Postseismic deformation following the 2010 Haiti earthquake: Groundwater flow in response to a sudden uplift

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Abstract

The 2010, M=7.0 Haiti earthquake was one of the worst natural disasters of the past century with more than 230,000 fatalities. The earthquake ruptured a 40 km long fault and had a seismic moment of 5.44 x 10^{26} dyne cm. A magnitude 7 earthquake typically displaces the Earth's crust by 3-5 meters and deforms the crust over a wide area along the fault. It also induces large transient displacements, termed postseismic deformation. In this research project we used Synthetic Aperture Radar observations acquired by the German satellite TerraSAR-X (TSX) to detect postseismic deformation induced by the 2010 Haiti earthquake. The advantages of using TSX data are their very high spatial resolution (1-5 meters) and short repeat time (11 days). However, the satellite acquires data over a narrow swath (30 km) and its X-band signal degrades within short time, except over urban areas. We obtained 22 scenes covering the eastern portion of the earthquake rupture area, from before and after the earthquake. Interferometric data processing, which compares phase observations between pairs of acquisitions, allows us to detect surface deformation induced by the earthquake. Our analysis shows a patch of postseismic deformation at the northeastern extent of the Leogane delta. The deformation is time-dependent and occurred in the first 24 days after the earthquake. The deformation occurred due to groundwater flow as the water table adjusted to the hydraulic conditions imposed by the sudden uplift of the delta by ~80 cm with respect to unchanged sea level.

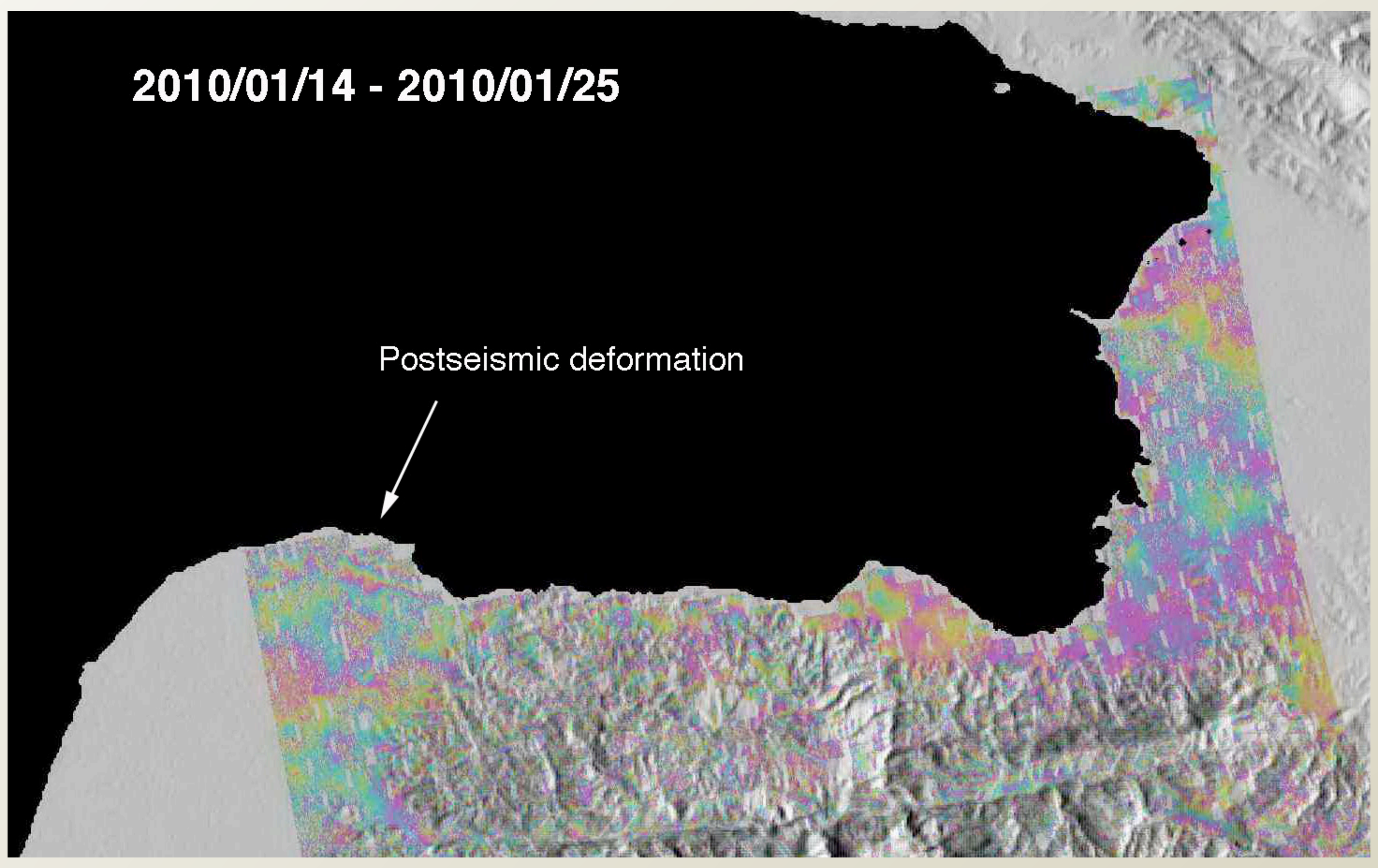
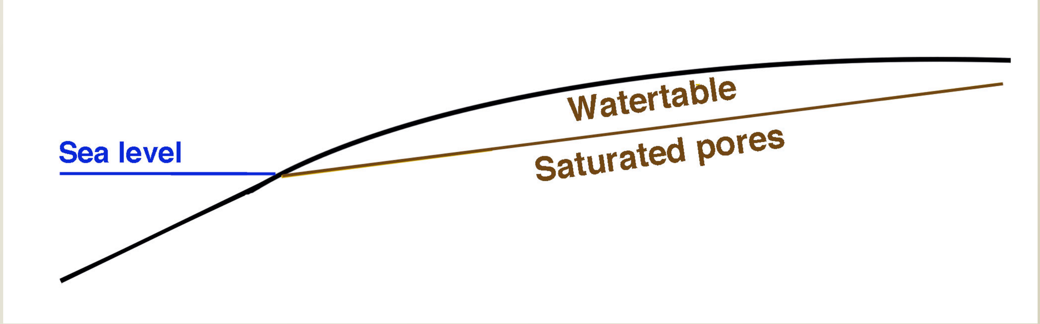


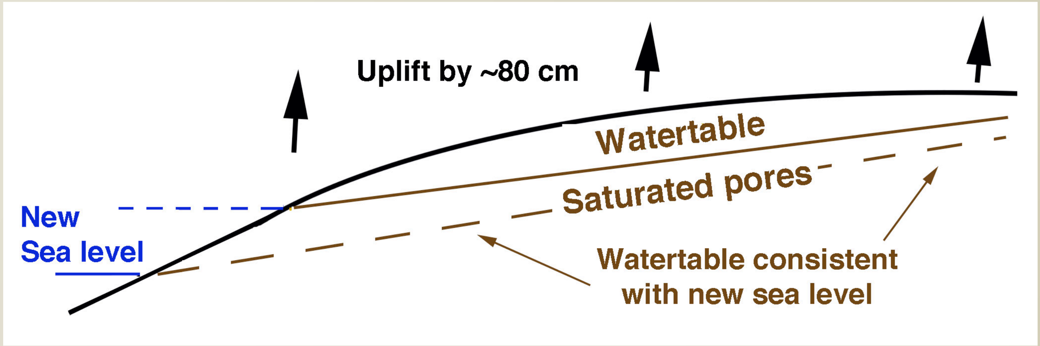
Figure 2: TerraSAR-X interferogram detecting postseismic deformation in the northern section of the Leogane delta. The 11 day interferogram shows a good coherence in most areas. . Each fringe cycle represent 2 cm of vertical displacement.

<u>Conceptual model</u> explaining the cause for the observed postseismic deformation



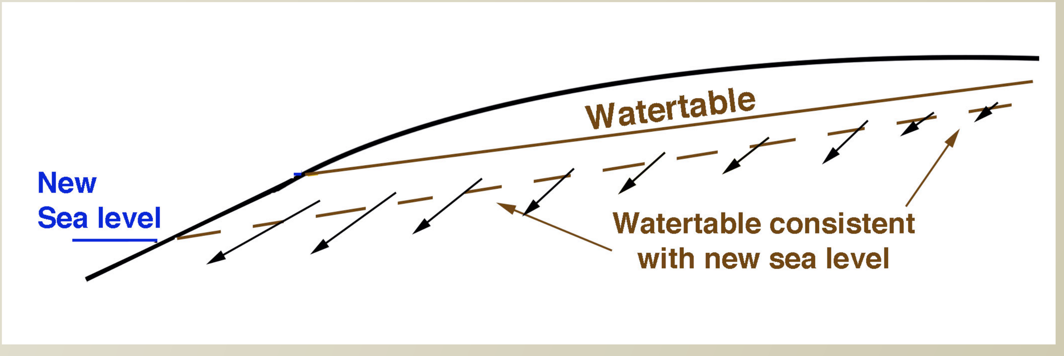
Before the earthquake

Water table is in equilibrium with sea level.



During the earthquake (~ 20 seconds)

Uplift of the delta by ~80 cm disturbed the water table equilibrium.



After the earthquake

Groundwater flew downward toward the sea in order to reach an equilibrium with the "new" sea level. Sediment compact in response to water loss. It is a time dependent process.

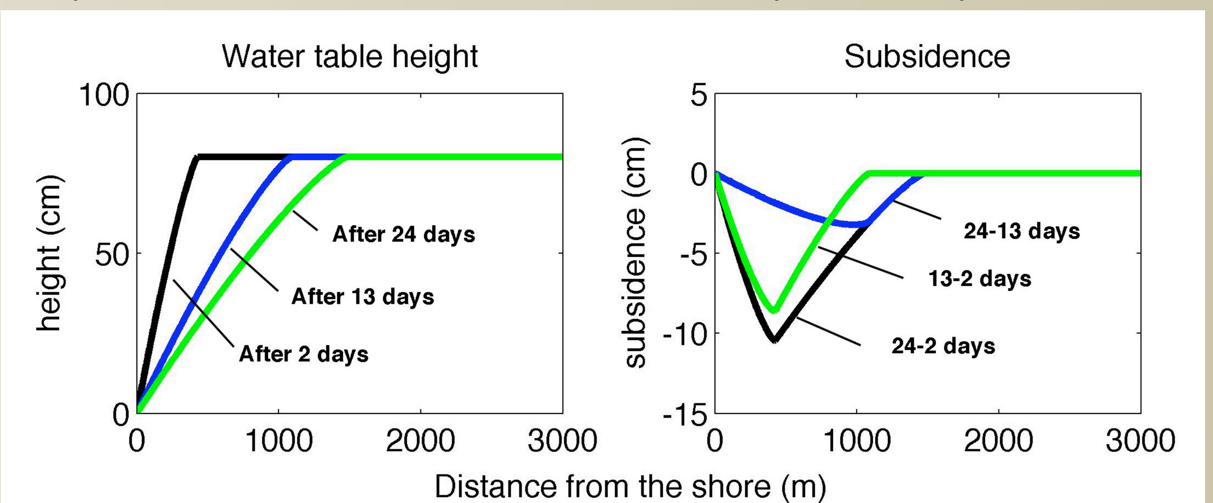


Figure 4: Calculated water table levels and differential subsidence based on the analytical solution of Lockington (1997) for aquifer discharge due to a sudden change in boundary head. The model assumes 80 cm of sudden drop and 20% sediment compaction.

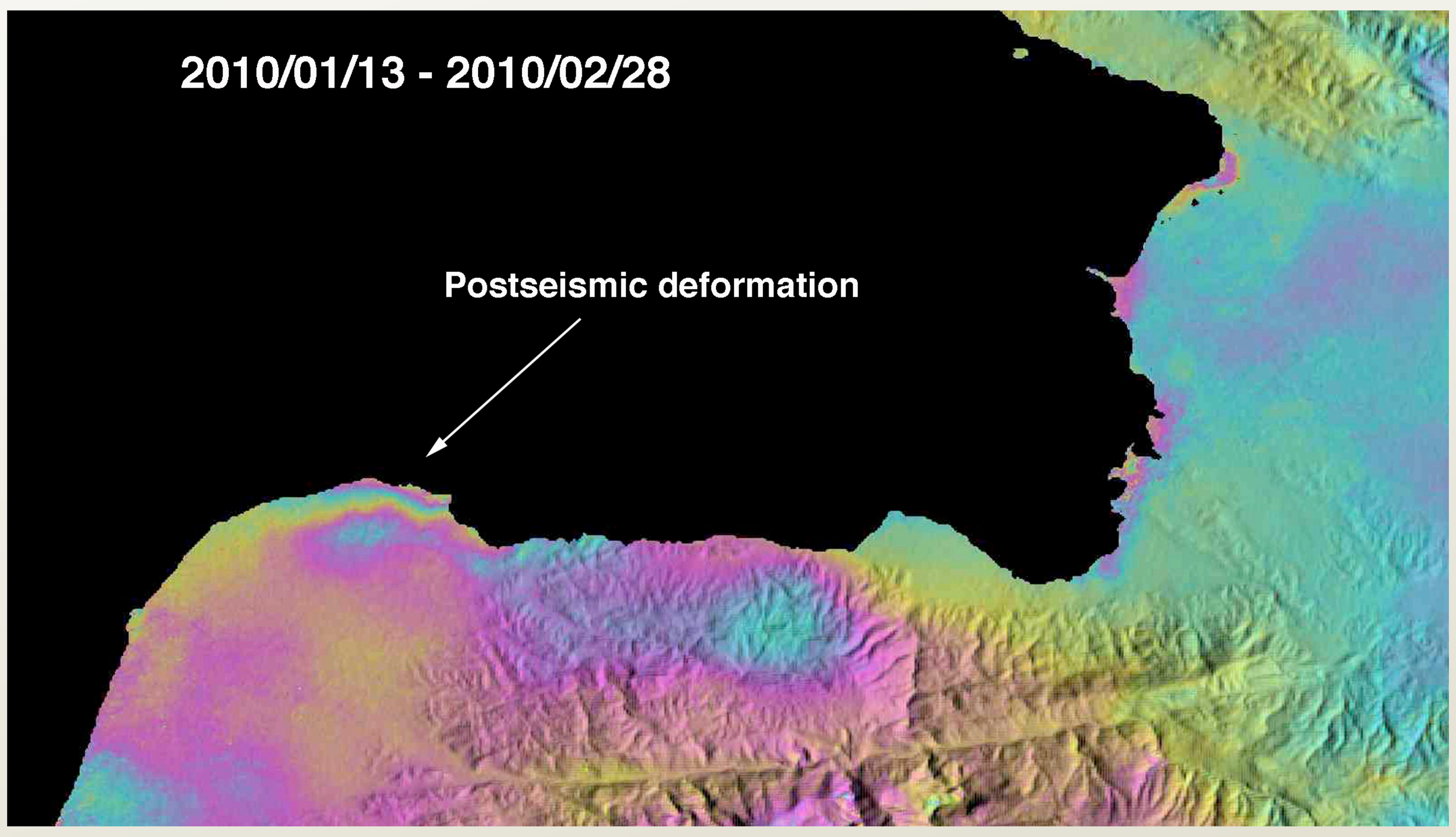


Figure 1: Post-earthquake ALOS interferogram (phase changes) detecting postseismic deformation in the northern section of the Leogane delta. The 45 day interferogram shows 10-12 cm of subsidence. Each fringe cycle represent 8 cm of vertical displacement.

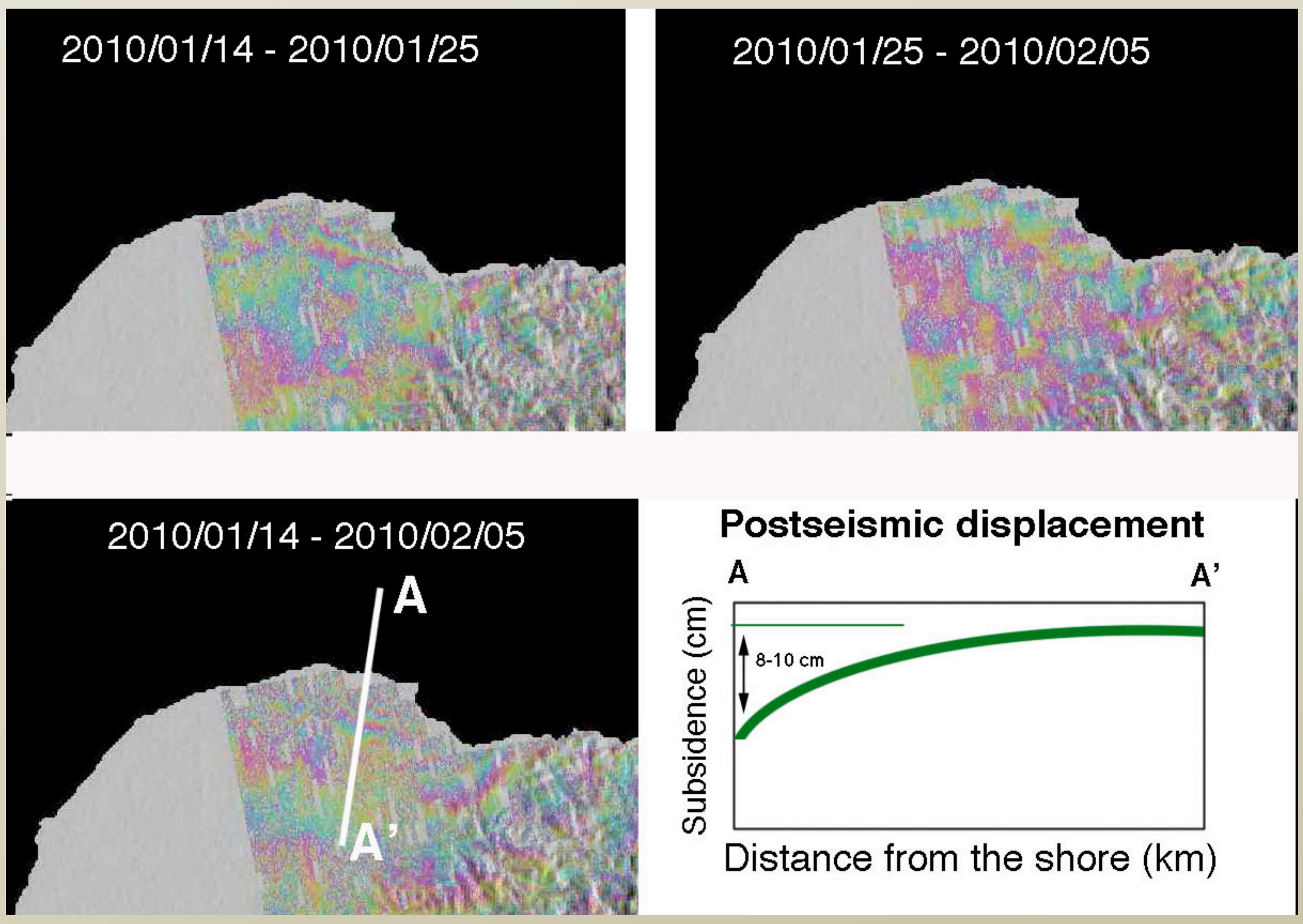


Figure 3: Three post-earthquake TerraSAR-X interferograms showing time-dependence postseismic deformation (subsidence). Most deformation occurred between January 14th and January 25th, 2010 and a smaller amount between January 25th and February 5th. The total deformation during the 22 days following the earthquake are shown in the third interferogram, which indicates a maximum subsidence of 8-10 cm. A profile normal to the shoreline (A-A') shows an increasing subsidence from inland areas toward the shore, with maximum subsidence of 8-10 cm.

Conclusions

- TerraSAR-X observations detected postseismic deformation that occurred along the northern part of the Leogane delta during 24 days after the earthquake.
- The coseismic deformation of the 2010 Haiti earthquake has been under-estimated (up to ~10%), because the coseismic deformation analysis is based on interferograms that include both coseismic and postseismic deformation.
- The TSX observations led to a discovery of a new postseismic deformation type that is caused by groundwater table adjustment to a new sea level.
- It is very important to task SAR satellites to monitor surface deformation right after a large earthquake. Fast response of space agencies will allow the acquisition of the time-dependent postseismic deformation. It is important to start acquiring data immediately after the earthquake, when the postseismic signal is the largest.

Reference

Lockington, D. A., Response of an unconfined aquifer to sudden change in boundary head, *J. Irrig. Drain. Eng., 123, 24–27, 1997.*