16. Characteristics of Air Pollution Transport in Jakarta Area in Dry Season - Numerical Simulation of SO₂, NO₂, and O₃ Dynamics in August, 2004-

乾季のジャカルタ地方における大気汚染の輸送特性：2004年8月のSO₂, NO₂, O₃の動態

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ABSTRACT ; Air pollution in Jakarta in the dry season (6–19 August, 2004) was numerically investigated by using CTM. Some of the obtained results are as follows. Pollutants rich marine air was found as source of ozone rich air mass brought into Jakarta by sea breeze. Shallow sea breeze and thermal internal boundary layers capped by strong stable layer resulted in a characteristic ozone concentration profile with low at ground and high at 300 m. Shallow sea breeze layer was due to synoptic easterly-southeasterly in this season.

KEYWORDS ; Photochemical smog, Jakarta, Land and sea breezes, Ozone, NO₂, SO₂

1. INTRODUCTION

Jakarta, located at about 6.2 °S and 106.8 °E in Java Island, Indonesia has two distinct seasons of “dry” and “wet”. The dry season continues from May to October and various local flows such as land and sea breezes develop every day in the season under weak synoptic southeasterly wind and low precipitation, potentially leading to serious air pollution in Jakarta whose population is about 10 million; in particular the air pollution due to O₃ and SPM (suspended particulate matter). In this study we have done chemical transport simulation for 6 – 17 August, 2004, by using a CTM(Kitada et al., 1993¹⁾; Kitada and Regmi, 2003²⁾) to understand dynamics of air pollution over Jakarta and to propose air pollution control strategy in the area. Some of the obtained results showed: (1) pollutants once transported from land area to Java Sea during the nighttime react to photo-chemically produce O₃ and others in the morning, and the pollutants-rich air mass again comes into Jakarta with sea breeze in the early afternoon, (2) then the polluted air entirely covers the Jakarta plain north to the southern mountains in the west Java, and (3) that pollutants originally discharged over Jakarta tend to accumulate in the air mass is suggested. Observed NO₂ and SO₂ distributions will also be discussed in the light of the calculation.

2. METEOROLOGICAL CHARACTERISTICS IN JAKARTA IN DRY SEASON

2.1. Climate

Dry season continues from May to September with the averaged monthly precipitation of about 58 mm for 1961 to 1990. In the dry season, synoptic-scale easterly and southeasterly dominantly blows over Java Island (see Fig.1 for typical

Figure 1. Surface streamlines and sea-level isobars (mb, first two digits omitted) in July. Areas with pressure above 1020 mb are shaded; below 1008 mb hatched (adapted from Riehl, 1979³⁾).

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streamlines and surface pressure distribution in July). These easterly and southeasterly, however, are blocked below about 1 km by the mountains extending from west to east along the southern coast line in the south part of the western Java (shown in Fig. 2⁴⁾). Hence, in Jakarta local winds such as land/sea breeze tend to develop in the lower layer under this weak synoptic wind⁴⁾.

2.2. Diurnal variation of surface wind: sea/land breezes

Meteorological simulation was performed for the period from 6 to 19 August in 2004 by using MM5 (PSU/NCAR Meteorological Model, version 5) to reproduce detailed three dimensional wind fields embedding sea/land breezes. Figure 3 shows calculated sea breezes with observation on 9 Aug. as a typical example, suggesting that sea breeze starts in the late morning around noon, covers entire Jakarta at 15LST, and finally reaches the foot of the southern mountains at 18LST. Wind s similar to those in Fig. 3 was repeated everyday during the simulation period. Figure 3 also shows good agreement of the calculated wind s with observations. (Detail of the calculation is described elsewhere⁴⁾).

Figure 2. An example of wind fields at ground level over the Western Java in the dry season (at 15LST, 9 Aug. 2004). Synoptic scale southeasterly is blocked by the mountains in north-western Java.

Figure 3. Typical temporal change of the calculated sea breeze field in the dry season: (a) 0900, (b) 1200, (c) 1500, and (d) 1800LST on 9 Aug 2004. Observed winds are also plotted as SH (Sukarno Hatta), WJ (West Jakarta), CJ (Central Jakarta), and EJ (East Jakarta).

3. CHEMICAL TRANSPORT SIMULATION

3.1 Chemical transport model, simulation period, and emission inventory

By using the calculated meteorological fields as inputs, chemical transport simulation for 11 days, started at 0600LST on 6 Aug 2004, was performed. Calculation domain for the CTM (the chemical transport model used for this study^{1,2,5)} simulations is shown in Fig. 4. Emission inventory for NO_x and SO_x were prepared based on the JICA estimation in 1995 by considering a GDP growth rate from 1995 to 2004. Detail for the estimation is described elsewhere⁴⁾.

3.2 Evaluation of the CTM simulation

During the simulation period, we conducted field observation of NO_2 and SO_2 in Jakarta⁶⁾ by using passive samplers distributed at 50 locations. Figure 5 compares observed and calculated NO_2 distributions for one day averaged concentration (i.e., 9 Aug 2004). Nitrogen oxides (nitrogen dioxide) are one of the most important chemical species controlling ozone concentrations through photochemical smog reactions. Figure 5 indicates the calculation quite well captures the observed NO_2 distribution. Further to examine the accuracy of the CTM simulation, the calculated concentrations of NO_2 and SO_2 are compared point for point with the

observed values in Fig. 6. As can be seen in Fig. 6, agreement between calculation and observation is excellent for NO_2 with a correlation coefficient, $R=0.91$ and acceptable for SO_2 with $R=0.76$.

Fig.4. Calculation region for CTM simulation: the area enclosed with thick solid line. Vertical cross sections of ozone etc. were analyzed along the "thick dotted line".

Figure 5. One day averaged NO_2 concentrations: (a) observed, and (b) calculated on 9 Aug. 2004.

3.3. Typical diurnal variation

of ozone under sea/land breezes: distribution on vertical plane

Sea and land breezes in Jakarta develop under the influence of synoptic scale easterly and southeasterly blowing in

Figure 6. Point by point comparison of observed and calculated one-day-averaged NO_2 (a) and SO_2 (b), and scatter plots for them..

the upper layer, though the synoptic wind is weak below 1 km over Jakarta since it is blocked by the high mountains (see Fig. 2). The calculated wind field shows that the combined sea breeze and valley wind, i.e. northerly, do not penetrate to the south over the ridge of the southern mountains, and that extent of the land breeze toward Java Sea is about 40 km from the Jakarta coast line. These features produce a characteristic development of ozone dynamics shown typically in Fig. 7, where north-south vertical cross sections of ozone, running over Jakarta (see Fig. 4), are plotted from 0300LST on 9 Aug to 0300LST on 10 Aug. Similarly, Fig. 8 illustrates NO₂ concentration for 0300, 0600, and 0900LST, 9 Aug.

Figure 7. Diurnal variation of ozone vertical cross section along north-south line running through the city center of Jakarta. The coast line of Jakarta is located at about 6°S. Time is from the top-left panel to the bottom-right panel: 0300., 0600, 0900, 1200, 1500, 1800, 2100, 2400 LST on 9 Aug, and 0300 on 10 Aug. 1° on the axis corresponds to about 111 km.

Figure 8. Same as in Fig. 7 but for NO₂: 0300, 0600, 0900LST on 9 Aug. from left to right.

Figures 7 and 8, with assistance of calculated wind fields on vertical and horizontal planes which are not shown here, indicate the followings on ozone dynamics in Jakarta: (1) during the nighttime southerly (land breeze) transports

NO_x-rich and the other primary pollutants-rich but ozone-poor air mass over Jakarta to Java Sea. The polluted urban air can finally reach about 40–50 km off the coast as suggested in the right-most panel at 0900LST in Fig. 8; (2) at 1000LST sea breeze circulation starts to develop at the Jakarta coast, and a height of the sea breeze front head reaches more than 1 km at 1100LST. The subsidence associated with the circulation brings down ozone in the upper layer over Java Sea off the Jakarta coast. Thus the background ozone concentration off the coast is increased by about 10 ppb from 20–30 ppb to 30–40 ppb; (3) at the same time photochemical smog reactions start in the polluted air mass over Java Sea, and ozone concentration increases in the air mass; (4) after 1200LST the ozone-rich air over Java Sea starts to intrude into Jakarta with sea breeze and entirely covers Jakarta at 1600LST; (5) the marine air dominates Jakarta until 2000LST, though at 1700LST the sea breeze/valley wind reaches the maximum distance about 60 km from the Jakarta coast line; (6) one interesting feature of the sea breeze in Jakarta in the dry season, found in Fig. 7, is its shallowness; the depth of sea breeze is at most 400 m besides it just behind the sea breeze front. One important reason for this will be the over-mountain flow, which is generated by synoptic scale easterly and southeasterly and the direction of which is opposite to the sea breeze and valley wind on Jakarta side, limits or suppresses the height of sea breeze front by forming stable stratification in the upper layer on the lee side of the mountains and also enhances the sea-breeze's return flow.

In the following subsection we will discuss characteristics found in calculated ozone vertical profiles at various sites from coastal to mountainous areas; how the arrival of the sea breeze and its associated vertical thermal structure change ozone profile there.

3.4. Vertical profiles of ozone in coastal, urban, and mountainous areas

Figure 9 shows the sites where vertical profiles of ozone concentration will be discussed; the “circle” is for the “Coastal” site, the “square” is for the “City-Center” located about 17 km from the “Coastal”, and the “triangle” is for the “Mountainous” site, which is about 56 km from the “Coastal” site. As can be inferred from Fig. 7, ozone is first produced by photochemical smog reactions in pollutants-rich air mass over Java Sea; the air mass migrated from Jakarta during the previous night and in the early morning. Temporal change of ozone at the “Coastal” in Fig. 10a clearly shows this situation; after the start of sea breeze at noon at the Jakarta coast, ozone concentration continuously increases with time and reaches its maximum at 1700LST; that the O₃-rich layer over Java Sea is relatively shallow with about 400 m deep is also suggested in the profiles.

About 1500LST the sea breeze front reaches the “City-Center” located at 17 km from the coast, as can be inferred from Fig. 3c. By this arrival of the sea breeze front ozone at the “City-Center” suddenly increases, and then gradually decreases with time at ground level while in the upper layer (for example, 300 m high) ozone continues to increase till 1700LST and remains high until sunset (see Fig. 10b). This ozone profile under the sea breeze situation (that is, after the passage of the front) can be thought due to thermal structure of the sea breeze layer; at the top of the sea breeze a stable stratification of marine air remains, while in the lower part of the sea breeze so-called thermal internal boundary layer (TIBL) develops after the landing of the sea breeze. Fresh NO discharged in Jakarta, therefore, quickly disperses in the TIBL and consumes ozone in the marine air mass, but the upper stable layer does not allow penetration of the NO rich urban air. Hence, as suggested in the ozone profiles at 16–18LST in Fig. 10b, high ozone concentration around 300 m in the stable layer remains high.

Ozone profiles at the “mountainous” site in Fig. 10c show little variation with only slight increase during 12 to 16LST and decrease below 300 m high at 17 and 18LST, indicating no significant influence by the polluted urban air till 16LST and arrival of the polluted air with NO_x rich and ozone poor nature after 17LST.

Figure 9. Map of the sites where temporal change of vertical ozone profiles were discussed: $\circ$ for "Coastal (6.1°S)", $\square$ for "City-Center (6.25°S)", and Δ for "Mountainous (6.6°S)" sites; 0.1 degree $\approx$ 11.1 km.

Figure 10a. Temporal change of O3 vertical profile from 1200 to 1800LST on 9 Aug at the "Coastal" site (see Fig. 9).

Figure 10b. Same as in Fig. 10a but for "City-Center".

Figure 10c. Same as in Fig. 10a but for "Mountainous".

4. CONCLUDING REMARKS

Air pollution in Jakarta in the dry season (6–19 August, 2004) was investigated by using CTM. A number of interesting features were found. Some of them are: (1) synoptic scale easterly and southeasterly limits depth of mixed layer and thus thickness of the sea breeze in Jakarta by forming strong stable layer due to over-mountain flow; the base of the stable layer is lower than 1 km high in the coastal area and 1.5 km high in the central plain area; thus sea breeze layer itself is also shallow only at 400 m with top of the layer being stably stratified, and the thermal internal boundary layer is consequently shallow; this nature results in NO (primary pollutant) rich and thus ozone poor situation in Jakarta. (2) ozone is mainly produced in polluted marine air off the Jakarta coast, which was transported from Jakarta by the land breeze during the nighttime; this ozone rich marine air intrudes Jakarta area, and because of thermal stratification described above, the profile of ozone concentration with low at ground and high at 300 m in upper layer.

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