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Wavelet filter analysis of local atmospheric pressure effects in the long-period tidal bands

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Abstract

It is well known that local atmospheric pressure variations obviously affect the observation of short-period Earth tides, such as diurnal tides, semi-diurnal tides and ter-diurnal tides, but local atmospheric pressure effects on the long-period Earth tides have not been studied in detail. This is because the local atmospheric pressure is believed not to be sufficient for an effective pressure correction in long-period tidal bands, and there are no efficient methods to investigate local atmospheric effects in these bands. The usual tidal analysis software package, such as ETERNA, Baytap-G and VAV, cannot provide detailed pressure admittances for long-period tidal bands.

We propose a wavelet method to investigate local atmospheric effects on gravity variations in long-period tidal bands. This method constructs efficient orthogonal filter bank with Daubechies wavelets of high vanishing moments. The main advantage of the wavelet filter bank is that it has excellent low frequency response and efficiently suppresses instrumental drift of superconducting gravimeters (SGs) without using any mathematical model. Applying the wavelet method to the 13-year continuous gravity observations from SG T003 in Brussels, Belgium, we filtered 12 long-period tidal groups into eight narrow frequency bands. Wavelet method demonstrates that local atmospheric pressure fluctuations are highly correlated with the noise of SG measurements in the period band 4–40 days with correlation coefficients higher than 0.95 and local atmospheric pressure variations are the main error source for the determination of the tidal parameters in these bands. We show the significant improvement of long-period tidal parameters provided by wavelet method in term of precision.

Keywords: Long-period Earth tide; Pressure; Superconducting gravimeter; Wavelet filter

1. Introduction

There are long-term continuous and stable tidal gravity observations from superconducting gravimeters (SGs) in the Global Geodynamics Project (GGP) database (Crossley et al., 1999; Hinderer and Crossley, 2004). The SG data at Brussels station were accumulated for over 18 years, in which 13.5-year data is uninterrupted data. It is thus possible to make detailed study of long-period tides with this data. However, noise of atmospheric origin and instrumental drift significantly disturb long-period tidal signal in the SG data. The efficient reduction of the two perturbations is the key for the precise long-period tidal analysis.

Atmospheric perturbation presented in the SG data is a colored noise covering the entire spectrum. The

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atmosphere affects SG data through two effects: the direct Newtonian attraction of the air masses on the sensor of SG which is sensitive to local pressure fluctuations; the vertical displacement of the ground caused by atmospheric loading deformation which is relative to regional or global pressure variations. For a plane Eearth model Warburton and Goodkind (1977) showed that the Newtonian admittance and loading admittance to be approximately $-3.7\,\mathrm{nm\,s^{-2}\,h\,Pa^{-1}}$ and $0.2\,\mathrm{nm\,s^{-2}\,h\,Pa^{-1}}$, respectively, for a stationary column of air above a gravimeter station.

There are primarily two kinds of methods for correcting the atmospheric pressure effects in gravity observations: empirical methods using the local atmospheric pressure and loading response methods using the regional and global atmospheric pressure. The empirical methods correct the pressure effects by gravity data minus local pressure data multiplied by the pressure admittance (Warburton and Goodkind, 1977; Spratt, 1982; Richter, 1983). The pressure admittances can be estimated in the time domain by a determination of the regression coefficient between gravity and local atmospheric pressure time series. This admittance is frequency-independent but its value is depended on the length and epoch of the time series, thus it is called time-dependent admittance (e.g. Crossley et al., 1995; Hu et al., 2005, 2006). The frequency-dependent pressure admittances are estimated in the frequency domain (e.g. Crossley et al., 1995; Neumeyer, 1995; Neumeyer et al., 1998; Kroner and Jentzsch, 1999), but they lose almost all time information thus they are time-independent. The loading response methods (Green's function method) are based on the calculation of gravity changes caused by an air column load on the Earth's surface using the appropriate Green's functions for the deformation and Newtonian attraction term (e.g. Merriam, 1992; Boy et al., 1998).

In the study of short-period Earth tides, the atmospheric effects in the SG data can be efficiently corrected using an empirical method. The pressure correction based on local atmospheric pressure data accounts for some 90% of the total atmospheric effect on short-period tides (Crossley et al., 1995). The local atmospheric pressure effects in the long-period tidal band have not been studied in detail. It was believed that, for monthly and seasonal periods, large scale atmospheric variations become important and the local pressure is not sufficient for an effective correction. The local correction can be improved by using the loading response method by employing global atmospheric data sets. However, this computation requires a fair amount of work to collect the data and convert it into a useful time series for each station at a certain epoch. Moreover, there still remain uncertainties in the oceanic response and the correction result does not allow a significant reduction of gravity residual for period longer than 90 days versus a local pressure correction (Boy et al., 2002). Thus, the empirical method still predominates in most of previous studies of long-period Earth tides (e.g. Ducarme et al., 2004; Iwano et al., 2005; Sato et al., 1997). Admittances obtained through the short-period tidal analysis were often used in these previous studies. This may be because there is no good way to estimate effective pressure admittance for long-period tidal band. In fact, all of the commonly used tidal analysis package, such as ETERNA (Wenzel, 1996), Baytap-G (Tamura et al., 1991) and VAV (Venedikov et al., 2001), cannot provide detailed pressure admittances for long-period tidal bands. Local pressure admittance is known as time- and frequency-dependent (e.g. Mukai et al., 1995; Neumeyer, 1995; Neumeyer et al., 1998; Kroner and Jentzsch, 1999; Meurers, 1999; Crossley et al., 1995, 2002), and it usually shows larger values at high frequency and smaller ones at low frequency band (Hu et al., 2005, 2006). When SG data are corrected using admittances for short-period tidal, long-period tidal signal will be overcorrected and noise may be injected. This could lower the precision for long-period tidal analysis.

The instrumental drift is in fact is aperiodic signal in SG data, mostly from instrumental origin. Although the SG drift is very weak, less than $40\,\mathrm{nm\,s^{-2}}$/year, it is quite large for the analysis of long-period tides. The SG drift is stable ramp which can be locally approximated by a polynomial over a short interval, but it is unreasonable to model drift using an unchanged function over a long interval as the drift may have jumps or change its behavior in a long period (Ducarme et al., 2004). Determining a set of best polynomial approximation for the SG drift is an important but not an easy work. In order to separate the SG drift from the long-period tidal signal, Venedikov et al. (2001) considered the drift as a constant in a day and model it as a stepwise function with a time step $\Delta t = 24\,\mathrm{h}$.

In this paper we introduce wavelet method to investigate the local atmospheric pressure effects on surface gravity in long-period tidal bands and determine pressure admittances for these bands. The vanishing moment property of wavelet can easily cancel the SG drift well approximated by polynomial. In the following sections, we first introduce the advantage of wavelet orthogonal filter banks constructed by Daubechies wavelets of high vanishing moments in the analysis of SG data. Then, we apply wavelet filter banks to the 13-year gravity and air-pressure records from SG station in Brussels, Belgium.