Spatial-Temporal Analysis of Sea States for Sailing Activities in Dapeng Bay National Scenic Area, Taiwan

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Abstract

Sailing is one of the most weather-exposed sports. Categories of sea state were defined through literature review. The observations from data buoys were used to derive the sea state. Then it was used to evaluate the appropriate timing and zoning for sailing activities. Some missing observations of the wave were considered highly related with bad weather; multiple regression models combined with linear interpolation were used to supplement the missing data. From the imputed complete data set, sea conditions were derived hourly. Generally, only 2.3% of hourly data reached hazardous sea states in Dapeng Bay National Scenic Area. Half of those hazardous hours occurred during typhoon warning periods. This implied typhoons were the major cause of risky sea. However, only 23.8% of the hours were classified as hazardous during the typhoon warning period. Despite wind conditions in summer are more suitable for sailing, hazardous sea states occur more frequently from June to September also. Considering both weather conditions and sea states, we believed May was the best month for having a long distance regatta. The Dapeng Bay (DB) area is a better site for sailing activities than Little Liuqiu (LL) because of its calmer sea state and windier weather.

Keywords: sea state analysis, sailing activity, missing data imputation, data buoy

Introduction

Sailing is one of the most weather-exposed sports; it is susceptible to maritime weather conditions. Sailboat racing in the first Olympic Games was canceled because of severe weather. It is necessary to recognize the local weather conditions and sea states before hosting a regatta. A national regatta is held each year in the Dapeng Bay (DB) National Scenic Area, which is known as an international tourism and leisure zone in Taiwan. A round-trip race from DB to the nearby island of Little Liuqiu (LL) is hosted each year (Figure 1). This is the most popular and longest distance regatta in Taiwan. To acknowledge and provide meteorological and oceanic circumstances before and during the game, two data buoys were placed in the racing sites to collect real-time hourly data including wind speed, wind direction, significant wave height (SWH), wave period, air temperature, sea surface temperature, and barometric pressure. The meteorological records from the buoys were examined by researchers (Wu, Chuang, & Wu, 2012) to determine when is the best time of year to hold a regatta in this area. The appropriate period or better months were projected from a statistical perspective. The relationship between waves and other meteorological factors observed from the data buoys was reviewed to describe the general sea conditions in this area, and to determine the proper season for sailing activities.

Method

Definition of sea state

The International Sailing Federation categories different levels of wind conditions to set the race policy for Olympic games. They include lowest and highest wind speed, the wind shifting angel. Plenty of researches focus on wind condition for sailing activities management. The real time wind direction and speed data in Shenzhen was analyzed by Wang, Zhang, and Li (2010) to determined the race area of the 26th summer Universiade in Shenzhen. A lot of effort put on the wind forecast for Olympic Games (Dunsmuir, Spark, Kim, & Chen, 2003; Powell & Rinard, 1998; Spark & Connor, 2004). The wind condition is not the only consideration for a race, sea states are also involved. The policy states, "Races will not be started in excess of 25 knots. … For the 49er and Star classes this upper limit is approximately 2 to 5 knots less in heavy seas and/or gusty winds." (International Sailing Federation, 2011). Powell and Rinard (1998) provided marine forecast for the 1996 Centennial Olympic Games. Except wind condition, their study also involved current and wave forecast. Unfortunately, only the monitoring of SWH was mentioned. A clear definition of "heavy sea" does not exist. The following statements typically describe heavy seas. "The vessel rolls or pitches excessively while underway in heavy seas." "The boat can easily be rolled by the action of breaking waves in heavy seas." And "Heavy seas could cause the boat to be knocked down." These statements imply that a heavy sea is a sea state that can cause a boat to be unstable. Toffoli, Lefevre, Bitner-Gregersen, and Monbaliu (2005) discussed the warning criteria by analyzing the ship accident database. They investigated ship accidents with factors, such as SWH, wave steepness, and crossing seas, and they provided recommendation criteria accordingly. Although the criteria vary for different boat types, boat length to wave length is the first factor that should be considered. The average wave period in DB is approximately 4.7 s; the corresponding wave length is longer than 20 m, significantly longer than most sail boats. Experienced mariners believe hazardous conditions exist when height (ft) and period (sec) are approximately equal (Lovegrove, 2003). Niclasen, Simonsen, and Magnusson (2010) also suggested combining the wave height and steepness as a safety criterion, particularly for smaller vessels. The U.S. National Weather Service (NWS) typically issue advisories for small vessels when specified criteria are met. One of the criteria for small craft advisories use steepness and SWH for guidance

(Lovegrove, 2003). The first step of this advisory is selecting the steepness category according to the following rules (see Table 1).

By combining steepness with SWH, whether to send an advisory is decided from the information in Table 2.

Table 1 Definition of the sea steepness level

$Val = e^{-3.3\ln(f_p)}$	here the f_p is the peak frequency
$SWH > \frac{Val}{250}$ very steep	
$SWH > \frac{Val}{500}$ steep	
$SWH > \frac{Val}{1000}$ normal	

We determined the sea state by using the hourly observed historical data from the data buoys using the criteria from Table 2. In addition, a regatta event, particularly for a long-distance race, typically lasts between 3 and 5 hr. The racing and the supporting boats may spread across the racing route during this period. It is risky to face continuously changing sea states. An aggregated daily hazard is defined. A suitable day for a long-distance race is judged by "at least seven consecutive hours of non-hazardous sea state between 8 AM to 6 PM."

Missing data supplement

In researchers' previous study (Wu et al., 2012), it is found that missing observations of wind most likely occurred during light wind conditions because the wind speed was too low to be verified by the QC/QA procedures. In this study, the researchers found barometric pressures in those records with missing data of wave are generally lower than those wave data were completely observed (Figure 2). Low air pressure most likely occurred with higher waves. If we ignore those observations with missing wave data, we may underestimate the sea conditions. Linear interpolation is the easiest method to impute missing values into time series data. However, certain long-interval consecutive missing data are replaced with a simple upward or declining trend (Little & Rubin, 2002). A correlation analysis has shown that the observations from DB and LL buoys are highly correlated. Less than 20% of wave observations were missing simultaneously in both buoys. Regression models from existing data can be used to predict approximately 80% of the missing values. SWHs, and PWPs from both buoys were the 4 dependent variables. Four regression models were fitted. We substituted missing data by using regression prediction as first priority, and used liner interpolation for the remaining data.

Findings

After exploring multiple relationships within variables on both buoys, we chose SWHs and PWPs observed from the other buoy, air pressure and gusting-wind speed were taken from the local buoy. They are used as multiple predictors for SWH. SWHs explain the majority of the variations in the regression model. The resulting positive regression coefficient of gusting-wind speed represents wind sea generated by local gusts. Lower air pressure that causes higher wave is also reflected in the resulting negative coefficient (Table 3). Two regression models for predicting SWH on DB and LL show the same goodness of fit with $R^2 = 0.87$.

The regression imputation for PWPs is more difficult than the model of SWHs. PWP varied significantly when SWH is low, which causes poor fit in the regression model. Because we knew that the steepness was not used for investigation of hazardous seas (Table 2), we built the PWP model on the observations where SWH larger than 5 ft were used instead of including the whole data set. The resulting R^2 of the PWP model improved from 0.47 to 0.73 in DB, and R^2 increased from 0.36 to 0.65 in LL. The regression prediction of PWPs is used to substitute for the missing PWPs when SWH is greater than 5 ft; the linear interpolation method is applied to the remaining data.

After substituting the missing wave data, we explored the overall wave climate. Unlike wind conditions which change rapidly within a day, the SWH pattern is relatively stable over the day. The major differences in SWHs are caused by different seasons (Figure 3). SWH in LL is greater than DB in both scale and variation. This is because LL is further away from the coast. SWH is significantly higher from June to September in both buoys. This is probably because of typhoons occurring more frequently during this season, and the lack-of-shadow from the waves came from SW direction.

From the classified sea states, we found that the criteria we used in this study (Table 2) coincide with the sea state categories by experienced mariners' rule. However, when PWPs are small, mariners' criteria are stricter than ours when PWP is high (Figure 4). Obviously, LL has more hazardous sea state than DB.

The frequency analysis shows 3.5% of the hours in LL are considered hazardous; however, only 1.2% of the hours in DB are dangerous. The overall percentage is 3.9% when either one of the buoys data were considered hazardous. We further investigated the relationship between typhoons and hazardous seas. The rate of hazard sea increases to 32% and 17% for LL and DB, respectively, in the typhoon warning period. Although typhoons are a major cause of heavy seas, the percentage of hazardous sea is less than expected. When discarding the typhoon warning period, 2.1% and 0.4% of the sea times were considered hazardous in LL and DB, respectively.

From a daily perspective, only 3.8% of days are considered hazardous. There are 14 and 41 hazardous days in DB and LL, respectively, based on a 2-years period of data. A total of 31 of the 55 days of hazard were during typhoon warning periods. Half of the hazard days (20 days) in LL were not during a typhoon (Table 4). The most hazardous day occurred between June and September. The sea state was calm (0% of hazardous day) from December to March in both areas (Figure 5).

Conclusion

It may mislead the conclusion if ignoring the missing data when the sea state is derived from the data buoys' observations. Multiple regression models can be used as implementing methods for those missing data. The regression analysis also shows that both typhoons and gusting wind can cause hazardous sea states. Sea conditions may worsen when gusty wind increases.

In general, DB National Scenic Area is safe for sailing activities according to the statistical perspective of sea conditions. Most hazardous seas occur in the summer, particularly during typhoon warning periods. Researchers' previous study has shown that the wind conditions in summer are more suitable for sailing activities in this area. However, it is unwise to plan a regatta during the typhoon season, which runs from June to September. Base on both weather conditions and sea states, May appears to be the best month for holding a long-distance regatta. The DB area is more suitable to conducting sailing activities because of its relative calmer sea condition. Only 4 days in 2 years' observation data were at high risk level excluding typhoon warning periods; there are still more than 70% of the days were not hazardous during the period when typhoon warnings were issued.

The sea state is quite safe from December to March, even though these days were not considered as most ideal time for sailing activity due to lack of wind (Wu et al., 2012). However, the observed area is the warmest marine recreation area in Taiwan. Winter is still a perfect season for kayaking, fishing and diving.

Suggestion

First, typhoons occur in Taiwan every summer. Although the sea state is relatively dangerous, a further investigation of the path of typhoons and sea states will free the coastal area where marine activities are prohibited during typhoon warning periods. Second, we investigated metrological and sea state data separately in two studies. However, maximum waves and maximum winds seldom occurred simultaneously. The join distribution of wind and waves should be considered simultaneously, then “crossing sea” situations described by Toffoli et al. (2005) can also be evaluated. Finally, the minimum sea surface temperature is 23 ^{o}C, which is warm enough for marine recreation. Less winds cause poor sailing conditions in winter. However, together with the generally flat sea, it may be interesting to kayak or fish from December to March.

Acknowledgments

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Tables and Figures

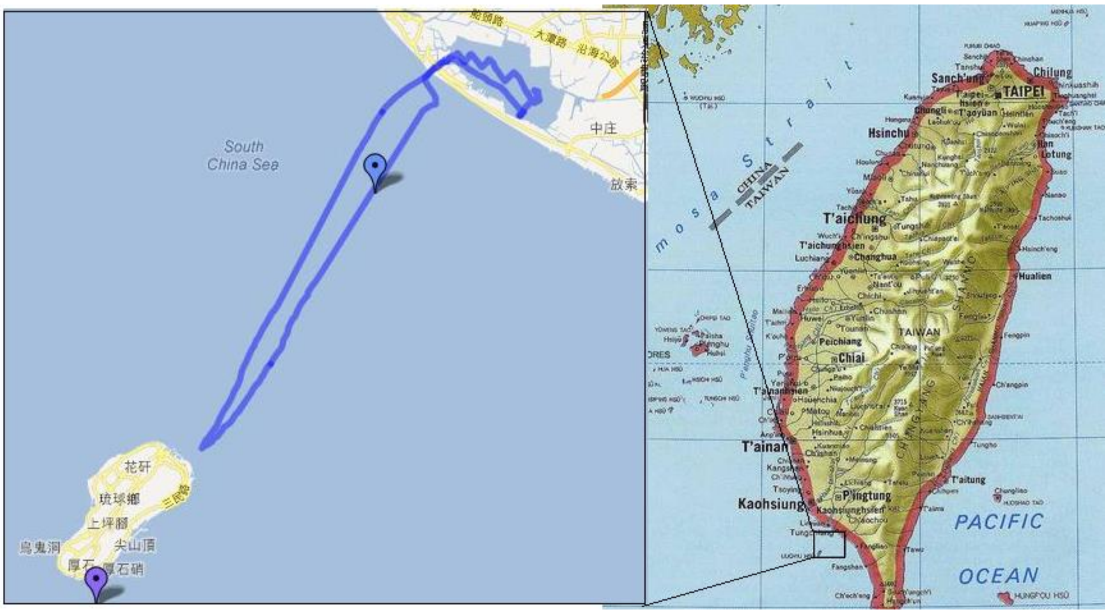

Figure 1 the area of study

The line (left) shows the route of the long distance race and the two blue marks are the location of data buoys which gathering the data of this study.

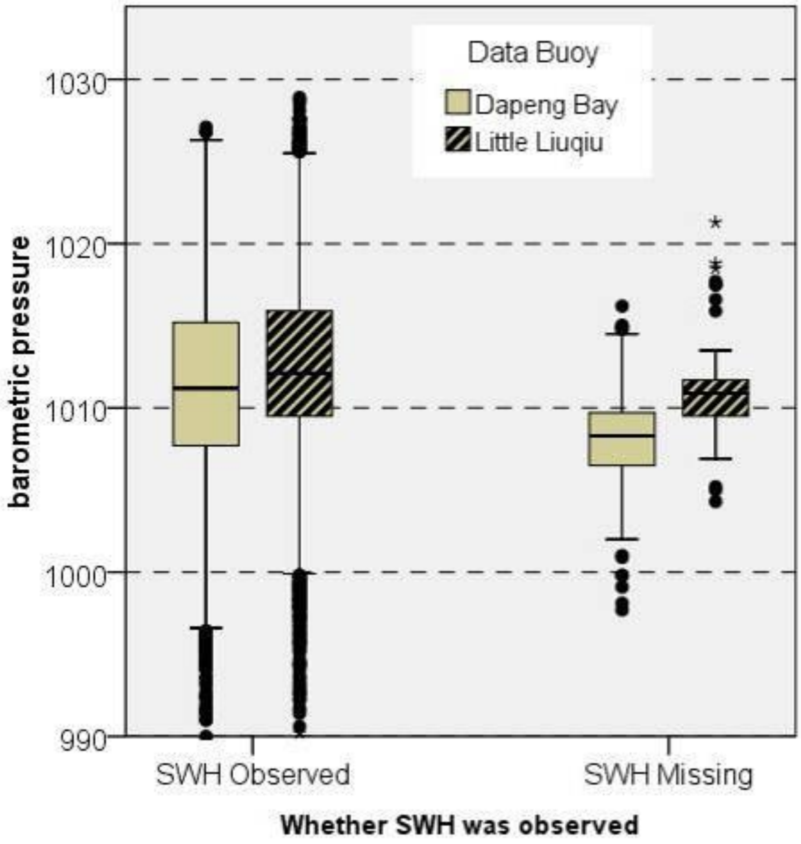

Figure 2 Box plot of air pressure whether wave was observed

The barometric pressure is lower when wave data is missing.

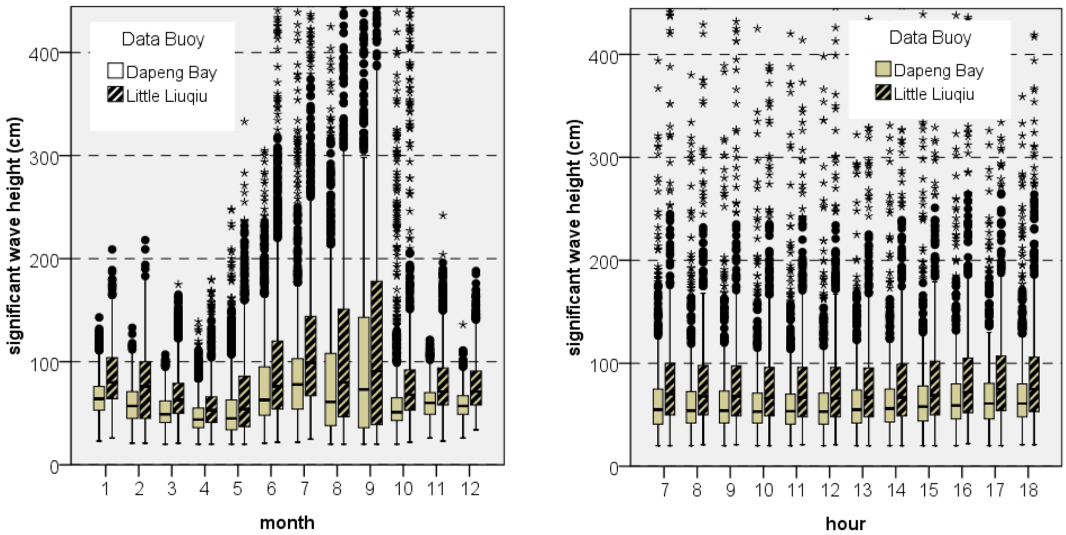

Figure 3 Box Plots of SWH

The monthly (left) and the hourly (right) patterns of SWH

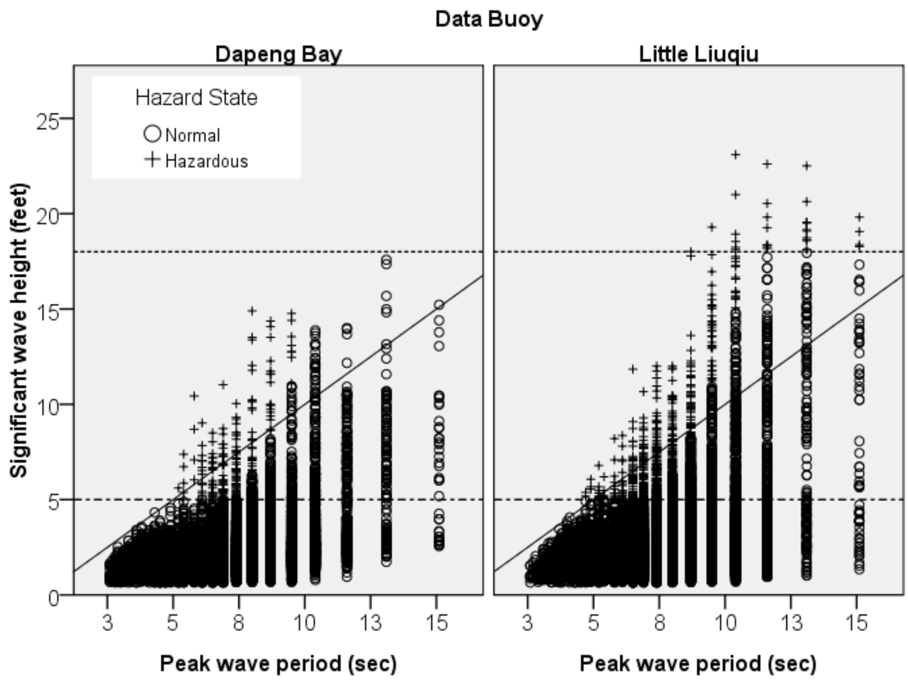

Figure 4 Scatter plots of PWP and SWH in DB and LL

The two horizontal reference lines are SWHs used to classify sea state from (Table 2);

Points above the oblique line are considered unsafe by experience mariner.

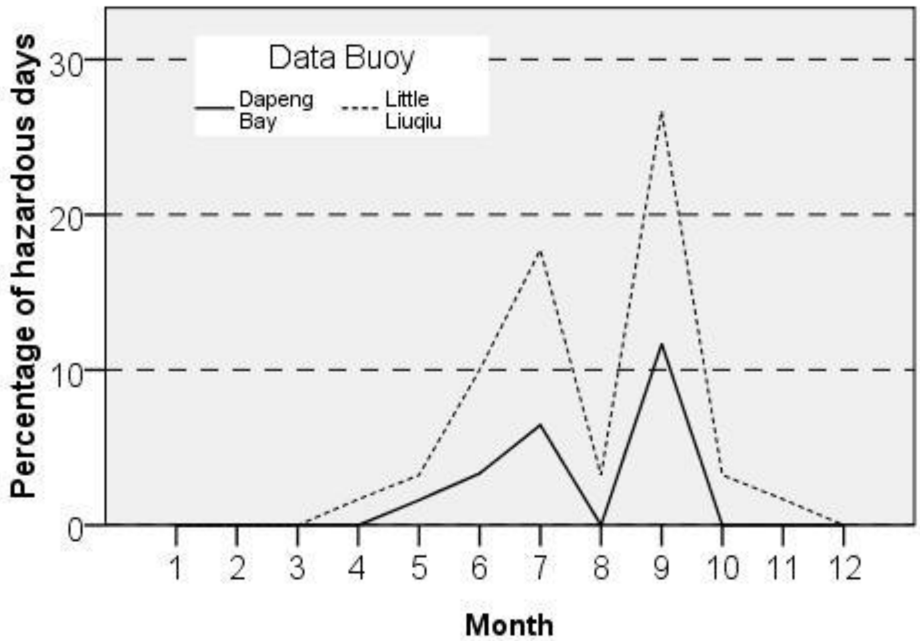

Figure 5 Percentage of hazardous day by month

Sea state is heavier during the summer time

Table 2 Hazardous criteria for small craft advisory

SWH	Steepness	Advisory
SWH < 5feet	NA	nonhazardous
$5 \leq$ SWH < 18 feet	Steep or very steep	hazardous
$18 \leq$ SWH	NA	hazardous

Steepness should be considered when SWH is between 5 and 18 ft for judgment of hazardous seas.

Table 3 Result of multiple regression with SWH in DB as dependent variable

Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	378.529	24.461		15.475	.000
	SWH_LiuChu	.588	.003	.851	230.755	.000
	avg_gust_DaPon	1.856	.054	.113	34.116	.000
	air pressure_DaPon	-.372	.024	-.047	-15.361	.000
	peak period_LiuChu	.520	.068	.025	7.668	.000

Table 4 Cross-table of hazard days versus typhoon warning days

Hazardous day vs. Typhoon warning day Cross tabulation

Data buoy			Typhoon warning day?		
			no warning	warning	Total
DB	Hazardous day?	hazardous	4	10	14
		non hazardous	691	26	717
LL	Hazardous day?	hazardous	20	21	41
		non hazardous	675	15	690