CHAPTER 4 – INSAR MONITORING OF SLOPES

PROSSER

Acquisitions

For the Prosser slide, most acquisitions in the ERS-1/2 archive are along Ascending Track 20, Frame 2673[1]. In this location, there are 13 ERS-1 images from 1992 to 1996, and a further 36 ERS-2 images between 1995 and 2000. Within the scope of this project, four ERS images, as listed in Table 1, having suitable satellite baselines and acquired during favorable weather conditions, were procured in the 1998-2000 timeframe to establish limits on the ability to apply InSAR to long timeframe acquisitions from the archive. The high coherence experienced in this area was speculated to facilitate the longer-term analysis. However, there are sufficient acquisitions in the archive to perform traditional interferometry over much shorter time intervals, or to perform Interferometric Point Target Analysis (IPTA). The IPTA technique, which is sometimes referred to as PS or Point Scatterer InSAR, requires a large stack of images (15 minimum, 25-35 preferred), which was beyond the scope of this project. However, this technique may be considered at some future date, since the technique holds promise for long timescale analysis over this region.

A tandem mode pair was also selected in the 1995 timeframe to facilitate the generation of a DEM for the InSAR analysis. A DEM was generated using this pair; however, a more recent Shuttle Radar Topography Mission (SRTM) DEM from 2000 was used in its place.

Table 1. Prosser ERS images procured for analysis.

Date	Temperature ° Celsius	Meteorological Conditions, Pasco Weather Station
November 10, 1995*	~6°	clear
November 11, 1995*	~5°	clear
July 18, 1998	27°	cloudy
January 9, 1999	4°	clear
September 11, 1999	22°	clear
December 9, 2000	3°	overcast

*Tandem Pair for DEM

In the case of RADARSAT-1, acquisition planning began for this area in September 2003, with an Ascending Fine Mode F3F chosen for acquisition. There were also additional acquisitions captured with this mode prior to September 2003. In total, 35 acquisitions were captured over the site with this beam mode between November 2002 and June 2005.

[1] The Track and Frame of the ERS satellites fix the position of the SAR image on the Earth. Often times, there are multiple choices of track and frame combination for an area, due to multiple overlapping tracks.

Within the scope of this project, scene selection was made on roughly a quarterly basis over the duration of the contract from September 2003 to June 2005. An additional four scenes prior to this period were also procured to maximize the overall timeframe of the RADARSAT data. The rationale for this was to ensure the likelihood that sufficient movement would occur over the site to be measurable by the satellite SAR. The scenes were chosen with particular emphasis on minimizing the baseline (to less than 500 meters (1600 ft)) and choosing scenes acquired on days without precipitation. The list of RADARSAT-1 scenes procured is given in Table 2.

Table 2. Prosser RADARSAT images procured for analysis.

Date	Temperature ° Celsius	Meteorological Conditions, Pasco Weather Station
January 15, 2003	4°	mist
February 8, 2003	2°	mist
June 8, 2003	18°	clear
August 19, 2003	17°	clear
October 6, 2003	10°	clear
October 30, 2003	4°	clear
December 17, 2003	-1°	clear
April 15, 2004	14°	cloudy
June 2, 2004	28°	clear
August 13, 2004	39°	clear
October 24, 2004	14°	clear
February 21, 2005	-6°	clear
May 28, 2005	14°	clear
June 21, 2005	19°	clear

Analysis

Differential interferograms were computed for ERS and RADARSAT image pairs with perpendicular baselines around 500 m (1600 ft) or less, and with timeframes no longer than four months for RADARSAT, but up to fifteen months for ERS. Three ERS and eleven RADARSAT interferograms, as listed in Table 3, were generated.

The generation of the SAR interferograms was performed mainly through the use of the Gamma and Atlantis SAR 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, and/or by using ground control points with accurate horizontal and vertical information. The differential interferogram is generally spatially filtered to reduce phase noise. The phase of the differential interferogram is unwrapped to remove the 2π discontinuities inherent in the measured values. The unwrapped phase is directly proportional to the change in distance along the look vector of the radar and can be converted to ground movement assuming either vertical displacement or a principal direction of motion. The conversion of the measured movements to an absolute scale, that is, removing any offsets or simple trends in the data, relied on identifying known stable areas that could be used to define the zero displacement level.

Table 3. Prosser SAR interferometric image pairs.

Figure	Acquisition Dates	SAR Sensor	Perpen-dicular Baseline (m)	Δ Time (days)	Mean Coherence	Standard Deviation
20	Jul 18, 1998–Jan 09, 1999	ERS-2	-163	175	29%	17%
21	Jan 09, 1999–Sep 11, 1999	ERS-2	228	245	15%	8%
22	Sep 11, 1999–Dec 09, 2000	ERS-2	127	455	22%	13%
23	Jan 15, 2003–Feb 08, 2003	RSAT	235	24	53%	19%
24	Feb 08, 2003–Jun 08, 2003	RSAT	-414	120	27%	22%
25	Jun 08, 2003–Aug 19, 2003	RSAT	173	72	40%	27%
26	Aug 19, 2003–Oct 06, 2003	RSAT	-486	48	47%	31%
27	Oct 06, 2003–Oct 30, 2003	RSAT	258	24	59%	28%
28	Oct 30, 2003–Apr 15, 2004	RSAT	66	168	35%	25%
29	Jun 26, 2004–Aug 13, 2004	RSAT	89	48	28%	23%
30	Aug 13, 2004–Oct 24, 2004	RSAT	-36	72	28%	22%
31	Oct 24, 2004–Feb 21, 2005	RSAT	26	120	54%	21%
32	Feb 21, 2005–May 28, 2005	RSAT	-55	96	36%	26%

Results

The resulting ground movement maps as derived from the ERS and RADARSAT SAR interferograms are shown in Figure 20 to 22 and 23 to 33, respectively (negative values denote subsidence). In these figures, the background is an orthophoto and the landslide area of immediate concern is outlined by the green polygon, with the two larger prehistoric landslide areas given by the red and orange polygons. For individual interferograms, displacements that are less than 10 mm (0.4 inch) are considered to be within uncertainty levels and therefore are transparent in the above figures. Movement greater than 10 mm (0.4 inch) should be interpreted within the constraints associated with the phase variations and systematic uncertainties. Since areas of low temporal coherence stem from changes in the radar-scattering characteristics of the ground, such areas produce noisy interferometric phase. Further, systematic uncertainties may arise due to residual inaccuracies in the orbit modeling, atmospheric variations between the two acquisition times, and inaccuracies in the DEM and / or its co-registration to the SAR images. Except for small-scale atmospheric effects, these systematic variations will generally be aligned with the topography and can therefore be identified.

From Table 3, it is evident that the ERS interferograms have only limited coherence, with mean values ranging from 15% to 29%. It should be noted that these interferograms are over relatively long timeframes, from 6 to 15 months. From Figure 34, it is seen that there are no extended areas of consistently good coherence. Thus, the displacement derived from these interferograms appears to contain many small areas of noise that fluctuates by around 20 mm (0.8 inch). Given the limited coherence and the absence of any consistent displacement signatures in these ERS interferograms, it appears that no movement has been detected along the slopes of interest.

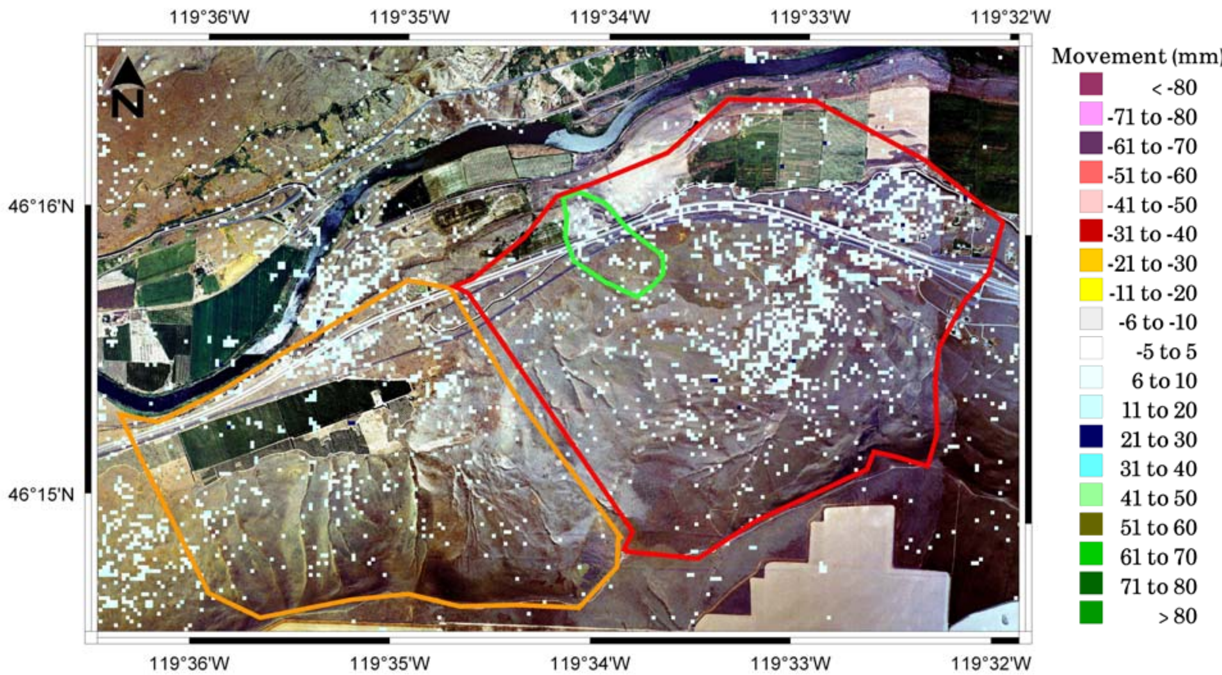

Figure 20. Graph. ERS InSAR derived height change for July 18, 1998 to January 9, 1999.

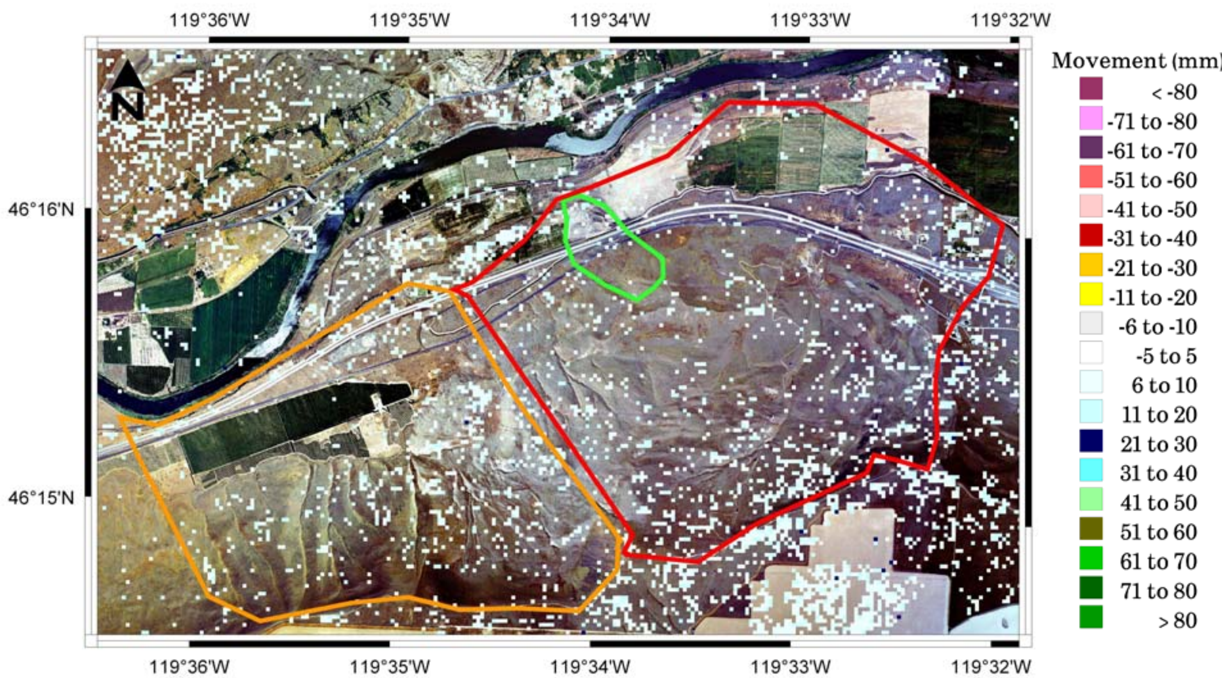

Figure 21. Graph. ERS InSAR derived height change for January 9 to September 11, 1999.

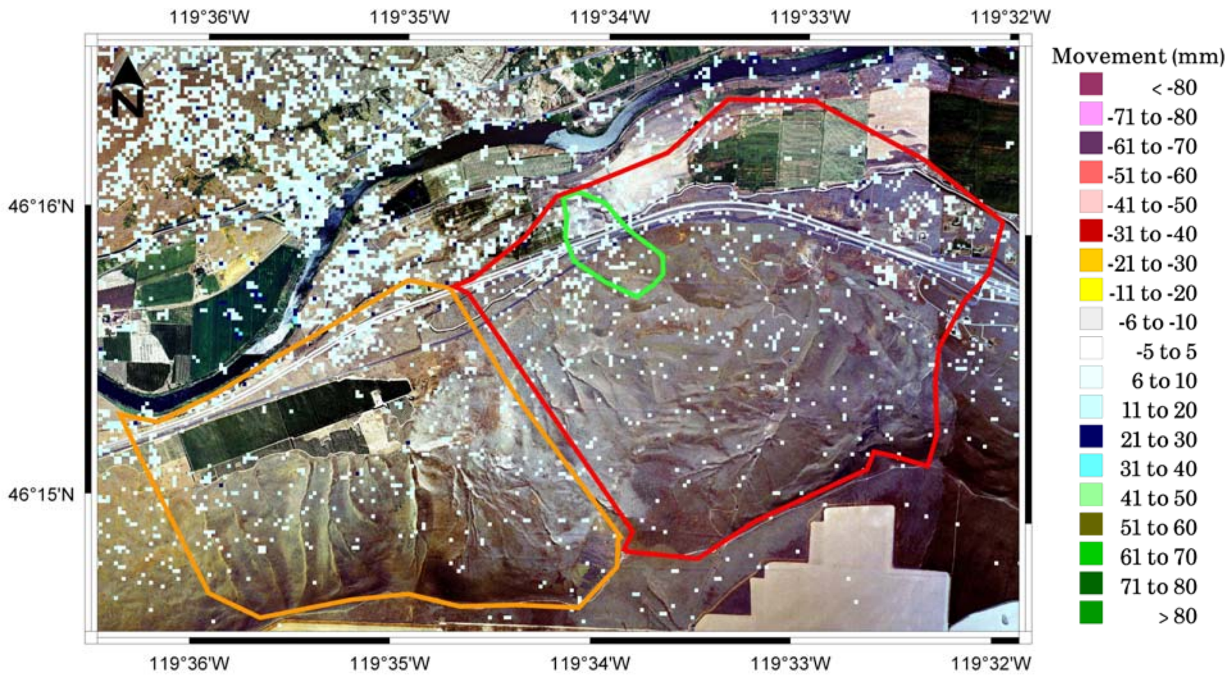

Figure 22. Graph. ERS InSAR derived height change for September 11, 1999 to December 9, 2000.

The RADARSAT image pairs in general have good coherence, with mean values in the range of 30% to 60%. Indeed, the average scene coherence along the slope of interest is consistently higher than elsewhere in the image, as seen in the coherence maps of Figure 35 and 36, where, for example, on the north side of the river the agricultural fields obviously reduce the temporal coherence. The precipitation in this area is relatively low, which contributes to the generally good coherence. From Figure 37 it is seen that the monthly precipitation values generally range between 1 mm (0.05 inch) to 8 mm (0.3 inch) with maximum monthly values less than 20 mm (0.8 inch).

For the ten RADARSAT interferograms shown in Figure 23 to Figure 32, there is no obvious movement detected along the slope of interest — at least to the 10 mm (0.4 inch) level of uncertainty. However, the notable feature within all the displacement maps is the residual values aligned with the ridges that are to both the east and the west of the area of interest. Since this residual interferometric phase is strongly correlated with topography, it may arise from errors in the orbit baseline modeling, from errors in either the magnitude or co-registration of the DEM, or from homogeneous atmospheric effects.

Since any movement along the slope of interest is within the measurement uncertainty of the individual interferograms, all ten displacement maps were combined to attempt to reduce the random errors. The associated level of uncertainty is roughly estimated as the square root of 10 times 10 mm (0.4 inch), or about 30 mm (1.2 inch). The resulting total displacement is shown in Figure 33. There appears to be some displacement on the slope of interest, just above the rock buttress adjacent to the canal and highway, which is consistent with the location and the magnitude of the expected movement. However, the magnitude of the movement is also within the above noted uncertainty level. Any indication of movement from this composite would imply slight heave at the base of the slope above the rock buttress.

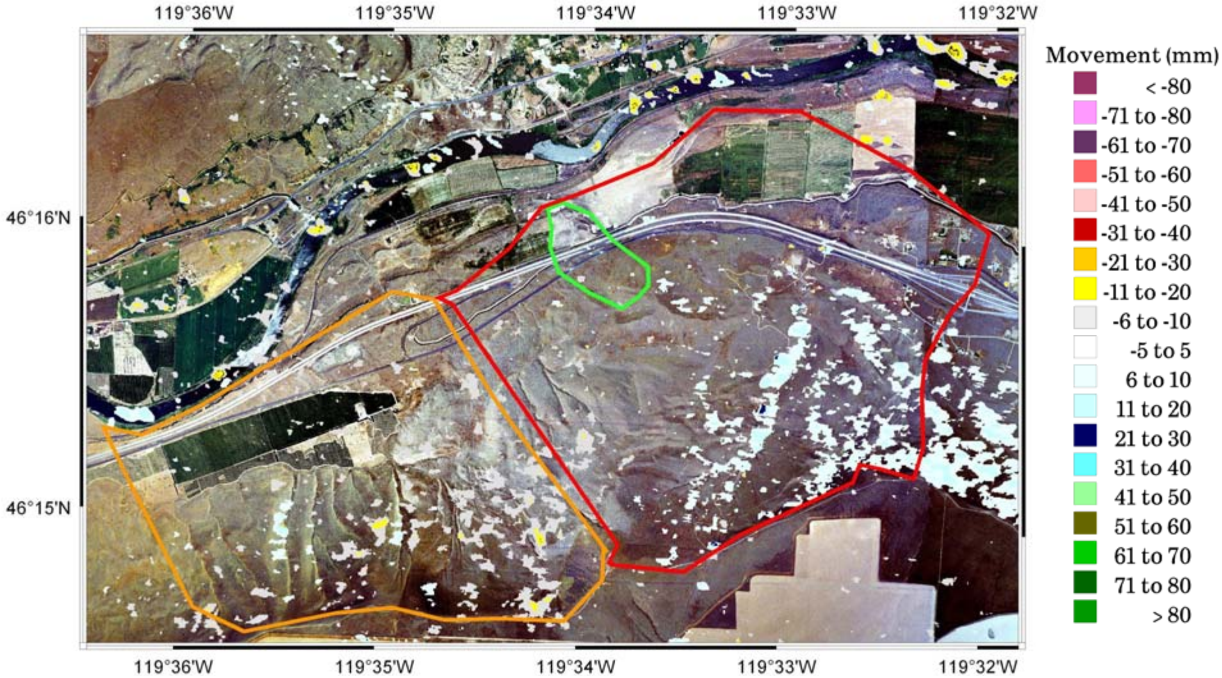

Figure 23. Graph. InSAR derived height change for January 15 to February 8, 2003.

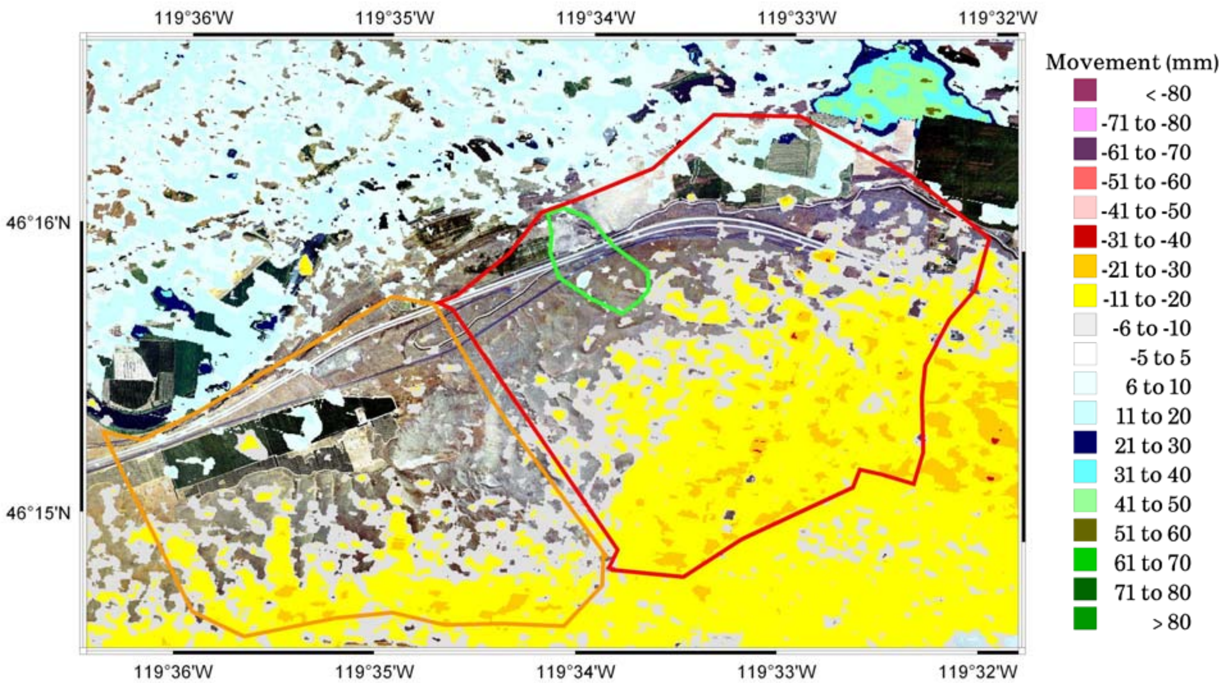

Figure 24. Graph. InSAR derived height change for February 8 to June 8, 2003.

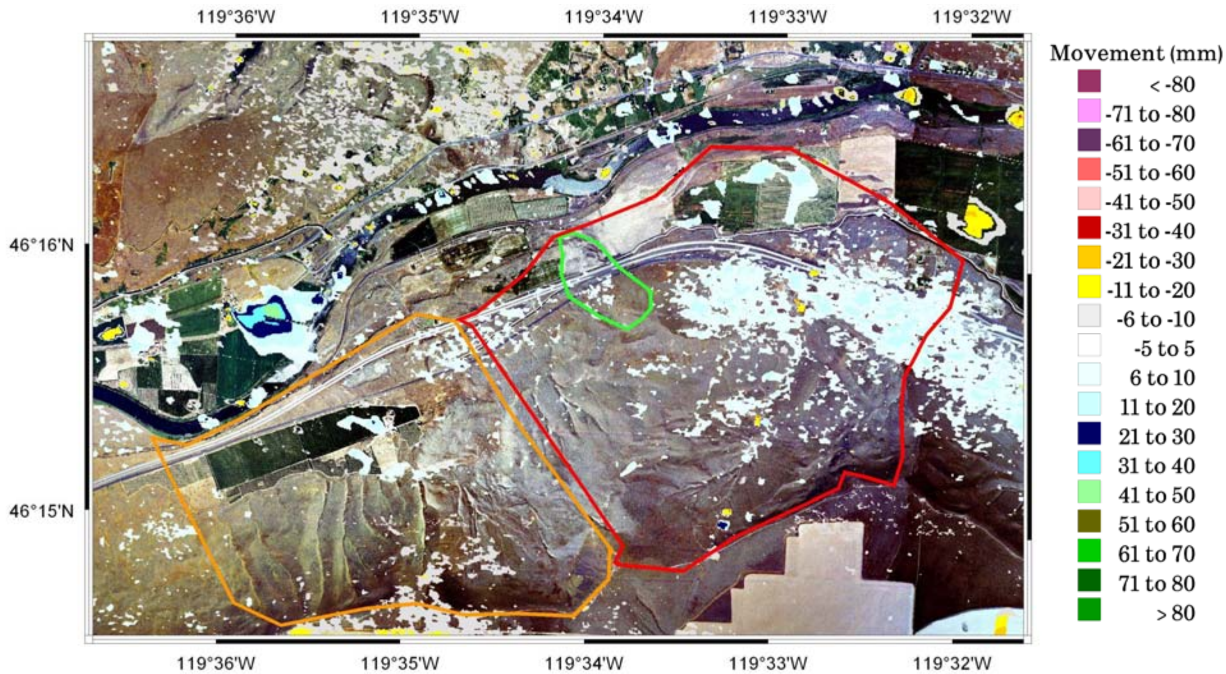

Figure 25. Graph. InSAR derived height change for June 8 to August 19, 2003.

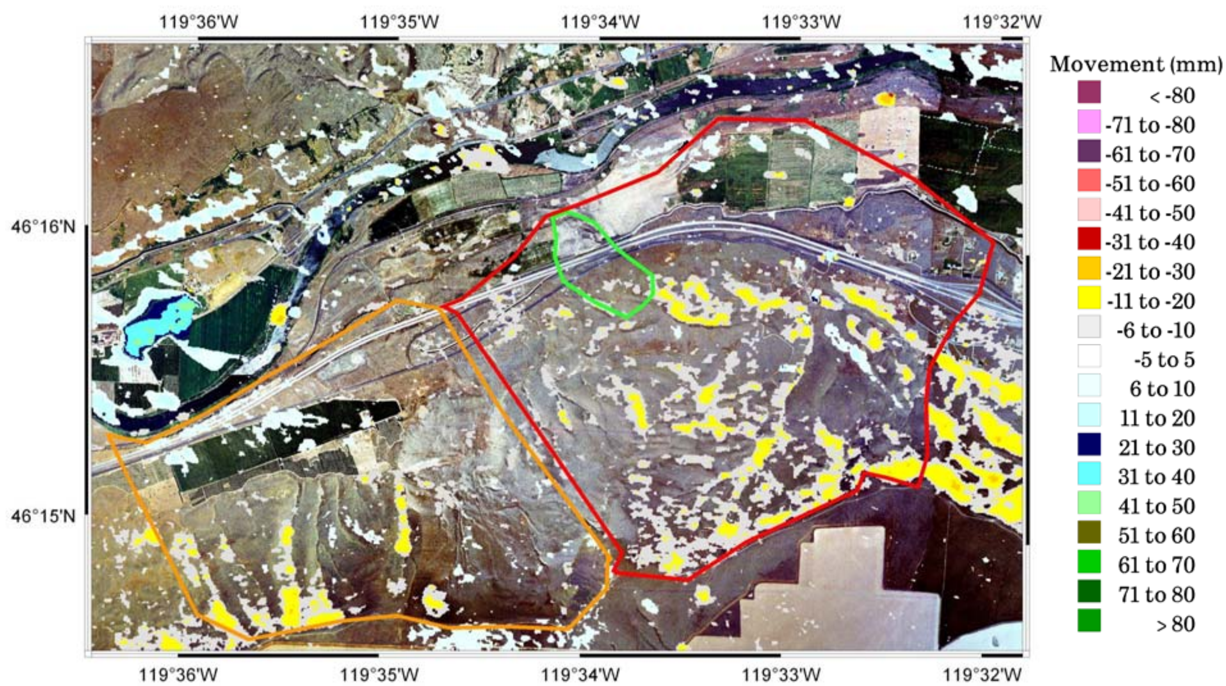

Figure 26. Graph. InSAR derived height change for August 19 to October 6, 2003.