SYNOPSIS OF THE TIDAL OBSERVATIONS ALONG THE BELGIAN COAST
CONCLUSIONS WITH RESPECT TO THE HIGH WATER, THE MEAN SEA AND THE LOW WATER LEVELS.

by

C. VAN CAUWENBERGHE

Coastal Hydrographic Service - Ostend - Belgium
DIENST DER KUSTHAVENS
HYDROGRAFIE
OOSTENDE.

SYNOPSIS OF THE TIDAL OBSERVATIONS ALONG THE BELGIAN COAST —
CONCLUSIONS WITH RESPECT TO
THE HIGH WATER, THE MEAN SEA LEVEL AND THE LOW WATER LEVELS.

by Ing. C. Van Cauwenberghe.

1. INTRODUCTION.
Many scientists accept that the increase in carbon dioxide (CO2)
and other gases, concentrated in the atmosphere, which are
generated by industry, may, in a not too distant future, lead
to irreversible global changes in sea level, i.e. may produce the
so called "greenhouse effect".
The analysis of reliable past, and more recent, tidal elevation
data, such as those of High Water (HW), Mean Sea Level (MSL) and
Low Water (LW), can yield information about this development.
The prognosis of future events should be based on a wide range of
climatic research and applied to the production of climatic
models.

2. THE QUALITY OF THE DATA.
Before attempting to analyse the data, we must consider its value
and usefulness. The observations need to have been reliable and
to have been obtained over extended and uninterrupted periods.
The Annexes 1, 2 and 3 give a synopsis of the periods of the
tidal observations along the Belgian coast, i.e. for Oostende,
Zeebrugge and Nieuwpoort; here the periods, for which a harmonic
analysis occurred, are also indicated.
As can be seen from these, there are significant gaps in these
series, particularly for Oostende.
In the case of Oostende (see Annex 1), reasonably good observa-
tions began as long ago as 1820, but unfortunately the data are
lost; all the other earlier records, predating World War I, were
carefully examined.
The usefulness of those records were judged to be:

(1) For the period 1835-1852, the monthly values of HW/LW are
based on continuous records, read from a tide-gauge, close to
a lock in the harbour of Oostende (Ref 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 correct mean tide levels, we were also able to determine the MSL-value for each year of the period concerned.

(2) The period 1878-1914 is NOT useful for this study, because there are too many interruptions in the data and because the reference datum is uncertain. There are some data for the periods 1878-1885 and 1902-1914, which are unfortunately frequently interrupted. Comparing the yearly values for these periods with those of Vlissingen (The Netherlands), we found sometimes differences of more than 10 cm, whereas only 3 or 4 mm are the normal values for years with reliable observations.

(3) From 1925 till now, the records of the years 1925, 1926 and most of the years during 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 3.2).
For Nieuwpoort and Zeebrugge continuous data are only available respectively from 1967 and 1962 onwards.

3. LOCAL TRENDS FOR HW, MSL AND LW.

As periods of 25 and 30 years for Nieuwpoort and Zeebrugge are rather short, we decided not to use this information for the time being. Only the records of Oostende were considered for further examination.

3.1. Linear curve fittings.

Annex 4 represents the values of HW, MSL and LW. These data are referred to TAW (Tweede Algemeene Waterpassing), being the Belgian National Reference Level. Best fit calculations through these 3 annual values (linear, exponential, logarithmic, binomial) are also available, but only the equation of the least squares linear fit, is indicated in the same Annex.

For the 3 values a linear increase of 0.01 m/decade can be noted, if the two periods are taken into account: 1835-1852 and 1927-1991 (less the 4 years of the World WarII). On the other hand, if only the last period, less the years as mentionned, is considered, we find for HW, MSL and LW a rise of 0.02 m - 0.015 m and 0.01 m/decade.

From the Dutch Rijkswaterstaat we kindly received the corresponding information for Vlissingen, for a reliable period of 102 years (1890-1991). We transformed the data by referring these to TAW as well.
In the Annex 5 we see some increases of 0.03 m - 0.02 m and 0.015 m/decade for the 3 levels, as mentionned before.

3.2. Cyclic curve fittings.

To understand why this method of curve fitting is used, it is necessary to explain the movement of the moon’s node on the ecliptic (solar orbit).
The point, where the moon crosses the ecliptic from the south to the north/the north to the south is called the ascending node/the descending node. The length of the ascending node has the vernal equinox (first point of Aries) as reference; with values of 90° and 270° as length of the ascending node, the tidal range has a mean value, while with 0° and 180° the tidal range has a minimum/maximum value.

The regression of the ascending node is just the movement westwards along the ecliptic. Due to the regression of both of the nodes, the obliquity of the lunar orbit to the celestial equator will change progressively with each orbit between a variable maximum and a minimum value (i.e. 23°27'+ 05°09'= 28°36' or 23°27'- 05°09'= 18°18') with a periodicity of 18,61 years.

In other words, the declination of the moon is characterised generally by 2 periodicities, first the lunation-period of 29,53 mean solar days (synodic period), due to the rotation of the moon around the earth (which, on its turn, moves around the sun), and secondly the period of 18,61 years, which is called the nodal cycle.

The Annexes 6 and 7 show the values of HW and LW for Oostende with the fittings of a cyclic trend; for reasons of comparison the similar curves for Vlissingen also have been given in the Annexes 8 and 9.

For Oostende nearly the same increase of 2 mm/year for HW and 1 mm/year can be noted, while for Vlissingen again the annual increase amounts to nearly 3 mm/year for HW and to 1 mm/year for LW.

### 3.3. Moving averages.

Further it was considered that the use of moving averages could be interesting in order to eliminate the oscillations and afterwards to detect any acceleration in the increase of HW, MSL and LW levels; also the similar values of Vlissingen have been added in the Annexes 10, 11, 12, 13, 14 and 15, where successively groups of observations of 1, 7, 13, and 19 years have been taken into consideration for the period 1927-1991.

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

***

These conclusions on the rise of the 3 levels only are valid if the land is not subject to crustal movements from isostatic or eustatic origin.

However, geologists in our country have good reasons to believe that Oostende has had a rather high degree of stability of the substratum since the quaternary period. Probably this statement is not valid for Vlissingen, where indeed we see a greater increase in the levels, due to the subsidence of land.
As time passes by, it will be highly desirable to pay attention to the evolution of the sea levels very closely.

REFERENCES

Ostend, 04 March 1993

Ing. C. Van Cauwenberghe

Head of the Coastal Hydrographic Service
PERIODS OF
THE TIDAL OBSERVATIONS
for OOSTENDE (Belgium).

<table>
<thead>
<tr>
<th>Period</th>
<th>Tide pole(a) or automatic tide gauge(b)</th>
<th>Harmonic analysis</th>
<th>References/Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1820-1834</td>
<td>(a)</td>
<td>No</td>
<td>Ref 1 &amp; 2 Data are lost</td>
</tr>
<tr>
<td>1835-1853</td>
<td>(a)</td>
<td>No</td>
<td>Ref 3 Only monthly mean values available</td>
</tr>
<tr>
<td>1866-1871</td>
<td>(a)</td>
<td>No</td>
<td>Ref 4 Data are lost</td>
</tr>
<tr>
<td>1878-1914</td>
<td>(b)</td>
<td>Yes for 1882-1888 and for 1894-1912</td>
<td>Ref 5 &amp; 6 Many interruptions Reference level not well known</td>
</tr>
<tr>
<td>1925-1940</td>
<td>(b)</td>
<td>No</td>
<td>Ref 1 &amp; 7 Interruptions for 1925, 1926 &amp; 1940</td>
</tr>
<tr>
<td>1941-1970</td>
<td>(b)</td>
<td>Yes for 1943-1968</td>
<td>Ref 7, 8 &amp; 9 Interruptions for 1941, 1942 &amp; 1944</td>
</tr>
<tr>
<td>1971-1980</td>
<td>(b)</td>
<td>Yes for 1976-1980</td>
<td>Ref 10 Continuous records</td>
</tr>
</tbody>
</table>
PERIODS OF THE TIDAL OBSERVATIONS for ZEEBRUGGE (Belgium).

<table>
<thead>
<tr>
<th>Period</th>
<th>Tide pole(a) or automatic tide gauge(b)</th>
<th>Harmonic Analysis</th>
<th>References/Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1932-1939</td>
<td>(b)</td>
<td>No</td>
<td>Ref 7 Intermittent observations for 1932</td>
</tr>
<tr>
<td>1941-1943</td>
<td>(b)</td>
<td>Yes for 1943</td>
<td>Ref 7 Intermittent observations from 1940 to 1943</td>
</tr>
<tr>
<td>1959-1970</td>
<td>(b)</td>
<td>Yes for 1963-1966</td>
<td>Ref 8 Intermittent observations from 1959 to 1961</td>
</tr>
<tr>
<td>1971-1980</td>
<td>(b)</td>
<td>No</td>
<td>Ref 10 Continuous records</td>
</tr>
<tr>
<td>1981-1991</td>
<td>(b)</td>
<td>Yes for 1983</td>
<td>Ref 11 Continuous records</td>
</tr>
</tbody>
</table>
PERIODS OF
THE TIDAL OBSERVATIONS
for NIEUWPOORT (Belgium).

<table>
<thead>
<tr>
<th>Period</th>
<th>Tide pole(a) or automatic tide gauge(b)</th>
<th>Harmonic Analysis</th>
<th>References/Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1933-1938</td>
<td>(b)</td>
<td>No</td>
<td>Ref 7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Interruptions for 1933, 1937 &amp; 1938</td>
</tr>
<tr>
<td>1941-1943</td>
<td>(b)</td>
<td>Yes for 1943</td>
<td>Ref 7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Interruptions for 1942 &amp; 1943</td>
</tr>
<tr>
<td>1959-1970</td>
<td>(b)</td>
<td>Yes for 1967-1969</td>
<td>Ref 8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Interruptions for 1959, 1961 &amp; from 1963 to 1966</td>
</tr>
<tr>
<td>1971-1980</td>
<td>(b)</td>
<td>No</td>
<td>Ref 10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Continuous records</td>
</tr>
<tr>
<td>1981-1991</td>
<td>(b)</td>
<td>Yes for 1983</td>
<td>Ref 11</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Continuous records</td>
</tr>
</tbody>
</table>
LINEAR TRENDS calculated on the Annual Values of HW, MSL and LW for OOSTENDE (Belgium).

**

Periods: 1835-1852
1927-1991
(-1940, 1941, 1942, 1944)

\[ Y = A + B \cdot X \]

- **Period: 1927-1991**
  - \( A = 3.9195 \)
  - \( B = 0.0020 \)
  - Error = 0.0390 m

- **Period: 1835-1852**
  - \( A = 4.0874 \)
  - \( B = 0.0010 \)
  - Error = 0.0412 m

Error = \[ \sqrt{\frac{\sum (y_i - \bar{Y})^2}{n - 2}} \]

with \( y_i = \text{HW, MSL or LW-value of a year} \)

\[ Y = A + B \cdot X \]

- \( A = 2.0846 \)
- \( B = 0.0010 \)
- Error = 0.0245 m

- \( A = 2.0151 \)
- \( B = 0.0014 \)
- Error = 0.0253 m

- \( A = 0.2043 \)
- \( B = 0.0010 \)
- Error = 0.0418 m

- \( A = 0.2139 \)
- \( B = 0.0010 \)
- Error = 0.0439 m

**JAAR 1800 = 0**
LINEAR TRENDS calculated on the Annual Values of HW, MSL and LW for VLISSINGEN (The Netherlands). 

***** Period: 1890-1991

\[ Y = A + B \cdot X \]

\[
A = 3,7255 \\
B = 0,0033 \\
Error = 0,0402 \text{ m}
\]

\[ * \text{Standard error of estimate of Y on X} \]

\[
A = 1,8919 \\
B = 0,0021 \\
Error = 0,0312 \text{ m}
\]

\[
A = 0,1603 \\
B = 0,0019 \\
Error = 0,0423 \text{ m}
\]

\[ \text{JAAR} \ 1800 = 0 \]
Oostende HW van 1925 tot 1991

\[ H = A \times Yr + B \times \sin((YR - \text{ORIG}) \times 2 \times \pi / \text{period}) + C \]

Period: 18.612 ORIG 1922.5

\[ A = 0.01787 \text{ m} \quad B = 0.0408 \text{ m} \quad C = 4.3 \text{ m} \]

\[ \mu = 7.026 \times 10^{-16} \text{ m} \quad \sigma = 0.0895 \text{ m} \]

<table>
<thead>
<tr>
<th>Year</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1925.5</td>
<td>4.4</td>
</tr>
<tr>
<td>1930.5</td>
<td>4.3</td>
</tr>
<tr>
<td>1935.5</td>
<td>4.2</td>
</tr>
<tr>
<td>1940.5</td>
<td>4.4</td>
</tr>
<tr>
<td>1945.5</td>
<td>4.3</td>
</tr>
<tr>
<td>1950.5</td>
<td>4.2</td>
</tr>
<tr>
<td>1955.5</td>
<td>4.4</td>
</tr>
<tr>
<td>1960.5</td>
<td>4.3</td>
</tr>
<tr>
<td>1965.5</td>
<td>4.2</td>
</tr>
<tr>
<td>1970.5</td>
<td>4.4</td>
</tr>
<tr>
<td>1975.5</td>
<td>4.3</td>
</tr>
<tr>
<td>1980.5</td>
<td>4.2</td>
</tr>
<tr>
<td>1985.5</td>
<td>4.4</td>
</tr>
<tr>
<td>1990.5</td>
<td>4.3</td>
</tr>
</tbody>
</table>

Annex 6
Oostende LW van 1925 tot 1991

\[ H = A \times Yr + B \times \sin((YR - ORIG) \times 2\pi / \text{period}) + C \]

PERIOD 18.612 ORIG 1992.5
\[ a = 0.01056 \text{ m} \]
\[ b = -0.04527 \text{ m} \]
\[ c = 0.3989 \text{ m} \]

\[ \mu = -8.451 \times 10^{-17} \text{ m} \]
\[ \sigma = 0.124 \text{ m} \]

1925.5 1930.5 1935.5 1940.5 1945.5 1950.5 1955.5 1960.5 1965.5 1970.5 1975.5 1980.5 1985.5 1990.5
Viessingen H van 1925 tot 1991

Period: 1925-1991

***

For Viessingen (The Netherlands).

The annual values of HM calculated on cyclical trend.

Annex 8

Costambre

Hydrographic

Reef

Damin Kusthavens
\[ H = A \times YR + B \times \text{SIN}(YR-\text{ORIG}) \times 2\pi/\text{period} \]

\[ \text{PERIOD} = 18.512 \]

\[ \text{ORIG} = 1992.5 \]

\[ A = 0.001192 \, \text{m} \]

\[ \mu = -2.519 \times 10^{-15} \, \text{m} \]

\[ \sigma = 0.1049 \, \text{m} \]

\[ B = -0.03502 \, \text{m} \]

\[ C = 0.4992 \, \text{m} \]

---

**Period: 1925-1991**

**For Vlissingen (The Netherlands)**

The annual values of LW calculated on cyclic trend

---

Annex 9
MOVING AVERAGES

calculated on
the Annual Values of HW
for OOSTENDE (Belgium) and for VLISSINGEN (The Netherlands).

Period: 1925-1991

1 year

7 years
MOVING AVERAGES calculated on the Annual Values of HW for OOSTENDE (Belgium) and for VLISSINGEN (The Netherlands).

**

Period: 1925-1991

<table>
<thead>
<tr>
<th>Year</th>
<th>Oostende</th>
<th>T.N.W.</th>
<th>Vlissingen</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>1925</td>
<td>VI 4.5 m</td>
<td>T.N.W.</td>
<td>VI 4.5 m</td>
<td>1925</td>
</tr>
<tr>
<td></td>
<td>V.G. Oostende per 13 jaar</td>
<td>V.G. Vlissingen per 13 jaar</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1945</td>
<td></td>
<td></td>
<td></td>
<td>1945</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1965</td>
<td></td>
<td></td>
<td></td>
<td>1965</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1975</td>
<td></td>
<td></td>
<td></td>
<td>1975</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1985</td>
<td></td>
<td></td>
<td></td>
<td>1985</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

13 years

<table>
<thead>
<tr>
<th>Year</th>
<th>Oostende</th>
<th>T.N.W.</th>
<th>Vlissingen</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>1925</td>
<td>VI 4.5 m</td>
<td>T.N.W.</td>
<td>VI 4.5 m</td>
<td>1925</td>
</tr>
<tr>
<td></td>
<td>V.G. Oostende per 19 jaar</td>
<td>V.G. Vlissingen per 19 jaar</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1945</td>
<td></td>
<td></td>
<td></td>
<td>1945</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1965</td>
<td></td>
<td></td>
<td></td>
<td>1965</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1975</td>
<td></td>
<td></td>
<td></td>
<td>1975</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1985</td>
<td></td>
<td></td>
<td></td>
<td>1985</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

19 years
MOVING AVERAGES calculated on the Annual Values of MSL for OOSTENDE (Belgium) and for VLISSINGEN (The Netherlands).

Period: 1925-1991

1 year

7 years
Annex 13

MOVING AVERAGES calculated on the Annual Values of MSL for OOSTENDE (Belgium) and for VLISSINGEN (The Netherlands).

** Period: 1925-1991

<table>
<thead>
<tr>
<th>Year</th>
<th>MSL 3m</th>
<th>TRH</th>
<th>MSL 2.5m</th>
</tr>
</thead>
<tbody>
<tr>
<td>1925</td>
<td>1935</td>
<td>1945</td>
<td>1955</td>
</tr>
<tr>
<td>1965</td>
<td>1975</td>
<td>1985</td>
<td>1995</td>
</tr>
</tbody>
</table>

---

** Period: 1925-1991

<table>
<thead>
<tr>
<th>Year</th>
<th>MSL 2.3m</th>
<th>TRH</th>
<th>MSL 2m</th>
</tr>
</thead>
<tbody>
<tr>
<td>1925</td>
<td>1935</td>
<td>1945</td>
<td>1955</td>
</tr>
<tr>
<td>1965</td>
<td>1975</td>
<td>1985</td>
<td>1995</td>
</tr>
</tbody>
</table>

---

** Period: 1925-1991

<table>
<thead>
<tr>
<th>Year</th>
<th>MSL 1.2m</th>
<th>TRH</th>
<th>MSL 1.5m</th>
</tr>
</thead>
<tbody>
<tr>
<td>1925</td>
<td>1935</td>
<td>1945</td>
<td>1955</td>
</tr>
<tr>
<td>1965</td>
<td>1975</td>
<td>1985</td>
<td>1995</td>
</tr>
</tbody>
</table>
MOVING AVERAGES calculated on the Annual Values of LW for OOSTENDE (Belgium) and for VLISSINGEN (The Netherlands).

**Period: 1925-1991**

1 year

7 years
MOVING AVERAGES calculated on the Annual Values of LW for OOSTENDE (Belgium) and for VLISSINGEN (The Netherlands).

Period: 1925-1991

13 years

19 years