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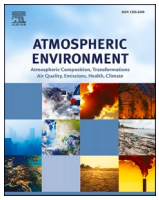

A very rare event of sand/dust weather in Hong Kong in late spring in 2025 – observational and forecasting aspects

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HIGHLIGHTS

- Satellite-based PM products monitor closely southward spreading of sand/dust to southern China.
- Global sand/dust models capture the arrival of sand/dust at southern China, yet there are discrepancies between the actual and forecast PM values.
- Local chemical composition products capture well the arrival of sand/dust at Hong Kong.

ABSTRACT

A rare event of sand/dust weather in Hong Kong occurred in the evening of April 12, 2025 and lasted till April 17, 2025. It is very uncommon because the sand/dust, originating from Mongolia, managed to climb over the mountains at Nanling in central-southern China with heights reaching about 2000 m above sea level, and reached the coast of southern China. Analysis of local observations confirming the occurrence sand/dust weather, namely, PM_{10}, $PM_{2.5}/PM_{10}$ ratio, AERONET observations and chemical speciation analysis, are presented in this paper. The trajectory and thickness of the sand/dust is also studied using synoptic weather observations and geostationary meteorological satellite aerosol products. Finally, the forecasting aspect of the sand/dust weather is discussed, from the forecasting by a few days ahead to possibly at the sub-seasonal scale. It turns out that the forecast aerosol concentrations serve as a useful product to hint the occurrence of sand/dust weather in Hong Kong, even though there are still discrepancies between the observed and the forecast values. There is also signature of conditions favourable for sand/dust transport to southern China in model sub-seasonal forecast outputs, and the recurrence of similar synoptic patterns in middle and lower troposhere in late spring (April) in the future may hint the potential of sand/dust weather over Hong Kong again.

1. Introduction

With its proximity to various desert basins, northern China is frequently affected by sand and dust storms (SDS) in late winter and spring, which leads to considerable environmental impacts as well as hazards to human health (Qian et al., 2004). Located on the south China coast and more than 1600 km away from the nearest deserts, it is very uncommon for Hong Kong to be affected by sand/dust weather. In particular, at about 26° latitude North which is around 400 km to the north of Hong Kong, there is the generally east-west oriented Nanling mountain ranges with peaks rising to about 2000 m above sea level. As such, Nanling acts as a natural barrier to block the southward spreading of the sand/dust from the north. According to the historical records of the Hong Kong Observatory (HKO), the meteorological authority of Hong Kong, March 2010 saw the first time which the territory was known to be affected by sand/dust weather, as supported by satellite and particulate matter (PM) observations locally and upstream (Lau and Choy, 2011). During that event in which an intense SDS affected large parts of East Asia (Li et al., 2011), sand/dust originated from the Gobi Desert spread towards the southern coast of China, including Hong Kong, along the southeastern coast of China and Taiwan Strait, where there are no terrain barriers to stop the suspended particulates.

More than 15 years after, during the overnight period of April 12–13, 2025, Hong Kong once again started to be affected by a sand/dust weather episode. The effect lasted till April 17, 2025. Unlike the previous event in 2010, this event is novel in a way that the northerly winds were strong and thick even in late spring/early summer, so that sand/dust managed to climb over Nanling and spread towards the south China coast. Various pieces of observational evidence indicating the occurrence of this sand/dust event, including satellite, aerosol measurements

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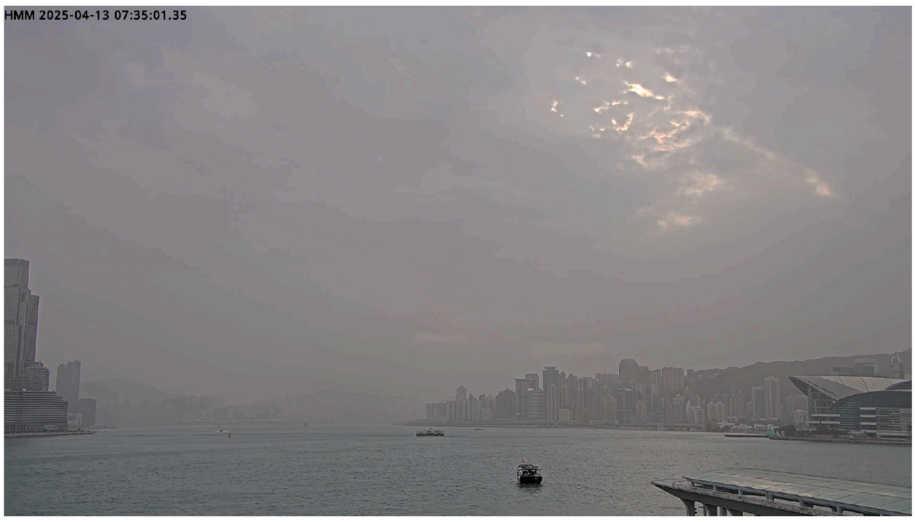


Fig. 1. The weather camera image overlooking eastern Victoria Harbour at 07:35 a.m. Hong Kong Time (UTC+8), April 13, 2025.

and chemical speciation analysis are discussed in this paper.

The environmental and health impacts of these sand/dust events in southern China are considerably less severe compared to other places affected by severe sand and dust storms (e.g. Zhang et al., 2023) due to much diluted sand/dust concentration. Nevertheless, in the event of April 2025, the minimum visibility in Hong Kong dropped to around 5000 m, and the distant mountains appeared to be blurred by a layer of yellow colour (Fig. 1). The health risk category for the local Air Quality Health Index (Wong et al., 2013) also reached "serious" level, the highest level of the system, for which members of the public, especially people who are susceptible to air pollution, were advised to reduce physical exertion and outdoor activities. This suggests that forecasting of whether and when sand/dust weather would affect Hong Kong is still important for giving early and sufficient alerts to the public. As discussed later in this paper, various sand/dust models managed to forecast a few days ahead the rather rare arrival of sand/dust weather to Hong Kong, yet for some models the forecast concentration turned out to be quite different from the actual observations. As such, it is still not possible to confidently conclude the arrival of sand/dust weather at Hong Kong several days in advance, especially with the rather rare occurrence of such an event. However, forecast outputs from such models, together with analysis of synoptic patterns favourable for the southward transport of sand/dust, may facilitate early preparation for the potential occurrence of such uncommon events in the future.

2. Observations

2.1. Synoptic surface and upper air observations

The synoptic weather reports at the surface, including the wind and the weather type, are given in Fig. 2(a)–(c) for 11 April, 12 April and 13 April respectively. From Fig. 2a, sand/dust weather or even sand/dust storms were widely reported in Mongolia over the Gobi Desert, with strong to gale force northwesterly winds. On the following day (Fig. 2b), the sand/dust spread southwards across the central part of China. The 10-min mean northerly winds also reached strong force, which is not common for the northeast monsoon in the late spring season. It took less than 48 h for the sand/dust to reach southern China from the desert to the north. As seen in Fig. 2c, sand/dust weather had been reported in a number of stations over southern China. The one closest to Hong Kong was Shangchuan Dao, at about 200 km to the west of the territory.

The backward trajectory map for Hong Kong in the morning of April 13, 2025 (Fig. 3a) based on NOAA's HYSPLIT transport and dispersion model showed that airmass reaching Hong Kong went all the way from Mongolia, across northern and central parts of China, towards the coast of southern China. At around the location of Nanling (indicated by the black dashed line on the map), the air parcel had a height of about 2000–3000 m above sea level, which suggests that the sand/dust managed to climb over the mountains and spread southwards. The upper-air pattern at the time was indeed favourable for rapid southward transportation of sand/dust. As shown in the 500 hPa geopotential height reanalysis field on April 14, 2025 (Fig. 3b), there was a prominent cut-off low over northeastern China and East China Sea. Previous studies (e.g. Li et al., 2024; Yang et al., 2019) suggested severe SDS over northern China are often related to the presence of a cold vortex over the region, yet it is rather rare to have a cut-off low extending to such low latitudes in the late spring season. The associated intense northerly monsoonal flow in the middle and lower troposphere allowed the southward advection of sand/dust, as shown in the corresponding 700 hPa (about 3000 m above sea level) pattern (Fig. 3c), in which gale force north to northwesterly winds prevailed over the latitudes of Nanling, such that sand/dust brought by the strong winds managed the mountain ranges and subsequently reached the south China coast.

2.2. Satellite images

The aerosol optical depth (AOD) products at 354 nm from the Geostationary Environment Monitoring Spectrometer (GEMS) of GK-2B satellite are shown in Fig. 4 as a large-scale overview of the southward spread of sand/dust. On April 11, 2025 (Fig. 4a), high AOD areas could be identified in Mongolia. In the following couple of days (Fig. 4b for April 12, 2025 and Fig. 4c for April 13, 2025), the higher AOD areas spread to the south. However, due to the presence of high clouds, the AOD over southern China was not available. On April 15, 2025, the higher AOD areas existed over the south China coast and the northeastern part of the South China Sea. However, there is no in-situ measurement to confirm the presence of high AOD over the sea, though this is found to be consistent with the prediction of some numerical models (to be discussed later).

The GEMS products also include the aerosol effective height (AEH; Park et al., 2025). An image on April 12, 2025 is shown in Fig. 5. At about the location of Nanling, the AEH was found to be around 3000 m above sea level. This is consistent with synoptic upper-air analysis and the backward trajectory results that the sand/dust weather managed to climb over the terrain barrier and reached the southern coast of China.

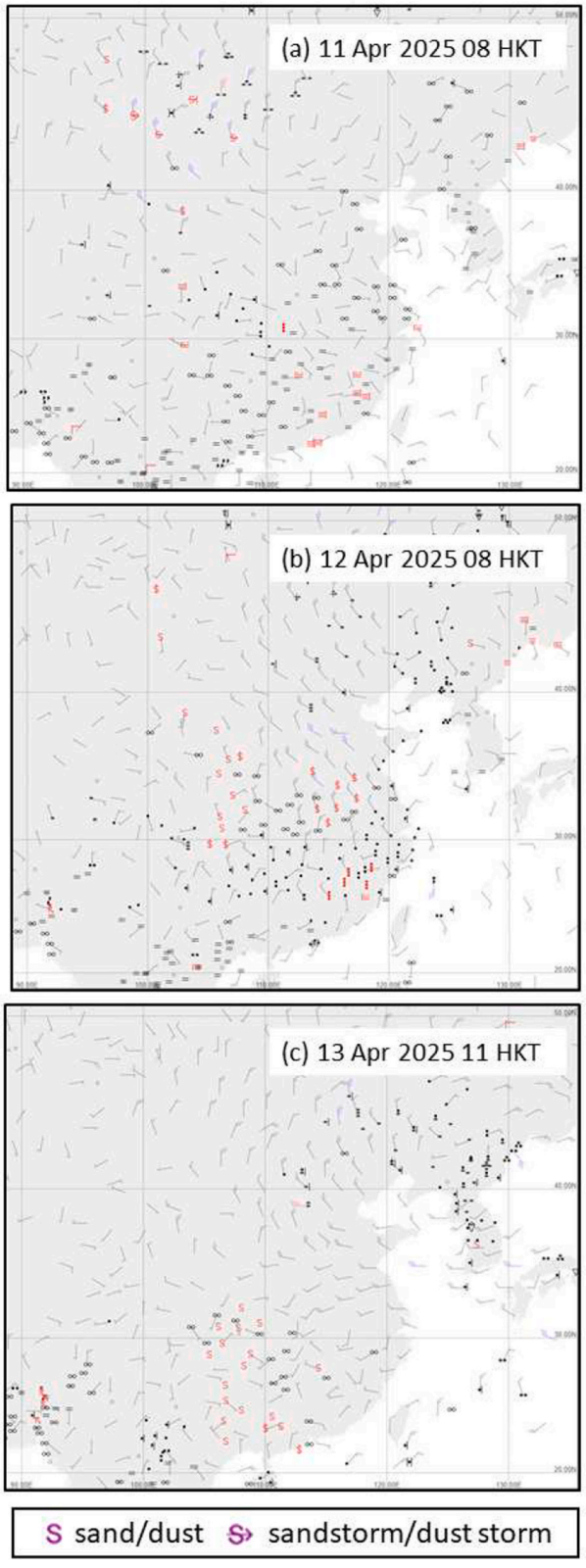


Fig. 2. The observed surface winds and weather observations at three time instances on 11–13 April 2025.

2.3. Local observations of $PM_{2.5}$ and PM_{10}

With the spreading of the sand/dust to southern China, the local observations of $PM_{2.5}$ and PM_{10} could be used to monitor its southward movement. Three stations in southern China are considered, namely, Shaoguan (SG) at the northern boundary of the Guangdong province, Guangzhou (GZ) at the northern part of the Pearl River Estuary, and Tung Chung (TC) in Hong Kong. The time series of PM_{10} at the three stations are shown in Fig. 6a. It could be seen that response of SG first appeared in around noon local time of April 12, 2025. The signature appeared later in GZ, in the evening, while the rapid increase at TC happened later at night. The PM_{10} also rose above 200 $\mu g/m^3$ upon the arrival of the sand/dust, consistent with that in the previous event in March 2010 (Lau and Choy, 2011).

According to Lau and Choy (2011), the $PM_{2.5}/PM_{10}$ ratio can be a useful indicator of the occurrence of sand/dust with the absence of chemical composition analysis, namely, the ratio would be lower than about 0.5 when the place is affected by sand/dust weather. The time series for the calculated ratio at the three stations is given in Fig. 6b. This criterion about the ratio was met for the present event. The time of the sharp rise in PM_{10} was also generally consistent with that of the sharp decrease of $PM_{2.5}/PM_{10}$ ratio. The rarity of this event can be demonstrated in the time series of daily mean PM_{10} and the $PM_{2.5}/PM_{10}$ ratio at TC from April 1999 to April 2025 (Fig. 7). The event in April 2025 was only the first time after the previous sand/dust event in March 2010 where the daily mean PM_{10} exceeded 200 $\mu g/m^3$ and the $PM_{2.5}/PM_{10}$ ratio was lower than 0.5 at the same time. The values of latter ratio were 0.32 and 0.35 on 13 and April 14, 2025 respectively, more than 2 standard deviations below the mean ratio of 0.65 during the period.

As the time progressed, following deposition of the sand/dust, PM_{10} decreased generally but slowly (Fig. 6a). However, up to the morning of April 18, 2025, the $PM_{2.5}/PM_{10}$ ratio still remained below 0.5 (Fig. 6b). Thus while the ratio could be useful for identifying the arrival of the sand/dust weather, considering this ratio alone may have limitations in determining the cessation of the event.

2.4. AERONET measurements

There are two AERONET stations in Hong Kong, namely, at the Hong Kong Polytechnic University (PolyU) in the city centre and Sheung Shui, a rural location in the northern part of the territory. The size distributions of aerosols from these two stations on April 11, 2025 (day 100 UTC 23:48:17, available at Sheung Shui only because of cloud cover over the urban area of Hong Kong), April 14, 2025 (day 104) to April 16, 2025 (day 106) are shown in Fig. 8a-b. There are two peaks on day 100 at Sheung Shui, namely, about 0.2 μm and 2 μm. However, on April 14 and April 16, 2025, both stations capture the prominent peak at about 2–3 μm. There is clearly a change in the characteristics of the aerosols in the air, converting from fine mode aerosols to coarse mode aerosols as the dominant aerosols. This evidence indicates that dust aerosols, a typical type of coarse mode aerosol, occurred during this period.

The single-scattering albedos (SSAs) and Asymmetry factor at PolyU and Sheung Shui from day 104 to day 106 are shown in Fig. 8(c and d) and 8(e-f) respectively. The SSAs of 440 nm–1020 nm are in the region of 0.8–0.99, and the asymmetry values are mainly in the 0.7 to 0.8 region. The high values of SSA illustrate the aerosols had a high scattering strength dominated by forward scattering, they are generally consistent with the other observations of sand/dust as reported in Sun et al. (2015) and Ortiz et al. (2025), providing further evidence that sand/dust occurred in Hong Kong at that time.

The AODs at 440 nm, 675 nm, 870 nm, and 1020 nm varied with time from day 100 to day 106 (10 April to 16 April) are shown in Fig. 9. The AOD values at 440 nm dropped from ~0.8 on day 100 to ~0.4 on day 104 at both PolyU site and Sheung Shui site, while no obvious AOD variations at longer spectral wavelengths.

The AOD at 440 nm is plotted against the Angstrom exponent for 440 nm over 870 nm in Fig. 10. The data in the period of 11–April 16, 2025 are considered. For both sites, there is a general trend that the Angstrom exponent decreases with an increasing AOD at 440 nm. This observation is consistent with the reports in the literature for sand/dust weather, e.g. Yu et al. (2015) and Ortiz et al. (2025).

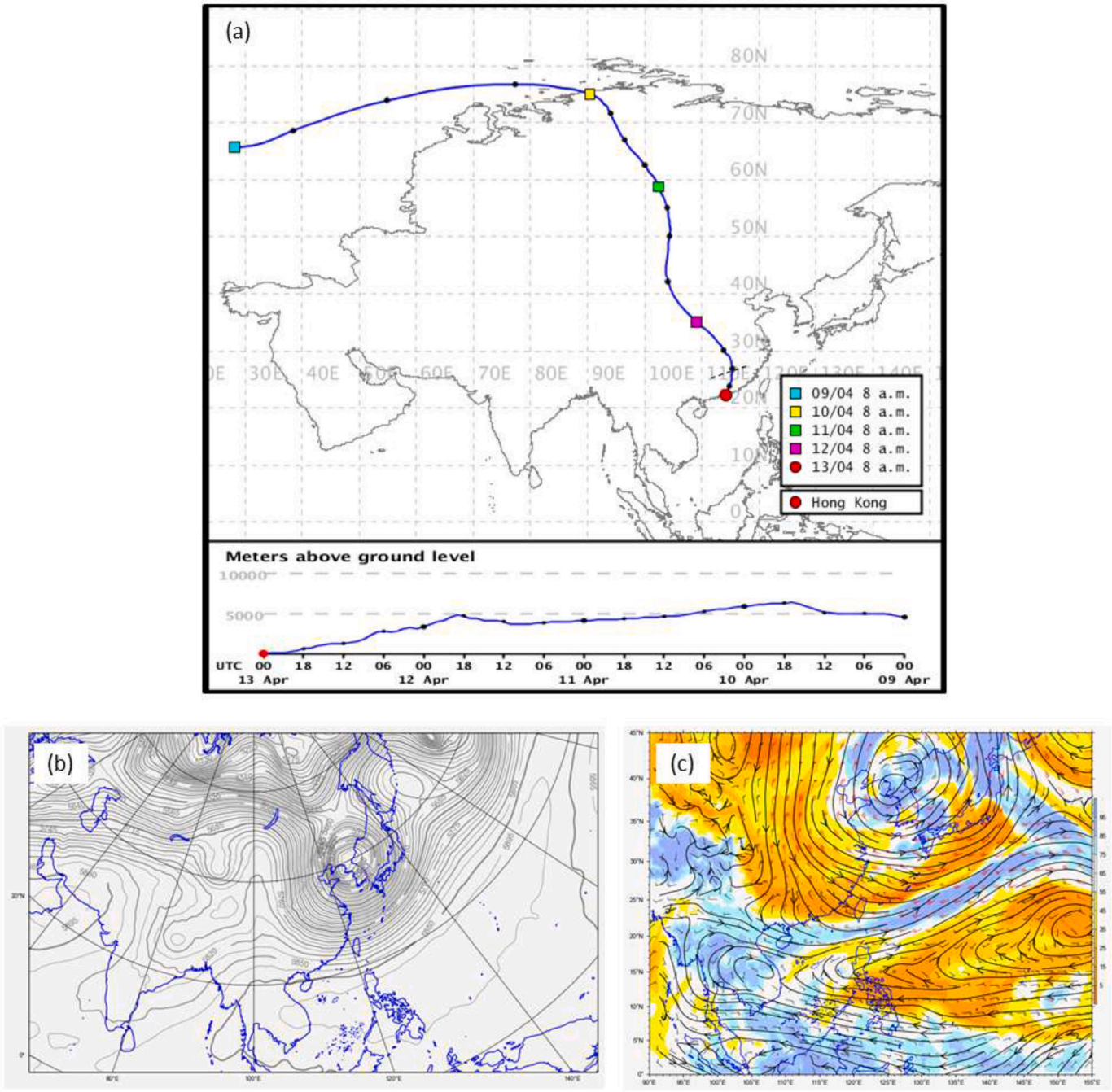


Fig. 3. (a) The backward trajectory of airmass reaching Hong Kong at 8 a.m., April 13, 2025, with the approximate location of Nanling mountains annotated by the black dashed line on the map. (b) The 500 hPa geopotential height over Asia and (c) 700 hPa wind and humidity over east Asia at 00 UTC, April 14, 2025 based on ECMWF ERA5 reanalysis data.

3. Analysis of chemical species

Chemical analysis of aerosols, in particular the concentration of silicon and aluminium, has been used in previous studies to indicate the arrival of sand/dust from distant desert dust sources (e.g. Gatz and Prospero, 1996). Within Hong Kong, a number of air quality monitoring stations are set up, including an analysis of the $PM_{2.5}$ species. The results of the speciation at Mong Kok, a typical roadside station in the urban area of the territory are shown in Fig. 11 in the period 11 to April 17, 2025. From Fig. 11a, the dominant species in the period include silicon, aluminium, calcium and iron, among others. This is consistent with previous studies of the chemistry of dust from sand/dust weather (Lawrence and Neff, 2009). From the time series of the concentrations of the elements in Fig. 11b, such elements do not normally have high values on a typical day in the daytime of April 12, 2025. Their concentrations shot up rapidly at around 7–9 p.m. local time on that day, especially for silicon which ambient level is normally very low in Hong Kong. This is expected to be the time of the arrival of the sand/dust from the continent. $PM_{2.5}$ and others dust-related elements (Al, Ca, Fe, Ti, Mn) have the similar trend to silicon during the reported period (not shown) and hence supporting the arrival of dust event. Silicon remained at a rather high level of about 10 $\mu g/m^3$ on 13 and April 14, 2025, showing some diurnal variations with a maximum at about sunrise (around 6 a.m. local time) and a minimum shortly before midnight.

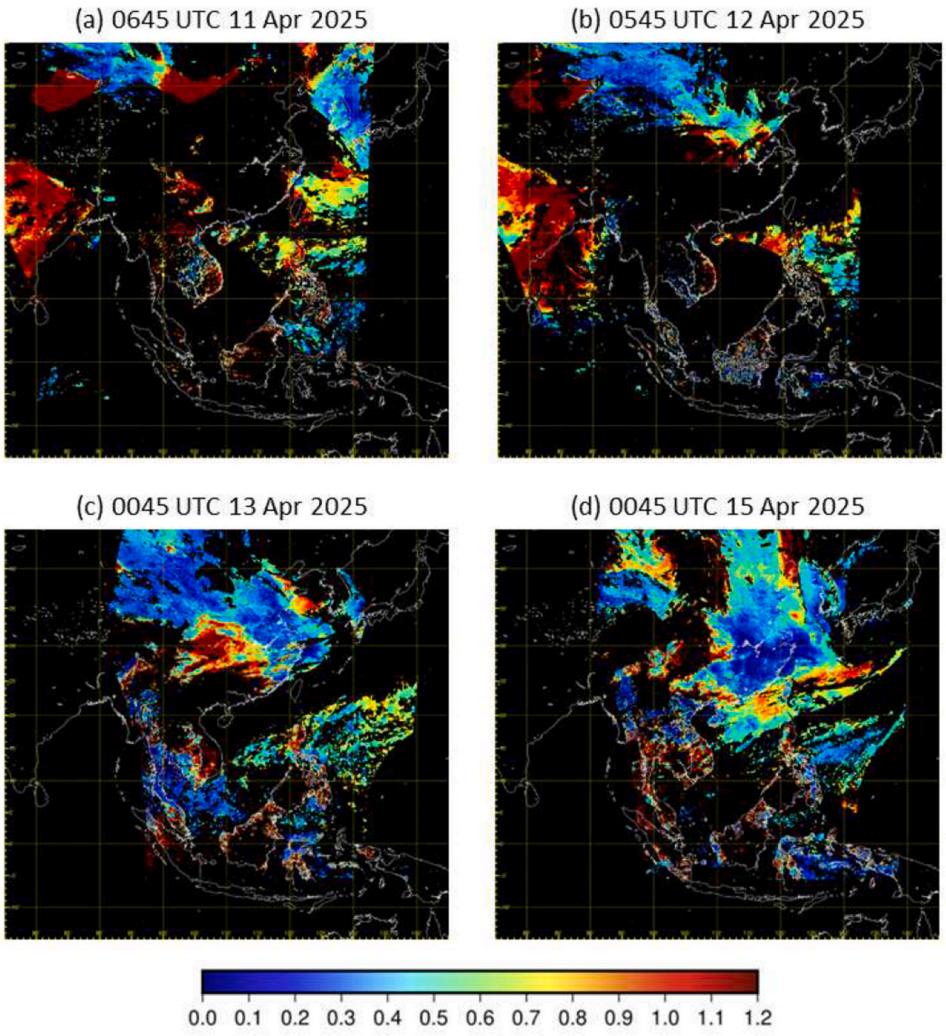


Fig. 4. The GK-2B satellite images of aerosol optical depth (AOD) at four time instances.

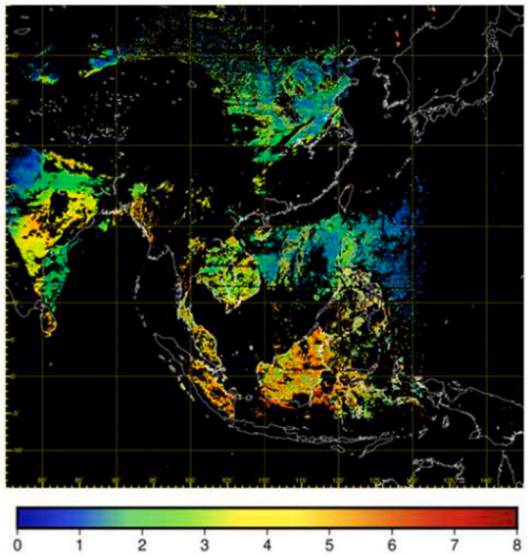


Fig. 5. The GK-2B aerosol effective height (AEH) image at 0745 UTC, April 12, 2025.

Afterwards the concentration fell gradually following the cessation of transportation from the source and local deposition. The speciation analysis of $PM_{2.5}$, coupled with meteorological data such as wind speed and direction, further confirms the occurrence of sand/dust weather affecting Hong Kong in the said period. The time of the sharp rise in silicon is generally consistent with the timing of the sharp increase of PM_{10} (Fig. 6a), thus confirming that the sharp increase of PM_{10} to an exceptionally high level itself may serve as an indicator about the potential occurrence of sand/dust weather, based on the chemical speciation analysis results.

The level of silicon in the period April to September 2025 is considered. The highest silicon level outside the reported period was around 1.6 μg/m^3 whereas the peak value recorded during the reported period was around 16.7 μg/m^3. The peak silicon level during the reported period was at least 10 times higher than the typical level, thus anomalous.

4. Forecasting aspects

The forecasting of the sand/dust weather event in southern China is studied by considering the dust concentration products available from the World Meteorological Organization (WMO) Sand and Dust Storm Warning and Assessment System (SDS-WAS) Asian Region Centre (http://www.asdf-bj.net/), namely, the ensemble product and the China Meteorological Administration (CMA) Chinese Unified Atmospheric Chemistry Environment (CUACE) model (Zhou, 2008), as well as the

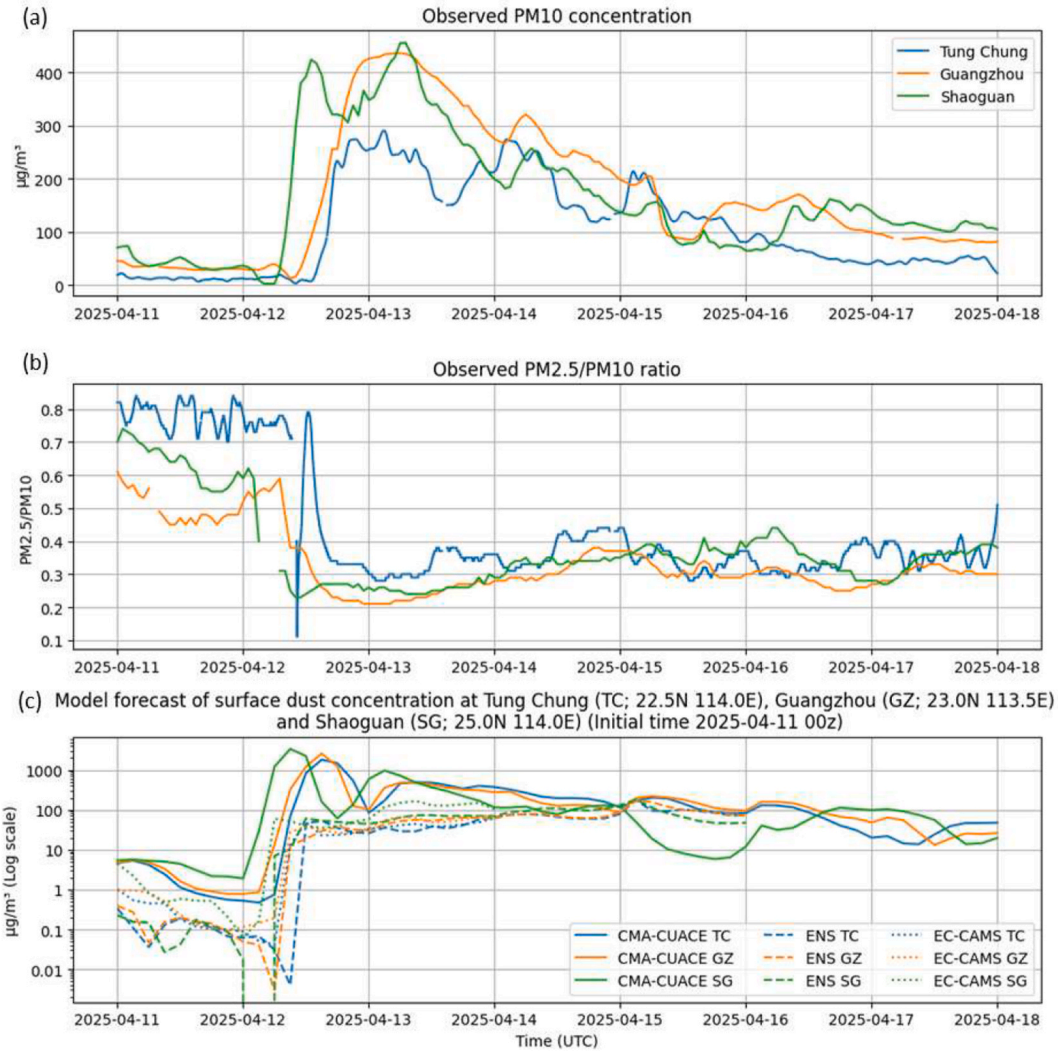


Fig. 6. The PM_{10} time series (a), $PM_{2.5}/PM_{10}$ ratio time series (b) at Tung Chung, Guangzhou and Shaoguan, as well as the time series of forecast surface dust concentration at the nearest grid points for the three sites (c). The time shown are in UTC (with local time = UTC + 8).

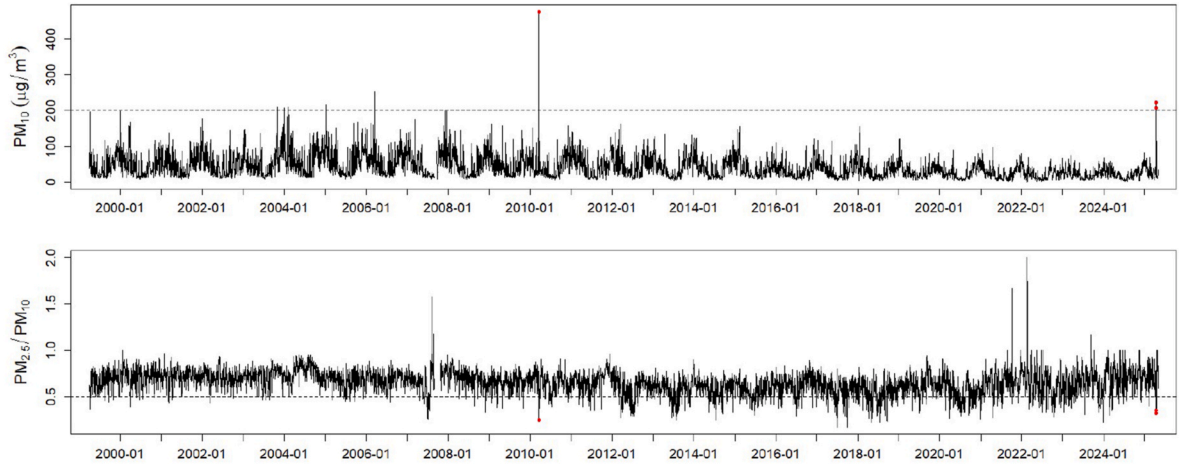


Fig. 7. Time series of (a) daily mean (calculated from midnight local time) PM10 and (b) PM at Tung Chung from April 1999 to April 2025. Days on which both the daily mean PM10 exceeded 200 μg/m^3 and the $PM_{2.5}/PM_{10}$ ratio was lower than 0.5 are highlighted by red dots.

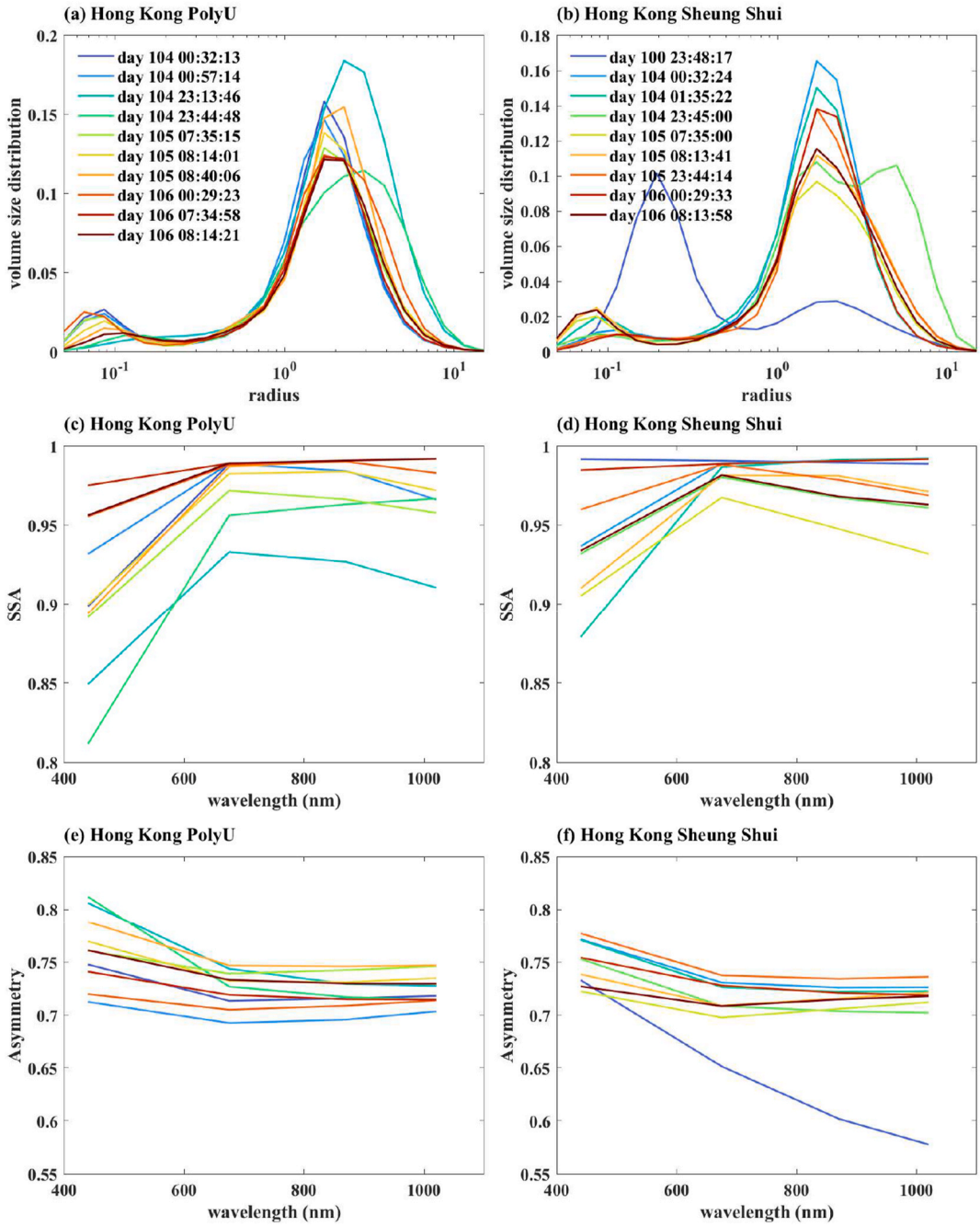


Fig. 8. (a–b) Aerosol size disribution, (c–d) Single Scattering Albedo (SSA), and (e–f) Asymmetry Factor from AERONET at the Hong Kong Polytechnic University, PolyU (first column) from day 104 (April 14, 2025) to day 106 (April 16, 2025) and Sheung Shui (second column) from day 100 (April 11, 2025) to day 106.

European Centre for Medium Range Weather Forecast (ECMWF) Copernicus Atmosphere Monitoring Service (CAMS) forecast. The results of the model run initialized at 00 UTC, April 11, 2025 are shown in Fig. 12 for the three models, including the analysis (T+0) as well as T+48 h and T+96 h forecast (where available).

It could be seen that the various models managed to forecast the spreading of the sand/dust towards southern China (Fig. 12). The forecast timing of the arrival of the sand/dust was also considered to be satisfactory, as shown in the time series of the forecast concentration at the three stations SG, GZ and TC in Fig. 6c. However, the forecast concentrations of ensemble product and ECMWF are generally less than reality, with the maximum forecast concentrations in the order of 100–200 μg/m^3. On the other hand, forecast concentrations of CMA-CUACE are much higher than reality, namely, in the order of 1000 μg/m^3, though the higher concentrations could serve as an early alert of the occurrence of sand/dust weather, but the forecast air quality turns out to be much worse than actual observations. The discrepancies between forecast and actual observations may be related to the insufficient physical representation of the process of sand/dust transport and deposition over continental China, including when the dust moves over the Nanling mountains. Potential variation in dust concentration over southern China with complex topography and urban development might also be not well represented in the models. Nevertheless, the availability of the model products this time does give an early enough alert to the

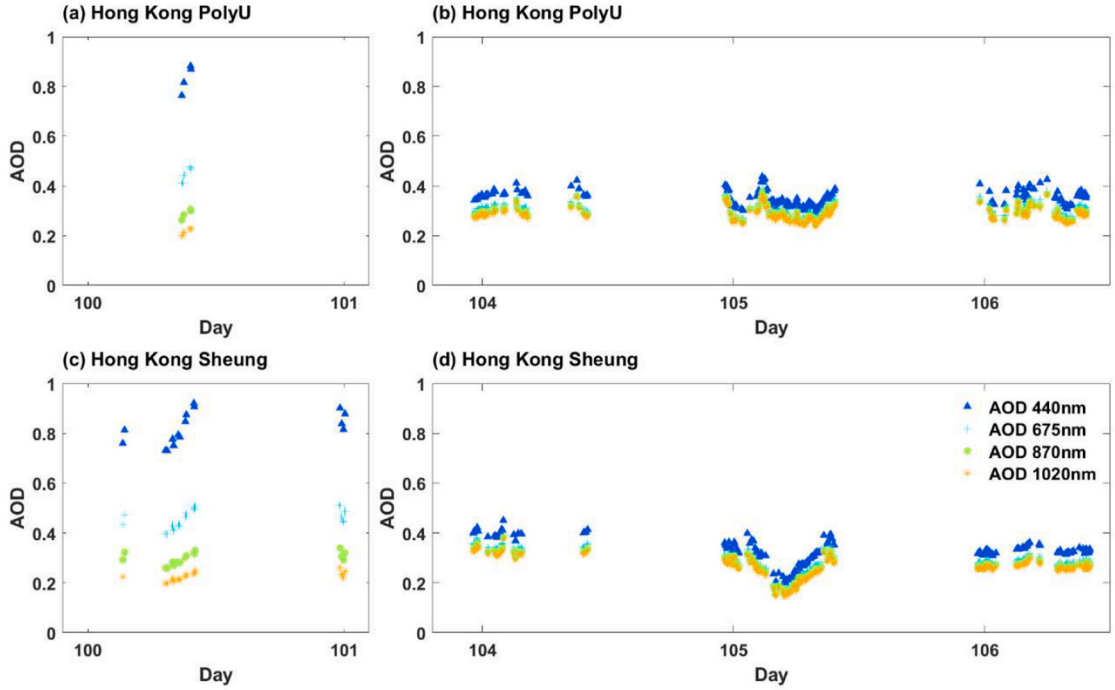


Fig. 9. Aerosol optical depth (AOD) from AERONET at the Hong Kong Polytechnic University, PolyU (a–b) Sheung Shui (c–d) from day 100 (April 10, 2025) to day 106 (April 16, 2025).

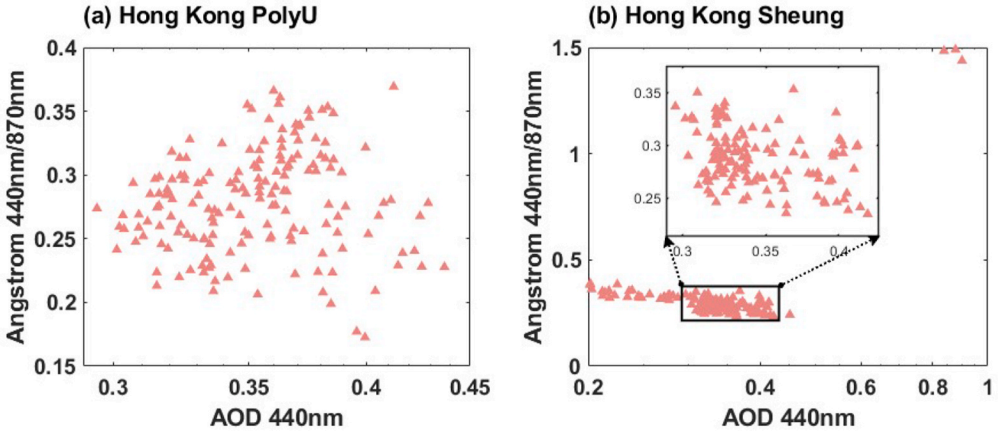
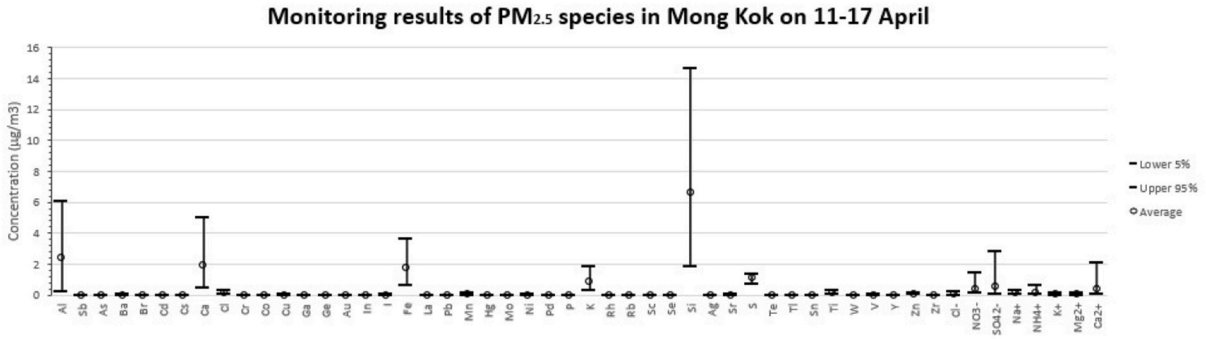


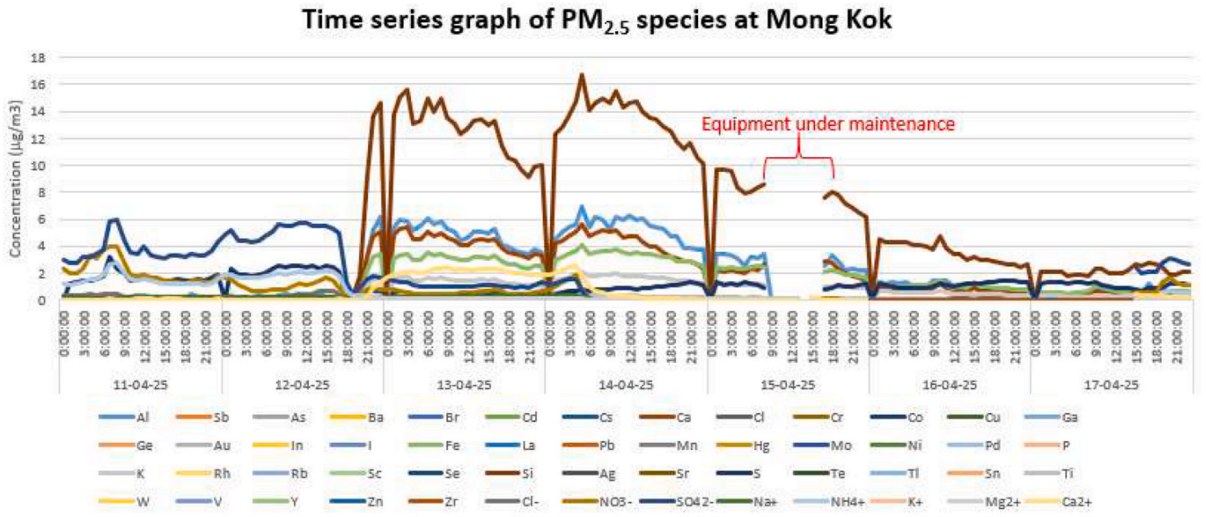
Fig. 10. The Angstrom exponent as a function of aerosol optical depth (AOD) at 440 nm from 11 to April 16, 2025 at Hong Kong Polytechnic University (a) and Sheung Shui (b).

occurrence of sand/dust weather in Pearl River Estuary, as compared to the previous event in 2010 when such products were not widely available. The trend of the decrease of sand/dust concentrations with time as forecast by the models is also consistent with actual observations from April 14, 2025 onwards (Fig. 6a).

It turns out that there may be indication of the sand/dust weather over southern China in the sub-seasonal scale. First the climatology of 850 hPa wind pattern over China in 2005–2024 is given in Fig. 13a. In this season, over southern China, a broad anticyclone would cover the region and the winds would be generally southerly. However, in the sub-seasonal (46 days) forecast of ECMWF IFS model as initialized at 00 UTC March 30, 2025, there is a significant area of negative anomaly over eastern China and East China Sea in the 500 hPa geopotential height field (Fig. 13b) in the week 7–April 13, 2025. At 850 hPa, there were anomalous strong northwesterly winds in northwestern part of China as well as anomalous northerly winds in southern China (Fig. 13c). Such patterns turn out to be correct, e.g. in the discussion of synoptic pattern above (Fig. 3) as well as the JRA3Q re-analysis (Fig. 13d and e respectively). The strong northwesterly winds over Mongolia and then northerly winds over central China helped bring the sand/dust towards the south. An implication of this analysis is that, in addition to the presence of a prominent cut-off low over northeastern China, which is known to be associated with severe SDS in northern China (Li et al., 2024; Yang et al., 2019; Yin et al., 2022), anomalously strong northerly winds at middle and lower levels of troposphere over southern China, even in late spring or early summer, may hint the potential spreading of sand/dust from the north towards the region.



(a)



(b)

Fig. 11. The distribution of components of $PM_{2.5}$ at Mong Kok in the period 11 to April 17, 2025 (a) and the time series (b). For (b), values jumping to zero mean missing data due to equipment maintenance.

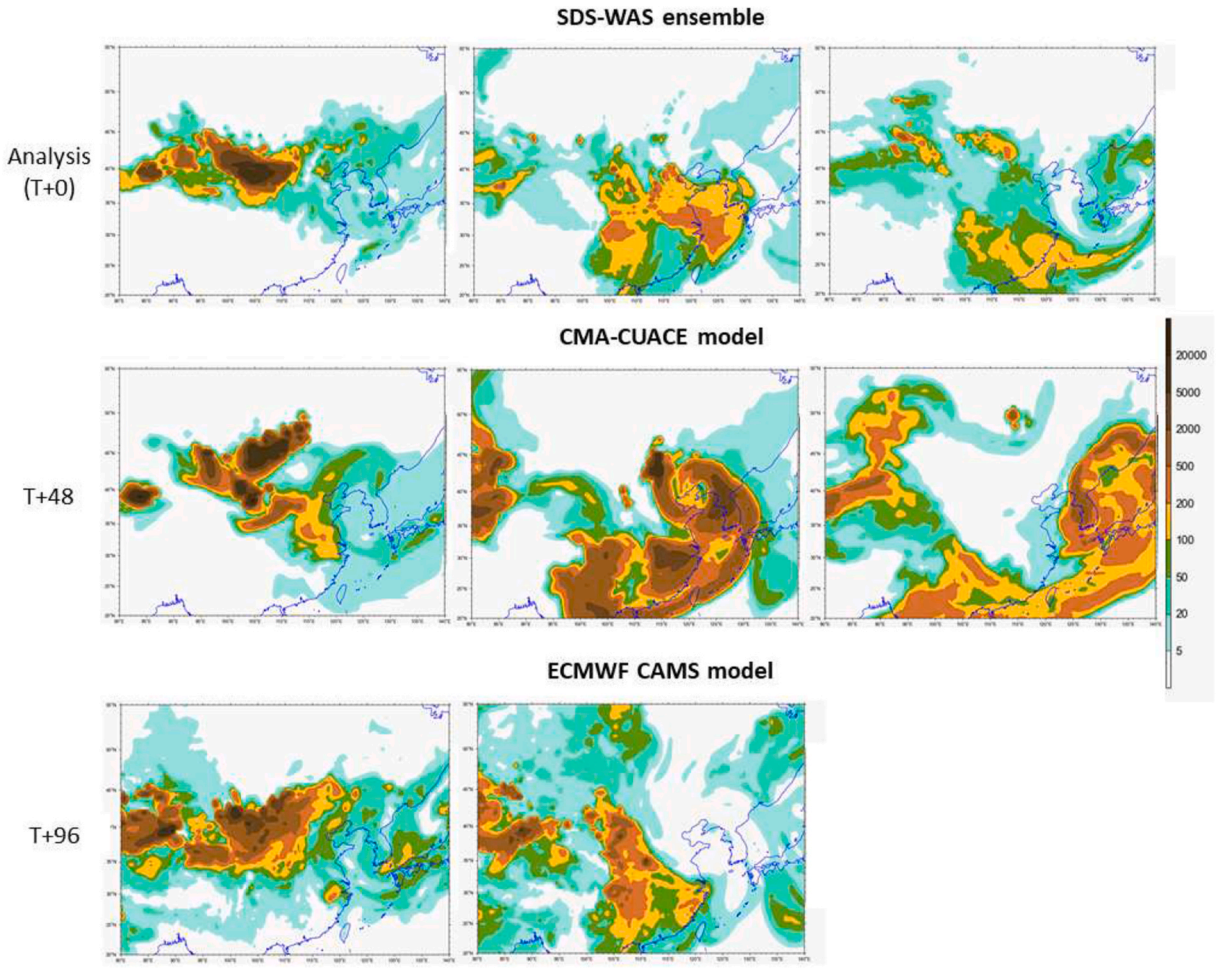


Fig. 12. The T+0, T+48 and T+96 forecast concentration outputs (μg/m^3) from three NWP models with initial time of 00UTC April 11, 2025.

5. Conclusions

Located more than 1600 km away from the nearest deserts, it is very uncommon for Hong Kong, located on the south China coast, to be affected by sand/dust weather, especially due to the barrier of Nanling mountain ranges to our north. This paper presents a very rare event of sand/dust weather in Hong Kong in April 2025, late in the spring season. Synoptically, carried by abnormally strong northwesterly winds over northwestern China and thick northerly winds over central China, sand/dust originated from Mongolia managed to climb over the Nanling mountains towards the coast of southern China. All the observational indicators, namely, particulate matter measurements, AERONET observations and chemical speciation analysis, are consistent with each other and pointing to the arrival of the sand/dust at Hong Kong.

This event was only the second known sand/dust weather event in Hong Kong supported by a range of observational evidence. While the environmental impacts of such events are considerably less severe than other parts of East Asia frequently affected by sand and dust storms, the potential impacts of sand/dust on visibility and health, as demonstrated by the elevated particulate concentration, suggest that monitoring and forecasting of sand/dust weather are still important even for Hong Kong, so that early alerts to the public about the sand/dust weather could be given. There remain challenges by global numerical weather prediction models in accurately forecasting the aerosol concentration over southern China, probably due to the insufficient understanding and representation of the related physical mechanisms, and that further work on improving such predictions is required. Nevertheless, this case demonstrated that the models could generally capture the onset and cessation of sand/dust weather in the region. The availability of aerosol concentration forecast products, together with careful analysis of synoptic patterns favourable for effective spreading of sand/dust from the north, such as the presence of a prominent cut-off low and anomalously strong northerly flows in the middle and lower atmosphere, early preparation for the potential occurrence of such uncommon events could be possible in the future.

CRediT authorship contribution statement

P.W. Chan: Writing – original draft, Formal analysis, Conceptualization. **Y.W. Chan:** Formal analysis, Data curation. **C.K. Ho:** Software, Methodology. **W.P. Tse:** Formal analysis, Data curation. **J.Q. Jin:** Formal analysis, Data curation. **M.S. Wong:** Formal analysis, Data curation. **A.K.H. Lau:** Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

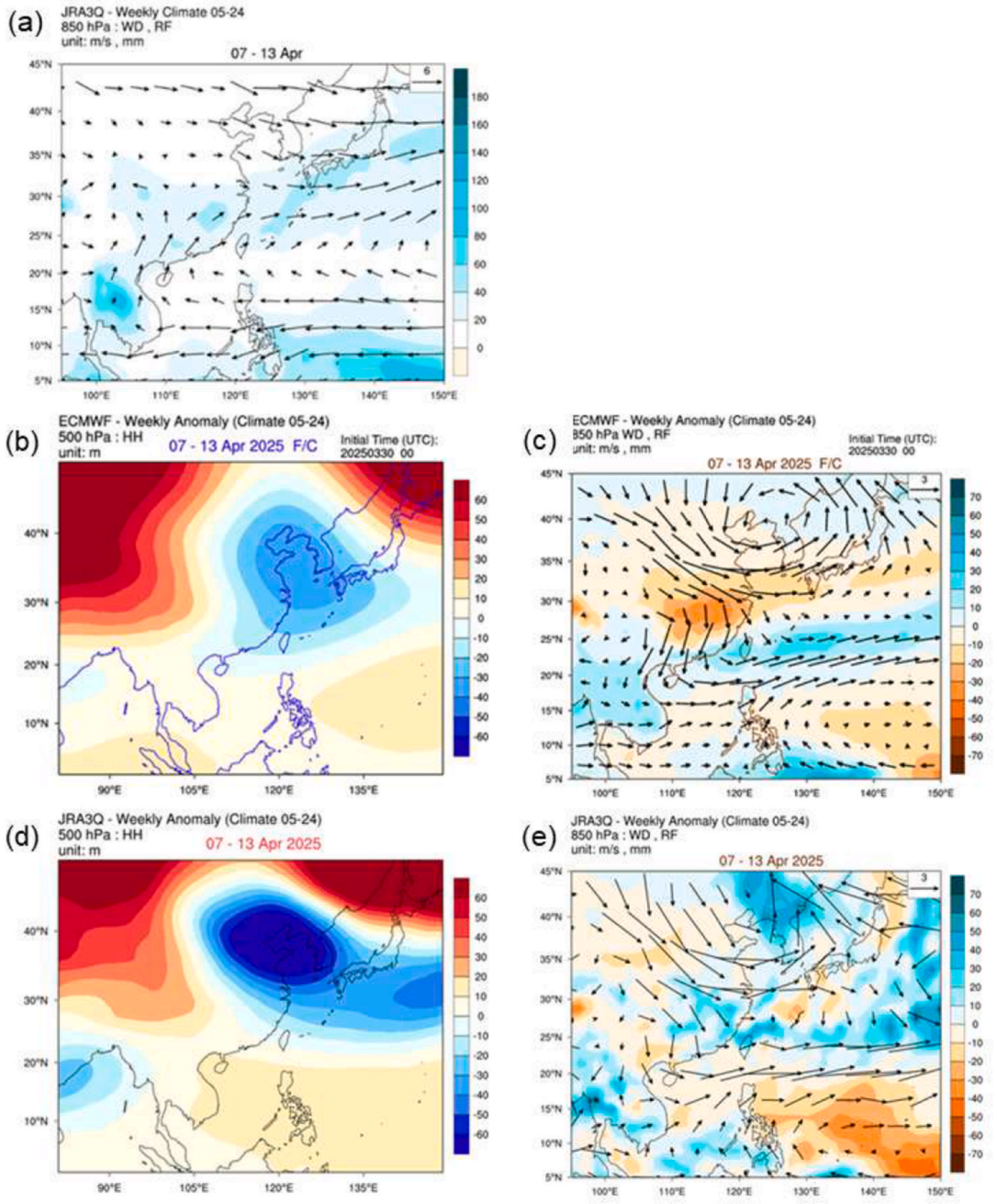


Fig. 13. The 2005–2024 850 hPa climatological wind (vector) and precipitation (contour) pattern for the period 7 to April 13, 2025 (a); the ECMWF IFS forecast for 500 hPa height anomaly and 850 hPa wind anomaly (vector) and precipitation anomaly (contour) based on 00 UTC March 30, 2025 forecast (b) and (c); and the corresponding JRA3Q re-analysis (d) and (e).

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Data availability

Data will be made available on request.

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