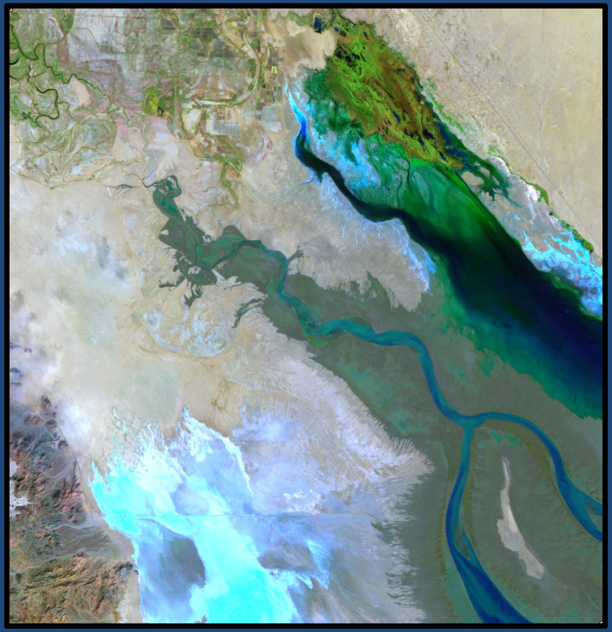
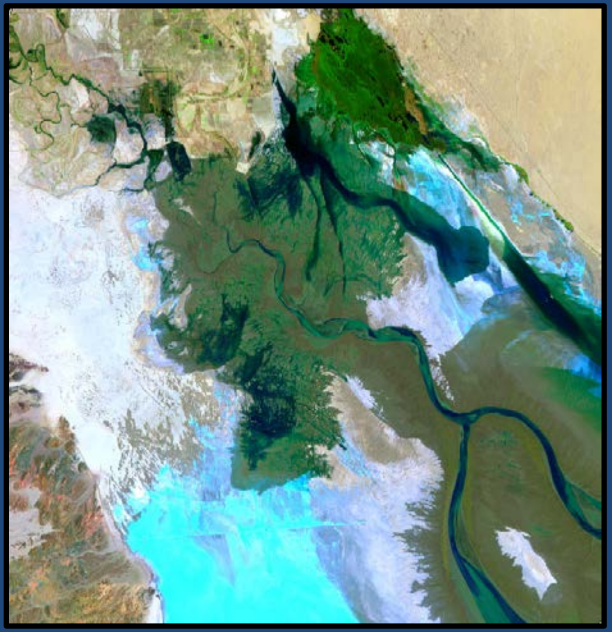
UAVSAR studies of earthquake related surface deformation in the Colorado River estuary, Mexico





1. Steven M. Nelson, 6101 NE 102nd Avenue Apt 5, Vancouver, WA 98662

2. Eric J. Fielding, Jet Propulsion Laboratory, California Institute of Technology, M/S 300-233, 4800 Oak Grove Drive, Pasadena, CA 91109

3. Francisco Zamora-Arroyo, Sonoran Institute, 44 E. Broadway Blvd., Suite 350, Tucson, AZ 85701

4. Karl Flessa, Department of Geosciences, University of Arizona, Tucson, AZ 85721

G Model
ECOENG-2312; No. of Pages 13

ARTICLE IN PRESS

Ecological Engineering xxx (2012) xxx–xxx
http://dx.doi.org/10.1016/j.ecoleng.2012.09.004

Contents lists available at SciVerse ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

ELSEVIER

Delta dynamics: Effects of a major earthquake, tides, and river flows on Ciénega de Santa Clara and the Colorado River Delta, Mexico

Steven M. Nelson[a,*], Eric J. Fielding[b], Francisco Zamora-Arroyo[c], Karl Flessa[d]

[a] 6101 NE 102nd Avenue Apt 5, Vancouver, WA 98662, United States
[b] Jet Propulsion Laboratory, California Institute of Technology, M/S 300-233, 4800 Oak Grove Drive, Pasadena, CA 91109, United States
[c] Sonoran Institute, 44 E. Broadway Blvd., Suite 350, Tucson, AZ 85701, United States
[d] Department of Geosciences, University of Arizona, Tucson, AZ 85721, United States

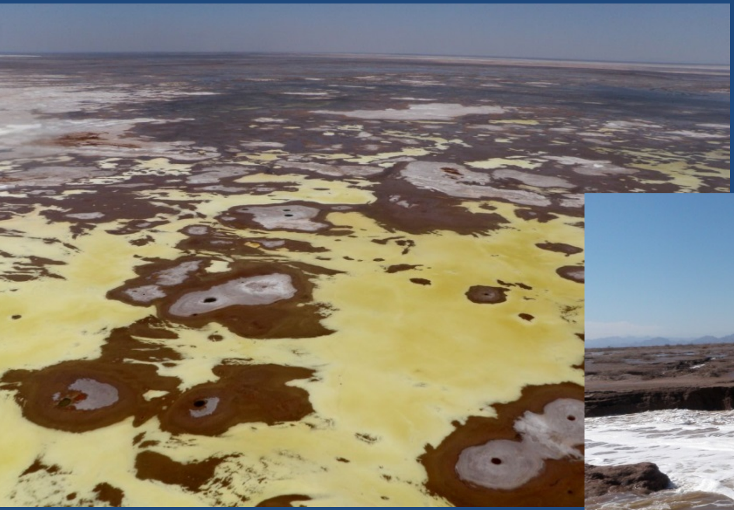
http://dx.doi.org/10.1016/j.ecoleng.2012.09.004

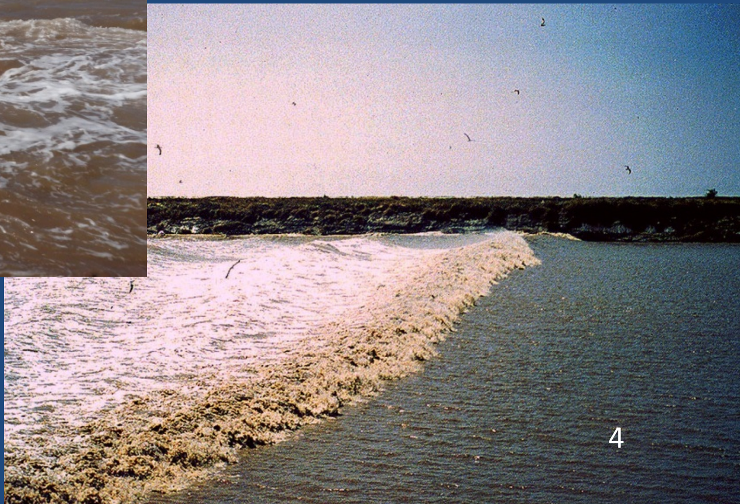
This study:

- Reviews historical interactions of tectonic, fluvial, and tidal forces
- Examines effects of the 2010 Mw 7.2 El Mayor-Cucapah Earthquake on changing patterns of tidal inundation
- Assesses effects of tidal changes on the fluvial/ hydrological regime of the Colorado River estuary and nearby Ciénega de Santa Clara wetland
- Provides information of practical value in planning and designing management measures and restoration projects for the estuary and Ciénega

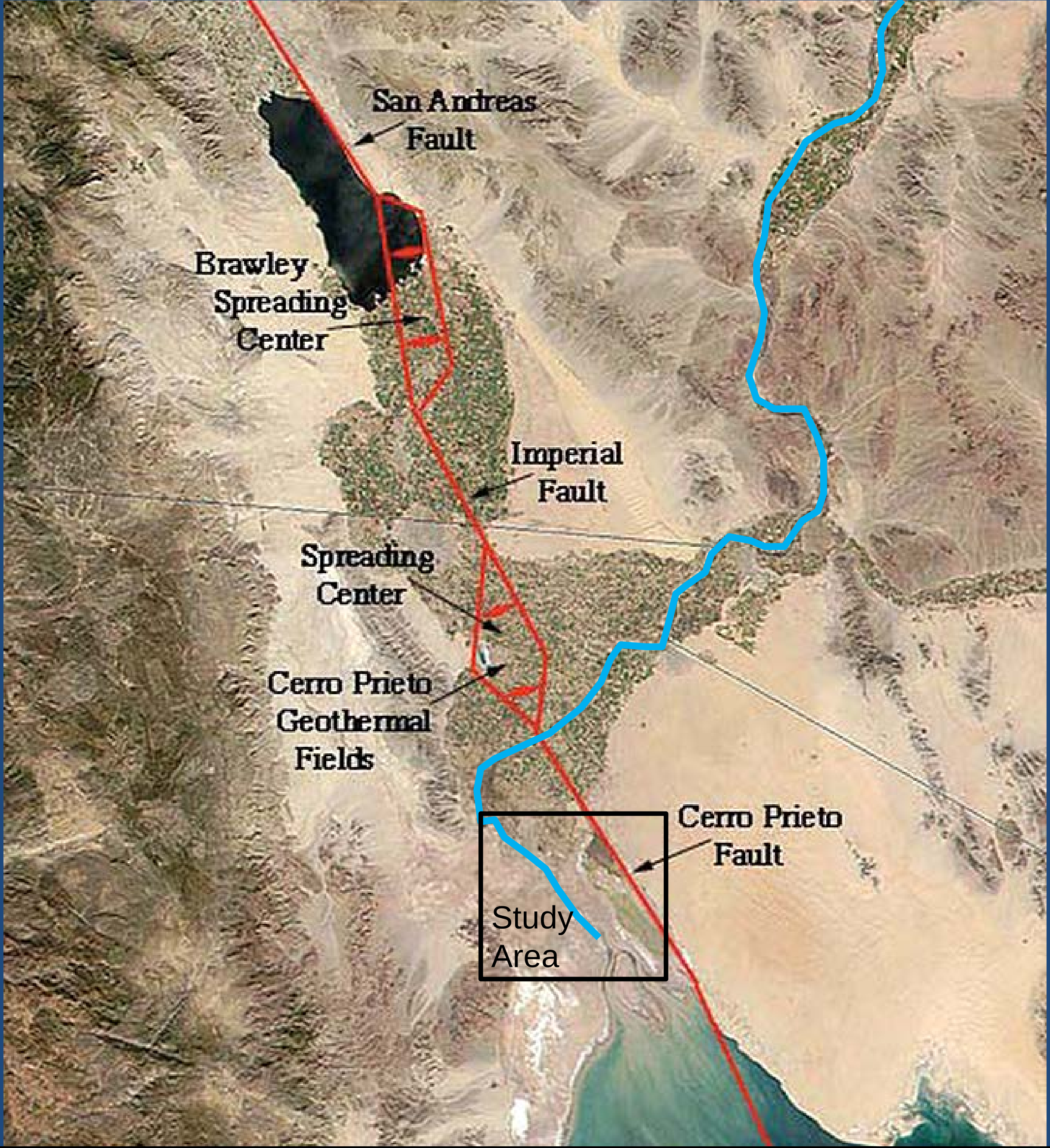
The Intertidal Colorado River Delta:

A dynamic environment subject to complex interactions of tectonic, fluvial, and tidal forces at the head of the Gulf of California.

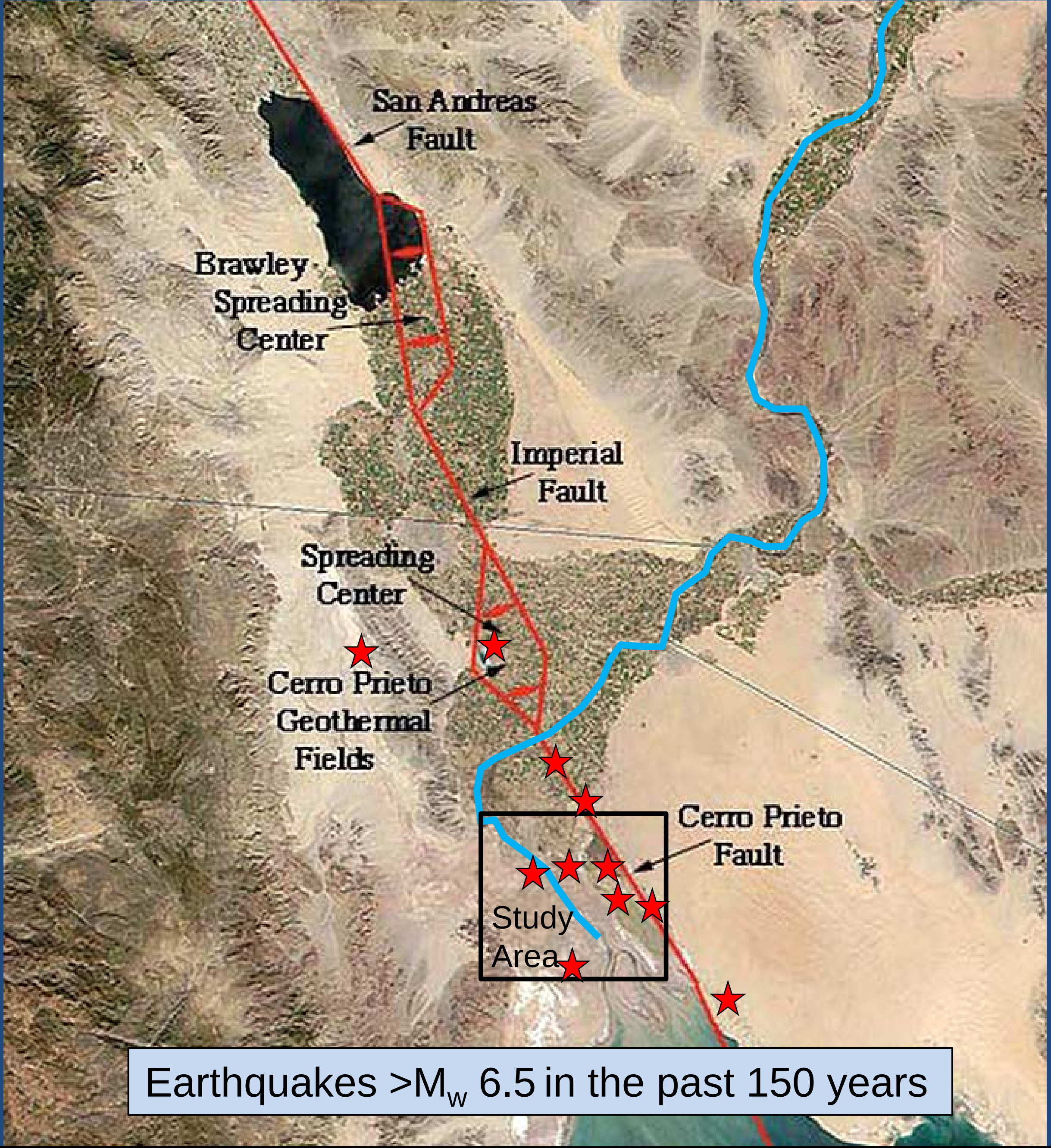




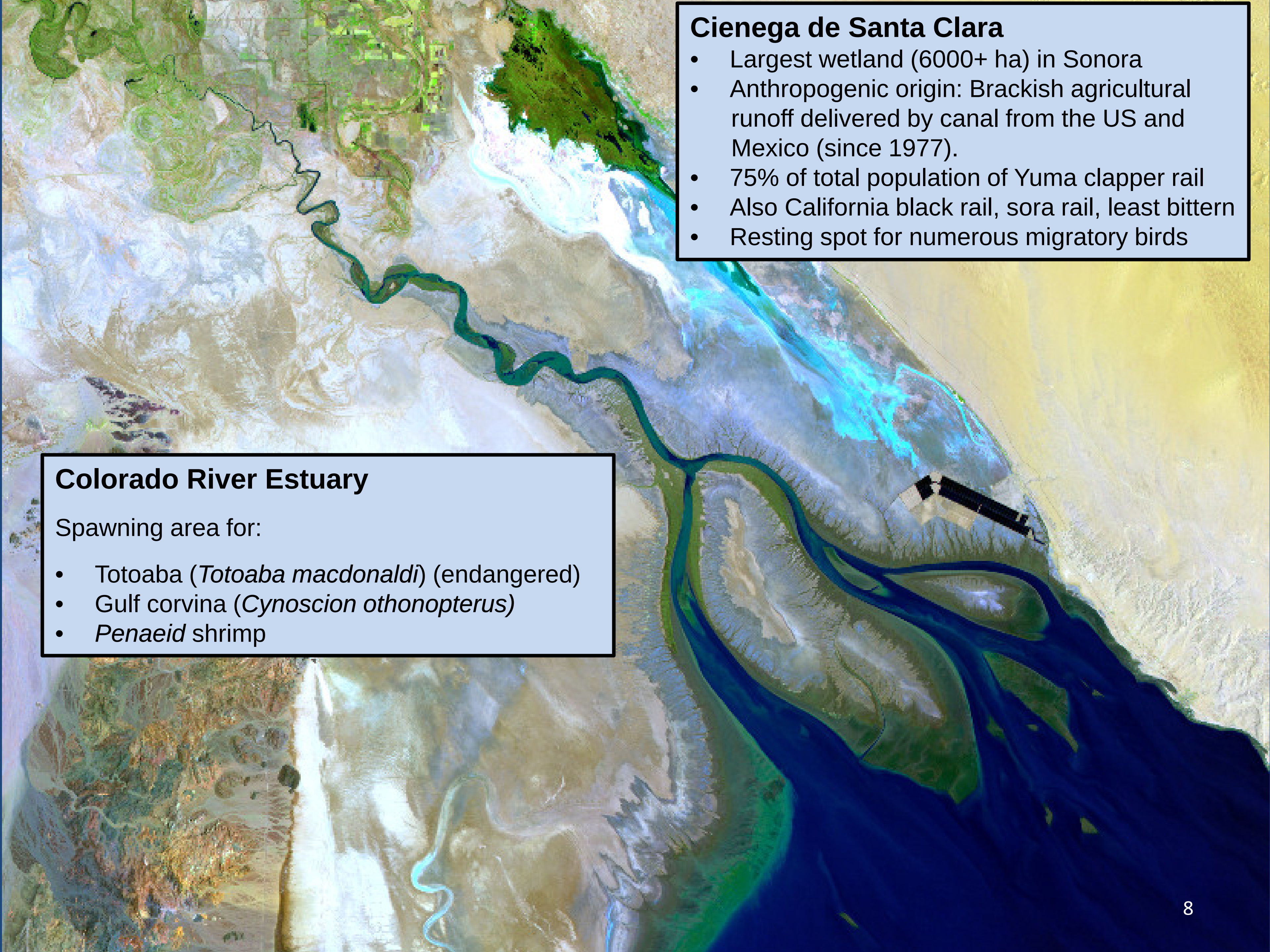
Modified from: Alles, D.L. 2011. Geology of the Salton Trough. Retrieved from http://fire.biol.wwu.edu/trent/alles/GeologySaltonTrough.pdf on February 25, 2012.



Modified from: Alles, D.L. 2011. Geology of the Salton Trough. Retrieved from http://fire.biol.wwu.edu/trent/alles/GeologySaltonTrough.pdf on February 25, 2012.



Modified from: Alles, D.L. 2011. Geology of the Salton Trough. Retrieved from http://fire.biol.wwu.edu/trent/alles/GeologySaltonTrough.pdf on February 25, 2012.



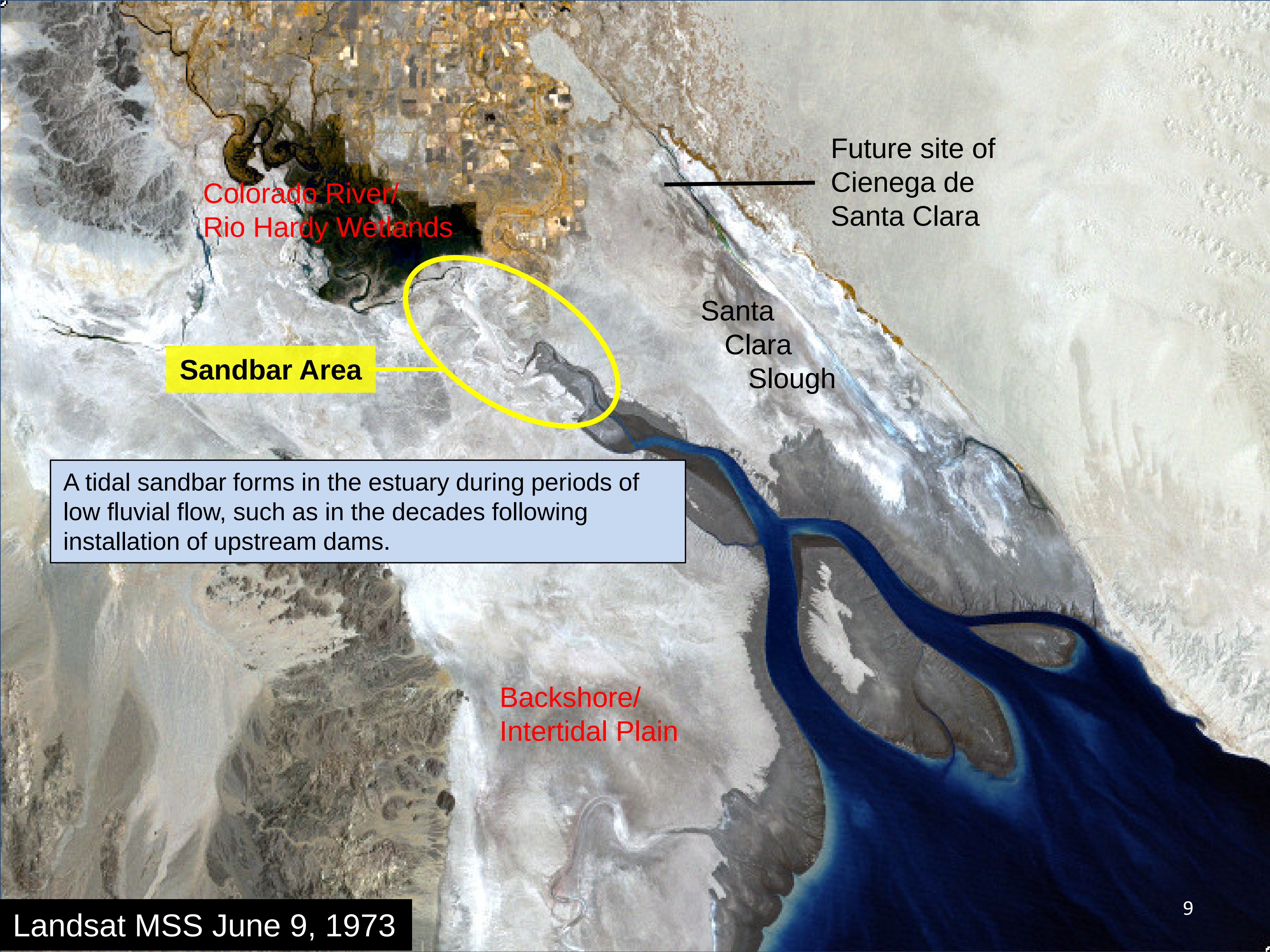
Cienega de Santa Clara

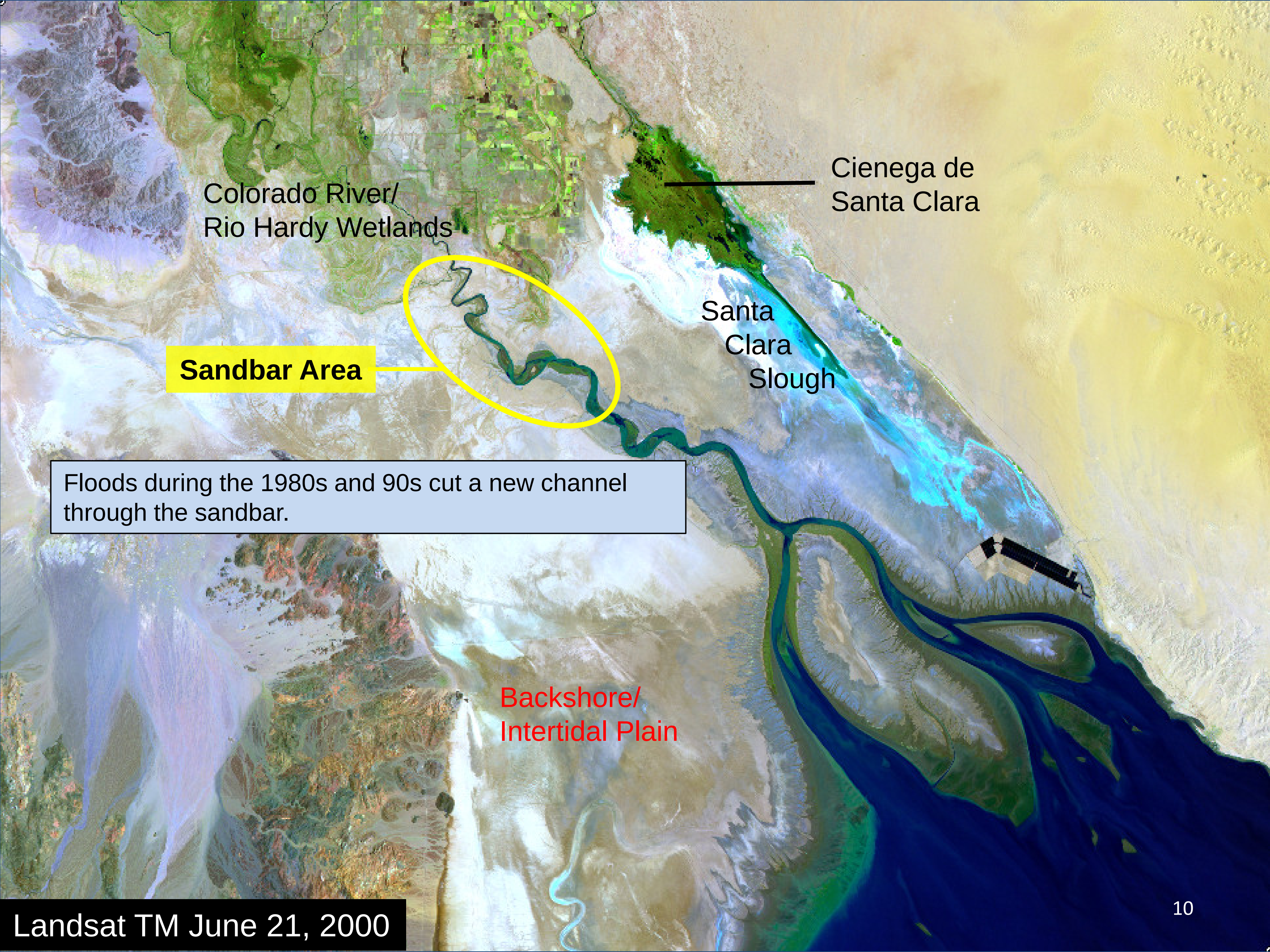
- Largest wetland (6000+ ha) in Sonora
- Anthropogenic origin: Brackish agricultural runoff delivered by canal from the US and Mexico (since 1977).
- 75% of total population of Yuma clapper rail
- Also California black rail, sora rail, least bittern
- Resting spot for numerous migratory birds

Colorado River Estuary

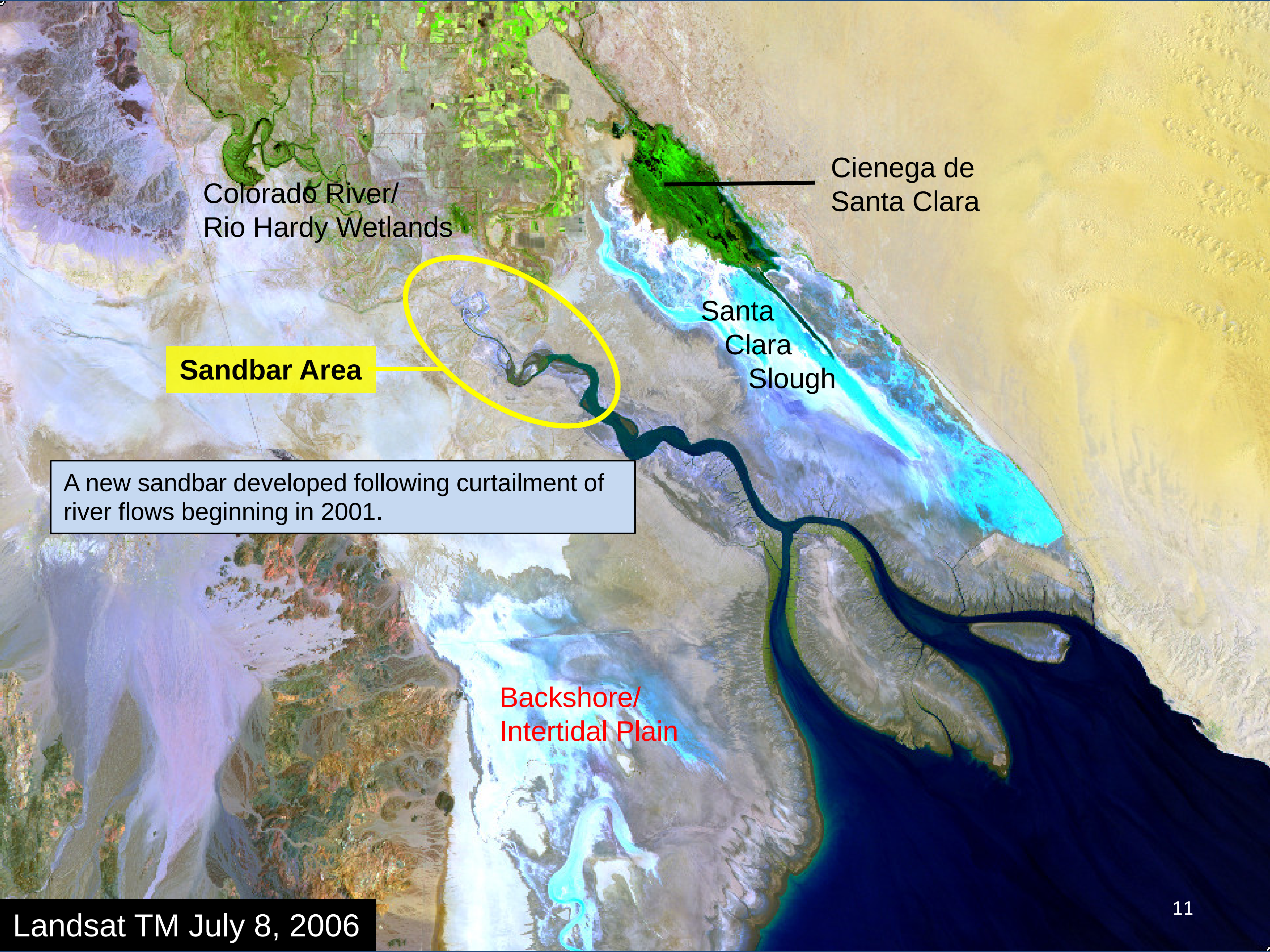
Spawning area for:

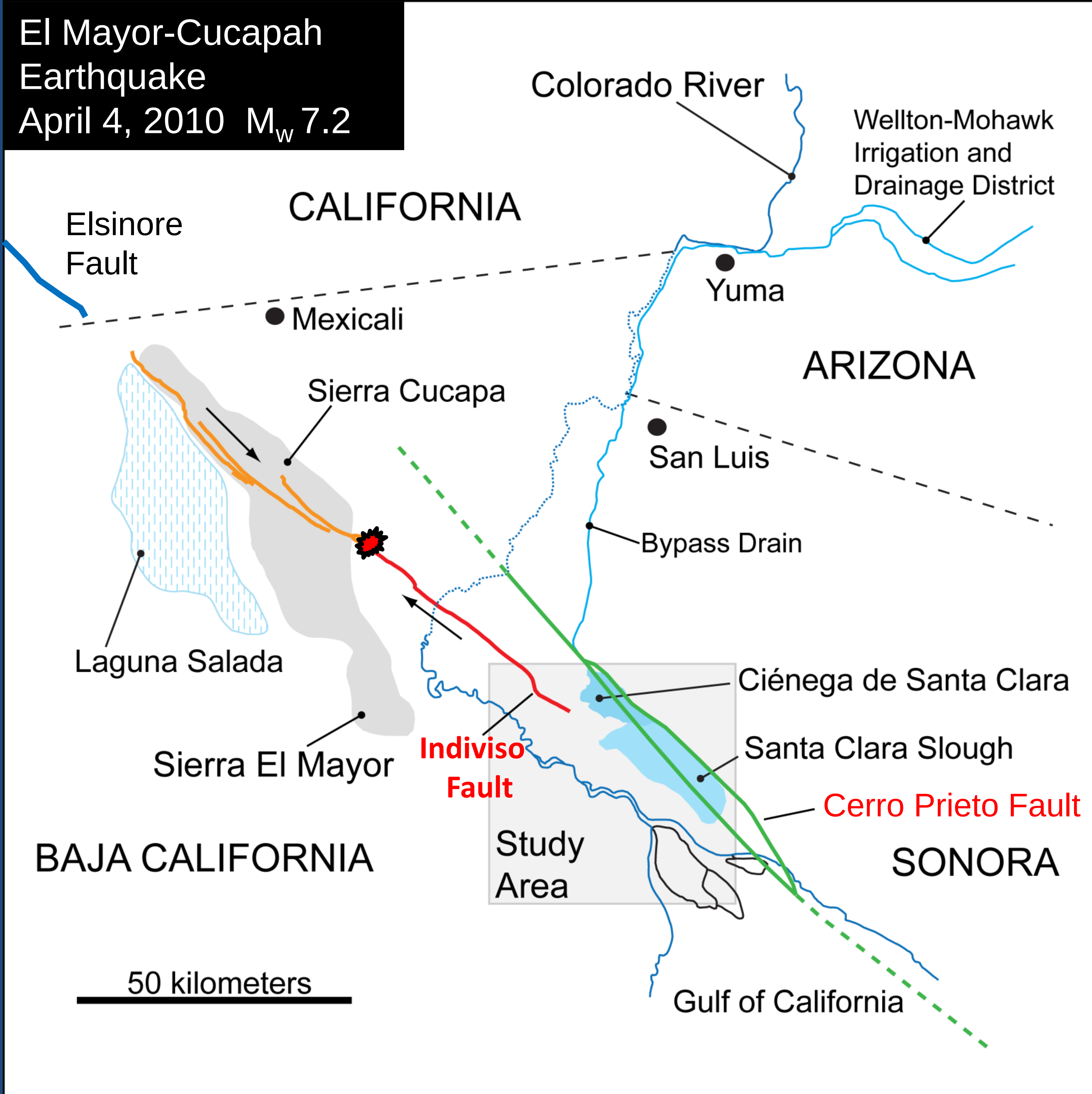
- Totoaba (*Totoaba macdonaldi*) (endangered)
- Gulf corvina (*Cynoscion othonopterus)*
- *Penaeid* shrimp

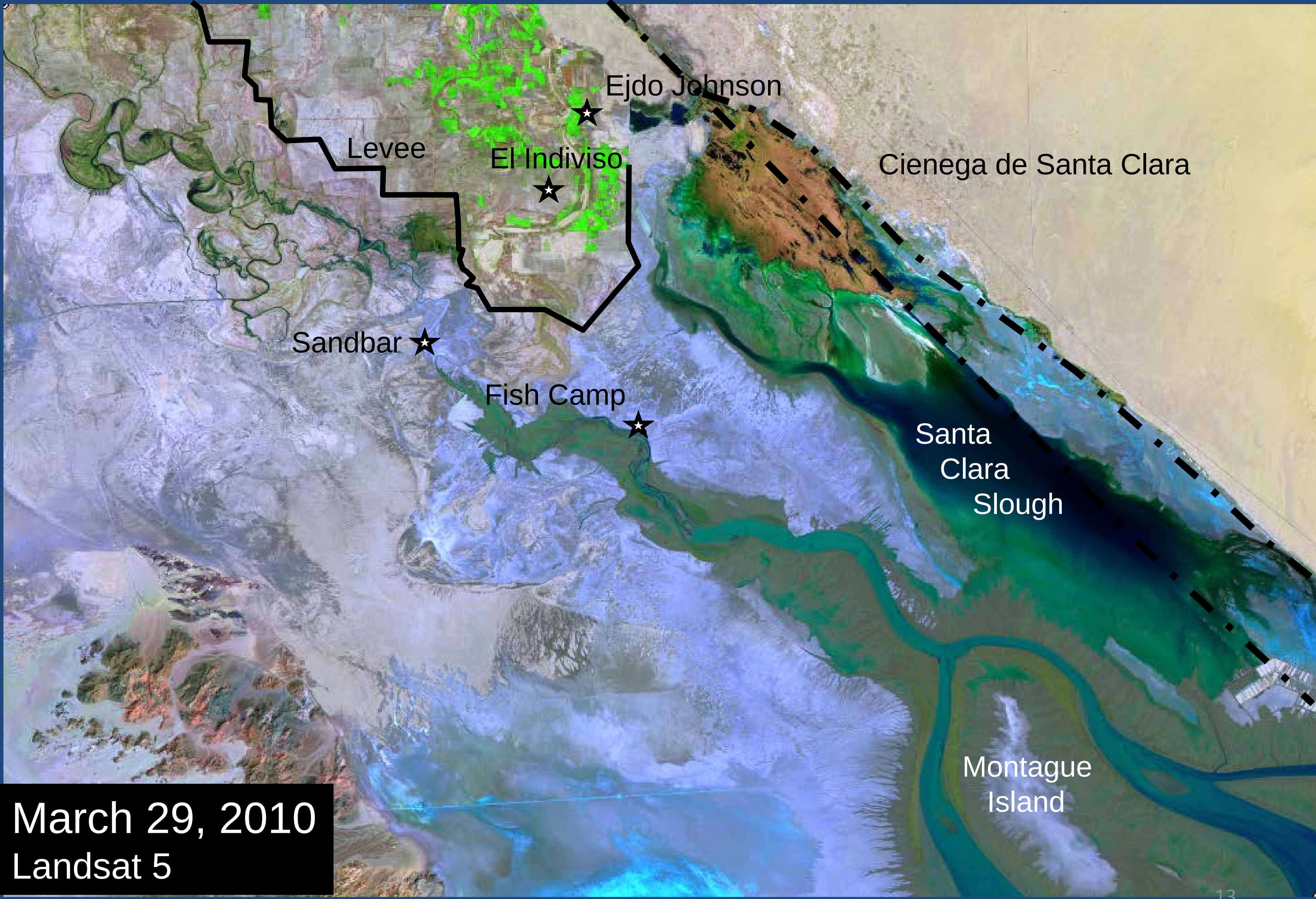

Future site of Cienega de Santa Clara
Colorado River/ Rio Hardy Wetlands
Santa Clara Slough
Sandbar Area
A tidal sandbar forms in the estuary during periods of low fluvial flow, such as in the decades following installation of upstream dams.
Backshore/ Intertidal Plain
Landsat MSS June 9, 1973



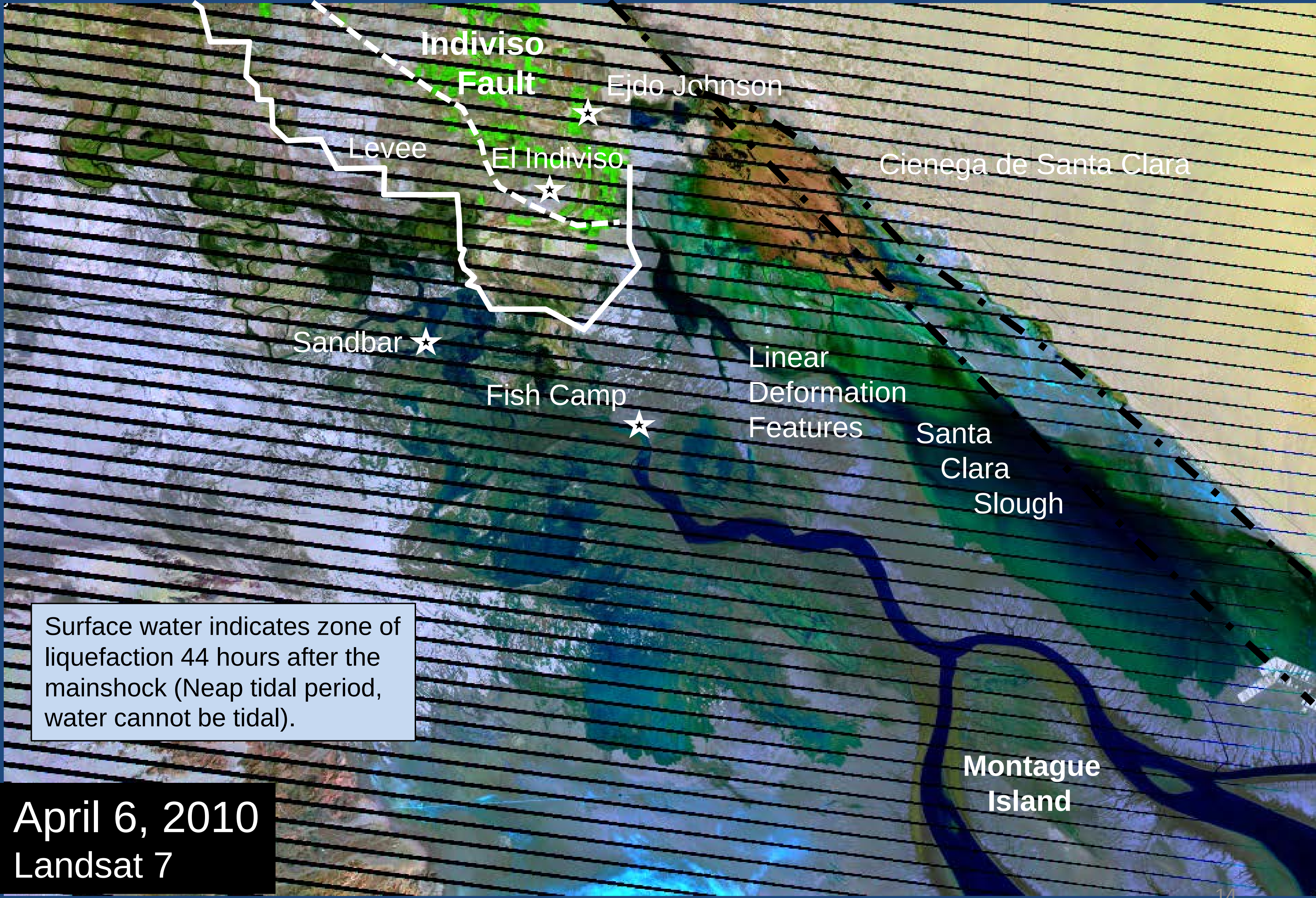
Cienega de
Santa Clara
Colorado River/
Rio Hardy Wetlands
Santa
Clara
Slough
Sandbar Area
Floods during the 1980s and 90s cut a new channel through the sandbar.
Backshore/
Intertidal Plain
Landsat TM June 21, 2000


Cienega de
Santa Clara
Colorado River/
Rio Hardy Wetlands
Santa
Clara
Slough
Sandbar Area
A new sandbar developed following curtailment of
river flows beginning in 2001.
Backshore/
Intertidal Plain
Landsat TM July 8, 2006

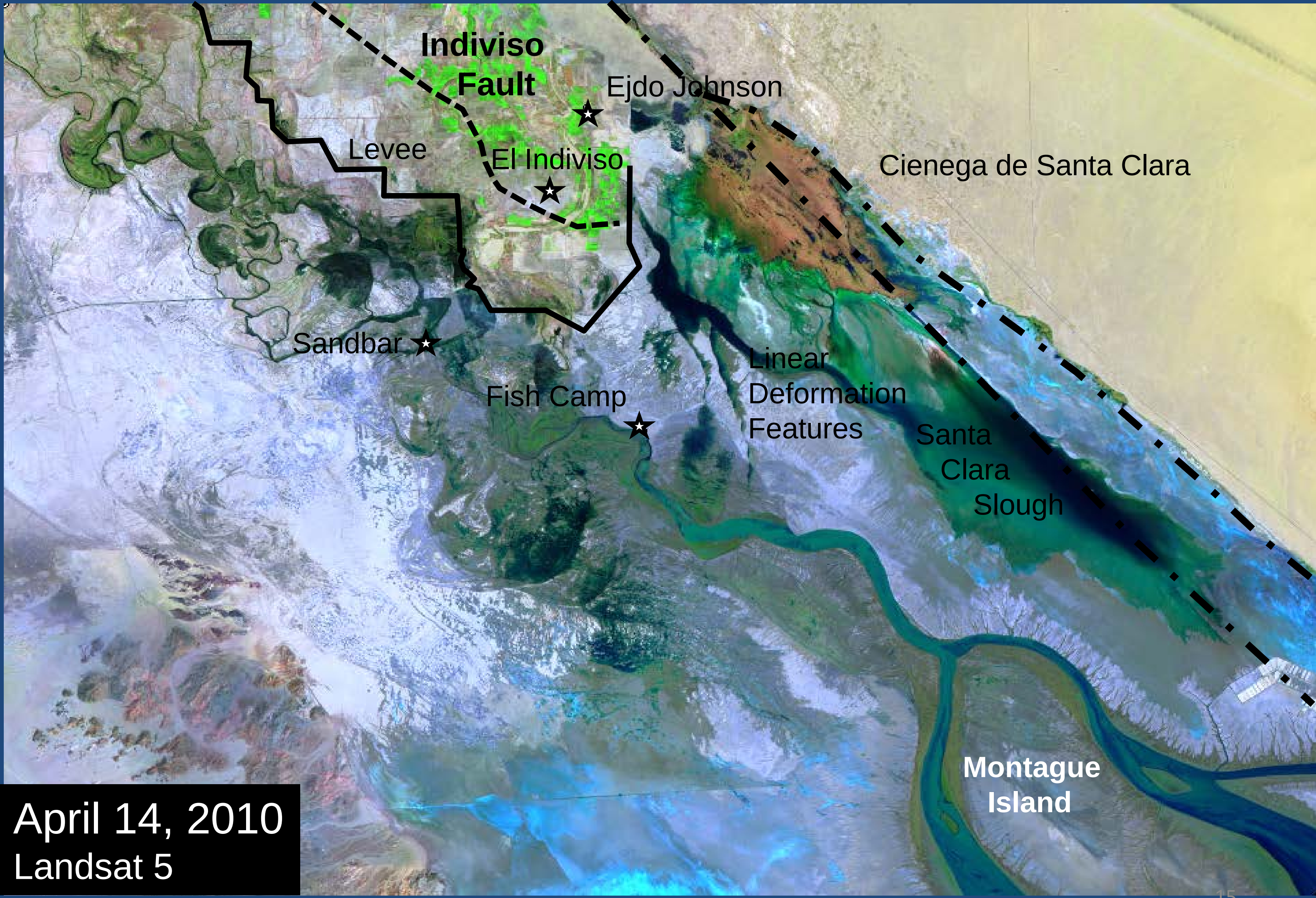

El Mayor-Cucapah
Earthquake
April 4, 2010 M_w 7.2
Colorado River
Wellton-Mohawk
Irrigation and
Drainage District
CALIFORNIA
Elsinore
Fault
Yuma
Mexicali
ARIZONA
Sierra Cucapa
San Luis
Bypass Drain
Laguna Salada
Ciénega de Santa Clara
Santa Clara Slough
Sierra El Mayor
Indiviso
Fault
Cerro Prieto Fault
Study
Area
BAJA CALIFORNIA
SONORA
50 kilometers
Gulf of California



March 29, 2010
Landsat 5



Surface water indicates zone of liquefaction 44 hours after the mainshock (Neap tidal period, water cannot be tidal).



Indiviso Fault
Ejdo Johnson
Levee
El Indiviso
Cienega de Santa Clara
Sandbar
Linear Deformation Features
Fish Camp
Santa Clara Slough
Montague Island
April 14, 2010
Landsat 5

At the tidal sandbar:

Before (August 2009)

El Mayor-Cucapah Earthquake
April 4, 2010 M_w 7.2

After (July 2010)

Photos: Francisco Zamora

Liquefaction at the sand bar, with subsided ground to the east, May 4, 2010

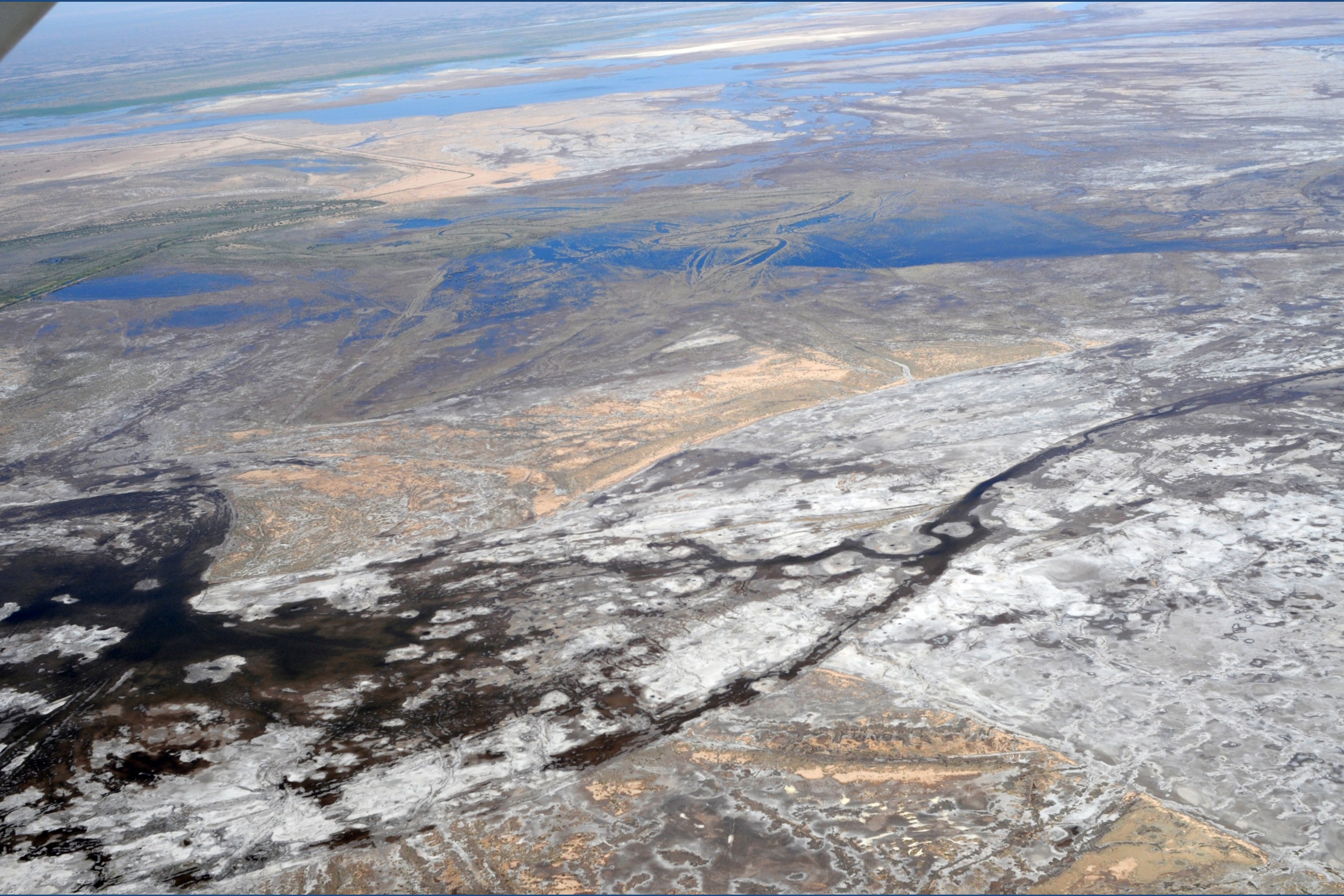


Photo by Francisco Zamora

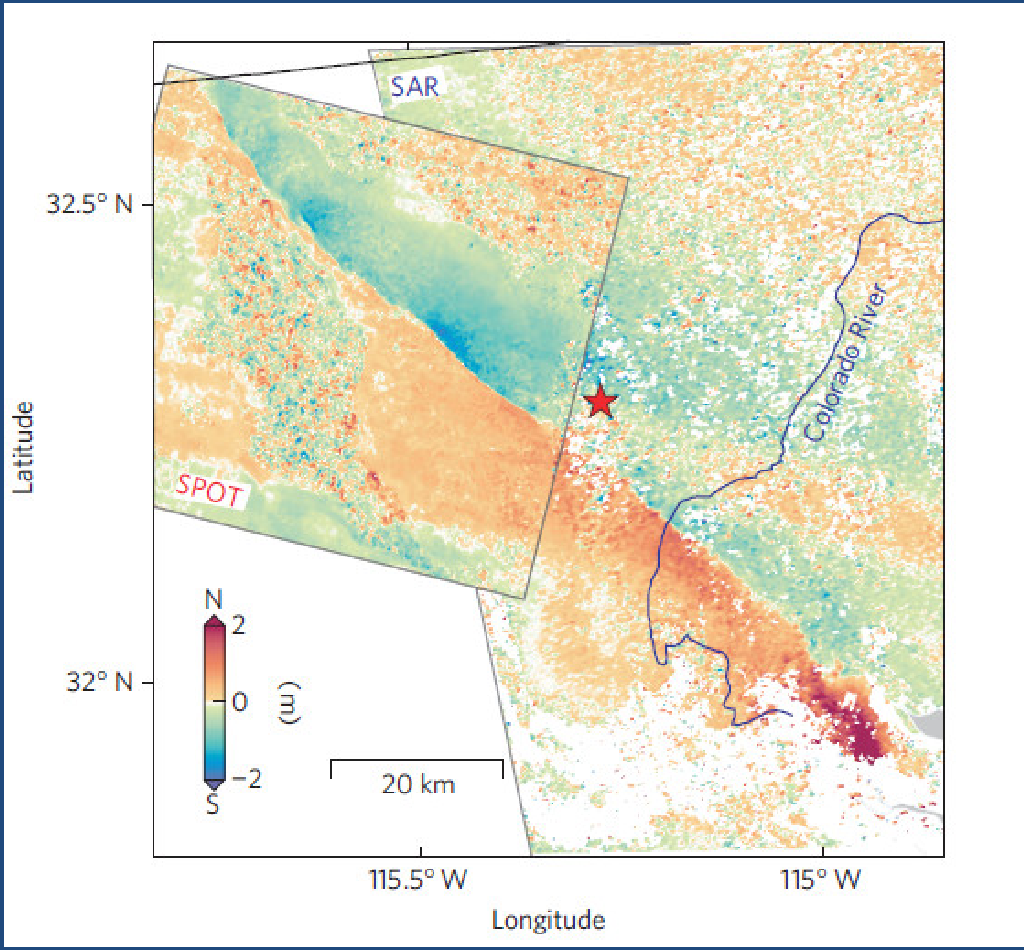
How can surface deformation be better identified and measured?

Interferometric Synthetic Aperture Radar!

ALOS-Palsar Interferogram prepared by Eric Fielding and posted on the Southern California Earthquake Data Center website, May 2010.

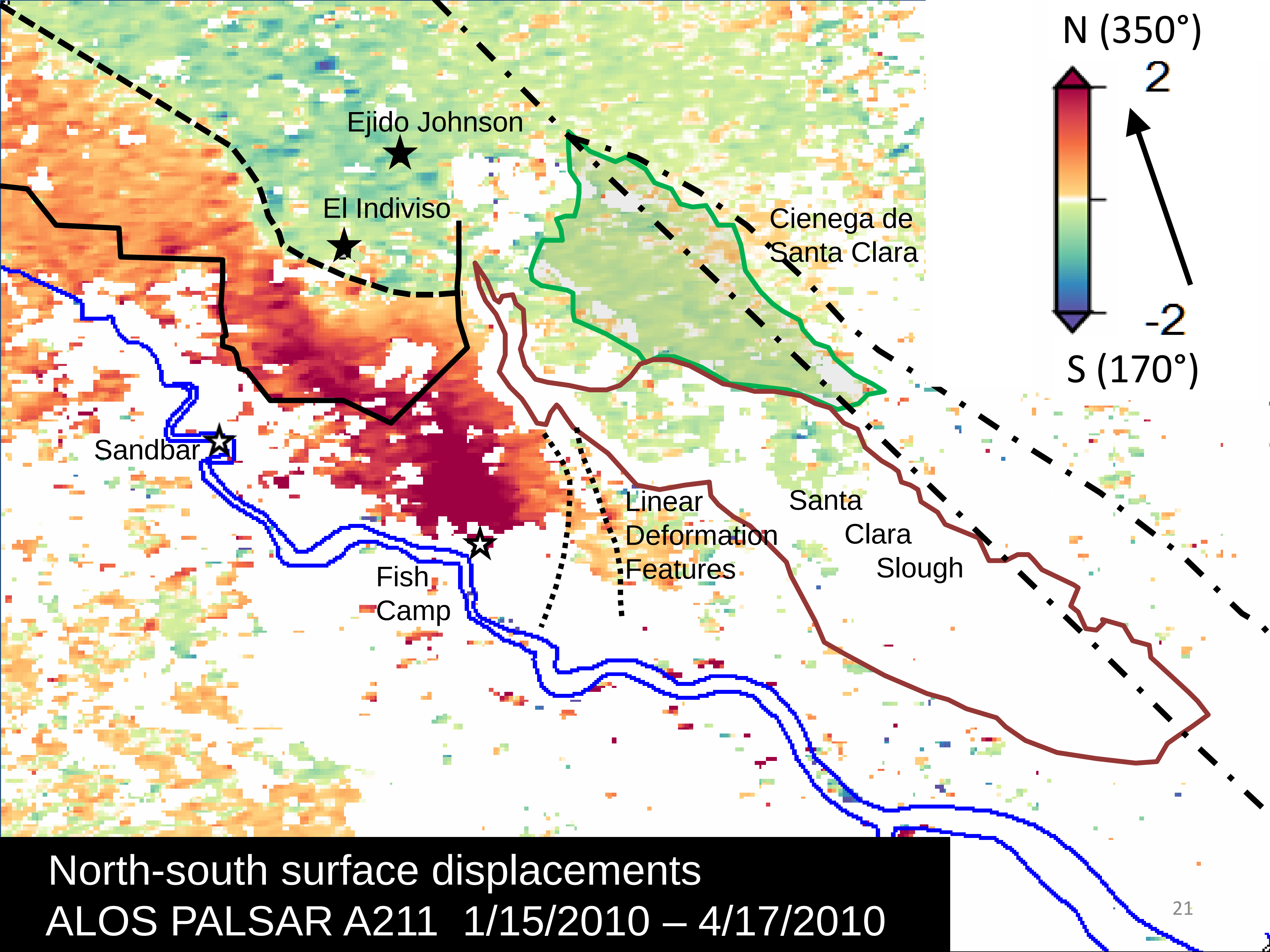
Methods:

- **Landsat, ASTER, and MODIS imagery, overflights, and field monitoring visits:** To identify tectonic lineaments, and document tidal inundation changes (as an indicator of surface deformation)
- **Predicted tide heights:** Areas inundated by high tides of similar height as predicted by CICESE for Puerto Peñasco, Sonora were compared to provide a general indication of changes in land surface elevation over time.
- **Synthetic aperture radar pixel tracking:** To measure horizontal displacement
- **Interferometric synthetic aperture radar (InSAR) data analysis:** To measure vertical surface deformation

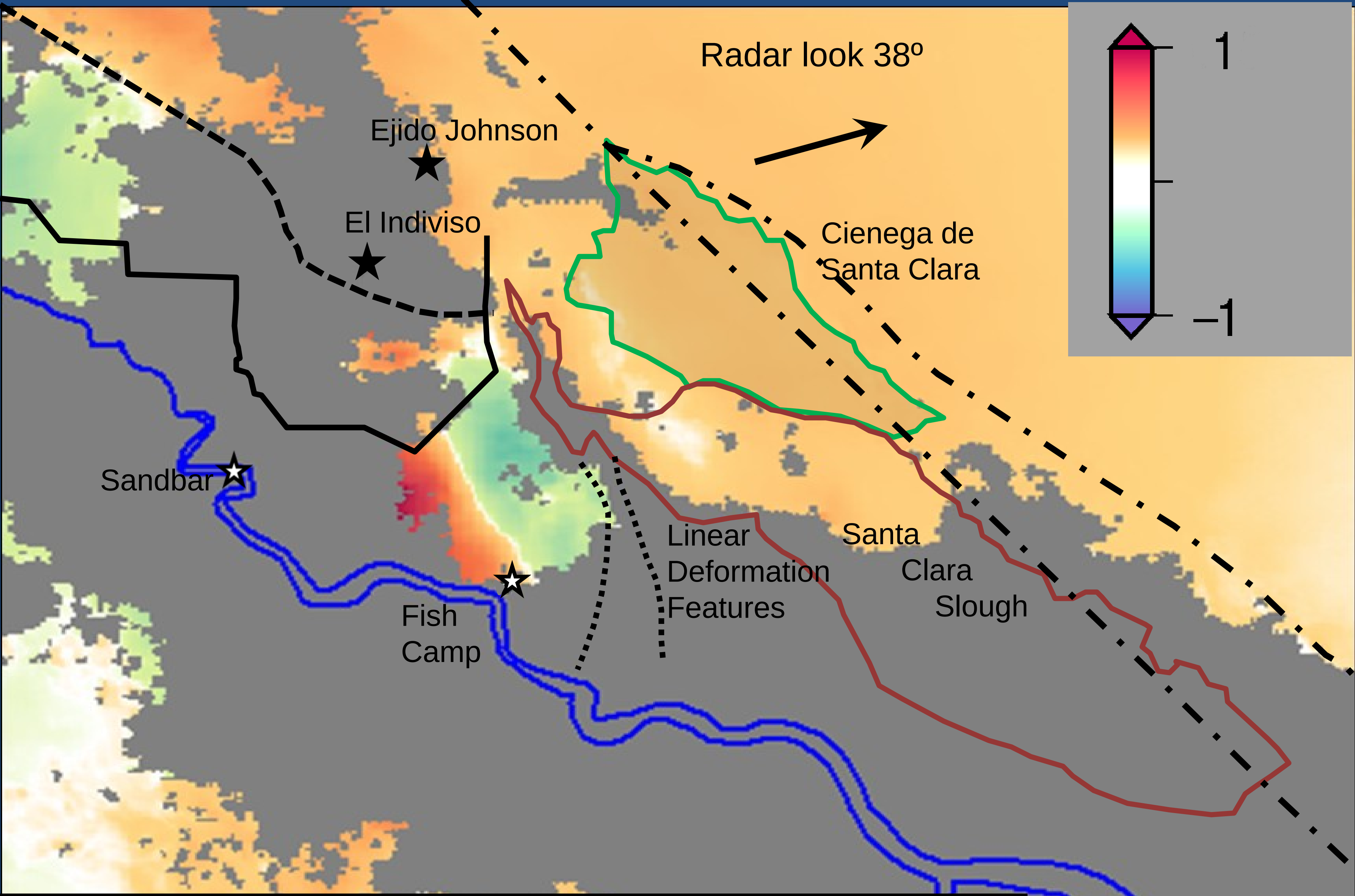


Near field coseismic ground displacement measured from subpixel correlation of SAR amplitude images and optical SPOT images acquired before and after the earthquake.

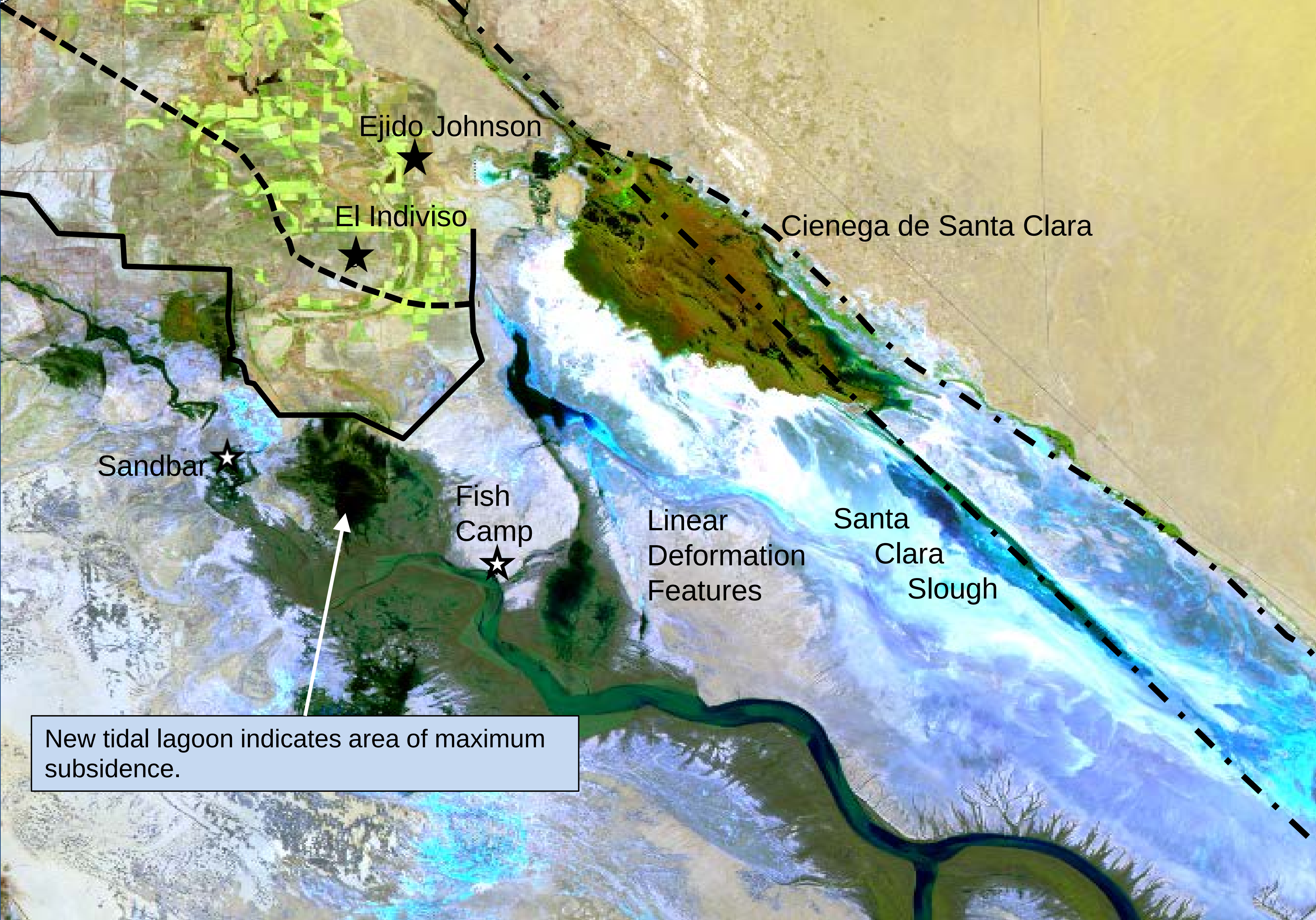
From Figure 2: Wei, S., Fielding, E., Leprince, S., Sladen, A., Avouac, J.-P., Helmberger, D., Hauksson, E., Risheng, C., Simons, M., Hudnut, K., Herring, T., Briggs, R., 2011. Superficial simplicity of the 2010 El Mayor–Cucapah earthquake of Baja California in Mexico. Nat. Geosci. 4, 615-618.



North-south surface displacements
ALOS PALSAR A211 1/15/2010 – 4/17/2010

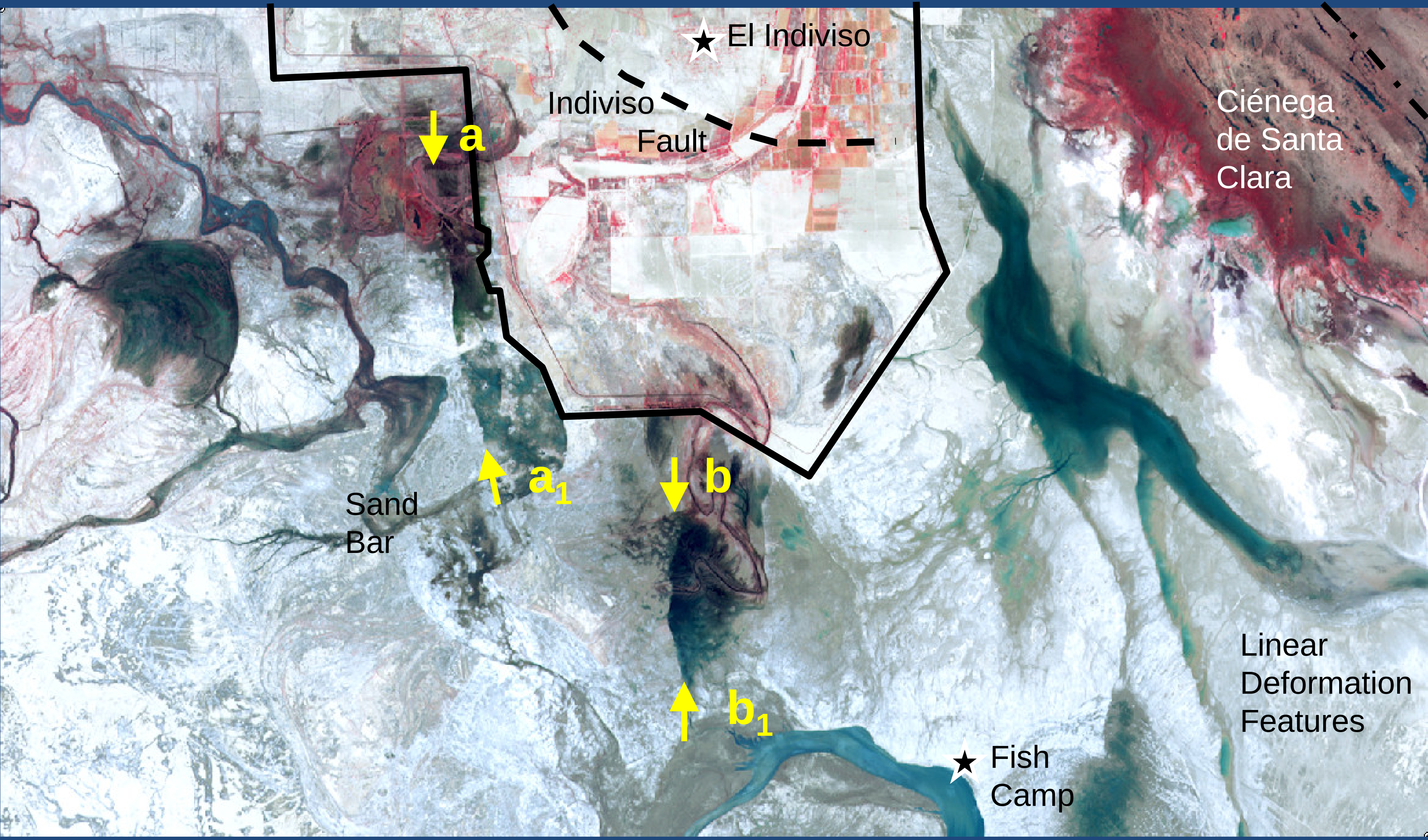


Coseismic ground displacements
ALOS PALSAR A211 1/15/2010 – 4/17/2010



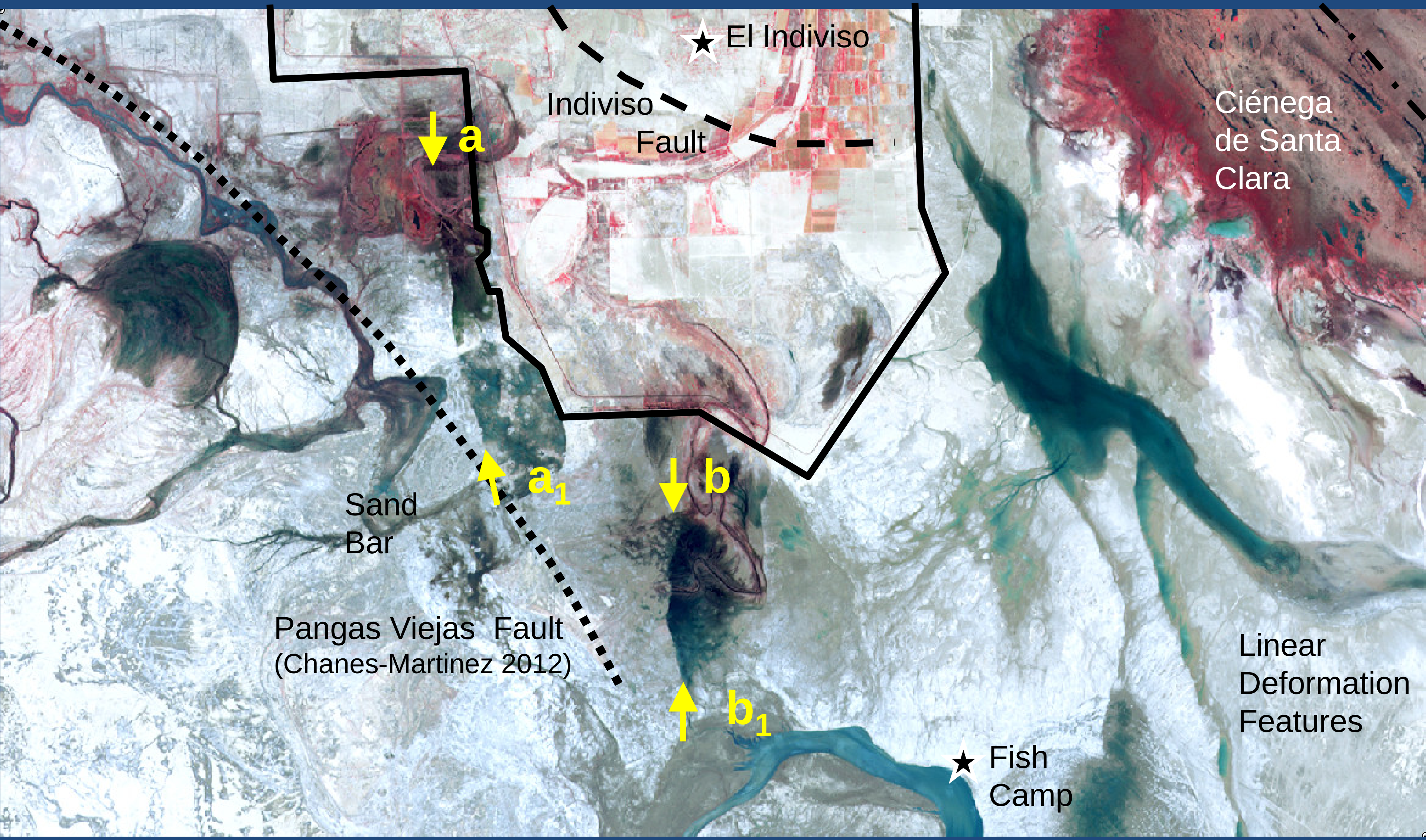
Landsat 5 June 17, 2010 (5.28 m tide June 13)

Lineaments

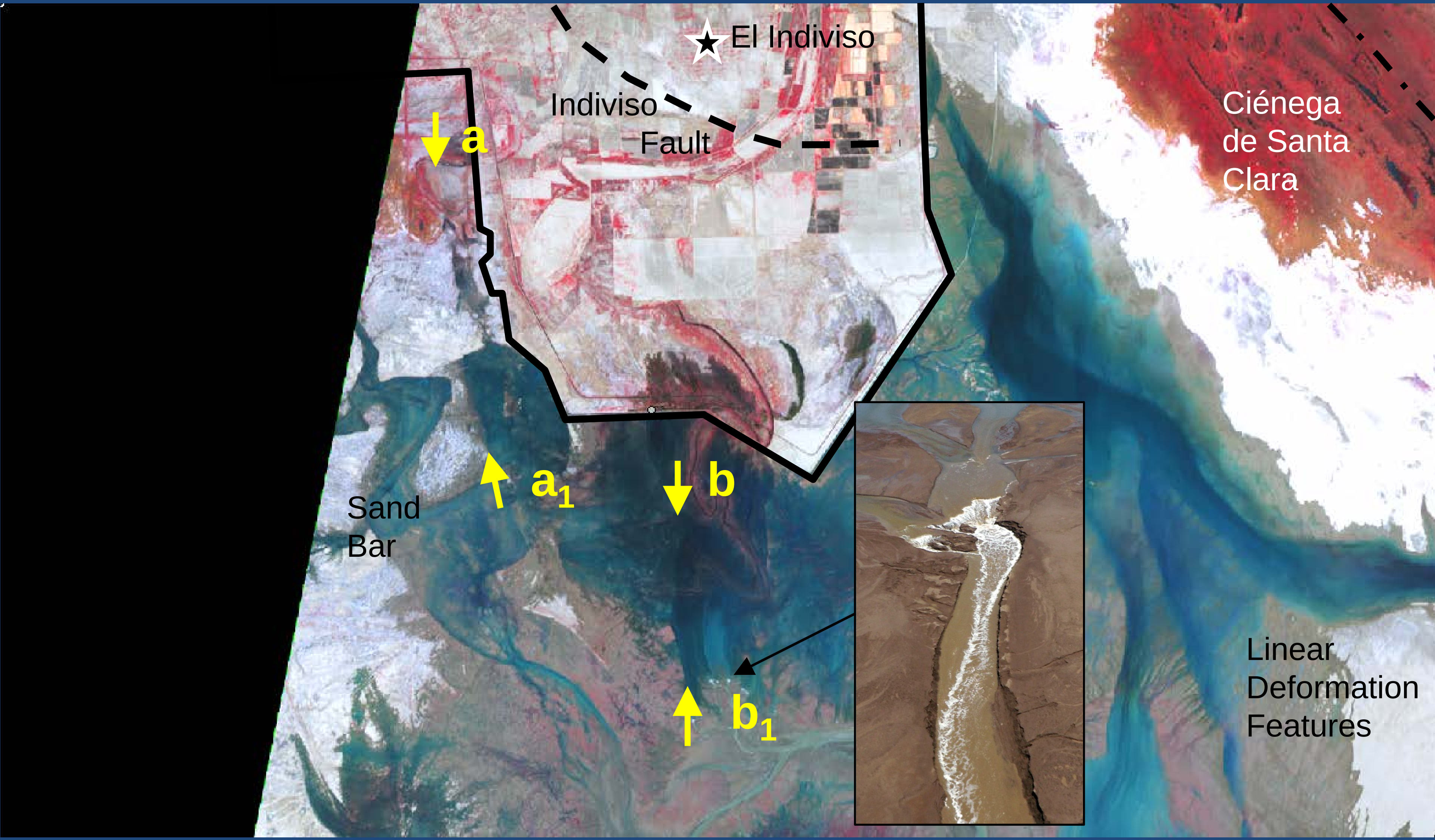


May 8, 2010 ASTER

Lineaments

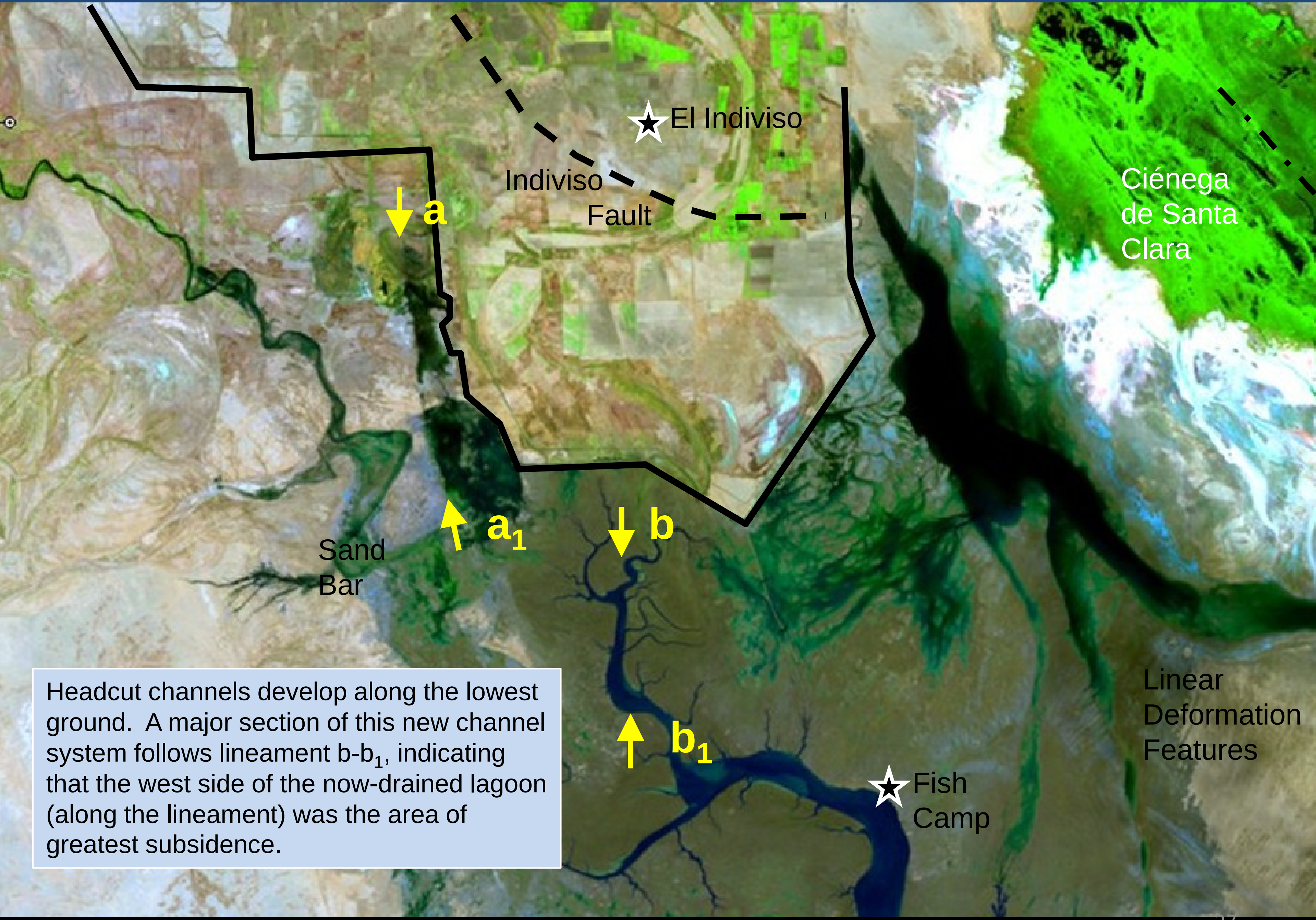


Chanes-Martínez, J.J. 2012. Características estructurales y sismoestratigráficas en un sector del delta del Río Colorado, noroeste de México, a partir de sísmica de reflexión. Centro de Investigación Científica y de Educación Superior de Ensenada, Departamento de la Ciencias de la Tierra, Ensenada.



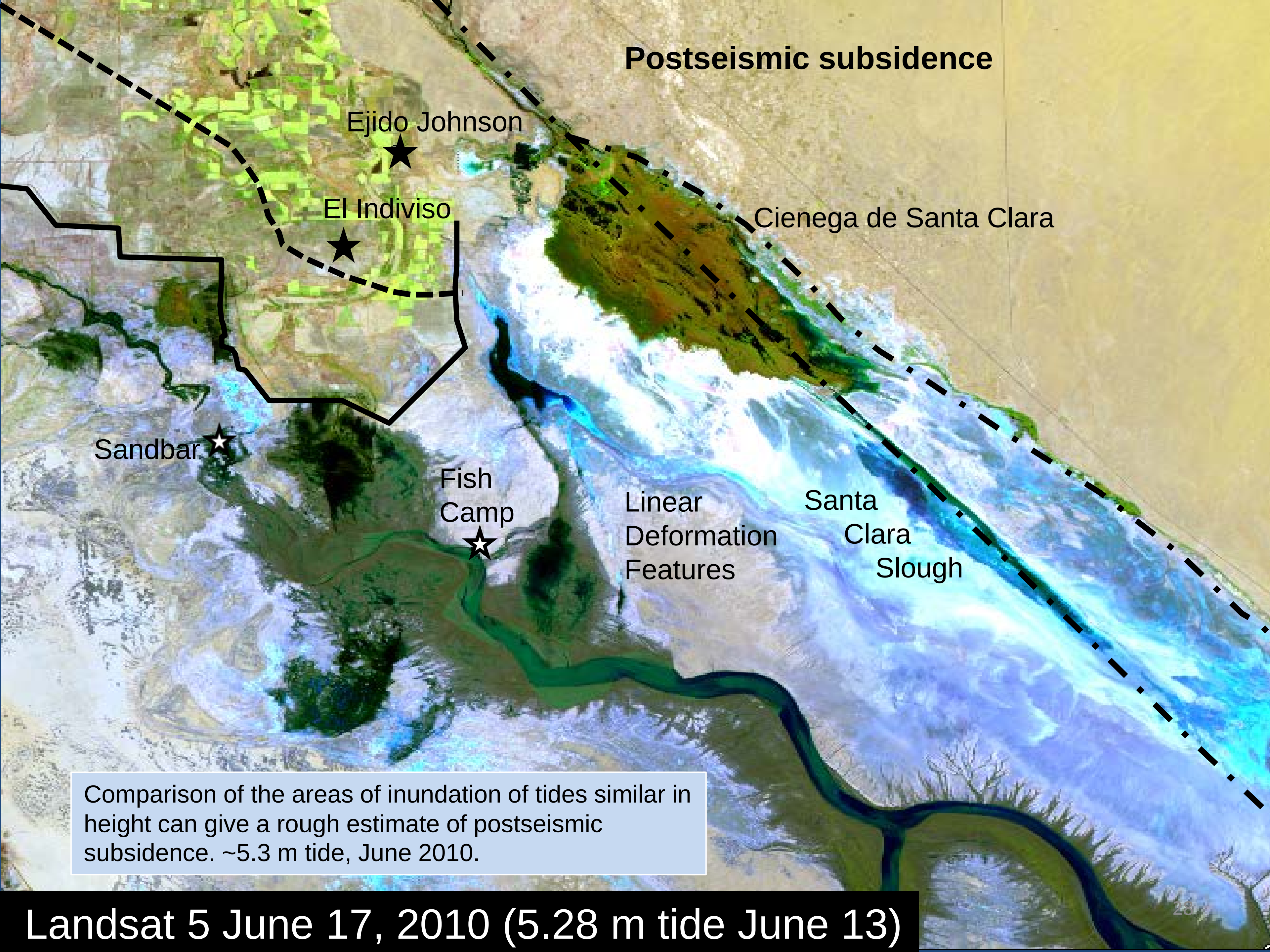
Tidal drainage from newly subsided ground resulted in headcut erosion of new tidal channels in the subsided areas.

August 12, 2010 ASTER   5.84m (August 10)



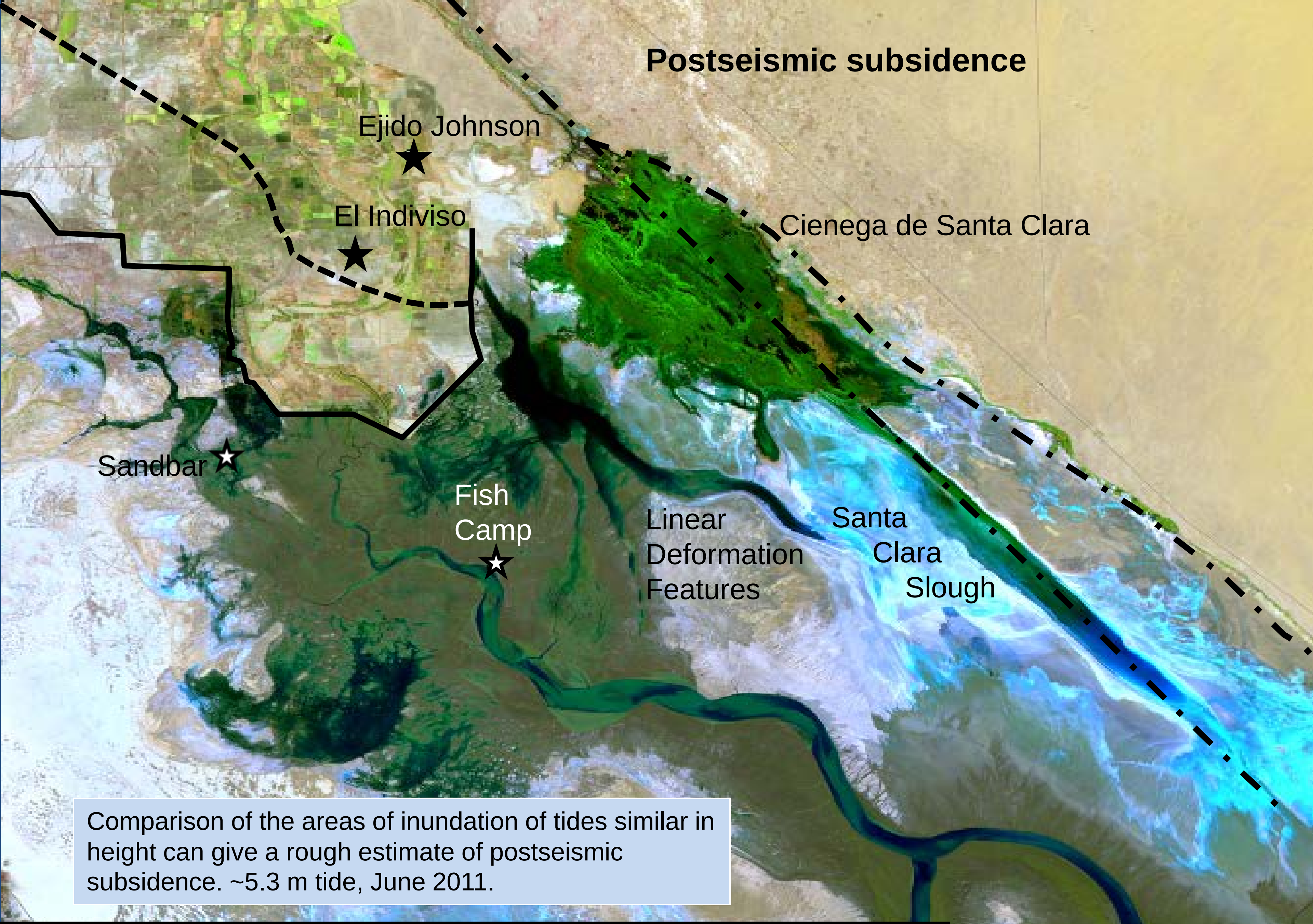
Headcut channels develop along the lowest ground. A major section of this new channel system follows lineament b-b_1, indicating that the west side of the now-drained lagoon (along the lineament) was the area of greatest subsidence.

August 7, 2011 Landsat 5 TM



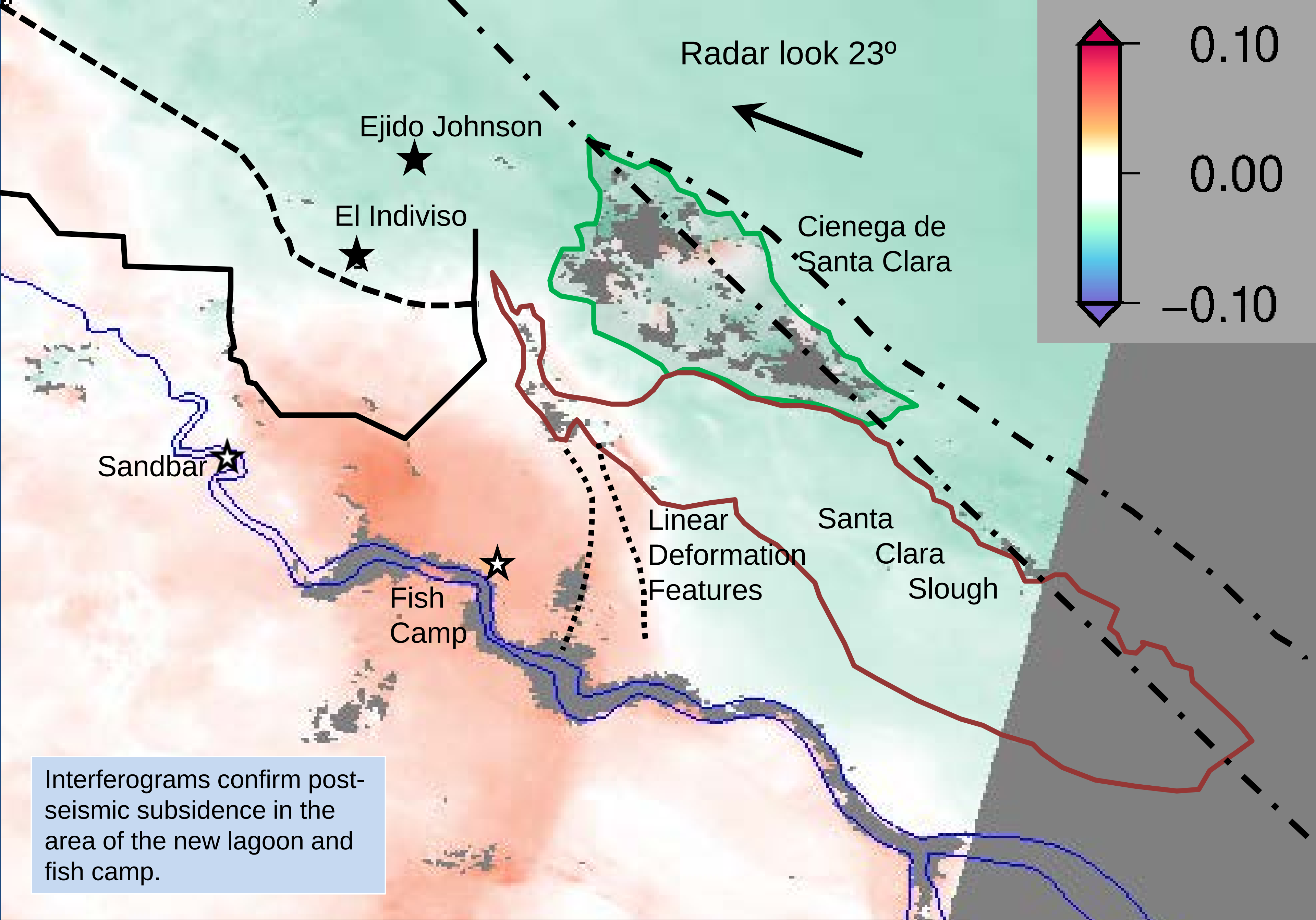
Comparison of the areas of inundation of tides similar in height can give a rough estimate of postseismic subsidence. ~5.3 m tide, June 2010.

Landsat 5 June 17, 2010 (5.28 m tide June 13)



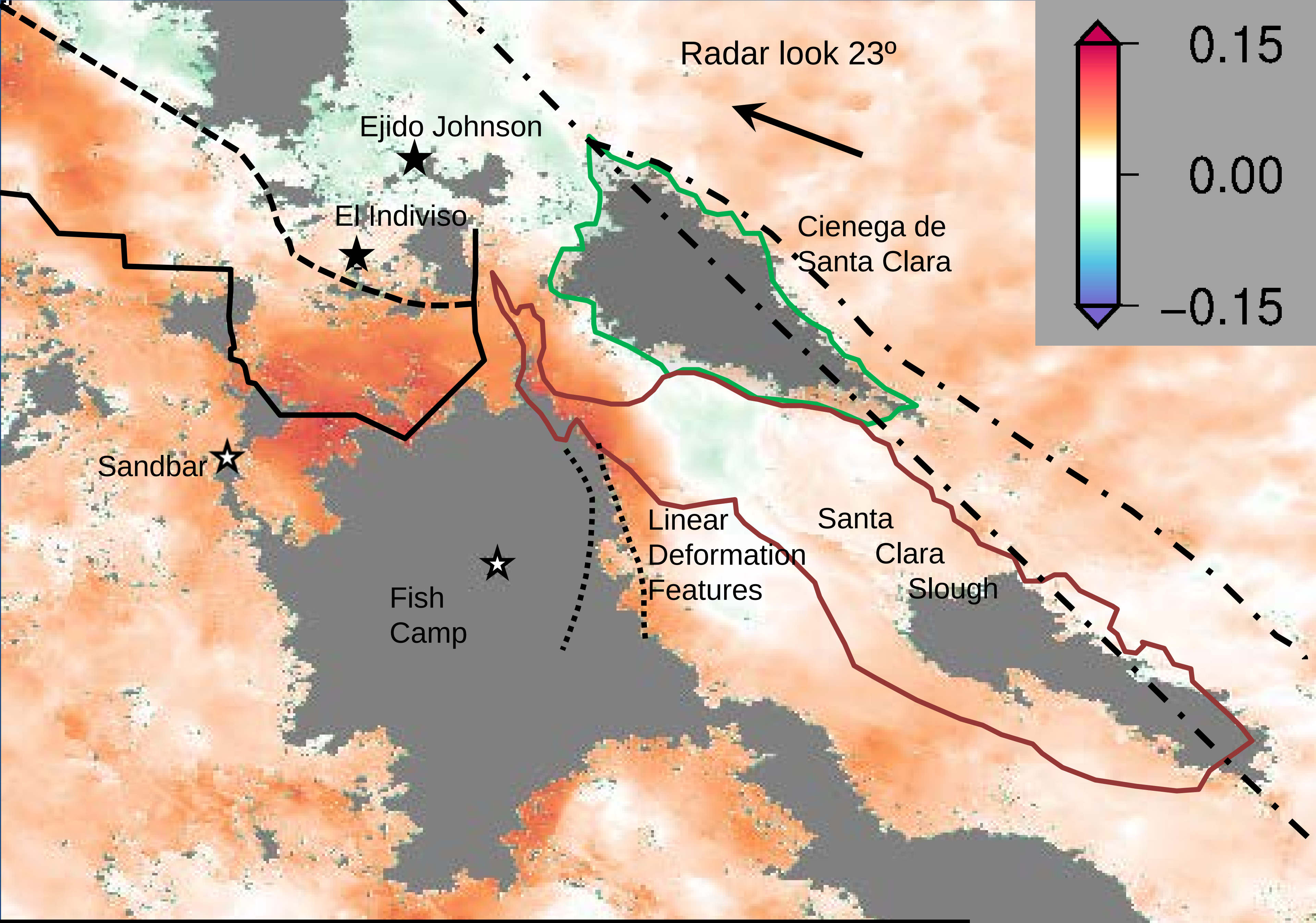
Comparison of the areas of inundation of tides similar in height can give a rough estimate of postseismic subsidence. ~5.3 m tide, June 2011.

Landsat 5 June 20, 2011 (5.31 m tide June 15)

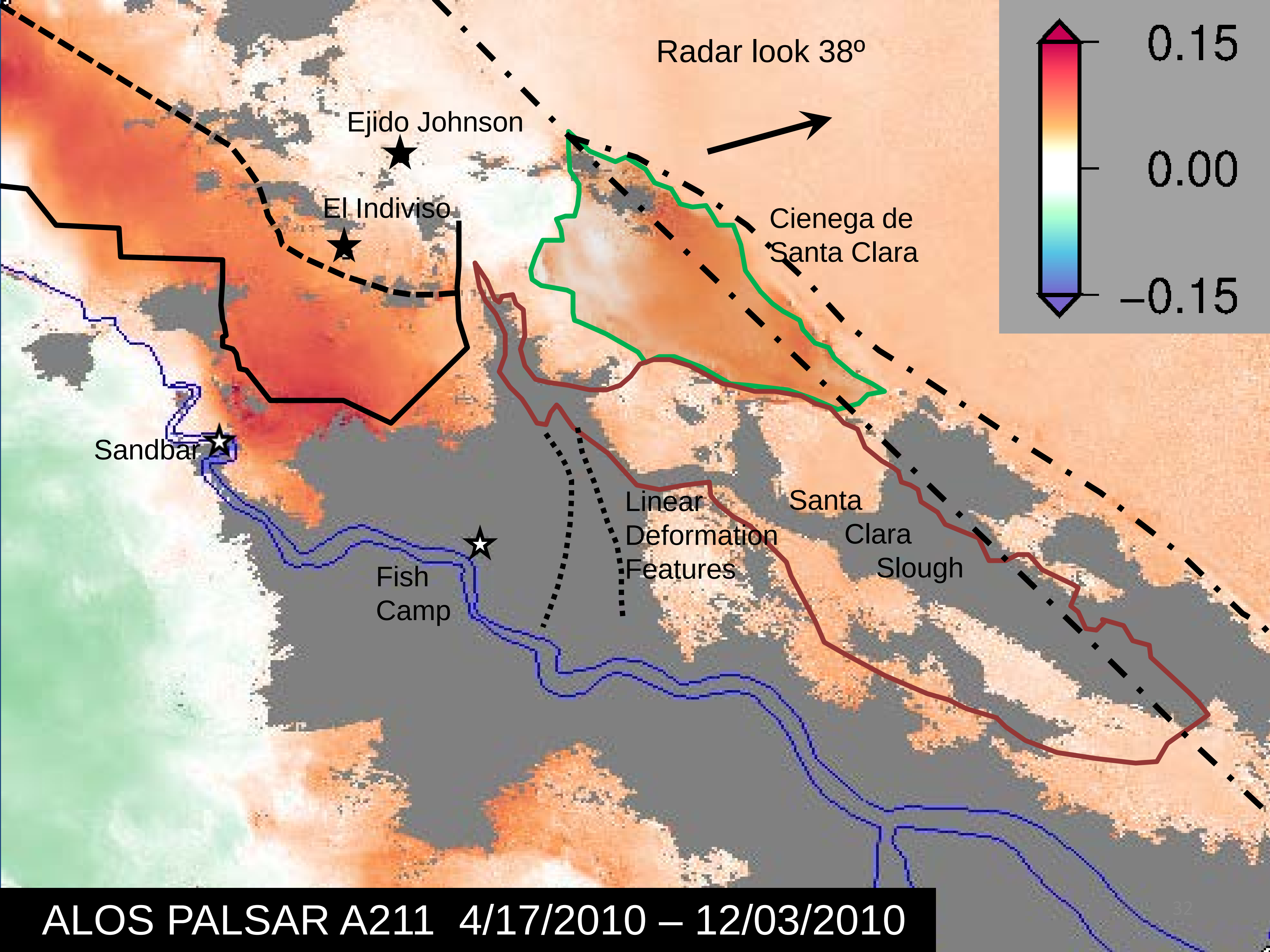


Interferograms confirm post-seismic subsidence in the area of the new lagoon and fish camp.

Envisat ASAR D084 5/02/2010 – 6/06/2010



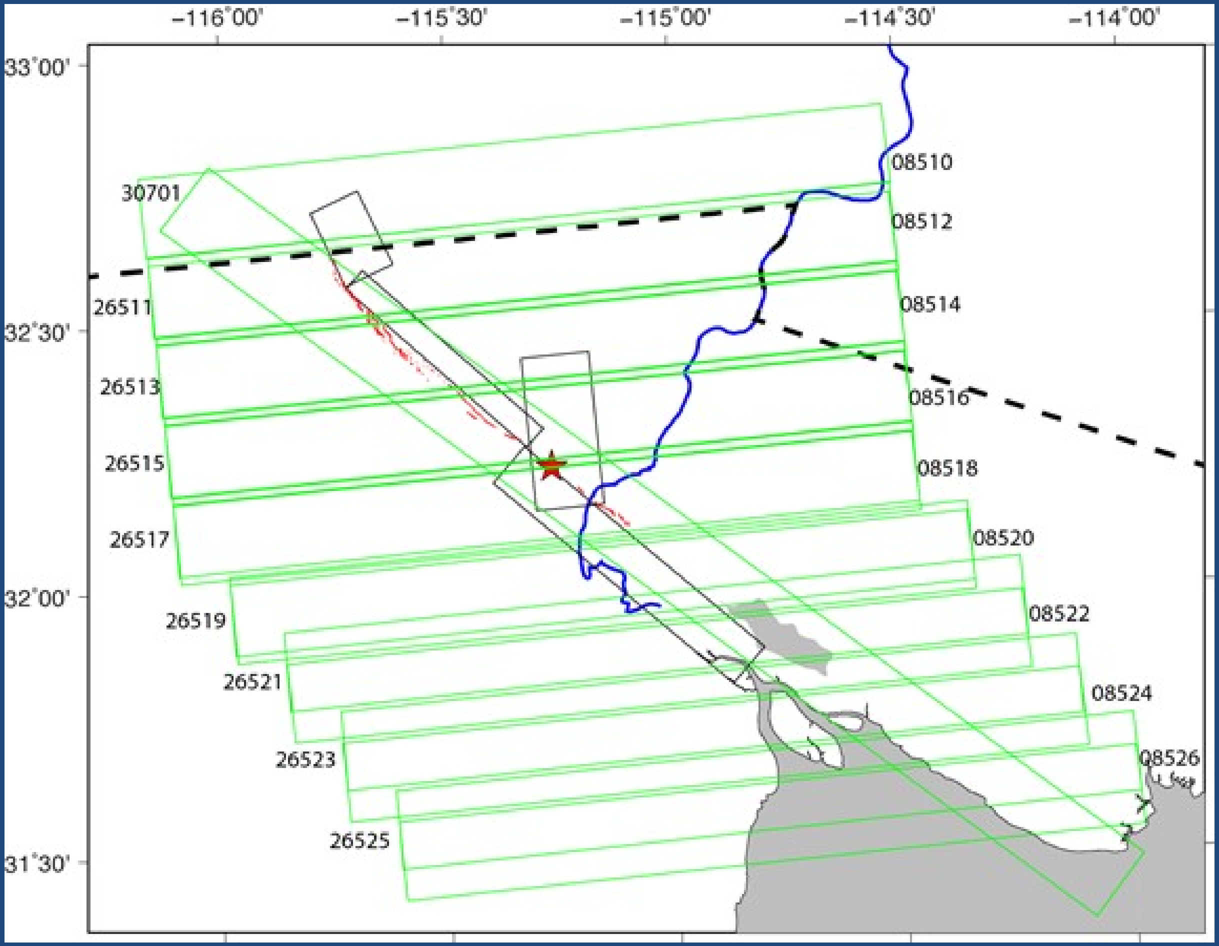
Envisat ASAR D313 4/13/2010 – 8/31/2010


Radar look 38º
0.15
0.00
−0.15
Ejido Johnson
El Indiviso
Cienega de
Santa Clara
Sandbar
Linear
Deformation
Features
Santa
Clara
Slough
Fish
Camp
ALOS PALSAR A211 4/17/2010 – 12/03/2010

Prior to the earthquake, it was possible to drive to the fish camp directly on the surface of the normally-dry tidal mudflats. After the earthquake the area was inundated by the spring tides almost every month, and a causeway had to be built to provide fishing access.

Causeway to fish camp, March 10, 2012

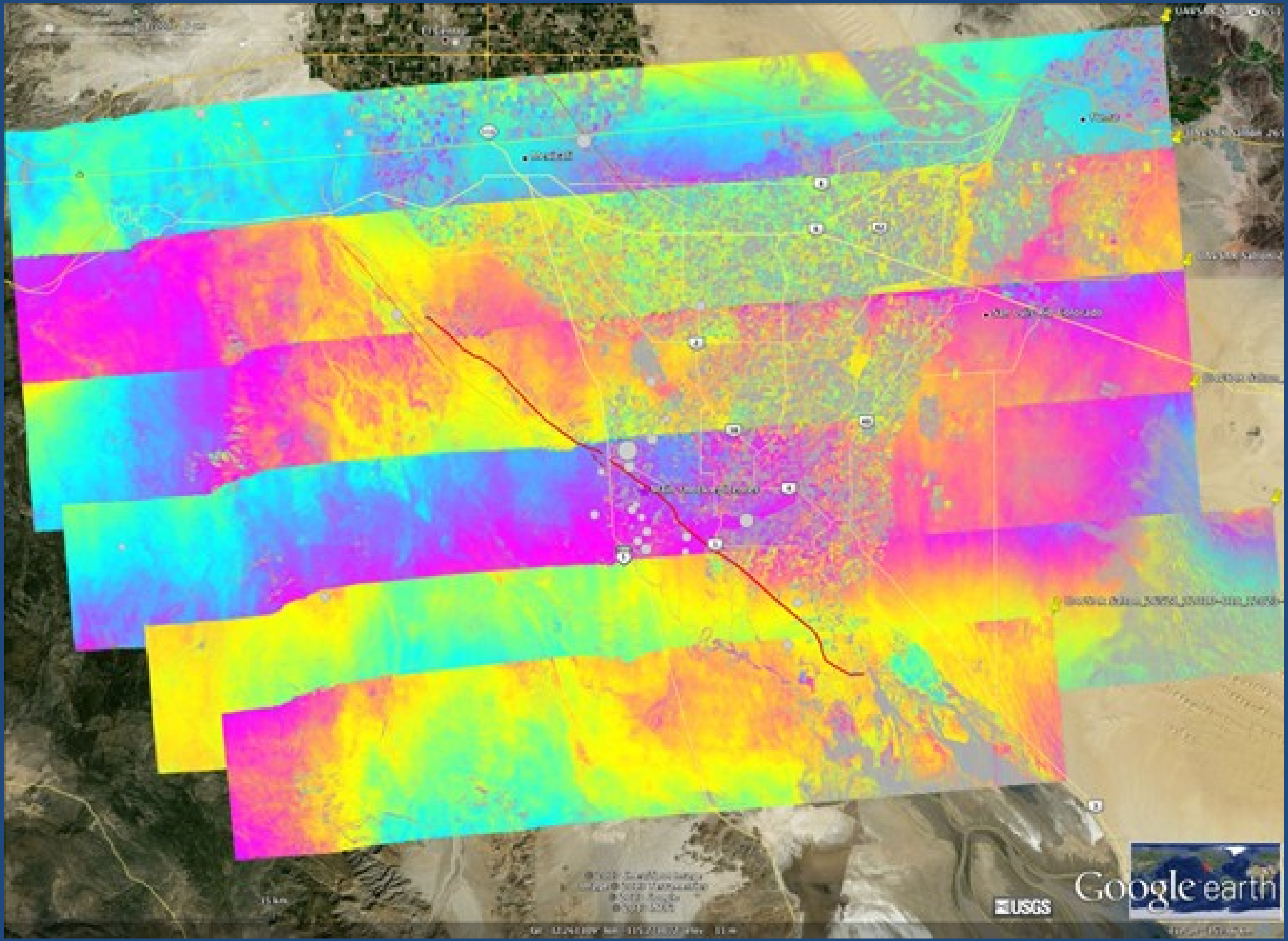
Causeway to fish camp, August 2, 2012 5.51m spring tide Photo by Francisco Zamora



UAVSAR Flight Lines, Mexico Earthquake Study

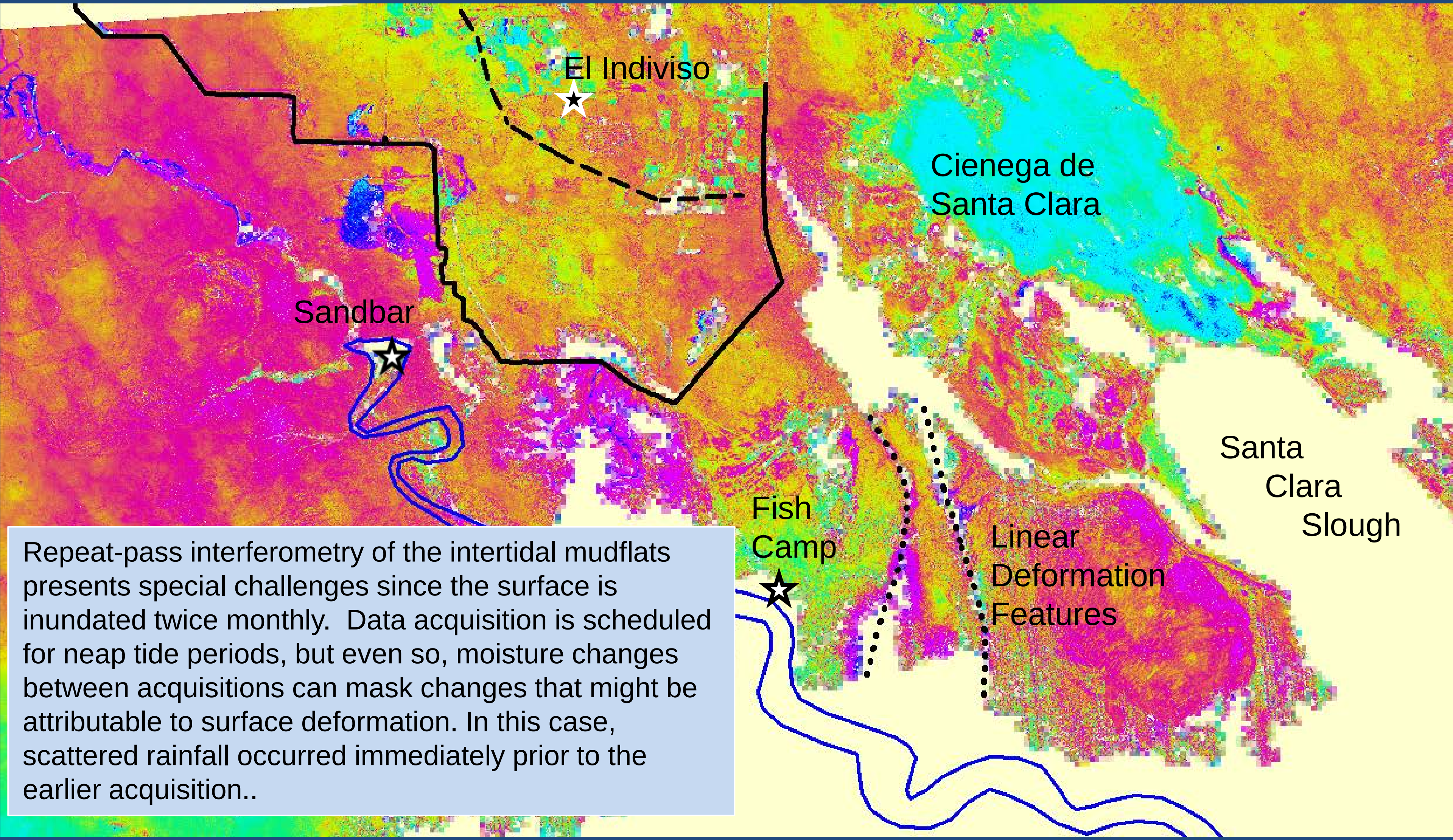
The UAVSAR Mexico Earthquake Study combines InSAR analysis of satellite and airborne radar imagery with Global Positioning System (GPS) analysis to estimate the distribution of coseismic fault ruptures, and to measure the postseismic deformation.

UAVSAR products: repeat-pass interferometry (RPI) (two dates)



RPI interferograms from the February and May 2012 UAVSAR data. Wrapped interferogram phase is shown over base imagery from Google Earth sources. Thick red line is main surface rupture (Wei et. al 2011). Gray circles are 2010 El Mayor-Cucapah mainshock (largest) and aftershocks from the USGS NEIC.

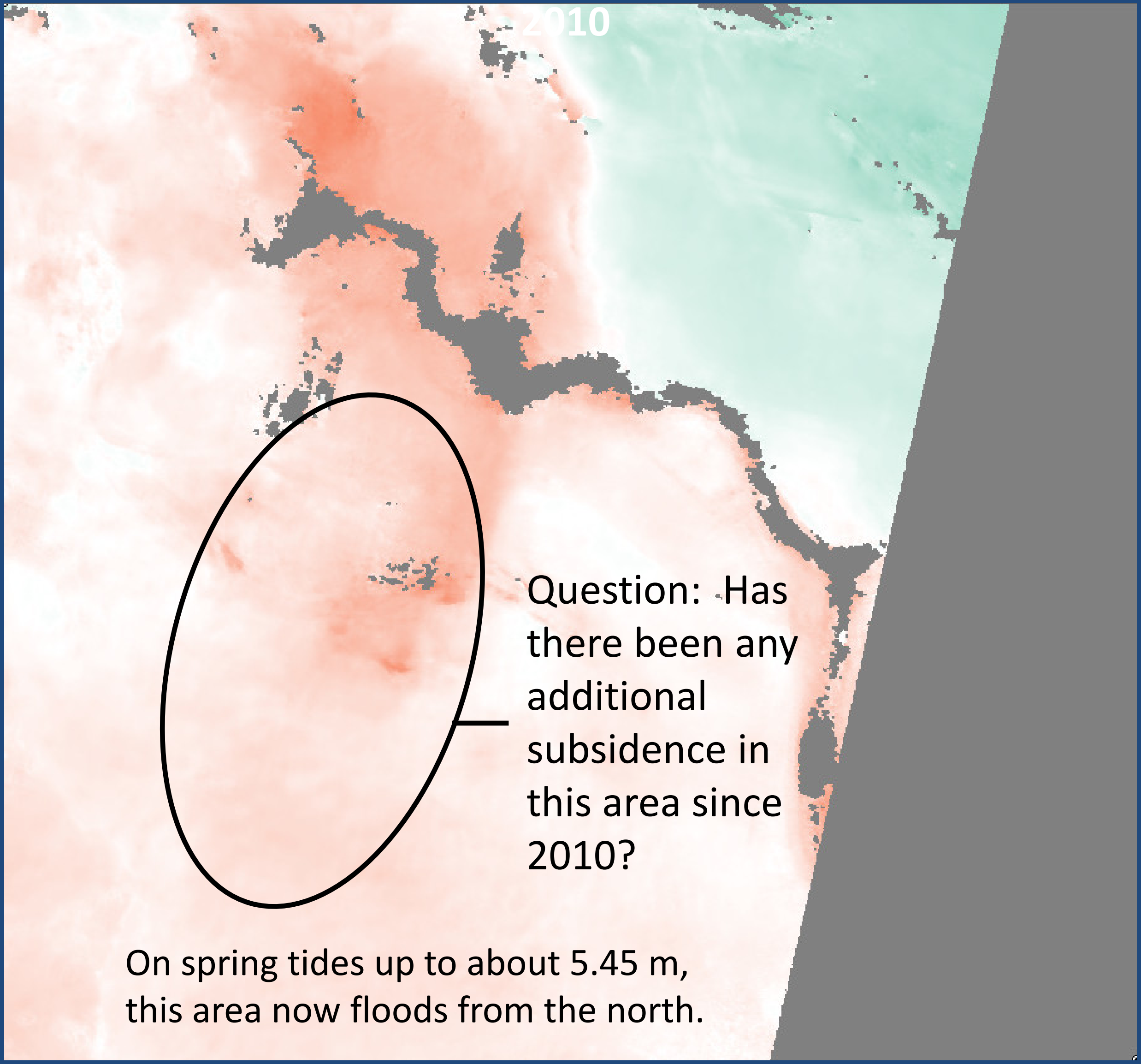
UAVSAR repeat-pass interferometry (RPI)



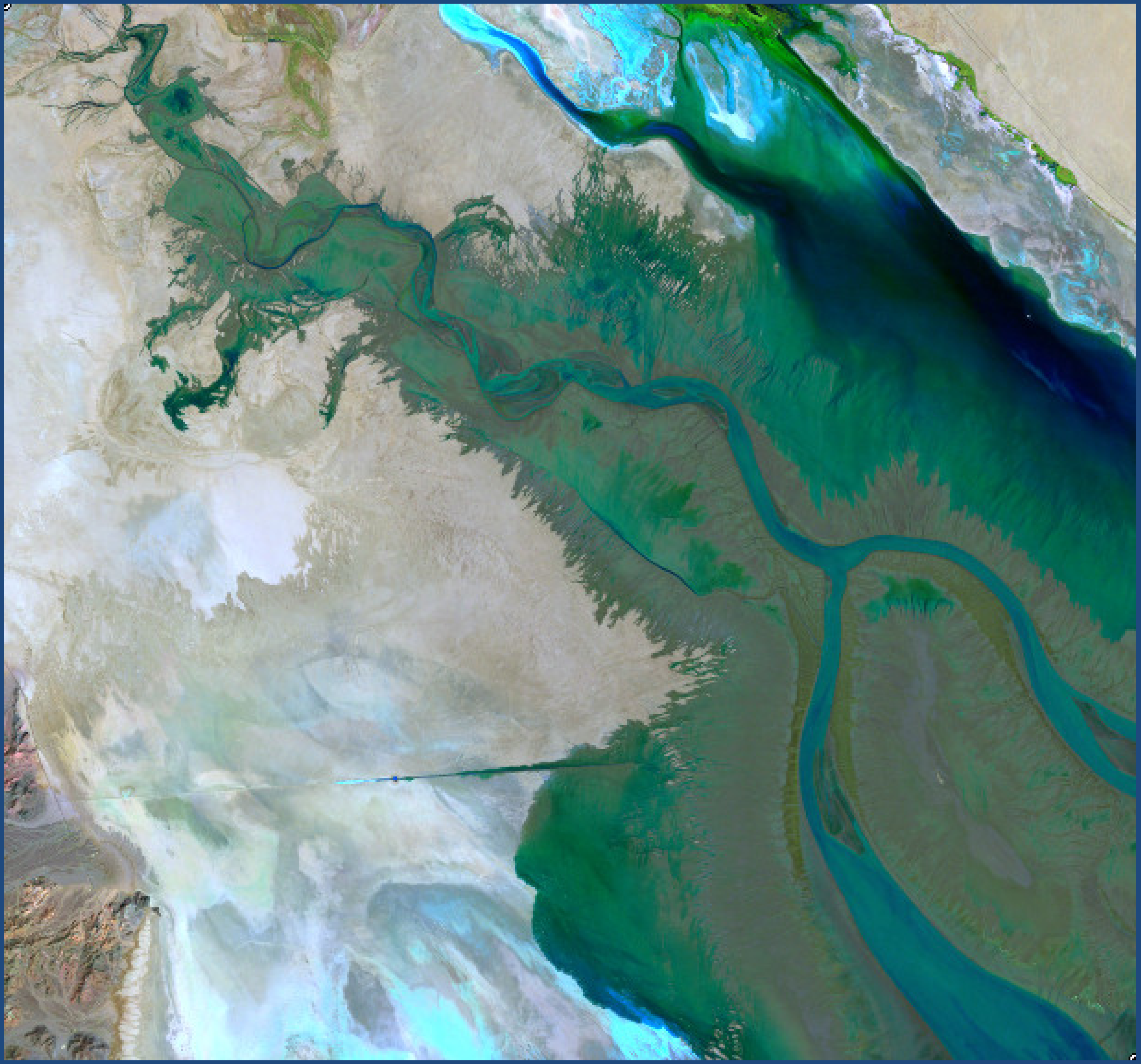
Repeat-pass interferometry of the intertidal mudflats presents special challenges since the surface is inundated twice monthly. Data acquisition is scheduled for neap tide periods, but even so, moisture changes between acquisitions can mask changes that might be attributable to surface deformation. In this case, scattered rainfall occurred immediately prior to the earlier acquisition..

Salton_26521_12010-018_12023-005_0089d_s01_L090HH_01.unw
2/03/2012 - 5/02/2012 Acquired at neap tide.

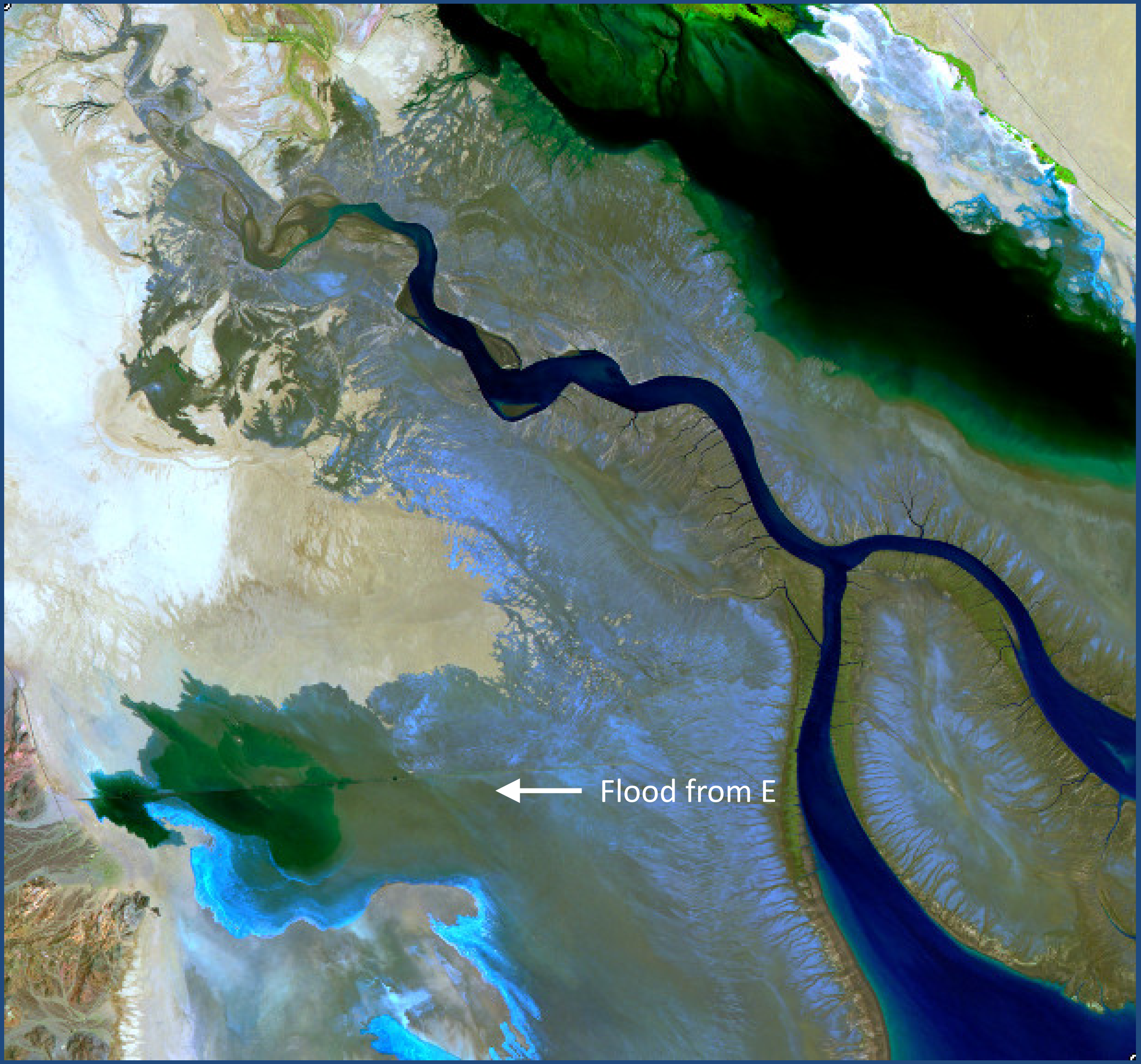
Envisat D084 post-seismic interferogram May-June 2010



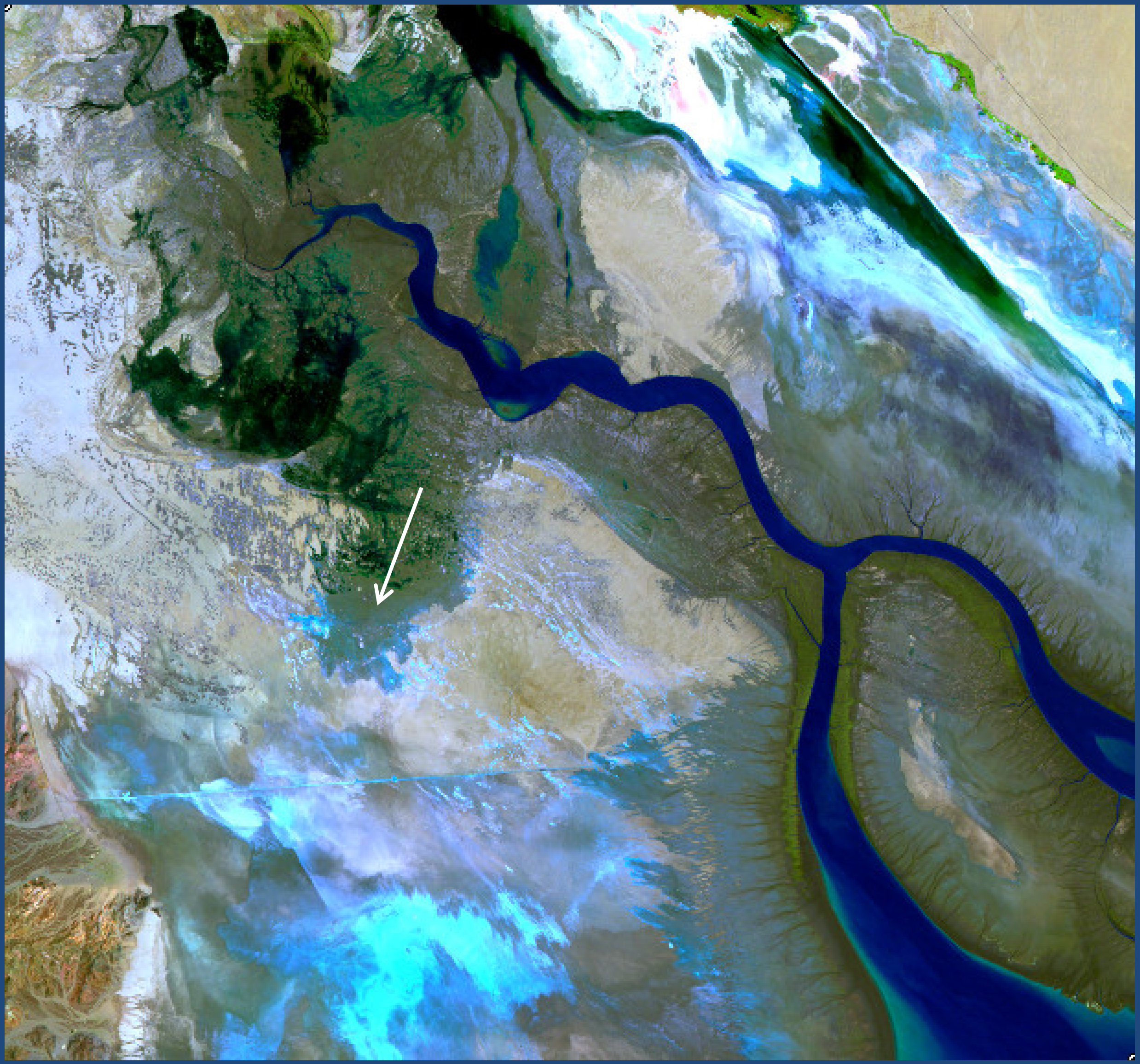
September 29, 2009 5.60m (Sept 28) Pre-earthquake



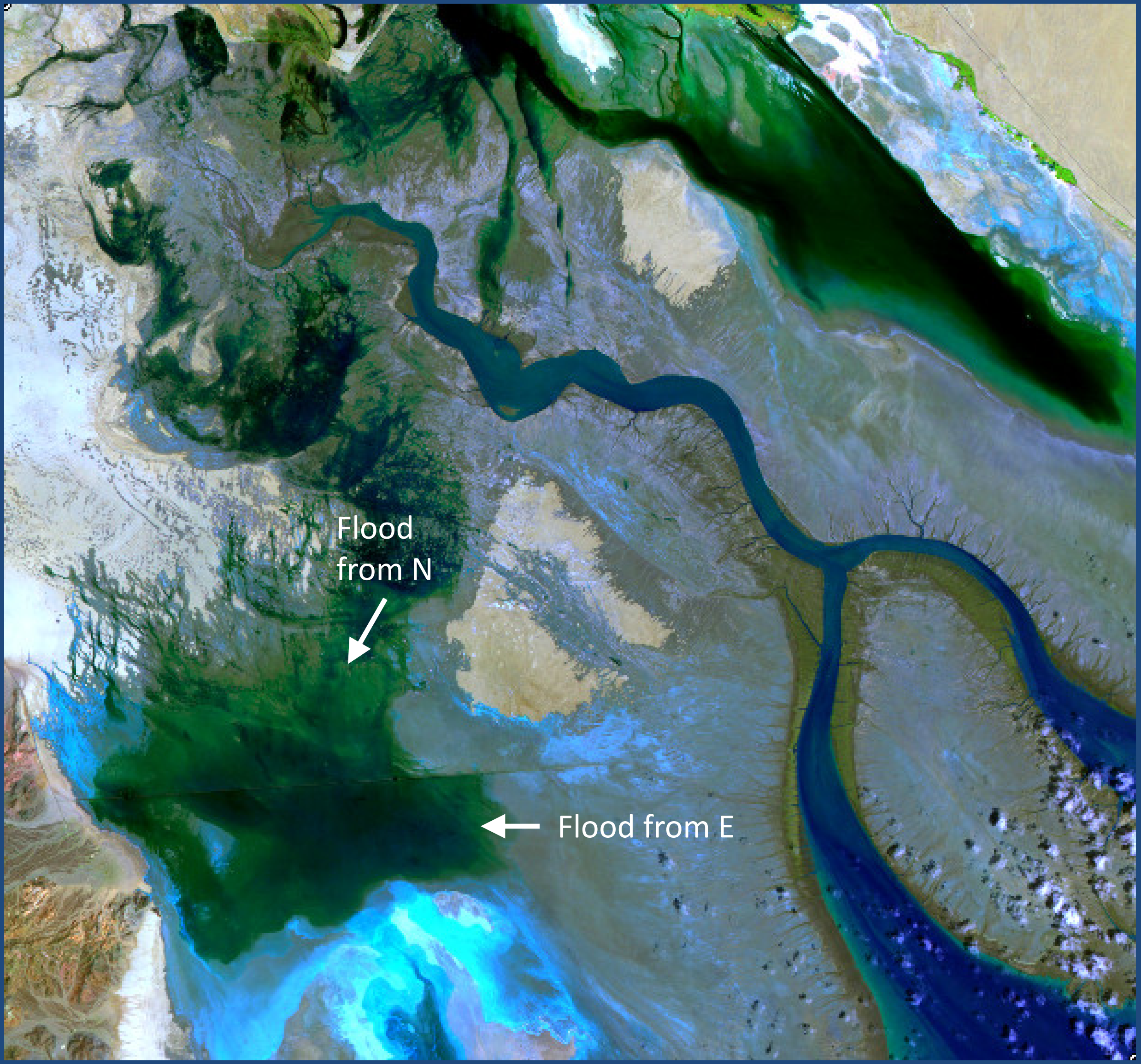
August 1, 2009 5.81m (July 22) Pre-earthquake



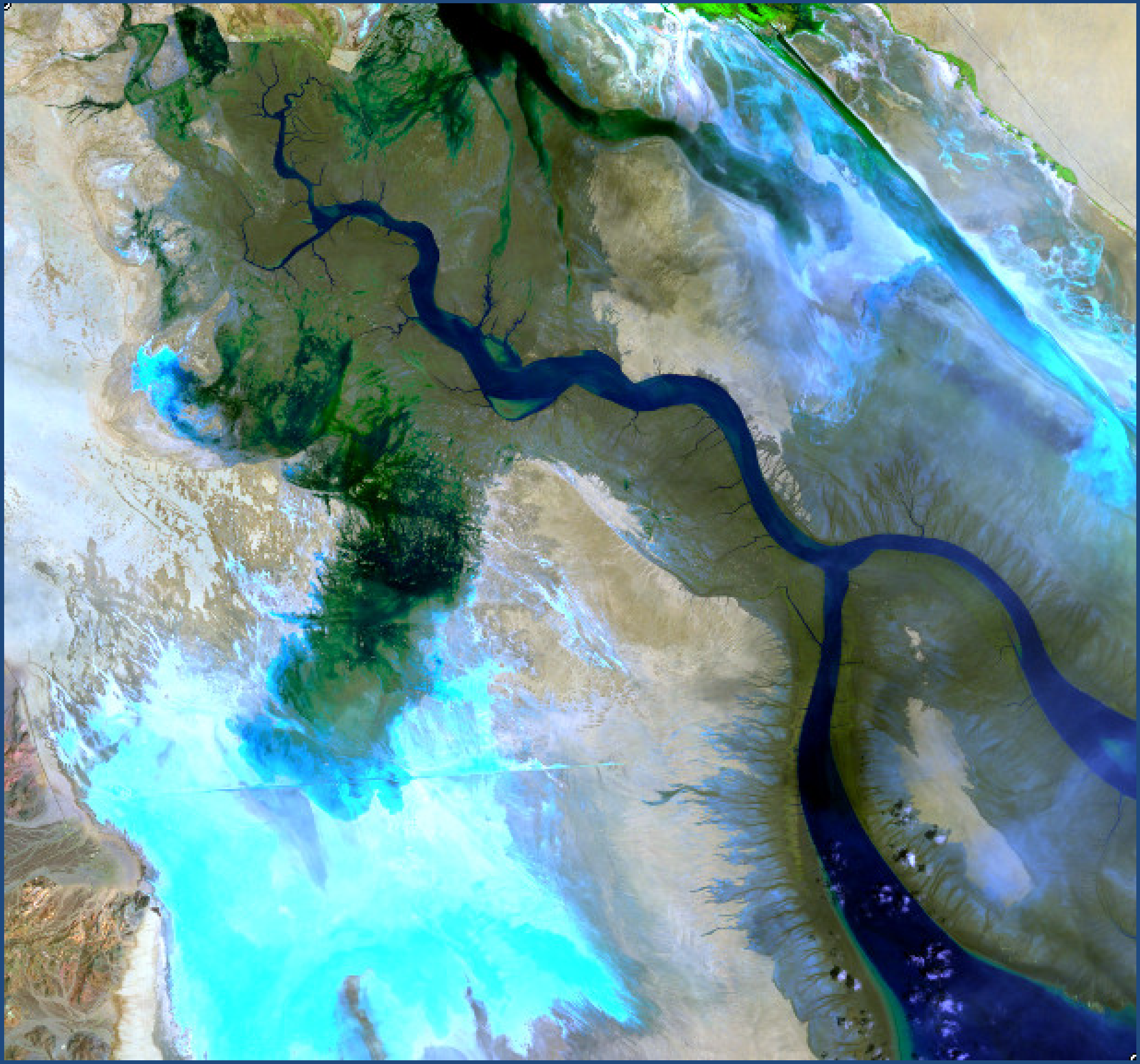
July 19, 2010 5.64m (July 12) Post-earthquake



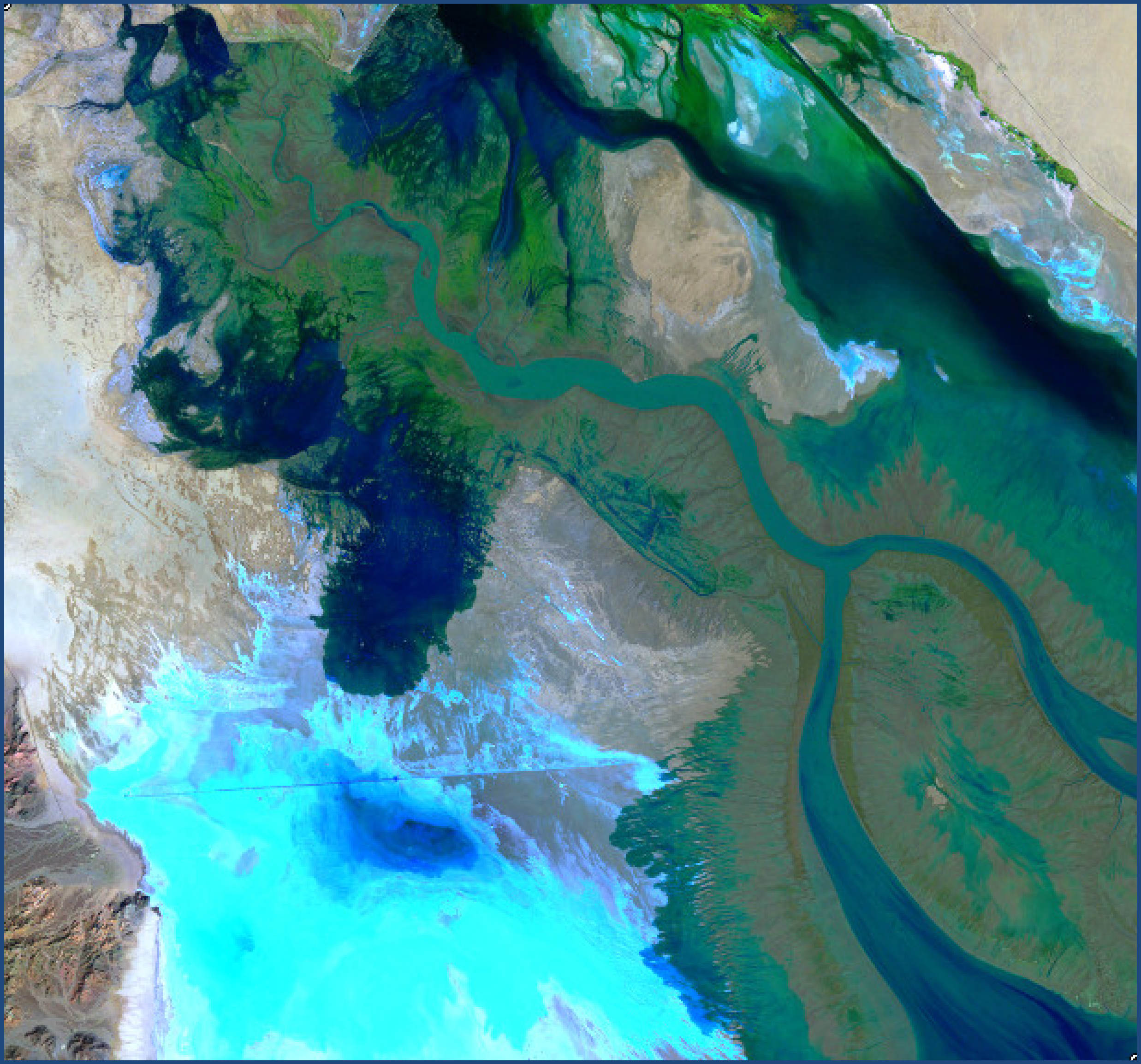
August 20, 2010 5.84m (August 10)



August 7, 2011 5.47m (August 1)



October 26, 2011 5.59m (October 26)



September 2, 2012 5.33m (August 30)

September 18, 2012 5.37m (September 17)

In conclusion…

- InSAR studies can be effective in measuring ground deformation within the intertidal zone when images are acquired during successive neap tide periods.

- Analysis of changing patterns of tidal inundation as revealed by earth observing satellites, overflights, and field observations can be used to describe conditions within inundated areas producing a random or incoherent INSAR phase from the ground reflection.

- The UAVSAR Mexico Earthquake Study holds great promise for continuing these intertidal zone studies, especially if southern UAVSAR flight lines continue to be acquired during neap tide periods.