Systematic search for remotely triggered earthquakes in Tibetan Plateau following the 2004 Mw 9.0 Sumatra and the 2005 Mw 8.6 Nias Earthquakes

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i. Introduction

Earthquake can interact with other events within a much wider region during an unexpected longer time period. The development of high sensitive broadband seismographs and advanced techqnues reveal that the dyanmic stress associated with passing seismic waves can trigger events globally. The passing seimic waves can trigger local events simultaneously. However, it can also trigger events days to weeks even months later, which is the so-called delayed-triggering. There are still many debates on the mechanisms which lead to this phenomena. One possible mechanism is that the distant events trigger slow slip in slow-slip zone, which finally leads to local events (Figure 1a). The way to establish a triggering relationship between two events replies on complete seismic catalogs.

Here we show a case study in Tibetan Plateau: in 04/07/2005 a M6.3 earthquake shook the Zhongba region 10 days after the 03/28/2005 Nias earthquake, which may be a delayed-triggering case.

We use the recently developed match filter technique to detect more events to achieve more complete catalogs. These catalogs help to establish the link between these two events. Specifically, we use 32 reloated earthquakes as templates to scan though continuous waveform. After manual inspection, we find some clear triggered events 350 km north to the Zhongba after 12/26/2004 Sumatra and 2005 Nias events. We use Antelope software to pick and locate events within that region, then apply the waveform matching technique to get clear seismicity pattern changes within interaction of large teleseismic events.

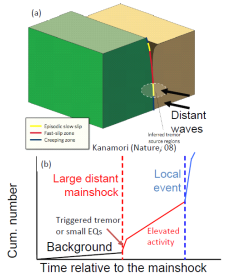

Figure 1. (a) Illustration of the brittle seismogenic zones (red), slow-slip zone (yellow) and stalbe sliding zone (blue) for a vertical fault. Distant events may trigger slip in the red zone and induce slow-slip events, which finally causing the local events. **(b)** The predicted cumulative number of earthquakes for a delayed triggering case. Right before the large distant mainshock, we have the background seismicity. After the large distant mainshock, there would be an elevated activity, finally leading to local event, followed by the aftershock activities.

ii. Study region

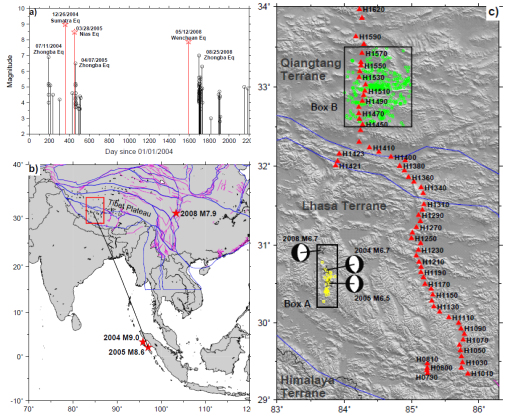

Figure 2. a) Magnitude distribution of catalog events in Zhongba county from 2004 to 2009.**b)** The map of Tibet plateau. Blue bold lines are terrane boundaries. Active faults in China are indicated by pink lines. The study region is shown by the red rectangle. The 2004 Sumatra, 2005 Nias as well as 2008 Wenchuan earthquakes are marked by red stars. The ray path between the Nias and the study region is shown by the black bold line. **c)** The map of study region. The background is the topography in this region. Red triangles represent the stations, with names labeled on the right side. Box A shows the Zhongba county and the 2004, 2005 and 2008 Zhongba earthquakes are shown by the open black stars together with their focal mechanisms. Yellow open circles are relocated catalog events. Box B is 350 km north of Zhongba county. Green stars in Box B show picked and located events from 12/01/2004 to 04/30/2005 by Antelope software.

iii. Waveform matched filter technique

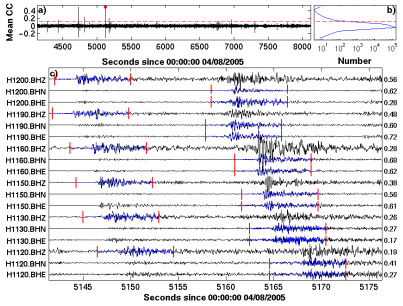

Figure 3. A positive detection by template 20050408104704(M3.74) with mean CC (correlation coefficient) = 0.583 and a magnitude 2.34. **a)** The distribution of mean CC values 1000s before and 3000s after the origin time of this detection. Red dash line gives the threshold for positive detections. The detected event is indicated by the red circle.**b)** Histogram of the mean CC values. **c)** Waveform comparison of template waveforms (blue) and continuous waveforms (black). The station name and channel as well as corresponding CC value are shown on both sides.

iv. Triggered events 350 km north to Zhongba county (Box B in Figure 2c)

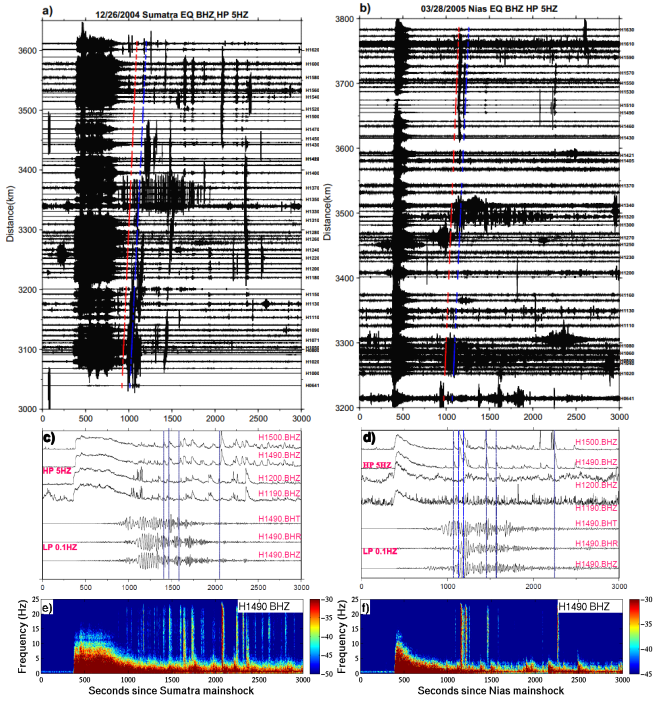

Figure 4. a) and **b)**: Waveforms aligned according to the distance between the epicenters of the 2004 Sumatra and 2005 Nias Earthquake and recorded stations. The moveout shows the vertical component with 5 HZ high-pass filter. Red and blue dash lines are predicted Love and Rayleigh wave arrivals. Station names are labeled on the right side.**c)** and **d)** The 5 Hz high-pass filtered envelope functions and 0.1 Hz low-pass filtered surface wave trains of the 2004 Sumatra Earthquake and the 2005 Nias Earthquake. The vertical blue dash lines indicate possibly triggered events during the surface wave trains. Station names and channels are labeled on the right side.**e)** and **f)** Spectrograms within 3000s after the Sumatra and Nias mainshocks.

v. Detection results in Zhongba county (Box A in Figure 2c)

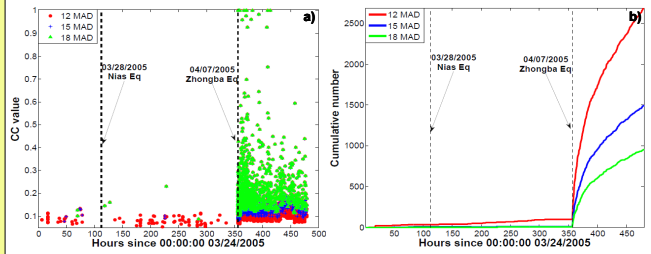

Figure 5. a) CC values of detected events in Zhongba county versus time. Different colors indicate different thresholds with legends on left top corner. The two vertical dash lines mark the 03/28/2005 Nias earthquake and 04/07/2005 Zhongba earthquake. There are many detections after the 2005 Zhongba event with relatively high CC values. Only a small number of events before the Nias event ,as well as between the Nias and the Zhongba events, are detected with very low CC value.**b)** Cumulative number of detected events versus time. There is no obvious seismicity change before the Nias event and between the Nias and the Zhongba events. After the Zhongba event, we find a sharp seismicity increase(Figure 1b).

vi. Detection results in Box B in Figure 2c

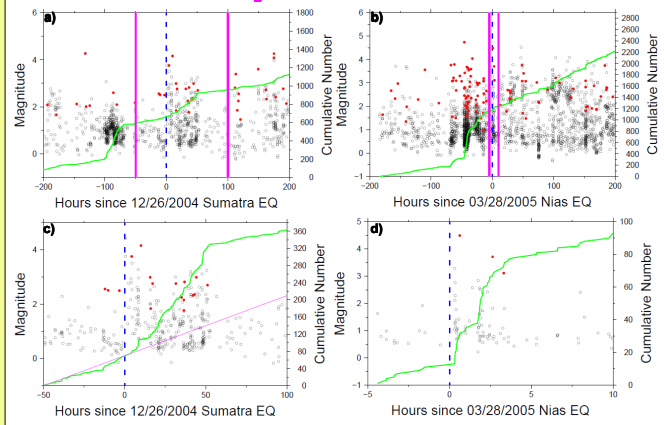

Figure 6. **a)** and **b)** are magnitude distribution vs time. The green lines are cumulative earthquake numbers. Blue vertical dashed lines indicate the origin time of 2004 Sumatra EQ and 2005 Nias EQ. The black open circles are deteced events, and red filled cricles are template events. Two vertical bold pink lines gives you the starting and ending time of smaller time windows showing in Figure c) and d). **c)** and **d)** are zoomed in distribution of earthquake 50 hours before and 100 hours after Sumatra event, 5 hours before and 10 hours after Nias event. The vertical dashed lines, the symbols and colors are the same with a) and b). As we can see from the plot, the seismicity increases slowly after the Sumatra earthquakes (the pink line predicts the background seismicity) and lasts for 50 hours. However, after the Nias earthquake, we obsever sharp increase in seismicity and lasts for only less than 5 hours.

Summary:

- **No obvious seismicity rate change were found near the Zhongba region. It is possible that smaller-size events are triggered but not recorded by the network.**
- **The 2004 Sumatra and 2005 Nias events triggered clear high frequency signals 350 km north to Zhongba, with sources close to station H1490.**
- **The 2004 Sumatra event triggered local events which lasted for 2 days; however, it only lasted for several hours for 2005 Nias event.**

Reference:

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