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On the errors in the delimitation of maritime spaces

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Abstract

The Law of the Sea tacitly assumes that the boundaries delimiting maritime and other spaces on the earth surface are known exactly. This is clearly unwarranted: like any position on the surface of the earth, maritime boundaries have positional errors associated with them. Yet the assumption of boundaries being errorless is shared not only amongst the lawyers, but amongst the mariners as well. The usual attitude encountered in maritime practice is: yes, there may be some errors in the boundaries, but these are so small that they are practically irrelevant. In the case of trespassing, the only uncertainty ever taken into consideration is the uncertainty of the trespasser's position vis-a-vis the boundary in question.

In this contribution, we are going to discuss the errors in the boundaries from the technical point of view. We shall try to answer the following questions:
1) How large can the errors in maritime boundaries be and do they matter?
2) Where are these errors coming from?
3) What can be done to eliminate the gross errors and keep the systematic errors to a minimum?
4) What can be done with the random errors?

Introduction

Geodesy is a science interested, among other things, in the shape and size of the earth. The main tool used in the studies of the earth's shape and size are positions of points on the surface of the earth. Consequently, geodesy became the science of "positioning", the theoretical foundation for surveying, mapping, boundary delimitation, and a whole host of disciplines of a similar nature. After all, for example a boundary delimitation is nothing but positioning of points and lines on the surface of the earth. It is not surprising, therefore, to see geodesists taking a lively interest in the Law Of the Sea (LOS), or, more specifically, in the maritime boundary delimitation.

No law that deals with positions recognizes that there is no such a thing as a perfectly known position, yet: <u>no position of an object on the surface of the earth can be determined without errors creeping in</u>. The UNCLOS II is no different. Time and time again, the argument one encounters among lawyers and technical professionals involved with the LOS alike, is that even though these errors may exist, they are too small to make any difference as far as the LOS is concerned. But how small do the errors have to be not to make a difference? One centimetre? One metre? Hundred metres? A few kilometres? Hundred kilometres?

The only way of testing if the errors are really sufficiently small is through court cases, where technical evidence has to be presented. Looking at the past cases, one quickly realizes that the outlook changes from case to case: an error of a few hundreds metres, that may make no difference in a fishing dispute, would not be negligible in a dispute over mineral rights, where one metre difference may be worth millions of dollars. It is clearly of importance to the maritime country to know what is the magnitude of the errors, or uncertainties, associated with its maritime boundaries (any boundaries, for this matter). It is equally important for the skipper of a vessel in a position of a potentially trespass, to know the uncertainty associated with his positioning system.

Generally, the errors in maritime boundaries have three distinctly different origins. First, they originate in the measurements used directly or indirectly in the construction of the boundary; these errors would display both random and systematic behaviour and they cannot be eliminated. Second, they originate in a misunderstanding, or a misrepresentation of the definitions and the concepts used in the delimitation; these conceptual errors can be eliminated if all the parties have the requisite knowledge of the involved concepts. Third, they originate in transformations of coordinates (positions) between two or more coordinate systems in which land positions (used for the derivation of marine positions) are expressed.

In all our discussion here, we will assume that boundaries are defined numerically, by coordinates of the corner points and points on interconnecting lines, following the recommendations by the International Hydrographic Organization. If the boundaries are defined only graphically, as points and lines on a map, then the encountered errors become much more serious and less predictable.

Conceptual errors

Let us begin by addressing the sources of the conceptual errors first. When dealing with coordinates - note that we use the terms "positions" and "coordinates" interchangeably, as positions are invariably expressed in terms of coordinates - it is necessary to know what <u>coordinate system</u> are these coordinates referred to. Many different coordinate systems are used in determining and describing positions, some very similar to each other, others very different from each other. Two vastly different positions may be described by the same numerical values of their coordinates, and, conversely, one and the same position may be described by vastly different coordinate values in two different coordinate systems. It is thus of the utmost importance, when dealing with coordinates, explicitly to mention the coordinate system they refer to. This pertains particularly to horizontal coordinates such as the latitude and longitude. These horizontal coordinates are reckonned on various horizontal geodetic datums, called also geodetic reference ellipsoids. It also pertains to the northing and easting on a map, where, in addition to the horizontal datum, one has to define the map projection (i.e., the projection of the reference ellipsoid onto the map) used in producing the map. A failure to understand the appropriate coordinate system, datum or map projection may result in errors of many kilometres and more.

Another common conceptual error comes from a misinterpretation or a misunderstanding of what is meant by a straight line connecting two adjacent boundary points. The term "straight line" refers to the surface on which the (horizontal) positions are reckoned: the connecting line is a straight line (geodesic line) only on the stipulated surface. It may be either the geodesic line on the horizontal datum, or a straight line on the Mercator map (loxodrome, also known as the rhumb line), or a straight line on some other map. All these straight lines are, of course, different ifrom each other n the real world and thus the coordinates of points on these lines are different. The differences between the individual straight lines depend on the kind of stipulated surfaces, on the length and direction of the straight lines, and they may be quite sizable, perhaps in kilometres. It is clearly essential that all the interested parties have the proper understanding of what kind of straight lines are stipulated to form the boundary.

The third source of conceptual errors are boundary directions or headings. If a stretch of a maritime boundary is defined by its heading then it must be made clear just what exactly is meant by that heading. A curve in the real world, representing a specific straight line on a stipulated surface, would have different and generally continuously changing headings on other surfaces. The error committed by improper understanding of how the heading is defined may be fairly significant, particularly if the curve is long.

Transformation errors

Often, land-based points needed in defining the maritime boundary, are referred to two, or more datums, i.e., the coordinates of one set of points (typically in one country) are expressed in one coordinate system while another set (typically in another country) is expressed in a different coordinate system. In order to compute the coordinates of the maritime boundary from these land-based points, the land-based point coordinates must be given in a single coordinate system so that the configuration used for deriving the maritime boundary is on a single surface, a stipulated horizontal datum or a stipulated map. This problem is usually solved by transforming one set of land-based point coordinates into the coordinate system of the other set.

Transformation of coordinates from one coordinate system into another requires a knowledge of some transformation parameters. These parameters reflect the translation of the origin of one coordinate system with respect to the other, the misalignment of the two sets of coordinate axes, possible differences in the size and shape of the two horizontal datums. If one, or both sets of coordinates are map coordinates, then also the parameters which define the involved mapping or mappings, must be known. Consequently, the transformation equations may be quite complicated.

While some of the transformation parameters will be known exactly, (e.g., the parameters of the mapping(s)) the translation and the misalignment angles will have to be determined. This determination is not simple: it has to use some land-based points, whose coordinates are known in both coordinate systems. As these coordinates are burdened with errors (see the next section), these errors inevitably make their way into the transformation parameters and, through these transformation parameters, into the transformed coordinates. These transformation errors may reach tens and even hundreds of metres, depending on the way the transformation parameters are derived.

The real problem is that some agencies, that are in charge of determining the transformation parameters, do not publish, or even compute the transformation parameter error estimates. Hence, users of these parameters are lead to believe that the transformation parameters are perfectly known. An advice of a knowledgeable professional should be sought to avoid potentially large errors arising from this source.

Positional errors

The most common and the most videly accepted errors in positions originate from the positioning process itself. The land-based points, which are the basis of maritime boundary delimitation, have been positioned by means of either one of the terrestrial techniques, or by means of one of the available space technique. The terrestrial, i.e., the classical geodetic techniques, use the angular and distance measurements in a (national) geodetic network and its densification, which are then put together in a process called an "adjustment", to produce the statistically optimal estimates of coordinates of the individual points, under the assumption that the measurements contain only random errors. The modern, space techniques (e.g., the Transit, or the Global Positioning System, known as GPS) use measurements to satellites or to some celestial objects (e.g., the Very Long Baseline Interferometry, known as VLBI, which uses quasars) instead of terrestrial measurements. In either case, we shall be discussing here only the horizontal positions as only the horizontal positions find an application in marine boundary delimitation and definition.

None of these measurements, either terrestrial or spatial, is perfect. The measurements contain errors, both systematic and random, i.e., predictable and unpredictable. The adjustment process is hopefully designed in such a way, that it eliminates the systematic errors and produces estimates of the effect of random errors in the measurements on the estimated positions. Note that we speak about "estimated positions" as it is not possible to come up with perfect positions from imperfect measurements. If the adjustment process used for estimating the positions is not designed properly, i.e., if it does not eliminate the systematic errors in the estimated positions, we end up with also with systematic errors in the estimated positions and the whole situations becomes the worse for it.

Let's assume that the adjustment process used for estimating the coordinates of points in a national geodetic network has been designed properly and that the only errors in the estimated coordinates are those of a random nature. How do we know then, what errors do the positions have? Well, we do not! The random errors cannot be computed! The only thing we can do is to estimate the statistical uncertainty (confidence limits associated with a specific level of probability) in each coordinate. Better still, we can estimate the confidence limits, really a region, for each horizontal position given by a pair of horizontal coordinates. Each confidence region has an elliptical shape and as such is commonly referred to also as an "error ellipse".

The idea of an error ellipse (horizontal position confidence region) is that, with the stipulated probability, the "real position" lies somewhere within the ellipse. In geodesy, when we talk about a position, we really talk about its estimate AND its confidence region on a specific probability (confidence) level, such as the usually selected 95%. It makes all the difference in the world, whether the confidence region, on a reasonable confidence level, is small, medium, or large, and if large, how large. For example, a position with a 20,000 km radius of its 95% confidence circle can be anywhere on the surface of the earth. By comparison, a position with a 95% confidence circle of radius of 1 cm is extremely precisely known. If one knows nothing about the confidence region, one does not know if one is dealing with a position which is completely useless, reasonably well known, or very precise. This concept should be well understood by anyone wishing to use positions of points on the surface of the earth for applications such as maritime boundary determination.

How large can these confidence regions be in practice and are these positional uncertainties something to worry about in maritime boundary delimitation? This really depends on the land-based points one contemplates using in the exercise. If these points belong to the "first order national network", the confidence regions would be smaller than those for some derived detailed points along the coastline. It also depends on the adjustment process used for estimating the coordinates. It is not uncommon that the size of the 95% confidence regions is many metres, even tens of metres. Thus, if a hundred metre accuracy of the maritime boundary is all what is required, one can probably forget about the random error effect. The confidence regions for individual positions should be available from national agiencies responsible for establishing and maintaining national networks.

Conclusions

Maritime boundary delimitation is one of the applications of positioning, therefore, what we are dealing with, are positions on the surface of the earth. The common notion is that a position is such a simple thing to understand! But is it? As a matter of fact, a position, particularly a horizontal position given by a pair of horizontal coordinates, is anything but a simple notion. There is a whole range of concepts hidden behind this notion which should be well understood by anyone who tries to work with horizontal positions.

As we have seen in the above (grossly simplified and abbreviated) discussion, there are all kinds of pitfalls one should be aware of when dealing with horizontal positions. The idea enshrined in UNCLOS II, that positions are self-evident and perfect is ill-advised. It is the conviction of the author that countries that are engaged in delimiting their maritime territories should be advised to pay due attention to the geodetic aspects of maritime boundary delimitation. A failure to do so may be quite injurious to their national interests.

An earlier version of his paper was presented to the **Curso de Derecho del Mar**, organised by "Comision Permanente del Pacifico Sur" and "Academia Diplomatica del Peru", Lima, August 28, 1997 and will be published in the proceedings of the "course" in Spanish.