Two-year Microwave Radiometric Observations of Low-level Boundary-layer Temperature Inversion Signatures

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Abstract—**Temperature inversion indicates that the atmospheric temperature decreases with increasing height. Its occurrence tends to inhibit vertical motion of the atmosphere. Under the occurrence of temperature inversion, air pollutants cannot be dissipated through vertical mixing of the atmosphere and are accumulated near the surface. When temperature inversion lasts for a long time, human health can be in jeopardy due to deterioration of air quality and secondary pollutants, which are formed through atmospheric photochemistry and more toxic than original ones. It is vital to investigate the dynamics of temperature inversion for understanding and resolving its resulting problems.**

In this paper, temperature inversion signatures 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 supported by the Environment Protection Agency (EPA) of Taiwan. Characteristics of temperature inversion at the three cities are extracted using different classification methods. The characteristics of temperature inversion in Taichung and Kaohsiung show a similar trend but are different from that in Taipei. The numbers of the occurrence of temperature inversion in Taichung and Kaohsiung were much larger than that in Taipei. The main types of temperature inversion in Taiwan are radiation and frontal inversions. Compared to frontal inversion, radiation inversion on average occurs at a lower altitude, lasts a longer period, has a deeper thickness, and reaches a higher temperature difference of inversion. Frontal inversion plays a significant role for the inversion event lasting over 12 hours.

Temperature inversion; radiation inversion; frontal inversion; microwave radiometer (key words)

I. Introduction

Temperature inversion tends to inhibit mixing of the atmosphere. Its occurrence likely puts human health in jeopardy either through locally produced pollutants or long range transport pollutants especially by the dust storms. In recent years, China's dust storms that transport dust cloud not only to the East Asian countries but also across the continental United States have raised fears of impending catastrophe. In response to the threatening of the dust storms, the Environmental Protection Agency (EPA) of Taiwan starts a series of control programs. One of them is to create a temperature inversion monitoring program by using microwave radiometers.

Microwave radiometric sensing of atmospheric temperature profiles with sufficient temporal and vertical resolutions have been developed for decades. It can provide enough information of atmospheric temperature profiles to study temperature inversion phenomena. One sensing technique is to deploy an angular-scanning single-channel microwave radiometer with an operating frequency around 60 GHz, which is in an oxygen absorption band [1-3]. 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 by MTP-5HE of EPA of Taiwan are used to study characteristics of low-level temperature inversion phenomena in Taipei (northern Taiwan), Taichung (middle Taiwan), and Kaohsiung (southern Taiwan).

II. Description of Radiometers

MTP-5HE of Kipp & Zonen is an angular-scanning single-channel microwave radiometer that is improved upon those used by [1] and [3]. Its specification is briefly addressed here. The operating frequency based on the manufacture's specification is 56.7 GHz, although the exact operating frequency is higher near 58.7 GHz through a theoretical analysis and the result is confirmed by Kipp & Zonen. The sensitivity of MTP-5HE is 0.08 K 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.

Table I. MTP-5HE observation data

	Taipei	Taichung	Kaohsiung
Total observation number	90575	93394	89653
Number of the inversion condition	6194	28253	28379
Probability of the inversion condition	6.8%	30.2%	31.7%

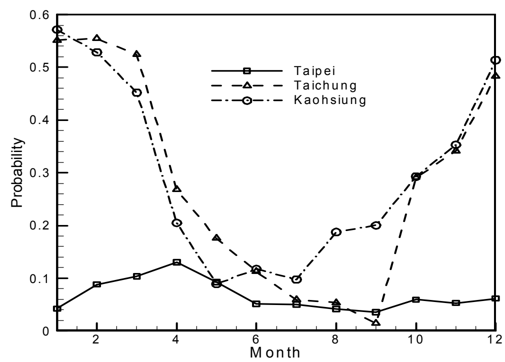

Figure 1. The probabilities of the inversion condition in different months for three sites.

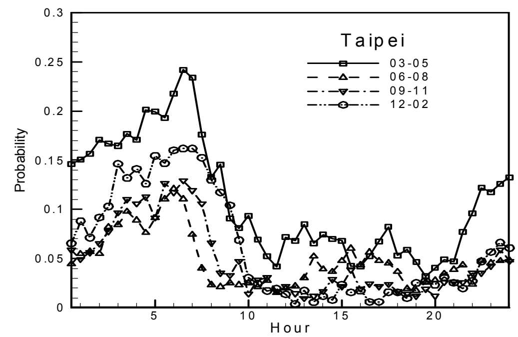

Figure 2. Hourly probabilities of the inversion condition of different seasons in Taipei.

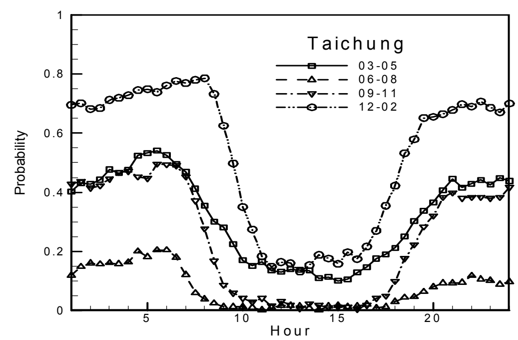

Figure 3. Hourly probabilities of the inversion condition of different seasons in Taichung.

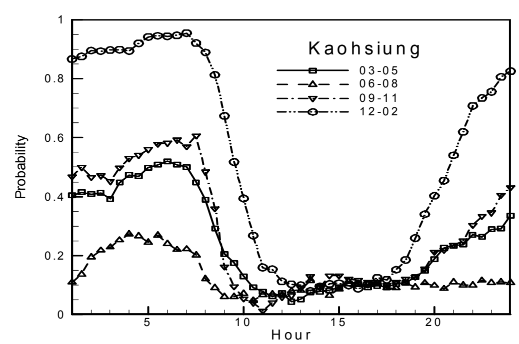

Figure 4. Hourly probabilities of the inversion condition of different seasons in Kaohsiung.

III. RESULTS

The observation data from December 2002 to December 2004 are used to study the temperature inversion phenomenon in the low level boundary layer in Taipei, Taichung and Kaohsiung. Table I tabulates total observation numbers, and numbers and probabilities of occurrence of the temperature inversion condition at three cities. The inversion condition whose starting height exceeds 800 m is excluded due to relatively high retrieval errors at higher altitudes. The probabilities of the inversion condition in Taichung and Kaohsiung just exceed 30 % and the probability in Taipei shows the lowest value, 6.8 %, among the three cities. The numbers of the occurrence of temperature inversion in Taichung and Kaohsiung are much larger than that in Taipei. The main cause for this low value is likely due to stronger heat island effect in Taipei basin, which reduces the radiation cooling effect and decreases the intensity of an inversion event. In winter, the average daytime temperature in Taipei is the lowest in three sites, but the average nighttime temperature in Taipei is higher than in Taichung. The differences between the average maximum and minimum temperatures in a day in winter are 7.5 K, 6.4 K, and 3.3 K in Kaohsiung, Taichung, and Taipei, respectively. This shows the heat island effect in Taipei reduces the temperature difference and significantly decreases the number of the occurrence of temperature inversion.

Fig. 1 shows the probabilities of the inversion condition in different months for three cities. For Taichung and Kaohsiung, the probabilities exceed 50% in late winter and early spring. The probability reaches a minimum of 10% in summer for Kaohsiung, while it decreases to a minimum of 1 % in September for Taichung. The probability for Taipei varies little as compared to the other two cities. The maximum value is 13 % in April and the minimum value is 3.5 % in September.

Fig. 2-4 show hourly probabilities of the inversion condition of different seasons in three sites, and a similar pattern emerges. After sunset, because radiation cooling effect dissipates the low level atmospheric energy, the probability of the inversion condition increases as time advances and reaches a maximum at dawn. The main type of temperature inversion is radiation inversion. After sunrise, the solar energy replenishes the low level atmospheric energy so that the probability of the inversion condition decreases abruptly to a minimum and

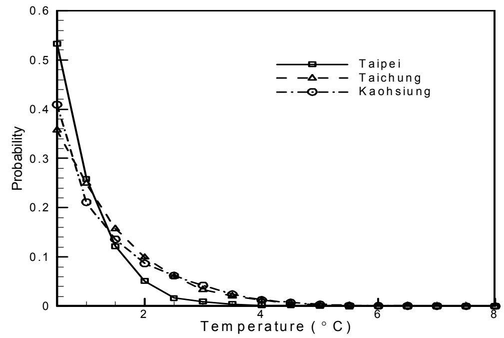

Figure 5. Probabilities as a function of the temperature difference (the inversion intensity).

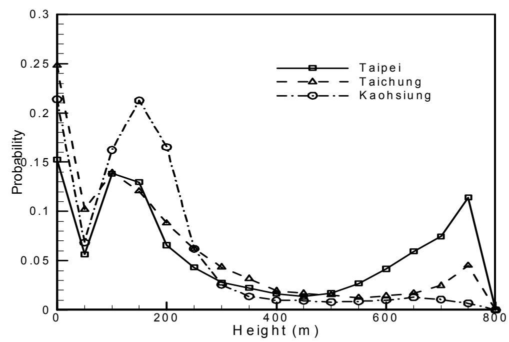

Figure 6. Probabilities as a function of the starting height of the inversion condition for three sites.

maintains this trend until nightfall. The main type of temperature inversion in this period becomes frontal inversion.

Fig. 2 shows spring gets the highest probability of the inversion condition among seasons for Taipei, and its probability reaches a maximum of 24 % at 6:30 a.m. Winter is the secondary with the maximum probability of 16 % at 6:30 a.m., and the probabilities of the inversion condition are the lowest in summer and autumn.

Fig. 3 shows winter has the highest probability of the inversion condition among seasons for Taichung, and its probability reaches a maximum of 79 % at 8 a.m. The probability in spring is slightly larger than that in autumn, and their main difference lay between 9 a.m. to 6 p.m. in which frontal inversion is the dominant type of temperature inversion. In Taichung, frontal inversion occurs almost in winter and spring.

Fig. 4 shows winter has the highest probability of the inversion condition among seasons for Kaohsiung, and its probability reaches a maximum of 95.5 % at 7:30 a.m. The value is the highest among three cities and indicates that radiation inversion occurs almost every day in winter. The probability in autumn is slightly larger than that in spring except from 9 to 12 a.m., and this trend is different compared to the other cities. The probability reaches a maximum of 60 % at 8 a.m. in autumn, while the value is 50 % at 7 a.m. in spring. Frontal inversion occurs evenly in all seasons in Kaohsiung.

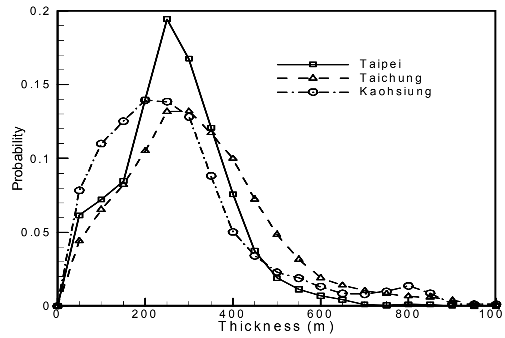

Figure 7. Probabilities as a function of the thickness of the inversion layer for three sites.

Fig. 5 shows the probabilities as a function of the temperature difference (the inversion intensity). It indicates the probability increases as the temperature difference decreases for the three cities. The probabilities in Taichung and Kaohsiung show a similar trend, and the decline rate of the probability in Taipei is larger than those in the other cities. The accumulated percentages of the temperature difference smaller than 2 degree are 96%, 86%, and 84% for Taipei, Taichung, and Kaohsiung, respectively.

Fig. 6 shows the probabilities as a function of the starting height of the inversion condition for three sites. The main types of temperature inversion in the low level atmosphere are radiation inversion and frontal inversion. Contrast to frontal inversion, radiation inversion tends to occur at a lower altitude. The accumulated percentages of the starting height lower than 300 m are 61 %, 80 %, and 91 % for Taipei, Taichung, and Kaohsiung, respectively. This shows that the dominate type of temperature inversion in Taichung and Kaohsiung is radiation inversion. The percentages of the ground inversion are 15.2 %, 24.8 %, and 21.4 % for Taipei, Taichung, and Kaohsiung, respectively. A local maximum occurs between 100 m and 200 m for all three sites. While the starting height exceeds 500 m, the probabilities in Taipei and Taichung increase as the starting height increases and the probability in Kaohsiung maintains about 1 %. This shows the starting height of frontal inversion in Kaohsiung is much lower than those in Taiwan and Taichung.

Fig. 7 shows the probabilities as a function of the thickness of the inversion layer for three sites. The maximum probability occurs between 250 m and 300 m for all three sites. The accumulated percentages of the thickness lower than 300 m are 72 %, 56 %, and 72 % for Taipei, Taichung, and Kaohsiung, respectively.

Fig. 8 shows hourly average Tav-Ti for the three sites where Ti is the ground temperature while an inversion condition occurs, and Tav is the average ground temperature at the same time over previous 7 days. Tav-Ti's from 0 to 8 a.m. for all three sites remain flat, and their values are about 0.1 K, 0.2 K and 0.5 K for Taipei, Taichung and Kaohsiung, respectively. After dawn, Tav-Ti's increase abruptly to about 2 K for Taipei and Taichung, and 1.2 K for Kaohsiung and remain the same magnitudes to 4 p.m. for Taichung and 6 p.m. for the other two sites. The value becomes larger while the

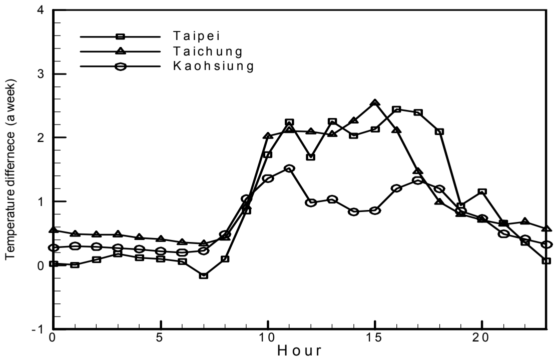

Figure 8. Hourly average T_{av}-T_i for the three sites where Ti is the ground temperature while an inversion condition occurs, and T_{av} is the average ground temperature at the same time over previous 7 days.

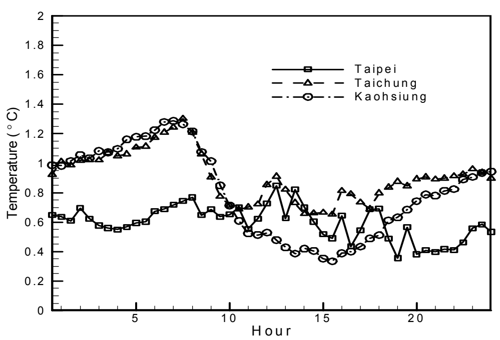

Figure 9. Hourly average temperature difference (inversion intensity) in the three sites.

inversion condition stems from the transient weather condition such as the passage of a cold front. After nightfall, Tav-Ti's decrease rapidly for the three sites because radiation inversion regains the dominant role gradually.

Fig. 9 shows the hourly average temperature difference (inversion intensity) in three sites. The inversion intensity increases hourly from 6 p.m. to 8 a.m. in Taichung and Kaohsiung, and from 4 to 8 a.m. in Taipei. The temperature differences at 8 a.m. are about 1.3 K for Taichung and Kaohsiung, and 0.75 K for Taipei. This indicates the duration of a radiation inversion and its intensity in Taichung and Kaohsiung are much larger than those in Taipei.

An inversion event is defined as consecutive temperature profiles with occurrence of the temperature inversion condition. Fig. 10 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 5 and 6 p.m. for Taichung and Kaohsiung, respectively, and sustain 2 and 4 hours for Taichung and Kaohsiung, respectively. This shows the inversion events occurring in this period, mostly radiation

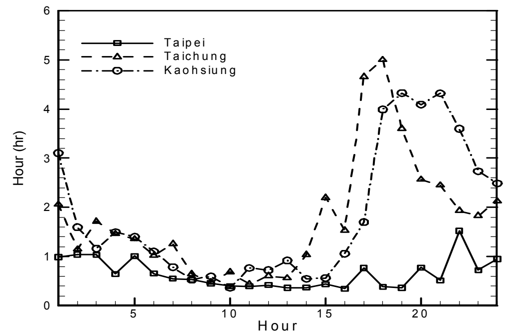

Figure 10. Average duration of the temperature inversion event as a function of the starting time of the event.

inversion, are robust. After this period, the durations decrease fast for Taichung and Kaohsiung.

IV. Conclusions

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

The characteristics of temperature inversion in Taichung and Kaohsiung show a similar trend, but are different from that in Taipei. The numbers of the occurrence of temperature inversion in Taichung and Kaohsiung are much larger than that in Taipei. The main types of low-level temperature inversion in Taiwan are radiation and frontal inversions. Compared to frontal inversion, radiation inversion on average occurs at a lower altitude, lasts a longer period, has a deeper thickness, and reaches a higher temperature difference of inversion. Frontal inversion plays a significant role for the inversion event lasting over 12 hours.

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