Automatic Program of Gravity tide Pre-processing

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Abstract. In order to improve efficiency of pre-processing gravity observations, the theoretical tides are simulated on the basis of the foregone tidal parameters, and the simulating gravity observations are obtained by combining the local atmospheric gravity, the pole gravity and the length of day gravity. Based on the gravity observations, repairs the abnormal data such as jumps、steps and spikes in gravity observations. In this paper, the software FTsoft, which can automatically identify and repair data such as jumps、steps and spikes and other abnormal data, is designed and implemented on the Matlab platform, which improves the work efficiency. Comparing the results of treatment with FTsoft and Tsoft, it is found that the standard deviation of the result of Ftsoft is smaller than Tsoft, it further proved that Ftsoft is a effective method of pre-processing gravity tides.

Keywords: Gravity tide; FTsoft; Automatic pre-processing; Matlab.

1 Introduction

As the influence of instrument, observation environment, voltage and so on, there are inevitable anomalies in the original gravity tide observations. These anomalies greatly effluence the accuracy of calculation of gravity tidal parameters. Therefore, it is necessary to carry out effective pre-processing before the tidal signal are reconciled and analyzed, eliminate the disturbance signals as fully as possible, and provide high precision gravity tide signals for tidal data processing[1-3]. It is proved that the accuracy of the results can be greatly improved by the effective pretreatment.

In recent years, Nakai is the first one to be used in the Pre-processing of gravity tide. It is proposed by Nakai of Japan. The Preterna package, published in 1994 by Professor Wenzel of Germany, is a comprehensive software package dedicated to the pre-processing of gravity tide observations. Tsoft is a new pre-processing software, developed by Vauterin of the Royal Observatory of Belgium on the basis of Preterna software, has been listed by the International Geotide Center as the standard pre-processing software for the GGP International Superconducting Gravity Instrument for Gravity and Tidal Observation Data Exchange. Chen Xiaodong and others proposed a new method for pre-processing and analyzing gravity tide signals at 2002[4]. Xiong Xianbao introduced the common methods in the pre-processing of gravity tide observations and the computer software to complete the pre-processing of gravity tide observatios at 2006[5]. Xu Chuang of Wuhan University has designed the pre-processing method of gravity tide observations, which can use the average filtering and wavelet filtering methods to process the original gravity tide, and use the linear interpolation and cubic spline interpolation methods to process interrupt tide signal. The automatic pre-processing software APTsoft for gravity tide observations is developed, which realizes the automatic calibration and corrects the abnormal tidal signal, including jumps、steps and spike at 2013[6-8]. In 2015, the pre-processing process of continuous gravity tide observations data introduced by YangKaii and Weijin from Institute of Geodesy and Geophysics, Chinese Academy of Sciences. It describes the methods of how to deal with the missing, steps and jumping processing in the platform of continuous gravity observation data were described, which laid the foundation for further tidal analysis, non-tidal analysis and instrument drift analysis[9].

*Recive data:

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At present, the current software of solid tide data pre-processing (except APTsoft) is mostly manual operation, and the data processor should have some experience, the process is more cumbersome, the automation is not good, as the time is consuming. Based on TSOFT pre-processing, we design and development Ftsoft, which is a set of data pre-processing program, and it can automatically recognize the anomaly data position and can be corrected by one key.

2 Caculating the simulated theoretical tides

The simulated theoretical gravity measurements yobs(t) which change along the time can be caculated as[10]:

$$y_{obs}(t) = y_{\mathrm{mod}}(t) + bP(t) + \varepsilon(\mathrm{t}) \quad (1)$$

$y_{\mathrm{mod}}(t)$ is model gravity measurements，bP(t) is atmospheric gravity, P(t) is the observation of atmospheric pressure which changes as time.b is Atmospheric admittance, ε(t) is Gravity residuals, Gravity residuals obtions the effection of pole tide、the effection of LOD(Length Of Day) and drift and other non-tidal signals.

At present, most of tidal data are preprocessed by Tsoft gravity tidal data which preprocessed by Vauterin, it's the latest gravity solid tidal data preprocessed software. The software preprocesses the data by removing the various interference signals in the observation residual(T) and correcting the interference signal with a modifier. Then, using the recovery method to remove the residual and brought back to the formula(1), and received the repaired signal. But the work of the correcting of gravity residuals is Tedious and manually.

The changes of the gravity tidal signal on the surface of the Earth caused by the polar gravity tide can be calculated with the Geodetic coordinates (λ, φ) and polar coordinates (x, y) of the point. Polar coordinates (x, y) can be obtained from the file which is about Earth rotation parameters provided on the IERS website. The polar motion has a lower proportion in the influence of gravity tidal residuals, and its amplitude of the influence of gravity tidal signal is about 10×10-8 ms-2.The changes of the gravity dg1 caused by the polar gravity tide can be calculated as follows[9]:

$$dg_1 = 2\times 1.16\times a\varpi^2 \times \sin(90^\circ-\varphi)\cos(90^\circ-\varphi)(x\cos\lambda - y\sin\lambda) \quad (2)$$

a is the average radius of the Earth, a =6378137.0m, $\overline{\omega}$ =7.292115×10-5 rad/s, is average angular rate of earth rotation，φ is the latitude of the station and λ is the longitude of the station.

The LOD gravity is smaller than the Atmospheric gravity and the polar gravity, it's less than 0.3×10-8 ms-2, it's usually be ignored. Polar gravity tide and LOD gravity tide has a large proportion on the gravity residuals, but drift of the instruments is much smaller, is simillar to have no effect on gravity tide, it's usually be ignored too. The LOD gravity as a constant can be removed from gravity signal. DLOD is the differences of the LOD.LOD=TAI (International Atomic Time)-UT1 (Universal Time 1). TAI and UT1 can be provided on the IERS website. The LOD gravity dg2 can be calculated as follows:

$$dg_2 = 2\times 1.16\times \varpi^2 \times dLOD \times a\times \cos^2(psi)\times 1.0\times 10^9/86400 \quad (3)$$

$\overline{\omega}$ is the same as formula(2), φ is the latitude of the station; psi is geocentric latitude, psi =arctan((e2-1)×tanφ), e is The first earth eccentricity, e2=0.0066943799013.

3 The gravity tides of pre-processing

Due to various factors, gravity tidal observation usually have anomalies (mainly spikes, jumps, steps, etc.). Therefore, the gravity tidal signal must be preprocessed before calculate the gravity parameters. If the accuracy is not effect, remove the interference in the data as much as possible. Now the methods and software using to process gravity tides are Nakai、Preterna、Tsoft and so on. This study mainly deals with data anomalies and obtains the "clean" data needed for tidal data analysis.

FTsoft is a software of pre-processing which can process the gravity tide automatically. The program is written by Matlab language and has an object-oriented operator interface. The interface is concise and the process is clear. It can realize automatic processing of anomalies such as breaks, steps, and spikes. It is simple and convenient(fig1.). This program will processes the jumps, steps and spikes with synthesized gravity tides、polar gravity tide、LOD gravity tide, finally saves the processed gravity tides.

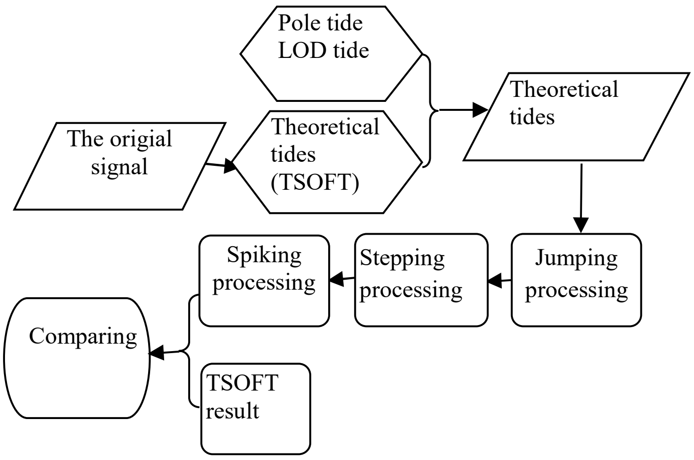

Figure 1. FTsoft processing.

3.1 Calculate the synthesized gravity tides

The theoretical tides are calculated with theory gravimetric amplititude factor and phase lead with TSOFT, at the same time calculate the polar gravity tide and the LOD gravity tide as formula(2) and (3). and then calculate the synthesized gravity tides($y_{obs}'(t)$)as formula(4)

$$y_{obs}'(t) = y_{\mathrm{mod}}(t) + bP(t) + dg_1(\mathrm{t}) + dg_2(\mathrm{t}) \quad (4)$$

3.2 Jumping processing

For the processing of jumping, at first the null value (it's 99999.999) in the original data is automatically recognized and instead it with the average value of all the data before the discontinuity is used, then connect all of the data.

3.3 Stepping processing

Investigate the step data in the gravity tides, and enter the number of step point, according to that number, the original gravity tides is divided into several segments, each segment is independent. And then calculate the differences between the average value of each segment and the average value of the first segment, and then remove all data of the segments except the first one to the level of the average of the first segment.

3.4 Spiking processing

Caculate the differences between the gravity tides after implemented jumping processing and step processing and the synthesized gravity tides. And then set the threshold value according to the average of differences its standard deviation. You can set threshold value to three times the standard deviation of the differences. The average value exceeding the threshold value is replaced by the synthesized gravity tides, so that the spikes are processed and obtained a prefect gravity tide finally.

4 The results of calculation

The gravity tide in this paper is recorded at Jiufeng station in Wuhan at 2014, which is a second sample. The longitude of the Wuhan station is 114.4898 angle and the latitude is 30.5159 angle. At the same time download the polar coordinates (x, y) and the values of TAI and UT1 of 2014 on the IERS website and calculate the polar gravity tide and the LOD gravity tide, and to interpolate the result from day to seconds. Figure 1 gives the processing to process gravity tide of FTsoft.

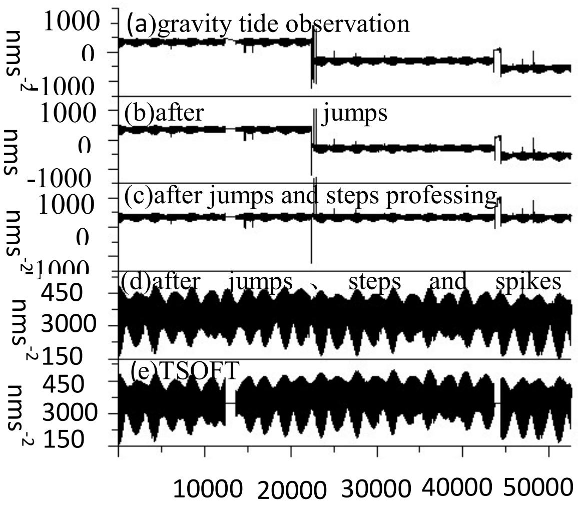

Figure 2. FTsoft processing.

Figure 2 gives the gravity tide observations and the result of Tsoft professing. There are a big jump appeared about 120000 seconds (it's appeared between March 27 and April 5)、a spike at 225000 seconds and two steps between 225000 and 440000 seconds in the gravity tide observations in figure 2(a). The gravity tide observations are clearly divided into three segments. From figure 2(b), we can see the jumps are insteaded by the average of the data appeared before the jumps, the jumps are perfectly corrected. After jumps and steps professing the second and the third segments tidal signals are clearly pan to the first segment tidal signal from figure 2(c), the jumps are perfectly corrected too.

After jumping、steping and spiking processing the gravity tides become very smoothly. Specifically, during the spiking processing, not only corrected the seven-segment spikes, but also corrected the spikes which left after jumping processing, all gravity tide observations are perfectly corrected. The gravity tide signal are obtained by FTsoft preprofessing in Figure 2(d),and by Tsoft preprofessing in Figure 2(e).The maximal differences of the tidal signal of Figure 2(d) and Figure 2(e) is 4.5 nms-2, except the differences of the jumps professing is relatively large. This result has little effect on the solution of tidal parameters.

In order to verify the preprofessing effection of Ftsoft and Tsoft, calculate the differences between the Ftsoft processing results and the Tsoft processing results. The differences between the results of Tsoft processing and simulated gravity tide signal is about 124nm/s-2,and the differences between the results of FTsoft processing and simulated gravity tide signal is about 108nm/s-2.The results of Tsoft processing and FTsoft processing are at the same level. Calculate the standard deviation of the differences as formula (5)

$$s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2} \quad (5)$$

x is the differences between gravity tide after Tsoft professing or Ftsoft professing simulated gravity theory tide, $\bar{x}$ is the average value of x.

The standard deviation of differences between the result of Tsoft and the FTSOFT is 204.4090nms-2 and standard deviation related to FTsoft is 55.3929nms-2, the latter is smaller than the former, so it proved that Ftsoft is a effective method of pre-processing gravity tides.

5 The conclutions

The FTSOFT software can automatically identify the anomalies in the gravity observations, such as jumps、steps and spikes. It saves time and improves work efficiency. It repaires the jumpings throuth automatically recognized the null value (it's 99999.999) in the original gravity tides and instead of it with the average value of all the data before the discontinuity is used. According to the differences of the average of each segment of gravity tides, which divided according to the number of the steps, remove all data of the segments except the first one to the level of the average of the first segment, and the repaird the steps;

The standard deviation of the differences between the FTsoft processing results and the simulated theory gravity tide is smaller than the Tsoft, so it proved that Ftsoft is an effective method of pre-processing gravity tides.

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