GPS Signal Propagation in Tropospheric Ducts

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Abstract

The objective of this work is to predict the field strength of low elevation GPS (*Global Positioning System*) signals in the presence of tropospheric ducts. Two numerical methods were used: 1) Ray Tracing (geometrical optics), a qualitative method based on the successive application of Snell's law in which the rays are traced with the radius of curvature depending on the local refractive index gradient; 2) The Parabolic Equation Method (physical optics), a simplification of the wave equation that provides full wave solution to problems concerning low elevation propagation in a two-dimensional refractive index structures. The power and elevation of the confined signals could be observed and the possibility of positioning error occurrences due to the presence of ducts is verified.

1. Introduction

The *Global Positioning System* (GPS) was designed in order to attend innumerous users over the Earth without interfering in other communication systems. Each satellite transmits, at 1575.42 MHz (L1 frequency), an unique binary pseudo-random code (C/A code) and the minimum received power specified (in L1) is -160 dBw, about -20 dB under the local thermal noise. The pseudorange is estimated through correlation between the received signal and its replica generated by the receiver.

The GPS receiver demodulates L1 signals with power levels between -130 and -160 dBw (in an optimal case) corresponding to a dynamic range of 30 dB and its antenna gain ranges from about 0 (horizon) to 10 (zenith) dB in order to eliminate some multipath effects. Signals from at least four satellites reach the receiver and one or more satellites can be at low elevation. The signals from these low elevation satellites are not used in range calculations (mascara) but they may cause interferences (they will be present in the correlation channel) [1].

In normal situations, when all the received signals present the same power level, the (undesired) raising signals do not interfere significantly in range calculations because the peak of cross-correlation between the undesired signals and the replicas of the desired ones is low. If the undesired signal presents power levels higher than the desired ones interferences are probable to occur [2].

The objective of this work is to predict the GPS signal propagation in tropospheric ducts and verify the possibility of positioning errors occurrences due mainly to two reasons: 1) The high strength of the confined signal may saturate the receiver; 2) The confined signal may reach the receiver with an apparent elevation such as a signal from an elevated satellite.

Low elevation GPS signal propagation in tropospheric ducts is simulated making use of two numerical methods: 1) Ray Tracing (RT), a qualitative method based on the successive application of Snell's law in which the rays are traced with the radius of curvature depending on the local refractive-index gradient; 2) The Parabolic Equation Method (PE), a simplification of the wave equation that provides full wave solution to problems concerning low elevation propagation in a two-dimensional refractive index structures.

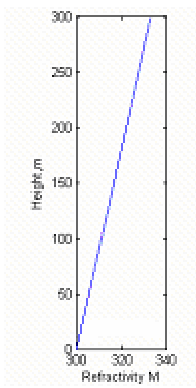
For comprehensive reference about the physics of ducts, RT, PE and the procedure for obtaining the simulations results please see Balvedi and Walter [3].

2. Simulations results

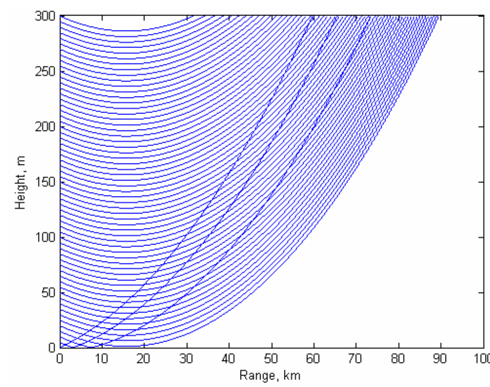
The ducts profiles used are those found in literature [4]. Two distinct situations were addressed: 1) Only the direct signal from a satellite was considered in the incident boundary; 2) Both the direct and reflected signals are present in the incident boundary. The direct incident GPS signal is a plane wave with elevation angle equal to the elevation angle of GPS satellite. The reflected signal comes from the same satellite and suffers reflection just before the incident boundary (where the duct begins) [5].

The satellite is setting or rising in horizon (with low elevation angle). The initial direct field was normalized to present -160 dBw in the incident boundary. In all simulations the incident rays reach the duct in *Range = 0* (incident boundary) and propagates to the right.

The profile for a standard atmosphere is illustrated in Figure 1a. The RT, considering only the direct signal from satellite, is shown in Figure 1b. The PE results are shown in Figures 2a,b.

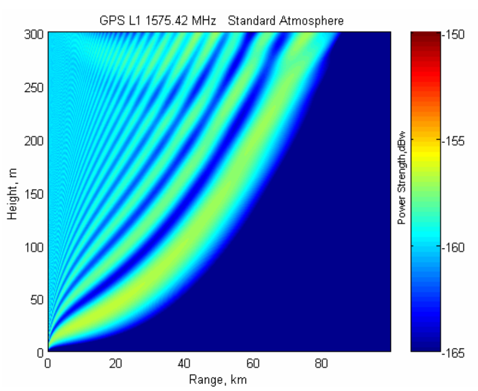


(a) Profile for standard atmosphere

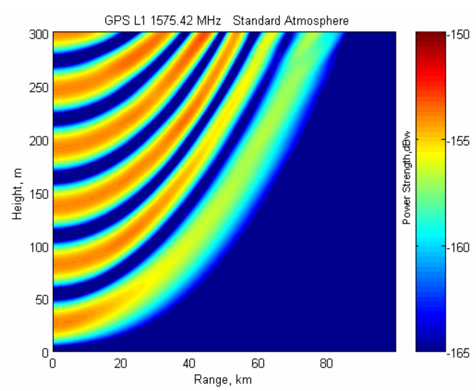


(b) RT for standard atmosphere

Figure 1. (a) Profile for standard atmosphere; (b) Ray Tracing for standard atmosphere (direct signal only).



(a) Direct signal



(b) Direct and reflected signal

Figure 2. PE method – standard atmosphere: (a) direct signal from satellite; and (b) direct signal from satellite plus reflected signal. Color bar indicates the power strength in dBw.

The profile for an evaporation duct is illustrated in Figure 3a. Figure 3b shows the RT considering only the direct signal. One can note that some trapped rays are present. Figures 4a,b shows the PE for the same profile and some confined energy can be observed in the region of the duct.

The profile for an elevated duct is illustrated in Figure 5a. Figure 5b shows the RT considering only the direct signal. Once again trapped rays in the duct can be noted. Figures 6a,b show the PE for the same duct and the confined energy can be seen.

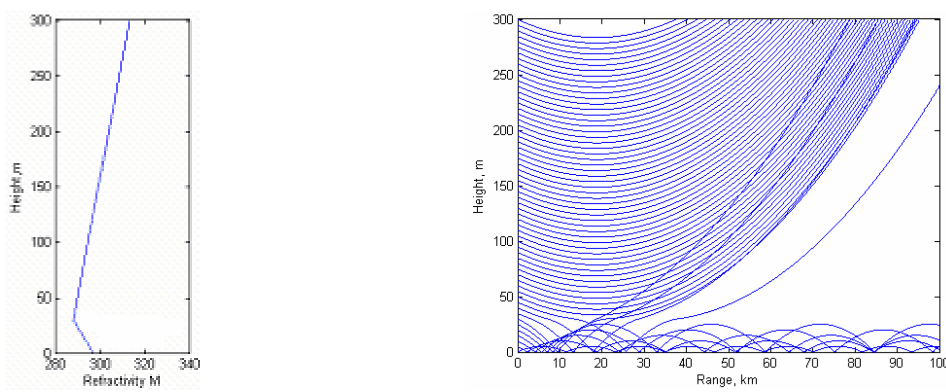
3. Discussion and conclusion

The field strength and the ray path of low elevation GPS confined signals were calculated using two prediction methods: Ray Tracing and Parabolic Equation. It is possible now to evaluate if positioning errors may occur due tropospheric ducts [6].

Concerning the field strength of confined signals it can be observed in simulations (Figures 4a,b and 6a,b) that they can reach values around -150 dBw (the dark red regions in field plot), value inside the receiver dynamic range. It can be concluded that the confined signal can't, unless extreme improbable conditions (when the desired signal reaches the receiver with power less than -160 dBw), saturate the receiver.

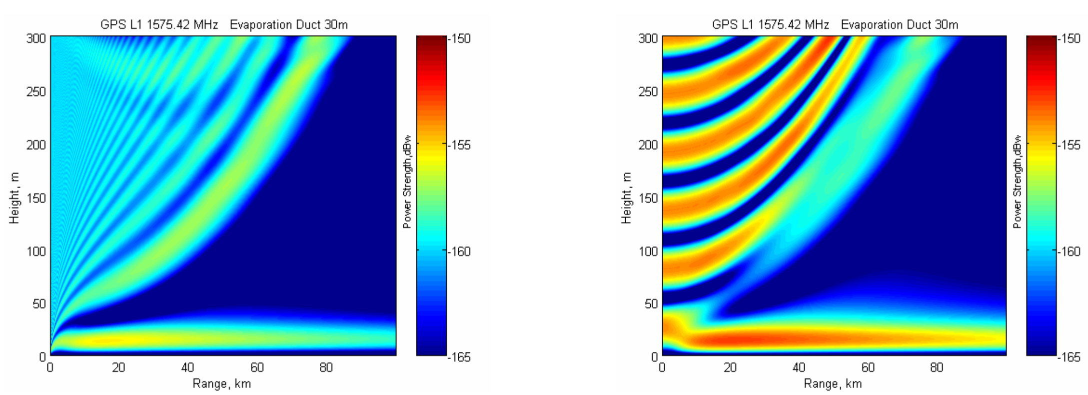
Concerning the trajectory of the confined signal it can be noted that the rays inside the duct can reach high elevation (Figures 3b and 5b). As mentioned before, the antenna gain of standard GPS receiver ranges from 0 (horizon) to 10 dB (zenith). A signal from a low elevation GPS satellite can reach the receiver with an "apparent" high elevation and this undesired signal could be interpreted as a desired one (with a significant strength). Its power level may be higher than other valid GPS signals, which could lead to tracking error. This situation does not last more than approximately 2 minutes since the satellite doesn't stay in horizon for a long time. In critical high dynamic flight situations like approximation and landing this factor could make impracticable the use of the GPS.

It is important to emphasize that some major airports are close to the ocean, regions with high ducts occurrence probability. One future work would be to choose a place like an airport near the coast, obtain the profiles of the ducts and observe if there are periods when the GPS receiver saturates and if there are one or more satellites on the horizon at that time. Important information like number and period of duct occurrences and probability of positioning errors could be acquired and the GPS users on that area could be alerted.



(a) Profile for a 30 m evaporation duct (b) RT for a 30 m evaporation duct

Figure 3. (a) Profile for a 30 m evaporation duct; (b) Ray Tracing for a 30 m evaporation duct (direct signal only).



(a) Direct signal (b) Direct and reflected signal

Figure 4. PE method – 30 m evaporation duct: (a) direct signal from satellite; and (b) direct signal from satellite plus reflected signal. Color bar indicates the power strength in dBw.

4. Acknowledgements

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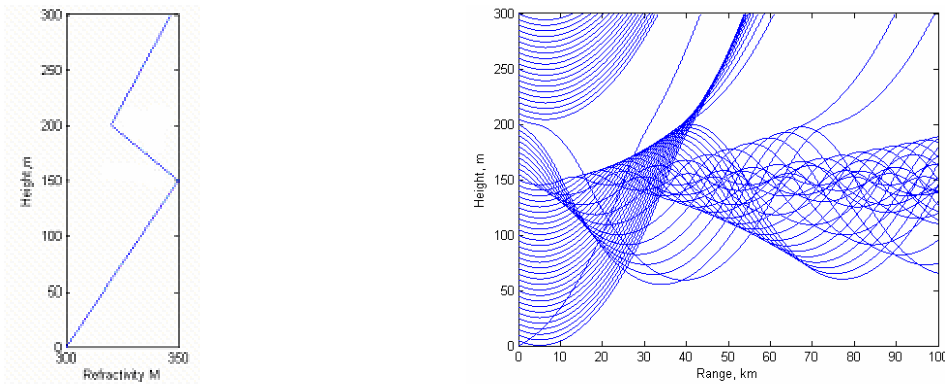
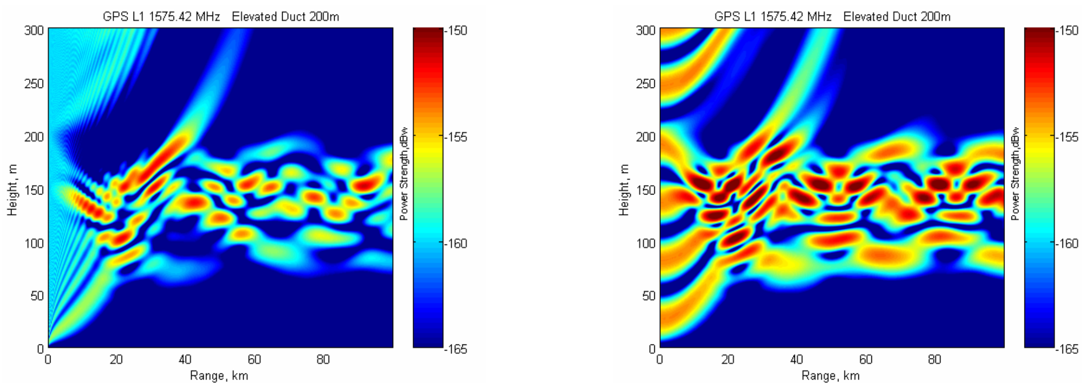


(a) Profile for an elevated duct (b) RT for an elevated duct

Figure 5. (a) Profile for an elevated duct; (b) Ray Tracing for an elevated duct (direct signal only).



(a) Direct signal (b) Direct and reflected signal

Figure 6. PE method – elevated duct: (a) direct signal from satellite; and (b) direct signal from satellite plus reflected signal. Color bar indicates the power strength in dBw.

5. References

1. P. Misra and P. Enge, *Global Positioning System: Signals, Measurements and Performance*, Ganja-Jamuna Press, USA, 2001.

2. D. Zandonadi Jr., "Superação do Problema Near/Far em Pseudo-Satélites GPS Mediante Técnica de Realimentação do Receptor do Usuário", Ph.D. Thesis, Instituto Tecnológico de Aeronáutica, São José dos Campos, SP, Brazil, 2005.

3. G. C. Balvedi and F. Walter, "Analysis of GPS Signal Propagation in Tropospheric Ducts Using Numerical Methods", *11th URSI Commission F Open Symposium on Radio Wave Propagation and Remote Sensing Proceedings*, Rio de Janeiro, RJ, Brazil, 2007.

4. M. P. M. Hall, L. W. Barclay and M. T. Hewitt, *Propagation of Radiowaves*, IEE Electromagnetic Wave Series, The Institution of Electrical Engineers, England, 1996.

5. B. Hannah, "Modelling and Simulation of GPS Multipath Propagation", Ph.D. Thesis, The Cooperative Centre for Satellite Systems, Queensland University of Technology, 2001.

6. G. C. Balvedi, "Efeitos dos Dutos Troposféricos na Propagação e Recepção de Sinais GPS", MSc. Thesis, Instituto Tecnológico de Aeronáutica, 2006.