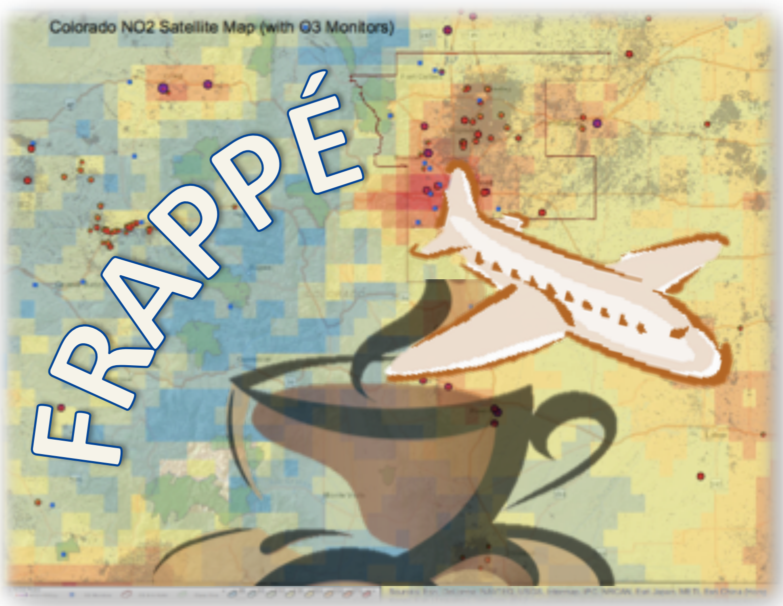
Front Range Air Pollution and Photochemistry Éxperiment
FRAPPÉ

A Proposed Field Experiment in Colorado for Summer 2014

PIs: Frank Flocke and Gabriele Pfister
National Center for Atmospheric Research (NCAR)
Earth Systems Laboratory, Atmospheric Chemistry Division
3450 Mitchell Lane, Boulder, CO 80301, USA

Steering Committee: James Crawford (NASA Langley)
Ron Cohen (UC Berkeley)
Detlev Helmig (CU Boulder-INSTAAR)
Ken Pickering (U Maryland)
Patrick Reddy (CO Dept. of Public Health and Environment)
John Orlando and David Edwards (NCAR)



http://www2.acd.ucar.edu/frappe

January 2013

Project Summary

The Front Range Air Pollution and Photochemistry Experiment –FRAPPÉ– aims to characterize and understand summertime air quality (AQ) in the Northern Front Range Metropolitan Area (NFRMA). Despite efforts to limit emissions, the NFRMA is still experiencing AQ problems and is exceeding the National Ambient Air Quality Standard (NAAQS) for ozone on a regular basis in summer. The complex meteorology and the mix of diverse pollution sources present challenges with respect to characterizing, modeling and forecasting the transport and photochemical processes contributing to local AQ. In addition, long-range transport of pollution into the area and its impact on surface AQ is poorly characterized, as is the effect of NFRMA outflow on its surroundings.

The FRAPPÉ campaign will involve a series of coordinated NSF/NCAR C-130 flights and ground-based measurements that address the following main science question: ***What are the factors controlling NFRMA surface ozone and are current emission controls sufficient to reduce ozone levels below the NAAQS?*** FRAPPÉ will be closely linked to two other campaigns taking place in the Front Range at the same time. The first is the NASA DISCOVER-AQ (DAQ) aimed at improving satellite capability to interpret AQ conditions near the earth's surface, via deployment of two instrumented NASA aircraft, and remote sensing and in-situ ground equipment. The other campaign is the proposed FRONT-PORCH - an investigation of meteorological and hydrological processes in the Colorado Front Range. These three missions together provide an outstanding opportunity to study and characterize local AQ at a level of detail not possible previously. We expect additional support in the form of collaboration, ground site access, ground-based instrumentation, data access, and modeling and forecasting support from the Colorado Department of Public Health and Environment (CDPHE), NOAA Chemical Sciences Division (CSD), The University of Colorado Institute of Alpine and Arctic Research (INSTAAR), Colorado State University, The National Park Service, and other local groups and agencies.

Intellectual Merit: The observations from these campaigns together with modeling studies will be used to better describe and understand the AQ situation in the Front Range. The project will characterize the regional background conditions, inflow and outflow of pollution, recirculation patterns over the complex mountain terrain, and source regions of specific pollutants (e.g., urban centers, transportation, oil and gas extraction facilities and agricultural activities, as well as natural emissions from the biosphere). FRAPPÉ will focus on the interaction and chemical processing of these emissions and, combined with inflow assessments, their integrated impact on AQ in the NFRMA as well as the impact of the NFRMA on the surrounding areas. FRAPPÉ, in combination with DISCOVER-AQ and FRONT-PORCH, will provide a comprehensive and unique data set that will result in advancements in understanding and knowledge of emissions, photochemical processes, small and regional scale transport, boundary layer development and large-scale inflow. The data will be used to evaluate and improve the representation of physical and chemical processes in models, and thus will improve AQ-related predictive capabilities.

Broader Impact: The study of AQ in the NFRMA is of high interest both in terms of scientific importance and societal relevance. Improved AQ models and forecasting systems and constraints on emission sources leads to improved predictive capabilities, more confidence in developing AQ assessment and mitigation strategies and, ultimately, societal benefits from a cleaner environment. The results will be highly relevant to the NFRMA, but also to other regions in the U.S. and the world, through improved representations of processes in models, better characterization of background and long-range pollution transport, and more precise knowledge of emissions. Specifically, oil and gas development has undergone large changes in the NRFMA and elsewhere, and this study will better characterize the impacts of these activities on AQ.

The project will have a strong education and outreach component and will be carried out in close collaboration with university partners, local and regional air quality agencies. The project will connect with the public, with K-12 educators, and with university students, for example, through NCAR E&O Activities, the NCAR SOARS and RETI programs, and involvement of the Global Ozone (GO3) project.

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Motivation and Science Questions

Despite considerable progress in controlling anthropogenic emissions, air quality (AQ) remains a significant health and financial issue across the continental USA and in 2010, approximately 124 million people lived in counties that exceeded one or more National Ambient Air Quality Standards (NAAQS) ("Our Nations Air", http://www.epa.gov/airtrends/2011/). A recent study (Fann et al., 2011) suggests that more than 100,000 premature deaths occur per year in the US as the result of inhalation of particulate matter and/or ozone, with a resultant decrease of about 8 months in life expectancy. The economic impact of this, together with increased hospital admissions and emergency visits, for example for respiratory causes attributed to air quality, is substantial (Fann et al, 2011, Committee on Estimating Mortality Risk Reduction Benefits from Decreasing Tropospheric Ozone Exposure, National Research Council, 2008; http://www.nap.edu/catalog/12198.html). Further AQ-related economic loss, estimated to be about $1-6B/year for the US (Murphy et al., 1999; van Dingenen et al., 2009), occurs as a result of crop damage caused by exposure to elevated levels of ozone.

The Northern Front Range Metropolitan Area (NFRMA) is located between the Rocky Mountains to the west and the High Plains to the east. Denver, one of the top ten mega-urban regions in the U.S., is the largest urban area with about 2 million inhabitants, followed by Colorado Springs, and Ft. Collins with about 250,000 inhabitants each, and Boulder with about 100,000 people. Smaller communities embedded between the larger cities fill in the remaining space on the west side of the NFRMA, and in recent years, considerable urban expansion has taken place towards the eastern plains. The entire area between the mountains to the west and Interstate Highway 25 to the east has experienced massive urban growth since the mid- 1990s. The metropolitan area and is also one of the nation's fastest-growing urban centers with Denver's population expected to increase by nearly 50% by 2030.

Despite efforts to limit emissions, the NFRMA is still experiencing air quality (AQ) problems and is exceeding national AQ standards for ozone on a regular basis in summer posing a hazard to human health as well as to vegetation and ecosystems. The NFRMA area is currently designated as an ozone non-attainment area by the U.S. Environmental Protection Agency. The Regional Air Quality Council (RAQC) and the Colorado Department of Public Health and Environment (CDPHE) have aggressively pursued controls to limit ozone precursor emissions since 2003. Still, on average, there are about 25 exceedance days per year of the current 0.075 ppm National Ambient Air Quality Standard (NAAQS) from the 20 NFRMA ozone sites. A proposed lowering of the current NAAQS to around 65 ppbv, which is closer to the range other countries are imposing, would put much of the rest of Colorado into non-attainment for ozone.

The study of AQ in the NFRMA presents some complex and unique challenges. First, flow patterns are highly complex due to the unique meteorological situation, driven in particular by mountain-valley circulation effects, as well as the high elevation and varied terrain. This complex meteorology, coupled with the mix of diverse pollution sources (e.g., urban emissions of NOx and NMHC, strong point sources such as large power plants and industrial complexes and airports, and area sources such as agricultural emissions, emissions from oil and gas development, biogenic emissions and wildfires) in the NFRMA present challenges with respect to characterizing, modeling and forecasting the transport and photochemical processes contributing to local air quality.

We propose to conduct the FRAPPÉ (Front Range Air Pollution and Photochemistry) Experiment, a coordinated set of measurements (ground- and aircraft-based) that will address outstanding AQ issues in the NFRMA. Specifically, the campaign will address the following major scientific questions:

1) What are the factors controlling NFRMA surface ozone and are current emission controls sufficient to reduce ozone levels below standards?
2) What are the relative contributions of local mountain-valley recirculation patterns and long-range transport to buildup of photochemical oxidants and particulates during smog episodes in the NFRMA in the summer?

3) What are the relative contributions of the diverse local sources of pollution to air quality degradation and photochemical oxidant formation in the NFRMA?
4) To what degree does pollution from both NFRMA sources and long-range transport contribute to photochemical smog / ozone pollution, visibility degradation, and nitrate deposition in Rocky Mountain National Park and other Wilderness Regions to the west of NFRMA?
5) What is the impact of ozone precursor emissions from oil and gas extraction and exploration activities on the photochemical regime and the ozone production efficiency?
6) How is pollution from NFRMA affecting background mixing ratios of oxidants, specifically ozone and NOx in surrounding rural areas? Are commonly used air quality models able to adequately represent the urban-rural interface?
7) Is the NFRMA like many other urban areas in the U.S. shifting to a more NOx limited chemical regime, and what are the implications for future air quality predictions and policy decisions?

As outlined in detail below, the campaign will include measurements from numerous ground sites operated by partnering Universities and agencies and from a series of flights of the NSF/NCAR C-130, associated forecasting, and modeling activities. The mission is designed to run concurrent with the DISCOVER-AQ (DAQ) campaign, which will include two additional NASA aircraft, and with the proposed FRONT-PORCH campaign, which will provide detailed meteorological context for the AQ measurements being made.

Scientific Tasks

Task 1: Role of thermally driven circulation in transporting emissions and pollutants

The NFRMA is located at an elevation of roughly 1600-1800 m, on the plains just to the east of the Central Rocky Mountains. To the west of the NFRMA, the terrain becomes mountainous, mostly wooded, with scattered smaller communities up to elevations below 3000 m, and then transitions into the mostly uninhabited alpine region along the Continental Divide, reaching up to 4200 m altitude. A good climatological overview of the Front Range is given in Barry (1972). Several major river canyons extend from the high terrain down into the NFRMA, such as the South Platte, Clear Creek, Coal Creek, Boulder, St. Vrain, Big Thompson, Cache La Poudre canyons (in order from S to N). In the summer months, particularly during weak synoptic conditions, the local meteorology is mainly controlled by thermally driven, terrain-induced, diurnal flow patterns (Johnson and Toth, 1982; Toth and Johnson, 1985, and references therein). This has unique consequences for the transport, mixing and photochemical processing of local emissions (Haagenson, 1978; Greenland, 1980; Doran, 1996; Baumann et al., 1997; Olson et al., 1997). Briefly, during the night, radiative cooling of the land surface causes downslope drainage flows from the Continental Divide in the West, far into the Eastern Plains. The drainage flows are most pronounced in the canyons and river valleys (Johnson and Toth, 1982; Doran, 1995). During the morning hours, solar heating of the ground and mountain slopes causes upslope flow to develop, starting a few hours after sunrise in the foothills and slowly extending far out into the eastern plains about three hours later. Typically about mid-day, the upslope flow also reaches the top of the continental divide. In the late afternoon, flow reversal starts at the top of the Continental Divide and a convergence line forms and moves down and East during the evening hours. Finally, downslope winds take over the entire region again around midnight (Johnson and Toth, 1982, and references therein).
This meteorology causes pooling of nighttime emissions (urban, agricultural, and oil and gas development) in the lower elevations, particularly the Platte River Valley. These emissions start to be photochemically processed after sunrise, and are transported to the west (back into the urban area) after onset of the upslope flows. Fresh emissions from the NFRMA, mixed with these partially processed air masses, are then transported into the mountains during the day. Once lofted above the Continental Divide,

air is entrained into the free troposphere, typically dominated by westerly flow in this latitude range. This way, at night, processed air masses from the previous day can be transported back into the NFRMA with the downslope winds developing in the evening. In addition, especially during weak synoptic conditions, air masses entrained into the westerly flow over the Continental Divide can be mixed down from the free troposphere into the expanding boundary layer during the next morning. Both mechanisms act as an enhancement to photochemical processing of current emissions, causing the concentrations of ozone and other photooxidants to build up over the course of several days. Many such episodes have been observed over Denver and elsewhere (see figure 1). In addition, upslope transport of photochemically active air masses impact ecologically sensitive and/or recreationally important areas west of the NFRMA, such as Rocky Mountain National Park, and numerous nearby Wilderness areas, for example through reduced visibility, enhanced deposition of nitrogen (Benedict et al., 2011, Darrouzet-Nardi et al., 2012) and elevated ozone concentrations (Brodin et al., 2010; Brodin et al., 2011). In contrast, stronger frontal passages can induce outflow of NFRMA pollution to the East, impacting the agricultural areas located downwind in the central Great Plains. Such events, as well as thunderstorms (see also page 11), are the major driver for cleaning out accumulated pollution from the NFRMA.

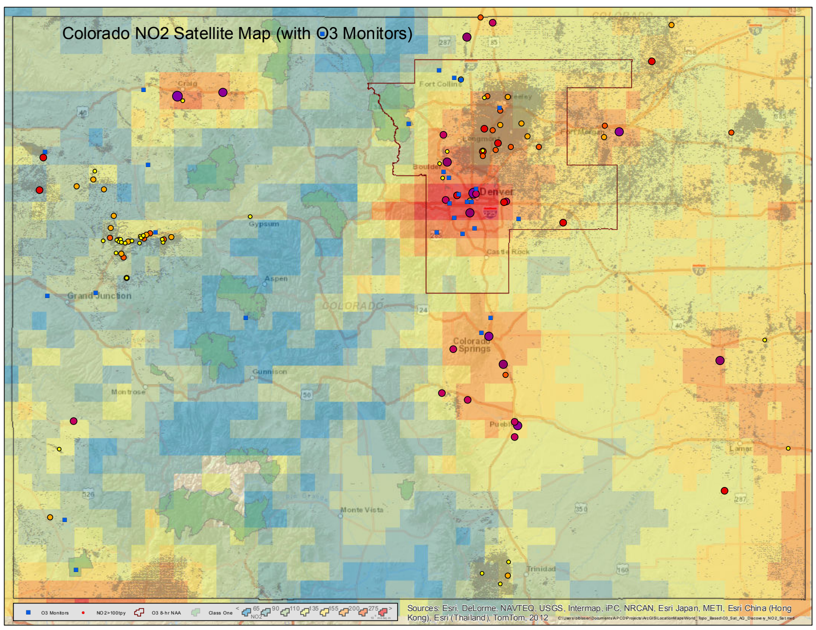


Figure 1: Map of mean July OMI NO_2 in 10^{15} molecules/cm^2 for 2009 through 2012 over the Front Range region. Also shown are NO point sources colored by emission strength (yellow-red circles) and location of ozone monitors (blue squares). Emissions will tend to pool overnight and in the early morning along the broad Platte Valley from Denver north to Greeley. The OMI overflight is at about 1330 MST. By this time, thermally driven upslope is transporting NO_2 to the northwest, west, and southwest into the higher terrain from the Wyoming border to just southwest of the Denver metro area. A large pattern of higher NO_2 is preferentially transported up the Clear Creek Canyon toward Idaho Springs, Georgetown, the Eisenhower Tunnel, and the Continental Divide in Clear Creek County. Power plant emissions from the Brush facility can be seen in Morgan County. Graph courtesy CDPHE.

Mountain-Valley circulation effects are not unique to the NFRMA area. Studies have shown that thermally driven local meteorology plays a role in a number of urban areas in the US (the Central Rockies, California's Central Valley, and the Appalachia Region (Mueller, 1994, Aneja, 1994, Bytnerowicz et al, 2002; Burns, 2003; Bytnerowicz, 2005;Choi, 2011)) and around the world (The Mediterranean and the Alps, the Tibetan Plateau, and others (Seibert et al, 1998, Gangoiti et al., 2001, Fock and Schlunzen, 2012)).

FRAPPÉ, in conjunction with FRONT-PORCH and DISCOVER-AQ, will present a very unique opportunity to study this phenomenon in a never before possible detail. Detailed meteorological ground observations will be combined with meteorological and chemical tracer measurements made from the C-130 and the NASA aircraft to provide highly detailed input and validation data to the models. FRAPPÉ is committed to include some microphysics instrumentation to aid goals of the FRONT-PORCH science team, if both campaigns are funded. All flight patterns shown below will contribute to this task. Careful planning will have to be done concerning flight timing and coordination with ground and tower measurements.

Task 2: Emission Characterization and Evaluation

As is also the case for other regions in the country, pollution levels in the Northern Front Range are impacted by a myriad of different sources including urban sources, power plants, agricultural activities, oil and gas extraction and exploration and also natural sources like wildfires, biogenic VOCs or windblown dust. Emissions pose one of the major uncertainties in understanding and modeling air quality and the climate impact of short-term pollutants, and the uncertainties in inventories are associated with the spatial distribution, temporal variability, emission rates and emission ratios. Targeted aircraft flights and comprehensive surface sampling will provide essential input to reduce these uncertainties.

Most inventories are compiled from bottom-up methods relying on reported input; atmospheric measurements of a range of species are crucial for evaluating and improving upon the emissions themselves as well as the methods used to derive them. Various studies have shown that the lowest uncertainties in regulatory inventories for the U.S. are overall associated with power plant emissions (Peischl et al., 2010; Kim et al., 2006), which is due to continuous emission monitoring systems (CEMS) installed in these point sources, while much larger uncertainties are found for urban areas and industrial sources (e.g. Harley et al., 2005; Parrish, 2006; Warneke et al., 2007; Washenfelder et al., 2010; Kim et al., 2011; Brioude et al., 2011). These studies also demonstrate the feasibility in using field campaign data and modeling tools in constraining sources.

Specifically large uncertainties are associated with fast changing sectors including oil and gas operations and agriculture. Recent studies such as Katzenstein et al. (2003) for the South-Western U.S., Schnell et al. (2009) for Wyoming, Ryerson et al. (2003) and de Gouw et al. (2009) for the Houston area, or Simpson et al. (2010) for Alberta, Canada reported elevated emissions of methane and NMHC from oil and gas operations indicating a significant underestimate of current inventories with differences of up to an order of magnitude (Mellqvist et al., 2010). Oil and gas production in Colorado has been on the rise since the 1980s and in 2008 the State accounted for 5.4% of the national natural gas production and 1.3% of the nationally produced oil (U.S. Energy Information Administration, 2006). From the analysis of measurements taken in North-Eastern Colorado, Petron et al. (2012) conclude notable inconsistencies between their bottom-up estimates and state and national regulatory inventories and point out the need for targeted well-calibrated multi-species atmospheric measurements. This conclusion was also reached by the CDPHE from a case study that was conducted in Erie, Colorado in summer 2012.

Emissions from agriculture are also poorly characterized (Aneja et al., 2006), and are expected to continue to increase as result of growing population and demand. Ammonia, both in gaseous and particulate form, contributes to eutrophication of surface waters, soil acidification, fertilization of vegetation, changes in ecosystems and smog and decreased visibility. Globally, domestic animals and fertilizers and crops are estimated to account for 40% and 12% of the emissions, respectively. Besides reactive nitrogen, agricultural operations also emit sulfur species, PM and greenhouse gases; all of which are important for air quality and climate. For the U.S. agricultural activity is estimated to account for about 90% of total ammonia emissions, 16% of PM2.5, 18% for PM10, 29% of methane and 72% of nitrous oxide (Aneja, 2009).

Detailed emission measurements will allow for the determination of the degree to which increased emissions from these sectors might counteract emission controls put in place on the urban, industrial and powerplant sector. Large impacts are also possible from intermittent sources such as forest fires, dust outbreaks, or accidental releases and industrial upsets. These episodic sources require detailed characterization as they can lead to extremely high concentrations of criteria air pollutants or air toxics.

Task 3: NO_x-limited and NO_x-inhibited ozone regimes

The efficiency of ozone production is known to be a non-linear function of NO_x and VOC levels (e.g., Finlayson-Pitts and Pitts, 1999), and can generally be characterized as NO_x-limited (insufficient NO_x is available to efficiently propagate radical chains) or NO_x-inhibited (ozone production is limited by titration or via reaction of OH with NO_2). The latest NFRMA State Implementation Plan (http://www.colorado.gov/airquality/documents/deno308/woe_DraftFinal_w preface.pdf) points to a need for increased understanding of NO_x and VOC sensitivity in the region and how these vary in time and space. Non-linearities in ozone production are often manifest in a so-called 'weekend effect', as different anthropogenic emission patterns between weekdays and weekends lead to changes in observed ozone (e.g., Altshuler et al., 1995; Blanchard and Fairley, 2001; Pont and Fontan, 2001; Jimenez et al., 2005; Murphy et al,. 2006, 2007; Stephens et al., 2008; Koo et al., 2012, and references therein). While analysis of these weekend/weekday changes can be complex (e.g., Murphy et al., 2007), many urban centers (e.g., Los Angeles, San Francisco, Sacramento, Mexico City, Barcelona, Chicago, Detroit) show higher ozone levels on weekends than weekdays (e.g., Blanchard and Fairley, 2001; Jimenez et al., 2005; Murphy et al., 2006, 2007; Stephens et al., 2008; Koo et al., 2012), a result that can be an indication of a NO_x-inhibited photochemical regime. Studies of the weekend effect over the 2005-2007 timeframe in Denver (http://www.colorado.gov/airquality/documents/deno308/woe_DraftFinal_w preface.pdf) show a significant weekend enhancement in ozone levels at the downtown Denver CAMP site and in downtown Fort Collins, suggesting NOx-inhibited chemistry in these regions, while suburban sites show more modest (positive or negative) weekend effects. Given the general trend toward decreasing anthropogenic emissions (particularly with respect to NO_x emissions from power plants and older automobiles), and the important policy-related ramifications associated with understanding the impacts of these changing emissions (and future regulations) on ozone production in Denver and other urban locations, we propose here a detailed determination of the spatial distribution of the different photochemical regimes in the NFRMA. This can be achieved using NO_x and VOC measurements made aboard the aircraft, as well as at the ground sites. Satellite data may be useful to assess the regional distribution of NO_2, ozone, and H_2CO (as an indicator of photochemical processing) [Duncan et al., 2010]. For the C-130, the mountain valley, local and regional flight patterns (a-c) described below will contribute to this goal.

Task 4: The fate of NOx and production of aerosols in NFRMA outflow

A major focus of the FRAPPÉ campaign is to understand the impact of the NFRMA outflow on surrounding regions. Typically, oxidant production in this outflow will transition to a NO_x–limited photochemical regime, and thus proper accounting and modeling of NO_x chemistry is critical for assessing ozone formation rates in the outflow. Studies in the eastern US (Castellanos et al., 2011) suggest that some models underestimate NO_x in rural regions, possibly the result of improper accounting of organic nitrates derived from oxidation of biogenic VOC (Salawitch, private communication, 2012). While this issue is likely not as severe in the western US, where biogenic emissions are typically lower, the lifetime and fate of NO_x from the NFRMA might be highly complex, and may vary with meteorological conditions and the nature of the air masses encountered by the outflow. The key issue to be resolved is to assess the relative and overall rate of NO_x conversion to HNO_3, PANs and organic nitrates, and nitrate aerosol as a function of direction of the outflow. For example, mixing of the urban plume with agricultural emissions might lead to ammonium nitrate production, while mixing with VOC emissions from either gas/oil extraction or biogenic emissions may result in higher levels of organic nitrates and ozone as well as secondary organic aerosol (Fry et al., 2013). Note that the exact nature of the VOC mix is itself important, as this can affect the yield of organic nitrate formation as well as the amount of NO_x recycling from these nitrate species (e.g., Browne and Cohen, 2012). Emissions from wildfires, if present during the mission, may also play a role in determining the NO_x fate and lifetime. Thus, some C-130 flights (or portions thereof) will be dedicated to following outflow from the NFRMA, with an emphasis on determining the fate and lifetime of NO_x in the outflow and the resultant effect on oxidant and aerosol production. (See detailed flight plans below, particularly pattern (d)). The impacts of the resultant NO_x/NO_y distribution and concentrations on downwind chemistry will be examined, as will be the factors that control nitrogen deposition in RMNP. The NO_x lifetime and fate associated with major power plants (e.g., Four Corners, San Juan plants in NW New Mexico) will also be explored (Figure 3a).

Task 5: Importance and Origin of Background Ozone and other Pollutants in the U.S.

The EPA national emission inventory estimates that from 1990-2010 ozone precursor emissions have been cut roughly in half which has led to a decrease in extreme ozone events (Frost et al., 2006; Butler et al., 2011; Pozolli et al., 2011). However, several studies have shown that at the same time the baseline or background concentrations have been increasing (Jaffe and Ray, 2007; Parrish et al., 2009; Lefohn et al., 2010; Hogrefe et al., 2011) and that ozone reductions have been greater in the Eastern U.S. compared to the Western U.S. (Cooper et al., 2012). This suggests that increasing background ozone entering the U.S. is in part counteracting ozone reductions from domestic emission controls. A major component of this inflow is assumed to be due to Asian pollution reaching the lower free troposphere of the Western U.S. (Jacob et al., 1999; Parrish et al., 2004; Dentener et al., 2011) and mixing down to the surface (Parrish et al., 2010; Huang et al., 2010; Pfister et al., 2011; Lin et al., 2012). Evidence of long-range transport of pollution and its impact on surface AQ is not limited to ozone and ozone precursors, but has also been observed for other pollutants such as dust, sulfate or mercury (Husar et al., 2001; Jaffe et al., 2003; McKendry et al, 2008; Weiss-Penzias et al., 2007). Advancing the understanding of transported pollution to local surface concentrations is crucial input for assessing emission control strategies, estimating future air quality and for risk and exposure modeling.

A combined analysis of field campaign data for the free troposphere and the surface, satellite data and modeling tools will allow us to quantify the contribution and variability of background pollution over the Western U.S. and the mechanisms which bring free tropospheric pollution down to the surface. As an example of some ongoing work, Figure 2 shows a time series of observed and modeled surface ozone for Boulder, CO for summer 2008 (Pfister et al., in preparation). The model estimates are from a WRF-Chem simulation including an ozone tagging scheme (Emmons et al., 2012), which is used to quantify the ozone that is present due to inflow of ozone and ozone precursors from outside the U.S. The model fairly well represents the temporal variation of surface ozone, and the differences can mainly be explained by uncertainties in emissions, boundary layer dynamics and circulation patterns. Another source of error is the large-scale inflow of pollution; as is evident from the graphs, long-range transport from outside the U.S. can make a significant contribution to surface air quality not only in remote areas, but also in urban environments and needs to be well characterized for a full understanding of local AQ. Observations during FRAPPÉ will add significant value to improving upon these uncertainties and enhancing the skill of air quality modeling.

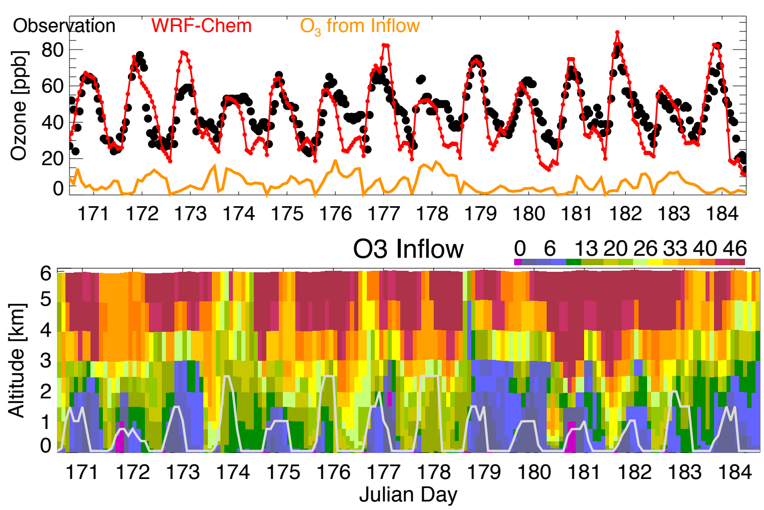


Figure 2: Top: Observed (black) and modeled total (red) and tagged (orange) surface ozone for Boulder, CO for 18 June – 10 July 2008. (Measurements are obtained from the EPA AQS Data Mart). Bottom: Vertical time-altitude cross section of tagged ozone. White lines indicate the height of the boundary layer.

Task 6: Evaluating/refining physical and chemical processes in chemical transport models

Adequate simulations of regional and local air quality require accurate representations of meteorological processes and transport, emissions and chemistry. Tasks 1 through 5 listed above provide the essential inputs in evaluating and improving model inputs (Task 2), and physical (Task 1 and 5) and chemical (Task 3 though 5) processes in state-of–the art chemical transport models. Simulations with the WRF-Chem model using the various parameterizations for physics, dynamic and chemistry incorporated in the modeling system allow evaluation of and, where possible, improvement of current schemes. Modeling will also be used to integrate the different surface, aircraft and satellite observations for a complete picture of NFRMA air quality and to support analysis of field campaign data. Similar analysis can also be conducted using other models commonly used in the research and air quality community as the entire data set will be made available to the broader atmospheric community.

Atmospheric chemistry and air quality are strongly influenced by meteorological processes and this campaign will address the major model deficiencies, specifically the representation of boundary layer dynamics and mixing, the ability of models to simulate small-scale circulation patterns (upslope/downslope) and its dependence on model resolution, as well as the representation of clouds.

In regard to model chemistry, the comprehensive set of measurements will allow a study of the photochemical processing in plumes and assess which chemical schemes best represent certain conditions and if and where improvements are needed. Evaluating the modeled NO_x and VOC sensitivities is crucial for testing emission scenarios and for assessing possible changes in surface ozone with changes in inflow.

Aerosols in air quality models are most often evaluated with mass PM measurements from operational surface sites as this often is the only information available. However, to assess deficiencies in the model representation of aerosols requires additional information such as number and size distribution and chemical composition, and in regard to SOA, knowledge about the precursor gases. The comprehensive set of coinciding meteorological and chemical measurements also provides a testbed for investigating the aerosol feedback on meteorology.

Experimental Design

Deployment timing

The proposed time frame for FRAPPÉ is 1-31 July, 2014. This would optimize overlap with FRONT-PORCH and at the same time ensure that strong photochemical processing was ocurring. To ensure 100% overlap with the FRONT-PORCH campaign the earliest start date for FRAPPÉ would be 1 June 2014 and the latest possible end date would be 15 August, 2014. NASA has the necessary scheduling flexibility to accommodate moving the campaign by 2 – 3 weeks in either direction.

Flight Operations

The NCAR C-130 will be used for larger area operations complementary to the NASA flights, which will focus mainly on the Denver metro area and immediate surroundings (see details on NASA flights below). C-130 operations will encompass the entire state of Colorado, including the border areas to the S, W, and into SE Wyoming. The payload of the C-130 aircraft will be optimized to not only measure photochemically active precursors and primary oxidants such as hydrocarbons, NO_x, NH_3, inorganic acids, and ozone but will also include many secondary products and intermediates such as PANs, organic nitrates, VOCs, and peroxides. These measurements will allow us to assess air mass photochemical processing as well as air mass age (in a chemical sense) to investigate recirculation of air from the previous day. The C-130 will also make extensive aerosol measurements, including physical parameters as well as chemical composition. Radical measurements will complete the payload and will enable us to

constrain photochemical processes, oxidant formation rates, and secondary aerosol formation as the NFRMA emission mix undergoes chemical transformation. By sampling the different chemical regimes in and surrounding the NFRMA, we will emphasize NO_x and VOC sensitivity of oxidant formation, radical budgets and lifetimes, interaction of urban emissions with emissions from agriculture and oil and gas fields to the N and E of the NFRMA, and on the lifetime of NO_x and its reservoir species and the resulting impact on NO_x availability in rural areas downwind of the Front Range. Figure 3a outlines the aerial extent of the C-130 operations around the DAQ flight operations.
C-130 flights will be designed to provide information on both, inflow conditions and pollution outflow pathways, chemical processes, as well as the potential recirculation of local pollution over and east of the Front Range Mountains. In addition, larger point- as well as area sources near the NFRMA will be characterized. Four basic flight types, or patterns, are envisioned for the campaign. The flight patterns shown can either be flown repeatedly during a dedicated research flight, or they can be combined in a modular fashion to maximize scientific return from each flight day. The flight patterns are described below.

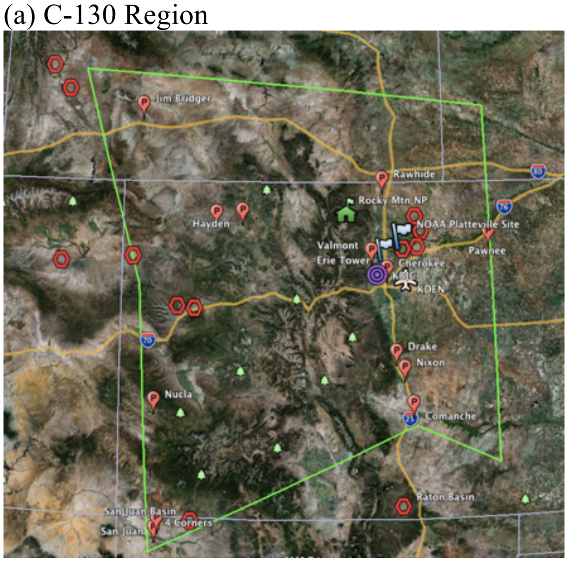
a. Large-scale survey/inflow/outflow flights: The general operations boundaries for the C-130 flights is depicted in figure 3a. These flights are designed to probe the large-scale background air masses transported into the NFRMA region and their photochemical characteristics depending on whether these air masses are influenced by large remote source regions such as Southern California, the Las Vegas region, or other large urban areas to the west and southwest. Altitude stacks (“walls”) would be flown roughly perpendicular to the synoptic meteorological transport direction. Moving the walls eastward along with the air mass flow will enable us to assess chemical processing of the large-scale outflow. The flights can be adjusted for wildfires that may be burning in the western states and contributing to background pollution. Wildfire activity has been significant in recent years and should also be characterized during these flights. Outflow flights would be conducted to the east of the NFRMA and characterize the pollution added by the NFRMA emissions to the background air masses and the influence of the NFRMA emissions on the rural areas of the Eastern Plains. These flights would be wall patterns, adjusted roughly perpendicular to prevailing large-scale winds, consisting of several stacked legs at altitudes between the boundary layer and max cruising altitude. If aircraft range is sufficient, it would make sense to try and fly both inflow and outflow stacks on the same day, but depending on the situation, these may also be flown separately. These flights directly address science questions 2, 4, and 6 and questions 1 and 5 indirectly.

b. Mountain-Valley Circulation (MV) flight pattern: The flight pattern includes a series of stacked legs at 3-4 altitudes from ~1000 ft AGL to above the boundary layer (likely 15-18 kft ASL, see figure 1b). Legs are oriented along a N-S axis over the Continental Divide (CD), the foothills, and over the plains as illustrated in Figure 3b. Flown in the afternoon and evening, this pattern will investigate the mountain-valley circulation driven by upslope transport of pollutants from the NFRMA towards the CD, where the air masses will be caught in the (normally) westerly synoptic flow in the upper troposphere. Flown in the morning, this pattern will address the recirculation of aged, photochemically processed material, which was transported upslope on the previous day, and the entrainment of this material into the expanding boundary layer as the day progresses and heating sets in. Extension of this pattern to the east could be considered if emission sources and outflow range warrant it. This flight pattern directly addresses science question 2 and 7, but indirectly addresses all others.

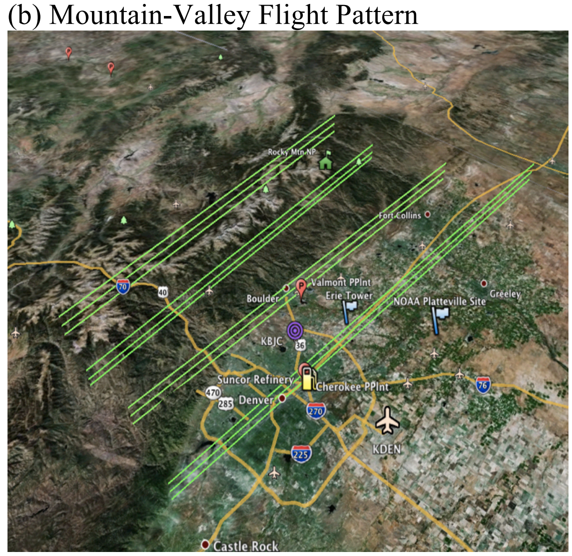
c. Local (L) flight pattern: This flight pattern is designed to characterize local point and area sources of fresh pollution, such as power plants, Denver International Airport (DIA) and the extensive natural gas and oil well areas to the northeast of the NFRMA (see figure 3c). Other large sources are the extensive livestock operations in the Greeley area. Flight tracks will be adjusted according to local winds and boundary layer heights, but will generally attempt to sample source areas at low altitude, with stacked legs up to the top of the boundary layer. The flights will look at the initial chemical processing of these plumes, and how they mix during the daytime, changing reactivity in the process. This flight type addresses directly science questions 2, 5 and 7, and indirectly addresses questions 1 and 4.

d. Regional (R) flight pattern: The purpose of this flight pattern is similar to the Local flight pattern, except that large, more remote, sources of pollution are targeted. Specifically, flights are planned to the southwest Wyoming oil and gas fields, northwest Colorado oil and gas fields, south Colorado Oil and Gas fields, Pueblo and CO Springs power plants, the four corners power plants, and the Bridger, Rawhide, Hayden and Craig power plants, as well as other large sources (see figure 3d). The flights will look at how these plumes are processed during transport and how much they influence total oxidant burden in the NFRMA. The RSC flights would also include flights measuring possible wildfire emissions in the CO area if such an opportunity arises. This flight pattern addresses directly science questions 5 and 6, and questions 2, 4 and 7 indirectly.

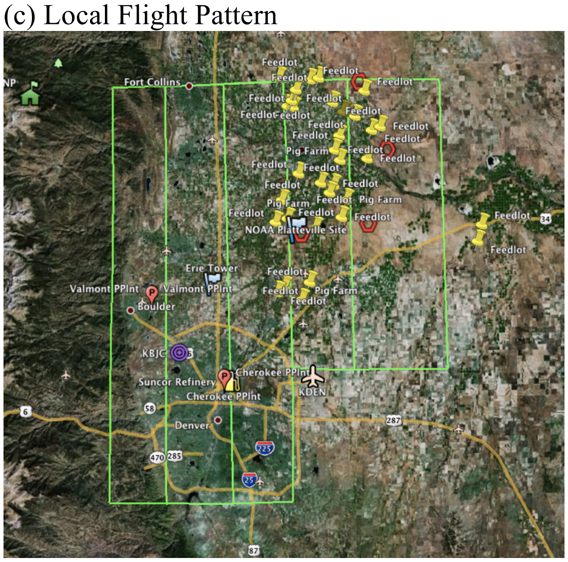
(a) C-130 Region



(b) Mountain-Valley Flight Pattern



(c) Local Flight Pattern



(d) Regional Flight Pattern

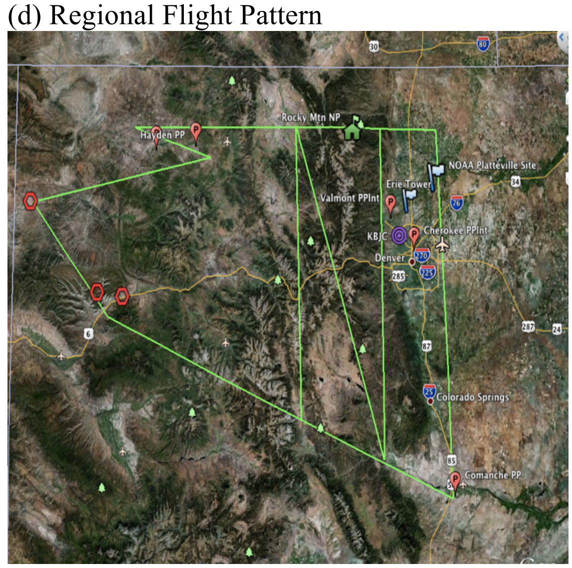


Figure 3: (a) Proposed NCAR C-130 operations area, with existing field sites and selected, large anthropogenic pollution point and area sources (P=powerplant, red hex = large oil and gas fields). Also shown are selected existing ground sites. (b) Mountain-valley circulation (MV) flight pattern (c) Local (L) flight pattern (d) Regional (R) flight pattern.

In addition to aircraft operations, the campaign will include extensive ground-based in-situ and remote sensing equipment (see following Section). Flight patterns will include comprehensive profiling over the ground sites to achieve a detailed 4-dimensional picture of the meteorological and chemical environment. The two NASA research aircraft, one profiling at low-medium altitudes with extensive in-situ sampling and one at higher altitudes equipped with a UV spectrometer for detecting trace gases and an HSRL aerosol lidar, will be flying over NFRMA repeating the same patterns on multiple days and at different times of the day, with about 12-15 flights in total. The flight area will focus on the Front Range region covering about 100 nm along the front range and extending about 50 nm to the east. The flights will be coordinated with satellite overpasses to provide information for linking remote sensing trace gas and aerosol retrievals to surface AQ. Figure 4 shows a possible DAQ flight pattern with profiling locations marked in yellow. The NASA P-3 aircraft would fly the circuit 3 times on each flight day, profiling 3 times at 6 predetermined ground sites from ~1000 feet AGL and just above the planetary boundary layer (likely around 6-9 kft AGL in the afternoon, lower in the morning). The B-200 aircraft would cruise along the flight track at a constant 28 kft ASL while deploying its nadir remote sensors for trace gases and aerosols.

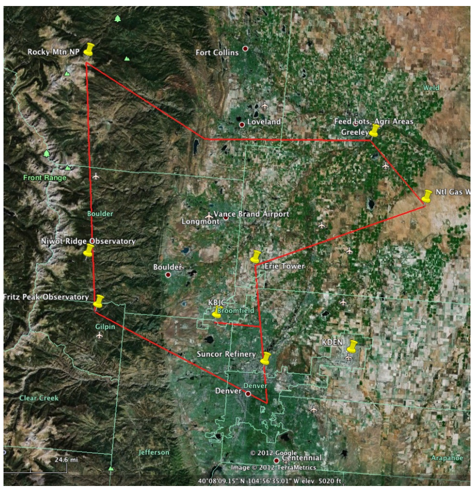


Figure 4. Possible NASA P3-B / B-200 operations with existing field sites and selected sources for anthropogenic pollution. The yellow markers show possible profile locations.

These flights will characterize extremely well the pollutant mix in the NFRMA, some of the local source contributions, as well as the boundary layer development during the day. In addition, these flights will characterize the diurnal photochemical processing of the emissions in the NFRMA, while the C-130 flights will be more focused on specific sources, import and export of pollutants into and from the NFRMA and meteorologically driven processes. The two campaigns together will thus cover all aspects of what controls air quality in the NFRMA and also how the NFRMA impacts surrounding regions. Flight patterns, and specifically the coordination with the NASA flights, ground stations and the FRONT-PORCH activities will be finalized during the pre-experiment workshop to be scheduled about 9-12 months before the mission.

Ground operations

CDPHE operates 16 surface ozone sites in NFRMA that report to EPA's AIRNow system and are used for attainment/non-attainment designations. The NPS also has one ozone site with similar reporting at Rocky Mountain National Park. In addition, NOAA operates ozone analyzers (as well as VOC's, nitryl chloride, carbon dioxide, methane analyzers) at their Boulder Atmospheric Observatory (BAO) tower near Erie (http://www.esrl.noaa.gov/csd/groups/csd7/measurements/2008Erie/), and ozone and meteorological sensors at the high elevation Niwot Ridge research facility, near Nederland, and the Platteville facility. The BAO tower has also been used for vertical profiling across its height of 300m. NOAA further releases ozone sondes on a weekly basis from Boulder; increased sampling frequency would be pursued during FRAPPÉ.

In addition to ozone, CDPHE operates a number of real-time particulate sites (both for PM10 and PM2.5) as well as two NOx sites, one reactive oxides of nitrogen site, three sulfur dioxide sites and five carbon monoxide sites in the northern Front Range area. CDPHE also samples and analyzes for non-methane organic compounds and carbonyls at three locations and many of the CDPHE sites are also equipped with meteorological sensors.

DISCOVER-AQ will provide augmentation to CDPHE sites by stationing ground-based remote sensors at 12 locations, 6 of which will be designated for aircraft profiling. Trace gas columns (O_3, NO_2, CH_2O) will be detected with Pandora spectrometers and aerosols (AOD) with Aeronet Cimel sunphotometers. Additional augmentation will include the NATIVE trailer and ozonesondes from Penn State, photolytic NO_2 sensors from the EPA, and an aerosol lidar from UMBC. These assets will be placed with advice and input from CDPHE.

We will seek to establish additional ground sites during FRAPPÉ. NOAA operates two ground stations; the BAO Tower mentioned above and another site near Platteville (see http://www.esrl.noaa.gov/csd/groups/csd7/measurements/platteville_o3/). Platteville would be a very suitable site for ground measurements, as this area acts as a pool for nighttime emissions and processed daytime air masses draining into the valley during the night. Upon breakup of the nighttime boundary layer in the morning, upslope conditions can entrain this air mass pool back into the NFRMA, enhancing daytime photochemistry. The BAO tower has the advantage of offering sampling between 0 and 1000 feet (tower height) and therefore should also be considered as a good option as a focus ground site. NOAA has state-of-the-art instrumentation available for the measurement of many photochemically relevant species and also has mobile lidars available for the measurement of vertical profiles of ozone and aerosols as well as air motion (see http://www.esrl.noaa.gov/csd/groups/csd7/measurements/2008Erie/TOmeasurements.html). Letters of support from NOAA CSD are included in the addendum.

The University of Colorado Institute for Arctic and Alpine Research (INSTAAR) operates a site at Niwot Ridge (high altitude site W of the NFRMA, see http://culter.colorado.edu/NWT/) and could provide measurements of photochemical constituents there during FRAPPÉ. CSU, together with the National Park Service, also operates a measurement site in Rocky Mountain National Park and is very interested in instrumenting this site with a number of relevant measurements during FRAPPÉ. A letter of support from Colorado State University is included in the addendum.

In addition, the Desert Research Institute operates a measurement station at Storm Peak Laboratory near Steamboat Springs. A support letter from the station manager is included.

Through 2B Technologies, the GO3 Project (http://www.go3project.com) has established a nationwide network of ozone and meteorological monitoring at schools. In the NFRMA, approximately 15 schools are currently participating along with about one dozen schools in other parts of Colorado. While there is some but not comprehensive quality assurance associated with the network and data, it can be a useful tool for helping characterize the distribution of ozone across the metro area, and is a wonderful opportunity to have students exposed to and be part of a vast field program (see letter of support in the addendum).

The concurrently proposed FRONT-PORCH study is an excellent complementary study for FRAPPÉ and vice-versa. The measurements proposed for FRONT-PORCH (see http://www.eol.ucar.edu/projects/front-porch/Front-Porch.html) would characterize the circulation along the plains and foothills all the way up to the CD in great detail. The C-130 aircraft in turn will carry a number of cloud microphysics instruments (the exact payload to be determined) and some limited cloud sampling in support of FRONT-PORCH is planned. Thunderstorms and the typical meteorological situations leading to their formation (e.g., Wilczak and Glendening, 1988) play a significant role in sweeping out pollution from the NFRMA and must be considered for FRAPPÉ science as well.

Modeling and forecasting

A strong modeling and forecasting component will complement FRAPPÉ. NCAR/ACD has significant experience in global (CAM-Chem, MOZART) and regional (WRF and WRF-Chem) chemical transport modeling and forecasting and will perform model simulations in support of the design and analysis for the campaign.

Our division has been involved in numerous field experiments in the past such as the NASA-led INTEX-A, INTEX-B and ACRTAS or the NSF-led MIRAGE or DC-3 campaigns, and is familiar with the forecasting, data handling and analysis (e.g. Pfister et al., 2006; Arellano et al., 2007; Apel et al., 2010; Emmons et al., 2010; Pfister et al., 2011). NCAR/ACD is also highly knowledgeable in the application of satellite trace gas products and has been leading the MOPITT and HIRDLS projects (e.g. Edwards et al., 2006; Deeter et al., 2010). In addition to NASA satellite products, the division is involved in the retrieval and application of trace gas retrievals from the European IASI instrument, and these and other satellite products would be implemented in the forecasting and analysis work for this project.

For FRAPPÉ we will collaborate with the forecasting activities planned for FRONT-PORCH, if that program is funded. FRONT-PORCH intends to run a 3 km x 3 km WRF forecast for meteorology during the campaign, to which we will add inert tracers (tracers for different emission sources, stratospheric and lightning, inflow, etc.) and, depending on available computing sources, a simple chemistry scheme (reduced hydrocarbon scheme, ~ 40 species). In the case of FRONT-PORCH not being funded, we will conduct these WRF-Chem forecast simulations on our own. NCAR/ACD runs continuous global model forecasts with the MOZART-4 model and assimilation of MOPITT CO, and these simulations will also be incorporated into the forecasting system (http://www.acd.ucar.edu/acresp/forecast/).

CDPHE forecasting will complement forecasts from NCAR. CDPHE forecasts air quality for all of Colorado with a particular focus on air quality conditions along the Front Range Urban Corridor. Air quality forecasts for the Front Range Urban Corridor take into account the effects of complex terrain and terrain-driven mesoscale circulations such as the Denver Cyclone, and how these affect concentration gradients and transport within the area. The U.S. EPA Region 8 office is engaged in these activities and is also actively involved with EPA's AirNow program and the development of the AirNow Satellite Data Processor (ASDP), which fuses NASA/NOAA satellite products with surface observations to improve Air Quality Index (AQI) maps. With more than 80 staff-years of experience in air quality forecasting and modeling in Colorado, CDPHE's meteorologists have the breadth and depth of experience to provide support for a major field campaign.

In turn, FRAPPÉ will provide extensive testing and evaluation of the forecasting systems and will point towards needed system improvements. The comprehensive set of observations will allow for better constraint of the major uncertainties in current chemical transport models, such as emission sources or long-range transport, boundary layer evolution and transport patterns in highly complex terrain. This ultimately will lead to more accurate air quality forecasts and improved modeling tools.

Expected Outcomes

The three field missions that are planned to happen during the same time period provide an outstanding opportunity to study and characterize local AQ at a level of detail not possible previously.

- A comprehensive suite of aircraft and ground-based sampling of meteorological parameters and chemical tracers such as CO or aerosols will provide a highly detailed view of the local and large-scale flow patterns of the NFRMA in summertime.
- Emissions pose one of the largest sources of uncertainty in air quality models and the results from this project will put essential constraints on the emissions of all relevant chemical species for a variety of source types.
- Intensive sampling during different times of the day and over, upwind and downwind of source regions will give essential insight into the transport of pollutants and the chemistry that takes place when emissions from different source types are mixed during transport.

The results will be of importance not only for AQ in the NFRMA, but provide benefits well beyond:

- The measurements will provide a basis for improving current parameterizations of small scale circulations and flow patterns in highly complex terrain and as such add to improving the performance of meteorological and chemical modeling in areas of complex terrain.

- The set of observations will allow for improved knowledge of photochemical processes and aging occurring when plumes from diverse emission sources mix during transport.
- The information on emission sources will provide an evaluation of current emission inventories and the methodology used to derive them. The constraints will be applicable to similar source types in other regions; specifically the impacts of oil and gas development, which has also undergone dynamic changes in other regions in the country are a point of controversy and results from this project would provide an important contribution to assessing how these developments affect air quality.
- Large-scale transport of pollution is of significance for many other regions in the U.S. and a thorough characterization of free tropospheric pollution flow provides essential input in estimating its influence on local surface AQ.

Societal Benefits

- Analysis of the comprehensive set of observations combined with meteorological and chemical modeling will provide the information needed to understand the driving forces of high pollution events in NFRMA. This will ultimately lead to a much improved forecasting of pollution events allowing people to limit harmful effects of poor air quality, saving lives and reducing the number of air quality-related respiratory and cardiovascular problems.
- The results of this project will lead to a more certain foundation on which to base mitigation strategies to reduce air pollution and set grounds for a cleaner environment.

Data Management Plan

FRAPPÉ will share the data management with NASA and FRONT-PORCH. Access to forecasting and remote sensing products as well as communications between field sites will be enabled through the EOL Field Catalog. This will be shared with the FRONT-PORCH project since many forecast and satellite products as well as radar products are of interest to both campaigns. Details will be worked out as time gets closer to the project. The PIs have plenty of experience with the use of the Field Catalog.

Field data will be collected in the NASA Langley Airborne Science data archive (see https://www-air.larc.nasa.gov/cgi-bin/ArcView/dc3-seac4rs for how this was structured for data from the DC3 project). Ground site data will also be collected there. After preliminary (and then final) data submission, NASA Langley personnel will produce data merges and secondary data products for use by the science community (and the public), just as was done for previous joint campaigns (DC3, MILAGRO).

Education and Outreach

The FRAPPÉ project provides an excellent opportunity for education and outreach activities involving K-12 and University students and teachers and the general public. We will take advantage of the local setting, the high relevance of air quality to the public and the involvement of a number of universities, local agencies and non-profit organization in the project to develop these activities.

A number of graduate and undergraduate students will be directly involved in the campaign, as we anticipate participation from numerous university groups on the aircraft, on the ground, and in modeling and forecasting efforts. Thus, participating graduate and undergraduate students will be introduced to the different aspects of field work, from mission planning and design, to hands-on operations and data analysis. We will also inform other University faculty working in relevant fields (e.g., Atmospheric Sciences, Chemistry, Meteorology) in the Front Range of the FRAPPÉ mission, and thus provide opportunities for additional students to tour the facilities, and participate in the experiment. The campaign also provides a stellar opportunity for students in the NCAR/UCAR Significant Opportunities in

Atmospheric Research and Science (SOARS) Program, a summertime internship for students from groups under-represented in science and which overlaps perfectly with the timing of the campaign. The PIs and CO-Is will serve as mentors to students participating in this program. Summer courses in atmospheric instrumentation could be integrated into the field campaign, such as was done during DC-3 with the University of South Dakota. CSU has summer classes, which could be integrated into the campaign, and fall semester instrument courses taught at CSU and CU in the fall semester could incorporate instrument information and data from FRAPPÉ.

K-12 students and teachers will be involved through the GO3 project (http://www.go3project.com) during the campaign (see letter of support) and the data and results will also provide ample opportunities for post-campaign projects. One of the Co-PIs (Pfister) has previously participated as scientific liaison in GO3 workshops and this campaign will significantly deepen the interactions. Participation of students involved in NCAR's pre-college internship will also be explored.

We will engage high school teachers in FRAPPÉ activities, via NCAR's Research Experience Teacher Institute (RETI), http://spark.ucar.edu/reti-ucarncar. RETI activities include a one month intensive stay at NCAR, where teachers are provided the opportunity to develop secondary school curriculum in climate and related sciences via interactions with NCAR scientists. The next RETI group will be in residence at NCAR in the summer of 2014, and thus overlap with FRAPPÉ is likely. Even if the overlap is not perfect, we will call upon the network of RETI alumni (many of whom are in the Front Range area) to participate in FRAPPÉ. Activities in which these teachers can engage include group tours of the planes and ground sites, involvement in some hands-on activities, and even (limited) seats (if possible) on the C-130 aircraft during a research flight.

We will request support from the NCAR E&O program for additional public outreach activities. Activities will be similar to those done during the DC3 and OASIS projects and will include an outreach website with a real-time blog and links to media presentations, public tours of the facilities and an open house, public talks and presentations in local venues, and potentially real-time data displays and educational movies (and potentially the deployment of a GO3 monitor) at Rocky Mountain National Park and possibly the Chautauqua Ranger Station in Boulder and Denver International Airport. These displays could be staffed part-time by students from participating universities. Our connections to local air quality agencies and the National Park Service will be very beneficial for conducting these activities. Other opportunities for public and K-12 outreach are presented through the Denver Museum of Nature and Science's "Scientists in Action" program and summer day and weekend science camps for children and adults.

Integrating these with E&O activities conducted for the DISCOVER-AQ (http://discover-aq.larc.nasa.gov/education.php) and the FRONT-PORCH missions (http://www.eol.ucar.edu/projects/front-porch/Front-Porch.html) and also public outreach through CDPHE will establish a most diverse and comprehensive educational and outreach program.

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Results from Prior NSF Support

Biography – Frank Flocke

National Center for Atmospheric Research – Atmospheric Chemistry Division
3090 Center Green Drive, Boulder, CO 80301
ffl@ucar.edu, https://staff.ucar.edu/users/ffl
Phone 303-497-1457, Fax 303-497-1400

A. Professional Preparation *(education, in chronological order)*

Dr.rer.nat. (Ph.D.) in Atmospheric Chemistry	1992	*Bergische Universität,* Wuppertal, Germany, and *Forschungszentrum* Jülich, Germany.
Diplom-Chemiker (Master's degree in Chemistry)	1988	*Bergische Universität,* Wuppertal, Germany, and *Forschungszentrum* Jülich, Germany.

Supervisors: Prof. Dr. K.H. Becker, Prof. Dr. D. Kley

B. Appointments *(in **reverse** chronological order)*

National Center for Atmospheric Research, Boulder, CO

Scientist III	7/2003 to present
Scientist II	7/1998 to 6/2003
Scientist I	8/1994 to 6/1998

Forschungszentrum Jülich, Germany

Staff Scientist	6/1993 to 7/1994

National Center for Atmospheric Research, Boulder, CO

Scientific Visitor	11/1993 to 12/1993
Postdoctoral Fellow	6/1992 to 5/1993

Forschungszentrum Jülich, Germany

Research Assistant/Graduate Student	6/1987 to 5/1992

C. Significant Publications *(limit 5)*

Flocke, F., A. Volz-Thomas, and D. Kley, 1991: Measurements of alkyl nitrates in rural and polluted air masses. *Atmos. Environ.*, **25A,** 1951-1960.

Flocke, F., E. Atlas, S. Madronich, S. S.M., K. Aikin, J. J. Margitan, and T. v.Bui, 1998: Observations of methyl nitrate in the lower stratosphere during STRAT: Implications for its gas phase production mechanisms. *Geophys. Res. Lett.*, **25,** 1891-1894.

Flocke, F., R. L. Herman, R. J. Salawitch, E. Atlas, C. R. Webster, S. M. Schauffler, R. A. Lueb, R. D. May, E. J. Moyer, K. H. Rosenlof, D. C. Scott, D. R. Blake, and T. P. Bui, 1999: An examination of chemistry and transport processes in the tropical lower stratosphere using observations of long-lived and short-lived compounds obtained during STRAT and POLARIS. *J. Geophys. Res.*, **104,** 26625-26642

Flocke, F. M., A. W. Weinheimer, A. Swanson, J. M. Roberts, R. Schmitt, and S. Shertz, 2005: On the measurement of PANs by Gas Chromatography and Electron Capture Detection. *J. Atmos. Chem.*, **52,** 19-43.

Zheng, W., F. M. Flocke, G. S. Tyndall, A. Swanson, J. J. Orlando, J. M. Roberts, L. G. Huey, and D. J. Tanner, 2011: Characterization of a thermal decomposition chemical ionization mass spectrometer for the measurement of peroxy acyl nitrates (PANs) in the atmosphere. *Atmos. Chem. Phys.*, **11,** 6529-6547.

D. Synergistic Activities

I have extensive experience leading, organizing and participating in atmospheric chemistry field campaigns, both ground based, and especially aircraft-based. I served as head flight planning scientist and mission scientist on the C130 during MIRAGE-Mex in 2006, shared responsibility for leading the OASIS ground based mission in 2009, and I was part of the DC3 lead science team and served as mission scientist on the GV for some of the DC3 flights. In the last 10 years I have participated in more than 25 major field campaigns and I have 15 years experience in designing and deploying airborne instrumentation. I have also been involved in a number of education and outreach activities during field campaigns, involving students (K-12, undergraduates and graduate students - direct and indirect supervision, atmospheric science courses, tours, etc.), teachers (RETI program, active teacher participation in field programs, etc), as well as public outreach (tours, blogging, lectures, etc.).

E. Collaborators & Other Affiliations

i. Collaborators and Co-Editors

James Crawford, NASA Langley; Gregory Huey, Georgia Inst. of Technol.; Mary Barth, NCAR; Chris Cantrell, NCAR; Steve Rutledge, Colo State Univ.; Ken Pickering, Univ. of MD; Paul Shepson, Purdue Univ.; Patrick Reddy and Gordon Pierce, Colorado Dept. of Public Health and the Environment; Ron Cohen, UC Berkeley; Detlev Helmig, Univ. of CO Boulder; Gabi Pfister, NCAR; Alfonso Saiz-Lopez, University of Madrid, Spain; Ursula Deister, University of Wiesbaden, Germany; Donald Stedman, Univ. of Denver.

ii. Graduate and Postdoctoral Advisors

Prof. Dr. D. Kley (em.), Dr. A. Volz-Thomas, Research Center Jülich, Germany
Dr. Elliot Atlas, University of Miami

iii. Thesis Advisor and Postgraduate-Scholar Sponsor

Nadine Jansky, Univ. of Wiesbaden, Germany, 2011/2012
Veronika Wied, Univ. of Wiesbaden, Germany, 2010/2011
Andreas Schön, Univ. of Wiesbaden, Germany, 2010
Olaf Kohrs, Univ. of Wiesbaden, Germany, 2009
Matthias Bogar, Univ. of Wiesbaden, Germany, 2008
Dennis Krämer, Univ. of Wiesbaden, Germany, 2007/2008

Graduate Students *(individuals for whom you've acted as advisor within the past 5 years)* *- none -*

Total Students: 6

Postdoctoral Fellows: *(individuals for whom you've acted as advisor within the past 5 years) – none -*

Total Students: 0

Biography – Gabriele Pfister

National Center for Atmospheric Research
Earth Systems Laboratory, Atmospheric Chemistry Division
3450 Mitchell Lane, Boulder, CO 80301, USA
Phone: +1 303 497 2915 Fax: +1 303 497 1400
e-mail: pfister@ucar.edu Homepage: www.acd.ucar.edu/~pfister

A. Professional Preparation *(education, in chronological order)*

Mag. Rer. Nat.	Meteorology and Geophysics, University of Graz, Austria, 1997 *(summa cum laude) Thesis Advisor: Prof. Dr. Siegfried Bauer*
Ph.D.	Geophysics, University of Graz, Austria, 2000 *(summa cum laude) Thesis Advisor: Prof. Dr. Siegfried Bauer*

B. Appointments *(in reverse chronological order)*

May 2010 - present	Scientist-II NCAR
2007- May 2010	Scientist-I, NCAR
2006-2007	Project Scientist I, NCAR
2004-2006	Advanced Study Program (ASP) Postdoctoral Fellow, NCAR
2002-2004	Erwin-Schrödinger Post-Doctoral Fellow (Austrian Science Fund), NCAR
2001-2002	Postdoctoral Researcher, National Institute of Water and Atmospheric Research, New Zealand
1996-2001	Research Assistant, Institute for Geophysics, Astrophysics, and Meteorology, University of Graz, Austria

C. Significant Publications *(limit 5)*

Pfister, G.G., J. Avise, C. Wiedinmyer, D. P. Edwards, L. K. Emmons, G. D. Diskin, J. Podolske, and A. Wisthaler (2011): CO source contribution analysis for California during ARCTAS-CARB, Atmos. Chem. Phys., 11, 7515-7532, doi:10.5194/acp-11-7515-2011.

Pfister, G.G., D. D. Parrish, H. Worden, L. K. Emmons, D. P. Edwards, C. Wiedinmyer, G. S. Diskin, G. Huey, S. J. Oltmans, V. Thouret, A. Weinheimer, and A. Wisthaler (2011), Characterizing summertime chemical boundary conditions for airmasses entering the US West Coast, *Atmos. Chem. Phys*., 11, 1769-1790, 2011

Pfister, G., C. Wiedinmyer, L.K. Emmons (2008), Impacts of the fall 2007 California wildfires on surface ozone: Integrating local observations with global model simulations, *Geophys. Res. Letters*, VOL. 35, L19814, doi:10.1029/2008GL034747.

Pfister, G., A.M. Thompson, L.K. Emmons, P.G. Hess, J.-F. Lamarque, Y.E. Yorks (2008), Analysis of the Summer 2004 Ozone Budget over the U.S. using IONS observations and MOZART-4 simulations, *J. Geophys. Res.,* VOL. 113, D23306, doi:10.1029/2008JD010190.

Pfister, G., et al. (2005), Constraints on Emissions for the Alaskan Wildfires 2004 using Data Assimilation and Inverse Modeling of MOPITT CO, *Geophys. Res. Lett.,* Vol. 32, No. 11, L11809, 10.1029/2005GL022995.

D. Synergistic Activities

I have been actively involved in the fields of in-situ measurements and satellite retrievals as well as in atmospheric chemistry modeling (global models CAM-Chem and MOZART-4, regional model WRF-Chem) and numerical analysis such as inverse modeling and data assimilation. In more recent work I have been using these tools to look into connections of global, regional and local air quality, e.g. studying the changes in atmospheric composition due to boreal fires, the intercontinental transport of pollution or changes in future AQ; the focus of my work is on the contiguous U.S.. I participated in a number of NASA field campaigns (INTEX-A, INTEX-B and ARCTAS) through flight forecasting and planning, and data analysis. I am active in various E&O activities including participation in GO3 workshops, presenting to NCAR Journalism Fellows, advisor and collaborator with CDPHE and the Regional Air Quality Council (RAQC), serving on the South Coast Air Quality Management District (AQMD) Advisory Group, partook in teaching an ACD lead course to a graduate atmospheric chemistry class at North Carolina A&T State University, and others. I am also member of the NASA Air Quality Applied Sciences Team (AQAST) working in partnership with US air quality managers to exploit the power of Earth Science tools to address air quality issues.

E. <u>Collaborators & Other Affiliations</u>

ii. Collaborators and Co-Editors *(include all for the past 48 months)*

(U.S. Collaboators only) Arellano, A. (Univ. Arizona); Avis, J. (California Air Resources Board); Grell, G., Parrish, D., Oltmans, S., Pierce, B. (NOAA); Hess, P. (Cornell University); Lapina, K., Henze, D., Helmig, D. (CU Boulder); Randerson, J. (UC Irvine); Rasch, P., Fast, J. (PNNL); Diskin, G., Sachse, G., Crawford, J. (NASA Langley); Podolske, J. (NASA Ames); Thompson, A. (PSU); Val Martin, M. (CSU); Jaffe, D. (U Washington); Pickering, K., Dickerson, R. (U Maryland); Reddy, P., Pierce, G. (CDPHE); Ellenburg, J. (GO3), Morris, R. (Environ), Jacob, D., Chance, K. (Harvard); Reid, C., Coen, R. (UC Berkeley); Quesada, D. (St. Thomas University); Worden, J., Osterman, G., Neu, J. (JPL), Purvis-Roberts, K. (U Claremont). Kramer, L. (MTU), Carmichael, G. (U Iowa); Duncan, B. (NASA Goddard); Streets, D. (Argonne NL); Liu, Y. (Emory U), de Foy, B. (Saint Louis U); Huey, G. (Georgia IT); Barth, M., Campos, T.; Emmons, L., Flocke, F., Edwards, D., Gille, J., Wiedinmyer, C., Holland, G., Guenther, A., Lamarque, J.F., Orlando, J., Weinheimer, A., Hodzic, A., Worden, H., Coen, J., Gochis, D., Deeter, M., Madronich, S. (NCAR);

iv. Graduate and Postdoctoral Advisors
- none -

v. Thesis Advisor and Postgraduate-Scholar Sponsor
-none-

Graduate Students *(individuals for whom you've acted as advisor within the past 5 years)*
- none -

Total Students: 0

Postdoctoral Fellows: *(individuals for whom you've acted as advisor within the past 5 years)*
Kumar, Rajesh (NCAR/ASP); Acting advisor for ACD Postdocs Boynard, A. and Barre, J. (official advisor: D. Edwards)

Total Students: 1

Current and Pending Support

Frank Flocke

In the event that an unanticipated overlap does occur, the level of effort would be adjusted, and/or additional personnel would be added, in concurrence with funding sources. Some projects may be ending as others are beginning.

Project Title: Measurements of NO, NO2, NOy, and O3 on the NASA P-3B during DISCOVER-AQ
PI: Andrew Weinheimer
Time Committed to the Project: 1.4 person-months
0.0 person-months/year support by NSF base funds
Source of Support: NASA
Contact Information: James Crawford, (202) 358-0915, James.H.Crawford@nasa.gov
Award Amount (or amount requested): $1,068,280.00
Duration of Award: 7/1/10-6/30/15
Award Status: Award

Gabriele Pfister

In the event that an unanticipated overlap does occur, the level of effort would be adjusted, and/or additional personnel would be added, in concurrence with funding sources. Some projects may be ending as others are beginning.

Project Title: Integration of Satellite Products into a Chemical Weather Forecasting System
PI: Gabriele Pfister
Time Committed to the Project: 2.8 person-months
0.0 person-months/year support by NSF base funds
Source of Support: NASA
Contact Information: David B. Considine, David.B.Considine@nasa.gov, (202) 358-2277
Award Amount (or amount requested): $300,000.00
Duration of Award: 11/1/09-10/31/12
Award Status: Award

Project Title: Integrating carbon monoxide and aerosol retrievals: Improving estimates of aerosol vertical distribution, carbon component & local radiative forcing
PI: David Edwards
Time Committed to the Project: 6.0 person-months
0.0 person-months/year support by NSF base funds
Source of Support: NASA
Contact Information: Lucia Tsaoussi, (202) 358-4471, Lucia.S.Tsaoussi@nasa.gov
Award Amount (or amount requested): $832,681.00
Duration of Award: 10/1/10-9/30/13
Award Status: Award

Project Title: Collaborative Research: Type 1: Chemistry and Climate over Asia: Understanding the Impact of Changing Climate and Emissions on Atmospheric Composition (L02170219)
PI: Mary Barth
Time Committed to the Project: 0.0 person-months
0.0 person-months/year support by NSF base funds
Source of Support: NSF
Contact Information: Tanja Pietraß, (703)-292 2170 , tpietras@nsf.gov
Award Amount (or amount requested): $438,033.00
Duration of Award: 2/15/11-1/31/14
Award Status: Award

Project Title: A Framework for Regional-Scale Atmospheric Composition Observation System Simulation

Experiments (OSSEs)
PI: David Edwards
Time Committed to the Project: 0.0 person-months
0.0 person-months/year support by NSF base funds
Source of Support: NASA
Contact Information: Richard Eckman, Richard.S.Eckman@nasa.gov, 757-864-5822
Award Amount (or amount requested): $745,650.00
Duration of Award: 4/1/2011-3/31/14
Award Status: Award

Project Title: NCAR Chemical Forecasting and Analysis for SEAC4RS
PI: Louisa Emmons
Time Committed to the Project: 1.8 person-months
0.0 person-months/year support by NSF base funds
Source of Support: NASA
Contact Information: Hal Maring, (202) 358-1679, Hal.Maring@nasa.gov
Award Amount (or amount requested): $375,000.00
Duration of Award: 1/1/11-12/31/14
Award Status: Award

Letters of Support

Attached letters of support from the following organizations:

- CDPHE
- CSU Dept. Atmos. Sci.
- DRI Storm peak Lab.
- EPA Reg. 8
- FRONT-PORCH PIs
- GO3 Foundation
- NASA DISCOVER-AQ
- NOAA CSD
- NOAA Lidar Group
- NPS Air Res. Div.

January 8, 2013

Gabriele Pfister and Frank Flocke
Atmospheric Chemistry Division
National Center for Atmospheric Research
Boulder, CO 80305

Dear Gabriele and Frank,

I am excited that you are planning to propose the FRAPPE campaign for summer 2014. From my experience in the planning and execution of previous DISCOVER-AQ campaigns, I can say that FRAPPE is an ideal complement to our plans. If FRAPPE is funded, there is a firm commitment from the DISCOVER-AQ team to conduct our final deployment in the Denver/Front Range area. In terms of our schedule, we are flexible enough to deploy anytime during the summer of 2014.

While the primary objective of DISCOVER-AQ is focused on the improvement of remote sensing, the combination of remote sensing and in situ observations deployed by DISCOVER-AQ in the air and on the ground will also be of great value to understanding how emissions, chemistry, and meteorology work together to influence air quality along the northern Front Range. DISCOVER-AQ will execute a very strict and repetitive sampling pattern integrated with the existing air quality network operated by the Colorado Department of Public Health and Environment. This is great for building statistics and observing the diurnal behavior of air quality over the Front Range, but it is a spatially limited perspective. In contrast, FRAPPE will enable broader sampling and dynamic flight planning to focus on specific meteorological regimes, transport and chemical evolution, specific sources, and background conditions upstream and downstream of the Front Range. These two perspectives together will provide a powerful and unprecedented view of air quality in a metropolitan area and the sensitivity of day-to-day conditions to local versus remote influences.

Any partnership between FRAPPE and DISCOVER-AQ team would include close coordination on the planning and implementation of observations as well as full data sharing both during the field campaign and during post-mission analysis. I look forward to working with your team in summer 2014 and beyond.

Sincerely,

James H. Crawford, PhD
Principal Investigator, DISCOVER-AQ
Science Directorate
NASA Langley Research Center

NCAR

National Center for
Atmospheric Research

Research Applications
Laboratory

3450 Mitchell Lane, Boulder, CO
80301 USA
Phone: 303-497-8422 Fax: 303-497-
8401
www.ral.ucar.edu

Nov. 14, 2012

To whom it may concern,

I am writing this letter in support of the facility request being put forward as part of the FRAQ/DISCOVERAQ research effort. This project has particular synergy with another recently proposed effort entitled the Front Range Observational Network Testbed - Precipitation Observations and Research on Convection and Hydrometeorology (FRONT-PORCH). The aim of the FRONT-PORCH research effort is to investigate meteorological and hydrological processes that are important to accurately predict the timing, location and intensity of orographic and convective precipitation and its hydrological response in complex terrain. The multi-organizational FRONT-PORCH experiment that has been proposed for the summer of 2014 will provide critical insight into a comprehensive range of processes contributing to convective and orographic precipitation over the mountains, foothills and plains in the Rocky Mountain Front Range region. The synergy that exists is that, if funded, FRONT-PORCH program will provide unprecedented characterization of atmospheric thermodynamic, circulation and cloud hydrometeor structures at spatial resolutions on the order of 1 km which the FRAQ/DISCOVERAQ project aims to quantify the transport and fate of atmospheric pollutants along the FRONT RANGE urban corridor-mountain front complex. Under FRONT-PORCH, the proposed instrument network of dual polarization, multi-doppler radars, atmospheric soundings, surface meteorological observations and hydrometeorological sampling locations provide an ideal backdrop for such studies. The region is persistently an area which suffers from poor air quality and frequent exceedences of key air quality standards, particularly ozone. A critical uncertainty in this region that exists is how do mesoscale circulation processes associated with diurnal mountain-plain thermal forcing modulate boundary layer structure, low level winds and, ultimately the fate of atmospheric constituents. The linkage of these two project would provide a first-in-time depiction capability for understanding how regional pollutants are controlled by atmospheric processes. Conversely, the FRAQ/DISCOVERAQ project via its linkage to regional air quality monitoring networks and the request of the NCAR C-130 aircraft will provide a need airborne measurement capability for probing the diurnal boundary layer over the mountain front region, a component which is currently not requested under FRONT-PORCH.

In summary, as one of the principal investigators of the FRONT-PORCH research effort, I find strong mutual benefit in the coordination of these two proposed activities.

NCAR

National Center for
Atmospheric Research

Research Applications
Laboratory

3450 Mitchell Lane, Boulder, CO
80301 USA
Phone: 303-497-8422 Fax: 303-497-
8401
www.ral.ucar.edu

Please feel free to contact me directly via phone or email (listed below) should you have any questions.

Sincerely,

David J. Gochis
Scientist III
National Center for Atmospheric Research
Boulder, CO USA
Tel: +01 303 497 2809
Email: gochis@ucar.edu

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Office of Oceanic and Atmospheric Research
Earth System Research Laboratory
325 Broadway – David Skaggs Research Center
Boulder, Colorado 80305-3337

October 26, 2012

Dr. Frank Flocke
Atmospheric Chemistry Division
Earth System Laboratory
National Center for Atmospheric Research
3450 Mitchell Lane
Boulder, CO 80301

Dear ~~Dr. Flocke~~ Frank,

I am writing to indicate our interest in and potential collaboration with the proposed Front Range Air Quality Study, intended to be conducted during July, 2014.

The Chemical Sciences Division of the NOAA Earth System Research Laboratory (NOAA/ESRL/CSD) has a long history of research in air quality and climate, and we have a keen interest in research in and around the Colorado Front Range. We would be interested in coordinating future research activities, which may include, among other things, participation in an intensive field campaign, characterization of emissions sources, and analysis and assessment of the study results. Specific activities would, of course, depend on the project schedule and resource availability. Our potential in-kind contribution to this project will consist of the staff time needed to plan and coordinate future activities and taking part in the field studies if resources allow at that time.

Sincerely,

Dr. Eric J. Williams
Deputy Director for Planning
Chemical Sciences Division
Earth System Research Laboratory
National Oceanic and Atmospheric Administration
325 Broadway, R/CSD
Boulder CO 80305

email: eric.j.williams@noaa.gov
Phone: 303/497-3226
Fax: 303/497-5126

STATE OF COLORADO

John W. Hickenlooper, Governor
Christopher E. Urbina, MD, MPH
Executive Director and Chief Medical Officer

Dedicated to protecting and improving the health and environment of the people of Colorado

4300 Cherry Creek Dr. S.
Denver, Colorado 80246-1530
Phone (303) 692-2000
Located in Glendale, Colorado

Laboratory Services Division
8100 Lowry Blvd.
Denver, Colorado 80230-6928
(303) 692-3090

http://www.cdphe.state.co.us

Colorado Department
of Public Health
and Environment

20 November 2012

Gabriele Pfister
Frank Flocke
National Center for Atmospheric Research
Atmospheric Chemistry Division
P.O. Box 3000
Boulder, CO 80307-3000

Dear Ms. Pfister and Mr. Flocke:

This letter is to provide support for the National Center for Atmospheric Research's (NCAR's) proposed National Science Foundation request for their C-130 aircraft and ground based operations support for the Front Range Air Quality (FRAQ) field campaign in the summer of 2014. The FRAQ will supplement and support the currently planned National Air and Space Administration (NASA) DISCOVER-AQ project at the same time.

The North Front Range area of Colorado is currently designated as a non-attainment area for ozone in the ambient air. Significant efforts have occurred in the past to reduce ambient ozone levels, including a number of modeling efforts. However, the photochemistry of the ozone formation process is complex and not completely understood. Topography and meteorology in the North Front Range area of Colorado are complex, and emissions sources are numerous, including oil and gas, power plant, agriculture, urban and vehicular. Background levels of ozone also confound the modeling and analysis of local contributions to ozone formation.

The Colorado Department of Public Health and Environment – Air Pollution Control Division (CDPHE-APCD) operates a number of ozone monitoring sites in the North Front Range of Colorado for public health protection. Data from these sites are used on a daily basis for forecasting and reporting of air quality to the public. However, these ground-based sites do not cover the entire North Front Range area, and localized meteorology can play a significant factor in ozone formation, which can make air quality forecasting and modeling difficult.

NASA currently provides satellite measurements of atmospheric concentrations of pollutants related to air quality. However, rather than surface measurements, they are total column measurements. The primary goal of the NASA DISCOVER-AQ project is to distinguish between pollution high in the atmosphere and that near the surface where people live and breathe. With an improved ability to monitor pollution from satellites, it is then possible to make better air quality forecasts, more accurately determine the sources of pollutants in the air and more closely determine the fluctuations in emissions levels.

NASA's DISCOVER-AQ project will employ two aircraft, working in tandem. The addition of the NCAR C-130 aircraft would greatly enhance the project by providing additional air quality measurements over a wider area. Also, with an expanded area, the NCAR aircraft would better define meteorological inflow and outflow patterns.

The CDPHE-APCD is committed to providing support to the NASA DISCOVER-AQ project by:

- Continuing to operate its existing network of ground-based ozone sites;
- Continuing to operate its existing network of ground-based oxides of nitrogen sites;
- Operating ground-based volatile organic compound collection sites;
- Adding short-term ozone and oxides of nitrogen sites in the area;
- Providing air quality forecasting capabilities; and
- Providing data analysis and modeling capabilities.

The CDPHE-APCD would strongly endorse National Science Foundation support for NCAR, specifically for their C-130 aircraft and ground based support for the FRAQ field campaign in 2014, in conjunction with the NASA DISCOVER-AQ project. Validation of satellite measurements for air quality would enhance local forecasting and modeling efforts by CDPHE-APCD and others.

Please feel free to contact me with any questions. I can be reached at (303) 692-3114 or at wiliam.allison@state.co.us.

Sincerely,

William C. Allison
Director
Air Pollution Control Division
Colorado Department of Public Health and Environment

United States Department of the Interior
NATIONAL PARK SERVICE
Air Resources Division
P.O. Box 25287
Denver, CO 80225

TAKE PRIDE IN AMERICA

IN REPLY REFER TO:

November 21, 2012

Gabriele Pfister and Frank Flocke
National Center for Atmospheric Research
Atmospheric Chemistry Division (ACD)
P.O. Box 3000, Boulder, CO 80307-3000 USA

Dear Gabriele and Frank,

I am writing in support of the Front Range Air Quality (FRAQ) field campaign coordinated with the NASA DISCOVER-AQ project. Rocky Mountain National Park is located within the study region and experiences a number of deleterious effects from air pollution. The eastern portion of the park is located in the Denver-Boulder-Greely-Fort Collins ozone nonattainment area and has measured exceedances of the current ozone standard. The park also has documented effects from nitrogen deposition to aquatic and terrestrial ecosystems and has degraded visibility from aerosols reaching the park from both the Front Range Urban Area and from more distant sources. The National Park Service Air Resources Division has been studying the transport and fate of air pollutants reaching the park to identify air pollution sources that are contributing to these various problems at Rocky Mountain National Park.

We anticipate that if the combined study can go forward it will help us better understand the complex transport pathways that bring pollutants to the park. We also look forward to a better understanding of the gaseous and aerosol species aloft that may be transported to the park; our studies to date have been limited to surface measurements. We feel that the suite of measurements, at both the surface and aloft, in this study can fill in many questions that remain unanswered. If the study proceeds, we hope to deploy our mobile laboratory, with collaboration from our colleagues at Colorado State University. We also anticipate making other in situ measurements at various elevations in Rocky Mountain National Park.

The combined FRAQ and DISCOVER-AQ project will provide a wealth of information that will help the National Park Service better understand the air pollution that affects Rocky Mountain National Park and ultimately lead to the protection of park resources.

Sincerely,

John C. Vimont
Chief, Research and Monitoring
National Park Service, Air Resources Division

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 8
1595 Wynkoop Street
DENVER, CO 80202-1129
Phone 800-227-8917
http://www.epa.gov/region08

Ref: 8P-AR

December 4, 2012

Dr. William Keene
Division of Atmospheric and Geospace Sciences
National Science Foundation
4201 Wilson Boulevard,
Arlington, Virginia 22230

Dear Dr. Keene:

I am submitting this letter of support from the Environmental Protection Agency (EPA) for National Science Foundation (NSF) participation in studies of air quality in the Denver Metropolitan Area and Northern Front Range (DMA/NFR). While EPA cannot endorse any specific proposal or research institution, this letter demonstrates EPA's general support for NSF participation in studies of atmospheric chemistry and ozone formation in the DMA/NFR.

The DMA/NFR has a population of approximately 4 million people and is currently designated by EPA as non-attainment for the ozone National Ambient Air Quality Standard (NAAQS). The DMA/NFR has an unusual and unique mixture of sources that contribute to violations of the ozone NAAQS, including typical urban emissions, anthropogenic emissions from industrial sources, impacts from large wildfires and other biogenic precursors, and high background ozone concentrations that could be due in part to long range transport and stratospheric intrusion of ozone. The Denver metropolitan area borders the Rocky Mountains and the DMA/NFR nonattainment area has complex terrain with elevations ranging from 1600 to over 4000 meters. Exceedances of the ozone NAAQS have been measured both in urban areas and in relatively remote and pristine areas, such as Rocky Mountain National Park. Additional air quality concerns include visibility impairment and nitrogen deposition in Colorado's national parks and national forests, including several Class I visibility protection areas.

While the Colorado Department of Public Health and Environment has made significant progress in reducing ozone precursor emissions during the past decade, there remain important uncertainties in the sources that contribute to high ozone concentrations in the DMA/NFR. Future air quality studies will provide essential data needed by the state of Colorado and the EPA to validate air quality models and to identify the most effective approaches to reduce ambient ozone levels.

For more information, please contact Gail Tonnesen at (303)-312-6113 of my staff.

Sincerely,

Carl Daly

Carl Daly, Director
Air Program

DEPARTMENT OF ATMOSPHERIC SCIENCE
COLORADO STATE UNIVERSITY
1371 CAMPUS DELIVERY
FORT COLLINS, CO 80523-1371
(970) 491-8682 PHONE
(970) 491-4889 FAX
http://www.atmos.colostate.edu

Dr. Flocke-

We are very interested in the DISCOVER-AQ / FRAQ study proposed for summer 2014, and we are intending to submit a joint proposal (PIs: Emily Fischer and Delphine Farmer) for complementary ground-based measurements. Our proposed measurement suite is designed to quantify O_3 production in air masses with diverse histories using two different approaches. We intend to simultaneously deploy an O_3 production sensor and a VOC reactivity sensor alongside measurements of NO_x, SO_x, CO and VOCs. Instruments will be staged on the CSU Department of Atmospheric Science mobile lab. One potential location for the mobile lab would be the long-term O_3 monitoring site in Rocky Mountain National Park, but we will coordinate with other proposed ground based measurements before committing to this location. The planned observations will complement the photochemistry payloads proposed for the different aircraft. Our proposed observations will allow us to differentiate between long-range pollution transport, local O_3 production and re-circulated air masses. Thus these observations will also provide useful constraints for regional photochemical models.

As Assistant Professors at Colorado State University, we are particularly excited about the pending local FRAQ study. We look forward to collaborating with you and contributing to the larger proposed campaign. Please do not hesitate to contact either of us if you need any additional information.

Emily Fischer
Assistant Professor (arriving August 2013)
Department of Atmospheric Sciences
Colorado State University
efischer@seas.harvard.edu

Delphine Farmer
Assistant Professor
Department of Chemistry
Colorado State University
Delphine.Farmer@colostate.edu

GO3 Foundation
2100 Central Avenue
Suite 105
Boulder, CO 80301

October 16, 2012

Dr. Gabriele Pfister
NCAR
1850 Table Mesa Drive
Boulder, CO 80305

Dear Dr. Pfister,

We look forward to partnering with you on the DISCOVER AQ Campaign 2014 – Colorado North Front Range. The GO3 Project works with schools around the world to facilitate their participation in atmospheric science by providing them with instruments to measure air pollutants. The project began with a focus on ground level ozone measurements and has recently expanded to include black carbon and carbon dioxide monitoring.

There are now more than 85 schools participating in the project and uploading ozone data in 25 countries. Their data are uploaded every 15 minutes for viewing on Google Earth or online graphing at go3project.com. For ozone measurements, the project uses an extremely accurate UV absorbance instrument manufactured by 2B Technologies, so the students are able to collect high quality, useful data.

Colorado currently has the highest density of GO3 Stations in the US. There are ozone monitors at approximately 30 schools in Colorado, many of which are located in the Front Range (see map below for monitor locations). The ozone data generated by the GO3 Stations is available to researchers through the project's website and also through AIRNow. GO3 data is automatically sent to AIRNow every hour and is available for display in a staging area of AIRNow Tech. AIRNow ingests all student-collected data to analyze the impacts the additional data have on their air quality models and forecasts, with a focus on Colorado. Their preliminary results are promising and show that the GO3 Schools produce high quality data that reduce model uncertainty and increase the number of people served by accurate forecasts.

Although the DISCOVER-AQ Campaign will take place during the summer when schools are not in session, we will work with teachers in the Front Range to ensure they have their stations uploading data at that time. We will also recruit schools, teachers, and students to get involved in the campaign through research of their own, discussion of the campaign on the GO3 Social Network and other planned activities to promote community engagement.

We look forward to working with you and getting Colorado students and teachers involved in exciting, cutting edge atmospheric research.

Sincerely,

John Birks

Dr. John Birks
Director, GO3 Project
Professor Emeritus, University of Colorado

Letter of Support

Gabriele Pfister & Frank Flocke
NCAR/Atmospheric Chemistry Division
Co-PIs for proposed 2014 Front Range Air Quality Study

30 November 2012

Dear Gabriele, Dear Frank

We enthusiastically support your proposal to conduct a comprehensive air quality study in the Colorado Front Range area in the summer of 2014.

In collaboration with the 2014 Front Range Air Quality (FRAQ) study, we are tentatively planning deployment of an ozone lidar and a Doppler wind lidar to investigate local and regional transport processes of ozone. These ground-based lidar systems measure profiles of ozone concentration, aerosol backscatter, boundary layer height, and wind parameters, including wind speed/direction, vertical velocity variance and skewness, and horizontal velocity variance, from near the surface to several kilometers above ground with high temporal and spatial resolution. Both lidars are easily deployable to locations in the Front Range area.

Our group at NOAA/ESRL/CSD has extensive experience deploying lidar remote sensing systems at air quality studies. Since 1995, we have participated in many large, multi-agency field campaigns (most recently the UBWOS 2012 and CalNex 2010 experiments) aimed at studying the transport, chemical transformation, and sources and sinks of air pollutants including ozone. During the summers of 2007 – 2009, we took measurements with the airborne version of our ozone lidar and a co-deployed Doppler lidar in the Colorado Front Range area. From these observations we were able to characterize the 3D distribution of ozone and wind flow patterns that tend to push pollutants from the greater Denver area up against and in some cases over the Front Range mountains. We are excited at the prospect of continuing and expanding this research as part of a much larger team during the FRAQ 2014 campaign.

We look forward to taking part in the Front Range Air Quality Study during summer 2014. Please keep us informed on developments as the planning progresses.

Sincerely,

Christoph Senff, Research Scientist, Ozone Lidar PI, CIRES/CU & NOAA/ESRL/CSD

Wm. Alan Brewer, Research Scientist, Doppler Lidar PI, NOAA/ESRL/CSD

R. Michael Hardesty, Chief, Atmospheric Remote Sensing Group, NOAA/ESRL/CSD

Desert Research Institute

SCIENCE ●● ENVIRONMENT ●● SOLUTIONS November 29, 2012

Dr. Gabriele Pfister National Center for Atmospheric Research P.O. Box 3000 Boulder, CO 80307-3000

Dear Dr. Pfister,

I welcome your research field project to use Storm Peak Laboratory as part of the Front Range Air Quality Campaign. We are very interested in a collaboration with your project, and are planning to submit a proposal for collaboration to the National Science Foundation after the Atmospheric Chemistry Division has submitted a proposal. As you are aware, Storm Peak Laboratory (SPL) is located near Steamboat Springs, Colorado. It is a high elevation, mountain-top atmospheric research facility which is readily accessible under all weather conditions. SPL is operated by the State of Nevada System of Higher Education.

The laboratory is an excellent site to sample aerosols and trace gases under both pristine conditions as well regional influences for you proposal titled “Front Range Air Quality (FRAQ) Field Campaign”. SPL provides an ideal location for long-term research on the interactions of atmospheric aerosol and gas-phase chemistry with cloud and natural radiation environments. The ridge-top location produces almost daily transition from the clean free tropospheric to boundary layer air which occurs near midday in both summer and winter seasons. Long-term observations at SPL document the role of orographically induced mixing and convection on vertical pollutant transport and dispersion. A comprehensive set of continuous aerosol measurements was initiated at SPL in 2002. The laboratory is currently well equipped for aerosol measurements. Particles are sampled from an insulated manifold that was recently upgraded through a National Science Foundation funded ARRA grant for research infrastructure upgrades.

SPL includes a full kitchen and two bunk rooms with sleeping space for nine persons, allowing for a round-the-clock science field missions. Typically research groups work and live within SPL, enabling continuous measurements and monitoring. The laboratory holds a special use permit with the U.S. Forest Service for the use of the site. SPL also has a long history of providing educational experiences to students of all ages, and this will continue under the proposed project. The proposed project will allow these students and researchers to work together during the field deployment. Research at SPL has been the subject of ongoing coverage in local and national news media, including local cable TV in Steamboat Springs, CNN news, The History Channel, The Weather Channel, and National Geographic Explorer.

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With this collaboration, SPL will run all of the aerosol instrumentation including size distribution (3 nm to 20 µm), aerosol optical properties, aerosol concentration and a cloud condensation nuclei counter. In addition we will run our trace gases instrumentation including CO, CO_2 (NCAR-EOL), NO_x, O_3, and SO_2. The trace gases instrument, except the NCAR CO_2, were recently acquired through a National Science Foundation Major Research Infrastructure grant. SPL also has column remote sensing instruments, including a UV and Visible Multi Filter Shadow Band Radiometer (MFRSR) for calculating Aerosol Optical Depth (AOD). Recently in collaboration with NOAA, a GPSMET station was installed for calculating precipitable water above SPL. All of the above instruments will be calibrated prior to and run for the period of the FRAQ and DISCOVER-AQ flights. SPL is also equipped to accept additional instrumentation for intensive operating periods. I, Ian McCubbin site manager of SPL, will be responsible for all logistics to transport the equipment and supplies to the laboratory. SPL has all the necessary equipment (i.e. snowmobiles, snowcat, 4-wheel drive vehicles) to handle this task. The staff is experience with the requirements of this type of field work. At the laboratory, there is adequate space for your research group, equipment and supplies. We welcome you to the laboratory and look forward to working with you.

Cordially,

Ian B. McCubbin Site Manager - Storm Peak Laboratory DRI – Division of Atmospheric Sciences