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An Application of the crossover adjustment technique for processing of altimetry data in the East Sea

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Abstract

This paper presents an application of crossover adjustment technique for processing of altimetry data. The relative rough sea surface height above the reference ellipsoid can be determined from altimetry data. The calculated height value contains geoid height, the mean value and temporal variation of dynamic sea surface topography. In order to remove the temporal change of dynamic topography from altimetry data the crossover adjustment technique was applied through the following steps: (1) determination of crossover locations, and modeling the temporal change of dynamic sea surface topography with bias and tilt parameters; (2) crossover adjustment for determining the parameters of model. The approach was experimentally tested on ENVISAT satellite altimetry data on the East Sea of Vietnam. The experimental results show the capability of crossover adjustment technique for removing the temporal variation effect of dynamic sea surface topography from altimetry data.

1. Introduction

Satellite altimetry is a new technology of satellite geodesy, which is used widely and effectively in the world, in areas such as: determining geoid at ocean area, determining ocean gravity anomalies, study ocean geophysical. mapping and ice monitoring… High measuring satellites which fly above sea surface, generated radar signals to sea surface. These signals reflect back to satellite. By measuring the two-way time of signal propagation, we can determine distance from satellite to sea surface. Locations of satellites on their orbits are determined by Global Positioning System (GPS) or other methods, such as: Doppler Orbitography and Radiopositoning Integrated By Satellites (DORIS), Satellite Laser Ranging (SLR).

Meaning: could determine satellite height (H) above reference ellipsoid (Figure 1). Sea surface height (SSH) was determined by the formula (Rosmorduc V. 2009):

$$SSH = H - h + h_{corr} \tag{1}$$

In particular, h_{corr} were corrections.

Sea surface height was determined through geoidal height (N) and dynamic sea surface topography, with formula (Figure 1)

$$SSH = N + h_d \tag{2}$$

Dynamic sea surface topography was divided into 2 parts: Mean Dynamic Topography h_{MDT} and the time-variable dynamic sea surface topography h_t (Нгуен Ван Шанг 2012). Then sea surface height are represented by the formula:

$$SSH = N + h_{MDT} + h_t \qquad (3)$$

From formula (3):

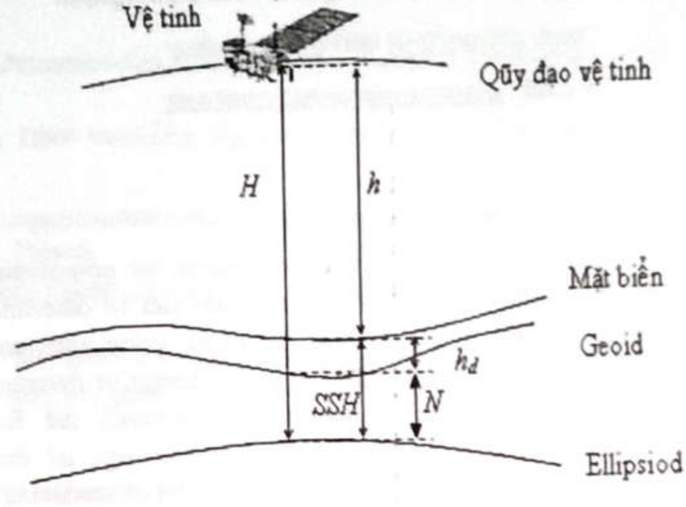

Figure 1. Satellite altimetry principle.

If mean dynamic topography is known then we could determine geoidal height at the ocean area. This is an issue which the geodesy specialists are interested. Conversely, if heights of ocean geoid are known, then mean dynamic topography could be determined. This is an issue which the oceanographer are interested.

The problem in the both of two exercises: need to remove time varying sea surface topography h_t. This problem will be resolved by crossover adjustment technology.

2. The distribution of satellite altimetry data on the East Sea of Vietnam

Lines joining altimetry measurement points on the sea are called "tracks" or "arcs"(Figure 2a). Tracks are divided into descending tracks and ascending tracks, which depend on directions of satellites. The locations where descending and ascending tracks intersect each other are called the single satellite crossover location (Figure 2b).

Figure 2a. Satellite altimetry locations.

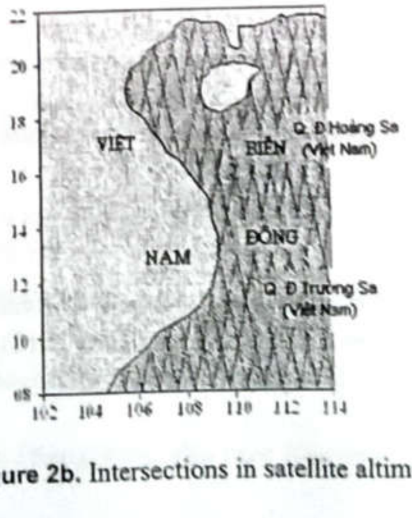

Figure 2b. Intersections in satellite altimetry.

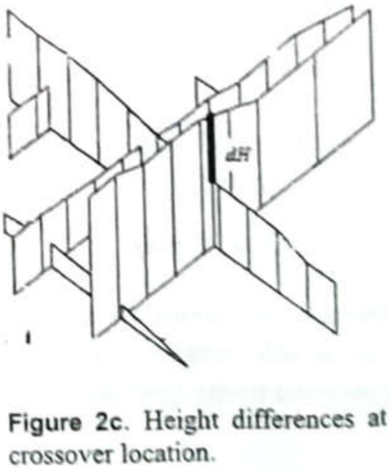

Figure 2c. Height differences at crossover location.

Because there are time-variable sea surface topography at the crossover locations, height differences between descending and ascending tracks are dH (Figure 2c) (Gunter Seeber 2003). Crossover adjustment were based on these quantity dH to determine time-variable sea surface topography. Crossover locations usually disparity with measuring locations. So the first step in crossover adjustment, we need to determine crossover locations and height differences at crossover location between ascending and descending tracks.

3. Determining crossover locations and height difference at crossover locations

3.1. Simulations of ascending and descending tracks by the second polynomial

Guest on ascending (or descending) tracks, there are n points, which coordinates were (φ_i, λ_i, $i = 1, 2, \ldots n$). These tracks should be described by the 2^{th} polynomial: $\lambda_i = a\varphi_i^2 + b\varphi_i + c$

(4)

In (4) a,b,c are unknown parameters, need to be determined.

On this situation, determination of these parameters need to know at least 3 points (or 3 locations), in which coordinates were known. If the numbers of these locations > 3 then parameters should be determined by the least square principle. Corrective function was:

$$v_i = a\varphi_i^2 + b\varphi_i + c - \lambda_i \tag{5}$$

In matrix form:

$$V = AX + L \tag{6}$$

Where:

$$A = \begin{bmatrix} \varphi_1^2 & \varphi_1 & 1 \\ \varphi_2^2 & \varphi_2 & 1 \\ \ldots & \ldots & \ldots \\ \varphi_n^2 & \varphi_n & 1 \end{bmatrix}; X = \begin{bmatrix} a \\ b \\ c \end{bmatrix}; V = \begin{bmatrix} v_1 \\ v_2 \\ \ldots \\ v_n \end{bmatrix}; L = -\begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \ldots \\ \lambda_n \end{bmatrix}$$

Parameters a,b,c are found base on least square principle with condition that every points's coordinates have the same level of precision. System of normal equation has been written with following form:

$$(A^T A)X + (A^T L) = 0 \tag{7}$$

Parameters a,b,c have been determined by formula:

$$X = -(A^T A)^{-1}(A^T L) \tag{8}$$

Precision of these parameters has been assessed

$$\begin{cases} m_a = m_0\sqrt{Q_{11}} \\ m_b = m_0\sqrt{Q_{22}} \\ m_c = m_0\sqrt{Q_{33}} \end{cases} \tag{9}$$

Where m_0 was determined by formula

$$m_0 = \pm\sqrt{\frac{[vv]}{n-3}} \tag{10}$$

Q_{11}, Q_{22}, Q_{33} were 3 parts of variance-covariance matrix

$$Q' = \begin{bmatrix} Q_{11} & Q_{12} & Q_{13} \\ Q_{21} & Q_{22} & Q_{23} \\ Q_{31} & Q_{32} & Q_{33} \end{bmatrix} \tag{11}$$

Change determined parameters to formula (4) can be found the second polynomial, in which ascending and descending tracks were described.

3.2. Determination of crossover locations

If ascending tracks have been described by polynomial $\lambda = a_t\varphi^2 + b_t\varphi + c_t$ and descending tracks have been described by polynomial $\lambda = a_g\varphi^2 + b_g\varphi + c_g$ then crossover locations should be results of function system

$$\begin{cases} \lambda = a_t\varphi^2 + b_t\varphi + c_t \\ \lambda = a_g\varphi^2 + b_g\varphi + c_g \end{cases} \tag{12}$$

2 roots will be solved by the system of equations (12), corresponding to 2 crossover point locations. These crossover locations were stood on 2 parts of parabola graph of the second polynomial, which ascending and descending tracks were described. Sensible crossover locations should be points which stay on ascending and descending tracks. Compare these 2 points with beginning point and ending point of ascending (or descending) should be found needed crossover locations.

Foundly crossover locations still have not been exact locations. These are also approximate locations. After foundation of approximate locations, compare these coordinates with coordinate of points on ascending and descending tracks, should be found 4 points next to crossover location. There are i, i+1, j and j+1 (Figure 3). From these 4 points should be determined exact crossover locations (c) and height difference at crossover location dH (Нгуен Ван Шанг 2012).

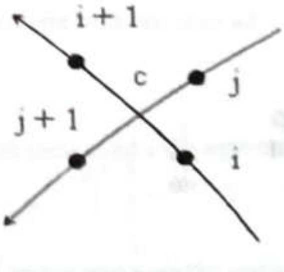

Figure 3. Exact crossover

4. Crossover adjustment

With ocean area as East Sea (the length tracks < 2000 km), time-variable dynamic sea surface topography h_t can be modelled by bias term and tilt terms. Therefore, height difference at crossover locations of ascending tracks i and descending tracks j should be described by formula:

$$dH_{ij} = (a_i + b_i.\mu_j) - (a_j + b_j.\mu_i) + v_{ij} \quad (13)$$

When:

a_i, a_j - bias parameters

b_i, b_j - tilt parameters

μ_i, μ_j - the coordinates along the i-th and the j-th track of the crossover points of the j-th and i-th track respectively. In this case relative longitude are used as coordinates.

Equation was written in matrix

$$L = A.x + V, \quad (14)$$

Where:

x – matrix containing the unknown parameters a and b

V – correction matrix

L - number matrix, containing dH

Could write this function system in formula

$$V = A.x - L. \quad (15)$$

This is missing function system. To do this exercise can be used 2 fixed arc method. However, arcs in satellite altimetry haven't got the same precision, so choose which arcs to be fixed arcs are too hard. Equation (15) was carried out least squares principe $V^T PV = \min$ with minimum standard condition $x^T P_x x = \min$. Then the best result was determined:

$$x = (A^T PA + P_x)^{-1} A^T PL \quad (16)$$

5. Interpret data and experimental results

We practised with satellite altimetry data ENVISAT on East Sea at 91-th period. There are 4162 measuring points that are divided to 45 tracks and 92 crossover locations in this period. Data were provided by AVISO (AVISO 2010). On the table 1 there are results of determination parameters of the second polynomial, which describe arcs in satellite altimetry.

Table 1. Parameters of the 2nd polynomial, describing satellite altimetry arcs

No	Arcs	*a* (deg)	*b* (deg)	*c* (deg)	No	Arcs	*a* (deg)	*b* (deg)	*c* (deg)
1	91021	-0.0002	-0.2195	108.6388	24	91507	-0.0010	-0.2008	117.1403
2	91036	0.0004	0.2157	100.0428	25	91522	0.0008	0.2077	108.7107
3	91049	-0.0009	-0.2054	116.4620	26	91565	-0.0006	-0.2123	107.8906
4	91064	0.0008	0.2081	107.9888	27	91580	0.0005	0.2149	99.3297
5	91107	-0.0023	-0.1849	107.0552	28	91593	-0.0008	-0.2084	115.7695
…	…	…	…	…	…	…	…	…	…
19	91408	0.0008	0.2087	102.2367	42	91937	-0.0006	-0.2124	110.0457
20	91421	-0.0007	-0.2128	118.7145	43	91952	0.0006	0.2117	101.5002
21	91436	0.0006	0.2117	110.1236	44	91965	-0.0011	-0.1959	117.8120
22	91479	-0.0004	-0.2161	109.3438	45	91980	0.0007	0.2094	109.4192
23	91494	0.0004	0.2163	100.7591					

The table 2 presents results determination of approximate and exact crossover locations and difference between them. Difference between approximate and exact coordinates has been determined by following formula:

$$\begin{cases} \delta\varphi = \varphi^{GD} - \varphi^{CX} \\ \delta\lambda = \lambda^{GD} - \lambda^{CX} \\ \delta S = \sqrt{\delta\varphi^2 + \delta\lambda^2} \end{cases} \tag{17}$$

Where:

Φ^{ap}, λ^{ap} – approximate coordinates

Φ^{ex}, λ^{ex} – exact coordinates

Table 2. Results of determination crossover locations and height difference at crossover locations.

No	Crossover locations	Approximate coordinates		Exact coordinates		Coordinate differences			*dH* (m)
		φ (deg)	λ (deg)	φ (deg)	λ (deg)	δφ (deg)	δλ (deg)	δS (deg)	
1	91021 - 91236	8.09144	106.84865	8.09414	106.84809	-0.00270	0.00056	0.00276	0.119
2	91036 - 91279	9.70398	102.17744	9.70380	102.17770	0.00018	-0.00026	0.00032	0.205
3	91036 - 91737	11.30524	102.53765	11.30543	102.53781	-0.00019	-0.00016	0.00025	0.109
4	91036 - 91823	8.09901	101.81866	8.09959	101.81866	-0.00058	0.00000	0.00058	-0.069

5	91049 - 91064	19.06309	112.23706	19.06596	112.23697	-0.00287	0.00009	0.00287	-0.004
…	…	…	…	…	…	…	…	…	…
26	91135 - 91608	17.53977	111.15968	17.54347	111.15948	-0.00370	0.00020	0.00371	-0.151
27	91135 - 91694	20.57089	110.44143	20.56104	110.44116	0.00985	0.00027	**0.00985**	-0.130
28	91135 - 91894	9.70115	112.95576	9.69996	112.95579	0.00119	-0.00003	0.00119	0.039
…	…	…	…	…	…	…	…	…	…
90	91851 - 91866	19.06841	107.20849	19.06965	107.20860	-0.00124	-0.00011	0.00124	-0.152
91	91937 - 91952	19.06862	105.77164	19.06955	105.77092	-0.00093	0.00072	0.00118	0.055
92	91965 - 91980	19.06938	113.67527	19.06918	113.67557	0.00020	-0.00030	0.00036	-0.029

From results on the 1^{st}table, coordinate difference between approximate locations and exact locations was very small. The maximum difference was 0.00985 degree (intersection of tracks 91135 and 916994), equivalent to 1.08 km. Distance between measuring points on the same one track of satellite ENVISAT was 7.5 km then precision of approximate location totally satisfy a require to find exactly 4 points next to crossover location.

Crossover locations were described by program AutoCad with measuring locations and realize that crossover locations totally coincide with crossover graphics. These results prove that determinations of crossover locations by this method total exactly.

On table 3 there are parameters describing time-variable dynamic sea surface topography .

Table 3. Bias and tilt parameters

Arcs	*a* (m)	*b* (m/deg)	Arcs	*a* (m)	*b* (m/deg)	Arcs	*a* (m)	*b* (m/deg)
21	-0.14	0.00	36	0.17	0.26	49	-0.14	0.04
107	-0.01	0.00	122	0.03	-0.10	135	0.04	0.07
193	-0.01	0.05	221	-0.02	0.06	236	-0.20	0.10
307	0.05	-0.06	322	0.01	-0.01	350	0.07	0.00
…	…	…	…	…	…	…	…	…
64	-0.08	-0.07	436	-0.02	-0.02	823	0.11	0.00
150	-0.11	0.06	522	0.01	0.01	909	0.08	0.00
279	-0.07	-0.14	608	-0.05	0.04	980	0.00	0.12

After determining bias parameters and tilt parameters, change these parameters into formula $h_t = a + b.\mu$ (18) to determine time-variable dynamic sea surface topography for each measuring point. Correct these quantity into formula (3), receive sea surface height not containing time-variable dynamic sea surface topography.

Check for effect of crossover adjustment, we re-determine height differences at crossover locations. Computing results have been seen that after crossover adjustment, height differences at crossover locations were small. Prove that time-variable dynamic sea surface topography has been deleted.

6. Conclusions

We can totally applicate the crossover adjustment technology for processing of altimetry data in the East Sea. Determination method of crossover location by describing the second polynomial has been shown in this paper allowed determine exactly crossover locations in satellite altimetry. After crossover adjustment, time varying dynamic sea surface topography has been deleted.

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