Stochastic models for wildfire spread

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We present an integro-differential space–time continuous stochastic model for wildfire spread together with a differential limit derived from the latter considering only the short range fire propagation and neglecting the firebrand spotting. Both models describe the state of the system through subprobability densities for green, burning, and burnt vegetation.
As regards the first model, the formulation leads to a system of integro-differential equations, where dynamics is driven by a nonlocal kernel encoding wind, slope and spotting. The model can directly ingest georeferenced data (e.g., satellite products via KDE), and provides probabilistic forecasts without resorting to massive ensembles of cellular automata simulations. This construction, its physical interpretation, and initial simulations in idealized scenarios (including crossing a river via spotting) are detailed in refererence 1, together with the proof of well-posedness.
In reference 2, from this model we derive an approximating reaction–diffusion –convection–ODE system for the same macroscopic fields. The nonlocal transport operator with short–range kernel of the first model is asymptotically expanded (second–order moment closure) into a uniformly parabolic diffusion–convection operator that retains wind– and slope–driven biases, while firebrand spotting is neglected.
The two descriptions are compared on identical scenarios: when spotting is inactive and kernel support is short (relative to the domain and timescale), the macroscopic fields from the local model track those from the stochastic model, while discrepancies appear precisely when long–range spotting drives spread (a regime intentionally excluded in the differential limit). This clarifies the range of validity of the approximation and connects the data–driven stochastic formulation to a tractable PDE model suitable for analysis and fast forecasting.
The well-posedness of the differential model has been also proved.
Keywords: Wildfire modelling; stochastic integrodifferential systems; reaction–diffusion–convection equations; Schauder estimates; fixedpoint methods.

[1] Reference 1. R. Beneduci, G. Mascali, Forest fire spreading: a nonlinear stochastic model continuous in space and time, Studies in Applied Mathematics, 153 (1), (2024), 26 pp.

[2] Reference 2. R. Beneduci, G.Mascali, A Reduced Stochastic Model for Wildfire Spread based on PDEs, submitted (2025).

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