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The Impact of Dust Storms on Aerosol Optical Depth and Radiative Forcing

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Abstract

Iraq is one of the most affected countries in Middle East concerning of dust storms events. They have several environmental effects on the climate. This study summarized the simulation of severe dust storm using Regional Climate Model version 4 (RegCM4) and then examine its application to estimate the total amount of dust (dust load), Aerosol Optical Depth (AOD) and dust radiative forcing. As a result, RegCM4 reproduced the selected case of severe dust storm occurred in 03 May 2005. The spatial distribution of values of dust load, AOD and radiative forcing are achieved at every three hours. During the dust storms AOD reaches their maximum values. It shows that the highest value of average concentration for the dust in this case is larger than 200 mg / m^2.

Keywords: RegCM4, AOD, Dust load, Radiative forcing.

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آثر العواصف الترابية على السمك البصري للعوالق والقوة الإشعاعية

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الخلاصة

العراق احد بلدان الشرق الاوسط المتأثرة جداً بظواهر العواصف الغبارية التي لها تاثيرات بيئية عديدة على المناخ. تتلخص هذه الدراسة بمحاكاة عاصفة غبارية شديدة باستعمال انموذج المناخ الاقليمي أصدار 4 (RegCM4) ومن ثم تم فحصه بتطبيقه لتخمين الكمية الكلية للغبار (الغبار المحمول) وعمق الهباء البصري (AOD) والقوة الاشعاعية للغبار. نتيجة لذلك، تمكن RegCM4 من اعادة انتاج الحالة المدروسة للعاصفة الغبارية الشديدة الحادثة بتاريخ 03 ايار 2005 . التوزيع المكاني لقيم حمل الغبار وAOD والقوة الاشعاعية انجزت عند كل ثلاث ساعات. خلال العواصف الترابية AOD تصل إلى أقصى قيمهمن وبينت الحالة المختارة أن أعلى قيمة لمتوسط تركيز للغبار بلغت اكثر من 200 ملغم / م^2.

الكلمات المفتاحية: أنموذج المناخ الاقليمي، السمك البصري للعوالق، الغبار في عمود الهواء والقوة الاشعاعية.

Introduction

Dust in the air column is the most present in the atmosphere of all other aerosols and salt aerosols in some coastal marine areas [1]. Mobilization dust appears as a determinant of the natural sources of dust in dry areas on the global scale [2]. Changing surface topography of desert lands is a cause of mineral dust in the atmosphere, because in these areas metal dust can spread from fine particulate matter transported by rainwater and driven by wind during the dry season. There are several factors specific to this process, including the type of soil particles, wind speed, physical properties of soil (Volumetric particle distribution, soil moisture and particle thickness). For soil surface conditions (surface roughness and vegetation), they are more sensitive to the formation of mineral dust, which lacks vegetation while decreasing the moisture content of the soil [3] and contain readily erodible sediments of fine particles [4]. Dust emissions from vegetation and sand dunes are common, but the main source of dust remains deserts and drylands. Soil particles having a diameter of less than 0.6 mm are known as dust, although the word dust is released on all particles with a diameter smaller than 100 µm, which can be attached to the atmosphere by a cloud of dust. There are also three patterns of dust particles moving and depending on their sizes, shapes, and densities, designated as "suspension", "saltation" and "creep", see figure 1 [5].

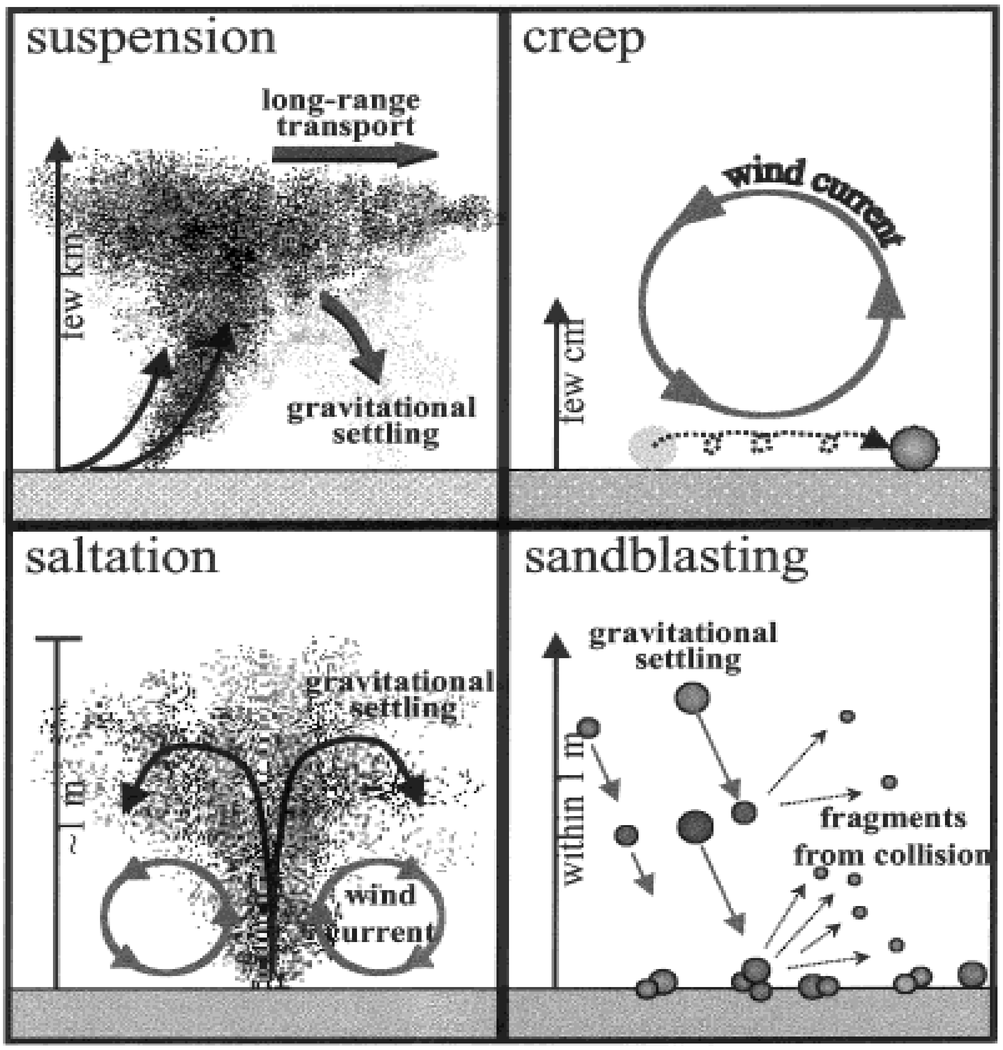

Figure 1: The possible wind-induced processes to move, emit and transport mineral dust particles from source into the troposphere [6]

Dust has a long-term impact on the climate through direct and indirect radiative forcing, depending on the properties of dust, vertical distribution, albedo from cloud cover and the bottom surface. Other environmental impacts of dust include reduced soil fertility and crop damage, reduced solar radiation on the surface and, as a result, reduced efficiency of solar devices, damage to telecommunications and mechanical systems, increased incidence of respiratory diseases and other effects on human health [7]. Dust deposition in the ocean, however, provides nutrients to ocean surface water and the seabed [8].

In recent years, some researches have been carried out their investigations on the analysis of dust storm events over Iraq and their impacts on aerosol optical properties (AOP). For example, Al-Dabbagh [9] studied dust events using BSC-DREAM8b Regional Model and NCEP data over West Asia (Iraq) which simulates dust outbreaks cases which are intense and considered as natural hazards. Also, Halos et al. [10] estimate with mapping aerosol optical properties over Iraq and surrounding regions. They analyzed and assessed AOP at two different wavelengths and then evaluated the impact of dust events on AOP.

To avoid the similarity with the paper published in the same journal, the readers are invited to see the basic description of the regional climate model version 4. Also, the domain of this study, used data, methodology and synoptic analysis of the severe dust storm occurred in 03 May 2005 are reported in detail by Abed et al. [11]. However, this study focuses on the simulation of aerosol optical depth (AOD), dust load, radiative forcing and surface emission flux of dust using the above model.

Aerosol Optical Depth

AOD is the measure of aerosols (e.g. urban haze; smoke particles; desert dust; sea salt) distributed within a column of air from Earth's surface to the top of the atmosphere which prevent the transmission of light due to extinction processes and it is directly correlated with the aerosol loading in the total atmospheric vertical column [12]. This parameter indicates the attenuation in a beam of radiation as it passes through a layer of the atmosphere which contains aerosols and it is commonly measured by ground based on sun photometers, retrieved by satellite products and calculated by aerosol models. It is a dimensionless parameter and is typically reported at certain values of wavelength which is usually around 550 nm for solar wavelengths because this is so close to the wavelength of peak intensity of the solar spectrum and many instruments measure extinction in this range.

The Ångström wavelength exponent (α) is a commonly used parameter to illustrate the wavelength dependence of AOD. It is mainly driven by the scattering efficiency and can be expressed by means of the classical Ångström's equation [13]:

$$\mathbf{AOD}\ (\lambda) = \beta\, \lambda^{-\alpha} \qquad \mathbf{(1)}$$

where β is the turbidity coefficient. The exponent α is used to obtain basic information on the aerosol size distribution in the solar spectrum. It is used to describe the AOD dependency on wavelength. It is inversely proportional to average size of aerosols in which the smaller the particle, the larger the exponent. Thus, it is considered as an indirect measurement of the aerosol size in a given column of air.

Aerosol radiative forcing

The radiative forcing (RF) of aerosols is a measure of the influence of aerosols on Earth's energy balance, and is quantified as the rate of energy change per unit area, in units of Watts per square meter. When radiative forcing is evaluated as positive, the energy of the Earth-atmosphere system will increase, leading to a warming of the system. In contrast, for a negative radiative forcing, the energy will ultimately decrease, leading to a cooling of the system [14].

The aerosol RF is defined as the difference in the net radiative flux between the present-day total aerosol loading (natural and anthropogenic) and an initial state. The initial state can be defined as no aerosols, pre-industrial aerosol concentrations, or the current estimation of natural aerosol loading.

Aerosol RF therefore varies according to each initial state implemented in model simulations [15]. The RF can be defined as the difference in the net radiative flux (downwelling minus upwelling) between the present-day total aerosol loading and the case of no aerosols.

The aerosol RF measured at the top of the atmosphere is called TOA, whereas that measured at the surface is termed by surface radiative forcing. Because of the aerosol absorption, mainly by soot, and some desert dust particles, the aerosol direct radiative forcing at the surface can be much greater than that at TOA [16].

The scientific understanding of the direct and the first indirect aerosol forcing still accounts for a large source of the uncertainty in the climate change projections, according to IPCC [11], and it has been designated as "medium low" and "low", respectively and also the estimate of direct forcing still contains significant uncertainties [13].

This uncertainty is due to the wide variety of aerosol composition (e.g. sulfate, black carbon, organic carbon, dust, sea salt, and nitrate), sources (e.g. rural, urban, deserts, or oceans), the short lifetime of the aerosols in the air, and the chemical and microphysical processes occurring in the atmosphere, including the aerosol cloud interactions [12, 17].

Results and discussion

Dust load

Calculation of dust load is useful in classifying the dust storms according to their strength by calculating the mean of dust-load (mg / m^2) simulated by using RegCM4 for this study. Dust load amounts were estimated at every three hours for this extreme weather situation and presented in figure 2. It is noted that the largest dust loads were at the beginning of dust storm and then they were continuously decreasing at the ending of day. The average dust load over Iraq during that day was 232 mg / m^2.

By taking dust concentrations in the air column, it is found that this year 2005 had the high dust rate mentioned above. Figure 3 shows spatial distribution of dust load for each three hours of 03/ 05/ 2005. The main mass of dust storm concentrated over south of Iraq, Kuwait and Saudi Arabia as shown in the figure. Later the figure of 12 UTC represents the entrance of the dust storm to the south of Iraq.

Then the storm started to spread outside to the west of Iran. Lastly, with different directions it can drive and diffuse to other areas outside of the center of dust storm as the dust suspended in the atmosphere.

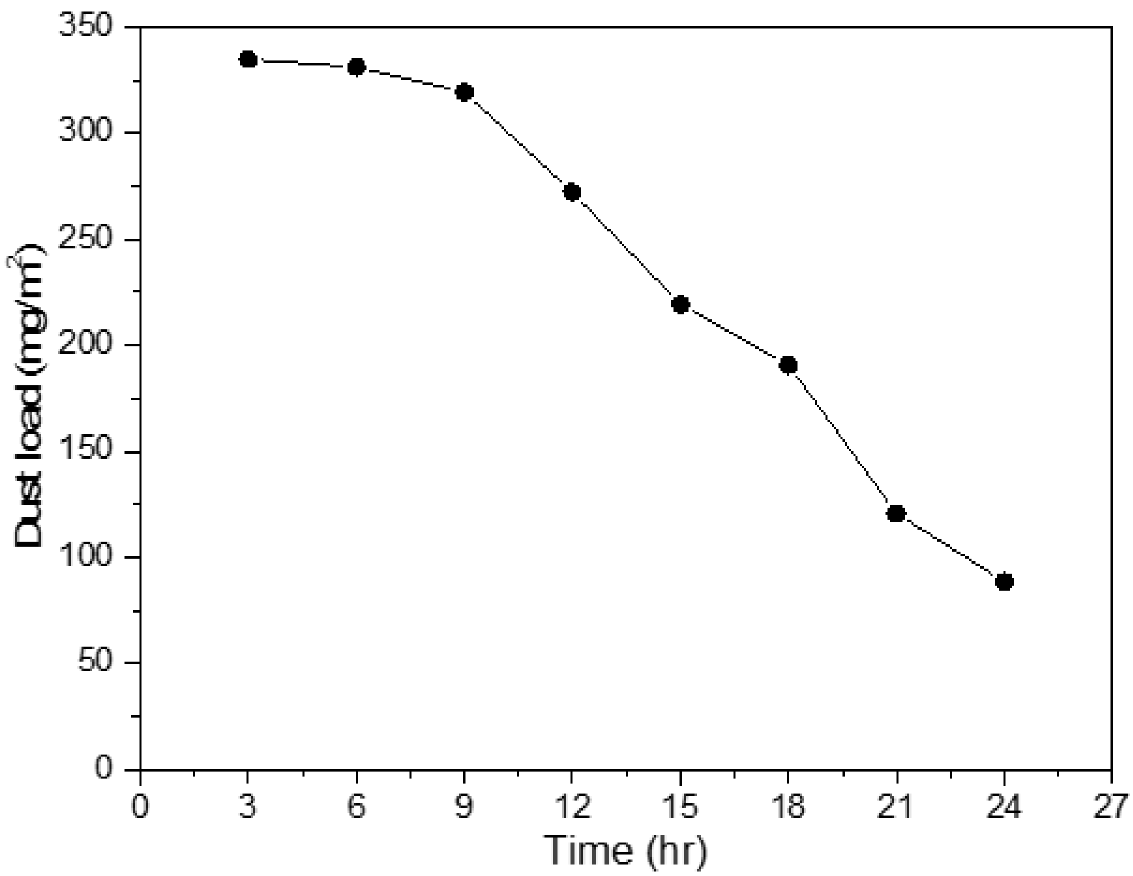

Figure 2: Hourly variation of dust load simulated by using RegCM4 over Iraq

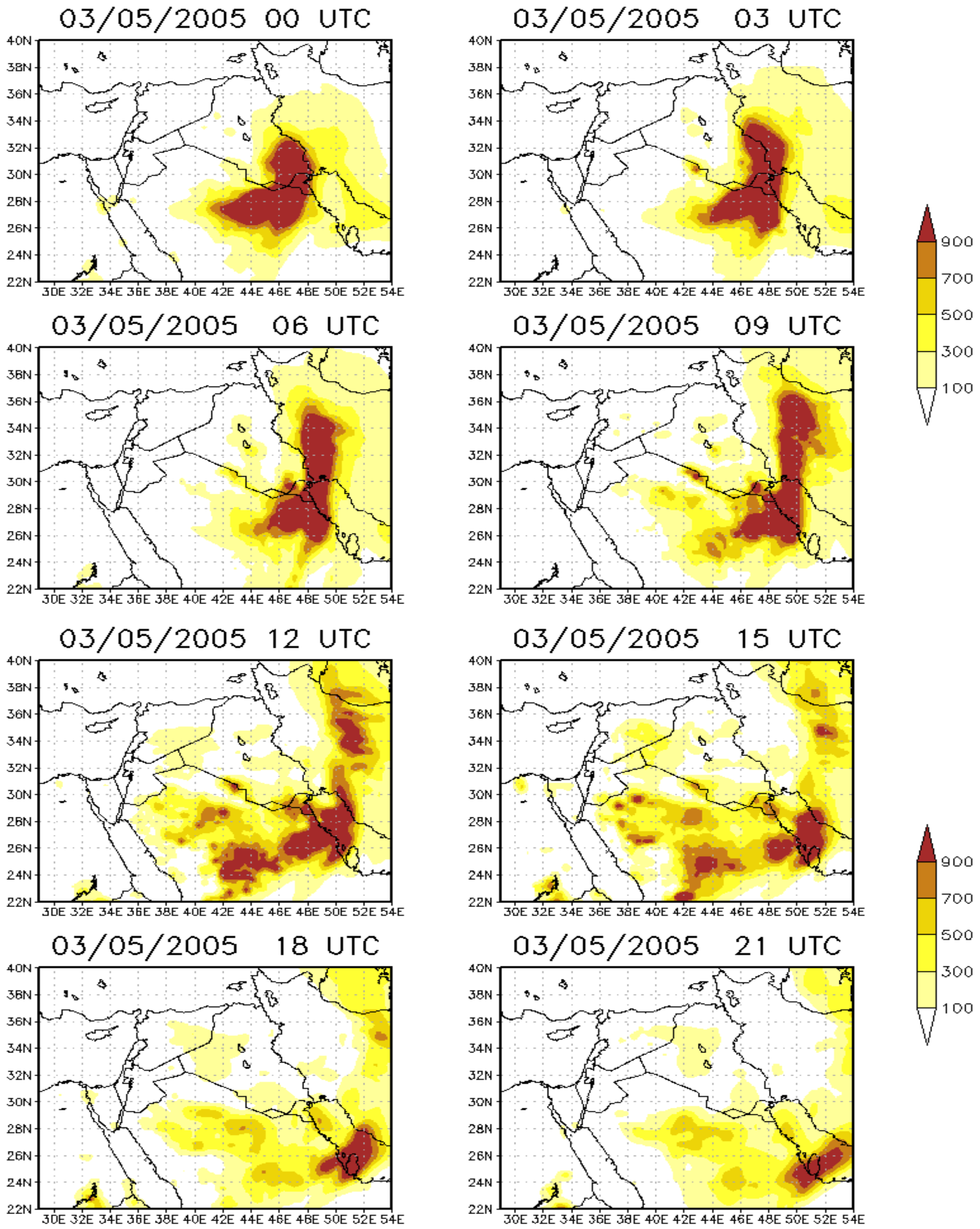

Figure 3: Spatial distribution of dust load (mg / m^2) simulated by RegCM4 during 03 May 2005

The effect of aerosol optical depth

Aerosol optical depth (AOD) is a unitless quantity which expresses the extension of the incident solar radiation on the surface due to the existence of the aerosols. During the dust storms AOD reaches its maximum value. In this section we will discuss the simulated AOD by RegCM4 model during the selected cases and compare their spatial and temporal distribution with the AOD derived from MODIS on Terra and Aqua. By taking the original data of Terra and Aqua images after downloading them for the days of the selected study cases, they are drawn using a grid program.

The AOD values extracted from the MODIS, Satellite image in figure 4 shows different values when compared to the AOD values derived from the RegCM4 simulation, see figure 5.

In searching for the cause, the AOD values obtained from the satellite were affected by factors other than dust, especially for two satellites: Terra crosses the ground at 10 UTC while Aqua crosses at 01 UTC, so this difference is justified.

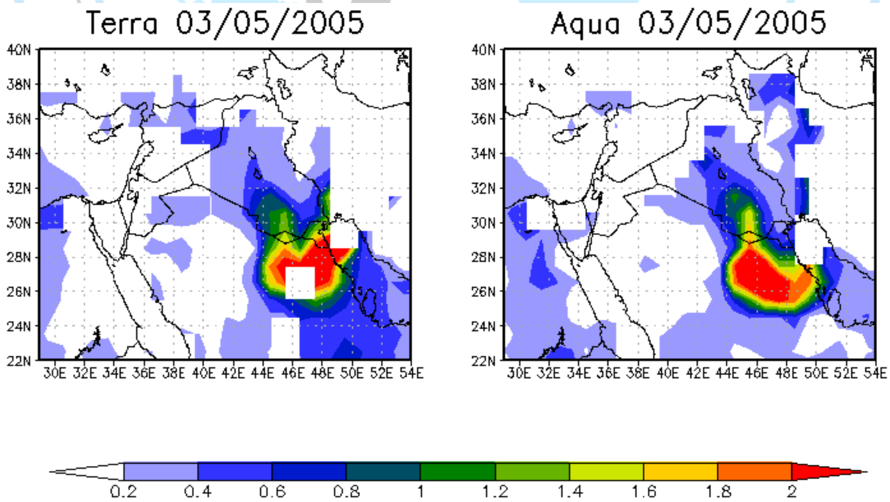

Figure 4: AOD derived from MODIS combined Dark Target and Deep Blue at 550 nm (Terra on the left and Aqua on the right panel) during 03 May 2005. Netcdf data were downloaded from the web [18] and plotted by GrADS

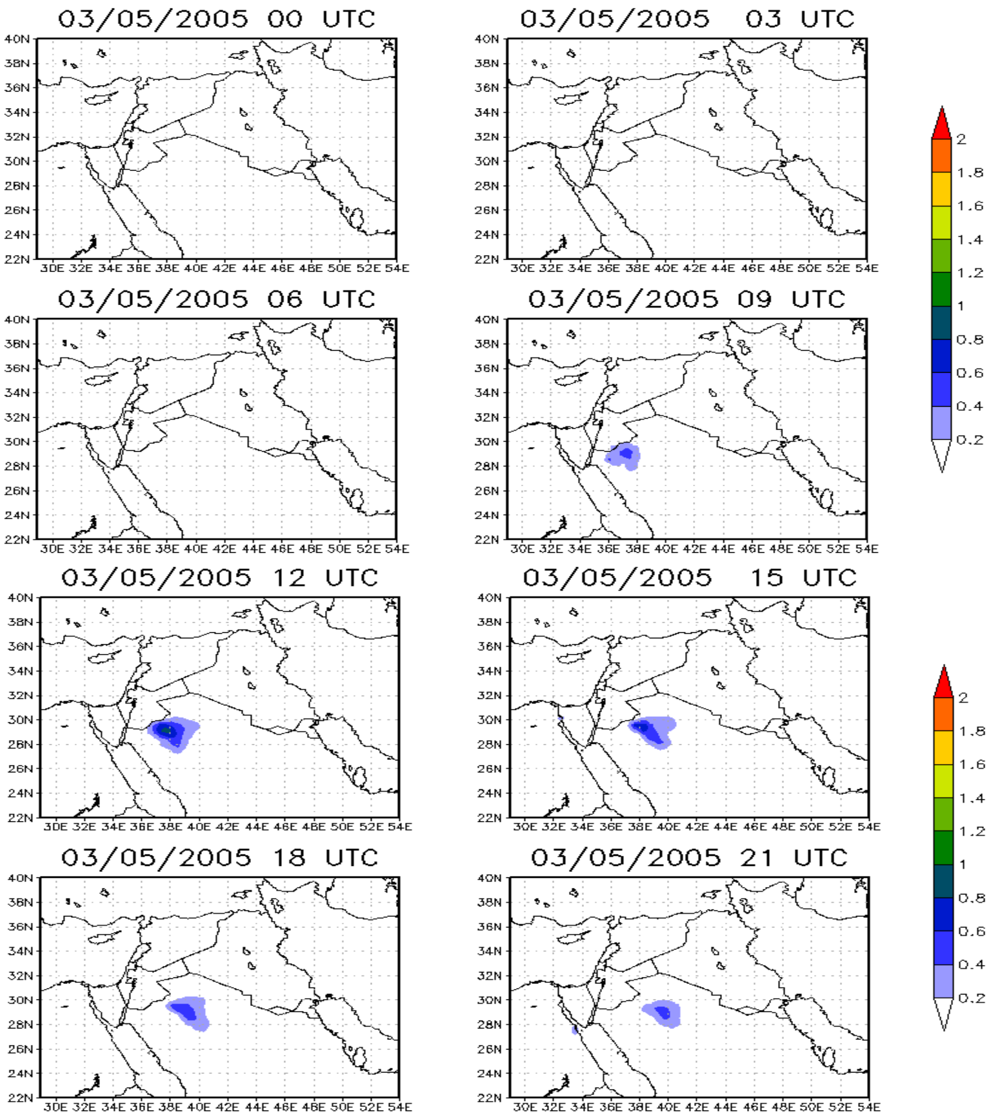

Figure 5: AOD at 550 nm simulated by RegCM4 during 03 May 2005, every 3 hours

The effects of radiative forcing

In this section RegCM4 model is used to simulate the dust radiative forcing. The aerosol radiative forcing of the surface-troposphere system due to the perturbation in the aerosol concentrations is the change in net (down minus up) irradiance (solar plus long-wave; in

W/m^2) at the tropopause. We will discuss the top of atmosphere shortwave radiative forcing, and the surface shortwave radiative forcing over the studied domain during the simulating dust intrusion events. The results of shortwave radiative forces are displayed at diurnal time of day for the studied case starting from 06 to 15 UTC by every three hours.

Figures 6 and 7 show the spatial distribution of radiative forcing over Iraq and its surrounding for both top and bottom of the atmosphere respectively. In these cases, it is observed that the values of the radiation energy at the top of the atmosphere range from (-20 to 5 W/m^2) especially at noon time of 09 and 12 UTC. At the surface, the radiative forcing values are between (-20 to 0 W/m^2). There is large contrast in which occupies most of map area, especially from Saudi Arabia, passing south of Iraq and eastern Iran. The high radiative values of radiative forcing are predicted over south of Iraq at two times 06 and 15 UTC.

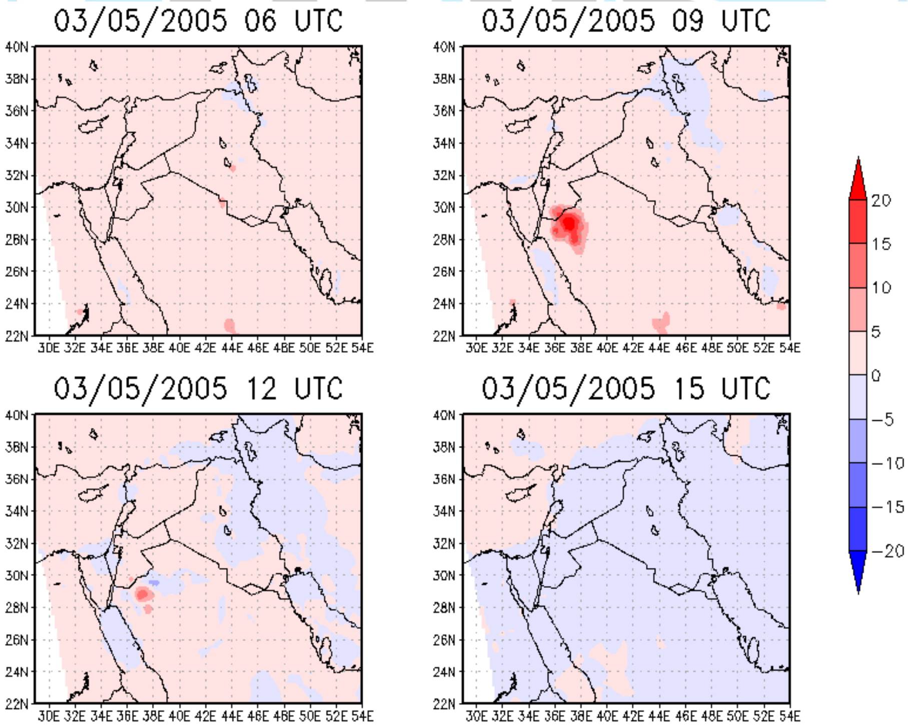

Figure 6: Spatial distribution of top of atmosphere shortwave radiative forcing (W/m^2) simulated by RegCM4

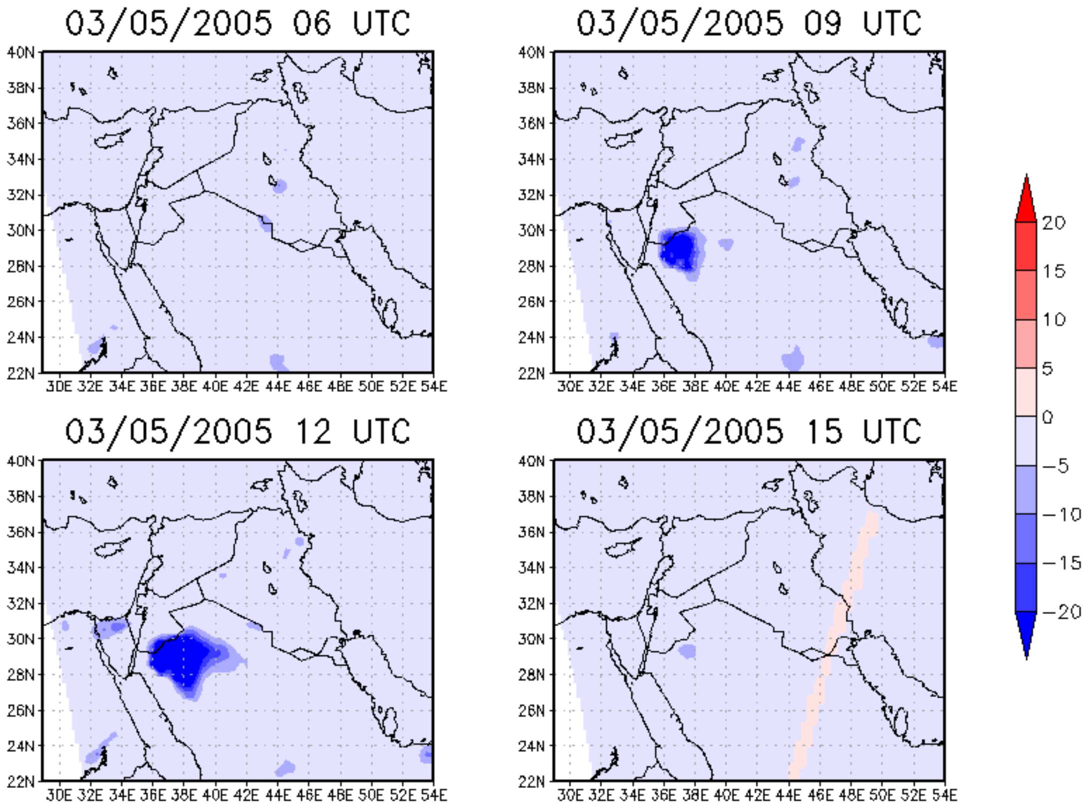

Figure 7: Spatial distribution of surface shortwave radiative forcing simulated by RegCM4

Conclusions

When running the RegCM4 model for the selected day of 03 May 2003, which characterized severe dust storm, it gives a good estimate of the amount of dust in the air column per mg / m^2 according to the initial conditions and boundary conditions of the selected study area in Iraq and in time step 3 hours. This appeared by drawing the output by the Grads program. The classification of the amount of dust in dust-loads that extracted from the simulation of RegCM4 gave a maximum value of 330 mg / m^2 with average value of 232 mg / m^2.

When comparing the results of AOD at 550 nm simulated by RegCM4 during the day of case study at every 3 hours with those obtained from MODIS on Terra and Aqua, they show the same distribution of AOD.

This study could extract the value of the dust radiative forcing related with climate effects of dust aerosols using RegCM4 model. This forcing is the difference between shortwave radiative forcing at the top of atmosphere and the surface shortwave radiative forcing over the model domain during the simulated dust intrusion events. It is found that the high radiative forcing values with -20 to 5 W/m^2 are predicted over south of Iraq at two times 06 and 15 UTC.

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