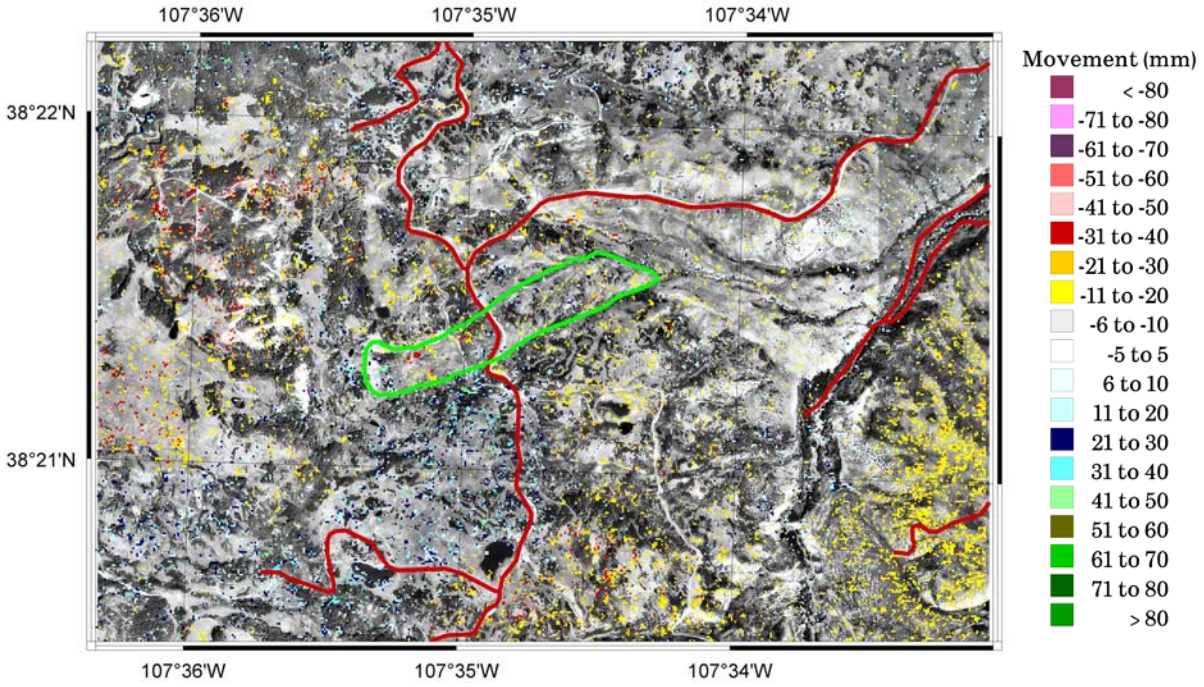

Figure 47. Graph. InSAR derived height change for April 25 to June 12, 2005.

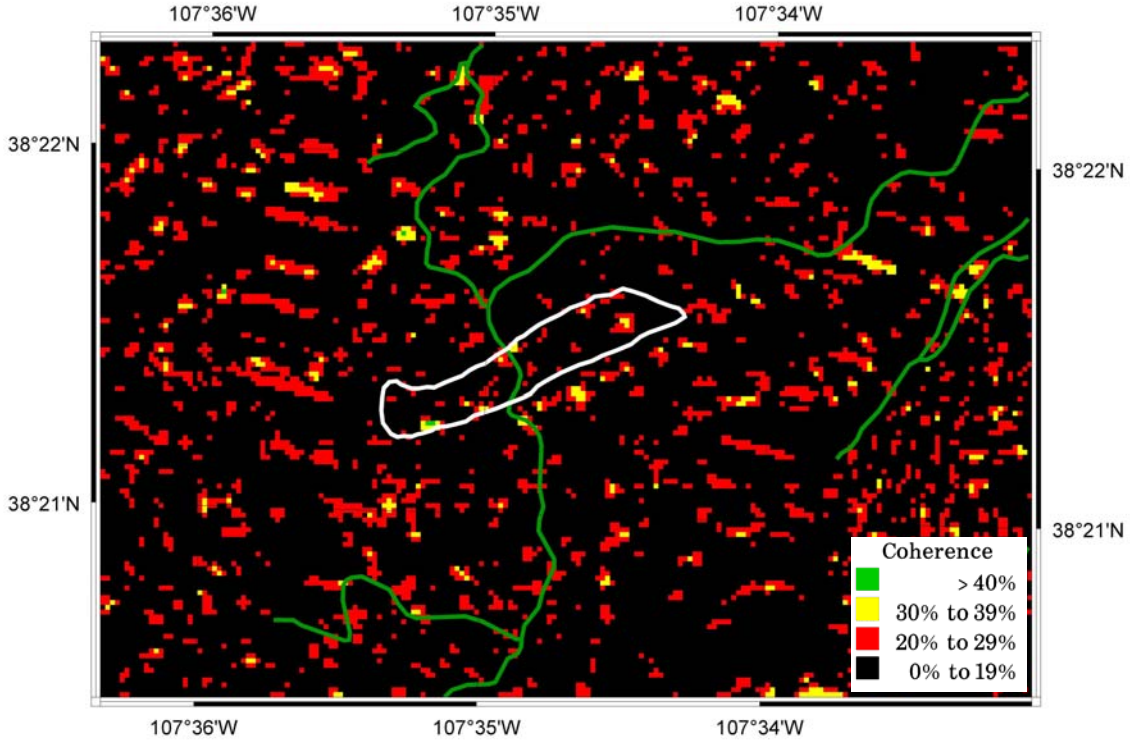

Figure 48. Graph. ERS SAR coherence for acquisitions on July 27 and October 5, 1997.

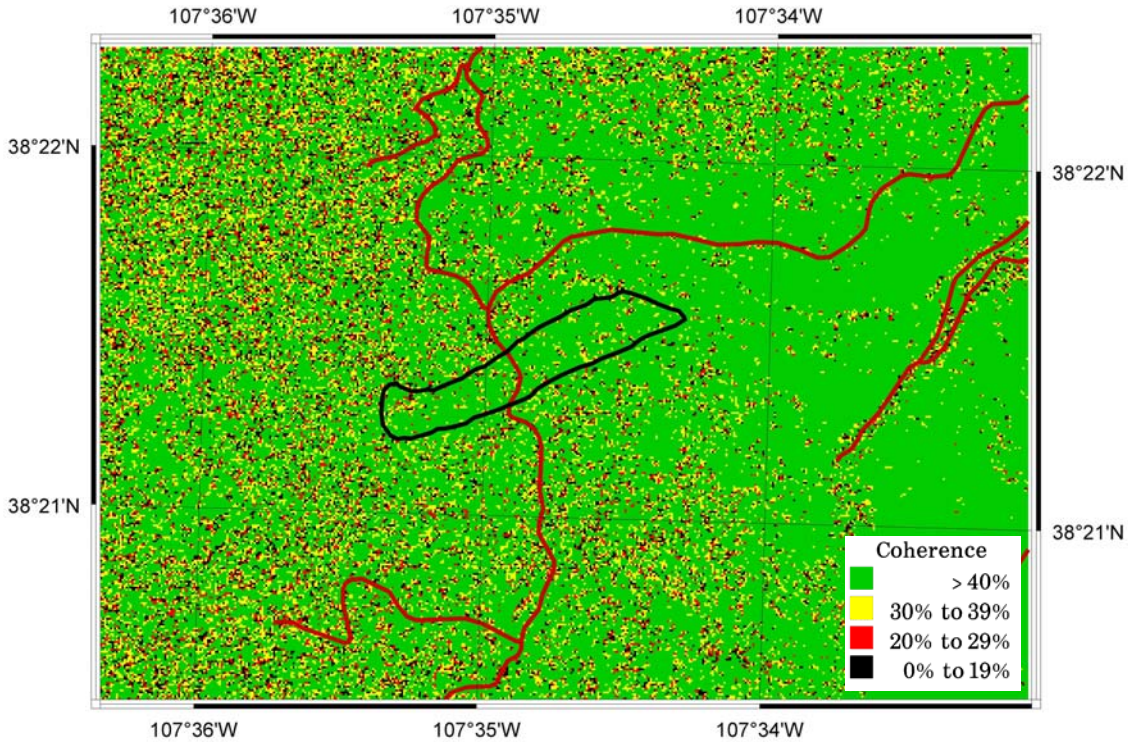

Figure 49. Graph. RADARSAT SAR coherence for acquisitions on September 21 and October 15, 2004.

Interpretation

The only evidence of movement observed over the monitoring period was during the autumn of 2003 and 2004, for the upper, reactivated section of the Wells Basin Landslide. During each of these two timeframes, subsidence or downslope movement of roughly 10 mm (0.4 inch) to 20 mm (0.8 inch) was measured along a 300 m (1000 ft) section near the top of the 1997 reactivated slide. Any detection of movement during the other monitoring intervals was limited due to the generally poor temporal coherence of the area. Good coherence would obviously help to determine limits on the amount of movement occurring at the site, as well as the exact area experiencing movement.

The reason for the observed movement signatures during the autumn is unclear. It is assumed that the slide activity depends on the amount of ground water, and since snowmelt is the principal source, the major movement would be expected to occur during the spring. The monthly precipitation from January 2003 to August 2005 is shown in Figure 50, from which it is evident that the autumn of 2003 and 2004, as well as the spring of 2004, received precipitation amounts well above the other months. However, the relative influence of direct precipitation compared to accumulated snowmelt is unknown at this time.

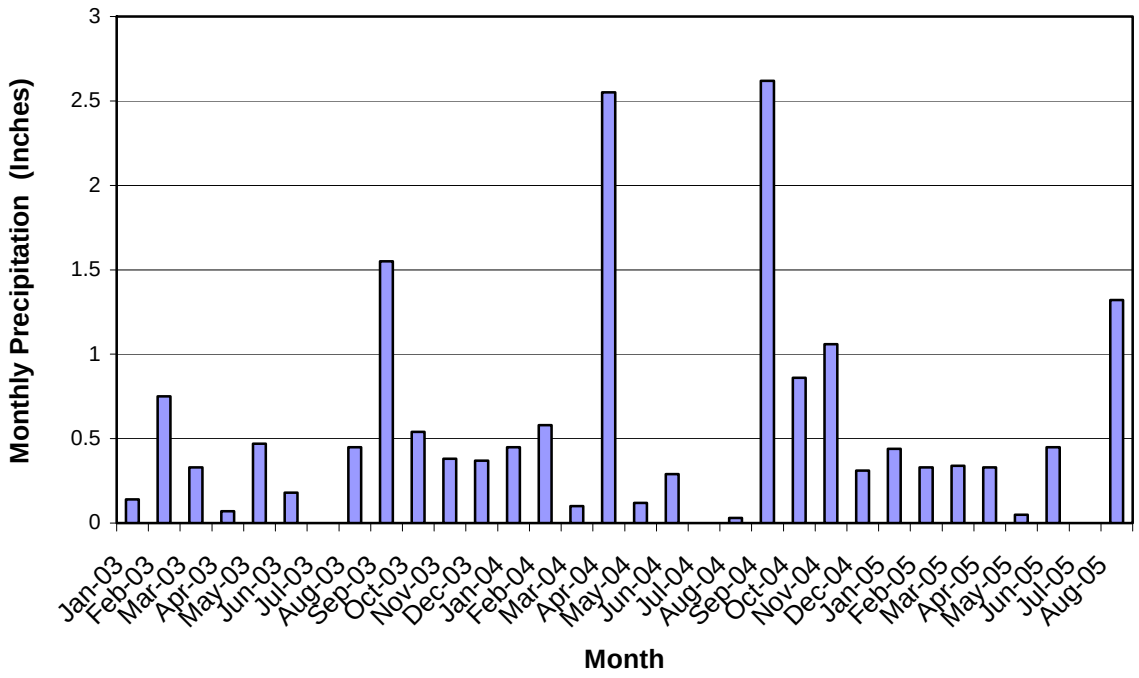

Figure 50. Graph. Monthly precipitation from January 2003 to August 2005 for Montrose, Colorado.

MESA VERDE

Acquisitions

For the slide areas along the access highway in the vicinity of Point Lookout, the best available ERS archive data were acquired during the descending satellite pass along track 413, for which there are 16 ERS-1 acquisitions spanning 1992 to 1996, and 12 ERS-2 acquisitions from 1995 to 1999, with three additional acquisitions in 2002. Three ERS images, as listed in Table 7, were procured initially. The ERS-1/2 tandem pair from May 27 and 28, 1996 was obtained as an option for generating a DEM of the Mesa Verde area. The standard DEM used in the InSAR processing was obtained from the SRTM data available through the USGS. The third scene from September 10, 1996 was obtained to generate a differential pair spanning May to September 1996, thereby enabling the general coherence in the area to be evaluated.

Table 7. Mesa Verde ERS images procured for analysis.

Date	Temperature ° Celsius	Meteorological Conditions, Cortez Weather Station
May 27, 1996*	N/A	N/A
May 28, 1996*	N/A	N/A
September 10, 1996	18°	precipitation

*Tandem Pair for DEM

Fine mode F2 RADARSAT acquisitions along the descending satellite pass were programmed specifically for this project, starting in August 2004 and continuing until August 2005. A total of thirteen acquisitions were made during this two-year timeframe, with seven being used in the InSAR analysis, as indicated in Table 8. These scenes were chosen to obtain maximum coherence, according to the weather during the acquisitions, the short time intervals for image pairs, and the small perpendicular baselines.

Table 8. Mesa Verde RADARSAT images procured for analysis.

Date	Temperature ° Celsius	Meteorological Conditions, Cortez Weather Station
August 1, 2004	11°	clear
August 25, 2004	7°	clear
October 12, 2004	3°	overcast
March 5, 2005	6°	overcast
May 16, 2005	24°	clear
July 3, 2005	33°	clear
August 20, 2005	23°	clear

Analysis

Differential interferograms were computed for ERS and RADARSAT image pairs with perpendicular baselines less than 500 m (1600 ft), and with maximum timeframes of around three months. One ERS and five RADARSAT interferograms, as listed in Table 9, were generated.

The generation of the SAR interferograms was performed through the Gamma processing software. The SAR signal data were first processed to yield image data, which were then co-registered so that all images were aligned in the SAR acquisition geometry. An external DEM was obtained for the study area from the 30 m (100 ft) SRTM DEM data available from the USGS. This DEM was co-registered to the SAR data as well, and then used to determine the topographic phase contribution for each interferogram. Both the curved-Earth and topographic phase were calculated based on the SAR acquisition geometry, and initially relied on the intrinsic satellite orbit information. The orbit baseline information was then refined by using the curved-Earth fringe rate evident in the differential interferogram. Further issues relating to residual phase were dealt with at the interferogram stage.

Table 9. Mesa Verde SAR interferometric image pairs.

Figure	Acquisition Dates	SAR Sensor	Perpen-dicular Baseline (m)	Δ Time (days)	Mean Coherence	Standard Deviation
	May 28, 1996–Sep 10, 1996	ERS-2	98	105	33	17
	Aug 1, 2004–Aug 25, 2004	RSAT	12	24	74	18
	Aug 25, 2004–Oct 12, 2004	RSAT	250	48	38	18
	Mar 5, 2005–May 16, 2005	RSAT	299	72	30	15
	May 16, 2005–Jul 3, 2005	RSAT	196	48	36	17
	Jul 3, 2005–Aug 20, 2005	RSAT	389	48	35	17

Results

The InSAR interferograms for the intervals given in Table 9 were computed. As noted previously, the coherence in the areas of interest along the mountain slopes was generally poor, with regions of radar layover and shadow. The mean coherence values for the InSAR interferograms are included in Table 9, and are seen to generally be in the 30% range. However, as previously seen in Figure 19, the Mesa Verde area is characterized by quite good coherence in the low relief regions, and poorer coherence in the more rugged regions.

The ERS InSAR pair from May to September 1996 was used to evaluate the longer-term coherence, and estimate the likelihood of obtaining movement measurements in the specific areas of interest. No useful movement results were obtained from this interferogram, and further attempts concentrated on short timeframe InSAR pairs, as well as the higher resolution Fine mode of RADARSAT in order to help isolate specific slopes of interest.

The short timeframe interferograms generated from the RADARSAT Fine mode data provided the best coherence, and, in particular, the 24-day InSAR pair from August 2004 yielded average coherence of roughly twice the typical value. The precipitation for Cortez, which is 15 km (10 mi) to the west of Point Lookout, is given in Figure 51, from which it is seen that the amount of precipitation varied substantially from month to month.

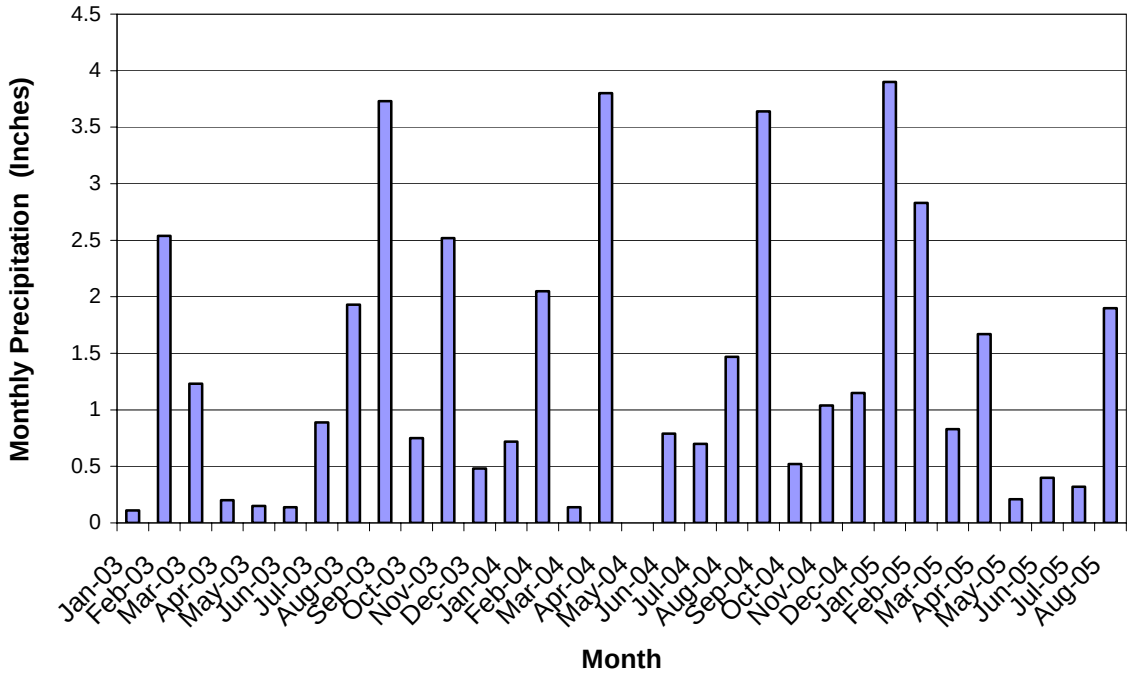

Figure 51. Graph. Monthly precipitation from January 2003 to August 2005 for Durango, Colorado.

All InSAR interferograms showed significant residual phase that was correlated to the topography. To date, this has not been eliminated, and therefore it is a major source of uncertainty in these datasets. This combined with the radar layover and shadow and the poor coherence associated with the mountain slopes, has prevented useful movement maps from being obtained.

The InSAR pair from August 2004 has the advantage of a short timeframe, of only moderate precipitation, and of, especially, an exceptionally good baseline of only 12 m (40 ft). The residual phase, interpreted as differential height, is shown in Figure 52, with the SAR intensity image in the background and the road network given by the red lines. It is seen that the residual phase is correlated with topography. Further, areas of radar shadow are seen as extremely dark regions in the SAR intensity image, while areas of radar foreshortening and layover are seen as extremely bright areas in the image, both of which are aligned with the large ridges and slopes. Regardless, within these obvious artifacts, no movement signatures are visible.

A more typical representation of the residual phase in the Mesa Verde region is given for the July to August InSAR pair as given in Figure 53. This pair has a more typical baseline value of near 400 m (1300 ft), as well as a longer timeframe of 48 days. Here, the correlation of residual phase and topography is still visible, but interpretation is further hampered by the increase in phase noise associated with the lower coherence.

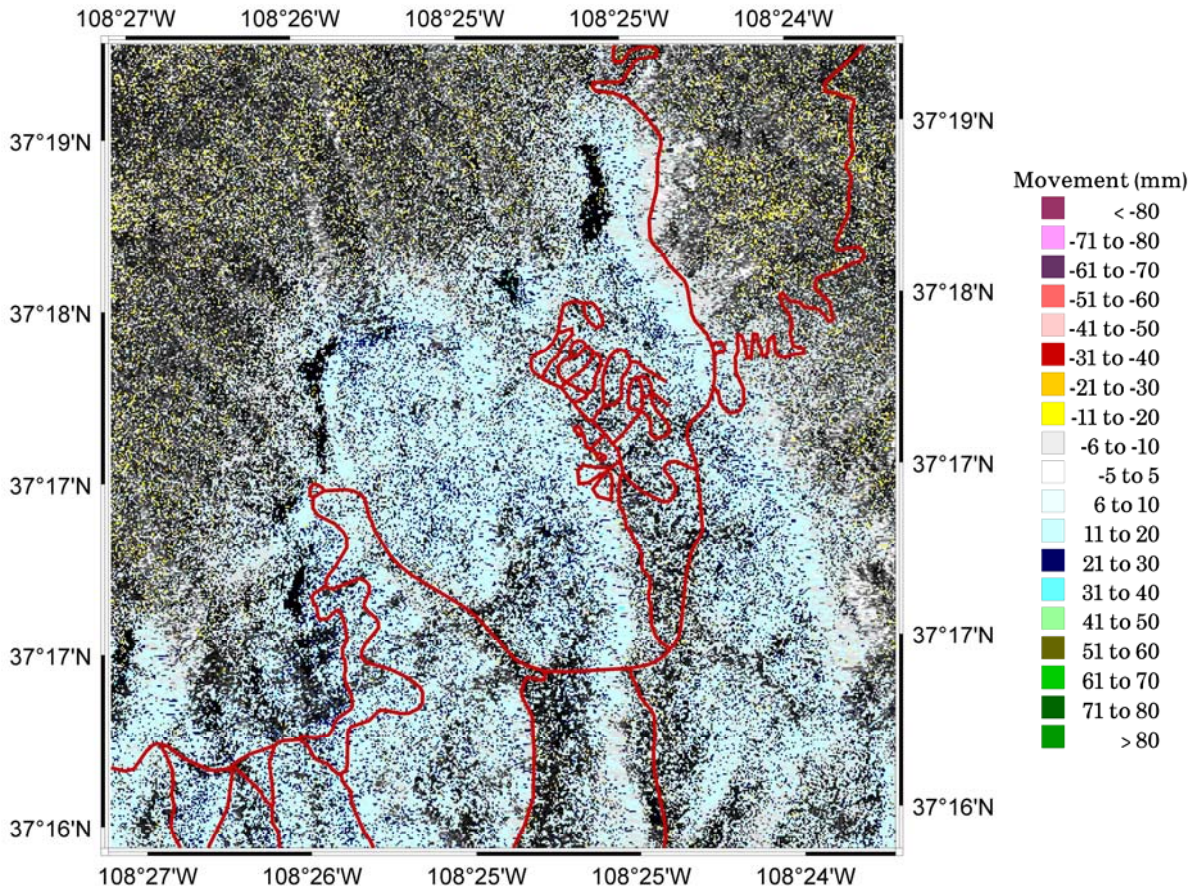

Figure 52. Graph. Residual phase, displayed as height change, for the August 1 to 25, 2004 InSAR pair.

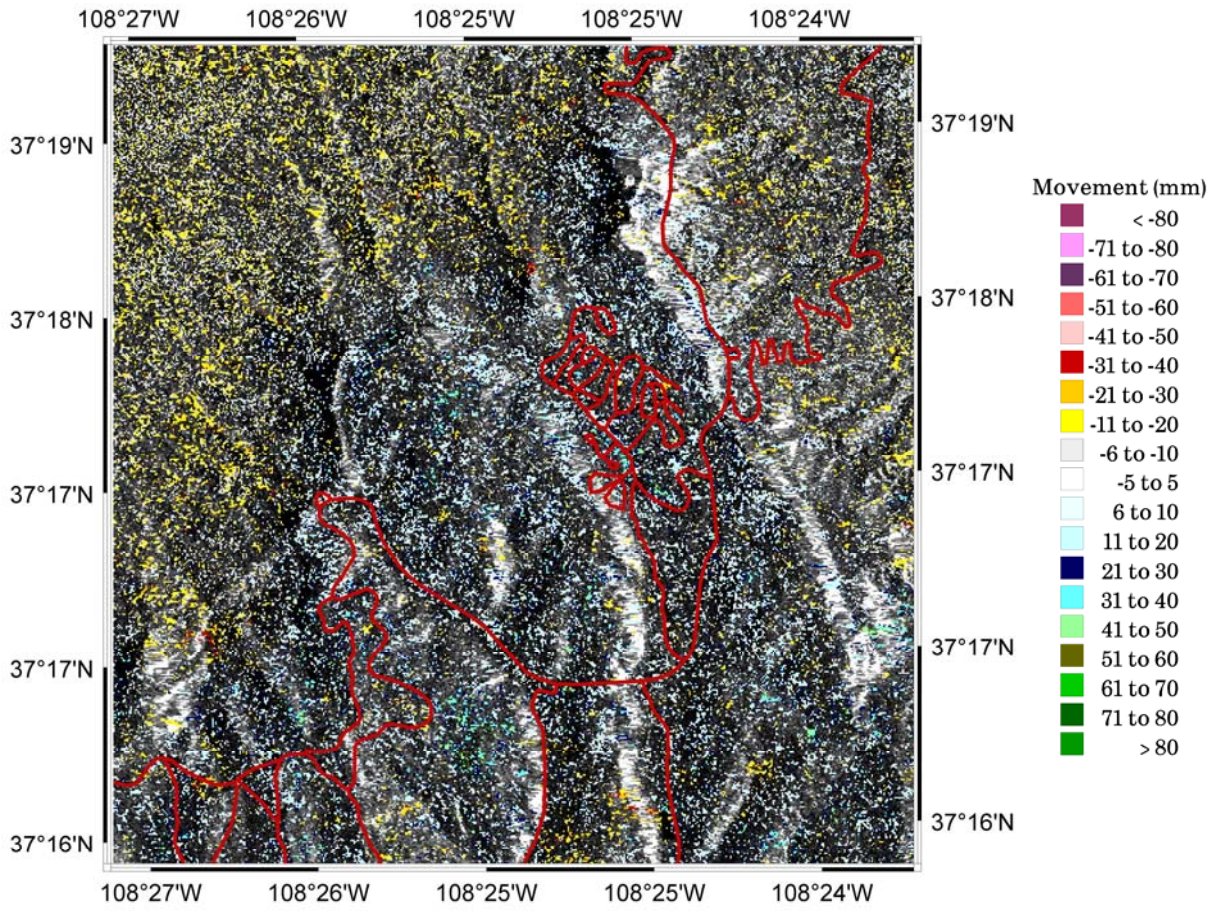

Figure 53. Graph. Residual phase, displayed as height change, for the July 3 to August 20, 2005 InSAR pair.

Interpretation

The Mesa Verde area, and in particular, the slide areas located on the slopes of Point Lookout, have rugged topography that has prevented InSAR determination of the movement. In some instances, the slopes are simply obscured by radar shadow or layover, and no movement information can be obtained. In the remaining mountain areas, there are generally poor InSAR coherence and residual topographic phase that preclude meaningful interpretation of the InSAR data.