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EFFECTS OF INCREASING THE SURFACE REFLECTANCE OVER AIR QUALITY LEVELS USING WRF-BEM/AEMM/CMAQ. APPLICATION OVER THE CITY OF MADRID.

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Abstract: The effects of increasing the surface reflectance by albedo modifications have been evaluated using an air quality modelling system. We have evaluated the influence over pollutant concentrations of increasing from 0.20 to 0.55 the roof surface albedo (scenario called albedo1) and increasing from 0.15 to 0.30 the ground surface albedo and from 0.20 to 0.55 the roof surface albedo for all urban categories. To obtain a better representation of the local processes we have considered very high resolution (333.33m) and up to 10 different urban categories. Changes in albedo cause changes in different meteorological parameters (planetary boundary layer height, radiation and temperature), modifying the pollutant concentration in every single scenario. Results show that this mitigation measure is effective during summer periods, providing not high NO_2 increments and O_3 reduction on the urban areas of the city of Madrid. Whilst during winter periods the measure induces NO_2 increments over polluted areas with high NO_x emissions. In this way, the benefits of the measure, from the point of view of urban heat island effects, are greater than the detriments during summer periods, in comparison with air quality effects.

Key words: *WRF, BEM, CMAQ, Urban Albedo, Air Quality, Madrid City, Cool Roofs.*

1. INTRODUCTION

The alterations of the land surface physical properties caused by the human occupation of a territory can disturb the climate through changes in the radiative energy balance. Small changes in surface albedo can lead to changes in global temperature equivalent to those commonly associated with increased greenhouse gases. Mitigation of the impact of climate change by increasing the reflectance of the Earth's surface is a simple and cost-effective strategy with great potential for development worldwide.

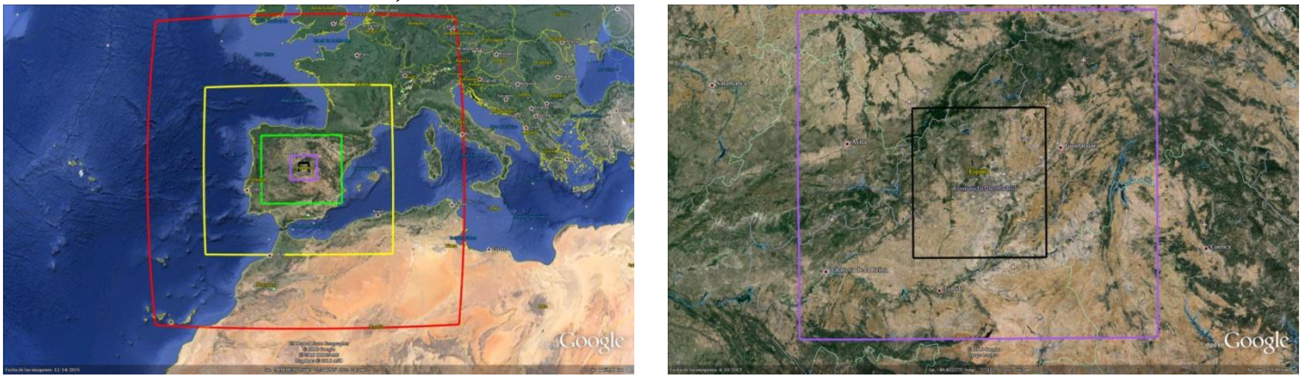
Previous authors' studies (Campra et al., 2008; Campra et al., 2017b) have analyzed the effects of changes in albedo parameter over temperature, radiation balance and planetary boundary layer height in latitudes with high annual insolation. In theses papers the benefits of applying this mitigation strategy are commented, and changes in temperature, radiation and urban heat island phenomenon are showed. In this contribution we would like to evaluate the effects of low changes in the surface albedo over the air quality levels in an urban environment as Madrid (Spain). In this way, the effects of applying this strategy over meteorological parameters and air quality can be balanced.

To do this, we have used an air quality modelling system, coupling a meteorological model, an emission model and a photochemical model. Meteorological simulations have been conducted using BEM module as urban module (Salamanca et al., 2010). We have considered up to 10 urban categories, using the same meteorological configuration that the previous analysis developed in Campra et al., 2017b. Numerical simulations have been executed for 96 hours during a winter and a summer periods in 2008. A total amount of 6 simulations have been carried out, considering two periods and three scenarios from the point of view of urban albedo.

2. METHODOLOGY

Madrid is the studied area, located in the centre of the Iberian Peninsula over the Central Plateau. Anthropogenic contribution dominates pollutant air emissions in Madrid. Transport emissions (road and non-road traffic) from the metropolitan area of Madrid are the main CO, NO_x and particulate matter emission sector, representing between 53 and 86% of the total emissions (Arasa et al., 2016). Traffic sector is the main responsible to NO_2 and O_3 levels with contributions between 73-89% and 57-77% respectively (Arasa et al., 2016). On the other hand, industrial emissions dominate SO_x and NMVOCs (non-methane volatile organic compounds) emissions.

In Figures 1 we show modelling domains used in forecasts over the city of Madrid. Modelling is built over a mother domain (called d01) with 27 km spatial resolution, centred at 40.383ºN 3.717ºW, and inner nested domains have 9-3-1-0,333km as horizontal resolution.



Figures 1. Modeling domains for simulations: d01, d02, d03, d04 and d05 (left), and d04 and d05 (right). [Images generated using Google Earth]

Emission and photochemical simulations have been done for the same periods that simulations used in the previous meteorological analysis (Campra et al., 2017b). Concretely, simulations have been conducted in different periods of the year 2008. Numerical simulations were executed for 96 hours included in the period between 06/29/2008 and 07/02/2008 (hereinafter referred to as summer period) and the period between 12/31/2007 and 01/04/2008 (hereinafter referred to as winter period). The first 24 hours are taken as spin-up time to minimize the effects of initial conditions. A total amount of 6 simulations have been done: three simulations corresponding to the winter period and different albedo scenarios and three equivalent simulations corresponding to the summer period. Albedo scenarios have been defined for the meteorological analysis as:

- Default scenario: using default value of albedo for all urban categories.
- Scenario defined as Albedo1: increasing from 0.20 to 0.55 the roof surface albedo for all urban categories.
- Scenario defined as Albedo2: increasing from 0.15 to 0.30 the ground surface albedo and from 0.20 to 0.55 the roof surface albedo for all urban categories.

The air quality modelling system used to evaluate albedo scenarios from the point of view of air quality is composed by a meteorological model (WRF), an emission model (AEMM) and a photochemical model (CMAQ). To configure it, authors have followed the recommendations and requirements indicated in the Guide on the use of models for the European Air Quality Directive (Denby, 2010; Arasa et al., 2016). For this contribution, the annual anthropogenic emission inventory that belongs to the Regional Government of Madrid with 1x1 km^2 of horizontal resolution has been used, version 2010. This Inventory includes emissions classified by Selected Nomenclature for Air Pollution (SNAP) sectors, and it has been adapted to d04 and d05 domains.

In Table 1 we summarize the configuration options used in the simulations carried out. Simulations have been executed over a computing cluster owned by Meteosim S.L. formed by 28 nodes and 308 cores.

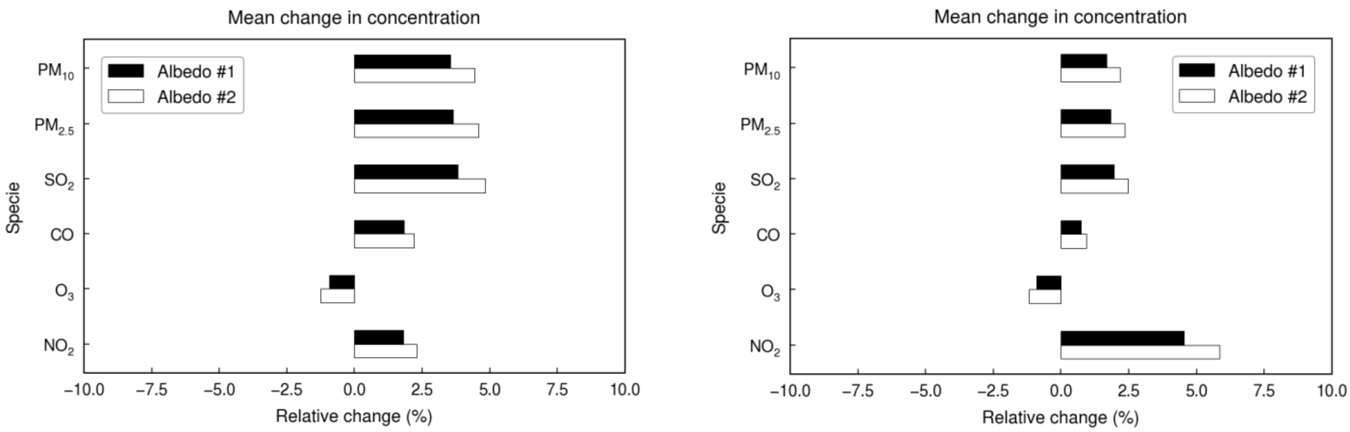
Table 1. Configuration options selected for numerical simulations

Model	**Configuration**	**Selected option**
Meteorological	Version	WRFv3.2
Meteorological	Initialization	CFSv2
Meteorological	Microphysics	WRF Single-Moment 3-class

Meteorological	Longwave radiaion	RRTM
Meteorological	Shortwave radiation	Dudhia
Meteorological	Cumulus	Kain Fritsch (applied over domains d01 and d02)
Meteorological	Surface Layer	MM5 similarity
Meteorological	Planetary Boundary Layer	BouLac PBL
Meteorological	Urban Parameterization	BEM (Salamanca et al., 2010)
Meteorological	Vertical levels number	51
Meteorological	Time step	60 s (d01-d02-d03-d04) 1 s (d05)
Meteorological	Topography	ASTER (applied over domains d04 and d05)
Meteorological	Land Uses	CLC2006 (applied over domains d04 and d05)
Meteorological	Nesting and domains	Two way nesting (d01-d02-d03-d04) One way nesting (d04-d05)
Emissions	Version	AEMMv3.0
Emissions	Temporal profiles	From the Unified EMEP Model
Photochemical	Version	CMAQv5.0.1
Photochemical	Meteorological preprocessor	MCIPv4.3
Photochemical	Gas Module	CB-05
Photochemical	Aerosol Module	AERO5
Photochemical	Domains	d04 and d05

3. RESULTS AND DISCUSSION

The increase of albedo causes an increment of NO_2 concentration and a reduction of O_3, whilst changes in albedo do not affect remarkably the levels of CO, SO_2, PM_{10} and $PM_{2.5}$. Changes in average NO_2 and O_3 concentration between the default and albedo scenarios for d05 domain are showed in Figures 2 The increment for NO_2 is more intense during the winter period, when the levels of this pollutant are higher. And the reduction of O_3 is more intense during the summer period, also coinciding with the period with highest ozone levels. Between scenarios, the albedo 2 scenario represents higher increases/reductions of NO_2/O_3 in comparison with albedo 1 scenario.



Figures 2. Mean relative change in pollutants concentration after albedo increase for the winter period (left) and for the summer period (right).

Considering that over the region of Madrid NO_2 levels during winter and autumn periods are high (Cuevas et al., 2014), the measure of increasing the surface reflectance, as climate change mitigation measure, does not seem effective. Furthermore, NO_2 increments are produced over urban regions (cities of Madrid, Alcobendas and Coslada) with high traffic emissions, due to representative changes in temperature and planetary boundary layer height (PBL) associated to changes in albedo (Figures 3).

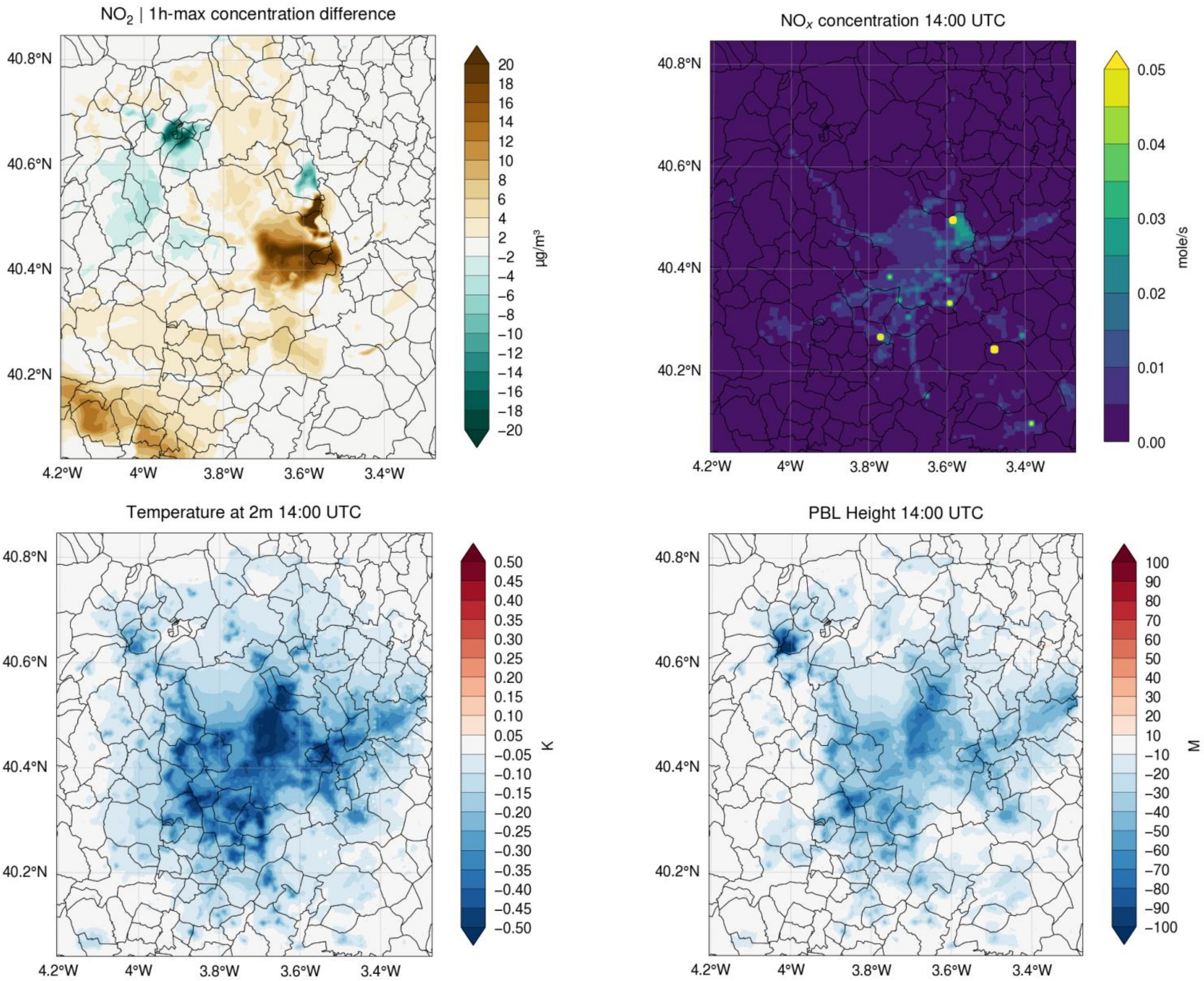


Figure 3. Difference concentration between NO_2 daily maximum 1-h for the albedo2 scenario and default scenario during the winter period (upper left). NO_x emissions distribution for the winter period at 14 UTC (upper right). Temperature at 2m and PBL height difference between albedo2 scenario and default scenario for the winter period at 14 UTC (lower left and right respectively).

For all hours, the albedo increment causes NO_2 concentrations higher that in the default scenario. For the winter period, the maximum difference between albedo and default scenarios is at 15UTC, whilst in the summer period is at 19 UTC. During the winter period, the differences are overlapped with the maximum temperature and PBL height difference, and the increment is more regular during the whole day in comparison with the summer period profile. On the other hand, in the case of the summer period, the maximum NO_2 difference is just around the maximum NO_x emission at 19 UTC. This maximum NO_2 difference corresponds with and it is due to a considerable descent of PBL height when albedo changes are applied.

In view of previous results, the reflectance increment of the Earth's surface causes an increment of NO_2 concentration during winter and summer period. In any case, this increment could be assumed during periods with low NO_2 concentration as summer periods. In this same period, ozone concentration, which is the pollutant with highest concentration, is reduced as consequence of albedo increase. The greater differences of ozone concentration are produced over the city of Madrid and surroundings, in the same areas where NO_2 increments are located. In the same way, the most intense hourly difference between scenarios is located around 19 UTC, coinciding with the maximum NO_2 difference (associated to a PBL height descens). For this pollutant, the reduction of the concentration is mainly due to the NO_2 increment and secondarily to changes in meteorological conditions. Urban areas as Madrid are Madrid are typically characterized as VOCs sensitivity areas (Sillman et al., 2003). In these areas, if NO_x levels rise and volatile organic compound (VOC) concentrations are practically constant, the ozone is reduced.

4. CONCLUSIONS

Numerical experiments have been developed to evaluate and estimate the effects over air quality levels of an increasing of reflectance Earth's surface using a coupled air quality modelling system composed by the meteorological model WRF, the emission model AEMM and the photochemical model CMAQ. The air quality modelling system has been executed using a very high resolution, 333.33m, and considering an urban module to obtain a better representation of the urban scale in the meteorological model. Different scenarios from a point of view of albedo have been executed, increasing the surface albedo of ground and/or roof for all urban categories. Only anthropogenic emissions have been considered.

Results show that measure of increase the surface albedo is not effective during winter periods because causes NO_2 increments in areas where the concentration of this pollutant is typically high. This behaviour is mainly due to the reduction of the PBL height as a consequence of changes in surface albedo. On the other side, during summer periods, when the NO_2 levels are lower, the measure could be effective because causes not high NO_2 increments and O_3 reductions. In this case, O_3 differences are associated to NO_2 increments in a VOC sensitivity area. In this way, this study demonstrates that this geoenginneering measure could be effective if it is time dependent and if it is applied during summer time.

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