The International Beacon Satellite Symposium *BSS2010*
P. Doherty, M. Hernández-Pajares, J.M. Juan, J. Sanz and A. Aragon-Angel (Eds)
Campus Nord UPC, Barcelona, 2010

SIMULATING IMPACTS OF IONOSPHERIC SCINTILLATION ON GROUND- AND SPACE-BASED RADARS USING TIRPS

Neil C. Rogers* **and Paul S. Cannon***

*QinetiQ
St Andrews Road, Malvern Worcestershire, WR14 3PS

Key words: Scintillation; ionosphere; radar; SAR; TIRPS.

Abstract. Radar simulation studies using the Trans-Ionospheric Radio Propagation-Simulator (TIRPS) 1 are reviewed and compared. The impacts of ionospheric irregularities have been simulated on both ground-based satellite-tracking radar and space-based synthetic-aperture radars (SAR) in the VHF/UHF band. The level of Doppler- and range spreading of targets and the associated corruption of SAR images of point targets (raised image sidelobes in the along-track and cross-track directions respectively) is well modelled by varying the parameters of the ionospheric phase screen over their natural range. Doppler spreading (raised along-track image sidelobes) is a frequent problem and leads to a familiar along-track streaking in SAR images. Range defocussing due to pulse dispersion may normally be compensated using autofocus techniques. However in a scattering environment, simulations for both satellite tracking radar and Low-Earth Orbiting (LEO) SAR show that irreducible range spreading (beyond the target range) would be observed (assuming sufficient waveform bandwidth) as a result of scattering in the equatorial ionosphere under conditions of simultaneously high turbulence strength (CkL) and low spectral index in the turbulence spectrum (p).

1 INTRODUCTION

VHF and UHF frequencies may be used by space-based radar for enhanced ground- or foliage penetration and are also used extensively by ground-based satellite-tracking radars. This paper reviews various simulations of ionospheric scattering on these systems using the TIRPS model1. Below 1 GHz, diffractive effects of ionospheric irregularities may be significant so TIRPS uses a Parabolic Equation (PE) approach2 to model both amplitude and phase perturbations of radar waveforms as they pass through a phase screen representation of the ionosphere.

Two radar geometries have been modelled:
(i) a ground-based radar tracking LEO satellites and

(ii) a space-based LEO synthetic aperture radar (SAR) imaging stationary point targets on the ground.

These are discussed and compared below.

2 TIRPS SIMULATION OF VHF/UHF SATELLITE TRACKING RADAR

In the absence of truth data for satellite radar modelling, the TIRPS propagation algorithm was validated by comparing simulations of target Doppler and range spreading with measurements from orbiting calibration spheres using the ALTAIR ground-based satellite tracking radar operated by the US Department of Defense on Kwajalein Island 3,4,5. The model replicates the channel scattering function (CSF) of the ionosphere (a 2D representation of the pulse-compressed target return in delay and Doppler) using a range of parameters of a phase screen representing the irregularity spectrum. Below a scale size Lo, the spectrum was defined as log-log linear with the linear portion defined by the strength of turbulence CkL and a spectral index p. Two simulated CSFs are shown in Figure 1. Both are simulations of the delay and Doppler profiles from a 3.6s period of 150MHz ALTAIR chirp returns from a LEO calibration sphere. The signal return in the CSF is scattered into a wings pattern in which the signal delay (or equivalently, range) increases with increasing positive or negative Doppler offset. Doppler spreading is significant at high turbulence strengths but only where the spectral index p is below (¡1.5), does significant range (delay) spreading occur beyond the target (as seen in the left panel of Figure 1).

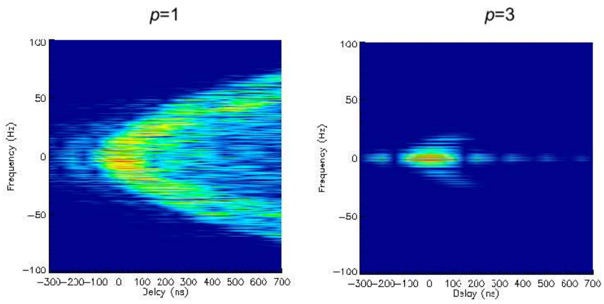

Figure 1: TIRPS Simulations of a delay-Doppler profile of ALTAIR 150MHz radar returns from a LEO calibration sphere. L_o=5km, $C_kL=10^{34}$, p=1 (left panel) and p=3 (right panel).

3 SPACE-BASED SAR SIMULATIONS

TIRPS has been developed into SAR-TIRPS in which the unprocessed RF signal for SAR waveforms returned from point targets are simulated after a 2-way passage through the phase screen. These signals are then processed into SAR images using the appropriate orbital, waveform and signal processing parameters. An element of a strip-map SAR image is reconstructed using standard range compression, range walk correction and azimuthal (or equivalently, Doppler) compression techniques. The background TEC of the ionosphere (modelled as a phase shift applied across the phase screen) leads to shifting and a small amount of range spreading of the target return (due to frequency dispersion). In many cases this range spreading may be compensated using autofocusing methods.

Examples of reconstructed SAR images of a point target are presented in Figure 2 appropriate to the JPL/NASA SEASAT radar, a 1.275 GHz radar in a 794 km orbit1. The upper panels (a,b) of Figure 2 are simulated using a moderate strength of turbulence (CkL = 1034) and illustrate how the tail-off of the Doppler (along-track) sidelobes is proportional to the value of the spectral index p in the phase screen. An analytical model6 of the SAR point spread function which incorporates the phase screen parameters has been shown to provide a good fit to the simulated image profiles. Panel (c) of Figure 2 illustrates the effect of high strength of turbulence (cf. panel (b)) and shows that the azimuthal localization of the target is poor. Panel (d) illustrates that by further reducing the spectral index p to 1.0 there is considerable reduction of image contrast in the range direction beyond the target range, due to diffractive scattering. This pattern of behaviour is directly comparable to the Doppler and range spreading effects noted in the satellite-tracking radar example presented above.

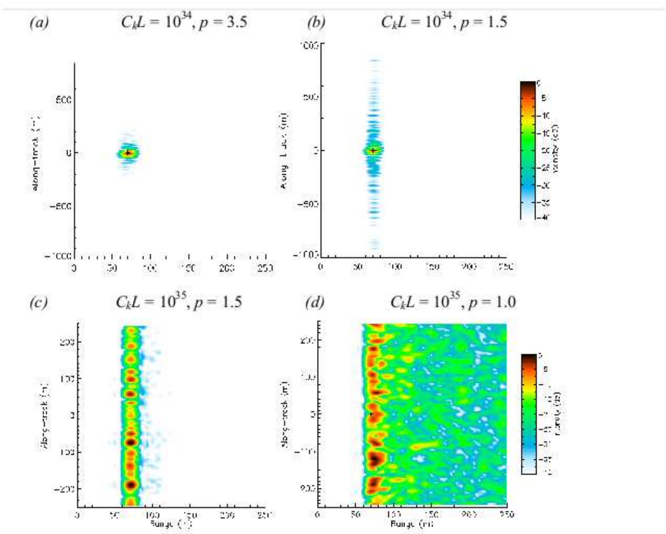

Figure 2: Examples of SEASAT 1.3GHz LEO radar simulations for varying values of C_kL and p (as marked). In each case L_o =10km. The true position of the target is indicated by a '+'.

4 CONCLUSIONS

- The TIRPS model provides a means of simulating the effects of ionospheric scintillation and dispersion on radar waveforms.

- The propagation algorithms have been tested by comparison with a ground-based radar, and the software adapted to simulate proposed space-based SAR.

- The PE algorithm used ensures that amplitude scintillation effects due to diffraction (which may be significant at lower frequencies) is not neglected.

- Simulated SAR point target images display predictable behaviours with regard to Doppler (along-track) and range spreading as a function of the ionospheric phase screen parameters, which closely parallel the behaviours observed in the ground- based satellite tracking radar.

REFERENCES

[1] N.C. Rogers and P.S. Cannon, *The synthetic aperture radar transionospheric radio propagation simulator (SAR-TIRPS).* The Institution of Engineering and Technology 11th International Conference on Ionospheric Radio Systems and Techniques, 2009 (IRST 2009).

[2] M. Levy,*Parabolic Equation Methods for ElectromagneticWave Propagation*, IEE Electromagn. Waves Ser., Vol. 45, Institution of Electrical Engineers, London, U. K. (2000).

[3] P.S. Cannon, K. Groves, D. J. Fraser, W. J. Donnelly, and K. Perrier,*Signal distortion on VHF/UHF transionospheric paths: First results from the Wideband Ionospheric Distortion Experiment*, Radio Sci., Vol. 41, RS5S40, doi:10.1029/2005RS003369 (2006).

[4] N.C. Rogers, P. S. Cannon, and K. M. Groves,*Measurements and simulation of ionospheric scattering on VHF and UHF radar signals: Channel scattering function*, Radio Sci., Vol. 44, RS0A07, doi:10.1029/2008RS004033 (2009).

[5] N. C. Rogers, P. S. Cannon and K. M. Groves, *Measurements and simulation of ionospheric scattering on VHF and UHF radar signals: Coherence times, coherence bandwidths, and S4*, Radio Sci., Vol. 44, RS0A33, doi:10.1029/2008RS004035, (2009).

[6] D.P. Belcher and N.C. Rogers, *Theory and simulation of ionospheric effects on synthetic aperture radar*, Radar, Sonar and Navigation, IET Vol 3, Issue 5, 541 - 551 doi:10.1049/iet-rsn.2008.0205 (2009).