Surrogate-based analysis of turbulence and fire-spotting in wild-land fire modelling: unravelling the secrets of fires

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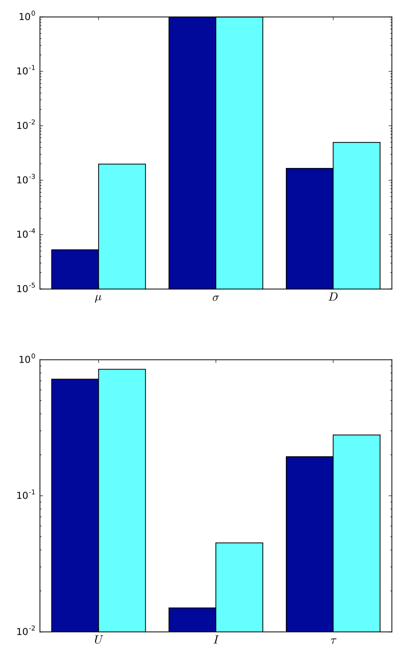
In the framework of wild-land fire modelling, before implementing a sub-model to a fully fledged operational simulator, its sensitivity on the input parameters needs to be established, as well as the quantification of the uncertainties that affect the observables given by each simulation. In this work we consider the model discussed in [1]. We recall that this model accounts for the effect of turbulence and fire spotting via implementing the effect of statistical fluctuations over the deterministic contour of the fireline, that can be given by any front propagation algorithm. A lognormal distribution with mean and standard parameters μ and σ is employed to describe the downwind distribution of the firebrands. On the other hand turbulent diffusion is assumed to be isotropic and modelled by a Gaussian PDF characterised by its turbulent diffusion coefficient, D. The ignition of the falling embers is governed by a time scale parameter τ, and the fireline follows the Byram formula with fire intensity I.

The objective of this work is the variance-based sensitivity analysis and the determination of the statistical properties of the burnt area at a given time, $h(t)$, given the uncertainties on the input parameters, divided here in two sets. The first one is made of parameters that act on the PDFs, that is $\{\mu, \sigma, D\}$, while the second one is made of the wind speed U, the fireline intensity I and the time scale τ. In this scenario, a Montecarlo approach is not viable due to the high computational cost of the model evaluations. A surrogate modeling approach is therefore pursued, designing surrogate fire spread observable h with a weighted finite sum of basis functions:

$$\widehat{h}\,(\mathbf{x}) = \sum_{i=0}^{r} \gamma_i \, \Psi_i \,(\mathbf{x})\,, \tag{1}$$

where the coefficients γ_i and the basis functions Ψ_i are calibrated by the training set $\mathcal{D}_N$ of the actually performed simulations. Different families of surrogate models are investigated, Gaussian Process Surrogates (GP) and Polynomial Chaos (PC) [2, 3]. To overcome the low budget of the training database, the performances of recent advancements in sparse techniques for PC surrogates [4], such as Hyperbolic Truncation, sparse basis selection strategies, and Least Angle Regression (LAR) are evaluated and discussed. This extensive and complete analysis assessed the relevance of U and σ in the fire spotting phenomenon.



Partial (dark blue) and total (sky blue) Sobol Indices:
for the set $\{\mu, \sigma, D\}$ (top) and for the set $\{U, I, \tau\}$ (bottom).

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