UNCERTAINTY FACTORS IN MODELLING DISPERSION OF SMOKE FROM WILD FIRES IN A MEDITERRANEAN AREA

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Abstract: We present a modelling system for the estimation of forest fire emissions (*prebolchem-fire*) and their inclusion in the atmospheric composition model BOLCHEM. Emission fluxes have been estimated following the methodology proposed by Seiler and Crutzen (1980) and using MODIS "Burned Area Product". Then they are modulated following the WRAP approach (WRAP Fire emission inventory 2005). This approach, integrated with information from a lagrangian backward model, is also used for the estimations of fire emission height. Model simulations have been performed for the period 22 - 30 August 2007, in which fires were most severe in Greece, Albania and Algeria. The emissions fluxes estimated for the gas species CO, NO_x, SO_2 and NH_3 and the particulate matter $PM_{2.5}$ and PM_{10} have been compared with those estimated by the global model FINNv1 (Fire Inventory from NCAR) and the difference between the two emissions have been discussed. To put into evidence the sensitivity of the results to the modulation of emission fluxes and height, modelling simulations have been performed with different model settings. Moreover, the concentrations of black carbon aerosol predicted by the model are compared with measurements at Tito Scalo, Potenza (40.63°N, 15.80°E, 760 m asl), where an unusual layer of aerosol was detected by the PEARL station lidar on 30 August 2007. We discuss the discrepancies between the measured and modelled vertical distribution concentrations of black carbon aerosol, probably due to uncertainties related to the estimation of the total flux and of the injection height of the smoke.

Key words: *fire emission, air pollution, Mediterranean area.*

1. INTRODUCTION

Southern Europe and the Mediterranean basin are frequently affected by fires which can burn thousands of hectares in a few days, especially during summer. Previous studies have shown that the atmospheric compounds directly emitted by biomass burning (BB) or produced by photochemical processes occurring within BB plumes can be transported over long distances, from local to regional and global scales, thus affecting both air quality and climate (Val Martin, M. et al., 2006). To accurately simulate smoke transport in the atmosphere and to quantify its impact in meso-scale models, the fire emissions and their transport patterns need to be accurately estimated. This is a challenging task (Giglio, L. et al., 2006) because of the large uncertainties that lie in the detection of fire sources and their spatial and temporal variability, the knowledge of emission factors related to the vegetation cover, and the determination of the vertical distribution of buoyant smoke plumes. To take into account the thermal updraft of smoke plumes in a dispersion model, if the plume rise growth is not included as sub-grid process (Freitas, S.R. et al., 2006), we need specific parameterizations to determine the injection altitude of emissions.

In this work we present the pre-processor *prebolchem-fire* that estimates the wildfire emissions and injection heights, starting from latitude and longitude of wildfires and taking into account the characteristics of soil (vegetation), the area burned and the diurnal cycle of fires (WRAP Fire emission inventory 2005). The emission fluxes are estimated following the methodology proposed by Seiler, W. and P.J. Crutzen (1980), the burnt area is obtained from MODIS Collection 5 Burned Area Product. The emissions fluxes estimated for the gas species CO, NO_x, SO_2 and NH_3 and the particulate matter $PM_{2.5}$ and PM_{10} have been compared with those estimated by the global model FINNv1 (Fire Inventory from NCAR) (Wiedinmyer, C. et al, 2012).

Simulations with the air quality model BOLCHEM (Mircea, M. et al., 2008) have been performed for the period 22 - 30 August 2007, in the Mediterranean Area, using different model settings. The simulated black carbon aerosol concentrations were compared with lidar measurements at IMAA-CNR in Tito Scalo, Potenza (40.63° N, 15.80° E, 760 m asl).

2. FIRE EMISSION AND MODEL ASSESSMENT

The emission of a species X resulting from fires, E(X), is expressed following the methodology proposed by Seiler, W. and P.J. Crutzen (1980):

$$E(x) = A \cdot B \cdot BE \cdot e(X) \qquad (1)$$

where A is the burnt area (m^2), B is the fuel load (kg/m^2), BE the burning efficiency and e(X) the emission factor of species X. B provides the available biomass per surface unit; BE corresponds to the percentage of the biomass which effectively burns; e(X) gives the amount of chemical species emitted for a given amount of biomass burned. B and e(X) are function of the land cover classification and BE is a function of the tree cover. The species considered are CO, CO_2, NO_x, SO_2, NH_3, $PM_{2.5}$ and PM_{10}. In this study, the burnt area is obtained from MODIS Collection 5 Burned Area Product - MCD45. The NASA Moderate Resolution Imaging Spectroradiometer (MODIS) on the Terra (morning) and Aqua (afternoon) satellites has specific features for fire monitoring and has been used to systematically generate a suite of global MODIS land products (Justice, C. et al., 2003). To assign fuel loadings for pixels in which fires were identified, we refer to the land cover used by BOLCHEM, that is the UMD Global Land Cover Classification (GLCC) (Hansen, M.C. et al., 2000), derived from AVHRR. The global land cover is characterized with 14 different classes at a resolution of 1 km. We have estimated values of fuel load and burning efficiency at each class of vegetation, referring to values estimated for GLC2000 vegetation cover class (Wiedinmyer, C. et al., 2006). Finally, for any vegetation type, we have assigned emissions factors at the different emitted species and we have calculated the corresponding emission fluxes (Pizzigalli, C. et al., 2012).

The emission flux and emission height are modulated following the WRAP approach (WRAP Fire emission inventory 2005). Emissions are supposed to not be constant during the day, but exhibiting a diurnal cycle. The injection height is related to the flaming intensity of the fire and can be estimated based on fire characteristics (such as the fire size or temperature) and atmospheric conditions. Therefore, fires are classified into size classes, and maxima and minima plume height ($Ptop_{max}$ and $Pbot_{max}$) are assigned (Pizzigalli, C. et al., 2012). The hourly top and bottom of the plume are then calculated as follows:

$$Ptop_{hour} = BE_{hour} \cdot BE_{size} \cdot Ptop_{max} \,; \qquad Pbot_{hour} = BE_{hour} \cdot BE_{size} \cdot Pbot_{max} \tag{2}$$

where BE_{size} is the buoyant efficiency from the size class and BE_{hour} is the hourly bouyant efficiency.

Once estimated, the transport and dispersion of smoke flux is modelled using BOLCHEM model. BOLCHEM (Mircea, M. et al., 2008) is an atmospheric composition model which couples online the meteorology and atmospheric chemistry. It is based on the mesoscale meteorological model BOLAM (Buzzi, A. et al., 1994), the gas phase chemistry module SAPRC90 (Carter, W.P.L., 1990) and the aerosol dynamics module AERO3 (Binkowski, F.S. and S.J. Roselle, 2003). The evaluated chemical species are speciated according to these chemical schemes. NOx and PM2.5 have been disaggregated respectively as follow: NOx = 95%NO_2 + 5%NO; $PM_{2.5}$ = 10%BC+ 86%OC + 4%S. The coarse mode is obtained from the difference between PM_{10} and $PM_{2.5}$. Black carbon (BC), organic carbon (OC) and sulphites (S) are then divided into accumulation (99%) and aitken (1%) modes.

3. A CASE STUDY: SIMULATION RESULTS AND DISCUSSION

The described procedure has been used to study emissions and dispersion from wildfires occurred in Greece, Albania and Algeria in the period 22 to 30 August 2007.

Emission fluxes have been calculated by means of *prebolchem-fire* and then compared with those estimated by the global model FINNv1 (Fire INventory from NCAR).

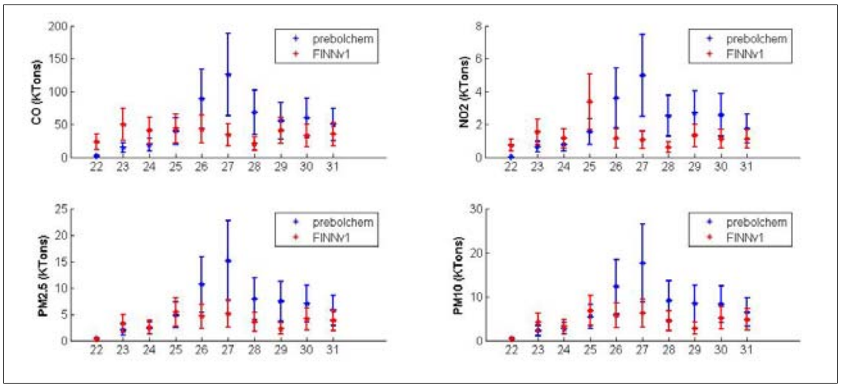


Fig. 1. Daily emissions (KTons) of CO, NO_2, $PM_{2.5}$ and PM_{10} estimated by means of prebolchem-fire (blue) and FINNv1 model (red).

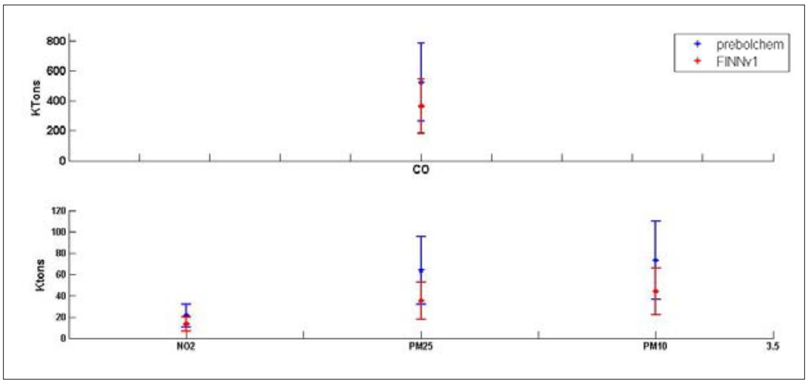


Fig. 2. Total emissions (KTons) of CO, NO_2, $PM_{2.5}$ and PM_{10} estimated by means of prebolchem-fire (blue) and FINNv1 model (red) for the period 22-30 august 2007.

Figures 1 and 2 show the computed emissions of CO, NO_2, $PM_{2.5}$ and PM_{10} . The uncertainty associated with the land cover classifications, the fire detection, the assumed area burned, the biomass loading, the amount of fuel burned and emission factors is assigned as a factor of two. From Figure 1 we can infer that our model overestimates the wildfires emissions, especially when major emissions peaks are found (26 and 27 August 2007), although only on 27th August estimates does not overlap. The agreement is better when we consider the total quantity emitted during the whole case study period (Fig. 2). Differences between the two emissions are mainly due to different vegetation maps and due to different feature of used MODIS products. MCD45 is based on a bidirectional reflectance change detection and classifies "daily burn area" associating every burnt pixel to a single date, with horizontal resolution of 500 m^2. FINNv1 model is based on Fire Radiative Power operational MODIS product that provides daily fire detections with a nominal horizontal resolution of 1 km^2 and include the location and overpass time of the fire detection.

The WRAP diurnal profile has been applied to estimated emissions, resulting in a peak during early afternoon (13-16 h UTC) and very low values during the night. Emissions heights, also modelled following the WRAP approach, show that during the night fire emits only at ground level, while during afternoon fire emits also in the troposphere. In Figure 3 an example of modulated emission (left) and injection height (right) is shown.

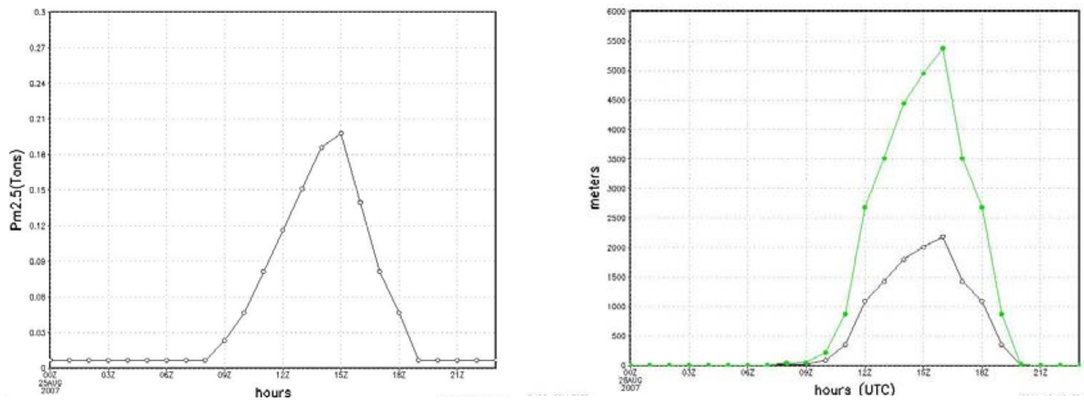


Fig. 3. Example of diurnal cycle of $PM_{2.5}$ emission (left) and corresponding maximum (right, in green) and minimum (right, in black) injection height from a forest fire.

The dispersion simulations have been performed using the atmospheric composition model BOLCHEM. The model domain used in this study includes Europe and North Africa: NW (−5°,51°); NE(30°,51°); SW(−5°,31°); SE(30°,31°). We adopted a 25km horizontal resolution grid with 40 vertical levels in sigma coordinate, with the lowest layer approximately 40 m thick. ECMWF analyses are used as initial and boundary conditions for meteorology. The simulations are re-initialised every 24 h with the ECMWF fields. Lateral boundary conditions are updated every 6 h. Climatological boundary conditions are used for atmospheric composition as the simulation domain is large enough to avoid the influence of external sources. The anthropogenic emission fields have been generated from the TNO inventory for the year 2003 made available in the frame of GEMS project (Visschedijk, A. et al., 2007). Biogenic emissions are based on an inventory providing potential emissions and generated by NKUA (National and Kapodistrian University of Athens) in the frame of GEMS project (Symeonidis, P. et al., 2007) and are calculated run time by the model.

The contribution of fire emissions on pollutants concentrations has been evaluated as difference between concentration fields obtained by two different a model run: one including anthropogenic, biogenic and wildfire emissions (*ant-bio-fire* simulation), the other one including only anthropogenic and biogenic emissions (*ant-bio* simulation). Figure 4 shows the concentration of black carbon aerosol (BC) for the 30th August 2007 at 18UTC at about 1500m for *ant-bio-fire* simulation (left), and evidences (right) the contribution of wildfire emissions to BC to the centre and south of Italy. The triangle locates the PEARL station lidar, located at Tito Scalo, Potenza (40.63°N, 15.80°E, 760 m asl), where an unusual layer of aerosols has been detected on 30th August 2007. A study of backscatter coefficient indicated that the aerosol layer between the boundary layer and 4800 meters contained particulate from forest fire (Monti, F., 2009).

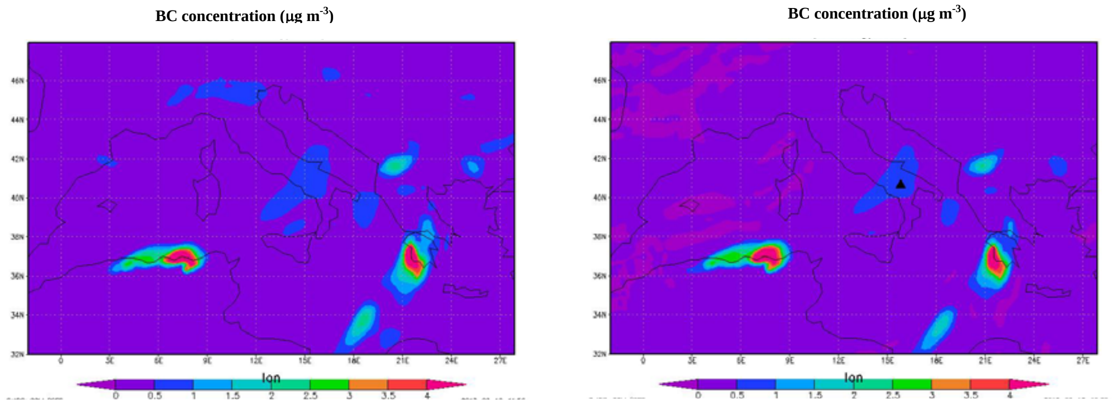


Fig. 4 Concentration field of BC (µg m^{-3}) at about 1500 meters for the 30th August 2007 17UTC. Left side: simulation *bio-ant-fire*; right: difference between simulation *bio-ant-fire* and *bio-ant*.

The vertical distribution of BC concentration simulated has been compared with lidar observations at Tito Scalo. In Figure 5 is shown the measured profiles of aerosol backscatter coefficient at the PEARL station (left) and BC concentration profile for the simulation *ant-bio-fire* (in red) and *ant-bio* (in green).

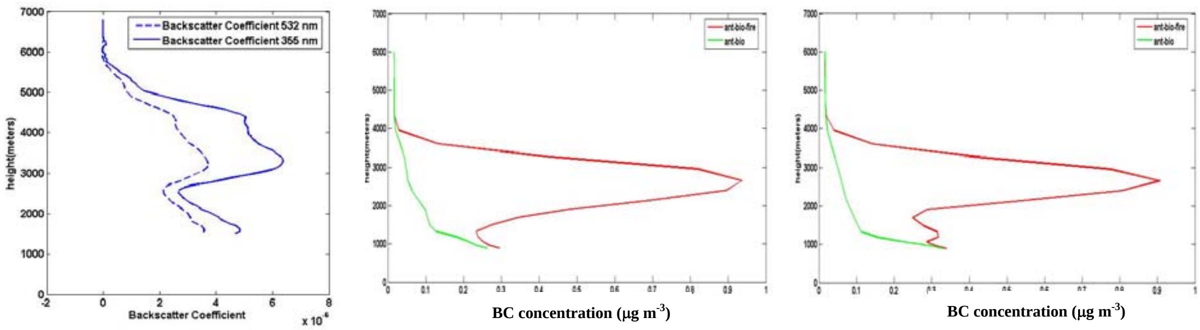
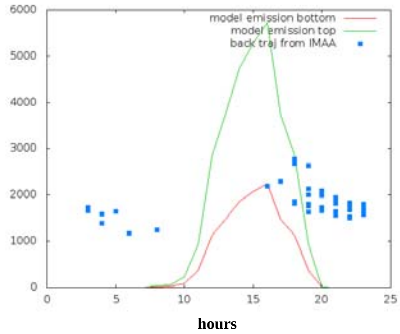


Fig. 5 Backscatter profiles in PEARL station for the 30 August 2007 at 18 hour (left) and BC concentration (µg m^{-3}) profile from BOLCHEM output at 18 ITC (middle) and 21UTC (right) at Tito Scalo.

From Figure 5 and from back trajectories simulations we can infer that probably WRAP modulation is not suited for fire in the Mediterranean Area. Figure 6 (left) shows the height of the air mass that, starting from Tito Scalo, intercepts a forest fire source, and emission height modulated using WRAP. The right panel of Figure 6 shows the simulated BC concentration profile at PEARL station with a model set up (hereinafter labelled *wrap2*) that, referring to WRAP, increases the emission height for night time hours, and decreases both minimum and maximum emission height for early afternoon hours.

The profile obtained from lidar observations is not well reproduced by BOLCHEM simulations: the model captures the formation of aerosol layer, although difference in both vertical distribution and observation time are present. They are probably due to the uncertainties related to the estimation of emission fluxes and the adopted daily modulation of fluxes and emission height. From back trajectories simulations we can argue that, during night time, fires in a Mediterranean Area emit not only at ground level, but also in the boundary layer. It is also highlighted by *wrap2* simulation, that better reproduce BC vertical profile at lower heights. Further work will be carried out to test *wrap2*, comparing the output model with different measurement stations data.



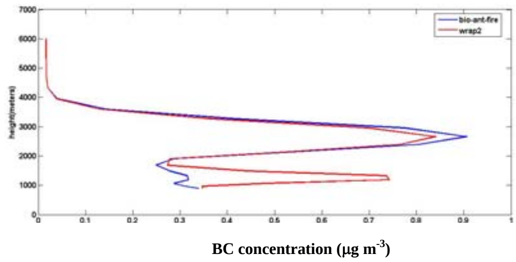


Fig. 6 Back trajectories heights (m) starting from Tito Scalo (30th August 2007 18UTC) (left) and BC concentration profile (μg m^{-3}) from BOLCHEM at 21UTC at Tito Scalo (right).

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