

Forecast of Red Tide in the South China Sea by Using the Variation Trend of Hydrological and Meteorological Factors

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Abstract: Many studies point out that weather conditions involving temperature, wind power, monsoon transform, air pressure, sea condition, tide, ocean current, salinity, eutrophic environment and so on are key factors causing Red Tide^[1]. In the red tide high frequency areas of the South China Sea, the eutrophic environment of sea water has already existed, so the key elements such as meteorological and hydrological conditions play an importance role in the occurrence of red tide. The atmospheric circulation maintenance and variation decide whether meteorological phenomena, and hydrological key elements stabilize or change. Moreover, the red tide organisms' breeding from the initial stage to the blooming reproduction stage, until reaching the biological density of the red tide, generally takes 4 - 5 days. In the paper, the red tide examples are analyzed in the past 10 years, and the weather circulation situation and hydro-meteorological key elements of it are counted to find the previous circulation mode and bring out important factors inducing the blooming of red tide. The predicted result in 2003 according to this method was satisfactory.

Keywords: Red tide; meteorological condition; weather circulation

Introduction

Red tide is one of marine catastrophes in our country's inshore waters. For the recent ten years, red tide disasters have taken place frequently on a large scale, as a result of littoral economic development, accelerated process of urbanization and marine pollution. To carry out red tide forecast, prevention and control of red tide is a very urgent mission for effectively mitigating the catastrophic loss resulted from red tide.

Red tide forecast is a difficult scientific subject, and, there are no successful red tide forecast tools available for operational application in the world. It is reported that an expert in US applied the wind direction to forecast the red tide occurrence in a bay, that is to say, red tide is easy to take place when

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southwest wind prevails for a period over the bay. Up to now, there is no red tide forecast tools professionally applied in Japan even though it conducted red tide prevention and study earlier, established a complete monitoring system and made certain progress. What can be done for the occurrence of red tide is only follow-up monitoring, even the monitoring by means of satellite remote sensing is only a follow-up measure. Many researchers at home and abroad are in dire need of the forecast tools of professional operation. The variation trends of hydro-meteorological factors of ten days are applied to forecast whether red tide takes place in a period, which is of a great help for mariculture farmer to take countermeasures in advance. The followings discussion finds out the primary conditions and important factors triggering the red tide.

1 Analysis and choice of forecast factors for red tide

Previous research has pointed out that variation of the hydrological and meteorological factors is an essential inducement for the red tide blooming^[2]. In the littoral waters where red tide occurs frequently, the water quality of South China becomes eutrophic especially in the rivers outlets and mariculture farms. Professor Qi Yuzao has pointed out: “Not all the eutrophic waters are the places in which red tide takes place frequently. Meteorological and hydrological factors, such as wind, current, tide and water temperature” triggering red tide are key factors^[3]. This paper statistically analyzes the hydrological and meteorological factors in the red tide occurring cases in recent more than ten years. As compared with the biological and chemical data observed in recent two years in the monitored waters of red tide, the analysis results show that the water quality is eutrophic, and pH, DO, chlorophyll a, COD, phosphate, nitrite, nitrate, ammonia exist. However, the annual, monthly, ten days’ and five days’ variations of these biological and chemical data are weak. There is no evident distinctness for pH and DO when the data, which were observed with red tide occurrence or without red tide occurrence in the monitored waters of red tide, are compared with each other. As yet, to forecast red tide has not been successful only by means of biological and chemical data (mid-term red tide forecast). The atmospheric circulations, hydrological and meteorological factors, which have an effect on red tide organisms’ reproduction, are of predictability while the biological and chemical factors are not. Therefore, the hydrological and meteorological factors (wind, wave, sea current, SST and sunlight) are dominant factors for the forecast of red tide. The hydrological and meteorological factors, moreover, depend on the weather circulation, which controls and affects a certain waters, and predicting the status variation of weather circulation is a key to forecasting red tide.

2 Choice of weather circulation status model in prophase of red tide blooming (the first 5-7 days before)

The reason why the statistical counting of weather circulation status is conducted in the prophase of red tide blooming, i.e., the first 5 - 7days, is that the culture testing of red tide organisms is carried out mostly at constant temperature, and that the testing course from the prophase, the blooming of red tide

up to reaching the red tide density takes four or five days at lab. In fact, SST in the waters in which red tide occurs varies a little daily as affected by tidal, wave, wind current as well as sunlight. In addition, there are a variety of marine algae and interaction between them, and then the evolution course of red tide organisms needs a longer time, generally five to seven days. Thus, taking five to seven days to statistically count is suitable.

Based on the count and classification of weather circulation in the red tide prophase from the year 1984 to 2001, the similar weather circulation models have been found and the results are very satisfactory. That is, the hydrological and meteorological factors keep under the stable weather circulation situation, lasting four or five days or more. The weather circulation conditions in the prophase of red tide are analyzed and classified to choose one weather circulation, which affects the occurrence of red tide, as a forecast model. And then, the forecast testing is conducted in combination with the hydro-meteorological factors. The selected forecast model and factors are as follows.

2.1 Statistical analysis of weather circulation conditions at the 500 hPa altitude in the prophase of red tide blooming

By statistically counting, it is found that the weather circulation conditions at the 500 hPa altitude in the prophase of red tide (around the first one week) mostly are controlled by the ridge back and trough front of subtropical high, while by a weak high-pressure or isobaric zone in spring and autumn, and by a 500 hPa high-pressure zone in winter. The contour of mid-latitude and high-latitude is found to be straight and there is no long-wave trough affecting the forecasted waters. It is fine, with sufficient sunlight and there is no cold air stroke over the waters under the control of this weather system. The airflow drops down and warms up adiabatically, and then the air temperature goes up rapidly, so does the water temperature. In summer, near the edge of high-pressure zone the southwest airflow from the trough front provides the condition for transporting warm and humid airflow. On the 30th Apr. to the 3rd May in 1990, a red tide event occurred in the waters nearby Changhua River and Lin'gao Bay off northwest Hainan, with an area of 5 000 km², when the southwest airflow coming from the western side of subtropical high had been controlling the waters in the prophase of red tide blooming (as shown in Fig. 1).

In summer, i.e., in Jul., Aug. and Sept., SST is high and sometimes goes beyond 30°C, which is unfavourable for the reproduction red tide organisms even though the waters controlled by a 500 hPa high is calm and sunny.

As yet, in the 500 hPa high-pressure map, in the prophase of red tide (the first 4 - 5 days) there are no sea areas found in the rear end of the thick and large East Asian Trough because on the sea surface, corresponding to the thick and large East Asian Trough, the strong cold air prevails. In such a way, if the waters is dominated by the thick and large East Asian Trough with 500 hPa recently or several days later, the hydrological and meteorological conditions of waters are not suitable for the red tide to take place in aftertime. Otherwise, red tide organisms would die away soon (in 24 hours) if the red tide occurs before the advent of the large East Asian Trough.

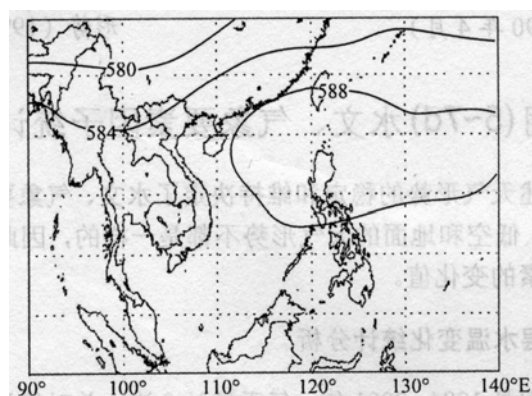


Fig.1 500 hPa weather conditions in favor of red tide occurrence (Apr., 1990)

2.2 Statistical analysis of weather circulation conditions at 850 hPa low altitude in prophase of red tide blooming

The results of analysis based on multi-annual data observed previously (from the year 1984 to 2001) indicate: in spring or autumn the southwest airflow of trough front at the 850 hPa low altitude overwhelms most waters in the prophase of red tide blooming, and the southwest wind velocity is larger (wind velocity amounts to 8 - 12 m/s). Affected by the southwest airflow of trough front, the air temperature over waters goes up, the air pressure lowers relatively and the weather is sweltering. Under the high air temperature condition for a long time, SST rises and keeps for a certain period. All of these are of great advantage to the red tide organisms' growth. The denaturalized high-pressure zone at 850 hPa or the back of high pressure controls the waters in winter (as shown in Fig. 2).

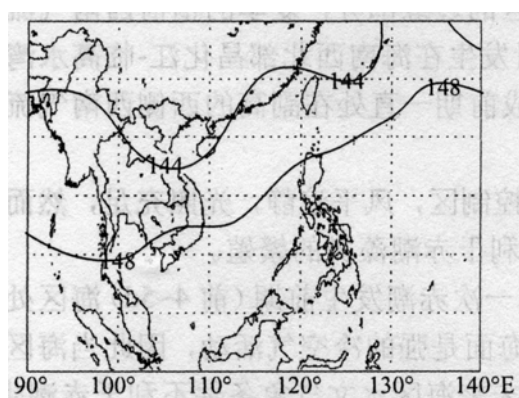


Fig.2 850 hPa weather conditions in favor of red tide occurrence (Apr., 1990)

2.3 Statistical analysis of weather circulation conditions over ground in the prophase of red tide blooming

On the basis of the previous data analysis, in the prophase of red tide blooming the weather situation over ground behaves as follows: frequently there are stationary fronts in spring in the Nanling region, the waters off South China is controlled by the southwest airflow or the southeastern side of the southwest low eddy, with the southwest a wind blowing and wind power of less than force 4. In autumn, the waters are controlled by a weak high or isobaric field while controlled by a denaturalized high or warm high in the prophase of red tide blooming in winter. Thus, in or over the waters there are little waves, poor exchange among water bodies, strong sunlight, high air temperature, which results in the rise of water temperature. In this way, the rise and stability of SST are advantageous to the red tide organisms' growth (Fig. 3 presents an example).

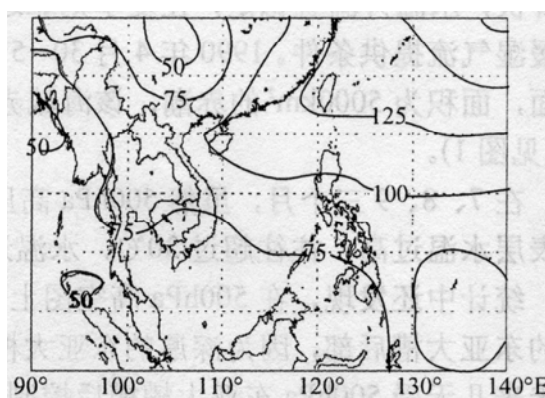


Fig.3 Ground weather circulation conditions in favor of red tide occurrence (Apr., 1990)

3 Statistical analysis of hydrological and meteorological factors in the prophase of red tide blooming (the first 5 - 7 days)

In the prophase of red tide blooming, variation and stability of the hydrological and meteorological elements depends on the stability and maintenance of the above-mentioned weather situation, and the weather is distinct at high, low altitude and ground, thus it is necessary to statistically analyse the variation of hydrological and meteorological factors.

3.1 Statistical analysis of SST variation in the prophase of red tide blooming

The SST counting period is from 1984 to 2001, counting three times every day. These data have been statistically analyzed and the results are as follows (as shown in Table 1).

In the prophase of red tide occurrence, based on the table, SST keeps stable, ranging from 18 to 30 °C (less than 30 °C accounting for 94.0 %). Therefore, the SST range between 18 °C and 30 °C is taken as one of the judging conditions favourable red tide blooming.

In addition, there is no evident SST daily variation found in accordance with the analysis (SST keeps the quasi-constant temperature in the prophase of red tide occurrence^[5]), with a daily range of 0.6 °C on the average. As above, the SST daily average variable less than 1 °C (making up 90 %) is employed as one of the judging conditions favourable for red tide growth (as shown in Fig 4).

The distinct genera of red tide algae adapt themselves to different water temperatures (due to the limited data, no relationship among algae species and water temperature has been exactly and statistically counted as yet).

Tab.1 SST daily variation and wind velocity average (Seven days before red tide occurrence)

No	Blooming time of red tide	Blooming place	Algae genera or species	Cloudage & weather	Daily mean variation of water temperature in the prophase of red tide blooming and average water temperature in the red tide course /°C		Average wind velocity /m·s ⁻¹	Wind direction
1	Jul. 16 - Aug. 3, 1984	Waters near Dangan Islands	<i>Trichodesmium</i> sp	Partly cloudy	0.8	28.9	6.7	SW
2	Jul. 27, 1984	Waters off Leizhou Peninsula	<i>Trichodesmium</i> sp	Cloudy	0.7	30.7	7.7	SSW
3	Feb. 15-17, 1988	Dapeng Bay	<i>Noctiluca scintillans</i>	Light fog	0.2	17.8		
4	May 9-19, 1988	Shenzhen Bay	<i>Dinophyceae</i>	Cloudy	0.9	24.1		
5	Dec. 23-26, 1988	Yantian, Dapeng Bay	<i>Noctiluca scintillans</i>	Cloudy		18.3		
6	2-4 Apr, 1989	Chiwan, Shenzhen	<i>Prorocentrum</i> sp.	Cloudy	0.6	28.8	4.9	ENE
7	Apr. 17-20, 1989	Dapeng Bay	<i>Noctiluca scintillans</i>	Partly cloudy	1.0	21.5	4.3	E
8	Jan. 26-27, 1990	Yantian, Dapeng Bay			0.4	16.7	4.0	NNE
9	Feb. 13-17, 1990	Dapeng Bay	<i>Noctiluca scintillans</i>	Cloudy	0.6	16.7	3.4	ENE
10	Mar. 10-13, 1990	Dapeng Bay	<i>Noctiluca scintillans</i>	Cloudy	0.7	16.3	3.9	E
11	Mar. 18-19, 1990	Dapeng Bay	<i>Noctiluca scintillans</i>	Cloudy	0.9	19.2	4.0	ENE
12	Mar. 20-24, 1990	Dapeng Bay	<i>Noctiluca scintillans</i>	Cloudy	0.7	19.2	4.7	ENE
13	Apr. 1-2, 1990	Yantian, Dapeng Bay		Partly cloudy - Cloudy	0.5	21.4	5.0	SSE-SSW
14	Apr. 7-9, 1990	Shenzhen Bay	<i>Noctiluca scintillans</i>	Cloudy	0.9	21.6	4.9	ENE
15	Apr. 7-10, 1990	Guishan Island	<i>Noctiluca scintillans</i>	Fine	0.4	21.6	5.3	S-ENE
16	Apr. 15-17, 1990	Dapeng Bay	<i>Noctiluca scintillans</i>	Cloudy	0.5	21.1	4.1	E
17	Apr. 18-20, 1990	Dapeng Bay	<i>Noctiluca scintillans</i>	Cloudy	0.4	21.1	4.1	E-NE
18	Apr. 19-20, 1990	Yantian, Dapeng Bay		Cloudy	0.3	21.1	5.4	ENE
19	May. 10-15, 1990	Dapeng Bay	<i>Noctiluca scintillans</i>	Partly cloudy		24.2	3.6	E
20	Jun. 10, 1990	Dapeng Bay	<i>Thalassiosira subtilis</i>	Cloudy	0.6	27.1	4.9	SSW
21	Dec. 5, 1990	Dapeng Bay	<i>Pseudo-nitzschia pungens</i>	Cloudy	0.5	20.8	5.3	NNE
22	Dec. 23, 1990	Dapeng Bay	<i>Pseudo-nitzschia pungens</i>	Partly cloudy	0.2	20.3	3.4	NNE
23	Mar. 1, 1991	Shekou, Shenzhen		Partly cloudy	0.3	17.8	3.9	ENE
24	Mar. 10-13, 1991	Dapeng Bay	<i>Gymnodinium</i> sp.	Partly cloudy	0.5	20.3	4.6	E
25	Mar. 19-21, 1991	Yantian, Dapeng Bay	<i>Phaeocystis pouchetii mican</i>	Cloudy	0.4	21.0	3.9	E
26	Apr. 9, 1991	Dapeng Bay	<i>Noctiluca scintillans</i>	Partly cloudy	0.5	20.6	4.3	ENE
27	Apr. 17-18, 1991	Yantian, Dapeng Bay		Fine	0.8	23.7	6.2	S

**Tab.1 SST daily variation and wind velocity average (Seven days before red tide occurrence)
(continued)**

28	May 5-6, 1991	Yantian, Dapeng Bay	<i>Eonyaulax polygramma</i>	Overcast to cloudy	0.6	25.0	5.9	ENE
29	Jun. 2, 1991	Dapeng Bay	<i>Leptocylindrus danicus</i>	Cloudy	1.0	29.3	4.5	SSW
30	Jul. 6, 1991	Dapeng Bay	<i>Pseudo-nitzschia delicatissima</i>	Cloudy	0.9	28.9	7.3	S
31	Sept. 4, 1991	Dapeng Bay	<i>Pseudo-nitzschia delicatissima</i>	Partly cloudy	1.1	29.5	2.9	ENE
32	Dec. 23-24, 1991	Yantian, Dapeng Bay	<i>Noctiluca scintillans</i>	Partly cloudy	0.5	20.3	3.6	NE
33	Apr. 21-22, 1992	Yantian, Dapeng Bay	<i>Noctiluca scintillans</i>	Cloudy	0.9	20.5	3.8	S
34	Apr. 24, 1992	Yantian, Dapeng Bay	<i>Noctiluca scintillans</i>	Cloudy	0.8	21.3	5.8	S-SSW
35	Apr. 29, 1992	Dapeng Bay	<i>Noctiluca scintillans</i>	Partly cloudy	1.1	23.9	5.1	S
36	May 5, 1992	Dapeng Bay	<i>Noctiluca scintillans</i>	Partly cloudy	1.1	25.7	6.3	SSW
37	Oct. 22, 1992	Dapeng Bay	<i>Thalassionema nitzshoides</i>	Partly cloudy	0.3	25.4	4.2	E
38	Nov. 3, 1992	Dapeng Bay	<i>Rhizosolenia alata f. gracillima</i>	Partly cloudy	1.0	23.8	4.0	ENE
39	Apr. 26-30, 1996	Shekou, Shenzhen	<i>Skeletonema</i> sp.	Cloudy	0.7		4.9	SE
40	Nov. 26, 1997	Zhelinwan, Guangdong	<i>Phaeocystis</i> sp.	Partly cloudy	0.6	21.7	2.9	ENE
41	Dec., 1997	Zhelinwan, Guangdong	<i>Phaeocystis</i> sp.	Partly cloudy	0.5	19.0	4.1	ENE
42	Jan.-Feb., 1998	Qiuanzhou, Shanwei	<i>Phaeocystis pouchetii</i>	Partly cloudy	0.5	16.8	4.0	ENE
43	Mar.-Apr., 1998	The Pearl River Estuary	<i>Gymnodinium mikimotoi</i>	Partly cloudy	0.6	21.1		
44	Apr., 1998	Waters off West Shenzhen	<i>Pyrrophyta, Bacillariophyta</i>	Partly cloudy	0.5	23.9		
45	May 18, 1998	Daya Bay	<i>Pyrrophyta</i>	Cloudy	0.7	28.8		
46	Sept. 10, 1998	Daya Bay	<i>Scippsiella trochoidea</i>	Cloudy	0.5	28.7		
47	Nov. 8-9, 1998	Daya Bay	<i>Mesodinium rubrum</i>	Partly cloudy	0.3	23.1		
48	Mar. 14-15, 1999	Nan'ao, Dapeng Bay	<i>Eonyaulax polygramma</i>	Partly cloudy	0.6	21.1	3.8	ENE
49	Mar. 25-29, 1999	Dapeng Bay		Cloudy	0.4	21.2	4.1	SE
50	May 20-26, 1999	Huizhou, Daya Bay	<i>Peridinium pentagonum</i>	Cloudy	0.9	26.9	4.8	S
51	Aug. 17-20, 2000	Aotou, Huiyang	<i>Scippsiella trochoidea</i>	Partly cloudy	0.9	30.4	3.7	S
52	Sept. 3-6, 2000	Daya Bay	<i>Scippsiella trochoidea</i>	Partly cloudy	0.5	28.4	3.9	S-SE
53	Sept. 3-6, 2000	Dameisha, Xiaomeisha, Shenzhen		Partly cloudy	0.5	28.4	3.9	S-SE
54	Feb. 3-23, 2001	Dapeng Bay	<i>Gymnodinium sanguineum</i>	Cloudy	0.2	18.8	2.6	N
55	Feb. 26 - Mar. 1, 2001	Dachanwan, The Pearl River Estuary		Partly cloudy	0.9	20.2	2.9	S-SW
56	Mar. 5-7, 2001	Yantian, Dapeng Bay	<i>Heterosigma</i> sp.	Cloudy	0.4	19.9	3.4	ENE
57	Mar. 17-25, 2001	Shenzhen Bay	<i>Thalassiosira</i> sp.	Cloudy	0.5	21.8	3.2	ENE
58	Mar. 22-28, 2001	Yantian, Dapeng Bay	<i>Eonyaulax polygramma</i>	Cloudy	0.9	22.7	3.3	SW SE
59	Apr. 18-23, 2001	Xiaomeisha, Shenzhen	<i>Heterosigma</i> sp. & <i>Phaeocystis pouchetii</i>	Cloudy	0.6	22.9	3.1	S-E
60	Apr. 23-28, 2001	Beiguan, Shenzhen	<i>Phaeocystis pouchetii</i>	Cloudy	0.6	23.5	4.0	SE
61	Apr. 28 - May 2, 2001	Dameisha, Xiaomeisha, Shenzhen	<i>Heterosigma</i> sp.	Cloudy	0.6	24.0	3.8	SE
62	Jul. 10-13, 17, 2001	Waters near Hongkong Island, Daya Bay		Partly cloudy	0.5	28.0	6.9	SE
63	Sept. 10-20, 2001	Beiguan, Dongshen, Shenzhen		Partly cloudy	0.6	29.0	3.4	ENE-E
64	Average				0.6		4.6	

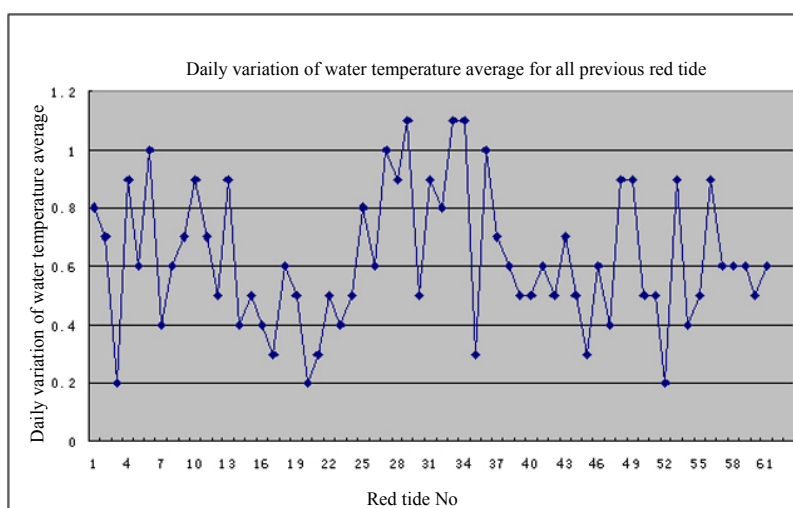


Fig.4 Daily variation curve of SST for 63 red tide events from the year 1984 to 2001

3.2 Statistical analysis of wind direction and velocity in the prophase of red tide blooming

The counting results of wind velocity during red tide occurrence in the past years show that in the prophase of red tide the average daily wind speed amounts to below force 4 (7 m/s); for wind direction, in winter the southwest or south wind blows mostly in the prophase but the wind power is force 3 (5 m/s) when the north or northeast wind prevails, and the wind direction variation is not obvious in summer. Statistical results indicate that there is no red tide event occurring under the gale (force 6 or over) and rough sea conditions, in other words, the red tide event will not soon take place in the waters where the gale overwhelms several days in succession (as shown in Table 1). Thus, the average daily wind speed less than force 4 (7 m/s) serves as one of the judging conditions favourable for the red tide blooming.

3.3 Statistical analysis of wind wave and surge in the prophase of red tide blooming

The condition of wind wave height larger than 1.5 m is disadvantageous to the red tide formation. Because of larger wind wave, the upper and bottom seawaters exchange evidently, and then the daily SST varies greatly and unstably, which is unfavourable for the red tide organisms' reproduction. The statistical data indicate: the wind wave height is mostly below 1.2 m in the prophase of red tide occurrence. For instance, five days before two red tide events, one occurred in the outer waters of the Pearl River Estuary, i.e. Dangan Island (in Jul., 1984) and the other in the waters near Weizhou Island, the wave heights on the average amounting to 1.1 m and 0.8 m respectively. According to the wind speed mentioned in the above table, the wave height can be calculated to be less than 1 m. As a result, the wave height less than 1.2 m is taken as one of the judging conditions favourable for the red tide blooming.

3.4 Sunlight variation analysis in the prophase of red tide blooming

Some studies point out that the sweltering weather, continuous drought and high temperature (not in summer) is an important factor triggering the red tide ^[7]. For example, the following red tide events, one at Zhelinwan of Shantou from Dec., 1997 to Feb., 1998, the other in the waters off Shantou respectively from Nov., 2003 to Jan., 2004 and Nov., 2004, occurred when there were successive drought and enough sunlight.

The statistical analysis of cloudage based on the above-mentioned table indicates that the weather is partly cloudy or cloudy when most red tides occur, that is to say, the sunlight is enough. In different seasons, the sunlight effect on the red tide is different. In summer (Jul. – Sept.), strong sunlight irradiates the sea surface, results in a higher SST (larger than 30 °C) which is disadvantageous to the red tide organisms' growth. The cloudy or overcast weather is in favor of red tide organisms developing. In autumn and winter (only limit to the South China Sea), there are drought and few rainfalls, the weather is fine – partly cloudy, with enough sunlight, and warm SST, all of which is advantageous to the red tide blooming. Sometimes, even it is cloudy or overcast but sweltering, the ambient waters is still suitable for red tide organisms to grow up in weak sunlight. Thus, the long sunlight duration is accounted as one of the judging conditions in favor of the red tide blooming.

3.5 Statistical analysis of sea surface current variation in the prophase of red tide blooming

Based the analysis of sea current and climatic data of the South China coast, in spring and autumn, the southwest wind prevails over the inshore off South China for a long time, easily resulting in a warmer wind-born current by south, and a higher SST in the waters, which is advantageous to the red tide organisms' occurrence and the outbreak of red tide. In winter, the northeast wind overwhelms for a long time with an alongshore cold sea current and surge-born current occurring, and under such circumstances, the red tide is not easy to take place as the waters is disadvantageous to the red tide organisms' reproduction.

3.6 Analysis of salinity variation in the prophase of red tide blooming

Due to the limited data, there are few samples for salinity variation analysis in the waters, in which the red tide occurs. But, in general, the salinity becomes smaller ^[6] in the prophase of red tide while the red tide is not easy to occur in the higher salinity waters (salinity is over 32). Thus, the seawater salinity is considered as one of the judging conditions in favor of the red tide blooming as well.

4 Establishment of forecast tools

Based on the above hydrological and meteorological factors, the forecast map of distinguishing flow is established, and then the forecast model of synoptic picture is configured in combination with the synoptic map category. The duration of future weather advantageous to the red tide occurrence is reckoned to judge whether the waters is in favor of red tide outbreak or not, according to the index values of hydro-meteorological factors.

4.1 Forecast model depending on weather circulation

The weather situation, which is advantageous to the red tide blooming, is accounted as an important judging criterion. The four primary categories are presented as follows.

4.1.1 Southwest monsoon category

In the northern waters of the South China Sea, red tide takes place every season all the year around (as shown in Fig 5), but most occur in the end of winter, spring and early summer (from Feb. to Jun.). When the weather is fair and warms up with enough sunlight after rainstorm^[6], the red tide is easy to take place.

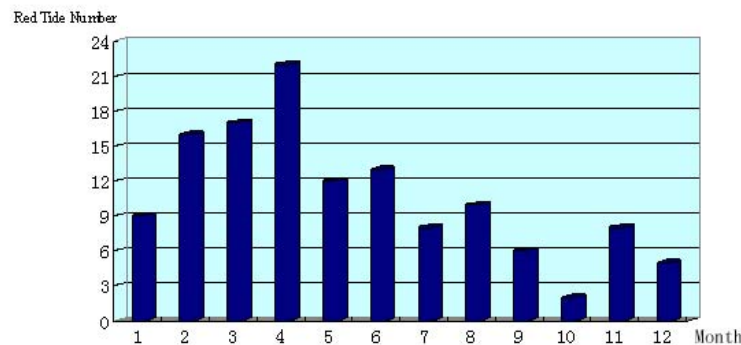


Fig.5 Monthly distribution of red tides from 1980 to 2004 in the waters of the South China Sea

4.1.2 Southwest inverse trough category

Spring and early summer see this category frequently, now and then there are inverse troughs found in the western part and the east of the southwestern part of South China. At this time, the southwest airflow, coming from the southern part of the inverse trough, dominates along the South China coast. The warm and humid airflow heads for the South China coast, which is under the control of the southwest airflow from the northwest side of the 500 hPa sub-tropical high ridge.

4.1.3 Linnan stationary front category

Most of this category is seen in the early spring. The stationary front is situated near the Nanlin Mountain, and the warm and humid airflow on the south side of frontal surface overwhelms over the South China coast. At high altitude, the 500 hPa sub-tropical high frequently controls the South China coast; at low altitude, i.e. 850 hPa, the shear line prevails near the Nanlin Mountain. The southwest race is obvious at low altitude (the figure is omitted), the corresponding sea surface is the southwest wind but the wind power is less than force 4.

4.1.4 Category of cold high denaturalization at low altitude

In the end of spring, early summer and autumn, the cold high denaturalization is constantly detained

in the South China coast. The waters, dominated by the denaturalized high, see drought and little precipitation, calm sea and enough sunlight. These conditions are advantageous to the going up of seawater temperature, but the seawater temperature has little daily variation.

The appearance and maintenance of above four categories of weather circulation are one of the essential and natural environment conditions supporting red tide organisms' reproduction. What is more, only when the occurrence of any kind of categories maintains for 5 days or more, can red tide organisms bloom. Thus, to exactly predict the weather situation one week in the future is a key to the forecast of red tide occurring conditions.

4.2 Forecast and judgement model establishment of red tide occurring conditions

The above-mentioned hydro-meteorological factors, such as wind, wave, seawater temperature, salinity, are digitized.

By means of the successful digital weather forecast, the future variation trend of wind, wave, seawater temperature, and salinity are analyzed to distinguish if these factors arrive at or approach the forecast values. The variation trend of sea surface current and sunlight are analyzed, and then the future weekly status (or a period of ten days) is analyzed to see whether not only anyone of the above weather circulation categories will take place but also this circulation will keep five days and more in succession. The waters is forecasted to be advantageous to the red tide occurrence, if the waters meets with the above conditions, otherwise it is disadvantageous to the red tide occurrence. The discriminatory flow chart of red tide forecast is shown as follows.

4.2.1 Forecast flow chart of red tide (as shown in Fig. 6)

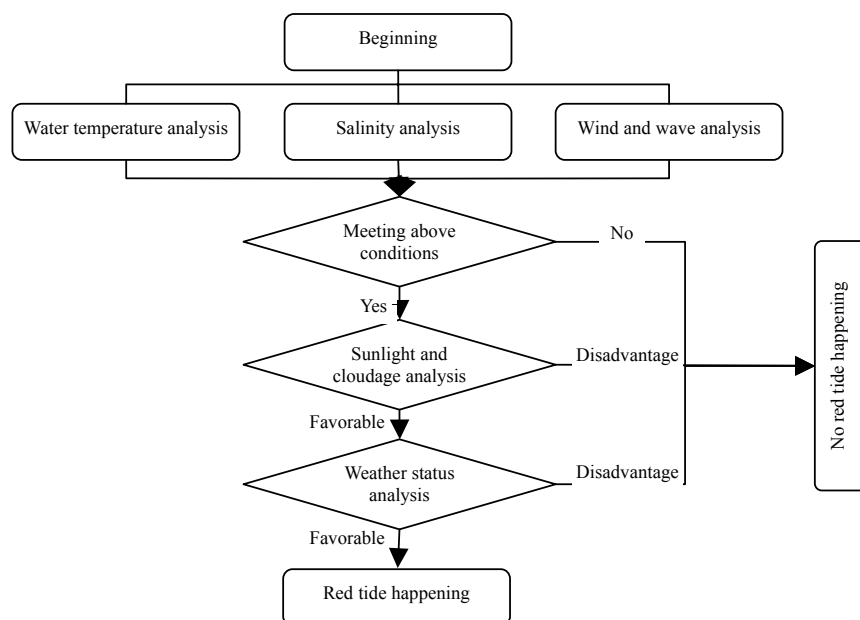


Fig.6 Flow chart of red tide forecast

5 Experiment and validation of forecast tools

By means of various tools, the forecast of red tide occurrence conditions was conducted from 2003 to 2004, and the result was satisfactory. The successful examples were the red tide conditions contrast between the forecast and what was actually happening in the year 2003. In the South China Sea, the eleven red tide events occurring in 2003 (fourteen events in total) were forecasted more precisely. As the observational and seasonal conditions are limited, the data obtained in the Hong Kong observatory network of red tide have been used to validate and supplement the forecast and observation.

Successful examples of the red tide forecast in 2003:

a) In the middle ten days of February, it was forecasted that abnormal phenomena in the waters would appear (A few red tides would take place) near the Pearl River Estuary; in fact, on Feb. 8, a red tide event occurred in the waters off Naozhou Island. The forecast delayed two or three days as compared with the fact.

b) In the last ten days of February, the waters off Guangxi was predicted to present abnormal phenomena; actually, on Feb. 24, the Zhuhai Marine Observatory reported a red tide with a large sea area occurring in the waters off the western side of Leizhou Peninsula. The forecast was precise.

c) In the first ten days of April, the marine environmental conditions were forecasted to be advantageous to the red tide algae growing from the Pearl River Estuary to West Guangdong coast; what was actually happening on Apr. 2, 7 and 8 was reported by the Hong Kong observatory network of red tide: red tide events were found in the Shenshui Bay, Baisha Bay of Xigong and Qianshui Bay individually. The prediction was right.

d) It was forecasted that there would be a red tide happening on the western side of the Pearl River Estuary in the last ten days of April; in fact, the Monitoring Center of Guangdong Marine and Fishery Administration reported on April 27 in the waters near Guishan and Jiuzhou Island off Zhuhai, a red tide event was found with a sea area of 350 km²; on Apr. 29 the Zhuhai Marine Observatory reported a red tide with a large sea area occurring in the waters surrounding Wanshan Islands. The forecast was exact.

e) In the last ten days of May, the marine environmental conditions were predicted to be in favor of red tide algae reproduction from the Pearl River Estuary to East Guangdong coast; the fact was on May 25 a red tide event was discovered at the mouth of Jieshi Bay (22°7'N, 115°7'E); on May 27 another red tide event with a sea area of 15 km² was reported to happen from Shekou to Shenzhen Bay.

f) It was predicted, in the first ten days of Jun, a red tide would take place from the Pearl River Estuary to Shanwei coast; as a matter of fact, on Jun. 9 and 10 in the waters of Shenzhen Bay, Dongjiaotou Fishing Port, Zhaoshang Port, Mawan Port of SCT and Santudi of Shekou Port a red tide with a sea area of 41 km² was discovered. The prediction was right.

g) In the middle ten days of June, a red tide was forecasted to happen from the Pearl River Estuary to Daya Bay; in fact, on June 13 and 14 a red tide event with an area of 15 km² occurred in the waters

adjacent to Meishawan, Dameisha, Xiaomeisha, Yantian Fishing Port and Yantian Port. The forecast was precise.

h) It was forecasted, in the last ten days of June, a red tide would occur from the Pearl River Estuary to Shanwei coast; in fact, a red tide with a sea area of 20 km² took place on June 23-25 in the waters of Houhaiwan, Dongjiaotou Fishing Port, Zhaoshang Port and Santudi of Shekou Port. The prediction was right.

i) In the first ten days of August, the marine environmental conditions were predicted to be advantageous to the red tide organisms' blooming; what was actually happening was that a red tide was discovered in the waters of Daya Bay, Dongsheng mariculture farm and fishery administrative wharf of Aotou port. The forecast was exact.

j) In the middle ten days of August, the marine ambient from the Pearl River Estuary to East Guangdong coast was forecasted to be in favor of red tide algae growing; as a matter of fact, on Aug. 6-13 a red tide took place in the Dongsheng mariculture farm and fishery administrative wharf of Aotou. The prediction was right.

k) In the end of the first ten days of September, it was predicted that a small red tide would happen in some waters from the Pearl River Estuary to East Guangdong coast; in fact, on Sept. 8 a red tide occurred and faded away in the waters of Shatoujiao. Besides, on Sept. 10 a red tide event was discovered in an aquaculture farm of Shawan of Hong Kong. The red tide did not vanish on Sept. 11 as yet, and the forecast was precise.

According to the above exact forecast analysis of 11 red tide events, the forecast tools are feasible and accord with the judgment criterion of mid-range weather forecast specified by the State Meteorological Administration, though the predicted area is large and the duration is long. This is a great progress in the red tide forecast.

7 Conclusions and discussion

a) The weather circulation status is stable and lasts a long period of time in the prophase of red tide blooming.

b) The SST keeps stable with a daily variation of less than 1 °C in the prophase of red tide outbreak.

c) The wind speed is small and daily is less than force 4 on the average in the prophase of red tide blooming.

d) The weather is fine, or partly cloudy, with enough sunlight, or sweltering in the prophase of red tide outbreak.

The weather circulation status, hydrological and meteorological factors are chosen to forecast the red tide happening. The red tide sets used in the analysis occur in recent 20 years. It indicates as well that the variation of hydro-meteorological factors plays an important role in triggering the red tide occurrence. The statistical analysis shows the red tide will never take place under gale and rough sea conditions. The red tide will not happen in lower water temperature (less than 16 °C) and higher water

temperature (higher than 30°C).

SST stability (quasi-normal temperature) and maintenance depend on the weather circulation's control of and impact on a certain region. Up to now, the 15-day atmospheric circulation prediction and 7-day hydro-meteorological factors prediction in future can be figured out by means of marine meteorological numerical forecast. Thus, the numerical model is a key to the mid-range forecast of red tides.

Red tide forecast is still a rising subject. At present, red tide monitoring and prediction are separated, and the definitions of red tide are not uniform. Red tide monitoring and prediction should be combined just like meteorology. Nowadays, at home and abroad there are no successful and professional forecast tools for red tide and there are a variety of different professional opinions on it. "In terms of hydro-meteorology, red tide happening can be predicted." The above examples show up clearly: making use of hydro-meteorological factors to forecast red tide happening is valid and accords with the judgment criterion of mid-range weather forecast. Hydrology and meteorology are full-grown disciplines, the weather of one week in future can be predicted by means of numerical forecast tools, and the biological and chemical factors are not full-grown to be used in the mid-range forecast of red tide. Different views and opinions are always allowed on the discussion of rising disciplines. The experts in different professions can understand each other, particularly those whose specialty are not prediction, should know the status of the development of marine meteorological forecast red tide prediction and forecast tools at home and abroad, as well as red tide forecast veracity. Only by comparing can one distinguish.

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利用水文、气象要素因子的变化趋势预测南海区赤潮的发生

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摘 要: 有些文献指出: “赤潮发生起因因种而异, 但大体上气候气象条件诸如温度、风力、风向, 季风转换、气压等; 海况、潮汐、流等以及海水的理化特征, 如盐度、营养元素等, 这些皆会成为某种赤潮爆发的因子或诱导因素^[1]”。根据赤潮监控区监测资料分析: 在南海赤潮多发区, 海水富营养化条件已经具备, 因此气象、水文要素条件就成为赤潮爆发的重要启动因子, 而天气环流的维持与变化决定了气象、水文要素因子的稳定与变化, 再根据赤潮生物培养试验, 从初期繁殖到后期的爆发性繁殖, 直至达到赤潮生物密度, 这一过程一般都需要 4 ~ 5 d 的时间。针对这一现象, 通过对近 10 a 的赤潮发生个例进行统计分析, 统计其生成前期的天气环流形势和水文气象要素, 分析出赤潮生成前期的环流模式和筛选出诱发赤潮爆发的重要因子, 并依此来作为预报赤潮生成的方法, 依照此方法对 2003 年的赤潮进行预报, 其效果是另人满意的。

关键词: 赤潮; 气象条件; 天气环流