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Monitoring and Analysis of a Persistent Sea Fog in Qiongzhou Strait

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Abstract: From January 21 to January 27, 2021, there was a continuous foggy weather process in Qiongzhou Strait, which caused ships to stop sailing and a large number of passengers and vehicles to stay. Based on the data of laser visibility radar and FY-4A multi-channel scanning imager, combined with multi-source data fusion products independently developed by China, reanalysis data and observation data, this paper analyzes the process and causes of the formation of this sea fog from the atmospheric and ocean conditions, and draws the following conclusions: 1) Cooling and humidifying and low wind speed are the basic conditions for the generation and development of sea fog, while the inversion layer near 700-850hpa provides a better background environment for the generation and maintenance of sea fog; 2) Due to the influence of different weather systems in the two periods before and after the whole sea fog generation and development process, the generation and development orientation and moving direction of sea fog in the two periods before and after are different, resulting in two different types of sea fog, radiation fog and advection fog; 3) There is a certain temperature difference between the sea temperature near the coast of South China and the large warm sea area east of Qiongzhou Strait, which provides the background field and hydrological conditions for the formation of sea fog. In addition, the wind field determines the transportation and accumulation of heat, which blows the warm ocean currents to the near-shore cold sea area, thus causing the sea temperature difference. The sea fog can be developed and maintained by cooling and humidifying.

1. Introduction

Generally speaking, sea fog is a weather phenomenon that occurs on the sea surface or in the near-shore area, formed in a large amount of water vapor condensation in the atmospheric boundary layer, resulting in less than 1 km visibility, which affects marine transportation, marine fisheries, aviation, and military activities at sea, and it is classified as a marine meteorological hazard, along with high winds at sea[1-2], storm surges, waves, and strong convective weather at sea[3-4]. Based on incomplete statistics, there are a large number of chemical pollutants in the fog water of the sea fog, which can also cause severe hazards to agricultural production and human health, and pose threats to maritime transportation safety[5-9]. For example, on April 14th, 1912, the Titanic collided with a huge iceberg in the south of Landbanks, off Newfoundland Island, with 1,513 passengers killed, due to sea fog in the North Atlantic Ocean and poor visibility in the middle of the night[10]. China Sea and its adjacent waters are also areas with frequent sea fog. According to incomplete statistics, in the last 50 years of the 20th century, there were 59 maritime accidents and shipwrecks caused by sea fog in Shandong coastal areas alone, with 128 deaths. In the coastal areas of South China, only in January 2005, there were four marine ship collisions caused by sea fog, which caused three ships to sink, three people died and four people were missing, resulting in huge economic losses[11].

The research on fog can be traced back to Aristotle's meteorological research (284-322 BC)[12]. However, the study of sea fog is relatively late, which began in the early 20th century. The early observation of sea fog mainly depends on the observation of other elements or by means of coastal island weather stations, sea buoys and ships[13-15]. With the continuous progress of modern observation technology, it is no longer limited to the observation of simple meteorological elements. At the end of 1970s, the Cooperative Experiment in West Coast Oceanography and Meteorology (CEWCOM) made use of the observation network composed of wpr, sonar, balloon sounding, scientific research aircraft, satellites, offshore buoy stations and conventional weather detection to explore and study the coastal coast of California, USA, and found that dynamic subsidence and warming had an important influence on the formation of inversion layer[16-17]. The main goal of the European Union's COST722 (European Related Research Action on Science and Technology) program is to "develop a very short-term forecast technology for fog, visibility and low clouds", and to distinguish low clouds and fog by means of ground observation, ground-based remote sensing, satellite remote sensing, numerical model, etc.[7,18]. Based on a large amount of data information, it can be analyzed and discussed[19], thus improving the forecasting method[20] and further developing the numerical model[21-24]. It can be seen that the study of sea fog is developed on the basis of a large number of observation data, and it is also closely related to the thermal and dynamic processes in the atmospheric environment. Taylor[25] first explained the generation and elimination mechanism of sea fog using turbulence theory. Tachibana et al.[26] found that weather circulation dramatically influences the formation, development, and dissipation of fog upon their research. Wang Binghua[6] summarized, classified, analyzed, and published the only work on sea fog, "SEA FOG" systematically based on years of research results. Sun and Diao et al.[27-28] summarized the weather situation of Qingdao and offshore generating advective fog into four main types: Western Type of Transgressive High, Northern Margin Type of Subtropical High, Northern Upper Type of Southern Low and Front Type of Northern Low. Zhang et al.[29] found from the analysis of interannual variation of spring sea fog in the Yellow Sea that the high altitude circulation provides warm and humid air transport conditions for the formation of sea fog, while the low altitude wind field and surface wind field bring low latitude water vapor from the western Pacific Ocean to the Yellow Sea, and the temperature difference of water vapor is helpful to the formation and maintenance of sea fog on the Yellow Sea.

Qiongzhou Strait is the research area of this paper. It is an important waterway connecting Hainan Province in China. Every year, the late winter and early spring season is the season with the most frequent foggy weather in Hainan Province, in which the inland and mountainous areas of Hainan Province are dominated by radiation fog, while the northern and eastern coastal areas are dominated by advection fog[30-31]. Xu et al.[32] analyzed the pattern of fog occurrence and the generation and elimination mechanism of the Leizhou Peninsula using multi-year meteorological observation data from Zhanjiang, Leizhou, and Xvwen stations on the Leizhou Peninsula. Liu et al.[33] analyzed the spatial and temporal distribution characteristics of sea fog in the sea area of the South China Sea using fog monitoring products from FY-3B meteorological satellite data from January to March 2011-2016. Qu[34], on the other hand, analyzed a sea fog process that occurred on March 24-25, 2007, along the coast of South China using real-time reanalysis data of 1°×1° at an interval of 6 hours with ground-based observations, boundary layer soundings and fog droplet spectral observations, and used the WRF model to simulate and analyze the change characteristics of SST and the influence of radiation on the advection cooling fog process during this sea fog process. Xu et al.[35] analyzed the climatic statistical characteristics of fog along the Qiongzhou Strait using aerial and ground observations from 1961-2006 at Haikou station, and summarized the three weather situations affecting and causing fog along the Qiongzhou Strait by combining the reanalysis data from 1987-2006, and also proposed relevant forecast indicators according to the fog types. On the other hand, Huang et al.[36] analyzed the persistent six-day fog weather process in Qiongzhou Strait during the 2018 Spring Festival mainly from meteorological satellite monitoring. They analyzed the causes of formation and maintenance of persistent sea fog by atmospheric ocean conditions. Therefore, on the basis of using and analyzing the observation data obtained by multi-dimensional detection means including sea, land and air, this paper analyzes a sea fog process in January 2021 from two angles of atmospheric circulation background and meteorological and hydrological conditions, so as to obtain the reasons and characteristics of the formation and maintenance of this sea fog project, and to provide some basis for improving the meteorological service level of sea fog.

2. Data Sources

2.1. Ground Observation Data

2.1.1. Laser Visibility Radar

It can be seen from Figure 1 that one laser visibility radar is deployed on the north side of the Qiongzhou Strait, while two laser visibility radars are deployed on the south side of the Qiongzhou Strait. The deployment of three radars can basically cover the main channels and harbor basin of Qiongzhou Strait, it can monitor the sea fog in the Strait around the clock, without being affected by smoke and other conditions.

Figure 1: Location map of three laser visibility radars in Qiongzhou Strait

2.1.2. CLDAS 5km Hourly Visibility Data Fusion Product

The CLDAS visibility data fusion product has a temporal resolution of 1 hour and a spatial resolution of 0.625°×0.625°. Comparing it with the observed data, the spatial distribution of the visibility fusion live product is more reasonable, the product magnitude distribution is sound. There is no apparent systematic error in the product, and the overall quality is more stable and reliable.

2.1.3. The Ground-Based Meteorological Observation Data

The ground-based meteorological observation data are about visibility, temperature, relative humidity, dew-point temperature, and wind speed per 10 minutes hour by hour from January 21th to 27th, 2021.

2.2. Ocean Observation Data—Centigrade of Global Ocean Day Analysis System (CODAS)

The CODAS, Centigrade of global ocean day analysis system, which is a fusion analysis product which covers the global area with a spatial resolution of 0.25°×0.25° with equal latitude and longitude grids. The data collection is created by using multiple sources of satellite, ship, buoy and other observations and using key technologies such as bias revision and fusion analysis, and the RMSE of the fusion product is less than 0.5K (Kelvin). The data product generates the SST fusion product of the previous day (08-08 BST) at 10:00 BST daily.

2.3 High Altitude Observation Data

2.3.1. Satellite Data

Select L1 grade products of FY-4A meteorological satellite independently developed by China. The L1 product of FY-4A has 14 channels, the highest spatial resolution is 500m, and the resolutions of near infrared band and infrared band are 1000m, 2000m and 4000m.

2.3.2. The CMA Global Reanalysis Product Dataset(CRA-40)

CRA-40 is a global reanalysis dataset developed by the National Meteorological Information Center (NMIC) of the China Meteorological Administration (CMA), covering the period of 1979–2018. It is China's first generation of global atmospheric reanalysis product released recently. It employs the NCEP GFS/GSI (Global Forecast System/Grid point Statistical Interpolation) 3D-Var system with 64 vertical levels. The horizontal resolution is 34 km (T574)[37-39].

2.3.3. Sounding Data

As Xuwen Station has no high-altitude observation service, only the sounding data of Haikou Sounding Station on the south bank of Qiongzhou Strait from January 21th to January 27th, 2021 are selected.

3. Actual analysis of Persistent Fog

3.1. Ground Real Monitoring Analysis under Low Visibility

Figure 2 shows the 10-minute average visibility and air temperature, dew point temperature and relative humidity at Xuwen Station on the north bank of Qiongzhou Strait and Haikou Station on the south bank of Qiongzhou Strait from January 21th to 27th, 2021. It is necessary to explain Xuwen Station is located in the north-west position of Haikou Station. Figure 2(a) and Figure 2(c) show that at 14:00 on the 21th to 23th, the visibility of Xuwen Station was low, basically below 5,000 meters, the relative humidity was high, the air temperature and dew point temperature decreased, the wind speed was basically low, and the wind direction changed from northeast to northwest. Only in the early morning of the 22th the wind speed increased, the wind direction changed to the northeast wind, the visibility increased, and the sea fog dissipated. After that, the temperature dropped again, the relative humidity increased, the wind speed was low, the wind direction turned to the west wind, and the sea fog did not completely dissipate, but developed again and remained until 14: 00 on 23th. The same is true of Haikou Station on the south bank of Qiongzhou Strait (Figure 2(b) and Figure 2(d)), except that the change time of each element is later than that of Xuwen Station, which indicates that the sea fog is generated and developed in this period, the temperature and wind speed will decrease, and the relative humidity will rise rapidly and continuously. Influenced by the weather system and the change of wind direction and wind speed, the moving path of sea fog is from west to east and from north to south. In the phase of sea fog dissipation, the air temperature and dew point temperature increased, the relative humidity was lower, the wind speed increased, and the wind direction changed to easterly or northeast.

Different from the low visibility period at 14:00 on 21th-23th, the low visibility period at Xuwen Station was mainly from noon to afternoon after 14:00 on 23th, and lasted until after the next morning, with visibility records of less than 500 meters at 14-23:00 on 23th, 13-18:00 on 24th, 02:00 on 24th, and 00:00 on 26th. Combined with other meteorological factors, it is found that the wind speed has weakened in the above period, and the wind direction was basically northeast or easterly. The relative humidity was around 94%, and the temperature at this time was between 15-19℃, which was relatively low. On the contrary, when the visibility rised, the temperature rises above 20℃. The dew point temperature is similar to the air temperature. When the visibility was less than 500 meters, the dew point temperature was between 13-18℃, and the value was also low. On the contrary, when the visibility increased, the dew point temperature rised above 19℃. The same is true of Haikou Station, only later than Xuwen Station. The period of low visibility was mainly from night to noon. However, what the two stations have in common is that the wind direction was mainly northeast and the wind speed is low, which shows that the generation and moving path of sea fog in Qiongzhou Strait would spread from east to west after 14:00 on 23th.

It can be seen that the basic conditions for the generation and development of sea fog in two periods are cooling and humidifying and lower wind speed. With the temperature rising and humidity decreasing, the wind speed gradually increases, and the sea fog in both periods dissipates. And the sea fog in the two periods is different in both the origin of generation and development and the moving direction.

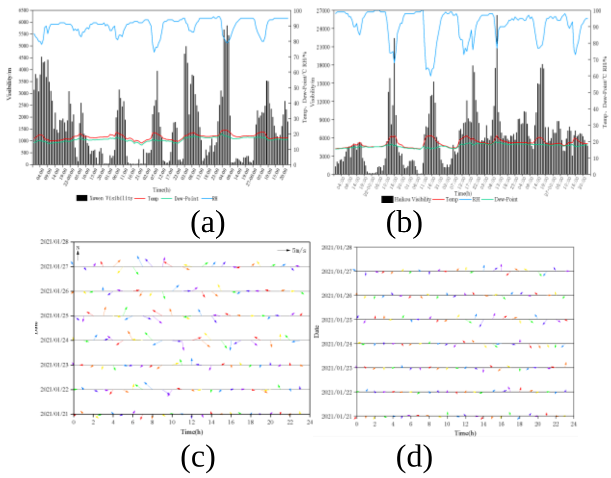

Figure 2: average visibility (unit: m) and relative humidity (blue line, unit: %), air temperature (red line, unit: ℃) and dew-point temperature (green line, unit: ℃) per 10 minutes hourly live variation at Xvwen station (a) and Haikou station (b) from January 21-27th, 2021; average wind speed at Xvwen station (c) per 10 minutes and average wind speed at Haikou station (d) per 10 minutes.

3.2. Visibility Radar Analysis

From January 21th to 27th, Qiongzhou Strait was affected by foggy weather, which caused the ports on both sides of the strait to be suspended for many times. Now, taking Haikou New Port Radar as an example, the observation results and the port suspension time are analyzed. According to the suspension standard of Qiongzhou Strait, when the visibility is less than 500 meters (shown by solid yellow line in Figure 3), the port on the south bank of Qiongzhou Strait will be suspended. When the visibility is less than 1000 meters (shown by red solid line in Figure 3), the port on the north shore of Qiongzhou Strait is suspended. As can be seen from the figure, there were five times of suspension during this period (the red box in Figure 3 indicated the suspension period), and the suspension time was consistent with the low visibility period observed by radar.

(1) The ship was suspended on January 21-22th, 2021. Figure 4 is the visibility change chart of laser visibility radar in Haikou New Port. It can be seen from Figure 4(a) that at 20:30 on 21th, the visibility of the south bank of Qiongzhou Strait was lower than 200 meters, and a yellow warning of fog at sea was issued, which has reached the standard of suspension of navigation. By around 23:09 on the same day, the visibility of Qiongzhou Strait was less than 50 meters, and the sea fog on the south bank of Qiongzhou Strait was the strongest. After 15:00 on 22th, the visibility gradually recovered to more than 500 meters, and both sides of Qiongzhou Strait gradually resumed navigation. From the overall changes in Figure 4 (a) to 4(f), we can see that the visibility was low from the night of 21th to the afternoon of 22th. From the scanning range of radar, we can see that the visibility in the east of the strait was lower than that in the west, and it gradually spread to the east and south, which was basically consistent with the previous ground data, and the overall sea fog generally developed and moved from west to east.

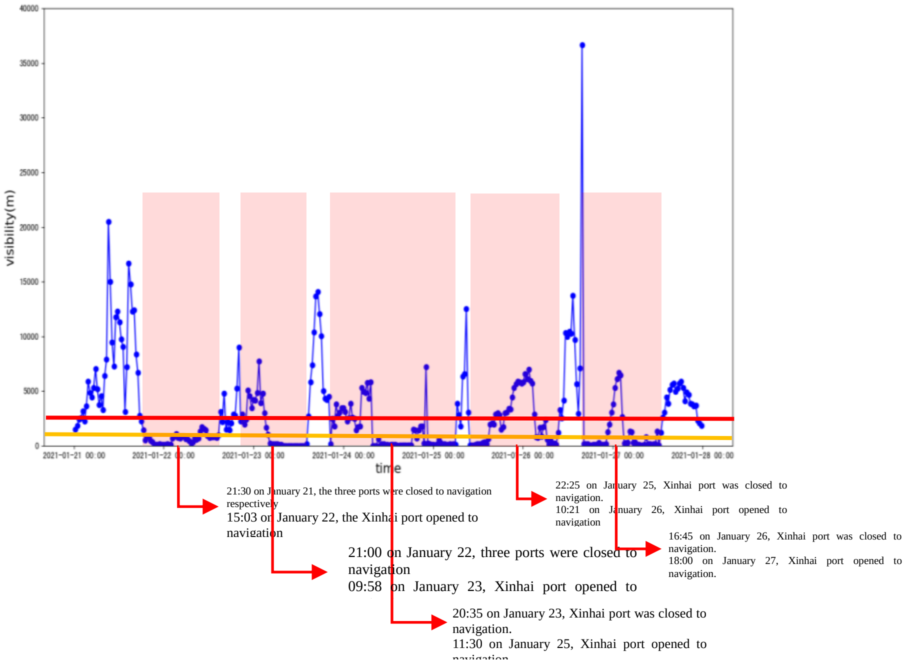

Figure 3: Comparison of the laser visibility radar observation results of Haikou Xinhai port and Qiongzhou Strait suspension period

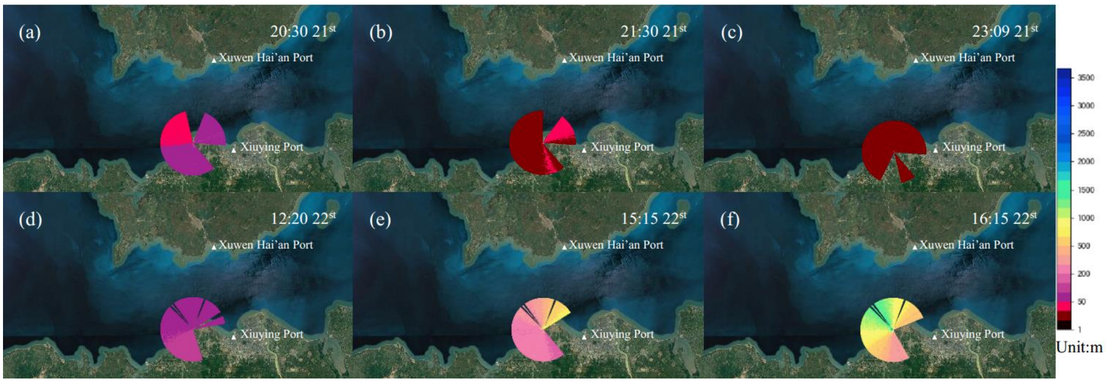

Figure 4: Laser radar visibility distribution at different times on 21th and 22th January 2021

(2) The ship was suspended on January 23-25th, 2021. Different from the previous suspension, the suspension lasted longer. Figure 5 is the visibility change chart of laser visibility radar in Haikou NewPort. As can be seen from Figure 5(a), at 21:17 on 23th, the visibility of the south bank of Qiongzhou Strait gradually decreased to less than 1,000 meters, and sea fog began to gradually form, and an orange warning of sea fog was issued. At 04:05 on 24th (Figure 5(b)), the visibility of Qiongzhou Strait was below 500 meters, only on the west side of the laser visibility radar of Xinhai Port, and the visibility near the coast was between 500 meters and 1,000 meters. By noon on 24th, the visibility of the south bank of Qiongzhou Strait was further reduced to less than 50 meters. Combined with the analysis of the ground, the sea fog was thick at this time, and it was spreading to the inland of Hainan. This situation lasted until around 15:00 on 25th, and the visibility began to gradually increase, which indicated that the sea fog began to gradually dissipate. By 17:30 on 25th (Figure 5(g)), the visibility recovered to over 500 meters, and both sides of Qiongzhou Strait resumed navigation. From the changes of radar scanning overall range in Figures 5 (a) to 5 (i), It can be seen that from the night of 23th to 25th, the visibility in the west of the strait was lower than that in the east, and gradually spread to the west and south. During this period, the wind direction was basically easterly or northeast, and the overall sea fog developed and moved from east to west.

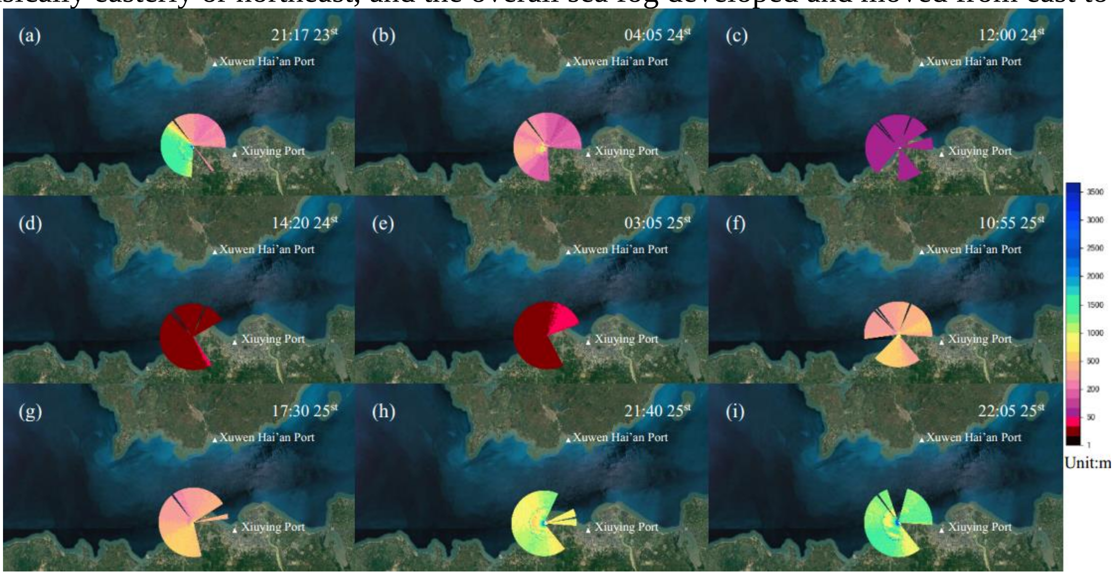

Figure 5: Laser radar visibility distribution at different times on 23th and 25th January 2021

Combined with CLDAS 5km Hourly Visibility data fusion product, it can be seen that (Figure 6) the visibility observed by the laser visibility radar in the Qiongzhou Strait was below 50 meters at 23:09 on 21th. The sea fog on the south coast of the Qiongzhou Strait reached the thickest, and the corresponding CLDAS in Figure 6(a). Until 15:15 on 22th, with the dissipation of the sea fog, the visibility observed gradually rose. But, there was low visibility on the east and west sides outside the strait.

During the second sea fog process, at 04:05 on 24th and 03:05 on 25th, when the sea fog reached its thickest, the visibility observed by the laser visibility radar Qiongzhou Strait was basically below 50 meters, and the visibility was also low (Figure 6(c) and (e)). At 12:00 on 24th, the visibility observed by the laser visibility radar in the Qiongzhou Strait increased slightly, and the range of low visibility was reduced in CLDAS (Figure 6(d)), and until 11:00 on 25th. It is basically consistent with the performance of the visibility observed by the radar.

To sum up, according to the conventional and unconventional ground observation data, the sea fog process can be divided into two periods. Although the reasons of generation, development and dissipation in the two periods are basically the same, the generation orientation and moving direction are different, which may be related to the development of weather system in the two periods. Next, the possible reasons for the generation and development of sea fog in two periods are analyzed from three aspects: circulation situation, dynamic conditions and water vapor conditions.

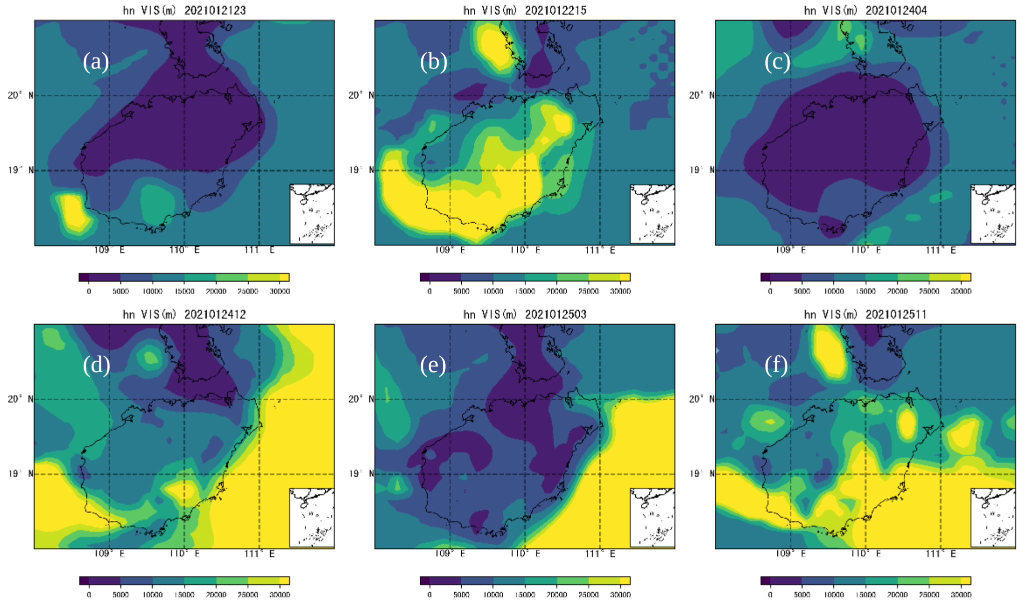

Figure 6: CLDAS visibility live at different times from January 21th-25th, 2021(BJT)

4. Cause Analysis of Persistent Fog

4.1. Analysis of Low Visibility Weather Situation

Before the appearance of this foggy weather, all of Hainan Province was affected by strong cold air on 17th, and strong cooling weather was observed island-wide. Then to 19th, with the weakening of the cold air, most of Hainan Island's temperature gradually rebounded (Figure omitted).As can be seen from Figure 7a, Hainan Island is located in front of the South Branch Trough, and the southwesterly wind over South China provides warm and humid air. The boundary layer humidity on Qiongzhou Strait is relatively high, which basically reaches the saturation state (Figure 7b), which shows that the moisture humidity over Qiongzhou Strait is relatively good, providing a good moisture condition for the generation and development of fog, while the subtropical high at this time is far away from the ocean surface to the east of the Philippines. At 925hpa, it is mainly northeast wind. Considering the sea level pressure field (Figure 7c), it is influenced by the infiltration of cold air southward. When the warm water vapor meets the cold underlying surface, it is easy to condense into water droplets, which is conducive to the generation and development of sea fog and the formation of radiation fog. With the cold air passing through and leaving the strait, the maintenance conditions of sea fog are destroyed. After 14:00 on 23th the south China area was basically flat westerly, while the subtropical high gradually moved westward, and Hainan Island was on the edge of the subtropical high. On the sea level pressure field, Hainan Island is at the back of the cold high (Figure 7f). Combined with the wind field of 925hpa, it gradually changed from northeast wind to easterly wind, to southeast wind at 08:00 on 24th, and then the east of Leizhou Peninsula and Hainan Island was basically southeast wind or easterly wind (Figure 7e). With the cold air from East Road gradually spreading southward, at sea level pressure field, 1015hpa gradually pressed southward to Hainan Island (figure omitted), combined with 925hpa wind field, the east wind direction of Leizhou Peninsula gradually changed to northeast wind again (figure 7h), but the east side of Hainan Island was still easterly, which changed the cold air from mainland into warm air flow into the sea, and the warm and humid air was transported to the coastal areas of Qiongzhou Strait through the lower layer from east to southeast, resulting in significant air mass temperature difference between land and sea. It is conducive to the condensation of warm moisture mass on the cold underlying surface, thus forming a advection fog at the coastal junction from the afternoon to the early morning of the next night, which is basically consistent with the previous time period of ground analysis.

According to the weather situation analysis, before and after the sea fog process, it was affected by the two different weather situations of the south branch trough and the cold air on the east road respectively, which also made the development orientation and moving direction of the sea fog in the two periods different.

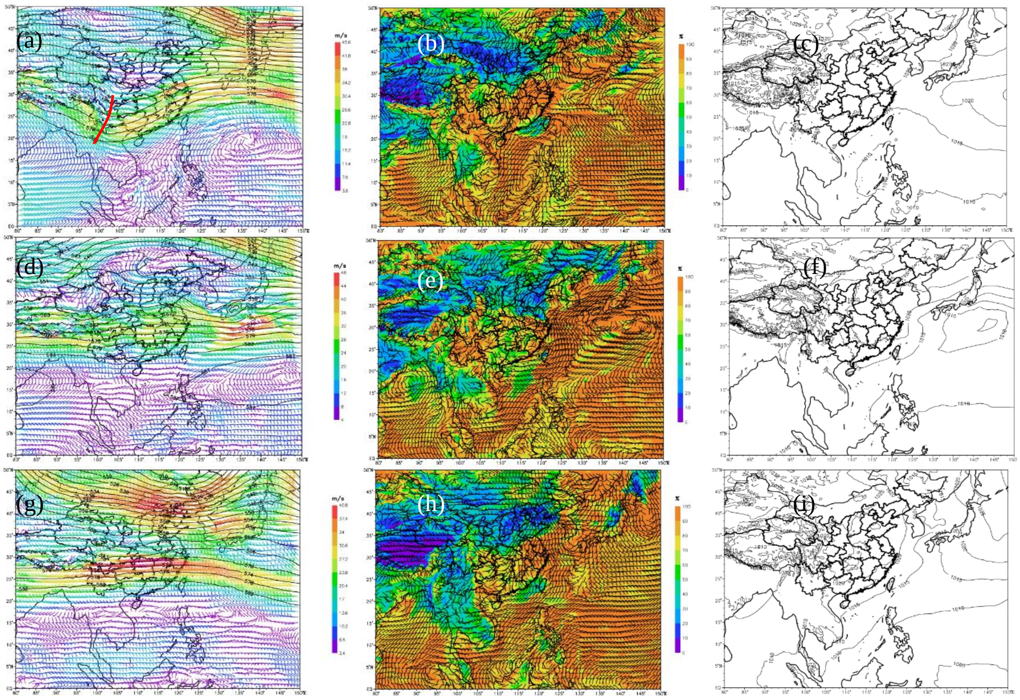

Figure 7: 500 gpm barometric field at 08:00 on January 22th (a; contours: gpm), 925 hpa humidity field (b; filled color: %), Sea level barometric field (c; contours, in gpm), 500 gpm barometric field at 02:00 on January 24th (d; contours: gpm), 925hpa humidity field (e; filled color: %), Sea level barometric field (f; contours, unit: gpm),500hpa barometric field at 14:00 on January 26th (g; contours: dagpm), 925hpa humidity field (h; filled color: %),Sea level barometric field (i; contours, unit: gpm)

4.2. Diagnosis of Low Visibility Weather

According to the previous analysis, in the ground environment, the low wind speed and the environment with high temperature and humidity are beneficial to the maintenance of sea fog. On the vertical structure of the atmosphere, the stable inversion layer makes convection difficult to occur, and a large number of aerosol particles and water vapor cannot diffuse under the inversion layer, which also provides conditions for the occurrence and maintenance of foggy weather[30].

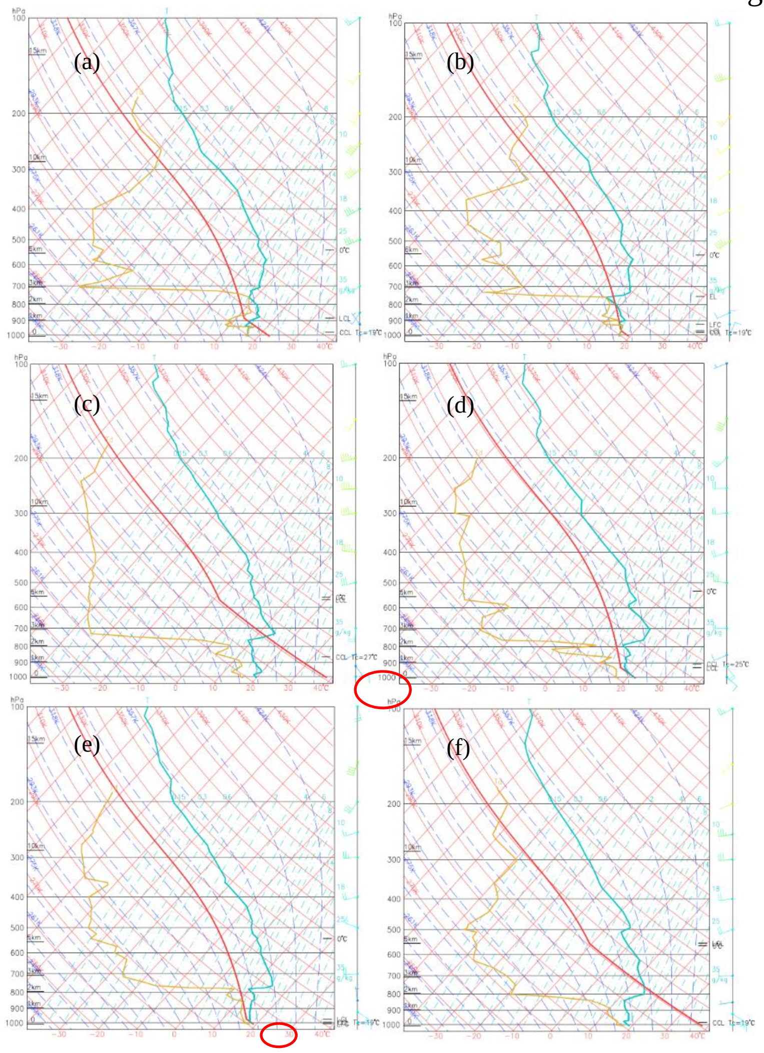

Figure 8: T-LnP diagrams of Haikou station at 20:00 on January 21th(a), 08:00 on January 22th (b), 20:00 on January 23th (c), 20:00 on January 24th (d), 20:00 on January 25th (e), and 20:00 on January 27th(f)

Figure 8 shows the sounding information of Haikou Station on the south bank of Qiongzhou Strait. As can be seen from Figure 8, due to the influence of Qiongzhou Strait located in front of the South Branch Trough, from 21th to 22th, the ground near 700hpa was nearly saturated, but it was slightly dry above 700hpa, and there was an inversion layer near 700hpa, which was consistent with the actual situation that there was always an inversion layer in the lower atmosphere when the sea fog formed, and basically consistent with the research of other researchers[6,16-17]. The northeast wind is from the ground to 925hpa, which is basically consistent with the previous ground analysis. On 23th-27th, the inversion layer was located at 700-850hpa, and the boundary layer was almost saturated, but the wet layer was thin. For example, at 20:00 on 25th, the wet layer was basically near the ground layer (red circle in Figure 8e). On 24th, the ground to 925hpa was southeast wind, and the rest time was easterly wind, which was basically consistent with previous ground analysis.

Combined with FY-4A satellite cloud picture (Figure 9), monitoring and tracking of two different periods of this sea fog process show that a large area of fog can be observed in Qiongzhou Strait, with clear edges, gray to white. Influenced by the northwesterly wind, the fog approached the south bank of Qiongzhou Strait at 13:00 on 24th, and by 17: 00 on 24th, most areas on the west bank of Leizhou Peninsula and the north bank of Qiongzhou Strait were basically free of fog or cloud cover. By 15:00 on the 26th, under the influence of easterly or northeasterly winds, sea fog accumulated in the offshore waters in the eastern part of Leizhou Peninsula and spread from east to west along the eastern coast of Leizhou Peninsula.

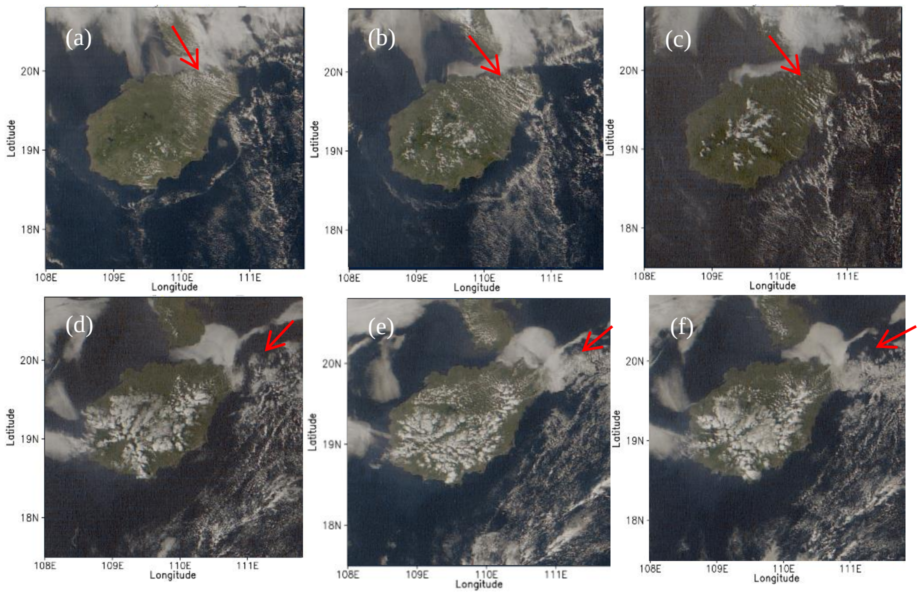

Figure 9: 13:00 (a), 15:00 (b), 17:00 (c) on January 24th, 15:00 (d), 16:00 (e), 16:30 (f) on January 26th, FY-4A satellite cloud map of Qiongzhou Strait

4.3. Analysis of SST Evolution

The fog in Qiongzhou Strait gradually forms and develops due to the specific atmospheric circulation situation with suitable relative humidity, wind speed, and other meteorological elements on the ground. The appearance of the inversion layer makes the atmosphere not easy to diffuse. But apart from that, the more important factor is also one of the essential reasons for the appearance and development of fog in Qiongzhou Strait - Sea Surface Temperature.

Figure 10 gives the monthly average SST distance level distribution in January for many years and the monthly average SST distance level distribution in January 2021. It can be seen from Figure 10(a) that the near-shore of the South China coast is a high SST pitch area, and there are three cold centers on the ocean surface east of Qiongzhou Strait and south of the South China Sea. On the contrary, it can be seen from Figure 10(b) that the SST level near the coast of South China is lower than the average of normal years, and the low SST level area exists from Beibu Gulf through Qiongzhou Strait to Taiwan Strait, while a large warm sea area exists on the ocean surface east of Qiongzhou Strait, which is higher than normal years. This shows that the cold SST in Qiongzhou Strait provides the background field and hydrographic conditions for the formation of sea fog, which is basically consistent with previous studies [6, 30, 33].

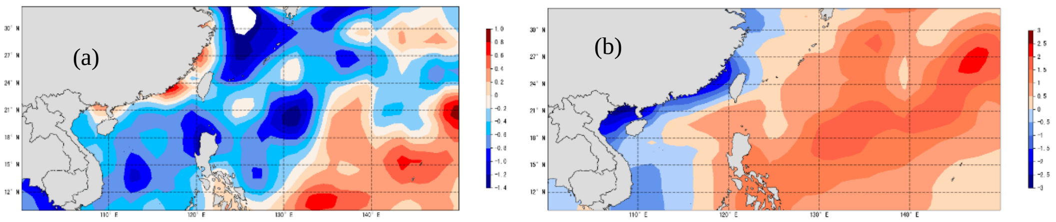

Figure 10: Monthly mean SST distance in January 1982-2020 (a; unit: ℃) and January 2021 (b; unit: ℃)

Further analysis of the superposition of CODAS daily integrated SST products and CRA-40 wind field (Figure 11) shows that in the late stage of this sea fog process, the sea temperature gradient in the coastal waters east of Leizhou Peninsula and Qiongzhou Strait is large, and the gradient direction is basically consistent with the wind direction. The easterly wind blows the warm ocean current to Qiongzhou Strait, and the ocean easterly airflow flowing through a large warm sea area east of Hainan Island is heated. When it reaches the offshore cold sea area, it causes the sea temperature difference, which is easy to be cooled and condensed into sea fog. Therefore, the wind field determines the heat transfer and accumulation, which may cause the sea-air temperature difference, and develop and maintain the sea fog by cooling and humidifying. However, if the wind speed is too high, it is not conducive to the maintenance of sea fog.

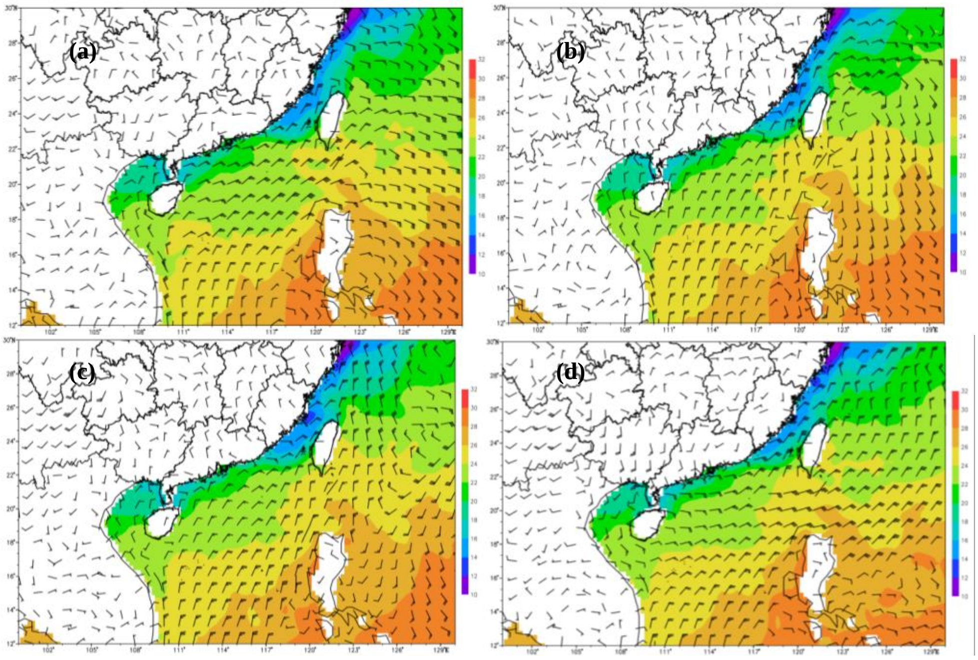

Figure 11: SST superimposed wind field at 08:00 and 14:00 (a, b) on January 24th and 08:00 and 14:00 (c, d) on January 25th

5. Conclusion

In this paper, the laser visibility radar and FY-4A multi-channel scanning imager (ARGI) data products are used to analyze the foggy weather process in Qiongzhou Strait from January 21th to January 27th, 2021 from three aspects: the high altitude situation, the ground and the ocean. It is found that the formation of sea fog is always accompanied by various observation data such as ground, CLDAS visibility data fusion, sounding, CODAS multi-source data fusion and CRA-40 China first-generation reanalysis. In addition, compared with other sea fog occurrence processes, this sea fog process is inconsistent in both the high-altitude situation and the ground situation, mainly divided into the following points:

(1) According to the conventional and unconventional ground observation data, the sea fog process can be divided into two periods, and the basic conditions for the generation and development of the sea fog in the two periods are cooling and humidifying and lower wind speed; In the maintenance stage, there are inversion layers near 700-850hpa over Qiongzhou Strait. In the phase of sea fog dissipation, the phenomenon of temperature rise and humidity reduction and wind speed increase gradually appeared. The FY-4A satellite cloud picture can clearly distinguish the development and movement process of sea fog in two periods.

(2) With the continuous eastward movement of the South Branch Trough, the air over South China turns to southwest wind, which provides warm and humid air for Qiongzhou Strait, which makes its boundary layer humidity higher and basically reaches saturation state, providing better water vapor conditions for the generation and development of fog. With the continuous southward replenishment of cold air, the warm and humid water vapor meets the colder underlying surface, and is easy to condense into water droplets, which is beneficial to the generation and development of sea fog. With the cold air passing through and leaving the strait, the maintenance conditions of sea fog are destroyed. In the later stage of this sea fog, with the cold air on East Road gradually spreading southward, the wind direction gradually changed to northeast to easterly, which caused the cold air on the mainland to change into warm air flow into the sea, and the warm and humid air was transported to the coastal areas of Qiongzhou Strait through the lower layer from east to southeast, resulting in significant temperature difference between land and sea air masses, which was conducive to the condensation of warm and humid air masses on the cold underlying surface, thus forming advection fog at the coastal junction.

(3) The sea surface temperature anomaly near the coast of South China is lower than normal. It is a low sea surface temperature anomaly area from Beibu Gulf through Qiongzhou Strait to Taiwan Province Strait, while there is a large warm sea area east of Qiongzhou Strait, which is higher than normal. In addition, the cold sea surface temperature in Qiongzhou Strait provides the background field and hydrological conditions for the formation of sea fog. In addition, the wind field determines the transportation and accumulation of heat, blowing warm ocean currents to the cold coastal waters, thus causing the sea-air temperature difference, and developing and maintaining sea fog by cooling and humidifying. However, if the wind speed is too high, it is not conducive to the maintenance of sea fog.

The above conclusions have certain reference value for the prediction and early warning of sea fog in Qiongzhou Strait, but it must be pointed out here that sea fog is a weather phenomenon in the atmospheric boundary layer, which is influenced by complex boundary layer processes, such as atmospheric turbulence structure, heat exchange between air and sea, radiation process, etc. Therefore, it is necessary to pay attention to the formation mechanism and mechanism of sea fog and study its close relationship with atmospheric stratification and turbulence intensity.

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