A Further Study of High Air Pollution Episodes in Taiwan Using the Microwave Temperature Profiler (MTP-5HE)*

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In the metropolitan areas of Taiwan with high population density, heavy traffic, and/or zones of heavy industries, serious air pollution episodes may occur during stable weather conditions. The information of mixing height is therefore essential to the air pollution control in this area. In this study, diurnal variation of the mixing height derived using the newly established EPA-Taiwan microwave temperature profiler (MTP-5HE) and that obtained through the CWB soundings are compared. The relationships between the air quality and the diurnal variation of the mixing height is discussed during different air pollution episodes.

Key Words: Mixing Height, Microwave Temperature Profiler, Air Pollution

1. Introduction

The mixing height depends on the intensity of turbulent mixing which is related to wind speed, surface roughness, solar heating of the ground and vertical temperature structure of the boundary layer. In metropolitan areas with high population density, heavy traffic and sometimes with zones of heavy industries such us steel, petroleum and power plants, serious air pollution episodes may occur during high emission and low mixing height situation. The forecast of mixing height is therefore essential to the air pollution control in these areas.

Traditionally, mixing height are determined mainly through the use of radiosonde data. However, remote sounding systems such as lidars, and sodars are introduced recently, which provide the continuous observation of the boundary layer structures. In this study, diurnal variation of the mixing height derived using the newly established EPA-Taiwan microwave temperature profiler (MTP-5HE) and that obtained through the Central Weather Bureau radiosondings are compared. Seasonal averages of the mixing height variation for Taipei, Taichung and Kaohsiung areas (which represent metropolitan areas of northern, central and southern part of Taiwan respectively) are studied. And finally, the relation between the air quality and diurnal variation of the mixing height during some air pollution episodes are discussed.

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2. Methods of Mixing Height Determination

In this study, two sets of mixing height (MH) values are obtained for Taipei, Taichung and Kaohsiung for the year 2003. First, we adopt the traditional method using Central Weather Bureau sounding data. The hourly values of MH are obtained through the interpolation of 00 UTC (Coordinated Universal Time) and 12 UTC sounding and four layers of near surface temperature profile, namely surface, 500 m, 1 000 m and 1 500 m.

The second set of MH values determined from the EPA-Taiwan microwave temperature profiler (MTP-5HE), which provide the 21 layers near surface passive microwave retrieved temperature profile. For both methods, hourly surface temperature, wind speed and direction, atmospheric stability and radiation data from CWB are used for the calculation of MH values.

2.1 Mixing height determination

During daylight hours, solar radiation reaching the ground produces an upward flux of sensible heat which causes the growth of a well mixed adiabatic layer. It is assumed that the mixed layer is a layer where all the main parameters of the boundary layer such as temperature, humidity and wind tend to be in equilibrium. This equilibrium is reached by turbulent mixing. In case of thermally induced mixing, the height of the mixing layer depends on the temperature lapse rate and sensible heat flux. If the hourly values of sensible heat flux is known, the mixing height Z_l at time $t+1$ can be estimated from Z_l at time t in a step wise manner given by the equations(1)–(4).

$$(Zi)_{t+1} = \left[(Zi)_t^2 + \frac{2H(1+E)\Delta t}{\psi_1 \rho c_p} - \frac{2(\Delta\theta)_t (Zi)_t}{\psi_1}\right]^{1/2} + \frac{(\Delta\theta)_{t+1}}{\psi_1}$$

$$(\Delta\theta)_{t+1} = \left(\frac{2\psi_1 E H \Delta t}{\rho c_p}\right)^{1/2}$$

where

ψ_1 : the potential temperature lapse rate in the layer above Z_i

Δt : the time step (1 h)

E : a constant (~ 0.15)

$\Delta\theta$: the temperature discontinuity at the top of the mixed layer

ρ : density of the air

C_p: the specific heat

The lapse rate, ψ_1 is determined through a layer ΔZ meters above the previous hour's convective mixing height. For daytime hours up to 23 UTC, the morning (12 UCT) sounding at the nearest rawinsonde station is used to calculate ψ_1. After 23 UTC, the evening (00 UTC) sounding is used.

The sensible heat flux is estimated by the equation(4)

$$H = \alpha R + H_0$$

where,

H : the sensible heat flux (Wm^{-2})

H_0: the heat flux in the absence of solar incoming radiation (Wm^{-2})

R : the incoming solar radiation (Wm^{-2})

α : the surface albedo (~ 0.3)

The incoming solar radiation R is estimated from the solar elevation angle ν using the equation

$$R = 950\beta \sin\nu$$

where β is a radiation reduction factor due to the presence of clouds.

In the case of neutral or stable boundary layer, mechanical turbulence production determines the vertical extent of dispersion. The mixing height is estimated using the empirical relationship given by Venkatram(5),(6).

2.2 The specifications of the MTP-5HE

The MTP-5HE is a microwave temperature profiler used by EPA Taiwan to retrieve the boundary layer temperature profile and to monitor the mixing height variation for air pollution control purposes.

The atmosphere at planetary atmospheric boundary layer is a very strong source of radiation, but the changes due to temperature are very small, so a very sensitive receiver should be used to retrieve the air temperature. MTP-5HE determines the air temperature profile based on the measurement of thermal radiation from the atmosphere at the center of the molecular oxygen absorption band around 5 mm in wavelength. An example of the temperature profiles obtained by MTP-5HE and radiosonde is given in Fig. 1. The specifications of the MTP-5HE are as follows,

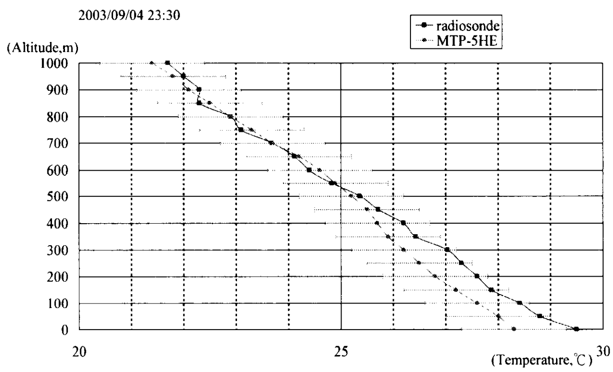

Fig. 1 An example of the temperature profiles obtained by MTP-5HE and radiosonde

Altitude range	1 000 m
Height resolution	50 m–100 m
Cycle period of measurement for one profile	120 sec
Accuracy of temperature profile retrieval (depends on types of profile)	0.2–0.5 K

3. Results and Discussion

3.1 Comparison between HM_{CWB} and HM_{EPA}

Figures 2–4 represent the seasonal averages of the diurnal variation of the MH for Taipei, Taichung and Kaoshiung respectively. The data cover the whole year of 2003 and disregard the weather or air pollution conditions. The correlation coefficients for the hourly values of the MH determined from two methods are given on the upper right hand corner of the panels as well as in Table 1. It should be noted that the correlation doesn't exclude the night time MH where two MH values are identical. During the daytime period, apparent differences between two MH curves can be observed. Generally speaking, the traditional method underestimate the MH during the morning and early afternoon hours, and overestimate the MH during late of afternoon. During midnight and early morning, the effect of mechanical turbulence prevails. Two MH curves are therefore coincide with each other. Table 2 summarizes the seasonal averages of the daily maximum MH. Since radiosonde data are available only twice daily at 00 UTC and 12 UTC, and the Taipei radiosonding data were applied to Taichung and Kaoshiung, the maximum MH during the day determined from traditional method is therefore, in general, lower than that obtained from the MTP-5HE. Also, the daily peaks have a two to three hours

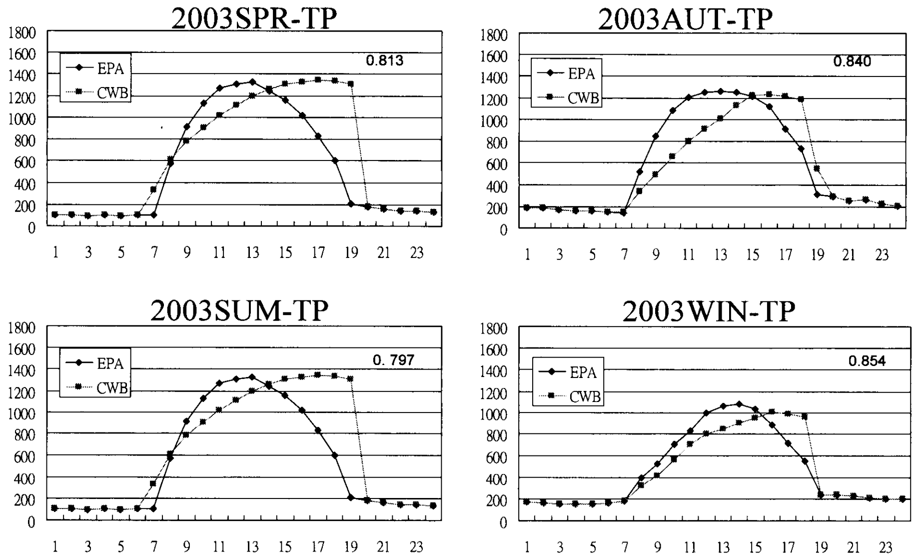

Fig. 2 2003 seasonal average mixing height determined by radiosonde (CWB) and MTP-5HE (EPA) in Taipei

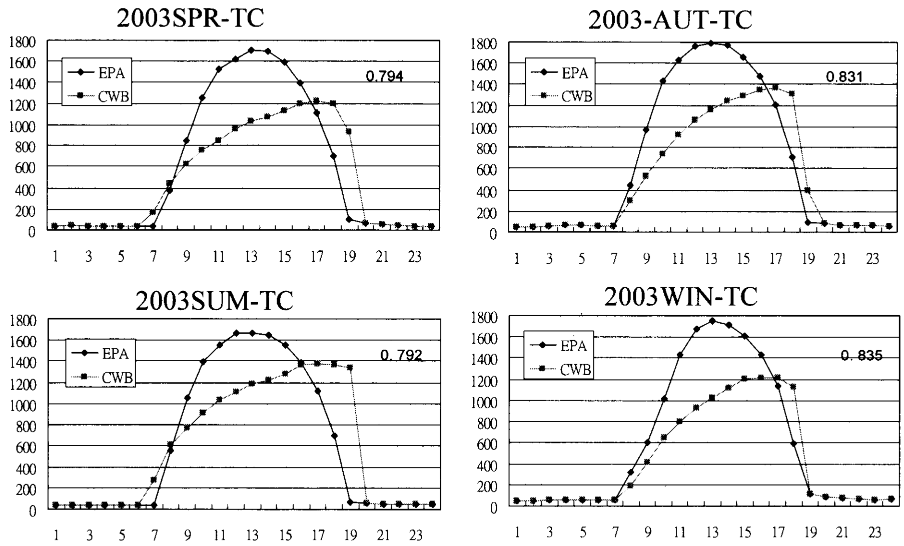

Fig. 3 2003 seasonal average mixing height determined by radiosonde (CWB) and MTP-5HE (EPA) in Taichung

Table 1 Hourly correlation of the mixing heights determined by radiosounde and MTP-5HE

Stations \ correlation	Spring	Summer	Autumn	Winter
Taipei	0.813	0.797	0.840	0.854
Taichung	0.794	0.792	0.831	0.857
Kaoshiung	0.801	0.789	0.835	0.858

Table 2 Seasonal averages of the daily extreme mixing heights

Stations \ correlation		Spring		Summer		Autumn		Winter	
		Max	Min	Max	Min	Max	Min	Max	Min
Taipei	EPA	1100m	190m~210m	1350m	100m~180m	1300m	180m~210m	1100m	180m~210m
	CWB	1100m	190m~210m	1350m	100m~180m	1200m	180m~210m	1000m	180m~210m
Taichung	EPA	1700m	40m~50m	1700m	40m~50m	1800m	50m~60m	1750m	50m~60m
	CWB	1200m	40m~50m	1380m	40m~50m	1350m	50m~60m	1250m	50m~60m
Kaoshiung	EPA	1800m	40m~50m	1750m	100m~120m	1780m	50m~60m	1770m	90m~100m
	CWB	1300m	40m~50m	1450m	100m~120m	1350m	50m~60m	1250m	90m~100m

lag in the afternoon.

Compared to Fig. 2, most of the differences of the peak MH values for Taichung (Fig. 3) and Kaoshiung (Fig. 4) is probably due to the use of the remote radiosonding data that doesn't represent properly the actual planetary boundary layer conditions. If this is true, the traditional method of calculating MH is still useful where a proper nearby radiosonde station is available.

3.2 Episodes of high air pollutant concentration

Episodes of high air pollutant concentration may occur due to high pollutant emissions and/or low mixing heights. The value of mixing height is in turn strongly influenced by the passage of weather systems. In a preliminary study using EPA-Taiwan monitoring station data,

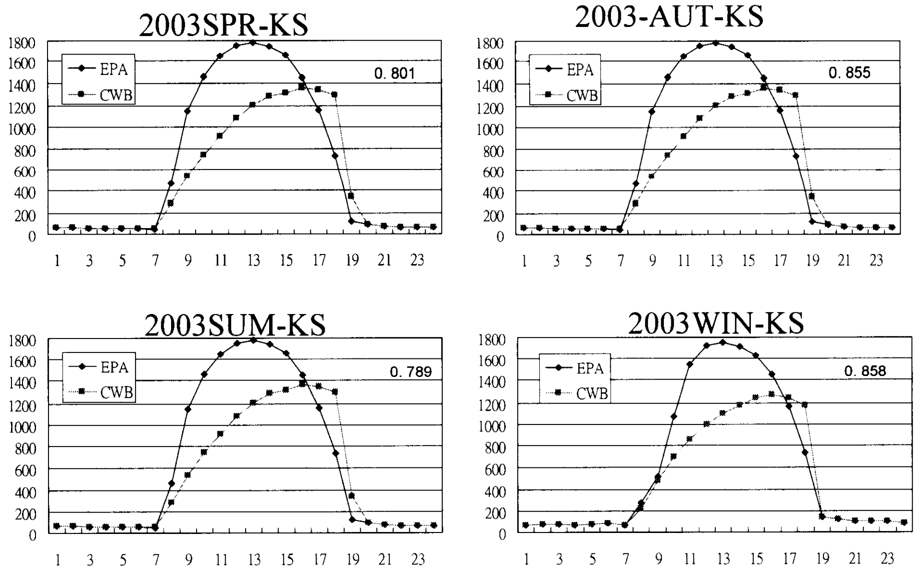

Fig. 4 2003 seasonal average mixing height determined by radiosonde (CWB) and MTP-5HE (EPA) in Kaohsiung

Table 3 Weather systems influencing Taiwan when high air pollution episodes occur

Area \ weather system	Prefrontal	High Pressure outflow return	NE Monsoon
Taipei	✓	✓	
Taichung	✓	✓	✓
Kaoshiung	✓	✓	✓

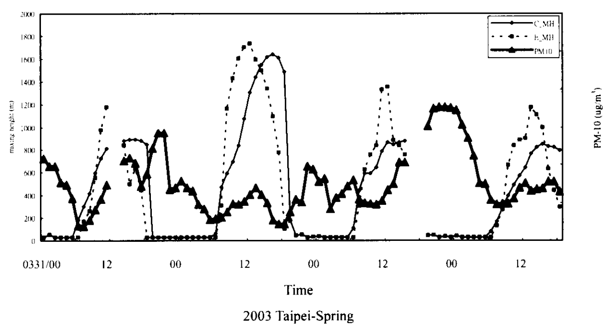

Fig. 5 Episodes of high air pollutant concentration in Taipei

weather systems influencing Taiwan when high air pollution episodes occur are summarized in Table 3. Some episodes are illustrated in Figs. 5–7. Prefrontal situation, high pressure outflow return and northeasterly monsoon are three major weather situations that caused low mixing height and high air pollutant concentrations.

Figure 5 illustrates a series of high air pollutant concentration episodes before and after a frontal passage during spring time in Taipei. In March 31, 2003 before frontal passage, the air was calm and the mixing height was relatively low, the concentration of pm10 build up even during the day time. The mixing height was high and the air pollutant concentration reduced rapidly during the frontal passage when the wind is strong and the air is convectively unstable. The mixing height dropped after the frontal passage, and the pm10 concentration reached a peak of 175 mg/m^3 when Taipei was influenced by high pressure return flow.

Figure 6 demonstrates a period of high air pollutant concentration for Taichung city during strong NE monsoon after frontal passage in winter. The city of Taichung is located on the lee side of the Central Mountain Range. The dry down slope wind causes very stable conditions during the night and the early morning hours. The convective instability occurs late in the morning after sunrise during this period. The mixing height obtained by MTP 5HE reflexes this situation quite well, while the underestimate of MH by traditional method is obvious under this situation. The ventilation effect of high MH causes minimum concentrations during late afternoon and the evening hours, while during the stable conditions, the pm10 concentration returns to their maximum values.

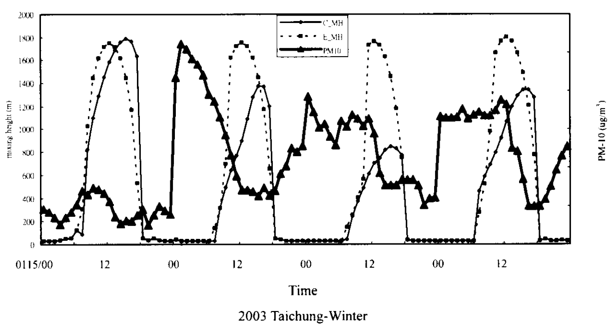

Fig. 6 Episodes of high air pollutant concentration in Taichung

Figure 7 is a case of high air pollution episode in Kaoshiung, a heavy industrial city in southern Taiwan, under the influence of high pressure return flow in winter. The mixing height reaches to a maximum value of

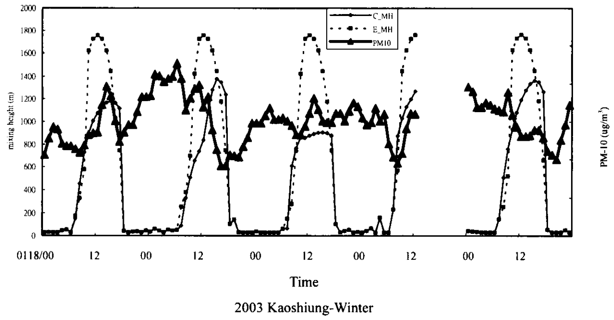

Fig. 7 Episodes of high air pollutant concentration in Kaoshiung

1 800 m during the day due to strong insolation and high surface temperature. But despite having good vertical ventilation, the pollutant concentration remained high during the period. This is in part due to high emission rate of the pollutant in this area, but more importantly due to the stagnation of the air caused by topographic effect in this area during this weather situation.

4. Conclusions

(1) High air pollution episodes tend to occur during low mixing height weather situations. Prefrontal condition, high pressure outflow return and northeasterly monsoon are three major weather situations that cause low mixing height and high air pollutant concentration in Taiwan.

(2) However a case study in Kaoshiung area reveals that high air pollution episodes may occur during high mixing height situation when the air is stagnant due to the topographic effect and the emission rate of the pollutant is high.

(3) The microwave temperature profilers (MTP-5HE) give the continuous measurement of the atmospheric boundary layer temperature profile and provide an economic and accurate way of monitoring near surface mixing height for air pollution control purposes.

(4) Compared to MTP-5HE derived MH values, traditional method using radiosonde data underestimates the mixing height during the morning and early afternoon hours and overestimates the MH during late afternoon hours. Also, the daily peaks have a two to three hours lag in the afternoon.

(5) The daily maximum MH values is compatible from both method, if a nearby radiosonding is available. However, significant differences may occur if a remote sonding is used.

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