Forecasting Thunderstorm Outflow Boundaries:

Impacts and Implications for Wildland Firefighting

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Introduction

Thunderstorm outflow research has primarily focused on the role of boundary interactions in convective initiation and tornadogenesis. However, the wildland fire 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 downdrafts 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

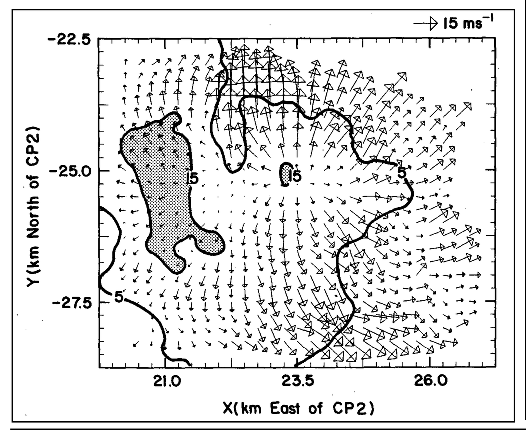
$$\frac{d\overline{w}}{dt} = -\frac{1}{\rho}\frac{\partial \overline{p}'}{\partial z} + g\left[\frac{\theta_v'}{\theta_{v0}} - \frac{c_v}{c_p}\frac{p'}{p_0} - \left(r_c + r_r + r_i\right)\right]$$

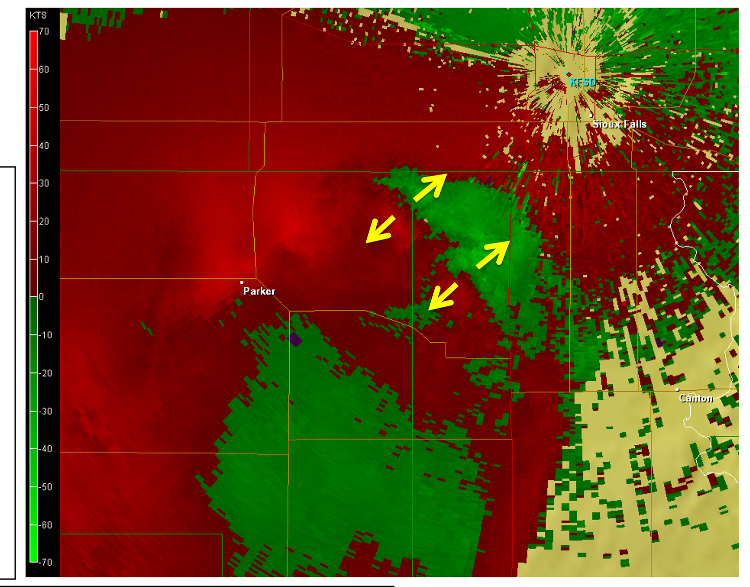
Vertical Momentum Equation (Wakimoto 2001)

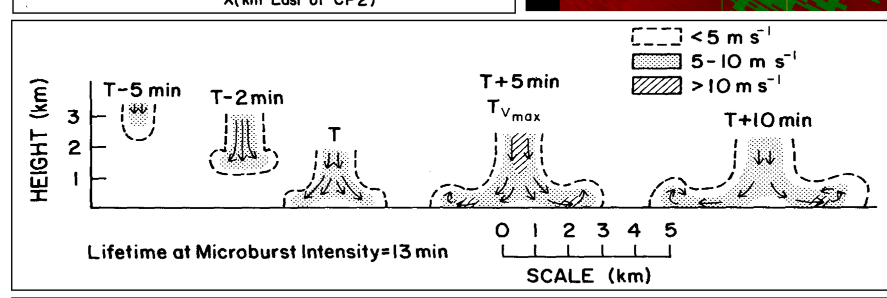
- Inviscid vertical momentum equation. Terms on RHS:
  - Vertical gradient of the perturbation pressure- generally small in non-supercellular thunderstorms
  - Thermal buoyancy
  - Perturbation pressure buoyancy
  - Condensate loading
  - Entrainment of environmental air (not included in the above equation, may also contribute to the strength of the downdraft [Wakimoto 2001])
- Importance:
  - Use of Virtual Temperature- Downdraft intensity may increase with higher RH at lower levels by increasing virtual temperature differences between the parcel and the environment (Srivastava 1985)
  - Phase Changes- melting and sublimation (Srivastava 1987)
  - Microphysical details of condensate loading: shape, size, downdraft speed, and intensity can affect downdraft
  - Entrainment- Virtual Temperature effects, low-level RH

Structural Characteristics of Downdrafts and Resultant Outflow Boundaries

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







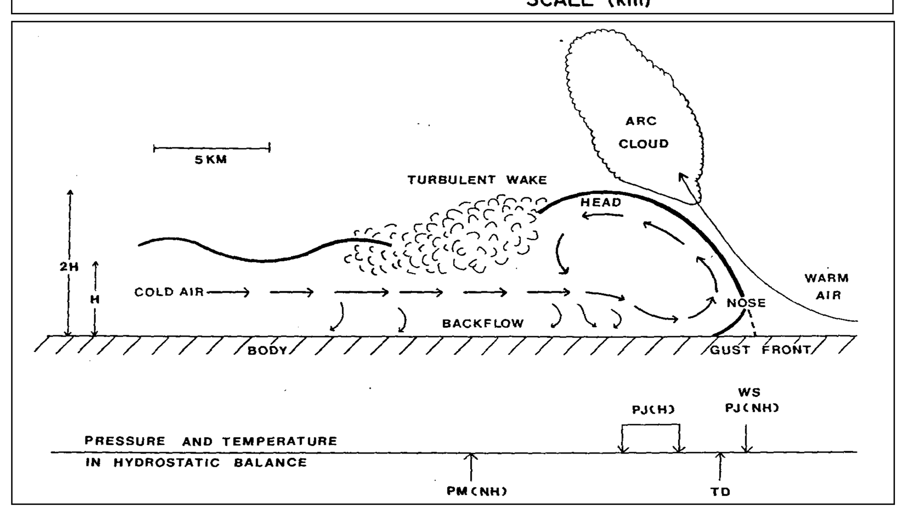


Fig. 1. Above Left. Microburst pattern. Note Divergence signature. (Hjelmfelt 1988)

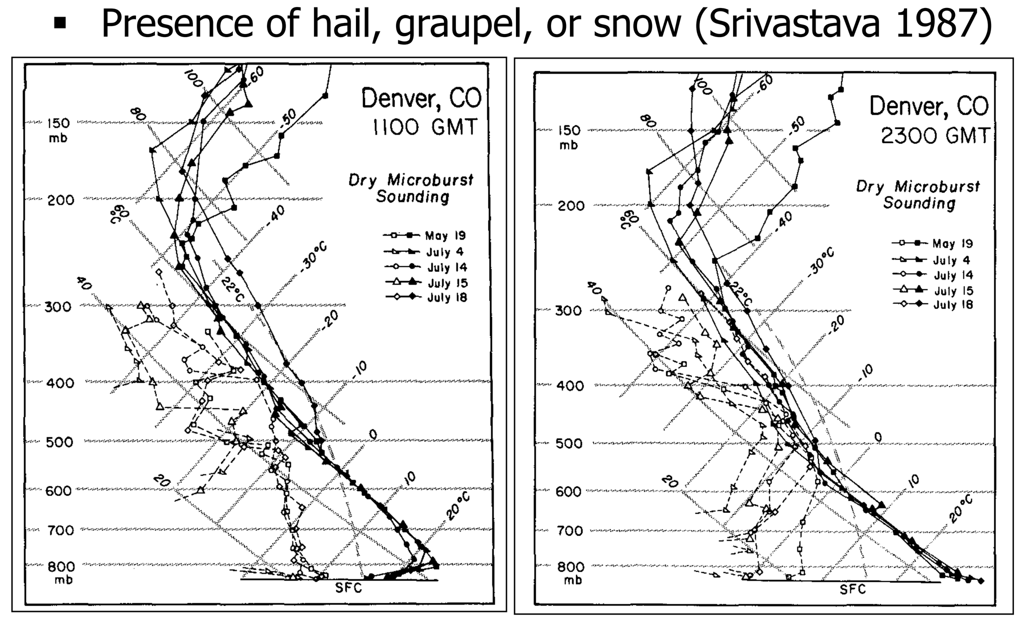
Fig. 2. Above right. KFSD velocity image showing wet microburst divergence. Note parallels to Fig. 1.

Fig. 3 Middle left. Microburst life cycle showing midair and surface microbursts (Hjelmfelt 1988; after Wilson et al. 1984).

Fig. 4. Bottom left. Schematic gust front cross section (Droegemeier and Wilhelmson 1987).

Conducive Environmental Conditions

- Thermodynamic profile
  - DCAPE > 1000 J kg^{-1} found to correspond to strong downdrafts (Gilmore and Wicker 1998, also see case study sidebar)
  - Low level RH and outflow strength, competing ideas:
    - Wakimoto (2001)- Stronger downdraft with higher low-level RH, increased virtual temperature difference between parcel and environment
    - Markowski and Richardson (2009)- 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)



Figs. 5 and 6. Denver CO soundings for 1100Z and 2300Z, respectively, for five different dry microburst days. (Wakimoto 1985)

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

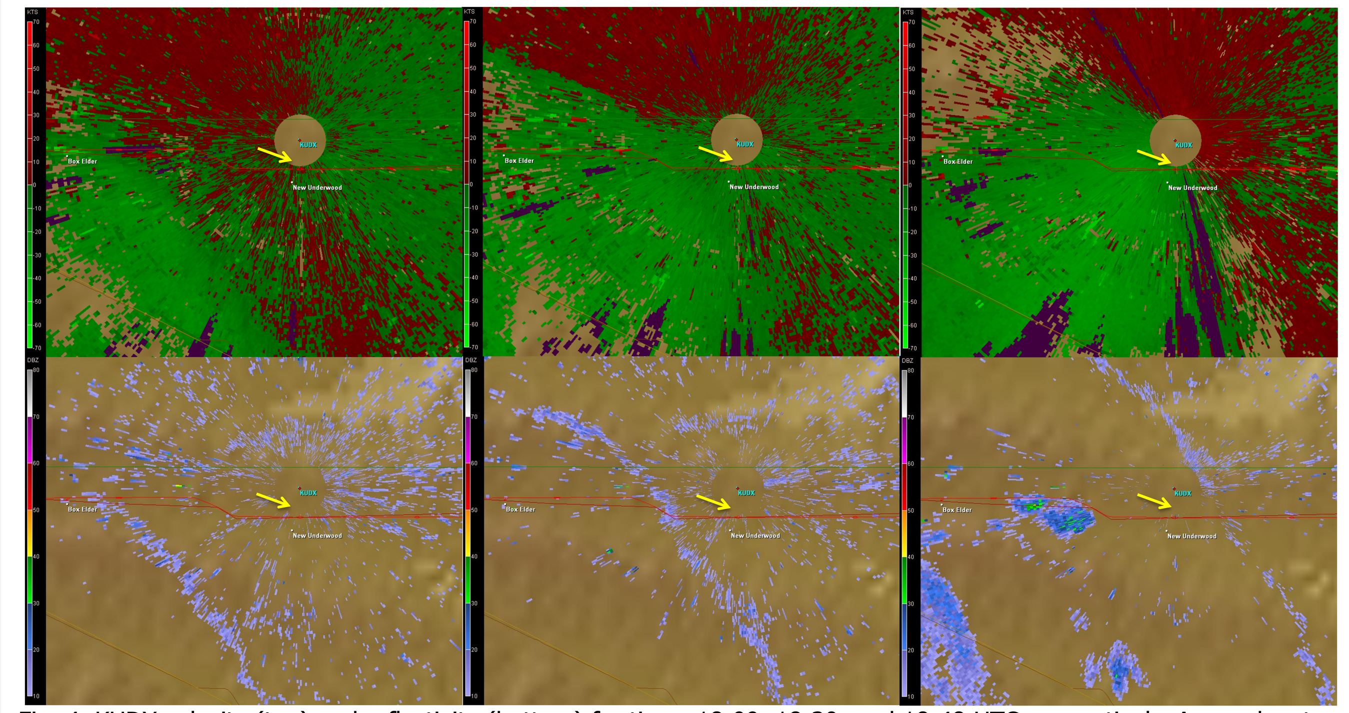
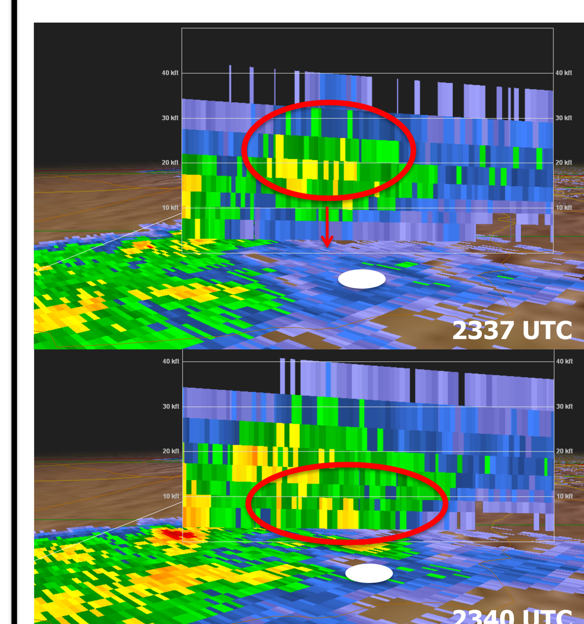


Fig. 4. KUDX velocity (top) and reflectivity (bottom) for times 18:09, 18:30, and 18:48 UTC, respectively. Arrow denotes location of burn. Note radar fine line depicting wind shift.

- White Draw Fire– MAFFS 7 Incident, 1 July 2012
  - Caused by localized microburst, 4 fatalities
  - DCAPE of 1994 J kg^{-1}
  - Noted descending reflectivity core and misoscale rotation aloft
  - Pulse-type convection in dry environment



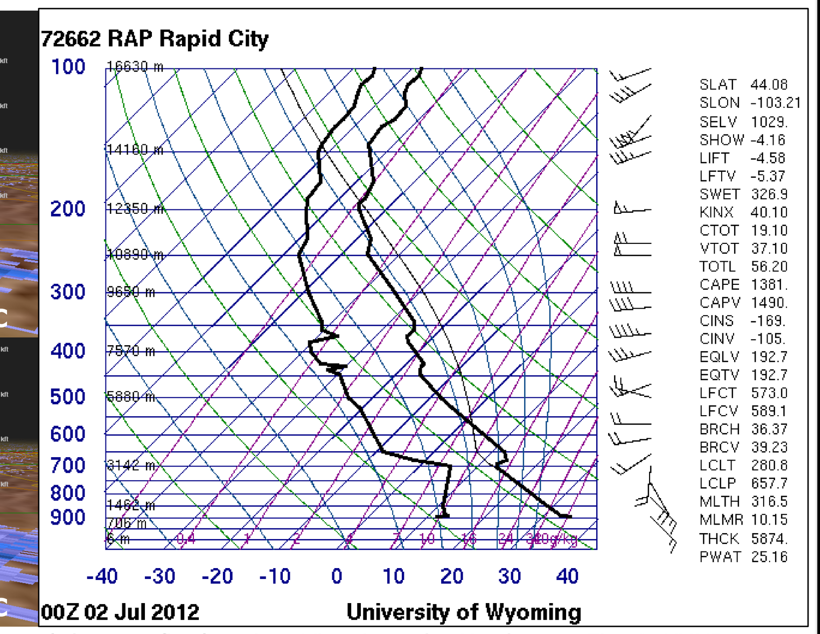
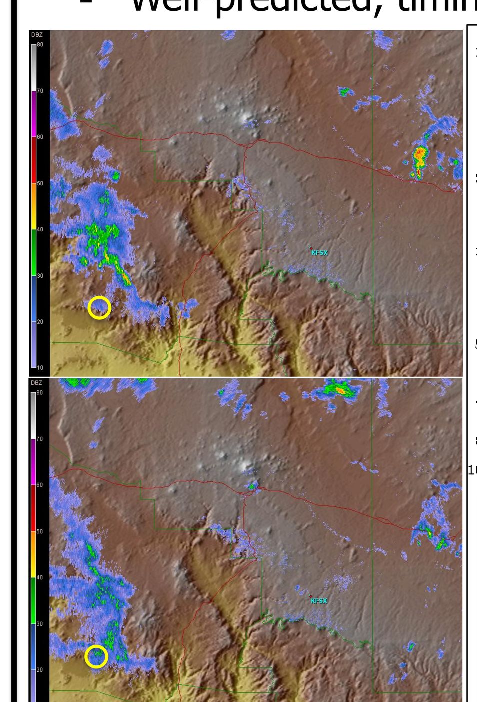


Fig. 5. KUDX reflectivity for noted times. White oval denotes fire location. View is to the Northwest. Fig. 6. KUNR sounding for 00Z 2 July 2012.

- Yarnell Hill Fire- 19 GMIHC Fatalities
  - Gust front moved across fire front
  - Well-predicted, timing was poorly communicated



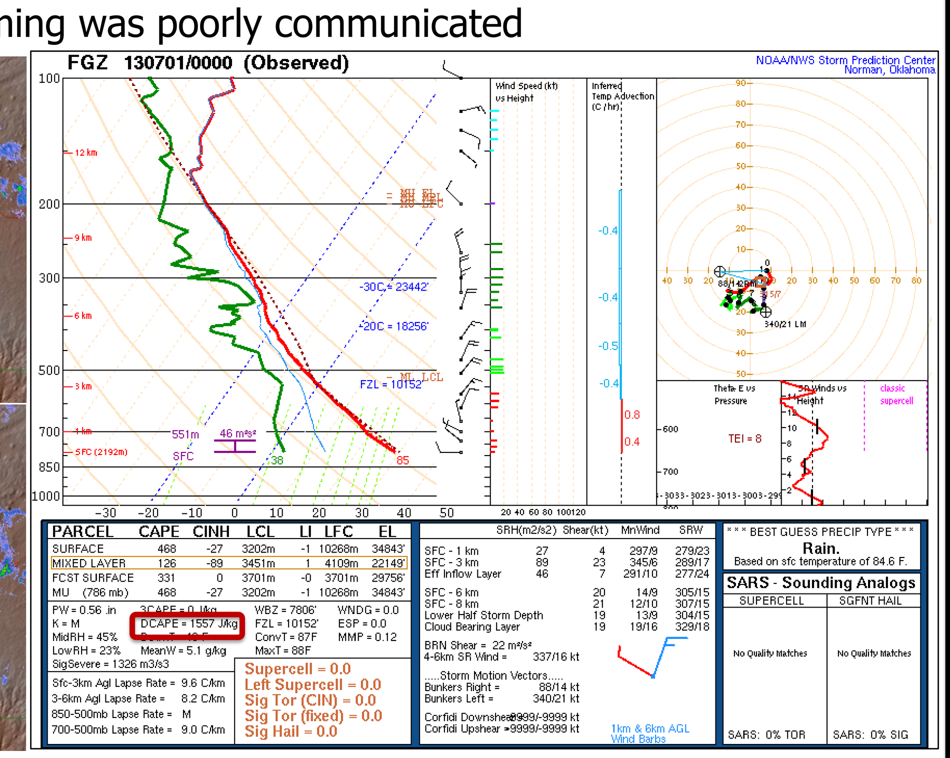


Fig. 7. KSFX reflectivity with approximate fire location circled. Fig. 8. KFGZ sounding from 00UTC on 1 July 2013.

Impacts to Fire Operations and Management

- Risk vs. Reward
  - High impact operations with high impact results
  - Operating in an unknown atmospheric environment
  - Role of fire weather forecasters and Incident Meteorologists (IMETs)
- Suddenness of changes
  - Outflow/microbursts happen on short time scales
  - Relationship to escape routes and safety zones
- Communicating uncertainty
  - IMETs need ability to convey uncertainty
  - Applications to fire operations: Plan A vs. Plan B
- Aviation vs. Ground Concerns
  - Movement of resources based on wind potential
  - Aircraft performance characteristics

Improving Forecast Methodology

- Forecast funnel- early identification of "problem of the day"
- Nowcasting and situational awareness
  - Immediate recognition of conducive environments
  - Soundings, DCAPE, 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, BUFkit

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?

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