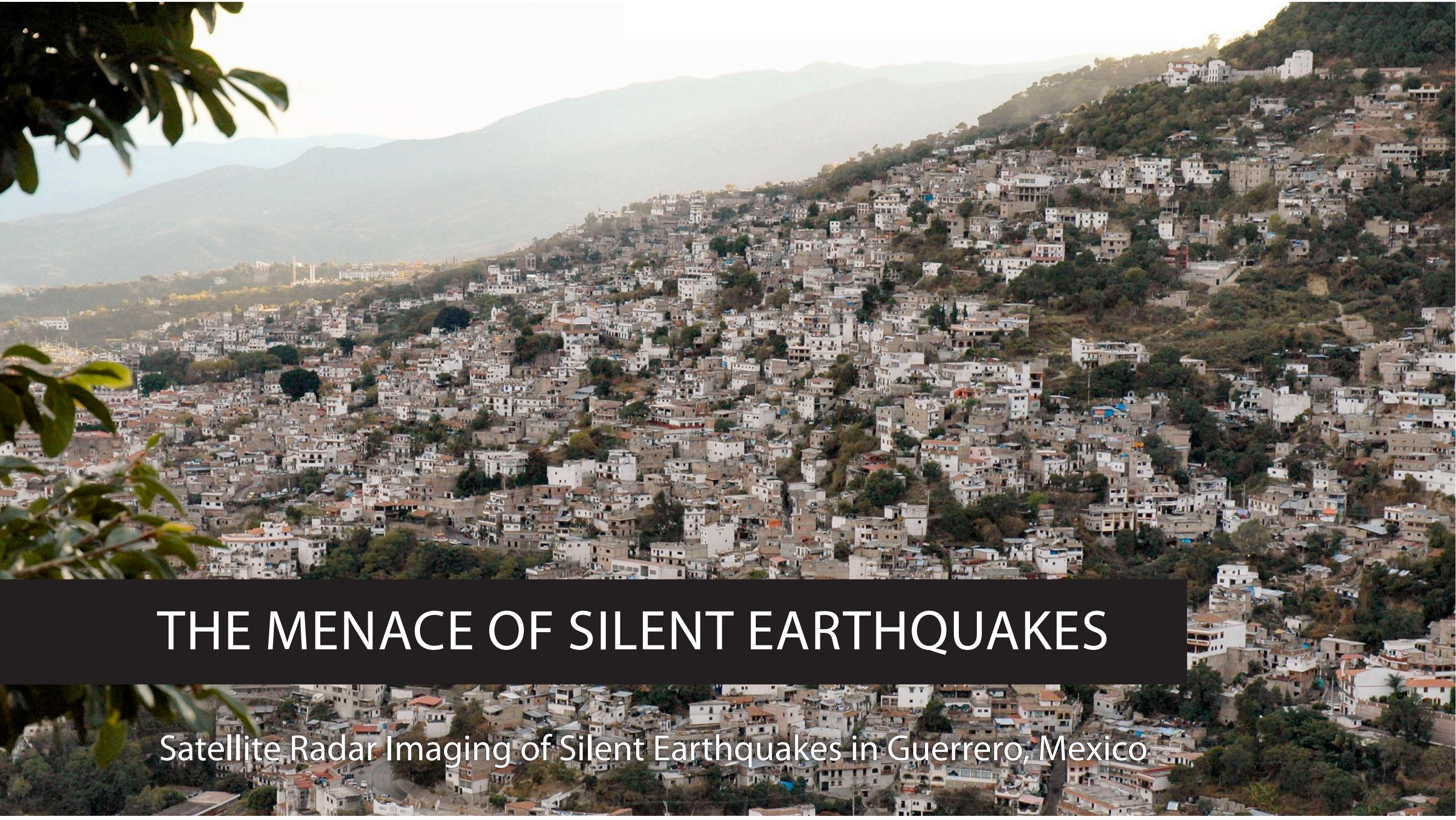

THE MENACE OF SILENT EARTHQUAKES

Satellite Radar Imaging of Silent Earthquakes in Guerrero, Mexico

On September 19th 1985, Mexico City was hit by a magnitude 8.1 earthquake on the Richter scale. An estimated 10.000 people were killed, 50.000 were injured, and 250.000 lost their homes – a dark day in Mexican history. To try to avoid a repetition of these disastrous consequences, hazard monitoring has become a priority. During the last decade, technological developments have led to the discovery of a new type of earthquakes, a silent one, waiting to show its force.

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The uppermost part of the Earth consists of a number of tectonic plates that move at rates of a few centimeters per year. The main driver for earthquakes is the motion between adjacent plates; one plate moving with respect to another causes a build up of stress. At deeper levels, these stresses are relaxed by ductile flow, but in the shallow, brittle part of the crust, these stresses are released by slip on faults. During earthquakes this slip occurs at high velocities, leading to the radiation of seismic waves that cause the shaking of the Earth's surface. However, this slip can also occur at slower rates, without the release of significant seismic energy. In the last decade these slow slip events, also known as silent earthquakes, have been discovered in many parts of the world, mostly at subduction zones where one plate descends beneath another. While the direct danger from these slow earthquakes is negligible, their occurrence alters the surrounding stress field. This has implications for the timing of subsequent, potentially damaging earthquakes.

SILENT EARTHQUAKES

Whereas the slip during earthquakes is over in minutes, silent earthquakes can occur over periods ranging from a few days to months, and in extreme cases a year [Schwarts and Rokosky, 2007]. It is not yet understood why the slip during these events occurs at such a snails pace. But at least in subduction zones, it is hypothesised that pulses of water, released by water-rich minerals deeper within the subduction zone, increase the pore pressure as they pass through. The high pore pressure acts against the pressure from the overlying rock, which clamps the two sides of the fault together, allowing slip to occur at lower stresses. Although this slow slip does not generate large seismic waves, it does cause an instantaneous elastic response in the surrounding rock, resulting in deformation of the Earth's surface. It is this signal that has been detected over the last ten years, through the deployment of highly-accurate GPS stations embedded in the crust.

Just like regular earthquakes, the size of silent earthquakes can be indicated using the moment magnitude (M_w) scale. This scale is based on the potential energy released by the earthquake, calculated from the area and amount of slip, and the elastic properties of the rock. This scale is now routinely used rather than the Richter scale. Like the Richter scale, which is calculated from seismic wave amplitudes, the moment magnitude scale is logarithmic – a 7.0 is 10 times larger than a 6.0 - but unlike the Richter scale, it does not saturate for large earthquakes. Silent earthquakes measured until now have magnitudes ranging up to M_w 7.5, large enough to cause significant damage if the energy were released in a normal earthquake.

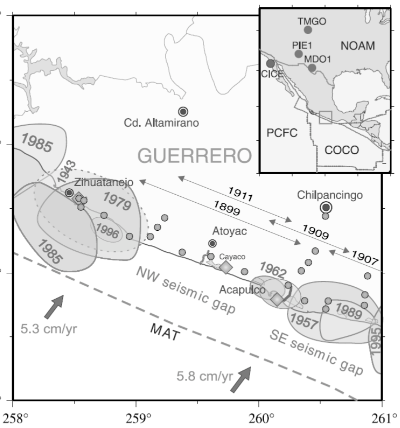
GUERRERO SEISMIC GAP

Guerrero is a province in the southern part of Mexico adjacent to the Pacific Ocean. Here, the Cocos plate to the southwest subducts beneath the North America plate just offshore (figure 1). The trench itself is located approximately 60 to 80km from the coast. In the past, large thrust earthquakes have taken place along the interface between the two plates. However, there is a region with a "seismic gap" where no large earthquakes have taken place since a M_w 7.6 earthquake in 1911. Taking into account the continued stress loading of ongoing subduction, it is estimated that a rupture of the gap now would result in a M_w 8.0 to 8.4 earthquake [Singh and Mortera, 1991], which would have devastating consequences for the surrounding area. In the past few years it has become apparent that the subduction interface is also very active with regard to silent earthquakes; at least one significant slow slip event, with magnitude M_w 5.0 to 6.0, has taken place every three years. The areas affected by the associated deformation are rather large, with the highest deformations usually near the coast and diminishing inland almost as far as Mexico City. The most important reason to investigate silent earthquakes at Guerrero is to assess the effect that these events have on the seismic gap region; does the perturbation to the stress field caused by these events lead to a delay or a hastening of the next large earthquake? Could one even be a trigger of a large earthquake, in which case, it would have predictive power? Bearing in mind the proximity of Mexico City and the destruction wreaked there by the 1985 earthquake, any knowledge gleaned about the timing of the next "big one" could prove invaluable.

WHY SATELLITE RADAR IMAGING?

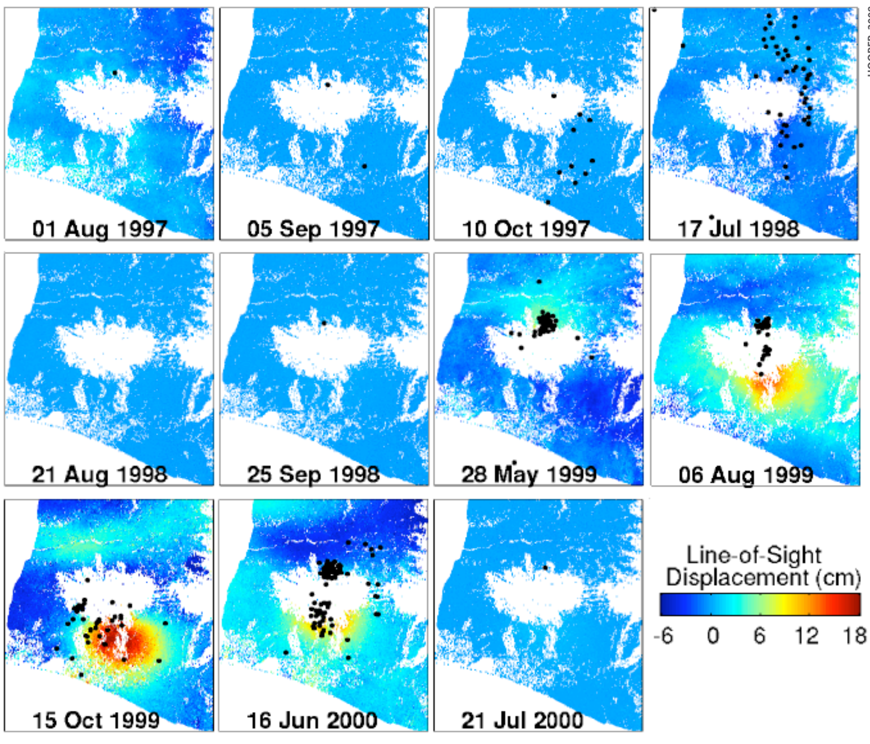
Up to now, surface deformation associated with silent earthquakes has been measured mostly by GPS stations. Although the temporal resolution from continuous GPS stations is excellent, the spatial resolution depends on the spacing of the stations. Good spatial resolution is important in order to model where exactly on the subduction interface, and with what magnitude, slip took place. This, in turn, provides an estimate of the stress change effecting the seismic gap region. However, the number of continuous GPS stations in Guerrero is limited. There are about 27 stations altogether, covering an area of 63.000km^2 (one and a half times the area of the Netherlands). Moreover, almost all stations are located near the coast, resulting in large "holes" where no observations are made. The problem of spatial resolution can be addressed using spaceborne synthetic aperture radar interferometry (InSAR). Where good correlation is maintained, displacement measurements can be obtained approximately every 20m. Unlike GPS, InSAR measurements are most sensitive in the vertical direction, which is where the largest displacements occur during the silent earthquakes. Furthermore, SAR images have been acquired since the launch of the ERS-1 satellite in 1992, allowing us to probe silent earthquakes that occurred even before the installation of the GPS network. One drawback to InSAR measurements is the level of associated error, mainly due to the varying delay in propagation through the atmosphere. The radar group of MGP section has been developing algorithms to reduce these errors, including time series analysis of multiple SAR images (figure 2) and the use of non-SAR data to estimate atmospheric path delay independently. By applying these advanced methods, we aim to quantify the stress changes caused by the silent earthquakes better than ever before, providing extra constraints on the earthquake forecast for the region.

If good results are obtained, our methods can be applied to other subduction zones experiencing silent earthquakes, such as the Cascadia region in north America and certain regions in Japan. Success is not guaranteed, but given the lives lost, and damage caused by large subduction zone earthquakes, it is surely worth a try.



LARSON ET AL., 2004

Figure 1. Tectonic setting of Guerrero. Arrows indicate the direction and magnitude of NUVEL1-A relative plate motion. Survey and continuous GPS sites (as in 2001) are shown respectively as circles and diamonds. Major earthquake slip zones are indicated with the year of the event. The impact the earthquakes on the seismic gap is given by the double-arrowed lines.



HOOPER, 2008

Figure 2. The ability of time series InSAR techniques to measure transient surface deformation events is demonstrated here on a volcano in Iceland.

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