Surface Scattering Characteristics and Snow Accumulating-melting Behaviors from GNSS Reflectometry

Shuanggen Jin and Nasser Najibi
Shanghai Astronomical Observatory, Chinese Academy of Sciences, Shanghai 200030, China

Abstract— GNSS-R (Global Navigation Satellite System-Reflectometry) can remotely sense Earth's surface characteristics and retrieve geophysical parameters, e.g., snow depth and soil moisture. However the surface reflectivity interaction and scattering characteristics from GNSS signals are not clear. In this paper, we model the scattering properties and investigate the surface's reflectivity characteristics interacting with GPS L1 and L2 signals in order to retrieve multipath signals and precisely infer surface characteristics. Furthermore, the effects of snow accumulating and melting together with bare soil and fixed snow depth are studied by GNSS-R. A case study from GPS observations at BAKE site is also presented as well as discussed.

1. INTRODUCTION

The Earth's surface is very complex, particularly the cryosphere, including the frozen hydrosphere (sea ice and river ice) and snowy products (snow-covered surface, permafrost and icy frozen ground) [5]. These areas are normally located far from human inhabitations with very severe climatic conditions, which are difficultly measured their variations using traditional techniques [4]. Moreover, cryospheric variations significantly affect the energy and mass balance exchange between the Earth's surface and the atmosphere [9] as well as environment changes. For example, the melting ice sheets result in the sea level rise, which may unfortunately affect human living conditions and environment. Therefore, it is very necessary to monitor snow changes and investigate the physical processes of snowy surfaces by using possible remote sensing techniques.

Recently, Global Navigation Satellite System (GNSS) reflected signals can be used to remotely sense the Earth's surface [2, 5], such as soil moisture [7] and snow depth [1, 8]. To retrieve the surface properties from ground GNSS-reflected signals, the physical surface reflectivity of the scattered and reflected signals should be taken into account. Furthermore, the chemical surface characteristic for different reflectance polarizations and different grazing angles in interacting with the GNSS signals should be known. However, most past works were focusing on the capabilities and methods of geophysical parameters retrieval (e.g., soil and snow density models), while the interaction of GNSS reflected signals with the surface is not clear. In this paper, the Surface scattering characteristics and effects of snow accumulation and snow melting as well as bare soil and stable snow surface on GPS reflected signals are modeled and investigated using the multipath from free geometrical linear combinations of GPS observations in Northern Canada.

2. THEORY AND METHODOLOGY

Two types of polarized signals from GPS satellite and surfaces are acquired by ground GPS receiver: Right-Hand Circular Polarization (RHCP) and Left-Hand Circular Polarization (LHCP) (Fig. 1). The reflected surface's signals are not only LHCP, but in fact is a combination of RHCP and LHCP signals. Generally, the incident RHCP with the angles of less than the Brewster angle produces mainly a RHCP reflected wave, while the incident RHCP for the angles with greater than the Brewster angle produces a LHCP reflected wave. At the Brewster angle, the reflected signal is linearly polarized.

In order to remotely sense the snow surface characteristics using ground GPS receiver's observations, the physical geometry of GPS reflected signals and the characteristics of surface reflected signals are analyzed. The reflected signals from the ground GPS receiver are carried by a time delay when they arrive at the GPS receiver antenna, which will result in a phase shift on the received GPS signals by the antenna. The phase change $\delta\Phi$ of received signal from the reflected surface is related to the attenuation factor that depends on the reflected surface and the height of GPS antenna as well as the reflected surface characteristics [8]. There are several methods to get reflected signals of GPS observations (code pseudorange, carrier phase and Doppler). Here using the ionospheric free geometrical linear combination is more practical due to eliminating the most effects of the ionosphere on the GPS signals. The GPS ionospheric free geometrical linear combination of carrier

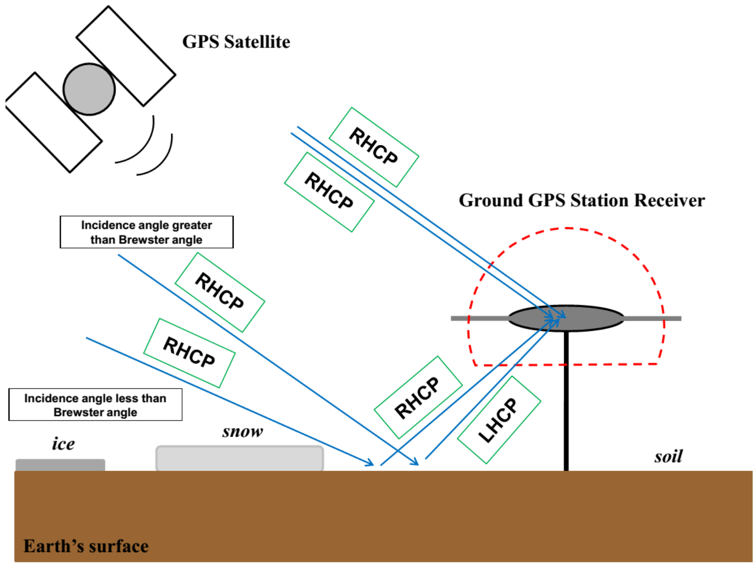


Figure 1: Surface reflectance process in GPS L1 and L2 signals for Right-Hand Circular Polarization (RHCP) and Left-Hand Circular Polarization (LHCP) components and the Brewster angle.

phase signals is expressed as [6]:

$$\text{GPS-L4} = \Phi_{IF} = -\frac{f_1^2}{f_1^2 - f_2^2} \times \Phi_1 + \frac{f_2^2}{f_1^2 - f_2^2} \times \Phi_2 \tag{1}$$

where Φ_{IF} is ionosphere free linear combination (GPS-L4), f_1 and f_2 denote the GPS frequencies ($f_1 = 1575.42\,\text{MHz}$, $f_2 = 1227.60\,\text{MHz}$), and Φ_1 and Φ_2 are the GPS dual-frequency carrier phase signals. Although the geometric information has been cancelled out by taking the difference, Φ_{IF} is geometry-free as well. The variability of reflected phase shift with respect to GPS antenna height variations (H) depends mostly on GPS satellite elevation angle (ε) and H contributes significantly to the physical reflectivity of ground GPS receiver environments The variability of GPS-L4 reflects these changes. In the following section, forward modeling of GPS reflected signals and GPS-L4 as well as their changes from real GPS observations for different snow depth changes scenarios will be

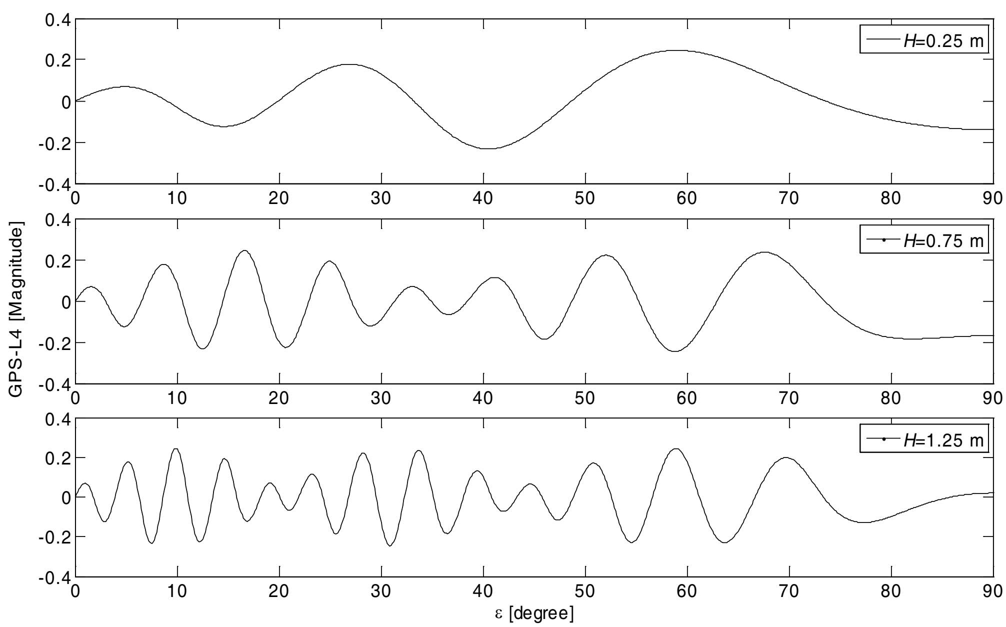


Figure 2: GPS-L4 values for snow surface ($H = 0.25\,\text{m}$), snow depth changes ($H = 0.75\,\text{m}$) and stable snow on the ground ($H = 1.25\,\text{m}$) with satellite elevation angles (ε) (GPS antenna length is assumed to be 1.5 m).

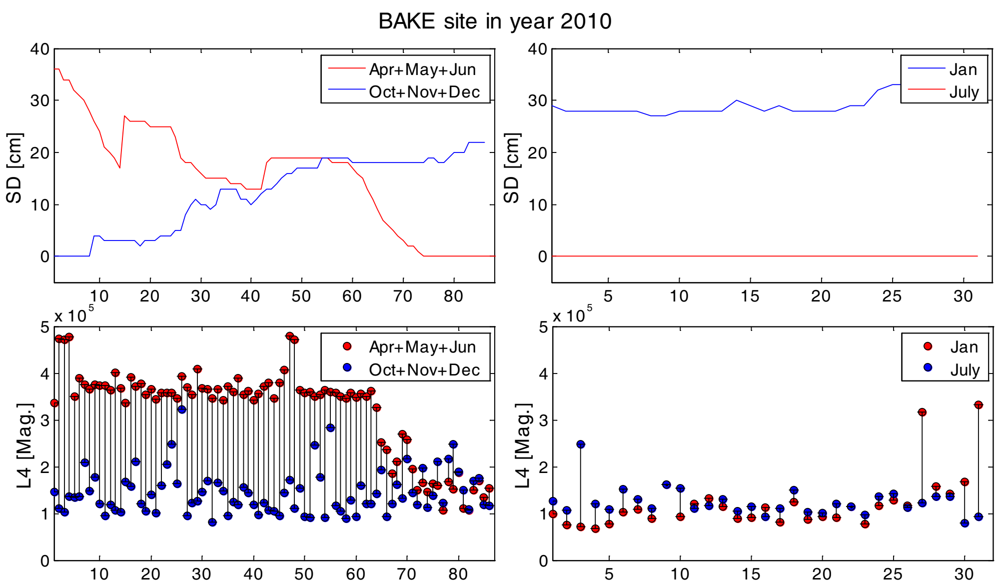
discussed in details.

3. RESULTS AND DISCUSSIONS

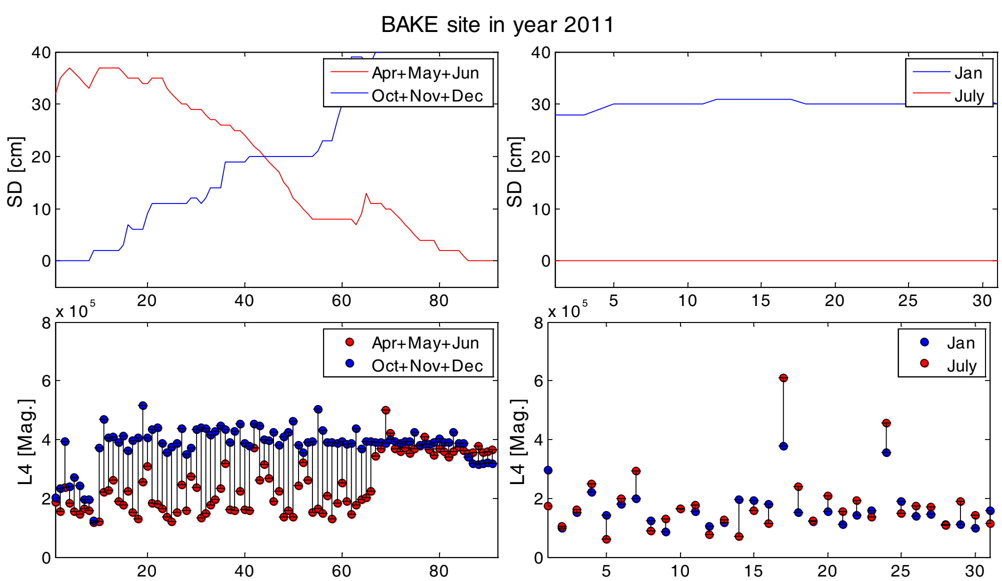
The effects of snow accumulation and melting and also fixed Earth surface (bare soil and stable snow surface) on GPS reflected signals are presented in the following. In general, the snow accumulation and snow melting are causing changes of the GPS antenna height with increasing or decreasing. The GPS antenna length is a constant and therefore depends on the existed physical environment around ground GPS receiver.

3.1. Variability of GPS-L4 Values Caused by Snow Depth Changes

The GPS-L4 values in different satellite elevation angles for snow depth variations (e.g., $H = 0.75\,\mathrm{m}$), stable snow on the ground and etc. are modeled as Fig. 2. It is clearly seen that the frequency of GPS-L4 values is increasing while the physical conditions around the GPS receiver is changing through the increase in the GPS antenna height. The amplitude of GPS-L4 value is



(a)



(b)

Figure 3: Variability of snow depth (SD) and GPS-L4 values for snow accumulation season (October, November and December) and snow melting season (April, May and June) and stable snow on the ground (January) and stable bare soil (July) at BAKE site in (a) 2010 and (b) 2011.

stable approximately, but is very sensitive to the caused changes on initial situation around GPS receiver. Furthermore, the GPS-L4's amplitude in each case is greater for those higher satellite elevation angles than low ones.

3.2. Changes of Snow States from GPS Observations

The average daily GPS-L4 values based on Eq. (1) for all possible GPS L1 and L2 carrier phase observables are computed for years of 2010 and 2011 at BAKE site in Northern Canada. The daily snow depth (SD) values are from the meteorological center at co-located BAKE GPS station. Fig. 3 shows the variability of SD and GPS-L4 for snow accumulation season (October, November and December) and snow melting season (April, May and June) and fixed snow on the ground (January) and bare soil (July) at BAKE site in 2010 and 2011. The GPS-L4 values as GPS reflected signals from ground GPS receiver show the changes in the GPS antenna height, reflecting the snow accumulating and melting.

4. CONCLUSIONS

The effects of physical reflectivity variability on the ground GPS reflected signals under conditions of snow accumulation and melting as well as bare soil and stable snow are presented and discussed, including the changes in reflected GPS signal phase shift and its variability as well as GPS-L4 values. The modeled snow depth changes are showing the capability of GPS reflected signals to sense the physical variations around the ground GPS receivers. The effect of simulated snow accumulation and snow melting scenarios on the reflected GPS signal phase shift is stable with similar pattern. GPS multipath by L4 reflects the physical situations around the ground GPS receiver and therefore the snow depth changes around the GPS receiver will cause changes of GPS-L4 values. Daily GPS-L4 observations are studied and validated at BAKE GPS station in Northern Canada for snow accumulation months (October, November, December) and snow melting months (March/April, May, June) in 2010 and 2012. The results show that the difference between snow accumulation and melting time series is constant approximately and depends on the caused changes into physical conditions around GPS receiver, while there is a difference in the amplitude of the accumulating and melting. This study presents the effects of snow depth changes on the GPS reflected signals. However, other more factors should be taken into account related to the surface characteristics polarization. Therefore, it needs to further study with considering varied types of snow for more cases in the future.

ACKNOWLEDGMENT

This work was supported by the Main Direction Project of Chinese Academy of Sciences (Grant No. KJCX2-EW-T03), Shanghai Science and Technology Commission Project (Grant No. 12DZ2273 300) and National Natural Science Foundation of China (NSFC) Project (Grant Nos. 11173050 and 11373059). We thank the IGS for providing the GPS data.

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