Synoptic circulation and ozone pollution over two major cities in eastern Thailand

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Abstract:
In this work, a back-trajectory modeling approach was applied to study the impact of synoptic circulation and long-range transport of ozone (O_3) and its precursors on surface O_3 level in Chon Buri and Rayong, two highly industrialized and urbanized cities in eastern Thailand. For each city, daily kinematic trajectories with backward migration of 3 days were simulated for 16 O_3 seasons (Nov-Apr) over 1997-2012, using FLEXTRA model. The K-means clustering method was then used to group all simulated trajectories into a number of unique clusters. The clustered trajectories and their corresponding citywide daily daytime (10-18 LT) maximum O_3 (DDMXO$_3$) were statistically analyzed. A total of five trajectory clusters were equally found for each city and the overall cluster patterns in both cities were similar. The corresponding DDMXO$_3$ values were found to be significantly different (p-value <0.05, Tukey's test) in almost all pair of trajectory clusters in each city. Furthermore, for both cites, the average DDMXO$_3$ found to be relatively large in trajectory clusters with continental origin as opposed to maritime cluster with relatively low values. It was also found that low-altitude trajectories are likely to be linked with higher O_3 than high-altitude ones. These findings indicate the potential association between O_3 and synoptic circulation.

Keywords*: ozone; back- trajectory; K-means clustering; long-rang transport; synoptic circulation*

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1. Introduction

Chon Buri (CB) and Rayong (RY) are two major cities in the eastern region of Thailand and situated along the coastal areas of the provinces of the same name (Fig. 1). Both cities have been steadily industrialized and urbanized over the past two decades, and each also has a large-sized industrial sector present, including petrochemical industry, oil refineries, seaports, etc. Accordingly, air quality has deteriorated and been a public concern. Recent studies (e.g., Pimpisut et al., 2005, Prabamroong et al., 2012; and Chusai et al., 2012) were implemented to help understanding the air pollution in different aspects and to help support air quality management in the region. Surface ozone (O_3) pollution is recognized as one of major environmental problems in both cities, with its observed level (i.e., concentration) exceeding the national ambient standard of 100 ppb (hourly) multiple times a year during 1997-2012 (PCD 2012). O_3 is a harmful secondary air pollutant, photochemically formed in the air by its precursors (mainly, nitrogen oxides or NO_x and volatile organic compounds or VOC). Prabamroong et al. (2012) investigated the underlying nature of O_3 formation and the roles of emissions over CB for two short-term episodes using photochemical box modeling. O_3 formed in the ambient air as well as its precursors emitted locally can be transported from one place to another. It is thus important to have better understanding of their long-range transport on O_3 level. The degree or pattern of transport is typically governed by synoptic circulation. Back-trajectory modeling is generally a practical tool for investigating the characteristics of long-range transport and associated synoptic circulation. Pochanart et al. (2001) used this modeling tool for potential-source attribution for O_3 observed at selected remote sites in Thailand. Pongkiatkul and Kim Oanh (2007) did similarly but for particulate matter in Bangkok. Prabamroong et al. (2013) conducted a preliminary study using back trajectories on surface O_3 in RYduring 2000-2010, finding that O_3 was potentially affected by the transport in different degrees, depending on the origin and migratory path of air mass. Here, we continued by extending the scope of analysis to the two cities, covering a longer period, and using enhanced input to trajectory modeling, with an aim to gain a more insight into this aspect of the O_3 pollution in the eastern region.

2. Methods

In this study, open-source Lagrangian trajectory model FLEXTRA (version 3.0) (Stohl et al., 1995) was used to simulate daily kinematic trajectories for a receptor site in each city, migrating backward in time for 3 days and driven by wind fields from 0.5°-resolution 6-hourly CFSR data (Saha et al., 2010). The arrival time and height of each trajectory are 1pm and 500 m above ground level, representing the time when convective mixing is typically strong and the mid-level of the atmospheric boundary layer, respectively. Next, the K-means clustering method in standard open-source R software (R development core team, 2011) was used to group all simulated trajectories into a number of unique trajectory clusters. The period of study covers the O_3 seasons of 1997-2012 (i.e., 16 seasons). The O_3 season was here defined as Nov.-Apr., which generally coincides with the typical dry season of the region. During this season, O_3 tends to elevate (Fig. 2) due to favorable weather conditions, e.g., minimal rainfall, less clouds, and then strong solar radiation. Also, O_3 exceedances were found substantially in this season, compared to the rest of the year. To address the impacts of long-range transport and synoptic circulation on observed O_3 in each city, the clustered trajectories and their corresponding daily daytime maximum O_3 (DDMXO_3) were statistically analyzed, and Tukey's test was used to inspect the significance of association. Here, O_3 data at six stations (Fig. 1) over 1997-2012 was from the Pollution Control Department (PCD): 3 in CB (PCD-32, PCD-33 and PCD-) and 3 in RY (PCD-29, PCD-30 and PCD-31). To compute DDMXO_3 for a city, hourly O_3 values at all stations within a city are pooled and averaged as citywide value, and then the maximum of the citywide values during daytime (10-18 LT) hours is assigned.

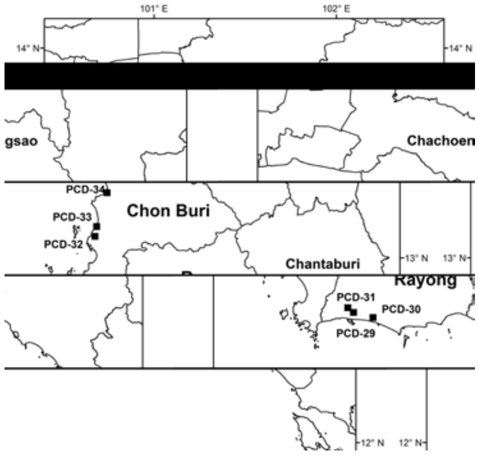

Fig. 1 Rayong and Chon Buri provinces and PCD stations.

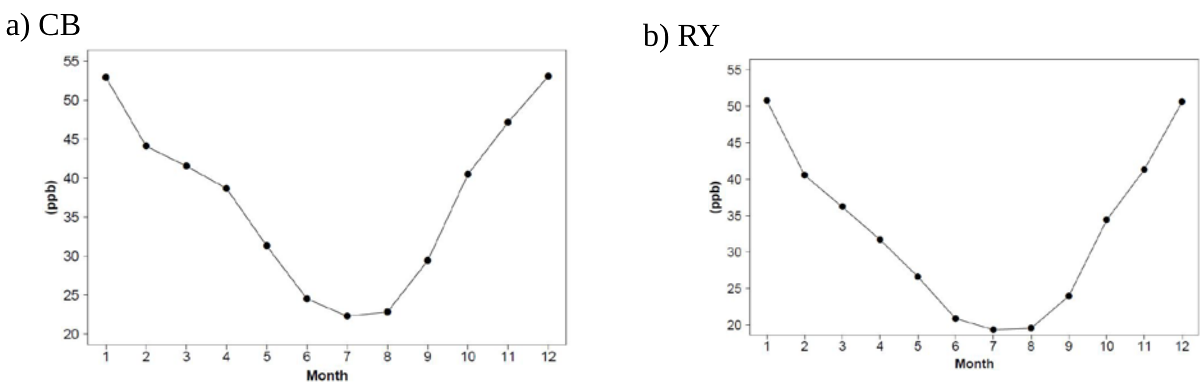

Fig. 2 Monthly average DDMXO_3 over 1997-2012.

3. Results and discussion

A total of five trajectory clusters were equally found for each city, and the overall cluster patterns in both CB and RY were also similar (Fig. 3). These suggest that both cities are under the same or similar synoptic conditions, which is possible since both are in the same region and vicinity (about 50-60 km apart). The five resulting clusters are designated as follows: 1) northeasterly at high level (NE_H) 2) northeasterly at low level (NE_L) 3) southeasterly, 4) undefined (i.e., non-directional) at low level (U_L) and 5) undefined at high level (Fig. 3). Their corresponding $DDMXO_3$ (averaged over within-cluster trajectories) values were found to be significantly different (p-value <0.05) in almost all pairs (9 out of 10) in each city (Table 1), indicating the potential association between O_3 and synoptic circulation. The trajectories in NE_H and NE_L mostly occur during Nov.-Jan. (Fig. 4), in agreement with the prevailing Northeast monsoon. In SE, its trajectories are of maritime origin and mostly occur during Feb.-Apr. when the regional Northeast monsoon starts to weaken as the monsoonal transition from the dry season to the wet season. Notice from both cities that average $DDMXO_3$ appears to be relatively large in NE_H and NE_L whereas the values in SE are relatively low (Fig. 5), which is possibly attributed to their corresponding origins (i.e., continental versus maritime). In general, a continental trajectory is likely to be polluted by emissions from various on-land human activities, as opposed to its maritime counterpart being relatively clean. Two undefined clusters (U_L and U_H) do not have a distinct directional pattern, and the U_L trajectories are seen across the months more or less uniformly. Both U_L and U_H tend to have a relatively short migration path, suggesting a longer residential time over the receptor and its nearby area and O_3 being more readily impacted by local emissions and local circulation. It is also seen that low-altitude trajectories are likely to be linked with higher O_3 than high-altitude ones (see NE_L vs NE_H or U_L vs U_H for comparison) because they tend to be closer to the surface and to stay within the atmospheric boundary layer longer.

a) CB **b) RY**

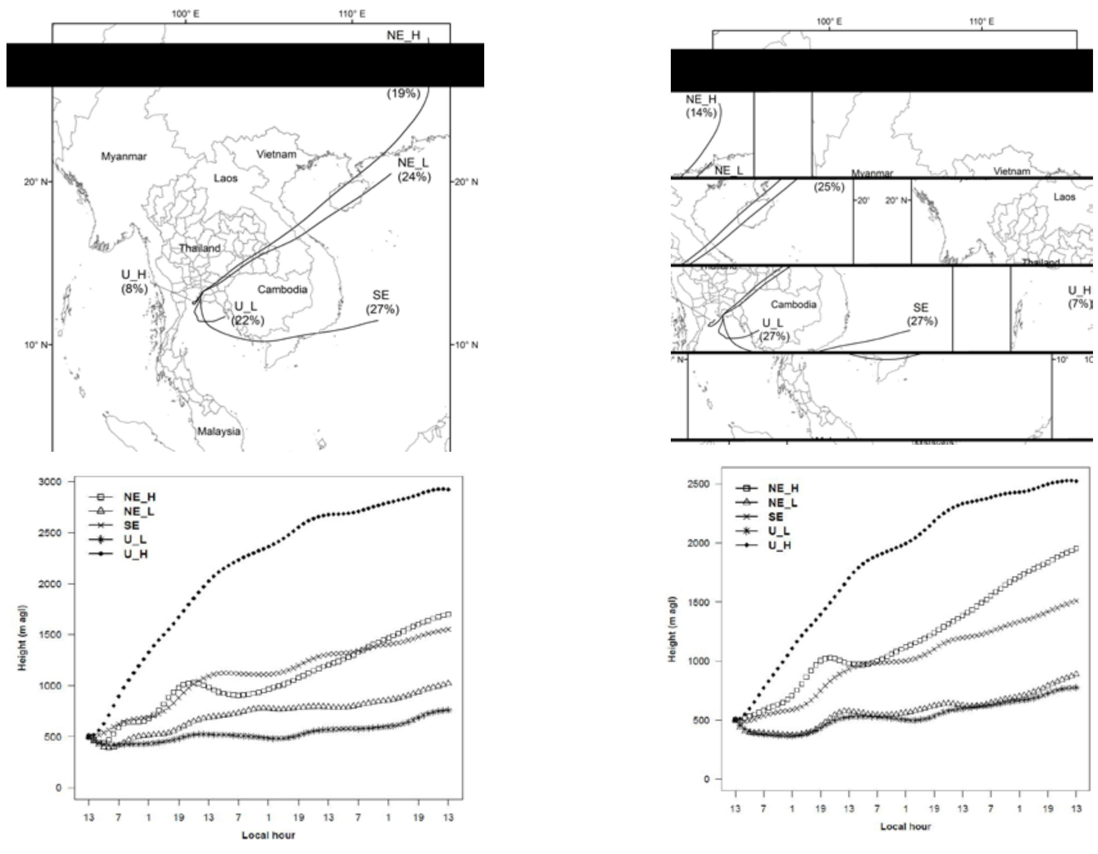

Fig. 3 Trajectory means by cluster (top: horizontal; bottom: vertical height above terrain with X-axis as hours backward in time from arrival).

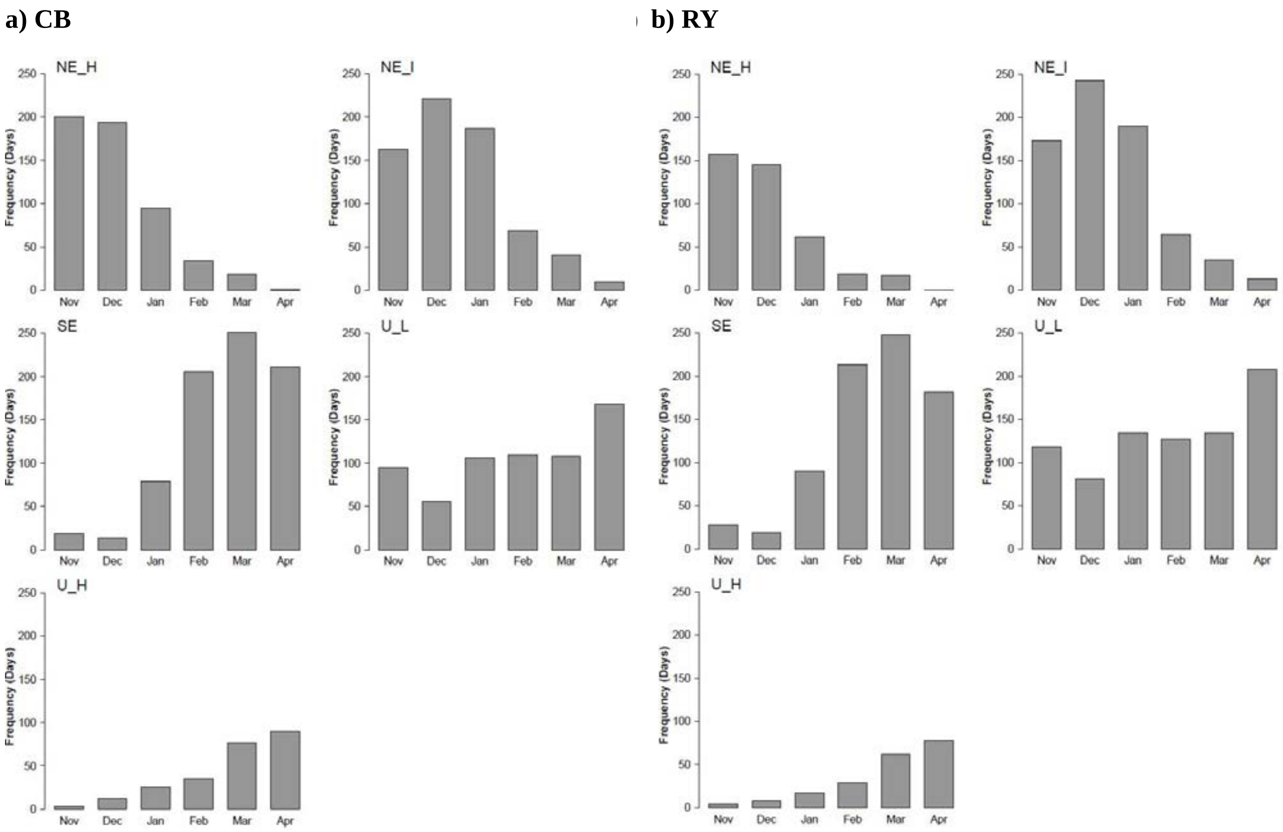

Fig. 4 Monthly distribution of trajectories found in each cluster**.**

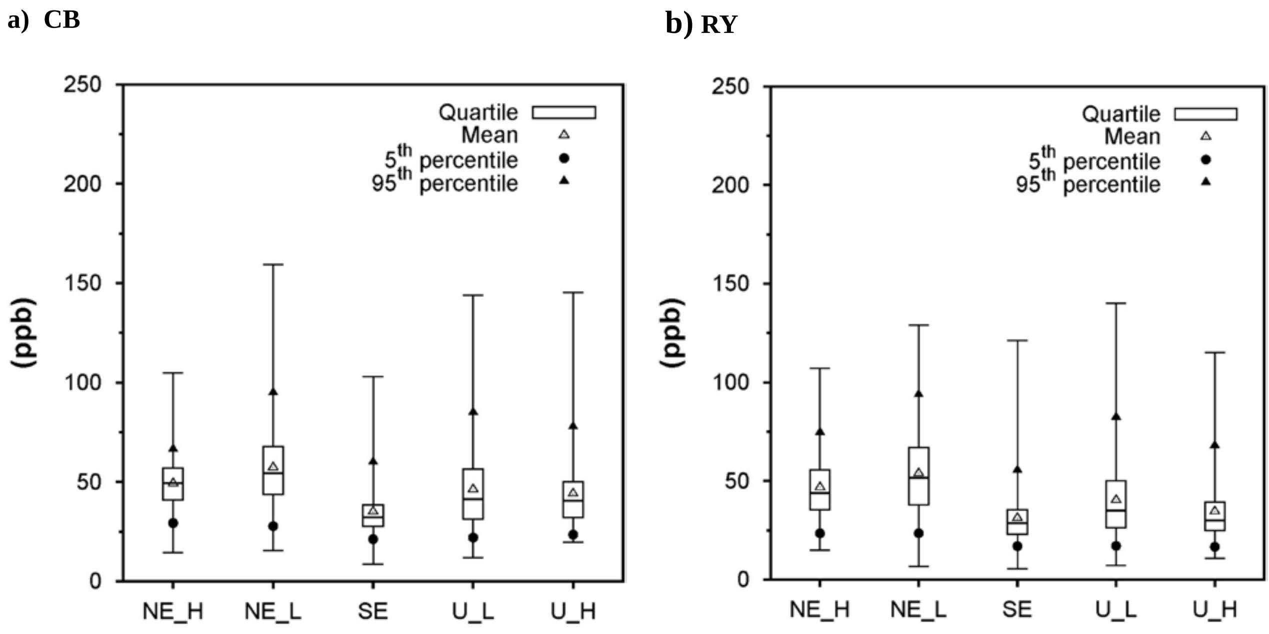

Fig. 5 DDMXO_3 by cluster.

Table 1 *p*-value from Tukey's test for average $DDMXO_3$ between two clusters

Cluster Pair	CB	RY
NE_H and NE_L	0.00	0.00
NE_H and SE	0.00	0.00
NE_H and U_L	0.02	0.00
NE_H and U_H	0.00	0.00
NE_L and SE	0.00	0.00
NE_L and U_L	0.00	0.00
NE_L and U_H	0.00	0.00
SE and U_L	0.00	0.00
SE and U_H	0.00	0.14
U_L and U_H	0.46	0.00

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