Emission Inventory Processing of Biomass Burning from A Global Dataset for Air Quality Modeling

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Emission inventory processing of biomass burning from a global dataset for air quality modeling

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ABSTRACT

Wildfires generate large amounts of atmospheric pollutants yearly. The development of an emissions inventory for this activity is a challenge today, mainly to perform modeling of air quality. There are free available databases with historical information about this source. The main goal of this study was to process the results of biomass burning emissions for the year 2014 from the Global Fire Assimilation System (GFAS). The pollutants studied were the black carbon, the organic carbon, fine and coarse particulate matter, respectively. The inputs were pre-formatted to enter to the simulation software of the emission inventory. In this case, the Sparse Matrix Operator Kernel Emissions (SMOKE) was used and the values obtained in various cities were analyzed. As a result, the spatial distribution of the forest fire emissions in the Southern Hemisphere was achieved, with the polar stereographic projection. The highest emissions were located in the African continent, followed by the northern region of Australia. Future air quality modeling at a local level could apply the results and the methodology of this study. The biomass burning emissions could add a better performance of the results and more knowledge on the effect of this source.

Keywords: Biomass burning, SMOKE, NCO, GFASv1.3, Black carbon, Organic carbon, Southern Hemisphere

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1. INTRODUCTION

Biomass burning, also known as vegetation burning, is considered a significant emission source of atmospheric pollutants. Natural causes could generate it due to local conditions for ignition. It is estimated that natural fires triggered by atmospheric lightning only account for 10% of all fires (Levine 1991). Unfortunately, it also could be started intentionally by human actions. Several studies have been reported the effect of this natural source emission in climate (Thornhill et al. 2018), photochemistry of the atmosphere (Yue and Unger 2018), biogeochemical cycles (Chen et al. 2010) and human health (Apte et al. 2018).

The estimation of an air emission inventory from biomass burning is complicated due to the large spatial and temporal variability of this source at a regional scale (Kaiser et al. 2006; Andreae 2019). There are some systems which monitor and forecast air quality from satellite-based observations of the burnt area (Reid et al. 2009). It could be used to obtain regional and global fire emissions. This information is crucial in order to observe the effects of biomass burning emissions on air quality by numerical modeling. Models like CMAQ (Byun and Schere 2006), CAMx (Corporation and Way 2013), and WRFChem (Grell et al. 2005) have been used to report the transformation of air pollutants in the atmosphere. These air quality models need two essential inputs: the meteorological data and the emission inventory. The last one is usually obtained from external software like PREP-CHEM-SRC (Freitas et al. 2011) and SMOKE (Baek and Seppanen 2018). Both software process the emission inventory that the user inserted as an input. SMOKE generates output files with the exact format as CMAQ or CAMx required; PREP-CHEM-SRC has been developed for WRFChem.

The effect of biomass burning or wildfire on the air quality has been studied recently using numerical simulations. Table 1 summarizes some publications using various biomass burning databases for a different region of analysis. (Johnson et al. 2020) reviewed other studies, including dispersion model characteristics. Unfortunately, the processing steps of emission inventories for air quality modeling are not exposed.

Table 1 Recent studies using biomass burning and wildfires as input in air quality simulation.

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Region	Emission inventory source	Dispersion model	Reference
USA	ICS-209 - SMARTFIRE v2	CMAQ	(Guan et al. 2020)
Canada	FireWork	GEM-MACH	(Matz et al. 2020),
Colombia	FINN	WRF-Chem	(Ballesteros-González et al. 2020)
Brazil	3BEM, FINN	WRF-Chem	(Nurzahziani et al. 2020)
India	GFAS	HYSPLIT	(Ojha et al. 2019)
Indonesia	GFAS	HYSPLIT	(Uda et al. 2019)
Spain	GFAS	HYSPLIT	(Sicard et al. 2019)
Northeast Asia	FINN	CMAQ	(Uranishi et al. 2019)
Brazil	NSRI Brazil	HYSPLIT	(Targino et al. 2019)
East Asia	GFAS	NICAM	(Goto et al. 2019)
Southeast Asia	FINN	CMAQ	(Pimonsree et al. 2018)
Southeast Asia	FINN - GFAS	CMAQ	(Vongruang et al. 2017)

In order to bring accurate estimates of aerosol, reactive gas, and greenhouse gas emission fluxes to the atmospheric systems, the Global Fire Assimilation System (GFAS) was being developed by Max Planck Chemical Institute, Germany (Kaiser et al. 2012). It is established on satellite-based fire radiative power products from the MODIS instrument present in Terra and AQUA satellites. The emissions are daily published (https://permalink.aeris-data.fr/GFASv1.3), and they are inside a global map of 0.1 º grid resolution in the NetCDF file format.

There are many pollutants studied using this methodology, being black carbon (BC) and fine particulate matter ($PM_{2.5}$) included. BC is generated in an incomplete combustion process (Petzold et al. 2013), and the effects of either aerosol on climate change can only be estimated with extremely vital emissions inventories (Koch et al. 2009). Biomass burning is one of the primary

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sources of BC and $PM_{2.5}$ worldwide (Bond et al. 2013). Due to the adverse effect of this pollutant on climate change, absorbing radiative energy, the study of BC in the last decades has been increasing.

During the last decade, many efforts have been developed simulating air pollutants in regional and hemispheric scales, to observe long transport in the atmosphere (Huang et al. 2015). The biomass burning in Southern Hemisphere is several and frequently, and it has been associated with particulate matter deposition in glaciers and Antarctica. (Shi et al. 2019a; Cereceda-Balic et al. 2020). Unfortunately, there is not available studies with the estimated contribution of this source in this region and it is due to the lack of information

The main goal of this study was to process the results of biomass burning emissions from GFASv1.3. The NetCDF files from this database expose the emission in the unit $kg \cdot m^{-2} \cdot s^{-1}$, which is required for processing in SMOKE. The pollutants studied were BC, organic carbon (OC), $PM_{2.5}$ and coarse particulate matter (PM_{10}), respectively. It is a crucial step to obtain processed emissions files to simulate in air quality models mentioned before.

2. METHODS

The files of biomass burning of GFASv1.3 were freely downloaded from the database of the Global Emissions Initiative (www.geiacenter.org). Each pollutant´s file has daily emissions from 2003 to 2016. A preprocessing stage was made to change the GFASV1.3 files format to get the input required in SMOKE. For every day, the NetCDF Operator (NCO) commands were used (Zender 2008). Details are shown in Table 2.

Table 2 Modification of GFASv1.3 files for SMOKE input requirements.

Step	NCO command	NCO statement
1	ncks	ncks -d time, “number_of_file” in_file.nc out_file.nc
2	ncwa	ncwa -a time in_file.nc out_file.nc

3	ncks	ncks -3 in_file.nc out_file.nc
4	ncpdq	ncpdq -O -h -a -lat in_file.nc out_file.nc

The first step was the extraction of the information in the period of interest (2014, January 1st – December 31st). SMOKE does not process files with variable time when NetCDF format is used as input of emission inventory. That is the reason for step 2 when the attribute time was deleted in each file generated in step 1.

Next, in step 3, the files were formatted to classic NetCDF format as SMOKE requirement.

Then, the files generated were processed in SMOKE and observed the preliminary results in VERDI, as shown in figure 1.

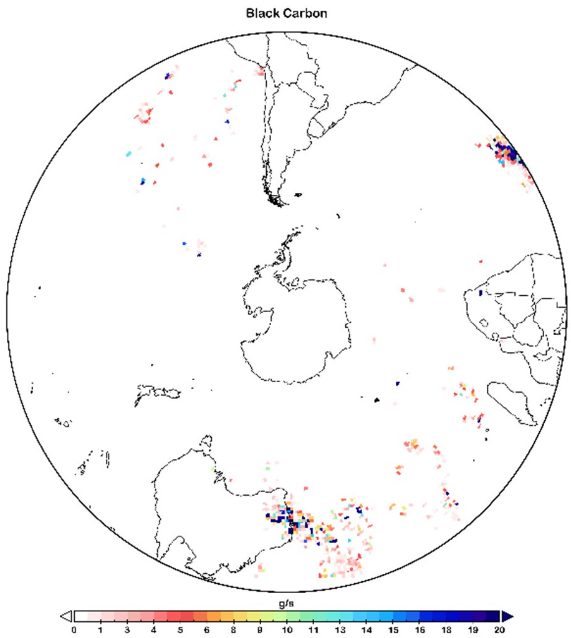

Figure 1 Emissions of black carbon obtained without step 4.

Figure 1 suggested errors in the input files due to registries in the ocean, which is impossible for biomass burning emission sources. The solution was made in step 4 when the latitude information was inverted in the file generated in step 3. Finally, the simulation in SMOKE was made for the year 2014. The emission files were centered in GWT-03 containing 180 grid cells for each side of

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the domain and 108 km of horizontal resolution. The hourly profile was set to constant because there is no information about it for this source. The processing steps in SMOKE and the postprocessing of the output files were recently exposed in (Pino-Cortés et al. 2020).

3. RESULTS AND DISCUSSION

Each output file generated in SMOKE4.5 was merged to obtain one file with all the emissions of OC, BC, $PM_{2.5}$, and PM_{10} from biomass burning for the year 2014. The highest total emissions of black and organic carbon in important cities during 2014 are shown in Fig 2.

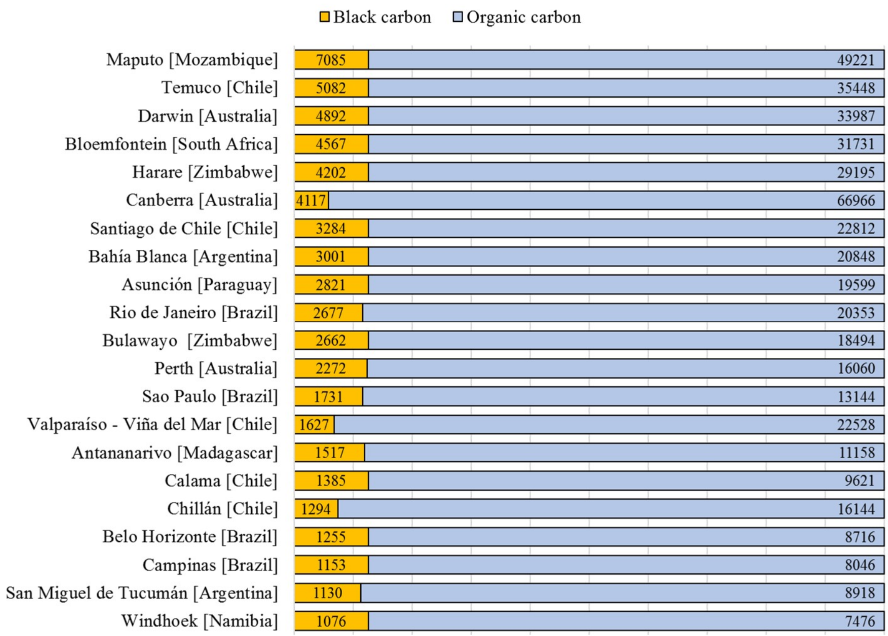

Figure 2 Highest BC and OC emissions (ton/year) during 2014.

The individual results exposed in Fig 2 cannot be compared to official reports or published papers due to the lack of information. The highest emissions of black carbon were observed in Maputo, Temuco and Darwin, in decreasing order. The registries in South America, specifically in big cities like Santiago de Chile, Asunción and Rio de Janeiro, also have high emissions of black carbon. Therefore, the organic carbon registries are incredibly high in Canberra and Maputo, compared to the rest of the cities. Also, it is remarkable the distribution of the emissions through Southern

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Hemisphere, where large registries are located in Southern America, Southern Africa and Australia. These results could tell us how forests are the main cities studied.

The OC/BC ratio is between 6 and 16, and it is in the range reported by (Ballesteros-González et al. 2020), but the minimum limit is widely distributed. The organic carbon is produced by the condensation of organic vapors generated in incomplete combustion like biomass burning. The higher ratio of OC/BC is generated in forest and crop residues fires due to their characteristically high fuel loads (Shi et al. 2019b). In contrast, lower values are shown in savanna burning (Bond 2004). This last land type is the majority biomass burned during 2014 according to the OC/BC ratio from GFAS emissions, and it is exposed in (Shi et al. 2020) for the same year.

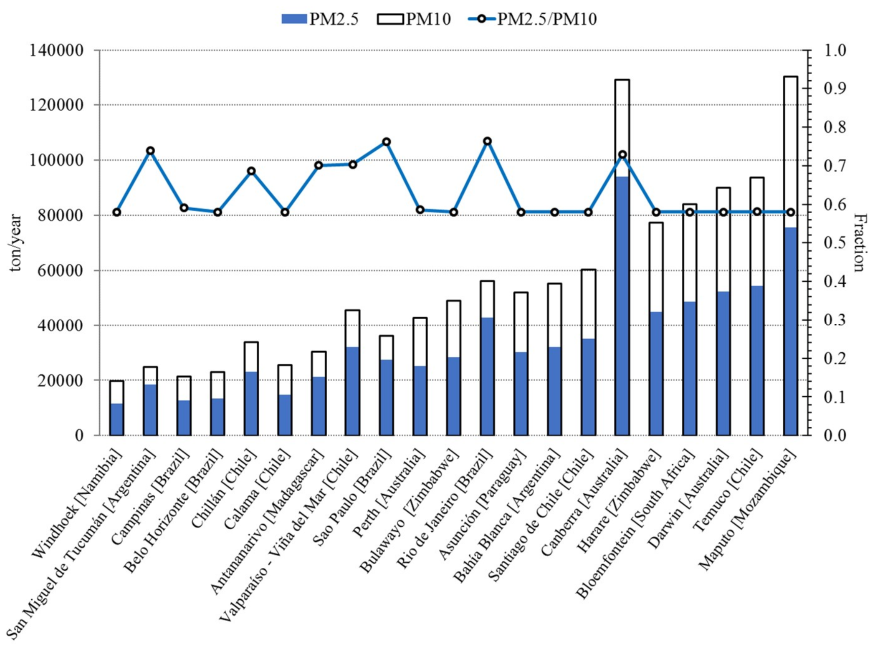

Figure 3 Highest $PM_{2.5}$ and PM_{10} emissions during 2014.

The values in Fig 3 suggests that PM_{10} generated in biomass burning includes 60-75 % of $PM_{2.5}$. The highest values are the same as reported in Fig 2. In this case, Canberra and Maputo registered the uppermost fine and coarse particulate emission, respectively. It shows a direct relation between particulate emissions and their speciation.

The average black carbon fraction in fine particulate matter resulted mainly in 4 %, but this variable could be up to 10 %. This result is similar to other studies (Chow et al. 2011) for this source emission. Otherwise, the OC/$PM_{2.5}$ ratio showed a wide range between 47 and 72 %. The higher values were located in Eastern Australia, New Zealand, Paraguay and Northern Argentina. In contrast, lower ratios were observed in Southeast Brazil and Eastern Madagascar. The distribution of those ratios in the domain is shown in Fig S1.

The temporal profile of the total emissions of pollutants from biomass burning is exposed for eight cities in Fig 4. This variable is useful for best knowledge of this source emission.

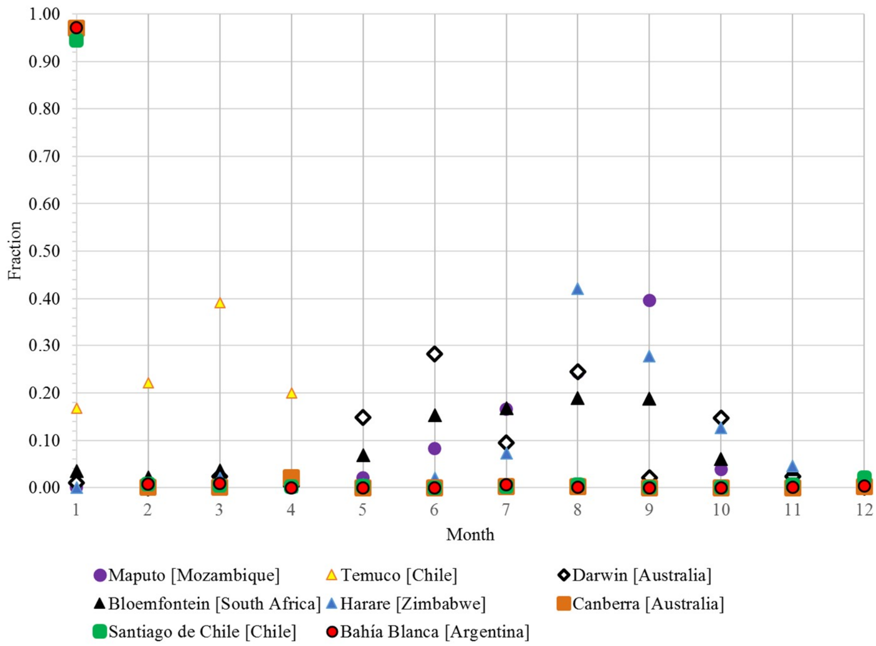

Figure 4 Monthly profile of black carbon emission during 2014.

The emissions from Santiago de Chile, Canberra and Bahia Blanca occurred up to 95 % in January (Summer season in South Hemisphere). It could be explained by the direct positive effect of mean temperature and agricultural on the number of fires and burned areas. Both variables are the significant ecological predictors of fire activity in Chile (Gómez-González et al. 2019). Those results also could explain the registries in Temuco, where biomass burning emissions were registered from

January to April (included) in 2014. African cities like Maputo and Harare registered their majority emissions from June to September. This profile was also reported by (Shi et al. 2020)

Finally, there are zones with significant emissions in the entire domain of study, as shown in Figure 5. Detailed records for many cities in Southern Hemisphere are exposed in Table S1 in Supplementary Material.

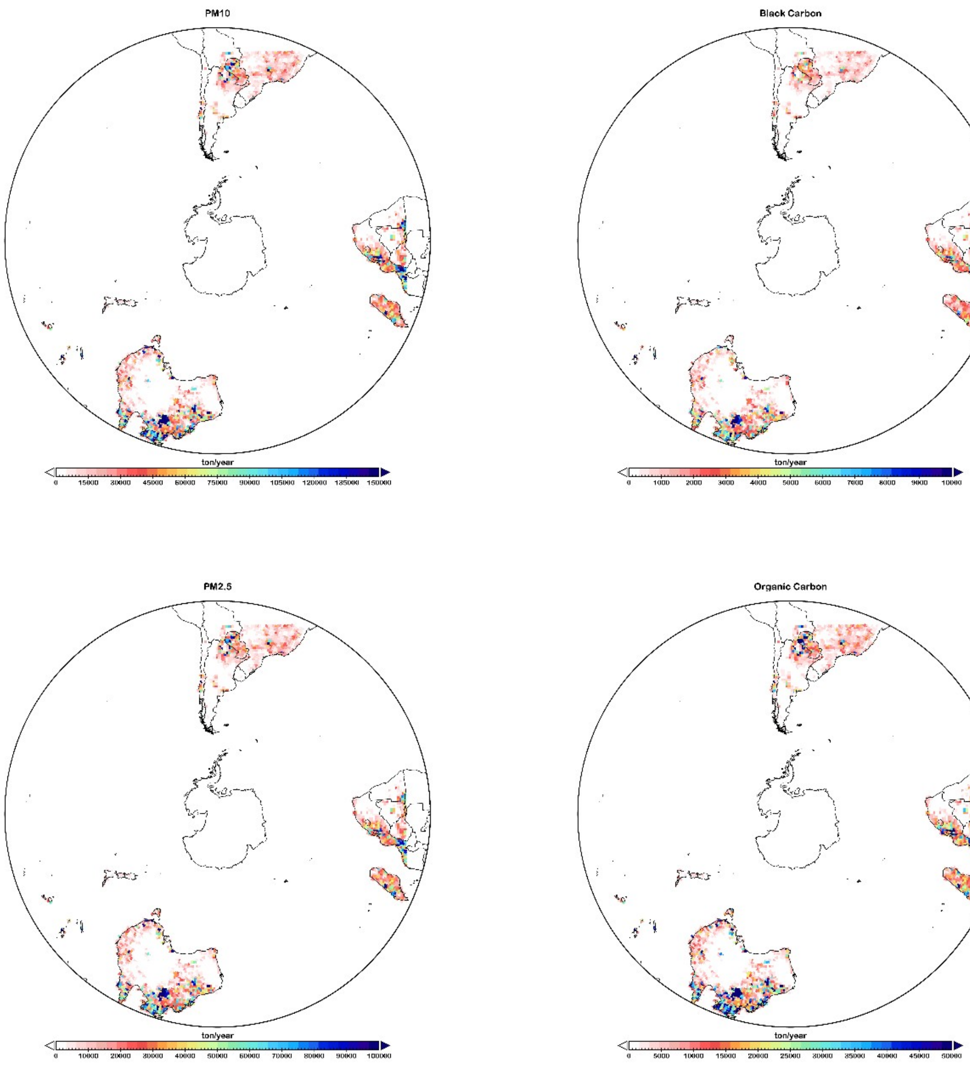

Figure 5 Annual emissions in South Hemisphere during 2014.

The emissions were higher in the African continent. Also, the emissions in the North of Australia are highly remarkably. Both regions are affected every year by wildfire, generating higher emissions of many pollutants.

In South America, it has highlighted total emissions in the Paraguay and Northern region of Argentina, similar to reported in (Shi et al. 2020). Also, in Central-Southern areas in Chile are shown a high amount of emissions. In this country, the highest number of wildfires and burnt hectares occurred in 2014 since 1960 (Úbeda and Sarricolea 2016). Unfortunately, that study did not report the air pollutant emissions and the effect of this source is not exposed.

4. CONCLUSION

This study showed a practical method to process the biomass burning files from GFASv1.3 in SMOKE. The NCO commands were applied in four steps to change them to obtain the required format as NetCDF input.

The results and the methodology exposed could bring important information to Southern Hemisphere countries, especially in highly populated cities with several episodes with high air quality index of pollution. Also, national emission inventories could be improved, and future air quality modeling could be applied. The biomass burning emissions could add a better performance of the results and more knowledge on the effect of this source.

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