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Research Article

Bangkok port and coastal regions of Thailand under atmospheric PM2.5 pollution: A hypothetical nuclear power plant accident

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Abstract
The atmospheric transport pathways of 1) a hypothetical accident of aerosol at Ninh Thuan Nuclear Power Plant (NPP) in Vietnam to the coastal area of Thailand and 2) the source of PM2.5 near the area of Bangkok port were selected for case studies. The overviews of atmospheric transport patterns were analyzed using the long-term mean wind and the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model for simulating the transport pathway. The results found that the possible pathway of aerosol from Ninh Thuan NPP to coastal regions of Thailand was present over the entire year, except for the southwest monsoon month. The percentage of aerosol transport reaching the coast of Thailand is highest in the southern coastal part, found in January-April and October-December, with a maximum in January (approximately 84 %). For PM2.5 pollutants on a poor day, strongly positive and negative significant relationships with relative humidity (RH) (r = 0.44, rs = 0.46) and wind speed (r = -0.46, rs = -0.47) were found, respectively. The concentration of PM2.5 is slightly negatively correlated with wind direction. In addition, the upper air transport may bring PM2.5 pollutants from neighboring provinces or Southeast Asia to Bangkok port, Thailand, which appeared in anticyclone form in the upper atmosphere before the day which exceeded the safety level of PM2.5.

1. Introduction

Bangkok port, also called Khlong Toey port, is an international port on the Chao Phraya River in the District of Bangkok's capital. As a result, many sources of air pollution can be found in Bangkok port. These air pollution sources are ship traffic, industry, traffic, and usual sources such as household emissions (Mueller et al., 2011). Bangkok has many policies to solve the air pollution problem, such as supporting people to use public transport, controlling dust sources, and asking for cooperation from activities that generate dust, such as construction sites or truck transportation (Environment Department, 2023). Moreover, the Port Authority of Thailand (PAT), under the transport ministry, has also gradually moved over 80 % of the port's cargo activities to Laem Chabang Port in Chon Buri province over the past decade. However, air pollutant concentrations are still too high, and air quality problems persist.

In addition to emission sources, weather conducive to the accumulation of pollution is another reason to consider. Adverse weather conditions are considered one of the main reasons for Southeast Asia and Thailand's severe air pollution in recent years, as can be seen from many

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researchers who studied meteorological factors during air pollution (Amnuaylojaroen et al., 2020; Bran et al., 2022; Chao & Min, 2021; Liu et al., 2020; Ma et al., 2022; Qi et al., 2021; Wang & Li, 2022). These researchers found that most air pollution and meteorological factors have prominent seasonal and regional characteristics. There are complex and changeable atmospheric pollutants with meteorological factors that affect air quality. Therefore, the different meteorological factors have different effects on the concentration of the same pollutant, while the same meteorological conditions have different effects on the concentration of different pollutants. However, wind speed is generally considered to be a significant factor affecting the concentration of air pollutants in meteorological conditions.

Assume that, each day, Bangkok has the same pollutant emissions. Therefore, part of the exceeding air pollution problem comes from unfavorable meteorological conditions, or may be caused by regional transport, such as biomass burning and forest fires (Punsompong et al., 2021; Reid et al., 2013). Wind can move air pollution away from its source, locally and globally, and accounts for historical patterns of air pollution disparities according to prevailing wind patterns. Therefore, the primary purpose of this study is to examine possible atmospheric patterns that can transport pollutants to Bangkok port and the coastal area of Thailand by analyzing wind patterns. There are 2 cases studies, 1) an analysis of the wind pattern and other meteorology factors while exceeding the safety level of PM2.5 over Bangkok port, and 2) an analysis of the possible transport pathway from an accident at Ninh Thuan NPP in the south-central coast region of Vietnam to Bangkok port and the coastal regions of Thailand.

2. Data and methods

2.1 Data analysis

Atmospheric Research (NCEP/NCAR) Reanalysis was analyzed using the long-term mean wind (from 1984 to 2013) to understand the atmospheric transport pattern. The long-term mean wind (*ltm*) is calculated as follows;

$$ltm = \frac{1}{n}\sum_{i=1}^{n} x_i \tag{1}$$

where x is the surface wind at time i and n is the number of times. The standard deviation (*sd*) is also used to quantify the variation or dispersion of radioactive substances from the surface wind data. The standard deviation is expressed as follows;

$$sd = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(x_i - \overline{x}\right)^2} \tag{2}$$

Meteorological data from the pollution control department (PCD) station near Bangkok port in Thailand were analyzed using Pearson’s and Spearman’s correlations. Pearson’s correlation measures the strength of a linear relationship between PM2.5 and meteorological factors, and Spearman measures the non-linear correlation.
Pearson’s correlation coefficient is as follows:

$$r = \frac{\sum_{i=1}^{n}\left(x_i y_i - n\overline{xy}\right)}{\left(n-1\right)s_x s_y} \tag{3}$$

where

$$s_x = \sqrt{\frac{1}{(n-1)}\sum_{i=1}^{n}(x_i - \bar{x})^2} \tag{4}$$

$$s_y = \sqrt{\frac{1}{(n-1)}\sum_{i=1}^{n}(y_i - \bar{y})^2} \tag{5}$$

The range of relationships can be anywhere between −1 and +1. A correlation coefficient of −1 or +1 indicates a perfect linear relationship, and a correlation coefficient of zero indicates that no linear relationship exists between two continuous variables. If the value is close to ± 1, it is a perfect correlation. As one variable increases, the other tends to increase (if positive) or decrease (if negative).

If there are no tied ranks, then the formula for the Spearman correlation is as follows (McAleer, 2022) .

$$r_s = 1 - \frac{6\sum d_i^2}{n(n-1)^2} \tag{6}$$

where d_i is the difference between the two ranks of the dataset, and n is the number of datasets.

If there are tied ranks, then the formula for the Spearman correlation is as follows.

$$r_s = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2 (y_i - \bar{y})^2}} \tag{7}$$

Guidelines are used to interpret the correlation magnitude, as well as to estimate power. Specifically, r = 0.10, r = 0.30, and r = 0.50 were recommended to be considered small, medium, and significant in magnitude, respectively (McAleer, 2022).

2.2 HYSPLIT model and configuration

The HYSPLIT model, from National Oceanic and Atmospheric Administration Air Resources Laboratory (NOAA-ARL), is a Lagrangian particle and puff model which simulates simple air parcel trajectories to complex dispersion (NOAA-ARL, 2022). This model has been one of the most widely used to study pollutant transport and dispersion simulations (Athar & Faghihi, 2019; Long et al., 2012; Pirouzmand et al., 2018; Skrynyk et al., 2019; Stein et al., 2015; Zali et al., 2017). These researches show that the HYSPLIT model can calculate the airflow and transport of pollutant patterns over spatial and temporal ranges. However, the model results' accuracy depends mostly on adequate spatial and temporal meteorological data input.

In this study, the HYSPLIT trajectory model is used to simulate the air pollution pathway. The meteorological datasets used to drive the HYSPLIT model were archived from the Global Data Assimilation System (GDAS) with a 1-degree horizontal resolution, 23 vertical levels of pressure coordinates, and a temporal resolution of 3 hours. The results from HYSPLIT were used to identify the pollution pathway from the south-central coast region of Vietnam to the coastal area of Thailand and the source locations of the PM2.5 pollutants in the area of Bangkok port.

2.2.1 Case study

Two cases were run; one HYSPLIT forward trajectory run for the south central coast region of Vietnam, and one HYSPLIT backward trajectory run to identify the source locations of the PM2.5 pollutants that fell within the backward trajectory.

Case 1: HYSPLIT forward trajectory runs to generate the atmospheric transport pathways of pollutants from the south-central coast region of Vietnam. The results show the probability of pollutant transport from Vietnam reaching the coastal area of Thailand.

The emission source over the south-central coast region of Vietnam was selected for this study because Vietnam planned to build its first NPP. The construction was to begin in 2017-2018, in partnership with Russia. However, the government canceled the project in November 2016 due to slowing demand forecasts for electricity and the declining price of other energy sources (APERC, 2017). Although this plant has finally been withdrawn, the government of Vietnam might push the construction back to the future, as can be seen from Vietnam's National Assembly Economic Committee, who proposed that the government should remain committed to plans for two NPPs in the Ninh Thuan province, instead of scrapping the project, for the sake of its future development potential (Appleyard, 2022).

The radioactive materials released from NPP are principal risks to human health. Although there is great concern about the safety of the technology of the NPP reactor in controlling radioactive materials, the best technology can not completely eliminate all NPP accidents. The Fukushima Daiiachi NPP accident that occurred after an earthquake and tsunami in 2011 resulted in a large radionuclide released, which was transported across the Pacific Ocean to the North American continent and to Europe and Central Asia (Draxler et al., 2015; Kim et al., 2012; Lee et al., 2015; Leelőssy et al., 2011; Steinhauser et al., 2014). This accident showed clearly that the radioactive substance can spread from continent to continent, resulting in an environmental impact not only near the NPP site but all over the world, especially among neighboring countries.

The model setup for this case is based on the Fukushima Daiichi NPP accident. In the Fukushima Daiichi NPP accident, most released radioactive substances were volatile radionuclides (noble gases, iodine, cesium, and tellurium) (Steinhauser et al., 2014). Iodine 131 (I-131) was one of the released substances from Fukushima Daiichi NPP and can be accumulated in the thyroid gland for a few weeks and causes thyroid cancer. Therefore, to analyze the possible transport pathway when an accident in Ninh Thuan NPP occurs, the pollutants or radionuclides are assumed to be released from Ninh Thuan NPP with no deposition, as in the worst case, and the model runs through 2011 to generate forward trajectories calculated for 8-day or 192-hour following the half-life of I-131 with a level of 100m above the Ninh Thuan NPP site (Latitude:11.413333°N., Longitude: 108.974722°E.). According to this study, run in a worst case, a strong wind, La Nina, was found for the year 2011. So, the year 2011 was selected for calculating the pathway in the HYSPLIT model. The forward trajectory starting time was every 6 hours (00, 06, 12, 18UTC) (4 trajectories run per day) run. The number of trajectory runs each month are as shown in **Table 1**.

Table 1 Summary of the numbers of trajectory runs.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Trajectory runs (times)	124	112	124	120	124	120	124	124	120	124	120	124

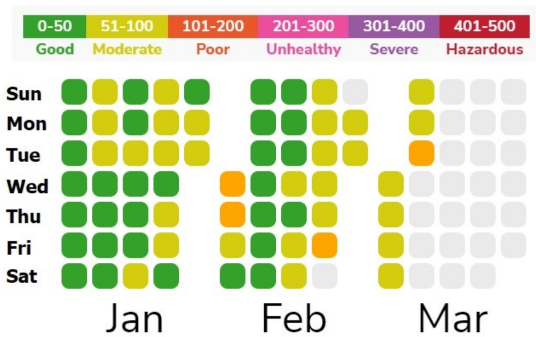


Figure 1 Bangkok PM2.5 Calendar 2023 (AQI, 2023).

Case 2: HYSPLIT backward trajectory was run on 7 March 2023 to identify the source locations of the pollutants in the area of Bangkok port that falls within the backward trajectory. In addition, this case evaluated possible long-range source contributions to the PM2.5 profile of Bangkok port, Thailand.

Currently, the Thailand ambient air quality standard for PM2.5 is not exceeding 50 micrograms per cubic meter of air (µg/m3) for a 24-hour average. Generally, the PM2.5 concentration in Bangkok is the worst-hit season in the winter, especially from January to April (Amnuaylojaroen et al., 2020). As in **Figure 1**, the PM2.5 air pollution in Bangkok was 33 days above the recommended limit of Thailand, and four days at a poor level (1-2 February, 24 February, and 7 March). Therefore, the meteorological factor from 1 February to 8 March 2023 was analyzed using statistical methods. Moreover, the PM2.5 concentration peak on 7 March 2023 was selected for this study. Due to this period, a PM2.5 concentration exceeded the safety level at a poor level and was also found at a poor level in Laos and Cambodia. When considering PM2.5 concentration on 2-8 March near Bangkok port in **Figure 2(a)**, the PM2.5 on 2 March and 4-8 Mar 2023 exceeded the safety level. The maximum PM2.5 concentration on 7 March 2023 was found at Bangkok port and around Bangkok. Hourly PM2.5 concentration peaks were in the early morning, especially at 07:00-08:00 UTC (129 µg/m3). To analyze the possible sources of PM2.5 near Bangkok port during this period, the HYSPLIT backward trajectory model was used. The model was set with starting time of 00:00UTC 4 March 2023 and ended at 00:00UTC 7 March 2023 at Bangkok port.

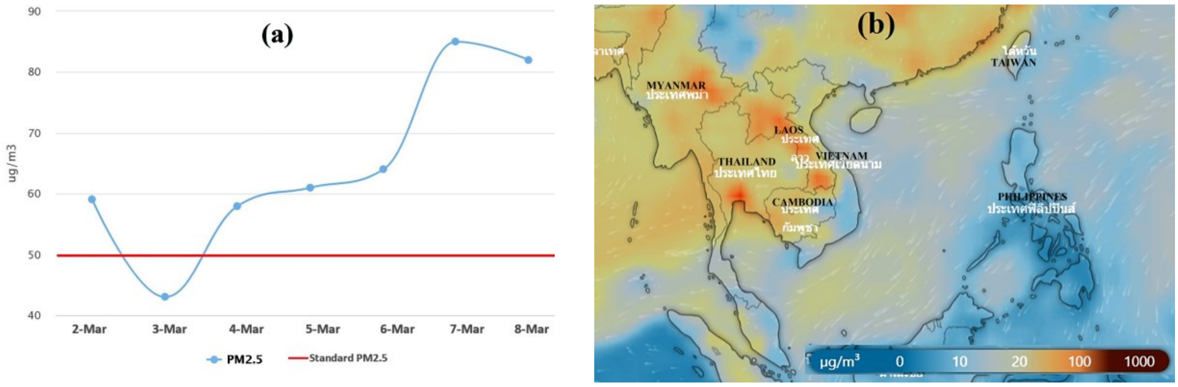


Figure 2 PM2.5 concentration (a) from PCD (2013-2022) measurements in the area of Bangkok port District Office during 2-8 Mar 2023 and (b) from CAMS Model (OpenStreetMap, 20) on 7 Mar 2023 at 00:00 UTC.

3. Result and discussion

3.1. Long-term mean wind analysis

The atmospheric transportation of the pollutant from any source to Thailand strongly depends on the meteorological conditions. Primarily, wind speed and direction significantly affect the arrival time and direction of the released emission path after release from the source. Therefore, the meteorological wind data was first analyzed using the long-term mean surface wind.

When considering the wind direction over the South China Sea based on long-term monthly mean wind characteristics from the NCEP/NCAR reanalysis (1984 - 2013), as shown in **Figure 3**, it can be categorized into three patterns: southwest wind, northeast wind, and weak wind. The standard deviation was used to quantify the variation of surface wind data, as shown in **Figure 4**.

Southwest wind over Ninh Thuan NPP appears during the southwest monsoon from June to September. By June through August, the prevailing southwest wind blows over the Ninh Thuan NPP with a wind speed of approximately 4-7 m/s, the South China Sea, and China, resulting in pollution transport from the Ninh Thuan NPP to the South China Sea and toward China. In September, the northeast monsoon starts over China, weakening the southwest wind over Ninh

Thuan NPP. Therefore, it is probable that the pollutants are transported from the Ninh Thuan NPP to the upper part of Vietnam and turn toward to the northern or northeast parts of Thailand.

The northeast wind over Ninh Thuan NPP appears from January to March and November-December. From November to December, there is a prevailing northeast wind over Ninh Thuan NPP and the Gulf of Thailand. Therefore, it is probable that the air pollution is transported from the Ninh Thuan NPP to the Gulf of Thailand and toward the lower southern part of Thailand. From January to March, a northeast wind blows over Ninh Thuan NPP, and an east to south wind blows over the Gulf of Thailand, causing air pollution transport from the Ninh Thuan NPP to the central-upper southern part, central Thailand, and the eastern part of Thailand.

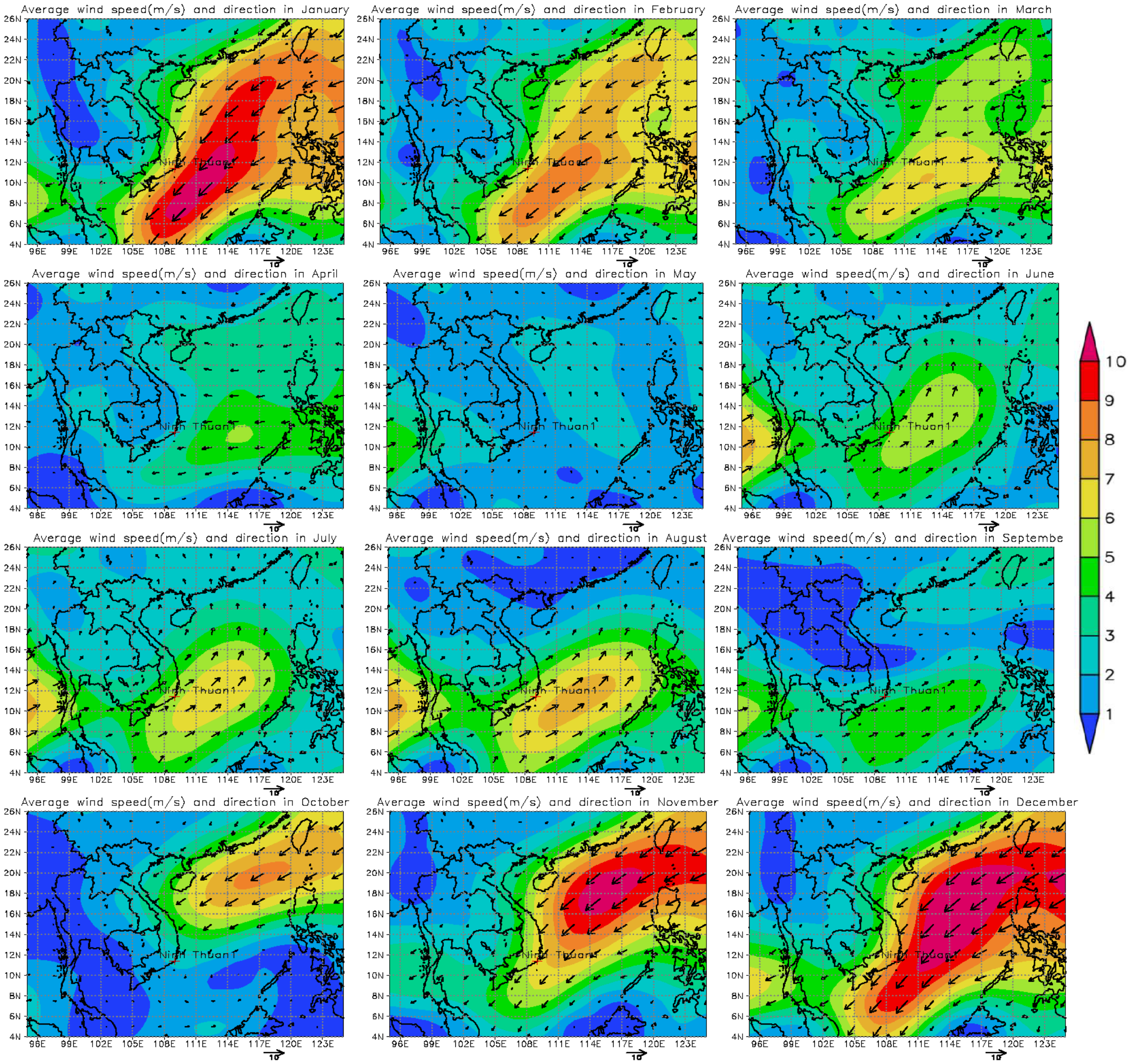


Figure 3 Long-term monthly mean wind.

The weak wind over Ninh Thuan NPP appears in April, May, and October at a wind speed of less than 3m/s. Therefore, uncertainty in the radionuclides transport pattern occurs in these months due to weak winds and uncertain wind direction.

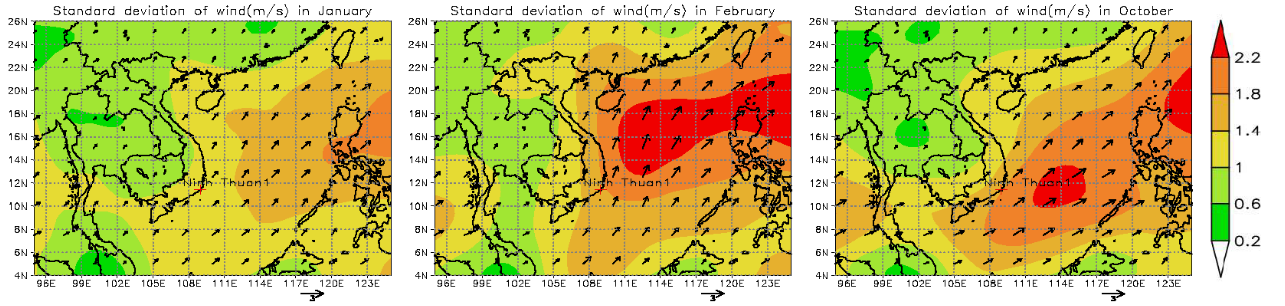


Figure 4 Example of standard deviation of monthly wind in January, February, and October.

3.2 Model result

3.2.1 Forward trajectory

The HYSPLIT trajectory model was used to calculate atmospheric transport using meteorological wind data from the Global Data Assimilation System (GDAS) to understand the possible pathway of 192 hour forward trajectories of aerosol from the Ninh Thuan NPP accident.

The results show that the probability of aerosol reaching the boundary of Thailand is different depending on month. For example, as can be seen from **Table 2**, if an accident occurs in the Ninh Thuan NPP site from January to April and October to December, the region of Thailand that has the highest risk from the release of radionuclides is southern Thailand.

Table 2 Summary of the radionuclide transport from the Ninh Thuan NPP reaching the boundary of Thailand.

		Month											
Statistical	**Region**	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Min. arrival time (hrs.)	N	-	-	-	-	-	84	-	78	84	-	-	-
	NE	-	72	42	60	66	-	162	78	63	114	84	-
	C	-	-	72	-	-	-	-	-	-	-	-	-
	E	-	42	36	49	-	-	-	-	-	30	-	-
	S	24	45	30	42	-	-	-	-	-	24	24	24
Min. arrival time (hrs.)	N	-	-	-	-	-	120	-	180	174	-	-	-
	NE	-	120	60	180	84	-	174	180	192	174	138	-
	C	-	-	96	-	-	-	-	-	-	-	-	-
	E	-	144	72	144	-	-	-	-	-	42	-	-
	S	120	153	186	144	-	-	-	-	-	54	150	84
Trajectory reaching (%)	N	0	0	0	0	0	3.3	0	4.5	8.3	0	0	0
	NE	0	4.5	3.5	15	9.7	0	2.4	5.2	30.8	23.4	0.8	0
	C	0	0	4.4	0	0	0	0	0	0	0	0	0
	E	0	8.9	21.9	30	0	0	0	0	0	7.3	0	0
	S	83.9	75.9	62.3	42.5	0	0	0	0	0	52.4	62.2	66.9

Figure 5 shows some results from the HYSPLIT simulations started at a) 18UTC 10 Jun 2011, b) 18UTC 8 April 2011, c) 00UTC 1 July 2011, and d) 18UTC 2 September 2011. The model was set up to simulate the trajectory of a radionuclide every 6 h with 192 hours forward in time to see the possible partway in 2011. Among trajectory simulations of radionuclide transportation, a plot of the possible pathway of radionuclide transport from the Ninh Thuan NPP accident site to Thailand can be categorized into four patterns: 1) Ninh Thuan NPP- South China sea-Gulf of Thailand and reaches the southern part; 2) Ninh Thuan NPP- South China sea-Gulf of Thailand and reaches the central or eastern parts; 3) Ninh Thuan NPP- South China sea-northern part of Vietnam-

Laos and reaches the northeastern part of Thailand, and 4) no trajectory reaching to Thailand. **Figure 5** shows some results from the HYSPLIT simulations represented in each pattern.

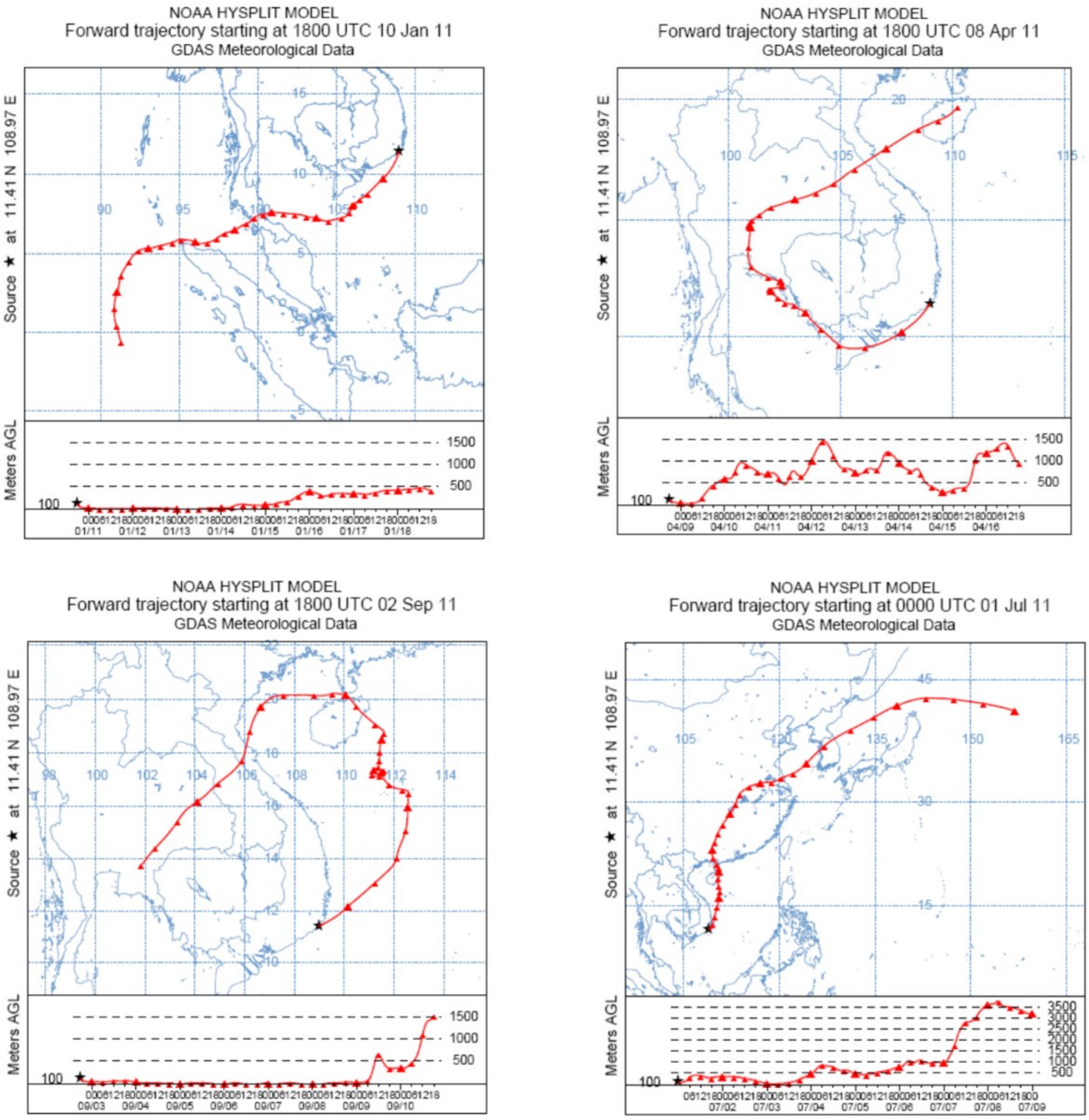


Figure 5 Forward trajectory released at height of 100m from the Ninh Thuan NPP starting at a) 18:00UTC 10 January, b) 18:00UTC 08 April, c) 00:00UTC 01 July, and d) 18:00UTC 02 September 2011, by the HYSPLIT model.

3.2.2 Backward trajectory

Meteorological data analysis

The meteorological factors of PM2.5 pollutants near Bangkok port from 1 February to 8 March 2023 were selected for analysis by Pearson's and Spearman's correlations. This study used hourly meteorological data at the Bangna monitoring station of PCD, including wind speed, wind direction, and surface temperature, compared with hourly PM2.5 concentration, as shown in **Table 3**. These results show that PM2.5 was negatively correlated with wind speed ($r = rs = -0.52$) and RH ($r = -0.31$; $rs = -0.37$). In addition, the concentration of PM2.5 was slightly correlated with wind direction and air temperature. Nevertheless, when correlation coefficients between hourly PM2.5 and meteorological factors ranged on a poor day, as in **Table 4**, the temperature correlated strongly negatively with PM2.5.

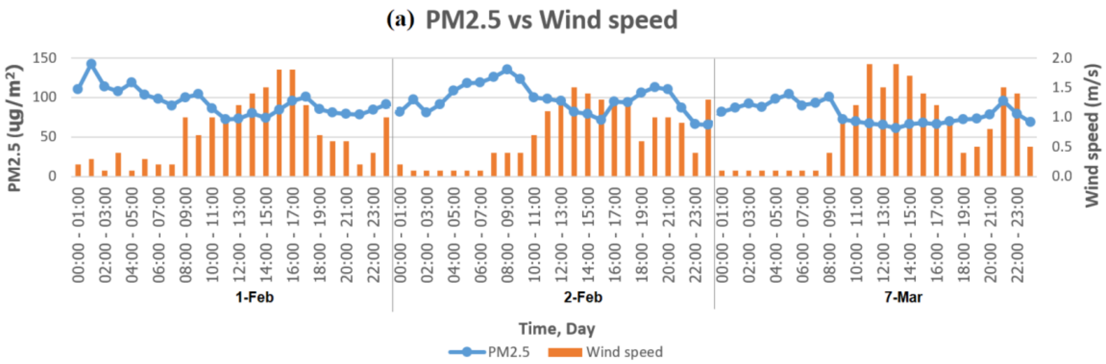
The relationship between meteorological factors (wind speed, wind direction, and air temperature) and the concentration of PM2.5 on 1-2 February and 7 March 2023, on the days of PM2.5 concentration exceeding safety standards at a poor level, was considered, as shown in **Figure 6**. On a poor day level of PM2.5, PM2.5 had a positive correlation with RH, so when the relative humidity increased/decreased, PM2.5 concentration increased/decreased. The RH near Bangkok port was about 30 to 100 % on a poor day. Considering the negative correlation between PM2.5 pollutants and surface wind speed, the PM2.5 concentration levels increased (decreased) when the surface wind speed decreased (increased). The wind was lower than 2 m/s on these poor days.

Table 3 Correlation coefficients between hourly PM2.5 and meteorological data near Bangkok port from 1 February to 8 March 2023.

	PM2.5 vs			
	Wind speed	Wind direction	Temperature	RH
R	-0.52	0.004	-0.18	-0.31
R_s	-0.52	-0.11	-0.15	-0.37

Table 4 Correlation coefficients between hourly PM2.5 and meteorological data near Bangkok port during PM2.5 on poor day, 1-2 February and 7 March 2023.

	PM2.5 vs			
	Wind speed	Wind direction	Temperature	RH
R	-0.46	-0.08	-0.52	0.44
R_s	-0.47	-0.09	-0.54	0.46



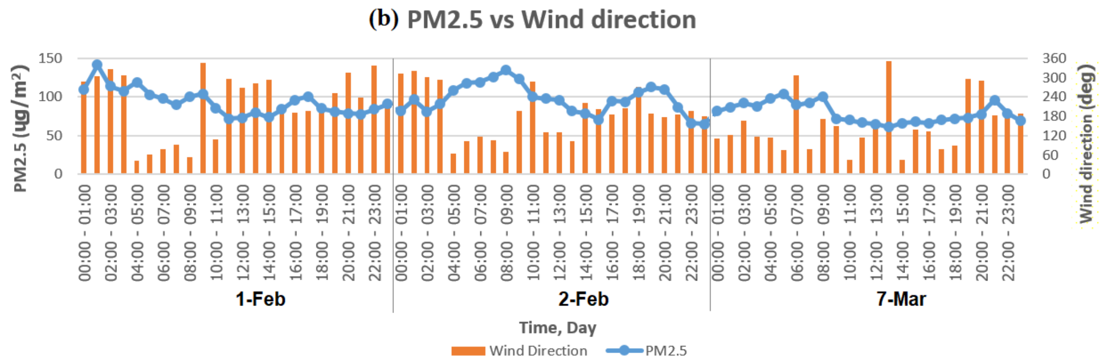


Figure 6 Relationship between hourly (a) PM2.5 and wind speed, (b) PM2.5 and wind direction, (c) PM2.5 and surface air temperature, and (d) PM2.5 and RH.

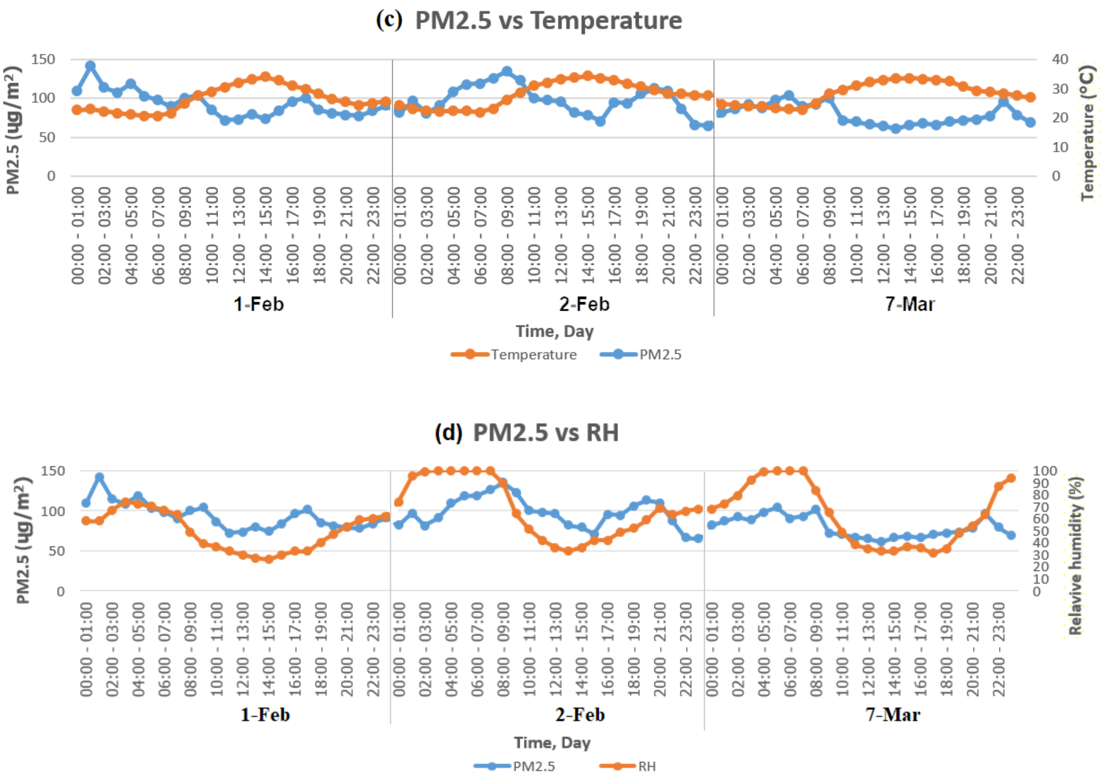


Figure 6 (continued) Relationship between hourly (a) PM2.5 and wind speed, (b) PM2.5 and wind direction, (c) PM2.5 and surface air temperature, and (d) PM2.5 and RH.

Based on the assumption that if the amounts of pollution released from each location in the Bangkok area were the same daily, some excess pollution would likely come from adverse weather conditions. In general, wind can be helpful in the dispersion of pollutants. When pollutants are released and collected over Bangkok port, wind may disperse pollutants out of the area and reduce concentrations of PM2.5. Moreover, the movement of wind by the upper air transport may bring pollutants from neighboring provinces or Southeast Asia to Bangkok port, Thailand. Research shows that, when there is a significant source of pollutants high above the surface, upper-level winds can help transport it large distances (Nguyen et al., 2022; Reid et al., 2013; Wylie, 2021). Therefore, as a source of long-term pollution, such as biomass burning, the strong upper air wind may bring pollutants from neighboring provinces or Southeast Asia to Bangkok port.

This study also analyzed the wind map at the upper level of the Meteorological Department during the study period. As a result, wind at the upper air level of 925 and 850 hPa over Bangkok port, the lower atmosphere, mostly appears as the northeast wind to east wind, which moves the air system from Vietnam, Cambodia to Thailand, and Bangkok Port. Meanwhile, the mid-level atmosphere, 700 and 500 hPa, over Bangkok port, wind appears predominantly as northwesterly to easterly winds. Therefore, PM2.5 pollutants in the low atmosphere level (850 and 925 hPa) can be transported from the northeast to Bangkok port along the direction of the wind. In the mid-level atmosphere, PM2.5 pollutants are mainly transported from the northwest and the northeast.

The upper wind patterns during the high pollution exceeded the standard during the study period, as shown in **Figure 7**. It can see that the upper atmosphere at levels 500, 700, and 850hPa at 12:00 UTC on 6 March 2023 appears the anticyclonic wind. The anticyclone center, which air circulates clockwise in the Northern Hemisphere, was found in the South China Sea near the coast of Vietnam and Northeastern Thailand near the border with Cambodia and Cambodia, respectively. It is likely to be the main factor in the dispersion of PM2.5 pollutants, and a wind speed of about 15 knots, or about 28 km/s, around an anticyclone was found. The displacement distance from the center of the north anticyclone of Cambodia to Bangkok Port is about 370 kilometers. This means that, if the pollution moves along the displacement distance at a speed of 28km/s, it will take about 13 hours to arrive at Bangkok port, likely arriving in Bangkok in the morning on 7 March 2023, which corresponds to the maximum PM2.5 concentration in the morning at 00:00-01:00 UTC on 7 March 2023.

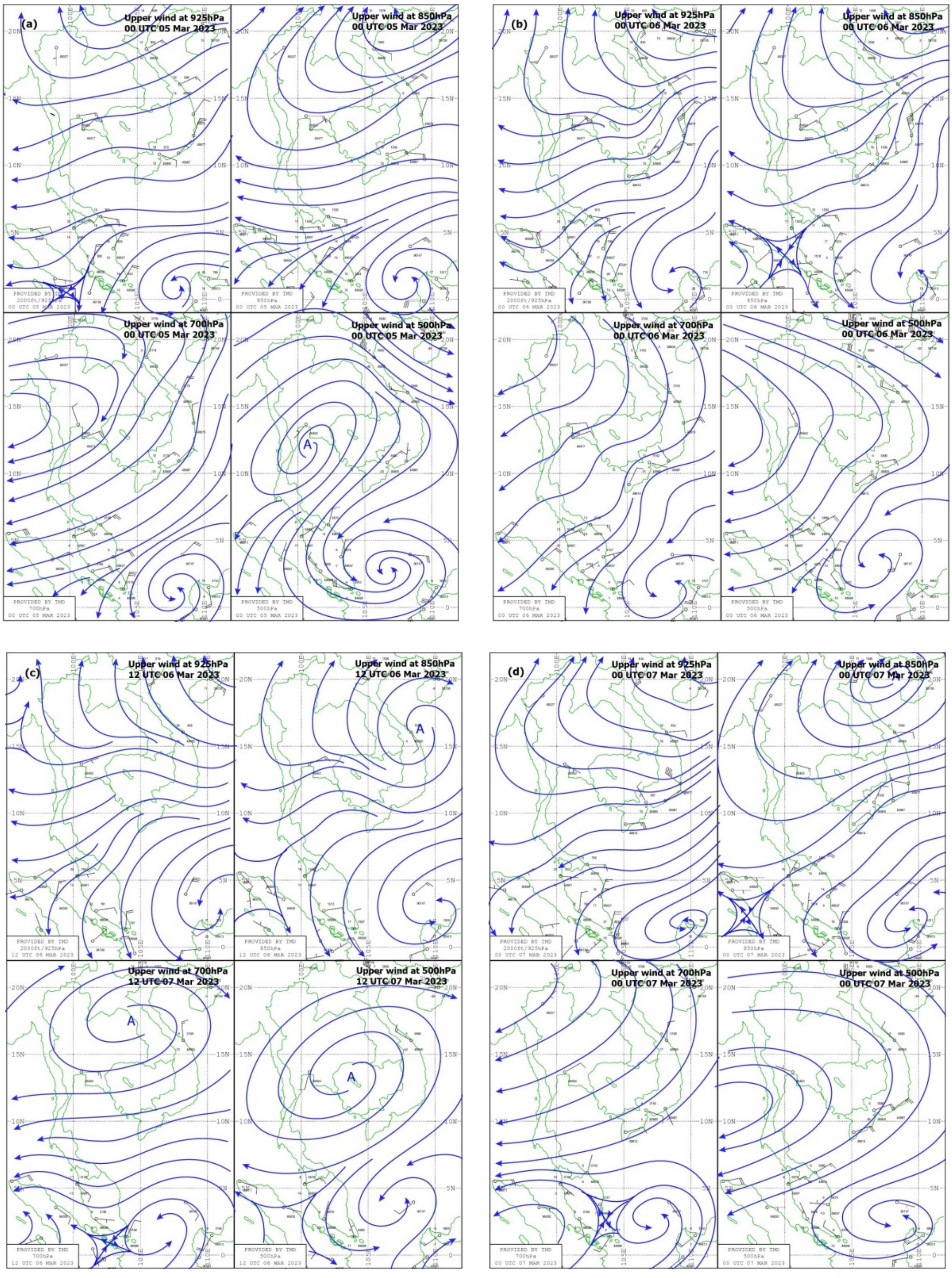


Figure 7 Upper wind at levels 950, 850, 700, and 500 hPa on (a) 00:00 UTC 5 March, (b) 00:00 UTC 6 March, (c) 12:00 UTC 6 March, and (d) 00:00 UTC 7 March 2023 (TMD, 2023).

Backward trajectory

The HYSPLIT backward model was used to calculate, in this case, from 4 March to 7 March 2023, to determine the transport of particulate air parcels. The backward trajectories started above the location of Bangkok port at altitudes 100, 500, 1,000, and 1,500 m above ground level. The backward trajectory map in **Figure 8** mainly shows the air mass that reached Bangkok port, Thailand, which originated in the northeast. The atmospheric transport path from the HYSPLIT model corresponds to the level wind map (**Figure 7**). At 100 m above ground, the airflow from the northeast is likely to bring some pollutants from Cambodia, Vietnam, and Laos to Bangkok port, Thailand. Biomass burning is one source of PM2.5 concentration. When considering the biomass burning situation in this region by using fire hotspot data from NOAA satellites during the last 7 days, 28 February to 6 March 2023, fire hotspot locations in Southeast Asia were abundant in Cambodia, Laos, and some areas in Vietnam, as shown in **Figure 9**. The results of the HYSPLIT backward model with fire hotspot data agreed on consistency. However, the airflow at 500, 1,000, and 1,500 m from Myanmar also dominated some PM2.5 pollutant emission sources to Bangkok port, Thailand.

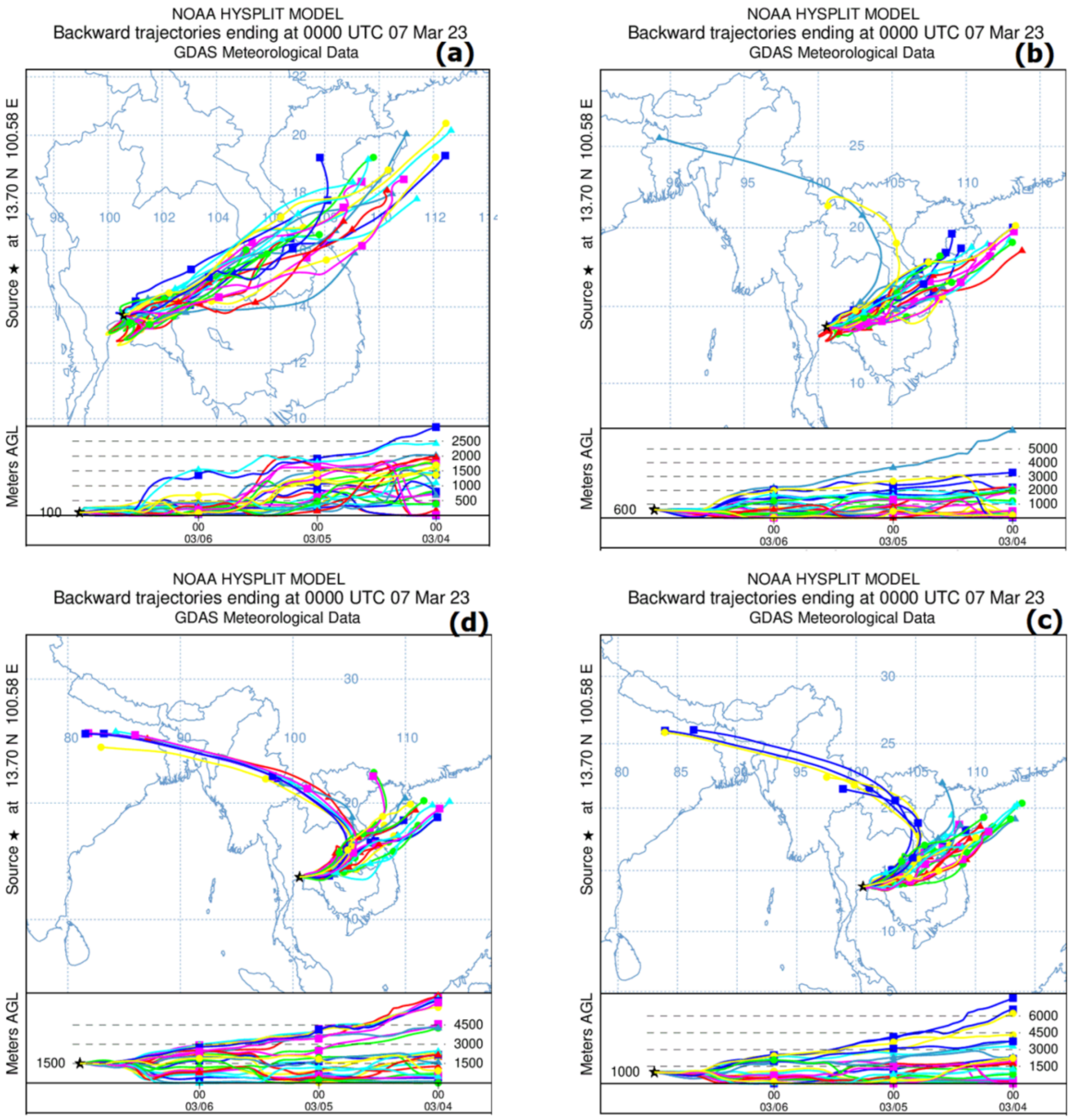


Figure 8 HYSPLIT backward ensemble table (a) 100 m, (b) 500 m, (c) 1,000 m, and (d) 1,500 m, beginning at 00:00UTC 4 March 2023 and ending at 00:00UTC 7 March 2023 at Bangkok port.

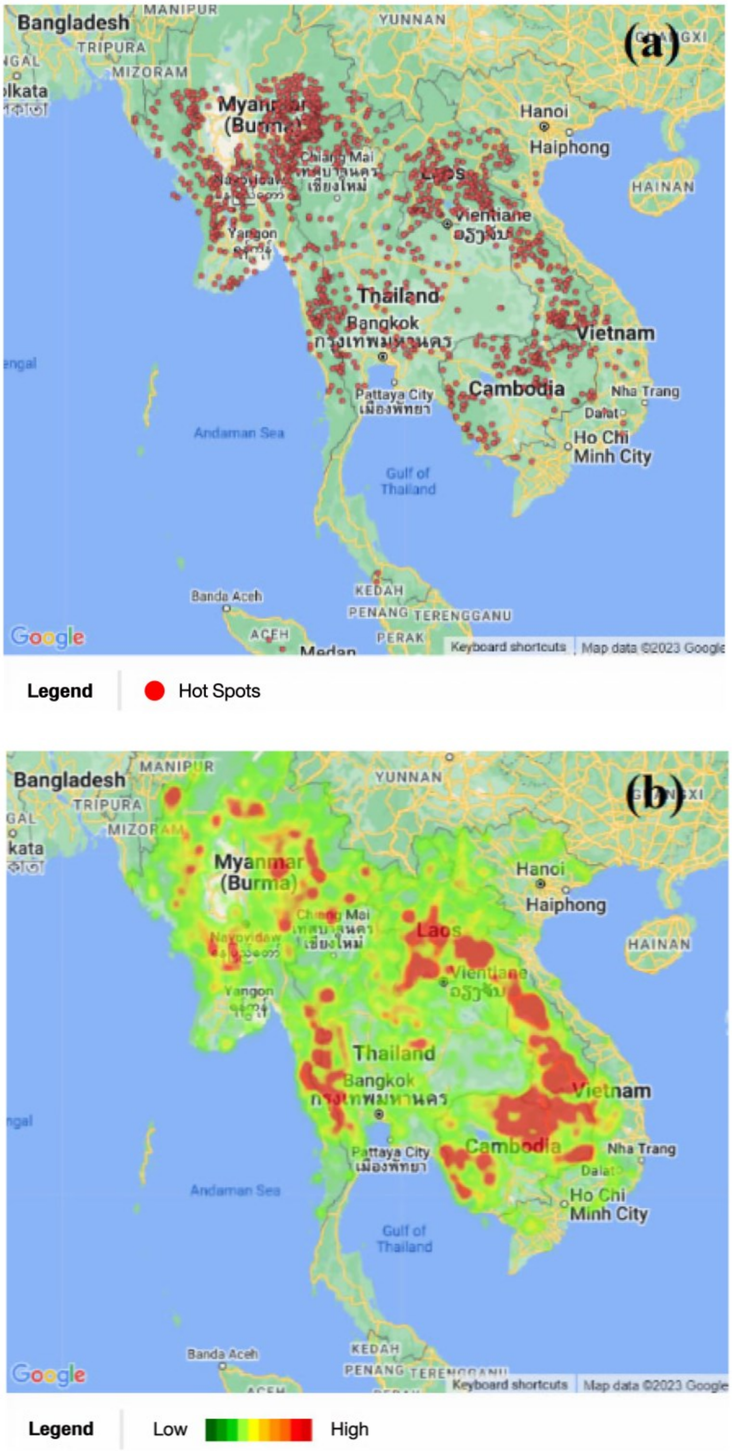


Figure 9 (a) Hotspot distribution map on 6 March 2023, and (b) hotspot density map during 28 February to 6 March 2023 (ASMC, 2023).

4. Conclusions

The atmospheric transportation of pollutants to coastal regions and Bangkok port, Thailand, strongly depends on the meteorological conditions. Primarily, wind speed and direction significantly affect the arrival time and direction of the released emission path after release from the source. The probable pathway for aerosol transported from Ninh Thuan NPP to the coastal regions of Thailand was investigated. Based on an analysis of wind data from the NCEP/NCAR reanalysis, together with the use of HYSPLIT model, the results show that the percentage of radionuclides transport reaching Thailand was the highest in the southern coastal part, found in January-April and October–December, with a maximum in January (approximately 84 %). Radionuclide transport to the southern coastal part in January could occur in 24-120 hours. During the southwest monsoon in June-September, the probability of radionuclides transport reaching Thailand could occur in the northern and northeastern parts of Thailand, especially in September, where the percentage of trajectories reached in the northern and northeastern parts were approximately 8 and 31 %, respectively. The pathway for radioactive material reached the northern and northeastern parts due to the northeast monsoon starting over China and weak southwest wind over Ninh Thuan NPP, causing the possibility of radionuclide transport from Ninh Thuan NPP to the upper part of Vietnam and turning toward the northern or northeastern parts of Thailand. When considering Bangkok port, Thailand, the possible pathway of aerosol from Ninh Thuan NPP to Bangkok port was from February to April. The model showed that the possible pathway of aerosol from Ninh Thuan NPP to Bangkok port, Thailand, was approximately 4.4 % in March.

For PM2.5 pollutants, when considering PM2.5 concentration on 1-2 February and 7 March near Bangkok port, the maximum and exceeding safety level PM2.5 concentration was found at Bangkok port and around Bangkok. In this poor day period, PM2.5 concentration had strong positive significant and negative significant relationships with RH ($r = 0.44$, $rs = 0.46$) and wind speed ($r = -0.46$, $rs = -0.47$), respectively. During concentrations of PM2.5 exceeding the safety level, there was a relative humidity of about 30 to 100 % and low wind (wind speed <=2). The concentration of PM2.5 was slightly negatively correlated with wind direction.

Based on the assumption that if the amounts of pollution released from each location in the Bangkok area were the same daily, some excess pollution would likely come from adverse weather conditions. In addition, the movement of wind by the upper air transport may bring pollutants from neighboring provinces or Southeast Asia to Bangkok port, Thailand. Based on analysis of upper-level wind maps and simulations from the HYSPLIT model, another possible cause was PM2.5 transportation in the upper atmosphere, where on March 6, anticyclone formation appeared in the upper atmosphere. This was centered over the northeastern region of Thailand, near the coastal area of Vietnam and the Cambodian and Laos borders at atmospheric levels of 850, 700, and 500 hPa, respectively, which could be contributing to the transport of PM2.5 pollutants to Bangkok port.

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