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OBSERVATION AND ANALYSIS OF SEA SURFACE WIND OVER THE QIONGZHOU STRAIT

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Abstract: The spatial variation and diurnal fluctuation of sea surface wind over the Qiongzhou Strait were described using verified datasets from automatic weather stations on board a ferry, buoys, and on the coast. Results are as follows: (1) On average, sea surface wind speed is 3–4 m/s larger over the Qiongzhou Strait than in the coastal area. Sea surface wind speeds of 8.0 m/s or above (on Beaufort scale five) in the coastal area are associated with speeds 5–6 m/s greater over the surface of the Qiongzhou Strait. (2) Gust coefficients for the Qiongzhou Strait decrease along with increasing wind speeds. When coastal wind speed is less than scale five, the average gust coefficient over the sea surface is between 1.4 and 1.5; when wind speed is equal to scale five or above, the average gust coefficient is about 1.35. (3) In autumn and winter, the diurnal differences of average wind speed and wind consistency over the strait are less than those in the coastal area; when wind speed is 10.8 m/s (scale six) or above, the diurnal difference of average wind speed decreases while wind consistency increases for both the strait and the coast.

Key words: Qiongzhou Strait; sea surface wind; observational analysis; statistical characteristics

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1 INTRODUCTION

Since the end of the 20th century, the observation of sea surface wind fields has aroused significant concern from meteorologists. A main reason for this is that sea surface wind stress is an important link in air-sea interactions, as well as a key factor in driving ocean models and improving model quality[1, 2]. As conventional observation does not help in acquiring sea surface wind field data, remote-sensing data—an effective means of making up for a lack of conventional observations—have been widely used in the monitoring and research of sea surface wind fields while assimilated remote-sensing data have contributed much to improved model capabilities[3-7]. Studies have shown that remote-sensing data, now widely used for the vast ocean surface, are not applicable for surfaces near the coast. Based on an analysis of the statistical characteristics of vector wind data from QuikSCAT scatterometers, Liu et al.[8] revealed better consistence of wind direction between data determined with QuikSCAT over the vast ocean surface and those observed on islands; the QuikSCAT wind direction is not consistent with that observed on the coast. Such contrast is attributed to satellite seams: land disturbs the backward scattering signals of the scatterometer within a detecting range of 50 km off the coast, bringing a series of difficulties to the meteorological and oceanographic study of the coastal areas[9].

As a water channel flanked by Hainan Island and Guangdong Province, the Qiongzhou Strait is one of the three main straits in China. It is 80 km long in the east-west direction and 29.5 km wide on average in the north-south direction, with the narrowest distance at only 18 km. Keeping marine navigation safe through the Qiongzhou Strait is important for the economic

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development of both the provinces of Guangdong and Hainan. As measurements of sea surface wind are difficult to obtain via conventional means, and those retrieved from remote-sensing are not applicable in the Qiongzhou Strait, which is too narrow for the purpose, the forecasting of strong winds across the strait has been bewildering local forecasters. In theory, differences in wind speed should exist between the sea surface of the strait and the coasts due to the difference in underlying roughness between them. How large is the difference in wind speed? Is there always "wind enhancement through straits" for any given strait? These are the scientific issues urgently calling for solutions in weather service and verification of transportation engineering projects across the strait. For coastal bands and terrain-dependent wind fields of straits, a large amount of field observational experiments and mesoscale numerical simulations have been conducted both at home and abroad, and the boundary layer physics, dynamics, and thermodynamics of these wind fields have been studied in detail[10-12]. Conclusions based on these works are all constrained by local observational experiments, lacking universality. In view of the scientific and socio-economic implication of the knowledge about the sea surface wind field across the Qiongzhou Strait, the meteorological departments of Hainan Province deployed in July 2007 their first weather buoy at the middle of the strait and a number of effective observations were made. Unfortunately, the buoy stopped working in March 2008 due to equipment failure. Then in August 2008, the Hainan Meteorological Science Institute installed a ship-borne automatic weather station (AWS) on board a ferry conducting shuttle service between the coasts for an observational experiment on the sea surface wind field of the strait. Having verified the relevant data for reliability, this study used wind measurements acquired from the AWS on board the buoy and the ferry during the experiment to probe into the distribution of wind fields across the Qiongzhou Strait, provide technical advice for the pre-construction verification of a cross-strait engineering project, and work toward solving the potential crisis in weather support for shipping transportation across the strait.

2 DATA AND METHODS

2.1 *Account of the data*

The data used in this study include wind measurements recorded at the ship-borne AWS (Type ZQZ-C), the buoy (Type WXT510), and a coastal AWS (Type ZQZ). The ship-borne AWS was installed on board the railway ferry "YueHai-1" going across the strait at fixed time intervals. Sailing 10 times daily, the ferry travels 5 times from south to north and 5 times from north to south, with departures from port at 0150, 0430, 0700, 0930, 1130, 1400, 1630, 1840, 2100, 2320 Beijing Standard Time (BST). Taking about one hour for a one-way trip, the ferry moves basically at the middle of the strait. Observations were transmitted starting on October 4, 2008 after installation, adjustment, and testing by comparative observation. Due to the breakdown of a GPS module in the device, no observations were obtained from December 19, 2008 to April 4, 2009. Observations were resumed on April 5, 2009. The time series of ship-borne observations used in this study covers two periods, one from October 4 to December 18, 2008 and the other from April 5 to June 3, 2009. The elements measured include the direction and speed of 2-min. and 10-min. mean winds, transient wind, 1-hour max. wind, and 1-hour extreme wind, with a temporal resolution of 1 min. The buoy station was mounted above sea surface about 5 km off the southern coast of the strait and meteorological sensors were about 3 m above sea level. The time series of the buoy-station data used in this study spans August 2007 to February 2008. Elements measured comprise the direction and speed of 10-min. mean wind and 1-hour max. wind, with a temporal resolution of 10 min. The coast station was an AWS at Nangang, which was 2 m above sea level and about 40 m from the ship-borne AWS in stationary state. Elements measured include 2-min. and 10-min. mean winds, transient wind, 1-hour max. wind, and 1-hour extreme wind, with a temporal resolution of 1 min. Refer to Fig. 1 for the geographic location of the observation stations.

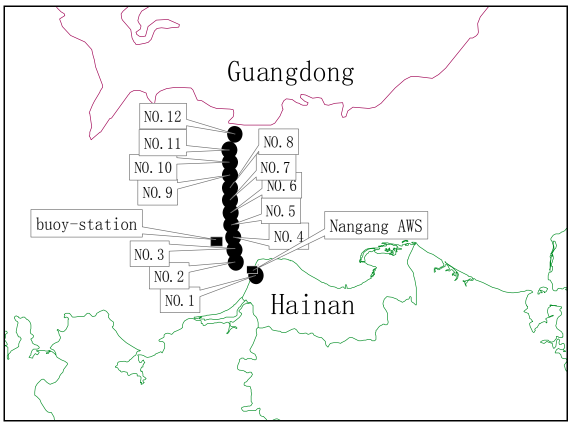

Fig. 1. Schematic diagram of the geographical location of the ship-borne station, buoy station, and AWS at Nangang

2.2 *Principles of wind measurement by ship-borne AWS and methods of data computation*

During sailing, a ship produces a wind, known as ship wind, which blows at a direction opposite to that of the ship's movement and at a speed that is the same as that of the ship. It is a transport speed vector produced by the ship speed vector (Fig. 2). The composite of true wind and ship wind is called composite wind. With the stem taken as the reference direction, the composite wind is observed by wind sensors during ship navigation. To obtain the data of true wind, the composite wind measured by the sensors need to be processed by the methods introduced in [13].

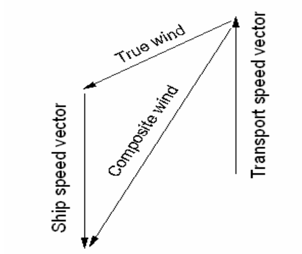

Fig. 2. Schematic diagram of vectors of true wind, ship wind, and composite wind

3 CONTRASTIVE MEASUREMENTS AND VERIFICATION

3.1 *Contrastive analysis of wind speed and direction from ship-borne station*

Figure 3 presents a point map of 10-min. mean wind speed and direction for identical time of measurement for the ship-borne AWS and onshore AWS at Nangang. The diagonal line indicates equal wind speeds between the two measuring sites. There is divergence among the wind measurements from both the AWSs, which concentrate around the isopleths of wind speed and direction.

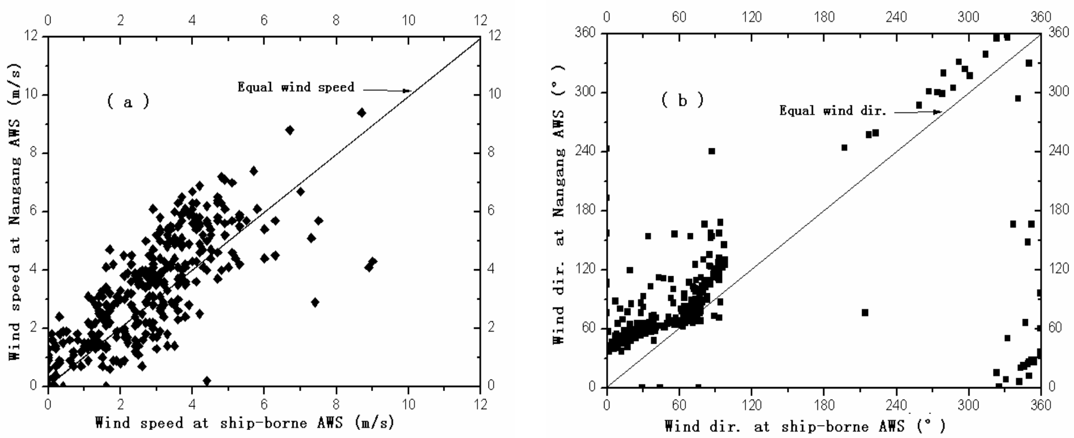

Fig. 3. Wind speed (a) and wind direction (b) compared between ship-borne AWS and onshore AWS at Nangan

To learn more about how one of the two sets of wind measurements deviates from the other, Table 1 presents their statistical characteristics in contrast to the 2-min. mean wind, 10-min. mean wind, 1-hour max. wind, 1-hour extreme wind, and transient wind. Statistical differences in wind speed are little among the 2-min. mean wind, 10-min. mean wind, and transient wind, with their deviations of mean wind at 0.4, -0.6, and -0.7 m/s, respectively; mean absolute deviations of 1.3, 1.2, and 1.6 m/s, respectively; and root mean square of 1.6, 1.5, and 2.1 m/s, respectively. Mean deviations of wind direction are the averages of the differences in wind direction angles between measurements from the ship-borne AWS of the same observation time from all study samples and those from the onshore AWS at Nangang. During calculation, the absolute value of the deviation was constrained to be ≤180°. For instance, if the observed wind direction is 350° by the ship-borne AWS and 10° by the Nangang AWS (i.e., distributing on both sides of the N direction), then the deviation of wind direction is set at -20° instead of 340°. As a result, positive values indicate counterclockwise deviations of the wind direction at the ship-borne AWS with respect to that at the onshore AWS while negative values denote clockwise deviations. Similar methods were used to compute the consistency of wind direction in the next section. As shown in the statistics, the 10-min. mean wind has the least deviation of direction, with a mean deviation of 27°, and mean absolute deviation and root mean square of 33° and 45°, respectively. The 1-hour max. wind and 1-hour extreme wind have slightly larger speed deviations, with mean absolute deviations of 2.6 and 3.2 m/s, respectively. In general, the deviations of wind direction are larger than those of wind speed. The largest deviation was found in the 1-hour extreme wind, with a mean absolute deviation of 43° and root mean square of 69°. Analysis showed that observations from the ship-borne AWS are within a range of differences of accuracy allowable in research and are thus reliable for use.

3.2 *Contrastive observation and analysis of wind speed and direction from buoy station*

Contrastive observation of the quality of wind measurements from the buoy station was conducted from an automatic anemometer installed at the same spot on the southern shore of the strait. In this study, the rate of consistency in wind speed and direction was calculated following the technical specifications required by the National Climate Center for assessment of AWS measurements:

$$\text{rate of consistency (\%)} = \frac{\text{incidents of contrastive differences falling into range of consistency}}{\text{total number of effective incidents}} \times 100\% \qquad (1)$$

Table 1. Mean deviations, root mean square, and absolute deviations of wind speed/direction observed at the ship-borne and Nangang AWS

Parameter	Speed deviations (m/s)	Root mean square of speed (m/s)	Mean absolute deviation of speed (m/s)	Direction deviations(°)	Root mean square of direction (°)	Mean absolute deviation of direction (°)	Sample size
2-min. mean	0.4	1.6	1.3	-26	45	33	4 410
10-min. mean	-0.6	1.5	1.2	-27	46	33	4 410
1-hour max.	1.6	3.3	2.6	-4	69	53	4 410
1-hour extreme	2.3	4.9	3.2	-23	68	57	4 410
Transient	-0.7	2.1	1.6	-24	57	43	4 410

Analysis of a two-month contrastive measurement for the same time of measurement showed that the rate of consistency are 93.6% and 93.2%, respectively, for the direction and speed of the 10-min. mean wind and 93.0% and 72.5%, respectively, for those of the transient wind. Except for poor consistency in the transient wind speed, other indicators all meet the requirement set for the observation and the measurements are reliable.

4 SPATIAL VARIATIONS OF WIND SPEED ACROSS QIONGZHOU STRAIT

4.1 *Mean wind speed*

To understand the spatial variations of mean wind speed from both the shores of the strait to the sea surface off the coast under normal circumstances, Fig. 4 presents the mean deviations of wind speed between the 12 sampling sites and the AWS at Nangang at an identical time of measurement. Regardless of the mean wind or transient wind, sea surface wind speed tends to vary consistently over the strait. Over the sea surface 3–4 km from the coasts of the strait (or at the observation points of No.1–No.4 and No.12–No.9), wind speed increases along with the distance from the shore; it varies little at the middle of the strait (about 6 km from the coasts or an area between the observation points of No.4–No.9) and is about 3.4 m/s larger than that on the coast. Wind speed is the greatest at an area 6–7 km from the northern coast.

4.2 *Effect of environmental wind speed on strait surface wind speed*

To investigate the effect of environmental wind speed on the spatial variations of wind speed across the strait surface, the environmental wind field (represented by the AWS at Nangang) was divided into a sub-scale three (v < 3.4 m/s), scale three (3.4–5.4 m/s), scale four (5.5 m/s ≤ v ≤ 7.9 m/s), and scale five and above (v > 7.9 m/s). The four scales of wind speed were used to calculate the mean deviations of wind speed between the coastal point of observation and the individual points at sea. The curves of deviations (Fig. 5a) showed that with the environmental wind below scale five, the wind speed deviations are generally consistent between the coast and sea surface of the strait, with the mean wind speed at the middle of the strait being 3–3.5 m/s larger than that on the coast, differing little from normal conditions. However, with the wind speed increasing to scale five on the coasts, the deviations tend to accelerate, reaching 6 m/s and more. Further study is needed for the mechanisms.

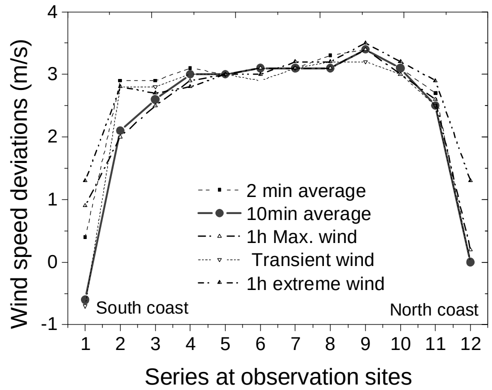

Fig. 4. Mean deviations of wind speed for the ship-borne AWS and onshore AWS at Nangang at an identical time of observation

Due to turbulence disturbance in the atmosphere, mean wind speed was superimposed to wind speed fluctuation to produce gusts. A gust coefficient is a parameter that describes the relative intensity of gusts and expresses the ratio of maximum mean wind speed to 10-min. mean wind speed for a short time interval[14]. This can be shown by the following equation.

$$k = \frac{v_g}{\bar{v}} \tag{2}$$

where v_g is the speed of gusts (m s^{-1}), $\bar{v}$ is the mean wind speed (m s^{-1}), and k is the coefficient of gusts.

For a duration of 3 s, the maximum transient wind speed is more than 1.2 times the 10-min. mean wind speed; for durations of 0.5 and 0.1 s, the former can be as large as 1.5–3 times the latter[14] according to relevant studies. Charged with such high levels of energy, transient wind speed often poses enormous threats to marine operation and construction. To determine the spatial variation of gusts over the strait, the maximum transient wind speed (averaged over 3 s) and 10-min. mean maximum wind speed were used to calculate the mean coefficients of gusts on the four scales of environmental wind speed for the 12 points of observation (Fig. 5b). To avoid singularly large computed values associated with undesirably small denominators, samples with 10-min. mean maximum wind speed of <0.5 m/s are eliminated. The gust coefficient is remarkably smaller at the middle of the strait, but it tends to decrease, at an area 3–4 km offshore, with the increasing distance from the shore. Meanwhile, the gust coefficient decreases along with the increase of wind speed; the mean gust coefficient over the strait surface is between 1.4–1.5 when the coastal wind speed is smaller than scale five and it is 1.34 when the wind speed is larger than or equal to scale five.

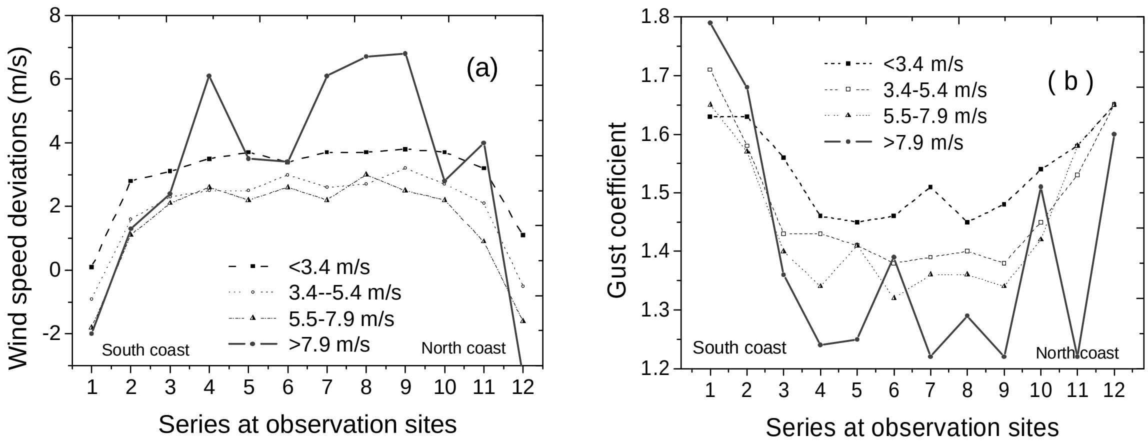

Fig. 5. Mean deviations of wind speed and gust coefficients for the strait sea surface and the coasts with different environmental wind speeds

4.3 Contrastive analysis of *measurements* from the buoy and ship-borne AWSs

To avoid errors of measurements arising from using only one type of means of observation, the methods described above were used to calculate the mean deviations of wind speed between the strait surface measured by the buoy AWS and those measured simultaneously by the onshore AWS at Nangang. Table 2 presents the results of wind speed deviations between the buoy AWS and the ship-borne AWS at site No.4, which is nearest to the buoy. They differ by only 0.2 m/s for the 10-min. mean wind speed and by 1 m/s for the maximum wind speed. Overall, wind speed at the buoy AWS is slightly larger than that at the ship-borne AWS.

Table 2. Mean deviations of wind speed for AWSs at the buoy- and ferry- stations

Mode of measurement	Maximum wind speed (m/s)	10-min. mean wind speed (m/s)
Buoy	4.4	3.7
Ferry	3.4	3.5

4.4 *Estimation of sea surface wind speed over the strait*

In view of the absence of conventional data of sea surface wind speed, an estimate based on onshore AWSs is one of the feasible ways of forecasting sea surface wind speed. With the consistency of measured 10-min. mean wind generally verified between the AWSs on board the buoy and ferry, and with the buoy-measured data representing the wind speed of the strait sea surface and the Nangang AWS-recorded wind data representing that of the coast, existing data were used to conduct linear, logarithmic, power-function, and exponential-function fitting. Linear fitting was the best (refer to Table 3 for the fitting equation) and agreed with the results of the study of Du et al.[14]. The fitting results were verified with those from the ship-borne AWS. Results showed that the wind speed computed with the fitting equation is at a ratio of 1.13:1 with that observed by the ship-borne AWS.

Table 3. The fitting equation and verification results

Fitting equation	R	Computed value /observed wind
Y=1.39X+2.33	0.83	1.13

5 SPATIAL VARIATIONS OF WIND SPEED ACROSS QIONGZHOU STRAIT

Due to the limited length of available buoy data (August 2007 to February 2008), the analysis below stands for the diurnal variation of the strait wind field in fall and winter only.

5.1 Diurnal variation of mean wind speed

Figure 6a presents the curves of diurnal variations of mean wind speed over the strait and on the coast against the background of average conditions and strong winds. If there is no strong wind at sea, wind speed is greater during the day than at night over both the strait and the coast; maximum wind speed occurs at 1700 BST over the strait surface and at 1500 BST on the coast. The diurnal difference of wind speed is larger on the coast (2.1 m/s) than over the strait surface (1.6 m/s). If there is strong wind at sea, the maximum wind speed occurs at 2200 BST over the strait surface and at 1300 BST on the coast. The diurnal difference of wind speed tends to decrease with the increase of wind speed, being 1.3 m/s and 1.4 m/s, respectively.

5.2 Wind consistency

According to Stewart et al.[15], wind consistency is defined as the ratio of the wind's vector mean to its arithmetic mean:

$$C=\frac{\bar{V}}{v}=\frac{\left[\left(\frac{1}{N}\sum_{i=1}^{N}U_i\right)^2+\left(\frac{1}{N}\sum_{i=1}^{N}v_i\right)^2\right]^{1/2}}{\frac{1}{N}\sum_{i=1}^{N}\left(u_i^2+v_i^2\right)^{1/2}} \quad (3)$$

where N is the number of total sample. If both wind directions are consistent at a particular point of time, the rate of consistency is 1; if they are opposite, it is 0. Wind consistency is one of the parameters that describe the turbulence of wind.

Figure 6b shows the diurnal variation of wind consistency with and without the background of strong winds following the algorithms above. The wind consistency is shown to be much smaller over the strait surface than on the coast. In the course of a day, wind consistency is the highest over the strait surface at 1000 BST, while the highest wind consistency on the coast was at 1500 BST. With the presence of strong wind, strait-surface wind consistency is much higher and the difference in wind consistency between the strait surface and the coast is reduced.

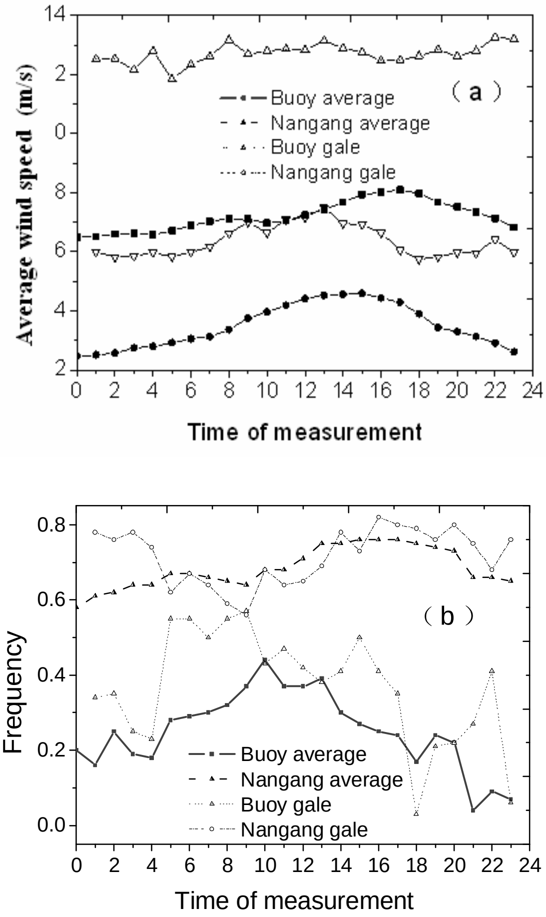

Fig. 6. Diurnal variation and wind consistency of wind speed over the strait surface and on the coast a. Diurnal variation of wind speed; b. Diurnal variation of wind consistency

Such phenomenon occurs when the sea surface wind field is subject to factors that depend on the presence of strong winds. With strong winds, the strait wind field is mainly under the dynamic forcing of the barometric pressure gradient. Affected by large-scale circulation, wind is mainly of advection, with small vertical mixing, high wind consistency, and small diurnal variation. When the environmental wind is weak, the strait wind field is mainly affected by the thermodynamic forcing from the mesoscale terrain; the circulation of land-sea breeze results in large diurnal differences of the wind field and strong land-sea breeze circulation on the coast, giving rise to high wind consistency and large wind speed. Land-sea breezes are relatively weak at the middle of the strait, leading to low wind consistency. In the meantime, land-sea contrasts in thermal capacity results in higher nocturnal temperatures and stronger turbulence over the ocean than over the land. It also partly explains why the diurnal difference of wind speed is smaller and wind consistency is weaker at sea than over land.

5 SUMMARY AND CONCLUSIONS

(1) Two types of wind measurements, one by a ship-borne AWS and another by a buoy AWS, were studied with the understanding that the wind field above the Qiongzhou Strait is distributed with the following characteristics. On average, wind speed is 3–4 m/s faster over the surface of the strait than on the coast. With coastal wind speed at scale five (⩾ 8.0 m/s), wind speed is 5–6 m/s larger over the strait surface than on the coast. At 3–4 km from both coasts, wind speed increases along with the increase of the distance off the coasts; the gust coefficient increases along with the decrease of the distance off the coasts. At 6 km from the coast (the middle of the strait), wind speed and gust coefficients do not vary much. Over the surface of the strait, gust coefficients decrease along with the increase of wind speed. When coastal wind speed is smaller than scale five, average gust wind coefficients are between 1.4 and 1.5; when it is larger than or equal to scale five, average gust wind coefficients are around 1.35.

(2) In fall and winter, both the diurnal difference of mean wind speed and the wind consistency are smaller over the strait surface than on the coast. When strong winds (⩾ 10.8 m/s, scale six) occur over the strait, the diurnal differences of wind speed decrease while wind consistency increases between the strait surface and the coast. This shows that there are different factors that exert force on the strait wind field with different weather situations. With a strong wind background, dynamic forcing from barometric gradients mainly control the wind field over the strait surface; under the conditions of large-scale circulation, wind consistency is high and diurnal variation is small. However, with weak environmental wind, the strait wind field is mainly subject to thermal forcing from the mesoscale terrain. Moreover, land-sea breeze circulation results in large diurnal variation of the wind field, strong land-sea breeze regimes on the coast, and high wind consistency on the one hand, and weak land-sea breeze systems at the middle of the strait and low wind consistency on the other.

(3) Due to the relatively short time series of the data collected and the limited size of strong wind sample, some deviations may exist in the strait wind field of statistical strong wind weather background. To determine more accurately how strong wind is distributed temporally and spatially over the strait, intensive marine observation is still a priority. Many scientific issues related to strong winds over sea surface, such as the seasonal and interdecadal variations of the wind field, and terrain effect and its associated mechanisms in strong wind weather, cannot be revealed until more observational data are accumulated or numerical simulation is conducted.

REFERENCES:

[1] CARDONE V J, GREENWOOD J G. On Trends in Historical Marine Data [J]. J. Climate, 1990, (3): 113-127.
[2] BUSALACCHI A J, O' BRIEN J J. Interannual variability fo the equatorial Pacific in the 1960s [J]. J. Geophys. Res., 1986, 10: 901-907.
[3] DA SILVA A,YOUNG C, LEVITUS S. Atlas of Surface Marine Data 1994, 1: Algorithms and Procedures. NOAA Atlas NESDIS 6 [R]. Washington D.C.: U.S. Government Printing Office, 1994: 83.
[4] HELLERMAN S, ROSENSTEIN M. Normal monthly windstress over the world ocean with error estimates [J]. J. Phys. Oceanogr., 1983, 13: 1 093-1 104.
[5] HAMMONO, D L, MENELLA R A, ALSH E J. Short pulse radar used to measure sea surface wind speed and SWH [J]. IEEE J. Ocean. Eng. OE-2: 61-67.
[6] COX C, MUNK W. Statistics of the sea surface derived from Sun glitter. [J]. J. Mar. Res. 1954, 13: 198-227.
[7] BROWN G S, STANLEY H R, ROY N A. The wind speed measurement capability of spaceborne radar altimetry [J]. IEEE J. Ocean. Eng., 1981, 6(2): 59-63.
[8] LIU Chun-xia, HE Xi-cheng. The analysis on the statistical character of QuickSCAT scatterometer winds and strong wind frequency using remote sensor data from QuickSCAT [J]. J. Trop. Meteor., 2003, 19(Suppl): 107-117.
[9] ISOGUCHI O, KAWAMURA H. Coastal Wind Jets Flowing into Tsushima and Effect on Wind-Wave Development [J]. J. Atmos. Sci., 2007, 64(1): 564-578.
[10] LACKMANN G M, OVERLAND J E. Atomspheric structure and momentum balance during a gap-wind event in Shelikof Strait, Alaska [J]. Mon. Wea. Rev. 1989, 117: 1 817-1 833.
[11] XU Jia-liang, MU Hai-zhen. Numerical simulation and analysis of offshore wind field features in Shanghai under the influence of typhoon [J]. J. Trop. Meteor., 2009, 25(3): 281-286.
[12] HUANG Ji-zhang, FAN Shao-jia, SONG Li-li, et al. A case study of the characteristics of strong wind near the ocean surface during a strong cold air process in Bohe, Guangdong [J]. J. Trop. Meteor., 2009, 25(5): 635-640.
[13] Jiangsu Province Radio Scientific Research Institute Co. Ltd. ZQZ-C Ship-Borne Automatic Weather Station System Solutions [M]. Nanjing: Jiangsu People's Printing House, 2006: 6-7.
[14] DU Yao-dong, SONG Li-li, MAO Hui-qin, et al. Wind speed observation and design wind speed calculation for cross-channel project over Qiongzhou Strait [J]. Acta Sci. Nat. Univ. Sunyatseni. 2005, 44(2): 98-101.
[15] STEWART J Q, WHITEMAN C D, et al. A climatological study of thermally driven wind systems of the U.S. Intermountain West [J]. Bull. Amer. Meteor. Soc., 83: 699-708.

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