Geophysical Research Abstracts
Vol. 18, EGU2016-10827, 2016
EGU General Assembly 2016

Observations of large earthquakes in the Mexican subduction zone over 110 years

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Fault slip during an earthquake is observed to be highly heterogeneous, with areas of large slip interspersed with areas of smaller or even no slip. The cause of the heterogeneity is debated. One hypothesis is that the frictional properties on the fault are heterogeneous. The parts of the rupture surface that have large slip during earthquakes are coupled more strongly, whereas the areas in between and around creep continuously or episodically. The continuously or episodically creeping areas can partly release strain energy through aseismic slip during the interseismic period, resulting in relatively lower prestress than on the coupled areas. This would lead to subsequent earthquakes having large slip in the same place, or persistent asperities. A second hypothesis is that in the absence of creeping sections, the prestress is governed mainly by the accumulative stress change associated with previous earthquakes. Assuming homogeneous frictional properties on the fault, a larger prestress results in larger slip, i.e. the next earthquake may have large slip where there was little or no slip in the previous earthquake, which translates to non-persistent asperities.

The study of earthquake cycles are hampered by short time period for which high quality, broadband seismological and accelerographic records, needed for detailed studies of slip distributions, are available. The earthquake cycle in the Mexican subduction zone is relatively short, with about 30 years between large events in many places. We are therefore entering a period for which we have good records for two subsequent events occurring in the same segment of the subduction zone.

In this study we compare seismograms recorded either at the Wiechert seismograph or on a modern broadband seismometer located in Uppsala, Sweden for subsequent earthquakes in the Mexican subduction zone rupturing the same patch. The Wiechert seismograph is unique in the sense that it recorded continuously for more than 80 years, without changes in the instrument response. Furthermore, it has a relatively short natural period and is at a 90 degree angle from the Mesoamerican trench, making it highly sensitive to lateral variations in location. In total we have registers from more than 20, M>6.9 earthquakes in seven along trench segments.

Events in this region are known to have a relatively short and simple rupture history, which has been interpreted as compact isolated asperities breaking in each event (Stewart et al 1982). Due to their short duration we assume that in the period range of the Wiechert instrument they are practically point sources, and any differences in waveforms are due to differences in location. This is not true for the largest events, as well a small number of the intermediate sized earthquakes, but these events can be identified by their complex P-waves.

Of the seven different along trench segments, the Ometepec segment, on the border between the states of Guerrero and Oaxaca, has the largest number of earthquakes during the time period, or a total of five. Of those, three have near-identical waveforms, which we interpret as a repeatedly breaking asperity. The central Oaxaca segment also has had two earthquakes with highly similar waveforms, indicating comparable rupture areas in the two events. In other areas we find that subsequent earthquakes breaking the same segment do not have similar waveforms, indicating that different areas of the fault surface break in each event, or in a few cases, a more complex rupture history.

Our observations therefore indicate that both processes are important, perhaps with varying relative importance depending on the region. In other words, some asperities are persistent over time, whereas others are not.