RELATIVE SEA LEVEL RISE ALONG THE BELGIAN COAST:

ANALYSES AND CONCLUSIONS WITH RESPECT TO

THE HIGH WATER, THE MEAN SEA AND THE LOW WATER LEVELS

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1. INTRODUCTION

1.1. Tide gauges stations only measure locally the Relative Sea Level (RSL)-oscillations.

These variations, measured relative to the land, are originated by *periodic* (tidal effects), *random* (meteorological and hydrological influences), *isostatic* (redistribution of the mass of the earth, due to geological processes), *tectonic* (crustal movements) and *eustatic* (changes of the capacity of the water-volumes of the seas and the oceans) *agents*[1,2,3,4].

The so called uplift of Scotland and Scandinavia is isostatic; it is the result of the glacial melting of the former ice-sheets, by which the shape of the geoid gradually changed (geological process, due to the post glacial rebound).

Local earthquakes (crustal movements) are tectonic and also can modify the geoid.

Eustacy will produce changes in the capacity of the water-volumes of the seas and the oceans and is due to the melting of large amounts of glaciers and polar ice-sheets (glacio- eustacy), to tectonic movements (tectono-eustacy) and to the sedimentation, originated by the erosion of the continents on the long run (sedimentation eustacy).

We may consider the periodic and random effects as being short term influences, while the isostatic, tectonic and eustatic changes have mostoften a long-term character.

1.2. The world today is consuming its resources at a relatively high speed and is producing large amounts of waste. Some of these products, the so called greenhouse gases, such as carbon dioxide ($C0_2$), nitrous oxide (N_2O), methane (CH_4), chlorofluorocarbons (CFC's), etc., are concentrated in the atmosphere; mostoften they are generated by industry, but also by other human activities.

The "Intergovernmental Panel on Climate Change" or IPCC assumed already in 1990 that a doubling of the $C0_2$-content in the atmosphere will cause an increase in global mean temperature from 1,5° to 4,5° C[5].

This may lead, probably in the second half of the next century, to irreversible global changes in sea level, i.e. this phenomenon may produce the so called "greenhouse effect".

For the low-lying areas, like the Dutch and the Flemish coastal plains, being nearly situated at about mean sea level and only being protected from the sea by dikes and dunes, it thus looks very opportune to monitor and to investigate this evolution.

1.3. The present paper is in an updating of two earlier studies[6,7], both being contributions of the Coastal Waterways Division-Hydrographic Service, Oostende, to former EC-contracts.

2. CHOICE AND QUALITY OF THE DATA

The analyses of the relevant tidal elevation data along the Belgian coast in the past, such as the annual levels of High Water (HW), Mean Sea Level (MSL) and Low Water (LW) for Oostende, Zeebrugge and Nieuwpoort, can yield information both about the short and about the long term trends.

At the same time we found it interesting to make a comparison with the same levels, calculated for Vlissingen (the Netherlands).

Before attempting to analyse the tidal data, we must consider its value and usefulness.

As the history of the tidal observations for the 3 locations, mentionned above, has been given already in an earlier paper 6, we found it useful to repeat and to update all of it once more.

The *Annexes 1, 2 and 3* give a synopsis of the periods of these observations along the Belgian coast (Oostende, Zeebrugge and Nieuwpoort); here the periods, for which a harmonic analysis occurred, are also indicated[8 to 19].

We want to stress that the tidal observations needed to be reliable and to be obtained over extented and uninterrupted periods.

As can be noticed from the tables, for some years, there are significant gaps in these series, mainly for the earlier periods.

It can be noticed that **Oostende** has the longest records (see *Annex 1*); so, this location can be considered as the main tide gauge station for the Belgian coast.

Reasonably good observations (readings of HW and LW on a tide pole) began already in 1820, but, unfortunately, these data have been lost.

All the other earlier records, mainly predating World War I and II, were also carefully examined:

(1) For the period 1835-1852, the monthly values of HW/LW are based on continuous HW/LW records, read from a tide-pole, close to a lock in the harbour of Oostende (Reference 3) and near to a reliable benchmark, to which the gauge was referred. This benchmark was incorporated in a quay wall.

Because only monthly mean values of HW/LW were available, mean tide levels (i. e. the mean of HW and LW) could be calculated. The difference between this level and MSL along the Belgian coastline is nearly constant; e. g. for the period 1949-1988 the difference is +0,063 m. So, knowing the mean tide levels, we were able to determine the MSL-value for each year of the period concerned.

(2) For many reasons the period 1878-1914 was not useful for this study: some data have been lost, there are too many gaps in the data and the reference datum is uncertain.

If we compare also the yearly values of these periods with those of Vlissingen (the Netherlands), we sometimes found differences of more than 10 cm, whereas only 3 or 4 mm are the normal values for years with reliable observations...

From 1925 till now (1998), the records of the years 1925, 1926 and of most part of World War II (1940, 1941, 1942 and 1944) are very discontinuous; so we decided not to use them in this study, except when using the technique of moving averages (see further sub 3.3).

From the Rijksinstituut voor Kust en Zee (RIKZ) of the Dutch Rijkswaterstaat in The Hague, we kindly received the analogous information for **Vlissingen**, related to a reliable and continuous period of 109 years (1890-1998).

For **Zeebrugge** and **Nieuwpoort**, the observations started in the early thirties, but the data for 1932-1940 and 1941-1943 were also very discontinuous.

Continuous data are only available respectively from 1964 and 1967 onwards, as indicated in the Annexes 2 and 3.

3. LOCAL TRENDS FOR HW, MSL AND LW

For the EC-project EPOC[6], only the tidal elevation data for Oostende and Vlissingen have been taken into consideration, i.e. those for High Water (HW), for Mean Sea Level (MSL) and for Low Water (LW).

In the later study[7], besides the data of Oostende and Vlissingen, we also made use of the data of Zeebrugge and of Nieuwpoort.

For the determination of the local trends, we used, so far, the *following methods*:

- *linear curve fittings* [6 and 7],
- *cyclic curve fittings* [6],
- *moving averages* [6],
- *singular spectrum analysis* [7].

The first three methods will be applied again for this publication: see further sub 3.1., 3.2. and 3.3.

As the last method, applied in our second paper (Reference 7), did not supply so much added value, we did not use it in the present paper any more.

Another additional method is to make *an investigation on the values of the main harmonic components* for our main tide gauge station (Oostende): this has been carried out in 3.4.

3.1. Linear curve fittings

The *Annex 4* represents the yearly values or scatter diagrams of HW, MSL and LW for **Oostende**. These data are referred to TAW (Tweede Algemeene

Waterpassing) , being the Belgian National Reference Level.

Further on, the linear best fit calculations through these 3 diagrams values have been carried out by means of the method of least squares; the outcome of these curve fittings have been represented on the same Annex; the linear correlation coefficient (Pearson r) and the 95% confidence limits are determined as well.

For the 3 annual values we see a linear increase of nearly 0,01 m/decade, if the two periods, i.e. 1835-1852 and 1927-1998 (less 4 years of the World War II), are taken into account.

On the other hand, if only the last period, less the years as mentionned above, is considered, the 3 regression lines for HW, MSL and LW indicate a rise of 0,0217 m/decade, of 0,0144 m/decade and of 0,0084 m/decade.

In all cases, the correlation coefficients are rather high, except for LW (period 1927-1998). This is normal because the HW- and LW-configuration is subject to the same nodal fluctuations (see further sub 3.2.); as a matter of fact, a linear best fit will be better at HW than at LW.

Anyway, all correlation coefficients are high enough: for a severe one-tailed test of 0,5%, r has to be at least 0,3076 if n or the number of the pairs of observation equals 68.

Also for LW, the significance of the regression line is thus not compromised at all.

The *Annex 5* shows the yearly values of HW, MSL and LW for **Vlissingen**, being referred to TAW as well; on the left of this Annex, the regression lines for the period 1890-1998 have been indicated, mentioning at the same time increases of 0,0329 m/decade, 0,0206 m/decade and 0, 0174 m/decade for the 3 main levels.

In the same Annex, on the right, we only, for reasons of making a comparison with Oostende, took the more recent period 1927-1998 into account; this period indicates nearly the same value for HW (a rise of 0,0339 m/decade), but differs for MSL (0,0162 m/decade) and even more for LW (0,0099 m/decade).

In all cases, the correlation coefficients are rather high, except at LW for the period 1927-1998, where we obtain r = 0,49648; nevertheless, as the n pairs of observation equal 72, the test of significance causes no problem (e.g. for the same one-tailed test of 0,5%, r is due to be 0,2988).

In our former report, we considered the results of the linear trends for Zeebrugge (31 years available: 1964-1994) and for Nieuwpoort (with a period of continuous records of 28 years: 1967-1994) as being rather disappointing, because they did not follow the same trendsetting, as found for Oostende and Vlissingen.

Meanwhile we re-examined the data of **Zeebrugge** (1964-1998) and we discovered a serious offset for the period 1964-1970...

In the *Annex 6*, after having made the necessary corrections and after adding 4 more years (thus the period 1964-1998), we now can notice for Zeebrugge an increase of 0,0170 m/decade for HW, of 0,0150 m/decade for MSL and of 0,0086 m/decade for LW.

These values are a bit lower than the ones for Oostende, but nevertheless they have nearly the same order of magnitude.

For the same one-tailed test of 0,5%, r has to be 0,418 (with n = 35).

The correlation coefficient for MSL (0,46138) is thus the only one, being high enough.

The other two r-values are too small and, as a matter of fact, the significance of the 2 regression lines for HW and for LW are thus compromised.

At **Nieuwpoort**, for the period 1967-1998, we found: 0,0412 m/decade for HW, 0,0277 m/decade for MSL and 0,0188 m/decade for LW. See also *Annex 7*.

These higher values are due to a local subsidence of the quay wall, on which the tide gauge has been installed. Earlier, we already corrected for this phenomenon, but probably we did not do it as comprehensive as it should be...

For the same one-tailed test of 0,5%, r has to be 0,454 for n = 32.

The r-values for HW and MSL (0.77146 and 0.69848) are high enough, but this is not the case for the r of LW, being only 0.36152.

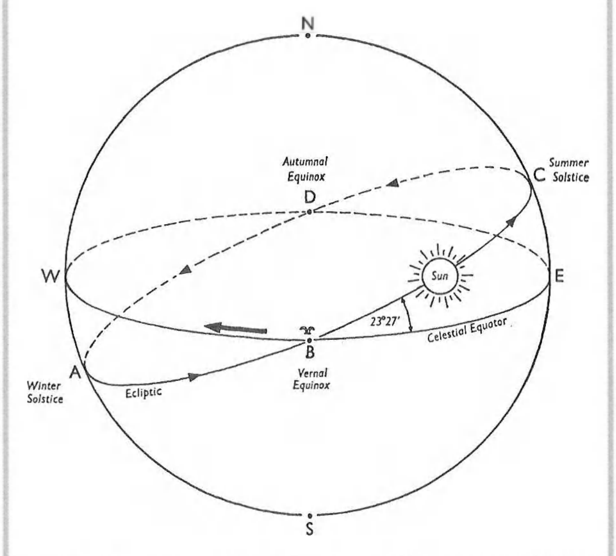
We can notice that the periods, taken into account for Nieuwpoort and Zeebrugge, represent only 1,72 and 1,88 nodal cycles, while the periods, used for the curve fitting for Oostende (1927-1998) and Vlissingen (1890-1998), are 3,87 and 5,86 nodal cycles.

Here we thus have to consider that - due to the nodal ondulations, as mentionned before - some misinterpretations may occur, if we cannot use multiples of a nodal cycle.

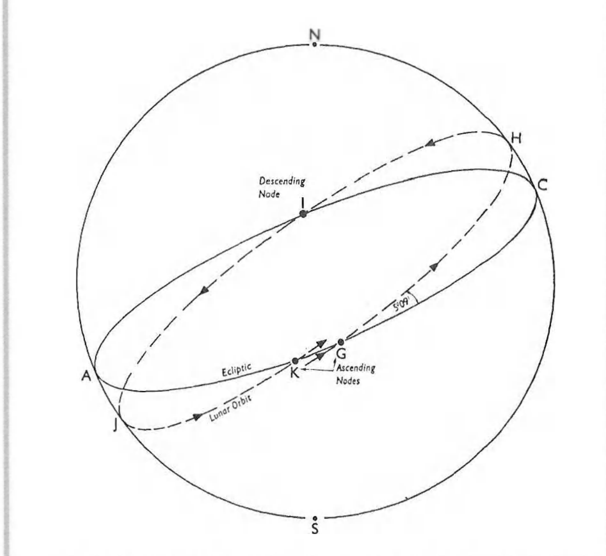
3.2. Cyclic curve fittings

In order to understand why this method of curve fitting is used, it looks useful to explain briefly the basic theories behind the so called "nodal cycle".

FIGUUR 1



FIGUUR 2



First we will have a look on the movements of the sun and the moon, relative to the earth; since Newton's time (1642-1727) we know that the attraction of one mass upon another in general and the gravitational forces of the sun and mainly the moon particularly are responsible for the tidal movements of the oceans and of the seas...

Relatively we can consider the sun and the moon as moving eastwards around the earth on the celestial ecliptic and on the moon's orbit. The *Figures 1 and 2* below show the move- ments of the sun and the moon round the earth, supposed to be in the middle of the circles.

As the moon is much nearer to the earth than the sun, its movement, relative to an observer on the earth, is much faster than the relative movement of the sun around the earth.

The sun completes its orbit in about one year (365,25 mean solar days [AWK1]days), while one revolution of the moon needs less time: it amounts, relative to the sun, to 29,5306 mean solar days (or one lunar month or one lunation or 1 synodic period).

The plane of the sun is inclined to the celestial equator at an angle of about 23°27', being the obliquity of the ecliptic.

The moon's path has an inclination of about 05°09', relative to the plane of the ecliptic.

The points, where the moon's orbit crosses the ecliptic, are called nodes; the point, where the moon's orbit crosses the ecliptic from the south to the north/the north to the south is called the ascending node (at G in Fig. 2) / the descending node (at I in Fig. 2).

The length of the ascending node or L has the vernal equinox (first point of Aries - at B in Fig. 1) as reference. Point D in Fig. 2 is the ascending node on one lunar orbit, while point K is the next ascending node for the following moon's path. The regression of the ascending node is just the movement westwards along the ecliptic; one single regression of the nodes on the ecliptic is completed after 18,61 years, being one nodal cycle.

Due to the regression of the 2 nodes, the obliquity of the lunar orbit to the celestial equator (moon's declination) will change gradually with each orbit between a variable maximum (23°27'+ 05°09'= 28°36') and a variable minimum value (23°27'- 05°09'= 18°18').

As the length of the ascending node amounts to 90° and 270°, the yearly tidal range has a mean value, while, with values of 0° and 180°, the yearly tidal range has a minimum/maximum value; the last values of L coincides with a maximum/minimum declination of the moon.

The Royal Observatory of Belgium (Brussels) kindly provided us the dates of the relevant values of L, mentioned before, and this for more than a century,. See also *Annex 8*.

The motions of the moon and the sun, relative to the rotating earth, produce thus different tidal patterns on the so called "equilibrium tide", being the hypothetical tide, which would be produced if the earth should be fully covered with a global deep ocean.

The cyclic fluctuations, due to the nodal cycle, only can be noticed on the configuration of the yearly values of HW/LW of a certain tidal station.

The *Annexes 9 and 10* show these values for **Oostende** with the fittings of a cyclic trend. The rather irregular shape of the yearly data is random and is originated by meteorological influences; as a matter of fact, the μ-value is very small , but the σ-value can be more than 10 cm, due to these random influences...

In the equations of this cyclic curve fitting we found (with the A-coefficient) an increase of 0,01758 m/decade for HW and 0,01149 m/decade for LW; the first is slightly less than the similar value of the Annex 4, but for the second we just come to the opposite conclusion.

Any way, here also we noticed the same global increase of 2 and 1 mm/year for HW and LW.

Also for reasons of comparison, the similar curves for Vlissingen have been given in the *Annexes 11 and 12.* The cyclic equations provide now A-coefficients of 0,03166 m/decade and 0,0123 m/decade; these values too are comparable with the ones of Annex 5.

The annual increase of nearly 3 mm/year for HW and 1 mm/year for LW is thus confirmed.

We did not carry out the analog exercises for **Zeebrugge** and **Nieuwpoort**, because there we considered the time series as being too short for this sort of exercise.

3.3. Moving averages

Further we thought that the use of moving averages could be interesting, in order to eliminate the oscillations, due to the nodal cycle and to meteorological influences.

By applying this sort of filtering, we are able to detect accelerations in the increase of HW, MSL and LW levels of **Oostende**, if any; also the similar values of **Vlissingen** have been added in the *Annexes 13, 14, 15, 16, 17 and 18*, where successively groups of observations of 1, 7, 13, and 19 years have been taken into consideration for the period 1925-1998 (included the 4 years during World War II).

In none of the pictures of both places we see up to now any significant indication of an acceleration in the increase of the concerned values.

3.4. Harmonic analysis

From the Annexes 1, 2 and 3 we can learn that **Oostende** has the longest series of harmonic analysis; the first occured already for the period 1882-1888 and for the period 1894-1912 13.

However, as there were big gaps in the records of the periods, last mentioned, we were wondering if the analysed data would form a good basis for a possible reference.

The *Annex 19* represents a spreadsheet, where for 2 periods of 19 years (nearly 1 nodal cycle), the vector averages of the 12 main components for Oostende have been given.

These are in the order of magnitude of the amplitude: **M2, S2, N2, K2, 2MN2, M4, MU2, O1, NU2, 2MS6, MS4 and M6**.

The first period is related to 1944-1964[16] and the second period concerns 1980-1998[19]; in between the last years of the 2 periods, there is a difference in time of 34 years.

Although we can consider a period of 34 years as being not so long (nearly 1,83 nodal cycles), we found it worth while to compare the Hi and Gi-values of the 12 components, mentioned before, between the first and the second period.

Concerning the **Hi-values**, we directly can notice that the amplitude of M2, being from far the biggest in the row, increases with 15,16 mm/34 years or 0,4511 mm/one year or 0,84%/34 years; from these figures we can calculate that the yearly increase of the range of M2 (being twice the amplitude) amounts to nearly 1 mm.

The last figure already explains partly the increase of the rise we found before.

Apart from NU2, all the amplitudes of the 10 other harmonic constants were subject to an increase. If we look at column (6), we can see that, from far, the shallow water components M4, 2MS6, MS4 and M6 underwent the biggest increase; here MS4 (with 12,75%/34 years), M4 (with 7,44%/34 years) and 2MS6 (with 5,17%/34 years) are the biggest in the row; no doubt, these increases are due to changes in the configuration of the bathymetry.

As a matter of fact, the amplitudes of these constituents are smaller than the one of M2; nevertheless also these, together with the others, will contribute to the increase of RSL.

The **Gi-values** also change slightly; M2 and N2 advances with more than 1 minute/34 years, but for S2, K2 and 2MN2 a certain retardation occurs.

Mostoften, the smaller ones (from M4 on), advance also; only the diurnal O1 and the shallow water constituent MS4 are delayed.

O1 and K2 indicate the biggest delay, being 3,33 minutes and 2,41 minutes for 34 years.

As expected already with the findings, mentioned sub 3.1. and 3.2., we can confirm that the amplitudes of the main harmonic constituents increased; also the phases of those constants were subject to some changes.

4. CONCLUSIONS

After the application of the different techniques on the configuration of the annual values of HW, MSL and LW for Oostende, Vlissingen, Zeebrugge and Nieuwpoort and on the evaluation of the harmonic tidal analysis for Oostende, we come to the following general conclusions:

4.1. During the last 70 years, a Relative Sea Level rise occured for the main Belgian coastal tide gauge, **Oostende**, being 2 mm/one year at HW, 1,5 mm/one year for MSL and 1 mm/ one year for LW; as this rise is higher at HW than at LW, an increase of the range of the tide is happening as well

These findings have been evidenced by linear and by cyclic trends.

On the one side, Belgian geologists have good reasons to believe that Oostende has had a rather high degree of stability of the substratum since the quaternary period; on the other hand we still consider this sea level rise as "relative", because we do not know for sure how stable the benchmarks near the tide gauge are and how the stability of the area, surrounding the tidal stations, is, as the time is passing by.

If we also take the data of 1835-1853 into consideration, we only come to a global increase of 1 mm/year for all three levels; however, here we are less sure about the vertical references.

4.2. The stability of the area, neighbouring the tide gauge in **Vlissingen** is probably not so high as for Oostende [20]. The phenomenon of subsidence of the substratum in Zeeland (the Netherlands) may cause the bigger increases of the RSL's for HW (3,3 mm/one year), MSL (2,1 mm/one year) and for LW (1,7 mm/one year), as can be noticed in the Annex 5 for the period 1890-1998.

On the other hand, if we just consider the period 1927-1998 in the same Annex, this higher increase is just valid for HW (3,3 mm/one year), but not for MSL (1,6 mm/one year) or for LW (1,0 mm/one year). The last two figures are thus very similar to those for Oostende...

4.3. Although the continuous time series for **Nieuwpoort** and **Zeebrugge** are not very long so far, we nearly come to similar conclusions as for Oostende, as far as the linear trend calculations are concerned.

4.4. So far, the method of moving averages (see 3.3.) did not depict any acceleration in the relative sea level rises of Oostende and Vlissingen.

4.5. As we expected before, the comparisons of two vector averaging results of tidal harmonic analysis also show increases for the amplitudes of 11 of the 12 most important harmonic components.

The impact of the amplitude of M2 in the RSL-rise amounts already to nearly 1 mm/one year; expressed in percentages, the amplitudes of the most important shallow water constants increased mostly.

The phases of these components were subject to advancements or to retardations.

4.6. Similar amounts of RSL-rise for comparable areas in the UK and the Netherlands also can be found in some recent papers [21, 22, 23 and 24]

4.7. Will the Relative Sea Level rise go on in the next century in the same way?

Is there a chance that, from a certain moment, an acceleration of RSL will occur?

A prognosis of coming developments in this field is extremely difficult to set up and should be based on a wide range of international climatic research, leading to the establishment of reliable climatic models.

So far, the models of the Intergovernmental Panel on Climate Change (IPCC) only provided information, which was related to different possible scenarios, going from a lower increase to a higher increase of the RSL.

4.8. Any way, as time passes by, it will be further a must to pay great attention to the measurements of the sea levels all over the world in general and of our coastal areas particularly.

A thorough quality controll on the tidal records in the field never should be forgotten; once again, I want to repeat that, for this sort of studies, continuous data are indispensable.

A better monitoring of the benchmarks, nearby the gauges, with modern techniques as Differential Global Positioning System (DGPS) - On The Fly, will allow the hydrographers to be still more sure about the absolute referencing for the future.

For this discipline an international cooperation between specialists is also a need.

Since many years the Coastal Waterways Division-Hydrographic Service, Oostende, provides information (hourly values on a yearly basis) to the Permanent Service for Mean Sea Level (PSMSL) at the Proudman Oceanographic Laboratory (POL), Bidston Observatory, Birkenhead (UK), which is wordwide a source of maregraphical data.

The Global Sea Level Observing System (GLOSS) is an Intergovernmental Oceanographic Commission (IOC) project, which is aimed to improve the quality and quantity, supplied to the PSMSL; this is a program for the establisment of nearly 300 scientific, quality controlled tide gauges for global climate change and oceanographic sea level monitoring.

In this context, Euro-GLOSS is more meant as a local densified network of GLOSS.

Finally we may mention a recent European program for the observation of sea level, called "European sea level Observing System" (EOSS) - COST Action 40.

In its memorandum of understanding for EOSS, it is stated that "the most important outcome of it is expected to be an organism, that guarantees and coordinates the long-term monitoring activities and data exchange along the European coastline". Since the very start of this project (November 1996), the Coastal Waterways Division-Hydrographic Service, Oostende, participates in this program.

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RESUMÉ:

Montée relative du niveau de la mer le long de la côte Belge - analyses et conclusions pour les niveaux de la marée haute, du niveau moyen et de la marée basse.

Les gaz à effet de serre dans l'atmosphère de notre planète seraient à l'origine de la montée relative du niveau de mer en général et de celle le long de la côte Belge en particulier.

Les données marégraphiques de longue durée pour notre côte, ayant un caractère continu et étant d'une haute qualité, ont permis au Service Hydrographique de la Côte, Ostende, à mettre au point quelques méthodes pour étudier cette phénomène plus profondément.

Une comparaison avec les données de Flessingue (Pays Bas) était aussi très valable.

A l'aide des calculs des moindres carrés, on a démontré qu' au courant de ce siècle, une montée du RSL à la côte Belge est différent selon le niveau de la mer concerné: marée haute, niveau moyen ou marée basse.

SAMENVATTING:

Relatieve zeespiegelrijzing langs de Belgische kust: analyses en conclusies met betrekking tot de niveaus van hoogwater, van gemiddeld zeeniveau en van laag water.

De broeikasgassen in de atmosfeer van onze planeet zouden aan de basis liggen van de relatieve zeespiegelrijzing (RSL) in het algemeen en van deze langs de Belgische kust in het bijzonder.

Aan de hand van langdurige, continue en betrouwbare gegevens van de 3 kustmaregrafen kon men in de Hydrografische Dienst van de Kust te Oostende enkele methoden vooropstellen om de genoemde stijging van het zeeniveau na te trekken.

Hierbij was een vergelijking met de gegevens van het nabije Vlissingen (Nederland) zeer waardevol.

Met lineaire en cyclische best-fit berekeningen kon men aantonen dat een stijging van RSL aan de Belgische kust in de loop van deze eeuw verschillend is naargelang men de jaarlijkse niveaus van hoog water, van middenstand of van laag water beschouwt.

Afdeling Waterwegen Kust
Hydrografie
Oostende

Annex 1

SYNOPSIS OF THE TIDAL OBSERVATIONS FOR OOSTENDE (Belgium)			
Periods	**Tide pole (a) or automatic tide gauge (b)**	**Harmonic Tidal Analysis**	**References Remarks**
1820-1834	(a)	No	Ref. 8 & 9 Data are lost
1835-1853	(a)	No	Ref. 10 Only monthly mean values available
1866-1871	(a)	No	Ref. 11 Data are lost
1878-1914	(b)	Yes for 1882-1888 and for 1894-1912	Ref. 12 & 13 Big gaps in the records Reference level not well known
1925-1940	(b)	No	Ref. 8 & 14 Big gaps in the records for 1925, 1926 & 1940
1941-1970	(b)	Yes for 1943-1968	Ref. 14, 15 & 16 Big gaps in the records for 1941, 1942 & 1944
1971-1980	(b)	Yes for 1976-1980	Ref. 17 Continuous records
1981-1990	(b)	Yes for 1981-1990	Ref. 18 Continuous records
1991-1998	(b)	Yes for 1991-1998	Continuous records

Afdeling Waterwegen Kust
Hydrografie
Oostende

Annex 2

SYNOPSIS OF THE TIDAL OBSERVATIONS FOR ZEEBRUGGE (Belgium)			
Periods	**Tide pole (a) or automatic tide gauge (b)**	**Harmonic Tidal Analysis**	**References Remarks**
1932-1940	(b)	No	Ref. 14 Big gaps in the records for 1932 and 1940
1941-1943	(b)	Yes for 1943	Ref. 14 Big gaps in the records from 1941 to 1943
1959-1970	(b)	Yes for 1963-1969	Ref. 15 Big gaps in the records from 1959 to 1961
1971-1980	(b)	No	Ref. 17 Continuous records
1981-1990	(b)	Yes for 1981-1990	Ref. 18 Continuous records
1991-1998	(b)	Yes for 1991-1998	Continuous records

Afdeling Waterwegen Kust
Hydrografie
Oostende

Annex 3

SYNOPSIS OF THE TIDAL OBSERVATIONS FOR NIEUWPOORT (Belgium)

Periods	Tide pole (a) or automatic tide gauge (b)	Harmonic Tidal Analysis	References Remarks
1933-1938	(b)	No	Ref. 14 Big gaps in the records for 1933, 1937 & 1938
1941-1943	(b)	Yes for 1943	Ref. 14 Big gaps in the records for 1942 & 1943
1959-1970	(b)	Yes for 1967-1969	Ref. 15 Big gaps in the records from 1959 to 1961 & from 1964 to 1965
1971-1980	(b)	Yes for 1980	Ref. 17 Continuous records
1981-1990	(b)	Yes for 1981-1990	Ref. 18 Continuous records
1991-1998	(b)	Yes for 1991-1998	Continuous records

Afdeling Waterwegen Kust
Hydrografie
Oostende

Annex 4

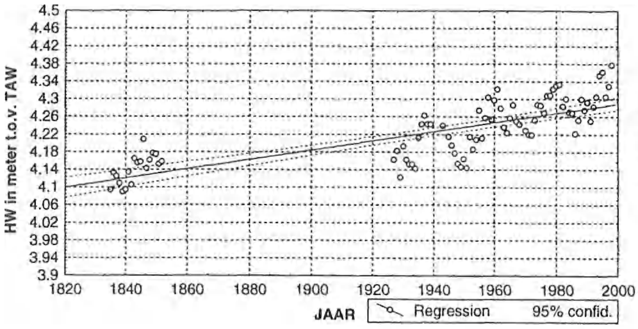
LINEAR TRENDS,
calculated on
the ANNUAL VALUES of HW, MSL and LW
for OOSTENDE (Belgium)

*****

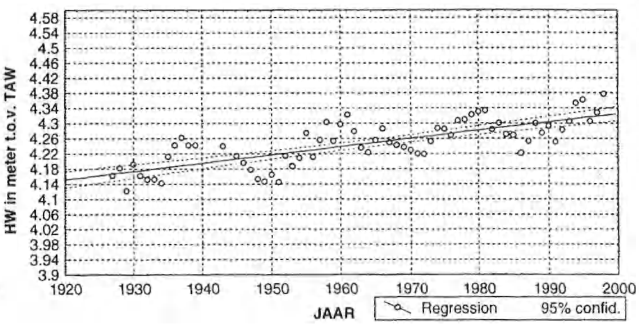
Period: 1835-1852
1927-1998
(-1940, 1941, 1942, 1944)

Period: 1927-1998
(-1940, 1941, 1942, 1944)

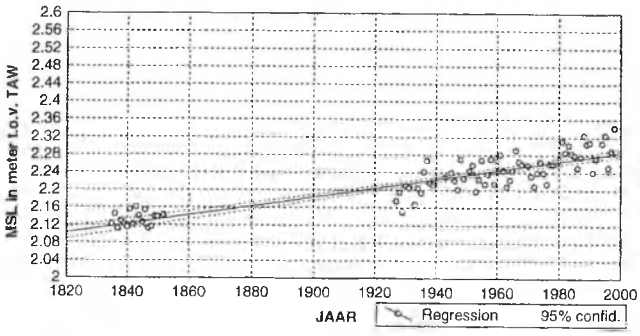
JAAR vs. HW
HW = 2.1819 + .00105 * JAAR
Oostende HW 1835-1852 / 1927 - 1998 Correlation: r = .79230



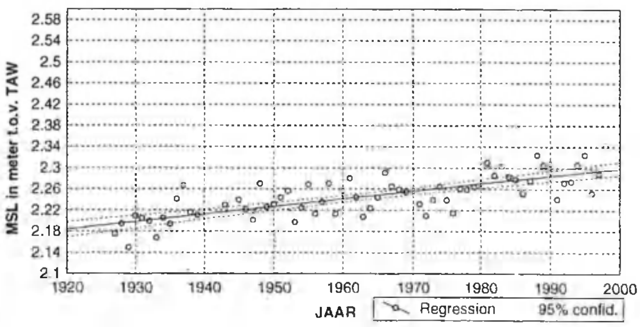
JAAR vs. HW
HW = -.0106 + .00217 * JAAR
Oostende HW 1927-1998 Correlation: r = .76353



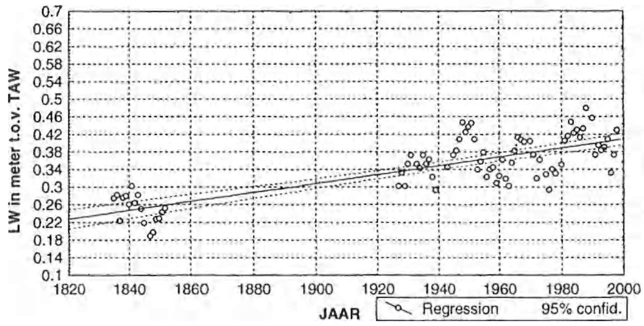
JAAR vs. MSL
MSL = .25183 + .00102 * JAAR
Oostende MSL 1835-1852 /1927-1998 Correlation: r = .90585



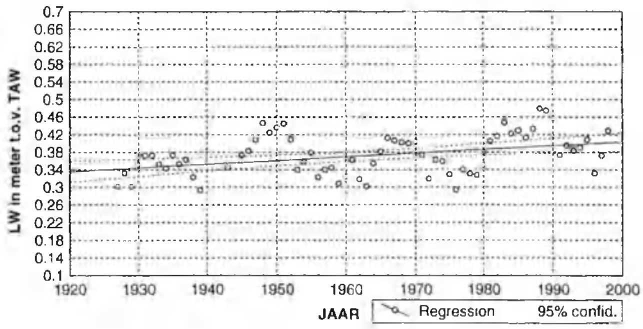
JAAR vs. MSL
MSL = -.5811 + .00144 * JAAR
Oostende MSL 1927-1998 Correlation: r = .76372



JAAR vs. LW
LW = -1.604 + .00101 * JAAR
Oostende LW 1835-1852 / 1927-1998 Correlation: r = .79116



JAAR vs. LW
LW = -1.278 + .00084 * JAAR
Oostende LW 1927-1998 Correlation: r = .38247



Afdeling Waterwegen Kust
Hydrografie
Oostende

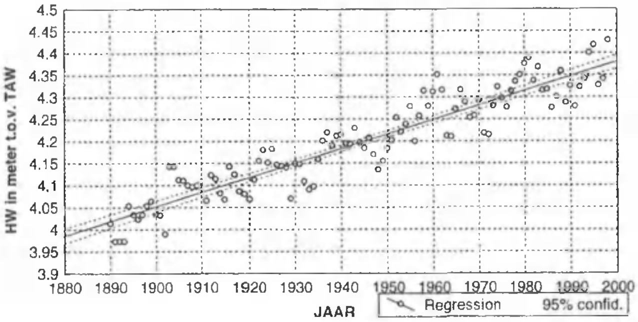
Annex 5

LINEAR TRENDS,
calculated on
the ANNUAL VALUES of HW, MSL and LW
for VLISSINGEN (The Netherlands).

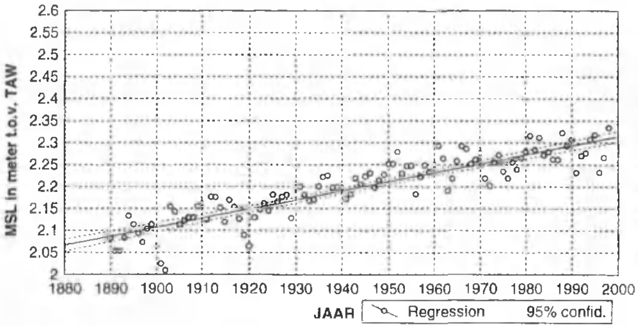
*****

Period: 1890-1998

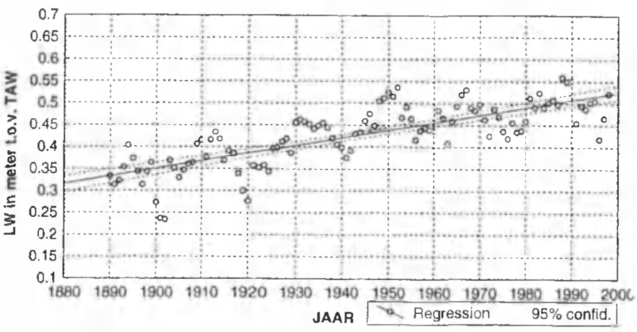
JAAR vs. HW
HW = -2.194 + .00329 * JAAR
Vlissingen HW 1890-1998 Correlation: r = .93334



JAAR vs. MSL
MSL = -1.814 + .00206 * JAAR
Vlissingen MSL 1890-1998 Correlation: r = .90030

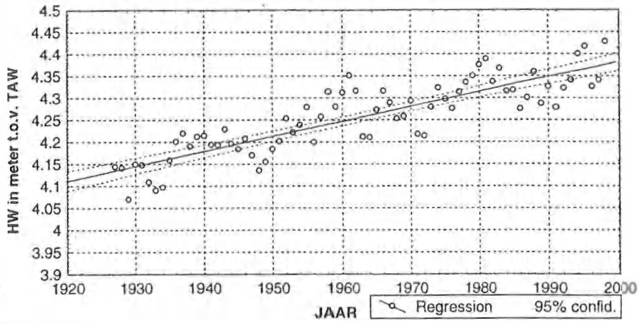


JAAR vs. LW
LW = -2.948 + .00174 * JAAR
Vlissingen LW 1890-1998 Correlation: r = .79069

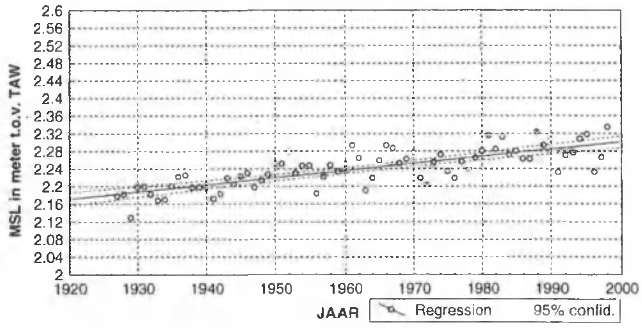


Period: 1927-1998

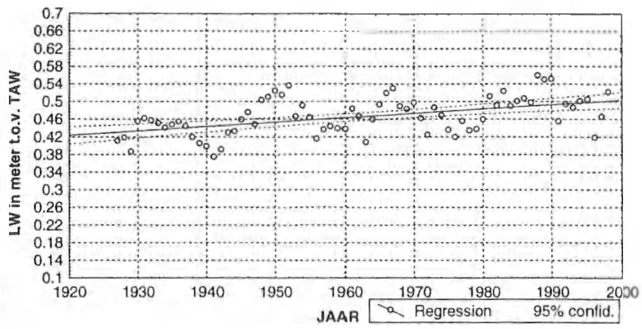
JAAR vs. HW
HW = -2.396 + .00339 * JAAR
Vlissingen HW 1927-1998 Correlation: r = .86208



JAAR vs. MSL
MSL = -.9338 + .00162 * JAAR
Vlissingen MSL 1927-1998 Correlation: r = .77693



JAAR vs. LW
LW = -1.482 + .00099 * JAAR
Vlissingen LW 1927-1998 Correlation: r = .49648



Afdeling Waterwegen Kust
Hydrografie
Oostende

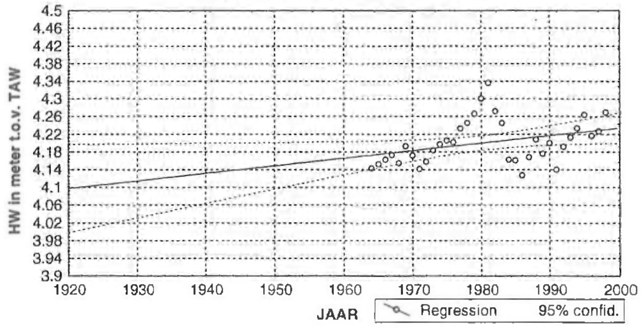
Annex 6

LINEAR TRENDS,
calculated on
the ANNUAL VALUES of HW, MSL and LW
for ZEEBRUGGE (Belgium).

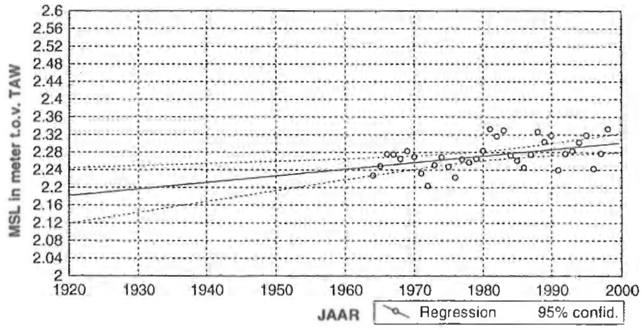
*****

Period: 1964-1998

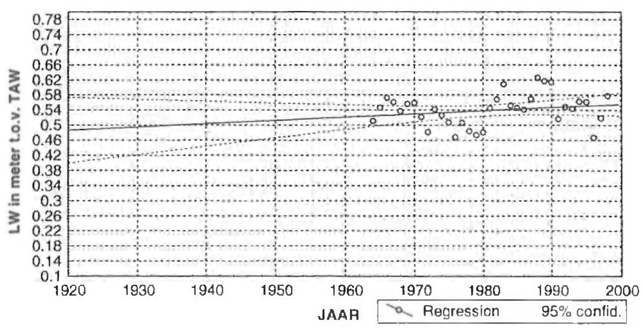
JAAR vs. HW
HW = .82499 + .00170 * JAAR
Zeebrugge HW 1964-1998 Correlation: r = .35134



JAAR vs. MSL
MSL = -.6937 + .00150 * JAAR
Zeebrugge MSL 1964-1998 Correlation: r = .46138



JAAR vs. LW
LW = -1.169 + .00086 * JAAR
Zeebrugge LW 1964-1998 Correlation: r = .21145



Afdeling Waterwegen Kust
Hydrografie
Oostende

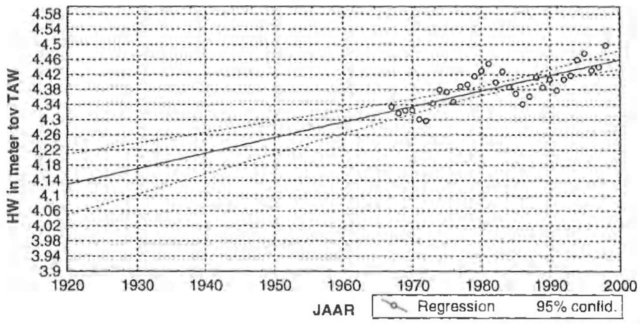
Annex 7

LINEAR TRENDS,
calculated on
the ANNUAL VALUES of HW, MSL and LW
for NIEUWPOORT (Belgium).

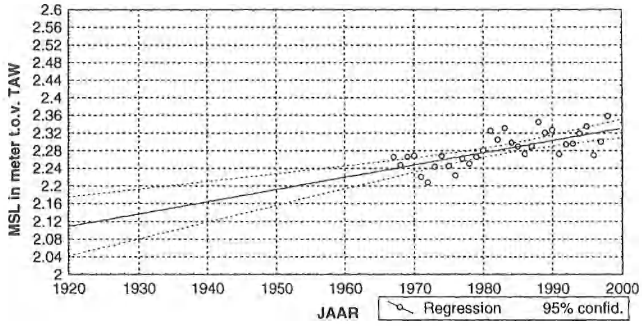
*****

Period: 1967-1998

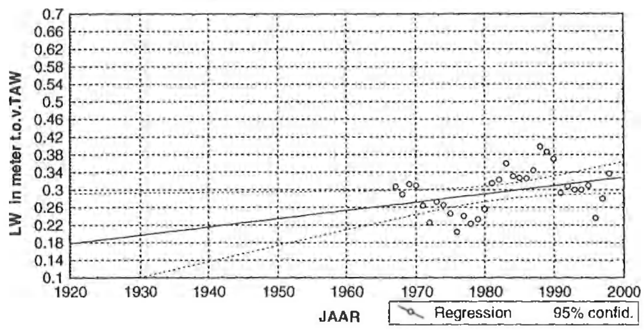
JAAR vs. HW
HW = -3.772 + .00412 * JAAR
Nieuwpoort HW 1967-1998 Correlation: r = .77146



JAAR vs. MSL
MSL = -3.205 + .00277 * JAAR
Nieuwpoort MSL 1967-1998 Correlation: r = .69848



JAAR vs. LW
LW = -3.428 + .00188 * JAAR
Nieuwpoort LW 1967-1998 Correlation: r = .36152



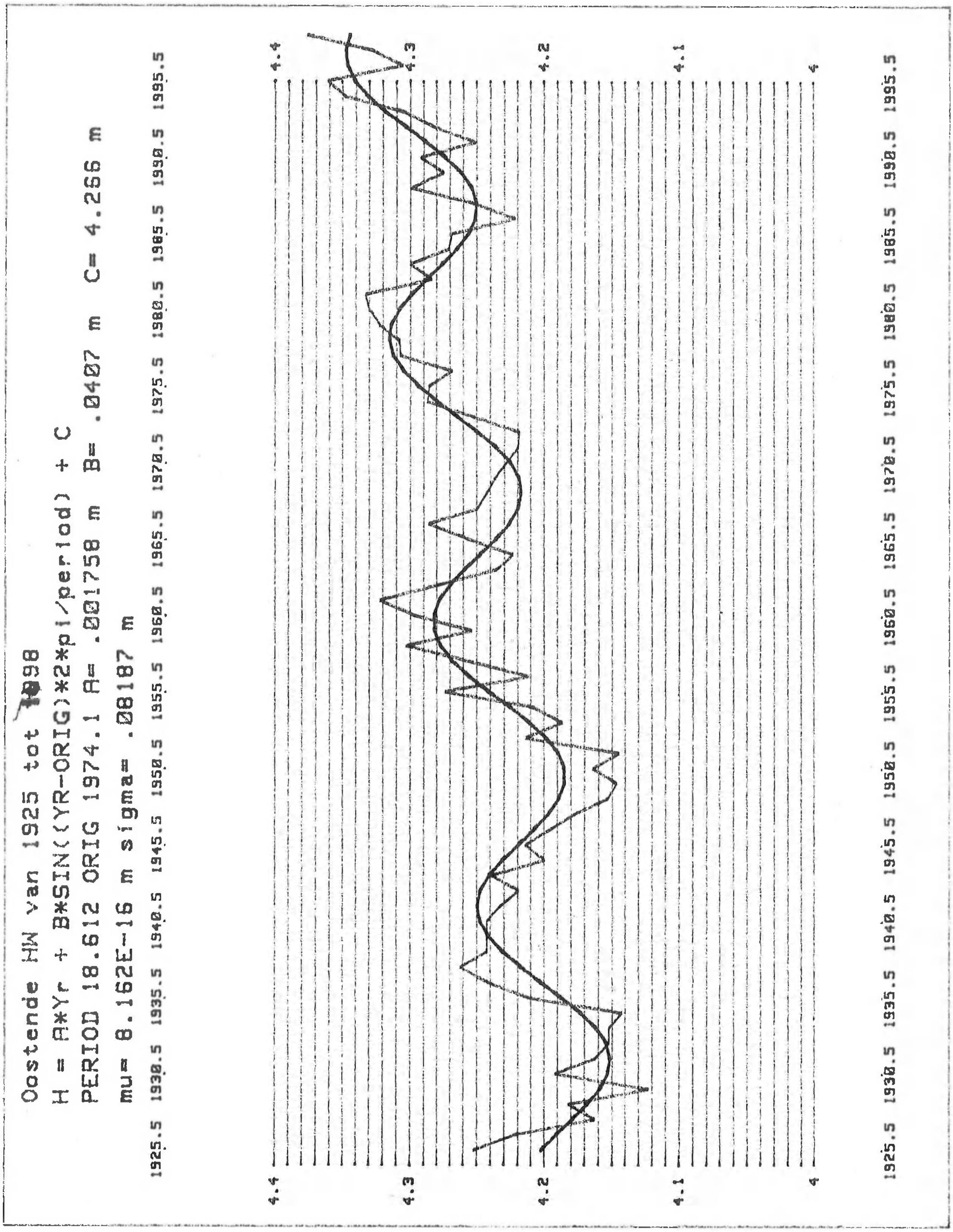
Afdeling Waterwegen Kust
Hydrografie
Oostende

Annex 8

NODAL CYCLES FROM 1913 TO 2025				
L or the Lenght of the Ascending Node	Date and Time in GMT	Time Difference in days	Range of the Tide	Remarks
0° = 360° ◦	27/05/1913 0:09:14		Minimum	
		1699,59140		
270° ◦	20/01/1918 14:20:51		Mean	
		1699,59156		
180° ◦	16/09/1922 4:32:42		Maximum	
		1699,59174		
90° ◦	12/05/1927 18:44:48		Mean	
		1699,59190		
0° = 360° ◦	6/01/1932 8:57:08		Minimum	
		1699,59207		
270° ◦	31/08/1936 23:09:43		Mean	
		1699,59225		
180° ◦	27/04/1941 13:22:33		Maximum	
		1699,59242		
90° ◦	22/12/1945 3:35:38		Mean	
		1699,59258		
0° = 360° ◦	17/08/1950 17:48:57		Minimum	
		1699,59275		
270° ◦	13/04/1955 8:02:31		Mean	
		1699,59292		
180° ◦	7/12/1959 22:16:19		Maximum	
		1699,59310		
90° ◦	2/08/1964 12:30:23		Mean	
		1699,59326		
0° = 360° ◦	29/03/1969 2:44:41		Minimum	
		1699,59343		
270° ◦	22/11/1973 16:59:13		Mean	
		1699,59361		
180° ◦	19/07/1978 7:14:01		Maximum	
		1699,59377		
90° ◦	14/03/1983 21:29:03		Mean	
		1699,59395		
0° = 360° ◦	8/11/1987 11:44:20		Minimum	
		1699,59412		
270° ◦	4/07/1992 1:59:52		Mean	Mean year in the nodal cycle
		1699,59428		
180° ◦	27/02/1997 16:15:38		Maximum	
		1699,59446		
90° ◦	24/10/2001 6:31:39		Mean	
		1699,59463		
0° = 360° ◦	19/06/2006 20:47:55		Minimum	
		1699,59480		
270° ◦	13/02/2011 11:04:26		Mean	
		1699,59497		
180° ◦	10/10/2015 1:21:11		Maximum	
		1699,59514		
90° ◦	4/06/2020 15:38:11		Mean	
		1699,59531		
0° = 360°	29/01/2025 5:55:26		Minimum	

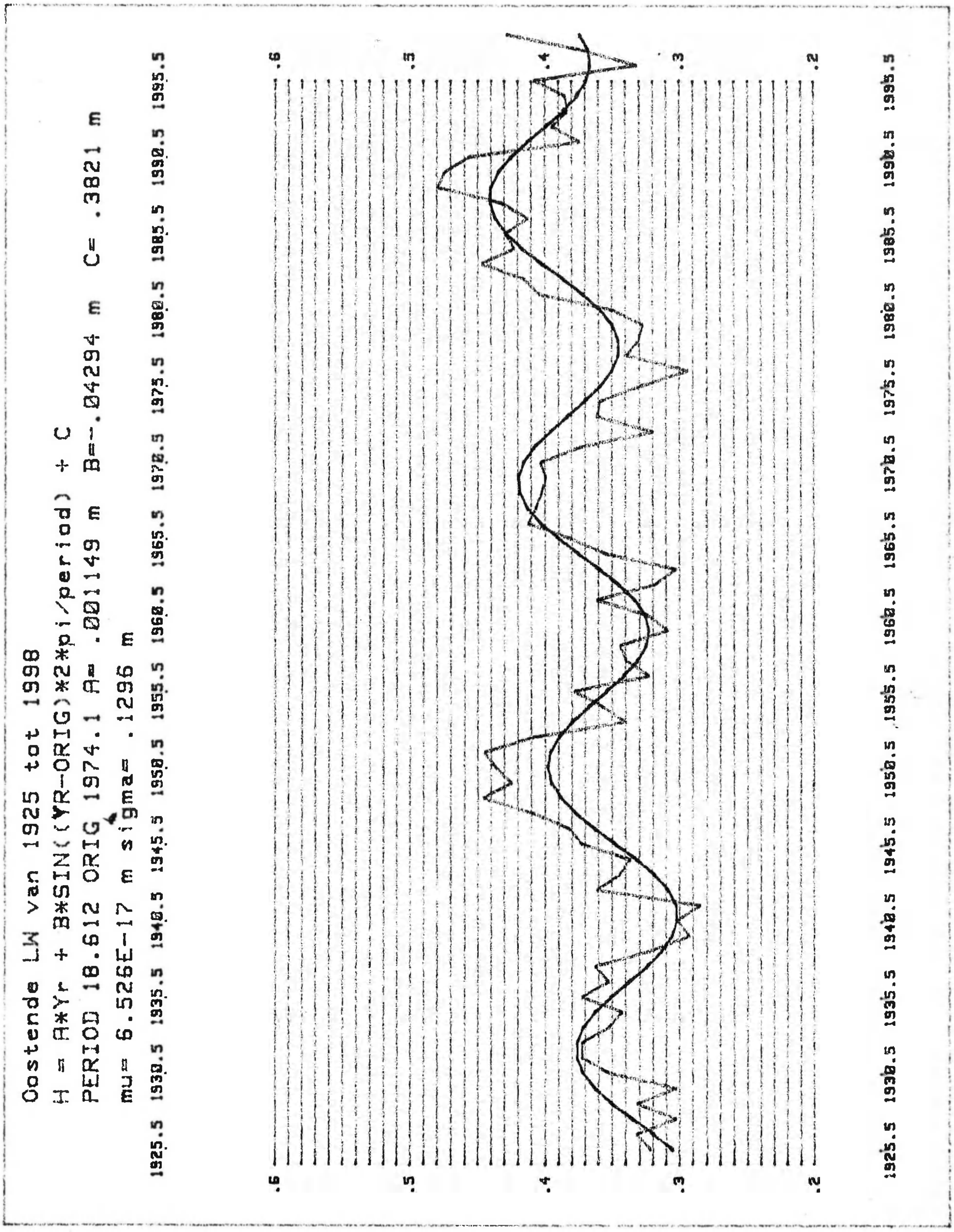
Afdeling Waterwegen Kust
Hydrografie
Oostende

Annex 9



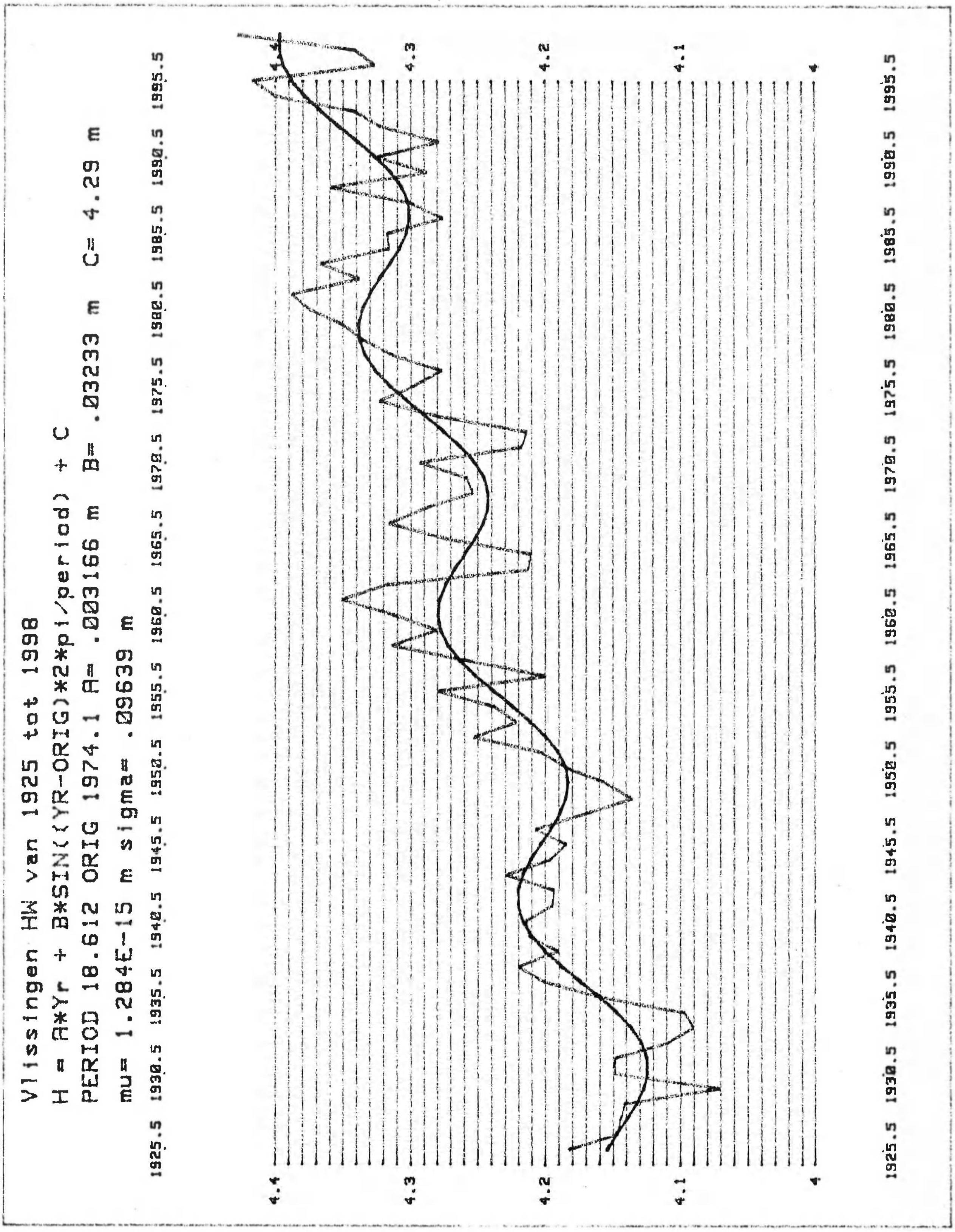
Afdeling Waterwegen Kust
Hydrografie
Oostende

Annex 10



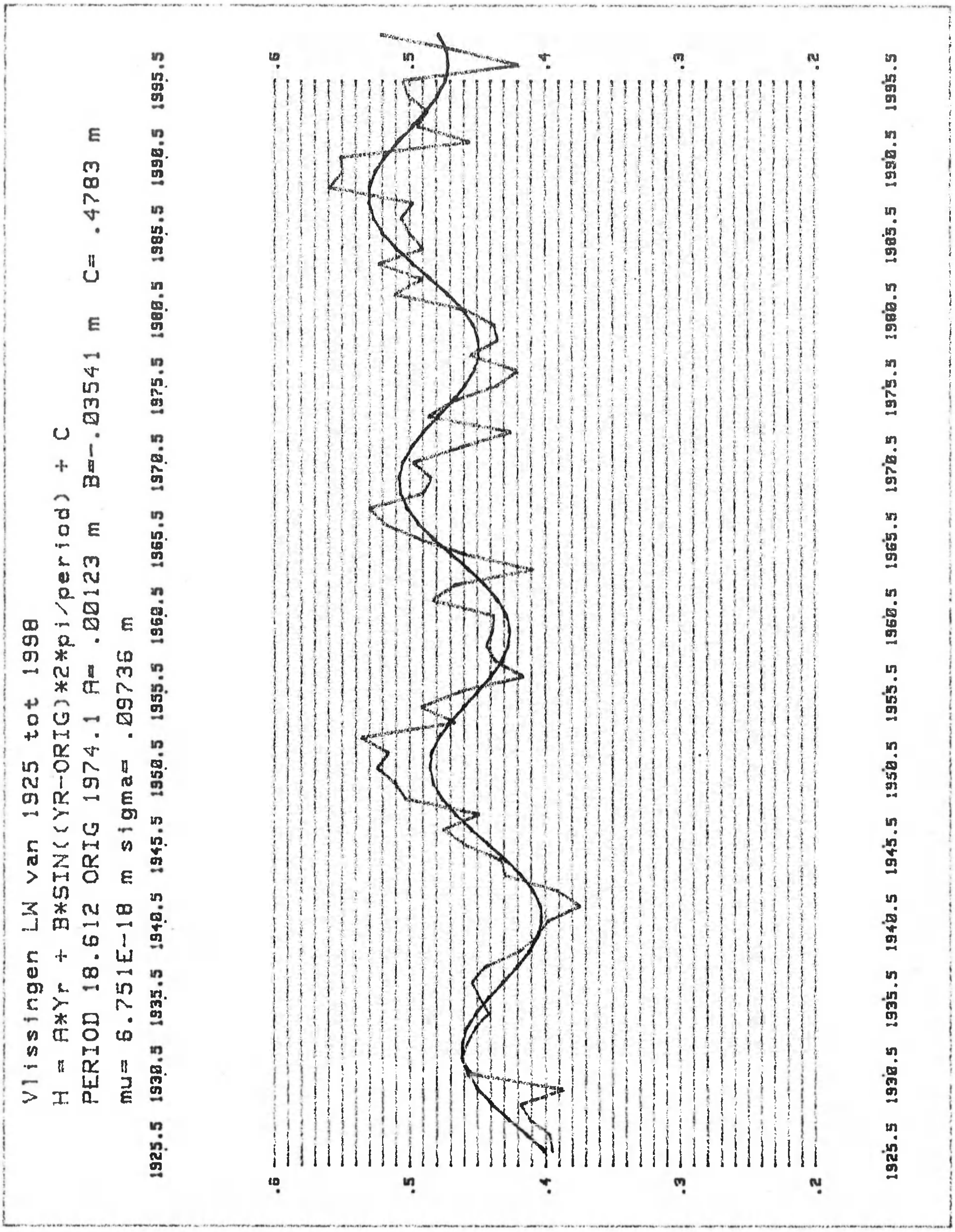
Afdeling Waterwegen Kust
Hydrografie
Oostende

Annex 11



Afdeling Waterwegen Kust
Hydrografie
Oostende

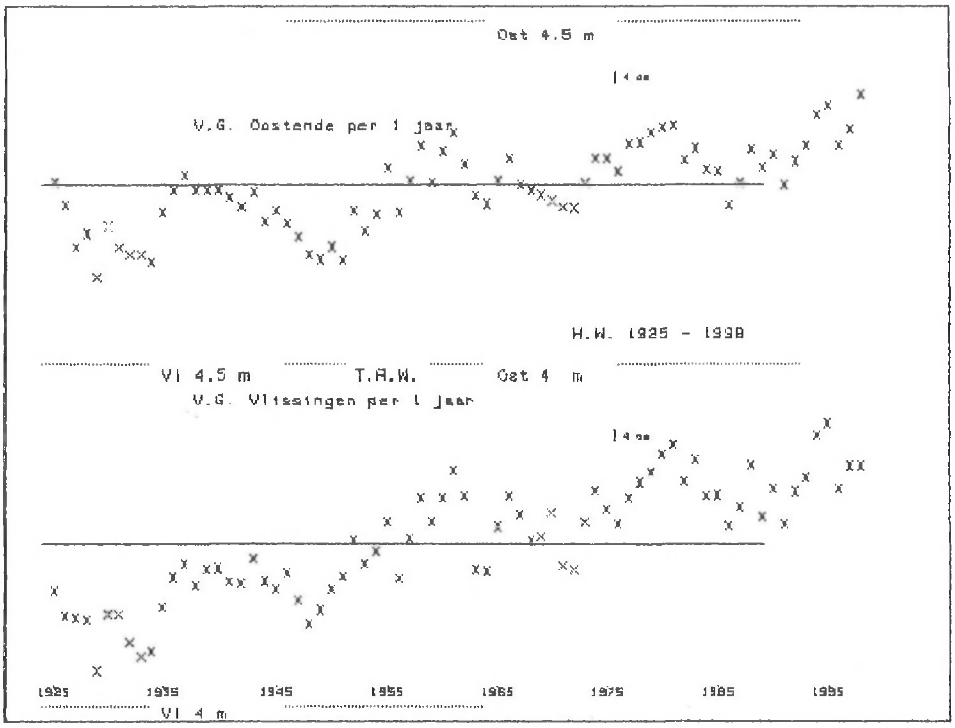
Annex 12



Afdeling Waterwegen Kust
Hydrografie
Oostende

Annex 13

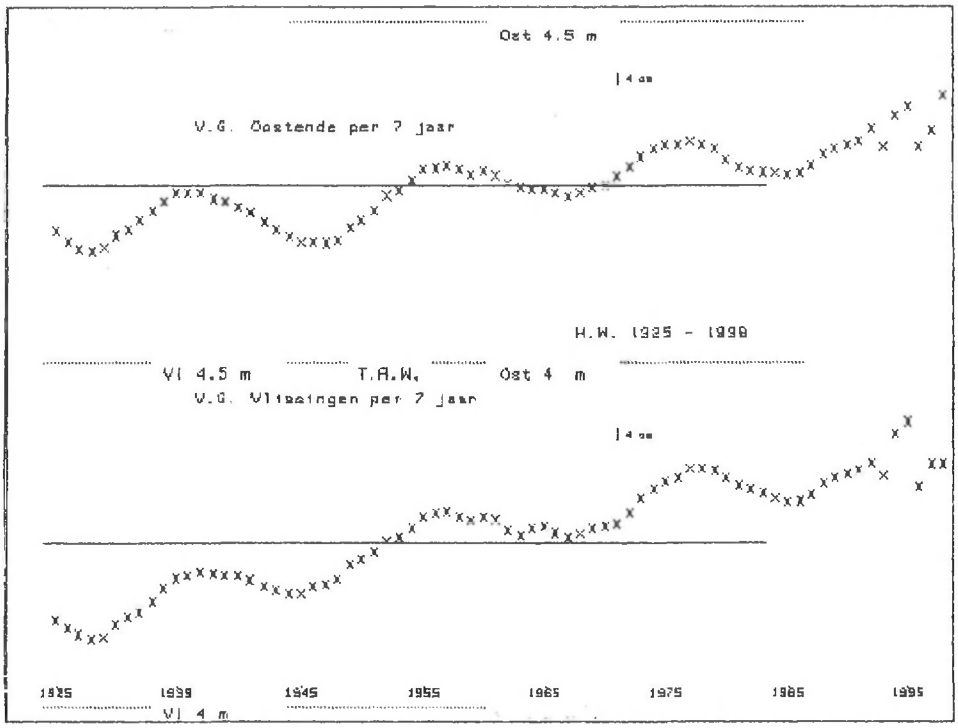
MOVING AVERAGES,
calculated on
the ANNUAL VALUES of HW
for OOSTENDE (Belgium) AND FOR VLISSINGEN (The Netherlands).
Period: 1925-1998



Moving averages, calculated on the annual values of HW for Oostende

ONE YEAR

Moving averages, calculated on the annual values of HW for Vlissingen



Moving averages, calculated on the annual values of HW for Oostende

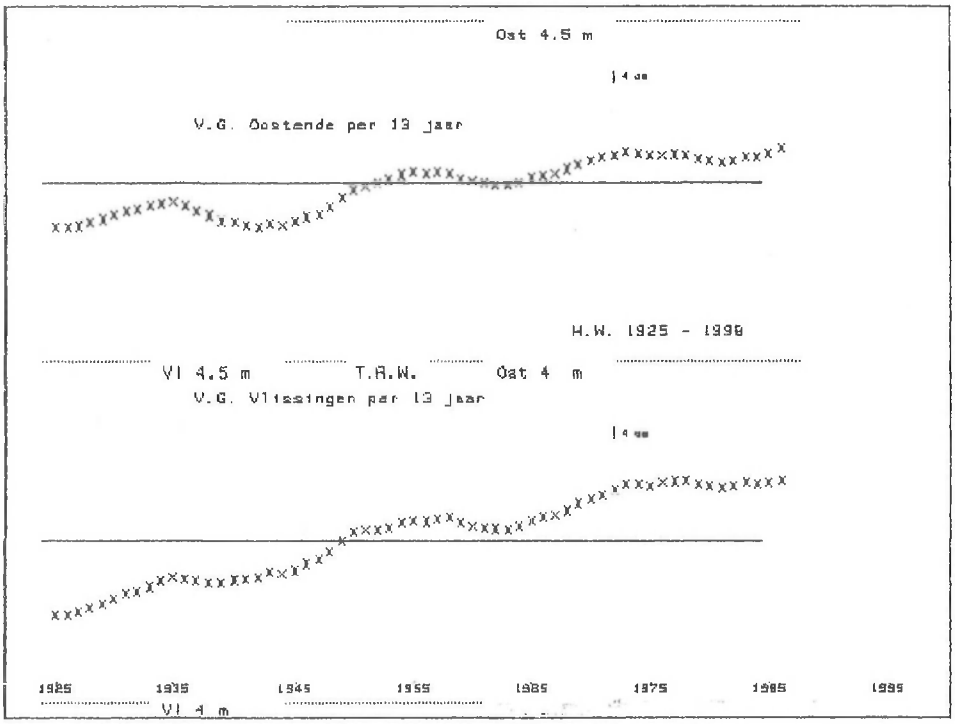
SEVEN YEARS

Moving averages, calculated on the annual values of HW for Vlissingen

Afdeling Waterwegen Kust
Hydrografie
Oostende

Annex 14

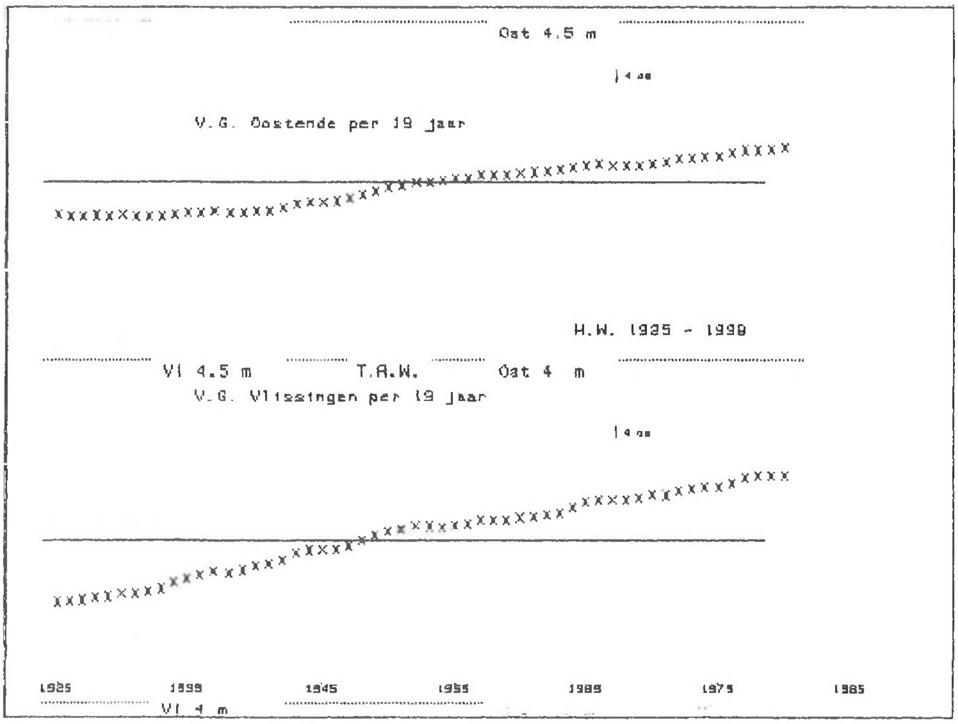
MOVING AVERAGES,
calculated on
the ANNUAL VALUES of HW
for OOSTENDE (Belgium) AND FOR VLISSINGEN (The Netherlands).
Period: 1925-1998



Moving averages, calculated on the annual values of HW for Oostende

THIRTEEN YEARS

Moving averages, calculated on the annual values of HW for Vlissingen



Moving averages, calculated on the annual values of HW for Oostende

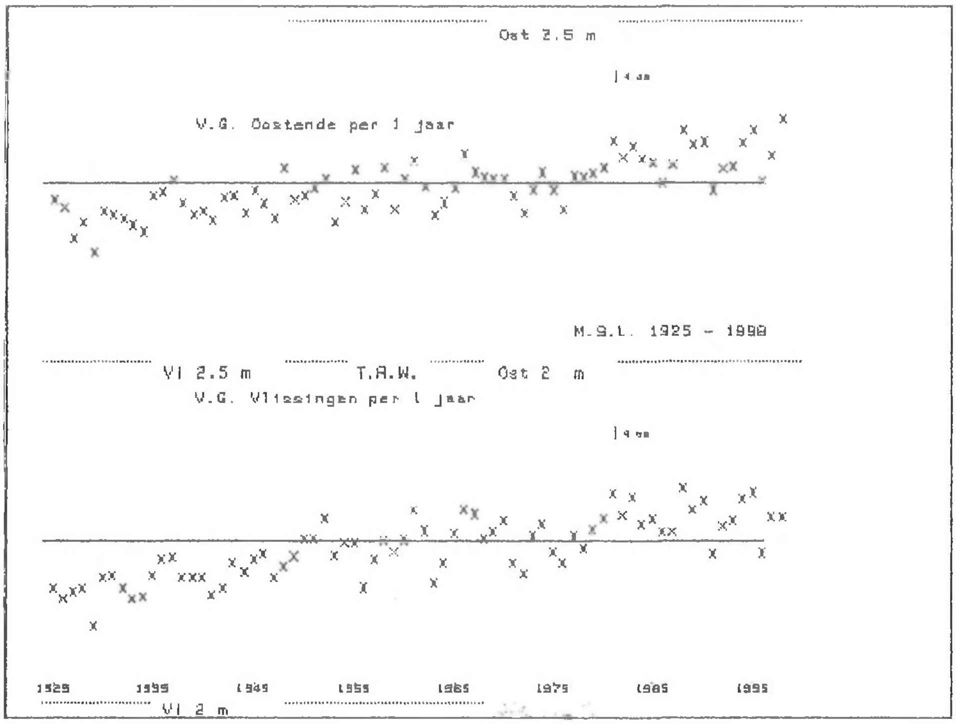
NINETEEN YEARS

Moving averages, calculated on the annual values of HW for Vlissingen

Afdeling Waterwegen Kust
Hydrografie
Oostende

Annex 15

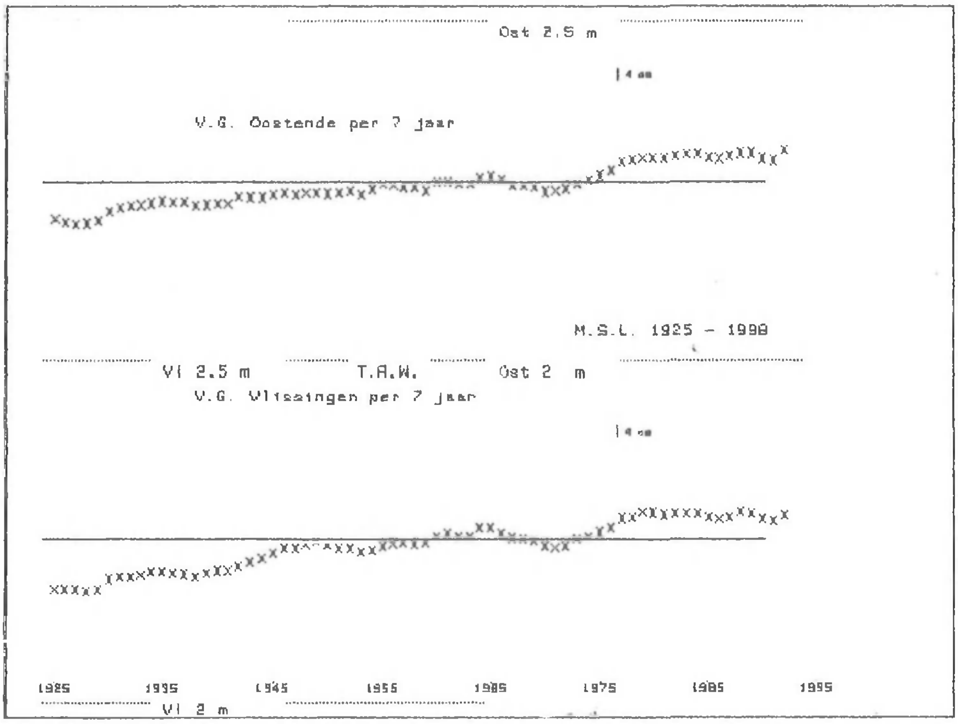
MOVING AVERAGES,
calculated on
the ANNUAL VALUES of MSL
for OOSTENDE (Belgium) AND FOR VLISSINGEN (The Netherlands).
Period: 1925-1998



Moving averages, calculated on the annual values of MSL for Oostende

ONE YEAR

Moving averages, calculated on the annual values of MSL for Vlissingen



Moving averages, calculated on the annual values of MSL for Oostende

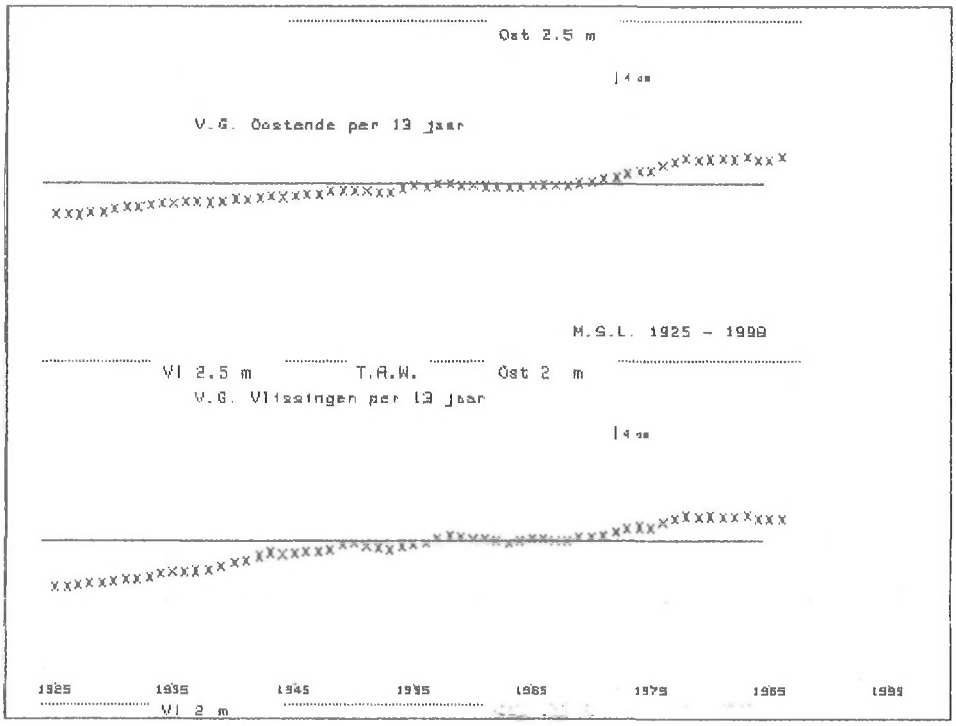
SEVEN YEARS

Moving averages, calculated on the annual values of MSL for Vlissingen

Afdeling Waterwegen Kust
Hydrografie
Oostende

Annex 16

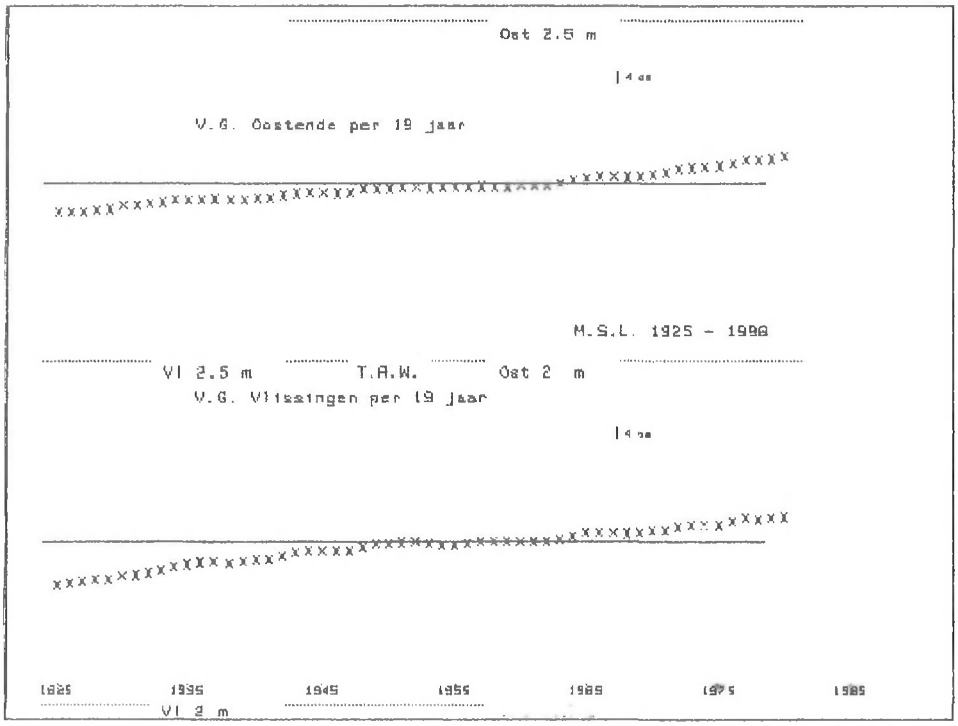
MOVING AVERAGES,
calculated on
the ANNUAL VALUES of MSL
for OOSTENDE (Belgium) AND FOR VLISSINGEN (The Netherlands).
Period: 1925-1998



Moving averages, calculate on the annual values of MSL for Oostende

THIRTEEN YEARS

Moving averages, calculate on the annual values of MSL for Vlissingen



Moving averages, calculate on the annual values of MSL for Oostende

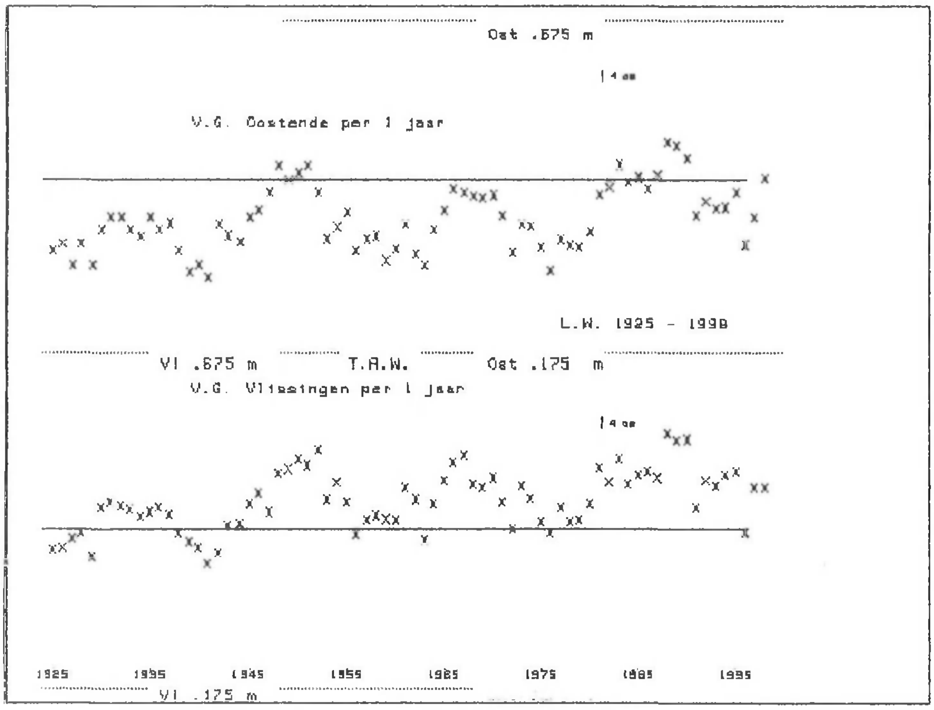
NINETEEN YEARS

Moving averages, calculate on the annual values of MSL for Vlissingen

Afdeling Waterwegen Kust
Hydrografie
Oostende

Annex 17

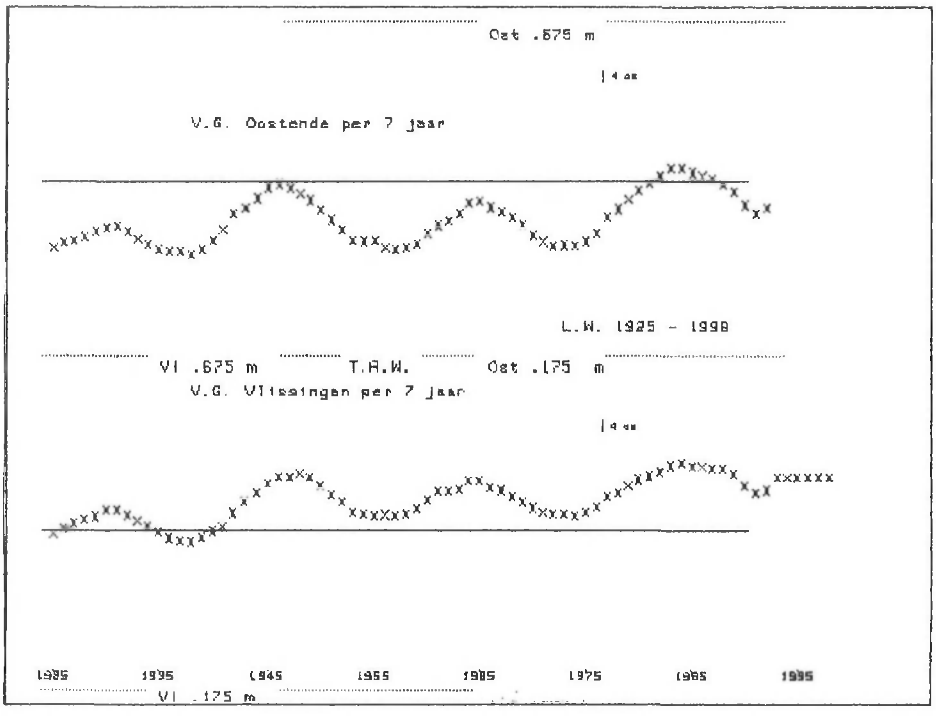
MOVING AVERAGES,
calculated on
the ANNUAL VALUES of LW
for OOSTENDE (Belgium) AND FOR VLISSINGEN (The Netherlands)
Period: 1925-1998



Moving averages, calculated on the annual values of LW for Oostende

ONE YEAR

Moving averages, calculated on the annual values of LW for Vlissingen



Moving averages, calculated on the annual values of LW for Oostende

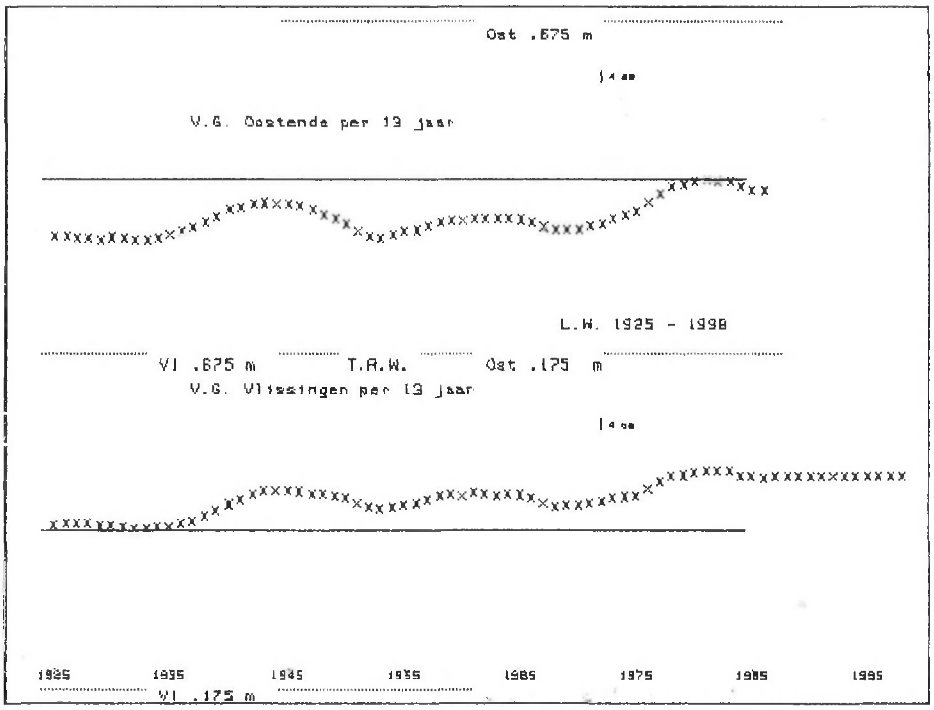
SEVEN YEARS

Moving averages, calculated on the annual values of LW for Vlissingen

Afdeling Waterwegen Kust
Hydrografie
Oostende

Annex 18

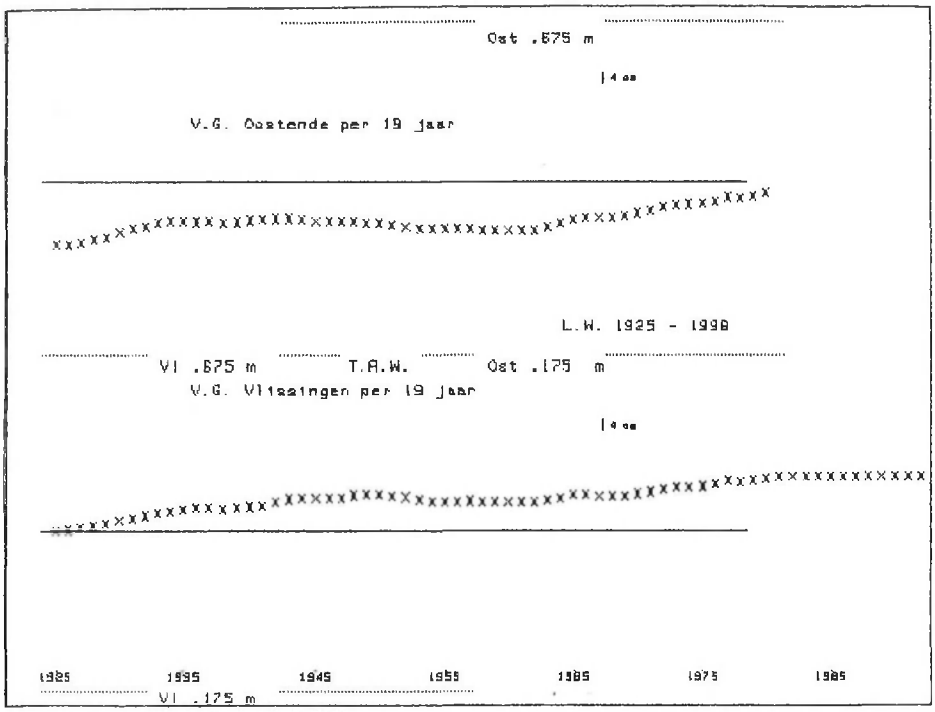
MOVING AVERAGES,
calculated on
the ANNUAL VALUES of LW
for OOSTENDE (Belgium) AND FOR VLISSINGEN (The Netherlands).
Period: 1925-1998



Moving averages, calculated on the annual values of LW for Oostende

THIRTEEN YEARS

Moving averages, calculated on the annual values of LW for Vlissingen



Moving averages, calculated on the annual values of LW for Oostende

NINETEEN YEARS

Moving averages, calculated on the annual values of LW for Vlissingen

Afdeling Waterwegen Kust
Hydrografie
Oostende

Annex 19

EVOLUTION OF THE MAIN HARMONIC COMPONENTS FOR OOSTENDE

	1944-1964		1980-1998						
HARMONIC COMPONENT OOSTENDE	Hi in cm (1)	Gi (GMT) in ° (2)	Hi in cm (3)	Gi (GMT) in ° (4)	Δ Hi in cm (34 years) (5) =(3)-(1)	Δ Hi in % (34 years) (6)=((3)-(1))*100/(1)	Δ Hi in cm (yearly) (7)=(5)/34)	Δ Gi in ° (34 years) (8)=(4)-(2)	Δ Gi in minutes (34 years) (9)
M2	179,56	5,26	181,08	4,68	1,52	0,84	0,045	-0,57	-1,18
S2	52,42	57,68	52,62	57,95	0,20	0,38	0,006	0,27	0,54
N2	30,55	341,19	30,80	340,44	0,25	0,83	0,007	-0,75	-1,58
K2	15,22	56,90	15,34	58,10	0,12	0,79	0,004	1,21	2,41
2MN2	12,18	200,41	12,38	200,58	0,20	1,66	0,006	0,16	0,34
M4	10,48	335,32	11,26	332,55	0,78	7,44	0,023	-2,77	-2,87
MU2	9,94	113,64	10,05	111,26	0,11	1,11	0,003	-2,38	-5,11
O1	9,48	167,54	9,69	168,31	0,21	2,22	0,006	0,77	3,33
NU2	9,07	335,58	8,97	334,02	-0,10	-1,10	-0,003	-1,56	-3,27
2MS6	6,96	345,44	7,32	343,76	0,36	5,17	0,011	-1,68	-1,15
MS4	6,43	37,35	7,25	38,22	0,82	12,75	0,024	0,87	0,88
M6	6,79	298,68	7,01	295,25	0,22	3,24	0,006	-3,43	-2,36