Mapping Landslide Surfaces using Fully Polarimetric SAR: AIRSAR Coverage of the 1999 Taiwan Landslides

Jeffrey Weissel[*] and Kristina Rodriguez[*†]
[*] Lamont-Doherty Earth Observatory of Columbia University,
Palisades, NY, 10964, USA
[†] Department of Earth and Environmental Sciences, Columbia University,
Palisades, NY, 10964, USA

Each year, down-slope mass-movements (landslides, in the broad sense) exact a continuing toll on society in terms of loss of life and damage to the built environment (Spiker and Gori, 2000). In 1999, for example, heavy rains on the Caribbean coast of Venezuela caused disastrous landslides and floods that killed an estimated 30,000 people and destroyed many coastal towns (Larsen et al., 2001). That same year a magnitude 7.6 earthquake in central Taiwan generated around 10,000 landslides, killing hundreds, damming major rivers, and severely damaging towns and villages in valleys (Sitar, Bardet et al., 2001). Our research is motivated by the clear need for a better understanding of landslide processes and triggering mechanisms, and the hazard landslides pose to society.

We are evaluating airborne Synthetic Aperture Radar (SAR) polarimetry (AIRSAR and TOPSAR) for the rapid assessment of landslide disasters. Our work with TOPSAR data over the landslides generated by the 1999 Mw7.6 Chi Chi earthquake in central Taiwan indicates that polarimetric SAR might provide the means for rapid landslide disaster assessment in humid, seismically active mountain belts. The fully polarimetric L- and P-band SAR data were acquired about a year after the landslide event, capturing the two major slides, Tsaoling and Mt. Juo-feng-err, and numerous smaller slides. The initial focus of research is the L-band data for the Tsaoling area, a slide area of several km^2 about 40 km south of the epicenter. Landslides typically denude forested hillsides of vegetation, changing dominant scattering from multiple bounce to single bounce. SAR polarimetry can be used to determine dominant scattering mechanism of the terrain on a per pixel basis. Thus, hillslopes affected by landslides may be distinguished easily from adjacent, unaffected hillslopes. From the covariance matrix, $[T] = cc^*$, where $c = [S_{hh}\ \sqrt{2}\ S_{hv}\ S_{vv}]^T$ and * indicates complex conjugate, the relevant terms $\langle|S_{hh}|^2\rangle$, $\langle|S_{vv}|^2\rangle$, $\langle S_{hh}S_{vv}^*\rangle$ and $\langle|S_{hv}|^2\rangle$ can be extracted. Based on the polarimetric eigenvalue decomposition and the relative amplitudes of these terms, dominant scattering mechanisms can be determined (van Zyl, 1989, Freeman and Durden, 1992). These mechanisms, odd or single bounce (surface), double bounce, and volume scattering describe the total radar returns for each pixel. Kim and van Zyl (2001) modify this approach to include the Radar Vegetation Index, pedestal height and entropy, all representative of forest. Scattering mechanism signatures have been used extensively in forest cover change detection, but this is the first time scattering mechanisms have been combined with other radar parameters to identify and characterize landslides.

Our analysis (Fig. 1) reveals that the landslide scar area is dominated by single bounce, surface scattering and the surrounding vegetated regions are dominated by volume scattering. There is some volume scattering near the toe of the scar, suggesting a repository for vegetation debris and perhaps re-growth.

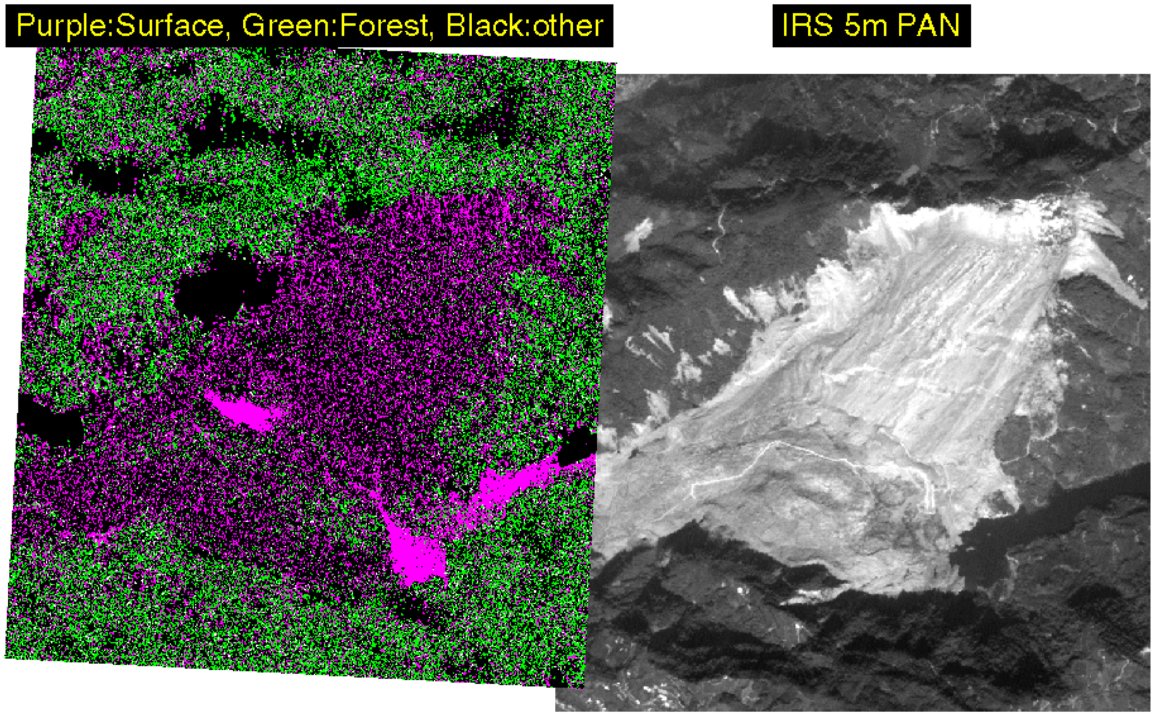

Figure 1. Comparison of radar scattering mechanisms determined from L-band AIRSAR polarimetry (Left), and IRS panchromatic data (Right) over the Tsaoling mega-slide south of the 09/1999 Chi Chi main shock epicenter. In the scattering mechanism map the pixels colored purple are dominantly surface scattering, green pixels are dominated by "diffuse" scattering from forest, and black pixels have no data or other dominant mechanism. As expected the single-bounce surface scattering areas correlate with the landslide scars and debris fields depicted in the IRS data, and with water bodies trapped behind the landslide runout debris in the river valley. The images measure ~4 x 4 km.

We found that SAR polarimetry provides direct measurements of the hillslope areas disturbed by landsliding. Inversion of SAR polarimetry for terrain scattering mechanisms offers a new approach for landslide mapping that has significant operational advantages over traditional methods that rely on optical sensors for rapid response to, and management of landslide (and perhaps flood) disasters.

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References:

Freeman, A., and Durden, S., 1992, A three-component scattering model to describe polarimetric SAR data, SPIE, 1748, 213-224.

Kim, Y., and van Zyl, J., 2001, Comparison of forest estimation techniques using SAR data, Proc.IGARSS2001 Conf., IEEE (CDROM).

Larsen, M.C., Wieczorek, G. F., Eaton, L.S., and Torres-Sierra, H., 2001, The rainfall-triggered landslide and flash-flood disaster in northern Venezuela, December 1999: 7th Federal Interagency Sedimentation Conference, March, 2001, Reno, Nevada.

Sitar N., Bardet, J.P. et al., 2001, Landslides, Ch. 5 in: 1999 Chi-Chi, Taiwan, earthquake reconnaissance report, Earthquake Spectra, 17 (Suppl. A), 61-76.

van Zyl, J., 1989, Unsupervised Classification of Scattering Behavior Using Radar Polarimetry Data, IEEE Trans. Geosci. Rem. Sens., 27, 36-45.