5A.4 FOREST FIRE IMPACT ON AIR QUALITY: THE LANCON-DE-PROVENCE 2005 CASE

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1. INTRODUCTION

In Mediterranean region climate change is making weather conditions more extremes, allowing huge forested areas to become ignited. Forest fires are a risk to the environment and to communities, moreover wildfire represent a significant source of gas and aerosols. Depending on the meteorological conditions, these emissions can efficiently perturb air quality and visibility far away from the sources.

The aim of this work is to simulate the interactions of a mediterranean fire with its environment both in terms of dynamics and air quality.

2. FIRE-ATMOSPHERE COUPLING

The fire spread model ForeFire has been coupled with the French mesoscale atmospheric model Meso-NH to better characterize the impact of fire dynamics and chemistry on the air quality downwind of the burnt area.

The case study is Lançon-de-Provence 2005 forest fire: a typical Mediterranean wildfire burst in the South-East of France. This fire burnt 700 ha of Mediterranean ecosystem in a few hours in a complex topography context.

The Lançon-de-Provence case has already been simulated successfully by several fire propagation models, including ForeFire, and thus constitutes a good benchmark for testing the coupling and its forecasting performances.

2.1. Meso-NH

Meso-NH is an anelastic, non-hydrostatic mesoscale meteorological model, designed for simulating the atmospheric motions from large (synoptic) to small (large eddy) scales (Lafore et al., 1998). The model was developped jointly between Meteo-France and Laboratoire d'Aerologie (CNRS). In the present study, Meso-NH is run with four interactively nested domains whose horizontal mesh sizes are, respectively, 25, 5, 1 km and 200 m (Figure 1). The simulation starts on June 29, 2005, 00:00 UTC, and is integrated for 72 h, with different time steps for each domain. The initial and boundary conditions for the dynamical variables are taken from ECMWF operational reanalyses.

The vertical grid had 72 levels up to 23 km with a level spacing of 40 m near the ground and 600 m at high altitude. The microphysical scheme included the three water phases with five species of precipitating and nonprecipitating liquid and solid water (Pinty and Jabouille, 1999). The turbulence parametrization was based on a 1.5-order closure (Cuxart et al., 2000). For the coarser grid, the mixing length followed the method of Bougeault and Lacarrère (1989) and the turbulent fluxes were purely vertical, whereas three-dimensional turbulent fluxes were modelled for the innermost domain. Radiative processes are represented with the ECMWF radiation scheme RRTM (Mlawer et al., 1997). The surface energy exchanges are parameterized according to four different schemes depending on the surface types (nature surfaces, urban areas, oceans, lakes). The natural land surfaces are handled by the Interactions Soil-Biosphere-Atmosphere (ISBA) scheme (Noilhan and Planton, 1989). The model simulates the concentration of 40 chemical species with 73 chemical reactions (Crassier et al., 2000).

In the following only the results of the 1 km grid-mesh domain are shown.

2.2. ForeFire

ForeFire is a simplified physical wildifire model developped at the University of Corte (Filippi et al., 2009).

The advance of the front fire is simulated using an

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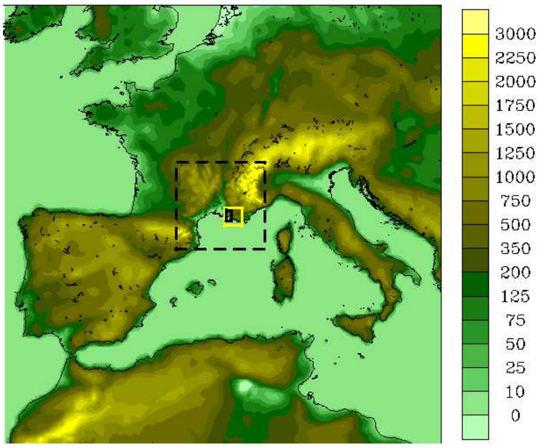


Figure 1: Geographical domains used for the nested simulation. The outer frame shows the 25 km grid-mesh model domain and its topography (in m). The location of the 5 km grid-mesh domain is indicated by the dashed square, the solid yellow square shows 1 km model boundaries, the innermost domain is the 200 m grid-size model.

analytical formulation for the Rate of Spread (RoS) given a slope, a wind speed and fuel parameters. At each time step, a front tracking algorithm (Figure 2) reconstructs the shape of the front fire by displacing each front agent according to RoS information.

Compared with the well-known Rothermel model, ForeFire provides a physical formulation for the RoS. In ForeFire wind and slope effects are explicitly taken into account in the RoS model by calculating a flame tilt angle; instead in the Rothermel model effects of wind and slope are expressed as coefficients experimentally fitted to wind values *as if the fire was not there* (Filippi et al., 2009).

At finer resolution, forest fires are subgrid scale processes. A one-way coupling is initiated between the fire and atmospheric models and is accomplished through the surface scheme ISBA. Radiative temperature, heating and water vapour fluxes from the fire model are taken as inputs at the lowest level and at each timestep of the atmospheric model. ForeFire also provides the information on the burnt area which is used to calculate the chemical emissions. Emissions are obtained in a two-step process. First, an estimate of the emission of carbon is calculated based on biomass burned density and emissions factor found in the litterature for mediterranean scrublands, *garrigues* (Miranda, 2004; Miranda et al., 2008). Second, an estimate of the emissions for the other gases is deduced using emissions ratios with respect to carbon (Andreae and Merlet, 2001).

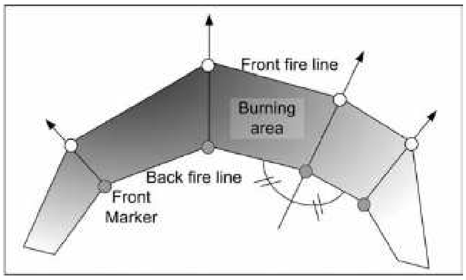


Figure 2: The front tracking method of markers adopted by ForeFire. Grey circles represent markers along the back fire line. Arrows show the propagation vector (bisector of the local angle at the marker). White circles along the front fire line show the projected locations of the markers after the local burning duration (Filippi et al., 2009).

3. APPLICATIONS

3.1. A case study: Lançon-de-Provence 2005

On 1 July 2005, a forest fire broke out southeast of Lançon-de-Provence (SouthEast France), threatening downwind inhabitated areas and cultivated lands. The fire started at about 09:40 AM local time. Thanks to low humidity and strong winds, it lasted nearly 8 h. Lançon-de-Provence fire spread over 626 ha (roughly 6 square kilometers), on a surface mainly covered by *garrigues*, a type of low, soft-leaved scrubland found around the Mediterranean Basin, generally near the seacoast.

On 30 June, 2005, the Meso-NH simulated synoptic situation over western Europe is characterized by a strong pressure gradient with high pressure over the Atlantic Ocean and a cyclonic situation over the Gulf of Genova. This gradient together with the tunnel between the Alps and the Massif Central favours a strong northwesterly wind, the so-called *Mistral* (Figure 3(a)).

On 1 July, 12:00 UTC, the wind speed is around $11\,\mathrm{m\,s^{-1}}$ South-East of Lançon where the fire lighted up. Figure 3(b) shows the sensitivity of the wind intensity to the fire at the same time, 3 hours after the fire ignition: the wind intensity more than doubled close to the ignition area, with a decreasing sensitivity further downwind. The simulated behaviour of surface wind speed is consistent with the observations by Clements et al. (2007).

Fire impacts on the atmospheric stability have been analyzed along the tilted axis shown in Figure 4(b) on July 1, 2005 at 12:00 UTC.

3.2. Fire impacts on atmospheric dynamics

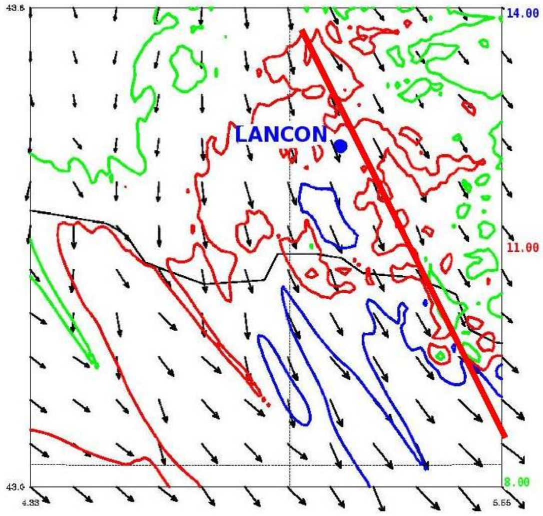
Without the fire forcings, the boundary layer had a well stratified stable vertical structure (not shown). When the fire is activated, the vertical structure of the equivalent potential temperature, θ_e, is strongly perturbed. Figure 4 shows the vertical cross section of $\Delta\theta_e$: the difference of θ_e calculated between the fire forced and no fire simulation. Negative differences for θ_e are simulated below and above the fire plume as evidences of dryer conditions downwind of the fire.

The extreme conditions reached for this fire induce the formation of fire clouds above the burnt area. Figure 5(a) shows the water vapor flux (colors), expressed in kg/kg m/s, and heating flux (hatching), in K m/s, along the same axis as above. The heating fluxes reach maximum altitude and intensity over a very localized region. Maximum in water vapor fluxes marks the location of the clouds in the free troposphere downwind of the ignition area.

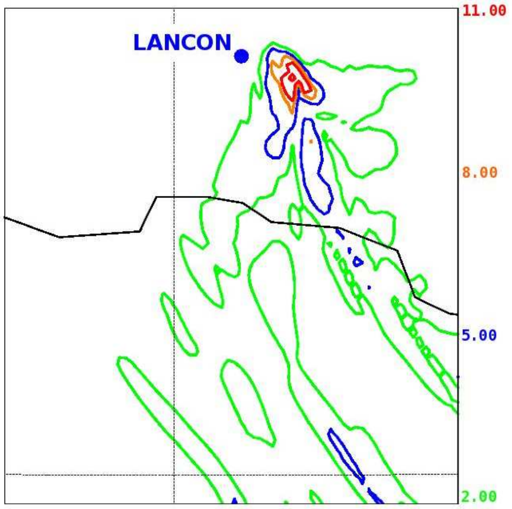
A passive tracer is emitted proportionally to the burnt area in the model. Figure 5(b) presents the vertical cross section along the wind direction of the concentration, in ppbv, of a passive tracer (colors) which mimic the fire emissions, and the Turbulent Kinetic Energy (TKE) in m^2 s^{-2} (hatching). This figure illustrates the strong vertical transport of the fire tracer up to 4.5 km altitude, which is in the higher range of observed injection heights above Portuguese fires, for exemple Hodzic et al. (2007).

The sensitivity studies reveals that the dynamics of the atmosphere is perturbed by the injection of water vapor fluxes by the fire. The importance of latent heat fluxes was highlighted by Clements et al. (2007) and Parmar et al. (2008), in contrast with the study of Trentmann et al. (2006) who rejected this influence in their modeling study. Finally, the impact of fire on atmospheric tracers is effective several hundreds of kilometers downwind of the burnt area.

Figure 3: Horizontal ground pattern of wind on July 1, 2005 at 12:00 UTC.



(a) Wind module (m s^{-1}) and vectors. The tilted axis shows the direction along with fire impact on atmospheric dynamics have been investigated.



(b) Difference on wind speed (m s^{-1}) between a simulation with and without forcings by the fire.

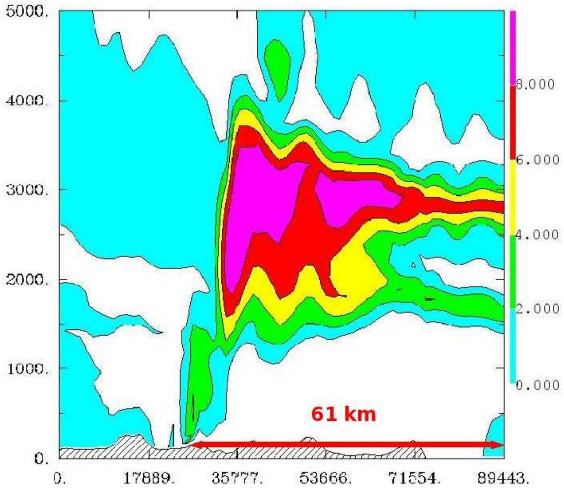


Figure 4: Vertical cross section of the difference on Equivalent Potential Temperature (K) between a simulation with and without forcings by the fire. The cross section is obtained along the wind direction on July 1, 2005 at 12:00 UTC. Both the height and the distance along X axis are expressed in meters.

3.3. Air quality downwind of the fire

Preliminary results on the chemical composition of the fire plume reveal high concentrations of CO, NO and others VOCs near the fire. The chemical plume extends toward the sea with a strong decreasing concentrations as shown by the horizontal pattern of CO concentration (in ppbv) shown in Figure 6.

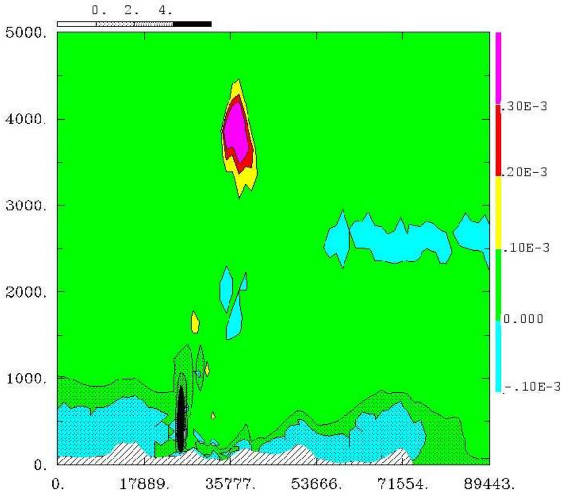
In order to investigate the air quality downwind of the fire, the simulation of Section3.2 was run introducing additionally a correction for the difference in resolution between the finest Meso-NH grid and ForeFire grid. This correction results in a dilution of the latent and sensible heat fluxes produced by ForeFire. As a result, the height of the plume, shown in Figure 7, is 1.5 km lower than that of the uncorrected simulation, Figure 5(b).

4. CONCLUSIONS AND PERSPECTIVES

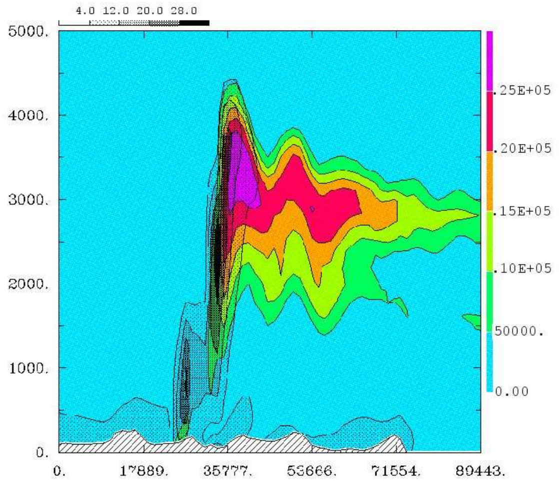
The study illustrates the sensitivity of the atmospheric dynamics and air quality situation to the coupling between a fire and an atmospheric model.

Concerning atmospheric dynamics, the coupled atmosphere-wildfire modeling recreates some of the

Figure 5: Vertical cross sections of some atmospheric variables on July 1, 2005 at 12:00 UTC. The cross sections are obtained along the wind direction. In the plots, both the height and the distance along X axis are expressed in meters.



(a) Water vapor flux in Kg/Kg m/s (colors) and heating in K m/s (hatching) flux.



(b) Passive tracer concentration (colors), in ppbv, which mimic the fire emissions and TKE (hatching) in m^2 s^{-2}.

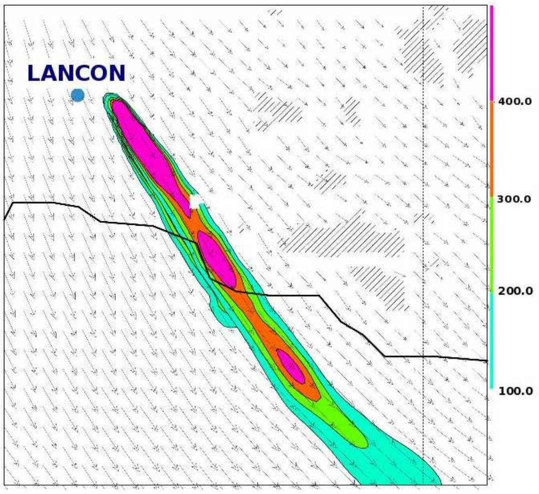


Figure 6: Horizontal pattern of CO concentration (in ppbv) at 1000 m above sea mean level on July 1, 2005 at 17:00 UTC.

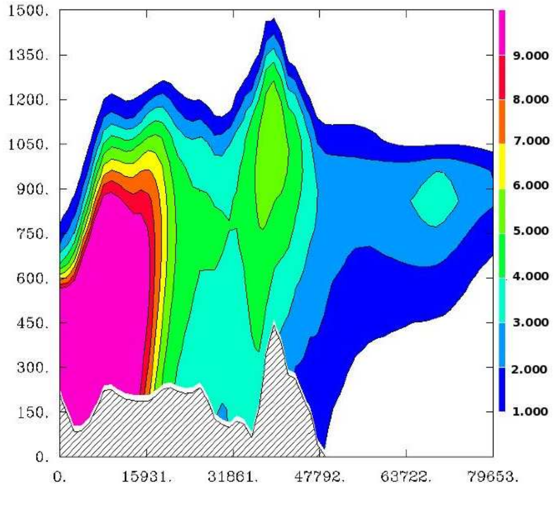


Figure 7: Vertical cross sections of NO_2 concentrantion (in ppbv) on July 1, 2005 at 17:00 UTC. The cross sections is obtained along the wind direction. In the plots, both the height and the distance along X axis are expressed in meters.

documented perturbations induced by forest fires on the atmosphere, in particular fire-induced surface winds. Fire emissions injection height are particularly sensitive to both latent and sensible heat fluxes from the fire. Finally, the impact of fire on atmospheric tracers is effective several hundreds of kilometers downwind of the burnt area.

Air quality forecast will be compared with the ground-based measurements of pollutants provided by the French air quality network. Emission factors will be refined based on the definition of the vegetation types in the ISBA surface scheme. A particular effort is also needed in the chemical reaction schemes to account for fire specific products (mercury, HCN, ...). Sensitivity studies are also planned on the ozone production efficiency in the fire plume as a function of the dynamics of the plume and the strenght of the emissions.

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