TOWARDS A MODERNIZED GEODETIC DATUM FOR NEPAL: OPTIONS FOR DEVELOPING AN ACCURATE TERRESTRIAL REFERENCE FRAME FOLLOWING THE APRIL 25, 2015 MW7.8 GORKHA EARTHQUAKE

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ABSTRACT

Along with the damage to buildings and infrastructure, the April 25, 2015 Mw7.8 Gorkha earthquake caused quite significant deformation over a large area in central Nepal with displacements of over 2 m recorded in the vicinity of Kathmandu. Correcting for this will require a national deformation mode (NDM) that will have the capacity to correct for the earthquake displacements and ongoing tectonic deformation associated with Nepal's location on the India/Eurasian plate boundary. The NDM discussed here contains models of the velocity field and co-seismic deformation. The velocity model for Nepal is based on a compilation of published velocity measurements used to study the boundary between the Indian plate to the south and the overriding Eurasian plate to the north. The co-seismic deformation associated with the Gorkha earthquake and its 12th May Mw7.3 aftershock was modeled using published dislocation models. By combing the velocity and co-seismic models we have developed an NDM that can correct coordinate for both the effect of the earthquakes and continuous deformation associated with Indian / Eurasian plate boundary. Preliminary tests of the model demonstrate that applying the NDM makes a significant improvement when adjusting survey data sets that were acquired both before and after the earthquakes.

I. INTRODUCTION

The current Nepal-Everest datum is a classical datum developed in 1984 by the Military Survey branch of the Royal (UK) Engineers in collaboration with the Nepal Survey Department. However, Nepal is located at the conjoint of two converging plates: the Indian plate to the south and the overriding Eurasian plate to the north. Due to the regular convergence of these plates the existing passive geodetic control network has become distorted with time. This combined with the effect of the April 25, 2015 Mw7.8 Gorkha earthquake, which caused significant deformation over a large area centered at Kathmandu means that the integrity of the current Nepal-Everest datum cannot be assured. In this paper we consider options for a modernized geodetic datum for Nepal that will have the capacity to correct for the earthquake displacements and ongoing tectonic deformation associated with Nepal's location on the India/Asia plate boundary.

Semi-dynamic vs conventional datums

Because of the effect of plate tectonic motions, the actual position of points on the earth change continuously. However nearly all users find it difficult to deal with continuous coordinate change. There are two quite different ways in which geodetic datums can deal with tectonic motion. Modern semi-dynamic datums are based on a version of the International Terrestrial Reference Frame. Stable coordinates are produced by projecting each coordinate to its position at a common date called the reference epoch. In order to make this technique work we need a model of how the earth is moving due to plate tectonics. In stable areas, the effect of earthquakes will be small and the motion of the points will follow the motion of the tectonic plates. In areas that are located on the boundaries of tectonic plates, the motion is more complicated because the points are deforming or moving relative to each other in complex ways.

In this case a mathematical model, usually called a National Deformation Model, is used to calculate the trajectory of points. This usually includes a way of estimating the constant or secular velocity of each point and a way of calculating the effect of any earthquakes that may have occurred between the time that the coordinates were measured (epoch of observation) and the reference epoch. The effect of earthquakes is an instantaneous offset while the effect of the velocity increases linearly with time. The total motion is just the sum of the earthquake and constant velocity terms. In practice both the velocity and earthquake shifts are stored as a series of grid files which are used to estimate the appropriate values for an arbitrary point by linear interpolation. The basic idea of a National Deformation Model is illustrated in Figure 1, which shows the trajectory of a point affected by a constant velocity and two earthquake shifts.

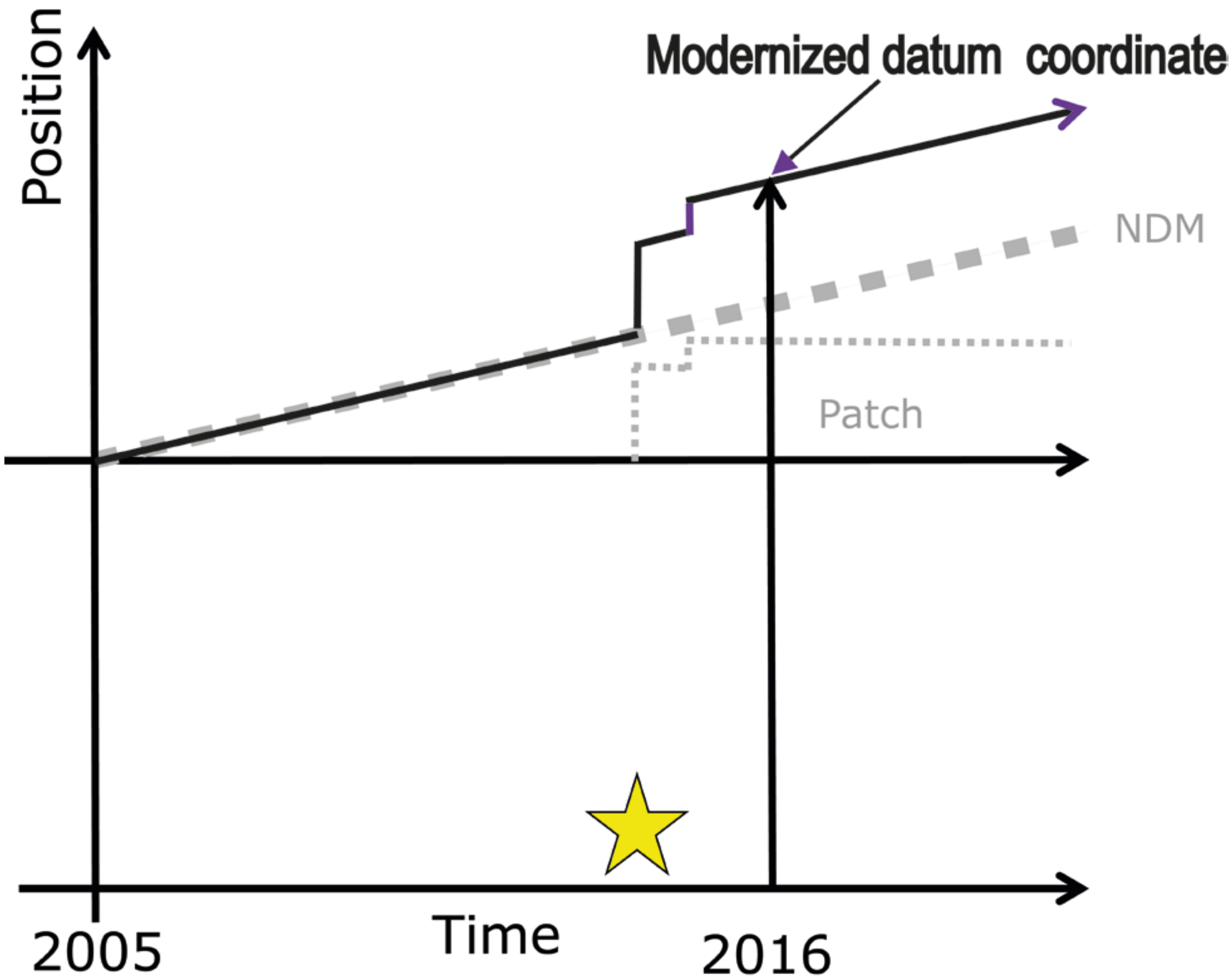

Figure 1 Schematic diagram of a dynamic datum. Heavy dashed gray line shows the secular velocity and thin gray dotted line co-seismic contribution to the deformation model. The solid black line shows the deformation model with both contributions combined.

In contrast, older classical datums, which were usually established before the reality of plate tectonics was widely accepted, establish fixed coordinates for a network of control points with no mechanism to correct for the tectonic motion. As a result the marks will drift off their true positions. However, the relative position of points will not change significantly with time in stable areas such as the interiors of plates since the entire region is moving rigidly. For regions on plate boundaries such as Nepal, ongoing deformation means that the relative position of points will change with time due to an non-homogeneous velocity field and earthquakes. Thus the datum will become distorted as the bearings and distances between marks calculated from their coordinates become increasingly different from what we would measure on the ground.

II. SEMI-DYNAMIC DATUM FOR NEPAL

Nepal is located at the conjoint of two converging plates: the Indian plate to the south and the overriding Eurasian plate to the north. A significant amount of the convergent component of plate motion is accommodated within Nepal resulting in the crustal velocities changing from a northeast trend in Northern India to an east-northeast trend in southern Tibet. Due to the regular convergence of these plates Nepal has been subjected to a series of great earthquakes including the 25th April 2015 Mw7.8 Gorkha earthquake.

The Deformation model is the tool that allows coordinates to be projected either backward or forward in time to the reference epoch. Typically, a deformation model contains two distinctly different elements. The first is a model of the variation of the long term (or secular) crustal velocity across the country and the second is a model or models of the co-seismic deformation associated with any large earthquakes that have occurred since the datum was introduced. Both the velocity model and the co-seismic deformation models are grid files so that the estimates of the velocity or co-seismic shifts can be determined by linear interpolation (Stanaway et al. 2012).

Our model of the velocity field for Nepal was developed by combining published velocities for Nepal and adjacent parts of China and India from four geodetic studies in the Nepal region (see Pearson et al 2016 for a detailed discussion). The velocities are shown in Figure 2.

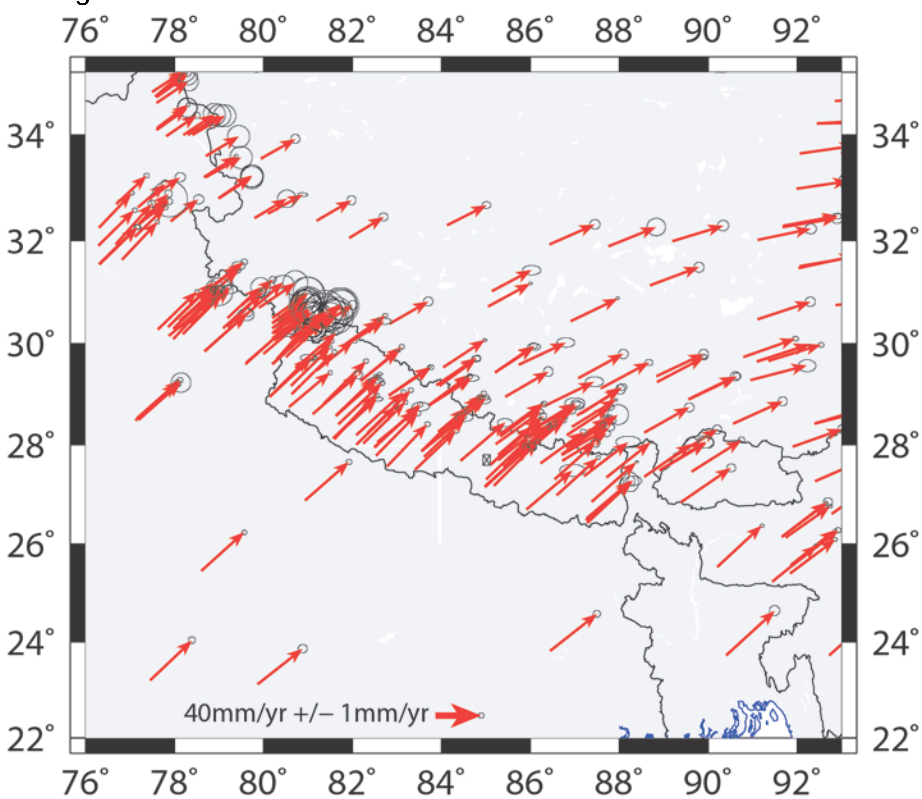

Figure 2 Compilation of velocity measurements for Nepal and surrounding parts of India and China. (Pearson et al 2016).

Using these velocities we developed a grid file that covers the region from 80°E to 89°E and 26°N to 31°N (Figure 3). While Figure 3 shows velocity vectors on a half degree spacing the actual gridded velocities have a spacing of 20 points/degree (0.05°).

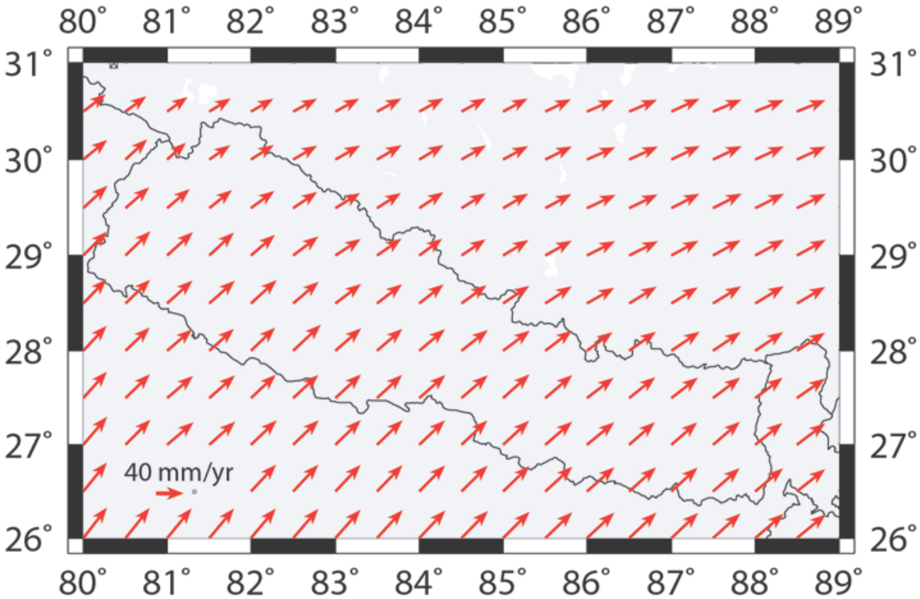

Figure 3 Velocity grid for Nepal. (Pearson et al 2016).

The NDM must also include patches or gird files that can be used to predict the earthquake deformation at any point. Our model of the velocity field for Nepal was developed by combining published velocities for Nepal and adjacent parts of China and India from four geodetic studies in the Nepal region (see Pearson et al 2016 for a detailed discussion). An NDM also must include patches or gird files that can be used to predict the earthquake deformation at any point. In order to reduce latency we adopted an initial model developed by inversion of seismic data combined with limited geodetic and INSAR information (Melgar et al. 2015). This is the first time a model of this type has been incorporated into a deformation model. While this model did a good initial job of correcting coordinates for the earthquake, it still has residuals of up to 0.5 m for some test points so we replaced it with more conventional model using much more geodetic data which reduced the maximum uncertainties to 0.15m. Figure 4 shows the co-seismic slip from the 25th April 2015 Gorkha Earthquake. Note that the Kathmandu Valley has moved by up to 2.5 m.

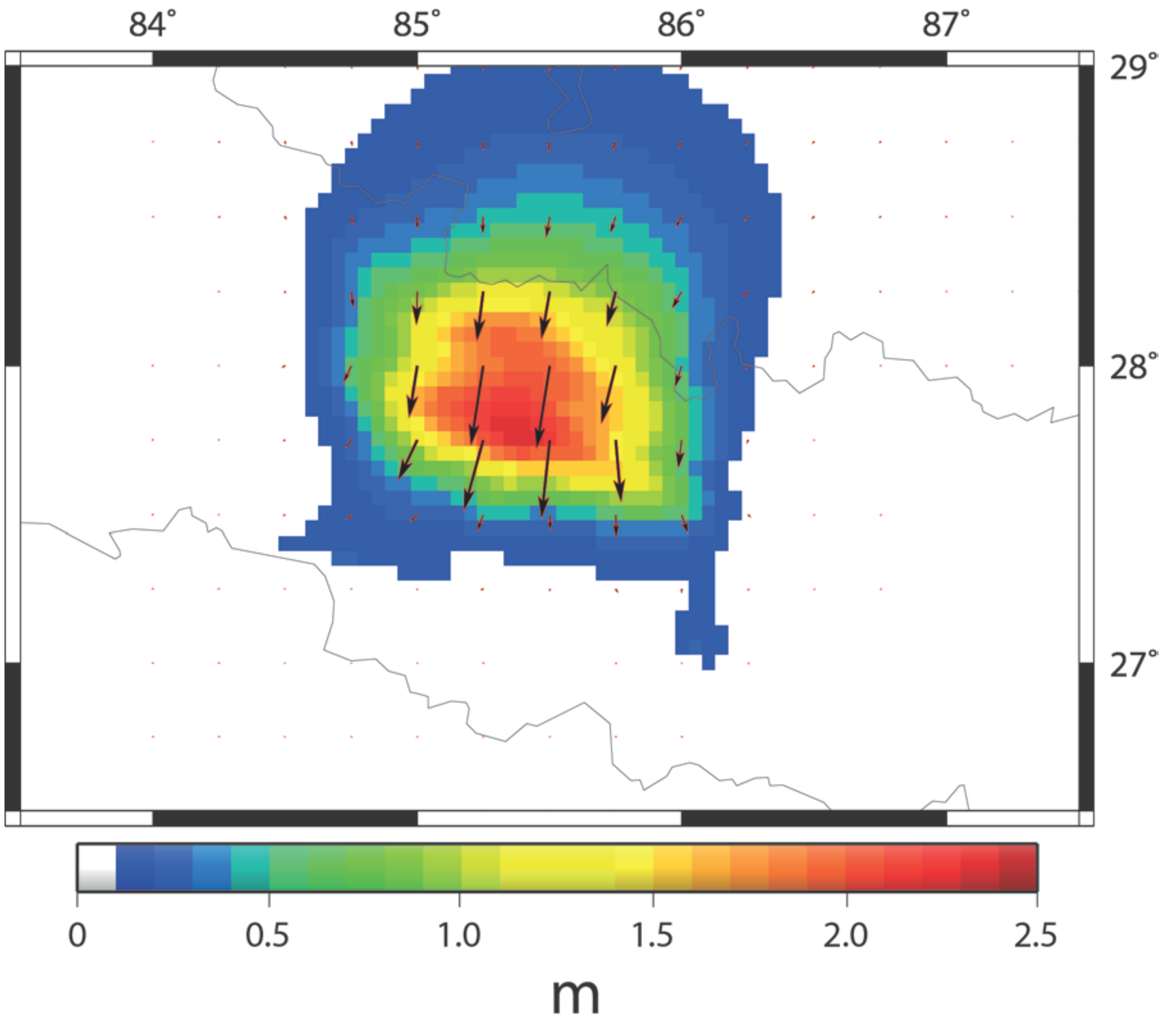

Figure 4 Predicted displacement associated with the 25th April 2015 Mw7.8 Gorkha Earthquake

The deformation model would form a key part of a semi dynamic datum for Nepal which could be based on ITRF2014 with a reference epoch set some time after the end of the current sequence of earthquakes (Pearson et al 2016).

In order to test the effectiveness of a semi-dynamic datum to correct for the deformation from the April 25, 2015 Mw7.8 Gorkha earthquake, we adjusted the GPS data that contained both pre and post-earthquake measurements. These test points define a polygon extending about 40 km in the NW SE direction centered at Kathmandu. Between these points there are nine GPS baselines, three of which were recorded in April 2013, before the earthquake and six of which were observed on 08 May 2015, in the period between the 25th April 2015 Gorkha Earthquake and the 12th May Mw7.3 aftershock. The first adjustment was conducted without using a deformation model while, in the second adjustment, the deformation model was used to correct all the measurements to pre-earthquake values. The Standard error of unit weight for the adjustment which does not apply the NDM is more than 3 times greater than the SEUW for the model which does apply the NDM. This difference demonstrates that the deformation model is effective in correcting for crustal deformation between the two surveys. The improvement in the SEUW due to applying the NDM is significant at the 99.99% level of confidence.

For the people of Nepal to benefit from the new datum, it must be possible to calculate coordinates in the new datum. This requires that we have In the case of Nepal we started with the Nepal GNSS array, a network of continuous GNSS stations similar to the National Geodetic Surveys CORS network. These stations will be the top level control for Nepal. The next step is to determine coordinates for existing control marks by adjusting them relative to these continuous cGNSS stations. We have started this process by adjusting the old Nepal first order control network using measurements made entirely before the earthquake. By comparing the Nepal Everest coordinates with the coordinates in the new datum, we are in the process of developing an accurate datum transformation grid to allow GIS users to transition to the new system.

III. CONCLUSIONS

Because of the effect of the 25th April, 2015 Gorkha earthquake, significant earth deformation has occurred in a large area of Nepal centered on Kathmandu Valley. As a result, the geodetic control in this region is significantly distorted with published geodetic control coordinates being displaced from their true position on the ground by up to 2m. Correcting these distortions will require a new geodetic datum. In this paper we consider the possibility of Nepal adopting a semi-dynamic datum, which would be based on ITRF2014 and include a national deformation model capable of correcting for the recent earthquakes and normal tectonic motion. We demonstrate that it is possible to develop a deformation model for Nepal incorporating the Gorkha earthquake and the variation of the long term (or secular) crustal velocity across the country using published information. While this model is preliminary our test shows that its use does a good job of correcting survey measurements for the effect of the earthquake.

References: and Further Readings

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