INCREASE OF OZONE CONCENTRATION IN AN INLAND BASIN DURING THE PERIOD OF NOCTURNAL THERMAL HIGH

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(Received August 2002; accepted 5 January 2003)

Abstract. Since ground level ozone concentrations in the basin on one day before the occurrence of unusually high air temperature with nocturnal thermal high showed a typical urban type of a maximum ozone concentration at 1300 LST and a minimum at night. However, a maximum ozone concentration under extremely high air temperature of 39.2 °C was detected at 1700 LST or 1800 LST at two environmental monitoring sites, which was 4 or 5 hr delayed from the typical occurrence time, 1300 LST. Its maximum value showed about 50 or 70% increase of the concentration more than the typical maximum value and its concentration gradually decreased until 2100 LST. After 1200 LST until 1800 LST, air temperature was maintained over 35 °C and the high temperature made a great contribution to the increase of O_3 for several hours. The deviated occurrence time of a maximum ozone concentration is mainly attributed to meteorological and topographic effects – shifted occurrence time of maximum air temperature, shrunken atmospheric boundary layer depth and wind. While daytime O_3 concentration due to photochemical production of O_3 from NO_2 increased, NO_2 concentration decreased, with their reverse respondent patterns each night. A secondary maximum concentration of O_3 at 2300 LST or 2400 LST is due to a much shallower depth of nocturnal surface inversion layer with daytime producing more O_3 than that of the daytime convective boundary layer, resulting in the increase of ozone concentration, though the reduction of ozone occurred under the reversal process of O_3 into NO_2.

Keywords: convective boundary layer, NO_2, nocturnal surface inversion layer, nocturnal thermal high, O_3

1. Introduction

In the recent years, frequent nocturnal warming such as tropical night has occurred in urban areas and its driving mechanism has not been solved for many different reasons (Andre and Mahrt, 1981). When air temperature higher than 25 °C is continuously maintained at night, it is called the occurrence of tropical night (Choi and Kim, 1997). Kondo *et al.* (1989) and Kuwagata, *et al.* (1990) presented that on calm and cloudless days, more sensible heat had to be accumulated in the valley region than over the mountainous areas.

Baird (1995) explained that oxidation can react to convert NO to NO_2 via the O_3 process and more than one NO molecule must be oxidized to NO_2 per hydrocarbon molecule broken up to permit ozone to accumulate for the day. The transport of chemical species between stratosphere and troposphere may also play an important role in the atmospheric chemistry near the surface. The highest ozone concen-

Water, Air, and Soil Pollution: Focus **3:** 31–51, 2003.

trations were generally connected with an efficient stratosphere-troposphere exchange, under the downward transport from the stratosphere (Girdzine, 1991; Austin and Midgley, 1994; Moon, *et al.*, 2002; Seinfeld and Pandis, 1998). Stratosphere-troposphere exchange is associated with tropopause folding in the rear of an upper jet streak, in the cut-off low in the mid-latitude and surface high-pressure system (Cooper, *et al.*, 1998; Davis and Schuepbach, 1994; Kondratyev and Varotsos, 2000; Kim, *et al.*, 2002).

In general, ground level O_3 concentrations for daytime hours in an urban area show a maximum value near 1300 LST and a minimum one at night, due to a photolytic cycle of NO_2-NO-O_3. Kimura (1983) and Kimura and Takahashi (1991) explained that as the nitric oxide was oxidized to nitrogen dioxide through the reaction of the hydrocarbons, the ozone at an urban city could build up, showing its maximum concentration near 1300 LST and the minimum one at night. Evans, *et al.* (1983) showed that with ozone measurements from a network of remote sites, air temperature variations were usually very well correlated with solar radiation changes and the latter produced variations in the photochemical activity, there by leading to ozone variability.

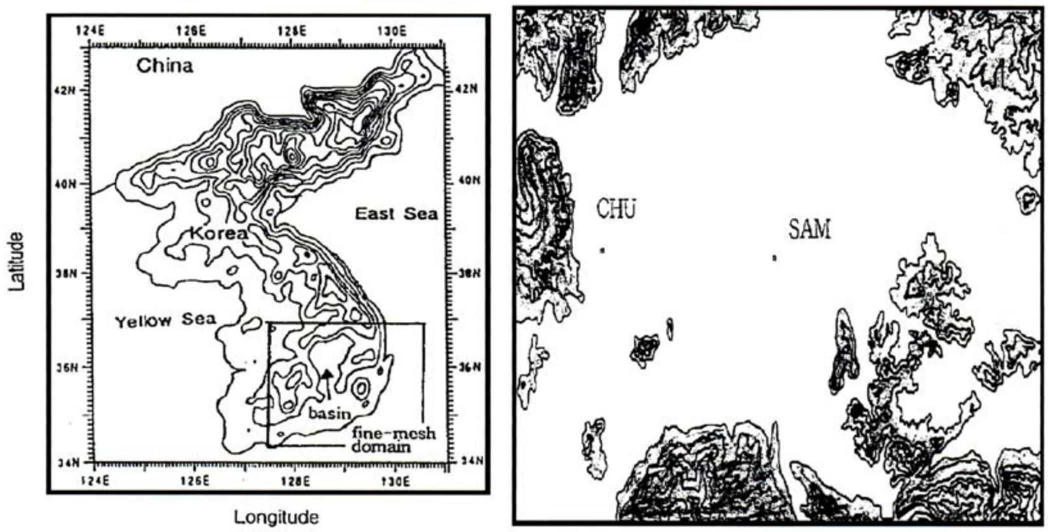
In the current study, when an unusual nocturnal thermal high occurred, daytime air temperature was very high reaching above 39 °C which is 2 °C higher than the day before. On a usual day, ground level concentration of O_3 had a maximum at 1300 LST and a minimum near midnight. However, on unusually high temperature days, the concentration of O_3 had its maximum value at 1700 LST or 1800 LST and a minimum at the time just before sunset.

The purpose of this study is to investigate how different a diurnal variation of ground-level O_3 concentrations on unusually high temperature days was from usual O_3 concentrations at Taegu city (35°53′N, 128°37′E; 57.8 m above mean sea level) in a basin of about 25 km width, under nocturnal thermal high (tropical night). Further consideration was given to the relationship of O_3 with NO_2 and O_x (= O_3 + NO_2).

2. Data Acquisition and Numerical Analysis

2.1. Topographical Feature and Data Acquisition

The study area in a fine-mesh domain consists of complex terrain characterized by high mountains in the west and relatively low mountains in the north and east, but by almost plain topographical features or very low mountains in the south as an inlet. Tae Bak mountains run from south to north along the eastern coast of the Korean peninsula and were connected with another branch of mountains toward the south-west, off Tae Bak mountains in a coarse-mesh domain (Figure 1). Taegu city is located in a basin, almost in the central part of the fine-mesh domain and is about 50 km away from the eastern coast as shown in Figure 2.



(a) (b)

Figure 1. Topograpical features in Korean peninsula and study area in a fine-mesh domain. Box denotes a fine-mesh domain for the meteorological model operation and Taegu city (35°53′N, 128°37′E) is in a basin (a). SAM and CHU denote Samduck and Chungli environmental observatories, inside the city.

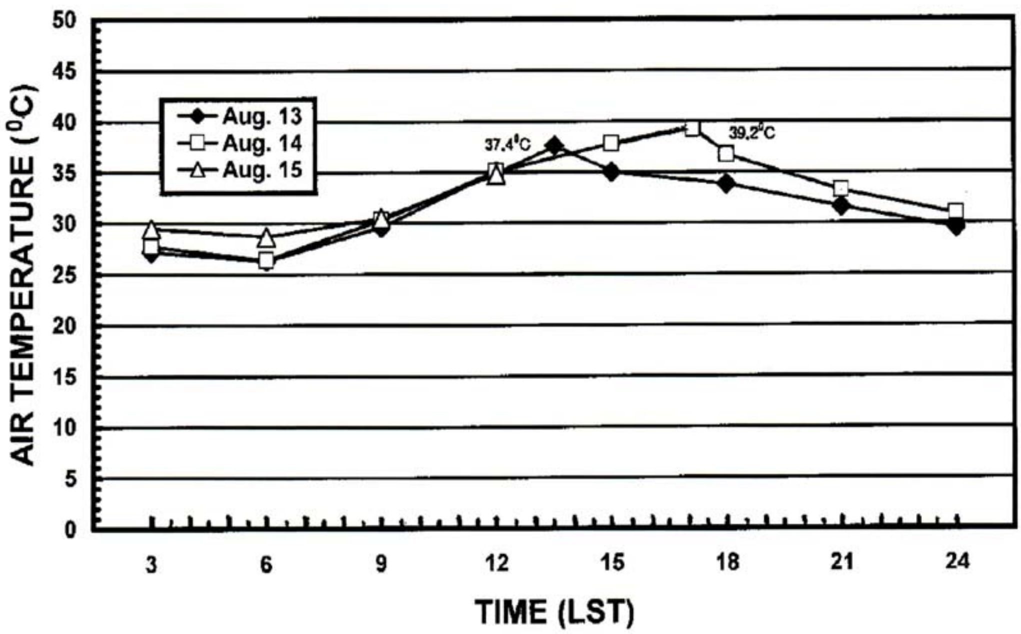


Figure 2. Air temperature (°C) at Taegu city from 0300 LST, August to 1200 LST August 15, 1995. Values outside line indicate maximum air temperatures.

In order to investigate a diurnal variation of ozone concentrations at Taegu city in a basin surrounding high mountains, for the period of unusual occurrence of daytime high air temperature with nocturnal thermal high, hourly ground level concentrations of O_3 were measured by Taegu Regional Environmental Agency (TREA, 1995), the Ministry of Environment of Korean Government were used. As photochemical reaction of NO_2 into O_3 can induce ozone production during the day, the relationship of O_3 with NO_2 and O_x were investigated in detail. Hourly concentrations of O_3 from 0000 LST on August 13 through 2400 LST on August 15, 1995 were automatically measured by DASBI-1108 and the concentrations of $NO_x$by DASBI-2108, were established at Samduck and Chungli Environmental Observatories, inside Taegu city. The accuracy of the DASIBI analyzer was maintained while measuring the air quality. The Ministry of Environment reanalyzed automatically the acquired data (TREA, 1995). From the detectors measured the concentrations of NO_x and NO_2, NO concentration should be regarded as the difference between two measured values.

2.2. Numerical Model and Input Data

A three-dimensional hydrostatic and non-hydrostatic grid point model with a one way double nesting technique in a complex terrain following coordinates (x, y, z*), called LAS-V model, was devised by Meteorological Research Institute (MRI), Japan Meteorological Agency (JMA). It was used to investigate the occurrence of unusual high air temperature with nocturnal thermal high at Taegu city in a basin with surrounding high mountains and thermal circulation, due to different heat and moisture budgets between basin and mountain. For understanding nocturnal thermal high, atmospheric circulation pattern, heat budgets such as turbulent fluxes for heat and momentum and sensible and latent heat fluxes, temperature field, moisture content were estimated in detail. Numerical simulation for 48 hr, from 0900 LST, August 13 through 0900 LST, August 15 were undertaken by a Hitachi super computer at MRI (Takahashi, 1998).

The model domain consists of 50×50 grid points with a uniform horizontal interval of 20 km and 5 km in coarse-mesh and fine-mesh domains and vertically 16 levels (15 layers) from 10 m to 6 km of the model top with sequentially larger intervals. 12 hourly global analysis data (G-ANAL) of 1.25° resolution – pressure, wind, potential temperature and specific humidity on five levels from surface to 100 mb height made by JMA were horizontally and vertically interpolated to the coarse-mesh model domain as input data for a three-dimensional hydrostatic numerical model. Then, simulated values by hydrostatical model were treated as input data in the lateral boundary of a fine-mesh domain for operating a three-dimensional non-hydrostatical model. National Fisheries and Development of Agency reanalyzed GMS satellite pictures for obtaining sea surface temperature data (SST) and the evaluated SST data were used as input data of the numerical model in the open sea of two model domains (NFRDA, 1995).

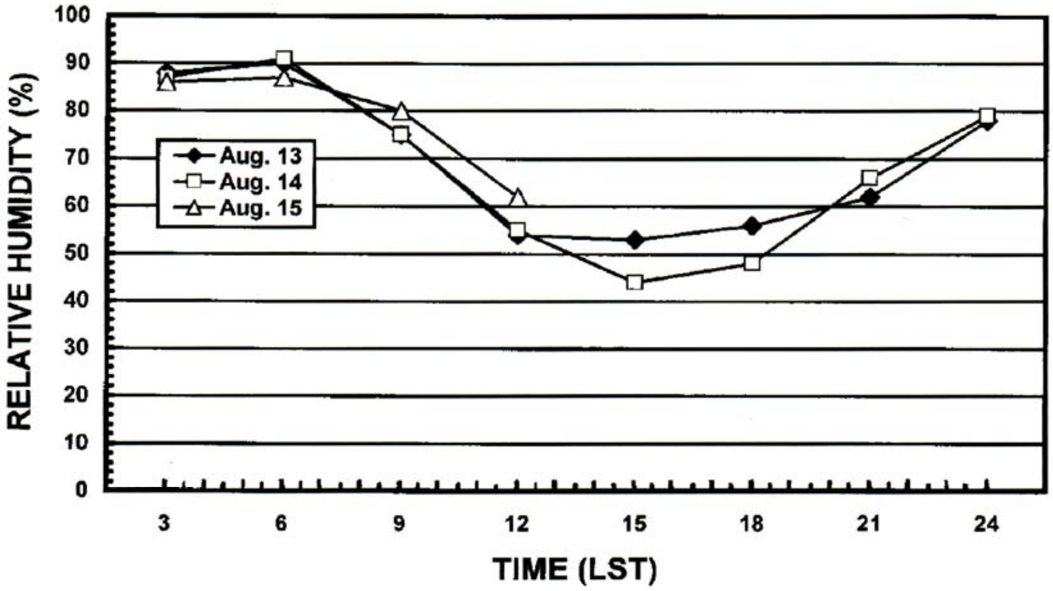


Figure 3. As shown in Figure 2, except for relative humidity (%).

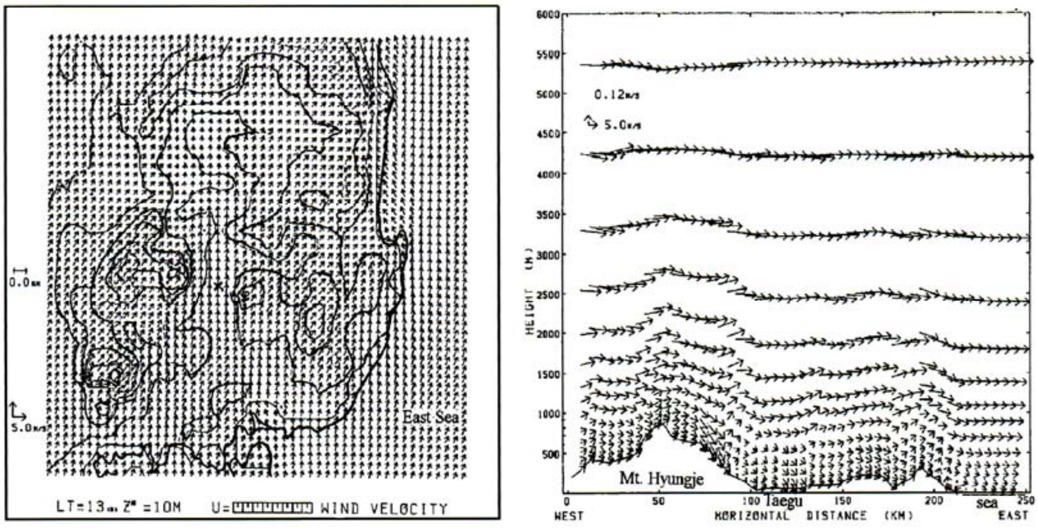
3. Result and Discussion

3.1. Meteorological Situation

3.1.1. *Day Before High Concentration of Ozone*

On August 13, 1995, the ozone concentration at Taegu city as inland basin was very high, especially near the downtown area under a maximum temperature of 35 °C and relative humidity was 45% (Figures 2 and 3). During the day, synoptic-scale southwesterly wind blew from the western mountain sides toward the East Sea, passing through an inland basin (Figures 4a and 4b). At 1300 LST (LST; local standard time = 09 h + Green Witch Mean Time), on the vertical profiles of wind vector on a straight cutting line from Mt. Hyungje-Taegu city (x)-East Sea, westerly downward wind along the slope of the mountain was interrupted by thermally induced valley wind from the down town of the city toward the mountain, resulting in calm or very weak wind in the bottom of the mountain in the west.

Vertical diffusion coefficient of turbulent heat (K_h) is a good index to find the turbulent process such as the development of convective boundary layer or nocturnal surface inversion layer (Figure 5a). Figure 5b shows potential temperature deviation lies (K; $\theta' = \theta - \Theta$), which implies to subtract mean potential temperature from each potential temperature, from the ground surface to the top of the model domain, and its meaning is the same of potential temperature. Under the strong thermal heating of the ground surface for the daytime hours, atmosphere over the basin was unstable and in the afternoon, it becomes neural due to the vertical mixing of air masses with a thickness of 800 m, up to the height of 1500 m. Even if valley wind blew from the basin (Taegu city) toward the top of the mountain,

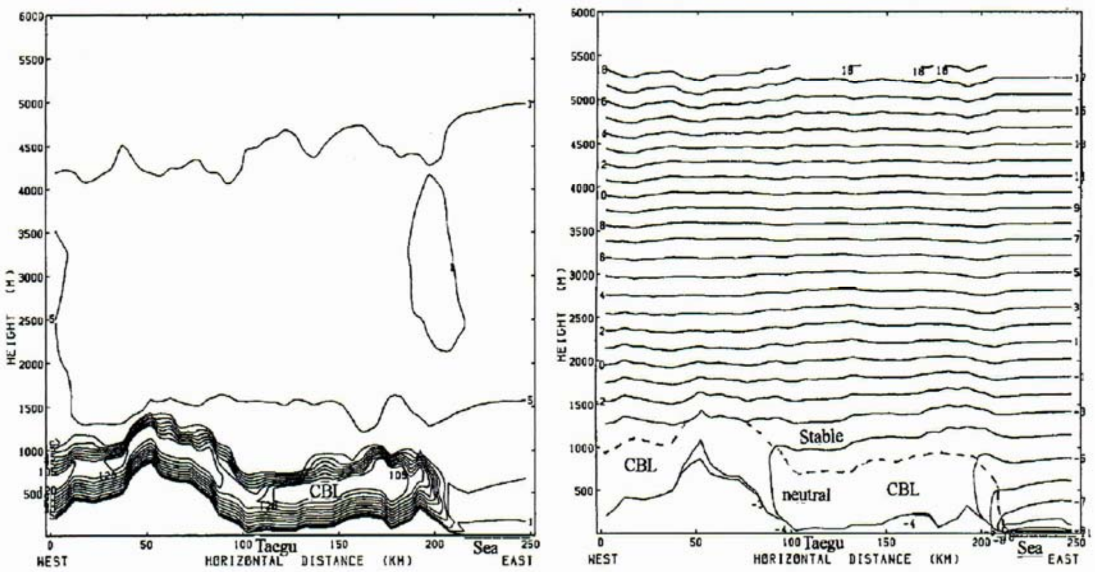


(a) (b)

Figure 4. (a) Wind vector (m s^{-1}) at 1300 LST (near noon), August 13, 1995 in a fine-mesh domain near Taegu city. Thin line and x denote topography and Taegu city. (b) Vertical profiles of wind (m s^{-1}) on a straight cutting line (Mt. Hyungje-Taegu (x)-East Sea) in Figure 4(a) show that westerly moderate wind prevails at the city in the basin.

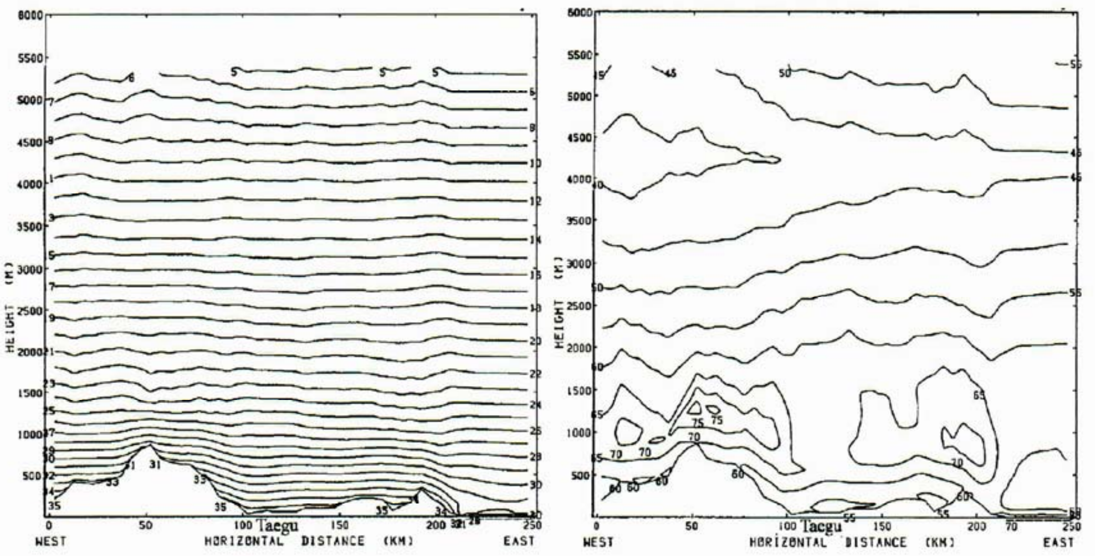
south-westerly wind interrupted the westward intrusion of valley wind, resulting in only the existence of calm or weak westerly wind. At this time simulated air temperature at Taegu city in the basin was 36 °C and observed temperature was 37.4 °C (Figure 6a). Relative humidity was 55% and the air in the basin was very dry (Figure 6b).

After sunset, near 1900 LST, synoptic-scale westerly wind associated with mountain wind from the top of the mountain toward the inland basin became a very strong westerly wind (Figures 7a and 7b). Due to the cooling of the ground surface, nocturnal surface inversion layer with a thickness of about 200 m was developed over the basin surface, and nocturnal atmospheric boundary layer was much shrunken than daytime convective boundary layer (Figures 8a and 8b). Even if thermal circulation of valley wind (day) and mountain wind (night) in the basin, due to the different heating and cooling rates of mountain and basin surfaces, itself was generated, prevailing westerly synoptic-scale winds were interfered with local thermal circulations like valley wind for the day and associated with mountain wind at night. As the daytime heated air masses in the basin were not much cooled down by the nighttime cooling of the ground surface, the phenomenon of nocturnal thermal high occurred with air temperature of 34 °C and this hot night continued to exit before sunrise. In Figure 9a, warm pool existed over the nocturnal surface inversion layer and the long wave radiation toward the ground surface could main-



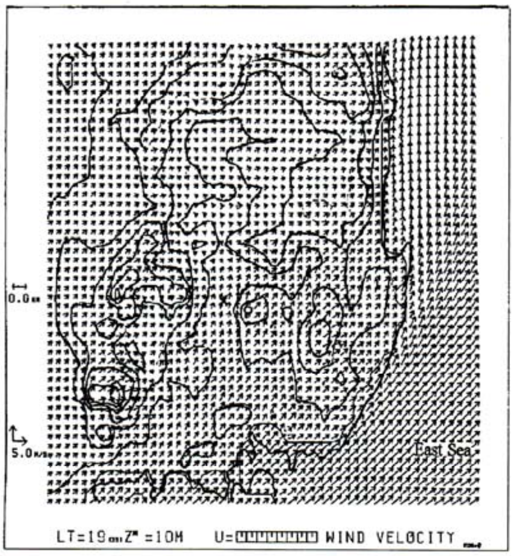
(a) (b)

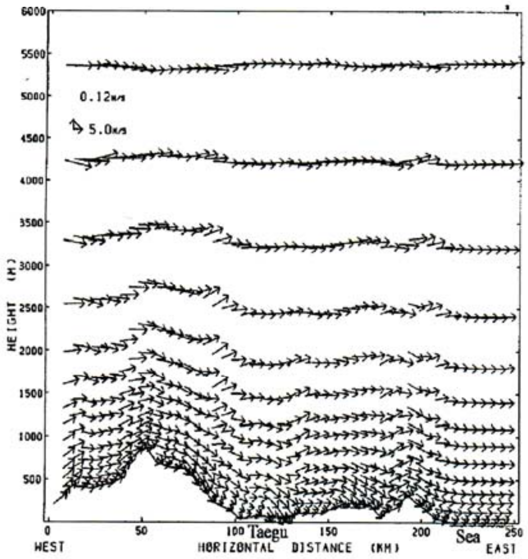
Figure 5. (a) As shown in Figure 4(b), except for vertical diffusion coefficient for turbulent heat (K_h; m^2 sec^{-1}) and potential temperature deviation (K; $\theta' = \theta - \Theta$). (b) In the vertical profiles, convective boundary layer (CBL) with a thickness of 800 m at Taegu city in the basin is developed up to the height of 1500 m over the ground. Dash line and neutral denote the top of CBL and neutral atmosphere with mixing of air masses.



(a) (b)

Figure 6. (a) As shown in Figure 4(b), except for air temperature (°C) and (b) relative humidity (RH; %). Air temperature at Taegu city is 35 °C and RH is 55%.





(a) (b)

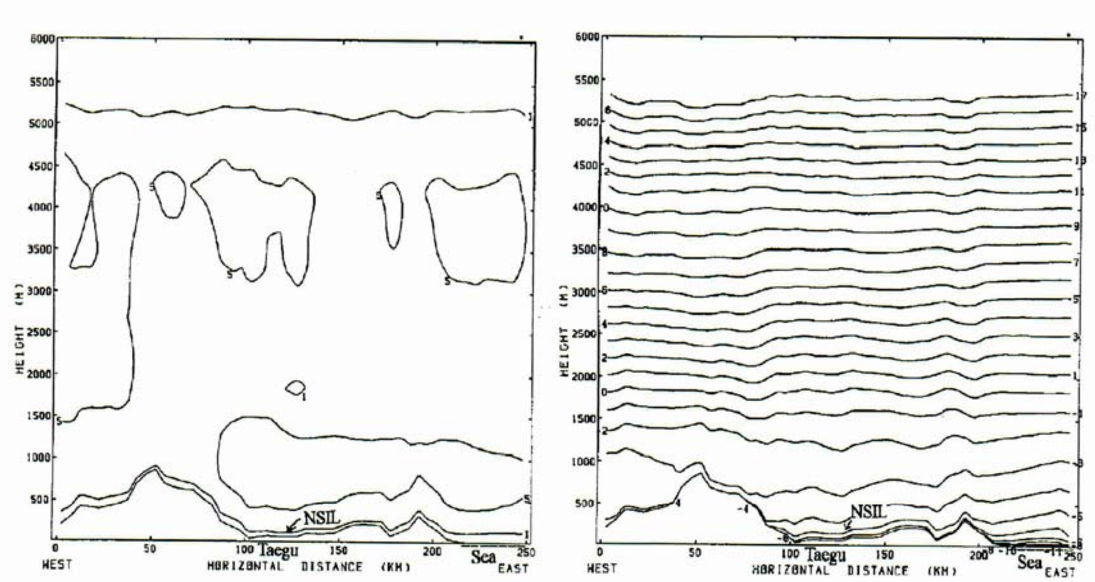
Figure 7. (a) Wind vector (m s^{-1}) at 1900 LST (near sunset), August 13, 1995 in a fine-mesh domain near Taegu city. Thin line and x denote topography and Taegu city. (b) Vertical profiles of wind (m s^{-1}) on a straight cutting line (Mt. Hyungje-Taegu (x)-East Sea) in Figure 4(a) show that westerly moderate wind prevails at the city in the basin.

tain the occurrence of nocturnal thermal high. Relative humidity increased up to 75%, with an increasing amount of 20% (Figure 9b).

Near midnight, similar to 1900 LST, at 0100 LST, August 14, westerly wind became more intensified by downward mountain wind and strong westerly wind prevailed through the basin (Figures 10a and 10b). The depth of nocturnal surface inversion was almost same as that at 1900 LST or slightly shrunken, as nighttime went on (Figures 11a and 11b). The long wave radiation from a warm pool of 33 °C over the nocturnal surface inversion layer could still maintain nocturnal thermal high, and relative humidity of 70% was also slightly lower than that at 1900 LST (Figures 12a and 12b).

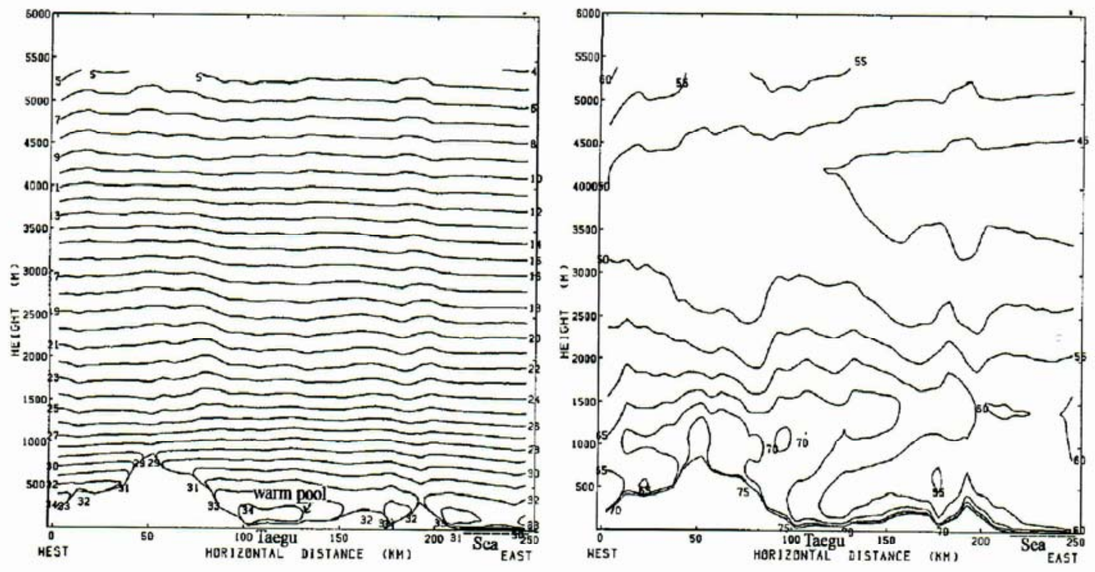
3.1.2. *Day of High Concentration of Ozone*

At 1300 LST in the next day, westerly wind was stronger than the wind at 1300 LST, August 14 (Figures 13a and 13b). Convective boundary layer was more developed with a thickness of 800 m and it reached up to the height of 1500 m (Figures 14a and 14b). Since air temperature was above 35 °C, up to 39.3 °C, air was very dry under 45% of relative humidity (Figures 2, 15a and 15b). It is believed that air temperature variations are usually very well correlated with solar radiation changes and the latter produces variations in the photochemical activity, by leading to ozone variability (Evans, 1983). Under this circumstance, a great amount of ozone could be produced by photolysis process of NO-NO_2-O_3,



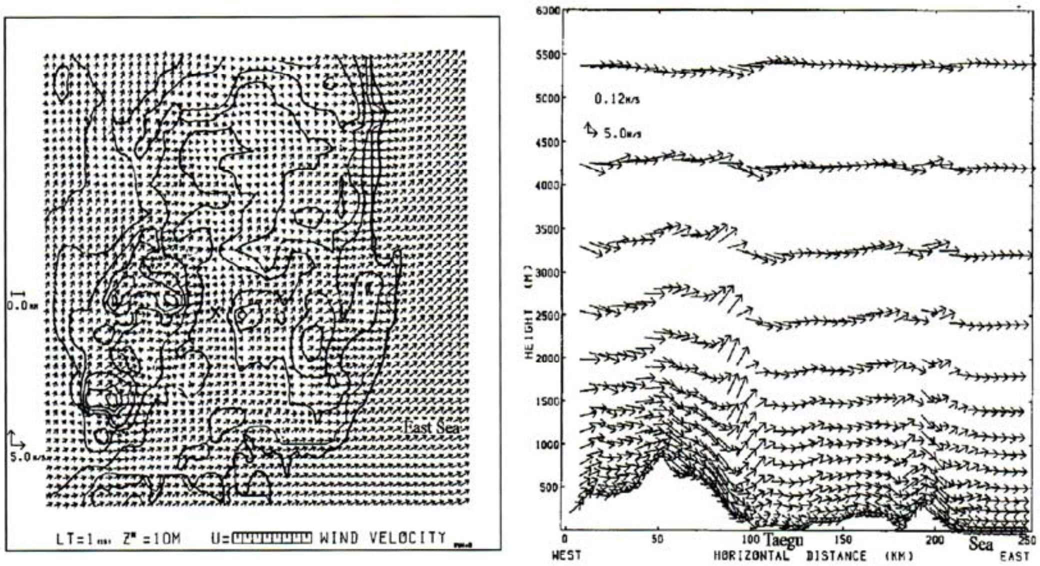
(a) (b)

Figure 8. (a) As shown in Figure 7(b), except for vertical diffusion coefficient for turbulent heat (K_h; m^2 sec^{-1}) and (b) potential temperature deviation (K; $\theta' = \theta - \Theta$). In the vertical profiles, nocturnal surface inversion layer (NSIL) is developed with a thickness less than 150 m at Taegu city in the basin.



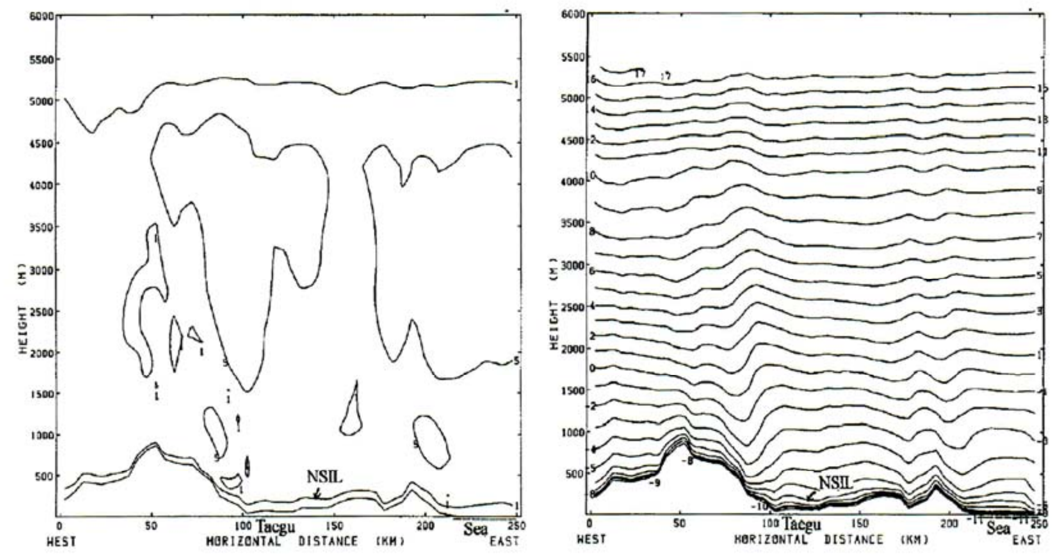
(a) (b)

Figure 9. (a) As shown in Figure 7(b), except for air temperature (°C) and (b) relative humidity (RH; %). There is a warm pool of 34 °C over the ground surface and nocturnal thermal high occurs. RH is 75% at Taegu city and the NSIL is still shallow.



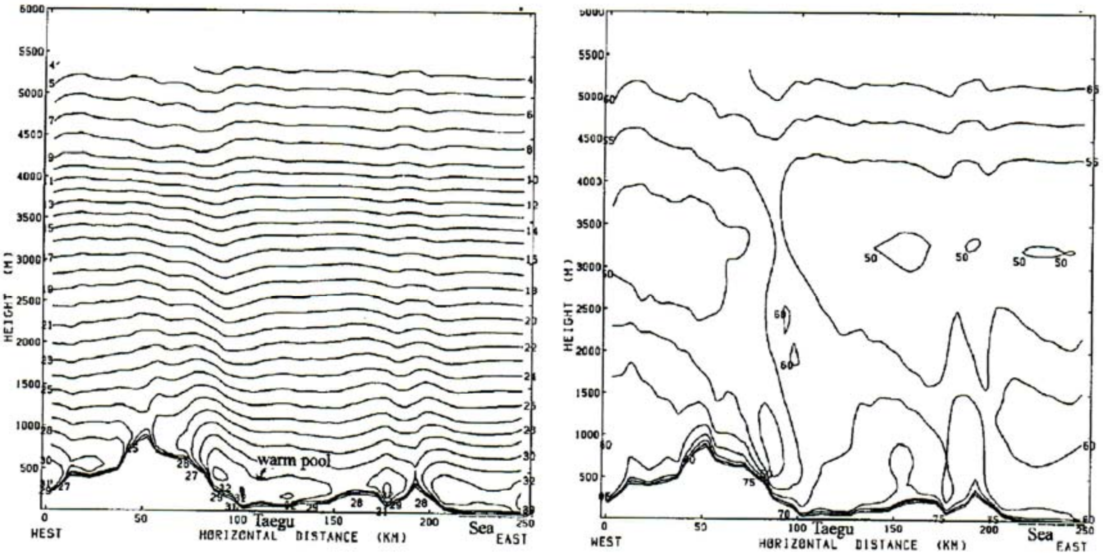
(a) (b)

Figure 10. (a) Wind vector (m sec^{-1}) at 0100 LST (near midnight), August 14, 1995 in a fine-mesh domain near Taegu city. Thin line and x denote topography and Taegu city. (b) Vertical profiles of wind (m sec^{-1}) on a straight cutting line (Mt. Hyungje-Taegu (x)-East Sea) in Figure 10(a) show that strong westerly wind prevails at the city in the basin.



(a) (b)

Figure 11. (a) As shown in Figure 10(b), except for vertical diffusion coefficient for turbulent heat (K_h; m^2 sec^{-1}) and (b) potential temperature deviation (K; $\theta' = \theta - \Theta$). In the vertical profiles, nocturnal surface inversion layer (NSIL) is developed with a thickness less than 150 m at Taegu city in the basin.



(a) (b)

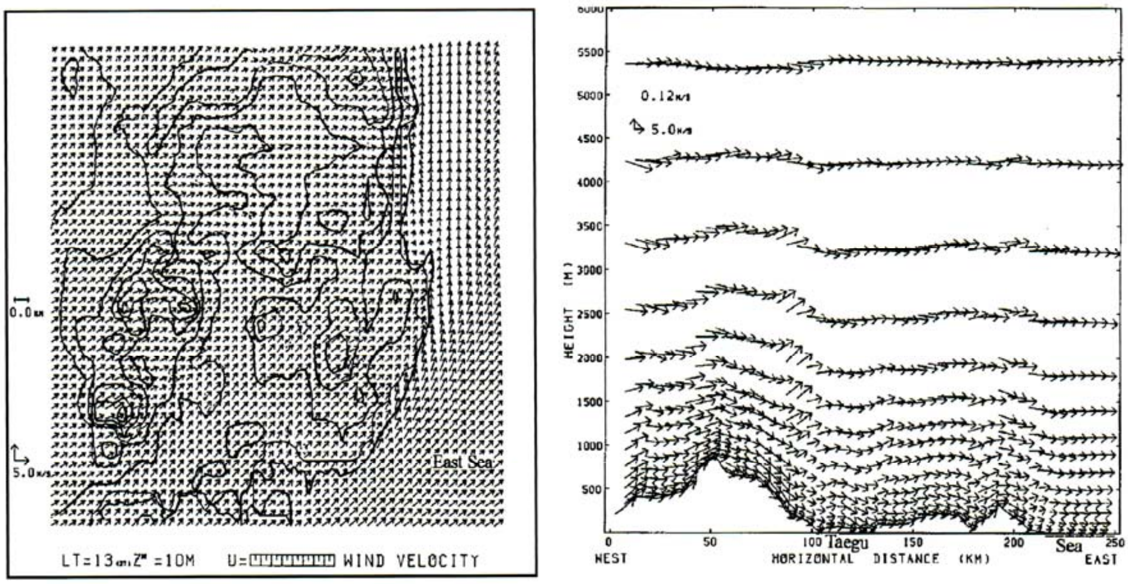
Figure 12. (a) As shown in Figure 10(b), except for air temperature (°C) and (b) relative humidity (RH; %). There is a warm pool of 33 °C over the ground surface and nocturnal thermal high occurs. Taegu city has RH of 70%, which is 5% lower than that at 1900 LST, under the transport of dry air along the slope from the top of the mountain.

comparing with one on August 13. Compared to weak westerly wind on August 13, strong westerly wind above 5 m s^{-1} compressed air parcels near the surface in the bottom of the mountain and in the basin, adiabatic heating process of air could make some contribution to the increase of air temperature, resulting in a good atmosphere for the production of ozone.

At 1900 LST, just after sunset, strong westerly wind prevailed, whole basin and nighttime cooling of ground surface induced the formation of nocturnal surface inversion (Figures 16a, 16b, 17 and 17b). As a warm pool of 37 °C, which was 4 °C higher than the previous night existed, air was still dry with relative humidity of 55 or 60% (Figures 18a and 18b). The depth of nocturnal surface inversion changed little, compared to the previous night. Thus, the reason why secondary maximum concentration of ozone found at 2300 LST and 2400 LST at Samduck and Chungli measurement points was due to the existence of the greater amounts of ozone produced under higher air temperature for daytime hours inside the shallower nocturnal surface inversion layer.

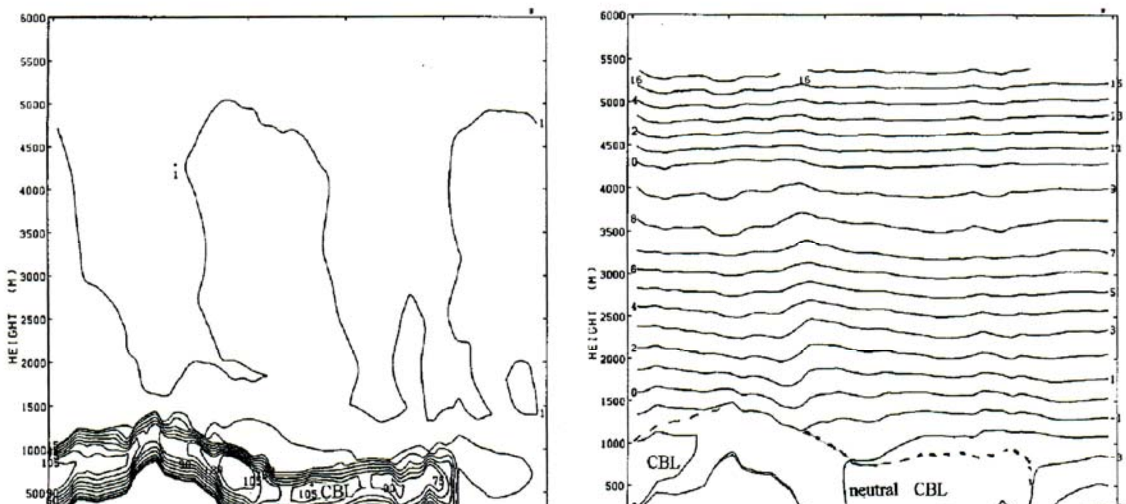
3.2. Ozone concentration in an inland basin

On August 13, one day before extremely high air temperature with the occurrence of nocturnal thermal high, a typical urban type of ground-level ozone concentrations at Taegu city, which showed a maximum at 1300 LST under a maximum air temperature around 1300 LST of 37.4 °C and a minimum at night occurred



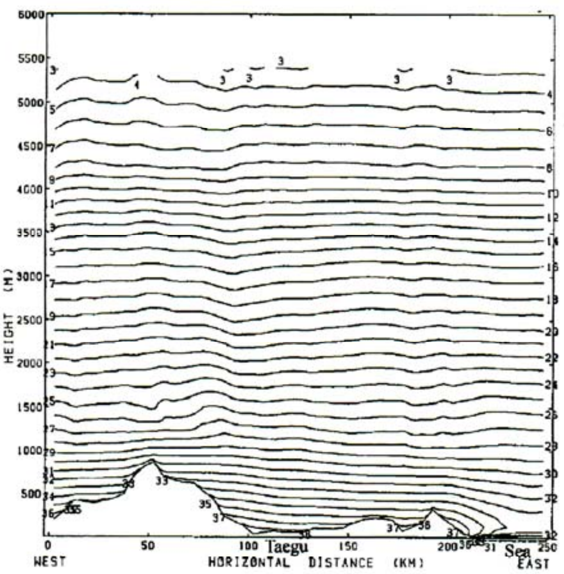
(a) (b)

Figure 13. (a) Wind vector (m sec^{-1}) at 1300 LST, August 14, 1995 in a fine-mesh domain near Taegu city. Thin line and x denote topography and Taegu city. (b) Vertical profiles of wind (m sec^{-1}) on a straight cutting line (Mt. Hyungje-Taegu (x)-East Sea) in Figure 13(a) show that strong westerly wind prevails at the city in the basin.

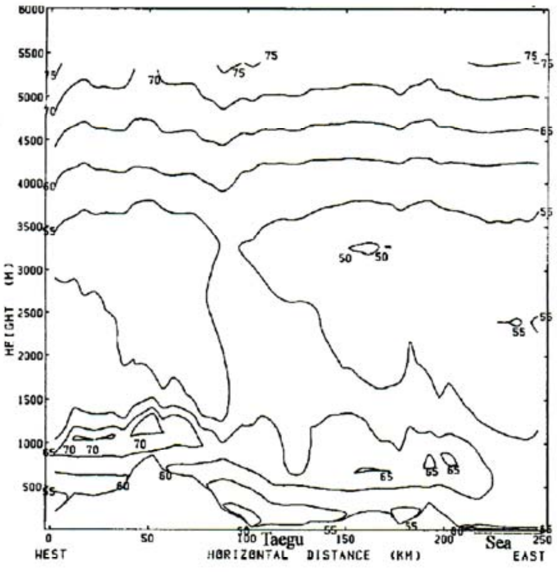


(a) (b)

Figure 14. (a) As shown in Figure 13(b), except for vertical diffusion coefficient for turbulent heat (K_h; m^2 sec^{-1}) and (b) potential temperature deviation (K; $\theta' = \theta - \Theta$). In the vertical profiles, convective boundary layer (CBL) with a thickness of 800 m at Taegu city in the basin is developed up to the height of 1500 m over the ground. The CBL on August 14 is more developed than that on August 13. Neutral line moves to the central part of Taegu city.

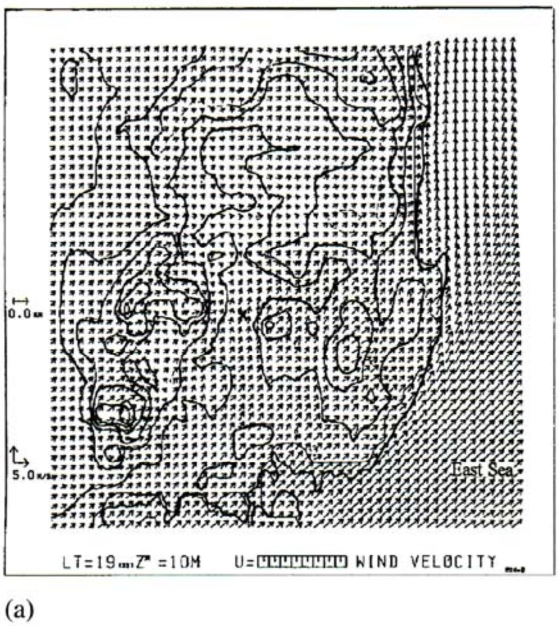


(a)

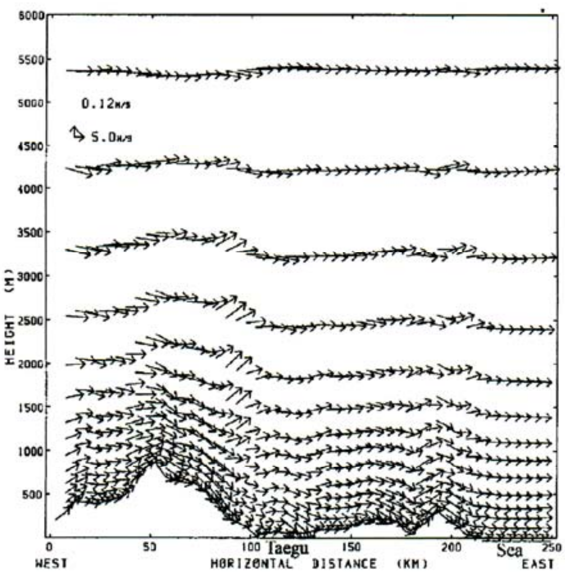


(b)

Figure 15. (a) As shown in Figure 13(b), except for air temperature (°C) and (b) relative humidity (RH; %). Air temperature at Taegu city is 39.3 °C (simulated one, 39 °C) and RH of 50% on August 14 decreases 5% than on August 13.

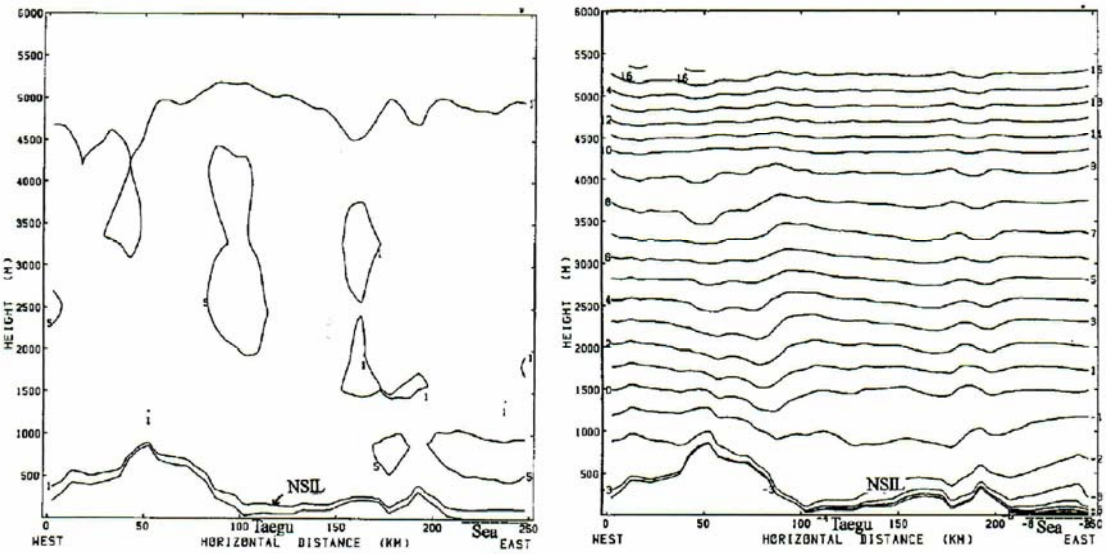


(a)



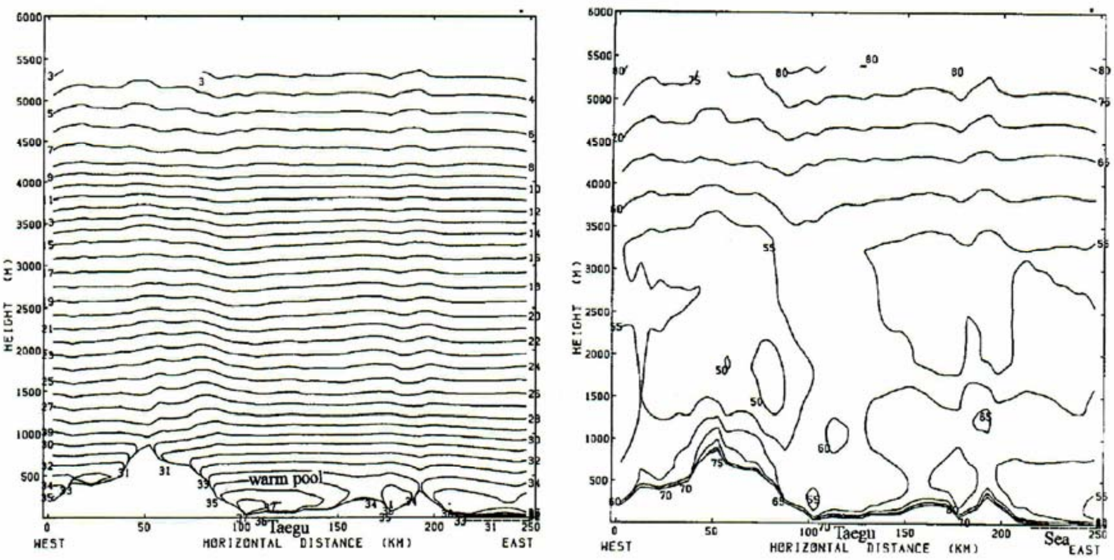
(b)

Figure 16. (a) Wind vector (m sec^{-1}) at 1900 LST (near sunset), August 14, 1995 in a fine-mesh domain near Taegu city. Thin line and x denote topography and Taegu city. (b) Vertical profiles of wind (m sec^{-1}) on a straight cutting line (Mt. Hyungje-Taegu (x)-East Sea) in Figure 16(a) show that strong westerly wind still prevails at the city in the basin.



(a) (b)

Figure 17. (a) As shown in Figure 16(b), except for vertical diffusion coefficient for turbulent heat (K_h; m^2 sec^{-1}) and (b) potential temperature deviation (K; $\theta' = \theta - \Theta$). In the vertical profiles, nocturnal surface inversion layer (NSIL) is still shallow with a thickness less than 150 m at Taegu city in the basin.



(a) (b)

Figure 18. (a) As shown in Figure 16(b), except for air temperature (°C) and (b) relative humidity RH; %). There is a warm pool of 37 °C over the ground surface and nocturnal thermal high occurs. RH of 60% at Taegu city is much lower than that on the previous day, and the NSIL is still shallow.

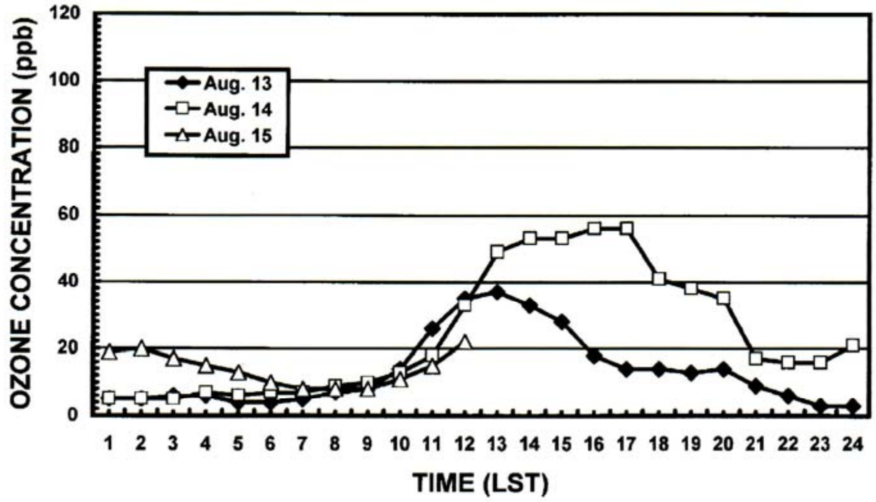


Figure 19. O_3 (ppb) on the ground-level at Samduck Environmental Observatory inside Taegu city from 13 to 15 August in 1995. Maximum concentration of O_3 was found under maximum air temperature of 35 °C at 1300 LST on August 13, but it was detected under unusual maximum air temperature of 39.2 °C at 1700 LST on August 14 with the occurrence of nocturnal thermal high.

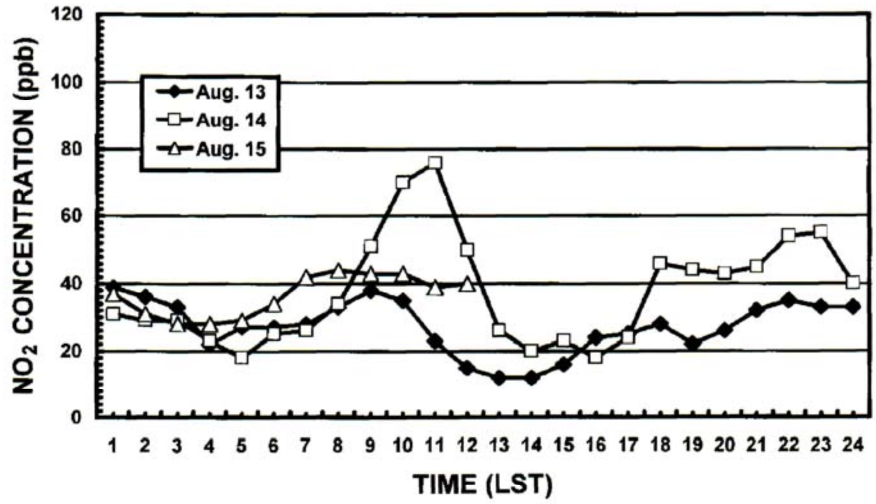


Figure 20. As shown in Figure 19, except for NO_2 (ppb).

at the two environmental monitoring sites of Samduck and Chungli (Figures 19 and 22). On the other hand, a maximum ozone concentration on August 14 under a maximum air temperature of 39.2 °C at 1700 LST was detected at 1700 LST or 1800 LST in the afternoon, which was 4 or 5 hr delayed from the typical occurrence hour, 1300 LST. Its maximum value showed a 50% increase of the concentration at Samduck monitoring site or 70% at Chungli more than typical maximum value.

Then, the trend of O_3 concentration gradually decreased until 2100 LST. After 1200 LST until 1800 LST, on August 14, temperature still maintained over 35 °C and this high temperature made a great contribution to the further increase of

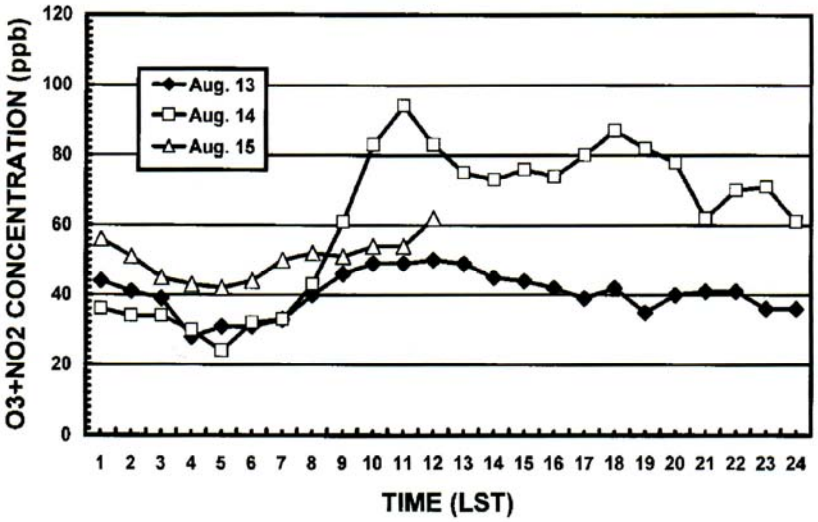


Figure 21. As shown in Figure 19, except for O_x (= O_3 + NO_2) (ppb).

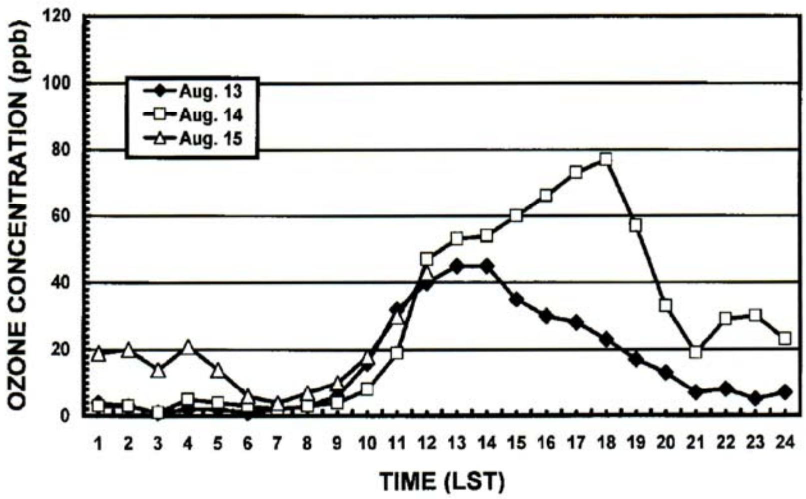


Figure 22. O_3 (ppb) on the ground-level at Chungli Environmental Observatory near the mountain in the western part inside Taegu city from 13 to 15 August in 1995. Maximum concentration of O_3 on August 13 occurred under maximum air temperature of 35 °C at 1300 LST and it on August 14 was found one hour later than the time of maximum air temperature of 39.2 °C, 1700 LST.

O_3 under the accumulation of the produced O_3 through photochemical reaction of NO_2 by vertical mixing in the neutral atmosphere inside the convective boundary layer over Taegu city in the basin (Figures 14a and 14b). Near sunset, the depth of convective boundary layer in the basin became much shallower than that around 1300 LST, causing a maximum O_3 concentration around 1700 LST or 1800 LST.

At Samduck in the downtown of Taegu city, NO_2 concentration showed reverse responses to O_3 concentration due to the photolysis process of NO-NO_2 and O_3, when O_3 increased and NO_2 decreased (Figure 20). Especially, since the hourly distribution of O_3 concentration well matched the distribution of surface air temperature, the production of O_3 was directly influenced by air temperature. As shown in Figures 2 and 3, since the temperature on August 13 had a maximum value of 37.4 °C at only 1300 LST and then it gradually decreased before sunrise, ozone concentration with its maximum at 1300 LST also decreased after 1300 LST. Thus, the daytime deviated occurrence time of a maximum ozone concentration was mainly attributed to the shifted occurrence time of maximum air temperature, which was greatly affected by meteorological and topographical effects. High O_3 concentrations for daytime hours were due to the maintenance of high air temperature over 35 °C, in order to make a contribution to the strong photochemical reaction of NO_2 into O_3.

Then, surface ozone concentration continued to decrease from 1800 LST to 2300 LST and then slightly increased to 2400 LST. The nighttime decrease of ozone concentration mainly resulted from the transformation of O_3 into NO_2, which correspondently increased at night. Even if the ozone concentration decreased at night, much more ozone for daytime hours could be initially produced under high air temperature over 35 °C, especially 39.2 °C than other days and the nighttime ozone concentration could remain to be twice as high on August 14 than other days, under the shrunken surface inversion layer. For nighttime hours, the depth of nocturnal surface inversion layer on August 13 was almost same as that on August 14. Simultaneously, in the nighttime dissipating process of O_3 into NO_2, the shrinking of nocturnal surface inversion layer could cause the increase of O_3 concentration with more daytime produced ozone.

Oxidant capacity being as $O_x(= NO_2 + O_3)$ was considered in order to find a natural O_3 background such as any relation between O_x among and O_3 and NO_2. It is due to the fast reaction like

$$O_3 + NO \rightarrow O_2 + NO_2 \tag{1}$$

O_3 is stored as NO_2 and it will be released again by photolysis during the day as

$$NO_2 + hv \rightarrow NO + O \tag{2}$$

Thus, O_x represents the natural O_3 background in the absence of NO_x (= NO + NO_2). By the fast stationary state among them on sunny days, the following photochemical processes are taken.

$$NO + O_3 \rightarrow NO_2 + O_2 \tag{3}$$

$$NO_2 + hv \stackrel{O_2}{\rightarrow} NO + O_3 \tag{4}$$

That is an implication for the transport process of aged chemical air masses into remote area. In Figure 21, the diurnal variation of O_x at Samduck had a similar tendency of O_3. On August 13, when there was usual air temperature distribution, O_x concentration was almost the same regardless of time, but its concentration was slightly low at 0500 LST, just before sunrise. On the other hand, on August 14, O_x concentration was much higher than that on August 13. The O_3 concentration rapidly increased at 1100 LST at the time of maximum concentration of NO_2 and then it decreased until 1400 LST. After 1400 LST, the O_x concentration increased again following the tendency of NO_2. It means that natural O_3 background greatly depends upon the amount of NO_2. Thus, the increase of O_3 concentration at Samduck monitoring site on August 14 might be partially affected by the increase of NO_2, under its more production from the downtown of the city or its transport from the other place in the upwind side, because wind was moderate on August 13, but it became strong on August 14.

At Chungli, a maximum ozone concentration in the western measured point of the city at 1800 LST was about 20% higher than in the central point, Samduck observatory at 1700 LST for daytime hours, while their concentrations at night are not much different from each other. Air temperature with the maximum ozone concentration at Chungli measure point is one degree higher than that at Samduck point as shown (Figures 15a and 18a). Similar to Samduck, while the daytime concentration of O_3 increased, the concentration of NO_2 decreased. It means that their reversal respondent patterns were due to photochemical production of O_3 from NO_2. One interesting thing under the occurrence of nocturnal thermal high on August 14 was that the ozone concentration at 2300 LST increased with twice the magnitude than other days. From 2100 LST, O_3 concentration increased again with a secondary maximum value at 2300 LST, when the tropical night phenomenon of air temperature over 26.4 °C persisted for the whole night. After sunset, that is, 1900 LST, air temperature became lower than 35 °C and the production of O_3 under no solar radiation disappeared.

It may be possible to say that the depth of nighttime atmospheric boundary layer (or nocturnal surface inversion layer) of 150 m is much shallower than the depth of daytime convective boundary layer of 800 m, resulting in the increase of ozone concentration under the shrunken depth with daytime more produced ozone and showing a secondary maximum concentration, though the reduction of O_3 occurred due to the reversal processes of O_3 into NO_2. From 2100 LST, O_3 concentration increased again with a secondary maximum value at 2300 LST, when tropical night phenomenon of air temperature over 26.4 °C persisted for the whole night. After sunset, that is, 1900 LST, the air temperature became lower than 35 °C and the production of O_3 under no solar radiation disappeared.

At Chungli observatory, O_3 concentration decreased after sunset, 1900 LST, due to the transformation of O_3 into NO_2, and its pattern still remained at 2100 LST, especially showing a maximum concentration of NO_2 at 1900 LST of one hour later (Figure 23). During the decrease of O_3 concentration after 1900 LST, NO_2 did not increase, but decreased, due to the decrease of NO emission amount from the decrease of vehicles on the road at early night. O_3 concentrations at 2200 LST and 2300 LST slightly increased again. During the transformation of O_3 into NO_2, nocturnal surface inversion layer due to greater cooling of the ground surface

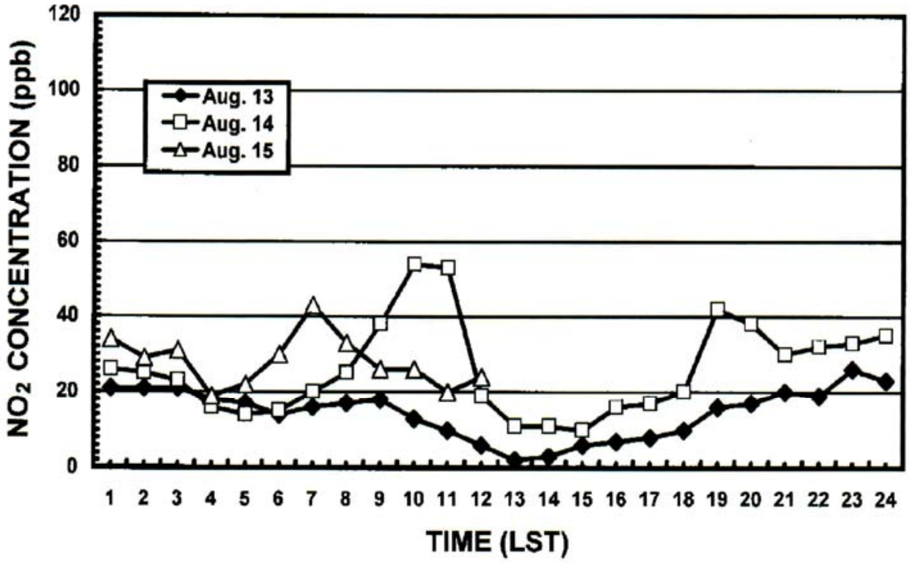


Figure 23. As shown in Figure 22, except for NO_2 (ppb).

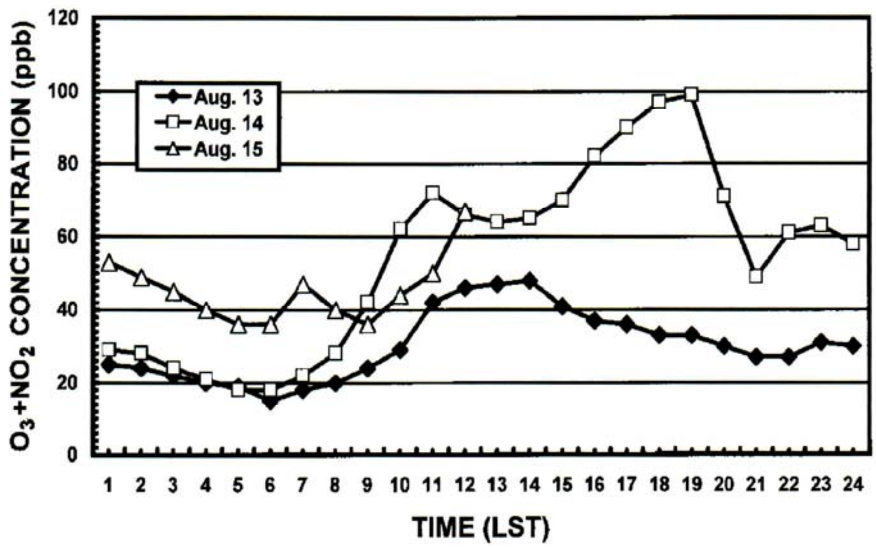


Figure 24. As shown in Figure 22, except for O_x (= O_3 + NO_2) (ppb).

at 2300 LST and 2400 LST than near sunset, 1900 LST became much shallower, causing the increase of O_3 concentration.

Then, as the depth of nocturnal inversion layer after 2400 LST was almost the same, O_3 concentration should decrease under the transformation of O_3 into NO_2, and NO_2 concentration gradually decreased until next day early morning. Similarly, daytime more production of O_3 could be transformed into more amounts of NO_2 and shallow nocturnal surface inversion layer caused the increase of NO_2 concentration.

Another important mechanism on the increase of NO_2 concentration in the central part of the basin (city) was related to thermally induced wind called mountain wind from the top of the mountains toward the inland basin, due to the thermal contrast between the mountain and basin surfaces, the mountain wind induced the merging of NO_2 into the area near Samduck observatory, enhancing a very high concentration of NO_2. Diurnal variation of O_x at Chungli near the mountain, on August 13 a similar tendency of O_3 and O_x concentration was not much changed regardless of time (Figure 23). On the other hand, the variation of O_x on August 14 still had the same tendency of O_3concentration. Its hourly concentration was not constant, but changed greatly. The increase of O_x concentration was mainly due to the increase of O_3 concentration. The increase of O_x concentration at Chungli was different from that at Samduck, which was due to the increase of NO_2.

4. Conclusion

The distribution of surface ozone concentration in the inland basin before the occurrence of unusual high air temperature showed a typical urban type of maximum ozone concentration found at 1300 LST and minimum at night. However, a maximum ozone concentration on the day of extremely high air temperature of 39.2 °C with nocturnal thermal high over 35 °C at night was detected at 1700 LST and 1800 LST at two environmental monitoring sites. Its maximum value showed a 70% increase of concentration more than the typical maximum value. Then, the trend of ozone concentration gradually decreased until 2100 LST. After 1200 LST until 1800 LST, temperature still stayed over 35 °C and this high temperature made a great contribution to the further increase of O_3 for several hours. The deviated occurrence time of a maximum ozone concentration may be mainly attributed to the sifted occurrence time of maximum air temperature. While the daytime concentration of O_3 due to photochemical production of O_3 from NO_2 increased, the concentration of NO_2 decreased with their reverse respondent patterns at night.

From 2100 LST, O_3 concentration increases again with a secondary maximum value at 2300 LST, when nocturnal thermal high phenomenon over 26.4 °C was in persistence. As the depth of nocturnal surface inversion layer was much shallower than the depth of daytime convective boundary layer, resulting in the increase of ozone concentration and showing a secondary maximum concentration, despite the reduction of ozone through the reversal processes of O_3 into NO_2.

Acknowledgements

I am grateful to Mr. Syunji Takahashi, Dept. of Numerical Forecasting, Japan Meteorological Agency for helpful comments on this study. I would like to thank two anonymous reviewers for constructive comments on the original manuscript.

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