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A temperature inversion in "Chinese Arctic Research Expedition 1999"

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Abstract Using the boundary layer observation data collected by "Arctic Upper Air Observation 1999" in Chinese Arctic Research Expedition 1999, a strong temperature inversion in summer is studied. It shows that the intensity (6.3℃/(100 m)) is much stronger than the climatology average value in summer and winter. The temperature inversion took on a remarkable diurnal variation. The intensity of inversion gradually weakened from night to daytime.
Key words Arctic, temperature inversion, diurnal variation.

1 Introduction

The Arctic area, as the background of global climate and environment, draws people's attention with its impact on global change (IPCC 1990). Great amount of energy and mass are exchanged between the sea and air with special interface, air-ice-sea surface, in this area. Therefore it is important to study the exchange. It would benefit understanding the role of Arctic in the change of global climate and environment, and improving forecast skill of weather, climate and natural disasters (Adams *et al*. 2000).

The exchange of mass and energy between sea, ice and air occurs in the boundary layer, so the temperature inversion of atmospheric boundary layer has great influence on the exchange. The height of temperature inversion lid has been identified as the height where concentration of pollution gases and aerosols occur (Bridgman *et al*. 1989). The height of inversion base is used to estimate the geostrophic drag coefficient for input of sea-ice models (Overland 1985; Overland and Davidson 1992; Hibler and Bryan 1987). The inversion layer has been linked to the photochemical destruction of boundary layer ozone at Arctic sunrise, through a "meteorology modulation" process in which free tropospheric ozone-rich air penetrates through the inversion to displace low-level, ozone-depleted air (Barrie *et al*. 1988; Oltmans *et al*. 1989; Mickle *et al*. 1989). In addition, the intensity of the inversion influences the height of heat and mass exchange over the sea-ice cover (Andreas and Murphy 1986; Schnell *et al*. 1989; Serreze *et al*. 1992). In a word, understanding the inversion layer, including its spatial and temporal variability, is important in Arctic research.

First of all, Belmont (1957) and Vowinckel and Orvig (1967) attempted to describe the spatially and temporally variable climatological features of the Arctic temperature inversion. Recently, Kahl *et al*. (1992) analyzed 10 - 40 a of rawinsonde data from 13 Canadian Arctic sites and pointed out that the temperature inversion there has clearly seasonal variation. In winter, the inversion occurring frequency is 98% (February), the inversion depth about 545 – 1177 m, and the temperature difference across the inversion about 5 – 14℃. On the contrary, in summer, the frequency is lower (50%, in August), the depth shallower (212 – 447 m), and the temperature difference less (1℃ – 2℃). The variable of inversion is complicated in transit seasons, e.g. in autumn (Paluch *et al*. 1997). In addition, seasonal and regional variations in the Arctic boundary layer temperature inversion are examined using 12 a of twice-daily rawinsonde data from 31 inland and coastal sites of the Eurasian Arctic and a total of nearly six station years of data from three Soviet drifting stations near the North Pole by Serreze *et al*. (1992). They drew the similar conclusions: the winter inversions are strong (the mean inversion depth is over 1200 m, temperature difference c.a. 12.6℃, and frequency 95%, in March), and most of them are likely surface based inversions; the summer inversions are weak (the inversion depth is 400 m, temperature difference 2.8℃ and frequency a little more than 50%, in August), and alike to be elevated inversions.

All the studies above showed that the Arctic inversion is a complicated phenomenon, including not only radiative cooling, warm air advection, subsidence processes, radiative properties of clouds and ice crystals, surface melt, and topography, but also turbulent mixing and surface fluxes of heat and moisture (Busch *et al*. 1982; Curry 1983). On the other side, although these studies provided useful summaries of temperature inversion characteristics in the Arctic, the limited observation data are insufficient to identify the climatological features of the Arctic inversion and its diurnal variation.

This study analyzed the sonding data obtained from the Chinese Arctic Research Expedition over the Chukchi Sea in August 1999. A very strong summer temperature inversion was found, and its diurnal variation is discussed.

2 Data and method

China carried out its Arctic research expedition from July 1999 to September 1999. The Institute of Atmospheric Physics, Chinese Academy of Sciences completed the upper air observation successfully. On August 5, the scientists set up a temporary ice camp at 73.37°N, 165.00°W and carried out the atmospheric structure observation with GPS sonding system. They released four sondings altogether at an interval of 6 hours. The observation time was 11:45, 17:04, 23:11 GMT on August 5 and 4:30 GMT the next day, equivalent to about 00:00, 06:00, 12:00 and 18:00 local time, respectively. Although each observation range is above twenty kilometers a.s.l., the data below 700 m are used in this study. The data include air temperature, pressure, humidity and wind. The sonding system reports a group of data each 30 – 50 m in vertical resolution.

In this study, the vapor density (ρ_v) is adopted as humidity parameter. From the observed humidity parameter, dew-point temperature, we adopt the following equations to calculate the vapor density:

$$\rho_v = \rho q \tag{1}$$

$$\rho = p/RT \tag{2}$$

$$q = \frac{622 \times 6.11 \exp\left[\frac{a(T_d - 273.15)}{T_d - b}\right]}{p - 0.378 \exp\left[\frac{a(T_d - 273.15)}{T_d - b}\right]} \tag{3}$$

where ρ_v, ρ is vapor density and atmosphere density, respectively, q specific humidity, p air pressure, R dry atmosphere constant, T and T_d the air temperature and dew-point temperature, respectively, and a and b constants (here critical temperature for sea ice and water is selected as 263K, i.e., while T > 263K, $a = 17.26$, $b = 35.86$, and T < 263K, $a = 21.87$, $b = 7.66$).

3 Results

3.1 Air temperature inversions

In general, the temperature inversion base is defined as the layer where air temperature rises with height, and the top of inversion, the first layer where air temperature descends with height. The observed temperature profile in the early August is showed in Fig.1. At midnight, the air temperature increased from −1.1℃ at 2 m to 17.7℃ at 300 m. The inversion intensity approached 6.3℃/(100 m), which not only exceeds the mean intensity greatly in summer of this area (0.5℃/(100 m)), but surpasses that in winter (1.0℃/(100 m)) (Kahl *et al*. 1992; Paluch *et al*. 1997). At dawn, the inversion lid lifted to 400 m, but the temperature difference was almost of no variation, i.e., the inversion intensity decreased more or less (the average is 4.7℃/(100 m)). At noon, mixed layer began to grow because of the ground temperature rising with absorbing short wave radiation of the sun. Air temperature of 2 m was higher than that of 100 m, in another word, the surface based inversion was broken up and turned into elevated inversion. The inversion lid rose to 500 m, the temperature difference was 17℃ and the intensity decreased to 4.25℃/(100 m). Near nightfall, the ground temperature dropped below 0℃ again, so the mixed layer disappeared. At the same time, the top of inversion descended to 400 m and the intensity weakened to 4.11℃/(100 m). From above, we can see the diurnal variation of Arctic inversion takes on a special phenomenon that the intensity decreased while the depth increased. In our opinion, this kind of distribution is on the base of its complex structure of topography. As we know, Arctic surface is made up of ice and water in summer, which keeps the temperature stable around the ice point. But the air temperature rises with radiation, advection process *et al*. and then forms temperature inversion. No matter how the intensity decreased, one of the most important things is that the temperature intensity was still much stronger than the climatology mean value. In another word, sometimes it can form strong inversion weather in summer at Arctic area.

The depth of temperature inversion ($\triangle Z$) and the temperature difference ($\triangle T$) are good parameters to show inversion intensity. To avoid the inconsistent expression of temperature inversion intensity with them two, someone defined their combination $(\triangle T)^2/(\triangle Z)$ as the parameter to show inversion intensity (Belmont 1957; Stone and Kahl 1991). With this method, we calculated the inversion intensity with the observation data. Its temporal and spatial distribution is showed in Fig.2. It is obviously that the strongest inversion occurred at second half night at about 170 m a.s.l.. And in the afternoon the mixed layer is formed.

3.2 Atmospheric humidity

Similar with strong temperature inversion, there existed humidity inversion in the atmospheric boundary layer over the Chukchi Sea, i.e., the humidity increased with the rising of

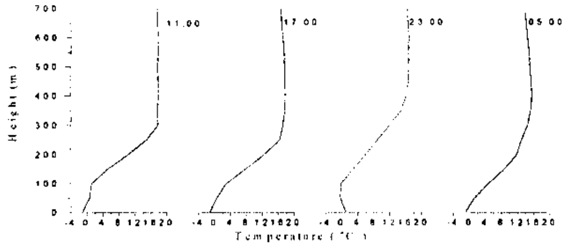

Fig.1. Diurnal variation of temperature inversion at 73.37°N, 165.00°W.

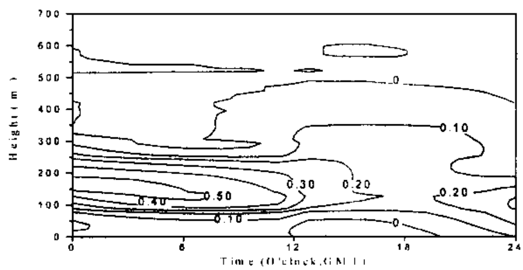

Fig.2. Temporal and spatial distribution of temperature inversion intensity.

height (Fig.3). We can see that both the humidity inversion lid (the first layer where humidity decreases with height) and the most humidity difference experienced a low-high-low pattern. The top of humidity lifted from 200 m at 11:00 (GMT, same as the following) to 250 m at 17:00, and then to 300 m at 23:00, at 05:00 the next day it decreased to 250 m. The most humidity difference in the inversion layer also increased from 3.6 g/m^3 at 11:00 to 6.4 g/m^3 at 17:00, then decreased to 6.2 g/m^3 at 23:00 and 5.6 g/m^3 at 05:00. This varying pattern is the same as that of the temperature inversion, both of which got to their peak at the second half night. Therefore, the atmospheric boundary layer of Arctic area at summer night is rather stable, which stops the transportation of mass and energy, as well as air pollutant.

4 Discussion

The observation site was on a 1 km^2 ice floe, with other multi-scale floes around. Furthermore, there was no cloud in the low space during that period of time. As we all know, the temperature of mixture of ice and water is always near 0℃. So in summer, the air above is warmer than the interface, which forms temperature inversion. This kind of inversion is different from that formed on continent. The latter will vanish with time going on after sunrise. As we mentioned above, the temperature was highest at 300 m high at midnight. The temperature gradients induced transporting sensible heat upwards and downwards and the gradients reduced down. The upward heat heated up the air above while the downward heat can't increase the temperature of sea surface. This process lifted the top of temperature inversion at dawn but the temperature difference was kept steady, which we called the intensity of temperature inversion bated. After sun-

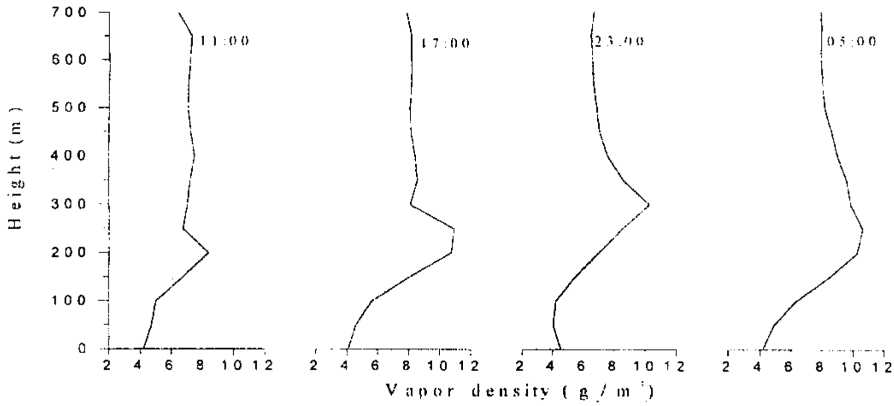

Fig.3. Diurnal variation of vapor density at 73.37°N, 165.00°W.

rise, the ground overfall developed and the low air stratification trended to be unstable. Both the base and the top of the inversion lifted but the temperature difference minished, and the intensity went on bating. This process lasted to nightfall.

5 Conclusions

We analyzed a temperature inversion with the atmospheric observation data obtained by Chinese Arctic Research Expedition 1999 and drew out some results as follows:

(1) There was a strong temperature inversion layer over the Chukchi Sea during expedition. The intensity not only surpassed the average inversion intensity in summer, but also that in winter. The inversion has a remarkable diurnal variation and its intensity weakened from midnight to the next day. At the same time, the inversion lid lifted at first, and then fell.

(2) There existed a humidity inversion in the boundary layer at the explored area. Both the top of it and the maximum difference humidity experienced a low-high-low process diurnal variation.

We considered the special topography of the expedition area is the main reason for the strong temperature inversion. But because of the limitation of observation data at Arctic area, the research on diurnal variation of temperature inversion need further discussion.

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