3.5 CHARACTERISTICS OF LOCAL FLOW IN JAKARTA, INDONESIA AND ITS IMPLICATION IN AIR POLLUTION TRANSPORT

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1. INTRODUCTION

Jakarta, Indonesia has experienced serious air pollution problems associated with the use of energy in the transport, domestic, and industrial sectors. Meteorological conditions in a region often play a dominant role in building up severe air pollution. Yet the local flow system in this large tropical coastal city is not well understood. Thus our primary concern in this study was to investigate characteristics of meteorology over western Java area, especially Jakarta city and its implication for air pollution transport.

2. METHODS

To understand the characteristics and the development mechanism of complex local flows, numerical simulation over western Java area was performed using the Fifth-Generation Pennsylvania State University-National Center for Atmospheric Research Mesoscale Model Version 3.6 (hereafter will be abbreviated as MM5; see Dudhia et al., 2003 for the detail of the software). The simulations were done for 8-13 February 2001 in "rainy" season and for 6-19 August 2004 in "dry" season. Latitude and longitude at the southwest and northeast corners of the outermost domain were 8^0 S and 105^0 E, and 5^0 S and 109^0 E, respectively. The domain system used in this calculation is a triply nested two-way interacting mesh. The domain 1 has 50 X 37 horizontal grids points, the domain 2 has 73 X 73 grids point, and the domain 3 has 82 X 82 grids points. The horizontal grid size was constant at 9, 3, and 1 km for the domain 1, 2, and 3, respectively (see Fig 1). Each domain has 23 vertical grid points for the depth from the earth's surface to 100 hPa. The framework of meteorology in larger scale was provided by ECMWF data with a resolution of 0.5^0 X 0.5^0.

We conducted also field observation for air quality over Jakarta city using a number of passive samplers for NO_2 and SO_2 in August 2004. Fifty samplers for each species were distributed over the greater Jakarta to measure both 1 day and 1 week averaged concentration distributions.

Fig. 1. Domain system for MM5 simulation in Western Java area; horizontal grid size for the domain 1, 2, and 3 was 9, 3, and 1 km, respectively.

3. RESULTS

3.1 Climate system in Indonesia

Climate in Indonesia is classified roughly into two types, one in the "rainy" season from November to March, and the other in the "dry" season from May to September. Over Java Island, in the rainy

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season, northwesterly blows from the equator and the northern Pacific Ocean, and the wind forms a convergence line with westerly from Indian Ocean and results in occasional heavy rainfall. This synoptic flow seems largely influenced by the low pressure developed over the northern Australian continent (shown in a figure of surface pressure distribution and streamlines in Riehl, 1979). On the other hand, in the dry season between May and September, southeasterly dominates synoptic scale wind field over Java Island, no large scale convergence is formed, and thus precipitation is scarce; this southeasterly from the Australian continent and the Indian Ocean is regarded as part of “trade wind”. Figure 2 demonstrates typical seasonal variation of monthly rainfall in Jakarta associated with the change of the climate system. A few weeks around April and October are the period of transition between the dry and wet seasons, and in the period wind is light and its direction is variable.

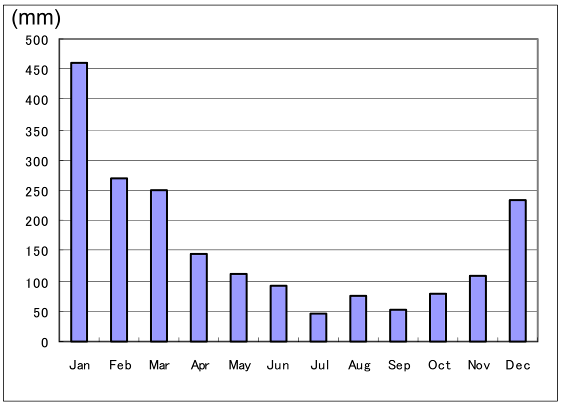
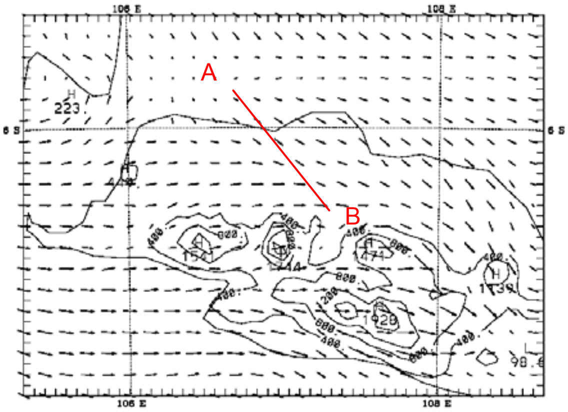
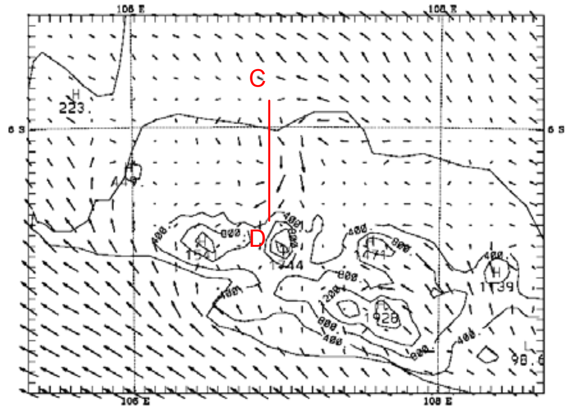


Fig. 2. Average monthly rainfall of Jakarta city (data from BMG Jakarta, 1960-1999)

As described above, in the “rainy” season, synoptic scale wind over western Java is westerly in the southern part and northwesterly in the northern coastal part, and thus a synoptic scale convergence line tends to be formed over the northern part of Java Island. Figure 3a shows calculated surface wind field at 1300LST on 9 Feb 2001, illustrating local flows developed under the above-described synoptic condition. This flow pattern, however, can be changed significantly from day to day mainly because of rainfall. On the other hand, in “dry” season the synoptic scale wind over Java Island is southeasterly. Figure 3b is also calculated surface wind at 1300LST on 7 August 2004. As shown in Fig. 3b, the synoptic scale southeasterly is blocked near surface level by the mountains along the south coast of Java Island. Thus the local winds such as sea breeze are visible in Jakarta area of the island.



(a) Surface wind in the “wet” season.



(b) Surface wind in the “dry” season.

Fig.3. Calculated near-surface wind field over the Java Island: at 1300LST on (a) 9 Feb 2001 and (b) 7 Aug 2004. Contour shows terrain height with its interval of 400 m.

3.2 *Characteristics of Sea Breeze Circulation in Wet/Rainy and Dry Seasons*

As described in subsection 3.1, different climatic background in “wet” and “dry” seasons should lead to difference in appearance of local flows such as sea breeze. Thus we investigated local flows for two different periods: 8-13 Feb 2001 in the “wet/rainy” season and 6-19 Aug 2004 in the “dry” season. Figure 4a, b show diurnal variations of calculated surface temperatures in Jakarta for the wet and dry seasons, respectively; in the figure, temperatures over the sea surface by 10 km off the coast of Jakarta are also plotted.

As can readily be seen in Fig. 4, diurnal temperature variation over the land is not stable and changes from day to day in the "rainy" season (Fig. 4a), while almost same pattern is repeated in the dry season (Fig. 4b). Apparently, in the rainy season rainfall events lower the maximum temperature at the land site, typically on 8 and 11 Feb (Fig. 4a), and cause an irregular diurnal variation. However, solar zenith angle in early February is rather favorable for the heating of the surface compared with it in August (remember the latitude of Jakarta, 6.5^0S). Thus the daily maximum temperatures in Fig. 4a are even higher on 9-10 Feb when there is no rainfall.

Temperature difference between sea surface and land surface can be an index for driving force of land/sea breeze and thus for the prediction of its extent and strength. As shown in Fig. 4b, the days of 6-19 August in the dry season show maximum temperature difference is about 3-4 ^{0}C during the daytime, and about 1 ^{0}C during the nighttime. Hence periodic development of sea breeze and weak land breeze might be expected; since the synoptic scale wind in the upper layer is the southeasterly which is adverse to the sea breeze and favorable to the land breeze in Jakarta area, the surface temperature difference may not be the only factor for determination of the land/sea breeze and further examination will be necessary.

Synoptic scale wind is another important factor for the development of local flows. In Java Island, even in the rainy season, land and sea temperature difference on sunny days is large (for example, 9 and 10 Feb 2001 in Fig. 4a) and does not show much difference from that in the dry season (i.e., 6-19 Aug 2004 in Fig. 4b). Thus, on these days, the difference in synoptic scale wind in the wet and dry season may cause an important difference in the nature of sea breeze. In fact, under synoptic WSW wind as background in the "rainy" season, significant sea breeze developed on sunny days of 9 and 10 February (see Fig. 4a). In particular, on 10 February, the sea breeze penetrated to around 20 km inland to the south from the coast of Jakarta. However, convergence line due to the synoptic WSW and local NW (sea breeze) was formed over Jakarta area, and this convergence occurred whenever sea breeze developed in this wet season; the convergence line typically runs from the west of the coastal Jakarta to the south-east of the city, indicating that the synoptic WSW wind tends to prohibit inland-ward penetration of the sea breeze originated from Java sea (see Fig. 3a). Subsidence behind the convergence line lowered the depth of the sea breeze, by warming upper part of the wind layer; the depth was 0.5, 0.8, 0.4, and 0.2 km at 1200, 1300, 1400, and 1500 LST on 10 February, respectively. Figure 5a shows vertical cross section of the calculated wind and potential temperature at 1300LST along a line parallel to the sea breeze, illustrating location of the sea breeze front at 40 km, the structure of subsidence behind the front, and the depth of the sea breeze (i.e., 800m). It can be said that the Jakarta region is divided into two areas by the convergence line; that is, the eastern part affected by marine air from the Java Sea and the western part not-affected (see Fig. 6).

By this convergence and the subsidence behind the top of the front (i.e., convergence), relatively shallow stable layer was formed over the Jakarta area, indicating possible trap of the air pollutants below the layer and increased air pollution potential (see Fig. 5a).

In the dry season, though synoptic scale wind in upper layer is southeasterly, the southeasterly is blocked in lower layer by the mountains extending along the south coast of the Java Island (see Fig. 3b). Thus, in the northern plain of Java, the synoptic scale effect on the wind is weak, and therefore sea breeze from the Java Sea tends to easily develop as shown in Fig. 3b. Simulation results show that in this season sea breeze becomes much stronger and continues for longer time. For example, during 6-19 August 2004 the sea breeze developed every day, and penetrated to around 60 km inland from the coast of Jakarta. Furthermore, the sea breeze was connected to the valley wind developed in the

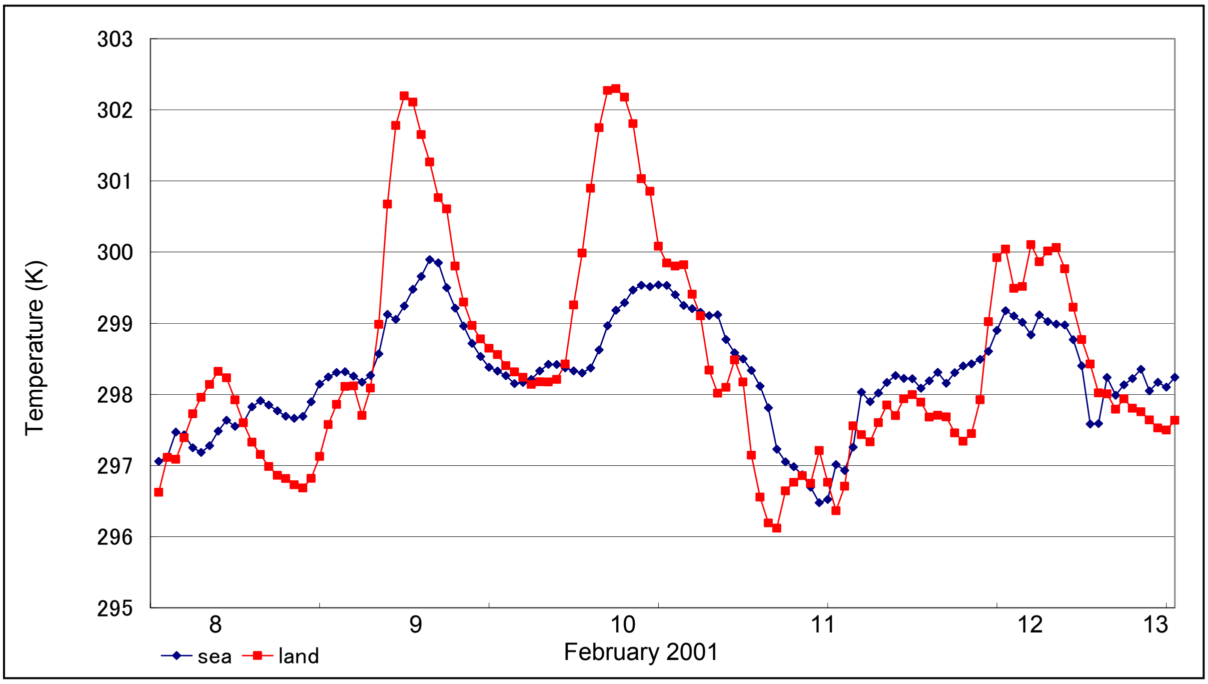


Fig. 4a. Temporal variation of calculated temperature (K) at near-surface level for 8-13 February 2001 : -◆-over the Java sea, about 10 km from coastal line, and -■- at 10 km inland from coastal line.

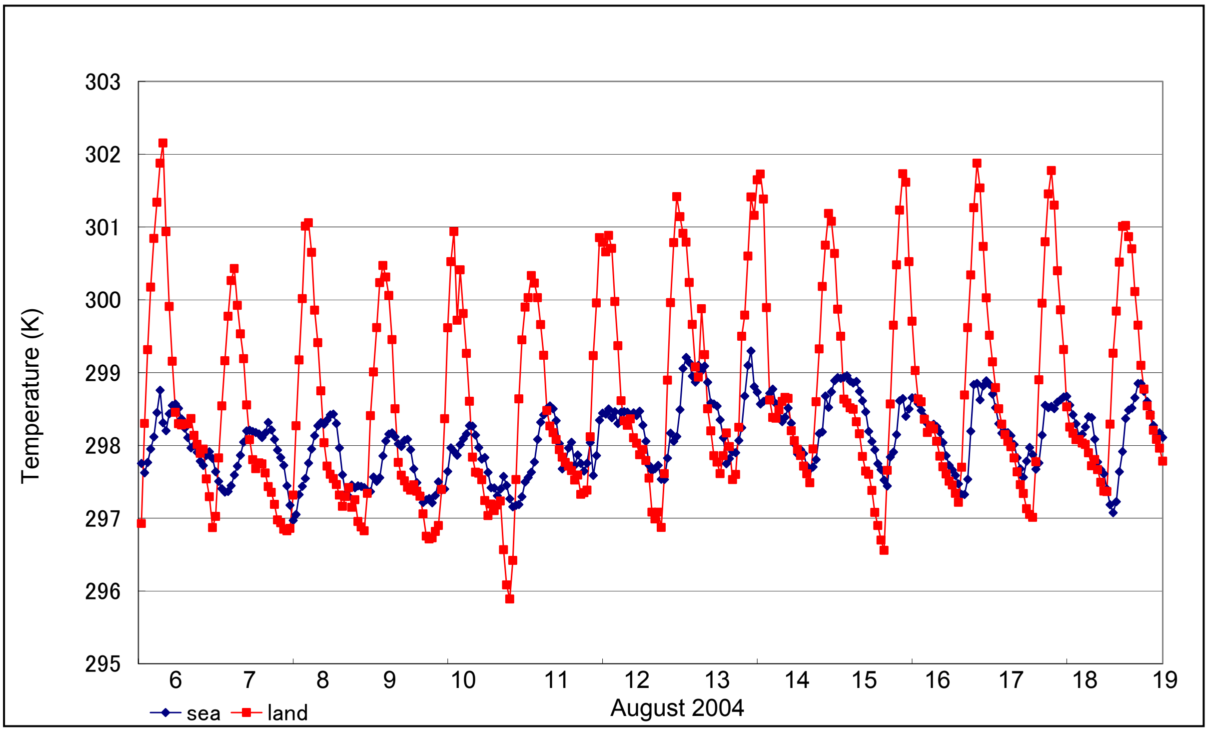


Fig. 4b. Same as Fig. 4a but for 6-19 August 2004 : -◆- over the Java sea, about 10 km from coastal line, and -■- at 10 km inland from coastal line.

southern mountainous area, resulting in one large scale local flow from the coast to the mountains (see Fig. 5b). Compared with the rainy season, it can be said that ventilation of polluted air over Jakarta may be better in the dry season, but also it may be thought that long range transport of air pollutants discharged in the coastal area tends to occur.

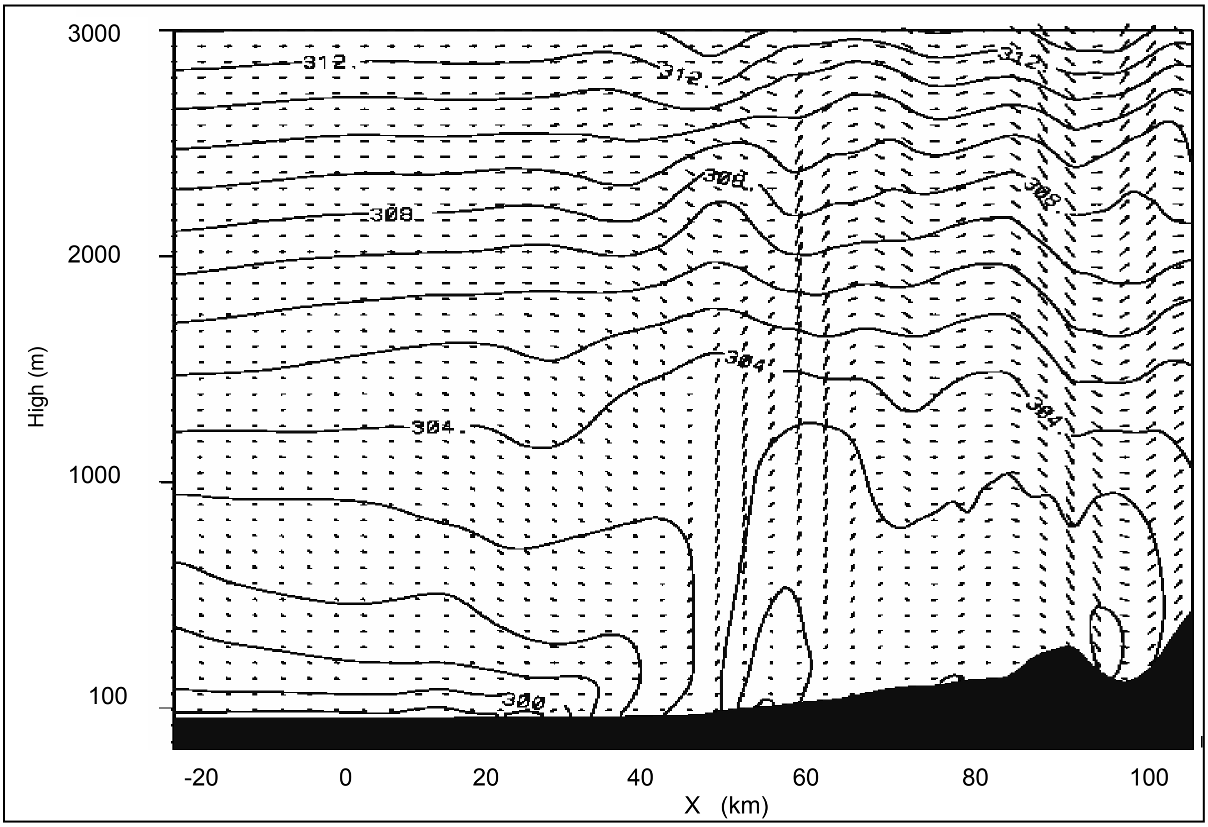


Fig.5a Vertical cross section of wind and potential temperature (K) in Jakarta area at 1300LST on 10 February 2001 (along line AB, see Fig. 3a for location).

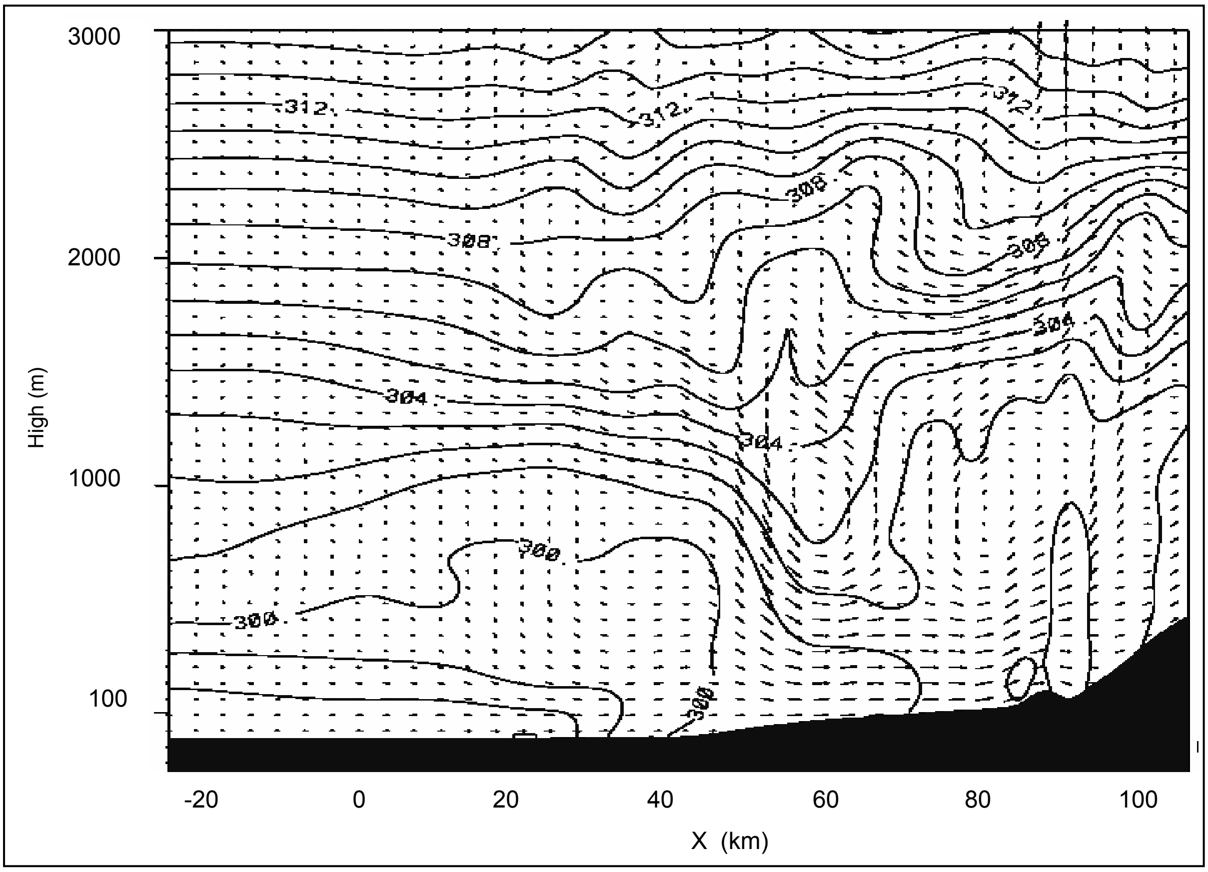


Fig.5b Vertical cross section of potential temperature (K) in Jakarta area at 1500LST on 8 August 2004 (along line CD, see Fig. 3b for location).

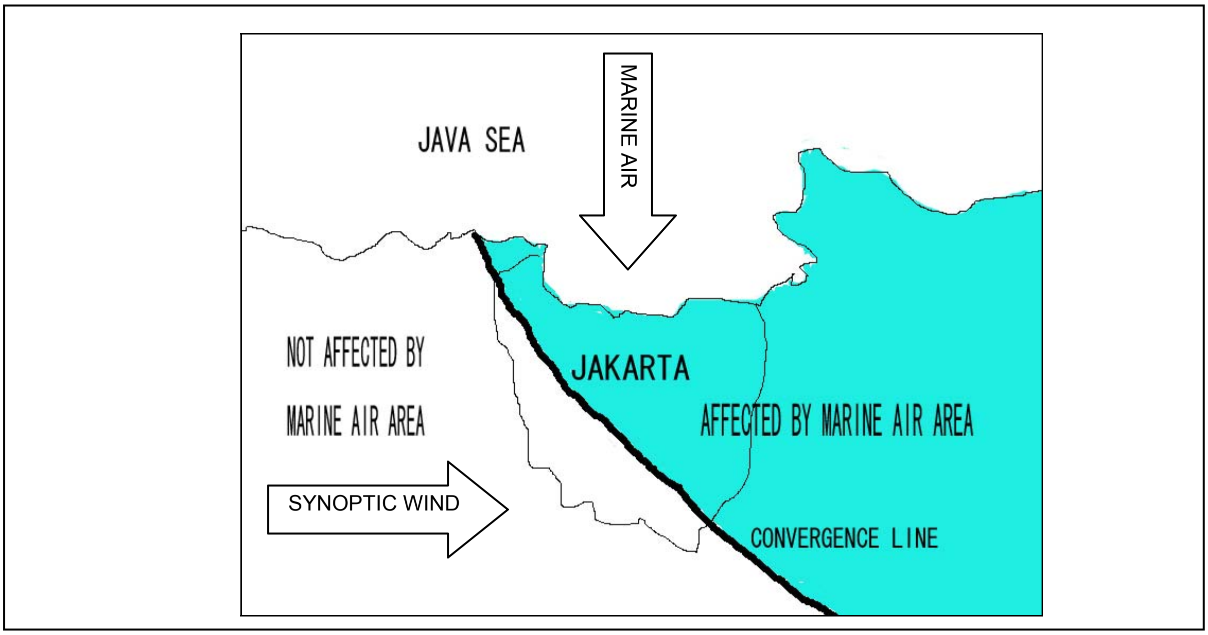


Fig. 6. On the sea breeze day in the “rainy” season Jakarta is divided into 2 parts by the convergence line formed with the synoptic WSW and the sea breeze (NW wind) from the Java Sea; the eastern part is affected by marine air from the Java Sea and the western part is not.

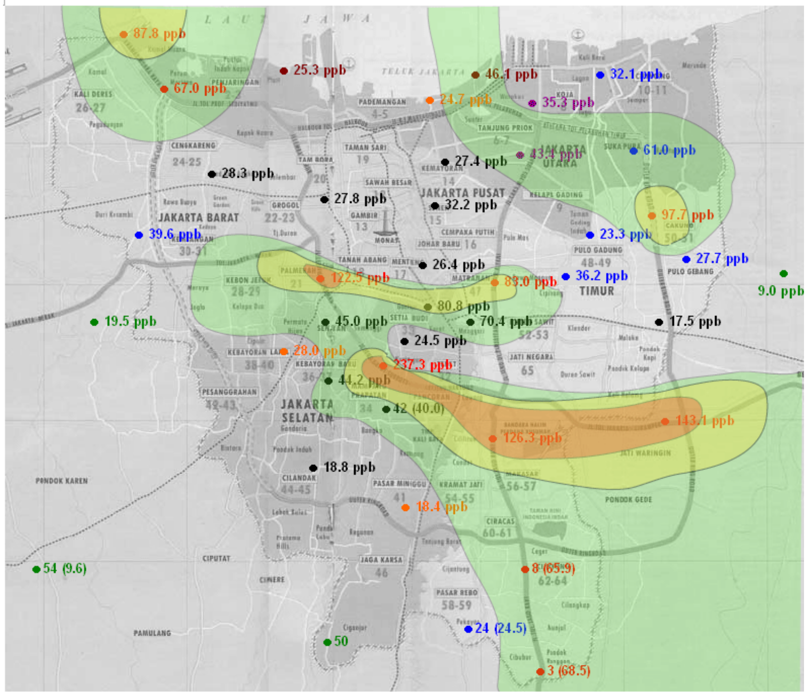
In the mountainous area to the south of Jakarta, another local flow of northerly valley wind independently develops in both wet (rainy) and dry seasons. As described above, in the dry season both sea breeze and valley wind form one combined local flow (see Fig. 5b). In contrast, in the wet season sea breeze and valley wind are never connected each other (see Fig. 5a), because the strong synoptic WSW wind always suppresses further penetration of the sea breeze, and separates the sea breeze from the valley wind.

3.3 NO_2 and SO_2 distribution over Jakarta

For planning of long term better air quality, to know quantitative relationship between air quality and emission sources’ distributions in the area is the first but the most important step, since air flow and other meteorological factors which are characteristic in the area largely affect the relationship in complex manner. As a “first” step to this purpose, we conducted field observation for air quality over Jakarta city using a number of passive samplers for NO_2 and SO_2 in August 2004. The samplers were distributed in 50 locations to measure both 1 day and 1 week averaged concentration distributions. Using the observed values, contours of NO_2 and SO_2 were plotted together with the model simulated surface wind fields (see Figs. 7 and 8). The obtained spatial distributions of NO_2 and SO_2 show that the highest concentration appears near the high traffic main highway, and then higher concentrations in business center and industrial areas. The highest “one-day” NO_2 was 446.1 μg/m^3, appeared at a site near toll highway in central Jakarta; 16 observation points including this site exceeded 92.5 μg/m^3, which is the Jakarta ambient air quality standard (Jakarta AAQS). On the other hand, “one-day” SO_2 concentrations were below the Jakarta AAQS 260 μg/m^3, though these at two sites exceeded the WHO AAQS 125 μg/m^3.

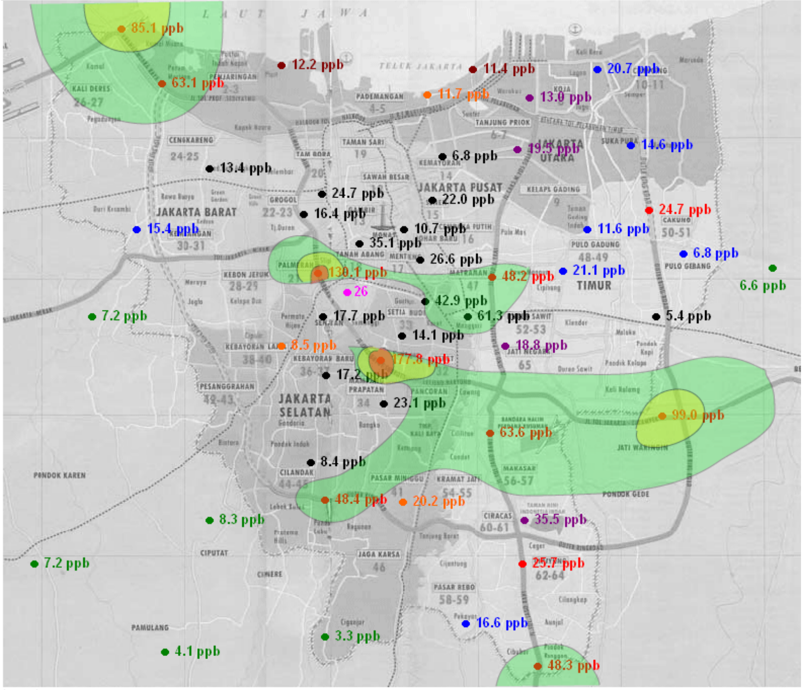
Vertical profile, up to 110 m high, of air pollution was also studied using a high building in business center of Jakarta. The “one-day” NO_2 concentrations were 119.8, 101.3, 87.6, and 100.4 μg/m^3 at 10, 30, 55, and 110 m high, respectively, and similarly those for SO_2 were 7.3, 1.8, 6.5, and 16.2 μg/m^3. It is interesting that the SO_2 increases with height, suggesting huge point sources of power plants located along the coast in the north-eastern part of Jakarta may have resulted in this profile under the sea breeze condition (see Fig. 9).

Concentration of NO$_2$ short term (1 day) measurement



Land use:
1. Toll Road (11) 2. Near Toll Road (4) 3. Near Powerplant (3) 4. Industrial Area (7)
5. High Building (1) 6. Urban Area (15) 7. Sub Urban (3) 8. Rural (6)

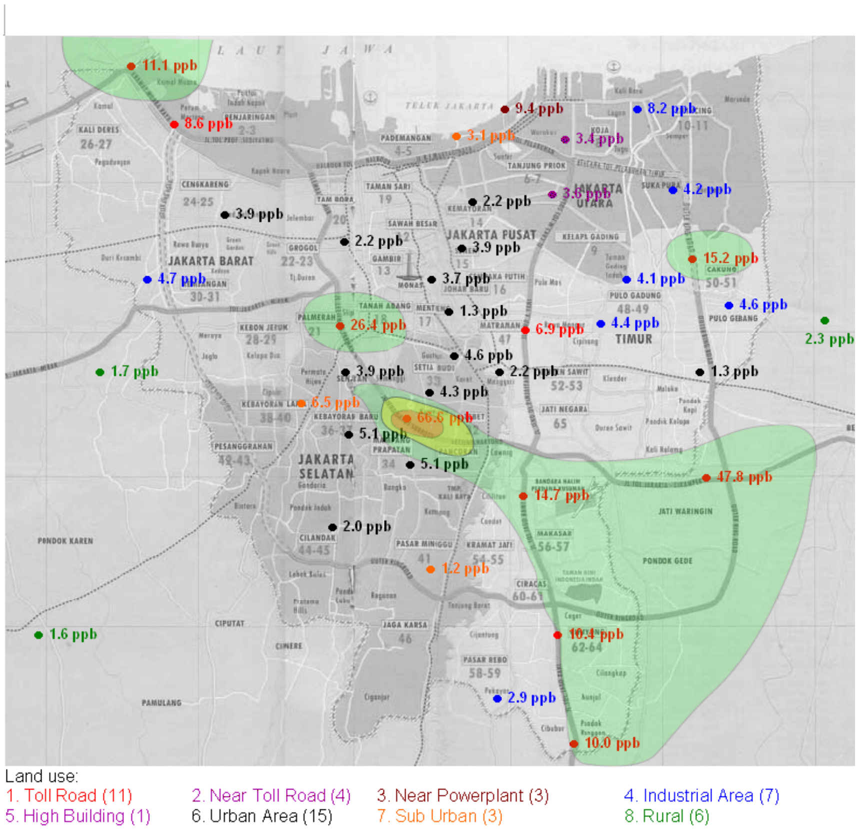
Concentration of NO$_2$ long term (1 week) measurement



Land use:
1. Toll Road (11) 2. Near Toll Road (4) 3. Near Powerplant (3) 4. Industrial Area (7)
5. High Building (1) 6. Urban Area (15) 7. Sub Urban (3) 8. Rural (6)

Fig. 7 Observed spatial distribution of NO$_2$; measured with 50 passive samplers distributed over the greater Jakarta during short and long term measurements in August 2004.

Concentration of SO$_2$ short term (1 day) measurement



Concentration of SO$_2$ long term (1 week) measurement

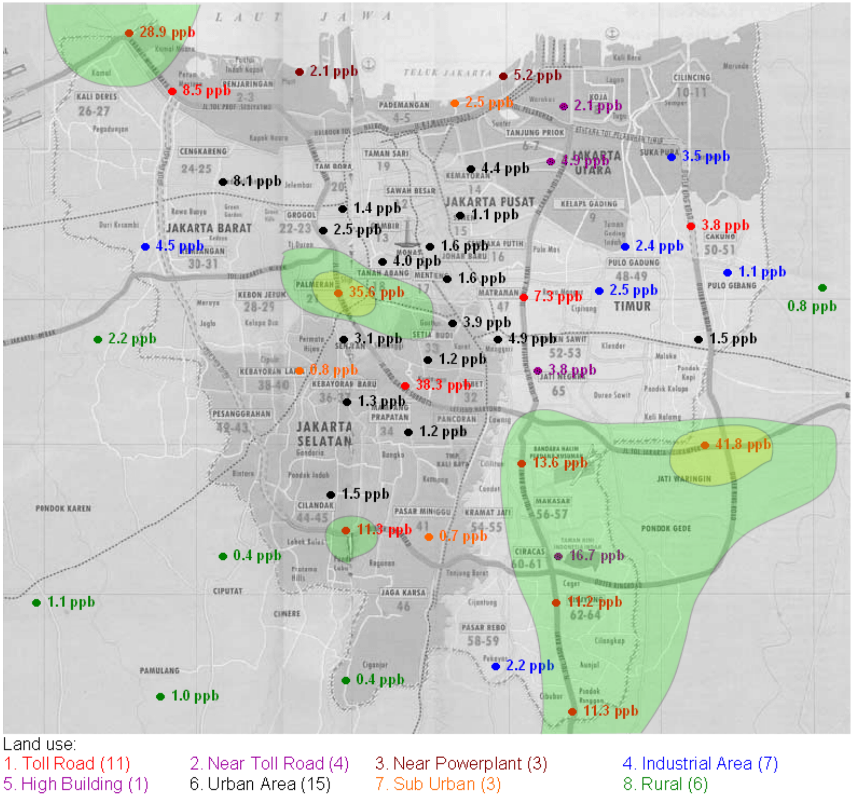


Fig. 8. Observed spatial distribution of SO$_2$; measured with 50 passive samplers distributed over the greater Jakarta during short and long term measurements in August 2004.

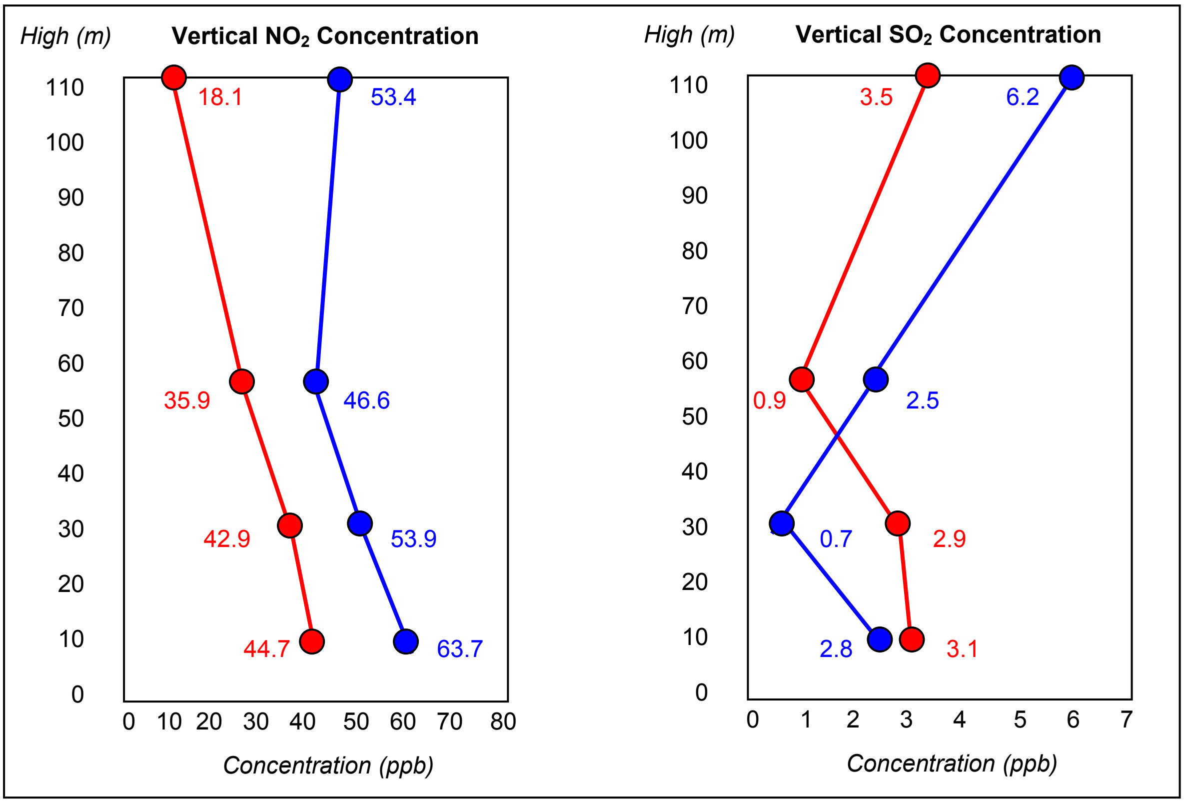


Fig. 9. Vertical profiles of measured NO_2 and SO_2 at business center of Jakarta: “blue” for short term (1-day) and “red” for long term (1-week) term measurements.

4. SUMMARY AND CONCLUSION

Characteristics of local flow in Jakarta area were numerically investigated for wet (rainy) and dry seasons. In the “rainy” season of 6-13 Feb, 2001, strong synoptic scale WSW wind regularly existed, and it suppressed penetration of NW sea breeze from the Java Sea on sunny days by forming a convergence with the sea breeze. Subsidence behind the convergence line (the sea breeze front) generated stable thin-layer above the sea breeze and thus part of the Jakarta area, indicating possible trap of the air pollutants below the layer and increase of air pollution potential. In the “dry” season of 6-19 Aug, 2004, though synoptic scale wind in upper layer was constantly southeasterly, it was very weak in the plain area of Jakarta because the synoptic SE wind was blocked by the mountains along the south coast of the Java Island. Hence, local winds of sea breeze from the Java Sea and valley wind over the northern slope of the southern mountains fully developed, forming one large scale combined local flow from the Java Sea to the mountains. This situation might give better ventilation of polluted air mass over Jakarta, though the “better ventilation” means export of air pollutants into the rural area.

6. REFERENCES

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