An Examination of Extreme Fire Behavior and its Impact on Smoke Injection Altitude using Remote Sensing and Meteorological Data

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1. Importance of Extreme Fire Behavior

A variety of regional smoke forecasting applications are currently available to identify air quality, visibility, and societal impacts during large fire events. However, these systems typically assume a static smoke injection altitude and persistent fire activity, which can produce large errors before, during, and after short-term periods of extreme fire behavior. This study employs data collected during SEAC4RS, along with additional ground, airborne, and satellite observations, to examine the conditions required for both extreme fire spread and pyrocumulonimbus (pyroCb) development. Variations in smoke plume altitude and transport are also explored.

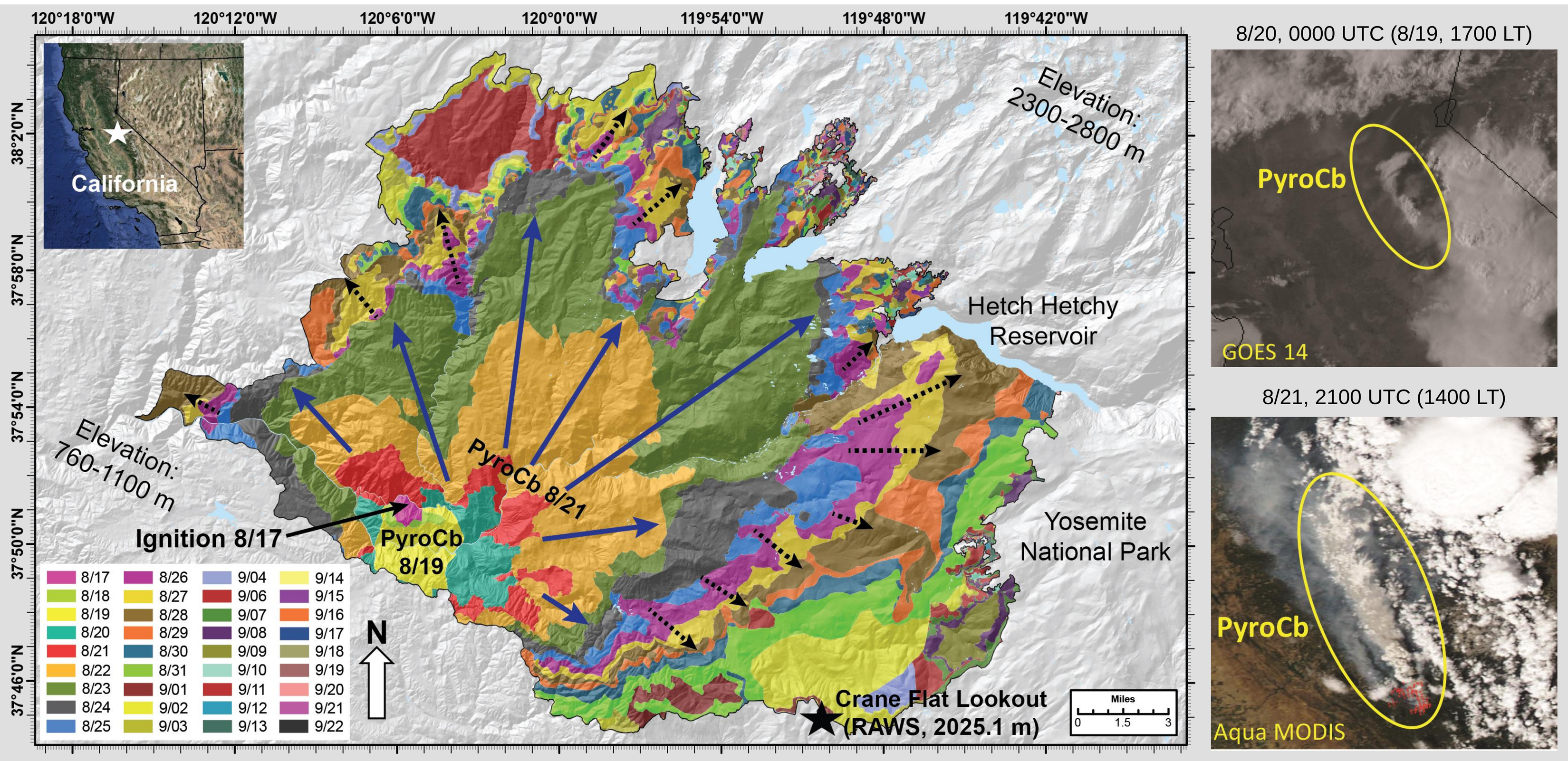


Fig. 1. Rim Fire progression map during 17 August to 22 September 2013 (left). Solid blue and dashed black arrows indicate the approximate area burned during the two largest spread events. Satellite imagery for the Rim Fire's two pyroCb events (right).

2. 2013 Rim Fire

- Third largest fire in California's history (104,131 ha), burned 30,000 ha in Yosemite NP, and endangered San Francisco's power and water supply.
- High frequency of extreme fire behavior!
  - Impact on smoke plume altitude?
- Smoke plume extended across North America, producing local and regional air quality and visibility impacts!

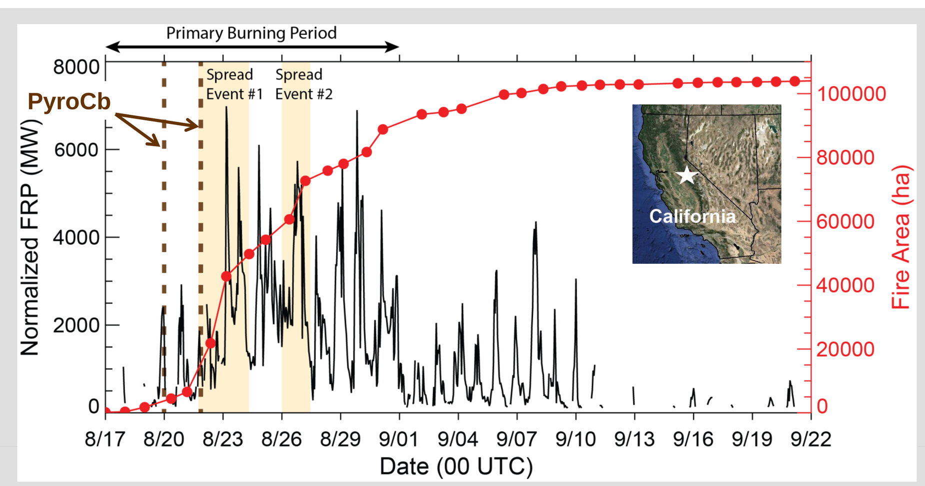


Fig. 3. Time series of normalized hourly fire radiative power (FRP) from GOES-West (black) and cumulative fire area from nighttime airborne observations (red).

Fig. 2. BAMS cover story, 2015 February issue.

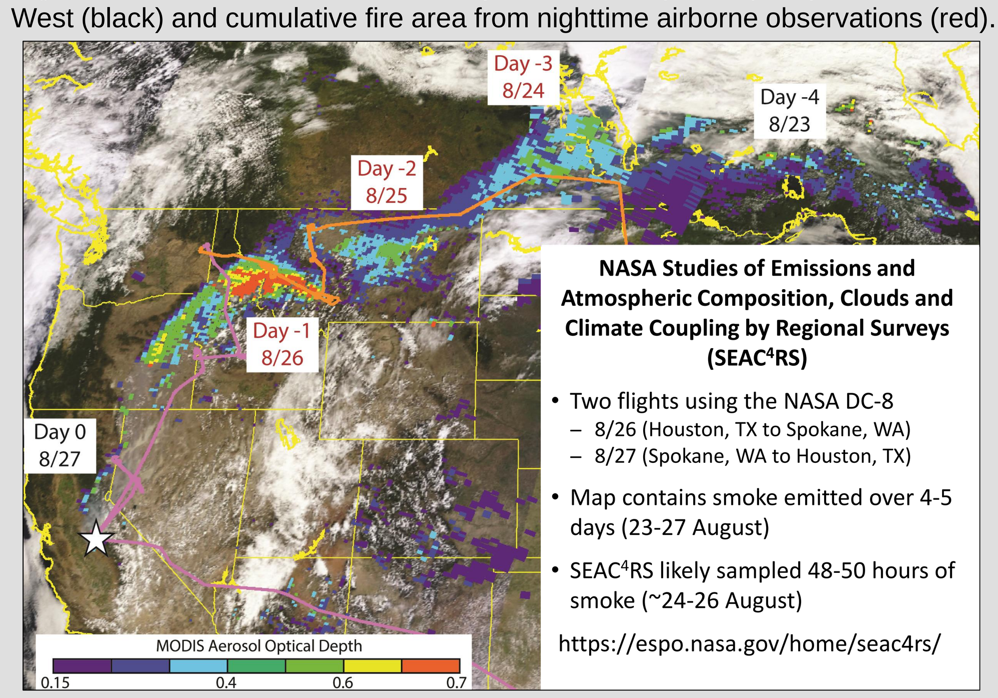


Fig. 4. Terra MODIS true color imagery on 27 August 2013, with aerosol optical depth retrievals superposed. Segments of the NASA DC-8 flight paths on 26 August and 27 August are highlighted in pink and orange, respectively.

3. Primary Drivers of Extreme Fire Spread (Rim Fire)

Wind Speed
- Most intense when disturbance is near the fire
- Remained strong at night!

Relative Humidity
- Below 35% for two nights during spread event #1
- Higher during event #2
- A reason for reduced spread?

Implications
- Fire weather indices are limited by not including nocturnal and upper-level info!
- Top-down approach required for extreme spread forecasts?
- **Nocturnal smoke emissions much higher than climatology!** (Saide et al., in press, GRL)

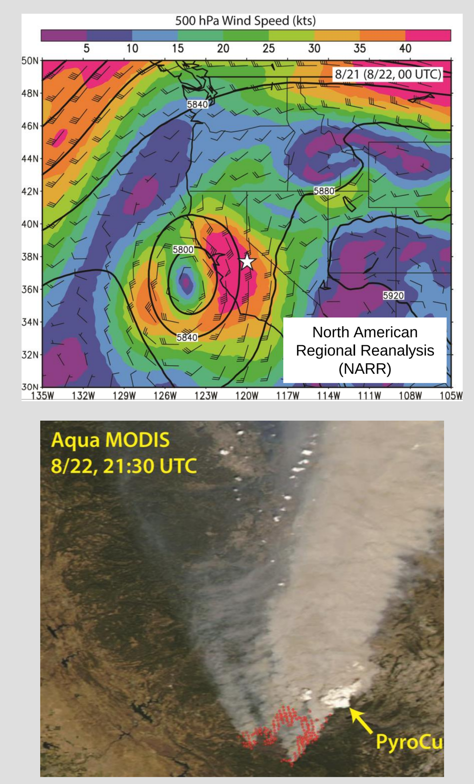


Fig. 5. NARR 500 hPa heights & winds on 21 Aug. (top). Aqua MODIS true color image on 22 Aug. (bottom).

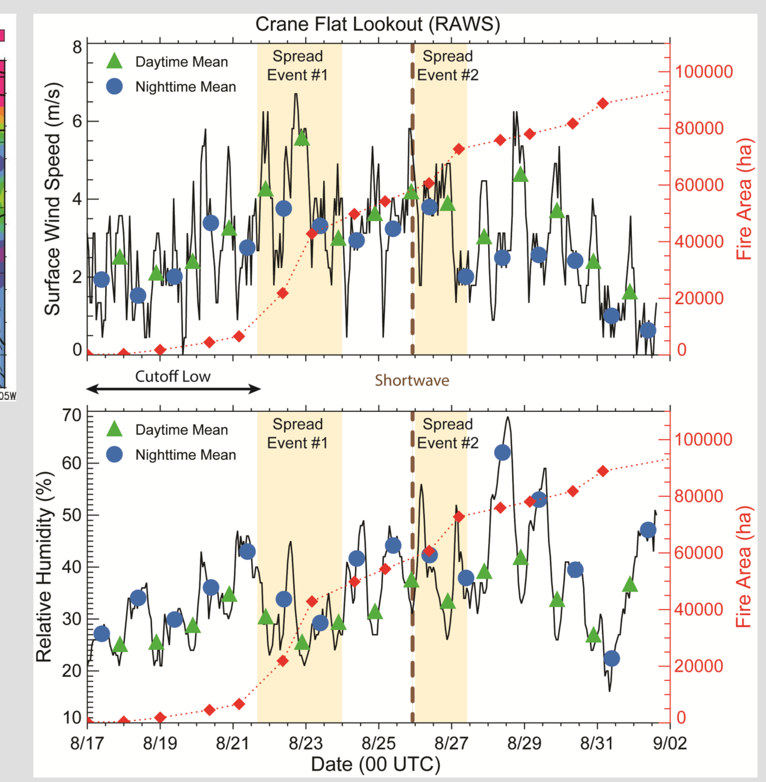


Fig. 6. Primary burning period surface observations of hourly wind speed (top) and relative humidity (bottom) from the RAWS station at Crane Flat Lookout in Yosemite NP.

4. Smoke Plume Characteristics During Extreme Spread

Despite extreme fire intensity and pyroCu, smoke particles are located below 3-5 km AGL, within the mixed layer.

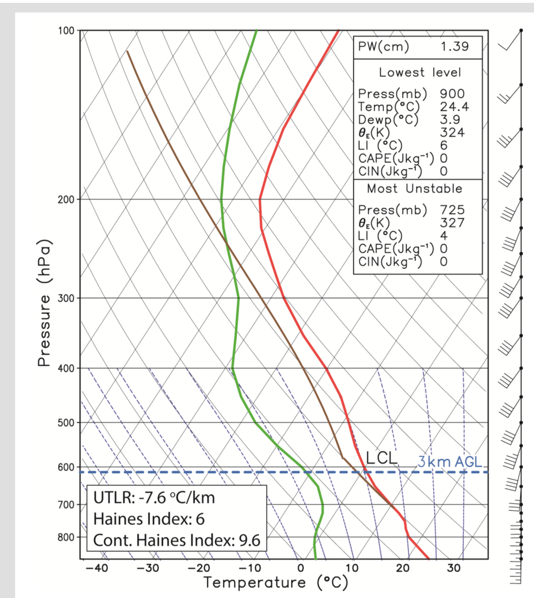


Fig. 7. NARR-derived sounding at 21 UTC on 22 August, during peak fire spread.

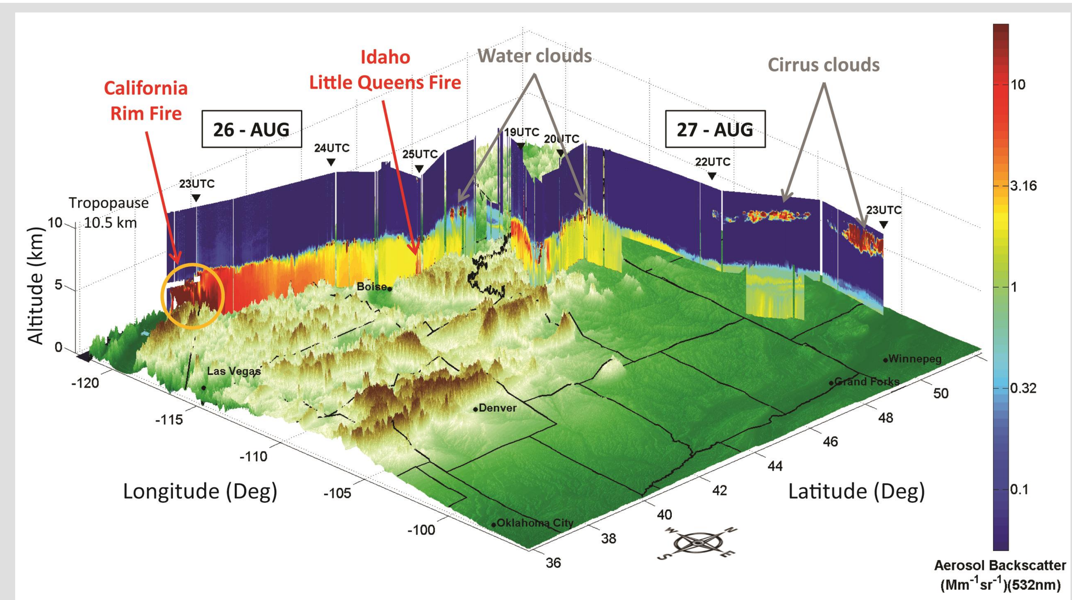


Fig. 8. Atmospheric backscatter observed by the DIAL/HSRL lidar during the two Rim Fire DC-8 flights on 26 and 27 August 2013, corresponding to spread event #2.

5. High-Altitude Smoke Observed During SEAC4RS

PyroCb are the most efficient avenue for lofting smoke, occasionally reaching the lower stratosphere.

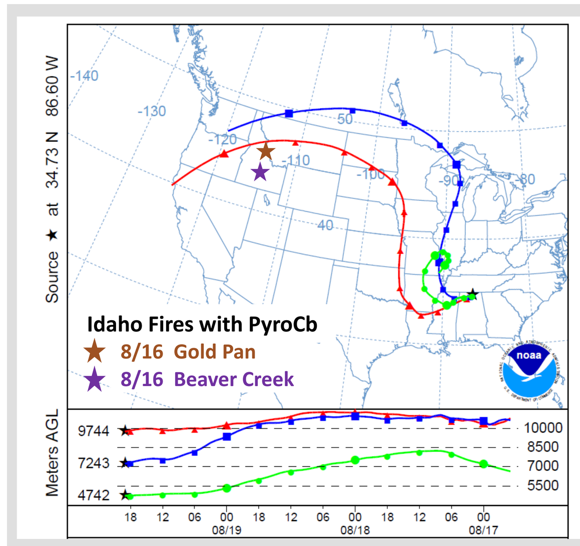
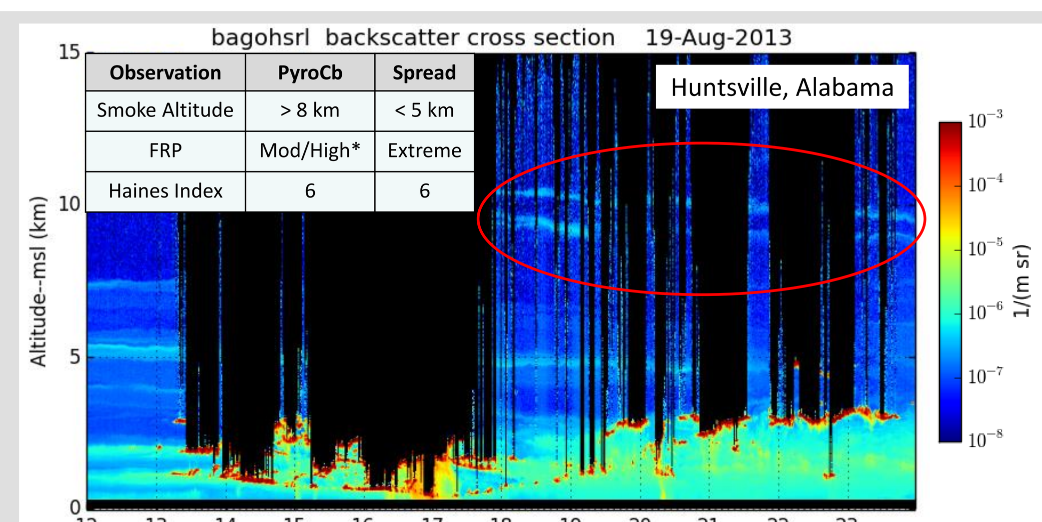


Fig. 9. Backward HYSPLIT trajectories initialized on 19 August at Huntsville, AL.



Observation	PyroCb	Spread
Smoke Altitude	> 8 km	< 5 km
FRP	Mod/High*	Extreme
Haines Index	6	6

Fig. 10. Atmospheric backscatter observed by the HSRL lidar in Huntsville, AL (19 August). Red circle indicates elevated smoke from the 16 August Idaho pyroCb.

6. PyroCb Detection and Monitoring (2013 Fire Season)

PyroCb are commonly undetected and undercounted. NRL's goal is systematic detection and characterization!

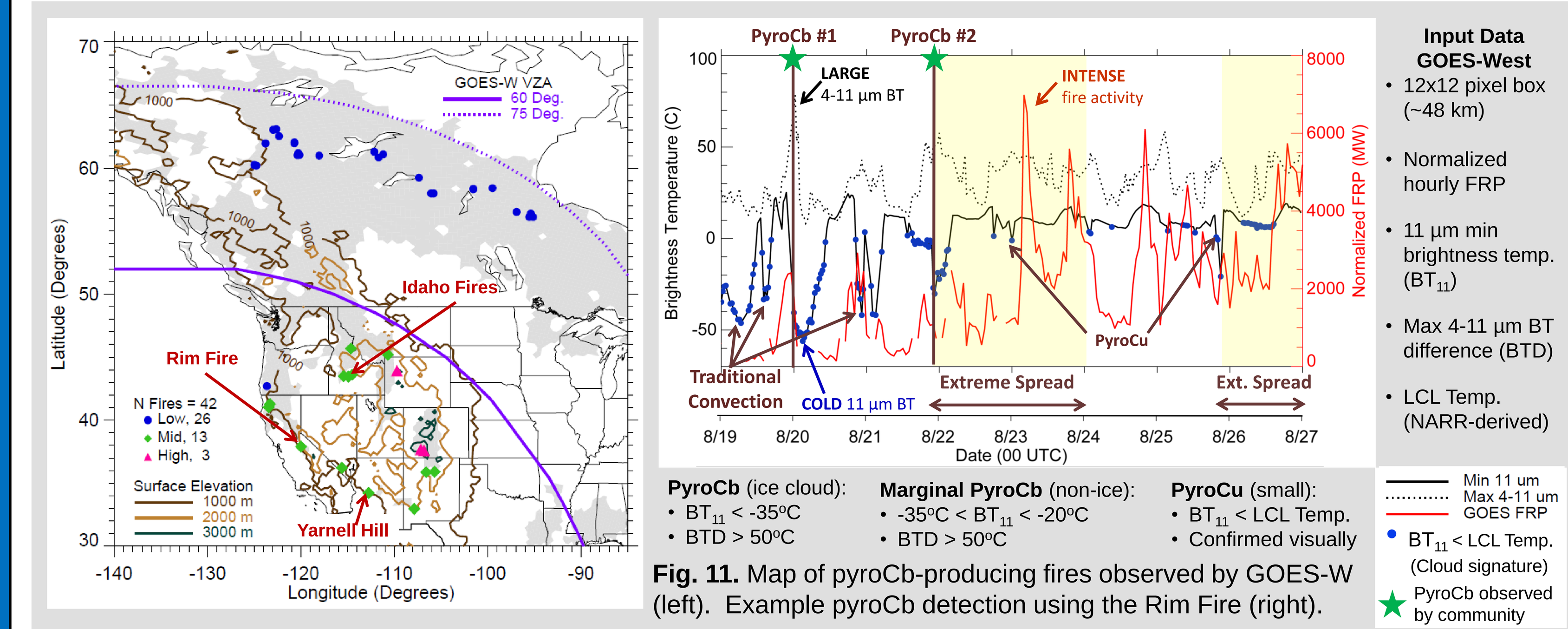


Fig. 11. Map of pyroCb-producing fires observed by GOES-W (left). Example pyroCb detection using the Rim Fire (right).

7. Conceptual Model for PyroCb Development

The meteorological conditions driving development are highly uncertain. We hypothesize a relationship to traditional high-based dry thunderstorms, which require the presence of mid-level moisture and instability.

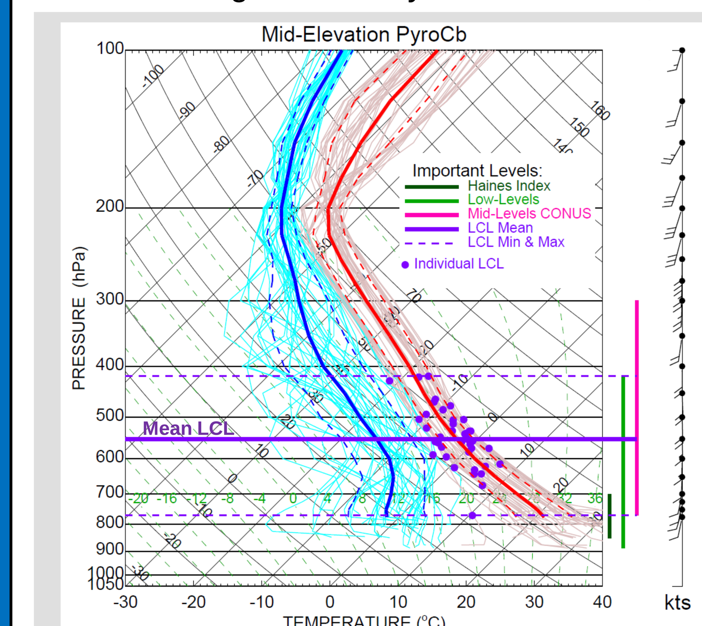


Fig. 12. Composite NARR-derived sounding for the 40 mid-elevation (1-3 km) pyroCb observed during 2013.

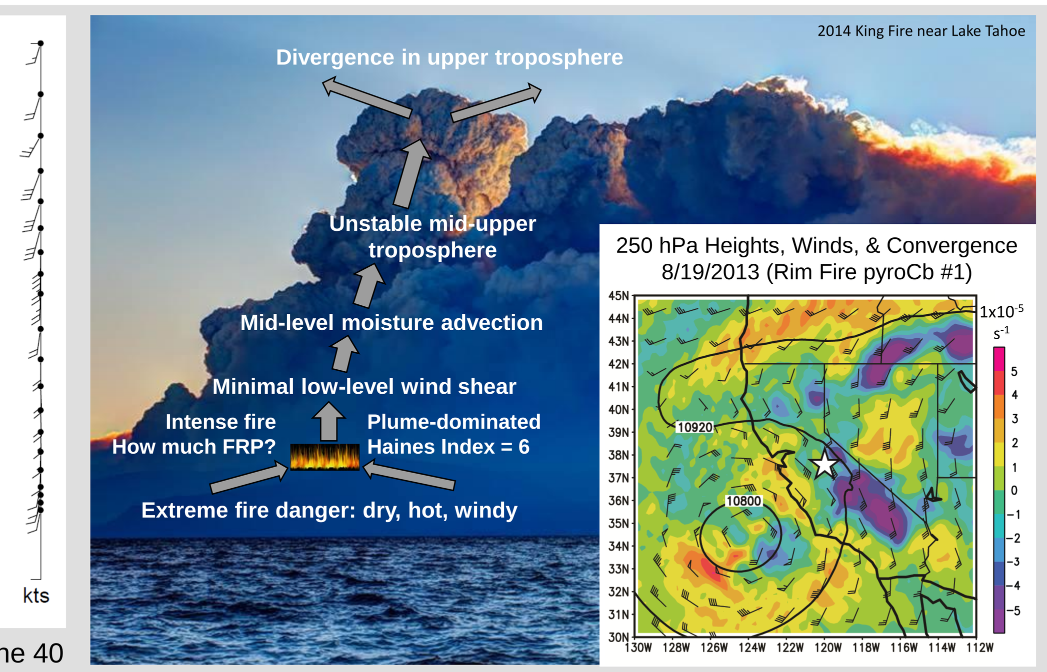


Fig. 13. Components of a working hypothesis for pyroCb development.

8. Conclusions and Future Work

- Extreme fire spread is likely initiated by the passage of an upper-level disturbance. The effect on nighttime meteorology is key! Upper-level info may be useful for regional applications using NWP data.
- PyroCb development likely requires entrainment of ambient mid-level moisture in an environment favorable for high-based dry thunderstorms. Important meteorology for smoke particle lofting, less important for spread?
- Geostationary satellite data are useful for separating pyroCb from traditional convection. This suggests that automated pyroCb detection is possible at global-scale with high temporal frequency.
- **Ultimate goal:** Use detection algorithm & conceptual model to build an NWP-based pyroCb prediction system!

Relevant Papers

Peterson, D., Hyer, E., Campbell, J., Fromm, M., Hair, J., Butler, C., Fenn, M., 2015: **The 2013 rim fire: implications for predicting extreme fire spread, pyroconvection, and smoke emissions. BAMS,** 96, 229–247. http://dx.doi.org/10.1175/BAMS-D-14-00060.1

Saide, P. E., Peterson, D. et al., 2015: Revealing important nocturnal and day-to-day variations in fire smoke emissions through a multiplatform inversion, Accepted in Geophysical Research Letters.

Peterson, D., Hyer, E, and Wang, J., 2014: Quantifying the potential for high-altitude smoke injection in the North American boreal forest using the standard MODIS fire products and subpixel-based methods. Journal of Geophysical Research: Atmospheres, 119, 2013JD021067.

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