Slip rates and rheology of the southern San Andreas-San Jacinto fault system from earthquake cycle models constrained by GPS and InSAR observations

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Outline

**Motivation:** geodetic data such as InSAR and GPS can be used to constrain fault slip rates and crust/mantle rheology.

**Data:** InSAR (next slides) and SCM3 GPS

**Modeling:** Viscoelastic earthquake cycle FE model

**Application:** Southern San Andreas - San Jacinto fault models (preliminary)

Southern California seismicity (Lin et al., 2007)
InSAR mean velocity analysis: ERS track 356

**SBAS** $[v_m \text{ dh}]$ least-squares solution

- baselines under $\sim 200$
- throw out bad ints.
- de-ramp final $v_m$ based on masked area in Mojave
LOS mean velocity + SCM3 GPS projected into the radar LOS
Earthquake cycle modeling

Analytical shear zone model (Pollitz, 2001)

$H=30$ km
$D=15$ km
$\tau_0 = \mu T/(2\eta)$ (number of relaxation times per earthquake cycle $T$, with shear modulus $\mu$, and viscosity $\eta$)

Higher viscosity

Lower viscosity
Earthquake cycle models for 100-800 cycles using GeoFEST 4.3

Edge-driven far-field shear viscoelastic earthquake cycle model

We generate Greens functions for unit slip rate for each fault: San Jacinto (SJF) and San Andreas (SAF).

Model divided into 9 domains:
- top layer - elastic
- lower two layers - Maxwell viscoelastic

Earthquake repeat time $T$ considered 250 years for both faults, both late in their cycle.
Recent viscosity ($\eta$) estimates for lower crust/upper mantle

<table>
<thead>
<tr>
<th>Study</th>
<th>Location</th>
<th>$\eta$ lower crust</th>
<th>$\eta$ upper mantle</th>
<th>$\eta$ plastosphere</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fay and Humphreys, 2005</td>
<td>S. San Andreas</td>
<td>1e20</td>
<td>5e19</td>
<td></td>
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<tr>
<td>Johnson et al., 2007</td>
<td>Mojave segment San Andreas</td>
<td>1-3e19</td>
<td>1e21</td>
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<tr>
<td>Pollitz, 2001</td>
<td>Mojave segment San Andreas</td>
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<td>1e19</td>
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<tr>
<td>Schmalzle et al., 2006</td>
<td>Carrizo segment San Andreas</td>
<td></td>
<td></td>
<td>2-5e19</td>
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<tr>
<td>Gourmelen and Amelung, 2005</td>
<td>Central Nevada</td>
<td>&gt;1e20</td>
<td>1-7e18</td>
<td>1e18-1e19</td>
</tr>
</tbody>
</table>
InSAR velocity and seismicity

We seek to use the InSAR and GPS velocity profile to understand questions regarding:

Rates of the SAF and SJF
- Large uncertainties remain and are model dependent.
- Earthquake hazard depends on slip rate estimates.

Rheology of the crust/upper mantle
Recent studies have attempted to understand the rate versus rheology with significant material contrast required in some cases (Fialko, 2006).

Fault geometries and location
Vertical vs dipping, which SJF?
InSAR velocity and seismicity

Vertical faults
InSAR velocity and seismicity

60° dipping faults
Vertical faults - San Jacinto at -42 km

\[ \mu = 3e9 \]
\[ \eta = 5e19 \]
\[ \eta = 1e20 \]
\[ \eta = 1e21 \]

\[ v_{SJF} \text{ 16.7 mm/yr} \]
\[ v_{SAF} \text{ 29.0} \]
\[ \text{rms 219.0} \]

\( \mu = 30 \text{ Gpa} \)

Grid search among values for viscosity \( \eta \) in:
- Lower crust (LC): \( 10^{20}, 10^{21} \text{ Pa-s} \)
- Upper mantle (UM): \( 5 \times 10^{19}, 10^{20} \text{ Pa-s} \)
- Salton trough (ST): \( 5 \times 10^{19}, 10^{20} \text{ Pa-s} \)
North profile

LOS + SCM3 GPS

Seismicity (Lin et al., 2007)
Seismicity (Lin et al., 2007)
Vertical faults - San Jacinto at -42 km

N cross-section

S cross-section

$v_{SJF}$ 18.8 mm/yr
$v_{SAF}$ 27.2
rms 101.9

$v_{SJF}$ 10.9 mm/yr
$v_{SAF}$ 33.6
rms 160.7
Vertical faults - San Jacinto at -33 km

\[ \mu = 3 \times 10^9 \]

\[ \eta = 5 \times 10^{19} \]

\[ \eta = 1 \times 10^{20} \]

\[ \eta = 1 \times 10^{21} \]

\[ v_{SJF} = 20.5 \text{ mm/yr} \]

\[ v_{SAF} = 22.6 \]

rms 209.5
Vertical faults - San Jacinto at -33 km

N cross-section

$\mu = 3 \times 10^9$
$\eta = 5 \times 10^{19}$

S cross-section

$\eta = 1 \times 10^{20}$
$\eta = 1 \times 10^{21}$

$v_{SJF}$ 25.4 mm/yr
$v_{SAF}$ 20.4
rms 190.9

$v_{SJF}$ 16.5 mm/yr
$v_{SAF}$ 26.8
rms 143.4
$\mu = 3e9$

$\eta = 5e19$

$\eta = 1e20$

$\eta = 1e21$

$\nu_{SJF}$ 30.5 mm/yr

$\nu_{SAF}$ 11.1

rms 212.48

60° dipping faults, San Jacinto at -33 km
60° dipping faults, San Jacinto at -42 km

\[ \mu = 3e9 \]
\[ \eta = 5e19 \]
\[ \eta = 1e20 \]
\[ \eta = 1e21 \]

\[ v_{SJF} = 19.1 \text{ mm/yr} \]
\[ v_{SAF} = 24.4 \]
\[ \text{rms} = 209.0 \]
Conclusions

➢ InSAR time series (mean v in this case)
  • Alternative to stacking.
  • Maintains the ability to analyze the temporal signal.
  • Some issues remain with regard to residual ramps.

➢ Viscoelastic earthquake cycle modeling
  • More physically appealing approach.
  • Potential for resolving heterogeneous rheologic structure versus fault locations and slip rates.
  • Of the models tested, cannot significantly differentiate between vertical and 60° dipping SAF and SJF.
  • Models favor high viscosity lower crust and lower viscosity upper mantle.
  • Location of the SJF depends on North vs South sub-profiles.
  • Slip rates for the best fitting models on the order of 19 and 25 mm/yr for the SJF and SAF, respectively.
Thank you