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Research Article

Vertical Variation of Nitrogen Oxide (NO_x) Concentration Using a Backward Air Mass Trajectories Model in an Urban Area of Bangkok, Thailand

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Abstract

Bangkok Metropolitan is a rapidly growing city with both industrial and urban area expansion resulting in the generation of a significant air pollutant; Nitrogen Oxide ($NO_x = NO + NO_2$). This research studied the variation of Nitrogen Oxide concentration in an urban area at 30 m and 110 m above ground by applying the HYSPLIT model to simulate the backward trajectories movement of air mass using the past 3 days of data from an air quality and microclimate monitoring station at Kasetsart University, Bangkok from January 2016 to February 2017. The results showed that the concentration of Nitrogen Oxide at 30 m above ground is higher than the concentration at 110 m above ground. The concentration trended to increase in winter (October 2016 to February 2017). According to the backward trajectories modeling, the major direction of air mass movement at 30 m above ground, category 1 (N-NE) and category 2 (NE-E), occupying 86% of total movement direction (concentration of NO_x ranged from 4.02 to 96.35 ppb) meanwhile the major direction of air mass movement at 110 m above ground, category 1 (N-NE) and category 2 (NE-E), occupying 79% of total movement direction (concentration of NO_x ranged from 3.93 to 51.50 ppb). The air mass moved through the different land use types, human activities and industrial areas. This study can be applied as a guideline for microclimate surveillance and monitoring of NO_x concentration influenced by air mass movement.

Keywords: Backward trajectories, HYSPLIT model, Nitrogen oxide, Air pollution, Urban area

1 Introduction

Air pollution is a severe problem with broad impacts. A significant worldwide pollutant released directly from sources is Nitrogen Oxide ($NO_x = NO + NO_2$) [1], [2] because it introduces acid rain and photochemical smog that weakens human respiration system [3], [4]. The expansion of urban areas, economic and industry development accelerates the deterioration and toxicity of the environment [5]. Significantly, human activities are a source of Nitrogen Oxide released from both airplanes and ground level (including anthropogenic sources and biomass combustion) [6]. This research emphasizes the relationship between the concentration

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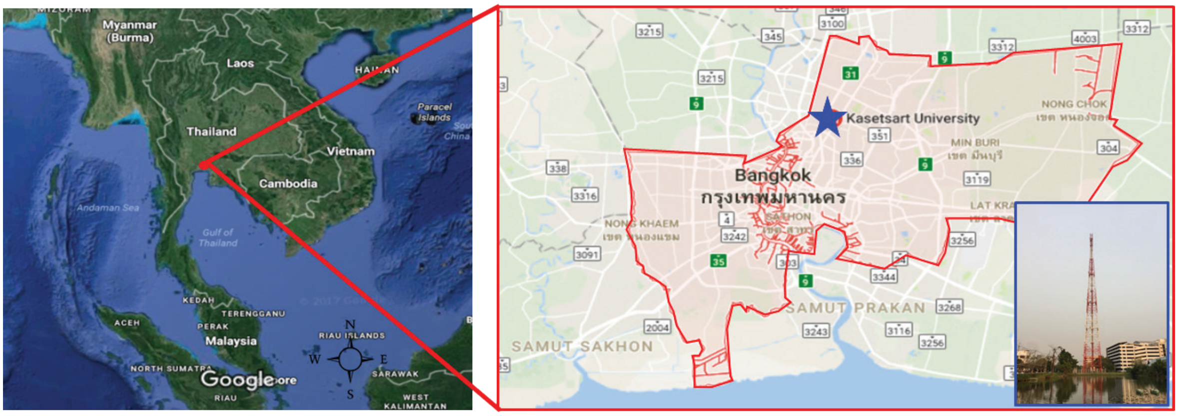


Figure 1: Map of the air quality monitoring site (Kasetsart University, Bangkok, Thailand) investigated in this study.

of pollutants and microclimate conditions in urban area in order to study the variation of Nitrogen Oxide concentrations at different heights using a backward air mass trajectories model. This study can be applied as a guideline for monitoring meteorological conditions and concentration of pollutants in the influenced areas in order to manage and control the concentration of NO_x in urban area.

1.1 *Study area and site description*

Bangkok Metropolitan is a rapidly growing city with both industrial and urban area expansion. At present, travel demand in Bangkok is up to 17 million trips per day and is predicted to increase to 26.2 million trips per day in 2021 [7]. The highly dense traffic in urban areas is a major source of Nitrogen Oxide [8], [9] which impacts severely on human health and the environment. The study was performed at Kasetsart University, Bangkok (Latitude: 13.854529N, Longitude: 100.570012E) as presented in Figure 1. The variation of Nitrogen Oxide concentration at 2 different levels; 30 m and 110 m was investigated.

1.2 *HYSPLIT model*

The HYSPLIT Model was developed by Air Resource Laboratory (ARL), National Oceanic and Atmospheric Administration (NOAA), United State of America to simulate the atmospheric transport and dispersion of air pollutants [10], [11] by modeling backward air mass trajectories. The model is a complete system for computing trajectories, complex dispersion, and deposition simulations using either puff or particle approaches [12] and calculation method is Hybrid-Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model [13]–[16]. The HYSPLIT Model can show the trend and the origin of air mass movement that pass through area or sources before reaching the study area that has been considered to be the source of Nitrogen Oxide in Bangkok.

2 Materials and Methods

The framework of this research is to investigate factors and pollutant sources influencing the variation of Nitrogen Oxide concentration as different heights. Figure 2 presents a flow chart of the study.

2.1 *Study area*

The boundary of the study area is the Bangkok Metropolitan, Thailand as shown in Figure 1. The samples were collected from January 2016 to February 2017 at KU Tower, air quality and microclimate monitoring station, at Kasetsart University, Bangkok, Thailand (Latitude: 13.854529N, Longitude: 100.570012E).

2.2 *Data*

2.2.1 Pollution data

Nitrogen Oxide in ambient air at 30 m and 110 m above ground was analyzed for 24 hours per day by

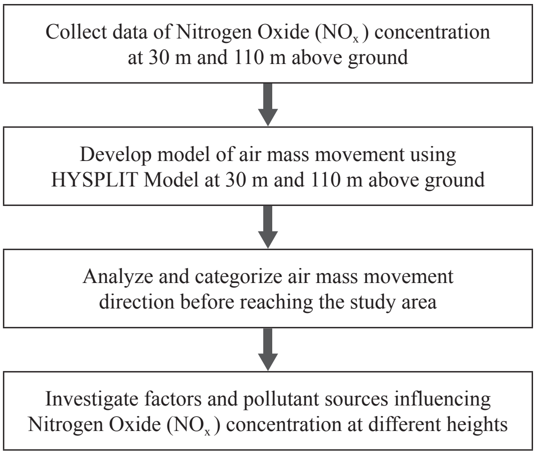


Figure 2: Flow chart of the study of Nitrogen Oxide concentration and backward air mass trajectories at different heights.

using NO_x analyzer located at KU tower. The daily concentration was analyzed to investigate trend and cause of variation of Nitrogen Oxide concentration at different height level.

2.2.2 Meteorological data, Global Re-Analysis

The HYSPLIT Model was applied together with the global reanalysis data prepared by applying meteorological database GDAS (0.5 degree, global, 09/2007 – present)

2.3 *Methodogy*

2.3.1 Backward trajectories

The air mass remote movement was studied by developing backward air mass trajectories model using HYSPLIT trajectories model of Air Resource Laboratory (ARL) Advancing Atmospheric Science and Technology Through Research [15], [16] (http://www.ready.noaa.gov/HYSPLIT.php) to simulate backward air mass trajectories of the past 3 days (72 hours) in order to determine the area that the air mass passed by until reaching KU Tower. The air mass movement was modeled in winter season of Thailand (October 15, 2016 to February 15, 2017) at 2 height level; 30 m (124 set of data) and 110 m (124 set of data).

2.3.2 Analyze and categorize air mass movement direction before reaching the study area

The backward air mass trajectories modeling was applied in winter season (October 15, 2016 to February 15, 2017) at 2 heights; 30 m (124 set of data) and 110 m (124 set of data) for analyzing and categorizing air mass movement direction before reaching the study area using HYSPLIT Model Version 4.0 by simulating backward air mass trajectories of the past 3 days (72 hours)

2.3.3 Cluster analysis

Cluster analysis was applied to group trajectories with similar paths. The aim of any clustering technique is to maximize the homogeneity of elements [17]. The execution of Hysplit4 is an integrated system for computing trajectories, air concentration and deposition. The cluster analysis was conducted at 30 m above ground for 124 data set and at 110 m above ground for 124 data set. The air mass movement was grouped to 8 main directions which are; North (N), NorthEast (NE), East (E), SouthEast (SE), South (S), SouthWest (SW), West (W) and NorthWest (NW).

2.4 *Investigate factors and pollutant sources influencing Nitrogen Oxide (NO_x) concentration*

Investigate factors and pollutant sources influencing Nitrogen Oxide (NO_x) concentration at different heights by analyzing the category of air mass movement direction before reaching the study area together with pollutant sources expected to influence the concentration of Nitrogen Oxide at 30 m and 110 m above ground.

3 Results and Discussion

3.1 *Variation of NO_x concentration at different heights*

The average comparison of the concentration of NO_x at 30 m and 110 m above ground at air quality and microclimate monitoring station at Kasetsart University, Bangkok, Thailand was conducted to investigate factors influencing the variation of NO_x concentration. Table 1 presents NO_x concentrations and Table 2 shows meteorological data in an urban area at 30 m and 110 m

Table 1: NO_x concentration in urban area at 30 m and 110 m above ground

Height level (m)		2016												2017	
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
30	Average	26.50	23.72	14.84	2.85	9.35	23.64	19.94	17.06	20.61	18.27	24.29	26.91	25.45	37.68
	Max	54.57	74.02	72.89	15.00	30.98	74.79	39.41	30.45	36.50	29.33	47.08	47.48	48.50	96.35
	Min	11.00	8.87	4.69	0.00	2.96	3.77	8.24	9.97	12.23	7.55	4.02	9.20	9.17	5.65
	SD	13.97	15.74	13.01	3.48	5.14	15.12	8.45	4.16	5.65	9.01	10.44	10.55	11.59	31.16
110	Average	20.65	17.05	11.91	2.59	7.52	17.59	15.35	11.66	14.53	11.56	17.40	18.66	16.11	13.51
	Max	43.40	39.25	41.17	12.21	28.00	51.74	32.79	20.80	28.63	14.05	36.58	34.63	30.97	24.10
	Min	7.68	7.60	4.53	0.00	2.41	2.16	5.64	5.83	6.80	7.22	3.51	4.73	3.93	3.95
	SD	9.52	7.76	6.79	3.14	4.79	9.80	6.70	2.96	6.13	3.77	8.04	7.33	7.45	7.46

Unit : $\mu g.m^{-3}$

Table 2: Micrometeorology data at 30 m and 110 m above ground in winter season of Thailand (October 2016 to February 2017)

Height	Parameter	2016			2017	
		Oct	Nov	Dec	Jan	Feb
30 m	Mean temperature (°C)	28.67	28.89	27.47	27.41	28.31
	Mean Relative humidity (%)	73.06	66.61	56.70	62.52	52.96
	Mean wind speed (deg)	229.51	101.90	147.67	168.44	187.09
	Mean wind direction ($m.s^{-1}$)	4.24	9.10	1.86	1.87	1.65
	Mean 24 h NO_x concentration ($\mu g.m^{-3}$)	18.27	24.29	26.91	25.45	37.68
110 m	Mean temperature (°C)	27.76	28.14	26.71	26.65	27.72
	Mean Relative humidity (%)	75.91	68.70	58.97	64.86	53.67
	Mean wind speed (deg)	253.07	156.81	129.81	170.70	196.58
	Mean wind direction ($m.s^{-1}$)	2.46	2.73	3.30	3.09	2.75
	Mean 24 h NO_x concentration ($\mu g.m^{-3}$)	14.33	17.40	18.66	16.11	13.51

above ground. Figure 3 shows the NO_x concentration in winter (October to February) trend to be higher than those in summer and rainy season. In addition, NO_x concentration at 30 m above ground was higher than those of at 110 m above ground because urban areas are influenced by pollution from traffic which is the major source of NO_x generated by diesel engines [18]. The concentration at 30 m and 110 m above ground complied with the standard and the monitoring results conducted by Pollution Control Department of Thailand in 2016 [19].

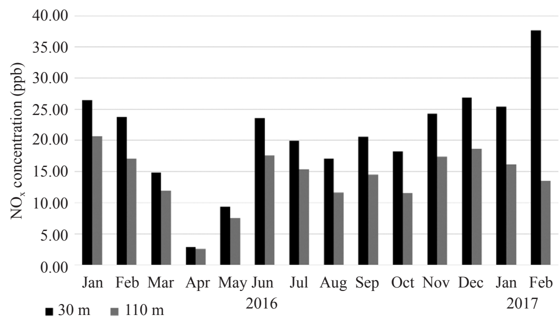


Figure 3: NO_x concentration in urban area at 30 m and 110 m above ground.

3.2 *Modeling backward air mass trajectories using HYSPLIT model*

The results of backward air mass trajectories modeling of the past 3 days (72 hours) data in winter season (October 15, 2016 to February 15, 2017) at 2 heights; 30 m (124 set of data) and 110 m (124 set of data) revealed that the direction of air mass movement at both heights is similar as shown in Figure 4. Air masses mostly moved from a northeastern direction and changed direction at some period of time.

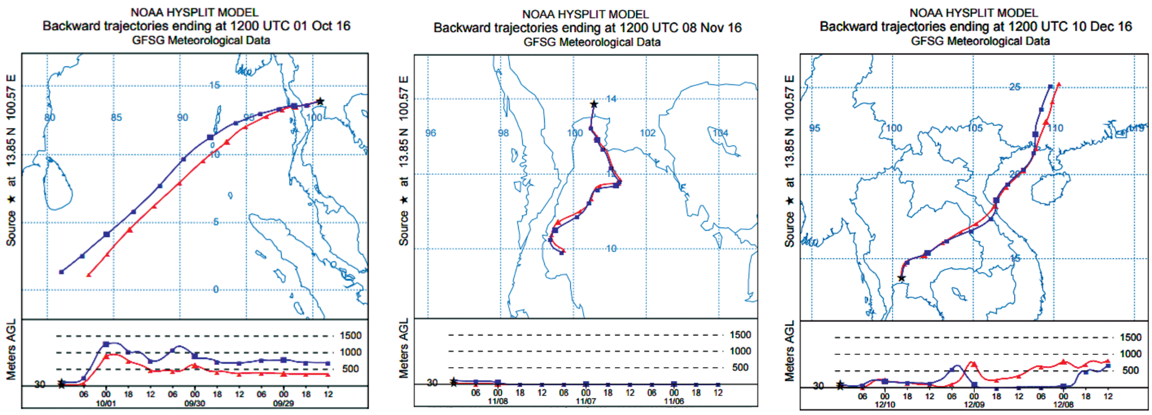
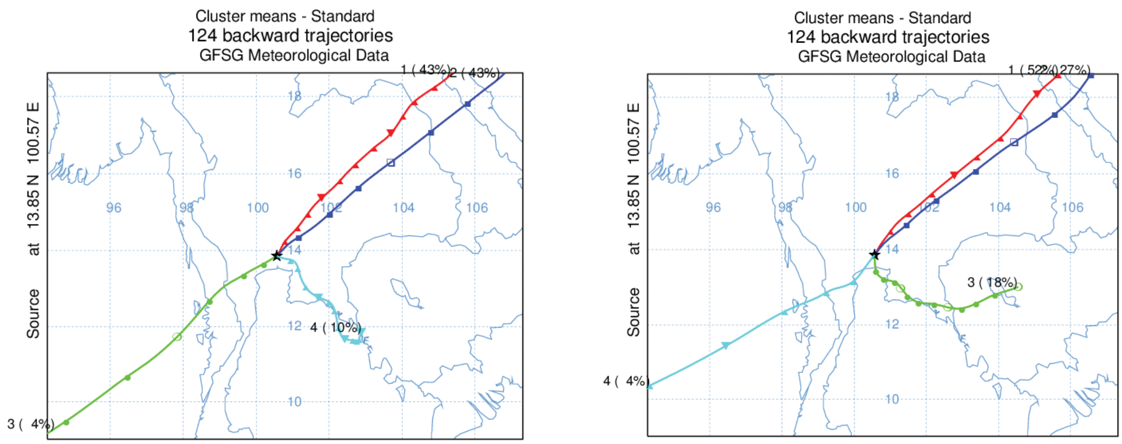


Figure 4: Example of backward air mass trajectories modeling in winter season (October 15, 2016 to February 15, 2017).



(a) (b)

Figure 5: Backward air mass trajectories in urban area at (a) 30 m above ground and (b) at 110 m above ground.

Table 3: Percentage of backward air mass trajectories direction in an urban area during winter (October 15, 2016 to February 15, 2017,124 day totally)

High level (m)	Category 1 (N-NE)	Category 2 (NE-E)	Category 3 (SE)	Category 4 (SW)	Total
30	43%	43%	10%	4%	100%
110	52%	27%	18%	4%	100%

3.3 *Trajectory analysis and air masses categorization before reach the study area*

The trajectory analysis revealed that the air masses that flowed through the study area at 30 m and 110 m above ground in winter season of Thailand (October 15, 2016 to February 15, 2017) can be assigned to 4 major direction categories which are category 1 (N-NE), category 2 (NE-E), category 3 (SE), and category 4 (SW) as presented in Figure 5 and Table 3.

1) At 30 m above ground, air masses mainly flowed from 3 directions. The major movement direction was from northeastern of Thailand which are category 1 (N-NE) (43%) and category 2 (NE-E) (43%) passing urban areas, agricultural areas, and industrial areas. The concentration of NO_x from these

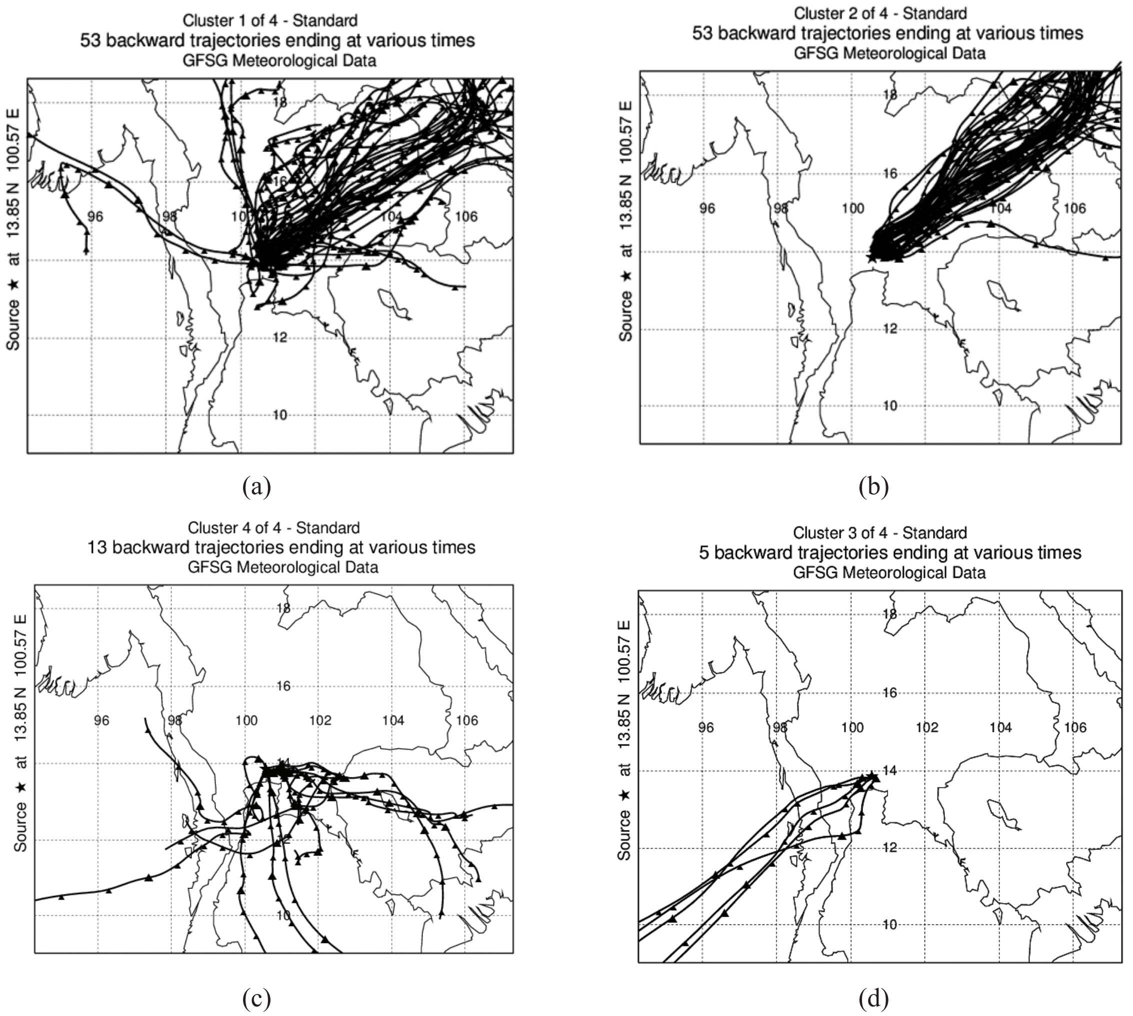
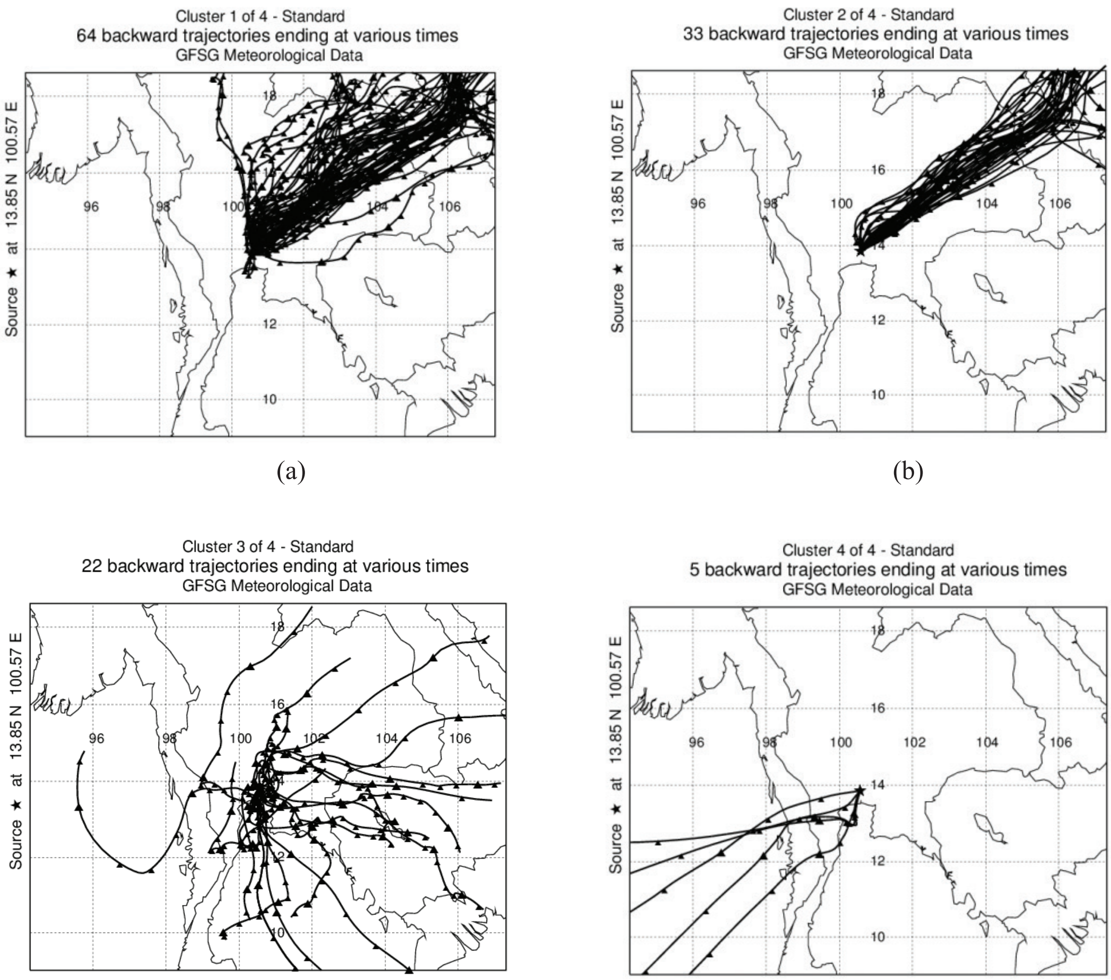


Figure 6: Backward air mass trajectories at 30 m above ground (a) category 1 (N-NE), (b) category 2 (NE-E), (c) category 3 (SE), and (d) category 4 (SW).

directions ranged from 7.21 to 48.50 ppb (average concentration was 25.53 ppb). Furthermore, some air masses flowed from a southeast direction; category 3 (SE) (10%), passing community areas and industrial areas. The concentration of NO_x from this direction ranged from 4.02 to 96.35 ppb (average concentration was 30.36 ppb) as shown in Figure 6.

2) At 110 m above ground, air masses mainly flowed from 3 directions. The major movement direction was from the northeast of Thailand which are category 1 (N-NE) (52%) and category 2 (NE-E) (27%) passing urban areas, agricultural areas, and industrial areas. The concentration of NO_x from these directions ranged from 3.93 to 51.50 ppb (average concentration was 17.40 ppb). Furthermore, some air masses flowed from a southeast direction; category 3 (SE) (18%), passing community areas and industrial areas. The concentration of NO_x from this direction ranged from 3.51 to 36.58 ppb (average concentration was 18.17 ppb) as shown in Figure 7.

After the influence of the southwest monsoon, there is the northeast monsoon passing Thailand from mid October to mid February. This monsoon comes from high-pressure area of the northern hemisphere, Mongolia and China which bring cold and dry air mass to Thailand [20].



(a) (b) (c) (d)

Figure 7: Backward air mass trajectories at 110 m above ground (a) category 1(N-NE), (b) category 2(NE-E), (c) category 3(SE), and (d) category 4(SW).

3.4 *Factors and sources influencing the vertical concentration of NO_x at different heights*

At 30 m above ground, air masses mainly flowed from northeastern direction; category 1 (N-NE) (43%) and category 2 (NE-E) (43%). The concentration of NO_x under the influence of these directions ranged from 7.21 to 48.50 ppb (average concentration was 25.53 ppb). In addition, at 110 m above ground, air masses also mainly flowed from northeastern direction; category 1 (N-NE) (52%) and category 2 (NE-E) (27%). The concentration of NO_x influenced by these directions ranged from 3.93 to 51.50 ppb (average concentration was 17.40 ppb). The air masses flowed through various types of land use and anthropogenic sources including industrial areas. It was found that the concentration of NO_x at 30 m above ground was higher than at 110 m above ground because of ground-level sources such as diesel engines [18], [21] activities in communities, and industrial areas including the remote movement such as from marine vessels. Meanwhile, NO_x at the higher level is under the influence of sunlight resulting in the Photochemical reaction [21], [22].

4 Conclusion

The investigation of NO_x concentration at 30 m and 110 m above ground during January 2016 to February 2017 revealed that concentration of NO_x at 30 m above ground is higher than at 110 m above ground because the major source of NO_x is diesel engine (Lu *et al*. [9], Degraeuwe *et al*. [18]) in urban areas with dense traffic. In addition, the concentration of NO_x decreased to a minimum in April for both at 30 m and 110 m above ground then increased in winter (October 2016 to February 2017) due to the change of air masses movement direction. Air masses at both 30 m and 110 m above ground moved from a similar direction; northeast side, flowing through various types of land use and anthropogenic sources including industrial areas. This study can be applied as a guideline for microclimate surveillance and monitoring of NO_x concentration influenced by air mass movement.

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