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Impact of wildfire-induced land cover modification on local meteorology: A sensitivity study of the 2003 wildfires in Portugal

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ABSTRACT

Wildfires alter land cover creating changes in dynamic, vegetative, radiative, thermal and hydrological properties of the surface. However, how so drastic changes induced by wildfires and how the age of the burnt scar affect the small and meso-scale atmospheric boundary layer dynamics are largely unknown. These questions are relevant for process analysis, meteorological and air quality forecast but also for regional climate analysis. Such questions are addressed numerically in this study on the case of the Portugal wildfires in 2003 as a testbed. In order to study the effects of burnt scars, an ensemble of numerical simulations using the Weather Research and Forecasting modeling system (WRF) have been performed with different surface properties mimicking the surface state immediately after the fire, few days after the fire and few months after the fire. In order to investigate such issue in a seamless approach, the same modelling framework has been used with various horizontal resolutions of the model grid and land use, ranging from 3.5 km, which can be considered as the typical resolution of state-of-the art regional numerical weather prediction models to 14 km which is now the typical target resolution of regional climate models.

The study shows that the combination of high surface heat fluxes over the burnt area, large differential heating with respect to the preserved surroundings and lower surface roughness produces very intense frontogenesis with vertical velocity reaching few meters per second. This powerful meso-scale circulation can pump more humid air from the surroundings not impacted by the wildfire and produce more cloudiness over the burnt area. The influence of soil temperature immediately after the wildfire ceases is mainly seen at night as the boundary-layer remains unstably stratified and lasts only few days. So the intensity of the induced meso-scale circulation decreases with time, even though it remains until full recovery of the vegetation. Finally all these effects are simulated whatever the land cover and model resolution and there are thus robust processes in both regional climate simulations and process studies or short-time forecast. However, the impact of burnt scars on the precipitation signal remains very uncertain, especially because low precipitation is at stake.

1. Introduction

The Mediterranean basin is the major European region where wildfires occur, with about 90% of the European burnt area (Chuvieco, 2009). Some ecosystems tend to be sensitive to fires as they have a deep impact on vegetation changes, soil loss and soil chemistry dynamics (Certini, 2005; Pausas et al., 2008). The year 2003 was one of the most severe years in Europe. Nearly 800,000 ha were burnt across southern Europe and in Portugal 4218 km^2 were burnt. A total of 20,864 wildfires were ignited that year for this country. Between 1980 and 2003, 57% of the total burnt area and 38% of all ignited fires in Europe were found in Portugal (EFFIS, 2003). The greater occurrence of wildfires in Portugal must however be analyzed knowing that over time, smaller wildfires were included in the data bases (Pereira et al., 2011).

These wildfires have become over the past ten years an active research field in geophysics and ecology (Westerling et al., 2006; DeBano, 2000). Large forest or bush fires cause dramatic changes in atmospheric composition by the release of gaseous and solid combustion products that in turn alter the local (Davies and Unam, 1999) and global (Seiler and Crutzen, 1980) atmospheric composition. The large release of heat and cloud condensation nuclei (Petters et al., 2009) modifies deeply the meteorology during the fire event, as seen in the fire propagation models (Clark et al., 1996; Morvan and Dupuy, 2004). At the catchment level, the water cycle is also impacted by fire. For example the response time of the topsoil moisture can be significantly lowered by wildfires, inducing quicker drying after rainfall (Stoof et al., 2012). Local meteorology can also be impacted after the fire ceases. Mölders and Kramm (2007) showed that in boreal regions fires tend to thaw the permafrost layer of the soil, blacken the surface and decrease the roughness length. Their numerical experiment showed an increase over the burnt areas and a decrease downwind of cloud-water, rainwater and graupel mixing ratios. A rearrangement of precipitation

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pattern is also simulated over the burnt area due to modifications of surface flux and buoyancy. Such effects are similar to anthropogenic or natural modifications of the landscape which can change in return the surface heat budget and therefore the surface–atmosphere coupling. These surface heterogeneities induce meso-scale circulations (Segal et al., 1988; Pielke et al., 1991; Avissar and Schmidt, 1998) which can have consequences on the local meteorology (Wendt et al., 2007; Kilinc and Beringer, 2007). Tryhorn et al. (2008) also showed evidence of the link between flash floods that occurred in the Alpine Shire, Australia with 37.2 mm recorded precipitation. The numerical experiment showed that without accounting for the fire occurrence the simulated precipitations were 3.9 mm versus 31.7 mm when accounting for the fire occurrence. At a larger time scale, Görgen et al. (2006) showed by using a fire/regrowth scheme in a climate model, that the vegetation regrowth time scale depends on the intensity of the fire. The impact of fires on landscape dynamics and their possible impact on global climate make them an interesting field of research for more accurate future climate forecasting (Trouet et al., 2010). Burnt scars and wildfires have not yet been incorporated into climate simulations, but their contributions to vegetation dynamics (Mouillot et al., 2002), carbon balance (Schimel and Baker, 2002) and aerosol concentrations (Spracklen et al., 2009) in a context of climate change have been investigated. These study did not focus on the Mediterranean region, which has however a long record of large wildfire events.

However, several questions remain unanswered in the current literature, which will be addressed in the present study. We do not know precisely what is the magnitude of the changes in small and meso-scale atmospheric dynamics that occur above large fire burnt scars. The change in energy budget being drastic compared to what is observed usually in studies about land-cover contrasts, large modification of the boundary layer dynamics should be expected. How that the age of the burnt scar impacts the boundary-layer dynamics is also largely unknown. These questions are relevant for process analysis, meteorological and air quality forecast but also for regional climate analysis. In order to investigate such issue in a seamless approach, the same modelling framework will be used with various horizontal resolutions of the model grid and land use. It will range from 3.5 km, which can be considered as the typical resolution of state-of-the art regional numerical weather prediction models (Davies et al., 2005; Seity et al., 2011), to 14 km which is now the typical target resolution of regional climate models (Flaounas et al., 2013; Jacob et al., 2014). The 2003 Portuguese fire season is used as a testbed for such sensitivity study experiment (Fig. 1). The study uses the Weather Research and Forecasting model (WRF) for the sensitivity analysis and the Moderate Resolution Imaging Spectroradiometer (MODIS) observations for the description and map of the burnt area.

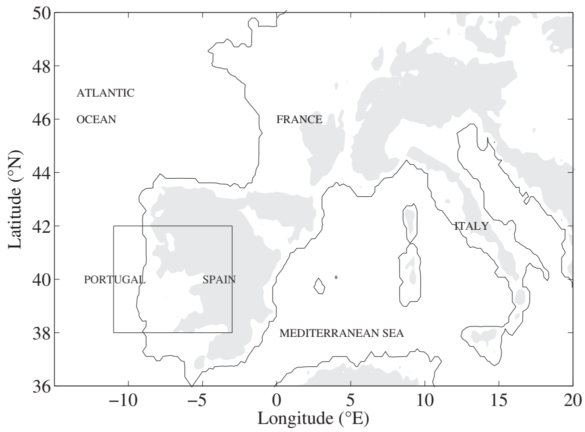

Fig. 1. Map of the western Mediterranean region with shaded area indicating topography higher than 500 m. The rectangle indicates the simulation domain for this study.

In Section 2, the experimental set-up is described, with emphasis on the change in surface properties operated in order to account for the effects of the wildfire on geomorphological characteristics of the ground. Section 3 presents the results obtained for a grid model and land cover resolution of 14-km. The robustness of the results with respect to the model and land cover resolution is then discussed. Section 5 concludes the study.

2. Numerical experiments with WRF model

Version 3.1 of the model WRF of the National Center of Atmospheric Research (NCAR) (Skamarock and Klemp, 2007) is used, with a simulation domain covering the western region of the Iberian Peninsula (Fig. 1) with horizontal resolutions of 3.5, 7 and 14 km. The corresponding time steps are 15 s, 30 s and 60 s. The model has 28 sigma-levels in the vertical. Initial and lateral conditions are taken from the European Center for Medium-range Weather Forecast (ECMWF) ERA-interim reanalysis provided every 6 h with a 0.75° resolution (Simmons et al., 2006). To avoid unrealistic departure from the driving fields, indiscriminate nudging is applied with a coefficient of $5 \times 10^{-5}\ s^{-1}$ for temperature, humidity and velocity components above the planetary boundary layer (Salameh et al., 2010; Omrani et al., 2013) (even though the small domain size damps the effect of nudging with strong control by lateral boundaries; (Omrani et al., 2012; Omrani et al., 2013)). A complete set of physics parameterizations is used with the WRF Single-Moment 5-class microphysical scheme (Hong et al., 2004), the new Kain–Fritsch convection scheme (Kain, 2004), the Yonsei University (YSU) planetary boundary layer (PBL) scheme (Noh et al., 2003) and a parameterization based on the similarity theory (Monin and Obukhov, 1954) for the turbulent fluxes. The radiative scheme is based on the Rapid Radiative Transfer Model (RRTM) (Mlawer et al., 1997) and the Dudhia (1989) parameterization for the longwave and shortwave radiation, respectively. For the land surface, the NOAH land-surface model is used (Ek et al., 2003). It uses four soil layers of respective depths from top to bottom 10 cm, 30 cm, 60 cm and 100 cm. The geographical data are from 30-second resolution USGS (United States Geophysical Survey) data. The output time interval for the simulations presented hereafter is 1 h.

Reference simulations (hereafter referred to as REF) have been run at 3.5, 7 and 14 km horizontal resolutions with the standard land use characteristics from the USGS database, i.e. without accounting for the wildfire impact. Additional simulations have been performed by modifying the land use characteristics (albedo, emissivity, roughness, and vegetation) and initial state (soil temperature and moisture) to account for the fire impact (Fig. 2):

- Simulations FIRE-ST include modified soil temperature and moisture in the uppermost layer in the initial state (+300 K additional temperature and 0.05 $m^3.m^{-3}$ soil moisture at the beginning of the simulations) as well as modified land-cover (see hereafter for details). These simulations performed at 3.5, 7 and 14 km horizontal resolutions mimic the situation when the fire has ended at the beginning

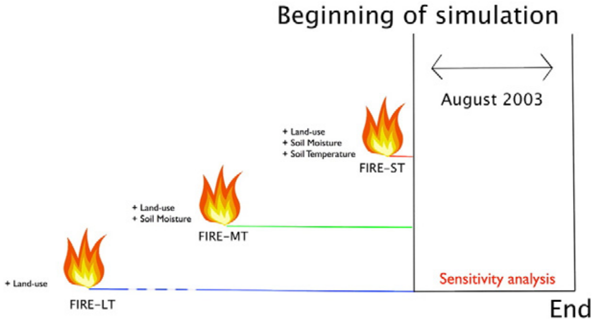

Fig. 2. Sketch of the numerical sensitivity experiment.