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On Spatiotemporal Characteristics of Sea Fog Occurrence over the Northern Atlantic from 1909 to 2008

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Abstract In this paper, the International Comprehensive Ocean and Atmosphere Data Set (ICOADS) is utilized to investigate the horizontal distribution of sea fog occurrence frequency over the Northern Atlantic as well as the meteorological and oceanic conditions for sea fog formation. Sea fog over the Northern Atlantic mainly occurs over middle and high latitudes. Sea fog occurrence frequency over the western region of the Northern Atlantic is higher than that over the eastern region. The season for sea fog occurrence over the Northern Atlantic is generally from April to August. When sea fogs occur, the prevailing wind direction in the study area is from southerly to southwesterly and the favorable wind speed is around $8\,\mathrm{m\,s^{-1}}$. It is most favorable for the formation of sea fogs when sea surface temperature (SST) is 5℃ to 15℃. When SST is higher than 25℃, it is difficult for the air to get saturated, and there is almost no report of sea fog. When sea fogs form, the difference between sea surface temperature and air temperature is mainly −1 to 3℃, and the difference of 0℃ to 2℃ is the most favorable conditions for fog formation. There are two types of sea fogs prevailing in this region: advection cooling fog and advection evaporating fog.

Key words atmospheric visibility; sea fog; occurrence frequency; the Northern Atlantic

1 Introduction

Fog is a weather phenomenon with tiny water droplets or ice crystals suspended in the atmosphere near the ground, so that the atmospheric visibility of fog is less than 1-km (American Meteorological Society). A general definition of sea fog is the fog occurring over the sea. Wang (1983) suggested, based on the results of previous research, that sea fog is a product of the interaction between the ocean and the atmosphere, which contains a countless number of water droplets or ice crystals due to condensation occurring at sea or in coastal areas. It is a dangerous weather phenomenon in the sense that a dense layer of mixed air and hydrometeors suspended over the planetary boundary layer makes the level of atmospheric visibility less than 1 km. In the present paper, we will use the sea fog definition of Wang (1983).

Previous studies have provided a comprehensive view of sea fogs over the world in the context of the characteristics of satellite imagery and evolution (Fu *et al.*, 2004; Gao *et al.*, 2009; Huang *et al.*, 2015; Zhang and Yi, 2013), modeling (Koračin *et al.*, 2005; Heo and Ha, 2010; Kim and Yum, 2010; Wang *et al.*, 2014; Gao *et al.*, 2014; Lu *et al.*, 2014), climatology (Zhou *et al.*, 2004; Wang *et al.*, 2006; Zhang *et al.*, 2009; Lee *et al.*, 2010; Zhang *et al.*, 2014), and large-scale environmental factors (Cho *et al.*, 2000; Lewis *et al.*, 2003; Li *et al.*, 2011). However, horizontal distribution of sea fog occurrence frequency is still a challenge task facing meteorologists now. The main reason is that sea fog observations are rare over the ocean. There are only a few research results about sea fog occurrence frequency map over the world (*e.g.*, US Department of Agriculture, 1938; Wang, 1983; Hahn and Warren, 2007). The most comprehensive set of charts displaying sea fog over the global oceans is found in the Atlas of the Climatic Charts of the Oceans (Lewis *et al.*, 2004; US Department of Agriculture, 1938). The chart from this atlas gives the sea fog occurrence frequency during the months of June, July, and August based on 5.5 million ship reports. Wang (1983), based on climate atlas of the world and Atlantic, a few coastal stations and the existing data, supplied monthly distributions of sea fog occurrence frequency over the Northern Pacific, the Northern Atlantic and India Oceans. However, due to lack of the observational data of atmospheric visibility, the sea fog distributions mentioned above contain much uncertain information. Hahn and Warren (2007), based on 50 million reports from 1954 to 1997 (44 years), compiled

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an ocean atlas of clouds. However, due to lack of high-resolution information, they only published this data on coarse grid boxes with 5˚×5˚ (or grid boxes with 10˚×10˚ for some quantities in the ocean), which cannot reflect the more detailed distribution.

Based on the previous analyses, the study of sea fog uses the data obtained from the coastal, island stations, and offshore buoys. Because the data far from the shore is sparse, previous researchers could only get a distribution of sea fog occurrence frequency along the seashore. Furthermore, some of these results are too coarse to give an accurate description of sea fog occurrence frequency. Lastly, previous sea fog occurrence frequency was not calculated based on adequate observations, therefore there were a lot of uncertainties in the results. In the present study, the International Comprehensive Ocean-Atmosphere Data Set (ICOADS) is utilized to investigate the temporal variation and spatial distribution of sea fog over the Northern Atlantic. This dataset has more than 200 million records from 1784 until now and continuously updated. It can provide a more detailed and accurate distribution of sea fog occurrence frequency than before. Hence, it is of practical significance to re-examine the spatiotemporal characteristics of distribution of sea fog occurrence frequency over the world oceans. In this study, the distribution of sea fog occurrence frequency over the Northern Atlantic is particularly investigated and documented.

The present paper is organized as follows. The data and methodology employed in this study are described in Section 2. Section 3 describes temporal and spatial distribution of sea fog occurrence frequency. Section 4 investigates the characteristics of meteorological variables related to sea fog. Conclusion and discussion are presented in Section 5.

2 Data and Methodology

2.1 Data

In this paper, ICOADS is used to investigate temporal and spatial distribution of sea fog occurrence frequency over the Northern Atlantic. This dataset is cooperatively established by the NOAA Earth System Research Laboratory (ESRL), the National Climatic Data Center (NCDC), the Cooperative Institute for Research in Environmental Sciences (CIRES), and the National Science Foundation's National Center for Atmospheric Research (NCAR). The data has been deemed as one of the most comprehensive and authoritative ocean observational datasets, and used widely around the world.

ICOADS (http://icoads.noaa.gov) stored in IMMA (The International Maritime Meteorological Archive Format) format containing the sea surface observations (global marine surface observations) and monthly mean data (monthly summary statistics). Sea surface observations covering the whole world are mainly obtained through the ships (merchant ships, military vessels, and scientific survey research vessels), drifting or moored buoy, coastal observation stations and other offshore platforms. The observation report has more than 200 million records from 1784 until now and is continually updated. There are many missed data before 1808, and the earliest data is mainly obtained from the logbook. Considering the quality and accuracy of the data, we only use the data from 1909 to 2008 to analyze sea fog in this paper. Such a long-time series of data ensures that we can get more observational data of sea fog. ICOADS includes the information of time, latitude, longitude and observational methods in the detailed records. In addition, many ocean and meteorological variables are available, such as wind direction, wind speed, atmospheric visibility, past and present weather conditions, sea level pressure, temperature, wet bulb temperature, dew point temperature, sea surface temperature and cloud cover. All variables related to this paper are shown in Table 1.

We focus on the Northern Atlantic as the research area. Fig.1 shows the location information of ships, buoys, and various observational platform devices during the whole month of August 2008. Each black dot represents an observation report. It appears that the observations mainly concentrate along the ship routes and coastal areas in middle and high latitudes. The routes are sparse in low latitudes with fewer observations. With the development of observation techniques and observation methods, more and more observational data are obtained. For example, there are more than 1 million reports in the Northern Atlantic from 1909 to 2008, of which the records of sea fog are presented about 110000 times.

ICOADS is composed of a series of independent observation messages, which were observed by many countries through different equipment and methods. To eliminate observation errors due to environment, equipment and communication conditions, the following measures were taken to make sure the quality of original data: 1) Examine data by climatology methods. The data with abnormal value is excluded according to the numerical range of physical variables. 2) Based on the 'quality control tag' of each variable, only the data with high reliability is utilized in this paper. 3) The duplicate reports are deleted according to the ship call signs, observing time and location. 4) Physical characteristics of elements are important criteria to check data. Low atmospheric visibility may be caused by various reasons, such as precipitation, fog, air pollution or aerosol particles. By analyzing the weather conditions, we could determine the presence of fog by ruling out other causes of low visibility. Sometimes fog occurs accompanied by precipitation. When rainfall is small, it is harder to distinguish the difference between fog and precipitation. In this paper, data of low atmospheric visibility caused by precipitation are not used.

The occurrence of fog is judged by visibility and weather conditions in ICOADS. Visibility is a leading indicator to reflect atmosphere transparency. Variables standing for visibility information of ICOADS are VI and VV. VI means visibility indicator (0: estimated value; 1: measured value; 2: fog present). VV stands for the level

Table 1 The description of time, location and meteorological element in ICOADS

Variable	Variable description	Min	Max	Unit (code)
YR	Year UTC	1600	2024	(AAAA)
MO	Month UTC	1	12	(MM)
DY	Day UTC	1	31	(YY)
HR	Hour UTC	0	23.99	0.01 hour (Δ GG)
LAT	Latitude	−90.00	90.00	0.01°N (Δ LaLaLa)
LON	Longitude	−179.99	359.99	0.01°E (Δ LoLoLoLo)
DI	Wind direction indic.	0	6	
D	Wind direction (true)	1	362	°, 361-2 (Δ dd)
WI	Wind speed indicator	0	8	(Δ iW)
W	Wind speed	0	99.9	0.1 m s^{-1} (Δ ff)
VI	VV indic.	0	2	(Δ •9)
VV	Visibility	90	99	(VV)
WW	Present weather	0	99	(ww)
W1	Past weather	0	9	(W1)
SLP	Sea level pressure	870.0	1074.6	0.1 hPa (Δ PPPP)
A	Characteristic of PPP	0	8	(a)
PPP	Amt. pressure tend.	0	51.0	0.1 hPa (ppp)
IT	Indic. for temperatures	0	9	(Δ iT) 0.1℃
AT	Air temperature	–99.9	99.9	(Δ sn, TTT)
WBTI	Indic. for WBT	0	3	(Δ sw)
WBT	Wet-bulb temperature	–99.9	99.9	0.1℃ (Δ sw, TbTbTb)
DPTI	DPT indic.	0	3	(Δ st)
DPT	Dew-point temp.	–99.9	99.9	0.1℃ (Δ st, TdTdTd)
SI	SST meas. method	0	12	(Δ •30)
SST	Sea surface temp.	–99.9	99.9	0.1℃ (Δ sn, TwTwTw)
N	Total cloud amount	0	9	(N)
NH	Lower cloud amount	0	9	(Nh)
CL	Low cloud type	0	9, 'A'	(Δ CL)
HI	H indic.	0	1	(Δ •9)
H	Cloud height	0	9, 'A'	(Δ h)
CM	Middle cloud type	0	9, 'A'	(Δ CM)
CH	High cloud type	0	9, 'A'	(Δ CH)
WD	Wave direction	0	38	
WP	Wave period	0	30, 99	Seconds (PWPW)
WH	Wave height	0	99	(HWHW)
SD	Swell direction	0	38	(dW1dW1)
SP	Swell period	0	30, 99	Seconds (PW1PW1)
SH	Swell height	0	99	(HW1HW1)

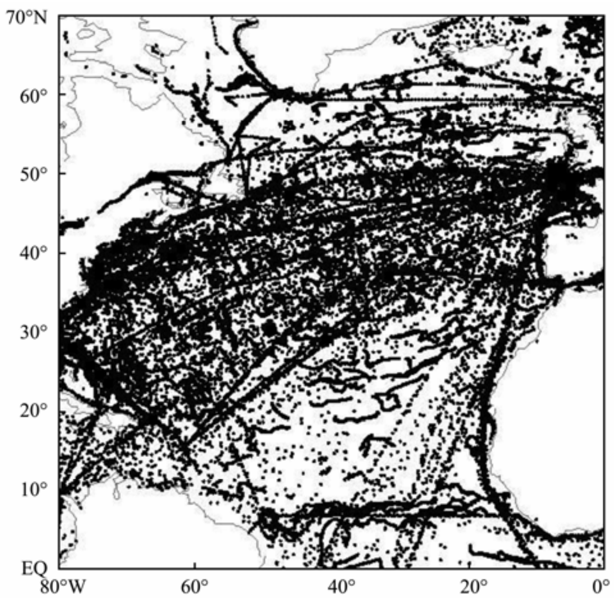


Fig.1 The black dots are ship observational positions in August 2008.

of visibility, ranging from 90 to 99, and represents different visibility values (unit: km). The visibility less than 1 km (the code of VV is 90–94 in ICOADS) is defined as sea fog occurrence in this paper. In this study, the rain effect has been ruled out by judging the current weather condition variables in order to give sea fog occurrence frequency more precisely. By limiting the relative humidity ≥90%, the effects of air pollution and aerosol particles have been ruled out.

2.2 Methodology

In order to reveal the temporal and spatial distribution of sea fog over the Northern Atlantic, the occurrence frequency of sea fog is analyzed. First, the research area is divided into small grids with the resolution of 2°×2°, Based on the level of visibility and the definition of sea fog, the total number of observation reports and occurrences of sea fog are then counted in each small grids. The sea fog occurrence frequency is defined as the total number of occurrences of sea fog divided by the total number of observations.

3 Temporal and Spatial Distribution of Sea Fog Occurrence Frequency over the Northern Atlantic

In this section, temporal and spatial distribution of sea fog occurrence frequency over the Northern Atlantic is analyzed. Fig.2 shows monthly distribution of frequency of sea fog occurrence over the Northern Atlantic from April to August. It can be seen that sea fog over the Northern Atlantic mainly occurs over middle and high latitudes. Sea fog occurrence frequency over the western region of the Northern Atlantic is higher than that over the eastern region. The maximum sea fog occurrence frequency is distributed along a belt region from Long Island to east of Newfoundland. In terms of seasonal variation, sea fog occurrence frequency gradually increases from April to July and then rapidly reduces from August with the maximum sea fog occurrence frequency dropping down to slightly over 10% during this period. Therefore, the fog season in the Northern Atlantic is from April to August. The sea fog occurrence frequency is relatively small (less than 10%) during the cold season (from September to the next March, figures not shown).

Spring and summer are favorable seasons for sea fog to occur. Fig.2a provides the sea fog occurrence frequency distribution in April from 1909 to 2008. The sea fog occurrence frequency over Newfoundland Sea increases up to 10%. Contour of 2% over Southern Greenland Sea extends southward. Sea fog occurrence frequency increases up to 4% in April in the area east to Iceland, and north to British Isles.

In May (Fig.2b), both the spatial coverage of sea fog and sea fog occurrence frequency increase significantly. The 2% contour extends to the south of Cape Hatteras in the vicinity of 35˚N and covers most area of the Northern Atlantic. Sea fog occurrence frequency over Norwegian Sea waters increases up to 8%. There are two closed contour regions with maximum value of sea fog occurrence frequency greater than 14% over the sea from Long Island to Newfoundland.

In June (Fig.2c), a similar distribution pattern of sea fog occurrence frequency is shown as in May. Sea fog occurrence frequency from Long Island to Newfoundland shows a further increase with a maximum value of 21%. Two maximum centers become more obvious: the larger one is located in the southeast of Newfoundland with a central value of 21%; the other is in the east of Long Island and Nova Scotia, Canada with a central value of 15%. Beyond these two maximum centers to higher latitudes, sea fog occurrence frequency decreases gradually. Sea fog occurrence frequency and coverage of sea fog are larger in the Labrador Sea in June than those in May (Fig.2b). The frequency of sea fog over the Norwegian Sea reaches up to 9%. Contours are more dense in the western region than those in the eastern region.

Sea fog occurrence frequency over the Northern Atlantic attains the peak value in July (Fig.2d). The maximum is located at the northeast sea of Newfoundland with a center value of over 24%. Meanwhile, the second maximum over the sea south to Newfoundland does not change much compared with that in June. As a result, these two maxima present an appearance of 'one strong, one weak'. The coverage of sea fog extends northward to the Davis Strait with sea fog occurrence frequency maintaining over 10%. Over the sea of middle and high latitudes, the characteristics of sea fog occurrence frequency of 'western region higher than eastern region' becomes more obvious. Compared with previous months, sea fog occurrence frequency over the Northwest Atlantic increases significantly, whereas it almost remains unchanged over the Northeast Atlantic. Sea fog occurrence frequency of Norwegian Sea north to British Isles increases basically up to 12%. Compared with Wang (1983), the distribution pattern of sea fog occurrence frequency in July is similar, whereas sea fog occurrence frequency calculated based on ICOADS data is smaller than that in Wang (1983).

In August (Fig.2e), sea fog occurrence frequency over the Northern Atlantic decreases rapidly compared with that in July. There is almost no sea fog occurrence over the Northeast Atlantic. Over the Northwest Atlantic, the maximum value centers at the sea from Long Island to Nova Scotia shrink. In this case, the number of maximum center reduces to only one located in the southeastern Newfoundland Sea with the maximum value of 15%. Extending from this center to higher latitudes up to the Labrador Sea, sea fog occurrence frequency is stable at about 10%. East to Greenland, sea fog occurrence frequency is above 6% from Denmark Strait to Norwegian Sea.

4 Characteristics of Meteorological Variables Related to Sea Fog

Sea fog occurring in low level of atmosphere is a kind of mesoscale weather phenomenon. The formation and development of sea fog must be under some ocean and atmosphere conditions. It can be concluded from previous studies that wind, temperature and moisture of air have important effect on sea fog occurrence. In this section, meteorological elements associated with sea fog occurrence are studied using ICOADS. Considering the frequency of sea fog occurrence and the impact on human life and economics, the enclosed rectangular area in Fig.2d is selected to analyze the air-sea conditions for sea fog occurrence.

4.1 Wind

Wind plays an important role in the formation and maintenance of sea fog. In ICOADS, wind is divided into 16 directions. Wind speed and direction in every direction are counted respectively. In Fig.3, the wind rose chart shows the distribution of wind direction. It can be seen that southerly and southwesterly winds prevail during sea fog occurrence, which dominates 60% of all the directions. When northerly winds prevail, sea fog happens very infrequently. Mean wind speed is obtained in every direction when sea fog occurs. It suggests that wind speed ranges from 6.33 to 8.62 $m s^{-1}$ and prevail winds are at the speeds of 8.01–8.62 $m s^{-1}$ when sea fog occurs.

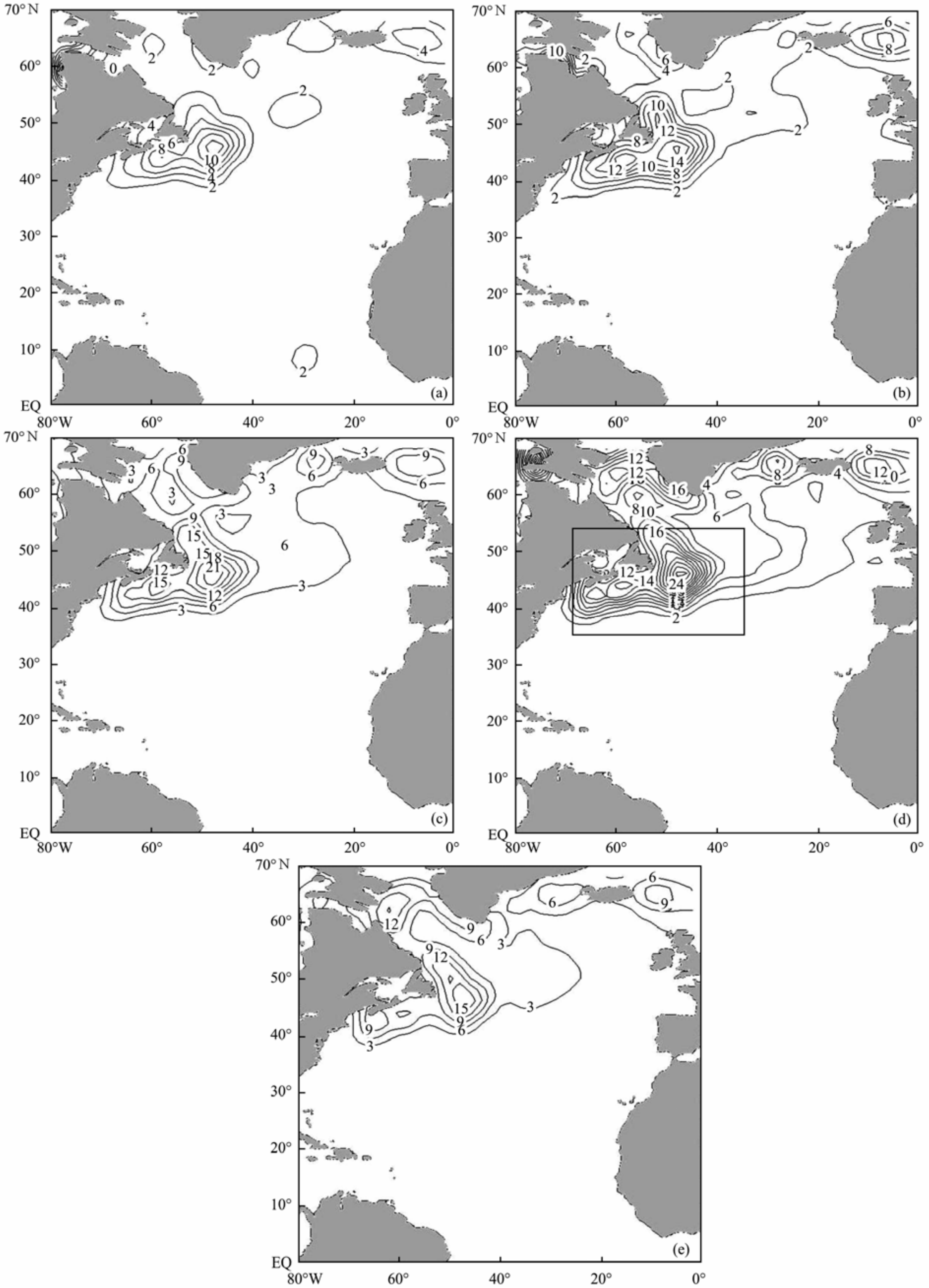
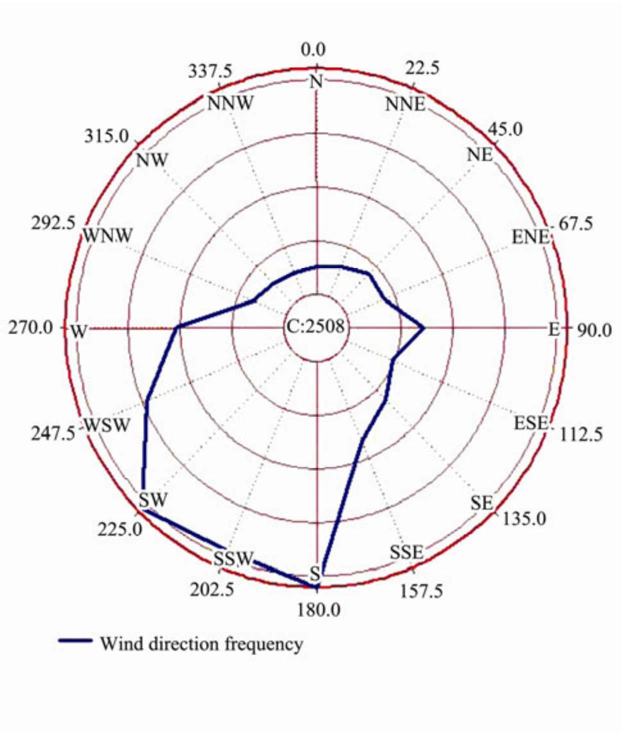


Fig.2 The frequency of visibility less than 1000 m in (a) April, (b) May, (c) June, (d) July, (e) August from 1909 to 2008 (unit: %). The rectangular region in (d) is a specific area to be referred to in Section 4.



Wind rose chart (1982.1–2008.12)			
	Wind direction frequency (reports)	Wind direction frequency (%)	Average wind speed (m s^{-1})
N	2661	1.97	7.23
NNE	3100	2.30	6.87
NE	3954	2.93	6.89
ENE	3976	2.95	6.88
E	7116	5.28	6.79
ESE	4793	3.55	6.70
SE	6344	4.70	7.02
SSE	8297	6.15	7.64
S	21071	15.62	8.01
SSW	19327	14.33	8.62
SW	20591	15.27	8.53
WSW	14610	10.83	8.23
W	10405	7.71	7.09
WNW	3444	2.55	6.33
NW	2700	2.00	6.35
NNW	2494	1.85	6.52
C	2508	0	0

Fig.3 The wind rose chart. Blue line represents wind direction in different quadrants.

In order to investigate the overall characteristics of wind speed pattern, we statistically analyzed the wind speed pattern when sea fogs occurred without distinguishing the wind directions. From Fig.4, we can see that the wind speed is mostly between grades 3 to 6 (4.4 to 12.3 m s^{-1}). Sea fogs occur most frequently when wind speed is at grade 4 (6.7 m s^{-1}). Beyond this range, the frequency of sea fogs drops drastically. It suggests that too weak or too strong winds are not in favor of the formation and maintenance of sea fogs.

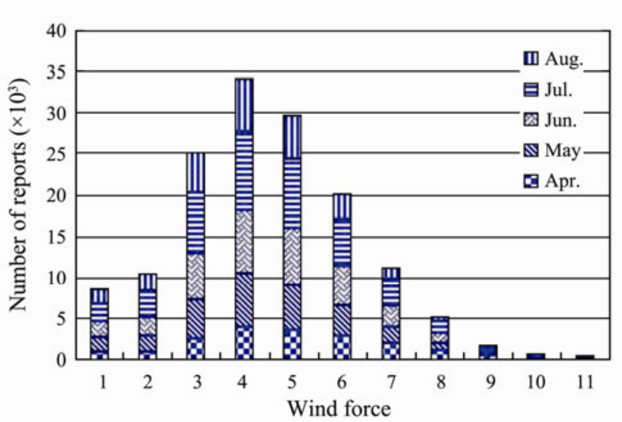


Fig.4 The wind speed of observations in different wind force scale; horizontal axis represents wind force, vertical axis represents number of reports in thousand.

4.2 Temperature and Dew Point Temperature

The formation of sea fogs has two promoting processes: increase of humidity and decrease of temperature. Thus, temperature and humidity can directly influence the formation and maintenance of sea fogs (Wang, 1983). In order to investigate the air humidity condition of the study area, ICOADS is utilized to analyze the difference between air temperature and dew point temperature, as shown in Fig.5. From the figure we can see that when sea fogs occur, the difference between air temperature and dew point temperature is mainly distributed between −1℃ to 1℃, and temperatures between −1℃ to 0℃ are most frequent, which were registered about 35000 times. When the difference between air temperature and dew point temperature is above 2℃, the occurrence frequency of sea fogs drops dramatically from less than 5000 sea fog reports. Thus, when the air humidity is high, which is near saturated or supersaturated, it is favorable for the formation and maintenance of sea fogs.

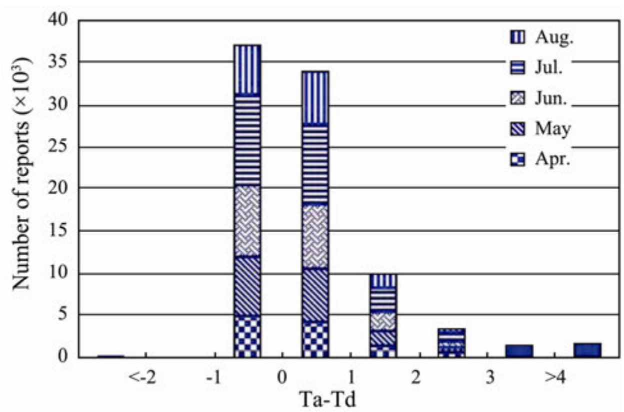


Fig.5 The difference between air temperature and dew-point temperature (Ta-Td) for different wind force scales; horizontal axis represents temperature (unit: ℃), vertical axis represents number of reports in thousand.

4.3 Sea Surface Temperature (SST) and Air-Sea Temperature Difference

Fig.6 shows the sea surface temperature of study area when sea fogs occur. Sea fog mainly occurs when SST is between 5–15℃ with sea fog reports of more than 65000 times in the fog season from April to August. Beyond this range, sea fog reports decrease dramatically, especially when SST is less than 0℃ and larger than 20℃. When SST is larger than 25℃, there is no report of fog. In terms of seasonal variation, from April to May, sea fogs occur most frequently when SST is between 0℃ and 5℃. In June, SST is between 5℃ and 10℃, and the occurrence frequency of sea fog is higher. From July to August, SST is between 10℃ and 15℃, which tends to be more suitable for fog formation.

Air-sea temperature difference (ASTD) is another main factor for affecting occurrence and development of the sea fog. Wang (1983) pointed out that the ASTD (Ta-Ts) is between 3℃ and 0.5℃ for the occurrences of advection fog in Zhoushan, Zhejiang Province, China. In Fig.7, air-sea temperature difference is shown. It can be seen that when air-sea temperature difference is between 0℃ and 2℃, sea fog forms most frequently based on more than 40000 times of fog reports, which is consistent with the results of Wang (1983).

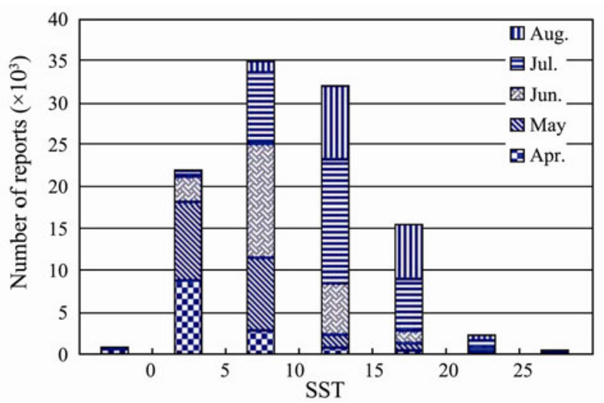


Fig.6 The sea surface temperature from different records. Horizontal axis represents temperature (unit: ℃); vertical axis represents number of reports in thousand.

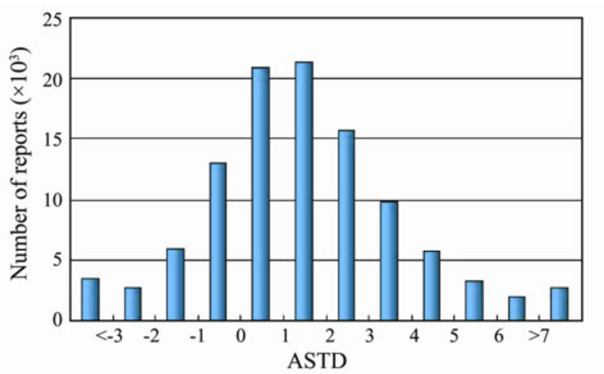


Fig.7 The difference between air temperature and sea surface temperature based on different records. Horizontal axis represents temperature (unit: ℃); vertical axis represents number of reports in thousand.

Based on Fig.7, we can divide sea fogs into advection cooling fog and advection evaporating fog. When air temperature is higher than SST, sea fog is advection cooling fog. When air temperature is lower than SST, sea fog is advection evaporating fog. In the following the relative frequency of sea fog when air temperature is higher or lower than SST is calculated. Fig.8 is the spatial pattern of the frequency of sea fogs when air temperature is higher than SST. As shown in the figure, the frequency is about 80% in the area (45˚W to 70˚W, 40˚N to 45˚N). It decreases southward and northward from this area. Fig.9 shows the distribution of frequency of sea fogs when air temperature is lower than SST. It can be seen that the frequency decreases from south to north with the range being from 40% to 15%.

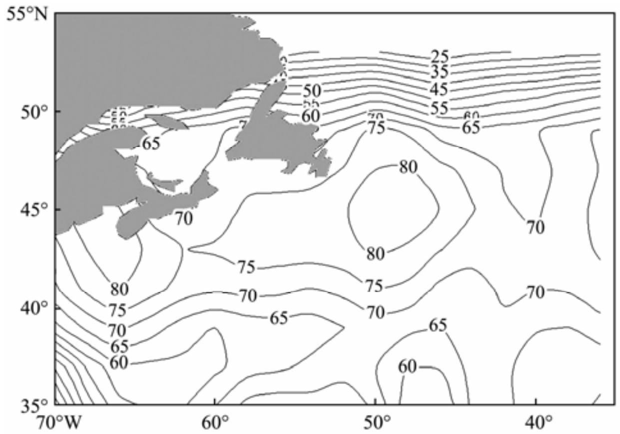


Fig.8 The frequency for cases of air temperature being higher than sea surface temperature during sea fog occurrence from 1982 to 2008 (unit: %).

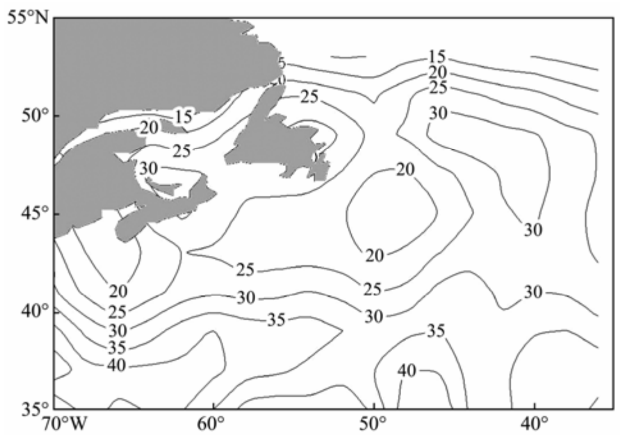


Fig.9 The frequency for cases of air temperature being lower than sea surface temperature during sea fog occurrence from 1982 to 2008 (unit: %).

5 Conclusions and Discussion

In the present study, ICOADS dataset is utilized to analyze the sea fog occurrence frequency over the Northern Atlantic and the meteorological and oceanic conditions favorable for the formation of sea fogs. Sea fog over the Northern Atlantic mainly occurs over middle and high latitudes. Sea fog occurrence frequency over the western region is higher than that over the eastern region. The reason for more sea fog occurrence over the western region may be related to the Gulf Stream and Labrador Current. The Labrador Current is a cold current in the North Atlantic Ocean which flows from the Arctic Ocean southward along the coast of Labrador and passes around Newfoundland. It meets the warm Gulf Stream at the Grand Banks southeast of Newfoundland. The combination of these two currents produces a favorable condition for fog formation. Southerly winds bring warm air toward and over the cold water and advection cooling fog forms. The maximum sea fog occurrence frequency is distributed along a belt region from Long Island to east of Newfoundland. In terms of seasonal variation, sea fog occurrence frequency gradually increases from April to July and then rapidly decreases from August with the maximum sea fog occurrence frequency dropping down to slightly over 10% during this period, as opposed to over 24% in July during the peak month. It suggests that the fog season in the Northern Atlantic is from April to August. Sea fog occurrence frequency is relatively small (less than 10%) during the cold season (from September to the next March). In the East China Sea, sea fog forms more frequently in the area of Zhoushan Islands. Here sea fog can be observed for more than 50 days a year (Fig.1 in Zhang and Bao, 2008). Sea fog occurrence frequency gradually increases from March to June (Fig.1 in Zhang *et al.*, 2009). Comparing sea fog over the Northern Atlantic with sea fog over the East China Sea, it can be seen that there is only one prominent sea fog occurrence area in East China Sea, whereas in the Northern Atlantic sea fog is distributed along a belt region. Fog season starts and ends earlier in the East China Sea than in the Northern Atlantic.

When sea fogs occur, the prevailing wind direction in the study area is from southerly to southwesterly and the favorable wind speed is around $8\,\mathrm{m\,s^{-1}}$. Without distinguishing the wind direction, the favorable wind speed is between $4.4\,\mathrm{m\,s^{-1}}$ to $12.3\,\mathrm{m\,s^{-1}}$. The wind speed of $6.7\,\mathrm{m\,s^{-1}}$ is the most favorable. Under the wind from south to southwest, the warm wet air from low latitudes moves northward to the study area, the air becomes near saturated or supersaturated above the cold sea surface. This is favorable for the formation and maintenance of sea fogs. It is most favorable for the formation of sea fogs when sea surface temperature is 5℃ to 15℃. When SST is higher than 25℃, it is difficult for the air to get saturated, and there is almost no report of sea fog. When sea fogs form, the difference between sea surface temperature and air temperature is mainly −1 to 3℃, and the difference of 0℃ to 2℃ is most favorable for fog formation. There are two types of sea fogs: advection cooling fog and advection evaporating fog. The study suggests that the advection cooling fog occurs much more frequently than advection evaporating fog in the study region. The mechanisms of sea fog over the North Atlantic have been rarely discussed. Especially, the role of turbulence for fog formation and dissipation is scarcely discussed. There are two main sources for turbulence to be generated: buoyancy and wind shear. In the case of advection cooling fog, sea water temperature is lower than air temperature. Thus, buoyancy may play an important role in the production of turbulence. However, in an advection cooling case study, Li *et al.* (2012) revealed that fog layer extended higher vertically with the aid of turbulence which is produced by wind shear. In the case of advection evaporating fog, air temperature is lower than SST. Thus, wind shear may produce turbulence under windy weather conditions. However, in both fog types, inversion layer is an important factor needed to be considered for fog formation and dissipation. Inversion layer suppresses the activities of turbulence. Therefore, fog layer can only reach the bottom of the inversion layer. Fog is a shallow weather phenomenon in the marine atmospheric boundary layer (MABL) and is a result of very delicate banlance among all the processes. Hence, any change in the MABL could destroy the balance and lead fog to demise. The present study is mainly to provide a vision for the sea fog occurrence frequency over the Northern Atlantic and the meteorological and oceanic conditions favorable for the formation of sea fogs. The mechanisms of sea fogs will be discussed in the future work with the help of numerical models.

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