Geodetic monitoring of the November 16, 2000 - New Ireland Earthquake

Progress Report

Paul Tregoning, Herb McQueen, Kurt Lambeck and Richard Stanaway
Research School of Earth Sciences, The Australian National University

Steve Saunders, Ima Itikarai and John Nohou
Rabaul Volcano Observatory

Bob Curley and Job Suat
Department of Surveying and Land Studies
The Papua New Guinea University of Technology
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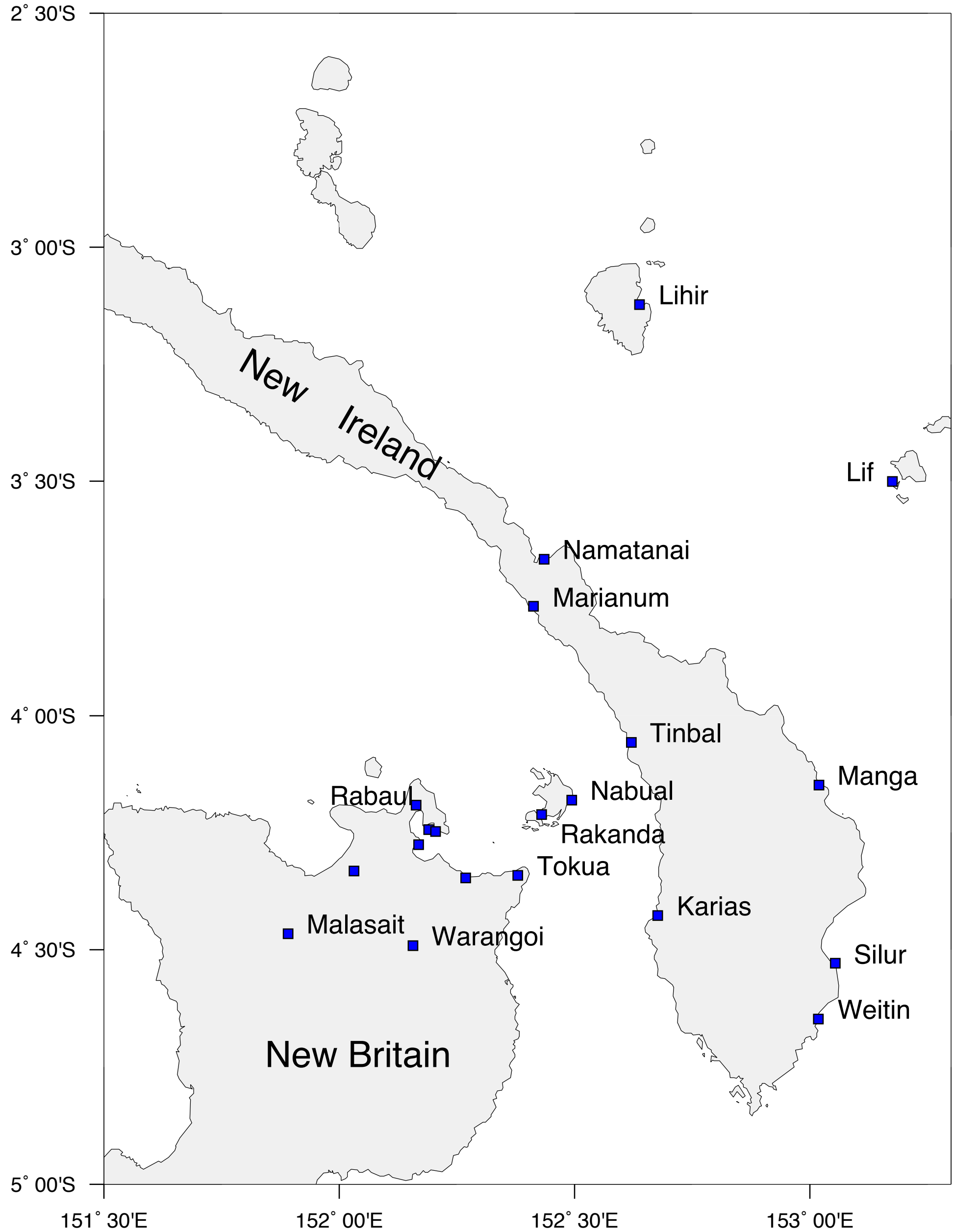
SUMMARY

On 16 November 2000 a Magnitude 8.0 earthquake occurred off the west coast of New Ireland, north of the Duke of York Islands. The event, a major left-lateral strike-slip earthquake, ruptured the Weitin Fault over hundreds of kilometres and caused massive horizontal land movements in the Gazelle Peninsula and New Ireland. The earthquake occurred on the boundary between the Pacific and South Bismarck Plates and represents a release of strain that has built up over several decades during the time that the plate boundary was locked.

Measurements from a GPS monitoring network show co-seismic displacements ranging from $\sim$0.3 m in the west at Malasait to over 5.5 m near the fault at Weitin. Further to the east on the Pacific Plate, Lihir Island was displaced by 0.1m. Significant post-seismic relaxation has been observed at the continuously-operating GPS sites run by the Rabaul Volcano Observatory and at other sites in the Gazelle Peninsula and southern New Ireland. All pre-earthquake coordinate systems in the New Ireland/East New Britain regions (e.g. the PNG geodetic datum) will be distorted by amounts of up to 5m of more and some of this distortion is still continuing four months after the earthquake.

Front cover: 5 m offset of a track crossing the Weitin Fault near the Weitin River, 1 km inland from the coast. Photo by Bob Curley.



The New Ireland/New Britain region affected by the earthquake. The GPS monitoring network of sites are shown. See Appendix 1 for a full list of site names and locations.

Contents

1 Introduction

The boundary between the Pacific and South Bismarck Plates runs through the southern part of New Ireland, most likely along the Weitin Fault. The region of southern New Ireland and the Gazelle Peninsula, New Britain, is strongly affected by the large-scale motion of these two tectonic plates (Figure 1). When the plate boundary is locked, strain accumulates and deforms the region as a whole. When the strain becomes too great it is released in the form of earthquakes. As a result of a series of GPS surveys over the past decade, a region of major strain accumulation had been identified and was being studied with precise GPS techniques when a massive release occurred on 16 November 2000 in the form of a magnitude 8 earthquake initiated north of the Duke of York Islands. This was the most powerful earthquake to strike Papua New Guinea for over eighty years.

A network of GPS sites has been observed since 1998 across this region from the Baining Mountains to the islands east of New Ireland as part of a long-term tectonic monitoring program involving the Research School of Earth Sciences of The Australian National University (RSES), The Department of Surveying and Land Studies of The Papua

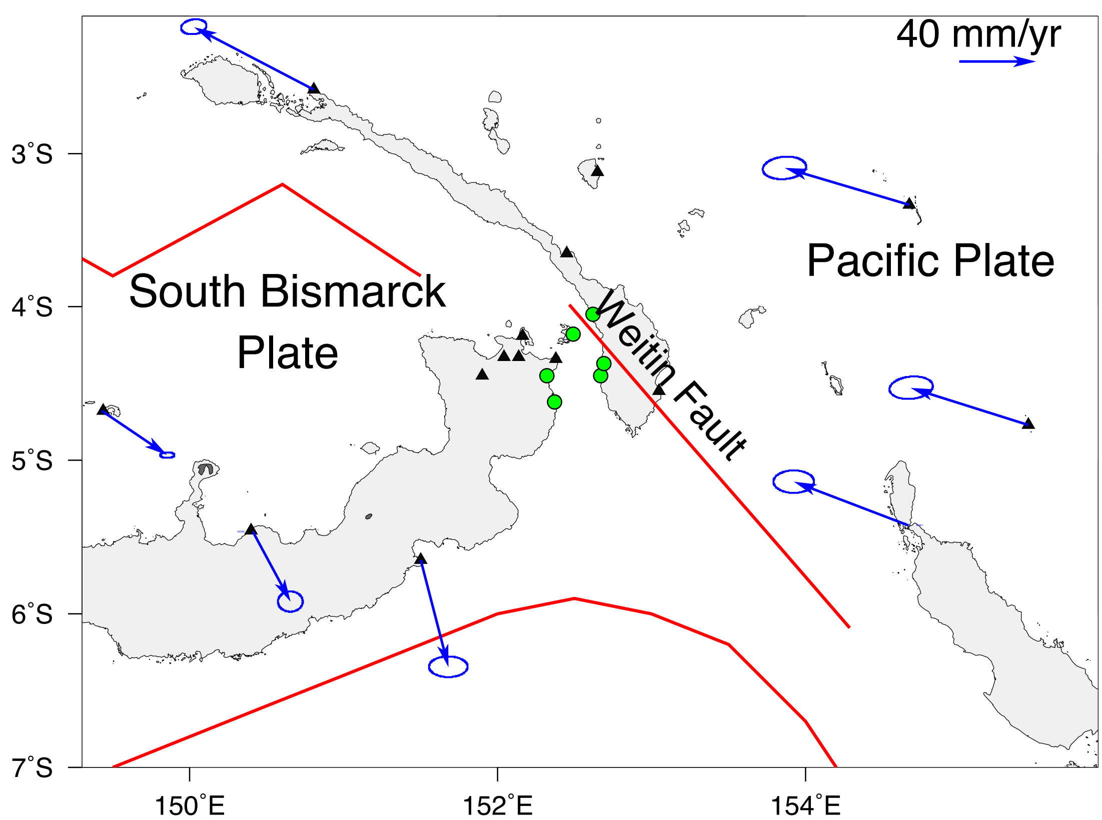


Figure 1: Tectonic setting and rigid plate site velocities.

New Guinea University of Technology (Unitech), the Rabaul Volcano Observatory (RVO) and the National Mapping Bureau in Port Moresby (NMB). Measurements from 1998 to October 2000 showed clear evidence that the whole region was undergoing inter-seismic strain, indicative of a locked plate boundary (Figure 2).

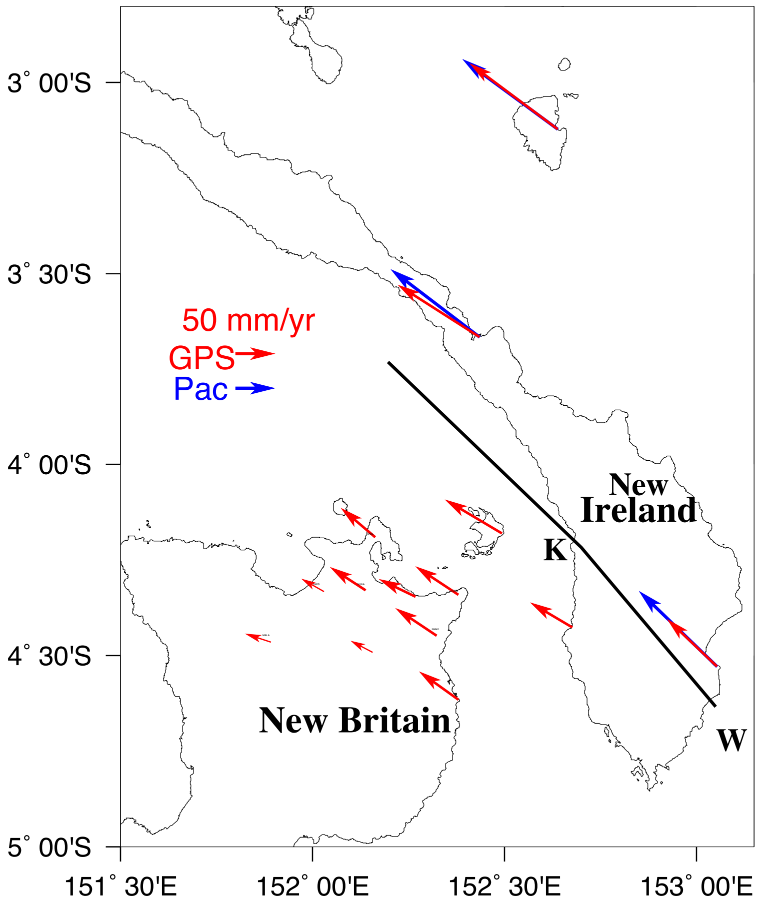


Figure 2: Site velocities between 1998 and 2000. Observed GPS velocities (red arrows) and predicted Pacific Plate velocities (blue arrows) are shown relative to the South Bismarck Plate. If the Weitin Fault was not locked and all relative motion occurred freely there then all the arrows on the New Britain side of the fault would be zero and all those on the Pacific side would show full Pacific Plate velocity (the blue vectors). The fact that this was not the case indicated that the fault was locked.

2 Effect of the earthquake - physical damage and social impact

Field parties from RVO and Unitech who have visited some regions of New Ireland report that the region has been damaged by both the earthquake itself and by the tsunamis that it generated. One villager was buried by a landslide caused by the earthquake. The earthquake ruptured the surface at both the Kamdaru River end (K in figure 2) and also at the Weitin River end (W in figure 2) and the surface rupture is also visible inland in the mountainous terrain. At the mouth of the Kamdaru River the river bed subsided by as much as 3 metres.

A small surge was reported in Rabaul harbour and along the shores of Kokopo. It was also reported at Bougainville and along the southern coast of New Ireland. Public awareness worked very well - most people moved to higher ground after the first earthquake.

An aerial inspection of southern part of New Ireland by fixed wing aircraft revealed a lot of land slips, with more on the north side of the Weitin Fault than south of it. Some collapse of semi-traditional houses was observed, along with evidence of tsunami run-up. Some parts of Duke of York Island were flooded by the high water and there were reports of houses collapsing. People moved to high ground when the quakes were felt.

At Karias (west coast of southern New Ireland) the field parties reported that there were almost continuous tremors in early January. They described sudden bangs heard up in the mountains followed by strong earthquakes $\sim$10 seconds later.

Along the southern coast of New Ireland the local villagers reported that a tsunami occurred after the first earthquake and that it seemed to be generated on the east coast rather than wrapping around from the St Georges Channel. At Silur, the tsunami approach was from the east while at Weitin the approach was from the north. These reports suggest that a tsunami was generated east of New Ireland independent of the one in the St Georges Channel. There was no tsunami generated by the second earthquake at 0742 GMT.

The earthquake triggered a series of aftershocks, many of which were greater than magnitude 6. A total of 20 events with magnitude > 5 occurred in the month following the major earthquake. Scientists at RVO have estimated the locations of the aftershocks using seismic waves recorded by the Rabaul Harbour Seismic Network (Figure 3). The expected accuracy of each location is 5-10 km.

3 Completed fieldwork

GPS studies of tectonic motion in Papua New Guinea began in 1990 and a network has been established that spans most of the country, including sites on most of the known tectonic plates. From these data a model of the regional tectonics was developed, including the first estimate of the motion of the South Bismarck Plate.

From this model we identified the regions of eastern New Britain and southern New Ireland as a likely zone of deformation between the Pacific and South Bismarck Plates (Figure 2). The predicted relative motion between these two plates is $\sim$130 mm/yr. In 1998 a new GPS monitoring network spanning this region - from Malasait in the southwest to Lihir in the northeast - was observed by an ANU/Unitech team, with a repeat of the observations two years later. Between these campaigns, periodic observations were made on several New Britain sites by RVO in addition to their continuous monitoring of the Rabaul harbour sites.

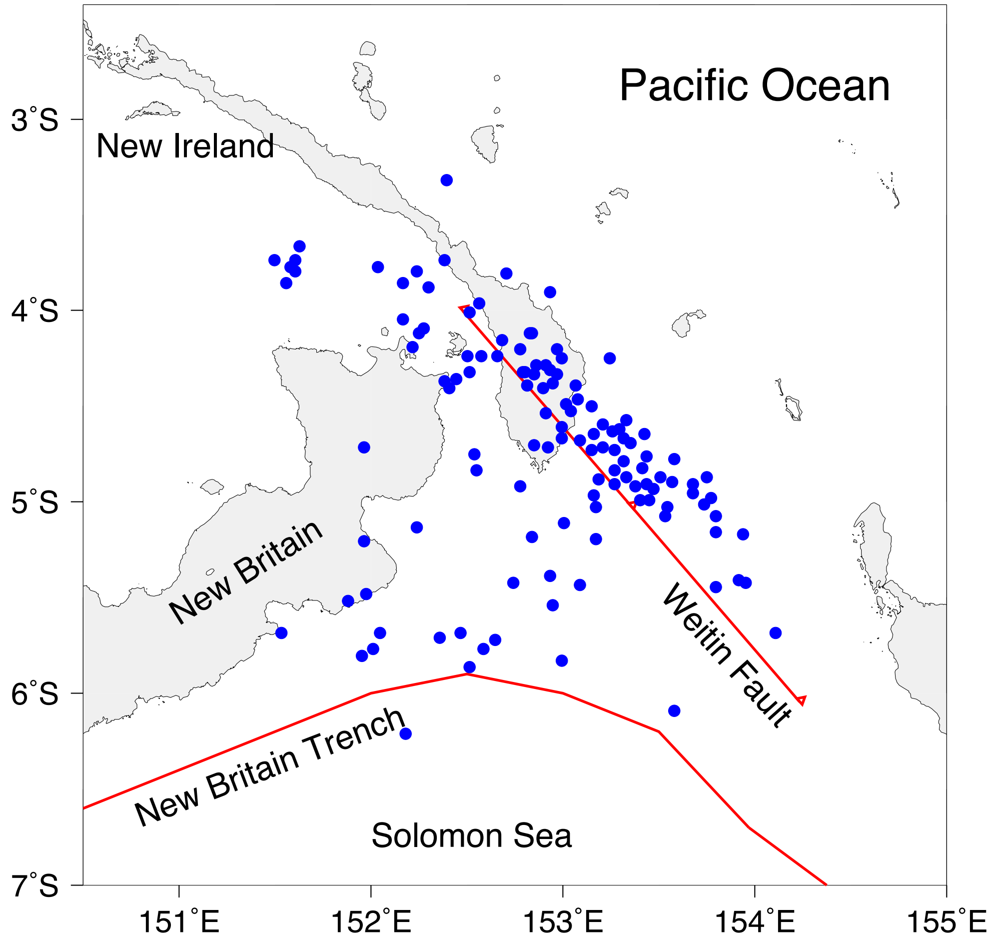


Figure 3: Aftershocks up to 10 January 2001. Events were located by RVO using the Rabaul Harbour Seismic Network. Also plotted is the surface trace of the fault as computed in the dislocation model (see section 4.1).

3.1 Pre-earthquake - 2000 fieldwork

During August and September, 2000, all sites in the regional network were reobserved. The fieldwork was conducted primarily by Richard Stanaway (RSES) with significant assistance from RVO and Unitech. The days of observation are shown in Figure 4.

3.2 Fieldwork during the post-seismic period

All sites of the network have been reobserved at least once after the earthquake. Only the four sites involved in the Rabaul volcano monitoring program (RVO_ SDA_ SPT_ VIS_) have operated on a continuous basis.

3.2.1 RVO

The staff at the Rabaul Volcano Observatory have observed the following sites:

Tokua, Karias, Rakanda, Nabual, Tinbal, Malasait, Kenabot, Warangoi

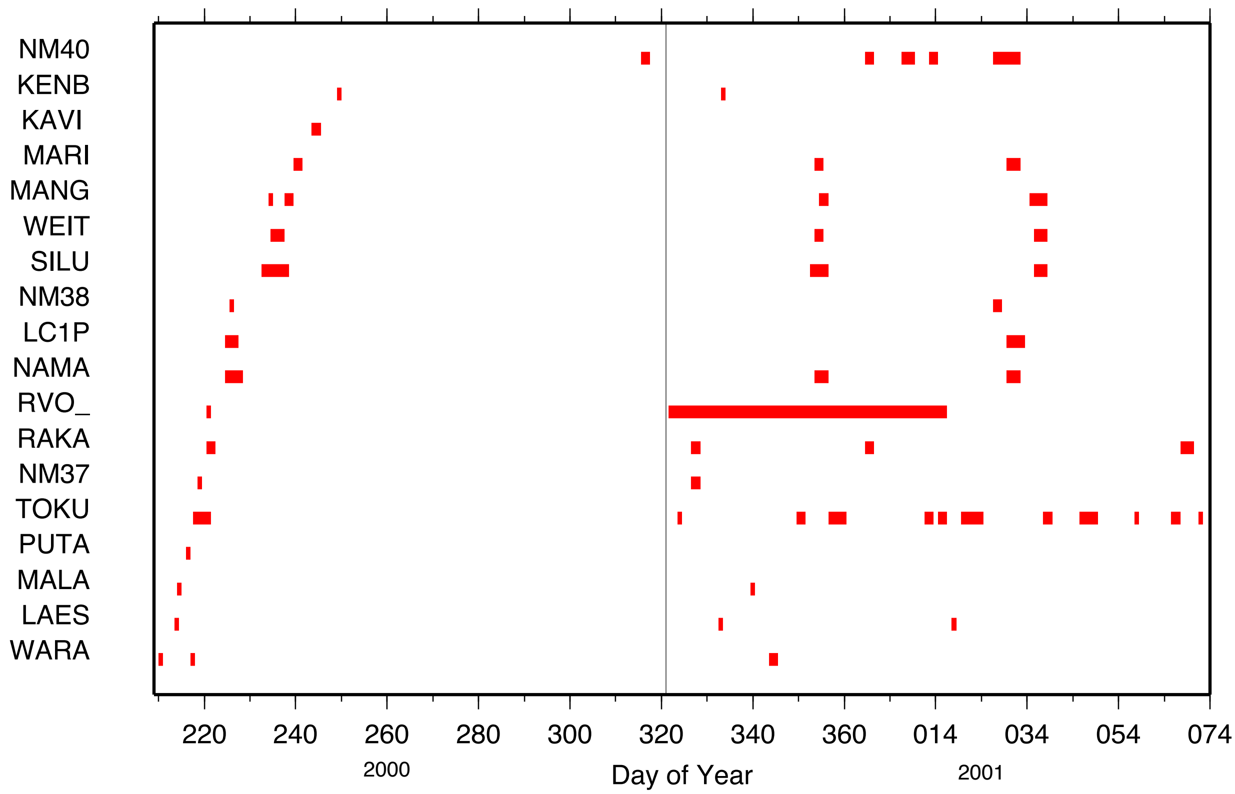


Figure 4: Days-of-Year 2000 site occupations. Site name/code information is given in Appendix 1. Data which have been collected but are not yet processed are not shown.

with the sites listed in order of decreasing occupations and only the first three having more than one post-seismic occupation. A GPS receiver has been installed at Karias since 28 December 2000 and is periodically visited to retrieve the collected data and to check the operation. Similarly, a receiver is operated at Tokua airport every few weeks and periodically downloaded. All data are sent to RSES by email for analysis.

3.2.2 Unitech

Staff and students from Unitech have conducted two repeat occupations of the network of sites in New Ireland. With the exception of Lihir (which was only observed in the second campaign), the following sites were reobserved in mid-December and again in early February:

Namatanai, Marianum, Manga, Silur, Weitin, Lihir

The sites were observed in a 'campaign-style' with 2-3 sites being occupied simultaneously. The difficulty of accessing these sites increases both the time it takes to reach the sites and the costs associated with the occupations. No attempt has been made to leave receivers operating unattended at these sites.

4 Results

During the earthquake, a left-lateral strike slip event, the Pacific and South Bismarck Plates slid past each other, with the majority of the motion being horizontal (Figure 5). The pattern of the inter-, co- and post-seismic deformation at sites surrounding the fault through the recent part of the earthquake cycle is illustrated in Figure 6.

4.1 Co-seismic displacements

The co-seismic displacements (movement of the sites at the time of the earthquake) measured by GPS are shown in Figure 7. The displacements were calculated by first computing the site positions at the time of the earthquake (using the pre-existing velocity estimates to project the coordinates to the date of the quake) then subtracting the position measured after the quake. The post-earthquake positions have been corrected for any post-seismic movement which may have occurred between the time of the earthquake and the time of the first post-quake measurement.

Using a dislocation model in an elastic half-space, we have modelled the expected displacements at the GPS sites. The model requires input parameters of fault location, depth, dip and strike and length of the fault and co-seismic displacements on the fault in three directions (along-strike, down-dip and normal to the fault plane). The modelled

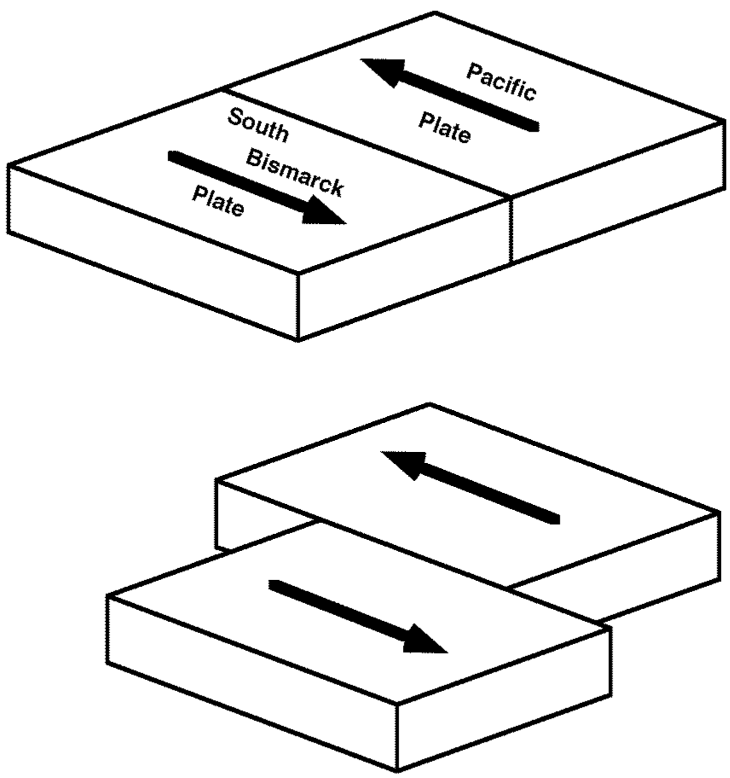


Figure 5: Diagrammatic representation of a left-lateral strike slip earthquake.

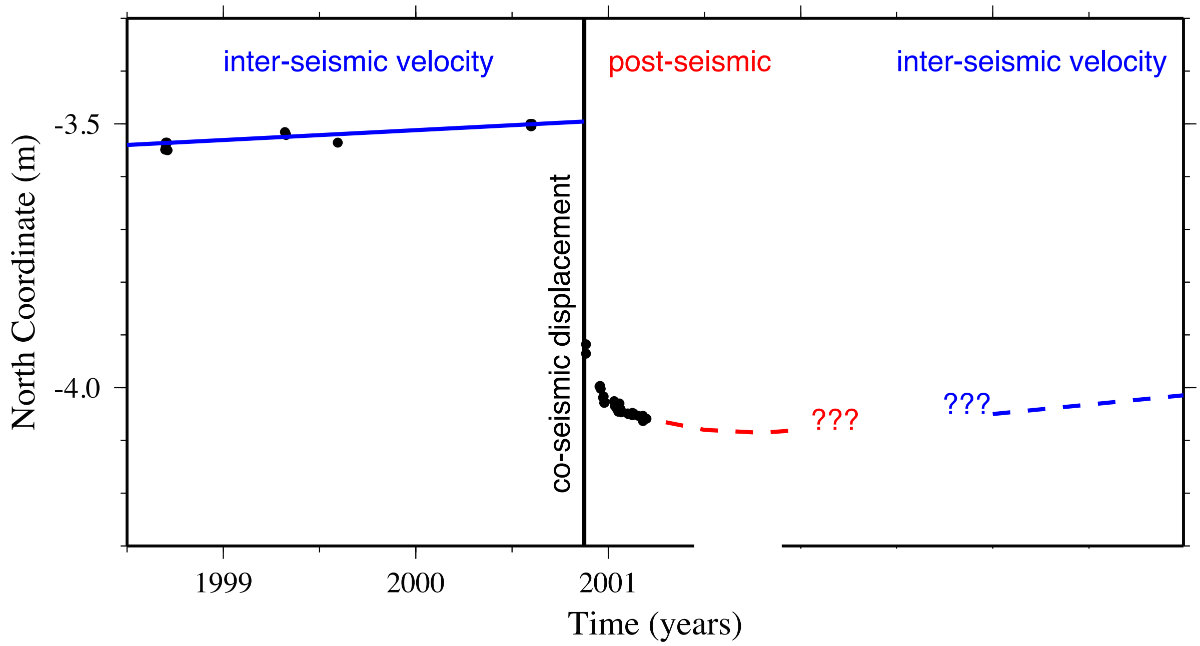


Figure 6: The deformation cycle through the earthquake showing inter-, co- and post-seismic movement. Actual measured site positions at TOKU relative to the South Bismarck Plate are shown in black dots. At this stage we do not know when the post-seismic period will end and when the next inter-seismic period will commence. Continued GPS observations will provide this information.

displacements shown in Figure 7 (green arrows) are obtained using the following values

1. fault location: from 3.99°S, 152.46°E to 6.09°S, 154.29°E
2. fault length: 276 km
3. fault depth: 12 km
4. fault dip: 81°
5. fault strike: 148°
6. co-seismic slip: along-strike 11.2 m; down-dip: 0.43 m; normal-to-dip: 0.0 m

NOTE: These parameters have been derived from a search of parameter space using the 'Neighbourhood Algorithm' approach. The fit is reasonable at most sites; however, the limitations of the simple dislocation model become apparent close to the fault at Tinbal (NM38) where the magnitude of displacement is over-estimated.

Although the displacement vectors at Lihir seem very small in comparison with sites much closer to the fault, the displacement measured there is ∼100 mm in a north direction. This shows that even far-field regions have been significantly affected by the strain release associated with the earthquake.

4.2 Post-seismic relaxation

It is clearly apparent from the time series of the continuous sites (Figure 8) that significant post-seismic relaxation is occurring. Even the quasi-continuous sites (ie sites with repeat observations after the earthquake) show that the whole region is still undergoing rapid deformation at rates varying from 0.25 to 0.7 mm/day.

The most comprehensive time series exists at the Rabaul Volcano Observatory base station, (RVO_) (Figure 8). This receiver was observing continuously before, during and after the earthquake. Post-seismic movement of ∼120 mm occurred in the first 5 days

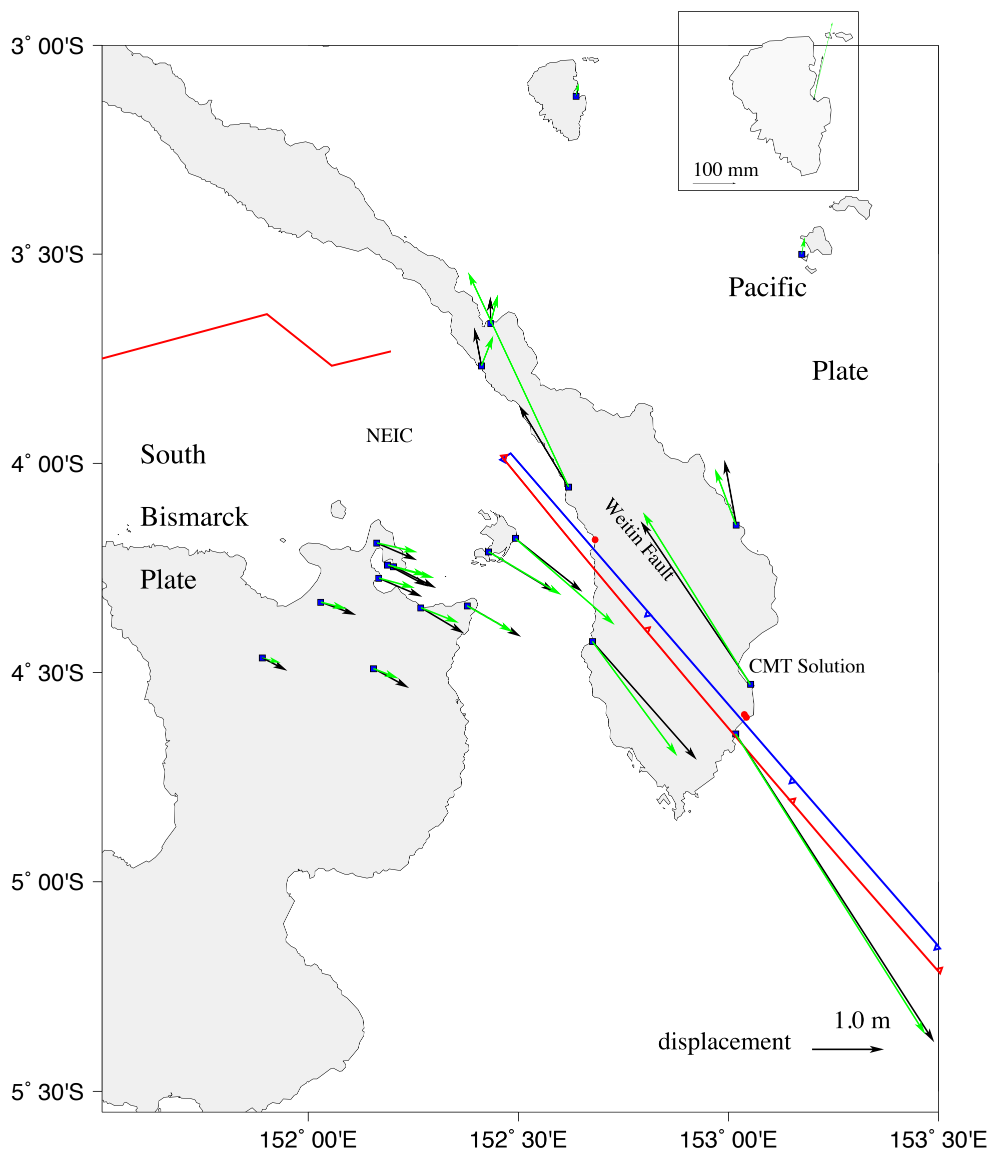


Figure 7: Co-seismic displacements at the GPS monitoring sites. Measured displacements (black arrows) and those modelled from an elastic dislocation model (green arrows) are shown. The surface trace (red) and base (blue) of the fault are plotted.

after the earthquake, with a further ∼100 mm occurring over the next two months. The post-seismic relaxation is likely to continue for at least 12 months - possibly 2-3 years - although the rate will decrease exponentially.

The pattern of post-seismic relaxation reveals information about the inelastic behaviour of the crust and the coupling of the lithosphere to the mantle beneath the region. We plan to use this information to investigate the nature of this coupling and the implications for conditions in the mantle underlying this volatile area. This has implications for estimates of the recurrence intervals of such events.

5 Future Plans

This event provides us with a brief window on processes affecting the region that will not be available again for several decades or more. In order to capture information about the post-seismic movement which is occurring at the sites across the region, it is imperative that the geodetic fieldwork be continued. If we can measure this we will have the opportunity to model the complete post-seismic motion, including the part that occurred in the few days after the earthquake, before the first post-seismic GPS measurements were made. As shown by the RVO_ timeseries (Figure 8), this amounts to up to 150 mm in only a week after the event. By being able to separate from the co-seismic movement the amount of post-seismic motion which occurred before the first measurements, we will be able to generate an accurate co-seismic displacement field; this will allow us to model accurately the parameters of the fault location, depth and orientation, dip, amount of slip etc. This should provide initial estimates of the recurrence interval between successive earthquakes of similar large magnitude.

Another important reason to continue regular observations of the geodetic network is to identify the transition from strain release to strain accumulation. Relative to the steady plate motion, the direction of deformation during and immediately after the earthquake is in the opposite sense to the deformation during the strain accumulation stage while the fault was locked. If the fault becomes locked again, we anticipate a return to the strain accumulation pattern seen before the earthquake. The time between the earthquake and the transition back to strain accumulation is an important timescale in the major earthquake cycle. Periodic reobservation of the network is necessary to enable us to determine whether the fault has locked again and to measure the timescale of strain release in this region.

5.1 Fieldwork

Observations at Tokua and Karias are continuing on a sporadic basis. More observations will be made at other sites in the Gazelle Peninsula in March and April. In addition, plans are being made to occupy a site at Lif Island (Tanga Group) in March - a site which was first occupied in July 1999.

A repeat survey of the New Ireland network is being planned for the first two weeks of April and will be conducted by Unitech staff and students during the university mid-

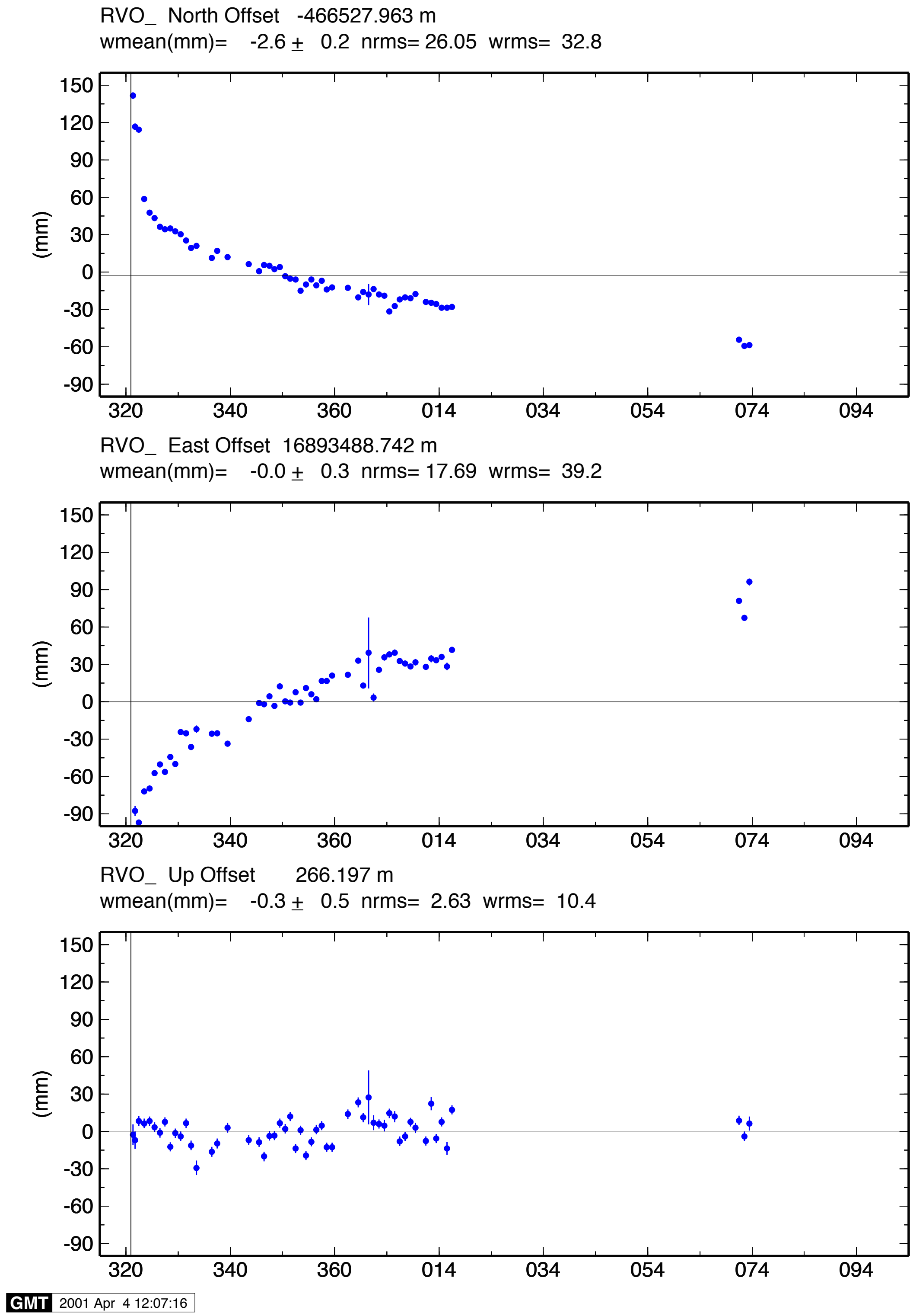


Figure 8: Time series of positions at RVO_ showing the post-seismic movement.

semester break. This will provide the third occupation of these sites. It is hoped that three observations in 3.5 months will be sufficient to show the shape of the post-seismic motion curve.

Other sites which need to be observed again include Kavieng, Hoskins and Buka. Each of these sites has been observed at least twice before the earthquake. The first two of these sites are likely to be outside the deformation zone - although the dislocation model predicts co-seismic displacements of ∼20 to 30 mm at such far-field sites. Our current dislocation model for the earthquake predicts 300mm displacement at Buka. A measure of the actual displacement of Buka will provide valuable information on the southeastern extent of the fault rupture which is poorly constrained at present.

5.2 Analysis

We have already developed a program using Neighbourhood Algorithm techniques to search the parameter space for the 'best-fitting' dislocation model to represent the co-seismic displacements caused by the earthquake. In addition, we intend to develop models to represent the post-seismic movements across the region. This will lead to a much greater understanding of the strain accumulation/release pattern which will enable better prediction of similar events in future. We will also be able to produce geodetic datum deformation estimates for the entire affected region resulting from both the earthquake rupture and the associated postseismic deformation.

It is imperative that the GPS data continue to be collected at as many sites as possible in New Britain and New Ireland. Given the limited funding available in 2001, we are working with RVO and Unitech to devise plans for the most efficient, cost-effective use of the funds while still capturing as much scientific information as possible.

6 Conclusion

The geodetic field observations conducted between 1998 and 2000 by RVO, RSES and Unitech provided an excellent frame of reference for estimating the effect of the November 16, 2000 earthquake which occurred in the New Ireland region. The rapid response of surveyors at RVO captured valuable GPS data at many sites in the Gazelle Peninsula which is providing information about the co- and post-seismic displacements. Two successful field campaigns by Unitech staff and students in New Ireland have provided similar information on displacements to the northeast of the Weitin Fault. The difficulty of accessing some of the New Ireland sites means that the occupations are less frequent. Therefore, with fewer occupations, it is not yet possible to see the same detail in the post-seismic time series of these sites.

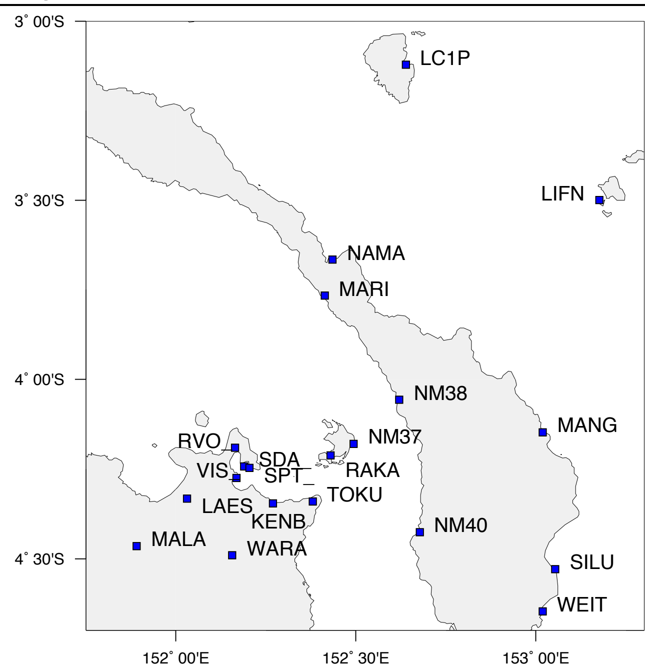
With continued monitoring of the movement of the GPS network and careful analysis of the data we will be able to produce accurate information about the regional tectonic pattern caused by the relative motion of the Pacific and South Bismarck Plates.

7 Acknowledgements

Steve Saunders, Ima Itikarai and John Nohou (Rabaul Volcano Observatory) organised and conducted the GPS fieldwork in New Britain after the earthquake and Bob Curley and the staff at Unitech have performed the New Ireland fieldwork. GPS data analysis has been performed by Paul Tregoning (RSES) using the GAMIT/GLOBK software.

8 Appendix 1 - Site Names, Codes and Locations

Site	Code	Latitude	Longitude
Karias	NM40	-4 25 34.10	152 40 36.31
Kenabot	KENB	-4 20 45.12	152 16 07.99
Keravat	LAES	-4 19 56.09	152 01 50.63
Lif Island	LIFN	-3 30 00.27	153 10 31.69
Lihir Mine	LC1P	-3 07 19.08	152 38 18.25
Malasait	MALA	-4 27 54.21	151 53 28.62
Manga	MANG	-4 08 51.83	153 01 08.99
Marianum	MARI	-3 46 00.80	152 24 47.94
Nabual	NM37	-4 10 48.18	152 29 38.10
Namatanai	NAMA	-3 39 58.54	152 26 06.14
Rakanda	RAKA	-4 12 42.58	152 25 47.44
Rabaul	RVO_	-4 11 27.20	152 09 49.51
SDA Church	SDA_	-4 14 35.96	152 11 22.51
Sulphur Point	SPT_	-4 14 51.07	152 12 14.42
Silur	SILU	-4 31 44.41	153 03 12.22
Tinbal	NM38	-4 03 26.41	152 37 12.16
Tokua	TOKU	-4 20 27.78	152 22 45.81
Vulcan Is. South	VIS_	-4 16 30.19	152 10 06.80
Weitin	WEIT	-4 38 50.80	153 01 05.32
Warangoi	WARA	-4 29 27.44	152 09 22.99



9 Appendix 2 - Postseismic plots of sites observed twice or more

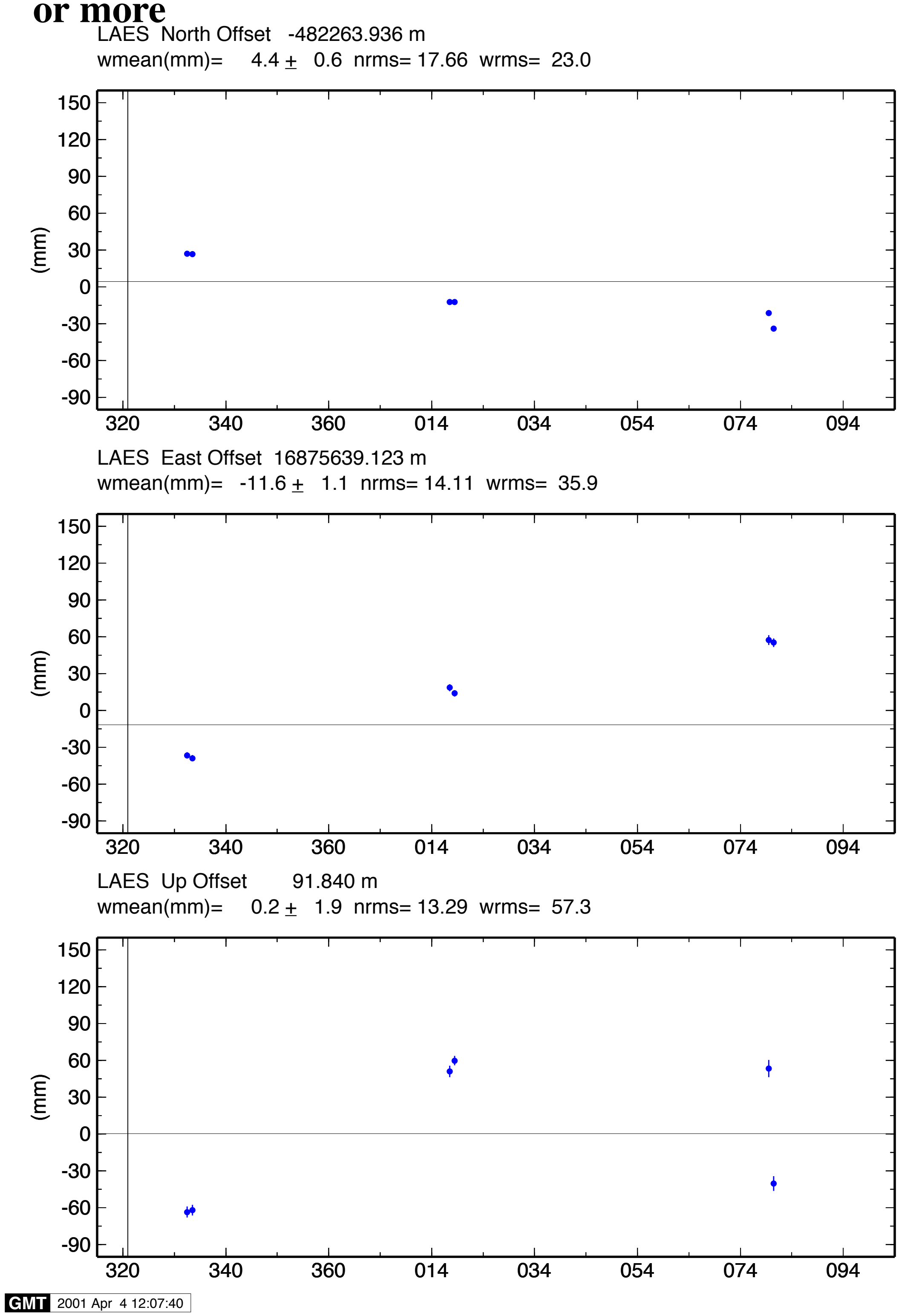


Figure 9: Time series of positions at LAES (Keravat) showing the post-seismic movement.

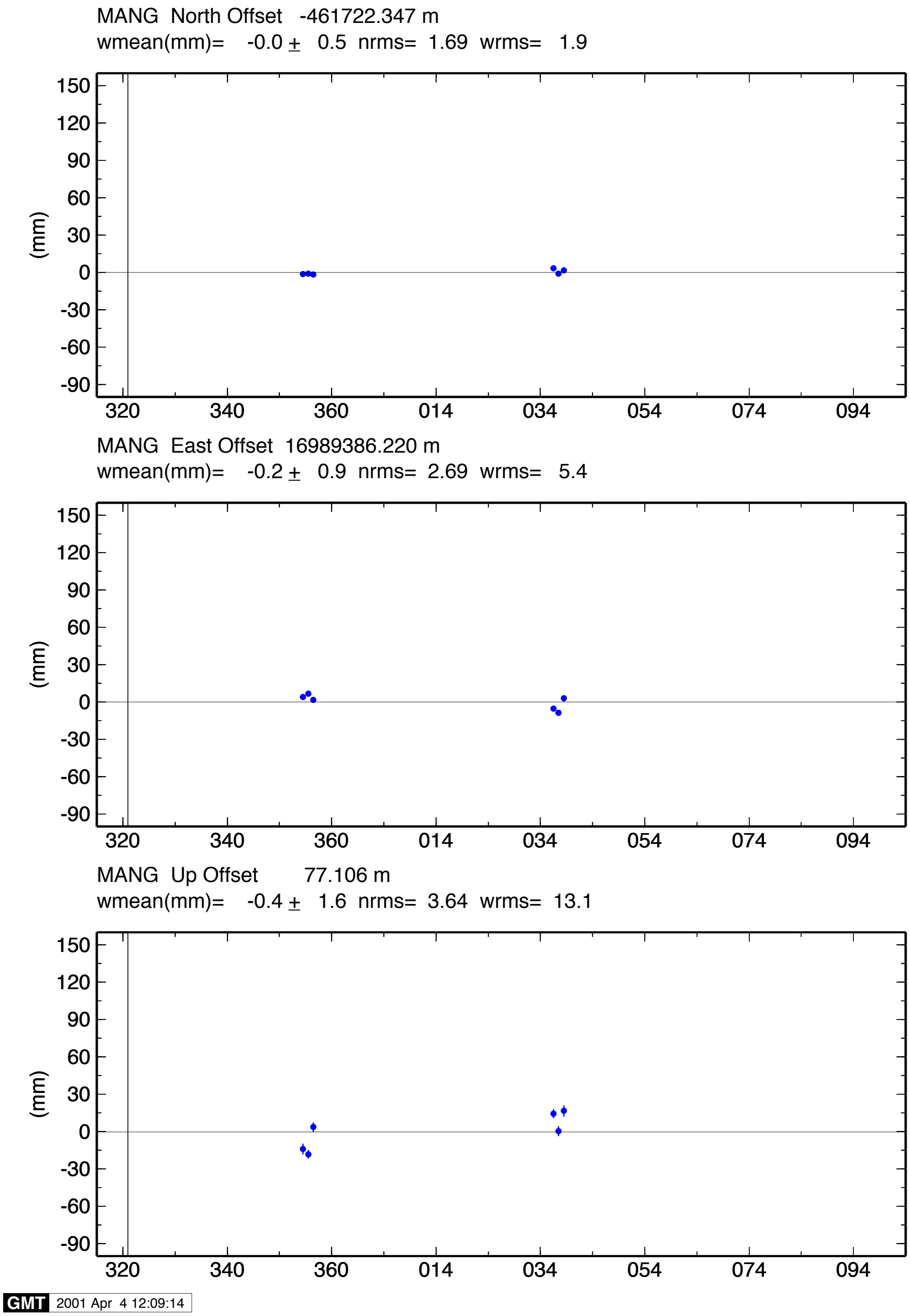


Figure 10: Time series of positions at MANG (Manga) showing the post-seismic movement.

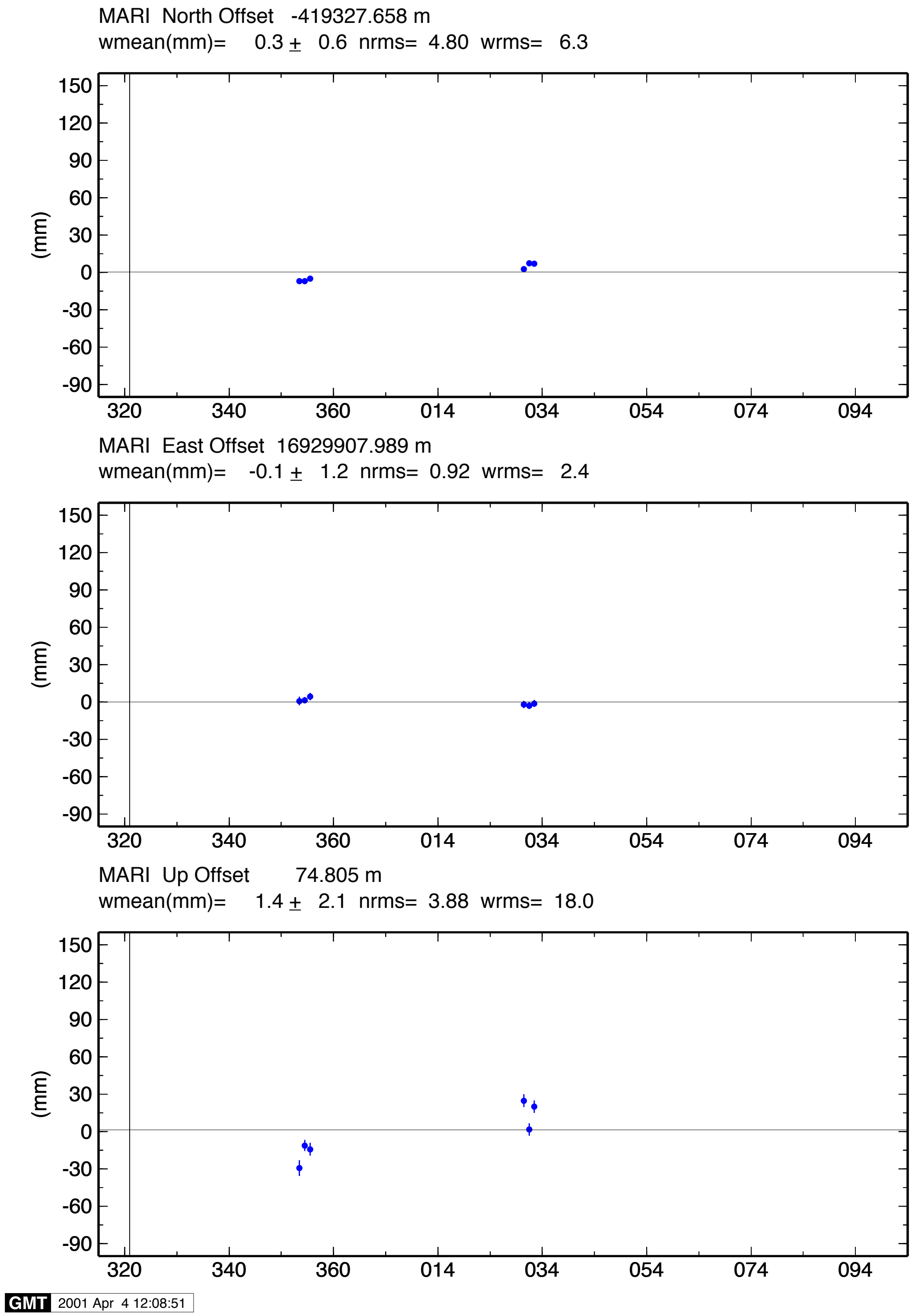


Figure 11: Time series of positions at MARI (Marianum) showing the post-seismic movement.

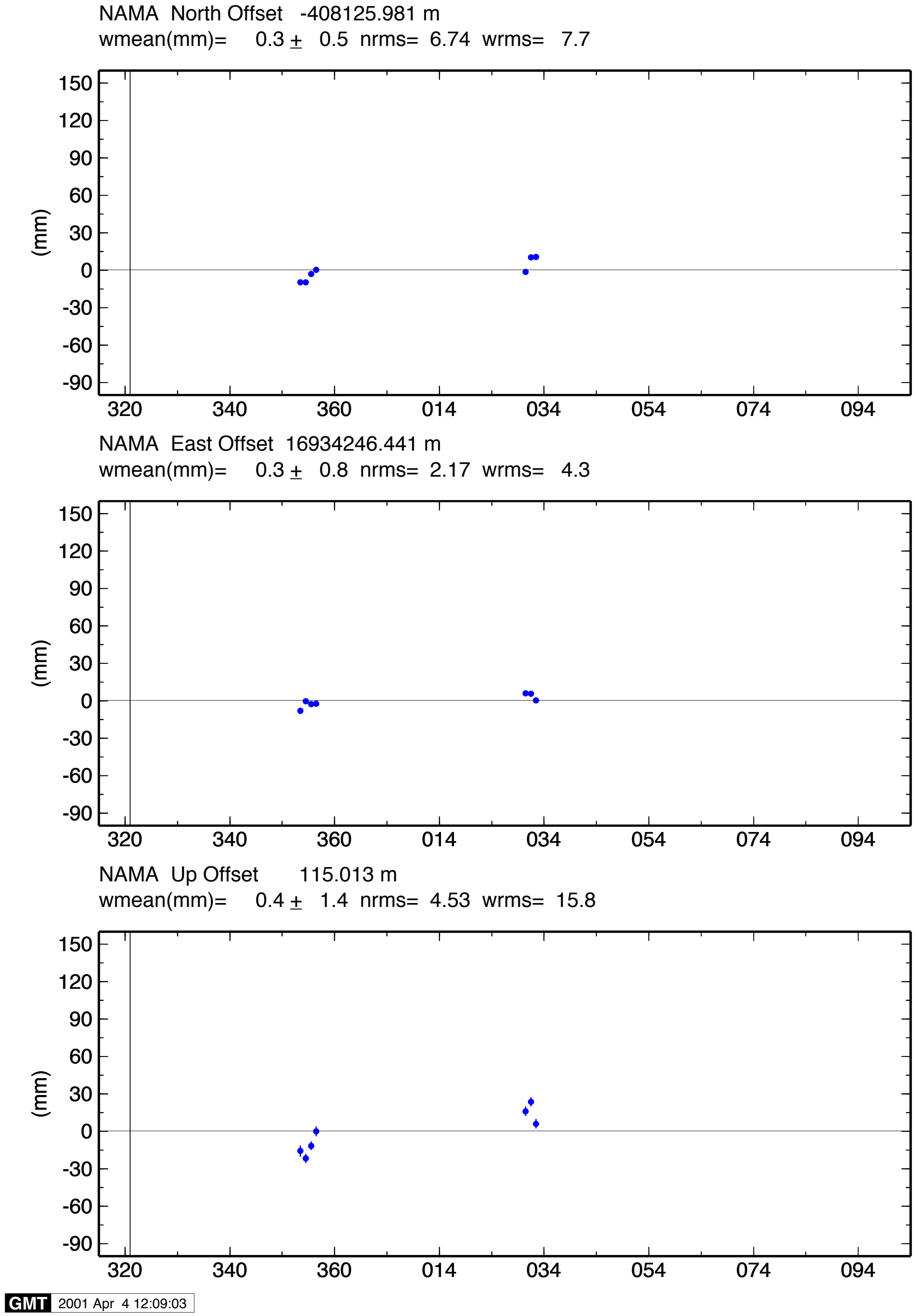


Figure 12: Time series of positions at NAMA (Namatanai) showing the post-seismic movement.

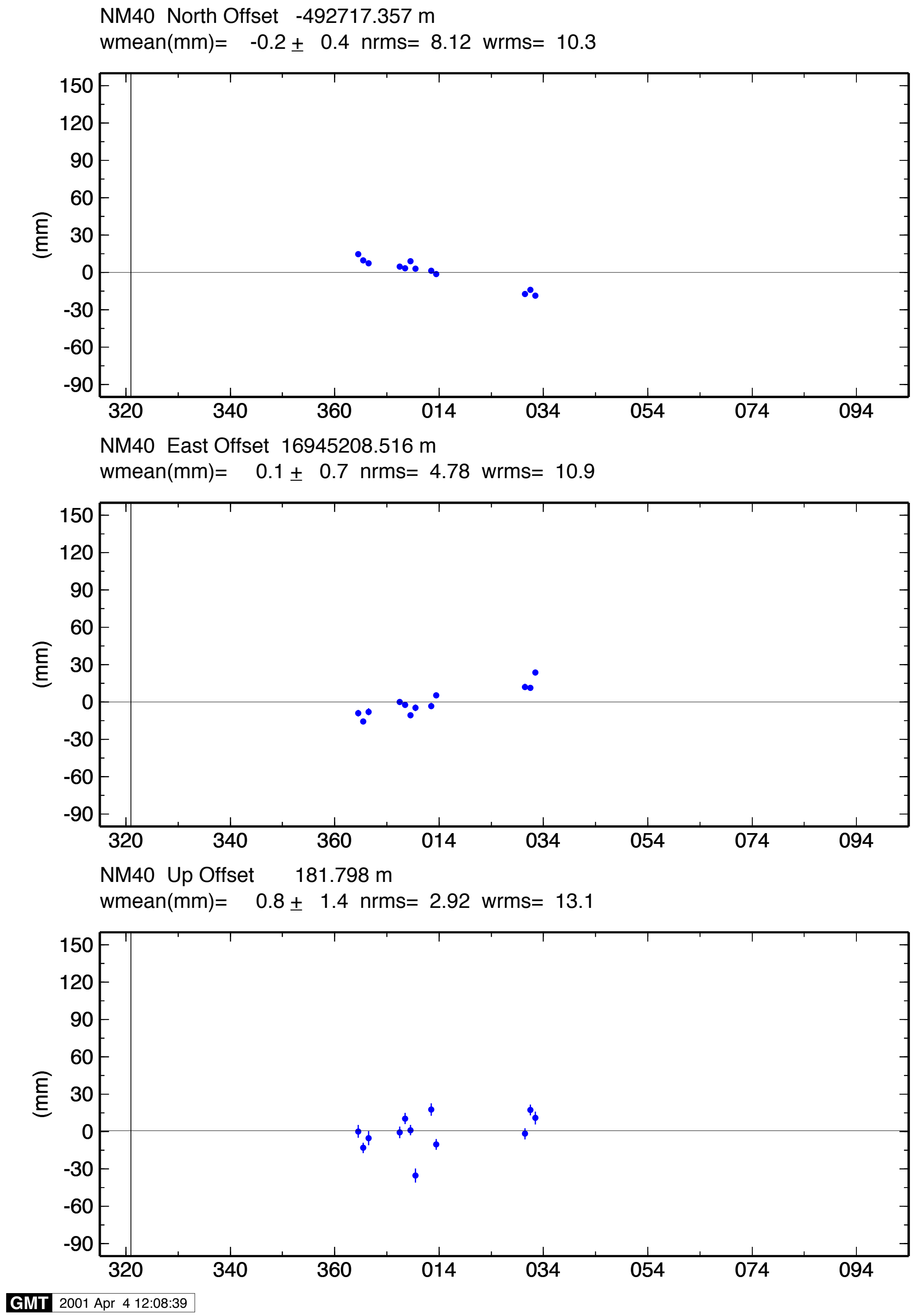


Figure 13: Time series of positions at NM40 (Karias) showing the post-seismic movement.

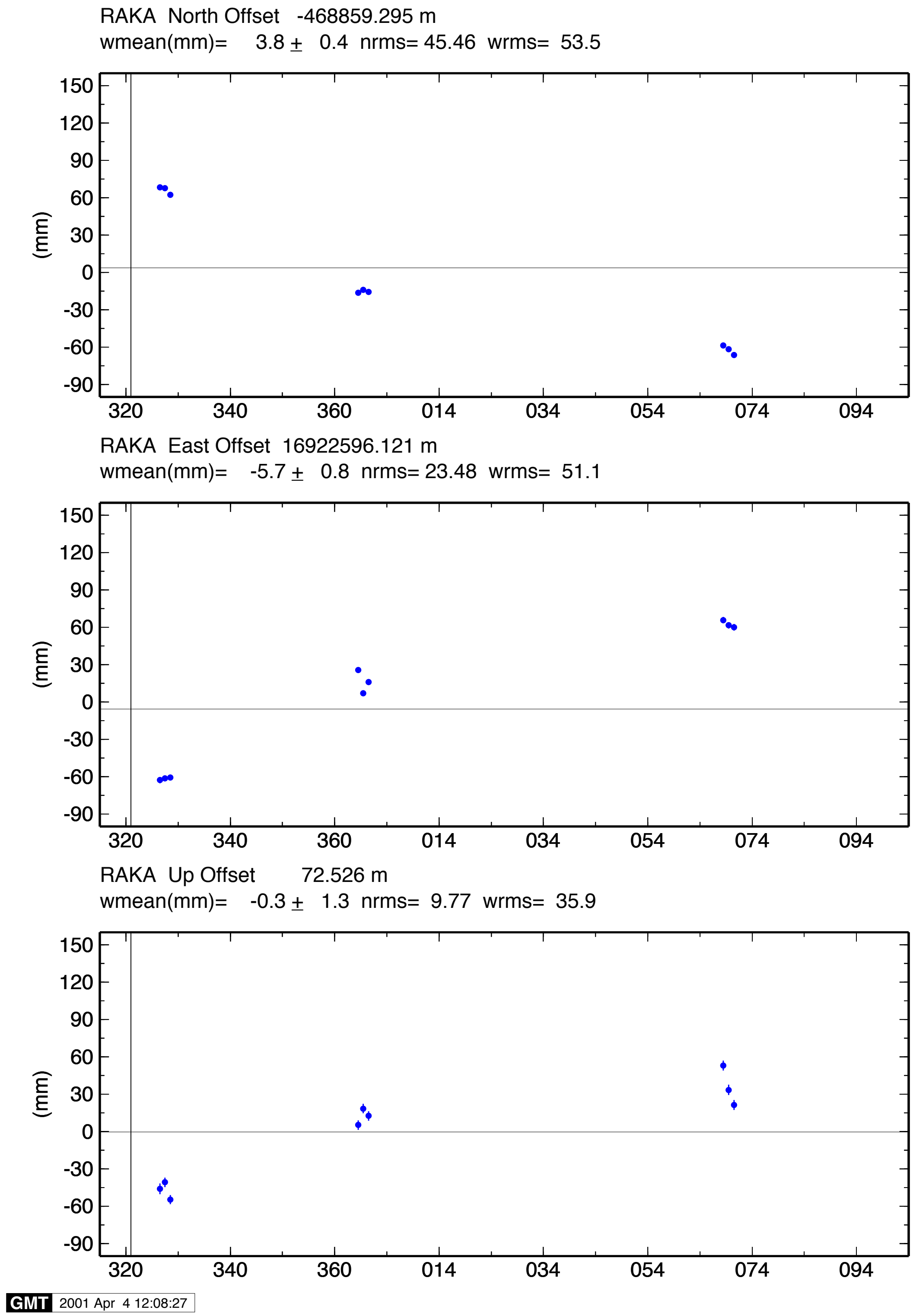


Figure 14: Time series of positions at RAKA (Rakanda) showing the post-seismic movement.

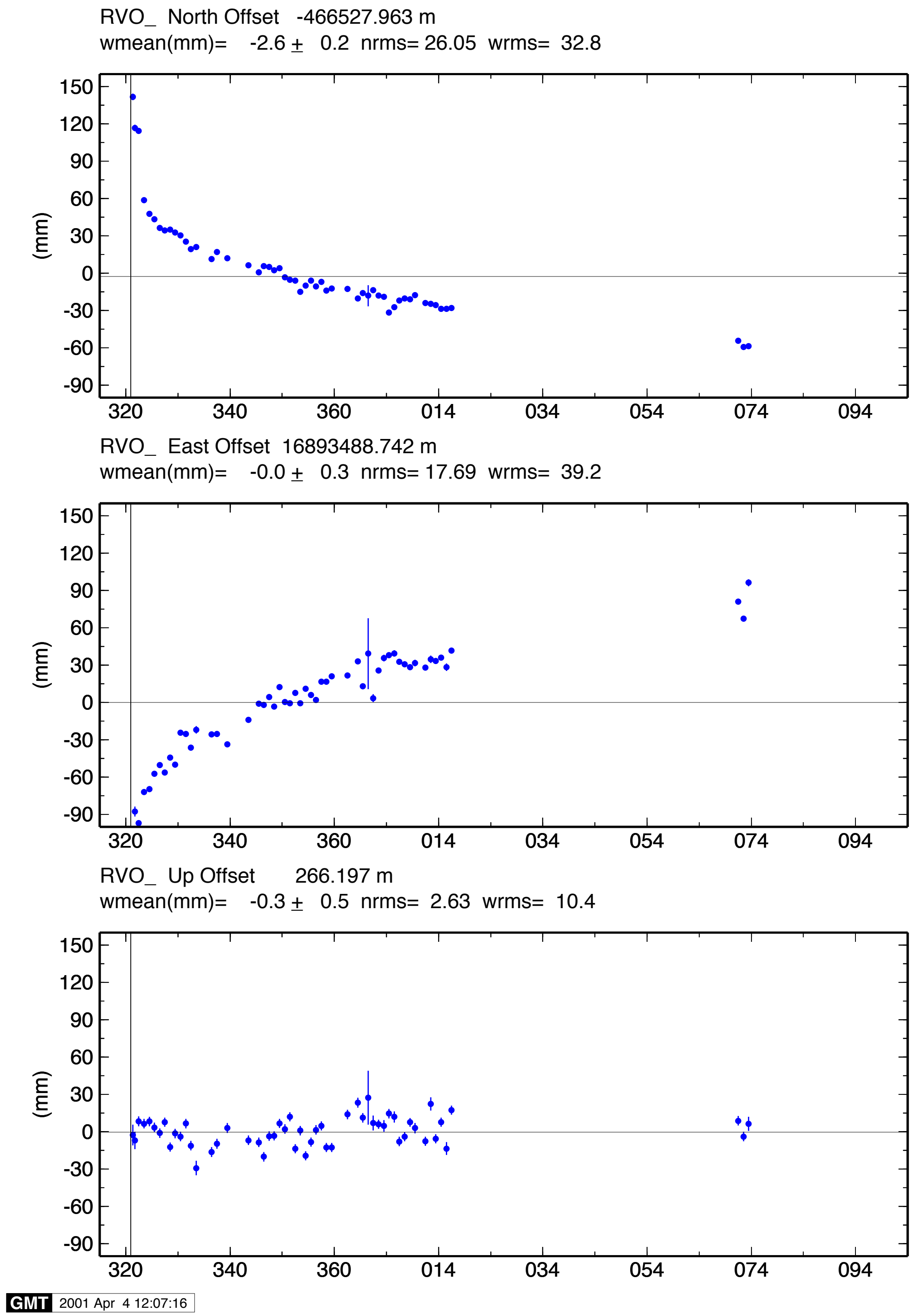


Figure 15: Time series of positions at RVO_ (Rabaul VOlcano Observatory) showing the post-seismic movement.

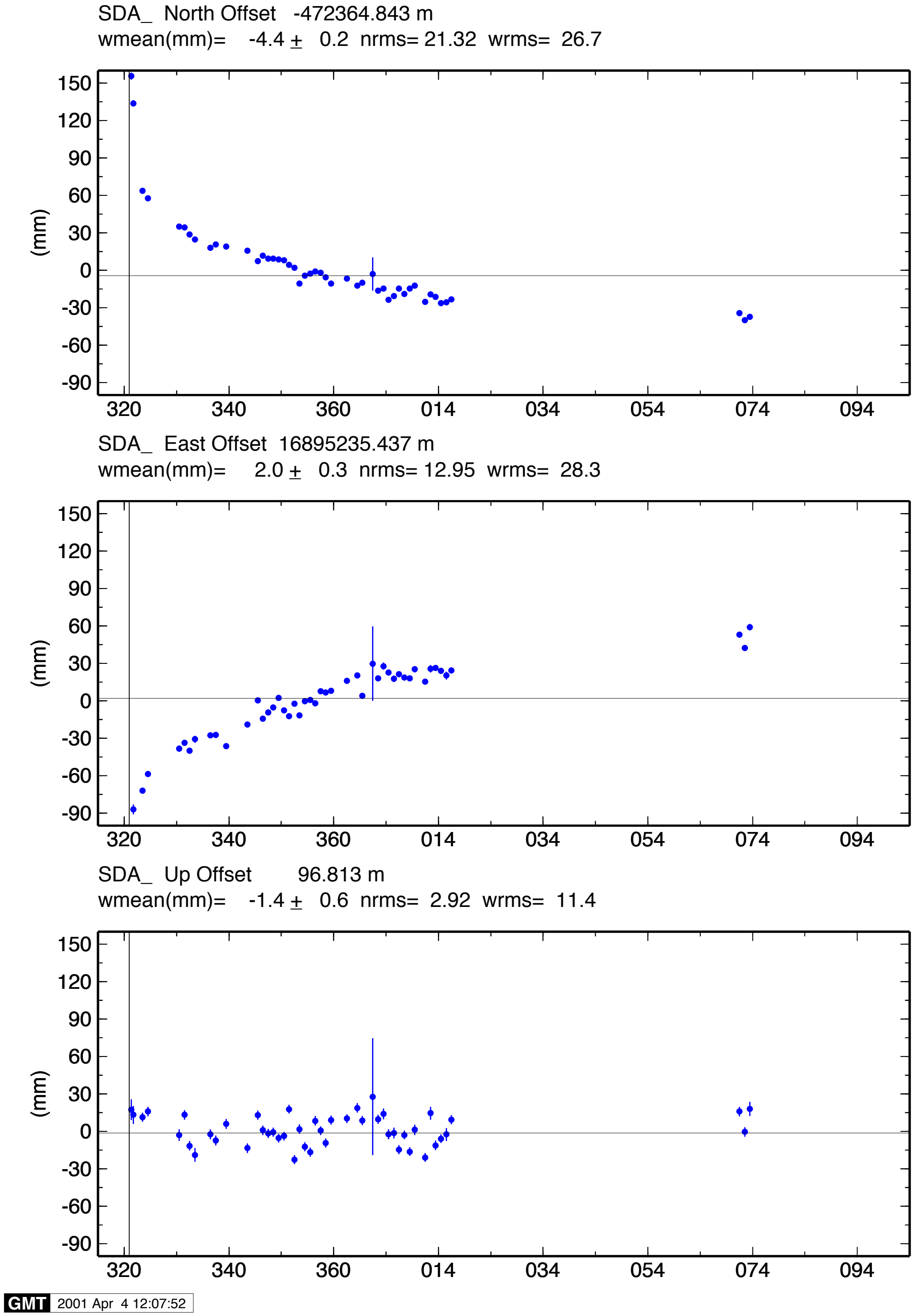


Figure 16: Time series of positions at SDA_ (SDA Church) showing the post-seismic movement.

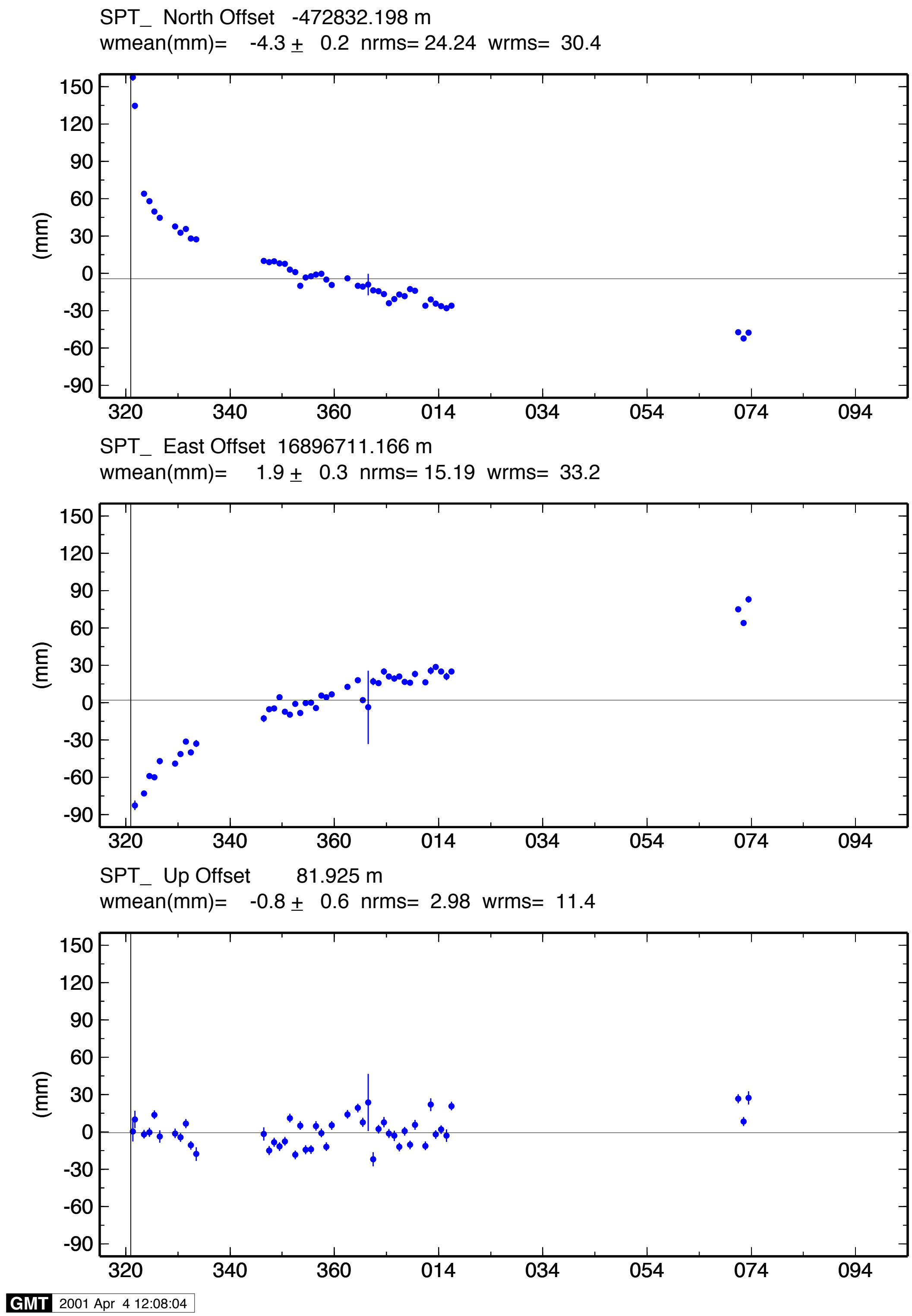


Figure 17: Time series of positions at SPT_ (Sulphur Point) showing the post-seismic movement.

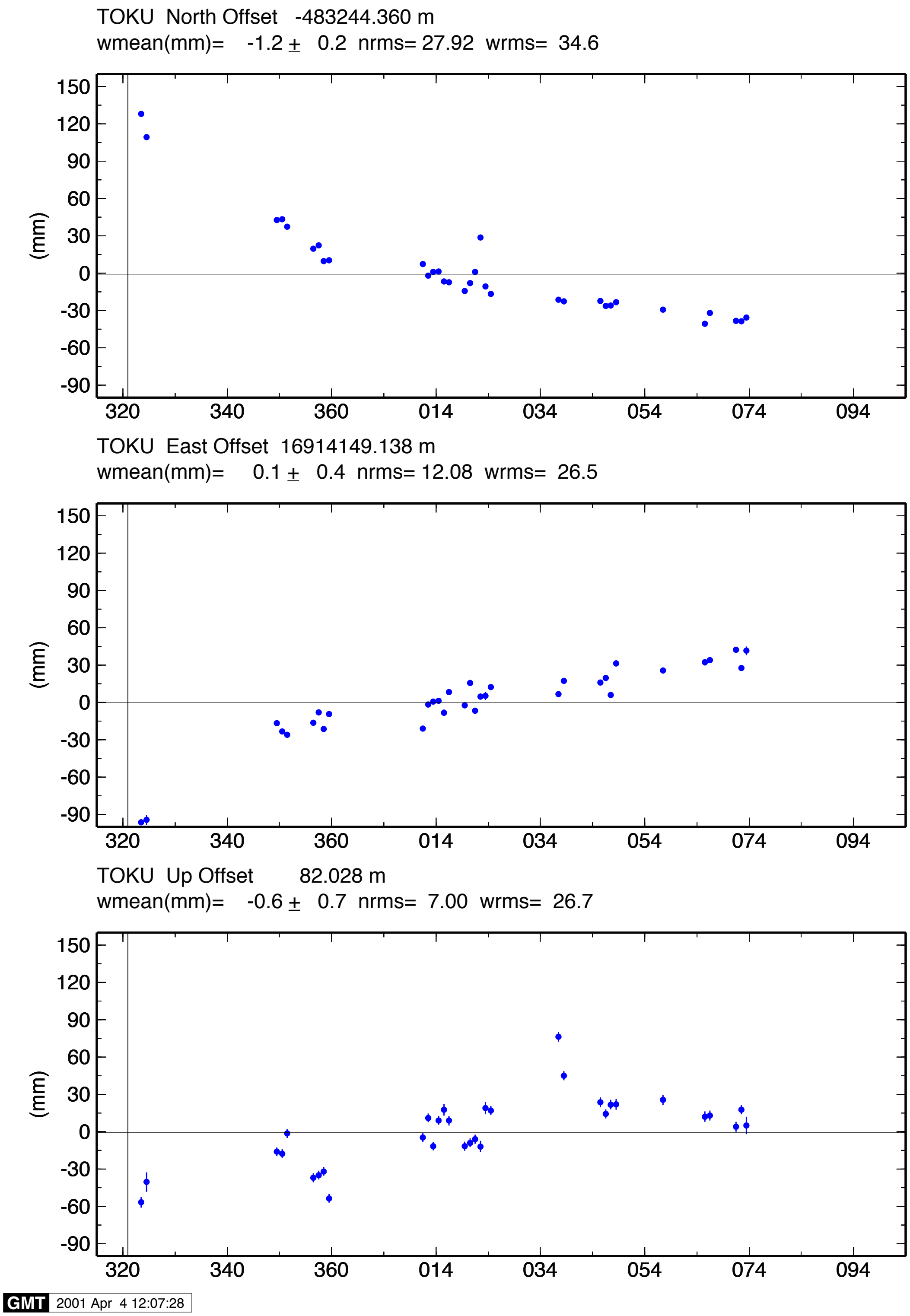


Figure 18: Time series of positions at TOKU (Tokua Airport) showing the post-seismic movement.

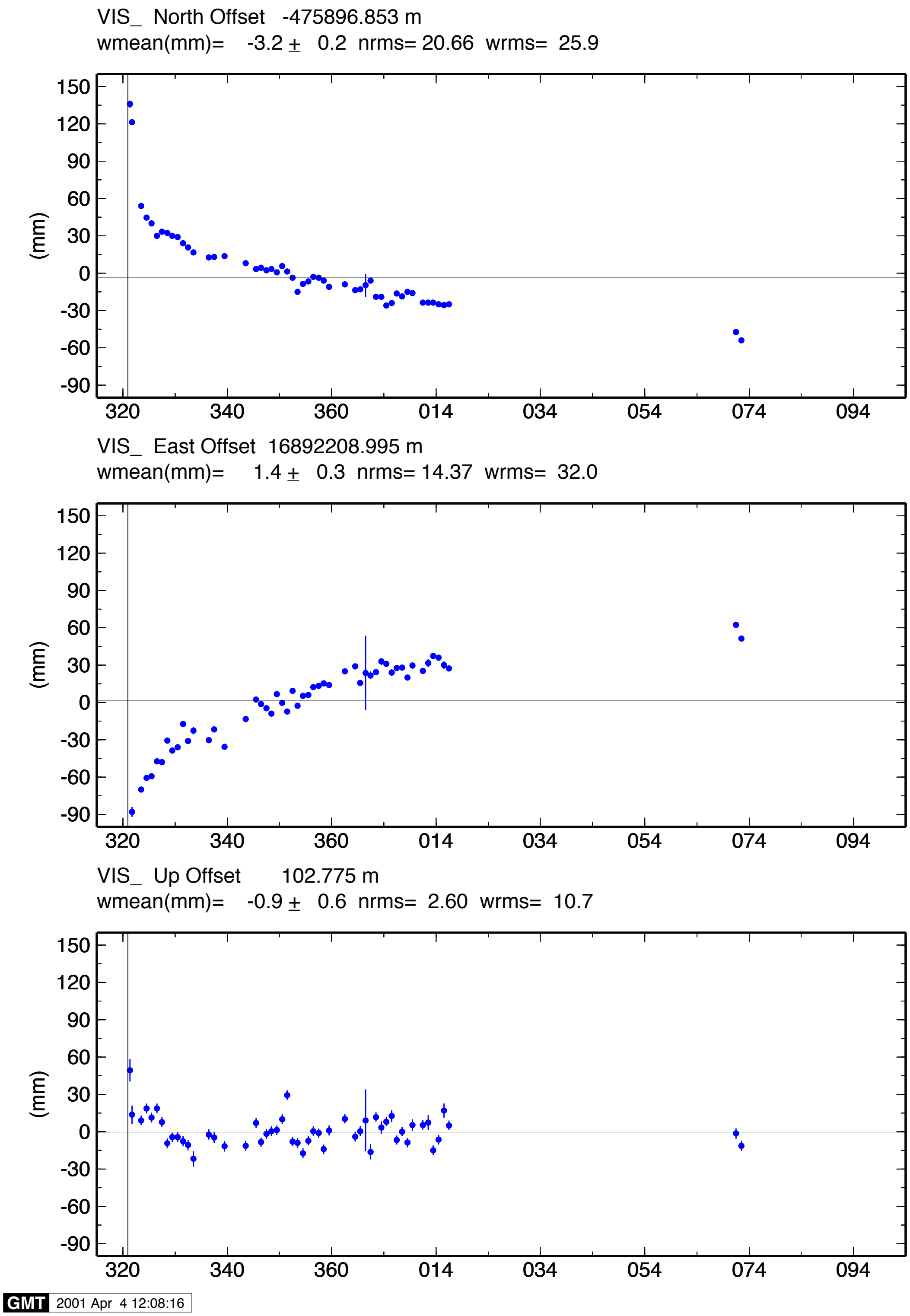


Figure 19: Time series of positions at VIS_ (Vulcan Island South) showing the post-seismic movement.

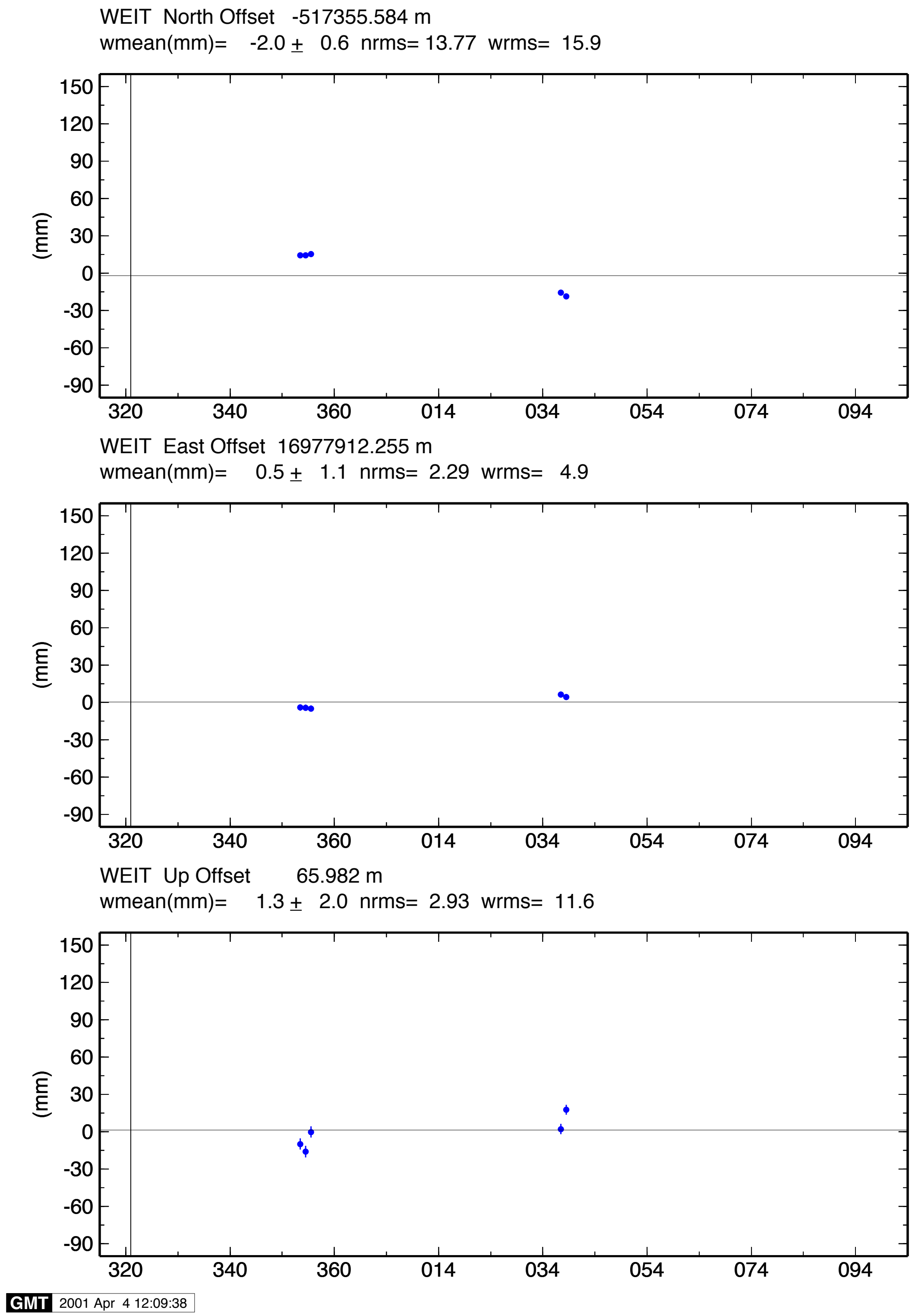


Figure 20: Time series of positions at WEIT (Weitin School) showing the post-seismic movement.