Triggering of the 2010 Haiti earthquake by hurricanes and possibly deforestation

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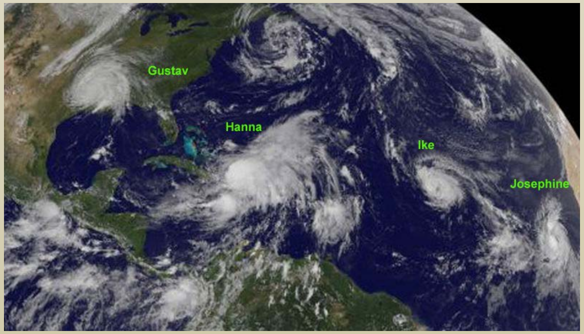


Haiti's 2008 hurricane season

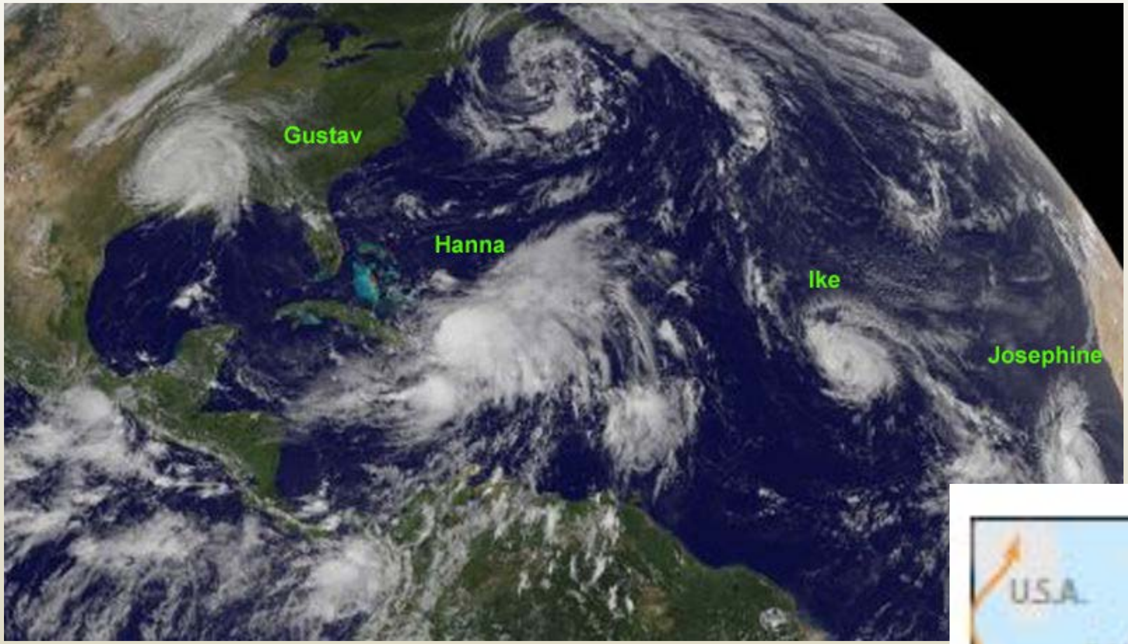
Death toll: > 800
Injuries:
Homeless: > 150,000

2010 Haiti earthquake

Death toll: > 230,000
Injuries: > 300,000
Homeless: > 2,000,000

Are the two events related?

Haiti's 2008 hurricane season



Are the two disasters related?

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A Science Service Feature

? WHY THE WEATHER ?

Dr. Charles F. Brooks,
of Clark University.
discusses:

EARTHQUAKES AND STORMS

The coincidence of earthquakes and intense cyclones has often been noted. Where conditions are ripe for an earthquake the earth's crust is in an unstable condition. It is possible that the stresses accompanying the passage of a severe cyclone may be sufficient to initiate the quake.

It is clear that tropical cyclones subject the earth's crust to an appreciable and relatively sudden strain, especially on coasts. A drop of two inches in baro-metric pressure means that a load of about two million tons is removed from each

Dynamic triggering of the 1923 Kanto (Tokyo) earthquake

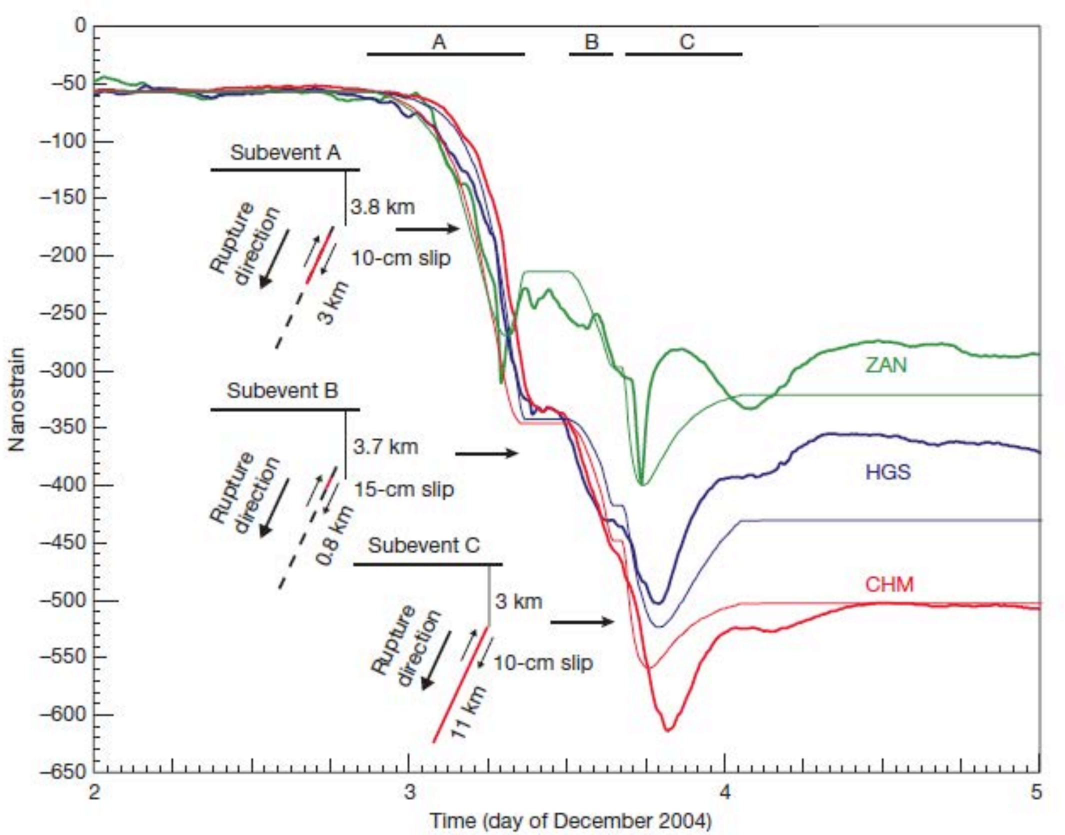
Brooks (1924)

Are the two disasters related?

Slow earthquakes triggered by typhoons

ChiChing Liu[1], Alan T. Linde[2] & I. Selwyn Sacks[2]

Nature 2009



Slow strain release 2-3 days after the typhoon.

<u>Mechanism:</u>
The typhoon's lower pressure results in a very small unclamping of the fault that must be close to the failure condition for the typhoon to act as a trigger.

Are the two disasters related?

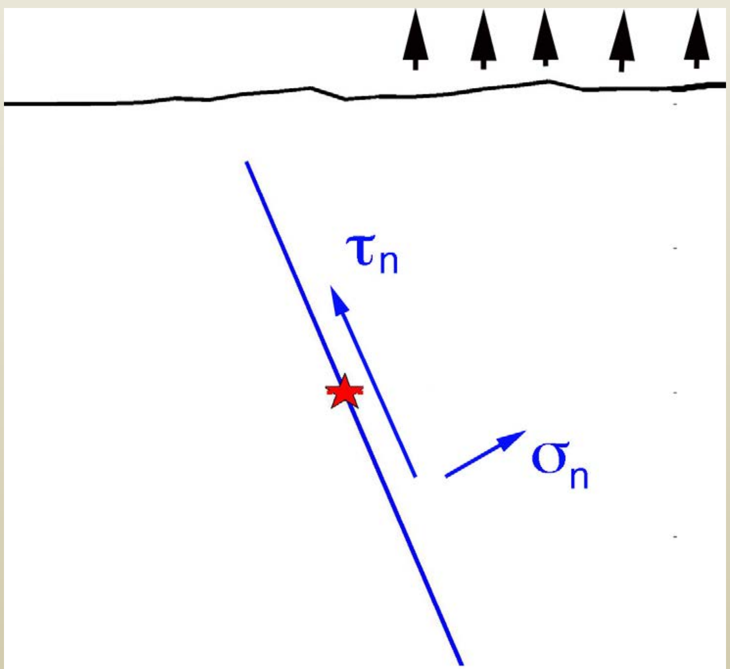
Deforestation

Hurricanes

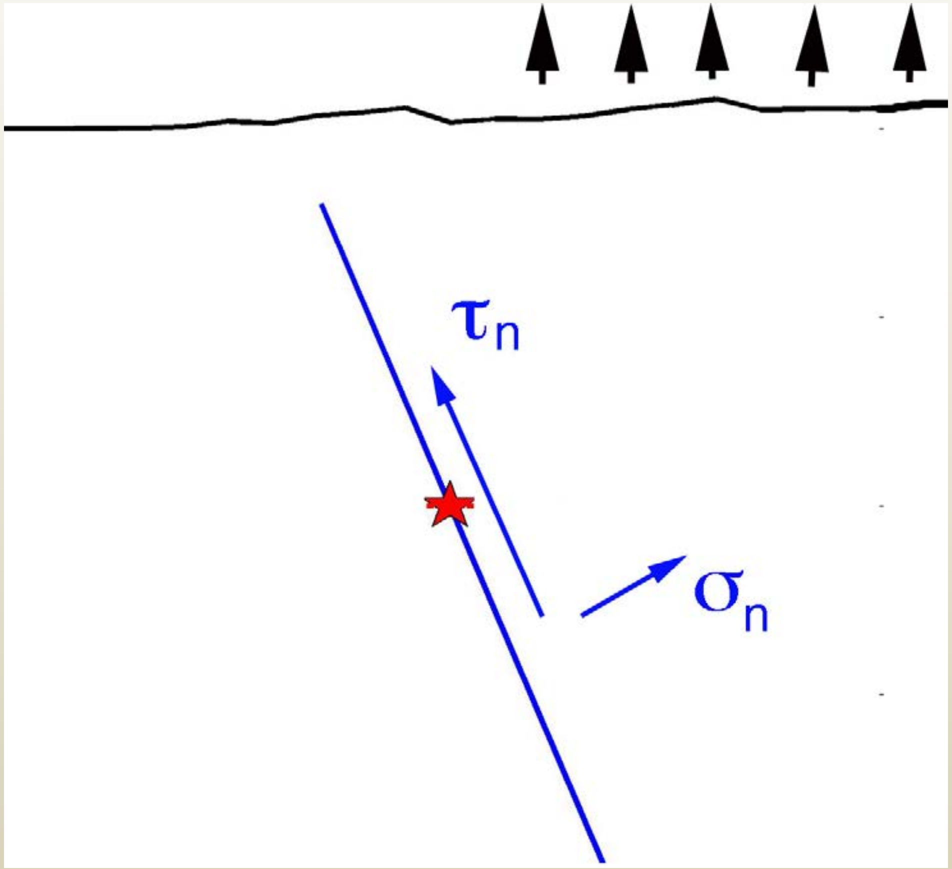
Rapid erosion ⇔ Surface unloading

Stress change at hypocenter

Earthquake triggering

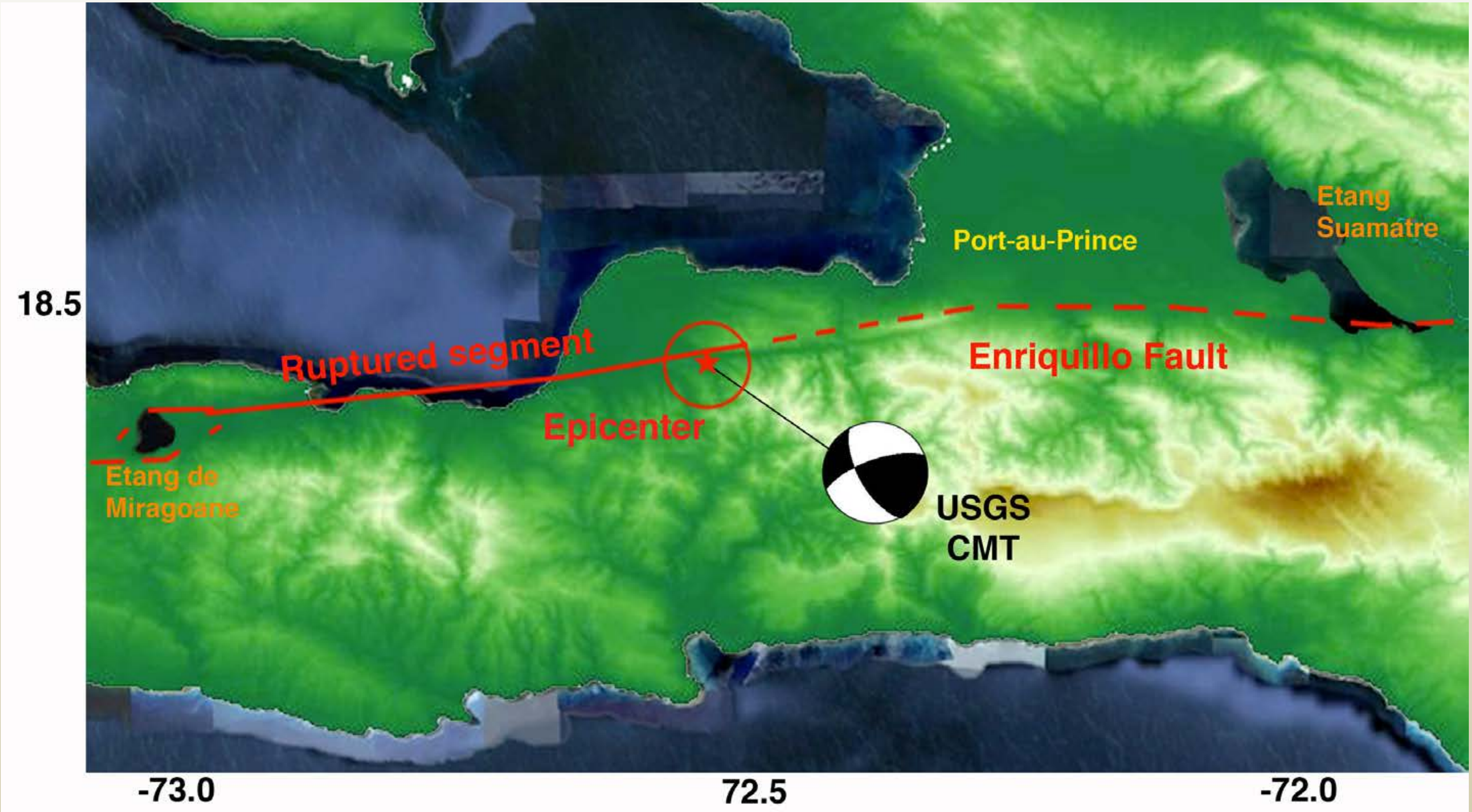


Coulomb failure calculations

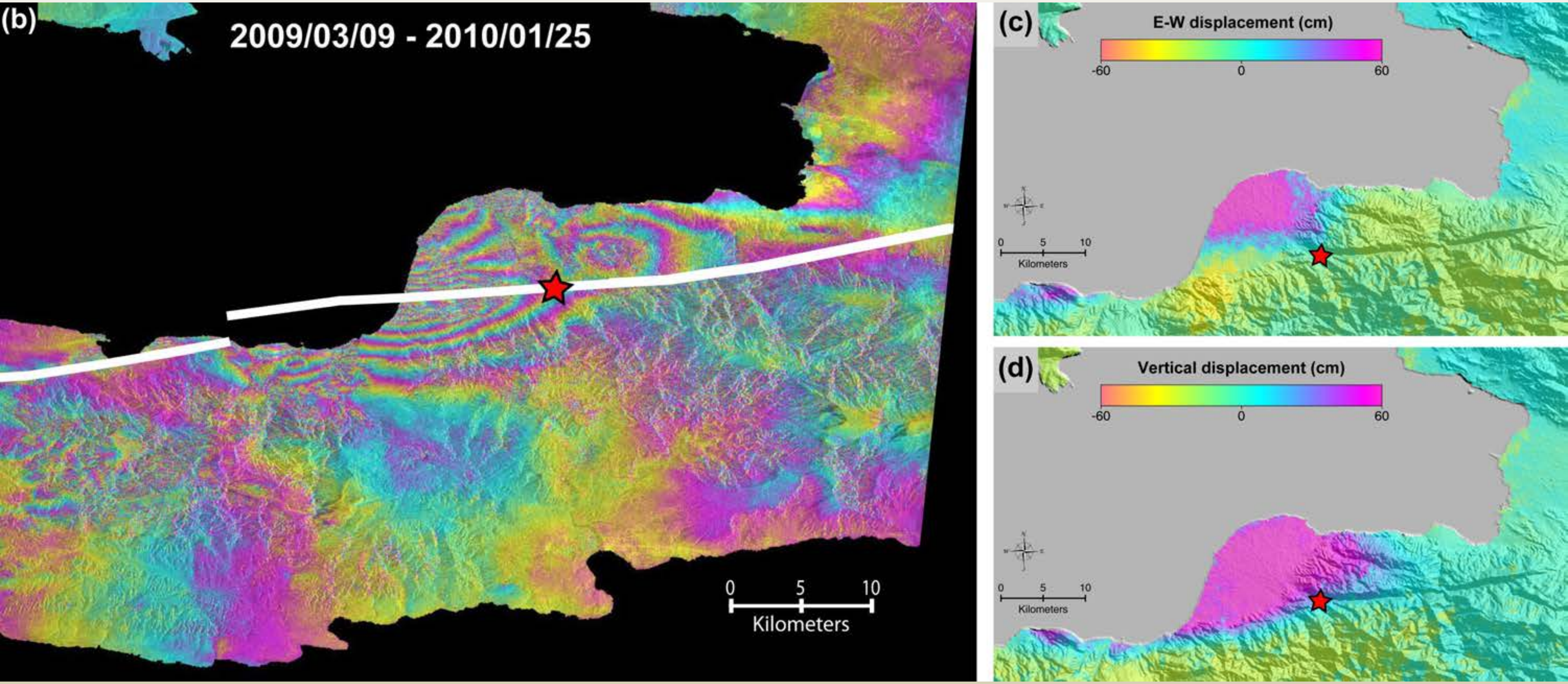


Surface unloading encourages reverse faulting due to:
Increase of vertical shear (τ)
Decrease in normal stress (σ_n) – unclamping the fault surface

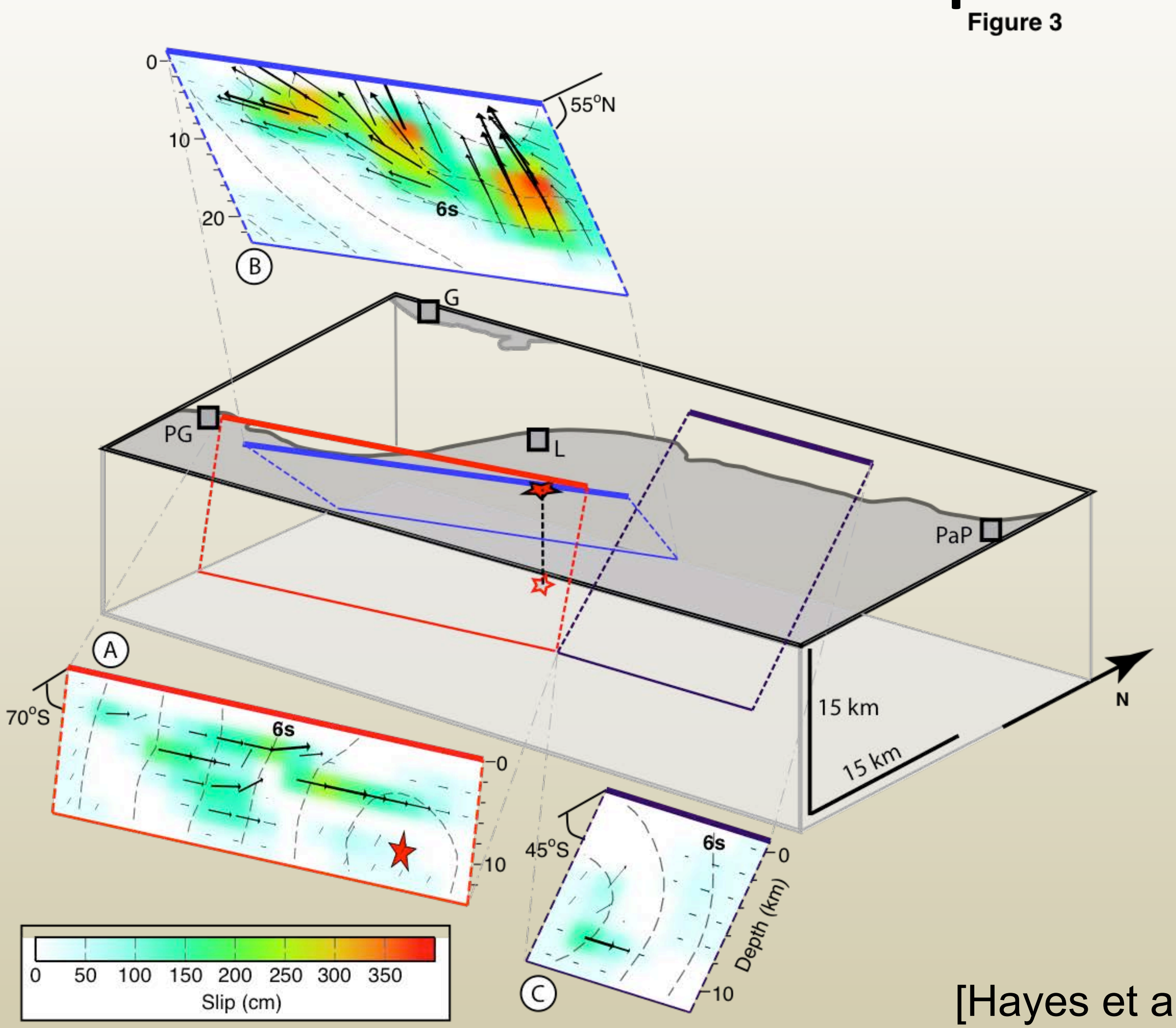
The 2010 Haiti earthquake



Geodetic observations



The 2010 Haiti Earthquake



[Hayes et al., 2010]

Epicenter location

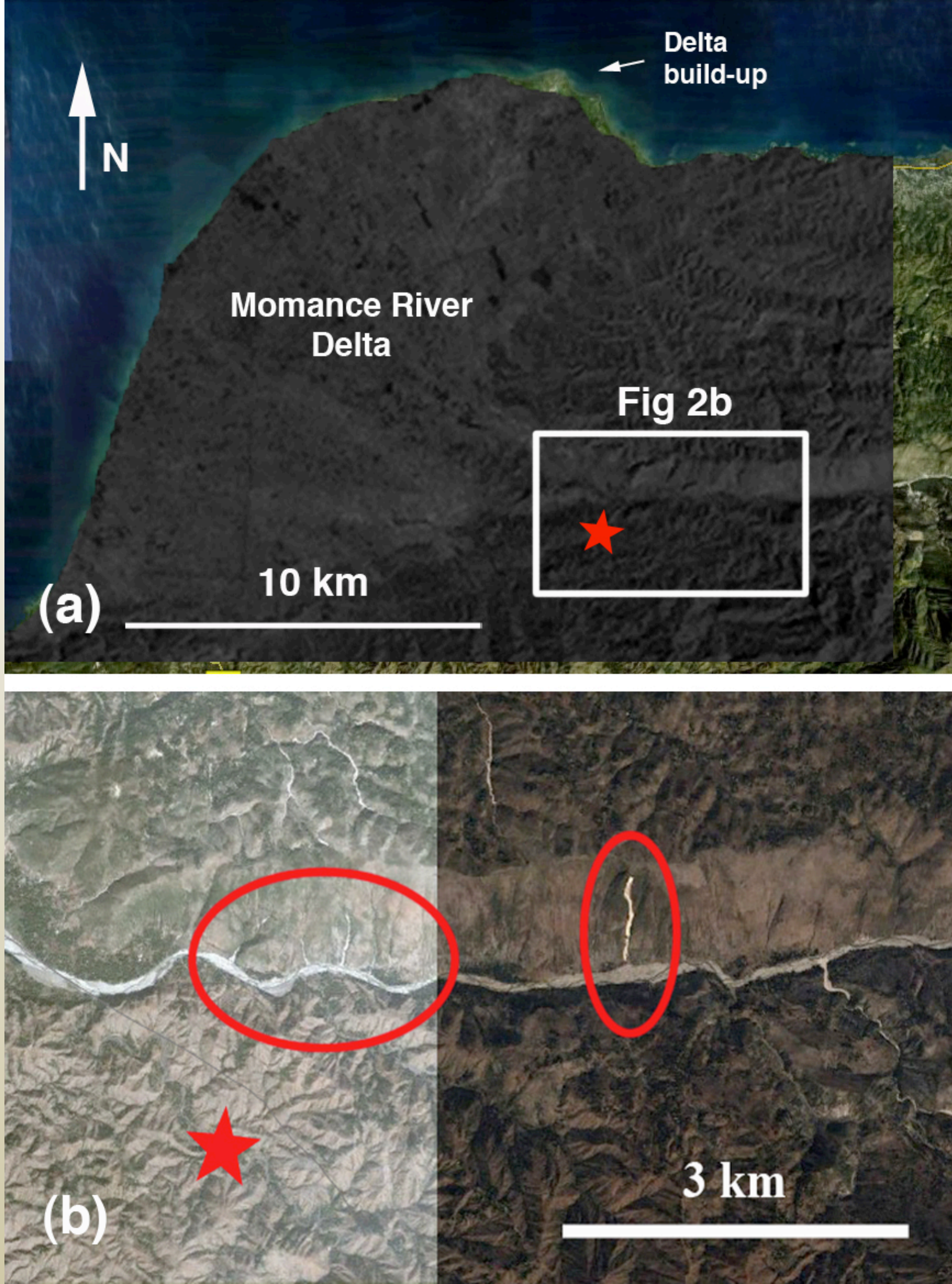
Why here?
Why in 2010? - 18 months after the 2008 hurricane season.

Epicenter location

Mountainous area with drainage to the largest delta in Hispaniola

Suggested mechanism:
Earthquake was triggered due to surface unloading (erosion)

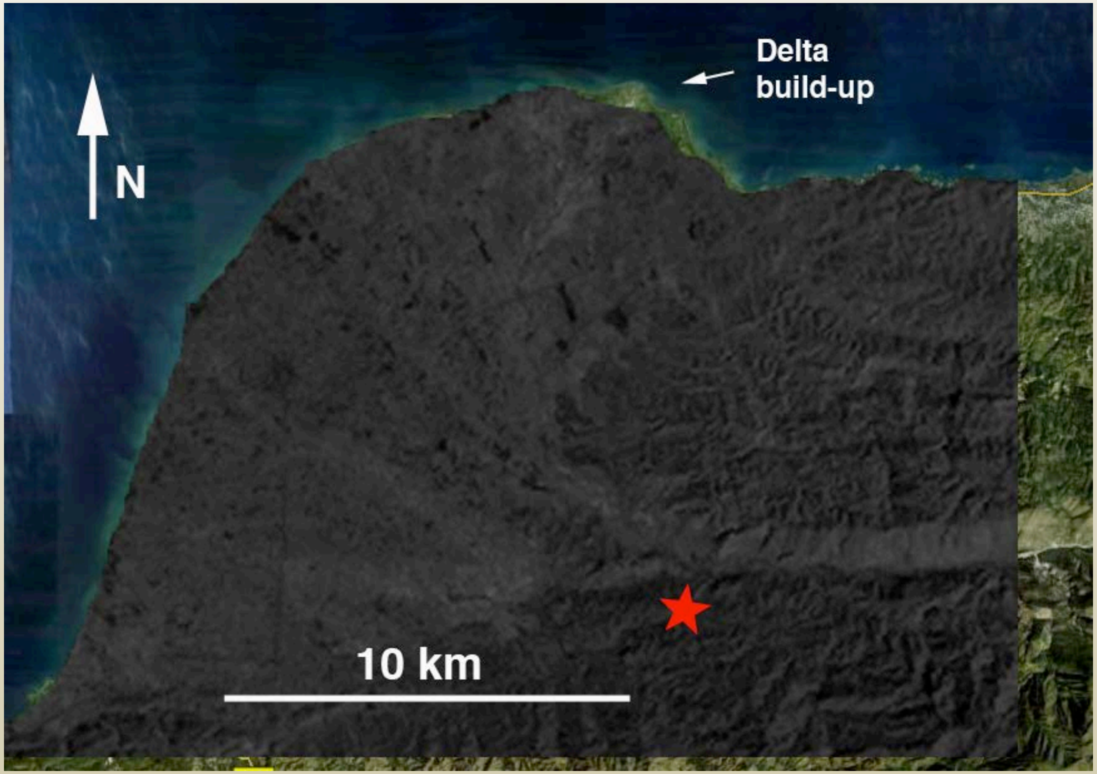
Surface unloading



Comparison between 2010 GoogleEarth and 1975 Landsat images

Landslides formed in 2008 after the hurricane season.

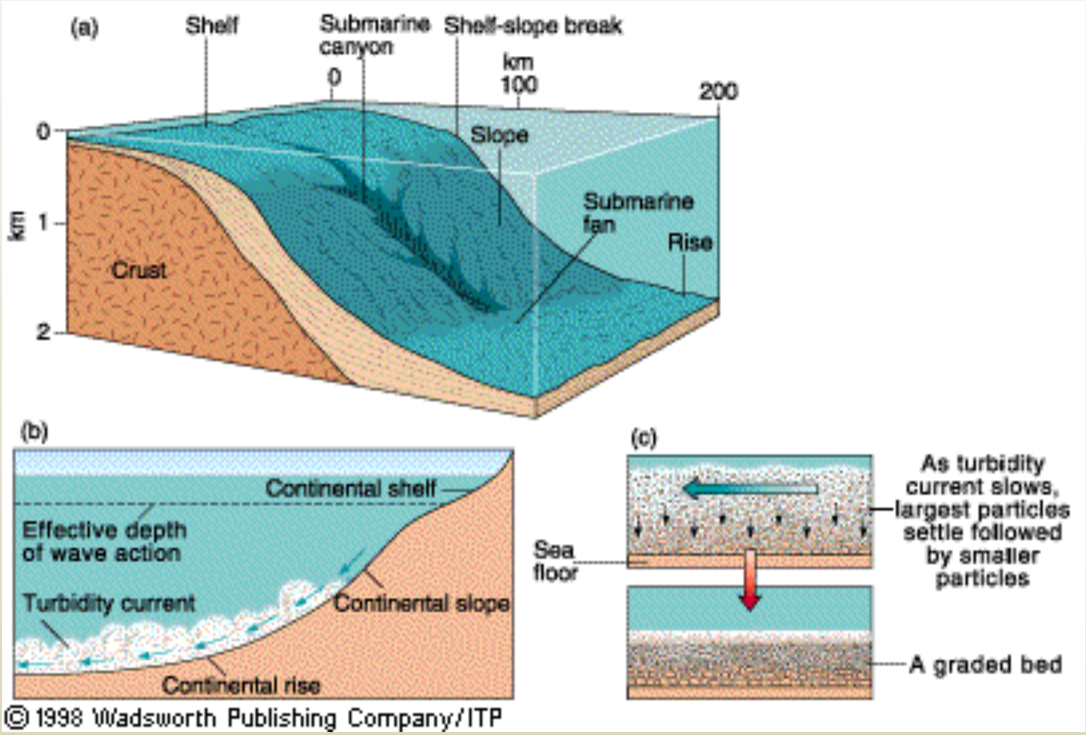
Sediment removal from the epicenter area



Comparison between 2010 GoogleEarth and 1975 Landsat images

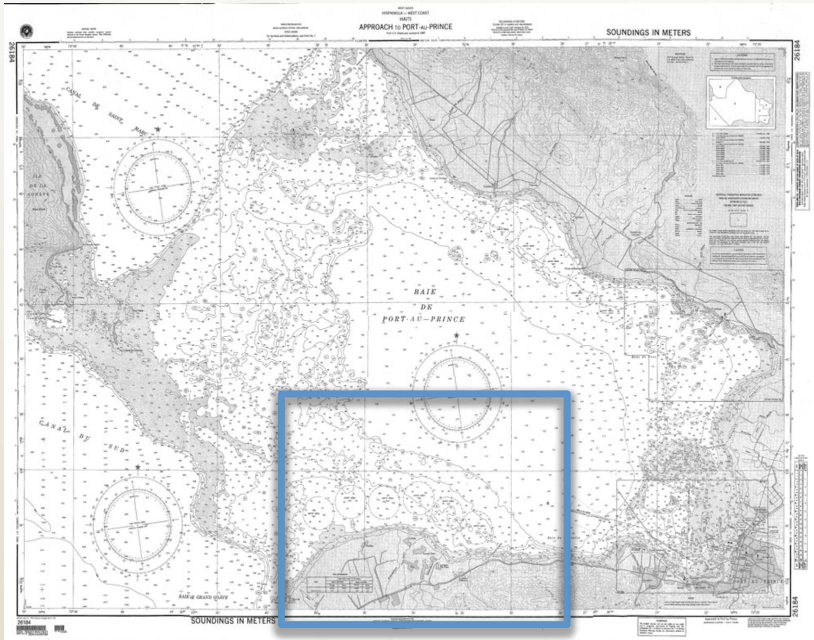
Delta build-up ~300 m surface addition along 3 km shoreline

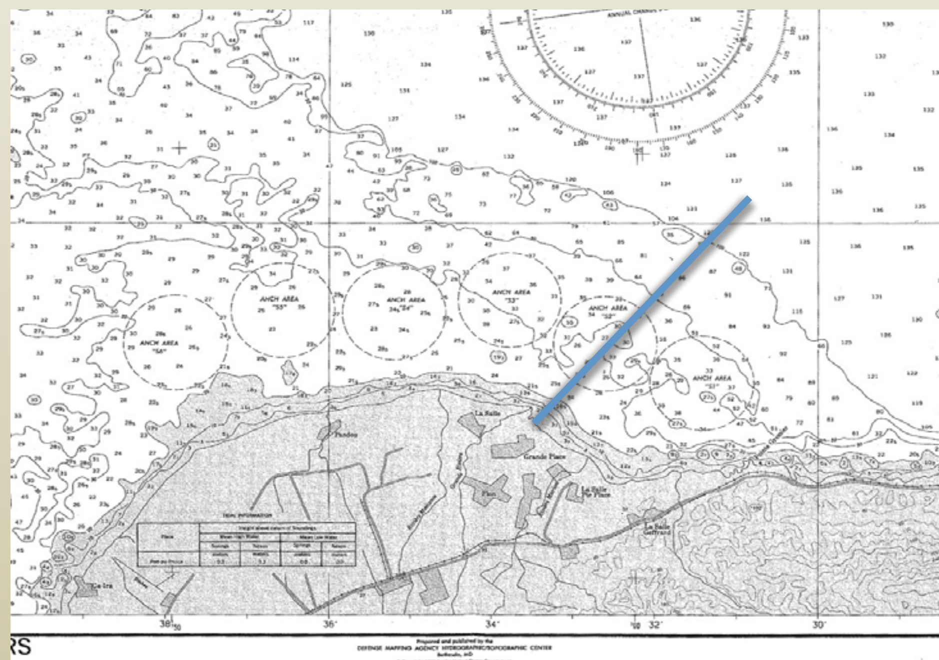
Sediment deposition in the delta



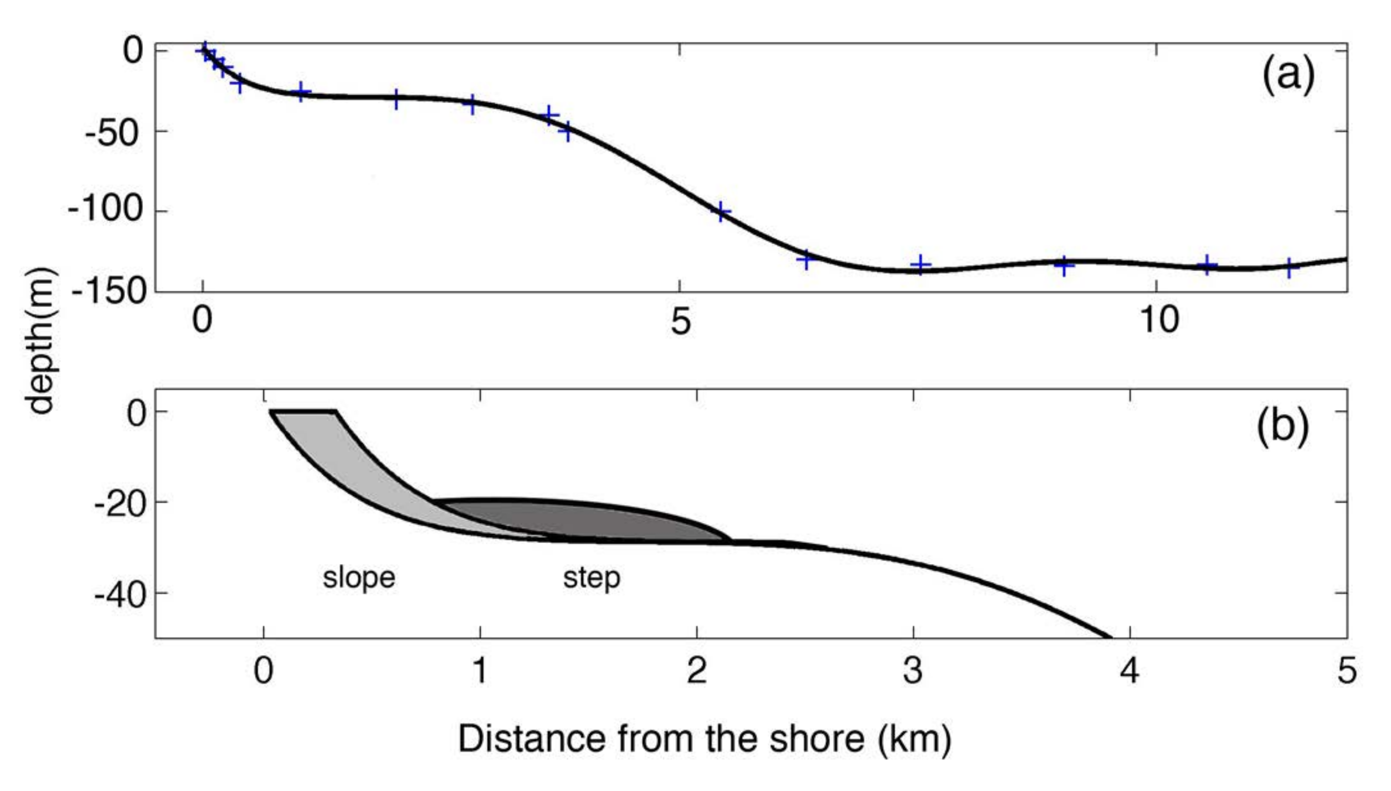
Submarine delta slopes are 1-2%
Any onshore land addition must be supported by sediment accumulation along the slopes.

Nautical Chart





Sedimentation deposition in the delta



Sediment accumulation 1975-2010 (slope only)

Lower bound $V = 3x10^7\ m^3$

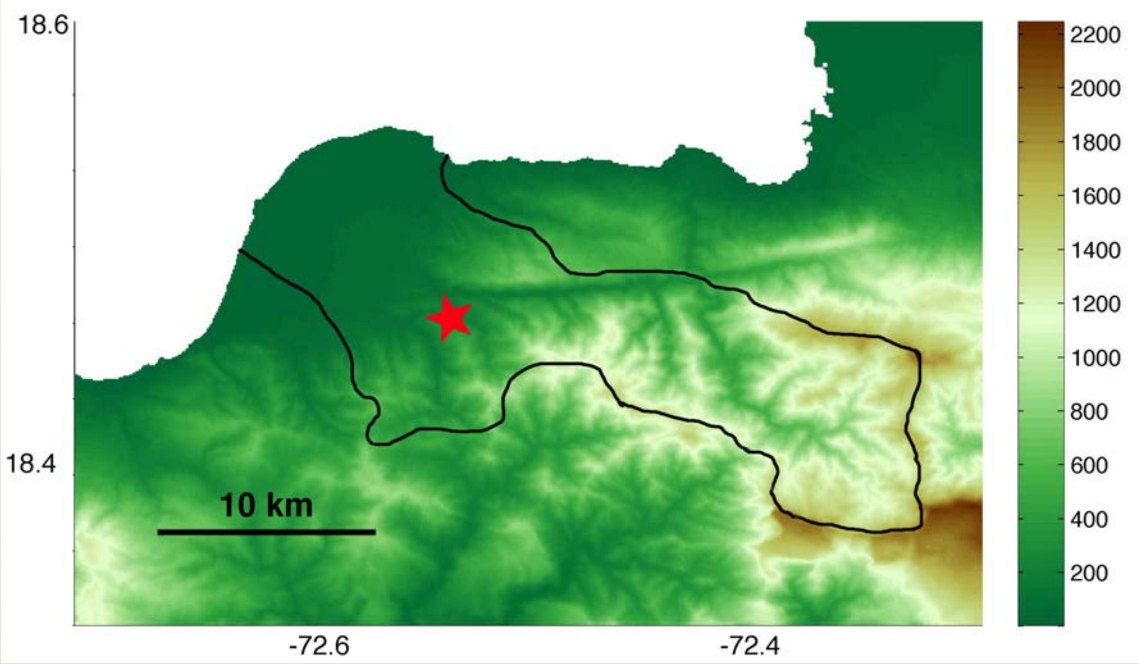
Unloading estimate

$$\text{Erosion rate} = \frac{\text{sediment volume}}{\text{watershed area*}} = \frac{3\text{x}10^7\ m^3}{140\ km^2} = 6\ mm/yr$$

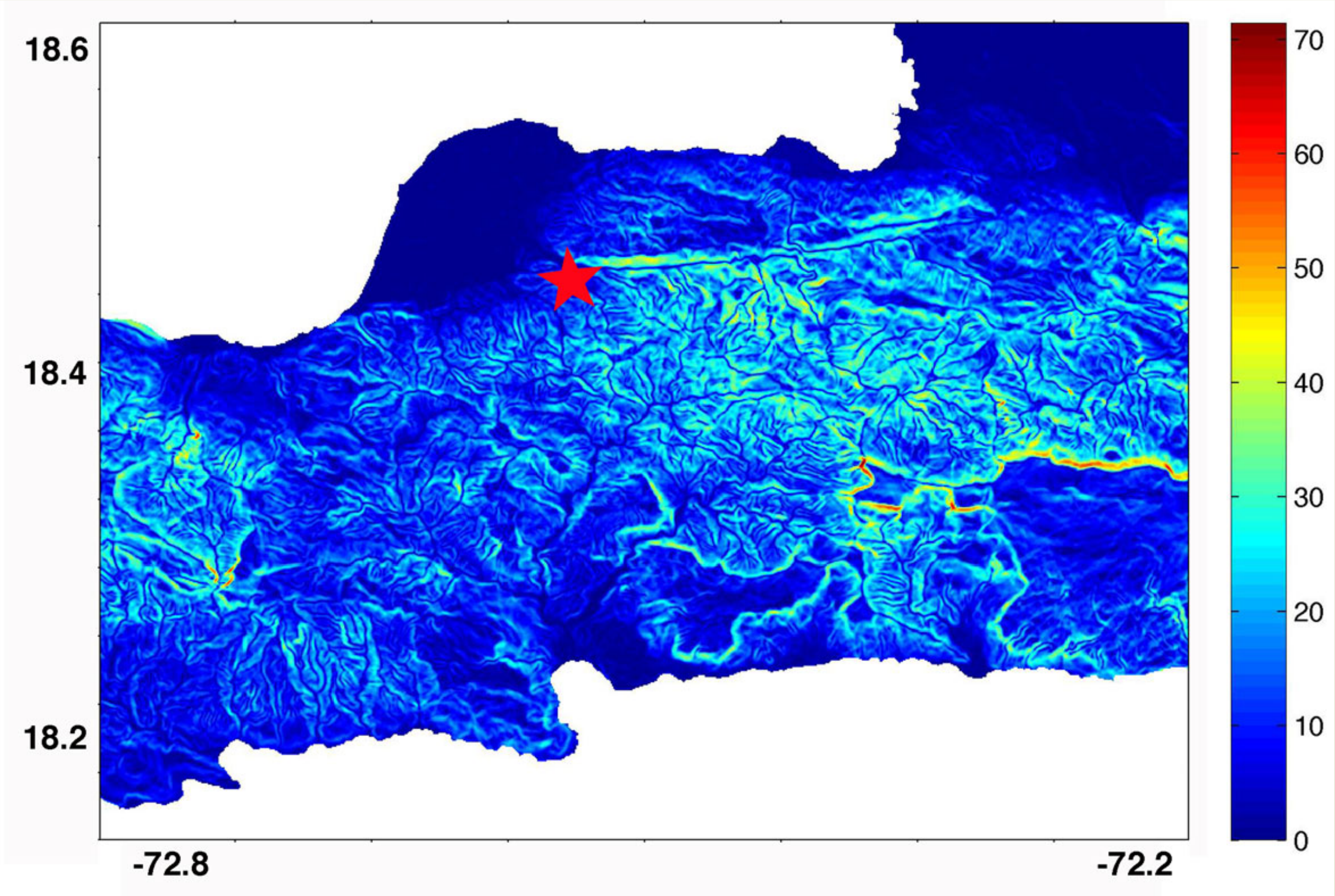
* Watershed area – high relief area that contributed to erosion

Erosion rates

- Tropical vegetated area < 1 mm/yr
- Active mountain belts in the tropics (Taiwan) 2-6 mm/yr.
- High erosion rate due to deforestation (?).

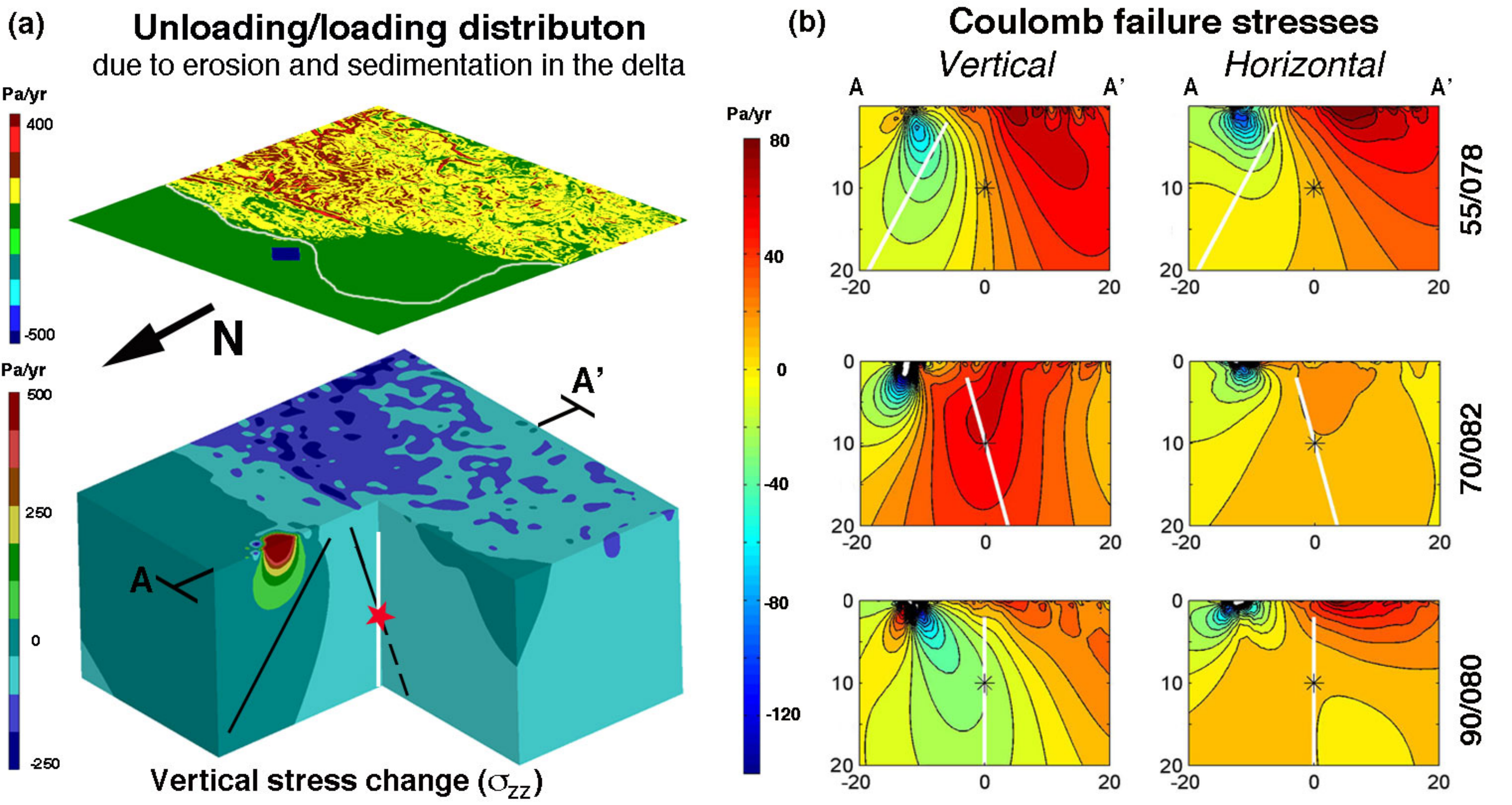


Stress changes due to distributed unloading



Assumption: Erosion $\propto$ Topography gradient

Stress changes due to distributed unloading



Can erosion trigger the 2010 Haiti earthquake?

Tectonic loading **Failure stress change**

Strike-slip on the Enriquillo Fault - 6±2 mm/yr ➔ ~10^4 Pa/yr

Convergence normal to Enr. Fault ~1 mm/yr ➔ ~10^3 Pa/yr

Coulomb failure stress changes due to erosion

Strike-slip 10-15 Pa/yr (~ 0.1% of tectonic loading)

Reverse-slip on south dipping fault – 50-60 Pa/yr

(~5% of tectonic loading)

Recurrence interval for thrust events 2500-3500 years

(2.5-3.5 m of slip / ~ 1mm/yr strain accumulation)

Accumulated failure stress changes over earthquake cycle

1-2x10^5 Pa >> triggering threshold (10^3-10^4 Pa)

Why did the earthquake occurred after the 2008 hurricane season?

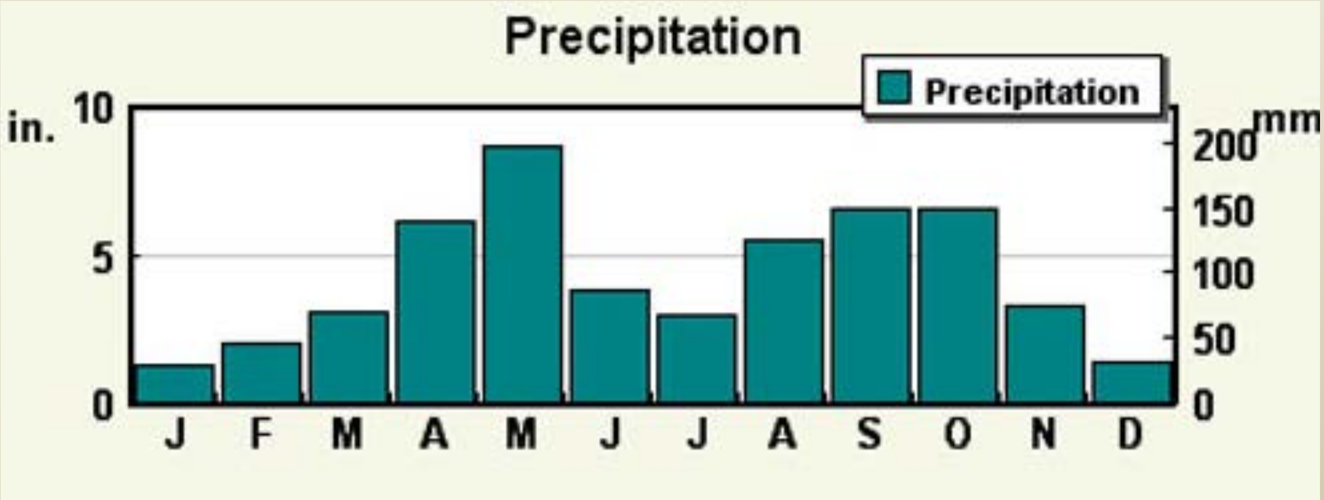
- Average Hurricane/T.S. occurrence in Haiti < 1 a year
- The 4 Hurricanes/T.S. occurred in 2008 is ~ 6 *x* average.
- 3 of the storms (Fay, Gustav, Hanna) were unusually wet
- The heavy rain occurring in 2008 was capable of transporting massive sediments from the epicenter area to the Bay.

Estimated Coulomb failure changes for 2008

- 6-10 times the average change
- 300-500 Pa (occurring within 30 days)

Why did the earthquake occurred 18 months after the 2008 season?

- Some of the rain was stored as soil moisture, serving as a load inhibiting slip (earthquake).
- When some of the moisture was released, during the dry season, the earthquake occurred.



Possible anthropogenic triggering contributions

- The calculated a high erosion rate - 6 mm/yr
  - was obtained from remote sensing data
  - represents erosion processes in the past 35 years.

- Erosion rates over the past 35 years might be higher than before because:
  - <u>Higher hurricane destructiveness </u>(Emanuel, 2005), which correlate with increasing Sea Surface Temperature (global warming).
  - <u>Deforestation</u>.

- Understanding the role of these two possible effects require additional research.

Summary

- The 2010 Haiti earthquake occurred within a transcurrent plate boundary deformation zone and had a complex rupture.
  - The earthquake was initiated on a 70* southward dipping fault.
  - Most of the seismic energy was released from a 55* northward dipping blind thrust.
- The suggested denudation/sedimentation mechanism explains:
  - The earthquake was triggered on the southward dipping fault due to unloading.
  - The earthquake released a large amount of seismic energy on the northward dipping fault, which have accumulated due to the increasing sediment load of the delta.
- Hurricanes have contributed to efficient sediment transport from the epicentral area to the Bay. The 2008 hurricane season was efficient enough to remove a large load and trigger the earthquake.
- Triggering of the 2010 EQ may had an anthropogenic component due to higher hurricane destructiveness and deforestation in the past 35 years.

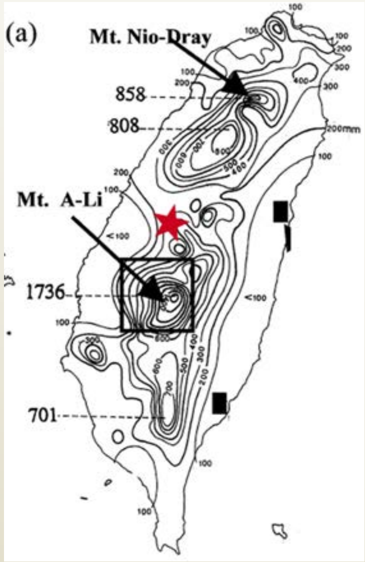
Other cases of earthquake triggering by tropical cyclones

The 1999 M=7.6 Chi-Chi earthquake

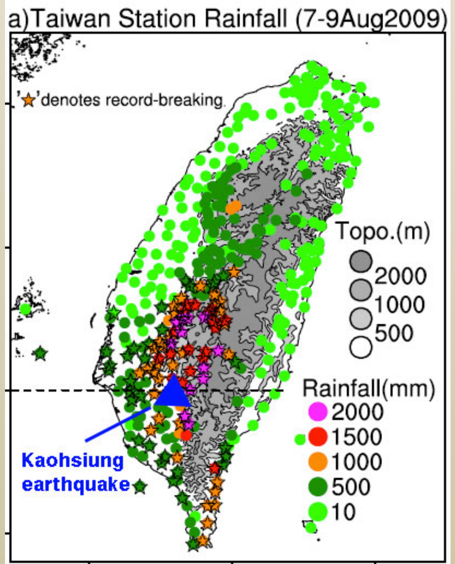
- Occurred 3 years after the 1996 Typhoon Herb poured heavy rain (> 1700 mm in 48 hours) in the same area and caused record high sediment discharge.

The 2010 M=6.4 Kaohsiung earthquake

- Occurred 6 months after the 2009 Typhoon Markot poured heavy rain (> 2800 mm in 100 hours) in the same area and caused hundreds of landslides



Wu et al. (2002)



Hong et al. (2010)

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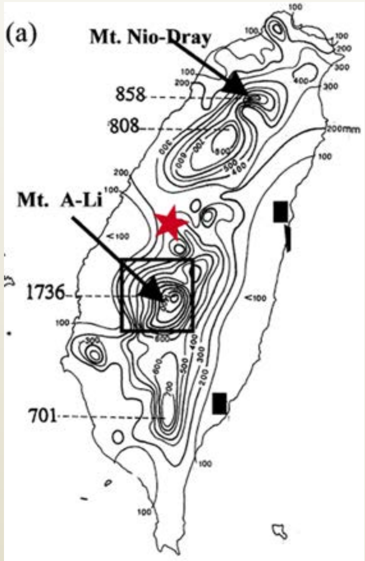

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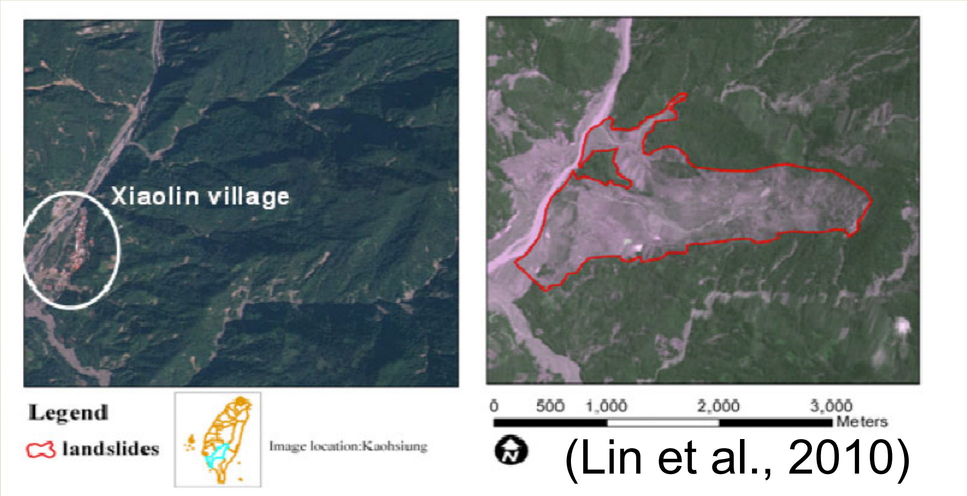
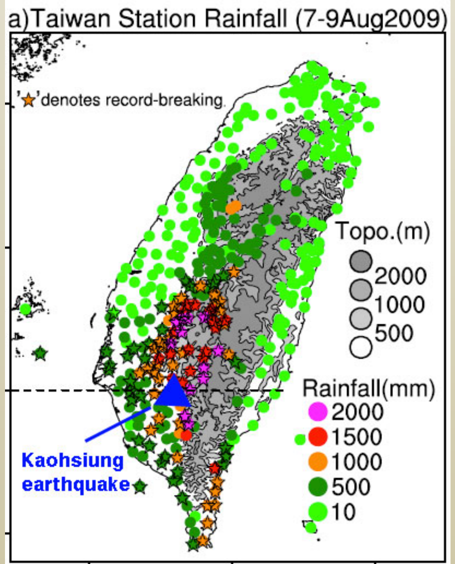
- 9
in
same



(Lin et al., 2010)



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