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The Study of time variation process of MSL by satellite altimetry

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Abstract. In the paper the exact mean sea level of observations TOPEX-/Poseidon satellite Instantaneous sea level height between 1992 and 2003 have been determined. It is assumed that the sea level height, in addition to tidal changes and polar motion, expose increasing the risk of permanent polar ice melting phenomena and moving tectonic plates. to implementation property of repetition time observations of sea level height and time series observations collected in the satellite motion is used Gulf of Oman and the Persian Gulf. In here the observations with a linear series of periodic tidal changes and changes in polar motion is uniformly formulated. Computing was used by least squares method to remove the tidal effects can result.

Keywords: Instantaneous sea level, Topex-/Poseidon satellite, polar motion, tidal changes, time series

1. INTRODUCTION

The base level height in various countries traditionally been determined using spectral analysis tide gauge observations that is not high precision. due to the need to determine the level of high precision in the regional and global levels, especially in the Persian Gulf and Gulf of Oman, which is of great importance and given the important role of the tide phenomenon that the main cause of instantaneous changes of sea level, and for all offshore projects such as construction operations (Construction of docks, oil rigs,....) In coastal and offshore waters, Maritime Offshore constructions and hydrographic, studying ocean currents, study of sedimentation mode in sea bed, aware on the tidal changes is essential. According this, there have been many attempts to model this phenomenon. but it is not possible in the waters offshore. to determine changes in sea level the best method is satellite altimetry. Altimetry is a technique for measuring height. Satellite altimetry measures the time taken by a radar pulse to travel from the satellite antenna to the surface and back to the satellite receiver. Combined with precise satellite location data, altimetry measurements yield sea-surface heights. The positioning systems, such as systems using DORIS, GPS and SLR models on the other hand, due to the gravity field, precise, precision orbit determination of satellite altimetry is greatly improved. In this article, we decided to Topex-Poseidon satellite altimetry data to calculate the MSL.

2. A REVIEW OF PAST RESEARCH:

In recent years a lot of research on the use of satellite altimetry to modeling Sea levels changes in the Persian Gulf and Oman are presented as follows:

1. To modeling topography sea level in Persian Gulf and Oman sea by satellite altimetry is paid[5]

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2. To determine the topography of water level in Gulf and Oman through the integrate GPS data and tide gauge observations is paid[4]

3. To analyze the spectral point analysis Topex- Poseidon altimetry satellite observations in order to modeling MSL is paid[11]

4. To integrate various altimetry data for accurate modeling of sea level topography in the Persian Gulf and Oman Sea, 2012[7]

5. Sabzevari to integrate of altimetry satellite and Tide gauge for determine maps co-amplitude of both phases of the tidal Persian Gulf region and Oman sea is paid,the effect of tides earth crust calculated to compare the difference between altimetry and tide gauge coastal is used.[9]

6. To investigate hydrodynamic models and repair its accuracy in Persian Gulf and Oman sea by applying oceanographic data and measurements of local tidal. [3]

2.1. Introduction a different method to perform

Satellite Altimetry observations is as a point. And Series of observations data analysis, results again in the formula relevance to Fourier method and linear regression insert and new time series that usually is different to our time series observation obtain that is the distinctive feature of this study with other studies. [8]

2.2. Altimetry data analysis

In the first phase data in raw format readable by ground stations can be received. In the second phase, information such as timing delay, accurate Global Positioning System satellite and with device correction e is received. Finally, with sending to special processing center that precise orbit satellites are calculated there, Data for more processing and elimination of errors in file format GDR disposal to users. The data prepared by BRAT software information output the software in figure 2 is shown. Figure 1 shows the satellite ground tracks in the Persian Gulf and Gulf of Oman.

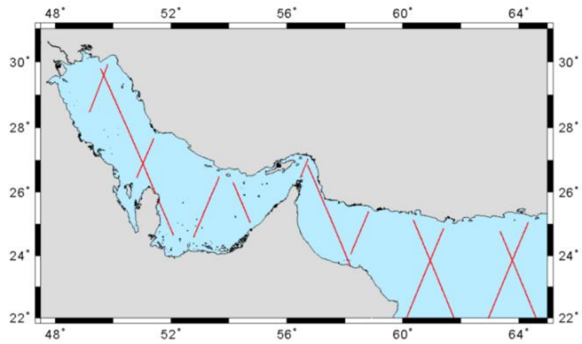

Figure 1. Topex-Poseidon satellite track.

2.3. Modeling instantaneous sea level heights

Observations as a time series according to the following format:

$$\{h(t_1), h(t_2), \ldots, h(t_n)\}$$

The time series can be formed at the track of the satellite sea level. The time series analysis using spectral analysis methods, can be modeled tides in the satellite's track [2]. In this project the first, data files using the software BRAT and apply the necessary corrections is provided. and its output as a data in each cycle was obtained in the form of a matrix. This information includes the number of the day, time with a resolution of milliseconds, microseconds figures, the off-nadir point Latitude, off-nadir point longitude, Satellite distance from the sea level, and cycle numbers, and its passes which finally, for the study area with latitude and longitude filtering the matrix was formed, using of matrices and set up a time series for each point. It should be noted that each series at one point to coordinate will be formed. This point, in fact the geometric center points of successive satellite passes that in a search circle with a radius of 3 km is located. after the formation of the final time series that consists only of points on the international seas, the time series to should be analyzed. The time series average of 250 observation of instantaneous water level at a time rate of about 10 days [1].

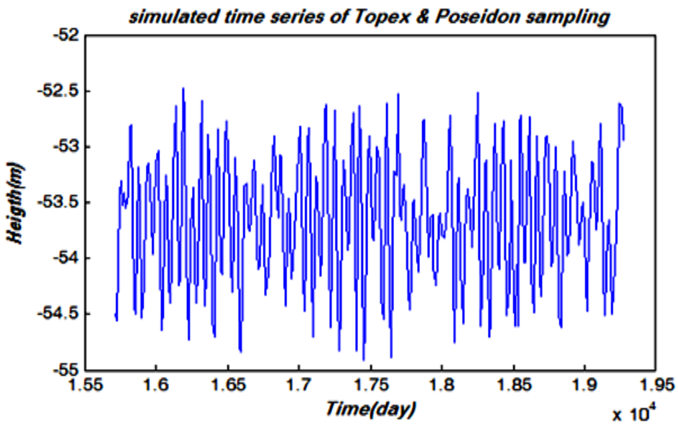

Figure 2. Simulated time series of satellite Topex -Poseidon the period 9156/9 repeated daily for 10 years in the (28.83, 50.04) point.

2.4. Tide modeling

Since, in the oceans movement of waters are mainly linear, the modeling of the sea level changes with the number of components daily, half-daily and long periods very accurate can be done. In shallow waters, especially in the Gulfs, the waters fully nonlinear behavior have followed and the tides behavior is complex. In the case study of area, Persian Gulf and Oman Sea due to coastline shape and the presence Strait of Hormuz tidal frequencies to international waters are different. Therefore it could not use the global tide models, and required to achieve high precision modeling of sea level, the tides is studied. In this paper, to modeling of sea level [6]. least square regression analysis and Fourier spectral analysis methods is used.

2.5. Fourier spectral analysis

Fourier spectral analysis to breakdown a complex harmonic function which is used to execute simple harmonic, suppose that the time series

$$\{h(t_i)\}_{i=1,2,..,n}$$

Observations of sea level height at certain points. Appropriate tide model as follow:

$$h(t) = a_0 + b_0 t + \sum_{k=1}^{m} A_k \sin(2\pi f_k t + \phi_k)$$

Where A_k amplitude, f_k frequency, f_k is relevant phase and m is the frequencies number in the model. In a time signal with the data co-interval set of discrete of fi frequencies by below relation is obtained.

$$f_i = \frac{j}{\Delta t_{total}} = \frac{j}{t_n - t_1} \quad ; \; j = 1,2,\ldots,\left(\frac{N-1}{2}\right)$$

t_i = the first observation, tn= the last observation

$$f_N = \frac{N}{\Delta t_{total}}$$ Nyquist frequency

Assuming that in accordance with the following table function:

$$\{h(t_i)\}_{i=1,2,\ldots,n}$$

In the period T and intervals ΔT is given. Then the table 1 is a example of time serial $f(t_i)$ in period T.

Table 1. An example of a time series in T period.

i	0	1	2	3	.	.	.	.	n
t_i	0	ΔT	$2\Delta T$	$3\Delta T$	.	.	.	.	$n\Delta T = T$
f_i	f_0	f_1	f_2	f_3	.	.	.	.	f_n

In here we can assume that the given function of n simple periodic components with known periodic from the biggest period T to the smallest period, the table 2 indicates ΔT the above matters [7].

Table 2. The access frequency in the time series $f(t_i)$

i	0	1	2	3	.	.	.	.	n
t_i	0	ΔT	$2\Delta T$	$3\Delta T$	.	.	.	.	$n\Delta T = T$
f_i	f_0	f_1	f_2	f_3	.	.	.	.	f_n

In Table 2, T is the length of the time series and as well as the biggest access period into the time series, Thus, the n frequency of the phenomenon, n range is obtained. Table 3 shows the number of tidal component of an altimetry cell [7].

Table 3. The number of tidal component of an altimetry cell.

i	0	1	2	3	.	.	.	405
p_i	0	405	405/2	405/3	.	.	.	1
ω_i	0	$2\pi/405$	$4\pi/405$	$6\pi/405$	.	.	.	2π

$$h(t)\big|_{(\lambda,\varphi)} = a_0 + b_0 t + \sum_{i=1}^{k} a_i \cos(\omega_i t) + b_i \sin(\omega_i t)$$

In view of the above equation and with a frequency with Prorated least squares to below form the amplitude of each frequency is calculated.

$$\begin{bmatrix} 1 & t_1 & \cos(\omega_1 t_1) & \sin(\omega_1 t_1) & \dots & \dots & \cos(\omega_k t_1) & \sin(\omega_k t_1) \\ 1 & t_2 & \cos(\omega_1 t_2) & \sin(\omega_1 t_2) & \dots & \dots & \cos(\omega_k t_2) & \sin(\omega_k t_2) \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 1 & t_n & \cos(\omega_1 t_n) & \sin(\omega_1 t_n) & \dots & \dots & \cos(\omega_k t_n) & \sin(\omega_k t_n) \end{bmatrix}_{n\times 2(k+1)} \times \begin{bmatrix} a_0 \\ b_0 \\ a_1 \\ b_1 \\ \vdots \\ \vdots \\ a_k \\ b_k \end{bmatrix}_{2(k+1)\times 1} = \begin{bmatrix} h(t_1) \\ h(t_2) \\ \vdots \\ \vdots \\ \vdots \\ \vdots \\ h(t_{n-1}) \\ h(t_n) \end{bmatrix}_{n\times 1}$$

$$AX = L \quad \Rightarrow \quad \hat{X} = (A^T A)^{-1} A^T L$$

In the above equation is the value. Given the range of frequencies can be detected much more effective in the signal.

2.6. Least-squares regression analysis

As previously mentioned, the signal changes in sea level can be written as follows:

$$SSH(\varphi,\lambda,t_i) = MSL(\varphi,\lambda) + C\Delta t + \sum_{j=1}^{k} A_j sin(2\pi f_j t_i) + \sum_{j=1}^{k} B_j cos(2\pi f_j t_i)$$

Where the instantaneous water level, MSL and C, is linear changes in sea level

The above model as a observation equation in t time and in point to position(φ,λ) in sea surface, if for all observations in times written, the observation equation device as below [3]:

$$\begin{bmatrix} SSH(t_1) \\ SSH(t_2) \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ SSH(t_{n-1}) \\ SSH(t_n) \end{bmatrix} = \begin{bmatrix} 1 & \Delta t_1 & \cos(2\pi f_1 t_1) & \sin(2\pi f_1 t_1) & \cdot & \cdot & \cos(2\pi f_k t_1) & \sin(2\pi f_k t_1) \\ 1 & \Delta t_2 & \cos(2\pi f_1 t_2) & \sin(2\pi f_1 t_2) & \cdot & \cdot & \cos(2\pi f_k t_2) & \sin(2\pi f_k t_2) \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ 1 & \Delta t_n & \cos(2\pi f_1 t_n) & \sin(2\pi f_1 t_n) & \cdot & \cdot & \cos(2\pi f_k t_n) & \sin(2\pi f_k t_n) \end{bmatrix} \times \begin{bmatrix} MSL \\ C \\ a_1 \\ b_1 \\ \cdot \\ \cdot \\ a_k \\ b_k \end{bmatrix}$$

Where L Vector of instantaneous water level observations, A Structure Matrix Equations, X Unknown vector containing MSL and a,b amplitudes.

$$l = Ax$$

To this we considered, four elements daily four elements half-daily, the four components long period of half- monthly, monthly, half yearly and yearly tidal which over 95% tidal signal is involved. and analysis of time-series Altimetry observations and as a point in the Persian Gulf and Oman Sea with the original frequency tides have done. To find the coefficients of the model amplitude and phase unknown is extracted. Figure 3 the quality of fit the resulting mode on observations is shown [3].

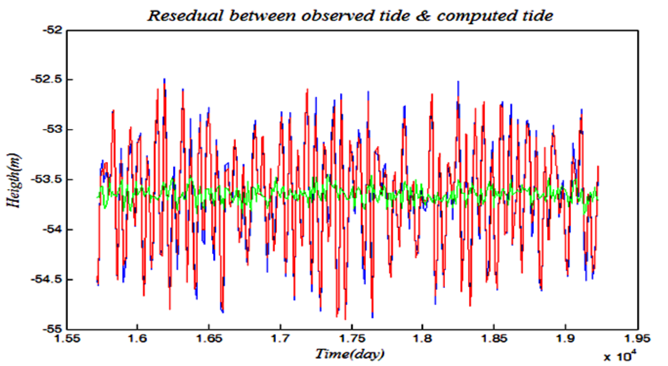

Figure 3. Signal tidal observations (blue) and calculated (red) differences between them (green) in the Topexs satellite in point (28.83, 50.04)

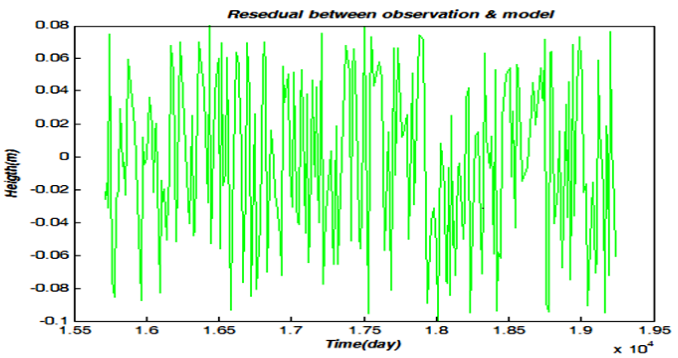

Figure 4. The difference between the observed tidal signal and the time series of satellite Topexs in point (28.83, 50.04)

2.7. Test results obtained from a least-squares method Results

The above estimate is assumed that the instantaneous level observations with the same precision and the same weight. Variance estimate unit weight or Variance observations obtained from the following formula:

$$\hat{\sigma}_0^2 = \frac{\hat{r}^T \hat{r}}{n - 2k - 2}$$

Where $\hat{r}$ the residual vector of observations is prorated. Variance unit weight However, the fitting model 3.14, show instantaneous level observations The model can be estimated from test variance against the initial observations of the moment, if known, won. Passive matrix equation (4-24) is an estimated.

$$C_{\hat{x}} = \hat{\sigma}_0^2 (A^T A)^{-1}$$

So for an efficient estimate should be true chi-square test is correct The test results indicate that the range accuracy and completeness of the mathematical model. If the value $\hat{\sigma}_0^2$ is not place in the should be to increase and decrease the tidal frequency and control value $\hat{\sigma}_0^2$ the best fit to observations will done. and the current frequencies we find. to determine the height of sea level in observations point than to the reference ellipsoid the first systematic errors satellite distance the sea level by altimetry measurements is corrected. In order to prepare the observations and modeling in this study the 20 main data including. Date and time number, to resolution of milliseconds and figures microsecond time, the latitude of Nadir point, the longitude of Nadir point, the altitude satellites of level elliptical, the distance of satellites from sea level, the RMS value, the distance of satellite from sea level, the correction changes the center of gravity of the antenna altimeter, dry troposphere correction, reverse pressure correction, wet troposphere correction, electromagnetic bias correction, the MSL, geoid altitude, elastic sea tide, polar tide, deep sea and the kind of land pointer from view of water or ice /soil from binary files is extracted. with corrections applied to the data, corrected distance of each point is calculated. Finally, the matrices contains the desired cycle intended for satellite missions, including latitude and longitude, and height of sea level then we form a time series. to create a time series at each point we should note that successive passes in satellite altimetry is not exactly on the same previous points, thus we must consider the extent to accept the assumption that the tide situation this points to reason of the closeness is same. Given that the minimum distance between two consecutive surveys at sea level is about 6 km radius of the search for acceptance as the tide with the same 3 km would be considered. in continue we applied the require corrections to the satellite distance to Nadir point, and data as configured that the current information in the same passes relate to different cycles save in the matrix. From the matrix we use and time series each point is performed. It is necessary each time series in a point reach to coordinate and indeed this point the geometry successive passes satellite that place in a circle. The linear serial of tidal periodic changes, polar motion and uniform changes is formulated. The calculations as a least squares method is used to remove the effects of tidal, due to range 11 years of data, in tide model, all known components in tide potential such as O1, K1, S2, M2, and monthly periods, 14 nights, half- year, annual, 8.5 years, 18.6 years to 12 frequencies known is considered. MSL than to reference ellipsoid WGS84 and for 1992,1997, 2000,2007 is considered

3. RESULTS

1. Consideration and attention to the Aliasing phenomenon and using an alias frequencies instead of the actual frequency of tides can be a solution for the problem of minimizing in the sampling analysis altimetry

2. The average difference of four main components in the analysis of the Persian Gulf and Oman Sea are respectively, 25 mm for m2 component, 40 mm for s2 component, 23 mm for k1 component and 7 mm for O1 component.

3. In Fourier analysis the linear changes term in sea level is not detectable, while in linear regression analysis the term is simply is accessible.

4. SUGGESTIONS

In this paper, the modeling of variation MSL process via satellite (in the field of space and time) (SSH), (MSL), the major component of the tidal amplitude and phase in the Persian Gulf and Oman Sea using satellite altimetry data and satellite altimetry observations as a point and observation serial analysis Altimetry data and the results of them again in relevance formula as a Fourier method and linear regression and the new time series to our observations are obtained is different that is the new work.

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