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Lidar Instrumentation for the California Fire Dynamics Study

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Abstract

The California Fire Dynamics Study (CalFiDE) is a collaborative effort between the Chemical Sciences Laboratory (CSL) at National Oceanic and Atmospheric Administration (NOAA), Wildfire Interdisciplinary Research Center (WIRC) at San Jose State University (SJSU) and the University of Nevada Reno (UNR), to investigate wildfire dynamics in Northern California in late Summer and Fall 2022. Further information on the instrumentation and scope of this study can be found in the Valero et al. short paper. During CalFiDE, the contributing organizations plan to deploy four Doppler lidar systems in addition to infrared imaging and chemical measurements to quantify the fire dynamics and atmospheric coupling of large scale wildfires. These systems will be installed on a range of mobile platforms including; a Twin Otter aircraft, pickup trucks, and trailers. The mobile ground based installations allow researchers to rapidly deploy the systems to areas of interest during the study, while the aircraft installation will cover a larger range of spatial scales. Systems will operate in scanning modes to quantify 3D winds, vertical stares to resolve fine scale vertical velocities, and coordinated scans where the measurement volumes of nearby systems are overlapped to provide high resolution measurements of 3D winds. The coordinated scanning technique will be used to target fine scale features within fire plumes such as helical updrafts, counter-rotating vortices, and inflow/outflow dynamics. Collectively these lidar observations will provide validation data sets for simulated fire-generated winds.

1. Introduction

Doppler lidar is a proven technology to study atmospheric dynamics and recently has expanded its scope to measurements of wildfire dynamics (Charland et al. 2013, Lareau et al. 2017). These systems can provide measurements of 3D wind fields, boundary layer dynamics, and aerosol backscatter intensity allowing for characterization and ultimately a better understanding of the dynamics which govern wildfire behavior. Coupling Doppler lidars with mobile platforms enables measurements of both the spatial and temporal evolution of wildfires. Additionally, these mobile installations enable fast deployment of the lidar systems for time sensitive and dynamic deployments such as wildfires. Here we present the Doppler lidar instrumentation which will be deployed for the California Fire Dynamics Study (CalFiDE) in Northern California in August-September 2022. A total of four Doppler lidar systems will be deployed for this experiment consisting of; one aircraft based Doppler lidar, one ground based mobile Doppler lidar, and two ground based stationary Doppler lidars. The aircraft based measurement will primarily focus on profiling incoming winds and measuring plume structure. The ground based mobile system will perform continuous measurements while driving the periphery of the fire. The two ground based stationary systems will be located at the fire front to monitor fire generated winds.

Deploying multiple Doppler lidars within the same geographic region allows for more complete measurement coverage. Additionally, by overlapping measurement volumes from multiple Doppler systems, measurement resolution of 3D winds can be drastically improved (Newman et al. 2016, Choukulkar et al. 2017). This technique will allow for targeted measurements of smaller scale features such as entrainment/lateral mixing of core updrafts over wildfire fire plumes, and will help address the horizontal and vertical structure of the dynamics governing transport.

2. Aircraft Based System

2.1. Installation on the Twin Otter

Dynamics of the plume and wind fields surrounding the fires will be measured using a Doppler lidar installed on board the NOAA Twin Otter aircraft. The Doppler lidar is a microjoule-class pulsed Doppler lidar designed by the NOAA Chemical Sciences Laboratory (Schroeder et al. 2020). The lidar will provide measurements of turbulence intensity and 3-D winds around the fire as well as aerosol intensity backscatter distributions as seen in Figure 1b. The system has a maximum range of 7.2 km with a resolution of 60m. The lidar is paired with a partial hemispheric scanner which will extend out the port-aft window of the aircraft (Figure 1a) allowing for measurements below the aircraft as well as above the aircraft, which will be used when flying at low altitudes for in-situ sampling. The scanner can be operated in a scanning mode for measurements of 3-D wind fields around the fire. An inertial navigation system feeds back to the scanner for real-time stabilization of aircraft motion during the flight. This stabilization enables vertical stares and target tracking.

Ultimately these scanning data will provide the upstream wind profile impacting the plume development and thus important context for other plume rise observations. The motion compensated stares and target tracking will provide data on fine scale structures occurring within the plume and the surrounding flows.

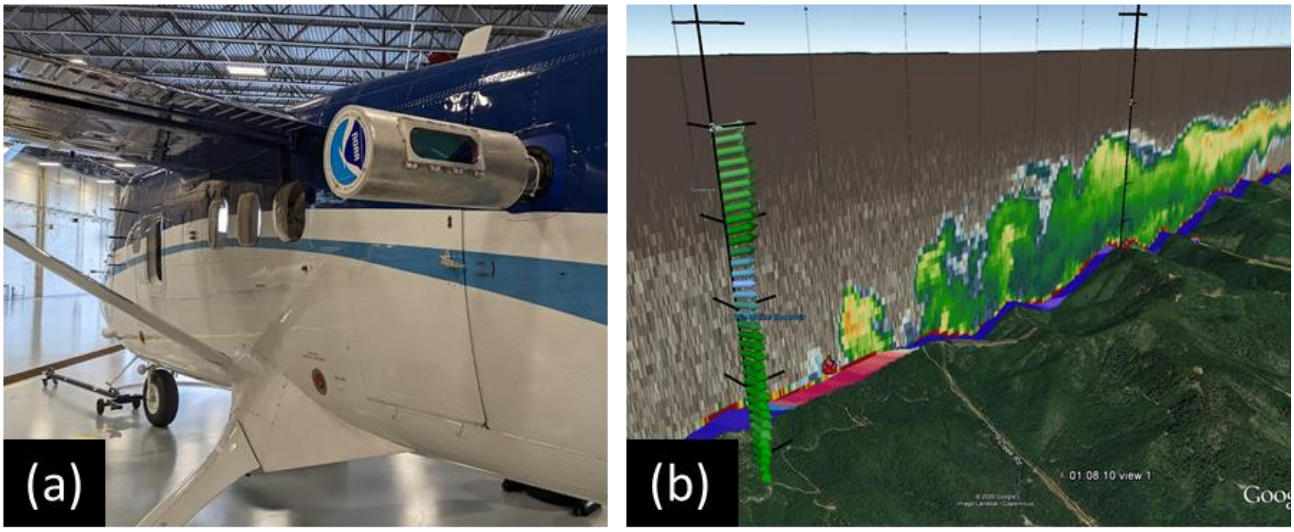

Figure 1- a) Doppler lidar scanner installed on the NOAA Twin Otter. b) Data from a wildland fire during a 2019 measurement campaign. The red area at the surface indicates the fire area. Arrows on the left axis indicate wind speed and direction. Coloration indicates aerosol backscatter intensity.

3. Ground Based Systems

In addition to the aircraft based Doppler lidar, there will be three ground based Doppler lidars deployed for the CalFiDE experiments. Fire-generated winds close to the fire front, including convergent and rotating inflow winds will be sampled by two Doppler lidar systems from UNR and SJSU. These data are critical for understanding the coupling of fire and atmospheric processes that can drive rapid fire spread and intensification.

A NOAA motion-stabilized truck-based lidar will measure convective boundary layer (CBL) depth, vertical velocity, and horizontal wind profiles proximal to the fire, but away from the fire front. The Doppler lidar installed in the NOAA F-250 pickup truck, known as the PickUp based Mobile Atmospheric Sounder (PUMAS), is shown in Figure 2. The Doppler lidar system itself has also been designed by the ARS group within NOAA CSL. The system has similar operating characteristics as the system installed on the Twin Otter, with an effective range of 7.2 km and 60m along path resolution. The unique characteristic of this system is it has two output beams. One beam is coupled with an optical wedge scanner for continuous scans for 3D wind fields. The second channel is directed vertically for continuous measurements of vertical velocities. The optical head of the lidar is housed in a motion stabilizing cradle which stabilizes the platform in both pitch and roll, enabling continuous measurements while the truck is underway.

Figure 2- Doppler lidar and scanner installed in the bed of an F-350 pickup truck.

4. 3-D Measurements of Wildfire Winds: Improved Scan Patterns and Multi-Lidar Systems

The NOAA airborne Doppler lidar system has previously flown on the Twin Otter for the 2019 FIREX-AQ campaign to study the impact of fires on air quality and climate. During this campaign, the system was outfitted with an optical wedge scanner which allowed for scans and motion compensated vertical stares below the aircraft, but did not allow for more complex scan geometries or upward looking measurements. The partial hemispheric scanner which will be deployed for CalFiDE was developed in response to this need for improved scanning strategies and coordinated scans between multiple lidar systems which was noted in the FIREX-AQ data.

The wildfires sampled from the Twin Otter during FIREX-AQ were done with a single Doppler lidar. While the vertical stare captured the spatial distribution of updrafts/downdrafts within a wildfire, the conical scan attempted to characterize the inflow/outflow structure near the fire front. Analysis of the data collected during FIREX-AQ revealed that features central to transport, such as rigorous updrafts centered over wildfire hotspots, offered an opportunity to study the structural variability of these updrafts and dynamics associated with lateral mixing during parcel ascent.

A key shortcoming of this dataset, however, was the lack of temporal information related to the evolution of the updraft as well as the rather narrow observation window associated with beam slice intersecting the updrafts/downdrafts along track. Measurements which were not completely centered on core updrafts/downdrafts made quantifying their role in transport challenging, and thus has led to the development of new and improved strategies that are planned for CalFiDE.

To address the temporal evolution of hotspots and the updrafts therein, an inverted triangle, either vertically pointing or off-angle, will be used to target specific core features over areas of high FRP as the Twin Otter flies within range of the fire front. The inverted triangle will have a denser cluster of points near the base of the updraft which will widen with height. Additionally, two ground-based mobile systems – one upwind and one downwind – will be used in conjunction with the inverted triangle scan to map out the 3-D structure in order to quantify the spatiotemporal characteristics and associated dynamics. Figure 3 shows a proposed configuration of the three Doppler lidar systems that would be coordinating in real-time, such that the beams from the respective Doppler lidar systems will intersect to construct the 3-D wind vector in a gridded format. The idea is not only to quantify the spatiotemporal characteristics over wildfires, but to determine the vortical structure associated with counter-rotating vortices at the flanks of updrafts, whether there is a helical component associated with certain core updraft features, and how the inflow/outflow dynamics assists in the spatial structure and temporal evolution of the most rigorous updrafts.

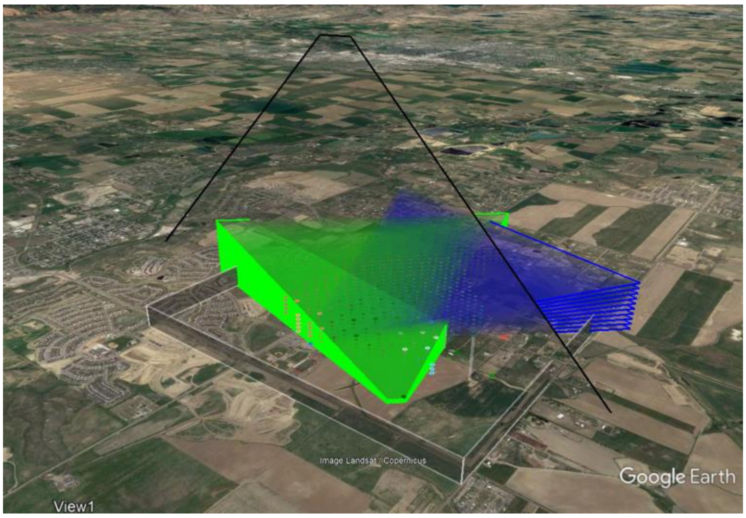

Figure 3- Demonstration of scan geometry for CalFiDE multi-Doppler coordinated scans.

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