Fire-Atmosphere Dynamics and Chemistry Measured from Mobile Platforms: The California Fire Dynamics Experiment (CalFiDE)

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Introduction

Wildfire threats to the general public, first responders, and ecology are increasing. This drives a need for fire models and forecasts, with observations being essential for development and validation.

- 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.
- Plume properties and chemical evolution are important for air quality over short- and long-range transport.
- Intensive measurements at active wildfires are very challenging, especially in complex mountainous terrain.

CalFiDE targeted these challenges with diverse instrumentation on airborne and mobile ground-based platforms. Measurements spanned 26 Aug – 26 Sep 2022.

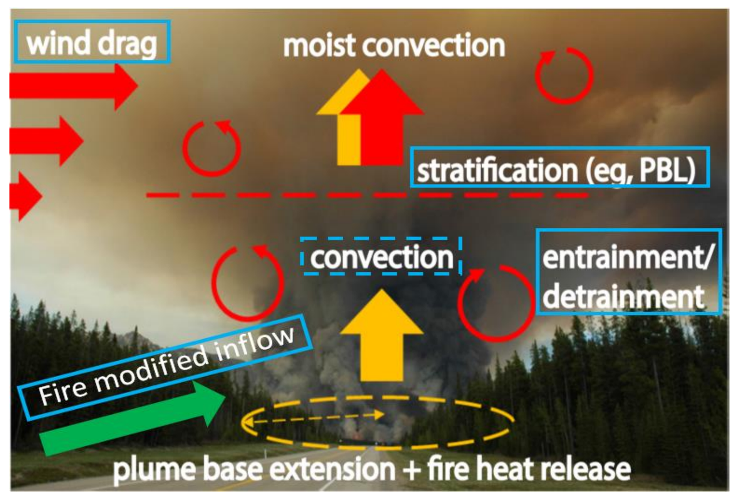

Fig. 1. Some fire-atmosphere coupled processes.

Instrumentation and Sampling Strategies

- Twin Otter aircraft
  - Doppler lidar - winds, smoke
  - Infrared imager - fire
  - In situ chemistry
- Pickup-Based Mobile Atmospheric Sounder (PUMAS)
  - Doppler lidar
- MISR and ground platforms from collaborators (only some days) for a more complete picture

CalFiDE sampled each fire on multiple consecutive days, capturing:

- Blow-up phase
- Smoldering phase
- Varying ambient conditions

Measurement priorities included:

- Repeat overpasses of fire hotspots
- Smoke plume transport, chemistry, and mixing
- Ambient and inflow winds

Fig. 2. Fires, Twin Otter bases (black) with 1-hour range rings, and platforms.

State-of-the-art Doppler lidars measure 3-D winds from moving platforms, and attenuated aerosol backscatter for smoke plume profiling. Resolution: ~60 m vertical; along-track <1 km.

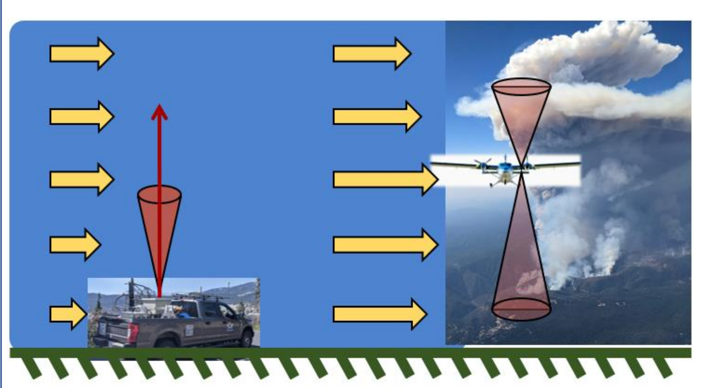

Fig. 3. Example sampling strategy for a large fire (could not fly over or through active pyroCb). Airborne instruments measured upwind edge fire and updraft structures.

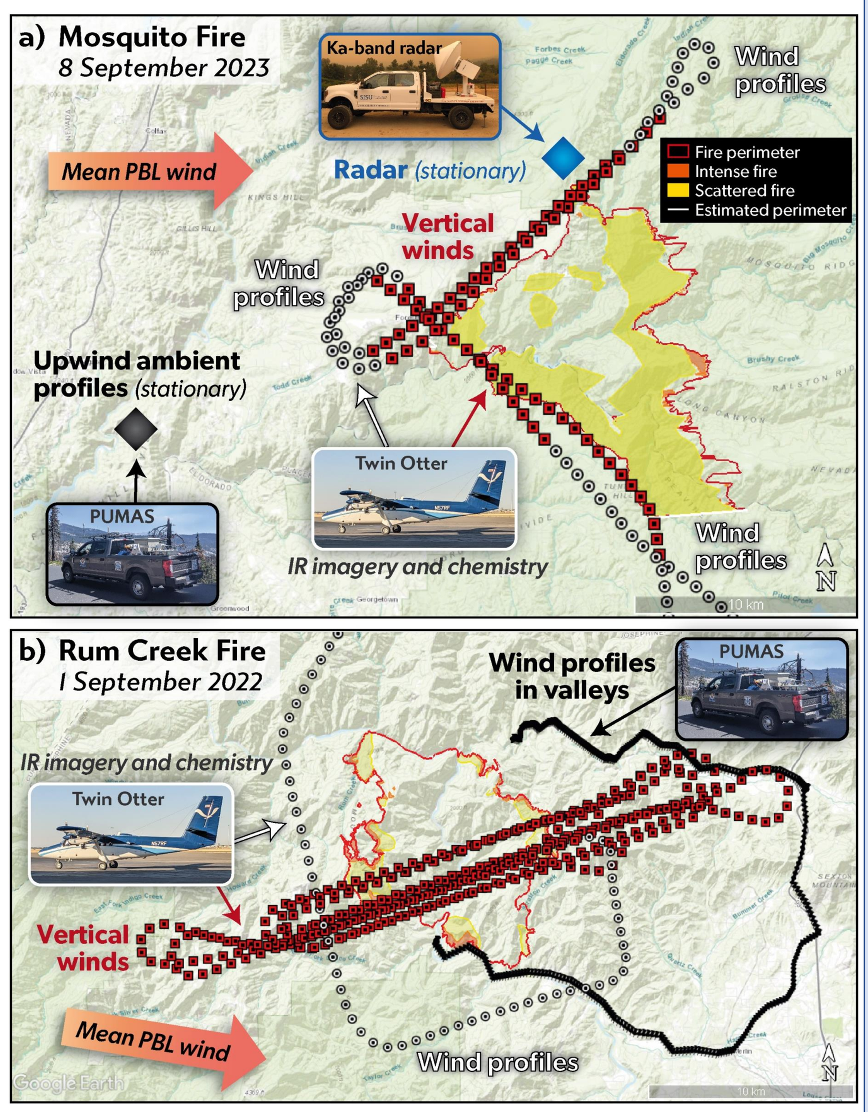

Fig. 4. Mobile platform sampling strategies (a) like Fig. 3, and (b) directly over a smaller fire.

Coupled Fire-Atmosphere Dynamics

The aircraft often repeated legs over one area of the fire every 5 – 25 min. This captured coupled evolution of fire behavior, atmospheric dynamics, and chemistry. Fig. 5 – 7 are from the Mosquito Fire, the largest fire in California in 2022.

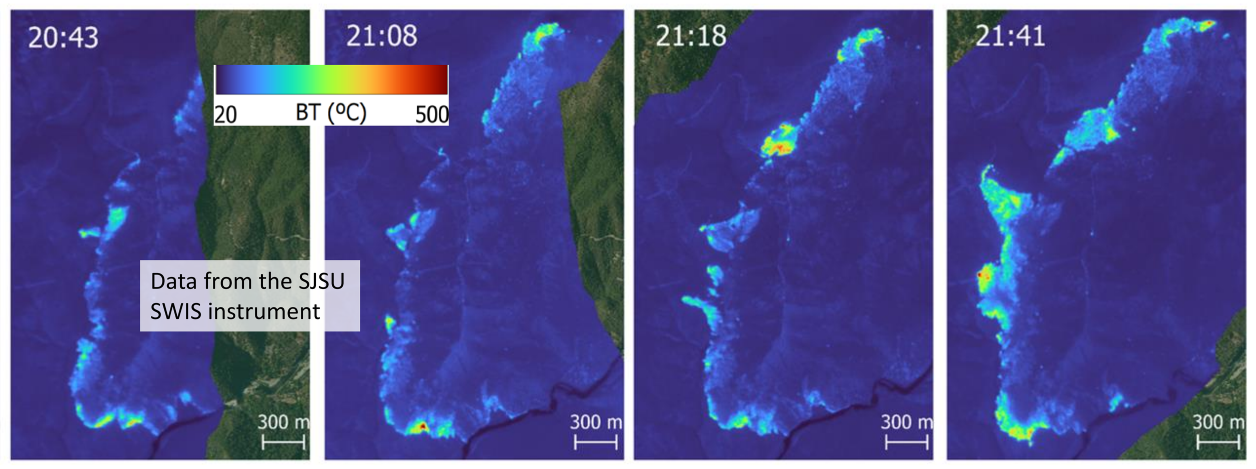

Fig. 5. Infrared mapping of fire growth. Color is uncorrected brightness temperature. ~3 m resolution.

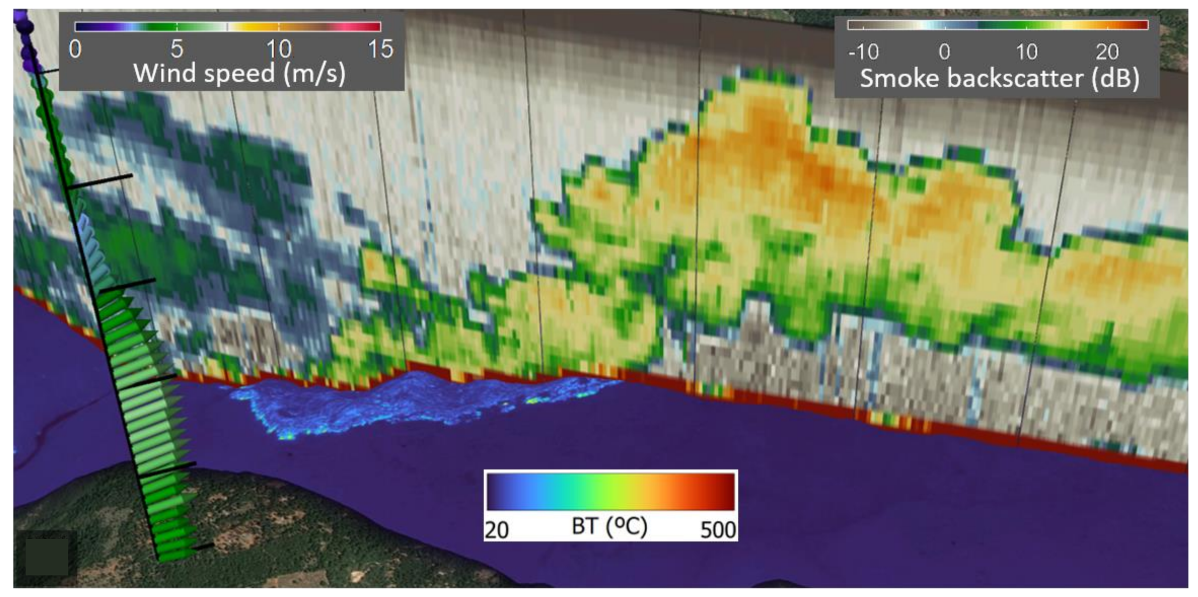

Fig. 6. Smoke plume visualized from airborne lidar, inflow wind profile from lidar, and infrared mapping at surface. Same plume as Fig. 7b.

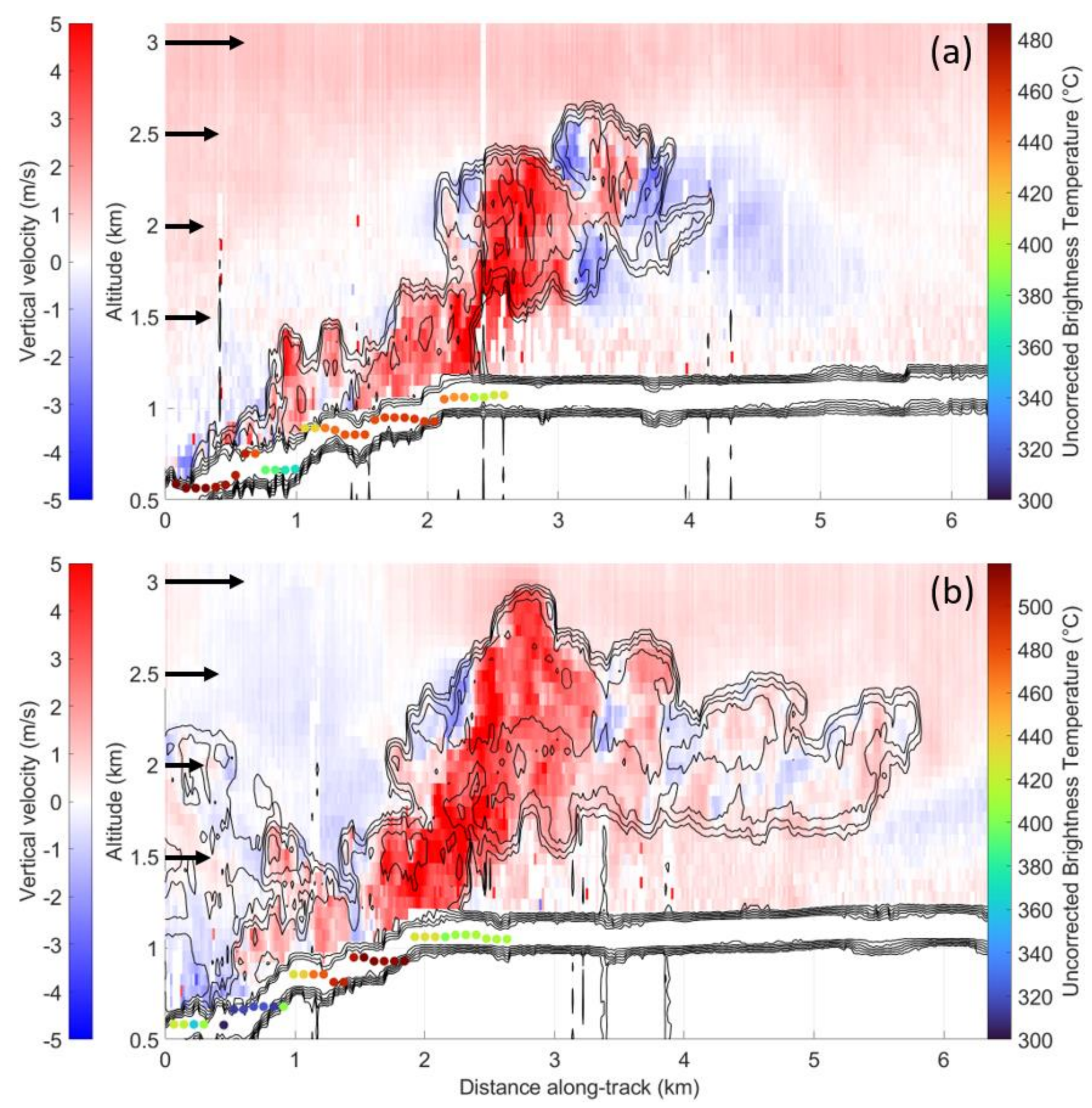

Fig. 7. Airborne lidar vertical velocity curtain showing (a) a new smoke plume, and (b) the same plume 14 minutes later (same as Fig. 6). Black contours are lidar backscatter showing smoke and the ground. Black arrows are the ambient wind profile from lidar. Colored dots are surface infrared brightness temperature.

This plume evolved from a billowing mushroom shape (a) to a series of oscillations advecting downwind (b).

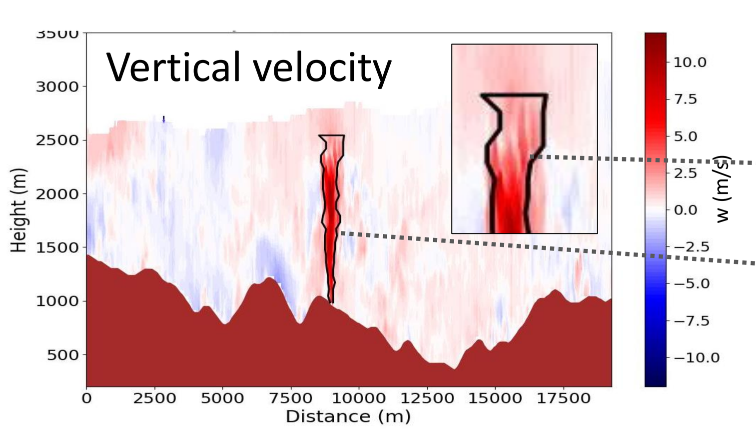

Fig. 8. Vertical velocity from airborne Doppler lidar for an isolated updraft plume. Black line shows updraft area identified by Gaussian fit.

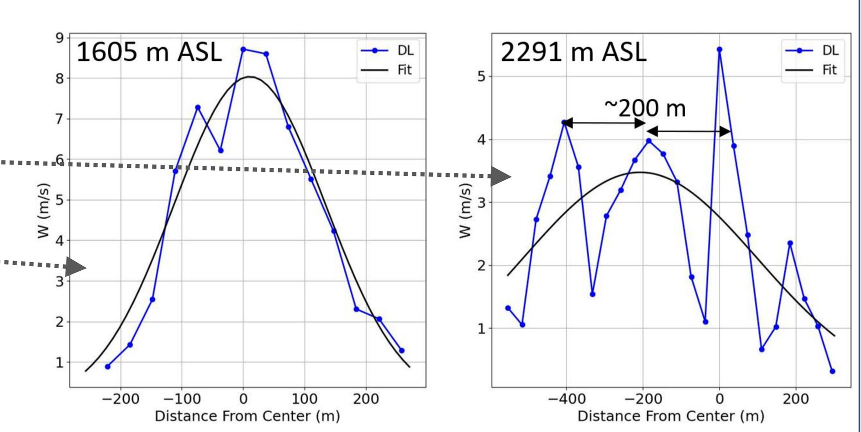

Fig. 9. Observed updraft cores tended to be Gaussian at all heights (left) until near plume-top where entrainment features are identifiable with distinct length and intensity structures (right).

Acknowledgements

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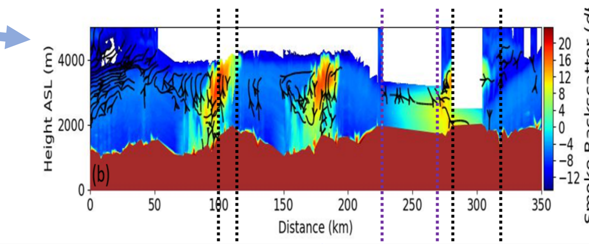
Air quality and Chemistry

In situ measurements characterized the smoke plume emissions, which should vary with observed fire intensity, and subsequent ozone formation.

The lidar profiled smoke layers in real-time, which informed altitude choices for the in situ flight legs.



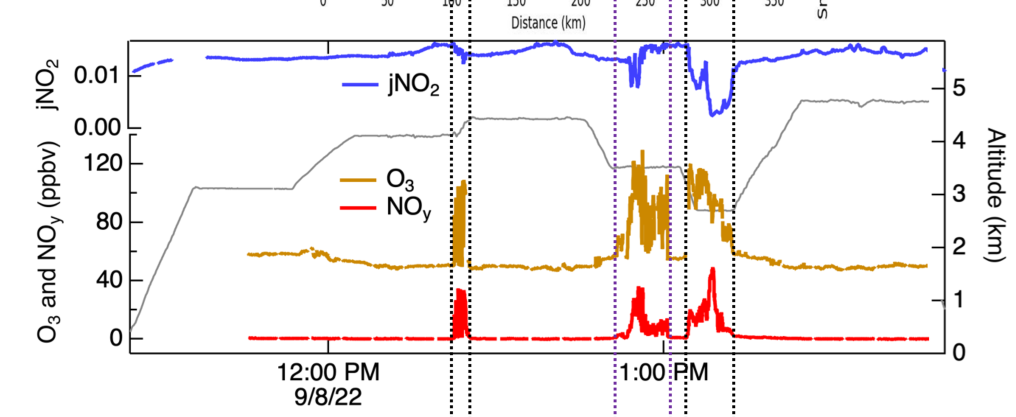


Fig. 10. Timeseries of O_3, NO_y, and NO_2 photolysis rate (jNO_2) for the three plume transects shown in the top panel and in Fig. 11.

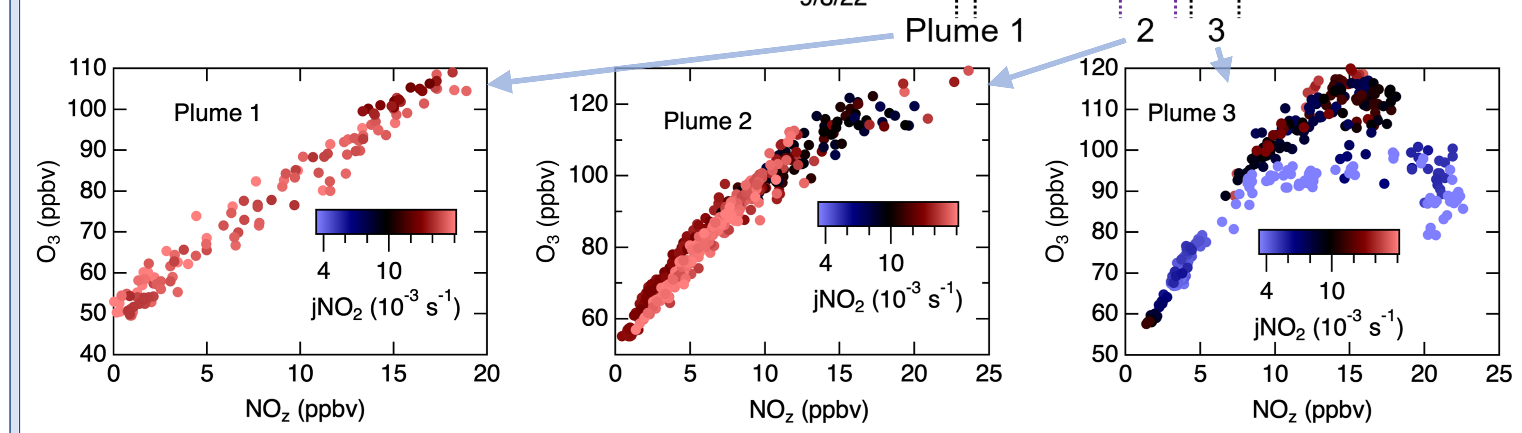


Fig. 11. Ozone production efficiency plots for the three plume transects shown in Fig. 10. Increased shading from the smoke plume (transects at lower altitudes) resulted in lower ozone concentrations.

- Ozone chemistry and emissions ratios from a variety of fires and fire intensities/phases will be studied
- The lidars provided meteorological context for the air quality impacts, e.g., smoke-filled valleys and flows, and mixing/detrainment of the smoke plume.

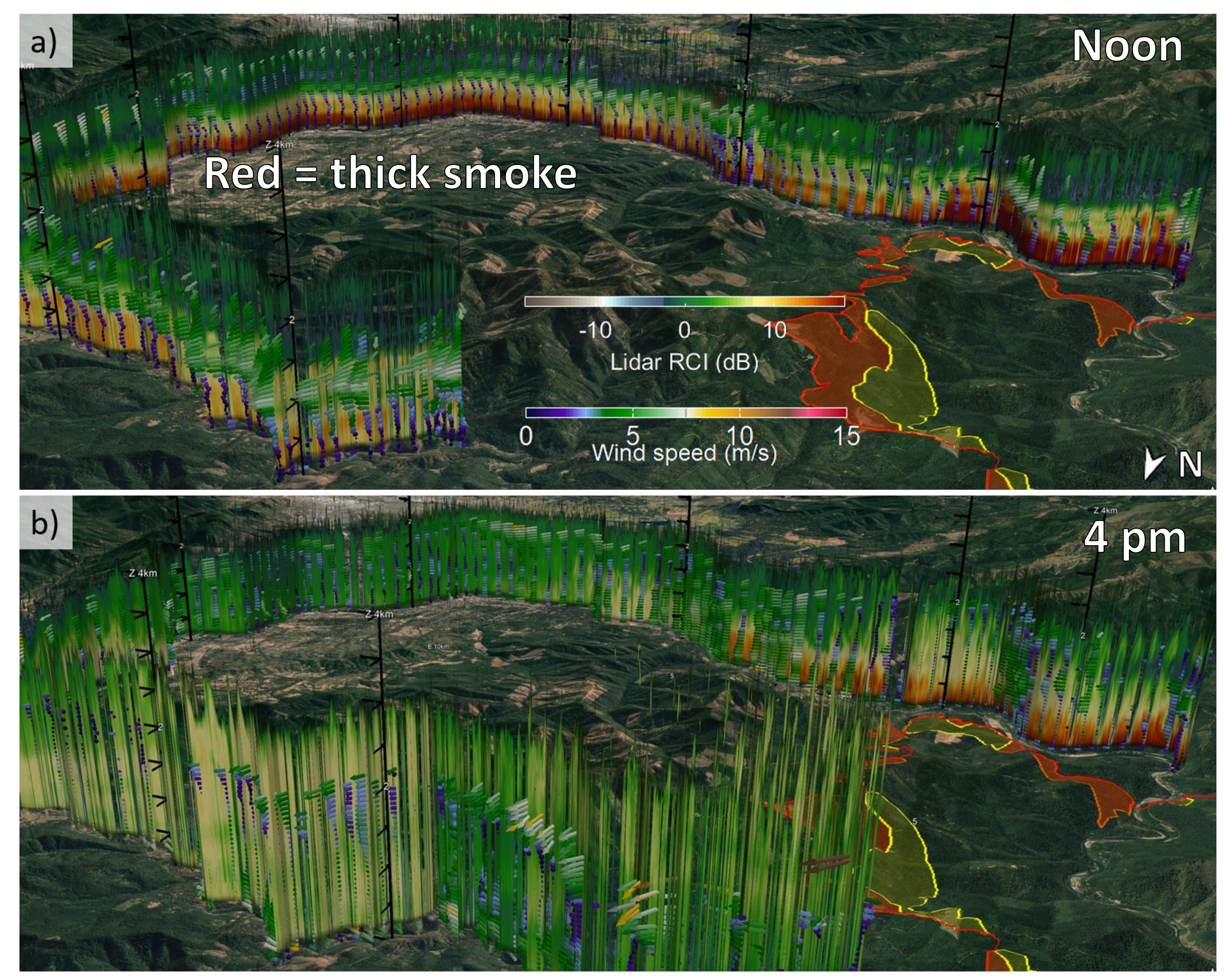


Fig. 9. PUMAS lidar backscatter (curtain) and winds (arrows) showing the change from (a) morning smoke-filled valleys to (b) a cleaner afternoon boundary layer associated with a sea breeze. Red outline is the fire perimeter.

Summary

A diverse suite of instrumentation on mobile platforms enabled new observations of active wildfires, coupling fire intensity mapping to atmospheric dynamics and chemistry. These high-resolution measurements enable much-needed development and validation of fire and air quality models.

Summary article: Carroll et al. 2024, Measuring coupled fire-atmosphere dynamics: The California Fire Dynamics Experiment (CalFiDE). *BAMS*.