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Recent Advances in Data-Driven Wildland Fire Spread Modeling: Treatment of Position Errors and Joint State-Parameter Estimation

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Real-time forecast of wildland fire spread is still a key challenge for fire emergency response. Current operational wildfire behavior simulators lack the ability to provide accurate prediction of the active flame burning areas at regional scales due to two main challenges: a modeling challenge associated with providing accurate mathematical representations of the complex physico-chemical processes underlying wildfire behavior on the one hand; and a data challenge associated with providing accurate estimates of the initial fire state and the physical parameters that are required as inputs to the fire spread models on the other hand. As recent progress made in remote sensing technology provides new ways to monitor wildfires, a promising approach to improve wildland fire forecasting capability is to integrate fire modeling and fire sensing technologies using data assimilation [1].

The main objective of the present work is to design and evaluate a dynamic data-driven application system for wildfire spread monitoring and forecasting, which is able to properly handle the anisotropy in regional-scale wildfire spread due to the significant spatial heterogeneity in the model parameters and to the temporal changes in the wildfire behavior. At these scales, the wildland fire is represented as a propagating front separating burnt/unburnt areas and referred to as the "fireline".

In its early version, our data-driven application system treated the observed fireline as a discretized contour with a finite set of markers. The distance between these simulated and observed fronts (referred to as the "innovation") was computed by pairing each observed marker with its closest neighbor along the simulated front. However, this selection procedure is difficult to scale up to regional scales at which wildland fires feature complex front shape and topology. To overcome this issue, we propose a new method to represent the distance between observed and simulated firelines. This method – deriving from object detection in image processing theory and already adapted in the context of electrophysiology data assimilation [2] – formulates a shape similarity measure based on the Chan-Vese contour fitting functional. We thus propose a new innovation term based on this shape similarity measure that is able to handle position errors and not only amplitude errors as in standard data assimilation formulations. The resulting innovation formulation is adapted to both Level-Set and Lagrangian front-tracking solvers.

To retrieve more accurate physical values of the input parameters and improve forecast performance, we also developed a joint state-parameter estimation method based on this new innovation term. In our case, we choose to base our state estimation on direct nudging correction, whereas the input parameters of the fire spread model are estimated with an ensemble-based Kalman algorithm. To ensure a meaningful feedback on the controlled parameters is achieved, the sensitivity of the innovation to changes in the parameters is studied using metamodel methods.

All these efforts aim at providing solutions to better simulate regional-scale wildfires [3][4]. These new methodological elements are illustrated using verification tests as well as validation tests against the 2012 S5 RxCADRE controlled burn [5] and the Rim fire hazard [6]. We obtained promising results paving the way towards the real time monitoring of wildfire behavior. These results are the fruit of a collaborative work between CERFACS, Inria, LIMSI and the University of Maryland in the USA, which was strengthened by the 2016 CEMRACS Summer Program. This research was partly funded by a LEFE-MANU grant.

References

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