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Air Pollution Monitoring in Taiwan: An Application of Tethersonding in Coastal Central Taiwan

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Abstract : The atmospheric transportation and dispersion processes of air pollutants are important issues in dealing with air pollution problems. Air pollutants originated from biological and anthropogenic activities are not only limited to the local emission sources, but could also be transported and dispersed to other regions by synoptic weather systems. Besides, the complexity of topography of central Taiwan helps accumulating air pollutants to promote high-concentration episodes. The techniques of tethersonding were applied to monitor the vertical profiles of winds, air temperatures and humidity, as well as to collect air samples, to be analyzed for pollutants (O_3, NO_2, NO and NMHC) from the ground up to 1000 m. A time period of about one week, 19-26 October 2002, was chosen as the sampling period due to the high frequency of episode occurrence in autumn based on the past records. Associating with the analysis of weather patterns, the atmospheric characteristics over high-concentration areas can be resolved in more detail. The result of the tethersonding studies showed that weak northerly sea breeze (with thickness about 300 m) with low wind speed (about 1 to 2 m/sec) could help develop high ozone concentrations in the down-wind areas. It is also important to have a built-up aloft of precursors and ozone to develop high concentration on the previous day.

Keywords : air pollution, tethersonde

Introduction

With the rise of population density and the rapid development of industrialized communities, notion to prevent environmental degradation has been given more emphasis, especially the control of air pollution. While the Taiwan Environmental Protection Administration (Taiwan EPA) has endeavored to mitigate air pollution problems, as evidenced by the less frequency of episode (PSI 100) occurrence from 4.5% in 1999 down to 3.4% in 2003 (Table 1), the ozone (O_3) episodes has nevertheless increased from 33.9% up to 51.4% during the same span.

Table 1. The statistical data of PSI in coastal central Taiwan during 1999 to 2003 (Taiwan EPA, 2004)

Year	PSI > 100 (Percentage)	PM_{10} (Percentage)	O_3 (Percentage)
1999	4.5%	66.0%	33.9%
2000	4.9%	66.8%	33.1%
2001	3.2%	56.1%	43.7%
2002	3.2%	56.3%	43.5%
2003	3.4%	48.6%	51.4%

Ozone is a secondary pollutant formed in the boundary layer through photochemical reactions involving the precursor nitrogen oxides (NO_x) and volatile non-methane hydrocarbons (NMHC) in the presence of strong solar radiation (*hv*):

$$NO_x + NMHC + M \xrightarrow{hv} O_3 + \text{other photochemical products}$$

where NO_x is comprised of NO and NO_2, and M is denoted to participating molecules that return to its original state. Ozone concentrations at any one location also depend significantly on adverted emissions and vertical mixing rates, and consequently on the local variation of the wind field and parcel trajectories. Well known studies have been completed in the United States (Holland *et al.*, 1999; US EPA, 1998) and Tokyo (Wakamatsu *et al.*, 1999), in the Yahagi basin (Kitada *et al.*, 1986), at Los Angeles (McElory and Smith, 1986), in Southern Ontario (Hastie *et al.*, 1999), and at Athens (Kambezidis *et al.*, 1998).

In the recent years, several large-scale campaigns have been launched using light aircrafts to monitor the air pollutants and meteorological elements at high altitudes, however the efforts were without much success (Lin *et al.*, 2004). Not only the

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ultra-sensitive instruments and the experimental flights are costly, but also the high-altitude measurements usually result in pollutant concentrations too low to make meaningful interpretation because the pollutants mainly stay in the planetary boundary layer (Seinfeld and Pandis, 1998). Pollutants emitted anywhere in the planetary boundary layer are transported and diffused through the height of the layer, which is known as the mixing height. The mixing height increases as the sun heats up the surface to expand the layer to a maximum height (typically about 1000 m) in the afternoon, followed by rapid decreases to its nighttime height in the proximity of 200 m or even lower after sunset cooling (Arya, 1999). Quite a few of tethersondings has been conducted for monitoring high up to 1000 m, such as those reported by Cheng (2002), Baumbach and Vogt (1999) and Pisano (1997), while others have been conducted at lower altitudes down to 500 m, such as those reported by Piringer and Baumann (2001) and Oettl *et al.* (2001).

This study, therefore, aims to analyze the role of the topographic and atmospheric factors in the central Taiwan by correlating the ozone episodes between the weather pattern, air quality pattern, and the factual data.

Materials and Method

The meteorological data were collected from the air quality monitoring station of Taiwan EPA, our own monitoring stations and those of the Central Weather Bureau in the central air quality region and the nearby areas (Yunlin and Miaoli). These information, used to establish a horizontal database of weather field grid data (Fig. 1), were compared with air pollution monitoring data to analyze the correlate the air pollution episodes with the meteorological conditions. The tethersonde monitoring data was taken every three hours (samples are taken from 50, 100, 300, 600, 1000 m above

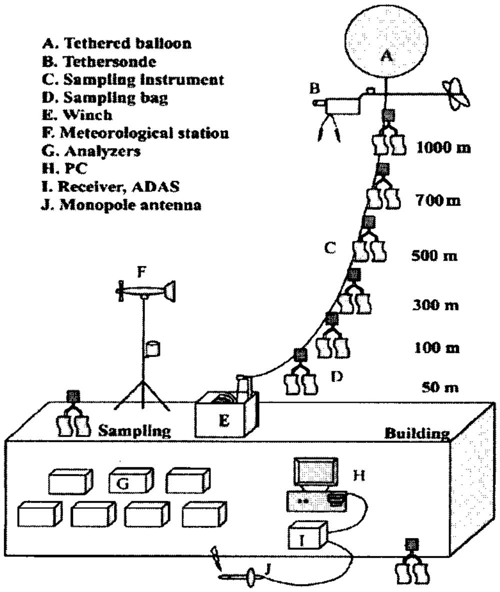

Fig. 2. Operational diagram of instruments.

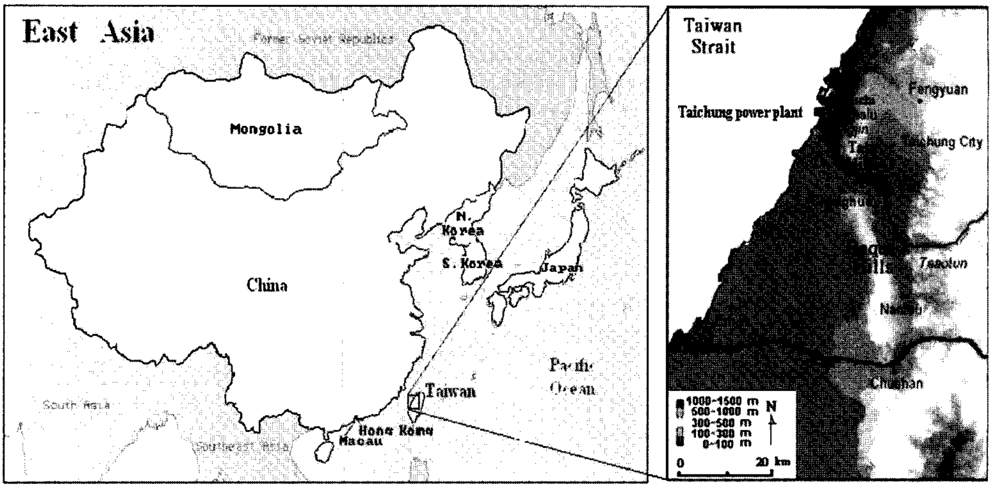

Fig. 1. Location of monitoring stations in coastal central Taiwan.

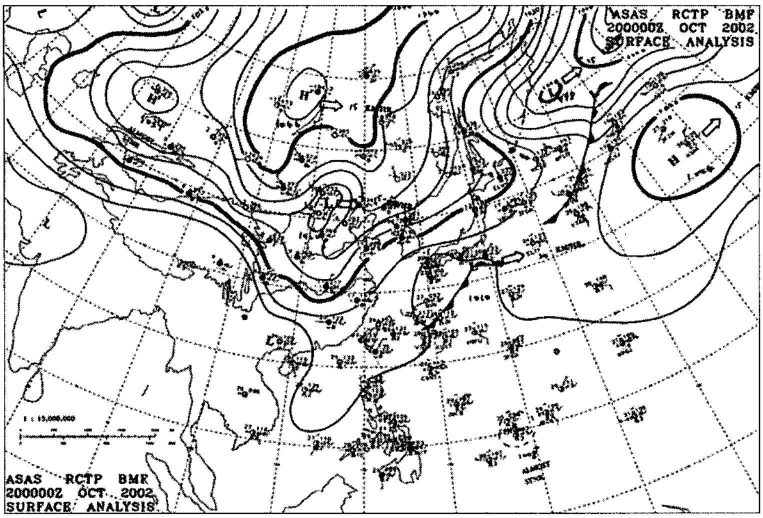

Fig. 3. Surface synoptic weather map in the greater Taiwan on 0000UTC 20 October 2002.

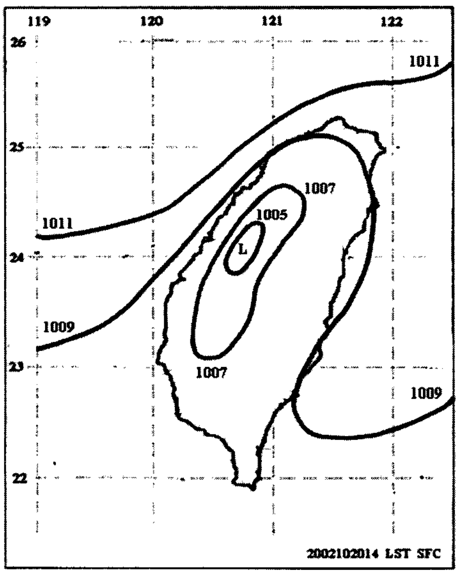

Fig. 4. Micro-scale synoptic map (mb) at 14:00 h on 20 October 2002.

ground) throughout the experimental period. The monitoring items include air pollutants concentration (O_3, NOx, NMHC) and atmospheric data (wind direction, wind speed, temperature and humidity), as shown in Fig. 2. The detailed instrumentation and monitoring procedures using the tethersonde system have been described elsewhere (Cheng, 2000, 2001).

Results and Discussion

During 19 and 20 October 2002, a weak cyclone moving eastwards over the East China Sea was centered at the northeast of Taiwan, with relative gentle northeasterly-to-easterly wind covering the area (Fig. 3). The easterly winds were blocked by the mountainous barrier and split into two currents that passed around the Central Ridges (mostly 3000 m-3500 m) to the north and south. The extent of this effect created a low pressure at the lee side on west central Taiwan, which was unfavorable for pollutant dispersion and led to high ozone concentrations (Fig. 4). In these two days, mild sea breeze circulations developed as shown from the wind field in the region (Fig. 5) and its vertical profile (Fig. 6). On the afternoon of 20 October, the sea breeze inflow reached altitudes of 300 m. At ground level, the O_3 concentration became highest at the southern end of the basin (down-wind) at 15:00 h. As a result, 20 October was the day with the highest O_3 concentration, although the pollution level did not qualify as an episode with PSI about 90 at four stations (Fig. 5).

It is interesting to note that the NOx had a peak concentration of 45 ppb from the ground up to 1000 m (Fig. 9) and the NMHC had a peak concentration of 3 ppm at 800 m on the night of 19 October and on the early morning of 20 October

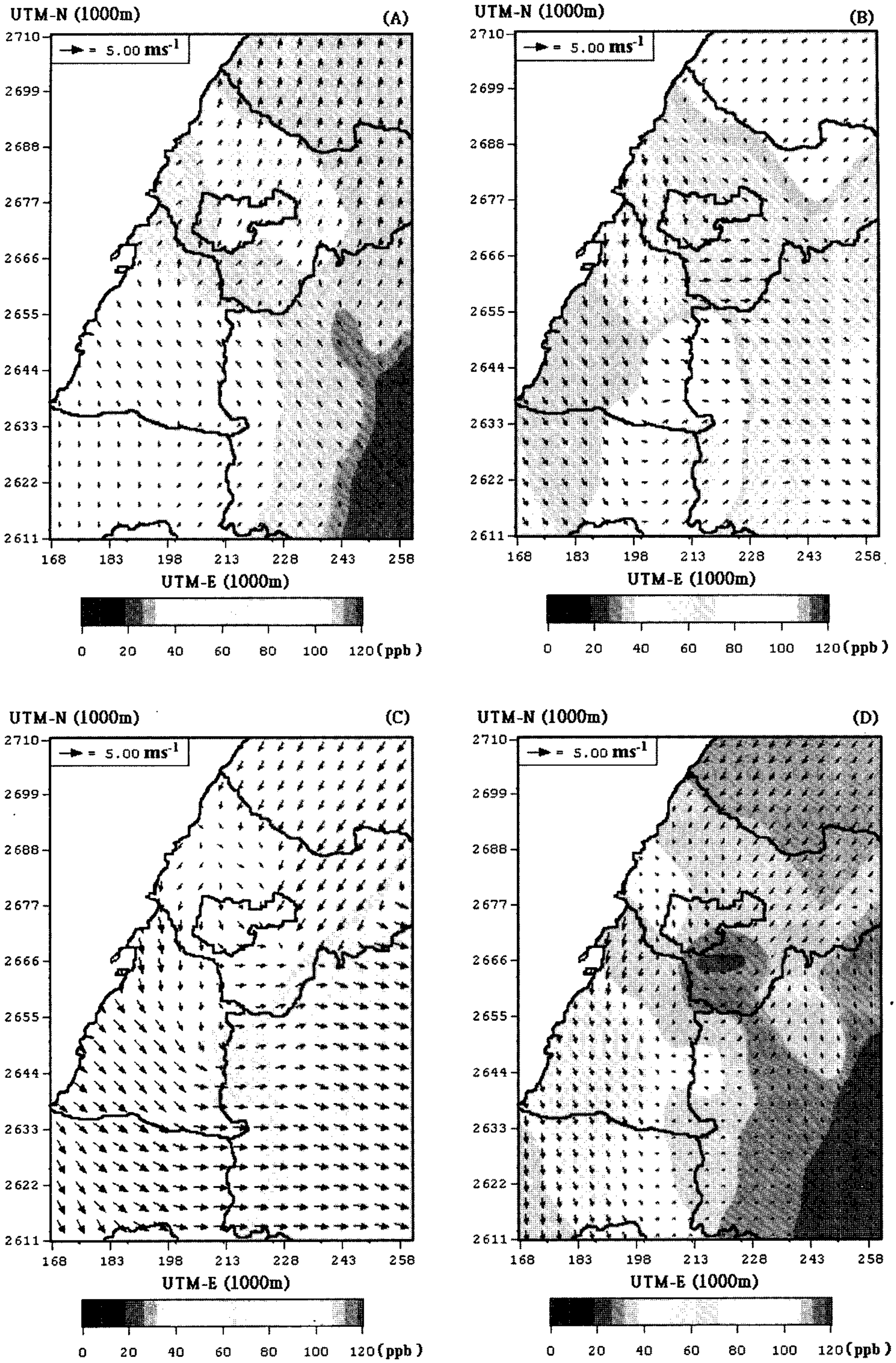

Fig. 5. Wind field and O_3 (ppb) concentration in coastal central Taiwan on 20 October 2002. (A) 09:00 (B) 12:00 (C) 15:00 (D) 18:00.

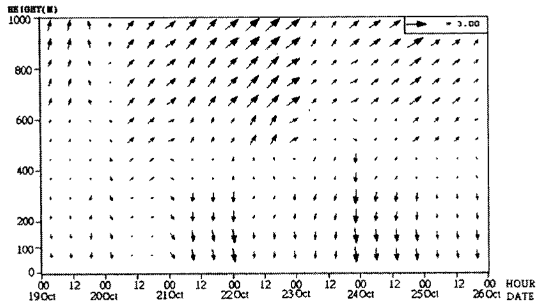

Fig. 6. Vertical profile of wind field in coastal central Taiwan between 19-26 October 2002.

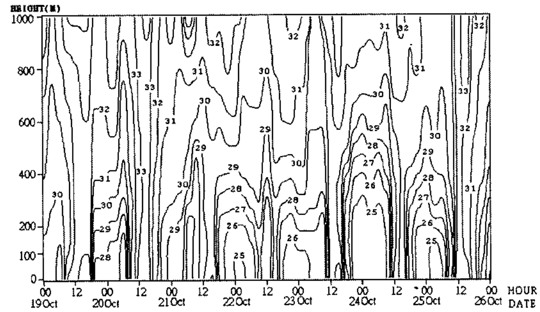

Fig. 7. Vertical profile of virtual potential temperature concentration (°C) between 19-26 October 2002.

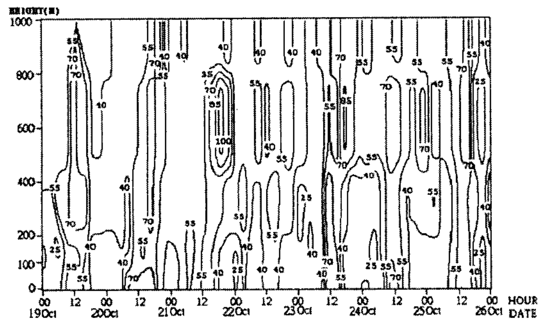

Fig. 8. Vertical profile of O_3 concentration (ppb) between 19-26 October 2002.

(Fig. 10) to give O_3 peak concentration of 70 ppb on the afternoon of 20 October (Fig. 8). This result concurs with the studies by Aneja et al. (2000) and Gusten *et al.* (1998), as they also reported that ozone and its precursors may be stored aloft on the previous day (and night) and mixed downward to the ground on the following day as the ground is

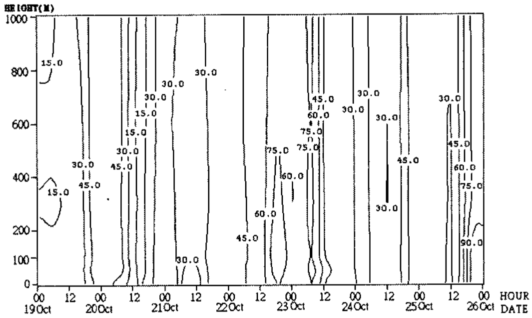

Fig. 9. Vertical profile of NO_x concentration (ppb) between 19-26 October 2002.

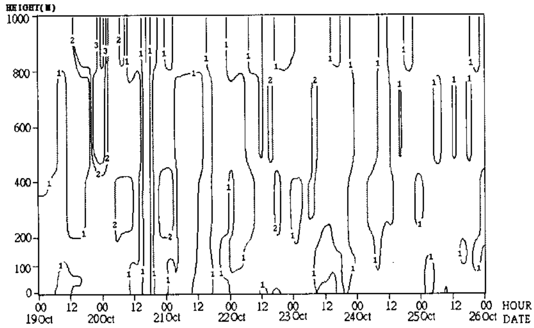

Fig. 10. Vertical profile of NMHC concentration (ppm) between 19-26 October 2002.

heated by solar radiation (Fig. 7) (Cheng, 2002).

The vertical profiles of the wind field show that a weak sea breeze started right at 12 noon of 20 October. Under synoptic conditions, ozone concentration increased by up to 50 ppb within 2 to 3 hours. These increases occurred simultaneously with the sea breeze development, suggesting that pollutants from industrial and traffic emissions have been transported inland by the sea breeze.

Although the O_3 had a peak concentration of 100 ppb at 400-800 m on late 21 October, due to rather strong southwest wind aloft there was no chance to develop an O_3 episode in the following days. Nevertheless, there was another built-up on the afternoon of 23 October, when O_3 concentration reached 85 ppb at 500-700 m leading to relatively high O_3 pollution on the following day.

Conclusion

Tethersonding study shows that the weak northwesterly sea breeze plays a vital role in developing high ozone concentrations in the down-wind areas. The results of this campaign also reveal the importance of sea breeze patterns and built-up aloft of pollutants for regions with frequent sea breezes, such as the coastal plain of central Taiwan.

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