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A NUMERICAL MODEL FOR THE TIDAL OSCILLATION AND CURRENT IN THE GULF OF TONKIN

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ABSTRACT. in this paper results of a numerical model, based on the TIDEFLOW-2D Software, for the tidal oscillation and current in the Gulf of Tonkin (GT) are presented. The model was tested as follows: i) the observed values of the four main tidal constituents M_2, S_2, K_1, O_1 at the 44 coastal stations and islands were compared with computed ones; ii) the computed tidal levels ware compared with the correlative ones in the Tide Tables at the six stations: Hon Gai, Cua Ong, Hon Dau, Cua Hoi, Cua Gianh and Cua Tung in many monthly periods; iii) the results of computed tidal levels and currents were compared with the observed data. The results of testing show a good agreement between the available data and computed values, therefore we can use this model for simulation tide level and current of GT.

The results of using this model in GT: distribution of the major harmonic constituents; the tidal elevation and current patterns; the extremal values of the tidal level and current, ... will be published later.

1. Introduction

Up to now, in Vietnam, tidal regime for the Gulf of Tonkin (GT) has been studied and simulated by many authors. In the Gulf, there exist six national tidal stations measuring tidal oscillation: Cua Ong, Hon Gai, Hon Dau, Cua Hoi, Cua Gianh and Cua Tung. However, research results on tidal current in the region are limited. Very few comparisons between observed tidal currents and computed ones had been done for GT.

There exist several 2D models [4] for tidal, wind drift level and current have been developed by Center for Marine Survey, Research and Consultation (CMESRC), Hanoi Institute of Mechanics, which have overcome quite well this lack. In this paper we present only the software TIDEFLOW-2D, provided by Hydraulics Research Wallingford Ltd (UK) [1]. A numerical model for GT based on this software has been established since nearly ten years in CMESRC.

The testing for the simulation of the tidal oscillation and currents has been made. The results of testing show a good agreement between the available data and computed values and therefore we can use this model for simulation tide level and current of GT [5].

Some results of using this tested numerical model in GT:

- the major harmonic constituents M_2, S_2, K_1, O_1 for tidal level and current,
- the tidal elevation and current patterns,
- the extremal values of the tidal level and current [6, 7]

will be published later.

2. Basic equations, initial and boundary conditions

In order to simulate the tidal regime in GT, TIDEFLOW-2D software is used. The basic equations for the software are the following two-dimensional nonlinear shallow water equations:

Conservation of mass

$$\frac{\partial z}{\partial t} + \frac{\partial}{\partial x}(ud) + \frac{\partial}{\partial y}(vd) = 0.$$

Conservation of momentum

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -g\frac{\partial z}{\partial x} - f\frac{u}{d}\left(u^2+v^2\right)^{1/2} + D\left[\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right] + \Omega v + \tau_{sx}\rho d$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = -g\frac{\partial z}{\partial y} - f\frac{v}{d}\left(u^2+v^2\right)^{1/2} + D\left[\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right] - \Omega u + \frac{\tau_{sy}}{\rho d}$$

where:

u, v are depth-averaged components of velocity in the x-direction and y-direction (m/s),

z - water surface elevation above reference datum (m),

h - water depth below reference datum (m),

d - total water depth ($d = h + z$) (m),

Ω - Coriolis parameter (s^{-1}), which is derived from the latitude specified when setting up the model,

g - gravity acceleration (m/s^2),

D - horizontal eddy viscosity coefficient (m^2/s),

τ_{sx}, τ_{sy} - the components of wind stress in x-and y-directions (kg/ms^2),

f - the friction coefficient calculated by the models using the rough channel law:

$$f = \frac{1}{32}\left[\log_{10}(14.8d/k_s)\right]^{-2}, \quad \text{here } k_s \text{ is roughness length (m).}$$

- At $t = 0$ an equilibrium is assumed.
- For the solid boundary: $u = v = 0$.
- At the liquid boundaries water levels are prescribed as follows:

$$Z(t) = Z_0 + \sum_{i=1}^{n} F_i(t)h_i\cos(\sigma_i t - g_i + P_i(t))$$

where:

Z_0 is value of the average water level (m),

h_i - Amplitude harmonic constant of the i-tide constituent (m),

g_i - phase harmonic constant of the i-tide constituent (degree)

(the above constants are varied along the open boundaries),

$F_i(t)$ - amplitude astronomical constant,

$P_i(t)$ - phase astronomical constant (degree)

(the above constants are varied with time at all open boundaries),

σ_i - angle velocity of the i-tide constituent (degree/second),

t - time (s),

n - tide wave number.

For GT water elevation values at liquid boundaries were computed according to the distribution of amplitudes and phases for the four main tidal constituents: M_2, S_2, K_1, O_1 at two bounds:

+ Quynh Chau Strait

+ GT Mouth Cross Section.

This distribution was obtained by CMESRC thanks to the tidal simulating of the South China Sea [2, 3], and calibrating with some data resources of field survey at the Gulf Mouth Cross Section. The bathymetry for the simulation was compiled by many maps and given by the Data Bank of GIS department of CMERSC.

In using TIDEFLOW-2D software, patching technique has been applied. According to this technique, the computed region can be divided into areas of difference grid size. The size of the fine grid is three times less then the adjacent coarse one. In this way, we can choose desired space size of grid for the simulated area and it equals $1/3^n$ the size of the beginning course grid, if number of patching times is n. For instance, if we need to make 100 m for the space size of the finest grid and will do 4 patching times, so we need to take 8100 m for the beginning grid size.

3. The model testing

3.1. Comparison between computed and observed harmonic constituents

Values of the four main tidal constituents M_2, S_2, K_1, O_1 at the 44 coastal stations, and islands were compared with computed ones. The result of comparison is given in Table 1. We can see that the errors of the comparison at majority of the stations are acceptable not only for amplitudes but also for the phases of the four constituents.

3.2. Comparison with Tide Tables

Computing for the tidal level in GT has been carried out at any moment of the year and in any monthly period. The computed tidal levels was compared with the correlative ones in the Tide Tables at the six stations: Hon Gai, Cua Ong, Hon Dau,

Table 1. Computation between given and computed harmonic constituents

No	Station's name	M2					S2					K1					O1				
		(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)
1	Lo Chuc San	25	145	5	2	18	7	186	3	48	37	80	68	2	16	2	79	18	7	6	8
2	Co To	20	138	2	6	8	5	198	2	36	30	75	83	3	4	4	91	18	-9	10	-10
3	Thien Mon	19	150	5	-3	26	7	200	1	37	14	72	81	9	6	13	81	16	4	11	5
4	Ke Bao	20	145	3	2	15	10	190	-3	50	-30	70	83	11	4	16	80	18	5	9	6
5	Van Hoa	26	166	-1	-19	-5	5	205	3	32	48	84	92	-2	-5	-3	91	29	-6	-2	-6
6	Dao Rua	12	130	4	20	29	2	148	3	89	163	75	84	2	3	3	87	15	-6	12	-6
7	Cua Ong	13	157	1	-10	6	4	158	0	88	8	81	92	-4	-2	-5	87	39	-5	-12	-6
8	Hon Gai	8	115	-4	74	-47	4	128	-2	214	-51	73	90	1	1	1	82	28	-3	-1	-4
9	Cua Binh Yen	5	146	-1	22	-20	2	144	-1	230	-50	69	78	4	12	6	74	22	4	5	5
10	Cat Ba	4	102	-2	0	-55	3	137	-2	-89	-67	72	89	-1	1	-1	79	26	-2	1	-3
11	Long Chau	0	0	2	135	0	0	0	1	51	0	70	88	0	2	0	70	24	6	3	9
12	Bach Long	9	103	-3	-13	-32	4	133	-2	17	-55	77	82	-14	5	-18	78	17	-7	7	-9
13	Cua NamTrieu	0	0	3	216	0	0	0	2	33	0	70	85	3	5	4	70	27	8	0	11
14	Do Son	4	102	-2	126	-50	3	136	0	-94	0	72	89	0	1	0	70	26	7	4	10
15	Hon Dau	6	38	-4	301	-67	5	101	-2	-53	-38	70	91	0	-1	0	78	26	-2	4	-2
16	Ba Lat	13	32	-3	304	-22	5	123	1	-69	22	62	102	3	-9	4	73	38	-2	-5	-3
17	Van Ly	17	357	0	-18	-1	9	91	0	-34	-1	51	89	10	7	20	69	25	-1	11	-1
18	Hon Ne	18	351	5	9	28	7	112	4	-49	57	68	92	-9	7	-13	69	17	-3	19	-4
19	Hon Me	20	357	7	-12	35	10	100	2	-34	20	60	92	-5	13	-8	60	38	3	1	5
20	Lach Truong	23	1	1	344	5	11	94	0	-31	-2	52	96	7	6	14	66	29	1	7	1
21	Lach Trao	25	17	0	328	-2	9	73	2	-7	20	55	94	3	8	6	64	40	1	-4	2
22	Hon Ngu	30	2	1	343	3	10	84	3	-12	30	50	87	1	24	2	59	30	0	12	0
23	Cua Hoi	29	5	1	340	4	9	76	4	-4	40	47	106	3	5	6	56	34	2	8	4
24	Cua Sot	28	306	1	39	4	10	64	2	8	22	38	94	9	20	23	55	33	0	12	-1
25	Vung Chua	20	10	3	-10	15	10	15	-1	57	-10	20	130	12	-7	60	40	37	0	8	0
26	Ron	21	355	3	-10	13	8	71	2	2	20	20	100	14	23	68	34	32	7	16	21
27	Cua Gianh	23	355	0	5	-1	6	53	3	19	43	23	106	8	20	34	33	34	5	14	17
28	Nhat Le	22	356	0	4	1	6	21	2	51	38	19	107	10	22	51	26	39	8	12	29
29	Cua Tung	17	353	2	-14	13	5	46	1	20	30	6	103	12	35	181	14	39	8	15	54
30	Con Co	19	351	0	-15	1	5	356	1	67	13	6	66	9	69	142	14	33	6	15	45
31	Thuan An	18	322	-2	5	-10	4	28	0	23	-5	3	255	6	-99	173	2	5	8	55	335
32	Chon May	17	310	-3	5	-18	3	0	0	33	0	16	285	-5	-39	-31	9	247	-7	-31	-78
33	Da Nang	17	301	-4	8	-24	6	340	-3	35	-48	20	290	-4	-32	-18	13	244	-5	-22	-38
34	Long Mon	30	160	15	-16	50	10	195	7	36	70	90	71	-2	10	-2	90	30	-1	-6	-1
35	Bac Hai	38	165	8	-24	21	12	201	5	24	42	3	72	-16	6	-16	13	38	-25	-20	-22
36	Vi Chau	30	185	10	-47	33	10	225	5	-3	50	80	73	2	2	3	80	30	5	-12	6
37	Dieu Thach	20	195	6	-63	30	15	260	-5	-41	-33	65	75	6	-15	9	70	20	2	-8	3
38	Xin In	22	200	1	-59	5	15	240	-6	-15	-40	70	75	-7	-6	-10	73	15	0	6	0
39	Duong Pho	20	180	0	-66	0	12	220	-5	-28	-42	65	70	0	2	0	70	10	5	8	7
40	Tung Hai Tan	18	62	-3	-32	-17	3	138	2	-27	67	52	57	-4	6	-8	62	356	-3	13	-5
41	Tang LouChiao	20	205	-9	-40	-45	20	250	-14	17	-70	60	76	-3	-28	-5	60	25	-4	-19	-7
42		13	353	1	-59	5	4	50	1	-44	14	28	354	-2	-36	-7	26	312	-2	-30	-6
43	Cu Lao Cham	17	300	-5	3	-29	6	340	-3	24	-50	23	294	-4	-33	-17	17	247	-5	-16	-29
44	Kikuik	17	292	-6	8	-35	6	339	-3	27	-50	27	298	-5	-34	-19	23	251	-7	-17	-30

(1) Given amplitude(cm) **(2) Given phase (degree)** **(3) Absolute error for amplitude (cm)**
(4) Absolute error for phase (degree) **(5) Relative error for amplitude (%)**

Cua Hoi, Cua Gianh and Cua Tung. The results of the comparison are acceptable. Fig. 1, Fig. 2 are examples of the comparison at Cua Ong St. in 7/1994, and 12/1994.

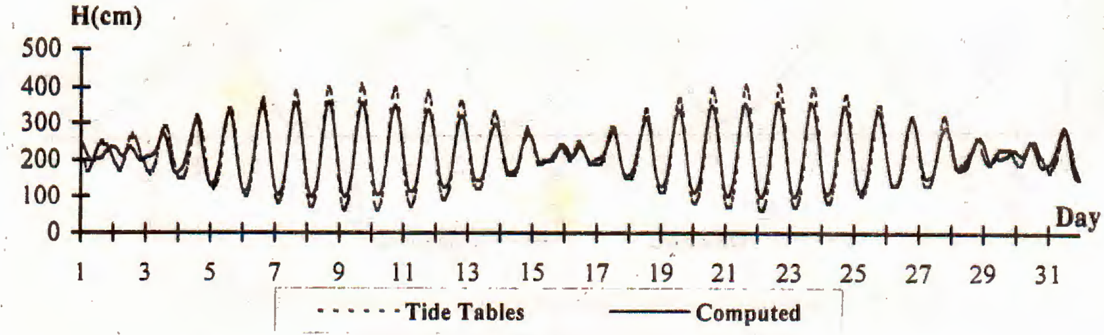

Fig. 1. Comparison between Tide Tables and computed tidal level at Cua Ong in July 1994

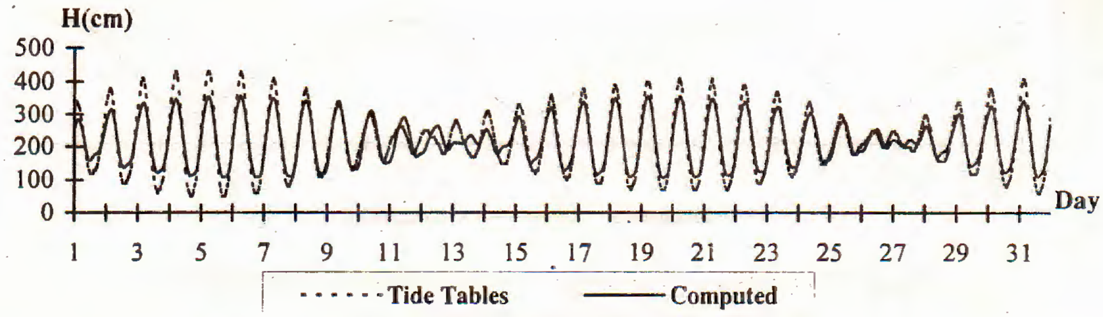

Fig. 2. Comparison between Tide Tables and computed tidal level at Cua Ong in December 1994

3.3. Comparison with observed data

The software had been tested also by comparison between computed results and the data observed by CMESRC since 1993 up to now. The data series are observed tidal levels and tidal currents measured continuously for 1, 3, 5 or 7-days periods. For GT, the comparison between computed tidal levels and observed values was carried out at about 10 stations. Nevertheless, it was done for tidal current at nearly 20 stations located along the coastal zone of GT. The figures, from Fig. 3 to Fig. 8, are examples of the comparison. Satisfying result for tidal regime comparison shows high simulation ability of TIDEFLOW-2D. However this remark denotes also high reliability of the CMESRC's observed data.

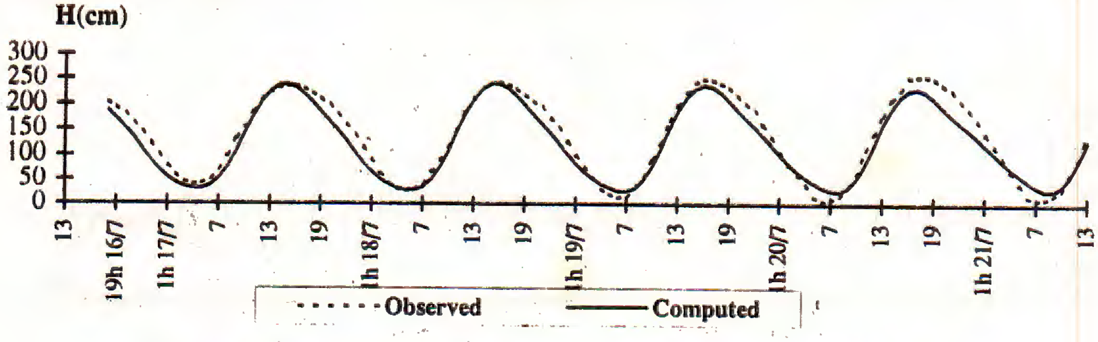

Fig. 3. Comparison between observed and computed tidal level at Nam Dinh from 16 to 21 July 1993

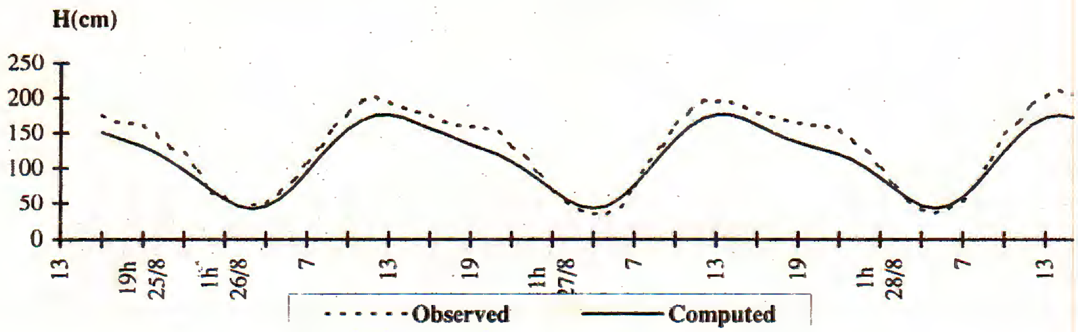

Fig. 4. Comparison between observed and computed tidal level at Vung Ang from 25 to 28 August 1996

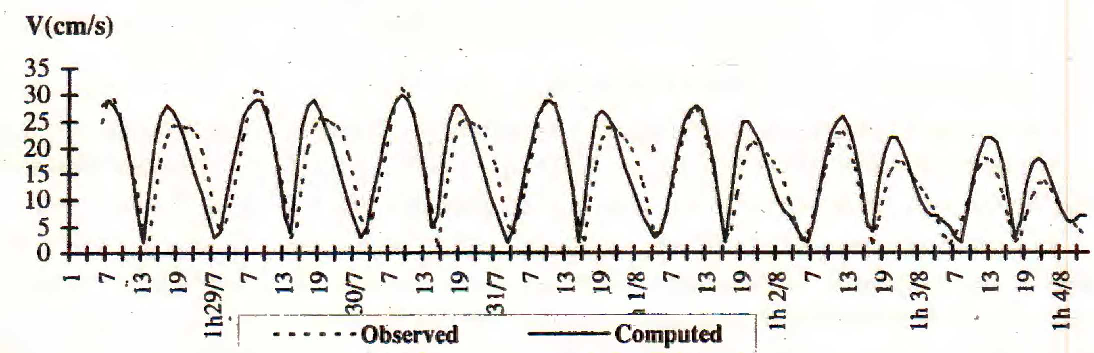

Fig. 5.1. Comparison between observed and computed velocities at Le Thuy (T20) from 28 July to 4 August 1996

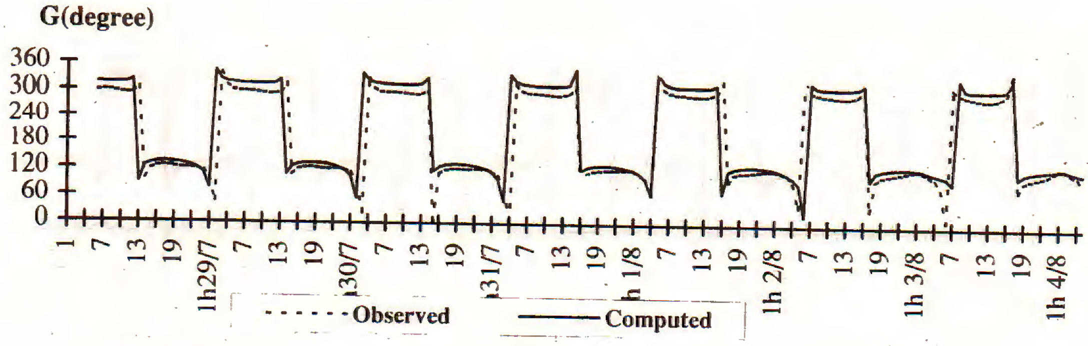

Fig. 5.2. Comparison between observed and computed current directions at Le Thuy (T20) from 28 July to 4 August 1996

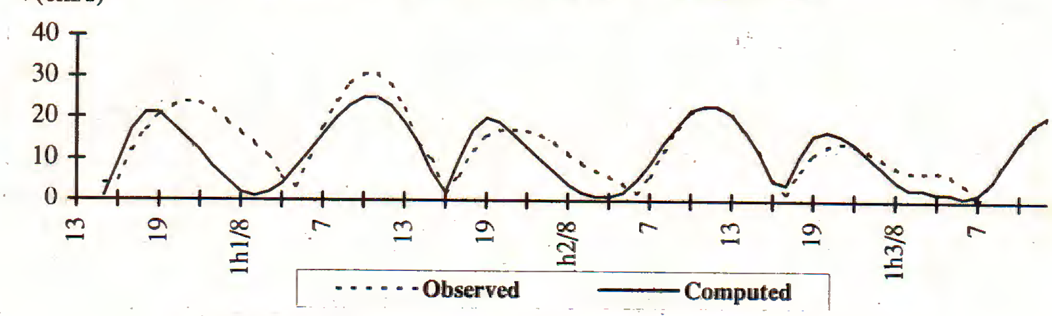

Fig. 6.1. Comparison between observed and computed velocities at Le Thuy (T10) from 31 July to 3 August 1996

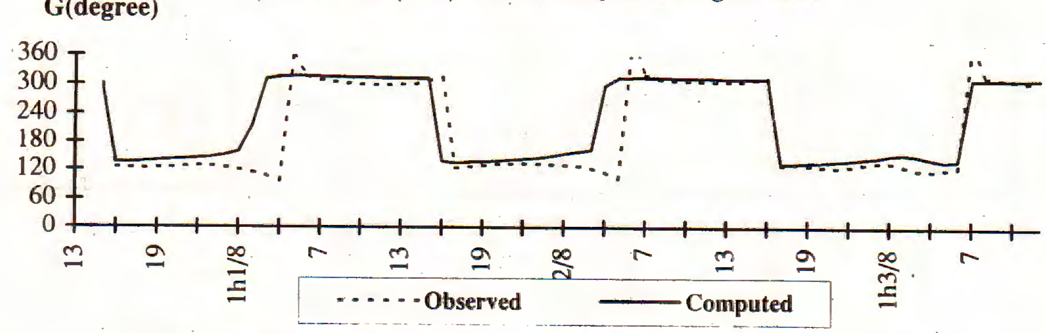

Fig. 6.2. Comparison between observed and computed current directions at Le Thuy (T10) from 31 July to 3 August 1996

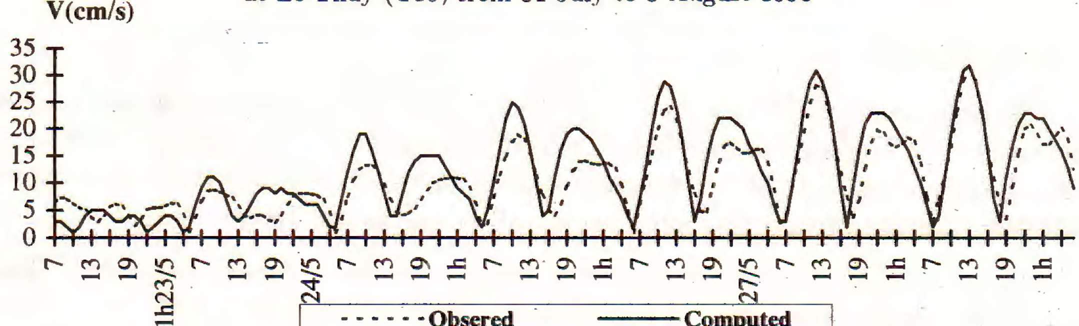

Fig. 7.1. Comparison between observed and computed velocities at Cua Sot from 22 to 29 May 1994

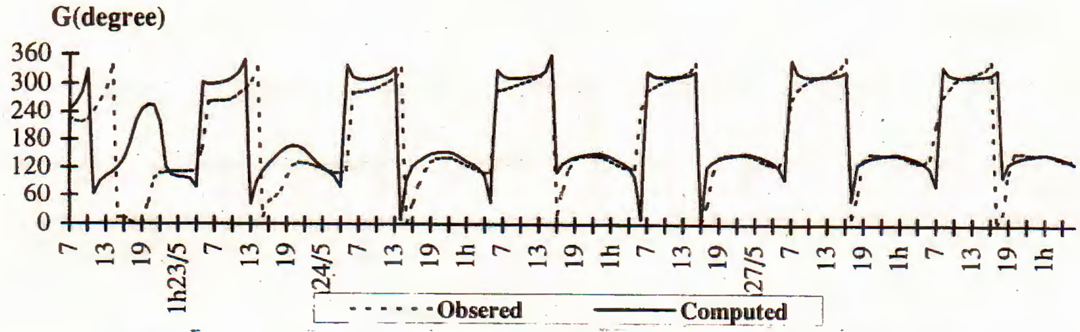

Fig. 7.2. Comparison between observed and computed current directions at Cua Sot from 22 to 29 May 1994

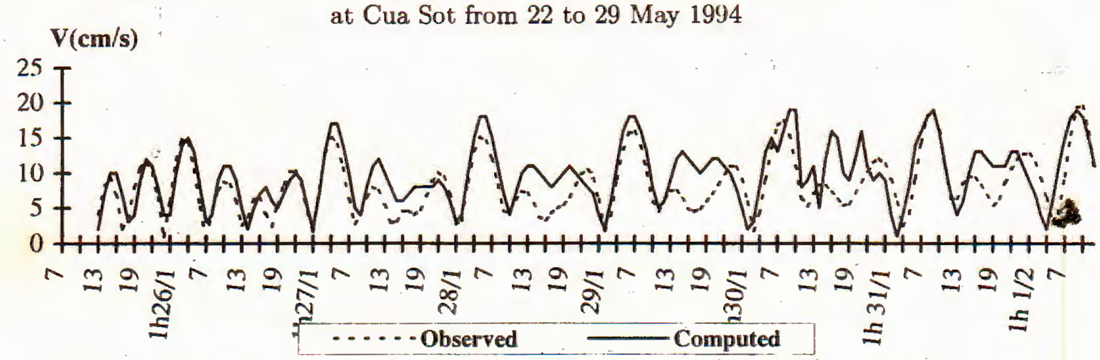

Fig. 8.1. Comparison between observed and computed velocities at Hoang Hoa from 25 January 1 February 1999

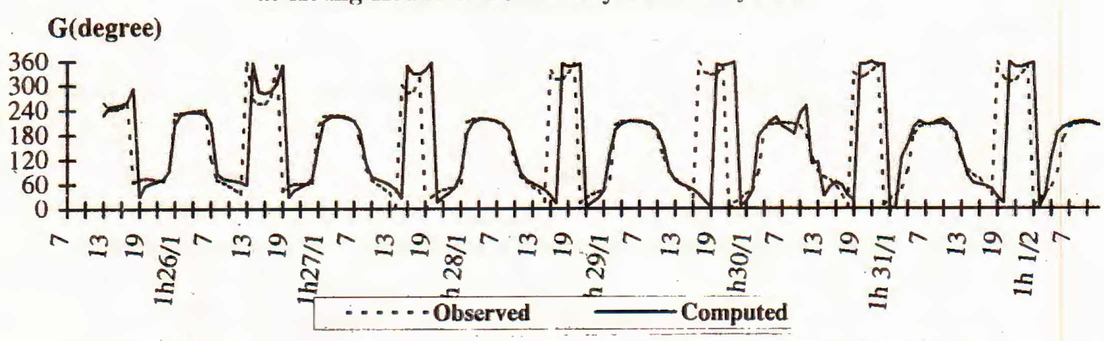

Fig. 8.2. Comparison between observed and computed current directions at Hoang Hoa from 25 January to 1 February 1999

4. Conclusion

The numerical model based on TIDEFLOW-2D for the tidal levels and currents for the Gulf of Tonkin was established and tested carefully. The testing results show a good agreement and this model can be used for simulation the tidal movement in the Gulf. Results of such like simulation will be published later.

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MÔ HÌNH SỐ TRỊ VỀ THỦY TRIỀU VÀ DÒNG TRIỀU TẠI VỊNH BẮC BỘ

Bài này trình bày kết quả của việc thiết lập mô hình số trị dựa trên phần mềm TIDEFLOW-2D nhằm tính toán mực triều tại vịnh Bắc Bộ. Mô hình được kiểm định bằng cách: i) so sánh số liệu quan trắc và tính toán hằng số điều hòa mực nước triều của 4 sóng chính: M_2, S_2, K_1, O_1 tại 44 trạm quan trắc ven bờ và các đảo của Vịnh; ii) so sánh giữa mực triều tổng hợp tính được với mực nước ghi trong bảng thủy triều tại 6 trạm quan trắc quốc gia: Cửa Ông, Hòn Gai, Hòn Dấu, Cửa Hội, Cửa Gianh và Cửa Tùng tại thời điểm bắt kỳ trong các chu kỳ kéo dài hàng tháng; iii) so sánh mực nước triều và dòng triều giữa đo đạc và tính toán tại nhiều trạm khác nhau trong các khoảng thời gian quan trắc liên tục và dài ngày kể từ năm 1993 đến nay.

Các kết quả thử nghiệm nêu trên cho thấy mô hình được thiết lập tốt và có thể sử dụng để mô phỏng các bài toán khác nhau về chuyển động triều ở Vịnh Bắc Bộ như i) hằng số điều hòa, ii) bức tranh dòng triều, iii) mực triều cực trị v.v... Các kết quả đó sẽ được công bố sau này.