

Estimation of radiative forcing values from a ceilometer network data: application to the COVID-19 lockdown period in the Iberia Peninsula

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Abstract: During the first half of the year 2020 because of the appearance of coronavirus SARS-CoV-2 and its associate illness “coronavirus disease 2019” (COVID-19) lockdown measures were adopted in Spain producing an exceptional situation in air pollutant emission scenarios due to a sharp decrease in road traffic and industrial activity. The main atmospheric effect related to the lockdown measures analyzed in this research, with the help of the GAME code, is the aerosol direct radiative forcing. The analysis presented in this study is based on the estimation of aerosol radiative forcing before and during the lockdown in Spain, using data from 6 stations scattered across the Iberian Peninsula that belong to the ICENET network and present very different climatic characteristics. As preliminary results, some statistically significant variations have been found between the radiative forcing before and during the lockdown both in the SW and in the LW components.

1. Introduction

During the first half of the year 2020 humankind challenged a great risk for human health because of the appearance of coronavirus SARS-CoV-2 and its associate illness “coronavirus disease 2019” (COVID-19). To fight against this challenge one of the main measures was the lockdown producing significant social and economic changes and an exceptional situation in air pollutant emission scenarios due to a sharp decrease in road traffic and industrial activity. In Spain, the lockdown measures were imposed to all non-essential industries and activities, allowing only acts of force majeure. For instance, during this lockdown, [1] and [2] found a large reduction in the concentration of pollutant gases and black carbon in Spain. Hence, it can be claim that the lockdown measures have caused a great opportunity to study the air composition before and during the lockdown in urban areas and evaluate the role of the main pollutants and aerosols in the Earth’s radiation budget.

These atmospheric aerosols present an heterogeneous distribution, which directly limits their vertical mixing [3], linking their optical and microphysical characteristics to changes in the radiation levels, and hence in the aerosol direct effects, including aerosol direct radiative forcing (ARF) [4]. The latter, is defined as the changes undergone by the radiation due to the presence of aerosol, estimated as the difference between the net atmospheric fluxes with and without aerosols [5]. Then, in order to estimate these ARFs, the Global Atmospheric Model (GAME [4, 6, 7]) is used thanks to its special characteristics. This model is able to estimate the ARFs in two different spectral ranges separately, specifically shortwave (SW) and longwave (LW). Besides this RTM (Radiative Transfer Model) presents a high adaptability, thanks to that, the input signals can be retrieved at the wavelength of 1064 nm [8].

Furthermore, thanks to measurement networks that deploy instruments covering large areas, limitations as the aforementioned

heterogeneous distribution of the atmospheric aerosols, can be overcome. For instance, one of the most recognized network for the retrieval of column-integrated aerosol properties is the global Aerosol Robotic NETwork (AERONET [9]). For their part, some lidar systems are part of the European Aerosol Research Lidar Network (EARLINET [10]). However, the complexity of these systems and the analysis procedures makes not possible, for many stations, their continuous operation.

These issues can be solved by means of the use of ceilometers, unmanned one-wavelength lidars that can run continuously and present low pulse energies with high pulse repetition frequencies. Ceilometers can be used for the retrieval of aerosol optical information from signals at 1064 nm. The present work takes advantage of the Iberian CEilometer NETwork (ICENET [11]), which has deployed six Lufft CHM15k-Nimbus systems covering a large part of the Iberian Peninsula, to estimate 2-D ARFs in absence of mineral dust following the methodology described in [12]. The assessment is performed by means of the estimation of ARFs at both spectral ranges, SW and LW, at the bottom (BOA) and at the top of the atmosphere (TOA) using ceilometer backscatter profiles of the first half of 2020 stored in the ICENET database. Then, the 2020 profiles were also compared to backscatter profiles of the four previous years, from 2016 to 2019, in order to avoid the effect of possible special atmospheric events. All the ceilometers used in the present research are co-located with AERONET sun-photometers, removing uncertainties associated to the distance between both instruments. In a preliminary approach statistically significant differences at the TOA and at the BOA at both spectral ranges between the ARFs before and during the lockdown were found, pointing out a sharp impact in the atmosphere caused by the lockdown measures. Therefore, it can be affirmed that the potential results of the present research can be considered of highly relevancy for the present and future air quality and climate change challenges.

2. Sites and Instrumentation

Table 1, sums up the six stations belonging to ICENET and Figure 1 shows the distribution of the stations listed in Table 1 over the Iberian Peninsula. The color code in this figure stands for the meters above sea level (m a.s.l.).

Table 1. ICENET sites

Site (code)	Institution
Badajoz (UEX)	UEX, AIRE group
Valladolid (UVA)	UVA, Atmospheric group
Madrid (MAD)	CIEMAT
Granada (UGR)	UGR, Physics group
Almería (PSA)	German Aerospace Center
Montsec (MSA)	IDAEA

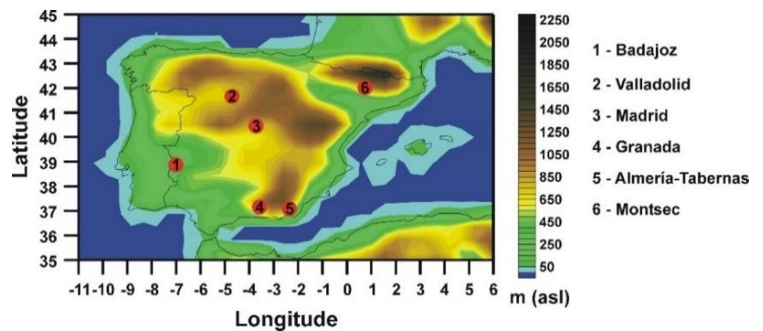


Figure 1. Geographical location of the monitoring sites (red circles).

GAME is a modular RTM that allows calculating upward and downward solar and thermal infrared fluxes at the boundaries of plane and homogeneous atmospheric layers. This RTM, which is fed by ceilometer signals, is used to estimate SW and LW radiative fluxes, with and without aerosols, that lead to the retrieval of ARF estimates at the BOA and at the TOA. A negative or positive sign in the ARF determines whether the aerosols produce a cooling or a heating effect respectively.

3. Results and Discussion

3.1. AERONET AOD₄₄₀ temporal evolution

Prior to the estimation of the ARFs from the ceilometer signals it is worth to assess the temporal evolution of the AERONET AOD₄₄₀ to give light to the temporal evolution of this parameter during the lockdown period. Figure 2 shows the temporal evolution of the AOD₄₄₀ weekly mean values for the period between March 6th and June 19th 2020 (black dashed line), the 6-year weekly AOD₄₄₀ average for the period 2014 to 2019 in the same dates (black solid line) and the difference between them (red solid line). For the sake of clarity only MAD station is showed as an example of the figures retrieved for every station. Green areas represent the lockdown period, blue areas point out a reinforced lockdown period and yellow

areas stand for the Saharan dust outbreaks excluded from the analysis. One can observe that during the lockdown periods, the 2020 AOD₄₄₀ values were lower (negative values) than the 4-year AOD₄₄₀ values, except during the weeks affected by dust events.

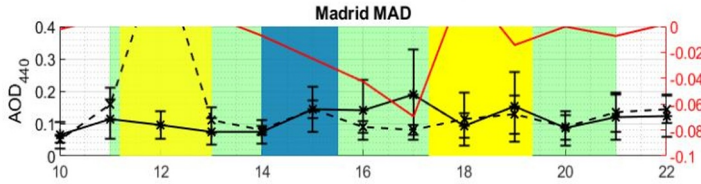


Figure 2. AERONET AOD at 440 nm temporal evolution.

3.2. SW ARF

Once AERONET data have shown strong variations in the AOD during the lockdown period, it can be assumed that the ARF derived from ceilometer signals at the SW and LA and at both heights should show significant variations too. The SW-BOA cooling effects computed for morning and afternoon before the lockdown are around 81.67% and 92.53% greater, respectively, than the cooling effects estimated for the TOA. During the lockdown the SW cooling effects for morning and afternoon at the surface are 76.60% and 72.74% greater, respectively. One can observe that the differences found during the lockdown are clearly lower than before it because of the decrease of the AOD (Figure 2) and by greater SSA₄₄₀ values (less absorbing particles) related to particles with non-anthropogenic origins.

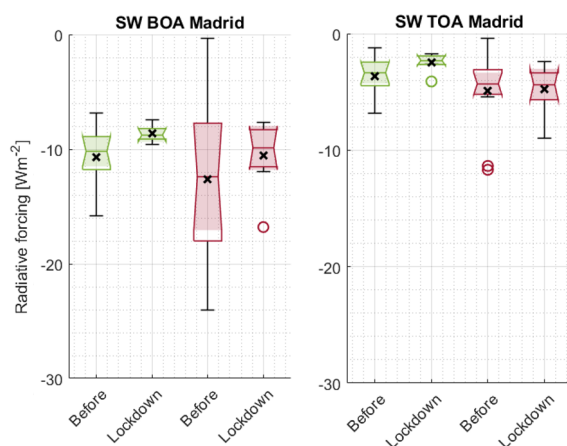


Figure 3. Boxplot of the aerosol radiative forcing in the SW spectral range estimated at the BOA and the TOA for the morning (green boxes) and afternoon (red boxes) before and during lockdown cases

3.3. LW ARF

During the lockdown, there were observed lower AOD values (Figure 2), being the aerosols present in the atmosphere during this period less absorbent, with higher SSA values than before. Additionally, the aerosols exhibit greater efficiency in scattering light in all directions, as indicated by the lower values of the asymmetry factor during the lockdown. However, during the lockdown there were more solar radiation interacting with the aerosols, offsetting the drag toward cooling of the optical properties. This result is consistent with [4], specifically observable in Tables 3 and 4 where cases with lower AOD than others but sharing high SSA values (> 0.90) and asymmetry factor values about 0.70 have a higher heating effect due to solar radiation (lower solar zenith angles).

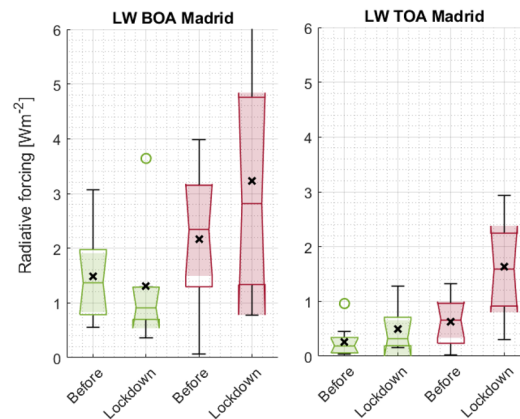


Figure 4. Boxplot of the aerosol radiative forcing in the LW spectral range estimated at the BOA and the TOA

4. Conclusions

The ARFs estimated by means of the ceilometer signals show statistically significant differences that can be found at the BOA in the SW spectral range for the morning cases, which is strongly influenced by variations in the AOD, and at the TOA in the LW spectral range for the afternoon cases, where scattering particles and variations of environmental conditions as the surface temperature lead to strong variations in the radiative forcing estimates. The statistically meaningless differences observed in the remaining scenarios can be explained because of the presence of absorbing particles and other atmospheric interactions that can affect the radiative forcing. However, the observed variations in the radiative forcing estimates in

the SW and LW spectral ranges at all levels before and during the lockdown are directly related with the decrease of emissions of aerosols from human activities. Besides, it is worth to note that the presence of anthropogenic aerosols in the atmosphere not only entails changes in the radiative budget but also generates extreme situations. It is worth to note also the strong capabilities shown by ceilometers in the assessment of the climate evolution.

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