where P_{σ_0} is the clutter power contribution of the surface element ΔS characterized by the backscattering coefficient σ_0. It is then assumed that the clutter is spatially stationary and isotropic, with a Gaussian spatial correlation coefficient given by:

$$p(r) = e^{-ln(10)(r/r_d)^2}$$

where r is the radial distance between the cell centres and r_d is the decorrelation distance. We define the instantaneous power $P_{\sigma_0}(t)$ corresponding to the surface element ΔS with σ_0 as "Instantaneous Surface Power Contribution" (ISPC). The implemented algorithm generates a matrix which columns and rows are respectively associated with the surface components (patch) of the radar footprint and with the pertinent time samples. In the presented clutter model the decorrelation time T_{dc} is assumed proportional to the radar transmitted pulse length by a scalable factor, hence the temporal correlation of ISPC depend on the operating radar bandwidth B.

7.2 Basic Simulation Concepts and Setup

The developed algorithm asks the user to define the OTHR geographic scenario in terms of radar site location and surveillance area extent. In this simulation we assumed the east Mediterranean coastline whose reference map together with some operating parameters is presented respectively in Fig. 7.7 and by the next list:

- OTHR-SW System Location: 37°5′N, 14°E (Sicily);
- Surveillance Area: $[600, 3000]$ km; $[50, 130]°$;
- Pointing Direction: $\phi = 100°$, $\beta = 16°$;
- Radar Beam: $\delta\phi = 5°$, $\delta\beta = 10°$;
- Operative Frequency: $f = 18$ MHz;
- Transmitted Pulse Length: $\tau = 0.1$ ms;
- Equivalent Ionospheric Reflection Height $h_{eq} = 260$ km.

The basic simulation process follows the steps described by the flow diagram presented in Fig. 7.8:

1. A coarse estimate of the radar footprint location is made on the basis of ionospheric statistical model and radar parameters.

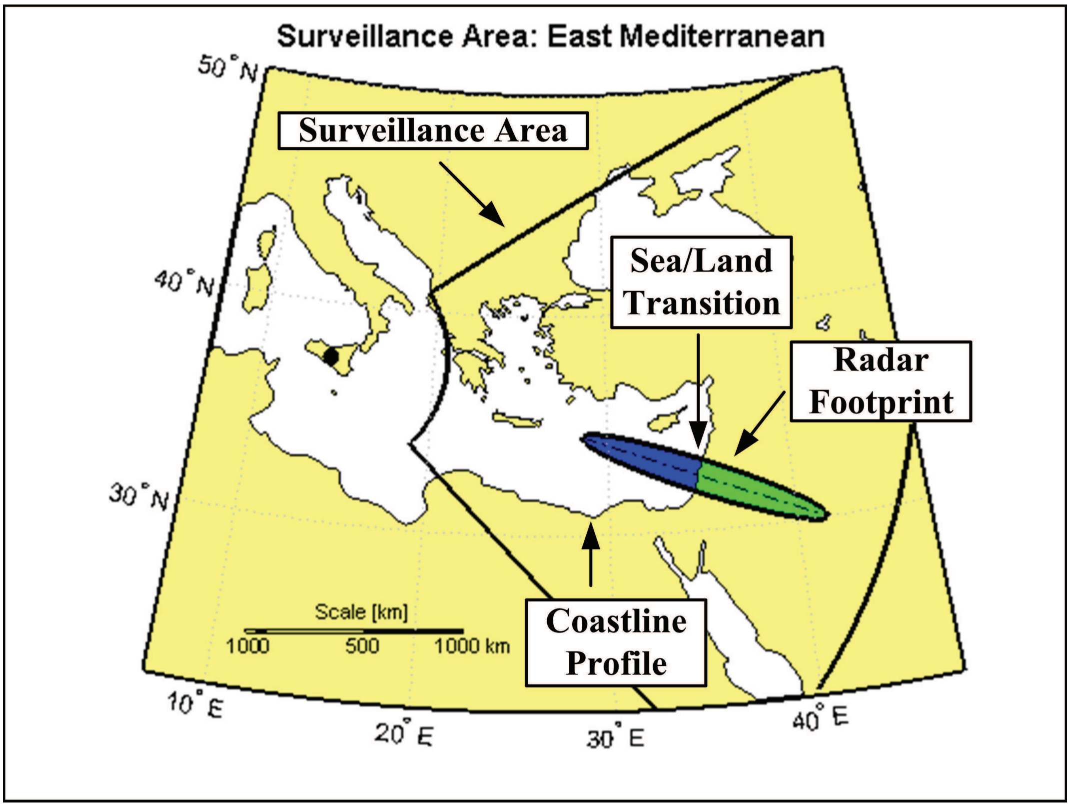

Figure 7.7. East-Mediterranean area with an OTHR-SW footprint sample including a sea/land transition. Simulation parameters are listed in the text.

2. For the selected area the normalized clutter profiles are extracted and evaluated from database.
3. The clutter profiles are cross-correlated with the received echo.
4. The maximum correlation coefficient (corresponding to the best match) is associated with the estimated footprint position.

In order to prove the SLTI approach it was necessary to simulate a received OTHR-SW echo, the one that is provided by the "Radar Rx" block of the flow diagram in Fig. 7.8. The visual scheme of the process employed to simulate the received echo is proposed by Fig. 7.9, that expands the 3-main-blocks scheme proposed at the beginning of the chapter.

After sketching the zoom of the footprint, the algorithm operates a regular segmentation of footprint interested geographic area, based on the user-selected parameter ΔS , and evaluates the backscattering coefficients σ_0 of every surface patch. A top view of the considered radar footprint, together with the resolution-grid of the simulated clutter map are presented in Fig. 7.10.

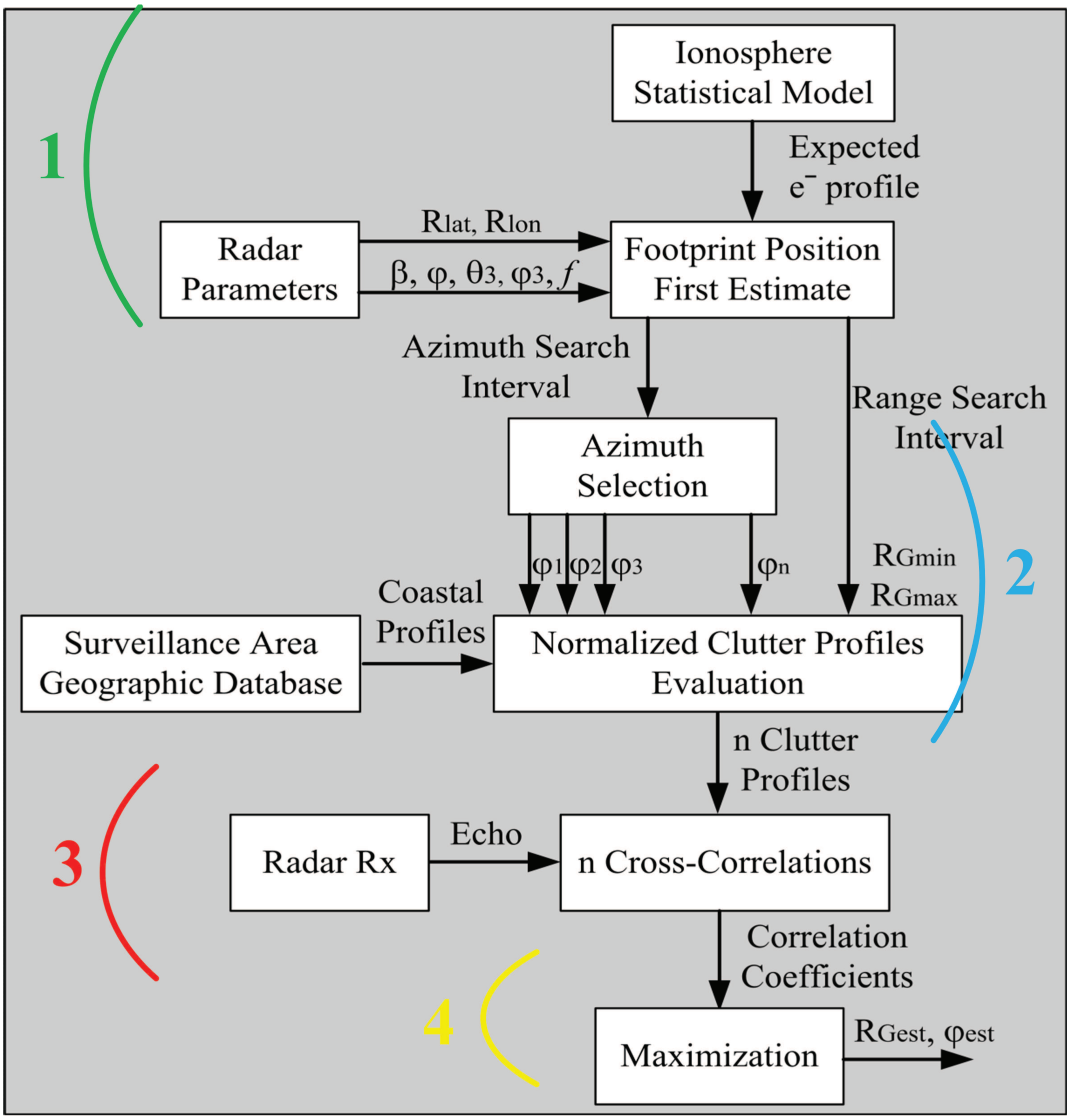

Figure 7.8. Flow diagram of the simulation process.

The backscattering coefficients are then employed as amplitude entries for the statistical simulation of the clutter process: the Gaussian stationary and isotropic spatial correlation is imposed, while the time correlation is taken as inversely proportional to the operating bandwidth B. In the proposed simulation the decorrelation distance is posed equivalent to 4 cells, namely according to the data shown in Fig. fig:ZoomImpronta, to about 105 km. The clutter band is set to one third of the radar bandwidth. The presented results are referred to a 1 ms transmitted pulse. The algorithm final output is structured as a rectangular matrix of complex values (in-phase and quadrature components). Each row rep-

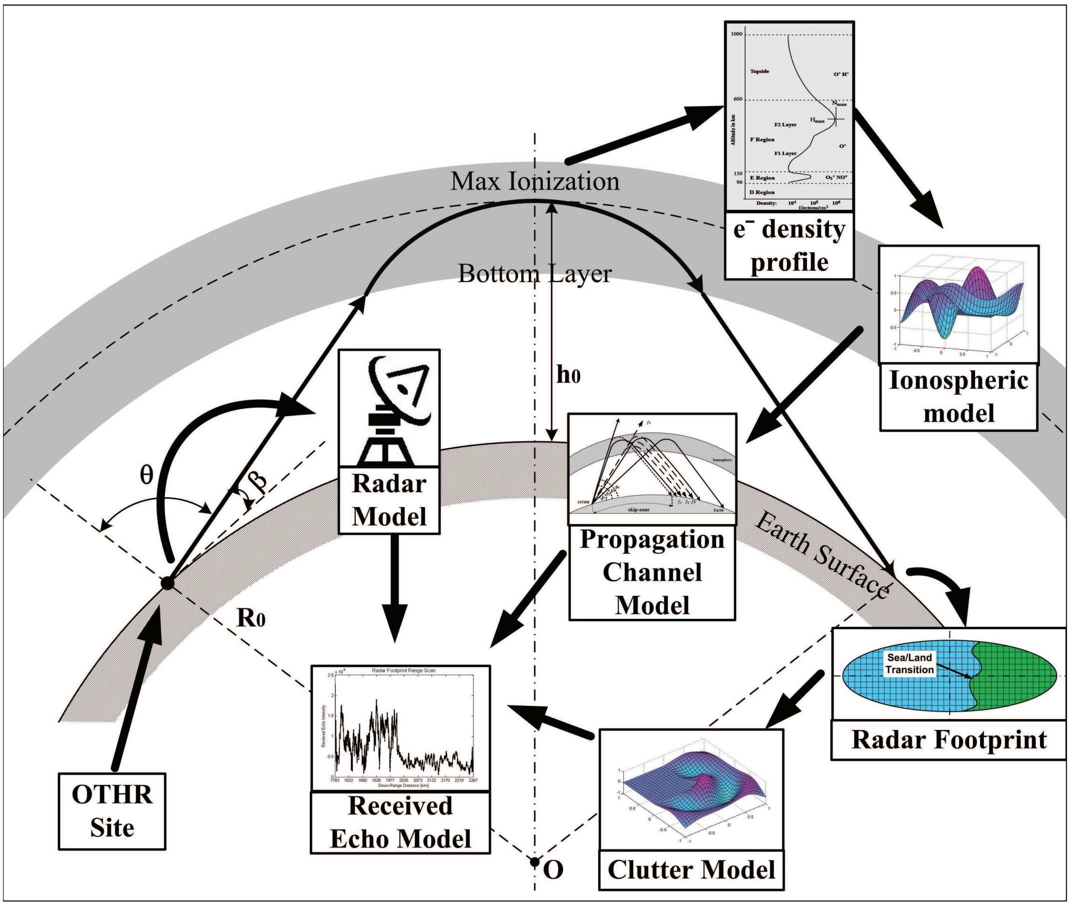

Figure 7.9. Visual scheme of the process employed to simulated the received OTHR-SW echo.

resent a clutter instantaneous realization of the considered surface (Fig. 7.11), while each column shows the time behaviour of amplitude and phase clutter for a specific patch (Fig. 7.12).

7.3 CR Simulation Results

Simulations have been performed under different geographic contexts, in terms of number and relative location within the radar footprint of sea-land transitions, intensity of backscattering coefficients, size of the clutter area, etc. The implemented simulation software allows to perform tests of the SLTI algorithm by variate the most significant radar and environmental parameters. Following the simulation process described by the diagram of figure 7.8 and assuming the hypothesis resumed in figure 7.2, we were able to prove the method alternatively

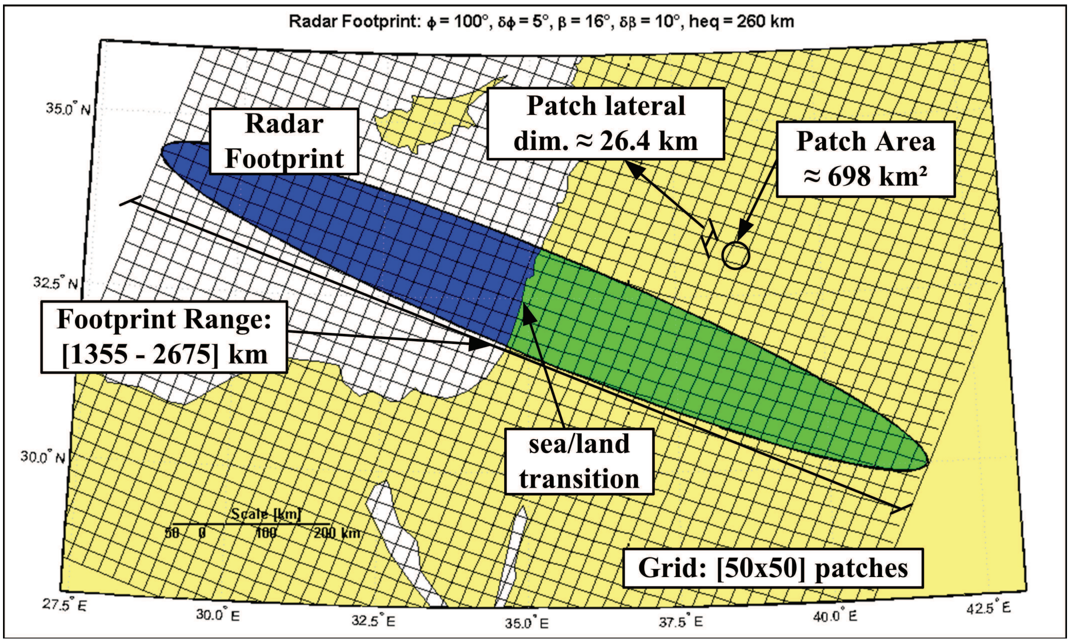

Figure 7.10. Zoom of the OTHR-SW footprint sample presented in Fig. 7.7, and segmentation of the geographic area in squared surface elements ΔS. The algorithm evaluates the backscattering coefficient for each single patch.

changing the various parameters.
Figure 7.13 shows the result of one of these simulations, with on the right hand the main parameters and results and on the left hand a plot of normalized amplitude versus down-range distance of the received radar echo (continuous line), the selected (cross-correlation maxima) binary clutter profile (dashed line) and the clutter area profile during the radar footprint scan (dash-dot line).

In the present study we have seen how the sea/land transition is identifiable for different values of $\Delta\sigma$ and, above all, we have demonstrated how its identification within the echo generated by the range scan of a single footprint (fixed pointing of the radar antenna) allows to georeference in range the radar echo, through the determination of the equivalent ionospheric reflection height h_{eq}, and consequently of the equivalent geometry of the signal's path. The scenario on which the SLTI algorithm is tested considers a binary conformation of the clutter: the only values of the backscatter coefficients are: σ_m and σ_t. This hypothesis, although quite simplifying of a more complex real scenario, allows us to make a preliminary study on the effectiveness of the georeferencing process based on the gradient of clutter, allowing also to highlight the dependence of the developed algorithm by this parameter.
The results of simulation trials in different scenarios suggest that in case of

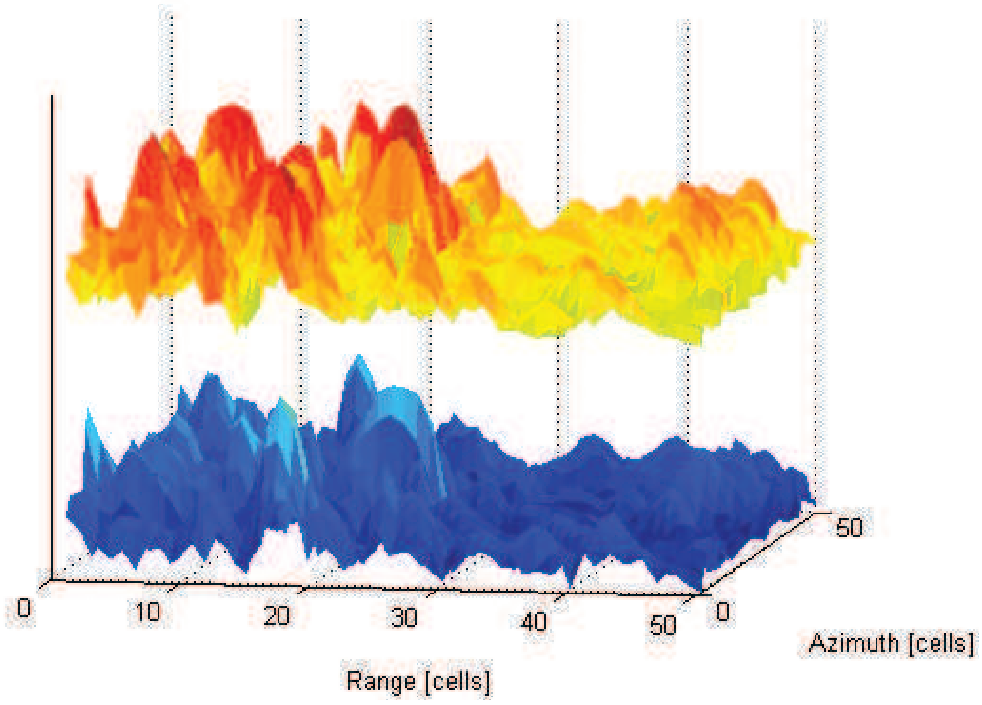

Figure 7.11. Two consecutive instantaneous clutter realization simulated for a squared (half sea, half land) surface partitioned into 2500 squared patches.

Clutter-to-Noise Ratio (CNR) higher than 3 dB ($CNR = 12.23$ dB in this test) a minimum differential sea-land backscattering coefficient ($\Delta\sigma = \sigma_m - \sigma_t$) of 7 dB/km^2 is required to guarantee an error smaller than 3 km in the estimate of the actual ionospheric equivalent reflection height (h_{eq}). Such requirement is promising for the feasibility of the proposed CR method. In fact, even if the bibliography about real HF sea-land backscattering coefficients is scarce, in [70] we find: *"Extensive observations [...] indicated that, averaged over a wide area, sea clutter power levels were about an order of magnitude higher than those from an area of similar size in the central United States."*. Note that in the proposed simulation a ionospheric reflection height bias of hundred meters leads to an error in the radar footprint range position estimation of about one kilometre. This value is quite satisfactory if compared with the OTHR-SW down-range resolution that, with a pulse length $\tau = 0.1$ sec and a take-off angle $\beta = 13°$, corresponds to about 15.4 km. In conclusion, the simulation results we presented here suggest that the proposed SLTI method, based on the a priori knowledge of the sea-land transition dislocation within the surveillance area, can be actually exploited for CR procedures in an OTHR-SW operative context. Note that the implemented system allows to perform tests only on simulated data and consequently the assessment

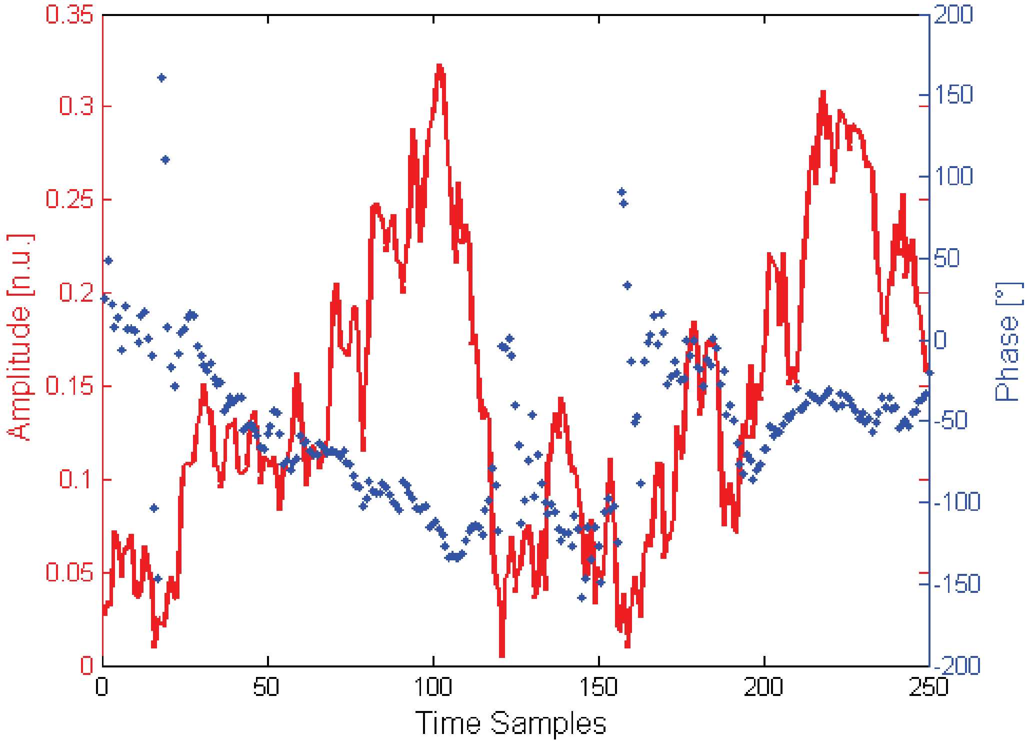

Figure 7.12. Temporal characteristic (250 samples) of clutter (amplitude and phase are plotted with a continuous line and dots, respectively) relative to one of the sea-patch elements composing the proposed simulation scenario. Simulation duration: 10 ms; sample period: 0.04 ms.

of the method's performances results affected by the simulation hypothesis. The block-structure of the algorithm allows to independently update the model of a scenario's block whenever a more realistic hypothesis is assumed.

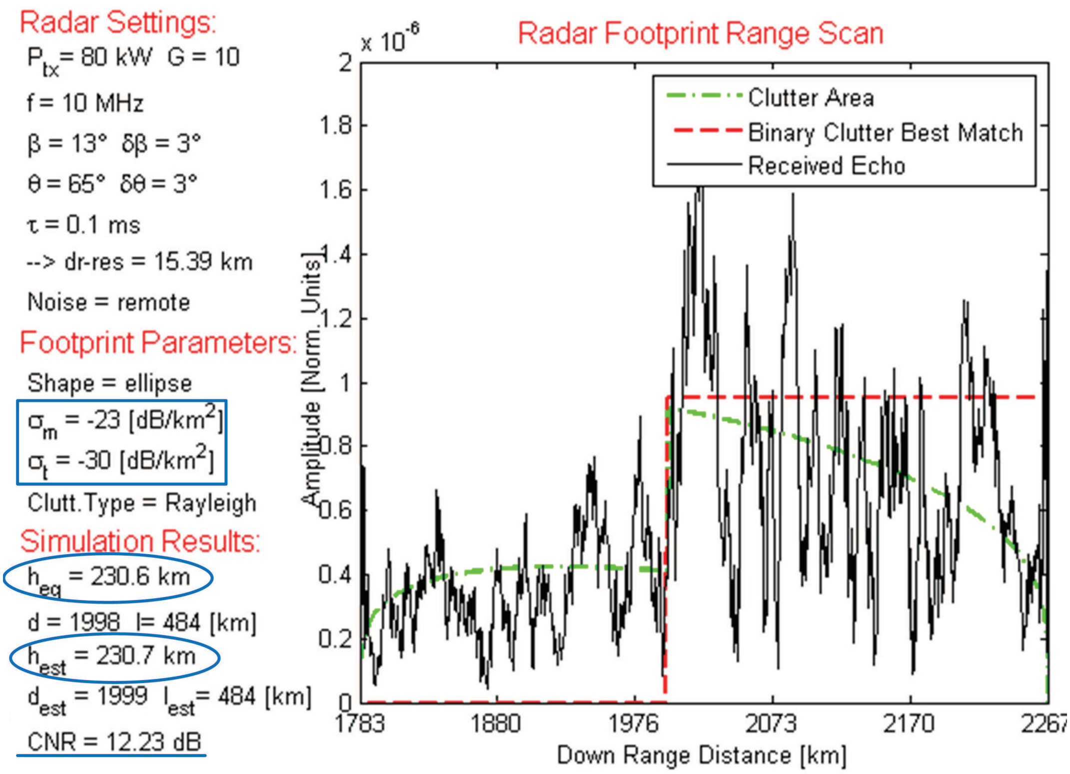

Figure 7.13. *Snapshot of a Simulation Result:* on the left side the main radar parameters are presented with emphasis on: sea and land backscattering coefficients (σ_m, σ_t); actual and estimated ionospheric reflection height (h_{eq}, h_{est}); Clutter-to-Noise Ratio (CNR). On the right side the plot of amplitude vs range.