COORDINATE REGISTRATION OF OTHR-SW REMOTELY-SENSED DATA
BY SEA-LAND TRANSITIONS IDENTIFICATION

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ABSTRACT
Over the Horizon Sky Wave Radar (OTHR-SW) systems can be employed as remote sensing tools over large oceanic areas. Anyway their employment is strongly effected by the instability and the dishomogeneity of the Ionosphere. Therefore their use requires a coordinate registration (CR) procedure in order to geo-referenciate the collected data. In previous papers we proposed a CR method for this class of systems, based on the a priori knowledge of the coastal profiles within the surveillance area.

Here we give a brief description of the method, remarking its advantages and limitations and outlining its possible applications and future developments.

1. INTRODUCTION
The interaction between EM waves in the HF band and sea swells can profitably be employed to extract sea state information from the HF radar echo [1],[2]. For this reason, several authors proposed to employ the OTHR-SW system as a remote sensing tool [3],[4],[5],[6]. In fact, by the ray reflection on the Ionosphere, this particular HF sensor is able to collect environmental data over a very large area, not comparable with the coverage area of any other ground based radar.

Many methods have been proposed to extract environmental information (e.g.: wind speed and direction [7],[8]; sea surface current [9],[10]; etc.) from the HF echo; however, the main problem about the use of OTHR-SW still remains the need for a CR process to associate the received data to geographic coordinates.

In fact, OTHR-SW signals are reflected by the Ionosphere and consequently affected by its instability and non-homogeneous structure. Many CR approaches rely on a periodically updated ionospheric model and on a ray-tracing program in order to estimate the actual radar footprint location. Then they convert the radar coordinates (i.e., slant range and apparent azimuth) into geographic coordinates. Nevertheless, the periodic update of the ionospheric model requires a complex and expensive ionosonde network and the updating period is anyway much bigger than the coherency time of the Ionosphere.

We recently proposed a single sweep basis correlation method to geo-referenciate the echo received by an OTHR-SW system. The method takes advantage of the a priori knowledge of the positions of the sea/land transitions within the radar coverage area and of the marked difference between the sea and land backscattering coefficients in HF band [11],[12]. This CR method allows to associate geographical coordinates to the radar data without requiring additional information from external sources and once fully developed it could lead to a significant enhancement of the radar accuracy, not only in remote sensing, but in every application involving an OTHR-SW system.

2. GEOREPHERENCING METHOD
Because of the dishomogeneity and of the instability of the Ionosphere, the CR for an OTHR-SW system requires the employment of a raytracing program that allows estimating the two-way ray path. Raytracing programs generally rely on an ionospheric model built on daily and seasonal statistics. Sometimes this model is just static, while more often it is periodically updated to fit ionospheric data locally gathered by vertical (VIS) or oblique (OIS) incidence ionosondes.
Anyway this method does account neither for the short-time variability of the Ionosphere (particularly marked at dawn and dusk), nor for its local dishomogeneity.

Assuming to do not have real time information about the Ionosphere (therefore about the actual ray path) we need to geo-referenciate the received echo just employing the information it intrinsically contains. If the received echo is relative to a radar footprint characterized by at least one coastal profile, then, by virtue of the difference between the backscattering coefficients of sea and land, we can estimate the range position of the footprint along the operating azimuth direction (see Fig. 2). In fact the echo power profile should be univocally recognizable among the possible profiles for the selected azimuthal direction.

![Fig. 2: Side and top views of the radar footprint model and of the binary clutter profile for the selected azimuth. Some parameters are given; $\beta$ = take-off angle; $\delta\beta$ = radar beam elevation span; $\tau$ = Tx pulse length; $\sigma_0$ = sea (land) backscattering coeff.; $c =$ speed of light; $(c\tau/2\cos\beta)$ = pulse’s ground projection.](image)

Of course the Ionosphere is not a perfect horizontal mirror and it is expected to introduce a deforming effect on the reflected echo, shrinking and displacing the corresponding footprint. In Fig. 3 it is shown an example of the possible effect of the Ionosphere on a radar footprint. Both images A and B represent the radar footprints as they are reassembled at the receiver, according to the time of arrival (TOA) of the single surface contributes. In other words the original footprint is segmented in a grid of surface units; for every unit the clutter contribution is evaluated (on the basis of its percentage of sea/land) and the ray path to the receiver is estimated. While in A the Ionosphere is modeled as a perfect reflecting mirror, in B it is assumed to be represented by a given electron density profile that is supposed to be constant for the whole footprint. The radar is operating in a static mode (i.e. with chosen azimuthal and elevation angles, with constant frequency and bandwidth, etc.), thus the $i^{th}$ surface contribute is characterized by a take-off angle $\beta_i$ and its interaction with the Ionosphere leads to a particular ray path with associated TOA $T_i$ as shown in Fig. 4.

![Fig. 3: Two reconstructed radar footprints: in A the Ionosphere is modeled as a perfect reflecting mirror at a given height while in B a locally-homogeneous electron density profile is associated to the Ionosphere. Therefore the echo associated to A will be coherent with the backscattering coefficients in the geographic area interested by the footprint, while the echo associated to B will lead to a distorted version of it. We aspect the echo relative to B to be shorter in time (because of the footprint fold back) and, probably, characterized by higher power peaks (the single surface contributions with equivalent TOA are combined according with their phase). Fig. 5, obtained with an algorithm that simulates the OTHR-SW received echo by combing (accordingly to the TOA) the footprint surface contributes confirms the predictions.](image)

![Fig. 4: five surface element echo contributions that because of their different take-off angles and of ionospheric dishomogeneity presents different time of arrival (TOAs). Even taking into account the ionospheric deformation effects, the proposed CR method should be profitably applied, accordingly with the shape of the binary clutter profile relative to the selected azimuth.](image)

3. FUTURE DEVELOPMENTS

The above mentioned ionospheric distortions that affect the received echo could eventually be employed to extract information about the Ionosphere. This technique is yet to be investigated and requires an appropriate parameterization of the adopted ionospheric model (in order to grant it a ‘real
time” connotation) to be employed, but it could bestow on the radar the ability to sense the Ionosphere too.

**Fig. 5:** Simulated received echo for the reconstructed footprints shown in Fig.3. A: black line; B: red-dotted line.

For what concerns the estimates of the azimuthal drift that affects OTHR-SW echoes when the system operates on an azimuthal direction not parallel to the Earths magnetic meridian, we do not have any simulation results available yet, but we are confident to achieve the task by reiterating the described method for several adjacent azimuthal directions and choosing the best match among them.

**4. CONCLUSIONS**

Many papers suggest the employment of OTHR-SW system as a remote sensing tool for sea conditions, wind speed and direction, storm tracking, tsunami warning, etc.

Here we briefly described a method, based on the *a priori* geographical knowledge of the coastline profiles within the surveillance area, to geo-referenciate the OTHR-SW echo. The method basically consists in the correlation between the received echo and the binary clutter profile defined for the selected azimuth by the down-range position of sea/land transitions. Due to its computational simplicity, the method can be employed on a real time basis, without interfering with the operative schedules of the radar system. Moreover by applying the same algorithm for several adjacent azimuths the eventual azimuthal drift, mainly due to the Earth magnetic field, could be estimated.

Such method represent a powerful tool to improve the CR method for this systems and, once fully developed and investigated, it could enable the use of the radar as a (real-time, wide-area) remote ionospheric sensor.

**8. REFERENCES**