Detection of Flow-pathway Structure upon Pore-pressure Distribution Estimated from Hydraulically Induced Micro-seismic Events and Application to the Soultz HDR Field

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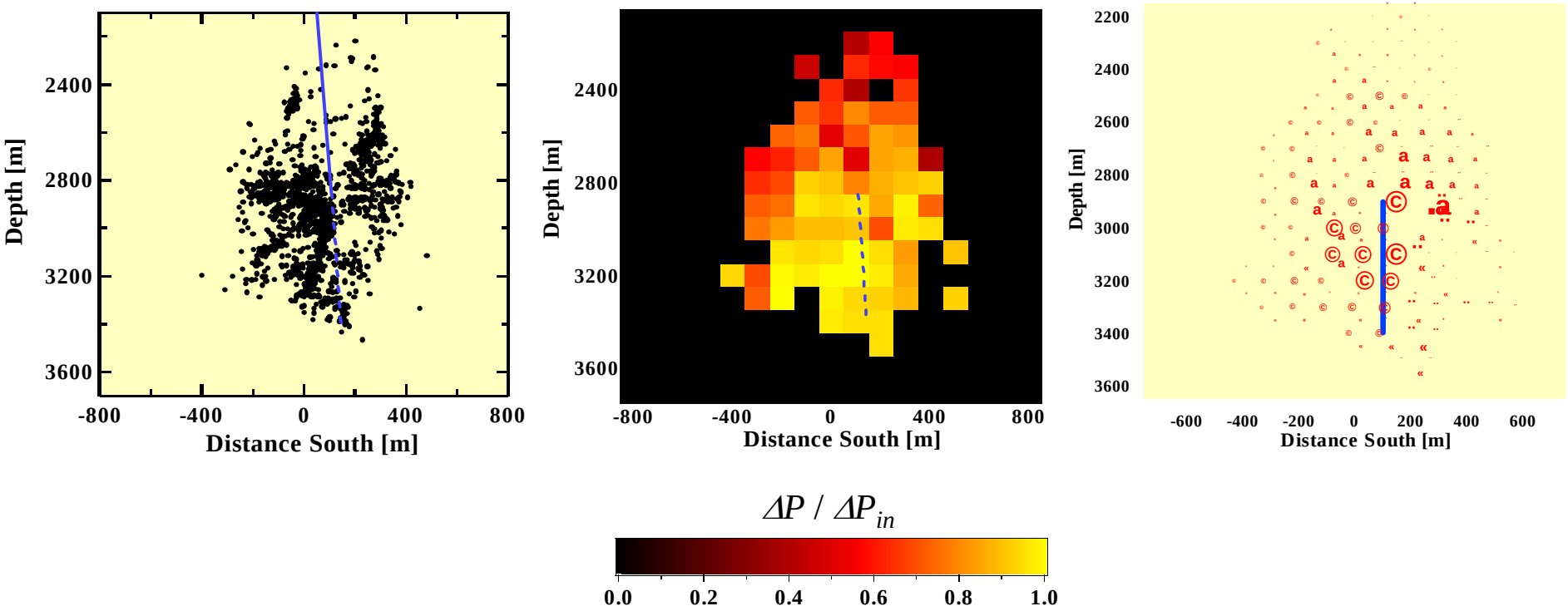
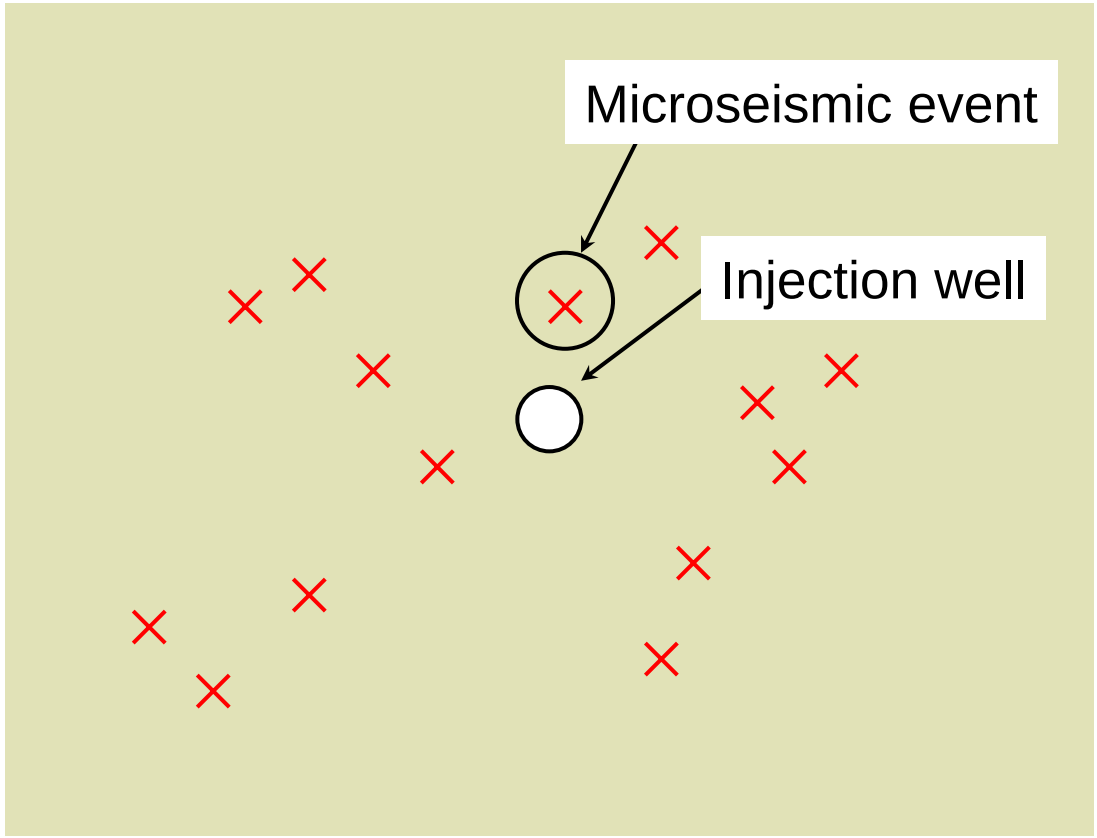
Hydraulic stimulation at Soultz in Sept. 1993

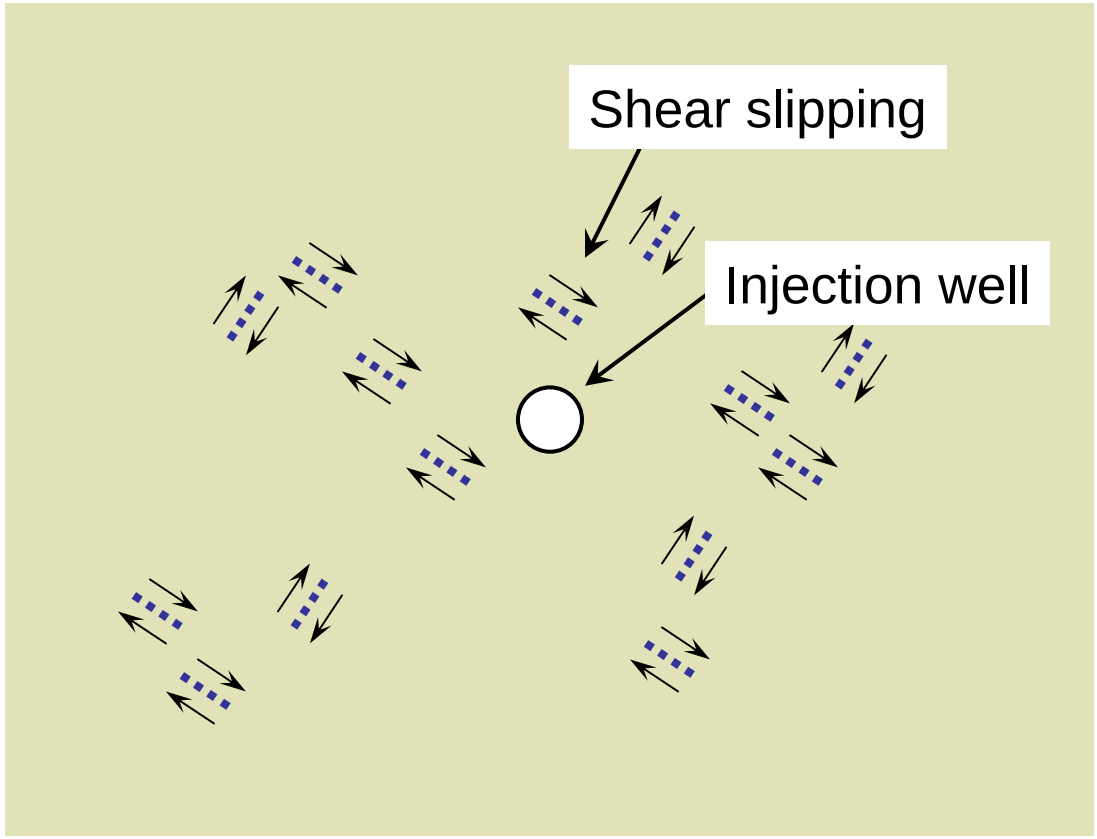
MS events → Pressure distribution → Flow distribution



Sequence of MS events

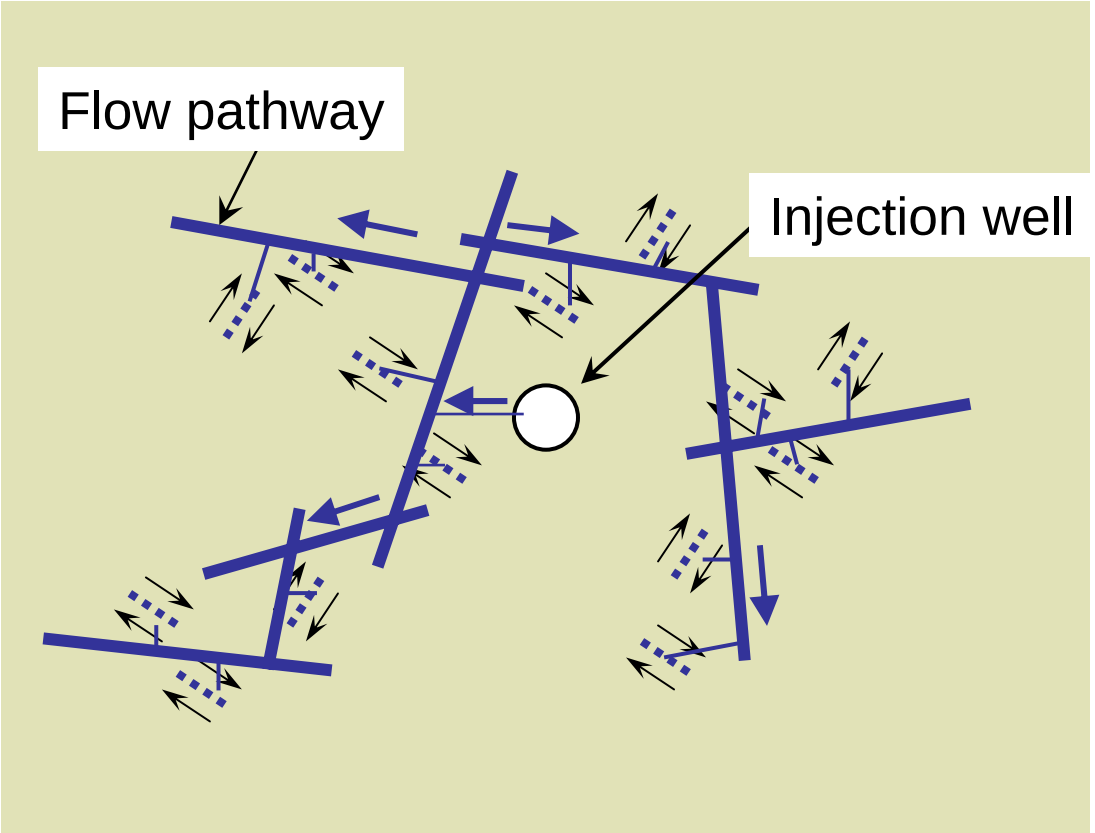


Sequence of MS events



What does trigger fracture slipping ?

Sequence of MS events



High fluid pressure delivered from a injection well

Critical pore pressure to induce fracture slipping

Pressure elevation

↓

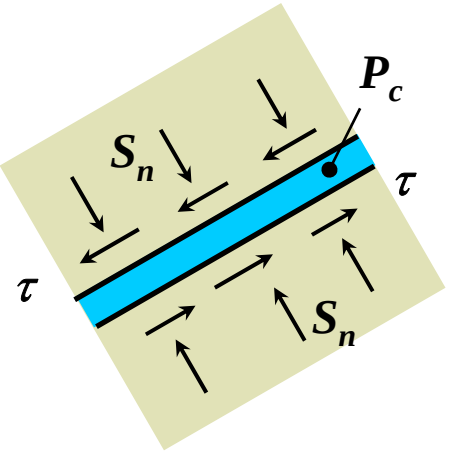
Reduction in friction between fracture planes

↓

(Friction) = (Shear stress) ⟷ *Coulomb criterion* $\mu(S_n - P_c) = |\tau|$

↓

Fracture slipping / Micro-seismicity



Microseismic event
(e.g., fault plane solution)

↓

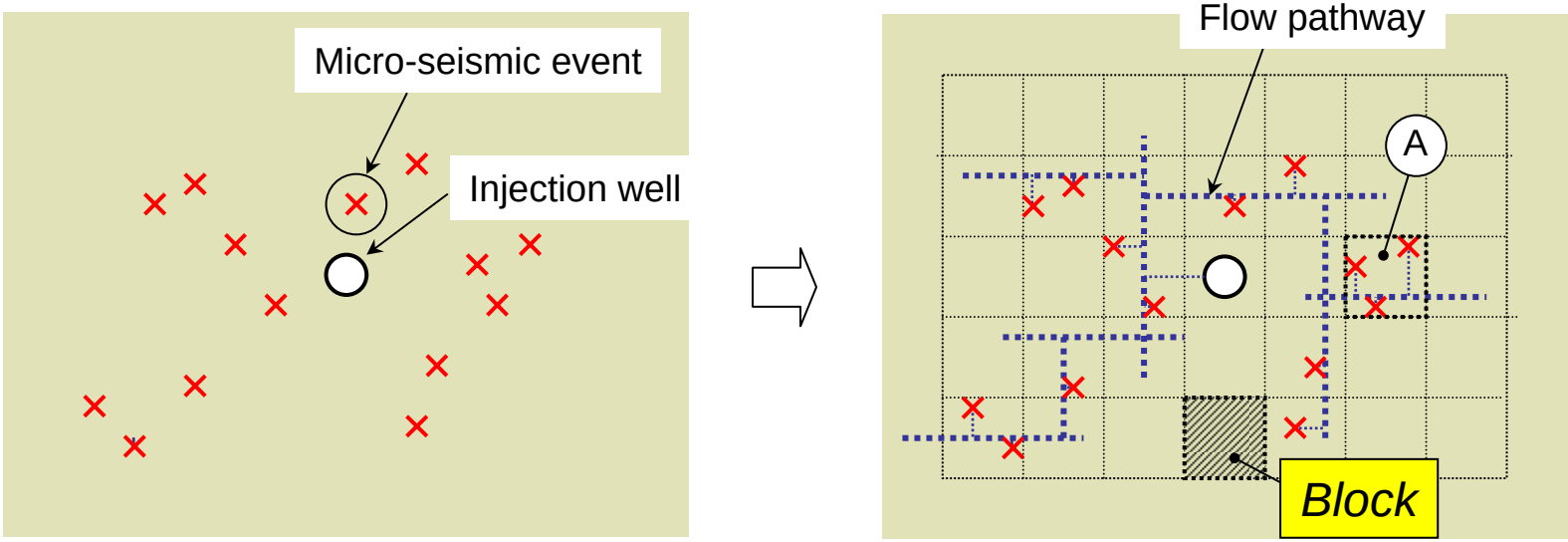
- *fracture orientation*
- *in-situ stresses*
- *friction coef.*

$$P_c = S_n - \frac{|\tau|}{\mu}$$

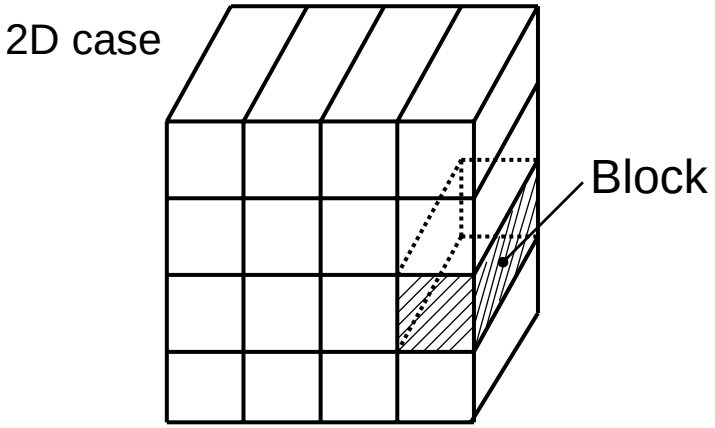
(Critical pore pressure)

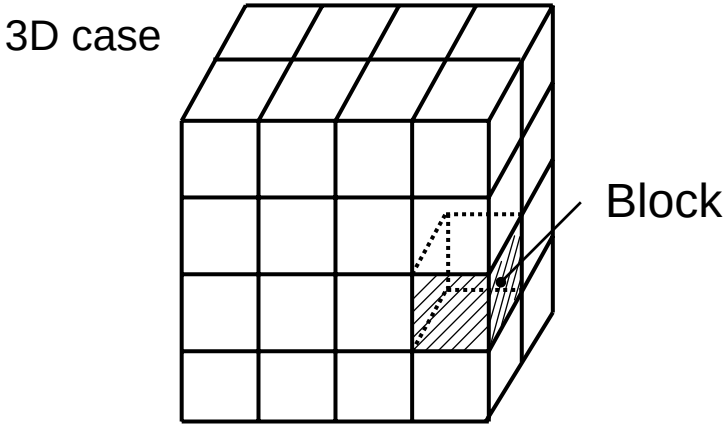
P_c ⇨ Pore pressure at the location and time of each MS event (Cornet & Yin, 1995) ⇨ **Spatial distribution of pore pressure and its variation with time** (Ito et al., 2004, Osada et al., 2005)

Concept of ”Block”

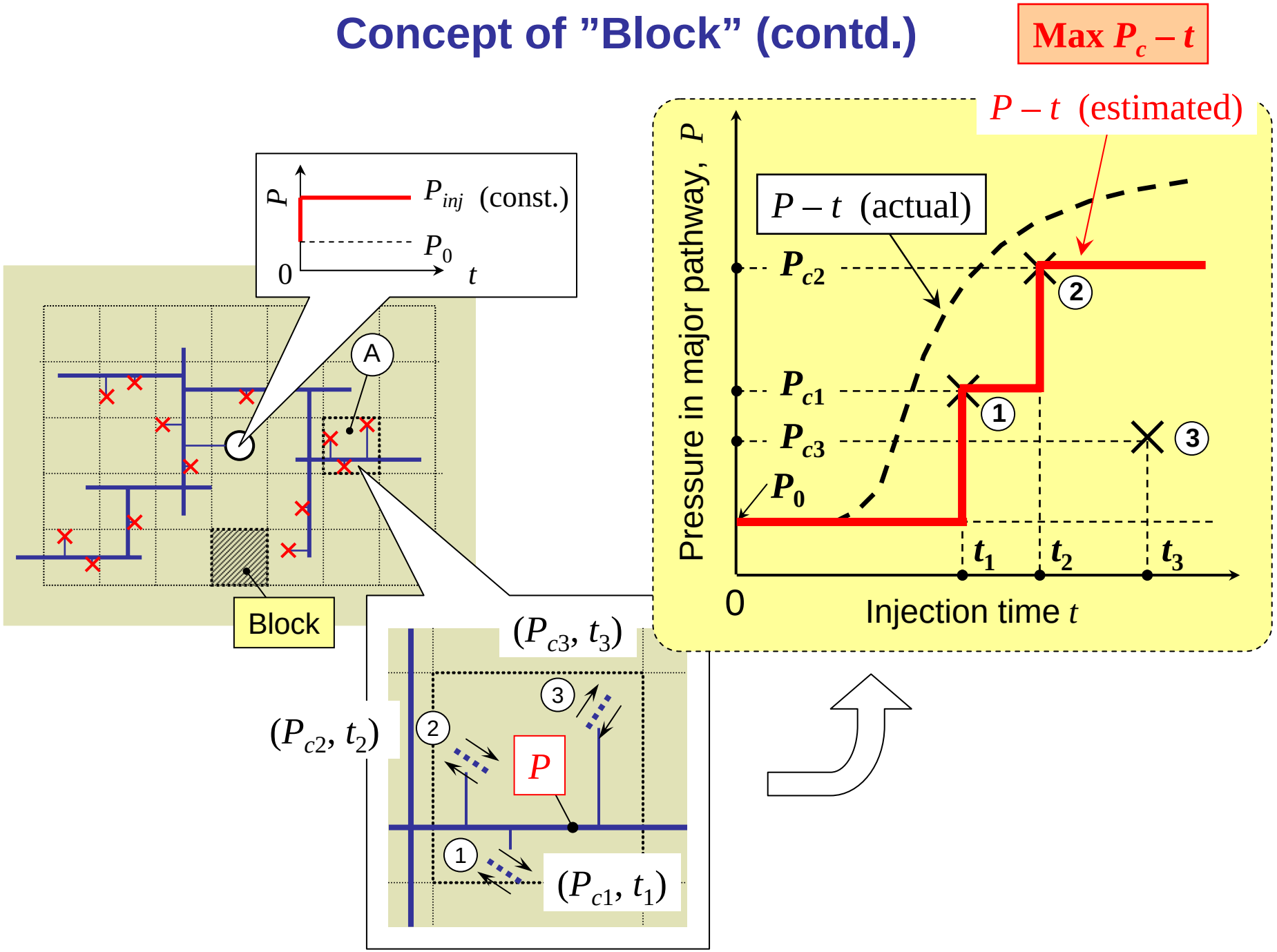


(We assume that the MS events involved in each block are induced by the elevated fluid pressure brought by a flow pathway passing through the block.)

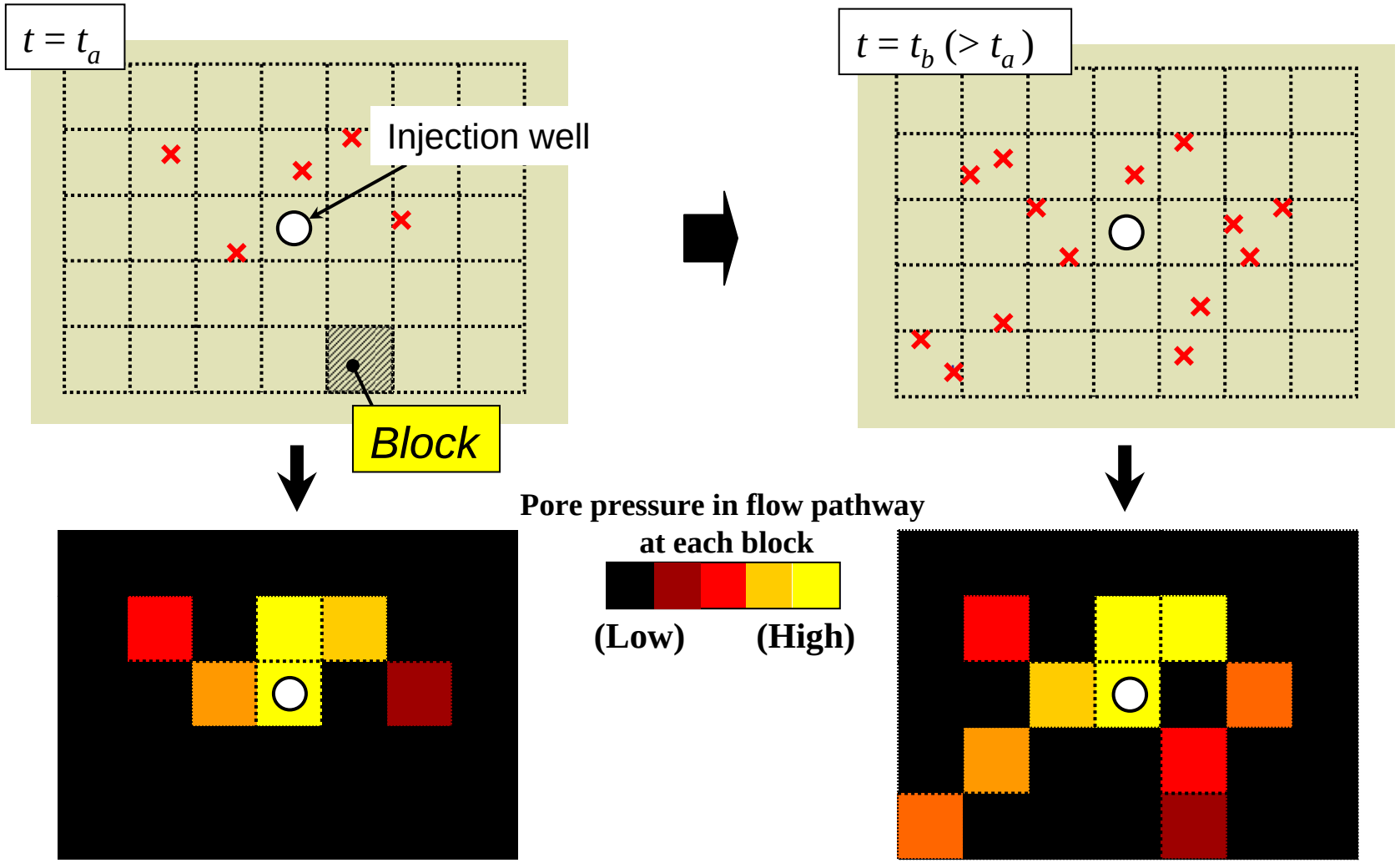




Concept of "Block" (contd.)



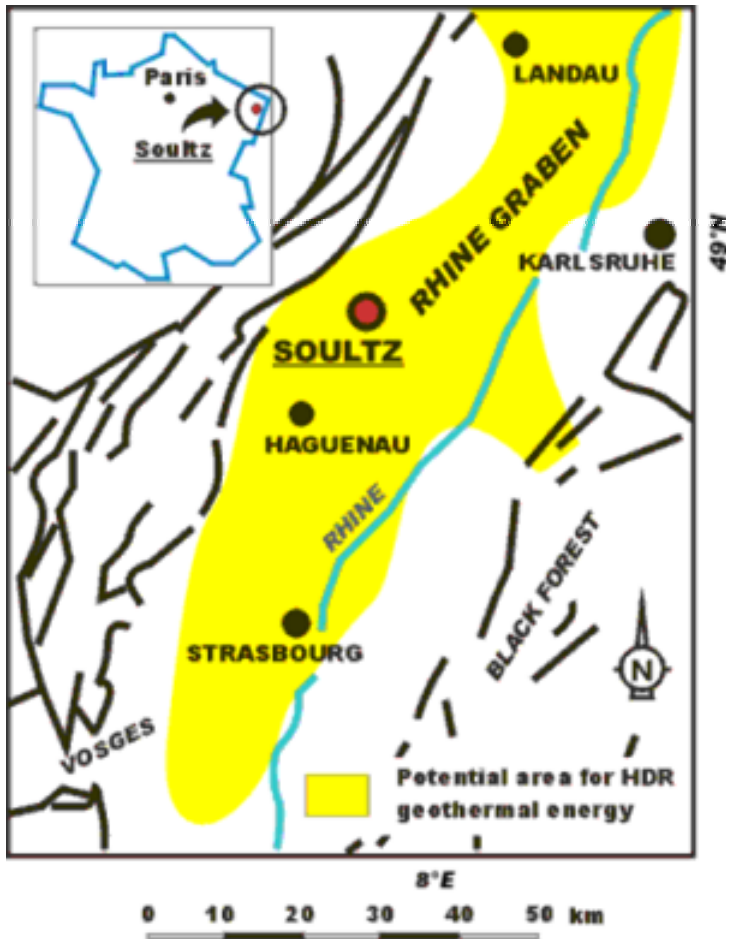
Spatial distribution of pore pressure along flow pathways



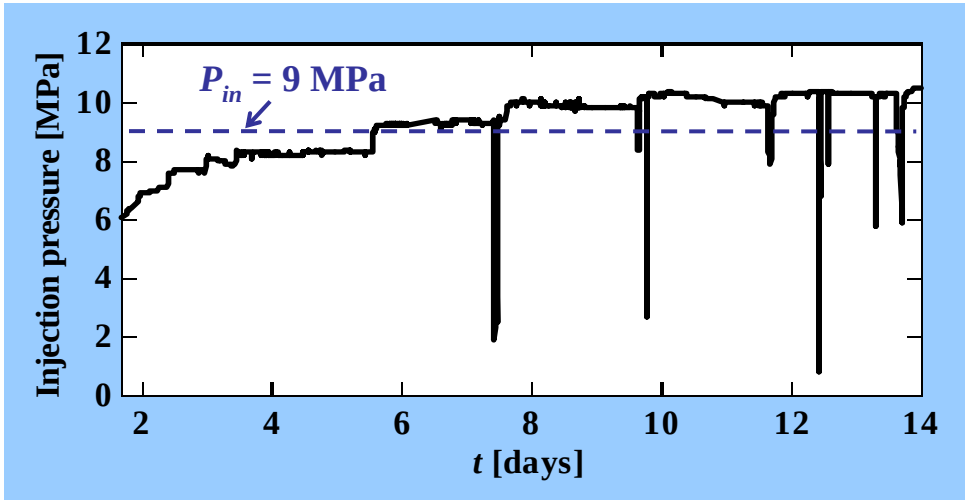
Field application at the Soultz HDR site

(Hydraulic stimulation in Sept. 1993)

Location of the Soultz field

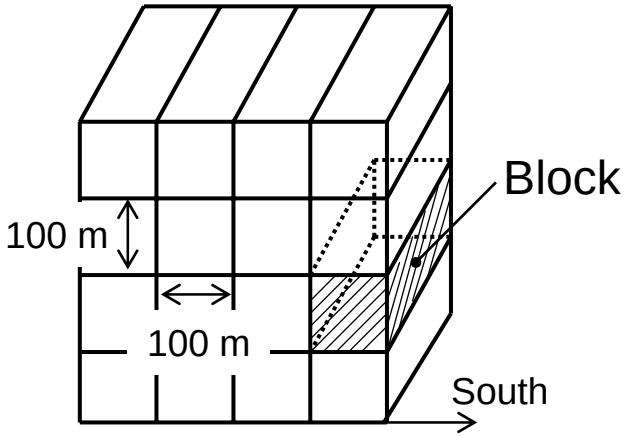


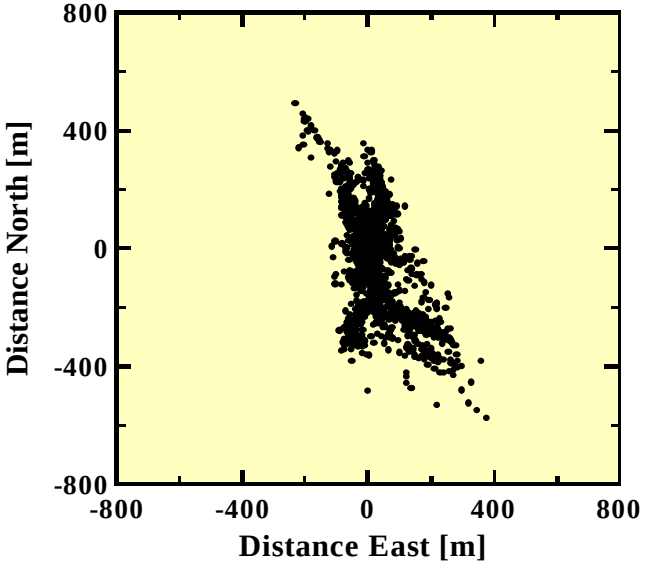
Well-head pressure in well GPK-1



MS events and block setting

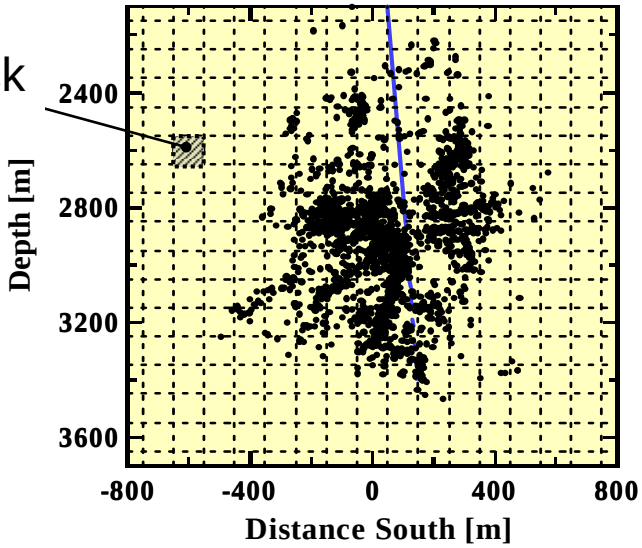
12,837 (location) → 2,285 (location & orientation) → (Focal mechanism)

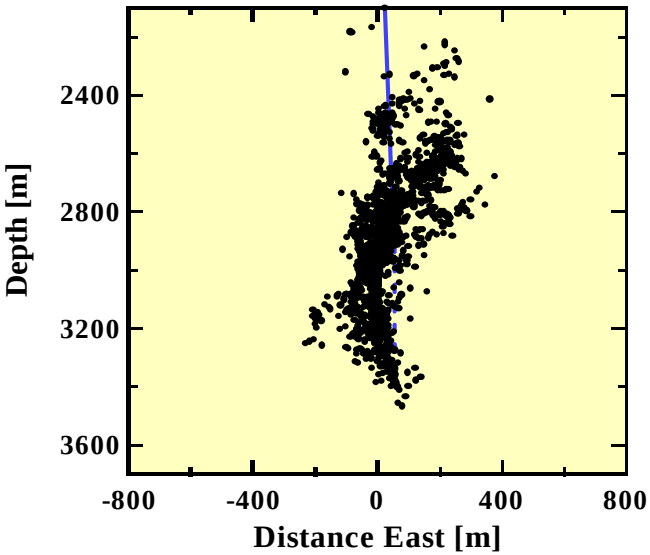




Assuming 2-D division

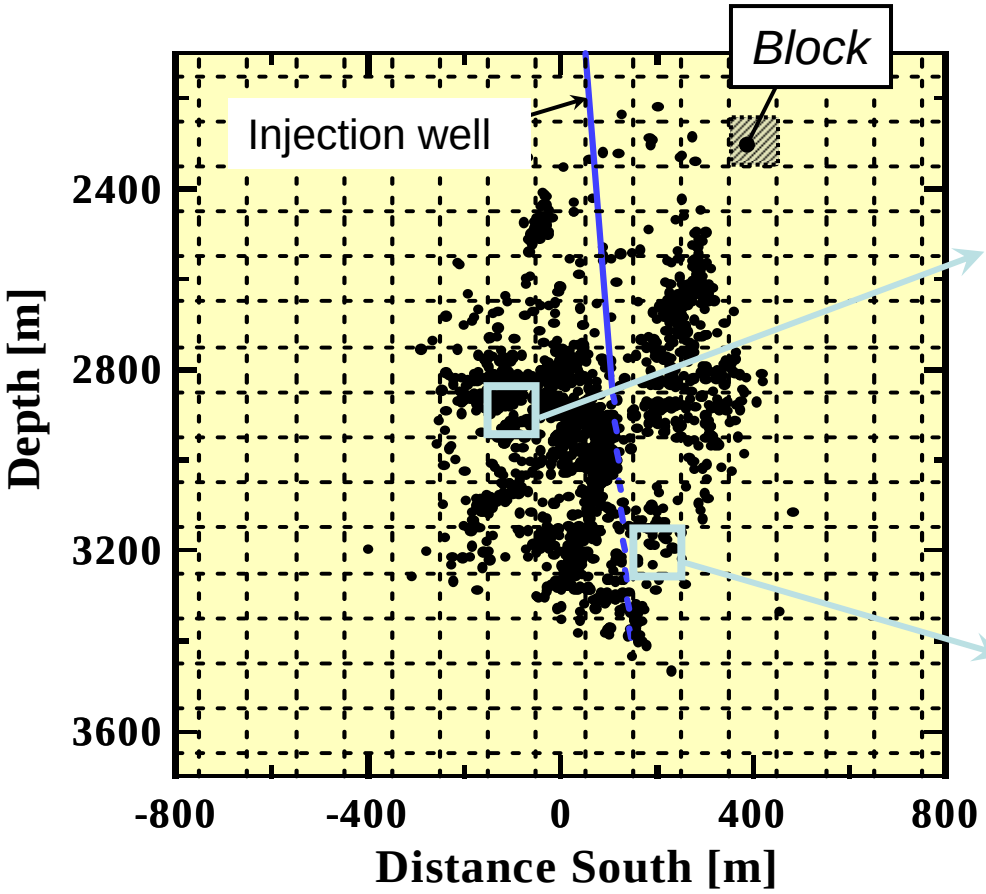
Block

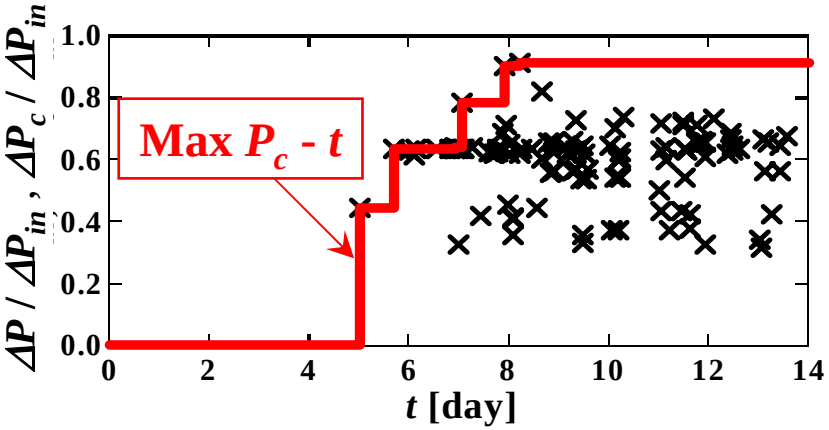


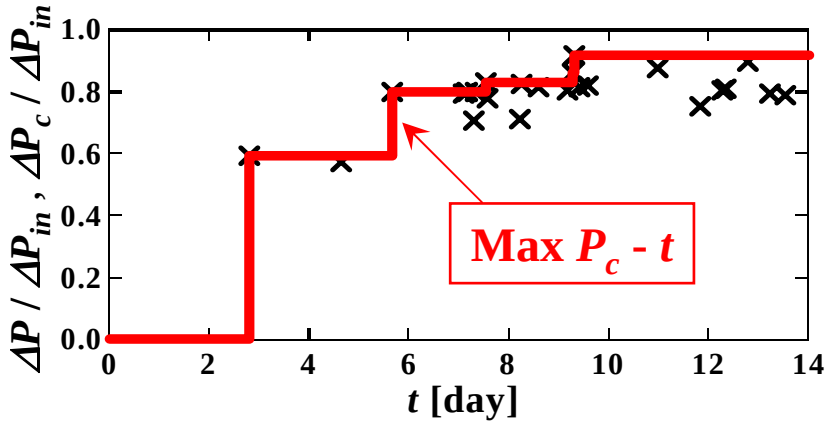


Variation of pore pressure with time

(100 x 100 m^2)





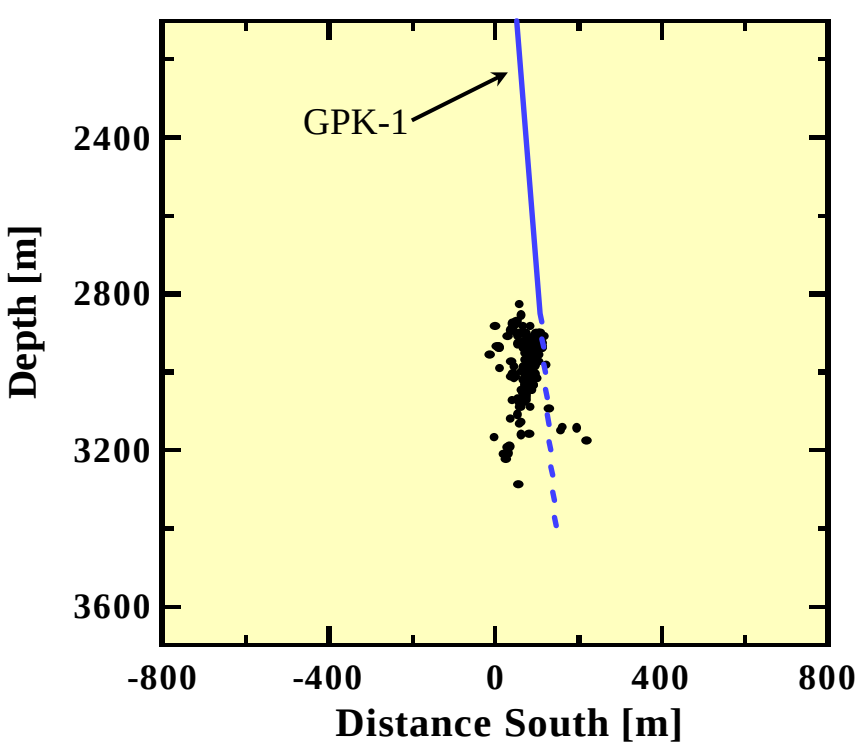


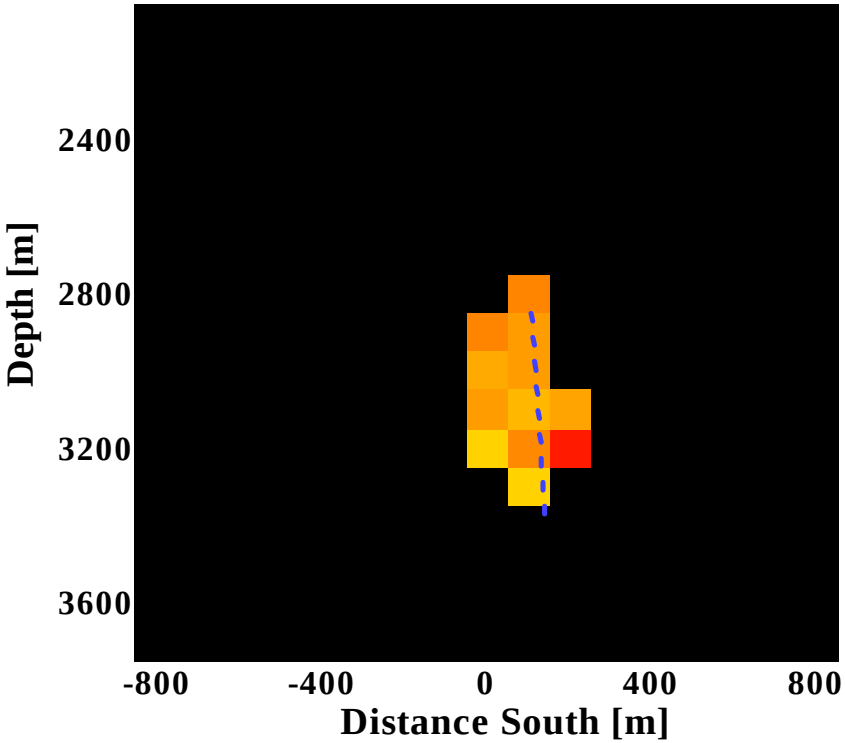
$$\Delta P = (P - P_0),\ \Delta P_c = (P_c - P_0),\ \Delta P_{in} = (P_{in} - P_{in0})$$

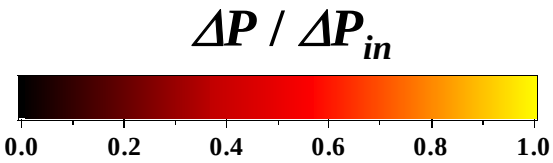
(ΔP_{in} = 9 MPa)

Pore pressure distribution & its variation with time

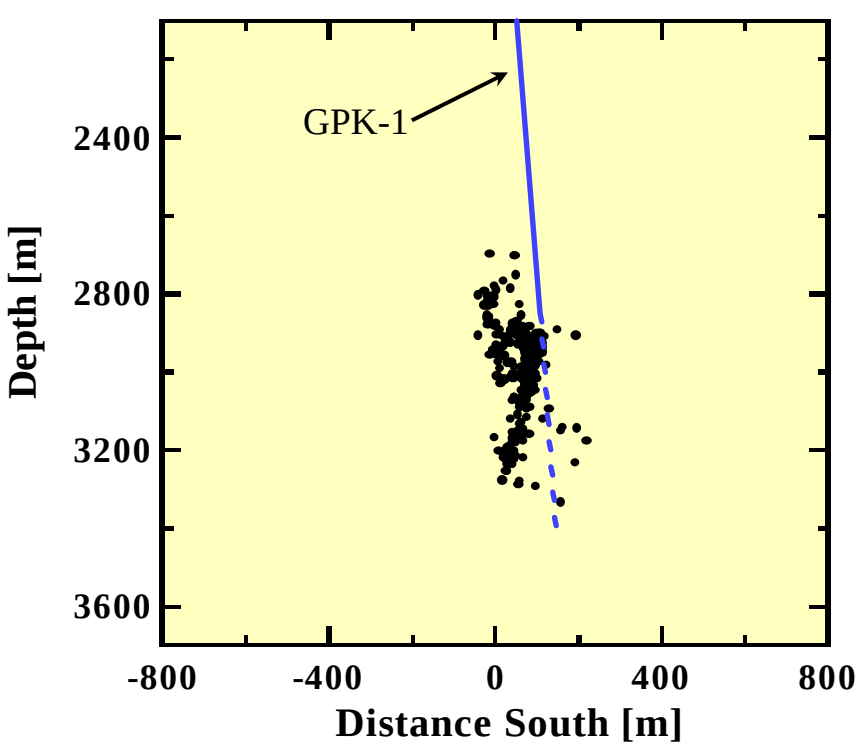
No. 1/6 t = 4 [days]

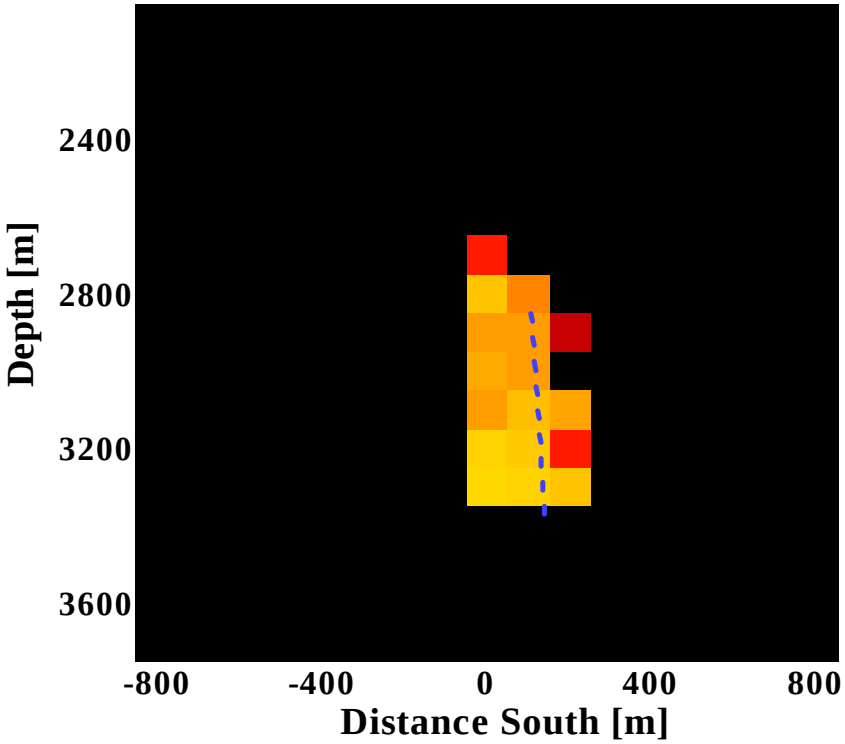




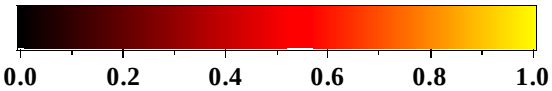


No. 2/6 t = 5 [days]

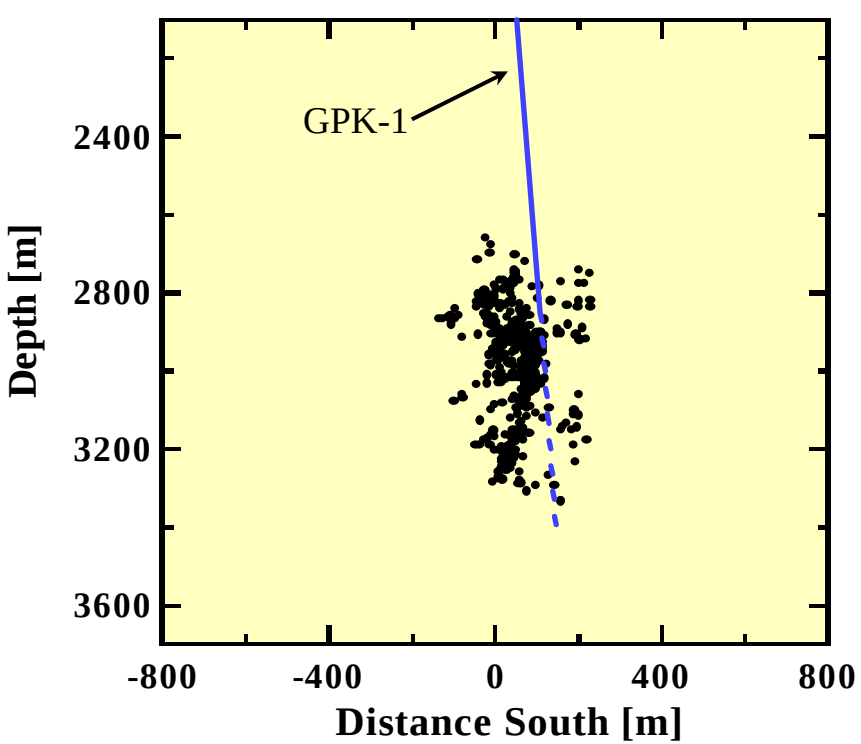


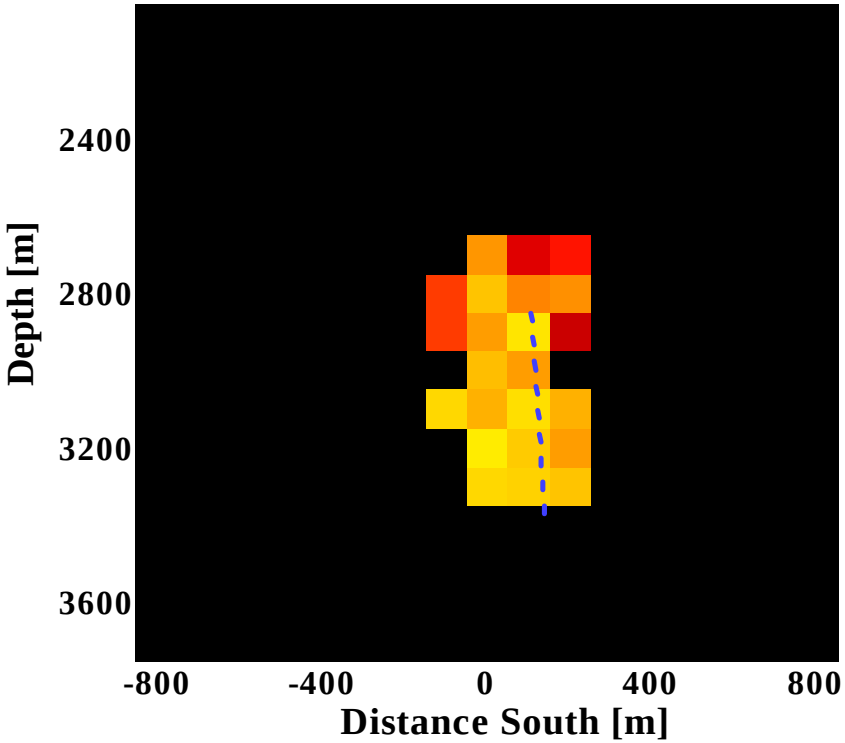


$\Delta P / \Delta P_{in}$

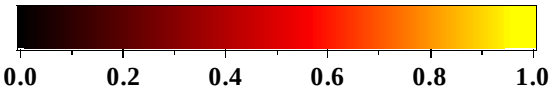


No. 3/6 t = 7 [days]

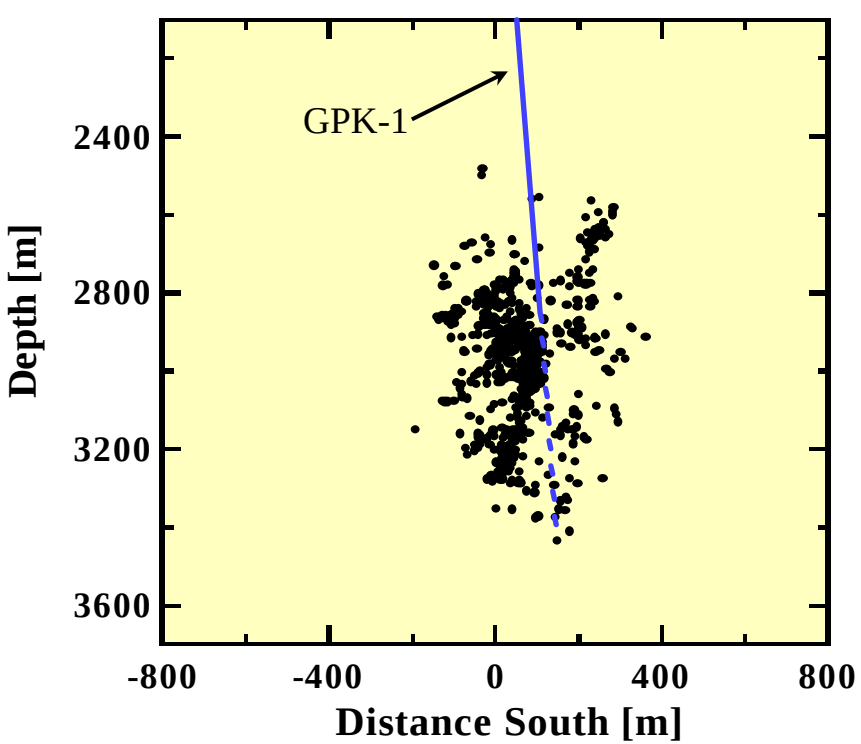


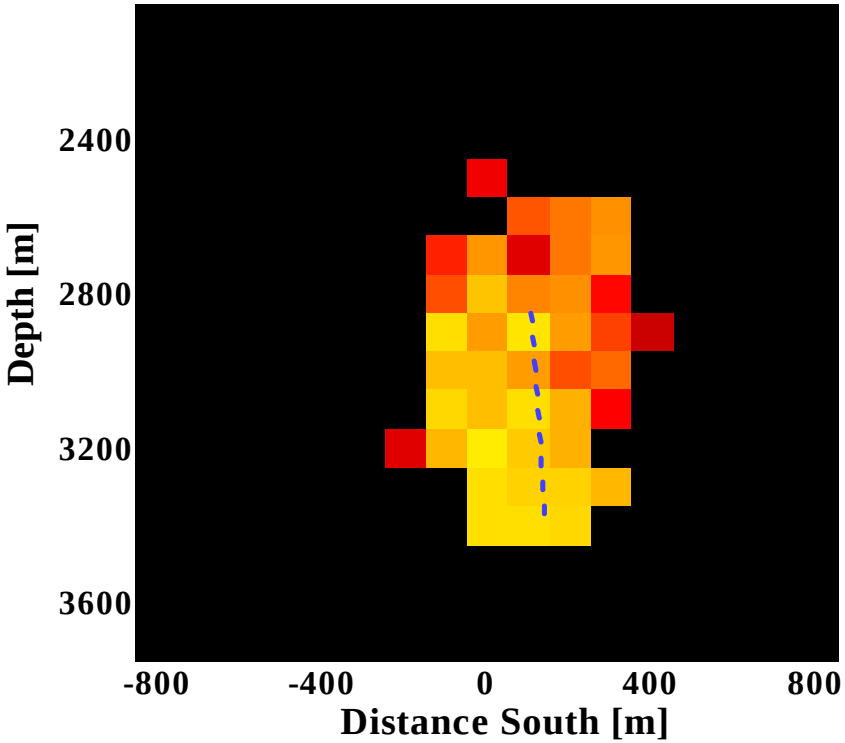


$\Delta P / \Delta P_{in}$

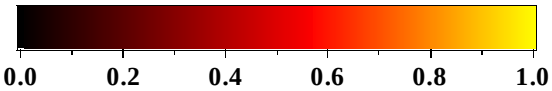


No. 4/6 t = 8 [days]

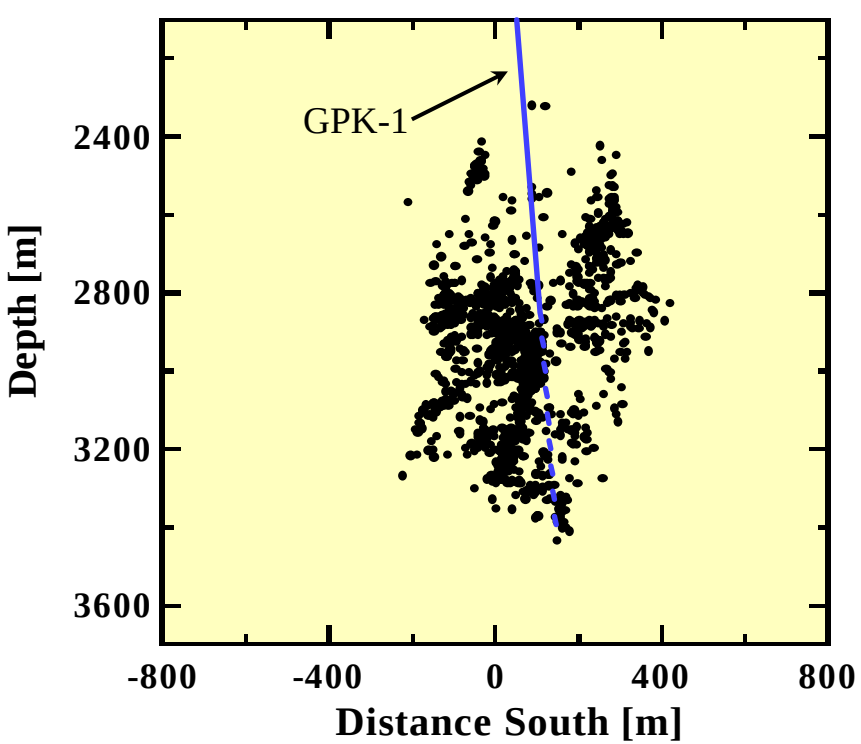


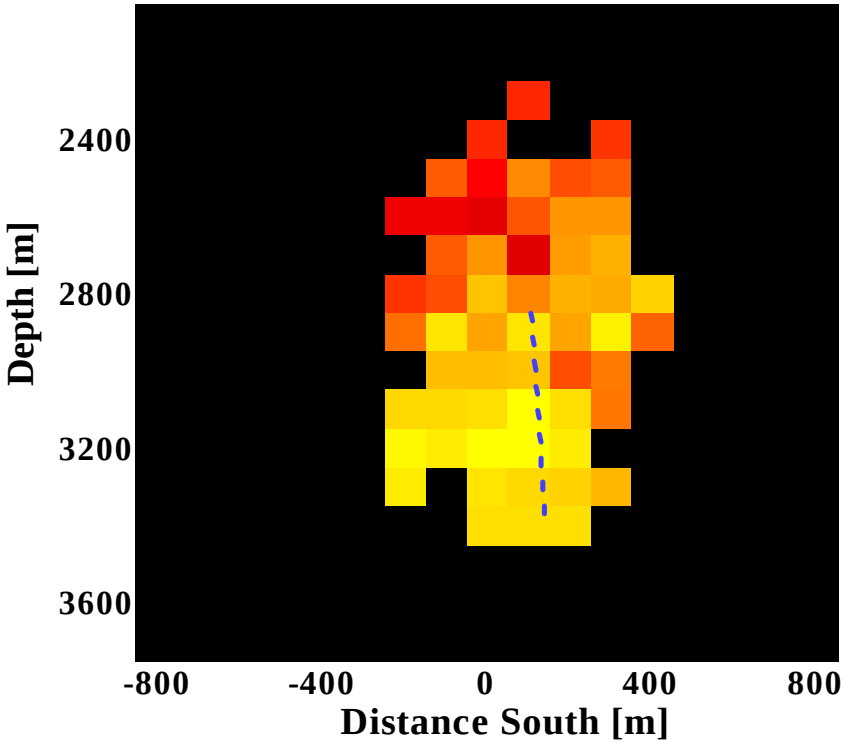


$\Delta P / \Delta P_{in}$

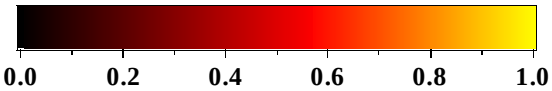


No. 5/6 t = 10 [days]

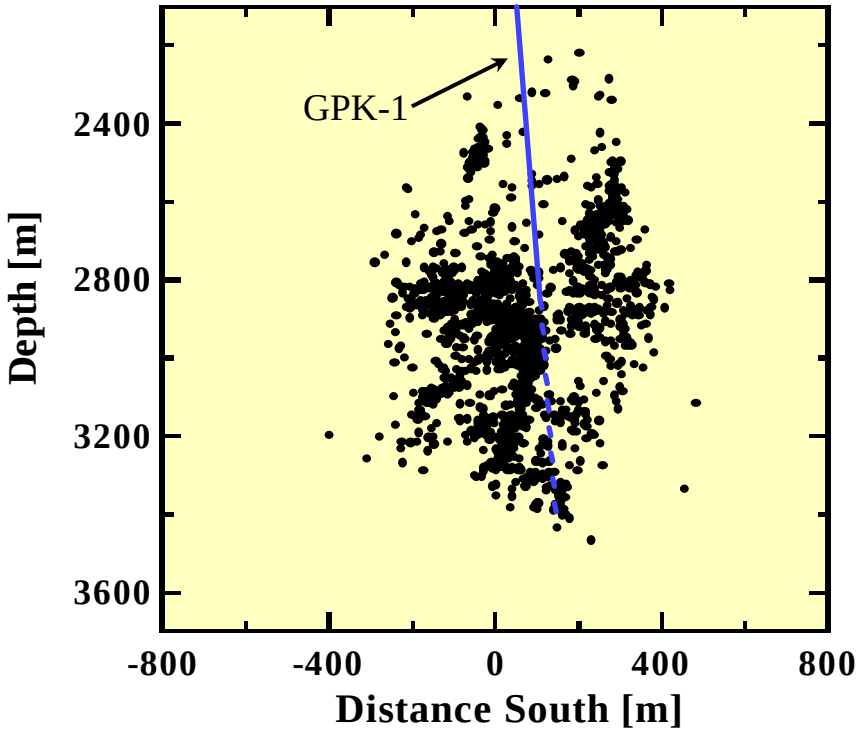


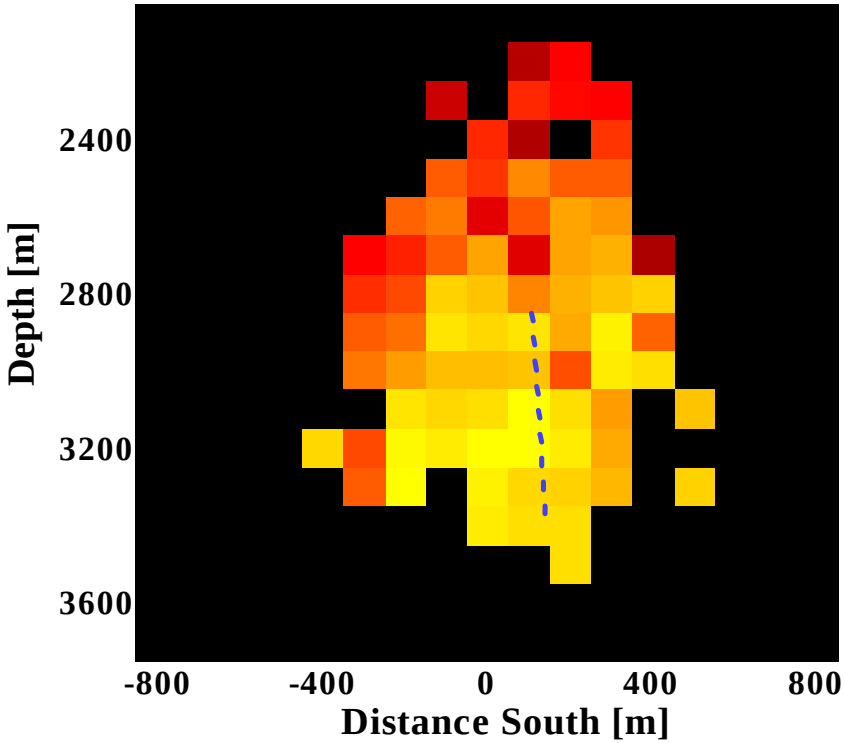


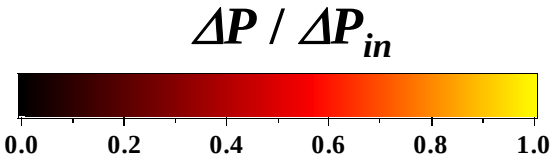
$\Delta P / \Delta P_{in}$

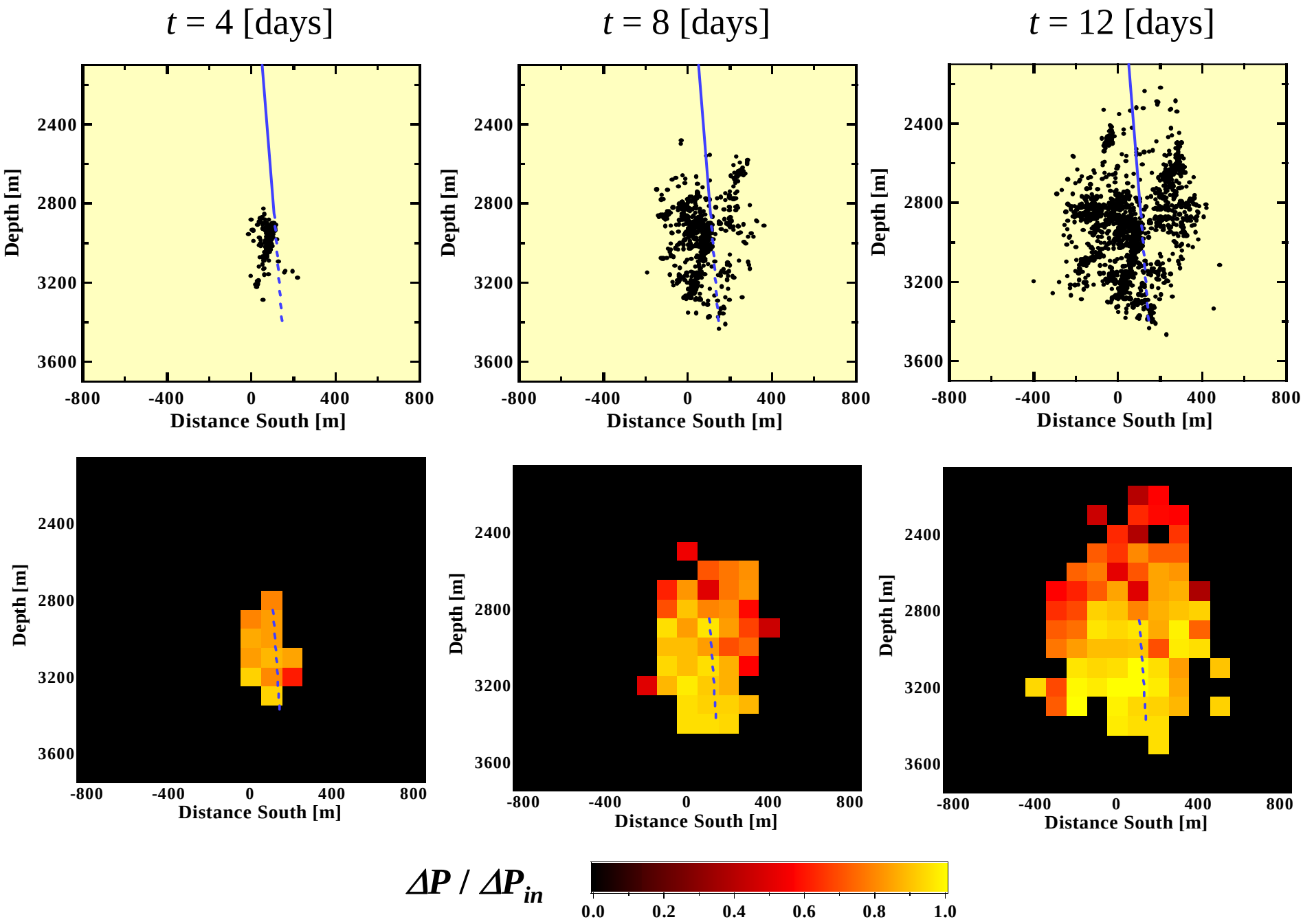


No. 6/6 t = 12 [days]

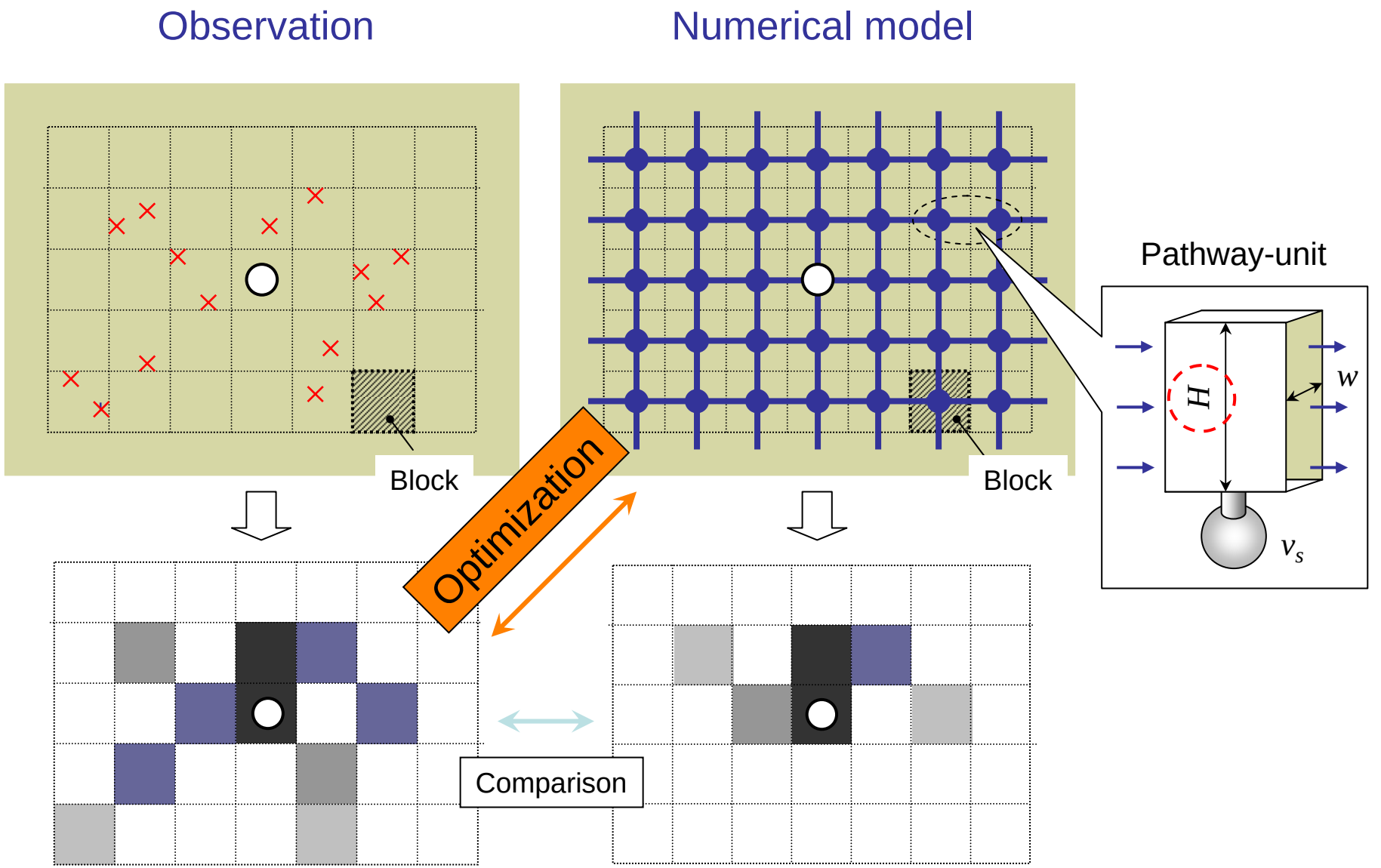




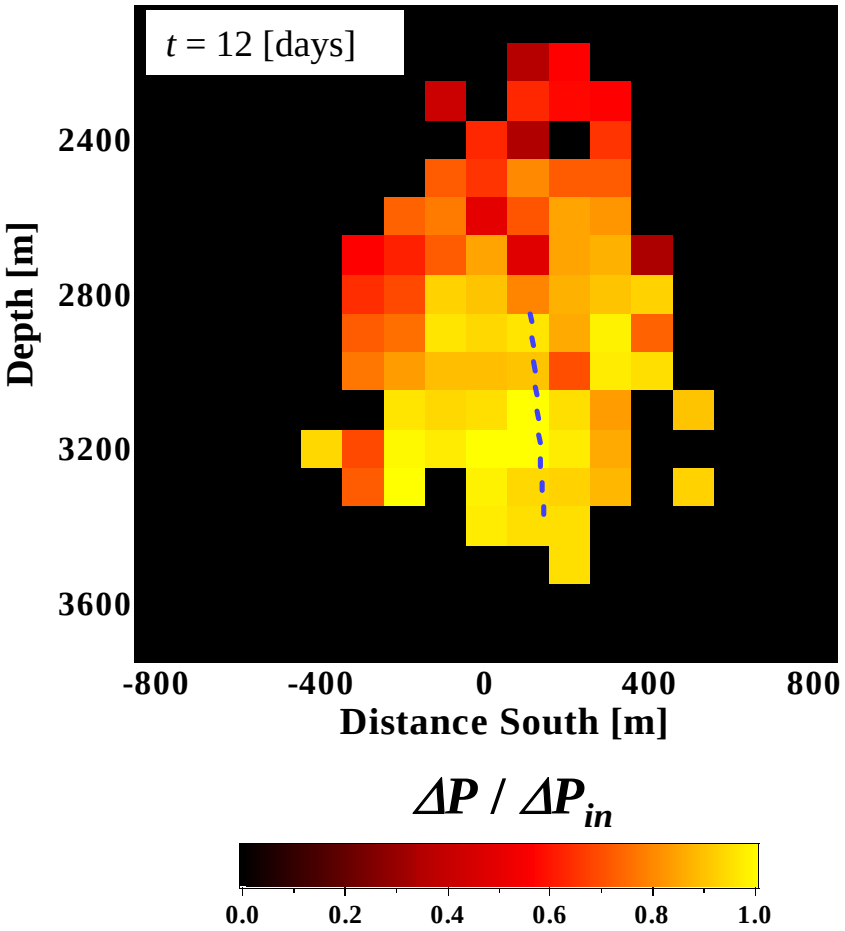



t = 4 [days]
t = 8 [days]
t = 12 [days]
Depth [m]
2400
2800
3200
3600
-800
-400
0
400
800
Distance South [m]
ΔP / ΔP_in
0.0
0.2
0.4
0.6
0.8
1.0

Estimation of flow pathway structure



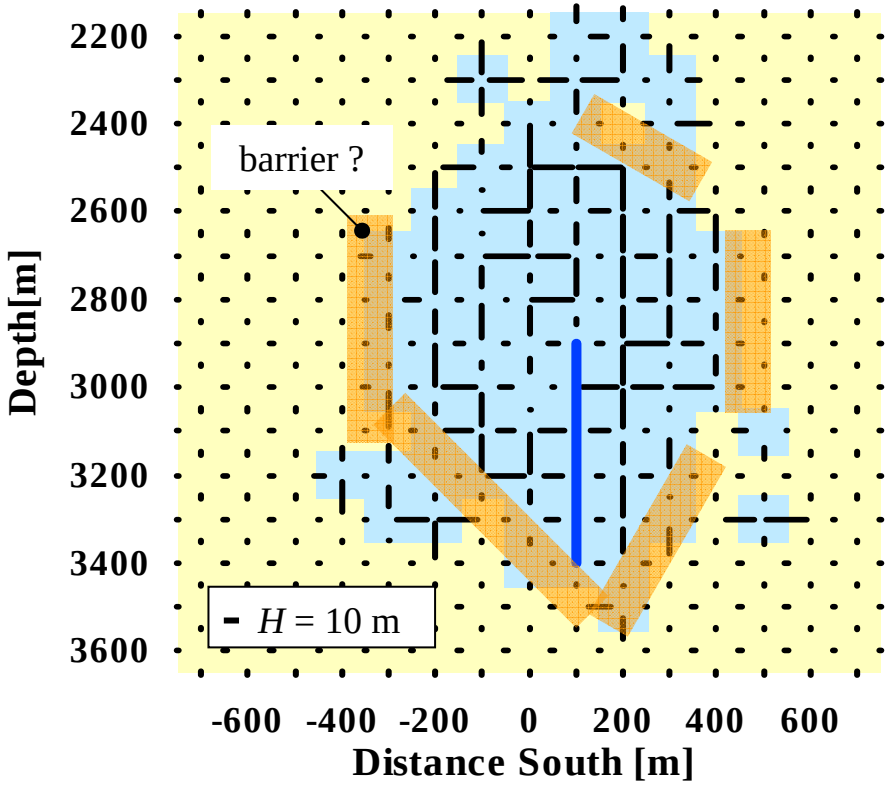
Pressure distribution



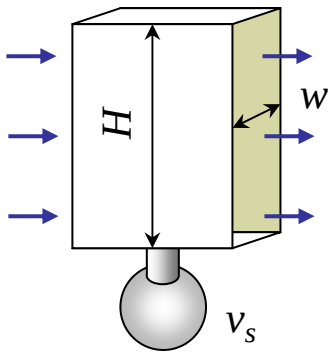
$\Delta P / \Delta P_{in}$

Pressure distribution at t = 4, 5, 7, 8 10, 12 [days] were used for estimating flow pathways.

Estimated flow pathways



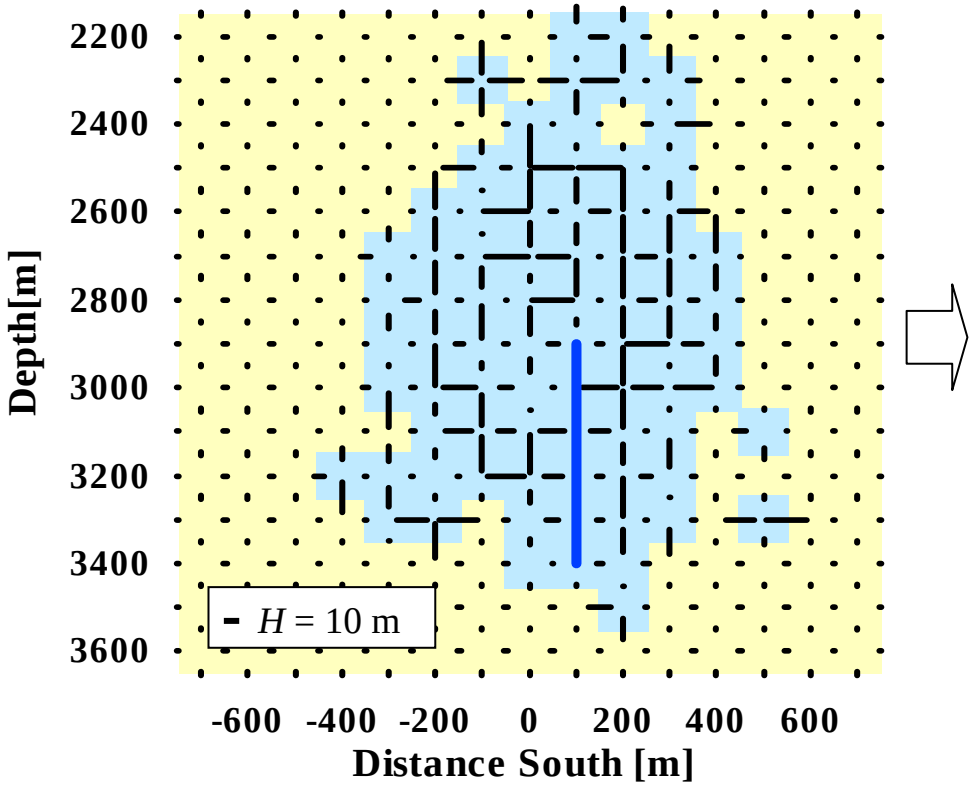
Pathway-unit



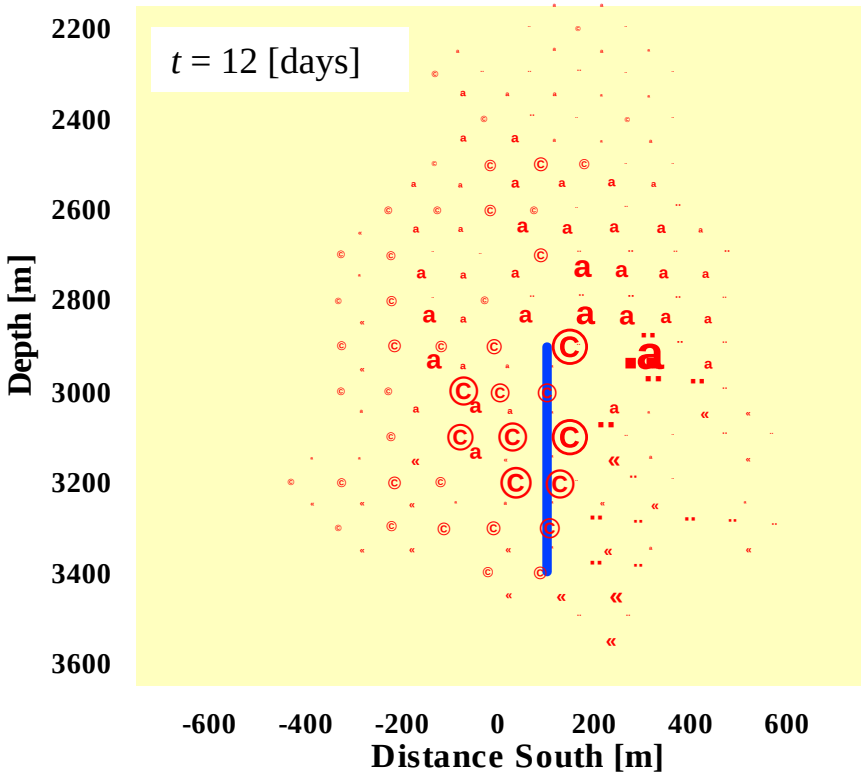
v_s = 400 [m^3/m]

(w = 0.1 [mm])

Estimated flow pathways

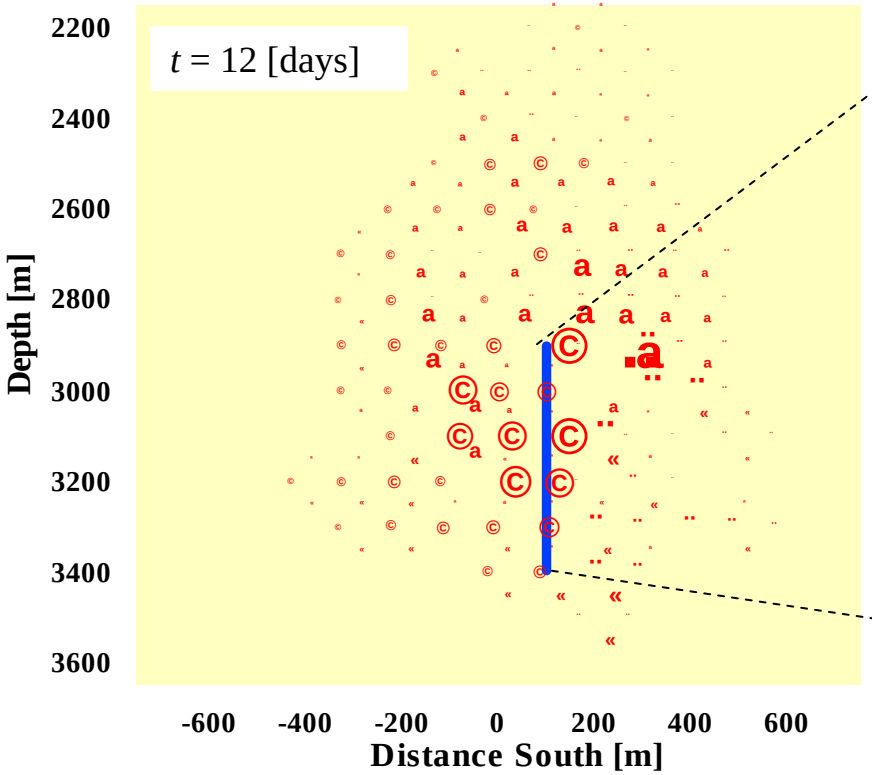


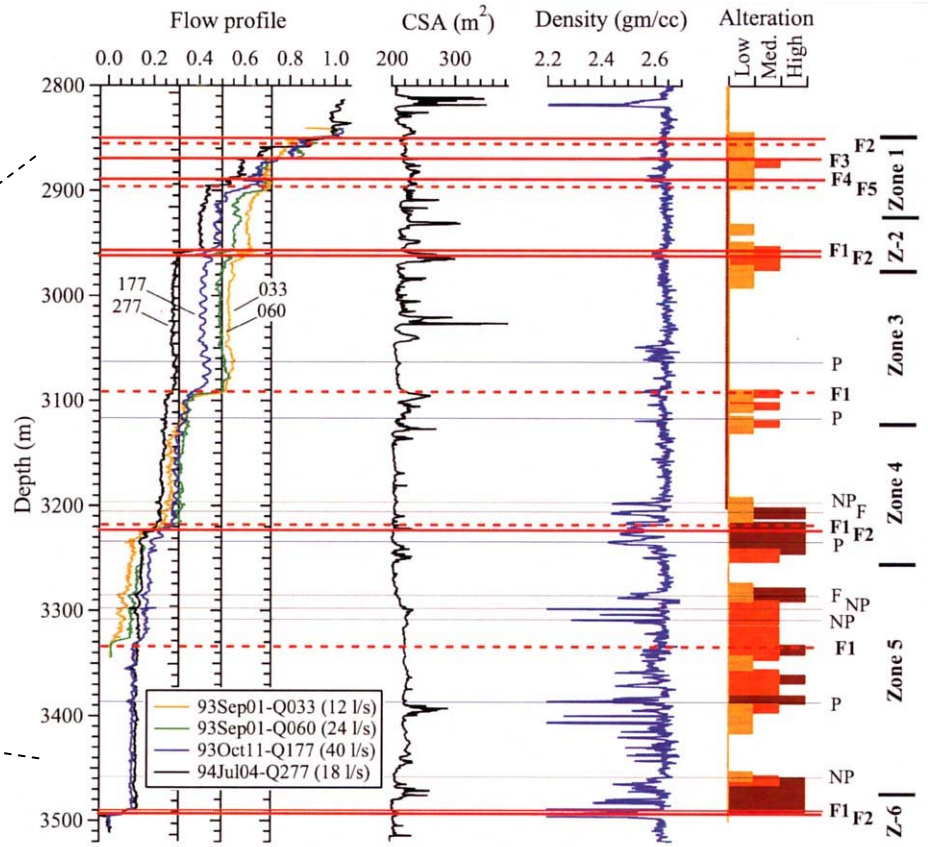
Estimated flow distribution assuming the 1993 stimulation



(Fig.8(b))

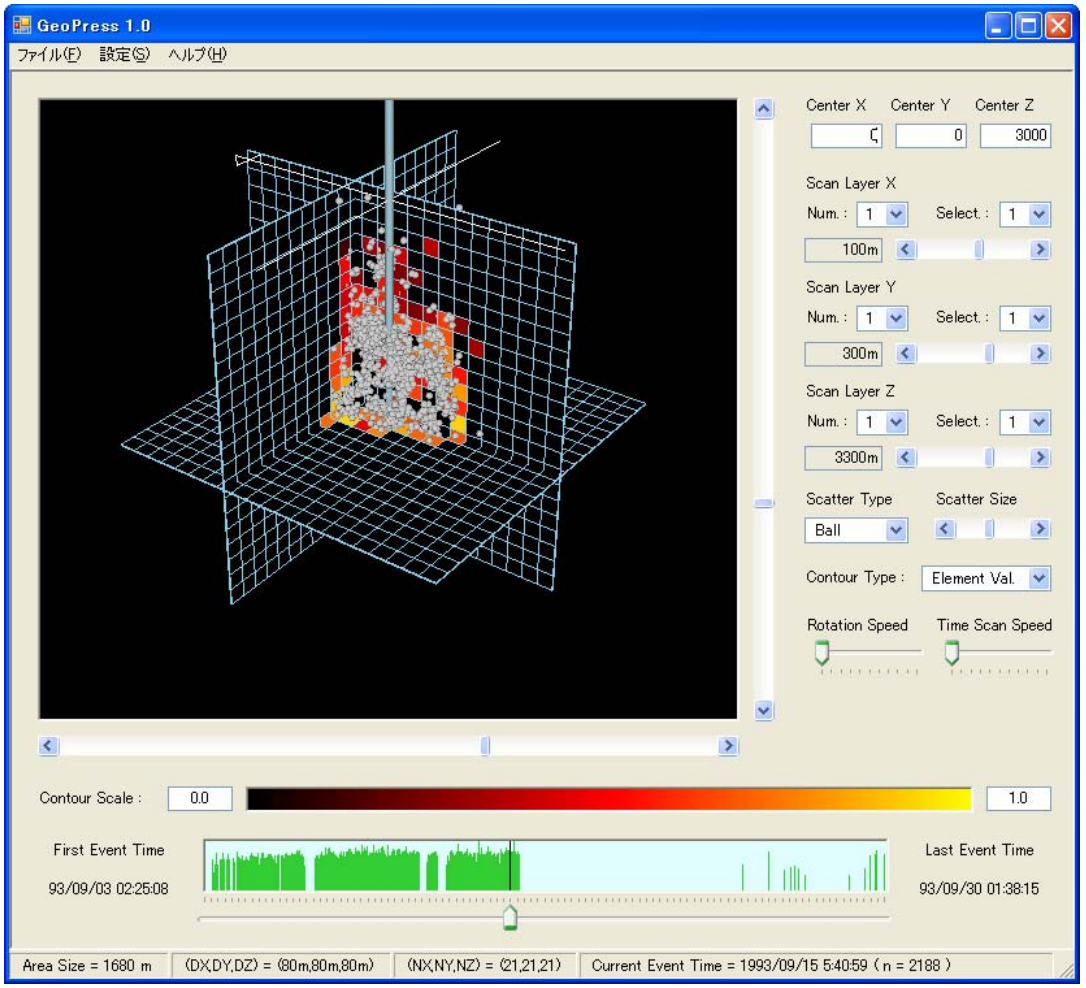
Estimated flow distribution assuming the 1993 stimulation



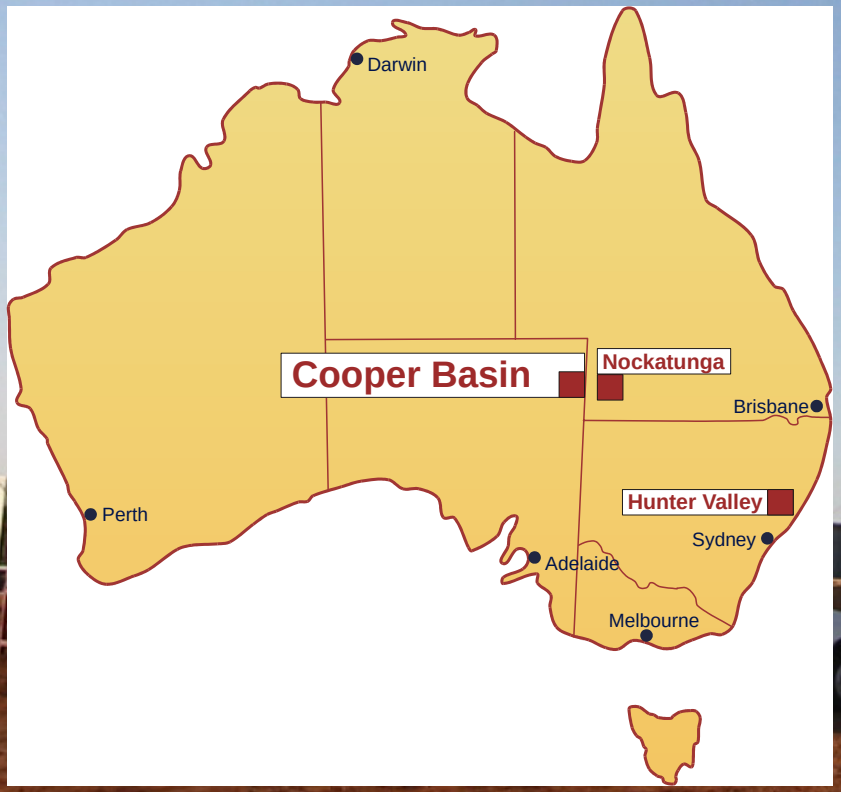


(Evans et al., 2005)

Developing a software aiding analysis, GeoPress

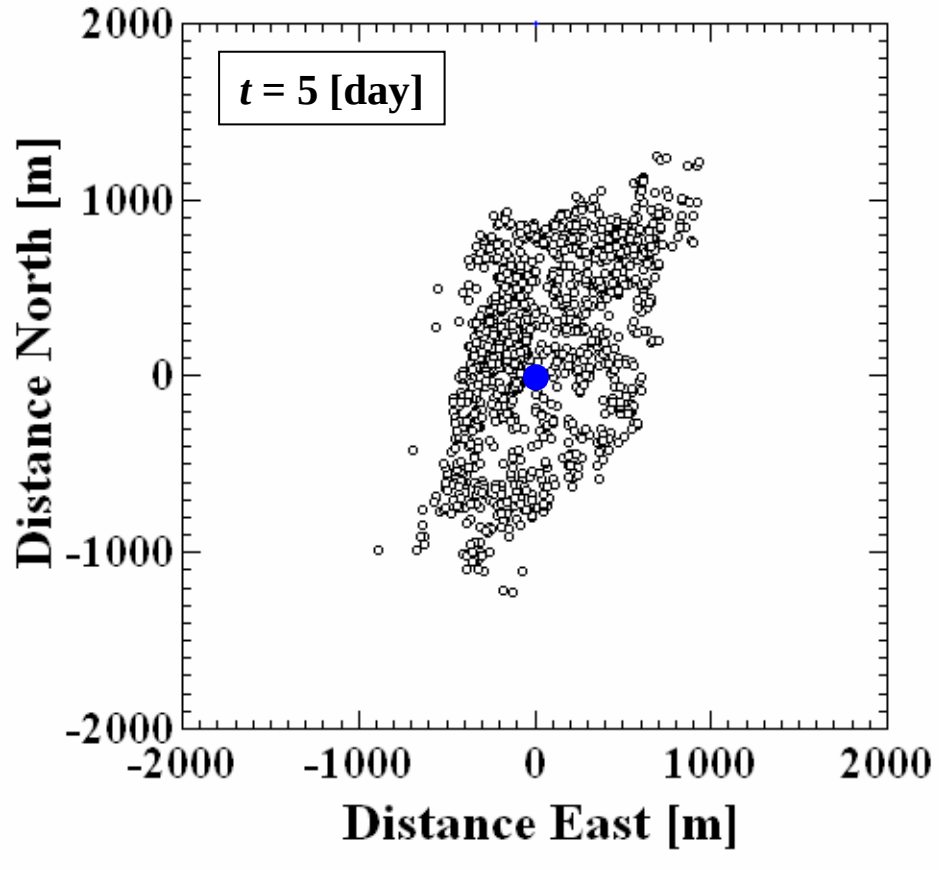


Field application at the Cooper Basin HDR site

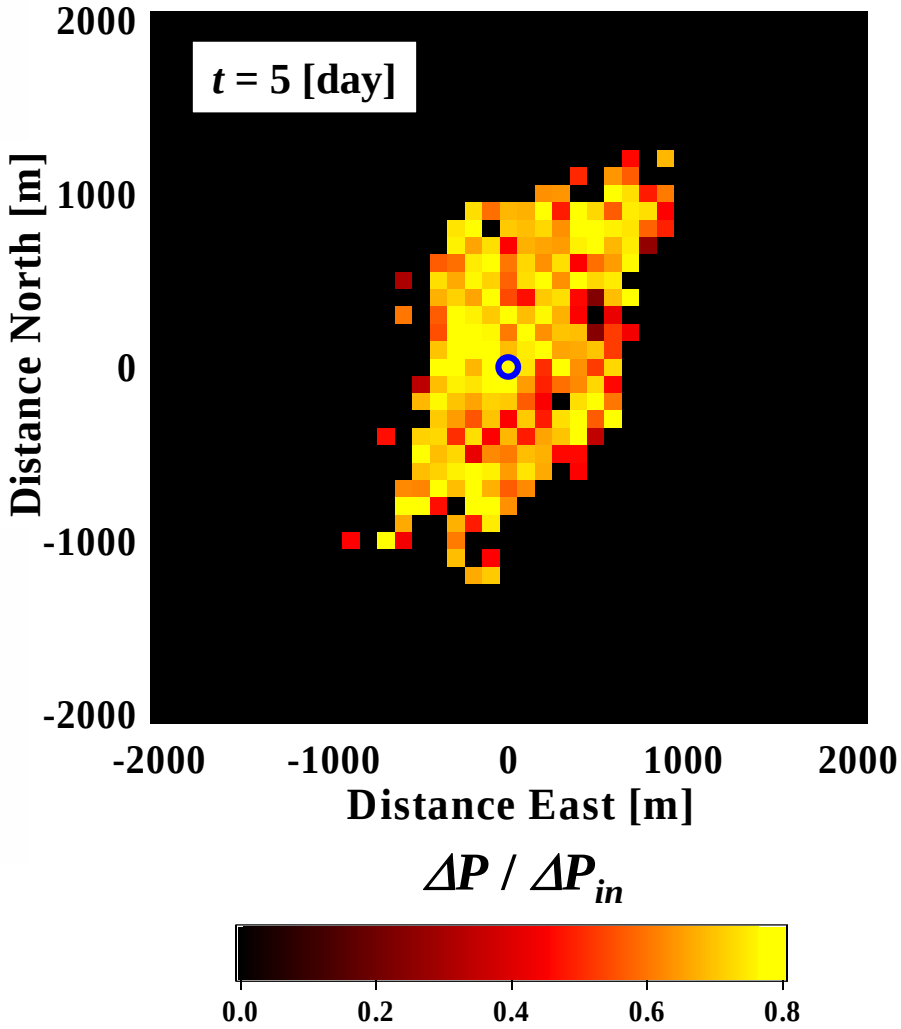


Hydraulic stimulation in Nov.-Dec. 2003

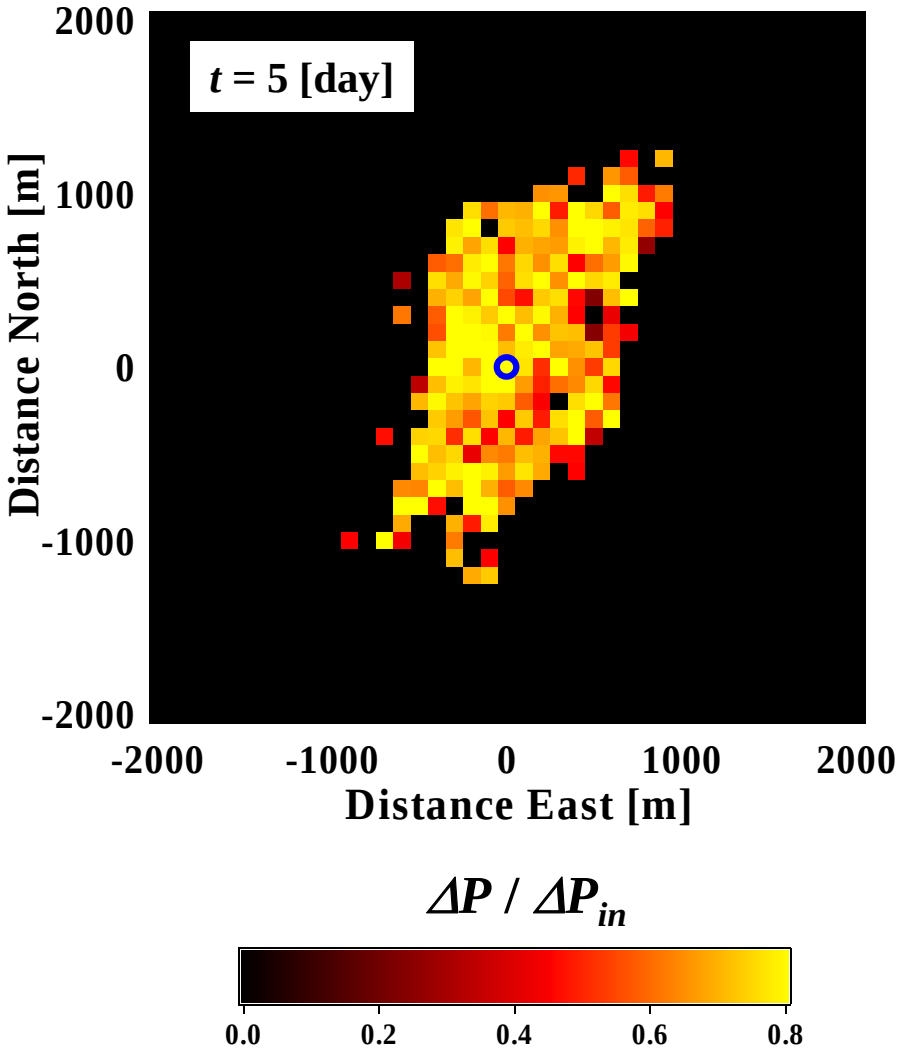
Distribution of MS events



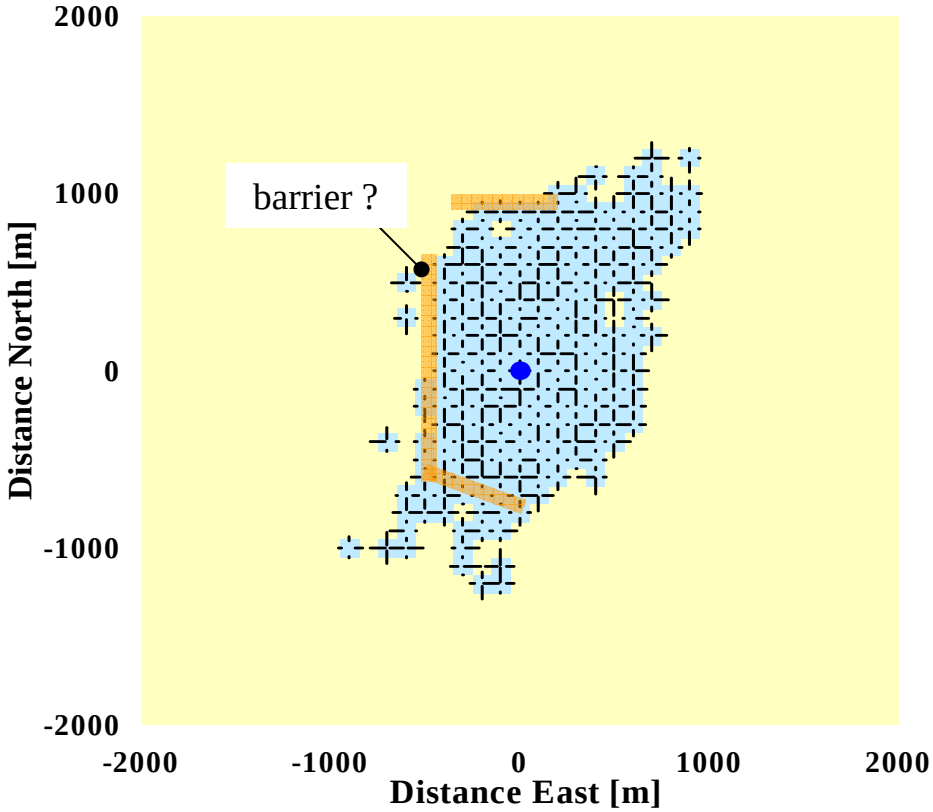
Pressure distribution



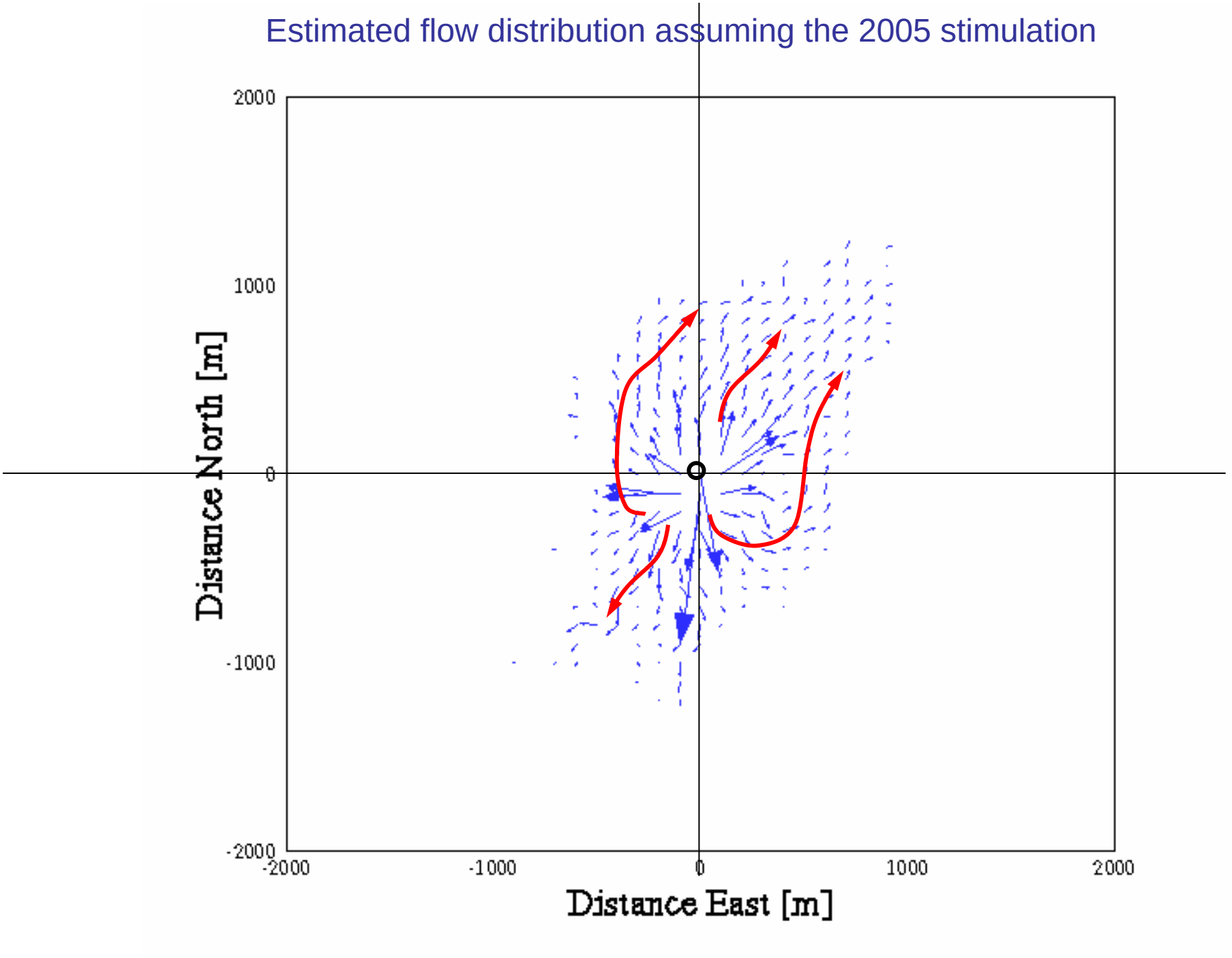
Pressure distribution



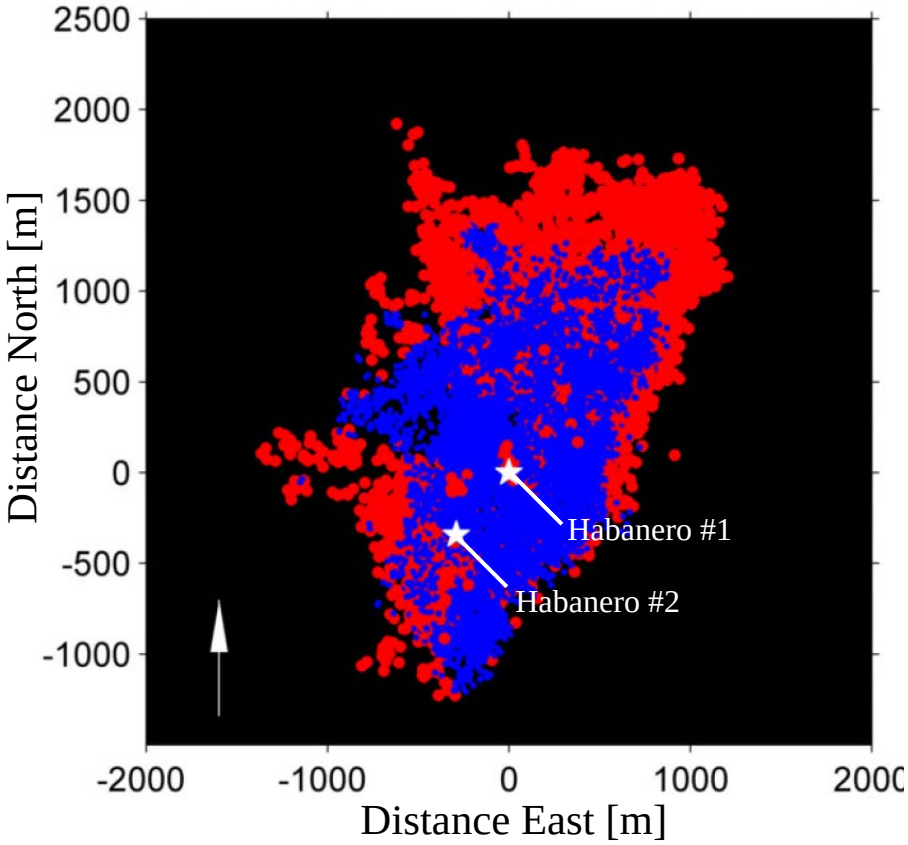
Estimated flow pathways



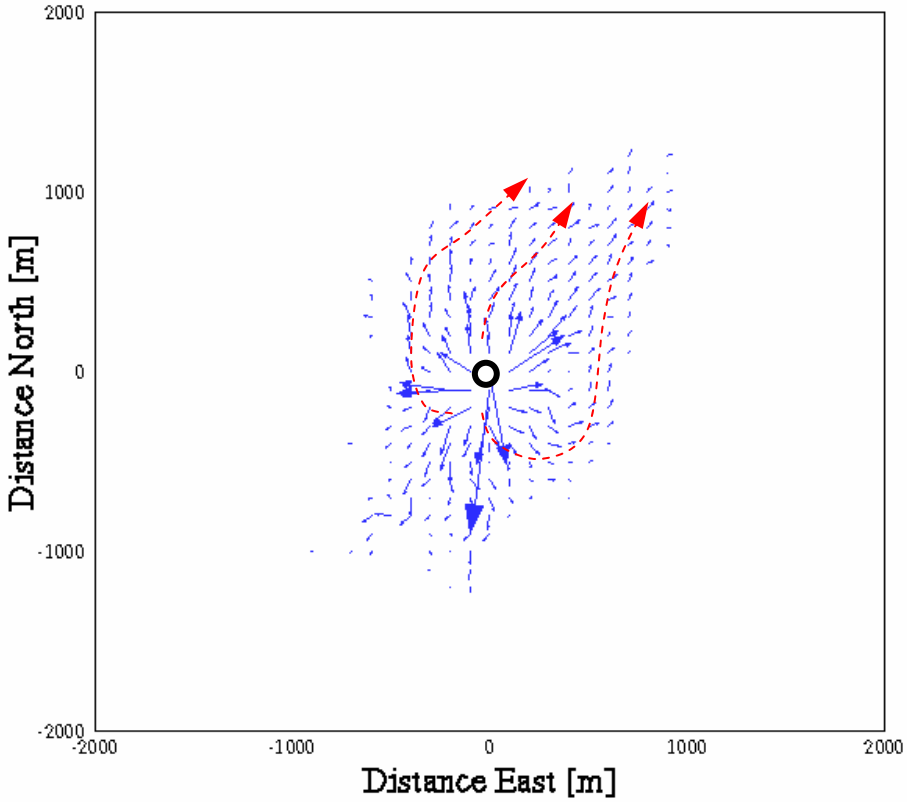
Estimated flow distribution assuming the 2005 stimulation



Comparison of MS events in 2003 (blue) and 2005 (red)

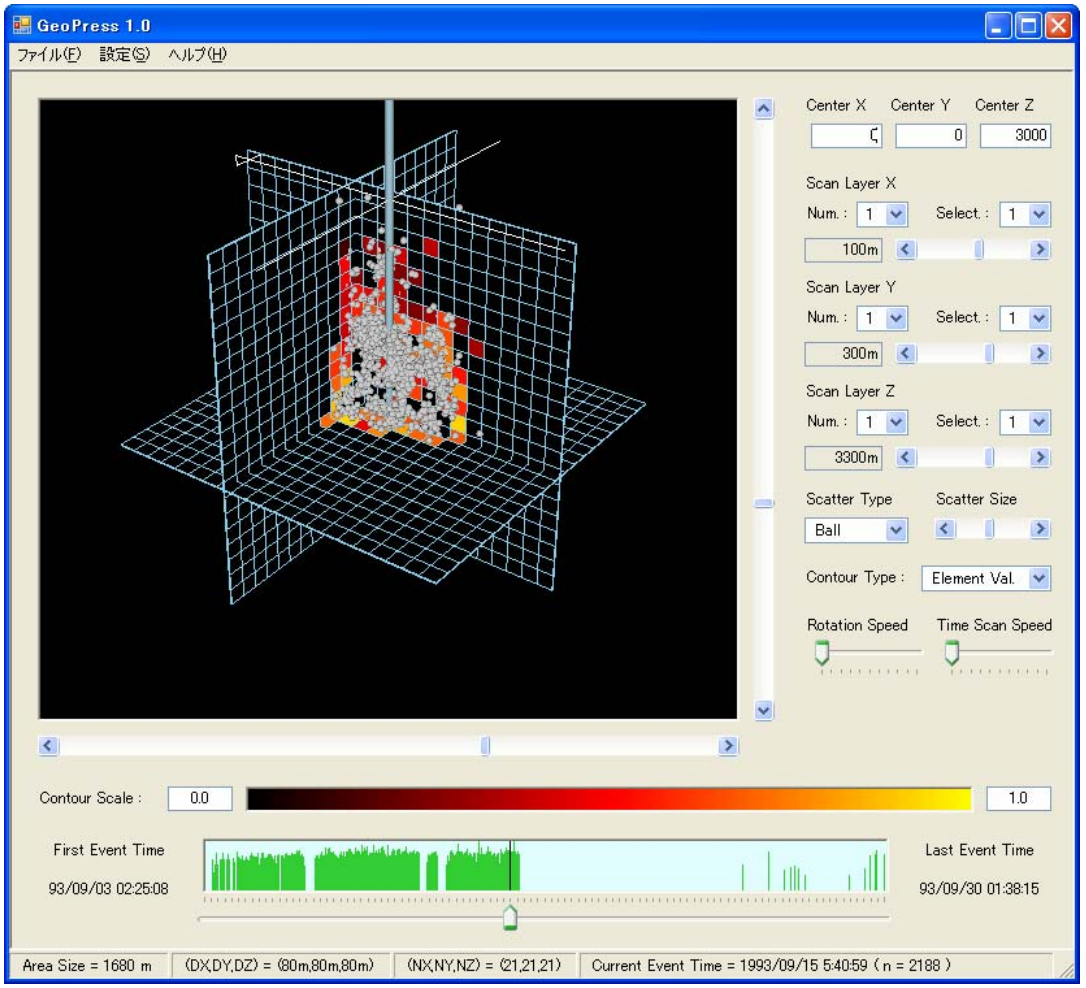


Estimated flow distribution assuming the 2005 stimulation



(Geodyanamics, Quartery Report,2005)

Developing a software aiding analysis, GeoPress



Application of microseismic (MS) data for detecting flow pathway structure

No way to detect directly thin structure of fractures from ground surface through a huge rock mass

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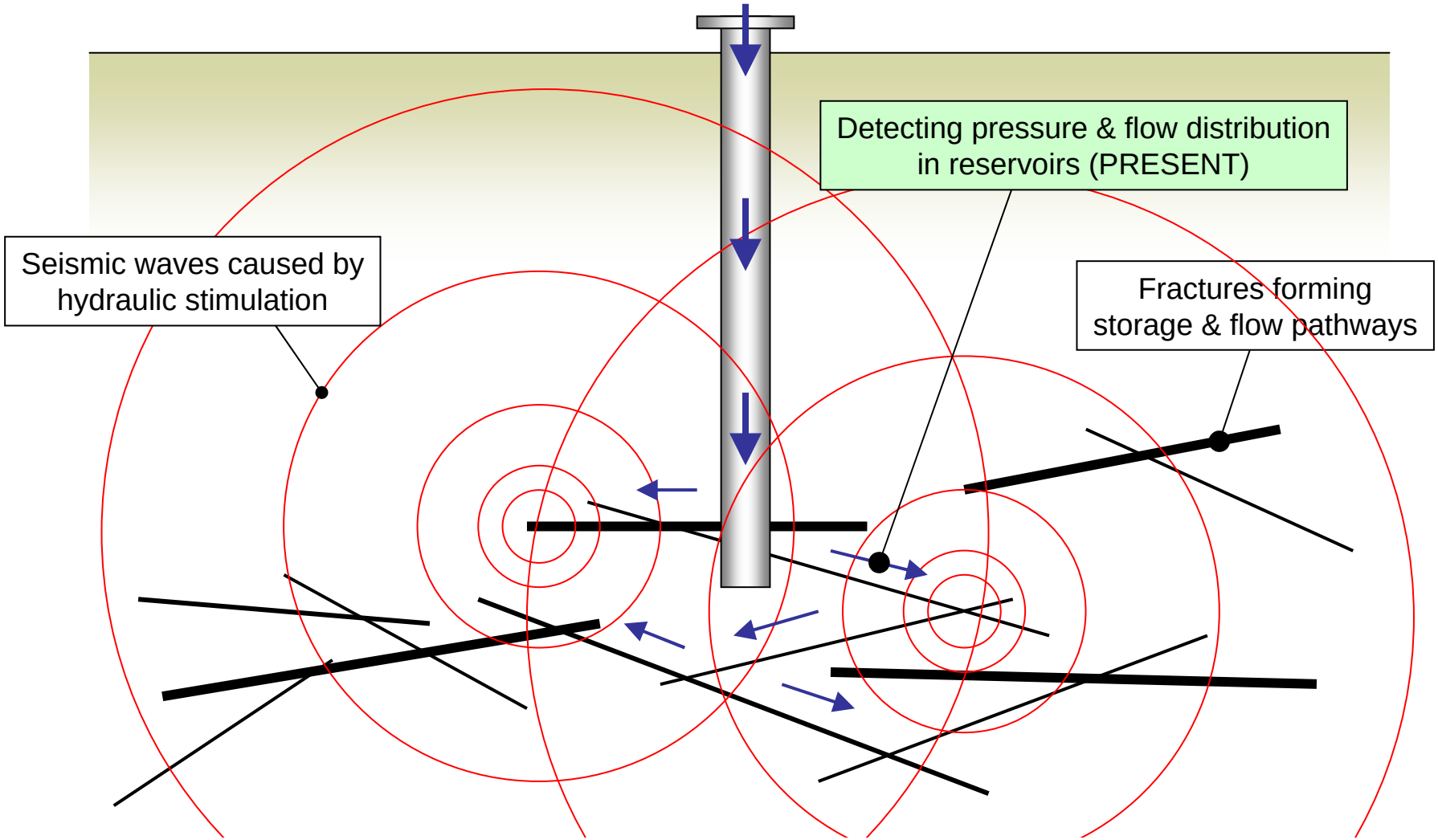
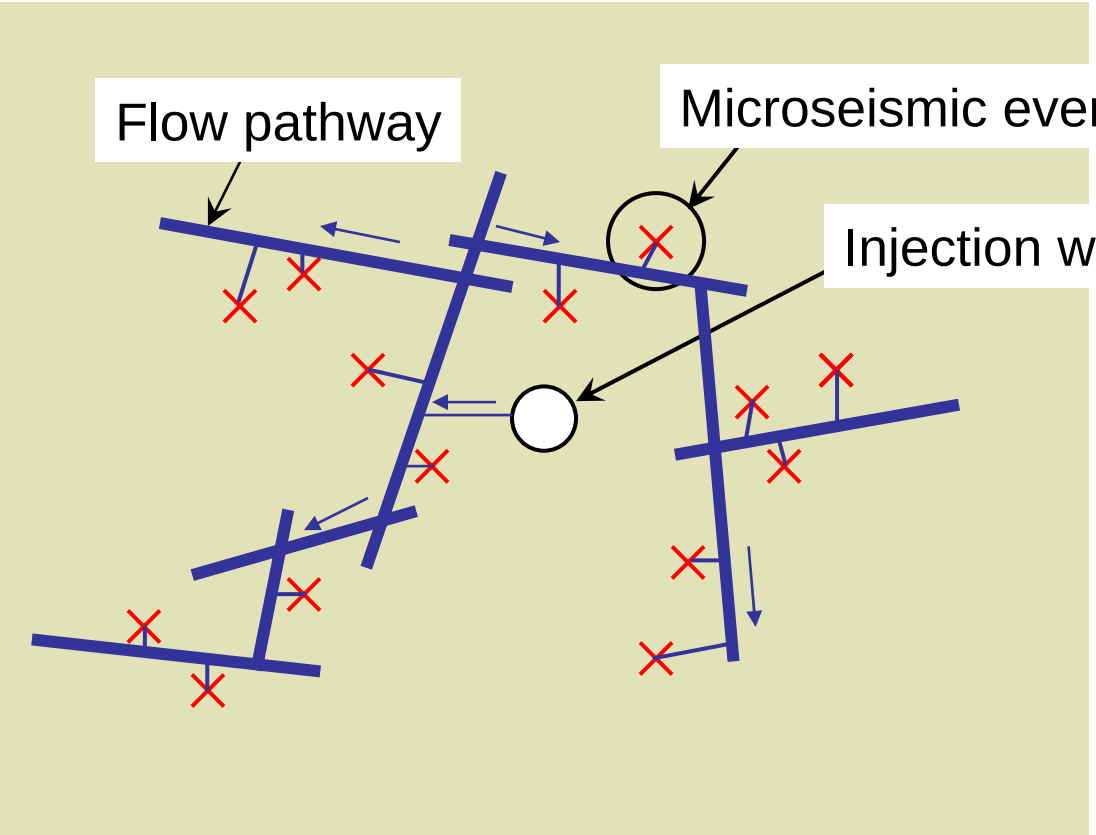
Application of MS induced by hydraulic stimulation





1. The hydraulic conductivity of flow pathways will vary with their locations.
2. The critical pore pressure P_c will vary with fracture orientation (dip, strike).

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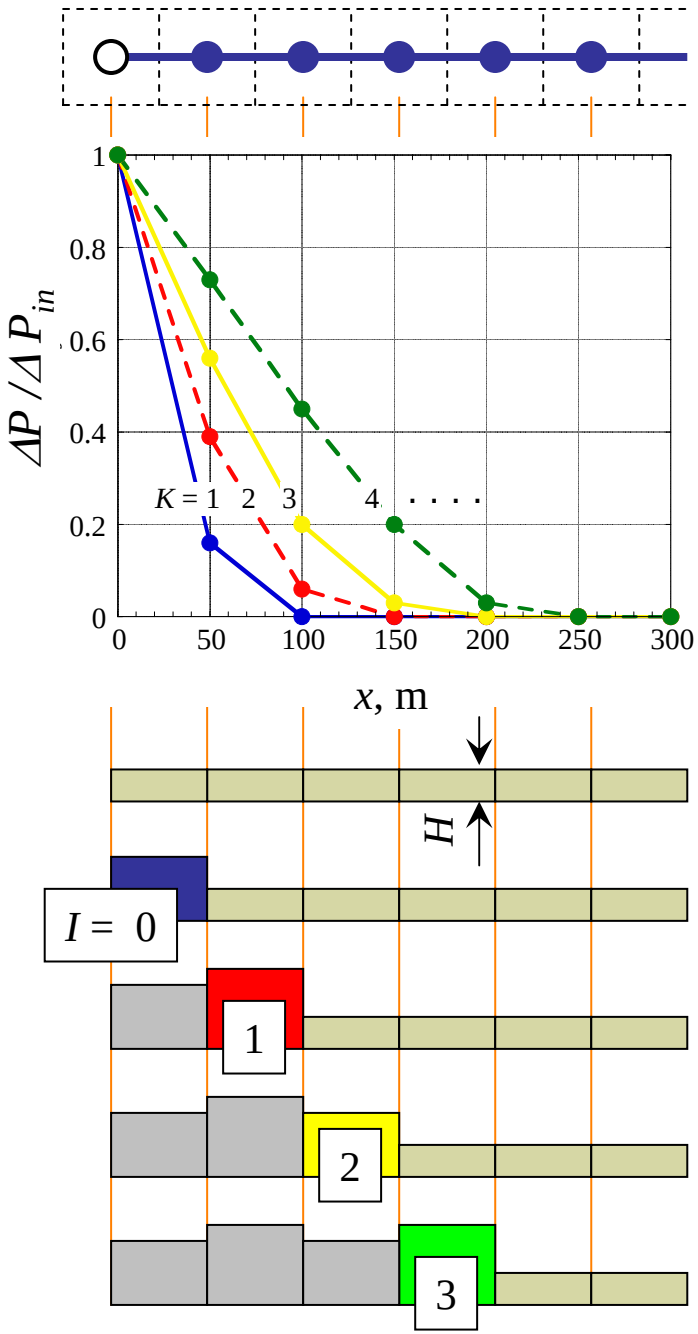
Each fracture will slip at different time and different P_c

Basic idea to estimate the distribution of *H* (assuming 1-D flow for simplicity)



- Set initial value of H
- Adjust H of $I = 0$ according to the pressure data of $K = 1$
- Adjust H of $I = 1$ according to the pressure data of $K = 2$

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(*Expandable easily to 2D and 3D cases*)