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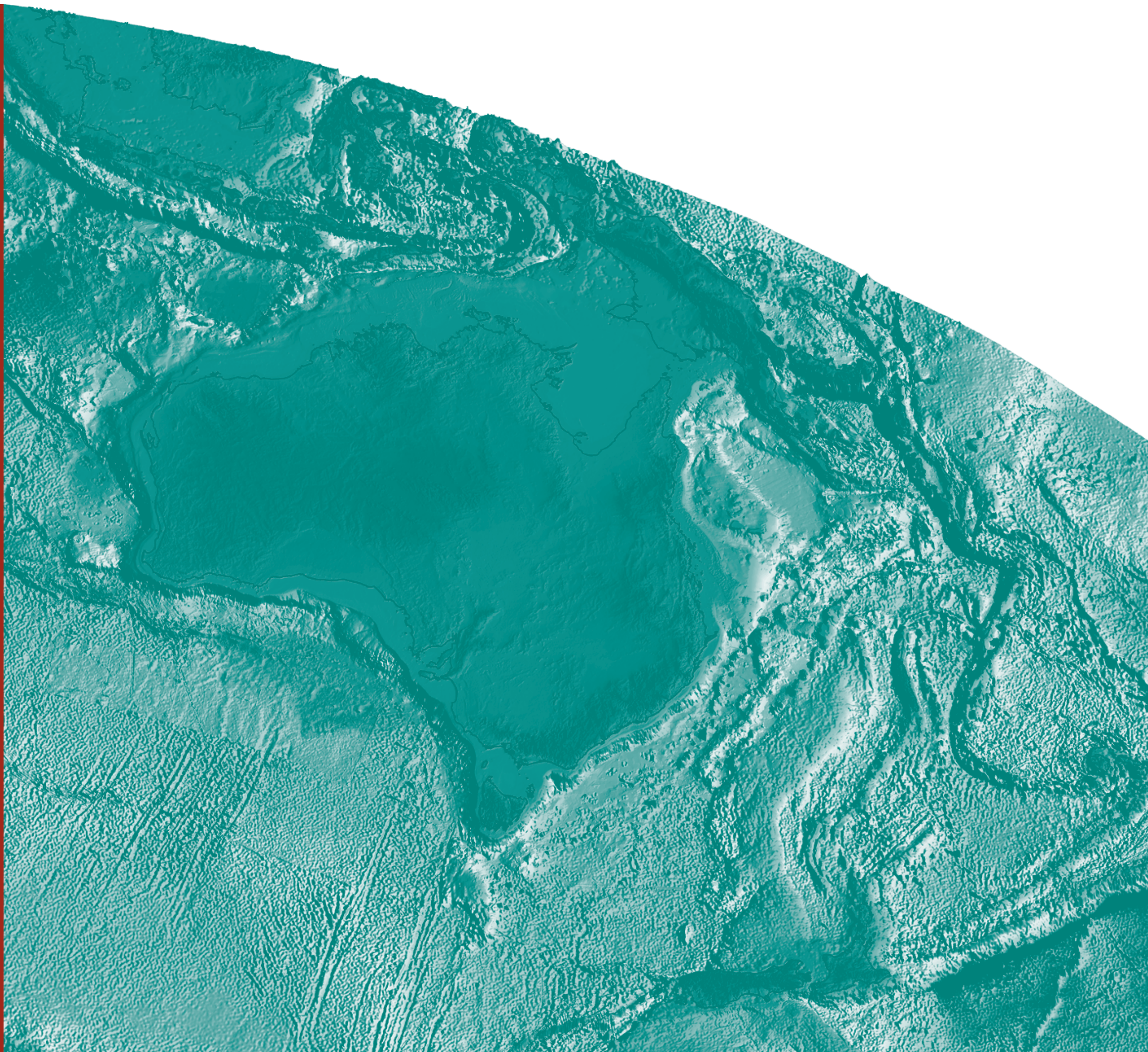

South Pacific Sea Level and Climate Monitoring Project: GPS Coordinate Time Series, 2007.0 to 2012.2

GEOSCIENCE AUSTRALIA
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by

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Contents

1.0 Introduction

This report presents the coordinate time series for the 12 Continuous GPS (CGPS) stations established under the AusAID funded South Pacific Sea Level and Climate Monitoring Project (SPSLCMP). The CGPS stations are located in Cook Is, Fiji, Kiribati, Manus Is – Papua New Guinea (PNG), Marshall Is, Nauru, Pohnpei – Federated States of Micronesia (FSM), Samoa, Solomon Is, Tonga, Tuvalu and Vanuatu. The time series is generated from 5 years of weekly GPS solutions for the period 2007.0 to 2012.2 to obtain station velocities in a globally consistent geocentric reference frame, the International Terrestrial Reference Frame (ITRF) 2008 (Altamimi et al., 2011). The vertical velocities is of prime importance in sea level determinations, since it indicates the vertical crustal deformation of the land mass, hence allows to correct for this motion when analysing the tide gauge data. The differential motion between the tide gauge sensor and the GPS station should also be considered in determining sea level changes.

An overarching factor to consider in accurate sea level determinations is the required precision of the absolute vertical velocity of the GPS station, corrected for any vertical motion between this station and the tide gauge sensor. The most recent global estimate for sea level rise in the past century is 1.7mm±0.2mm/yr (Church and White, 2011), which is similar to previous estimates by Tushinam and Peltier (1991) and Douglas (1997). Therefore, the precision of the net vertical velocity of the GPS station, corrected for differentials motions relative to the tide gauge sensor, must be better than the uncertainty of the sea level rise estimates in order to correctly determine absolute sea level changes. This will be considered when analysing station velocities.

Geoscience Australian (GA) has enhanced its GPS processing strategy in accordance with the latest conventions and standards. Some of the enhancements include adopting the latest International Earth Rotation Service (IERS) conventions (IERS, 2010); updating the mapping function for improved handling of tropospheric errors; and adopting the IGS08 reference frame, the International GNSS Service (IGS) realisation of ITRF2008. As a result of these enhancements, all existing data required reprocessing with the new standards and conventions. At the current stage, the backward processing has been completed till the beginning of 2007 and efforts are underway to progress further. Due to the relatively short period (~5years) of the time series, the results in this report should be treated with caution as this time period may be too short to estimate reliable vertical velocities. As the backward reprocessing and data collection into the future progresses, and the strategy for simultaneous estimation of velocities and periodical or seasonal signals is used, the estimates of the vertical crustal motion will become more accurate and reliable.

The first part of this report describes the input weekly solutions and combination strategy for generating the time series. Following this, the vertical velocity estimates are presented and discussed and conclusions are drawn. The next part shows a graphical representation of the raw and modelled time series. The raw time series are uncorrected for offsets due to equipment changes and earthquakes whereas the modelled time series are corrected for these effects.

2.0 Methodology

The input solutions for generating the station velocities are the weekly Solution Independent EXchange (SINEX) format solutions produced by GA. These solutions are produced by combining daily solutions and aligning to the IGS08 reference frame using a minimum constraint approach based on a set of core stations. The solution contains a set of globally distributed IGS08 core stations which provide consistent alignment to the IGS08 reference frame. The strategy for the GPS analysis is summarised in a summary file accompanying each weekly SINEX solution, available at ftp://ftp.ga.gov.au/geodesy-outgoing/gnss/solutions/final/weekly.

Any constraints are removed from the input SINEX solutions and minimum constraint is applied for all stations over all seven transformation parameters. The IGS08 core reference stations which have more than 80% of solutions available for the period are chosen to form the minimum constraint alignment to IGS08. This ensures stability of the combined solution with respect to IGS08, in terms of the transformation parameters. The time series combination is performed next, with the Combination and Analysis of Terrestrial Reference Frames (CATREF) software (Altamimi et al., 2011). The combination is iterated four times and outliers are removed, the rejection criteria being 0.01m horizontal and 0.025m vertical, in the last iteration. At the end of the combination, the station coordinates and velocities are available in the IGS08 reference frame. The residuals for the times series are generated for each site in a format acceptable for the Create and Analyse Time Series (CATS) software (Willams, 2008). The CATS software is used to determine realistic estimates for the station velocity, with appropriate handling of white noise plus random walk and flicker noise. Period seasonal signals are not estimated, since its effect on velocities is negligible if more than 4.5years of data is available for a station (Blewitt & Lavallee, 2002).

3.0 Results and Discussions

The vertical velocities, with uncertainties, determined by GA analysis are given in Table 1. The velocities for some of the SPSLCMP stations, available from the ITRF2008 solution (Altamimi et al., 2011), are also given for comparison. The stations Solomon Is and Marshall Is were not included in the ITRF2008 analysis since they are relatively new. Also note that the ITRF2008 velocities are determined from longer time series data, going back as far as 2001, when the stations were established.

Table 1: Vertical velocities, with uncertainties for the GA solution compared to the ITRF2008 solution.

CGPS LOCATION	VERTICAL VELOCITY ± UNCERTAINTY (MM/YR) – GA SOLUTION	VERTICAL VELOCITY ± UNCERTAINTY (MM/YR) – ITRF2008 SOLUTION
Cook Islands	-0.8 ± 0.8	+0.6 ± 0.1
Fiji	-1.8 ± 0.7	+0.3 ± 0.2
Kiribati	+1.1 ± 0.9	-0.4 ± 0.1
Manus Is (PNG)	-1.3 ± 0.5	+0.2 ± 0.2
Marshall Is	+0.9 ± 1.0	N/A
Nauru	+0.3 ± 0.8	-1.2 ± 0.2
Pohnpei (FSM)	+1.0 ± 1.1	-0.8 ± 0.2
Samoa	-8.8 ± 0.9	+0.1 ± 0.2
Solomon Is	+1.2 ± 0.5	N/A
Tonga	+2.3 ± 0.6	+2.2 ± 0.3
Tuvalu	-1.8 ± 0.7	+0.1 ± 0.2
Vanuatu	-6.0 ± 0.9	-3.5 ± 0.3

The differences between the GA and the ITRF2008 vertical velocities are generally within ±2mm/yr, except Samoa which has a large difference of -8.9mm/yr. On examining the Samoa time series, a strong post-seismic signal is evident after the Mag. 8 earthquake in October 2009. It is evident that the earthquake also impacts the velocity since the time the antenna was changed in July 2007. Further backward processing of the data may reduce this impact. Vanuatu, which has a difference between the two solutions of -2.5mm/yr is also affected by several earthquakes.

It is expected that the results will improve once GA has reprocessed the data back to 2001, hence has a longer time series.

HANDLING EQUIPMENT CHANGE AND EARTHQUAKE EFFECTS

Equipment changes and earthquakes have been noted for several of the stations, which create offsets or jumps in the time series. These jumps are handled by introducing discontinuities on the date of the event. Although the offsets are removed by this approach, the uncertainties of the velocity estimates become larger (Williams, 2003). Hence, it is best to prevent such nuisance parameters by avoiding changing and replacing equipment. However, the SPSLCMP station equipment required upgrade to avoid unexpected failure and to bring the network inline with tracking the next-generation multi-system GNSS constellations. All of the stations will have their antennas and receivers upgraded from tracking GPS only to tracking multi-GNSS satellites. Also, GA has altered the procedure for local monitoring surveys by avoiding removal of antennas during such surveys. In the new approach, the antennas are measured to using an indirect method. This minimises disturbances in the time series, which can be caused by removing and replacing the same antenna (Williams 2003).

Significant jumps were detected due to equipment changes at Nauru and Samoa whereas jumps due to earthquakes have been detected at Samoa and Vanuatu. A possible jump is expected in Cook Is, and other stations which have been/ are being upgraded. This will be confirmed after the upgrades are complete and the data after the equipment change has been thoroughly analysed.

4.0 Conclusions

Time series combination and analysis was carried out to determine the vertical velocities and their uncertainties for 12 CGPS stations in the South Pacific, using a relatively short period (~5 years) of data. Comparison of the velocities with the recent ITRF2008 solutions shows discrepancies at the 1-2mm/yr level, except for Samoa and Vanuatu, which are affected by earthquakes. It is expected that as the backward reprocessing progresses, the estimates of the vertical crustal motion will become more accurate and reliable. Therefore, the results in this report should be treated with caution as the period of data analysed may be too short for reliable estimation of vertical velocities.

5.0 Raw Time Series

GENERAL NOTES

- Error bars are 1 sigma. All variance-covariance has been re-scaled to better reflect actual precision.
- Each solution 'circle' represents a weekly combined solution. Outliers are not shown on plots.

5.1 COOK IS (CKIS)

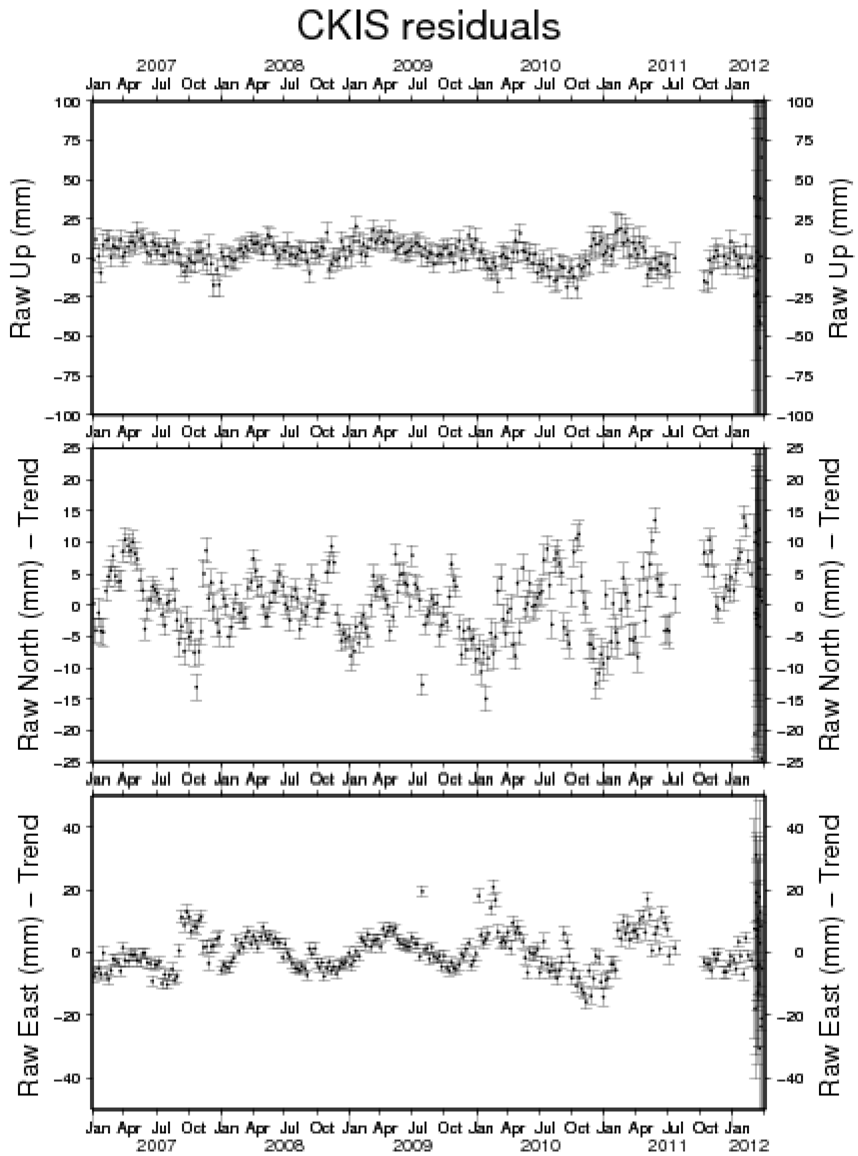


__Figure 1__ – De-trended in Up, North and East Time Series Plot – Cook Is

5.2 FIJI (LAUT)

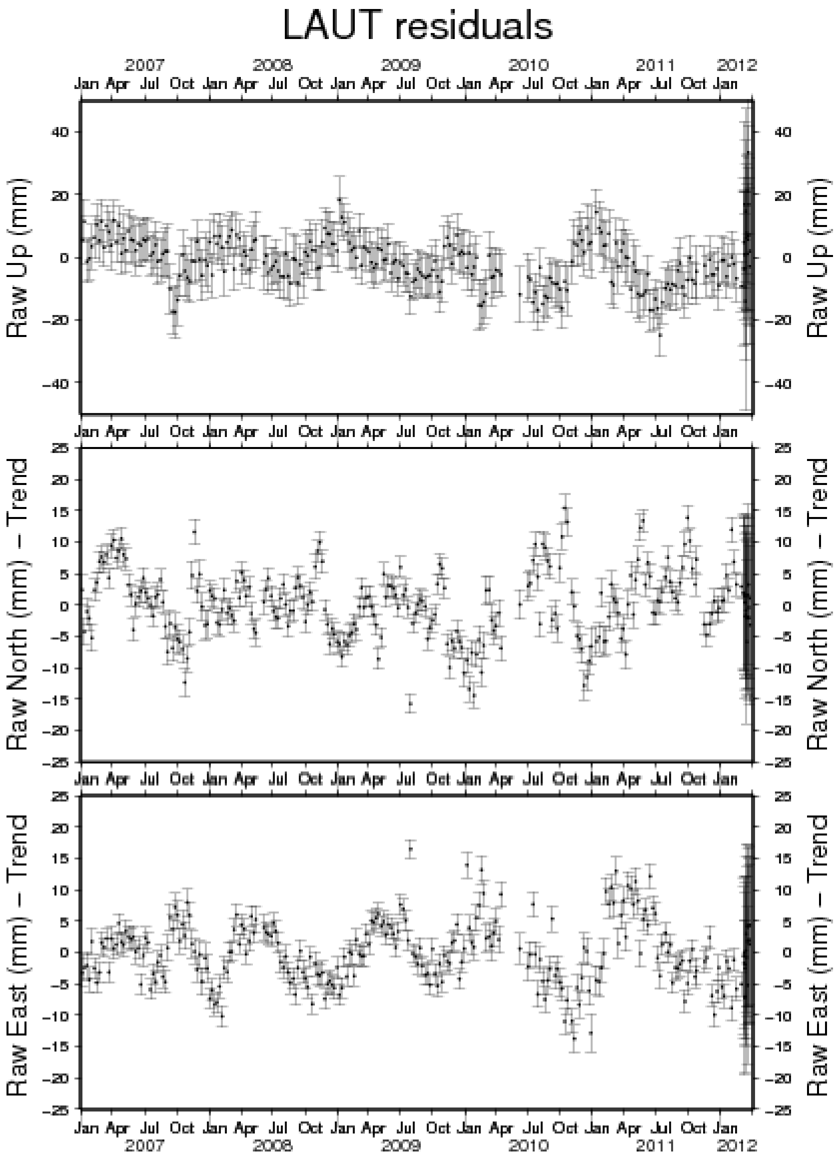


Figure 2 *– De-trended in Up, North and East Time Series Plot – Fiji*

5.3 KIRIBATI (KIRI)

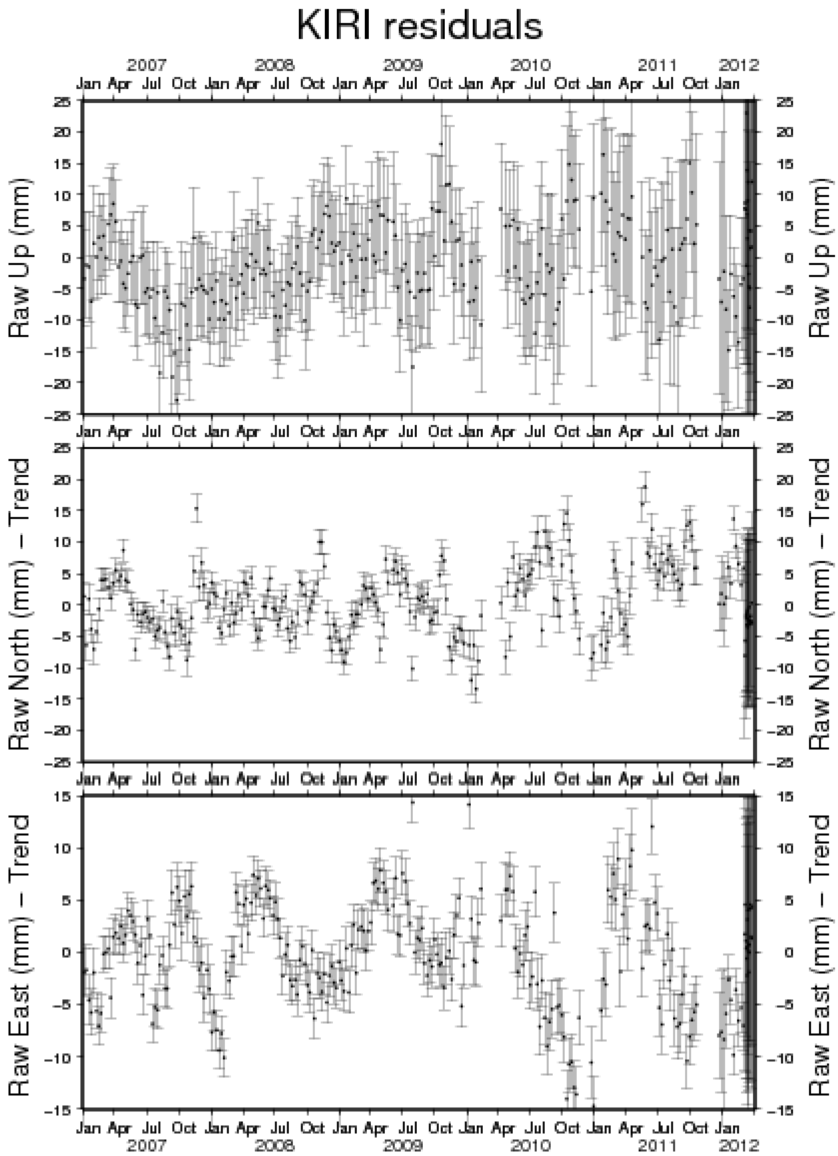


Figure 3 *– De-trended in Up, North and East Time Series Plot – Kiribati*

5.4 MANUS IS (PNG) – (PNGM)

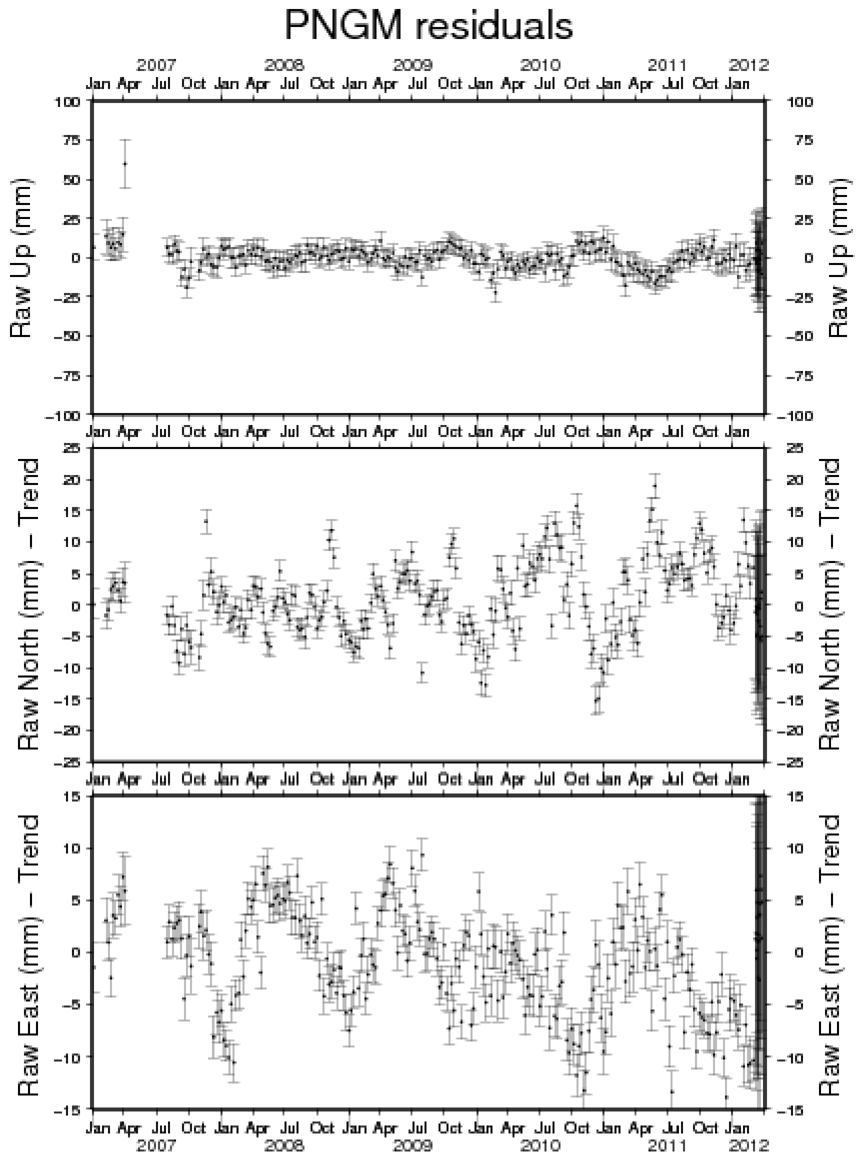


Figure 4 *– De-trended in Up, North and East Time Series Plot – Manus Is*

5.5 POHNPEI (FSM) - (POHN)

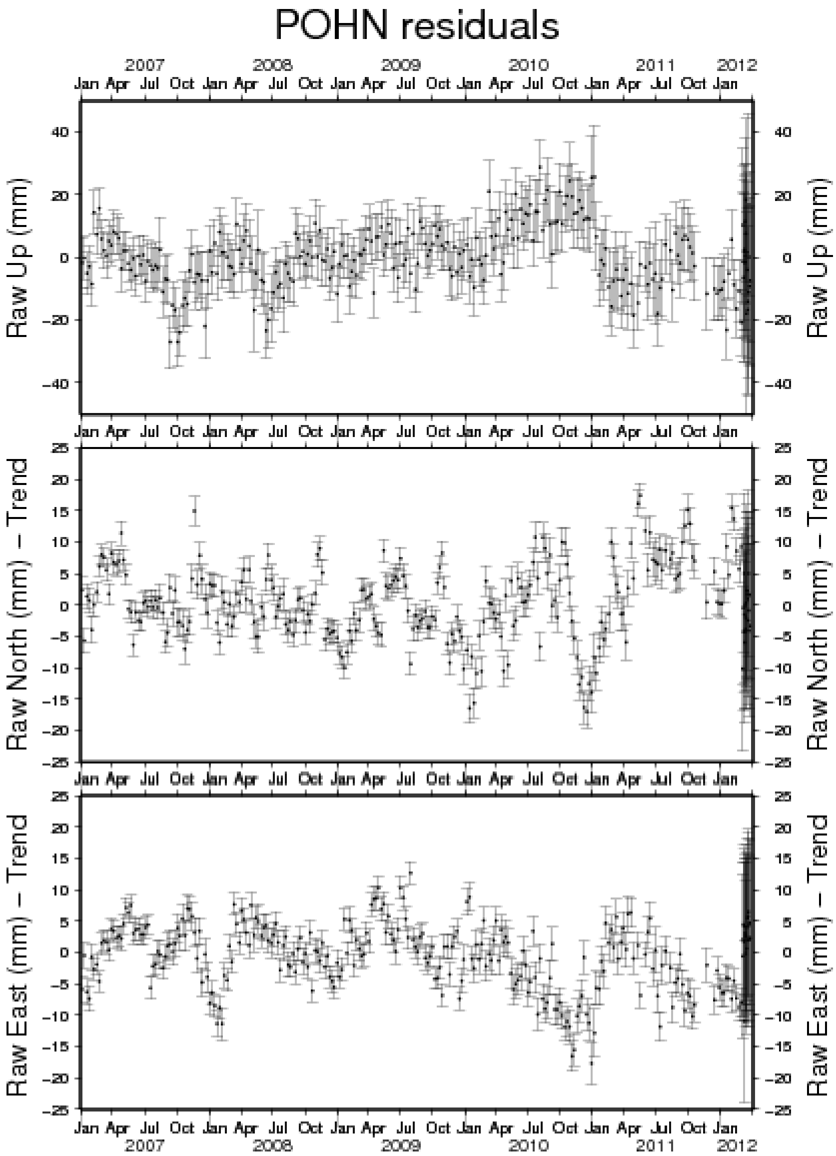


Figure 5 *– De-trended in Up, North and East Time Series Plot – Pohnpei (FSM)*

5.6 NAURU (NAUR)

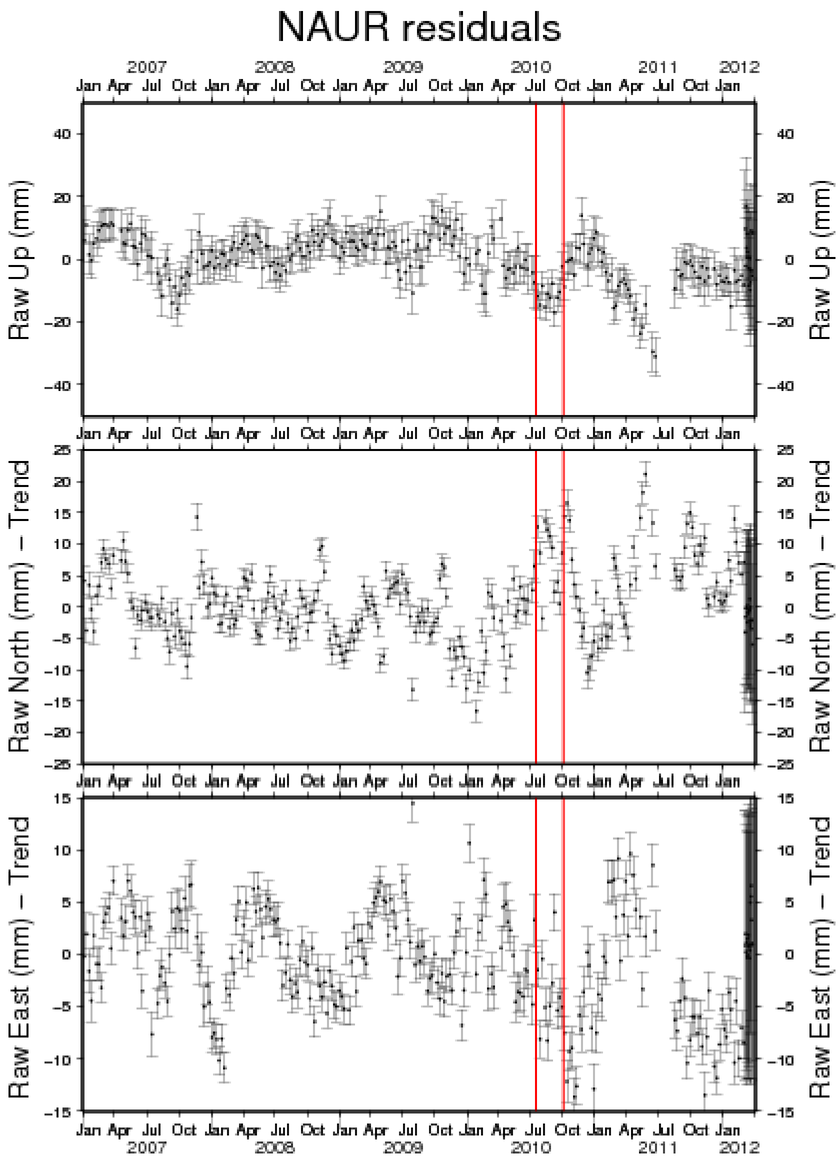


Figure 6 – De-trended in Up, North and East Time Series Plot – Nauru. The offset is caused by an antenna and receiver change in July 2010.

5.7 SAMOA (SAMO)

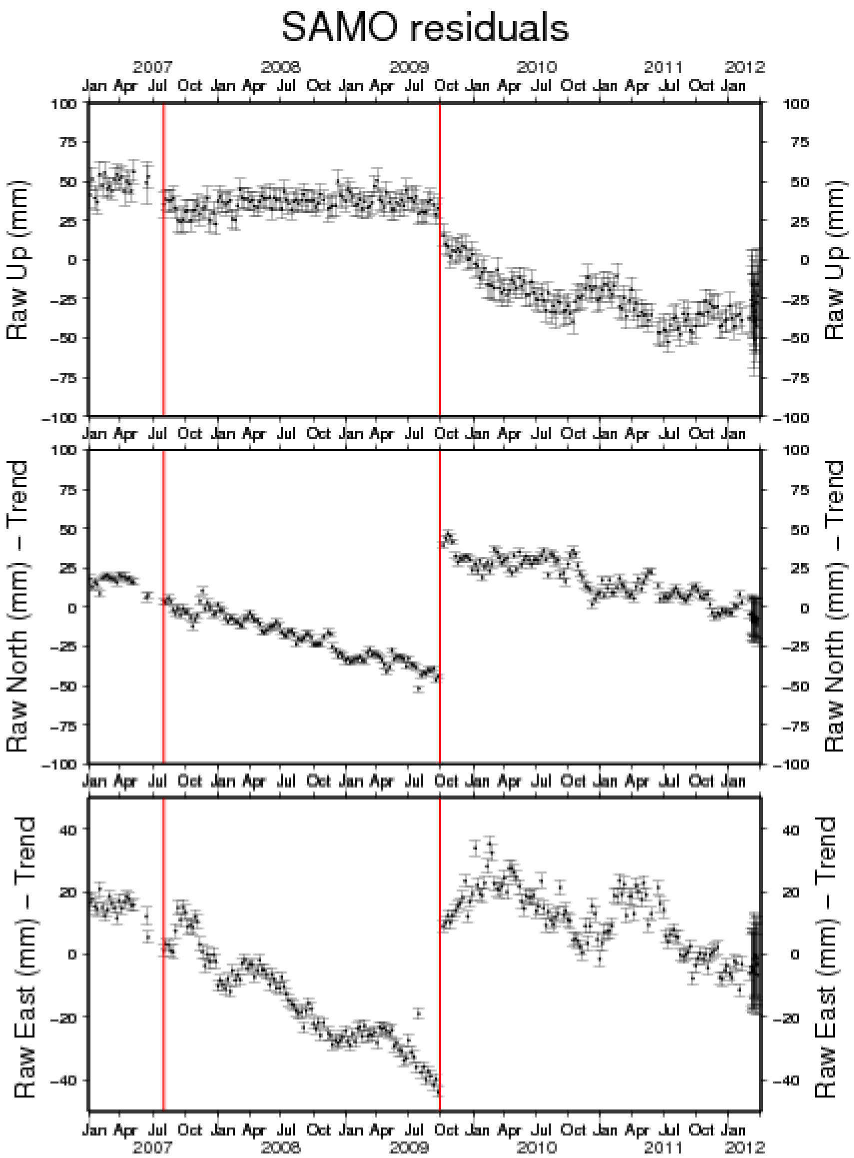


***Figure** 7 – De-trended in Up, North and East Time Series Plot – Samoa. The offsets have been caused by an antenna change in July 2007 and a Mag. 8 earthquake in October 2009.*

5.8 TONGA (TONG)

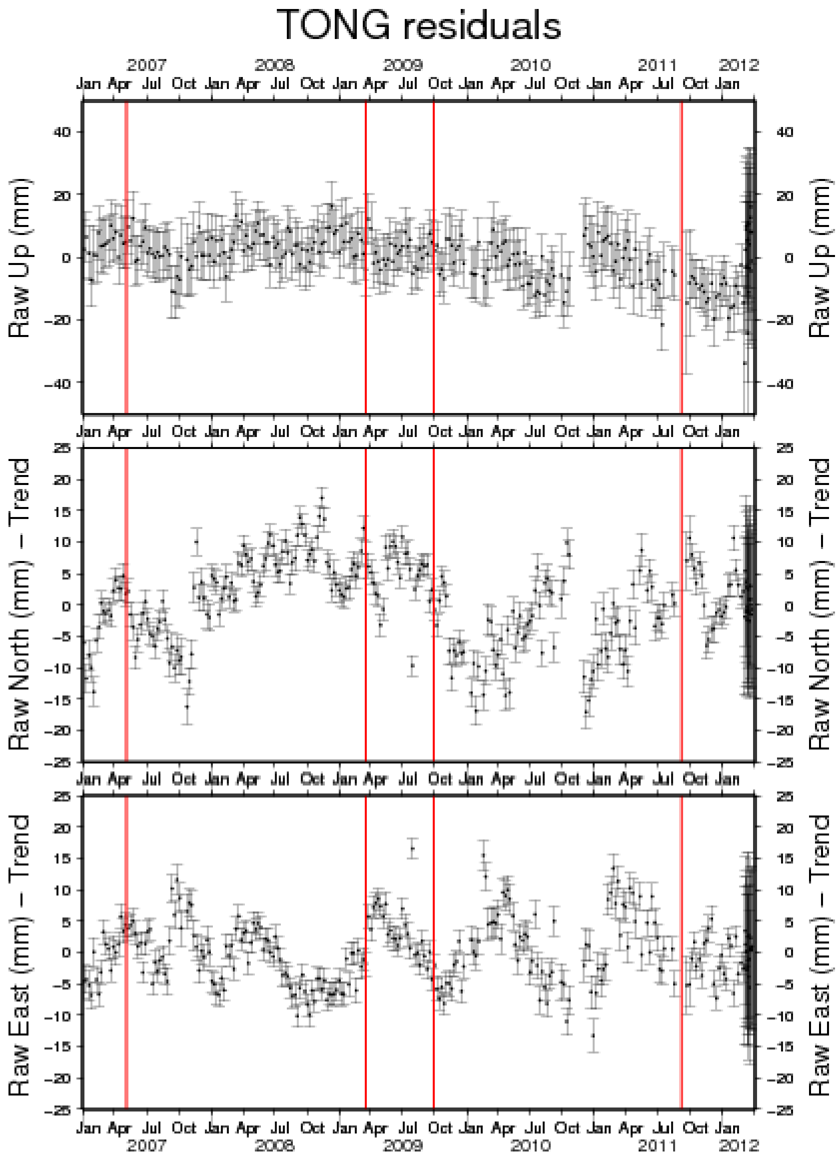


__Figure 8__ – De-trended in Up, North and East Time Series Plot – Tonga. The Offsets have been caused by several earthquakes in close proximity to the station.

5.9 TUVALU (TUVA)

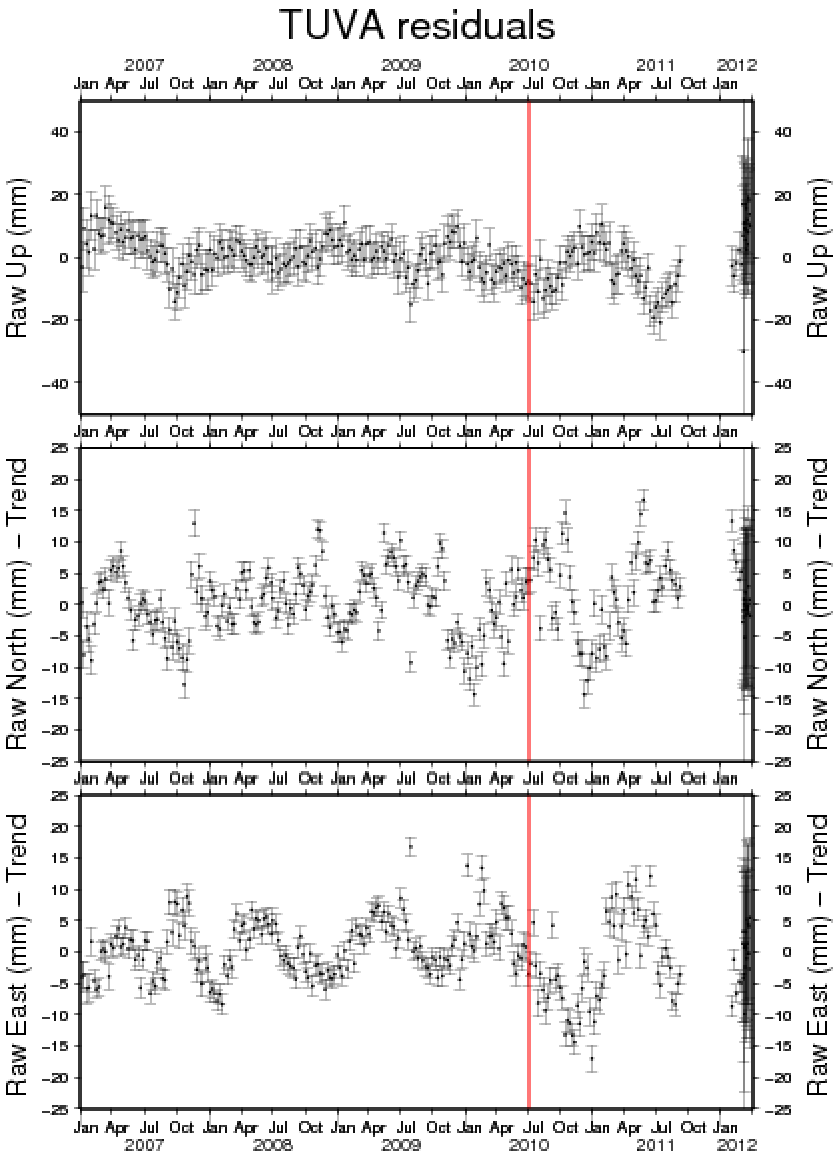


Figure 9 *– De-trended in Up, North and East Time Series Plot – Tuvalu. The discontinuity reported by IGS was due to an unknown cause and requires further investigation.*

5.10 VANUATU (VANU)

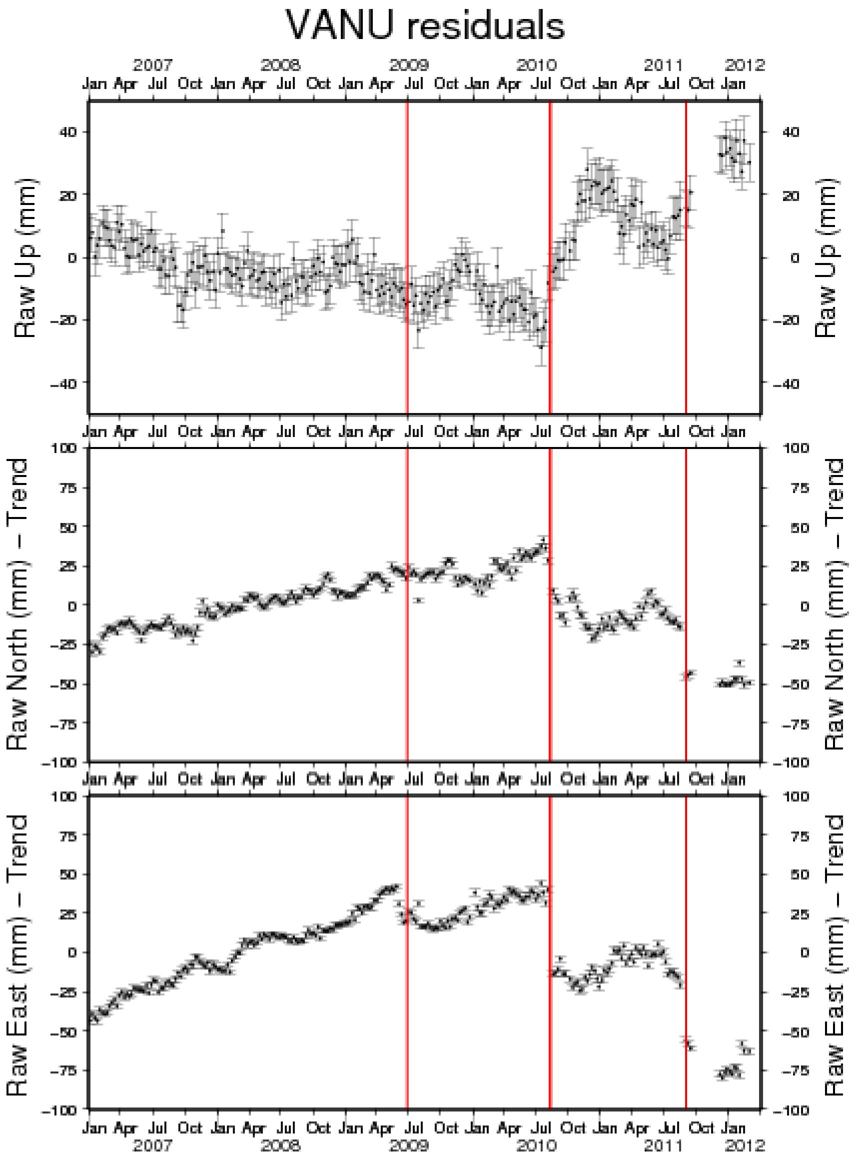


Figure 10 – *De-trended in Up, North and East Time Series Plot – Vanuatu. The Offsets have been caused by several earthquakes in close proximity to the station.*

5.11 MARSHALL IS (MAJU)

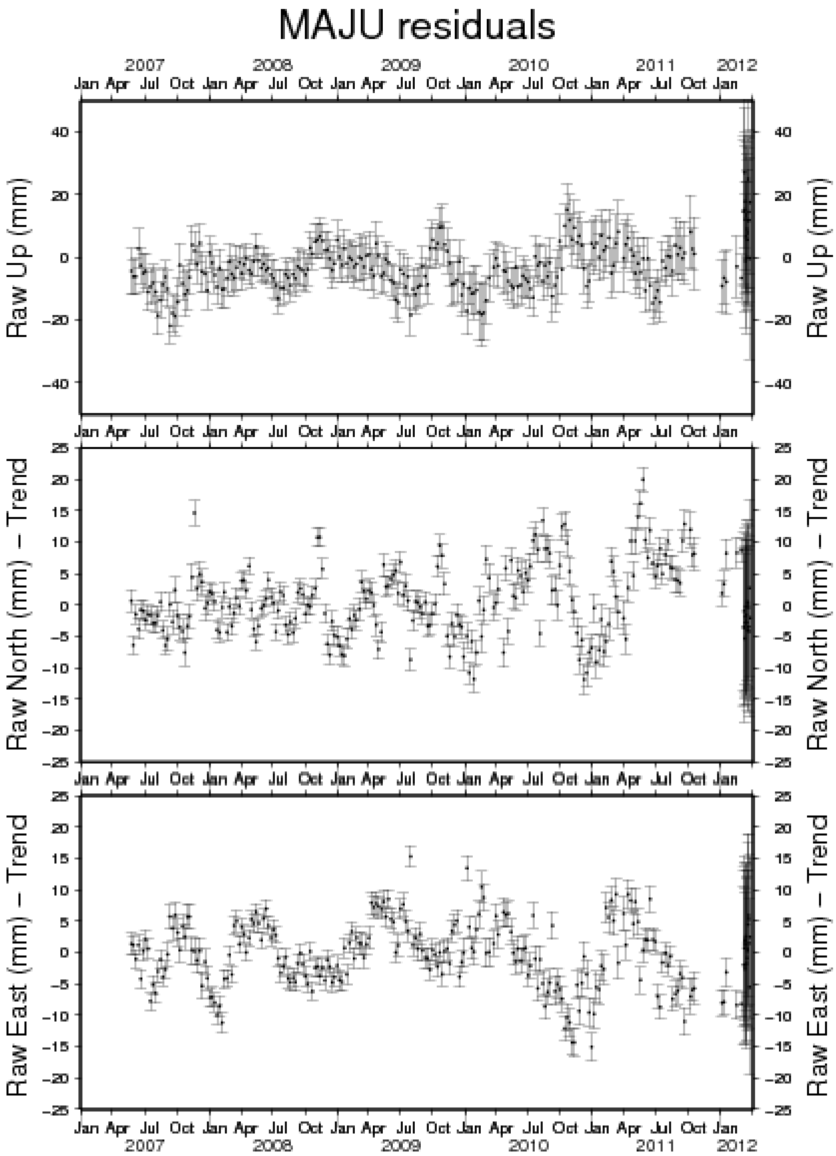


Figure 11 – *De-trended in Up, North and East Time Series Plot – Marshall Is*

5.12 SOLOMON IS (SOLO)

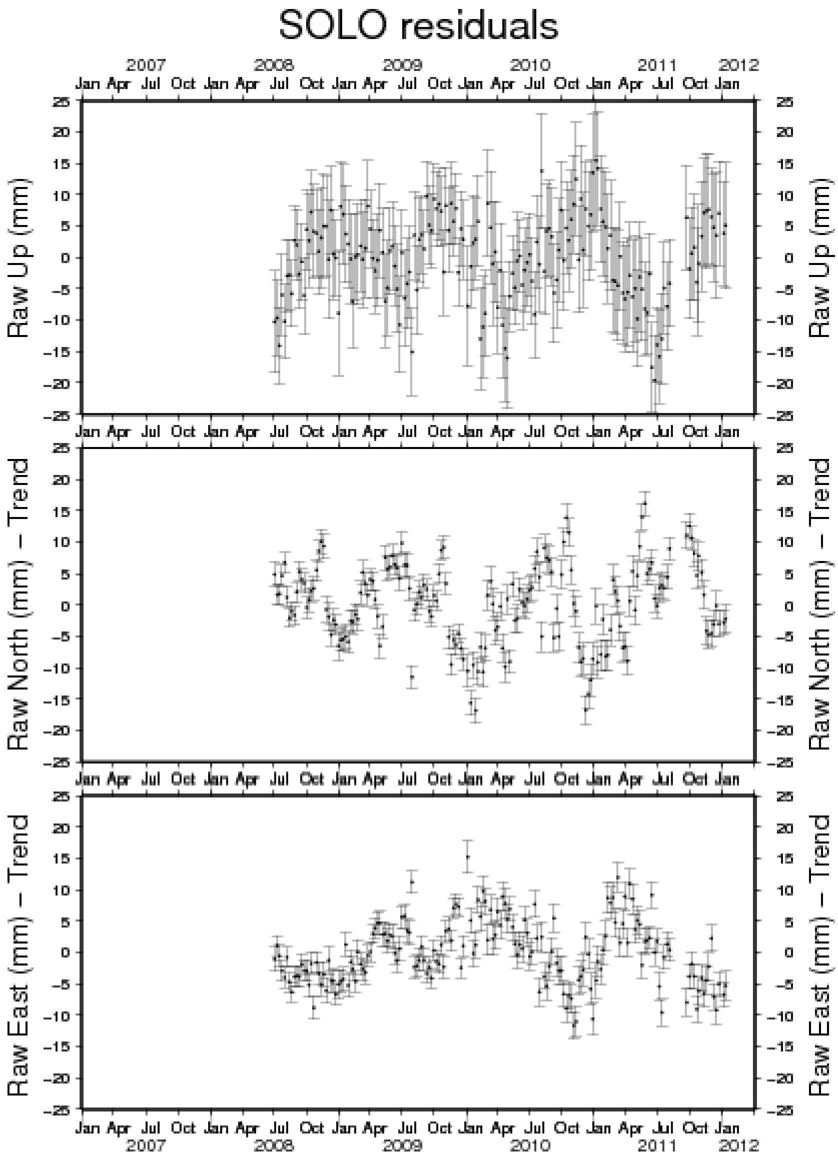


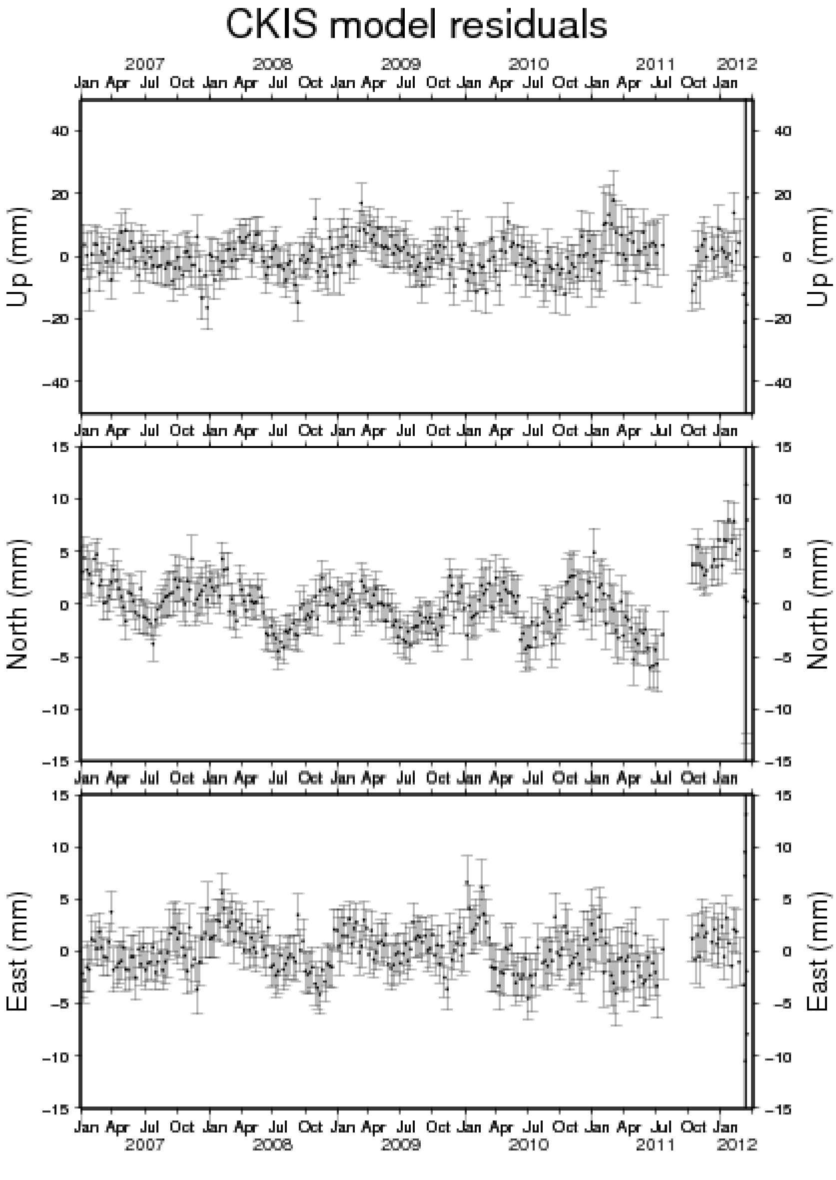
Figure 12 – De-trended in Up, North and East Time Series Plot – Solomon Is

6.0 Modelled Time Series with Jump Functions

GENERAL NOTES

- Error bars are 1 sigma. All variance-covariance has been re-scaled to better reflect actual precision.
- Each solution 'circle' represents a weekly combined solution. Outliers are not shown on plots.

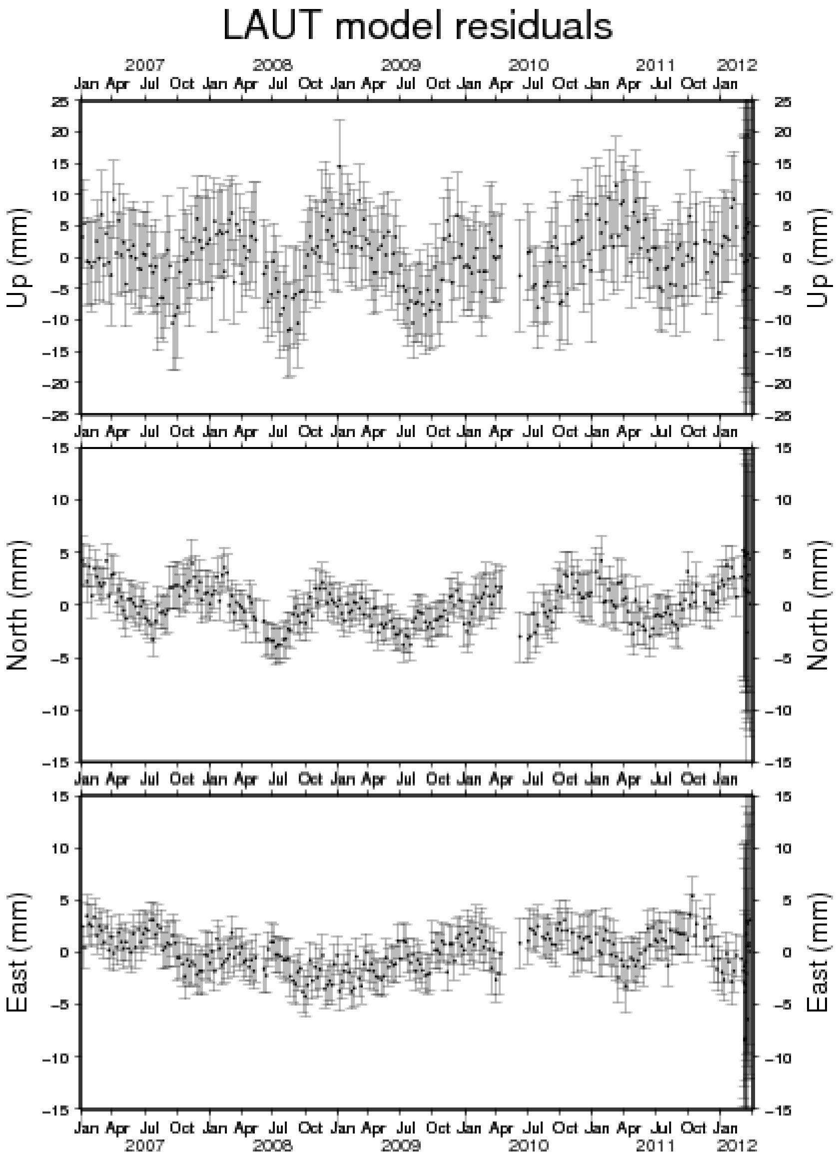
6.1 COOK IS (CKIS)



Velocities in East, North and Up (m/yr) -0.0636 0.0361 -0.0008

Figure 13 *– De-trended in Up, North and East Time Series Plot – Cook Is*

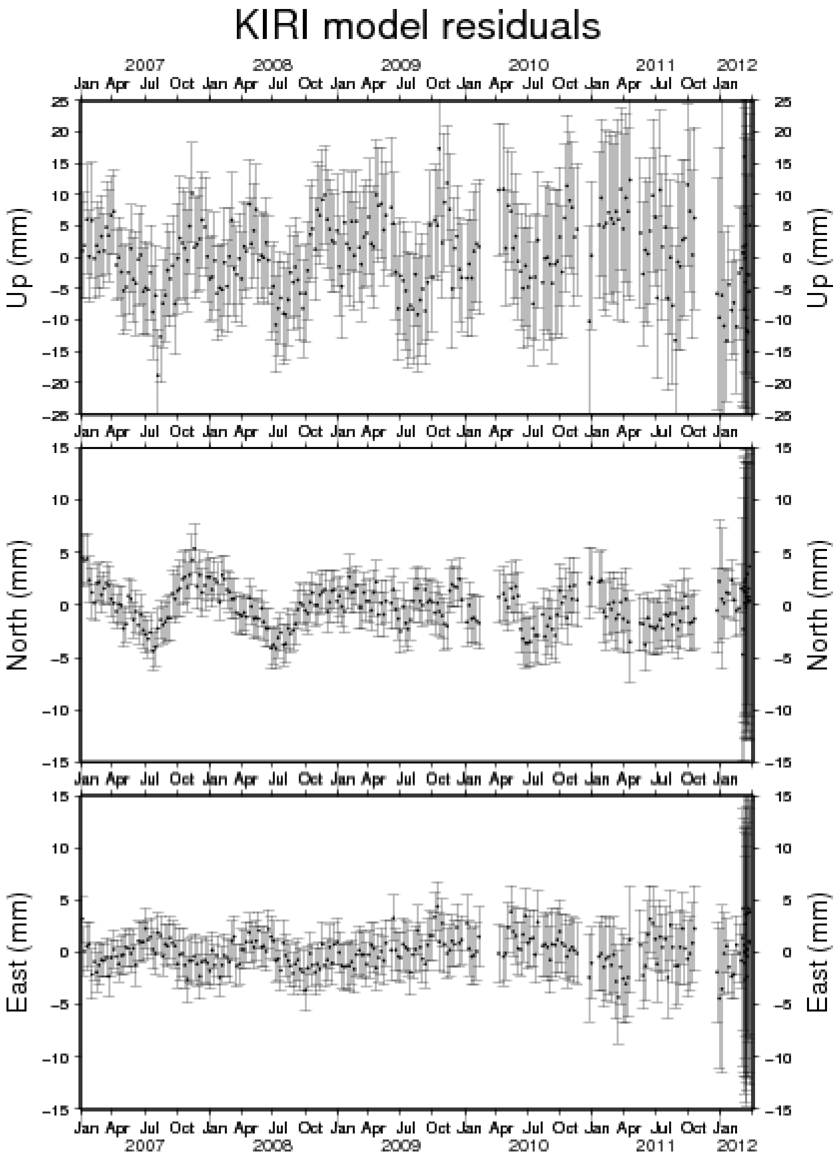
6.2 FIJI (LAUT)



Velocities in East, North and Up (m/yr) 0.0150 0.0323 -0.0018

Figure 14 *– De-trended in Up, North and East Time Series Plot – Fiji*

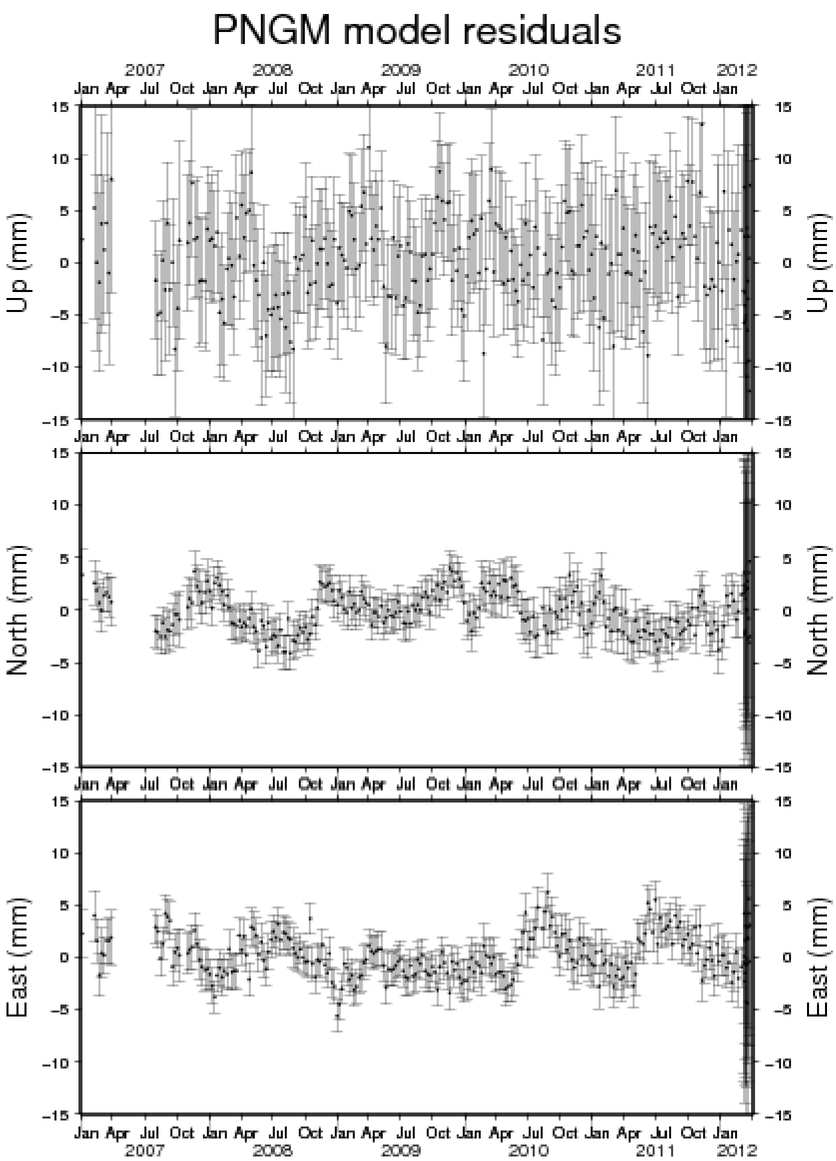
6.3 KIRIBATI (KIRI)



Velocities in East, North and Up (m/yr) -0.0677 0.0307 0.0011

Figure 15 *– De-trended in Up, North and East Time Series Plot – Kiribati*

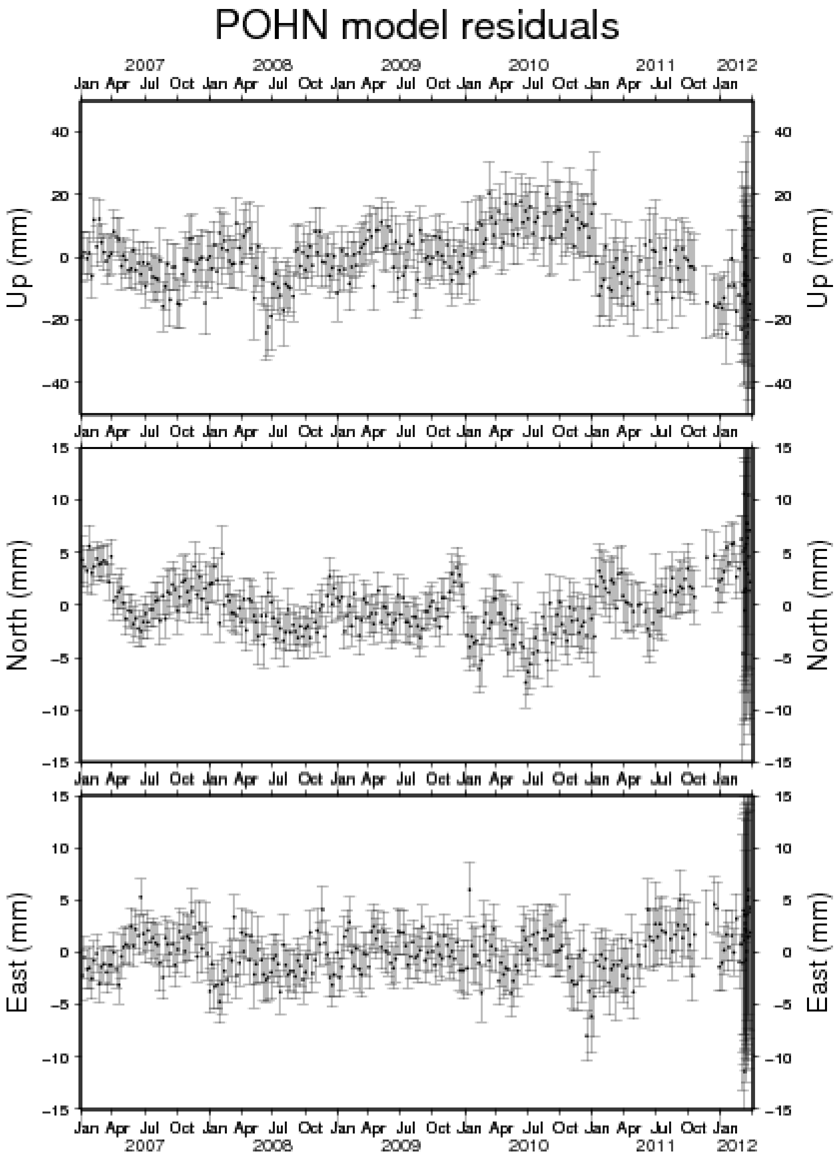
6.4 MANUS IS (PNG) – (PNGM)



Velocities in East, North and Up (m/yr) -0.0632 0.0242 -0.0013

***Figure 16** – De-trended in Up, North and East Time Series Plot – Manus Is*

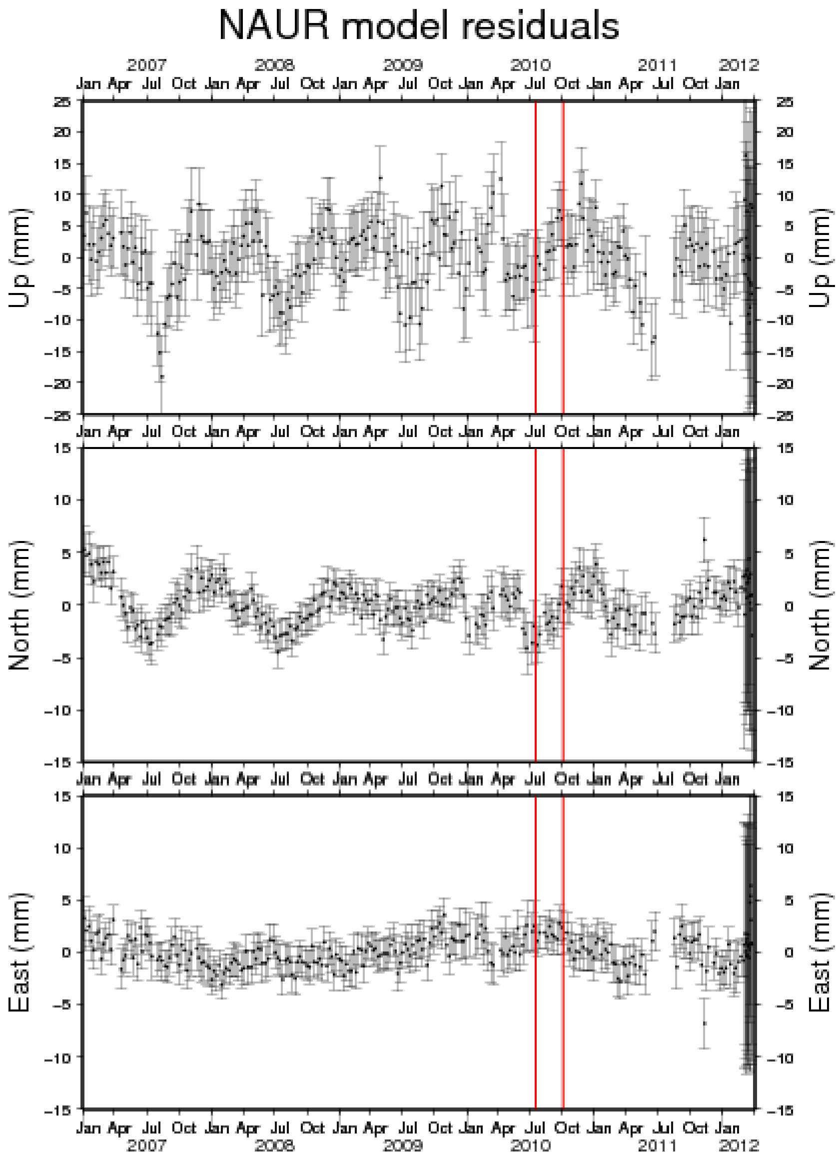
6.5 POHNPEI (FSM) - (POHN)



Velocities in East, North and Up (m/yr) -0.0699 0.0258 0.0010

Figure 17 *– De-trended in Up, North and East Time Series Plot – Pohnpei (FSM)*

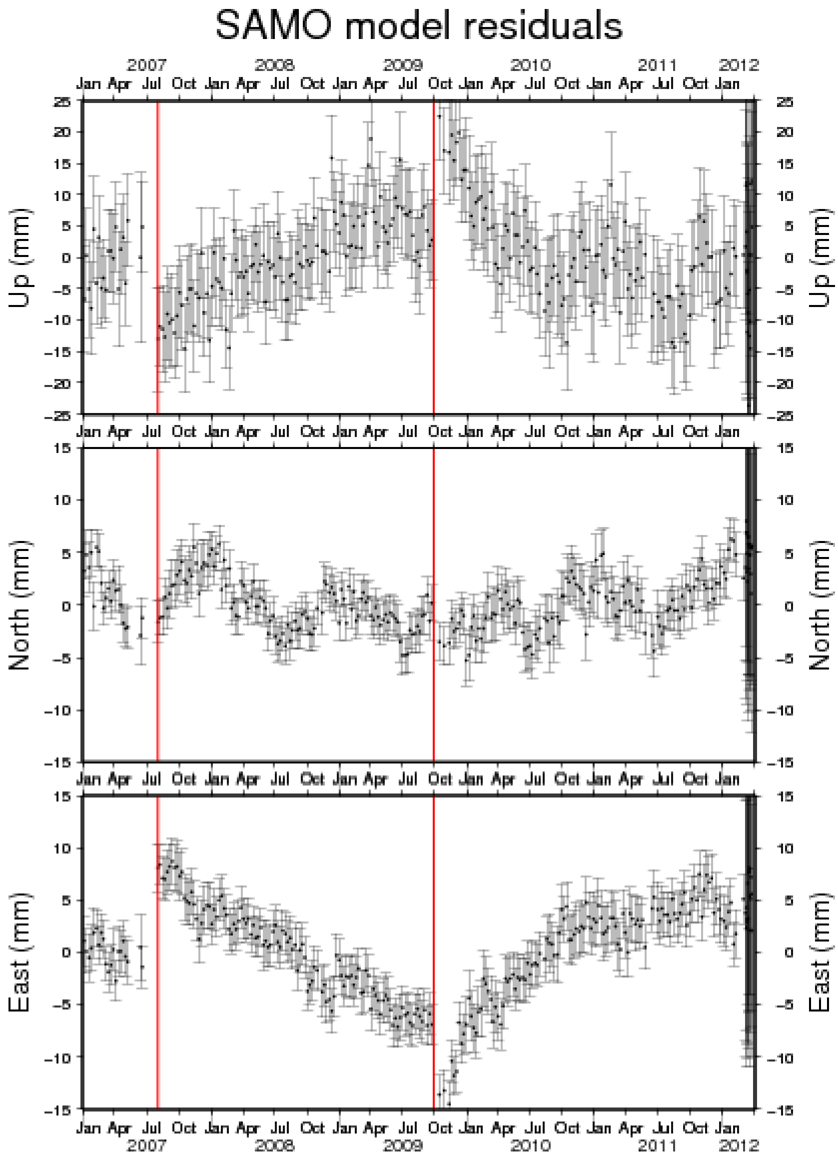
6.6 NAURU (NAUR)



Velocities in East, North and Up (m/yr) -0.0676 0.0290 0.0003

Figure 18 *– De-trended in Up, North and East Time Series Plot – Nauru*

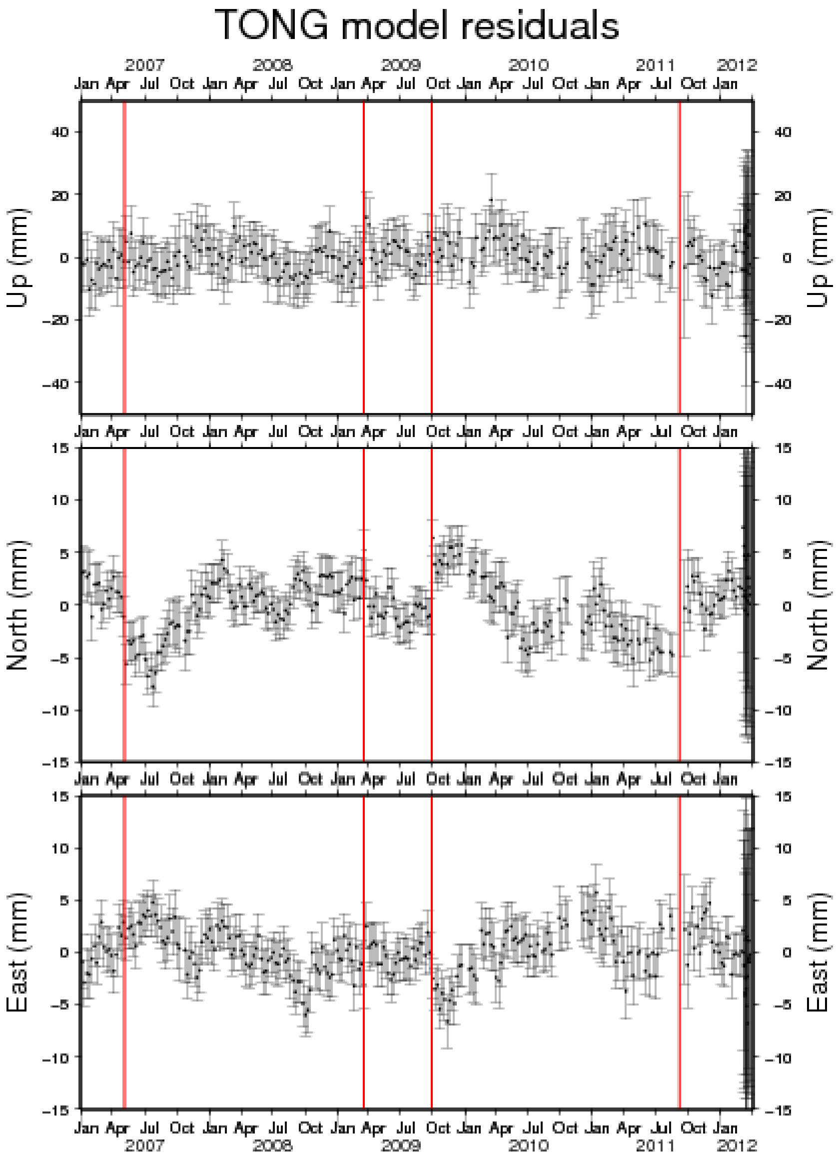
6.7 SAMOA (SAMO)



Velocities in East, North and Up (m/yr) -0.0572 0.0351 -0.0088

Figure 19 *– De-trended in Up, North and East Time Series Plot – Samoa. A strong post-seismic signal is evident after the Mag. 8 earthquake in October 2009. It is also evident that the earthquake is distorting the velocity since the time the antenna was changed. Further backward processing of the data is required to reduce this distortion.*

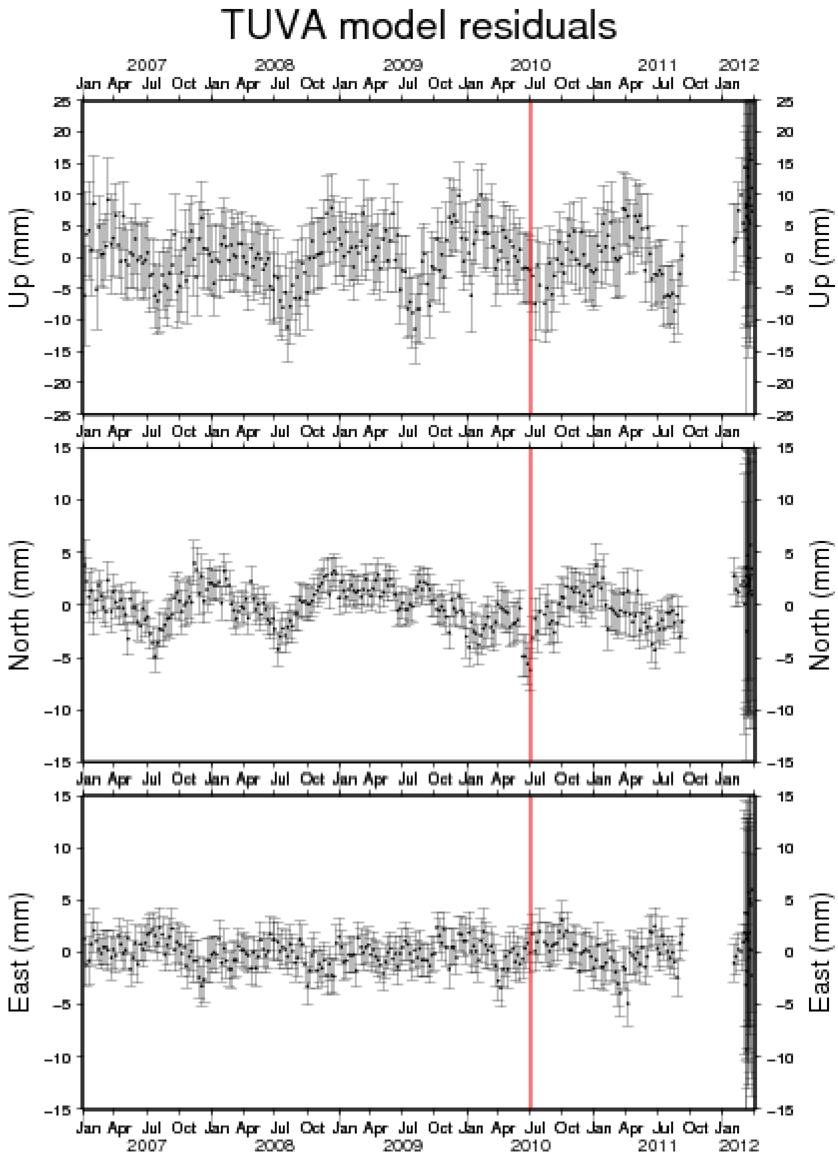
6.8 TONGA (TONG)



Velocities in East, North and Up (m/yr) 0.0923 -0.0069 0.0023

Figure 20 *– De-trended in Up, North and East Time Series Plot – Tonga*

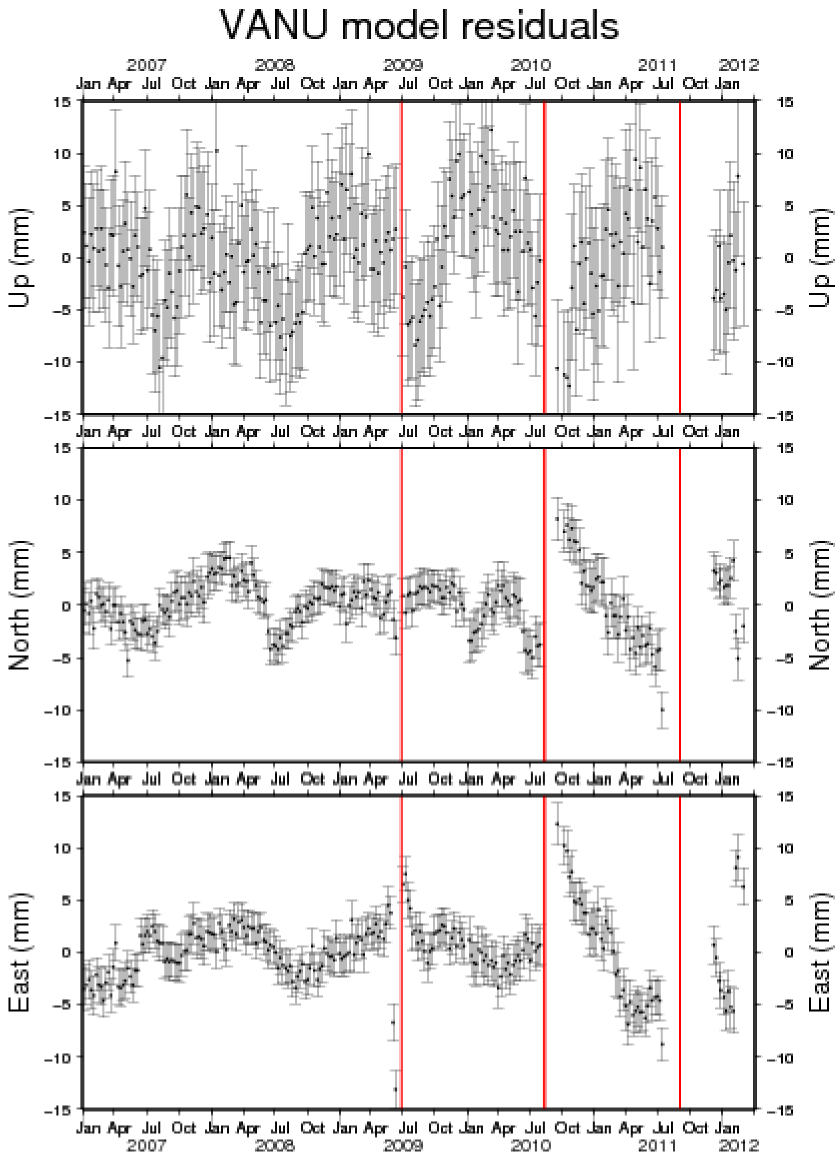
6.9 TUVALU (TUVA)



Velocities in East, North and Up (m/yr) -0.0639 0.0317 -0.0018

Figure 21 *– De-trended in Up, North and East Time Series Plot – Tuvalu*

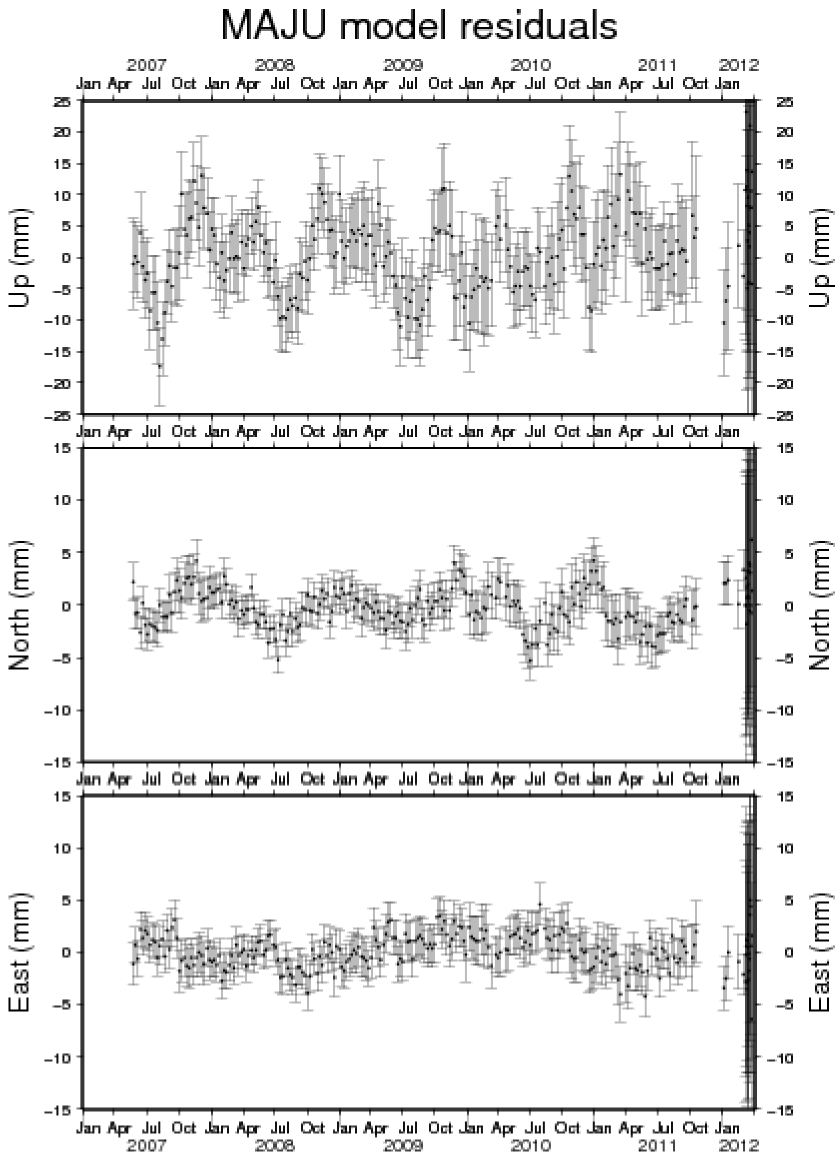
6.10 VANUATU (VANU)



Velocities in East, North and Up (m/yr) -0.0583 0.0092 -0.0060

Figure 22 *– De-trended in Up, North and East Time Series Plot – Vanuatu. The post seismic deformation is evident after the August 2010 earthquake. Also, the missing data between July to December 2011 makes it impossible to assess the displacement due to the earthquake.*

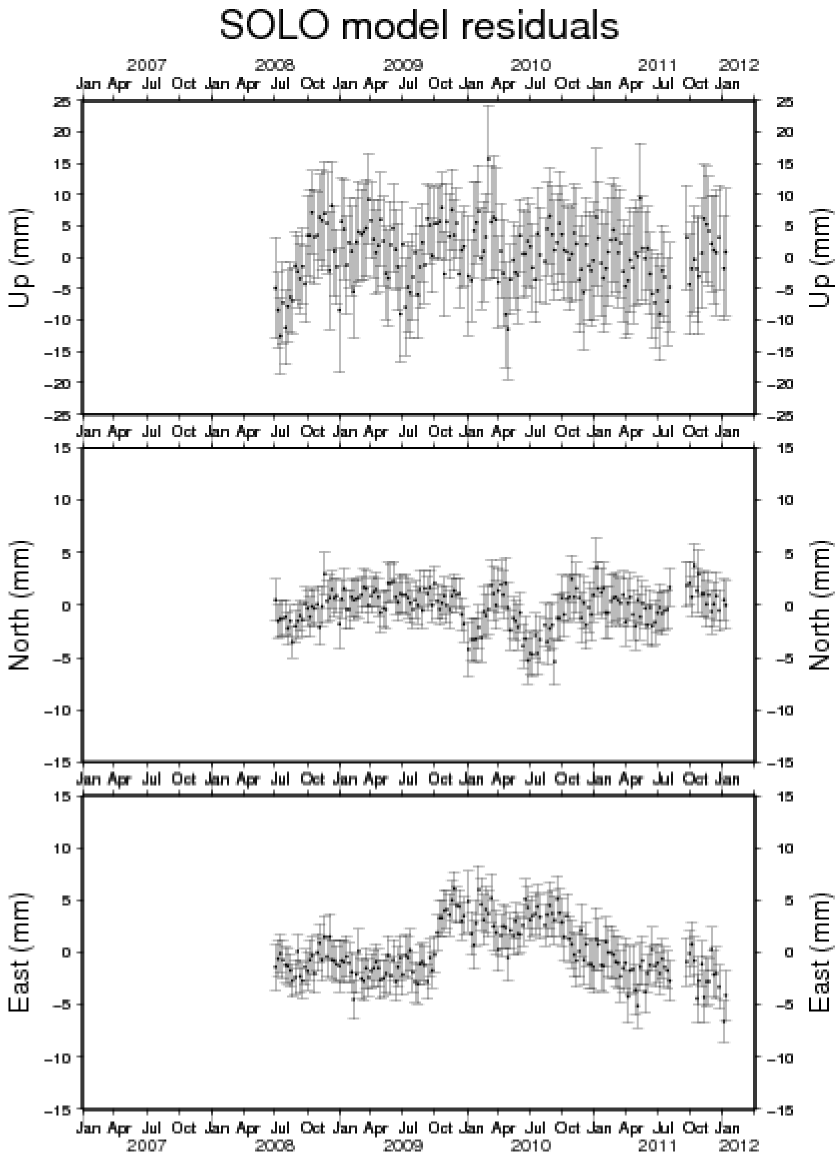
6.11 MARSHALL IS (MAJU)



Velocities in East, North and Up (m/yr) -0.0689 0.0304 0.0009

Figure 23 *– De-trended in Up, North and East Time Series Plot – Marshall Is*

6.12 SOLOMON IS (SOLO)



Velocities in East, North and Up (m/yr) -0.0324 0.0357 0.0012

***Figure 24** – De-trended in Up, North and East Time Series Plot – Solomon Is*

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