Temporal and spatial distribution characteristics and causes of sea fog in Jiangsu coastal area

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Abstract: Based on the observation data of Binhai and Lvsi stations in the past ten years, this paper analyzes the temporal and spatial distribution characteristics and formation conditions of sea fog along the coast of Jiangsu Province, and obtains some rules, such as: winter and spring are the seasons of frequent sea fog along the coast of Jiangsu Province, when the relative humidity is \( \geq 85\% \), the temperature difference between water and air is within plus or minus 8℃, when the southeast wind is easier to form fog, and the wind speed generally does not exceed 5 levels. In addition, the sea fog in Jiangsu coastal area can be generally divided into inverted trough type, low pressure type, cold air type and high pressure type, and it is easy to form fog when inverted trough. Continuous multi-day sea fog is often the continuous influence of various weather situations. All these provide ideas for the prediction of sea fog in Jiangsu coastal area.

1. Introduction
Sea fog refers to the fog generated in the sea under the influence of the sea, which is a high-risk weather for highway traffic, sea and high-altitude shipping. Although the observation of sea fog has been developed in recent years, the numerical study of sea fog is still less, mainly focusing on the Yellow Sea and Bohai Sea. Therefore, our forecasting method is still relatively backward, mainly relying on weather charts and hydrometeorological conditions to judge.

Although many scholars have analyzed and studied the sea fog along the coast of China\(^1\), there are few studies on the sea fog along the coast of Jiangsu Province, and the observation data used are not new enough. In this paper, the observation data of five stations in Jiangsu coastal area in recent years are used for research, which have relative advantages in the coverage of the stations and the updating degree of the data. Sea fog is generally divided into advection fog, radiation fog, mixed fog, and terrain fog\(^2\). Jiangsu coastal area belongs to coastal area, and the formation of sea fog is also very complicated due to the influence of dual air flow from ocean and land. Therefore, the sea fog discussed in this paper does not specifically distinguish which kind of sea fog it is.

2. Materials and methods

2.1 Data collection
There are 5 inshore stations in Jiangsu coastal area from north to South: Binhai, Dafeng port, Waikejiao, Yangkou Port and Lvsi. There are more stations and longer time series of observation data.
However, there are still some problems as follows: first, the starting time of continuous data of visibility at each station is different; second, some stations have the problem of missing elements. Therefore, considering the observation sequence and data integrity of each station, table 1 shows the time period and observation elements of the data used in this paper.

| site          | time interval | visibility | air temperature | Water temperature | R | H | wind direction | wind speed |
|---------------|---------------|------------|------------------|-------------------|---|---|----------------|------------|
| Binhai        | 2009–2018     | √          | √                | √                 | √ | √ | √              | √          |
| Dafeng Port   | 2015–2018     | √          | √                | √                 | √ | √ | √              | √          |
| Waikijiao     | 2015–2018     | √          | √                | √                 | √ | √ | √              | √          |
| Yangkou Port  | 2011–2018     | √          | √                | √                 | √ | √ | √              | √          |
| Lysi          | 2015–2018     | √          | √                | √                 | √ | √ | √              | √          |

2.2 Method
According to the content of the tenth "sea surface effective visibility and fog observation" in the "coastal observation specification", it is considered that fog occurs when the visibility is less than 1km, and as long as there is one visibility less than 1km on that day, it is regarded as a foggy day.

According to the division of seasons, winter is from December of the previous year to February of the next year, spring is from March to May, summer is from June to August, and autumn is from September to November.

There are 5 stations in Jiangsu coastal area, namely Binhai, Dafeng port, waikijiao, Yangkou Port and Lysi. As long as the visibility of one of the stations is less than 1km on the same day, it is defined as a foggy day in Jiangsu coastal area.

3. Spatial and temporal distribution characteristics

3.1 Annual variation characteristics of fog days
Statistics show that the annual average fog days in Jiangsu coastal waters is 54 days, but the annual difference is significant. Taking Binhai station as an example, the foggy days were the most in 2018, with 47 days, and the least in 2013, with only 4 days. In recent years, fog days are more than in previous years, and the fog days in 2015-2018 are significantly more than those in other years.

3.2 Fog diurnal variation characteristics
There is a significant monthly variation of fog days along the coast of Jiangsu Province. From August to October, sea fog occurred least. The reasons are as follows: first of all, after entering spring, the wind direction is mainly east or southeast wind, which can continuously transport a large amount of water vapor and heat necessary for fog formation to the fog area. In this way, when the air meets the cold sea surface and reaches saturation, it can form fog. Secondly, due to the influence of weak cold air in winter and spring, the temperature of water surface in the sea area drops, and the warm and humid air flowing over it is easier to change and cool, making water vapor condense into fog. However, from August to October, although the air humidification process can still be carried out, the cooling process can not be carried out due to the high temperature of seawater, and the water vapor can not reach saturation and can not form fog\[^3\], so the fog days in summer are the least.
3.3 Seasonal variation characteristics of foggy days
The fog days along the coast of Jiangsu Province have obvious seasonal characteristics. Winter and spring are the seasons of frequent sea fog. Spring is the most, accounting for more than 50% of the total fog days in the whole year, and autumn is the least, accounting for only 14%.

3.4 Diurnal variation characteristics of fog
Sea fog can occur at all times of the day in the Jiangsu coastal area, but it mainly occurs from night to 9 am, and the probability of fog formation from afternoon to evening is the lowest. This is due to the rapid rise in the temperature at noon and the instability of low-level stratification, so it is not easy to form sea fog at this time, and the sea fog is easy to dissipate.

3.5 Spatial variation characteristics of foggy days
Sea fog can be generated at all stations along the coast of Jiangsu Province from north to south. The number of fog days at the southernmost station of Lvsi station is obviously less than that of other stations, with an average annual fog day of 23 days. This may be because the surface temperature of sea water near other stations is lower than that of Lvsi station in winter and spring, so the air with the same temperature and humidity conditions is easier to condense into fog in these places.

4. Hydrometeorological conditions
The production of sea fog needs the cooperation of some hydrometeorological conditions. For this reason, the following mainly analyzes the water vapor, sea level, wind field and other conditions during fog formation along Jiangsu coast, so as to provide the basis for short-term forecast.

4.1 Relative humidity
When the vast majority of sea fog occurs, the relative humidity of the atmosphere reaches more than 85%, and the supply of warm and humid air flow provides necessary conditions for the formation of heavy fog [4]. Although the relative humidity is less than 50%, it can form fog, but this is an extreme situation, only once or twice in many years.

4.2 Water temperature difference
According to the data of Jiangsu coastal area, there is an obvious correlation between fog days and water temperature difference. 89% of sea fog occurs on the sea surface with water temperature lower than 25°C.

In addition to the condition that the surface water temperature is lower than a certain limit value, it also depends on the coordination between sea surface water temperature and air temperature. If the difference between water temperature and air temperature is too large, the saturated vapor pressure in the air will increase, which is difficult to reach saturation, which is unfavorable to the formation of sea
fog. Through a large number of observations, it is found that 93% of the sea fog in Jiangsu coastal area occurs when the temperature difference between air and water is within +8 ℃.

4.3 Wind speed and direction
The wind direction along the coast of Jiangsu Province has obvious seasonality, with northerly wind in winter and southerly wind in summer. Due to the increase of cyclone activity in spring and autumn, the wind mainly turns from southeast to northeast. According to the data, fog can form in Jiangsu coastal areas with downwind, and the wind speed will not exceed level 5, because the excessive wind speed will strengthen the turbulent exchange in the air, hinder the bottom cooling, and is not easy to form fog. Taking Binhai station as an example, the vast majority of sea fog occurs in the southeast wind, but there are still some sea fog in the north-east wind direction, but in this case, the wind force is mainly small wind below level 4.

This is because the existence of warm and humid air plays an important role in the formation of sea fog, it can transport a lot of water vapor and heat, so when blowing the southeast wind, it is more conducive to blowing the warm and humid air to the coast. In the case of northeast wind and southwest wind, although the water vapor condition is relatively weak, it can also form fog if other hydrometeorological conditions are properly combined [5].

5. Weather situation
The formation of sea fog in Jiangsu coast is often related to some specific weather systems. According to the ground map from 2005 to 2010, it can be seen that the sea fog mainly occurs in the following weather situations: inverted trough type, low pressure type, cold air type and high pressure type. According to the statistical analysis, it is easy to form fog when the tank is inverted, accounting for 53.2%; the low pressure type is the second, accounting for 25.5%; the proportion of cold air and high pressure situation is the smallest. Let's discuss these weather situations in detail.

5.1 Inverted groove type
Such weather systems often occur in winter and spring. It can be seen from the ground map (Fig. 3) that this type of sea fog generally occurs at the top of the inverted trough. Southeast or southerly winds blow along the coast, which is conducive to the transportation of warm and humid air to the coast. When the wind is not strong, it is easy to form fog. From the high altitude, there are short wave troughs or East Asian troughs moving eastward over the Jiangsu coast when the sea fog occurs, and the southwest airflow strengthens, which provides necessary warm and humid conditions for the formation of sea fog.

Figure 2. Ground map under inverted trough situation
5.2 Low voltage type
This type occurs all the year round, but mainly in winter, spring and early summer. In winter and spring, there will be obvious warm and humid air transport along the coast of Jiangsu Province due to the eastward movement of the East Asian Trough and the short wave trough. In the early summer, the subtropical high extends westward over the land and its intensity increases. Jiangsu coastal areas are generally located at the top of the low pressure or the bottom of the northeast low pressure. At the top of the inverted trough, the wind direction is mainly southeast or northeast, while at the bottom of low pressure, the wind direction is mainly from west to southwest, and the wind is not strong.

5.3 Cold air type
Under the influence of such weather system, except in summer, sea fog may be generated. Generally, the cold air flows southward through the warm and humid ocean surface, which causes the temperature above the water surface to drop and the water vapor on the sea surface condenses. The fog formation under the influence of cold air is generally dominated by weak cold air process, or when the cold air just comes down and the wind is not strong, the north-east wind blows on the coastal waters of Jiangsu Province, and the wind speed is small. If the cold air is too strong, the upper air will be affected by the northwest air flow, which will cut off the warm and wet gas to the coastal transportation, and the sea fog is not easy to generate, and the wind is too easy to disperse the sea fog.

5.4 High pressure type
This kind of sea fog mainly occurs in late winter and spring. From the high-altitude situation, the East
Asian trough gradually moved away from the sea area of China, and its position was relatively north. The coastal area of Jiangsu Province was mainly affected by the westerly flow at the bottom of the trough. On the corresponding ground map, when the high pressure center moves eastward into the sea, Jiangsu coastal area is at the back or top of the high pressure. When the wind speed is low, sea fog will be generated.

From the above analysis, it can be seen that sea fog generally occurs under some specific weather systems, but the continuous multi-day sea fog process is often combined with a variety of weather situations. For example, from December 19 to 21, 2016, sea fog occurred along the coast of Jiangsu Province for three consecutive days. From the ground situation, Jiangsu coastal area was first affected by weak cold air, the wind was not strong, combined with high-altitude warm and humid air flow, the coastal sea fog appeared. Due to the weak cold air this time, the coastal area of Jiangsu Province was immediately affected by the inverted trough, and the coastal wind was mainly southeast. Therefore, from the weather situation analysis, the fog has experienced cold air type and inverted trough type process, so the duration is longer than the general sea fog process.

6. Conclusion
According to the above analysis, it can be concluded that the formation of sea fog is related to the following factors, and these conditions can also provide reference for judging whether there is sea fog.

(1) The sea fog in Jiangsu coastal area has obvious spatiotemporal variation characteristics. It occurs from north to south, and the fog days in the southernmost station are less; the fog days are more frequent in winter and spring, but the fog days are obviously reduced in August to October; sea fog can be generated all day in Jiangsu coastal area, but the probability of sea fog formation before 9 am is higher.

(2) The requirements of water vapor for most sea fog in Jiangsu coast are as follows: relative humidity 85%, water temperature lower than 25 °C, water vapor temperature difference within +8 °C.

(3) In Jiangsu coastal area, fog can be formed in every wind direction, and it is easier to form fog in southeast wind, and the wind speed will not exceed 5.

(4) The weather situation of sea fog in Jiangsu Coast mainly includes: the top of inverted trough or low pressure, the bottom of northeast low pressure, weak cold air, and the back or top of high pressure. The continuous sea fog for many days is often the joint action of various weather situations.

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