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Analysis of Near-Surface Layer Meteorological Elements for a Summer Fog in Ninglang Airport

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Abstract

Based on hourly observation data from 2016 to 2019 and hourly automatic meteorological observation data from 2018 to 2019, we analyzed the annual, monthly and daily variation characteristics of fog days in Ninglang Airport, and diagnosed a case of summer fog. The results show that the average annual fog days in Ninglang Airport are 128 days and the annual characteristic of fog days is bimodal. Analyzed on fog cases in 2019, it was a summer fog process lasting more than 20 hours and visibility less than 500 m. The data from the automatic observational stations around Ninglang airport can describe the near-surface layer features of fog and illustrate the progress of fog. The meteorological elements of automatic observational stations changed suddenly 2 hours before fog, so the data of the automatic observational stations can be used to forscast fog.

Keywords

Summer Fog, Near-Surface Layer, Meteorological Elements, Ninglang Airport

1. Introduction

Fog is a weather phenomenon that the near-surface layer of air reduce horizontal visibility to less than 1 km caused by suspended water droplets or ice crystal particles [1]. Fog is one of the disastrous weather in China, which has the characteristics of high frequency and a wide range of influences. The long duration of fog seriously affects the atmospheric visibility and causes serious harm to traffic, public health, industrial and agricultural production, *et al.* It is an important meteorological factor that directly affects the normal implementation of flight tasks and the opening of the airport. Therefore, it is of great significance to study the characteristics of fog and the characteristics of near-surface meteorological elements to guarantee traffic safety and guide people to travel.

In recent decades, a lot of results have been made in the research on the synoptic and climatic characteristics, macro and micro physical characteristics, generation and extinction mechanism of fog and the establishment of fog forecast model. Fog days in China have obvious interannual and monthly variations and spatial distribution characteristics [2] [3] [4], and the annual variation of fog days shows a trend of increasing first (before 1980) and decreasing (after 1990) [5] [6] [7]. In terms of seasonal distribution, most areas in China have more fog in autumn and winter, and less fog in spring and summer, while fog in coastal areas is more frequent in spring and summer [8] [9], and fog in plateau areas also occurs in summer [10]. The daily evolution of fog weather is mainly influenced by thermal factors related to temperature and humidity [11] [12] [13]. Radiation fog, advection fog or mixed fog is mainly used in fog prediction and numerical model simulation studies [14] [15] [16] [17]. However, rain fog is also a common weather phenomenon found in actual observation and research [18]. Ninglang Airport in the northwest of Yunnan is located in the southeast of the Qinghai-Tibet Plateau with an altitude of 3293 m. It is the airport with the highest sea level in Yunnan. The west side of the airport is slightly higher and the rest area is a valley and dam area. There is the Lugu lake away from it 25 kilometers. In summer, the main water vapor comes from the southwest Indian Ocean and Bay of Bengal, and the southwest warm and wet air is uplifted by the topography of Hengduan Mountains. It is easy to make low clouds around the airport area, fog accompanied by local weak precipitation and other weather phenomena that affect the visibility of the airport, thus affecting the normal take-off and landing of aircraft at Ninglang Airport. In this paper, the variation characteristics of summer fog are obtained by using the hourly visibility (Vis) data from 2016 to 2019 at Ninglang Airport. To understand more detail about the near-surface features of summer fog in Nilang airport, a summer fog case was analysed based on the station-observated data of three automatic meteorological observation stations (No. 66, 88 and 90) around Ninglang Airport. It is of great significance work to provide a theoretical basis for the forecast and early warning of airport fog. Because of the rain and fog, the number of flight delays, alternate landings and cancellations due to account for more than 93.55% in Ninglang Airport in 2016 year. The results will show the dynamtic and thermodynamic characteristics of summer fog and get possible forecast signal for summer fog to guarantee the flight operation of Ninglang Airport.

Based on the atmospheric dynamic equation, the vertical vorticity and vertical velocity of near-surface air over the airfield are calculated by using the finite element interpolation method by the 10 min hourly wind speed and wind direction data of three automatic meteorological stations. Calculation formula is as follows:

The vertical vorticity is:

$$\zeta = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} \tag{1}$$

Equation of continuity:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial \omega}{\partial z} = 0 \tag{2}$$

2. Characteristics of Fog Days in Ninglang Airport

Visibility is the transparency of the atmosphere, and can be expressed by using the visible range of object. Based on "Fog Prediction Level (GB/T 27964-2011)", the judgment standard of fog is defined as visibility less than 1000 m, and the dense fog is that visibility between 200 m and 500 m. According to this judgment standard, when the visibility meets this standard in one observation day (00 to 23 o'clock on that day), it is judged that there will be fog in Ninglang Airport that day, and it is recorded as a fog day in Ninglang Airport. Hourly airport visibility data from January 1, 2016 to December 31, 2019 are statistically calculated to obtain the variation characteristics of fog days in a total of 4 years. The results show that the annual mean fog days of Ninglang Airport is 128 days, the maximum is about 155 days in 2017 yr, and the minimum is 107 days in 2016 yr. The fog days in the other two years are close to the average, 131 and 117, respectively. The biggest difference in annual fog days can be 48 days. The monthly average variation chart of fog days (see **Figure 1**) shows that the number of fog days at Ninglang Airport are larger in July and September than the other months. From this chart, the number of fog days is not only more in rainy season than in dry season, but also more in summer than in other seasons, which indicates that the summer fog is a usual weather phenomenon at Ninglang Airport. Application of high resolution interpolation data analysis showed that the fog often occurs in northwest or western Yunnan in summer [19], and the Yunnan plateau is a typical summer fog area [10], therefore, Ninglang airport is located in the northwest

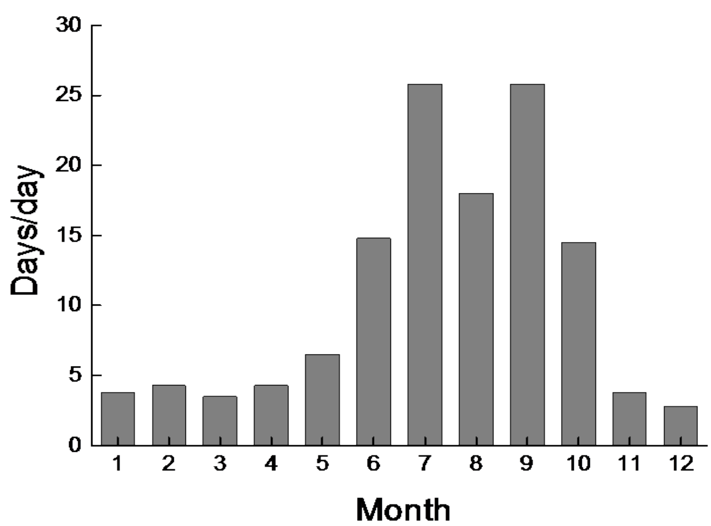

Figure 1. The annual variation of fog days in Ninglang Airport from 2016 to 2019.

Yunnan that is more summer fog, and its altitude is above 3000 m, the characteristics of summer fog are remarkable.

Figure 2 is the hourly fog variation curve of Ninglang Airport from 2016 to 2019. From this figure, the diurnal variation characteristics of fog in Ninglang Airport are obvious. The fog is easy to appear between 6 a.m. and 8 a.m., with the highest frequency of fog at 7 a.m. and at least 62 days per year on average. It is hard to produce the fog from 13:00 to 17:00, and the frequency of fog appearance is the least from 14:00 to 16:00. The probability values of the formation fog at any time are very small by statistically analyzing the fog time. The maximum probability value is only 10% at six o'clock in the morning, while the fog to generate probability is lowest 1% during 10 o'clock to 16 o'clock. These illustrate that the time of generating fog is random, and the fog may appear at any time.

According to the characteristics of fog in Ninglang Airport, a fog event defined with a fog break time of fewer than 6 hours is considered to be the same fog event. By calculating airport fog events from 2016 to 2019, a total of 493 fog events occurred in the four years. According to the generation and dissipation time of these fog events, the duration and accumulated days of every fog event could be obtained, as shown in Figure 3. The results show that the fog duration in Ninglang Airport concentrated in 1 - 10 hours in 4 years, and the fog that duration for 1 - 4 hours occurs more than 50 times, there 51 fog events that last longer than 12 hours account for 10% of the total fog events, and 19 fog events that last longer than 24 hours account for 4% of the total fog events, and 10 fog events lasting longer than 36 hours account for 2% of the total fog events.

3. Fog process at Ninglang Airport from 9-11 July 2019

The duration of summer fog in Ninglang Airport is usually less than 4 hours, but the duration over 20 hours of summer fog will seriously affect the operation and safety of flights in Ninglang Airport. As a new shipping airport, it is urgent to understand the various characteristics and causes of fog in the area around Ninglang Airport. Three automatic meteorological observation stations are installed in the vicinity of Ninglang Airport in 2018. In this paper, hourly data of

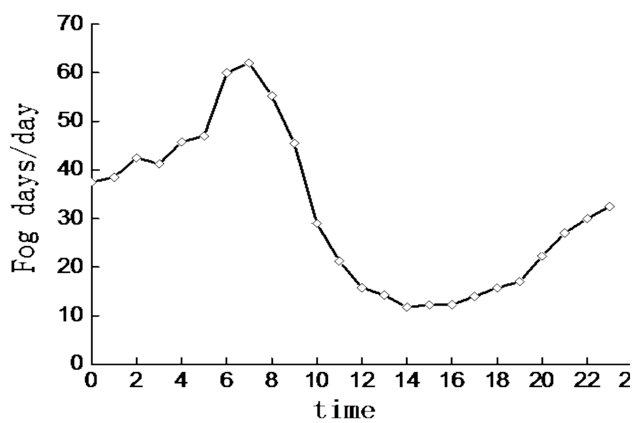

Figure 2. The average hourly fog days variation of Ninglang airport from 2016 to 2019.

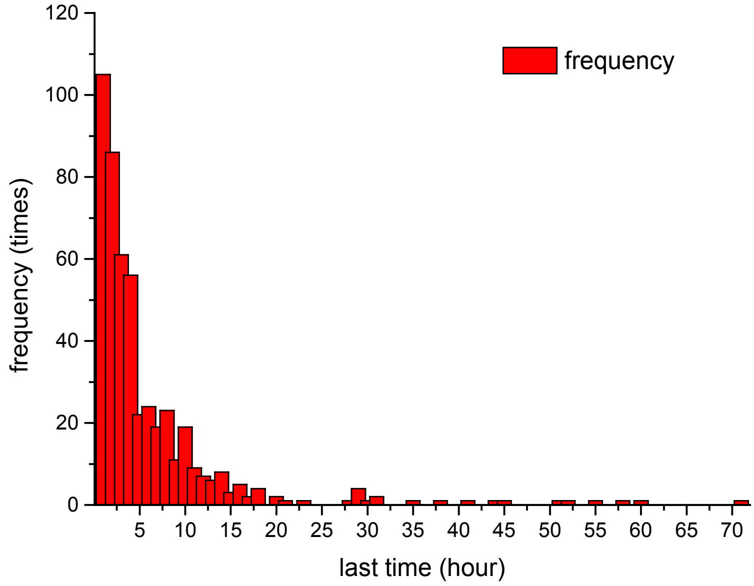

Figure 3. The distribution of fog duration variation in Ninglang airport from 2016 to 2019.

2019 with relatively complete data and quality control are selected to conduct case analysis of the fog event in Ninglang Airport. According to the visibility observation data of Ninglang Airport and combined with the actual weather data of the airport, a case analysis is conducted on the fog event with visibility below 500 m and duration over 20 hours during July 9-11, 2019, and the near-surface variation characteristics of the fog in Ninglang Airport are obtained.

3.1. Analysis of Near-Surface Layer Meteorological Elements during Dense Fog

Figure 4 shows hourly variations of visibility, relative humidity and depression of dew point at Ninglang Airport from the 9th to the 11th of July, 2019. **Figure 5(b)** clearly showed the thick fog less than 500 m began to appear at 15 o'clock on July 10th over airport. After two hours, visibility improved slightly, but fog turned to thick fog less than 500 m again 6 hours later and continued until 12 o'clock on 11^{th}. According to the previously defined time interval 6 hours or less as the same fog events, this fog process is a fog event lasting more than 20 hours. In addition, the occurrence period of this fog process is the period with the lowest probability of the occurrence of fog in Ninglang airport, so the formation reason of fog in Ninglang Airport can be found through the diagnostic analysis of individual cases.

The change curves of relative humidity and depression of dew point are shown in **Figure 5(a)**. The both reverse change characteristics are obvious, which the relative humidity value was higher and depression of dew point was lower. The air moisture content was higher from 0 o'clock on July 9th to 12 o'clock on July 10th, and depression of dew point changed around 1˚C over Ninglang airport area. When the visibility value was lower than 1000 m, depression of dew point

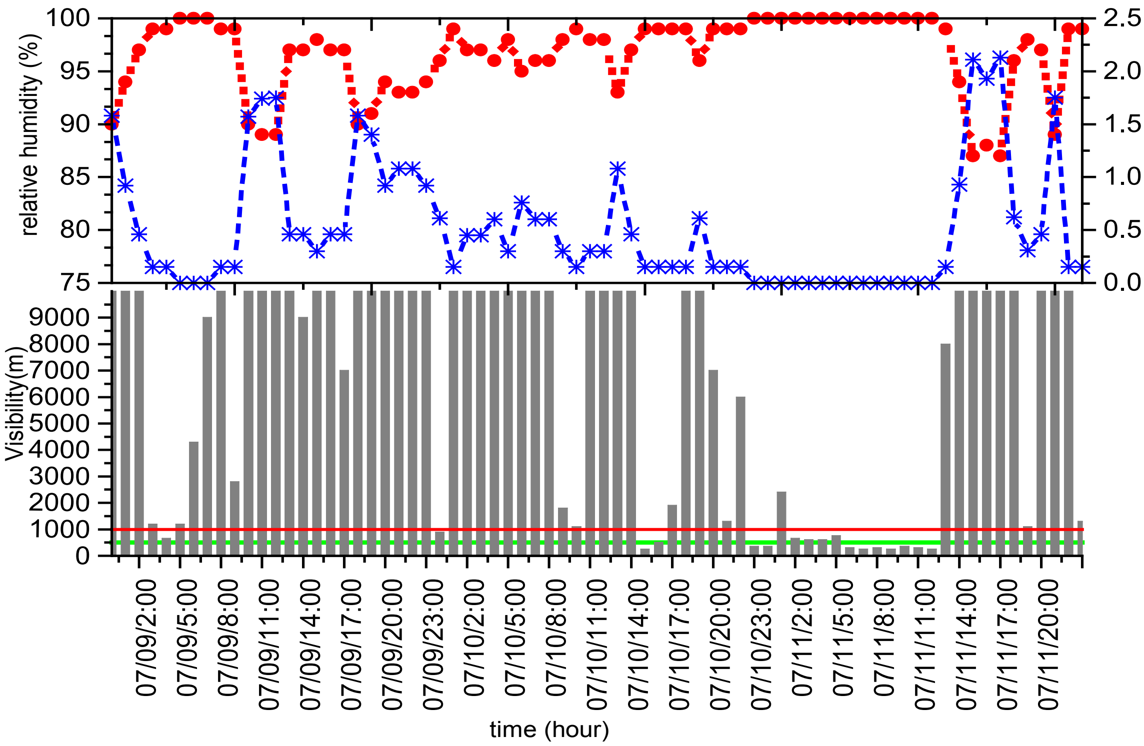

Figure 4. The variation of visibility (bar chart), relative humidity (red dotted line) and dew-point temperature difference (blue triangle dotted line) at Ninglang airport from July 9-11, 2019.

was lower than 0.5˚C and the relative humidity was higher than 95%. Between 15 o'clock on 10th and 12 o'clock on 11th July, the relative humidity was maintained above 98%, and depression of dew point was maintained below 0.5˚C, close to 0˚C. When the visibility was relatively good from 17 - 21 o'clock on 11th, the relative humidity was 95% and depression of dew point was close to 0.5˚C and below.

In this case, the thick fog occurred suddenly, with the visibility dropping from 40,000 m to 500 m below. Within 2 hours before the occurrence of fog, it could be seen that the relative humidity increased significantly from 85% to more than 98%. The depression of dew point decreased rapidly from 1.3˚C to 0˚C and the moisture was instantly saturated. The formation of fog is usually affected by the joint action of many factors. In practical observation and many studies, it is found that radiation fog, advection fog or mixed fog are the main fog in China. However, the rain and fog are usually concurrence on the plateau in summer. Rain fogs often occur in weak rainfall or before and after rainfall [20] [21]. In the process of the heavy fog, the hourly rainfall variation of 3 automatic meteorological observatory datas around Ninglang airport is displayed in **Figure 5(a)**. The results showed that it was no precipitation for 3 days on No. 66 automatic station which the highest altitude, and rainfall about 1 mm/h around No. 88 automatic stand and No. 90 automatic station during 0 to 4 p.m. every early morning, which altitude is lower 200 m - 300 m than No. 66 automatic station's. The relative humidity variations of three automatic stations remained above 90% in this

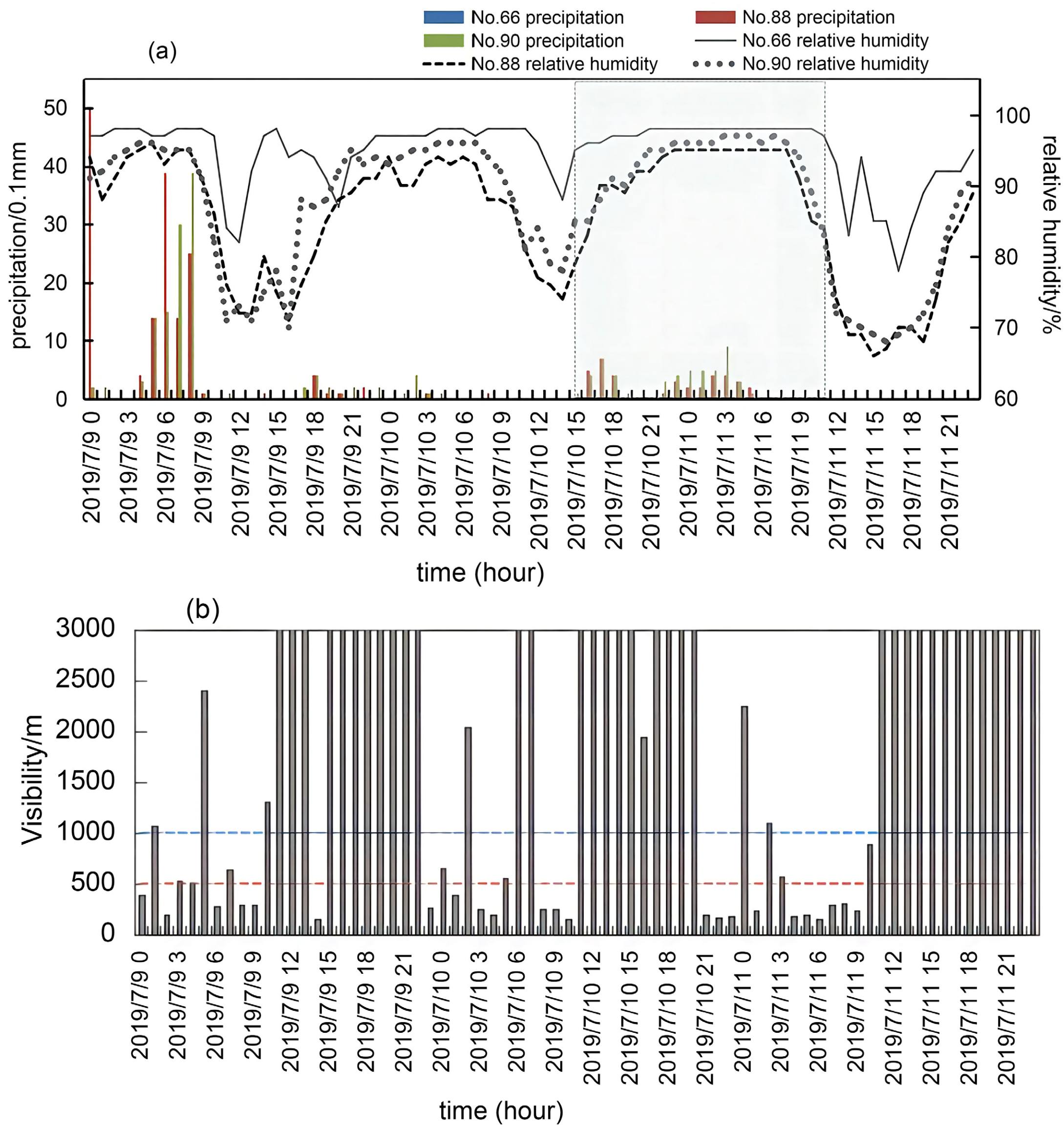

Figure 5. The rainfall and relative humidity characteristics of three automatic meteorological observation stations for July 9-11, 2019 (a); Hourly visibility's change at the No. 90 automatic meteorological observation station (b).

period. Affected by terrain, the relative humidity increases gradually with the increase of altitude, therefore, the relative humidity of No. 66 automatic stations was above 95% and higher than the other two stands.

Hourly variation of visibility at No. 90 station showed that there was weak precipitation and fog from 0 to 10 o'clock every day (Figure 5(b)). The rain intensity was most of the time below 2 mm/h, just only between 7 and 8 o'clock on 9th was above 3 mm/h, which exceeded the critical value of drag effect of raindrops on fog drops and had a clearing effect on fog drops [22]. Therefore, after the end of the precipitation on July 9th, there was a clear sky after the rain for a short time. Due to terrain uplift and low-level precipitation, the fog formation time in No. 66 station and the airport lagged behind that in No. 90 station.

3.2. Analysis of Near-Ground Dynamic Meteorological Elements in Dense Fog Process

Referring to the international standard of relative humidity 90% distinguishes fog from haze [23] [24]. When visibility drops below 500 m for the first time and relative humidity is above 90% at the same time, it's called the fog generation time. Similarly, when visibility rises to more than 1000 m and relative humidity drops below 90% at the same time, it is called the fog dissipation time. In this case, the fog generation time was 15 o'clock on July 10th, and the fog dissipation time was 13 o'clock on 11th.

On the 700 hPa atmospheric circulation graph (not list chat), before fog happened in Ninglang airport (*i.e.*, 8 o'clock on July 10th), Yunnan and surrounding area were located in the front of the Indo-Burmese through, the westerlies is the main over Yunnan. At the heavy fog generation time (July 10th, 14 o'clock), Indo-Burmese trough moved eastward and controlled the northern Diqing area, so the water vapor condensation with the warm moist airflows climbing from south to north and rainfall in Ninglang area. At 14:00 on November 11th, the India-Burma trough moves eastward out of Yunnan, and Ninglang was located in the weak high-pressure ridge, mainly controlled by the west-north air flow, and the weather begins to clear up in the afternoon. This process is mainly influenced by the Indo-Burma trough, and the southwest warm airflow brings sufficient water vapor under the effect of terrain uplift for Ninglang area to rainfall, but the rain strength is weak to facilitate the formation of rain and fog.

Ninglang Airport is located in the transition area of Tibet Plateau, Yunnan-Guizhou Plateau and Sichuan Basin, so its altitude is higher and the vegetational cover is better, that caused the near-surface layer wind speed around Ninglang Airport is lower. The variation of 10-minute wind speed from automatic meteorological observation station in Figure 6. It shows that the near-surface wind speed was maintained within the range of 3 m/s from July 9-11, and the wind speed was minimum at No. 90 station, which was usually below 2 m/s. Compared the

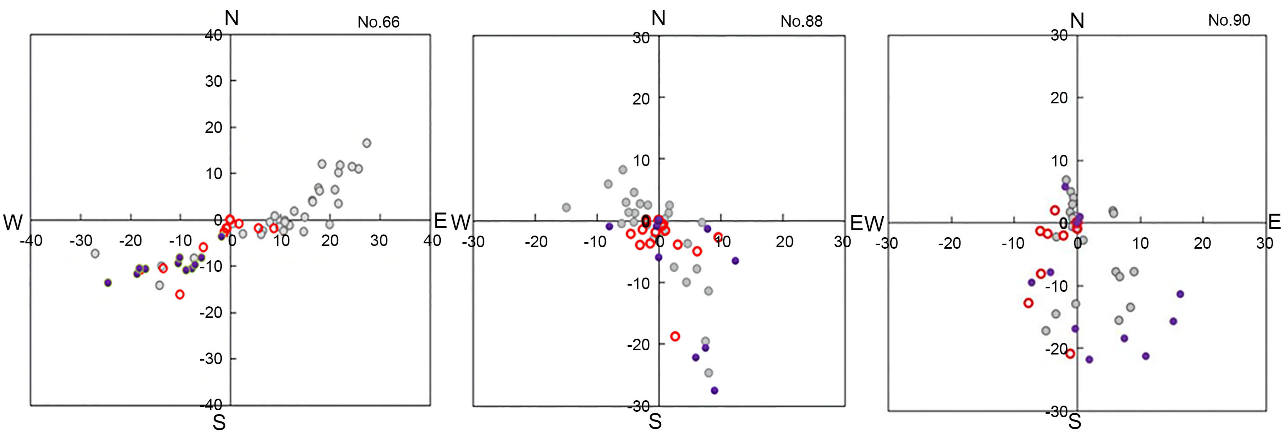

Figure 6. The hourly changes of wind speed and direction from 9-11 July 2019 for three Automatic Meteorological stations (gray dots represent conditions before the occurrence of fog; red hollow dots represent dense fog; the purple dots represent conditions after the fog clears; unit: 0.1 m/s).

meridional wind speed and the zonal wind speed at three stations, it was found that the meridional wind speed is greater than the zonal wind speed and the southerly wind velocity is greater than the northerly wind speed at No. 90 and No. 88 station, but the zonal wind speed is greater than the meridional wind speed at No. 66 station. In the large scale southwest monsoon circulation background, the characteristics of the near-surface wind are closely related to the topography. For No. 66 station, because it is located southwest to the northeast mountain ridges, where is in the south of the airport, zonal wind speed is greater than the meridional wind speed. While the No. 88 and No. 90 stations are located in a southwest to northeast vast valley at a slightly lower altitude, for this reason, the meridional wind speed is obviously greater than the zonal wind speed. So the effect of topography on the near-surface wind speed is more important.

Before the fog occurred, the wind was mostly northeast at No. 66 station, northwest at No. 88 station, and south or north alternately at No. 90 station. When the fog occurred, the wind direction changed and the wind speed decreased at all three automatic meteorological stations. At No. 66 station, the wind direction changed from northeast to southwest, and the wind speed weakened to less than 1 m/s. At No. 88 and No. 90 stations, the wind direction changed to southerly, and the wind speed also weakened to less than 1 m/s. After the fog dissipated, the wind speed increased significantly, but the wind direction did not change. The results show that the formation of fog depends on the condition of low wind speed. In the calm or weak wind weather, the weak precipitation process can sufficiently cool and retain water vapor in the air, which is conducive to the formation and maintenance of fog. When the wind speed increases to a certain intensity, the exchange interaction of dynamic conditions near-surface is enhanced, and fog is easy to disperse.

Based on the data of the automatic meteorological observation stations, the vorticity and vertical velocity changes of the near-surface near the airport are calculated by using the formula (1)-(2), as shown in **Figure 7**. The column is the near-surface vertical velocity, and the red dot line is the near-surface vorticity value. Before 11 o'clock on July 9th, the near-surface vorticity was a weak negative value, and the vertical velocity was below 0.5 m/s. There was weak subsidence movement in the near ground layer over the airport area, that mainly caused by the subsidence movement of the dry and cold northwest wind from the high altitude area nearby the western of the airport. As a result, the surface wind direction in the east side of the airport with a slightly lower altitude changed to northwest wind. When the dry and cold air descends along the terrain into the warm and wet area on the east side of the airport, the lower atmosphere is unstable and prone to weak precipitation. Therefore, precipitation occured at both No. 88 and No. 90 stations, but there was no precipitation at the highest No. 66 station, though high humidity. With releasing the latent heat of condensation, a weak inversion appeared in the near-surface layer about 150 m at the vally after rainfall (see **Figure 8**). The weak inversion of the near-surface

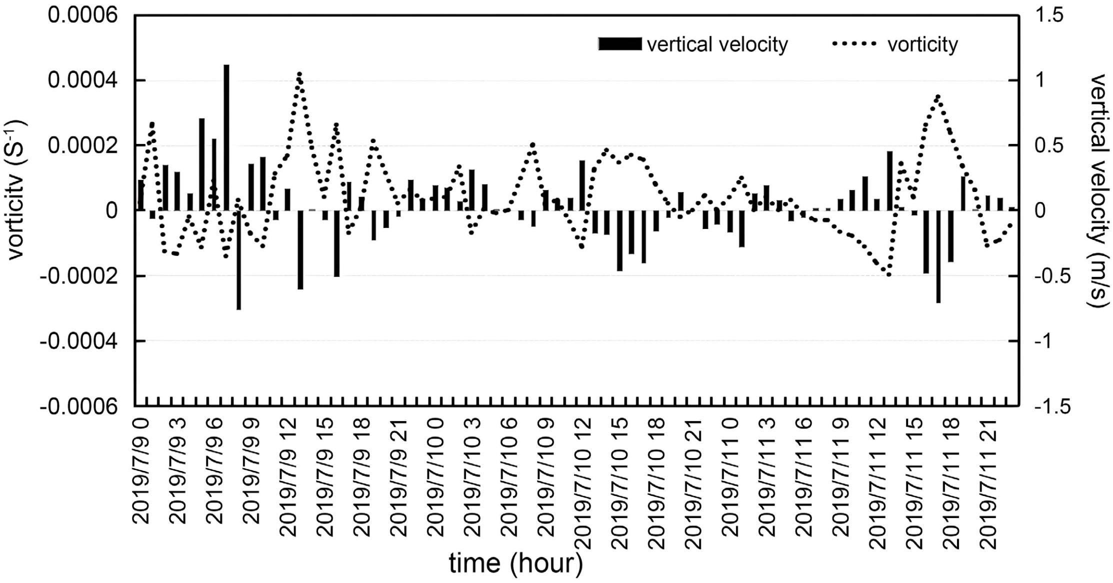

Figure 7. The characteristics of vorticity and vertical velocity over the near surface layer for Ninglang airport from 9-11 July 2019 (the red dots line means vorticity, unit: m/s, on the left side of the coordinates; and the bar means vertical velocity, unit: m/s, on the right side coordinates).

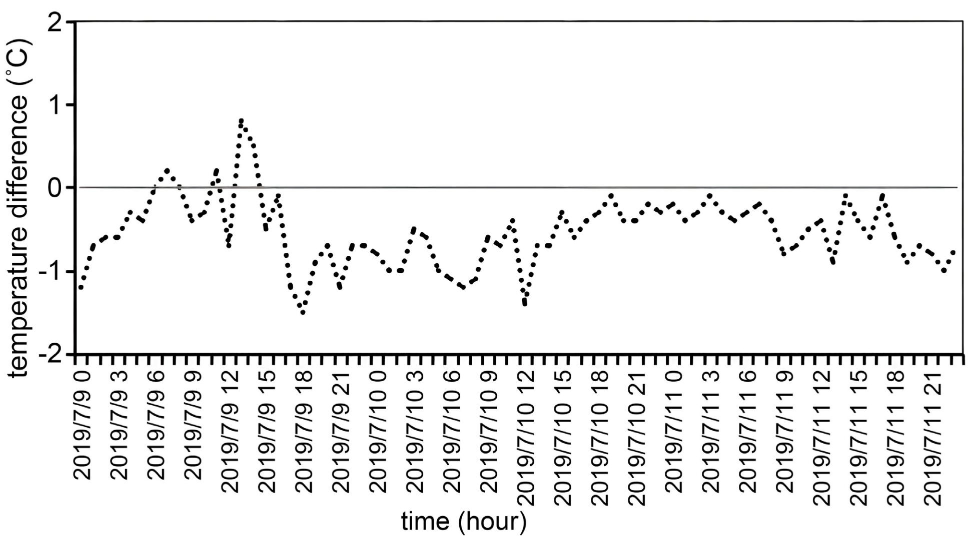

Figure 8. The temperature difference between the No. 90 and No. 88 stations over the east of Ninglang airport from 9-11 July 2019 (unit: ˚C).

layer after rainfall is beneficial to the outbreak of the fog [25], even the fog of visibility lower than 500 m. Due to the lower atmosphere, weaker sinking motion blocks the uplifting of fog, so there was no fog in the higher airport area at this time. After 10 o'clock on 9th, the weak atmospheric unstable stratification in the lower layer disappeared with the heating of the atmosphere by solar radiation, and the surface temperature rose. Then the vorticity of the lower atmosphere turned into a larger positive value and the vertical velocity turned into a larger negative value, that means the relatively strong upward movement appeared in the lower layer, and the fog completely dissipated. But the vorticity strenghth of positive vorticity controlled near-surface layer and of the vertical motion decreased with India-Burma trough cross Ninglang area between the afternoon of the 9th and the noon of the 10th. When the southwest warm moist airflow of before trough flows to north, the mountains would block it. Under the influence of terrain dynamic lifting effect, the air water vapour condensation gradually. They climb to the airport at 66 in the southwest of the station form the saturated moist air, air further north to the east, to the airport on the west side of a mountain stream area to promote the air moisture humidity increases, the meteorological observatory data shows relative humidity increase to more than 85%, close to formation of weak positive vorticity appear weak the upward movement of the ground, 88 and 90 stations have sustained weak rainfall occurs, Subsequently, the near-stratum positive vorticity gradually weakens and fog appears in Ninglang Airport. Six hours later, the vorticity value decreases to near zero and the vertical velocity is also close to zero. The atmosphere is in a static state, which is conducive to the maintenance of the fog. At the end of the fog, the atmospheric vorticity and vertical motion gradually increase, the vorticity turns to positive vorticity and increases, while the vertical velocity increases to negative value, indicating that the atmosphere begins to have strong upward movement, the horizontal wind speed also gradually increases, and the fog disperses.

By analyzing the case in July 2019, the results show that the data from the automatic observational stations around Ninglang airport can describe the near-surface layer features of fog and illustrate the progress of fog. Under the backround of the eastward moving Indian-Burma trough, the wind speed reduced and water vapour condensed to cooling in the near-surface layer by affecting the mountain terrain, so it is easy to drizzle around No. 90 and No. 88 stations and occur mist. Then fog would gradually rise to the north of airport. In actual observation, it is also found that the summer fog in Ninglang Airport gradually spreads southward from the northern to the whole airport, affecting aviation operation. The meteorological elements of automatic observational stations changed suddenly 2 hours before fog, so the data of the automatic observational stations can be used to forecast fog.

4. Conclusions

1) From 2016 to 2019, the annual average fog days at Ninglang Airport is 128 days, and the annual difference between the minimum and maximum fog days is 48 days. The results indicate that the interannual variation of fog days is obvious and the number of fog days in rainy season is more than that in dry season, especially, the number of fog days in summer is more than that in other seasons.

2) The generation time of fog in Ninglang Airport is highly random, and fog may be generated at any time in a day, in comparison, the probability of fog forming at 6 a.m. is up to 10%. Most of the fog lasts for 1 - 4 hours, but 10% of the fog lasts for more than 12 hours, that would affect greatly the operation of flights and is also difficult to forecast.

3) By analyzing a single case of summer fog at Ninglang Airport in July 2019, the results show that the characteristics of near-surface layer meteorological elements variation were prominent, such as wind speed, relative humidity and temperature and dew point. These meteorological elements had obviously changed before and after the formation and dissipation of fog, while in the fog maintenance stage, the characteristics of near-surface layer atmosphere have sufficient water vapor and stable stratification atmosphere.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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