Inference of regional viscosity structure from space-based geodetic data

Fred F. Pollitz

U.S. Geological Survey

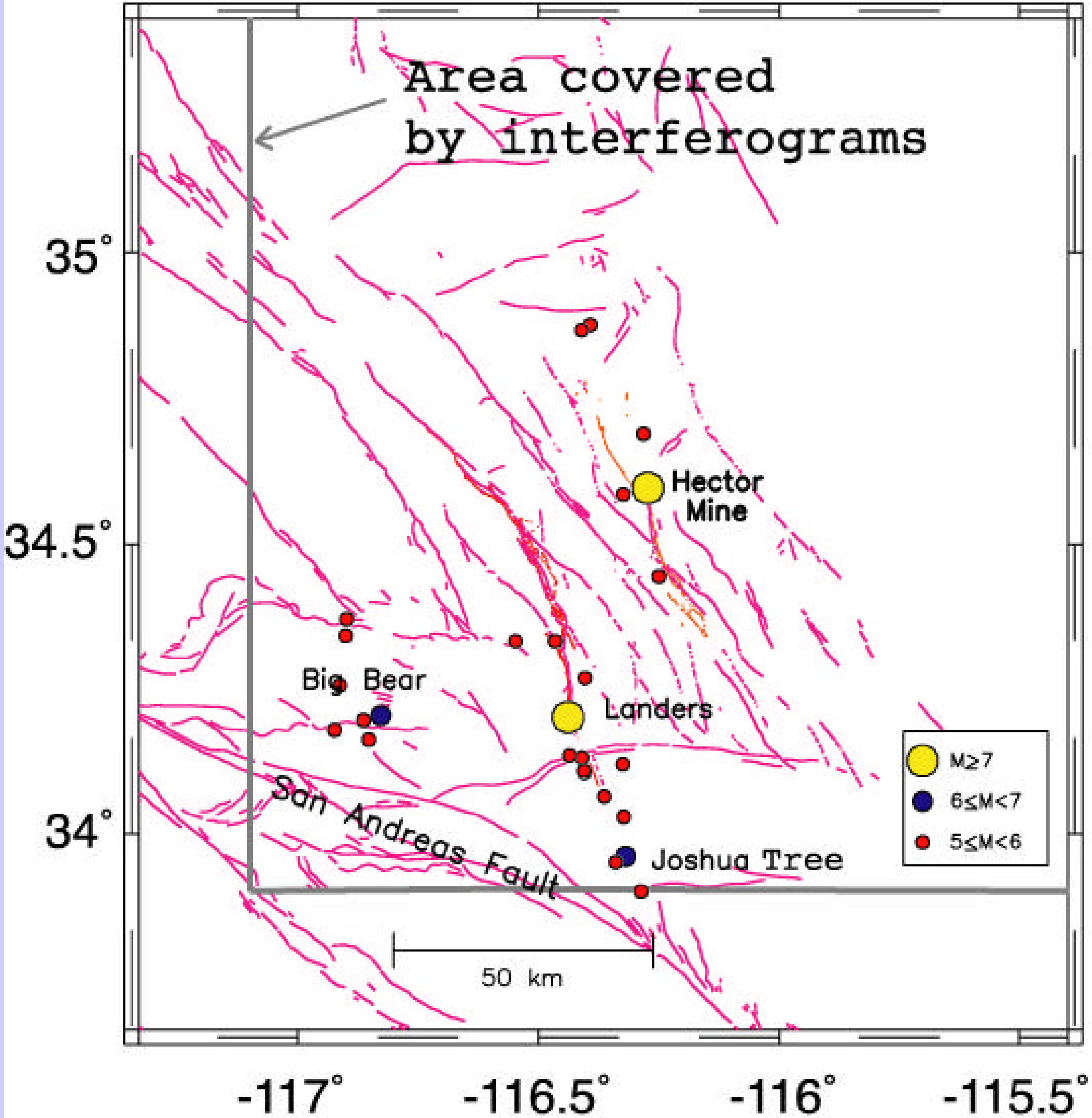
Menlo Park

1. **GPS and InSAR evidence for a strong crust and weak mantle beneath the Mojave Desert, southern California**

2. **Inference of transient mantle rheology beneath the Mojave Desert from three-component continuous GPS (SCIGN network) and campaign GPS (USGS network)**

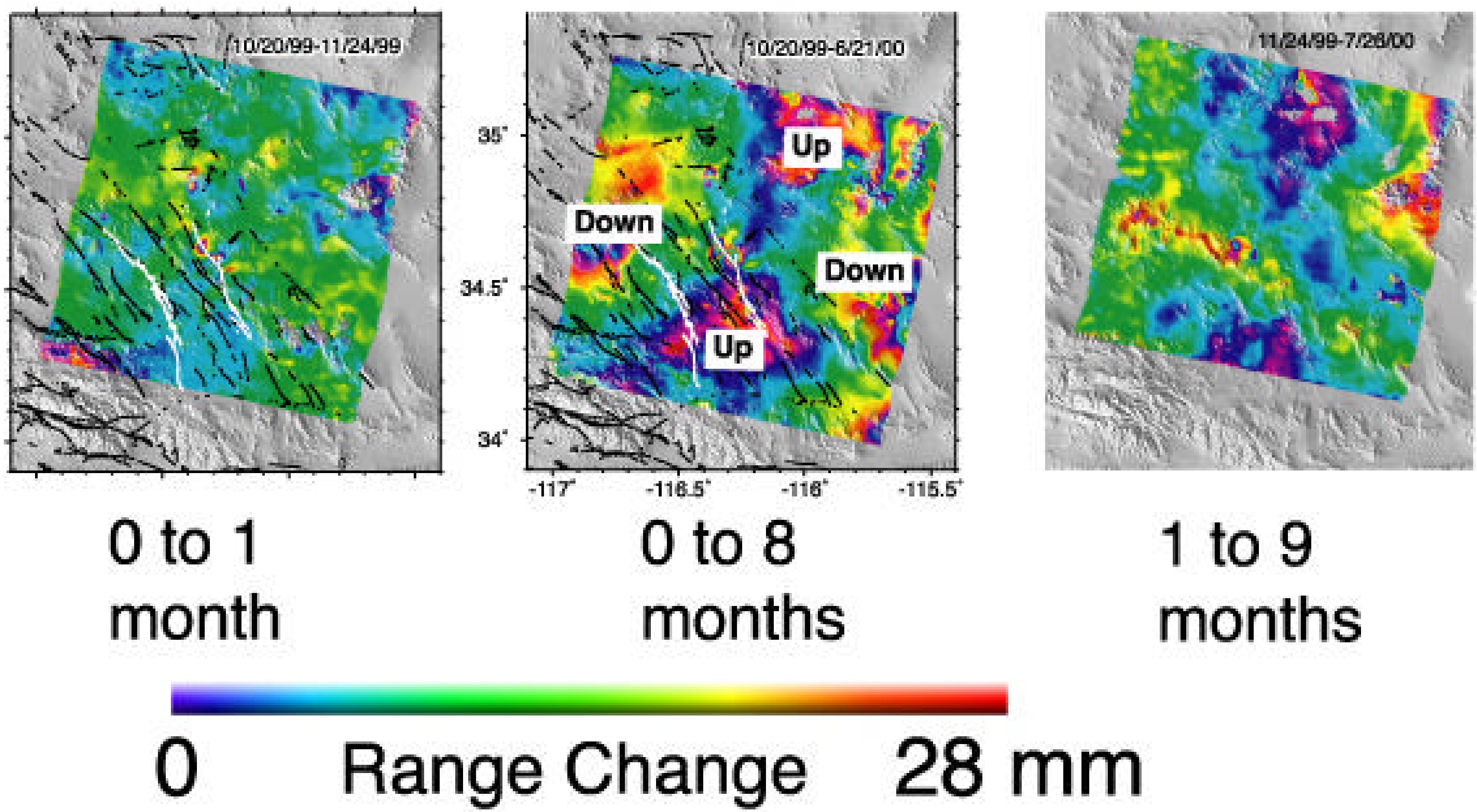
Acknowledgments: Jim Savage
Ken Hudnut
Wayne Thatcher

GPS and InSAR evidence for a strong crust and weak mantle beneath the Mojave Desert, southern California

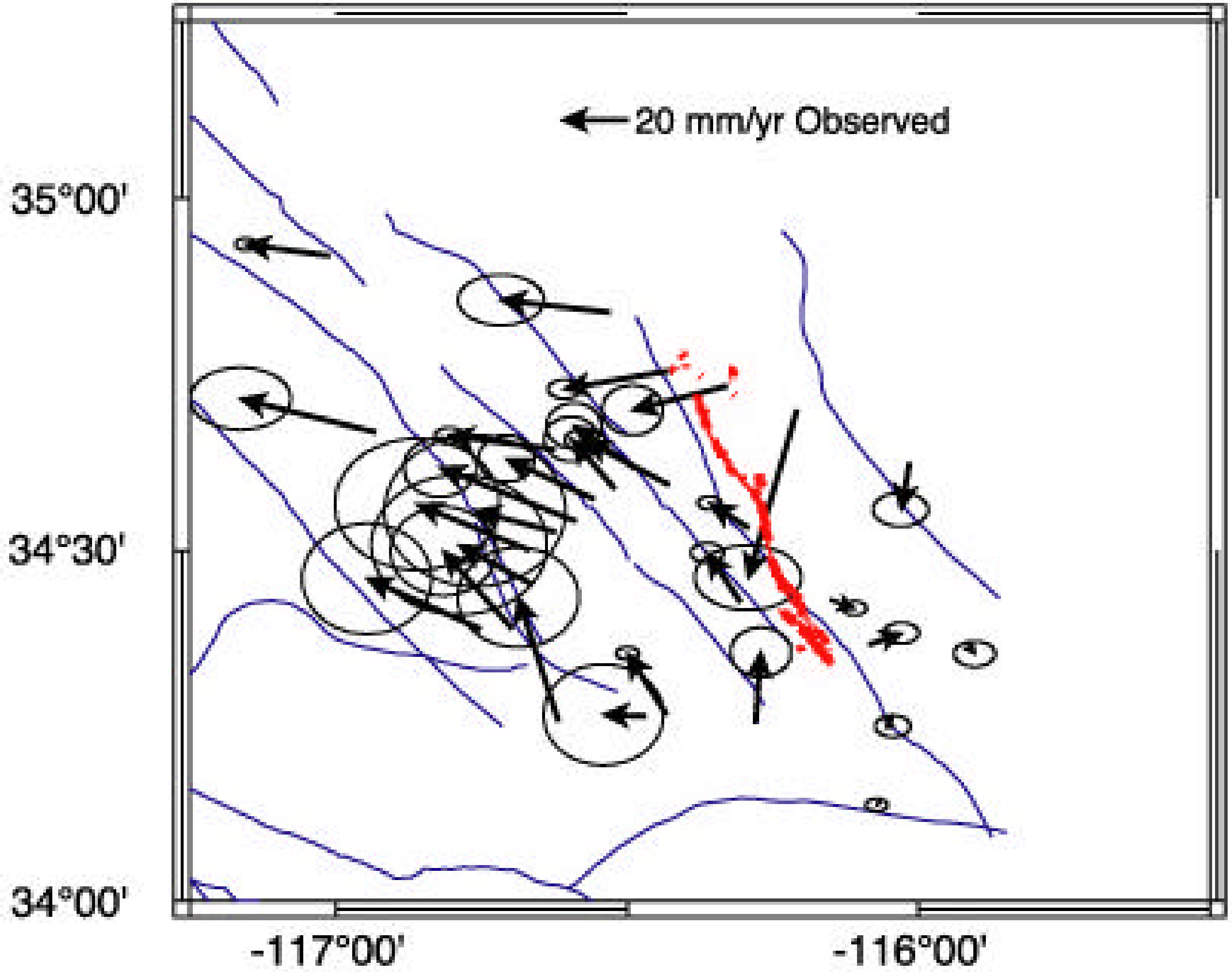

Area covered
by interferograms
Hector
Mine
Big Bear
Landers
San Andreas Fault
Joshua Tree
50 km
M≥7
6≤M<7
5≤M<6
35°
34.5°
34°
-117°
-116.5°
-116°
-115.5°

ERS interferograms provided by WINSAR

Postseismic Data



Postseismic Data



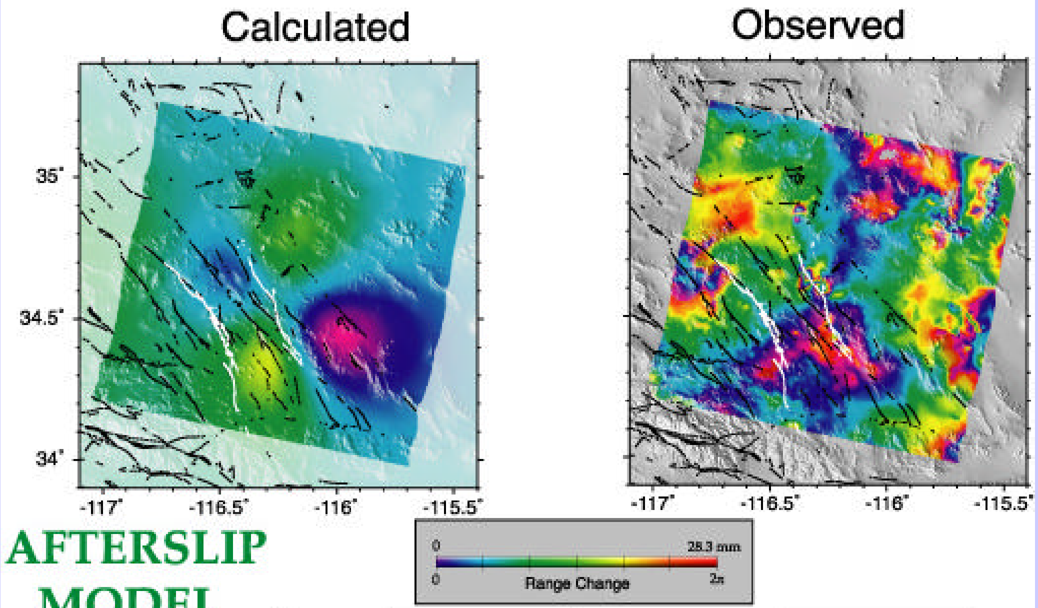
SCIGN continuous and USGS campaign GPS time series

0 to 8 months

Hector Mine

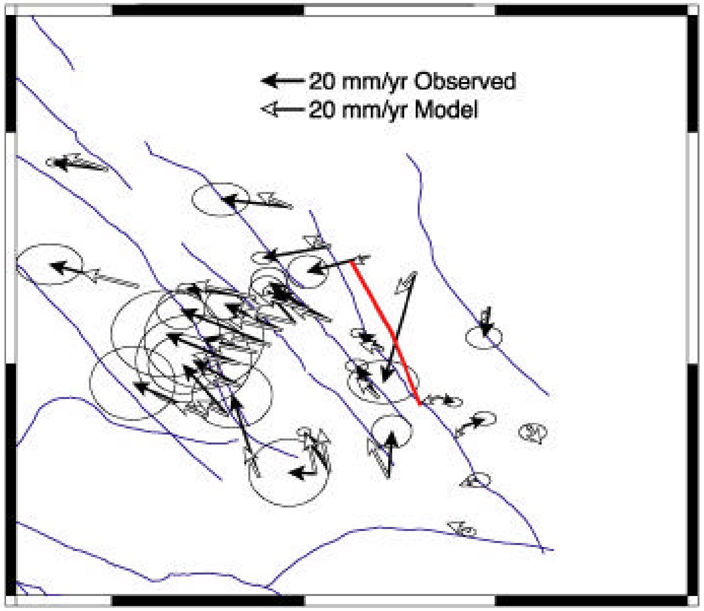
Postseismic Day 4 - Day 245

InSAR

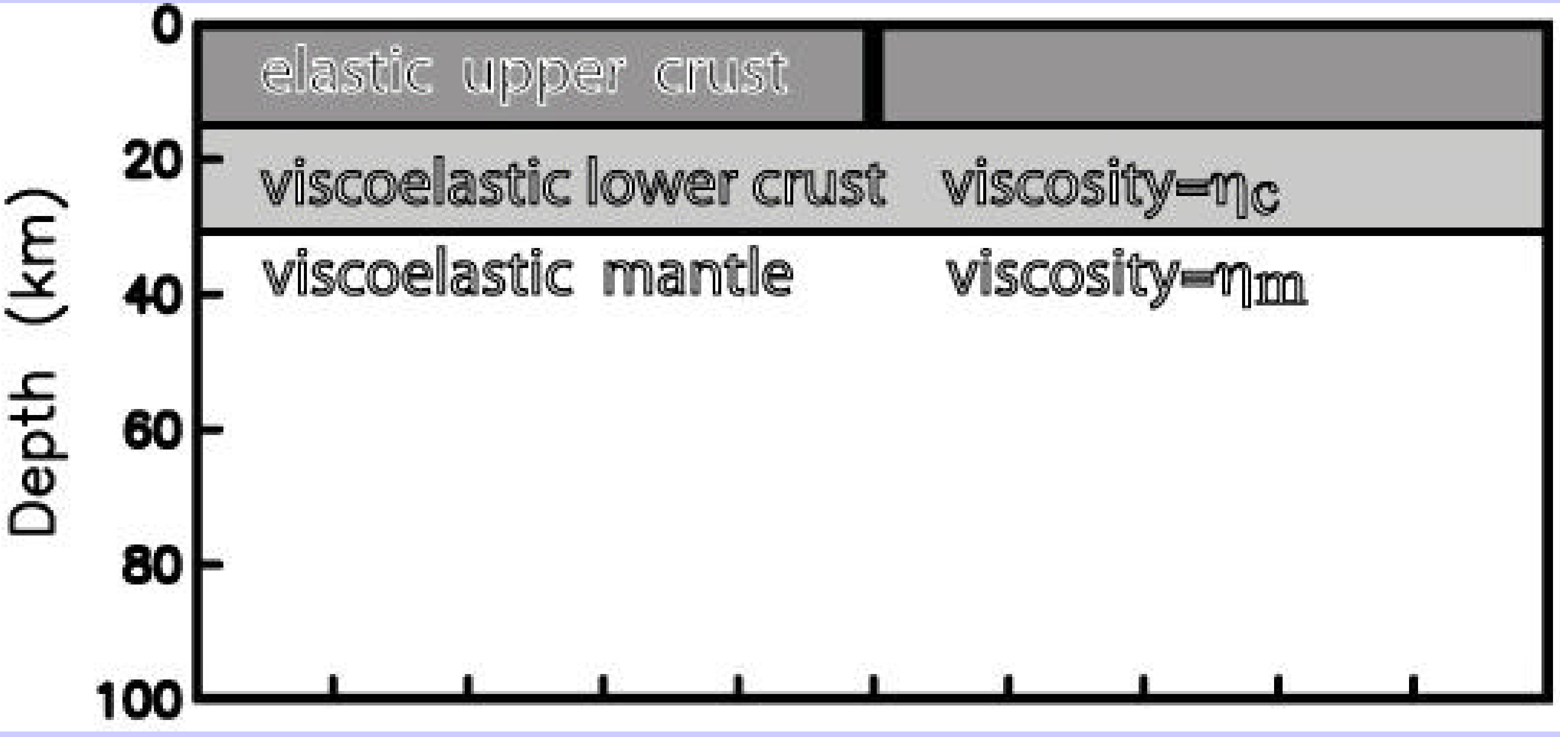


AFTERSLIP MODEL

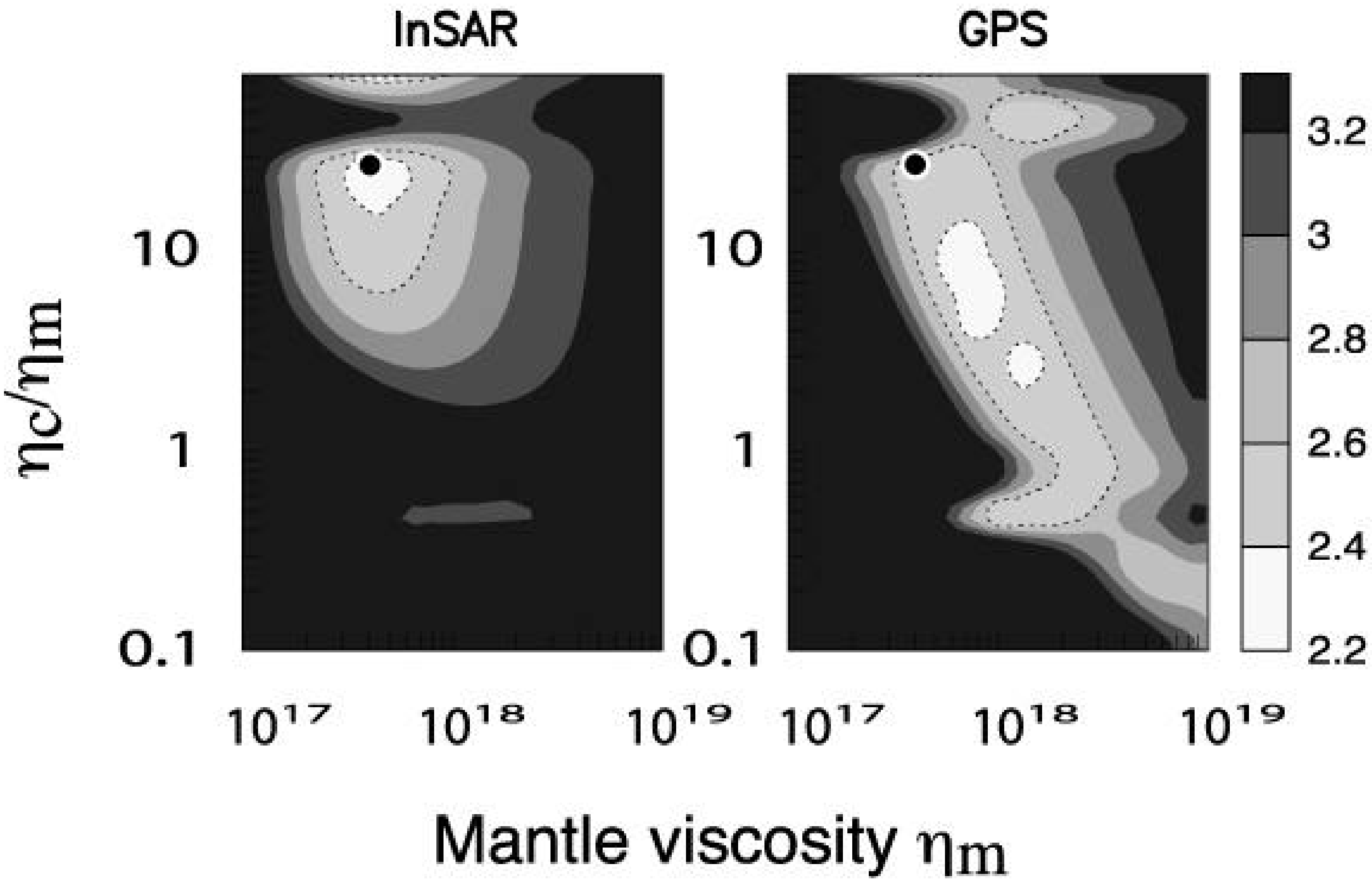
GPS



Viscoelastic Model



Results of grid search for η_m and η_c: $\log_{10}$(misfit)

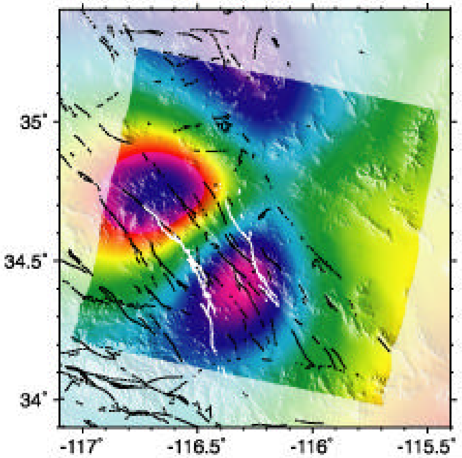


Hector Mine

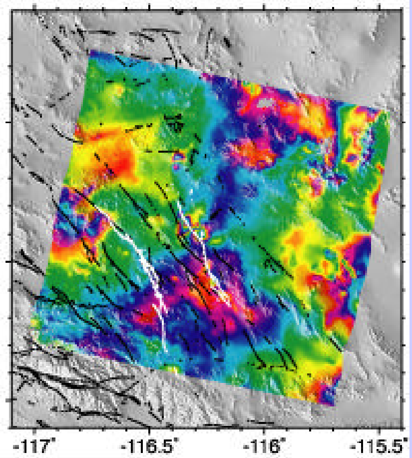
Postseismic Day 4 - Day 245

InSAR

Calculated

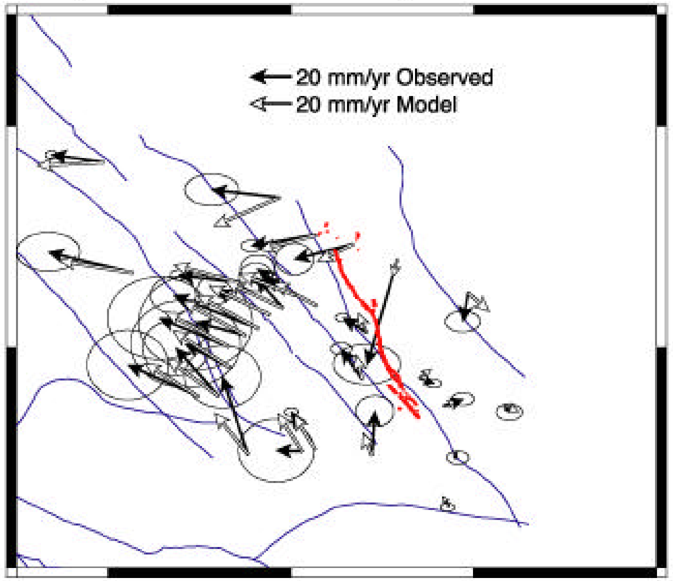


Observed

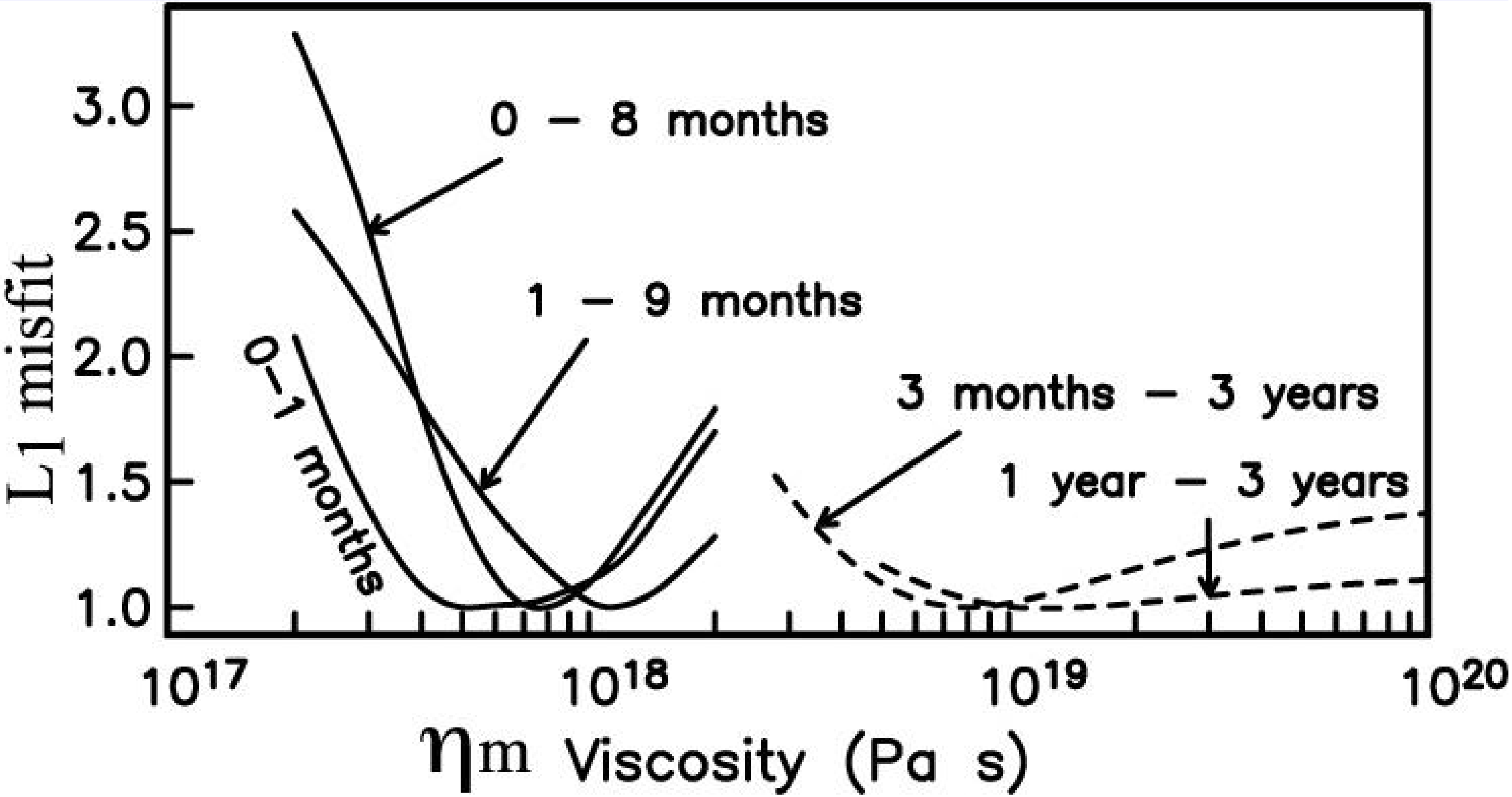


VISCOELASTIC MODEL

GPS



Inference of transient mantle rheology beneath the Mojave Desert from three-component continuous GPS (SCIGN network) and campaign GPS (USGS network)

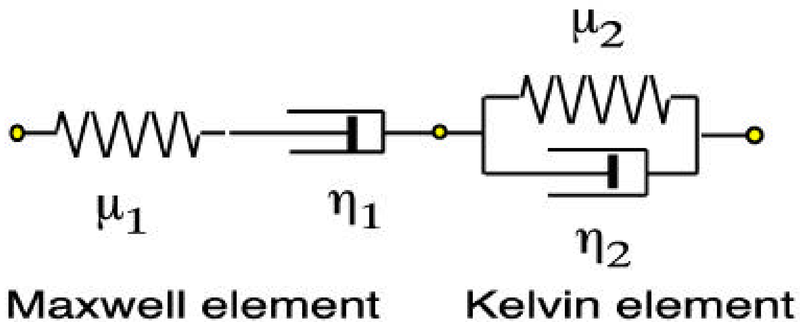


3.0
2.5
2.0
1.5
1.0
L1 misfit
0 – 8 months
1 – 9 months
0–1 months
3 months – 3 years
1 year – 3 years
10^17
10^18
10^19
10^20
ηm Viscosity (Pa s)

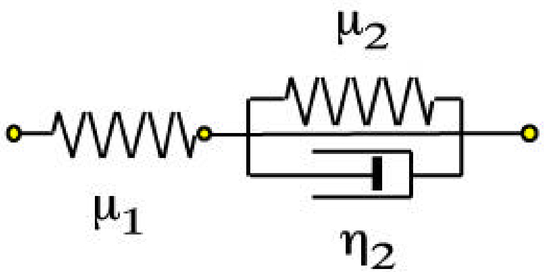
- Broadscale rapid postseismic strain after 1992 Landers earthquake (first 3 months)
- *Lower crustal afterslip (Shen et al., 1994)*
- *Biviscous lower crustal viscoelastic flow (Ivins, 1996)*

- Broadscale elevated postseismic strain rates (several years following 1992 Landers and 1999 Hector Mine earthquakes)
- *Lower crustal afterslip (Savage and Svarc, 1997; Owen et al., 2002)*
- *Univiscous lower crustal viscoelastic flow (Deng et al., 1998)*
- *Univiscous upper mantle viscoelastic flow (Pollitz et al., 2000)*
- *Biviscous upper mantle viscoelastic flow (Pollitz, 2002)*

Burghers Body



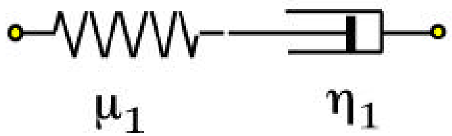
Standard Linear Solid



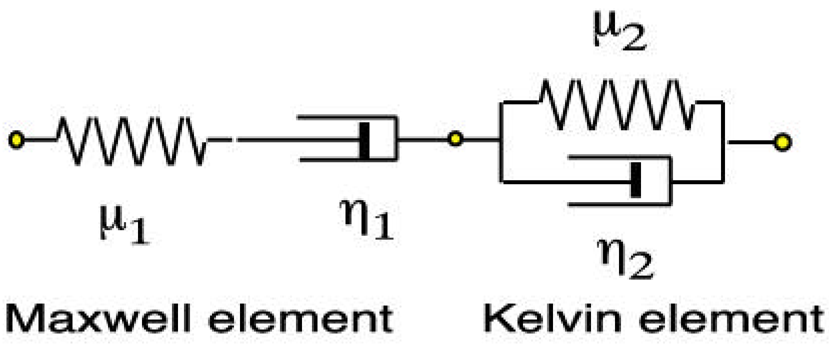
Relaxed Strength

$$\mu' = \mu_1 \, \mu_2 / (\mu_1 + \mu_2)$$

Maxwell Fluid



Transient Rheology



Burghers Body

$$2\eta_2\ddot{\varepsilon} + 2\mu_2\dot{\varepsilon} = \frac{\eta_2}{\mu_1}\ddot{\sigma} + \left[1 + \frac{\mu_2}{\mu_1} + \frac{\eta_2}{\eta_1}\right]\dot{\sigma} + \frac{\mu_2}{\eta_1}\sigma$$

ε = deviatoric strain

σ = deviatoric stress

$$\dot{\varepsilon} = \frac{\sigma_0}{2\mu_1} + \frac{\sigma_0}{2\mu_2}\left[1 - \exp(-t / \tau_2)\right] + \frac{\sigma_0}{2\mu_1}\frac{t}{\tau_1}$$

$\dot{\varepsilon}$ = instantaneous elastic response
+ transient response
+ steady state response

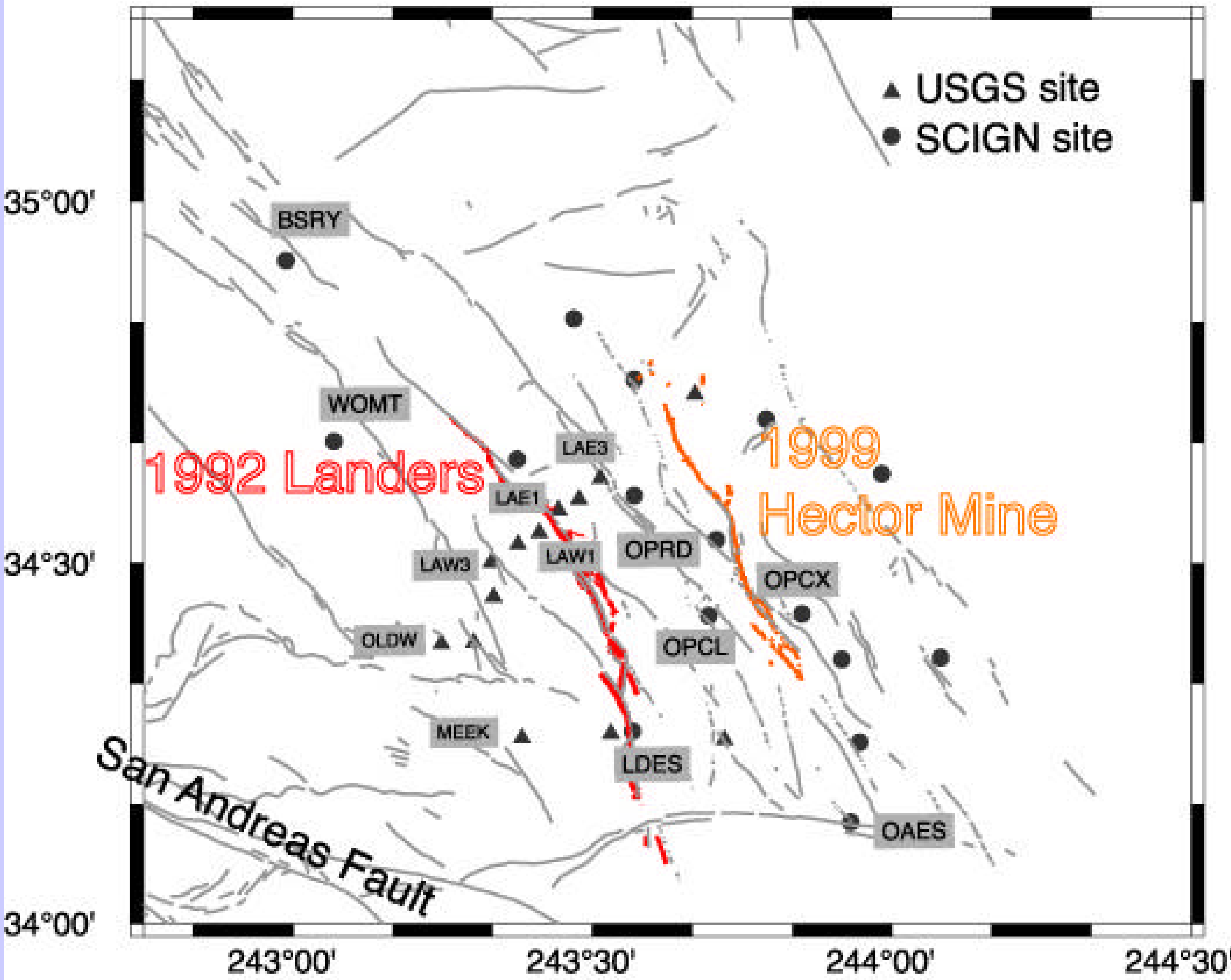
- Continuous GPS Data

16 sites from Southern California Integrated GPS Network

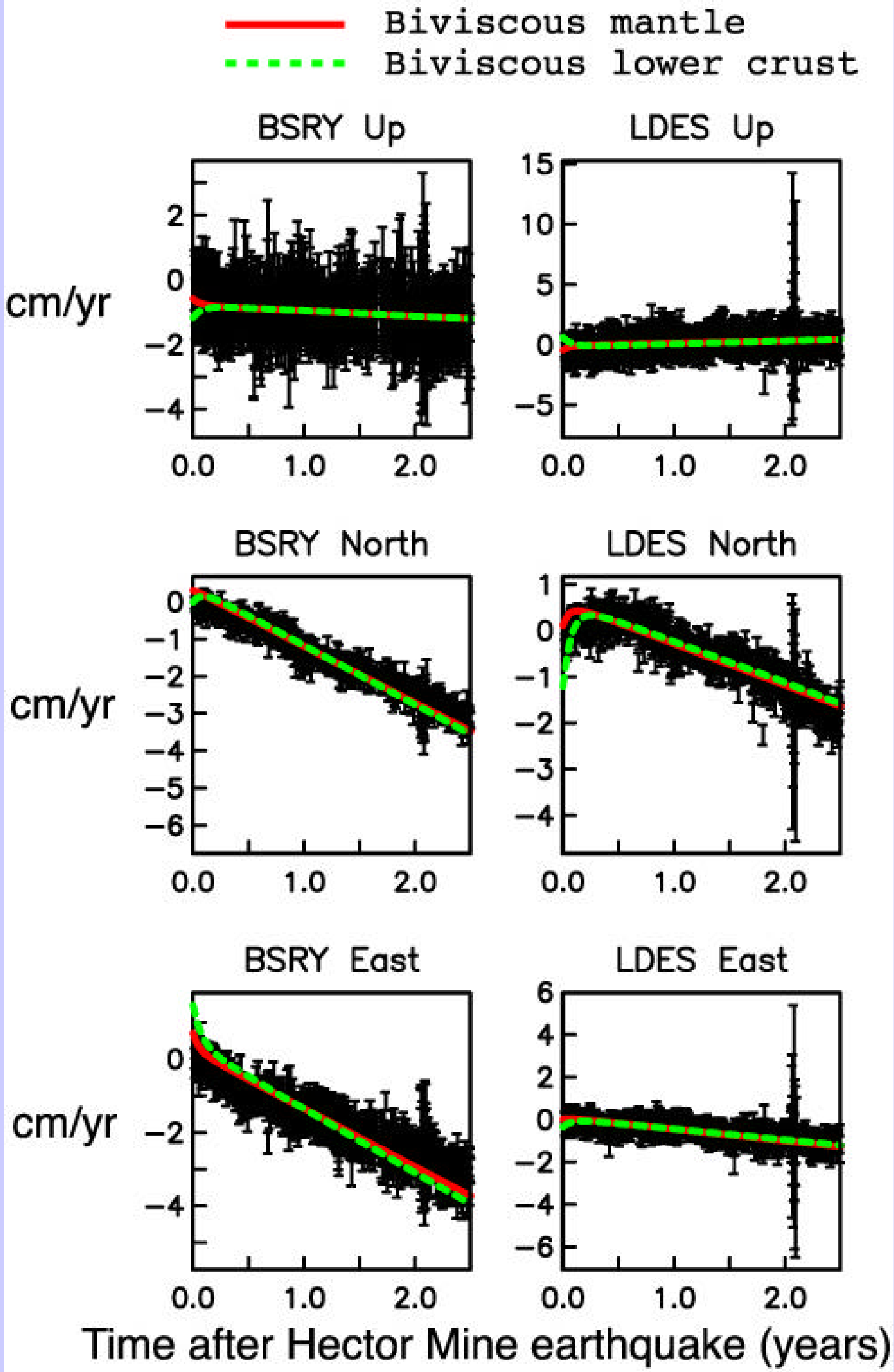
- Campaign GPS Data

13 sites from U.S. Geological Survey array

Total of 47526 samples from 87 time series (North, East, Up components)

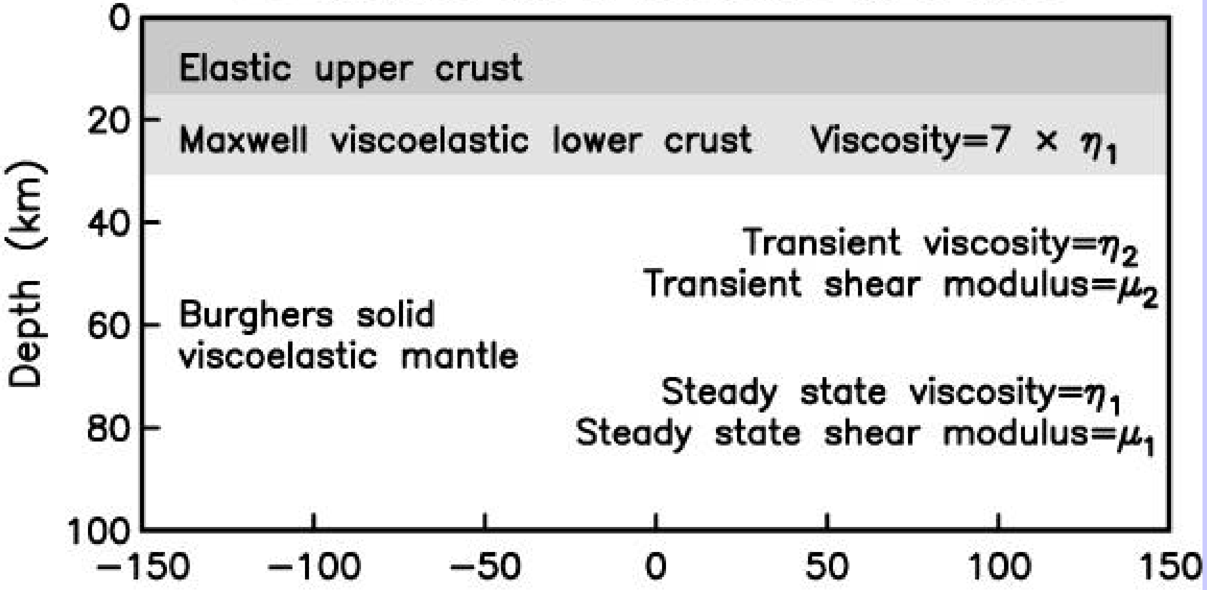


USGS site
SCIGN site
BSRY
WOMT
1992 Landers
LAE3
LAE1
LAW3
LAW1
OPRD
1999
Hector Mine
OPCX
OLDW
OPCL
MEEK
LDES
OAES
San Andreas Fault
35°00'
34°30'
34°00'
243°00'
243°30'
244°00'
244°30'

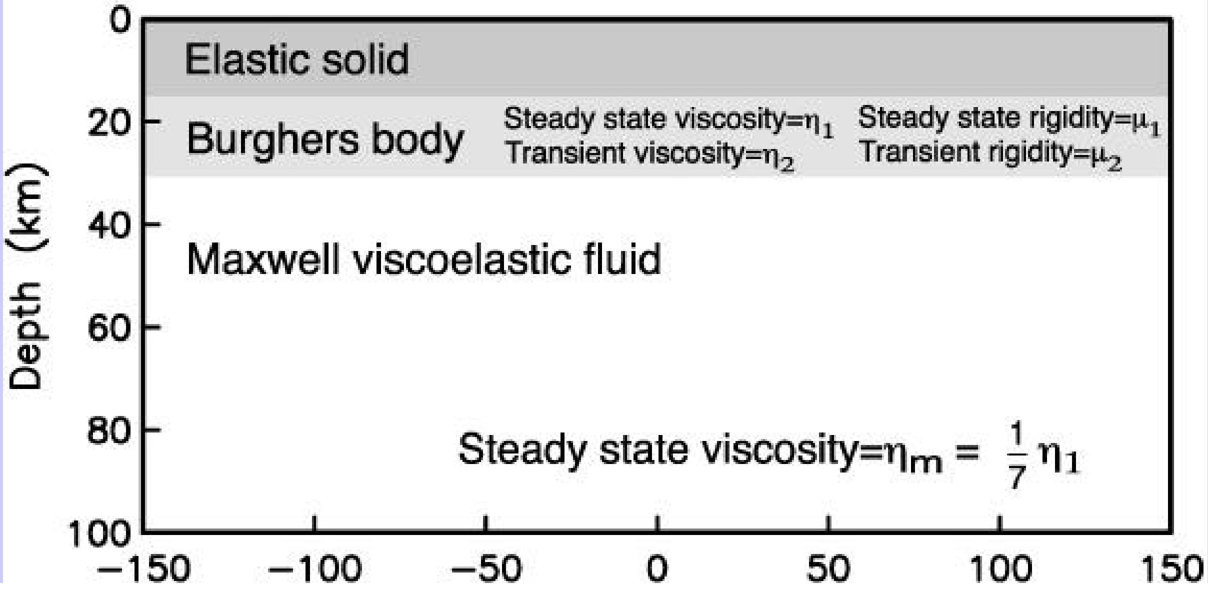


Biviscous mantle
Biviscous lower crust
BSRY Up
LDES Up
BSRY North
LDES North
BSRY East
LDES East
cm/yr
Time after Hector Mine earthquake (years)

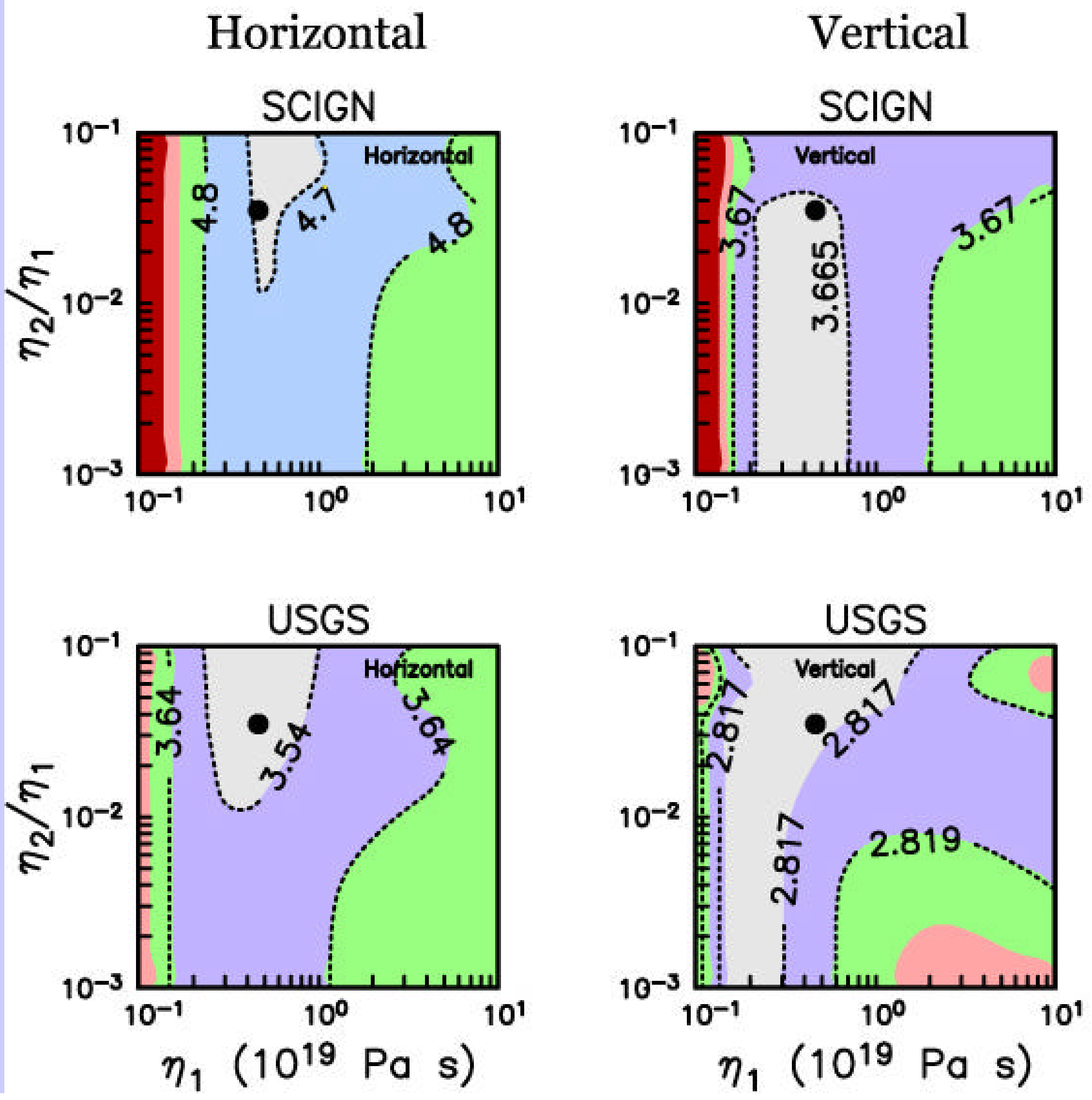
Biviscous mantle model



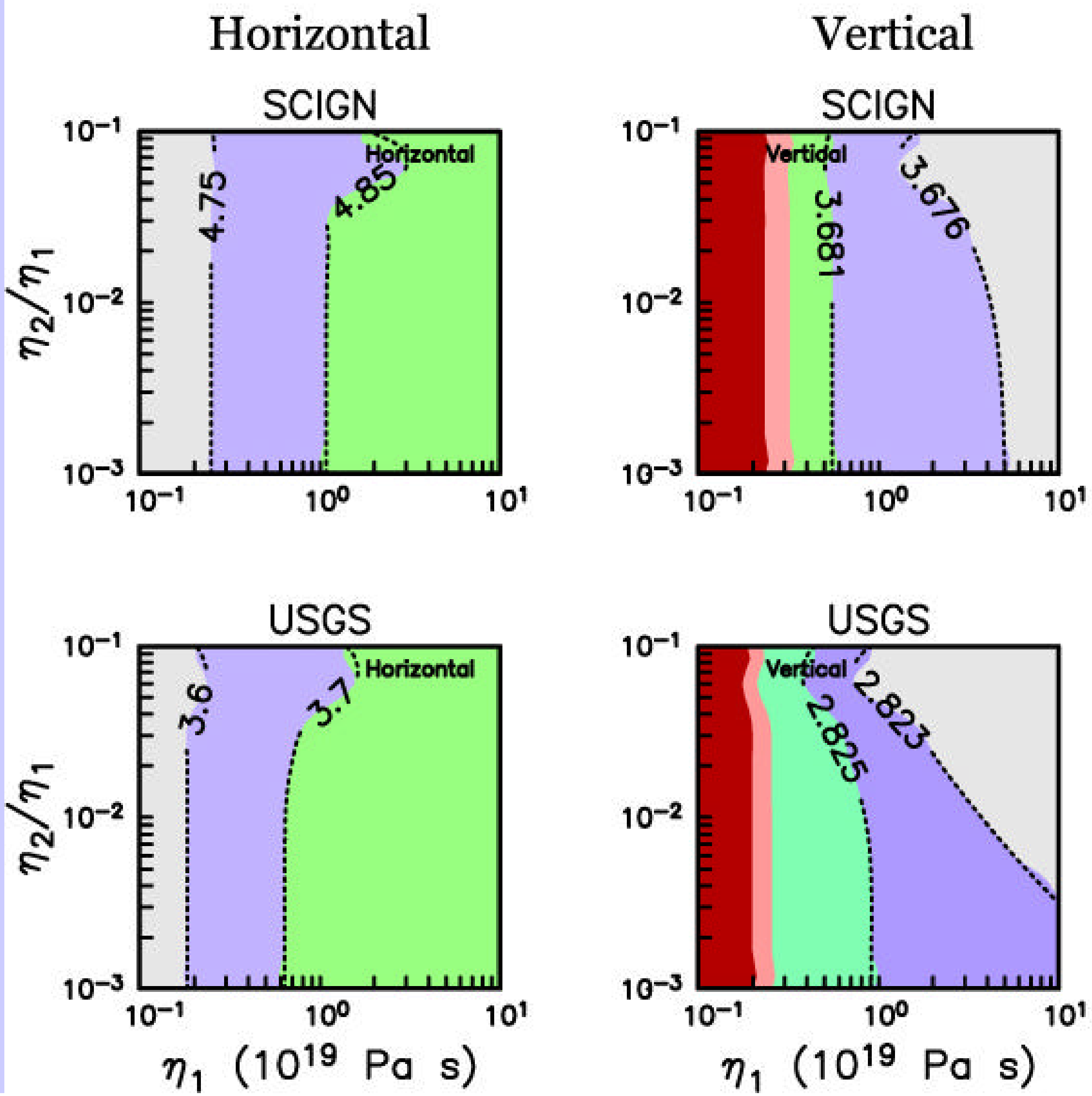
Biviscous lower crust model



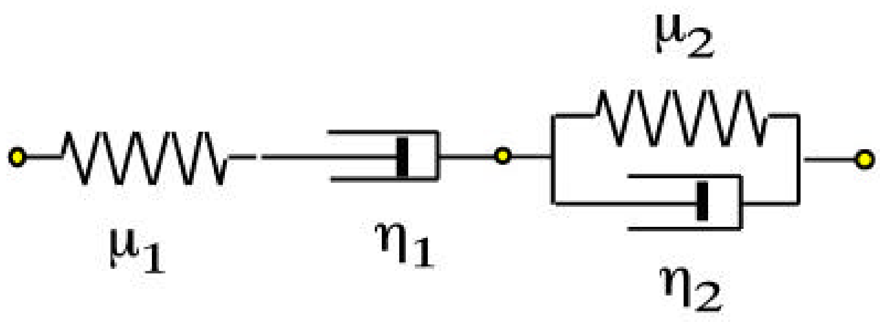
Results of grid search for η_1 and η_2 ($\mu'=0.5 \times \mu_1$): $\log_{10}$(misfit)



Results of grid search for η_1 and η_2 ($\mu'=0.75 \times \mu_1$): $\log_{10}$(misfit)



Preferred Transient Mantle Rheology

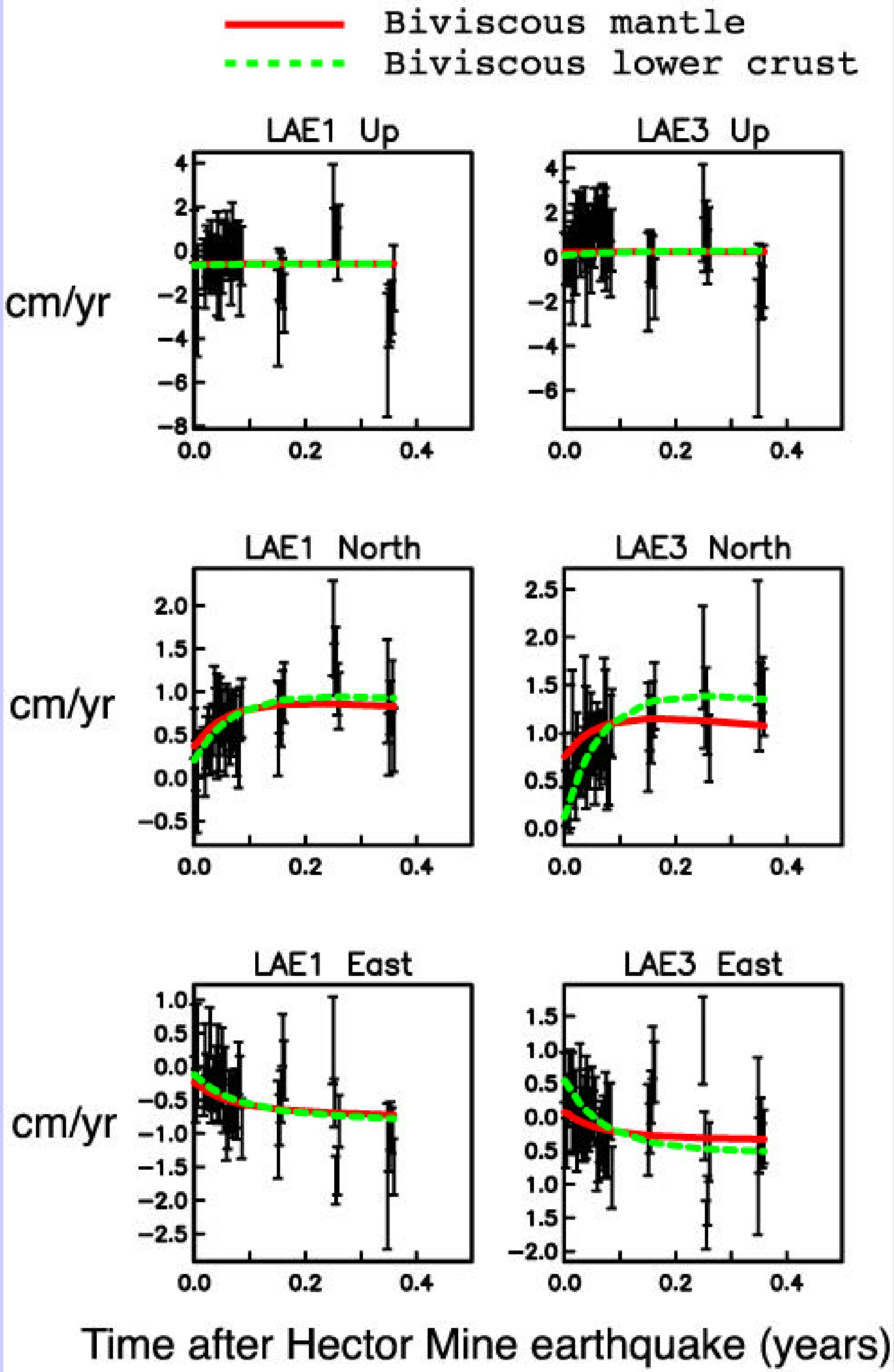


$\eta_1 = 4 \times 10^{18}$ Pa s

$\eta_2 = 1.6 \times 10^{17}$ Pa s

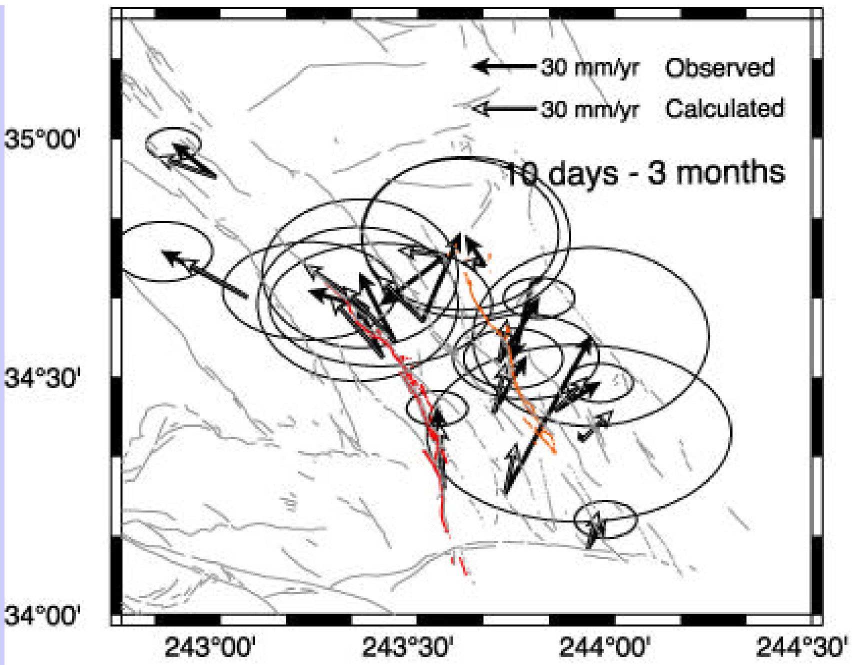
$\mu' = \mu_1 \mu_2 / (\mu_1 + \mu_2) = 0.5$

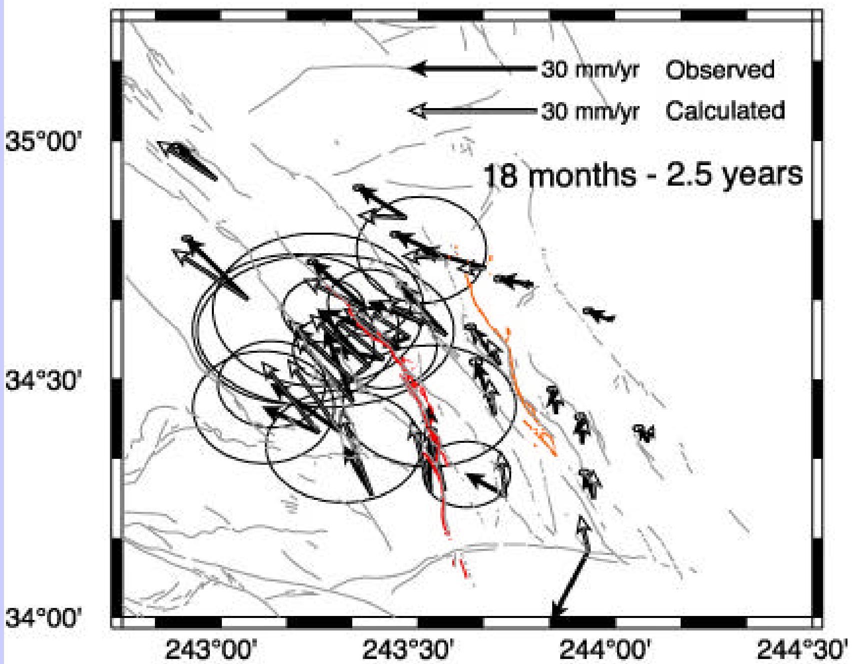
--> $\mu_1 = \mu_2 = 70$ GPa



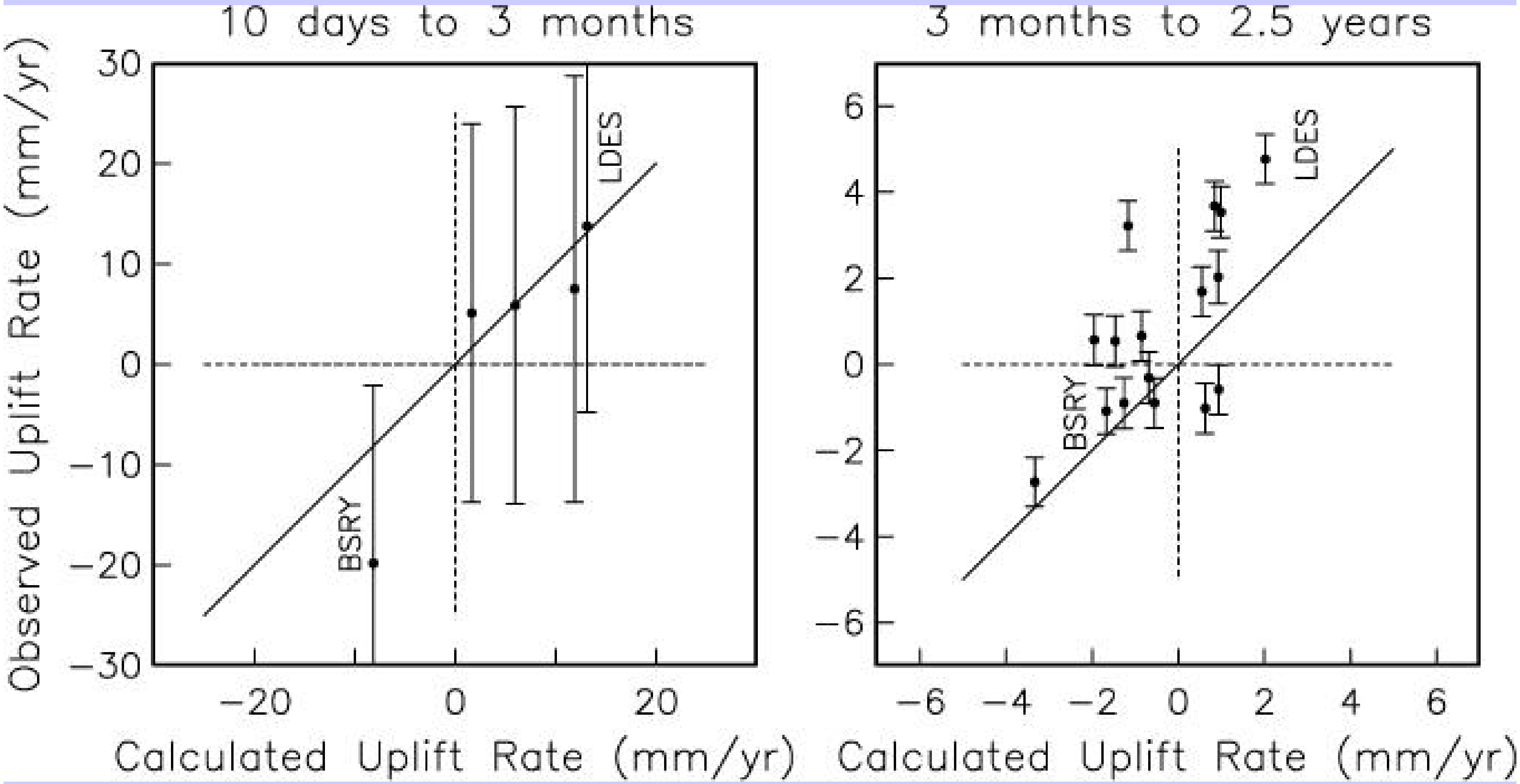
Biviscous mantle
Biviscous lower crust
LAE1 Up
LAE3 Up
LAE1 North
LAE3 North
LAE1 East
LAE3 East
cm/yr
cm/yr
cm/yr
Time after Hector Mine earthquake (years)

Fit of transient rheology model to horizontal velocity field



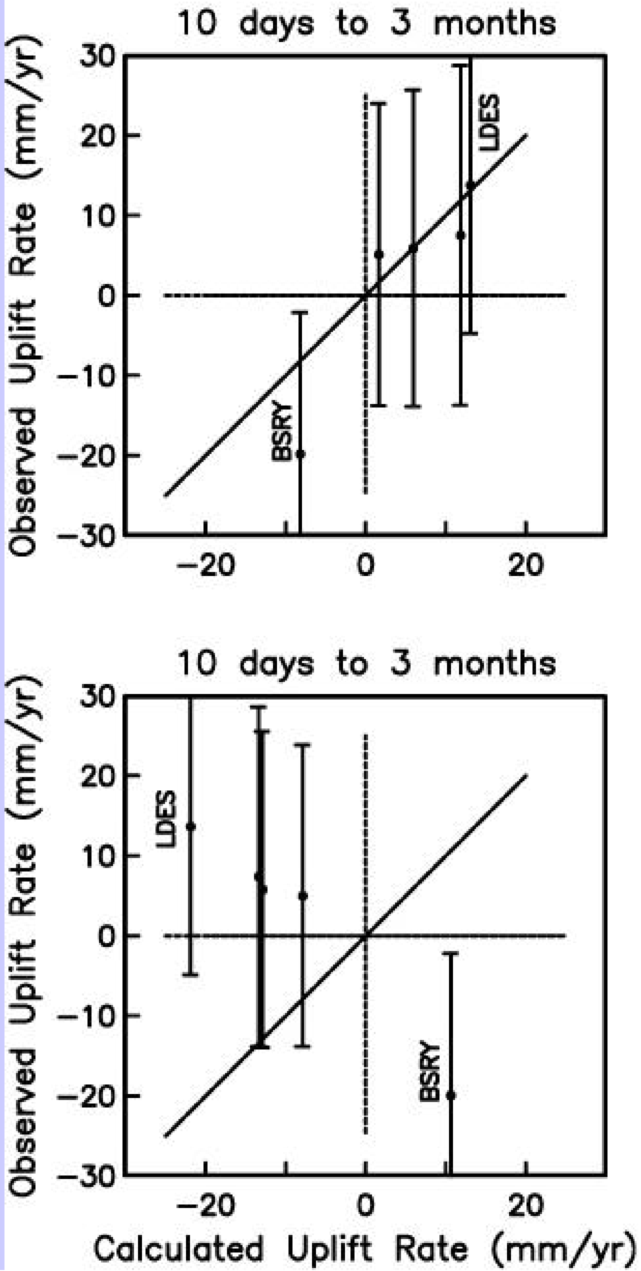


Fit of transient rheology model to vertical data



Evidence for biviscous upper mantle

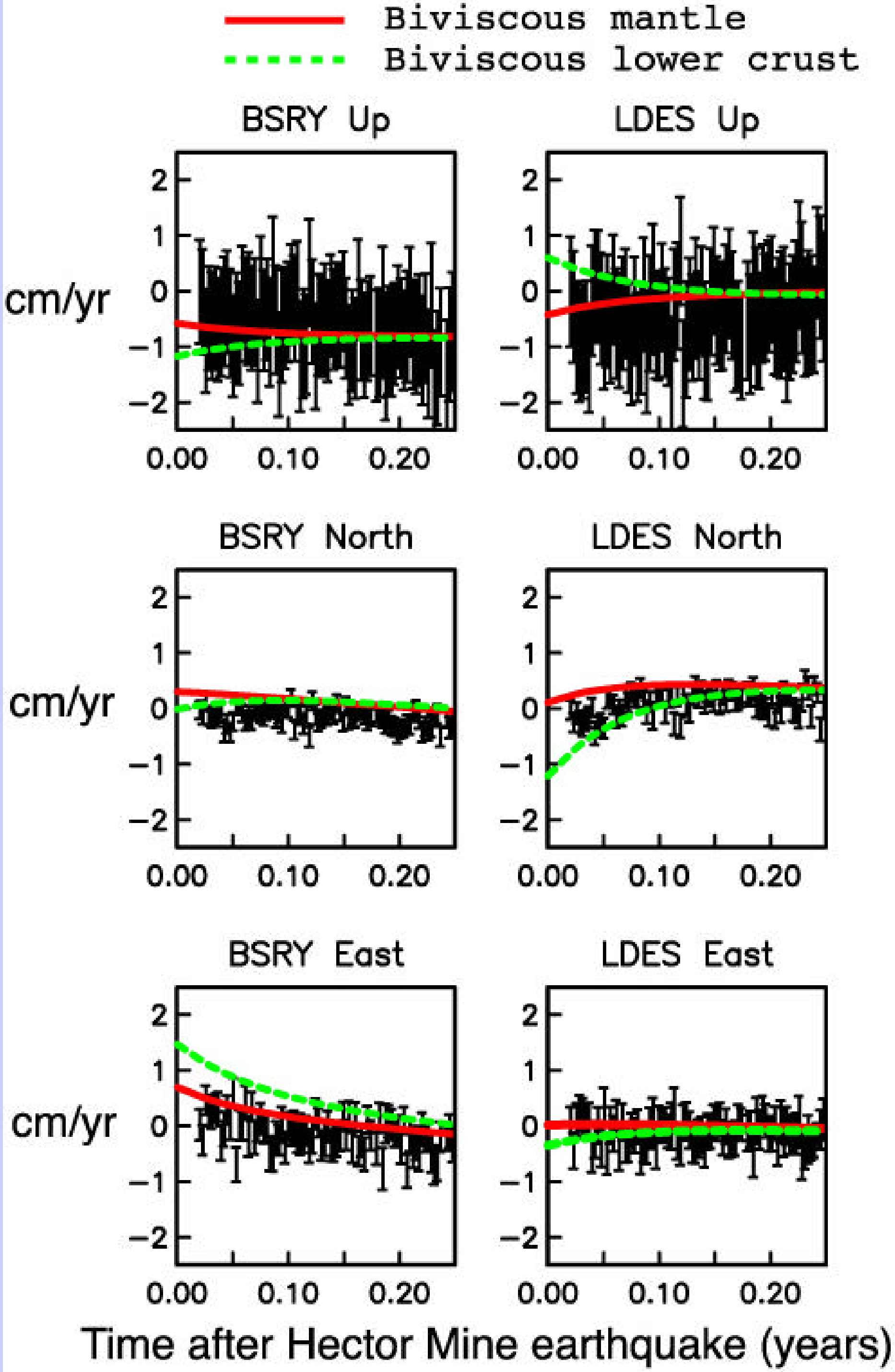
Observed & Modeled Uplift Rate



Biviscous Upper Mantle

Biviscous Lower Crust

Evidence for biviscous upper mantle



CONCLUSIONS

1. *InSAR data (0 to 8 months) and GPS data from the first 2.5 years following the Hector Mine earthquake constrain lower crust and mantle rheology*

2. *Postseismic crustal deformation following the Hector Mine earthquake is the response of an essentially elastic crust to* ***vigorous viscoelastic flow in the upper mantle*** *generated by relaxation of coseismic stress changes*

3. *The weak mantle is well characterized as a Burghers body with* **two material relaxation times: 0.07 years and 2 years**

4. *Constraining the details of depth-dependent rheology in this study is dependent on the continuous GPS observations provided by SCIGN network*