Open Loop Technique in FORMOSAT-3/COSMIC mission

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ABSTRACT

Radio occultation (RO) technique has been used in planetary science since 1960s. When signal goes through atmosphere, it is refracted due to the gradient of atmospheric refractivity. In 1995, the first low earth orbit (LEO) satellite, MicroLab-1, was launched to conduct RO mission. It receives the signal from global positioning system (GPS) satellites. After MicroLab-1, other RO missions, such as CHAMP, SAC-C, and GRACE, are executed in several years later. In 2006, Taiwan launched six LEO satellites for RO mission. The mission name is Constellation Observing System for Meteorology, Ionosphere and Climate (COSMIC). Under some abnormal situations, multipath and strong fluctuation in phase and amplitude of the signal appear in moist troposphere. Therefore, open loop (OL) technique has been applied to replace traditional phase lock loop (PLL) technique. In this paper, we will summarize the retrieval processing procedure and discuss the advantages and disadvantages of OL technique.

KEY WORDS: Phase Lock Loop, Open Loop

1. INTRODUCTION

With Global Positioning System (GPS), it is possible to use radio occultation (RO) technique, which has been used to research atmosphere of other planets, to study the characteristics of the atmospheric profiles of the Earth. The carrier of GPS signal is modulated with navigation code using phase shift keying (PSK) method. Propagation of RO signals through the moist troposphere possibly results in multipath and strong fluctuation of phase and amplitude. To track such signals by phase-locked loop (PLL) may result in large deviation of signal phase from the phase model, updated with the use of feedback from the received signal. Sokolovskiy (2001) noticed this and considered the open loop (OL) tracking. OL uses calculated phase model to track received signal. PLL uses feedback received signal phase model to track signal and it can modulate the influence of code. In OL, there is no information of code in calculated phase model, so it will affect the retrieval results by using excess phase. We have developed a method to resolve this problem.

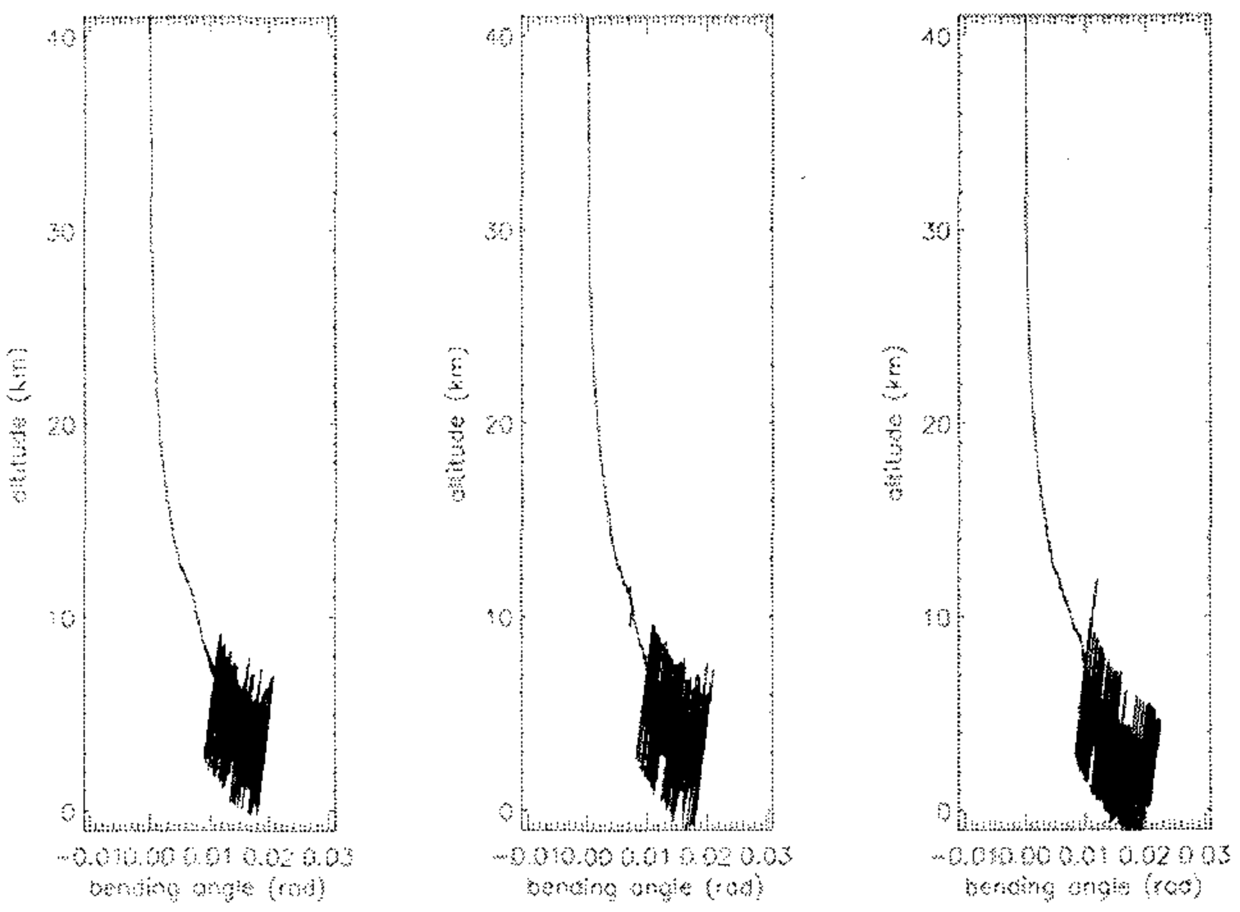

Figure 1. Bending angle profiles of FORMOSAT-3 without OL correction.

2. THE EFFECT OF OPEN LOOP

The effect of OL on bending angle is shown in Figure 1. In Figure 1, three profiles of bending angles retrieved by NCURO using excess phase data from FORMOSAT-3 without phase correction show large fluctuation at low altitude. In GPS wave pattern, phase shifts 180 degree when navigation code changes from 1 to 0 or 0 to 1 (as shown in Figure 2). To obtain excess phase, the effect of navigation codes has to be removed. It is intuitive to just recover the phase shift according to the variation of the navigation codes. However, the excess phase and navigation code are not recoded simultaneously in the gpsBit files. To recover the excess phase, the signal and navigation codes have to be synchronized first.

3. CORRECTION METHOD OF OPEN LOOP

3.1 Open Loop Correction with gpsBit

One Doppler of RO data is shown in Figure 3. The OL is activated at the beginning and results in three distinct lines. To converge these multiple lines into one, the navigation code embedded in the GPS signals has to be identified first. It is obvious that there is a time lag between these two sets of navigation codes. In order to calculate the time lag, the time correlation factor between both codes is calculated as shown in Figure 4. It is found that the time lag is $30 \times 0.02 = 0.6$ second.

Figure 5 shows three cases of Doppler after phase correction. In figure 5(up and middle), since the SNR is too low at low attitude, the information of excess phase is loss even with OL. These data of excess phase at low altitude can not be recovered using the navigation code and will be discarded. Figure 6 shows the profiles of bending angle retrieved from the excess phase profiles shown in Figure 6. Compared with the profiles shown in Figure 1, it is found the multiple lines has converged with phase correction, though there is still fluctuation due to low SNR.

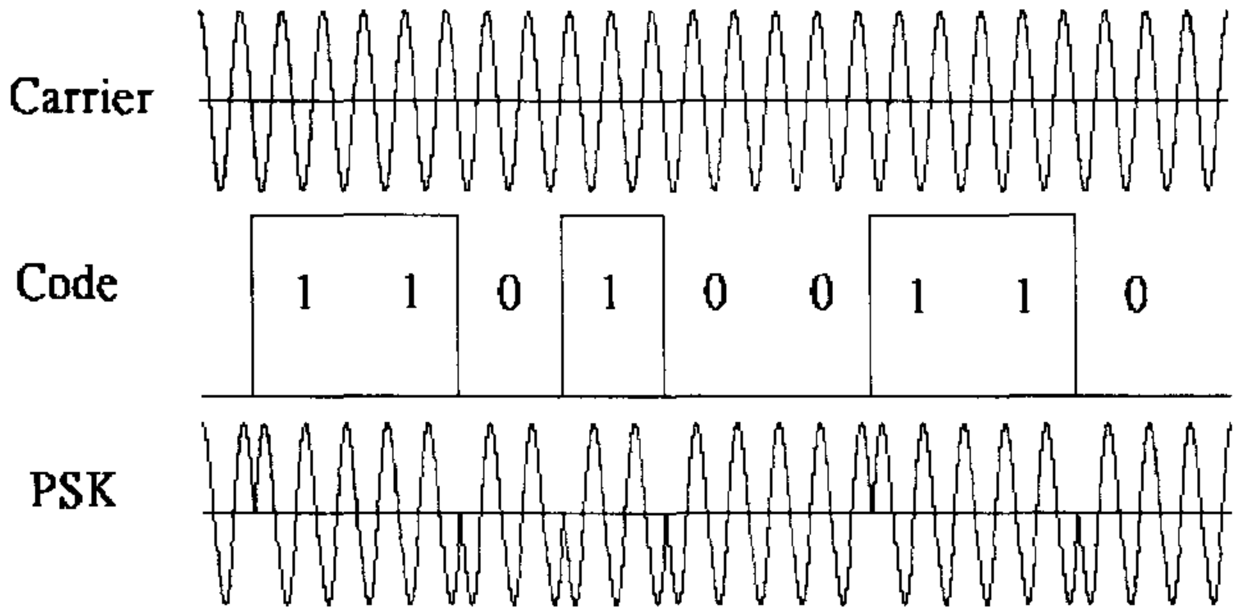

Figure 2. Modulation of the GPS signal. The carrier and the code of the GPS signal are combined using phase shift keying.

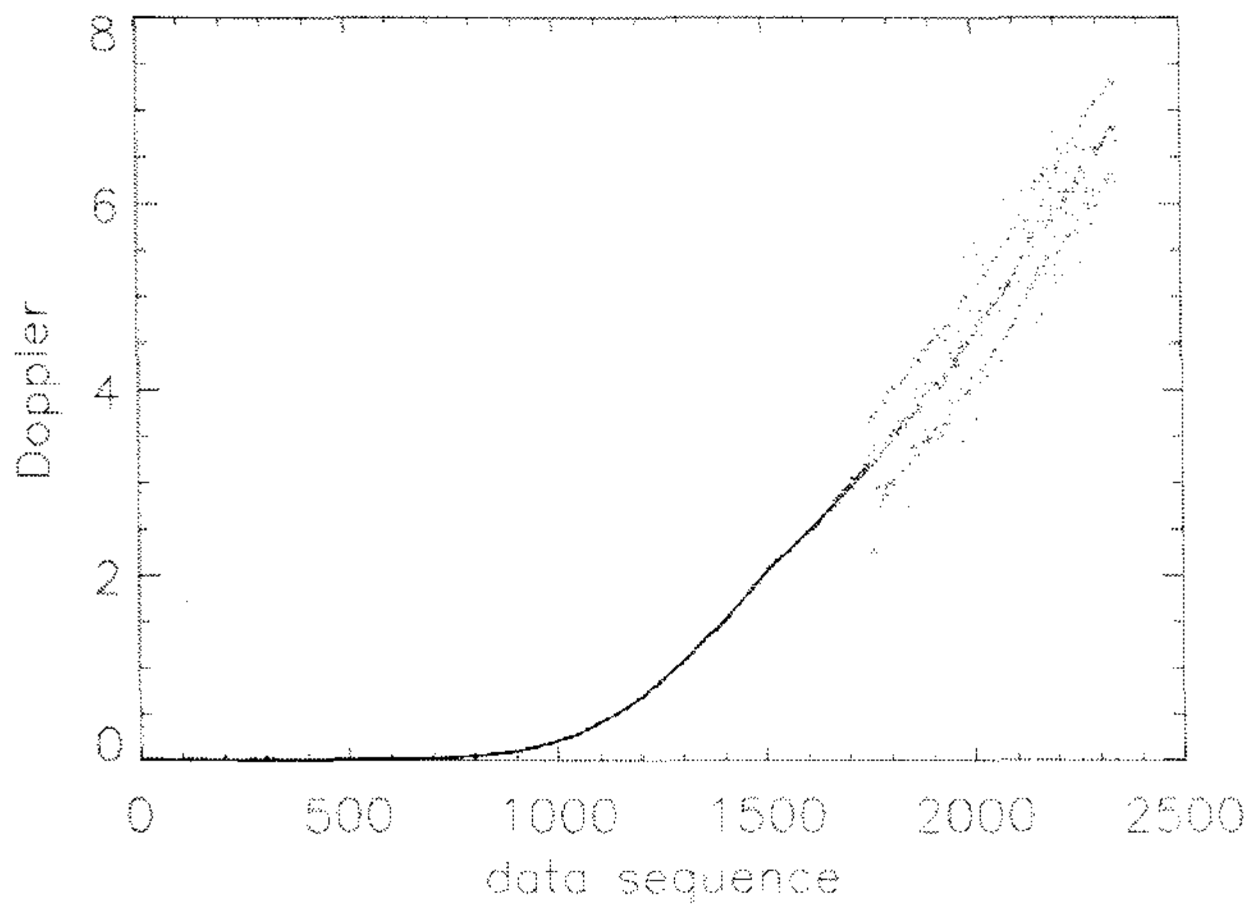

Figure 3. Doppler of the RO excess phase data. The three line situation appears once OL is activated.

3.2 Open Loop Correction without gpsBit

Not all excess phase can be corrected using the method previously mentioned since the navigation code is not always available. Therefore, a new method to correct phase without navigation code is proposed. Generally, the SNR of the signal with high impact parameter is larger than the signal with low impact parameter. Some continue data points of Doppler are first selected from the beginning of data with high impact parameter. Then with line fitting the selected point, data regression of these points is conducted. Substituting the value of abscissa of the follow point of Doppler into the regression equation, the theoretical ordinate position is obtained. If the difference value of real position and the ordinate position of the data point is close to half-wave length, shift the value of real position half-wave length to make it close to the value of theoretical position. The regression continues until the end of the data. The number of data for regression is 100 in experience.

The Doppler profiles after phase correction using navigation code and data regression are shown in Figure 7. Except the points of low SNR and fluctuations, the results from both methods are extremely similar.

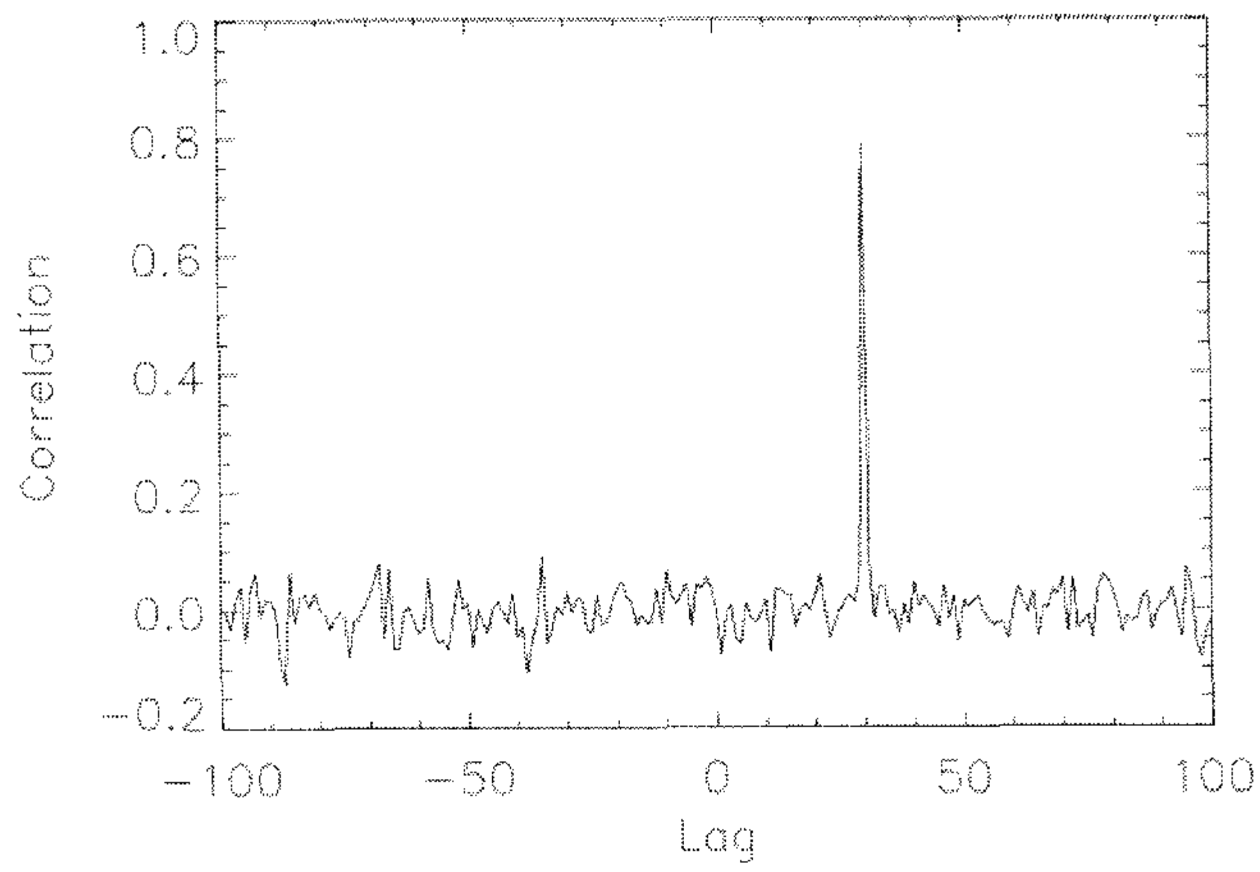

Figure 4. Cross-correlation between Doppler and navigation data.

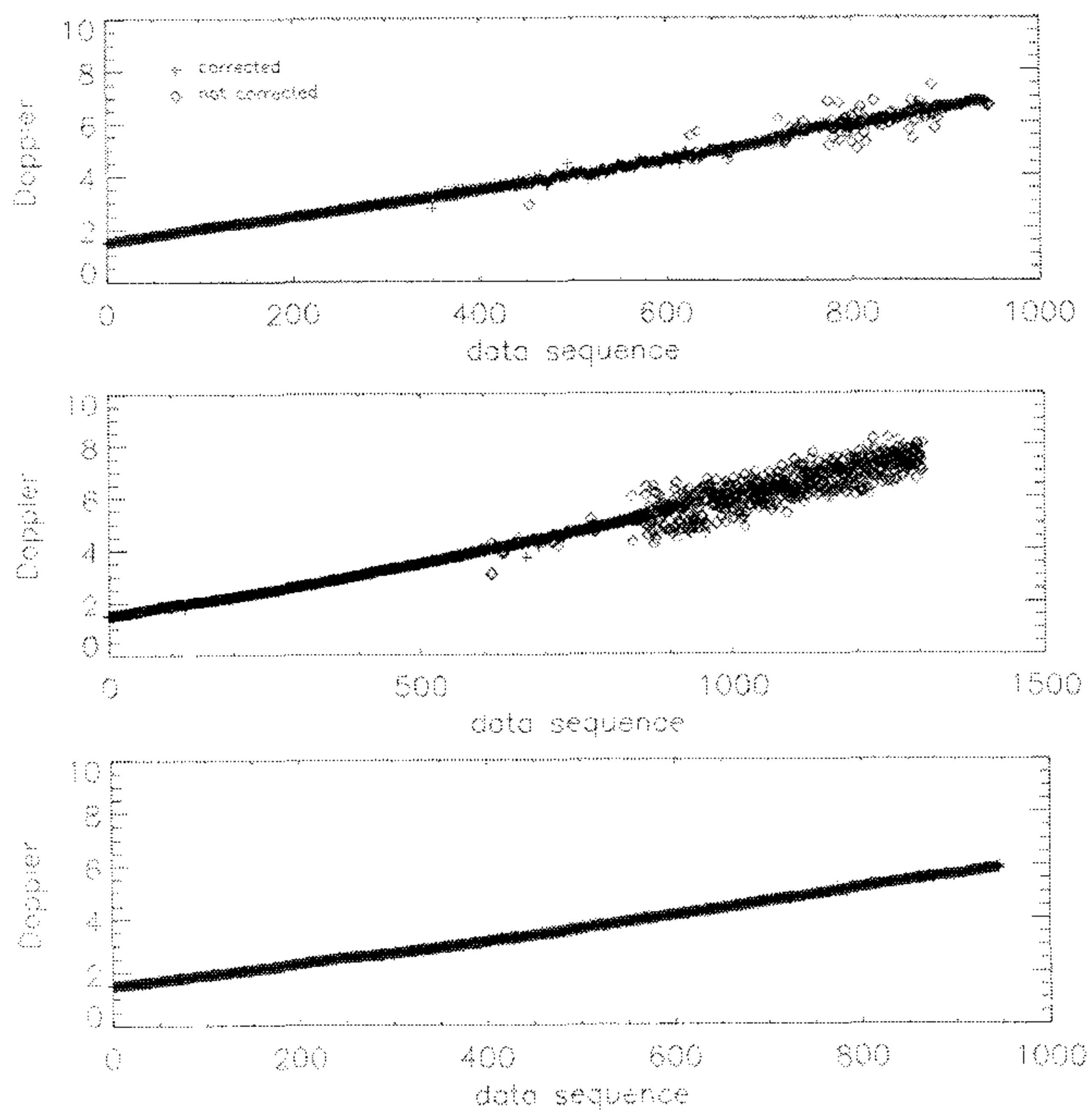

Figure 5. The data of Doppler with phase correction using navigation code.

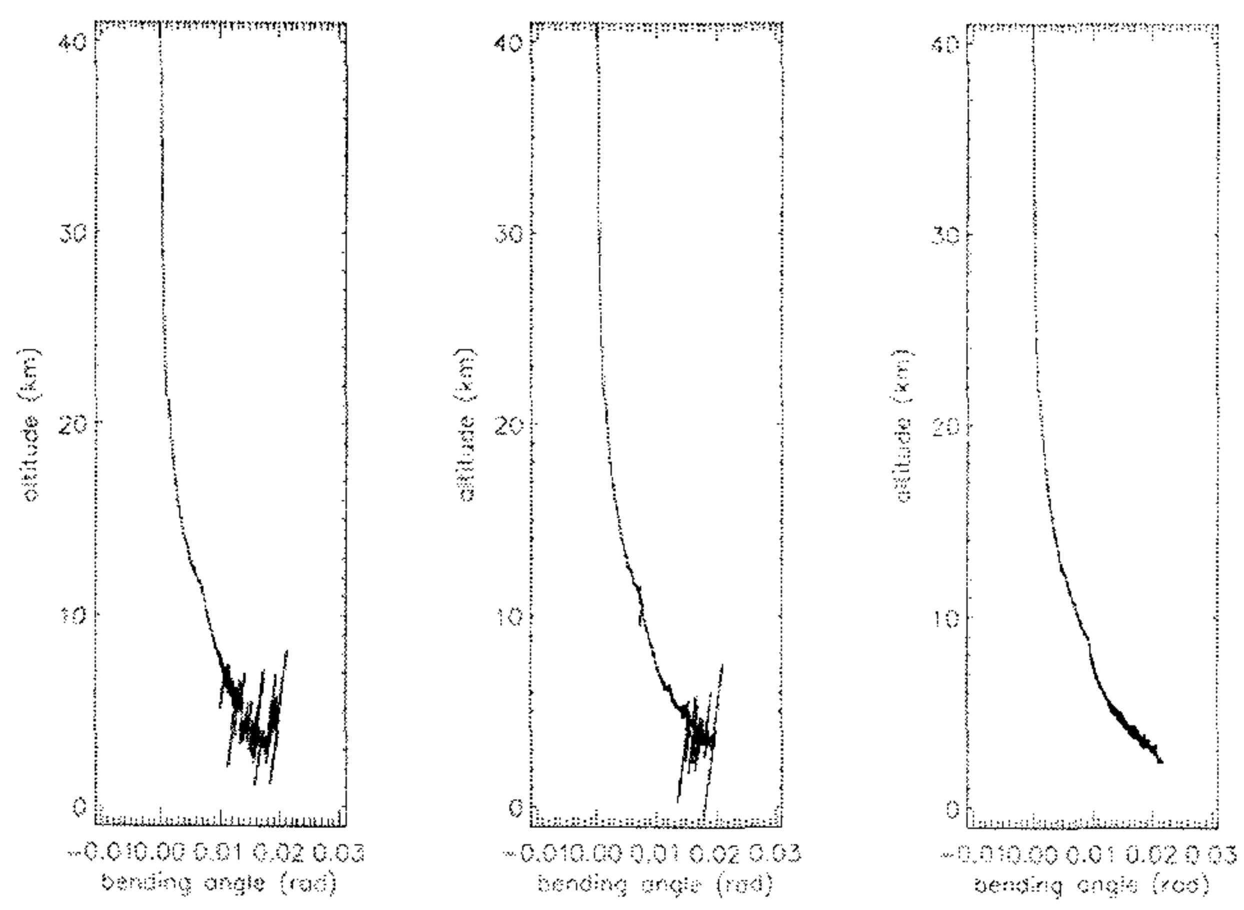

Figure 6. Retrieved bending angle profiles after OL correction

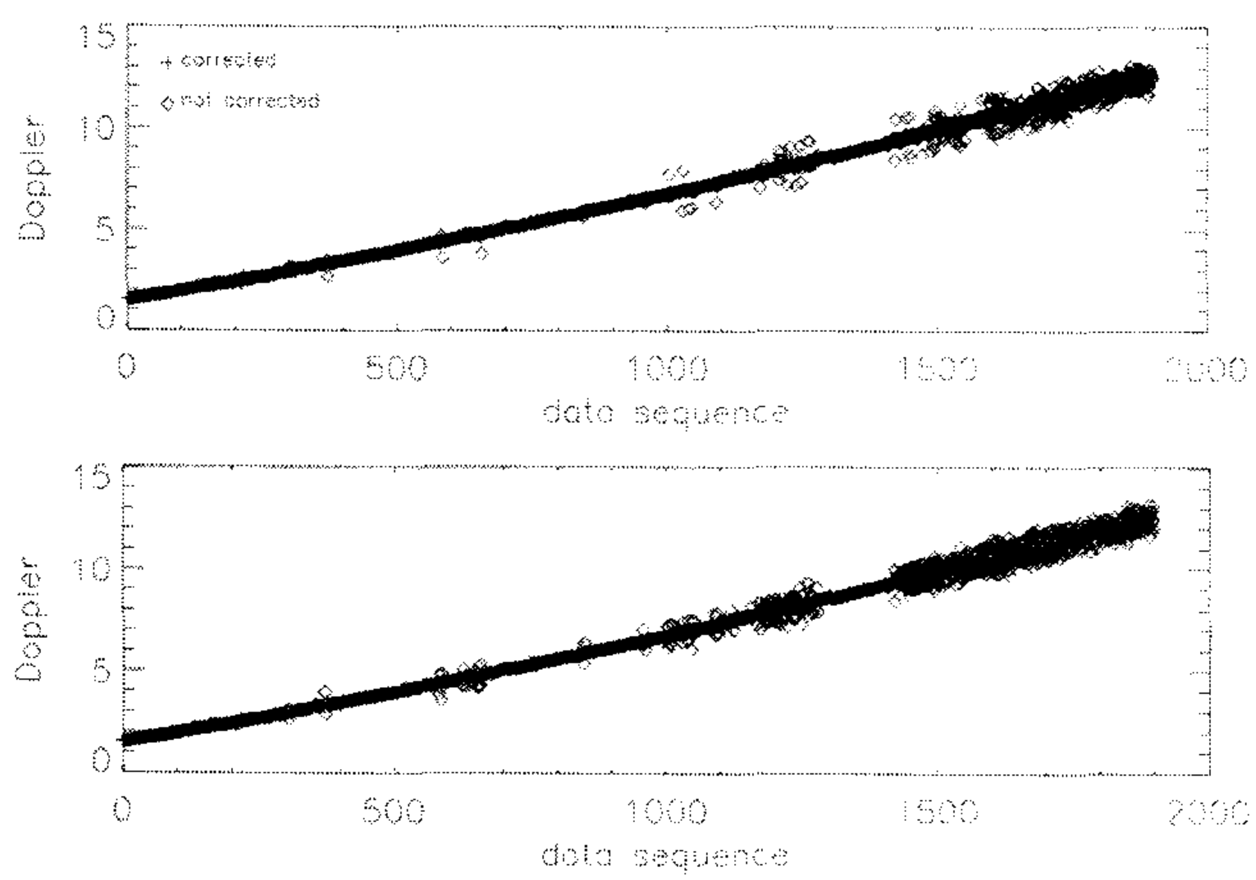

Figure 7. The Doppler data corrected by the phase correction methods with navigation code(up) and without navigation code(down).

4. CONCLUSION

We have developed algorithms to solve the problem of OL. The first method can generally be used when the navigation codes of satellites can be obtained in gpsBit files. However, the navigation codes may not always be available, and then the second method using data regression is developed to correct the excess phase in this situation.

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