Fuel moisture lag effects in fire spread calculations

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Abstract: Fine fuel moisture content (particularly dead fuel) strongly affects bushfire rate of spread, yet many operational systems assume fuels respond instantaneously to weather. Here we examine the implications of moisture response lag for fire spread calculations and present a lightweight approach suitable for operational integration in fire spread calculations. We consider fine-fuel moisture dynamics as a first-order linear system

$$\frac{dm}{dt} = \frac{\mu - m}{\tau},$$

where $\mu(t)$ is the equilibrium fuel moisture and τ is a fuel-specific response time. We then introduce an adiabatic approximation, valid in the limit of small fuel response time relevant to fine fuels. In this limit we show analytically that a 'shifted-weather approximation', which simply applies time-shift of the weather by τ, closely reproduces the full solution to Eq. (1). For weather varying on timescale T, the error scales as $(\tau/T)^2$.

To assess sensitivity to fuel response time, we then compare this approximation for two common examples: i) diurnal variations and ii) a sudden cool change. We compare the approximation against solutions to Eq. (1) and apply the resulting moisture predictions to Australian Fire Danger Rating System (AFDRS) rate-of-spread models for grasslands (CSIRO Grasslands Model) and eucalypt forest (Vesta Mk-I/II). Our analysis shows that this shifted weather approximation considerably reduces error in rate of spread and fire progression calculations, even outside the strict regime of the approximation's validity. We additionally show the approximation also generally reduces both error and bias for an example calculation using a real weather stream.

Finally, we discuss implications for operational fire spread calculations within the AFDRS, and for fire spread simulators such as *Spark Operational,* which largely use dead fuel moisture estimated from current meteorological conditions.

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