Tide and Wave Measurement Based on High Precision Dynamic GNSS Technology

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ABSTRACT: Nowadays the development of Global Navigation Satellite System (GNSS) has been increasing rapidly. GNSS has such advantages as all-weather working and high precision, widely applied in the field of crustal movement monitoring and high-rise building dynamic feature monitoring. However, GNSS is rarely used in the field of tide and wave monitoring. Wave and tide, as important movement phenomena in the ocean, have an impact on human activities at sea and nearshore. In this paper, the inversion of wave parameters and tide level changes using high-frequency dynamic GNSS has been studied. Combined with GNSS dynamic positioning technology (RTK, PPP, PPK modes), the shipborne GNSS positioning data is solved and the elevation change is corrected. Using the nearshore control points, the geoid-like model was constructed based on the EGM2008 model to realize height conversion and obtain the tide level changes based on the local tide datum. Then a high-precision GNSS single-point velocity model has been established using the GNSS carrier phase data through the epoch difference. After eliminating the zero drift caused by velocity integral through the sliding average processing, the high-precision surface wave motion can be obtained. Based on the spectral analysis, the wave power spectrum can be calculated to obtain wave period and wave height, which are well consistent with the results of the existing wave gauge and tide gauge.

1. INTRODUCTION

Ocean fluctuations are one of the important forms of seawater movement. As an important movement phenomenon in the ocean, the waves have a great impact on the sea and near-shore human activities.On the one side, wind waves and swells contain enormous energy, which can make ships swing and bump with ship speed reduced and heading offset, even causing shipwrecks.Thus wind waves and swells are very harmful to navigation, fishing, surveying and other offshore work; wind waves and swells have a great destructive effect on coastal protection, ports and breakwaters, and a handling effect on sediments, which even leads to harbor siltation, shallow waterways and insecurity of ship entry and exit. On the other hand, waves also have benefits whose enormous energy can be used to generate electronic power.In order to make full use of advantages and reduce damage, it is necessary to obtain accurate wave measurement. In recent decades, due to the development of marine exploitation and utilization, the demand for maritime wave observation data has also increased. The change of tidal level along the coast is directly related to the ship entry and exit. The design of the marine and coastal engineering, the depth of the mine's water distribution, the storm surge forecast, and the sea reclamation are all affected by the tide. Therefore, tidal measurements are of great significance in determining mean sea level and depth datum, commanding offshore work, and laying submarine cable.

1.1 Wave Measurement Technology

The most widely used wave observation technology is accelerometer-type wave gauge. The internationally recognized highest-precision wave gauge is the MARKII "wave knight" buoy produced by Datawell Company of the Netherlands. In addition, pressure-type, acoustic-type and vertical-line wave gauge that have been applied in different scales, are less used than acceleration-type wave gauge.

The above-mentioned wave measuring buoys and gauges can effectively observe the waves, but in some respects are also slightly insufficient. For example, the pressure-type and acoustic-type wave measurement are obviously affected by the water depth; the accelerometer-type wave gauge is of relatively high precision though, the disadvantages of which is high cost and several difficulties in operational observation. In addition, other positioning equipment is required to obtain the position information of the wave measurement.While traditional wave measuring instruments are constantly evolving, several new methods of wave measurement have been carried out, such as synthetic aperture radar wave remote sensing methods, X-band radar wave detection technology, stereophotometry wave-measurement, shipborne laser wave measurement and GNSS-R wave inversion studies, etc. These studies have greatly promoted the technological advancement in the field of wave measurement monitoring, and also promoted the emergence of new technologies for wave measurement. At the same time, these new technologies have more or less difficulties in application. For example, the X-band radar echo image derivation algorithm still needs improvement, especially the acquisition of effective wave height; the technology based on photogrammetry and laser measurement that needs aviation equipment cannot be implemented in fog, clouds, night or offshore; the space wave measurement technology such as synthetic aperture radar is not continuous, and the cost of using and maintaining the satellite platform is high.

Compared with existing methods such as accelerometers, the method of GNSS-based wave measurement has a simple system composition and relatively low cost (Harigae M. et al., 2005; Devries J.J. et al., 2007; Nagai T., et al., 2014). In order to verify the feasibility of GNSS technology applied to wave measurement, some scholars have conducted relevant researches. Jean uses GPS-RTK technology to obtain the wave parameters based on the buoy position information, and compares the obtained wave observations with the estimated wave heights of the accelerometers. The wave heights obtained by two methods are highly correlated (Jeans G et al., 2003). Paul made a detailed comparison of GPS position buoy measurement and ADCP measurement, proving that GPS monitoring results are superior to ADCP monitoring results (Paul A, 2008). The above researches are based on GNSS location information, while it is difficult to obtain accurate and real-time location information during GNSS positioning, especially single station positioning. Thus data post processing must be performed, which leads to the remarkable timeliness reduction of wave measurement monitoring and warning.

1.2 Tide Measurement Technology

Tide data is important basic information for conducting marine scientific research, marine resources exploration, and seabed topography surveying. Traditional tidal measurement often use staff gauge, tide gauge, and tide well that all require level-testing, which is time consuming and labor intensive. In addition, the traditional tidal measurement technology needs to be checked at a known point, which is obviously condition-constrained. With the development of GPS technology, it has been widely used in the fields of sea tide and sea level dynamic change monitoring (Galas, 2013; Dawidowick, 2014). According to the different carriers, the GPS tide is divided into the shipborne GPS and buoy GPS. The two methods are basically the same principles that tidal level is obtained by the inverse calculation of geodetic height with GPS carrier phase measurement technology as positioning basis Fujita used GPS-RTK to measure tidal level and compared it with the local tidal station measurement data, which concluded that the precision of GPS tidal level observation is comparable to the tidal station observation with consistent variation trend (Fujita T. et al , 2004); Kotsakis C. et al. used GPS positioning technology combined with the earth's gravity field model to calculate the tidal level change in Greece (Kotsakis C. et al., 2010); John A. et al. used GPS precision positioning technology to monitor global sea level rise from the end of the 19th century to the beginning of the 21st century, which is consistent with the data trend of the tide level monitoring station (Church J. A.,. et al., 2011); Simav et al. used GPS precision positioning technology to solve the change of tide level in Turkey, and achieved high consistency with the data of the tide level monitoring station (Simav et al., 2012). The above researches are based on location information.

2. METHODS

Based on GNSS velocity measurement technology, real-time acquisition of carrier high-precision velocity information can be realized. It is more flexible than positioning technology, and the accuracy of velocity measurement is less affected by positioning error. In addition, sea surface displacement modeling based on velocity information can better reflect the differential characteristics of sea surface fluctuations, which is more sensitive than the model based on GNSS receiver position information. Most of the GNSS receivers can record the original Doppler observations while recording the phase observations. However, the accuracy of the original Doppler observation is unstable. When the accuracy of the original Doppler observation recorded by the receiver is not high, it will lead to low speed measurement accuracy, which makes the result of wave height measurement unsatisfactory. Therefore, a more reliable and stable velocity measurement method should be used for wave measurement research.

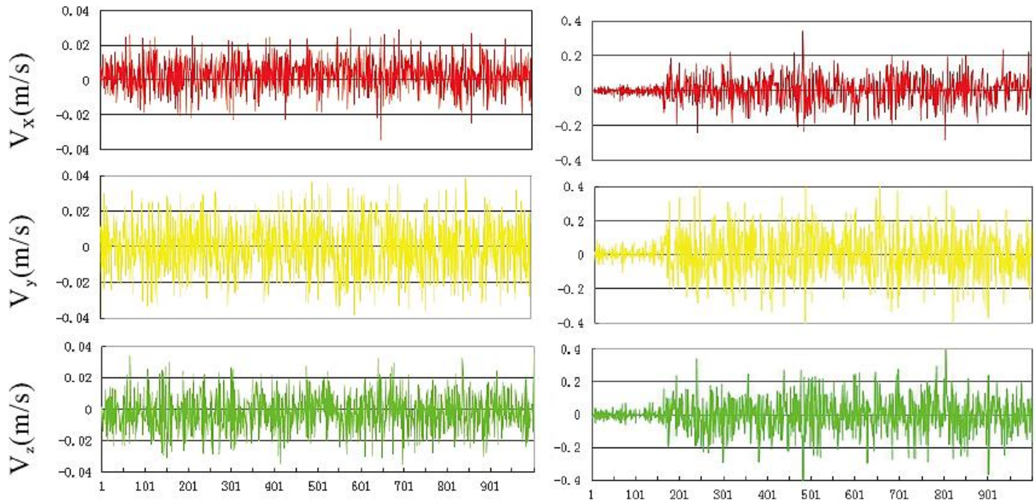

Figure 1 Calculation results using observation data of 0.5s

(a: Computed results using export Doppler value m/s;

b:Computed results using original Doppler value m/s)

Doppler value can be solved by the pseudo range or phase epoch difference. GPS receiver can record the original Doppler observed values and carrier phase observations. As shown in Figure 1, the accuracy of the carrier phase observations is much better than code phase observations, so the calculation of the export Doppler value in this study used the phase observations corresponding to L1 carrier. It is clear that the results solved by export Doppler observations are better than those solved by the original Doppler observations in the three directions.

3. RESULTS AND DISCUSSION

3.1 Ship Borne GNSS Wave Measurement & GNSS Wave Buoy

A high-precision GNSS single point velocity model is established using the GNSS carrier phase data through the epoch difference. After eliminating the zero drift caused by velocity integral through the sliding average processing, the high-precision surface wave motion can be obtained. Based on the spectral analysis, the wave power spectrum can be calculated to obtain wave period and wave height, which are well consistent with the results of the existing wave gauge and tide gauge.

A single GNSS sensor for ocean wave measurement greatly reduces the cost of maintenance thanks to its ability of obtaining location information at the measurement point and the wave parameters without the aid of other external sensors. The GNSS single point velocity mode cannot be limited by the operating range and the velocity accuracy is not subject to position accuracy constraints, thus especially appropriate for open sea applications.

As shown in Figure 2, the wave and tide measurement method has been realized based on GNSS single-point velocity measurement.

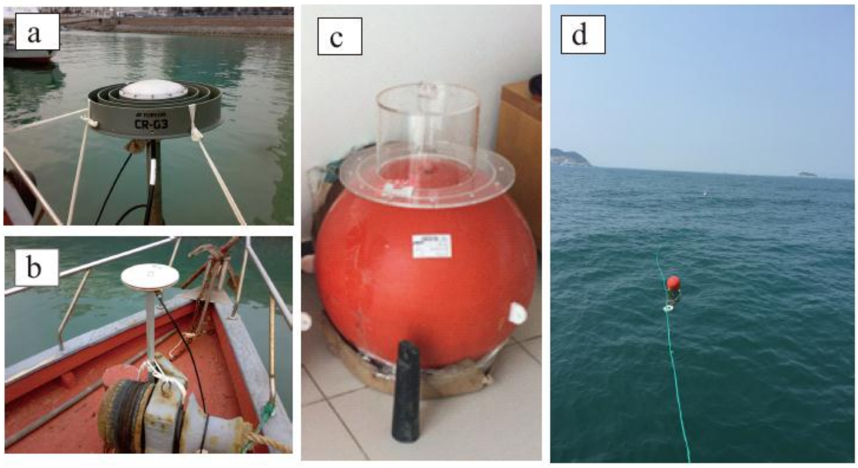

Figure 2 Ship borne GPS wave measurement & GNSS wave buoy
(a and b:Ship borne GPS wave measurement; c:GNSS wave buoy;
d:Wave measurement with GNSS wave buoy)

A large number of experimental data is collected by using the wave buoy. During the test, the buoy has a good wave fluctuation and can basically meet the acquisition of experimental data. Based on the measured data obtained, the Doppler velocity measurement method is used to deal with the zenith direction velocity at the measured point (the red line in Figure 3). The velocity time series is a good reflection of the fluctuation characteristics of the buoy with the sea surface fluctuation. After the integral transformation, the velocity value can reflect the long period characteristics of the change of the sea surface displacement, but the drift of the vertical displacement (the blue line in Figure 4), that is, the zero drift of the water level, can be found due to the existence of the external noise.

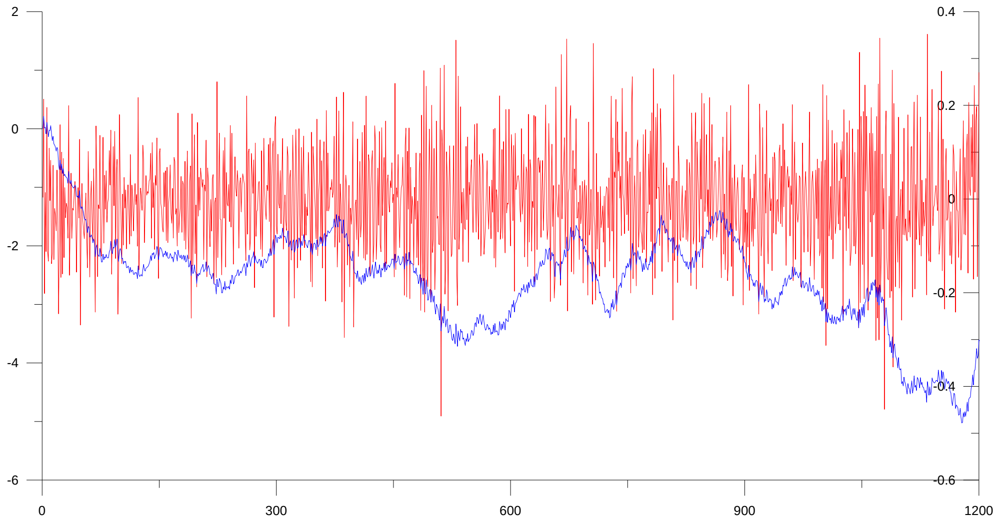

Figure 3 the vertical velocity and integral displacement time series of the GPS buoy

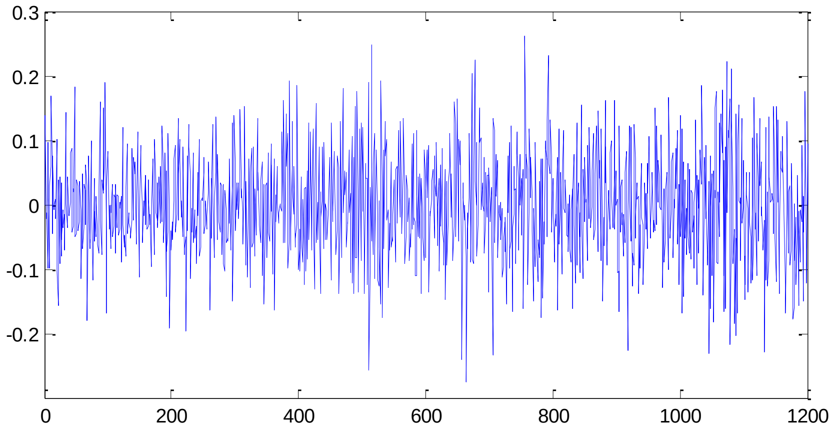

Figure 4 Sea surface displacement fluctuation

The low frequency trend term of the vertical integral displacement is obtained by the sliding mean method. The wave signal is obtained after the reduction of the trend in the original integral displacement data, as shown in Figure 6. It can be seen that through the research method of this project, we can get the wave fluctuation signal of buoy well through GPS velocity data.

3.2 Tide Measurements by Using GNSS Technology

Combined with GNSS dynamic positioning technology (RTK, PPP, PPK modes), the shipborne GNSS positioning data is solved and the elevation change is corrected. Random noise and the influence of wave are eliminated by threshold filtering to obtain the change of tide level based on the WGS84 ellipsoid at each measuring point. Using the nearshore control points, the geoid-like model was constructed based on the EGM2008 model to realize height conversion and obtain the tide level changes based on the local tide datum. Then the result is applied to the tide level correction in multi-beam water depth measurement. This method can greatly improve the efficiency of water depth measurement and tide correction accuracy.

3.3Application of GNSS Tide Measurement Technology

As the shipboard GNSS tide measurement research was shown in Figure 5, three GPS receivers were mounted on the deck of the survey ship, two on the port side and one on the starboard side. The data sampling interval was 1s. The relative position of the GPS receivers, the attitude indicator and the echo sounder transducer was accurately measured.

Figure 5 Tide measurement with Ship borne GPS receivers

The data shown in Figure 6 do not carry out any filtering and smoothing. It shows that the 3 sets of time series are in good agreement, showing a higher internal coincidence precision, which indicates that the dynamic data based on the ship borne GPS can respond well to the wave signal of the sea surface. The elevation data is corrected, including the heave correction, and the change of elevation direction caused by rolling and pitching .Then the GPS tide of the test time period is generated, which is used as the tidal correction data of the multi beam depth data. As shown in Figure 7, using GPS without tide measurement method, we can do well in the tidal level correction of multi beam results.

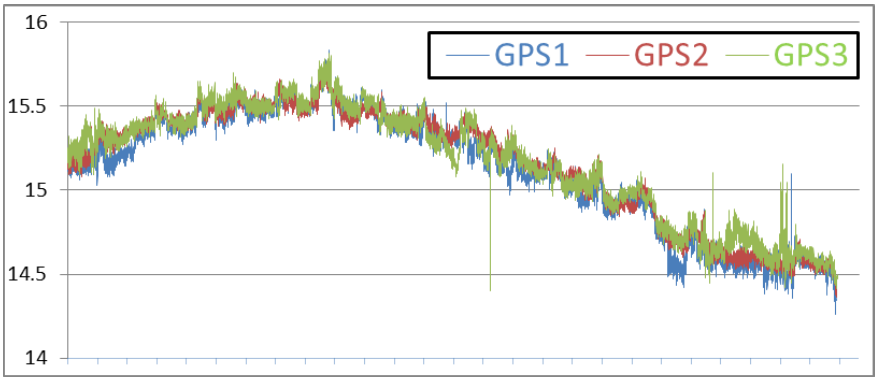

Figure 6 Time series of elevation change

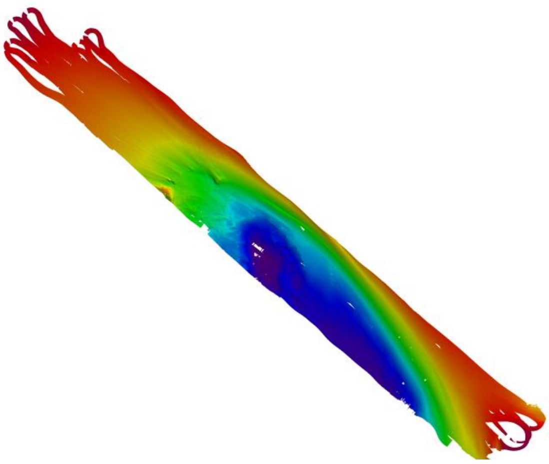

Figure 7 Bathymetric charts with GPS tide correction

4. CONCLUSIONS

The research on the characteristics and movement laws of ocean tides and waves is not only an important scientific issue, but also a significant application value. Existing related research and practice have greatly promoted the development and application of new wave measurement technology. Compared with other wave measurement techniques, the wave and tide measurement method of a single GNSS sensor can be used to obtain the position information, the wave parameters and the tide level change signal at the measuring point without using other external sensors, so the maintenance cost is greatly reduced. GNSS has all the advantages of all-weather availability and high precision. Thus, the study of wave and tide measurement methods based on GNSS technology has both scientific significance and application value.

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