Geodetic Monitoring in Nepal: Preliminary Results from Gorkha Earthquake (25 April 2015)

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INTRODUCTION AND GOALS

In this contribution we present the preliminary data and analysis from two GNSS stations located in Nepal, one near to the Everest Pyramid (PYRA - EvK2CNR), the other one near Nagarkot (NAGA). Both the antennas seem to have sensed and measured the deformation due to the last catastrophic quake occurred on 25 April 2015 on a segment of the Main Himalayan Thrust (Rajendran and Rajendran, 2011; Figure 1).

In particular, we aim to:

- compare our measured coseismic displacements with those from the other geodetic stations (Galetzka et al., 2015)
- test the compatibility of the observed surface displacements with those calculated from fault slip models, one from seismological solutions, the other from geodetic inversion
- assess the noise level in GNSS data in our Area. For geodetic monitoring of the interseismic deformation, it is important to estimate deformation components associated to other environmental factors (thermo-elastic, hydrologically induced…)
- estimate interseismic strain rate accumulation and compare it with the released coseismic strain.

GNSS PROCESSING

Our stations PYRA and NAGA were processed through the GNSS software Bernese 5.2, with RINEX data sampled at 30 seconds, CODE products for raw corrections, VMF1 for tropospheric model and atmospheric corrections.
Double Difference elaboration (DD) was used in order to resolve the position with millimetric accuracy. As to constrain the solutions, Lhasa (LHAZ) and Kitab (KIT3) stations belonging to the IGS Network were included in our processing.
The time series of displacements of our stations were estimated from Double Difference solutions using a Kinematic approach. Only for NAGA station processing on 25th of April, a Precise Point Positioning (PPP) elaboration with a Kinematic approach was used. In Figure 2 we present the three components (N,E,U) in UTM 45 R from original Bernese ECEF coordinates. We analyzed three days from 24th to 26th of April 2015.

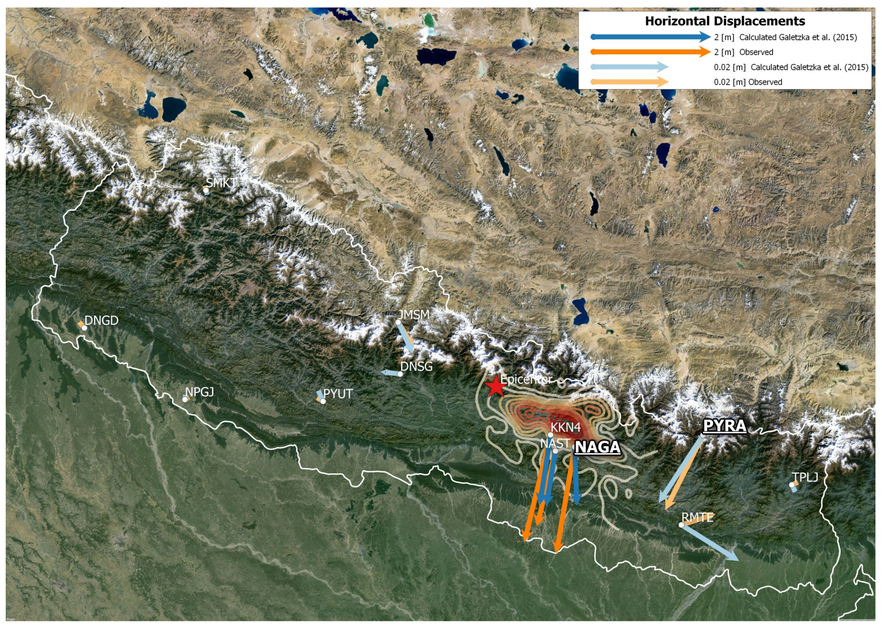

Figure 1: Observed and calculated horizontal displacements. Our stations (PYRA and NAGA) are underlined, others are taken from Galetzka et al., 2015. Red star locates the epicenter. The contour lines report the slip occured on fault, according to Galetzka et al. (2015).

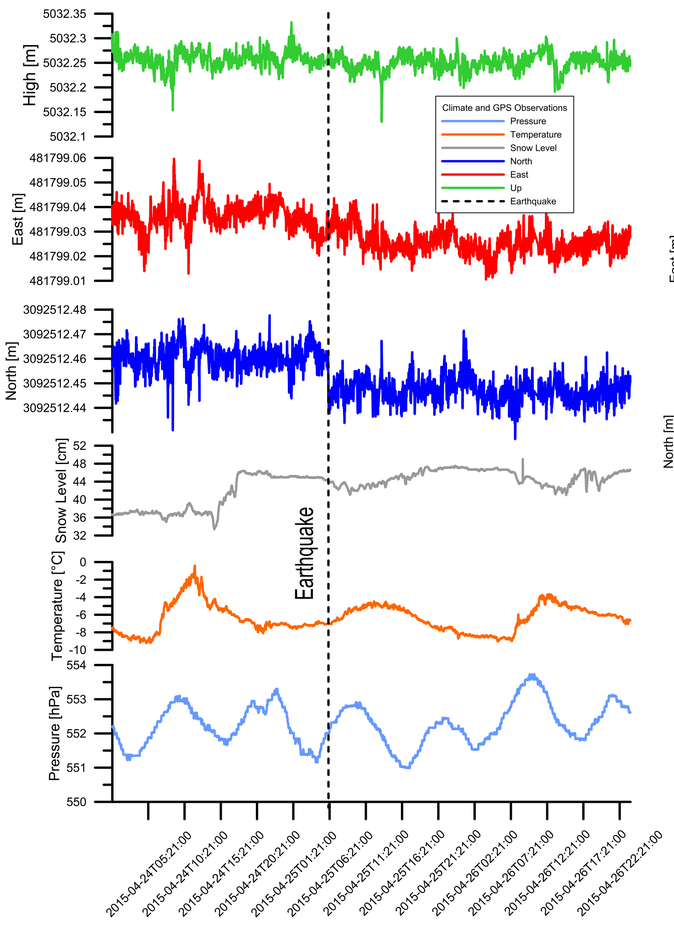

Figure 2: Observed displacement at PYRA station.Temperature, pressure and snow level time series are reported, showing the absence of relation with the observed displacement.

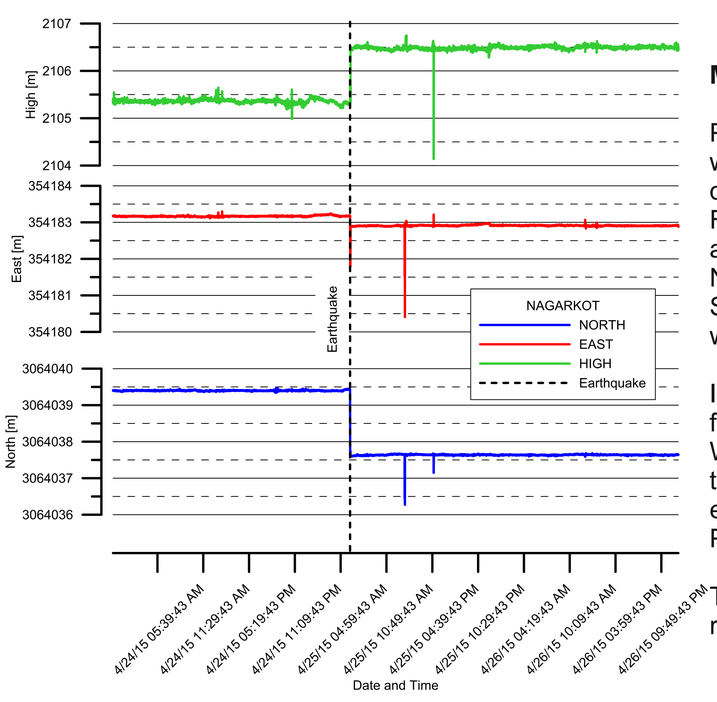

Figure 3: Observed displacement at NAGA station.

PYRA	North [m]	RMS [m]	East [m]	RMS [m]	High [m]	RMS [m]
24/04/2015	3092512.46151	0.00049	481799.03685	0.00056	5032.25657	0.00220
26/04/2015	3092512.44653	0.00044	481799.02426	0.00051	5032.25448	0.00198
Delta	-0.01498		-0.01259		-0.00209	

NAGA	North [m]	RMS [m]	East [m]	RMS [m]	High [m]	RMS [m]
24/04/2015	3064039.39881	0.00052	354183.16418	0.00063	2105.35817	0.00236
26/04/2015	3064037.63777	0.00047	354182.91115	0.00054	2106.49761	0.00204
Delta	-1.76104		-0.25303		1.13944	

Table 1: Differences in North, East and Up daily coordinates between 24th and 26th of April (with RMS).

MODELING THE CO-SEISMIC FIELD

PYRA station (Figure 2) sensed a small displacement: 1.5cm in the south direction and 1.2cm in the west direction. However the east-west coseismic component is hard to estimate, as a clear discontinuity is not evident and noise/signal ratio seems lower with respect to the north component. In Figure 2 climatological observations are reported together with the displacements, demonstrating the absence of correlation.
NAGA station (Figure 3) instead detected an impressive coseismic displacement of almost 1.8m in the Southern direction and a 1.15 m uplift; direction and magnitude of the displacement are in accordance with KKN4 and NAST stations considered in Galetzka et al. (2015).

In order to verify the compatibility of the observed displacement field with respect to the earthquake fault mechanism, particularly important for station PYRA, we implement the Okada model (1985).
We tested two rupture models for the Gorkha earthquake: one derived from inversion of waveform teleseismic (USGS) data and the other from inversion of GNSS and satellite interferometry (Galetzka et al., 2015). Our surface data are more in accordance with the last one: the coseismic observation of PYRA station appears compatible with that source, in terms both of magnitude and direction (Figure 1).

The superficial static displacement predicted by the USGS solution appears to be understimated with respect to observed data.

INTERSEISMIC DEFORMATION

Monitoring the interseismic deformation is an essential task to get insights into the earthquake mechanism and to assess and mitigate the risk associated to earthquakes like the 7.8Mw Gorkha. The strain rate field recorded by a GNSS network is however complicated by the superposition of hydrologic and environmental effects to the tectonic signal, target of interest. Here we discuss the long period GNSS time series from 2008 to 2012 (Figure 5), derived from the elaboration of CHLM (Chilime), KKN4 (Kakani 4 - Kathmandu) and TPLJ (Taplejung) stations. The elaboration processing for GNSS data is similar to what done before, except that we realized a daily solution for every station, always using a Double Difference approach.

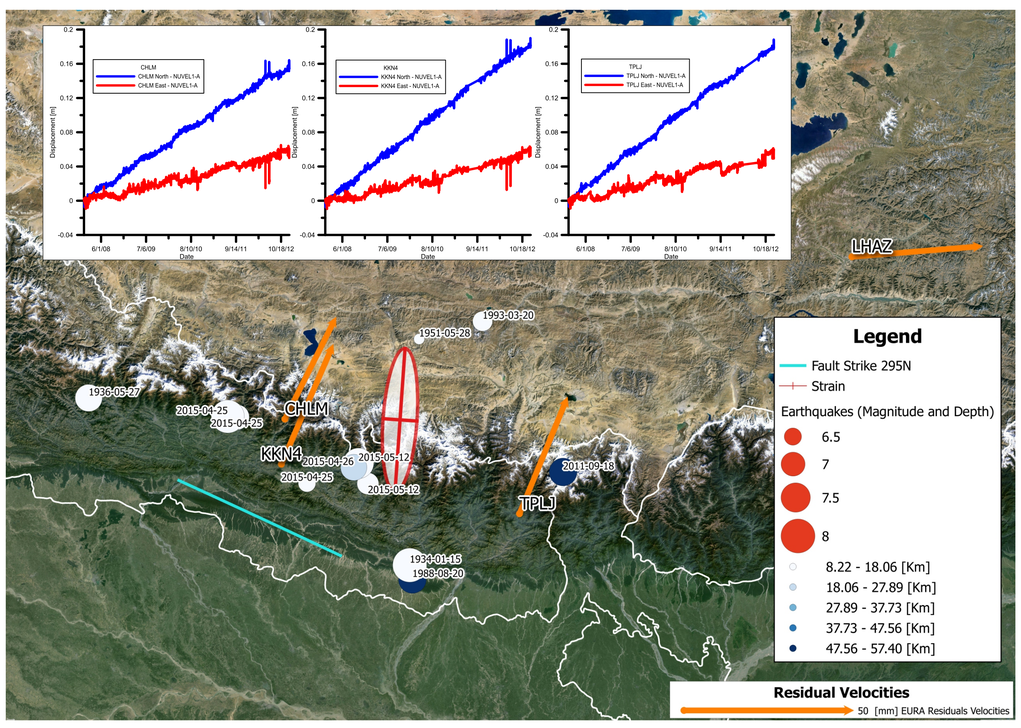

Figure 5: Vectors show the velocities residuals, with respect to EURA plate (NUVEL1-A model). The strain rate ellipse is reported togheter with the principal axes. Earthquakes from USGS catalog are shown with circles: size is proportional to Magnitude, colors report the hypocenter depth (white shallow eq.). The blue line represents the fault trace with strike 295N. The insets display the East and North displacement components of the time series after removing the NUVEL-1A model. Periodicities are evident in both the components.

A) SPECTRAL ANALYSIS

From spectral analysis of the 4 year timeseries, annual and semiannual periodicities are evident (Figure 4), probably these are related to seasonal induced thermoelastic and hydrologic deformation (Fu and Freymueller, 2012). A 2-year periodicity, that appears in the East and Up component, could not be excluded. Hydrologic local circulation could also contribute to the observed deformation signal. Interseismic deformation estimates for detailed reconstruction of spatial distribution of strain rate accumulation in an area, should take into account these effects and filter them out.

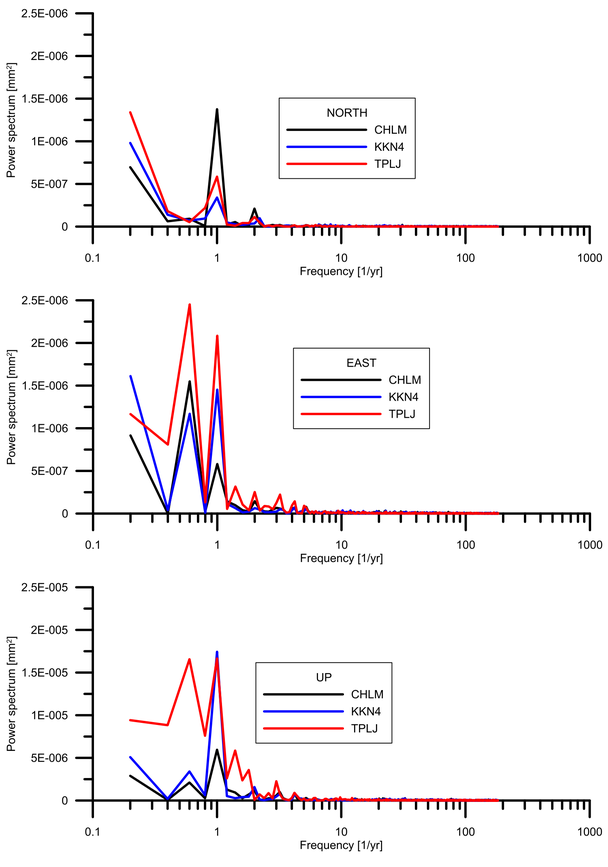

Figure 4: Power spectra of North, East, Up components, for the 4-year time series. The long term deformation was removed before performing the spectral analysis. Semiannual, yearly and multiannual periodic signals are visible.

B) STRAIN ANALYSIS

We estimate the interseismic deformation due to the velocity field recorded by the GNSS network and compare it with the cumulative coseismic strain released by the Gorkha earthquake. Velocities were estimated at four stations LHAZ, TPLJ,CHLM,KKN4, removing the velocity component due to the rigid rotation of the EURA plate, according to NUVEL1A model. LHAZ station shows a Eastward movement in accordance with the Eurasia plate, while the other three station move northwards. The relative motion between LHAZ and the other stations causes the collision and the catastrophic seismic activity occurring along the Main Himalayan Thrust. From the interseismic velocities we calculated the strain rate tensor representative of the Himalayan compression in the Gorkha area, using a least squares inversion similar to Shen (1996) approach.

Scarcity of long-term GNSS observations and the uncertainties of estimates limit us to calculate a unique strain rate value for the whole area. We tested two solutions: one including all the stations and the other excluding LHAZ . The strain rate ellipse reported in Figure 5 shows the solution without LAHZ station. The maximum axis of compression is oriented 8°N with magnitude 116 nanostrain/year, while the minor axis is a dilatation with modulus 32 nanostrain/year. The horizontal compressional strain rate acting on the Gohrka fault trace (295°N) is 110 nanostrain/year while the shear component amounts to 26 nanostrain/year. According to the 7.89 Moment Magnitude estimated by Galetzka (2015), that results in a realase of $7.61*10^{+20}$ N/m of Seismic Moment, we calculated the coseismic strain to be 9800 nanostrain, thus implying a 100 year time interval to store a comparable amount of interseismic strain.

CONCLUSIONS

- Data from two new GNSS stations NAGA and PYRA confirm the observed coseismic slip distribution on fault obtained by Galetzka et al.(2015)
- Spectral analysis of long-term GNSS timeseries in Nepal reveal seasonal signals and other periodicities (maybe multi annual) that should be taken into account for detailed interseismic deformation analysis.
- Comparison of strain rate esitmated from the 4year timeseries and the released earthquake strain lead us to estimate an 100year time interval to store an amount of energy similar to the Gorkha earthquake.

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