Seismic response to power production at the Salton Sea and Coso geothermal fields: using operational parameters to study anthropogenic seismicity rates

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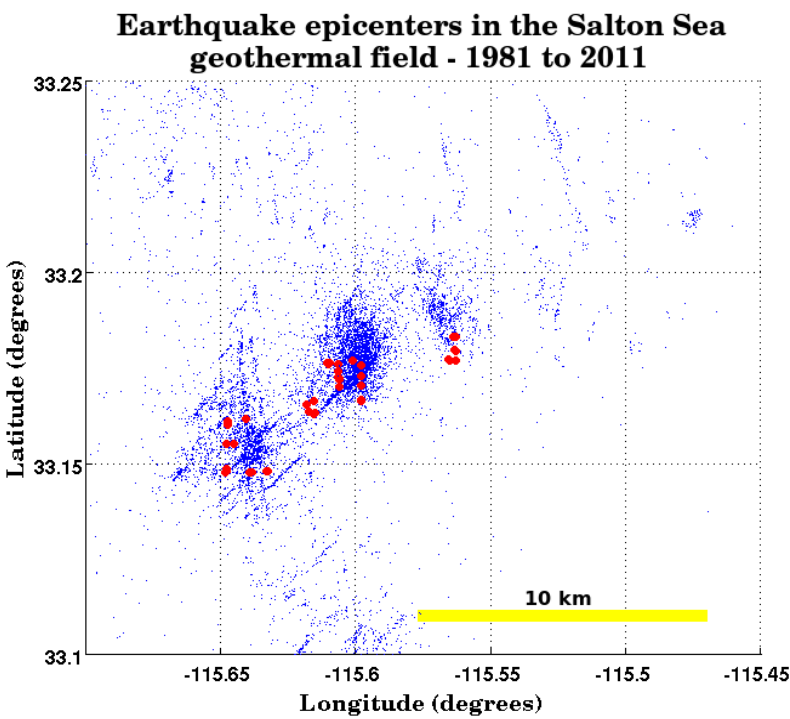
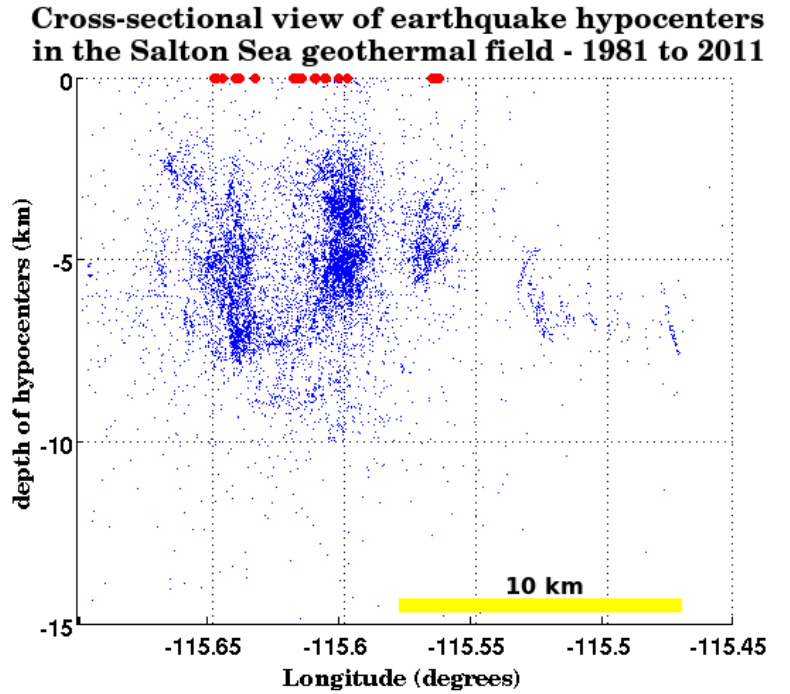
Overview

- Background
- ETAS
- Does geothermal induce EQs?
- How many EQs?
- Conclusions

Salton Sea Geothermal Field

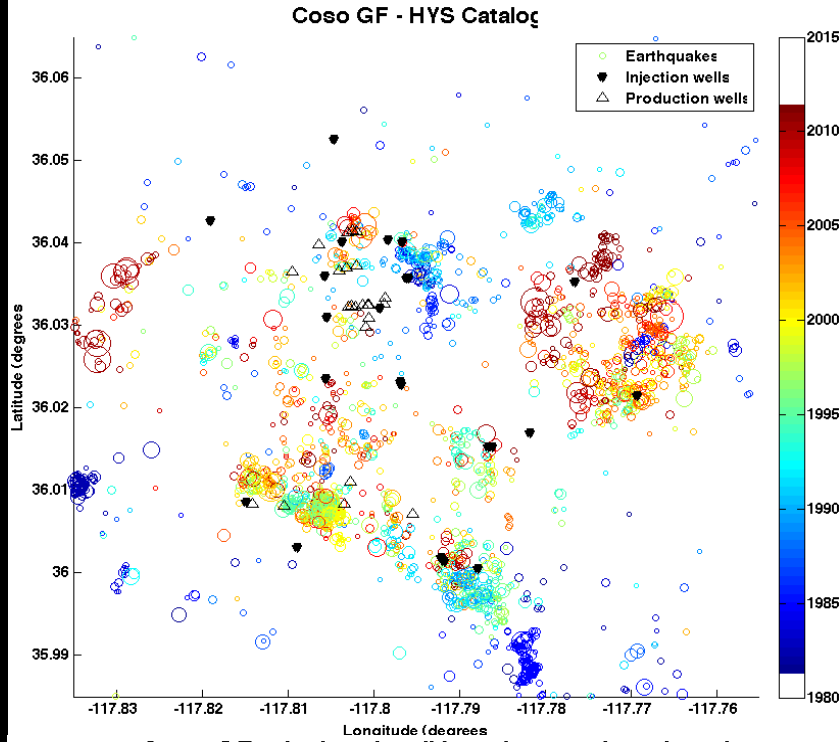
- Extensional basin
- Quaternary volcanics
- Hot wet rock geothermal
- SSGF: 10 plants, 330 MW
  - ~10^7 m^3/month production
  - 320° C (2 km), single flash
  - Exploratory drilling: 1960
  - Online: 1982
  - No fracking!

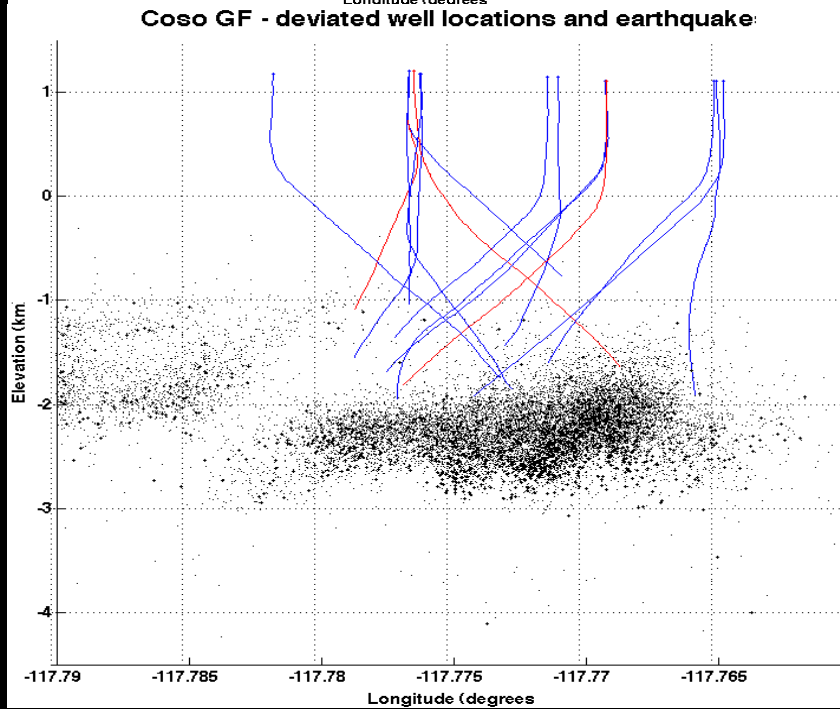




Coso Geothermal Field

- Naval Air Weapons Station, China Lake
- ECSZ – extensional basin
- Quaternary volcanism
- Hot wet rock geothermal
- 4 plants, 270MW
  - ~$2.5 \cdot 10^6$ m^3/month production
  - 300+° C (1.5-2 km), double flash
  - Exploratory drilling: 1977
  - Online: 1987





Does fluid injection induce earthquakes?

How many earthquakes are generated by geothermal power production?

Method: The ETAS model

- Looking for changes in background seismicity rate
- Earthquake statistics:
  - Omori's Law (modified)

    $n(t) = k/(t+c)^p$
  - Gutenberg-Richter

    $\log_{10}N(>=M) = a - bM$
- The ETAS model:

$$R_{ETAS}(t) = \mu + \sum_{t_i \le t} \frac{K \cdot 10^{\alpha(M_i - M_c)}}{(t - t_i + c)^p}$$

METHOD:
MAXIMUM LIKELIHOOD ESTIMATE

- Assume inhomogeneous Poisson process

$$\ln L(\Theta; S, T) = \sum_{j=1}^{N} \ln\left[\mu + \sum_{i=1}^{j} \frac{K \cdot 10^{\alpha(M_i - M_c)}}{(t_j - t_i + c)^p}\right] - \int_S^T \left[\mu + \sum_{t \le t_i} \frac{K \cdot 10^{\alpha(M_i - M_c)}}{(t - t_i + c)^p}\right] dt$$

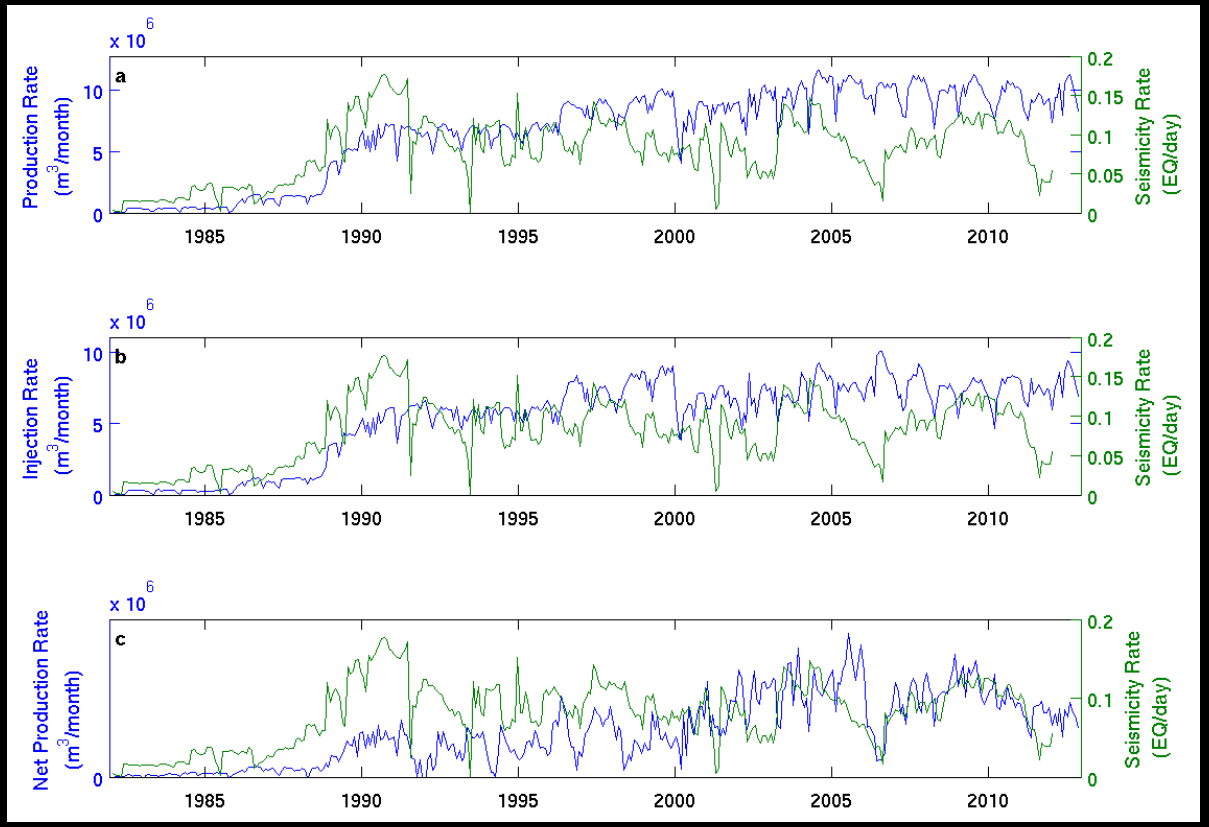
- Constrain $\alpha = 1$, calculate $M_c = 1.7$

Parameter	*ETAS value*	
K	$1.3 \cdot 10^{-2}$	$\pm 1.4 \cdot 10^{-3}$
c	0.30	$\pm 4.0 \cdot 10^{-2}$
p	1.5	$\pm 5.5 \cdot 10^{-2}$
μ	0.11	$\pm 4.6 \cdot 10^{-3}$
α	*1	

Does fluid injection induce earthquakes?

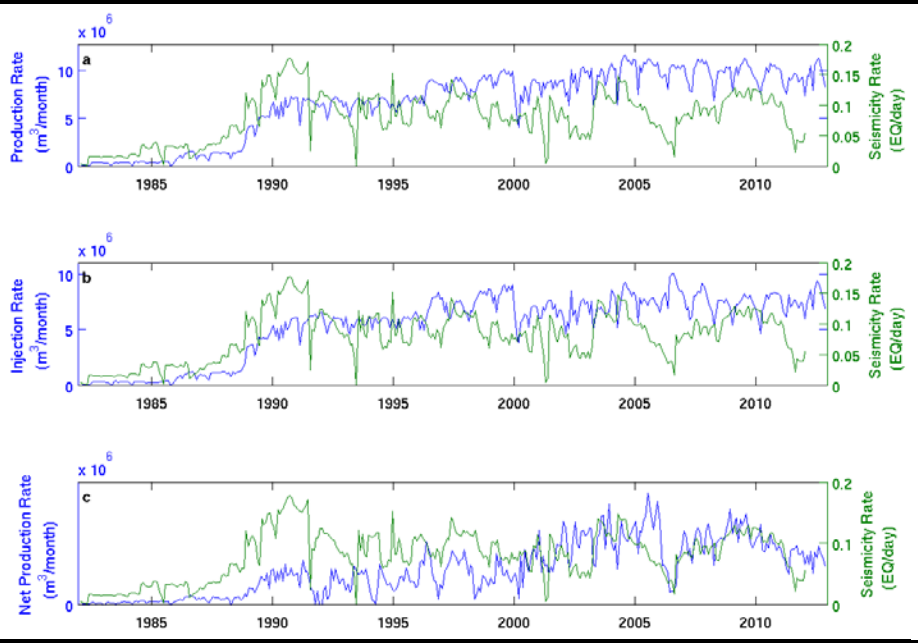
- ETAS inversion in overlapping 2 year windows
- μ = non-aftershock seismicity
- All fluid volumes match early catalog
- Net volume best fit for later time

$$R_{ETAS}(t) = \mu + \sum_{t_i \le t} \frac{K \cdot 10^{\alpha(M_i - M_c)}}{(t - t_i + c)^p}$$



Does fluid injection induce earthquakes?

SSGF



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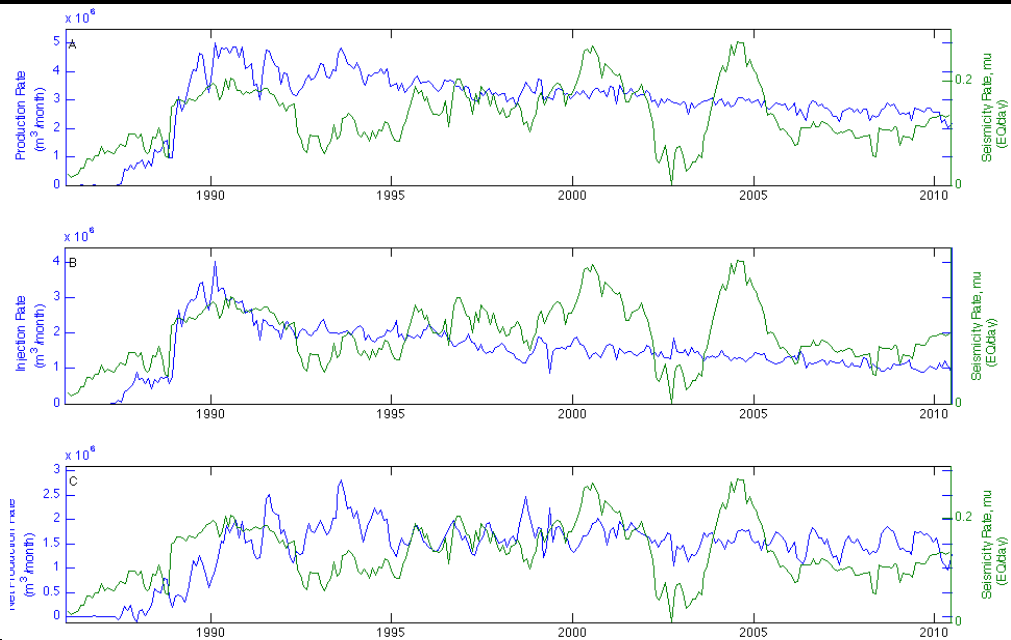
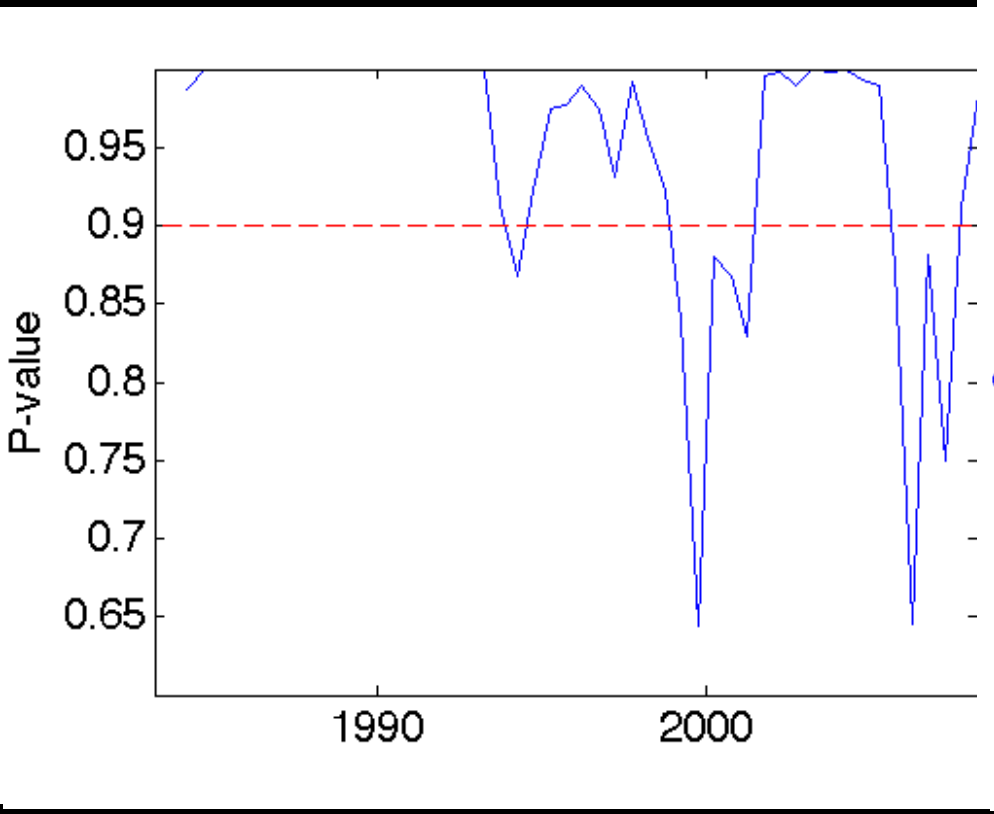
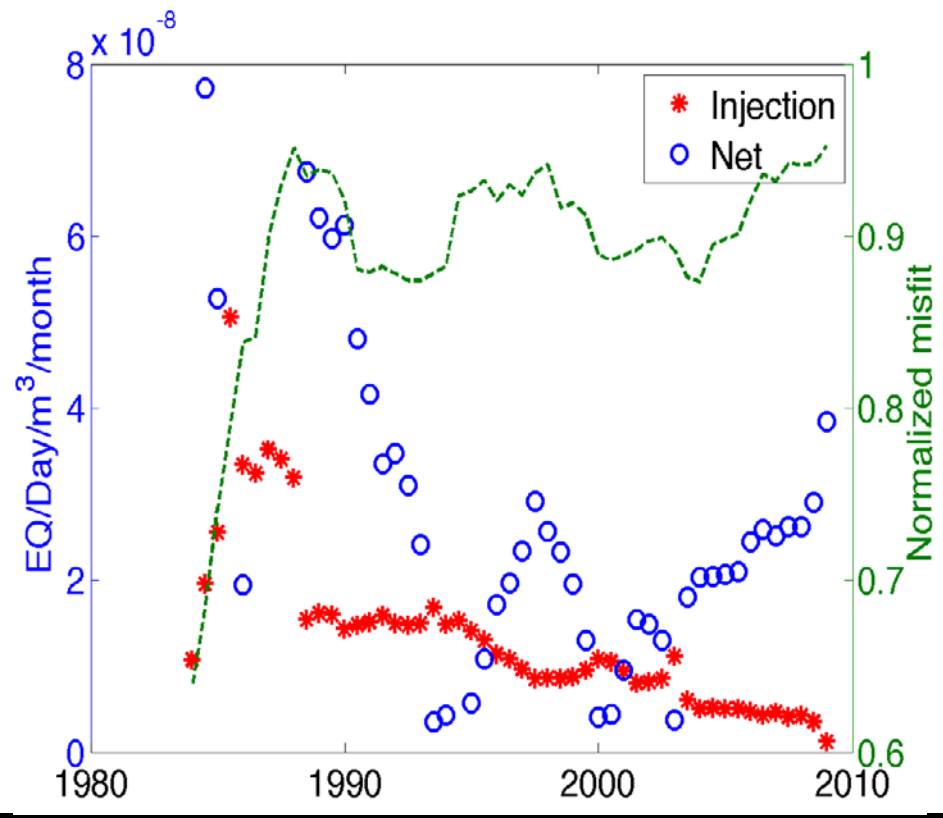


Background seismicity rate vs. operational parameters

Does fluid injection induce earthquakes?

$$\mu = c_1 I + c_2 N$$





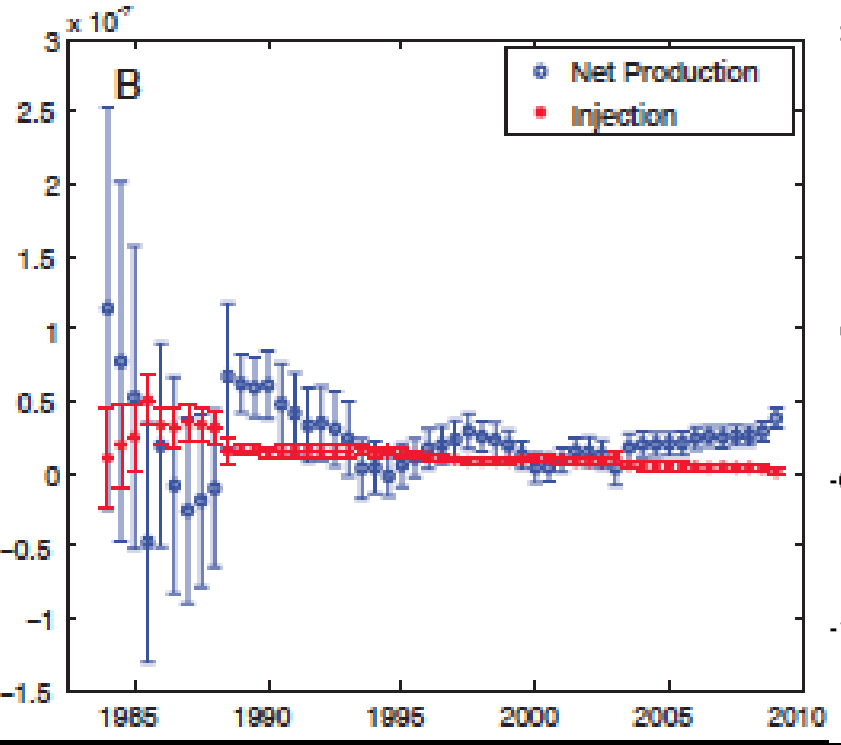
An F test rejects the null hypothesis of insignificant fit at the 90% level for all but 70% of observation windows

an initial period during the rapid growth of the field

How many earthquakes are generated by geothermal power production?

$$\mu = c_1 I + c_2 N$$

SSGF



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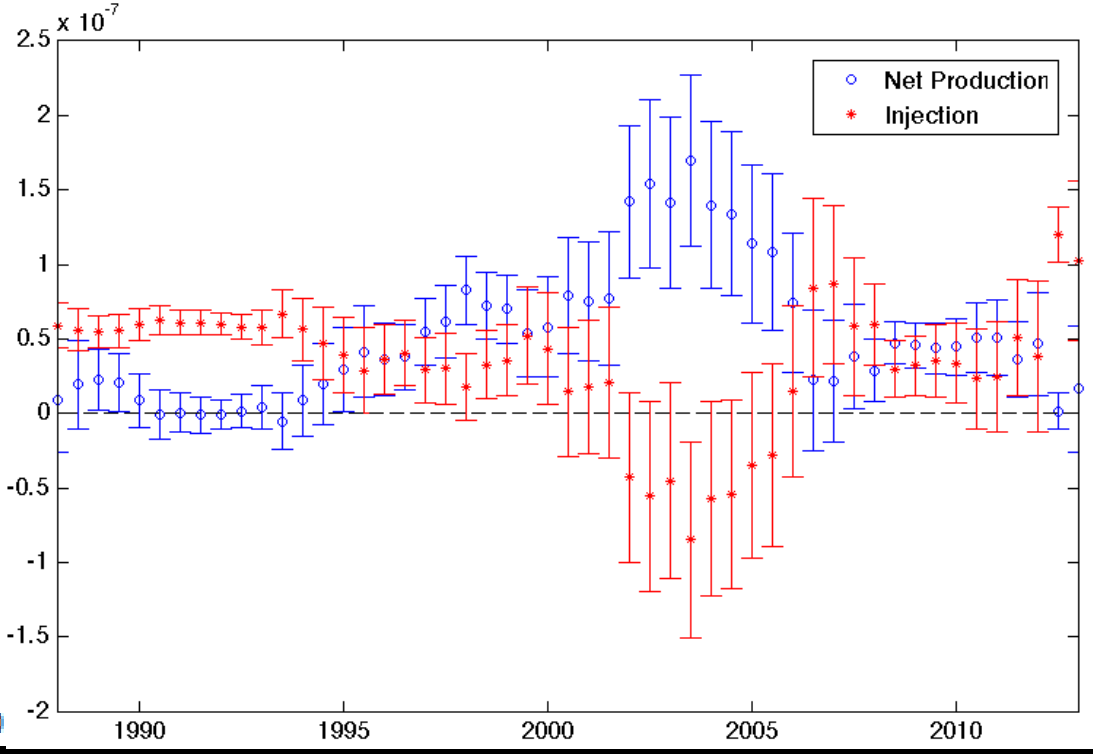

Number of earthquakes per unit of fluid (EQ/day/m^3/month)

Conclusions

- Net production and injection/production information can explain the majority of background seismicity in the geothermal fields
- Net production and injection/production information is a good predictor of seismic response in the short term
- Importance of net production volume suggests that increased pore pressure is not the only factor affecting anthropogenic seismicity rates
- Can begin to identify which fluid flux is most influencing seismicity in a given month
- Need more/better data

THANKS TO:

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GO SHARKS!!

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