AEROSOL-RADIATION-CLOUDS-PRECIPITATION INTERACTIONS DURING DUST OUTBREAKS OVER THE MEDITERRANEAN: A CLIMATE PERSPECTIVE WITHIN THE REPAIR PROJECT

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RESUMEN

Las intrusiones de polvo desértico de África producen impacto sobre el Mediterráneo y su clima. El polvo puede causar anomalías en la concentración troposférica de aerosoles y potencialmente modificar las propiedades microfísicas de las nubes (mediante interacciones aerosol-nube, ACI) afectando al ciclo hidrológico.

Este trabajo analiza simulaciones realizadas dentro del proyecto REPAIR, utilizando el modelo WRF-Chem versión 3.6.1. con la resolución de EURO-CORDEX 0.22º/0.44º, sobre todo el Mediterráneo con el objetivo de cuantificar la influencia de incluir las interacciones polvo-radiación-nubes-precipitación en un modelo climático regional acoplado en línea con química. El impacto de las interacciones del polvo se evalúa sobre variables de nubes y precipitación.

Los resultados de las simulaciones concuerdan satisfactoriamente con datos observacionales de satélite (MODIS) cuando se evalúa la profundidad óptica de aerosoles (AOD) a 550nm, lo que indica la capacidad del modelo para estimar la contribución del polvo africano sobre el Mediterráneo. La inclusión de ACI suprime la precipitación sobre el Mediterráneo; además pone de manifiesto un efecto de realimentación positivo mediante el cual se produce una reducción en la cobertura nubosa dando lugar a una mayor radiación de onda corta incidente, lo que aumenta la temperatura y la presión de saturación de vapor produciendo de nuevo una menos cobertura nubosa. Sin embargo, estos cambios apuntan la necesidad de futuros trabajos que caractericen de forma más precisa las interacciones aerosol-nube y reduzca su incertidumbre.

Palabras clave: polvo, aerosol, nube, microfísica, Mediterráneo, modelo.

ABSTRACT

Dust intrusions from African desert regions have an impact on the whole Mediterranean Basin and its climate. Dust may cause an anomalous aerosol load in

the tropospheric column and have the potential to modify cloud microphysical properties (by aerosol-cloud interactions, ACI), thus affecting the hydrological cycle. This work analyzes the simulations run in the framework of the REPAIR Project, using the WRF-Chem model version 3.6.1. with the EURO-CORDEX 0.22º/0.44º resolution, over the whole Mediterranean Basin with the objective of quantifying the influence of including dust-radiation-clouds-precipitation interactions in a regional on-line coupled climate/chemistry model. The impact of dust interactions is assessed on several clouds and precipitation variables.
Simulation results show a satisfying agreement when compared with satellite observations (MODIS) when assessing aerosol optical depth (AOD) at 550 nm and supports the skills of the model to estimate the African dust contribution over the Mediterranean. The inclusion of ACI suppresses the precipitation over the Mediterranean basin and points out a positive feedback in which the inclusion of ACI from dust produce lower cloud fraction, which results in higher shortwave radiation incoming, also resulting in higher temperatures and higher saturation pressure which produce again a lower cloud fraction. However, the aforementioned changes points to the need for further works to accurately characterize the aerosol-cloud interactions and reduce their uncertainty.

Key words: dust, aerosol, cloud, microphysics, Mediterranean, model,

1. INTRODUCTION

Atmospheric aerosol and clouds are the most uncertainty climate forcing agent nowadays. Atmospheric aerosol, depending on their properties, affect the Earth's climate by aerosol-radiation (ARI) and aerosol-clouds interactions (ACI) (Boucher et al., 2013). On the other hand, dust plays an important role because of its impacts, which may go beyond desert regions (Prospero, 1999). Dust intrusions from African desert regions have an impact on the whole Mediterranean Basin and its climate (Escudero et al., 2005; Calastrini et al., 2012; Palacios-Peña et al., 2017). Dust may cause an anomalous increase of aerosol load in the tropospheric column and have the potential to change the energy fluxes in the Earth-atmosphere system by modifying cloud microphysical properties, such as the cloud liquid water path (CLWP), cloud fraction (CFRAC), cloud top temperature (CTT), droplet number concentration (CDNC), or cloud particle size distribution (CPSD). Through aerosol-radiation-cloud interactions, dust can modify convective and large-scale precipitation under certain conditions, thus affecting the hydrological cycle.
Thus, the main objective of this work is to quantify the influence of including dust-radiation-clouds-precipitation interactions in a regional on-line coupled climate/chemistry model on several variables clouds and precipitation variables as convective precipitation, CLWP, CFRAC and CDNC.

2. METHODS

Simulations were run using the online climate/chemistry model WRF-Chem model (Grell et al. 2005) version 3.6.1. The modelling domain corresponds to EURO-

CORDEX at 0.22º/0.44º and simulations cover a present period between 1991 and 2010. Within this period, several case studies for desert dust outbreaks over the whole Mediterranean Basin have been studied with the objective of quantifying the influence of including dust interactions in a regional on-line coupled climate/chemistry model on several variables: convective precipitation, CLWP, CFRAC and CDNC. Two different runs have been evaluated: a base case, in which dust was not taken into account (WRF-alone); and a simulation with the GOCART dust scheme in WRF-Chem, in which dust-radiation-clouds interactions were taken into account online (ACI case). The model setup is summarized in Table 1. Physics parameterization were the same in both cases.

Parameterization	Name	Reference
Physics		
Microphysics	Morrison	Morrison et al., 2005
Radiation (Short & Longwave)	RRTM	Clough et al., 2005
Planetary Boundary Layer	YSU	Hong & Pan, 1996
Cumulus	Kain-Fritsch	Kain & Fritsch, 1993
Soil option	Noah	Tewari et al., 2004
Chemistry		
Gas-phase	RACM-KPP	Stockwell et al., 1997, Geiger et al. 2003
Aerosol	GOCART	Chin et al., 2000
Photolysis	Fast-J	Fast et al., 2006
Biogenic emissions	MEGAN	Guenther, 2006
Dry deposition	Wesely	Wesely, 1989
Wet deposition	Wet deposition + Grid-scale wet deposition	

Table 1: WRF-Chem Model setup for experiments including (or not) aerosol-cloud interactions

3. RESULTS

First, we evaluated the change in the precipitation due to the inclusion of ACI from a climatic perspective. Very low changes were found in this climatic evaluation (not shown) which indicates the need to focus our evaluation in certain case study in order to a better evaluation of the ACI due to the dust intrusion over the Mediterranean basin. From the previous experience (Baró et al., 2017, Palacios-Peña et al., 2018a, Palacios-Peña et al., 2018b) and for the sake of brevity results shown in this contribution correspond to the case study between 4 and 15 October 2010.

Simulated dust load reaches values above 100 µm/m^3 (on average) over the Mediterranean in the surface layer and these values become higher at around 1500 m agl which show the African dust contribution. Moreover, AOD at 550 nm was compared with satellite observation from MODIS (or Moderate Resolution Imaging Spectroradiometer) showing a good agreement which supports the skills of the model to estimate this dust contribution.

Figure 1 shows the total, convective and large-scale precipitation for those days when the daily mean precipitation was above 0.25mm/day. Variations around -16.29%, for total, -9.90% for convective and -8.06% for large-scale precipitation were found during the entire studied period.

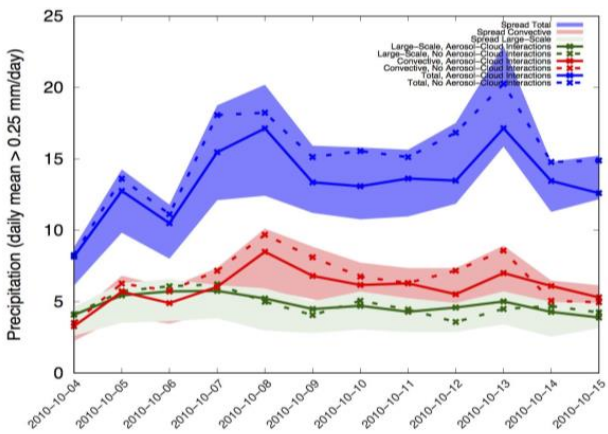

Fig. 1: Differences in convective (red), large-scale (green) and total (blue) precipitation. Continuous lines represent the ACI case and dashed the base case.

Figure 2 show at top-left the CLWP for the case base, at the bottom the bias of the comparison with ESA CCI satellite product (right is base case and left is ACI); the top-right figure represents the variation in the bias of the comparison due to the inclusion of ACI, that means, the differences in the bias between the ACI and the base case. Simulation bias results display absolute values of 58.09 g/m^2 for the base case and 87.78 g/m^2 for the ACI case. Figure 2 at the top-right show a clear increase in the CLWP when ACI from dust where taken into account (absolute variation around 28%).

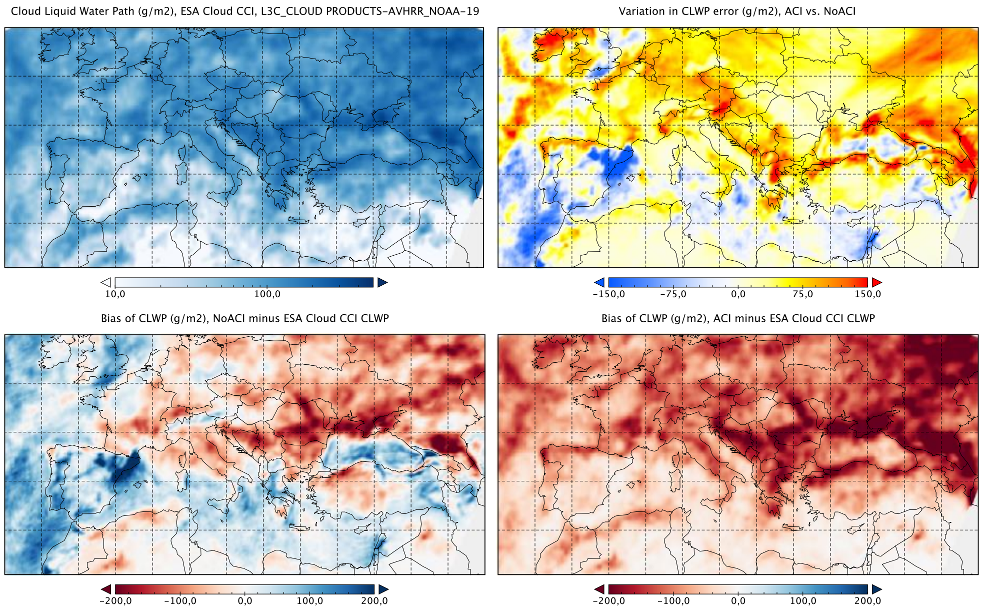

Fig. 2: CLWP evaluation against ESA CCI products.

Figure 3 indicates the daily shortwave radiation, maximum temperature and cloud fraction. This figure shows a reduction in the cloud fraction when ACI from dust were taken into account producing higher shortwave radiation incoming, which results in higher temperatures and higher saturation pressure, resulting again in lower cloud fraction.

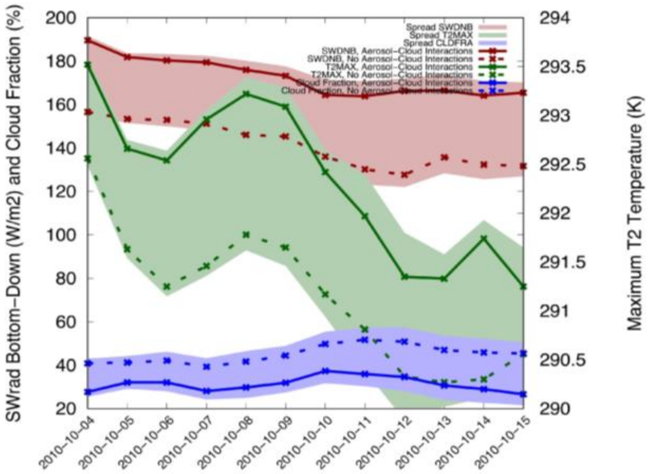

Fig. 3: Daily evolution of shortwave radiation, temperature and cloud fraction. Continuous lines represent the ACI case and dashed the base case.

Finally, Figure 4 shows a zonal profile at latitude 40º. On the left the dust load and on the right the differences in the temperature between ACI and base case. These figures reveal how the maximum differences in temperature were in the same layer where there was a higher dust load.

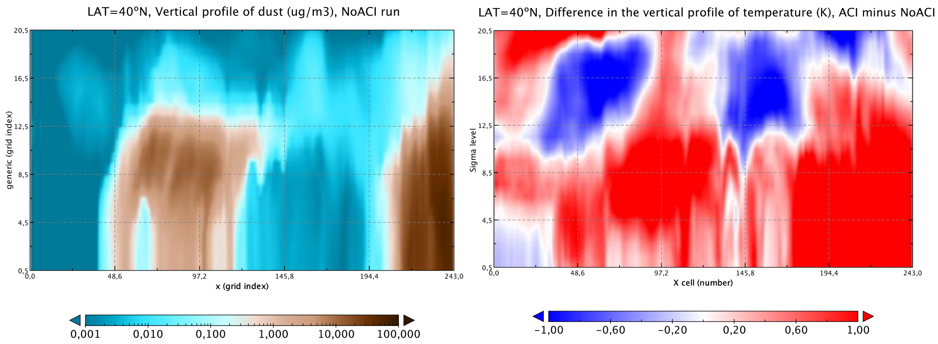

Fig. 4: Vertical profile of dust load and differences in temperature at latitude 40°.

4. DISCUSSION

The evaluation of the changes in precipitation due to dust ACI from a climatic perspective points the need to use study cases if our objective is a better process understanding. Moreover, the comparison between simulations show a satisfying agreement when compared with satellite observations (MODIS) when assessing aerosol optical depth (AOD) at 550 nm and supports the skills of the model to estimate the African dust contribution over the Mediterranean.

Overall, over the Mediterranean domain dust contributes to precipitation suppression. Aerosols affect cloud microphysics by decreasing the CLWP may due to a reduction in cloud droplet number by thermal effects. Thus, there is an observed reduction in cloud cover as a consequence of local heating caused by the aerosol layer. The increase in temperature produce a higher evaporation of cloud droplets results in an overall decrease in CLWP. Thus, a positive feedback may occur, the inclusion of the ACI from dust produce lower cloud fraction, which results in higher shortwave radiation incoming resulting in higher temperatures and higher saturation pressure which produce again a lower cloud fraction.

Despite the aforementioned changes, there is a low estimated significance of the changes observed between the diverse cases for REPAIR simulations (including or not dust interactions in the simulations of precipitation climatologies) in the period 1991- 2010. This low significance, estimated as the ratio between the change signal (difference between ACI and the base case) and the variability modelled in the base case, points to the need for further works to accurately characterize the aerosol-cloud interactions and reduce their uncertainty.

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