GPS Analysis Strategies to Minimize the Error Contribution to Geodetic GPS Determination

Key words: Global Positioning System (GPS), Troposphere Modeling, Heights, Accuracy

SUMMARY

The Indonesian Permanent GPS Station Network (IPGSN) is a network of continuously operating GPS reference stations. The primary purpose of the IPGSN is to maintain a geodetic reference frame over Indonesia region by making publicly available the precise coordinates of all the IPGSN stations in International Terrestrial Reference Frame (ITRF) and World Geodetic System 1984 (WGS84) reference ellipsoid. In recent development of processing strategies and algorithms, such as further improvements in models of solid Earth tide, ocean tide loading, absolute the phase center variation, tropospheric mapping functions and atmospheric pressure loading have lead to incremental improvements in geodetic GPS point positioning accuracy. In this study we evaluate the geodetic station coordinates accuracy and associated time series repeatability of a local network like IPGSN, with those models applied in GPS analysis strategies.

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1. INTRODUCTION

The islands of Indonesia lie between Indian Ocean and Pacific Ocean and at the junction of the Eurasia, India, Australia, Pacific, and Philippine Sea plates, resulting in rugged topography, frequent earthquakes, and active volcanism. In the west, the Australia plate is subducted beneath the Eurasia plate along the Java trench (~65mm/yr). The direction of convergence is normal to the trench of Java, but oblique to the trench southwest of Sumatra (~50mm/yr).

Further east, the island of New Guinea, the leading edge of the northward moving Australian continent, is dominated by the rapid oblique convergence (~110mm/yr) between the Pacific and Australian plates. The oblique convergence has produced a complex array of micro plates whose motions result in rapid shear, arc-continent collision, oceanic and continental subduction, continental rifting, and seafloor spreading. In West Papua a large section of the continent (the Bird's Head) is being detached along a rapid (~80mm/yr) shear zone and subducted at Seram trough.

The modern space geodesy has becomes a powerful tool for many applications in Earth Sciences, not just for any individual discipline, but truly interdisciplinary. Since 1989, at the early stage of GPS development, GPS has been used in Indonesia as a tool for crustal deformation monitoring, the data are collected by GPS campaign measurements. The Indonesian Permanent GPS Station Network (IPGSN) is a network of continuously operating GPS reference stations (Figure 1.). The primary purpose of the IPGSN is to maintain a geodetic reference frame in the active seismic and/or volcanic zones over Indonesia region by making publicly available the precise coordinates of all the IPGSN stations in International Terrestrial Reference Frame (ITRF) and World Geodetic System 1984 (WGS84) reference ellipsoid. Next to its key role in the maintenance of the geodetic reference frame as National Spatial Reference System, the IPGSN supports a wide range of scientific applications such as geodynamics, sea level monitoring, and is also designed to provide other societal benefits.

The recent results from various studies were obtained on global scales (e.g., *Steigenberger et al.*, 2006; *Wöppelmann et al.*, 2007) with a carefully implemented GPS analysis, using a strategy adapted to determine accurate geodetic station coordinates and their velocities. In this study we evaluate GPS data analysis of the IPGSN with included the recent models of solid Earth tide, ocean tide loading, absolute the phase center variation, troposphere mapping functions and geopotential modeling, and based on the recent ITRF2005 reference frame (*Altamimi et al.*, 2007).

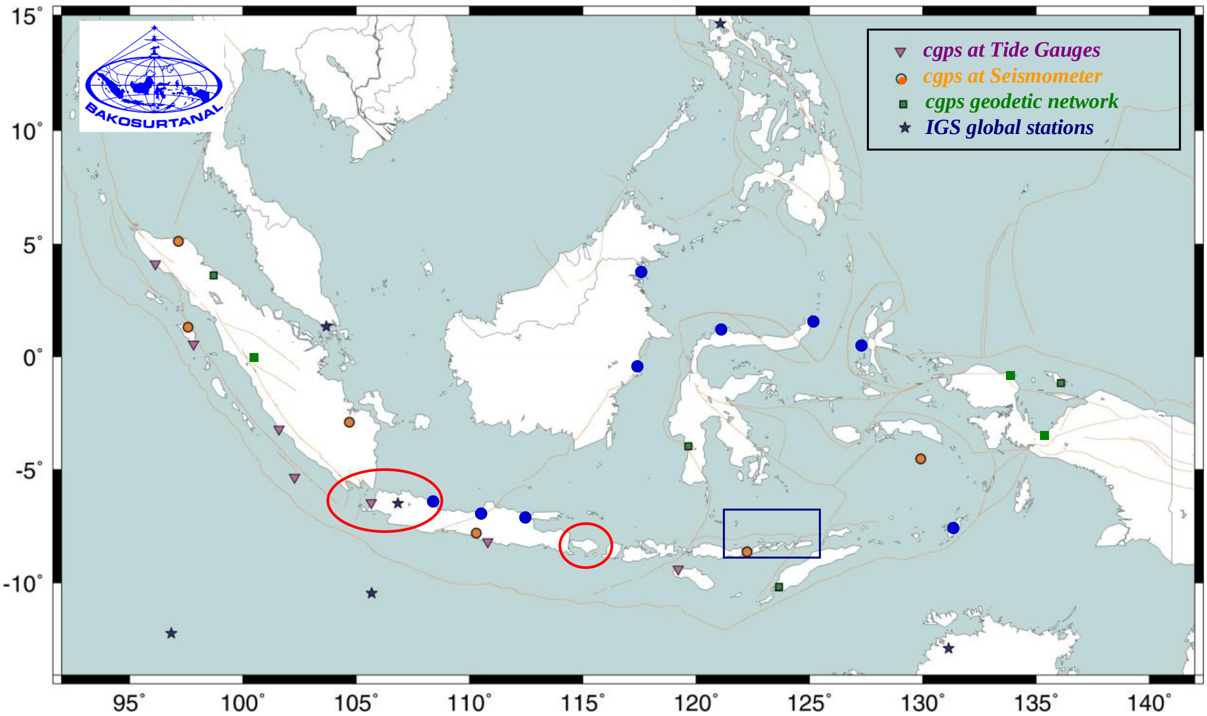

Figure 1. The current status of the Indonesian Permanent GPS Stations Network (IPGSN) consist of: 14 stations continuously GPS operating reference system are located around the Sunda Strait and West Java and 7 stations in eastern end of Java and Bali Island (open red circles); 10 stations are located along Flores thrust-fault (open blue square); 7 stations near seismometer stations (orange circle); 7 stations near or on tide gauge stations (reverse triangles); 7 geodetic (old) stations (green squares); and 10 stations will be install in 2010 (blue circle).

2. EQUIPMENT AND GEODETIC GPS DATA ANALYSIS

2.1 Equipment

The current status of all stations of the IPGSN receivers system incorporates the high-precision L1/L2 geodetic type (i.e. Ashtech UZ-12, Leica GRX1200 family, Topcon GB-1000 and Net G3, and Septrentio PolarX2) with Choke Ring antenna+radome and most of the GPS receivers equiped with meteorological (temperature, pressure and humadity) sensors. An equipment enclosure houses a GPS receiver, a radio or VPN-IP modem, sufficient batteries to operate the site, and solar panels to charge the batteries These stations record data every 1Hz and streaming real time and or near real time of 1 hour latency to data processing center at Bakosurtanal office, Cibinong-Indonesia.

Considering the stringent geodetic requirements for the IPGSN, stable geodetic monuments, accessible and secure, preferably with existing power and data communications infrastructure will need to be constructed at all locations. Due to main reasons of secure location and obstruction view to GPS satellites constellation, there is various type of geodetic monuments construction (Figure 2.) such as: on the top of concrete roof; concrete pillar, stainless-steel rod and on the tide gauge station. The GPS sites which is located with a good sky view, installation of geodetic monuments is drilling and installing a deep-drilled braced monument of the Wyatt-Agnew design and is considered to be the state-of-the-art in stable GPS monumentation. Deep drilled braced monuments are designed to anchor the GPS antenna to a depth of more than 5 m in order to isolate the antenna from expansion/contraction of the near subsurface from temperature or moisture variability.

Figure 2. The IPGSN geodetic monument types: a) on the top of concrete roof; b) stainless-steel rod; c) concrete pillar; d) on a tide gauge station.

2.2 GPS Observations and Processing

We analyzed GPS phase observations from the IPGSN of 31 stations using a consistent processing strategy over the whole period from January 2000 to December 2009. We used the GAMIT software version 10.35 (*Herring et al.*, 2009), estimating station coordinates, satellite orbits, Earth orientation parameters (EOPs), and zenith tropospheric delay parameters as a piecewise linear model with nodes every 1 hour. For individual day, dual-frequency carrier phase and pseudorange observations from all continuous GPS stations including International GNSS Service (IGS) global stations with satellite visibility concurrent to the regional network (IISC, DGAR, COCO, XMIS, DARW, KARR, GUAM, PIMO, CUSV and NTUS) on that day were combined in a weighted least squares adjustment implemented in GAMIT. We used an elevation cutoff angle of 10° in all solution and the 24h observations sampling rate data interval decimated in 120 seconds.

In this processing strategy incorporating many new models that have been added to the GAMIT suite software, these include IERS2003 solid Earth tide model (*McCarthy and Petit*, 2004), the precession/nutation model IAU2000, FES2004 ocean tide loading model (*Scherneck and Bos*, 2001), absolute satellite and antenna phase centre variations offsets (igs05_atx), the global geopential model EGM96, the troposphere Global/Vienna mapping function (*Boehm et al.*, 2006), atmospheric pressure loading at the observation level (*Tregonning and van Dam*, 2005).

This analysis produces daily estimates of site coordinates, satellite state vectors, tropospheric zenith delay parameters, Earth orientation parameters (EOPs) and phase ambiguities. The remaining IGS global tracking data were included at the next, multi-day adjustment stage. Daily observation file were grouped into one subnet with up to 50 stations. Loosely constrained daily regional subnet solutions were produced using a priori site coordinates in the ITRF2005 reference frame; a priori orbits from the IGS; and a priori EOPs from the IERS Bulletin B. The daily subnet solutions were then combined, using GLOBK (*Herring et al.*, 2009), with daily solutions from global subnet solutions provided by the MIT (http://everest.mit.edu/pub/MIT_GLL/). The result is a loosely constrained position time series for the entire years span. To obtain station coordinates in the ITRF2005, we performed an adjustment, using GLORG, constraining the ITRF2005 coordinates and velocities of appropriate global tracking sites that comprise the reference network. The obtained combined daily solutions were combined into weekly solutions in a second step.

3 ASSESSING THE QUALITY OF SOLUTIONS

A number of GAMIT routines provide the analyst with information on the quality of the analysis. The most important resulted of the quality estimator is the one that produces the smallest RMS has been used to assess the effectiveness of applying the models.

3.1 Resolving Ambiguities

The carrier phase observable is favoured in high precision geodetic measurements. The GAMIT software is based on the double difference formulation of this carrier phase observable that eliminates the effects of oscillator instabilities. A least squares solution for station positions, phase biases, and noise parameters is then obtained from an independent subset of doubly differenced phase observations.

For static point positioning (i.e. if the receiver coordinates are constant for all observation span), and in absence of cycle slips, observations from different epochs can be combined to yield a generally over determined solution. The least squares adjustment generally does not yield the correct (integer) value for the phase biases. Several algorithms (e.g., *Dong and Bock*, 1989) exist for bias fixing that is for resolving the integers and therefore increasing the accuracy of the geodetic position estimates. For dual frequency (L1 and L2) observations, a commonly applied method is sequential bias fixing. Since the wave length for the combined L2-L1 phase is considerably longer than for either of the individual phases, better constraints can often be applied to the L2-L1 biases. Once these so-called wide-lane (WL) ambiguities have been fixed, L1 biases (narrow-lane [NL] ambiguities) are determined in a second step. GAMIT has the option to fix the ambiguities in the double differences to integer values.

In this study, daily solutions of the IPGSN covering more than 10 years data span the percentage of correct fixing of the ambiguities is 80% – 95% for wide-lane and 70% – 80% for narrow-lane. Figure 3a and Figure 3b, shows the percentage of WL and NL ambiguities fixed to integer values with applying different model of troposphere mapping function respectively. The mapping function models which is implemented in existing GAMIT geodetic analysis software is Niell Mapping Function (NMF), Global Mapping Function (GMF) and Vienna Mapping Function (VMF1).

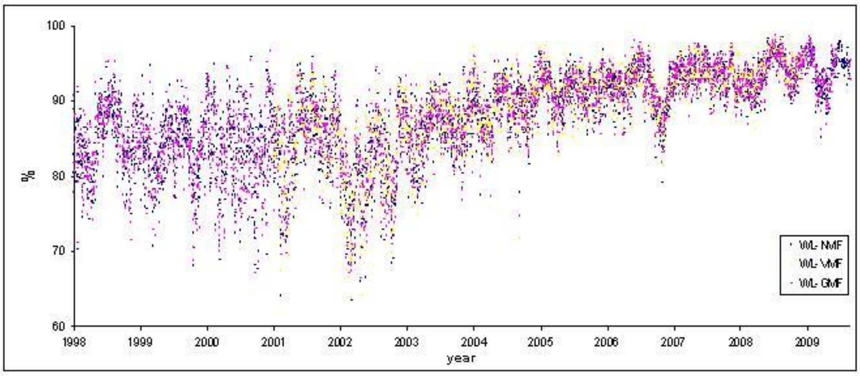

Figure3a. The percentage of wide-lane (WL) fixed to integer values
with models NMF (blue), VMF1 (yellow), and GMF (pink)

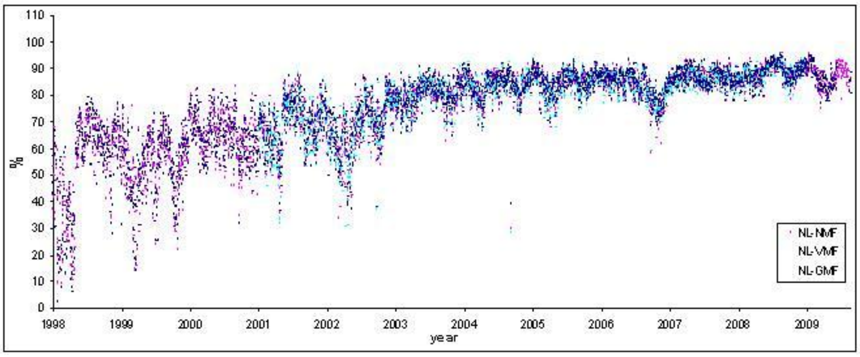

Figure3b. The percentage of narrow-lane (NL) fixed to integer values
with models NMF (blue), VMF1 (cyan), and GMF (pink)

Figures 3s above illustrates how the resolving ambiguities fixed to integer values in IPGSN is achieved in the daily solutions, which has inter-station baselines ranges from 30 km to thousands of kilometers in the network. The percentages of resolving ambiguities are not significantly different however will provides better precision to geodetic position estimates.

3.2 Geodetic GPS solutions

The GPS baseline solutions are to provide geodetic positions with precisions that are often as good as a few millimeters if the best model is applying correctly. Studied were carried out to evaluate the best strategy to implement new models includes the troposphere GMF mapping function (*Boehm et al.*, 2006), as well as the atmospheric pressure loading corrections (*Tregoning and van Dam*, 2005 and *Tregoning and Watson*, 2009). An analyses to assess the quality of GPS solution results by using different troposphere models (NMF, GMF and VMF1), the results are quite encouraging. Figure 4s shows that geodetic positions estimates are achieved in millimeter level accuracy for horizontal and vertical component coordinates as well.

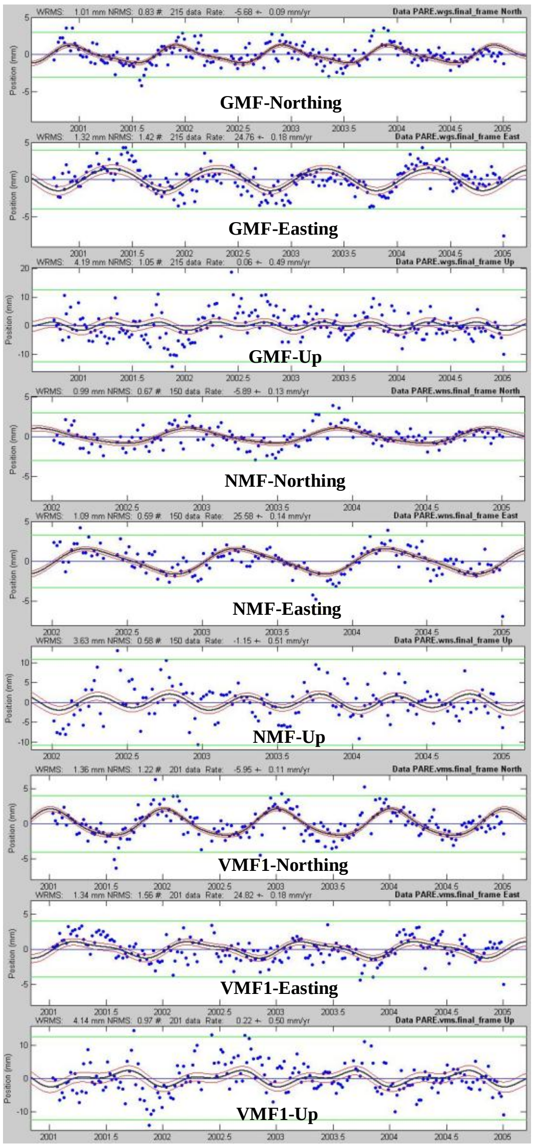

Figure 4a. The IPGSN 'PARE' site on top of concrete roof building.

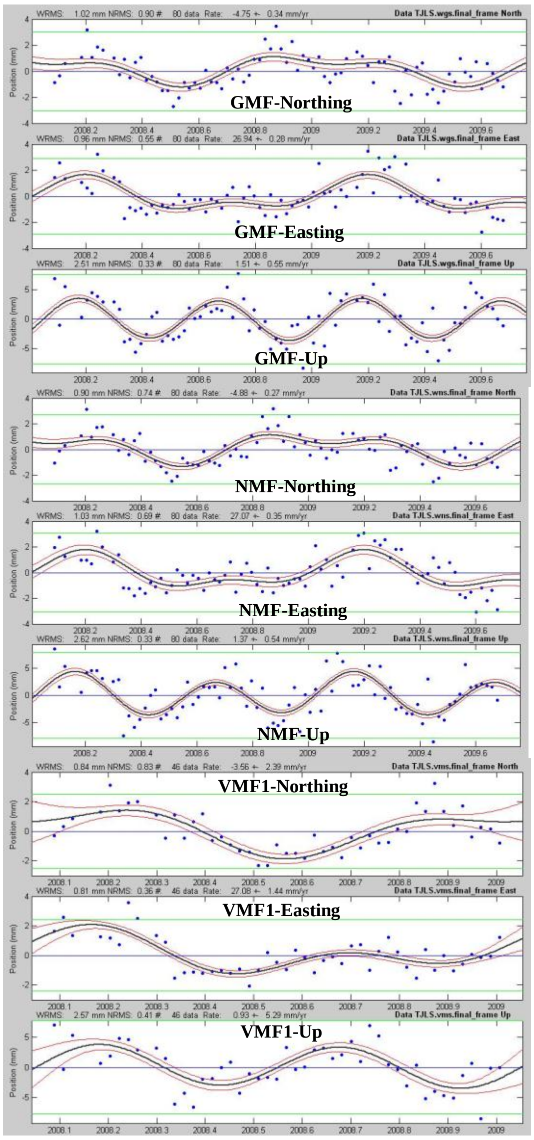

Figure 4b. The IPGSN 'TJLS' site on a tide gauge station.

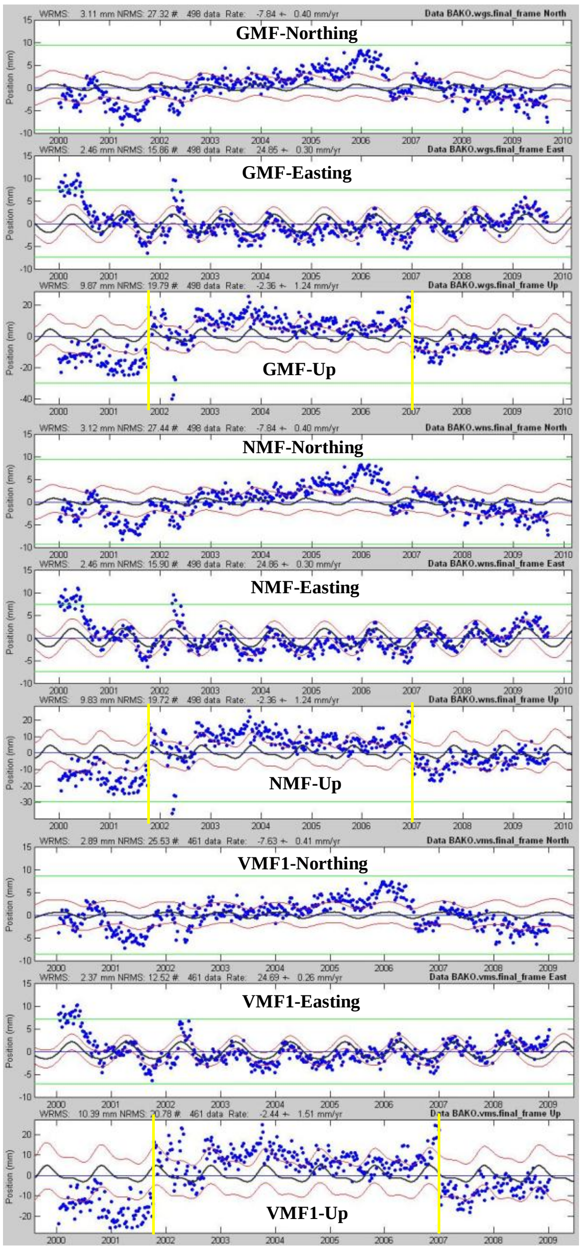

Figure 4c. The IPGSN 'BAKO' site of brace monument with coordinates offset (yellow lines) due to receiver and antenna changes.

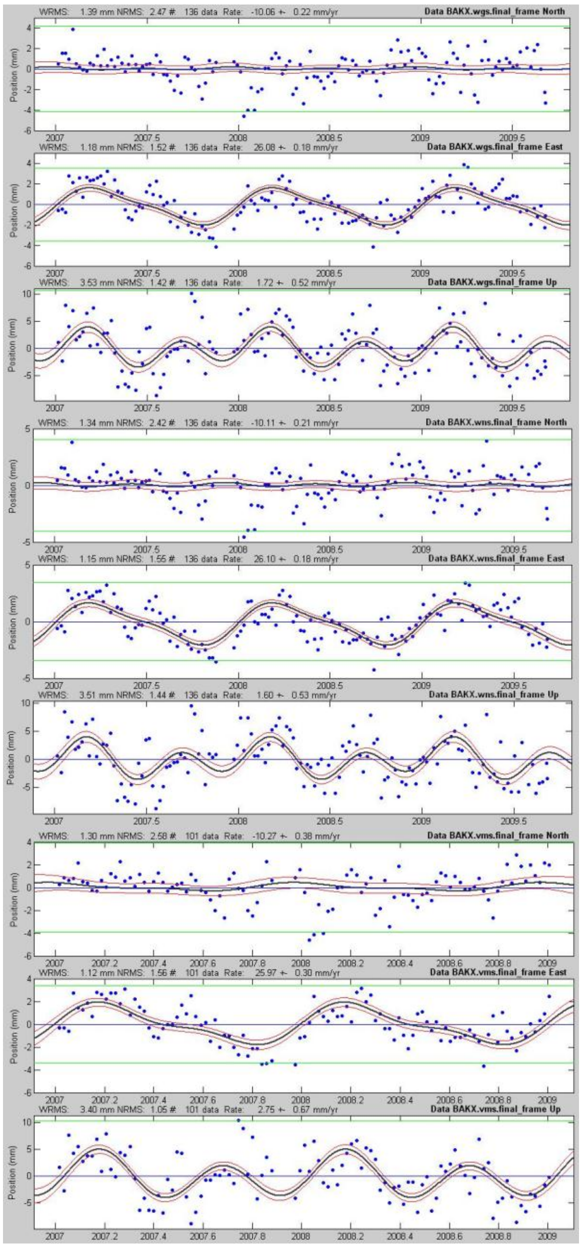

Figure 4d. The IPGSN 'BAKO' site of brace monument with coordinates offset due to antenna changes is not included.

The analysis of the IPGSN represented by sites "PARE", "TJLS", "BAKO" and "BIKL" with different type of monument construction and with applying NMF, GMF and VMF mapping functions shows that the precision of the geodetic station results is < 1.5 mm in Northing and Easting component of coordinates and < 4.2 mm in the station, after removing a timeseries span which was disturbing by station receiver and antenna changes and by earthquakes. We have used the Tsview software (*Herring*, 2003) for De-trended time series plot of weekly geodetic position estimates.

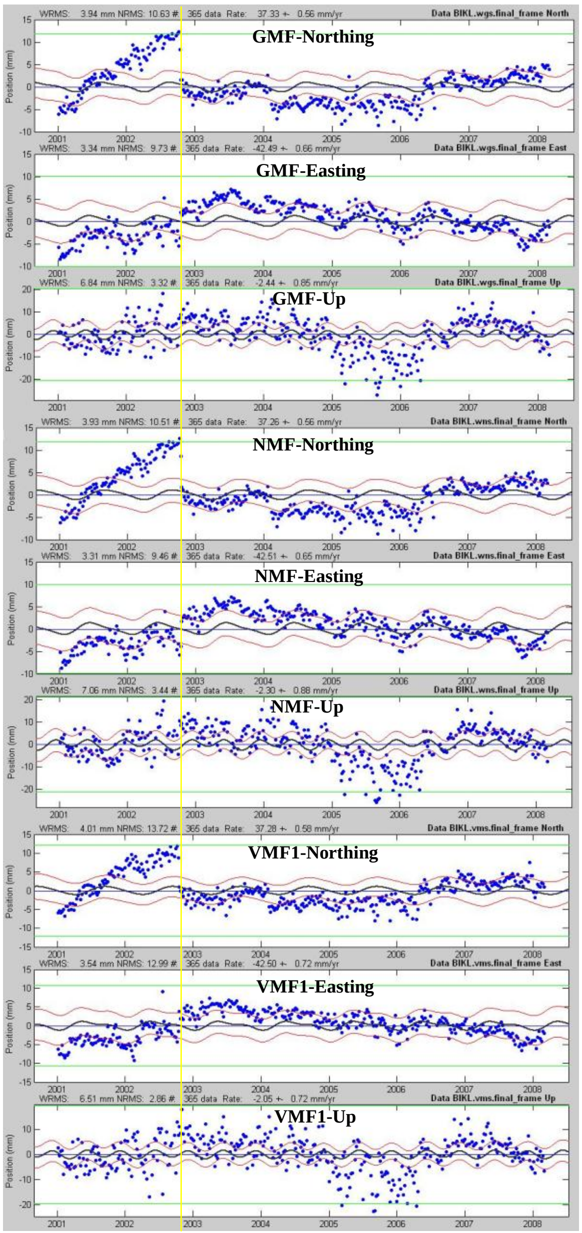

Figure 4e. The IPGSN 'BIKL' site of pillar monument with coordinate offset (yellow line) due to an earth-quake.

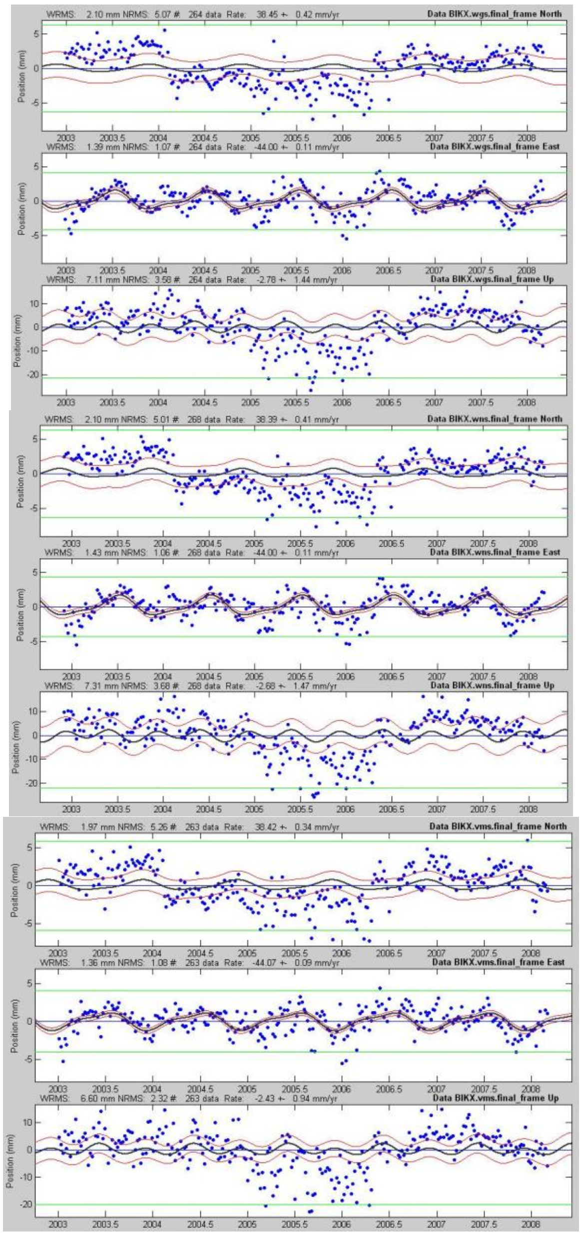

Figure 4f. The IPGSN 'BIKL' site of pillar monument without coordinate offset due to an earthquake.

CONCLUSIONS

The result of the evaluation shows that applying the recent new models in geodetic GPS analysis of the IPGSN which is already implemented in GAMIT space geodesy software package providing considerably improves the precision of the most accurate and reliable geodetic results. Efforts are still needed to further improve the positioning accuracy of the GPS height by incorporating surface meteorological data (temperature, pressure and humidity) into data processing.

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