OFF THE RICHTER: MAGNITUDE AND INTENSITY SCALES FOR WILDLAND FIRE

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INTRODUCTION

Quantitative scales of wildland fire magnitude and intensity are needed to assess and publicly communicate the unbiased potential of wildland fire to cause effects—harm, damage, and ecological change. Such scales already exist for earthquakes (Richter Scale and Mercalli Scale), hurricanes (Saffir-Simpson Scale), tornadoes (Fujita Scale), and even near-Earth objects (Torino Impact Hazard Scale). Standard quantitative scales of wildland fire magnitude and intensity would (1) set a standard for communicating important fire characteristics to the public, and (2) provide a context for public understanding of the potential for a fire to cause harm or damage (see Binzel 1997).

The magnitude of a natural event like wildland fire—its potential to cause effects—is a function of energy release rate. Magnitude is a measure an event as a whole; a high-magnitude event has great potential as a whole to cause harm or damage. That potential is not necessarily uniform. Some parts of a high-magnitude event have little potential to cause effects—the rear of a large fire, for example—whereas other parts have great potential. The potential for causing effects at any particular place is measured as intensity, the rate of energy release at that place and time. Magnitude and intensity are measures of *potential* to cause effects; actual effects are also a function of exposure—the presence of susceptible values in a hazardous situation. A high-magnitude event can cause no damage if no susceptible values are exposed to it.

A WILDLAND FIRE INTENSITY SCALE

Byram (1959) defines fireline intensity (I_B) is the rate of heat release per unit length of fire front ($kW \cdot m^{-1}$), regardless of flame front depth. I_B is a fundamental fire characteristic variable containing "…about as much information about a fire's behavior as can be crammed into one number" (Van Wagner 1977).

$$I_B = H * w_f * \left(R/60 \right) \qquad [1]$$

where H is the low heat of combustion ($kJ \cdot kg^{-1}$), w_f is the load of fuel consumed in the flaming fire front ($kg \cdot m^{-2}$), and R is the linear rate of spread ($m \cdot min^{-1}$). I_B can be estimated or simulated for any spatially explicit landscape element on a past or future fire. The resulting values of I_B span nearly five orders of magnitude, from less than 10 kW m^{-1} for a slow-spreading fire in light fuel to more than 100 000 kW m^{-1} for a fast-spreading fire in heavy fuel. This very large range of I_B makes communication and interpretation difficult. As a simple scale for communication with the media and public, I propose to use the common logarithm of I_B ($kW \cdot m^{-1}$) as a scaled measure of wildland fire intensity (I)

$$I = Log_{10}(I_B) \quad [2]$$

For the range of I_B noted above, I ranges from less than 1 to just greater than 5 (six classes).

A WILDLAND FIRE MAGNITUDE SCALE

The rate of energy release of a fire as a whole is termed total fire flux (Catchpole and others 1982). Total fire flux, $\int I_B$, is the integral of fireline intensity around the perimeter of a fire. If a fire perimeter is broken down into n segments of uniform I_B, then $\int I_B$ (kW) is the sum-product of I_B and segment length for all segments around the perimeter. Total fire flux can also be calculated as (Catchpole and others 1982)

$$\int I_B = \left(\frac{dA/dt}{60}\right) H w_f \quad [3]$$

where dA/dt is the rate of fire area increase ($m^2 \cdot min^{-1}$). For example, if a fire's area is known at two points in time, average area growth rate is simply the difference in area divided by the time interval. For an elliptical fire in uniform conditions

$$dA/dt = 2\pi abt \quad [4]$$

where t is the time (min) since start of point-source fire growth, and

$$a = \frac{R_{head}}{1 + \sqrt{1 - L_B^{-2}}} \quad [5]$$

$$b = \frac{a}{L_B} \quad [6]$$

where R_{head} is the linear rate of fire spread in the heading direction and L_B is the length-to-breadth ratio of the fire. Andrews (1986) estimated L_B as a simple function of effective mid-flame wind speed (U_e).

$$L_B = 1 + 0.155 * U_e \quad [7]$$

for U_e measured in $km \cdot h^{-1}$. It is not necessary to know t explicitly (which requires an unrealistic assumption of constant fire growth conditions throughout the time period) as long as current fire size is known, because for an elliptical fire the effective time required to achieve a given size is

$$t = \sqrt{A/\pi ab} \quad [8]$$

and therefore

$$dA/dt = \sqrt{4\pi abA} \quad [9]$$

where A is the area (m^2) of the fire.

Like I_B, total fire flux ranges over many orders of magnitude. An incipient fire of 1 m^2 with $L_B = 1.0$ that consumes 0.1 $kg \cdot m^{-2}$ in the flaming front and spreads at 0.5 $m \cdot min^{-1}$ produces 55 kW ($I_B = 15$ $kW \cdot m^{-1}$ around all portions of the perimeter). In contrast, a 100 000 ha fire of $L_B = 4.0$ that consumes 4.0 $kg \cdot m^{-2}$ in the flaming front and spreads 100 $m \cdot min^{-1}$ at the head produces a theoretical 3.5 billion kW (with corresponding $I_B = 125\ 000$ $kW \cdot m^{-1}$, and $I = 5.1$). Because of the huge theoretical range of $\int I_B$, and to satisfy the need for a simple measurement for communication with the media and public, I propose to use the common logarithm of total fire flux (kW) as a scaled measure of wildland fire magnitude (M), and to categorize magnitude by factors-of-ten.

$$M = Log_{10}\left(\int I_B\right) \qquad [10]$$

For the range of total fire flux noted above, M ranges from less than 1 for an incipient fire to greater than 9 for a large, fast-growing fire in heavy fuel (resulting in ten classes).

SUMMARY AND CONCLUSIONS

The magnitude and intensity scales defined here standardize the measurement and communication of two important fire characteristics with the public: intensity of any portion of a fire and its magnitude as a whole. Like the Richter Scale for earthquake magnitude, the wildland fire scales are logarithmic, which minimizes the effects of measurement error and fully exposes the wide range of variability of both I_B and $\int I_B$. The intensity scale relates to a particular point on a fire's perimeter at a particular time; it can be mapped for a past or potential fire. The magnitude scale applies to the whole fire at a particular point in time.

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