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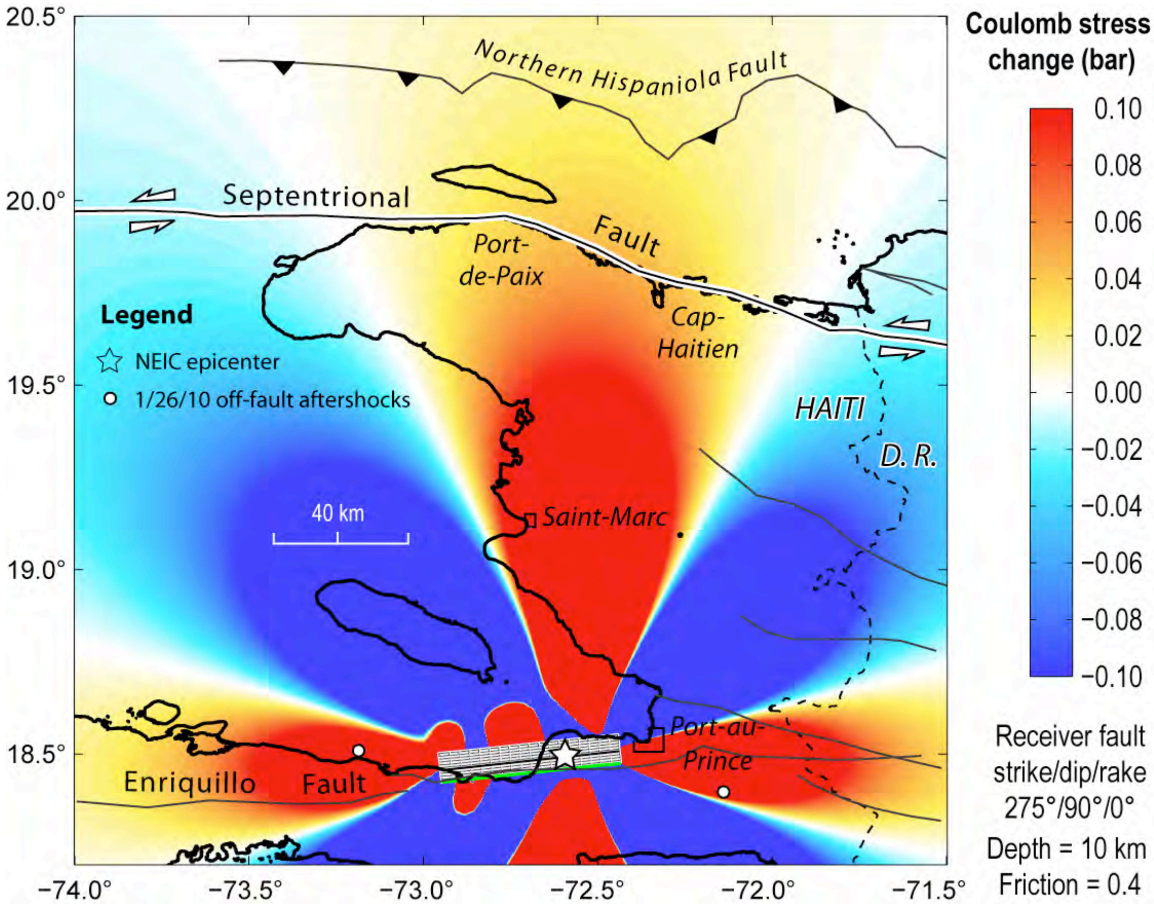

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Abstract

Using calculated stress changes to faults surrounding the January 12, 2010, rupture on the Enriquillo Fault, and the current (January 12 to 26, 2010) aftershock productivity, scientists from the U.S. Geological Survey (USGS), Woods Hole Oceanographic Institution (WHOI), and Disaster Prevention Research Institute, Kyoto University (DPRI) have made rough estimates of the chance of a magnitude (Mw)≥7 earthquake occurring during January 27 to February 22, 2010, in Haiti. The probability of such a quake on the Port-au-Prince section of the Enriquillo Fault is about 2 percent, and the probability for the section to the west of the January 12, 2010, rupture is about 1 percent. The stress changes on the Septentrional Fault in northern Haiti are much smaller, although positive.

Motivation

The 12 January 12, 2010, M_w=7.0 Haiti earthquake on the Enriquillo Fault transferred static stress to surrounding faults. The Enriquillo slips at 7±2 mm/yr, as inferred from global positioning system (GPS) surveys (Manaker and others, 2008), and it last ruptured on October 18 and November 21, 1751, and June 3, 1770, in what may have been a west-propagating sequence (Mann and others, 1998; Ali and others, 2008). These incomplete observations suggest that a portion of the Enriquillo Fault much longer than the ~35-km-long section that slipped on January 12 has accumulated about 1.7 m of tectonic loading. We have therefore constructed a preliminary model of the Coulomb stress change based on the limited information currently available on the earthquake source, its aftershocks, and surrounding active faults (fig. 1).

Interpretation of Stress Changes on the Enriquillo Fault

In general, stress increases of ≥1 bar are associated with increased rates of seismicity and therefore increased earthquake probability; stress changes of less than 0.1 bar are more rarely associated with seismicity changes. Coulomb stress increases are thought to amplify the background seismicity, and both the stress changes and the preceding rate of small (typically $M \geq 2$) shocks are needed to estimate earthquake probabilities (Stein, 1999; Toda and Stein, 2002). However, since we lack here any useable record of seismicity, we focus exclusively on the Coulomb stress changes, implicitly assuming a uniform rate of background earthquakes.

Under these criteria, the greatest area of concern for a large ($M_w \geq 6.5$) triggered shock is immediately to the east of the January 12, 2010, rupture on section 1 of the Enriquillo Fault, which comes within 5 km of Port-au-Prince, where stress is calculated to have been brought about 2-5 bars closer to failure, depending on location (fig. 1). Typically, stress increases of this magnitude are associated with aftershocks (Stein, 1999), but thus far no $M \geq 4.0$ shocks have struck on section 1. Because of the absence of local seismic recording stations, however, smaller aftershocks would go undetected, and so we do not regard the absence of such off-rupture aftershocks as significant. The next most loaded fault section lies to the west of the January 12 rupture along section 2, where the stress is calculated to have been brought about 1 bar closer to failure on the Enriquillo Fault, west of a 5-km-wide 'en echelon' or stepover offset. No $M_w \geq 4.0$ aftershocks have struck on section 2 either. We show the sensitivity of these results to fault friction and rake in figure 2. Aftershocks of $M_w = 4.4$ and 4.1 on January 26 locate farther from the rupture than any preceding events (figs. 1 and 3), but neither of these struck on the Enriquillo Fault and neither has a focal mechanism.

Probability of a Future Large Enriquillo Fault Rupture

On the basis of the temporal decay of aftershock frequency during January 12-21, the USGS estimates the probability of a $M_w \geq 7$ earthquake in the vicinity of the mainshock to be ≤3 percent during the period 22 January 22 to February 22, 2010 (U.S. Geological Survey, 2010). Combining this statistical forecast with our calculation that the highest stress changes were transferred to the east of the January 12 rupture, we roughly estimate the chance of a $M_w \geq 7$ rupture on the Port-au-Prince section to be approximately 2 percent and the probability on the section to the west of the January 12 rupture to be about 1 percent during January 27 to February 26, 2010. That two large and possibly adjacent 1751 earthquakes struck 33 days apart means that such an occurrence during the next 30 days would not be unprecedented in this region. Based on Omori aftershock decay statistics, the chances of a $M \geq 6.0$ rupture in these sections is about five times higher (10-15 percent).

Stress Imparted to the Septentrional Fault and Thrust Faults

We treat the Septentrional Fault as a left-lateral vertical fault following Mann and others (1998). It lies 155 km north of the January 12 rupture; farther east it slips at

9±3 mm/yr (Manaker and others, 2008). The last large rupture on the part of the fault in Haiti was on May 7, 1842 (Ali and others, 2008), and therefore about 1.5 m of slip has since accumulated. We calculate a small positive stress change of as much as 0.05 bar, centered between Port-de-Paix and Cap-Haitien (fig. 3), but we do not know if this is large enough to trigger or hasten earthquakes. No thrust fault sustained a calculated stress increase greater than about 0.5 bar, even though some are quite close to the January 12 rupture (fig. 1). The deepest 15-20 km of thrust 9 was brought 0.5 bar closer to failure, but the shallow portions are inhibited from failure by the same amount. Thrust faults 8, 9, and 10 might be capable of generating tsunamis if they ruptured. Thrust faults 3, 4, 6, and 8 are calculated to have been brought about 0.1 bar closer to failure, a relatively modest amount.

Modeling Parameters and Assumptions

We used the January 19, 2010, version of Gavin Hayes' 180-patch unilateral rupture model (hai_ffm2.inp) with a seismic moment of 5.44×10^{26} dyne-cm (M_w=7.09) for the source model. This model can be downloaded from *http://sicarius.wr.usgs.gov/haiti/hai_ffm2.inp*. The source lies on a single 70°-north-dipping plane and so oversimplifies the likely rupture geometry. InSAR and GPS-based models, which have yet to be produced, will undoubtedly contain significant differences. The surrounding faults are inferred from figure 5 of Mann and others (2002). In the absence of field data, we have assumed in figure 1 that the thrust faults extend to a depth of 20-25 km, dip 45°, and undergo pure reverse slip. We assume the strike-slip faults extend to 24-km depth, dip 70° to the north, and undergo pure left-lateral slip. These assumptions are varied in figure 2 for the Enriquillo Fault. We use a uniform elastic halfspace with shear modulus of 3.2×10^{11} dyne-cm^{-2} and a uniform fault friction of 0.4. Because lower friction might be appropriate on the strike-slip faults (Parsons and others, 1999; Toda and Stein, 2002), we also consider a friction coefficient of 0.0 in figure 2, for which the results are little changed. Calculations were made using Coulomb 3.1.09 (Toda and Stein, 2002; Lin and Stein, 2004), which can be freely downloaded from *http://www.coulombstress.org*, along with the user manual and tutorial files.

Ali and others (2008) performed a Coulomb analysis of the 250 years preceding the January 12, 2010, rupture. Under the assumption that the October and November 1751 events were M_w=8.0 and M_w=7.5, respectively, they concluded that the Enriquillo Fault was not close to failure. If, however, they overestimated the magnitudes and thus slip of these 1751 quakes, their modeled stress accumulation since 1751 would be too low. Reassessment of the historical earthquake magnitudes and locations would be invaluable.

Source-Model Tests

Coastal reef uplift and subsidence observations by Richard Briggs (USGS) are consistent with deformation produced by the source we used. Preliminary Advanced Land Observing Satellite (ALOS) interferograms indicate that the rupture endpoints in the hai_ffm2.inp model are approximately correct; most important, the interferograms indicate that there was no slip along section 1 of the Enriquillo Fault, nearest to Port-au-Prince, during the January 12 earthquake.

Acknowledgements

We are grateful to the Group on Earth Observations (GEO) for the extraordinary release of the ALOS interferograms to the research community. We thank Eric Calais (Purdue University) for Coulomb model calibration, Paul Mann (University of Texas, Austin) for the active fault map, Gavin Hayes (USGS National Earthquake Information Center) for source model guidance, and Tom Parsons, Jeanne Hardebeck, Ruth Harris, Patricia McCrory and Thomas Holzer (all at USGS) for rapid and thoughtful reviews.

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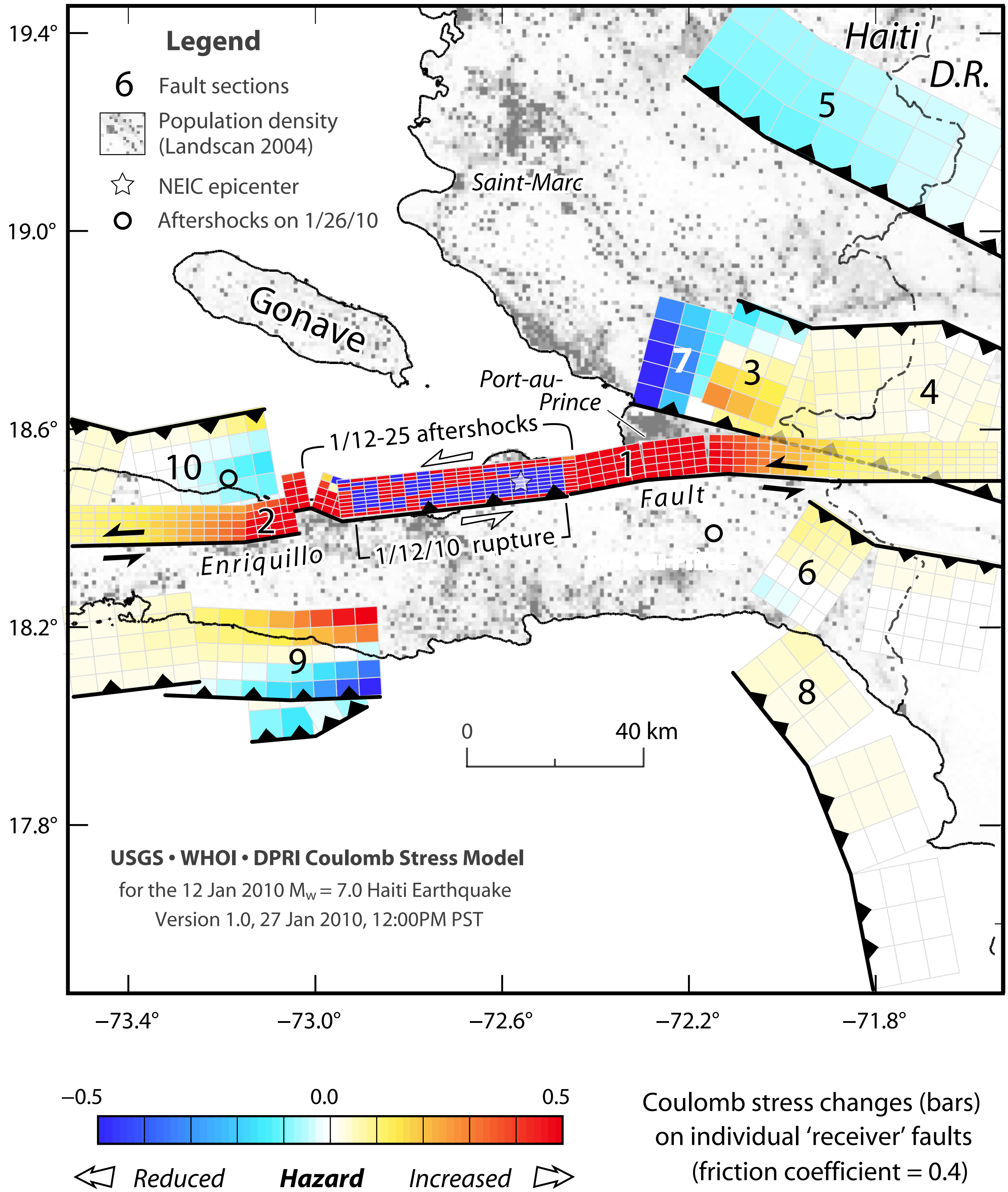

Figure 1. Coulomb stress changes imparted by the January 12, 2010, Mw=7.0 rupture resolved on surrounding faults inferred from Mann and others (2002). Thrust faults dip 45°.

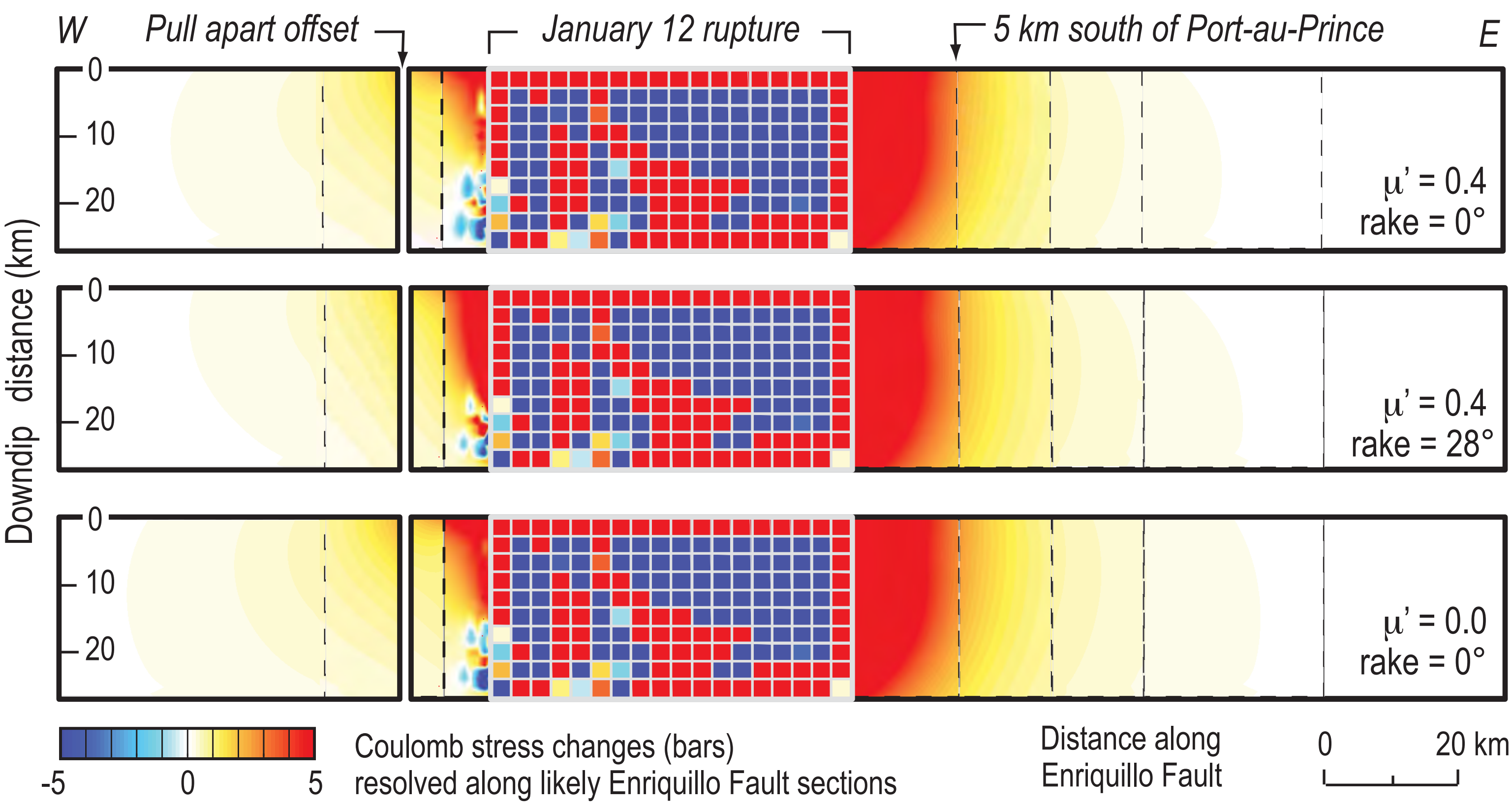

Figure 2. Coulomb stress changes imparted by the January 12, 2010, M_W=7.0 rupture resolved on the Enriquillo Fault (Mann and others, 2002), with fault friction varied over 0.0-0.4 (low to moderate values) and the fault rake varied from 0 to 28° (left-lateral to oblique left-reverse slip). Dashed vertical lines identify changes in fault strike.

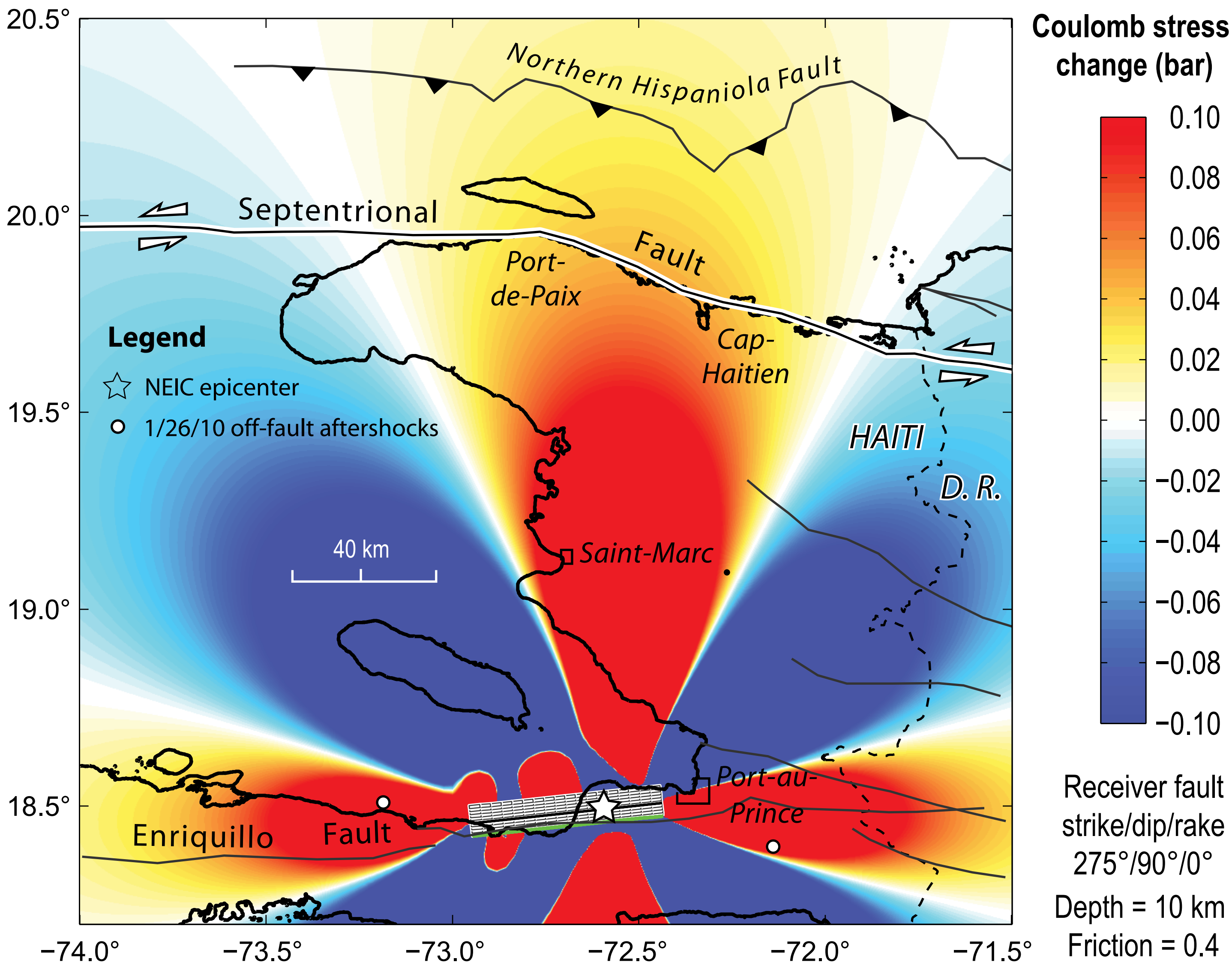

Figure 3. Coulomb stress changes imparted by the January 12, 2010, M_W=7.0 rupture to the Septentrional Fault, assuming a friction of 0.4 (a friction of 0.0 yields a similar result, with the peak stress shifted 25 km to the west). Stress changes are positive but very small. The two 1/26/10 aftershocks are the only events thus far to locate well off the source model; if they are left-lateral events on roughly E-W planes, then they would have been promoted by stress imparted by the January 12 mainshock rupture.