Potential for Dust Storm Detection Through Aerosol Radiative Forcing Related to Atmospheric Parameters

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Abstract— **The implications of climatic effects due to aerosols with a large variability like mineral dust serve as indicators of dust events and are examined. Airborne mineral dust can influence the climate by altering the radiative properties of the atmosphere. For instance, aerosols in the form of dust particles reflect the incoming solar radiation to space, thereby reducing the amount of radiation available to the ground. This is known as 'direct' radiative forcing of aerosols. Aerosols also serve as cloud condensation nuclei (CCN) and change the cloud albedo and microphysical properties of clouds, known as 'indirect' radiative forcing of aerosols. Direct and indirect radiative forcing by mineral dust are observed over a desert case study in China as well as a highly vegetated case study over Nile Delta, Egypt, using boundary layer dispersion (BLD), albedo, sensible heat flux (SHF), latent heat flux (LHF) and out going long wave radiation (OLR) parameters. During the presence of the dust event, shortwave fluxes largely decrease accompanied by an abrupt increase in the down-welling long wave fluxes resulting in surface forcing. This leads to absorption of the shortwave and long wave radiations resulting in a positive forcing in the top of the atmosphere. In this research we are focusing on the radiative impacts of the dust over some meteorological parameters.**

Keywords-Dust Storm; Sensible Heat Flux; Latent Heat Flux; Boundary Layer Dispersion; Albedo; Outgoing Long Wave Radiation.

I. INTRODUCTION

Aerosols in the atmosphere can be a mixture of different components. The detection and identification of a specific range of aerosol particles (dust in our context) requires knowledge of the microphysical and optical properties in the solar and terrestrial spectral range, i.e visible and IR ranges. Once identified, the ability of dust aerosols to modify the incoming solar radiation can be used to effectively identify the onset of dust storms and to monitor the same at different times of the year. We are making use of satellite datasets such as the radiation budget data and the Aerosol Optical Depth (AOD) from MODIS; the Aerosol Index (AI) from TOMS, to calculate the radiation at the top of the atmosphere (TOA) [1], [2]. Moreover, numerical models can be used to predict the radiation at the surface. The aerosol forcing at TOA, middle atmosphere and surface can be calculated based on a combination of satellite observations and numerical calculations [3]. Such monitoring of the variation in radiation budget throughout the year can be used to trigger an alarm whenever a change in net radiation budget at the surface is observed or a significant increase in the atmospheric backscattering is noticed. Two dust events are being studied in this research to monitor their forcing impact on some atmospheric parameters. The first one is a very strong sand-dust storm, which occurred on 5 May, 1993 in Northwest China, in remote locations, namely, Xinjiang, Gansu, Ningxia and Inner Mongolia. A detailed analysis of this dust event was carried out by [3] where improved physical processes and a radiation parameterization scheme were introduced resulting in a better simulation of the dust event as shown in Fig. 1. This figure shows the sand-dust wall also proceeding from north western Jinchang to the city, which further got intensified.

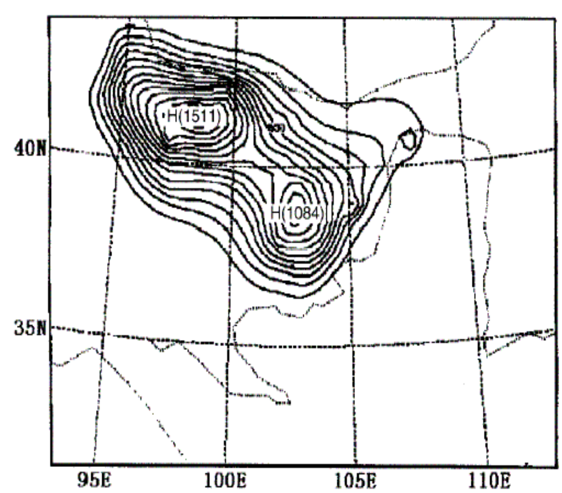

Figure 1. Simulated surface sand-dust concentration at 21 hr (17 BST) (mg m-3)

The second dust event occurred over the Nile Delta region, a highly vegetated area subjected to a massive dust event prevailing from the Western Desert as shown in Fig. 2. A detailed analysis of this dust event was carried out by [4], and

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the dust characteristics over different regions of the electromagnetic spectrum have been studied.

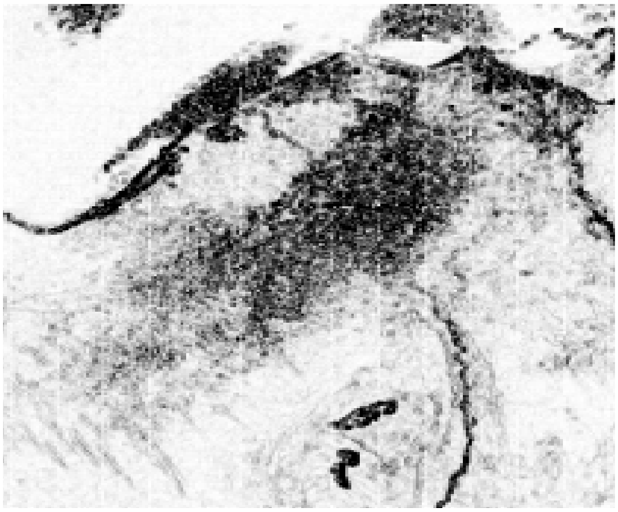

Figure 2. MODIS image showing dust invading the Delta region from the Western Desert, August 31, 2000

The previous two figures show these two strong sand and dust storms over Northern China and the Delta Region. The radiative forcing effect plays an important role during strong dust and sand events, hence, radiation fluxes are being studied in this research through different parameters. Over China we are studying the boundary layer dispersion, albedo, sensible heat flux and outgoing long wave radiation, while over the highly vegetated Delta region latent and sensible heat fluxes are more crucial.

II. Aerosol Radiative Forcing

The Sahara, Ghobi and Mongolia deserts are a major source of dust aerosols and the dust transport from them is an important climatic process [5], [6], [7]. Airborne mineral dust can influence the climate by altering the radiative properties of the atmosphere. For instance, aerosols in the form of dust particles reflect the incoming solar radiation to space, thereby reducing the amount of radiation available to the ground. This is known as 'direct' radiative forcing of aerosols. Aerosols also serve as cloud condensation nuclei (CCN) and change the cloud albedo and microphysical properties of clouds, known as 'indirect' radiative forcing of aerosols. Direct and indirect radiative forcing by mineral dust are observed over the desert case study in China and a highly vegetated case study over Nile Delta, Egypt, using boundary layer dispersion (BLD), albedo, sensible heat flux (SHF) and out going long wave radiation (OLR) parameters. In most areas, we can classify dust storms by the broad meteorological conditions that cause them. In the following we will show the forcing impact of dust storms on some atmospheric parameters.

III. Analysis and Discussion

The impact of the selected dust events over China and Egypt on the atmospheric parameters is being studied here. The importance of the two case studies is raised from the fact that the China event occurred over an arid desert region, while the Egypt event occurred over a highly vegetated area. Distinguishing between the two regions allows us to understand the importance of the different used atmospheric parameters being impacted by the dust events.

A. Boundary Layer Dispersion

Dispersion in the atmospheric boundary layer is a random process driven by the stochastic nature of turbulence [8]. Uplifting vertical wind currents are needed for dust uptakes and lofting, and such vertical motions are more common in the presence of an unstable boundary layer. This is attributed to the fact that stable boundary layer suppresses the vertical motions and inhibits dust lofting. In the China case study where there is extensive lack of vegetation over the region under study, extreme daytime heating of the ground is observed, which contributed in destabilizing the boundary layer and hence led to a high dispersion value. Therefore, as the amount of heating increased, one would expect the unstable layer to deepen. Thus, mid-latitude deserts, with their high daytime temperatures, are particularly prone to an unstable boundary layer. A higher dispersion value was observed over China where the boundary layer dispersion over the dust event reached a maximum value of 26.42 W/m2 as shown in Fig. 3 matching well with the simulated dust concentration shown in Fig. 1.

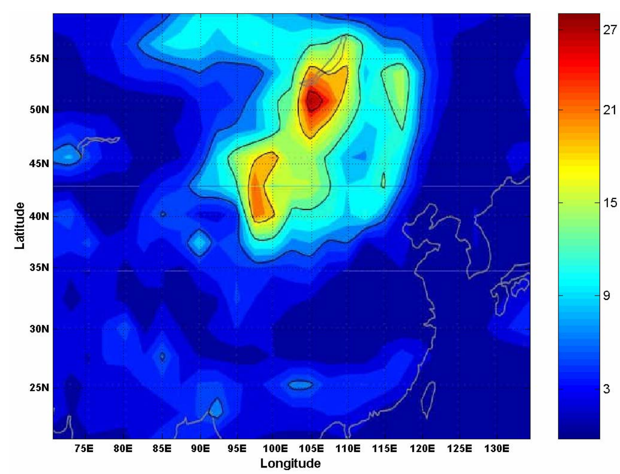

Figure 3. Boundary Layer Dispersion over China, May 5, 1993

B. Albedo

Large amounts of aerosol particles can be emitted through natural and anthropogenic activities into the atmosphere [9]. Dust storms are a major contributor to aerosols in the atmosphere. Hence, such aerosol concentrations as evidenced by high AOD values lead to a dual effect, cooling effect through scattering most of the solar radiation and hence, enhancing the local planetary albedo of the atmosphere and heating effect through strong heat absorption by the aerosol particles and hence, heating the earth-atmosphere-system. In addition, aerosols act in part as cloud condensation nuclei

(CCN) which leads to increasing the number of cloud droplets having smaller cloud droplet radii. Such increased number of cloud droplets together with a minimized droplet radius leads to an increase in the cloud albedo [10]. This has been observed in Fig. 4. over the northeastern region of China where high albedo values are observed in association with the dust concentration simulated from the model shown in Fig. 1. The albedo value ranges from 0.1 to 0.345 having the highest value over the region affected by the dust cloud.

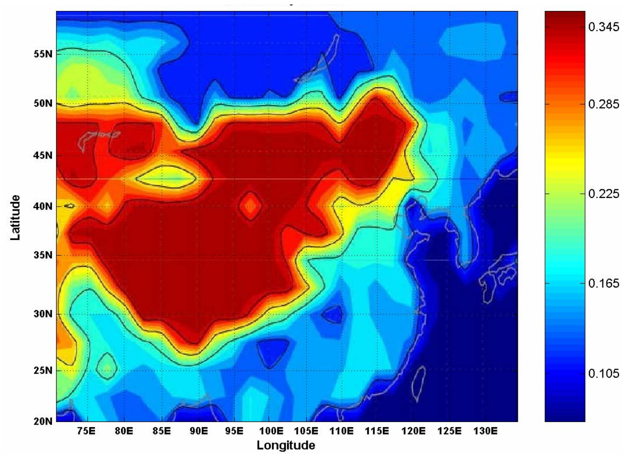

Figure 4. Albedo over China, May 5, 1993

C. *Sensible Heat Flux*

The positive surface radiation balance is partitioned into heat flux reaching the ground and turbulent heat fluxes going back into the atmosphere through sensible and latent heat flux. Sensible heat is the energy flow due to temperature gradients. SHF showed an apparent change with the strong sand-dust storm's passing. The daytime surface air temperature over a desert is regulated mainly by sensible heat flux from the ground into the surface air. The peak heat flux at the center of the plot occurs during the passage of a large dust event as shown in Fig. 5. representing the China event reaching a high value of 157 W/m2 and in Fig. 6. representing the Delta event reaching a high value of 160 W/m2.

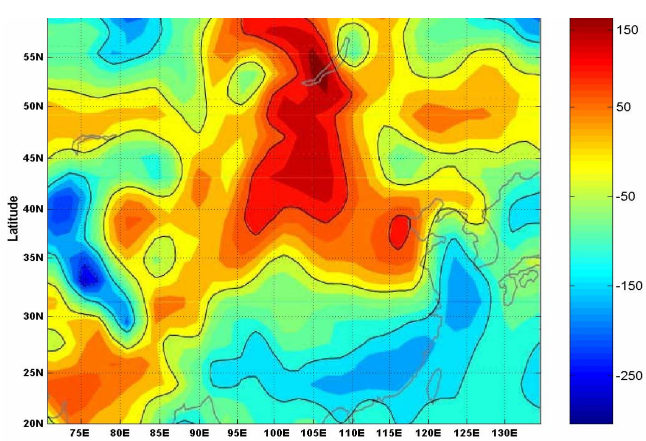

Figure 5. Sensible Heat Flux over China, May 5, 1993

However, the gradual decrease of the SHF over the Delta is discerned, towards the Mediterranean, since the dust event was not covering the northern part of the Delta as shown from MODIS in Fig. 2.

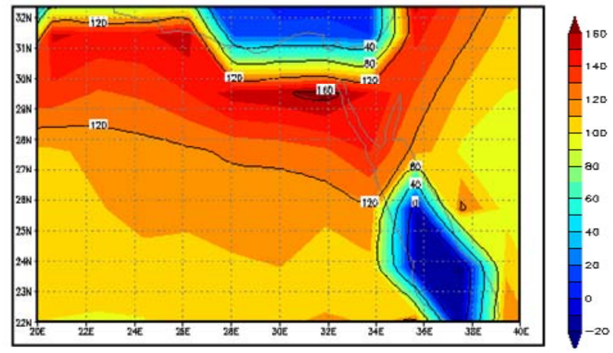

Figure 6. Sensible Heat Flux over Delta Region Egypt, August 31, 2000

D. *Latent Heat Flux*

SHF and LHF represent energy flowing from the Earth's surface into the atmospheric boundary layer. Latent heat is energy flow due to evapotranspiration (the sum total of water evaporated and transpired by plants into the atmosphere). Hence, heat flow from bare fields is dominated by sensible heat, while heat flow from vegetated areas and water bodies is dominated by latent heat. This is validated from the low SHF values over the Mediterranean Sea reaching below zero levels shown in Fig. 6. and the very high LHF over the sea 350 W/m2 as shown in Fig. 7.

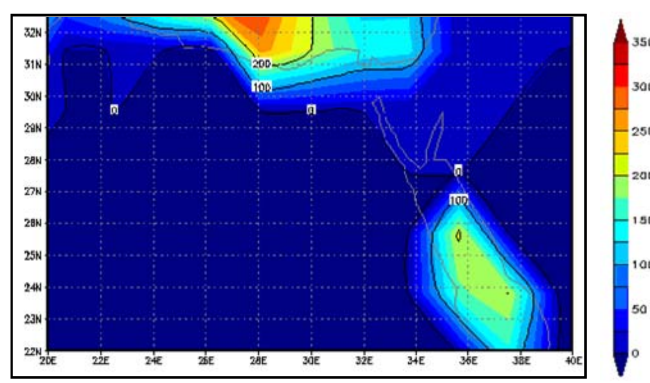

Figure 7. Latent Heat Flux over Delta Region Egypt, August 31, 2000

The LHF is expected to show a high value over the Delta region due to the high vegetation characterizing this region. However, a smaller value ranging from zero to 200 W/m2 is observed over the different parts of the Delta. This is because the dust occurrence absorbs most of the moisture going into the atmosphere and hence leads to a lower LHF value. However, as seen from Fig. 2. the northern part of the Delta did not experience as much dust as the rest of the area, which resulted in a higher LHF value to be observed.

E. Outgoing Longwave Radiation

The Earth's Radiation Budget (ERB) is the balance between the incoming energy from the sun and the outgoing reflected and scattered solar radiation plus the thermal infrared emission to space. Low OLR is generally due to low thermal emission from the top cold regions of extensive cloud cover. However, bright regions correspond to high OLR, associated with cloud-free scenes of high surface temperature. This is because direct surface solar heating is considerable over these regions of high surface temperatures and hence OLR values are also large. During the China dust event although the surface temperature was high, the dust cloud created a blanket that participated in cooling down the temperature and hence resulted in having a low OLR associated with the dust cloud over the region under study reaching a value of 142.5 W/m2.

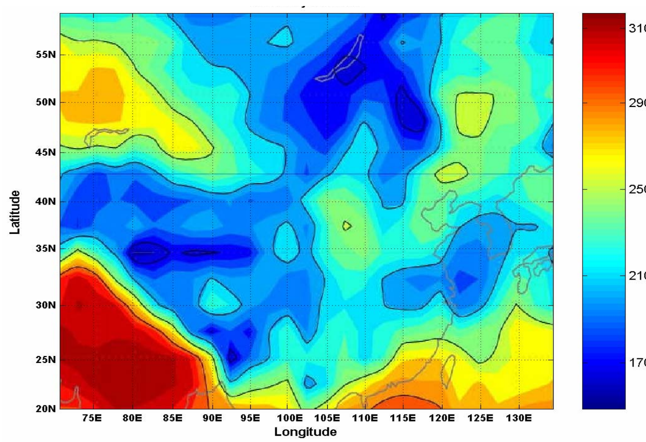

Figure 8. Outgoing Longwave Radiation over China, May 5, 1993

IV. Conclusions

When dust is present in the boundary layer, the vertical profile has a linearly decreasing mixing ratio of mineral aerosol with height, while above the planetary boundary layer height (PBLH), dust concentration goes to zero. The aerosol distribution is the solution to a Fick's Law type vertical diffusion [11], assuming there is a constant surface flux with strong mixing and removal from the column at the top of the boundary layer (presumably transport downwind). During dust events, the upper boundary layer heights are associated with regions where the SHF is greatest, and LHF is smallest due to lack of vegetation and water sources reaching almost zero W/m2 value. This is because SHF is secondary in its effect on the surface energy balance but is a prime thermal source in the onset of daytime boundary layer characteristics [12]. Boundary layer heights in very arid regions in the central part of the desert may be systematically higher than in slightly wetter regions on the edges of deserts, where human disturbances are more likely. This is well observed over the China region and hence such parameter is not as important as in the case of the Delta region. Over the Delta region LHF values are expected to be high enough since the Delta is highly urbanized and vegetated. However, due to the dust event impact we find the presence of a farley low value almost 150 W/m2 due to dust and aerosols as seen from the MODIS scene in Fig. 2. The studied dust fluxes showed close connection to the thermodynamic conditions over the dust source areas. Increased dust loading is believed to be strongly linked to the reduced precipitation seen over recent decades providing a possible feedback mechanism between surface and atmospheric processes [13]. In future research we will make use of MODIS on TERRA with CERES that present us the first opportunity to obtain the forcing directly from observations; and thus provide an independent data set to understand the importance of non-spherical shapes and unknown dust chemical composition.

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