Spatial variation of Radiation balance during the Dust Storm event of 2nd May 2018 over the Northern India

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ABSTRACT: The occurrence of dust storm not only change the air quality of any region but also alter the radiation balance pattern. The short-term changes in radiation balance components due to dust storms alter the weather and associated phenomena over the affected region. During the pre-monsoon season, northern India frequently encounters dust storms. The present study analyses the radiation balance components variation for one dust storm event, recorded on May 2nd, 2018, over New Delhi and nearby regions. This study utilized reanalysis and satellite data sets to quantify the changes in radiation balance components. The results show a significant variations in radiation components compared to a clear day.

Keywords: Dust storm, Radiation balance, ERA5, MODIS, MERRA-2

INTRODUCTION

The Earth's surface absorbs the short-wave solar radiation and re-radiates the long-wave radiation. It provides the baseline solution for the atmospheric response to heating. Latent heating is also a dominant diabatic process for Earth, but this is inconsequential primarily for the heating response. Dust storms are a naturally hazardous meteorological phenomenon commonly formed in semi-arid and arid regions. Based on the frequency of occurrence, this intrinsically impacts climate change, especially over dynamic processes. Their formation and development prediction are still uncertain due to insufficient instrumentations and datasets. The dust storms loaded with aerosols have a crucial role in changing radiation patterns and hence the atmospheric processes over a region (Badarinath et al., 2007). From a dynamic point of view, dust in the development process may hold more latent heat, which may support the updraft phenomenon. Dust storms have structural characteristics similar to convective thunderstorms. The behaviour of the storms does not depend only on the Convective Available Potential Energy (CAPE) and instability of the atmospheric boundary layers; it also depends on the wind flow and vertical shear.

These storms become complex when the dust particle mixes with the anthropogenic and mineral specks of dust. The interaction of more polluted chemicals with dust storms may end up causing the worst effects on the survival of the natural living ecosystem and limiting human's mortal period (Wang et al., 2020).

Dust aerosol plays a significant role in influencing the Earth's solar and terrestrial radiation budget balance, which increases evaporation and evapotranspiration in cloud droplets, causing changes in the variation of clouds and atmospheric structure. Dust particles impact Earth's radiation budget by following absorbing and scattering processes with incoming short-wave and outgoing long-wave radiation (Seinfeld et al., 2004; Zhao et al., 2011). Mineral dust particles absorb and scatter the incoming short-wave radiation, reducing the amount of energy reaching the Earth's surface (Kosmopoulos et al., 2017; Jia et al., 2018).

Mineral dust particles also alter the cloud microphysical and optical properties (Haywood & Boucher, 2000; Satheesh & Moorthy, 2005).

At the same time, the absorption of solar radiation and terrestrial radiation increases the greenhouse effect by reemitting longwave radiation (Heinold et al., 2008). The north-western parts of India have more dust storms originating from Rajasthan and middle eastern countries due to the presence of the Thar desert, with unique variation in the seasonal frequency during the pre-monsoon months (Kumar et al., 2014). The primary factors driving the atmospheric boundary layer are surface temperature and humidity, which often have an inverse relationship.

With the dust storm occurrence, the lower atmosphere is filled with dust, producing the cooling effect of the dust layer. Such activities in the boundary layer may cause a strong disturbance or delay the formation of the nocturnal boundary layer (Saha et al., 2022). There are various published works on radiation balance changes during dust storms, but only a few reported accountings for these changes over a spatial scale for India. The main objective of this study is to see the spatial variation for the dust storm event of May 2nd, 2018 (reported near the New Delhi area between 1700-1800 IST) and observe changes in radiation balance components.

STUDY REGION AND DATA

The present study focused on dust storm event over the Northern Indian region. The region is associated with the Indo-Gangetic plain (IGP), the most populated demography with over 600 million populations (Srivastava et al., 2012; Tripathi et al., 2006), and most of the dust storms cases are reported over this study area especially in north-western vicinity.

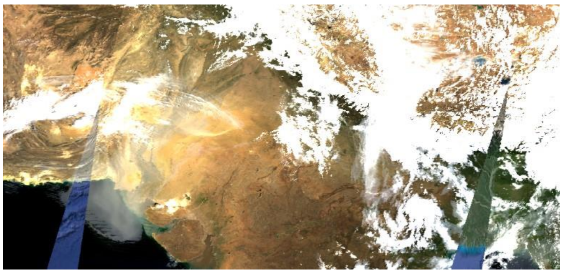

Fig. 1. Study Region for the dust storm investigation using MODIS surface reflectance dataset (for time period dates composite of 2018-05-01 and 2018-05-02)

Modern-Era Retrospective Analysis for Research and Applications, version 2 (MERRA-2) data is used for monitoring the Spatial variability of dust surface mass concentration with its spatial resolution of 0.625°×0.5°. The MODIS surface reflectance products have the estimated product of the surface reflectance values that are found to measure the absorption and scattering of the ground surface. The Terra product (version 6.1) is used for our study with its spatial resolution of 500m reflected values and provides bands 1-7 in a daily gridded L2G product. European Centre for Medium-Range Weather Forecast (ECMWF) ERA 5 reanalysis radiation variables are also used to address the radiation balance and to investigate the atmospheric dynamics of dust storm formation and development. ERA-5 contains higher temporal and spatial resolution (gridded to a regular lat-lon grid of 0.25 degrees), produced by a recent model and advanced data assimilation (Hersbach et al., 2020).

METHODOLOGY

To calculate the Radiation balance parameter certain algorithms were followed (Tyagi et al., 2012),

$$Q_N = R_{SI} - R_{SO} - R_{LO} + R_{LI} \quad (1)$$
$$R_{LO} = N_{LR} - R_{LI} \quad (2)$$
$$R_{SI} = N_{SR} - S_{SR} \quad (3)$$

Where Q_N (Net Radiation), R_{SI} (Radiation shortwave Incoming), R_{SO} (Radiation Shortwave Outgoing), R_{LO} (Radiation Longwave Outgoing), R_{LI} (Radiation Longwave Incoming), N_{LR} (Net Longwave Radiation), S_{SR} (Surface Shortwave Radiation), and N_{SR} (Net Shortwave Radiation) have been estimated in Wm^{-2} units.

RESULTS

Fig 1 is showing the mass concentration of the surface dust. It is clear from Fig 1 that the mass transport pattern for the present case study is from the parts of Africa, the Arabian Peninsula and the Indian subcontinent (parts of Pakistan and Afghanistan) towards the Northern Indian region. The coverage of such a large area shows the severity of the dust storm event that occurred on May 2nd, 2018. The study analysed the radiation balance using ERA5 radiation variables. In Fig 2, the Q_N is found to have ranges varying from 160 – 440 W/m^{-2} and R_{LO}

varying from -200 to -520 W/m^{-2}, and the negative signs are due to the outgoing direction sign convention.

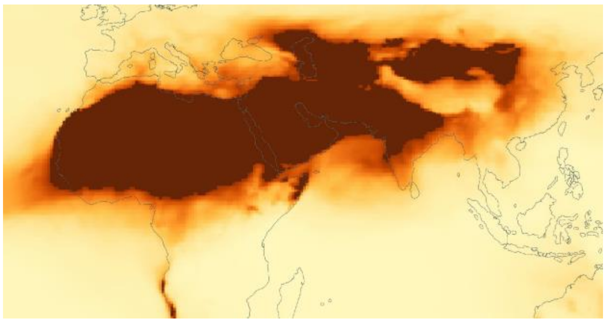

Fig. 1. Spatial variability of Dust surface mass concentration using MERRA-2

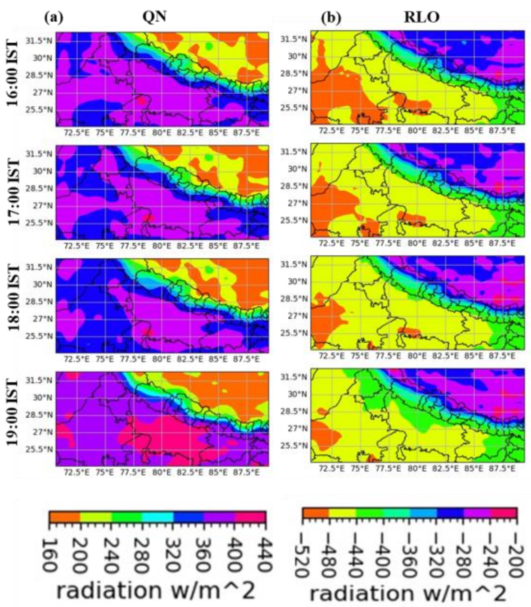

Fig. 2. Spatial variation of R_{LO} and Q_N During dust storm form ERA-5 Reanalysis dataset

Fig 2 shows the variation of net radiation balance and outgoing longwave radiation before, during, and after the dust storm event. The radiation balance was high over central India before the dust storm (16:00 IST) and decreased during the dust storm (17:00 IST to 18:00 IST) over central India. After the dust storm, the Q_N increased again over central India (~400 to 440 W/m^{-2}). These values of Q_N after the dust storm event are higher before the dust storm occurrence. The lower Q_N values before the dust storm may be due to increased dust particles in the atmosphere. Before the dust storm, the R_{LO} was ~480 to 521 W/m^{-2} (16:00 IST) over central India, leading to more latent heat consumption, which is assumed to develop dust storm convection processes. The R_{LO} started decreasing (17:00 IST to 18:00 IST) after the dust storm (19:00 IST). The R_{LO} spatial distribution area decreased in a splitting pattern compared to the variation of 16:00, 17:00, and 18:00 IST.

By analyzing the available MODIS Terra surface reflectance from 29 April – 05 May 2018, the results give a clear perspective of the abundant mass of dust with the diversified pattern from the western countries entering the Northwestern parts of India. The analysis shows a notch move towards the IGP and further found a movement towards the southern peninsular region near the Bay of Bengal (Figures not included here).

The spatial distribution pattern of radiation balance components shows significant variation compared to the non-dust storm event for the same period at different dates. On the dust storm day, Q_N got less radiation distribution pattern when compared to non-dust storm days from 16:00 to 18:00 IST. However, after the event, there was a shift in the pattern found with an increase in the Q_N ranges (~400-440 Wm^{-2}). The shift was towards the eastern direction, which might be due to the absorption of longwave radiation of the dust particles. When comparing the R_{LO} variation after and before the event, Fig 2 (b) shows the intrusion nature towards the south direction, which denotes the outgoing longwave radiation is returning to its normal phase compared with the non-dust storm event at the same time step.

CONCLUSION

The work analyzed changes in radiation balance components for one dust storm event (May 2nd, 2018) over northern India. The summary of this study is as follows:

- The net radiation pattern is found to decrease during the dust storm period (17:00 - 18:00 IST) when compared before (16:00 IST) and after (19:00 IST) the event.The change is significant to the areas east to Delhi where the Q_N values are in ranges of 320–360 Wm^{-2} during the dust storm, whereas the Q_N values are 360–400 Wm^{-2} before and after the event.
- After the dust storm, the outgoing longwave radiation (R_{LO}) decreased (~440 Wm^{-2}), compared to before and during the event (~480 Wm^{-2}). The decrease in R_{LO} may be due to reduced surface temperatures after the passage of dust storm. However this

decrease may also be due to the reduction in R_{SI} associated with sunset at the region. Also, one can observe that the region is not changing the R_{LO} pattern over a larger area during and after the event, which maybe due to large scale changes in the R_{LO} due to the event.

The results indiacate that the dust storm has a impact on radiation balance more than of its duration. The pattern needs to be further evaluated with more cases over the region before reaching to a conclusion.

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