

Estimation of Crustal Motions at the Permanent GPS Station SVEA, Antarctica from 2005 to 2009

Research article

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Abstract:

In November 2004 the permanent GPS station SVEA (Latitude: 74°34' 34" S, Longitude: 11° 13' 31" W, Height 1261.2 m) was installed in Drottning Maud's Land, Antarctica. The main aim of this paper is to evaluate the collected data for on-going crustal motions. About 40% ("3-days weekly") of the continuous four years GPS data from 2005 to 2009 was processed together with the simultaneous data of five IGS reference stations using Bernese GPS software V 5.0. A linear regression analysis was used to estimate the linear motion of the station, yielding the estimated velocities' components (in mm/year) of 6.6 ± 0.4 North, -1.4 ± 0.2 East and 4.4 ± 0.6 Up. Although all components appear highly significant, the abnormal development of the E-W component needs further analyses. Post-glacial rebound is estimated to contribute only to 0.2-0.3 mm/yr (James and Ivins, 1998) of the vertical uplift rate, suggesting that the observed vertical motion mainly has another origin, possibly tectonic. The crustal motion results should be regarded as preliminary, and they need both further data and analyses to be confirmed.

It is also concluded that the remote continuously running GPS station SVEA works well after more than five years of operation with only annual checks and data retrieval in the harsh environment of Antarctica.

Keywords:

Antarctica • crustal motion • GPS • SVEA

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1. Introduction

Since the early 1990-ties the SCAR working group on Geodesy and Geoinformatics has established a number of permanently operating GPS stations in Antarctica, primarily for contributing to studies on global plate and regional crustal motions. In addition, the stations, some of them being adopted as ITRF stations, serve as reference stations for various regional scientific projects that needs accurate positions. See e.g. Dietrich and Rülke (2008).

In Antarctic summer 2004 the permanent GPS station SVEA was installed in a rock at the Swedish summer camp Svea in Heimefrontfjella by the Division of Geodesy, Royal Institute of Technology (KTH), Stockholm. The station is equipped with a Trimble R7 GPS receiver with a power consumption of 1.8-2.3 W, choke ring antenna type ASHTECH with Radome code SNOW (ASH701945E_M SNOW) and steel mast "tripod" (see Figure 1). The R7 GPS receiver,

located in a hut, is a dual frequency system, and the operating temperature of this receiver goes down to -40°C . The recorded GPS data are logged in a 1 GB Compact Flash memory, which can also work down to -40°C . The data are collected annually by manual deloading or replacement of the memory card during summer expeditions.

The power supply for the station is six 12 V batteries, with a capacity of 600 Ah. These batteries are charged through solar panels when there is sunlight (in the Antarctic summer season) and by a wind generator during the Antarctic winter.

On 1st of December 2004 the station started to operate, providing continuous dual frequency code and phase GPS measurements and navigation data with a recording in a sampling rate of 15 seconds. In addition, Real Time Kinematic (RTK) service is available when the station SVEA is open. More descriptions can be found in (Sjöberg et al., 2006).



Figure 1. GPS station SVEA.

The main purpose of this study is to process the SVEA GPS data weekly with International GNSS Services (IGS) reference stations in Antarctica using the Bernese GPS software V 5.0 in order to estimate possible crustal deformation components at the station.

2. Data processing

In this work, the GPS data of the first three days, weekly, were processed day-by-day together with the simultaneous data of IGS reference stations Dav1, Maw1, Mcm4, Ohi2 and Syog as in Figure 2. These stations have been chosen with regard to approximate shortest distances from SVEA as in Table 1 and also with respect to the data availability and quality as a criterion.

Table 1. The approximate distances from station SVEA to the reference IGS stations.

Baseline	Distance in km
SVEA - DAV1	2879.1
SVEA - MAW1	2574.2
SVEA - MCM4	3050.7
SVEA - OHI2	2153.9
SVEA - SYOG	1804.8

The GPS double - difference-processing strategy (Dach et al., 2007) was implemented in order to process the data with the IGS reference stations. The precise orbit and pole information model provided by the International GNSS service and Center for Orbit Determination in Europe (CODE), respectively, were used.

The data processing started by synchronizing the receiver clocks, and the baselines were established between the station SVEA and the IGS reference stations. Also, the majority of GPS observation cycle slips were detected as well as the observations with detected large residuals were classified as outliers and removed from the observation files.

In the post processing steps the troposphere parameters were estimated using the map function Dry Niell for the dry part and function Wet Neill for the wet part (Dach et al., 2007). The fixing of the phase ambiguities is very important in such a precise study. In this work the Quasi-Ionosphere Free (QIF) ambiguity resolution strategy with Global Ionosphere Models provided by CODE (Dach et al., 2007) was used throughout the analysis. The success rate in fixing the ambiguities was around 80%.

Finally, for each daily session the network was adjusted by considering the IGS stations as fixed (with No Net Rotation) in the IGS00 reference frame, and the coordinates of SVEA and the normal equations were calculated and stored. Further details of the processing strategy can be found in (Waljeldeen 2009, p.17-21).

2.1. Combined adjustment

In order to introduce the SVEA coordinates weekly, the normal equations of the three days were combined to a single solution

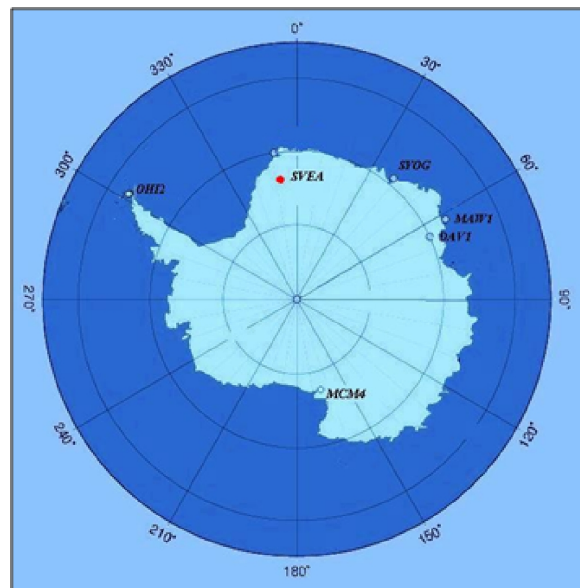


Figure 2. The geographical locations of SVEA and the five IGS reference stations.

using the principle of sequential least-squares estimation (ADDNEQ model) (Dach et al., 2007, p. 183).

To make sense of the motion of station SVEA, the geocentric coordinates (X, Y and Z) were transformed to the local topocentric coordinate system (North, East and Up) (see e.g. Leick, 2004, p. 45).

2.2. Daily Repeatability

In order to check the stability of the daily solutions the combined solutions were compared with the daily solutions. Figure 3 shows the Root Mean Square (RMS) differences in East, North and Up components as internal precessions of the daily solutions (Sjöberg et al., 2004).

The figures clearly show that the RMS differences in the up component are significantly larger than those in the East and North components, which is normal for GPS. In addition we can also note that there are some large RMS differences during the months of May, June, July and August, which one would expect as an effect of the variable signal propagation in the atmosphere, not the least due to much of snow, when considering the frequent severe weathers during the Antarctic winter. The snow and ice on GNSS antenna can cause ca 10 mm change in the estimated horizontal coordinates and 15 mm in height (Grácová et al. 2007).

3. The velocity estimation

Figures 4 to 6 show the temporal coordinate changes in the local topocentric coordinate system. The linear crustal motion velocity components of station SVEA were estimated by linear regression analysis (e.g., Sjöberg et al., 2004). The result was 6.6 ± 0.4 mm/year in the North component, -1.4 ± 0.2 mm/year in the East component and 4.4 ± 0.6 mm/year in the Up component. Fig. 5 shows that the E-W component is abnormal, being slightly increasing to April 2007 and then decreasing. For the vertical motion also Scheinert et al. (2005) estimated similar rates (of about 2 mm/yr) in Drottning Maud's Land. The vertical uplift rate of the crust induced by present-day and historical ice sheet changes are estimated to merely 0.2-0.3 mm/yr (James and Ivins, 1998). It is therefore concluded that the estimated crustal motion at site Svea has a different origin, possibly of tectonic nature.

The relatively large variations around the regression line can be attributed to the varying ice and snow coverage on the antenna (cf. Grácová et al. 2007).

4. Conclusions and final remarks

In this study, the 4-years of continuous GPS data from station SVEA was processed weekly by taking the first three days and processing each individual day with five IGS reference stations using the Bernese GPS software Version 5.0. Then the three-day solutions were combined in order to introduce the SVEA coordinates weekly. The linear crustal motion velocity components were estimated

from the mean weekly coordinates. From the above results, we can conclude:

- The estimated horizontal motion rate of station SVEA is 6.6 ± 0.4 and -1.4 ± 0.2 mm/year in the North and East components, respectively. The strange behaviour of the E-W velocity component needs a longer set of data for a reliable conclusion.
- There is a significant uplift rate of 4.4 ± 0.6 mm/year, which is possibly caused by tectonic motion.
- The relatively simple set-up of a remote/left-alone permanent GPS station for studying crustal motions works well even in the tough environment of Antarctica. The most serious challenge is the technical problem of getting sufficient power supply. However, after more than 5 years of operation the solar panels and the wind generator have not been seriously damaged or blown away by the strong winds during the variable Antarctic seasons.
- The above results should be regarded as preliminary, and they will be further studied by including all available data, at least to the end of 2009, with more computational checks on the results.

Remark:

The computations included data from only 3 days a week. This limitation was not based on that data collection was limited (e.g., due to power saving at SVEA) but all the weekly data were actually collected. As the project time for the junior author was limited, there was not sufficient time to process all the collected weekly data. Nevertheless we believe that this limitation did not significantly affect the final results, as more data would have had only a limited effect in reducing systematic errors, while the random errors are less important for the result.

Acknowledgments

Erick Asenjo established the station and cared for its over-all maintenance. The annual checks of operation and retrieval of data were partly performed by personnel from the Finnish Geodetic Institute and the German Alfred Wegner Institute. The Swedish Polar Secretariat provided logistic service for the project. All these supports are cordially acknowledged.

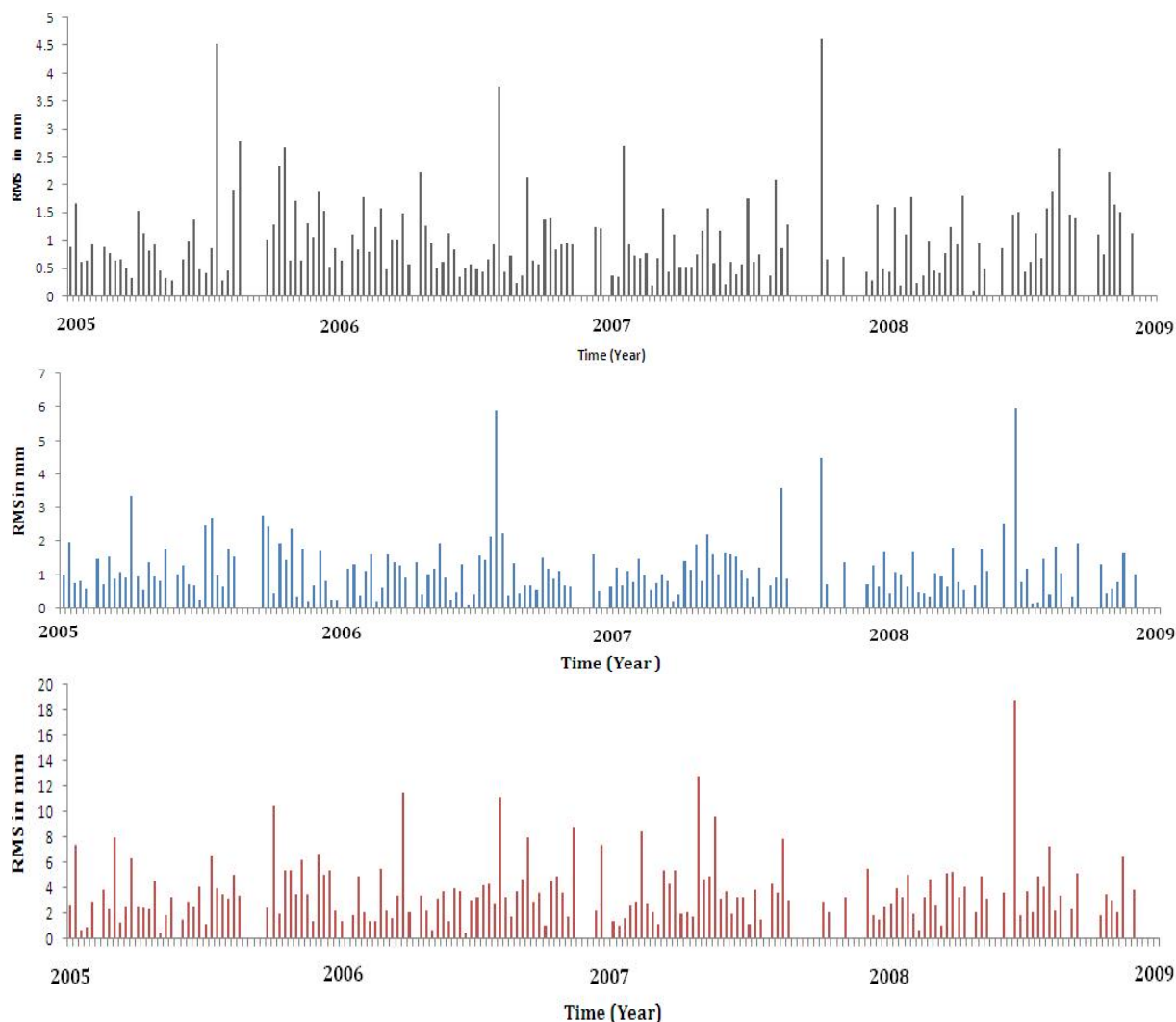


Figure 3. The RMS coordinate differences in the N-S component (top), in the E-W component (middle) and in the up component (bottom).

References

Ågren J., 2001. Processing of the 1992, 1994, and 1997 Campaigns on the Northern GPS deformation Traverse. Licentiate Thesis, Royal Institute of Technology, Stockholm.

Dach R., Hugentobler U., Fridez P., Meindl M., 2007. User manual of the Bernese GPS Software. Version 5.0, Astronomical Institute, University of Bern.

Dietrich R., Rülke A. (2008) A precise frame for Antarctica from SCAR campaign data and some geophysical implications. In: Capra A. and Dietrich R (eds) Geodetic and Geophysical observations in Antarctica. Springer, Berlin, pp 1-10.

Grácová M., Mantlík F., Schenk V., Schenková Z. (2007). Data Processing of GNSS Observations of the Geonas Network - Effects of Extreme Meteorological Conditions. Acta Geodyn. Geomater., Vol. 4, No. 4 (148), 153-161.

James TS., Ivins ER (1998). Prediction of Antarctic crustal motions driven by present-day ice sheet evolution and by isostatic memory of the Last Glacial Maximum. J Geophys Res 103(3): 4993-5017.

Leick, A., 2004. GPS Satellite Surveying, 3rd edition, Wiley-Interscience, New York.

King, M.A., 2011. Application of GPS in Glaciology. In V.P. Singh, P. Singh, and U.K. Varitashya, (eds.): Encyclopedia of Snow, Ice and Glaciers, Springer.

Scheinert M., Ivins E., Dietrich R., Ruelke A. (2005) Vertical crustal deformation in Drottning Maud Land, Antarctica: Observations versus Model Prediction. In: Fuetterer D.K., (Eds.), Antarctica: Contributions to global earth sciences. Springer-Verlag, Berlin, Heidelberg, New York, pp. 355-358.

Sjöberg L.E., Pan M., Asenjo E., 2004. An analysis of the Äspö crustal motion-monitoring network from 2000 to 2004. Report No. P-04-196, Swedish Nuclear Waste and Management Co.

Sjöberg, L.E. and Asenjo, E., 2006. Continuous GPS-monitoring at Station Svea. In: Rickberg, S. (Ed.), Polarforskningssekretariatets årsbok, 2005, pp 62-64, Stockholm: Swedish Polar Research Secretariat, Stockholm.

Walyeldeed H., 2009. Crustal motion at the permanent GPS station SVEA, Antarctica. MSc Thesis, Royal Institute of Technology, Stockholm, Sweden.

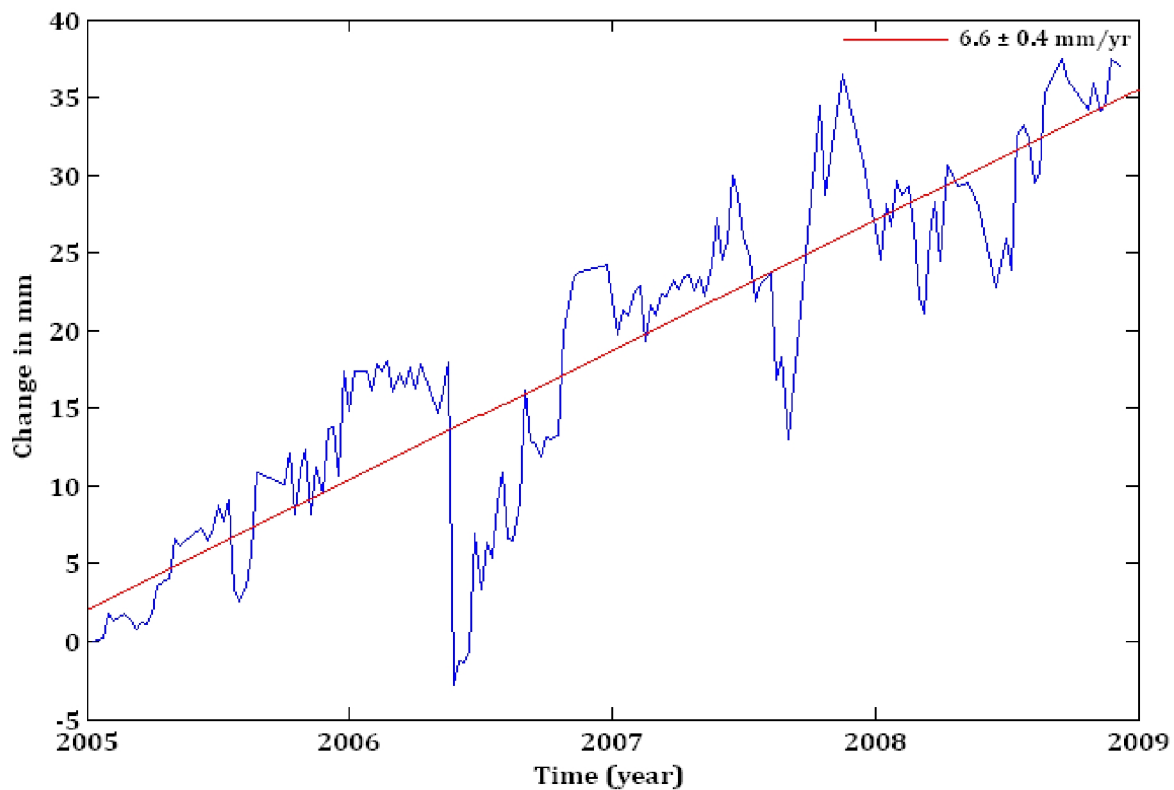


Figure 4. The temporal changes of station SVEA in the North component in mm/yr.

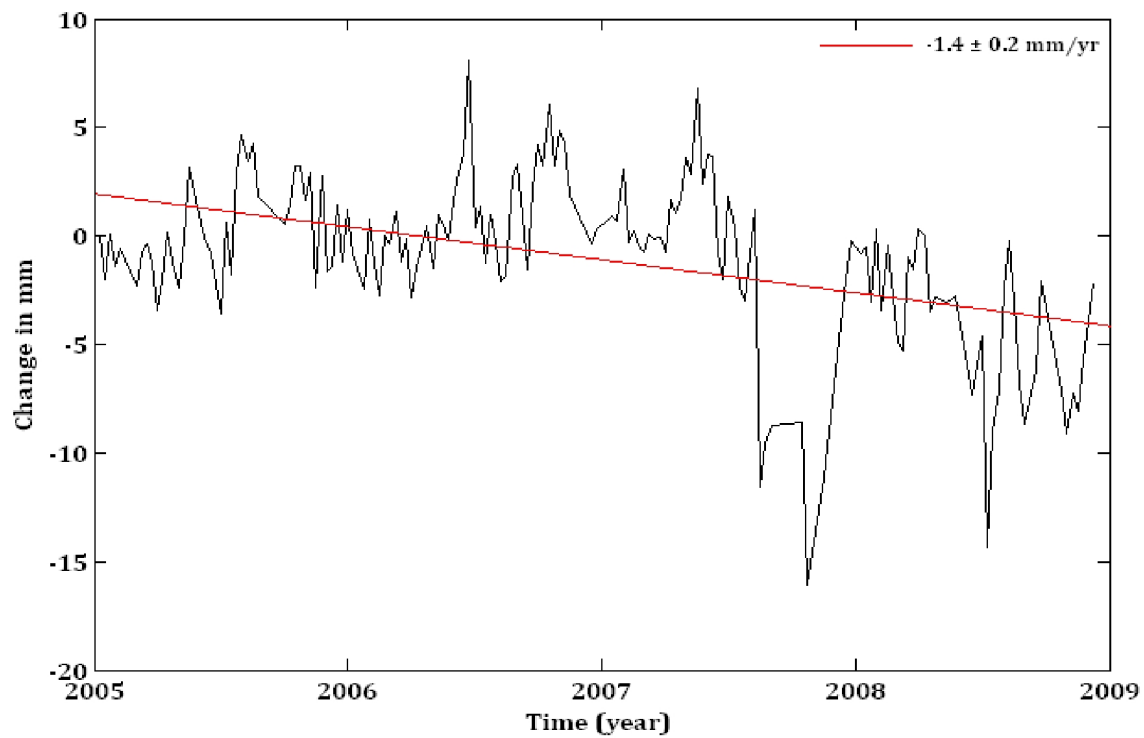


Figure 5. The temporal changes of station SVEA in the East component in mm/yr.

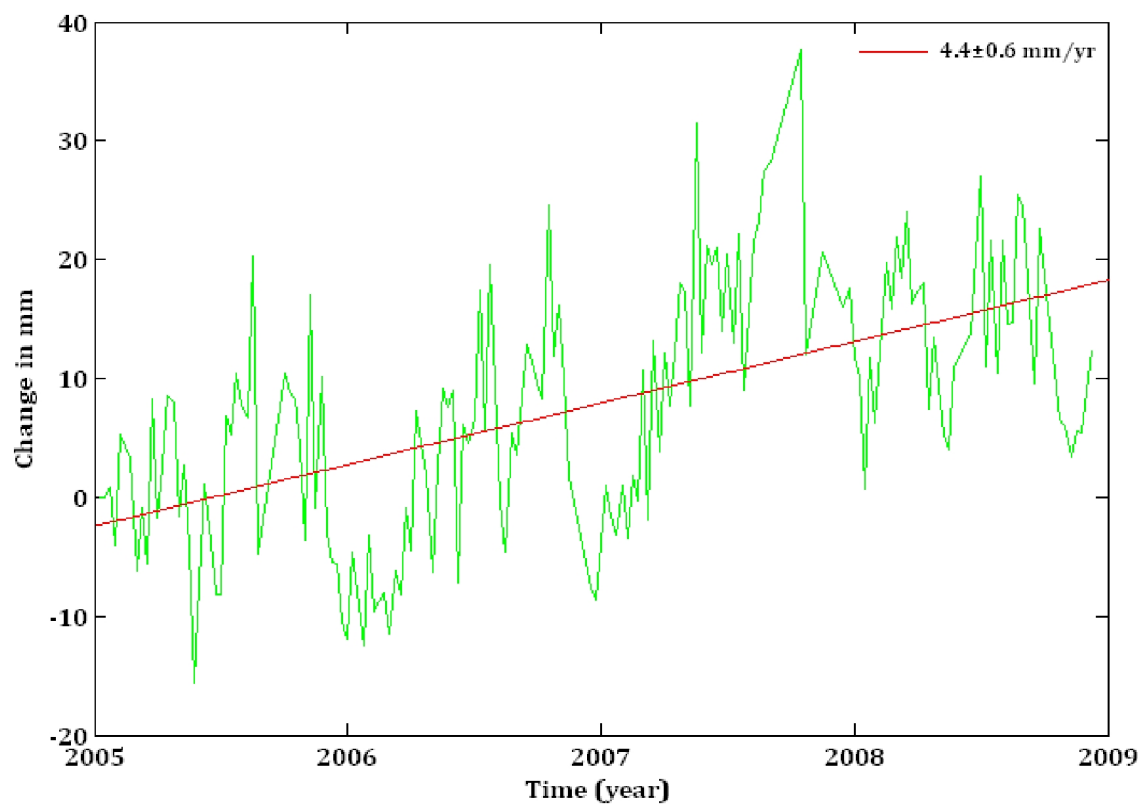


Figure 6. The temporal changes of station SVEA in the Up-component in mm/yr.