A STUDY OF LOW-LEVEL BOUNDARY-LAYER TEMPERATURE INVERSION EVENTS IN TAIWAN

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Temperature inversion may cause air pollution problems because air pollutants cannot be dissipated through vertical motion of the atmosphere and are accumulated near the surface. The air quality is worsen gradually if an inversion event lasts for a long time. An inversion event is defined as consecutive temperature profiles with occurrence of the temperature inversion condition. In this paper, temperature inversion events over three major cities on Taiwan are analyzed. They are measured by ground-based microwave radiometers installed in Taipei, Taichung, and Kaohsiung from 2002 to 2004 by the Environment Protection Administration (EPA) of Taiwan. Characteristics of temperature inversion events at the three cities are extracted using different classification methods.

KEY WORDS: Temperature inversion, Inversion event, Frontal inversion, Radiation inversion, Radiometer

1. INTRODUCTION

Temperature inversion indicates that the atmospheric temperature decreases with increasing the height. It occurrence tends to inhibit the vertical motion of the atmosphere. Under this condition, air pollutants can not be dissipated through vertical motion of the atmosphere and are accumulated near the surface. When a temperature inversion lasts for a long time, human health is significantly affected due to the deterioration of air quality and secondary pollutants which are formed through atmospheric photochemistry and more toxic than primary ones. It is vital to investigate the dynamics of temperature inversion.

Previous studies about temperature inversion used data from radiosondes (Brandley et al., 1992), TV tower (Baker et al., 1969), and locations with different heights (Wendler and Nicpon, 1975). Those observation methods didn't provided sufficient temporal resolution (radiosonde) or vertical resolution (TVtower). Remote sensing of atmospheric temperature profiles with sufficient temporal and vertical resolutions can provide enough information to study temperature inversion phenomena. A viable newly-developed technique is to deploy a angular-scanning single-channel microwave radiometer with an operating frequency around 60 GHz which is in a oxygen absorption band (Troitsky et al., 1993; Kadygrov and Pick, 1998; Westwater et al., 1999). Troitsky et al. (1993) developed a sensitive radiometer at 60 GHz for remote sensing of atmospheric boundary temperature profiles up to 500m. Its theoretical error is 0.1K-0.2K rms for the simple case and 0.3K-0.6K for the inversion case. Kadygrov and Pick (1998) evaluated the potential to retrieve temperature profiles with an angular-scanning single-channel microwave radiometer operating at 60 GHz with a bandwidth of 2 GHz. They found the RMSE between the retrieved temperature profiles and those from radiosonde up to 500m are within 1K rms, while no strong low level inversion occurs during the comparison period. Westwater et al (1999) evaluated boundary layer temperature profiles obtained from a scanning 5mm microwave and RASS. They found the temperature profiles up to 400m from the radiometer agree with those from radiosonde up to within 1K rms and elevated inversion above 500m is difficult to resolve with the radiometer. The instrument such as MTP-5HE of Kipp & Zonen can continuously provide low-altitude atmospheric temperature profiles with high vertical resolution.

In this paper, the observation data from MTP-5HE of environmental protection agency (EPA) of Taiwan are used to study characteristics of low-level temperature inversion events in Taipei (northern Taiwan), Taichung (middle Taiwan) and Kaohsiung (southern Taiwan).

2. DESCRIPTION OF RADIOMETER

MTP-5HE of Kipp & Zonen is an angular-scanning single-channel microwave radiometer similar to those used by (Kadygrov and Pick, 1998) and (Westwater et al., 1999). The operating frequency based on the manufacture's specification is 56.7 GHz, although the exact operating frequency is slightly higher through a theoretical analysis and the result is confirmed by Kipp & Zonen. The sensitivity of MTP-5HE is 0.08K for an integration time 1 second. MTP-5HE can measure the brightness temperatures at 31 different zenith angles ranging from 0° to 90° with an increment of 3°, and a complete scanning takes 600 seconds. The temperature profiles up to 1000 m are retrieved with a vertical resolution of 50 m. The accuracy of the temperature profile for the adiabatic condition is 0.3 K below 500 m and 0.4 K from 500 m to 1000 m, while for the inversion condition the accuracy is 0.8 K below 500 m and 1.2 K from 500 m to 1000 m.

3. RESULTS

The observation data from December of 2002 to December of 2004 are used to study the temperature inversion phenomenon in the low level boundary layer in Taipei, Taichung and Kaohsiung.

A inversion event is defined as consecutive temperature profiles with occurrence of the temperature inversion condition. Figure 1 shows the average duration of the temperature inversion event as a function of the starting time of the event. The average durations of the inversion event occurring in Taipei are almost less than 1 hour, and the hourly variation is small. The durations increase abruptly around 5pm and 6pm for Taichung and Kaohsiung, respectively, and sustain 2 hours and 4 hours for Taichung and Kaohsiung, respectively. This shows the inversion events occurring in this period, mostly radiation inversion, are robust. After this period, the durations decrease fastly for Taichung and Kaohsiung.

Figure 2 show the number of the inversion event as a function of the duration of the event for two years. In this figure a duration between n-1 and n hours belongs n hours. Most events, about 87% in Taipei and 70% in the other sites, last less than 1 hour. Taichung and Kaohsiung show a similar trend, and the decrease rate is much lower than that in Taipei. The longest duration in Taipei, Taichung and Kaohsiung are 15 hours, 63 hours and 30 hours, respectively.

Figure 3 shows the average temperature difference as a function of the duration. The average temperature difference increases with a similar rate for three sites when the duration is smaller than 18 hours. When exceeding 18 hours, the trends are unclear due to lack of data.

Figure 4 shows the average height as a function of the duration. The average height decreases with a increase of the duration when the duration is less than 5 hours because the contribution from frontal inversion decreases with increasing the duration. The initial average heights in Taipei and Taichung are above 400m much higher than that in Kaohsiung about 260m. When the duration approaches 5 hours, the average heights for all three sites reach nearly the same level. From 5 hours to 12 hours, the average height remains flat between 100m and 150m. Beyond 12 hours, the average height increases with the duration because the duration of a radiation inversion can

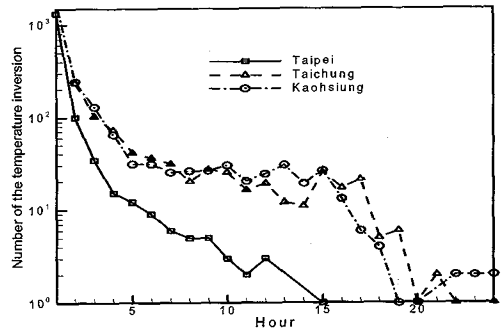

Figure 2. The number of the inversion event as a function of the duration of the event.

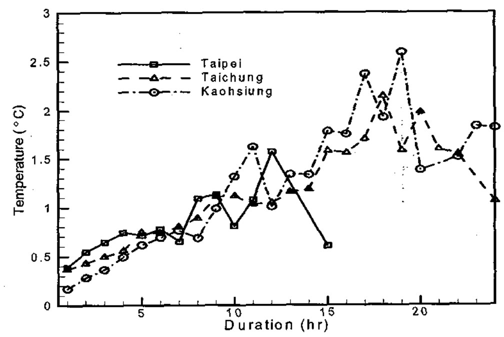

Figure 3. The average temperature difference as a function of the duration.

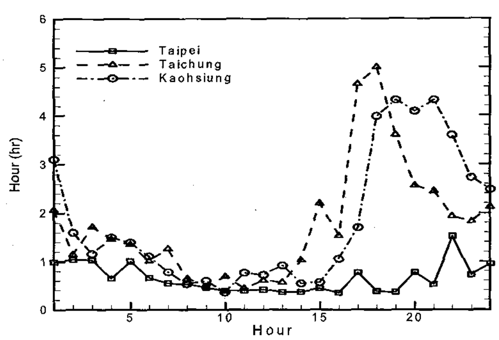

Figure 1. The average duration of the temperature inversion event as a function of the starting time of the event.

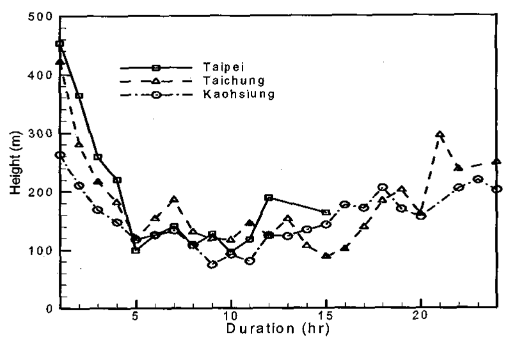

Figure 4. the average height as a function of the duration.

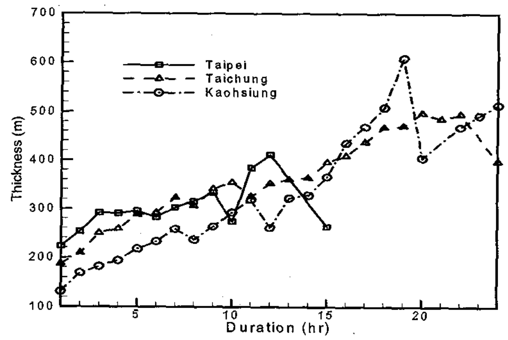

Figure 5. The average thickness as a function of the duration.

not exceed 12 hours and frontal inversion must play a role.

Figure 5 shows the average thicknesses of inversion as a function of the duration for three sites. The average thicknesses have tendency to increase with the similar rate while the duration increases.

The temperature inversion events with a longer duration have impact on environment, so the frequencies of occurrence of the inversion event lasting over 6 hours in three sites are studied. The numbers of the inversion

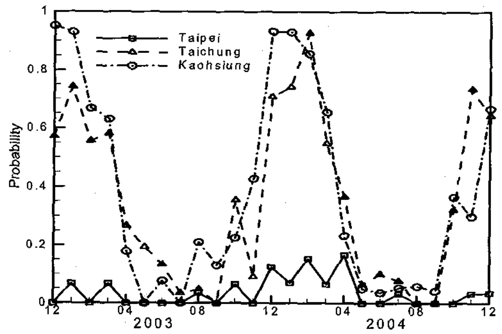

Figure 6. The monthly probabilities of occurrence of the temperature inversion event lasting over 6 hours.

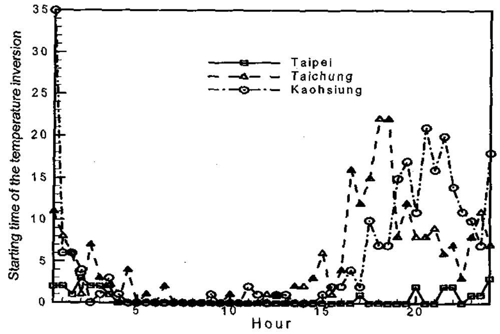

Figure 7. The hourly starting times of the long-time (> 6hours) inversion event in three sites.

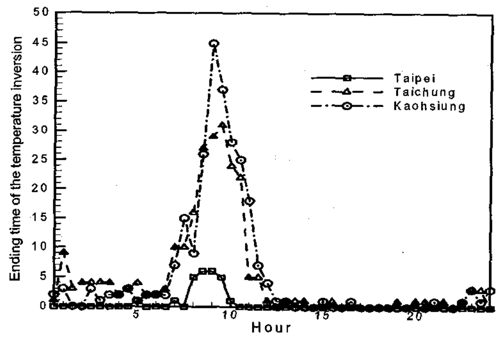

Figure 8. The hourly ending times of the long-time (> 6hours) inversion event in three sites.

event lasting over 6 hours in Taipei, Taichung, and Kaohsiung are 25, 240, and 257, respectively. Due to heat island effect, the long-time inversion events in Taipei are difficult to develop. Figure 6 shows the monthly probabilities of occurrence of the temperature inversion event lasting over 6 hours. The most frequent months in Taichung and Kaohsiung are from October to April, and the most frequent season is winter. The hourly starting times of the long-time (> 6hours) inversion event in three sites are shown in Figure 7. This shows most starting times concentrate from 5pm to 1am. The hourly ending times of the long-time (> 6hours) inversion event in three sites are shown in Figure 8. This indicates most long-time inversion events end between 7am and 12 am because the intensity of radiation inversion fades away.

4. CONCLUSIONS

The characteristics of temperature inversion events in Taipei, Taichung and Kaohsiung are studied. The average durations from 5 pm to 0 am in Taichung and Kaohsiung are much larger than that in Taipei. Trends of the average temperature difference, height and thickness are similar for three sites. The long-time inversion events occur mostly in winter and spring for three sites though the number in Taipei is only a tenth of those in Taichung and Kaohsiung due to the heat island effect. The most starting times of long-time inversion events concentrate from 5pm to 1am and the most ending times lay between 7am to 12am. Frontal inversion plays a significant role for the inversion event lasting over 12 hours.

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References

Askne, J. I. H., and E. R. Westwater, 1986. A review of ground-based remote sensing of temperature and moisture by passive microwave radiometers. *IEEE Trans. Geosci. Remote Sensing*, GE24, 340-351.

Baker, D. G., J. W. Enz, and H. J. Paulus, 1969. Frequency, duration, commencement time and intensity of temperature inversions at St. Paul-Minneapolis. *Journal of Applied Meteorology*, 8, 747-753.

Brandley, R. S., F. T. Keimig, and H. F. Diaz, 1992. Climatology of surface-based inversions in the north American arctic. *Journal of Geophysical Research*, 97, 15,699-15,712.

Kadygrov, E. N., and D. R. Pick, 1998. The potential for temperature retrieval from an angular-scanning single-channel microwave radiometer and some comparisons with *in situ* observations. *Meteorol. Appl.*, 5, 393-404.

Solheim, F., J.R. Godwin, E.R. Westwater, Y. Han, S. J. Keihm, K. Marsh, and R. Ware, 1998. Radiometric profiling of temperature, water vapor and cloud liquid water using various inversion methods. *Radio Sci.*, 33, 393-404.

Troitsky, A. V., K. P. Gajkovich, V. D. Gromov, E. N. Kadygrov, and A. S. Kosov, 1993. Thermal sounding of the atmospheric boundary layer in the oxygen absorption band center at 60 GHz, *IEEE Trans. Geosci. Remote Sensing.*, 31, 116-119.

Wendler, G., and P. Nicpon, 1975. Low-level temperature inversions in Faribanks, central Alaska. *Monthly Weather Review*, 103, 34-44.

Westwater, E. R., Y. Han, V. G. Irisov, V. Leuskiv, E. N. Kadygrov, and S. A. Viazankin, 1999. Remote sensing of boundary layer temperature profiles by a scanning 5-mm microwave radiometer and RASS: comparison experiments. *J. Atmos. Oceanic Technol.*, 16, 805-818.