Maritime Boundaries in the North Sea: a Review

Ina Elema, Hydrographic Service, RNLN, The Netherlands

Kees de Jong, Delft University of Technology, The Netherlands

In this paper an overview is given of the geodetic factors that should be taken into account when defining boundaries at sea. Particular attention is given to the North Sea, a sea surrounded by a relatively large number of countries. First, differences between several geodetic and vertical (chart) datums and their international standardisation on nautical charts are considered. Next, precision and reliability aspects of computed median lines are discussed. Attention in a technical way is given to the United Nations Convention on the Law of the Sea (UNCLOS) in relation to national rules and regulations. For The Netherlands in particular, this includes the mining legislation for the continental shelf, the fishing legislation and the regulations with regard to large infrastructural works. Finally, some recommendations will be given to preclude future ambiguities in boundaries at sea.

Introduction

When delimiting boundaries, one should be aware of geodetic subtleties and pitfalls of the applied techniques, [ABLOS, 1996]. In the next sections we will successively focus on differences in horizontal and vertical datum definitions between states establishing a boundary, error propagation and the precision and reliability of the median lines, which are used to define boundaries at sea.
Special attention will be given to the North Sea. Despite its relatively small size, the North Sea is surrounded by a large number of countries, as is shown in Figure 1. For exploration and exploitation of e.g. gas and oil, fishery, delimitation is important. The delimitation of the continental shelf in the North Sea started after the Convention of the Continental Shelf came into force in 1964. The first boundaries were established by bi- or trilateral negotiations and based on the method of equidistance. At the end of the 1960's the boundary treaties were affected by a decision of the international Court of Justice in the North Sea Continental Shelf Cases, which stated that equitable principles had to be taken into account as well [Charney and Alexander, 1993].

Geodetic Datums

At the end of the 19th and the beginning of the 20th century, many European countries developed their own national co-ordinate systems. These regional and national geodetic datums were based on an ellipsoid, which best fitted the area of interest. After selecting a proper reference ellipsoid, a map projection has to be chosen, to project the ellipsoid (directly or indirectly, e.g. using a conformal sphere) on a horizontal plane. Consequently, a wide variety of ellipsoids, with different locations and orientations in space, and many different map projections exist, see e.g. [DMA, 1991] and [Strang van Hees, 1994]. For offshore positioning, these local datums were in general extended towards the sea. In Table 1 some of the reference ellipsoids and map projections are given for the countries surrounding the North Sea. These local datums traditionally included astronomical observations.

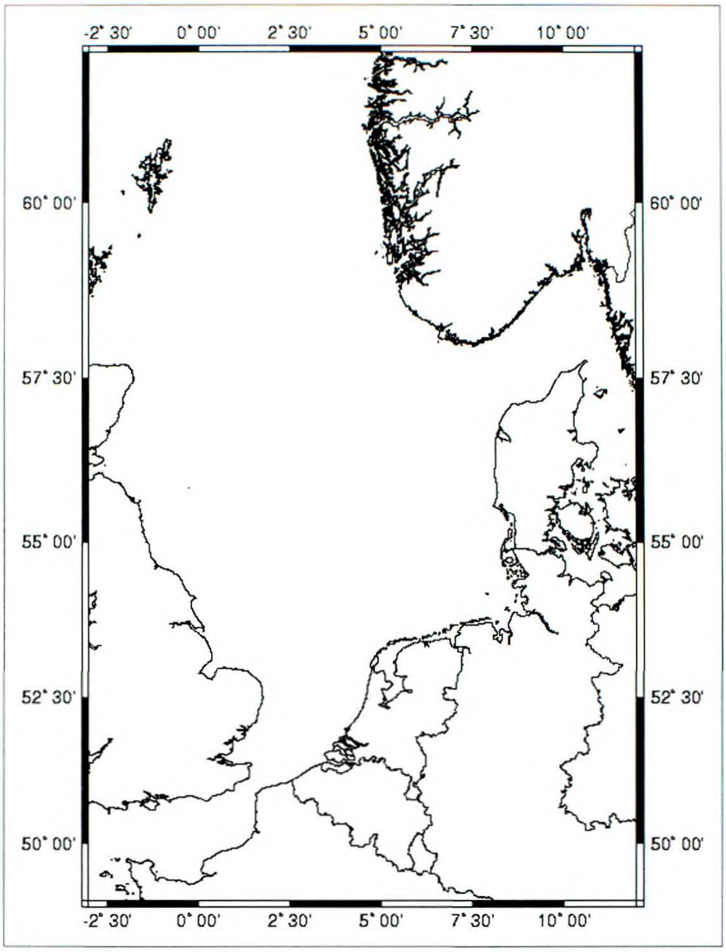

Figure 1: The North Sea and the countries surrounding it

The European Datum ED50

After World War II the USA initiated the work on a European first order trigonometric network. The adjustment was completed around 1950 and became known as European Datum 1950 or ED50. ED50 was established using existing terrestrial and astronomic measurements. It is based on the International Ellipsoid. Due to the inhomogeneity of the national networks, ED50 is inhomogeneous as well. This lack of homogeneity can be felt especially around the North Sea, see Figure 1. The width of this sea and the absence of islands made it impossible to establish a geometrically strong geodetic network covering this area. For example, the definition of ED50 in the UK was based on only one tie across the English Channel, [Bakkelid & Rekkedal, 1983].

Up to now, ED50 is often used for geographical reference at sea. Until recently it was for instance the datum used for all the official Netherlands nautical charts. Most of the maritime boundaries in the North

Country	Ellipsoid	Semi-major axis (m)	Flattening	Map projection
Belgium	Hayford	6378388	1/297	Lambert
Denmark	Hayford	6378388	1/297	TM
England	Airy	6377563.396	1/299.325	TM
France	Clarke 1880	6378249.145	1/293.465	Lambert
Germany	Bessel	6377397.155	1/299.153	Gauss-Krüger
Netherlands	Bessel	6377397.155	1/299.153	Stereographic
Norway	Bessel (modified)	6377492.018	1/299.153	TM
Europe	International	6378388	1/297	UTM

Table 1: Ellipsoids and map projections used around the North Sea and for Europe

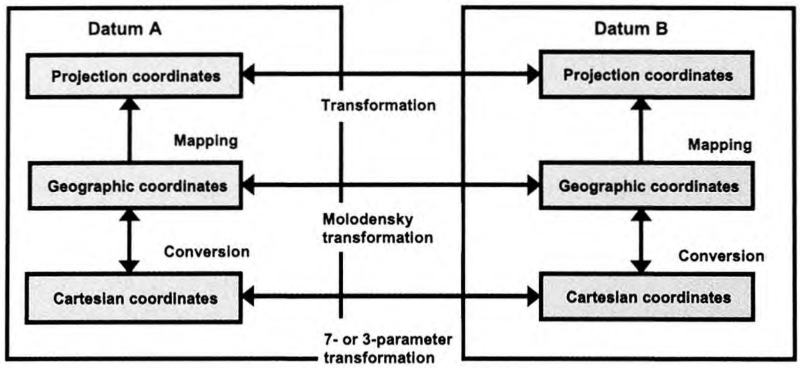

Figure 2: Datum transformations

Sea are defined in ED50. In the Dutch part of the North Sea, positions of concession boundaries still have to be defined, by law, in ED50. Also positioning data of pipelines have to be delivered in ED50 to the government. The present situation is that most modern positioning systems output positions in a geodetic datum, different from ED50 and usually more homogeneous, but eventually these positions have to be transformed to that datum.

Datum Transformations

Due to the variety of datum definitions, transforming co-ordinates from one datum into another is often required, e.g. when in a maritime delimitation case different geodetic datums are used by the states involved. In general, nations agree to use a common datum during negotiations on maritime delimitation. The process of transforming co-ordinates from one datum into another, see Figure 2, generally introduces imprecisions into the transformed co-ordinates. These imprecisions are in addition to any imprecision in the original co-ordinates. Several methods are available to transform co-ordinates from one datum to another. The transformation can be performed on geodetic co-ordinates, on Earth Centred Earth Fixed Cartesian co-ordinates or directly on projection co-ordinates. When performing the transformation on geodetic co-ordinates, the method of Molodensky is most commonly used. For many applications, use of the Molodensky Datum Transformation Formulae produces results that are of sufficient accuracy only when local, rather than mean, datum shifts are used [DMA, 1991]. However, in general only mean datum shifts are available. When transforming Cartesian co-ordinates, the 7-parameter Helmert transformation is most common. The 7-parameter transformation takes into account three translations, three rotations and one scale factor. Often the rotations and scale factor are taken as zero, resulting in a 3-parameter transformation, which consists of just three translations. The 7- and 3-parameter transformations assume the geodetic system has a consistent scale and orientation throughout the network. In practice this is not always the case. A minimum number of three stations with precisely known co-ordinates in both systems is required to determine the 7 parameters. A 7-parameter transformation produces co-ordinates that are in almost all cases equal or superior in accuracy to those obtained from a 3-parameter datum transformation. The former Defense Mapping Agency (DMA) (now part of the National Imagery and Mapping Agency (NIMA)) has published 3-parameter sets for many datums all over the world, see www.nima.mil. The 7- and 3-parameter transformations are the most commonly used and are often programmed, together with several sets, internally in GPS receivers and in various computer programs, such as the one described later in this paper.

Transformation parameters used in the North Sea area are determined by a number of organisations. Among them are those of NATO's STANAG (Standardization Agreement), UKOOA (United Kingdom Offshore Operators Association) and NIMA/DMA. In 1981 a working group of six nations around the North Sea recommended two sets of parameters for the transformation between WGS72 (World Geodetic System 72, the predecessor of WGS84) and ED50, [Ordnance Survey, 1981]. With the introduction of WGS84 and the establishment of ED87 (an extension of ED50, not only covering a wider area, but also including satellite data), this working group met again to define new, so called North Sea Formulae [Harsson, 1990]. For the transformation between WGS84 and ED87 seven parameters were defined, whereas for the transformation between ED87 and ED50 fourth degree polynomials as function of latitude and longitude were chosen to compensate for inhomogeneities. However, these transformation sets are hardly used, probably due to the complexity of the polynomial expressions.

In 1989 a start was made to establish a new European Reference frame (EUREF) based entirely on GPS observations. The realisation of EUREF, known as the European Terrestrial Reference System 1989 (ETRS89), is attached to the Eurasian plate and can currently be considered equal to WGS84 at the few decimetre level. Two sets of transformation parameters between ED50 and ETRS89 have been determined: one consisting of three translations only, the other consisting of three translations, three rotations and a scale factor, [van Buren et al, 1999]. According to van Buren et al. [ibid.] the different parameter sets currently available show levels of agreement that can be expected for ED50. This means that each of the parameter sets is equally valid. It should be noted that the area of applicability of the transformation parameters for the North Sea includes only those parts of the continental shelf, which belong to the participating countries, i.e., Denmark, Germany, Great Britain, Norway and The Netherlands. The Belgian part of the continental shelf is not covered, but the transformation parameters can be considered valid for this part of the continental shelf as well, due to its proximity to the area of applicability and its small size.

Precision of Datum Transformations

Strictly speaking a set of transformation parameters is only valid for a small area. When using a transformation set for a larger area, a generalisation is made. The larger the area, the larger the imprecision which is introduced. The precision depends on a number of factors. They are the type of equations used, the quantity and quality of geodetic control data from which the parameters were derived, the size of the area covered by the transformation parameters, and the distance from the control data, [Philip, 1988]. For some sets of transformation parameters, an estimation of the precision is known and given together with the transformation sets. By applying the law of propagation of covariances, the precision on the transformed co-ordinates can be computed. For example, NIMA/DMA in the second edition of its report on WGS84, [DMA, 1991], included an estimate of the precision of their sets. However, any precision statement will only apply to the geographical area covered by the data used to derive a set of transformation parameters. Extrapolation outside the stated area carries a risk of larger imprecisions.

Different organisations recommend using different transformation sets. Offshore operators, for example, are often advised by their clients to use the UKOOA set. The International Hydrographic Organization (IHO), on the other hand, advises the use of parameter sets provided by the NIMA/DMA when no other transformation sets are defined by a particular country [IHO, 1994]. The differences between the results of several sets of ED50 co-ordinates are in the order of several metres and depend on the location in the North Sea.

Before the satellite era, national geodetic systems were established using terrestrial methods. It appears that the precision of terrestrial networks tends to deteriorate with an increasing distance from the origin. Since the origin is often defined in the centre of the network, the worst precisions are obtained at the borders with other states. This should be kept in mind when boundaries have to be defined with high precision. In Figure 3 the differences are shown between points of the Netherlands national network, determined using terrestrial observations in the early 20th century, and a new realisation of it, determined by using GPS. The GPS network is homogeneous and the discrepancies between the two can almost entirely be attributed to errors in the terrestrial network. Figure 3 clearly shows how the precision of the co-ordinates of the current reference system deteriorates towards the borders. However, in 2000 it was decided to maintain the current co-ordinate system of

The Netherlands, see Table 1, despite its discrepancies with ETRS89 [Salzmann, 2000]. Instead of a new system, a new definition was adopted: the current 2D-grid co-ordinates will remain as they are, and in addition one-to-one relationships between this grid and ETRS89 were established. These relationships allow for the unambiguous connection with the international co-ordinate frame. Since ETRS89 is a 3D system, use should be made of a precise geoid model for The Netherlands [de Min, 1996] to obtain orthometric heights in the Netherlands' national height system NAP (Normaal Amsterdams Peil). This newly developed procedure is called RDNAPTRANS, see www.rdnap.nl.

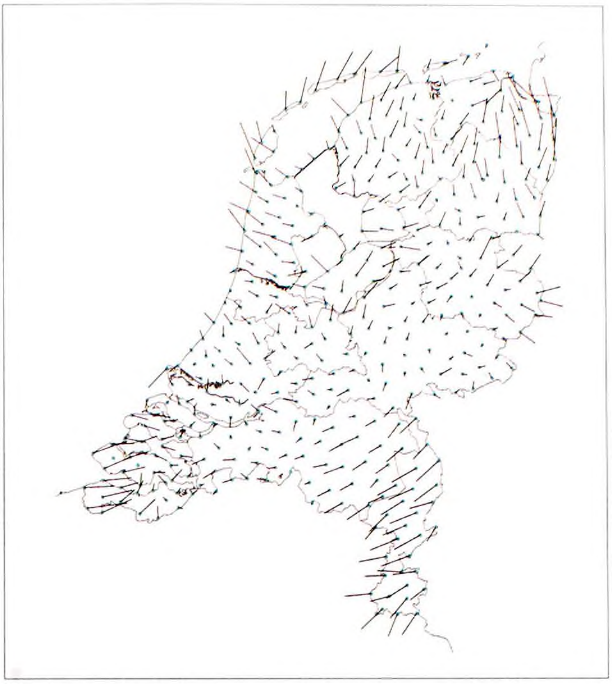

Figure 3: Discrepancies between the current reference system of The Netherlands and a realisation based on GPS. The maximum difference of almost 25 cm appears at the border with Belgium

Transition to WGS84

Nowadays, the IHO strongly supports any initiative of hydrographic services to reference charts to WGS84, [IHO, 1994]. In 1996, the NSHC (North Sea Hydrographic Commission) stated in Conclusion 73 of the North Sea Hydrographic Conference of that year: "*... to adopt WGS84 as the uniform horizontal reference system, for nautical charts within the NSHC area, as soon as practical.*" This process has started in most member states. The first chart of The Netherlands Hydrographic Service produced in WGS84 was published in 1998. At this moment about 50 per cent of all nautical charts has been transformed from ED50 to WGS84. The small craft charts have been produced in WGS84 since 2001. Furthermore the input for official Electronic Navigational Charts (ENC's), to be used in an ECDIS (Electronic Chart Display and Information System), has to be in WGS84 [IHO, 1996]. At this moment for The Netherlands, ENC's for the entire Netherlands part of the North Sea are available, although not for all scales. Progress can be monitored at www.primar.org. ARCS-charts (Admiralty Raster Chart Service) are available in WGS84 for the Dutch small craft charts and for some nautical charts. In boundary definitions, a transition to WGS84 or ETRS89 is also recognised; e.g. the maritime delimitation in the area between the Faeroe Islands and the United Kingdom is defined in ETRS89. The Netherlands are also considering, and looking into the consequences of, a transition from ED50 to WGS84 in its 'Mijnwet Continentaal Plat' (Mining legislation for the continental shelf). However, it should be kept in mind that since ETRS89 is attached to the Eurasian plate, the discrepancies between this system and WGS84 will increase as time proceeds. For navigation purposes both systems can be considered the same for the time being. The difference between ETRS89 and WGS84 is at this moment around 25 cm and increasing by approximately 2.5 cm per year.

Height Systems

According to [Rapp, 1994] there are about 100-200 different vertical datums in the world. Some are used solely on land, others only at sea. The vertical datum used as reference level in nautical charts is called Chart Datum. Due to the many varied tidal characteristics a large number of definitions of Chart Datum exists. Nevertheless, in areas affected by tide, the Chart Datum is nearly always some kind of low water level. For countries around the North Sea an overview of the chart datums in use is given in Table 2. Vertical chart datums are usually related to time-dependent mean ocean surfaces, such as Mean Lower Low

Country	*Chart Datum*	*Remarks*
Belgium	MLLWS	
Denmark	MLWS	
France	LAT	
Germany	MLWS	
Norway	LAT	
The Netherlands	MLLWS	Different from the Belgian datum, due to a different computation method
UK	Approximately LAT	

Table 2: Chart Datums used around the North Sea

Water (MLLW), Mean Low Water (MLW), Low Water (LW), Lowest Astronomical Tide (LAT), Mean-Low Water Spring (MLWS). An impression of the differences between several vertical chart datums is given in Figure 4. As stated in [IHO, 1993], the fact that there are different realisations of vertical datum means that adjacent or opposite states may use different levels at which to establish their baselines. An example of discrepancies arising due to different datum definitions is described in [Symmons, 1995]. France uses LAT, whereas Belgium uses MLLWS as its Chart Datum. The difference between both datums is approximately 0.3 m. As a result, features that were shown as sandbanks on French charts, were regarded to be constant underwater banks on Belgian charts. Consequently, after applying the two chart datums, two dividing lines, both based on equidistance, were produced. Finally, the area between the two median lines was divided in agreed parts. Usually, a common Chart Datum is agreed upon and used in negotiations for the delimitation of a boundary.

Standardisation of Vertical Datums

Just like horizontal datums, several organisations try to adopt one reference system to refer their heights (or depths) to. The IHO and IMO (International Maritime Organisation) already stated in the early 1980's that states should consider adopting an astronomical Chart Datum as reference system. Since 1995 the Tidal Working Group of the NSHC has proposed to use LAT as chart datum in the North Sea. At the 1996 NSHC conference, the North Sea Hydrographic Commission accepted "*...to adopt LAT for Chart Datum in the NSHC region and to encourage its members to implement this adoption at the earliest practicable opportunity.*" It was not possible to formally agree on a date of introduction. The NSHC order is now, under good co-ordinated bilateral and trilateral co-operation transition to LAT. At this moment The Netherlands are working on a new reduction chart for the North Sea based on LAT, which is expected to be published in 2002. Other products, which will be based on the new reduction chart, will become available no sooner than late 2003. A consequence of the transition from MLLWS to LAT is that the low-water line along the coast will change, and thus, the baseline. For the Netherlands part of the North Sea, depth values displayed on the charts will decrease by an amount of 20 cm on the average. Of course in reality depths will not change! The change in position of the baseline depends on the steepness of the seafloor. Preliminary results of the difference between MLLWS and LAT can be

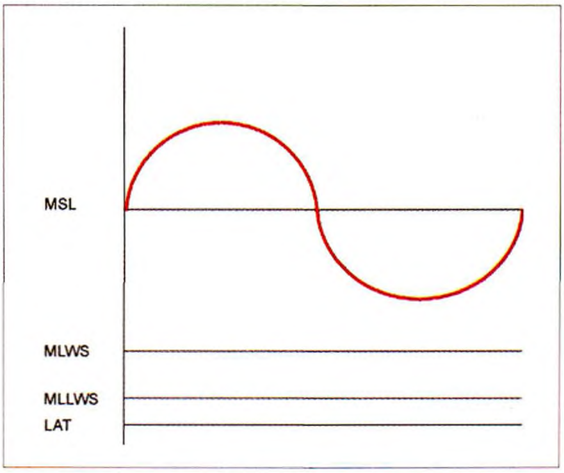

Figure 4: Vertical chart datum definitions; the curve depicts the actual tide (not to scale)

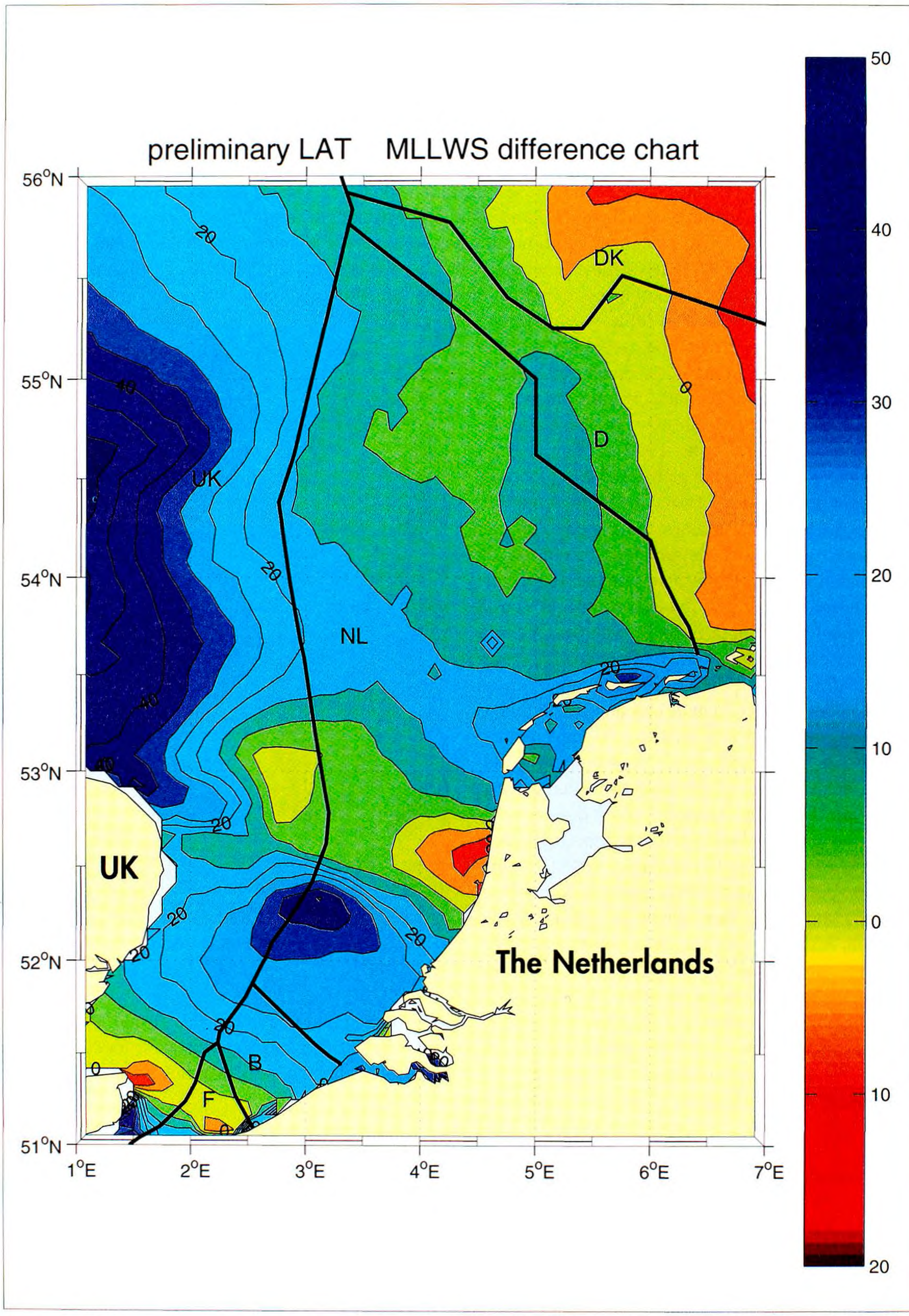

Figure 5: Differences between MLLWS ans LAT for the North Sea area

seen in Figure 5. At the moment, data of ENC's is not required to be defined with respect to LAT. If digital data to be used in ECDIS is not in LAT, the used Chart Datum must be permanently displayed, [IHO, 1996].

Geoid

Mean sea level (MSL) is often assumed to coincide with the geoid, whereas it actually consists of the geoid, superimposed by the time-dependent Sea Surface Topography (SST) [Vanicek & Krakiwsky, 1982]. The Sea Surface Topography can be considered as a long wavelength feature.

Precise 3D positions at sea can easily be obtained using GPS relative positioning techniques like LRK (Long Range Kinematic) or RTK-OTF (Real Time Kinematic – On The Fly). Heights obtained using GPS are related to the WGS84 ellipsoid and have only a geometrical meaning. Since one is mainly interested in heights related to reference surfaces like MSL, the difference between WGS84 ellipsoid and reference surface becomes important to know. For such purposes, a precise geoid-model should be determined. In 1997, a preliminary North Sea geoid-model was computed [de Bruijne et al, 1997]. Firstly, a gravimetric geoid based on the global EGM96 geopotential model and available gravity measurements was computed. Secondly, a correction model to this gravimetric geoid was determined, based on all external data from GPS, levelling and altimetry, combined in an optimal way. These two models form a geoid-model to compute the MSL with respect to a reference ellipsoid. The resulting preliminary North Sea geoid, shown in Figure 6, is assumed to have a precision better than 4 cm at sea and better than 6 cm along the coast. It is for example implemented in the PCTrans software, developed by the Hydrographic Service of the Royal Netherlands Navy, see below. Currently, plans are being developed to determine a new, second-generation precise geoid for the North Sea area [de Min et al, 1999]. For this new computation, data from other countries surrounding the North Sea should be obtained and included, so one geoid can be computed and connected to the different existing land geoids. The proposed plan not only foresees in the computation of one common geoid-model but also its acceptance, implementation and use in practice. When all the countries surrounding the North Sea provide the available data and accept this geoid, a leap forward will be made. This geoid, in conjunction with the use of precise GPS positioning, may help solve the ambiguities, which arise due to using the present different vertical chart datums.

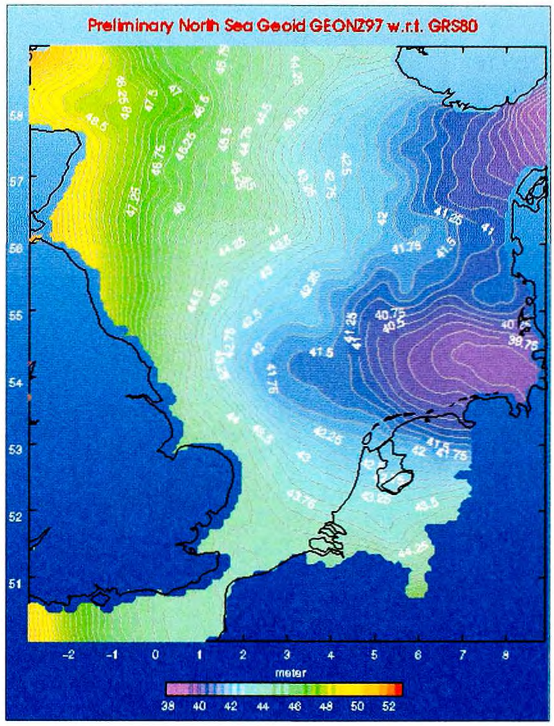

Figure 6: Preliminary North Sea Geoid (from 'de Bruijne et al, 1997')

Precision and Reliability of Boundaries

Maritime boundaries are often defined by median lines, having equal distances to the respective basepoints of nations. The basepoints are taken from the low water line. The median line consists of a number of sections, the start and end points, generally known as turning points, which are determined using the basepoints. As a result the precision of the turning points defining the median line depends on the precision of the basepoints from which they are derived.

As stated in [IHO, 1993], geographical co-ordinates of basepoints are usually given to the nearest second in latitude and longitude. As a result, their resolution is of the order of 30 metres in each component. Even today it is common practice to digitise basepoints from nautical charts. In order to be able to show any considerable length of coast, scales between 1:100,000 and 1:250,000, but preferably larger, have to be used, [IHO, 1993]. The actual precision of basepoints taken from such charts is usually of the order of several tens of metres. However sometimes a sort of artificial precision seems to be present in given basepoints, created by the large number of digits in which they are presented. The actual number of significant digits is often much smaller than the total number of digits given. The precision of basepoints, taken from nautical charts, depends on the accuracy of the surveys from which they were determined and the accuracy of the chart. Even some charts today are based on very old surveys. Occasionally even the geodetic datum used in a chart is unknown. Additional inaccuracy will be introduced when transforming co-ordinates from one datum into another, as explained above. When old charts or otherwise 'unreliable' charts are used for a delimitation case, they are sometimes used in combination with aerial photography or new surveys, as in the case of maritime delimitation between the USA and Mexico [Soler et al, 2001]. Also the IHO recommends greater precision in the co-ordinates of basepoints if the technology permits [IHO, 1993]. With the availability of carrier-based differential GPS positioning techniques, this is indeed the case: precisions of several centimetres or better are routinely obtained nowadays.

Precision of the points defining a median line, and thus of the median line itself, can never be better than the precision of the basepoints. In fact, it may even be several orders of magnitude worse, [Horemuz, 1999]. This can be explained by the linear(-ized) relationship between the two types of points, in which the relative geometry is included. When this geometry is unfavourable, small errors in the basepoints may become very large in the median line points. Examples of bad geometries are lines intersecting at angles close to zero or 180 degrees. The propagated covariance should be part of the definition of a computed median line point (besides its co-ordinates), as it gives a description of the quality of the point. However, one should bear in mind that often fixed co-ordinates, which may be based on a computed median line, define maritime boundaries.

Apart from precision, one should also take into account reliability. Positions can have a very good precision, but at the same time be very unreliable. Reliability in this context refers to the ability to detect possible gross errors in the given co-ordinates of basepoints and the observations used to derive the median line. Together with precision, reliability is said to constitute accuracy. For an overview of the mathematical concept of reliability, see [LGR, 1982].

To reduce the number of points defining a median line, this line may be simplified. It is for instance possible to simplify the median line by exchanging specific areas between states. The resulting sum of areas lost and gained should be zero. To this end, area computations on a reference ellipsoid are required, see e.g. [van Gein and Gillissen, 1993] and [Gillissen, 1993]. Using another datum affects the size of an area, due to different sizes of the ellipsoid used, see Table 1. For example, the area covered by the Netherlands continental shelf will become about 5 km^2 larger when changing from ED50 to WGS84. This change to another datum would have an impact on e.g. concession areas.

Once the turning points of the median line have been determined, they have to be connected. This can be done in several ways. For the delineation of limits this is often a source of confusion [van Gein and Gillissen, 1993]. For instance, many boundaries in the North Sea are defined using parts of great circles on a sphere, even though the horizontal datum is defined on an ellipsoid. In addition, in the treaties between states, often no reference surface (its size, shape and location in space) is mentioned. It also happens that limits that should be the same, such as those of a continental shelf and an Exclusive Economic Zone (EEZ), are defined in a different way. Nowadays, with sufficient computing power available, it is no longer necessary to revert to a sphere to determine segments of a median line. All computations can be performed on a (well-defined) reference ellipsoid. This will also avoid discussions on whether to use great circle arcs connecting segments, ellipsoidal geodesics, loxodromes, rhumb lines or that very nebulous term 'straight lines'.

Nowadays we also encounter the problem of precise navigation equipment and less precise boundaries. The co-ordinates of the turning points of most of the defined boundaries are given to the nearest full second of arc; their resolution is of the order of 30 metres. Differential GPS provides positions with a precision better than 5 metres. In earlier days very precise boundaries were not required, since the navigation systems were not precise either, but this situation has changed dramatically over the last 15 years.

The Hydrographic Service of the Royal Netherlands Navy

Established in 1874, the Hydrographic Service of the Royal Netherlands Navy is responsible for the publication of nautical charts, for which purpose they and other organisations perform surveys at the North Sea. In addition, the Hydrographic Service supports the Netherlands government, the Navy and a number of other organisations in the area of hydrography, maritime meteorology, oceanography and marine geodesy.
Part of its supportive function is the technical assistance the Hydrographic Service provides e.g. to the Ministry of Foreign Affairs in cases of maritime delimitation with neighbouring states of The Kingdom of the Netherlands.
To deliver quick assistance, software has been developed to perform various computations in the field of maritime delimitations. Among others, utilities have been developed for median (equidistant) computations, computation of limits of a particular distance (e.g., 12 or 24 nM) from basepoints, intersection of two lines, distance computations, area computations, and datum transformations. Most of these utilities (besides the first two mentioned items) have been integrated into one user-friendly package, called PCTrans, see Figure 7. Dutch and English versions of the freeware package can be downloaded from www.hydro.nl. Development and integration of the software is an ongoing task.

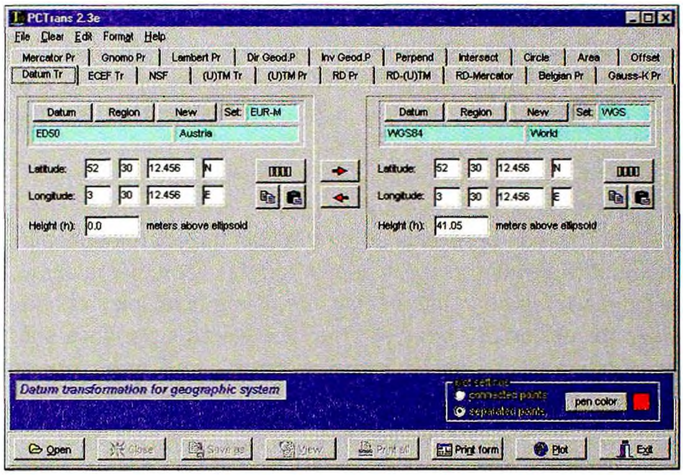

Figure 7: Screen snapshot of PCTrans

Datum transformations, which can be performed with PCTrans as well, are based on the 7-parameter method via Earth Centred Earth Fixed Cartesian co-ordinates. Many sets are included, based on NIMA/DMA, UKOOA or national parameters. It is also possible for users to define and add new sets. Furthermore several map projections are incorporated in PCTrans, like UTM, TM, Mercator, gnomonic, stereographic, Lambert and Gauss-Krüger (which is similar to UTM, but based on a different reference surface). It is also possible to transform co-ordinates from one projection into another. The geoid models for The Netherlands and the North Sea area (see Figure 5) are included. Also the new definition of the national co-ordinate system of The Netherlands, which includes the transformation between the horizontal grid and ETRS89, is implemented. Other geodetic computations that can be performed include the direct and indirect problem on the ellipsoid, computation of point of intersection between several kinds of lines or circles, perpendicular line and area computations. These computations can be performed by either manual input or file input. Besides a number of supported file formats, users can define their own formats. Results can be displayed on a background of a simple world map or a more detailed map of the North Sea area. Help screens provide on-line assistance while running the program.

UNCLOS in Relation to National Legislation

There is an increasing need for space in the North Sea, since the number of activities at sea (radio stations, windmill parks) is increasing and existing activities (cables, fishery, recreation) are getting more

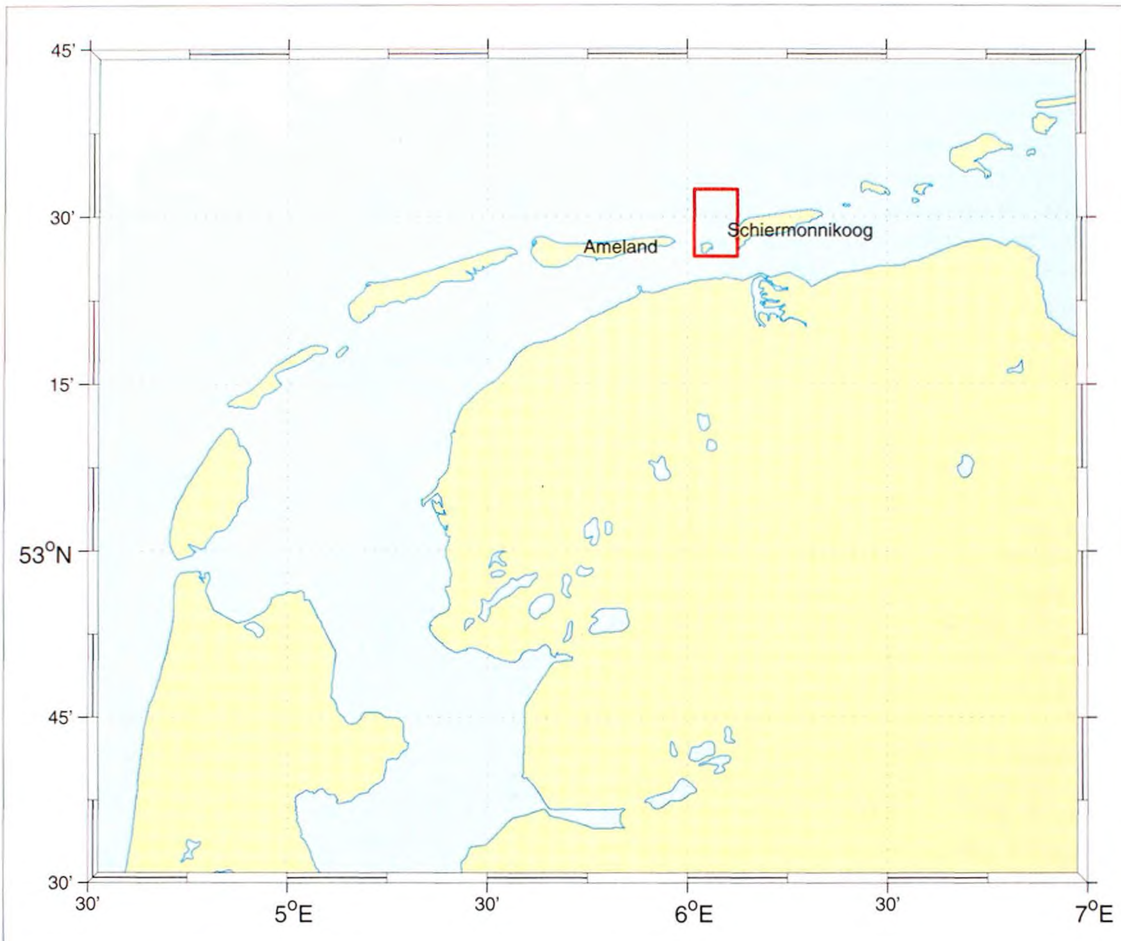

Figure 8: Location (red rectangle) of the low-tide elevations of figures 9 and 10

intensive. The area of the Netherlands Continental Shelf of the North Sea is approximately 50,000 km^2. This is about 1.5 times the land area of The Netherlands. However, all (future) needs for space in the North Sea add up to more than three times the available space. Nevertheless, some activities do not exclude other activities in the same space and could be combined. Because of this friction between need and availability of space, there is a necessity for more regulation. In order to have a tool to deny certain activities, The Netherlands has announced an EEZ in 1999, which came into force on 28 April 2000. Shortly afterwards, the first legislation came into force for the whole EEZ, instead of only for the territorial sea, where it was valid previously. Different government departments are still working on a review of legislation that may need to be adapted.

Additionally the Netherlands part of the North Sea will become for the first time a part of the policy document '5th Report on Physical Planning' (see www.vijfdenota.nl). The four predecessors were valid only for the land area of The Netherlands. The 5th Report is a national plan for the next 20 years. After a commentary round, the Report will be finally drawn up in 2002. In the Report, the government will probably assign areas in the North Sea where windmill parks are allowed or where new pipelines and cables can be laid.
UNCLOS states that outer limits like those of territorial waters and EEZ depend on baselines, which may be changing due to moving low tide elevations or human extensions of the land (or in general a changing low-water line). In national legislation one often prefers a defined limit or boundary with fixed co-ordinates, to have an area of constant size which is easier to regulate and to control. Concerning the fishery legislation, there exist European and national legislation. The regime for fishery in the Dutch fishery zone is

based on the common fishery policy of Europe. However, where the Dutch national fishery legislation mentions the establishment of a fishery zone from the current, changing baseline onwards (Machtigingswet instelling visserijzone 8-6-'77, art. 2), the European legislation (Regulation nr. 3760/92) fastens to the non-changing baseline of a certain moment. For The Netherlands the baseline as valid in January 1983 should be used for the European legislation. Since that time however, some low tide elevations disappeared or changed considerably, sometimes resulting in an impact of up to 1.5 nM on the 12 nM limit. Especially during the European embargo on cod fishing in the North Sea of spring 2001, this caused confusion. The mentioned Dutch mining legislation has defined co-ordinates for the continental shelf, even still for the old 3 nM limit. At the implementation of a 12 nM territorial sea in 1985 it was expected that soon the mining legislation was going to change. It still has not, although it is expected soon.

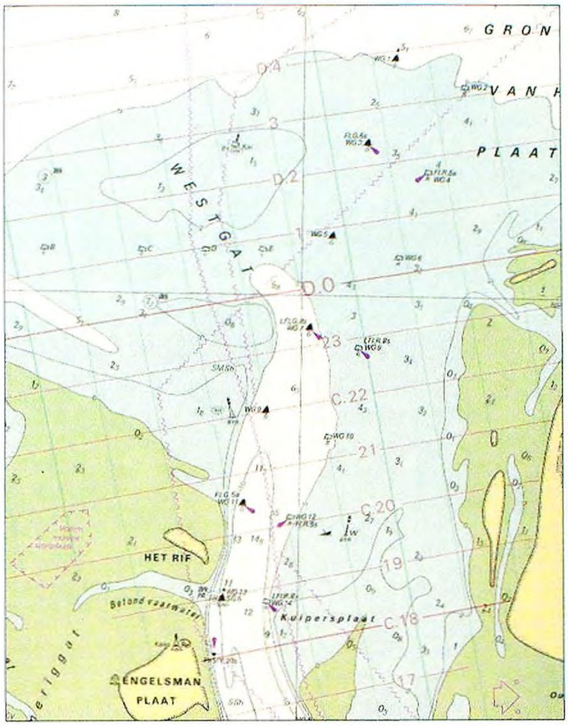

Figure 9: Location of low tide elevation of Figure 8 in October 1996

An example of an area where the low tide elevations change frequently is the area of the Frisian Islands. In the last edition of Chart no.1458 of April 2001, three small low tide elevations appeared between the Islands of Ameland and Schiermonnikoog, which caused the baseline dependent limits (like the territorial sea of 12 nM) to shift more than 1 nM. The three new low tide elevations can be found in the red rectangle of Figure 8. Figure 9 shows a part of the chart of October 1996 (in ED50, with Decca lanes), Figure 10 the same chart of April 2001 (in WGS84, without the Decca lanes). Besides the new low tide elevations, the whole area has changed considerably.

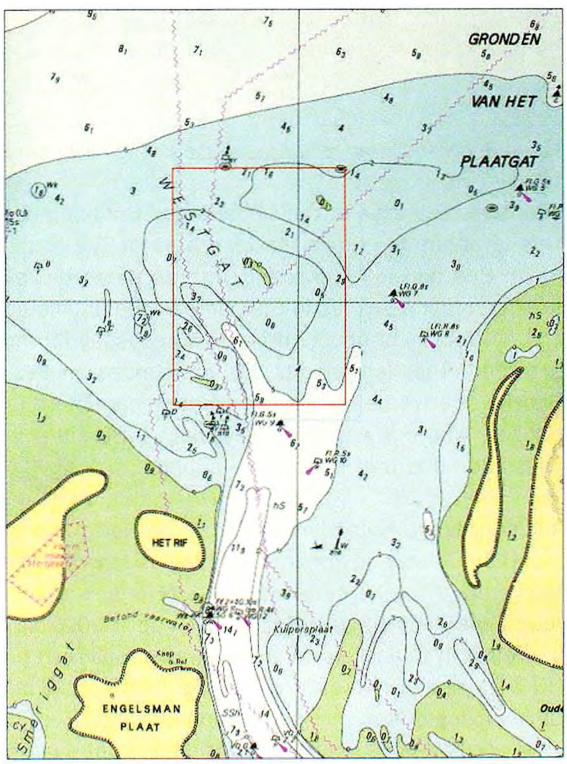

Figure 10: Location of low tide elevation of Figure 8 in April 2001

Also human intervention may change the baseline. An example, which may take place in the near future, is near the port of Rotterdam. One of the proposals for the expansion of the Rotterdam Harbour is land reclamation: a second Maasvlakte of 10 km² (see www.mainport-pmr.nl). This will automatically cause the baseline to shift. But as stated in UNCLOS (art. 5), the baseline only changes formally when it is realised and as well when its new location is depicted on an official nautical chart. Therefore, the non-finalised extension of the harbour of IJmuiden near Amsterdam was not taken into account during the negotiations about the boundary between the United Kingdom and The Netherlands, although it was drawn on the nautical chart with the text: work in progress.

Since there is an increasing need for up to date display of limits, the Netherlands Hydrographic Service decided to show several limits in the 'ordinary', frequently updated, medium scale nautical charts and therefore also in the electronic charts: ENC and ARCS. By means of a Notice to Mariners (NtM) changes in limits will be announced. Especially for ENC's and ARCS a change in a limit can immediately be effected to incorporate the new limit in the charts. Several limits based on the current baseline will appear on the paper nautical charts during the next two years. The fishery charts on which the limits were depicted by approximation were withdrawn since 1 January 2001. The information on the lattices of the Decca positioning system in these fishery charts was obsolete, (because the system had been phased out) and the charts were not updated frequently enough to show the most up to date limits.

Furthermore there is an initiative within the NSHC to establish a so-called BOMB (Base of Maritime Boundaries)-database in S-57 (IHO's official electronic chart exchange format). This is a database of maritime limits of countries surrounding the North Sea, which allows easy extraction of data by interested parties. The Danish Hydrographic Office was initiator and appointed as custodian of this database. The definition of the database has been finalised, but it has not yet been filled. It is an expansion of the initiative to make such a database for the Baltic Sea in the BSHC (Baltic Sea Hydrographic Commission).

Conclusion

Several factors affect the precision by which (equidistance) boundary lines can be computed. This contribution dealt with some of them, such as inhomogeneous geodetic datums, datum transformations, different definitions of chart datums and the precision of basepoints. All these factors should be taken into account when determining the precision of the computed turning points, which define the median line. This can be accomplished using the propagation law of covariances, which also takes into account the relative geometry between base- and turning points. In addition, reliability is an important measure, which, together with the precision, should be used to describe the quality of a point. The definition of the median line itself may be ambiguous since it is often not clear what type of 'straight' lines were used to connect the turning points. The authors support the IHO recommendation that these lines consist of geodesics, defined on the ellipsoid of revolution of the datum involved. While boundaries between states consist of defined co-ordinates, limits that are dependent on baselines vary, when new large-scale charts are published on which the baselines are changed. Traditionally national legislation often prefers defined co-ordinates for limits.

References

- ABLOS (1996): *Geodetic commentary to TALOS manual.* Appendix to Special Publication 51, International Hydrographic Bureau, Monaco
- Bakkelid, S., S, Rekkedal (1983): *Analysis of positioning in the North Sea.* Marine Geodesy, Vol. 6, No. 2, pp. 117-137
- de Bruijne A.J.T., R.H.N. Haagmans, E.J. de Min (1997): *A preliminary North Sea Geoid model GEONZ97.* MD-report MDGAP-9735, Survey Department, Ministry of Transportation, Public Works and Water Management
- van Buren, J., J. Ihde, B.G. Harsson, P. Davies, F. Madsen, M. Cory (1999): *Datum transformation between the reference systems ED50 and ETRS89 in the North Sea area.* Unpublished manuscript
- Charney, J.I., L.M. Alexander (1993): *International Maritime Boundaries.* Martinus Nijhoff Publishers, Dordrecht/Boston/London
- DMA (1991): *World Geodetic System 1984, its definition and relationship with local geodetic systems.* Defense Mapping Agency, TR8350.2, second edition, see also www.nima.mil

- van Gein, W.A., I. Gillissen (1993): *Area computation of polygons.* International Hydrographic Review, LXX:1, pp. 23-35
- Gillissen, I. (1993): *Area computation of a polygon on an ellipsoid.* Survey Review, vol. 32, no. 248, pp. 92-98
- Harsson, B.G. (1990): *The transformation between ED50 and WGS84 for exploration purposes in the North Sea.* Statens Kartverk, Hønefoss, Geodetic Publications, no. 1
- Horemuz, M. (1999): *Error calculations in maritime delimitation between states with opposite or adjacent coasts.* Marine Geodesy, vol. 22, pp. 1-17
- IHO (1993): *A manual on technical aspects of the United Nations convention on the Law of the Sea – 1982.* Special Publication No. 51, 3rd Edition, International Hydrographic Bureau, Monaco
- IHO (1994): *User's Handbook on Datum Transformations involving WGS84.* Special Publication No. 60, 1st Edition, International Hydrographic Bureau, Monaco
- IHO (1996): *Specifications for chart content and display aspects of ECDIS.* Special Publication No. 52, 5th Edition, International Hydrographic Bureau, Monaco
- LGR (1982): *The Delft approach for the design and computation of geodetic networks.* In: Forty years of thought, Delft Geodetic Computing Centre, Delft, pp. 202-274
- de Min, E.J. (1996) (in Dutch): *De geoïde voor Nederland.* Ph.D. dissertation, Netherlands Geodetic Commission, Publication No. 34
- de Min, E.J., R.H.N. Haagmans, G.W. van Willigen (1999): *North Sea (and Baltic Sea) region height reference system.* Project proposal, Survey Department, Ministry of Transportation, Public Works and Water Management
- Ordnance Survey (1981): *Report of an investigation into the use of Doppler satellite positioning to provide co-ordinates on the European Datum 1950 in the area of the North Sea.* Ordnance Survey of Great Britain, Southampton, professional paper new series no. 30
- Philip, D.R.C. (1988): *Satellite systems and U.K. offshore positioning.* The Hydrographic Journal, No. 48, pp. 5-14
- Rapp, R.H. (1994): *Vertical datums in land and marine positioning.* Proceedings INSMAP 94, Hannover, pp. 95-99
- Salzmann, M. (2000): *User-orientated Datum Redefinition.* GIM October 2000, pp. 12-15.
- Soler, T., R.E. Johnson, L.F. Thormahlen, R.H. Foote (2001): *Parting the Waters, Combining two GPS Techniques.* GPS World May 2001, pp. 28-33
- Strang van Hees, G. (1994): *Globale en lokale geodetische systemen.* Netherlands Geodetic Commissions, publ. no. 30, 2nd revised edition (in Dutch).
- Symmons, C. (1995): *Some problems relating to the definition of 'Insular formations' in international law: islands and low-tide elevations.* Maritime Briefing, International Boundaries Research Unit, University of Durham., Vol. 1, Number 5
- Vanicek, P., E.J. Krakiwsky (1982): *Geodesy: the concepts.* North Holland, Amsterdam

Biographies

Ina Elema is head of the Department of Geodesy and Tides of the Hydrographic Service of the Royal Netherlands Navy. Her main research interests are in the field of integrated navigation systems and geodetic aspects of maritime boundaries.

Kees de Jong is an assistant professor at the Department of Mathematical Geodesy and Positioning of Delft University of Technology in The Netherlands. Prior to joining Delft University in 1998, he worked for several private companies in The Netherlands and Japan as a software engineer in the field of precise GPS positioning, digital mobile telecommunications and car navigation. His current research interests are in real-time GPS positioning and quality control and marine geodesy.