Convection and Downbursts

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Convection and downbursts are connected meteorological phenomena with the potential to affect fire behavior and thereby alter the evolution of a wildland fire. Meteorological phenomena related to convection and downbursts are often discussed in the context of fire behavior and smoke. The physical mechanisms that contribute to these phenomena are interrelated, but the phenomena are often misinterpreted or misunderstood in the fire/smoke context.

In this article, we discuss the physical mechanisms associated with convection and downbursts, and we discuss terminology used in reference to fire-driven convection. We identify the role the phenomena could play in fire behavior and smoke, according to the scientific literature. We also discuss some of the misinterpretations and misunderstandings that are common in the fire community.

Convection

Convection has two different but related definitions (N.a. 2016), depending on whether the word describes the general flow of heated material in a fluid or whether it refers to a meteorological phenomenon. The more general definition of convection is "the transfer of heat by the circulation or movement of the heated parts of a liquid or gas." The meteorological definition is more specific: "the vertical transport of atmospheric properties, especially upward."

According to the meteorological definition, convection does not contribute directly to fire behavior: convective heat transfer, as related to fire spread, falls under the first definition. Meteorologically, convection affects fire behavior indirectly by altering the flow of air through the combustion zone or by contributing to changes in the wind speed and wind direction in the immediate vicinity of the fire (that is, within about 3 to 300 feet (1 to 100 m)). In this article, we discuss meteorological convection and its role in fire behavior and smoke movement.

Meteorological convection is a very common and extensively studied feature of atmospheric motion. Convection is the mechanism by which many clouds and all thunderstorms form in the atmosphere. Even when no condensation occurs in a convective updraft, the updraft contributes to mixing of the air between the Earth's surface and higher levels of the atmosphere. Weather forecasts routinely include assessments of the potential for convective clouds and thunderstorms to affect weather conditions during a forecast period.

A fire modifies the air directly over it by releasing heat and moisture into that air. A localized pocket of air that is warmer and moister than its surrounding environment at the same pressure is less dense and subject to an upward buoyant force. The effect of heating and moistening the air directly over a fire is that the air begins to rise.

The height to which the air rises and the vertical velocity it attains while rising are determined by a host of atmospheric conditions and processes that affect the buoyant force acting on the fire-modified air as it rises. The amount of buoyant force at a given altitude depends on the difference in density between the fire-modified air and the atmosphere at that altitude: larger differences in density increase the magnitude of the force. The maximum vertical velocity of the air can be determined by aggregating the buoyant force throughout the lower levels of the atmosphere, with a larger aggregated buoyant force corresponding to a stronger potential updraft. A common measurement that indicates the magnitude of the aggregated buoyant force is static stability, calculated as the vertical gradient of temperature over an atmospheric layer. Lower static stability corresponds to a larger vertical temperature gradient and indicates a larger aggregate

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buoyant force as air rises through the layer.

Changes in the speed and direction of horizontal winds as a function of height also play an important role in how high the buoyant force can lift air. Greater wind shear leads to increased turbulence and mixing and typically reduces buoyancy (Moeng and Sullivan 1994). The result is greater mixing but often less lofting of air from the surface.

Pyroconvection, Pyrocumulus, and Pyrocumulonimbus

Pyroconvection, pyrocumulus, and pyrocumulonimbus are three terms often used by the fire and fire weather communities. Although the terms are often treated as interchangeable, each term has a specific and distinct definition that parallels its respective nonfire definition but with “related to fire” added (see, for example, AMS (2012a)). Thus, pyroconvection is the vertical transport of atmospheric properties driven by or enhanced by fire. Every fire, no matter how small, produces some degree of pyroconvection.

A pyrocumulus (or pyroCu, fig. 1) forms when moist rising air from pyroconvection reaches a condensation level, producing a cumulus cloud. The formation of a pyroCu is not uncommon on prescribed fires and agricultural burns and is not necessarily cause for concern.

A pyrocumulonimbus (or pyroCb, fig. 2) is an extreme manifestation of a pyroCu. It develops when upward moving air over a wildland fire is reinforced by instability in the middle troposphere such that a very deep convective cloud forms (Fromm and others 2008, 2010).

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PyroCu and pyroCb are important for smoke lofting and transport, but studies have not established whether their formation signals a substantial change in upcoming fire behavior. In most cases, the character of pyroconvection is driven by earlier events that altered the energy released by the fire, such as a sudden change in fire size and intensity due to changes in surface winds, fuel load, or terrain.

Figure 1—*A pyrocumulus forming over a wildland fire. Moist rising air from pyroconvection reaches a condensation level, producing a cumulus cloud. Photo: Candace Krull, Forest Service.*

Figure 2—*A pyrocumulonimbus forming over a wildland fire. Upward moving air, reinforced by instability in the middle troposphere, results in the formation of a very deep convective cloud. The photo is of the 2013 Carpenter 1 Fire in Nevada. Photo: Zachary Parmentier, Forest Service.*

Downbursts

A downburst is an area of strong, often damaging winds produced by one or more convective downdrafts in a localized area (AMS 2012b). Convective downdrafts are a common occurrence during convective precipitation events, and they often lead to the formation of an outflow boundary and a change in surface wind speed, wind direction, and humidity. It is important for fire managers to be aware of the potential for outflow boundaries from any nearby convection to affect fire behavior and smoke. However, it is also important for fire managers to distinguish between convective downdrafts and downbursts.

A downburst is substantially less common than a convective downdraft, occurring when heavy precipitation evaporates in dry air beneath the base of a convective cloud (Wilson and Wakimoto 2001). Downbursts can contribute to very sudden changes in surface winds, moisture, and temperature (Byers and Braham 1949). The magnitudes of these changes are greater for a downburst than for a convective downdraft and are capable of affecting fire behavior (Fujita 1992).

In most cases, downbursts occur several miles away from the primary convective updraft (Wilson and others 1988). Downbursts usually require heavy precipitation, which can only occur when the updraft in the convective cloud produces significant condensation. For a downburst to form, the precipitation must fall into dry air and evaporate as it falls, which implies that it must fall somewhere other than into the (relatively moist) updraft that produced it. A meteorological environment capable of producing these characteristics would therefore have a horizontal wind that shifts the downburst to the other side of the updraft.

These requirements make it unlikely (though still possible) that a downburst produced by pyroconvection would reach the ground close to the fire. Only under rare circumstances would a pyroCu or pyroCb cloud generate a downburst that could alter fire behavior; it would occur only under the influence of a very particular wind shear configuration.

A cautious understanding of science and close collaboration between fire managers and meteorologists can help protect firefighters.

On two historic wildfires, however, fatalities are attributed, at least in part, to downbursts: the 2013 Yarnell Hill Fire and the 1990 Dude Fire. Both fires occurred with thunderstorms nearby. In the case of Yarnell Hill, the official investigation report suggests that downbursts only could have come from the nearby thunderstorms (ADFFM 2013). The documentation of the Dude Fire is less clear; it suggests that a nearby thunderstorm may have been intensified by the fire and subsequently produced a downburst (Goens and Andrews 1998). There are no clearly documented cases of pyroconvection alone producing a downburst.

Firefighters often state that downbursts occur soon after a visible change occurs at the top of a convective column during a fire (the so-called “plume collapse” or “capping”). The ingredients for downburst formation are the magnitude of the convective updraft, the amount of precipitation formed, very low relative humidity below the cloud base, and a supportive wind profile. There is no scientific evidence for downbursts forming as a result of visible features appearing at the top of a convective cloud. Additional research is needed to assess the credibility of cases in which plume collapse has been anecdotally associated with downburst formation and changes in fire behavior.

A Cautious Understanding

Fire activity clearly produces pyroconvection. However, what influence pyroconvection may have on the behavior of a wildland fire is not well understood, which makes it difficult to assess and predict. Clark and others (1996) found in a numerical modeling study that near-ground convection produced by a fire plays a role in the development of characteristic fire behavior patterns. However, the role of convection through deeper layers of the atmosphere (such as a pyroCb) in fire behavior is less clear. As indicated in Potter (2012), wildland fire studies that include an assessment of convection have yet to establish a clear quantifiable connection between convective characteristics (such as updraft strength and cloud depth) and fire behavior. Observational and numerical modeling studies of nonfire convection suggest that elevated updrafts are fed primarily by air entrained and mixed into the updraft well above the base of the cloud (Kain and Fritsch 1990; Kuang and

Bretherton 2006). The extent to which this applies to pyroconvection is not yet known.

Although convection-related phenomena have been extensively studied in meteorological field studies, in theoretical papers, and by using numerical models, there is still considerable uncertainty concerning precisely how they interact with wildland fires. Some of the anecdotal evidence for how these phenomena affect fire behavior does not agree with the meteorological understanding of the processes involved, and other possible connections have yet to be fully investigated and tested. A cautious understanding of the state of this science and close collaboration between fire managers and meteorologists can help protect firefighters from possible convective influences on fire behavior while the research community works to clarify the influences using improved modeling and observational tools.

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