Dynamic Earthquake and Tsunami Modeling Offshore Ventura, California

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SCEC Rupture Dynamics Code Validation Worksop

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March 11, 2011 Tohoku Earthquake and Tsunami

- M_w 9.0 Earthquake
- Max tsunami runup height over 30 m
- Over 15,700 people killed
- Economic loss in Japan over 300 billion U.S. dollars

Image from Jiji Press/RFP/Getty Images

March 11, 2011 Tohoku Earthquake and Tsunami

Tsunami Barrier Wall

- M_w 9.0 Earthquake
- Max tsunami runup height over 30 m
- Over 15,700 people killed
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Image from Jiji Press/RFP/Getty Images

December 26, 2004 Indian Ocean Earthquake and Tsunami

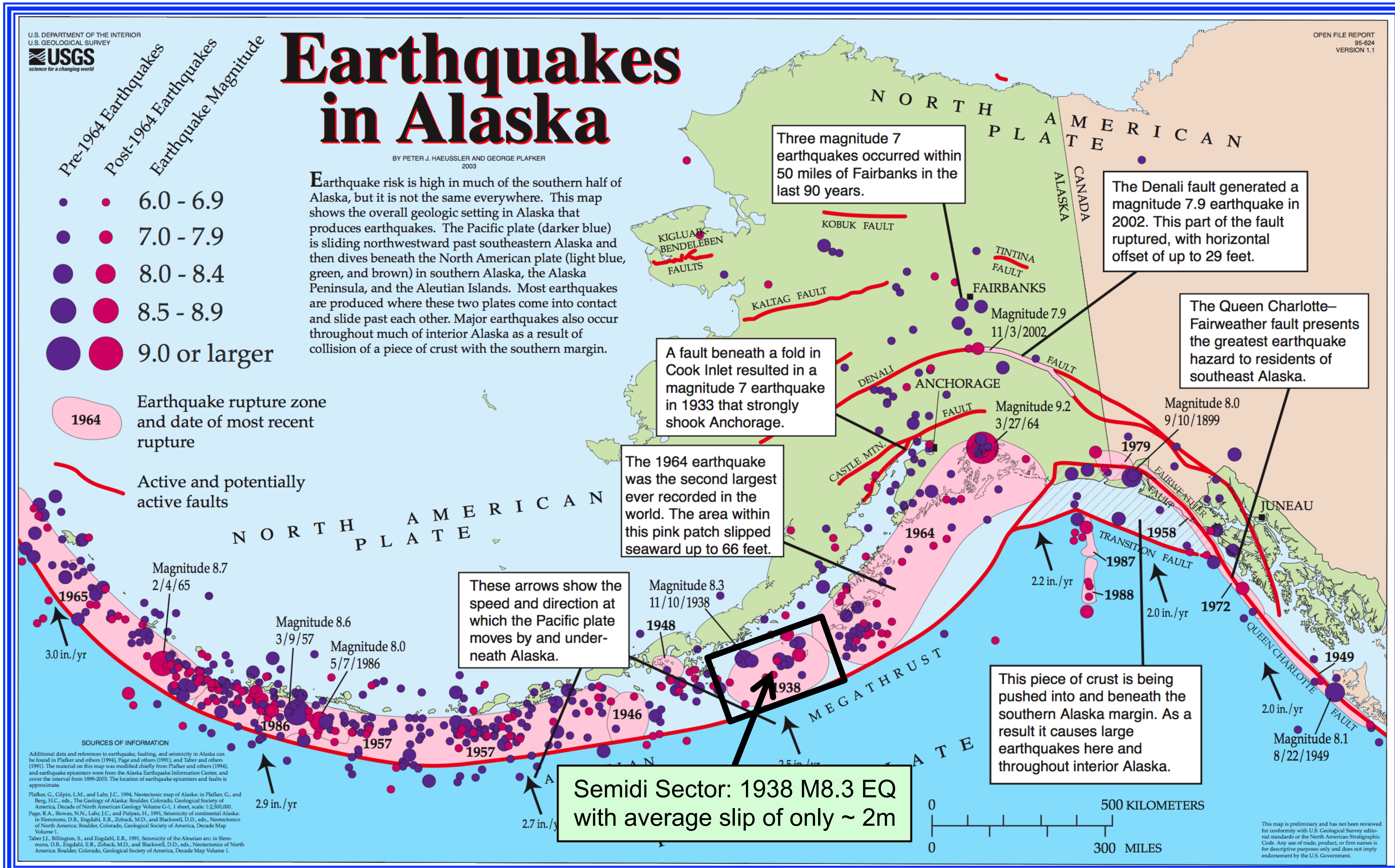
- M_w 9.1 Earthquake
- Max tsunami runup height over 30 m
- Over 225,000 people killed
- Local economies devastated

Image from AFP/Getty Images

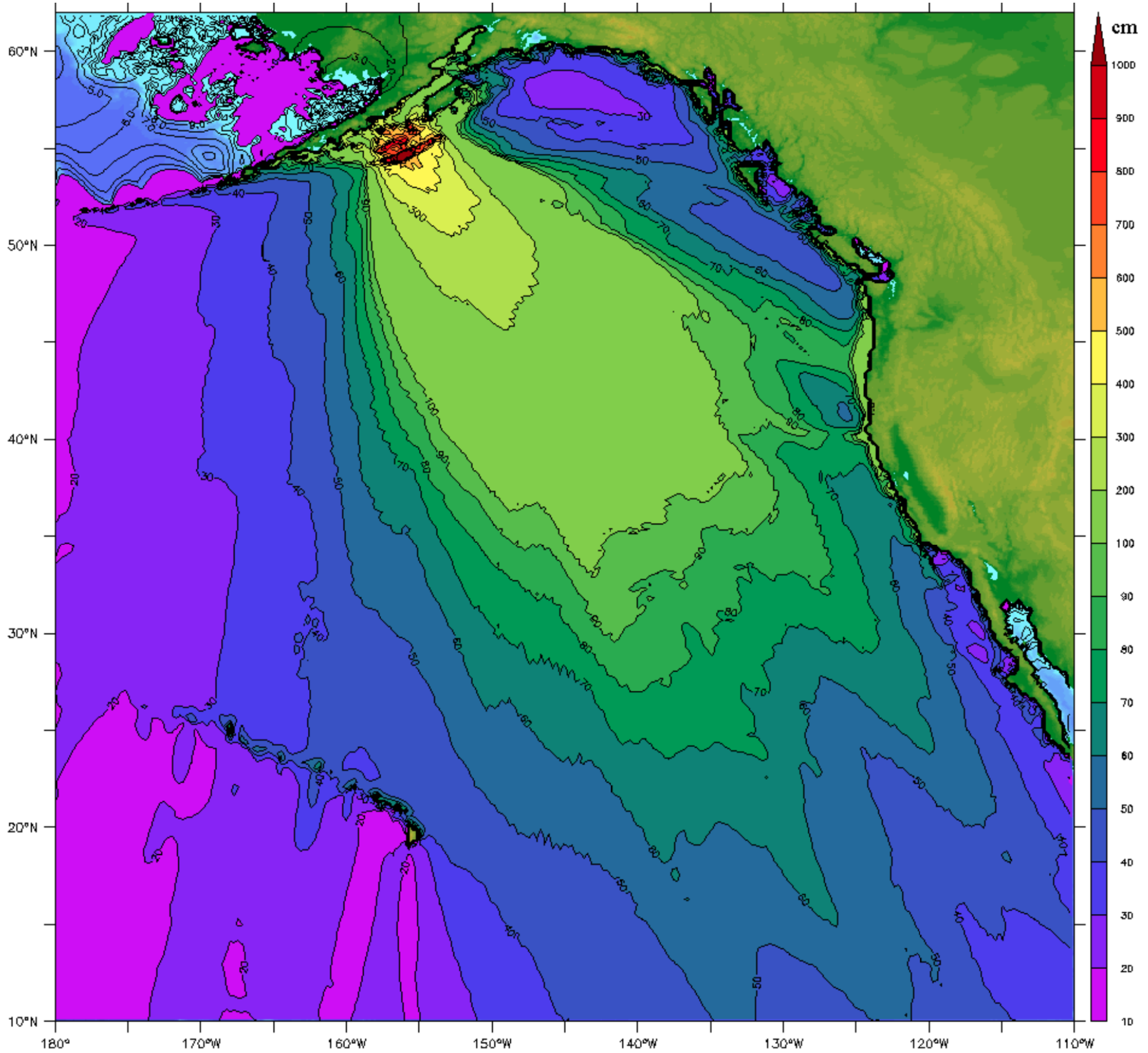
Outline

- Motivation for studying the dynamics of thrust faults and tsunamis
- Offshore Alaska earthquake and tsunami scenario
- Model workflow
- Offshore Ventura, California earthquake and tsunami scenario
- Implications for southern California (plus some caveats)

USGS Science Application For Risk Reduction (SAFRR) Offshore Alaska: Large Megathrust Earthquake Potential



Maximum Tsunami Amplitude of Tsunami Scenario
(North East Pacific Ocean, 0-10 meter colorbar)



(Courtesy: Vasily Titov, NOAA/PMEL, the Method of Splitting Tsunami (MOST) model)

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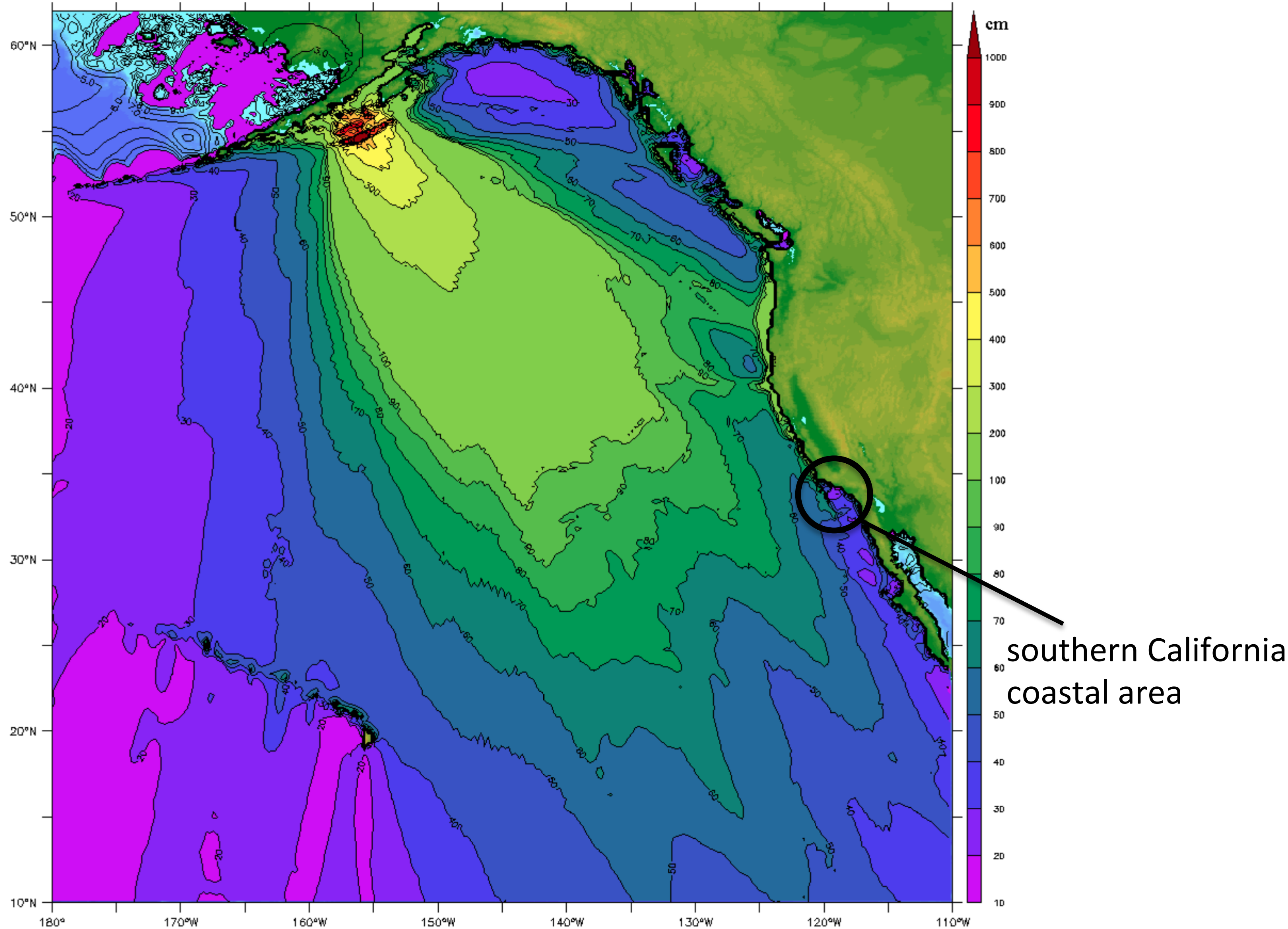
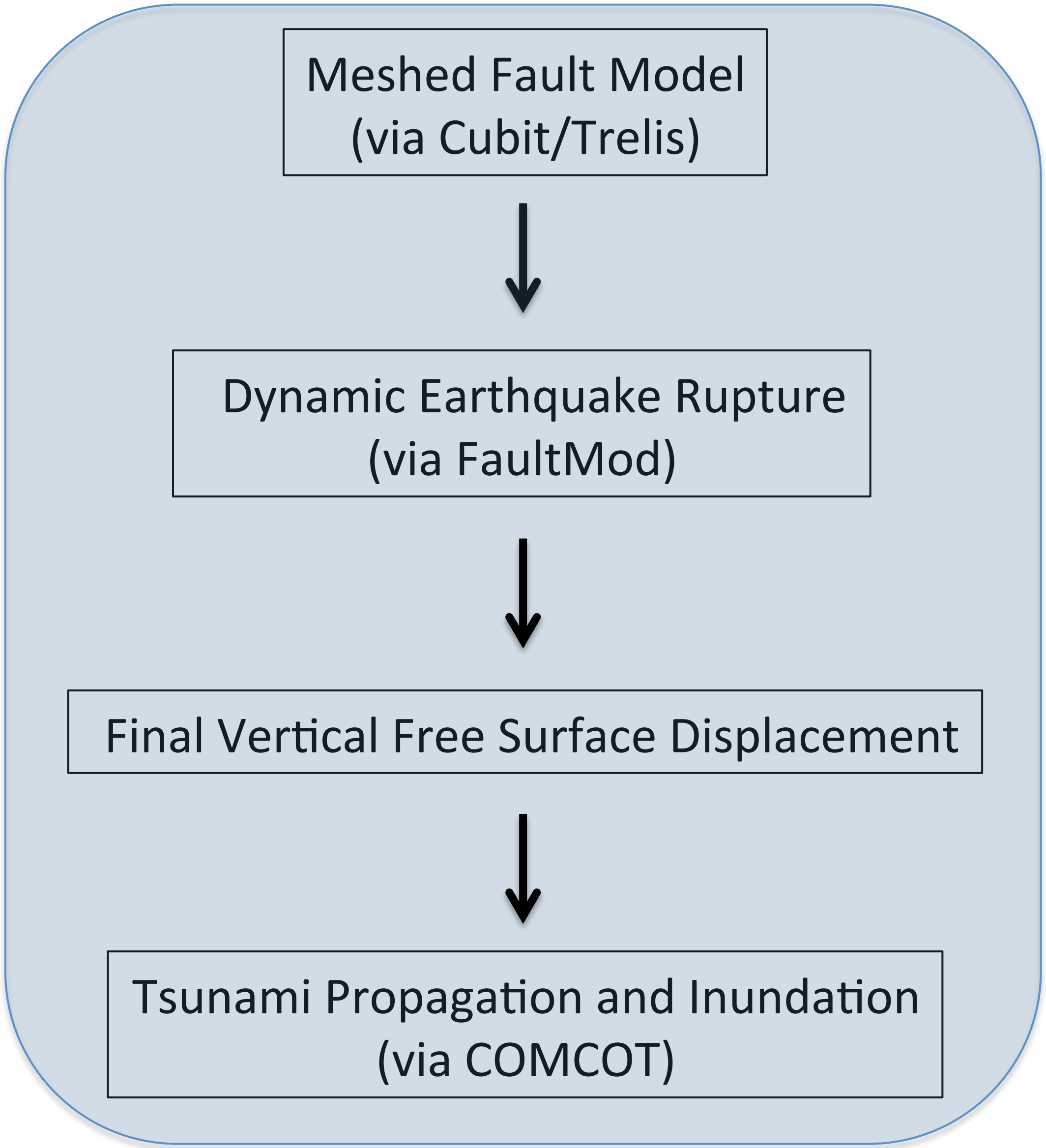


(Courtesy: Vasily Titov, NOAA/PMEL, the Method of Splitting Tsunami (MOST) model)

Model Workflow



Model Parameters

Elastodynamic Parameters

τ_o (initial shear stress)	49.14 MPa
σ_o (initial normal stress)	78.64 MPa
τ_o (initial shear stress in nucleation zone)	65.80 MPa
Density	2700 kg/m^3
S-wave speed	3162 m/s
P-wave speed	5477 m/s
Nucleation Radius	4000 m
Nucleation Speed	2000 m/s
Fault element Size	~200 m
Off-fault element size (~2 km away from fault)	~600 m
Rupture time step	1.000e-2 s
ψ_{ini} (initial state variable for friction)	0.1355
V_{ini} (initial slip speed for friction)	1.000e-12 m/s
V_o (reference slip speed for friction)	1.000e-6 m/s
a (constitutive value in rate-weakening zone)	8.000e-3
b (constitutive value in rate-weakening zone)	1.200e-2
a (constitutive value in rate-strengthening zone)	1.600e-2
L (length parameter in rate-state ageing law)	2.330e-2 m
μ_o (reference friction coefficient)	0.6000
α (normal stress dependence of state variable)	0 (no σ dependence)

Hydrodynamic Parameters

Hydrodynamic element size	~30 m – 600 m
Hydrodynamic time step	1.000e-1 s
Manning's coefficient	1.300e-2

Cornell Multi-grid Coupled Tsunami Model (COMCOT, e.g, Liu et al., 1995)

Based on the Shallow Water Equations

$$\frac{\partial \eta}{\partial t}+\frac{\partial P}{\partial x}+\frac{\partial Q}{\partial y}=-\frac{\partial h}{\partial t}$$

Explicit Leap-frog Finite Difference Method
-evaluation of water surface elevation and volume flux are staggered in space and time

$$\frac{\partial P}{\partial t}+\frac{\partial}{\partial x}\left(\frac{P^2}{H}\right)+\frac{\partial}{\partial y}\left(\frac{PQ}{H}\right)+gH\frac{\partial \eta}{\partial x}+F_x=0$$

$$\frac{\partial Q}{\partial t}+\frac{\partial}{\partial x}\left(\frac{PQ}{H}\right)+\frac{\partial}{\partial y}\left(\frac{Q^2}{H}\right)+gH\frac{\partial \eta}{\partial y}+F_y=0$$

Bottom friction is modeled via a shear stress relation (Manning's formula)

A moving boundary scheme is used to model run-up/run-down
-the 'moving shoreline' is defined as the interface between dry and wet grid cells

x , y = space coordinates

t = time

P , Q = volume fluxes in x and y directions

η = water surface elevation

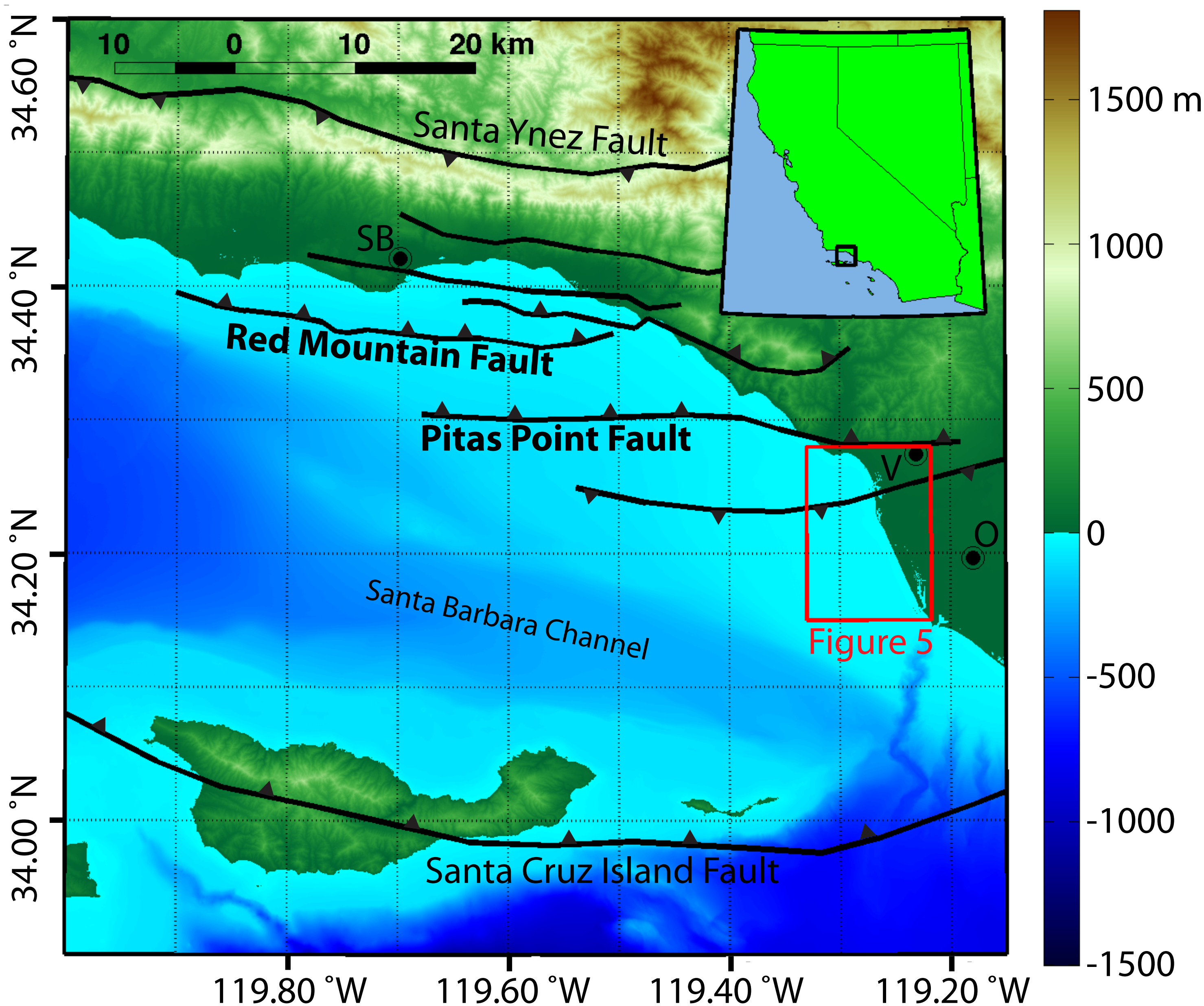
h = water depth

$H = \eta + h$

F_x , F_y = bottom friction in x and y directions

g = acceleration due to gravity

Geographic Area of Interest



Ventura, California Fault Structure

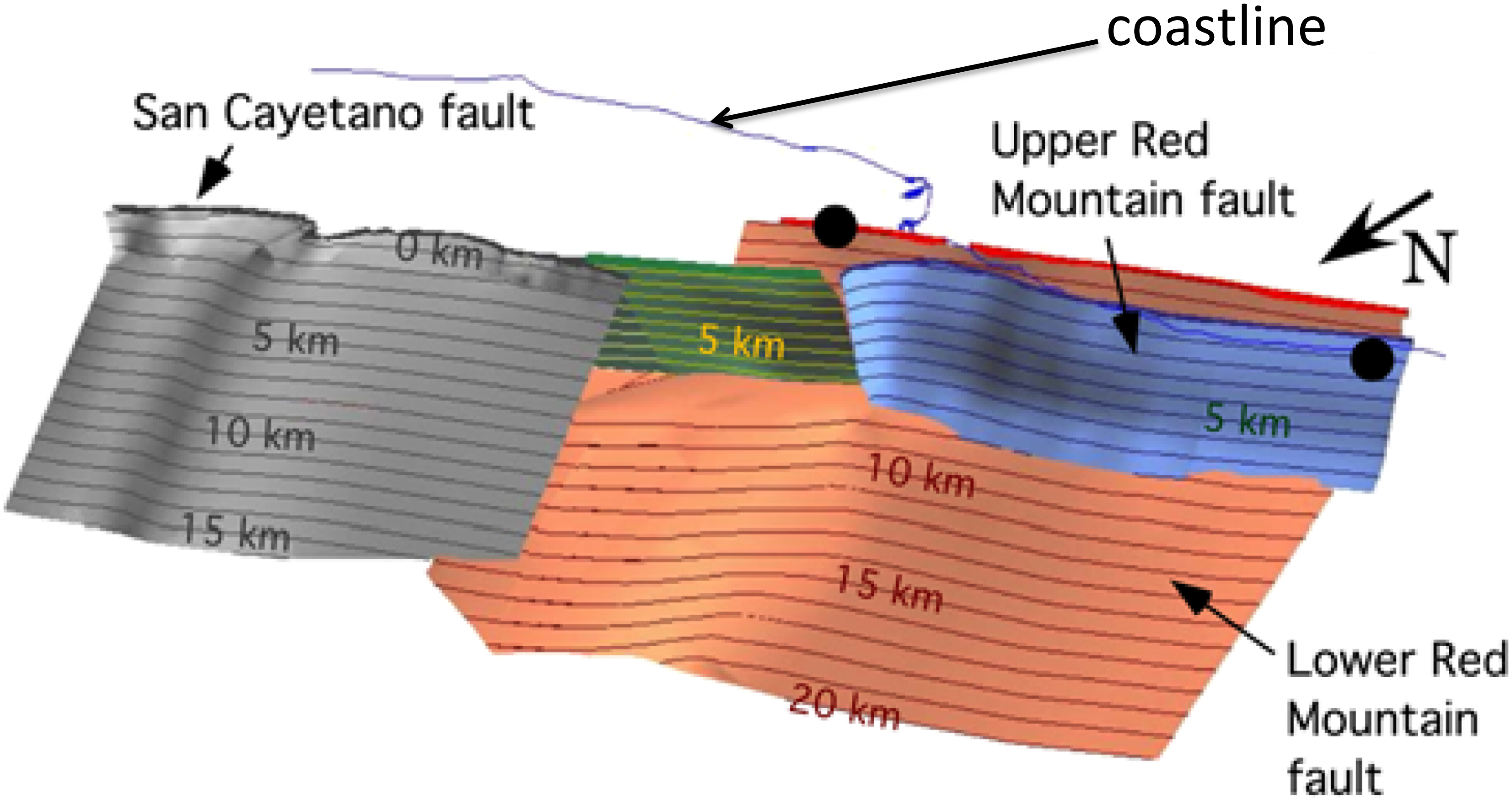


Figure from Hubbard et al., 2014

Hubbard et al. utilize well data and seismic reflection profiles

Interpreted Fault Geometry

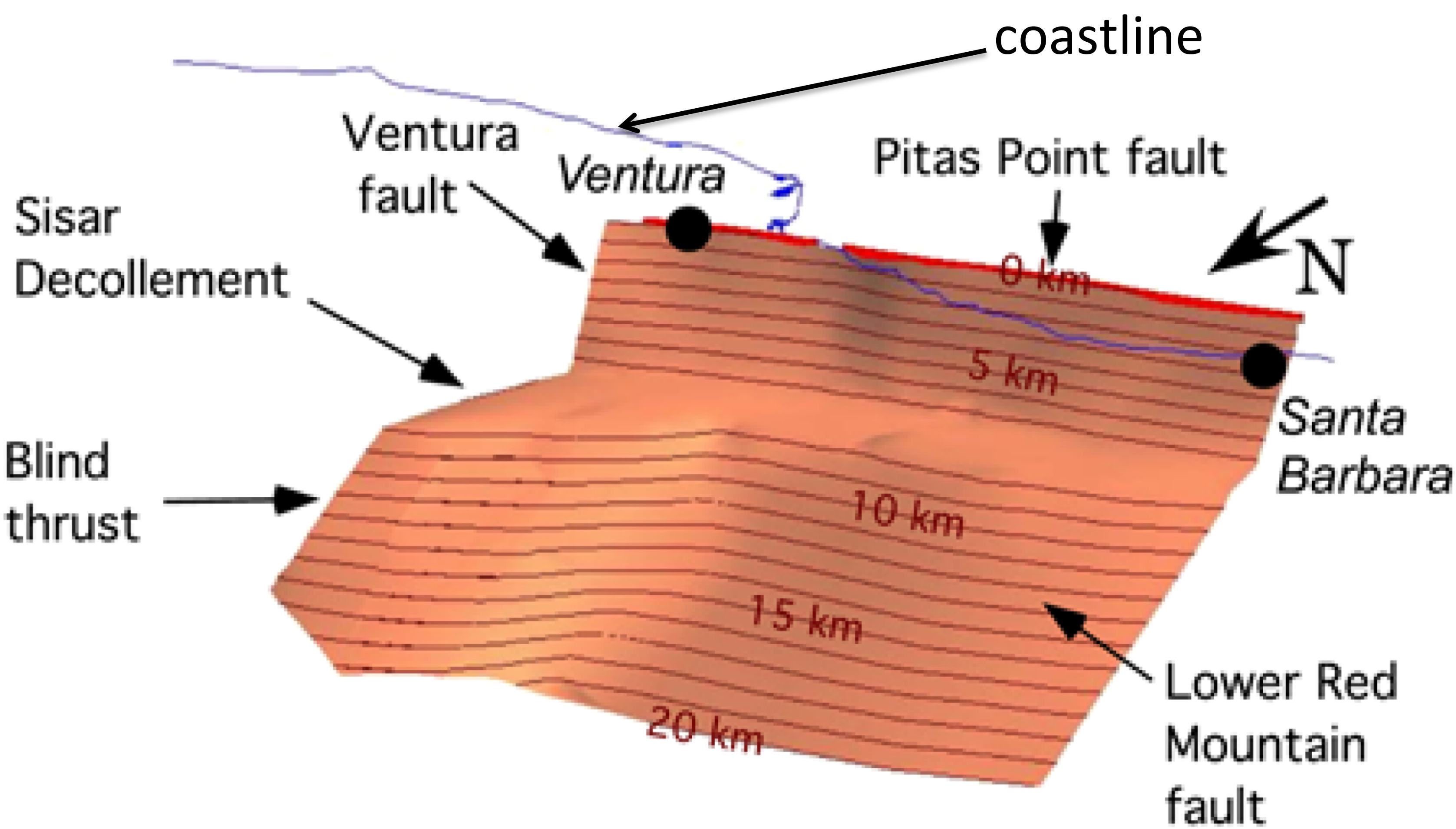
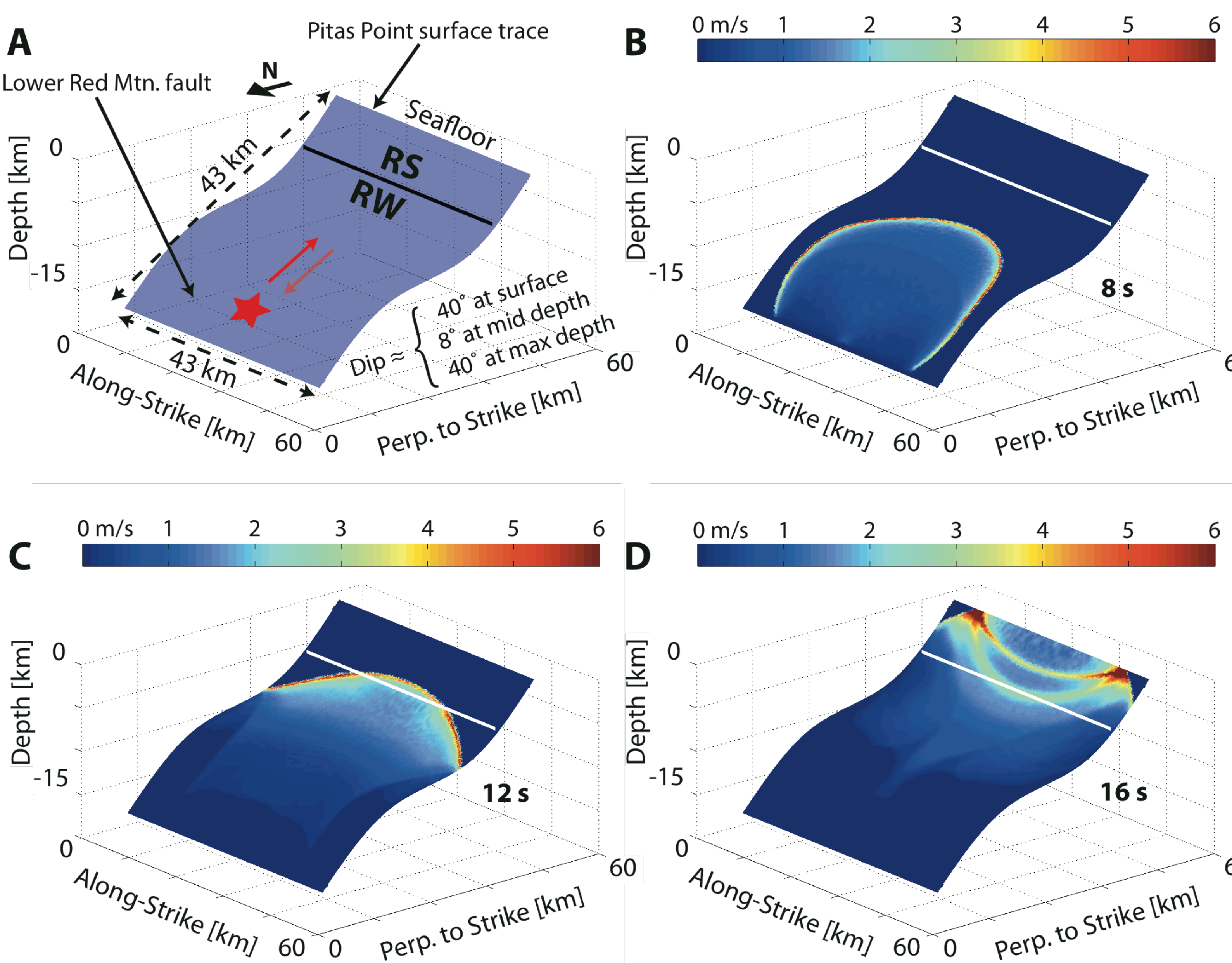
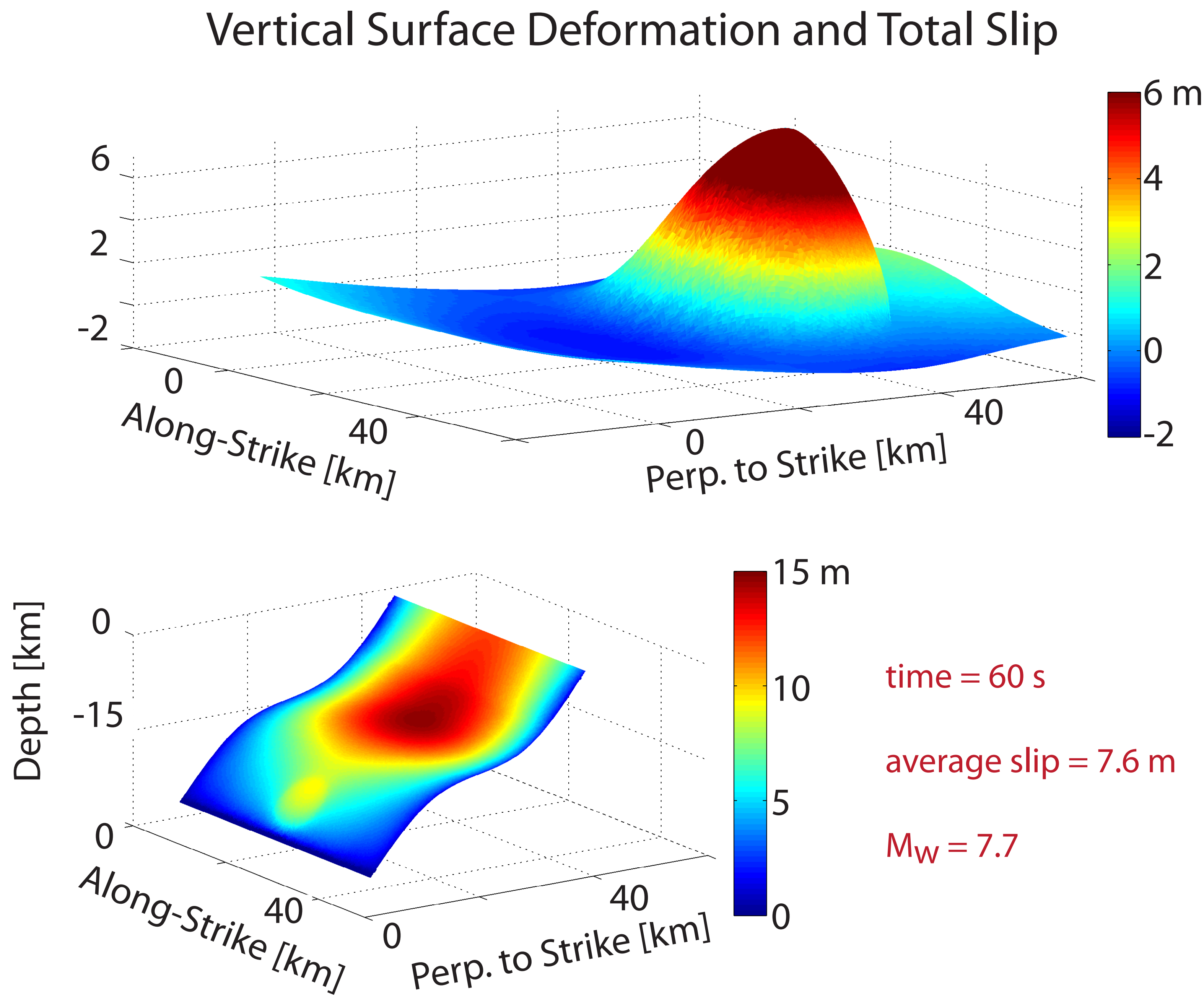


Figure from Hubbard et al., 2014

Fault Geometry and Dip Slip Rate Snapshots

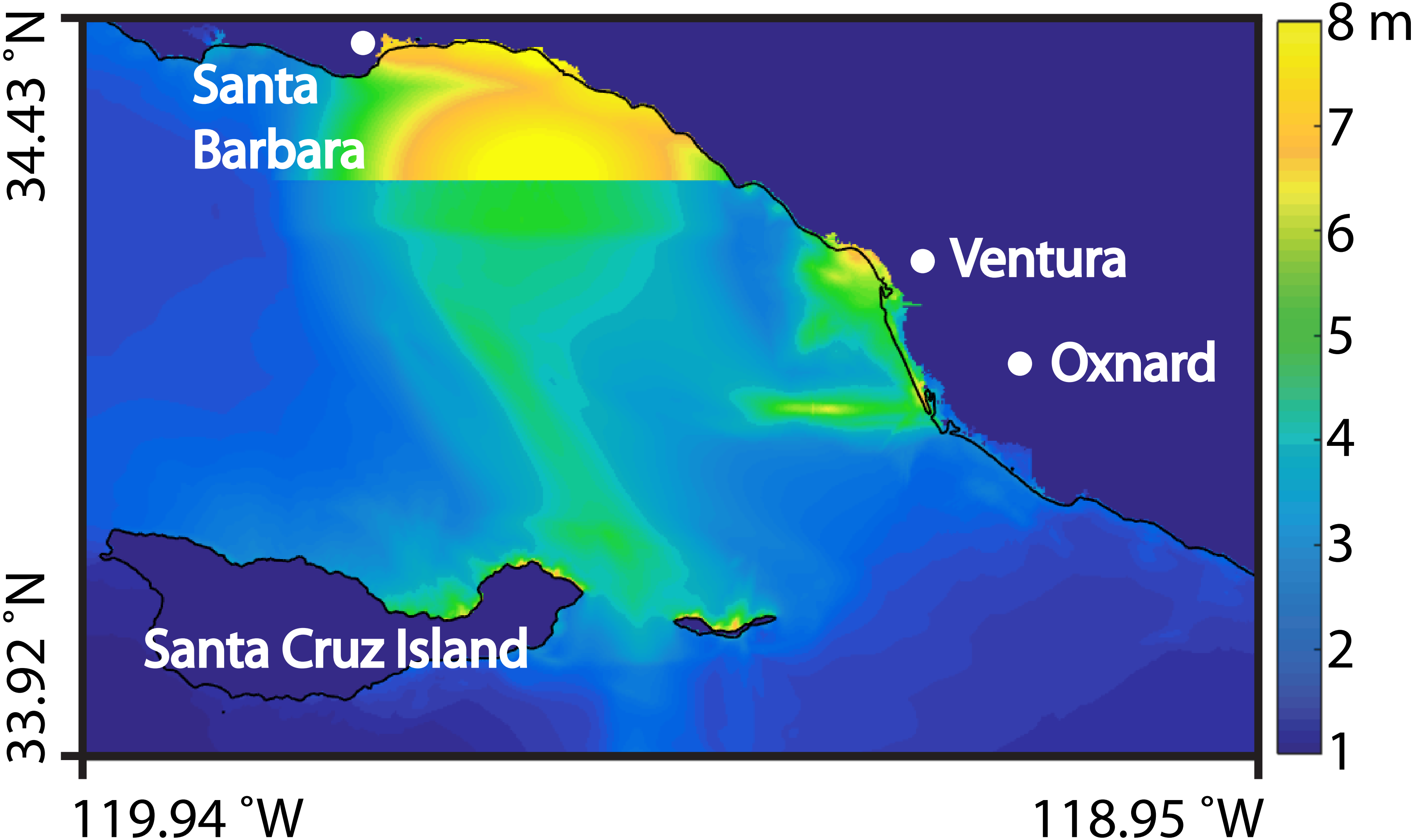


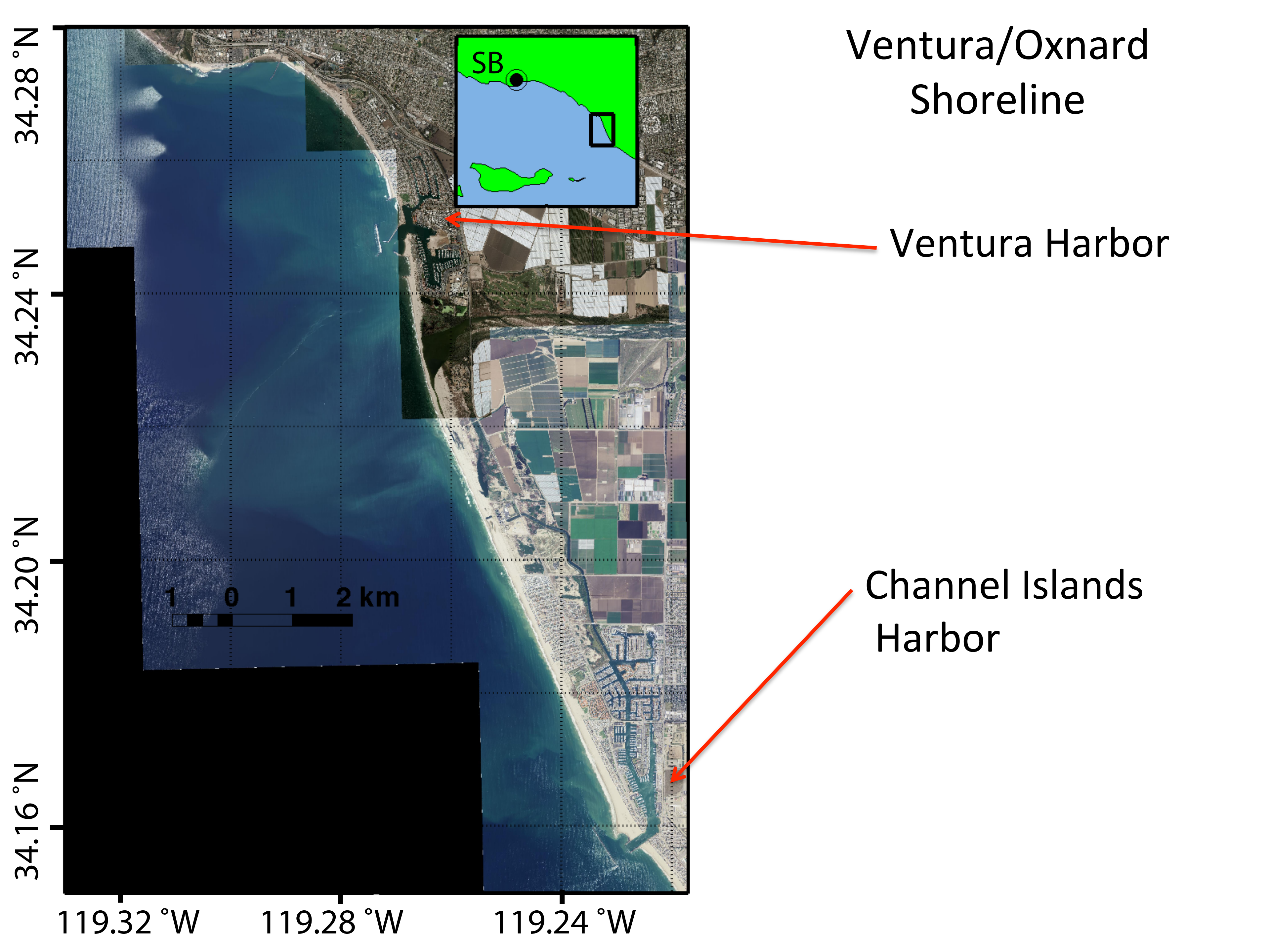
Vertical Deformation and Total Dip Slip (in meters)

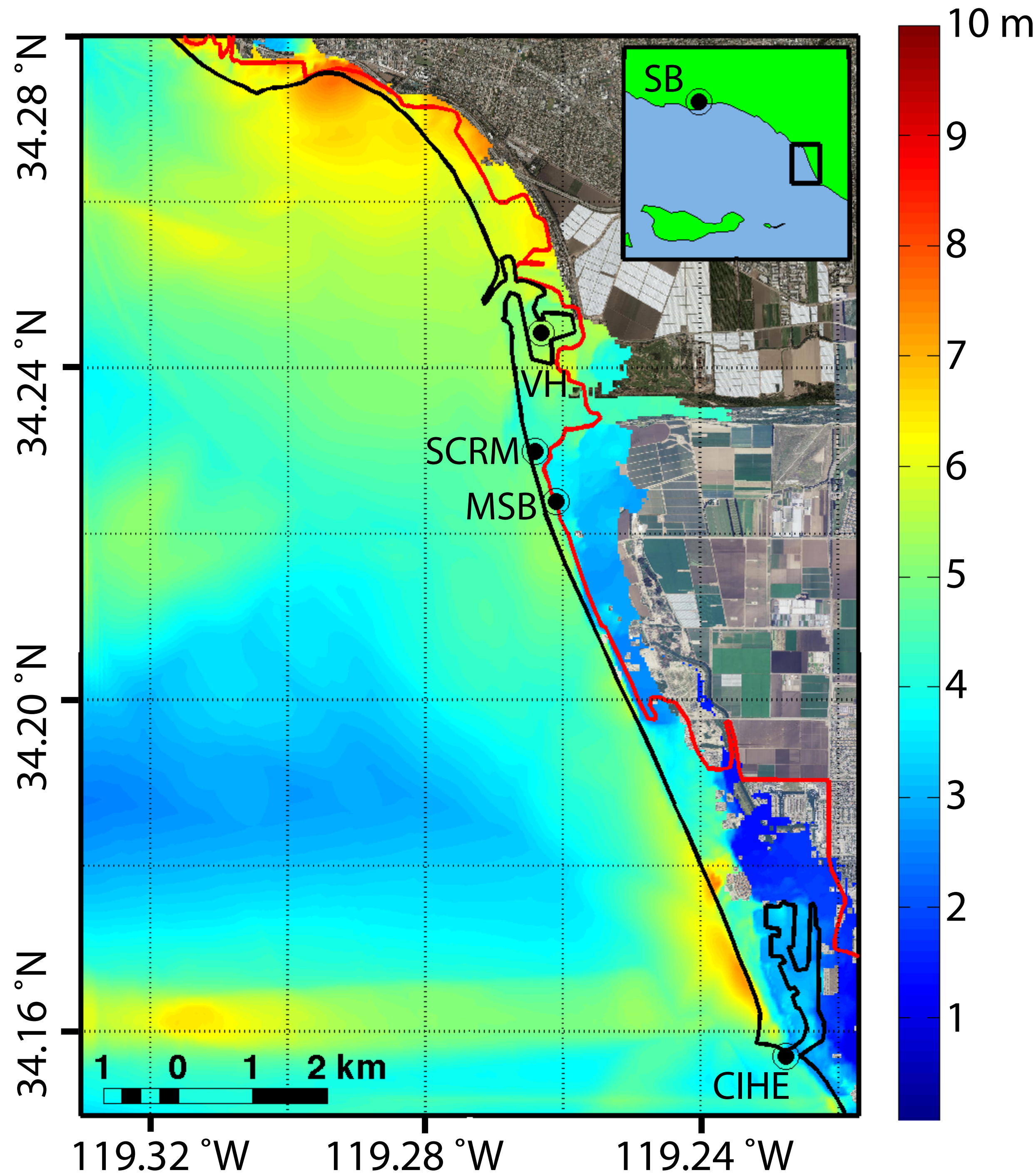


Movie of Tsunami Model

Regional Maximum Tsunami Amplitude




Ventura/Oxnard
Shoreline
Ventura Harbor
Channel Islands
Harbor
SB
1 0 1 2 km
34.28 °N
34.24 °N
34.20 °N
34.16 °N
119.32 °W
119.28 °W
119.24 °W



Localized Maximum Tsunami Amplitude

Black line indicates coastline

Red line indicates California state reference inundation line

Black circles indicate example locations such as:

SB = Santa Barbara
VH = Ventura Harbor
CIHE = Channel Islands Harbor Entrance

Implications

- It is important to investigate realistic earthquake and corresponding tsunami scenarios for a given region
  - Combining dynamic earthquake and tsunami models is a step in this direction
  - Local tsunamis do not provide as much warning time
- Earthquake sources on the Pitas Point and Red Mountain faults should be included in tsunami hazard assessments offshore California
- Inundation from this model exceeds the state inundation line that incorporates several tsunami scenarios
  - Large northward and eastward tsunami amplitudes from rupture on the Pitas Point and Lower Red Mountain faults

Some of the Caveats

- This parameterization results in a large earthquake!
- A range of earthquake models is needed for this area
  - Different prestress and velocity distributions
  - Different friction distributions
  - Encompass several faults

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- **H.K. Thio**

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