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THE SOUTHWARD COLD CURRENT ALONG THE COAST OF CENTRAL VIETNAM

Vo Van Lanh
Institute of Oceanography (Nha Trang)
Dang Van Hoan
Transport Engineering Design Incorporated

ABSTRACT The paper supplies new information about the existence of the Southward Cold Current along the coast of Central Vietnam (SWCC) on the basis of analyzing the great amount of current observation data collected in 44 mooring buoy stations and reviewing some important conclusions obtained from results of hydrographic observation and numerical simulation of the East Sea (ES) (South China Sea) circulation. The paper reflects the general features of the scope, structure, variability and intensity of SWCC in 4 seasons, especially, in summer and winter.

VE DONG CHAY LANH HÖÔNG NAM DOC BÔ MIEN TRUNG VIET NAM

Vo Van Lanh
Vien Hai Döông Hoc (Nha Trang)
Ñang Van Hoan
Cong Ty Tö Van Thiet Ke Giao Thong Van Tai

TOM TAT Bai bao cung cap thong tin môi ve sö ton tai Dong Chay Lanh Höông Nam doc theo bô Mien Trung Viet Nam (DCLHN) tren cô sô phan tích mot khoi löông lôn so lieu quan trac dong chay tai 44 tram phao co ñònh dai ngay va tong quan mot so nhan ñònh rut ra tö ket qua tính toan gian tiep dong chay Bien Ñong. Bai bao phan anh nhöng ñac ñiem cô ban ve quy mo, cau truc, cöông ño va sö bien ñong cua DCLHN trong 4 mua, ñac biet la mua he va mua ñong.

I. INTRODUCTION

The current along the coast of Central Vietnam changes very complicatedly having unique features unlike to the normal knowledge of many people, especially, in summer when here is a counter-wind current. The investigation on this current has an important role for the development of marine economic branches such as marine fishery, aquaculture, transport... for coastal defense, environmental protection in the coastal zone of the central and southern parts of Vietnam, and also for understanding many oceanographic problems of western part of the ES.

So far, there were many investigations on the ES circulation by foreign and Vietnamese scientists; among them some works were concerning the SWCC by analyzing hydrographic fields, mainly water temperature and salinity fields, or numerical simulation. Some time ago, the current was studied by field observation in framework of the State Program of Marine Research KT03 (1991-1995).

In the present paper, the authors would like to show some results of study on the scope, structure, variation and intensity of the SWCC on the basis of the above mentioned investigations, especially field observations.

II. REVIEW ON SOME RESULTS OF HYDROGRAPHIC ANALYSES AND NUMERICAL SIMULATION

On the basis of analyzing the hydrographic fields, mainly, water temperature and salinity fields, Chevey and Carton (1939) concluded that the SWCC exists not only in winter, but also in summer; in summer it exists in undersurface layers and can reach to the Cape Varella (Dai Lanh); Hoang Xuan Nhuan (1977) and Nguyen Kim Vinh (1990) suggested that the dynamical sources through the Taiwan and Luzon Straits create in the seasonal thermocline the strong southward current in narrow band along the coast of Central Vietnam.

The results of computation of the mean seasonal ES geostrophic current (Vo Van Lanh et al., 1985, 2001) showed the following important characters of the SWCC:

- SWCC essentially is the western branch of the cyclonic circulation in northern and north-western parts of the ES.

- SWCC exists throughout a year but with different scope and intensity in each season. In autumn and winter, it creates a wide band (50-100 miles wide), but in spring and summer, - only narrow band closed to the coast of Central Vietnam. In spring, it exists along the coast of some northern provinces and can reach to the latitudes 13-14^{0}N, but in summer, its southern boundary can reach to the latitudes 11-12^{0}N, i.e. to the strongest upwelling center in Ninh Thuan province (Vo Van Lanh et al., 1997). In autumn, the current occupies all coastal and shelf zone of Central Vietnam, and in winter - of Central and South Vietnam.

- For the coastal and shelf area SWCC exists in water layer from surface to bottom including seasonal thermocline.

- SWCC is strongly intensified in autumn and winter. In spring and summer, it becomes weaker and exists in western periphery of strong upwelling.

These are the important conclusions about SWCC following from the results of analyzing hydrographic data. Besides, the existence of the SWCC is clearly reflected in latest results of numerical simulation of the ES circulation by Chinese (See the review of Jianyu Hu et al., 2000) and Vietnamese (Dinh Van Uu, 1999) scientists, according to which the SWCC reaches to latitudes 11-13^{0}N in summer and occupies all western coastal and shelf zone of the ES in winter.

III. RESULTS OF FIELD OBSERVATION

So far, we have acquired a big amount of surface current data of the ES (mainly ship drift data) and no small amount of long-term (1-7 days and nights) series of direct current measurements at different layers of mooring buoy stations (Vo Van Lanh et al., 2000).

The first seasonal charts of observed surface currents of ES were published by Koninklijk Nederland Meteorological Institute in 1936 and the latest ones - by Siripong in 1984. From these charts it is clear that in summer, the current along the coast of the northern and middle parts of Central Vietnam is usually southward or southeastward and at the coastal region of Ninh Thuan province (11-12^{0}N) it meets with the northeastward current moving from the south and there both currents are separated from the coast and one of them joins the cyclonic circulation in northern and northwestern parts and other - the anticyclonic circulation in southern part of the ES. In winter, the SWCC occupies all coastal and shelf zone west of the ES.

In order to further investigate the current system and strong upwelling along the coast of Central Vietnam, in period 1992-1995, the National Projects KT03.01 and KT03.05 had organized current observation in 41 mooring buoy stations in coastal area with the depth no more than 100 meters from Quang Binh province to Binh Thuan province. The observation was made in a long-term period (1-7 days and nights) with record interval 15 - 20 minutes in different layers (1-6 layers) by current meters BPV-2R made in USSR and DNC-2M and DNW-5M made in England. In addition, the Projects used 3 stations made in summer period of 1980. This is very great and valuable current data sources which may be used for different research and practical purposes.

So far, a part of these data were used by some scientists for researching different dynamical aspects of coastal waters of Central Vietnam (Vo Van Lanh et al., 1995; Do Ngoc Quynh et al., 1995; Le Phuoc Trinh et al., 1997). For present paper, the authors tried to treat observation data of all 44 mooring buoy stations to verify the conclusions and remarks on SWCC mentioned in section II.

Information about the mooring buoy stations (station number, st. name, st. location, bottom depth, observation date, obs. depth and obs. time) is given in table 1 where the stations number 1-35 were made in period of prevailing southwest wind from June to September (summer) and stations number 37-44 - in period of prevailing northeast wind from December to February (winter). The stations were put in order of decreasing latitudes.

Some statistical characteristics of observed current such as maximum velocity V_{max}, minimum velocity V_{min}, arithmetic mean velocity $\bar{V}$, current stability E (relation between vector mean velocity and arithmetic mean velocity) and residual current (vector mean current excluding all periodic components) are given in table 2.

The direction frequency (%) of observed current is given in table 3.

Table 1: Information about the mooring buoy stations

St. No	Station name	Location	Bottom depth(m)	Obs. date	Obs. Depths (m)	Obs. time (hours)
1	Le Thuy 1	17°22'N,107°34'E	30	9, 1993	5, 15	24, 24
2	Le Thuy 2	17°19'N,107°32'E	12	9, 1993	5, 10	96, 96
3	Le Thuy 3	17°18'N,107°31'E	10	9, 1993	1, 5, 8	24, 24, 24
4	Hue 1	16°46'N,107°46'E	36	9, 1992	5, 15, 30	25, 25, 25
5	Thuan An 1	16°40'N,107°38'E	23	8, 1992	5, 20	132, 144
6	Thuan An 2	16°37'N,107°42'E	25	8, 1992	5, 15	168, 168
7	Thuan An 3	16°35'N,107°37'E	10	8, 1992	1, 8	169, 169
8	Da Nang 1	16°15'N,108°05'E	12	8, 1992	1, 5	169, 146
9	Da Nang 2	16°15'N,108°15'E	38	8, 1992	1, 10, 25	197, 73,196
10	Da Nang 3	16°15'N,108°25'E	68	8, 1992	1, 10	111, 157
11	Da Nang 4	16°04'N,108°24'E	30	8, 1992	5, 15, 25	24, 24, 24
12	Hoi An 1	15°58'N,108°37'E	35	6, 1992	5, 25	64, 41
13	Hoi An 2	15°56'N,108°26'E	20	6, 1992	5, 15	26, 72
14	Tam Ky 1	15°42'N,108°43'E	15	8, 1993	5,10,15, 20,30,40	168,168,168, 168,168,168
15	Tam Ky 2	15°38'N,108°38'E	20	8, 1993	1,5,10,15	168,168,168, 168
16	Tam Ky 3	15°36'N,108°34'E	12	8, 1993	1,5,10	168,168,168
17	Q. Ngai 1	15°08'N,108°54'E	20	8, 1993	10, 15	24, 24
18	De Gi 2	14°08'N,109°14'E	15	6, 1992	5, 12	58, 58
19	De Gi 3	14°07'N,109°15'E	30	6, 1992	5, 25	72, 72
20	Quy Nhon 2	13°44'N,109°17'E	20	6, 1992	5, 15	72, 72
21	Quy Nhon 3	13°44'N,109°18'E	30	6, 1992	5, 25	72, 72
22	Phu Long 1	13°13'N,109°22'E	30	8, 1993	10	24
23	Phu Long 2	13°12'N,109°19'E	20	8, 1993	10	24
24	Phu Long 3	13°12'N,109°18'E	10	8, 1993	5	24
25	Tuy Hoa 1	13°06'N,109°20'E	20	8, 1993	10	24
26	Da Vach 1	11°42'N,109°13'E	48	8, 1993	3,20,42	72,72,66
27	Ph. Rang 1	11°31'N,109°09'E	60	7, 1994	5, 25, 45	72, 72, 48
28	Ph. Rang 2	11°31'N,109°21'E	96	7, 1994	5, 90	120, 120
29	Ph. Rang 3	11°28'N,109°06'E	50	7, 1994	5, 45	120, 120
30	Ph. Rang 4	11°26'N,109°16'E	38	8, 1980	10,20,35	23, 23, 23
31	Ph. Ri 1	11°13'N,108°43'E	20	8,1992	5	15
32	Ph. Ri 2	11°05'N,108°40'E	24	8, 1992	5, 21	24, 24
33	Ph. Ri 3	11°01'N,108°39'E	25	8, 1993	10, 20	47, 26
34	Ph. Ri 4	10°55'N,108°45'E	28	8, 1992	5, 24	120, 120
35	Ph. Thiet 1	10°43'N,108°12'E	22	7-8,1980	5, 10, 15	72, 46, 72
36	Ph. Thiet 2	10°44'N,108°55'E	50	8, 1980	5,20,35	72,72,72
37	Dong Hoi 1	17°38'N,107°01'E	47	12, 1994	20, 30,40	26, 26, 26
38	Le Thuy 4	17°22'N,106°54'E	30	1, 1995	10, 25	48, 48
39	Le Thuy 5	17°18'N,106°51'E	20	1, 1995	10	48
40	Thuan An 4	16°39'N,109°00'E	98	12, 1994	10, 30	165, 167
41	Da Nang 5	16°18'N,108°41'E	98	12, 1994	30, 60	70, 24
42	Tam Ky 4	15°42'N,108°43'E	50	12, 1994	10, 48	125, 125
43	Tam Ky 5	15°38'N,108°37'E	20	12, 1994	10	142
44	Phan Ri 5	11°00'N,109°10'E	99	1, 1995	10,30,60,90	48,48,48,28

Table 2: Some statistical characteristics of observed current

St. No	Obs. depth (m)	V_{max} (cm/s)	$\overline{V}$ (cm/s)	V_{min} (cm/s)	E (%)	Residual current	
						Module (cm/s)	Direction (degs)
1	2	3	4	5	6	7	8
1	5	63	37.7	12	97	35	111
	15	54	31	4	98	29	109
2	5	56	27.2	8	100	27	135
	10	47	21.5	3	99	21	128
3	1	97	44.7	19	90	39	133
	5	68	34.9	21	100	34	131
	8	44	28.4	12	100	28	128
4	5	122	63.4	26	69	38	117
	15	49	8.5	3	56	5	135
	30	56	29.9	10	10	3	51
5	5	89	31.9	9	21	8	191
	20	52	25.5	6	10	2	260
6	5	64	32.9	10	12	5	118
	15	72	38	11	13	6	182
7	1	66	27.6	0	46	14	118
	8	50	26	7	53	15	118
8	1	29	11.9	0	19	3	163
	5	52	20	10	27	4	168
9	1	64	27.3	0	89	25	134
	10	56	23.8	4	72	17	143
	25	69	31.7	11	18	10	183
10	1	70	22.5	6	35	3	196
	10	52	27.8	12	68	8	300
11	5	84	56.2	32	75	40	119
	15	37	19.8	3	91	17	136
	25	44	25.8	12	72	18	173
12	5	46	20.9	10	12	3	306
	25	40	15.2	7	34	4	337
13	5	34	25	18	92	23	342
	15	31	17	10	76	14	352
17	10	45	24.9	16	86	21	196
	15	35	23.2	11	92	21	174
18	5	38	19.6	10	32	5	107
	12	38	20	12	75	15	220
19	5	45	25.8	14	37	10	146
	25	41	24.7	13	61	17	157
20	5	24	16.4	11	45	8	100
	15	27	16.7	10	29	6	258
21	5	38	24.1	12	23	5	128
	25	41	23.9	8	46	10	48
22	10	17	9.6	4	68	6	170
23	5	11	6.9	4	52	4	209

1	2	3	4	5	6	7	8
24	5	12	7.4	4	49	4	133
25	10	18	11.9	2	39	4	144
26	3 20 40	35 37 35	17 16.1 12.3	4 5 1	26 41 56	2 2 2	100 186 192
27	5 25 45	75 49 59	39.7 32.7 42.2	21 22 28	65 76 52	26 25 22	108 206 220
28	5 90	78 45	48.5 24.4	9 2	64 32	31 8	160 285
29	5 45	78 41	35.9 20.3	1 1	69 53	25 11	233 258
30	10 20 35	43 40 34	23.3 18.3 20.7	11 11 10	79 61 36	19 12 7	31 0 133
31	5	36	22.5	12	47	-	-
32	5 21	93 38	69.6 19.3	52 8	33 73	21 13	82 50
33	10 20	65 66	33.4 37.3	14 24	84 72	28 24	74 60
34	5 24	88 75	53 34.5	20 13	99 67	51 22	64 66
35	5 10 15	89 60 43	41.3 21.4 19.8	1 3 5	96 48 19	39 10 3	51 32 34
36	5 20 35	109 91 84	62.7 48.4 40.6	25 25 11	96 99 95	60 48 38	66 43 44
37	20 30 40	53 50 43	36.6 34.4 30.7	2 4 3	43 42 46	14 14 14	112 103 91
38	10 25	33 23	15.6 12.1	0 0	49 35	8 4	126 173
39	10	17	7.2	3	24	2	190
40	10 30	50 50	20.1 23.1	0 0	40 42	8 10	141 61
41	30 60	62 176?	23 70	1 7	65 65	15 46	171 183
42	10 48	80 27	49.3 11.1	16 0	97 22	48 3	152 265
43	10	16	10.8	5	49	5	219
44	10 30 60 90	82 68 58 76	53.6 50.9 37.3 23.9	4 18 10 1	99 99 98 76	53 50 37 18	278 193 193 190

Table 3: The direction frequency (%) of observed current

St. No	Obs. depths(m)	Direction of observed current							
		N	NE	E	SE	S	SW	W	NW
1	2	3	4	5	6	7	8	9	10
1	5	0	0	**62.5**	37.5	0	0	0	0
	15	0	4.2	**62.5**	33.3	0	0	0	0
2	5	0	0	0	**100**	0	0	0	0
	10	0	0	12.5	**87.5**	0	0	0	0
3	1	4.2	0	0	**87.5**	8.3	0	0	0
	5	0	0	0	**100**	0	0	0	0
	8	0	0	0	**100**	0	0	0	0
4	5	6.7	7.4	15.4	**48.3**	5.4	0	0	16.8
	15	4.0	3.3	4.0	**58.7**	3.3	4.0	11.3	11.3
	30	3.0	1.0	**33.3**	11.1	5.1	8.1	20.2	18.2
5	5	6.8	2.8	3.8	**28.0**	24.4	2.6	9.6	21.9
	20	5.0	1.7	12.2	24.0	8.3	3.0	15.5	**30.4**
6	5	5.3	3.6	13.8	**37.1**	5.9	2.1	5.3	26.6
	15	3.4	1.2	3.9	**35.4**	8.0	5.1	10.1	33.0
7	1	4.7	3.6	23.7	**37.3**	5.3	1.8	9.5	14.2
	8	0.7	1.6	35.0	**40.5**	2.7	0.3	10.8	8.3
8	1	23.7	4.1	4.1	**32.5**	9.5	4.1	8.9	13.0
	5	3.1	1.4	10.2	**39.4**	9.8	5.3	12.1	18.5
9	1	3.1	2.0	15.8	**60.7**	11.7	3.1	3.1	0.5
	10	4.1	1.4	4.1	**65.8**	5.5	2.7	6.8	9.6
	25	5.5	1.4	3.3	**24.3**	17.8	9.7	9.9	28.0
10	1	5.4	7.2	11.7	5.4	16.2	**27.9**	11.7	14.4
	10	7.6	1.9	1.9	4.4	7.0	6.0	26.8	**44.3**
11	5	0	19.9	**31.5**	24.0	24.7	0	0	0
	15	2.1	1.4	15.1	**56.8**	24.0	0.7	0	0
	25	1.0	0	0	**41.2**	29.9	11.3	14.4	2.1
12	5	8.5	15.1	9.7	11.6	9.7	9.7	14.7	**21.2**
	25	20.6	15.8	6.7	9.1	7.3	6.1	12.1	**22.4**
13	5	**51.9**	4.8	1.0	0	0	0	1.0	41.3
	15	**49.1**	14.9	2.8	1.4	4.2	0.7	2.4	24.6
14	5	**55.2**	3.0	0.6	1.8	4.2	3.0	1.2	30.9
	10	37.2	4.5	1.3	1.4	2.8	4.3	5.2	**43.2**
	15	**49.7**	4.2	2.4	1.2	2.4	3.6	1.3	34.6
	20	**46.3**	6.1	2.4	1.8	3.0	2.4	5.5	32.3
	30	**38.6**	6.8	3.7	1.2	3.7	0.6	9.2	36.2
	40	**43.5**	8.1	6.2	4.4	1.9	1.7	6.8	27.3
15	1	9.6	4.2	23.5	**30.7**	7.8	2.4	3.6	18.1
	5	8.4	5.4	19.3	**34.3**	6.6	4.2	3.0	18.7
	10	2.4	1.8	16.9	**33.1**	8.4	7.8	8.4	21.1
	15	1.2	1.8	21.1	**34.3**	4.2	3.0	13.9	20.5
16	1	18.5	3.8	4.5	**31.8**	10.8	3.2	5.7	21.7
	5	4.6	3.3	5.5	**29.3**	15.0	8.0	7.4	26.5
	10	10.6	3.1	0.6	**37.3**	13.7	0.6	1.9	32.3

	2	3	4	5	6	7	8	9	10
17	10 15	1.1 0	0 0	0 0	12.6 **58.9**	**48.4** 30.5	34.7 10.5	3.2 0	0 0
18	5 12	2.2 3.0	**27.6** 0.4	24.6 0.4	8.2 1.3	3.9 35.8	21.1 **37.1**	6.5 14.7	3.0 7.3
19	5 25	2.4 0.3	18.3 1.4	**22.8** 13.1	15.5 **38.6**	18.6 14.8	20.7 23.1	1.0 8.3	1.7 0.3
20	5 15	5.2 8.6	15.1 11.7	**31.6** 12.4	16.8 3.8	17.5 4.1	5.5 26.5	3.1 **29.2**	5.2 3.8
21	5 25	4.2 13.2	13.8 **37.8**	**28.0** 18.1	7.6 5.9	11.4 6.9	23.9 5.6	9.3 4.2	1.7 8.3
22	10	3.1	3.1	7.3	31.3	**35.4**	18.8	1.0	0
23	5	3.1	0	1.0	11.5	**33.3**	18.8	15.6	16.7
24	10	3.1	13.5	**29.2**	16.7	21.9	13.5	0	2.1
25	10	21.1	0	9.5	**43.2**	17.9	0	8.4	0
26	3 20 42	9.0 2.8 0	7.6 5.6 0.9	**34.0** 20.8 6.8	9.7 12.5 **33.2**	9.7 8.9 16.3	7.6 16.7 32.3	12.5 **23.0** 4.8	9.7 4.8 0.6
27	5 25 45	0.2 0 6.4	17.5 1.3 4.8	**33.6** 6.6 2.4	26.2 0 6.8	13.7 0.9 23.6	7.0 **48.9** **26.3**	1.2 41.0 22.0	0.6 1.3 7.6
28	5 90	1.1 **15.8**	6.9 9.4	20.5 5.8	10.8 5.5	**45.2** 9.4	12.7 14.1	2.2 22.4	0.6 15.5
29	5 45	2.5 1.1	5.5 4.2	10.8 9.1	15.5 21.1	15.8 **22.2**	**37.4** **22.2**	11.1 13.9	1.4 6.4
30	10 20 35	**37.7** **32.1** 10.1	31.9 23.1 7.2	18.8 13.0 10.1	7.2 0.7 **37.7**	0 0 11.6	0 2.1 1.4	2.9 4.4 0	1.4 24.4 21.7
31	5	12.2	24.4	**25.6**	2.2	1.1	3.3	15.6	15.6
32	5 21	4.9 15.6	5.6 **41.7**	**46.2** 24.0	7.0 3.1	2.1 0	13.3 1.0	12.6 11.5	8.4 3.1
33	10 20	9.4 7.5	17.0 22.6	**64.9** **52.8**	0.5 0	0 0	0 0.9	2.1 9.4	10.6 6.6
34	5 21	2.0 10.5	**73.1** 20.5	26.7 **47.9**	0 3.8	0 3.5	0 6.4	0 3.2	0 4.2
35	5 10 15	6.4 9.3 4.2	**85.8** **52.9** **28.8**	5.0 3.6 20.0	0 2.1 5.1	0 0.7 6.0	0.9 4.3 9.3	0.9 20.0 23.7	0.9 7.1 2.8
36	5 20 35	1.6 10.5 19.7	**50.2** **76.4** **73.7**	47.9 12.8 4.7	0.2 0.4 0	0 0 0	0 0 0.5	0 0 0	0 0 1.4
37	20 30 40	16.5 32.1 38.1	2.9 3.8 3.8	4.9 5.7 8.6	**56.3** **54.7** **49.5**	0 0 0	0 0 0	0 0 0	19.4 3.8 0
38	10 25	1.0 11.7	2.6 3.1	31.6 4.1	**32.1** **27.6**	8.2 16.3	5.6 20.4	8.2 4.1	10.7 12.8
39	10	5.9	1.1	5.3	**38.8**	15.4	6.4	18.6	8.5

1	2	3	4	5	6	**7**	8	9	10
40	10 30	1.5 1.5	0.9 12.6	21.1 **55.1**	**36.6** 0.3	16.3 0.3	5.4 0	9.7 17.1	8.5 13.2
41	30 60	2.1 4.1	2.1 2.0	4.3 4.1	**40.7** 24.5	24.3 26.5	7.9 **28.6**	9.3 8.2	9.3 2.0
42	10 48	0 7.1	0 8.6	0.2 12.4	**68.6** 5.9	31.2 7.5	0 18.1	0 **25.5**	0 14.9
43	10	5.2	10.2	7.0	3.4	18.2	**44.4**	9.6	2.1
44	10 30 60 90	0 0 0 5.3	0 0 0 6.2	0.5 0 0 7.1	1.0 0 0 8.8	0.5 **84.4** **78.2** **34.5**	0 15.6 20.7 27.4	**97.4** 0 0 8.0	0.6 0 0 2.7

Let us consider separately the observed (total) current and residual current.

1. Observed current

In summer:

From table 2, columns 3, 4, 5, 6, and table 3 it is clear that in summer, along the coast of northern provinces from Quang Binh to Quang Ngai and of southern provinces from Ninh Thuan to Binh Thuan the observed current usually has enough high intensity and stability with maximum velocity usually more than 50 cm/s, in some locations-more than 100 cm/s (Sts 4 and 36) and averaged velocity more than 30 cm/s. The current along the coast of middle provinces from Binh Dinh to northern Ninh Thuan has usually small intensity and stability with averaged velosity less than 25 cm/s.

Concerning the surface current direction in summer it is indicated that in majority of stations from Quang Binh province to northern Ninh Thuan province the directions having highest frequency are east, southeast, south and southwest, only in Hoi An and Tam Ky (Quang Nam province) - are north and northwest (in Tam Ky at nearshore station-are southeast, but at 2 offshore stations-are north: see table 3, Sts 14, 15, 16). Along the coast of southern Ninh Thuan and Binh Thuan provinces the prevailing current directions are northeast and east (Table 3, Sts 30-36), but along the coast of northern provinces - are southeast and east (Table 3, Sts 1-11). It is interesting to note that at some stations along the coast of the middle provinces the prevailing current direction in surface layer is eastward (i.e. from the coast), but in deeper or bottom layers - is westward (i.e. to the coast), e.g. at sts 20, 26, 27 (Table 3), that may be the evidence of existence of coastal upwelling.

In winter:

In winter, there were only 8 mooring buoy stations along the coast of the northern and southern parts of Central Vietnam. From table 2, columns 3-6, sts 37-44, and table 3 it is clear that the observed current has enough high intensity and stability with maximum velocity in surface layer usually more than 50 cm/s, and averaged velocity - more than 20 cm/s in the northern part and 30 cm/s in the southern part. The current directions having highest frequency are southeast in the northern part and southwest in the southern part of Central Vietnam.

2. Residual current

The residual current along the coast of Central Vietnam has the following characters:

In summer:

From table 2, columns 7 - 8, sts 1-35, and Figs 1 and 2 it is clear that, as the observed total current, the residual current along the coast of northern and southern Central Vietnam has relatively high intensity with maximum velocity reaching more than 25 cm/s, at some stations-more than 40 cm/s (Sts 12, 33, 35). Along the coast of middle provinces (Binh Dinh, Phu Yen, northern Ninh Thuan) it has small intensity (< 10 cm/s) with velocity in surface layer usually smaller than that in near-bottom layer. At majority of stations from Le Thuy (Quang Binh province) to Phan Rang (Ninh Thuan province) the surface residual current is southeastward excluding only the Hoi An and Tam Ky (Quang Nam province) area where it is northwestward and northward (Sts 12, 13), that may be the evidence of existence of some local eddies which have been preliminary revealed by some scientists (Phan Quang et al., 1999) and need to be studied in more detail in future. In deeper layers the current direction at number stations becomes southward (Sts 6, 9, 11, 17, 26). In the coastal area southward of Phan Rang the residual current in surface and deep layers is northeastward and northward (Sts 30-36).

And so, the results of analyzing the observed total and residual currents indicated that in summer time, along the coast of the northern and middle parts of Central Vietnam (to southern Phan Rang) there exists the southeastward and southward counter-wind current; in the meantime, in the southern part of Central Vietnam (in Binh Thuan province) there is the monsoon northeastward current.

In winter:

In winter time, the residual current velocity can reach to 48 cm/s at Tam Ky (Quang Nam province), 53 cm/s at Phan Ri (Binh Thuan province) and less than 15 cm/s at other stations. The surface residual current along the coast of northern provinces is southeastward and southward and in Phan Ri - westward. The residual current of near-bottom layer is mainly southward, only at some stations - southwestward, eastward or north-eastward (Table 2, columns 7-8, Sts 37-44 and Figs 1 and 2).

And so, although the amount of mooring buoy stations for winter time is very limited, they might indicate that the current along the coast of Central Vietnam in this season mainly is the wind-driven current according to the Ecman Theory with the general direction: southeast and south in northern and middle parts and southwest in southern part of Central Vietnam.

III. CONCLUSION

1. The results of analyzing a big amount of observation data, especially, of long-term series of current data allowed us to make conclusion that in winter, as soon as in summer, there is the Southward Cold Current along the coast of Central Vietnam making water here usually colder than that along the eastern coast of the ES. In winter, the current occupies all coastal and shelf zone of Central and South Vietnam. In

summer, the current can reach to southern Phan Rang (about the latitude 11°30'N) and here it meets with the Northeastward Warm Current moving along the southern coast and both currents are seperated from the coast and one of them joins the cyclonic circulation in the northern and northwestern parts and other - the anticyclonic circulation in southern part of the ES. In the coastal and shelf waters with bottom depth no more than 100m, this current tendency exists for whole water thickness with some changes in direction. However, in some locations, for example, in coastal area of Hoi An and Tam Ky (Quang Nam province) this tendency is disturbed, may be, by some local eddies. The current velocity along the coast of northern and southern provinces is bigger and more stable than that of middle provinces of Central Vietnam.

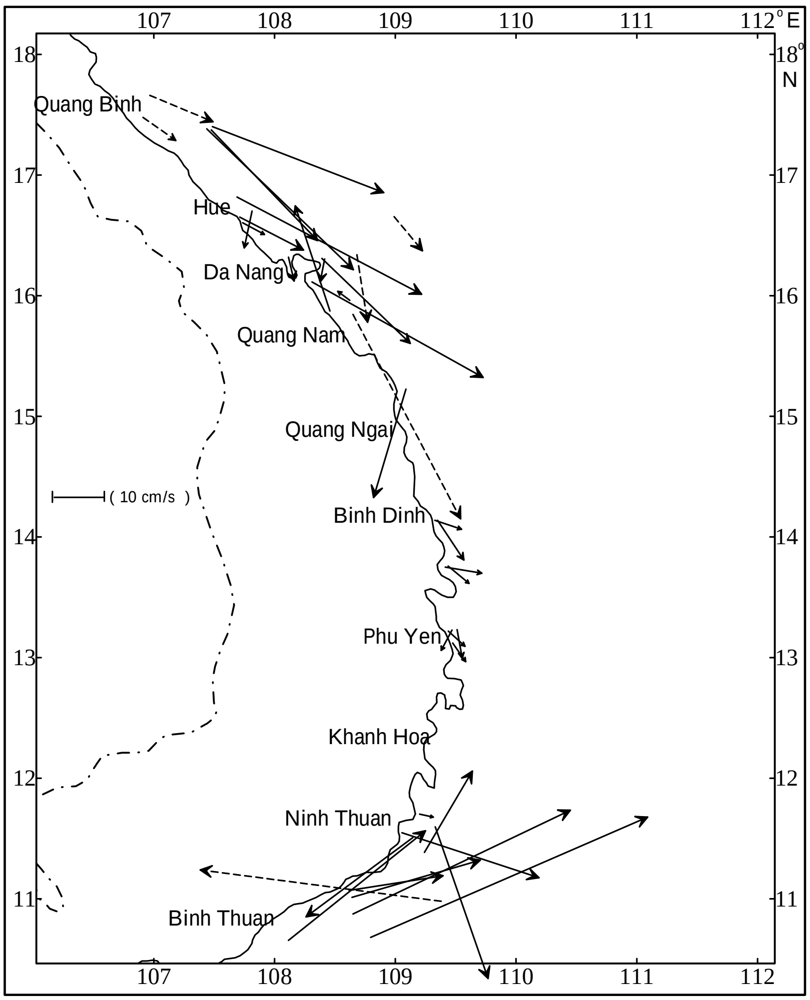

Fig. 1: Residual current in subsurface 0-10 m water layer along the coast of Central Vietnam in summer (⟶) and in winter (- - - ▸)

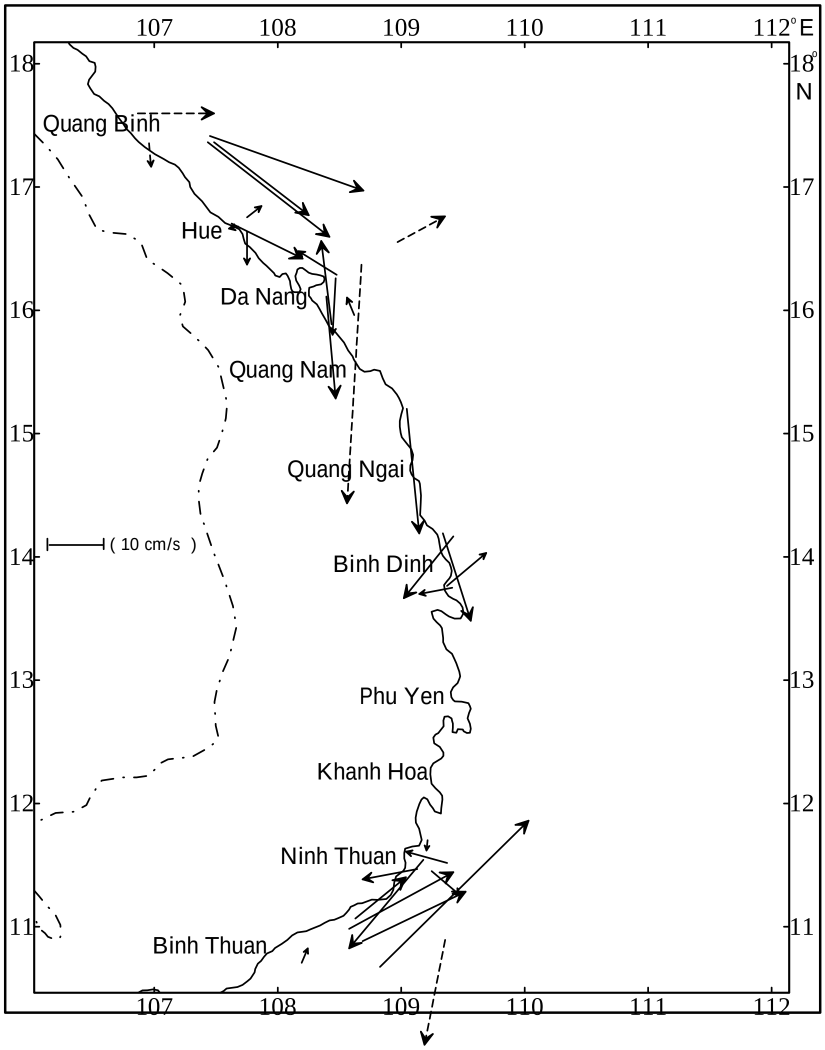

Fig. 2: Residual current in near-bottom 5-15 m water layer along the coast of Central Vietnam in summer (———►) and in winter (- - - -►)

2. The results of indirect determination of the SWCC characteristics indicated in section II are basically agreed with the above mentioned results of direct field observation.

3. It is necessary to say that the above-mentioned study results have been concerning general features of the SWCC. Many interesting aspects such as the current structure, the scope and intensity variation, the local eddies, and so on, need to be investigated in more detail in future. The pattern of SWCC would be improved if it were possible to organize some additional long-term mooring buoy stations along the coast of Khanh Hoa province where there is a lack of observed data.

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