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NUMERICAL INVESTIGATION OF M2-TIDE IN THE MEDITERRANEAN SEA WITH ITS REAL BOUNDARIES AND OF GRID SIZE 15'X 15'.

By

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Key Words: M2-Tides, Mediterranean Sea.

ABSTRACT

The M2- co-oscillating tide has been investigated numerically in the Mediterranean with grid resolution of 15'X 15'. The basin is co-oscillating with the Atlantic through Gibraltar Strait. The observed oscillatory movement of the water level at Gibraltar was taken to represent the boundary condition at the opening.

The co-oscillating motions caused a change in the time of occurrence of maximum amplitudes (co-tidal lines) for about one to two hours in the eastern and the western basins. The changes in the amplitude values due to such co-oscillations are more pronounced in the western basin than in the eastern one.

The ratios of the co-oscillating to the independent tides are relatively higher in the western basin than in the eastern basin. A minor influence has been observed in both Adriatic and Aegean Seas.

Generally, the results are mostly in good agreement with observations except at some locations where relatively higher amplitude values were obtained. These may be attributed to the high energy penetrating at the opened boundary, which may be improved if more fine grid resolution is used. The influence of shallow water depths has been considered. In addition, the spatial distribution of currents at different lunar times were also presented which showed the way of exchange of water between the different basins in the co-oscillating conditions.

INTRODUCTION

The tides in the Mediterranean Sea are known to be relatively weak in general (with ranges of about 50-70 cm) if compared with other adjacent seas as North Sea, Red Sea and Arabian Gulf. The Mediterranean Sea is composed only of two basins (eastern and western basins), though it is connected freely with two other small seas (Adriatic and Aegean Seas). Such structure makes its bottom topography and coastal configuration too complicated that they influence greatly its tidal pattern. The greatest depth is about 4500 m in the northern part of the Ionian Sea. Mostly, the shallow area is confined in front of Egypt, Libya and in the straits.

During the last four decades, different numerical methods have been developed by many investigators (e.g Hansen, 1956, 1962), concerning the study of tides and water circulation in the North Sea. Fischer (1929) Bretschneider (1968), Ramming (1968), Trepka (1968), Flather & Heap (1975), and Hunter (1984) have applied these methods in different regions to compute the tides mainly in shallow waters. Sterneck (1915) and Defant (1916 and 1961) found that the Mediterranean is of particular interest, because of its shape and depth, and hence they made attempts to compute its tides as canal - shaped sea areas. Their results are agreeable at some locations. The tidal motion in closed rectangular basins like the Mediterranean has been studied by Eid et al. (1993), while that with real shape and different boundary conditions has been considered by Abdallah et al. (1993). Krauss (1973) and Soliman & Mayiza (1993) have mentioned that the wave patterns change markedly with changes in depth. Such conclusion reveals that the resolution of the grid system must be increased which is the target of the present work. This work would require enormous computation effort The oscillations caused by the external forces are not only produced by the tide-generating forces but also through the co-oscillating motion with the Atlantic. At the entrance near Gibraltar, the water elevation was prescribed periodically from the observations. The computation has been repeated such that the shallow areas of less than 50.0 m have been assumed to be of constant depth of 50.0 m while the offshore deep water areas have not changed.

The spatial distribution of depth mean current deduced from the M2-independent and -co-oscillating tides are shown at intervals of three Lunar hours covering one tidal period.

THE MODEL

The model applied is of the Hansen type using the following hydrodynamical equations

$$\frac{\delta u}{\delta t} \quad fv + ku + g \frac{\delta \zeta}{\delta x} \quad X = 0 \qquad . \qquad (1)$$

$$\frac{\delta v}{\delta t} + fu + kv + g \frac{\delta \zeta}{\delta y} - Y = 0 \qquad ..... \qquad (2)$$

$$\frac{\delta \zeta}{\delta t} + \frac{\delta (Hu)}{\delta x} + \frac{\delta (Hv)}{\delta y} = 0 \qquad ... \qquad (3)$$

where:

x, y : cartesian co-ordinates in the east and north direction respectively,

t : time,

ζ : water elevation of the sea surface,

u, v : components of the depth mean current in x & y directions respectively,

H : total depth of water,

f : Coriolis parameter,

k : coefficient of bottom friction in the linear form,

g : acceleration of the earth's gravity,

X, Y : the components of the tide - producing force in east and north directions respectively.

Figure 1 shows the Mediterranean Sea with its basins, adjacent seas and the location of stations at which observations are available as given by Defant (1961), Mosetti (1987) and the Admiralty Tables.

The approximation method with an explicate finite difference scheme has been established and described by the authors in other work (Soliman et al.,1993).

The finite difference grid used is shown in Fig.2. The basic array comprises 10816 points with I = 64 and J = 169.

As initial values zero values were assigned for water elevation and current velocity components

According to Courant Friedrichs Lewy criteria Δx= 22.66 km. Δy 27.79 km. and Δt = 62.1025 seconds were chosen.

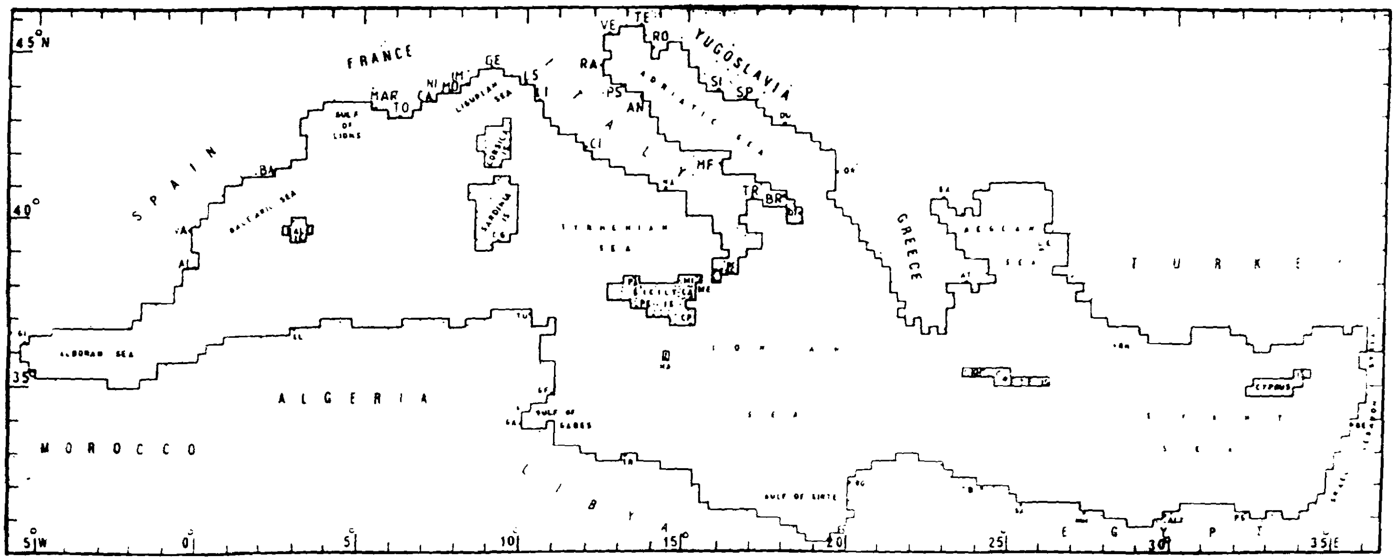

Figure 1: The Mediterranean Sea Map.

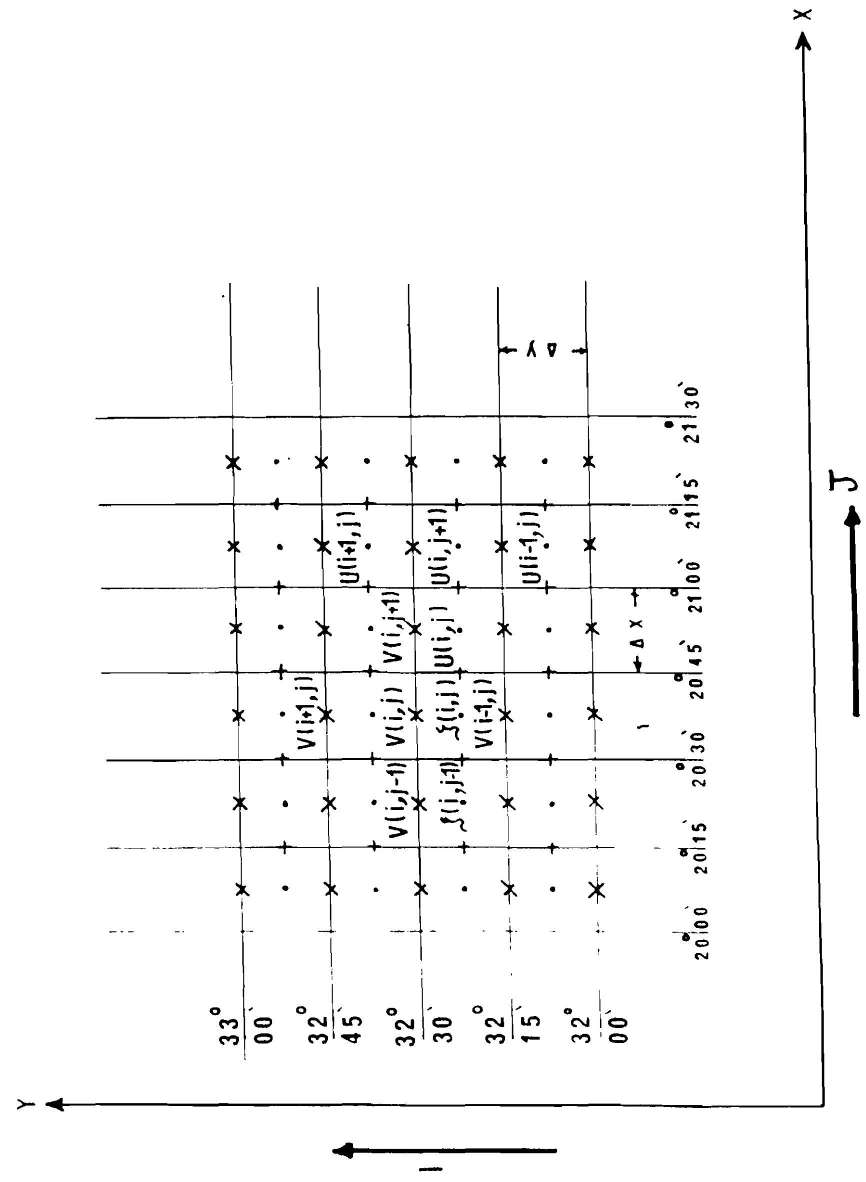

Figure 2: The grid system used in the numerical computation with the positioning of ζ-, u-, and v- points.

RESULTS AND DISCUSSION

The investigation of the tidal motion in the Mediterranean Sea has been carried out as previously mentioned, by few investigators as attempts to improve the methods used either analytically or theoretically in order to get as most as possible satisfactory results with the observations particularly along the coast. Actually, many difficulties arised on applying such methods due to the numerous irregularities found in the coastal and bottom configurations and the influence of frictional forces. Up-till now, and due to the disagreement between the theoretical values and observations, there is a continuous need for getting more informations through observations at different locations along the Mediterranean coasts. Indeed much efforts have been done in the last decades by fixing new tide gauges along these coasts specially along the European side. Meanwhile, on the African side there is still a great lack in getting such informations.

In fact, numerical methods have been improved considerably on studying tides and water circulation in oceans and seas. It is evident from numerical computations of M2-tide in closed basins of different shapes by the authors (Eid et al., 1993 ; Abdallah et al.,1993 ; Soliman and Maiyza, 1993) that the coastal boundaries and bottom topography influence greatly the tidal pattern. Accordingly, more fine grid resolution has been established with dimension 15' X 15'. The co-ranges and co-tidal patterns for M2-tide in the Mediterranean as a closed basin have been discussed (Fig. 3a & b), in another work (Soliman et al., 1993). The mean depth currents of that motion as well as the co-oscillating motions with the Atlantic will be considered in the present study.

Generally, the independent tide in the Mediterranean was found to consist of a nodal line in each basin as well as in the Straits of Missinia and Cicily. The nodal line in Cicily Strait has been developed into an amphidromy (Fig. 3a & b). Great tidal ranges were found in Syrits Minor and Gulf of Gabes (300 cm) north Adriatic (100 cm) and Agean Sea (60 cm). Meanwhile, small ranges were obtained in the eastern basin (30 cm), Ligurian Sea (14 cm) and Alboran (10 cm).

On considering the co-oscillation of the Mediterranean with the Atlantic Ocean, the water elevation at the opening (near Gibraltar) was assumed to vary periodically according to the relation:

$$\zeta = H \cos (\sigma' t - \phi).$$

where:
H : is the amplitude of the penetrating oscillation at the opening which is taken as 38.0 cm.,
σ' : is the frequency of the oscillation, and
ϕ : its phase angle.

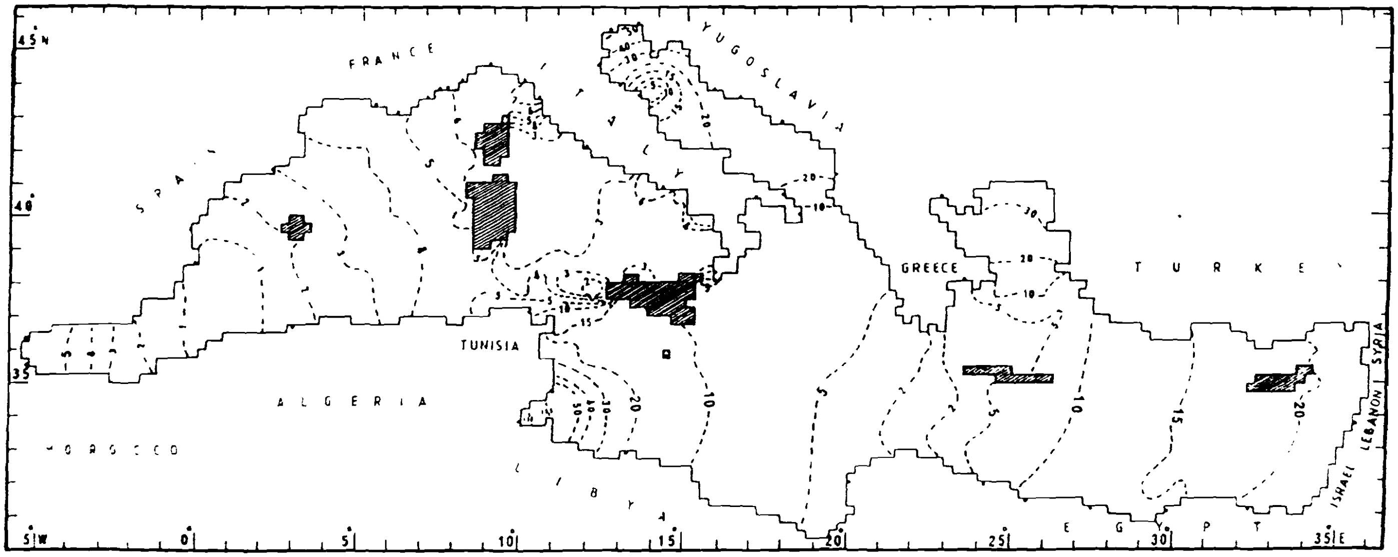

Figure 3a: M2-Independent Tide in the Mediterranean Sea with its real boundaries and depths and grid size 15' x 15':

a- The co-ranges are in cm.

b- The co-tidal lines correspond to lunar hours of high tide after lunar-transit at Greenwich.

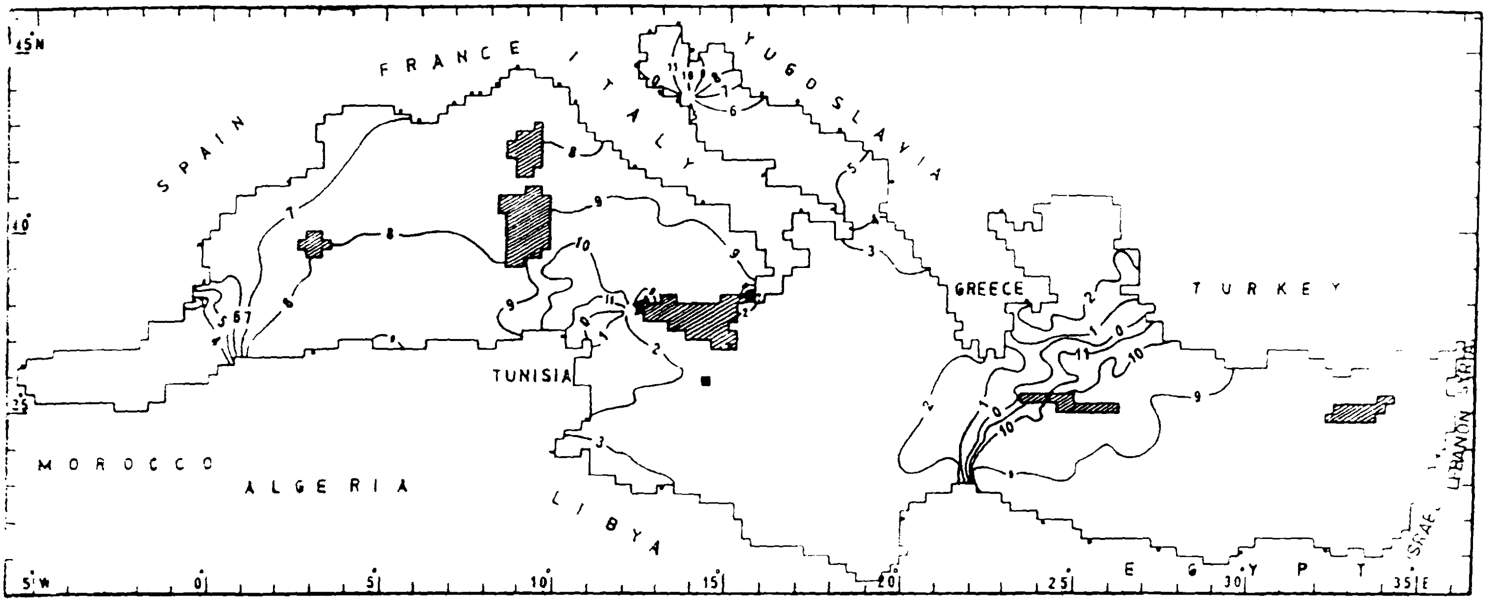

Figure 3b: M2-Independent Tide in the Mediterranean Sea with its real boundaries and depths and grid size 15' x 15':

a- The co-ranges are in cm.

b- The co-tidal lines correspond to lunar hours of high tide after lunar-transit at Greenwich.

M2-TIDE IN THE MEDITERRANEAN SEA ITS REAL BOUNDARIES.

By using the fine grid resolution with dimension 15'X 15' , a good agreement was found between the computed values and observations (Table 1). The results are presented in charts with co-ranges (in cm) and co tidal lines correspond to lunar hours of high tide after lunar - transit at Greenwich (Figs. 4a, b).

The patterns show the tidal distribution over the whole Mediterranean and the location of the nodal lines as obtained by computations. These lines have been described in previous works as being extended between two different regions. Defant (1961) mentioned that while one nodal line in the western basin is between Cape de la Nao, between Valencia and Alicante - and some point on the Algerian coast - between Alger and Oran, is existing in the Aegean Sea near its opening. He found that, as the establishment at Rhodes is about 10.6h while at Salonika is about 4.0h, a nodal line is thus existing somewhere north of Rhodes and south of Leros. Similar description was given with respect to the nodal line in the eastern basin. Hence, it is concluded that no accurate informations have been given to the nodal lines of the M2- tidal motion in the Mediterranean. Therefore, the presentations, as given in figures 4a-d can be considered as the most accurate patterns obtained till now.

The co-oscillating motion with the Atlantic shows wide variabilities from one location to another. This feature can be clearly observed on comparing the results obtained from both cases of the independent and co-oscillating tides. Instead of getting, during the co-oscillation motion, a clear variation in the time of occupancy of high tide in the western basin as in , the case of the independent tidal motion i.e. between Balearic, Ligurian and Thyrrhenian Seas the whole area is specified with the same establishment of 7.0h. This indicates that mostly the whole basin rises and falls simultaneously. The sea level is markedly increased which may be related to the great amount of tidal energy penetrating through the Strait of Gibraltar. e.g. the amplitudes at Niece Genova, Civita - Vecchia and Napoli showed values less than 7.0 cm in the case of independent tide, while in the co-oscillating conditions the amplitudes were greater than 10.0 cm.

Contrarily, in the eastern basin the amplitudes have been greatly reduced such as in the northern part of Levantine which decreased from 15.0 - 20.0 cm to about 10.0 - 15.0 cm, in the Gulf of Gabes from 300 cm to about 160 cm, in the Aegean Sea from 30.0 cm to 20.0 cm, in the northern part of the Adriatic from 50.0 cm to less than 35.0 cm. These peculiarities reveal that the co-oscillating motion with the Atlantic has a significant influence on the amplitude not only in the western basin but also in the eastern one. On the other hand, the establishments showed a minor influence in the eastern basin.

To understand the influence of the depth in the shallow areas upon the tidal motion, the model has been applied again in such a way that all depths less than 50.0 m have been assumed to be 50.0 m. Figure 5a & b presents the results obtained which do not differ greatly from that produced in the case of natural depths. This reveals that the shallow depths have only certain influences in a certain localized coast regions while the off-shore areas did not change (Table 1).

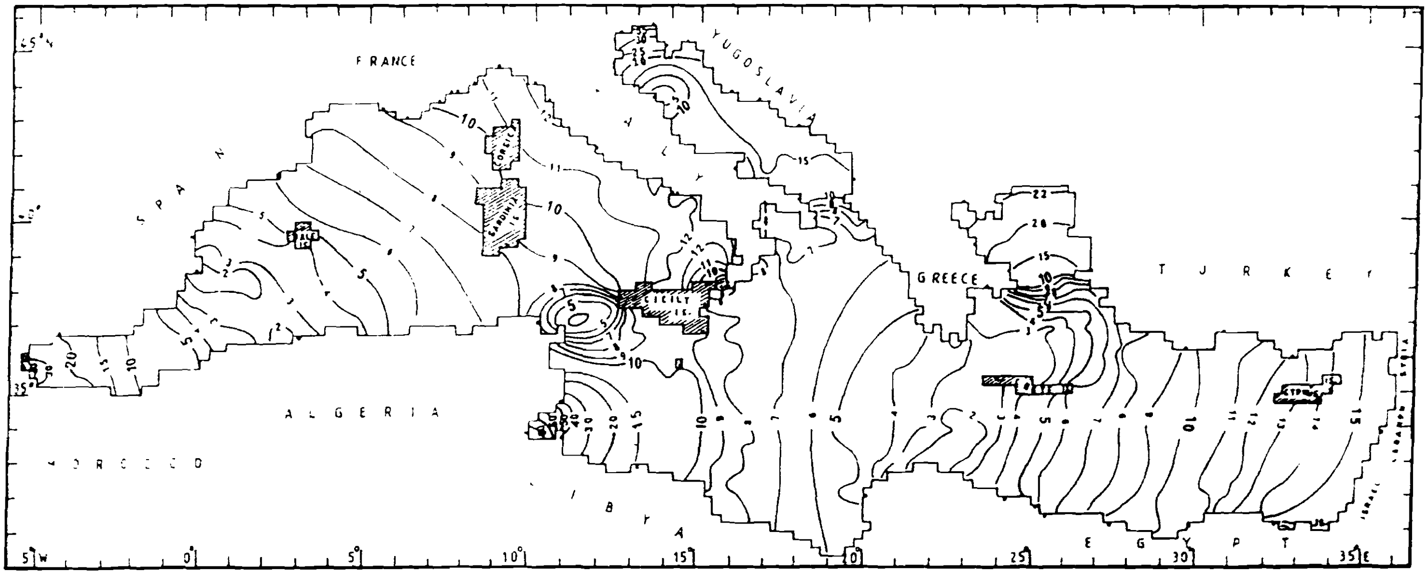

Figure 4a: M2-co-oscillating Tide in the Mediterranean Sea with its real boundaries and depths and grid size 15' x 15':

a- The co-ranges are in cm.

b- The co-tidal lines correspond to lunar hours of high tide after lunar-transit at Greenwich.

M2-TIDE IN THE MEDITERRANEAN SEA ITS REAL BOUNDARIES.

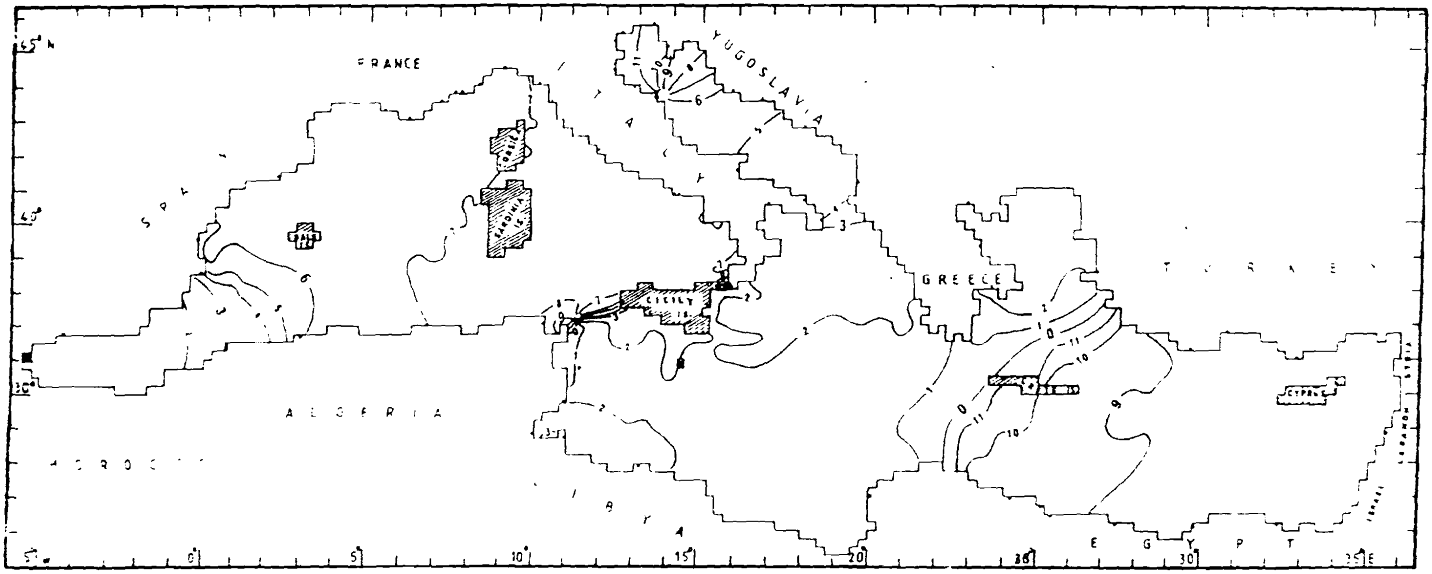

Figure 4b: M2-co-oscillating Tide in the Mediterranean Sea with its real boundaries and depths and grid size 15' x 15'.

a- The co-ranges are in cm.

b- The co-tidal lines correspond to lunar hours of high tide after lunar-transit at Greenwich.

Bretschneider (1968) has used the HN method that developed by Hansen (1956, 1962) to investigate the tides in the North Sea. He assumed a constant depth of 80 m at the center of the North Sea, while in the coastal area the natural depths have not been changed. He found that the course of the co-range and co-tidal lines is almost the same as that of the corresponding lines of the natural M2-tide. He concluded that the depth distribution of a narrow area appoint to coast is of great importance for the motion in the whole area and that the depth distribution in the deep water areas has no great influence on the results.

The tidal currents for both the independent and co-oscillating M2-tidal motions have been computed and represented for every three lunar hours (Figs. 6a-d and 7a-d). While the current pattern in the eastern basin showed a slight variation between the motions induced by the independent - and co-oscillating - tide, the patterns in the western basin reflect the strong influence of the co-oscillating motions that exerted between both the Atlantic and Ionian Sea from one side and the western basin on the other side.

During low tide (at zero lunar hour, Fig. 7a) the tidal current in the eastern basin is directed from Levantine into the Aegean, Adriatic and Ionian Seas and in particular Syrits Minor and Gulf of Gabes. While in the western basin, the current is partially directed from the Tyrrhenian into the Ionian and the rest is flowed out of the basin into the Atlantic with a speed of about 13.2 cm/sec. The same pattern is nearly observed during the last quarter (at nine lunar hour, Fig. 7d) except in the Adriatic where the water is flowing out and directed towards the Ionian Sea. The mean out-flowing current to the Atlantic attains its maximum value of about 36.0 cm/sec during that time. On the other hand, high tides were occurring during the other two quarter, when the current is flowing into the western basin from both the Atlantic (with a maximum mean speed of about 34.0 cm/sec) and the Ionian Sea.

CONCLUSIONS:

1- The application of the hydrodynamical numerical methods to investigate the M2-tide in the Mediterranean Sea showed a fairly good agreement between computations and observations. The results obtained encourage the continuity of the research program for investigating the other tidal components.

2- The results obviously indicate the location of the nodal lines and the developed amphidromies as well as the type of motion which is found to be stationary in both basins.

3- The slight increase that appeared in the amplitude particularly in the Levantine Sea may be attributed to the great amount of energy penetrating through the straits from one side and due to the constancy of the friction over the whole study area. The friction coefficient may not be considered as constant over all the grid points, but as a function of depth. Pekeris and Accad (1969) have considered this case in order to maximize the tidal friction in shallow waters, where they considered the friction coefficient as function of depth. This assumption may be considered in other work. More finer resolution of the grid points are required to get more reasonable current values through the straits.

4- The amplitudes and phases of M2-tide, as the lunar transit at Greenwich at several points along the Mediterranean coast, for both the computed and observed values were compiled and determined in table 1.

5- The co-oscillating motion of the Mediterranean with the Atlantic Ocean has a significant influence not only on the M2-tidal ranges of the western basin but also on the eastern basin and its adjacent seas.

6- The current patterns produced by the model , for both the independent and co-oscillating motions, showed in some detail the exchange of water between the two basins as well as between them and both the Atlantic and the adjacent seas

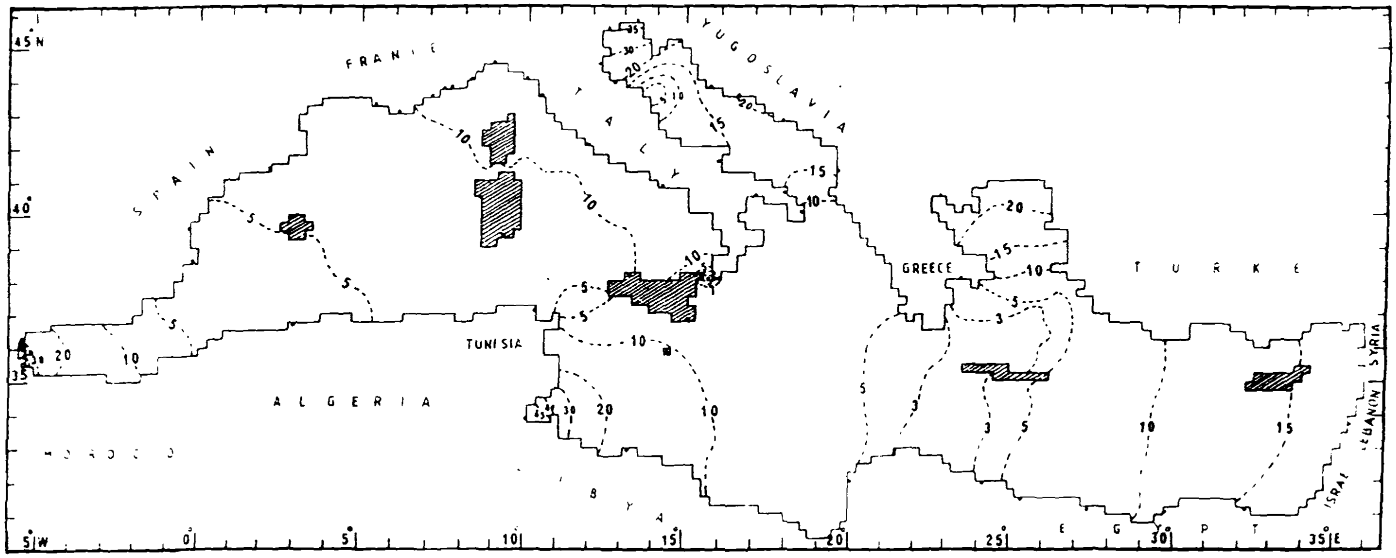

Figure 5a: M2-Co-oscillating tide in the Mediterranean Sea with its real boundaries and depths and with depths less than 50.0m be reblaced by a depth of 50.0m.

a- The co-ranges are in cm.

b- The co-tidal lines correspond to lunar hours of high tide after lunar-transit at Greenwich.

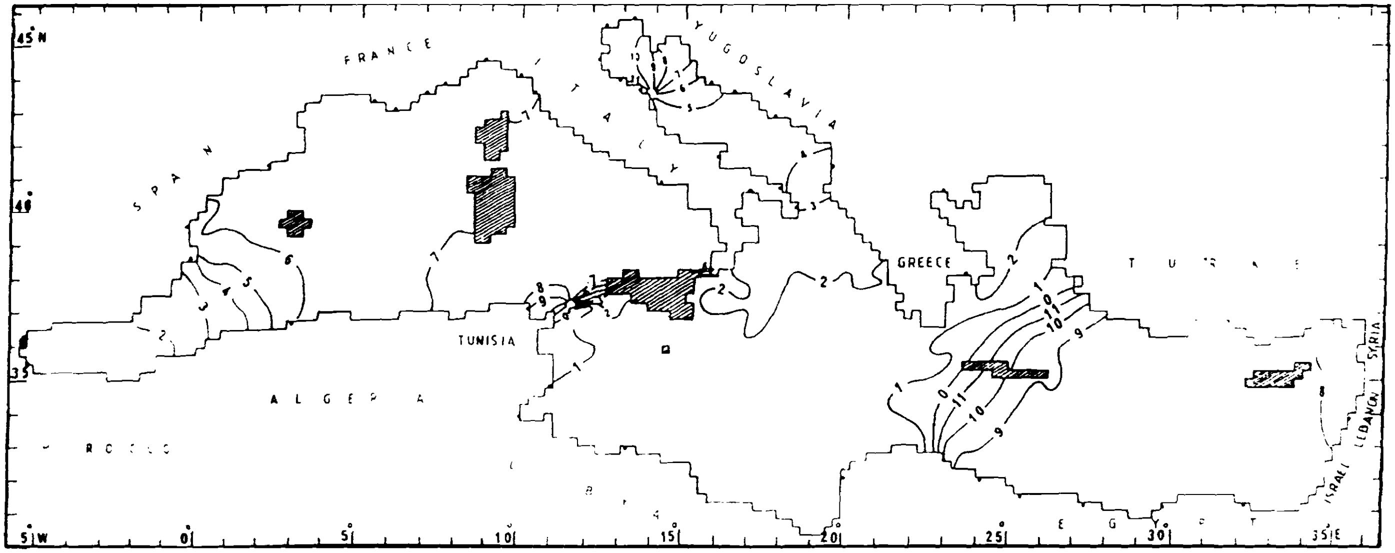

Figure 5b: M2-Co-oscillating tide in the Mediterranean Sea with its real boundaries and depths and with depths less than 50.0m be reblaced by a depth of 50.0m.

a- The co-ranges are in cm.

b- The co-tidal lines correspond to lunar hours of high tide after lunar-transit at Greenwich.

STATION	ABB.	LOCATION		PREVIOUS WORKS						PRESENT STUDY					
		LAT.	LONG.	CO- OSCILLATING TIDE						IND. TIDE		CO-OSCILLATING TIDE			
				OBSERVA - TION *		OBSERVA - TIONS **		CALCULA - TIONS +		REAL DEPTHS		REAL DEPTHS		IF H<50 THEN 50	
		N		A(cm)	ø	A(cm)	ø	A(cm)	ø	A(cm)	ø	A(cm)	ø	A(cm)	ø
		° ′	° ′								°		°		°
GIBRALTAR	GI	36 15	05 20 W	38.3	036	--	--	060.0	099	05.3	108	48.0	047	48.0	047
ALGER	AG	37 00	03 00 E	--	-	--	--	009.0	099	01.7	256	2.4	177	02.8	171
TUNIS	TU	37 00	10 10 E	--	-	--	--	17.0	099	09.1	338	6.6	265	07.3	271
SFAX	SF	34 35	10 45 E	42.0	106	--	--	080.0	099	84.0	081	48.6	064	34.8	039
GABES	GB	33 50	10 05 E	51.0	108	--	--	115.0	099	164.9	100	82.3	089	47.1	051
RAS TAGUERMESS	RT	33 48	11 04 E	27.0	098	--	--	060.0	099	66.1	098	37.7	076	31.9	053
TRIPOLI	TL	33 00	13 15 E	11.1	085	11.1	085	018.0	099	21.8	096	14.3	070	16.4	058
BANGHAZI	BG	32 10	20 20 E	--	--	--	--	001.0	099	04.9	066	04.8	044	05.9	048
TUBRUQ	TQ	32 10	24 00 E	01.0	343	--	--	001.5	279	07.0	259	04.5	280	03.6	260
BARDIA	BA	31 46	25 07 E	03.0	294	--	--	--	--	08.8	269	05.6	278	04.9	260
SALOM	SA	31 35	25 10 E	--	--	--	--	--	--	09.9	276	06.5	276	05.9	260
MARSA MATROH	MM	31 20	27 20 E	--	--	--	--	--	--	13.0	270	09.9	264	09.2	249
EL-HAMRA	HA	30 55	28 45 E	--	--	--	--	--	--	14.0	258	--	--	10.2	249
ALEXANDRIA	AX	31 10	29 50 E	07.2	305	--	--	014.0	279	15.0	262	10.6	260	10.7	246
PORT-SAID	PD	31 15	32 20 E	11.7	304	--	--	019.0	279	22.8	260	15.4	255	16.0	241
BEIROT	BE	33 50	35 30 E	13.4	304	--	--	021.0	279	20.8	256	15.1	252	16.3	241

STATION	ABB.	LOCATION		PREVIOUS WORKS						PRESENT STUDY					
		LAT.	LONG.	CO- OSCILLATING TIDE						IND. TIDE		CO-OSCILLATING TIDE			
				OBSERVA - TION *		OBSERVA - TIONS **		CALCULA - TIONS +		REAL DEPTHS		REAL DEPTHS		IF H<50 THEN 50	
		N		A(cm)	ø	A(cm)	ø	A(cm)	ø	A(cm)	ø	A(cm)	ø	A(cm)	ø
FAMAGUSTA	FA	35 07	33 57 E	11.0	323	--	--	--	--	19.5	262	14.3	256	15.5	243
KYRENIA	KY	35 20	33 20 E	10.0	322	--	--	--	--	18.1	260	13.1	255	14.1	242
ANAMUR	AM	36 05	32 50 E	--	--	--	--	--	--	17.9	259	12.5	257	13.4	244
ANATALYA	AN	36 53	30 42 E	--	--	--	--	--	--	15.0	262	10.5	257	11.2	244
MEYISTL	MY	36 08	29 35 E	07.0	303	--	--	--	--	15.1	267	9.2	267	10.0	252
SIMI	SI	36 35	27 45 E	04.0	327	--	--	--	--	11.0	276	7.2	285	7.4	269
COS	CO	36 53	27 18 E	04.0	329	--	--	--	--	09.9	307	6.2	302	6.2	285
LEROS	LE	37 08	26 50 E	03.0	002	--	--	--	--	06.3	340	5.6	340	5.4	323
STAMPALIA	ST	36 35	26 25 E	03.1	353	--	--	--	--	07.6	326	3.4	330	4.0	311
SALONIKA	SL	40 35	22 55 E	14.6	128	--	--	--	--	35.4	076	24.8	085	20.4	075
VOLOS	VO	39 21	23 00 E	22.9	100	--	--	--	--	29.2	074	21.3	081	20.4	071
AIWALI	AI	38 40	24 02 E	10.7	106	--	--	--	--	18.2	083	13.4	084	12.6	074
ATHENS	AH	38 00	23 40 E	--	--	--	--	--	--	04.3	060	03.8	062	03.5	056
KHANIA	KH	35 30	24 00 E	02.0	078	--	--	--	--	02.0	078	02.4	345	01.6	349
RHODES	RH	36 22	28 05 E	05.9	308	--	--	--	--	12.9	280	09.1	288	09.4	280
DURRES	DR	41 17	19 25 E	09.9	102	--	--	--	--	20.9	146	14.7	134	15.7	117
DUBROVNIK	DU	42 37	17 55 E	09.3	103	08.7	104	--	--	23.5	152	16.1	139	17.3	122
SPLIT	SP	43 30	16o25 E	--	--	07.6	121	--	--	25.6	172	19.8	156	18.3	148
SIBENIK	SI	43 40	15 55 E	06.3	135	06.3	135	--	--	23.4	181	18.2	171	20.1	142

STATION	ABB.	LOCATION		PREVIOUS WORKS						PRESENT STUDY					
		LAT.	LONG.	CO- OSCILLATING TIDE´						IND. TIDE		CO-OSCILLATING TIDE			
				OBSERVA - TION *		OBSERVA - TIONS **		CALCULA - TIONS +		REAL DEPTHS		REAL DEPTHS		IF H<50 THEN 50	
		N		A(cm)	ø	A(cm)	ø	A(cm)	ø	A(cm)	ø	A(cm)	ø	A(cm)	ø
ROVINJ	RO	45 05	13 40 E	--	--	17.8	263	--	--	38.5	329	27.7	309	17.8	156
RIJCKA	RI	45 20	14 25 E	10.0	249	--	--	--	--	29.7	263	22.8	247	20.1	232
PULA	PU	44 45	13 50 E	15.0	265	--	--	--	--	22.4	286	17.4	270	18.1	263
TR IESTE	TS	45 40	13 45 E	27.0	277	25.9	277	023.0	294	49.3	338	35.3	326	30.0	295
VENEZIA	VE	45 25	12 20 E	24.0	313	22.1	320	--	--	50.9	351	35.3	339	35.1	303
MALAMOCCO	ML	45 20	12 20 E	23.0	296	--	--	--	--	50.9	351	35.3	340	34.3	310
CHIOGGIA	CH	45 15	12 15 E	22.0	302	--	--	--	--	49.0	352	33.2	341	34.2	310
RAVENNA	RA	44 30	12 18 E	--	--	15.5	303	--	--	34.6	357	22.2	341	26.8	314
PESARO	PS	43 55	12 50 E	12.8	311	12.8	311	--	--	22.8	357	15.1	339	23.6	316
ANCONA	AN	43 37	13 30 E	06.7	329	06.0	345	--	--	02.3	040	00.6	334	03.7	334
MANEFRE DONIA	MF	41 35	15 55 E	--	--	10.0	113	--	--	23.9	153	15.8	142	17.1	121
BRINDISI	BR	40 37	17 55 E	08.7	104	08.7	102	009.7	114	19.1	151	11.7	140	13.2	122
OTRANTO	OT	40 10	18 30 E	--	--	06.5	110	006.5	114	08.0	124	07.3	109	08.7	097
TARANTO	TR	40 25	17 15 E	06.5	105	06.5	105	--	--	06.5	079	08.0	074	08.7	070
GALLICO	GL	37 55	15 45 E	--	--	05.8	098	008.5	114	07.3	073	05.9	047	06.6	043
REGGIO CALABRIA	RC	38 05	15 40 E	--	--	06.2	091	--	--	07.3	073	05.5	059	06.6	043
PUNTAFARO	PF	38 15	15 40 E	--	--	05.5	267	018.0	279	03.2	044	06.5	229	00.7	211
NAPOLI	NA	40 50	14 15 E	11.0	268	11.1	263	--	--	04.3	262	12.7	214	12.4	211
ISCHIA	IS	40 43	13 55 E	12.0	261	--	--	--	--	04.3	261	12.1	218	12.4	211

M2-TIDE IN THE MEDITERRANEAN SEA ITS REAL BOUNDARIES.

STATION	ABB.	LOCATION		PREVIOUS WORKS						PRESENT STUDY					
		LAT.	LONG.	CO- OSCILLATING TIDE						IND. TIDE		CO-OSCILLATING TIDE			
				OBSERVA - TION *		OBSERVA - TIONS **		CALCULA - TIONS +		REAL DEPTHS		REAL DEPTHS		IF H<50 THEN 50	
		N		A(cm)	ø	A(cm)	ø	A(cm)	ø	A(cm)	ø	A(cm)	ø	A(cm)	ø
CIVITA VECCHIA	CI	42 00	11 50 E	11.2	257	10.3	262	--	--	01.9	229	11.5	213	10.8	213
LIVORNO	LI	43 30	10 20 E	--	--	08.6	257	015.5	279	06.6	220	12.7	213	12.7	210
LA-SPEZIA	LS	44 05	09 50 E	--	--	09.4	244	015.5	279	07.0	217	12.2	211	12.5	209
GENOVA	GE	44 20	08 55 E	09.0	240	08.6	254	013.0	279	06.6	214	11.7	208	12.1	205
IMPERIA	IM	43 55	08 00 E	08.0	266	07.3	262	012.0	279	06.0	221	10.8	208	11.1	206
MONACO	MO	43 45	07 25 E	07.0	272	--	--	--	--	05.8	223	10.6	206	11.0	204
NIECE	NI	43 40	07 15 E	07.0	251	--	--	012.0	279	05.5	223	10.6	205	11.0	204
CANNES	CN	43 35	07 05 E	--	--	--	--	--	--	05.7	225	10.5	204	10.9	202
TOULON	TO	43 05	06 05 E	05.9	247	--	--	010.0	279	04.8	220	09.0	204	09.4	202
MARSEILLE	MS	43 15	05 20 E	06.7	230	--	--	008.0	279	05.1	209	08.8	201	09.3	198
BARCELONA	BA	41 20	02 10 E	--	--	--	--	000.5	279	03.1	194	06.4	191	06.9	189
VALENCIA	VA	39 30	00 20 W	--	--	--	--	002.0	279	01.0	168	03.5	172	04.1	170
ALICANTA	AL	38 20	00 30 W	01.8	059	--	--	006.5	099	01.1	134	01.7	093	02.2	165
MALAGA	MG	36 42	04 25 W	19.0	078			040.0	099	05.3	116	18.9	041	18.4	041
CAGLIARI	CG	39 10	09 10 E	08.5	255	07.6	264	013.0	279	06.0	284	08.2	218	07.9	219
PORTO EMPEDOCLE	PE	37 15	13 30 E	--	--	04.5	107	--	--	14.9	066	09.4	066	09.7	050
MAZARA DEL VALLO	MV	37 40	12 36 E	04.0	157	--	--	--	--	15.7	066	05.6	117	07.3	098
MARSALA	MR	37 45	12 28 E	07.0	236	--	--	--	--	07.0	236	07.5	210	06.6	214
CAPO PASSERO	CP	36 37	15 10 E	--	--	06.3	098	--	--	08.2	082	09.4	065	10.1	065

Table 1: cont

STATION	ABB.	LOCATION		PREVIOUS WORKS						PRESENT STUDY					
		LAT.	LONG.	CO- OSCILLATING TIDE						IND. TIDE		CO-OSCILLATING TIDE			
				OBSERVA - TION *		OBSERVA - TIONS **		CALCULA - TIONS +		REAL DEPTHS		REAL DEPTHS		IF H<50 THEN 50	
		N		A(cm)	ø	A(cm)	ø	A(cm)	ø	A(cm)	ø	A(cm)	ø	A(cm)	ø
CATANIA	CA	37 30	15 05 E	06.6	095	06.4	091	010.0	099	09.3	056	08.9	055	09.6	032
TAOR-MINA	TA	38 00	15 25 E	--	--	06.4	087	--	--	03.2	044	05.5	059	07.9	360
GANZI-RRI	GA	38 13	15 38 E	--	--	03.2	316	--	--	03.2	044	00.5	254	07.9	360
MESSI-NIA	ME	38 10	15 35 E	--	--	05.3	031	--	--	03.2	044	00.5	254	07.9	360
MILLAZZO	MI	38 17	15 15 E	--	--	11.8	269	018.0	279	03.1	300	09.7	217	07.4	214
PALERMO	PA	38 07	13 20 E	10.9	264	10.6	267	--	--	02.6	282	11.3	216	11.1	223
MALTA	MA	35 50	14 35 E	06.1	095	06.1	095	013.0	099	15.0	064	09.3	059	10.9	043

* Observed M2 - tide (after Defant , 1961)

** Observed M2 - tide (after Mosetti, 1987 and Admirality Tables)

* Calculated spring semi-diurinal tides (after Defant, 1961)

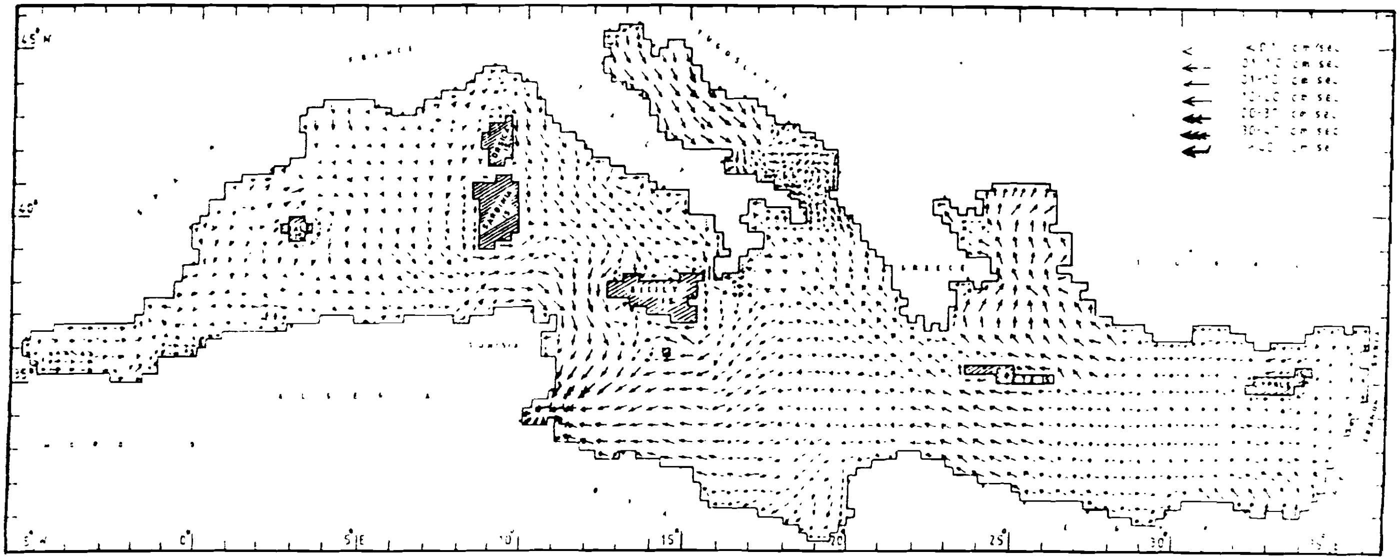

Figure 6a: The spatial distribution of depth mean current deduced from the M2-Independent tide at intervals of three lunar hours. (0,3,6, and 9h).

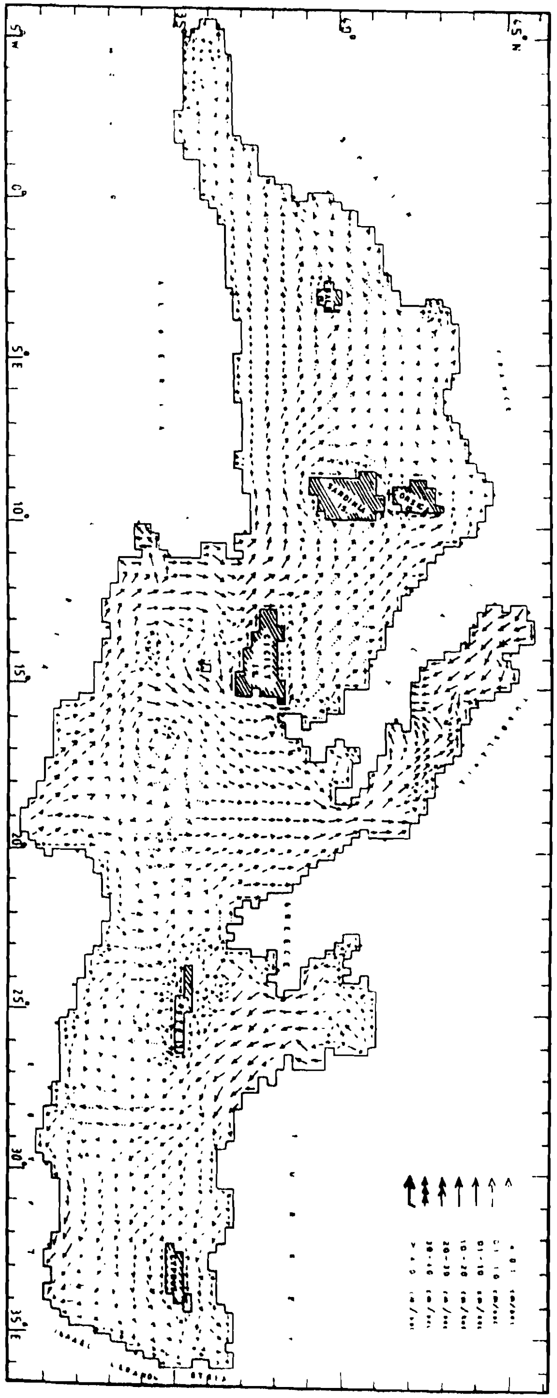

Figure 6b: The spatial distribution of depth mean current deduced from the M2-independent tide at intervals of three lunar hours. (0,3,6, and 9h).

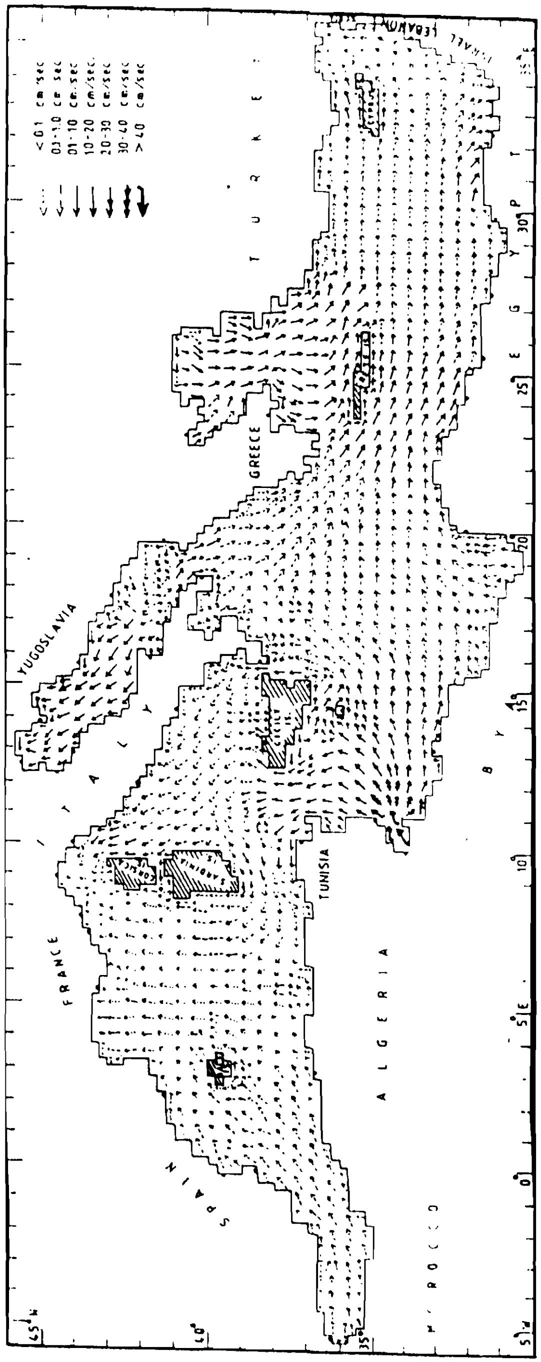

Figure 6c: The spatial distribution of depth mean current deduced from the M2-Independent tide at intervals of three lunar hours. (0,3,6, and 9h).

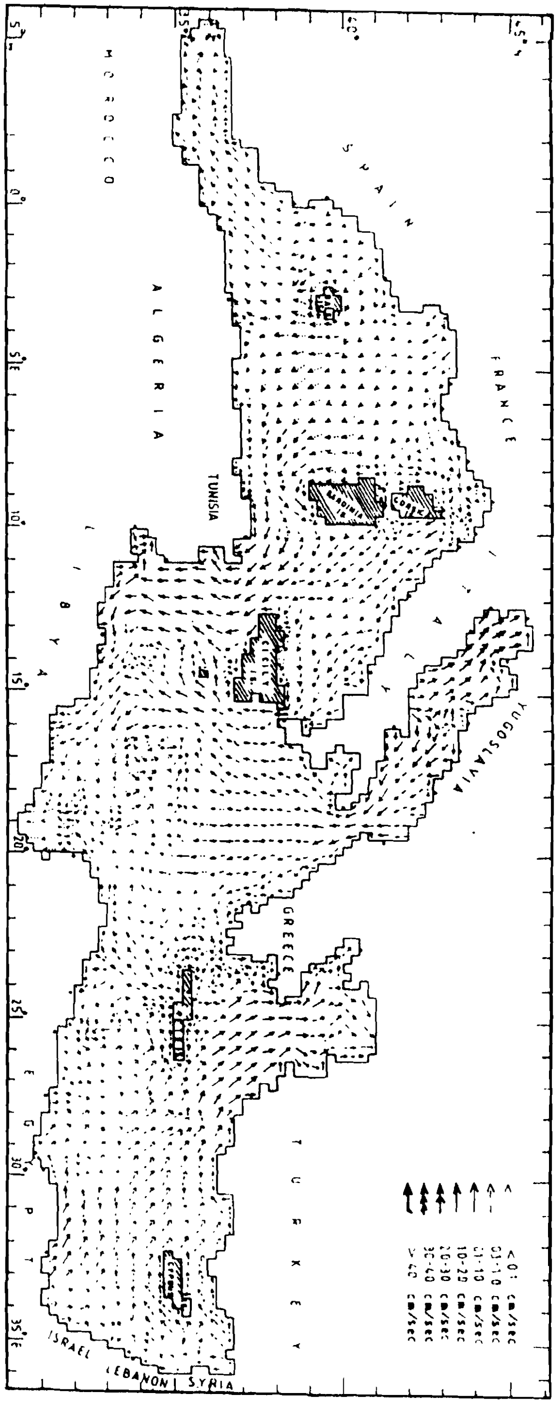

Figure 6d: The spatial distribution of depth mean current deduced from the M2-independent tide at intervals of three lunar hours. (0,3,6, and 9h).

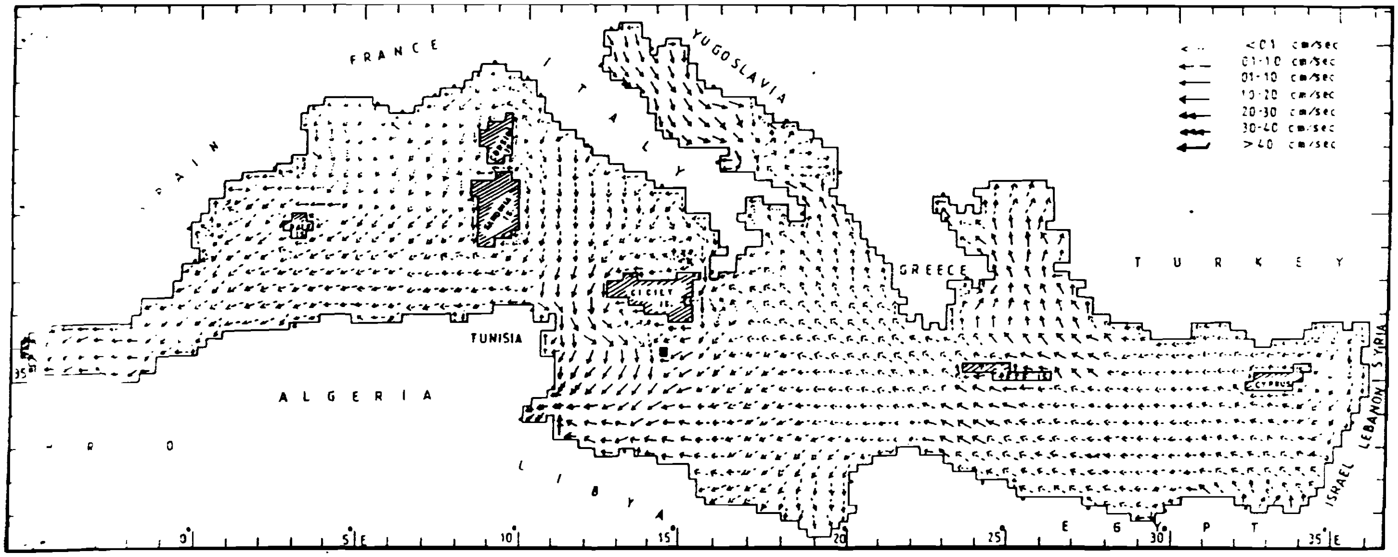

Figure 7a. The spatial distribution of depth mean current deduced from the M2-Co-oscillating tide at intervals of three lunar hours. (0,3,6, and 9h).

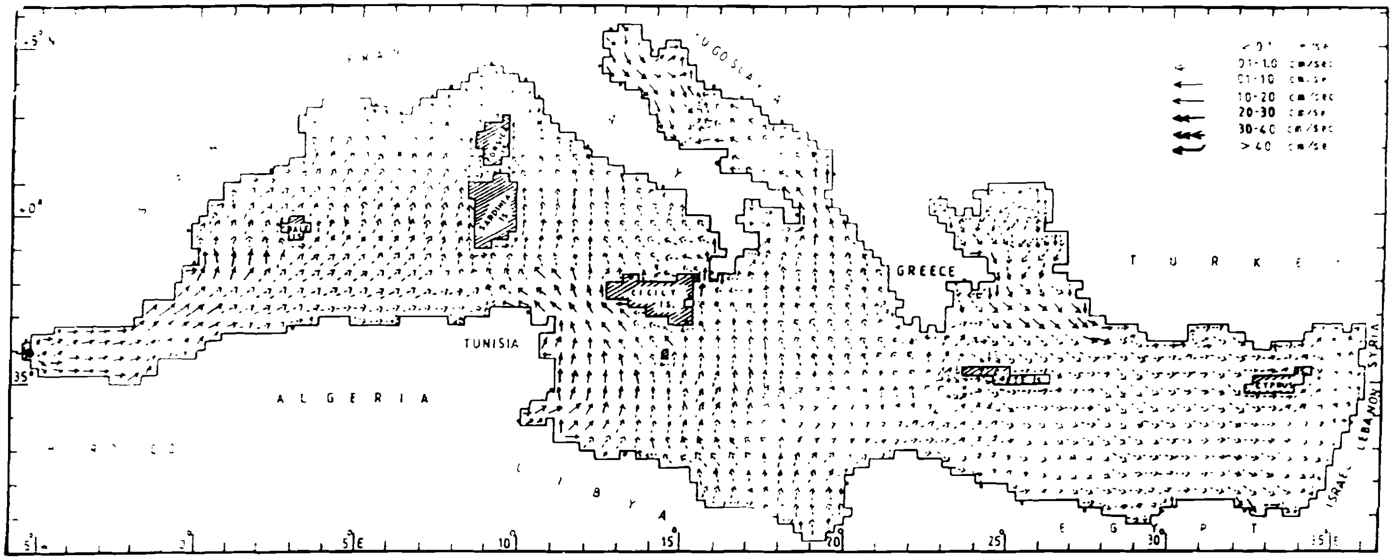

Figure 7b. The spatial distribution of depth mean current deduced from the M2-Co-oscillating tide at intervals of three lunar hours. (0,3,6, and 9h).

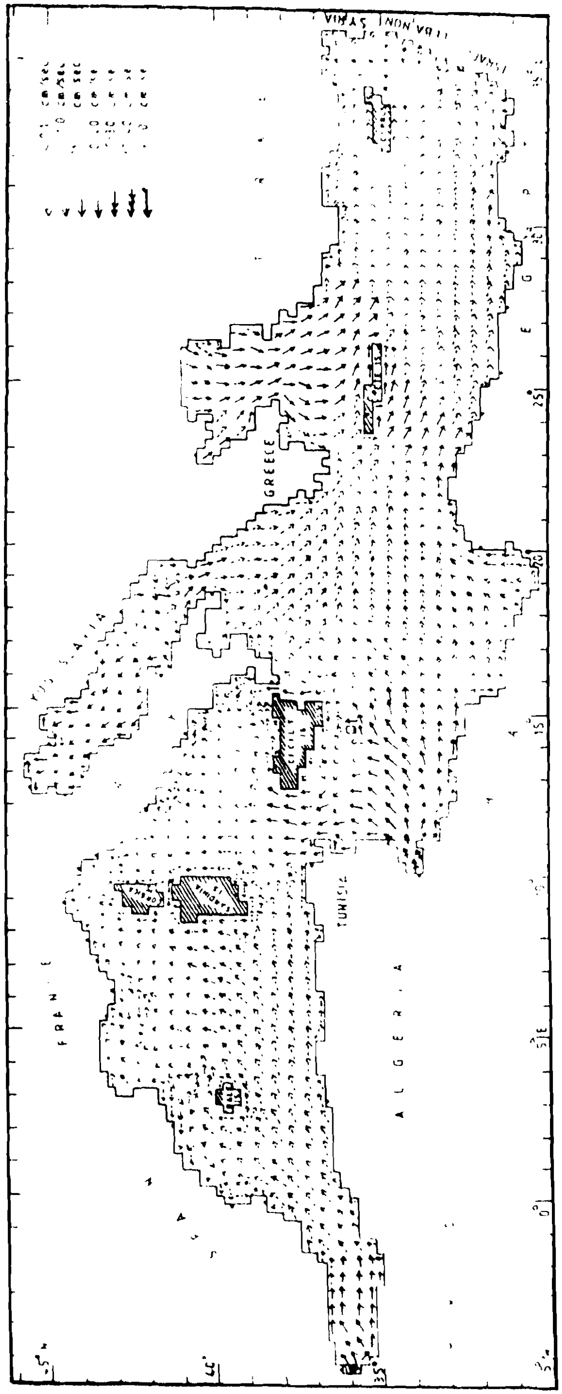

Figure 7c. The spatial distribution of depth mean current deduced from the M2-Co-oscillating tide at intervals of three lunar hours. (0,3,6, and 9h).

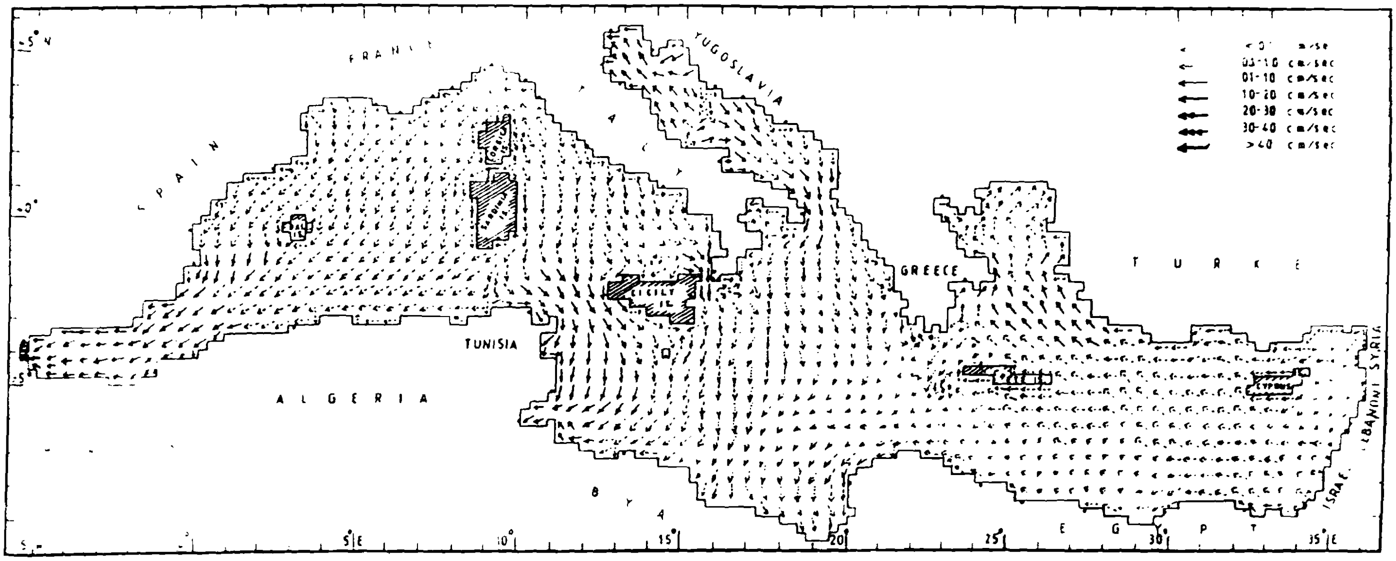

Figure 7d. The spatial distribution of depth mean current deduced from the M2-Co-oscillating tide at intervals of three lunar hours. (0,3,6, and 9h).

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