subsequently, two additional special studies were conducted during the winters of 2007-08 and 2008-09, but these were focused on $PM_{2.5}$ since no elevated winter ozone values had been observed in 2006-2007.

In the spring of 2009, EPA used consent decree funding to establish two monitoring sites at Ouray and Redwash in the oil and gas production area. These sites were instrumented to measure $PM_{2.5}$, NOx, ozone, and meteorological parameters year-round. In sharp contrast to the low ozone values found in the winter of 2006-2007, the winter of 2009-10 experienced very high ozone values, with the highest 8-hour average of 124 ppb being measured at the Ouray site.

2.2 Recent Studies Focused on Ozone

2.2.1 Winter 2010/11

The Energy Dynamics Lab and USU conducted a special study in the winter of 2010-11 to verify the high ozone concentrations recorded the previous winter by mapping the extent of the problem and determining the areas of highest concentrations. The results showed that ozone values were elevated throughout the Basin, with the highest concentrations tending to occur at lower elevations centrally in the Basin.. The highest 8-hour ozone value measured at the Ouray site was 139 ppb. The data also showed that elevated ozone correlated highly with the presence of snow-covered ground and a strong temperature inversion, and that elevated ozone values did not occur absent these conditions. A full report of the results can be found here http://rd.usu.edu/files/uploads/edl_2010-11_report_ozone_final.pdf

2.2.2 Winter 2011/12

In the winter of 2011-12, a full campaign was mounted to understand the factors contributing to high wintertime ozone in the Basin. This campaign was part of a multi-phased study to identify the emissions sources and the unique photochemical processes that cause elevated winter ozone concentrations and identify the most effective strategies for mitigation. This winter study phase included measurements of ozone and ozone precursor concentrations and meteorological conditions throughout the Uintah Basin.

The work was funded by support from the following: Uintah Impact Mitigation Special Service District (UIMSSD), Western Energy Alliance, Bureau of Land Management (BLM), National Oceanic and Atmospheric Administration (NOAA), Environmental Protection Agency (EPA), National Science Foundation (NSF), and the State of Utah. The work was conducted by researchers from Utah State University/Energy Dynamics Laboratory (USU/EDL); NOAA; Utah Department of Environmental Quality (UDEQ); University of Colorado, Boulder (CU); University of California, Los Angeles (UCLA); University of Wyoming (U of WY); Colorado State University (CSU); University of Washington (UW); and University of California, Berkeley (UC Berkeley).

The report covering this phase of the study is planned for release late 2012. Researchers have released interim findings to this multi-phase study drawn from preliminary analyses of data and results. These interim findings will be updated as the first phase report is prepared.

INTERIM FINDINGS

The winter 2012 measurements indicate:

- No exceedance of the 75 parts per billion (ppb) National Ambient Air Quality Standard (NAAQS) for ozone was observed. The snow cover and strong inversions with low boundary layer heights required for the formation of excessive winter ozone concentrations was absent last winter. The highest 8-hour average ozone concentration observed at the surface during the study period was 62 ppb.
- Local photochemistry made only small contributions to ozone formation, as evidenced by the quantification of radical sources and chemical processing of oxides of nitrogen (NO_x) and volatile organic compounds (VOCs).
- Stratospheric intrusion of ozone was not observed to cause increased ozone concentrations at the surface or in the boundary layer during the 2012 study. However, the lack of high ozone episodes during the study prevents the evaluation of possible stratospheric intrusions during meteorological conditions that cause high ozone levels. Additional study is needed to determine if stratospheric intrusion contributes to surface ozone during winter ozone episodes.
- Observed levels of ambient VOC species were highest in gas-production areas, lower in oil-production areas, and lower still in population centers. Examples of VOC sources include oil and gas production and on- and off-road vehicles.
- Observed VOC and methane concentrations at the Horsepool monitoring station (located in a gas-production area) were higher than those typically observed in U.S. urban areas. The mix of VOC observed in the Uintah Basin has a higher proportion of alkanes. These alkanes have lower reactivity for ozone formation as compared to the highly reactive alkenes found in typical urban mixtures. However, the higher VOC concentrations present in the Uintah Basin make the total reactivity about the same as found in an urban area. This is meaningful because the reactivity of the VOC mixture can affect the optimal ozone control strategy and it may be possible to reduce ozone levels more effectively by identifying targeted control strategies for high reactivity VOC, such as aromatic, aldehyde and alkene species.
- The highest NO_x concentrations were observed in the Basin's population centers (i.e., Vernal and Roosevelt). Concentrations were lower in gas-production areas and lower still in oil-production areas. Examples of NO_x sources include on- and off-road motorized vehicles, O&G production equipment, and coal-burning power plants.
- Methanol, a source of primary and secondary formaldehyde (an important ozone precursor), was observed in concentrations that could significantly contribute to ozone formation in the Uintah Basin.

Additional work is in progress using data from the 2012 study and these results will be reported in the integrated study report expected by year end 2012. Additional analysis still underway includes the following:

- Winter climatology analyses characterizing the meteorological conditions that increase winter ozone formation (USU effort).
- Estimates of VOC and NO_x emissions for specific source types and refined total-Basin estimates of VOC and NO_x emissions (USU effort; the BLM ARMS emissions study is also a valuable resource for this effort). Emissions data will support ozone modeling studies.

- VOC reactivity estimates that use hydroxyl radical (OH) rate constants and maximum incremental reactivity procedures (NOAA effort). The reactivity data is needed to model local ozone formation and to evaluate the sensitivity of ozone to VOC and NO_x mitigation.
- Quantification of emission speciation profiles (using NOAA's Mobile Laboratory data) for various NO_x and VOC point sources in the oil and gas field. Data from the NOAA light aircraft effort will also be analyzed in the coming months and will be integrated in future flux calculations for the region. The information gathered by the Mobile Lab will be shared with emission inventory developers to determine if some emission sources may have been underestimated in current bottom-up inventories, including the WRAP 2012 inventory projection.

3.0 Recommended Research Needs

The 2012 winter season did not have persistent snow cover or the winter inversion conditions that are linked to the formation of high winter ozone concentrations. Therefore, the study team was not able to perform measurements of chemistry or the meteorological conditions that cause high ozone in winter. While the data collected in the 2012 study are useful to estimate emissions inventories and to establish baseline conditions, additional measurements are needed to evaluate the sensitivity of winter ozone to VOC and NO_x and identify the most effective mitigation strategies for reducing winter ozone. Continuing study goals include the following:

1. Characterize spatial variability in ambient ozone, VOC and NO_x concentrations during ozone episodes. This is necessary to evaluate ozone sensitivity to VOC and NO_x in different areas within the Basin and to characterize emissions and transport across the Basin.
2. Continue development of a basin-wide emissions inventory (temporal and spatial distribution and speciation of VOC and NO_x) that integrates the gridded and activity-specific information of current inventories. There are three categories of emissions inventory development work, including:
    A. Bottom up estimates using activity data and equipment emissions factors.
    B. Top down estimates using ambient concentrations and modeling.
    C. Source testing and mass flux modeling to develop new emissions factors for specific sources.
3. Evaluate the importance of snow photochemistry and radical budgets. This addresses the potential for unique aspects of winter ozone chemistry to affect the sensitivity of ozone to VOC and NO_x.
4. Characterize transport of NO_x emissions within and above the inversion layer. Transport of NOx emissions above the inversion layer will affect VOC and NO_x concentrations within the inversion layer and could change the relative effectiveness of VOC and NO_x emissions mitigation.
5. Make additional meteorological measurements to characterize inversion height and winds. This is necessary for modeling ozone in the Basin and for evaluating the transport and dispersion of emissions.

6. Develop photochemical model simulations to evaluate effectiveness of VOC and NO_x mitigation. This is needed to quantify the level of VOC or NO_x mitigation needed to attain the ozone NAAQS.
7. Quantify day specific background ozone levels during high ozone episodes. This is needed to accurately estimate the amount of ozone formed locally in the Basin.
8. Evaluate trends in ozone, VOC and NO_x ambient levels over multiple years. This will provide data to evaluate effectiveness in reducing precursor emissions and progress towards attaining ozone NAAQS.

3.1 Priorities and Research Needs Addressed

Research needs are listed in approximate order of priority as recommended by the science team.

- **Distributed sites and research sites** *Goals 1, 2, 5, 6, 7 and 8.* Distributed measurements will support modeling studies and trends analysis which can be used to assess the accuracy of current emissions data and changes in future emissions.
- **Aircraft study** *Goals 1, 2, 4, 5 and 7*. Especially useful for understanding spatial variability of VOC and NO_x emissions and transport of NO_x within and above the inversion layer. Could be limited by reduced visibility during episodes.
- **Snow photochemistry and radical budget** *Goals 3, and 6*.
- **Source specific emissions studies** Goal *2C*. Emissions testing of poorly characterized source types.
- **Tethered balloon studies** *Goals 4 and 5.* This is valuable for assessing transport of NO_x within and above the inversion layer, but the tethered balloon provides data only at a single site and is less cost effective than the aircraft study.
- **Modeling studies of 2011 and 2012 study periods** *Goal 6*. Evaluate emissions inventories, meteorology and ozone chemistry in the Uintah Basin.
- **Doppler lidar** *Goals 4, 5, and 6.*
- **Ozone lidar** *Goals 1, 5, 6, and 7.*
- **Continuous fully automated ozone surface deposition measurements by eddy covariance** *Goals 3, 6, and 7*.
- **Monitoring boundary layer and wind patterns** *Goals 4, 5 and 6*

Additional Research Topics - These study topics have been identified as potentially important, but we do not currently have a study plan or estimated budget:

- Compare study outcomes to those from Wyoming's Upper Green River Basin.
- Investigate the discrepancy between recently observed alkene concentrations and those measured during previous Uintah Basin and Wyoming studies.
- Characterize nitrogen dioxide (NO2), HONO, and ammonia (NH3) emissions from NOx sources.
- Characterize VOC emissions from geogenic seeps.

3.2 Approach

The winter campaign of 2011-12 was designed to deploy instrumentation from December through March, with the intensive studies focused on the month of February. The approach was to have instrumentation in place when an ozone episode occurred. However, because the conditions that lead to high ozone formation (snow cover and temperature inversion) are somewhat unpredictable, the approach this year will be rapid deployment when conditions are right. Local experience indicates that winters conducive to ozone formation begin with snowfall in early to mid-December, with this snow cover persisting until March thaw. Thus, researchers will be ready to deploy on short notice by mid-January if conditions look promising. Researchers estimate that from 70-90 percent of the study component budget can be preserved if they do not deploy.

As described above, the conditions for high ozone episodes involve both snow on the ground and cold, stable meteorological conditions. The 2013 UBWOS project will be staged to allow the field deployment component to be delayed to a future year if the required weather conditions do not develop. The decision to deploy, or not, will made by consensus of the Oversight Team and Science Steering Committee (defined in Section 4.). In the event of postponement, only the first contribution from the funding agencies (Section 3.5) will be paid, and the subsequent contribution will be paid during the corresponding period in the year in which the field and data analysis activities occur.

Proposals for study research are listed in the appendices and include the purpose/need, approach, deliverables, schedule, and requested budget (note that for some proposals the actual amount funded, as shown in Table 1. below, was slightly less than requested and was made up through in-kind contribution increases).

3.3 Study Components

3.3.1 Aircraft

Winter photochemical ozone production in the Uintah Basin is driven by the presence of strong, shallow temperature inversions that persist throughout the day. Extensive snow cover in the Basin reinforces these inversions, trapping gas/oil field effluents that are the precursors for rapid photochemical ozone production, beginning shortly after sunrise. The inversions also constrain the ozone to a shallow layer near the surface.

Knowledge of the Basin-wide distribution of the temperature inversions as they evolve, the distribution and concentrations of the ozone precursor gases, the flow of the air in the Basin, and the potential contributions of NO_x emissions from the Bonanza Power Plant are crucial to understanding Uintah Basin winter ozone production.

The aircraft data will be crucial for the evaluation of all modeling efforts to reproduce ozone events and to test mitigation scenarios. Existing mesoscale models do not reproduce inversion events well. Model results may only be interpreted accurately if the model limitations and biases are known. Direct observations of the winter-time ozone, precursors levels and meteorological patterns over the whole region are necessary to increase understanding some of the mechanisms that come into play in ozone production and to place the Horse Pool and Roosevelt fixed site data into the larger context of the Basin. Availablity of a Basin-wide data package will make it possible to model the ozone production phenomena accurately.

The most cost effective and versatile means to address these questions is through focused measurements with a well-instrumented light aircraft. (APPENDIX I)

3.3.2 Balloon Tethersonde

The purpose of this study is to evaluate the vertical distribution of ozone and its precursors before and during high ozone episodes. Under stable, shallow temperature inversions, emissions can be isolated in stable layers where mixing is limited. It is important to understand the temporal and spatial distribution of precursor emissions to determine which are important to ozone formation. Several balloon tethersonde systems will be used and each brings its own strengths to the study.

1. NOAA Radiosonde and Ozonesonde Measurements - NOAA will conduct an ozone production and distribution study through tethersonde profiling and surface measurements similar to that undertaken in 2012, but with some additions and refinements. NOAA will have two fixed bases (Ouray Wildlife Refuge and Jenson Greenhouse) where they will conduct continuous profiling of ozone, temperature and water vapor 24 hours a day during and following a major ozone production event. Since they will be mobilizing when an ozone event is developing, NOAA will probably miss the first stage of the process but would be well placed to monitor its peak and demise. There is a possibility that NOAA could continue measurements into a second event if it occurred within a week or so of the original event. (APPENDIX II)

2. CU-Boulder Tethered Balloon System - The purpose of this study component is to investigate the vertical distribution and temporal behavior of ozone, nitrogen oxides, and hydrocarbons in the lower part of the atmosphere at a single site. This experiment will focus on the lowest 500 feet of the atmosphere where ozone production chemistry is expected to be the most prominent under strongly stable boundary layer conditions over snow.
   The experiment will build upon deployment of the INSTAAR CU Boulder tethered balloon vertical profiling platform. A 20-foot diameter Sky Doc balloon will be used as a ‘sky hook’ for raising a series of long sampling lines to three distinct heights above the ground (150, 300, 450 feet). Air pulled from the balloon-borne inlets will be analyzed for ozone, nitrogen oxides, and methane and non-methane hydrocarbons.   A second type of experiment raises and lowers a movable inlet with a second tether system. These measurements will yield continuous vertical profile data at 2 m height resolution. A meteorological instrument package will be deployed with the moving sample inlet for measurement of wind speed, wind direction, temperature, and humidity. A set of 40 canister samples will be collected for speciation of total hydrocarbon measurement in the balloon profiles. Studies of ozone fluxes will be conducted to quantify the ozone uptake rate to the snow-covered ground. Ozone surface fluxes and deposition velocities will be measured 24/7 using eddy covariance techniques. Measurements will be conducted both over snow and during non-snow-cover conditions to contrast the surface ozone uptake rates under both situations. Combined, these meteorological and chemical measurements will provide high resolution data on the temporal

and vertical dynamic behavior and coupling of meteorological and chemical conditions. (APPENDIX III Project 1and 2)

3. USU Tethered Balloon Meteorology and Ozone Measurements – The purpose of this study is to deploy two balloon-borne meteorology and ozone measurement systems at two sites to characterize inversion properties.
   The sites selected by USU will be dependent on whether other investigators perform similar measurements. USU will deploy its systems every day during at least three inversion episodes (assuming inversion conditions develop), collecting measurements from sunrise to sunset. (APPENDIX IV Project 2)

3.3.3 Snow Photochemistry

The production of O_3 requires NOx, VOCs, and a source of radicals, i.e. precursor compounds that produce radicals when photolyzed. Traditionally, O_3 photolysis and subsequent reaction of excited oxygen atoms with water vapor has been thought to be the major source of radicals in the lower atmosphere. Low water vapor concentrations during the winter have brought up the possibility of additional radical sources driving O_3 chemistry in the Uintah Basin. The UBWOS 2012 study included a comprehensive set of measurements of NO_y compounds and speciated VOCs, both primary and photochemically produced, along with the three major possible additional radical sources: formaldehyde, HONO and $ClNO_2$. Those data enabled a detailed radical budget to be constructed which was found to be quite a bit lower than budgets from urban areas that experience photochemical ozone pollution. This was consistent with the lack of high ozone during UBWOS 2012. The lack of conditions that produce high O_3 in the Uintah Basin did not permit any definitive examination of the individual contributions of particular radical sources. Detailed measurements of radical sources are therefore key to the UBWOS 2013 Study. The three non-traditional radical precursor species are known to have heterogeneous sources from reactions at particle, ground or snow surfaces. Thus, snow chemistry and surface flux measurements are an essential aspect of this study component. This study component will also involve 3-dimensional measurements of ozone and meteorological data which will be integrated with vertical flux data and ongoing research in source characterization (both stationary and mobile) and numerical modeling of tropospheric photochemistry. Appendix V provides details concerning the measurement approach, project deliverables, schedule and budget for the proposed project component. This study component will be carried out at the Horsepool site since the previous measurements at this site has been found to be representative of the emissions in the gas production side of the basin and critical site development and preparation has already been done. (APPENDIX V Project 1.)

3.3.4 Long-Term Trends

This work has three main purposes:

1. Continue a historical record of concentrations of ozone, ozone precursors, and meteorology in the Uinta Basin.
2. Allow us to quantify impacts of temporal changes in meteorological conditions and anthropogenic activity in the Basin on air quality. This will lead to more accurate predictions of air quality in the Basin based on these controlling factors.

3. Provide data to validate the air quality models critical to the research and regulatory process.

Large investments of funding, equipment, and time were made by several agencies and donors to establish the Horsepool and Roosevelt monitoring stations in 2011-12 and efforts to improve and fully establish the sites as permanent monitoring stations for ozone and precursors are ongoing. Continuing support for these sites is critical to maximize the benefit of those investments. (APPENDIX IV Project 1)

3.3.5 Distributed Monitoring

Results from 2011-12 show that ozone precursors are unevenly distributed around the Basin, and meteorology in the Basin, especially surface airflow, is extremely spatially variable. Very few meteorological stations exist in the oil and gas producing areas of the Basin and only a handful of NO_x and VOC monitors exist in the Basin. Measurements at these few sites will not be adequate to characterize ozone and precursor concentrations and transport in this complex environment.

Passive measurements of VOC and NO_x in 2011-12 (at 10 and 16 sites, respectively) showed the spatial distribution of these compound groups in the Basin, indicating that VOC concentrations in the Basin were strongly correlated with proximity to oil and gas extraction activity and that NO_x concentrations were highest in urban areas and in the gas producing areas of Uintah County. These measurements also showed that areas of greatest VOC and NO_x were not the same as the area of maximum ozone production in Winter 2010-11.

Repeating similar measurements in winter inversion conditions will provide information about how ozone and precursors are transported during inversions and how NO_x and VOC and their reaction products are transported from source locations to areas with higher ozone. This will allow a determination of whether some areas of the Basin have a larger impact on ozone production than others and whether some areas of the Basin are isolated from others in terms of ozone production. (APPENDIX IV Project 3)

3.3.6 Ozone and Doppler LIDAR

There are several aspects of the wintertime ozone phenomenon that can only be understood through 3-dimensional measurements of ozone and winds. It is important to understand how widespread the high ozone is and the depth of the impacted layer. It is also important to know if there are plumes within the impacted layer and what that implies for contributing sources, e.g. the Bonanza Power Plant. The structure of horizontal and vertical winds determines how stable and persistent ozone events are likely to be.

This work will essentially duplicate the 2012 effort. Ozone and Doppler lidars will be deployed at Horsepool or nearby sites and will measure for up to 6 weeks during the high ozone season. The costs associated with this activity are personnel time, travel, and expendables. The major equipment costs involved in retro-fitting the O_3 lidar for ground work were covered by the 2012 funding. (APPENDIX V Project 3)

Ozone LIDAR: The TOPAZ Lidar will provide the shallow elevation angle and zenith-pointing measurements necessary to provide profiles of ozone concentration extending from near the surface to several kilometers above ground. TOPAZ will be mounted in a truck to facilitate easy deployment at multiple measurement sites. Composite ozone profiles with a time resolution of several minutes on a continuous basis during Intensive Operational Periods (IOPs) are expected. These observations will provide important information on the height, thickness and evolution of surface-based and elevated ozone and aerosol layers. Availability of the ozone profiles will enable characterization of how much, if any, ozone is being transported downward from the free troposphere, the degree of homogeneity within the surface-based boundary layer, and the influence of transport of ozone from residual layers on surface ozone measurements.

Researchers also anticipate being able to investigate horizontal variability of surface ozone over ranges extended to about 4 or 5 km from the lidar. For these measurements, researchers will point the lidar beam horizontally just above the surface and observe spatial and temporal variability of surface ozone.

Doppler LIDAR: In the strongly stable atmospheric conditions that will lead to high O_3 concentrations during this study, temporal and spatial variability–and in particular, strong vertical layering—make point measurements difficult to interpret and often not representative of the wider area. In a field program using high-precision, state-of-the-art chemistry measurements, it would be desirable to pair these data with the best available meteorological measurements, which would provide insight into transport pathways and therefore the locations of source activity as well as the vertical extent of flow and turbulent layers. These kinds of measurement are especially needed in highly variable stable conditions, which are the most challenging and poorly understood conditions in the atmosphere.

The current state of the art in wind velocity measurements in the lowest few hundreds of meters of the atmosphere is NOAA/ESRL CSD's High-Resolution Doppler Lidar (HRDL). The effectiveness of this system in revealing atmospheric structure in stable conditions has been well documented in numerous journal articles over the past several years (Banta et al. 2003, 2006, 2007, Pichugina et al. 2008, 2010). For example, one revealing study showed that Doppler Lidar could be used to determine the depth of the stable boundary layer to better than 10%, a measurement that previously carried an uncertainty of 30-40% or more using available technologies such as surface measurements or sodar. Deploying a Doppler Lidar will allow ambiguities in the inference of source locations and other transport issues to be addressed and will extend the usefulness of the dataset into time periods where the chemistry data alone are impossible to interpret.

3.3.7 Monitoring the Atmospheric Boundary Layer

The proposed work consists of three components for the January-February 2013 period: (1) provide baseline support to analyze conventional weather observations, atmospheric model analyses and forecasts, satellite imagery and other weather-related products to diagnose the synoptic and mesoscale circulations affecting boundary layer winds throughout the Uintah Basin that control the evolution of winter ozone concentrations; (2) continuously monitor low-level clouds and boundary-layer height during cloud-free periods at several locations in the Basin as well as monitor near-surface winds (5-200 m) in the Fort Duchesne area; (3) when conditions warrant, rapidly deploy weather monitoring equipment in the Fort Duchesne-Ouray corridor and north slope of the Tavaputs Plateau to define near-surface winds as well as periodic releases of rawinsondes to monitor temperature, moisture, and wind throughout the troposphere. Outreach to students at K-12 schools in the Uintah Basin is a key component of our proposed work including siting and real-time monitoring of sensors at schools as well as demonstrating how weather observations are collected.

3.3.8 Modeling Studies

Ultimately, a validated photochemical model that simulates winter ozone formation will be needed to fully understand and quantify the effectiveness of mitigation strategies, and to tailor an emissions reduction program that is appropriate for the Uintah Basin. This modeling framework will rely on the data collected from studies in the Basin to provide emission inventory inputs, meteorological inputs, boundary conditions, and validation of ozone and precursor concentrations estimated by the model. Some modeling efforts are already in progress For example, Utah BLM is funding modeling for calendar year 2010 to support NEPA analyses and the this modeling may be useful for evaluating winter ozone in the Uintah Basin during winter 2010. NOAA researchers are also performing meteorological modeling of winter 2012 to support analysis of measurements made during the 2012 winter ozone study. Additional modeling efforts will be needed after suitable ozone episodes are identified during winter 2013. Alternatively, modeling could be performed for observed winter ozone episodes during winter 2011. However, very limited precursor measurements were available during the 2011 episodes. The study team will develop recommendations for additional modeling studies after winter 2013.

3.4 Analysis of Collected Air Quality Data

An important part of the 2013 Winter Ozone Study is analyzing and reporting on the collected data and providing information regarding the formation of winter ozone. An analysis of the field measurements will aid in the development of a plan for reducing winter ozone formation. Elements of this effort include:

- Analyses of meteorological data to determine the extent to which meteorology plays a role in increasing levels of winter ozone. Sufficient information has been gathered for Wyoming to conduct such analyses and these analyses may provide insights into winter ozone issues in the Uintah Basin. Additionally, as a result of this study, there may be enough information to perform these analyses for the Uintah Basin.

- Reconciliation of ambient measurements with emission inventories needs to be performed. It is important to compare the speciation of source characterization hydrocarbon measurements with the speciation of hydrocarbon in emission inventories. If possible, it is also important to verify the source emissions rates and activity data. These analyses will provide confirmation of the emission inventories.

- Analyses of ambient measurements coupled with emission density can provide information regarding the spatial representative nature of the measurements.

- Analyses of the chemistry measurements to determine the VOC/NO_x regime and relative benefit of VOC versus NO_x emissions reductions for ozone mitigation.
- Identify potential ozone pathways unique to the Uintah Basin, e.g., snow surface chemical pathways.
- Develop a list of potential mitigation strategies based on the conceptual model of ozone formation in the Uintah Basin.

3.5 Summary of Requested Study Funding and In Kind Contributions

Study Components	Purpose	Research Organizations	Funding and Source
1. Aircraft Basin–wide Measurements	• Determine the vertical structure of the meteorology controlling the temperature inversions and ozone production zone • Measure the composition of, and trace the dispersion of the Bonanza power plant plume above and below the inversion cap • Measure the concentrations and distributions of ozone precursors and the concentration and distributions of ozone within and outside the ozone production zone • Connect airborne measurements with the Horsepool and Roosevelt super sites and the distributed ozonesondes sites,	NOAA (APPENDIX I)	Total: $545,000 • $240,000 – WEA • $305,000 – NOAA In kind
2. Vertical Profiling of Meteorological Variables, Ozone, Nitrogen Oxides, Methane, and Total Hydrocarbons using Tethered Balloon	Study sources, sinks, and distribution of ozone, nitrogen oxides, and hydrocarbons in the Uintah Basin by vertical profiling these gases using a number of tethered balloon systems. Losses due to deposition on snow will also be measured.	CU (APPENDIX III Project 1, 2) NOAA (APPENDIX II) USU (APPENDIX IV Project 2)	Total: $813,909 • $177,009 - BLM • $200,000 - CU In kind • $175,000 - WEA • $203,400 – NOAA In kind • $58,500 – UIMSSD
3. Wintertime Ozone Formation Chemistry -Horse Pool	Understand core chemical processes which control the formation of winter ozone and its sensitivity to VOC and NO_x. Detailed measurements of radical sources including formaldehyde, HONO and $ClNO_2$ and the impact	NOAA (APPENDIX V Projects 1 and 2)	Total: $1,195,000 • $334,000 – WEA • $541,000 – NOAA In kind • $116,000 – WEA

	of snow chemistry and surface flux measurements are needed.		• $204,000 – NOAA In kind
4. Long-Term Trends Wintertime Monitoring for Ozone, and Key Precursor Species - two “Super Sites”. a. Source Site (Horse Pool) b. Receptor Site (Roosevelt)	Obtain data to evaluate trends in ozone and precursors (precursor trends: speciated VOC: aromatics, alkanes, alkenes, carbonyls, etc., and for speciated NO_x: NO, true NO_2 and total NO_y). These measurements would extend over several winter seasons to capture baseline trends.	USU UDEQ (APPENDIX IV Project 1)	Total: $390,000 + • $130,000 – UIMSSD • $60,000 – UDEQ In kind • $200,000 – USU In kind
5. Distributed Monitoring	Provide information about how ozone and precursors are transported during inversions and how NO_x and VOC and their reaction products are transported from source locations to areas with higher ozone.	USU	Total: $132,500 • $132,500 - UIMSSD
6. Ozone and Doppler LIDAR; Continuous 3-Dimentional profiles of ozone and metrological conditions.	A. Ozone LIDAR will provide important information on the height, thickness and evolution of surface-based and elevated ozone and aerosol layers. B. Doppler LIDAR reveals atmospheric structure in stable conditions conducive to ozone production.	NOAA (APPENDIX V Project 3)	Total: $300,000 • $135,000 - WEA • $165,000 - NOAA In kind
7. Monitoring the Atmospheric Bounardy Layer	Monitor the boundary layer winds and heights to characterize dispersion and recirculation of emissions in the basin	U of U (APPENDIX VI)	Total: $54,970 • $54,970 - BLM
8. Photochemical Modeling of the Basin’s Airshed	Develop a model that simulates winter ozone formation and can be used to understand and quantify the effectiveness of mitigation strategies and to tailor an emissions reduction program that is appropriate for the Uintah Basin.	UDEQ USU	Total: $0 • No Funding is Requested
9. Analysis, Conclusions, and Recommendations for Mitigation. Report Drafting.	Integrate reports, draw conclusions, understand potential ozone formation mechanisms, identify sources of ozone precursors, and outline potential mitigation options. Draft final study report.	PIs UDEQ	Total: $80,000 • $30,000 - UIMSSD • $50,000 - BLM
Total Funding			**Total: $3,511,379** • **$1,632,979 Total Funded** • **$1,878,400 Total In kind**

Table 1. Summary of Uintah Basin Winter 2012-13 Ozone Studies and funding.

4. Roles and Responsibilities

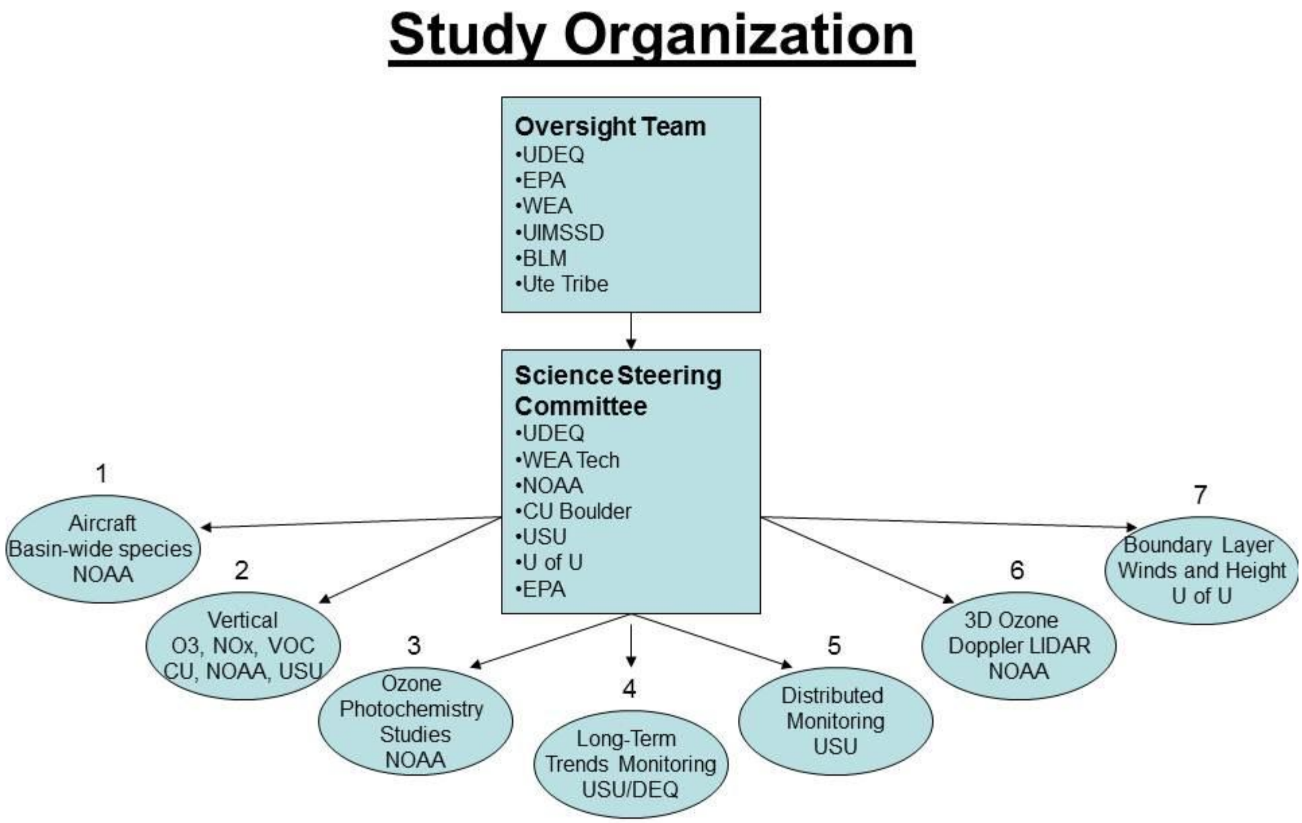
UDEQ will provide overall study management. The Oversight Team will be responsible for making high level study decisions and receiving periodic updates and reports from the Science Steering Committee. Oversight Team membership will consist of representatives from the agencies funding the Study. The Science Steering Committee will be responsible for coordinating the Study Component research, maintaining the study scope and schedule, and reporting progress. The Steering Committee will consist of representatives from each of the research groups and will be led by EPA.

Oversight Team

- Utah Department of Environmental Quality (UDEQ)
- Western Energy Alliance (WEA)
- Uintah Impact Mitigation Special Service District (UIMSSD)
- BLM (Utah Bureau of Land Management)
- EPA (Environmental Protection Agency)
- Ute Tribe

Science Steering Committee (research Principle Investigators (PIs))

- EPA
- WEA Technical Staff
- NOAA (National Oceanic and Atmospheric Administration)
- CU Boulder (University of Colorado at Boulder)
- USU (Utah State University)
- UDEQ
- U of U (University of Utah)



5. Deliverables and Schedule

5.1 Project Schedule

Study Plan Finalized (PIs)	November 1, 2012
Stake Holders/Funding Agencies Review Meeting	December 14, 2012
Science Team Meets to Evaluate Study Outlook	January 3, 2013
PI Window to Authorize or Cancel Study Begins	January 7, 2013
Bi-Monthly Status Calls Begin	January 15, 2013
End of Study Window	March 15, 2013
Preliminary Datasets Available	April 15, 2013
Individual Study Components Conclusion/Results Available	May 15, 2013
Post-Study Technical Meeting-Overall Conclusions (PIs)	May 31, 2013
Draft of Overall Study Conclusions/Recommendations	July 31, 2013
Draft Final Report with Study Conclusions/Recommends	August 1, 2013
Interim Findings Report Available	July 1, 2013

Draft Report Review Period	Aug-Sept 2013
Final Datasets Available	September 1, 2013
Final Report	October 1, 2013

5.2 Report Schedule

If conditions warrant conducting the Uintah Basin 2012-13 Winter Ozone Study, an integrated study report will be issued. . The integrated study report is scheduled for release on October 1, 2013. The report will integrate results and conclusions from the seven funded Study Components discussed previously, and will be edited by UDEQ or its contractor. The organizations responsible for submitting the individual study reports of results and conclusions for each Study Component are listed below:

<u>Responsible Organization:</u>

Study Component 1	NOAA
Study Component 2	NOAA/CU/USU
Study Component 3	NOAA
Study Component 4	USU
Study Component 5	USU
Study Component 6	NOAA
Study Component 7	UofU

In order to complete the final report on schedule, it is necessary that the various sections be contributed in a timely manner. The schedule for submitting the various sections of the report is shown below:

<u>Submission Schedule:</u>

Objectives	December 1, 2012
Approach	December 15, 2012
Implementation	April 1, 2013
Study Component Conclusions/Results	May 15, 2013

APPENDIX I

Proposed Airborne Trace Gas, Meteorology and Plume Tracking Measurements in the Uintah Basin, Winter 2013

Dr. Colm Sweeney, Director, CIRES and Carbon Cycle Aircraft Operations
Dr. Russ Schnell, Deputy-Director, Global Monitoring Division
Dr. Gabrielle Pétron, Scientist, CIRES and Global Monitoring Division
NOAA,
325 Broadway
Boulder, CO 80303
August 2012

1. Purpose and Needs:

Winter photochemical ozone production in the Uintah Basin is driven by the presence of strong, shallow temperature inversions that persist throughout the sunlight portion of the day. Extensive snow cover in the basin reinforces these inversions and traps gas/oil field effluents that are the ingredients for rapid photochemical ozone production beginning shortly after sunrise. The inversions also constrain the ozone to a shallow layer near the surface.

Knowing the basin-wide distribution of the temperature inversions as they evolve, the distribution and concentrations of the ozone precursor gases, the flow of the air in the basin and the potential contributions of NOx emissions from the Bonanza power plant are crucial to understanding the Uintah Basin winter ozone production phenomenon. The aircraft data will be crucial for the evaluation of all modeling efforts to reproduce ozone events and to test mitigation scenarios. Existing mesoscale models do not reproduce inversion events well such that model results may only be interpreted if the model limitations and biases are known. Direct observations of the winter-time ozone, precursors levels and meteorological patterns over the whole region are a necessary conditions to start understanding several of the mechanisms at play and put the Horse Pool and Roosevelt fixed site data into the larger context of the Basin. In other words, without this data in a basin-wide package it will not be possible to model the ozone production phenomena accurately.

The most cost effective and versatile means to address these questions is by conducting focused measurements with a well-instrumented light aircraft.

Aircraft Measurements in 2012: For the 2012 Uintah Basin Winter Ozone Study, NOAA brought in a high performance turboprop aircraft to track the distribution and flow of ozone and ozone precursors, measure gas and oil field effluents, map the basin wind field, measure the meteorology and to collect discrete air samples. The aircraft conducted 13 research flights of ~3-hour duration each and was able to profile to within 30 feet of the surface. This program, at no cost to the study sponsors, demonstrated the versatility and data gathering capabilities of the aircraft and produced a unique and very valuable data set. A view of the aircraft is presented in Fig. 1, gas inlets in Fig. 2, and the airborne gas sample flask collection system in Fig. 3.

Figure 1. 1998 Mooney TLS turboprop aircraft instrumented for high resolution in situ airborne gas and met measurements, and for collecting samples of VOCs and other gases for laboratory analyses.

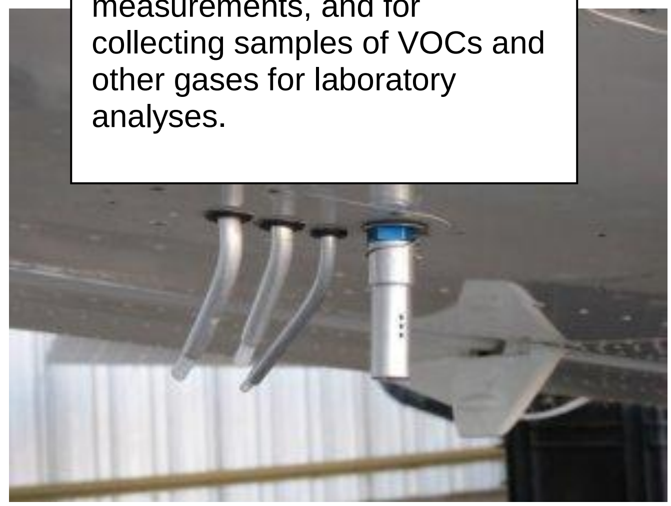


Figure 3. Automated aircraft flask (canister) sampler and pump package that can fill 12 flasks individually, either pre- programmed or on demand. Each flask can be filled in 10 seconds after flushing. Analysis of up to 60 gases or isotopes collected in the flasks are performed at laboratories in Boulder, Colorado. 120 flasks were collected and analyzed in the 2012 study.

Results from the 2012 Study: One of the more interesting and immediate results from the 2012 study was the observation that CH_4 was elevated to a much greater extent over the gas fields than over the oil field as shown in Fig. 4. Also in the 2012 study, power plant plume tracking was easily accomplished as shown in Figs. 5 and 6.

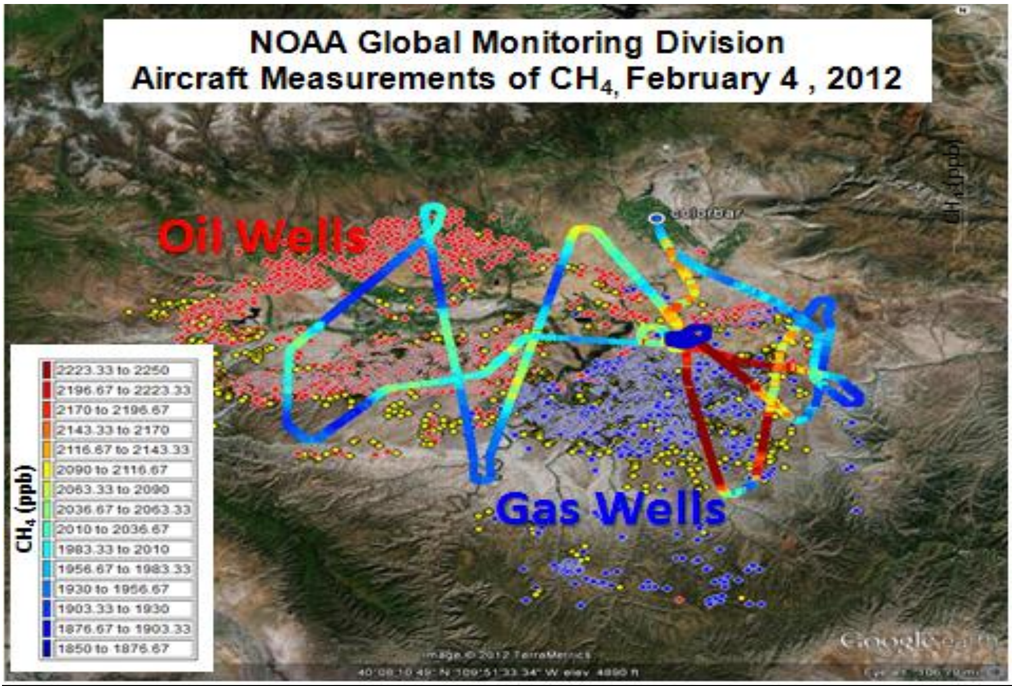


Figure 4. CH_4 concentrations measured in well mixed air over the Uintah Basin oil and gas fields showing higher CH_4 concentrations over the gas field relative to the oil field.

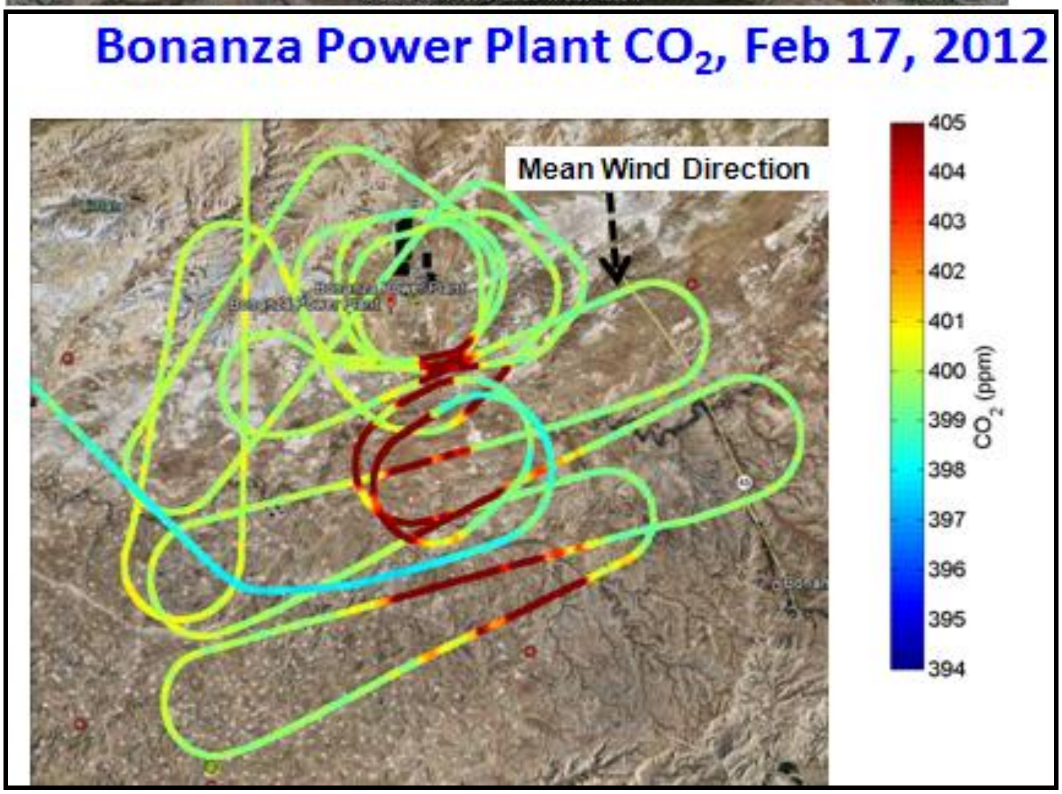


Figure 5. Tracking the Bonanza coal fired power plant plume by measuring the CO_2 in the plume. The plume was blowing southerly under light northerly winds.

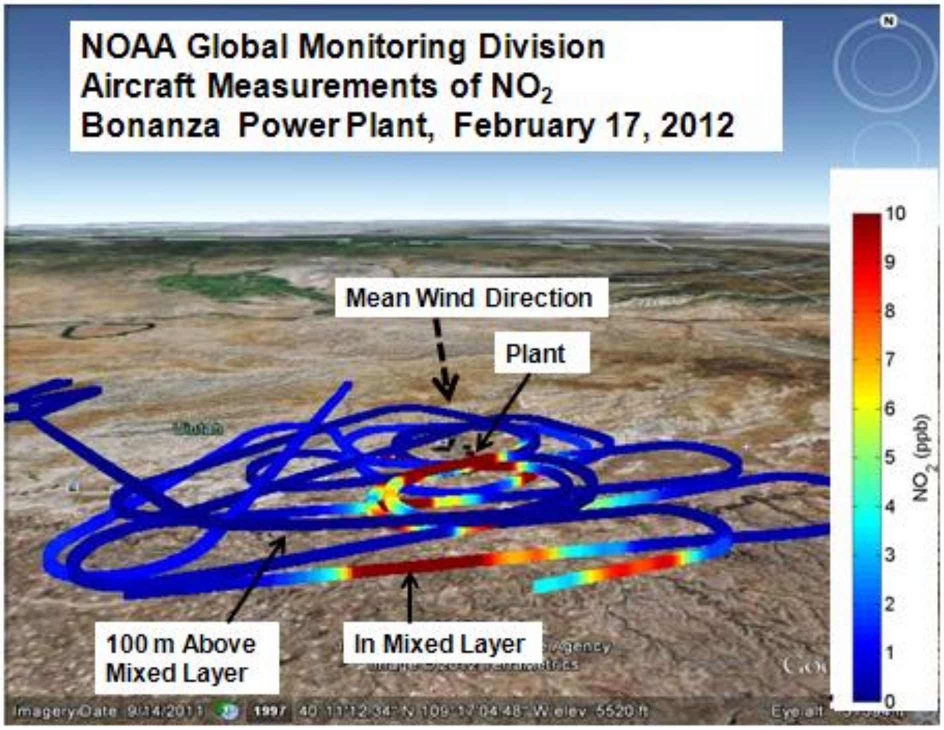


Figure 6. Tracking the Bonanza coal fired power plant plume by measuring the NO_2 in the plume.

The aircraft conducted numerous profiles upwind, within and downwind of the oil and gas fields to measure the concentrations of gas species of interest in the background air and concentrations of gas species originating within the fields. In Fig. 7 are shown profiles of CH_4 upwind and within the gas field, where it may be observed that significant enhancements of CH_4 were emitted from the gas field.

Data from discrete air samples collected by the aircraft are presented in Fig. 8. where it may be observed that concentrations of various hydrocarbons plotted against CH_4 concentrations show a high correlation. These data are used to estimate fluxes of Volatile Organic Compounds. The locations of the discrete air samples collected by the NOAA appointed light aircraft and the NOAA Mobile Lab are shown in Fig. 9.

Wasatch Front Measurements: There is a question of whether the Wasatch Front could be contributing precursor chemicals for ozone production in the Uintah Basin. To address this question, samples of air were collected with the NOAA operated aircraft in a well mixed boundary layer in the Salt Lake Valley and compared to air samples collected in the Uintah Basin. The locations of the discrete air samples collection are presented in Fig. 9. Fig.10 demonstrates that there are very low levels of alkanes in the Salt Lake Valley air samples suggesting the Wasatch Front is most likely not the source of the high alkanes observed in the Uintah oil and gas Basin. A similar flight could be conducted over the Wasatch Front during a high ozone episode to map the distribution of O_3 and its precursors over a more extended region. This work over extended distances can only be done with the aircraft.

Methane Profiles Upwind and Within the Uintah Basin Gasfield

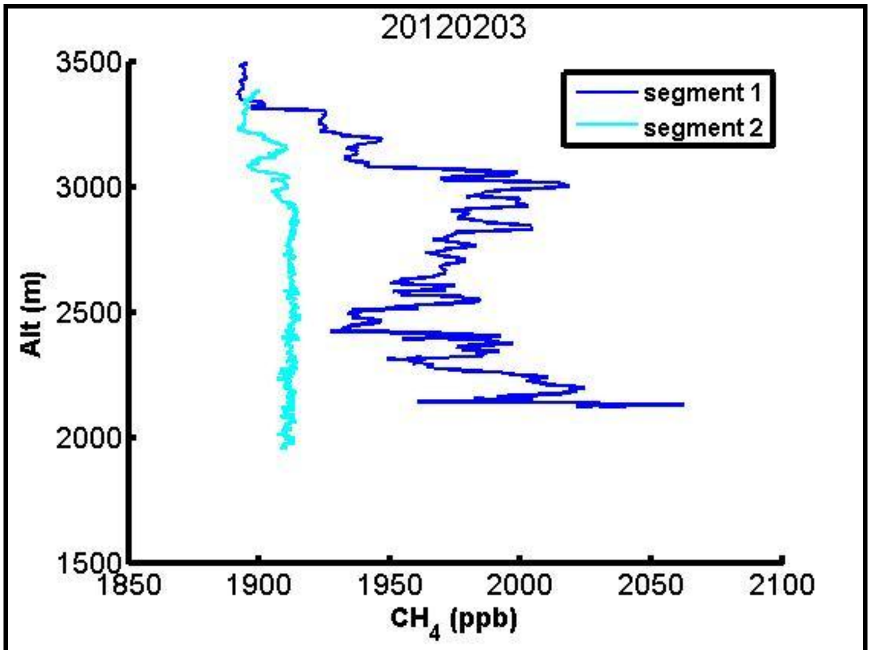


Figure 7. Profiles of CH_4 concentrations upwind and over the Uintah Basin Gasfield. The addition of CH_4 to the air as it flowed over the Gasfield is clear. This data is forming the basis for calculating a CH_4 emission factor for the Uintah gas field.

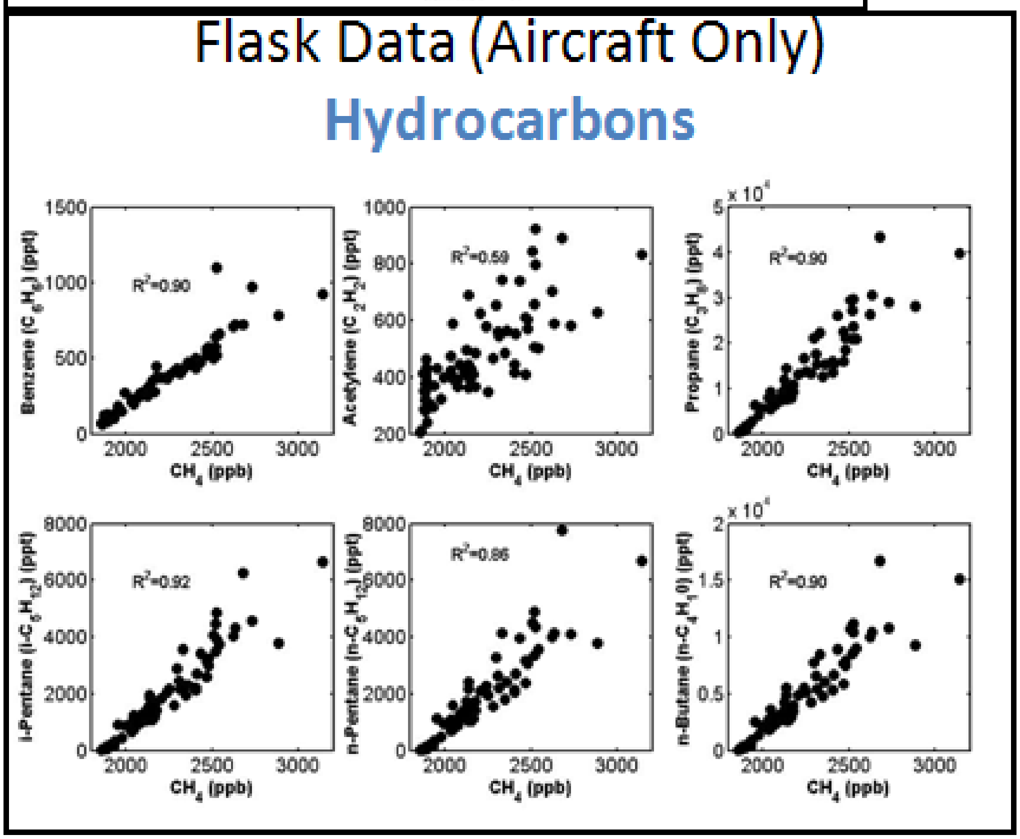


Figure 8. Various hydrocarbon concentrations plotted against CH_4 for air samples collected with the aircraft within the effluent plume of the Uintah Basin gas field.

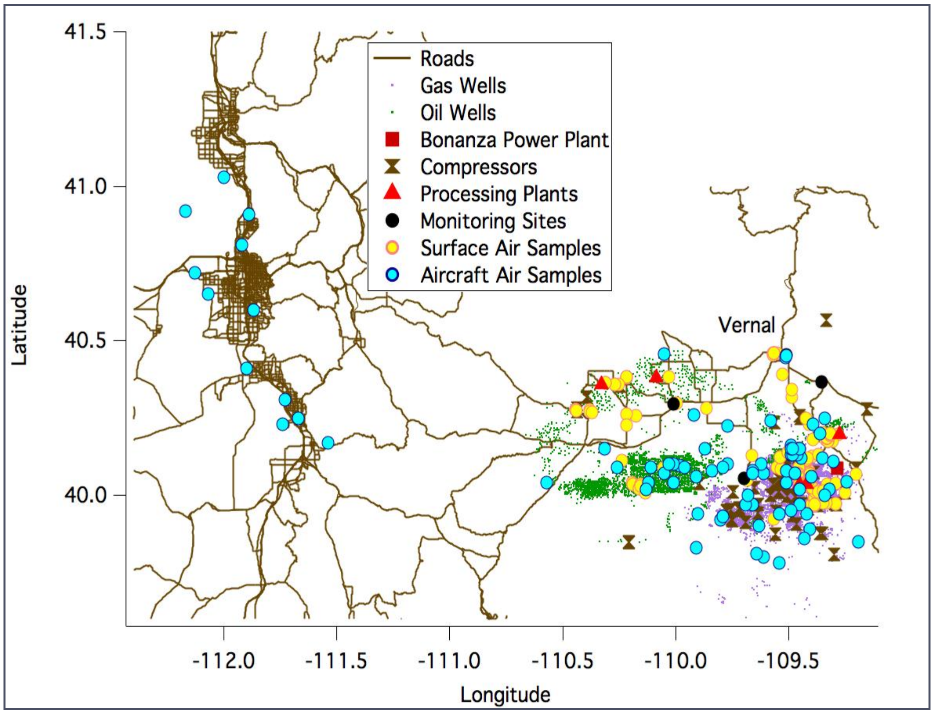


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Figure 9. NOAA airborne flask sampling in N.E. Utah, February 2 -21, 2012. Note the distribution of the samples in the Salt Lake Valley.

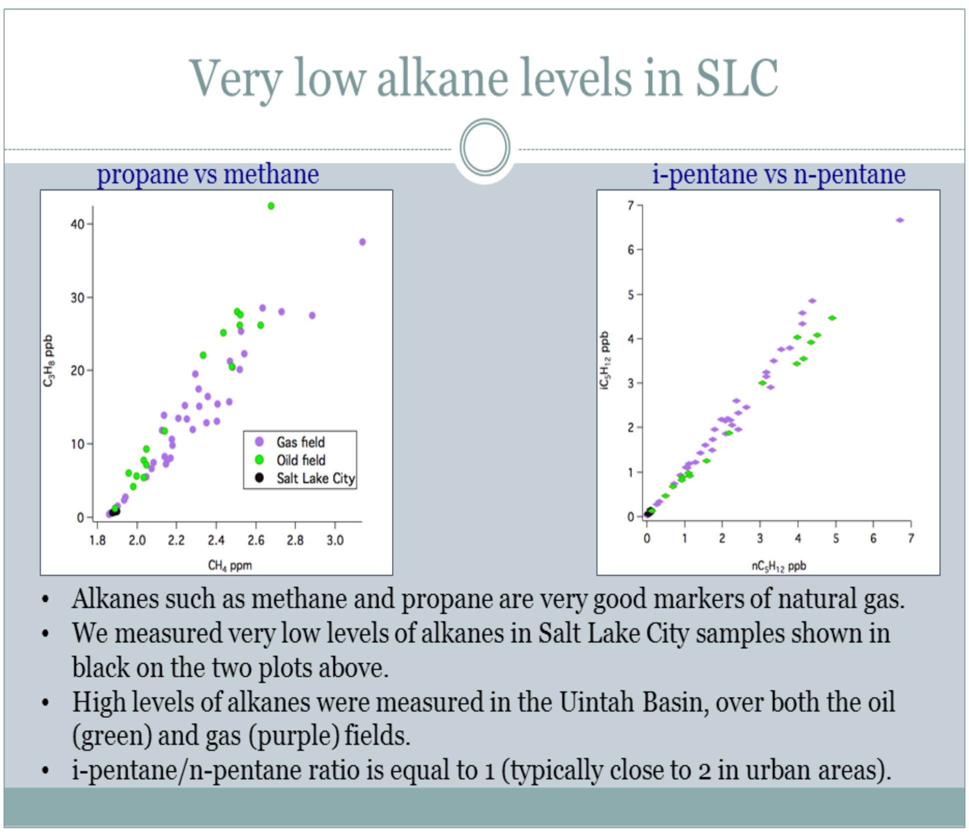

Figure 10. Concentrations of propane vs methane and i-pentane vs n-pentane in Salt Lake Valley and Uintah basin air samples showing that Salt lake City air is low in alkanes compared to Uintah oil and gas field air.

Similar measurements as demonstrated above, as well as new and enhanced measurements are proposed for the winter 2013 program. These are outlined later.

2. Approach and Deployment Plan for Winter 2013:

The aircraft will be instrumented and test flown in California the last week of January, 2013, or a week or two later depending upon the weather forecast. The aircraft will then be held on standby for deployment to Vernal on 2 days notice. On the third day after a "Go" it will be available for research flights.

The aircraft will fly 40 research hours over 11 days to:

- Determine the vertical structure of the meteorology controlling the temperature inversions and ozone production zone,
- Measure the composition of, and trace the dispersion of the Bonanza power plant plume above and below the inversion cap,
- Measure the concentrations and distributions of ozone precursors and the concentration and distributions of ozone within and outside the ozone production zone,
- Measure the ozone precursors, ozone and air mass tracers along the Wasatch Front during an ozone event and relate these measurements to the Uintah Basin,
- Connect airborne measurements with the Horsepool and Roosevelt super sites, the ground mobile labs, and the distributed ozonesondes sites,
- Profiles to as low as 30 feet above ground should be possible at a number of locations in the basin and the surface at a number of smaller airstrips in "touch and go" approaches.

3. Deliverables:

To understand the complex processes leading to wintertime high ozone levels in the Uintah Basin, we need to document how various precursor sources interact and are distributed throughout the basin. Oil and gas operations rely on a many different pieces of equipment with different VOC and NOx emissions profiles. Flying the instrumented aircraft above and into the inversion layer across the Uintah Basin will provide valuable information on how the boundary layer dynamics trap emissions and lead to ozone production and exceedences.

Specific deliverables will include:

- ✓ Airborne vertical profiles of NO_2, ozone, CH_4, CO, CO_2 (in-situ measurements) and VOCs (in canisters) upwind of, and across the Uintah basin to produce a three dimensional pictures of their distribution that, along with the ground based measurements, will help evaluate and constrain regional chemical models.

- ✓ Horizontal transects in the Basin and excursions above the boundary layer and beyond the basin's borders to provide key information on the contribution of background ozone and ozone precursors, vertical and horizontal mixing, and potential drainage effects.

- ✓ Determination of the possible contributions of the Bonanza power plant and the Wasatch Front airshed to elevated ozone production in the Uintah Basin.

- ✓ Development of emission factors for various gases released from the gas and oil fields.

- ✓ The data will be prepare and presented as illustrated in the Figures presented earlier in this proposal for data collected in the winter of 2012.

Species and Meteorology to be Measured by the Aircraft in 2013:
Table 1. Airborne In-Situ Real-time Measurements.

Species	**Precision**
O_3	1 ppb
NO_2	60 ppt (1- sigma, 1 second measurement)
CH_4/H_2O	1 ppb (each species at 10Hz)
CO_2	2 ppm
CO	7 ppb
Temperature	+/-0.1 C
Humidity	+/-5%
Wind Speed	+/-2 m/sec
Wind Direction	+/-20^0

Achievable Vertical resolution (aircraft speed: 3m/s):
CH_4, CO_2, Co, H_2O: 3 meters
O_3: ~30 meters
NO_2: 3 meters for high signals... ~30 meters in background.

Achievable horizontal resolution (aircraft speed: 50m/s):
The horizontal resolution will be more coarse as the speed of the airplane is faster.
CH_4, CO_2, CO, H_2O: ~ 50 meters
O_3: ~500 meters
NO_2: 50 meters for high signals... ~500 meters in background

Table 2. Trace Gases other than VOCs Measured in flasks (canisters).

Species	**Precision**
CO_2	0.1ppm
CH_4	1 ppb
N_2O	0.4 ppb
CO	1 ppb
H_2	0.3 ppb
SF_6	0.04 ppt

acetylene +/- 2% on the following species
propane
benzene
carbon tetrachloride
CFC-113
CFC-114
CFC-115
CFC-11
CFC-12
CFC-13
dibromomethane
dichloromethane
methyl bromide
methyl chloroform
methyl chloride
methyl iodide
bromoform
chloroform
carbon disulfide
Halon-1211
Halon-1301
Halon-2402
HCFC-141b
HCFC-142b
HCFC-22
HFC-227ea
HFC-125
HFC-134a
HFC-143a
HFC-152a
HFC-23
HFC-32
HFC-365mfc
i-pentane
n-butane
n-pentane
carbonyl sulfide
perfluoropropane

Table 3. VOC species.

AIRS No.	**Abbr.**	**Compound**	**Class**	Levels < 250 pptv Uncertainty	Levels > 250 pptv Uncertainty

43206	acety	Acetylene	Olefin	<20%	<10%
43203	ethyl	Ethylene	Olefin	<40%	<20%
43202	ethan	Ethane	Paraffin	<10%	<5%
43205	prpyl	Propylene	Olefin	<20%	<10%
43204	propa	Propane	Paraffin	<20%	<5%
43214	isbta	Isobutane	Paraffin	<20%	<5%
43280	1bute	1-Butene	Olefin	<20%	<10%
43212	nbuta	n-Butane	Paraffin	<20%	<5%
43216	t2bte	trans-2-Butene	Olefin	<20%	<10%
43217	c2bte	cis-2-Butene	Olefin	<20%	<5%
43221	ispna	Isopentane	Paraffin	<20%	<10%
43224	1pnte	1-Pentene	Olefin	<20%	<10%
43220	npnta	n-Pentane	Paraffin	<20%	<10%
43243	ispre	Isoprene	Olefin	<20%	<10%
43226	t2pne	trans-2-Pentene	Olefin	<20%	<10%
43227	c2pne	cis-2-Pentene	Olefin	<20%	<10%
43244	22dmb	2,2-Dimethylbutane	Paraffin	<20%	<5%
43242	cypna	Cyclopentane	Paraffin	<20%	<5%
43284	23dmb	2,3-Dimethylbutane	Paraffin	<20%	<5%
43285	2mpna	2-Methylpentane	Paraffin	<20%	<5%
43230	3mpna	3-Methylpentane	Paraffin	<20%	<5%
43246	2m1pe	2-Methyl-1-Pentene	Olefin	<20%	<10%
43231	nhexa	n-Hexane	Paraffin	<20%	<5%
43262	mcpna	Methylcyclopentane	Paraffin	<20%	<5%
43247	24dmp	2,4-Dimethylpentane	Paraffin	<20%	<15%
45201	benz	Benzene	Aromatic	<20%	<10%
43248	cyhxa	Cyclohexane	Paraffin	<20%	<5%
43263	2mhxa	2-Methylhexane	Paraffin	<20%	<5%
43291	23dmp	2,3-Dimethylpentane	Paraffin	<20%	<5%
43249	3mhxa	3-Methylhexane	Paraffin	<20%	<5%
43250	224tmp	2,2,4-Trimethylpentane	Paraffin	<20%	<5%
43232	nhept	n-Heptane	Paraffin	<20%	<5%
43261	mcyhx	Methylcyclohexane	Paraffin	<20%	<5%
43252	234tmp	2,3,4-Trimethylpentane	Paraffin	<20%	<10%
45202	tolu	Toluene	Aromatic	<20%	<10%
43960	2mhep	2-Methylheptane	Paraffin	<20%	<10%
43253	3mhep	3-Methylheptane	Paraffin	<20%	<10%
43233	noct	n-Octane	Paraffin	<20%	<10%
45203	ebenz	Ethylbenzene	Aromatic	<20%	<10%
45109	m/pxy	m/p-Xylene	Aromatic	<20%	<10%
45220	styr	Styrene	Aromatic	<20%	<10%
45204	oxyl	o-Xylene	Aromatic	<20%	<10%
43235	nnon	n-Nonane	Paraffin	<20%	<10%

45210	ispbz	Isopropylbenzene	Aromatic	<20%	<15%
45209	npbz	n-Propylbenzene	Aromatic	<20%	<15%
45208	124tmb	1,2,4-Trimethylbenzene	Aromatic	<20%	<15%
45207	135tmb	1,3,5-Trimethylbenzene	Aromatic	<20%	<15%
45211	oetol	o-Ethyltoluene	Aromatic	<20%	<15%
45212	metol	m-Ethyltoluene	Aromatic	<20%	<15%
45213	petol	p-Ethyltoluene	Aromatic	<20%	<20%
45218	mdeben	m-Diethylbenzene	Aromatic	<20%	<20%
45219	pdeben	p-Diethylbenzene	Aromatic	<20%	<20%
45225	123tmb	1,2,3-Trimethylbenzene	Aromatic	<20%	<20%
43238	ndec	n-Decane	Paraffin	<20%	<20%
43954	nundc	n-Undecane	Paraffin	<25%	<25%

4. Schedule:

- January, 2013: Stage aircraft ground support equipment and flask packages to Vernal, Utah,
- January/February 2013: Prepare aircraft for a fast deployment to Utah from California in anticipation of an intensive Uintah Basin operation,
- Begin aircraft operations the day after arrival in Vernal,
- Aircraft in situ data available in rough form either in real time transmitted from the aircraft or within 24 hours of completion of a flight,
- Preliminary aircraft data will be made available within two months of the end of the project,
- Flask sample data begins to be available within 2 months, complete data set in 5 months.
- First cut analysis available within 6 months,
- Completed data analysis in 9 months. Preliminary report prepared.
- Publications submitted in 12 to 18 months.

5. Budget:

		$K
• Flight hours (40 research @$675/hr)	=	27
• Test and ferry flight hours (10 @ $600/hr)	=	6
• Pilot and 2 support staff salaries and per diem	=	35

- Flask Analyses (76flasks, up to 66 @ $500/flask) = 38
- Senior research scientists (2 for 3 mo/each) = 75
- Per Diem (2 field scientists) = 4
- Ground transport for research staff and aircrew = 3
- Standard gases and supplies for aircraft instruments = 20

	Sub-total	= 208
NOAA Offsite Overhead Fee @ 20%		= 42
	Total Requested	**= $250K**

NOAA will contribute equipment (instruments on aircraft and in the NOAA Boulder laboratory), 2Ph.D. scientific staff, data processing, management and facility support, laboratory analyses and data publication at **no cost** to the project.

"**NOAA In kind" contributions for 2013 project.** = **$295K**

Should the program be cancelled after instrumentation was installed and test flown but prior to deployment, there would be a $25K cost to cover installation, flight and standby expenses.

END

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mponent 1 – Long-Term Wintertime Monitoring for Ozone and Key Precursor Species

APPENDIX II

Proposed NOAA Radiosonde and Ozonesonde Measurements in Support of the 2013 Uintah Basin Winter Ozone Study

Drs. Bryan Johnson, Irina Petropavlovskikh and Russ Schnell
National Oceanic and Atmospheric Administration
Global Monitoring Division
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Irina Petropavlovskikh irina.petro@noaa.gov

August 2012

1. Purpose and Needs:

Winter photochemical ozone production in the Uintah Basin is driven by the presence of strong, shallow temperature inversions that persist throughout the sunlight portion of the day. Extensive snow cover in the basin reinforces these inversions and trap gas/oil field effluents that are the ingredients for rapid photochemical ozone production beginning shortly after sunrise. The temperature inversions that are typical for winter season in Uintah Basin also constrain the ozone to a shallow layer near the surface and allow it to accumulate over several days before the inversion lifts and the boundary layer mixes with the free tropospheric air.

To understand the evolution of the temperature inversions and the associated photochemical ozone production, the vertical structure of the lower atmosphere in the Uintah Basin must be continuously monitored from the surface to above the top of the temperature inversion. It is important to track the spatial and temporal extend of the boundary layer prior to, during and following ozone production events. Since the ozone production events spatially evolve within a few hours, the atmospheric profiles of meteorological parameters and ozone concentrations must occur on a scale of under an hour, and be continued for up to 3-4 days.

This data is crucial to understanding the meteorological constraints on the ozone production and are requisites as inputs for initializing and verifying ozone production models.

This data is collected most economically, reliably and accurately with small meteorological balloons carrying ozonesonde and radiosonde instruments that are operated by a small computer-based controlled winch system that allows for profiling up to 1,000 feet above the surface. *Martin et al., 2011* showed that ozone capping temperature inversion in the Uintah Basin were under 1,000 feet in depth and most usually 200-300 feet above the surface.

Continuous data transmission from the sondes is received and recorded at the surface and is available for quality check and analyses within several minutes of collection. The balloons can complete vertical sampling of coincident ozone, temperature, humidity and GPS altitude profiles at one-second resolution and within 30 minutes from the launch. The same instrument packages can be continuously re-used for the duration of a project, while only requiring a battery exchange every four hours.

This system was developed for the 2012 Uintah Basin ozone production study (see Figure 6) and conducted measurements at 4 different sites for a total of 145 ozone profiles.

Data to be gathered in 2013. In 2013 we propose to conduct an extended **set of ozone and meteorological** measurements beyond that undertaken in 2012. Upper panel of Fig 1. presents an example of a typical tethered-sonde profile of ozone and temperature. The lower panel shows a graph of altitude of the sonde versus time of the tethersonde operations. Time recordings of ozone concentrations, temperature, battery voltages of the radio-sonde and pump temperatures are also presented in the lower panel. Keeping these operating parameters within a well-defined range is important in maintaining high quality data.

Fig. 2 (right panel) presents climatology of 145 ozone profiles conducted during the 2012 study. Left panel in Figure 2 shows location and number of ozone sond launches at several sites in the Uintah basin and location of gas wells/pump station (green and red points). Results of Fig. 2 reveal that there were no elevated levels of ozone production during the month-long study as 50 ppb and less ozone may be considered background ozone concentrations during this period.

A cross-section of ozone measurements during one day at Ouray Wildlife Refuge is constructed from 20 vertical profiles over 12 hours (Figure 3). It can be noticed that in the early morning ozone was depleted near the surface and by shortly after noon ozone concentrations were at the peak for the day and well mixed to 300 m and above.

Fig. 4 presents temperature profile/time cross-section derived from 20 tethersonde profiles that correspond to the dates and time of the ozone data presented in Fig. 3.

Similar profiles will be obtained in 2013. Data collected in Uinta by tethered balloon system will capture the timing, distribution and structure of the ozone production zones controlled by the ambient meteorology.

2. Measurement and Deployment Plan:

NOAA proposes to conduct an ozone production and distribution study through tethersonde profiling and surface measurements similar to that undertaken in 2012, but with some additions and refinements. We propose to have two fixed bases (Ouray Wildlife Refuge and Jenson Greenhouse) where we will conduct continuous profiling of ozone, temperature and water vapor for 24 hours a day, prior to, during and following a major ozone production event.

We would also have two additional mobile tethersonde systems that we could deploy anywhere in the Uintah Basin with the purpose to address measurements at daily detected hotspots or to help calibrate other fixed based measurements such those at Horsepool or Roosevelt.

Pre-Positioning and Cancellation costs. We would pre-position the tethersondes, other support equipment and helium in the Uintah Basin a few weeks prior to the expected study period. We would then deploy our personnel from Boulder, CO when an event was imminent or just getting underway. As such, we would be able to begin measurements within 12-18 hours after a "GO" is announced.

In the event of a project cancellation after the initial pre-positioning, there would be a cost of $20K for the preparation, travel, helium delivery, housing cancellation fees etc.

3. Deliverables:

NOAA will produce data such as presented in Figs. 1-5 from 3-5 sites in the Uintah Basin and in addition produce cross-sections of humidity in a similar manner. A continuous ozone monitor will be operated at the surface at Ouray and mobile ozone monitors operated in each of the 3 NOAA support vehicles as they drive around the Uintah Basin servicing the tethersonde sites. These mobile ozone monitors could also be used to map ozone production hotspots.

The tethersonde ascent and descent rates can be controlled to produce vertical resolution of 1 foot or less of the measured parameters dependent upon wind speed. Very fine detailed vertical profiles will be conducted to link the initiation of ozone production in response to accumulation of snow on the ground, whereas higher humidity is expected near the snow surfaces. Also, if ozone production is found to be initiated above the surface, the boundaries of these zones will be delineated as the data from the sondes would be plotted on a computer screen in real time. The tethersondes can be controlled to change height in discrete segments of inches within seconds of observing a zone of interest. Height and atmospheric pressure of sampled air mass is measured by the GPS system attached to the ozone sonde. .

The data to be collected will allow for unambiguous determination of where, when and under what meteorological conditions the photochemical ozone is produced. These data will be required for inputs to models describing and predicting the ozone formation processes.

4. Schedule:

- January, 2013: Pre-positioning of sondes, support equipment and helium.
- Within 6 hours of a “GO” decision staff will be on the road to the Uintah Basin.
- Day following a “Go” decision, measurements begin.
- Measurements continue for up to 11 days.
- Preliminary data available in near real-time.
- First plots and preliminary data report 30 days after project completion.
- More polished analysis and report available 90 days after project completion.
- Final report available 6 months after project completion.

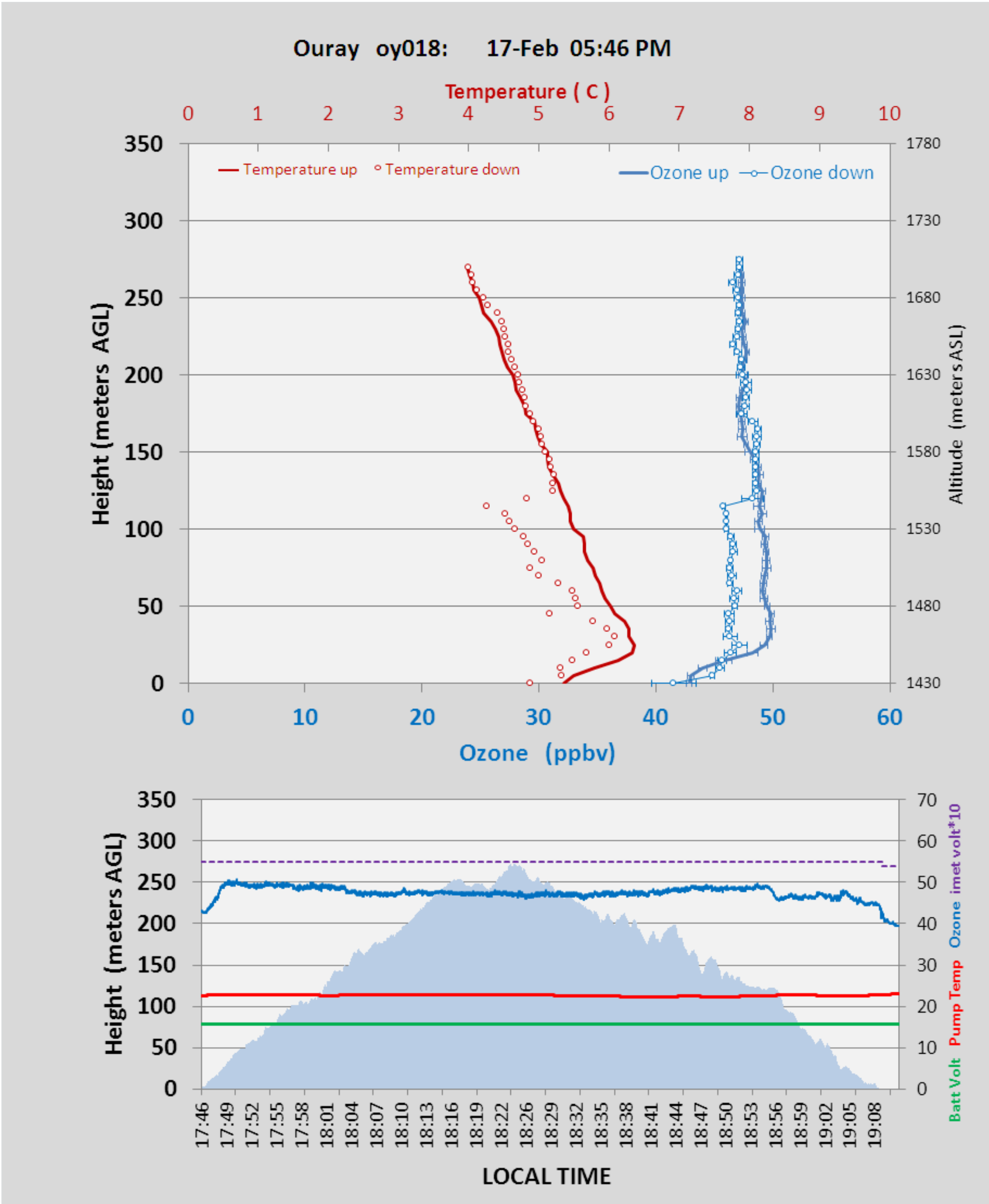

Figure1. Temperature and ozone concentrations in a vertical profile taken at Ouray Wildlife Refuge, February 17, 2012 (upper panel) and height versus time and sonde temperature and battery voltages for QA/QC during the profiles.

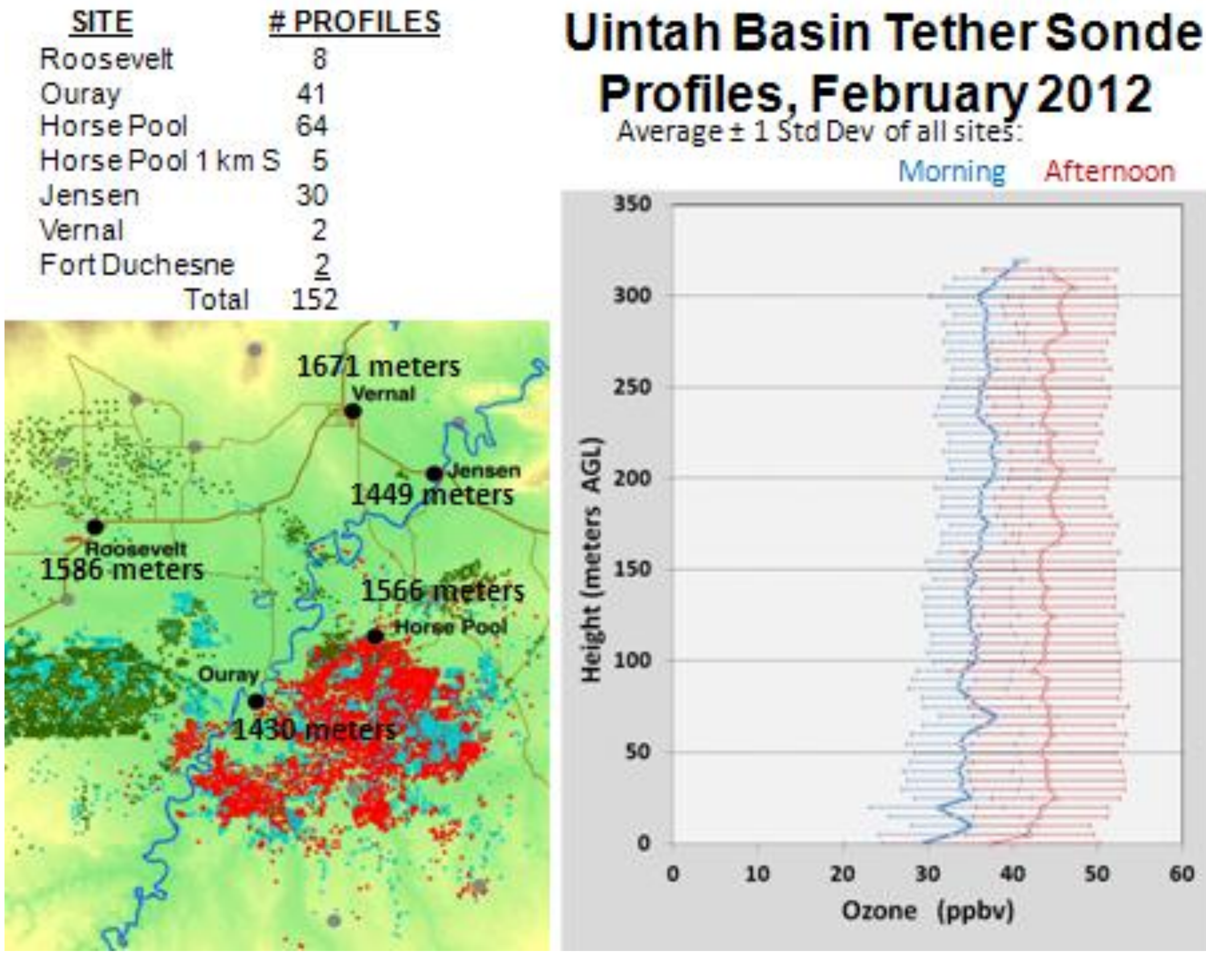

Figure 2. Vertical profiles of ozone ranging from 30-50 ppbv measured by tethered ECC ozonesondes with one standard deviation bars. The peak ozone values were measured between 2 and 4PM local time.

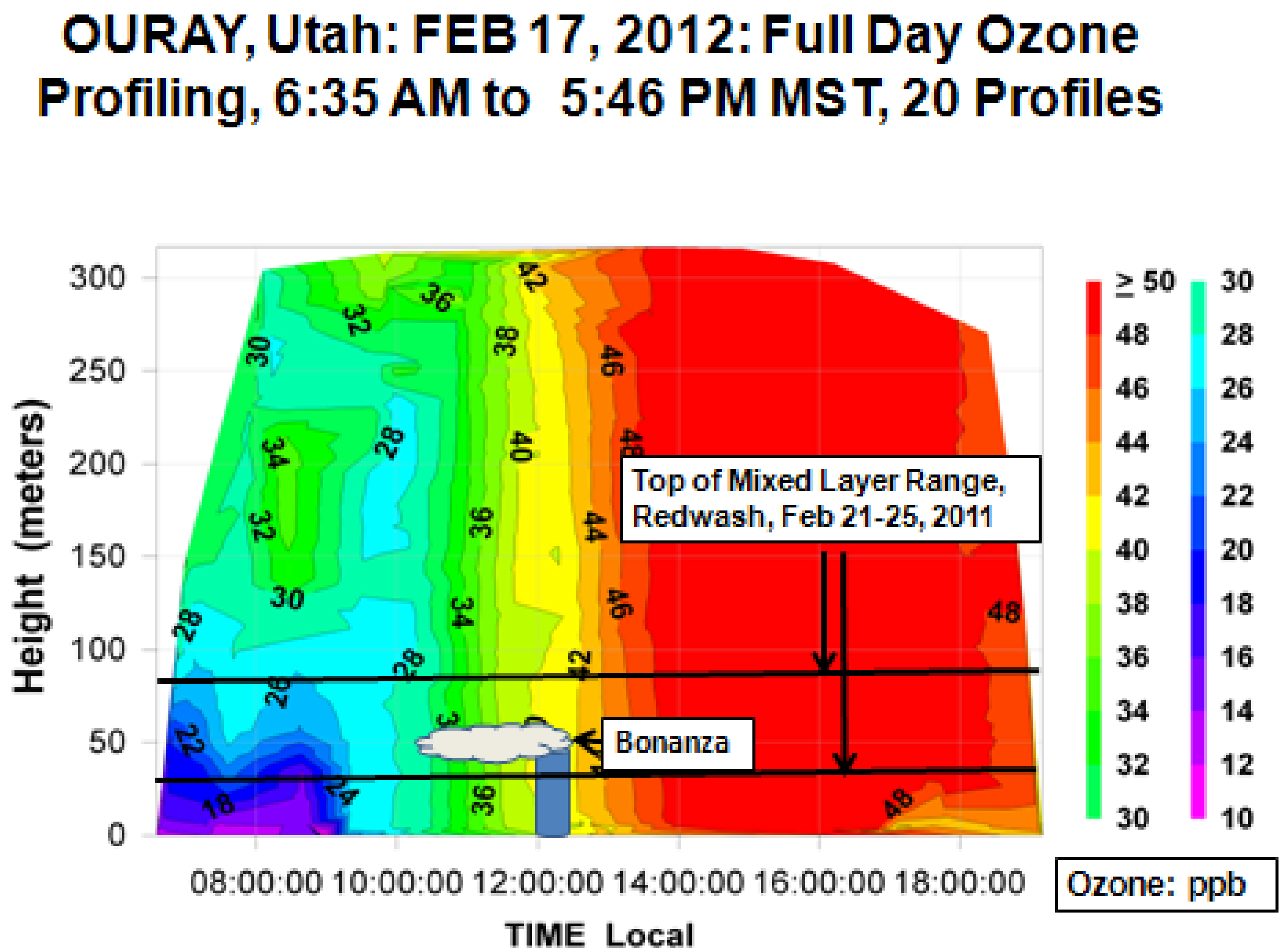

Figure 3. Cross-section of ozone concentrations for one day (February 17, 2012) at the Ouray Wildlife Refuge with the measured heights of the temperature inversion layer measured in the 2011 study. Also shown is a graphical presentation of where the Bonanza power plant stack would appear relative to observed range in the 2011 inversion layer.

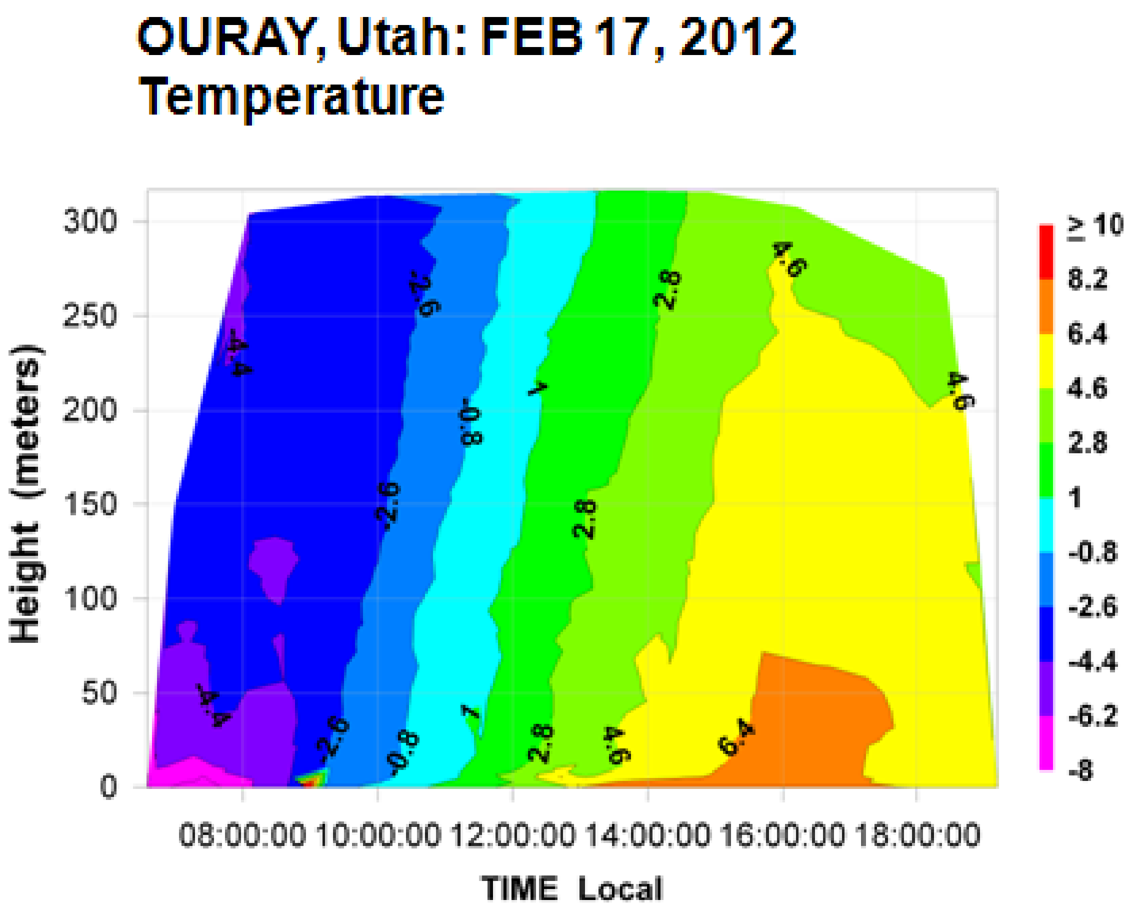

Figure 4. Temperature cross-section for February 17, 2012 from tethersonde measurements at the Ouray Wildlife Refuge showing the heating of the atmosphere during the day.

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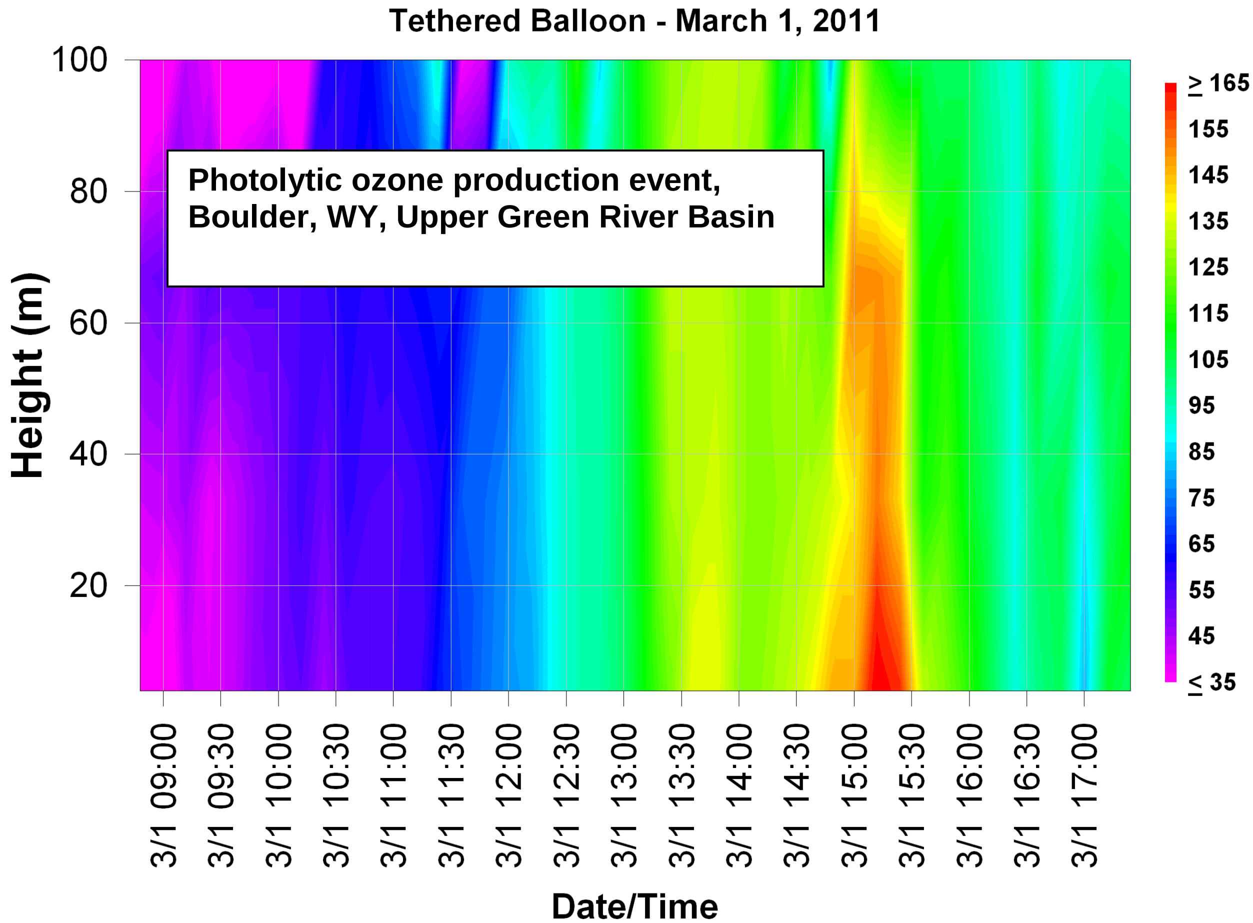


Figure 5. Wintertime ozone production event measured near the Boulder site in the Upper Green River Basin, Wyoming, March 1, 2011. The data were collected with a balloon system with stationary inlets at 4 heights. The system to be operated in the Uintah Basin in 2013 will produce data with 100 times better height resolution and will have temperature and humidity with the same resolution. *Data Source: Wyoming Department of Air Quality, Cheyenne WY.*

Figure 6. Tethersonde system demonstration, EDL, Vernal, UT, March 2012.

Table.1. Operational specifications for:
A. 2B Ozone Monitors.
B. ECC ozonesonde.
C. Radiosonde released with the Ozonesondes.

A. 2B Ozone Monitors
Principle: Dual path UV Absorption at 254 nm
Accuracy: 1.0 ppb
Precision: 1.0 ppb
Range: 1-250 ppb
Calibration: NIST Traceable
Data rate: 2 s
Data Availability: Basic data in near real-time, error checked and reprocessed data with 24 hours.

B. ECC Ozonesonde Measurement Specifications:
Principle: Electrochemical Concentration Cell
Accuracy Troposphere: ± 2 ppbv (parts per billion by volume)
Accuracy Stratosphere: ± 4% of reading.
Precision: ± 3%
Tethered Vertical Resolution: 1 foot

Altitude Range: surface to 35 km (free float); surface to 1,000 feet tethered
Data frequency: one second
Calibration: Absolute measurement method prior to launch. Regular instrument checks done at GMD ozone laboratory using UV calibrator traceable to NIST ozone instrument.
Data Availability: Real time to 95 % accuracy, reprocessed final data within 4 hours.
Number of free flying ozonesondes per day: up to 6
Number of tethersonde profiles per day: up to 100

C. Radiosonde Specifications :
Temperature accuracy/precision: ± 0.2 C / 0.2 C
Humidity accuracy/precision: ± <3% / 2%
Pressure accuracy/precision: ±0.5hPa (millibars) / 0.5 hPa
Range: up to 90 miles

5. Budget:

Salaries, benefits and overheads for 5 CIRES 24-hour operation of the tethersondes will require 8 staff in the field working 12 hour shifts for up to 10 days continuous. The salary component covers preparation, data acquisition, analysis and data publication. No salaries or benefits for 2 federal staff are requested as they are provided by NOAA in-kind contributions.	**$116,000**
Travel and per diem	**$22,000**
Transportation 4 vehicles, 14 days, rent and fuel	**$5,500**
Helium	**$2,500**
Ozonesondes, radiosondes, balloons, parachutes, tethers etc. These items are available from 2012 purchases	**0**
Post Study Meetings (salaries, travel and per diem)	**$6,000**
Sub Total	**$152,000**
NOAA Off-site administrative and facility support overhead @ 20%	**$30,400**
Total Requested	**$182,400**
NOAA matching funds) Federal salaries (2), benefits, OH and NOAA equipment costs	**$ 196,000**

APPENDIX III

Continuous Vertical Profiling of Meteorological Variables, Ozone, Nitrogen Oxides, Methane, and Speciated Volatile Organic Compounds from a Tethered Balloon and Ozone Deposition Rate Measurements during the Winter 2012/2013 Uintah Basin Ozone Study

A Proposal Submitted by

Detlev Helmig

Institute of Arctic and Alpine Research

University of Colorado, Boulder

August 24, 2012

1. Tethered Balloon Vertical Boundary Layer Profiling

Study Objectives

The objective of this project is to study the sources, sinks, and vertical distribution of methane, ozone, and the ozone precursor species nitrogen oxides, and volatile organic compounds (VOC) during snow cover conditions at the Horsepool site in the Uintah Basin. This research will be conducted by continuous vertical profiling of these gases from a tethered balloon platform, in a very similar manner to our previous winter experiment at the same site. A Sky-Doc balloon will be kept at 500 feet above the ground and used as a 'sky hook'. Vertical profiles will be obtained in two different manners. Air will be sampled from three stationary inlets attached to the balloon tether line at three heights through 600 feet long Teflon tubing. In a second type of experiment an inlet/sampling line will be moved from the surface to the balloon up and down using a second smaller tether/winch system. Meteorological variables that will be monitored in concert with the chemical observations will allow linking the chemical behavior of these important photochemical gas species to synoptic, micrometeorological, and boundary layer stability conditions and upwind source regions.

This experiment will build upon our experience using tethered balloons for investigating the vertical and temporal distribution of trace gases in the atmosphere [*Guenther et al.*, 1996] [*Helmig et al.*, 1998] [*Greenberg et al.*, 1999] [*Helmig et al.*, 2002] [*Helmig et al.*, 2008a] [*Helmig et al.*, 2008b]. An emphasis of this work has been the development of techniques and research applications over snow-covered landscapes. In this context we have developed novel approaches for the particular requirements of chemical measurements from tethered balloon platforms during harsh winter and polar conditions.

This experiment was deployed with high success during the 2012 Uintah Basin Ozone Study where we were able to operate the profiling platform for more than 80% of the time, yielding in excess of 500 hours of vertical profile observations (Fig/ 1). The few interruptions were due to inclement weather conditions, when it was deemed unsafe to operate the balloon in high winds. The density and resolution of our measurements from this experiment is unprecedented in tethered balloon profiling for atmospheric research. Obtained data proved to be highly valuable for defining the chemical and meteorological behavior of the lower atmosphere in the Uintah Basin. Highly variable and strong vertical gradients of nitric oxide ozone, NOx, methane, and non-methane hydrocarbons were found (see below). Concurrent meteorological measurements illustrate the dependency of chemical gradients on boundary layer (BL) conditions. Strong chemical gradients developed under conditions of increased atmospheric stability at nighttime.

Figure 1: *The CU Boulder Sky-Doc tethered balloon system deployed at the Horsepool site in the Uintah Basin during February 2012. The balloon winch and the instrument trailer are visible in the forground, below the balloon. At the time of this picture the balloon was kept near the surface for instrument maintenance.*

There were no snow precipitation events during the February 2012 study. Consequently, boundary layer mixing was not as strongly suppressed and chemical gradients of gases emitted from surface sources were not as strong/pronounced as what is typically observed above snow on the ground. To illustrate the type of stratification and concentration enhancement that can develop over snow, Figure 2 shows results from nitric oxide (NO) vertical profiling over the polar snow at the South Pole, Antarctica, as measured with our balloon system [*Helmig et al.*, 2008b]. With snow on the ground, vertical mixing is primarily driven by wind shear. Consequently, under calm conditions, even during daytime, the atmosphere remains very stable, allowing surface emission to accumulate over hours and days. The NO profile data shown in Figure 2 show NO levels that drop from 300 pptv to approximately 30 pptv, a mere one tenth, from the surface to 100 m height under such conditions. These chemical gradients and enhancements near the surface cause a very strong chemical gradient in photochemical reactivity and ozone production with height. We anticipate a similar behavior in the Uintah Basin during snow cover conditions on the ground, however, due to the lack of observations under such conditions we do not yet know to what concentration levels surface emissions will build up for the conditions found in this environment and at what rate concentrations decline with height above the ground. The tethered balloon measurements are an ideal and cost efficient way for achieving the high time and vertical resolution data that are needed for proving the surface chemistry in the shallow inversion layer that are typical over snow.

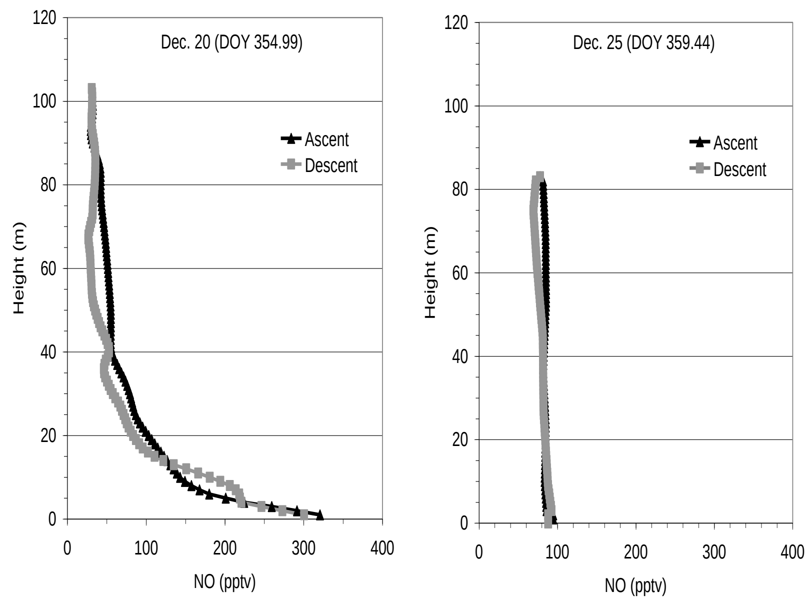


Figure 2: Vertical concentration profiles of NO over snow at South Pole. The data in the left graph were measured with the tethered balloon long sampling line experiment during a period

Experimental Approach

Federal Aviation Administration (FAA) approval: The proposed experiment will focus on the study of the surface/boundary layer over snow, which typically is rather shallow, many times on the order of <100-200 m. Therefore, the experiment will entail profiling within the 500 feet-above ground ceiling that is set by the FAA for balloon operation without requirement of special FAA permits and waivers. For operation to 500 feet, notification of the regional FAA flight operations office for placing a Notem is the only requirement. We will follow this procedure and fully apply with FAA regulations in all aspects of the tethered balloon operation.

Balloon platform: Our mobile equipment trailer will be deployed at the site for use as a field laboratory and instrument shelter adjacent to the balloon launch site. We will again use helium-filled Sky-Doc balloons (Fig. 1), which have a proven track record for field research under winter and polar climate conditions. Sky-Doc balloons combine properties of both blimps and kites, and can be flown in higher winds than blimp-type systems (http://www.skydocballoon.com). Since there is usually at least some moderate air motion in the boundary layer, Sky-Doc balloons do not need to be as large as conventional blimps for achieving the required lift. We have used Sky-Doc balloons in six experiments, three of which were in polar locations, at Summit, Greenland ([*Helmig et al.*, 2002], SP [*Helmig et al.*, 2008a] [*Neff et al.*, 2008] [*Helmig et al.*, 2008b], and Barrow, AK [*Helmig et al.*, 2012a]. We will be equipped with two complementary balloon systems, sized at 12 and 20 feet in diameter. This approach will have a number of advantages over working with a single platform as we will be able to: 1. operate an array of meteorological and chemical sensors on two balloons flown in parallel, 2. work under a wider range of wind conditions, 3. have a backup system, in case there is failure or accidental loss of one of the balloons. Balloon ascent and descent will be controlled with a hydraulic winch that is contained in a heated container and engineered for use in cold environments. This winch has previously proven to work well in the extreme conditions encountered during wintertime and polar applications. Balloons will be equipped with strobe lights and flags along the tether line according to FAA regulations. A 2-m surface tower will have the same inlets as those to be used on the balloon and will serve as surface reference measurement point. A sketch of the experiment configuration is shown in Figure 3.

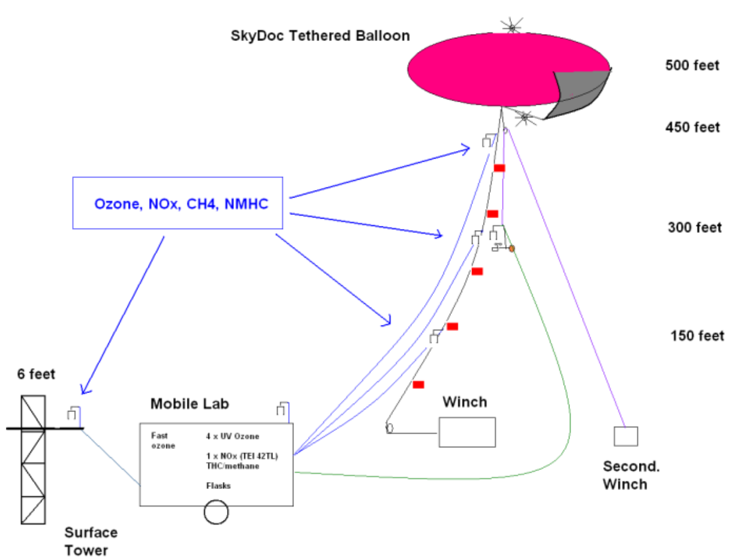


Figure 3: *Schematic illustrating the tethered balloon profiling experiment equipment and vertical profiling technical approach.*

Two different types of vertical profiling experiments will be performed. 1. Battery-powered, light weight balloon-borne sondes will be deployed for measurement of ozone and meteorological variables. 2. Long sampling lines with inlets attached to the tether line will be raised with the balloon and air will be analyzed at the ground with conventional gas monitors. Similar to the experiment we conducted last year, sampling inlets will be attached to the balloon tether line, for pulling air from up three heights to ground level for chemical gradient measurements. These sampling lines will be operated in parallel, with the Sky-Doc providing a 'sky hook', keeping these inlets at a constant height. The balloon will be raised to 500 feet above ground, with sampling line inlets attached to the tether line at heights of 450, 300, and 150 feet. All three sampling lines will be of equal length, at 600 feet, and made of thin-wall PFA Teflon. Lines will be continuously purged with air drawn from the inlets aloft. The other end of the sampling lines will be directed into the instrument trailer to a manifold from where chemical analyzers collect sample air from each line. The sampling sequence will be automated, allowing for around-the-clock vertical gradient concentration measurements. This experiment will be operated during day and night. The photograph in Figure 4 shows the long line sampling deployed from the stationary balloon during the 2012 experiment.

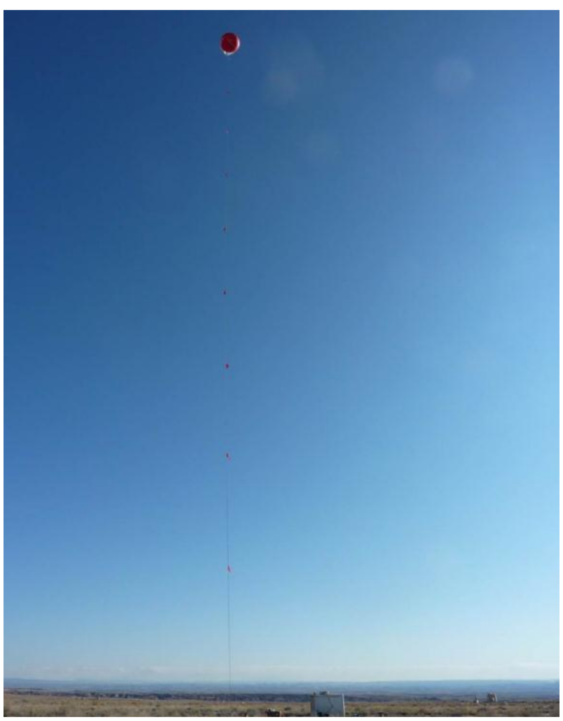


Figure 4: *Photograph showing the 20-foot diameter Sky-Doc tethered balloon at 500 feet above the ground with three sampling lines running up, parallel to the main tether and secondary flag line. Sampling inlets are at heights of 450, 300, and 150 feet above the ground.*

Balloon-borne meteorological parameters: Battery-powered Krestel meteorological sondes will be used for the measurement of meteorological parameters along vertical balloon profiles. This tethersonde measures pressure, temperature, relative humidity, wind speed, and wind direction.

Balloon-borne ozone sondes: Ozone will be measured using EN-SCI Model 2Z (EN-SCI Corporation, Boulder, CO) electrochemical concentration cell (ECC) sondes, which are based on the principle that ozone and iodide react within an electrochemical cell. The ECC ozonesondes are interfaced to an RS-80 (Vaisala) radiosonde, with data being transmitted to a ground receiver. We have spent a considerable amount of effort on characterizing the quality of this measurement; results from an intercomparison experiment at SP were reported by [*Johnson et al.*, 2008].

Ozone Ozone will be monitored in the air stream from the balloon inlets using three dedicated TEI Model 49 UV absorption instruments. A fourth TEI monitor will be deployed for the continuous monitoring of ground level (2 m) ozone. All monitors to be used will be calibrated prior and after the field experiment against a NIST standard located at the Boulder NOAA ESRL laboratory. These measurements will allow deciphering the dynamical evolution of ozone from the surface to 500 feet, as shown in the data example in Figure 5.

NOx A NOx chemiluminescence monitor will be used for measurement of nitrogen oxides (The TEI 42C-TL analyzer that was used in 2012 is committed to another study during the 2012/13 winter. We will therefore use a different, similar type monitor to be provided by the Utah Department of Environmental Quality (DEQ). This monitor has a 50 pptv detection limit, which is well suitable for the conditions anticipated in Uintah Basin. The TEI 42C-TL has 2 channels. The first channel measures nitric oxide (NO) via NO + O_3 chemiluminescence. The second channel measures nitrogen dioxide (NO_2) by redirecting air through a heated (325°C) molybdenum converter, which causes NO_2—including other oxidized nitrogen compounds—to be converted to NO. NO_2 is then determined by subtracting NO (obtained by the first channel) from the resulting NO_x signal. An example of this measurement from the February 2012 experiment is shown in Figure 6.

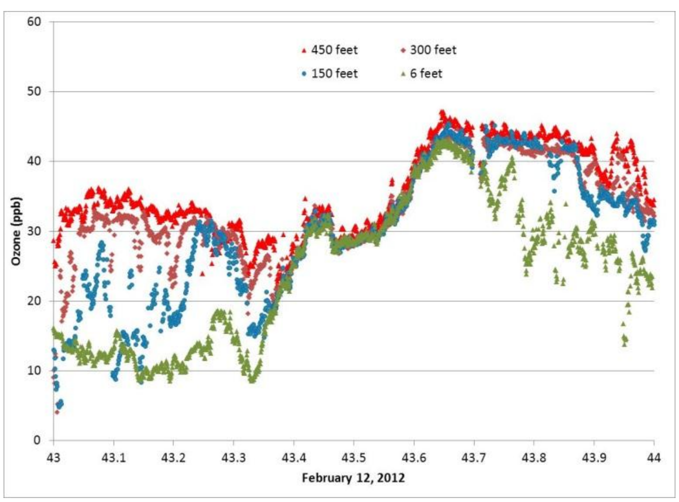


Figure 5: *Ozone measured on February 12 at Horespool at four inlet heights, one located on the surface tower (6 feet) and three on the tethered balloons, with air drawn through 600 feet of black Teflon tubing. The balloon inlets were at 150, 300, and 450 feet. Chemical analysis was done with four dedicated TEI ozone monitors that were housed in the instrument trailer. These data show how ozone gradients develop at night under the stable nocturnal boundary layer conditions and how stronger mixing during the day results in a more homogenous vertical ozone distribution during daytime.*

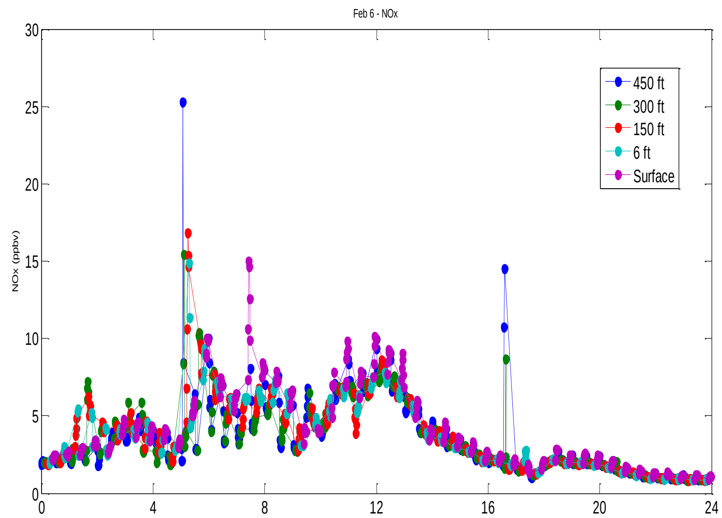


Figure 6: *Total nitrogen oxides (NOx) measured at Horsepool on Feb. 6, 2012, from three inlet heights on the tethered balloon (150, 300, 450 feet), one inlet on the surface tower (6 feet), and one inlet that was placed on the ground (Surface).*

<u>Methane</u> Methane quantification will be performed with a Baseline 8900 GC-FID Methane/Total Hydrocarbon (THC) analyzer that will be provided by the Utah DEQ. Measurements are continuous, at ~300 s time resolution. An example of data obtained during the February 2012 experiment is shown in Figure 7.

<u>Speciated Volatile Organic Compounds (VOC)</u> Two systems will be deployed for VOC monitoring. A sample-prefocusing system-gas chromatography (GC)-flame ionization detection (FID) instrument will be operated at the site for in-situ monitoring of VOC. Compounds to be quantified include C2 – C10 VOC. The time resolution of this measurement is 30 min. During events when the in-situ analyzer indicates elevated VOC levels whole air samples will also be filled into glass flasks from the tethered balloon inlet

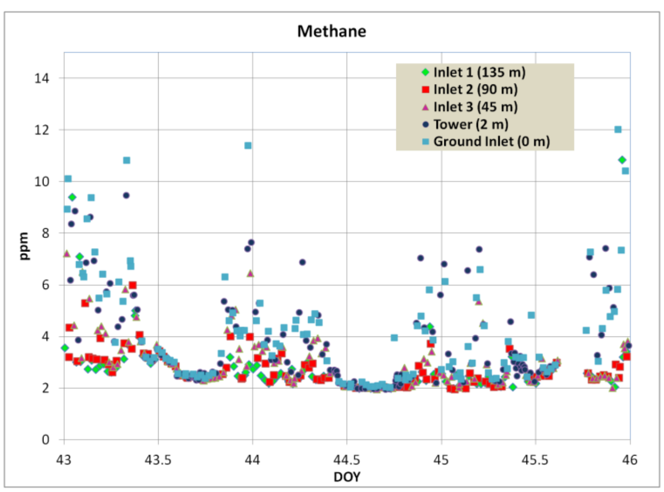


Figure 7: *Methane measured at Horsepool from February 12 – 15 (Day of year 32-46) from three inlet heights on the tethered balloon (150, 300, 450 feet), as well as one inlet on the surface tower (6 feet), and one inlet that was placed on the ground (Surface).*

lines into whole air sampling flasks. These samples will be transported to our VOC trace analysis laboratory on the CU campus where they will be analyzed with dual detection GC-FID/Mass Spectrometry instrument. C2-C10 VOC will be identified and quantified against a series of standards that are referenced against the Global Atmospheric Watch (GAW) volatile organic compound calibration scale. A data example from the 2012 experiment is shown in Figure 8.

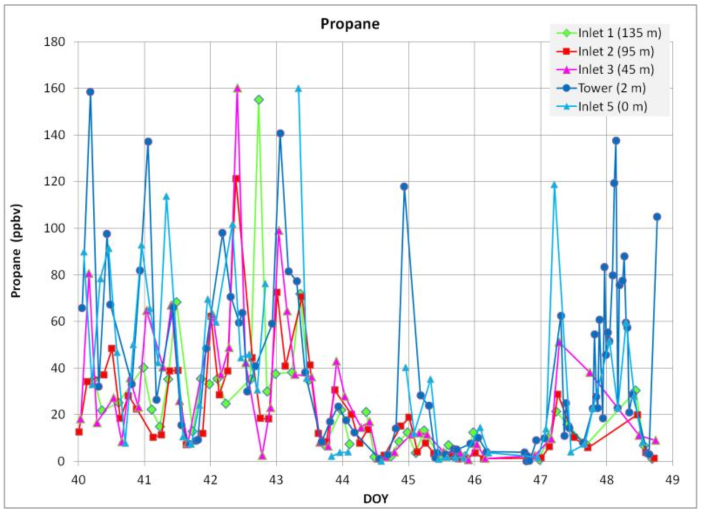


Figure 8: *Non-methane hydrocarbons measured at Horsepool from February 9 – 18 (Day of year 40-49) from three inlet heights on the tethered balloon (150, 300, 450 feet), on the surface tower (6 feet) and one inlet that was placed on the ground (Surface).*

Deliverables

Data from all measurements will be thoroughly quality controlled, analyzed and interpreted by CU scientists, and be shared with all other collaborating study participants. We will provide individual flight vertical profiles (such as in Figure 2, time series plots (Figures 5-8) for each measured variables as well as color contour plots that depict the vertical and temporal behavior of meteorological data and chemical data for ozone, nitrogen oxides, methane, and speciated VOC concentrations between the surface and 500 feet height above ground. The data will characterize the chemical BL condition when snow is covering the ground. These results will supplement and contrast the rich data set obtained under snow-free conditions from February 2012.

Our experiment will be in close collaboration with other groups participating in the Uintah Basin Winter Ozone Study. This project will offer an opportunity for 2-3 CU Boulder undergraduate and graduate students to gain experience in atmospheric field research.

Schedule

The field schedule will be coordinated with other institutions participating in this study. Our current plan is somewhat flexible, but is based on a 3-day setup period during late December 2012. All analytical systems will be installed at the site to be ready for operation. We will then evaluate the snow cover conditions and forecast and either begin the balloon operation at that time if snow cover is present, or return to Boulder and be there in a holding pattern, waiting to go back out to Utah in case of snowfall forecast. We would be able to be at the site within one day and be fully operational the next day. Our budget covers an overall one-month stay at the site with 24/7 balloon operation. To accommodate the all day/night schedule we will again rent an R/V vehicle and bring that out to the site for field accommodation for 2-4 researchers from our group who will be at the site at any given time.

Budget

All balloon and instrumentation needed for this experiment is already in place and will be made available for the experiment at no cost. The Methane and Total Hydrocarbon Analyzer, model Baseline 8900 GC-FID, and associated gas and standard delivery system, and a NOx monitor will be provided by the Utah DEQ. Expenses to be covered by the CU-INSTAAR budget include project personnel salary, benefits, travel, consumables, and CU Boulder Indirect Cost. We also need to cover $6000 repair cost for our largest, the 20-feet diameter Sky-Doc balloon, which was damaged during this year's experiment. Proposed funding period is Oct. 1, 2012 – Sept. 30, 2013.

Itemized Budget

Salaries (D.H., J.H., students, accounting)	$65,936
Benefits	$20,440
Travel	$9,632
Materials and Supplies, Balloon Helium	$6,000
Balloon repair	$6,000
Total Direct Costs	$108,008
Indirect Costs (26%)	$28,082
Total Project Total Cost	**$136,090**

In Kind Contributions

Most of the equipment to be used is already available and will be provided at no cost to the project. This includes the tethered balloon platform (with the exception of one replacement hull needed for our largest balloon), sampling tubing, switching manifold, a gas chromatograh for the VOC analyses, VOC calibration standards, and five ozone analyzers. The total value of this equipment is estimated at $200,000.

Contingency Plan in case there is no Snow

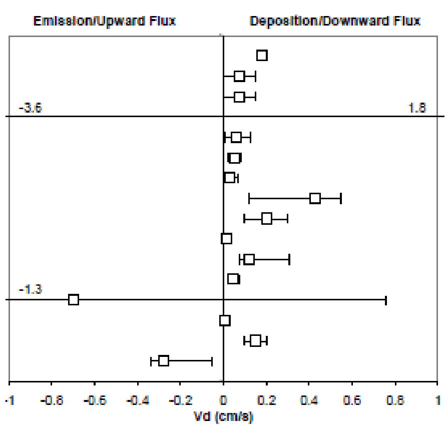
We do need approximately 3 months lead time to prepare for the experiment. During this time we need to order a new balloon hull, some new sampling tubing, clean all analytical components, reconfigure the GC system, obtain and test another NOx instrument, calibrate ozone monitors, get the methane instrument back from Utah State DEQ, obtain FAA approval, buy gases, etc. We plan to go out to the field site between Christmas and New Years for setting up the experiment. A conservative estimate is that that 20% of the overall funding request would be dedicated towards these preparations prior to the actual start of the field operation. This portion of funding would not be recoverable in case that there will be no snow and the field experiment would be cancelled or postponed to a later time.

2. Ozone Surface Flux Measurements

Study Objectives

One important variable that is urgently needed for proper modeling of the Uintah Basin winter ozone chemistry is the description of the ozone uptake rate to the snow-covered ground. As of right now, there are absolutely no data available that could be considered representative for this type of environment. A recent review of available ozone deposition measurements over snow is shown in Table 1 [*Helmig et al.*, 2007].

Table 1. *Review of literature with reports on ozone deposition (and emission) fluxes over snow-covered landscapes. References are sorted in order of the publication date. Error bars indicate the range of observed deposition velocities (respectively of standard deviation where indicated). In cases where upward fluxes were reported, fluxes were converted to "negative deposition rates" in order to allow a comparison with the deposition data. (Please see [Helmig et al., 2007] for a higher resolution image of this table).*



Location	Landscape Type	Comments	Reference
New Mexico, U.S.		Box decay	Aldaz, 1969
Mawson, Antarctica	Glacial snow field	Data is estimated upper limit	Galbally & Allison, 1972
Mt Buller, Australia	1.3 m Snow Depth	Old snow, data is upper limit of vd	Galbally & Allison, 1972
Mt Buller, Australia	1.3 m snow depth	New to one day old snow, upward flux over freshly fallen snow	Galbally & Allison, 1972
Australia	1.3 m snow depth	Deposition velocity increased with snow age.	Galbally and Roy, 1980a,b
Illinois, U.S.	Plowed field	Fresh Snow	Wesely et al., 1981
Illinois, U.S.	Plowed field	Aged Snow	Wesely et al., 1981
Lancaster/England	Grass field		Colbeck & Harrison, 1985
Canada	Deciduous forest		Padro et al. 1992, Padro 1993
Wyoming, U.S.	Coniferous forest	Downward flux, error bars are standard deviation	Zeller and Hehn, 1995
Colorado, U.S.	Grassland	Fresh snow	Stocker et al., 1995
Colorado, U.S.	Grassland	Aged snow	Stocker et al., 1995
Wyoming, U.S.	Coniferous forest	Consistent upwards ozone fluxes observed.	Zeller & Hehn, 1996
Camp Narwahl	Ice camp on sea ice	Data for ozone depletion events (Polar Sunrise)	Gong et al., 1997
Alert, Canada	Ice camp on sea ice	Estimate for surface depositon during ozone depletion events	Hopper et al., 1998
Wyoming, U.S.	Coniferous forest	Upwards ozone fluxes (mean 0.2 □g m-2s-1)	Zeller, 2000

Obviously, these data cover a wide range of ozone uptake rates to snow. Values of ozone flux, here expressed as ozone deposition velocity, v_d (v_d = - F/C; F = Flux, C = Concentration), range from -3.6 cm s^{-1} to + 1.8 cm s^{-1}. The extreme values are a bit questionable and most likely should not be considered representative of most snow cover conditions. However, there still is an abundance of measurements that point towards ozone uptake rates spanning a wide range, on the order of 0.01 – 0.2 cm s^{-1}. Surprisingly, there are at least three publications in the literature that report negative ozone deposition rates, which implies a positive, i.e. upwards flux of ozone. This would mean that ozone is produced and released in the snow, and then from there gets transported upwards into the atmosphere. These observations have been debated in the literature, as there is no convincing explanation for this chemical and ozone flux behavior.

Model descriptions of the diurnal ozone behavior will turn out much different depending on if one applies the low end, middle, or high end of these ozone surface uptake rates. For example, we conducted a sensitivity analysis for conditions that reflect variables present in the Uintah Basin during January. An ozone mole fraction of 50 ppbv was used, and 16 hours of nighttime conditions with a stable atmosphere and a nocturnal BL height of 50 m. We then applied a low end ozone deposition velocity rate of v_d = 0.01 cm s^{-1} and compared that with results obtained using a mid-range ozone deposition velocity of 0.05 and 0.1 cm s^{-1}. These values are by no means extremes, comparison with the data in Table 1 shows that they fall well within the range of previously measured ozone surface uptake rates. These simple box calculations neglect any ozone input from advection or entrainment. Results show that at v_d = 0.01 cm s^{-1} 12% of the ozone within the nocturnal boundary layer is removed due to surface uptake. At 0.05 cm s^{-1} 57% of the ozone is removed, and at 0.1 cm s^{-1} all of the BL ozone (100%) would be destroyed by surface uptake. Consequently, these scenarios would result in much different starting points for ozone ambient concentrations and ozone production the following morning. Clearly, modeling of the ozone chemistry over snow would result in large errors unless ozone deposition velocity data that properly reflect conditions for the Uintah Basin are applied. Current literature does not provide proper data to be used for that purpose. To close this gap in the representation of ozone chemistry we propose to conduct continuous ozone flux measurements during the 2012/2013 winter ozone study.

We have conducted ozone surface flux measurements over snow in a number of environments previously, including at two polar sites for a total of four seasons over the past five years. Figure 9 displays results from our work over the polar snowpack at Summit, Greenland. Findings from that polar environment show that the ozone uptake to the snowpack exhibits strong seasonal and diurnal dependencies. Ozone fluxes are significantly lower during the winter and spring months, remaining under v_d = 0.01 cm s^{-1} during most times. In the summer, however, fluxes increase by at least a factor of ~5, with ozone uptake to the snow showing a distinct diurnal cycle, with maximum uptake observed in the afternoon hours, and much lower values at night.

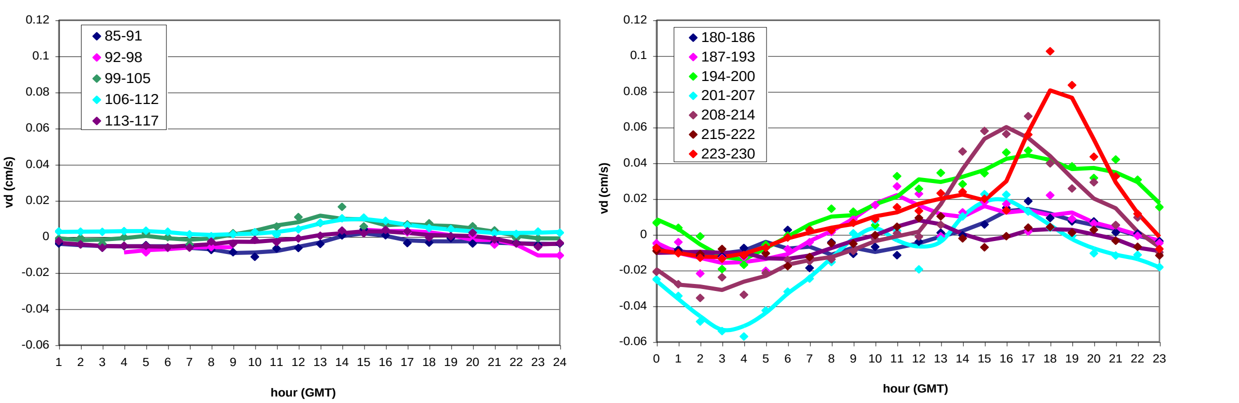


Figure 9: *Mean diurnal ozone deposition velocity (colored lines are the three-point running mean) for 5-6 day periods (indicated by the day of year) in spring 2005 (left graph) and summer 2004 (right graph) over the polar snowpack at Summit, Greenland.*

Approach

Ozone surface fluxes will be measured by the eddy covariance techniques. Development and deployment of this flux measurement has been a primary research focus of our work over the past five years. We have built with NSF support two fast response instruments that detect ozone by the ozone + NO chemiluminescence reaction for the fast and direct ozone flux measurements over snow and over the ocean. Both of these instruments have been tailored towards high sensitivity flux measurements of low ozone deposition rates. During recent deployments on the NOAA research vessel Ron Brown ozone deposition velocities below 0.01 cm s^{-1} were routinely resolved (see http://instaar.colorado.edu/outreach/ozone-oceans/index.html for more project information). Further information on the methodology and ozone flux data collected over snow and the ocean have been presented in several recent peer-reviewed manuscripts [*Bariteau et al.*, 2010] [*Helmig et al.*, 2009; *Helmig et al.*, 2012b] [*Helmig et al.*, 2012a].

Ozone fluxes will be determined continuously, 24/7. A sonic anemometer will be mounted at 5 m height on a 10 m flux tower that will be erected to the west of the CU instrument trailer. Air will be drawn at 10 *l* min^{-1} through a sampling line inside the trailer where ozone will be measured and logged at 10 Hz resolution. Calibrations will be performed against one of the TEI UV monitors to be operated at the site. Lag time for the sample transport through the tubing will be determined as describe in [*Bariteau et al.*, 2010]. Ozone fluxes and deposition velocities will be calculated using the eddy covariance data processing protocol detailed by [*Bariteau et al.*, 2010].

Deliverables

The experiment will yield ozone deposition velocity values at 15 min time resolution. Data will be statistically evaluated and diurnal and weekly average data will be determined in a similar fashion as for the results displayed in Figure 9. We will determine ozone flux values both over snow and during non-snow-cover conditions to contrast the surface ozone uptake rates under both situations.

Schedule

The experiment will be installed during the week between Christmas 2012 and New Year. This is a fully automated measurement that can be operated continuously without personnel needed to be at the site all the time. Our intention is to run the flux measurements for the full month of January, and possibly beyond depending on snow cover conditions and the overall length of the study.

Budget

The budget of this experiment is an add-on to the tethered balloon experiment. The budget does not include expenses for field travel, RV rental, etc. as those expenses would be covered already by the tethered balloon project.

Itemized Budget

Salaries (D.H., J.H., grad. student, accounting)	$22,500
Benefits	$6,975
Travel	$0
Materials and Supplies, Nitric Oxide	$3,000
Total Direct Costs	$32,475
Indirect Costs (26%)	$8,444
Total Project Total Cost	**$40,919**

In-Kind Contributions

Our group will provide all required equipment for this measurement (tower, tubing, sonic anemometer, fast response ozone monitor, computer) at no cost. The value of this equipment is estimated at $110,000.

Contingency Plan in case there is no Snow

Approximately 30% of the budget goes into the experiment preparation and field installation. 20% covers the field operation, and 50% the data reduction and interpretation. Ozone deposition fluxes were not determined during the 2012 experiment, so even without snow cover this experiment will yield valuable data. If the instrument would not be operated in the field and there were no data to be analyzed, approximately 50% of the funding could be preserved.

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APPENDIX IV

Proposed Winter Ozone Research for 2012-13

Project 1: Continued Operation of Meteorological and Air Quality Instrumentation at Horsepool and Roosevelt Stations

Purpose and Need:

This work has three main purposes:

4. It will continue a historical record of concentrations of ozone, ozone precursors, and meteorology in the Uinta Basin.
5. It will allow us to quantify impacts of temporal changes in meteorological conditions and anthropogenic activity in the Basin on air quality. This will lead to more accurate predictions of air quality in the Basin based on these controlling factors.
6. It will provide data to validate the air quality models that will be critical to the research and regulatory process.

Large investments of funding, equipment, and time were made by several agencies and donors to establish the Horsepool and Roosevelt monitoring stations in 2011-12, and efforts to improve and fully establish the sites as permanent monitoring stations for ozone and precursors are ongoing. Continuing support for these sites is critical to maximize the benefit of those investments.

Approach:

Utah State University's (USU) monitoring trailer at the Horse Pool site (Figure 1; 40.1437, -109.4672) has been collecting air quality and meteorological data since January 2012. Instrumentation at the trailer measure the following parameters:

- Ozone
- CO
- CO_2
- SO_x (SO_2 + H_2S)
- NO_x (NO + NO_2)
- NO_y (NO_x + other reactive nitrogen species)
- Methane and total non-methane hydrocarbons
- Speciated C2-C12 hydrocarbons
- $PM_{2.5}$ and PM_{10}

- Meteorological parameters, including snow depth, upwelling and downwelling solar radiation (shortwave, longwave, UV-A, and UV-B), temperature at two heights, humidity, barometric pressure, and 3-dimensional wind.

We will also measure carbonyls via DNPH cartridge sampling at Horsepool if this is measurement is not collected by other groups.

The Utah Division of Air Quality (DAQ) operates an air quality monitoring trailer in Roosevelt, Utah (Figure 1; 40.2942, -110.0090). Some instrumentation at this site is managed by DAQ, and some is managed by USU. The following parameters are measured at the site, or will be pending instrumentation delivery and installation:

- Ozone (DAQ)
- NO_x (DAQ)
- $PM_{2.5}$ (DAQ)
- NO_y (USU)
- Speciated C2-C12 hydrocarbons (USU; operational in Oct 2012)
- CO (owned by DAQ, operated by USU)
- Methane and total non-methane hydrocarbons (owned by DAQ, operated by USU; operational in fall 2012)
- Meteorological parameters, including snow depth, upwelling and downwelling solar radiation (shortwave, longwave), temperature at two heights, humidity, barometric pressure, and wind. (owned and operated in a cooperation between USU and DAQ)

Figure 1. Monitoring stations at Horsepool and Roosevelt.

USU operates instrumentation and manages data at both sites according to a comprehensive maintenance and QA/QC plan that follows manufacturer recommendations and EPA protocols. Instrumentation operated by DAQ at the Roosevelt site is operated according to EPA protocols and is considered regulatory.

Instrument and site operation and data management by USU will be carried out by technical staff, including undergraduate students at USU's Uintah Basin Campus. Additional labor is required for data analysis and interpretation, including preparation of presentations, reports, and other publications.

Schedule:

These sites are already in operation and will continue to operate regardless of season or weather conditions.

Deliverables:

1. A continuous dataset of the parameters listed above will be the primary deliverable for this project. Final data will be available 60-90 days after collection.
2. We will also analyze the collected data, along with existing data, to determine trends in ozone and precursors and how those trends are influenced by meteorology and changes in emissions.
3. These data will be critical to establishing whether winter ozone production in the Basin is VOC or NO_x limited (though they will be less useful without accompanying modeling).

Analysis of 2011-12 data from these sites is still underway, but they are already yielding valuable information, particularly regarding sources of ozone precursors. For example, the diel structure of the data shows that NO_x concentrations follow traffic patterns at the sites, indicating a dominant role for traffic-related emissions, even at Horsepool.

Budget:

All hardware for these sites is in place and functional, with the exception of the system at Roosevelt for C2-C12 hydrocarbon analysis, which will be operational within two months. Funding is needed for consumables, repairs, and labor.

Item	Details	Cost
Technician 1	50% salary support for 1 year for site maintenance and data processing and analysis	$15,600
Technician 2	50% salary support for 1 year for site maintenance and data processing and analysis	$47,000

Travel to sites	140 miles a week, $0.50 per mile	$3,600
Horse Pool upkeep	Repairs, maintenance, and consumables	$18,000
Roosevelt upkeep	Repairs, maintenance, and consumables	$8,000
Indirect cost	10%	$9,200
	TOTAL	$101,400

Project 2: Vertical Measurements of Ozone and Meteorology

Purpose and Need:

The only vertical measurements of meteorology during inversion conditions in the Uinta Basin were collected at one site (Red Wash) over a few days in 2011. The only vertical measurements of ozone during inversion conditions were collected over two days in 2011. Simultaneous vertical measurements of ozone and meteorology have not been collected during inversions

Without measurements of the physical and chemical structure of winter inversions in the Basin at several locations in different conditions (i.e. different days in a multi-day inversion, different times of day), it will be impossible to properly construct and validate meteorological models that will be utilized with air quality models for regulation of emissions relating to elevated ozone in the Basin.

The topography of the Basin—and, consequently, the surface meteorology—is exceedingly complex, and surface-level and vertical measurements at one site will not be useful for characterizing the Basin as a whole. Furthermore, locations with maximum ozone precursor concentrations in the Basin do not correspond with the location of maximum ozone production, and vertical measurements at a number of sites during inversions will elucidate flows at the surface and aloft that transport precursors and their reaction products in the Basin. This will be essential to understanding how to mitigate ozone problems, since transport patterns likely determine the influence that emissions from different parts of the Basin have on overall ozone production.

Approach:

If inversion conditions with adequate snow cover form in the Basin, we will deploy tethered balloon systems at two sites in the Basin. These systems measure ozone at 10 second intervals and also measure wind speed and direction, temperature, pressure, and relative humidity at one second intervals. The balloons have a vertical range of 250 m.

The exact sites at which we measure will be dependent on whether other investigators perform similar measurements, but we will ensure that vertical measurements of ozone and meteorology are collected at Horsepool and Roosevelt at a minimum. We will deploy our systems throughout inversion episodes from sunrise to sunset, with approximately one ascent and descent each hour.

Schedule:

If snow cover exists and inversions are forecasted, we will deploy our balloon systems at two sites and begin measurements before an inversion forms. We will continue measurements through the inversion period, and end measurements one day after the inversion breaks up. This will allow us to measure properties of inversion formation, strengthening, and break-up. We will repeat this for multiple inversion episodes up to a maximum of 30 days of measurements.

If snow cover and inversions do not exist in the Basin in the winter of 2012-13, we will not deploy the balloons.

Deliverables:

This work will produce a dataset showing meteorology and ozone concentrations from 0-250 meters at two locations in the Basin. These data will provide some information about spatial variability in inversion structure, flows at the surface and aloft, and vertical structure of ozone concentrations. They will provide detailed measurements for comparison against models of inversion meteorology.

Budget:

The two balloon systems are already operational. Costs will be for consumables and labor.

If the Basin doesn't experience extensive snow cover and inversions, no expenses will be incurred.

Item	**Details**	**Cost**
Salary costs	Two people at each balloon site	$33,000
Consumables	Helium, repairs	$2,000
Travel	Including travel to and from Basin	$6,500
Indirect cost	10%	$4150
	TOTAL	$45640

Project 3: Distributed Monitoring of Ozone, Meteorology, and Ozone Precursors

Purpose and Need:

Results from 2011-12 show that ozone precursors are unevenly distributed around the Basin, and meteorology in the Basin, especially surface airflow, is extremely spatially variable. Very few meteorological stations exist in the oil and gas producing areas of the Basin and only a handful of NO_x and VOC monitors exist in the Basin. Measurements at these few sites will not be adequate to characterize ozone and precursor concentrations and transport in this complex environment.

Passive measurements of VOC and NO_x in 2011-12 (at 10 and 16 sites, respectively) showed the spatial distribution of these compound groups in the Basin, indicating that VOC concentrations in the Basin were strongly correlated with proximity to oil and gas extraction activity and that NO_x concentrations were highest in urban areas and in the gas producing areas of Uintah County. These measurements also showed that areas of greatest VOC and NO_x were not the same as the area of maximum ozone production in Winter 2010-11.

Repeating similar measurements in winter inversion conditions will provide information about how ozone and precursors are transported during inversions and how NO_x and VOC and their reaction products are transported from source locations to areas with higher ozone. This will allow us to determine whether some areas of the Basin have a larger impact on ozone production than others and whether some areas of the Basin are isolated from others in terms of ozone production.

Approach:

We will operate eight monitoring sites for ozone at Duchesne, Mountain Home, Altamont, Pariette Draw, near Highway 88, near Seep Ridge Road, near Fiddler Road, and near Pleasant Valley. We will collect basic meteorological measurements at six of these sites during this period. If snow cover and inversion conditions develop, we will measure NO_2 and speciated C2-C12 hydrocarbons at eight sites during a winter intensive period.

We will use 2B ozone analyzers, some of which will use solar-powered shelters, to measure ozone at these sites. It will take about two weeks to set up the sites, and many of them are difficult to access after extensive snow cover sets in, so it is not feasible to wait until snow cover and inversion conditions arrive to establish these sites. Thus, we propose the set up the sites in November and operate them until the end of March. We will visit each site once every other week at a minimum. We will check site data daily via cell modem connections.

We will collect measurements of NO_2 and C2-C12 hydrocarbons only in the event of snow covered, inverted conditions that are likely to produce ozone. We will use Radiello passive samplers for NO_2 and 6 L summa canisters with automated sampling timers for C2-C12 hydrocarbons. The passive NO_2 samplers will be deployed for one-week intervals. The 6 L summa canisters will collect over a 24 hour period, and/or over a period of several days for 2-3 hours per day at the same time each day, depending on conditions. NO_2 samples will be analyzed in our laboratory. C2-C12 hydrocarbon samples will be analyzed by a commercial laboratory.

At the conclusion of the measurement period, we will use CALMET to develop a diagnostic meteorological model of the Basin with high spatial resolution (<1 km) for the time of the study. The model will use meteorological data we collect, as well as data collected by others throughout the Basin. We will use this model to simulate transport for ozone and precursors in the Basin. We are beginning this work for the 2011-12 dataset now. This approach was used successfully in Wyoming's Upper Green River Basin to determine the extent of the area that experiences high winter ozone, and to determine how surface transport affects ozone production.

Schedule:

Five monitoring sites are already operational. Three more will be installed in November 2012 and operated through March 2013. If funding allows, the original five sites will continue operation throughout 2013.

Measurements of NO_2 and VOC will occur if snow cover and inversions develop. We will deploy these samplers for a maximum of four weeks. Deployment will occur during inversion episodes.

Deliverables:

The dataset from this work will be combined with monitoring data from 2010-11 and 2011-12, creating a three year dataset of ozone, meteorology, and ozone precursors around the Uinta Basin.

These and other data will be analyzed to determine surface transport phenomena during ozone-producing inversion conditions, allowing for determination of sources and the extent of ozone production in the Basin.

Budget:

All hardware for these sites has already been purchased, with the exception of some of the automated sampling equipment for canisters. Costs will be for technical staff, travel, sample analysis, repairs, maintenance, and consumables.

If the Basin doesn't experience extensive snow cover and inversions, we will not conduct NO_2 and C2-C12 hydrocarbon sampling. This will save $10,000-$15,000 in labor costs and $42,000 in analytical costs.

Item	Details	Cost
Technician 1	100% salary support for 4 months	$24,000
Technician 2	100% salary support for 4 months	$32,000
Travel to sites	250 miles a week for 16 weeks, $0.50 per mile	$2,000
Ozone monitor upkeep	Repairs, maintenance, and consumables	$3,500
Solar site upkeep	Repairs and maintenance	$1,000
NO_x passive sampling	Consumables, analysis—assumes deploys for 4 weeks	$2,000
Canister sampling	Consumables and analysis	$41,000
Automated samplers	We have six. We will need ten more.	$15,000
Indirect cost	41%	$12,000
	TOTAL	$132,500

APPENDIX V

1. Wintertime Ozone Formation Chemistry, Vertical Mixing and 3-D Structure

Purpose and Need

The production of O_3 requires NOx, VOCs, and a source of radicals: compounds that produce radicals when photolyzed. Traditionally, O_3 photolysis and subsequent reaction of excited O atoms with water vapor is thought to be the major source of radicals in the lower atmosphere. Low water vapor concentrations in the winter has brought up the possibility that there are additional radical source driving O_3 chemistry in the Uintah Basin. The UBWOS 2012 study included a comprehensive set of measurements of NOy compounds and speciated VOCs, both primary and photochemically produced, along with the three major possible additional radical sources: formaldehyde, HONO and $ClNO_2$. Those data enabled a detailed radical budget to be constructed, which was found to be quite a bit lower than budgets from urban areas that experience photochemical ozone pollution, consistent with the lack of high ozone during UBWOS 2012. The lack of conditions that produce high O_3 in the Uintah Basin did not permit any definitive examination of the individual contributions of particular radical sources. Detailed measurements of radical sources are therefore a key need for the UBWOS 2013 Study. The three non-traditional source species are known to have heterogeneous sources from reactions at particle, ground or snow surfaces. Thus, snow chemistry and surface flux measurements are an essential aspect of this study component. This study component will also involve 3-dimensional measurements of ozone and meteorological data, which will be integrated with vertical flux data and on-going research in source characterization (both stationary and mobile), and numerical modeling of tropospheric photochemistry. The following sections provide details concerning the measurement approach, project deliverables, schedule and budget for the proposed project component. This study component will be carried out at the Horse Pool site, since the previous measurements at this site has been found to be representative of the emissions in the gas production side of the basin and critical site development and preparation has already been done.

Gas-Phase Chemistry – NOAA/CSD

Approach

The 2013 effort on ozone formation chemistry be smaller than the 2012 effort due to the large field commitment that NOAA/CSD has during the summer of 2013, and will be focused radical sources and VOCs. The instrumentation that will be fielded in 2013 is detailed in Table 3.1. The gas phase measurements on this list are the sub-set of those fielded in 2012 that are deemed necessary to define the ozone production chemistry happening in the Uintah Basin. It should be noted that this study component is predicated on the USU mobile lab being fielded at the Horse Pool site at the same time. The instrumentation for the gas-phase measurements will be housed in a single trailer that will be prepared ahead of time at our laboratory and will be ready to deploy on approximately 1 week notice. Additional infrastructure consists of a portable sampling tower that will have movable carriage to hold the instrument inlets. That tower is also at our laboratory and will be transported along with the trailer. A brief description and rationale for including each measurement is given below.

CaRDS

The oxides of nitrogen ($NO + NO_2$) are central to the catalytic cycle that produces O_3 in the lower atmosphere, and their measurement is essential to understanding ozone photochemistry at a given site. The higher oxides, NO_3 and N_2O_5 are involved in nighttime oxidation chemistry and the heterogeneous chemistry that activates chlorine through the reaction of N_2O_5 with chloride on particle and ground surfaces. In addition, the nature of VOC emissions in this basin are such that an independent method of measuring O_3 is very desirable, as it adds a measure of certainty about observed high O_3 values. Ozone and the oxides of nitrogen will be measured by a custom-built cavity ring-down spectrometer (Wagner et al., 2011). The instrument measures NO_2 at 405 nm wavelength and NO_3 at 662nm wavelength by means of a high-finesse absorption cavity that provides a long effective path-length and therefore high sensitivity. The other chemical species are measured by selective conversion to either NO_2 or NO_3. Ozone and NO are measured as NO_2 in separate channels after conversion: NO is measured by addition of excess O_3, and O_3 is measured by addition of excess NO, with both channels relying on the reaction $NO + O_3 => NO_2 + O_2$. N_2O_5 is measured by thermal decomposition: $N_2O_5 \; = > NO_2 + NO_3$ with detection of NO_3. The sampling scheme for this instrument does permit the use of a long inlet, provided certain inlet stability tests are performed, so the CaRDS inlet will be mounted on the moving carriage as part of the vertical gradient work described below.

PAN/$ClNO_2$ CIMS

Peroxyacyl nitrates (PANs = $RC(O)OONO_2$) are key intermediate species of the NOx-VOC chemistry that produces O_3 in the lower atmosphere, as such, their measurement relative to other NOx-product species such as nitric acid (HNO_3) provides important diagnostic information. Nitryl chloride ($ClNO_2$) is produced at night by the reaction of N_2O_5 with chloride on surfaces (mainly particles), and is photolyzed at sunrise, creating highly react chlorine atoms. Measurements during the 2012 UBWOS study found levels of $ClNO_2$ as high as 2 ppbv at times. It is not clear if this chemistry occurs to the same degree during high O_3 periods. PANs and $ClNO_2$ will be measured during UBWOS 2013 by iodide ion chemical ionization mass spectrometry, CIMS (ref). This instrument was fielded during UBWOS 2012 during which several improvements were made that permitted the use of a long sampling inlet. As a result UBWOS 2013 work will feature routine measurement of $ClNO_2$ vertical gradients. The ambient levels of $ClNO_2$ will be used to calculate the strength of the Cl atom source from this compound, and vertical gradient measurements will define whether the ground or snow are sources or sinks of $ClNO_2$.

CO_2/CH_4

Carbon dioxide and methane will be measured by integrated cavity output spectroscopy, a variant of CaRDS, and high sensitivity and high time-resolution. This is the same experiment that was fielded in 2012. These species are key markers for combustion sources (CO_2) and fugitive emissions from oil and gas production (CH_4), that are essential to quantitative emissions work.

PTR-MS and VOC Samplers

The Proton-Transfer Reaction Mass Spectrometer measures a range of VOCs, including oxygenates, aromatics and alkenes. This instrument was used during the UBWOS 2012 study and was used to identify local in-field methanol as the source of elevated formaldehyde. In addition, the instrument observed that aromatic species are major constituents of open flow-back operations. The experiment in UBWOS 2013 study will employ a long sampling inlet to assess the extent of snow pack formation of formaldehyde and other potential contributors to the reactive VOC pool. The scale of effort proposed for 2013 does not permit the fielding of the GC/MS system that was used in 2012. However, CSD has developed the capability to analyzed samples collected in canisters. The 2013 project will use these canisters to augment the VOC sampling by PTR-MS, and they will allow the measurement of some species, such as light alkanes, that cannot be done any other way.

Acid CIMS

Gas phase acids will be measured by Negative Ion Proton Transfer Chemical Ionization Mass Spectrometry (NI-PT-CIMS). This system uses acetate ions to react with a wide range of species that we readily recognize as acids, such as nitric acid, HNO_3, hydrochloric acid, HCl, nitrous acid, HONO, and carboxylic acids (aside from acetic acid) and a number of compounds that are typically not considered acids but may be important in a highly impacted atmosphere such as Uintah Basin. This instrument will provide high sensitivity (detection limits of <20 pptv) of many acid species on a 1-minute timescale. The acids of most interest to this project are HONO, HCl and organic acids. Nitrous acid is a radical source, that is formed on both ground and particle surfaces, from NOx and NOy species. Measurements during UBWOS 2012 showed HONO to be low, with a very small daytime contribution. However, in the Upper Green River during the winters of 2010 and 2011 (B. Rappengluck, UGWOS Studies 2010, 2011) have indicated mid-day HONO levels that were well above 1 ppbv, a range at which that source is a significant contributor to radical production. It is not clear at this point where that HONO is coming from, but a leading candidate is snow-pack photochemistry. Hydrochloric acid is a key intermediate in the surface conversion of oxides of nitrogen to nitryl chloride ($ClNO_2$) an active chlorine compound. HCl was low during UBWOS 2012 (<0.15 ppbv), however it is not clear what the contribution of gas-pahse HCl is during high ozone events. We will be measuring $ClNO_2$ and the parent oxides of nitrogen (NO_3, N_2O_5) as part of our core measurements, so gas-phase HCl and soluble particle chloride (see below) would complete the chloride/chlorine budget. Formic acid (HC(O)OH), and the other organic acids we will also measure, are important intermediates in VOC oxidation and will yield valuable diagnostic information on that process. The measurements proposed for the 2013 Horse Pool/Uintah site will be made with a moveable inlet, attached to a small instrument tower. Surface flux measurements of HONO will provide quantitative values of HONO surface sources that will define the importance of this radical pathway.

Filter Radiometers

Photolysis rates of key chemical species are an essential part of the study proposed for UBWOS 2013. These will be measured by broadband filter radiometers that are matched to the photolysis action spectrum of the two common photolytic species: NO_2 and O_3. These instruments will be deployed in pairs to give simultaneous upward- and downward-looking measurements. The photolysis rates of the other radical sources of interest: CH_2O, HONO, and $ClNO_2$ will be calculated from combinations of the measured photolysis rates using known absorption spectra and quantum efficiencies. This method has been shown to yield rates that are within 30% of values derived from spectral radiometer measurements.

Deliverables

The deliverables for this part of the project will be a set of high sensitivity, high time-resolution measurements made both at single heights and in gradient mode at two or more heights. These measurements will result in an assessment of the radical sources operating in the UBWOS environment. The data from these measurements will be available according to the schedule given below. First-look data from the grab samples, to be analyzed by GC/MS, will be available within a few days to a week after the samples are collected. All data will be archived and made available to all study participants via a password-protected website. NOAA/CSD will analyze the data, in the same fashion as was done during the UBWOS 2012 project, and report results to the UBWOS community in both weekly informal meetings and in any mid-term meeting or workshop that is organized as part of the project. The UBWOS 2013 results will be further analyzed and reported at scientific meetings and in journal articles as appropriate.

Schedule

Completion of Study Plan and QA/QC Procedures – October 1, 2012.

Trailer Installation- January 15, 2013 – as weather dictates

Measurement Period: January 15, 2013 – March 8, 2013 – 4 weeks within this window

Data Availability-

First look data – 2 days following acquisition, password protected website
Mid-Experiment Data Meeting – week of Feb 15, 2013 (this is open for discussion). To be held at the Bingham Energy Research Center, Vernal, UT.
Final QA/QC'd data - September 2, 2013.
Final report on supported measurements – October 1, 2013

Budget – Gas Phase Measurements

Salary, benefits, overhead		$210,000
Travel and shipping		$40,000
Equipment		$50,000
Expendables and Supplies		$50,000
	Total	$350,000

Of this amount, $100,000 will be expended in preparation for the project and would not be saved in the event that the field portion of the effort is canceled or postponed. The in-kind contribution for this part of the NOAA/CSD effort is estimated to be $525,000.

2. Particle and Snow Chemistry – NOAA/PMEL

Purpose and Need

The interaction of gas and particle phase chemistry is an important aspect of key processes that might be driving ozone production during winter. The presence and persistence of particle phase chloride and it's availability for $ClNO_2$ formation is one obvious connection. In addition, the apparent dependence of O_3 events on snow cover brings up questions about whether there are contributing chemical processes occurring on snow surfaces. These processes might serve as sources of HONO or formaldehyde that would accelerate O_3 production. The formation of secondary organic aerosol (SOA) is a sink for the high VOC concentrations in the area. Understanding and quantifying this process will be key in determining the VOC budget in the study area.

Approach

The aerosol and condensed phase measurements proposed for 2013 will duplicate those fielded in 2012. This will entail size-dependent measurements of aerosol chemical composition with both virtual impactors and particle-into-liquid samplers (PiLS). In addition, measurements of aerosol physical and optical properties will be conducted. The snow sampling protocol will entail measuring both fresh and aged snow around the Horse Pool site, with and without soil underneath. Since we now recognize the importance of soil chloride and the potential for fugitive emissions from evaporation ponds, sampling of those materials will be added to this activity. The cost of this activity represents the marginal cost of personnel time, travel, and expendables. No capital equipment costs are envisioned. The NOAA/PMEL effort can also be ready on an approximately one week notice, to deploy only when conditions conducive to high ozone events are predicted.

Deliverables

Snow and atmospheric aerosol chemical composition
Soil and pond water chemical composition
Aerosol physical size distribution (to determine the particle surface area)
Aerosol light scattering and absorption coefficients
All data will be made available on our data server (saga.pmel.noaa.gov)

Schedule

Completion of Study Plan and QA/QC Procedures – October 1, 2012.

Trailer Installation- January 15, 2013 – as weather dictates

Measurement Period: January 15, 2013 – March 8, 2013 – 4 weeks within this window

Data Availability-

First look data – 2 days following acquisition, password protected website
Mid-Experiment Data Meeting – week of Feb 15, 2013 (this is open for discussion). To be held at the Bingham Energy Research Center, Vernal, UT.
Final QA/QC'd data - September 2, 2013.
Final report on supported measurements – October 1, 2013

Budget

Salary, benefits, overhead		$80,000
Travel and shipping		$15,000
Equipment		$5,000
Expendables and Supplies		$20,000
	Total	$120,000

Of this amount, $40,000 will be expended in preparation for the project and would not be saved in the event that the field portion of the effort is canceled or postponed. The in-kind contribution for this part of the NOAA/PMEL effort is estimated to be $200,000.

3. Deployment of the NOAA/ESRL/CSD TOPAZ Ozone Lidar and HRDL:

High-Resolution Doppler Lidar Measurement of Winds and Turbulence at the Uintah Basin Experiment in February 2013-NOAA/CSD

Purpose and Need

Several aspects of the wintertime ozone phenomenon can only be understood through measurement of continuous, high-resolution ozone, wind, and turbulence profiles. By deploying ozone and wind lidars to provide these important observations, we will address the following key questions:

- *What is the depth of the polluted boundary layer (BL)?*
- *How much ozone is present in the BL during high ozone events?*
- *To what extent are shallow BL depths over snow-covered ground responsible for the observed high ozone concentrations?*
- *Do local point sources (e.g. the Bonanza power plants) and/or long-range or stratosphere-to-troposphere transport of ozone contribute to high ozone levels in the BL?*
- *How much mixing and ventilation of the lower troposphere, which determines the stability and persistence of ozone events, occurs during high ozone episodes?*

The Doppler lidar wind profiles will also be used to compute highly resolved local-scale trajectories as demonstrated during UBWOS 2012. These trajectories proved very useful in helping to interpret the collocated in situ observations by tracing individual measurement events to particular local sources. Observations of wind profiles during periods of aircraft observations were invaluable for calculating horizontal fluxes of emissions during the 2012 study.

Approach

This measurement element would essentially duplicate the 2012 effort. Ozone and Doppler lidars will be deployed at Horse Pool or nearby sites and will measure for 4 weeks during the high ozone season. The Doppler lidar will be operated continuously during the 4-week deployment period, whereas the ozone lidar will be run on a continuous basis during high ozone episodes, but only intermittently between high ozone events. The costs associated with this activity are for personnel time (preparation, deployment, and data analysis), travel, spare parts and expendables, and publication costs. The major equipment costs involved in retro-fitting the ozone lidar for ground-based measurements have been covered by the 2012 funding.

Schedule and Deliverables

Completion of Study Plan and QA/QC Procedures – October 1, 2012.

Trailer Installation- January 15, 2013 – as weather dictates

Measurement Period: January 15, 2013 – March 8, 2013 – 4 weeks within this window

Data Availability-

First look data – 2 days following acquisition, password protected website
Mid-Experiment Data Meeting – week of Feb 15, 2013 (this is open for discussion). To be held at the Bingham Energy Research Center, Vernal, UT.
Final QA/QC'd data - September 2, 2013.
Final report on supported measurements – October 1, 2013

Budget

Salary, benefits, overhead		$80,000
Travel and shipping		$20,000
Equipment		$20,000
Expendables and Supplies		$20,000
	Total	$140,000

Of this amount, $40,000 will be expended in preparation for the project and would not be saved in the event that the field portion of the effort is canceled or postponed. The in-kind contribution for this part of the NOAA/CSD effort is estimated to be $160,000.

APPENDIX VI

Monitoring the Atmospheric Boundary Layer in the Uintah Basin

Principal Investigator: Prof. John D. Horel (john.horel@utah.edu)
Department of Atmospheric Sciences, University of Utah
Core funding: $54,970; Optional equipment purchase: $24,470; In-kind contribution: $109,000

Purpose and Need

This proposed work follows directly from the "*2012 Uintah Basin Winter Ozone and Air Quality Study: Summary of Interim Findings, Ongoing Analyses, and Additional Recommended Research*." Specifically, we intend to help address Recommendation 5: **Make additional meteorological measurements to characterize inversion height and winds. This is necessary for modeling ozone in the basin and for evaluating the transport and dispersion of emissions.** Further, that report states: "the 2012 winter season did not have persistent snow cover or the winter inversion conditions that are linked to the formation of high winter ozone concentrations. Therefore, the study team was not able to perform measurements of chemistry or the meteorological conditions that cause high ozone in winter." We propose to provide additional meteorological measurements during the 2013 winter that are critical for understanding the linkages between weather and ozone concentrations in a manner that will be highly complementary to the data collection efforts of other research teams.

The proposed work consists of three components for the January-February 2013 period: (1) provide baseline support to analyze conventional weather observations, atmospheric model analyses and forecasts, satellite imagery and other weather-related products to diagnose the synoptic and mesoscale circulations affecting boundary layer winds throughout the Uintah Basin that control the evolution of winter ozone concentrations; (2) continuously monitor low-level clouds and boundary-layer height during cloud-free periods at several locations in the Basin as well as monitor near-surface winds (5-200 m) in the Fort Duchesne area; (3) when conditions warrant, rapidly deploy weather monitoring equipment in the Fort Duchesne-Ouray corridor and north slope of the Tavaputs Plateau to define near-surface winds as well as periodic releases of rawinsondes to monitor temperature, moisture, and wind throughout the troposphere. Outreach to students at K-12 schools in the Uintah Basin is a key component of our proposed work including siting and real-time monitoring of sensors at schools as well as demonstrating how weather observations are collected.

Approach

a. Overview

The research team will be led by Dr. John Horel in the Department of Atmospheric Sciences at the University of Utah. His research group has been involved in a number of field campaigns in northern Utah related to basin circulations over a range of scales (e.g., Vertical Transport and Mixing Experiment- VTMX- Doran et al. 2002; Peter Sinks- Clements et al. 2003; and the Persistent Cold-Air Pool Study- PCAPS- Lareau et al. 2012). The 2010-2011 PCAPS winter field campaign in the Salt Lake Valley and related research supported by the National Science Foundation are very relevant to the proposed work in the Uintah Basin. For example, an elevated ozone episode in the Uintah Basin during late January 2011 was contemporaneous with elevated PM 2.5 in the Salt Lake Valley while another Uintah ozone event during mid-February 2011 was not. An outgrowth of the PCAPS research is our improved understanding of stable boundary layers in basins: (1) how to diagnose their formation, structure, and dissipation and (2) the relative impacts on them of synoptic and mesoscale systems, local topography, presence of snow cover, and cloudiness (Crosman et al. 2012; Horel et al. 2012; Lareau et al. 2012; Young and Whiteman 2012).

The Mountain Meteorology Group in the Department of Atmospheric Sciences has instrumentation that can be deployed for long-term monitoring during the 2013 winter as well as the capability to respond rapidly once conditions warrant collecting enhanced observations consistent with the developing 2013 study. Our proposed deployments of equipment will help to provide additional capabilities to monitor the near-surface winds and boundary layer heights that were not available during the 2012 winter campaign.

For continuous monitoring with real-time access to the data during winter 2013, we propose to deploy by early December 2012 the following:

- 2-5 Vaisala CT-12K ceilometers in the Uintah Basin to monitor the depth of the surface aerosol layer and inversion heights,
- ASC miniSodar in Fort Duchesne to monitor winds from 15-200 m,
- 6 meter surface flux tower in Fort Duchesne with sonic anemometer and radiation sensors to monitor near-surface turbulence and the radiation balance.

When conditions warrant during January or February 2013, we propose to deploy the following rapidly deployable portable equipment:

- 2 GRAW rawinsonde base stations with the intention to launch sondes twice daily during up to 10 days of operation to define the profiles of wind, temperature , and moisture throughout the troposphere ,
- 3 portable rapidly deployable three meter meteorological towers with pressure, temperature, wind, solar radiation, and moisture sensors to characterize local meteorological conditions,

- Trailer mounted Vaisala CT-12K ceilometer and 3 meter meteorological tower with meteorological sensors for deployment dependent on local conditions,
- 2 vehicle mounted AirMar all-in-one sensor packages (temperature, moisture, pressure, wind, and GPS) to continuously record meteorological conditions while traveling through the Basin.

Core funds are requested in the amount of $54,970 to support the deployment of this field equipment valued as an in-kind contribution of $85,000 with additional in-kind computer and staff services valued at $24,000 to provide baseline support. This baseline support will help to examine mesoscale and synoptic-scale influences on boundary layer winds. Optional funding of $24,469.90 is requested to purchase a Vaisala CL 31 ceilometer for evaluation as an improved long-term monitoring tool for aerosol concentration and boundary layer depth in the Uintah Basin.

b. Diagnose Synoptic-Scale and Mesoscale Winds Affecting the Boundary Layer Winds in the Basin

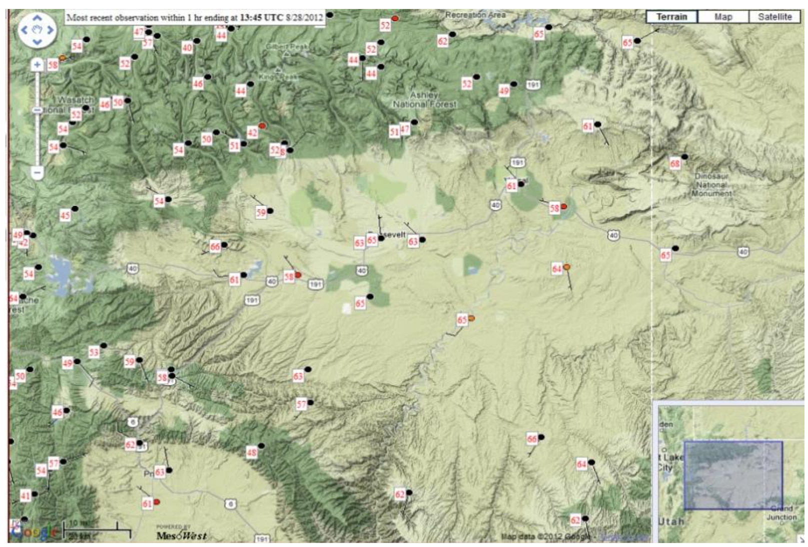

Figure 1. MesoWest software (http://mesowest.utah.edu) provides a framework to collect routine and research observations from diverse sources within and external to the Uintah Basin and provide them to the research community, public policy makers, and the public. Surface temperature and wind observations from stations available in August 28 2012 are shown.

Our activities build on our record over many years of providing real-time and retrospective access to weather information throughout the nation as part of MesoWest (Horel et al. 2002). As shown in Fig. 1, we have considerable expertise and capabilities to collect, archive, and disseminate weather observations throughout the region (Colorado, Utah, and Wyoming (see http://mesowest.utah.edu). In addition to those available from the EPA at Ouray and Red Rocks, sensors are deployed within the Uintah Basin by: the Utah Department of Transportation; SnoTel network by the National Resource Conservation Service; RAWS network by the U.S. Forest Service, Bureau of Land Management and Ute Tribe; Colorado Basin River Forecast Center and Hydrometeorological Automated Data System; and private citizens. Combining the in situ observations with the enhanced observations during specialized field campaigns is critical for diagnosing the interactions between weather conditions within and external to the basin.

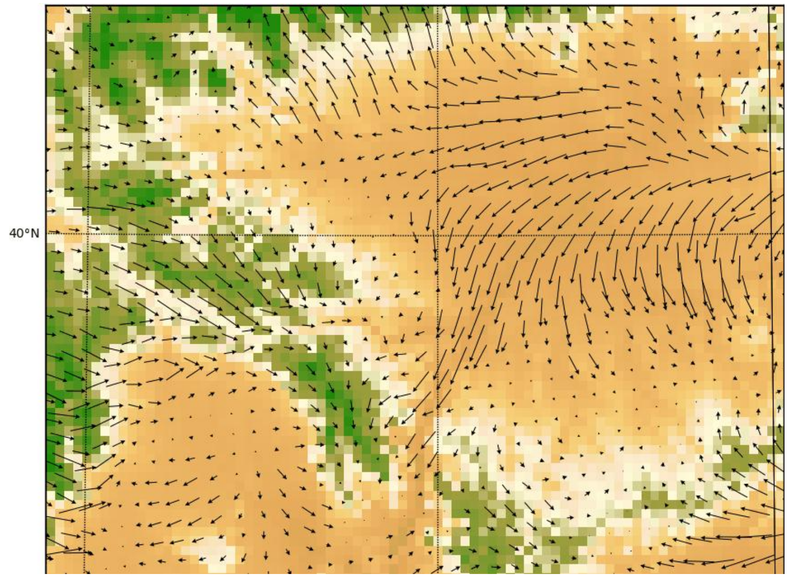

Figure 2. The UU2DVAR analysis system is run hourly over the continental United States at 2.5 km resolution. The analysis of surface wind at 16 UTC 16 August 2012 is shown by vectors at every other grid point (longest is 8 m/s) and the shading denotes the terrain with the Uintas on the upper edge of the image.

In addition, we routinely download and archive terabytes of environmental data, model grids, and satellite imagery in order to conduct research related to projects such as those proposed here. In addition, as demonstrated in Fig. 2, we have a surface analysis system (UU2DVAR) running every hour over the continental United States at 2.5 km resolution to diagnose surface wind, temperature, and moisture. The analysis system is used primarily for quality control of surface observations and assessment of the impact of surface observations collected from heterogeneous sources (Horel and Dong 2010; Tyndall and Horel 2012). For PCAPS, we have done research reanalyses in the Salt Lake and Tooele Valleys at ~150 m horizontal resolution incorporating all the in situ observations as well as those collected during the field campaign only (Horel et al. 2012).

The MesoWest staffing, computer infrastructure and software makes it possible to integrate field campaign data with the existing in situ observations in an efficient manner. We also offer to participate in the planning for rapid deployment based on our experience in forecasting weather in northern Utah. *These capabilities are valued as an in-kind contribution of $24,000.*

c. Continuous Monitoring During Winter 2013- laser ceilometers

A valuable lesson learned from the PCAPS 2010-2011 field campaign was the utility of applying eye-safe laser ceilometers to estimate the depth of the aerosol layer in stable conditions within the Salt Lake Valley and monitor the presence of low lying clouds (Young and Whiteman 2012; Lareau et al. 2012). Capabilities of this type were not available for the 2012 winter field campaign in the Uinta Basin.

Based on our experience regarding the utility of a Vaisala CL 31 ceilometer during the field campaign, we obtained from the National Weather Service (NWS) over a half dozen Vaisala CT-12K laser ceilometers that otherwise would have been destroyed as part of a nationwide upgrade supported by the NWS/Federal Aviation Administration. (The newer Vaisala CL 31 ceilometers monitor cloud base to higher elevations above ground level as well have improved temporal resolution and sensitivity to boundary layer aerosols compared to CT-12K's. However, the NWs/FAA deployment strategy is simply to use them to estimate cloud presence and cloud base.)

Two of the CT-12K ceilometers have been continuously reporting in the Salt Lake Valley: University of Utah campus (since January 2012) and NWS office near the airport (since March 2012). State-of-the-art software has been developed to utilize and monitor the backscatter information in real time (http:/mesowest.net/ceil). We have

also encouraged other universities to obtain the CT-12K ceilometers and provided instructions on their installation and requisite software (e.g., Florida Institute of Technology, San Jose State University, Texas A&M, University of Virginia, University of Washington, Valparaiso University). Within the next couple of years, we hope to foster a national-scale program to upgrade such ceilometers to the CL 31 models to provide improved understanding of the depth of the boundary layer and the variability of aerosol concentration within the boundary layer. This field campaign represents an excellent opportunity to test such capabilities and we propose as an option to purchase a CL 31 ceilometer for comparison. The CL 31 sensor would greatly aid our interpretation of boundary layer height and aerosol concentrations in the Uintah Basin of the CT-12K sensors based on our field campaign experiences in the Salt Lake Valley. Nonetheless, we expect the deployment of multiple CT-12K sensors in the Uintah Basin to provide an unprecedented documentation of the temporal evolution of cloudiness and boundary layer depth at key locations.

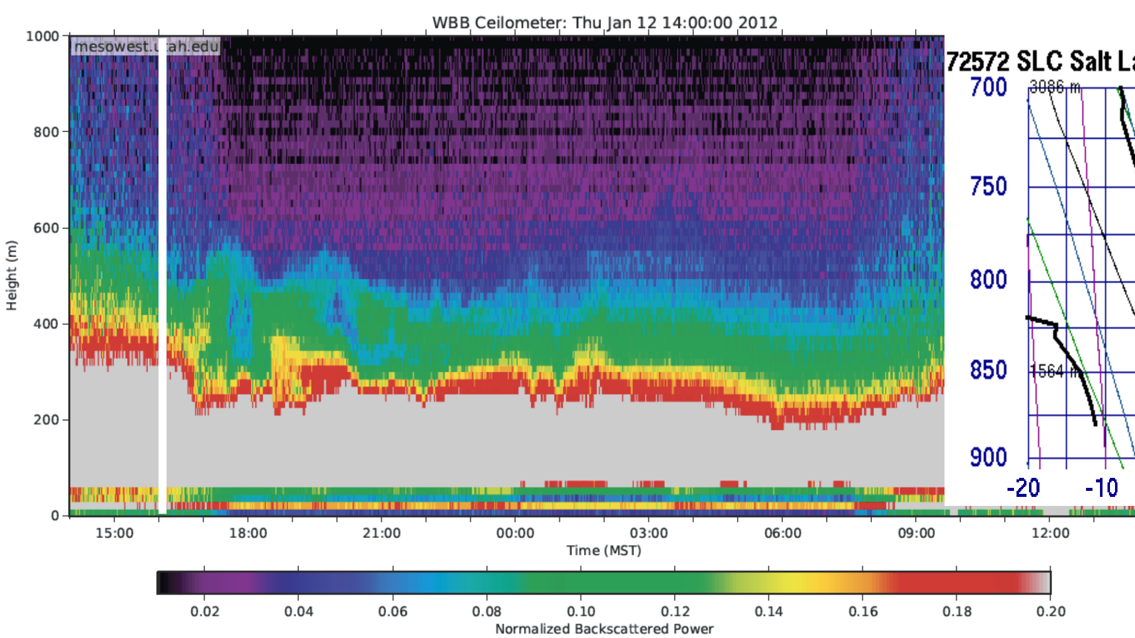

Figure 3. Aerosol backscatter from the University of Utah campus CT-12K laser ceilometer with 15 m vertical resolution from 21 UTC (14 MST) 12 January to 16 UTC (9 MST) 13 January 2012. The top-most gradient in backscatter power (transition from green to dark blue-purple) has been subjectively tied to the top of the boundary layer. Vertical profile of temperature and dew point temperature at the time denoted by the vertical white line near the Salt Lake Airport is also shown.

Figure 3 shows an example of the aerosol backscatter beginning at 20 UTC 12 January 2012 and continuing overnight until 15 UTC 13 January on the University of Utah campus during a cloud-free period. Note the height of the topmost gradient in aerosol backscatter (transition from green to blue/purple) beginning at 600 m AGL and fluctuating overnight to ~400 m AGL. Based on subjective evaluation of the ceilometer backscatter over the past six months, this gradient appears to correspond roughly with the height of the boundary layer. For example, the sounding from the Salt Lake Airport launched at 2300 UTC 12 January (indicated by the heavy white line) suggests a boundary layer depth of ~500-600 m.

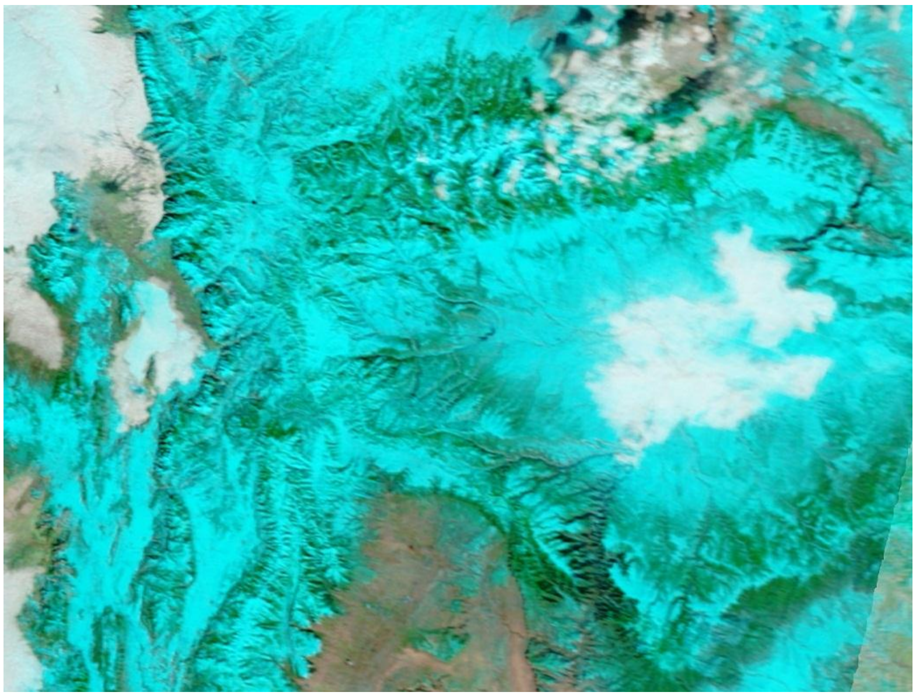

Figure 4. MODIS fog product with snow cover evident by the blue tints, areas free of snow and clouds in tan colors (e.g., Price area), and fog/stratus in white (e.g., Fort Duchesne, Vernal, and Ouray areas). Manual and automated reports at the Vernal airports document the persistence of the ice fog and stratus on this day (29 January 2011).

The experiences gained from PCAPS as well as the data collection and analysis efforts during the past two winters in the Uintah Basin by others illustrate the need for additional continuous monitoring of boundary layer depth and the extent of clouds that influence strongly the surface radiation balance along with the presence of snow cover. Of particular interest are the episodes during which ice fogs and low-lying stratus form within parts of the Basin that may be removed by radiative heating during the day; however, in some instances such episodes can persist for days. For example, Fig. 4 shows a MODIS fog product image that delineates the fog/stratus remaining near solar noon in the Basin (white areas encompass Fort Duchesne, Vernal, and Ouray areas) on 29 January 2011, while
the north-facing slopes of the Tavaputs Plateau and south facing slopes of the Uintas are snow covered, but cloud free. Similar partial coverage within the Salt Lake Valley during PCAPS was common, and we have been examining the factors that control the partial mix outs of the valley due to terrain-flow interactions on the synoptic- and meso-scale. Documenting such variations between cloud free and cloudy areas is critical for understanding the creation, transport, and eventual removal of ozone in the Uintah Basin.

By deploying laser ceilometers at key locations in the Uintah Basin, we expect to be able to provide a better delineation of the temporal evolution of these fog and low stratus episodes that are often tied to periods with high levels of particulates and ozone. In addition, we expect to be able to delineate boundary layer height during cloud free periods.

In preparing this proposal, we have done a preliminary site survey and received permission to install a CT-12K laser ceilometer on the roof of the Uintah River High School on the Ute Reservation in Fort Duchesne. In addition, we have received permission to site another ceilometer at Vernal Middle School and will identify and obtain permission at other schools as well. There are two key threads regarding siting the eye-safe laser ceilometers at schools:

- Available infrastructure: power, internet access, unobstructed views, and secure locations,
- Opportunities for community outreach and involvement of K-12 students in the research program.

Real-time access via the internet to the deployed ceilometers is of high interest, so we will pursue those options first with the highest priority finding appropriate sites at schools. However, it is also possible to deploy them simply in a secure location with 110v power. Data from the ceilometers can be recorded to a serial device and visited infrequently (e.g., monthly or end of the season) to retrieve the data. Such a procedure has already been done this past year by siting a couple of the laser ceilometers temporarily in the vicinity of the Rio Tinto mine in the Oquirrh Mountains.

d. *Enhanced Continuous Monitoring During Winter 2013- ASC mini-sodar and surface flux tower near Fort Duchesne*

We also propose deploying an ASC mini-sodar that will provide near-surface winds (ranging reliably between 15-200 m) throughout the winter with the exception of snowstorm periods. The location of the mini-sodar is proposed to be in the Fort Duchesne area, but there are factors to consider: impact on nearby residents of the transmitter's sound "chirps"; security; cell phone communications; nearby obstacles, etc. The mini-sodar was very beneficial to study the low-level flow entering the Salt Lake Valley from the Great Salt Lake during the PCAPS field campaign (Crosman and Horel 2012). We prefer to deploy this sensor within the flood plain of the Uintah River near or to the south of Fort Duchesne in order to diagnose aspects of the low level winds such as the nocturnal drainage flows into the Ouray area. The Uintah River-Ouray corridor drainage likely plays a significant role in the local flows within this critical part of the Basin where high concentrations of ozone have been observed. We also propose siting near the mini-sodar a 6 m tower with a sonic anemometer, meteorological sensors (temperature, moisture, pressure), and net solar and infrared radiation to be able to characterize more completely the near-surface flows.

e. *Rapid Sensor Deployment During January-February 2013*

We have considerable experience deploying equipment and collecting research-quality data at short notice. The 9 Intensive Observing Periods during PCAPS involved over 55 launches of GRAW rawinsondes from sites selected the previous day in combination with another 100 rawinsonde launches from a fixed site. We also deployed surface meteorological towers in support of the field campaign and collected data from vehicle-mounted sensors. Most recently, we carried out a successful mini-field campaign with a final "go" decision with only one-day's lead time in order to study the 1 December 2012 downslope wind storm in Davis County (Lawson and Horel 2012). That included: launching rawinsondes from two sites (one in the presence of 40 m/s surface winds); deploying three light-weight 3 m towers with meteorological sensors; and driving two vehicles during the storm equipped with AirMar all-in-one sensor packages (temperature, wind, pressure, moisture, and GPS).

Assuming conditions develop by early January 2012 that may contribute to elevated ozone levels in the Uintah Basin, we propose to be prepared to participate in Intensive Observing Periods. We will pre-position all of our necessary equipment to a storage facility in the Uintah Basin to simplify set up and reduce our response time. A sleeping trailer in the Roosevelt/Fort Duchesne area will be used as a base site for field operations. Based on the conditions, we would deploy lightweight tripods with meteorological sensors as well as deploy a trailer mounted ceilometer and meteorological tower at the beginning of an IOP.

Specific details regarding the rapid deployment of equipment will need to wait for coordination with other research team members. However, there is a clear need to understand the profile of wind, temperature, and moisture throughout the troposphere with greater attention on conditions within the boundary layer. We have considerable experience with lightweight balloons (50g) to provide slow ascents after launch. A typical deployment pattern might be to position two crews at Fort Duchesne and Ouray with rawinsonde launches daily at 14 UTC and 23 UTC (close to sunrise and sunset) to capture the minimum and maximum boundary layer heights. Data from these sondes can then be compared to those from Salt Lake City and Grand Junction at 11 UTC and 23 UTC as well as other ozonesonde data provided by other teams. The GRAW sondes are relatively inexpensive (~$200 each) and the equipment required is quite simple (laptop with radio base station and helium tank). We anticipate launching twice daily at two sites for as many as 10 days of field operations. The PCAPS field program has demonstrated the value in having two (or more) sondes within 20 km of each other to capture details within and immediately above the boundary layers. The two crews between launches would drive predefined routes to collect additional surface meteorological conditions. For safety reasons, we anticipate operations primarily during daylight hours.

Our experience gained from the PCAPS field campaign will be to operate in a "storm chasing" mode as there can be large spatial and temporal variations in high ozone concentrations in the Uintah Basin that depend on the meteorological conditions. We will rely closely on staff and students at the University of Utah to monitor conditions and provide guidance to those in the field. We will develop several targeted strategies in advance to define critical observations that are likely to depend on the synoptic and mesoscale situation. Are low clouds and fogs present in some locations and not in others? Which areas are snow-covered and which are not? Where

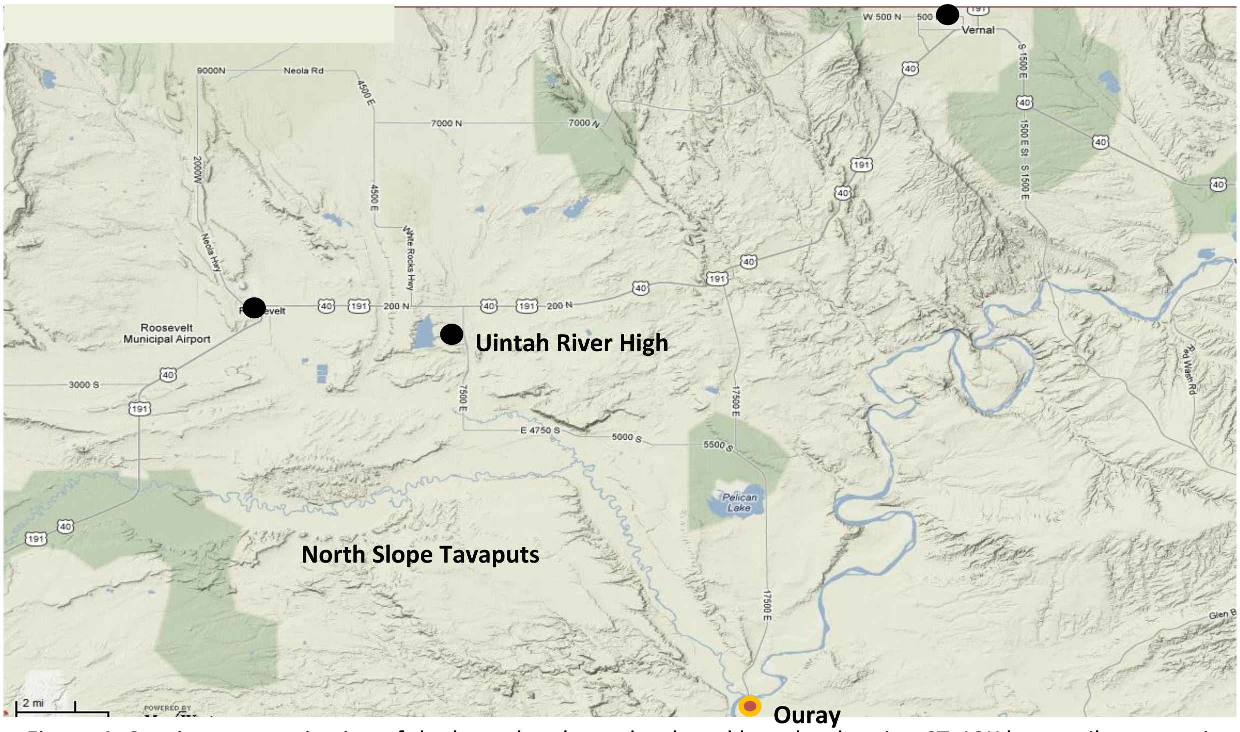

Figure 4. Continuous monitoring of the boundary layer depth and low clouds using CT-12K laser ceilometers is proposed at the Uintah River High School in Fort Duchesne as well as at other schools in the Uintah Basin in Vernal and Roosevelt (black dots). A trailer mounted ceilometer is also proposed to be deployed in the vicinity of Ouray during Intensive Observing Periods only. Rawinsondes at two sites are proposed to be launched simultaneously, e.g., Fort Duchesne and Ouray. Vehicle mounted observations and light-weight tripods will be deployed depending on the circumstances with emphasis on the north slope of the Tavaputs and Uintah River drainage.

is the synoptic-flow penetrating into the Uintah Basin and in what regions does it appear to be shielded? How can we assist filling in gaps in the observational coverage based on the deployments of other research teams?

Deliverables and Schedule

Real-time and retrospective products from MesoWest will be available continuously (http://mesowest.utah.edu). Other analysis, model and satellite products of interest to the field program will be displayed on a University of Utah web page.

Site location and deployment of ceilometers will be completed during November 2012. The minisodar will be deployed during mid-December 2012. Output from ceilometers with internet communications will be accessible in real time (http://mesowest.net/ceil). We anticipate output from the minisodar will be accessible with a few hours delay to allow for intermittent cell phone communications.

Selection of sites for possible temporary deployments of meteorological towers will be completed during November 2012. Data collected from any Intensive Observing Periods will be available within 48 hours for quick look applications. Quality control of all data will be completed by May 1, 2013. Dates of interim and final project reports will be defined to be consistent with the overall project plan.

Personnel

Prof. John Horel will coordinate this project and participate in some of the deployment and field operations at no cost to the project. He has a reduced instruction load this academic year in order to work on research projects. Asst. Res. Prof. Sebastian Hoch will help set up the minisodar and monitor its performance at no cost to the project. Maggie Schoonover, Instrumentation Manager for the University of Utah's Mountain Meteorology Instrumentation Facility, will coordinate the deployment of the equipment and be the contact person for field operations in the Uintah Basin. Ms. Schoonover will also coordinate outreach to the schools in the Uintah Basin. Dr. Erik Crosman, who has helped lead two field campaigns in northern Utah, will also participate in the equipment deployment and field operations. He also will lead the baseline collection, monitoring of the data streams, and analysis of model grids and satellite imagery. He has extensive experience working with MODIS and AVHRR satellite products. As schedules permit, a pool of graduate students (Neil Lareau, Alex Jacques, Matt Lammers, John Lawson) will be monitoring conditions in the Uintah Basin, help launch rawinsondes and operate other equipment.

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Tyndall, D., and J. Horel, 2012: Impacts of mesonet observations on meteorological surface analyses. *Wea. Forecasting*. In press.

Young, J., and C. Whiteman, 2012: Observing Characteristics of Wintertime Cold-Air Pools Using Laser Ceilometers. *15th Conference on Mountain Meteorology*. 20-24 August 2012, Steamboat, CO.

Budget

PI John Horel will participate at no cost to this project and provide overall coordination. Maggie Schoonover, Mountain Meteorology Instrumentation Facility manager, will lead the site deployment and field coordination. She will be supported for 4 months as part of this project. Postdoctoral researcher Dr. Erik Crosman will assist Ms. Schoonover in the field installation and participate in the field campaign. Four months of total support for graduate students is requested that reflects the participation in installation and take down of equipment as well as conducting field data collection and providing.

40 rawinsondes from GRAW, Inc. will be purchased. Due to demand and delivery of the sondes from Germany, they need to be purchased as soon as possible. Additional miscellaneous parts and supplies are requested for the installation of the ceilometers and other equipment (Ethernet and power cables, mounting hardware, etc.).

Travel to and within the Uintah Basin will rely primarily on a truck owned by the Department of Atmospheric Sciences. Field operations requiring a second vehicle will rely on a second vehicle rented from the University of Utah.

Our proposed project would be enhanced significantly with the purchase of a Vaisala CL 31 ceilometer for improved characterization of boundary layer depth from enhanced sensitivity to aerosol backscatter. However, funding for that purchase is considered optional.

The indirect cost rate is defined here to be 10% by assuming the funding originates from the Utah Department of Environmental Quality. If from a non-state source, the indirect cost rate would be 49.5%.

University of Utah Atmospheric Sciences Budget		
Budget period :	**Oct 15, 2012-Oct 14, 2013**	
Expense Category (Account Name)	**Amount**	
Salaries		**Fringe Rate**
PI John Horel (0.5 Mo)	$0	
Maggie Schoonover (4 Mo.)	$11,667	
Total Staff	$11,667	*37.00%*
Total Faculty Salaries	$0	*37.00%*
Erik Crosman (2 Mo.)	$8,755	
Total Post Docs	$8,755	*22.00%*
Graduate students (4 Mo.)	$8,000	
Total Graduates	$8,000	*14.00%*
Total Fringe Benefits	$7,363	
Travel- Domestic	$0	
Technical Supplies (40 sondes @ $200 each) + $1500 field related supplies	$10,500	
Subcontract Expenses-less than $25,000	$0	
Other Expenses (itemize by category below)		
Publication charges	$0	
Dept. of Atmos. Sci. truck mileage (including gas) & daily usage - 10 weeks	$2,939	
Trailer hookup/space rental - 2 mos	$600	
Storage unit- 3 mos.	$150	
Items Excluded from F&A Calculation		
Equipment (equal to or greater than $5000 per asset)		
CL 31 ceilometer	$24,790	
Total Direct	**$74,763**	
Indirect (F&A) Cost	**$4,997**	*10.00%*
Grand Total	**$79,760**	