DATA REPORT OF CURRENT, TEMPERATURE AND PRESSURE OBSERVATIONS.

STRATIFIED CENTRAL NORTH-SEA

1980 - 1982

Leo Maas and Hans van Haren

July 1986

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Netherlands Institute of Sea Research
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Texel, Netherlands
DATA REPORT OF CURRENT, TEMPERATURE AND PRESSURE OBSERVATIONS

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Introduction

During springs, summers and autumns of 1980, 1981 and 1982 a collaborative study on the seasonal stratification of the Central North Sea was performed by the Netherlands Institute for Sea Research, the Institute of Meteorology and Oceanography Utrecht and the Royal Netherlands Meteorological Institute. Table 1 lists mooring positions (shown in fig. 1), local depths, meterdepths, operational periods and sampling periods of current meters, pressure gauges and thermistor chains. Additional current meter datasets on periods not covered in this data report exist with the Royal Netherlands Meteorological Institute, the periods shown here being characterized by the existence of simultaneous current, temperature and pressure records.


The data processing

All instruments were deployed at approximately the same time (within one day). A mutual origin of time was adopted, dictated by the latest starting instrument. By simple time-averaging, current, pressure and temperature data were reduced to hourly values, which datasets formed the basic timeseries to be presented here.

Four types of standard analyses were used to produce: 1) Low-frequency fields, 2) Tidal Harmonic series, 3) (Tidal band ) residual signals and 4) Fourier Spectra.

1) Low-frequency fields

In order to produce low-frequency fields we performed a "50 hour running mean procedure" twice. This procedure is best demonstrated by focussing on the processing of the temperature signals in 1980. Consider the original timeseries of the eleven temperature sensors in fig. 2a. After applying a 50 hour running mean, corresponding to averaging over four semidiurnal periods, figure 2b shows that the semidiurnal tidal signal is strongly reduced, but still present. A
Table 1 Positions, depths, local sea depth, operational periods and sampling periods of current meters, pressure gauges and thermistochains in 1980-1982.

### Current meters

<table>
<thead>
<tr>
<th>N</th>
<th>E</th>
<th>depths(m)</th>
<th>water depth(m)</th>
<th>period (day nr)</th>
<th>year</th>
<th>dt (min)</th>
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</thead>
<tbody>
<tr>
<td>A</td>
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<td>3°38'</td>
<td>16</td>
<td>46</td>
<td>1980</td>
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</tr>
<tr>
<td></td>
<td></td>
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<tr>
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<td>3°47'</td>
<td>14</td>
<td>46</td>
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<td></td>
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<td>240-275</td>
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<tr>
<td>C</td>
<td>54°41'</td>
<td>3°47'</td>
<td>13</td>
<td>46</td>
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<td>10</td>
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<td></td>
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<td>240-273</td>
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<tr>
<td>D</td>
<td>54°41'</td>
<td>3°38'</td>
<td>27</td>
<td>46</td>
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<td>10</td>
</tr>
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<td></td>
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<td></td>
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<tr>
<td>F</td>
<td>54°35'</td>
<td>4°31'</td>
<td>13,29,45*</td>
<td>50</td>
<td>1981</td>
<td>5</td>
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<tr>
<td>G</td>
<td>54°27'</td>
<td>4°22'</td>
<td>13,29,45*</td>
<td>50</td>
<td>1981</td>
<td>5</td>
</tr>
<tr>
<td>H</td>
<td>54°28'</td>
<td>4°38'</td>
<td>12,28,42</td>
<td>47</td>
<td>1982</td>
<td>10</td>
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<tr>
<td>I</td>
<td>54°30'</td>
<td>4°30'</td>
<td>12,24,30,37</td>
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<td>10</td>
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<tr>
<td>J</td>
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<td>4°30'</td>
<td>12,43</td>
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<td>L</td>
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<td>12,27,42</td>
<td>47</td>
<td>1982</td>
<td>10</td>
</tr>
</tbody>
</table>

* the bottom current meter at G, 1981 was eliminated due to compass failure.

### Pressure gauges

| P1 | 54°00' | 3°38' | 239-255 | 1980 | 60    |
|    |        |       |         |      |       |
| P2 | 54°36' | 0°38' | 240-305 | 1980 | 60    |
| P3 | 54°36' | 4°47' | 240-305 | 1980 | 60    |
| P4 | 54°36' | 4°47' | 240-305 | 1980 | 60    |
| P5 | 54°39' | 4°30' | 133-175 | 1981 | 60    |
| P6 | 54°30' | 4°13' | 133-174 | 1981 | 60    |
| P7 | 54°30' | 4°30' | 133-174 | 1981 | 60    |
| P8 | 54°30' | 5°54' | 214-252 | 1982 | 15    |
| P9 | 54°30' | 5°54' | 214-252 | 1982 | 15    |
| P10| 54°20' | 4°30' | 214-252 | 1982 | 15    |

### Thermistor chains

| A  | 54°46' | 3°38' | 12-32   | 239-280 | 1980 | 15    |
|    |        |       |         |         |      |       |
| E  | 54°30' | 4°30' | 12-32   | 133-155 | 1981 | 15    |
| I  | 54°30' | 4°30' | 11-31   | 215-253 | 1982 | 15    |
| K  | 54°27' | 4°22' | 11-31   | 215-253 | 1982 | 15    |
| L  | 54°27' | 4°38' | 9-29    | 215-253 | 1982 | 15    |
Figure 1 a) Map of the North Sea with 40 m isobath, central positions of mooring networks in 1980 (A) and 1981, 1982 (B) and mooring positions of pressure gauges $P_j$ ($j=1,2,\ldots,10$)
b) Current meter (+) and thermistor chain (o) mooring positions within the areas A and B.
Figure 2 Temperature (°C) at the eleven sensors for the original (a), filtered (b) and twice filtered (c) timeseries. From the latter graphs inverse interpolation gives timeseries of depths of isotherms (in °C) (d).
second application of this 50 hour running mean operation yields figure 2c, from which the tidal signal is virtually absent. This procedure corresponds to applying a spectral triangular Bartlett window (Jenkins and Watts, 1968) to the data. Note that a 50 hour running mean procedure in principle gives a data loss of 25 hours at both the beginning and end of the timeseries. For this reason a correction procedure was performed over these points in that the first and last 25 datapoints were subjected to a 25 hour running mean, of which the first and last 12 points were treated with a 12 hour running mean, of which, finally, the first and last 6 points were kept constant. In our opinion this still gives some information, although the errors introduced will increase towards the endpoints and some discontinuities result at the matchingpoints (see fig. 2c). If it is preferred, the reader may just drop the information contained in the first and last 50 hours (50, because of the repeated running mean procedure).

2) Tidal Harmonic Series

The original timeseries of currents and pressures were subjected to a Harmonic Analysis (Dronkers, 1964) with 7 frequencies (table 2), of

Table 2 Tidal and inertial frequencies used in the harmonic analysis.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>frequency (x 10^{-4} s^{-1})</th>
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<tr>
<td>$f$</td>
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<tr>
<td>$O_1$</td>
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</tr>
<tr>
<td>$K_1$</td>
<td>0.792116</td>
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<tr>
<td>$M_2$</td>
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</tr>
<tr>
<td>$S_2$</td>
<td>1.454441</td>
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<tr>
<td>$M_4$</td>
<td>2.810378</td>
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<tr>
<td>$M_6$</td>
<td>4.215853</td>
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Table 3  
Amplitudes and phases from Harmonic Analysis of a) East (u) and North (v) velocities (cm/s) b) surface elevation (cm)

<table>
<thead>
<tr>
<th>X(cm)</th>
<th>u</th>
<th>v</th>
<th>X(cm)</th>
<th>u</th>
<th>v</th>
<th>X(cm)</th>
<th>u</th>
<th>v</th>
<th>X(cm)</th>
<th>u</th>
<th>v</th>
<th>X(cm)</th>
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<td>2.6</td>
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<td>273</td>
<td>6.6</td>
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<td>244</td>
<td>11.3</td>
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<td>255</td>
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<td>171</td>
<td>3.8</td>
<td>158</td>
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<td>300</td>
<td>7.8</td>
<td>168</td>
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<td>239</td>
<td>11.9</td>
<td>151</td>
<td>4.1</td>
<td>127</td>
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<table>
<thead>
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<th>Y(cm)</th>
<th>u</th>
<th>v</th>
<th>Y(cm)</th>
<th>u</th>
<th>v</th>
<th>Y(cm)</th>
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</table>

The table shows the amplitudes and phases for harmonic analysis of East (u) and North (v) velocities and surface elevation (z) for different X and Y coordinates. The values are given in centimeters (cm) for the amplitudes and degrees for the phases.
which only the local inertial frequency is of a non-tidal nature. Resulting amplitudes and phases have been tabulated (table 3), where phases refer to 1 January 00.00 of the corresponding year.

3) (tidal band) residual signals

The low-frequency fields and harmonic timeseries (for current and pressure fields) are subtracted from the original timeseries to produce residuals. The Fourier spectrum of this high frequency, noisy signal is then bandpassed filtered, with a cosine bell window (fig. 3) incorporating the semidiurnal frequency band, with half width points at $1.22 \times 10^{-4}$ and $1.55 \times 10^{-4}$.

![Figure 3 Bandpass filter](image)

Figure 3 Bandpass filter, i.e. a spectral weighting factor as a function of frequency. Labels L and M give the width of the sloping region and plateau in units of the fundamental frequency bandwidth.

4) Fourier spectra

Both the original as well as residual signals were Fourier transformed. The raw spectra (2 degrees of freedom) are presented in the dimensional magnitudes, allowing a direct determination of amplitude values (instead of giving the power spectrum, from which the energy contained in a frequency band can be derived).

Each of the physical fields requires some specific analyses which will now be described:
Current field

a) The low-frequency current vectors are presented as stick-plots, in which the direction corresponds to the observed current direction and the length of the stick is determined by the key given at the top of each plot e.g. fig. 10.

b) In 1982 the current vectors have been projected into a specific direction (33° T, the inferred frontal direction) and a corresponding perpendicular direction (303° T). In these planes velocity contours (isotachs) have been determined (e.g. fig. 59).

c) Current spectra for V (North component) have been displaced two orders of magnitude for clarity. Currents are sometimes better described by separating the ellipsoidal motion into two counter rotating circular current components (fig. 4). The corresponding timeseries have been analyzed to give rotary spectra (e.g. fig. 77).

\[ \begin{align*}
\mathbf{V}(t) & = R_+ \mathbf{e}_+ \cos \Theta_+ \mathbf{e}_+ + R_- \mathbf{e}_- \cos \Theta_- \\
& = R \cos \Theta \mathbf{e}_+ + R \cos \Theta \mathbf{e}_-
\end{align*} \]

Figure 4 Decomposition of tidal current ellipse (frequency \( \sigma \)) specified by the four ellipse parameters (long axis \( U \), excentricity \( e = V/U \), inclination \( \psi \) and phase angle \( \phi \)) into two counterrotating circular currents of constant magnitude \( R_\pm \) and phase angles \( \Theta_\pm \).

d) The low-frequency current fields, obtained at different vertical positions, have been separated in a shearing and advecting current field, a separation suggested by the thermal wind relation (Holton, 1979). Note in figure 5 that the separation is not complete in the sense that \( \mathbf{v}_o \) and \( \mathbf{v}_i \) do not allow a reproduction of the original \( \mathbf{v}_o \) and \( \mathbf{v}_i \). The velocity difference \( \mathbf{v}_o - \mathbf{v}_i \) has been divided by current meter depth differences \( dz \) (e.g. fig. 11).
Figure 5. Relation between turning of geostrophic current (bottom $\vec{v}_b$; surface $\vec{v}_s$) and temperature advection: a) cold advection b) warm advection. The shearing "thermal" current vector has warm water at its right hand side (on the Northern Hemisphere). After Holton (1979).

e) The tidal harmonic series of current amplitudes and phases have been combined into i) current ellipses, e.g. fig. 93, and ii) vertical graphs showing the vertical profiles of these variables, e.g. fig. 98. In the latter graphs phases were taken relative to the surface current meter phase value of the same mooring. An alternative way to display the information is by forming the amplitude and phase diagrams of the counter rotating circular velocity components. The physical advantage and meaning of the theoretical curves in these figures is discussed in Maas and van Haren (1986).

Pressure field

The pressure fields are converted hydrostatically to elevations. These, however, have no fixed datum, i.e. the corresponding elevations are accurate up to an additional constant. This means that an unknown mean spatial gradient may exist.
Temperature field

The observed temperature at each of the sensors of the thermistorchain can either be displayed directly as a function of time or as vertical displacements to which they can be converted. This conversion process, performed by an inverse cubic spline interpolation, is illustrated in fig. 2c and 2d, applied to the low-passed temperature observations.

By subtracting the low-passed temperature field from the original data, the temperature fluctuations at the sensor depths are obtained and may be readily compared to the low-passed elevation field itself.

Acknowledgements

We are happy to thank captain Blok and his crew, of R.V. Tyro, for the pleasant cooperation during the hydrographic cruises in 1981 and 1982.

Thanks are also due to Dick Riepma of the Royal Netherlands Meteorological Institute, to Hendrik van Aken of the Institute for Meteorology and Oceanography Utrecht and to the Hydrographic Service of the Royal Navy for providing us with current, temperature and pressure data respectively.

The financial support from the Netherlands Council of Sea Research is gratefully acknowledged.
Reports on the stratified North Sea Project and References


Aken, H.M. van, 1984. A one-dimensional mixed-layer model for stratified shelf seas with tide- and wind-induced mixing, Dt. Hydrogr. Z., 37, 3-27


## Contents of figures

<table>
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<tr>
<th>Figure</th>
<th>1980</th>
<th>1981</th>
<th>1982</th>
</tr>
</thead>
</table>

### Current fields

1. U (East) and V (North) velocity components of hourly timeseries of stations listed in table 1.  

2. Low-frequency stickplots and, when available, advection and shear graphs  

3. Residual band-passed U and V timeseries  

4. (Raw) spectra of U and V  
   - 1980: 16-17, 1981: 72-76
   - 1982: 77-82

5. (Raw) rotational spectra

### Pressure fields

1. Hourly timeseries of surface elevation field at each station  

2. Low-passed pressuresignals  

3. Residual band-passed elevation series  

4. (Raw) spectra of the elevations  

### Temperature fields

1. Original timeseries  
   - 1980: 22

2. Low-passed timeseries  

3. Corresponding low-passed internal elevation field  

4. Temperature deviations (unfiltered and filtered)  

5. (Raw) spectra of the temperature deviations, the resulting values being displaced by an order of magnitude for clarity  
   - 1980: 26, 1982: 92

To compress the bulk of information not all of these graphs are shown for all stations. These figures are followed by some graphs showing combined information for the three years, such as:

4) Current ellipses following from Harmonic Analysis  
   - 1980: 93 - 97

5) Ellipse parameters, of original current ellipses as well as of their rotary components, as a function of depth  
   - 1980: 98 - 109
Figure 6 Timeseries of hourly current velocities in East (a) and North (b) direction at position A, 1980. Notice the different vertical scaling used.
Figure 7 As fig. 6 at B.
Figure 8 As fig. 6 at C.
Figure 9 As fig. 6 at D.
Figure 10 Stick plots of low-frequency currents in 1980.
Figure 11 Stick plots of shear and advection.
Figure 12 Bandpassed semidiurnal residual currents at position A, 1980. Labels L and M refer to their use in fig. 3.
Figure 13 As fig. 12 at B.
Figure 14 As fig. 12 at C.
Figure 15 As fig. 12 at D.
Figure 16 (Raw) current spectra at position A, 1980.
Figure 17 As fig. 16 at B.
Figure 18 Hourly pressure timeseries converted to sea level variations.
Figure 19 Low-passed elevation field.
Figure 20 Bandpassed residual elevation fields. Labels L and M refer to their use in fig. 3.
Figure 21 Spectra of elevations. Notice the difference in scales used.
Figure 22 a) Original timeseries of temperatures at 11 sensor depths.
b) Timeseries after applying a 50 hour running mean.
Figure 23 a) Temperature timeseries after applying the 50 hour running mean twice.

b) Inverse interpolation of (a) yielding depths of isotherms (°C) as a function of time.
Figure 24 Temperature variations (°C) at the 11 sensor depths of A, 1980 unfiltered (a) and filtered (b).
Figure 25 Inverse interpolation of the original temperature timeseries in fig. 22a directly yields a timeseries of the internal elevation field of isotherms (°C).
Figure 26 Spectra of the residual temperature timeseries \( (T - T) \) at the eleven depths.
Figure 27 Hourly timeseries of East velocities (u) at position E, 1981
Figure 28 As fig. 27 for North velocities ($v$). Notice difference in vertical scaling with previous picture.
Figure 29 As fig. 27-28 at F.
Figure 30 As fig. 27-28 at G.
Figure 31 As fig. 27-28 at H.
Figure 32 Stick plots of low-frequency currents in 1981.
Figure 33 Stick plots of advection in 1981.
Figure 34 Stick plots of shear in 1981.
Figure 35 Bandpassed semidiurnal residual East velocities (u) at position E, 1981. Labels L and M refer to their meaning in fig. 3.
Figure 36 As fig. 35 for North velocities (v).
Figure 37 As fig. 35-36 at F.
Figure 38 As fig. 35-36 at G.
Figure 39 As fig. 35-36 at H.
Figure 40 Hourly pressure timeseries corrected to sea level variations in 1981.
Figure 41 a) Low-passed elevation field.

b) Bandpassed residual elevation field.
Figure 42 Spectra of elevations in 1981. Notice the difference in vertical scales.
Figure 43 a) Temperature timeseries at 11 sensor depths (m) at E, after applying the 50 hour running mean twice.

b) Inverse interpolation of (a) yielding depths of isotherms (°C) as a function of time.
Figure 44 Temperature variations (°C) at the eleven sensor depths of E unfiltered (a) and filtered (b).
Figure 45 Timeseries of hourly current velocities in East direction ($u$) at position I, 1982.
Figure 46 As fig. 45 for North direction (v)
Figure 47 As fig. 45-46 at J.
Figure 48 As fig. 45-46 at K.
Figure 49 As fig. 45-46 at L.
Figure 50 Back cast timeseries using tidal harmonic velocities in East direction (u) at I.
Figure 51 As fig. 50 in North direction (v).
Figure 52 As fig. 50-51 at J.
Figure 53 As fig. 50-51 at K.
Figure 54 As fig. 50-51 at L.
Figure 55 Stick plots of low-passed current velocities in 1982.
Figure 56 As fig. 55.
Figure 57 Stick plots of advecting currents in 1982.
Figure 58 Stick plots of vertical shear in 1982.
Figure 59 Isotachs (contours of iso-current velocities in cm/s) in $33^\circ$ T and $303^\circ$ T at position I, 1982.
Figure 60 As fig. 59 at J.
Figure 61 As fig. 59 at L.
1982 DEPTH = 44 M

1982 DEPTH = 37 M

1982 DEPTH = 30 M

1982 DEPTH = 24 M

1982 DEPTH = 18

1982 DEPTH = 12 M

Figure 62 Residual East velocities (u) at position I, 1982 after subtracting tidal harmonics.
Figure 63 As fig. 62 for North velocities (v).
Figure 64 As fig. 62-63 at J.
Figure 65 As fig. 62-63 at K.
Figure 66 As fig. 62-63 at L.
Figure 67 Bandpassed residual East velocities (u) at position I, 1982.
Figure 68 As fig. 67 for North velocities (v).
Figure 69 As fig. 67-68 at J.
Figure 70 As fig. 67-68 at K.
1982 L=9 M=4 DEPTH = 12 M

1982 L=9 M=4 DEPTH = 27 M

1982 L=9 M=4 DEPTH = 42 M

Figure 71 As fig. 67-68 at L.
Figure 72 Current velocity spectra in East and North direction at I.
Figure 73 As fig. 72 at different depths.
Figure 74 As fig. 72 at different depths.
Figure 75 As fig. 72 at J.
Figure 76 As fig. 72 at K.
Figure 77 Rotational current velocity spectra at 1, 1982.
Figure 78 As fig. 77 at different depths.
Figure 79 As fig. 77 at different depths.
Figure 80 As fig. 77 at J.
Figure 81 As fig. 77 at K.
Figure 82 As fig. 77 at L.
Figure 83 a) Timeseries of pressure signals, converted to sea level elevations in 1982.

b) Low-passed timeseries of elevations.

c) The difference of the latter low-passed signals in b).
Figure 84 Spectra of elevations in 1982.
Figure 85 Timeseries of temperature at 11 sensor depths after applying the 50 hour running mean procedure twice.
Figure 86 Inverse interpolation of fig. 85 yielding depths of isotherms (°C) as a function of time.
Figure 87 Unfiltered timeseries of temperature residuals (°C)
Figure 89 Timeseries of internal elevations of isotherms (°C) after directly applying the inverse interpolation procedure to the original temperature data at 1.
Figure 92 Spectra of temperature variations $\Delta T$ obtained after subtracting the low-passed temperature field from the original temperature data.
Figure 93 Tidal current ellipses from Harmonic Analysis for the given tidal frequencies in 1980.
Figure 94 As fig. 93 in 1981.
Figure 95 As fig. 93 in 1981.
Figure 96 As fig. 93 in 1982.
Figure 97 As fig. 93 in 1982.
Figure 98 Current ellipse parameters (fig. 4) as a function of depth for the $O_1$ frequency. Drawn lines give theoretical relations.
Figure 99 Rotary current components (fig. 4) as a function of depth. for the $O_1$ frequency.
Figure 100 As fig. 98 for $K_1$. 
Figure 101 As fig. 99 for $K_1$. 
Figure 102 As fig. 98 for $N_2$. 
Figure 103 As fig. 99 for $N_2$. 
Figure 104 As fig. 98 for $M_2$. 
Figure 105 As fig. 99 for $M_2$. 
Figure 106 As fig. 98 for $S_2$. 
Figure 107 As fig. 99 for $S_2$. 
Figure 108 As fig. 98 for $M_4$. 
Figure 109 As fig. 99 for $M_4$. 