CREATION OF VERTICAL REFERENCE SURFACES AT SEA USING ALTIMETRY AND GPS

by

L. Pineau-Guillou, French Hydrographic and Oceanographic Service, 13 rue du Chatellier, CS 92803 29228 Brest Cedex 2, France

and

L. Dorst, Hydrographic Service of the Royal Netherlands Navy, Van der Burchlaan 31, 2597 PC, The Hague, Netherlands

ABSTRACT

The creation of vertical reference surfaces at sea, related to a reference ellipsoid, is a necessary step to enable the use of GPS (Global Positioning System) for referencing depth measurements at sea. Several projects exist for specific parts of the oceans, resulting in surfaces that partly overlap. As an example, we will present the French BATHYELLI project in detail, followed by a comparison of results for the North Sea area.

RÉSUMÉ

La création des surfaces de référence verticale en mer, en particulier le zéro hydrographique par rapport à l'ellipsoïde, est une étape nécessaire pour permettre d'utiliser le GPS pour référencer les sondages hydrographiques, mais également pour connecter les références marines (zéro hydrographique) et terrestre (IGN69). Divers projets sont développés à travers le monde, et parfois les surfaces calculées se chevauchent. A titre d'exemple, l'article présente en détail le projet français BATHYELLI, suivi d'une comparaison des résultats obtenus par les différents services hydrographiques en Manche et Mer du Nord.

1. INTRODUCTION

The BATHYELLI project (for BATHYmetry referred to the ELLIpsoid) is a set of models of reference surfaces at sea around the French coasts, and a computer program allowing for the transformation of data between one reference and another. The vertical reference surfaces included in this project are: Mean Sea Level (MSL) on the period of tide gauge measurements and on the period of spatial altimetry, Lowest Astronomical Tide level (LAT), Chart Datum (CD), ellipsoid, Land Datum (IGN69 in France) and geoid. In the BATHYELLI project, the surfaces MSL, LAT and CD have been computed with respect to the GRS80 ellipsoid.

The BATHYELLI project results will allow for Ellipsoidally Referenced Hydrographic Surveys (ERS) with GPS around the French coasts, avoiding tidal and meteorological corrections. It will also allow for the merging of land and sea, moving from a marine to a terrestrial reference. And, finally, it will allow for a comparison with similar surfaces realised by other countries.

2. TECHNICAL DEVELOPMENTS

2.1 Methodology

The methodology is based on Mean Sea Level computation; other surfaces (LAT, CD) are easily deduced by tidal modelling and the defined relations between LAT and CD.

The Mean Sea Level is obtained using several techniques (see Fig. 1) :

- spatial altimetry provides the Mean Sea Level far off the coasts. Close to the coasts, the Mean Sea Surface is not well calculated due to technical limitations. Because of excessive errors, these results cannot be used at less than 10 miles offshore ;
- tidal observations analysis provides Mean Sea Level on coastal sites. SHOM is responsible for the French Sea Level Observation Network, which includes 30 permanent tidal gauges along french metropolitan coasts, in addition to temporary tidal gauges ;

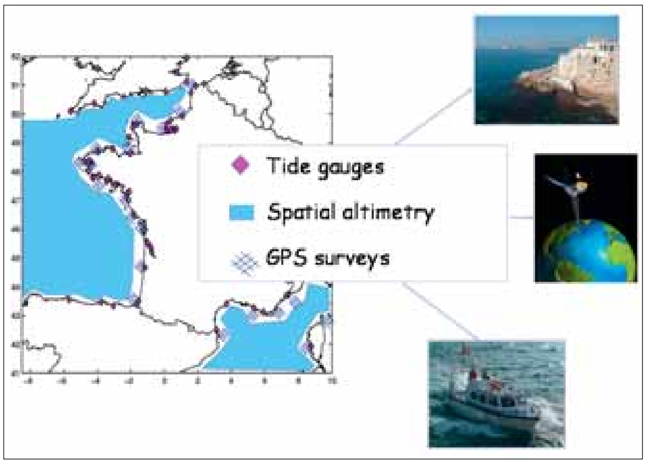

Fig. 1 Methodology to compute Mean Sea Level: interpolation of tide gauges, spatial altimetry and GPS data

- to fill the gap between altimetry and tide gauge data, SHOM has planned surveys to measure the Mean Sea Level with reference to the ellipsoid using kinematic GPS.

The data sets resulting from altimetry, GPS surveys and tide gauges have been interpolated in a joint study carried out by SHOM and a company called Noveltis, for computing Mean Sea Level with a high associated precision, calculated explicitly. The data sets have been merged by a least squares method with covariance functions; see Jan (2009).

2.2 Spatial Altimetry

The currently available Mean Sea Surface is not fully satisfying for hydrographers, because the global tidal model used is not precise enough, and the water levels are corrected for the inverse barometer effect. Therefore, an alternative surface has been computed, called Hydrographic Mean Sea Surface.

The differences between Hydrographic Mean Sea Surface and usual Mean Sea Surface are:

- the tidal model used is the SHOM tidal model, instead of a global model, showing differences up to 25 cm,
- the Hydrographic Mean Sea Surface does not coincide with the geoid,
- water levels are not corrected for the inverse barometer effect, for consistency with tide gauge processing; indeed, meteorological cyclic effects are a part of the tides, called radiational tide (contributiong to harmonic constituents like Sa, Ssa or S_1).

The Hydrographic Mean Sea Surface, and associated precision, were computed in 2007 in a joint study carried out by SHOM, the Toulouse-based company CLS, and La Rochelle University, see Lefèvre and *al.* (2007). Altimetry data were processed between 1992 and 2005, from Topex/Poseidon, ERS1, ERS2 and GFO. The Hydrographic Mean Sea Surface is shown in Fig. 2.

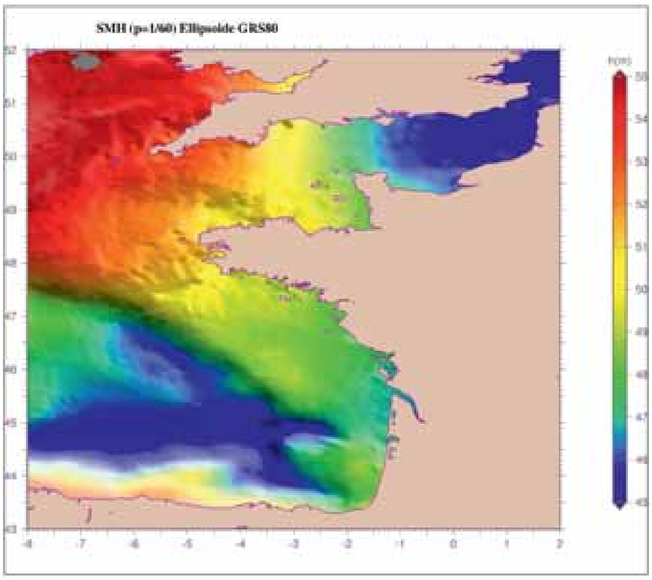

Fig. 2 Hydrographic Mean Sea Surface with respect to the GRS80 ellipsoid

2.3 GPS surveys

A GPS survey campaign has been run by SHOM in about 20 sites along the French coasts and is now complete. The surveys were planned between 2006 and 2008. The survey locations are shown in Fig. 3.

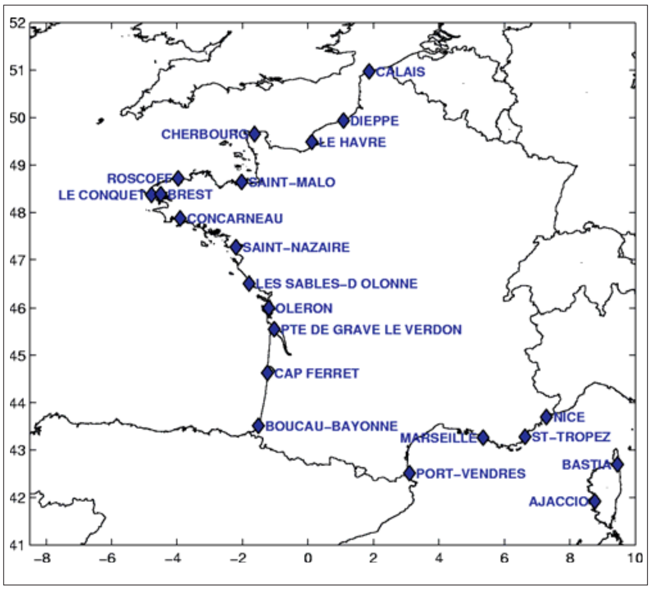

Fig. 3 2006 - 2008 GPS survey campaign locations

For each site:

- a precise determination of Chart Datum at the tide gauge (fixed mark nearby the tide gauge) is made using a long GPS acquisition (at least 24 hours, 48 hours recommended); this operation is very important to ensure a precise MSL referred to the ellipsoid at the tide gauge;
- a GPS reference station is installed as close as possible to the tide gauge;
- another GPS station is installed on board of a SHOM ship or launch (see Fig. 4), followed by a calibration procedure that allows for a precise computation of antenna height to take dynamic draught into account;
- the surveys are conducted using PPK differential GPS (centimetre accuracy); the survey generally extends about 15 nautical miles around the tide gauge and takes about 3 days; an example of a GPS survey is shown on Fig. 5;
- GPS data and attitude data are registered during the surveys.

The survey procedure is described in more detail in Pineau-Guillou and Dupont (2007).

Fig. 4 SHOM ships and launches for GPS survey campaign

Fig. 5 GPS survey around Brest

The GPS data are post-processed, filtered, corrected for ship motions (pitch, roll and yaw), antenna height, surges, and the tides in order to compute the Mean Sea Surface related to the ellipsoid. An example of the processed GPS data is presented in Fig. 6.

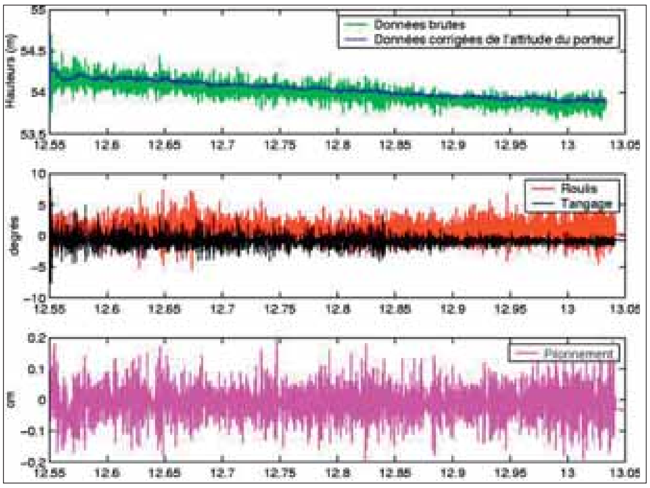

Fig. 6 Example of processed GPS data

The accuracy of each survey is evaluated:

- the "consistency" of the survey is the difference between the MSL at tide gauge and the MSL determined by GPS nearby the tide gauge. This difference must be at the centimeter level, it ensures that the antenna height has been correctly computed;
- the "precision" of the survey is the averaged difference (and its associated standard deviation) at the track intersections.

It is important to correct the data for ship motions during the survey. Attitude data are systematically recorded by a motion sensor. GPS data are corrected using ship motions, only when it is more appropriate than filtering (default method). Even if meteorological conditions are very good, the average roll and pitch of a vessel are not always zero. For example, they can reach 3 or 4 degrees. Not taking into account attitude data in such a case can cause a 15 cm bias in the results.

The antenna height must be calculated very precisely above the instantaneous sea level. This height depends on the vessel speed, as it modifies the draught of the vessel. Different tests show a draught variation of about 1 cm per knot, even at low speeds.
The survey must be conducted at a constant speed and the antenna height must be determined at this very speed.

The reference station must be positioned nearby the tide gauge in order to avoid a bias between MSL computed by GPS and MSL at tide gauge. Generally, the reference station is installed on the tide mark, where the ellipsoidal height has been precisely determined in ITRS.

3. RESULTS

3.1 GPS surveys

An example of Mean Sea Level surface from GPS around Bastia is shown in Fig. 7. MSL varies from 47.3 to 48.5 metres. The survey "precision" is 3 cm, with a standard deviation of 2 cm, which is really satisfying. The survey "consistency" is better than 1 cm, which ensures that antenna height was correctly computed.

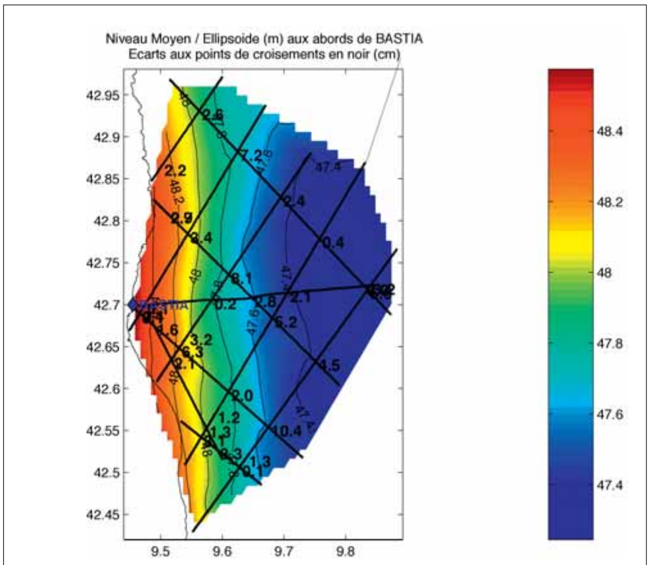

Fig. 7: Mean Sea Level related to ellipsoid around Bastia, France

The MSL-variation is larger than 1 metre on 15 nautical miles, and this variation is nonlinear. This confirms that GPS surveys will really help the interpolation between tide gauges and altimetry.

The values of precision, consistency, and survey period for all the surveys are shown in Table 1.

Table 1: Survey locations, precision (cm), consistency (cm) and period.

Location	Precision Mean / Std (cm)	Consistency (cm)	Period
Bastia	3,0 / 2,4	<1	May 16 – 18, 2007
Le Havre	8,4 / 6,8	3,7	May 21 – 23, 2007
Saint-Malo	7,6 / 6,6	<1	July 17 – 18, 2007
Marseille	4,7 / 3,7	1	July 23 – 25, 2007
Brest	2,5 / 1,8	3	July 9 – 11, 2007
Sables d'Olonne	6,2 / 3,7	9	Sept. 20 – 23, 2007
Saint-Nazaire	6,8 / 2,9	2	Sept. 18 – 19, 2007
Oléron	6,8 / 4,7	1,5	June 6 – 8, 2007
Port-Vendres	8,0 / 4,6	3	Oct. 25 – 27, 2007
Concarneau	6,3 / 3,5	11 (for 5 Nm)	Sept. 17 –19, 2007
Bayonne	3,0 / 1,8	Not computed	July 13 – 17, 2006
Cap Ferret	5,6 / 4,9	Not computed	Feb. 23 – 24, 2008
Pointe de Grave 2007	5,0 / 0,4	7,4	Sept. 27 – 28, 2007
Pointe de Grave 2008	11,5 / 9,6	Not computed	Feb. 15 – 21, 2008
Dieppe	4,3 / 3,1	<1	May 25 - 26, 2007
Roscoff	4,0 / 4,0	1	Nov. 09 – 11, 2007
Cherbourg	8,9 / 5,2	6,3	Nov. 03 – 08, 2007
Saint-Tropez	5,5 / 4,2	<1	Oct. 08 – 11, 2007
Le Conquet	6,2 / 4,1	2	Nov. 11 – 13, 2007 June 30 – July 2008
Mean	6,6 / 4,6	2,9	

3.2 Vertical reference surfaces

The data have been interpolated on a finite element grid, see Jan (2009). The LAT surface, which is seamless, is shown in Fig. 8. CD, which is not seamless, and its associated error are shown in Fig. 9 and Fig. 10.

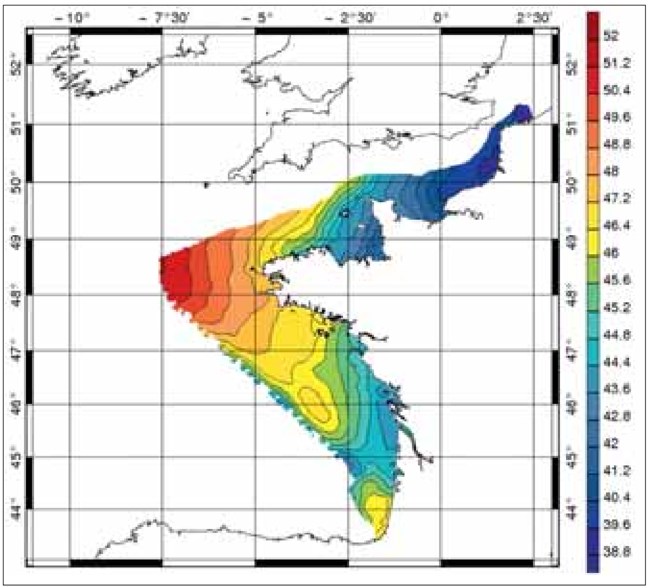

Fig. 8 LAT referred to ellipsoid (m)

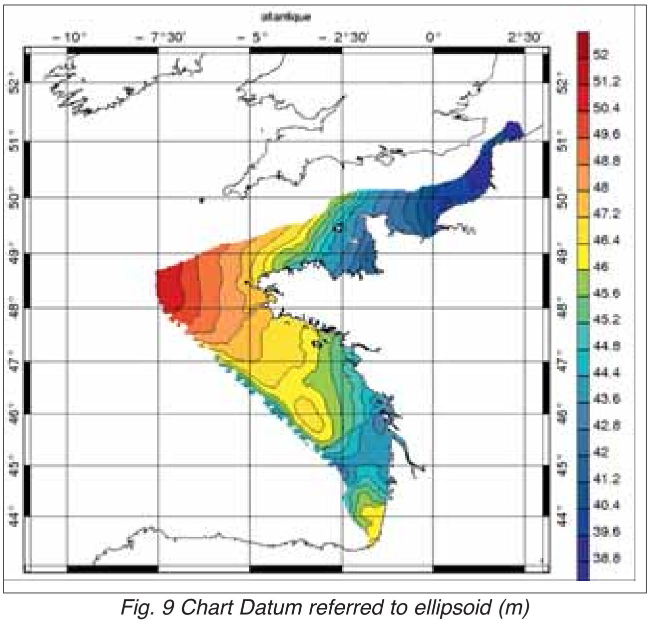

Fig. 9 Chart Datum referred to ellipsoid (m)

3.3 Comparison with results in the North Sea area

The Tidal Working Group of the IHO (International Hydrographic Organization) North Sea Hydrographic Committee (NSHC) took the initiative to evaluate differences between the overlapping projects for the North Sea region. The result, constructed by the Hydrographic Service of the Royal Netherlands Navy, is a set of merged surfaces, to be used as a common LAT-level, MSL, and Chart Datum, see NSHC Tidal Working Group (2010) and Dorst and *al.* (2010).

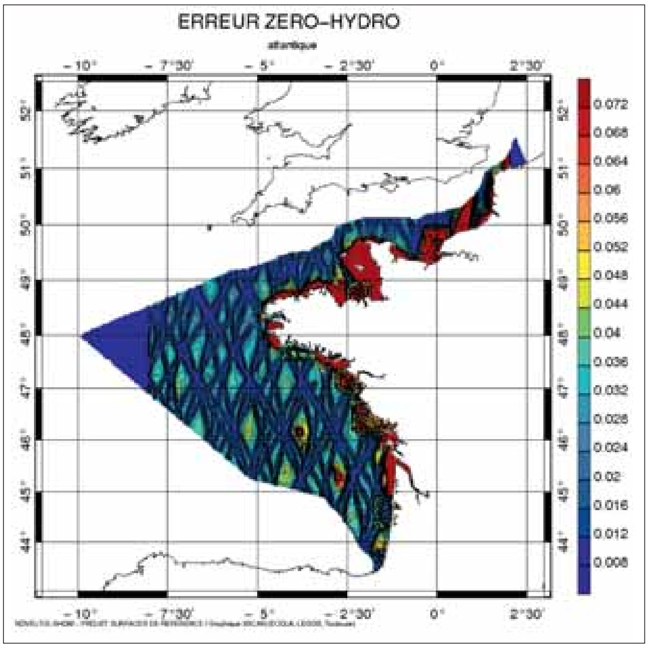

Fig. 10 Error associated to Chart Datum computation (m)

Data sets referred to the ellipsoid collected from Belgium, Germany, France, Netherlands and UK have been interpolated to a grid of 0.02° for both Easting and Northing. Denmark and Norway only have data available at specific coastal locations.

MSL, LAT and Chart Datum referred to the ellipsoid are shown in Fig. 11, Fig. 12, and Fig. 13.

At maritime boundaries, differences for MSL and LAT are less than 0.6; for Chart Datum, differences are less than 0.8 m.

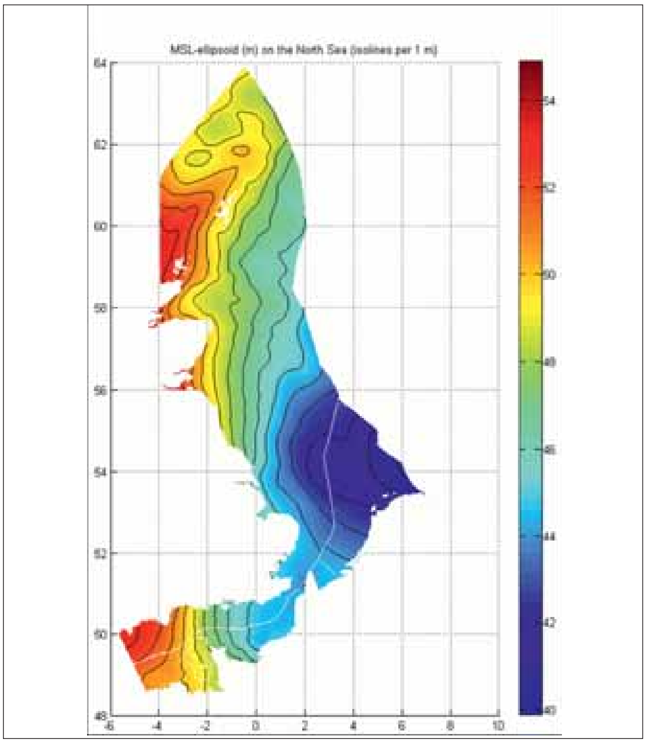

Fig. 11 MSL surface in relation to the ellipsoid, including one metre isolines in black and maritime boundaries in white

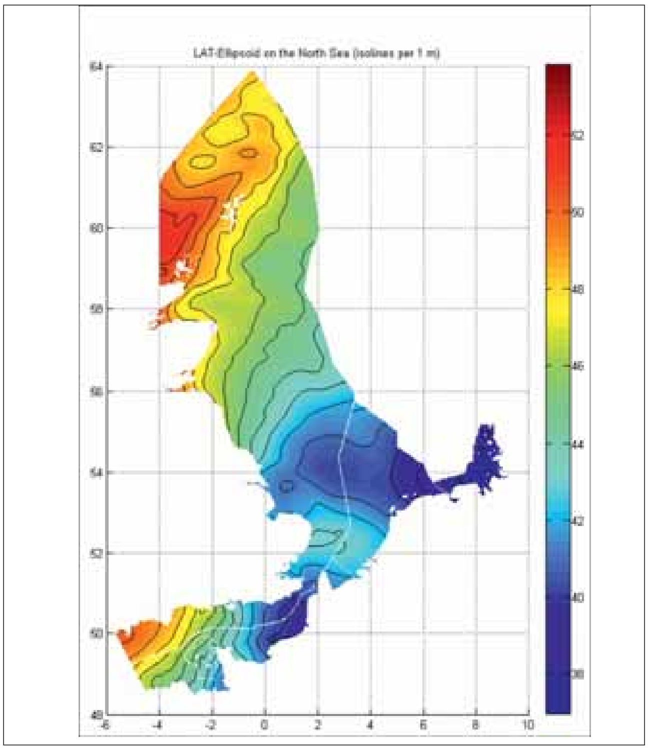

Fig. 12 LAT surface in relation to the ellipsoid, including one metre isolines in black and maritime boundaries in white

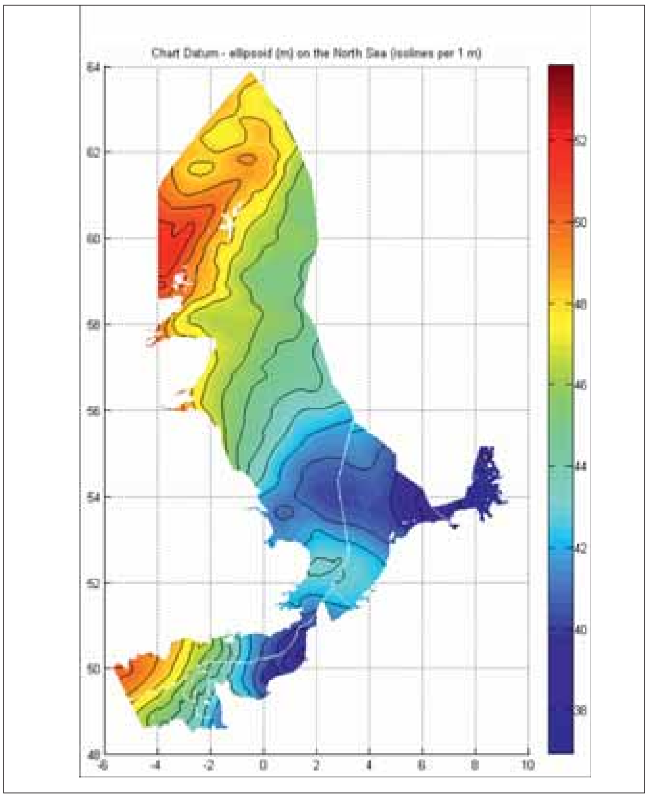

Fig. 13 Chart Datum surface in relation to the ellipsoid, including one metre isolines in black and maritime boundaries in white

4. CONCLUSION

As a result of the BATHYELLI project, reference surfaces have become available since 2009, for studies only, not yet for "operational" purpose (Ellipsoidally Referenced Hydrographic Surveys).

The next step is the improvement and validation of these reference surfaces (addition of 7 GPS surveys, validation by a comparison of a classical survey and a GPS survey in different areas). The next version should be an "operational" product.

A computer program that allows users to change easily from one vertical reference to another, is planned.

At the end of the project, SHOM plans to realize Ellipsoidally Referenced Hydrographic Surveys.

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