Tropospheric Refractivity profile Estimation Using Ground-based GPS

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Abstract

Measurements of phase delay form Ground-based GPS are traditionally used to derive the quantity of water vapor content. New techniques have been developed to retrieve refractivity profile using single mountain-based or general ground-based GPS observations recently. These developing techniques of obtaining tropospheric refractivity profile are introduced in the paper. Results comparing refractivity profiles retrieved by single general ground-based GPS and the Hopfield model are illustrated, which demonstrate ground-based GPS method has a better agreement with radiosonde profiles.

1. Introduction

Tropospheric refractivity has noticeable effects on the performance of radio systems such as radar, communication and navigation systems. GPS-Met has become a promising method for the inversion of tropospheric refractivity profiles. In the late 1980s, a group at JPL proposed observing GPS signals from space to make atmospheric soundings 1. Radio occultation measurements using a receiver in a low-Earth orbit (LEO) have been shown to provide accurate profiles of refractivity with high vertical resolution. While GPS occultation has the advantage of being global, refractivity estimation by a ground-based GPS receiver can be used to provide data over specific areas of interest 2. GPS-Met mostly refer to GPS radio occultation or ground-based GPS network techniques. With a GPS receiver installed on top of a mountain, the method similar to radio occultation to retrieve the tropospheric refractivity profile was proposed by *Zuffada* et al. 3 in 1999. Mountain-based GPS Occultation method was applied by *Mousa* 3.A in Fuji Campaign and *Hu* et al. 4 in Jiugong mountain. Another single ground-based method (herein called general ground-based GPS) was first proposed by *Lowry* et al. 5 in 2002 and developed by *Lin* et al. 6 in recent years. The goal of this paper is to introduce the techniques of tropospheric refractivity profile estimation using single GPS receiver located on the surface of the earth, including mountain-based GPS occultation and general ground-based GPS method.

2. Mountain-Based GPS Occultation

In the occultation applications, the excess phase delay between a GPS satellite and a mountain-based receiver induced by the Earth’s troposphere and ionosphere, is measured and used to reconstruct profiles of tropospheric refractivity. The excess phase delay as a function of time (Doppler frequency shift) is related to the bending angle of the ray path. This bending angle can be used by the Abel transform to retrieve the tropospheric refractivity profiles. Fig.1 is a schematic diagram for the geometric relationship between the GPS satellite and the receiver installed on the top of a mountain.

The refractive index profile can be inverted with an Abel transform as

$$n(a) = \exp\left[\frac{1}{\pi}\int_a^\infty \frac{\alpha(a')}{\sqrt{a'^2 - a^2}} da'\right] \tag{1}$$

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where α is the bending angle, n is the index of refraction. Since the mountain-based receiver lies inside the atmosphere at radius r_r, only measurements of $\alpha(a)$ for $a < n_r r_r$ are available. A least squares ray tracing method can be used to recover the atmospheric refractivity *N* profiles.

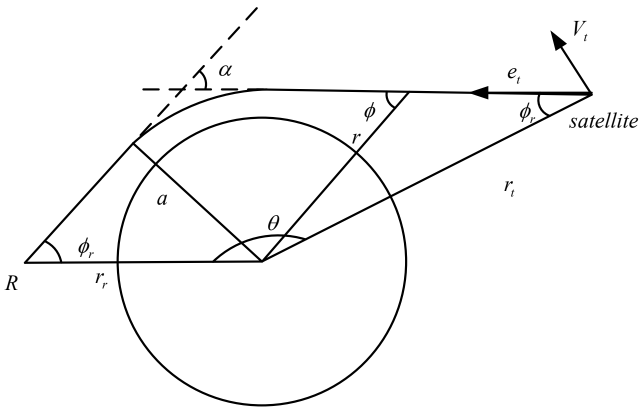

Fig.1 Schematic diagram of mountain-based GPS occultation

3. General Ground-based GPS METHOD

When the altitude of ground-based receiver is low, the Abel integral equation can't be used to yield refractivity profiles. Lowry et al. estimated refractivity structure using ray propagation models to fit measured GPS tropospheric delays in a least-squares metric. *Lin* et al. developed some new methods recently for retrieving tropospheric refractivity profiles based on single ground-based GPS, such as refractivity profile model based method by the zenith wet delay of GPS receiver, and the neural network method by slant-path delay.

Table 1 Errors of retrieval results (N) (April 2008) 7

Height	Ground-based GPS		Hopfield model	
m	Mean	RMS	Mean	RMS
500	4.39	9.89	5.81	13.81
1000	7.67	16.03	8.96	18.90
1500	5.22	16.01	5.67	17.49
2000	3.61	14.42	2.98	18.65
2500	0.45	11.56	-1.29	17.16
3000	-0.79	8.02	-3.51	14.18
3500	0.16	5.84	-3.37	11.96
4000	2.67	7.38	-1.46	10.93
4500	4.91	8.31	0.37	9.05
5000	5.70	8.15	0.93	7.27
< 5000	3.40	11.16	1.51	15.50

The results of ZTDs obtained by PPP method and radiosonde in Shanghai are compared. The precise ephemeris of IGS is utilized to get ZTD, which delay about 13 days. Table 1 shows the errors for tropospheric levels below 5000 m in the experiments in April 2008. The experimental dates are from 12 to 24 April 2008. It is obvious that the grounded-based method gives better results than those obtained by the Hopfield model. The RMS value of errors for tropospheric levels below 5000 m has been lessened by more than 3N.

4. Conclusion

Tropospheric refractivity profile estimation using single ground-based GPS has a lot of advantages such as convenient and low cost et al. Preliminary techniques have demonstrated the feasibility of retrieving refractivity profile using mountain-based and general ground-based GPS receiver measurements. These profiles obtained from ground-based GPS receivers may prove quite useful for applications such as regional weather forecasting, radar and communication systems, especially using general ground-based GPS technique. It should be noted that general ground-based refractivity profiling is further hampered by means of accurately signal delay measurements and retrieving method at the low satellite elevation angles. The techniques based upon the slant total delay should be developed in the future.

5. Acknowledgments

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6. References

1. T.P. Yunck. "An Overview of Atmospheric Radio Occultation". Journal of Global Positioning Systems Vol. 1, No. 1: 58-60. 2002.
2. Y.C. Cao, Y.M. Bi, and Z.Y. Fang. "Two methods for sounding the wet refractivity profile by GPS". Proceedings of the 3rd International Conference on Recent Advances in Space Technologies, RAST 2007, p 337-340, 2007.
3. C. Zuffada, G.A. Hajj, and E.R. Kursiniski. "A Novel approach to atmospheric profiling with a mountain-based or airborne GPS receiver". J. Geophysis. Res., 104, 24435-24447. 1999.

A. Mousa, and T. Tsuda. "Inversion algorithm for GPS downward looking occultation data: Simulation analysis", J. Meteo. Soc. Japan, 82-1B, 427-432, 2004.

4. X. Hu, X. X. Zhang, X. C. Wu, et al. "Mountain-based GPS observations of occultation and its inversion theory". Chinese J. Geophys. (in Chinese), 49(1):22-27. 2006.
5. A.R. Lowry, C. Rocken, S.V. Sokolovskiy, et al, "Vertical profiling of atmospheric refractivity from ground-based GPS", Radio Sci., 37(3), pp.13.1-13.10. 2002.
6. L.K. Lin, Z.W. Zhao, Y.R. Zhang, et al. "Tropospheric refractivity profiling based on single ground-based GPS". 2008 International Conference On Microwave and Millimeter Wave Technology, pp. 788-91, 2008.
7. L.K. Lin, Z.W. Zhao, Y.R. Zhang, et al. "Tropospheric refractivity profiling based on refractivity profile model using single ground-based global positioning system". IET Radar Sonar Navig., Vol.5, lss.1, pp.7-11, 2011.
8. Q.L. Zhu, Z.W. Zhao, L.K. Lin, et al. "Accuracy Improvement of Zenith Tropospheric Delay Estimation Based on GPS Precise Point Positioning Algorithm", Geo-spatial Information Science, 13(4) 306-310. 2010.
9. Y.Y. Wu, Z.J. Hong, P. Guo, et al. "Simulation of atmospheric refractive profile retrieving from low-elevation ground-based GPS observation". Chinese J. Geophys. (in Chinese), 53(5):1085-1090. 2010.