

Chapter 41

A Global Wildfire Emission and Atmospheric Composition: Refinement of the Integrated System for Wild-Land Fires IS4FIRES

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Abstract The current study intends to evaluate the fire emission estimates obtained from IS4FIRES v1.5. The system provides spatially and temporally resolved emission fluxes originated from wild-land fires. The emissions were obtained by utilising remote-sensing products of MODIS and SEVIRI instruments: TA and FRP. The primary scaling is based on emission factors for PM_{2.5} determined for seven land-use types: grass, crop residue, shrub, tropical, temperate and boreal forest, and peat. The PM_{2.5} emission fluxes can be converted to total PM and gaseous species using literature-reported scaling factors.

To evaluate the system, the fire emission fluxes were used as input to the SILAM model, which evaluated the dispersion and transformation of the released smoke. The observational datasets included AOD observations from MODIS. To facilitate the comparison and estimate the contribution from fires to AOD, SILAM inorganic chemistry calculated formation of secondary inorganic aerosol. Primary PM emissions from anthropogenic and natural sources were also included.

The model-measurement comparison showed that spatial and temporal distributions of the fire smoke are well reproduced. Nevertheless, the smoke from fires occurring in central Africa and South America are overestimated, and fires occurring in areas where peat and crop are dominant are underestimated. The optimization of the system, in general, results on a reduction of the emission coefficients, with exception of peat and crop, as expected; it reduces emission substantially especially for the areas where tropical and grass are dominating and fires tend to be very intense (Africa). Nevertheless, in some cases reduction seems to be counterproductive, emissions are heavily reduced.

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41.1 Introduction

The quantification of fire emissions and its impact, in terms of atmospheric composition, air quality, human health and climate forcing, is a continuous challenge due to numerous uncertainties and stochastic behaviour of wild-land fires. This study intends to evaluate the fire emission estimates obtained from IS4FIRES v1.5.

41.2 Methodology

41.2.1 *Fire Input Data: IS4Fires v.1.5*

The FAS provides spatially and temporally resolved emission fluxes originated from wild-land fires. IS4Fires consists of two parallel branches based on partly independent Level 2 MODIS Collection 4 and 5 active-fire products: the Temperature Anomaly (TA) and Fire Radiative Power (FRP). The TA and FRP-based branches are partly independent and demonstrate somewhat different features: the first is more sensitive to small-scale fires, but the latter is based on a physically a better grounded quantity for the determination of the fire emissions, since the release of radiative energy is approximately proportional to the number of carbon atoms oxidised per second. Sofiev et al. [7] showed that the combination of both methods improves the representation of emission of small fires. The algorithms of converting the fire information to the emission fluxes of atmospheric pollutants are described in Sofiev et al. [7]. The primary scaling is the emission factor to total PM and other species are obtained with cross-scaling factors from the review of Andreae and Merlet [2]. However, the simulations discussed in this study are based on optimized emission factors, which were obtained for seven land-use classes (grass, crop residue, shrub, tropical, temperate and boreal forest, and peat) using Akagi et al. [1] and merged with the original coefficients of Sofiev et al. [7], are in use on the IS4Fires v1.5. In addition, the emission injection is dynamic; with the injection height being calculated using the formula suggested by Sofiev et al. [9]. The diurnal variation of emissions is static and taken from SEVIRI re-analysis.

41.2.2 *Modelling Tool: SILAM v.5.3*

The modelling tool used in this study is the System for Integrated modeLLing of Atmospheric composition, SILAM ([5]; Sofiev et al. [6]). For aerosols, the mechanisms of dry deposition varies from primarily turbulent diffusion driven removal of fine aerosols to primarily gravitational settling of coarse particles [4]. The wet deposition distinguishes between sub- and in-cloud scavenging and

between rain and snow [5]. The physical-chemical modules of SILAM cover inorganic chemistry, size-resolved primary particles of various types, radioactive nuclides and probability distribution. For the current study, the SILAM simulations included anthropogenic [3], fire-induced (described in Sect. 41.2.1) and sea salt Sofiev et al. [8] emissions. Meteorological information and necessary geophysical and land cover maps are taken from ECMWF meteorological models. Wild-land fires source was obtained from FAS v1.5 system described above. To facilitate the comparison and estimate the contribution from fires to AOD, SILAM inorganic chemistry calculated formation of secondary inorganic aerosol. Primary PM emissions from anthropogenic and natural sources were also included. The results shown in this study are based on global runs for time period between 2001 and 2012 with a horizontal resolution of $1^{\circ} \times 1^{\circ}$ and the vertical profile was represented by nine uneven layers reaching up to the tropopause, the lowest layer is 50 m thick. All simulations had 15 min internal time-step while the output was averaged over 1 h.

41.2.3 Environmental Monitoring Data

The predicted aerosol optical thickness of aerosols has been compared with remote-sensing observations. The results of the simulations were compared with MODIS (Aqua and Terra) AOD, at 550 nm wavelength, using full collocation of the datasets. Firstly, MODIS observations were projected to the grid of SILAM output and all grid cells with less than 50 MODIS pixels excluded – for each hour. Secondly, SILAM results were filtered using mask built of existing MODIS data (also for each hour): SILAM results with no counterpart in MODIS observations were excluded. Finally, the AOD in the grid cells that pass all filters was averaged to daily and monthly levels and compared with the corresponding MODIS data.

41.2.4 Optimization of IS4Fires

The optimization was based on the AOD predicted and the AOD obtained by remote sensing data, as described in Sect. 41.2.3. The selection of data was based only on the fire dominating cells – all active fires are accounted for: a temporal and spatial selection was done based on the grid cells where the daily average for fire PM AOD was bigger than non-fire PM AOD. Values for MODIS AOD were collected for the same time and grid cell, resulting two vectors: one of modelled and one of predicted values. Subsequently, seven vectors with modelled values will be obtained, one for each individual land-use type fire computation, based on these spatial and temporal records. Meaning that for the same day and grid-location there is a value for each land-use category fire-related concentrations: the matrix for the optimization process. The observation vector was obtained by subtracting the MODIS AOD and the non-fire PM AOD estimated by SILAM, so that only fire

AOD is evaluated. The final step of the optimization fit was to run an unconstrained nonlinear optimization, a function that finds the minimum of a scalar function of several variables, starting at an initial estimate:

$$\left(A\vec{X} - \vec{y} \right)^T \left(A\vec{X} - \vec{y} \right) \rightarrow \min \vec{X} \quad (41.1)$$

where A is the matrix of estimated values (no. land-use types*no. predicted values), \vec{y} is the vector with observed values (1*no. observations), and \vec{X} is the vector of the emissions factors for each land-use type presently in use in IS4Fires system (1*no. emissions factors per land-use), the initial estimate.

41.3 Results and Discussion

The model-measurement comparison showed that spatial and temporal distributions of the fire smoke are, in general, well reproduced. Routinely the smoke from fires occurring in central Africa and Amazonia is overestimated and fires occurring in areas where peat and crop are abundant are occasionally underestimated. The overestimation is possible due to under-representation of local phenomena facilitating fast dispersal of plumes, such as deep convection and/or misattribution of land-use types. The latter was responsible for $\sim 10\%$, in average, for the overestimation of the plumes (not shown here). The optimization of the system revealed, as expected, reduction of the emission coefficients, with exception of peat and crop (Fig. 41.1). The signal for each land-use type is similar, year to year, with exception of crop. Figure 41.2 shows an example of the spatial distribution of SILAM AOD for October 2008 before and after the optimization, and the spatial distribution for MODIS AOD, both at 550 nm. The figure shows that the optimization of the systems brings closer the model to the remote sensing measurements.

41.4 Conclusion

The IS4FIRESv1.5 clearly shows improvement compared to its previous version. The model-measurement comparison showed that spatial and temporal distributions of the fire smoke are well reproduced. Nevertheless, the smoke from fires occurring in central Africa and South America are overestimated, possibly due under-representation of local phenomena facilitating fast dispersal of plumes, such as deep convection. On the other hand, fires occurring in areas where peat and crop are dominant are underestimated. A better distribution of land-use improves the model results by reducing the overestimation of the plumes in $\sim 10\%$ and brings the predictions closer to the measurements. The optimization of the system, in general, results on a reduction of the emission coefficients, with exception of peat and crop,

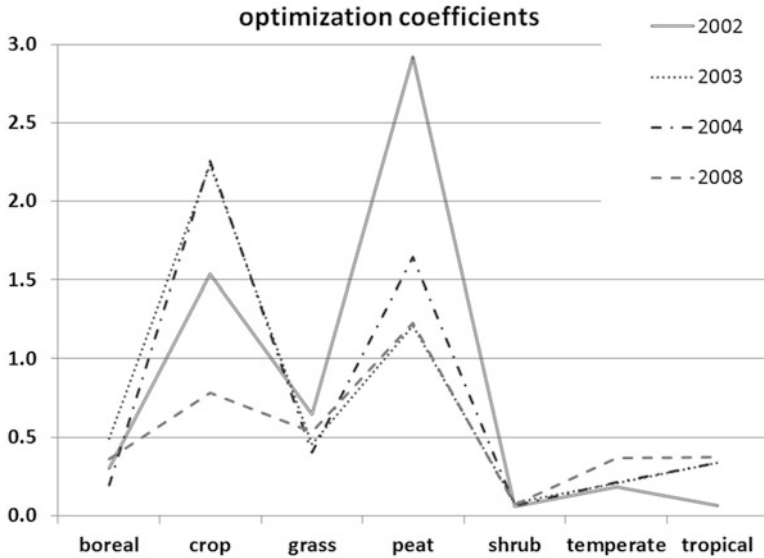


Fig. 41.1 Optimization of the emission coefficient for each land-use type, year 2002–2004 and 2008

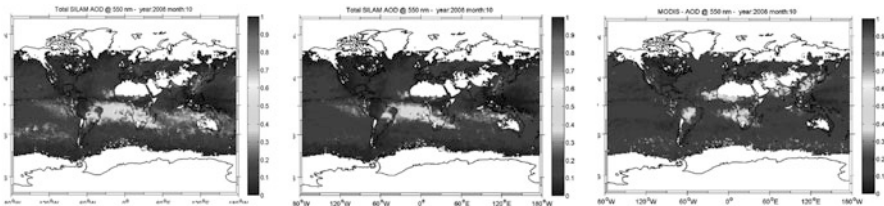


Fig. 41.2 AOD spatial distribution for SILAM before (*left*) and after (*centre*) optimization, and MODIS (*right*). Monthly average for October, 2008

as expected; it reduces emission substantially especially for the areas where tropical and grass are dominating and fires tend to be very intense (Africa). Nevertheless, in some cases reduction seems to be counterproductive, emissions are heavily reduced.

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Question and Answer

Questioner Name: George Pouliot

Q: Explain the optimization that was done for the wild Fire emissions.

A: The optimization is described on the Sect. [41.2.3](#).