Impact of amphan cyclone on environment modification

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ABSTRACT
The Amphan a Tropical super Cyclone (TC) had grown in the background of high Sea Surface Temperature of 320°C-340°C, over the Bay of Bengal and in an artificially controlled pollution-free status of the Indian zone during the COVID-19 lockdown; thus providing an opportunity in examining the cyclone effects on the atmospheric dynamics in this special background. The paper presents the contributions of the Amphan wind to the atmosphere/environment of the North Eastern (NE) part of India along its track-path, after its landfall at 24.650N, 88.300E on May 20, 2020. The analysis supported by the troposphere temperature, relative humidity, precipitation, and suspended particles along with respective temporal and spatial profiles, finally offered that the Amphan-wind had brought down the temperature for a weeklong period, reduced the pollution level by 20% to 30% for more than a week but produced short-lived changes in humidity and precipitation over the NE-zone. The contribution of pollution is brought in to ambit of discussion to the weeklong sustenance of low temperature and in reducing the precipitation intensity when the growth environment of the CCN was artificially curtailed. The data sources are ground-based sensors, AWS, model profiles, and satellite observations.

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1. Introduction
The physics and dynamics on the growth of a Tropical Cyclone (TC) are well documented both from the observational platforms as well as from model computations (Miller 1958; Emanuel 1987, 1988; Chan 1995; Ginis 2002; Emanuel 2004; Vecchi and Soden 2007; Goni et al. 2009; Govindankutty et al. 2010; Kossin et al. 2013; Devi et al. 2013; Kossin et al. 2014; Devi et al. 2013; Knutson et al. 2015), but modifications contributed by a cyclone to the atmospheric system dynamics compounded by the increased global anthropogenic pollution status are still one of the need-based subjects of such studies. Evidence shows that global warming, environmental or anthropogenic sources could alter the severity of tropical cyclones (Holland 1983;
Gray 1988; Shen et al. 2000; Knutson and Tuleya 2004; Emanuel et al. 2004; Landsea 2005; Pielke et al. 2005; Vecchi et al. 2006; Rao et al. 2008; Zeng et al. 2007; Hill and Lackmann 2009; Knutson et al. 2015; Walsh et al. 2019) along with modifications in meteorological parameters and changes in rainfall intensities & flooding pattern (Rosenfeld et al. 2007; Allan and Soden 2008; Xie et al. 2010; Lin et al. 2015; Risser and Wehner 2017; Chauhan et al. 2018; Sarkar et al. 2018; Chauhan et al. 2021a). Thus, the influence of the environment on a TC and the impact of a TC on atmospheric modulations are the two equally important aspects necessary for a comprehensive view of the contribution of one to the other. Here, an artificially controlled environment could provide an opportunity to understand such effects as the case of Amphan, one of the powerful TCs that developed and matured at the Bay of Bengal (BoB) during the time of partial lockdown (May 2020) in the Indian subcontinent due to outbreak of Covid-19.

In brief, the Tropical Cyclone is a term used by meteorologists to describe special states of organized weather situations of a rotating system of clouds and thunderstorms that originate in the zone encompassing the Tropic of Cancer and the Tropic of Capricorn (lat. ±23° to ± 2°). A few requirements that favour the growth of a TC are the high average Sea Surface Temperature (SST) and the presence of Coriolis force. The severity of a storm is expressed by the wind speed and is assessed from the pressure at the central position of the circulatory structure of the cloud known as an eye; minimum the pressure value at the eye, the stronger would be the intensity of the expected storm. On receiving a warm water surface and an atmosphere with requisite environments, a favourable situation is formed for the growth of strong winds around the eye. The magnitude of wind when reaches greater than 60 km/h speed, the phenomenon is termed as a tropical storm. Farther, with the increase in the wind speed to around 120 km/h or beyond, the tropical cyclone status is achieved. The requisite atmospheric environment for such growth is also dictated by the

Figure 1. (a) Track of Amphan, its landfall location on May 20, 2020 (source: Regional Specialized Meteorological Centre Tropical Cyclones, New Delhi, India) and (b) the study zone, the NE part of India. The position of Guwahati is also marked.
convective situations of the troposphere where temperature, humidity, and wind play as fundamental inputs. Additionally, aerosols or suspended particles take a significant part in inhibiting/intensifying the process of development of convective clouds around the eye (hence precipitation) through Cloud Condensation Nuclei (CCN) sizes and types. Finally, on landfall, the energy accumulated by a TC in the growth process, loses the intensity in absence of its fuel source and dissipates the wind power through physical destructions on the coastal zone; a part of energy goes to the atmospheric circulation modifications. The paper aims to study particularly the latter aspects by analyzing the impact of the Amphan on atmospheric and environment modification of the North East (NE) region of India, after the cyclone made its landfall on May 20, 2020, at 24.65°N & 88.3°E. Figure 1a shows the track of Amphan along with the landfall location and the study zone is marked in Figure 1b; also shown in the map is the position of Guwahati, the main observational station.

The Amphan originated in the southeast BoB on 13th May 2020 and became a cyclonic storm on May 16. With the explosive growth, it became a Severe Cyclonic Storm in the morning of May 17 and transformed into a Very Severe Cyclonic Storm (VSCS) in the afternoon of May 17. With further rapid intensification it came into the category of Extremely Severe Cyclonic Storm (ESCS) in the early hours of May 18, and within six hours it transformed into Super Cyclone status and finally made its landfall on May 20 near Bakkhali, West Bengal (Figure 1(a)) as VSCS with a maximum sustained speed of 155-165 km/h (Source: Regional Specialised Meteorological Centre Tropical; Cyclones, New Delhi India). The destructive potential of a TC increases with the cube of its strongest winds, the Amphan is thus considered to be one of the most hazardous storms that had left trails of devastation. It is thus expected that a part of such accumulated energy may go for atmospheric modulations by appreciably modifying the environment even at places away from the direct landfall zone of Amphan (24.65°N & 88.3°E, Figure 1(a,b)). Our analysis here will be in this direction, initiated through the extraction of signatures on tropospheric temperature, humidity and precipitation contributed by the Amphan wind as it moved along the NE region (Figure 1(b)). Finally, an analysis on scattering co-efficient (particulate concentration) of aerosols/suspended particles will be presented in search of source identification associated with cyclone time changes in atmospheric physical quantities, with special reference to the artificially cut down pollution-free environment.

2. Analysis and results

2.1. Atmospheric temperature, humidity, and precipitation: role of the amphan

TC is evolved through the motion of the atmosphere which is governed by the well-known physical principles, i.e., conservation of mass, momentum, and energy, where the temperature is the prime mover or the controller. Along with the rate of changes in temperature with time/latitude/altitude that lead to air motion, the transports of heat & water vapor in the horizontal and vertical directions that result in winds and shears are the integral tropospheric phenomena in the development/inhibition of a TC. Therefore, as the aims require, the paper examines and presents the contributions of Amphan wind field to these variabilities. For such views, satellite data or global
weather models though could provide the temperature/humidity/precipitation profiles from the state of depression to the growth of a cyclone, finally to its landfall and beyond, but for the localized fine-scale changes in meteorological variabilities, we analyze round the clock data available from AWS as well as from the fast response sensors installed at Gauhati University, Guwahati (26.1445° N, 91.7362° E).

2.1.1. Amphan induced effects on temperature with special reference to the NE environment

In search of modification, if any contributed by the Amphan wind field on atmospheric temperature, its maximum (T$_{\text{max}}$) and minimum (T$_{\text{min}}$) figures recorded by the sensor system (with a resolution of 0.1°C) are first examined with respect to the diurnal status for May 2020 (Figure 2). Within the day-to-day variations of T$_{\text{max}}$ and T$_{\text{min}}$, the anomalous change in temperature on May 21, was distinct with practically no diurnal modulation, when T$_{\text{max}}$ has drastically dropped to 26°C by almost 25% from its average maximum of 32°C – 34°C and a difference of only 1.6°C was registered on this day between the T$_{\text{max}}$ and T$_{\text{min}}$ magnitudes (Figure 2). We consider this abnormal temperature feature as the cyclone induced, as it synchronizes with the entry of the Amphan track to the NE. But the significant issue is the slow recovery of T$_{\text{max}}$ that took more than a week time to attain the average temperature status of this month (Figure 2). The cyclone time drop in temperature as observed in this case is an expected phenomenon, but the important feature is in the T$_{\text{max}}$ magnitudes that retained low in status even beyond May 30 (Figure 2). Therefore, additional inputs in explanation to such observations become a necessity and we thus extend our study by examining temperature modulation status across different sectors of the NE region (along the track as shown in Figure 1) covering 90°E – 98° E and 24°N-28° N. The contour maps of the diurnal temperature maximum within the defined study area are then drawn with the NCEP (National Centers for Environmental Prediction) data of 0.25° resolution and are presented in Figure 3 for five days, i.e., before the cyclone landfall (May 18), the day of the landfall (May 20) and the days after the landfall (May 21, 22 & 28). The temperature maps reveal a sudden drop in T$_{\text{max}}$ almost by

![Figure 2](image-url). T$_{\text{max}}$ and T$_{\text{min}}$ (°C) variations over Guwahati, during May 2020. The arrow mark shows the landfall day of the Amphan.
10°C from its average (Figure 3(a)) on the day of landfall (May 20), over east Bangladesh (bordering India), west of Assam, and a part of Meghalaya. This status

Figure 3. Temperature maps (T_max) drawn with NCEP data of 0.25° resolution: (a) a normal day profile of mid-May, 2020, (b) May 20 on the day of the landfall of Amphan, (c) May 21, the day cyclone wind penetrated the NE zone, and (d) May 22 and (e) May 28. The Guwahati location is marked by a star.
then gradually shifted towards further northeast direction on May 21 (Figure 3(b)) covering Guwahati and around (91°E- 96°E & 24°N – 28°N) bringing down the $T_{\text{max}}$ to as low as 18°C (from the average $T_{\text{max}}$ value of 32°C-34°C) in the entire area. Interesting to note that this low-temperature spell then persisted over most of the NE sectors even up to May 28 (Figures 3(c,d)) with slow recovery to reach the average May-time $T_{\text{max}}$ value (Figure 3(a)), a feature similar to that recorded by the sensor at Guwahati (Figure 2). These results though suggest the role of cyclone wind field on temperature as it moved along its track, the issue of sustenance of low $T_{\text{max}}$ value by more than a week after the landfall, needs more parameter-involved analysis especially by introducing humidity and precipitations as other relevant inputs.

2.1.2. Amphan induced humidity features over the study zone

The TC wind field that carries humid air is supposed to be a good contributor to the changes in temperature along its track, even after landfall. Considering the presence of such inextricable link between TC induced temperature, humidity, and precipitation as well, we will analyze in this article and in the following one, the Amphan induced humidity/precipitation status at Guwahati and the rest of the NE by using data from the humidity sensors and AWS, along with the observational profiles received from India Meteorological Department (IMD) and relevant parameters from the NCEP.

Before we look for Amphan induced humidity features and their effects on temperatures and environment, the normally prevailed association between the two is projected first (in Figure 4(a,b)), by presenting representative temperature and humidity profiles of May 2020, drawn from the data collected at Guwahati from AWS and sensor systems. One can see from the figures the existence of a well-governed inverse relation between the humidity and temperature, with almost 25%-30% modulations in respective diurnal profiles. The interesting case now is of May 21 (Figure 5(a)). Because of the increase in the daytime humidity level (almost to 90%) on May 21 (Figure 5(a)), there was “no modulation in the diurnal humidity profile” and with only 8% variations from its maximum to minimum ($\Delta H = H_{\text{max}} - H_{\text{min}}$) value on this day (Figure 5(c)), it is an exception from the usually registered 25%−30% changes in diurnal humidity content over Guwahati for this month. But, with
a fast recovery to 20% on May 22 (Figure 5(b)), the $\Delta H$ attained the average day magnitude on May 23 (Figure 5(c)), unlike the observed week-long low in temperature. Thus, the sudden modification in daytime humidity on May 21 is the likely effect of the Amphan wind in the sudden drop of $T_{\text{max}}$ value on this day, but the contribution of humidity towards the sustenance of the abnormal low temperature for a week is unlikely because of the nature of its variations.

This analysis is then further extended to different sectors of the NE zone by drawing humidity maps from the NCEP data and presented in Figure 6 for May 18, 21, 22, and May 28, covering pre-Amphan landfall day to beyond. The enhancement of the daytime humidity content around the landfall zone on May 20 (Figure 6(b)) compared to that of a normal day status is clear (Figure 6(a)) and with further increase in the humidity level by more than 25% (along the track direction of Amphan wind) during May 21, it had covered the entire NE region, thereby presenting the features similar to those displayed in Figure 5. Here, we also see that the humid air had not only engulfed this region of India but did spread to Myanmar, China (25°N- 32°N and 96°E – 100°E) on this day. The maps also project the short-lived character of high daytime humidity status with the waning phase started from May 22, similar to those as recorded by the AWS/sensors at Guwahati (Figure 5).
Figure 6. Daytime Humidity in percentage from NCEP data: (a) in the normal environment of May 2020; (b) May 20, the landfall day; (c) May 21 (more than 85% humid air covered NE region and beyond) (d,e) recovery process to reach the average humidity status.
Thus, we see that a remarkable modification in the daytime humidity level did occur with the penetration of Amphan wind to the NE but with a fast recovery, it came to the average status within two days (i.e., on May 23). Now, if we look into Figures 2 and 5, the events of May 21 bear the significant importance for exercising a correlative analysis between humidity and temperature in understanding the atmospheric dynamics under the influence of cyclone wind field. A few significant characters evolved through such correlative analyses between temperature and corresponding humidity level of May 21 (Figure 7(b)) with respect to the normal day status (Figure 7(a)) are: (i) Temperature on May 21 within the same humidity margins, is lower (at least by 3°C to 4°C) compared to that of the average daily value and (ii) the correlation coefficient (r) between humidity and temperature on May 21 is not well defined (average around r = 0.5), unlike r = 0.9, that maintained for a normal environment of the month.

The overall conclusion thus we draw is that the humidity has an effect on the observed fall in temperature over the study zone on May 21 but with deviations from the generally governed relations between the two, it losses full control on temperature/environment. Also, in the sustenance of the week-long low temperature, its role is weak as supported by the ΔH diurnal modulation trend (Figure 5(c)). Farther, when anthropogenic sources over the Indian subcontinent are artificially reduced, contributions of pollution to temperature and in precipitation trend and finally in their inter-associated role to the environment modification cannot be ruled out. Because, precipitation, global temperature modulated by natural and anthropogenic sources and TC intensity (Allan and Soden 2008; Lin et al. 2015; Risser and Wehner 2017; Emanuel 2017) all are interrelated phenomena.

Our next exercise is thus to examine the role of Amphan wind in the precipitation trend of the NE and the resultant impacts on the environment. The data include high-resolution temporal rain parameter (mm/minute) from AWS, precipitation profiles from India meteorological Department (IMD), and relevant maps from global sources (NOAA Centre for Weather and Climate Prediction, Ventusky weather forecast details based on models GFS, ICON, GEM).
2.1.3. Precipitation trend and amphan wind

During the early part of May 2020, over the NE region, a relatively warm condition prevailed with practically no precipitation. The lack of precipitation in general in the NE during May 2020, was displayed in CPC analysis-based weather maps (with spatial coverage of 0.50° latitude x 0.50° longitude grid, NOAA Centre for Weather and Climate Prediction) of May 17 and May 18 (Figure 8(a,b)). But precipitation on May 20, around the landfall zone of Amphan, as displayed in Figure 9 a,b (cumulative amount), is cyclone induced & triggered by the moist warm wind carried by its wind field. By utilizing SAR data from the SENTINEL-1 satellite Kumar et al. (2021) have also observed very heavy rainfall (65-115 mm/day) over the landfall zone of Amphan cyclone on May 20 and 21, 2020. Naskar and Naskar (2021) have shown the presence of the heavy rainwater content on May 20 on the landfall area and that its value significantly decreases along the track but away from this zone. One can also view from Figure 9(a,b) that the rest of India as well the NE region was not affected by rain on May 20. But the sudden onsets of precipitations in the ‘west and mid sector’ of NE on May 21 as displayed in the daily accumulated precipitation data of Figure 9c, and then to the further north of this zone on May 23 (Figure 9(d)) around the TC path are the results of Amphan wind field. Precipitation along the track of a cyclone is a well-expected phenomenon but for evaluating its impact on the environment one of the modes is to examine the association of rain events with other meteorological parameters. Also important is to identify the inbuilt features of precipitation like its severity, type, and duration. Thus, under the Amphan background, these qualities associated with precipitation over different sectors of NE are examined by analyzing model (Ventusky weather forecast details based on GFS, ICON, GEM) predicted rain data for May 21 and 22 (Figure 10). The model outputs display (Figure 10) the occurrences of short periodic events with a gradual temporal shift towards the further north-east direction of the NE region for the sectors (a) 26.14° N, 91.73° E,(b) 26.5°N 97°E; (c) 27°N 97°E, are the result of Amphan induced precipitation along its track. One can also note that except for May 21, the rain over Guwahati (station1)
was weak, and even on May 22 only a short spell of low rain (maximum 2 mm) during the evening hours was detected. The presence of such weak cumulative rain during May 21 and 22 at other stations 2,3 of the NE (of Figure 10) (or the absence of strong precipitations) is also important to note here. Because such low magnitude rain with a maximum of 10 mm is not generally expected along the track of a VSCS. One more issue here is the precipitation being short-lived over a location, the system may not sustain week-long low temperature, thus it is difficult to couple the role of Amphan induced liquid water content in environmental modification in the studied region.

Coming to environment modifications, we present here a test case of correlative analysis amongst temperature, its rate of change, and precipitation for the events of May 21 over Guwahati in Figures 11. These inter-coupled analyses (Figures 11) drive at: (i) relatively weak role of precipitation on temperature during May 21 with a correlation coefficient of −0.36 (Figure 11(a)) and (ii) virtually absence of association between the onset of the rain event and the corresponding “rate of change of temperature “on May 21 (Figure 11(c)). This feature (ii) is a deviation from the generally

![Figure 9. Precipitation status over Indian subcontinent during Amphan landfall and beyond: cumulative weekly data on: (a) May 20 heavy rain in landfall zone, (b) May 21 precipitation at the NE. One day accumulated data on: (c) May 21 and (d) May 23 (Source: NOAA Centre for Weather and Climate Prediction).](image-url)
expected atmospheric system dynamics because prior to a rain event temperature falls through thermodynamical heat exchange processes and we present in Figure 11b, a normal precipitation case when a 10% decrease in the temperature is noted with the onset of a weak rain event. This observational analysis thus supports that precipitation is only partially effective in bringing a short time modification in temperature even on May 21. Farther, the precipitation magnitude is observed to be low in intensity for such a powerful TC, perhaps here, the pollution-free environment of the Amphan-time and the CCN effects need to be evoked. We, therefore, finally examine the quality of air under the Amphan influence and its possible impact on atmospheric physical parameters and the consequent dynamics.

2.1.4. Air quality, pollution, environment and amphan cyclone

To understand the interactive roles between pollution and meteorological variability, the ocean–land-atmosphere coupled model needs to be evoked as demonstrated by Chauhan et al. (2018) while analyzing the atmospheric parameters along the track of the Hudhud cyclone after its landfall. Such study is important as the cyclone wind carries along with it the suspended particles/aerosols right from its formative stage and based on the level of such pollutants (contributed largely by anthropogenic sources) the strength of a TC could get changed (Dunion and Velden 2004; Jenkins et al. 2008; Vecchi et al. 2006; Cotton et al. 2007; Zhang et al. 2007; Khain et al. 2008; Zhang et al., 2009) with consequent effects on the atmosphere by the TC wind field.

In view of the availability of a unique platform with an artificially controlled low pollution environment over the BoB, we present here atmospheric aerosol features recorded at Guwahati, by Nephelometer (with 525 nm probing wavelength), prior to during and after the landfall of Amphan to examine the contribution of air quality in modifying the meteorological variabilities mainly on temperature. Also, we will
present the air quality maps from PM$_{2.5}$ data of the MERRA 2 Model to examine pollutant levels along the track of the TC covering the study zone.

The cyclone wind field impact on aerosol scattering co-efficient as received from the Nephelometer observation (Figure 12(a)), is clear on May 21 when its value attain a maximum of only 40-50 mm$^{-1}$ with minimum goes almost to zero, unlike a maximum of 300-400 mm$^{-1}$ and a minimum of 50 to 100 mm$^{-1}$ (Figure 12(a), May 18-19) as obtained in an average normal day. The sudden decrease in scattering coefficient on May 21 is also seen in (its) maximum (average) and minimum profile plots (Figure 12(b)) for the month of May 2020 (covering the days before and after the landfall of Amphan). The low profile of scattering coefficient of May 21 as displayed in Figure 12a,b, is an index of low particulate concentration (by equation 1), projecting a sudden purification of air quality and interesting to note here that this status prevailed for almost a week with recovery process continued to May 30 (Figure 12(b)).
Figure 12. (a) A few profiles of scattering coefficients received by Nephelometer observation at Guwahati during May 2020; (b) The maximum and minimum values of scattering coefficient for the month of May 2020. The abrupt decrease of its magnitude on May 21 and slow recovery to the average value are significant. The arrowheads identify the day of the landfall of the Amphan.
where \( N \) is the number concentration of the particles with diameter \( D \), \( Q_{sc} \) is scattering efficiency and \( \sigma \) is the scattering cross-section.

The striking similarity in the diurnal maximum and minimum profiles between temperature and scattering coefficients (Figures 2 and 12(b)), both presenting low values from May 21 to May 30, suggests the presence of an interdependent role between the two parameters. The quantitative relation between \( T_{max} \) and scattering coefficient was also observed to be strong with a correlation coefficient value of \( r = 0.87 \) (Figure 13), an index of the existence of a coupling effect between pollution and temperature.

Equally important is to examine the relation between scattering coefficient and humidity because air quality controls the scattering coefficient magnitude which is directly associated with particulate concentration and in general, humidity always plays a role in it. This feature is more or less well reflected when a correlation coefficient of 0.3 to 0.4 is observed between the scattering coefficient and humidity in the normal day situation of May 2020 (Figure 14(a)) over Guwahati. But the status changed drastically during May 21 (Figure 14(b)) when humidity–scattering coefficient association seems to be lost and that it took days to come back to the normal situation as we see from Figures 14c (May 26) and 14d (May 27). We could not however isolate the type of aerosol present, but the Amphan wind field is supposed to carry with it less particulate (while tracking through an artificially controlled pollution-free platform) perhaps also of hygroscopic components and therefore, the weak humidity-scattering coefficient relation is not unexpected.

Along with this exercise, we present in Figure 15 the concentration maps of \((N)\) of P 2.5 (kg/m3) over the study area covering the days from May 18 to 22 and for May 28, by using data from the Merra Model (GIOVANNI) with a resolution of 0.50\(^0\) × 0.625\(^0\) & of one-day time average. One can view from the figures that the normally existing high-level pollution in the NE region before the Amphan landfall
(Figures 15(a, b)) (bordering India-Bangladesh) improved in its quality on the day of landfall by about 45% (May 20, Figure 15(c)) and that on May 21(Figure 15(d)), a dramatic reduction on pollution levels by 80% was seen throughout the NE (covering 91°E – 94°E, 25.5°N – 27°N) along with 60% low in pollution level in and around the Sub Himalayan range (94°E – 96°E, 24°N-28°N). This abrupt purification of air is likely to have a significant contribution from Amphan wind field as it moved along the track to the NE carrying with it the pollution-free air. Also interesting is to note that (Figure 15(e,f)), the pollution level over this zone remained low by 50% to 45% till May 28 and yet to recover completely to the pre-Amphan status, a feature similar to that of temporal temperature variations. The analysis thus provides supportive evidence that the pollution-free status is one of the prime indices resulting in the observed week-long maintenance of low temperature and hence in environment modifications.

3. Discussions and conclusions

In a study involving TC-induced effects either on the environment or in the atmosphere, the prime parameter is the strength of a cyclone (Emanuel 1987; Emanuel et al. 2004; Chan 2006; Cotton et al. 2007). Therefore, the sources associated with the growth of intense TC come as fundamental issues in the discussion. In the Indian ocean, the intense cyclones are identified with high SST values and the outflow-layer
Figure 15. Air quality maps for particulate matter 2.5 micron PM$_{2.5}$ (MERRA Model, Giovanni) covering pre-Amphan landfall day to beyond: (a) May 18, (b) May 19, (c) May 20, (d) May 21, (e) May 22 and (f) May 28. The study zone is marked by a circle and the Guwahati position is shown by a star.
Figure 16. HYSPLIT Back trajectory model shows the wind direction to NE prior to, during, and after the landfall of Amphan: (a) May 15, (b) May 19, (c) May 21, and (d) May 22 and (e) the Forward trajectory model, displaying the track of Amphan wind from NE to beyond on May 21, 2020.
temperature in the upper troposphere, especially by anthropogenic ocean warming (Du and Xie 2008; Hu and Fedorov 2019). Therefore, the number of cyclones that develop in the North Indian Ocean though limited within 7% of the global total, impacts are observed to be severe mainly on the east coast (Du and Xie 2008; Rao et al. 2008; Devi et al. 2013; Devi et al. 2013; Chauhan et al. 2020, 2021b). As a result, the BoB cyclones provide a wealth of scientific materials for understanding the sources leading to enhancements in the speed of a TC and the resultant contributions to the atmospheric system as well as in environment modifications. Naskar and Naskar (2021) have observed that high SST, weak vertical wind shear, the high-temperature gradient between warmer and sea surface along strong upper-level divergence are associated with the increase in the strength of tropical cyclone Amphan. Farther, the Amphan cyclone is expected to offer special dynamics on atmospheric modulations as it had grown in an artificially controlled pollution-free environment of the Indian subcontinent.

Our work in this paper directs towards the understanding of atmospheric modification by Amphan carried wind field along its track to the NE part of India. The HYSPLIT model outputs (Figure 16) show that prior to the cyclone landfall, the wind direction to the NE comprises mainly of western components (Figure 16(a,b)) but after its landfall, the southeast components (Figure 16(c,d)) from the BOB to NE are distinct, indicating entry of cyclonic component of wind to the zone. The forward trajectory (Figure 16(e)) supports that the wind moved further to the northeast direction from Guwahati, the platform of our study.

Therefore, the entire NE region is appeared to be under the influence of the Amphan wind track, especially because of the strong build-up energy of the TC. In the process of building up of energy, one relevant issue here is the manmade activity associated with Global warming where anthropogenic aerosols stand as key parameters with TC intensity and also to the resultant effects on the ocean-atmospheric modifications (Zeng et al. 2007; Rosenfeld et al. 2007; Khain et al. 2008; Cotton et al. 2007; Reissell et al.2008; Krall and Cotton 2012; Rosenfeld et al. 2012). We can refer here to an extensive study presented by Chauhan et al. (2018) along the track of cyclone Hudhud (generated at BoB), where they have shown that the changes of the sea surface temperature as well as that of the land, may result to atmospheric parameter modulations along the track after its landfall. Their analyses also demonstrate that the enhancement of concentration of CO at lower altitudes, the H2O mass mixing ratio at the middle troposphere along with strong mixing of anthropogenic aerosols, biomass aerosols, and dust over central and coastal regions are the impact effects of the cyclone.

Our study no doubt is also along in that direction but in an artificially controlled pollution-free environment. In brief, this analysis shows a significant relationship between temperature and pollution level when atmospheric temperature and aerosol scattering coefficients (particulate concentration) remained low after the landfall for a week and beyond, while the precipitation events induced by the TC are relatively low in intensity and are of short-lived. Similar was the status of daytime humidity level, though it increased by 25% on 21 March, its resultant contributions to the week-long environment cooling are not effective because of its fast recovery to the average status.
It is necessary to emphasize here that pollution-free air quality is a rare event over this East Asian zone which otherwise is one of the most concentrated aerosol source regions on the globe contaminated by emissions from the industrial outlet, biomass burning, and also by dust storms. The presence of concentrated aerosol belt over the Indian subcontinent is well confirmed through dedicated experiments, INDOX the Indian Ocean experiment, and Asian Pacific Regional Aerosol Characterization Experiment(ACE-Asia), to name a few. It is also observed under the ACE-Asia experiment that during vernal equinoxial months (April-May) aerosols are carried to the west pacific (Hubert et al. 2003) region enhancing its belt towards the study area. Under this normally heavy contaminated environment, the decrease of aerosol optical thickness around the Indian subcontinent as seen from AOD maps (Figures 17(a,d)) for the 2020 year in comparison to 2019 (equinoxial months, Figure 17(b,c)) and also from Nephelometer observations over Guwahati during the lockdown periods are
significant. One can also refer here to the background status of the Fani cyclone that had developed at BOB in late April with landfall in the early part of May of 2019. Analyzing the meteorological and atmospheric variability along the track of Fani, Chauhan et al., (2020, 2021b) observed changes in ocean parameters such as chlorophyll concentration, dissolved oxygen, salinity, sea surface and sub-surface temperature with a strong coupling process between the land-ocean-atmosphere.

We note that, unlike the Amphan time temperature that remained low for a week, the Fani induced temperature change over Guwahati was short-lived, i.e., seen only on May 4 (Figure 18), after a day of its landfall on May 3, 2019, and also that when Amphan time-temperature shows practically no association with humidity (though cannot be defined by a single slope) such correlation was observed to be strong during Fani cyclone with $r = 0.76$, as expected during a TC. Also accumulated rain contributed by the Fani cyclone over Guwahati comes to 33 mm (maximum on May 4, 2019), more than two times compared to 14 mm (maximum) recorded along the Amphan track.

Therefore, the Amphan and Fani cyclones as had grown and dissipated in two different air quality backgrounds, the consequent effects on the atmosphere are expected to differ. The contribution of tropical cyclones to air quality is no doubt a subject of interest for decades (Dunion and Velden 2004; He and Soden 2015; Sarkar et al.2018; Chauhan et al. 2020, 2021b). The TC-induced modification in the air quality of Hong Kong was also well presented by Chow et al. (2018). The study conducted by them during the TC active season (July–October) from 2000 to 2015 results to that on 57.55% of days, the concentrations of particulates PM$_{10}$ above 90th percentiles are the effect of TC activity, and depending on the origin of TC the affected days may be as high as 65.5% and also of O$_3$ concentration.

Thus, in the case of Amphan, the effect of its wind field as it moved along the track was seen as cleaning of the air quality making the environment cooler. The
confirmation of such less contaminated air during this period was also received through the US space agency NASA’s satellite sensors reporting that pollution levels in northern India plummeted to a 20-year-low due to the lockdown imposed for the coronavirus. The record low aerosol scattering coefficients over Guwahati also is evidence of improvement in air quality by Amphan carried wind.

Farther, we present a 3-D plot in Figure 19 associating (i) pollution level and (ii) temperature variations over Guwahati prior to and during the entry of Amphan wind to NE. The figure shows a strong correlation coefficient of 0.87 between these two parameters from May 21 onwards, when a weak relation ($r = -0.365$, Figure 11a) exists between temperature and rain during the same period. It is thus necessary to assess the possible contribution of pollution-free status to the lowering of temperature, its sustainability for a week after the landfall, and its overall contribution to the environment. There are innumerable documents associating an increase in pollution level with climate change and temperature especially with heatwaves (Meehl and Tebaldi 2004; Fischer et al. 2008; De Sario et al. 2013; Kalisa et al. 2018). Thus, a reduction of pollution by about 80% (Figure 19) might work in lowering the temperature by a few degrees as we see in our case. However, quantifying a change of weather/temperature with pollutions or aerosols yet remained in uncertain status because of a wide range of reported results (Knutti and Hegerl 2008). In the case of aerosols, while the absorbing type like BC, mineral dust, and some OC components are sunlight absorbers and have the inherent property to heating the surrounding air and thereby increasing atmospheric temperature (Hansen et al. 1997), the scattering-type aerosols mainly scatter solar radiation to have a cooling effect. During lockdown over the Indian subcontinent, the anthropogenic resources of pollutants are drastically reduced. The record low values of 2.5 µ over NE for a week-time (Figure 15) is an index of reduction of suspended particles (of D ≥ 1 µ) generally associated with
manmade activities like grinding and other mechanical disintegration processes, thereby heating effect is subdued significantly as observed in the study. Also important is to highlight here the service of atmospheric aerosols to the formation of CCN, the prime elements in dictating hygroscopic cycle and hence in climate modification. With a low in the number of aerosols less will be the formation of CCN, and this may result in less intense precipitation as observed in this case. However, the net effect needs quantitative analysis which is beyond the scope of this work as the involvements of aerosols in the formation of CCN and precipitation are complex processes controlled by aerosol-cloud microphysics.

Finally, we conclude that significant modifications in meteorological variabilities are observed along the track of Amphan wind field as it penetrated to the NE on May 21, the day after the landfall of the TC. The important aspects that this cyclone contributes to the atmospheric/meteorological parameters over the NE as we have noted are: (a) fall in temperature \((T_{\text{max}})\) by more than 25\% on May 21 and that it took almost a week to recover to the average \(T_{\text{max}}\) status, (b) the day time humidity level (in \%) shoots to almost 20\%-30\% high from the average on May 21, but with a fast recovery, the level almost returned to its average on the next day (May 22), (c) precipitation events over NE at different sectors were low in intensity and short-lived following the track of the Amphan wind field and (d) air quality showed its sudden purification and maintained this status for a week similar to that observed in temperature profiles.

Thus, we see that unlike the normally reported observations on increase in pollution level in the near-earth environment by a TC induced effects, the Ampahn wind field has made the air cleaner as it carried with it less particulate while tracking through an artificially cut down anthropogenic pollution-free environment over the Indian subcontinent, a unique platform not possible to achieve in the normal situation. We also see the short span effect of humidity and rain in bringing down temperature especially on May 21, but the contribution of a pollution-free environment is strong in this process of cooling and also in the observed low precipitation intensity. Perhaps the orography of the NE region offers a platform for retaining the clean air for a week and hence lowing of temperature till a strong convective situation develops. Thus sea-land-air interactions are fully effective right from the formation of the TC to the landfall and beyond.

The ultimate result is that Ampahn wind had made the NE environment cleaner and significantly cooler. The study thus shows how an artificially controlled pollution level can bring down the temperature, a vital issue in climate change. The orography of the zone might contribute to the sustenance of a cool environment along with purified air over the NE over a week time, a future plan of our work.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

Data availability statement

Sources utilized Temperature and humidity data: National Centers for Environmental Prediction, NCEP
Aerosol optical depth data: NASA(https://giovanni.gsfc.nasa.gov/giovanni).
Precipitation data: Regional Specialized Meteorological Centre Tropical Cyclones, New Delhi India: Super Cyclone storm “Amphan” over the southeast Bay of Bengal (16th-21 May 2020: Summary
NOAA Centre for Weather and Climate Prediction: https://www.cpc.ncep.noaa.gov/products/JAWF_Monitoring/SEAAsia/index.shtml
Ventusky weather forecast details based on models GFS, ICON, GEM: https://www.ventusky.com/

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