Short-term precursors of the M=5.5-7.2 earthquakes in South California revealed from the simulated stress-strain state patterns

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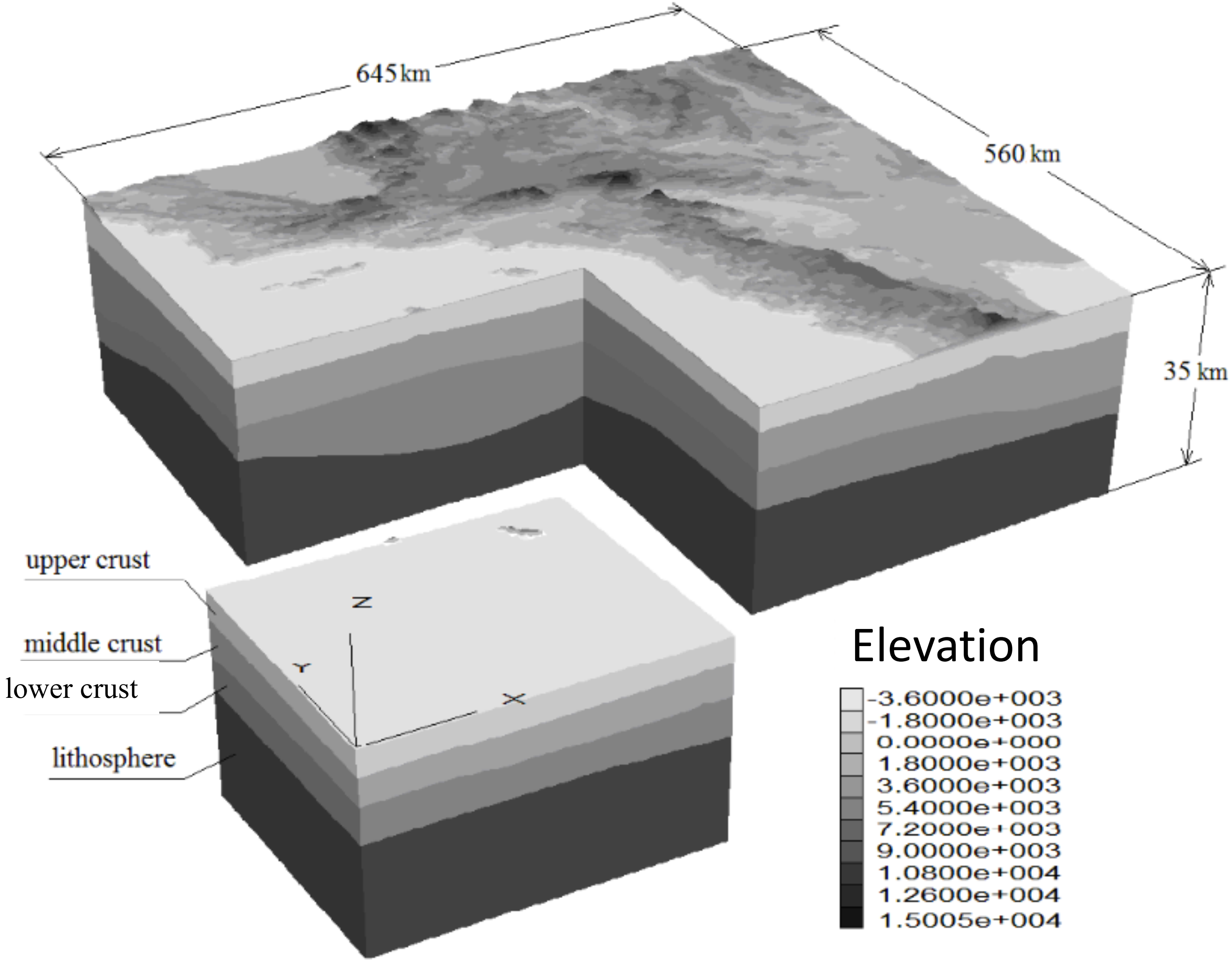
3-D geomechanical model of the Southern California region: key structural elements



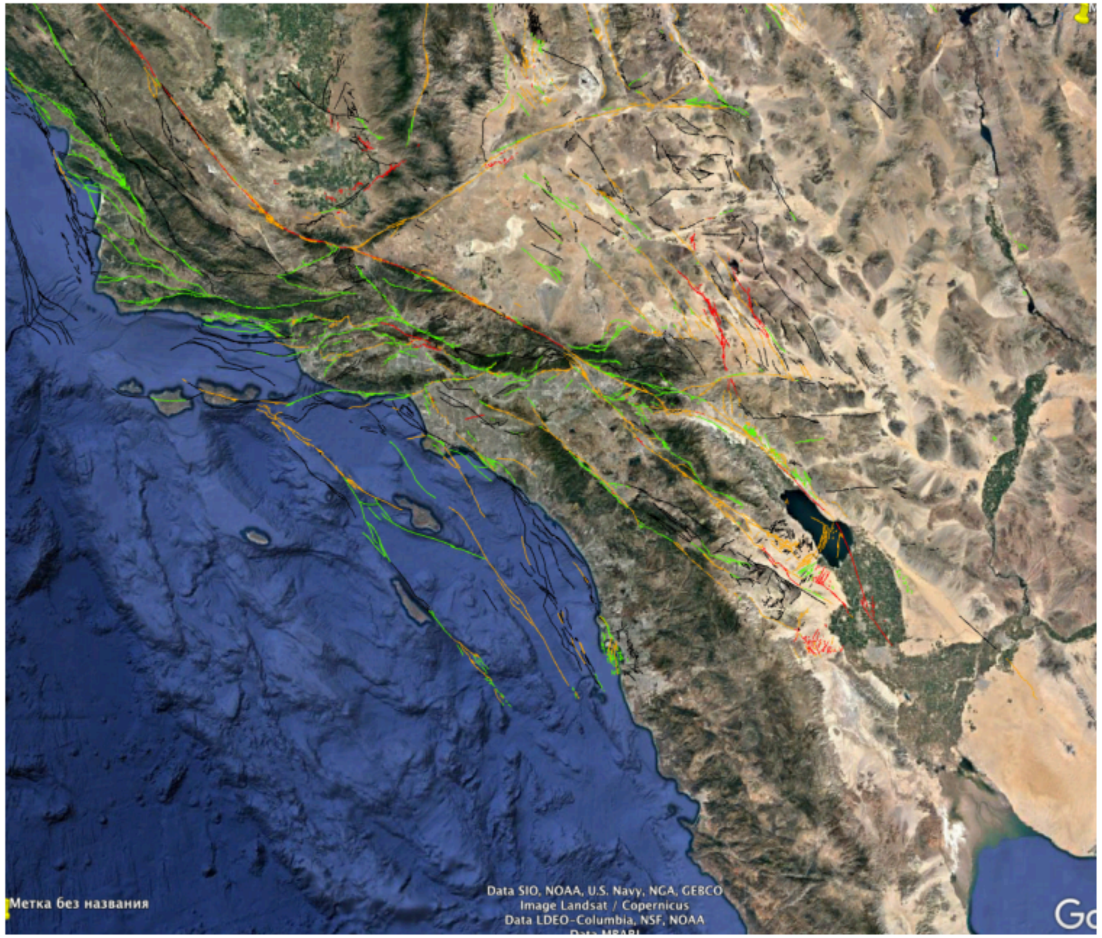
We have created a geomechanical model of the Southern California, with realistic structure featuring surface topography, tectonic faults and major structural boundaries

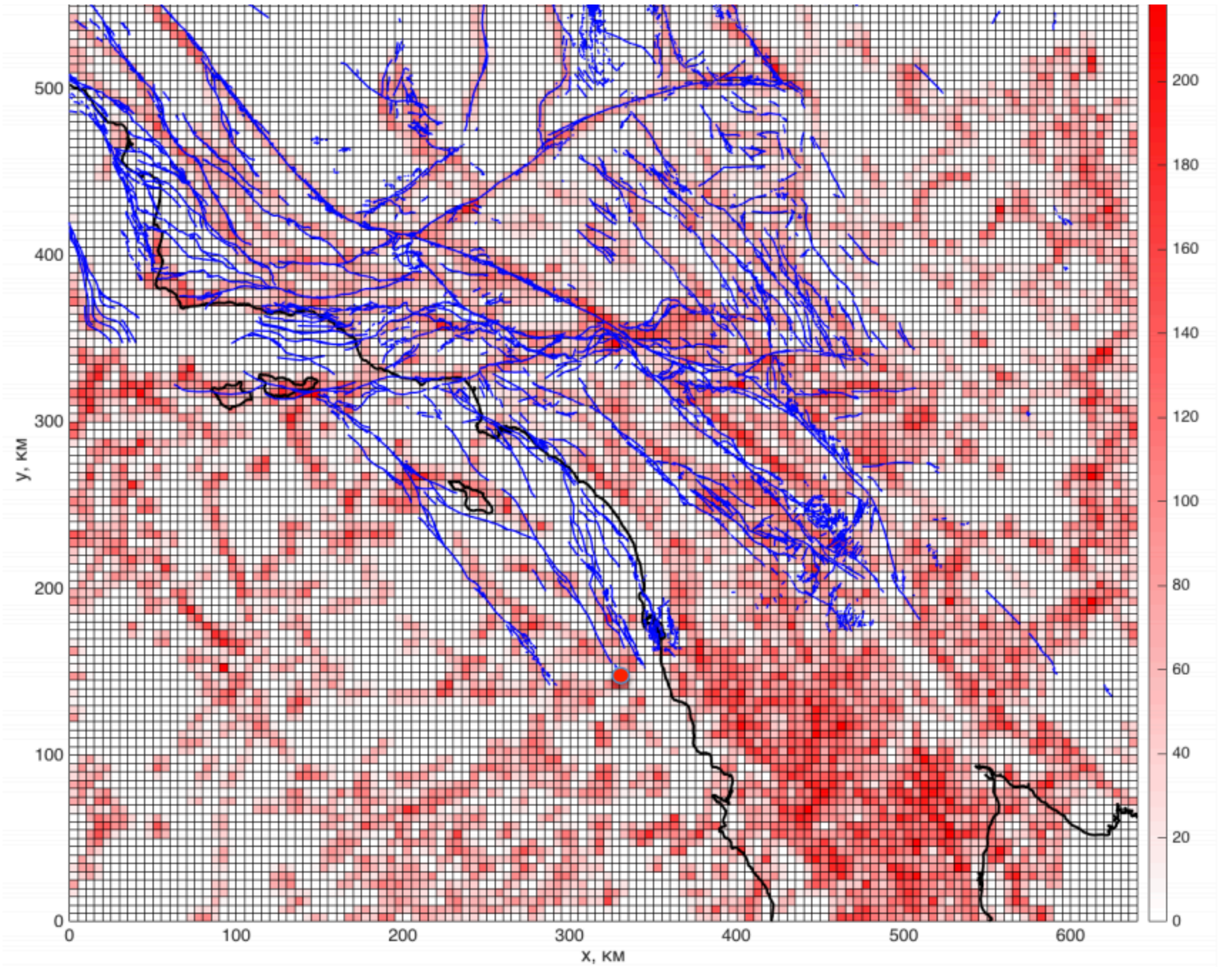
Earth crust is represented by 5 layers, assuming Coulomb-Mohr yield function

The static stress state was calculated assuming the gravity load and horizontal tectonic stresses

Simulation has been performed with FLAC software

Model correction based on tectonic faults data and rock damage parameter (initial damage)

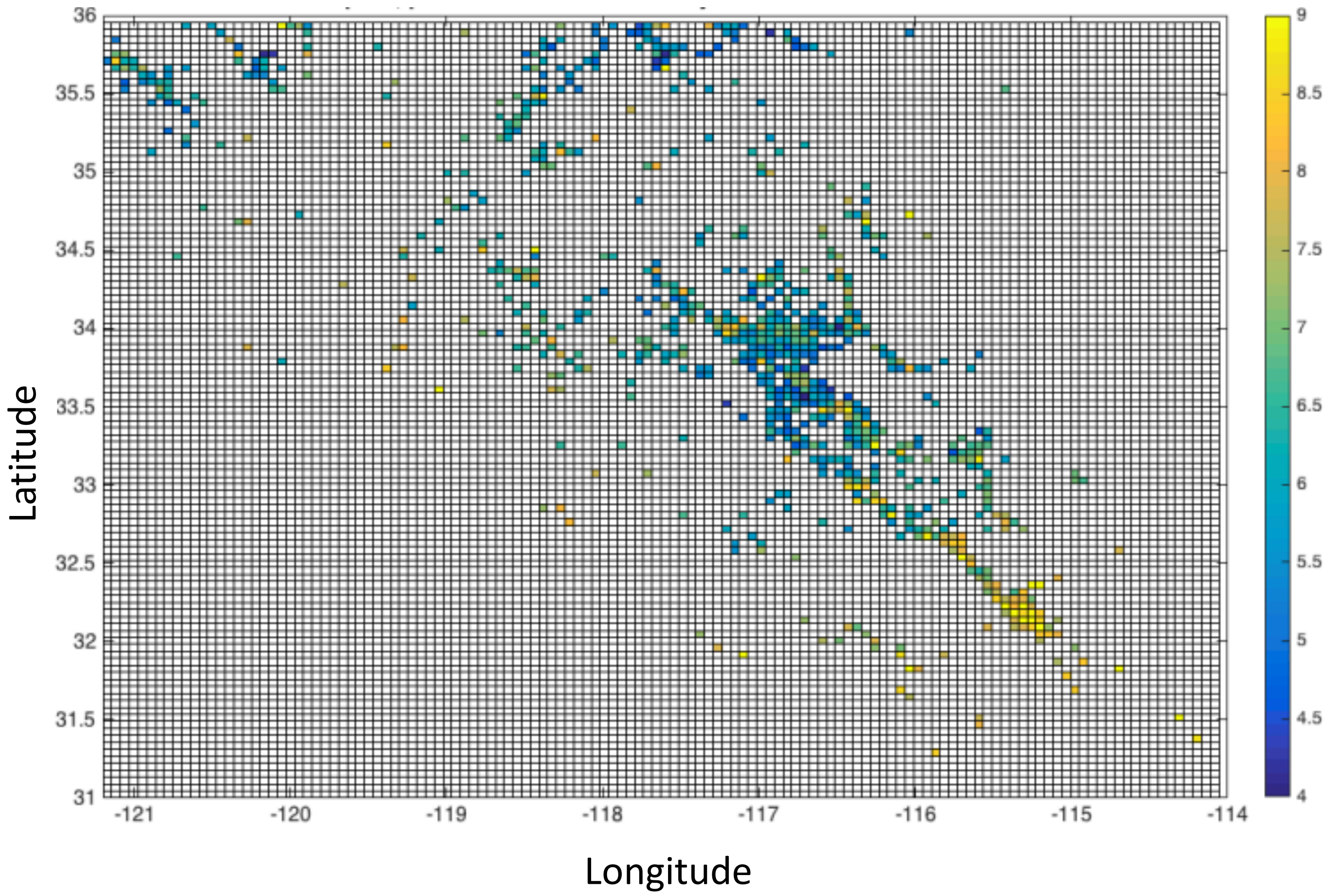


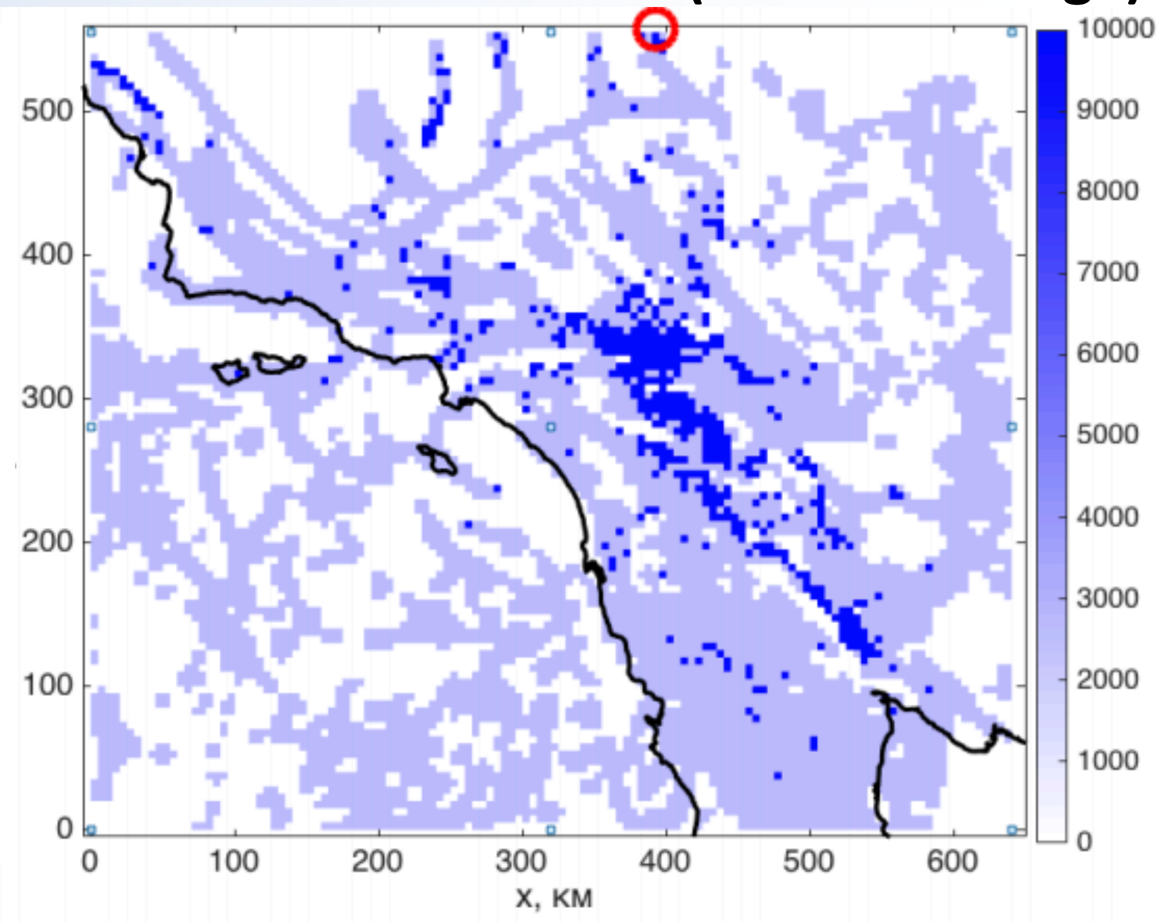


Left: Satellite image of the model region and fault lines from USGS dataset
Right: Distribution of damage parameter for upper crust layer 1

Proceeding from the upper layer, damage distributions are obtained for deeper layers via smoothing
We apply damage function as multiplicative factor to all geomecanical parameters over entire model domain

Iterative model correction based on seismic data-derived rock damage parameter (current damage)



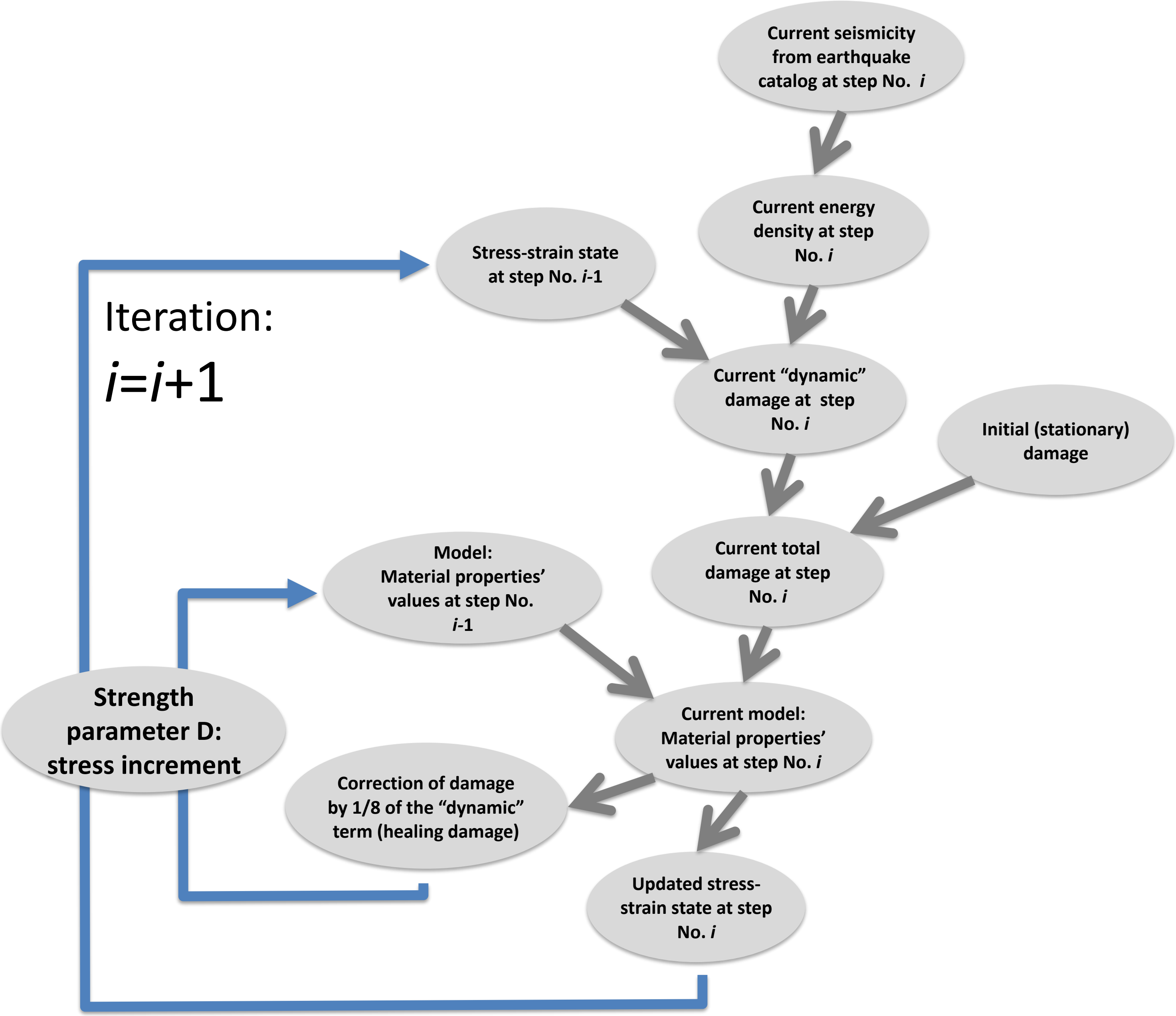


Left: Elastic energy calculated from seismic magnitudes for a series of earthquakes (M>1) during 3-month interval, ComCat dataset, log scale

Right: Distribution of cumulative (initial + current 3-month seismicity-caused) damage parameter for upper crust layer 2

Each model run (repeated every 15 days) involves model correction with damage function, evaluated for the previous 3-month period from seismic magnitudes data

Strength parameter monitoring and simulation sequence

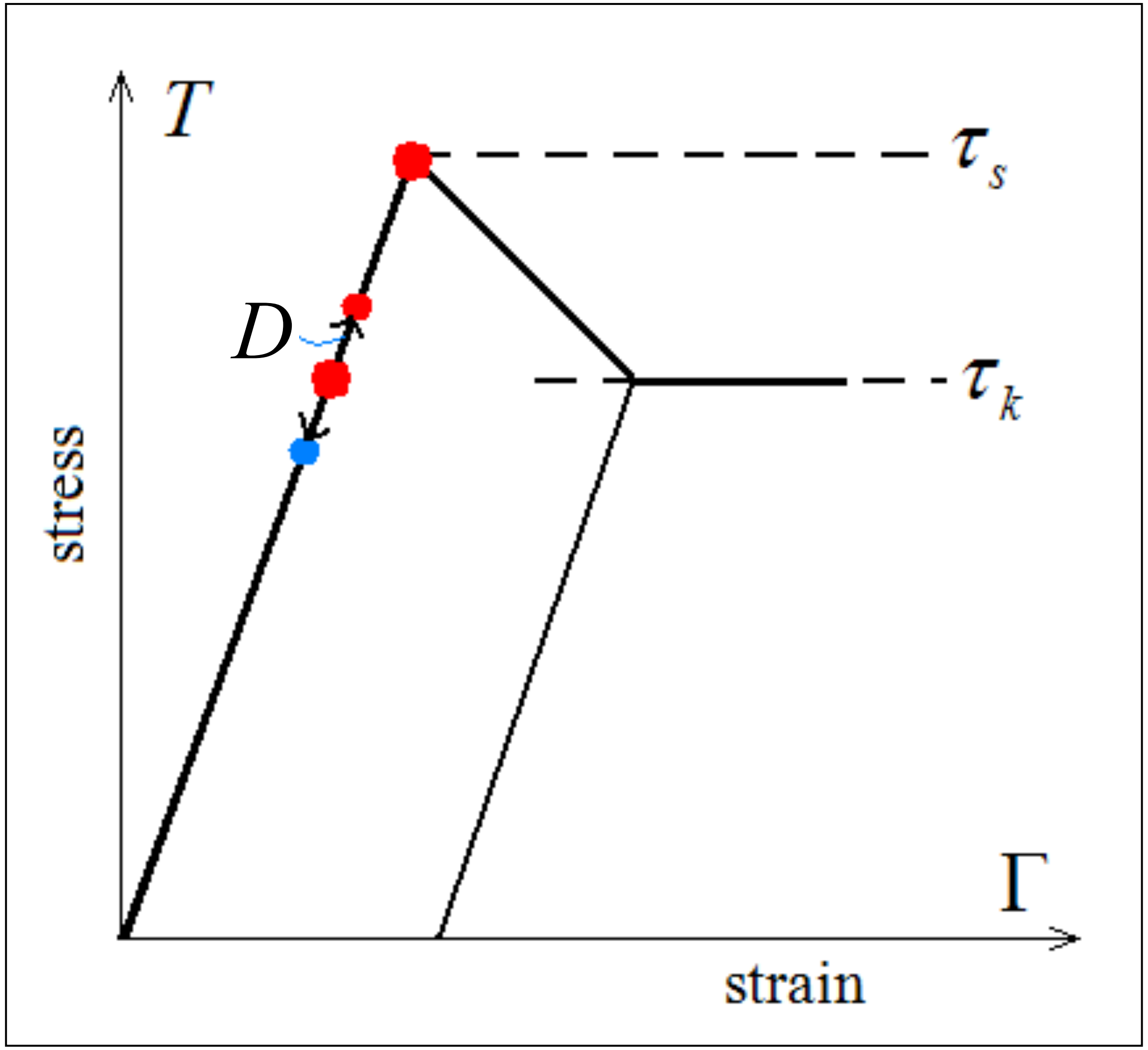


The model stress-strain state is updated through a series of successive recalculations in which the mechanical properties are corrected based on available seismic catalog data for a 3-month window. The cycle is repeated every 1/2 month.

Thus, the current seismicity data serves as a model input, where every new shock is interpreted as crustal damage causing redistribution of strain, accumulated elastic energy and ultimate strength of the Earth crust.

Every new stress distribution is converted into a 3-D pattern of the D-parameter (the measure of proximity of the earth's material to the ultimate strength) revealing the particular areas having the higher chance for the future earthquakes. This approach shows pretty high success rate for the given time range.

Concept of strength parameter increment monitoring



We evaluate the stress variation in the model by making use of the strength parameter *D*, indicating how close the structure is to the ultimate strength

$$\sigma_1^* = \sigma_1 + \Delta\sigma_1 \qquad \sigma_3^* = \sigma_3 + \Delta\sigma_3$$

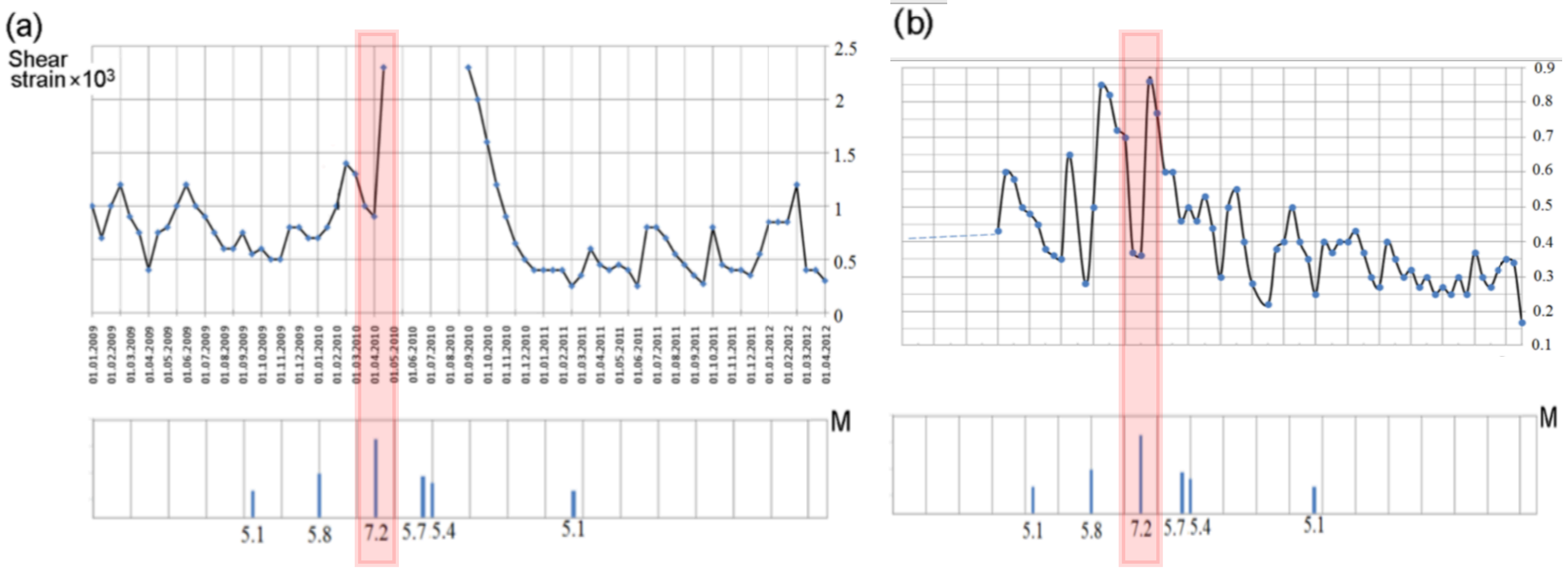
$$D = \left(\frac{\Delta\sigma_1 - \Delta\sigma_3}{2} + \frac{\Delta\sigma_1 + \Delta\sigma_3}{2}\sin\varphi\right)$$

$\sigma_1 > \sigma_2 > \sigma_3$ are the main stresses $\qquad$ φ is the friction angle

T, Γ are the shear stress intensity and shear strain intensity, respectively

τ_s is the maximum strength value $\qquad$ τ_k is the residual strength

Variation of stress-strain parameters in 2009-2012 and M 7.2 2010 Earthquake

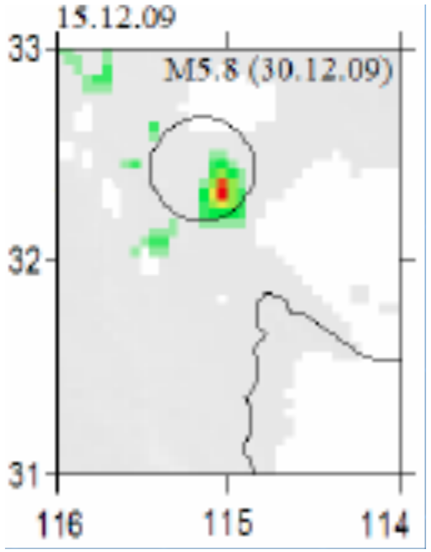


(a) Shear deformation intensity maximum in layer 2 (3.5–10 km depth)

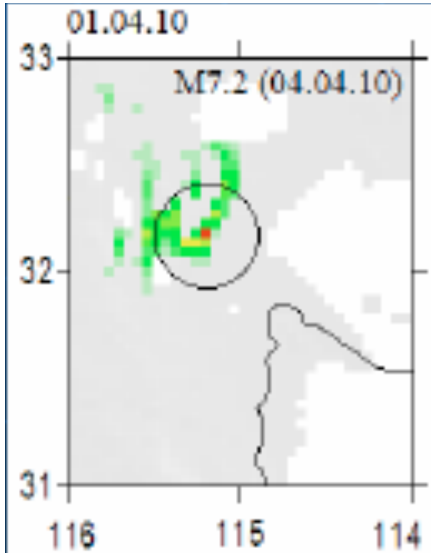
(b) Variation of the maximum value of parameter D

Anomalies of normalized strength parameter D, preceding earthquakes in 2009-2012

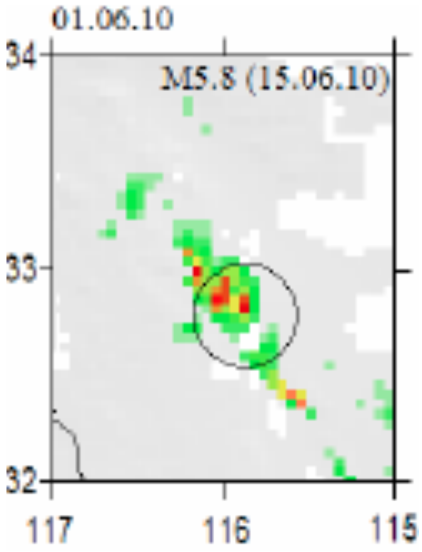
15 days prior to earthquake



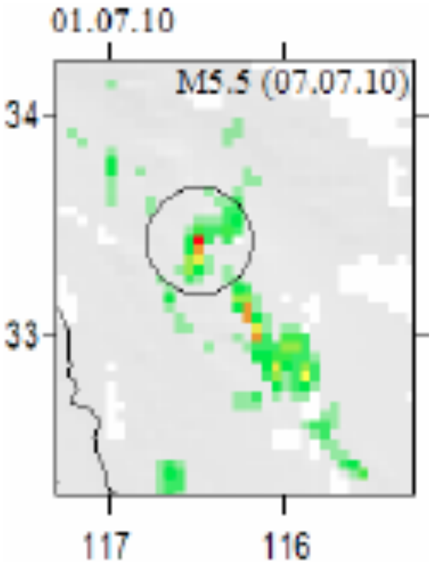
3 days prior to earthquake



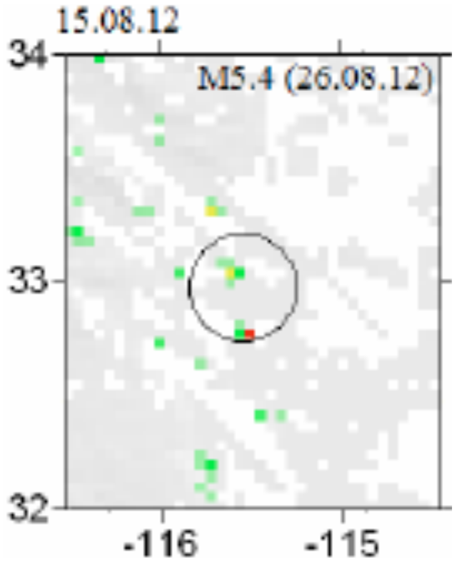
14 days prior to earthquake



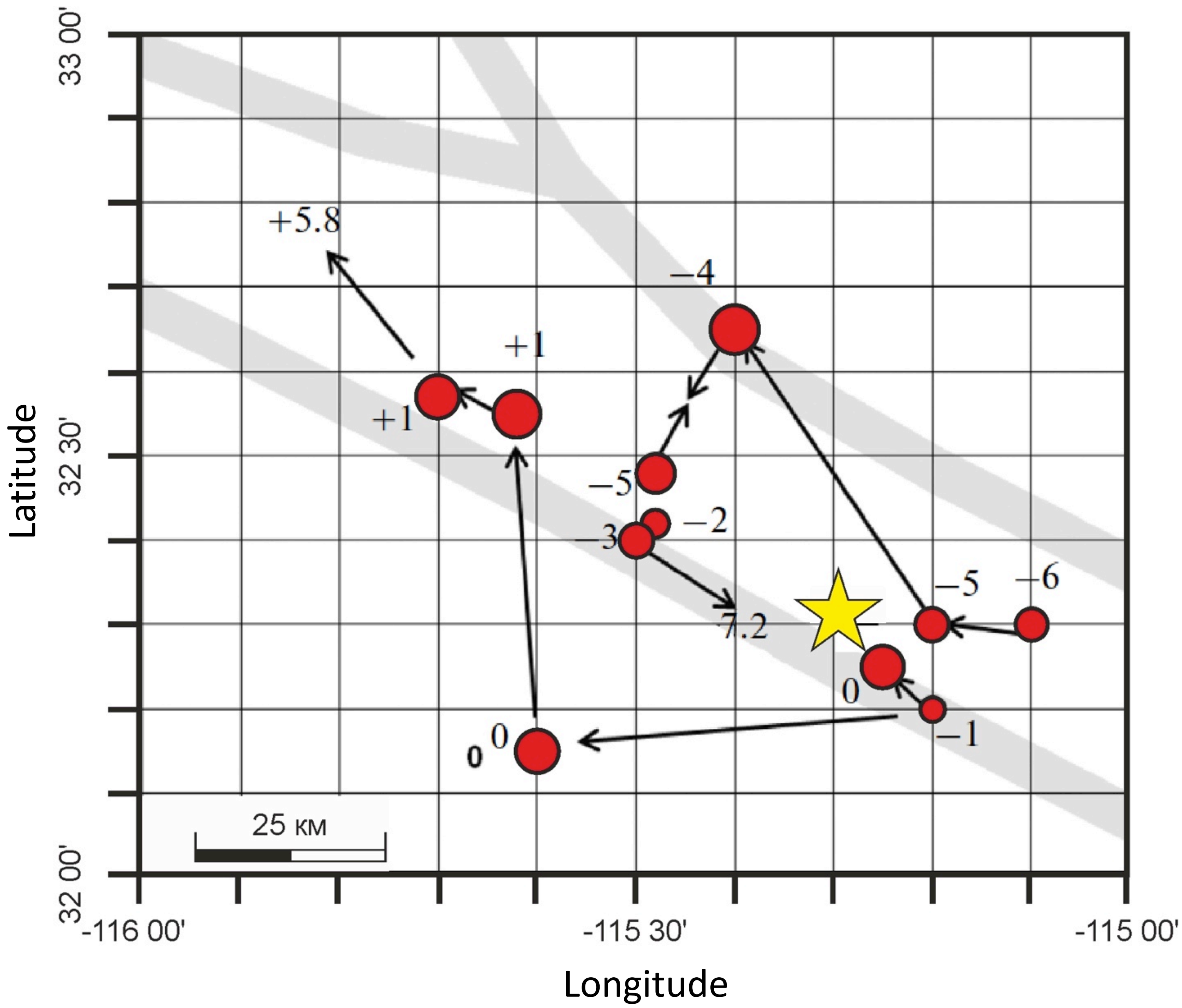
6 days prior to earthquake



11 days prior to earthquake



M 7.2 Earthquake, 04 April, 2010

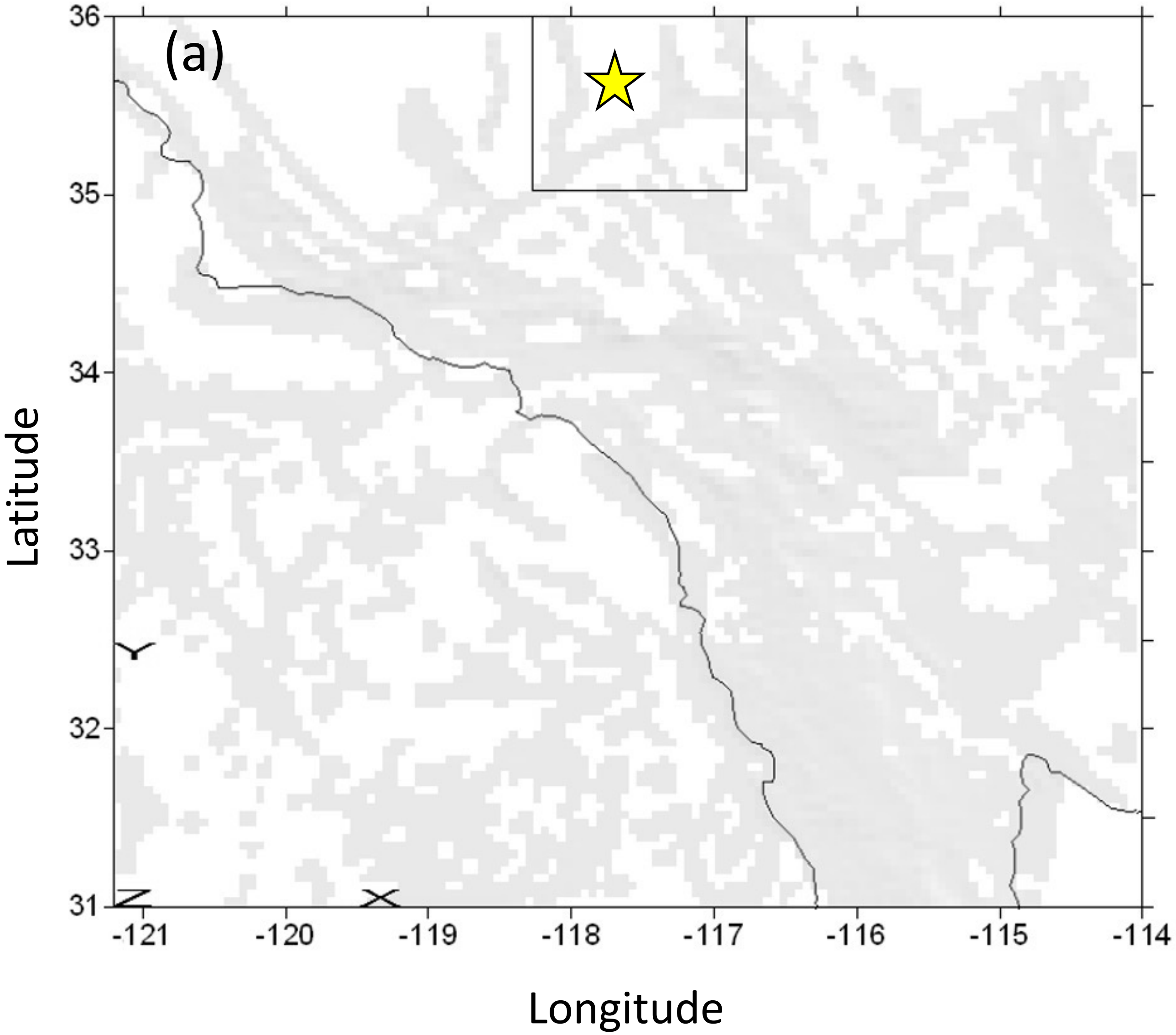


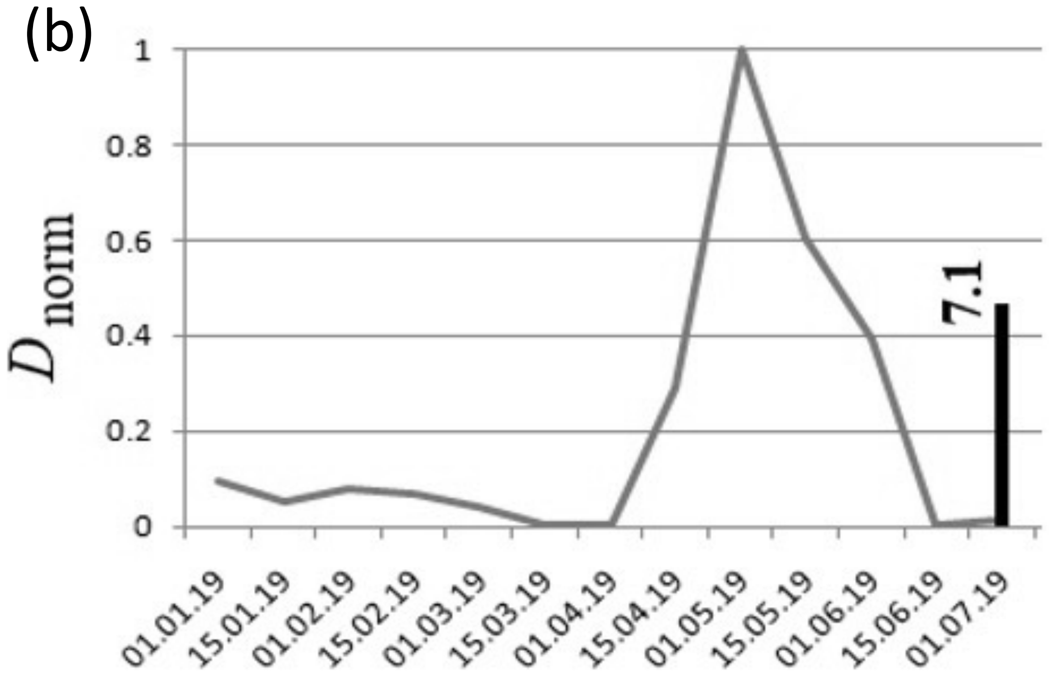
Temporal-spatial migration of the strength parameter maximum (red circles) around the epicenter (yellow star) of M 7.2 04 July 2010 Earthquake during January-April 2010

Gray lines indicate major fault zones in the area, characterized by elevated rock damage

Position numbering:

-6	01/01/2010
-5	15/01/2010
-5	15/01/2010
-4	01/02/2010
-3	15/02/2010
-2	01/03/2010
-1	15/03/2010
0	01/04/2010
1	15/04/2010
2	01/05/2010

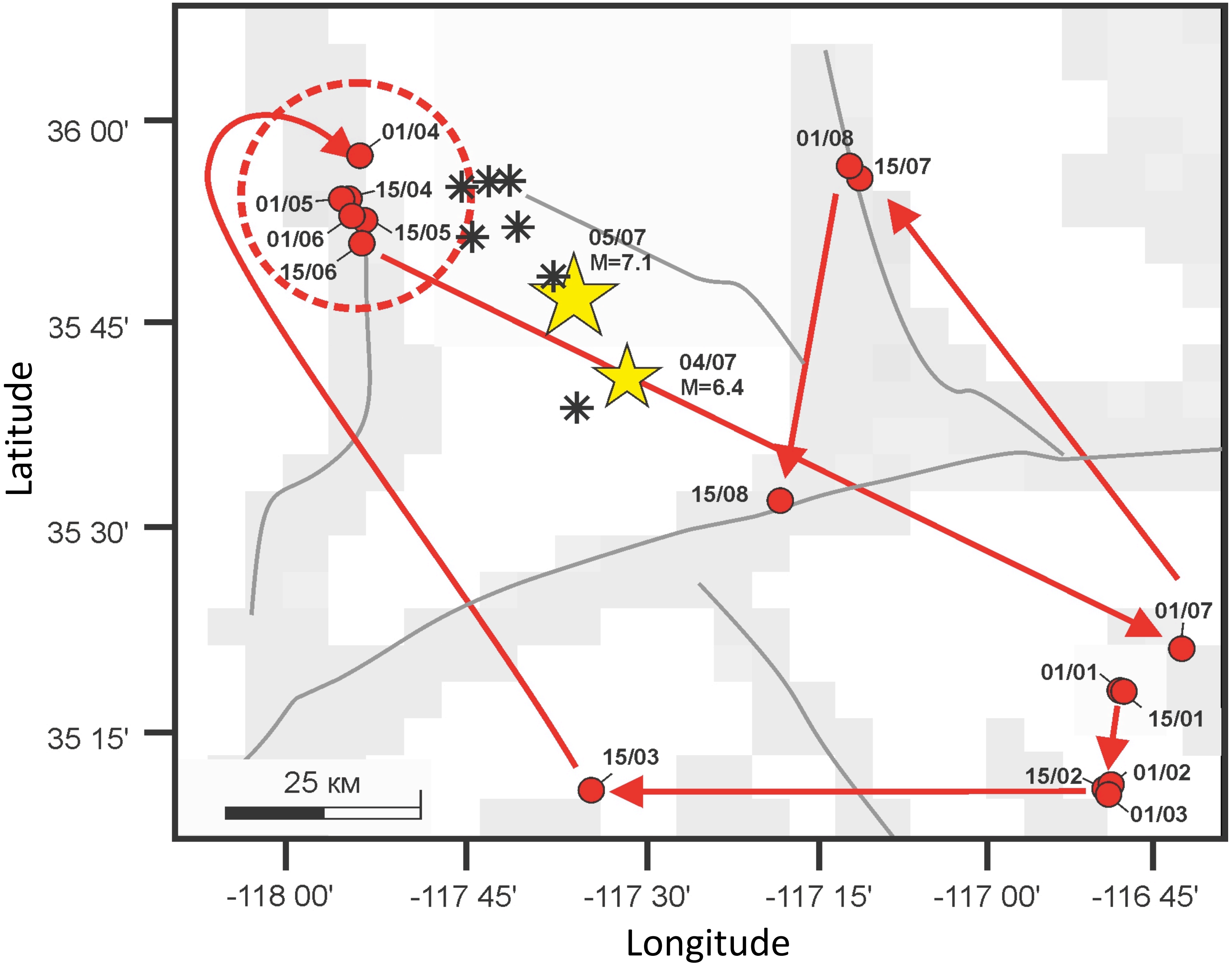




(a) Model subdomain and Ridgecrest EQ epicenter

(b) Variation of the maximum value of D over subdomain during Jan-Jul 2019

Ridgecrest earthquake, M 7.1, 05 July 2019



Temporal-spatial migration of the strength parameter maximum (red circles) around the epicenters (yellow stars) of M 6.4 and M 7.2 Ridgecrest earthquakes (04 and 05 July 2019 during January-July 2019

Gray regions indicate major fault zones in the area, characterized by elevated rock damage

Conclusions

Since 2009, the stress-strain state of the earth’s crust in South California region is being tracked utilizing the geomechanical model accounting for all the current seismicity. Every new earthquake is treated as a new defect in the Earth's crust, causing the stress-strain state redistribution.

Through the continuous stress-strain state update, we found that all the significant earthquakes in the area, including those with M ~ 7 in 2010 and 2019, had been preceded by the anomalies in the strength parameter, located within 20 km from the epicenter of the future seismic event.

Tracking the maximum of normalized D-parameter in each model layer reveals
its specific behavior (it tends to stay in the neighborhood of future epicenter) weeks before the earthquake.

3D geomechanical models enables the geological, geophysical,and seismological data to be jointly used for monitoring the stress state variations which occur during the seismic process

Acknowledgements and Publications

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