Estimation of the Sea State Bias effect on the altimetric measurements using a parametric model

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Abstract : The sea state bias (*SSB*) which affect the altimetric measurements on the sea surface is estimated using empirical parametric model (*BM*4), calibrated by the analysis of the altimeter data. This model is a simple linear function that links the *SSB* with the significant wave height (*SWH*), the wind speed (*U*) and the backscatter coefficient (σ_0).
The knowledge of the backscatter coefficient determined by altimetric signal processing allows to determine the significant wave height and the wind speed.
The use of Topex / Poseidon and Jason-1 altimetric data to calculate the sea state bias with the *BM*4 model and the comparison of the results obtained with the *SSB* value transmitted in the message of each satellite allowed us the validation of the methodological approach developed.
The proximity of the results obtained with Topex / Poseidon data is sufficient for the most altimetric applications as the determination of the mean sea level which was calculated on the western Mediterranean Sea during a period of 72 cycles.
Concerning Jason-1, the difference of the results in the determination of the *SSB* can be explained by the nature of the instruments on board and also the type of model used.

Keywords : Estimation, Parametric model, Empirical, Sea State Bias, Topex / Poseidon, Jason-1.

1. Introduction

The principle of satellite altimetry is based on the theory of the interaction of an incidental electromagnetic wave with an uncertain rough surface, in order to determine the physical process and model it by analytic expressions permitting to estimate the different parameters characterizing the surface.
The major mechanism of scattering of an incidental electromagnetic wave is the resonance of **BRAGG**; an important exception which altimetry, is based is the hopeless impact where the dominant phenomenon is the specular reflection. The mean strength distributed per unit of surface is proportional to the mean number of specular points. The quantity really measured by the altimeter is the backscatter coefficient which is defined as being the ratio of the distributed strength to the incidental strength, per unit of surface.

2. Sea State Bias

The aim of the satellite altimetry is to provide the height of the sea surface with regard to a referential. This height changes on scales of centimetres essentially owing to the waves, a part of the radar wave is sent back by crests of waves and the remainder will be sent back by wave hollows. Besides, the instrument is adjusted so that it can make the mean of these two measures automatically to determine the mean sea surface height by a symmetrical algorithm of the height probability density. The obtained result is biased, this bias called sea state bias, is necessary to understand the phenomenon of sea state bias, based on the study of the physical principle of altimetric measure that use the theory of radio scattering by the surface of the sea [2].

2.1 Radio Scatter Theory

2.1.1. Scattering Cross Section

Near the vertical diffusion, the received energy is provided by the reflexion of the wave facets towards the captor. The ratio (incident energy / received energy) is expressed by the Scattering Cross Section. Let a radar illuminating an ocean surface Fig. 1.

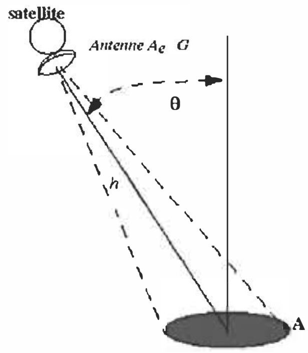

Fig. 1 Geometry of a radar illuminating an A surface according to the incidence angle θ at the distance h .

The scattering cross section of the surface A is defined as 4Π times the ratio of the radiant intensity I_S and the incidental strength ϕ_i on the surface, as [12] :

$$\sigma = 4\pi * \left(\frac{I_S}{\phi_i}\right) A \cos\theta \qquad (1)$$

Where :

A : The illuminated surface.
θ : The incidence angle.
The relation between the strength transmitted by the radar P_T and the strength received P is given by the equation [3] :

$$P = \frac{P_T G}{4\pi h^2} * \frac{\sigma}{4\pi} * \frac{A_e}{h^2} \qquad (2)$$

Where :

G : The gain of the antenna ;
A_e : The efficient surface of the antenna ;
h : The distance.

- The first term of the Eq.2 represents the intensity of the incidental wave along of the distance satellite-level of the sea.
- The second term is the intensity produced in the direction of the radar by the diffusion of infinitesimal target of cross sectional surface σ.
- The last term represents the solid angle of the efficient surface A_e of the antenna.

If targets are distributed on a surface A, the scatter is described by the scattering cross section per unit surface σ_0 defined by [12] :

$$\sigma = \int_A \sigma_0 dA \qquad (3)$$

Where :

σ_0 : backscatter coefficient defined per unit of surface.
So a Lambert surface has a cross section varying with the cosine of the impact angle.
The problem of the scattering intensity becomes a calculating σ_0 from the scattering surface known.

2.1.2. Specular Points Theory

Mathematically, the approach to calculate σ_0 based on facets, is called approximation of the tangent plan. Two general methods to solve the problem can be used [12].
If the solution is found from Maxwell equations, we talk about a physical optics approach.
If we consider waves like a set of rays and then we calculate the diffusion of these rays, we talk about geometric optics.

In the setting of the physical optics, a facet is approached by an elliptic paraboloïd of curvature radius r_1 in the plan (X,Z) and r_2 in the plan (Y,Z). We calculate the diffusion of every paraboloïd and then, we add these diffusions on the illuminated surface using the probability of slopes distribution of the surface.

For a radar oriented in the direction (OX) we get [3]:

$$\sigma_0 = |\rho(0)|^2 \sec^4(\theta) * P(\tan\theta, 0) \qquad (4)$$

Where :

$\rho(0)$: The Fresnel coefficient with zero incidence, it is equal to 0.785 for a frequency of 13 GHz ;
$P(\tan\theta, 0)$: The joint probability of the ζ_x slopes in the X direction and ζ_y in the Y direction, as :

$$\zeta_x = {d\zeta}/{dx} \quad \text{and} \quad \zeta_y = {d\zeta}/{dy}$$

With a good approximation, the slope distribution can be considered as Gaussian and isotropic in the direction of winds. We get then [3] :

$$\sigma_0(\theta) = \frac{\rho(0)^2}{2S^2} \sec^4(\theta) \exp\left(\frac{-\tan^2\theta}{2S^2}\right) \qquad (5)$$

S is the mean quadratic slope of the surface where [12] :

$$S^2 = \overline{\zeta}^2 \qquad (6)$$

3. *SSB* Processing

It exists several models which permit to calculate the *SSB*, we find the physical models based on using the electromagnetic theory and others as an empiric models, calibrated from an analysis of the altimeter data. Actually, the models currently used are the empiric models, which suppose that the *SSB* can be assigned as a parametric form [6] :

$$SSB = f(X, \Psi) \qquad (7)$$

Where :

f: Priori indicated function ;
X : Relative parameters of the state of the sea ;
Ψ : Vector of parameters.
Generally, the function f is formed of simple polynomial, and the components of X are always chosen among the some relative parameters to the sea state that can be measured directly by the altimeter, notably the significant wave height *(SWH)*, the wind speed *(U)*, and the backscatter coefficient (σ_0).

A process of adjustment by the least square method is used to estimate the vector Ψ, while minimizing the measures deviation of the sea surface height (*SSH*) on the crossover points [6].

3.1 Parametric Model *BM4*

The parametric models for the determination of the *SSB* are chosen as a simple linear hierarchy that links the *SSB* with the significant wave height *SWH* and the wind speed *U* [5].
Currently the best model for the determination of the sea state bias for Topex / Poseidon is the four parameters model *BM4*.
Given by [7] :

$$SSB = SWH\left(a_1 + a_2 U + a_3 U^2 + a_4 SWH\right) \qquad (8)$$

Table 1. The estimated parameters for the determination of the *SSB*.

Altimeter	a_1	a_2	a_3	a_4
Topex	-0.0203	-0.00369	0.000149	0.00265
Poseidon-1	-0.0539	-0.00225	0.000097	0.00183

3.2 Significant Wave Height

The waves emitted by the satellite are propagated spherically and intersect the surface of the sea, which is a flat surface, as the reflection of these waves are not being instantaneous, the altimeter will receive an extended echo. The delay due to the height of waves justifies the form of the echo received by the altimeter.
The significant wave height is calculated by [11] :

$$SWH = 2C\sigma_S \qquad (9)$$

With :

$$\sigma_S = \sqrt{\sigma_C^2 - \sigma_P^2} \qquad (10)$$

Where :

C : The celerity.
σ_C : The delay caused by the stain in sea expressed in seconds ;
σ_P : The length of the echo expressed in seconds.
$\sigma_P = 0.513\, r_t$ is a sufficient approximation for σ_P [9].
r_t is the temporal resolution, as the time interval between two samples of the wave form shape of *B* length ; it is equal to $1/B$ [1].

For Poseidon-2 altimeter (B = **320** *MHz*), the value of r_t is 3.125 ns.

3.3 Wind Speed

The only process which permits to determine the wind speed is the signal analysis received at the satellite, based on the physical characterization of the energy of the wave. Indeed, when the wind at the sea level surface, is stronger, the reflexive signal will be more dispersed, what indicates that its energy will be weaker.

The best adapted model is the operational model proposed for altimeters of the Topex / Poseidon satellite ; this model is gotten by least squares polynomial adjustment of order 5 ; given by [7].

$$U = c_0 = c_1\sigma'_0 + c_2\sigma'_0 + c_3\sigma'_0 + c_4\sigma'_0 \qquad (11)$$

Where :

σ'_0 is the backscatter coefficient, is equal to σ_0 for the Geosat and ERS-1 altimeter.

For the Topex / Poseidon altimeter [7] :
$\sigma'_0 = \sigma_0 - 0.63$ dBs.

Table 2. Polynomial coefficients for the determination of the wind speed.

σ'_0 limits	c_0	c_1	c_2	c_3	c_4
$\sigma'_0 < 10.8$	51.045307042	-10.982804379	1.895708416	-0.174827728	0.005438225
$10.8 \le \sigma'_0 \le 19.6$	317.474299469	-73.507895088	6.411978035	-0.248668296	0.003607894
$\sigma'_0 > 19.6$	0.0	0.0	0.0	0.0	0.0

4. Processing and analysis

4.1 Data Processing

To validate our software, we used the 085 pass number of the cycles (393,394,395) for Topex / Poseidon and the 085 pass number of the cycles (052,053,054) for Jason.

These data are provided on CD by Aviso (CNES) : « *Jason-1 and TOPEX/POSEIDON GDR products* » (June 5th - July 3rd, 2003).
The processing of the 085 pass number of the 395 cycle number for Topex / Poseidon satellite and the 085 pass number of the 054 cycle number for Jason-1 gives us the following results :

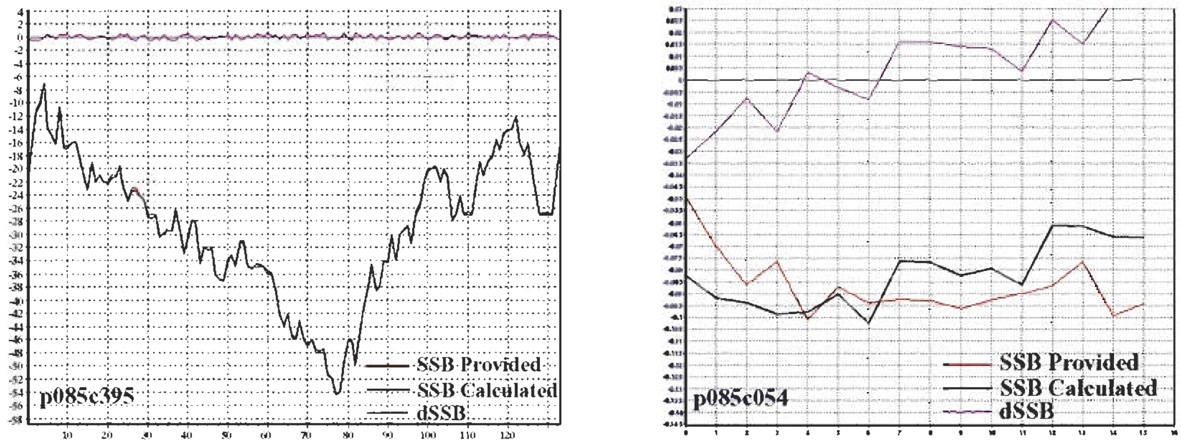

Fig. 2 Difference between *SSB* provided and *SSB* calculated.

The results of processing the cycles (393,394,395) for Topex / Poseidon satellite and the cycles (052,053,054) for Jason-1 satellite are represented in the following table :

Table 3. Means and standard deviation.

Satellite	Cycle	*SSB* Provided (mm)		*SSB* Calculated (mm)	
		Mean	Standard deviation	Mean	Standard deviation
T/P	Cycle 393	-21.48	0.297	-21.496	0.297
	Cycle 394	-11.71	2.3143E-05	-11.678	2.3571E-05
	Cycle 395	-22.40	6.3714E-05	-22.398	6.3429E-05
Jason-1	Cycle 052	-73.40	0.148	-82.31	0.360
	Cycle 053	-76.52	0.164	-89.38	0.297
	Cycle 054	-86.39	0.163	-96.89	0.350

4.2 Results Analysis

The graph which represents the sea state bias calculated from Topex / Poseidon satellite data is similar to the graph of the SSB provided by AVISO. This convergence is due to the simplicity of the processing model used (BM4). The difference of the standard deviation and means which is a few tenths of millimetres is due to the approximations for processing data provided by AVISO.

Besides, the graph that represents the sea state bias calculated from Jason-1 satellite is shifted to the graph that represents the SSB provided by AVISO, notably when we compare means and standard deviation that present some more important differences (some centimetres).

This divergence is due to the algorithms used which are not necessarily the same and to the problem of defected values.

5. The mean sea level determination

The determination of the altimetric geoïd in the western Mediterranean is done from the Topex / Poseidon data corrected of the different effects used in the precedent model for the correction of the sea state bias effect.

The used data (*GDR-M* passfiles) are those well stocked by Aviso on CD : « *Jason*-**1** *and TOPEX / POSEIDON GDR products* » from April 4th, 2002 to the March 28th, 2004, what corresponds to 72 cycles.

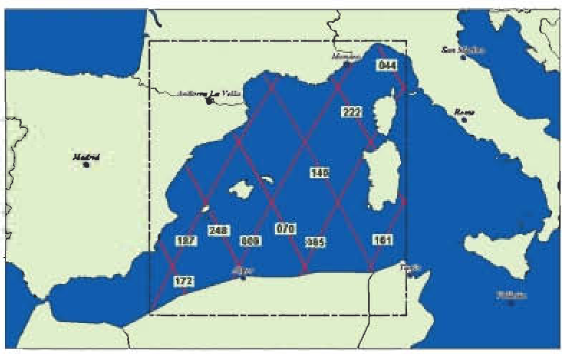

Fig. 3 Traces of the Topex / Poseidon satellite covering the processing zone.

5.1 Deviation Correction on the Crossover Points

For the crossover points coincides two different measures of the sea level. The deviation between these two measures must be corrected and must be distributed on the whole of the two profile measures. The used method for the distribution of this deviation on altimetric profiles is the polynomial interpolation method, whose principle is as following [10] :

Let N a crossover point of one same altimetric profile $y_1 = f(x_1), y_2 = f(x_2) \ldots\ldots\ldots y_N = f(x_N)$ where the y_i represent corrections to bring to the crossover points x_i and the longitudes of the crossover points. The orbital correction for a point of the longitude profile will be expressed then by the Lagrange classic formula as follows :

$$y = \frac{(x-x_2)(x-x_3)\ldots(x-x_N)}{(x_1-x_2)(x_1-x_3)\ldots(x_1-x_N)} y_1 + \frac{(x-x_1)(x-x_3)\ldots(x-x_N)}{(x_2-x_1)(x_2-x_3)\ldots(x_2-x_N)} y_2 + \ldots + \frac{(x-x_1)(x-x_2)\ldots(x-x_{N-1})}{(x_N-x_1)(x_N-x_2)\ldots(x_N-x_{N-1})} y_N$$

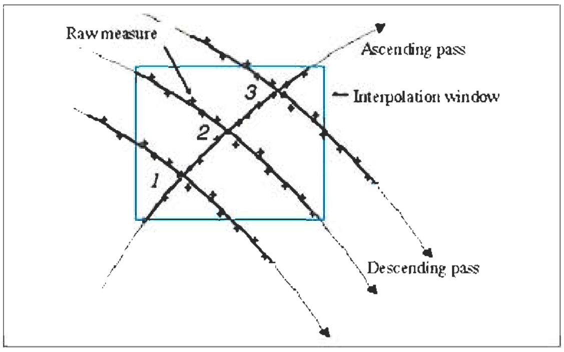

Fig. 4 Crossover point between ascending pass and descending pass.

5.2 Model of Processing the Altimetric Geoid

The formulation of the processing model of the altimetric geoid height (N) is given as follows [12] :

$$N = Hp\_Sat - (H\_Alt + \Sigma) \tag{12}$$

Where :

Hp_Sat : Altitude of satellite above the reference ellipsoid ;
H_Alt : Altimeter range ;
Σ: Whole corrections to be added to the altimeter range, given by [12].

$$\begin{aligned} \Sigma = {} & CG\_Rang\_Corr + Dry\_Corr + Wet\_Corr \\ & + Iono\_Corr\_K1 - SSB + INV\_Bar + \\ & H\_Eot\_Fes + H\_Set + H\_Pol \end{aligned} \tag{13}$$

Where :

CG_Range_Corr : Correction to the altimeter tracker range for gravity centre movement ;
Dry_Corr : Dry tropospheric correction ;
Wet_Corr : Wet tropospheric correction ;
Iono_Corr : Ionospheric correction ;
SSB : Sea state bias ;
INV_Bar : Inverse barometer correction for altimeter measurement ;
H_Eot_FES : Height of the elastic ocean tide at the measurement point computed from FES 95.2 model;
H_Set : Height of the solid earth tide at the measurement point ;
H_Pol : Geocentric pole tide height at the measurement point.

5.3 Results

The nappage of the mean profiles corrected of the orbit error by a regular grid (0.25° x 0.25°) (in longitude and in latitude) permits to have a mean sea surface.
The used method is the linear interpolation (triangulation of DELAUNAY) ; who was used to exclude the regions that have not been observed by altimetry [8].

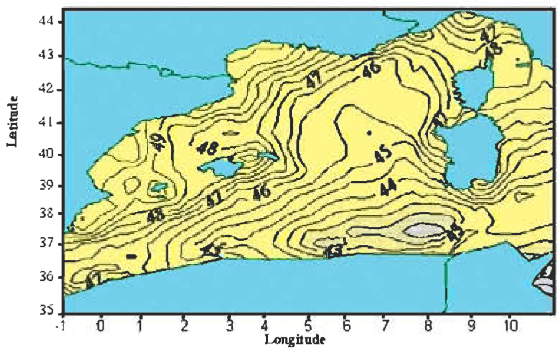

Fig. 5 Altimetric geoid height determined from Topex / Poseidon.

6. Conclusion and Perspectives

The *BM*4 parametric model, which is a function of the significant wave height and the wind speed on the sea surface, is very effective to estimate the sea state bias effect on the altimetric measurements from data of the Topex / Poseidon satellite. The correction of altimetric data of the Topex / Poseidon satellite on a period of two years, from the sea state bias effect using the *BM*4 model and also the other geophysical effects and orbit errors, permitted us to determine with a good accuracy the mean sea level of the western Mediterranean.

Besides, the BM4 model gave us less satisfactory results for the Jason-1 satellite, then we have to use other models (no parametric models) to improve these results.

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