A REVIEW OF SEA LEVEL MONITORING STATUS IN ISRAEL

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Introduction

Sea-levels have been measured since the early 1920's at Jaffa fishing port, but these data are not available, except for some data found at the PSMSL in UK during the 1950's.

New sea-levels were gathered at Ashdod and Haifa ports, and since 1992 at Hadera. Recently sea-level is being recorded also in Tel-Aviv, inside the Gordon marina, and at Ashkelon marina.

The information presented in this report was derived using historic sea-level data gathered originally by PRA and archived at the Permanent Service for Mean Sea-Level (PSMSL) in UK. Additional sea-level data were gathered in the recent years by IOLR for PRA in Haifa. Correlation between simultaneous data gathered at Haifa and Ashdod in the past, and between Haifa and Hadera in the recent years allowed determining the relationship between long-term elevations at Haifa, Hadera and Ashdod.

Recent History of Sea-Level Monitoring on the Mediterranean Coast of Israel

Sea-level has been monitored in Israel during the British mandate in Jaffa harbour, in Haifa port and in Eilat. The measurements were performed using a float-type mechanical mareograph (sea-level recorder as in fact it measures the total sea-level due to astronomic tide as well as other parameters (temperature, atmospheric pressure, wind surge, wave induced set-up, etc.). However, the records of sea-level data gathered during the period prior to the establishment of the State of Israel are not available and have probably been lost forever.

Sea-level data were gathered since then in Israel by a number of authorities for certain periods and certain locations as follows: Ports and Railways Authority (Haifa, Ashdod and Eilat), Meteorological Service (Haifa, Eilat), Survey of Israel (Eilat, Jaffa shifted now to Tel-Aviv), Geological Survey Institute (Atlith), Israel Oceanographic and Limnological Research (Hadera, Haifa, Eilat). During the 50's and 60's (monthly averages) at Jaffa harbour (1955-1959, 1962-1967) were transmitted to PSMSL and thus are found in its archive. Also monthly average values of sea-level data gathered at Haifa port (1956-1959, 1965-1976) and from Ashdod port (1958-1980) were found archived there. Yearly reports of measured hourly values of sea-levels were published by the PRA during the period 1958-1984. However, only some of those of the 60's and 70's included sea-levels gathered at Haifa port, while all the reports included hourly sea-levels gathered at Ashdod port (and some also at Eilat port). A survey of the Israeli sea-level data has been conducted in the past by Goldsmith and Gilboa (1985), who uncovered some additional data from Jaffa at the Survey of Israel and reported the monthly means.

Since April 1985, the Ports and Railways Authority (PRA) division responsible for the preparation of the yearly reports was dismantled, and the gathered data on paper chart remained unprocessed, until 1989, when the Survey of Israel (SOI) started gathering and manual processing these data. However, the manual processing of the data included only the daily highs and lows at Ashdod port, without recording of the time at which they occurred. The data between 1989 and 1992 were provided to the author by the SOI. The newer data from Ashdod and Haifa (1989-1995) are presently undergoing digitized by SOI, including recording of the times of the lows and highs, following author's remark on the importance of time recording. The Jaffa station, which used originally as the benchmark for the establishment of the sea-level reference, was dismantled and since 1996 a new station was installed in Marina Gordon at Tel-Aviv, site which however is not best suited for long-term sea-level monitoring, being located in shallow water and consequently affected by wave set-up. The Ashdod, Tel-Aviv and Ashkelon stations are maintained by SOI.

In 1992 IOLR installed a next generation digital sea-level monitoring station at Hadera, which became since 1994 one of the primary stations (No. 80) of the Global Sea-Level Observing System (GLOSS) network of the Intergovernmental Oceanographic Commission (IOC) of UNESCO. Sea-levels gathered at Hadera are considered to be of superior quality due to the equipment used and due to the location of the station, 2.1km offshore, far beyond influence of wave induced sea-level set-up occurring in the surf zone. Since 1994, IOLR started digital gathering of long-wave data in Haifa port which, as a by-product enabled also gathering of sea-level data there.

Previous analyses of sea-levels in Israel were performed by Gilboa and Goldsmith (1986), by Vajda(1989), and by Inman and Aubrey (1990). However, all these authors used for their analyses monthly average values, and could thus not determine the nominal values of mean lower low water (MLLW), mean sea-level (MSL), or mean higher high water (MHHW). These according to their definitions must be determined over a datum Epoch period (averaging period of 19 years to cover for the sun periodicity of 18.6 years). Hence, until recently their relative positions from the Israel Land Survey Datum (ILSD) were unknown and only roughly estimated to be some few centimeters to few tens of centimeters away from the ILSD.

A few years ago, within the framework of a High-School final thesis in Physics by Blank (1988) under author's supervision, Blank digitized 19 years of hourly data from Ashdod (1966-1984), which, after verification for errors in digitizing or of data recording with the aid of the TASK software package developed by the Proudman Oceanographic Institution in UK (maintaining the PSMSL and its archives), were used to determine corrected hourly values for the above mentioned period as well as the respective contributions of the astronomic tide and those of the meteorological induced residuals. Blank and Rosen (1998) determined the relative values of the MSL, MHHW and MLLW from the ILSD for Ashdod for the period 1966-1984. Assuming that the ILSD is the constant along the Israeli coast (which unfortunately are known to differ in the old ILSD system, now being reestablished by the SOI in a new unified ILSD datum) one may provide only a rough estimate. This estimate, is due to the fact that the location of the Ashdod benchmark and monitoring site was moved twice at least between 1958 and 1984. Once by moving from Eshkol cooling basin (Ashdod coast) to Ashdod port in January 1968 (+6 cm thereafter according to Goldsmith and Gilboa-1985), and once again within the port from the inner part to the entrance sector of the port at an unknown date (record lost). Using the available data, the sea-level monthly average values were plotted in Figure 6a,b,c. A very good coincidence appears among Haifa, Jaffa and Ashdod in many occasions, leading to the conclusion that the differences between the stations benchmarks are no more than about 10 cm, probably less.

The analysis of the old hourly records (available only as printed hard copy data), included digitizing of the printed hourly data, followed by a corrective process to remove random or systematic errors. Due to this cause, it may be said that the Ashdod data published in the past could not provide a reliable estimate of the tidal datums as they did not passed such error correction.

The investigation covered more than a full Epoch (a 18.6 year cycle, representing the largest astronomic solar cycle relevant to human life-time changes) period (1966-1984), for which all the hourly data were digitized, analyzed, corrected and processed to obtain the MSL, MHHW and MLLW.

According to the results of Blank and Rosen (1998), the MLLW is 12 cm (11.92) below the ILSD at Ashdod (1958-1984 period), while the MSL is 2.73 cm above ILSD and MHHW is 18 cm (17.77) above ILSD. Assuming that no changes in the position of the bench mark at Ashdod occurred since 1984, the above data may be used also for the present sea level state, until a new ILSD is finalized as mentioned before. Yearly values of average and extremes of astronomic tide and meteorological residuals of the sea-level determined at Ashdod are presented in Table 2.

As explained in the next section, attempts to assess long-term sea-level change based on the Ashdod data until 1985 led us to the conclusion that due to the shifting of the Ashdod sea-level gauge station and reference bench mark location a number of times and due to the large seasonal sea-level change (up to 20 cm), does not enable to reliably determine if any long term sea-level change has occurred at the Israeli coast. It is expected that with the new accurate and continuous sea level data gathered at the Hadera GLOSS station no. 80, combined with the simultaneous in situ systematic gathering of atmospheric pressure, waves, currents, wind, sea water temperature and reference bench mark elevation, it will be possible in the forthcoming years, after a sufficient amount of accurate data have been collected, to reliably determine the extent of the forecasted global warming induced sea-level rise on the Mediterranean coast of Israel.

Characterization of the Sea-Level Climate at the Mediterranean Coast of Israel

The tidal (astronomic) range on the Mediterranean coast of Israel is characteristic of the low-tide range of the Eastern-Mediterranean basin, being induced by the combined effect of the attraction forces of the moon and of the sun, and by the location of this coastal sector on the globe. Analyses of the local constituent contributions conducted by the author have shown however that the latter are only of very minor importance, and thus the sea-levels are in general very similar along the Mediterranean coast of Israel (see Figures 1, 2 and 3). The tide usually varies between 0.4 m during spring tides (occurring in spring and autumn), and 0.15m during neap tides (occurring in winter and summer). The tide contribution exhibits semi-diurnal periodicity (twice a day highs and lows) as well as fortnight (14 days) periodicity. An example of daily variations is presented in Figure 5.

Extreme sea levels may occur in combination with extreme meteorological conditions. However these may differ from site to site along the coast of Israel. An example is shown in Figure 4 for December 22-23, 1967, whereas the sea-levels at Ashdod located on the open coast reached a very high elevation, but not so at Haifa Port. During spring and particularly in

November – December months, easterly winds occurring at Haifa reduce sea-levels in Haifa port and bay area, while that effect is not detected at other locations further south along the coast.

Low sea-levels occur in winter during February-March months, while high sea-levels occur in August-September, with a second maximum in December. Although the high levels are coincident to the warm and cold seasons (steric effect of water volume change due to temperature) it was found that the major contribution is due to the astronomic tide and that the steric contribution is minor in this respect. Thus, the main reason for the seasonal sea-levels is the relative position of the sun versus earth in winter and in summer (see Figure. 5).

Assessment of extreme sea-levels was based on two methods: (a) using values of yearly maxima and minima from Ashdod, (2) using astronomic tide and extreme yearly residuals (maxima or minima) from the 19 years of hourly data analyzed for Ashdod (See Figure 7).

In Table 1 below are presented the sea-levels for average return periods of 1, 50 and 100 years.

Table 1 – Extreme Sea-Levels at the Israeli coast

Average Return Period	Low Sea Level	High Sea Level
[years]	[m]	[m]
1	-0.38	0.64
50	-0.74	1.04
100	-0.87	1.10

The above values do not include the expected sea-level rise due to the "greenhouse effect". According to Warrick and Oerlemans (1990) the most probable assessed average global sea-level rise for 2030 is 18 cm and 70 cm for year 2100. However, it is agreed by the professional bodies involved with this assessment that the sea-level rise can differ from the above depending to the location on the globe. A regional change may significantly differ from the above assessment because of local plate tectonic movements, land rebound due to groundwater withdrawal, etc. As the worming is expected to accelerate only in the next century, the signs of sea-level rise are difficult to detect presently, being masked by other factors like seasonal warming and cooling of the sea-water (steric effect), wind induced sea-level rise during storms (wind surge), wave induced sea-level set-up in the surf zone, atmospheric loading by passing high and low atmospheric.

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Table 2 – Ashdod Yearly Values of Average and Extremes of Astronomic Tide and Meteorological Residuals of the Sea-Level

year	Residual			Tide			Sea-level		
	max	Average	min	max	average	min	max	average	min
	cm	cm	cm	cm	cm	cm	cm	cm	cm
1966	52.9	0.0	-34.9	32.3	-1.1	-42.4	71.0	-1.1	-58.0
1967	75.0	0.0	-27.3	32.4	-3.2	-37.5	93.0	-3.2	-55.0
1968	44.3	0.0	-17.1	41.1	9.0	-29.5	69.0	9.0	-39.0
1969	38.7	0.0	-22.8	41.9	9.0	-20.9	66.0	9.0	-34.0
1970	29.3	0.0	-24.3	39.0	6.8	-25.6	56.0	6.8	-35.0
1971	39.4	0.0	-36.9	41.5	5.4	-25.5	44.0	5.4	-38.0
1972	37.4	0.0	-19.8	33.0	3.3	-28.3	44.0	3.3	-42.0
1973	32.0	0.0	-34.0	45.0	6.8	-30.4	46.0	6.8	-46.0
1974	30.5	0.0	-18.7	35.7	7.5	-24.0	45.0	7.5	-37.0
1975	34.5	0.0	-11.8	40.1	5.1	-27.7	46.0	5.1	-33.0
1976	39.9	0.0	-16.1	33.2	5.7	-25.7	44.0	5.7	-40.0
1977	45.9	0.0	-31.2	35.6	2.4	-30.3	52.0	2.4	-47.0
1978	25.7	0.0	-22.6	44.4	11.9	-15.2	51.0	11.9	-31.0
1979	33.5	0.0	-15.4	45.9	15.0	-19.8	59.0	15.0	-32.0
1980	36.5	0.0	-27.3	48.3	15.3	-14.7	61.0	15.3	-37.0
1981	30.3	0.0	-15.8	38.3	7.5	-24.8	46.0	7.5	-33.0
1982	28.3	0.0	-14.3	36.1	5.5	-26.7	49.0	5.5	-36.0
1983	35.3	0.0	-15.9	36.7	8.3	-24.8	48.0	8.3	-33.0
1984	32.7	0.0	-15.8	40.4	9.6	-20.2	50.0	9.6	-33.0

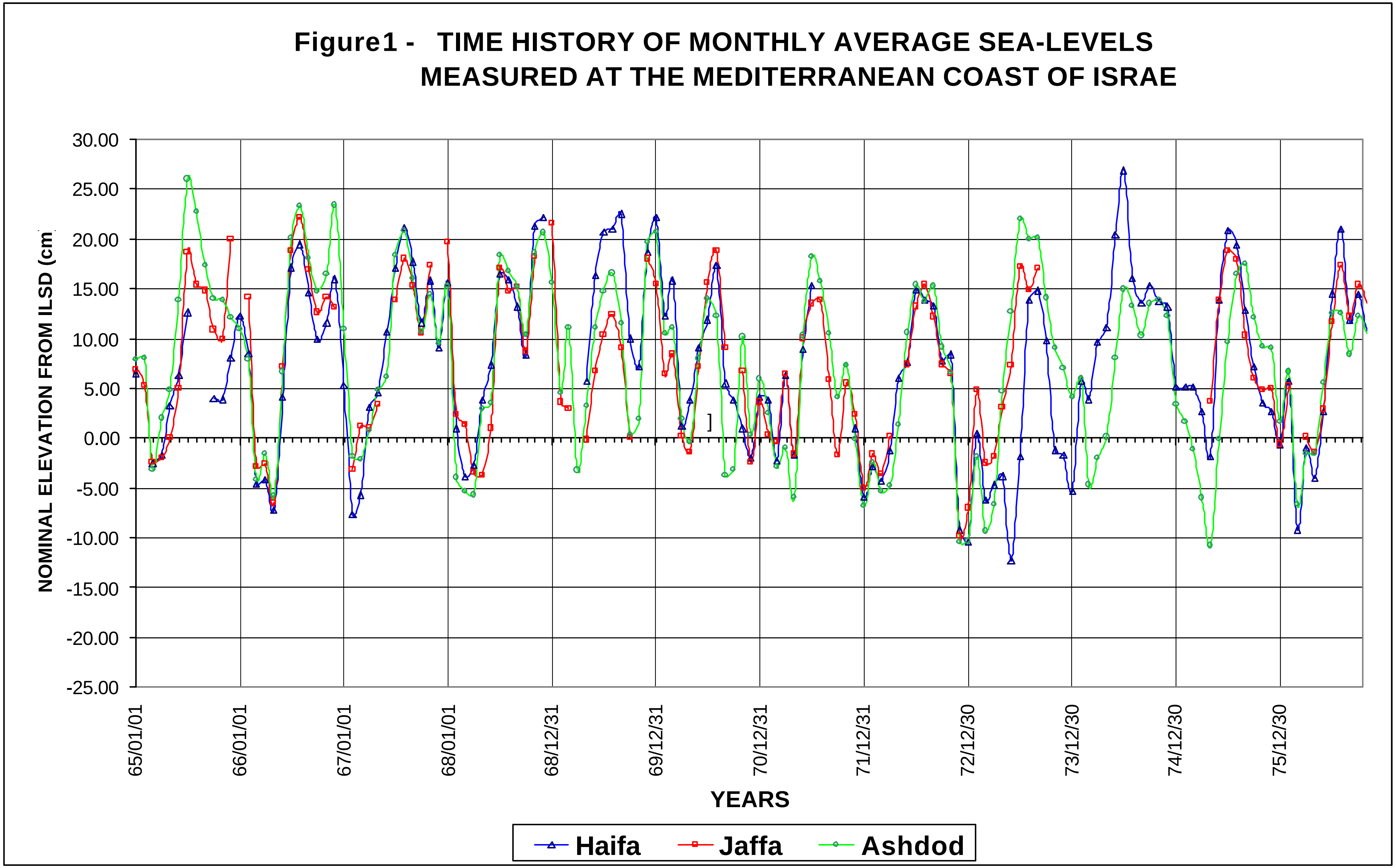
Figure1 - TIME HISTORY OF MONTHLY AVERAGE SEA-LEVELS
MEASURED AT THE MEDITERRANEAN COAST OF ISRAE
NOMINAL ELEVATION FROM ILSD (cm)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
-15.00
-20.00
-25.00
65/01/01
66/01/01
67/01/01
68/01/01
68/12/31
69/12/31
70/12/31
71/12/31
72/12/30
73/12/30
74/12/30
75/12/30
YEARS
Haifa
Jaffa
Ashdod

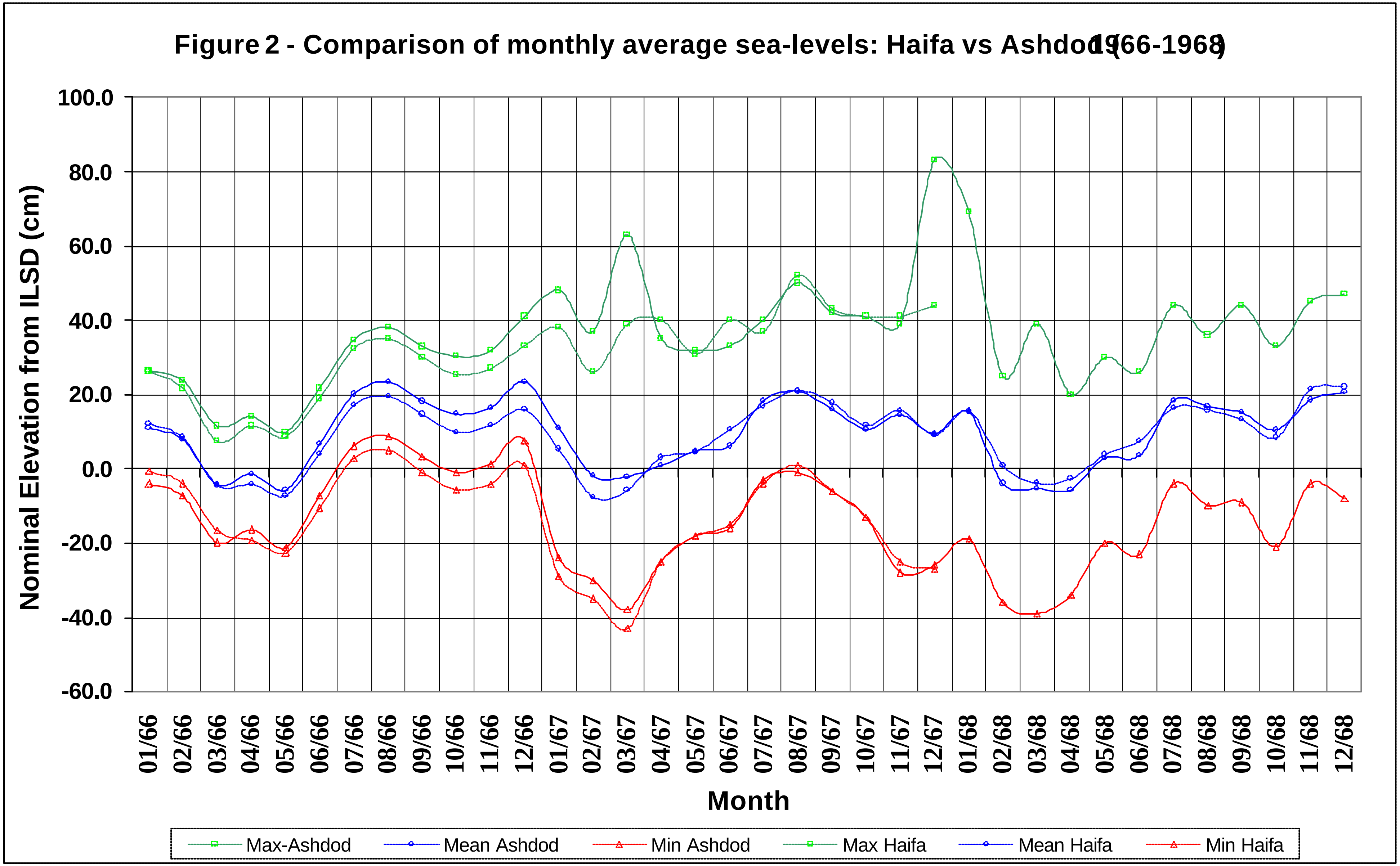
Figure 2 - Comparison of monthly average sea-levels: Haifa vs Ashdod (1966-1968)
100.0
80.0
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
Nominal Elevation from ILSD (cm)
01/66
02/66
03/66
04/66
05/66
06/66
07/66
08/66
09/66
10/66
11/66
12/66
01/67
02/67
03/67
04/67
05/67
06/67
07/67
08/67
09/67
10/67
11/67
12/67
01/68
02/68
03/68
04/68
05/68
06/68
07/68
08/68
09/68
10/68
11/68
12/68
Month
Max-Ashdod
Mean Ashdod
Min Ashdod
Max Haifa
Mean Haifa
Min Haifa

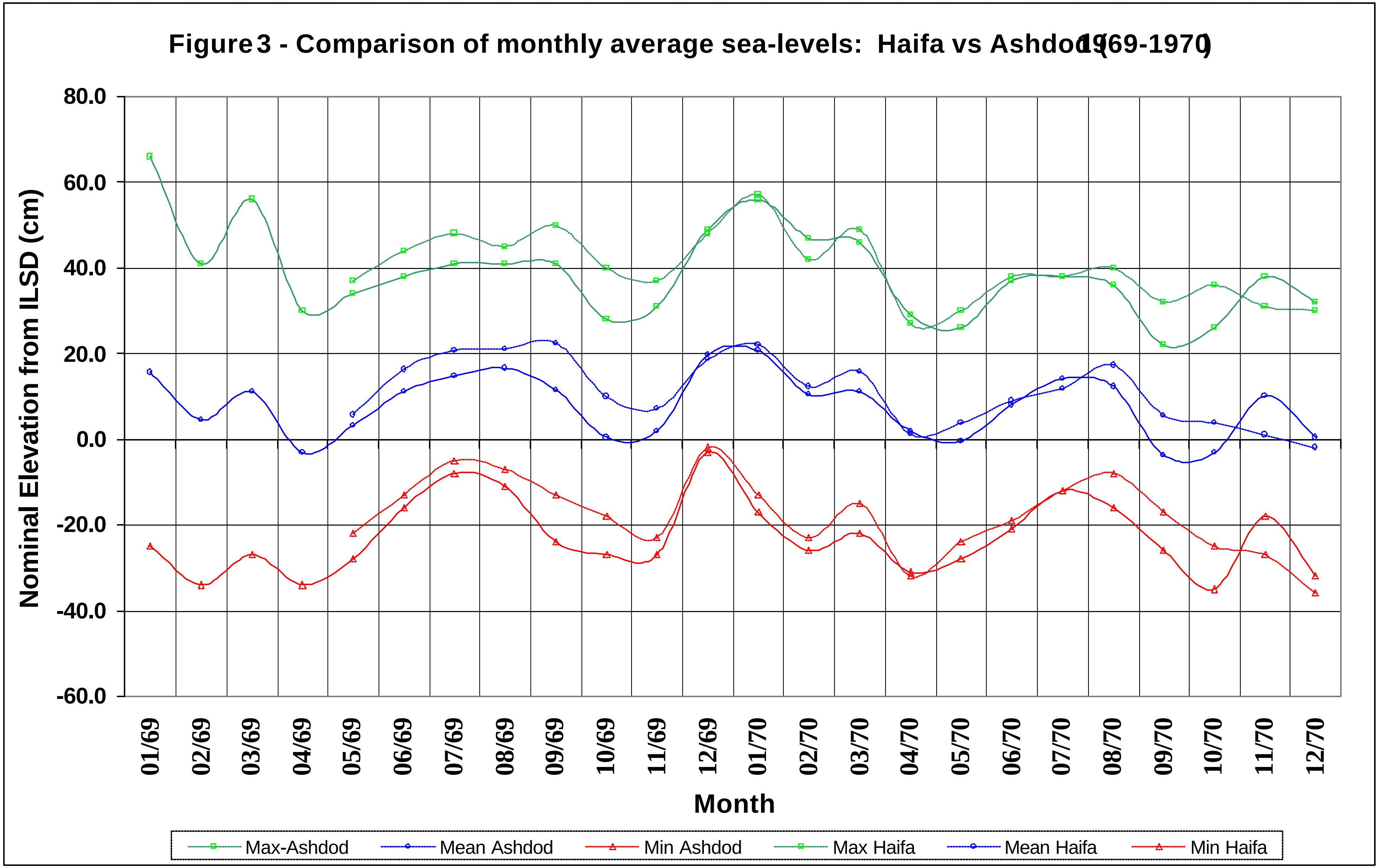
Figure 3 - Comparison of monthly average sea-levels: Haifa vs Ashdod (1969-1970)
80.0
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
Nominal Elevation from ILSD (cm)
01/69
02/69
03/69
04/69
05/69
06/69
07/69
08/69
09/69
10/69
11/69
12/69
01/70
02/70
03/70
04/70
05/70
06/70
07/70
08/70
09/70
10/70
11/70
12/70
Month
Max-Ashdod
Mean Ashdod
Min Ashdod
Max Haifa
Mean Haifa
Min Haifa

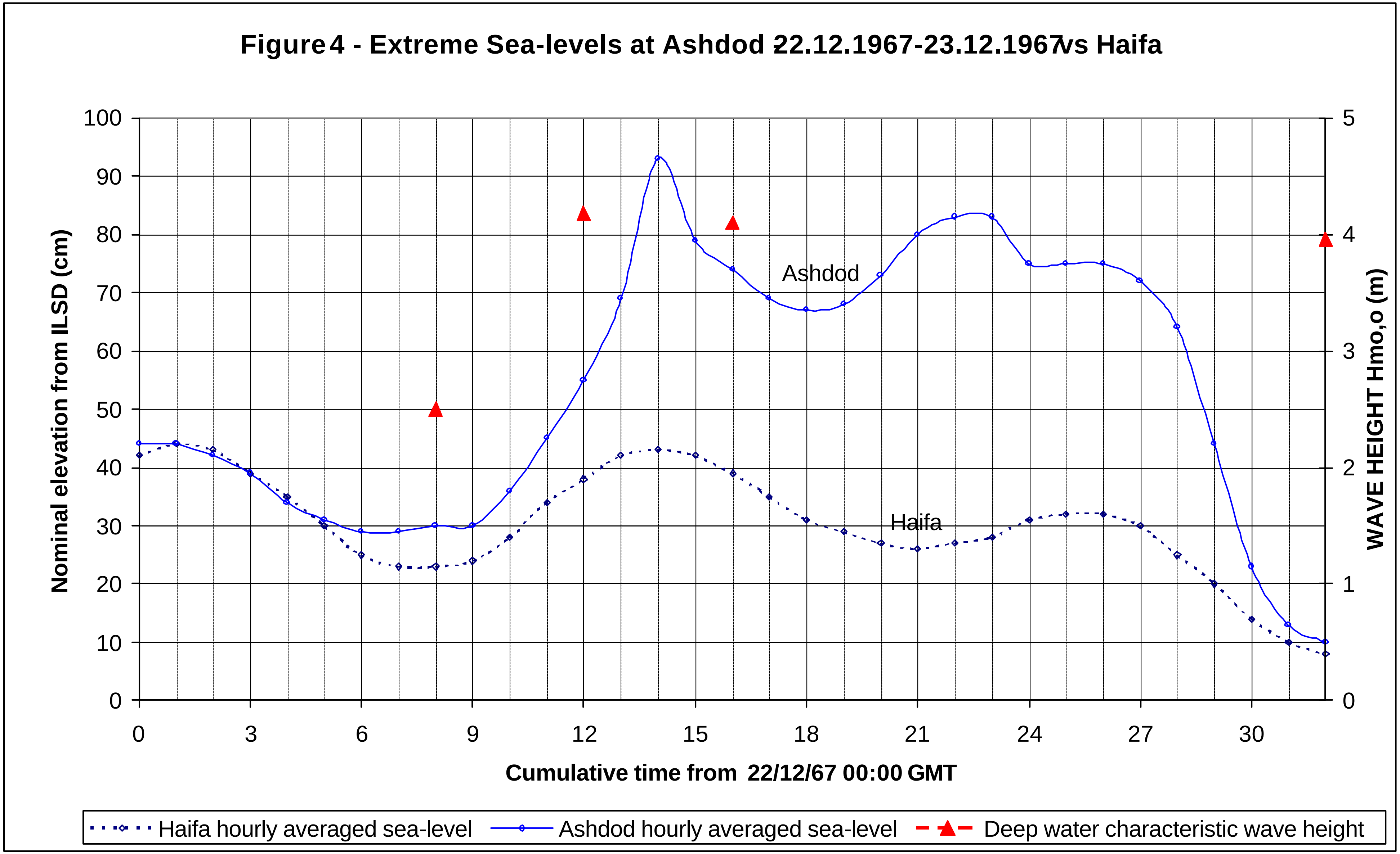
Figure 4 - Extreme Sea-levels at Ashdod 22.12.1967-23.12.1967 vs Haifa
Nominal elevation from ILSD (cm)
WAVE HEIGHT Hmo,o (m)
Cumulative time from 22/12/67 00:00 GMT
Ashdod
Haifa
Haifa hourly averaged sea-level
Ashdod hourly averaged sea-level
Deep water characteristic wave height

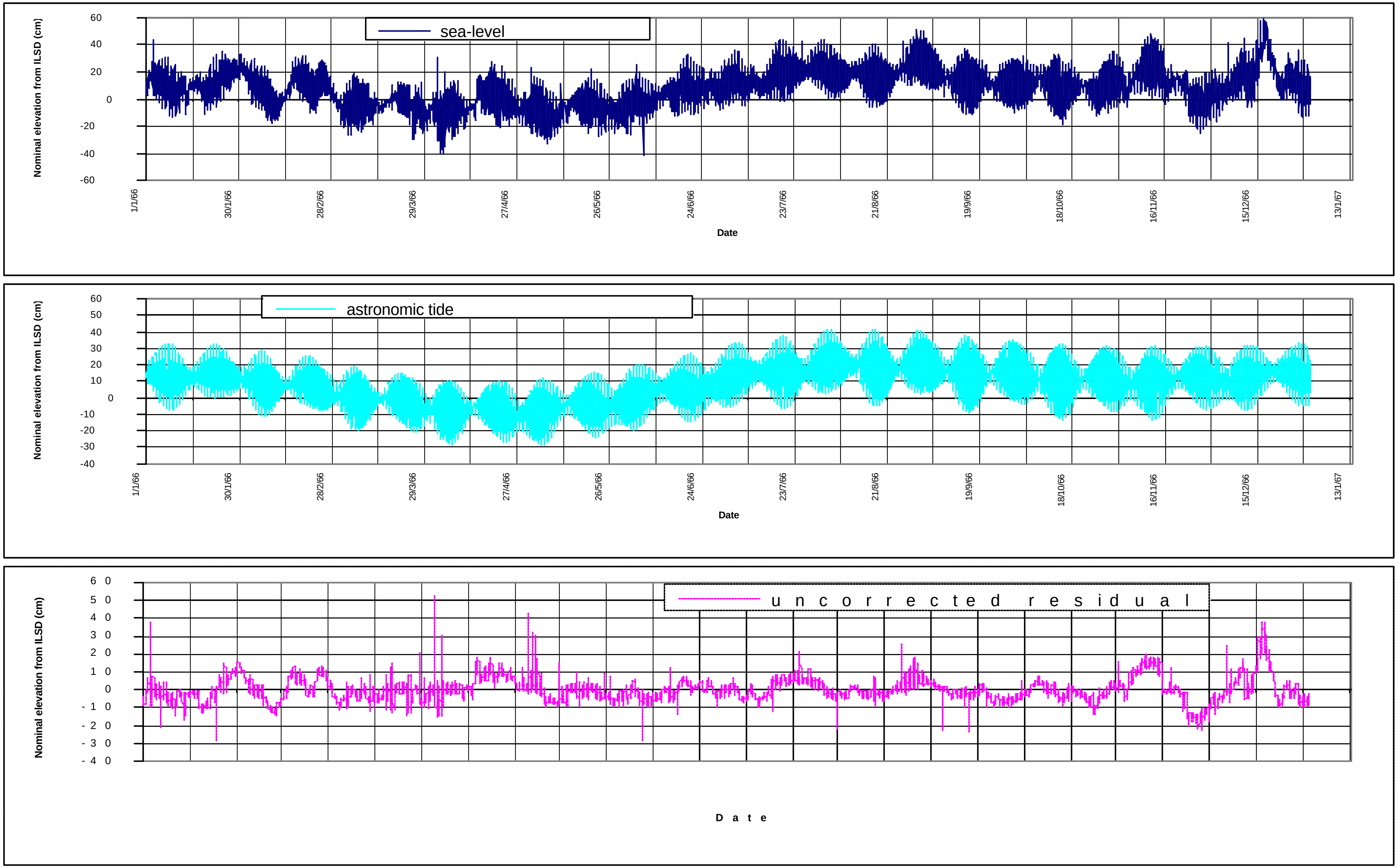

Figure 5 - Example of 1 year of hourly sea-levels - Haifa 1966

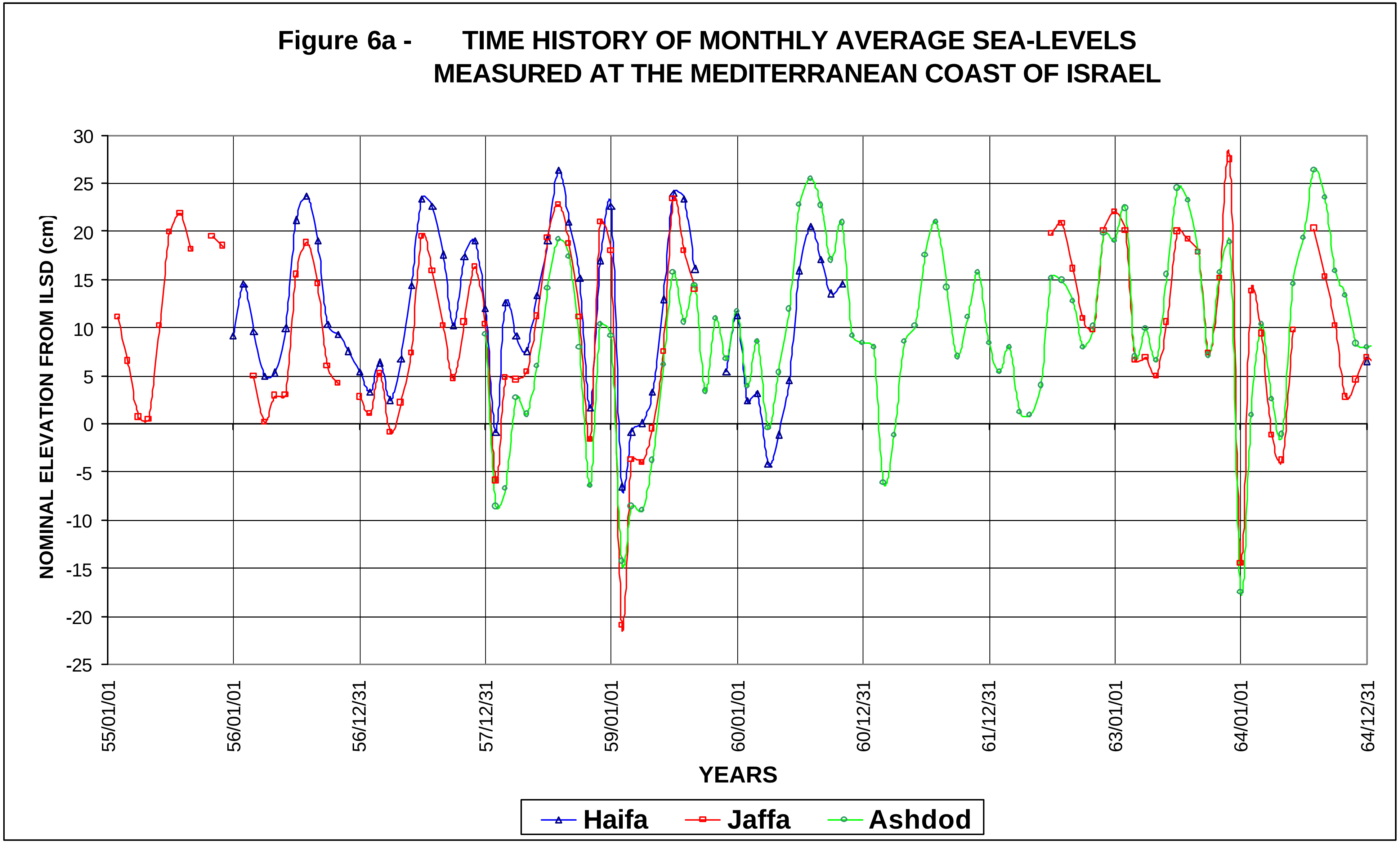
Figure 6a - TIME HISTORY OF MONTHLY AVERAGE SEA-LEVELS
MEASURED AT THE MEDITERRANEAN COAST OF ISRAEL
NOMINAL ELEVATION FROM ILSD (cm)
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
55/01/01
56/01/01
56/12/31
57/12/31
59/01/01
60/01/01
60/12/31
61/12/31
63/01/01
64/01/01
64/12/31
YEARS
Haifa
Jaffa
Ashdod

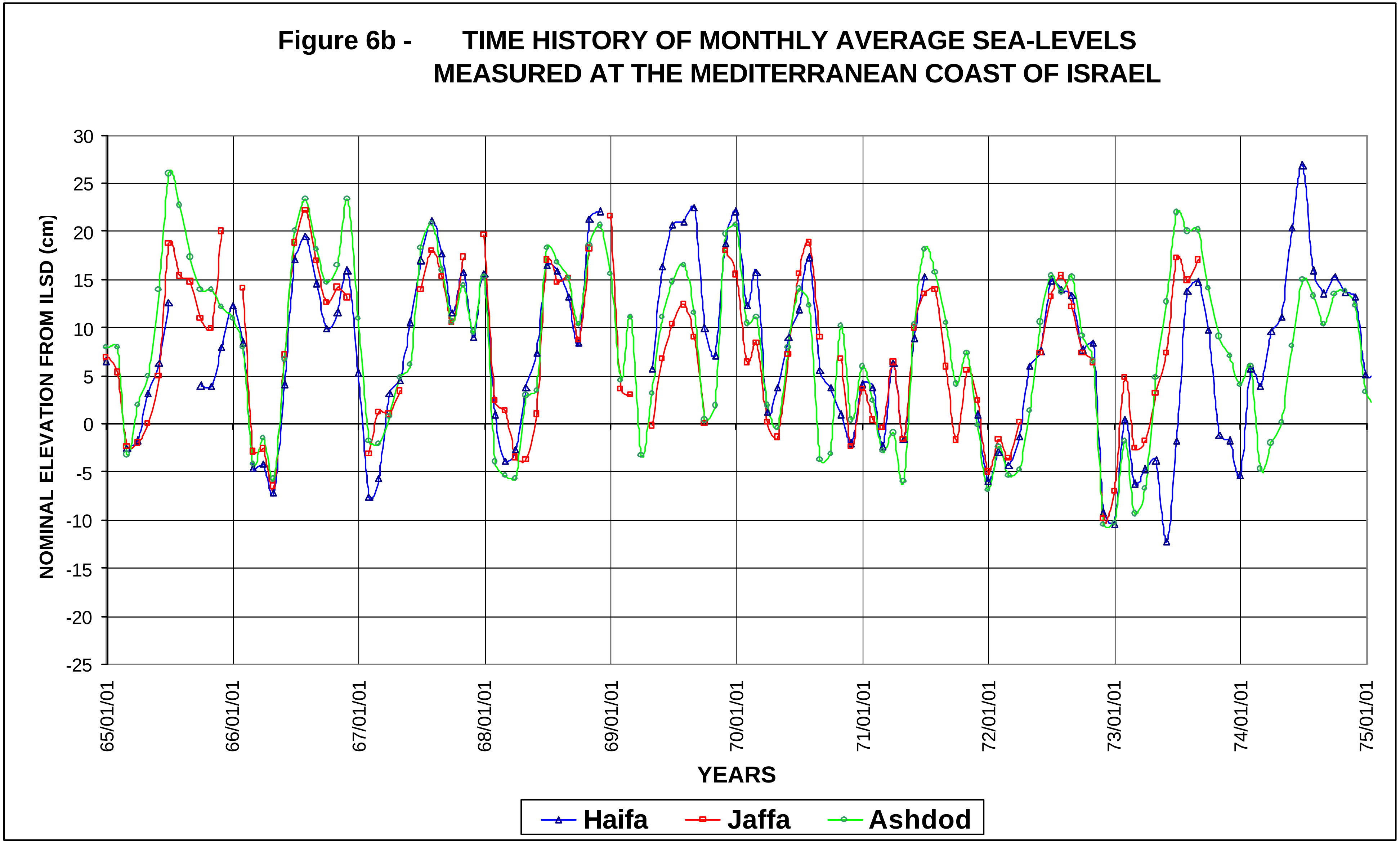

Figure 6b - TIME HISTORY OF MONTHLY AVERAGE SEA-LEVELS MEASURED AT THE MEDITERRANEAN COAST OF ISRAEL
NOMINAL ELEVATION FROM ILSD (cm)
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
65/01/01
66/01/01
67/01/01
68/01/01
69/01/01
70/01/01
71/01/01
72/01/01
73/01/01
74/01/01
75/01/01
YEARS
Haifa
Jaffa
Ashdod

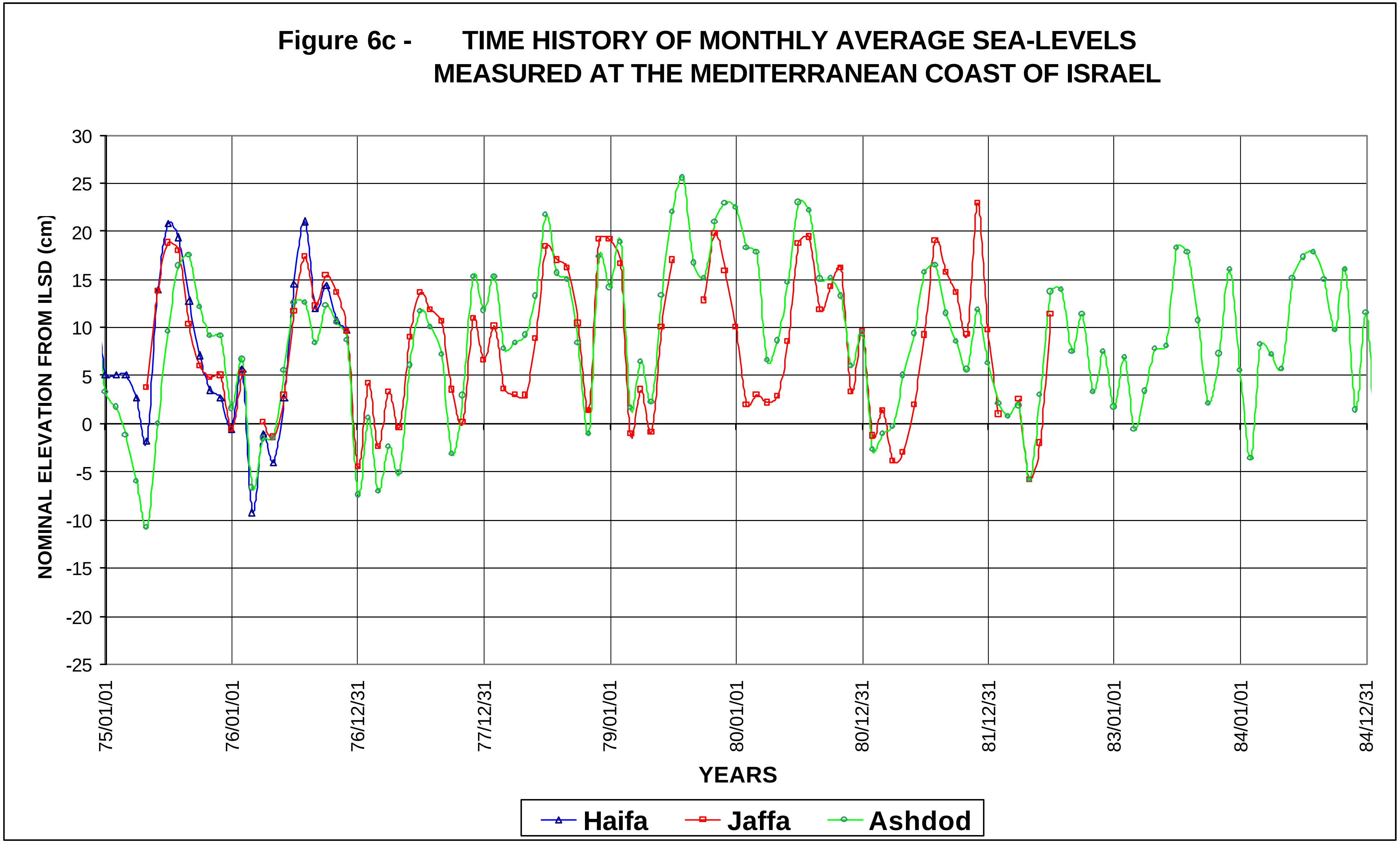

Figure 6c - TIME HISTORY OF MONTHLY AVERAGE SEA-LEVELS MEASURED AT THE MEDITERRANEAN COAST OF ISRAEL
NOMINAL ELEVATION FROM ILSD (cm)
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
75/01/01
76/01/01
76/12/31
77/12/31
79/01/01
80/01/01
80/12/31
81/12/31
83/01/01
84/01/01
84/12/31
YEARS
Haifa
Jaffa
Ashdod

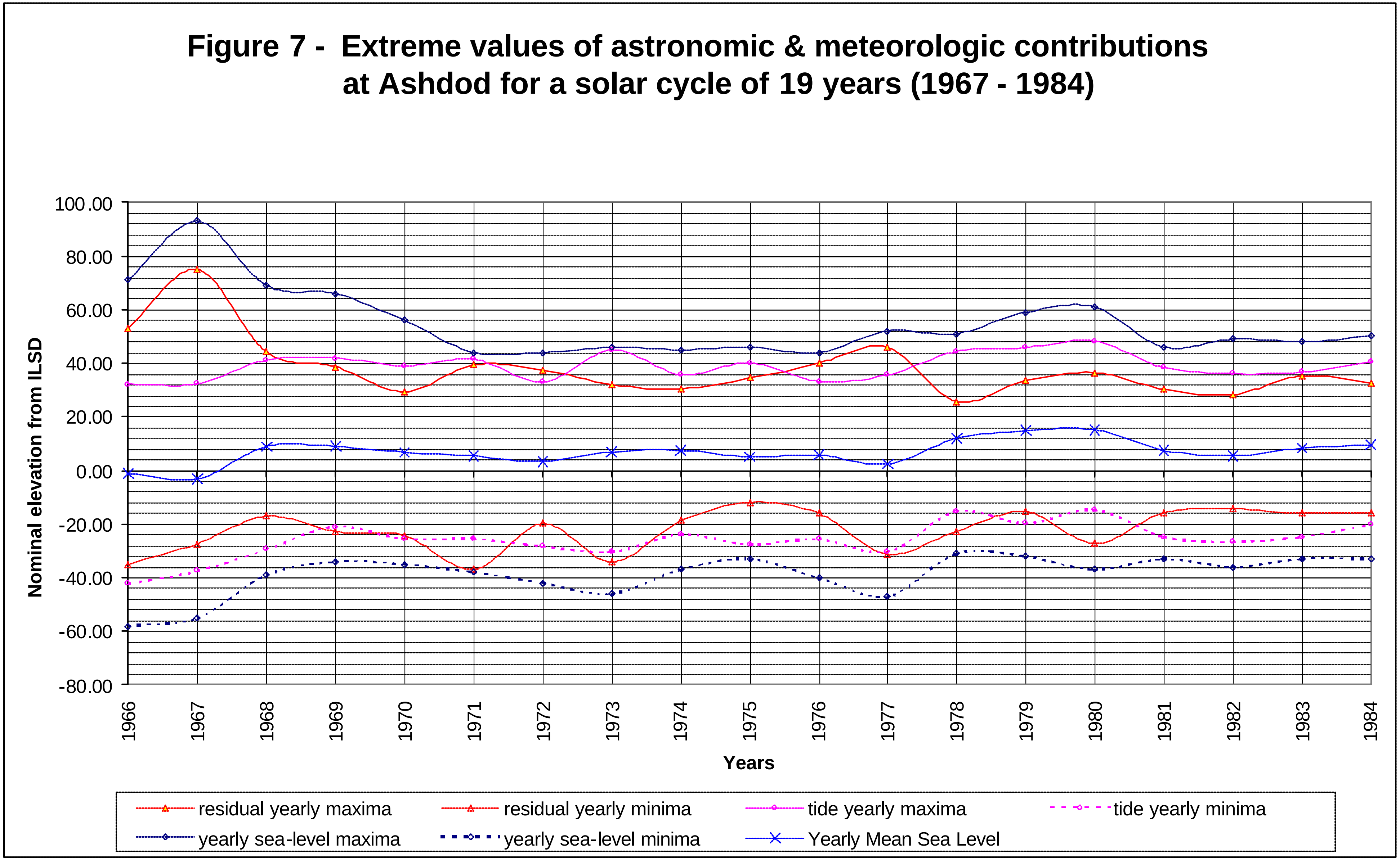
Figure 7 - Extreme values of astronomic & meteorologic contributions
at Ashdod for a solar cycle of 19 years (1967 - 1984)
Nominal elevation from ILSD
100.00
80.00
60.00
40.00
20.00
0.00
-20.00
-40.00
-60.00
-80.00
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
Years
residual yearly maxima
residual yearly minima
tide yearly maxima
tide yearly minima
yearly sea-level maxima
yearly sea-level minima
Yearly Mean Sea Level