Geophysical Research Abstracts
Vol. 15, EGU2013-9521, 2013
EGU General Assembly 2013

High-resolution numerical coupling of wildfire and lava flow simulation with a micro scale atmospheric model

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A coupled approach between Meso-NH (Non-Hydrostatic) LES (Large Eddy Simulation) meso/microscale scale atmospheric model and ForeFire area simulator is proposed for predicting fine-scale properties of surface propagating systems. Originally developed for large wildland fire simulation (with or without atmospheric coupling) ForeFire has been extended for the simulation of lava flow with the same numerical methods.
Similarities in both problems include the requirement to take into account high-resolution topography for the simulation of front dynamics and the requirement to use atmospheric sub-mesh models in order to quantify surface energy and species fluxes to the atmosphere.
To be representative of the phenomenon, typical resolution required for the simulation of a fire front or a lava flow is sub-meter (to have an explicit flame depth or narrow flow width) while atmospheric simulation of a typical domain (several tens of square kilometres) may not be performed at a resolution of finer than 50 meters in a reasonable computational time.
Front tracking is performed by means of Lagrangian markers that allow simulating interface dynamics at high spatial resolution, temporal scheme is event based with a Courant–Friedrichs–Lewy constant time step calculated for each marker iteration, allowing efficient simulation focused on active flow areas.
The Lagrangian front dynamics is used to construct a “time of arrival” high-resolution field that is used to perform local budgets of the different surface fluxes models in a way similar to the level-set method.
The two way coupling in a Meso-NH/ForeFire simulation typically involve the surface wind to drive the fire or cool the lava surface, and heat and water vapour fluxes to be injected in the atmosphere at each atmospheric time step.
The ForeFire code has been built so that several front velocity function could be easily defined and applied at different locations of the surface (e.g. a fire front velocity model could be different in forest with canopy than in grassland), likewise surface fluxes models (combustion, eruption) can be added and defined in the same way, superposed as surface layers with each layer corresponding to an energy, mass or species flux that will be forced in the atmospheric model.
Meso-NH and ForeFire resolutions are independent and the computational time needed by the surface model is a typically a fraction of the atmospheric simulation. Parallel strategy for the surface model mimics the one in the atmosphere model (with Lagrangian markers sent between parallel sub-domains), thus recovering the parallel efficiency of the atmospheric optimized parallel design.
High-resolution simulation on a large wildfire experiment shows that coupled simulation does compare with the experiment with a better behaviour and more insight (atmospheric flow) than non-coupled simulations. Simulation of the 2007 eruption of Piton de la Fournaise (La Reunion Island, France), as well as the 2009 3000 Ha Aullène fire (Corsica Island, France) show that computations can be performed at large scale in good accordance with observation in a reasonable computational time.