SIMULATION OF THE SEA STATE BIAS

AN ORIGINAL APPROACH USING SEA SURFACE MODELING AND ALTIMETER WAVEFORM COMPUTATION

IGARSS '99

This work is the first part of my PHd thesis which is supported through a CNES/CLS grant. This thesis deals with CNES studies of post Jason future missions and its main goal is to improve the accuracy of the estimated sea state electromagnetic and skewness biases as these biases are some of the main altimeter performance limits. To this end we generate sea surface heights and slopes according to classic spectrums and then compute an altimeter waveform by using radar equations. To simulate the sea state bias we modify some of the sea surface characteristics and the electromagnetic model.

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RADAR EQUATION

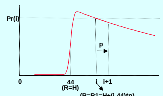
$$P_r = P_e \frac{\lambda^2}{(4\pi)^3 R^4} G^2 \sigma_0$$

with :

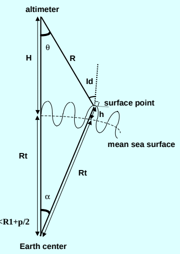
$$R = \sqrt{R_t(R_t + H)\alpha^2 - 2Hh + H^2}$$

$$G^2 = G_0^2 \exp\left(-8\ln 2 \left(\frac{\theta}{\theta_{3dB}}\right)^2\right)$$

$$\sigma_0 = \frac{|R_{fresnel}|^2}{\cos^4 Id * mss} \exp\frac{-\tan^2 Id}{mss}$$



$$Pr(i) = Pe \frac{\lambda^2}{(4\pi)^3} \int_{Area} \frac{G^2 \sigma_0}{R^4} dA \quad \textit{for} \quad R1-p/2<R<R1+p/2$$



ALTIMETER

λ : radar wavelength
Θ_{3dB} : half-power antenna beamwidth
P_e : transmitted power
G_0 : one-way gain along antenna axis

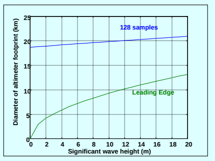
ESTIMATOR

The estimator is based on a maximum likelihood estimator (MLE) and uses the Brown's model. The estimated parameters are mean sea surface level, significant wave height, backscatter cross section ...

SIMULATOR

On Cray YMP :
surface simulation : 120 s CPU
waveform simulation : 800 s CPU

SURFACE CHARACTERISTICS



Diameter of altimeter footprint necessary to simulate the 128 samples of the waveform (top curve) and to simulate only the leading edge of the waveform (bottom curve). The two curves are plotted versus significant wave height.

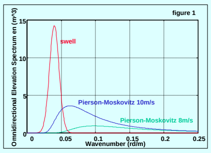
SURFACE DIAMETER : 20 km

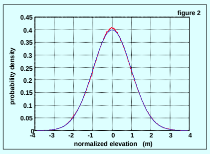
SURFACE RESOLUTION : Long and intermediate waves : 1meter resolution

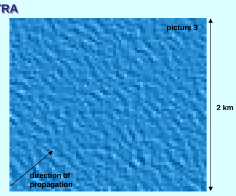
CONCLUSION

- 20000 X 20000 points
- 25 small areas of 4096 x 4096 points

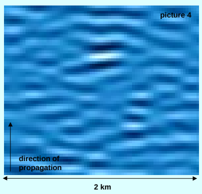
MODELING SEA SURFACES FROM SPECTRA

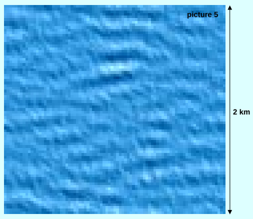




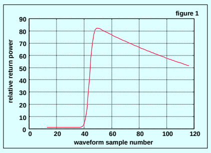


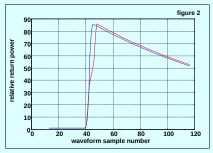
Pierson-Moskovitz for wind speed of 8 and 10 m/s and swell spectra (figure 1). The peaks of these spectrums are at 58, 91 and 157 meters wavelength respectively. These spectra are combined to random phases and then by computing the inverse FFT, sea surface heights and slopes are obtained. The resulting surface heights PDF (figure 2) and slopes PDF are Gaussian by comparison to a theoretical Gaussian PDF. Pictures 3, 4 and 5 confirm that these sea surfaces are realistic. Picture 3 shows wind waves for a 10 m/s wind speed propagating towards 45° direction. Picture 4 shows swell of 157 meters wavelength propagating towards the vertical axis. Finally, the combination of these two kinds of sea surfaces is in picture 5.

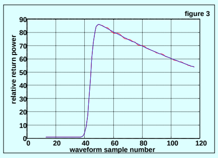




FIRST RESULTS







Altimeter waveform for random Gaussian sea surface (figure 1) is equivalent to Brown's waveform as this surface respects Brown's assumptions. However for a sinusoidal sea surface, the corresponding waveform (figure 2) is different in the leading edge because the surface is not Gaussian. The resulting height bias is -70 cm. Figure 3 shows altimeter waveform from a more realistic sea surface issued from previous spectra. The corresponding height bias is less than 0.2 cm. All these sea surfaces have a significant wave height of 4 m.

ELECTROMAGNETIC BIAS

Since the average backscatter is known to be modulated along the wave profile with higher returned power at throughs than at crests, an attempt is made to take into account such a phenomenon by simply considering the local backscatter as :

$$\sigma_{0_1}(\xi_x,\xi_y,h) = \frac{|R_{Fresnel}|^2}{mss} e^{-\frac{\xi_x^2+\xi_y^2}{mss}} \left(1-\alpha\frac{h}{\sigma_h}\right)$$

With ξ_x and ξ_y the local slope components in x and y directions, σ_h is the rms height of the surface (SWH = 4 σ_h), mss the short wave mean square slope and α a positive modulating factor. The electromagnetic bias characterizes the distribution of specular points along the sea surface elevations. Its value is theoretically given by :

$$\text{Bias} = \frac{<h\sigma_0>}{<\sigma_0>}$$

According to our 2-scale scheme, theoretical predictions are :

$$<\sigma_0> = \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} \sigma_{0_1}(\xi_x,\xi_y,h)\,pdf(\xi_x,\xi_y)\,pdf(h)\,d\xi_x d\xi_y dh$$

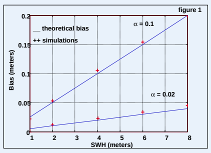
$$<\sigma_0 h> = \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} h\sigma_{0_1}(\xi_x,\xi_y,h)\,pdf(\xi_x,\xi_y)\,pdf(h)\,d\xi_x d\xi_y dh$$

with

$$pdf(\xi_x,\xi_y) = \frac{1}{2\pi\beta_x\beta_y}\exp\left(-\frac{\xi_x^2}{2\beta_x^2}-\frac{\xi_y^2}{2\beta_y^2}\right) \quad \textit{and} \quad pdf(h) = \frac{1}{\sqrt{2\pi}\sigma_h}\exp\left(-\frac{h^2}{2\sigma_h^2}\right)$$

So we have :

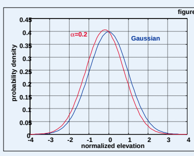
$$<\sigma_0 h> = \frac{-\alpha\sigma_h|R_{Fresnel}|^2}{\sqrt{(2\beta_x^2+mss)(2\beta_y^2+mss)}} \quad \textit{and} \quad <\sigma_0> = \frac{|R_{Fresnel}|^2}{\sqrt{(2\beta_x^2+mss)(2\beta_y^2+mss)}}$$



We then obtain for the electromagnetic bias :

$$\frac{<h\sigma_0>}{<\sigma_0>} = -\alpha\sigma_h = -\frac{\alpha SWH}{4}$$

Figure 1 compares height biaises issued from the theory above to those obtained from simulations. The results are equivalent.



Now let 's determine the estimated SWH. Equations (3) and (4) remain inchanged if pdf(ξ_x,ξ_y) and pdf(h) were replaced with the following formulas :

$$\sigma_{0_1}(\xi_x,\xi_y,h) = \frac{|R_{Fresnel}|^2}{mss} e^{-\frac{\xi_x^2+\xi_y^2}{mss}} \qquad pdf(h) = \frac{1}{\sqrt{2\pi}\sigma_h}\exp\left(-\frac{h^2}{2\sigma_h^2}\right)\left(1-\alpha\frac{h}{\sigma_h}\right)$$

The new pdf is given by figure 2 and its characteristics are :

Mean : - α σ_h
Median : - α σ_h
Standard deviation : $\sqrt{(1-\alpha^2)}\,.\sigma_h$

So, in conclusion : $SWH_{estimated} = \sqrt{(1-\alpha^2)}SWH_{real}$

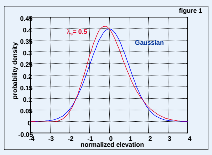
SKEWNESS BIAS

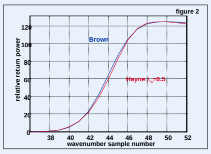
To modelize the skewness bias, heights of long waves are skewed according to the equation above :

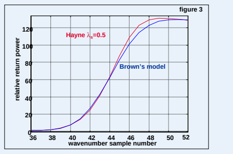
$$pdf(h) = \frac{1}{\sqrt{2\pi}\sigma_h}\exp\left(-\frac{h^2}{2\sigma_h^2}\right)\left[1+\frac{\lambda_s}{6}\left(\left(\frac{h}{\sigma_h}\right)^3-3\left(\frac{h}{\sigma_h}\right)\right)\right]$$

This new pdf is compared to Gaussian pdf in figure 1 and its characteristics are given by :

Mean : 0
Median (Skewness bias) : -λ_s/6.σ_h
Standard deviation : σ_h







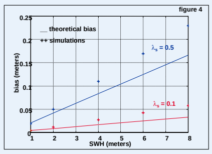


Figure 2 compares Brown's echo to Hayne's one where heights pdf is skewed according to Eq. 1. These two waveforms are different in the leading edge which causes a bias on the height estimation.
Figure 3 shows the estimation of Hayne's waveform by the MLE estimator based on the Brown's model. The height bias estimated is larger than the predicted one because the estimator waveform does'nt fit the echo to estimate very correctly.
Figure 4 compares theoretical height biaises and those issued from simulations.

CONCLUSIONS AND PERSPECTIVES

A simulator of sea surface altimeter waveform was developed and validated by testing several sea surfaces and by comparing the estimated parameters to surface characteristics. We simulated the electromagnetic bias according to the common observation that the average backscatter cross-section is modulated along the wave profile. Following a linear modulation, to describe such a phenomenon, this development is seen to be equivalent to introduce a height-slope cross-skewness coefficient α. The skewness of long waves height has also been modelized and the relating bias simply computed analytically. But the MLE estimator gives an additional bias which is due to the different shape between Brown's and Hayne's models.

In the next future, this simulator will be improved to enable us to further take into account other sea surface characteristics which are at present neglected in a Brown 's type of modelization :

- Hydrodynamic modulation will be introduced to modify locally the intermediate scale (1-10 m) on the numerical surface.
- Improving the electromagnetic model to better model the frequency dependency (Ku and C) on backscatter cross section

According to the results, the altimeter design and the corresponding optimal processing will possibly be modified.

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