Wildfire Observations by Airborne and Truck-based Mobile Doppler Lidars during the California Fire Dynamics Experiment (CalFiDE)

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Introduction

Wildfires and their threat to first responders, the general public, and ecology have increased over the last decade. This has led to an increased need for fire-related products and forecasts, with observations being essential as "ground truth" for development.

- New observations of fire behavior and coupled atmospheric dynamics such as fire-generated winds and plume rise processes (Fig. 1) are important to advancing model performance.
- 4-D profiling of wind fields is very challenging around active wildfires, especially in complex mountainous terrain where wildfires often occur.

CalFiDE was designed to target these challenges with state-of-the-art Doppler lidars on airborne and mobile ground-based platforms supported by additional remote sensing and in-situ instrumentation to couple atmospheric dynamics to fire behavior. CalFiDE spanned 26 Aug – 26 Sep 2022.

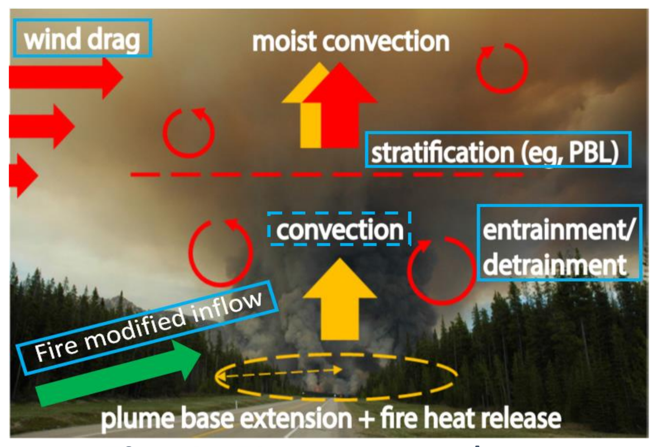
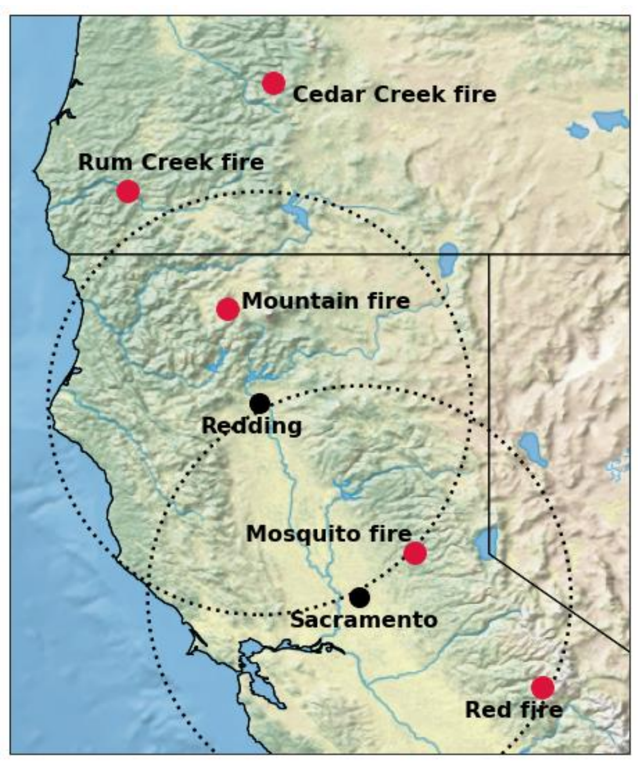
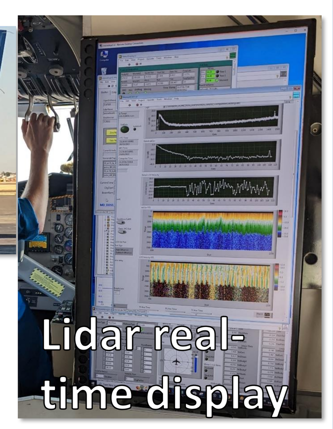


Fig. 1. Fire-atmosphere coupled processes.

Instrumentation and Sampling Strategies

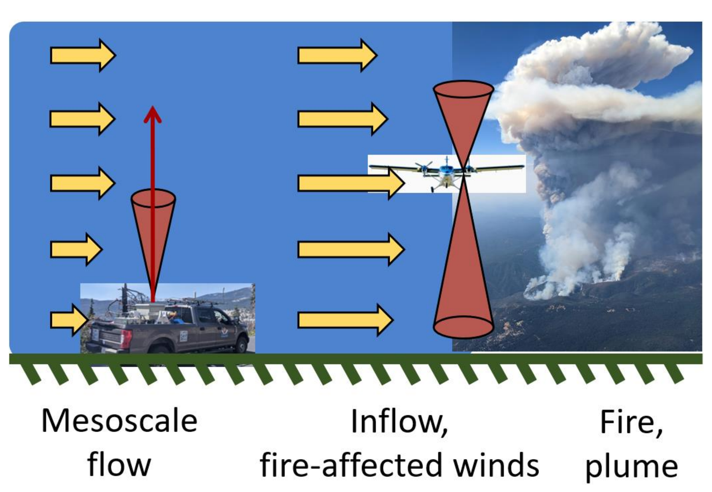
A NOAA Twin Otter aircraft and the unique Pick-Up Based Mobile Atmospheric Sounder (PUMAS) sampled the five fires shown in Fig. 2. Both hosted unique Doppler lidar systems designed from the ground up for mobile measurements. The Otter also carried an infrared camera for fire behavior and in situ chemistry instrumentation for emissions and air quality studies.





Partner platforms/instruments:
- MISR plume property retrievals [NASA]
- Mobile radar [SJSU] • Doppler lidar [UNR]

Fig. 2. Fires (red) and aircraft bases of operation (black).



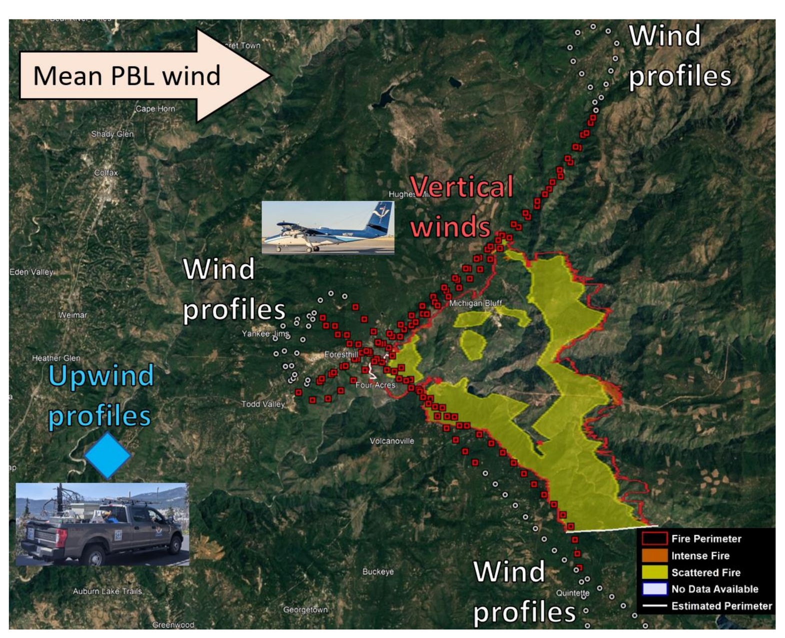


Fig. 3. Example sampling strategy for a large fire (could not fly over or through active pyroCb). Airborne lidar measured updraft structures directly over upwind edge burns, and contextual wind profiles.

- Lidars scan for horizontal winds, stare for vertical winds
- Airborne lidar looks up or down
- PUMAS lidar has two channels for continuous 3-D winds
- Vertical resolution ~60 m for both lidars; along-track resolution varied

Coupled Fire-Atmosphere Dynamics

These figures are from a single flight leg. We often sampled such legs repeatedly with 5 – 15 min period. From this rich dataset, coupled evolution of fire behavior, atmospheric dynamics, and chemistry will be studied.

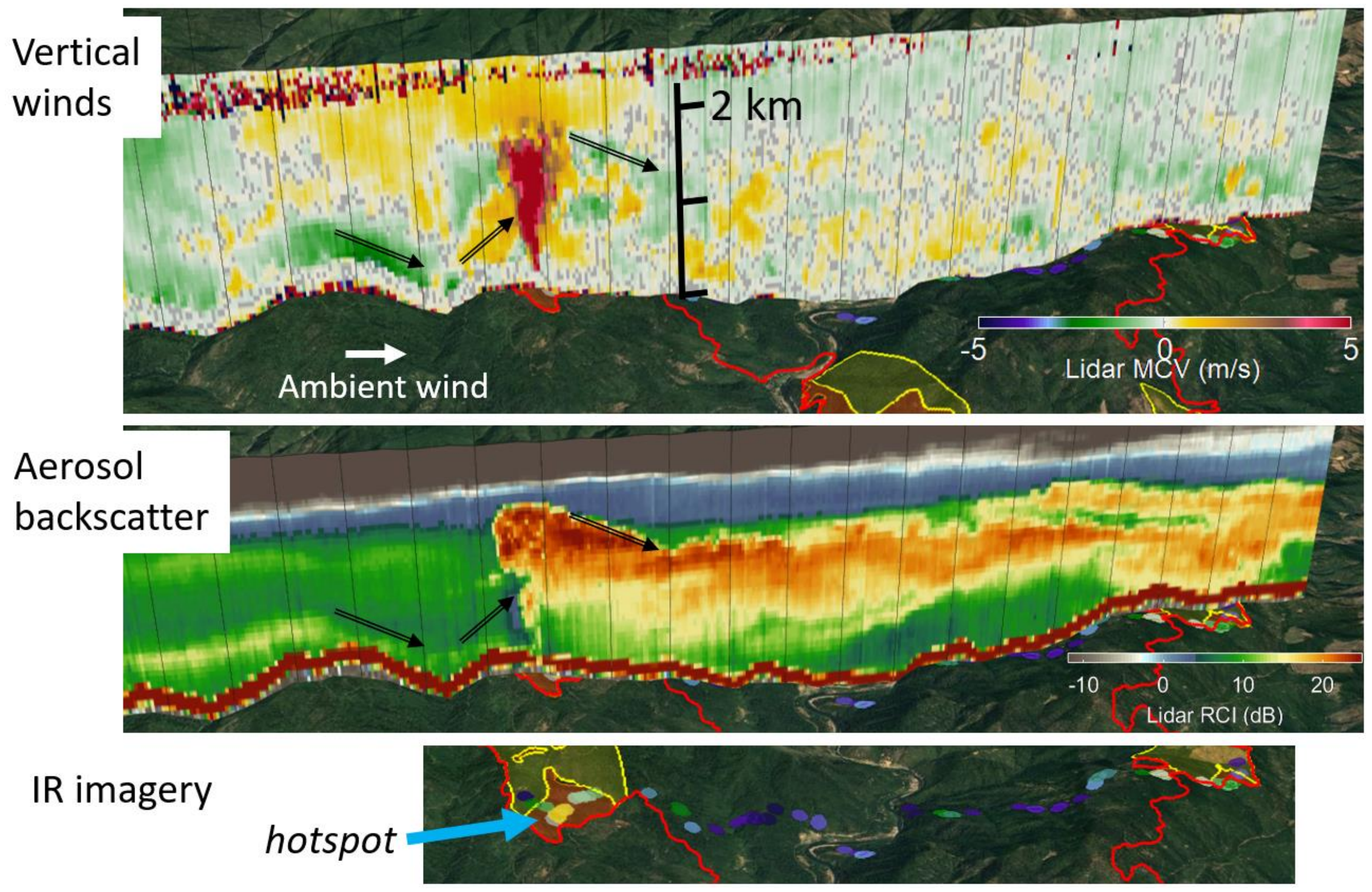


Fig. 4. Airborne lidar vertical velocity (top), normalized SNR as a proxy for aerosol backscatter / smoke plume location (middle), and IR camera data showing the temperature hotspot below the updraft plume jet (bottom).

- ~1500-m updraft core depth, with maximum speed ~12 m/s
- Downward motion at top of the updraft coincides with downward displacement of smoke
- Downslope flow evident on the upwind side of the updraft
- Complete geospatially resolved IR imagery is not yet available, but will provide a high-resolution quantitative depiction of the fire behavior.

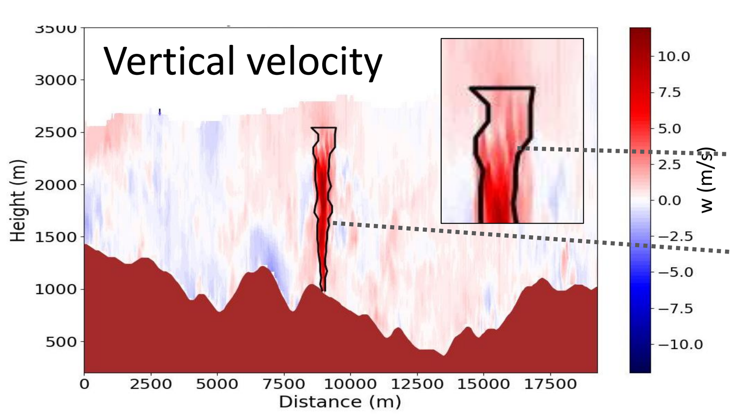


Fig. 5. Vertical velocity, same data as top panel of Figure 4. Black line shows updraft area identified by Gaussian fit.

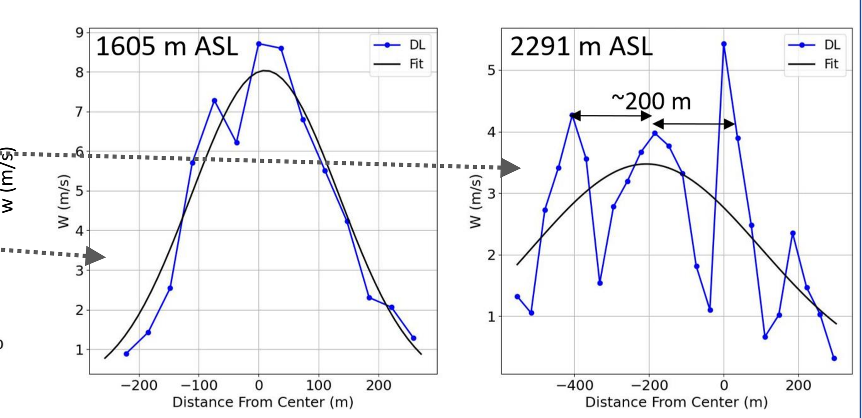
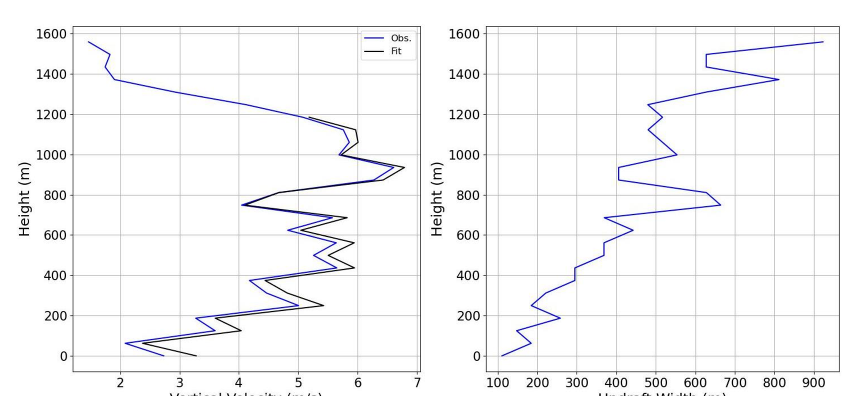


Fig. 6. Observed updraft cores tended to be Gaussian at all heights (left) until near plume-top where entrainment features are identifiable with distinct length and intensity structures (right).

Fig. 7. Velocity increases roughly linearly with height until reaching the capping inversion ~1200 m AGL (left). Updraft width also increases linearly (right).



Acknowledgements

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Smoke shading and other regional context

PUMAS typically sampled upwind or regional context, including valleys and other areas that are traditionally hard to sample well.

In this case, stagnant conditions persisted through midday with very poor air quality due to a thick smoke layer trapped near the surface. Air quality improved later in the afternoon, due in part to a sea breeze.

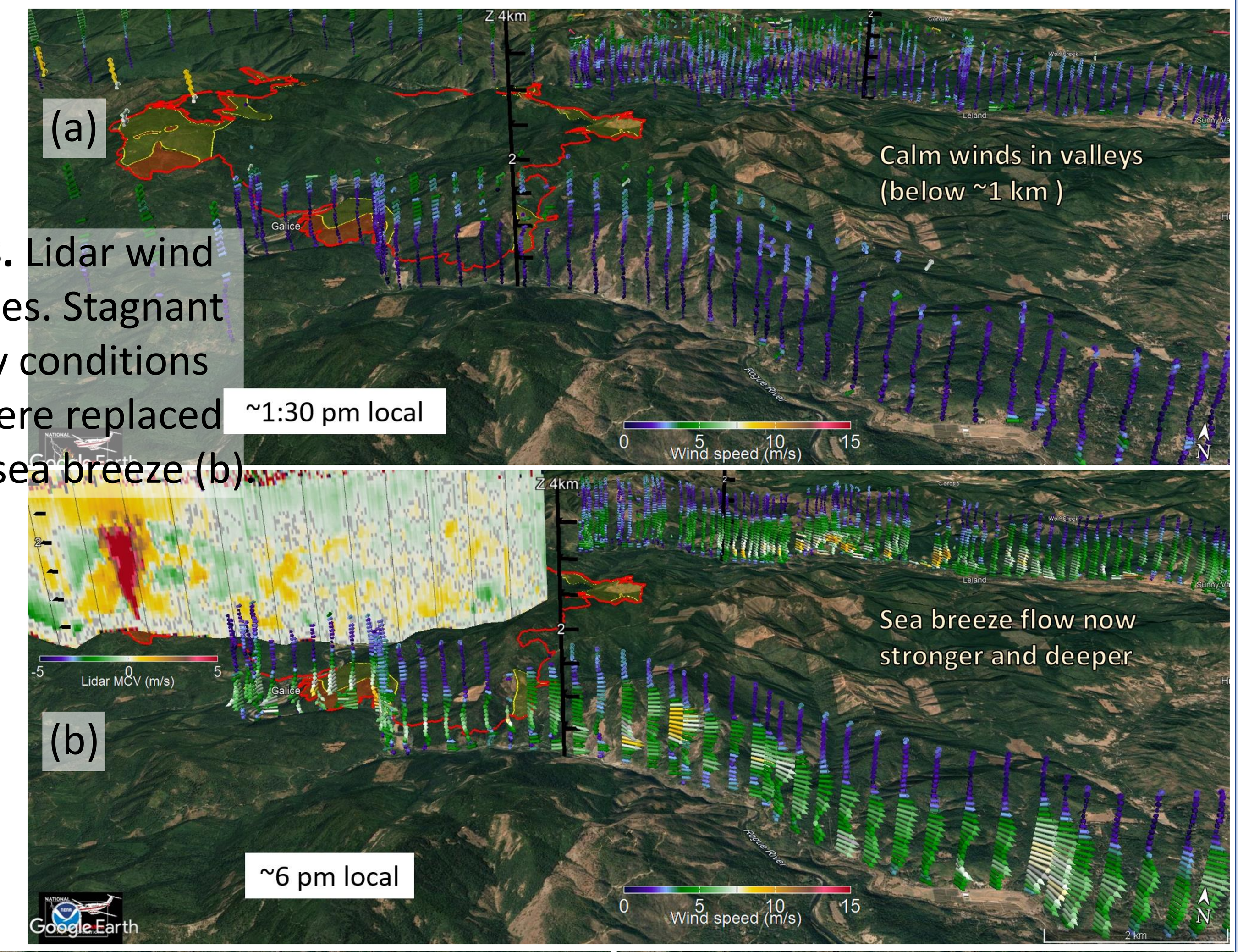


Fig. 8. Lidar wind profiles. Stagnant valley conditions (a) were replaced by a sea breeze (b).

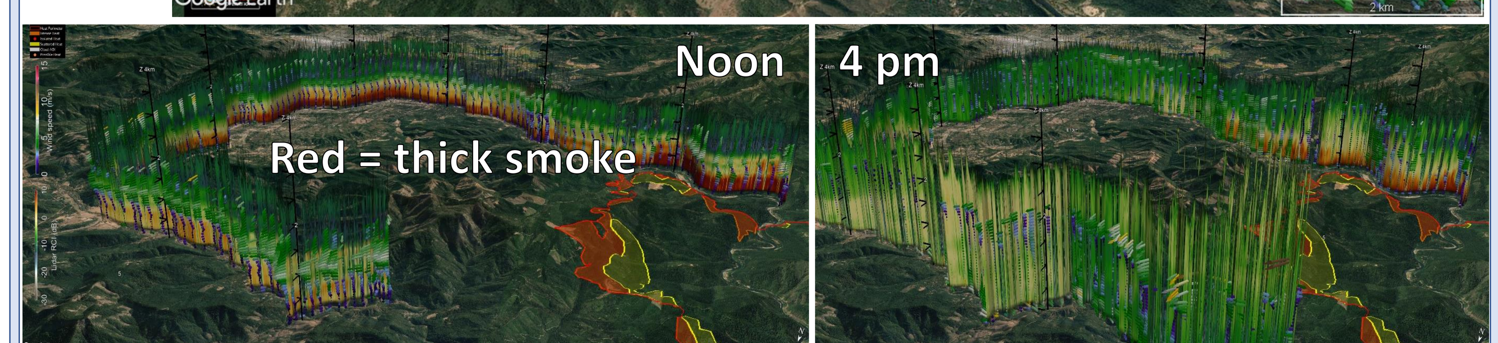


Fig. 9. Aerosol backscatter proxy showing a thick smoke layer in the lowest 500 m that is cleared out in the afternoon.

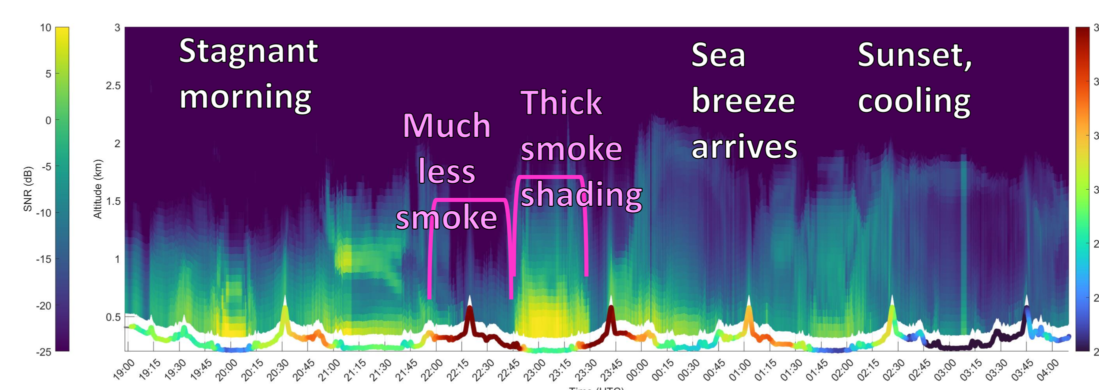
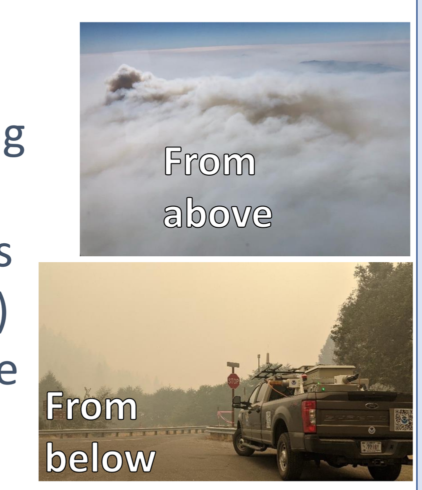


Fig. 10. Time-height curtain of aerosol backscatter proxy along with in situ temperature plotted at the surface.

Smoke shading prevents solar radiation from heating the surface, resulting in sharp gradients of surface temperature. This temperature difference also leads to sharp gradients in planetary boundary layer (PBL) mixing and depth, often including a persistent stable layer trapping the smoky layer near the surface.



Summary

Recently developed Doppler lidars designed from the ground up to make unprecedented mobile measurements are uniquely capable for sampling near active wildfires.

High-resolution atmospheric dynamics coupled to fire behavior and chemistry will improve our understanding of fire processes, and enable model evaluation and improvement of fire and air quality forecasting.