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The Frequency Distributions of the Residual Sea Level along the Suez Canal

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ABSTRACT. The residual sea level at five stations (Port Said, Kantra, Defersoir, Gineva and Port Tawfik) located along the Suez Canal are estimated by eliminating the predicted tide from the observed heights of sea level for two years 1984 and 1985.

The shapes and behaviors of the frequency distributions of the residual sea level are determined by calculating the first four moments (mean, variance, skewness and kurtosis) for each month at the investigated stations.

The maximum residual height is observed at Port Tawfik, where it varied between 130 and 150 cm either for positive or negative residuals. The maximum positive residual height at the other stations varied between 34 cm at Kantra and 70 cm at Defersoir, while the maximum negative ones changed between – 32 cm at Kantra and – 66 cm at Defersoir.

At northern stations (Port Said and Kantra), the positive residual heights occur most frequently during the summer months, while the negative one are predominant during the winter months. At the southern stations (Port Tawfik and Gineva), the reverse is true. Defersoir is considered as a transition region between the two regions.

Introduction

The regular tidal movements of the sea are continuously modified to a greater extent by the effect of the weather. The non-tidal component which remains after the regular tides are removed from data is called the residual, or surge. The surge at any location, derived from the observation of the sea level may therefore be regarded as consisting of a part generated by wind stress acting tangentially over the sea surface, and a part generated by barometric pressure (Heaps, 1967).

The average duration of a positive storm surge, as a rule consisting of the increase in the sea level to a peak which is followed by a decrease in level covers a time span extending from a few hours to two or three days (Lisitzin, 1974). Many theoretical analysis have been attempted to study storm surge, but Wiegel (1964) concluded that it is very difficult to arrive at solutions applicable to natural conditions, due to the fact that storm move, winds are not steady, the water depth is not constant and the coastline is not regular.

El-Sharkawy and Sharaf El-Din (1981) studied the effect of water density on the mean sea level in the Suez Canal. They concluded that the density effect is unimportant compared with the meteorological effect.

The effect of weather system on the fluctuation of sea level along the Suez Canal is studied by Sharaf El-Din *et al.* (1993). They concluded that the atmospheric pressure is one of main parameters affecting sea level variation at Port Said, while it does not affect directly on the fluctuation of sea level at Port Tawfik. The winds are significant factor affecting sea level at both Port Said and Port Tawfik. The increase in sea level (positive surge) is mainly caused by the northerly and westerly winds at Port Said and by westerly ones at Port Tawfik. The decrease in sea level (negative surge) is caused by the southerly and easterly winds at Port Said and by northerly ones at Port Tawfik.

In the present work the residual sea level is statistically studied at five sea level stations located along the Suez Canal.

Material and Method

The Suez Canal lies between latitudes 31°15′N and 29°55′N and longitudes 32°17′E and 32°35′E and connects the Mediterranean and the Red Sea.

There are eleven tide stations along the Suez Canal. Kuwakino (1988) in his report to the Research center of Suez Canal Authority described the types of these tide gauges, the position of the tide stations and its reference levels. Also, he investigated briefly the tide and tidal currents at some stations. The gauges at these eleven tide stations are the water level gauges (float and weekly type). The gauge operating speed was 2 mm per hour as the scale of the time. Fig. (1) shows the position, distance from Port Said and the time within gauge operation started for all stations.

The hourly records of sea level at five stations (Port Said, Kantra, Defersoir, Gineva and Port Tawfik) are obtained for two years (1984, 1985).

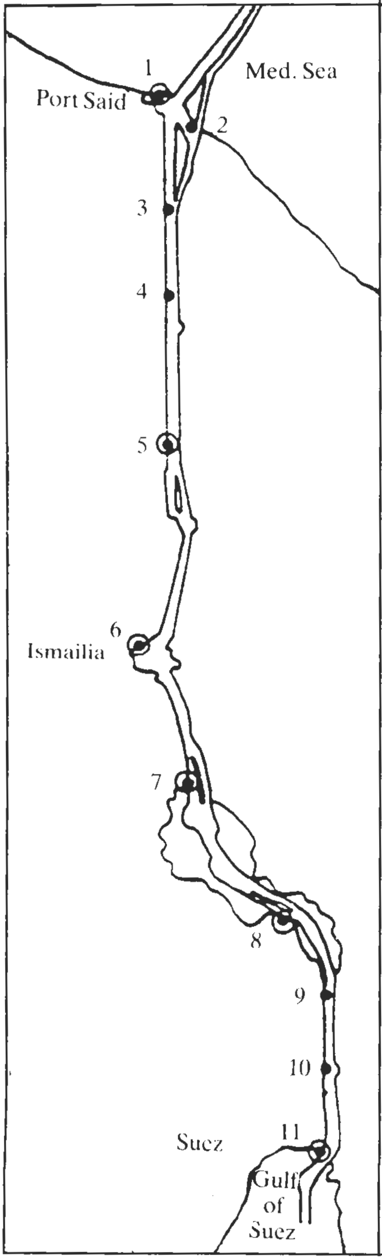
To compute the residual sea level from a sea level record, it is necessary to eliminate the astronomical tide. In this study, the residual sea level is calculated by subtracting the predicted tide from observed heights of sea level (Rossiter, 1959 and Pugh, 1987) as given by:

$$S(t) = H(t) - T(t) - Z_o(t)$$

where

$S(t)$ is the residual sea level at the time t.

● Existing Tidal Station.
◉ Proposed Positions Pneumatic System.



Station No.	Name	Km	Working Since
1	Port Said	–	1900
2	Port Fouad	–	21 / 11 / 1985
3	Ras El-Eish	14.304	20 / 12 / 1984
4	El-Tina	24.750	5 / 6 / 1983
5	Kantara	45.130	25 / 5 / 1982
6	Ismailia	77	10 / 11 / 1977
7	Defersoir	97.875	29 / 5 / 1976
8	Kabrit	120.827	6 / 1 / 1985
9	Gineva	133.850	6 / 4 / 1976
10	Shalloufa	145.125	26 / 3 / 1983
11	Port-Tawfik	160.400	≃ 1900

FIG. 1. The location of the tide stations along the Suez Canal.

$H(t)$ is the observed height of sea level.

$T(t)$ is the predicted time at time t.

$Z_o(t)$ is the mean sea level.

The predicted tide $T(t)$ at any time (t) is calculated using Murray (1962) formula :

$$T(t) = Z_o + \sum_{i=1}^{n} F_i H_i \cos [(V + U)_i - g_i + \sigma_i t]$$

where

z_o	: The mean sea level.
i	: The considered tidal components.
F_i	: Nodal correction factor for the amplitude.
H_i	: The amplitude of the *ith* tidal components as determined by tidal harmonic analysis (cm).
$(v + u)_i$	: Argument of the *ith* tidal components (in degrees).
g_i	: Phase of the *ith* tidal components (in degrees).
σ_i	: Angular velocity of the *ith* tidal component.
t	: Time from the starting hour to the required predicted one.

The amplitude (H) and phase (g) of seven tidal components (M_2, S_2, N_2, K_1, O_1, M_4 & MS_4) are calculated using the modified Doodson (1921) method throughout the period of investigation for different central days (Alam El-Din, 1993). The average values of these harmonic constituents are given in Table (1).

TABLE 1. The harmonic constituents for a given tidal stations along the Suez Canal (H in cm and g in degrees).

	Port Said		Kantra		Defersoir		Gineva		P. Tawfik	
	H	g	H	g	H	g	H	g	H	g
M_2	10.6	304	4.6	39	11.9	179	10.2	45	51.1	339
S_2	6.2	317	2.6	23	4.3	162	3.7	75	14.6	4
N_2	1.8	304	1.8	80	4.9	93	3.7	13	15.9	315
K_1	2.1	302	1.9	313	1.8	256	2.3	255	4.4	175
O_1	1.7	283	0.9	302	1.1	139	0.9	312	1.5	224
M_4	0.3	339	0.4	132	0.5	12	1.4	243	1.2	359
MS_4	0.3	355	0.3	246	0.4	350	0.9	275	1.0	54

Results and Discussion

Using the hourly values of the observed sea level, the residual sea level are estimated by eliminating the predicted tide from the observed heights at five stations

(Port Said, Kantra, Defersoir, Gineva and Port Tawfik) located along the Suez Canal during two years (1984-1985). Figures (2-6) show the height of observed sea level, tide and residual sea level at these stations during one month (June, 1985). The

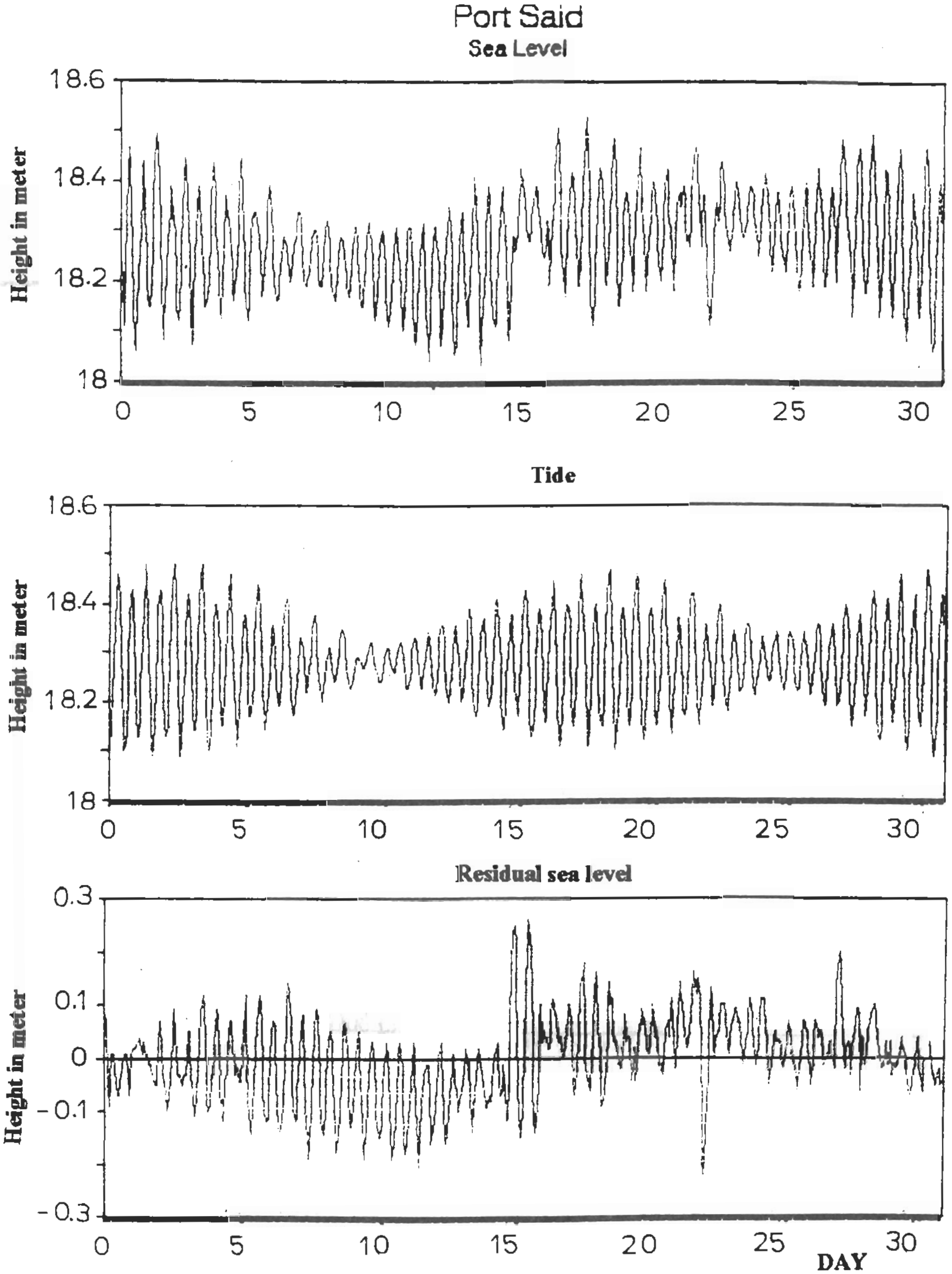


FIG. 2. Height of sea level, tide and residual sea level at Port Said in June 1985.

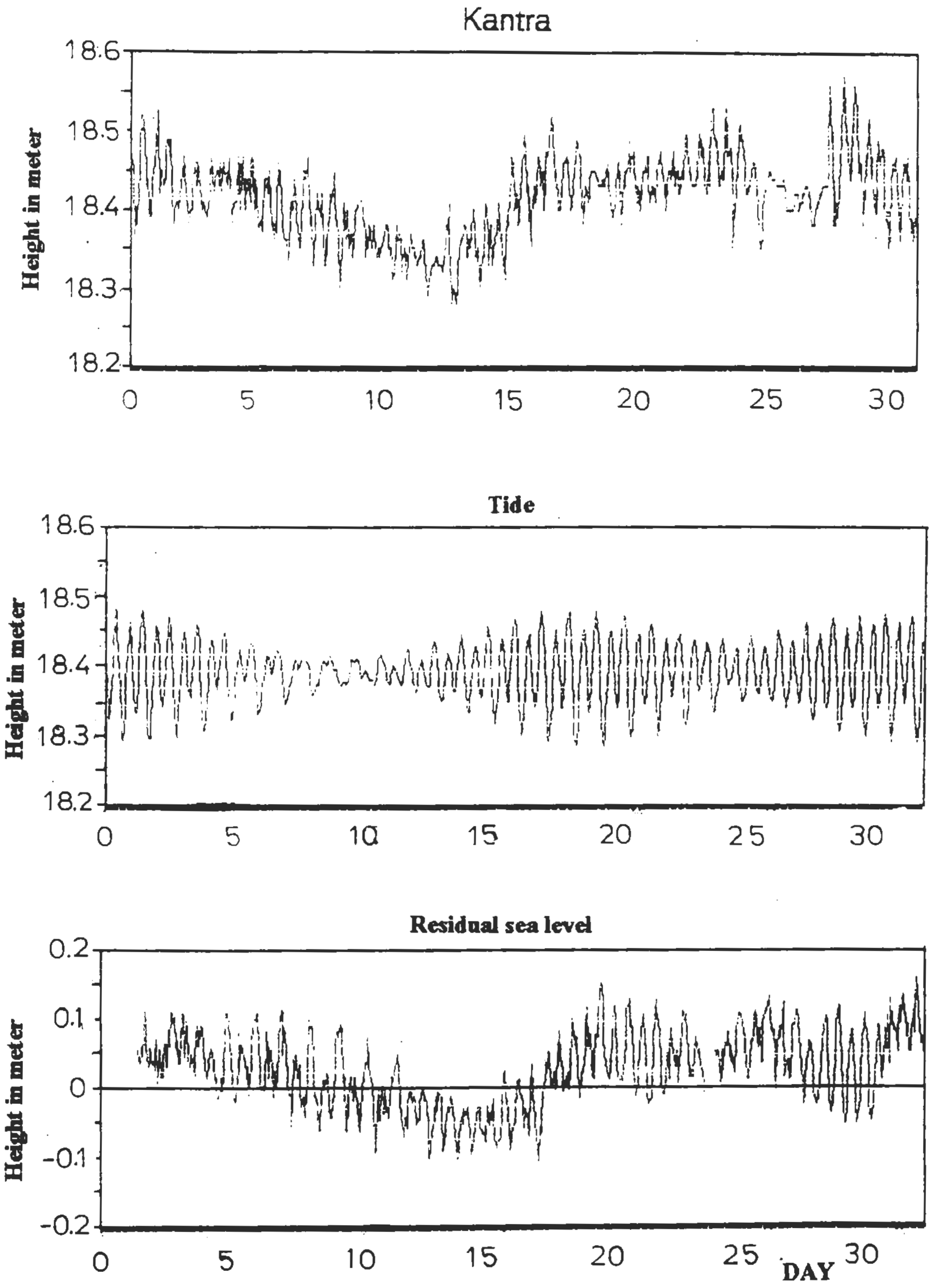


FIG. 3. Height of sea level, tide and residual sea level at Kantra in June 1985.

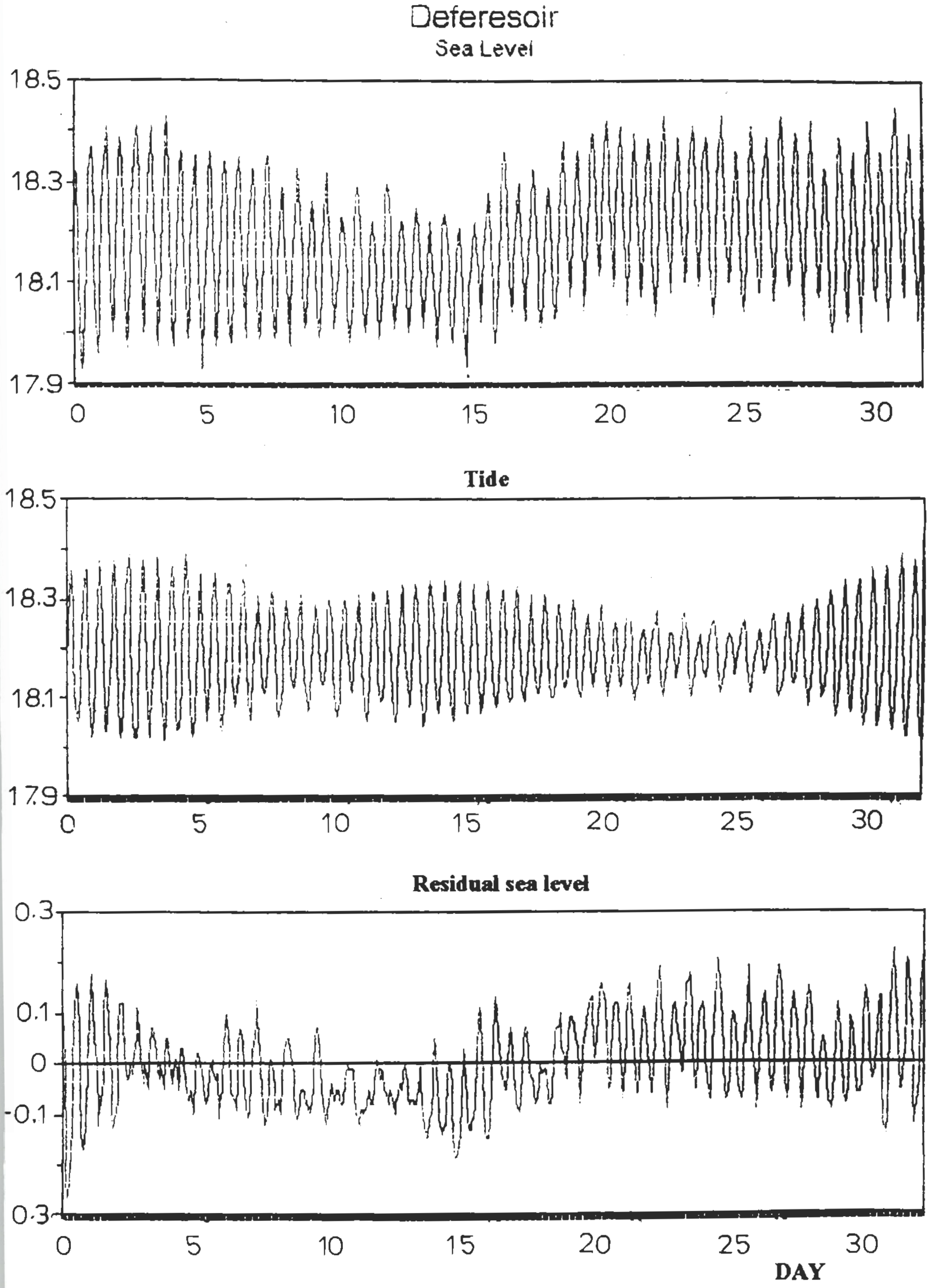


FIG. 4. Height of sea level, tide and residual sea level at Defersoir in June 1985.

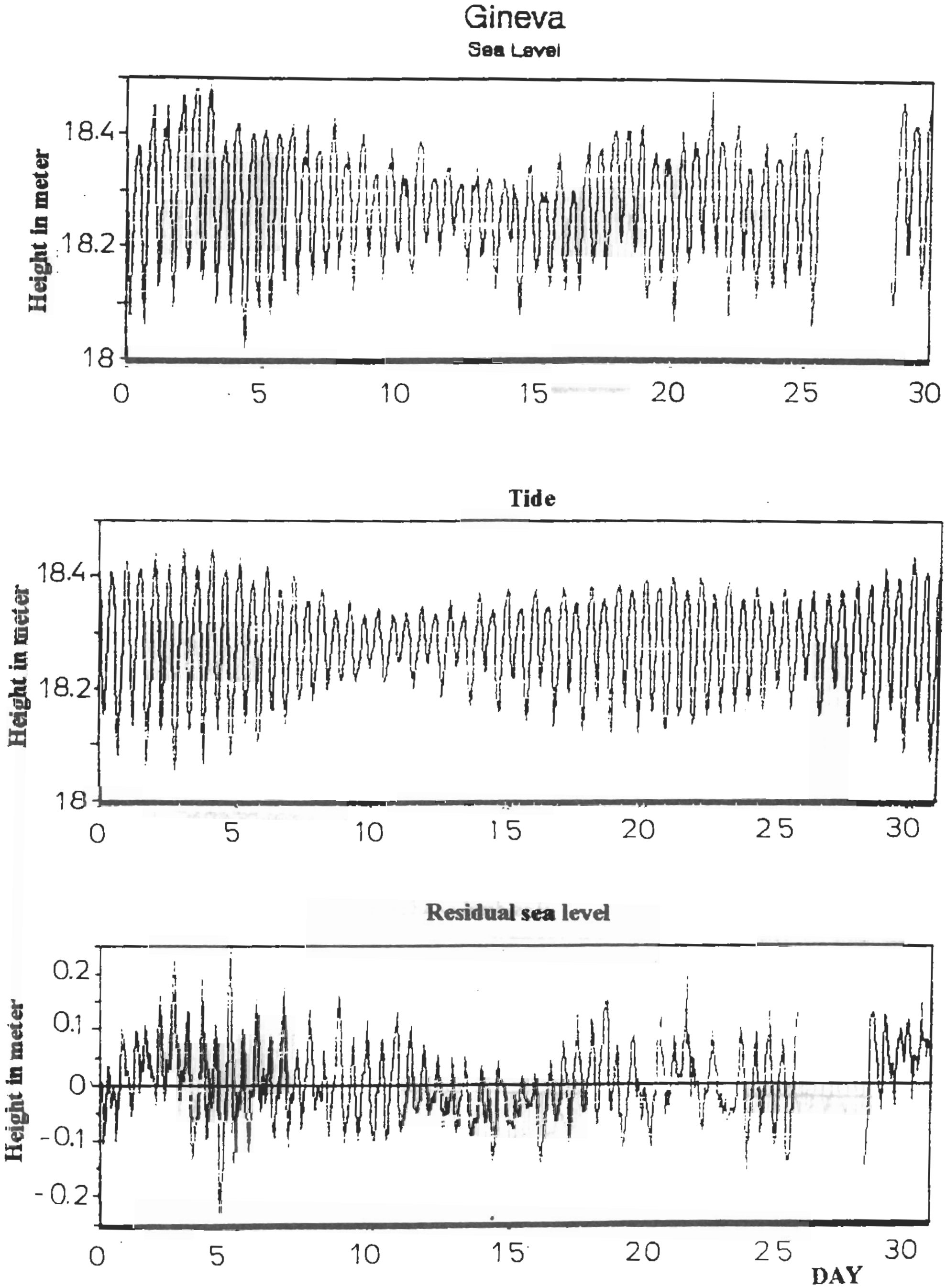


FIG. 5. Height of sea level, tide and residual sea level at Gineva in June 1985.

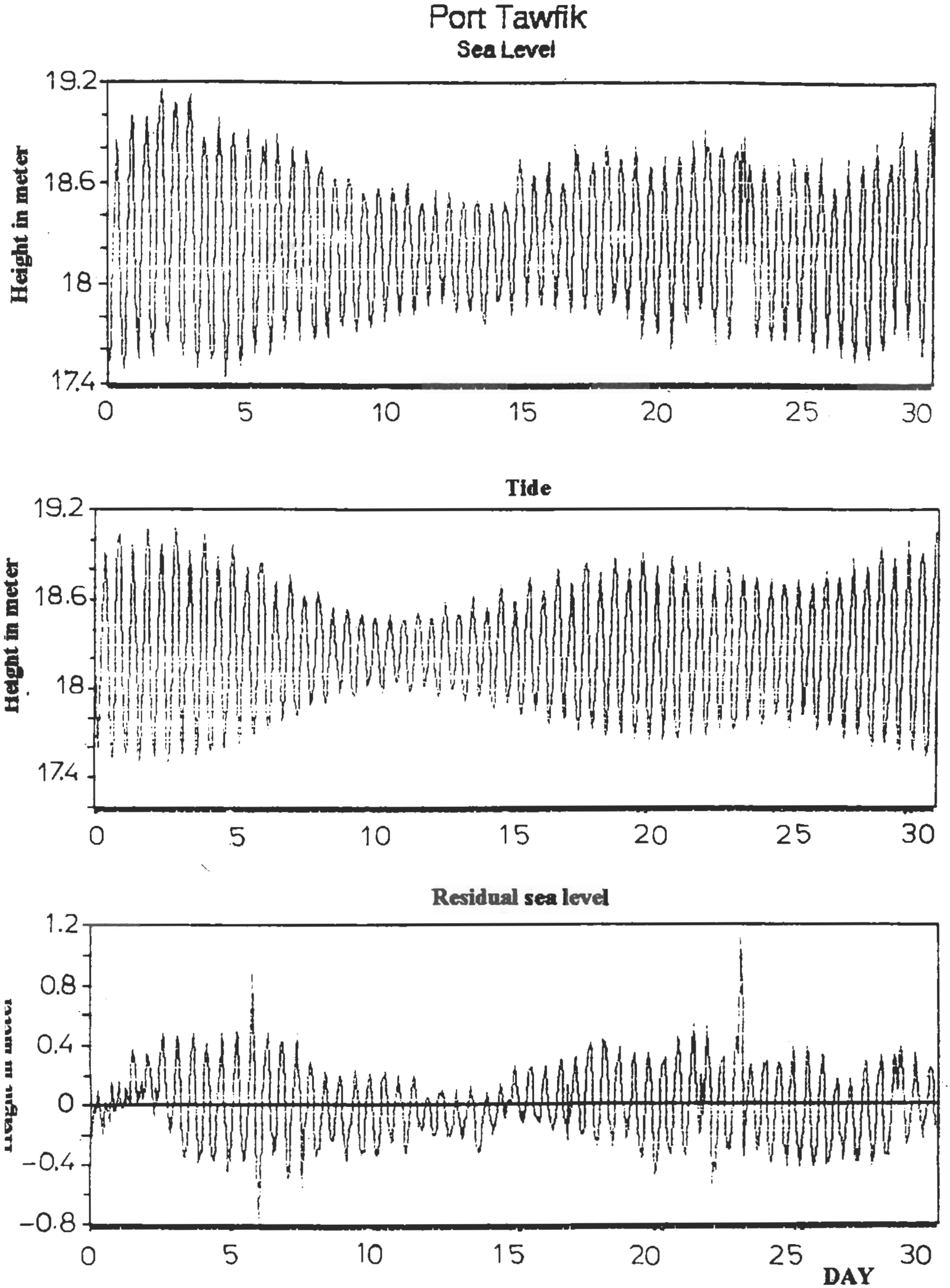


FIG. 6. Height of sea level, tide and residual sea level at Port Tawfik in June 1985.

sea level variations as well as the tidal prediction are out from the present work. Only the residual sea level would be discussed here statistically.

1) Statistical Moments for Residual Sea Level

To illustrate the shapes and the behaviors of frequency distribution of the residual sea level and to give more information concerning variations and deviations about the mean, the first four moments (mean, variance, skewness and kurtosis) have been calculated for each month during 1984 at the different stations. The result of these calculations are listed in Tables (2-6). It is seen that, the monthly means at Port Said and Kantra are usually lower than the annual mean except in the summer months, while the monthly means for stations Defersoir, Gineva and Port Tawfik are lower than the annual mean in the summer months and higher in the rest of the year.

TABLE 2. The first four moments about the mean at Port Said during 1984.

Month	Mean	Standard deviation	Skewness	Kurtosis
January	– 0.007	0.083	0.308	1.739
February	– 0.041	0.073	0.114	2.872
March	0.002	0.082	– 0.368	2.400
April	– 0.008	0.092	0.241	2.716
May	– 0.025	0.074	– 0.069	3.015
June	0.004	0.059	– 0.008	2.889
July	0.030	0.088	– 0.493	1.868
August	0.037	0.047	– 0.135	2.527
September	0.037	0.055	– 0.381	2.470
October	– 0.025	0.051	0.089	1.225
November	0.097	0.063	0.078	2.359
December	– 0.100	0.079	0.234	2.979
Average	0.000	0.070	– 0.032	2.422

TABLE 3. The first four moments about the mean at Kantra during 1984.

Month	Mean	Standard deviation	Skewness	Kurtosis
January	0.005	0.144	0.183	1.803
February	– 0.039	0.085	– 0.047	2.461
March	– 0.011	0.087	– 0.443	2.260
April	– 0.017	0.100	0.108	1.824
May	– 0.044	0.130	0.287	2.771
June	0.022	0.092	– 0.737	3.160
July	0.054	0.081	0.013	3.905
August	0.072	0.057	– 1.354	3.426
September	0.046	0.116	0.296	3.484
October	– 0.004	0.083	– 0.059	2.336
November	0.021	0.111	– 0.522	2.768
December	– 0.105	0.069	0.390	2.936
Average	0.000	0.096	– 0.157	2.761

TABLE 4. The first four moments about the mean at Defersoir during 1984.

Month	Mean	Standard deviation	Skewness	Kurtosis
January	0.142	0.119	– 0.677	2.414
February	– 0.267	0.210	0.415	2.251
March	0.087	0.252	– 0.407	2.745
April	0.023	0.154	0.890	4.461
May	0.032	0.098	– 0.271	2.811
June	– 0.021	0.085	– 0.233	1.623
July	– 0.014	0.069	– 0.412	3.426
August	– 0.012	0.093	– 0.115	2.279
September	– 0.110	0.328	0.010	1.016
October	– 0.058	0.093	– 0.216	2.559
November	0.132	0.122	– 0.305	2.143
December	0.071	0.124	– 0.498	2.810
Average	0.000	0.146	– 0.152	2.545

TABLE 5. The first four moments about the mean at Gineva during 1984.

Month	Mean	Standard deviation	Skewness	Kurtosis
January	– 0.009	0.095	– 0.037	2.483
February	0.022	0.108	– 0.083	2.071
March	0.066	0.153	– 0.080	1.194
April	0.061	0.093	0.051	2.388
May	0.027	0.075	0.000	2.050
June	– 0.097	0.088	– 0.136	2.548
July	– 0.088	0.086	0.092	3.901
August	– 0.099	0.100	0.093	2.795
September	– 0.054	0.117	0.046	2.522
October	0.052	0.096	0.245	1.860
November	0.105	0.110	– 0.484	2.555
December	0.031	0.119	0.386	4.030
Average	0.000	0.103	0.008	2.533

TABLE 6. The first four moments about the mean at Port Tawfik during 1984.

Month	Mean	Standard deviation	Skewness	Kurtosis
January	0.082	0.512	– 0.357	2.936
February	0.151	0.219	– 0.585	3.332
March	0.231	0.206	– 0.409	2.987
April	0.122	0.163	– 0.270	5.033
May	0.129	0.217	0.184	3.141
June	– 0.092	0.354	0.050	3.132
July	– 0.120	0.300	– 0.124	2.806
August	– 0.206	0.314	0.017	2.119
September	– 0.141	0.334	0.049	2.510
October	0.012	0.215	– 0.628	5.172

TABLE 6. Contd.

Month	Mean	Standard deviation	Skewness	Kurtosis
November	0.245	0.196	0.052	3.827
December	0.119	0.225	0.600	4.047
Average	0.000	0.271	– 0.119	3.420

Also, it is seen that, the residual sea level at Port Tawfik is mostly more deviated from the average value at all months with annual mean of standard deviation (0.271), minimum value of standard deviation (0.163) during April and maximum one (0.512) in January. The standard deviation at stations Port Said and Kantra is mostly small with minimum values at Port Said (annual mean is 0.070) and larger values generally in winter months.

For the skewness, although the average value is very near to the normal or a symmetric distribution, where skewness equal to zero, it differ in some months specially at Kantra and Defersoir. In general the average values of skewness in all stations are negative which means that the peak is shifted slightly to the right from the mean value.

With respect to the fourth moment (Kurtosis), which measures the degree of peakedness of distribution, it is showed that most values of kurtosis coefficient are near to the normal value, where the coefficient of kurtosis equal 3, except in some months where it is less than 2. Also, it is seen that, the kurtosis coefficient is sometimes larger than 4 in few months at Defersoir and Port Tawfik. In general, the distribution of residual sea level at Port Tawfik tends to large peakedness, while at Port Said, it is of small peakedness.

2) Frequency Distribution of Residual Sea Level

The histograms of positive and negative residual heights at the investigated stations for two years (1984 and 1985) are shown in Fig. (7 to 11). The result of these histograms are summarized in Table (7).

From these figures and table, it may be noticed that the interval of highest frequency of residual height oscillate between 0-2 cm and 2-4 cm either for positive or negative residual at all investigated stations except at Port Tawfik, where it changed between 5-10 cm during 1984 and between 0-5 cm during 1985.

Also, it is seen that, with the exception of Port Tawfik, the frequency of residual height less than 10 cm changed between 24.18% at Defersoir during 1985 and 37.73% at Kantra during 1984 for positive residual. While it varied between 25.53% at Defersoir during 1985 and 36.71% at Kantra during 1985 for negative one. But at Port Tawfik, it is clear that, the frequency of the residual height less than 10 cm is much less than that at the other stations. It varied on an average between 13 and 14%.

For the larger surge height, it is seen that, the frequency of the residual height

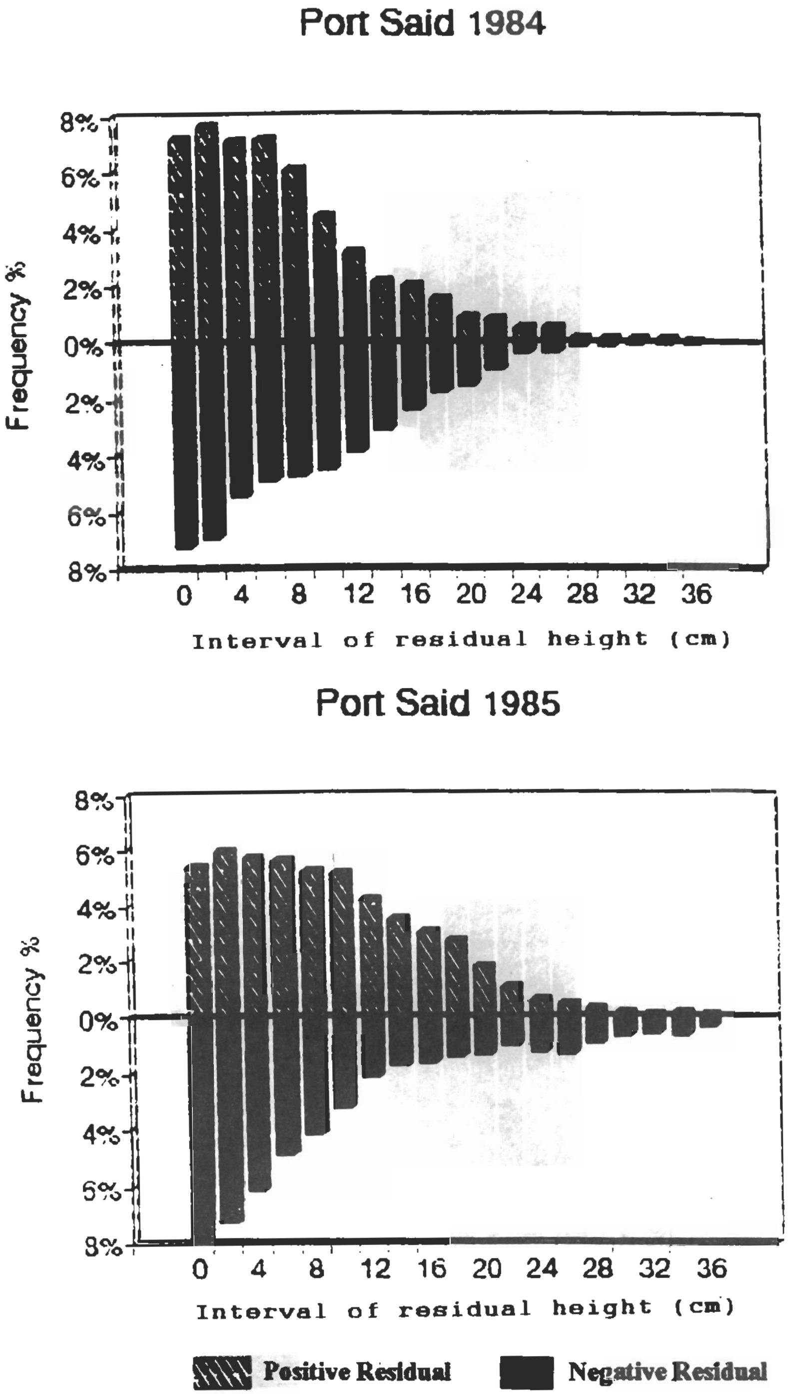


FIG. 7. Frequency distribution of residual sea level at Port Said for the years 1984 and 1985.

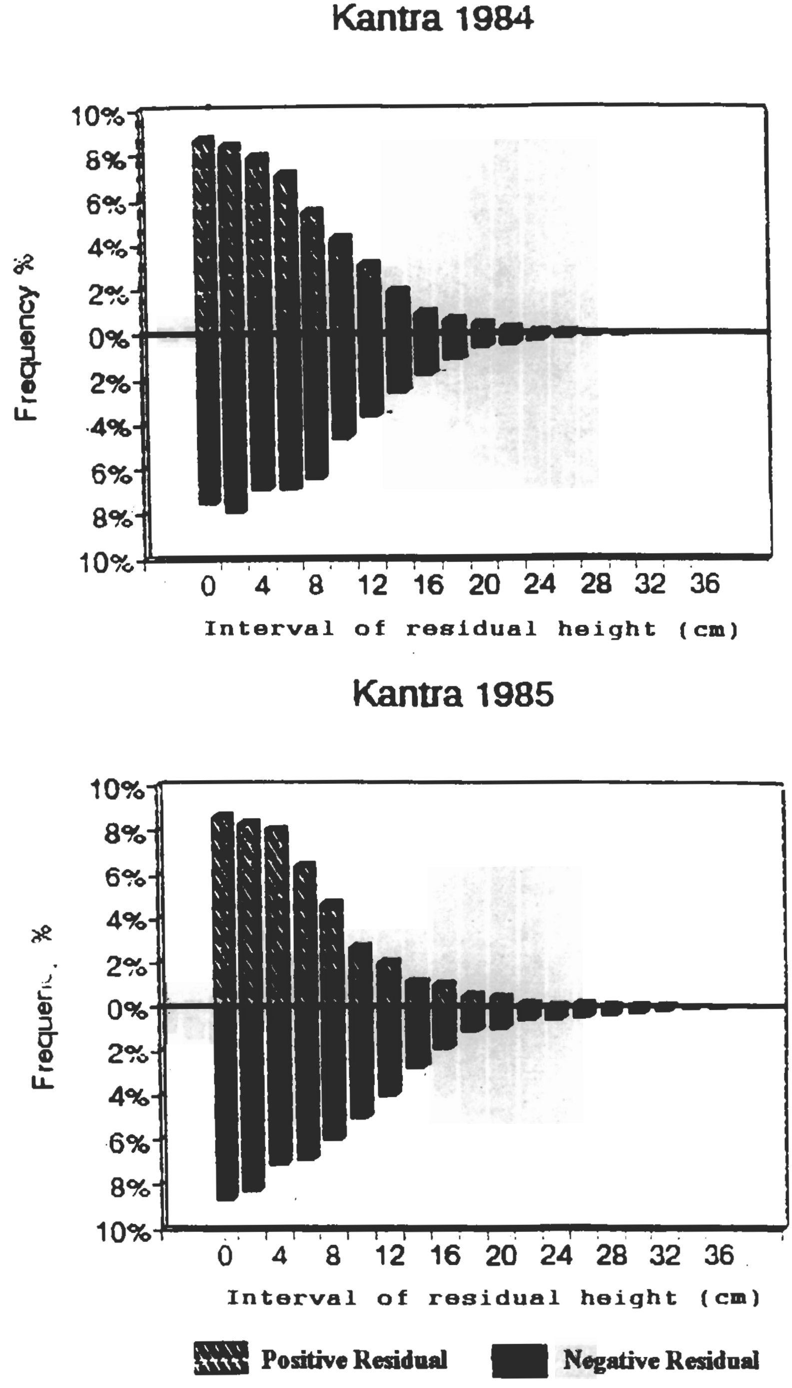


FIG. 8. Frequency distribution of residual sea level at Kantra for the years 1984 and 1985.

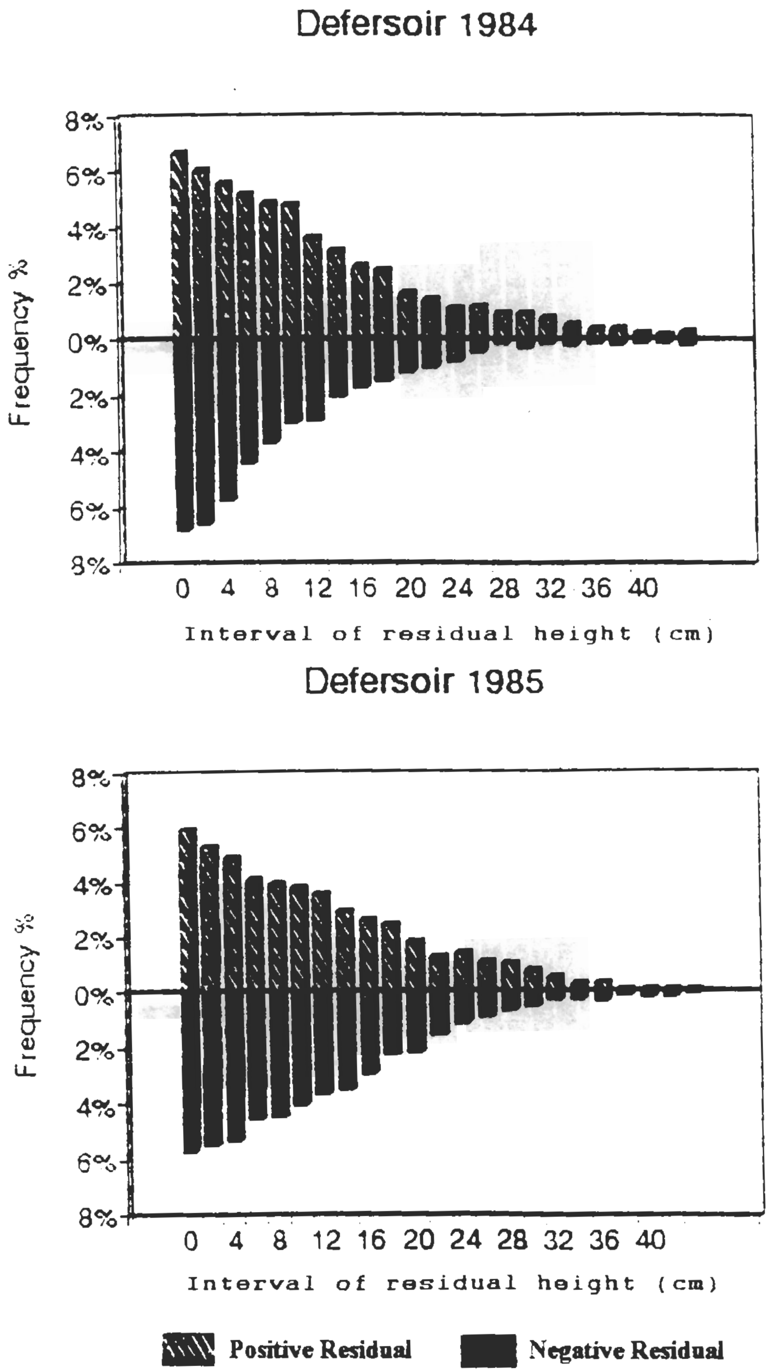


FIG. 9. Frequency distribution of residual sea level at Defersoir for the years 1984 and 1985.

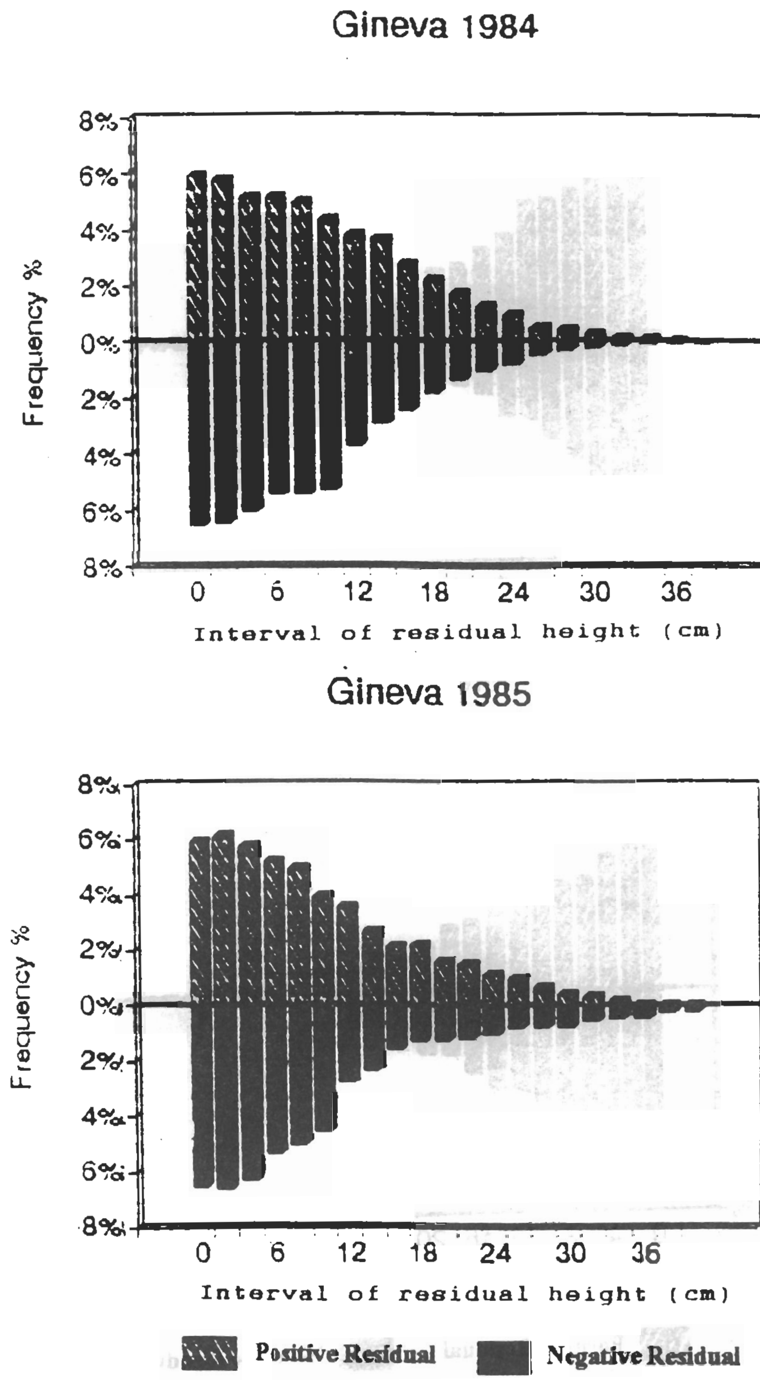


FIG. 10. Frequency distribution of residual sea level at Gineva for the years 1984 and 1985.

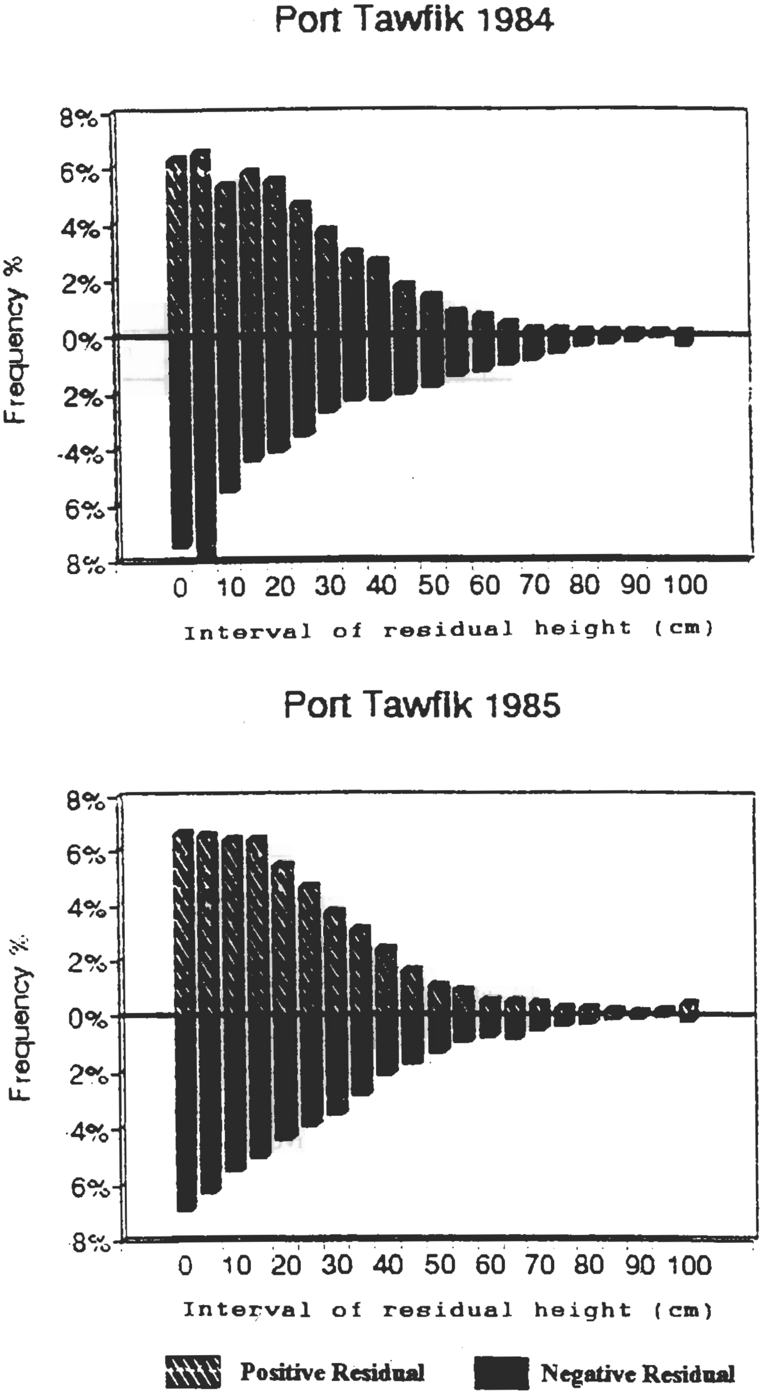


FIG. 11. Frequency distribution of residual sea level at Port Tawfik for the years 1984 and 1985.

TABLE 7. Some statistical characteristic of residual sea level at the investigated stations during two years (1984 and 1985).

Station	Year	Highest frequency in percent		Interval of highest frequency in (cm)		Frequency of residual heights < 10 cm in %		Frequency of residual heights > 30 cm in %		Maximum residual height in (cm)	
		Positive	Negative	Positive	Negative	Positive	Negative	Positive	Negative	Positive	Negative
Port Said	1984	7.71	7.23	2 – 4	0 – 2	35.35	29.12	0.63	0.42	40	– 44
	1985	5.92	7.95	2 – 4	0 – 2	27.87	30.37	0.80	3.92	44	– 46
Kantra	1984	8.72	7.89	0 – 2	2 – 4	37.73	35.42	0.01	0.05	40	– 32
	1985	8.59	8.62	0 – 2	0 – 2	36.14	36.71	0.11	0.93	34	– 44
Defersoir	1984	6.70	6.80	0 – 2	0 – 2	28.47	27.16	4.77	2.25	70	– 66
	1985	5.95	5.70	0 – 2	0 – 2	24.18	25.53	2.29	2.07	56	– 52
Gineva	1984	5.99	6.50	0 – 2	0 – 2	27.15	29.94	1.04	0.83	42	– 44
	1985	6.15	6.63	2 – 4	2 – 4	28.15	29.80	1.92	3.68	50	– 44
Port Tawfik	1984	6.63	7.89	5 – 10	5 – 10	12.93	15.35	29.87	29.27	130	– 150
	1985	6.70	6.90	0 – 5	0 – 5	13.33	13.16	20.65	15.67	150	– 130

more than 30 cm is large at Port Tawfik, where it changed between 20.65% and 29.87% for positive residual and between 15.67% and 29.27% for negative one. At other stations, the frequency of residual height more than 30 cm is small. It varied for positive residual between 0.01% at Kantra during 1984 and 4.77% at Defersoir during 1984. For negative residuals, it changed between 0.05% at Kantra during 1984 and 3.92% at Port Said during 1985.

Finally, the maximum residual height is calculated at Port Tawfik. It varied between 130 and 150 cm either for positive or negative residual during the two years. With the exception of Port Tawfik, the maximum positive residual height at the other stations varied between 34 cm at Kantra (1985) and 70 cm at Defersoir (1984). The maximum negative residual height changed between – 32 cm at Kantra (1984) and – 66 at Defersoir (1984).

3) The Cumulative Frequency of Residual Sea Level

For an attention presentation of the data, the percentage of duration which a given positive or negative residual has been reached or passed any residual height, the cumulative frequency distribution, are computed for each month for all stations during one year (1984) and is presented graphically in Fig. (12 to 16) for the positive and negative residuals.

Concerning Fig. (12), at Port Said the most pronounced frequencies of high positive residual occurred during summer and autumn months (93.11%) during August. The maximum positive residual reach to more than 30 cm in September, while the highest frequency of negative residual observed during December with the maximum one reached to more than 30 cm in June.

The general pattern of positive and negative cumulative frequencies at Kantra, Fig. (13), is similar to that at Port Said where the pronounced frequencies of high positive residual occurred during summer and autumn months. The highest frequency of positive residual is observed in November, while the highest one of negative residual is observed in November, while the highest one of negative residual is found in July. The frequencies of positive and negative residual heights more than 30 cm are less than that at Port Said.

In contrast, at stations Gineva and Port Tawfik (Fig. 15 & 16), the lower frequencies of positive residual occurred during summer months, while the higher positive one occurred during the rest of the year. The maximum frequency of positive residual is observed during November at Port Tawfik and during April and November at Gineva, while the maximum frequencies of negative residual occurred during August at Port Tawfik and during June, July and August at Gineva.

Figure (14) shows the cumulative frequency distribution of residual height at Defersoir. This station considered as a transition station between the northern stations (Port Said and Kantra) and the southern one (Port Tawfik and Gineva).

Conclusion

The residual sea level is estimated at five stations located along the Suez Canal (Port Said, Kantra, Defersoir, Gineva and Port Tawfik) by eliminating the predicted tidal height from the observed sea level for two years (1984 and 1985). The first four moments (mean, variance, skewness and kurtosis) have been calculated for each month during 1984 at these stations. From the results it is evident that :

The maximum residual height is calculated at Port Tawfik. It varied between 130 and 150 cm either for positive or negative residual during the two years. The maximum positive residual height at Port Said varied between 40 and 44 cm, while that of negative ones varied between – 44 and – 46 cm. At the other stations the maximum positive residual varied between 34 cm at Kantra (1985) and 70 cm at Defersoir (1984). The maximum negative residual height changed between – 32 cm at Kantra (1984) and – 66 cm at Defersoir (1984).

The duration of both positive and negative residual were determined. At Port Said and Kantra, the summer months have the maximum recorded duration of positive residual, while the highest frequency of negative residual occurred during winter months. At Port Tawfik and Gineva the lower frequencies of positive residual occur-

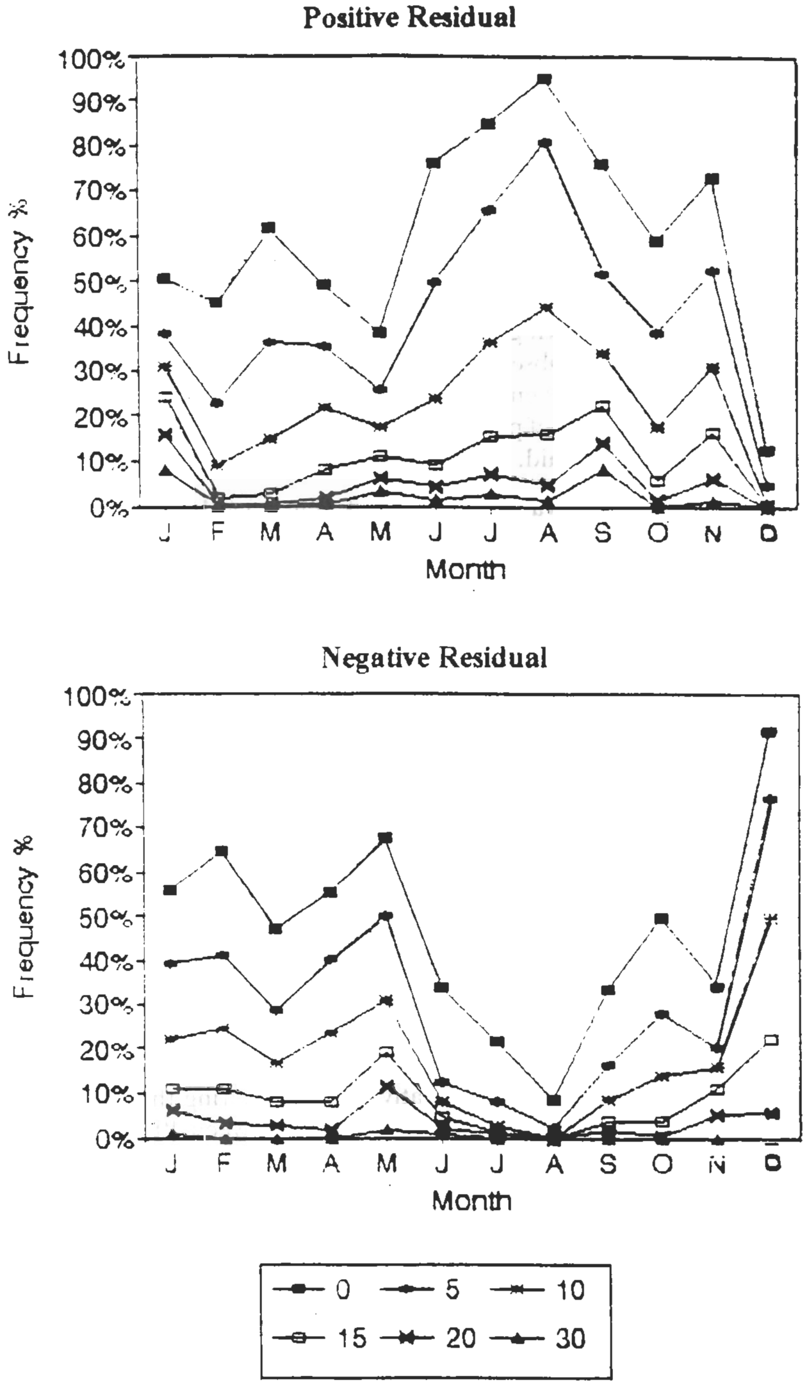


FIG. 12. The cumulative frequency distribution of residual sea level at Port Said during 1984.

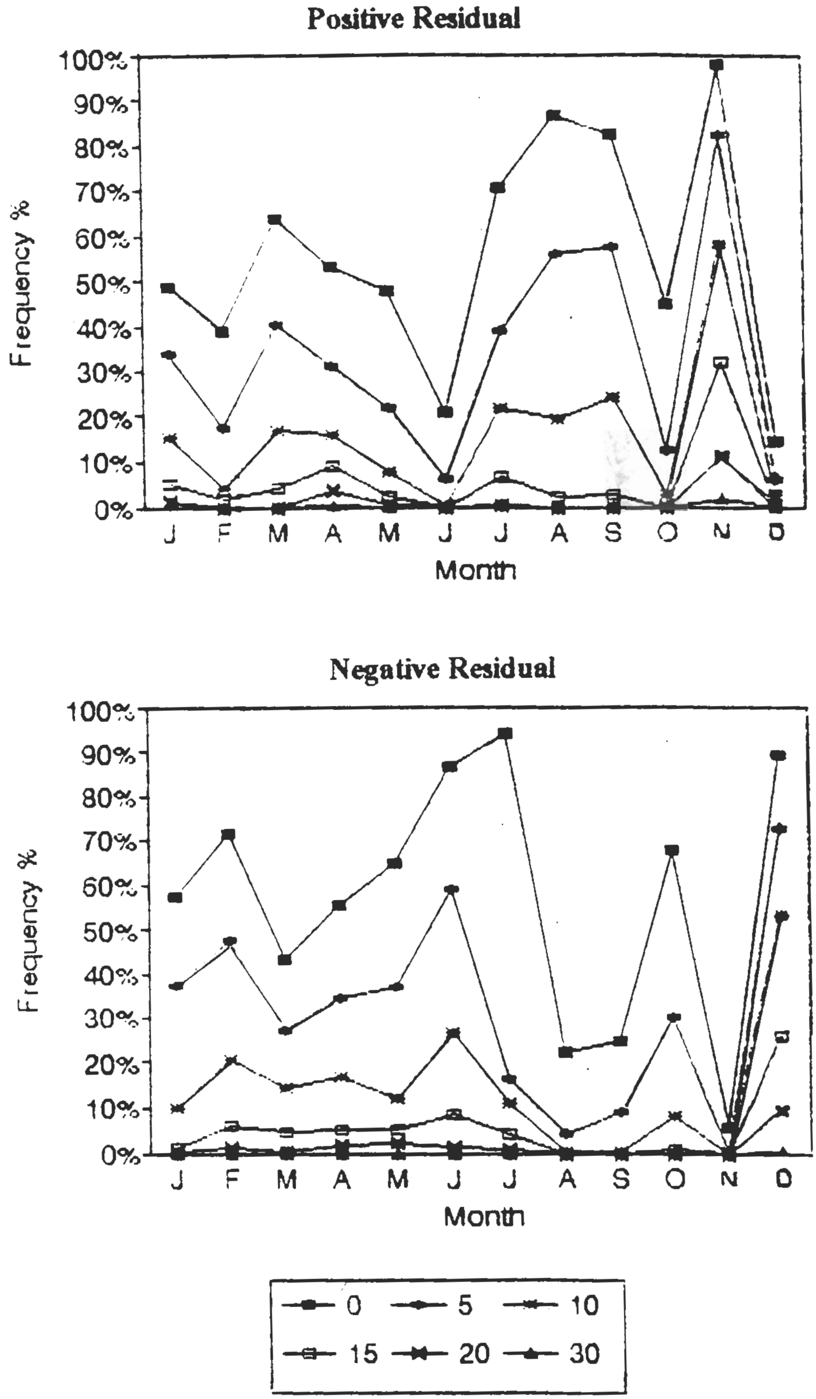


FIG. 13. The cumulative frequency distribution of residual sea level at Kantra during 1984.

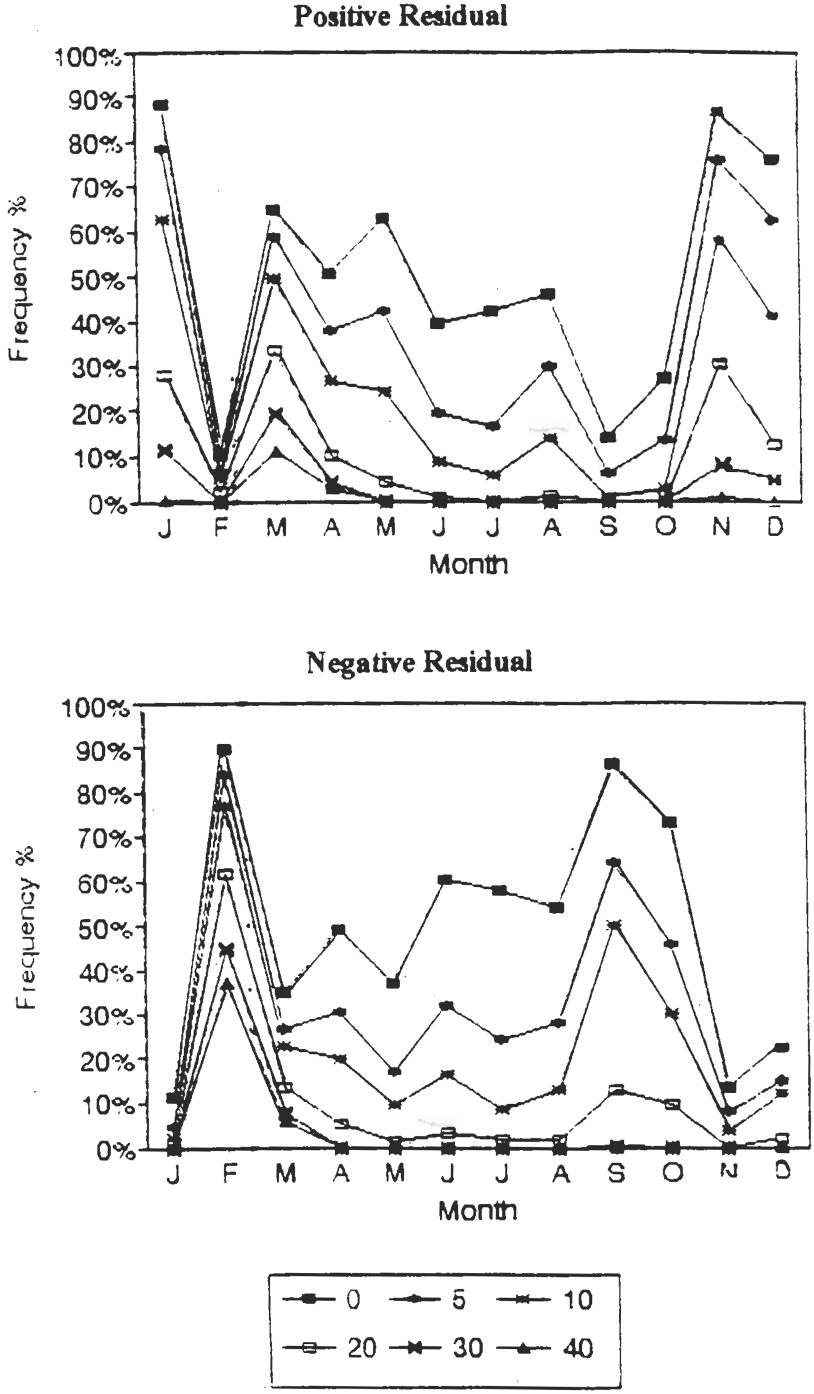


FIG. 14. The cumulative frequency distribution of residual sea level at Defersoir during 1984.

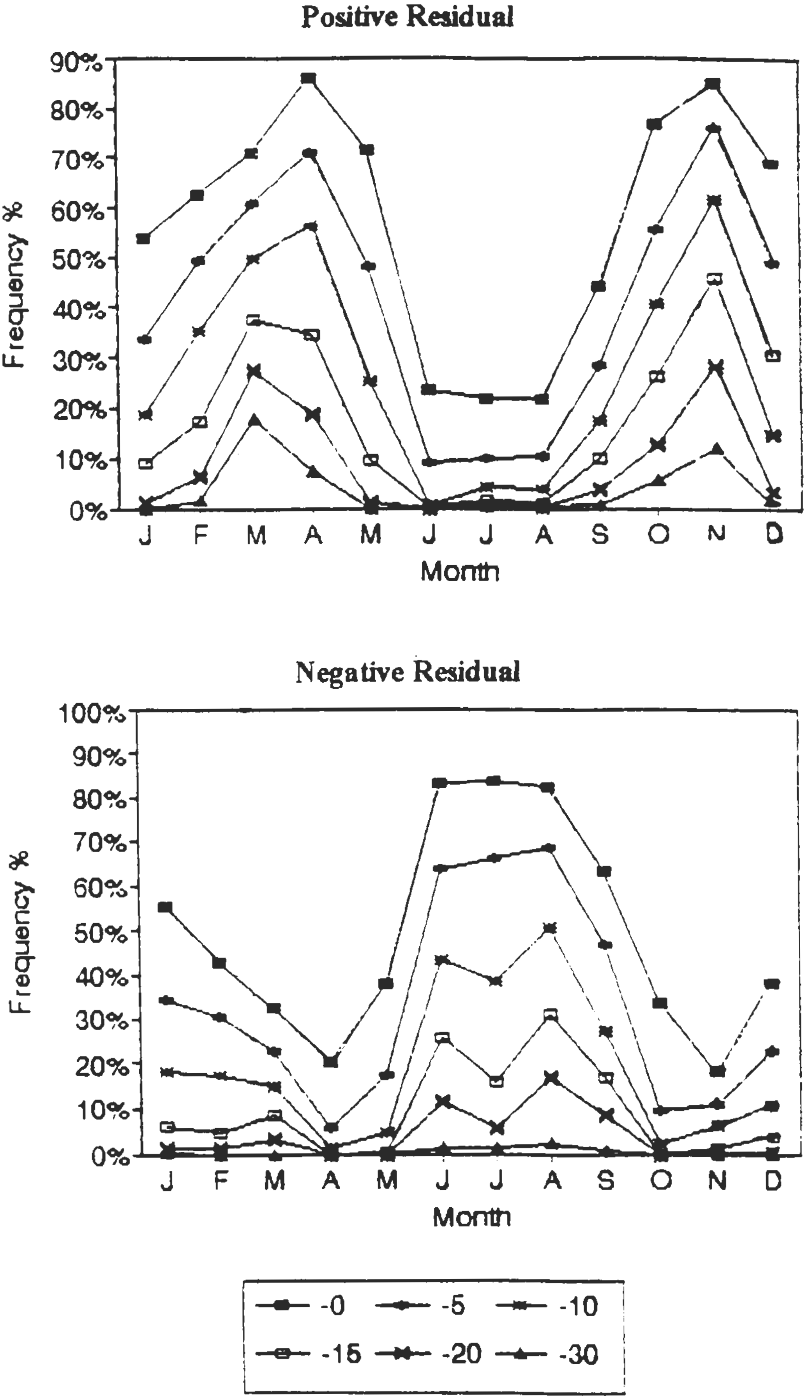


FIG. 15. The cumulative frequency distribution of residual sea level at Gineva during 1984.

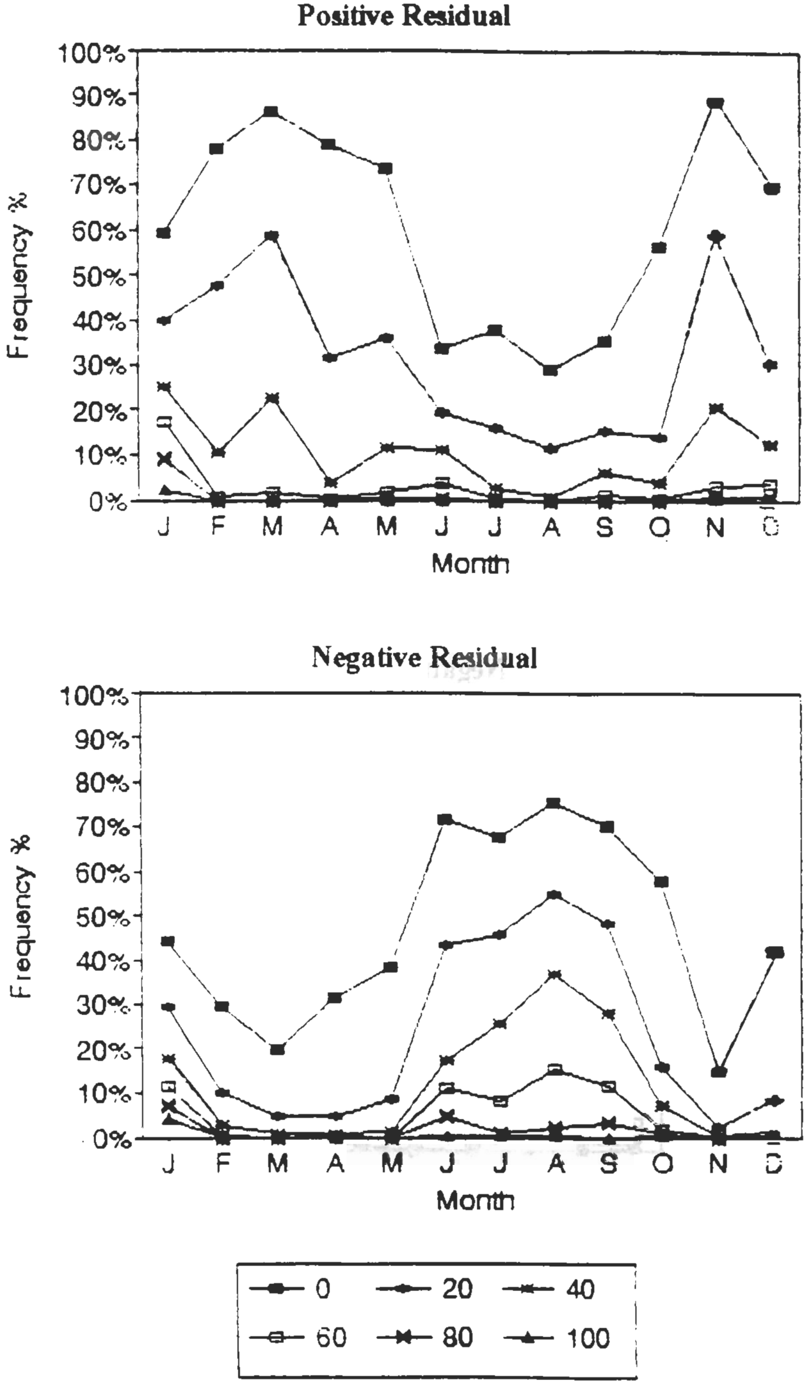


FIG. 16. The cumulative frequency distribution of residual sea level at Port Tawfik during 1984.

red during the summer months while the higher one occurred during the rest of the year. Defersoir is considered as a transition region between the northern stations (Port Said and Kantra) and southern ones (Port Tawfik and Gineva).

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التـوزيـع التـكـراري لمستـوى سـطح البحـر المتبـقي بعـد حـذف المـد والجـزر عـلى امتـداد قنـاة السـويس

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المستخلص . تم حساب ارتفاع سطح البحر الناشيء بعد حذف مركبة المد والجزر من القراءات المسجلة لمنسوب سطح البحر عند خمس محطات (بور سعيد ، القنطرة ، الدفرسوار ، جينيفا ، بور توفيق) واقعة على امتداد قناة السويس خلال عامي ١٩٨٤ و ١٩٨٥م .

تم تحديد شكل وسلوك التوزيع التكراري لمستوى سطح البحر المتبقي وذلك بحساب بعض المعاملات الإحصائية مثل المتوسط العام ، معامل التشتت ، معامل التماثل للتوزيع التكراري ، ومعامل القياس القممي للتوزيع التكراري لكل شهر خلال فترة الدراسة .

أظهرت النتائج أن أكبر ارتفاع لمستوى سطح البحر المتبقي كان عند محطة بور توفيق ، حيث تغيرت قيمه مابين ١٣٠ و ١٥٠ سم في كلا حالتي مستوى سطح البحر المتبقي الأعلى أو الأدنى من متوسط مستوى سطح البحر عند هذه المحطة . أما عند باقي المحطات ، فقد لوحظ أن أكبر ارتفاع لمستوى سطح البحر المتبقي الأعلى من متوسط مستوى سطح البحر قد تغير مابين ٣٤ سم عند محطة القنطرة و ٧٠ سم عند محطة الدفرسوار . بينما كان أكبر ارتفاع لمستوى سطح البحر المتبقي الأدنى من متوسط مستوى سطح البحر واقعًا مابين -٣٢ سم عند محطة القنطرة و -٦٦ سم عند محطة الدفرسوار .

أظهرت النتائج أيضًا أن مستوى سطح البحر المتبقي الأعلى من متوسط مستوى سطح البحر عند المحطات الشمالية (بور سعيد ، القنطرة) يحدث خلال أشهر الصيف ، بينما المستوى الأدنى كان سائدا خلال أشهر الشتاء . أما عند المحطات الجنوبية (بور توفيق ، جينيفا) فقد اختلف الوضع بصورة عكسية عما هو سائد بالنسبة للمحطات الشمالية . أما محطة الدفرسوار ، فهي تعتبر محطة انتقالية بين المحطات الشمالية والمحطات الجنوبية لقناة السويس .