87 Detection of Vertical Temporal Behaviour of IGS Stations in Canada Using Least Squares Spectral Analysis

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Abstract

Unambiguous, consistent and homogeneous GPS station coordinates are the fundamental requirement in the appropriate determination of geodetic velocities that are often used for the derivation of geodetic and geophysical models for a variety of applications [Segall and Davis, Ann Rev Earth Planet Sci 23:201–336, 1997]. Because of this, there have been significant efforts to improve the modeling and parameterization of global GPS solutions in order to get stable and homogeneous positions and velocities. This paper presents a study aiming at detecting least-squares spectral peaks present at the best available (at the time) IGS weekly vertical component time series of five permanent stations in Canada. These peaks are the result of short and long term effects of mismodelled and unmodelled geophysical phenomena on the height. The LSSA approach is used. Results show strong periodic constituents in the LSSA spectrum below or at the 1 year window but most notably constituents with periods longer than a year.

87.1 Introduction and Motivation

Since early 1990s, geodetic coordinate time series have been generated from continuous observing GPS stations and used for many geodetic and geophysical applications that include the derivation of input velocities to geophysical models. Examples of them include, among others, modeling of plate boundary dynamics, postglacial rebound, surface mass loading and other deformations of the solid Earth, Earth rotation, variations in the hydrosphere as well as satellite orbit determination and time and frequency transfer (Segall and Davis 1997). However, operational GPS time series are known to be inconsistent and inhomogeneous for a number of reasons such as changes in reference frame, atmosphere biases, biases due to Earth Rotational Parameters (ERP), and phase center variations. Significant efforts have been underway in the last decade to improve the modeling and parameterization of global GPS solutions in order to get stable and homogeneous positions and velocities. One of the latest improvements is the availability of new absolute phase center variations models that have been adopted by the International GNSS Service (IGS) in all their products since November 5, 2006 (GPS Week 1400) (Schmid et al. 2007). This adoption has caused changes in the IGS solution processing strategy and

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necessitated the reprocessing of all of the historical GPS data. This ongoing effort by the IGS will generate the so-called REPRO1 solution, not available by the time of this work.

The primary objective of the research presented in this paper is to investigate the height component of the GPS solutions of a few IGS stations in Canada. It looks into short and long term periodic effects within and beyond 1 cycle per year, caused by either mismodelled or unmodeled phenomena, in the official (and best available by the time of this study) IGS weekly coordinate time series from IGS public archives. It should be noted that the data used in this analysis is not the REPRO1 solution since it had not been made available yet. It is our intention to perform a similar and more comprehensive study using the REPRO1 data set, including a thorough analysis. Therefore, the work presented in this paper can be considered as an initial step towards a more comprehensive study.

Past and recent spectral studies of GPS position time series have shown the existence of significant variation in the respective spectrum. They include studies by Blewitt and Lavellee (2002), Penna and Stewart (2003), Agnew and Larson (2007), Collilieux et al. (2007), Ray et al. (2007) and Fritsche et al. (2009). Most of them were based on solutions not yet using absolute phase center variation models and were limited to annual variations (except the last study). These studies attributed the variations to both known and unknown errors arising from different mathematical models and parameters.

87.2 Data and Computational Tool

The Least Squares Spectral Analysis (LSSA) technique has been applied to vertical time series of five IGS stations in Canada, shown in Fig. 87.1. The data sets are from the IGS weekly coordinate time series for stations ALGO (Algonquin), CHUR (Churchill), YELL (Yellowknife), DRAO (Penticton) and STJO (Saint John's). Our analysis is based on 10 years (1999–2009) of unequally spaced weighted height time series, all of them shown in Figs. 87.2–87.4.

Least Squares Spectral Analysis (LSSA) is based on the developments by Vaníček (1969, 1971) and

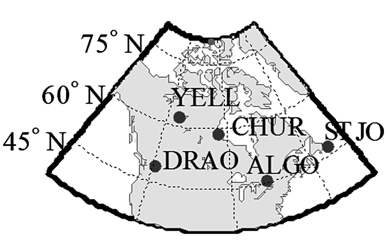

Fig. 87.1 The five (5) Canadian IGS stations used in this study

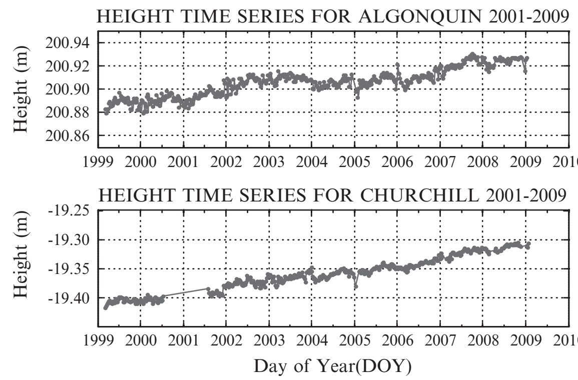

Fig. 87.2 Height time series for the IGS stations Algonquin (*top*) and Churchill (*bottom*)

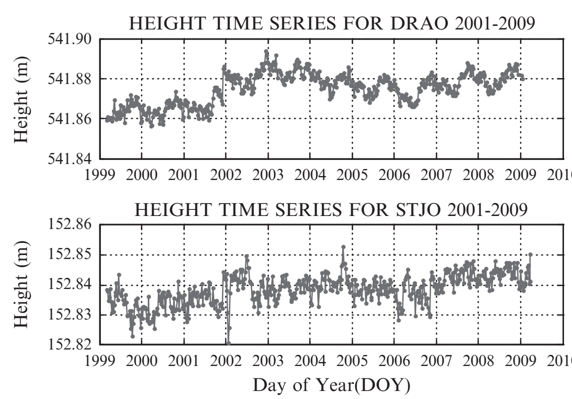

Fig. 87.3 Height time series for the IGS stations DRAO (*top*) and STJO (*bottom*)

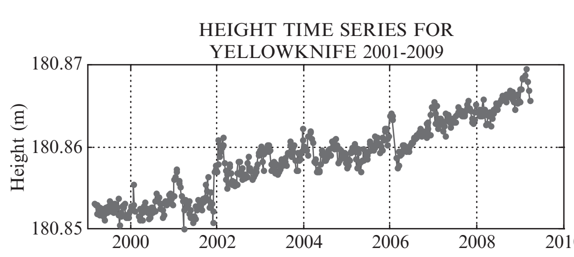

Fig. 87.4 Height time series for the IGS station Yellowknife for the period of 1999–2009

later improvements and implementation by Wells et al. (1985) and Pagiatakis (1998). LSSA has been adopted as the main tool of analysis because of the software capabilities that allow analysis of data time series with known and unknown a-priori variance factor. The analyzed data may also be correlated or uncorrelated. LSSA can also handle unequally spaced time series without a pre-processing requirement, rigorous analysis of systematic noise without shifts in the spectral peaks and the ability to test the statistical significance of the spectral peaks in the spectrum (Pagiatakis 1998).

87.3 Processing, Results and Assessment

LSSA is applied in a stepwise mode, in which consecutive runs can be performed. In each run, the most prominent (and statistically significant) spectral peak(s) estimated in the previous run can be enforced (removed) in the following one, allowing other peak(s) to be detected. The least squares spectra of the GPS time series for each station were detected in this way, first determined without enforcing any periodic constituents. Significant peaks from these spectra were then identified and enforced in subsequent spectra determinations until all statistically significant peaks were identified at the 99% confidence level. The procedure is repeated in successive analysis stages in a manner which would be meaningful through the observation of the significant reduction of the Chi-Squared (χ^2) test on the variance and the quadratic norm of the residuals as well as the Chi-Squared goodness-of-fit test of the histogram of the residual.

The results of the LSSA for all five stations are shown from Figs. 87.5–87.14. The letters "EF" followed by a number represent the number of enforced periods in that particular LSSA run. The vertical axis of the figures is in units of power spectral density (PSD) and the horizontal axis is frequency in units of cycles per year (CPY).

The results show there exist at least six different groups of strong periodic constituents in the LSSA spectrum window of 0.05–2.5 cycles per year, but only a few of them can be explained (Dong et al. 2002). The group ranges are subject to minor shifts yet to be verified, that could be caused by regional and site dependent effects.

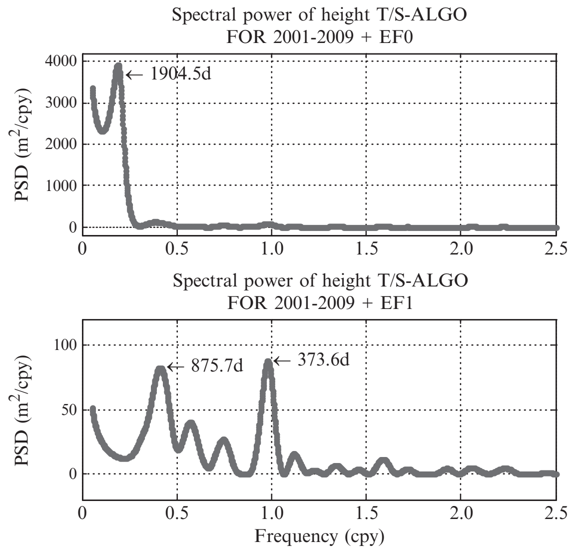

Fig. 87.5 Power spectral density for station ALGO. *Top plot* is with no periods enforced. The *bottom plot* is after enforcement of period 1,904.5 day

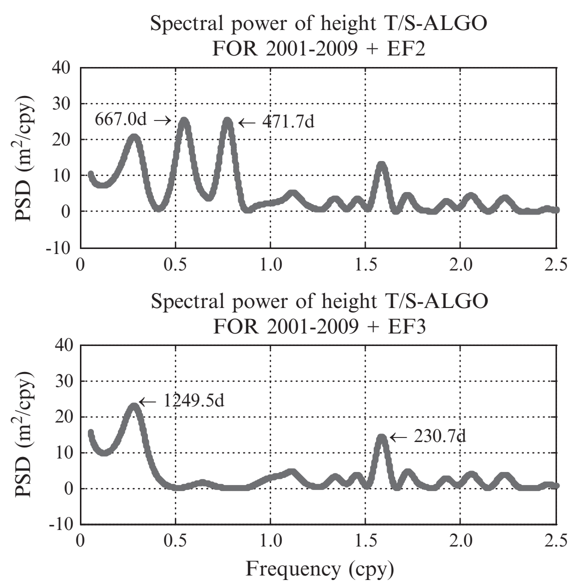

Fig. 87.6 Power spectral density for station ALGO (Algonquin). *Top plot* is after enforcement of periods 1,904.5, 875.7 and 373.6 days. *Bottom plot* is after enforcement of periods 1,904.5, 875.7, 373.6, 667.0 and 471.8 days

The first group corresponds to a known constituent with periodicities between 177 and 200 days. Based on Melchior (1983), this group of periodic signals could be the impact of semi-annual solar waves.

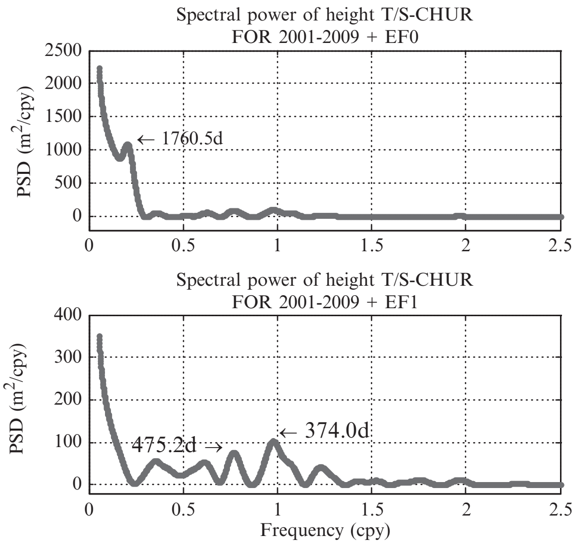

Fig. 87.7 Power spectral density for station CHUR. *Top plot* is with no periods enforced. *Bottom plot* is after enforcement of period 1,760.5 day

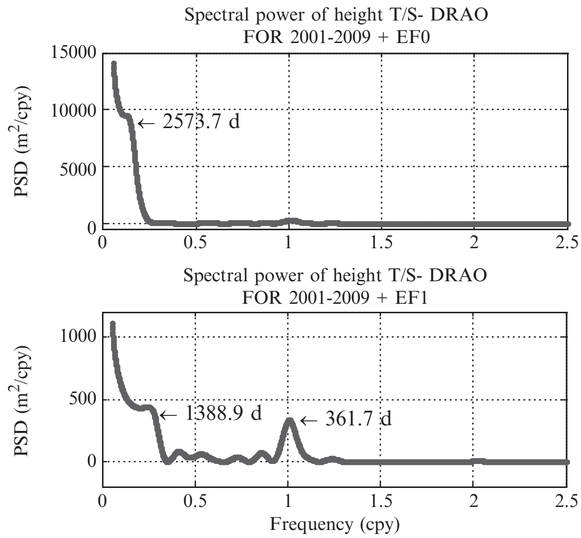

Fig. 87.9 Power spectral density for station DRAO. *Top plot* is with no periods enforced. *Bottom plot* is after enforcement of period 2,573.7 day

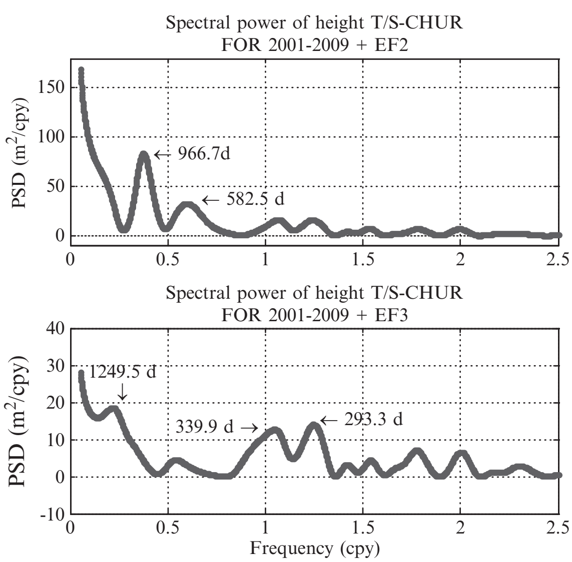

Fig. 87.8 Power spectral density for station CHUR (Churchill). *Top plot* is after enforcement of periods 1,760.5, 475.2 and 374.0 days. *Bottom plot* is after enforcement of periods 1,760.5, 475.2, 374.0, 996.7 and 582.5 days

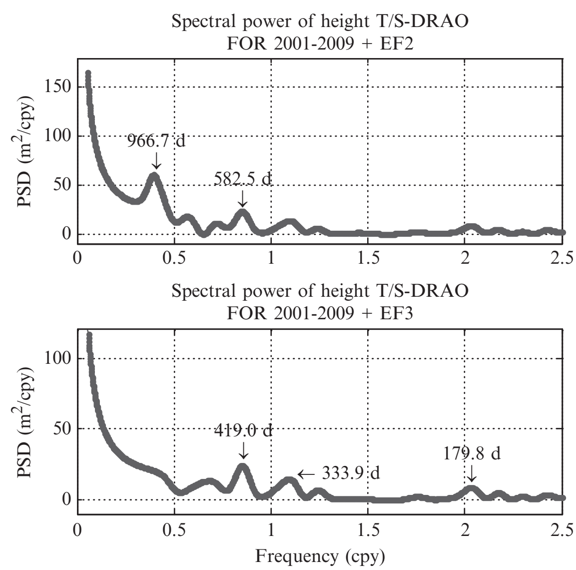

Fig. 87.10 Power spectral density for station DRAO (Penticton). *Top plot* is after enforcement of periods 1,388.9 and 361.7 days. *Bottom plot* is after enforcement of periods 966.7 and 582.5 days

The second group corresponds to a known constituent with periodicities between 200 and 400 days with most of them closer to the sidereal year (365.25 days) and 351.2 days, which is the time taken by the GPS constellation to repeat its inertial orientation with respect to the sun also known as the GPS year (Agnew and Larson 2007). Subject to proper quantification in the ongoing research, possible reasons for them could be the effects of annual solar (elliptical) waves and the systematic errors related to satellite

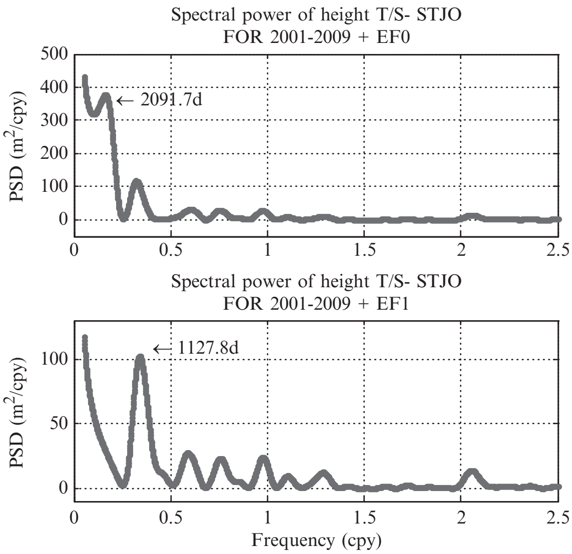

Fig. 87.11 Power spectral density for station STJO. *Top plot* is with no periods enforced. *Bottom plot* is after enforcement of period 2,091.7 days

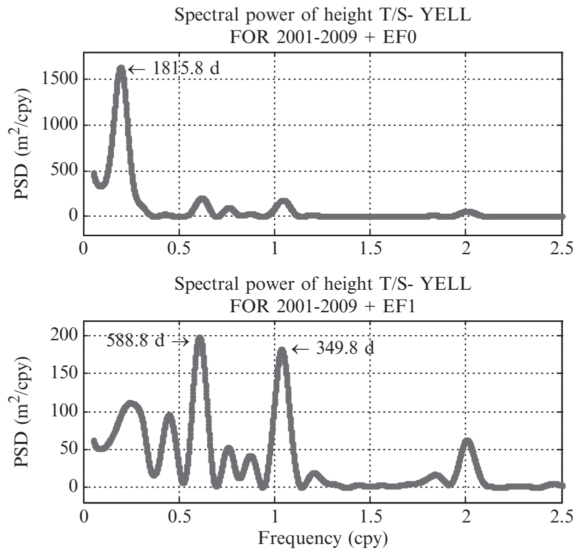

Fig. 87.13 Power spectral density for station YELL. *Top plot* is with no periods enforced. *Bottom plot* is after enforcement of period 1,815.8 day

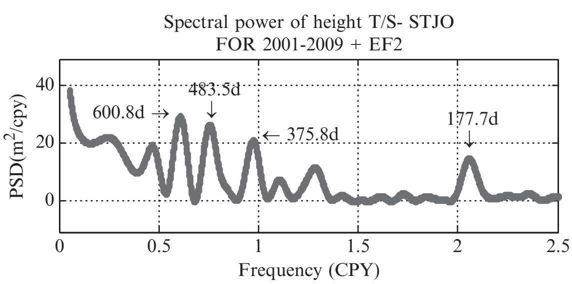

Fig. 87.12 Power spectral density for station STJO after enforcement of periods 2,091.7 and 1,127.8 days

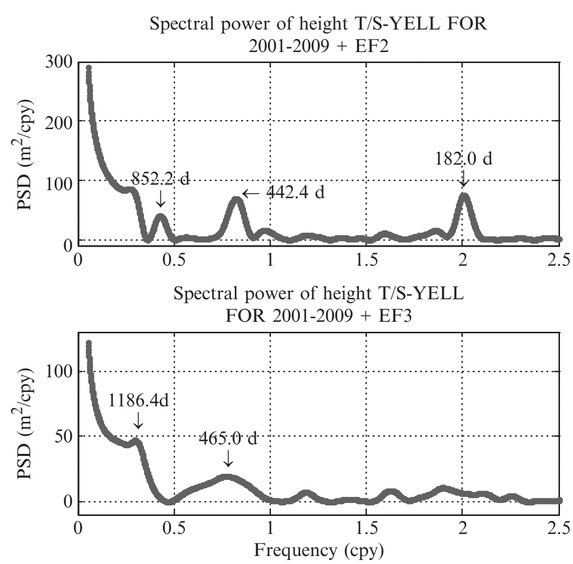

Fig. 87.14 Power spectral density versus frequency for station YELL. *Top plot* is after enforcement of periods 1,815.9, 588.8 and 349.8 days. *Bottom plot* is after enforcement of periods 1,815.85, 588.79, 349.831, 852.2, 442.4 and 182.0 days

orbits such as orbit mismodeling and varying satellite geometry and the local multipath effects. Other possible reasons are the long periodic effect due to unmodeled tidal effects in diurnal and semi diurnal waves as well as the impact of hydrological and atmospheric loading (Van Dam et al. 2001).

The third to sixth groups correspond to periodic constituents with long frequencies of, respectively, 400–600, 600–1,000, 1,000–2,000 and over 2,000 days. The physical causes of the periodic constituents for these groups have not been established nor has the extent of their bias in the present solutions. In other words, even though interesting periods longer than one year have been detected, we do not have a convincing explanation for them yet.

Conclusions

The primary objective of the work presented in this paper is to detect periodic components in the vertical component of GPS solutions for five IGS stations in Canada using the Least Square Spectral Analysis. It uses the IGS weekly coordinate time series (1999–2009) of stations ALGO, CHUR, DRAO, STJO and YELL.

The LSSA results indicate the existence of significant periodic frequencies between 0.05 and 2.5 cycles per year. They have different spectral power with periodicities ranging from about 160 to over 2,000 days that are statistically significant at the 99% confidence level. They may be the effects of the temporal behavior of unmodeled geophysical phenomena and the accumulated impact of earth tides that are not properly modeled. Besides verifying the results of similar past and recent spectral studies, our results have also indicated the existence of a number of significant long periodic signatures in the LSSA spectra for all stations under investigation. The probable causes of the long periodic signatures (longer than 1 year) have not been discussed and are still under investigation.

As part of future work, there is the intention to replicate this study using the final reprocessed IGS weekly coordinate solutions that include the new absolute antenna phase centers (REPRO1) once they become available. Similar effort will be made using the residuals provided in REPRO1. In this case, spectral corresponding to position and residual domain will be generated and will go through a full investigation and analysis of their causes, i.e., identifying any eventual unmodelled or mismodelled effect still present. Those results will also be compared to results for the previous IGS weekly solutions based on relative antenna phase centers in order to quantify the impact of the phase center models.

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