

# On the role of processes interaction in the triggering of post-injection seismicity in Enhanced Geothermal Systems

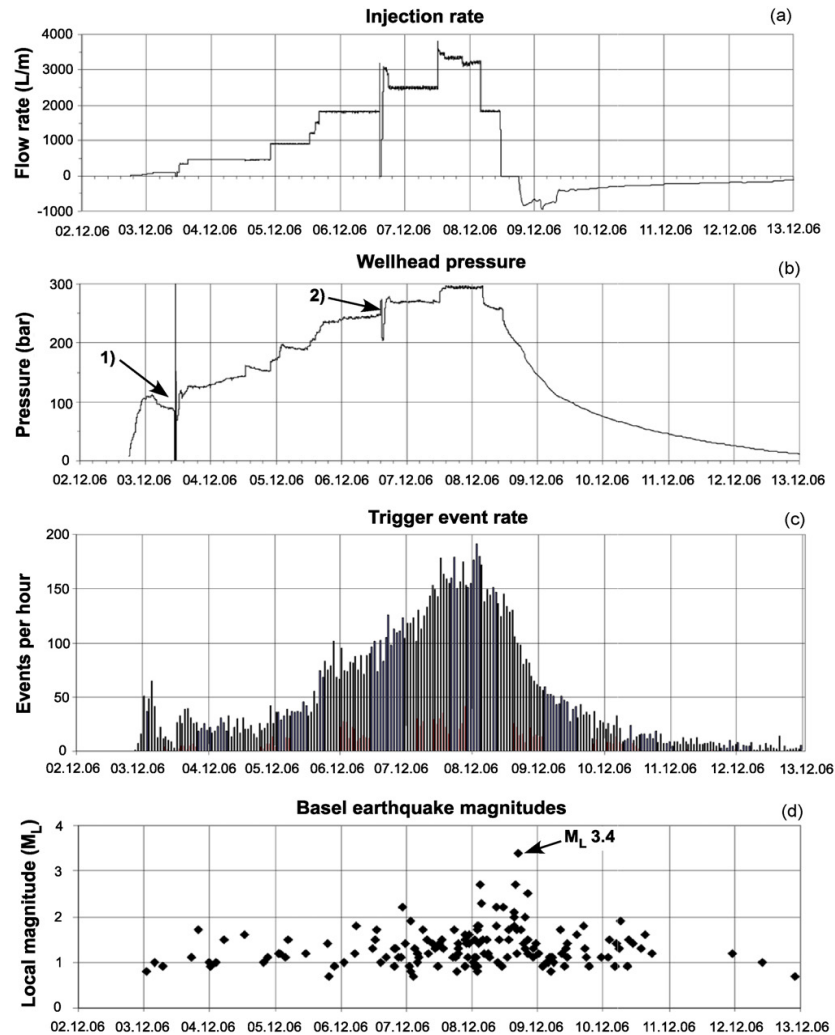
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Grupo de Hidrología Subterránea (GHS). IDAEA, CSIC - Universitat Politècnica de Catalunya UPC

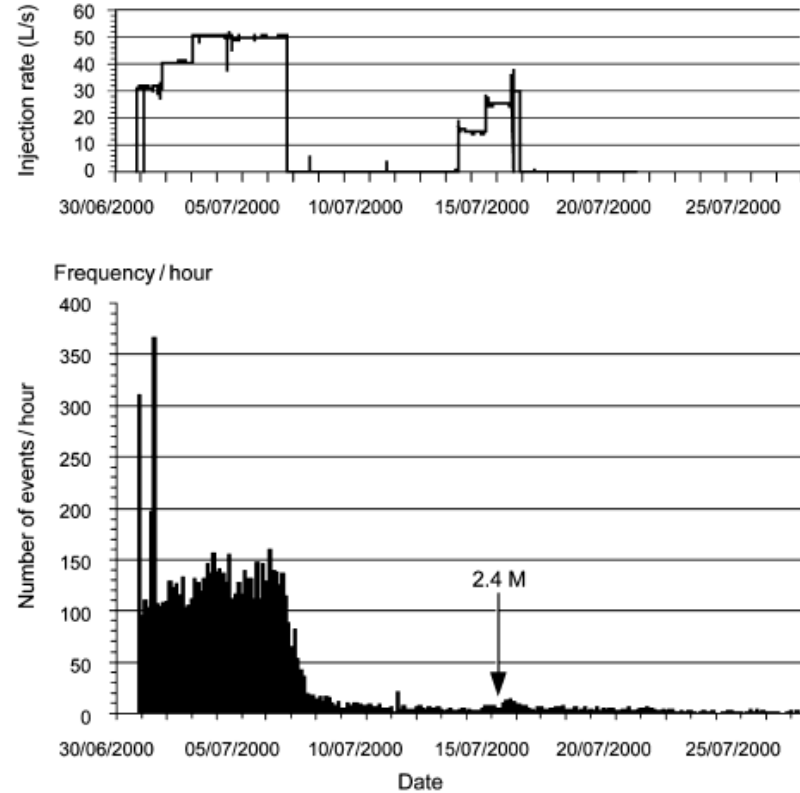
Induced Seismicity Workshop - Davos, 10 -13 March 2015

# Motivation

- Induced seismicity greater than the expected
- Post-injection seismicity still not completely understood

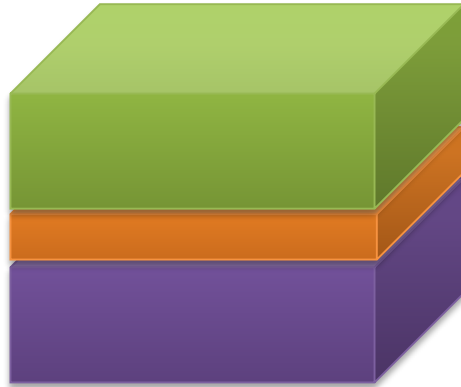


Basel (Häring *et al.*, 2008)

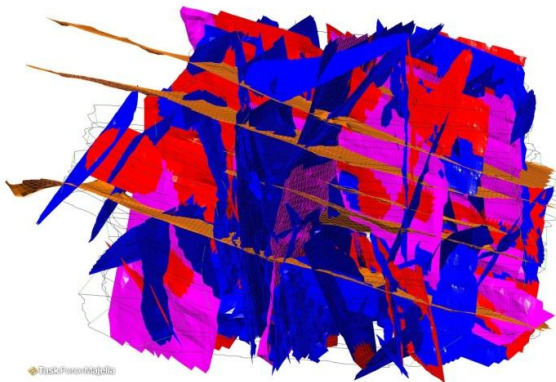


Soultz-sous-Forêts (Majer *et al.*, 2007)

# Modeling of induced seismicity



heterogeneous host rock



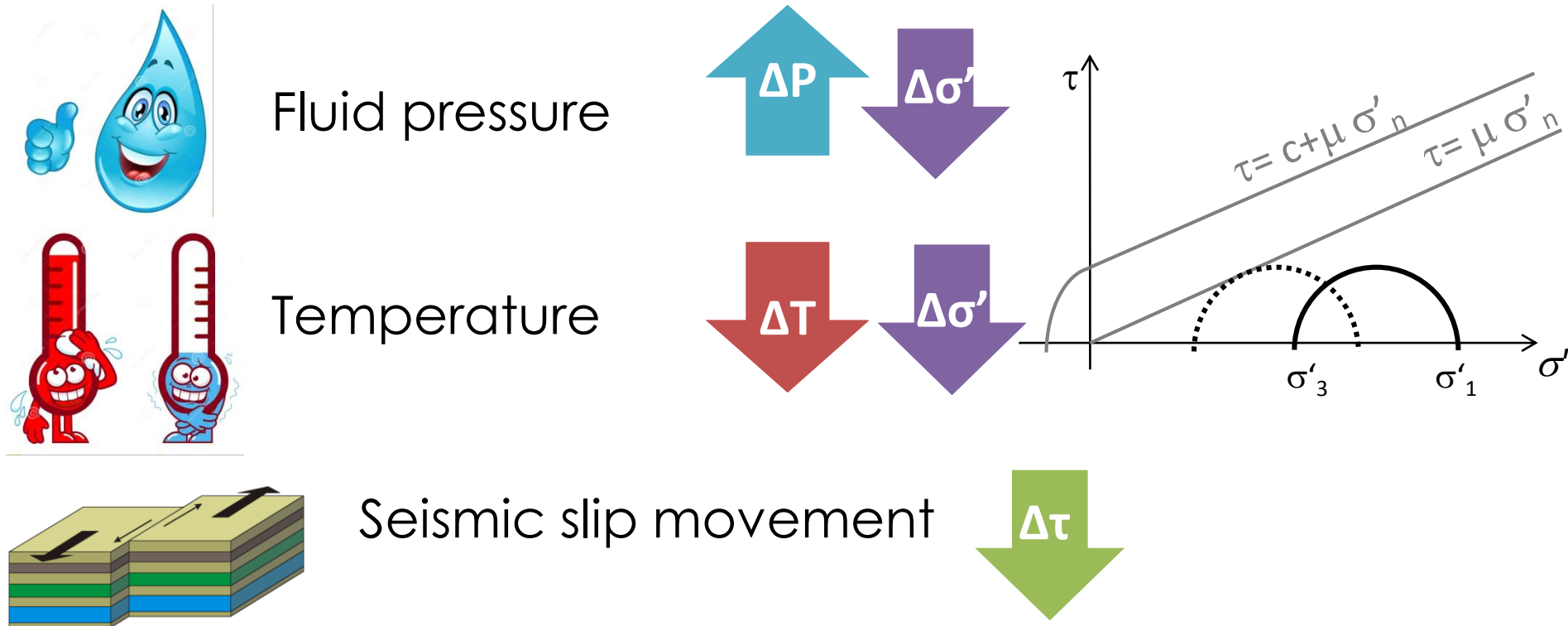
fracture network

- Pressure variations (HM coupling)
- Temperature variations (THM coupling)
- Fracture failure and seismic shear slip
- Permeability increase (elastic + dilation)
- Chemical reactions

**Realistic but the complexity hinders the conceptual understanding of the processes**

## Aim

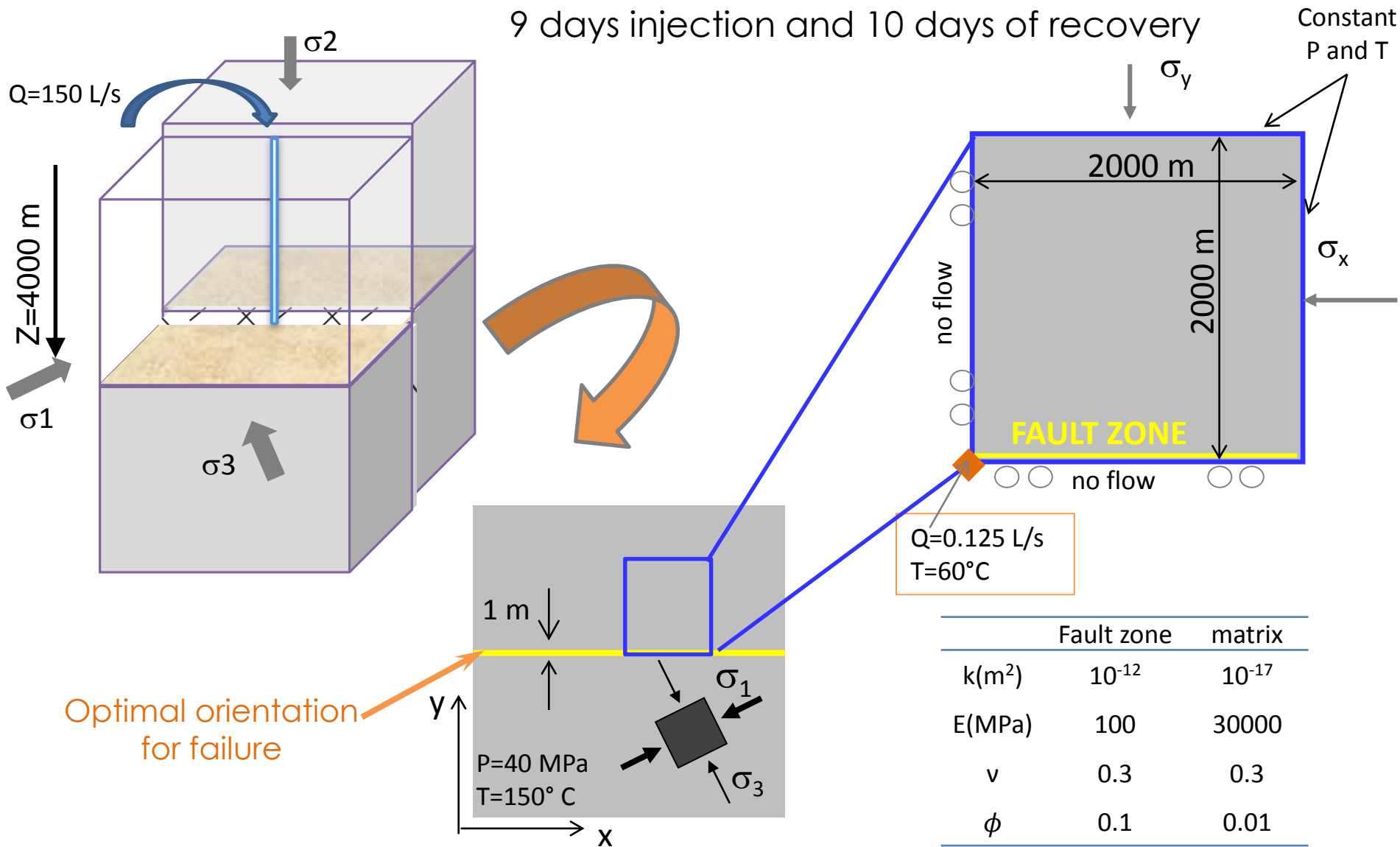
Identify how each process affect the stress field and the reservoir stability during and after injection



**Not so trivial !!!**

# Hydraulic and thermal effects

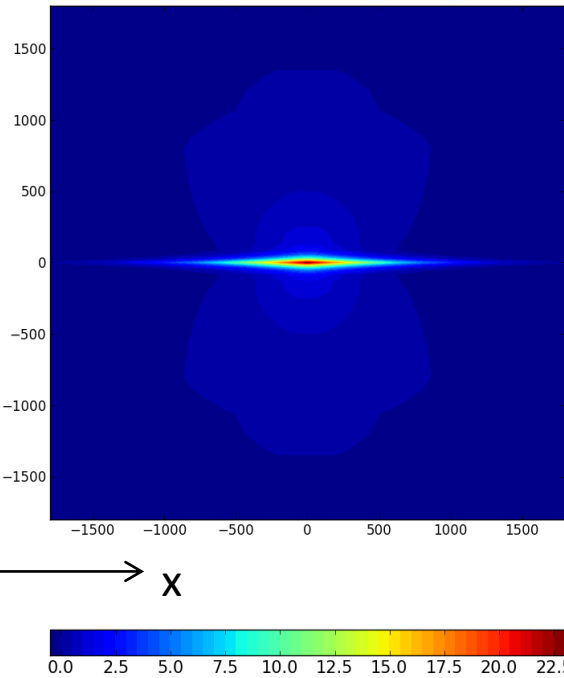
9 days injection and 10 days of recovery



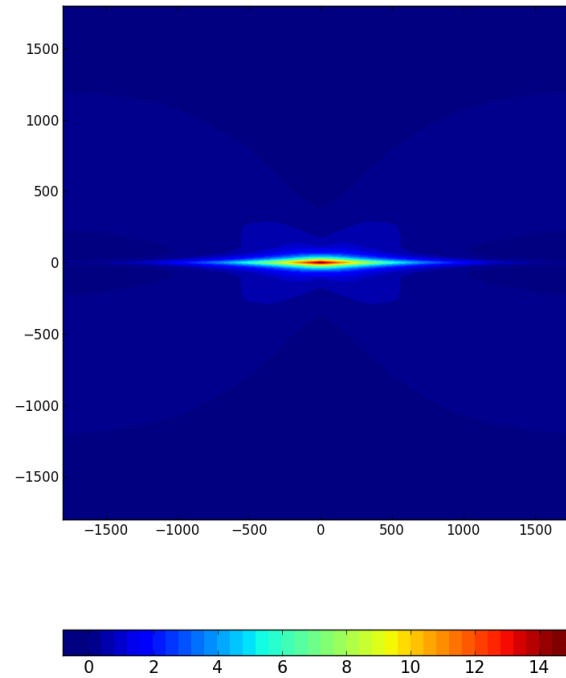


# Hydraulic effects (HM)

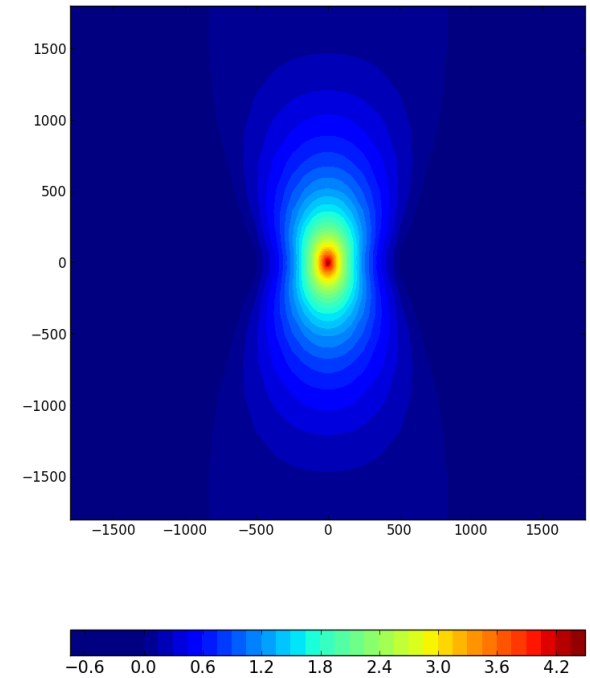
$\Delta P$  (MPa)



$\Delta\sigma_x$  (MPa)



$\Delta\sigma_y$  (MPa)

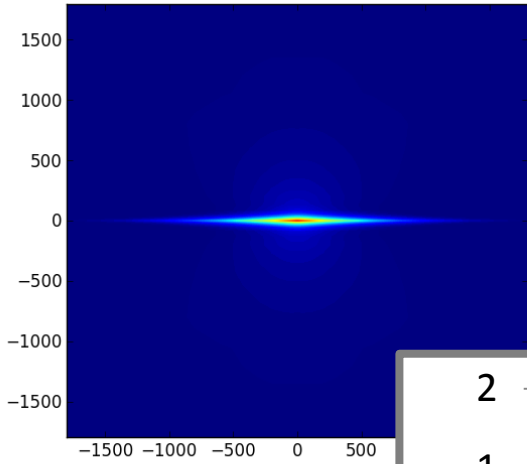


After 9d of injection

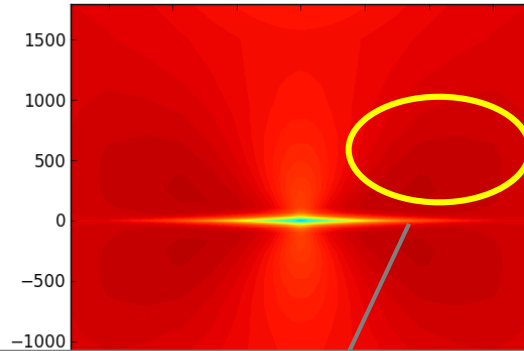
# Hydraulic effects (HM)



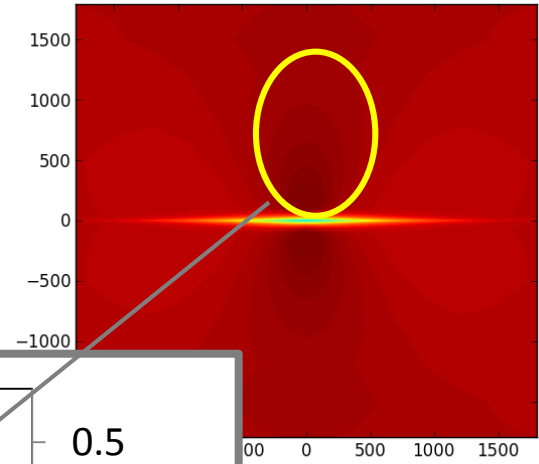
$\Delta P$  (MPa)



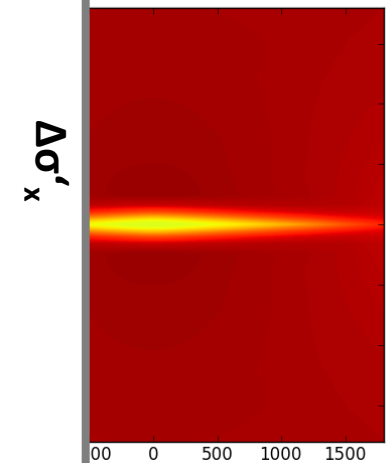
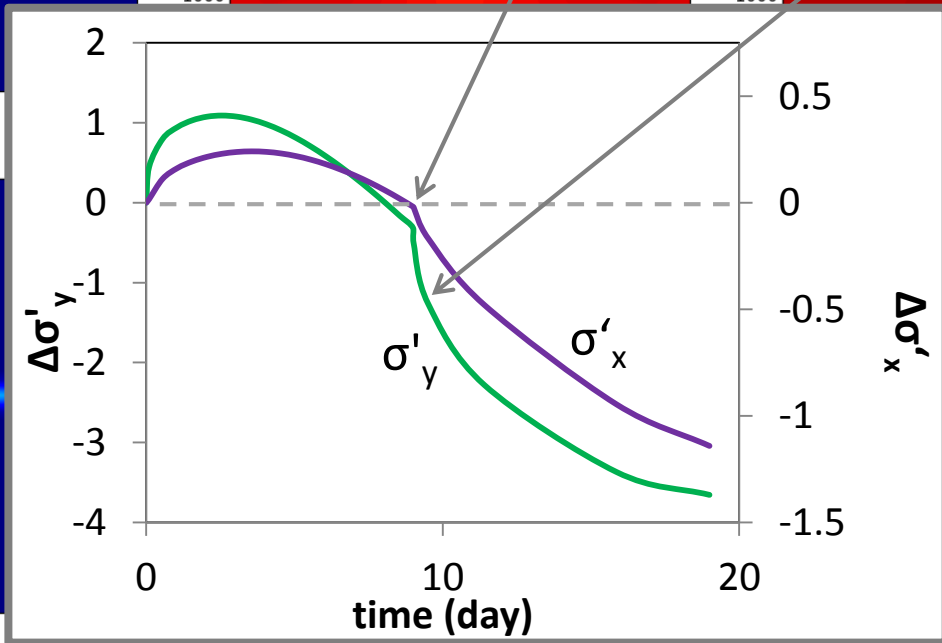
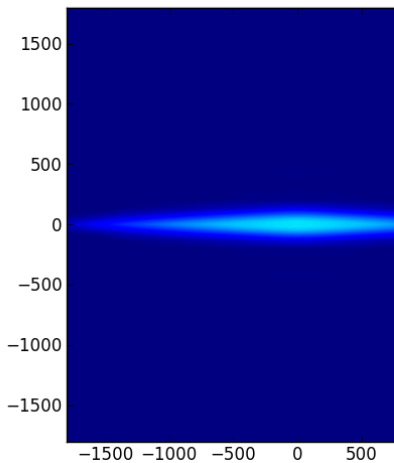
$\Delta\sigma'_x$  (MPa)



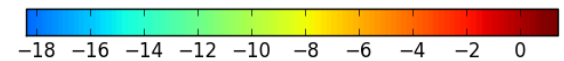
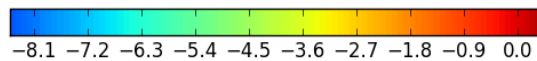
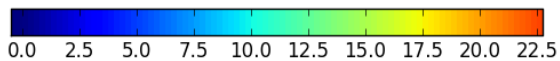
$\Delta\sigma'_y$  (MPa)

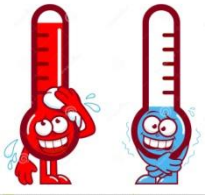


After 9d of injection



10d after shut-in

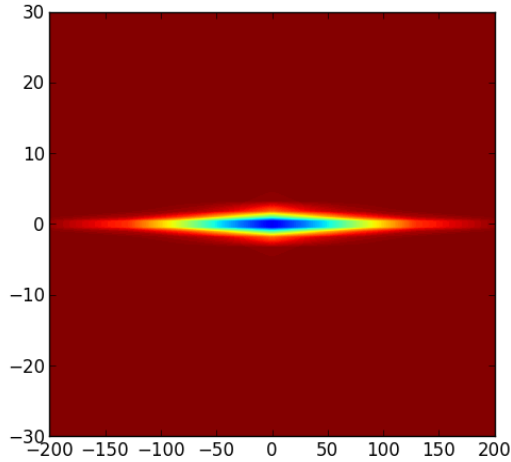




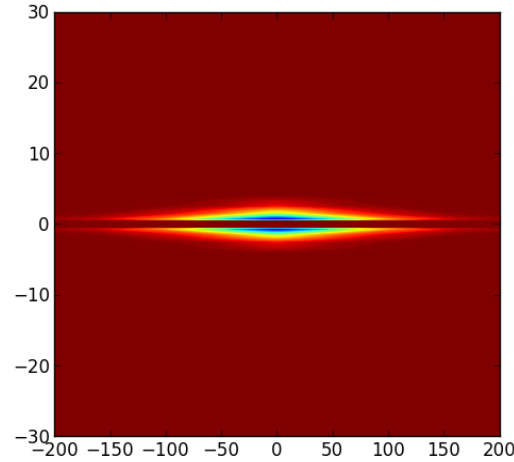
# Thermal effects (TM)

(for temperature distribution due to advection+conduction)

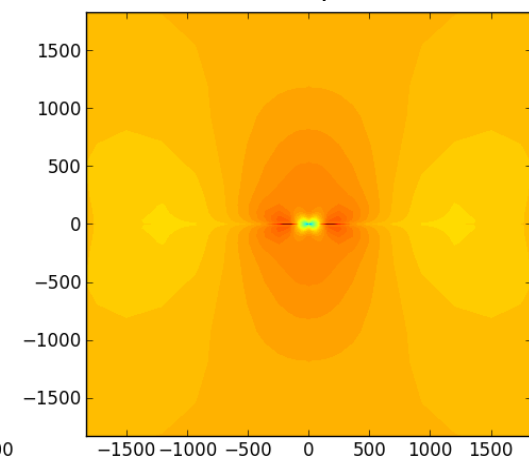
$\Delta T$  ( $^{\circ}\text{C}$ )



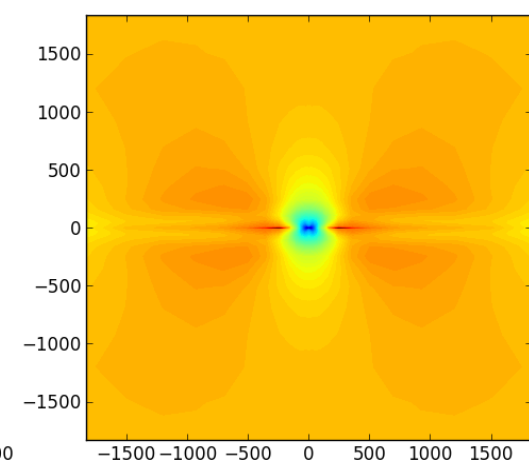
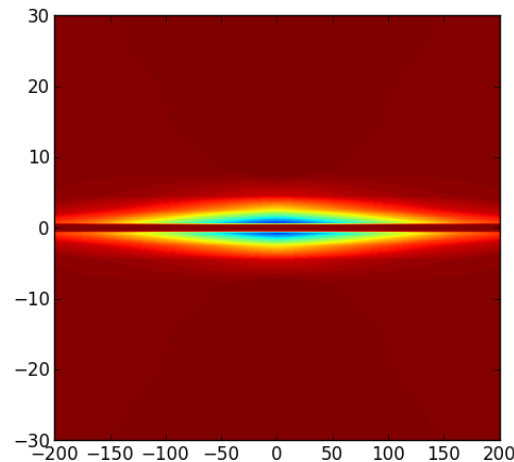
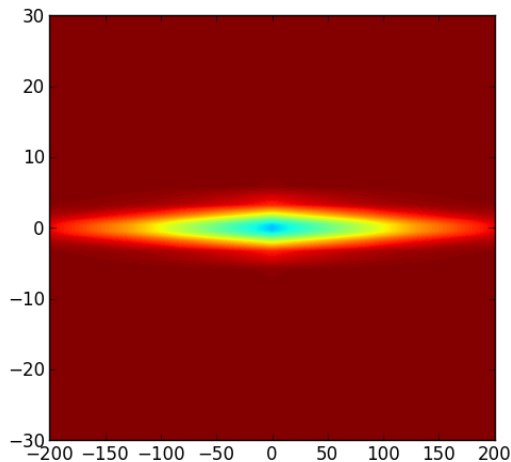
$\Delta\sigma'_x$  (MPa)



$\Delta\sigma'_y$  (MPa)



After 9d of injection

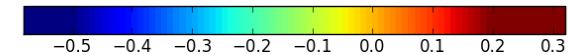
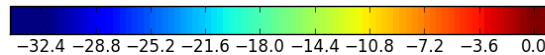
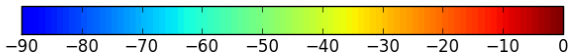


100d after shut-in

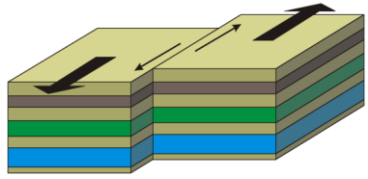
8

y  
↑

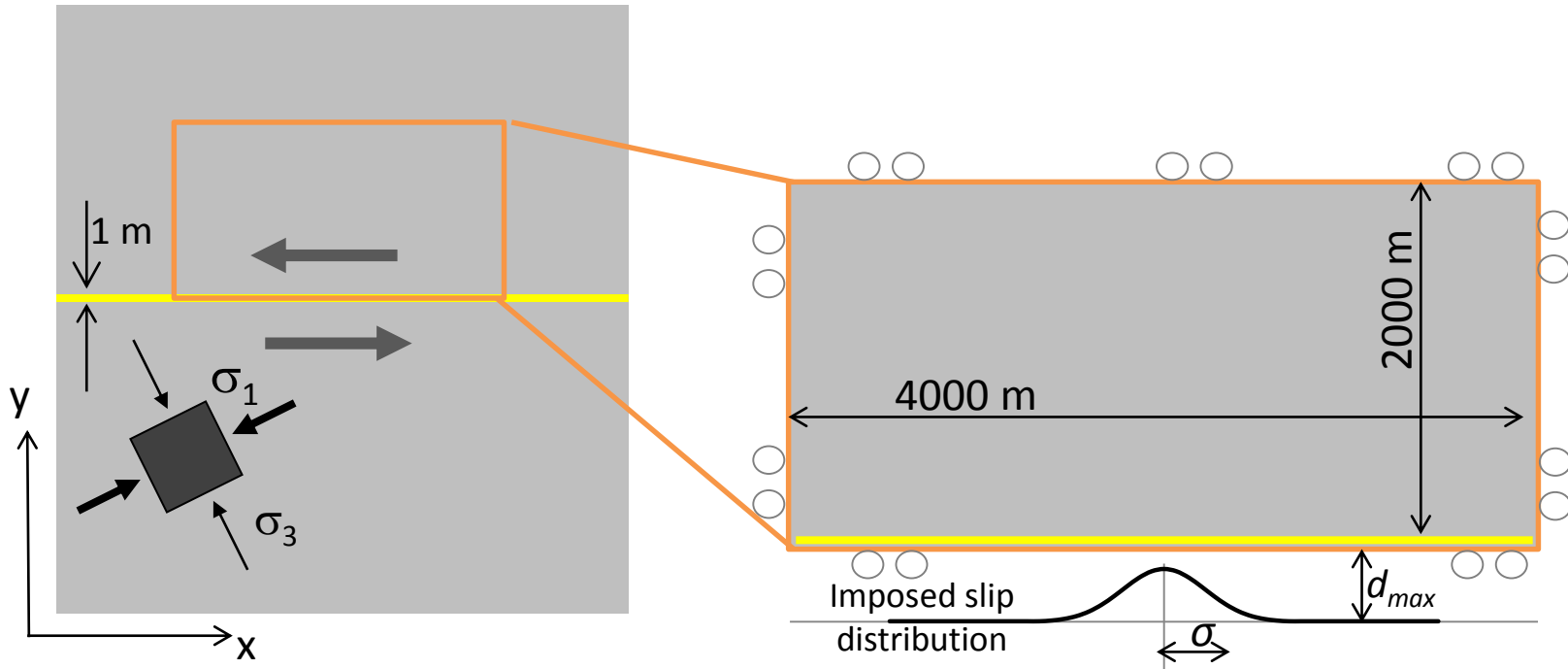
x  
→







# Shear slip movement effects



$$d_{max} = 0.02 \text{ m}$$

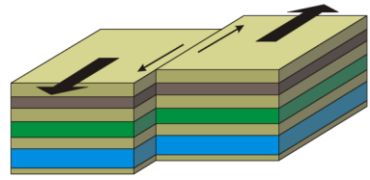
$$\sigma = 12 \text{ m}$$



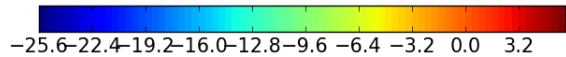
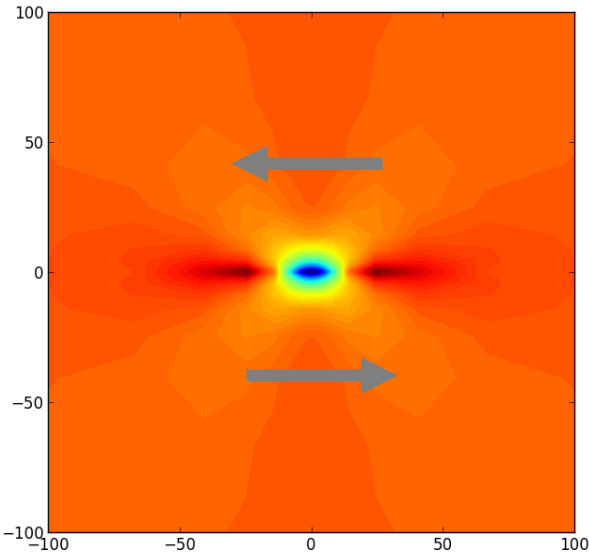
$$M \approx 2.0$$

$$\left\{ \begin{aligned} Mo &= G \cdot d \cdot S \\ Mw &= \frac{\log Mo}{1.5} - 6.07 \end{aligned} \right.$$

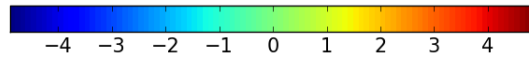
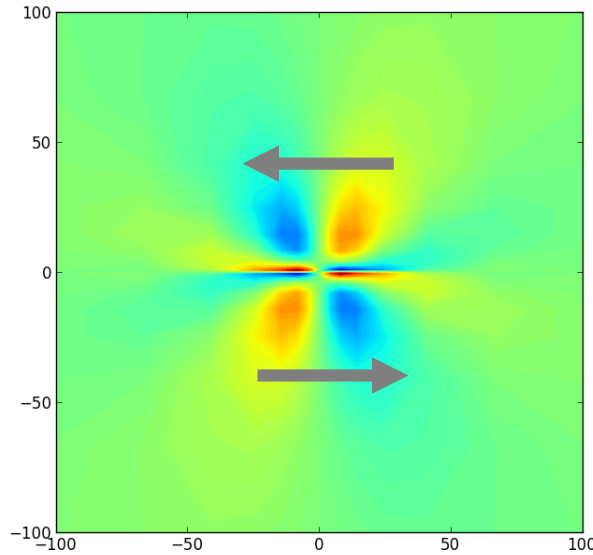
# Shear slip movement effects



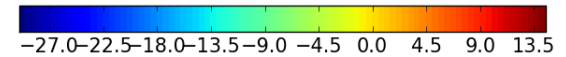
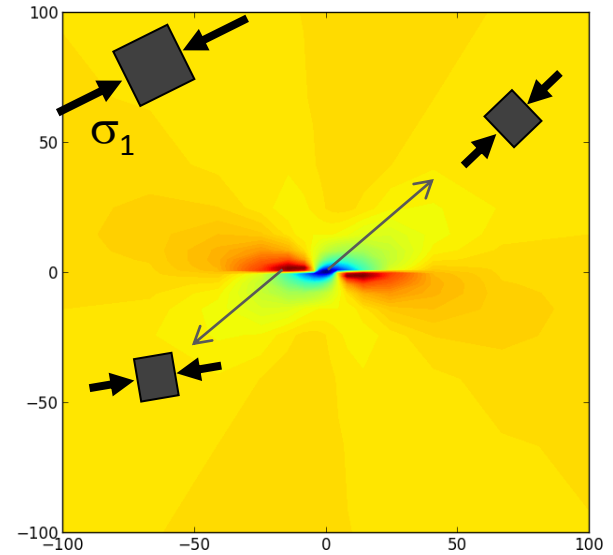
$\Delta\tau_{xy}$  (MPa)



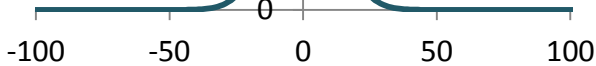
$\Delta\sigma_y$  (MPa)



Stress field rotation (°)



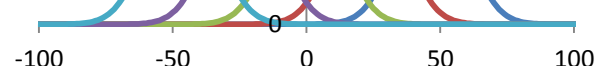
0.02



x (m)



0.02



x (m)

# Superposition of effects

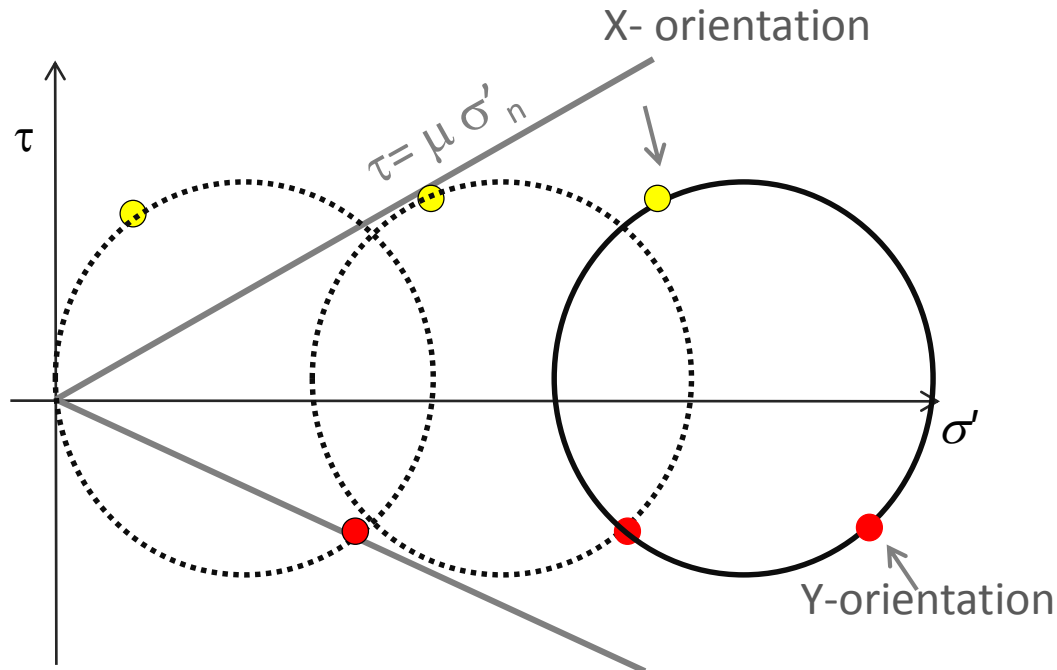
## Mohr-Coulomb failure criterion

$$CFS = \tau - (c + \mu \cdot \sigma'_n)$$

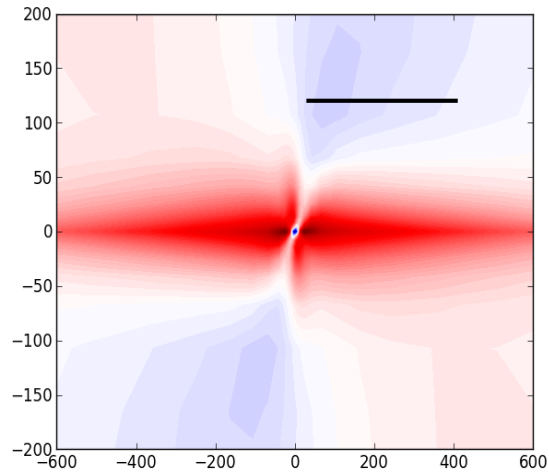
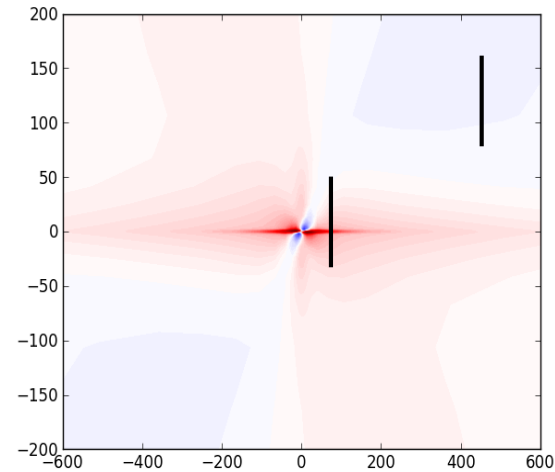
$CFS > 0$  means failure

$$\Delta CFS = CFS^t - CFS^0$$

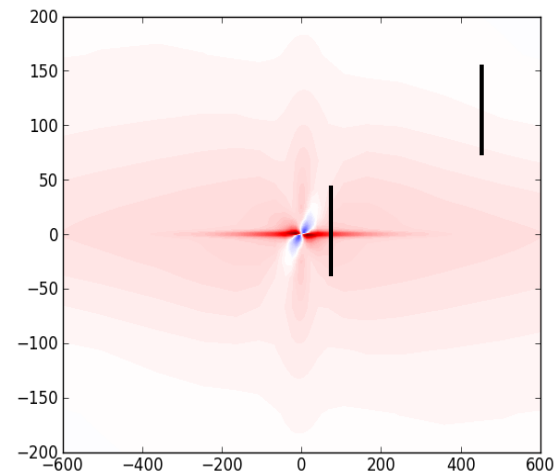
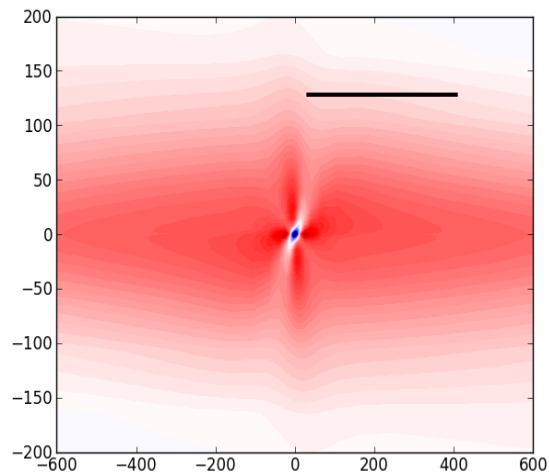
$CFS$  increase ( $\Delta CFS > 0$ ) correspond to stability worsening



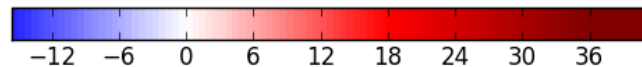
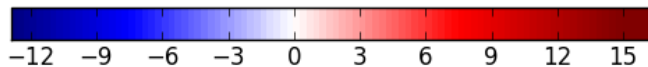
# Superposition of effects: Stability variation

 $\Delta CFS$  for orientation x $\Delta CFS$  for orientation y

After 9d of injection

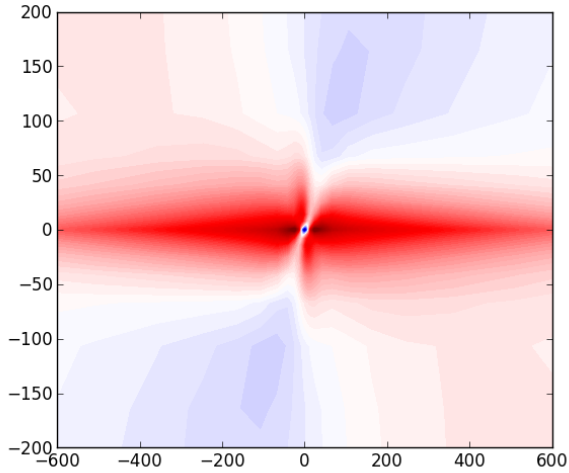


10d after shut-in

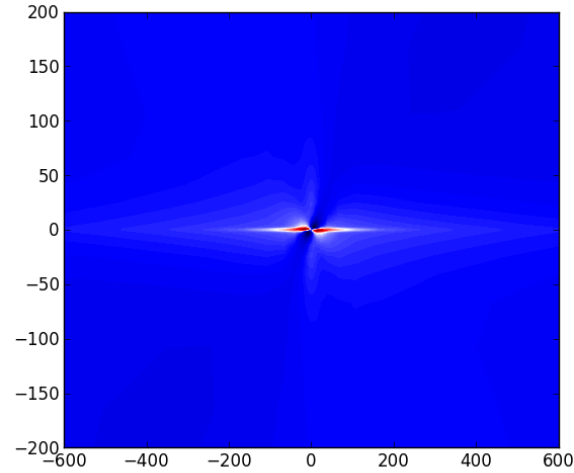


# Superposition of effects: failure

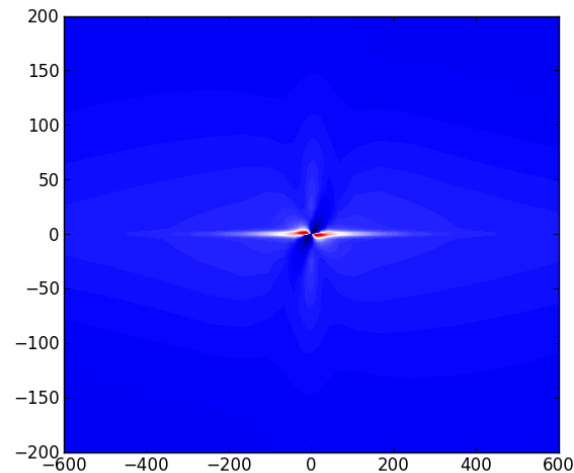
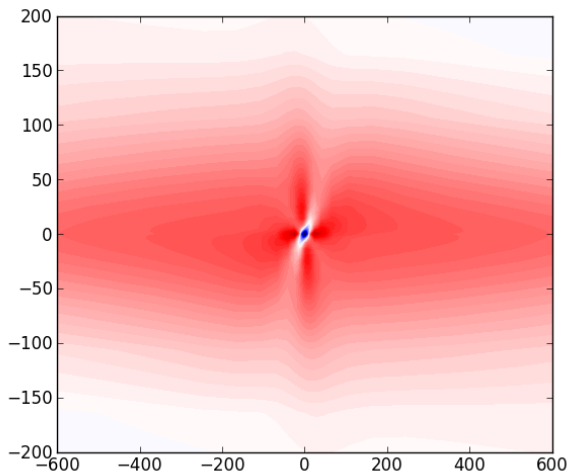
CFS for orientation x



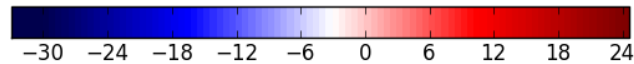
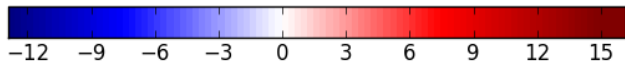
CFS for orientation y



After 9d of injection



10d after shut-in



# Conclusions

- **Hydraulic** effects produce seismicity in the vicinity of the well and along the main fault zone, but also stabilize fractures placed far away from the injection point, thus delaying their failure;
- **Hydraulic** effects rapidly disappear after the injection stop, but at early times they may induce seismicity in previously stabilized fractures;
- **Thermal** effects remain for long times after injection stop and reduce stability along not optimally oriented fractures, but they are localized to the area close to the injection well;
- **Slip stress transfer** may sensibly rotate the stress tensor;
- The superposition of these effects may induce seismicity along not optimally oriented fractures .

# Thank you for the attention!!



Aknowledgements: "FI-DGR 2012" Grant - AGAUR

