A statistical approach considering ocean current effects in wave scatter diagrams for maritime safety

*Wataru Fujimoto[1], Tsutomu Fukui[1], Rei Miratsu[1], Tingyao Zhu[1]

1. Nippon Kaiji Kyokai

Existing studies have pointed out that strong ocean currents, such as the Agulhas Current, may increase wave heights (Ardhuin et al., 2017; Quilfen et al., 2018). Some studies ran wave models with the Agulhas Current and found that the significant wave height increased by several tens of percent compared to the case without the current (Ponce de León & Guedes Soares, 2021; Rautenbach et al., 2020). As many merchant ships navigate coastal area of the Cape of Good Hope where the Agulhas Current flows, the wave-current interaction is an important issue for maritime safety (Lavrenov, 1998).
The International Association of Classification Society (IACS) provides a so-called "Standard Wave Data" in the IACS Recommendation No. 34 (IACS, 2001) for estimating extreme design wave loads at a probability level of approximately 10^{-8} regarding merchant ships carrying goods at sea (Table 1). This "Standard Wave Data" is a wave scatter diagram which is a histogram of significant wave heights and wave periods based on visual observations of waves by ships since 1949 (Hogben et al., 1986). Here, the North Atlantic Ocean, which is considered as the most severe seas in the world, was chosen. On the other hand, sophisticated wave models have been developed nowadays, it is possible to aggregate the wave scatter diagram from wave hindcast data. Also, the actual shipping routes can be reflected to the wave scatter diagrams. Then, ocean currents should be considered for the wave scatter diagram where the ocean current is strong as the significant wave heights may be increased by current mentioned above. However, due to influence of small-scale eddies on wave heights (Ardhuin et al., 2017), it is still difficult to verify wave models including ocean currents. The wave model calculations including ocean currents remain at the research level. Operational wave hindcast data do not include ocean currents (Barnes & Rautenbach, 2020), and there should be some errors caused by ocean currents in the data. For example, we compared ERA5 (Hersbach et al., 2020) and satellite-observed significant wave heights (Ribal & Young, 2019) for six years from 2015 to 2020. Figure 1 shows the mean and standard deviation of the difference in the significant wave height in each 0.5-degree grid. The mean and the standard deviation correspond to the bias and the uncertainty of the significant wave heights between the hindcast and satellite data. In fact, Figure 1 indicates that the bias and uncertainty were larger in the area where the Agulhas Current, the Kuroshio Current, and the Gulf Stream.
This study proposes a statistical approach to modify the wave scatter diagram including the ocean current effects. Here, a predicted value and a truth of wave parameters are denoted as X and Y, respectively. The wave scatter diagram obtained from the wave model without ocean current corresponds to the probability distribution p(X) of the predicted value X. Also, we assume that the conditional probability distribution of the predicted value X and the truth Y, i.e., the error distribution p(Y|X) is obtained. From Bayes' theorem, the probability distribution of the truth, p(Y), can be evaluated as the marginal distribution. Since it is impossible to know the truth exactly, we will regard the observed value as the truth. For example, p(X) can be estimated using ERA5, while the error distribution of wave height p(Y|X) can be estimated using ERA5 and the satellite data (Ribal & Young (2019)). By estimating the distribution of wave period errors and the correlation between wave height and wave period errors, we will attempt to analyze wave buoy data in the near future.

Keywords: Wave-Current Interaction, Ocean Wave, Design Condition

Table 1. “Standard Wave Data” specified in the IACS Recommendation No. 34 (IACS, 2001) is shown. This table indicates probability of sea-states in the North Atlantic and derived from BMT’s Global Wave Statistics (Hogben et al., 1986).

Hs (Significant Wave Height) [m]	Tz (Zero-up Crossing Wave Period) [sec]																		
	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5	16.5	17.5	18.5	SUM
0.5	0	0	1.3	133.7	865.6	1186	634.2	186.3	36.9	5.6	0.7	0.1	0	0	0	0	0	0	3050
1.5	0	0	0	29.3	986	4976	7738	5569.7	2375.7	703.5	160.7	30.5	5.1	0.8	0.1	0	0	0	22575
2.5	0	0	0	2.2	197.5	2158.8	6230	7449.5	4860.4	2066	644.5	160.2	33.7	6.3	1.1	0.2	0	0	23810
3.5	0	0	0	0.2	34.9	695.5	3226.5	5675	5099.1	2838	1114.1	337.7	84.3	18.2	3.5	0.6	0.1	0	19128
4.5	0	0	0	0	6	196.1	1354.3	3288.5	3857.5	2685.5	1275.2	455.1	130.9	31.9	6.9	1.3	0.2	0	13289
5.5	0	0	0	0	1	51	498.4	1602.9	2372.7	2008.3	1126	463.6	150.9	41	9.7	2.1	0.4	0.1	8328
6.5	0	0	0	0	0.2	12.6	167	690.3	1257.9	1268.6	825.9	386.8	140.8	42.2	10.9	2.5	0.5	0.1	4806
7.5	0	0	0	0	0	3	52.1	270.1	594.4	703.2	524.9	276.7	111.7	36.7	10.2	2.5	0.6	0.1	2586
8.5	0	0	0	0	0	0.7	15.4	97.9	255.9	350.6	296.9	174.6	77.6	27.7	8.4	2.2	0.5	0.1	1309
9.5	0	0	0	0	0	0.2	4.3	33.2	101.9	159.9	152.2	99.2	48.3	18.7	6.1	1.7	0.4	0.1	626
10.5	0	0	0	0	0	0	1.2	10.7	37.9	67.5	71.7	51.5	27.3	11.4	4	1.2	0.3	0.1	285
11.5	0	0	0	0	0	0	0.3	3.3	13.3	26.6	31.4	24.7	14.2	6.4	2.4	0.7	0.2	0.1	124
12.5	0	0	0	0	0	0	0.1	1	4.4	9.9	12.8	11	6.8	3.3	1.3	0.4	0.1	0	51
13.5	0	0	0	0	0	0	0	0.3	1.4	3.5	5	4.6	3.1	1.6	0.7	0.2	0.1	0	21
14.5	0	0	0	0	0	0	0	0.1	0.4	1.2	1.8	1.8	1.3	0.7	0.3	0.1	0	0	8
15.5	0	0	0	0	0	0	0	0	0.1	0.4	0.6	0.7	0.5	0.3	0.1	0.1	0	0	3
16.5	0	0	0	0	0	0	0	0	0	0.1	0.2	0.2	0.2	0.1	0.1	0	0	0	1
SUM:	0	0	1	165	2091	9280	19922	24879	20870	12898	6245	2479	837	247	66	16	3	1	100000

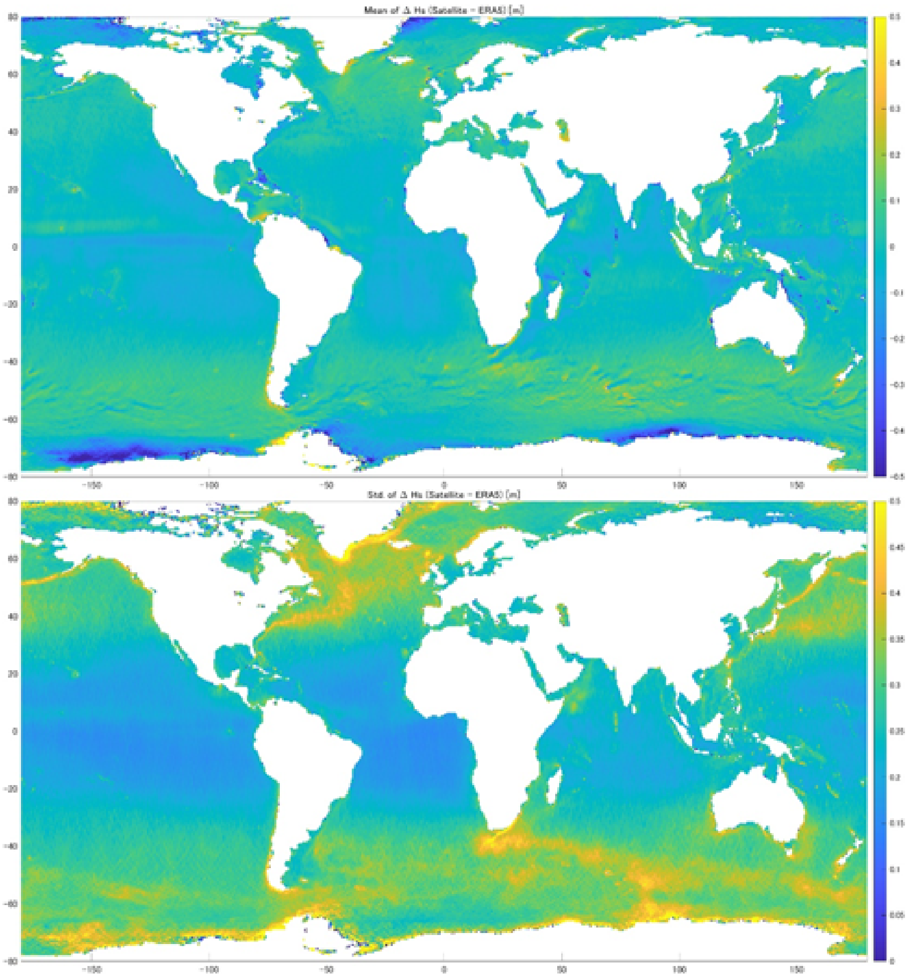

Figure 1. ERA5 and satellite observation (Ribal & Young 2019) are compared. The mean (upper) and standard deviation (lower) of the difference in the significant wave height in each 0.5-degree grid are shown.