Forecasting Thunderstorm Outflow Boundaries: Impacts and Implications for Wildland Firefighting

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Introduction
Thundertoos outflow research has primarily focused on the role of boundary interactions in convective initiation and tornadoogenesis. However, the wildfire community has a unique demand for understanding outflow boundaries. Fire managers are aware that outflow winds can present challenges to fire suppression and safety in wildland fire operations. Subtle changes in wind speed and direction can have large and potentially devastating consequences to aerial and ground firefighting operations. This paper reviews empirical and theoretical studies on thunderstorm outflows and resultant outflow boundaries and places this knowledge within the context of wildland fire management. Case studies are presented to illustrate the impacts of outflow boundaries, followed by a review of wildland fire operations. Subsequently, forecasting methodologies and best practices for fire weather meteorologists will be discussed. Finally, recommendations will be provided to improve communication between fire meteorologists and fire managers to address the challenges posed by imminent threats associated with outflow winds.

Motivation: Microscale Forecasting of Low Frequency-High Impact Events

• Low frequency-High Impact: Downdrafts inherently not low frequency, occur on all precipitating storms. However, situations that will negatively impact fire personnel are low frequency.

• What tools are available to fire weather and incident meteorologists to better predict the occurrence and strength of downdrafts and outflow boundaries?

Downdraft Theory

\[
\frac{dV}{dt} = \frac{1}{\rho} \frac{\partial p}{\partial z} + g \left[ \frac{\partial \theta}{\partial \phi} c_p + \frac{\partial \theta}{\partial \phi} c_v \right] \left( \rho + \beta \frac{\partial \phi}{\partial \phi} \right)
\]

Vertical Momentum Equation (Wakimoto 2001)

Conductive Environmental Conditions

• Thermodynamic profile: DCAP > 1000 J kg⁻¹ indicates potential for strong downdrafts (Gillmore and Wicker 1998, also see case study sidebar)

• Low level RH and outflow strength, competing ideas:
  - Wakimoto (2000): Stronger downdrafts with lower low-level RH, increased vertical temperature difference between parcel and environment
  - Houtz and Richardson (1996): - Stronger cold pools with lower low-level RH

• Mid-level dryness near melting layer (Proctor 1989)

• Thunderstorm microphysics
  - Droplet size as function of evaporation rate, sub-cloud lapse rate
  - Sublimation vs. evaporation alone
  - Presence of hail, graupel, or snow (Srivastava 1987)

Structural Characteristics of Downdrafts and Resultant Outflow Boundaries

• Microbursts/Microbursts, Gust Fronts
  - Divergence signatures
  - Descending dBZ cores
  - Rotation aloft
  - Radar fine lines

Case Studies

• New Underwood RX
  - Successful forecast and prescribed burn implementation

• Light east-northeast winds would have impacted I-90
  - Gust front changed winds to SW providing good burning conditions

• White Draw Fire- MAPPS Incident, 1 July 2012
  - Caused by localized microburst, 4 fatalities
  - DCAP of 1994 J kg⁻¹
  - Noted descending reflectivity core and miso-rotation aloft
  - Pulse-type convection in dry environment

Improving Forecast Methodology

• Forecast funnel- early identification of "problem of the day"

• Nowcasting and situational awareness
  - Immediate recognition of conducive environments
  - Soundings, DCAP, low level RH
  - High resolution models
  - HRRR has shown ability to predict strong gust fronts; qualitative use
  - Three dimensional radar perspectives
    - Midlevel rotation couplets
    - Descending reflectivity cores (Roberts and Wilson 1989)
    - Operational use of polarimetric radars
      - Note droplet shape size, phase
    - Onsite visual indicators
      - Virga, precipitation curls
    - Field tools
      - Mobiles, RadarScope, BuFlit

Concluding Thoughts and Research Questions

• Prompt identification of conducive conditions for convectively-driven winds is necessary for wildland fire managers.

• Can a suitable link be found between downdraft strength and outflow wind speeds?

• Does aviation management need to reassess flight policy around thunderstorms in particularly dangerous conditions?

• How can meteorologists ensure their forecasts are properly understood?

Acknowledgments
The authors would like to thank Drs. Matthew Bunkers, Mark Hjelmfelt, and Adam French for their help in the preparation of this presentation.

References

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