Analysis of Vertical Velocities from BARGEN Continuous GPS Data at Yucca Mountain, Southern Nevada

Emma Hill and Geoffrey Blewitt
Nevada Bureau of Mines and Geology/178
University of Nevada, Reno
Reno, Nevada 89557-0088, USA

Abstract. We present vertical velocity results for the continuous GPS network located in the region of Yucca Mountain, southern Nevada. Based on local and regional tectonics, we hypothesize that vertical velocities at Yucca Mountain are likely to be very small. Data from the network, from May 1999 to January 2003, was processed using the GIPSY-OASIS II software, with ambiguities resolved on a line-by-line basis to produce baseline velocities relative to a station located in the center of the Yucca Mountain network. Radome changes made in late-1999 produce a signal in the data, due to the fact that radomes were changed first at Yucca Mountain itself and later at stations in the far-field. Final results show vertical baseline velocities in the local Yucca Mountain network, relative to a station in the center of the network, clustered tightly around zero. All vertical velocities < 55 km from Yucca Mountain range between -0.6 ± 0.2 mm/yr and 0.7 ± 0.2 mm/yr, with an RMS of 0.63 about zero. We also show that stations in the regional network around Yucca Mountain show small velocity trends in their timeseries.

Keywords. GPS, Yucca Mountain, Basin and Range, vertical workshop

1 Introduction

1.1 The Yucca Mountain GPS network

Yucca Mountain has been selected as the location at which a repository will be built to store the tens of thousands of tons of nuclear waste currently being housed at nuclear power plants across the United States. Due to the obvious importance of determining an accurate picture of the seismic hazard of the region, the U.S. Department of Energy has funded a project to install and operate a dense, continuous GPS network around the site. This network has been in full operation since May 1999 as part of the Basin and Range Geodetic Network (BARGEN - http://cfa-www.harvard.edu/space_geodesy/BARGEN [May 2003]; Bennett et al. 2003; Wernicke et al. 2000). The network is small and dense, which minimizes many of the signals associated with larger GPS networks, and has been carefully designed to produce precise and robust results. All stations within the network are similar, with identical hardware (Trimble 4000 SSI receivers and Trimble choke-ring antennas with Dorne Margolin elements). Antennas are mounted with one vertical and three slanted braces 5-10 meters into bedrock. Horizontal velocities for the Yucca Mountain network have proven reliable even for velocities < 0.5 mm/yr (Davis et al, 2003).

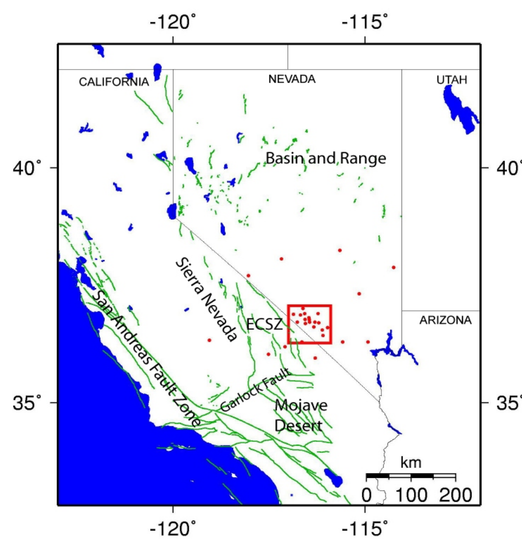

Figure 1 Location map. BARGEN GPS stations used in this analysis are indicated by dots. Quaternary faults are indicated in solid lines. Only faults in Nevada and California are shown (Dohrenwend et al. 1996; Jennings et al, 2002). Area shown in Figure is outlined by square.

1.2 Tectonic Setting

Yucca Mountain is located within the Walker Lane belt, a topographically complex zone of right- and left-lateral faulting and large-scale extension, forming the boundary zone between the Basin and Range to the east and right-lateral shear associated with the San Andreas Fault zone to the west. The eastern California shear zone (ECSZ) is located approximately 40 km to the west of Yucca Mountain (Figure 1). This right-lateral shear zone, which at the latitude of Yucca Mountain includes the Owens Valley, Panamint Valley - Hunter Mountain and Death Valley - Furnace Creek fault zones, is acknowledged by many to accommodate around 25% of total relative motion between the Pacific and North American plates. Although there is some element of oblique slip along the faults of the ECSZ, motion is primarily strike-slip (Dokka and Travis 1990; Hearn and Humphreys 1998). Since only a small portion of the horizontal strain due to these faults is likely to reach Yucca Mountain, it is very unlikely that any vertical motion due to the ECSZ could be detected.

Yucca Mountain is also located in the southern Basin and Range, a region dominated by extensional faulting along mostly northeast-trending normal faults, which by definition will result in vertical displacement. The level of tectonic activity in the southern Basin and Range, however, is deemed to be quite low compared to slip rates in the northern Basin and Range so, again, vertical velocities at Yucca Mountain due to this regional tectonic setting are likely to be small (Bennett et al. 2003; Dixon et al. 1995).

Yucca Mountain is itself a Basin and Range-style range block and is cut by a number of north-south trending normal faults (Figure 2). Several of these faults show evidence of Quaternary displacement, but geologic slip rates are very low, on the order of

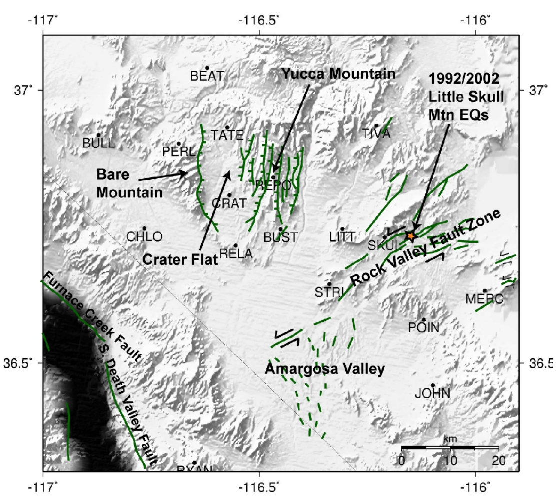

Figure 2 Local tectonic setting of Yucca Mountain. BARGEN GPS stations are labeled in block capitals.

0.01-0.02 mm/yr (Simonds et al. 1995; Whitney and Keefer 2000). The ENE-trending Rock Valley Fault zone, located to the south of Little Skull Mountain, is likely to be the largest source of seismic hazard in the local Yucca Mountain area. Quaternary offsets show primarily left-lateral strike-slip displacements, although it should be noted that the 1992 and 2002 Little Skull Mountain earthquakes have had down-to-the-southeast, normal focal mechanisms (Smith et al. 2000). A number of late Pleistocene/early Holocene basaltic centers exist at Crater Flat and at the south end of Yucca Mountain, which could cause localized uplift, particularly at station CRAT, which is situated on top of Black Cone in central Crater Flat (Wells et al. 1990). Overall, however, we can hypothesize that vertical velocities at Yucca Mountain should be extremely small, if not negligible.

2 GPS Processing

Continuous data from May 1999 to January 2003 (3.8 years) was processed using the GIPSY-OASIS II software developed by the NASA Jet Propulsion Laboratory. Data was initially processed using the precise point positioning (PPP) technique (Zumberge et al. 1997), with non-fiducial precise orbits from JPL. The results were then transformed to produce timeseries and velocities relative to ITRF-00, and, in order to minimize common-mode signals, baseline timeseries and velocities were calculated in this frame relative to station LITT, which is located in the central Yucca Mountain network (Figure 2). Ambiguity resolution was performed on a line-by-line basis to station LITT to produce baseline velocities relative to LITT. Although results for the horizontal improved dramatically when ambiguities were resolved, ambiguity resolution had limited effect on vertical velocities. All processing was carried out with an elevation cutoff angle of 15^o.

3 Radome Changes

An interesting feature of the vertical results was the ability of antenna radome changes to create not only an error but also a signal in the velocity results. Radomes were changed to SCIGN radomes within the local Yucca Mountain network in mid-August 1999. It then took several months to change radomes at stations further from the mountain, with the final radome changed in mid-January 2000. Baseline timeseries for far-field stations therefore show a box-car effect, with one offset caused by the radome change at Yucca Mountain and a second offset caused by the radome change at the station itself (Figures 8,

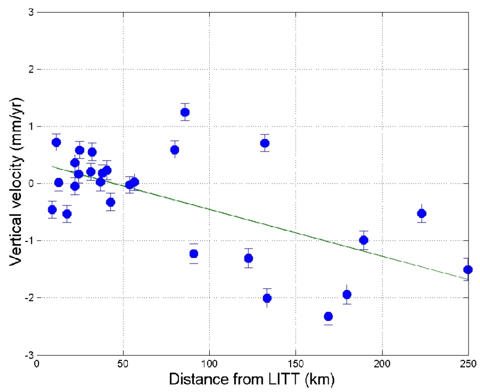

Figure 3 Baseline velocities for the vertical component, relative to station LITT, including the effects of radome changes.

9 and 10), or vice-versa in a few cases. Ignoring this effect resulted in a signal that gave Yucca Mountain the appearance of uplifting relative to stations in the far-field (Figure 3).

Two different methods were used to rectify the radome problem. We first just removed all data between the first radome change and last radome change and recalculated the baseline velocities without this data. Secondly we attempted to estimate the magnitude of the radome offsets and then ignore these offsets in the velocity calculations. The second method has the advantage of using all the data, but the disadvantage of adding extra unknowns to the calculations. Although both techniques produced similar results, with similar formal errors, all attempts to automatically estimate the offset produced an overestimate (for example 18mm compared to the 13 mm we estimated by simple examination of the timeseries by eye). This was probably due to the fact

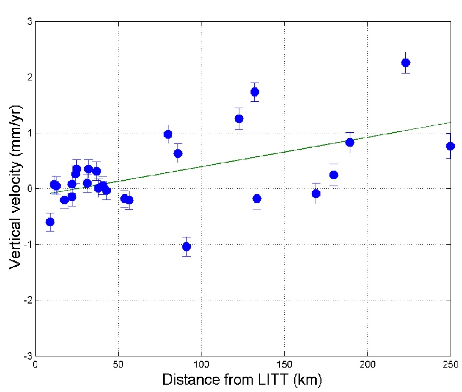

Figure 4 Baseline velocities for the vertical component, relative to station LITT, with radome offsets estimated using GIPSY's sta_event function and velocities calculated with these offsets ignored.

that the radome changes occurred so early in the timeseries. When velocities were calculated using the offset estimated by GIPSY's sta_event function, the overestimated offset produced velocities as shown in Figure 4. We therefore decided to use the results obtained through simply removing the contaminated data. This is a good illustration of the importance in future projects of obtaining accurate measurements of radome offsets for particular antenna-radome configurations.

4 Results

4.1 Local vertical velocities

With the effects of radome changes removed, vertical velocities across the Yucca Mountain network are encouragingly well clustered about zero. All vertical velocities at distances <55km from Yucca Mountain range between -0.6±0.2 and 0.7±0.2 mm/yr, with an RMS value of 0.63 about zero (Figure 5).

Examination of the timeseries for stations at Yucca Mountain confirms that vertical velocities are negligible relative to station LITT (for example, Figure 6).

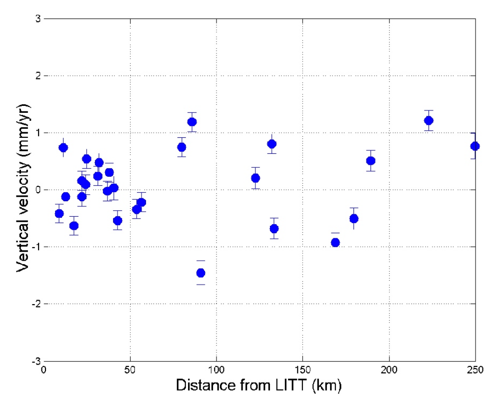

Figure 5 Baseline velocities for the vertical component relative to station LITT, with data between the first and last radome changes removed.

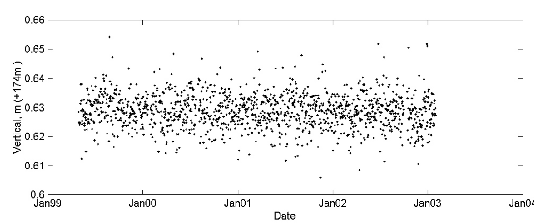

Figure 6 Baseline timeseries for station SKUL, relative to LITT

Beyond this, the differences in vertical velocities at stations close to Yucca Mountain are negligible, and impossible to interpret relative to sources of vertical deformation (Figure 7). As mentioned in Section 1.2, station CRAT is located on a Quaternary cinder cone, so the relatively large uplift shown in Figure 7 could be significant. It should be noted, however, that Black Cone is situated within a layer of thick alluvium, which may cause a greater degree of monument instability than at other stations in the area. CRAT is also at a lower elevation than other stations.

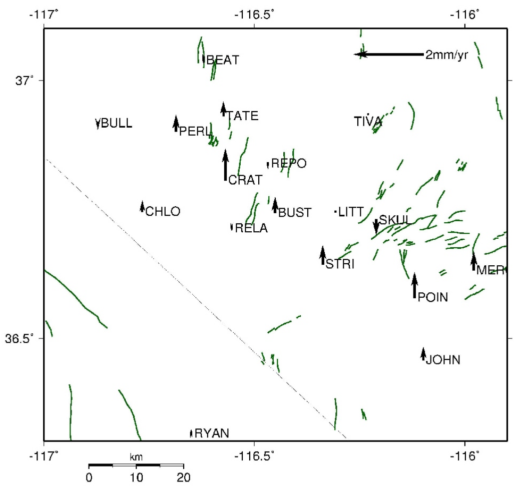

Figure 7 Vertical velocities at Yucca Mountain plotted relative to station TIVA (top right of figure). North pointing arrows indicate uplift, south-pointing arrows indicate negative vertical velocities.

1.2 Regional vertical velocities

Some of the stations in the regional network surrounding Yucca Mountain (those labeled in Figure 11) do show velocity trends in their vertical timeseries, for example LIND (Figure 8), TONO (Figure 9) and ECHO (Figure 10).

From these results we show that station LIND, located on the southern Sierra Nevada block, is moving up relative to Yucca Mountain by 0.76±0.22 mm/yr. We also see that although stations at the southeastern margin of the Great Basin are moving up relative to Yucca Mountain, for example APEX and ECHO at 0.8±0.2 mm/yr and1.2±0.2 mm/yr respectively, stations in the central Great Basin are moving down, for example TONO at -0.9±0.2 mm/yr and RAIL at -0.5±0.2 mm/yr.

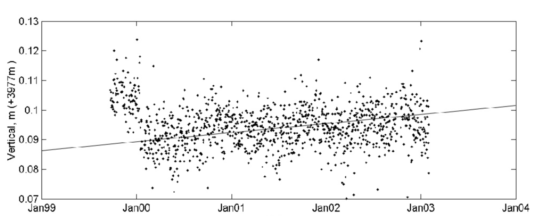

Figure 8 Timeseries for station LIND, relative to LITT. Offset in January 200 is radome change at LIND.

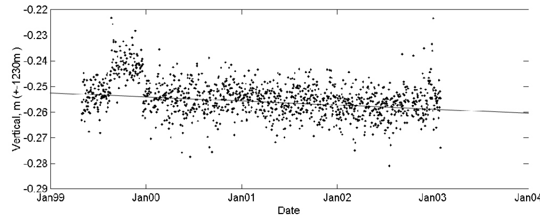

Figure 9 Baseline timeseries for station TONO, relative to LITT. First offset in 1999 is radome change at LITT, second offset is radome change at TONO

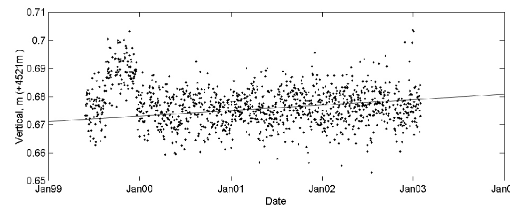

Figure 10 Baseline timeseries for station ECHO, relative to LITT. First offset in 1999 is radome change at ECHO, second offset is radome change at LITT.

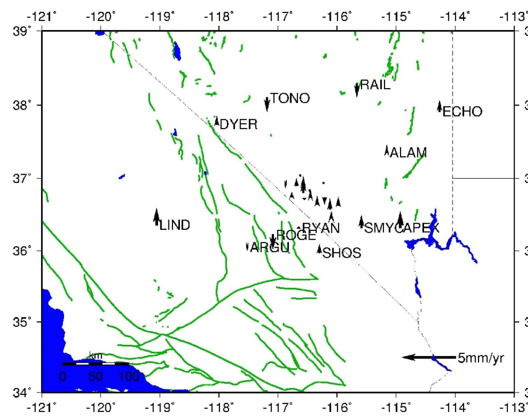

Figure 11 Regional vertical velocities, relative to station TIVA at Yucca Mountain (see Figure 7).

1.3 Vertical velocities relative to elevation

We have observed a possible, although not conclusive, inverse correlation between vertical velocities and the elevation of individual GPS stations (Figure 12). This is a topic that requires further investigation, but could be due to the fact that even with very short baselines we may not be completely removing the effects of periodic signals.

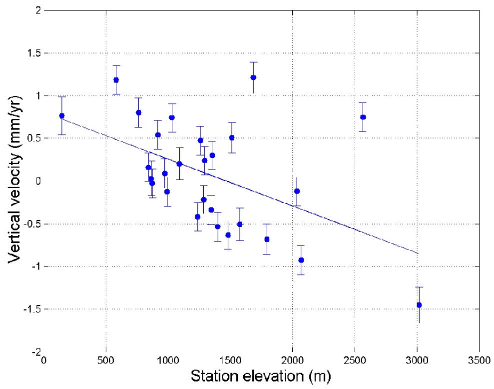

Figure 12 Baseline velocities, relative to station LITT, with respect to station elevation

5 Conclusions

Based on the hypothesis that vertical velocities at Yucca Mountain are likely to be negligible, the fact that all the velocities for the local Yucca Mountain GPS network are clustered tightly around 0.0 mm/yr indicates a good degree of precision. All vertical baseline velocities for stations <55 km from Yucca Mountain (relative to station LITT, which is within the local Yucca Mountain network) range between -0.6±0.2 mm/yr and 0.7±0.2 mm/yr.

Some of the far-field stations in our network reveal small velocity trends, evidenced by visual examination of the timeseries. Specifically, station LIND, which is located on the southern Sierra Nevada, is moving up 0.76±0.22 mm/yr relative to station LITT at Yucca Mountain. Although stations located in the central Great Basin, are moving down relative to Yucca Mountain, such as TONO and RAIL by -0.9±0.2 mm/yr and -0.5±0.2 mm/yr respectively, stations along the eastern margin of the Great Basin, such as APEX and ECHO, are moving up, by 0.8±0.2 mm/yr and 1.2±0.2 mm/yr, respectively.

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