Sea State Determination using Power Waveforms of Beidou GEO Satellite Direct and Reflected Signals

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Abstract

The remote sensing of global navigation satellite system (GNSS) is proposed to determine the condition of sea state in this study. The technique is proved as an effective tool for measurement of sea state, especially for sea wind speed estimation, sea wave height measurement, sea roughness measurement and so on. Firstly, this technique is utilized to generate the power waveforms of GNSS remote sensing of direct and delay signals from Beidou GEO satellite. Secondly, these waveforms are analyzed to retrieve information from sea surface. Two models are used for generation power waveforms from Beidou GEO satellite direct and reflected signals. The wave spectrum model is used to find out the up and cross variances of the sea surface. It is used the Z-V scattering model for generation of power waveforms from direct and reflected signals. The generated power waveforms are analyzed according to coherent integration time and wind speed. From analysis, it is observed that amplitude of power waveforms are different shape and nature for different sea surface conditions. There is a sharp relation between amplitude of the waveforms and conditions of sea surface. This relation is used to find the sea state condition. The obtained result of sea state is compared with sea surface real situation. It is found that sea states are closely matched with real condition of sea surface.

Keywords: Beidou GEO satellite; power waveforms; sea state; scattering model; wave spectral model

1. Introduction

The determination of sea surface state is very important for different purposes i.e. especially for issuing the sea bulletin, sea weather forecasting and so on. The sea surface condition can play a numerous advancement for sea state understanding. The sea is normally a noncoverage region of synoptic observation. For this why, the state observation is huge challenging continuously. Due to impact of global warming the sea level is rising. By melting of large amount of ice in polar and subpolar regions and go this water into ocean, thermal expansion of ocean water, and atmospheric changes and ocean circulation, these oceanic zones are highly exposed [1]. In particular there are severe consequences from extreme weather such as storms, extreme waves, and cyclones, which strike hard against the population and in addition impact on the economy [2]. The sea level can monitor by tide gauge in locally [3], and by satellite in globally. Many airborne experiments have been operated to research the suitability of the GNSS remote sensing technique to measure ocean surface winds during the last decade [4]. The signals scattered from global navigation can be used not only to identify the positioning, but also for remote sensing [5]. The scattered signals from GNSS satellites have been using a good option for remote sensing during last two decades [6]. This technique is known as GNSS reflectometry (GNSS-R), which is first proposed by Martín-Neira in 1993 for ocean altimetry [7]. The use of scattered signals is known as GNSS-R technique, has been using a field of interest [8]. The power waveforms analysis technique is already used to measure sea wind speed [9-10], sea roughness trend measurement [11], sea state monitoring [12] and so on in the previous research.

GNSS-R can be worked as a bistatic radar, in which the transmitter and the receiver are separated by significant distance [13]. The present research determines the ocean state & it's trend. There are many techniques for sea state, but this technique is a direct measurement technique which operates according to response of reflected signal. It is an innovative concept for determination sea state by using of power waveforms. Actually, it indicates the primary conditions of sea surface.

2. Experimental Setup & Methodology

2.1. The Bistatic Geometry of GNSS-R

The bistatic geometry of GNSS reflectometry is used in this research. When the direct signals from satellite incident on sea surface, they will be scattered in irregular processes. This irregularity actually depends on the condition of sea surface. When the surface is calm, the reflection will become regular which will follow the Snell's rule of reflection, if the surface is calm and regular reflections will occur on specular point on the sea. It is same and equal of incident and reflection angle on specular point. Delay and doppler situation are produced when the signal scattered from water surface. This system can generate delay doppler map (DDM). This DDM can establish a sharp relation between delay and doppler on the sea according to different sea state condition. The signal scattered from the sea surface can be collected by GNSS-R receivers and can be noted. When the signals interact with sea surface, it can generate a glistening zone (GZ) [14]. The size and shape of these GZs depend on sea condition. The magnitude of the GZs can determine according to surface roughness & distance between transmitter and receiver.

2.2. The Wave Spectrum Model

Tanos Elfouhaily is proposed a model named wave spectrum model. He developed and utilized this model to represent the sea surface waves. The model is usually used to retrieve the variances of ocean surface. The model input are wind speed and satellite elevation and output of this model are up and cross variances. The Elfouhaily wave model is (when a wave number k, wind velocity U_{10} and angle ϕ) as

$$\Psi\left(k,U_{10},\varphi\right)=\frac{1}{2\pi}K^{-4}[B_1(U_{10})+B_h(U_{10})][1+\Delta(k,U_{10})\cos(2\varphi)] \quad \ldots\ldots\ldots\ldots..(1)$$

where, subscripts l and h frequencies of low and high respectively. B_I = curvature spectrum for long wave, B_h = curvature spectrum for short wave, Δ= function of unified spreading.

The wave number elevation spectrum shown above is converted to a wave number wave slope spectrum for the purposes of calculating the omni-directional mean square wave slopes as described in

$$mss(U_{10})=\int_0^{*k}\int_{-\pi}^{+\pi}\Psi(k,U_{10},\varphi)d\varphi dk \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

The wave spectrum model is provided sea surface variance of slopes.

2.3. The Scattering Model

The scattering model is used to generate the power waveforms from Beidou GEO satellite direct and reflected signals. This model is also related to scattering coefficient with different types of sea roughness. The bistatic scattering model is effective to solve the GNSS-R problem considering Kirchhoff approximation (KA) and geometric optics (GO) [15]. The general formula of this scattering model is denoted by the below equation:

$$\langle Z(\Delta_\tau,\Delta_f)\rangle\infty\iint_D\frac{G_r(r)}{R_G^2(r)R_R^2}\frac{q^4}{q_z^4}P(-\frac{q^\perp}{q_z})*\Lambda^2(\tau(r)-\Delta_\tau)\theta^2(f(r)-\Delta f)dr \quad \ldots\ldots\ldots\ldots\ldots (3)$$

where, r is the spatial coordinate on the sea surface, Gr is the down-looking antenna gain, q is the scattering vector, P is the probability density function (PDF) of the sea surface slope, Λ is the auto correlation function (ACF) of the ranging code.

2.4. GNSS Data Collection

The GNSS raw data from Beidou MEO satellite is used in this research. This data is collected from Shandong Province of China. A data collection campaign was organized around 7 km distance from the coast of Bohai sea. The aim of the campaign is to record raw samples of GPS and BeiDou signals for different situation of sea.

2.5. Power Waveforms of Real Data

Power waveforms of real data are produced from direct and reflected signals of Beidou MEO satellite. A MATLAB geographical user interface (GUI) is designed to generate the power waveforms. The GUI is operated and it is generated the power waveforms from real data of direct and reflected signals as output. The operation technique of GUI, at first, it is loaded the tracking file of data file. Secondly, the algorithm reads the tracking information and displays results as code phase and doppler frequencies. Thirdly, the user has to select signal and integration time. Lastly, the user just presses the generate power waveform button to display the result on graph.

2.6. Power Waveforms of Model

The generation of power waveforms by modeling is discussed in this section. Mainly, two models are utilized to simulated reflected power waveform in this paper. At first, wave spectrum model is utilized to represent ocean waves for GNSS bistatic problem. The outputs of this model are sea wave up and cross slopes. Secondly, these up and cross slopes and the scattering model is utilized for generation of power waveforms. As input of wave spectrum model, the wind speed and satellite elevation angles are used.

2.7. Technique for Sea State Determination

To determine sea state, the amplitude and characteristics of the generated power waveforms are used in this research. It is analyzed and compared characteristics of the waveforms for different types of sea state conditions. The concept is designed for understanding the sea state according to amplitude of power waveforms in different sea conditions. It is found that the amplitude and characteristics of power waveforms is directly related to integration time, wind speed and satellite elevation angle. For the model and real data result is almost similar, the amplitude of power waveform obtained from GEO satellite data has greater amplitude from model. The amplitudes of the waveforms are inversely related to wind but directly related to integration time and satellite elevation.

3. Results and Discussion

3.1. Results of Power Waveforms for Raw Data

The direct and reflected power waveforms of Beidou GEO satellite of PRN No. 6 with different integration time are shown in Figs. 1, 2, 3 & 4. It is found that amplitude of the power waveforms is directly related to the integration time for both raw data and model. Figure 1 & 3 are shown the individual results of power waveforms for different integration time i.e. 1ms, 10ms, 50ms & 100ms and figure 2 & 4 are shown the combined results of direct and reflected signals of Beidou GEO satellite respectively. It is analyzed the results on the basis of two different parameters coherent integration time and wind speed.It can be found in the figure 1, 2, 3 & 4 with the increase of coherent time the amplitude of direct and reflected waveforms is increased.

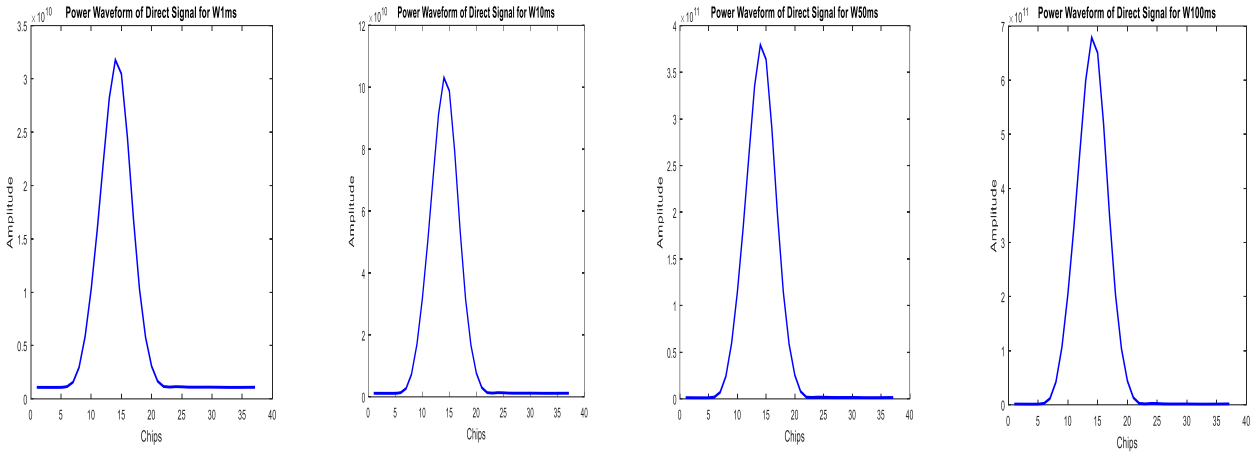

Fig. 1. Power Waveforms of different integration times (1ms, 10ms, 50ms & 100ms) for direct signals

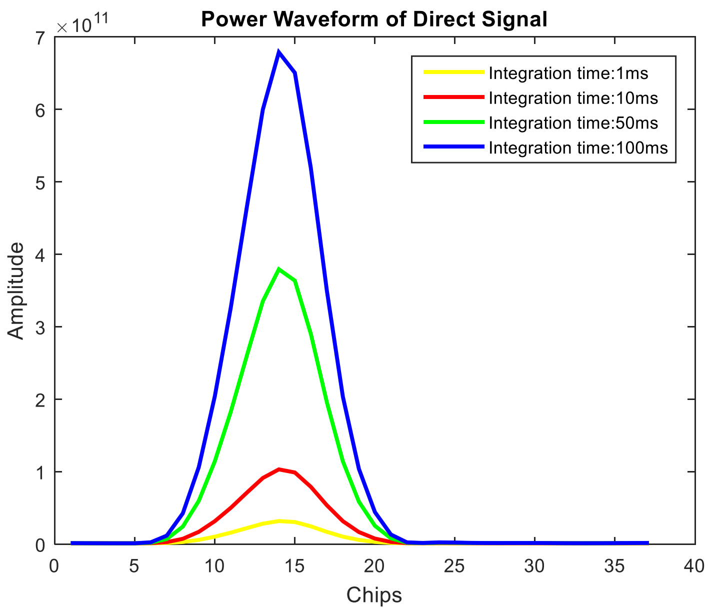

Fig. 2. Power waveforms of direct signal for different integration times (combined)

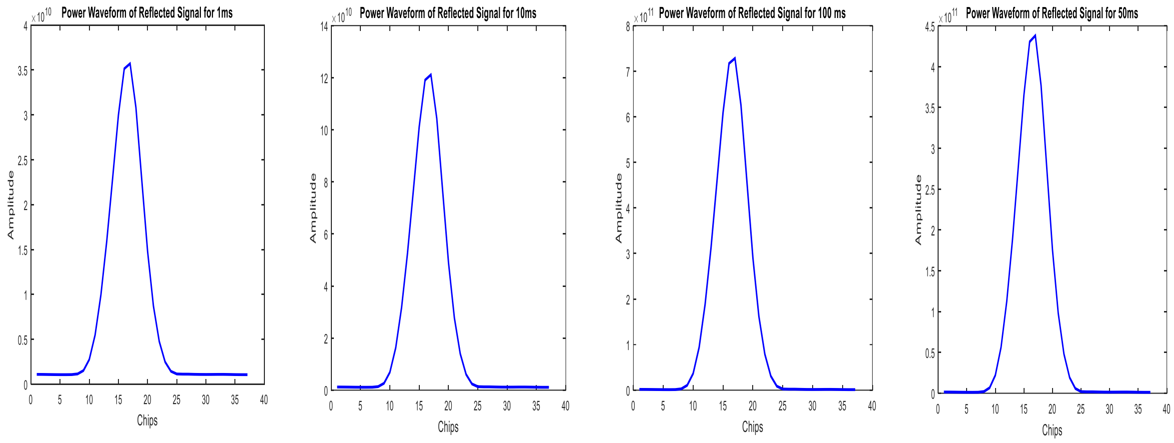

Fig. 3. Power waveforms of Reflected Signals for different coherent integration times (1ms, 10ms, 50ms & 100ms)

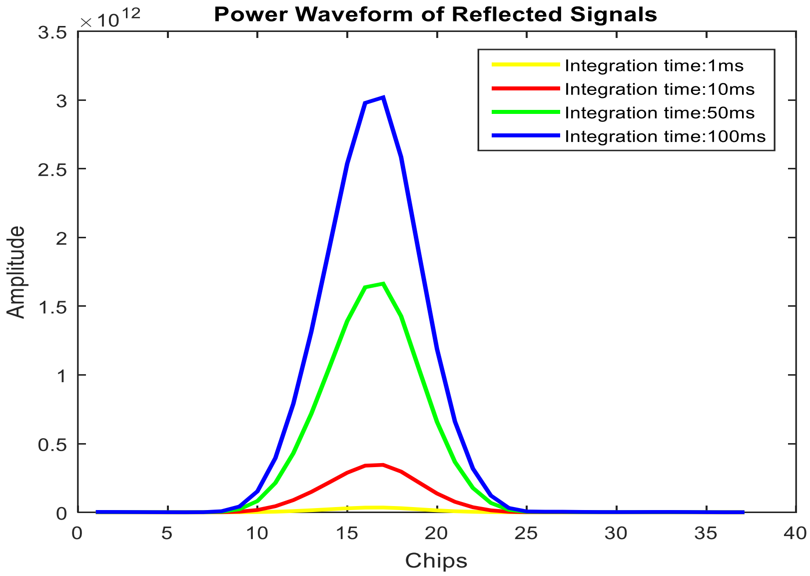

Fig. 4. Power waveforms of reflected signal for different integration times (Combined)

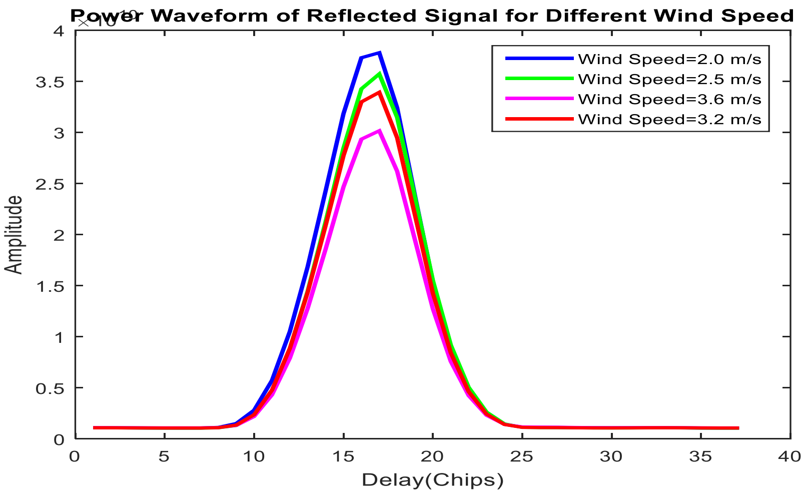

Fig. 5. Power waveforms of reflected signals for different wind speed

The result of generated power waveform's amplitude is analyzed according to different wind speed also and the obtained result is displayed by the figure 5. It is found that with increase of wind speed the amplitude of power waveforms is decreased. Power waveforms are produced for 4 different wind speed i.e. 3.6 ms-1, 3.2 ms-1, 2.5

ms-1, 2.0 ms-1 in figure 5. The shape of the power waveform is almost auto correlation function for very low wind speed.

3.2. Results of Power Waveforms for Model

The result of the power waveforms for model are almost similar to the data. In model, it is found that the amplitude of the waveforms is also increased with the coherent time and decreased with the wind speed. In figure 6, it is displayed amplitude of the waveforms of different integration times i.e. 1ms, 5ms and 10 ms.

For model, the amplitudes of the waveforms of different wind speed is shown by figure 7. It is displayed the waveforms for 4 different wind speeds i.e. 5 ms-1, 10 ms-1, 15 ms-1, 20 ms-1 and 25 ms-1. In figure 7, it is found that amplitude of the waveforms is increased with the decrease of wind speed. It indicates that there has an inverse relation between the wind speed and the amplitude of the waveforms.

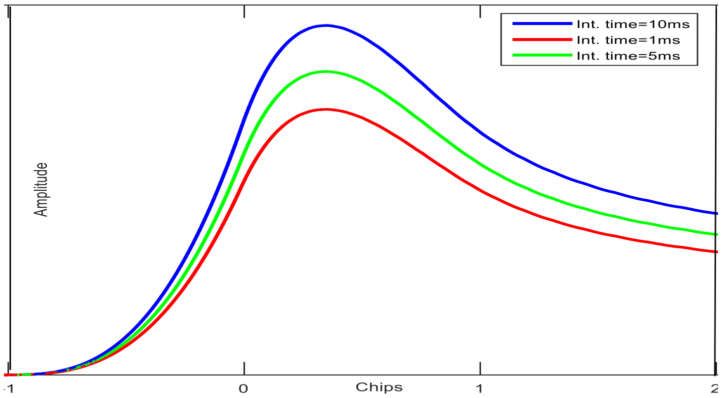

Fig. 6. Model power waveforms of different coherent integration time

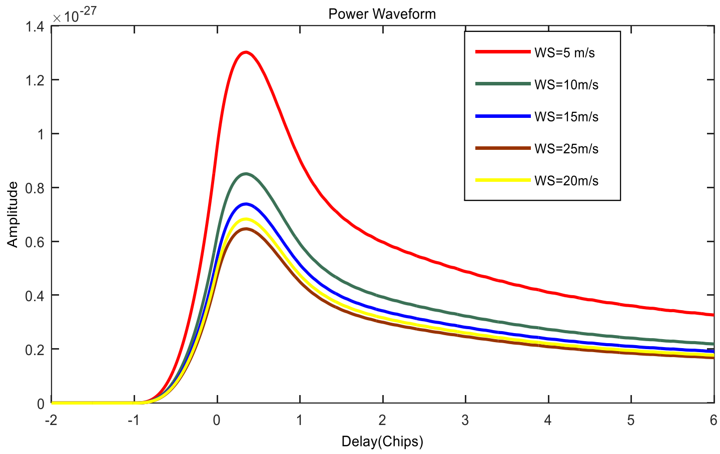

Fig. 7. Model power waveforms of different wind speeds

Power waveforms of direct & reflected signals of Beidou MEO satellite are analyzed and compared. It is found that the amplitude and characteristics of the power waveforms are similar for both type of signals i.e. direct and reflected signals. The amplitude of direct signal is higher than reflected. It is observed that the waveforms are sensitive to integration time. It is also observed that both real data and model, the result is similar. But the shape of the power waveforms is little different for the real data and model. When the surface is calm, the waveforms are auto correlation function. But the power waveforms for model is not smoothly shaped, it is delayed due to antenna gain. The sea state is determined by the relationship between amplitudes of the power waveform and the two parameters, which is shown as Table I.

Table 1: Sea State Determination from Power Waveform

Parameters	Trend of Parameters	Amplitude of PWs	Sea Roughness
Coherent Integration Time	Increase	High	More
	Decrease	Low	Less
Wind Speed	Increase	Low	Less
	Decrease	High	More

4. Conclusion

In this study generated power waveforms from direct and reflected signals of BD GEO SAT data and model are performed for determination of sea state condition. Sea state or sea roughness trend measurement from power waveforms is an innovative idea and this idea can be treated as a preliminary monitoring system of sea surface. Power waveforms are mainly analyzed for understanding the representation of the surface. But, in this research, sea state is determined using the combined features of power waveforms with two different parameters such as integration time and wind speed. It is analyzed the waveform in term of coherent integration time and wind speed. Sea state is determined using waveform's characteristics. When the wind speed is increased, the amplitude of the waveforms is decreased. This relationship is used to determine the sea surface state condition. These relations are structured for general compliments for sea state conditions and roughness.

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