# Geomatic Methods for Landslide Monitoring

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## Abstract

Within the wide range of methods commonly employed for landslide monitoring, researchers and practitioners often choose to rely on GPS-based techniques, the application of which has become a benchmark in such field. In this regard, the analysis of ground displacements related to the Corvara landslide, which is the main subject of this study, was carried out through the post-processing of a two years' collection of nearly-continuous GPS data (from February 2014 to January 2016) in cooperation with EURAC Research and the Province of Bolzano, which have been monitoring the landslide for years. The data were recorded by means of three GPS permanent stations (henceforth referred to as CR08, CR54, CR58) installed in the landslide area. In order to estimate the coordinates of each station for every epoch within the whole reference period, and therefore their variation over time, two distinct processing campaigns were conducted with a scientific-type software (Bernese GNSS Software) and an open source (RTKLIB) software, respectively. The decision to process all the available data twice, with both a scientific and an open source software, and to cross-check the results using the first series as a reference, had a two-fold aim. In fact, not only would it allow outcomes of proved reliability to be obtained using the former, but it would also provide a means whereby a quantitative evaluation of the actual level of accuracy guaranteed by the latter could be carried out. The underlying purpose of such assessment is to determine whether the open source software can prove to be a valid alternative to scientific-type ones in terms of accuracy, so as to gain in processing speed and user-friendliness, not to mention costs, given its free-of-charge availability.

Before making any comparison and in compliance with the main objective of this study, namely appraising the ground displacements related to the landslide, the data referring to the three permanent stations were processed in PPP-static mode (Precise Point Positioning) in order to provide absolute positioning at centimetre level. The output data consisted of a set of coordinate triads (X / Y / Z components of Earth-centered, Earth-fixed Cartesian coordinate system) containing daily solutions (i.e. one for each day/observation file). The results showed that the landslide is not characterized by a uniform motion, neither as to the extent of movement, nor as to its direction. In fact, the overall motion resulted in shifts of

different length for each station with values ranging from 20 cm/year to 2 m/year, and as for their direction CR08 moved north-westwards, CR54 south-westwards, and CR58 south-eastwards.

In order to fulfil the task concerning the evaluation of the level of accuracy provided by the open source software, the results deriving from both the processing campaigns were then compared by observing the statistical indexes related to the differences obtained through subtractions between values corresponding to the same epoch. The RMS values obtained, which ranged from 0.7 cm to 2 cm, proved that RTKLIB is perfectly up to scratch, at least with regard to this kind of applications. In this respect, a further validation was provided through the study of the Tropospheric delay associated with GPS measurements as the results obtained with the open source software were absolutely in line, at least at few millimetres level, with the reference estimates obtained with the scientific software. Again, the comparison of the data was made by considering the differences between those values belonging to the two different series of results which would correspond to the same epoch. Unlike the former comparison, a complication (due to the settings of each software) arose from the difference in the amount of estimates in each set of solutions which had therefore to be aligned along the same time scale first. The statistical indexes related to the differential vectors provided, once again, a numerical evaluation of the level of accuracy guaranteed by the open source software. The RMS values obtained, which were equal to 6-7 mm, provided a further demonstration of the fact that the accurate, quick, and lightweight performances offered by RTKLIB may turn out to be very useful. For instance, SAR range measurement techniques, the use of which has recently become frequent for the study of the Corvara landslide, require corrections for the Tropospheric delay since it is the factor that mostly affects their accuracy. RTKLIB may therefore be used to provide such corrections with sufficient accuracy.