THE COVID-19 LOCKDOWN PERIOD IN THE MEXICO MEGALOPOLIS: IMPACT ON SURFACE SOA AND OZONE

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1. INTRODUCTION

The Mexico Megalopolis is the region in Central Mexico that includes the Mexico Megacity and the 6 surrounding states: Puebla, State of Mexico, Morelos, Tlaxcala, Hidalgo and Queretaro (Fig. 1). It is a rapidly developing area which concentrates about 33% of the national population and represents one third of the Gross Domestic Product. Among the 10 most impacted States by wildfires, 4 of them are in the Megalopolis; and since 2017 the State of Mexico has the highest number of wildfires at the national level (CONAFOR, 2020). In addition, the southern part of the Megalopolis is adjacent to regions with high biomass burning emissions. Thus, biomass burning emissions have a substantial contribution at the national, regional and local levels.

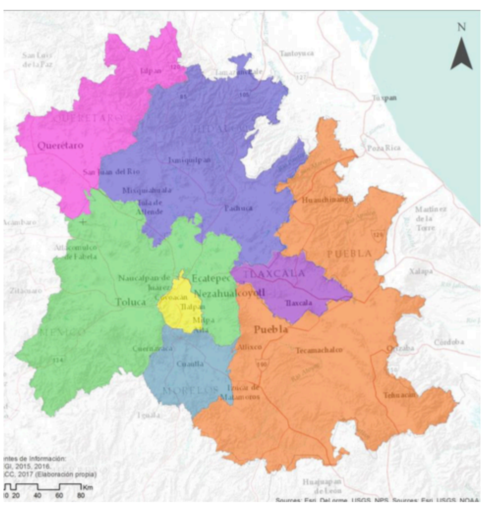

Fig. 1. Mexico Megalopolis region: Mexico Megacity (yellow) and the surrounding states of Morelos (blue); State of Mexico (green); Puebla (orange); Tlaxcala (violet); Hidalgo (purple) and Queretaro (Magenta).

Despite the many challenges derived from the COVID19 pandemic, the current worldwide lockdown measures still represent a unique opportunity for the development and evaluation of mitigation measures aimed to abate air pollution. In Mexico, the lockdown coincided with periods of high temperature and intense solar radiation, which can result in ozone episodes and biomass burning emissions (Fig 2).

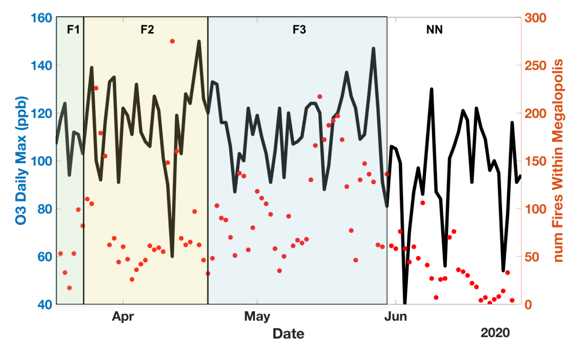

Fig. 2. Daily regional ozone maximum in the Mexico City Metropolitan Area (black) and the number of fires within the Megalopolis region (red dots) during all the lockdown (F1, F2, F3) and the beginning of the New Normal (NN).

There were 4 main phases during the lockdown in Mexico. On 24 March 2020 after exceeding one thousand COVID-19 confirmed cases in the country, led the Federal Government to declare lockdown Phase 2 (F2). And on 21 April, the total lockdown prohibited all non-essential activities as part of the Phase 3 (F3) (Hernandez-Paniagua et al, 2021).

Among all the emissions sectors, mobile emissions, showed large decreases worldwide contrasting with marked increases in residential mobility. In the Mexico Megacity, motor vehicles contribute to ~ 95% and 86% of total CO and NO_X annual emissions respectively (SEDEMA, 2021).

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Nevertheless, some emission sectors were considered as essential in Mexico during all the lockdown. Specifically, the activity of the power generation, construction, and part of the oil industry were roughly unchanged. Finally, the New Normal (NN) period began on 1 June 2020 and consisted of a gradual reopening of the non-essential activities.

The objective of this study is to estimate the regional contribution of emissions reductions for both the main stages of the lockdown period (F1, F2, F3) and the first month of the new normal (NN), over the Megalopolis area (CAMe) in Central Mexico. Section 2 presents the model configuration and the method to isolate the influence of biomass burning emissions is presented in Section 3. The main results and a brief discussion are presented in Section 4 and the conclusions are summarized in Section 5.

2. MODEL CONFIGURATION

Regional simulations were conducted with the WRF-chem model v4.2.1 using 2 nested domains of 25 km and 5 km. The main domain covered Mexico and parts of southern US and Central America. The nested domain covered Central Mexico. The simulation period spanned from 16 March to 30 June 2020. It includes the 3 phases of the lockdown and the first month of the New Normal. The simulation period was divided into 27 five-day slots with cycled chemistry. The first day was regarded as spin-up. The model employed the WSM-6 microphysics scheme, the Noah land-surface model and the RRTMG scheme for short- and longwave radiation. The model used the FNL 0.25º x 0.25º reanalysis data for boundary and initial conditions. The chemical initial and boundary conditions were defined with the NALROM (NOAA Aeronomy Lab Regional Oxidant Model ideal profile (Liu et al., 1996).

The model-ready emissions datasets are constructed with the DiETE pre-processor (García et al, 2018) developed at CCA UNAM using the National Emissions Inventory for Mexico (INEM), the National Emissions Inventory (NEI) for US, and the EDGAR global emissions inventory for the emissions over the ocean and Central America. Only the INEM emissions of 2016 are scaled for 2020. The biomass burning emissions were obtained with the FINN inventory (Wiedinmyer et al., 2011)

2.1 Emissions reductions

The CONFORM (COVID adjustmeNt Factor fOR eMisssions) gridded global dataset is used to represent the COVID-19 lockdown emissions reductions in Mexico. This database is based on activity data of individual sectors, which includes transportation, industry, residential sources and power generation. The adjustment factors are calculated as the ratio between the activity data for a given sector and day or month and the median value of the activity data over a 5-week period spanning from 1 January to 31 August 2020. The dataset provides for each location and sector an estimated average, as well as low and high values of the adjustment factors (Doumbia et al., 2021).

In this work, the adjustment factors (Fig. 3) are applied at the national level in the coarse simulation domain and to the surrounding states of the Mexico Megacity in the nested domain. Since some industry sectors were considered essential activities, only the residential and mobile sectors are considered for the simulations.

As for the mobile sector in the Mexico Megacity, official Mexican government data from the Mobility Secretariat based on TomTom activity data related to the changes in vehicle fleet (SEMOVI, 2021) are used only for the Metropolitan Area. The residential adjustment factors are used at the national level in both simulation domains.

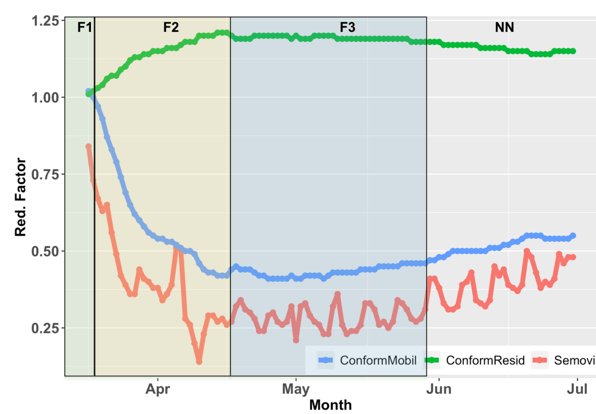

Fig. 3. Adjustment Factors profiles for the emissions reduction scenarios. Official data as published by the Mexico City Mobility Secretariat (red) based on TomTom information; and CONFORM Dataset average factors for mobile (blue) and residential (green) emission sectors.

3. METHOD

Given the highly nonlinear dynamics of ozone and particle formation, the effects on air quality might be different among regions according to the magnitude and spatial distribution of emissions. For that reason, evaluating the impact of one source among different sources needs to separate the single contribution of each source and the combined interaction of all the sources in a region of interest.

The Factor Separation Approach (FSA) is applied to separate the impact of one factor (source) from its interaction with all the factors (Stein and Alpert, 1993). In this work, the aim is to estimate the contribution of the: 1) lockdown emissions reductions; 2) biomass burning emissions and 3) their possible interaction. After applying the FSA four sets of simulations are required in order to estimate the impact of the lockdown period and its interaction with one of the main sources in Central Mexico.

Following the FSA, the set of simulations considers the lockdown emissions reductions (*L*), the wildfire emissions (*F*), their interaction considering both factors (*FL*) and the base case (*b*) without both factors: f_L, f_F, f_I, f_b. Thus, the pure impacts are expressed as:

$$f_L = L - b \quad (1)$$
$$f_F = F - b \quad (2)$$

and their interaction is expressed as:

$$f_I = LF - L - F - b \quad (3)$$

Please note that *F*, *L*, *LF*, and *b* denote the four sets of simulations needed to apply the Factor Separation Approach considering just these two main sources.

4. RESULTS

The impact of extended emissions reductions, biomass burning emissions and their interaction on the regional levels of ozone and anthropogenic secondary organic aerosols (ASOA) during the lockdown period is estimated with the FSA. As shown in Eqtn (3), the contribution from the interaction between the massive emissions reductions during lockdown and the biomass burning emissions to the surface regional levels of either chemical species, is the difference between its formation by the mixed emissions and the sum of the separate contributions.

Figure 4 shows the average temporal variation of the contribution of the lockdown period alone (pure-L), the biomass burning emissions alone (pure-F) and their interaction (intrctn) on the daily average (left panel) and maximum (right panel) ozone concentration for the Mexico City Metropolitan Area (MCMA), which encompasses the Mexico Megacity and some municipalities of the State of Mexico.

The biomass burning emissions contributed to both the average and maximum regional ozone during all the lockdown Phases, especially on Phase 3 (~ 15 ppb) where the strictest measures to non-essential activities were implemented.

The lockdown emissions reductions impacted more on the daily maximum (> 10 ppb) and had a small contribution on the daily average (< 5 ppb), decreasing the ozone episodes in the MCMA and hence no contingencies were declared by the authorities. Thus, even though ozone increased in during the pandemics, the results suggest that in some days the lockdown measures counteracted the effect of ozone formation from biomass burning emissions, potentially reducing the number of episodes. However, the net effect of the interaction between the regional emissions and the massive regional reductions during all the lockdown was to increase the ozone levels, particularly on Phase 3.

The emissions reductions also impacted the VOC/NOx regimes. The ozone production in the MCMA is under a VOC-limited regime (Peralta et al., 2021) so that the joint interaction might be negative (Li et al., 2014). This suggests that a shift to a NOX-limited regime in the MCMA was more likely during Phase 2 and Phase 3. In this regard, Peralta et al. (2018) found an increase in NOx-limited conditions in the MCMA with respect to 2019, and their data suggest that VOC-limited conditions heightened in some regions as well.

There was a dramatic decrease in the biomass burning emissions at the beginning of the New Normal period, due to both the burning and rainy seasons. In this period, the contribution to the daily average and daily maximum was smaller than in the main 3 Phases of the lockdown. During the New Normal, the interaction tended to counteract the small contribution of the biomass burning emissions to the daily maximum (< 5 ppb). However, in some days it tended to increase the ozone levels.

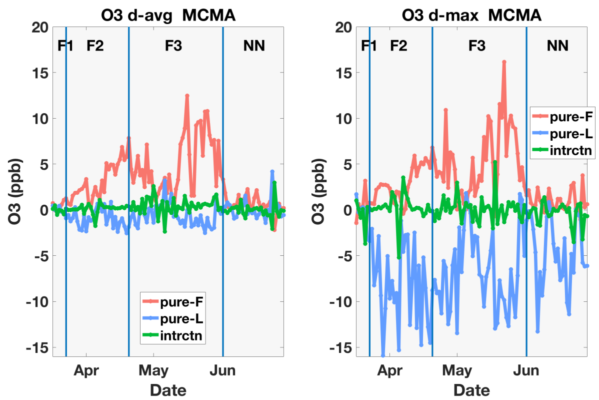

Fig. 4. Contributions to the ozone daily average (left) and ozone daily maximum (right) of biomass burning emissions (pure-F), lockdown measures (pure-L) and their interaction (intrctn; Eqn 3) in the Mexico City Metropolitan Area.

Figure 5 shows the average contribution of the interaction on the ozone daily maximum for the Megalopolis region. Each line corresponds to a Metropolitan Area of the states within the Megalopolis (Puebla, State of Mexico, Morelos, Tlaxcala, Hidalgo and Queretaro).

There was a significant enhancement in the ozone levels in Hidalgo State. It is located to the north of both Mexico City and State of Mexico, and it is home of the Tula-Vito-Apaxco corridor. In this industrial area, there is an oil refinery, a cement plant and a power plant. The Pachuca Metropolitan Area, close to the Tula-Vito-Apaxco corridor, had the highest regional contribution to the ozone levels in Phase 2, as well as the lowest contribution in Phase 3.

Nevertheless, the interaction in the Metropolitan Areas of the States in the Megalopolis with the highest biomass burning emissions (Toluca [Tol; yellow]; Morelos [Mor; blue]), had a relatively small contribution to the maximum ozone levels, suggesting that the downwind transport of emissions, ozone precursors, and ozone is important for the regional ozone dynamics. However, biomass burning emissions alone could have contributed more than in the MCMA, with about 20 ppb in Morelos.

Similar to the MCMA, the strongest variation in the VOC/NOx regimes in the Megalopolis was during Phase 2, mainly in Hidalgo; and during Phase 3 in the entire region, mainly in Puebla, Tlaxcala, Hidalgo and Morelos. During the New Normal the change in regimes was likely higher in Toluca, Tlaxcala and Morelos.

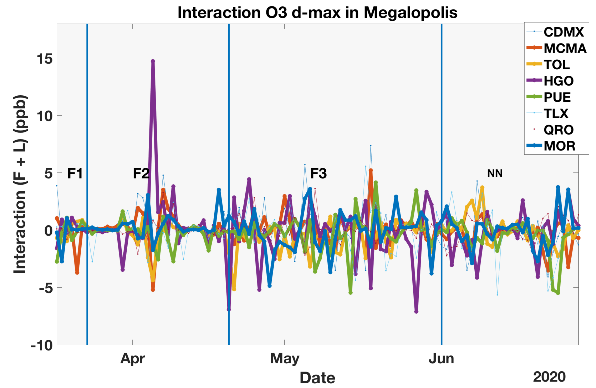

Fig. 5. Ozone daily maximum from the interaction of the mixed emissions from biomass burning and lockdown reductions for the main Metropolitan Areas in the Megalopolis region. Mexico Megacity (CDMX); Mexico City Metropolitan Area (MCMA); Toluca (TOL); Pachuca (HGO); Puebla (PUE); Tlaxcala (TLX); Queretaro (QRO) and Cuautla (MOR).

Figure 6 shows the spatial variation of the interaction on the ozone daily maximum, $PM_{2.5}$ and anthropogenic secondary organic aerosols (ASOA) for the Megalopolis. It corresponds to the average of selected days in each Phase of the lockdown. Averaging the entire period of each Phase tended to mask important spatial features of the interaction.

During Phase 2, the interaction of the mixed emissions (biomass burning plus lockdown reductions) tended to increase maximum ozone levels in some states (Morelos, Puebla) and to decrease ozone levels in other states (Tlaxcala, Hidalgo). Within the MCMA, there was an increase in the northern part of the basin and an increase in the center and the southwestern part close to Toluca. On the other hand, the $PM_{2.5}$ levels increased in the MCMA, Tlaxcala and in the Tula-Vito-Apaxco region in Hidalgo State. However, there was a higher regional decrease in the ASOA production. In this Phase, Toluca was the only Metropolitan Area that presented an increase in the maximum of all species.

In Phase 3 of the lockdown, the interaction tended to decrease the regional ozone levels more than in Phase 2, but local increases of a few ppbs are suggested in Hidalgo and Puebla. However, there was a significant increase in $PM_{2.5}$ maximum concentration in several states of the Megalopolis. In particular, the industrial area in Hidalgo, Puebla, Tlaxcala, the MCMA, and Toluca. Nevertheless, the interaction contributed to a regional increase in secondary organic aerosols in the entire

Megalopolis. The strictest measures of non-essential activities, and at the same time, the increase in residential emissions due to changes in working activities (home-office) and the highest number of fires in the burning season, changed the VOC/NOx regime so that a significant decrease in NOx emissions could have increased SOA production (Gaubert et al., 2021) in the entire Megalopolis. Figure 7 illustrates this generalized increase in the maximum of ASOA due to the interaction of the mixed emissions, from mid-May to beginning of June 2020.

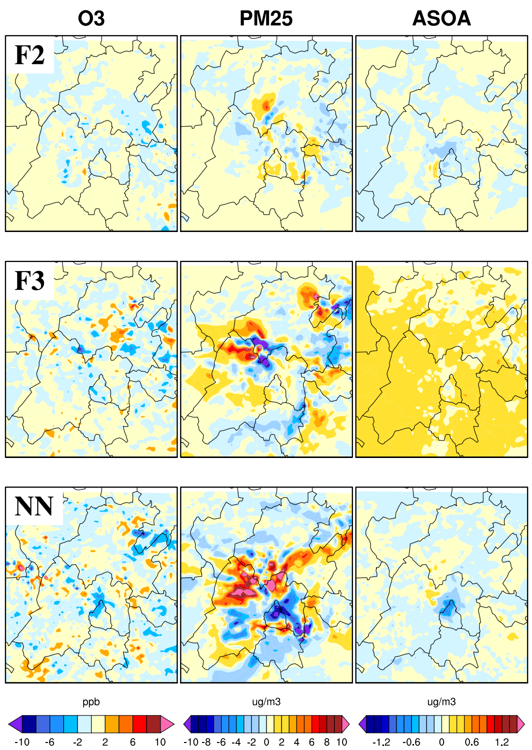

Fig. 6. Spatial distribution of the Interaction between biomass burning emissions and lockdown reductions for the main Metropolitan Areas in the Megalopolis region in Phase 2 (F2; upper row); Phase 3 (F3; middle row) and New Normal (NN; bottom row)

In the New Normal, there were more regions with local increases and decreases of maximum ozone levels. It is indicated that in the MCMA, the highest reductions in ambient levels were during the New Normal, where the gradual re-opening of non-essential activities began. This is in agreement with Figure 2. However, even though there were days with good air quality in the MCMA, and low ozone and $PM_{2.5}$ ambient levels during all the Phases, the results suggest that the effect of the lockdown measures started to be more evident after the biomass burning emissions decreased significantly, more likely at the beginning of the New Normal period.

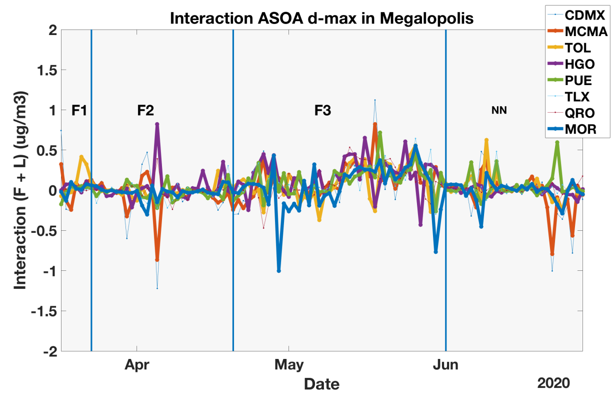

Fig. 7. ASOA daily maximum from the interaction of the mixed emissions from biomass burning and lockdown reductions for the main Metropolitan Areas in the Megalopolis region. Mexico Megacity (CDMX); Mexico City Metropolitan Area (MCMA); Toluca (TOL); Pachuca (HGO); Puebla (PUE); Tlaxcala (TLX); Queretaro (QRO) and Cuautla (MOR).

5. Conclusions

In this study, the impact of the lockdown period in surface ozone, $PM_{2.5}$ and ASOA levels in the Megalopolis region of Central Mexico is estimated. Global and official adjustment factors are used to represent the variation in emissions of the mobile, residential and industrial sectors.

The is applied to estimate the interactions of the biomass burning emissions and the massive reductions as a result of the lockdown. The contribution of each source, biomass burning and massive reductions due to lockdown, as well as their joint interaction is estimated with the Factor Separation Approach.

The impact on the averaged surface ozone levels due to the sole contribution of the lockdown reductions in the Megalopolis were more evident on the daily maximum than on the daily average, implying that the number of episodes could have decreased and hence no contingencies were declared by the official authorities for the lockdown period.

In addition, the contribution of biomass burning emissions was significant in the 3 main Phases of the lockdown and increased not only the ozone levels, but also de $PM_{2.5}$ and secondary organic aerosols levels.

The results suggest that the emissions from the biomass burning season could have masked the regional impact of the massive reductions due to the lockdown. After the biomass burning emissions decreased substantially in the New Normal period, the impact of the reductions on ozone levels were more evident in some states of the Megalopolis (MCMA, Puebla). At the same time, the impact on surface $PM_{2.5}$ was more regionally heterogeneous.

The interaction of mixed emissions also impacted the regional VOC/NOx regimes and in many states a change to NOx-limited conditions is suggested in most of the Phase 3, with the highest peak in Hidalgo during Phase 2.

A regional increase in the production of anthropogenic secondary organic aerosols in the entire Megalopolis is suggested for Phase 3, where the biomass burning emissions were highest.

Since we used the average adjustment factors of the CONFORM global data set, the results might be biased low. Nevertheless, the results are representative of the emissions variations as a result of the lockdown.

6. Acknowledgements

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7. References

CONAFOR, Reporte seminal de incendios forestales, 2021, Mexico.

Doumbia, T., Granier, C., Elguindi, N., Bouarar, I., Darras, S., Brasseur, G., Gaubert, B., Liu, Y., Shi, X., Stavrakou, T., Tilmes, S., Lacey, F., Deroubaix, A., and Wang, T., 2021: Changes in global air pollutant emissions during the COVID-19 pandemic: a dataset for atmospheric modeling, Earth Syst. Sci. Data, 13, 4191–4206, https://doi.org/10.5194/essd-13-4191-2021.

García-Reynoso, J. A., Mar-Morales, B. E., & Ruiz-Suárez, L. G. Modelo de distribución espacial, temporal y de especiación del inventario de emisiones de méxico (año base 2008) para su uso en modelización de calidad del aire (DiETE)., 2018, Revista Internacional De Contaminación Ambiental, 34(4), 635–649.

Gaubert, B., Bouarar, I., Doumbia, T., Liu, Y., Stavrakou, T., Deroubaix, A., et al. : 2021, Global changes in secondary atmospheric pollutants during the 2020 COVID-19 pandemic. J. Geophys. Res. 126, e2020JD034213.

Hernandez-Paniagua, I., Valdez, I., Almanza, V., Rivera, C., Grutter, M., Stremme, W., García, A., and Ruiz-Suarez, L.G., 2021, Impact of the COVID-19 Lockdown on Air Quality and Resulting Public Health Benefits in the Mexico City Metropolitan Area. Front. Public Health 9:642630. doi: 10.3389/fpubh.2021.642630, 2021
https://doi.org/10.1029/2020JD034213

Li, G., Bei, N., Zavala, M., and Molina, L., 2014: Ozone formation along the California–Mexican border region during Cal–Mex 2010 field campaign. Atmos. Env., 88, 370-389.

Liu, S., McKeen, Stuart., Hsie, E.Y., Lin, X., Kelly, K., Bradshaw, J., Sandholm, S., Browell, E., Gregory, G., Sachse, G., Bandy, A., and Thornton, D.,1996: Model study of tropospheric trace species distributions during PEM-West A. J. Geophys. Res. 101. 2073-2086. Doi:10.1029/95JD02277.

Peralta, O., Ortínez-Alvarez, A., Torres-Jardón, R., Suárez-Lastra, M., Castro, T., and Ruíz-Suárez, L. G., 2021: Ozone over Mexico City during the COVID-19 pandemic, Sci. Tot. Env., 761, 143183.

SEDEMA, 2021, last access november 15 2021 Mexico City Metropolitan Area Emissions Inventory 2018
http://www.aire.cdmx.gob.mx/descargas/publicaciones/flippingbook/inventario-emisiones-cdmx-2018/Inventario-de-emisiones-cdmx-2018.pdf

SEMOVI, 2021, last access nov 2 2021 https://datos.cdmx.gob.mx/dataset/diferencias-porcentuales-en-el-transito-vehicular-en-la-cdmx-tomtom/resource/cd8b65b8-8cbf-4166-91c8-d72ac7e09a71

Stein, D., and Alpert, P., 1993. Factor separation in numerical simulations. J. Atmos. Sci. 50, 2107-2115.

Wiedinmyer, C., S. K. Akagi, R. J. Yokelson, L. K. Emmons, J. A. Al-Saadi, J. J. Orlando, and A. J. Soja, 2011: The Fire Inventory from Ncar (Finn): A High Resolution Global Model to Estimate the Emissions from Open Burning, Geos. Mod. Devel, 4, 3. 625-41.