Assimilation of fire perimeter data into the fire spread model SFIRE coupled with the WRF model

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Abstract

Fire simulation starts from an ignition point, and when fire perimeter data are assimilated, the state of the fire spread model is changed to become closer to the data. This, however, presents a difficulty in coupled fire-atmosphere models. The fire has a very strong effect on the atmosphere and changes in atmospheric state, due to the fire, take time to develop, so the existing atmospheric circulation is no longer compatible with the modified fire. Moreover, linearized changes to the atmospheric state have no hope of establishing the properly changed circulation in a physical balance. We have recently developed a technique for the fire ignition calculation from the perimeter data, which goes back in time and replays an approximate fire history to allow the proper atmospheric circulation patterns to develop. Here, we extend this technique to the assimilation of a fire perimeter into a developed fire state with an established atmospheric state. The SFIRE model uses the level set method to simulate the fire spread. Our data assimilation approach takes advantage of the manipulation of the fire state through level set functions, which is much easier than manipulating the fire areas directly. The new method is applied to a real fire case study.

Problem

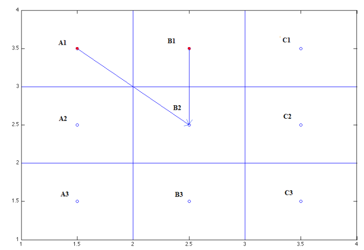
-How to get to a reasonable atmosphere state?
-How to avoid violating vertical CFL condition that occurs in cases of igniting the whole area within the perimeter simultaneously (as occurred in the original scenario)?
- In order to realize the above two conditions, the model needs to start from the ignition point.
-Solution: Artificial data to fill in the missing data history needs to be created

Algorithm

Goal: Calculate artificial data, which contains time of ignition of the area, based on the given perimeter and its time of ignition (time_now).

- The algorithm consists of two parts: in the first part, the points of the mesh that lie inside the perimeter are set to time_now, and the points outside of the perimeter are calculated; the second part is the opposite way (the points outside the perimeter are set to time_now, and the points inside are updated).
- Each point that is computed at least once is marked. The computation stops once all the points are marked. Marked points are continuously updated until all points are marked.
- The point will be updated if at least one of its neighbors is marked. If the point is outside of the perimeter, then the minimum of all the values that were computed from different marked neighbors is taken. If the point is inside, then the maximum is taken.

Calculation of time of ignition of point B2



(Figure 1)

In the example above, the time of ignition of point B_2, which is outside of the perimeter area, is being computed.

Points A_1 and B_1 are marked (were already computed);

Points A_2, A_3, B_3, C_1, C_2 and C_3 are not marked.

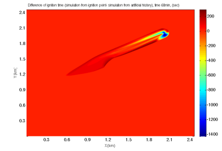
Thus, $tign(B_2) = \min\left(tign(A_1) + \Delta t_{A_1} ; tign(B_1) + \Delta t_{B_1} \right),$

where $\Delta t_{A_1} = \left| \overrightarrow{A_1B_2} \right| * ROS\left(\frac{\left\langle \overrightarrow{A_1B_2} \bullet \overrightarrow{V_{A_1}} \right\rangle}{\left| \overrightarrow{A_1B_2} \right|} \right),$

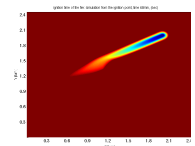
here $\overrightarrow{V_{A_1}}$ - the gradient of the wind at point A_1 ;

$ROS\left(\frac{\left\langle \overrightarrow{A_1B_2} \bullet \overrightarrow{V_{A_1}} \right\rangle}{\left| \overrightarrow{A_1B_2} \right|} \right)$ - the rate of fire's spread directed from point A_1 towards point B_2 also depends on the gradient of the wind.

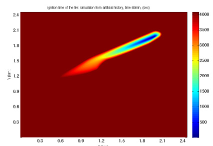
Computational results: Time of ignition



(Figure 2)



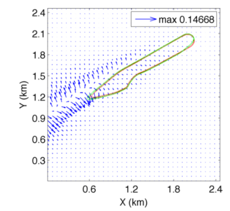
(Figure 3)



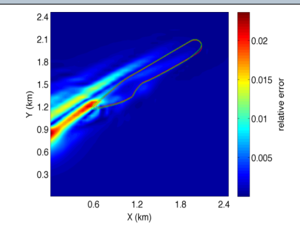
(Figure 4)

(Figure 2) -- Perimeter and time of ignition taken at time (40 minutes) are used to create the artificial data.
(Figure 3) – Time of ignition of the original simulation, that runs from the ignition point, taken at time (68 minutes).
(Figure 4) --Time of ignition of the propagation model, that runs from the artificial data history, taken at time (68 min).

Wind Difference



(Figure 5)



(Figure 6)

(Figure 5) – The difference in the winds of the original simulation and artificial propagation at 68 minutes.
(Figure 6) – The relative error in the speed of the wind at time 68 minutes.

Acknowledgments

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References

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