Advances in the detection and monitoring of mass-movement processes through high-resolution remote sensing data

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With advances in satellite technology, spaceborne data are becoming available to the public and scientific community at increasing temporal and spatial resolutions. These data open new opportunities to study Earth-surface processes in unprecedented detail. This thesis investigates the potential and challenges of high-resolution optical data for monitoring slow-moving landslides and the generation of digital elevation models (DEMs) to improve subsequent topographic analyses. The study area is set in the northwest Argentinean Andes – a region particularly susceptible to mass movement processes due to steep topography, heavy rainfall during the summer monsoon, and geologic pre-conditioning.

To obtain a more detailed reconstruction of local topography, tri-stereo SPOT-7 data were used to infer a 3-m DEM of the intermontane Quebrada del Toro basin through stereophotogrammetry. GNNS field measurements were employed to validate the derived elevations and identify optimal processing parameters. In steep mountain terrain, where global radar-derived DEMs frequently suffer from layover and shadowing effects, high-resolution stereo data can help to reduce artifacts and better resolve the traces of channelized processes. The longitudinal channel profiles extracted from the 3-m DEM contain topographic signatures of both fluvial erosion and debris flows, which are based on the relationship between slope and drainage area. Debris-flow activity is presumed to dominate in channels that exhibit minimal curvature despite an increase in drainage areas. The topographic signature of debris-flow activity is found throughout the Toro basin, fueled by pervasively fractured bedrock along the major bounding fault systems.

Mass-movement processes are also common in the neighboring Quebrada de Humahuaca basin. Here, correlation of multi-temporal imagery from medium to high-resolution optical satellites revealed reactivation of a slow-moving landslide on a slope that collapsed catastrophically in 2009. Between 2014 and 2024, the landslide acquired more than 35 m of displacement with three distinct acceleration phases that all coincide with the summer monsoon season and are likely driven by extreme rainfall events. For monitoring surface displacements, higher-resolution data can lower the detection threshold and allow a more detailed characterization of spatial variations in landslide motion, but may come with additional challenges inherent to the acquiring satellite constellation. This thesis focuses on the use of PlanetScope data, which offer near daily acquisitions at 3-m spatial resolution. PlanetScope imagery is acquired by different satellites from variable viewing angles, which introduces orthorectification errors

over dynamic terrain that may exceed the signal from surface displacement in magnitude. These errors can be mitigated through constraining correlation to image pairs acquired from a similar perspective, or by exploiting the variable acquisition geometries of the PlanetScope constellation to generate DEMs that more closely reflect the actual topography.

Another challenge that arises during correlation of multi-temporal optical data is the impact of shadows and seasonal illumination changes on measurement accuracy. Different illumination conditions in cross-seasonal image pairs can introduce systematic biases. In continuous displacement time series derived through inversion of a network of image pairs, these effects manifest as regular oscillations that overprint true seasonal signals in landslide motion. As correlation noise decreases linearly with increasing resolution, the magnitude of measurement errors appeared reduced in higher-resolution imagery, but additional mitigation strategies were needed to fully compensate for seasonal biases.

Through a detailed assessment of the error sources that obscure the signals extracted from satellite data, this thesis provides a framework for leveraging the full potential of high-resolution imagery for the analysis of Earth-surface processes from space. The associated open-source code repositories facilitate the transfer of the presented analyses to other targets and extend investigations to larger study areas. This paves the way for future research into mass-movement processes which are widespread, not only in the Argentinean Andes but throughout mountainous regions worldwide.