Prediction of soft-cliff retreat in Minuto de Dios, Southern Caribbean coast of Colombia, under a sea level rise scenario

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Accurate quantification of coastal hazards remains a crucial issue in light of predicted global sea level rise resulting from climate change. Current predictions, for the year 2100, propose a global mean sea level ~1 m above pre-industrial levels, which will exacerbate coastal impacts, especially along vulnerable coastlines of developing countries **[1, 2]**. Recent studies have predicted a future coastline retreat ~110 m between 2009 and 2044 along the soft-cliffs of Minuto de Dios, a sector near Arboletes municipality on the Caribbean coast of Colombia **[3]**. The aim of this study is to improve upon previous results by including a more accurate quantification of local mean sea level rise and a digital terrain model derived from light detection and ranging data **[4, 5]**. Future cliff-top positions were calculated for a ~1 km alongshore reach of coast located at the Minuto de Dios sector (MD) by means of a validated, simple model that relates retreat rates to sea-level rise **[6, 7]**. Mean end-point retreat at MD between 1938 and 2010 was 1.7±0.4 m/yr, which would increase to 2.6±0.6 m/yr between 2010 and 2046 due to accelerated global mean sea level rise, implying a future coastline recession of 92.5±20 m with a cumulative release of ~625,000 m^3 of rock. The calculated coastal retreat, presented herein, implies significant impacts on local infrastructure, including the loss of approximately 100 urban constructions of MD. In addition, the 2046 coastline would be located *ca*. 50 m from the main road that connects Arboletes with Montería city. As observed in this study, climate change-driven sea level rise may exacerbate already important coastal hazards along the littoral zone of MD. These results will help inform policy makers and enable improved local coastal management solutions.

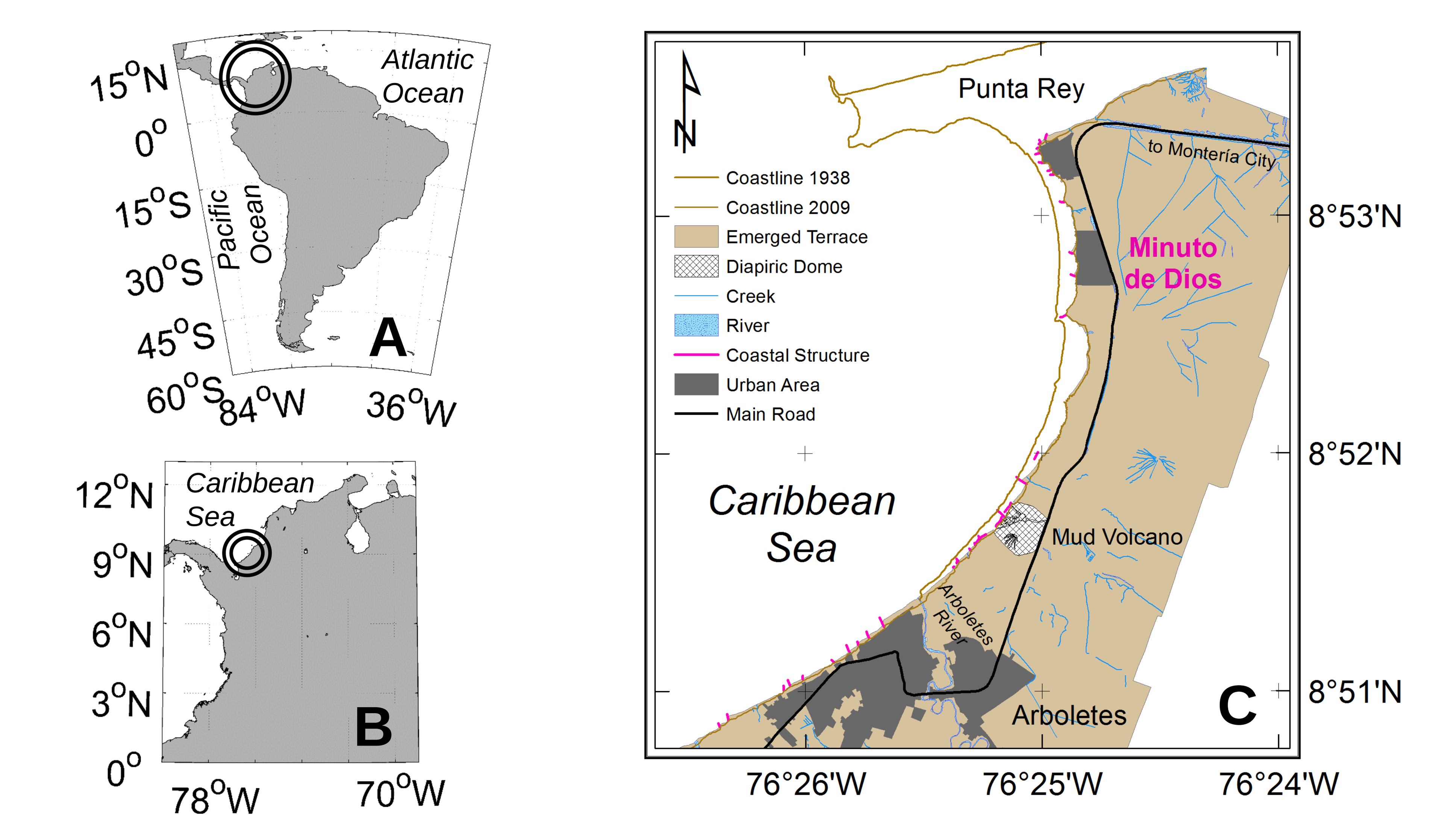

Figure 1. Study area showing the location of Minuto de Dios sector in the context of South America (**A**) and Caribbean of Colombia (**B**). Double ***black*** circles in **A** and **B** highlight the location of Southeast Caribbean and Arboletes, respectively. Map in **C** shows geomorphological information of the littoral of Arboletes as in 2009. Notice position of 1938 coastline, coastal structures, and diapiric dome associated to the mud volcano **[8, 9]**.

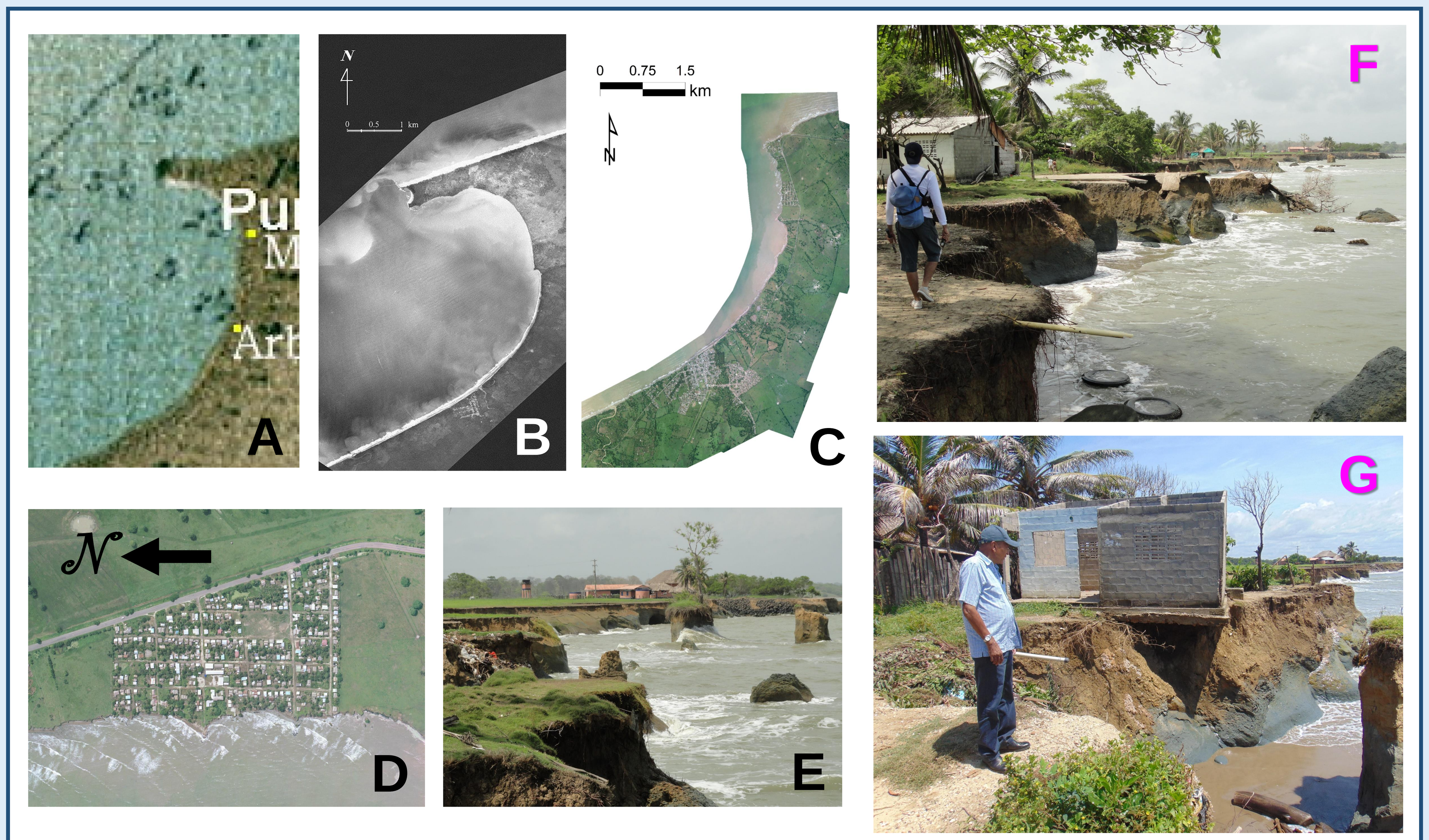

Figure 2. Physiography of Minuto de Dios coastline evidences recent, human-related coastline retreat. Historical cartography and aerial photos show Punta Rey peninsula in 1789 (**A**) and 1938 (**B**) that disappeared entirely by 2009 (**C**) **[9, 10]**. Aerial view of MD littoral is characterized by irregular, erosional contours (**D**) with presence of stacks, caves, mass movements, and notches (**E**). Urban constructions suggest an acceleration in coastline retreat since 2009: ~8 m in 2012 (**F**) and ~40 m in 2015 (**G**), *cf.* **Fig. 4**.

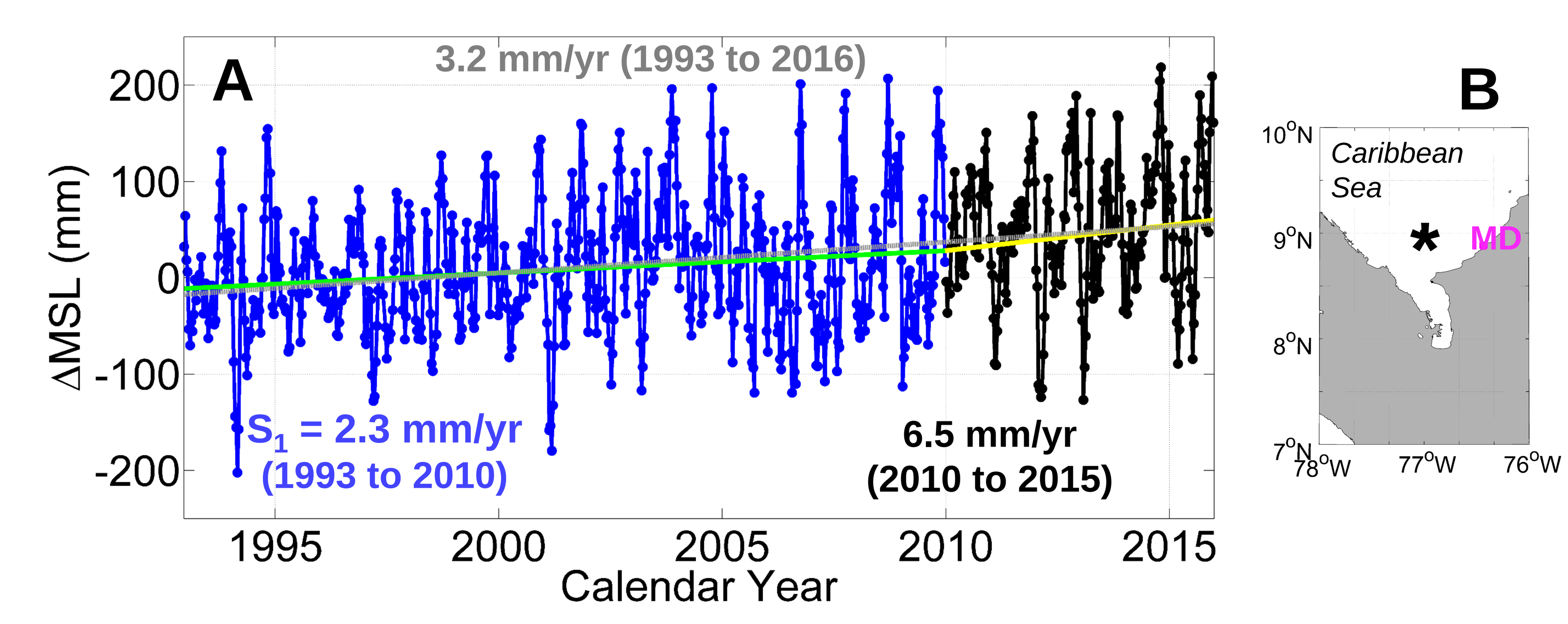

Figure 3. Mean sea level near MD littoral (**A**) measured by satellite altimeters at 9°N, 77°W (* in **B**). Values were discriminated in three groups: from **1993 to 2010** (**S_1 = 2.3 mm/yr**), between **2010 and 2015** (**rate 6.5 mm/yr**), and from 1993 to 2015 (3.2 mm/yr) **[11]**. Future rate in mean sea level, **S_2 = 5.1 mm/yr** was quantified as the slope of the line that matches the regression of blue values in 2010 and projected level in 2100 (~1 m above 19th century mean) **[1]**.

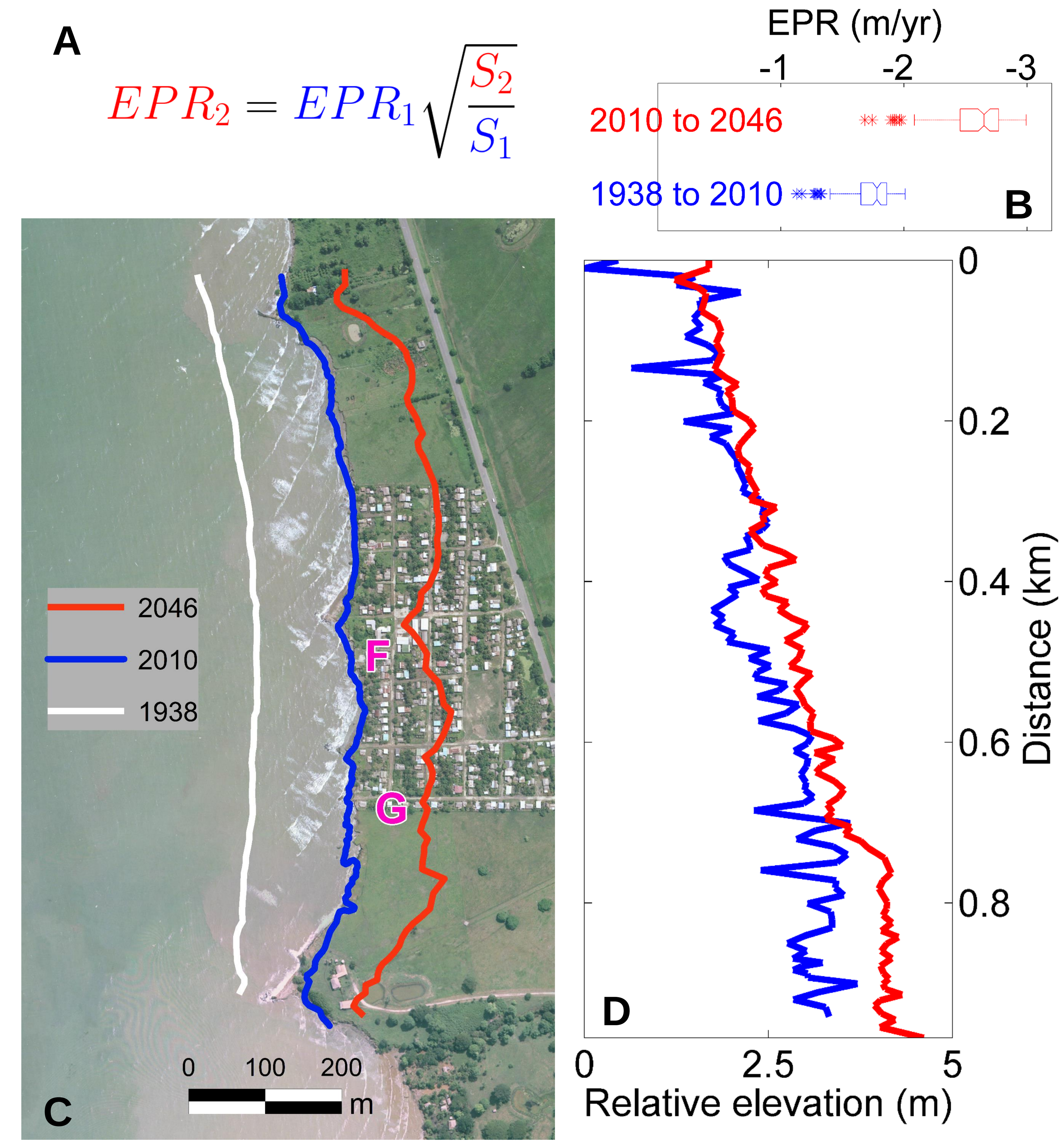

Figure 4. Coastline of 2010 was projected to 2046 using SCAPE equation (**A**) **[6, 7]** along with mean sea levels (*cf.* **Fig. 3**) and End-Point-Rate (EPR) values for each temporal window (**B**). Predicted coastline was drawn on top of available aerial imagery to assess possible infrastructure losses (**C**). Notice urban constructions in **Fig. 2** F and G that may indicate an acceleration in present erosional trends and the underprediction of future coastline retreat. Elevation of cliff-top positions relative to northernmost location (**D**) shows a southward-oriented positive gradient on terrace's surface that may account for strata deformation caused by mud diapirism.

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