Determination of accurate sea border lines of countries

Shabnam FARBOUD, Iran

Key words: Hydrography, Marine surveying, Median line, Territial Sea

SUMMARY

Coastal countries are particularly susceptible to the impact of the multitude of activities out at their sea borders. The sea borders of coastal countries are at risk from deteriorating situation brought on by the intense economic activity and also threatened by international organized crime, terrorism, drug and human trafficking so the security of the every country is influenced by various domestic factors as well as developments in neighboring countries and elsewhere. According to the Article 3 of United Nations Convention on the Law of the Sea (UNCLOS), state's sovereign maritime area extends to the outer limit of its territorial sea, which is defined as being as a maximum of twelve nautical miles from the closest point on that State's territorial sea baseline.

Based on international law of the sea, the border line between two countries connected with a sea, is the "median line" unless there would be another protocol between them, which defines the sea border otherwise. "Median line" is defined based on baseline. Baseline is a line over the coast, which shows the lowest low water level. Computation of the baseline requires tidal observations and tidal analysis. Therefore, realization of the sea border needs knowledge of geodesy and hydrography. To our knowledge, no technical study based on marine geodesy over the sea borders of Iran has been conducted.

This paper starts with review of all existed protocols and agreements on sea borders of Iran. Next, all the coordinates of the borderlines are transferred into WGS84 in order to be GPS-usable. Eight possible ways for definition of the "Median line" are considered and for each of them the equation of the corresponding locus is determined. As a case study, the different methods for definition of the median line are used for computation of the sea border between Iran and Kuwait and the obtained "Median lines" are compared with each other. The least computed total area of Iran including the territorial sea is 1,880,377 Km2, which significantly differs from commonly mistaken calculated number of 1,638,420km2 in which the territorial sea area was excluded.

SUMMARY

مرز آبی چه از لحاظ اهمیت آب و منابع آبی و چه از نظر منابع حیات آبزیان و ذخائر تحت الارضی همواره ارزشمند بوده است و بعضاً منشأ اختلاف بین کشورهای همسایه گردیده است.مرزهای آبی توسط قوانین بین المللی حقوق دریاها و توافقنامه ها یا پیمانهای مرزی بین دول همسایه تعریف می گردند.پیاده سازی و علامت گذاری این مرزها نیازمند تعیین مختصات نقاط مرز بر مبنای تعاریف مربوطه است که از توانایی های ژئودزی محسوب می شود.سه نقش مهم ژئودزی دریایی (هیدروگرافی) عبارتند از:

1- تعیین خط مبدأ ساحلی از طریق آنالیز جزر و مدی (با اندازه گیری تغییرات سطح آب دریا و آنالیز هارمونیک سری زمانی این تغییرات)

2- تعیین خط میانه (از طریق تفکیک های تعیین موقعیت و اطلاعات هندسه مسطحه و هندسه تحلیلی)
3- پیاده سازی مرز دریایی (با استفاده از تکنیک و روشهای مختلف تعیین موقعیت در دریا).

در این مقاله ، ابتدا کلیه توافقنامه مرزهای آبی کشور جمع آوری و سپس کلیه مختصات موجود به سیستم WGS84 منتقل شده تا امکان پیاده سازی آنها از طریق GPS ایجاد شود.

اگر دو کشور با مرزهای دریایی مجاور و یا مقابل باشند مرز دریایی بین دو کشور با ساحل مقابل یا مجاور با خط میانه تعریف می شود. علامتگذاری فیزیکی مرز دریایی معمولاً امکان پذیر نمی باشد بدین لحاظ به صورت محاسباتی و روی نقشه انجام می گیرد.

در ادامه مقاله با استفاده از 8 روش یافتن مرز آبی دو کشور با ساحل مقابل در حالتهای مختلف ، تعریف خط مبدأ ساحلی در دو ساحل مقابل ارائه و نحوه محاسبه نقاط شکستگی خط میانه در این روشها ارائه گردیده است.

در این مقاله ، همچنین مساحت ایران با احتساب دریای سرزمینی که با توجه به قوانین بین المللی جزو منطقه حاکمیت کشور محسوب می شود ، محاسبه شده است که این رقم با توجه به بالا بودن مجموع مرزهای آبی ایران در مقایسه با آنچه تا کنون منتشر شده است تغییر چشمگیری دارد.

به عنوان مطالعه موردی این روش برای تعیین مرز ابی بین ایران و کویت بکار رفته و نتایج حاصل از روشهای مختلف با یکدیگر مقایسه گردیده است.

Determination of accurate sea border lines of countries

Shabnam FARBOUD, Iran

1. Introduction

Coastal countries are particularly susceptible to the impact of multitude of activities out at their sea borders. The sea borders of coastal countries are at risk from deteriorating situation brought on by the intense economic activity and also threatened by international organized crime, terrorism, drug and human trafficking so the security of every country in influenced by various domestic factors as well as developments in neighboring countries and elsewhere. Marking borders requires knowing coordinates of points by using geodesy's abilities.
Marine geodesy's important roles are:
A: determination of sea baseline by tidal analysis (by measurement the changes of sea level and harmonic analysis chronological series of these changes).
B: determination of median line by techniques of position and information of plane and analytical geometry.
C: marking sea borders by methods of position on the sea.
This paper starts with some review of all existed protocols and agreements on the borders of Iran. Next, all the coordinates of the borderlines are transferred into WGS84 in order to be GPS usable. The borderlines contain boundary rivers, southern borders (Oman sea and Persian Gulf) and northern borders (Caspian sea). Importance of this subject is because of sea borders of Iran are about 3000 km, 2045km of it belongs to Oman sea and Persian Gulf, 855km to Caspian sea and other to boundary rivers such as Aras, Atrak, Hirmand, Harirood and Qaraasu.
Sea border in Caspian Sea starts from Astara River to Atrak river mouth in Hoseinqoli Gulf. Before division of Soviet Republics using was joint ownership but after division and violation of protocol, no new protocol has replaced yet.
Southern Sea border starts from Qoatr to Hormoz isthmus on Oman Sea, 785kms long and to Arvandrood, 1260kms long.
According to United Nations convention on the law of the sea (UNCLOS), state's sovereign maritime area extends to the outer limit of its territorial sea, which is defined as being as a maximum of twelve nautical miles from the closest point on the state's territorial sea baseline.
In southern of Iran, Marine law and territorial sea between countries is definite by protocols and agreements excepting some gaps between Kuwait.
Territorial sea is usually computed by ebb line (lowest mark of sea in coast). Determination of territorial sea has 2 types:
A: in straight coast without incision, territorial sea is determined by a parallel of ebb line with a width of territorial sea.
B: in coast with incision or when it was located along a big rock or an isle, determination of territorial sea will be more difficult; especially if some events don't appear in flow time. Then, some points on the baseline are selected and parallels of lines between them with a width of territorial sea show territorial sea.
Sea borders of two adjacent or opposite countries are determined by median line.

2. Methodology

2.1 Sea base line

Sea baseline is the base of determination of territorial sea, monopolistic economic zone and continental shelf. Then it is very important. Determination of sea baseline is basis on low water and in form of point, linear and mixture. Determination of sea baseline in each type needs information of tide and spectral analysis

2.1.1 Tidal analysis

Observation of tide and processing of finding available harmonic analysis is the base of datum chart and marine maps. Analysis of tide is for entering in the datum chart. Tide causes by forces of gravity of sun, moon and other planets. It's appeared in different phase and range depends on the shape and location of littoral regions. Sun, moon, orbits of their apparent movement and angle of earth rotation. On the whole, relative position of sun, moon and earth cause different frequencies of tide observation. More of tide ranges are belong to some frequencies e.g. Z_0, O_1, K_1, S_2, M_2. Range and phase of the frequencies are usually computed from analysis of tide gauges.
Accuracy of tidal analysis and charts and other numbers which are computed from the analysis are function of some different factors such as accuracy of observation, period of observation, method of analysis and modeling and atmospheric condition.
Observations are done by automatic tide gauge. Analysis and prediction also require data modeling because analysis of tide needs knowledge frequency of tide.

2.1.1.1 Tide in half a day

It happens because of gravities of moon and rotation of earth around axe and contains two ebbs and two flows in each day.

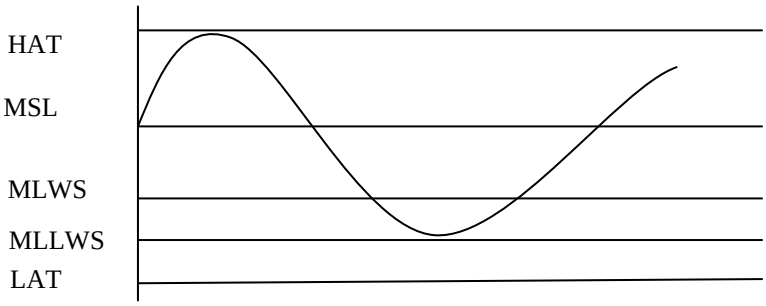
2.1.1.2 Tide in a day

Frequency of this type of tide is because of gravities of moon and contains one ebb and one flow in each day.

2.1.1.3 Monthly tide and half a month

This type of tide is because of gravities of moon and sun. Impressive forces of the frequencies have 4 types: Spring tide, Neap tide, Perigeon Spring tide, Apogeon Neap tide. Low water is more important than high water because it is the basis of determination sea baseline.
Datum chart of low water has some qualifications:
A: minimum elevation of low water never comes under it.
B: not be every low that shows unnecessary dips.
C: match with base surface of neighborhood.
Datum chart of low sea level is computed by this formula:

$CD=a_0-1.1(A_{m2}+A_{s2}+A_{k2}+A_{o1})$
1.1 is for increase in accuracy



MSL Mean Sea Level
HAT High Astronomy Tides
LAT Low Astronomy Tides
MHWN Mean High Water Neap
MLWN Mean Low Water Neap
MLWS Mean Low Water Spring
MHWS Mean High Water Spring

* There isn't any unique rule for datum chart. Indian spring low water for Persian Gulf is used in Iran.

2.1.2 Topex poseidan

Traditional way for determination of baseline is analysis tide gauges. In this paper data of Topex Poseidan are used instead of tide gauge. The main duties of Topex Poseidan are:
A: measuring surface of sea contained: dynamic of ocean, mean sea level, changes of movement of sea and tide
B: update data for users
C: creation long-term observation for oceanic circulation and changes
This satellite data is free for users.
In Oman Sea and Persian Gulf, there are 24 coastal point of this satellite. 7 of them are in Iran and others are in other countries. After 10 years each point would have chronological series of sea level and factors of tide are computed by Minimum Square of spectral analysis. Numbers of points are insufficient and determination of sea baseline is difficult by them. But with these points can determine middle line.
Satellite observations are two types: form of point and continuous and we use just form of point. A chronological series of sea level is produced by these 24 points closer to Persian Gulf and Oman Sea. It takes 9.915 day from two observations of one point. After 10years 368 data will be collected but all of them aren't good qualities. Topex Poseidan satellite records 122 other parameters then after 10 years product a 318*122 matrix. With chronological series of

sea level in 24 points, factors of tide can be computed by Minimum Square of spectral analysis to find low water in coastal zone. Observation equation after omitting linear trend is:

$Y(t) = a_1 \cos \omega_1 t + a_2 \cos 2\omega_2 t + \ldots$

$+ b_1 \sin \omega_1 t + b_2 \sin 2\omega_2 t + \ldots$

ω_i is known because tide frequencies are known. a_i and b_i are computable by observation of chronological changes in sea level by using Minimum Square. Minimum Square of spectral analysis is better than Fourier analysis because in spectral analysis, entry of observation at same intervals isn't necessary and it has freedom degree then it's possible to find and omit less quality observation.

$\omega = 2\pi/T$

In this paper 6parameters of tide are considered for determination of range and phase. Selecting just 6parameters of tide is high accuracy of observation of the satellite, shortness of range of other parameters and decrease accuracy of observation in the coast. Formula for 6 parameters of spectral analysis is:

$Y(t) = a_0 + a_1 \cos \omega_1 t + a_2 \cos \omega_2 t + \ldots + a_6 \cos \omega_6 t$

$+ b_1 \sin \omega_1 t + b_2 \sin \omega_2 t + \ldots + b_6 \sin \omega_6 t$

According to unknown coefficient parameters matrix in Minimum Square is:

$$\begin{pmatrix} Y(t_1) \\ Y(t_2) \\ . \\ . \\ . \\ . \\ . \\ . \\ . \\ Y(t_{25}) \end{pmatrix} = \begin{pmatrix} 1 & \cos \omega_1 t & \cos \omega_2 t & \ldots\ldots & \cos \omega_6 t & \sin \omega_1 t & \sin \omega_2 t & \ldots.. & \sin \omega_6 t \\ 1 & \cos \omega_1 t & \cos \omega_2 t & \ldots\ldots & \cos \omega_6 t & \sin \omega_1 t & \sin \omega_2 t & \ldots.. & \sin \omega_6 t \\ . & & & & & & & & \\ . & & & & & & & & \\ . & & & & & & & & \\ . & & & & & & & & \\ . & & & & & & & & \\ . & & & & & & & & \\ . & & & & & & & & \\ 1 & \cos \omega_1 t & \cos \omega_2 t & \ldots\ldots & \cos \omega_6 t & \sin \omega_1 t & \sin \omega_2 t & \ldots.. & \sin \omega_6 t \end{pmatrix} \begin{pmatrix} a_0 \\ a_1 \\ a_2 \\ . \\ . \\ a_6 \\ b_1 \\ . \\ . \\ b_6 \end{pmatrix}$$

Important point in chronological series for spectral analysis by Topex Poseidan is using period of the satellite (9.915 day); if you omit 9 days, the result is 2 days.

$T_1 = S_2 = 12" = 0.5\text{rad}$

$T_2 = M_2 = 12.420601" = 0.517525\text{rad}$

$T_3 = O1 = 25.819342" = 1.0758059\text{rad}$

$T_4 = K1 = 23.934470" = 0.997269\text{rad}$

$T_5 = MF = 327.85898" = 13.660790\text{rad}$

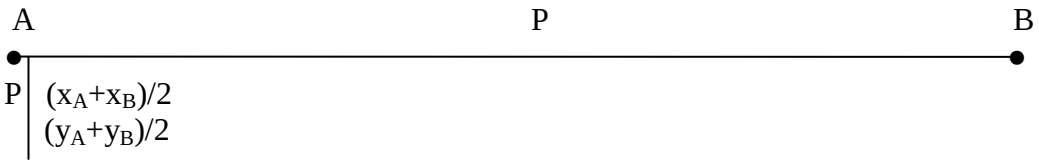
$T_6 = M_m = 661.30927" = 27.554552\text{rad}$

2.2 median line

Sea border between two countries is determined by median line. The base of determination of median line is sea baseline. According to UNCLOS, each point in median line should be in same distance from sea baseline of both countries. Sea baseline is basis on form of point, linear and mixture and 8conditions may be happened.

A: computation median point by two points in sea baseline in two opposite coasts.

In this situation the middle point of the line between the points is aim.



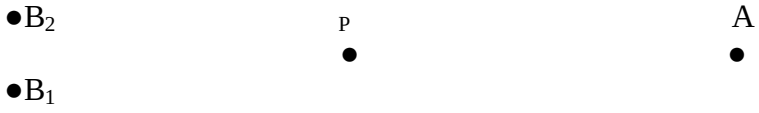
Accuracy of coordinate depends on accuracy of two points and not to their coordinates.

$\sigma^2_{xp}=(\sigma^2_{xA}+\sigma^2_{xB})/2$

$\sigma^2_{yp}=(\sigma^2_{yA}+\sigma^2_{yB})/2$

B: computation median point by 3 points on two opposite coasts.

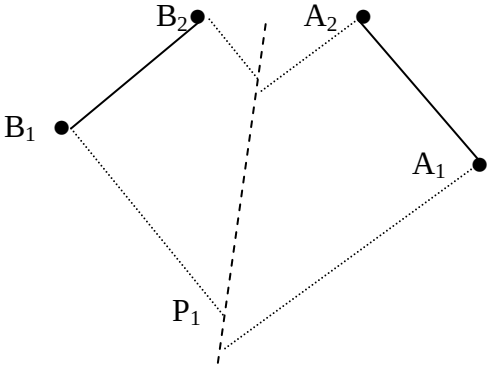
In this situation the middle point is intersection of vertical lines on the middle lines of the triangle.



$$P\left|\begin{array}{l}\frac{1}{2}\frac{[(x_A^2+y_A^2)(y_{B2}-y_{B1})+(x_{B2}^2+y_{B2}^2)(y_{B1}-y_A)+(x_{B1}^2+y_{B1}^2)(y_A-y_{B2})]}{y_A(x_{B1}-x_{B2})+y_{B2}(x_A-x_{B1})+y_{B1}(x_{B2}-x_A)}\\ \frac{1}{2}\frac{[(x_A^2+y_A^2)(x_{B2}-x_{B1})+(x_{B2}^2+y_{B2}^2)(x_{B1}-x_A)+(x_{B1}^2+y_{B1}^2)(x_A-x_{B2})]}{y_A(x_{B1}-x_{B2})+y_{B2}(x_A-x_{B1})+y_{B1}(x_{B2}-x_A)}\end{array}\right.$$

C: computation median point by using two lines on two opposite coasts.

In this situation at first draw bisector of angle between two lines, next draw perpendicular line from each point. Intersections of these four perpendiculars and the bisector are median points.



$$\frac{|a_1x+b_1y+c_1|}{\sqrt{a_1^2+b_1^2}} = \frac{|a_2x+b_2y+c_2|}{\sqrt{a_2^2+b_2^2}}$$

$$\begin{cases} a_1=y_{B2}-y_{B1} \\ b_1=x_{B1}-x_{B2} \\ c_1=y_{B1}x_{B2}-x_{B1}y_{B2} \\ a_2=y_{A2}-y_{A1} \\ b_2=x_{A1}-x_{A2} \\ c_2=y_{A1}x_{A2}-x_{A1}y_{A2} \end{cases}$$

$Ax+By+C=0$ bisector

$A=a_1\sqrt{(a_2^2+b_2^2)}-a_2\sqrt{(a_1^2+b_1^2)}$

$B=b_1\sqrt{(a_2^2+b_2^2)}-b_2\sqrt{(a_1^2+b_1^2)}$

$C=c_1\sqrt{(a_2^2+b_2^2)}-c_2\sqrt{(a_1^2+b_1^2)}$

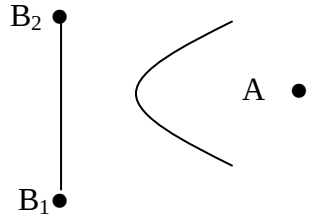
$x(x_{B2}-x_{B1})-y(y_{B2}-y_{B1})-x_{B1}(x_{B2}-x_{B1})-y_{B1}(y_{B2}-y_{B1})=0$ perpendicular line in B1

$$P1\left|\begin{array}{l} Cb-Bc_{B1} \\ \hline -Ab+Ba \\ Ca-Ac_{B1} \\ \hline -Ab+Ba \end{array}\right.$$

$$\begin{cases} a= x_{B2}-x_{B1} \\ b= y_{B2}-y_{B1} \\ c_{B1}=x_{B1}(x_{B2}-x_{B1})-y_{B1}(y_{B2}-y_{B1}) \end{cases}$$

D: computation median point by using a sea baseline in one country and one point in other country

In this situation locus is a parabola which focus point is known point and directrix is sea baseline. Equation of parabola is:

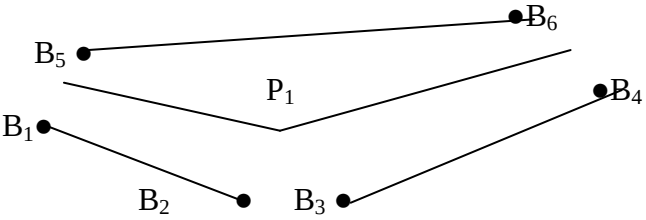


$(y-y_A)2=4a(x-x_A)$

a is distance from focus.

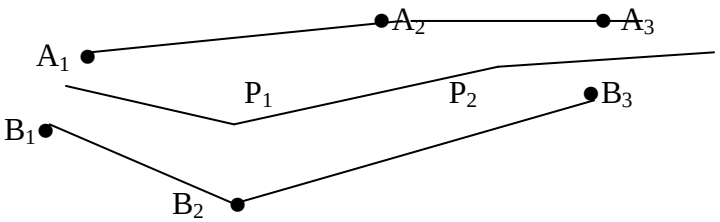
E: computation median point by using two sea baselines in one country and one sea baseline in other country

This situation is similar to C but in this situation draw bisectors of angles of each sea baselines of one country with sea baseline of other country. Intersection of two bisectors is aim.



F: computation the breakage of median line by using two sea baselines in each country

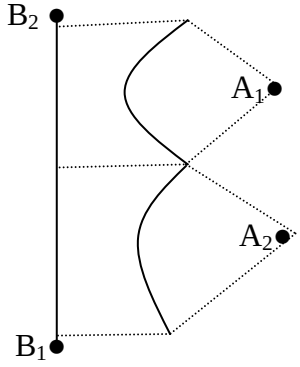
This method is basis on intersection of bisectors of four sea baselines. Breakages of median line are Intersections of bisectors.



$$P_1 \left| \begin{array}{l} \dfrac{B_1C_2\text{-}C_1B_2}{A_1B_2\text{-}A_2B_1} \\ \dfrac{C_1A_2\text{-}A_1C_2}{A_1B_2\text{-}A_2B_1} \end{array} \right. \qquad P_2 \left| \begin{array}{l} \dfrac{B_2C_3\text{-}C_2B_3}{A_2B_3\text{-}A_3B_2} \\ \dfrac{C_2A_3\text{-}A_2C_3}{A_2B_3\text{-}A_3B_2} \end{array} \right.$$

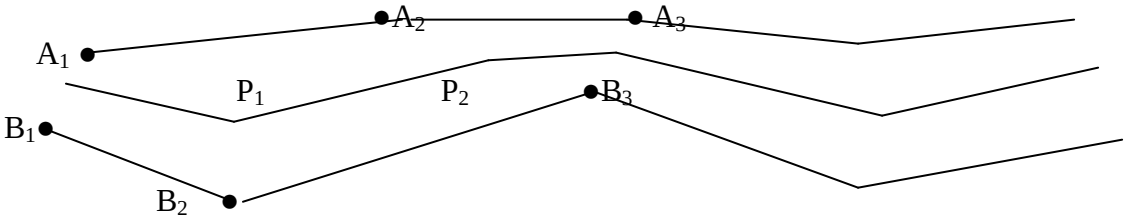
G: computation median point by using a sea baseline in one country and two points on the opposite country

This situation is similar to D. median points are intersections of parabola. Points are focuses of parabolas and sea baselines are directrix.



H: computation median line by using some sea baselines on each country

This situation is similar to F. median line is formed bisectors of sea baselines two by two.



3. conclusion

By transferation all existing coordinates into WGS84 and using Topex Poseidan data's, sea baseline is cleared by tidal analysis and determining sea baseline on Oman Sea and Persian Gulf.

Eight possible ways for definition of the median line and its breakage are considered and and for each of them the equation of the corresponding locus is determined. As a case study, the different methods for definition of the median line are used for computation of the sea border between Iran and Kuwait and the obtained "Median lines" are compared with each other. The

least computed total area of Iran including the territorial sea is 1,880,377 Km2, which significantly differs from commonly mistaken calculated number of 1,638,420km2 in which the territorial sea area was excluded.

REFERENCES

Cosquer G. and Hangout J.F. (2003) Determination of land and maritime boundaries: Geodetic and Geometric bases. FIG Working Week 2003. Paris, France

U.S. Department of the Interior Mineral Management Service Mapping and Boundary Beach (1999) three dimensional equidistant line computational techniques. OCS Report MMS 99-0045.

Fraser R., Collier P. and Leahy F. (2006) Positioning maritime boundaries with certainly a rigorous approach. Department of Geomatics. Victoria University, Australia. Report no. 3010.

Shalowitz A.L. and Reed M.W. (2006) shore and Boundaries. NOAA coastal Service center 2006.

Horenuz M., Sjoberg L.E. and Fan H (1999) The precision of the median line turning points for various reference surface and computing Algorithm. Proceeding of the international conference on Technical Aspects of Maritime Boundary Delimitation (including UNCLOS Article 76 issues). International Hydrographic Bureau, Monaco, pp. 120-132

Leahy F.J., Murphy B.A., Collier P.A. and Mitchell D.J. (2001) Uncertainty issues in the geodetic delimitation of maritime boundaries. Proceeding of the international conference on accuracies and issues in Maritime Boundaries and other limits. International Hydrographic Bureau, Monaco.

Murphy B.A., Collier P.A., Mitchell D.J. and Hirst W. (1999) Maritime zone boundary generation from straight baseline defined as geodesics. Proceeding of the international conference on Technical Aspects of Maritime Boundary Delimitation (including UNCLOS Article 76 issues). International Hydrographic Bureau, Monaco, pp. 133-141

Sjoberg L.E. (1996) Error propagation in maritime delimitation. Proceeding of the second international conference on geodetic aspects of the Low of the Sea (GALOS). International Hydrographic Bureau, Bali. pp. 153-168

United Nations (1997) United Nations Convention on the Low of the Sea. Publication no. E97.V10. United Nations. New York

BIOGRAPHICAL NOTES

CONTACTS

Shabnam FARBOUD
Institution Municipality of Tehran
Address Kamal ol molk sq. tehransar av.
Tehran
IRAN
Tel. +982188875294
Email:shabnamfarboud@yahoo.com