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PREDICTION OF SEA FOG OF GUANGDONG COASTLAND USING THE VARIABLE FACTORS OUTPUT BY GRAPES MODEL

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Abstract: By analyzing the NCEP 1° ×1° reanalysis (2004–2008), a number of predictors (factors of variables) are established with the output from the GRAPES model and with reference to the sea fog data from observational stations (2004–2008) and field observations (2006–2008). Based on the criteria and conditions for sea fog appearance at the stations of Zhanjiang, Zhuhai and Shantou, a Model Output Statistics (MOS) scheme for distinguishing and forecasting 24-h sea fog is established and put into use for three representative coastal areas of Guangdong. As shown in an assessment of the forecasts for Zhanjiang and Shantou (March of 2008) and Zhuhai (April of 2008), the scheme was quite capable of forecasting sea fog on the coast of the province, with the accuracy ranging from 84% to 90%, the threat score from 0.40 to 0.50 and the Heidke skill from 0.52 to 0.56.

Key words: sea fog forecast; coastal Guangdong; MOS-based distinguishing scheme; variable predictors

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1 INTRODUCTION

Sea fog is one of the major marine meteorological disasters in winter and spring along the coast of Guangdong province. The reduced visibility caused by sea fog brings inconvenience to the daily lives of people, transportation and marine operations in coastal areas; long-lasting and dense sea fog often leads to a variety of serious accidents that have significant impacts on the national economy and social life in these areas, causing enormous economic losses.

Fog is a phenomenon of water vapor condensing next to the underlying surface in the lower atmosphere and sea fog is generated over the ocean under marine influence[1]. Due to the differences in the processes of formation, maintenance and dissipation, sea fog differs regionally; its formation is even more complicated as it is subject to local geographical and climatic features and different weather background[2, 3]. Therefore, it is still difficult to forecast sea fog objectively. The forecasting methods are mainly based on synoptics, numerical prediction and Model Output Statistics (MOS)[1, 4]. For the forecasting of sea fog, synoptics is a general method, which has been mainly employed by coastal forecasters in the province[5]; most of the numerical prediction is still a subject of research. The MOS method searches for predictors from the output of numerical prediction products, establishes forecast equations using statistical approaches (such as stepwise regression), and formulates methods for sea fog forecasting. Matching the products of numerical prediction with local meteorological elements, MOS not only automatically takes into account the error of numerical models and the inaccuracy of calculations, but also includes the characteristics of local climate. Furthermore, MOS uses some important predictors with definite physical significance, such as the vertical velocity, vorticity and divergence, etc. The introduction of these factors help describe weather processes better and make more accurate prediction[6]. Since the late 1970s, MOS has been used to forecast sea fog at home and abroad. In the United States, Orman et al.[7-10] used MOS to study the forecast of sea fog in the North Pacific and achieved good results, with the accuracy of 24-h forecast being 70% to 78%. In a study of MOS

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forecast by Hu et al.[11], the fax maps of numerical prediction from Japan, observations from near-shore stations of China, and empirically designed factors and combined factors were employed to study the 24-h MOS forecast of sea fog for the coast of southern Shandong province in April to July. It was satisfactory in trial forecasts with an average accuracy of 77%. Previous studies showed that it is feasible to make 24-h forecast of sea fog using MOS.

A study was conducted on 24-h sea fog forecast for the coastal areas of Guangdong in this paper. The study was based on the climotology of coastal sea fog statistically determined for these areas[12, 13] and observations from conventional stations and field tests in 2006–2008[14]. Predictors are the model output from the Global and Regional Assimilation Prediction System (GRAPES) performed at Guangzhou Institute of Tropical and Marine Meteorology (GITMM). Methods included the Model Output Statistics (MOS) and some other identification methods (hereafter all referred to as MOS discrimination methods).

2 METHODS AND PROCEDURES

2.1 *Setup of MOS discrimination methods for sea fog*

i. From five-year (2004–2008) 1° ×1° reanalysis from the U.S. National Centers for Environmental Prediction (NCEP), data for the months of frequent sea fog occurrence in coastal Guangdong (January–April) were selected for analysis. Based on observations from stations in 2004–2008 and sea fog measurements obtained from the field tests in 2006–2008, predictors were searched that were highly sensitive to sea fog forecast and discrimination methods and criteria were set up for the coastal sea fog in Guangdong.

ii. Predictors were determined from the 0.12° ×0.12° numerical output products of GRAPES at GITMM. The three stations of Zhanjiang, Zhuhai and Shantou, representing the west, middle and east sections of the province shoreline respectively, were selected in the formulation of a set of MOS discrimination methods for the forecasting of sea fog.

2.2 *Verification of sea fog forecasts using MOS discrimination methods*

First of all, the discrimination methods were verified using the data of Zhanjiang station. The NCEP data in January–April of 2004–2008 were used to discriminate and analyze whether sea fog was likely to form, and then to verify the feasibility of the discrimination methods and criteria. Results were then used to study in detail problems stemming from associated weather patterns and observations and to make necessary adjustment and improvement of the MOS discrimination methods.

Lastly, real forecasts were verified. With March (April) of 2008 used as the time covered by forecast, the MOS discrimination methods for individual sections of the coast were verified for the accuracy of the predictors selected. The forecasted results were then scored according to the observations of individual stations.

3 SELECTION AND QUANTIFICATION OF PREDICTORS FOR FORECASTING

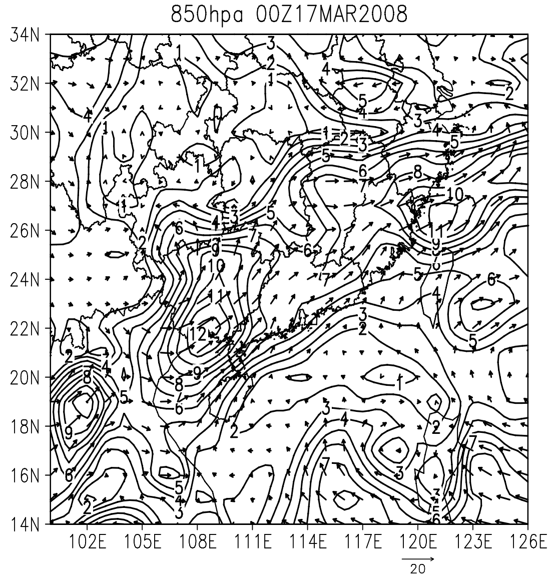
The selection and quantification of predictors is one of the key difficulties in MOS-based forecasting. Previous results of sea fog forecast must be reviewed carefully to choose the best predictors possible. As shown in previous studies, cooling and moistening are two main mechanisms in sea fog formation[1]. Meanwhile, favorable synoptic background and meteorological conditions are key to this process[4]. According to the two principles above, a number of main predictors were isolated on the basis of longtime, repeated analysis and comparison. Detailed study will be performed hereafter on the sea fog processes which occurred on 17–19 and 30–31 March, 2008 on the western coast and on 30 March, 2008 on the eastern coast.

3.1 *Southwest wind component at 850 hPa in main areas: Crieterion and quantification*

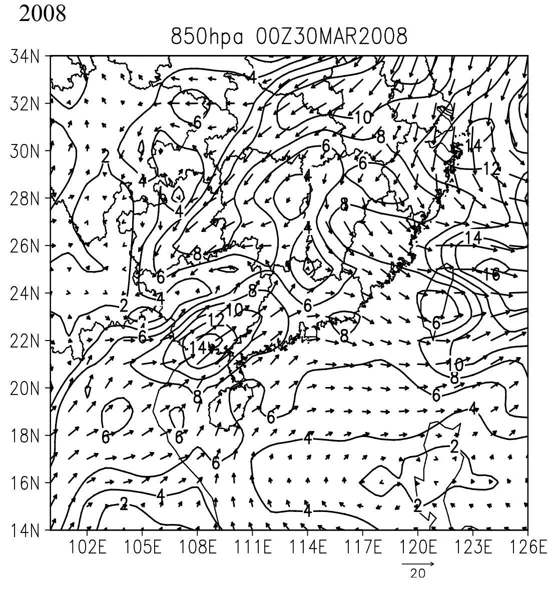
Low-level southwest jet streams are bands of strong wind at a certain isobaric layer below 600 hPa (usually at 700, 850 or 925 hPa) that acquire a certain force of wind (usually by a threshold of ≥12 m/s)[15] within a certain area. Over the past few years, further understanding has been achieved of the low-level southwest jet streams. Studies of climatological features of sea fog formed over the Yellow Sea in the spring and summer argued that the moistening process of the Yellow Sea fog could not be from local sources; instead, it could originate from low-level southwest jet streams that have been transported from the low latitudes[2, 3]. Studies on climatological characteristics of sea fog at the coast of Pearl River estuary also indicated that most of the sea fog takes place in the presence of the southwest low-level jet streams at 850 hPa and coastal Guangdong is, in general, located to the right of their axis, exposing itself to an anti-cyclonic shear of wind speed in an area of negative vorticity with stable stratification, which is favorable for fog formation[13]. Similarly, such fog-favorable weather patterns were also identified in works on coastal fog in the south of China[12].

In summary, the southwest jet streams act as an important source of atmospheric moisture by transporting abundant water vapor toward the south of China on the one hand, and these jet streams are likely to produce negative vorticity to their right on the other.

It then results in descending motion in the atmosphere, descent-accompanying temperature inversion and stable atmospheric stratification. This makes sea fog more likely to occur. Figs. 1a & 1b show the wind direction and speed at 850 hPa at 0000 UTC (Coordinated Universal Time) on 17 and 30 March, 2008. According to the figure, a southwest jet stream appeared over the Northern Bay (Tongkin Bay) through western Guangdong. Responding to this process, pronounced sea fog occurred on 17–19 and 30–31 March at the western coast and on 30 March at the eastern coast.



(a) 850-hPa wind direction and speed at 0000 UTC 17 March 2008



(b) Same as (a) but for 30 March 2008

Fig. 1. Relationship between westerly jet streams and sea fog formation (m/s)

To determine the percentage of westerly jet streams (e.g. with direction at southwest and wind speed > 12.0 m/s) in the selected areas for the isobaric surface of 850 hPa, areal averaging was applied to the areas of interest (i.e., the whole province of Guangdong and its coastal regions and neighboring provinces) for statistical mean.

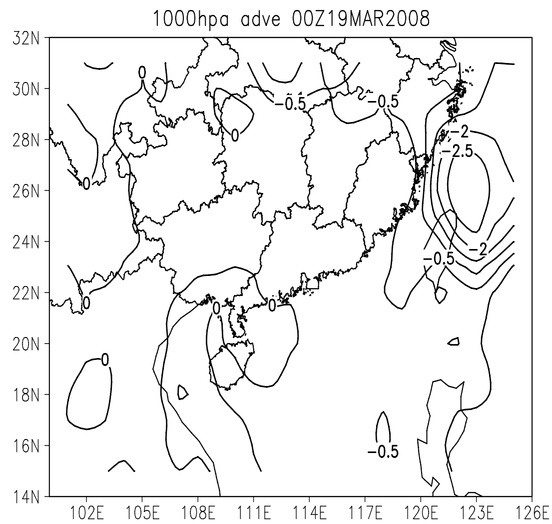
Here, an index is defined for the area of westerly jet streams:

$$W = A_1 / A_2 \quad (1)$$

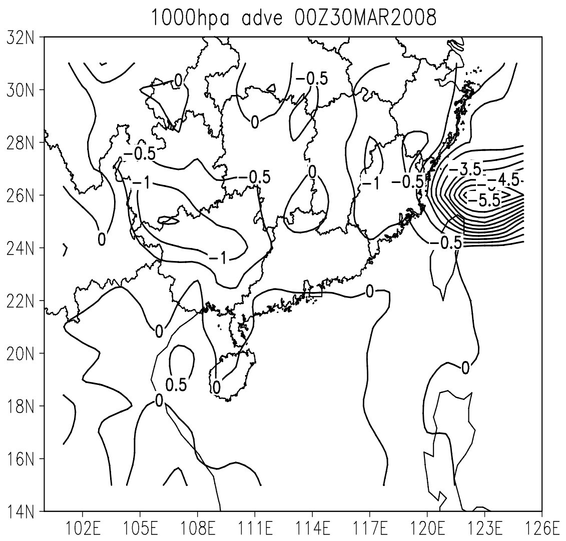
where W stands for the percentage of the westerly jet streams in the selected area, A_1 is the number of gridpoints within which the westerly jet streams appear in the selected area, and A_2 is the total number of gridpoints in the selected area.

3.2 *Low-level wind direction/speed and low-level warm advection at 850 hPa and beneath: Criterion and quantification*

One of the sea fog-favorable weather patterns is a pressure field in which warm and humid marine air blows toward the shore[1, 5, 13], as indicated by previous relevant studies. Applied locally, the finding above can be summed up as follows: The coast of Guangdong is likely to have sea fog when warm and humid easterly or southerly prevails in the low-level atmosphere. Figs. 2a & 2b show 1000-hPa temperature advection (from NCEP reanalysis) at 0000 UTC on 19 and 30 March, 2008. Warm advection extended to western Guangdong on 19 March while extending to the waters off the eastern province on 30 March. Correspondingly, a significant sea fog appeared in the offshore waters of western Guangdong on 19 March while sea fog occurred in the offshore waters of both the eastern and western parts of the province on 30 March.



(a) 1000-hPa temperature advection and speed at 0000 UTC 19 March 2008



(b) Same as (a) but for 30 March 2008

Fig. 2. Relationship between low-level warm advection and sea fog formation (10^{-4} °C/s)

The wind direction and speed for the three isobaric surfaces of 1000, 925, and 850 hPa were selected for analysis and statistical averaging was carried out over the areas corresponding to each of the three stations, usually within 2° longitude and 2° latitude, to determine representative wind direction and speed values for individual areas. The values for the three isobaric surfaces were then studied in composite analysis to judge whether warm advection would occur near the stations. Usually, warm advection is likely to develop when there is clockwise change of wind direction between 1000 and 850 hPa.

In this paper, W_3, a combined factor of wind direction/speed is defined as follows. When the direction/speed combination is judged to be favorable for the evolution of warm advection near the station, set $W_3=1$; when it is thought to be unfavorable, set $W_3=0$.

In the meantime, low-level temperature advection was calculated. Under normal circumstances, warm advection at the station would favor the formation of sea fog.

Here, *A*, a temperature advection index is defined as

$$A=-\vec{V}\bullet\nabla T\approx-\left(u\frac{\Delta T}{\Delta x}+v\frac{\Delta T}{\Delta y}\right). \quad (2)$$

When *A*>0, warm advection is defined; when *A*<0, cold advection is defined.

To calculate the temperature advection around the station, define

$$A_{i1,\,j1}=(A_{i-1,0}+A_{i+1,0}+A_{0,\,j-1}+A_{0,\,j+1}+A_{i,\,j})/5 \quad (3)$$

where $A_{i1,\,j1}$ is the calculated value of temperature advection for a station, $A_{i,\,j}$ the original advection of the station, and $A_{i-1,0}$, $A_{i+1,0}$, $A_{0,\,j-1}$, and $A_{0,\,j+1}$ the advection of locations 1° longitude or 1° latitude away from the station at four directions, respectively.

3.3 *Low-level pressure field: Criteria and quantification*

As shown in studies, isobaric lines are usually separated sparsely in surface weather maps associated with coastal fog in southern China[12, 13]. For this reason, patterns of surface pressure can be identified that are favorable for the formation of sea fog if low-level pressure fields are quantified. Figs. 3a & 3b show 1000-hPa geopotential isolines for 0000 UTC on 19 March and 0000 UTC on 30 March, 2008. In spite of different patterns of pressure fields, sparse distribution of the geopotential isolines is one of the main characteristics of sea fog formation in coastal Guangdong.

Pressure differences around the selected stations were calculated. Generally speaking, the smaller the pressure differences surrounding the station, the more favorable it is for the genesis of sea fog.

The pressure difference, d_p, is defined between the station and the surrounding by:

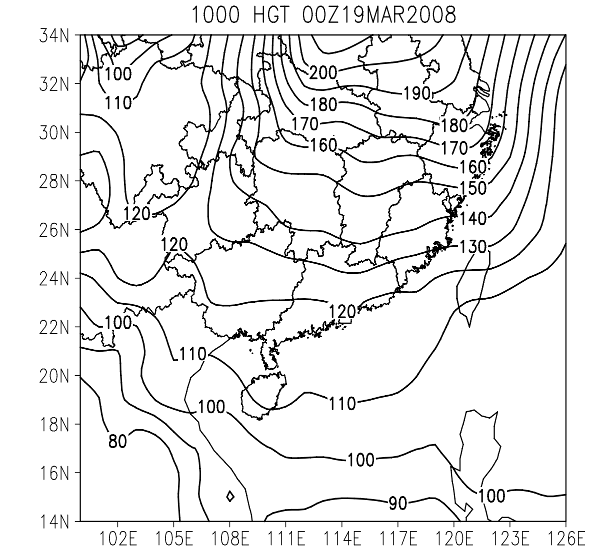
$$dp=(p_{i-3,0}+p_{i+3,0}+p_{0,\,j-3}+p_{0,\,j+3}-4p_{i,\,j})/4 \quad (4)$$

where d_p is the difference in sea level pressure, $p_{i,\,j}$ the pressure of the selected station, and $p_{i-3,0}$, $p_{i+3,0}$, $p_{0,\,j-3}$, and $p_{0,\,j+3}$ are the pressures that are three longitudinal or latitudinal degrees away from the station at four directions, respectively.

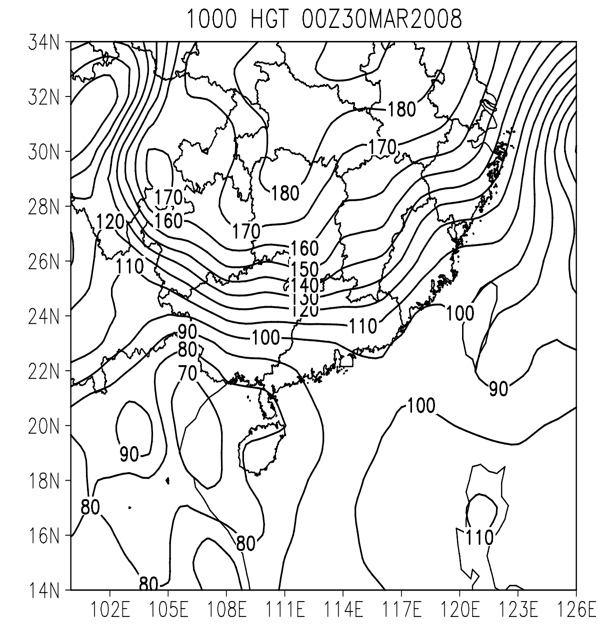
3.4 *Low-level temperature and humidity: Criteria for quantification and the methods*

Sea fog is a phenomenon of water vapor condensation in the atmospheric boundary layer above the ocean. As it moves toward the coast, sea fog is subject to land effect. Will it stay the way it is or will it be lifted upwards to become low clouds? The scenarios are closely related with the land surface and meteorological conditions of temperature, humidity and turbulence intensity at the lower atmosphere. In the meantime, the stability of the atmosphere and the transport of overall water vapor at the low levels of the atmosphere are both playing an important role in the genesis and maintenance of sea fog. Generally, favorable conditions include the presence of homogeneous temperature or temperature inversion at low levels, stable atmospheric stratification, large relative humidity (for quite a depth) at low levels (below 850 hPa), and small dewpoint at low levels[1].

It is then important to analyze the land surface and predictors, like the temperature, humidity and water vapor, in order to determine whether sea fog is generated, maintained and developed.



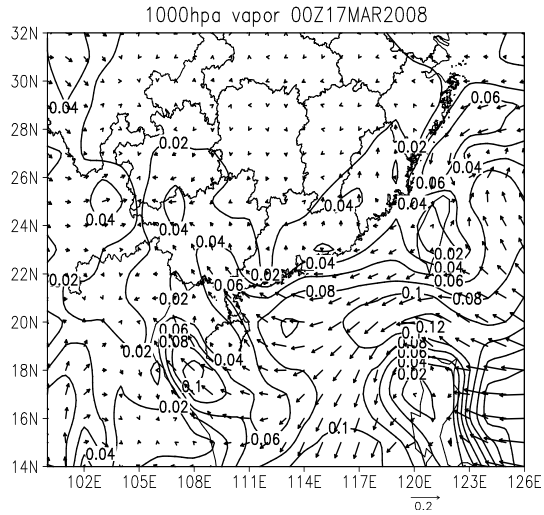
(a) 1000-hPa pressure field for 0000 UTC on March 19, 2008



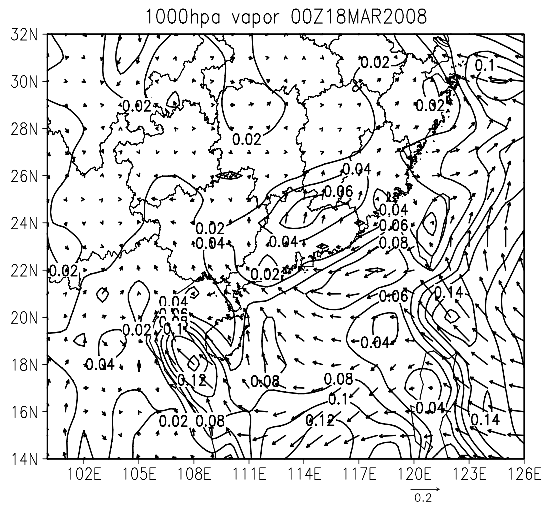
(b) Same as (a) but for March 30, 2008

Fig. 3. Relationship between homogeneous pressure fields and sea fog genesis (geopotental meter)

Figure 4 shows the 1 000-hPa water vapor transport for 0000 UTC on March 17 and 18, 2008. With the occurrence of sea fog, significant amount of water vapor was transported toward western Guangdong, indicating the role of low-level humidity in the formation of sea fog. Fig. 5 presents the distribution of low-level humidity differences ($t_{925\,\mathrm{hPa}} - t_{1\,000\,\mathrm{hPa}}$) for 0000 UTC on March 30 and 31, 2008. The presence of mild inversion or weak temperature-decreasing layers on the coast of western Guangdong on March 30–31 helped form the sea fog. A favorable layer of weak temperature decrease was also found on the coast of eastern Guangdong on March 30. However, there was no such phenomenon on March 31, resulting in the disappearence of sea fog on the same day.



(a) 1000-hPa water vapor transport for 0000 UTC on 17 March 2008



(b) Same as (a) but for 18 March 2008

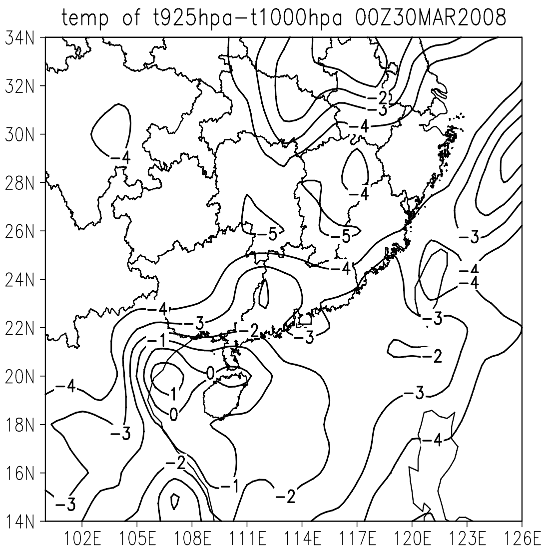
Fig. 4. Relationship between 1000-hPa water vapor transport and sea fog genesis unit: kg•m/(kg•s)

As shown in studies, surface humidity q_0 and 1000-hPa humidity q_{1000} can represent low-level humidity and well reflect the changes in low-level water vapor.

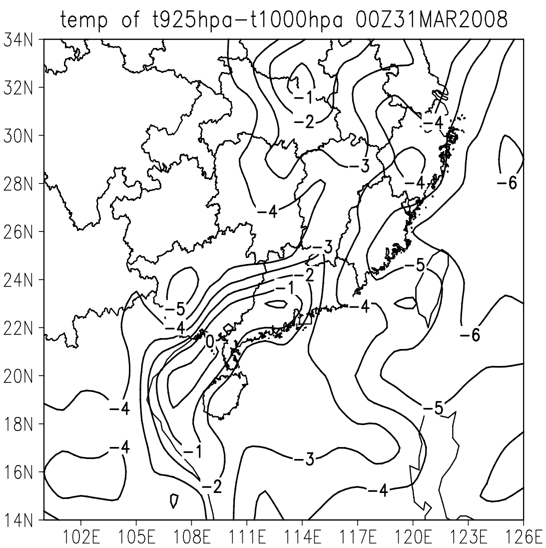
Low-level temperature inversion is one of the basic conditions for sea fog to generate and maintain, which is expressed by

$$\Delta t = t_{925\,\mathrm{hPa}} - t_{1\,000\,\mathrm{hPa}} \quad (5)$$

where Δt stands for the temperature difference between two isobaric surfaces, $t_{925\mathrm{hPa}}$ is the temperature at 925 hPa and $t_{1000\text{hPa}}$ that at 1 000 hPa. When the atmosphere is unstable, Δt is highly negative; when the atmosphere is stable and with the presence of temperature inversion, Δt is slightly negative or positive.



(a) Low-level temperature differences ($t_{925\ \text{hPa}}$-$t_{1\ 000\ \text{hPa}}$) for 0000 UTC on 30 March 2008



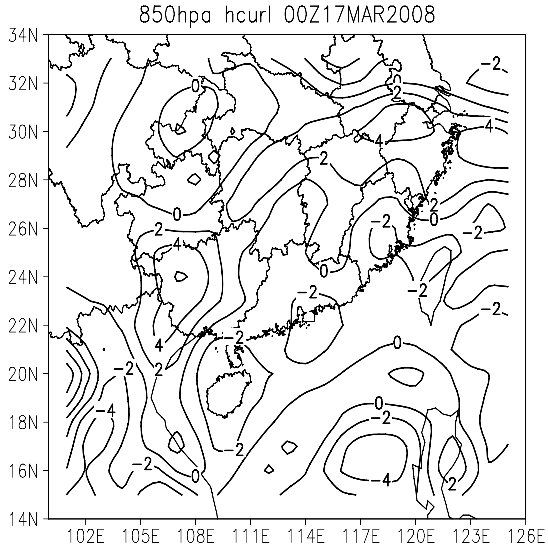
(b) Same as (a) but for 0000 UTC 31 March 2008

Fig. 5. Relationship between low-level temperature differences ($t_{925\ \text{hPa}}$-$t_{1\ 000\ \text{hPa}}$) and sea fog genesis (° C)

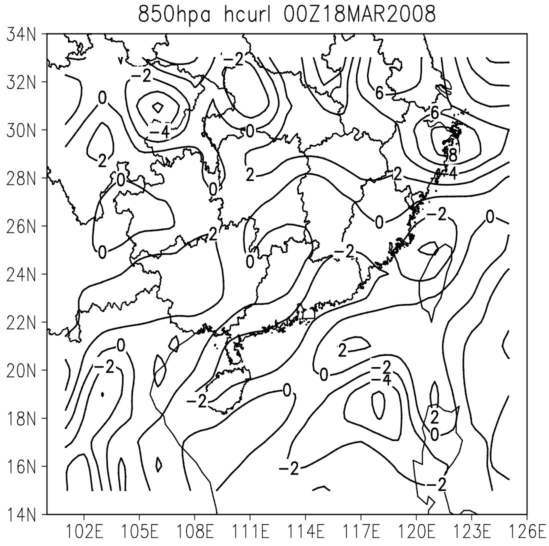
3.5 *850-hPa vorticity: Criteria and quantification*

As shown in factors analysis above, when there is a southwesterly jet stream at the middle and lower levels of the troposphere, the right-hand side of the flow axis (i.e., an area of wind speed divergence), is usually favorable for the generation of sea fog. A favorable vorticity field can be identified by determining the changes in 850-hPa vorticity in the mid- and lower-troposphere of the forecast region.

Figures 6a & 6b present the 850-hPa vorticity charts for 0000 UTC on 17 and 18 March 2008, which show that coastal Guangdong is all in a region of negative vorticity and likely to have sea fog formation.



(a) Distribution of 850-hPa vorticity for 0000 UTC on 17 March 2008



(b) Same as (a) but for 18 March 2008

Fig. 6. Relationship between variations of 850-hPa vorticity and sea fog genesis

On the 850-hPa isobaric surface, vorticity values were quantified for the surrounding area of the stations. Sea fog is likely to occur when the vorticity is negative.

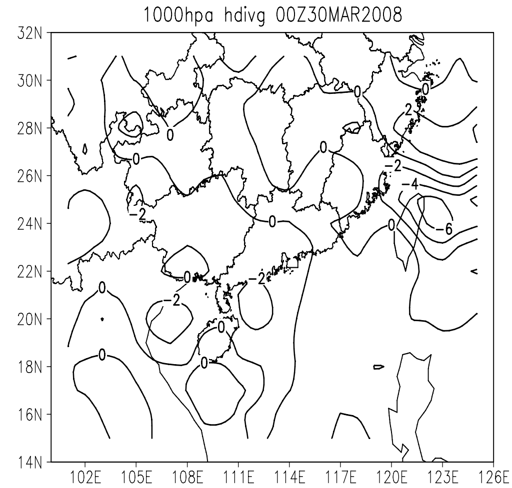
$$\xi_{i1,\,j1} = (\xi_{i-1,\,0} + \xi_{i+1,\,0} + \xi_{0,\,j-1} + \xi_{0,\,j+1} + \xi_{i,\,j}) / 5 \quad (6)$$

where $\xi_{i1,\,j1}$ is the computed vorticity around the station, $\xi_{i,j}$ the original vorticity of the station, and $\xi_{i-1,\,0}$, $\xi_{i+1,\,0}$, $\xi_{0,\,j-1}$, and $\xi_{0,\,j+1}$ the vorticity of locations that is 1° longitude or 1° latitude away from the station at four directions, respectively.

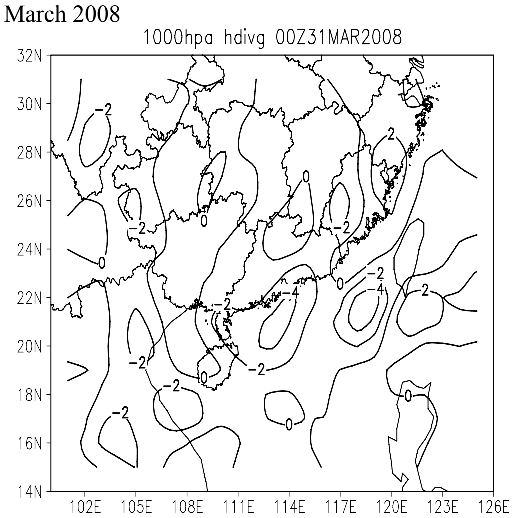
3.6 *1000-hPa divergence: Criteria and quantification*

Sufficient amount of water vapor is one of the necessary conditions for sea fog to form. The convergence and divergence of lower tropospheric atmosphere surely plays a key role in the distribution of humidity. As shown in studies, typical sea fogs are usually accompanied with water vapor being transported by the southerly and easterly flows from the South China Sea or West Pacific to the area where they are generated. Meanwhile, it is also discovered that sea fog appears when water vapor flux is usually negative in the local lower atmosphere and the convergence of water vapor helps sea fog develop in the vertical direction[13]. The low-level (1 000 hPa in this study) divergence of the forecast area can be used as one of the important criteria in sea fog forecasting.

Figure 7 shows the analysis of 1000-hPa divergence for 0000 UTC on March 30 and 31, 2008. The coast of Guangdong, especially the western part, was in an area of negative divergence, which helped low-level water vapor to converge and was favorable for sea fog to form.



(a) Distribution of 1000-hPa divergence at 0000 UTC on 30 March 2008



(b) Same as (a) but for 31 March 2008

Fig. 7. Relationship between variations of 1000-hPa divergence and sea fog genesis (unit: 10^{-5} s^{-1})

On the 1 000-hPa isobaric surface, divergence values were quantified for the surrounding area of the stations. Sea fog is likely to occur when the divergence is negative.

$$D_{i1,\,j1} = (D_{i-1,\,0} + D_{i+1,\,0} + D_{0,\,j-1} + D_{0,\,j+1} + D_{i,\,j})/5 \quad (7)$$

where $D_{i1,\,j1}$ is the computed divergence around the station, $D_{i,j}$ the original divergence of the station, and $D_{i-1,\,0}$, $D_{i+1,\,0}$, $D_{0,\,j-1}$, and $D_{0,\,j+1}$ the divergence in locations that is one longitudinal or one latitudinal degree away from the station at four directions, respectively.

4 DETERMINATION OF PREDICTORS AND DISCRIMINATION CONDITIONS

For this study, the platform of numerical prediction was based on the 0.12° ×0.12° products of numerical weather prediction (NWP) for 0800 BST (Beijing Standard Time, same below) in southern China. The products are the output from the GRAPES model at GITMM. The predictors determined with this NWP product were used to conduct MOS-discriminated forecast for the following day. Currently, in routine operation, the NWP product gives the output for 0800 BST of the current day before 1800 BST, i.e., it is able to perform, at 1800 BST, daily (24-h) sea fog forecasting for 0800 BST of the successive day.

To determine the predictors used in forecasting, a number of predictors were identified by statistically examining the forecast/analysis procedure and comparing the results with observations. Then, the conventional predictors from the output of GRAPES were transformed into principle predictors for forecasting. On this basis, the NCEP reanalysis and field observations were used to establish the criteria and conditions for each of these main predictors (Table 1). These criteria include necessary and optional conditions; when all of the necessary conditions are met, sea fog is forecast to appear and when not all of them are satisfied, no sea fog is forecast to appear.

Table 1. Analysis of predictors and establishment of criteria

Predictors	Relative Importance	Samples with sea fog	Probability of sea fog appearance	Criteria selected
850-hPa SW component in main regions	Optional	265	≥91.3% for 850-hPa westerly jet stream index W≥0.2 on the same day or in 24 h	W≥0.2
Combination of wind dir./speed at 850-hPa and below	Necessary	265	100% for warm-advection-favorable wind direction/speed combination W_3=1	W_3=1
Temp. advection at 1 000 hPa	Optional	265	70.2% for temp. advection A>0	A>0
Low-level pressure field	Necessary	265	98.5% for difference in sea level pressure being from 0–1.0 hPa	dp≤1.0
Low-level temp. & humidity	Necessary	265	98.1% for surface relative humidity q_0≥80%; 92.5% for 1 000-hPa relative humidity $q_{1\,000\ \mathrm{hPa}}$≥85%; 99.2% 925–1 000hPa temp. difference $\Delta t = t_{925\ \mathrm{hPa}} - t_{1\,000\ \mathrm{hPa}} \geq -4.0$	q_0≥80% $q_{1\,000\ \mathrm{hPa}}$≥85% $\Delta t \geq -4.0$
Vorticity at 850 hPa	Necessary	265	99.2% for $\xi_{i1,\ j1}$ between 0.0 and -4.0	$-4.0 \leq \xi_{i1,\ j1} \leq 0.0$
Divergence at 1 000 hPa	Necessary	265	99.2% for $D_{i1,\ j1}$ between 0.0 and -4.0	$-4.0 \leq D_{i1,\ j1} \leq 0.0$

5 VERIFICATION OF THE DISCRIMINATION METHODS FOR SEA FOG FORECASTING

The discrimination methods described above were verified for rationality. The Zhanjiang station was selected here. The NCEP reanalysis for January–April of 2004–2008 was analyzed to verify whether the listed criteria and conditions were able to capture the formation of sea fog. For each of the four-times daily NCEP reanalysis, discrimination results presented with these criteria and conditions were used to see whether sea fog was formed or not. If sea fog did appear during the three hours before and/or after the time of available NCEP reanalysis, sea fog was determined to occur at the time; no sea fog was said to be around otherwise. Such a qualitative method was tested using three ways of scoring: percentage correctness, threat score (TS) and Heidke skill score (HSS)[16] (Table 2). Results showed that the criteria and conditions were efficient and feasible in determining the sea fog formation.

Table 2. Verification results of the criteria and conditions for sea fog formation using the NCEP reanalysis (Zhanjiang station)

Year	Forecast duration	Sample size	Correct discrimination		Incorrect discrimination		Percentage correct/%	TS	HSS
			Sea fog	No sea fog	False alarm	Miss			
2004	Jan.–Apr.	484	20	432	20	12	93	0.38	0.52
2005	Jan.–Apr.	480	38	411	11	20	94	0.55	0.67
2006	Jan.–Apr.	480	43	388	28	21	90	0.47	0.58
2007	Jan.–Apr.	480	31	413	20	16	93	0.46	0.59
2008	Jan.–Apr.	484	21	428	29	6	93	0.38	0.51
mean		482	31	414	22	15	93	0.45	0.57

6 VERIFICATION OF FORECASTS

To see whether the MOS discrimination methods work, real forecasts need to be verified. The three stations of Zhanjiang, Zhuhai and Shantou were chosen to represent forecast areas of the western Guangdong, Pearl River estuary, and eastern Guangdong, respectively, and forecasts were verified and scored. For the two stations in Zhanjiang and Shantou, the duration of forecast is from 0800 March 1 to 0800 March 31, 2008; for the station in Zhuhai, it is between 0800 April 1 to 0800 April 30, 2008, as there was no sea fog in March. A daily 24-h forecast was made using the 0800 NWP products from the GRAPES output to determine whether there could be sea fog on the following day. As the forecasts are available once every hour, sea fog is defined to be present if it occurs at 0000–0800 with more than three forecasts of different initial time; it is defined to be absent otherwise. Besides, the verification follows the rules below: When sea fog appears at a station on a given day, it is verified to be present no matter how long it lasts; otherwise it is verified not to be present. Real forecasts and scores are presented in Table 3.

As shown in the results of Table 3, the MOS discrimination method has a certain degree of forecasting capabilities. The method was also successful in forecasting the two main sea fogs on March 17–19 and 30–31, 2008 (table omitted). It is therefore feasible to conduct 24-h sea fog forecasting for the coast of Guangdong using the MOS discrimination methods, together with the predictors in the output of the GRAPES model.

Table 3. Results and scores of sea fog forecasts with MOS discrimination methods

Station	Forecast period	Sample size	Correct discrimination		Wrong discrimination		Forecast accuracy/%	TS	HSS
			With sea fog	Without sea fog	False alarm	misses			
Zhanjiang	2008.03	31	5	21	2	3	84	0.50	0.56
Zhuhai	2008.04	30	2	25	2	1	90	0.40	0.52
Shantou	2008.03	31	2	24	1	2	90	0.40	0.52
mean		31	3	23	2	2	88	0.43	0.53

7 CONCLUSIONS AND DISCUSSIONS

A number of predictors were identified by studying five-year (2004–2008) NCEP reanalysis data in combination with observations from a number of stations over the same period and observations from the field experiments in 2006–2008. The predictors were then obtained from the output of the GRAPeS model. On the basis of it, criteria and conditions associated with the appearance of sea fog were then used to formulate a preliminary discrimination method based on MOS for the forecasting of sea fog in three Guangdong coastal regions represented by Zhanjiang, Zhuhai and Shantou, respectively. A 24-h sea fog discrimination forecasting was performed. From the verification of the forecasts for Zhanjiang and Shantou in March 2008 and Zhuhai in April 2008, the GRAPeS-based MOS discrimination method was shown to be capable of forecasting sea fog on the Guangdong coast, with the accuracy ranging from 84% to 90%, TS from 0.40 to 0.50, and HSS from 0.52 to 0.56.

Traditional MOS forecasting methods comprise three components: M (model), O (output) and S (statistics). As shown in studies on sea fog forecasting, methods using regression equations do not achieve satisfactory results. There are two reasons for it. One is that some predictors are more of necessary than principle factors and the other is that some predictors are mostly with definite “critical values”, as shown in real analysis. These factors cannot be truly reflected with the use of the methods employing regression equations. In view of this problem, this study tends to rely on more on methods of discrimination for forecasting once predictors are isolated with the GRAPeS model. To improve the performance of sea fog forecasting using the MOS discrimination method, a follow-up process of forecasting and verification is needed. This is to (1) continue to locate more visualized and more efficient predictors on the one hand, (2) to verify and improve the stability of the existing predictors in future practice of forecasting, and (3) to deal with possible variation of the effect of predictors on coastal sea fog at areas far from where they are identified to be effective in the original design. All of these need to be improved in future studies.

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