Near-surface Temperature Inversion over the East China Sea

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Abstract Temperature inversion structure affects the boundary layer activity and convective activity. The frequency, strength, and formation mechanism of near-surface temperature inversion are studied using sounding data at three stations over the East China Sea from 2000 to 2015. The results show that the frequency and strength of the inversion are larger in summer (over Cheju station) than in winter (over ROIG station). The inversion is mainly classified as advection inversion over Cheju station, while mainly classified as radiation inversion over ROIG station. Low cloud amount in winter is larger than that in summer over the East China Sea, which is opposite to the inversion frequency. The reason is that the frequent and strong inversions hinder the height of convection in summer, it is difficult for moist air to reach the lifting condensation level and form clouds.

1. Introduction
Temperature inversion often occurs over the East China Sea. It is characterized by a vertical temperature gradient that changes from negative to positive. Many inversion phenomena have been studied globally, such as tropospheric temperature inversion over central China[1], capping inversion at the top of planetary boundary layer (PBLH, 1 km height) in the subtropical oceans near California and Peru[2]. These studies have improved our understanding of the formation of temperature inversion. However, up to now we know very little about temperature inversion over the East China Sea.

Temperature inversion can hinder the mass and energy exchange from lower layers to upper layers of the inversion, thus affecting atmospheric dynamic and thermal processes[3-4]. Inversion structure plays an important role in chemical transport and convective activity[5-8]. Temperature inversion can also provide scientific basis for the prediction of cloud base/top height. Numerous studies have discussed the influence of cloud top inversion on cloud formation process[9]. However, little attention is focused on the relationship between near-surface temperature inversion and low cloud. The purpose of this study is to investigate the characteristics of near-surface temperature inversion over the East China Sea and its relationship with low cloud amount.

2. Dataset and method
Sounding data used in this study are from the University of Wyoming (http://weather.uwyo.edu/upperair/sounding.html), including Naze, ROIG and Cheju stations (Figure 1). Sounding data includes twice daily data from 2000 to 2015 at 0000 and 1200 UTC. Available meteorological elements include pressure level, geometric altitude, temperature, dew point, wind speed and direction. Before analysis, following the method of Li et al.[1], the quality control of the data was performed. This study also used the European Centre for Medium-Range Weather Forecasts interim reanalysis (ERA-Interim) from 2000 to 2015 with horizontal resolution of 0.5° × 0.5°.
The temperature inversion is defined as the upper level temperature greater than or equal to the temperature at lower level. The frequency is defined as the ratio of the inversion samples to the total data number. Strength is defined as the temperature difference between the upper and lower layers at intervals of 20 m. Low clouds layers are defined as layers of temperature-dew point difference less than 4 K and with a cloud base height of higher than 500 m (to separate from sea fog), a cloud top height of less than 4 km, and a cloud top covering an inversion layer.

3. **Characteristics of near-surface temperature inversion**

Both Cheju and ROIG Stations show that the near-surface temperature inversion mainly occurs in spring and summer (Figure 2 a-b). The lowest temperature inversion occurs below 1000 m over the East China Sea and touches the ground when station elevation is considered. For the Cheju station, the inversion mainly occurs at height of 100-800 m, with maximum frequency up to 40% in May. For the ROIG station, the inversion frequency is much less than that over the Cheju station, mainly occurring lower than 400 m. When we compared inversion strength, it is found that the strength is also larger over the Cheju station than that over the ROIG station, with the maximum strength of 0.3 K per 20 m over the Cheju station in May and 0.15 K per 20 m over the ROIG station in July (Figure 2 c-d).
Fig. 2. Seasonal variation of inversion frequency (%) over Cheju station (a) and ROIG station (b). Seasonal variation of inversion strength (K per 20 m) over Cheju (c) and ROIG stations (d).

The monthly average structure of the temperature and dew point also have significant seasonal variations over Cheju and ROIG stations. In January, temperature gradient is negative and temperature decreases as height increases (Figure 3a). The temperature-dew point difference is less than 4 K above 400 m over ROIG Station, indicating a relatively wet environment (Figure 3b). In May, the temperature profile is a straight line with a gradient close to zero between 100 to 500 m over Cheju station, and the temperature-dew point difference increases rapidly below 1000 m, which is related to the frequent inversions in May. When the inversion occurs, the top of the inversion usually treated as PBLH, and the moist water vapor from sea surface is hindered below the PBLH, resulting in relative dry environment above the PBLH.

Fig. 3. Monthly mean temperature (K, a) and temperature-dew point difference (K, b) in January and May at Cheju and ROIG stations.

To explore the formation mechanism of near-surface temperature inversion, the meridional wind of January and May are synthesized to determine whether they are advection inversion or not. In January,
both Cheju and ROIG stations are southward wind below 1000 m (Figure 4a). Cold air upon warm sea
surface indicates that the air-sea interface is unstable and convection develops frequently, which is
unfavorable to the formation of the inversion. Southerly wind prevails in both Cheju and ROIG
stations below 1000 m in May. The monthly average difference between SST and 2 m air temperature
(ΔT) is 1 K at ROIG station, which means cold air is upon warm sea surface, while ΔT is -1.5 K at
Cheju Station, indicating that warm air is upon the cold sea surface, which is favorable for the
formation of the inversion (Figure 4b). Therefore, the inversion is advection inversion at Cheju station.
Then, which kind of inversion at ROIG station is? The daytime and nighttime inversion frequency are
calculated respectively to determine whether they are radiation inversion. The diurnal variation of the
inversion over Cheju station is not significant, while the inversion mainly occurs in daytime over
ROIG station, and the nighttime frequency is near zero (Figure 4c-d). The more frequent inversion in
summer and its diurnal variation indicate that the inversion may be attributed to the radiation inversion
over ROIG station.

Figure 5 shows a negative correlation between low cloud amount and near-surface temperature
inversion frequency over Cheju and ROIG stations, reaching -0.87 and -0.85, respectively. The
inversion frequency is small and low cloud amount is large in January, oppositing to that in
May. Numerous studies have revealed that abundant low clouds in the subtropical oceans near
California and Peru occur with cold SST in summer. However, low cloud amount is the largest over
the East China Sea in winter. The influence factor for the difference between the eastern subtropical
oceans and the East China Sea may be the frequent near-surface temperature inversions in summer.
The inversion height is usually below 800 m, while the heights of lifting condensation level (LCL) at
Cheju, Naze and ROIG stations are usually near/above 900hPa (about 1000 m). Frequent and strong
near-surface inversions block the development of moist water vapor in summer, making it difficult for
moist air to break through the top of inversion layer and reach the LCL to form low clouds.
Fig. 5. Seasonal variation of low cloud amount (%) and inversion frequency (%) over Cheju (a) and ROIG (b) stations.

4. Conclusion

The near-surface temperature inversion frequency is frequent over the East China Sea in summer based on sounding data. The frequency and strength of the inversion are larger over Cheju station than over ROIG station. The inversion mainly occurs between 100-800 m over Cheju station, while mainly occurs below 400 m over ROIG station. The inversion is mainly advection inversion at Cheju station, while is radiation inversion at ROIG station.

Near-surface temperature inversion can block the mass and energy exchange from sea surface to upper layers of the inversion, thus affecting the formation and height of low clouds. There is a negative correlation between low cloud amount and near-surface temperature inversion frequency, which means that abundant low clouds form when the inversion frequency is small. The reason is that the frequent and strong inversion blocks the development height of convection and makes it difficult for moist air to reach LCL and form clouds in summer.

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