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EXAMINATION OF A DUST STORM EVENT IN AHMEDABAD REGION: ITS CONSEQUENCES ON AEROSOL PROPERTIES AND AIR QUALITY

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Abstract: The frequency of extreme weather events is continuously growing. This is because of the rapid change in the global climate. This has resulted in dust storm events across globe. In India, on April 27, 2021, a severe dust storm occurred in the Ahmedabad region. A study was done using a combination of satellite observations, reanalysis data, and ground-based measurements. The primary focus of the study is to determine the transport of dust storm and their effects on aerosol characteristics and air quality over the region. Further, back trajectory analysis observed that the air mass parcels originated from the desert areas of Pakistan, Iran, and Iraq. Some air parcels have origins in the Thar Desert. The study reveals that a sudden jump in PM concentrations was observed from the System of Air Quality and Weather Forecasting (SAFAR) dataset, indicating severe deterioration in the air quality during the dust storm event. The aerosol optical parameters, including Aerosol Optical Depth (AOD), show a big jump while the Ångström exponent (AE) shows a decline. This decreased AE value shows the existence of coarser aerosol particles in the region. Further, AI values exceeding unity show the presence of UV-absorbing aerosols in the region. This study collectively highlights the variations in atmospheric chemistry during the dust storm in the Ahmedabad region.

Keywords: Dust storm, Ahmedabad, SAFAR, Back-trajectory, Aerosol optical parameters.

I. Introduction:

Dust aerosols play a crucial role in the Earth's atmosphere. It has significant impacts on both the global and regional dynamics of the atmosphere (McTainsh, and Pitblado, 1987). These dust aerosols affect this climatic system by the absorption and scattering of solar radiation incoming to the Earth's surface. This results in variations in the micro-physical properties of clouds and the biogeochemical cycles of nature. Additionally, these dust aerosols have adverse consequences for the air quality and health of humans (Dumka et al., 2019, Middleton 2017). Annually, these dust emissions amount to roughly 1000–2100 Tera-grams (Tg), with the primary contributors from the regions of the North Hemisphere. These regions include the Arabian Peninsula, Central and South-East Asia, and the Sahara Desert. (He et al., 2022, Aher et al., 2014).

For longer duration, these dust particles under the specific conditions of surface heating and pressure gradient travelled large distances, resulted in the formation of dust storm. Thus, a dust storm is defined as a meteorological condition that arises due to strong winds and takes away loose debris and dust particles from the desert and arid areas (Prospero et al., 2002). However, the main challenge in dust storm is linked with uncertainty in its transportation patterns and complex conditions of local atmosphere (Cao et al., 2015, Albaqami et al., 2019). This dust particles are eliminated from the atmosphere through natural processes (Safar 1985). The coarser particles having a diameter greater than 2 micrometers and are found near the source, are eliminated from the atmosphere by the process of dry deposition. On the other hand, finer particles accumulated because of long-range transportation over the oceans are removed by the process of wet deposition Further, this dust particles when blended with finer man-made aerosols, resulted in the formation of a dense layer of aerosol. This layer is also known as atmospheric brown carbon, which has major consequences on the biosphere, and cryosphere of the Earth (Tiwari et al., 2019). Various researches have been carried out on an extensive scale to understand the behaviour of these dust aerosols and their impact on different aerosols parameters (Ahrafi et al., 2014, Chakravarthy et al., 2021, Aswini et al., 2021).

Across the Indian-subcontinent, the intense dust storm before the monsoon season can significantly impact the stability of the atmosphere. The pronounced effects of dust storms are particularly evident in the northern Indian states of Gujarat, Rajasthan, Punjab, Haryana, Uttar Pradesh, and Rajasthan during this period. These dust events also have the potential to influence the Indian summer monsoon (ISM) rainfall in northern part of countries (Lau et al., 2006), Moreover, during dust storm there is settlement of large amount of dust on the glaciers of Himalaya. This results in the melting of glacier at higher rate as there is reduction the snow surface albedo (Gautam et al., 2013). Also, elevated PM concentrations during dust storms in India resulted severely polluted atmospheric conditions over northern India (Tiwari et al., 2019, She et al., 2018, Huang et al., 2013).

Global concern has arisen regarding the dust storms due to significant impacts on various aspects, including socio-economy, human health, and the environment. These dust storms have the potential to disrupt the transportation sector by decreasing visibility, causing destruction to infrastructure, affecting telecommunications, and impacting crop yields (Shi et al., 2017). Furthermore, they result in increased desertification and drought, leading to reduced water supply and rise in soil salinity, ultimately contributing to more substantial socio-economic losses. Majorly, dust storms has poses primary threats to the human health, and the severity of risks associated with the size of the dust particles involved. The dust particles larger than 10 μ-metres are considered as non-breathable and can affect the external body parts of human. This may include eye irritation, skin infections and conjunctivitis. In contrast, dust particles smaller than 10 μ-micrometres are inhalable and can potentially lead to various respiratory problems. These finer particles enters the nose and upper respiratory tract, where they may get trapped, causing issues such as asthma, tracheitis, etc. The smaller size of the dust particles allows to penetrate deeper into the respiratory system. Furthermore, the finest dust particles, often measuring less than 2.5 micrometres in diameter, can travel even deeper into the lower respiratory tract and, in some cases, enter the blood stream. (Hofzumahaus et al., 2009, Nukapothula et al., 2023, Chauhan et al., 2023).

In this research work, a combination of different satellite observations, a reanalysis tool, and ground-based measurements are obtained during a five-day period from April 25, 2021, to April 29, 2021, over the Ahmedabad region to study the dust storm event. This investigation places particular emphasis on analyzing aerosol characteristics and impacts on air quality. The introduction of dust storm and its impact on India is studied in Section 1. The research significance of the present study is discussed in Section 2. The detailed description of different satellite data, ground-based measurements, tracking model and reanalysis tool is discussed in Section 3. The variations in PM concentrations using SAFAR data and aerosol characteristics using OMI and VIIRS dataset is studied in Section 4. This section also covers the tracking of dust particle using HYSPLIT Model and meteorological conditions using ERA5 reanalysis data. The conclusions of the study are discussed in Section 5.

II. Research Significance:

The research significance of the study involves the impact and influence of a dust event in the Ahmedabad region. This includes:

1. The analysis of the variations in meteorological parameters and changes in the chemistry of atmosphere is analysed during this dust event.
2. The variations in different aerosol parameters using satellite data are studied to find the impact of aerosols in local regional climate.
3. The back-trajectory of dust event will help in knowing the pathway of dust event. The variations in PM concentrations will help to study air quality in the Ahmedabad region.

III. Materials and Method:

3.1 European Centre for Medium-Range Weather Forecasts -ERA interim data:

ECMWF ERA-5 reanalysis data is used to get different meteorological data during dust storm study. This includes average-temperature, wind pattern and relative humidity in the region. The five-day variations of these parameters are taken at 850 hectopascal (hPa) in Ahmedabad region. For 24-hourly time period and at an horizontal resolution of 0.25° x 0.25°, the data of u-component and v-component of the wind is obtained. This data describes about the pattern and intensity of wind during this event. The average temperature is expressed at Celsius scale (ºC) and relative humidity is given in percentage scale (%). This data is accessible through https://cds.climate.copernicus.eu (Tiwari et al., 2019).

3.2 Visible Infrared Imaging Radiometer Suite (VIIRS):

The aerosol characteristics is obtained by VIIRS platform. VIIRS became operational in October 2011 and was included in S-NPP (Suomi National Polar Orbiting Partnership). It offers global coverage. It has 22 different spectral bands spanning from visible to infrared wavelengths, ranging from 0.412 to 12.05 micrometres. VIIRS provides a wider swath, covering 3000 kilometres compared to the 2330 kilometres of MODIS. VIIRS passes over the equator at around 13:30 local time, covering the entire Earth daily. It consists of two types of bands: M-bands (moderate resolution bands) and I- bands (imagery bands). The key feature of VIIRS is its dual gain bands, which enhance its range while maintaining a strong signal-to-noise ratio, making it useful for applications in oceans, land, and atmospheric observations. VIIRS generates over 20 products, including data on aerosol optical thickness (AOT), sea surface temperature (SST), albedo, volcanic ash, cloud properties, vegetation indices, aerosol particle characteristics, etc. (Liu et al., 2014, Goldberg et al., 2018).

For aerosol detection over land, VIIRS utilizes the aerosol detection product (ADP). This algorithm identifies dust in the region using sensor readings during the daytime. It can detect dust at the pixel level within a range of 750-1.2 kilometres, depending on the scan angle (Zhang et al., 2018). In this study, AOD at 550 nm is computed using VIIRS Level 2 data. Researchers can access VIIRS aerosol data, including information on dust storms in India, through the website (https://search.earthdata.nasa.gov/portal/idn/search?fi=VIIRS).

3.3 Ozone Monitoring Instrument (OMI):

The UV Aerosol Index (AI) data is obtained through the OMI aboard the Aura satellite. This satellite follows a sun-synchronous polar orbit at an altitude of 705 kilometres, with a precise repeat cycle of 16 days. It crosses the equator at 13:45 local solar time. The spectral range of OMI covers wavelengths from 264 to 504 nanometres, and it operates in nadir viewing mode, providing a wide swath of coverage. This instrument is equipped with 20 hyperspectral imaging spectrometers and has daily global observations with high spatial resolutions (13 km*24 km at nadir) (Levelt et al., 2006). In this research, Level 3 global-gridded OMI UV-AI data is utilized, having spatial resolutions of 0.25°*0.25°. This data is helpful in assessing the aerosol behaviour during long-range dust transport. A positive AI value depicts the presence of UV-absorbing aerosols like dust and smoke, while a negative value signifies the presence of non-absorbing aerosols such as sulphate. Researchers can access this OMI data through the Giovanni website (https://giovanni.gsfc.nasa.gov/giovanni/.

3.4 System of Air Quality and Weather Forecasting and Research (SAFAR):

The SAFAR system is developed by the Indian Institute of Tropical Meteorology, Pune, along with partner institutions, the National Centre for Medium Range Weather Forecasting (NCMRWF) and the India Meteorological Department (IMD). This SAFAR provides details about the location-specific air quality in near real-time. This programme covers four major cities, namely, Delhi, Ahmedabad, Pune, and Mumbai. This system has been integrated with the early warning systems for weather conditions. Under this system, air quality monitoring stations (AQMS) have been set up at different locations in these four cities to observe air quality. The ground-based observations of PM2.5 and PM10 concentrations are studied using SAFAR dataset during this dust storm event in Ahmedabad. The air quality station at Raikhad, Ahmedabad provides five days concentrations for the study period. The data of SAFAR is accessible through https://safar.tropmet.res.in/.

3.5 Hybrid Single Particle Lagrangian Integrated Trajectory Model (HYSPLIT):

The HYSPLIT Model is developed by National Oceanic and Atmospheric Administration (NOAA). This tool helps to track the movement of air-mass parcels. This model mainly deals with the transportation of different pollutants and dust particles in the regional atmosphere (Singh et al., 2022). The HYSPLIT Model combines two essential approaches: the Lagrangian method and the Eulerian method. The popular applications of the HYSPLIT model include computing the trajectory and forecasting of dust particles, smoke, and pollutants from various man-made sources. (Draxler and Rolph, 2003, Singh et al., 2021). In this study, the HYSPLIT Model uses the Global Data Assimilation System (GDAS) at a 1-degree resolution (corresponding to 11:30 AM Indian Standard Time). The five-day backward trajectories of air masses are computed at an elevation of 1000 metres in the Ahmedabad area. The access to the HYSPLIT Model is present at https://www.arl.noaa.gov/hysplit.

3.6 Verification of Dust Storm Event:

In this research study, validation of a dust storm event is done by true-colour images obtained by the MODIS sensors aboard the Terra and Aqua satellites. These images give a depiction of the dust plume heading towards the Ahmedabad region. To obtain these true-colour imagery, the NASA EOSDIS (Earth Observing System Data and Information System) World View tool is used. This tool is available for researchers at https://worldview.earthdata.nasa.gov/. For this dust storm event that hit the Ahmedabad region on April 27, 2021, true-colour images of five days were obtained. As shown in Fig.1, Ahmedabad experienced a dust layer on April 27, 2021, significantly impairing visibility in the region.

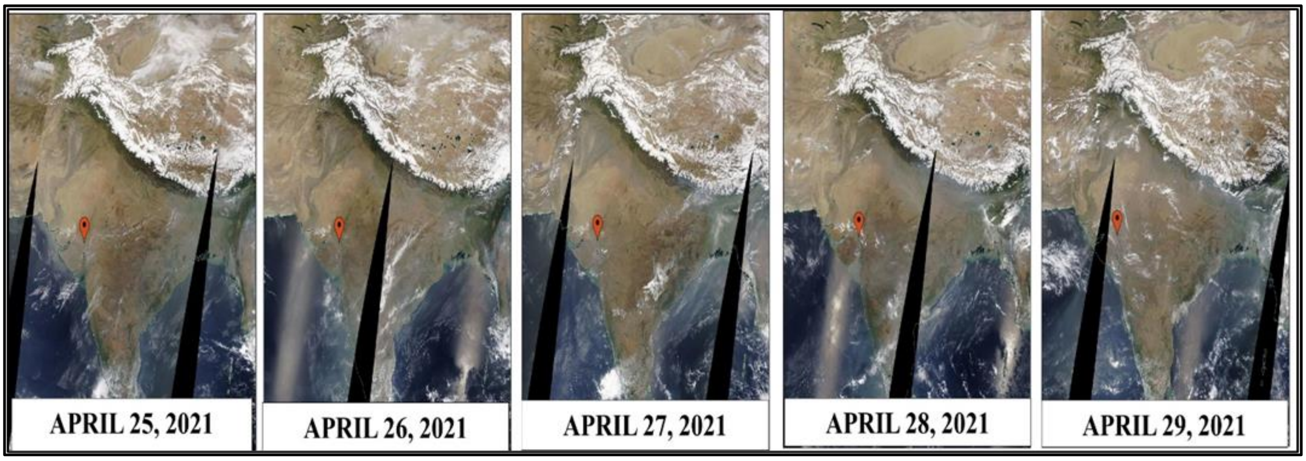

Fig.1: The True colour imagery of Dust Storm in Ahmedabad accessed from NASA WorldView.

IV. Results and Discussion:

4.1 Study of Different Meteorological Parameters:

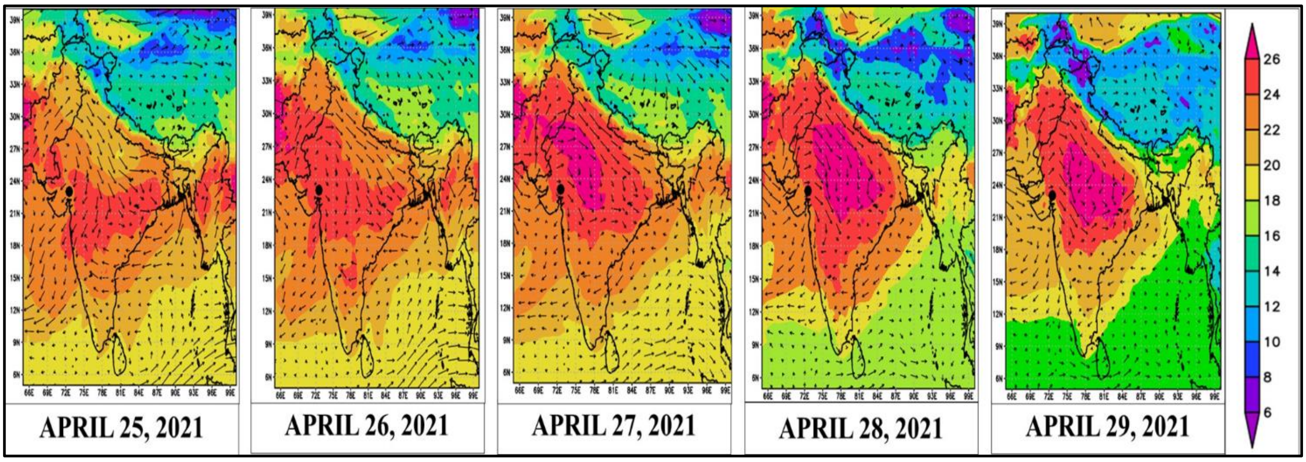

Fig. 2(a): Variations in Meteorological Factors (Temperature vs Wind Variation) taken by dataset of ERA-5.

In this study, the analysis of the synoptic meteorological conditions prevailing over the Indian subcontinent is done using the reanalysis dataset of ERA-5. This analysis involves key meteorological parameters such as average temperature, wind movement, and relative humidity, all assessed at the 850 hPa pressure level. Wind direction is visually represented by the arrows, with their length indicating wind speed in metres/second. Meanwhile, relative humidity (RH) is shown through a spectrum of shaded colours on the plots, where red denotes high RH and blue denotes low RH. Similarly, the average temperature (T) is shown by shaded regions, with warmer temperatures depicted in red and cooler temperatures in blue. The average temperature variation during the dust storm event in the Ahmedabad region is shown in Fig. 2(a). During this specific dust storm event, the average temperature ranged from 23°C to 25°C. However, the average temperature declined on the dusty day i.e., 23.4°C, and is characterized by heavy dust presence. This temperature drop can be primarily associated with the obstruction of sunlight caused by the abundance of dust particles in the atmosphere (Tiwari et al., 2019).

Moreover, the synoptic plot reveals an increase in the relative humidity on dusty days in Ahmedabad compared to the preceding day. Fig. 2(b) shows a relative humidity of 25% during a dusty day, a little increase from the previous day. This increase in relative humidity can be attributed to the influx of moisture-laden air brought by the dust storm in the region. Furthermore, the prevailing wind patterns during this event are characterized by the westerly to north-westerly winds. These prevailing winds originate from arid regions and facilitate the transportation of mineral dust across the Ahmedabad area (Chakravarthy et al., 2021)

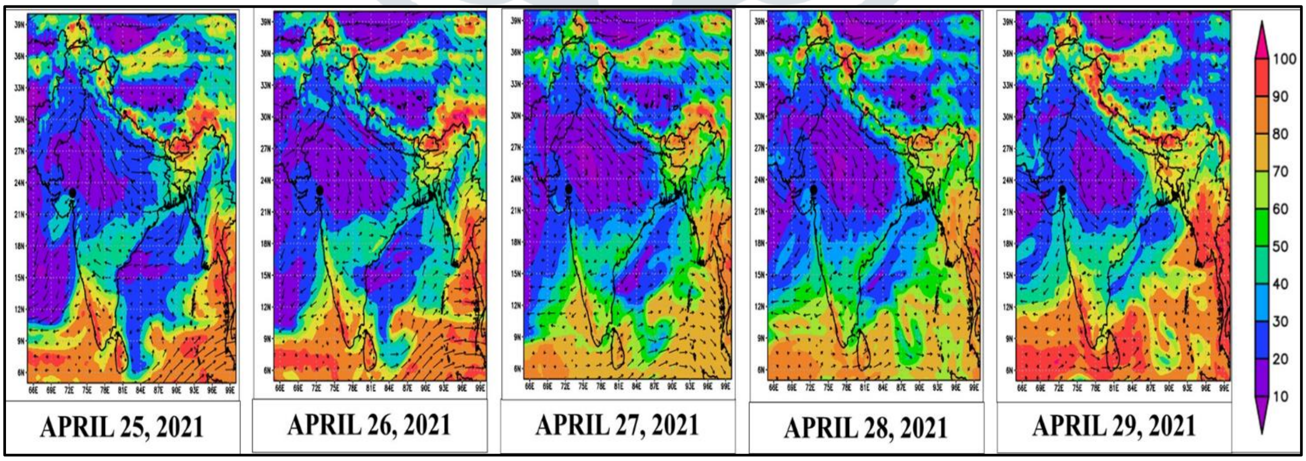

Fig. 2(b): Changes obtained in Meteorological Factors (Relative Humidity vs Wind Variation) taken by dataset of ERA-5.

4.2 Study of Variations in Aerosol Characteristics:

To assess the magnitude of the dust storm, two important aerosol optical parameters, Aerosol Optical Depth (AOD) and the Ångstrom Exponent (AE), are considered. The variations in AOD loading and AE values are studied using the VIIRS dataset. For this, VIIRS uses an aerosol detection product at a wavelength of 550 nanometers. AOD is defined as the overall aerosol concentration within the atmosphere. Conversely, AE characterizes the size of aerosols present in the atmosphere (Cao et al., 2015). The variations in AOD and AE were observed over a five-day period and are shown in

Fig. 3. High AOD and very low AE values are obtained during dust event. This results in the dominance of different coarser aerosols.

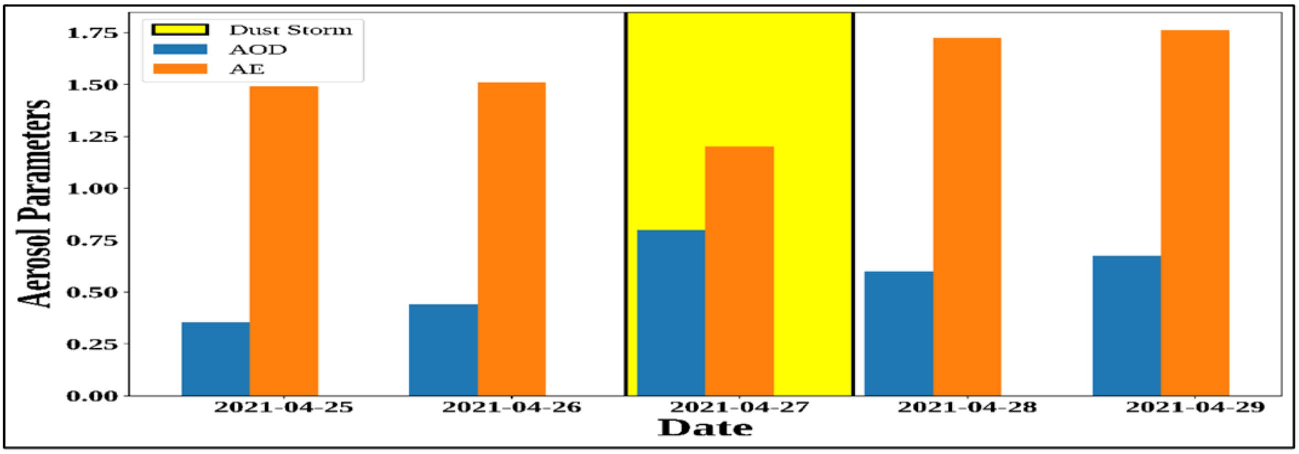

Fig. 3: Variation of Aerosol Optical Parameters taken from VIIRS platform.

4.3 Study of Variations in Aerosol Index:

The data of Aerosol Index (AI) is acquired through OMI to identify the types of aerosols present in regions affected by dust storms. A positive value AI denotes the presence of UV-absorbing aerosols, such as dust and smoke, whereas a negative AI value indicates the prevalence of non-absorbing aerosols like sulphates in the region. As shown in Fig. 4, the dust storm event witnessed a jump in AI values throughout the dust storm. The AI values surged from 0.65 on the pre- dust storm day to 0.90 during the dusty day in Ahmedabad. These elevated AI values serve as an indicator of the severity of dust storm. The obtained positive AI value during the dusty day in Ahmedabad region confirms the presence of UV-absorbing aerosols during the dust storm (Yarungta and Srivastava, 2016).

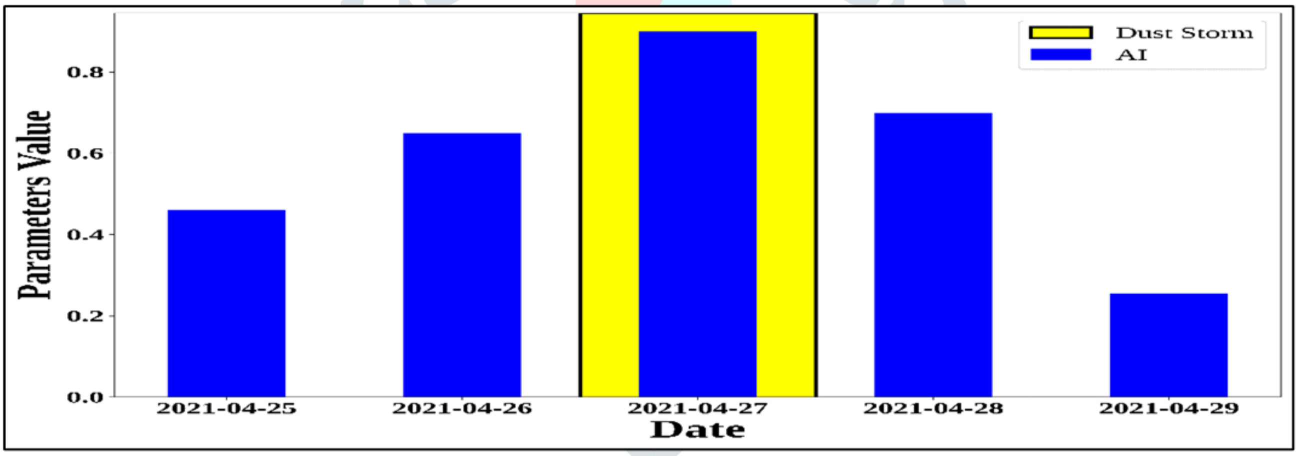

Fig. 4: Variation of Aerosol Index taken from OMI.

4.4 Study of change in $PM_{2.5}$ and PM_{10} concentrations:

The concentrations of $PM_{2.5}$ and PM_{10} are taken from the datasets of the System of Air Quality and Weather Forecasting and Research (SAFAR). These datasets help in assessing the air quality conditions in Ahmedabad during dust storm events. This monitoring process is done through the Air Quality Monitoring Station (AQMS) located in Raikhad. In this study, the change in the concentrations of $PM_{2.5}$ and PM_{10} is assessed for five days, as visually shown in Fig. 5. On the day of the dust storm, there was a jump in the daily average concentration of PM_{10}, rising from 225.5 $\mu g/m^3$ to 347.22 $\mu g/m^3$. Similarly, the concentrations of $PM_{2.5}$ also witnessed a surge, increasing from 105.52 $\mu g/m^3$ on the pre-dust storm day to 130 $\mu g/m^3$ on the dusty day. However, the higher concentrations of PM began to decline after the dust event. This is due to the settling of dust particles and precipitation in the region (He at al., 2022). This study shows that higher concentrations of $PM_{2.5}$ and PM_{10} result in poor air quality conditions.

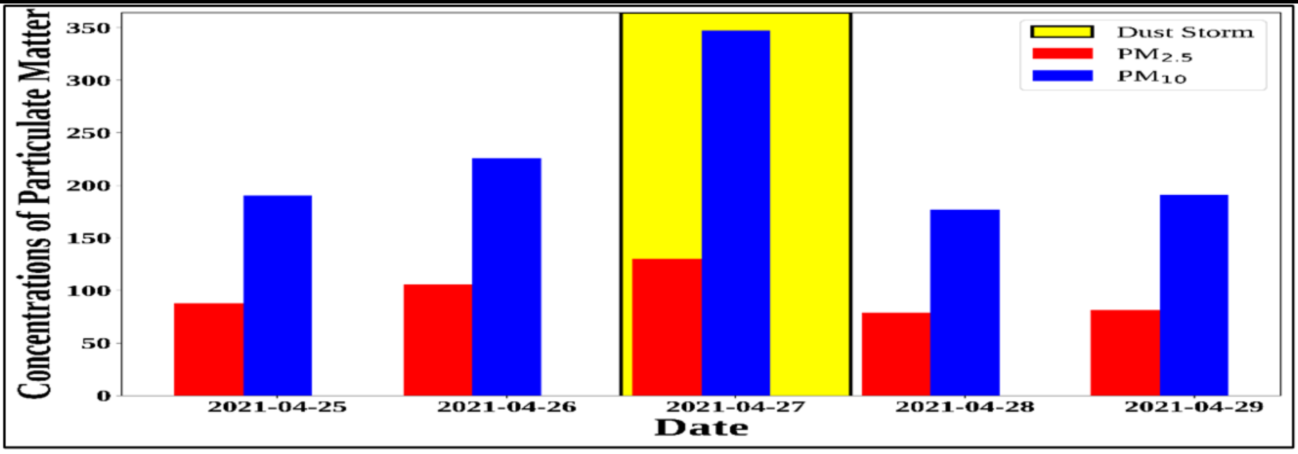

Fig. 5: Variation of $PM_{2.5}$ and PM_{10} concentrations obtained by SAFAR Dataset

4.5 Assessment of Pathway of Dust Storm Event:

To trace the origins of air-mass particles, five-day back trajectories were analyzed at an altitude of 1000 metres using the NOAA ARL HYSPLIT model. The back trajectories were computed, spanning from April 23, 2021, to April 27, 2021. The trajectory analysis is shown in Fig. 6. Most back trajectories trace their origins to the Thar Desert and deserts of Pakistan, Iran, and Iraq, with a few air parcels also originating from the Arabian Sea. This five-day back trajectory analysis confirms the observations taken from MODIS true-colour images This show the presence of extensive dust in the Arabian Sea and nearby areas of the Thar Desert. This analysis identified north-western and western deserts as the primary sources of the dust storm in this Ahmedabad region.

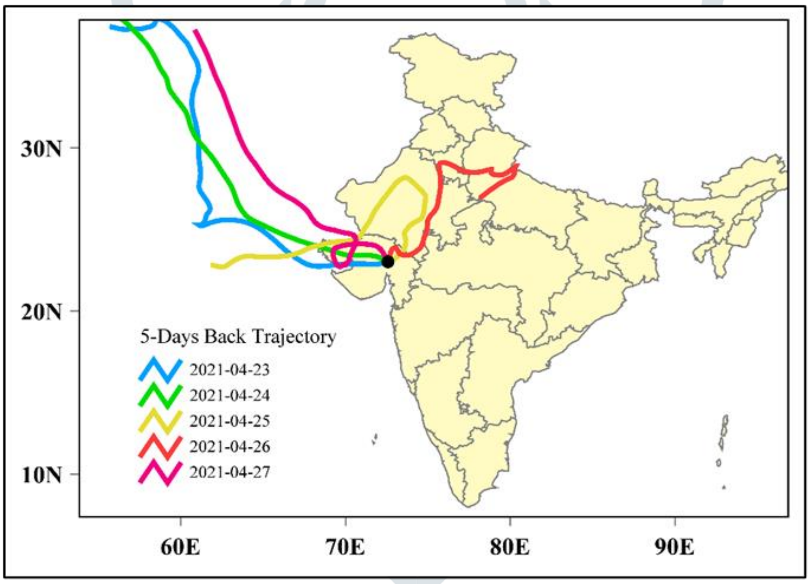

Fig. 6: Back trajectory analysis taken at an altitude of 1000 metres using the HYSPLIT Model.

V. Conclusions:

This study examined the impact of a dust storm that swept over the Ahmedabad region on April 27, 2021, using a combination of reanalysis tools, ground-based measurements, and satellite observations. It also analyzed the five-day back trajectory of the dust event. The primary findings from this research are given below:

1. During the dust storm event in Ahmedabad, there was a little fall in the average temperature. It dropped to 23.4°C. However, relative humidity surged, reaching nearly 25% on the dusty day.
2. A rapid increase in $PM_{2.5}$ and PM_{10} concentrations was observed on the dusty day. PM_{10} levels reached a peak of 347.22 µg/m³, while $PM_{2.5}$ levels increased to approximately 130 µg/m³ in Ahmedabad during a dusty day. This shows the presence of a large quantity of dust and other pollutants in the area, which resulted in complete darkness in the region.
3. A sudden rise in AOD values was observed using VIIRS at 550 nm during the dusty day. The value nearly doubled from the previous day. Meanwhile, lower Ångstrom Exponent (AE) values indicated an abundance of coarser aerosol particles in the Ahmedabad region. Further elevated Aerosol Index (AI) values verified the presence of UV-absorbing aerosols in the region.

4. Back-trajectory analysis shows the northwestern and western arid and deserts as the primary sources of dust in this event in the Ahmedabad region. A few air-parcels have also originated from the Arabian Sea, resulting in the bringing of mineral salts as to the region.

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