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Some Statistical Properties of Residual Sea Level along the Coast of Vietnam

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Abstract. This paper outlines some statistical properties of residual sea level (RSL) at six representative tidal stations located along the coast of Vietnam. It was found that the positive RSL varied on average between 9.82 and 19.96cm and the negative RSL varied on average between -16.62 and -9.02cm. The maximum positive RSL varied on average between 102.8 and 265.5cm with the maximum negative RSL varied on average between -250.4 and -66.4cm. It is seen that the biggest positive RSL ere appeared in the summer months and the biggest negative RSL ere appeared in the winter months. The cumulative frequency of RSL less than 50 cm occurred between 95 and 99% of the times while the frequency of RSL higher than 100 cm accounted for between 0.01 and 0.2%. It also was found that the cumulative frequency of duration of RSL less than 24 hours occurred between 90 and 99% while the frequency of duration longer than 72 hours was only in the order of 0.1 and 1%.

Keywords: The coast of Vietnam, residual sea level, residual water, surge, cumulative frequency.

1. Introduction

The RSL is the component of water level not attributable to astronomical effects. It is computed by subtracting the predicted astronomical tide from observed heights of sea level. In other studies residual sea level is called residual water or surge [1], [2]. These major surges usually occurred unexpectedly. The number of causalities would have been much lower if these surges could have been predicted reasonably well in advance allowing effective warning in the threatened areas. Up to now, many experts have published a great deal of research of the storm surges. F .M. Em et al (1997) studied the shapes and the behaviors of the frequency distributions of the residual sea level along the Suez Canal from tidal observations for during two years (1984-1985) [3]; D. Idier, F. Dumas, and H. Muller (2012) studied about the tide-surges interaction in the English Channel [4] while some other papers were gave a review of recent developments in predicting the storm surges [5]-[7]. Vietnam is a country with large cities, political and economic centers and population are concentrated predominantly in coastal areas and because of this any sea level change directly affects social development within these coastal regions so the study of sea level height along the coast of Vietnam is very necessary. In this paper we base the long-term hourly tidal observations at six representative tidal stations in order to study some statistical properties of residual sea level heights.

2. Data

In this paper, six tidal stations (HONDAU, HONNGU, DANANG, QUYNHON, VUNGTAU, RACHGIA) located along the coast of Vietnam were selected. These representative tidal stations have over 30 years of hourly observations data collected up to the year 2012 and they were provided by the Vietnam Institute of Meteorology-Hydrology and Environment (IMHEN). In particular, HONDAU station represents

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the northern coastal area, HONNGU station represents the northern-central coastal area, DANANG station represents Vietnam's central coastal area, QUYNHON station represents the southern-central coastal area, VUNGTAU station presents the Vietnam's southeast coastal area, and RACHGIA station represents the Vietnam's southwest coastal area, as shown in Table 1 and the chart below.

Table 1: Description of the data

Stations	**LAT**	**LON**	**Observation time**	**Note**	**Chart**
HONDAU	20^o 40'N	106^o 48'E	1960 to 2012	Sea level is above the chart datum	
HONNGU	18^o 48'N	105^o 46'E	1961 to 2009	Sea level is above the chart datum	
DANANG	16^o 06'N	108^o 13'E	1980 to 2009	Sea level is above the chart datum	
QUYNHON	13^o 46'N	109^o 15'E	1976 to 2009	Sea level is above the national datum	
VUNGTAU	10^o 20'N	107^o 04'E	1978 to 2010	Sea level is above the national datum	
RACHGIA	10^o 00'N	105^o 05'E	1978 to 2009	Sea level is above the national datum	

3. Methodology

The RSL is the component of water level not attributable to astronomical effects. It is computed by the following formulae:

$$R(t) = O(t) - P(t) \tag{1}$$

Where

$R(t)$ is the RSL at the time t, $O(t)$ is the observed height of sea level at the time t, $P(t)$ is predicted tidal height at the time t

The predicted tide is calculated using the following formulae:

$$P(t) = A_0 + \sum_{i=1}^{r} f_i H_i \cos[q_i t + (V_0 + u)_i - g_i] \tag{2}$$

Where

A_0 is the mean sea level, f_i is nodal correction factor for the amplitude, H_i is the Amplitude of the i^{th} tidal components, g_i is the Phase of the i^{th} tidal components, q_i is the Angular velocity of the i^{th} tidal components, $(V_0 + u)_i$ is the Argument of the i^{th} tidal components, i is the considered tidal components.

In this paper, firstly the amplitude and phase of 114 tidal components of six tidal stations are calculated using the least-square methods [8], [9] and then determined the predicted tidal height $P(t)$ using the formulae (2), after that calculated the RSL $R(t)$ by using the formulae (1) above.

4. Results and Discussion

Using the above methods, the RSL are calculated by eliminating the predicted astronomical tide from observed heights at HONDAU over a period of 52 years from 1960-2012; at HONNGU over 48 years, (1961-2009); at DANANG 29 years, (1980-2009); at QUYHON 33 years, (1976-2009); at VUNGTAU 32 years, (1978-2010) and at RACHGIA 31 years, (1978-2009).

In order to compare the long-term statistical properties of RSL changes across the study sites, the maximum and mean values of the RSL were calculated for five common periods and these are listed in Table 2. From the results, it may be noticed that in the northern coastal area of Vietnam (HONDAU) the positive RSL varied on average between 11.09 and 14.51cm and the negative RSL varied on average between -14.72 and -11.79cm Between 1960 and 2012 the maximum positive RSL was 161.1cm with the maximum negative RSL being -240.4cm.

In the northern-central coastal area (HONNGU) the positive RSL varied on average between 12.42 and 26.87cm and the negative RSL varied on average between -23.00 and -13.83cm. Between 1961 and 2009 the maximum positive RSL is 198.2cm with the maximum negative RSL being -143.5cm.

In the central coastal area (DANANG) the positive RSL varied on average between 9.77 and 9.97cm and the negative RSL varied on average between -10.51 and -7.33cm. Between 1980 and 2009 the maximum positive RSL is 139.1cm with the maximum negative RSL being -84.2cm.

In the southern-central coastal area (QUYNHON) the positive RSL varied on average between 10.68 and 18.78cm and the negative RSL varied on average between -16.93 and -9.05cm. Between 1980 and 2009 the maximum positive RSL is 174.4cm with the maximum negative RSL being -143.7cm.

In the southeast coastal area (VUNGTAU) the positive RSL varied on average between 12.45 and 19.74cm and the negative RSL varied on average between -20.48 and -12.62cm. Between 1978 and 2010 the maximum positive RSL is 265.5cm; the maximum negative RSL being -250.4cm.

In the southwest coastal area (RACHGIA station) the positive RSL varied on average between 9.22 and 18.66cm and the negative RSL varied on average between -11.67 and -7.91cm. Between 1978 and 2009 the maximum positive RSL is 102.8cm with the maximum negative RSL being -66.4cm.

Table 2: The Maximum and Mean Values of the RSL along the Coast of Vietnam with different periods in cm, (+) is positive RSL, (-) is negative RSL

Station	**Periods**	**Positive RSL**		**Negative RSL**	
		Max	**Mean**	**Max**	**Mean**
HONDAU	1960-1970	150.4	11.09	-83.3	-14.72
	1970-1980	157.7	11.25	-240.4	-14
	1980-1990	125.2	14.51	-80.8	-13.92
	1990-2000	161.1	11.66	-91.5	-12.2
	2000-2010	121.9	12.86	-74.2	-11.79
	Whole time	161.1	12.48	-240.4	-13.36
HONNGU	1961-1970	126.1	22.45	-104.6	-14.7
	1970-1980	145.8	26.87	-120.7	-23
	1980-1990	136.2	20.06	-108.6	-14.11
	1990-2000	198.2	18.51	-113.9	-13.83
	2000-2009	153.9	12.42	-143.5	-18.31
	Whole time	198.2	19.96	-143.5	-16.62
DANANG	1980-1990	85.5	9.97	-84.2	-10.51
	1990-2000	103.8	9.77	-41.3	-8.76
	2000-2009	139.1	9.77	-56.9	-7.33
	Whole time	139.1	9.82	-84.2	-9.02
QUYNHON	1976-1980	174.4	17.29	-116.3	-15.27
	1980-1990	133.3	18.78	-143.7	-16.93
	1990-2000	132.8	11.88	-57.2	-8.89
	2000-2009	117.7	10.68	-111.1	-9.05
	Whole time	174.4	14.45	-143.7	-11.88
VUNGTAU	1978-1980	117.6	19.74	-107	-20.48
	1980-1990	154.8	13.45	-185.5	-16.89
	1990-2000	265.5	12.45	-250.4	-12.62
	2000-2010	149.9	13.3	-104.9	-12.82
	Whole time	265.5	13.37	-250.4	-14.8
RACHGIA	1978-1980	102.8	18.66	-60.7	-11.06
	1980-1990	74.1	9.22	-63.8	-11.67
	1990-2000	78.3	10.61	-64.4	-10.4
	2000-2009	90.4	12.91	-66.4	-7.91
	Whole time	102.8	11.86	-66.4	-10.57

In order to study the influence of the monsoon in residual sea level changes. The monthly statistical values have been calculated for each month during the whole time of each station with the results listed in Table 3.

From these results, it is concluded that the positive RSL is mainly caused by the northeast wind at stations which located along eastern coastal areas (HONDAU, VUNGTAU), but the negative RSL is caused by the southwest wind at stations which located along the western coastal area (RACHGIA).

Also, it is seen that the biggest positive RSL ere appeared in the summer months (from June to October) and the biggest negative RSL ere appeared in the winter months.

Table 3: The Maximum and Mean Values of the RSL along the Coast of Vietnam for each months during the whole time in cm, (+) is positive RSL, (-) is negative RSL

Station		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
HONDAU	Max (+)	150.4	71.9	67.7	53.3	71.6	99.7	159.3	161.1	120.9	157.7	62.9	61.9
	Mean (+)	13.05	12.92	12.34	11.18	11.75	11.97	12.20	11.12	13.33	14.50	12.48	12.25
	Max (-)	-91.2	-63.8	-84.5	-82.9	-72.5	-83.3	-81.4	-72.5	-81.9	-240.4	-91.5	-82.0
	Mean(-)	-12.90	-12.33	-13.25	-14.41	-13.93	-12.16	-11.20	-12.30	-14.73	-14.88	-13.99	-13.75
HONNGU	Max (+)	100.9	136.2	102.0	107.4	121.7	123.9	145.8	198.2	133.3	130.8	115.5	127.1
	Mean (+)	19.32	19.26	17.23	17.28	19.04	19.11	17.24	16.46	20.50	25.36	23.26	21.77
	Max (-)	-100.9	-111.3	-108.6	-104.0	-143.5	-100.6	-120.7	-108.8	-113.9	-105.6	-107.3	-100.6
	Mean (-)	-15.11	-15.75	-17.45	-17.45	-17.01	-16.34	-16.35	-17.86	-18.74	-15.52	-15.33	-14.57
DANANG	Max (+)	50.6	37.7	52.9	44.0	85.5	48.9	64.4	66.9	103.8	139.1	79.0	60.0
	Mean (+)	8.97	9.34	7.78	7.60	8.95	7.89	7.63	8.90	9.83	14.35	13.77	11.45
	Max (-)	-35.8	-43.9	-37.1	-38.1	-56.9	-31.1	-43.5	-35.4	-57.9	-48.0	-46.5	-84.2
	Mean(-)	-8.82	-8.20	-7.42	-8.15	-7.59	-6.24	-7.03	-9.29	-11.26	-10.98	-11.92	-11.11
QUYNHON	Max (+)	119.2	122.3	103.5	109.5	117.9	174.4	133.3	78.6	117.7	79.0	97.7	95.7
	Mean(+)	12.94	14.10	14.57	15.29	15.76	15.18	14.43	12.79	13.82	14.06	16.48	13.79
	Max(-)	-99.1	-108.5	-62.1	-67.8	-115.8	-75.0	-120.0	-104.6	-116.3	-118.4	-143.7	-103.8
	Mean (-)	-11.14	-10.47	-9.48	-11.08	-10.84	-10.17	-10.62	-11.94	-14.48	-13.59	-15.27	-12.65
VUNGTAU	Max (+)	135.3	161.4	116.0	137.3	153.4	133.9	149.9	139.7	133.9	265.5	137.5	134.5
	Mean (+)	12.69	13.24	12.62	11.91	13.31	11.65	11.94	12.66	12.54	16.32	15.23	14.09
	Max (-)	-102.7	-133.9	-118.8	-149.2	-137.1	-185.5	-150.7	-152.9	-143.4	-250.4	-148.5	-160.6
	Mean (-)	-14.67	-16.04	-14.92	-13.90	-14.13	-14.98	-14.27	-15.03	-16.17	-15.13	-14.16	-13.88
RACHGIA	Max (+)	57.1	64.1	53.5	78.3	79.5	90.2	90.4	79.9	102.8	95.2	96.2	58.2
	Mean (+)	10.43	12.01	10.92	9.57	11.28	11.42	12.33	11.96	12.17	15.56	13.42	10.55
	Max (-)	-45.8	-53.8	-52.3	-46.8	-49.6	-50.5	-54.0	-57.1	-58.9	-57.4	-63.8	-66.4
	Mean (-)	-10.42	-10.50	-9.61	-9.45	-10.09	-10.12	-10.25	-10.91	-12.50	-11.07	-10.80	-10.91

To give information concerning characteristic of the RSL, the cumulative frequency distribution with different interval of heights are computed for all the investigated stations during the whole time and is presented graphically in Fig. 1 and Fig. 2. From the results in these figures, it may be noticed that the frequency of positive RSL less than 20 cm accounted for 60.6, 39.9, 69.3, 55.0, 59.4, and 64.4% for the HONDAU, HONNGU, DANANG, QUYNHON, VUNGTAU, and RACHGIA station respectively and the frequency of negative RSL less than -20cm accounted for 59.1, 47.6, 81.9, 65.5, 55.8, and 72.5% for the corresponding stations. In general the cumulative frequency of RSL less than 50 cm fell between 95 and 99% while the frequency of RSL bigger than 100 cm only appeared in the northern-central coastal area (HONNGU), in the southern-central coastal area (QUYNHON) and in the southeast coastal area (VUNGTAU), it fell between 0.01 and 0. 2%.

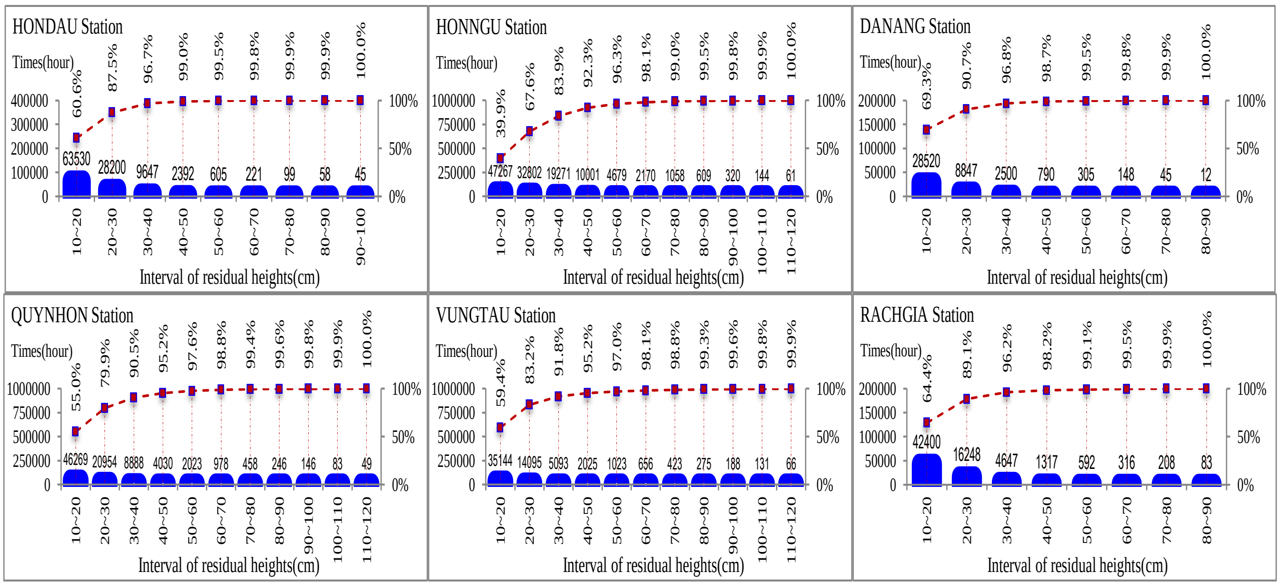

Fig. 1: Cumulative frequency of positive RSL along the coast of Vietnam with different interval of heights value

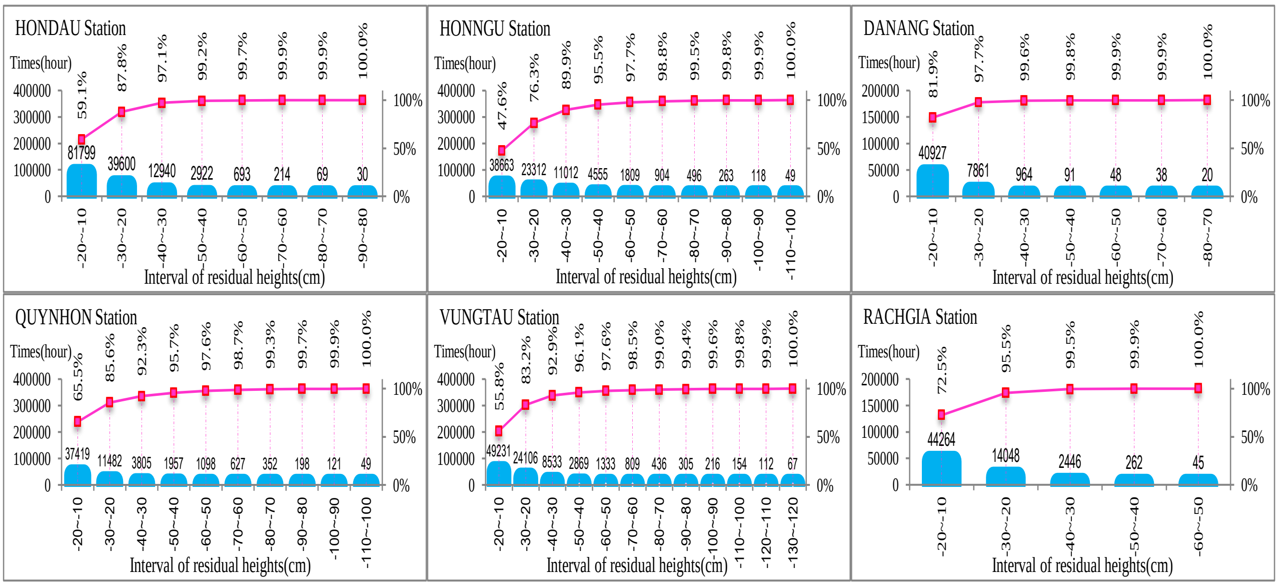

Fig. 2: Cumulative frequency of negative RSL along the coast of Vietnam with different interval of heights value

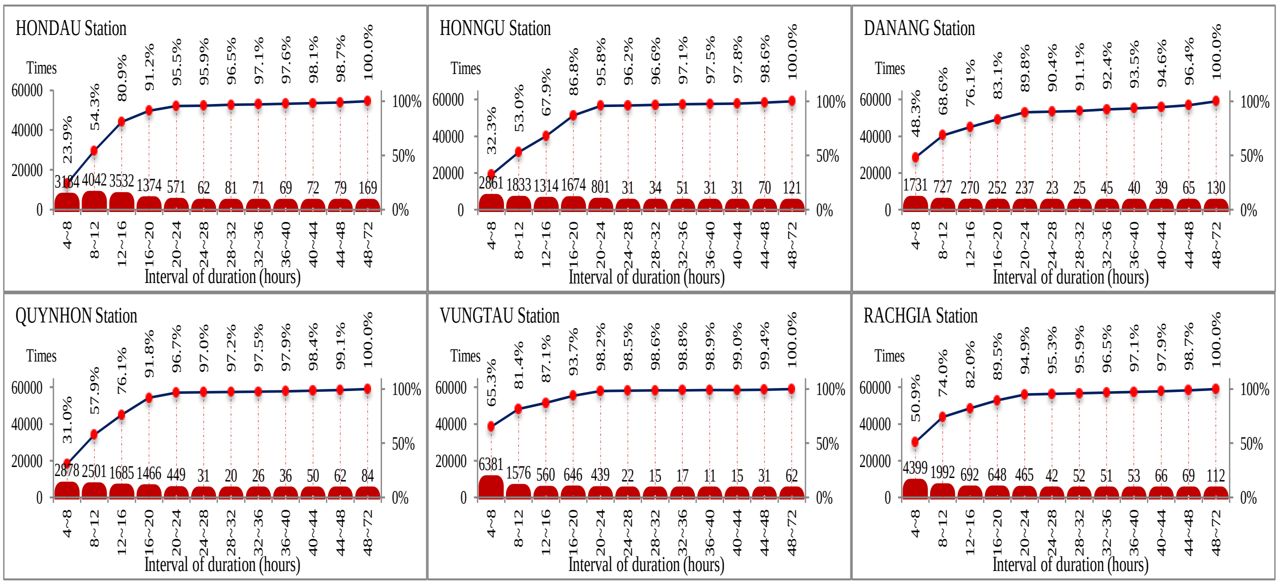

Fig. 3: Cumulative frequency of positive RSL along the coast of Vietnam with different interval of duration

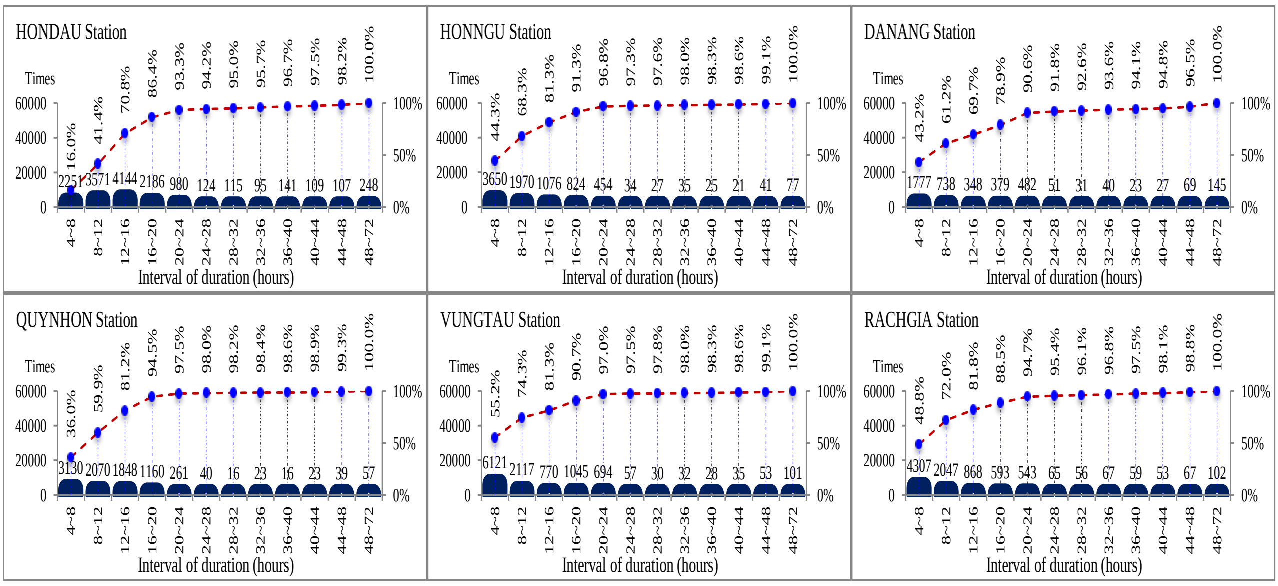

Fig. 4: Cumulative frequency of negative RSL along the coast of Vietnam with different interval of duration

In order to give more information concerning the duration of rising or falling of the RSL along the coast of Vietnam then the cumulative frequency distribution with different interval of duration are also calculated for all the investigated stations during the whole time and are shown in Fig. 3 and Fig. 4. From the figures, it may be noticed that the frequency of positive RSL less than 12 hours accounted for 54.3, 53.0, 68.6, 57.9, 81.4, and 74.0% for the HONDAU, HONNGU, DANANG, QUYNHON, VUNGTAU, RACHGIA station respectively, but the frequency of negative RSL less than 12 hours accounted for 41.4, 68.3, 61.2, 59.9, 74.3, and 72.0% for the corresponding stations. In general the cumulative frequency of RSL less than 24 hours accounted for 90 and 97% and the frequency of RSL longer than 72 hours accounted between 0.1 and 1%.

5. Conclusion

Some statistical properties of residual sea level along the coast of Vietnam were investigated based on the long-term time series of hourly observations at six tidal stations representing Vietnam's coastal areas.

It was found that the positive RSL along the coast of Vietnam varied on average between 9.82 and 19.96cm and the maximum positive RSL varied on average between 102.8 and 265.5cm whereas the negative RSL varied on average between -16.62 and -9.02cm and the maximum negative RSL varied on average between -250.4 and -66.4cm. The positive RSL is mainly caused by the northeast wind at stations which located along eastern coastal areas (HONDAU, VUNGTAU), but the negative RSL is caused by the southwest wind at stations which located along the western coastal area (RACHGIA). It is seen that the biggest positive RSL ere appeared in the summer months (from June to October) and the biggest negative RSL ere appeared in the winter months. It also was found that the cumulative frequency of RSL, being less than 50 cm, fell between 95 and 99% while the frequency of RSL higher than 100 cm only accounted for between 0.01 and 0.2%. The cumulative frequency of RSL less than 24 hours duration accounted for between 90 and 99% while the frequency of RSL longer than 72 hours only accounted for between 0.1 and 1%.

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