Fire **I**nfluence on **R**egional to Global **E**nvironments and **A**ir **Q**uality (FIREX-AQ)

A NOAA/NASA Interagency Intensive Study of North American Fires

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Motivation

The combination of a warmer, drier climate with fire-control practices applied over the last century has produced a situation in which we can expect larger and more frequent fires in the U.S. and Canada. The 20th century saw fire suppression become the standard response to wildfires, especially in western North America; this has led to a buildup of fuels in forested areas, a breakdown in the natural ecology of forests, and risks to life and property associated with the development of the urban-wildland interface. Prescribing fires and allowing some naturally-occurring fires to burn are some of the management practices that can address the above problem [*U.S. Dept. of Interior,* 2014].

Fire is important for many ecosystems, but it also poses costly risks to human health and property. These risks have increased in recent decades due in part to population growth in the wildland urban interface [*Westerling et al.*, 2006]. Extreme fire seasons attract mounting attention due to the increasing number of costly extreme wildfires that include: the 2016 fires that burned across 8 states in the southeast (48,158 ha); the 2016 Anderson Creek prairie fire that was the largest in Kansas history (161,874 ha); the 2016 Fort McMurray fire, which is the costliest fire in Canadian history ($2.7 B, 589,552 ha, 2400 structures destroyed); the 2004 Alaskan fire season (2.74 M ha), the largest in almost 80 years of Alaskan fire history and the extreme 2015 unusually-early-season Alaskan fires (2.07 M ha). Since 1960, total burned area in a single year has exceeded 3.6 M ha in the United States only 4 times - all of which occurred in last decade. Coupled with the direct threats to life and property, wildland fires have demonstrable detrimental air-quality related health impacts including aggravated asthma, chronic bronchitis, decreased lung function, congestive heart failure, and premature death [*Rappold et al.*, 2011; *Thelen et al.*, 2013].

1. Background and State of the Science

Fire impacts occur over wide time and distance scales, from local to global, via many complex, interdependent, and poorly understood processes. For example, primary fire emissions are affected by a wide variety of factors including fuel conditions (type, structure, quantity, and moisture content), fire intensity, and fire weather (cumulative temperature, relative humidity, wind speed and precipitation), which in turn can be rapidly and heterogeneously modified by fires as they burn. Over the life cycle of a fire, combinations of flaming and smoldering combustion lead to different emissions at different times and at different locations within a fire. These variables also influence plume rise and the subsequent transport and chemical evolution of fire emissions, which determine the secondary products (e.g. evolved gases and aerosol species). Wildfire initiation can be natural (by lightning) or human caused and prescribed fires are becoming a more frequent tool for land management (e.g., land clearing and agriculture). Fire growth is driven by weather conditions and is subject to the limitations of weather-based prediction. Fire activity can be predicted on a broad seasonal scale, but climatologies are inadequate to provide the detailed information needed to understand and predict fire impacts. This is especially true for impacts related to air quality, which depend on the intersection of fire emissions with populations and are sensitive to chemical transformations that can result when emissions from fires and anthropogenic sources combine.

The ubiquity of fire emissions is evident from previous airborne field studies. Some of the more recent missions observing these atmospheric impacts of fires are introduced here, followed by a more detailed explanation of state of the science organized by general subtopic. The international ICARTT study (2004) found strong biomass burning (BB) influence from Canadian and Alaskan fires in the northeast U.S. [*Warneke et al*., 2006], and NOAA's TEXAQS (2006) identified systematic differences in particle morphology between urban and biomass burning sources [*Schwarz et al*., 2008]. The international POLARCAT study (2008) focused on Arctic measurements, observed strong fire contributions in spring by Asian fires to arctic haze over Alaska [*Warneke et al*., 2009] and sampled local Canadian fire emissions during summer as well as unexpected fires in California, providing a broad cross section of fire emissions and impacts [*Hecobian et al*., 2011; *H. B. Singh et al*., 2012a]. NOAA's SENEX (2013) acquired data on the relative contribution of BB to organic aerosols and gases in the southeast U.S. and provided the first airborne measurements of nighttime smoke [*Zarzana et al*., 2017], while the NASA/NSF DC3 (2012) campaign had the good fortune to encounter a smoke plume interacting with a deep convective tower [*Apel et al*., 2015] and evidence for the broad influence of convection on the ventilation of fire emissions [*Huntrieser et al*., 2016]. Fire sampling during NASA's SEAC⁴RS (2013) study enabled evaluation of the plume from the Rim Fire, a large wildfire in California [*Peterson et al*., 2015] and emissions from a collection of 15 small agricultural fires in the Mississippi River Valley [*Liu et al*., 2016].

Despite this wealth of fire sampling over the years, field studies dedicated specifically to the sampling and characterization of fires and their impacts from the point of emission have been lacking. This need is being met through recent efforts such as the DOE BBOP (2013) mission which was focused on smoke optical properties, but also identified, via morphological analysis, evidence for evolving brown carbon materials in fire plumes [*Zhou et al*., 2017]. Also, recent laboratory studies, e.g., NOAA's FIREX FIRE Lab study in 2016 and the University of Montana led FLAME-4 study, produced some fuel specific emission factors (EFs) and smoke aging simulations [*Koss et al*., 2018]. FIREX-AQ will build directly on these contributions.

Below, broad science targets for the FIREX-AQ campaign are presented with background information and explanations of needs. Each target is associated with specific FIREX-AQ science questions (found in Section 3).

Fuel-specific Emission Factors

Fuel-type-specific emission factors are one of the fundamental needs for prediction and assessment of wildfire emissions on the atmosphere, but the long list of factors influencing fire emissions creates a difficult statistical challenge. In an intercomparison of four unique approaches to estimating fire emissions in the United States, *Al-Saadi et al*. [2008] found that even though patterns were similar, monthly estimates of CO could vary by a factor of 10. Similar difficulties were encountered by *Zhang et al*. [2014] for estimates of smoke emissions over sub-Saharan Africa.

One demonstration of this challenge is provided by considering the observations that form the basis for recommended emission factors used in models. *Akagi et al*. [2011] provide an extensive review of these observations, which include airborne, ground-based, and laboratory sampling. Screening is applied to ensure that observations are fresh, meaning sampled emissions have cooled to ambient temperature but have undergone minimal photochemical processing. When assessing the contributions of airborne field observations, the resulting data are rather limited. This is due to the lack of airborne samples focused on near-field fire emission characterization. More traditionally, airborne field campaigns have documented fire impacts through diagnostic tracers (HCN, CH_3CN, K^+) and plume interceptions at various distances downwind, often without detailed knowledge of the source. As a result, only eight airborne campaigns contribute to the *Akagi et al*. [2011] assessment of emission factors. For biomes relevant to North American wildfires, contributions are further limited to samples taken from 39 specific fire events (13 - boreal forest, 18 - temperate forest, 8 - chaparral). Airborne sampling of crop burning adds another 12 fires; hence only very limited statistics are available.

A good example of the current uncertainty in emission factors can be found in the recent work of *Liu et al*. [2016] comparing statistics from the recent SEAC^{4}RS study with previous observations. *Liu et al*. analyzed fifteen crop fires in the Mississippi River Valley in 2013 sampled from the NASA DC-8. Emissions derived from these fires showed statistically significant differences from previously published emissions estimates, indicating that the distribution of possible emission factors has not been adequately quantified. This example applies only to crop burning, but other fuels suffer a similar paucity of observations.

While there is a modest amount of ground-based sampling and laboratory observations available to augment airborne data, there is a compelling need for more ambient observations near active fires. This need becomes more evident when looking at the suite of measurements collected during each field study included in the *Akagi et al*. assessment. The overlap in measurements is limited to a handful of constituents (CO_2, CO, CH_4, NO and/or NO_2, C_2H_2). Measurements of other reactive hydrocarbons, tracers, and particulate emissions vary considerably between studies, leaving even fewer observations for estimating emission factors for many trace gas and particulate components. It is important to note that measurements of acetonitrile (CH_3CN) are largely absent from these previous studies. CH_3CN has emerged as the most reliable conservative tracer of biomass combustion, being widely measured in more recent airborne field studies to diagnose fire influence [*de Gouw et al*., 2003].

There continues to be significant progress in defining and quantifying the detailed chemistry of BB emissions as analysis methods applied to these measurements continue to evolve

in sophistication. Examples of recent new findings include measurements of isocyanic acid (HNCO) emissions and the observation of nitrous acid (HONO) as a consistent product of fires in both the laboratory and field at levels of 5-30% of NOx [*Burling et al*., 2010; *Roberts et al*., 2010]. There has also been increased effort to obtain detailed information on the semi-volatile organic compounds (SVOCs) that are an abundant class of secondary organic aerosol (SOA) precursors in fires. Attempts to reconcile the VOC emissions from fires with the observed SOA formation have shown that unidentified SVOCs, while perhaps only 20-50% of the VOC emitted [*Hatch et al*., 2014; *Stockwell et al*., 2014], can have a disproportionately large effect on the amount of SOA estimated by models [*Jathar et al*., 2014; *McMeeking et al*., 2014]. Recent laboratory work has led to the recognition that the relative amounts of BC and organic carbon aerosol (OC) emitted are strongly relevant to the optical properties because of light-absorbing OC aerosol (also called "Brown Carbon", BrC) [*Saleh et al*., 2014].

Recently, new analytical techniques were deployed during the FIREX Fire Lab 2016 experiment in Missoula, MT to characterize fire emissions in more detail. One example is that Koss et al., [2017] determined a significant fraction of volatile organic compounds (VOCs) and semivolatile VOCs (SVOCS) that were previously unidentified in emissions of North American wildfires. Over 90% of the mass detectable by a PTR-ToF-MS instrument were identified. In addition, a better process-level understanding of the emissions of trace gases was established: it was found that the variability in VOC emissions can be explained using the temperature of the pyrolysis and that the VOC emissions can be parameterized using a high and a low temperature pyrolysis factor that is independent of the fuel burned [*Sekimoto et al*., 2018]. These laboratory-determined emission factors and process understanding has yet to be applied to ambient measurements.

FIREX-AQ will provide ambient observations to complement these recent laboratory measurements using a near-comprehensive suite of chemical and aerosol measurements. The resulting information will broaden the characterization of fire emissions and be used to refine and improve emission inventories. These measurements will be critical to addressing FIREX-AQ science question #1 and associated sub-elements.

Emission Estimates using Satellites

Fire emissions can be estimated using the burned area, fuel loading, fuel consumption and compound-specific emission factors discussed above. The routine (or operational) determination of these parameters (except the emissions factors) relies on satellite observations in combination with information on ecosystem types [*Friedl et al*., 2010; *Giglio et al*., 2003; *Giglio et al*., 2006b].

Burned area estimates are derived from a variety of satellite data products (GOES and MODIS). These estimates have the advantage of being able to detect after the fires by collecting observations over a period of time that includes multiple satellite overpasses, thus increasing the chance to observe locations free of cloud cover [*Giglio et al*., 2006a; *Giglio et al*., 2009; *Roy et al*., 2008; *Roy et al*., 2005]. For instance, the MODIS burned area product is diagnosed from the 8-day surface reflectance product, providing information at 500m resolution. While this fine spatial resolution is adequate for large Western wildfires, it is not sufficient for detecting many small agricultural fires in the Southeast [*McCarty et al*., 2009]. Geostationary satellites were shown to capture more small fires, even though the instrument resolution was low, simply due to the fact that the instruments were overhead when small (brief) fires were burning [*Al-Saadi et al*., 2008; *Soja et al*., 2009].

Active fire detection based on satellite observations in the infrared offer complementary information capable of detecting such small fires, but at coarser resolution (1 km) and only when fires are actively burning and unobscured by clouds at the time the satellite is overhead. In an analysis of fire detection products over the U.S., McCarty concluded that 65% of active fire detections in croplands were not accompanied by a burned area detection. This number rose to 70% in the southeast. While these detections are valuable for detecting small cropland fires, they were found to add only 4% to total burned area estimated from the MODIS burned area product. Focusing more generally on small fires, *Randerson et al*. [2012] came to a different conclusion based on a global analysis of the same MODIS 500 m burned area products and 1 km active fire detections. Using a set of scaling factors developed to assign a burned area estimate to active fire detections lacking coincident burned area detections, it was estimated that small fires increase global burned area by 26%. As with emissions factors, the disparity in these results places emphasis on the need to validate information on the contribution of small fires to overall emissions. It is important to note that other satellite products (e.g., GOES-16, VIIRS, Landsat8/OLI) are now available, offering higher spatial resolution, more frequent coverage, and greater spectral information than was available for these previous studies.

Along with burned area, the amount of fuel consumed must also be determined. The amount of fuel contained in unique ecosystems can vary by 2 orders of magnitude, and the amount of fuel available (dry enough) to burn in each ecosystem varies with fire weather or fire danger conditions. *McRae et al*. (2006) demonstrated that even in the same ecosystem, the amount of fuel consumed by a fire can vary by an order of magnitude, dependent on the fuel conditions and fire severity. This adds credence to the value of accumulating statistics and connecting the ground to the atmosphere by connecting multiple-agency field campaigns.

More recently, Fire Radiative Power (FRP) and Fire Radiative Energy (FRE) have been related to fuel consumption [*Charles Ichoku et al*., 2008; *Wooster et al*., 2005], and FRE has been suggested as a methodology to estimate fire emissions from the top down [*C. Ichoku and Ellison*, 2014; *C. Ichoku and Kaufman*, 2005]. As these approaches have matured, their application has been hampered by a lack of quantitative validation data for fire energetics.

Satellite trace-gas retrievals of unprecedented spatial resolution will also be available during FIREX-AQ with an opportunity to evaluate TROPOMI observations of NO_2, CH_2O, CO, and CH_4. Observations from other satellites (e.g., MOPITT, AIRS, IASI) will also be useful for constraining trace gas emissions from fires. These satellites will provide additional value in diagnosing the extent of mixing between fire and anthropogenic emissions affecting air quality.

Satellite retrievals are relevant to many FIREX-AQ science topics, and are specifically called out in question #6, which addresses this explicitly.

Optical Properties of Smoke

Smoke is one of the most prominent and visible aspects of BB. Smoke is primarily comprised of gaseous and aerosol constituents including BC, BrC, OC, and mineral dust, all of which have critical climate, health, and air quality impacts. The aerosol, controlling most of the optical properties, evolves due to dilution, coagulation, and chemical processing on time scales of seconds to days [*Vakkari et al*., 2014]. Fire smoke has many impacts on the atmosphere; depending on the relative amounts of OC and BC/BrC, surface albedo and altitude, it can either heat or cool the atmosphere; it can provide ice and water active aerosols; affect visibility and air quality; be transported over global scales. BB is the largest source of black carbon to the atmosphere [*Bond et al*., 2013] and a singularly important source of BrC [*Saleh et al*., 2014]. There is evidence that

fires produce BC particles coated with particulate organic matter in a manner that enhances some of their optical properties, specifically short wavelength absorption by "lensing" [*Lack et al.*, 2012]. However, the net direct forcing effect of all aerosol species generated by BB is currently believed to be small while uncertain [*Bond et al.*, 2013].

The optical properties of smoke are relevant to science questions #3 - 6, as they determine the effects of smoke on visibility and climate, and influence interpretation of satellite retrievals. To the degree that FIREX-AQ determinations of smoke's intensive properties (including optical properties) can be linked more generally to smoke emissions globally, this topic could have meaning for understanding fires' wider impacts.

Transport, Transformation, and Plume Chemistry

The impact of wildfires on regional- to global-scale atmospheric chemistry depends on the physical and chemical transformations that take place as fire emissions are transported, diluted, and exposed to chemical oxidants. Ozone and other oxidants can be formed along the way, and particle mass-loadings can grow or shrink [*Akagi et al.*, 2012]. In addition, toxic gas and particle materials that have health impacts can be both formed and destroyed. Not all the factors that govern these processes are well understood, and individual fire plumes can have very different behaviors. Fire emissions contain a number of unusual compounds, some of which may have specific health effects [*Roberts et al.*, 2011], and more compounds are being discovered as more sophisticated analytical techniques have been applied [*Stockwell et al.*, 2014]. Fundamental atmospheric chemical behavior of some of these compounds is often unknown. Mueller et al (2016) used a PTR-ToF-MS to detect previously unreported compounds in a small understory fire in Georgia and successfully modelled some of these newly reported compounds, but still was not able to model several compounds with current chemical mechanisms. The FIREX FireLab 2016 results of smoke aging reactors were used to further update the chemical mechanisms of furan-type compounds and was able to model a much larger set of compounds. Yet still a large fraction of the initial reactivity remains unaccounted for in the updated chemical mechanism.

Photooxidation of the NOx and VOCs emitted by fire plumes shows complex behavior, sometimes leading to production of ozone and sometimes not [*Jaffe and Wigder*, 2012]. The reasons for this complexity are not understood and may have to do with how fast the plume was lofted and cooled, how efficiently NOx was converted to products such as peroxyacetyl nitrate (PAN), or whether the fire had substantial amounts of radical precursors such as HONO or carbonyls. What is clear is that fire emissions often have broad-scale impacts on ozone formation [*Pfister et al.*, 2006; *Wotawa and Trainer*, 2000], especially when mixed with urban emissions [*H.B. Singh et al.*, 2012b], and can be decisive factors in triggering air quality exceedances.

The physical and chemical processes governing the transformation of particles in BB plumes is quite complex, with evidence of both loss and gain of particle mass, and rapid atmospheric oxidation [*Vakkari et al.*, 2014]. Mass can be lost as smoke is diluted due to the physical equilibration of semi-volatile compounds [*Robinson et al.*, 2007]. Oxidation of both gas and particle phase compounds due to reaction with HO_x radicals (daytime) and NO_3 radicals, N_2O_5, and $ClNO_2$ (nighttime) can lead to mass loss or gain, and changes in the optical properties. The chemistry and surface coating properties of particles emitted by fires evolve as these physical and chemical changes take place and affect the optical, cloud nucleation, and toxicological properties of the particles. The chemical transformation of fire-sourced pollutants is the main focus of science question #2.

Plume Injection Heights

Another critical parameter needed to improve forecasts of fire emission transport, lifetime, chemistry, and impacts is plume injection height, namely the distribution in altitude space at which fire emissions are entrained into the boundary layer, the free troposphere, and even the lower stratosphere. By far, the most determinations of plume-height statistics are based on satellite retrievals [*Paugam et al*., 2016]. Currently there are two satellite instruments that are capable of capturing plume injection height: the Multi-angle Imaging SpectroRadiometer (MISR); and the Cloud-Aerosol LIdar with Orthogonal Polarization (CALIOP). Both of these instruments provide essential and unique information. MISR has a larger swath width, thus a greater ability to estimate near-fire plumes, and the MISR plume database is mature [*Kahn et al*., 2008; *Martin et al*., 2012; *Nelson et al*., 2013]. However, MISR is on Terra with a morning overpass, while smoke plumes occur most often in the late afternoon; their heights can also vary diurnally. MISR also requires distinct smoke edges to estimate plume height and large smoke plumes can fill the MISR field of view such that a distinct smoke boundary cannot be observed. CALIOP (active lidar, 30 m vertical resolution for height, 60 m vertical resolution of plume density via backscatter), paired with a back-trajectory model, can enhance the MISR morning database, by characterizing afternoon plumes [*Omar et al*., 2009]. While useful for historical context, CALIOP will not be available in 2019; however, the Cloud-Aerosol Transport System (CATS) onboard the International Space Station is another lidar that may prove useful.

Some parameterizations of fire plume injection height take into account the atmospheric stability appropriate for each fire, as well as the availability of latent energy via water vapor which strongly affect plume height. Plume injection height will be directly observed during FIREX-AQ for a large number of fires and meteorological conditions, providing information relevant to science questions #2, 3, and 6.

Regional and Nighttime Atmospheric Chemistry and Impacts

Wildfires have profound impacts on regional air quality due to their promotion of photochemical ozone production, emission of particle pollution of both primary and secondary origin, and emission of toxic materials. These impacts are often the most immediate acting on populations and ecosystems and are a high priority for consideration when making decisions on fire management, i.e., when to plan prescribed burns and when to allow naturally-initiated fires to burn. The research needed to understand and manage these impacts is one of the more challenging aspects of wildfire research, as it involves understanding all of the smaller-scale processes detailed above: fire weather, emissions, and transport and transformation. This information must then be incorporated into models that can be used to make policy decisions on all timescales, from the immediate: e.g. fire management and health advisories, mid-term: air quality waiver, to the long-term: ecosystem and urban-wildland interface management. Meeting the stricter National Ambient Air Quality Standards (NAAQS) for ozone and other criteria pollutants will require better understanding and prediction of fire impacts (along with long-range transport of pollution from other parts of the world).

Night-time plume evolution, air quality impacts, and exposure have not been studied in detail previously. Due to lower temperatures at nighttime the combustion efficiency of fires is generally lower than during the daytime and as a result smoke does not get lifted as high at night. A common pattern for western wildfire smoke is to accumulate in valleys overnight and often fires only "blow up" in late afternoon/evening. Regions with concentrated smoke from these sudden low-altitude intensifications are often visible in satellite images close to the fires or hundreds of

miles downwind of their source on following days. Nighttime dilution and chemistry will play a role in downwind impacts of these plumes. The smoke that accumulates in valleys leads to impacts and high exposure closer to the sources. These varying scenarios need investigation with a combination of mobile laboratory and small aircraft platforms.

Night flights may be particularly useful in constraining emission factors for highly reactive gases such as carbonyl compounds and nitrous acid (HONO) [*Selimovic et al*., 2018] that will undergo rapid photolysis during the day but should be longer lived at night. This rapid photolysis makes these compounds difficult to constrain from daytime observations but they are important to understanding of fire plume chemistry due to increased radical production. Therefore, night-time fire plume sampling may serve to provide robust emission factors for such compounds.

The regional impacts and nighttime emission and chemical transformation of fires are the main focus of science question #3.

Global Distributions and Impacts

The impacts of wildfires are mostly associated with short-term climate forcers; ozone and aerosols including BC, BrC and OC. Global climate impacts of BB result from its truly massive contributions to aerosol optical depth (AOD) over large areas. Regions such as the Arctic and the cloud decks of South America are uniquely sensitive to BB emissions and to secondary processes, such as cloud and ice nucleation that can magnify the radiative impact of the emissions. The research needed to advance our understanding of these impacts is broad on both spatial and temporal scales, and relates to a wide spectrum including BB inventories, satellite fire detection, chemical evolution of gaseous species, aerosol microphysical and optical properties, proper integration into models, interactions with warm, mixed phase, and ice clouds, and effects on the vertical structure of the thermal profile. For example, current fire emissions inventories undercount small fires and domestic BB because they are based on satellite fire detection schemes that have limited resolution and therefore regional airborne measurements of fire products are invaluable in assessing inventories. Improving the integration of wildfires and BB into global models requires more detailed emission estimates at finer spatial scales and better understanding of how to represent these emissions in relatively coarse-resolution treatment after significant chemical processing and dilution. These efforts will require combining new chemical details from emission measurements, new insights about chemical and physical transformation of smoke, supported by observations from the next generation of satellites.

The global impacts and climate relevant properties of fires are the main focus of science questions #4 and #5.

2. FIREX-AQ Objectives

Fire emissions in the US are approximately half from Northwestern wildfires and half from prescribed fires that burn mostly in the Southeast US (Figure 2). Wildfires burn slightly more fuel and therefore have overall larger emissions, but prescribed fires dominate the area burned and the number of fires. FIREX-AQ will investigate both wild and prescribed fires. Wildfires generally result in exposures with larger pollution concentrations over larger areas, and cause both local and regional air quality impacts. Their emissions are often transported thousands of miles and can impact large regions of the US at a time (Figure 3). Prescribed fires are usually smaller and less intense than most wildfires but occur more frequently and throughout the whole year. They are usually ignited during periods that minimize population expose and air quality impacts, but can cause regional backgrounds to increase, are generally in closer proximity to populations, and are responsible for a large fraction of the US $PM_{2.5}$ emissions. To date agricultural fire outputs are still poorly represented in emission inventories. **The overarching objective of FIREX-AQ is to provide measurements of trace gas and aerosol emissions for wildfires and prescribed fires in great detail, relate them to fuel and fire conditions at the point of emission, characterize the conditions relating to plume rise, follow plumes downwind to understand chemical transformation and air quality impacts, and assess the efficacy of satellite detections for estimating the emissions from sampled fires.**

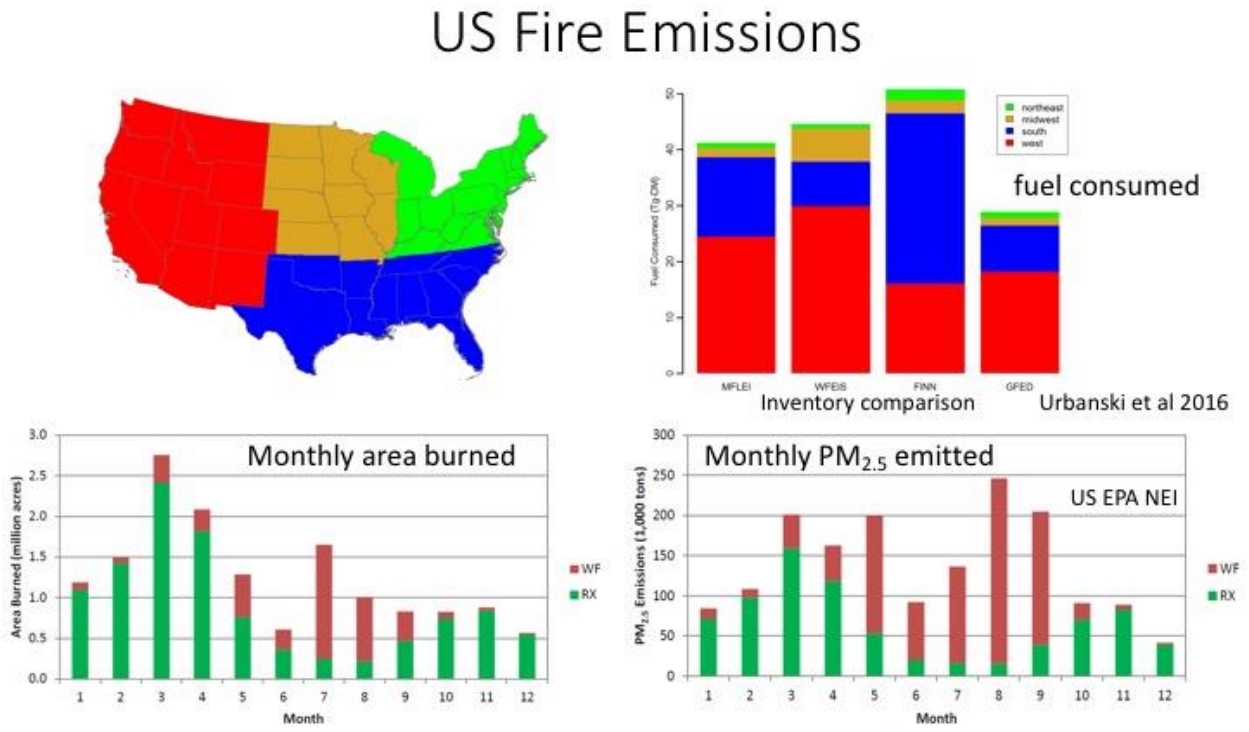


Figure 2: Monthly area burned and PM2.5 emissions for wild (WF) and prescribed (RX) fires in the US. Wildfires consume more fuel, but prescribed fires account for the majority of the area burned in the US.

1 – Sampling of Wildfires with Multiple Coordinated Aircraft

A primary objective of FIREX-AQ is to combine near and far-field observations to understand emissions, chemical evolution, transport and evaluate downwind impacts of wildfires in coordination with interagency partners. The airborne component of the FIREX-AQ effort, centered on the deployment of the NASA DC-8 with potentially two complementarily outfitted NOAA Twin Otters, will sample wildfire plumes from near the point of emission to downwind on a regional scale. These efforts will provide data to understand the influence of fire emissions on the atmospheric composition with continuity from initial emissions to evolved impacts far from the source. Wildfire plumes frequently affect many people directly by exposing population centers with large concentrations of pollutants, both close to the fires and potentially far downwind. Fire plumes affecting populated areas will be given priority in designing flight plans for sampling.

Partners from the Joint Fire Science Program (JFSP) will use their knowledge of ground conditions for fuel and fire characterization to advise on the best targets for airborne fire plume sampling. The NASA DC-8 has the ability to explore an extremely wide range of emission age and will coordinate with the NOAA Twin Otter instrumented aircraft that are focused on narrower ranges of emission age with complimentary payloads. For example, a Twin Otter will sample individual fires throughout the day to understand the diurnal changes of fire emissions and fire plumes at night to investigate the nighttime chemical evolution of fire plumes. Further, Twin Otters will generally be able to obtain higher spatial resolution measurements and undertake more focused studies of rapidly evolving chemical evolution over shorter spatial scales than the DC-8 instruments.

2 – Sampling of Prescribed Fires to Build Statistics

A second objective for FIREX-AQ is to exploit the range and endurance of the NASA DC-8 to sample a large number of small mostly prescribed fires to build statistics on emission factors and fuels, plume rise, satellite detectability, and integrated impacts for these types of sources.

Small fire activity will occur within the reach of the DC-8 every day during the deployment period. Thus, this objective will take priority when large wildfire activity is not occurring. Confidence that the DC-8 can adequately accomplish this objective comes from its demonstrated performance in sampling fifteen small agricultural fires during the recent SEAC^{4}RS campaign. Given the modest amount of flight time dedicated to small fire sampling during SEAC^{4}RS, it is expected that many more fires can be sampled during FIREX-AQ. This objective provides the best opportunity to build on the needed statistics for the variables described above and complements emission factor work of the FireLab study recently conducted by NOAA in advance of the joint field study in 2019. For best results, this objective requires liaison with state and local authorities to anticipate when and where to expect burning as well as to obtain ground-level data to the extent possible for understanding the fuel and conditions under which burning occurred. JFSP partners will be consulted for such advice, but funding for participation by an expert to assist in monitoring small fire activity and gathering information on ground conditions at sampled locations is also possible. The information gathered from small fires will also provide an opportunity to assess current satellite detection capabilities and reduce uncertainty in the contribution of small fires to total emissions.

3. FIREX-AQ Science Questions

1) What are the emissions of gases and aerosols from North American fires?

- How do emissions depend on meteorology, fuel, time of day or night, and fire conditions?
- How do the relative and absolute amounts of smoldering and flaming impact smoke composition and injection altitude?
- What is the amount, composition, and volatility of aerosol precursors including the previously unidentified fraction of the emissions including SVOCs, IVOCs, and BC, BrC and OC aerosols?
- What are the emissions of greenhouse gases and air toxics?
- How well do inventories represent BB emissions and their radiative properties, and what are the largest uncertainties affecting the inventories?

2) What chemical transformations affect those emissions?

- What are the formation mechanisms for secondary species (ozone and secondary aerosol) and what environmental or chemical conditions control their relative importance?
- How do aerosol optical and CCN properties evolve in fire plumes due to secondary production, particle phase transitions, and brown carbon bleaching and production?
- How large are the variations in fire emissions compared to the changes from chemical processing?
- What fraction of the organic aerosol is primary versus secondary at various time scales?
- How do nighttime chemical transformations involving NO_3, N_2O_5 and O_3 influence the composition and evolution and the production of secondary organic aerosol in smoke plumes?
- What are the mechanisms that lead to PAN formation in fire plumes during daytime and nighttime?
- What is the diurnal cycle of free radical and oxidant production in fire plumes, and how important are reactions with different oxidants at various times of day?
- How important is the formation of organic aerosol from aqueous-phase processes?

3) What is the local air quality impact of North American fires?

- How well do local models predict the BB impact on air toxics including gases and aerosols, and visibility?
- How does local meteorology impact fire evolution?
- How large are the small-scale temporal and spatial gradients in fire plumes?
- How important is nighttime smoke for populated areas and what are the health impacts?
- How large are the regional impacts of small prescribed fires?
- How much do small prescribed fires lead to population exposure?

4) What are the regional and long-term impacts of North American fires?

- How strongly are the composition and distribution of pollutants over North America influenced by BB?
- How far afield can BB emissions from prescribed fires impact air quality?
- What are the likely future changes in BB impacts that could result from climate change and changes to fire management practices?

5) What are the climate-relevant properties of BB aerosols?

- What roles do brown carbon and black carbon, other light-absorbing species, and internal mixtures play in the climate-relevant properties of smoke?
- What intensive properties of BB aerosols can remote (i.e. satellite and AERONET) observations determine globally?
- How well do regional and global models predict the BB influence on climate?
- How can FIREX-AQ measurements improve remote retrievals of smoke?

6) How can satellite measurements help with #1-5?

- How can improved measurements of plume height, fire intensity, and fire radiative power be used to adjust satellite retrievals?
- How can satellite data be complemented by information, such as modeling, fuel characterization, aircraft and ground observations, to fully exploit their potential for constraining the magnitude and impact of fires?
- How useful is thermal imaging of fires and documentation of field size for small fires for validating satellite active-fire count and burned-area products as well as fire radiative power (FRP)?
- What is the relationship between FRP and emissions based on in situ measurements and can remote sensing of fire intensity be more effectively used to estimate of fire emissions of trace gases and aerosols?
- Can lidar observations of depolarization contribute to speciation of aerosol types and evaluation of the age of smoke?
-How accurate are NO_2, CH_2O and other trace gas retrievals (e.g., CHOCHO) in fire plumes and can these gases be used to assess air quality impacts (e.g., O_3 sensitivities) associated with fires.

4. FIREX-AQ Research Strategies and Related Activities

4.1 Large-scale Coordinated Intensive Field Study

FIREX-AQ will be conducted during wildfire season in the summer of 2019 and coordinated with other agencies bringing various assets to the field. The following is a list of confirmed and highly likely collaborators and resources

- The **NASA DC-8** aircraft for measurements over all scales from the east to the west coast and from the boundary layer to the upper troposphere. The DC-8 will be the primary aircraft addressing most of the science questions outlined above.
- One **NOAA Twin Otter (FIREX-CHEM)** for detailed emissions, small scale photochemistry and nighttime chemistry in coordination with the DC-8. The Twin Otter will focus on the variability of the emissions measuring close to the fire for extended time periods, the fast evolution of smoke in the first few hours after emission and will coordinate with the DC-8 to study the chemical evolution on day to multi-day timescales. In addition, the Twin Otter will study the evolution of fire plumes at night.
- A second **NOAA Twin Otter (FIREX-MET)** to characterize the horizontal and vertical wind fields and turbulence intensities of wildfires. Flights will be planned to characterize the wind fields upwind, in the near-field (immediately downwind), and in the far-field to investigate all aspects of plume transport and fire weather phenomena. Remote sensing instrumentation (Doppler lidar) and trace gas and particle instrumentation will be deployed to fully investigate fire plume horizontal and vertical transport.
- The fuel consumption of fires investigated during FIREX-AQ will be studied during the Joint Fire Science Program **Western Wildfire Campaign.**
- Aerodyne will deploy their **Mobile Laboratory** to provide medium-scale surveys of fire impacts and exposure at night.
- NOAA CSD, the University of Colorado, and BlackSwift Technologies will deploy an instrumented UAV as part of the **NightFOX** project to characterize nighttime combustion efficiency, smoke, fire perimeter, and fire radiative power at high spatial resolution. This effort will potentially be coordinated with the Aerodyne Mobile Laboratory. The remote sensing data, along with measured meteorological parameters, will be used to inform, test, and improve fire weather modeling.
- Rapidly **deployable ground and mobile site** to include local scale chemical and physical measurements for near-source ground observations extending the aircraft domain and instrument suite, especially at night.

  - Brown University and University of New Hampshire plan to track wildfire derived nitrogen oxides and their influence on the oxidative formation of nitrate (particulate NO_3^-, gaseous nitric acid (HNO_3), and nitrous acid (HONO), using the concentration and isotopic composition of NO_x, and HONO using the NOAA CSD **mobile laboratory**.

  - In the fire seasons of 2018 and 2019, Aerodyne Inc. will deploy the **Aerodyne Mobile Laboratory** to sample BB plumes both during the day and night to investigate gas- and particle transformations and characterize the radical chemistry, chemical evolution and spatial extent of nocturnal biomass burning plumes, source specific gas- and particle-phase chemical markers, and initial and evolving properties of BC and BrC particles.

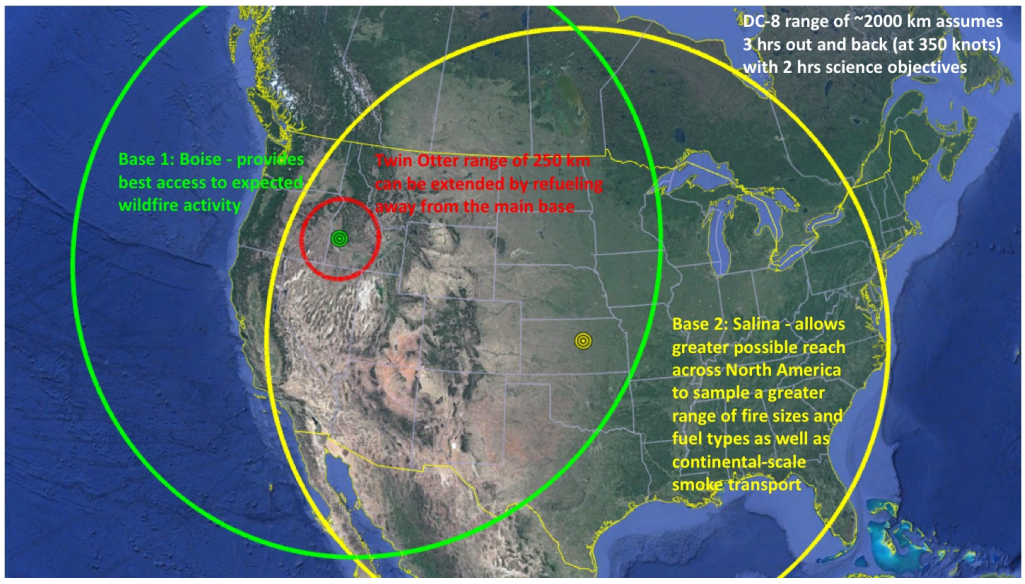
  - The University of Montana plans to deploy in the University of Wyoming mobile lab (UWML) from a base in Boise ID in 2018 and 2019 to sample near-ground wildfire smoke, especially at night and early morning to investigate enhanced smoldering combustion at night

that might be an important source of BrC emissions that are larger than expected based on daytime sampling.
- Additional **AERONET** monitors at the ground sites.
- **Satellite observations** of fire and plume locations and intensities, optical properties, and chemical constituents (e.g., GOES, MODIS, MISR, VIIRS, TROPOMI, etc.)
- **Modeling support** will be provided by several groups using an array of models, e.g., NOAA GSD HRRR smoke products, GEOS-5, WRF-CMAQ, CAM-chem, Flexpart, etc. to include assimilation models incorporating satellite observations of smoke and trace gases.
- Data on emissions and aging of laboratory fires that were studied during the NOAA **FIREX Fire Lab Experiment** in Missoula, Montana.
- Lesson learned from the NCAR/NSF deployment of the C-130 aircraft to Boise, ID during **WE-CAN** 2018 (NSF's Western wildfire Experiment for Cloud chemistry, Aerosol absorption and Nitrogen) will be used to inform FIREX-AQ strategy.

4.2 DC-8 Observations for FIREX-AQ in 2019

To meet the main FIREX-AQ science goals during the intensive field study in 2019, the DC-8 flying laboratory will be deployed to **Boise, ID and Salina, KS from around July 24 to September 15, 2019**. Boise, ID will provide superb access to the wildfires in the Northwest US via short transit flights (Figure 3) and the flight time used for science in and around the fires will be optimized. The most common transport pathways for the fire plumes from this area are across the continental US or South over the Pacific Ocean (Figure 3). From Boise, ID the plumes can be followed as far as the East coast or to southern California in a single flight (Figure 3). Flights from Salina, KS will allow more effective access to all parts of North America regardless of where small fires are active. From Salina, the DC-8 can still reach fires in the Northwest US and into southern Canada, if a large-scale fire event occurs (Figure 3).

The wildfire season in the Northwest typically peaks in August and September as shown in Figure 3 for 2017. Even during those two months, prescribed and agricultural fires are active across most of the continent with a high concentration of burning in the Southeast US. Figure 3b shows that it is highly likely that the DC-8 will have several fires to sample at any given time during the intensive field study in 2019.



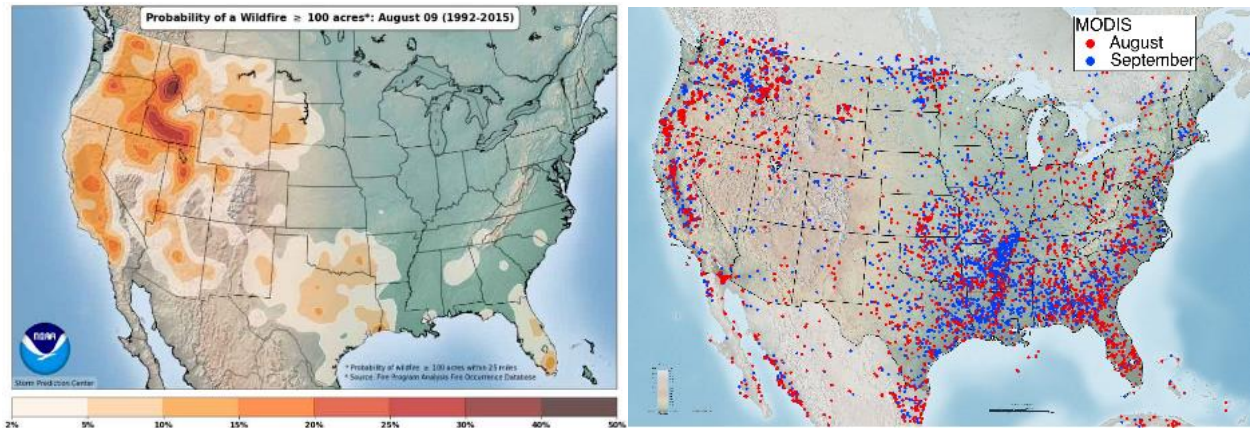


Figure 3: Top) The range of the DC-8 and Twin Otter aircraft. Bottom) Wildfire probability for August 09 (http://www.spc.noaa.gov/new/FWclimo/climo.php?parm=100ac) and MODIS/VIIRS fire counts in Aug and Sep 2017.

The planned **DC-8 instrument payload** for FIREX-AQ (Figure 4) is specifically tailored to the FIREX-AQ science questions and will provide the most detailed characterization of fire plumes from any aircraft platform to date. The DC-8 will have gas- and aerosol-phase measurements as well as remote sensing capabilities. Many of the in-situ measurements will have improved time resolution; up to 10 Hz for some instruments. When sampling small fires, plume penetrations as short as 5 seconds are expected [*Liu et al.*, 2016] and the value of sampling with a sub-second time resolution has been demonstrated by Müller et al. [2016].

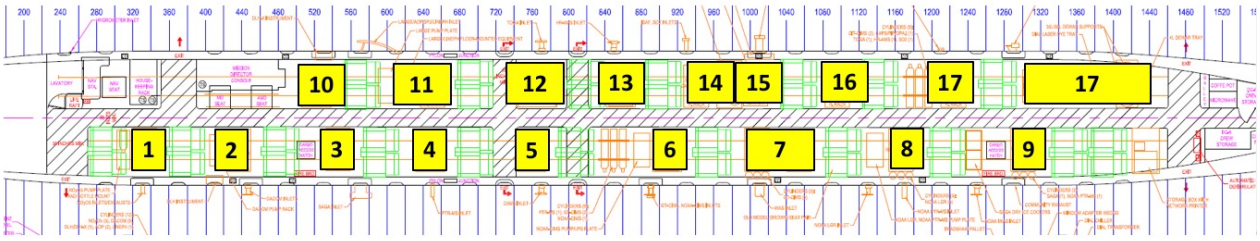


Figure 4: The potential payload of the DC-8 for FIREX-AQ.

Position	PI-Name	Institution	Species Measured	Technique
Gas phase measurements (Tracers and Reactive Nitrogen)				
1	Tom Ryerson	NOAA ESRL	O_3, NO, NO_2, NO_y	Chemiluminescence
2	Glenn Diskin	NASA LaRC	CO_2, CO, CH_4, H_2O	Laser Absorption Spectroscopy
4	Armin Wisthaler	U Oslo	NH_3	PTR-ToF-MS
6	Greg Huey	Georgia Tech	PAN, PPN, other PANs	CIMS
6	Patrick Veres	NOAA ESRL	HNO_3, HONO, HO_2NO_2, HNCO	Iodide ToF-CIMS
8	Carsten Warneke	NOAA ESRL	CH_3CN	H3O+ ToF-CIMS
8	Jeff Peischl	NOAA ESRL	CO	Cavity Enhanced Absorption
14	Andrew Rollins	NOAA ESRL	SO_2	Laser Induced Fluorescence
15	Paul Wennberg	CalTech	SO_2, HCN	CIMS

Gas phase measurements (Hydrocarbons and Oxidation Products)				
16	Mark Zondlo	Princeton	NH_3	Laser Absorption Spectroscopy
5	Dirk Richter	CU Boulder	CH_2O, CH_3OH, C_2H_4, C2H6	Laser Absorption Spectroscopy
7	Don Blake	UC Irvine	C_2-C_{10} Alkanes, C_2-C_4 Alkenes, C_6-C_9 Aromatics, C_1-C_5 Alkylnitrates, etc.	Whole Air Sampling
8	Carsten Warneke	NOAA ESRL	Speciated hydrocarbons and OVOCs	H3O+ ToF-CIMS
9	Jessica Gilman	NOAA ESRL	C_2-C_{10} Alkanes, C_2-C_4 Alkenes, C_6-C_9 Aromatics, C_1-C_5 Alkylnitrates, etc.	Whole Air Sampling
12	Eric Apel	NCAR ACOM	C_3-C_{10} hydrocarbons, C_1-C_7 OVOCs, HCN, CH_3CN, C_1-C_2 halocarbons, etc.	HR-ToF-GC/MS
14	Tom Hanisco	NASA GSFC	CH_2O	Laser Induced Fluorescence
15	Paul Wennberg	CalTech	H_2O_2, organic peroxides, organic acids, isoprene oxidations products, etc.	CIMS
Aerosol measurements (physical/optical/chemical)				
3	Dibb, Weber	UNH, GT, NOAA ESRL	BrC, bulk aerosol composition, HNO_3	Filter sampling, spectro-photometer, and mist chamber
10	Chuck Brock	NOAA ESRL	Aerosol absorption and extinction at multiple wavelengths and RH	Cavity ringdown extinction and photoacoustic absorption spectrometers
10	Dan Murphy	NOAA ESRL	Aerosol scattering phase function at UV and visible (blue) wavelengths	Laser Imaging Nephelometer
11	Bruce Anderson	NASA LaRC	Aerosol number, volatility, size dist., and optical/physical properties, CCN	Particle counters, nephelometers, etc.
12	Joshua Schwarz	NOAA ESRL	BC concentration, size, mixing state	Humidified-Dual SP2
13	Jose Jimenez	CU Boulder	Submicron aerosol composition	HR-ToF-AMS
14	Bernadett Weinzierl	U Vienna	Cloud and coarse mode size distribution	Optical wing probe detectors
Remote sensing measurements (active and passive)				
1/8	Sam Hall	NCAR ACOM	Zenith/nadir solar actinic flux and photolysis frequencies	4π-sr spectroradiometry
16	Jeff Myers	NASA ARC	Active fires (T ≤ 850 K) and burn scars at 10-20 m resolution	MODIS/ASTER Airborne Simulator (MASTER) scanning spectrometer
17	John Hair	NASA LaRC	Active remote sensing in the zenith and nadir directions for O3, aerosol backscatter, extinction, depolarizations,	Differential Absorption Lidar - High Spectral Resolution Lidar (DIAL-HSRL)
FIREX-AQ forecasting and modeling teams				
N/A	Bob Yokelson	U Montana	Forecast advice and decisions for optimized fire sampling	
N/A	Amber Soja	NASA LaRC/NIA	Forecast advice and real-time information on active and potential fires	

N/A	Dave Peterson and Ed Hyer	NRL	Forecasting meteorology, fire weather, plume rise, smoke transport, pyroCb, etc. using models and satellite observations
N/A	Pablo Saide	UCLA	Coordination of forecasting and ensemble predictions for flight planning
N/A	Brad Pierce	NOAA NESDIS	Forecast support using the RAQMS model
N/A	Ravan Ahmadov	NOAA HRRR	Forecast support using the HRRR-Smoke model
N/A	Arlindo DaSilva	NASA GSFC	Forecast support using the GEOS-5/GEOS-5-chem models
N/A	Louisa Emmons	NCAR ACOM	Forecast support using the CAM-Chem model
N/A	Greg Carmichael	U Iowa	Forecast support using the WRF-Chem model
N/A	Chris Holmes	FSU	Forecast support using HYSPLIT, bias-corrected fire detections, prescribed fires
N/A	Matt Alvarado, Daniel Tong, Jeff Pierce	AER, NOAA, CSU	Modeling of reactive nitrogen and smoke evolution (composition and size distribution) in fire plumes
N/A	Shantanu Jathar	CSU	Modeling the evolution of primary and secondary organic aerosol in smoke
N/A	Christine Wiedinmyer Kelley Barsanti Ann Marie Carlton	NOAA CIRES UC Riverside UC Irvine	Integration of Detailed Chemical Measurements and Predictive Biomass Burning Models

Table 1: The potential payload of the DC-8 for FIREX-AQ and the modeling/forecasting teams.

Separate **sampling protocols** are needed for small and large fires. The protocols discussed below build upon experience gained during SEAC⁴RS while sampling both crop fires in the Mississippi River Valley and large-scale wildfire plumes such as that from the California Rim Fire [*Forrister et al*., 2015; *Müller et al*., 2016].

Sampling of large fire plumes will largely be able to rely on pre-planned flight paths, coordinated with fire-fighting efforts, due to the size of these fires and their persistence over multiple days. In practice, flight scientists will need to make in-flight adjustments based on actual conditions, location of the plume, and opportunities for science. Large fire sampling will often include the use of satellite data and model forecasts and also multiple other platforms (e.g.: Twin Otter aircraft and mobile laboratory) and will require intensive coordination. A good rule of thumb for conditions warranting coordinated sampling is the presence of a smoke plume extending a few hundred kilometers or more. Interactions will include overflights of partner aircraft to link remote sensing with in situ observations and sampling of the smoke plume in a semi-Lagrangian fashion by the DC-8 and the Twin Otter. The DC-8 will also work independently to make measurements from the point of emission to locations far downstream of the fire. Priorities will be given to fires for which emissions are expected to impact areas with a high population, to large fires with smoke plumes stretching over long distances that persist for days to weeks, and to plumes for which satellite information enables effective tracking. Consideration will also be given to potential pyroconvective events

For *sampling small fires,* specific fire locations will typically not always be known, but the DC-8 will be directed to general areas where burning is expected. The goal is to observe many individual events with a combination of remote sensing and in situ sampling. Once fire activity is encountered, satellite active fire count products suggest that the distance between fires will be small enough to enable visual acquisition of other nearby fires. Thus, fire spotting will be an

important role for the flight scientist in directing the pilots to subsequent targets for sampling. As an example, the small fire will be overflown at two altitudes. The initial overflight would approach the fire from upwind and pass over it at the plume altitude to sample the smoke plume along the direction of the downwind transport. This would be followed by an overflight at a higher altitude measuring the plume with remote sensors. When sampling a region of small fires, it will also be desirable to fly transects upwind and downwind of the general area to assess the integrated and combined emissions.

4.3. NOAA Twin Otter Observations in Support of FIREX-AQ

To meet the FIREX-AQ science goals that are difficult to perform with the large DC-8 aircraft during the intensive field study in 2019, two NOAA Twin Otter aircraft will be requested to be deployed to **Boise, ID for four to six weeks** overlapping with the DC-8 in August of 2019.

The focus of the first Twin Otter deployment (**FIREX-CHEM**) will be large wildfires in the Western US and to investigate (1) the variability of the emissions by flying continuously close-in transects of the smoke plume, (2) detailed characterization of plume evolution during the first few hours of aging, and (3) the nighttime chemical transformation of smoke. Due to the short range and endurance of the Twin Otter, fires in close vicinity of Boise, ID will get priority, but multiple flights can occur during a single day, with intermediate stops for re-fueling, to investigate the diurnal changes in emissions of a single fire or to reach fires that are further away but are of high priority to the DC-8 sampling strategy.

The planned **Twin Otter payload** for FIREX-AQ (Figure 5) is designed to investigate the nighttime chemical transformation of fire plumes and is capable of monitoring the diurnal variation of the emissions from individual fire plumes.

The Twin Otter **sampling strategy** will involve daytime and nighttime flights, and multiple flights in a day over the viable range of this aircraft to sample emissions, short-range photochemistry, nighttime chemistry and variation in fire intensities over shorter time scales. The Twin Otter range of sampling is anticipated to be on the order of 100 – 200 km downwind of a fire source, corresponding to 3-10 hours of transport time for a range of wind speeds.

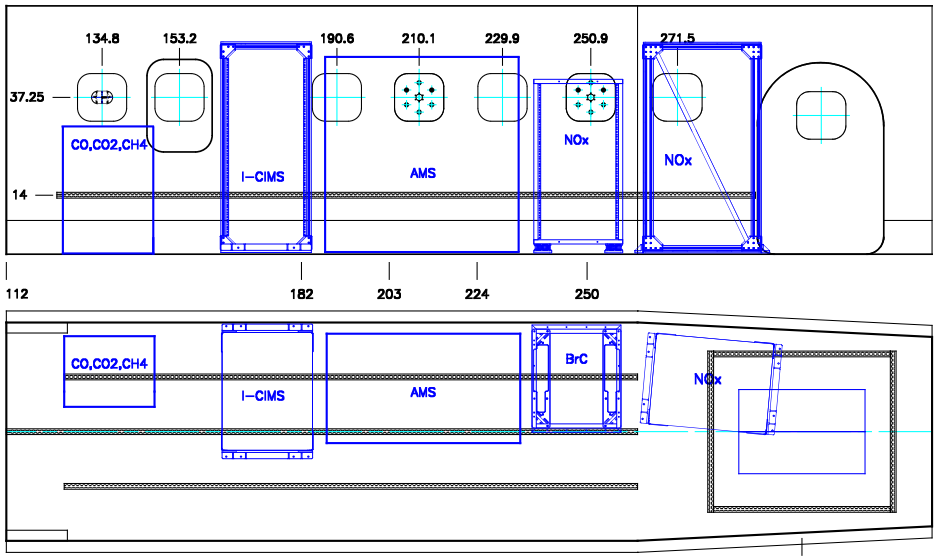


Figure 5: The potential payload for the NOAA Twin Otter for FIREX-CHEM: (1) CO, CO_2, CH_4, (2) O_3, NO, NO_2; (3) I-CIMS; (4) HR-AMS; (5) BrC-PILS.

Position	PI-Name	Institution	Species Measured	Technique
1	Steve Brown	NOAA ESRL	CO_2, CO, CH_4, H_2O	Laser Absorption Spectroscopy
2	Joel Thornton	U. Washington	HNO_3, HONO, HO_2NO_2, HNCO, SVOCs	Iodide ToF-CIMS
3	Ann Middlebrook Shao-Meng Li	NOAA ESRL Env. Canada	Submicron aerosol composition	HR-ToF-AMS
4	Andrew Weinheimer	NCAR	O_3, NO, NO_2, NO_y	Chemiluminescence
5	Rebecca Washenfelder	NOAA ESRL	water soluble Brown carbon aerosol absorption	BrC-PILS

The focus of the second Twin Otter deployment (**FIREX-MET**) will be to measure horizontal and vertical winds and aerosol spatial distribution to characterize the wind field feeding the fire, the dynamics associated with plume rise, and the transport and geometry of the downwind plume. This will be accomplished using remote sensing instrumentation (a scanning Doppler lidar, optical imager, and infrared radiometer) and a meteorological package to profile thermodynamic variables when the aircraft is changing altitudes and measure conditions at flight altitude (Figure 6).

The payload for this platform is purposely being kept light in order to maximize the endurance of the aircraft. The aircraft will fly above the plume when possible in order to provide complete vertical coverage of dynamics and aerosol concentration throughout the plume. When studying the inflow characteristics of the active fire, finer horizontal resolution requirements may dictate that the aircraft fly at lower altitudes.

With its lighter payload, the **FIREX-MET** Twin Otter will be able to remain aloft up to 5 hours. Figure 7 shows an example 5-hour flight plan for a fictional fire that is located just west of Boise, ID and being driven by a westerly wind. The plan includes a box pattern around the active fire at two altitudes to characterize inflow, closely spaced transects across the plume in a region just downwind of the fire to characterize plume rise and less densely spaced transects across the plume further downwind to characterize its horizontal and vertical extent and the amount of transport. The size of the pattern will be driven by the spatial extent of the fire and plume, the average wind speed, and the exclusion zone set by aerial firefighting activities.

The **FIREX-CHEM** and **FIREX-MET** Twin Otters will coordinate flight plans when possible so that plume geometry and trajectories determined from the **MET** Twin Otter will be used to optimize the **CHEM** Twin Otter flight plan. With prior knowledge of plume height and location, the **CHEM** Twin Otter will sample the plume at a single altitude and be able to perform more transects.

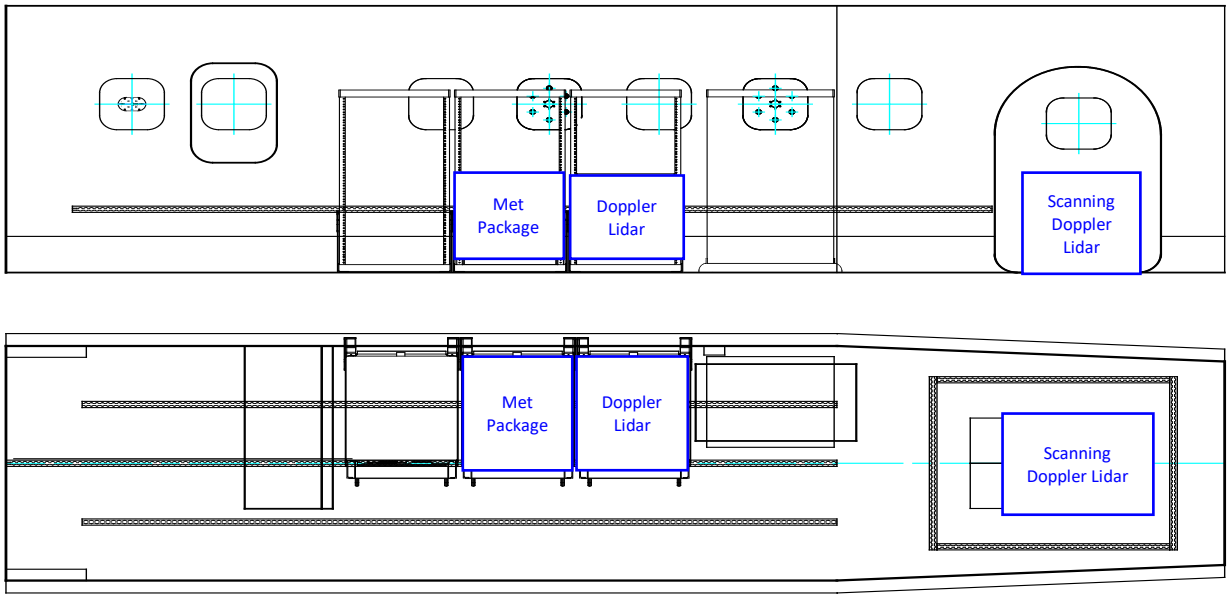


Figure 6: The potential payload for the NOAA Twin Otter for FIREX-MET: (1) Met Package, (2) Doppler Lidar, and (3) Scanning Doppler Lidar.

Position	PI-Name	Institution	Species Measured	Technique
1	Alan Brewer Paul Schroeder	NOAA ESRL	Wind fields and relative aerosol loading	Scanning Micropulse Doppler Lidar
2	Alan Brewer	NOAA ESRL	T, RH	Met package

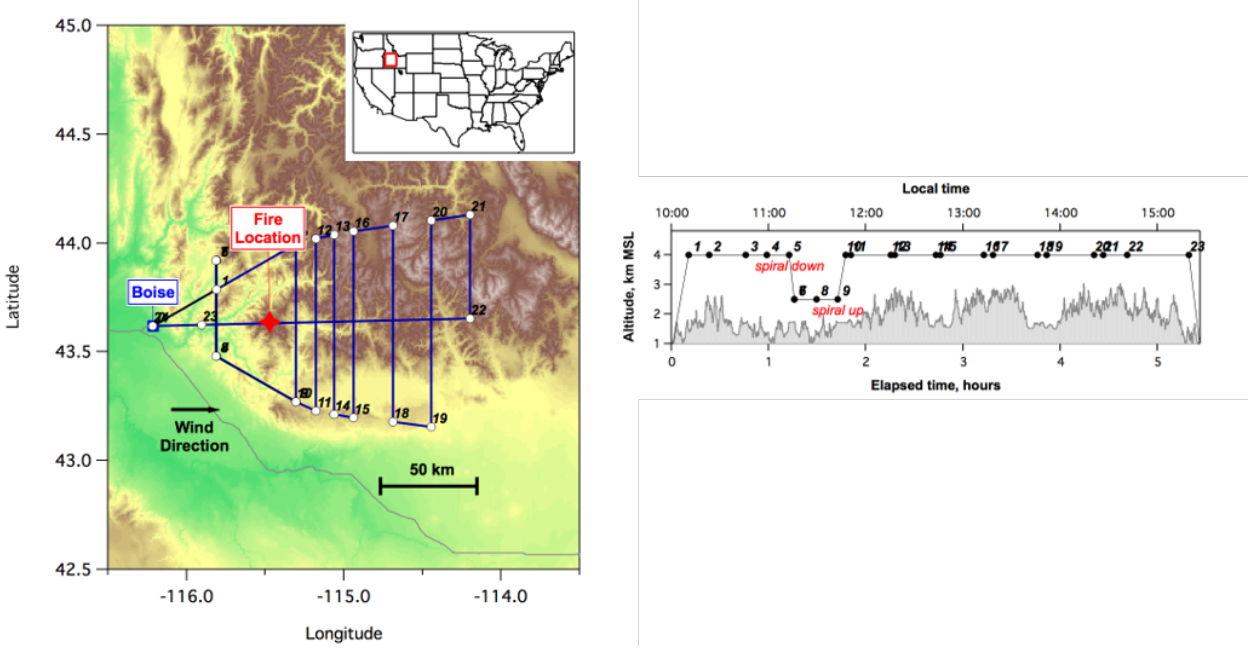


Figure 7: Example flight plan and height profile for FIREX-MET or FIREX-CHEM Twin Otters.

4.4 Major Activities Relevant to FIREX-AQ

The **Joint Fire Science Program's Fire Western Wildfire Campaign** will provide maps and metadata for the source characterization of wildfire events by mid-May 2018, in time for the 2018 wildfire season, and can therefore be used to assist FIREX-AQ and WE-CAN with site selection. The Joint Fire Science Program funded a related task to compile existing field and remotely sensed datasets of pre-fire LiDAR and field measures of fuels as the "Western Wildfire Campaign fuel data maps." Due to the inherent uncertainty in fuels mapping and informing consumption modeling from fire progression and burn severity maps, source characterization might be much improved with ground-based field sampling and verification in 2019. In this approach, the Western Wildfire Campaign would supplement the available maps with field data collected at fire sites measured by FIREX-AQ during the following spring and summer field season.

The possibility exists that the Fire and Smoke Model Evaluation Experiment (FASMEE) could offer the opportunity to sample one or more large prescribed fires planned and executed by JFSP partners. This objective will take priority when and if burns are announced. Planned and controlled burns are of special interest, because maximum information will be available on the variables affecting fire behavior, development, dynamics, and emissions. Along with the information gathered before, during, and after the fire, airborne observations gathered during FASMEE provide the best chance for bridging laboratory and ambient fires. Fuels from potential FASMEE burn sites were burned during the pre-campaign Fire Lab experiment at Missoula in 2016.

In preparation for FIREX-AQ, in 2016 emissions and aging of laboratory fires were studied during the NOAA **FIREX Fire Lab Experiment** in Missoula, Montana. A very comprehensive set of emission factors for various fire conditions, such as high and low temperature combustion, were measured and are available for trace gases and aerosol from fuels typical in the Western and Southeastern US. The Fire Lab Experiment also provided a better understanding of the mechanisms of trace gas emissions for different fire conditions. In addition, a large number of photochemical products of smoke aging were determined and used to update chemical mechanisms in various models.

The **Western wildfire Experiment for Cloud chemistry, Aerosol absorption and Nitrogen (WE-CAN)** will systematically characterize the emissions and first day of evolution of western US wildfire plumes. WE-CAN will focus on three sets of scientific questions related to fixed nitrogen, absorbing aerosols, cloud activation and chemistry in wildfire plumes. The data will be collected from the NCAR/NSF C-130 research aircraft stationed in Boise, ID in summer of 2018. The main focus will be on the first day of processing, which is a major driver of the eventual air quality and climate significance of wildfire smoke because the chemistry and micro-physics occurring during this time impacts the partitioning of reactive nitrogen, alters cloud chemistry and nucleation, and determines aerosol scattering and absorption. The results from WE-CAN will be used to improve the FIREX-AQ strategy.

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